BNL-52679
Formal Report

Proceedings of RIKEN BNL Research Center Workshop Volume 49

RBRC Scientific Review Committee Meeting

November 21-22, 2002

Organizers:

T. D. Lee and N. P. Samios

RIKEN BNL Research Center

Building 510A, Brookhaven National Laboratory, Upton, NY 11973-5000, USA

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Preface to the Series

The RIKEN BNL Research Center (RBRC) was established in April 1997 at Brookhaven National Laboratory. It is funded by the "Rikagaku Kenkyusho" (RIKEN, The Institute of Physical and Chemical Research) of Japan. The Center is dedicated to the study of strong interactions, including spin physics, lattice QCD, and RHIC physics through the nurturing of a new generation of young physicists.

During the first year, the Center had only a Theory Group. In the second year, an Experimental Group was also established at the Center. At present, there are seven Fellows and seven Research Associates in these two groups. During the third year, we started a new Tenure Track Strong Interaction Theory RHIC Physics Fellow Program, with six positions in the first academic year, 1999-2000. This program had increased to include ten theorists and one experimentalist in academic year, 2001-2002. With recent graduations, the program presently has eight theorists and two experimentalists. Beginning last year a new RIKEN Spin Program (RSP) category was implemented at RBRC, presently comprising four RSP Researchers and five RSP Research Associates. In addition, RBRC has four RBRC Young Researchers.

The Center also has an active workshop program on strong interaction physics with each workshop focused on a specific physics problem. Each workshop speaker is encouraged to select a few of the most important transparencies from his or her presentation, accompanied by a page of explanation. This material is collected at the end of the workshop by the organizer to form proceedings, which can therefore be available within a short time. To date there are forty-eight proceeding volumes available.

The construction of a 0.6 teraflops parallel processor, dedicated to lattice QCD, begun at the Center on February 19, 1998, was completed on August 28, 1998. A 10 teraflops QCDOC computer in under development and expected to be completed in JFY 2003.

T. D. Lee
November 22, 2002

*Work performed under the auspices of U.S.D.O.E. Contract No. DE-AC02-98CH10886.

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RBRC Scientific Review Committee Meeting

November 21-22, 2002
Brookhaven National Laboratory, Upton, NY 11973

The fifth evaluation of the RIKEN BNL Research Center (RBRC) took place on November 21-22, 2002, at Brookhaven National Laboratory. The members of the Scientific Review Committee were Dr. Jean-Paul Blaizot, Professor Makoto Kobayashi, Dr. Akira Masaike, Professor Charles Young Prescott, Professor Claudio Rebbi, and Professor Jack Sandweiss, Committee Chair. In order to illustrate the breadth and scope of the program, each member of the Center made a presentation on his research efforts. In addition, a special presentation was given jointly by our collaborators, Professors Norman Christ and Robert Mawhinney of Columbia University, on the progress and status of the RBRC Supercomputer program. Although the main purpose of this review is a report to RIKEN Management (Dr. S. Kobayashi) on the health, scientific value, management and future prospects of the Center, the RBRC management felt that a compendium of the scientific presentations are of sufficient quality and interest that they warrant a wider distribution. As such we have made this compilation and present it to the community for its information and enlightenment.

Thanks to Brookhaven National Laboratory and to the U. S. Department of Energy for providing the facilities to hold this meeting.

T. D. Lee & N. P. Samios

RIKEN BNL Research Center

Building 510A, Brookhaven National Laboratory, Upton, NY 11973 USA

RBRC Scientific Review Committee (SRC) Meeting
Brookhaven National Laboratory, Upton, NY
Physics Department, Building 510, Open Sessions – Large Seminar Room
November 21-22, 2002
Agenda

Committee Members: Jean-Paul Blaizot, Makoto Kobayashi, Akira Masaike, Charles Prescott, Claudio Rebbi, Jack Sandweiss, Chair

Thursday, November 21, 2002

8:00 AM to 9:00 AM — *Open Executive Session & Working Breakfast (Summary Presentations by T.D. Lee and N.P. Samios) Room 2-160*

Large Seminar Room

9:00 AM to 11:00 AM THEORY PRESENTATIONS—ANTHONY J. BALTZ, CHAIR

09:00	Baryogenesis and Dark Matter	Alexander Kusenko
09:15	Analysis of Heavy-Ion Collisions at RHIC with the Parton Cascade Model	Steffen A. Bass
09:30	Numerical Gluodynamics for AA Collisions at RHIC: An Update	Raju Venugopalan
09:45	Instantons at Large N_c	Thomas Schaefer
10:00	Applications of Perturbative QCD in Hadronic Collisions	Werner Vogelsang
10:15	Investigation of Nuclear Matter in Extreme Conditions	Sangyong Jeon
10:30	Recent Progress in Nuclear Effective Field Theory	Bira van Kolck
10:45	Fluctuations in Thermal QCD	Mikhail Stephanov
11:00	Break	

11:15 AM to 1:00 PM EXPERIMENTAL PRESENTATIONS—GERRY BUNCE, CHAIR

11:15	Introduction of Experimental Group and Discussion	Hideto En'yo Gerry Bunce
11:35	The First RHIC Spin Run	Naohito Saito
11:50	Luminosity for PHENIX--Absolute and Relative; A New Inner Detector for PHENIX	Yuji Goto
12:05	PHENIX Triggering and Belle Fragmentation Functions	Matthias Grosse Perdekamp
12:20	Level 1 Triggering for the PHENIX Central Arms	Kensuke Okada
12:30	π^0 and ET Measurements at PHENIX	Alexander Bazilevsky
12:45	Charged Particle Measurements at PHENIX	Federica Messer

1:00 PM to 2:00 PM — *SRC Executive Session - Working Lunch (Room 2-160)*

Large Seminar Room

2:00 PM to 3:20 PM **EXPERIMENTAL PRESENTATIONS —HIDETO EN'YO, CHAIR**

2:00	Polarimetry for RHIC	Osamu Jinnouchi
2:10	Local Polarimetry for PHENIX	Brendan Fox
2:25	South Muon Arm Operation in 2001/2 and North Muon Arm Construction	Douglas Fields
2:40	Muon Arm Alignment for 2001/2 and Optical Alignment System Construction for the North Arm	Hideyuki Kobayashi
2:50	Muon Measurements at PHENIX	Atsushi Taketani
3:05	Computing at CC-J at RIKEN	Yuji Goto

3:20 PM Break

3:35PM to 5:00 PM **THEORY PRESENTATIONS—SHIGEMI OHTA, CHAIR**

3:35	Lattice Calculation of the Lowest Order Hadronic Contribution to the Anomalous Magnetic Moment of the Muon	Thomas Blum
3:50	Proton Decay Matrix Elements with Domain-Wall Fermions	Yasumichi Aoki
4:00	Nucleon Matrix Elements with Domain Wall Fermions	Kostas Orginos
4:10	Calculation of Hadronic Matrix Elements for Kaon Decay in Quenched Domain-Wall QCD	Jun-Ichi Noaki
4:20	Effective Theory for Polyakov Loops in Lattice QCD	Yukio Nemoto
4:30	The Color-flavor Transformation and Lattice QCD	Tilo Wettig
4:45	Light Quark Masses from Domain Wall Fermions	Chris Dawson

5:00 PM *SRC Executive Session - (Room 2-160)*

7:00 PM Reception and Dinner (See Invitation)

Continued Next Page

Friday, November 22, 2002

8:00 AM to 8:30 AM	*SRC Executive Session and Continental Breakfast (Room 2-160)*

Large Seminar Room

8:30 AM to 9:30 AM	QCDSP/QCDOC: Physics Results and Prospects/Project Status Norman H. Christ and Robert Mawhinney	
9:30 AM to 10:00 AM	*QCDSP Tour (Optional)	
10:00 AM to 11:00 AM	*RHIC Tour (Optional)	
9:30 AM to 1:00 PM	Meetings with Individual RBRC Staff	
	Theorists	(Room 2-160)
	Host Liaison	Anthony Baltz
	Experimentalists	(Room 2-78)
	Host Liaisons:	Hideto En'yo and G. Bunce
1:00 PM to 2:00 PM	*SRC Executive Session and Lunch - (Room 2-160)*	
2:00 PM to 3:30 PM	Meetings with Individual RBRC Staff (Continued)	
3:30 PM to 5:00 PM	*SRC Executive Session - (Room 2-160)*	
5:00 PM to 6:00 PM	Meeting with T. D. Lee and N. P. Samios -(Room 2-160)	
6:00 PM	Adjourn	

*If you are interested in participating in one or both tours, kindly sign up with Rae Greenberg at the Registration Desk by Thursday afternoon.

11/15/02

RBRC Scientific Review Committee Membership 2002

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RBRC Theory Group

T. D. Lee

A Brief History of RBRC

1997 Inauguration

98 0.6 Teraflops QCDSP
began construction Feb 19
completed Aug 28

SC 98 Gordon Bell Prize
for Price Performance Nov. 13

99 Tenure Track / RHIC Fellows Program

2001 Polarized pp Collision at RHIC

02 Construction of 10 Teraflops
QCDOC March 31

Fifth Anniversary

T. D. Lee, RBRC Director
N. P. Samios, RBRC Deputy Director
Hideto En'yo, RBRC Associate Director
RBRC Research Scientists (2001 – 2002)
Theory Group
T.D. Lee, Group Leader
Anthony J. Baltz, Deputy Group Leader

Research Associates (Post Docs)

Aoki, Y.
Itakura, K.
Kretzer, S. (4/03 Joint BNL Appt)
Nemoto, Y.
Noaki, J.
Orginos, K.
Yamada, N. (12/02)

RBRC Theory Advisory Committee

Baltz, A.
Creutz, M.
Gyulassy, M.
McLerran, L.
Pisarski, R.

RSP Research Associates

Hirano, T. (4/03)
Ikeda, T.
Sugihara, T.

RBRC Young Researcher

Hatta, Y.

Fellows

Blum, T.
Dawson, C.
Vogelsang, W.

Consultants/ Visiting Scientists

Gyulassy, M.
Jaffe, R.
Ohta, S.
Shuryak, E.

Tenure Track/RHIC Fellows

Bass, S.	(Duke)
Kusenko, A.	(UCLA)
Jeon. S.	(McGill)
Schaefer, T.	(SUNY, SB)
Stephanov, M.	(U. of IL, Chicago)
van Kolck, U.	(Arizona)
Venugopalan, R.	(BNL)
Wettig, T.	(Yale)

Collaborators

Mawhinney, R.

Computer Scientist

Dong, Z.

Schaffner-Bielich, J. (Post Doc—10/31/01)
Nara, Y. (Post Doc—9/30/02)
Bödeker, D. (RHIC Physics Fellow, BNL—12/31/01)
Son, D. T. (RHIC Physics Fellow, Columbia—3/31/02)

THEORY PUBLICATION LIST

RBRC-1 H. Fujii and H. Shin, "Dilepton Production in Meson Condensed Matter," Prog. Theor. Physics 98, 1139 (1997).

• • • • • • • • • •

RBRC-31 D. Kharzeev, R. D. Pisarski, and M. Tytgat, Possibility of Spontaneous Parity Violation in Hot QCD, Phys. Rev. Lett. 81, No. 3, 512-515 (1998).

Presented at the First Anniversary Celebration, October 16, 1998.

THEORY PUBLICATION LIST (Cont'd)

RBRC-231. K. Orginos [RBC Collaboration] "Chiral Properties of Domain Wall Fermions With Improved Gauge Actions," [hep-lat 0110074], to appear in the *Proceedings of the XIX International Symposium on Lattice Field Theory "LATTICE 2001,"* Berlin, Germany, August 19-24, 2001; Nucl. Phys. B. (Proc. Suppl.)

Presented at RBRC Scientific Review Committee Meeting, November 29-30, 2001

• • • • • • • • • •

RBRC-293. B. Jäger, A. Schäfer, M. Stratmann, and W. Vogelsang, "Next-to-Leading Order QCD Corrections to High-p_T Pion Production in Longitudinally Polarized pp Collisions," [hep-ph/0211007], Phys. Rev. D (submitted).

Presented at RBRC Scientific Review Committee Meeting, November 21-22, 2002

Proceedings of RBRC Workshops (since Nov. 2001)

Volume 37 RHIC Spin Collaboration Meeting VI (Part 2) (BNL-52660)
November 15, 2001
Organizers: Les Bland and Naohito Saito

Volume 38 RBRC Scientific Review Committee Meeting (BNL-52649)
November 29-30, 2001
Organizers: T. D. Lee and N. P. Samios

Volume 39 RHIC Spin Collaboration Meeting VII (BNL-52659)
February 22, 2002
Organizer: B. Fox

Volume 40 Theory Studies for RHIC-Spin (BNL-52662)
Spring 2002
Organizer: W. Vogelsang

Volume 41 Hadron Structure from Lattice QCD (BNL-52674)
March 18-22, 2002
Organizers: T. Blum, D. Boer, M. Creutz, S. Ohta,.K. Orginos

Volume 42 Baryon Dynamics at RHIC (BNL-52669)
March 28-30, 2002
Organizers: M. Gyulassy, D. Kharzeev, and N. Xu

Volume 43 RIKEN Winter School on Quark-Gluon Structure of the Nucleon and QCD (BNL-52672)
RIKEN, Wako, Japan
March 29-31, 2002
Organizers: H. En'yo, N. Saito, T.-A. Shibata and K. Yazaki

Volume 44 RHIC Spin Collaboration Meetings VIII, IX, X, XI (BNL-)*
April 12, 2002, May 22, 2002, June 17, 2002, July 29, 2002
Organizer: Brendan Fox

Volume 45 Summer Program: Current and Future Directions at RHIC (BNL-)*
August 5-23, 2002
Organizers: A. Deshpande, A. Dumitru, J. Jalilian-Marian, N. Saito, D. Teaney, R. Venugoplan, W. Vogelsang

Volume 46 Large-Scale Computations in Nuclear Physics Using the QCDOC (BNL-)*
September 26-28, 2002
Organizers: Yasumichi Aoki, Anthony Baltz, Michael Creutz, Miklos Gyulassy, Shigemi Ohta

Volume 47 RHIC Spin Collaboration Meetings XII, XIII (BNL-)*
September 16, 2002 and October 22, 2002
Organizer: Brendan Fox

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*In preparation

Other RBRC Scientific Articles Proceedings Volumes:

Volume 1 **Prospects for Spin Physics at RHIC**
Gerry Bunce, Naohito Saito, Jacques Soffer, Werner Vogelsang
July 2000

Volume 2 **Status Report on the Calculation of ε'/ε**
RBRC-Brookhaven-Columbia Collaboration
November 2000

Volume 3 **Scientific Presentations: 7th Meeting of the Management Steering Committee of the RIKEN BNL Collaboration, RIKEN, Wako, Japan, February 13-14, 2001**

Volume 4 **CP Violation in K Decay From Lattice QCD**
Thomas Blum and Robert Mawhinney
RBRC-Brookhaven-Columbia QCDSP Collaboration
July 26, 2001

Volume 5 **Scientific Presentations: 8th Meeting of The Management Steering Committee of The RIKEN BNL Collaboration, RIKEN, Wako, Japan, March 11-12, 2002**

Volume 6 **BNL/RIKEN RHIC Spin Physics Symposium**
RIKEN BNL Research Center Fifth Anniversary Celebration, April 30, 2002

Weekly Seminars

Spin Physics *(Theory & Exp)*	Tuesdays (10:00 a.m.)	Organized by Y. Goto W. Vogelsang A. Deshpande
Nuclear Physics	Tuesdays (11:00 a.m.)	Organized jointly with BNL Staff
High Energy-RIKEN Theory	Wednesdays (1:30 p.m.)	Organized jointly with BNL Theorists
QCD and RHIC Physics *(Theory & Exp)*	Thursdays (12:30 p.m.)	Organized by C. Dawson
High Energy Theory Lunch Talks	Fridays (12:00 Noon)	Organized by S. Dawson
Nuclear Physics-RIKEN Theory	Fridays (2:00 p.m.)	Organized jointly with BNL Staff

The Outstanding Junior Investigator Award in Nuclear Theory was established by DOE in 2000. Since then form RBRC members have received the OJI Awards:

Son, D.T. (2000)

Stephanov, M. (2001)

van Kolck, U. (2001)

Schaefer, T. (2002)

RBRC is dedicated to the study of

Spin Physics

RHIC Physics

Lattice QCD

Having the equation $\neq$ knowing its solutions

N. R. Schroedinger equation

\+ Coulomb potential

$\neq$ understanding life

Standard QCD

\+ electroweak equations

$\neq$ understanding

Spin physics,

RHIC " ,

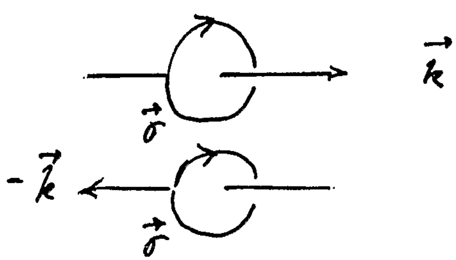
ϵ'/ϵ , ...

QED	QCD
Every e carries an ∞ no. $\int \frac{dk}{k}$ of infrared photons, with each photon of helicity ±1 & ∼ 0 energy. But, ∵ Bloch – Nordsieck Thm these infrared photons only give a wave function renormalization factor.	Every nucleon carries an ∞ no. of soft gluons, each of helicity ±1 & ∼ 0 energy. Because of confinement, soft gluons can be readily excited thro' helicity – change. ∴ The shape of a nucleon is determined by its soft gluons (& $q\bar{q}$).

helicity = $\vec{\sigma} \cdot \vec{k}$

−1 left – handed

+1 right – handed



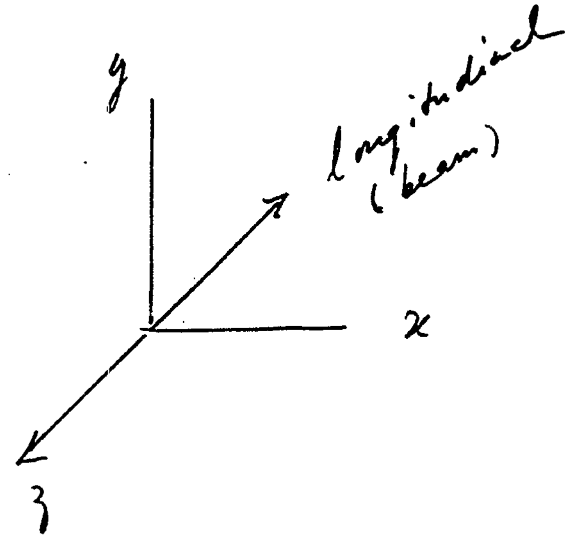
RHIC Physics

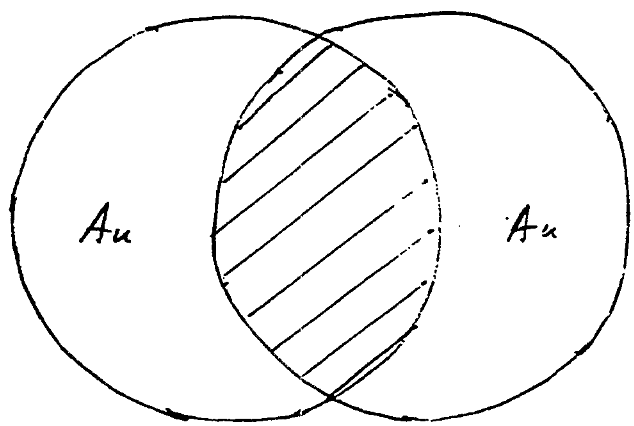
Elliptic Flow

vs

HBT Correlations

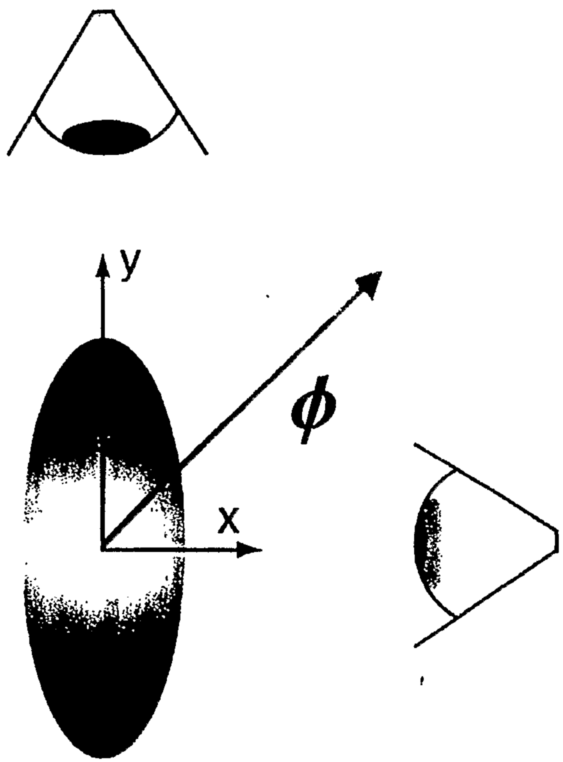
(A Puzzle)


y
longitudinal
(beam)
x
z


Au
Au

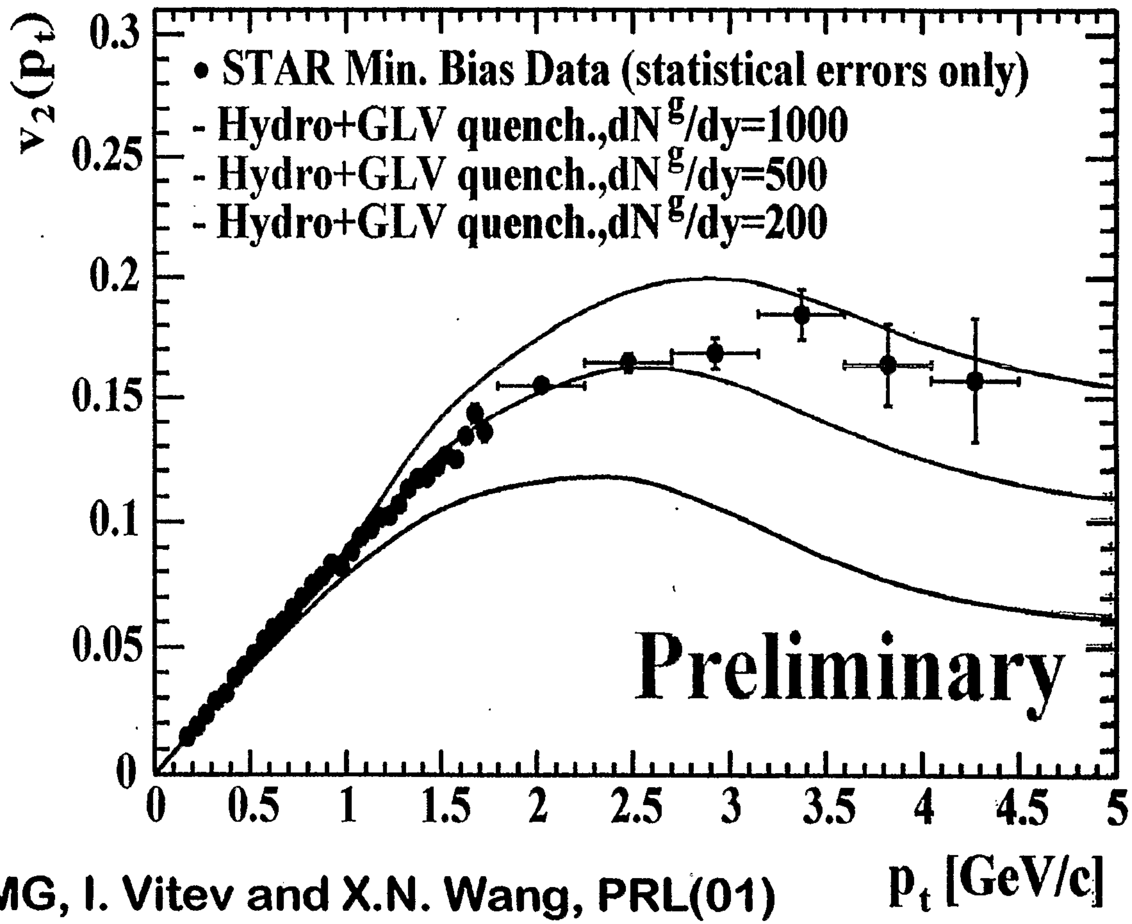
Azimuthal asymmetry of high p_t particles

* Finite dE/dx $\Longrightarrow v_2(p_t) \longrightarrow 0$ for $p_t \longrightarrow \infty$ *



Raimond Snellings

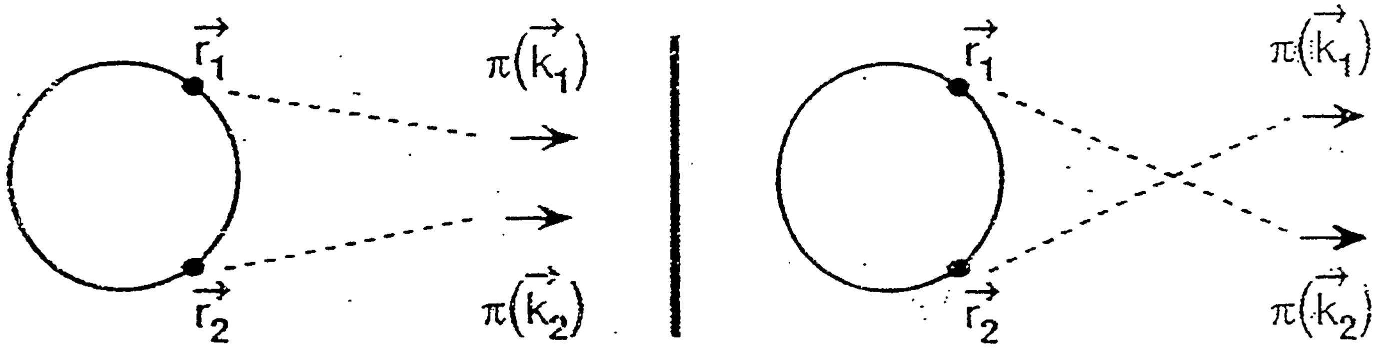
$$dN/dydp_T^2 d\phi \propto 1 + 2v_2(p_T)\cos(2\phi)$$



MG, I. Vitev and X.N. Wang, PRL(01)

Conversion of particle signals to volume measurements (Hanbury-Brown/Twiss)

Special case $t_1 = t_2$ (originally for stars)



$$|\text{Amp}|^2 \propto |e^{i\vec{k}_1\cdot\vec{r}_1 + i\vec{k}_2\cdot\vec{r}_2} + e^{i\vec{k}_2\cdot\vec{r}_1 + i\vec{k}_1\cdot\vec{r}_2}|^2$$

$$'' \quad = 1 + \cos \vec{q}\cdot\vec{r}. \quad \text{(varies from 1 to 2)}$$

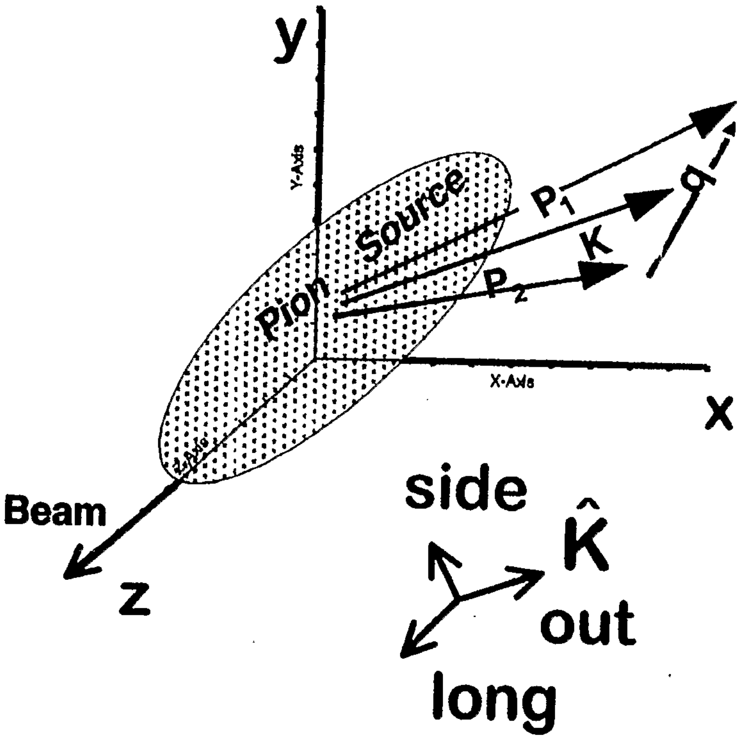
$$\vec{q} = \vec{k}_1 - \vec{k}_2 \qquad \& \qquad \vec{r} = \vec{r}_1 - \vec{r}_2$$

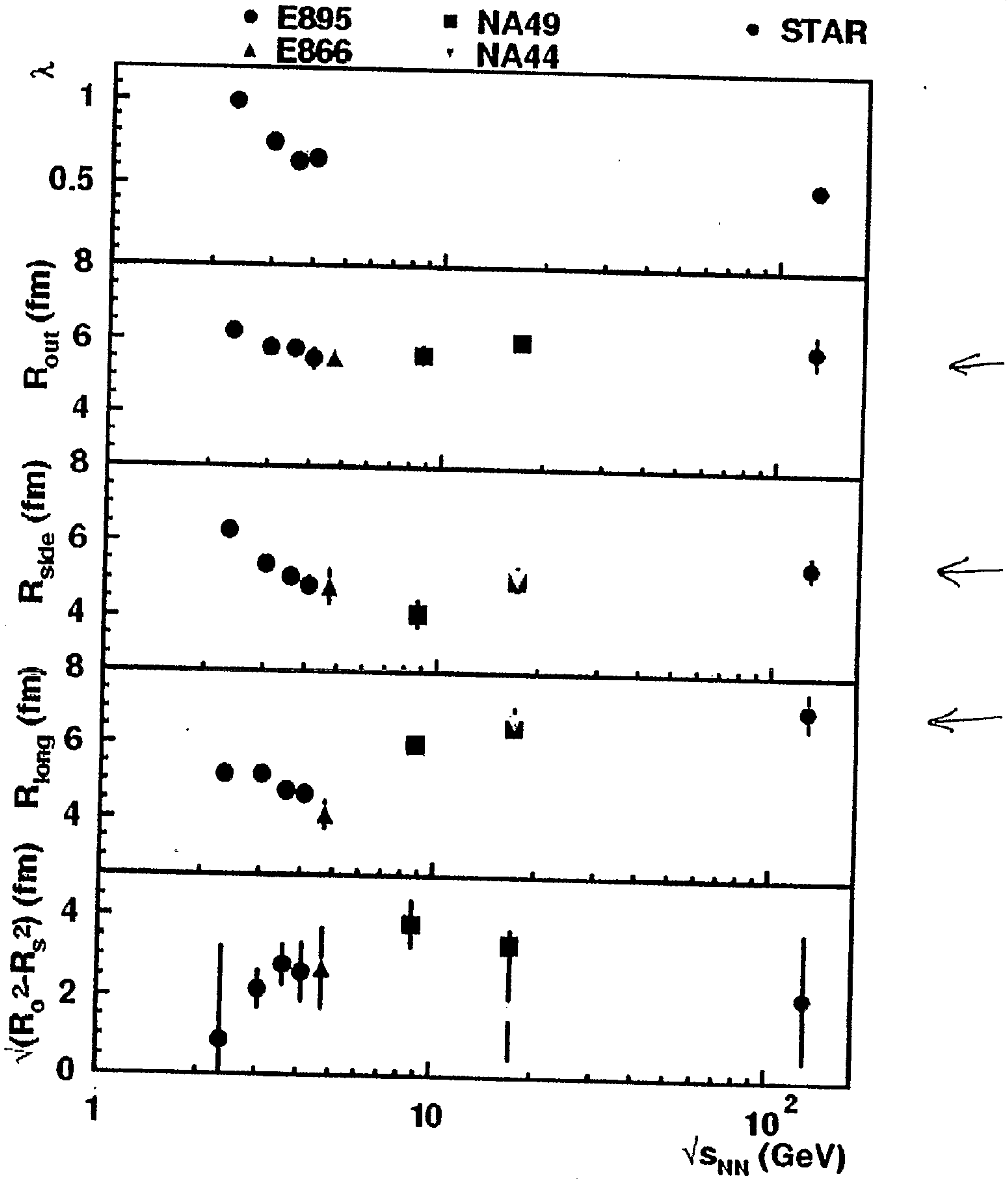
Here, π can be any bosonic channel.

For fermionic channel:

$$|\text{Amp}|^2 \propto 1 - \cos \vec{q}\bullet\vec{r}$$

AGS-SPS-RHIC
Pion Interferometry



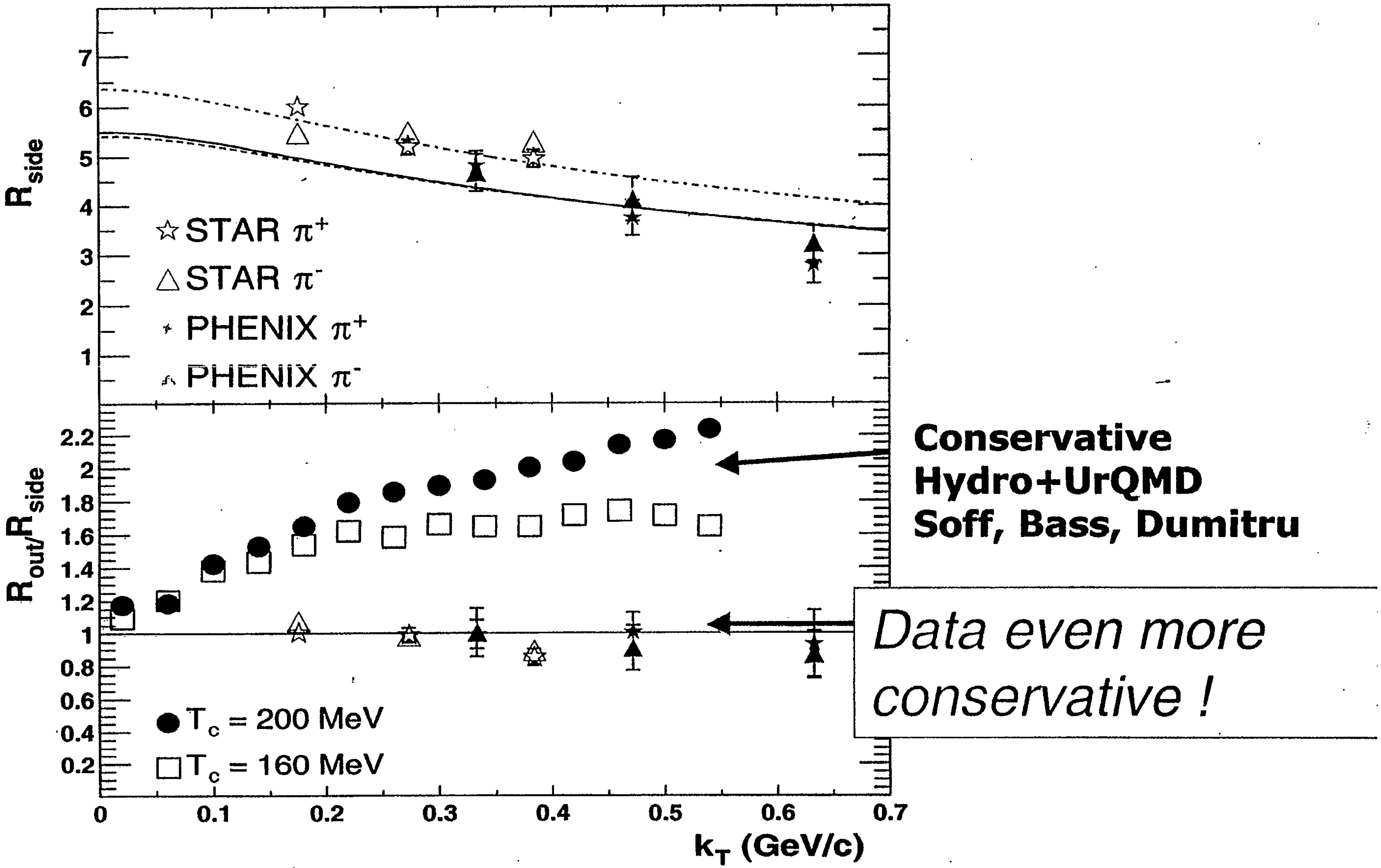


- Central AuAu (PbPb)
- R_{out}~R_{side}~R_{long}~6fm at any s??

2/7/02

Gyulassy-2

PHENIX and STAR at RHIC



QCDSP

Physics: 50 publications to date

- domain wall fermions
- CP violation (ϵ'/ϵ)
- $\Delta I = \frac{1}{2}$ rule
- phase transitions / thermodynamics
- nucleon structure (spin)
- hadron spectra

. . . . .

Personnel: 3 Fellows } RBRC
4 Postdocs
1 Visiting Scientist

The RBRC – Columbia – BNL Collaboration consists of about 20 physicists

RBRC Lattice QCD

Physics Topics

1. CP Violation
2. Nucleon structure/spin
3. Quark-gluon plasma

Personnel

2 Fellows (RBRC)

4 Postdocs (RBRC)

1 Faculty visitor (RBRC)

20 physicists (RBRC-BNL-Columbia)

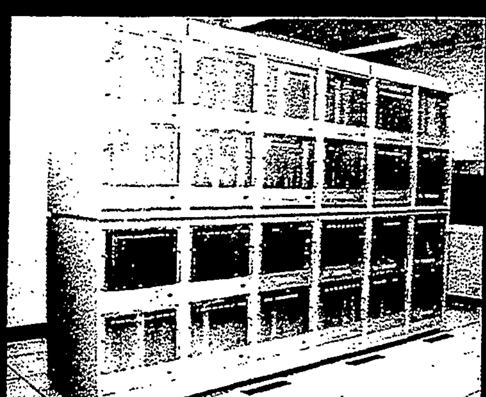
RIKEN • BNL • Columbia
Quantum Chromodynamics (QCD) Project

Quantum Chromodynamics (QCD) Project

Total Peak Speed: 1100.8 Gflops

Given the enormous computational demands of quantum field theory and the easily parallelized nature of this problem, it is natural to design and build massively parallel machines whose design is optimized for this type of calculation.

The QCDSP *(Quantum Chromodynamics on Digital Signal Processors)* computers designed at Columbia are such machines.



RIKEN • BNL Research Center

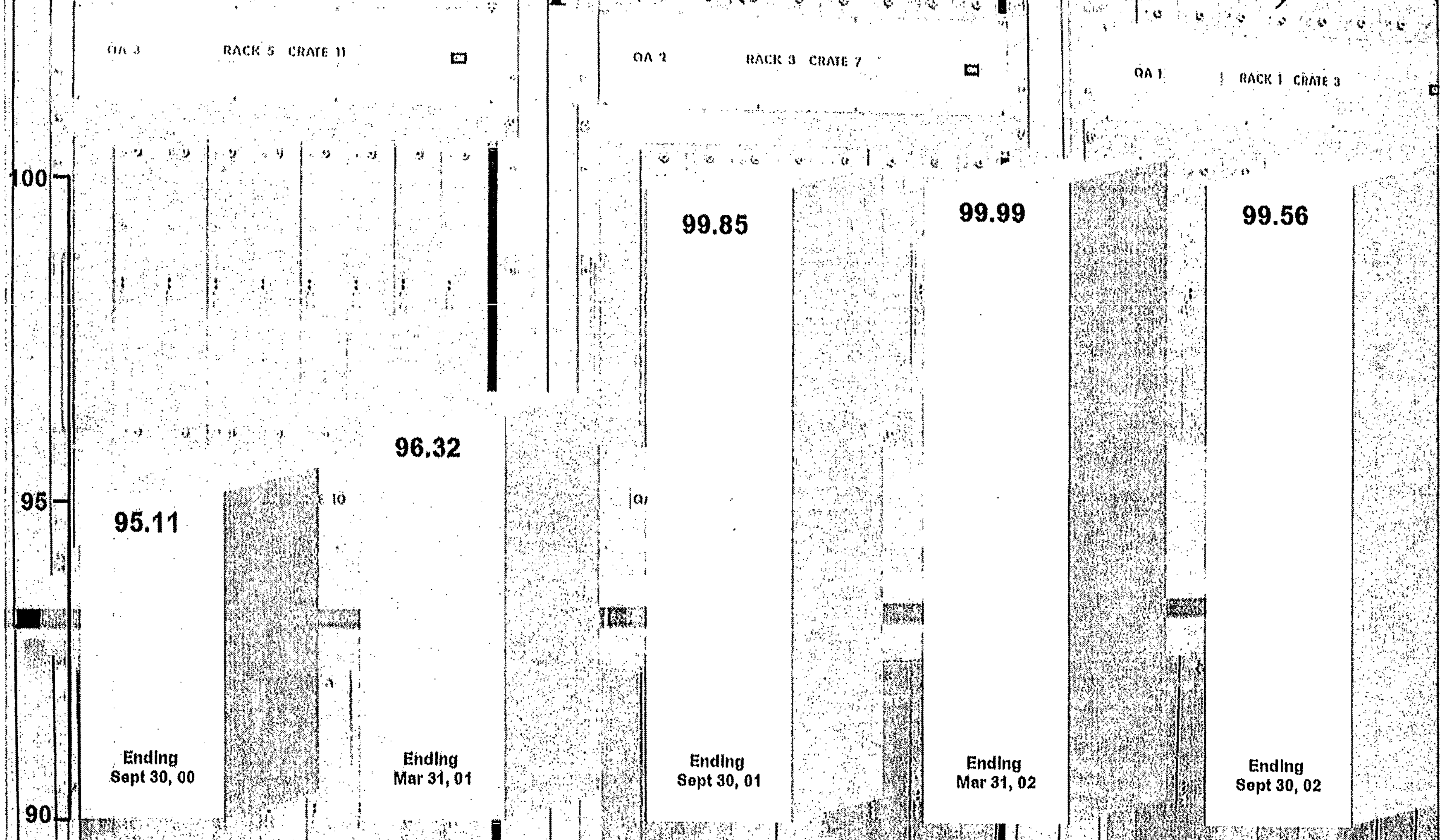
Columbia University Center

Awarded 1998
Gordon Bell Prize for
Price Performance!

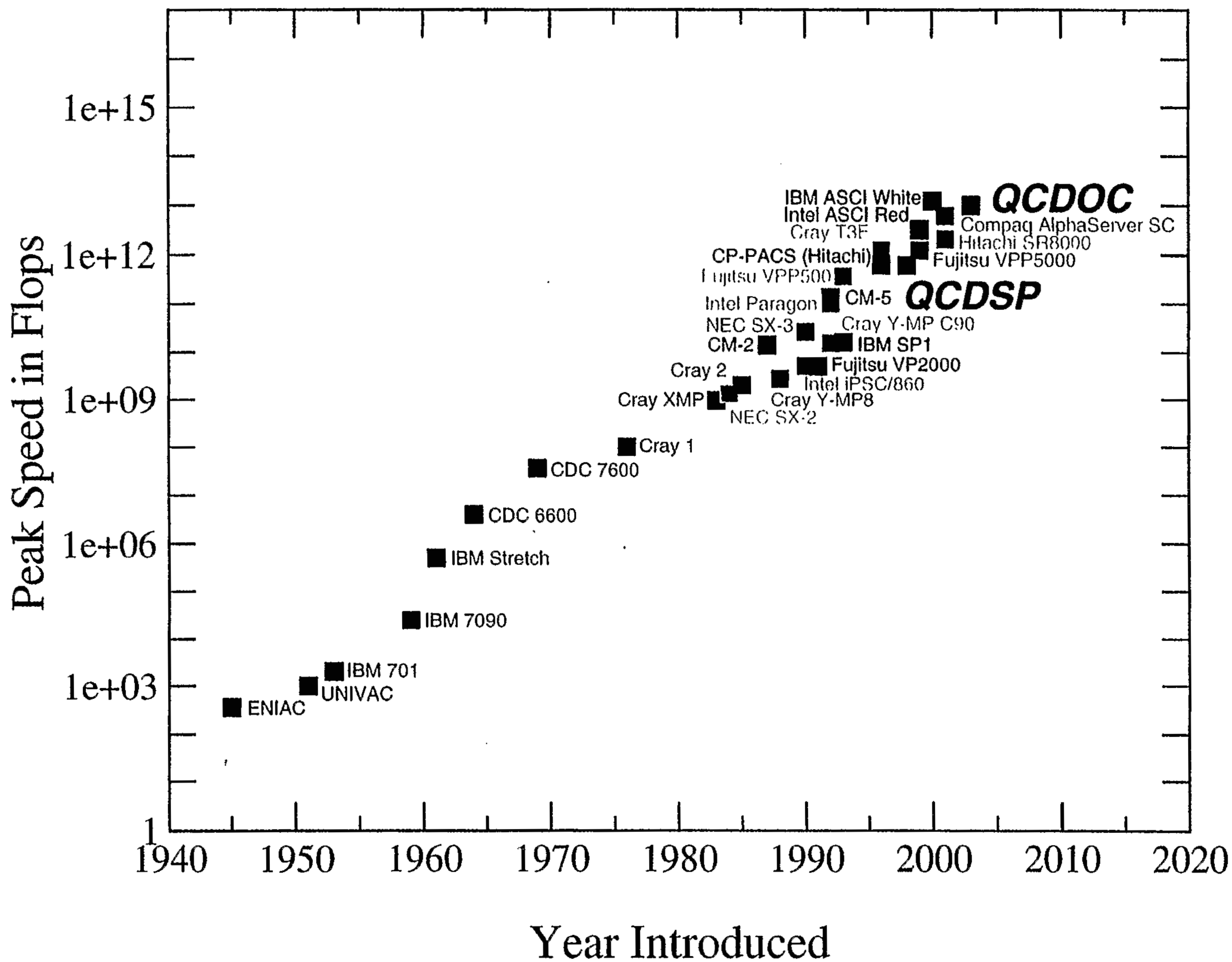
RIKEN Brookhaven Research Center

QCDSP (12,288 Nodes)

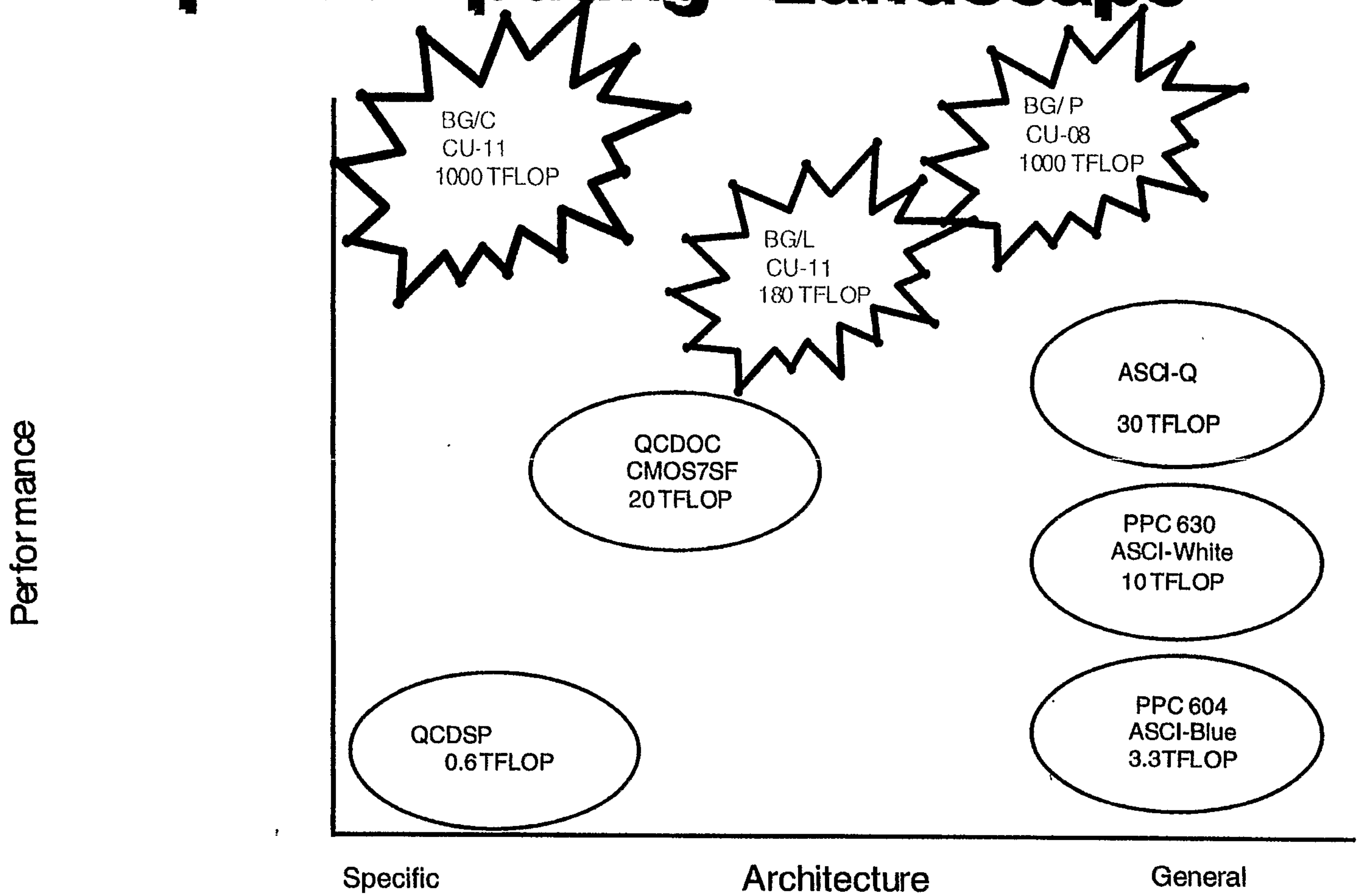
Percent of Uptime (6 month intervals)



Supercomputer Peak Performance



Supercomputing Landscape



Computer Architecture Evolution from IBM

Blue Gene Project Update at http://www.research.ibm.com/bluegene)

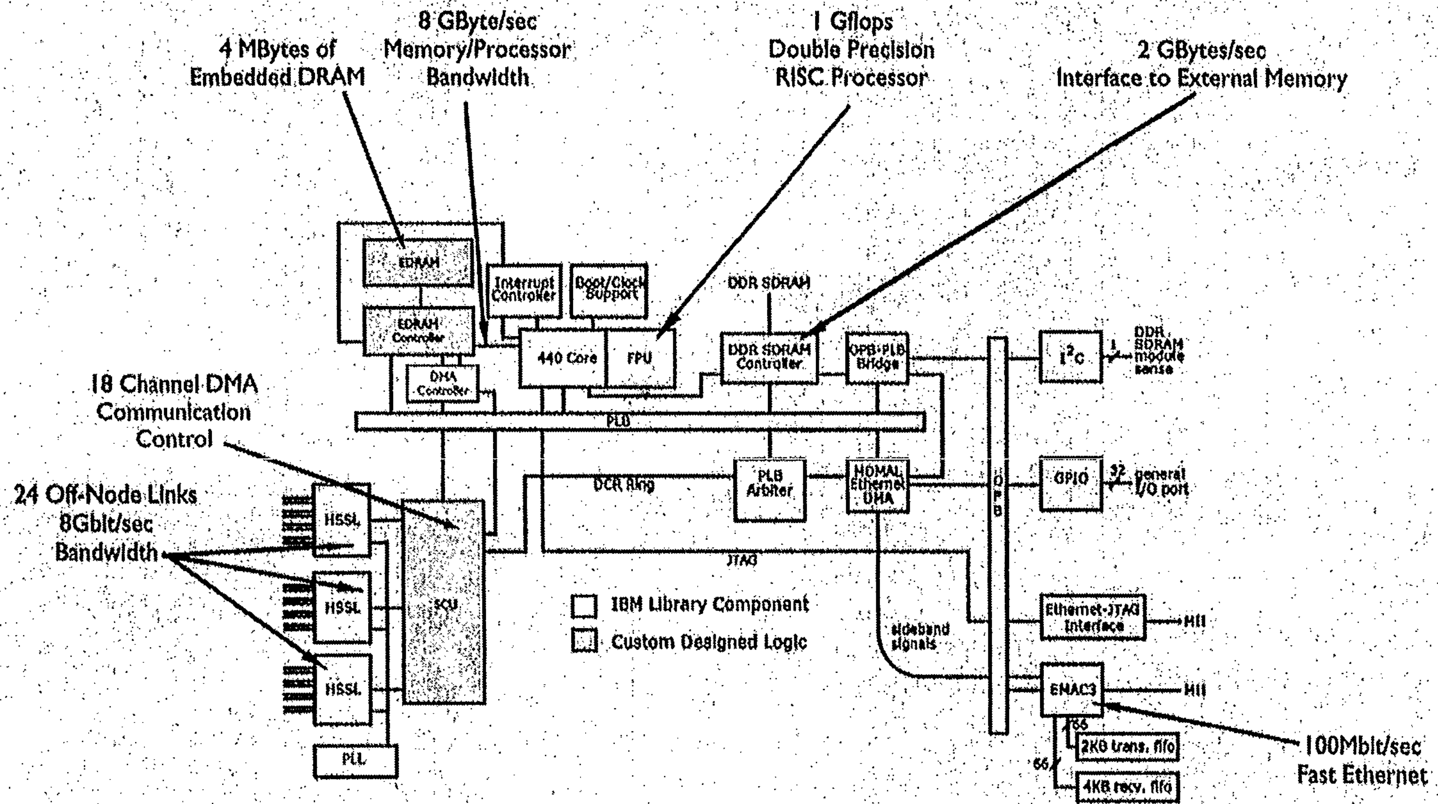
QCDOC at RBRC

1. $1 US per sustained Megaflops

2. 10 Teraflops peak speed

3. Producing physics in 2003

4. Cost: $5 Million/Funded by RIKEN



Complete Processor Node for QCD Supercomputer on a Single Chip Fabricated by IBM

RIKEN BNL Research Center

- An international research center of physics, funded by the Japanese government, but located at BNL in the U.S.

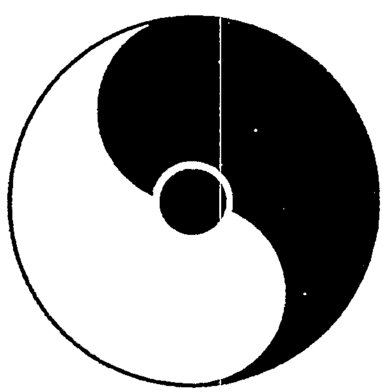
- Dedicated to the growth of a new generation of young physicists, where all senior scientists are volunteers.

道生一
一生二
二生三
三生萬物

老子

Tao creates the Unit.
The Unit creates Duality
Duality creates Trinity
Trinity creates ten thousand things

Laotse



TOL

Red sun is the emblem of Japan.
Red, Blue and White are the colors of the American flag.

RBRC Experimental Group

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N. P. Samios, RBRC Deputy Director
Hideto En'yo, RBRC Associate Director
* * * *

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Technical Collaborator
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Spin

AGS

Partial Snake
Room Temperature Solenoid
Operational for several years
~50% polarization (~30% Run I)

New Partial Snake
- Superconducting helical dipole
- ~70% polarization
- Design Completed

RHIC

Siberian Snakes (4) in tunnel Run I
Spin Rotators (8) Run II

- STAR
- PHENIX

Run I

100 GeV x 100 GeV
Transverse polarization

Performance

Sources	> 70% polarization Several x 10^{11} p pp
AGS	~30% polarization
RHIC	~80-100% retention of polarization
	$L = 1.5 \times 10^{30}/cm^2/sec$ $\beta^* = 3$ m

Run II 100 GeV x 100 GeV (250 GeV x 250 GeV)
Longitudinal Polarization ~50%
$L > 10^{31}/cm^2/sec$

Special Spin Collaboration Meetings

B. Fox (Organizer)

Physics, Accelerator } goals

Theory

Meetings and Proceedings

February 22, 2002	Volume 39
April 12, 2002 May 22, 2002 June 17, 2002 July 29, 2002	Volume 44
September 16, 2002 October 22, 2002	Volume 47

RBRC Experimental Group Publications
December 2001 to November 2002

1) J. Tojo et al., Measurement of analyzing power for proton carbon elastic scattering in the Coulomb-nuclear interference region with a 22-GeV/c polarized proton beam, Phys. Rev. Lett. 89, 052302 (2002) [arXiv:hep-ex/0206057].

2) K. Adcox et al. [PHENIX Collaboration], Measurement of the Lambda and anti-Lambda particles in Au + Au collisions at s(NN)**(1/2) = 130-GeV, Phys. Rev. Lett. 89, 092302 (2002) [arXiv:nucl-ex/0204007].

3) K. Adcox et al. [PHENIX Collaboration], Event-by-event fluctuations in mean p(T) and mean e(T) in s(NN)**(1/2) = 130-GeV Au + Au collisions, Phys. Rev. C 66, 024901 (2002) [arXiv:nucl-ex/0203015].

4) K. Adcox et al. [PHENIX Collaboration], Net charge fluctuations in Au + Au interactions at s(NN)**(1/2) = 130-GeV, Phys. Rev. Lett. 89, 082301 (2002) [arXiv:nucl-ex/0203014].

5) N. Saito, Spin Physics Program At RHIC: The First Polarized-Proton Collider, Nucl. Phys. Proc. Suppl. 105, 47 (2002).

6) M. Grosse Perdekamp, Future Transversity Measurements: Experimental Aspects, Nucl. Phys. Proc. Suppl. 105, 71 (2002).

7) K. Kurita, Proton Carbon Cni Polarimeter For RHIC, Nucl. Phys. Proc. Suppl. 105, 164 (2002).

8) A.L. Deshpande, The Eic Project: Physics Prospects And Present Status, Nucl. Phys. Proc. Suppl. 105, 178 (2002).

9) K. Adcox et al. [PHENIX Collaboration], Measurement of single electrons and implications for charm production in Au + Au collisions at s(NN)**(1/2) = 130-GeV, Phys. Rev. Lett. 88, 192303 (2002) [arXiv:nucl-ex/0202002].

10) J.T. Mitchell et al. [PHENIX Collaboration], Event reconstruction in the PHENIX central arm spectrometers, Nucl. Instrum. Meth. A 482, 491 (2002) [arXiv:nucl-ex/0201013].

11) K. Adcox et al. [PHENIX Collaboration], Transverse mass dependence of two-pion correlations in Au + Au collisions at s(NN)**(1/2) = 130-GeV, Phys. Rev. Lett. 88, 192302 (2002) [arXiv:nucl-ex/0201008].

12) K. Adcox et al. [PHENIX Collaboration], Centrality dependence of pi+-, K+-, p and anti-p production from s(NN)**(1/2) = 130-GeV Au + Au collisions at RHIC, Phys. Rev. Lett. 88, 242301 (2002) [arXiv:nucl-ex/0112006].

13) K. Adcox et al. [PHENIX Collaboration], First Results From RHIC-PHENIX, Pramana 57, 355 (2001).

THEORY PRESENTATIONS

Baryogenesis and Dark Matter

Alexander Kusenko

Baryogenesis and dark matter

- Roadmap of baryogenesis
- EW baryogenesis *at preheating*
- Affleck – Dine baryogenesis and non-topological solitons
- Baryogenesis and **dark matter**:
  Can we understand why $\Omega_{\rm matter}/\Omega_{\rm dark} \sim \mathbf{0.1}$?

Baryogenesis

$$\eta \equiv \frac{n_B}{n_\gamma} = 10^{-10}$$

(observations, nucleosynthesis, etc.)

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Conditions for baryogenesis

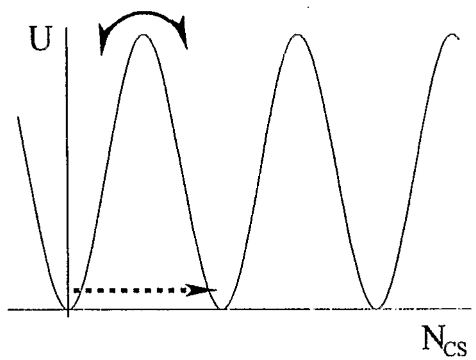
Baryogenesis requires [Sakharov '67; Kuzmin '70]:

- $\mathbf{B}, \mathbf{C}, \mathbf{CP}$ violation
- universe out of thermal equilibrium

N.B. In 1967 the only argument in favor of B violation was... theoretical ambitions

All three conditions are satisfied in the Standard Model (to some extent)

- **B** violation



Instantons violate B with
$\sigma \propto e^{-4\pi/\alpha} \sim 10^{-170}$
(tunneling)
too small!

At high temperature transitions occur via sphalerons, over the barrier. No suppression!

In the Standard Model

- $\mathbf{B}$ violation
- $\mathbf{B}, \mathbf{C}, \mathbf{CP}$ not conserved
- universe out of equilibrium at EW phase transition

ELECTROWEAK BARYOGENESIS!

[Kuzmin, Rubakov, Shaposhnikov '85]

[McLerran, a lot of people]

Unfortunately, EW baryogenesis in the SM does not work.

- **Phase transition too weak**. B asymmetry is washed out if sphaleron transitions proceed after PT.

  Need $(v(T_c)/T_c) > 1 \Rightarrow m_H < 45\text{GeV}$, ruled out!

- **CP violation too small**

  CKM $\Rightarrow \eta \equiv \frac{n_B}{n_\gamma} \sim 10^{-20} \times (\ldots)$ too small

Can SUSY help? (More scalar fields, more parameters...)

Cannot make baryons in SM $\Rightarrow$ need new physics

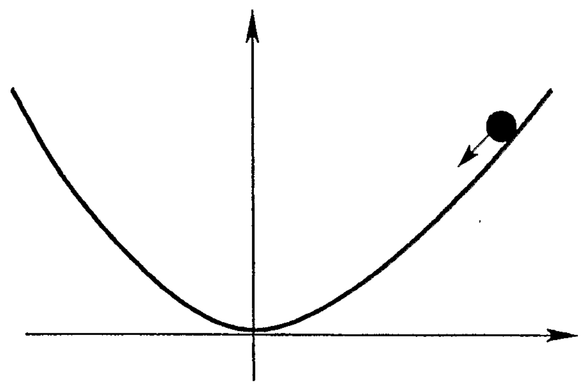
Inflation

Standard cosmology has problems:

- horizon problem
- flatness problem
- unwanted relics

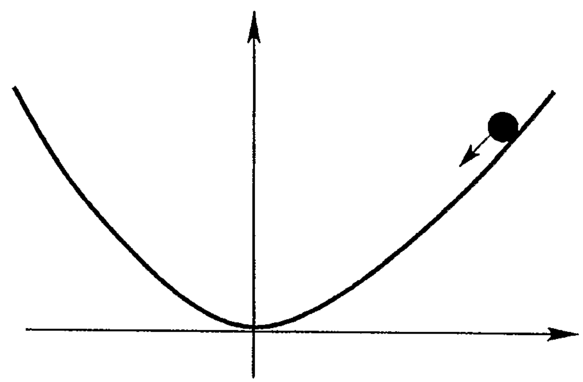
Inflation, a period of rapid expansion of the universe, solves these problems and explains the density perturbations in CMBR

Inflation



$$\ddot{\phi} + 3H\dot{\phi} = -V'(\phi)$$

Inflation

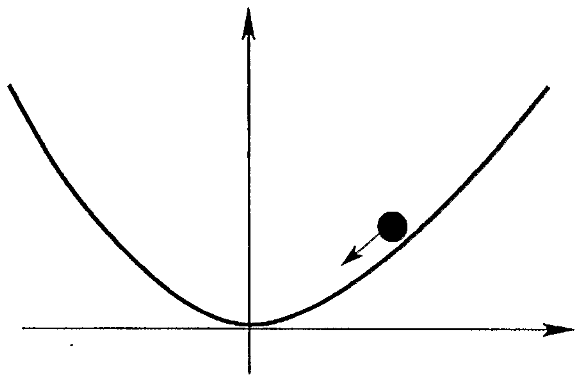


$$\ddot{\phi} + 3H\dot{\phi} = -V'(\phi) \approx \mathbf{0}$$

For $H \times (\phi/\dot{\phi}) \gg 1$, $T_{\mu\nu} \approx V(\phi) \times \delta_{\mu\nu}$

$\Rightarrow$ rapid expansion: $\boldsymbol{R(t) \propto \exp\{Ht\}}$, $H = \frac{8\pi G}{3} V(\phi)$.

Inflation



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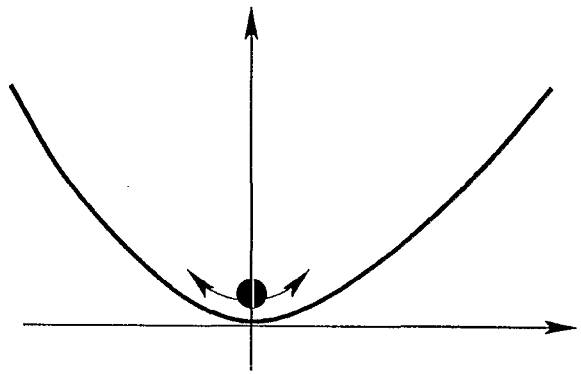
$\Rightarrow$ rapid expansion: $\boldsymbol{R(t)} \propto \mathbf{exp}\{\boldsymbol{Ht}\}$, $H = \frac{8\pi G}{3} V(\phi)$.

Reheating



A special kind of reheating, characterized by a **resonant** amplification of the field motions on superhorizon scales, is dubbed **preheating** .

All matter is produced during reheating. Universe out of equilibrium!

An opportune time for baryogenesis!

EW baryogenesis at preheating

- **B violation can occur non-thermally** [García-Bellido, Grigoriev, AK, Shaposhnikov] (*cf.* RHIC physics similar to $T > 0$)

- Preheating following inflation is a period when the universe is very far from thermal equilibrium

- Time-dependent scalar condensate $\Rightarrow$ CP non-invariant background

- Wash-out of baryon asymmetry can be prevented if $\boldsymbol{T_R < 100}$ **GeV**

$\Rightarrow$ EW baryogenesis at preheating

[Krauss, Trodden; García-Bellido,Grigoriev, AK,Shaposhnikov]

Parametric resonance:

Equation of motion for the Higgs has growing solutions:

$$\ddot{\phi}_k + [k^2 - M^2 + 3\lambda\langle\phi^2\rangle + g^2\sigma^2(t)]\phi_k = 0$$

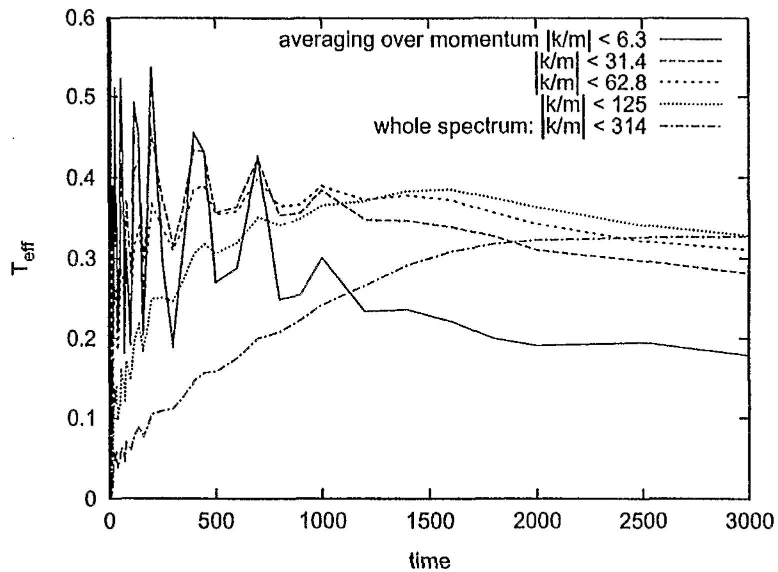
Energy flow: Inflaton $\rightarrow$ Higgs $\rightarrow$ W,Z,...sphalerons?

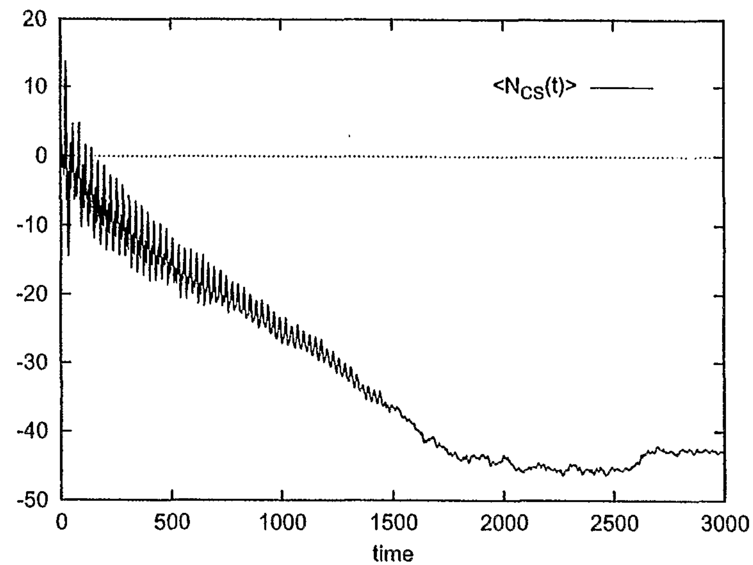
Estimate: $\Gamma_{\rm sph} \approx \alpha_W^4 T_{\rm eff}^4$ ($T_{\rm eff}$ from the low-energy modes)

This estimate agrees with numerical simulations in 1+1 dimensions

García-Bellido, Grigoriev, AK, Shaposhnikov Phys.Rev.D60:123504,1999

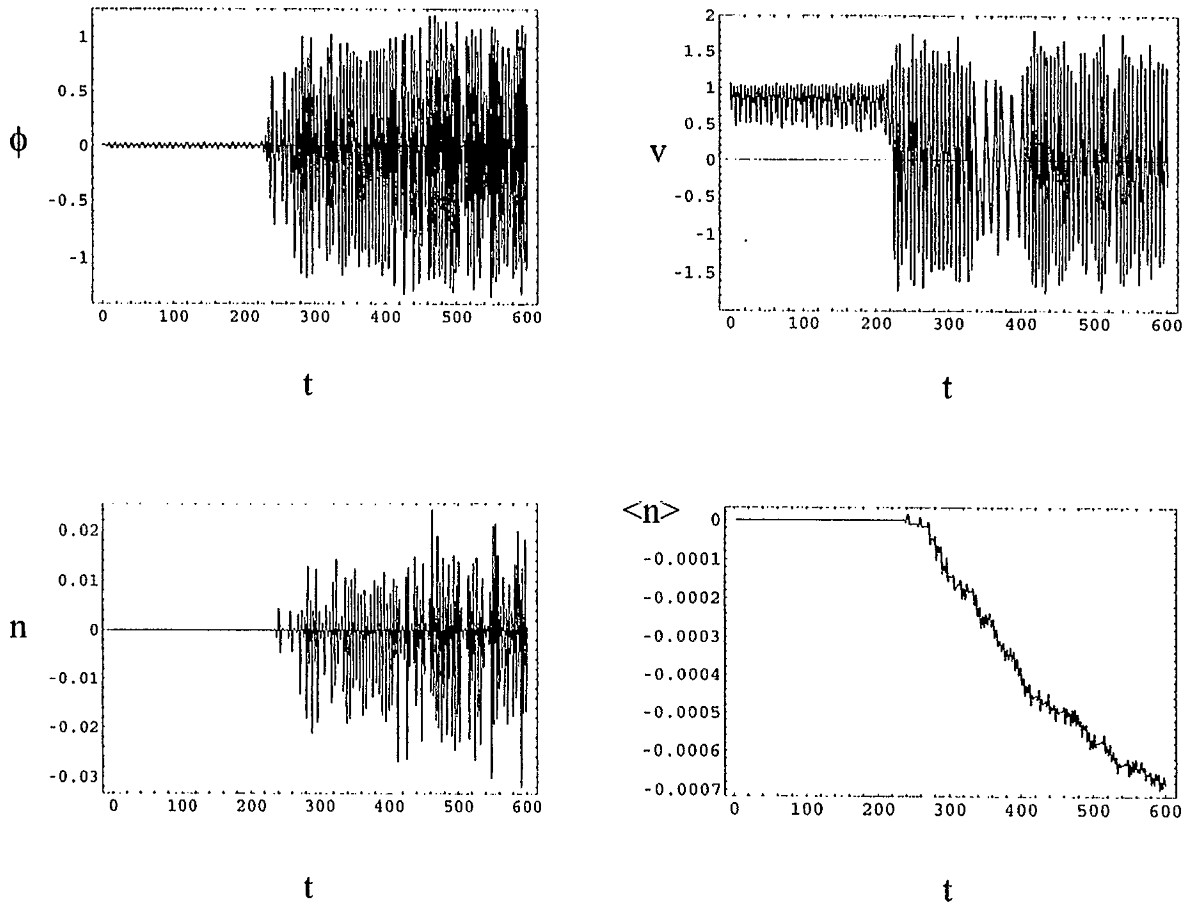
Numerical analyses





U(1) gauge field A_μ plus Higgs filed ϕ. C,CP violation introduced by term $\kappa\,\phi^*\phi\,\epsilon_{\mu\nu}F^{\mu\nu}$.
In 1+1, the analogue of anomaly is $\partial_\mu j^\mu_F = -\frac{e}{4\pi}\,\epsilon_{\mu\nu}F^{\mu\nu}$, where $j^\mu_F = \bar\psi\gamma^\mu\psi$

numerical simulations confirm B violation:



CP violation?

CP from CKM does not work: $\eta \ll 10^{-20}$

CP violation in the Higgs sector?

Lee model of CP violation.

Higgs potential:

$$
\begin{aligned}
V(H_1, H_2) &= \lambda_1 (H_1^\dagger H_1 - v_1^2)^2 \\
&+ \lambda_2 (H_2^\dagger H_2 - v_2^2)^2 \\
&+ \lambda_3 [(H_1^\dagger H_1 - v_1^2) + (H_2^\dagger H_2 - v_2^2)]^2 \\
&+ \lambda_4 [(H_1^\dagger H_1)(H_2^\dagger H_2) - (H_1^\dagger H_2)(H_2^\dagger H_1)] \\
&+ \lambda_5 [\mathrm{Re}(H_1^\dagger H_2) - v_1 v_2 \cos \xi]^2 \\
&+ \lambda_6 [\mathrm{Im}(H_1^\dagger H_2) - v_1 v_2 \sin \xi]^2
\end{aligned}
$$

$\lambda_5, \lambda_6 \neq 0 \Rightarrow$ *Spontaneous CP violation*

Spontaneous baryogenesis at preheating

[Cornwall,Grigoriev,AK] .

B violation much faster than thermalization $\Rightarrow$ baryon number has time to equilibrate to min of free energy

The effective chemical potential μ_{B} is proportional to $\dot{\theta}$, and the equilibrium value of baryon asymmetry is

$$n_{B} \sim \langle\dot{\theta}\rangle T_{R}^{2} \sim 10^{-10}\, T_{R}^{3} \left(\frac{10^{-5} t_{H}}{t_{R}}\right)$$

where t_{R} is the time of reheating and t_{H} is the Hubble time at the electroweak scale

One can make baryons if

- Inflation ended with reheat temperature $T_R < T_{EW} \sim 100$ GeV
- CP violation is present in the Higgs sector (Lee model)
- The inflaton is coupled to the Higgs.

Other (plausible) possibilities

- Leptogenesis (simple, plausible)
- Affleck-Dine baryogenesis (requires SUSY; can produce dark matter)

Leptogenesis

Electroweak sphalerons erase any primordial $(B+L)$

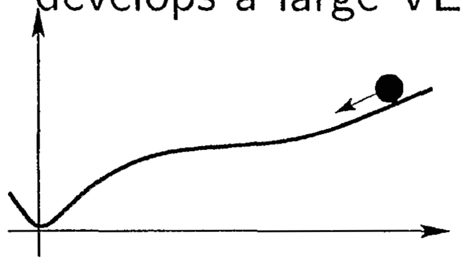
However, if high-scale physics produced some non-zero $(B-L)$, electroweak sphalerons could redistribute the asymmetry between B and L [Fukugita,Yanagida]

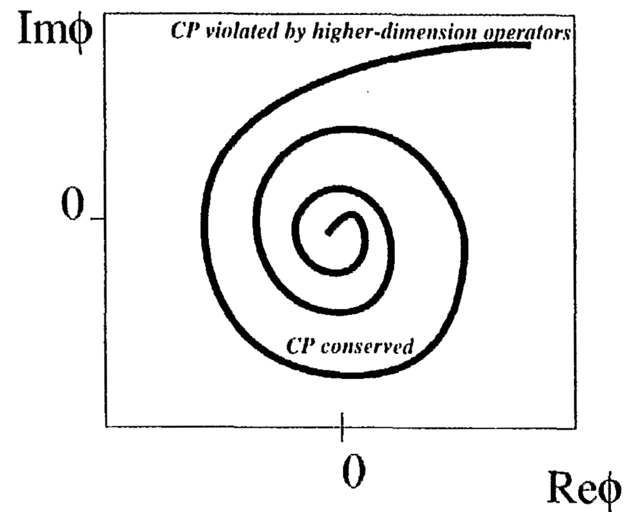
Example: decay of a heavy right-handed neutrino (L is not conserved)

CP violation in the neutrino mass matrix?

Affleck-Dine baryogenesis

at the end of inflation
a scalar B-condensate
develops a large VEV

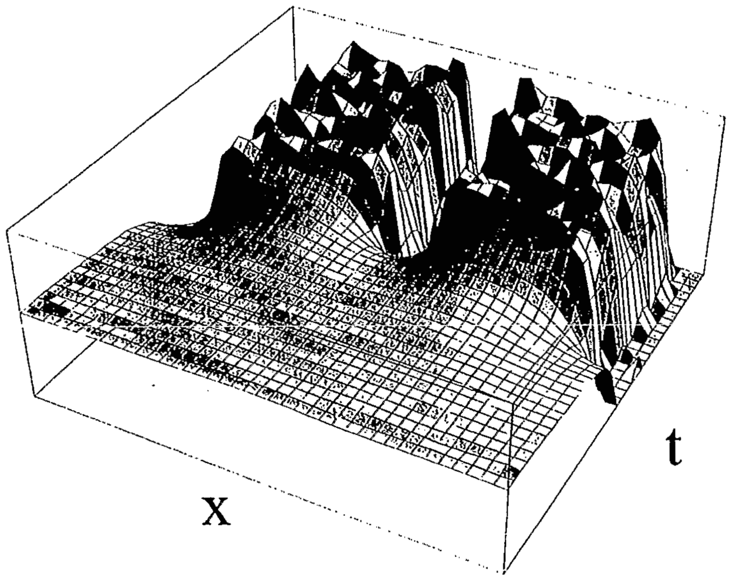




$$\phi = \rho(t) e^{i\omega t} \Rightarrow B \neq 0$$

CP violation is due to time-dependent background.
Seeds - from high-scale physics.

Fragmentation of the Affleck-Dine condensate



[AK, Shaposhnikov; Enqvist, McDonald]

small inhomogeneities can grow

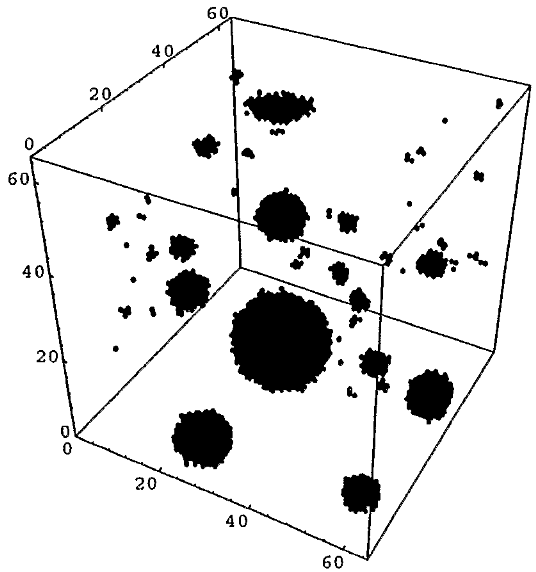
unstable modes:

$$0 < k < k_{\max} = \sqrt{\omega^2 - U''(\phi)}$$

$\Rightarrow$ **Lumps of baryon condensate**

$\Rightarrow$ **NTS**

Numerical simulations of the fragmentation



[Kasuya, Kawasaki]

Non-topological solitons (NTS)

Let us consider a complex scalar field $\phi(x,t)$ in a potential that respects a $U(1)_B$ symmetry: $\phi \to e^{i\theta}\phi$. vacuum: $\phi = 0$

conserved $\boldsymbol{B}$ charge: $\boldsymbol{B} = \frac{1}{2i}\int \left(\phi^\dagger \overleftrightarrow{\partial}_0 \phi\right) d^3x$

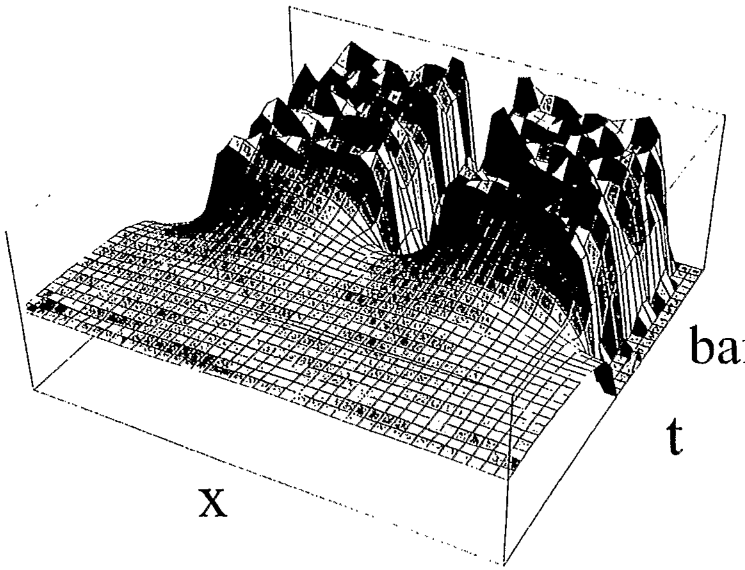
$\boldsymbol{B} \neq \boldsymbol{0} \Rightarrow \phi \neq \boldsymbol{0}$ in some finite domain

$\Rightarrow$ NTS [Friedberg, Lee, Sirlin; Coleman]

NTS appear in SUSY extensions of the Standard Model [AK]

The Affleck-Dine condensate is just a giant NTS: $\phi = \rho(t) e^{i\omega t}$

Fragmentation of Affleck-Dine condensate can produce NTS



SUSY NTS may be stable or unstable
if stable ⇒ **dark matter**

Affleck–Dine condensate → baryons
Affleck–Dine condensate → baryonic NTS
baryonic NTS → unstable → baryons
unstable ⇢ dark matter
baryonic NTS → stable → dark matter

[AK, Shaposhnikov]

One can relate Ω_{B} and Ω_{DARK}

Conclusions

- One can make baryons with just
  - the Standard Model
  - plus the second Higgs and CP violation [T.D. Lee]
  - plus an inflaton coupled to the Higgs sector

- Alternatively, in the Affleck – Dine scenario, both matter and dark matter form in the same process. Therefore, one can try to explain why $\Omega_{\rm matter}/\Omega_{\rm dark} \sim 0.1$.

Analysis of Heavy-Ion Collisions at RHIC with the Parton Cascade Model

Steffen A. Bass

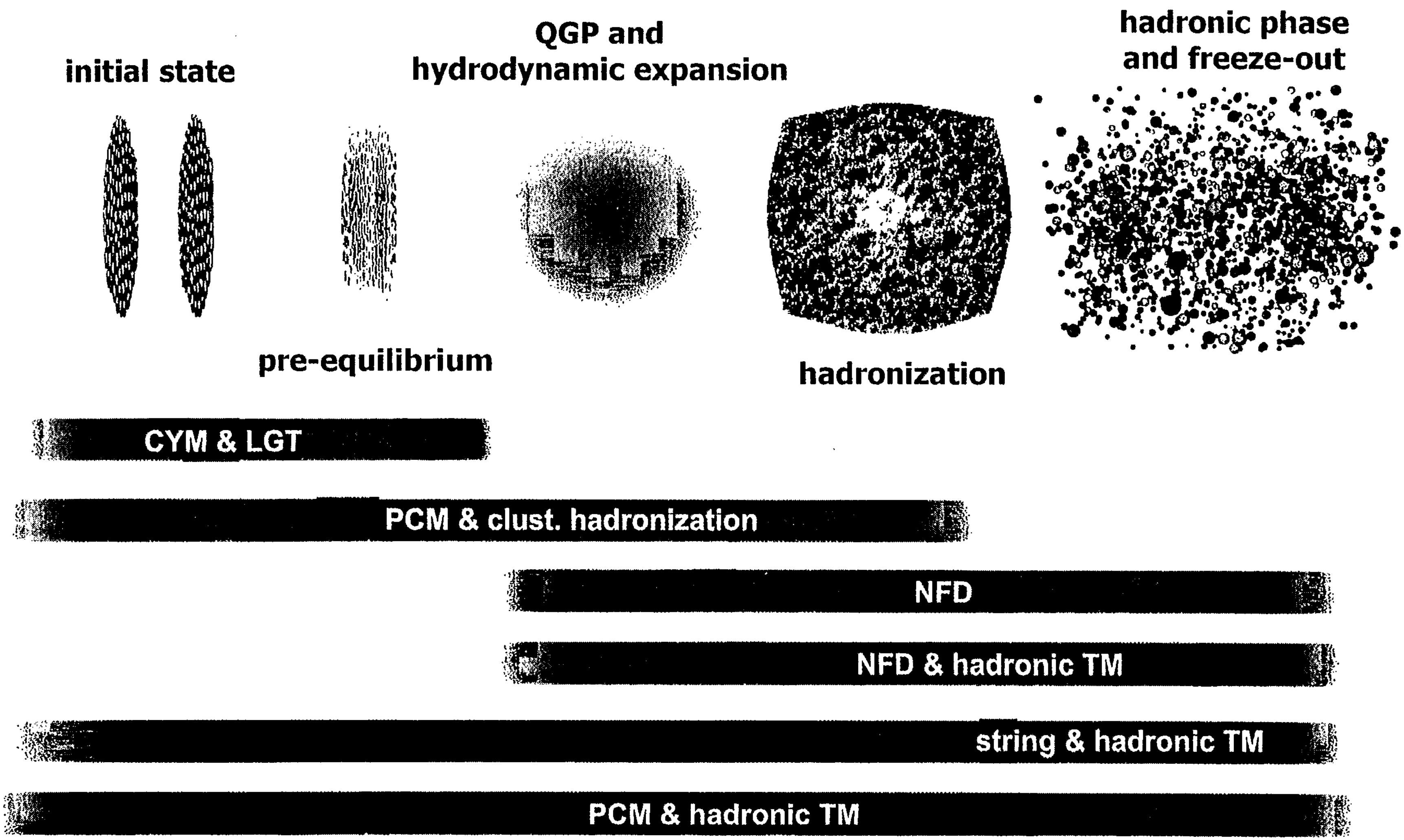
Analysis of Heavy-Ion Collisions at RHIC with the Parton Cascade Model

Steffen A. Bass, Berndt Mueller, Dinesh K. Srivastava

Duke University
RIKEN BNL Research Center
VECC Calcutta

- Motivation
- The PCM: Fundamentals & Implementation
- Tests: comparison to pQCD minijet calculations
- Application: Reaction Dynamics @ RHIC
- Outlook & Plans for the Future

Transport Theory at RHIC

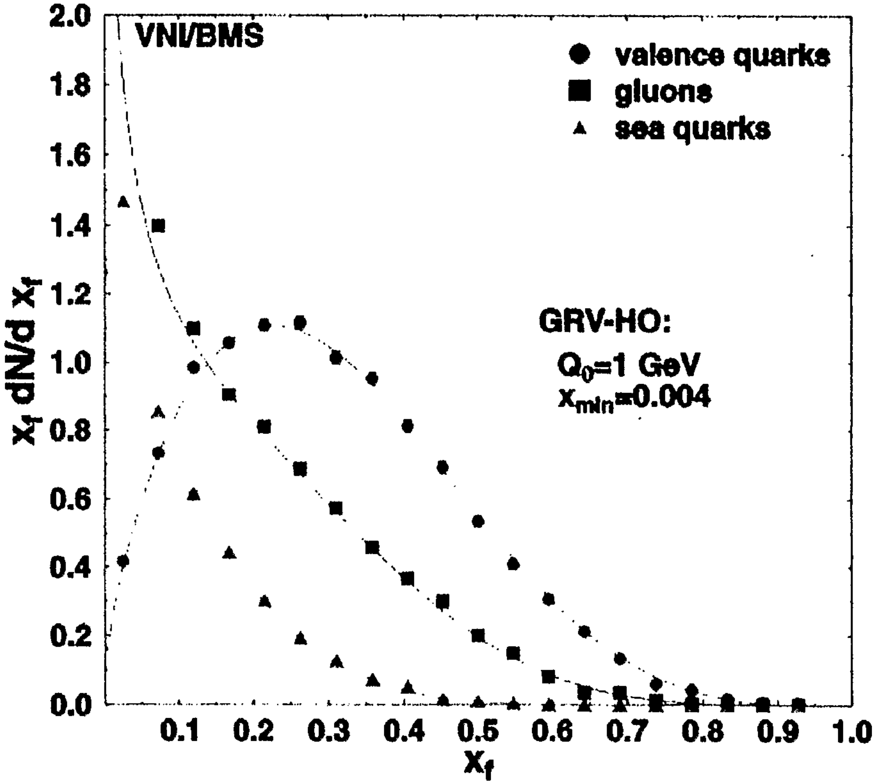


Basic Principles of the PCM

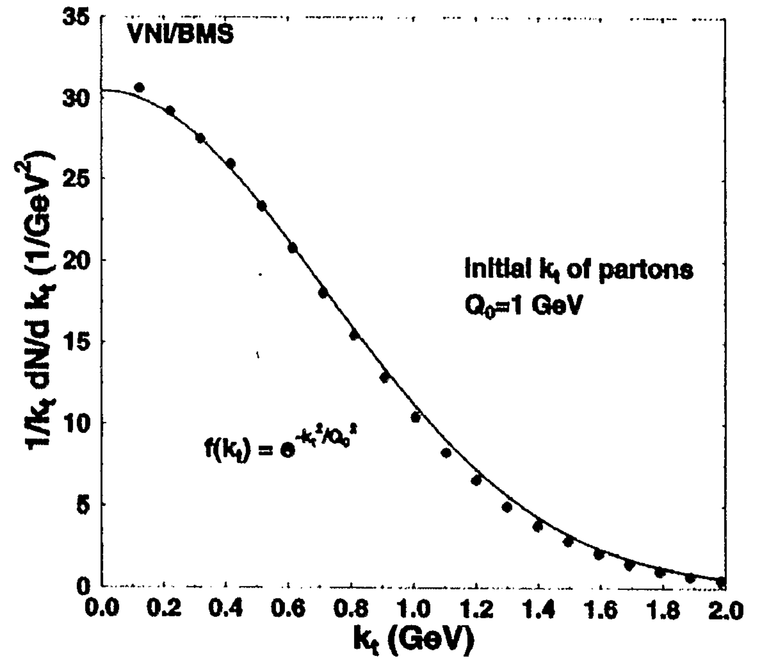
Goal: provide a microscopic space-time description of relativistic heavy-ion collisions based on perturbative QCD

- degrees of freedom: quarks and gluons
- classical trajectories in phase space (with relativistic kinematics)
- initial state constructed from experimentally measured nucleon structure functions and elastic form factors
- an interaction takes place if at the time of closest approach d_{min} of two partons
- system evolves through a sequence of binary ($2 \rightarrow 2$) elastic and inelastic scatterings of partons and initial and final state radiations within a leading-logarithmic approximation ($2 \rightarrow N$)
- binary cross sections are calculated in leading order pQCD with either a momentum cut-off or Debye screening to regularize IR behaviour
- guiding scales: initialization scale Q_0, p_T cut-off p_0 / Debye-mass $_D$

Initial State: Parton Momenta



- flavour and x are sampled from PDFs at an initial scale Q_0 and low x cut-off x_{min}
- initial k_t is sampled from a Gaussian of width Q_0 in case of no initial state radiation



- virtualities are determined by:

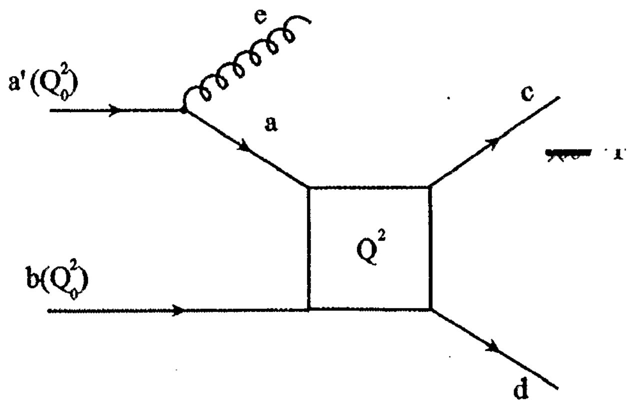
Parton-Parton Scattering Cross-Sections

g g → g g	[illegible]	q q′ → q q′	[illegible]
q g→ q g	[illegible]	q qbar→ q′ qbar′	[illegible]
g g → q qbar	[illegible]	q g →q _	[illegible]
q q → q q	[illegible]	q qbar → g _	[illegible]
q qbar → q qbar	[illegible]	q qbar → _ _	[illegible]
q qbar → g g	[illegible]		

- a common factor of $\pi_{\_s}^{2}(Q^{2})/s^{2}$ etc.
- further decomposition according to color flow

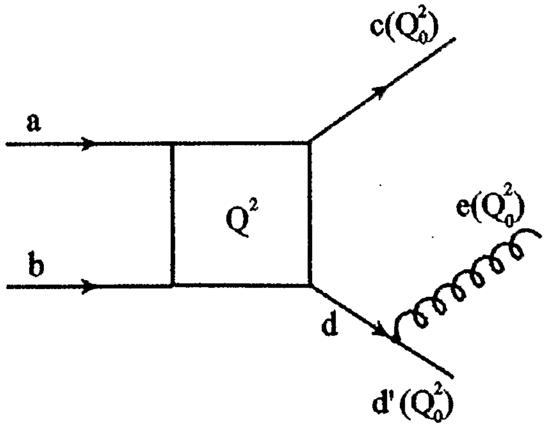
Initial and final state radiation

Probability for a branching is given in terms of the Sudakov form factors:



88

space-like branchings:



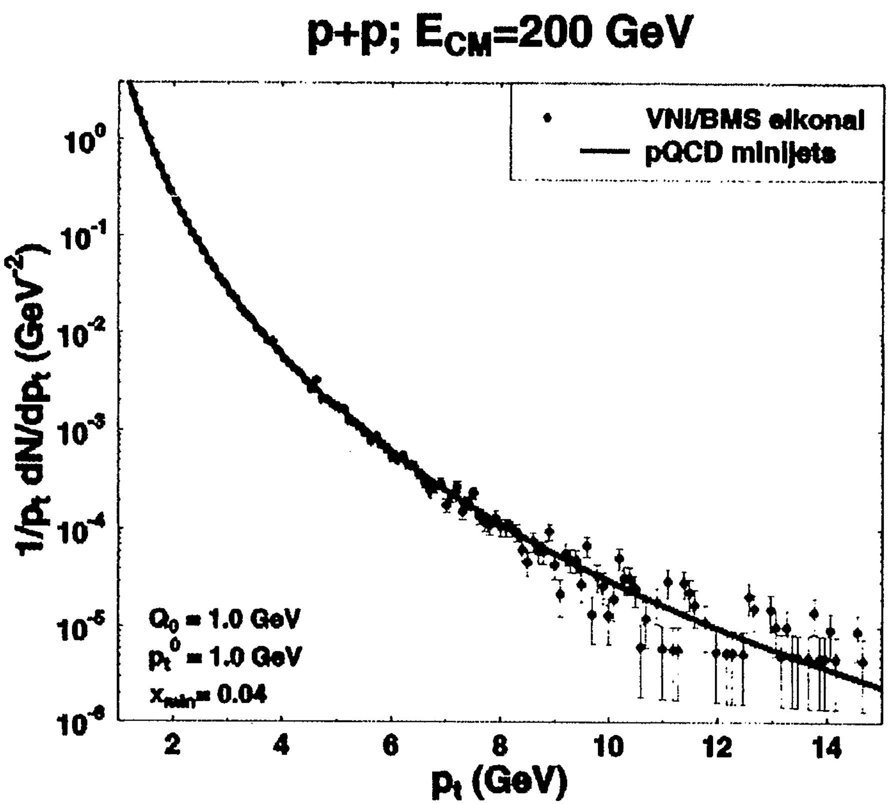
time-like branchings:

- Altarelli-Parisi splitting functions included:

$P_{q\to qg}$, $P_{g\to gg}$, $P_{g\to qqbar}$ & $P_{q\to q\_}$

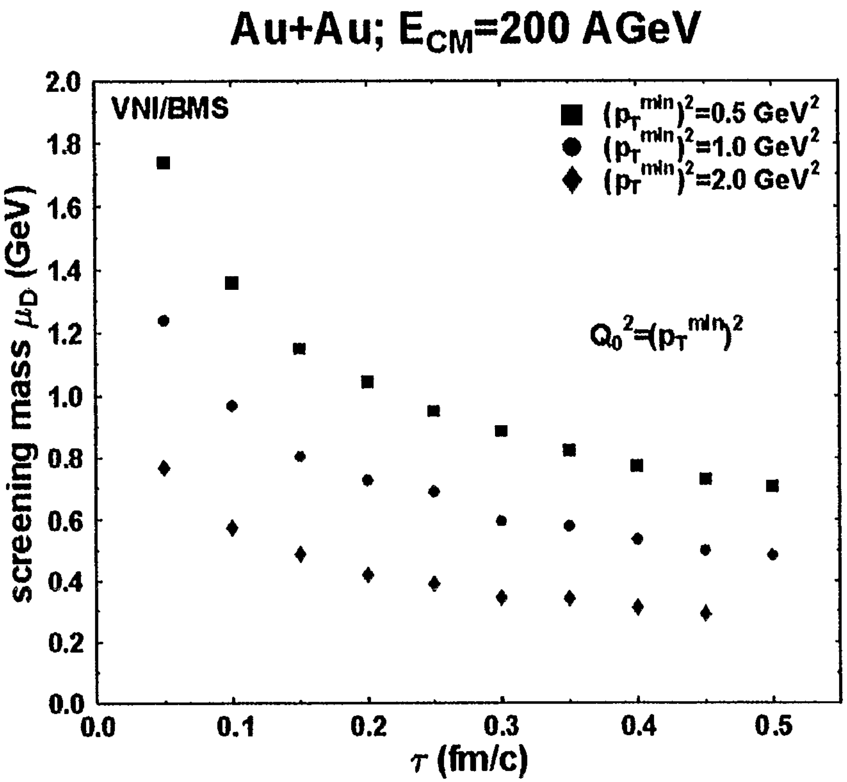
Testing the PCM Kernel: p_t distribution

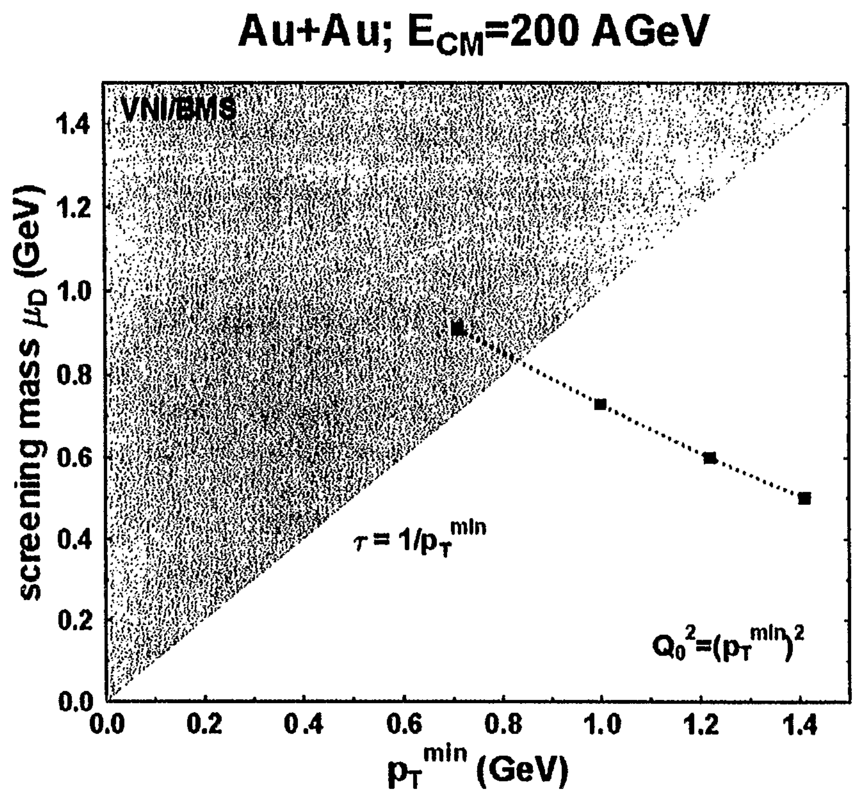
- the minijet cross section is given by:



- equivalence to PCM implies:
  - keeping the factorization scale $Q^2 = Q_0^2$ with _s evaluated at Q^2
  - restricting PCM to eikonal mode, without initial & final state radiation
- results shown are for b=0 fm

Choice of p_T^{min}: Screening Mass as Indicator



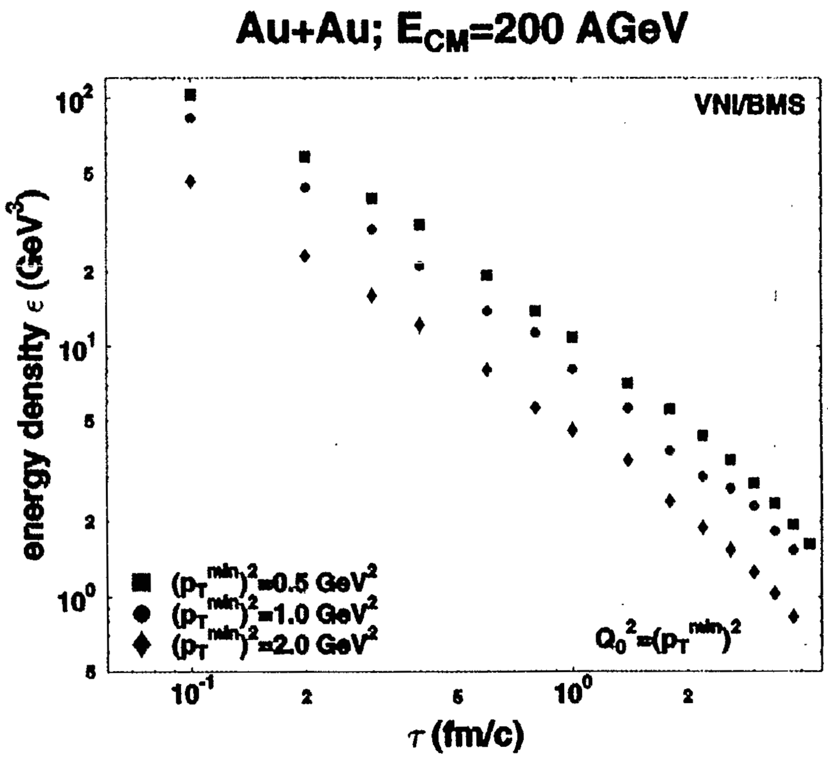


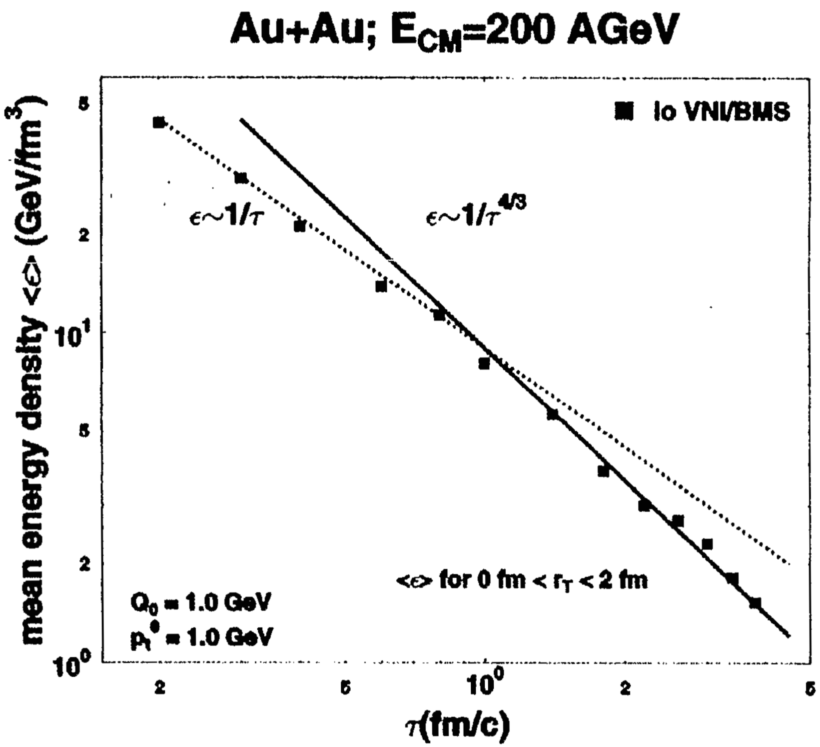
- screening mass $_D$ is calculated in one-loop approximation
- time-evolution of $_D$ reflects dynamics of collision: varies by factor of 2!
- model self-consistency demands $p_T^{min}> _D$:

➢ lower boundary for p_T^{min} : approx. 0.8 GeV

Time Evolution of Energy Density

energy-density at y_{CM} is caculated from:



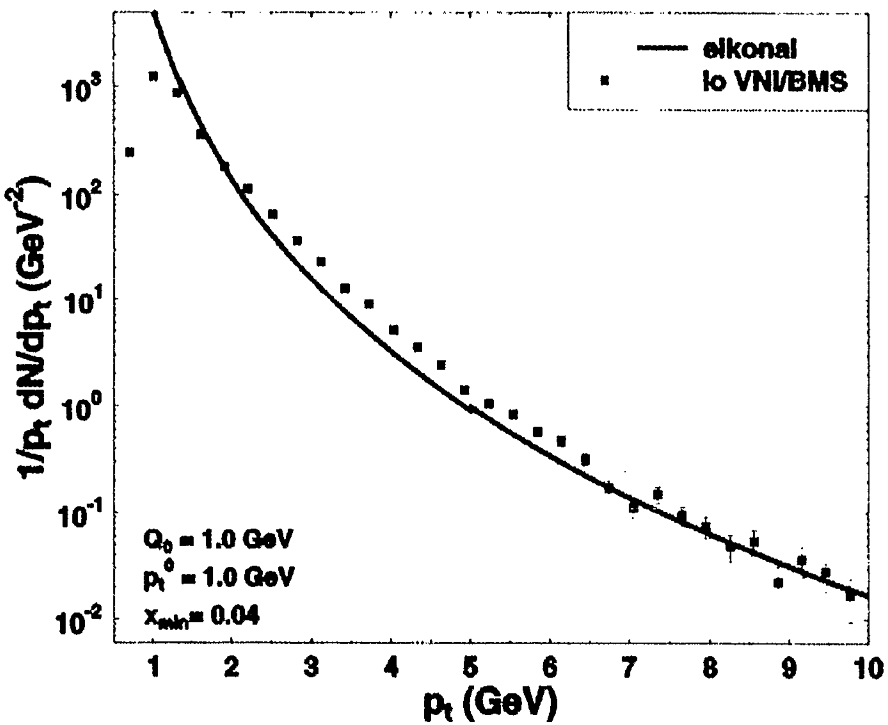


- maximum energy density ~100 GeV/fm^3
- scaling indicative for transition from 1D longitudinal to 3D expansion

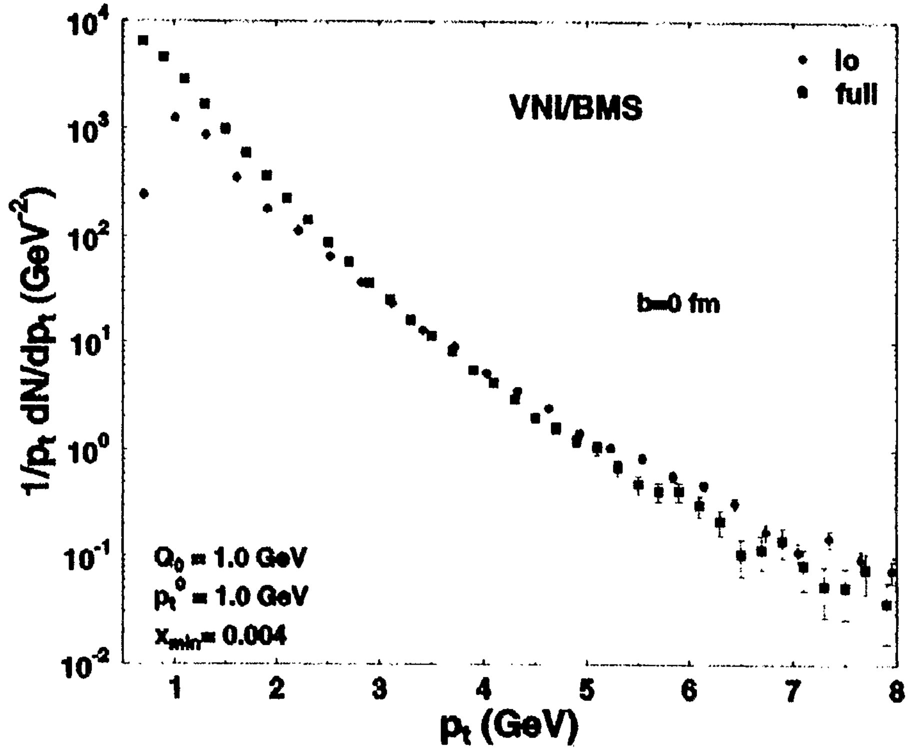
Bass, Mueller, Srivastava

Multiple Scattering and Radiation

Au+Au; E_{CM}=200 AGeV



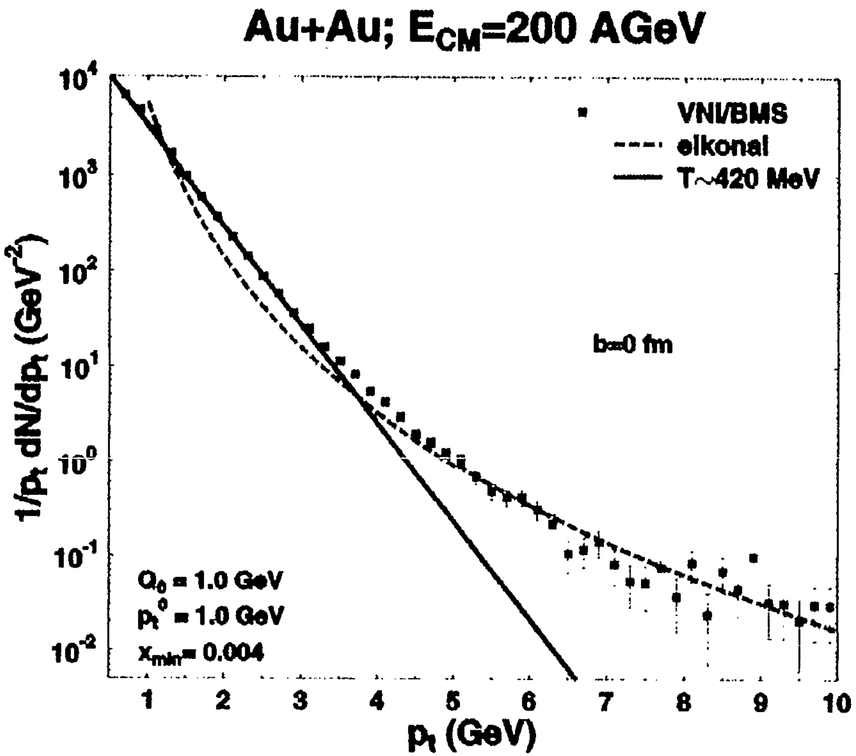
Au+Au; E_{CM}=200 AGeV

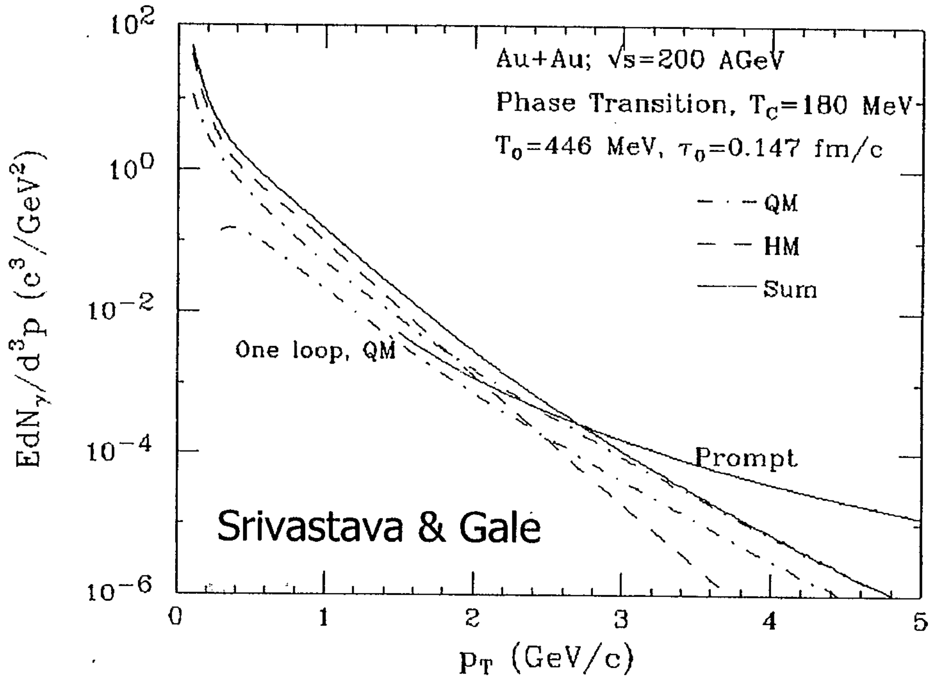


- multiple scattering broadens momentum distribution at intermediate p_t

- radiation enhances low p_t domain and leads to suppression at high p_t
  - ➢ Jet Quenching at p_t > 5 GeV?

Thermalization?





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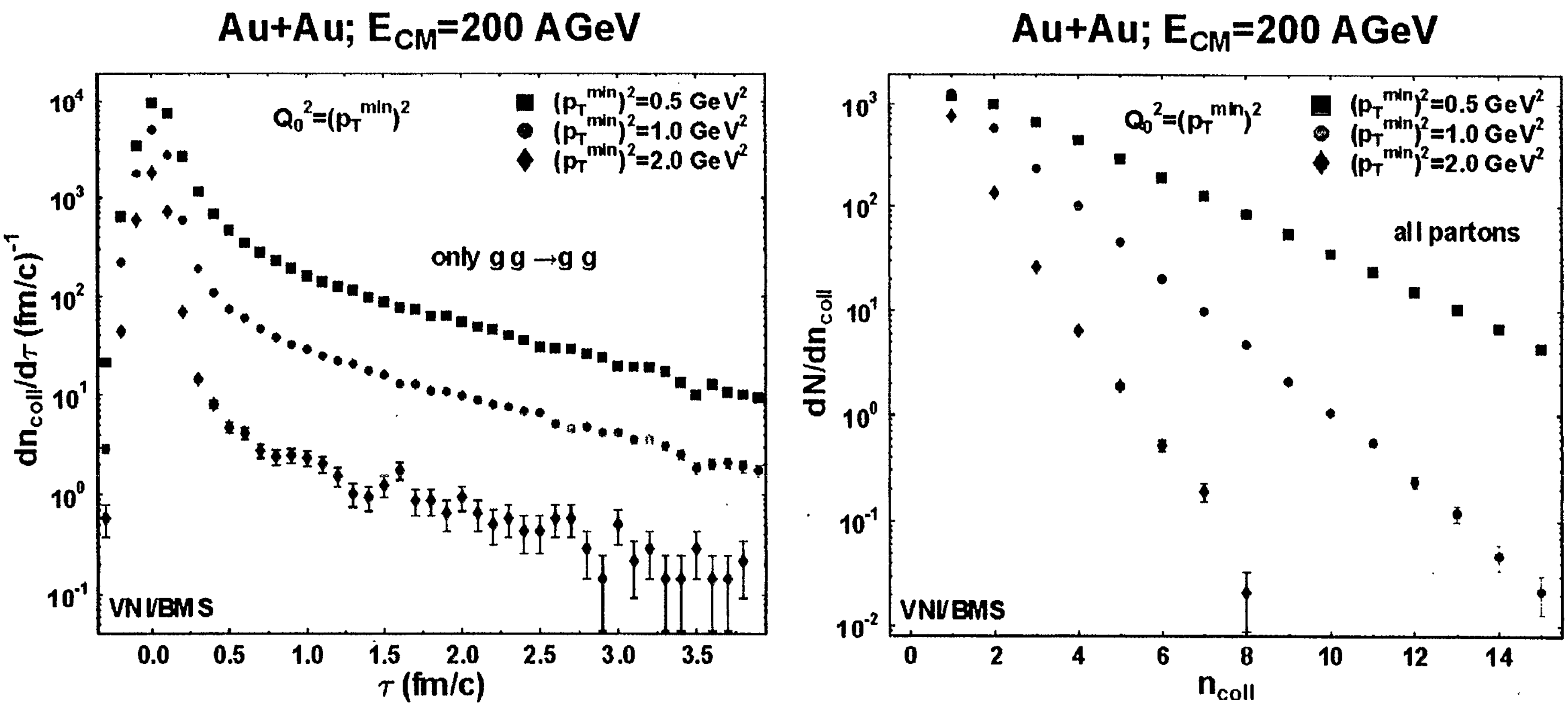
- spectrum exhibits thermal behaviour for p_t < 4 GeV
- thermalization due to radiation and rescattering?

Bass, Mueller, Srivastava

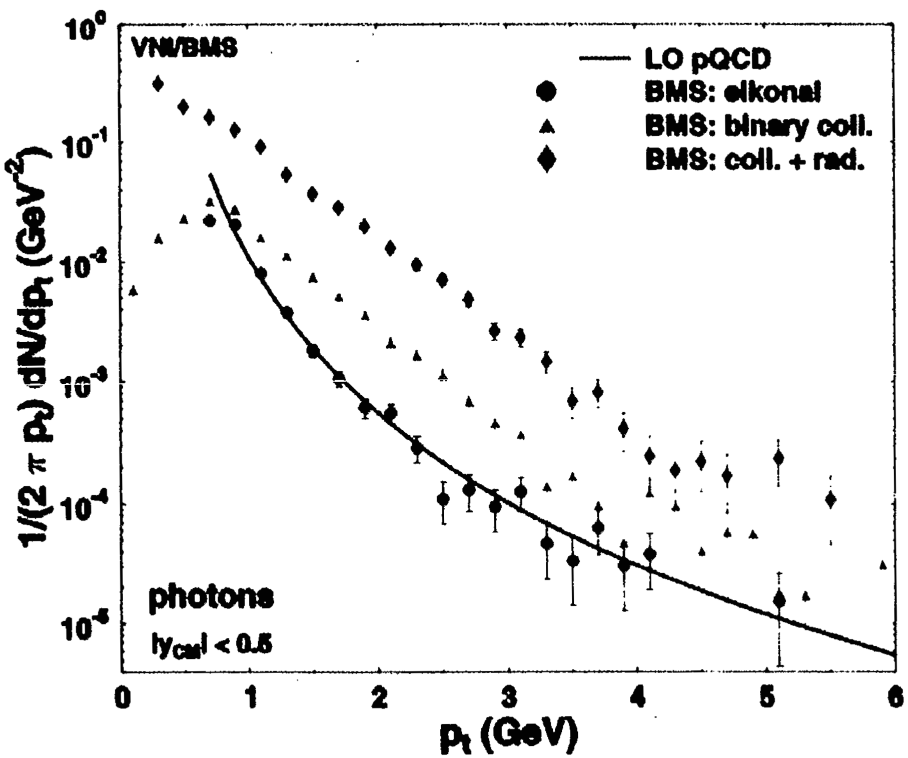
- initial temperature estimated from measured dN/dy and Bjorken's formula: 446 MeV

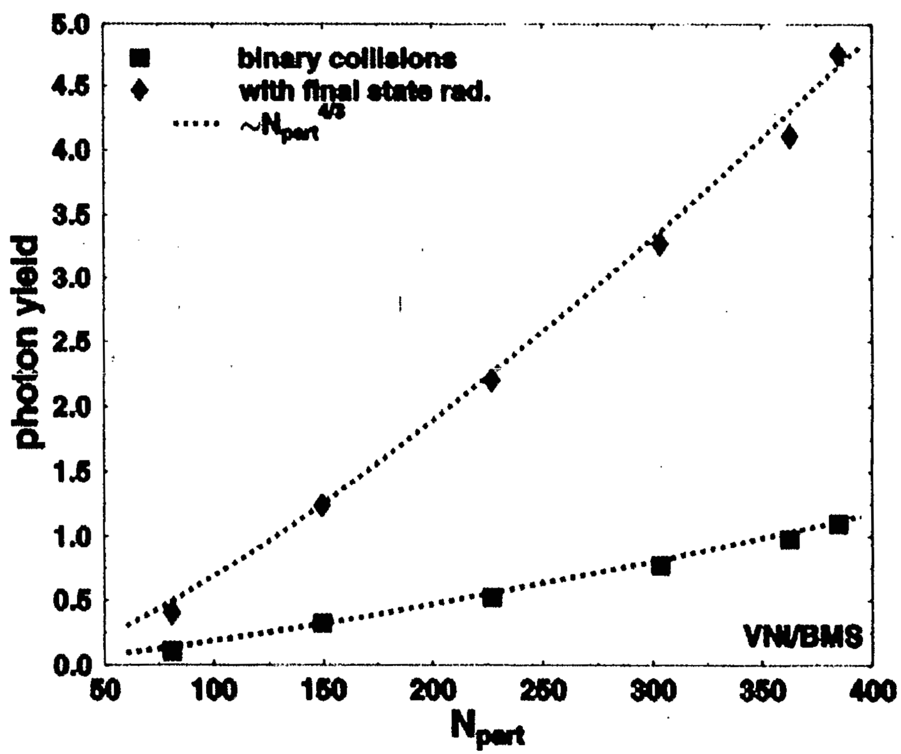
Parton Rescattering: cut-off Dependence



- duration of perturbative (re)scattering phase: approx. 2-3 fm/c
- decrease in p_t cut-off strongly enhances parton rescattering
- are time-scales and collision rates sufficient for thermalization?

Photon Production in the PCM





➢photon yield very sensitive to parton-parton rescattering

- photon yield scales with $N_{part}^{4/3}$

➢ photon yield directly proportional to the # of hard collisions

Bass, Mueller, Srivastava

Future Directions ...

The VNI/BMS approach provides an ideal framework for:

- study of event by event fluctuations
- investigating the detailed dynamics of jet-quenching
- study of medium modification of QCD processes
- studying the transition of a shattered Colour Glass to a QGP
- study of propagation & recombination of heavy quarks
- investigating models of hadronization
- dovetailing to hydrodynamics & hadronic cascades

- suggestions and collaborative endeavours on these and related issues are most welcome!

Numerical Gluodynamics for AA Collisions at RHIC: An Update

Raju Venugopalan

Melting the Color Glass Condensate

Initial Conditions at RHIC & LHC

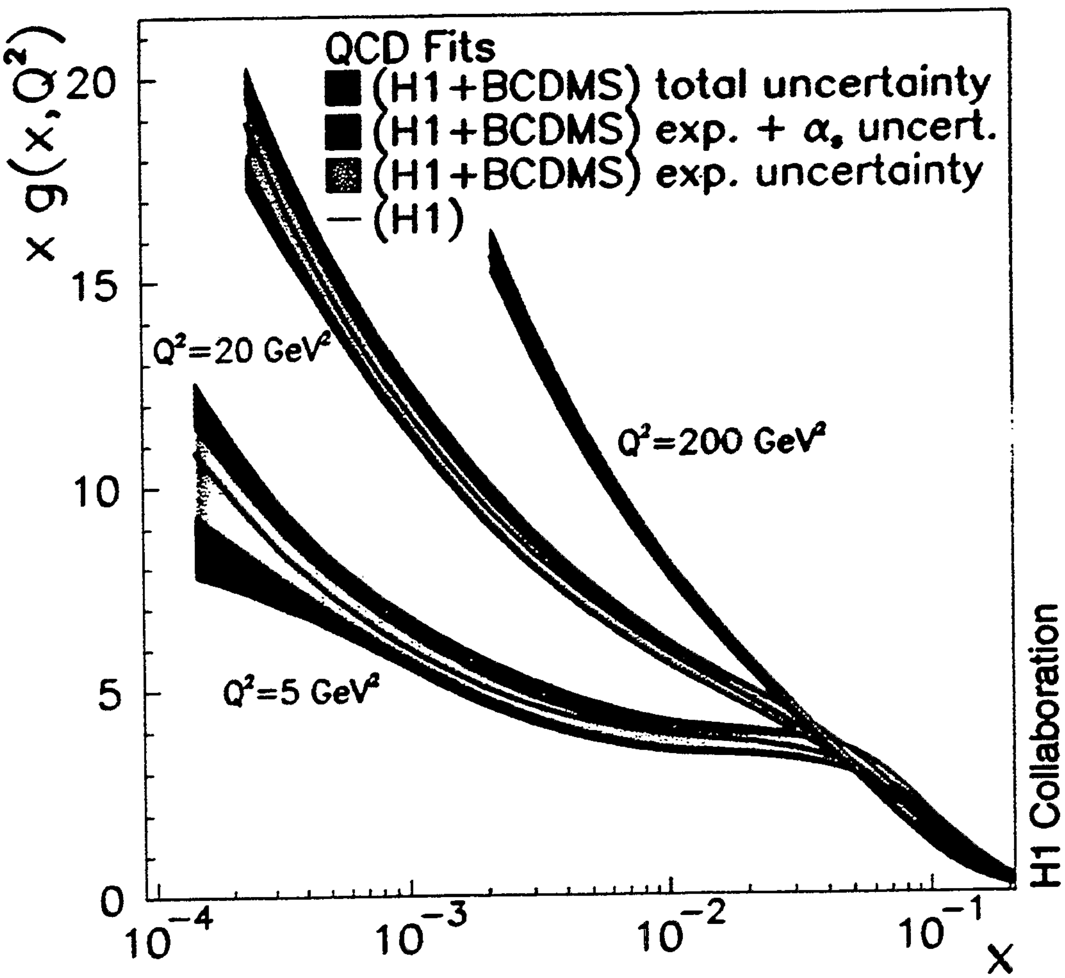
Raju Venugopalan

Physics Dept. & RIKEN-BNL Center
Brookhaven National Laboratory

Colored Glass Condensate

What is a C G C ?

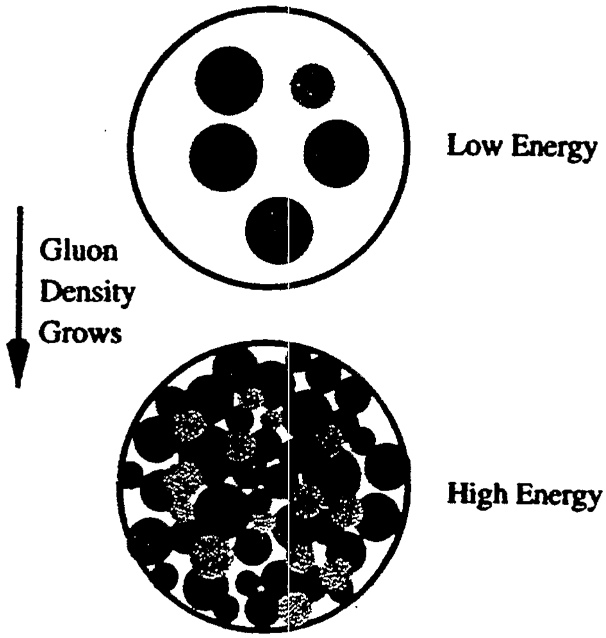
- QCD at high energy (small x_{bj})
  - Large number of gluons



Colored Glass Condensate

What is a C G C ?

- Gluon field strength is large $F^{\mu\nu} \sim 1/g$

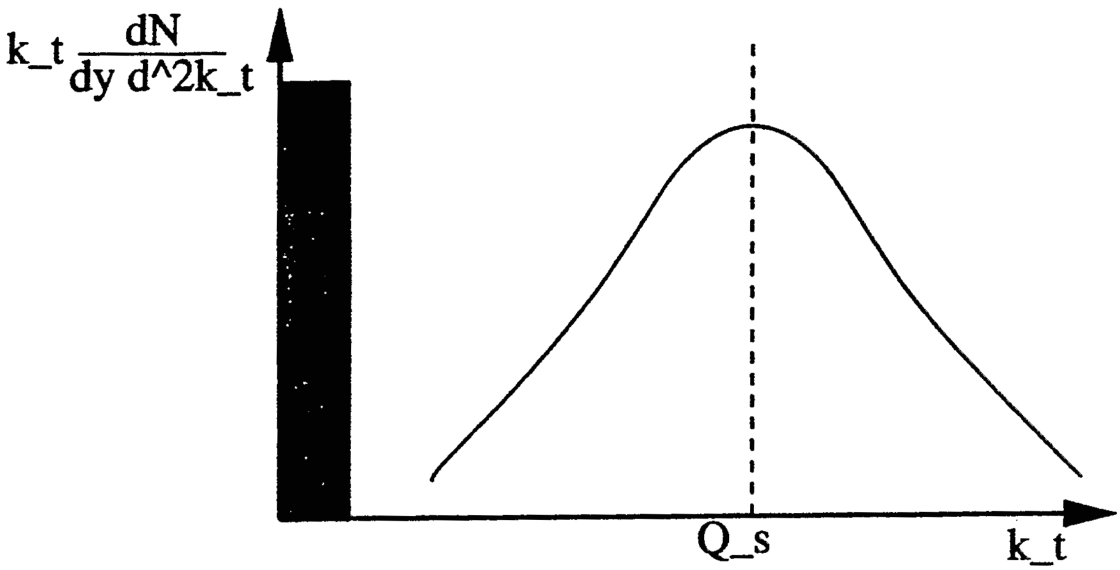


- Time scales of hard and soft gluons are very different (fast vs. slow)

Hadron/nucleus at high energy is a

colored glass condensate

The Color Glass Condensate

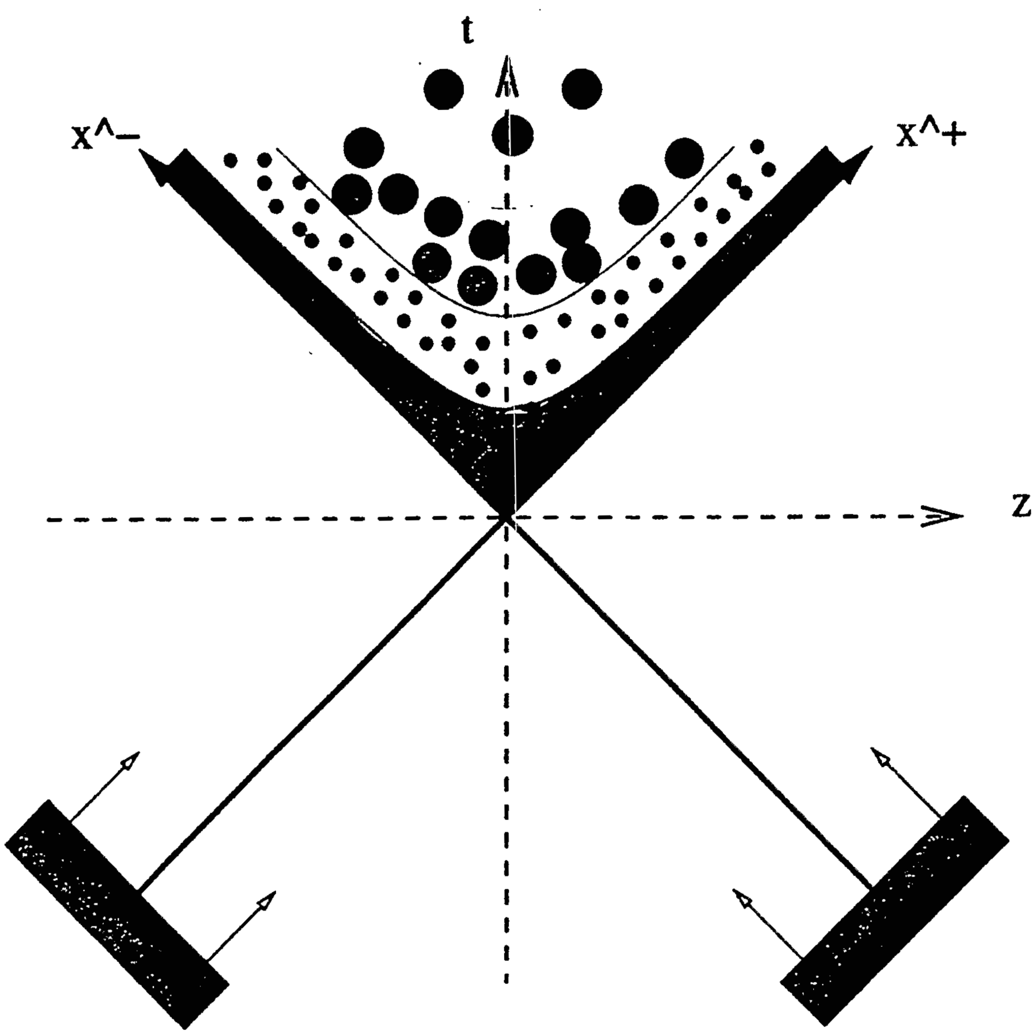


- Gluons have typical momentum of order Q_s
- Large occupation number $\sim 1/\alpha_s$
- Gluons are colored
- Time scales are similar to a glass
- They form a condensate

Hadron/nucleus at high energy is a colored glass condensate

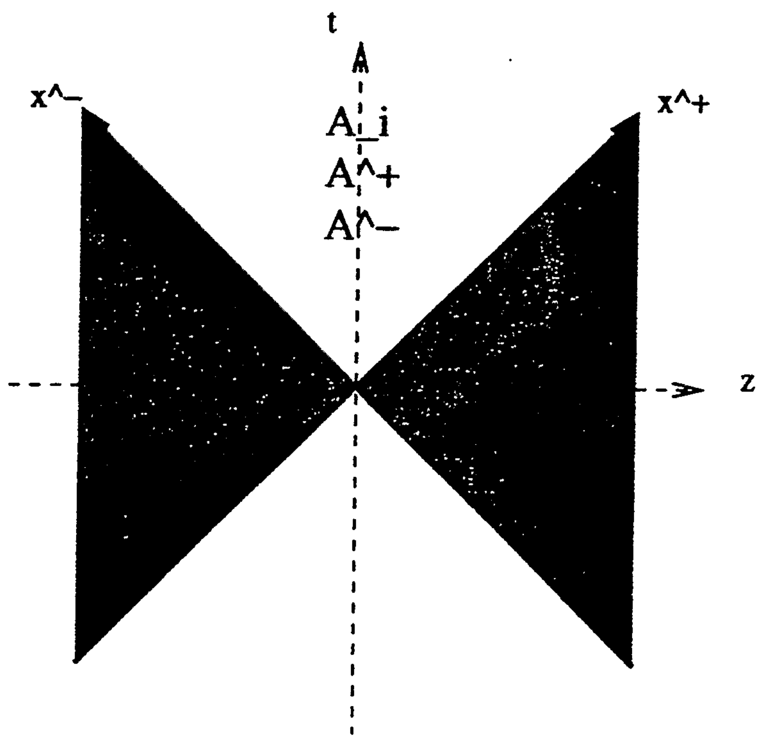
Melting the Color Glass Condensate

- High energy heavy ion collisions
- Initial conditions
- Melting C G C into quark gluon plasma
- Hadronization, freeze-out



Melting the Color Glass Condensate

- Classical equations of motion
- Two sources of color charge ρ_1, ρ_2
- Can be numerically solved on a lattice
- Can be analytically solved in the weak field limit



- Initial energy density, number density, etc.

Lattice formulation

The Hamiltonian formalism is better suited for numerical work. In the continuum

$$H = \frac{\tau}{2}\int \mathrm{d}\eta\,\mathrm{d}^2 r_t \left[p^\eta p^\eta + \frac{1}{\tau^2}p^r p^r + \frac{1}{\tau^2}F_{\eta r}F_{\eta r} + F_{xy}F_{xy}\right].$$

For "perfect pancake" nuclei we only consider boost-invariant configurations. Hence

$$A_r(\tau,\eta,\vec{r}_t) = A_r(\tau,\vec{r}_t), \quad A_\eta(\tau,\eta,\vec{r}_t) = \Phi(\tau,\vec{r}_t)$$

(this resembles a finite-T dimensional reduction: an adjoint scalar emerges).

Per unit rapidity

$$H = \frac{\tau}{2}\int \mathrm{d}^2 r_t \left[p^\eta p^\eta + \frac{1}{\tau^2}E_r E_r + \frac{1}{\tau^2}(D_r\Phi)(D_r\Phi) + F_{xy}F_{xy}\right].$$

Discretize on a 2d lattice

$$H_L = \frac{1}{2\tau}\sum_l E_l E_l + \tau \sum_{\mathrm{pl}} \left(1 - \frac{1}{N_c}\Re \mathrm{Tr} U_{\mathrm{pl}}\right) + \frac{\tau}{2}\sum_j p_j p_j + \frac{1}{4\tau}\sum_{j,n} \mathrm{Tr}\left(\Phi_j - U_{j,n}\Phi_{j+n}U^\dagger_{j,n}\right)^2$$

and solve (numerically) the resulting equations of motion for $x_\pm > 0$.

Interested in soft modes $\longrightarrow$ use classical approximation.

Just as in the continuum

- Average over the static color charge
- Determine initial conditions by matching

Relation to continuum physics

Dimensional quantities in the classical lattice theory:

- Λ_s
- R, the nuclear radius
- l, the color neutrality scale (a recent development!)
- a, the lattice cutoff

Hierarchy of scales (ideal): $1/a \gg \Lambda_s \gg 1/l \gg 1/R$

In the units of a, in the continuum limit $\Lambda_s \to 0$, $R \to \infty$, but $\Lambda_s R$ is constant.

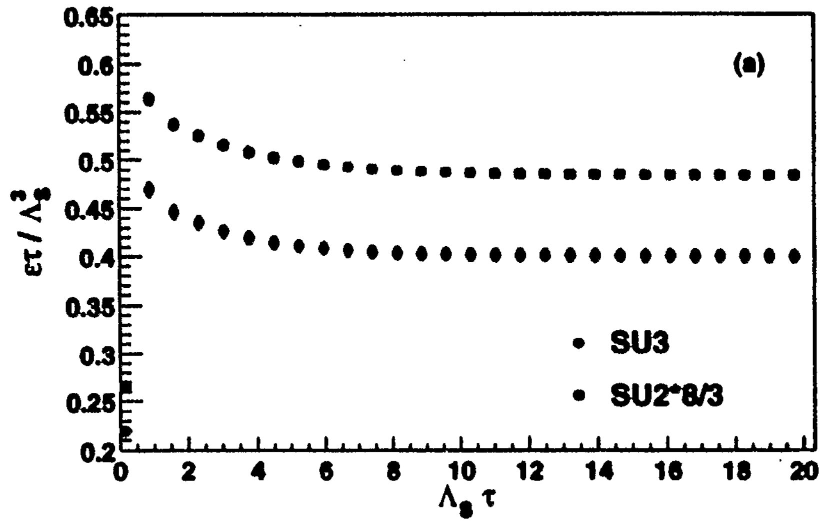
For any well-defined P of dimension d

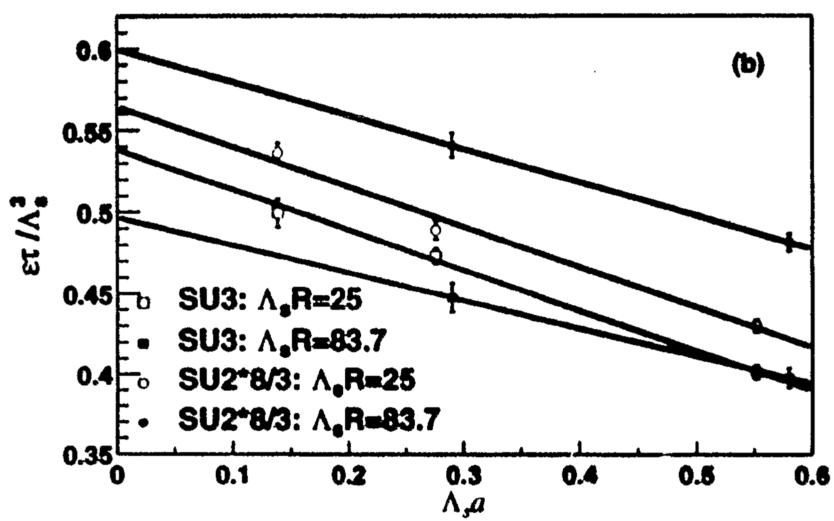
$$P = (\Lambda_s)^d f_P(\Lambda_s R),$$

where $f_P(\Lambda_s R)$ contains all the non-trivial physical information.

- RHIC – $\Lambda_s \approx 1.4$ GeV
- LHC – $\Lambda_s \approx 2.2$ GeV

Physics so far





Transverse energy

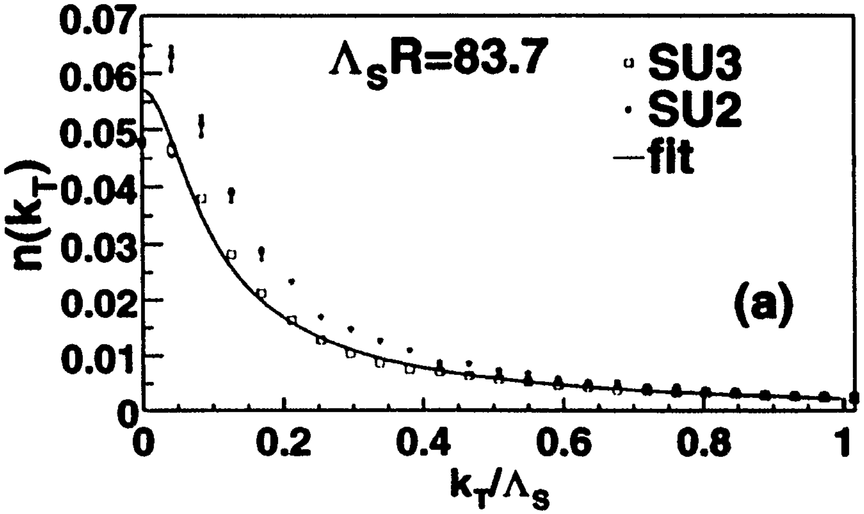
$$\frac{1}{\pi R^2} \frac{dE_T}{d\eta}\Big|_{\eta=0} = \frac{1}{g^2} f_E(\Lambda_s R)\Lambda_s^3$$

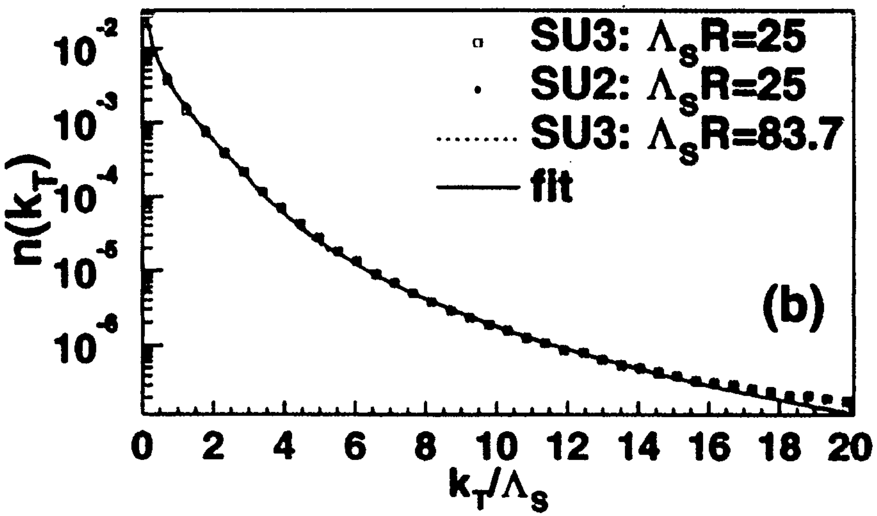
Proper time dependence:

$$\varepsilon\tau = \alpha + \beta \exp(-\gamma\tau)$$

$dE_T/d\eta/\pi R^2 = \alpha$ is the energy density, $\tau_D = 1/\gamma/\Lambda_s$ is the "formation time" of the glue (~ 0.3 fm for RHIC and ~ 0.13 fm for LHC).
In summary, the energy density at τ_D

$$\varepsilon = \frac{0.17}{g^2} \Lambda_s^4$$





Gluon multiplicity $n(k_T) = \tilde{f}_n/(N_c^2 - 1)$

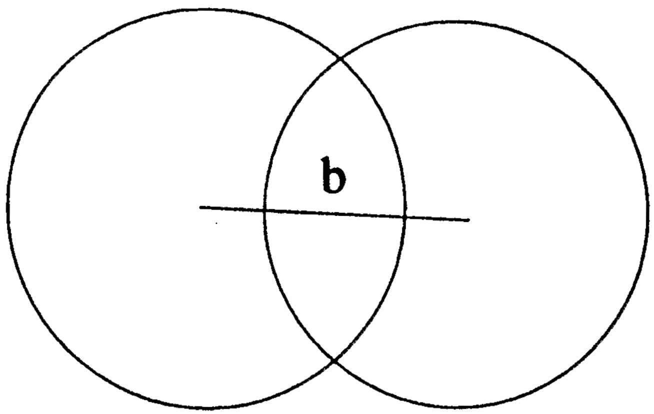
The SU(3) gluon momentum distribution can be fitted by the following function,

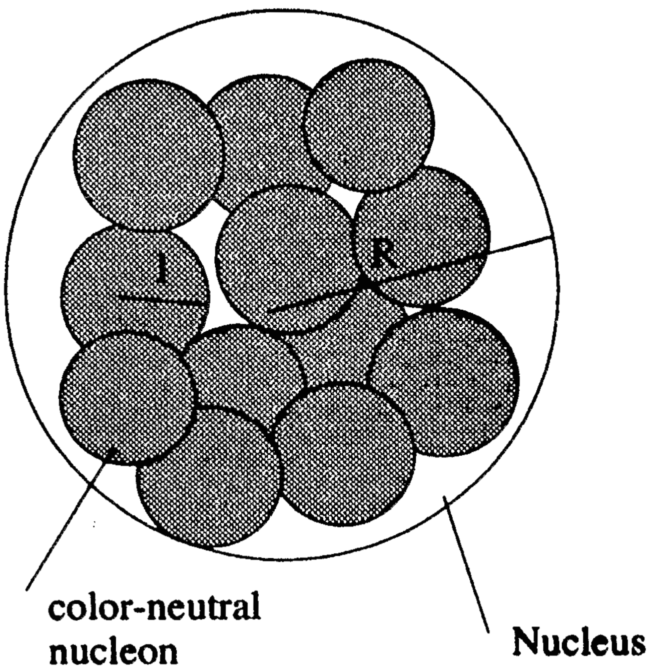
$$\frac{1}{\pi R^2}\frac{dN}{d\eta d^2k_T} = \frac{1}{g^2}\tilde{f}_n(k_T/\Lambda_s)\,, \qquad (1)$$

where $\tilde{f}_n(k_T/\Lambda_s)$ is

$$\tilde{f}_n = \begin{cases} a_1\left[\exp\left(\sqrt{k_T^2+m^2}/T_{\text{eff}}\right)-1\right]^{-1} \\ (k_T/\Lambda_s \leq 3) \\ \\ a_2\,\Lambda_s^4 \log(4\pi k_T/\Lambda_s) k_T^{-4} \\ (k_T/\Lambda_s > 3) \end{cases} \qquad (2)$$

with $a_1 = 0.0295$, $m = 0.067\Lambda_s$, $T_{\text{eff}} = 0.93\Lambda_s$, and $a_2 = 0.0343$.





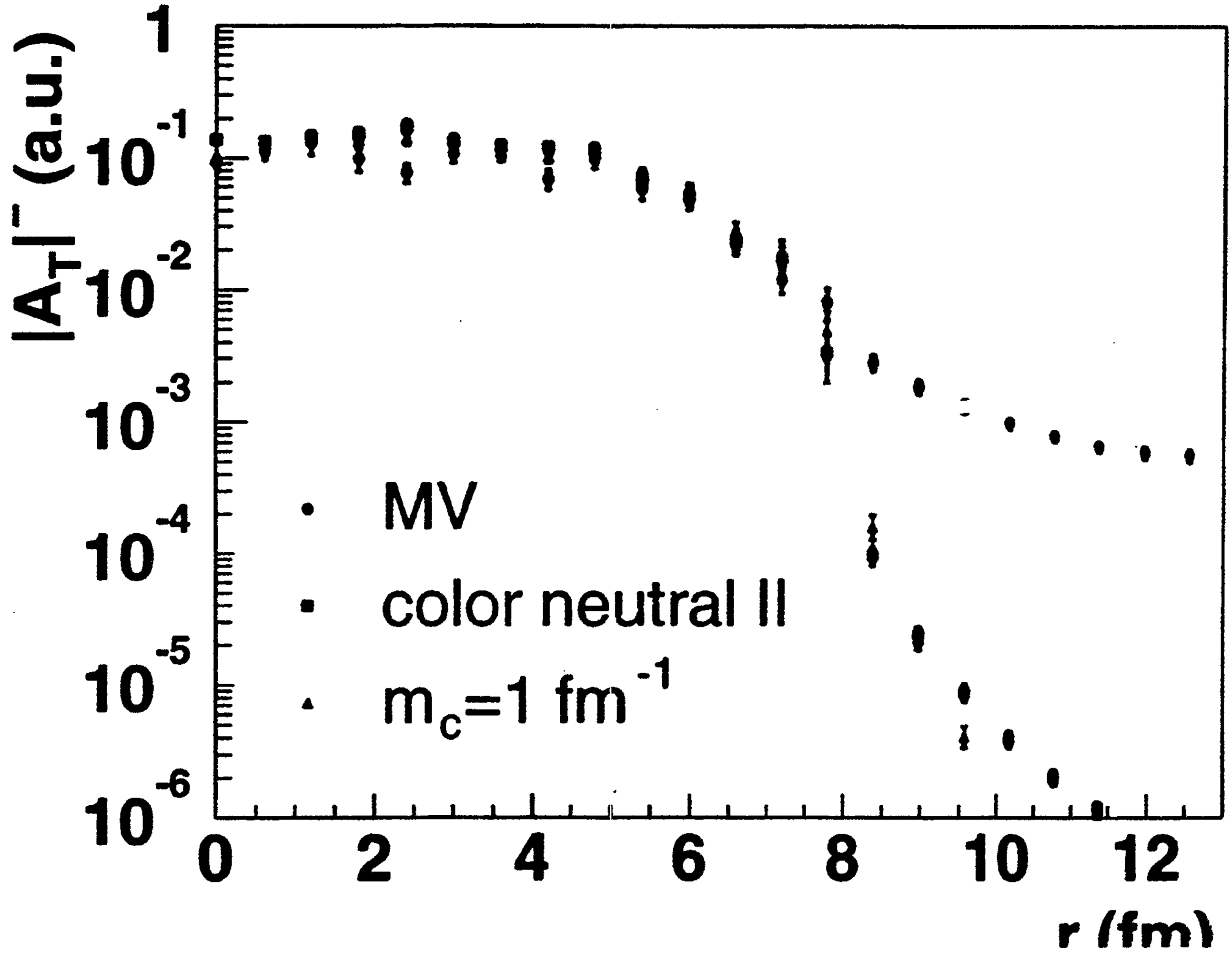
Refining the initial conditions

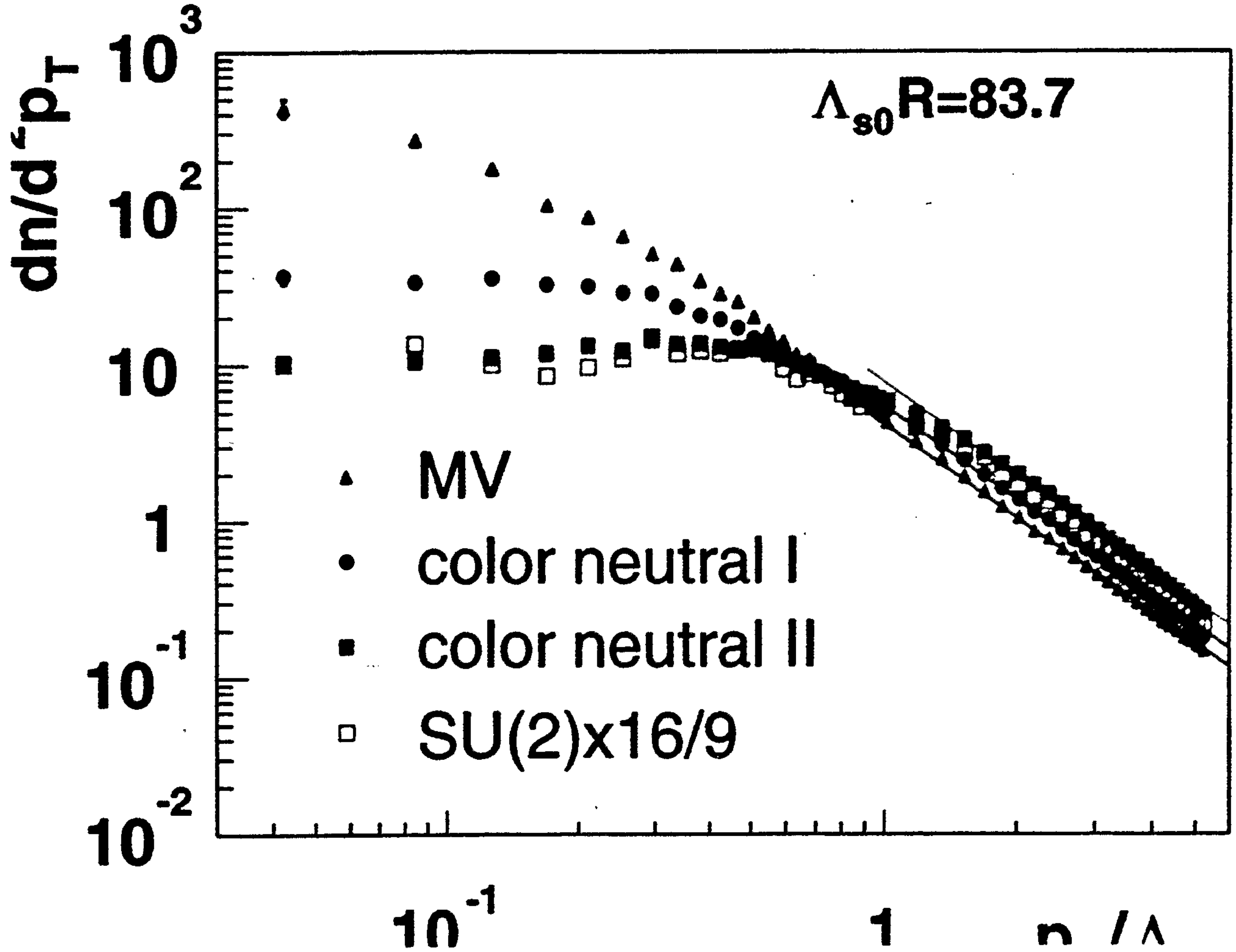
Impose neutrality w.r.t. color charge and color dipole moment of each nucleon.
In a nucleon, begin with

$$\langle \rho^a(\vec{r})\rho^b(\vec{r}')\rangle = \Lambda_n^2 \delta^{ab}\delta(\vec{r} - \vec{r}')$$

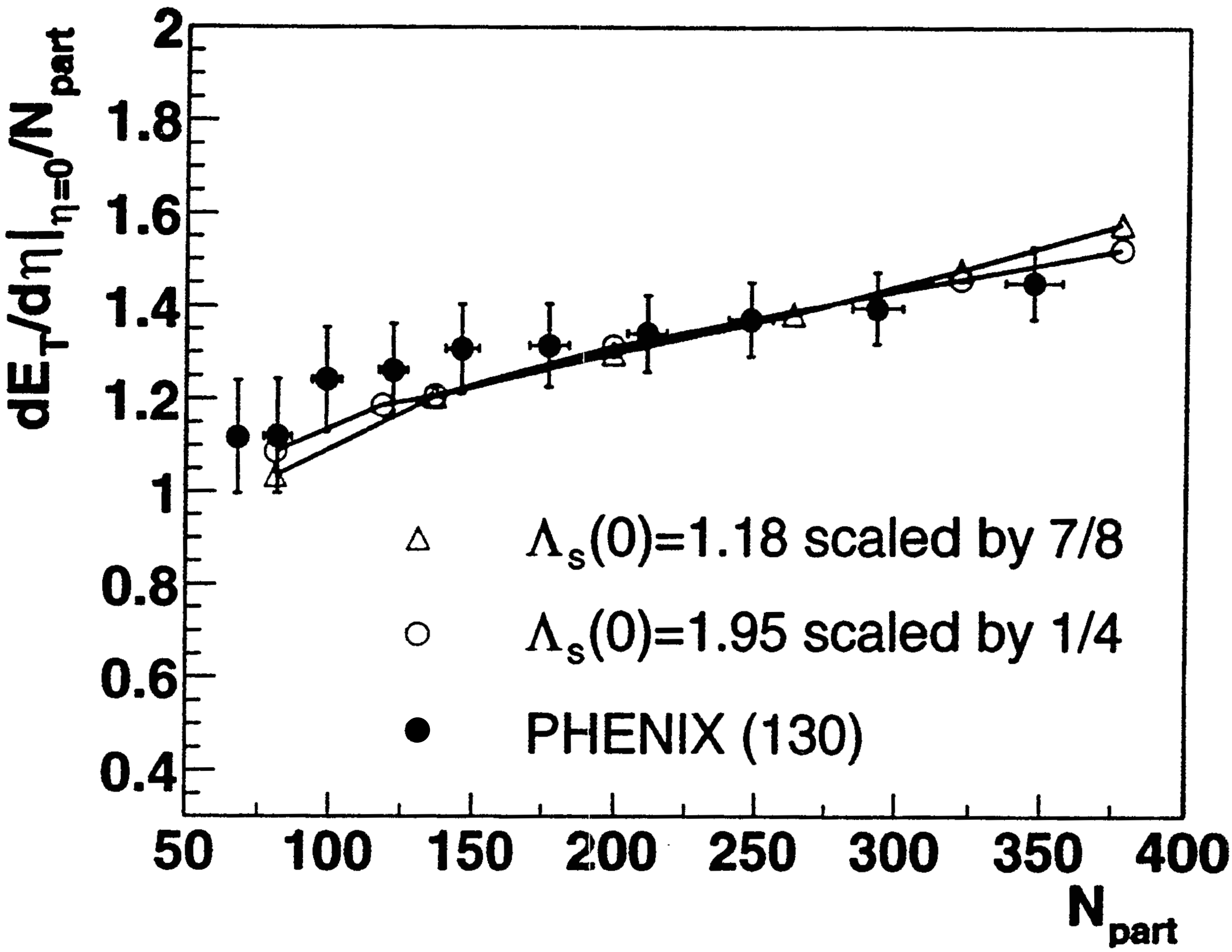
and remove the total color carge and dipole mc
by subtracting uniform distributions.
Nucleons uniformly distributed within a spherica
nucleus:

$$\Lambda_s^2(r) = \frac{2}{l}\Lambda_n^2\sqrt{R^2 - r^2}$$

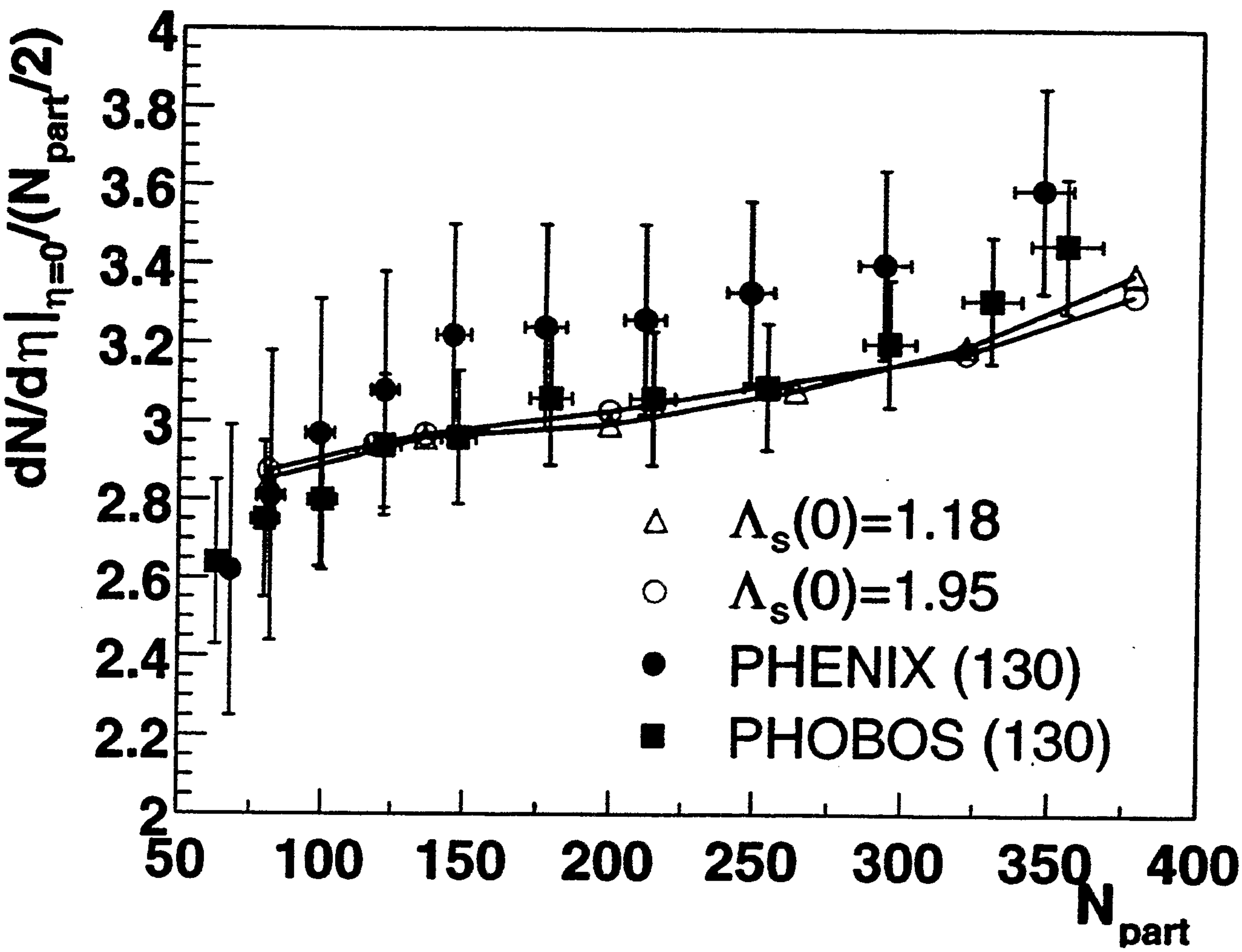

1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
$|A_T|^-$ (a.u.)
0
2
4
6
8
10
12
r (fm)
MV
color neutral II
m_c=1 fm^{-1}



dn/d²pT
10³
10²
10
1
10⁻¹
10⁻²
ΛsoR=83.7
MV
color neutral I
color neutral II
SU(2)x16/9
10⁻¹
1



$dE_T/d\eta|_{\eta=0}/N_{part}$
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
50
100
150
200
250
300
350
400
N_{part}
$\Lambda_s(0)$=1.18 scaled by 7/8
$\Lambda_s(0)$=1.95 scaled by 1/4
PHENIX (130)


dN/dη|η=0/(Npart/2)
4
3.8
3.6
3.4
3.2
3
2.8
2.6
2.4
2.2
2
50
100
150
200
250
300
350
400
Npart
Λs(0)=1.18
Λs(0)=1.95
PHENIX (130)
PHOBOS (130)

Elliptic flow at early times?

Elliptic flow parameter v_2 is defined by the second Fourier coefficient:

$$
\begin{aligned}
v_2 &= \langle \cos(2\phi) \rangle = \left\langle \frac{p_x^2 - p_y^2}{p_x^2 + p_y^2} \right\rangle \\
&= \frac{\int_{-\pi}^{\pi} d\phi \cos(2\phi) \int p_T dp_T \frac{d^3 N}{dy p_T dp_T d\phi}}{\int_{-\pi}^{\pi} d\phi \int p_T dp_T \frac{d^3 N}{dy p_T dp_T d\phi}}.
\end{aligned}
$$

1. Spatial anisotropy is maximal at early times. How long does it take to transform it into momentum-space anisotropy?
2. How much elliptic flow is produced before thermalization?

Goal: compute elliptic flow of gluons from the CGC

Defining v_2 for (classical) fields

Requires a definition of the gluon number → resort again to the cooling and the Coulomb-gauge definitions.

Cooling:

$$v_2 N = \sqrt{\frac{2}{\pi}} \int_0^\infty \frac{dt}{\sqrt{t}} (T^{xx}(t) - T^{yy}(t)) \,,$$

where

$$T_{xx} - T_{yy} = \int d^2 x_\perp \left[E_y^2 - E_x^2 + (D_x \Phi)^2 - (D_y \Phi)^2 \right] ,$$

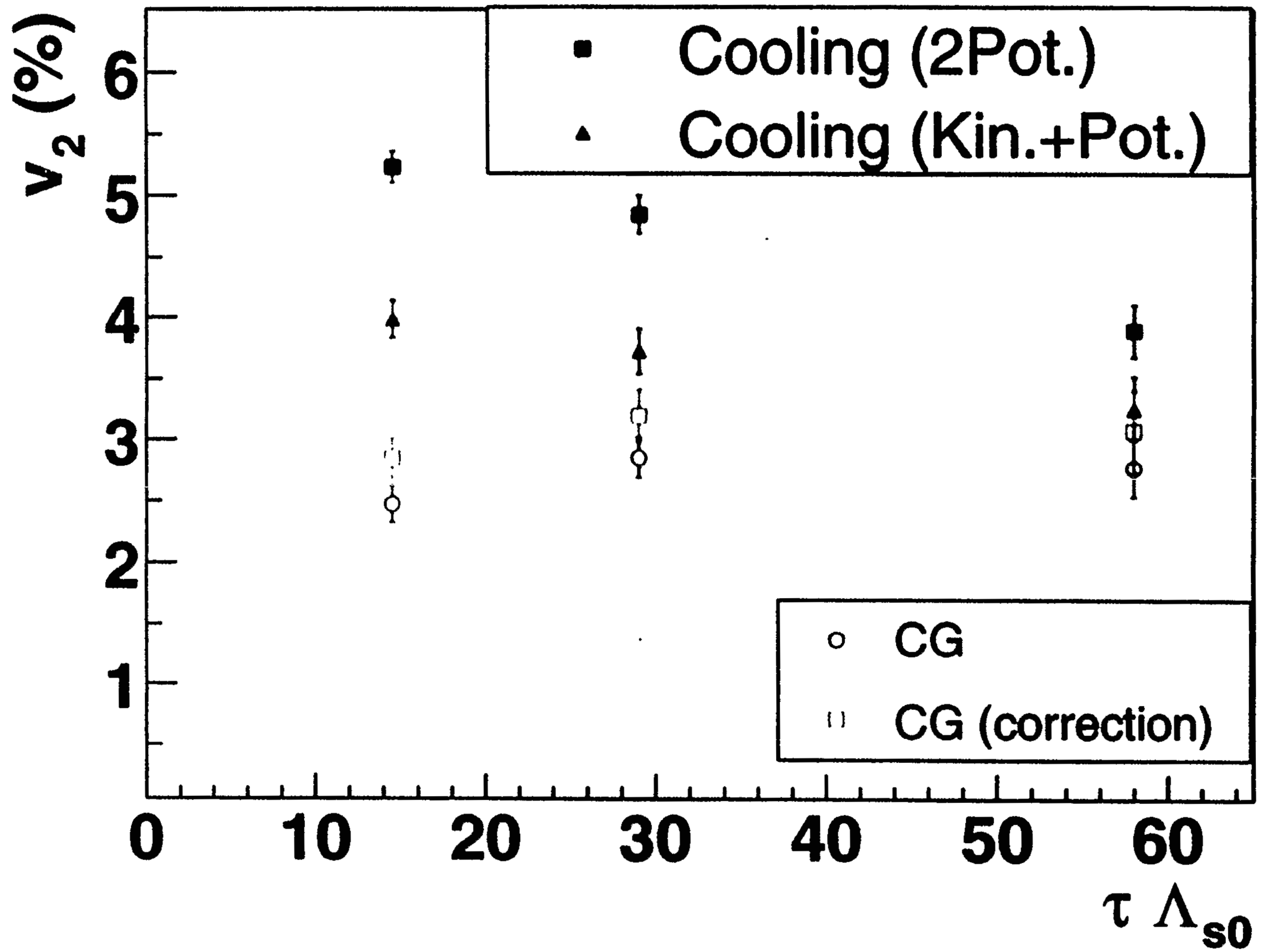
The two contributions correspond to different polarizations and a priori need not be equal.

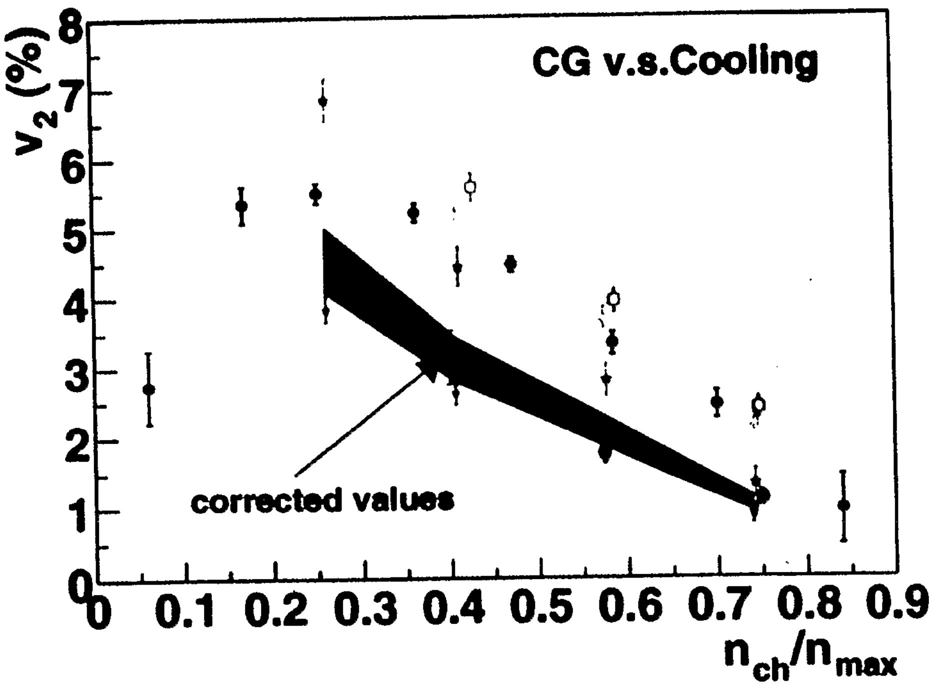
→ requires cooling of conjugate momenta, not just fields.

Cooling eqns for p_i follow from requiring that $\partial_\tau q_i = \{H, q_i\}$ at all cooling times.

Then, schematically,

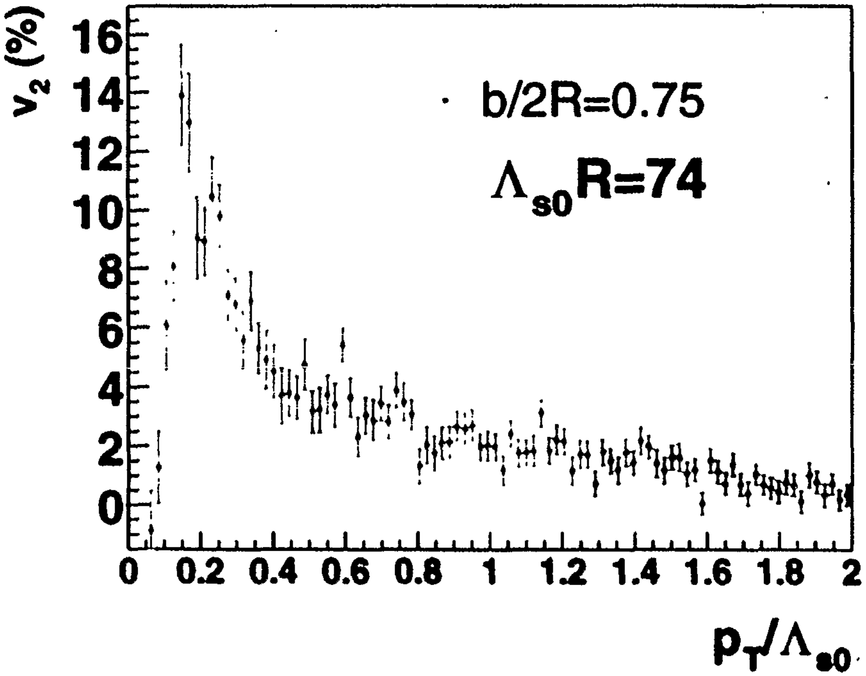
$$\partial_t p_i = - \frac{\partial^2 V}{\partial q_i \partial q_j} p_j$$


Cooling (2Pot.)
Cooling (Kin.+Pot.)
CG
CG (correction)
v 2 (%)
1
2
3
4
5
6
0
10
20
30
40
50
60
τ Λ s0



Centrality dependence of v_2

- $\Lambda_{s0}R = \square\, 18.5 \quad \Delta\, 37 \quad \star\, 74$
- Undershoot, but account for a significant fraction of the data.
- Little dependence on $\Lambda_s R$
- This is a true v_2, **not** $\langle \cos[2(\varphi_1 - \varphi_2)] \rangle^{1/2}$; the latter is significantly higher (in progres

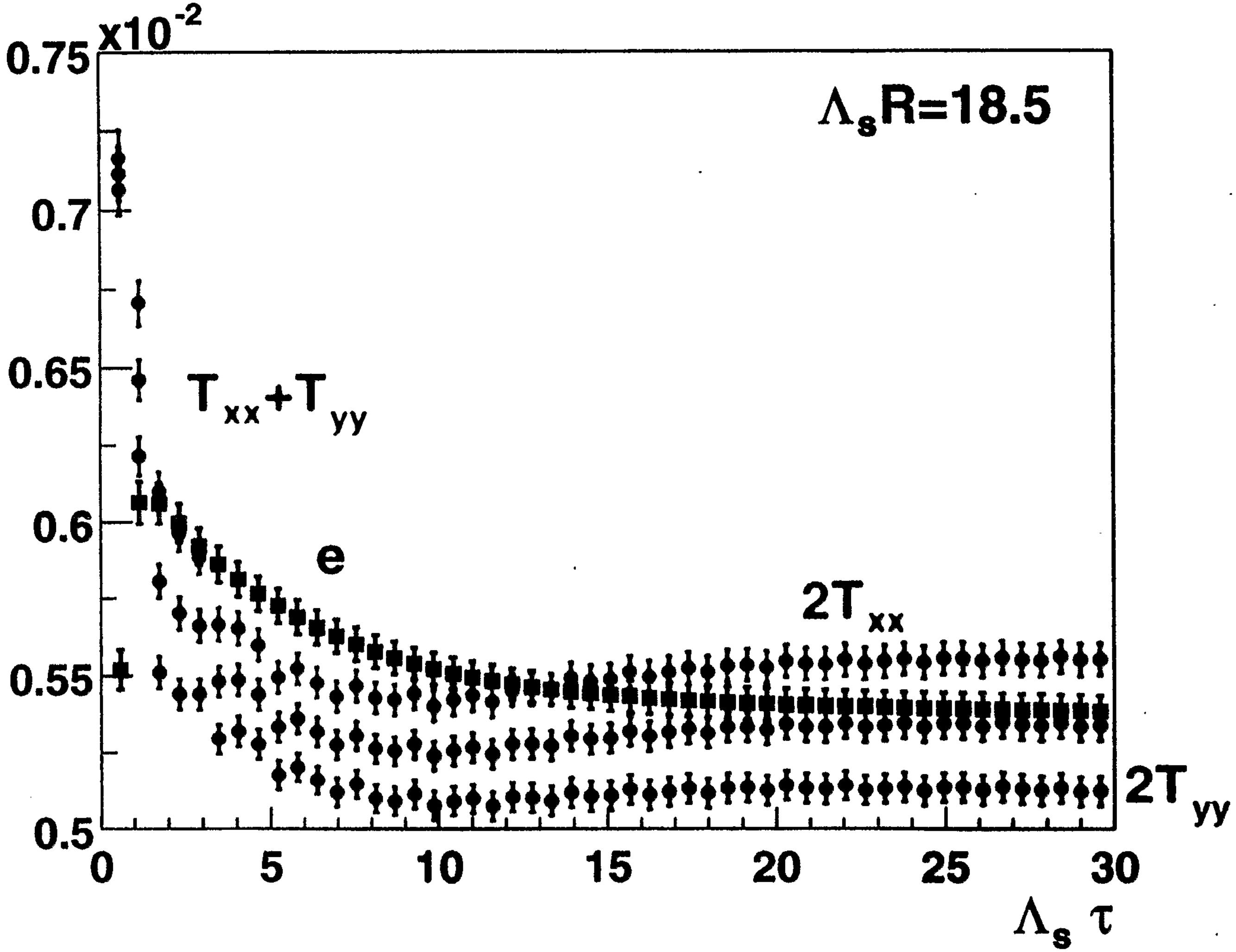


Differential v_2

- Peaked at $p_T \approx 0.25\,\Lambda_{s0}$
- Dominated by very soft momenta: helps explain the slow cooling → CG convergence

III - 18

Time evolution of energy momentum tensor

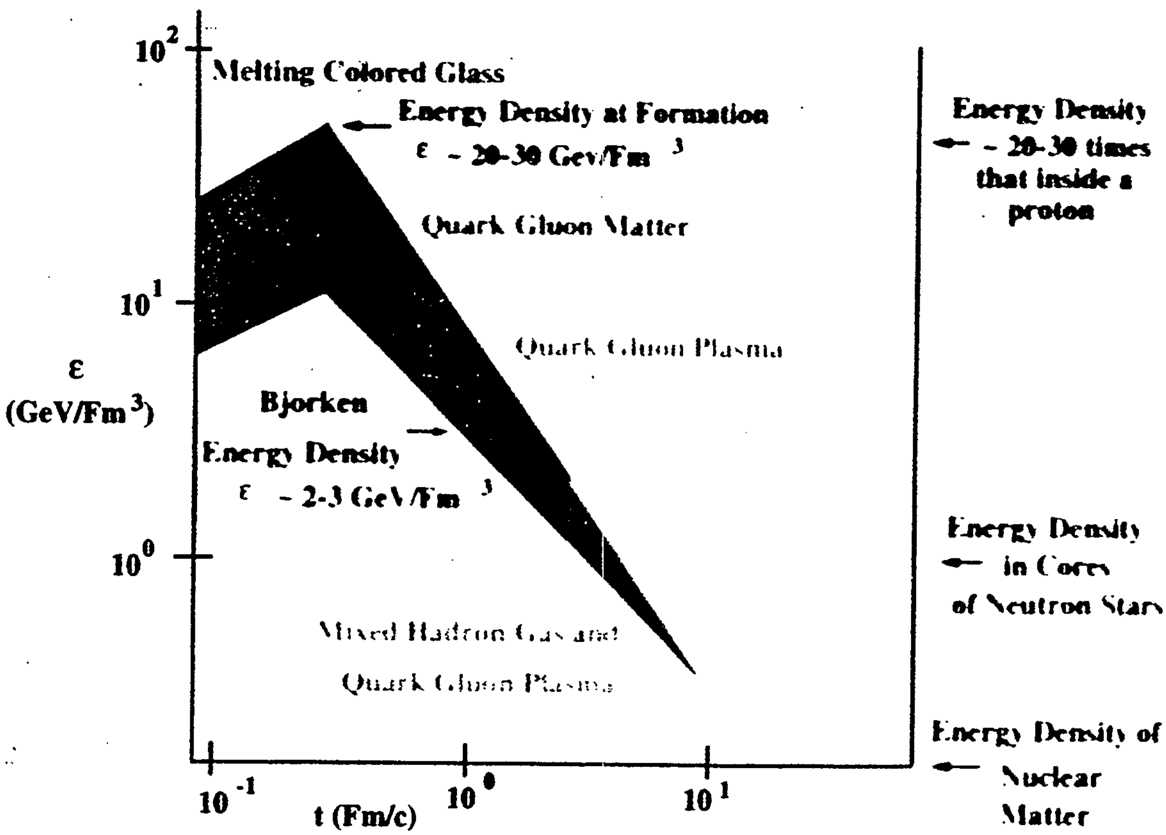


Colored Glass Condensate

Applications of C G C : *AA* at RHIC

- Solve classical equations of motion on the lattice

- Initial energy density



Instantons at Large N_c

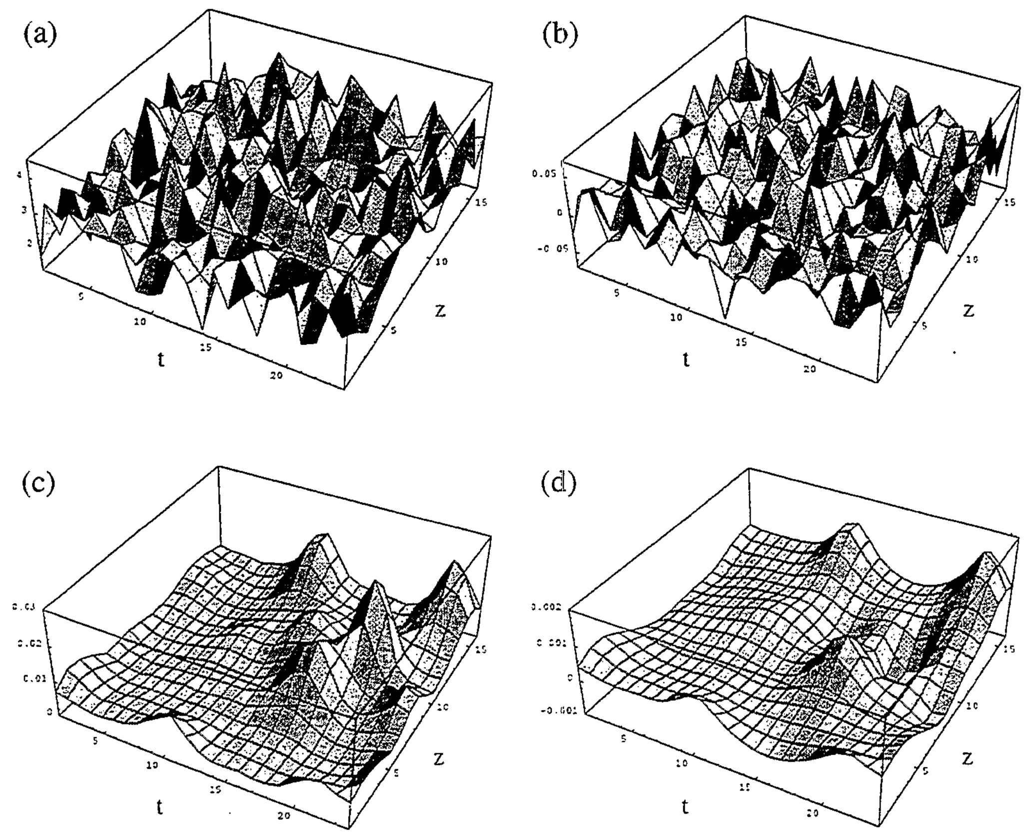
Thomas Schaefer

Instantons and large N_c

Thomas Schaefer

SUNY Stony Brook

and Riken BNL Research Center



QCD at large N_c

- QCD ($m = 0$) is a parmater free theory

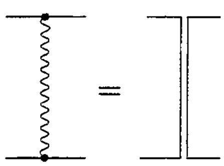
Very beautiful   But: No expansion parameter

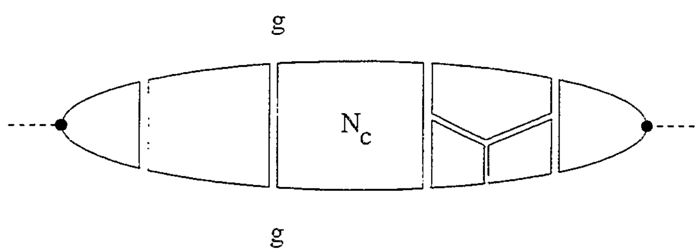
- 't Hooft: Consider $N_c \to \infty$ and use $1/N_c$ as a small parameter

$$N_c \to \infty \qquad \Rightarrow \qquad \text{classical master field}$$

- keep Λ_{QCD} fixed

$$\Rightarrow g^2 N_c = const$$





- Could the master field be a multi-instanton configuration?

Witten (1979) : No $\qquad dn \sim \exp(-\frac{1}{g^2}) \sim \exp(-N_c)$

$U(1)_A$ anomaly at large N_c

- consider θ term

$$\mathcal{L} = \frac{ig^2\theta}{32\pi^2} G^a_{\mu\nu}\tilde{G}^a_{\mu\nu},$$

- no θ dependence in perturbation theory.

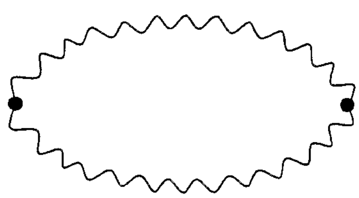
Witten: *non-perturbative θ dependence*

$$\chi_{top} = \left.\frac{d^2E}{d\theta^2}\right|_{\theta=0} \sim O(1)$$

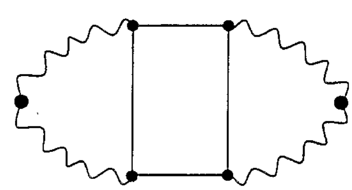
- massless quarks: toplogical charge screening

$$\lim_{m\to 0} \chi_{top} = 0$$

- How can that happen? Fermion loops are suppressed!



$g^4 N_c^2 \sim 1$



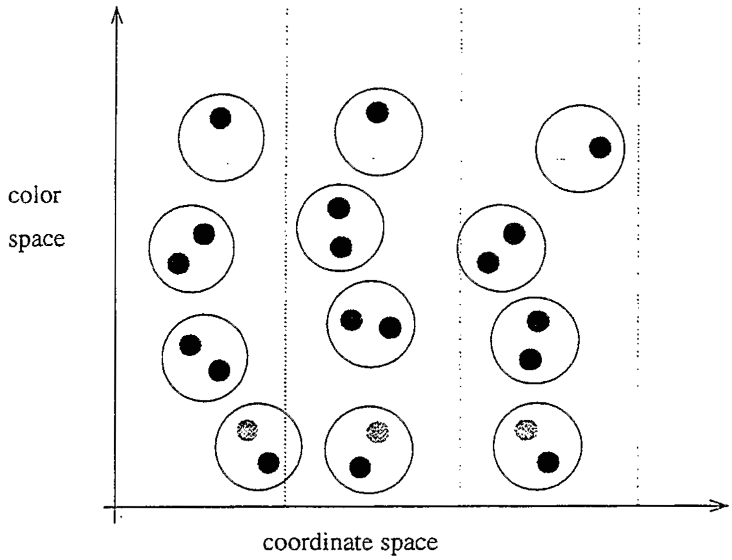
$g^8 N_c^3 \sim \frac{1}{N_c}$

Witten: *η' has to become light*

$$f_\pi^2 m_{\eta'}^2 = 2N_f\chi_{top} \quad\Rightarrow\quad m_{\eta'}^2 = O(1/N_c)$$

Instantons at large N_c

- semi-classical ensemble of instantons at large N_c



- instantons are $N_c = 2$ configurations

$$\left(\frac{N}{V}\right) = O(N_c) \quad \Rightarrow \epsilon_{vac} = O(bN_c) = O(N_c^2)$$

- instantons are semi-classical

$$\rho \simeq \rho^* = O(1) \quad S_{inst} = O(N_c)$$

- density $dn \sim \exp(-S_{inst}) = O(\exp(-N_c))$?

NO! *large entropy* $dn \sim \exp(-N_c)$

- topological susceptibility $\chi_{top} \simeq (N/V) = O(N_c)$?

NO! *fluctuations suppressed* $\chi_{top} = O(1)$

- instanton ensemble

$$Z = \frac{1}{N_I! N_A!} \prod_I^{N_I+N_A} \int [d\Omega_I \, n(\rho_I)] \, \exp(-S_{int})$$

$$n(\rho) = C_{N_c} \left(\frac{8\pi^2}{g^2}\right)^{2N_c} \rho^{-5} \exp\left[-\frac{8\pi^2}{g(\rho)^2}\right]$$

$$C_{N_c} = \frac{0.466 \exp(-1.679 N_c)}{(N_c-1)!(N_c-2)!} \qquad \frac{8\pi^2}{g^2(\rho)} = -b\log(\rho\Lambda), \qquad b = \frac{11}{3}N_c$$

$$S_{int} = -\frac{32\pi^2}{g^2}|u|^2 \left\{ \frac{\rho_I^2 \rho_A^2}{R_{IA}^4} \left(1 - 4\cos^2\theta\right) + S_{core}\left(\frac{\rho_I^2 \rho_A^2}{R_{IA}^4}\right) \right\}$$

- complicated ensemble, size distribution

$$\rho^* \sim O(1) \qquad \begin{cases} \rho < \rho^* & dn \sim \exp(-N_c) \\ \rho \sim \rho^* & dn \sim \exp(-N_c) \end{cases}$$

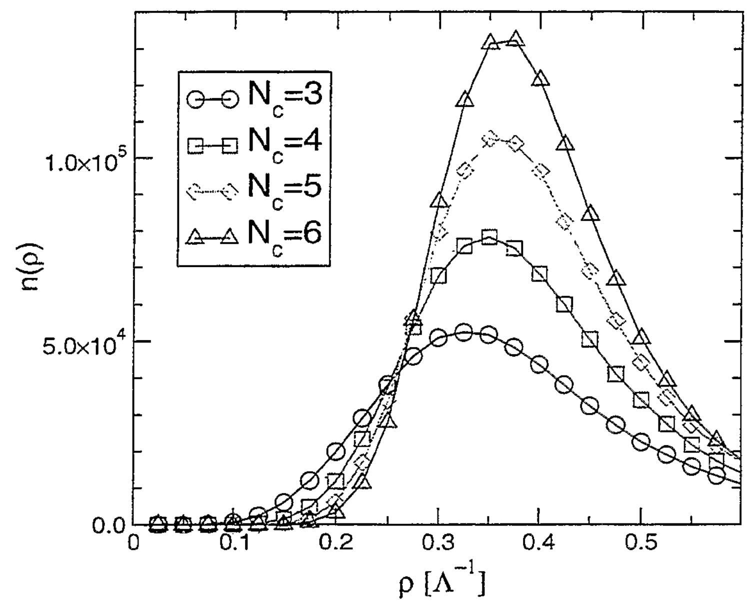
- total density determined by interactions

$S(1-body)$	$\sim$	$S(2-body)$
N_c	$\sim$	$N_c \times \frac{1}{N_c} \times \left(\frac{N}{V}\right)$
classical	$\sim$	*classical* $\times$ *color overlap* $\times$ *density*

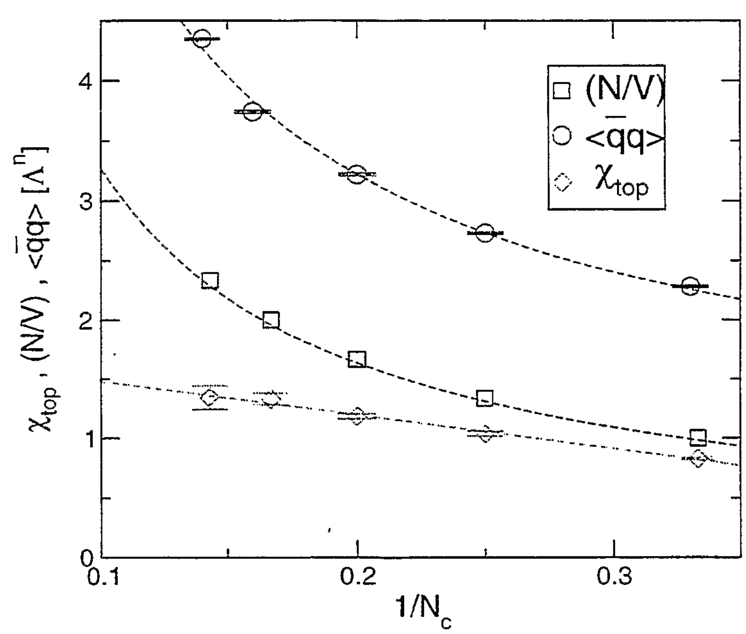
- conclude

$$\left(\frac{N}{V}\right) = O(N_c)$$

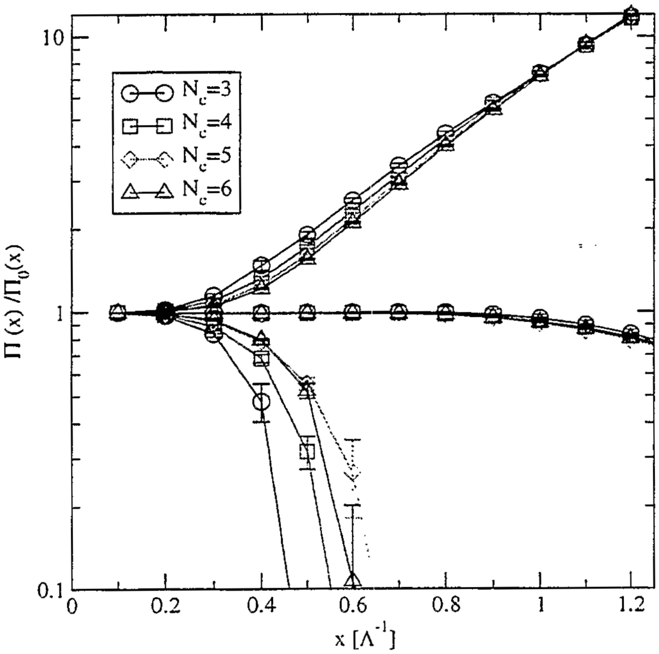
• instanton size distribution



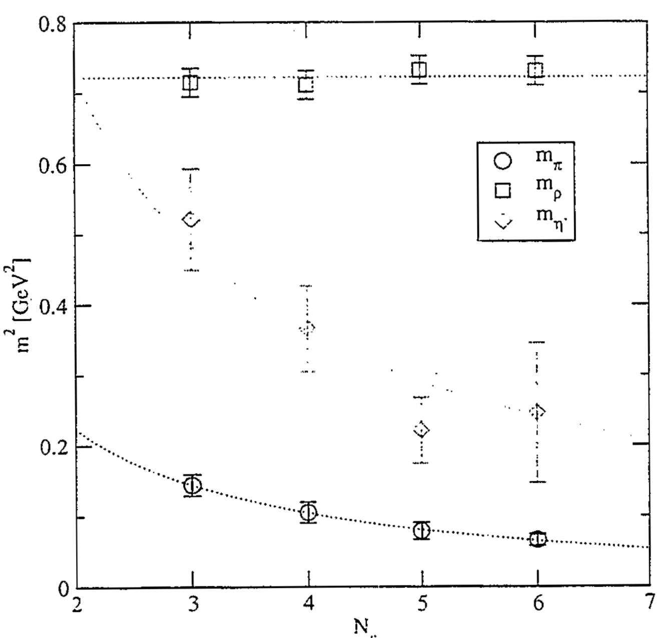
• instanton density, quark condensate, topological susceptibility



- meson correlation functions (π, ρ, η')



- meson masses: $m_\pi^2, m_\rho^2 \sim 1,\ m_{\eta'}^2 \sim 1/N_c$

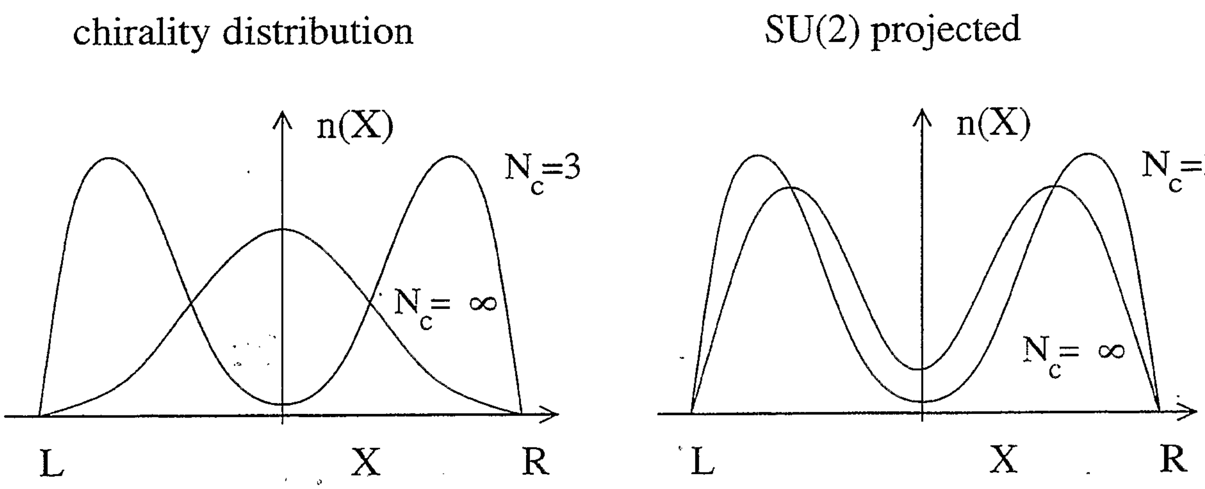


Summary

- instanton liquid can have a smooth large N_c limit

$$\left(\frac{N}{V}\right) = O(N_c), \qquad \chi_{top} = O(1), \qquad m^2_{\eta'} = O(1/N_c)$$

- how can we check this?



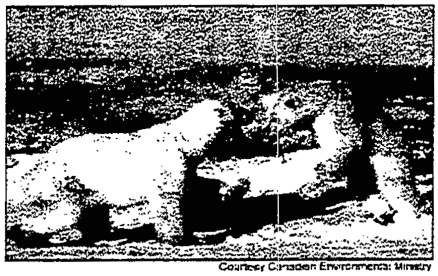
- can we identify the instanton contribution to the η' mass by its scaling behavior (Witten: $1/N_c$ vs $\exp(-N_c)$)?

$$\textit{consider } N_c = 2,\ \mu \neq 0 \quad \textit{or } N_c = 3,\ \mu_I \neq 0$$

Applications of Perturbative QCD in Hadronic Collisions

Werner Vogelsang

- Theory calculations for physics with POLARized BEAms at RHIC



Courtesy Canadian Environmental Ministry

work in collab. with M. Stratmann, B. Jäger. A. Schäfer, J. Soffer

→ discuss one example today

- **Studies in soft-gluon resummations** (electroweak bosons, Higgs, . . .)

work in collab. with A. Kulesza, G. Sterman

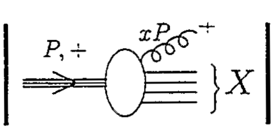
RHIC-Spin – a new laboratory for studying nucleon structure

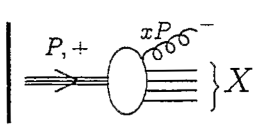
Recurring main theme of spin physics at RHIC :

- probe nucleon constituents with weakly interacting quanta of asymptotic freedom regime ⇝ pQCD hard scattering
- at the same time : test (and learn about) QCD spin interactions

Many applications. Prominent example :

- Polarization of gluons in the nucleon :

$\Delta g(x) = \Big|$ 

$\Big|^2 - \Big|$ 

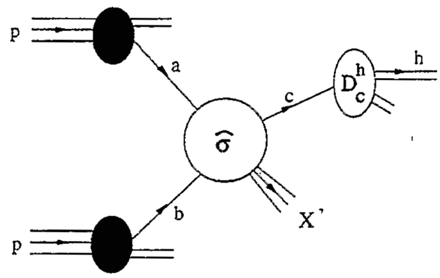
$\Big|^2$

$$= \frac{i}{4\pi\, x\, P^+} \int d\lambda\, e^{i\lambda x P^+} \langle P, S | G^{+\nu}(0)\, \tilde{G}^{+}{}_{\nu}(\lambda n) | P, S \rangle$$

Factorized cross sections :

consider pions with high-p_T : $\Rightarrow$ hard scale

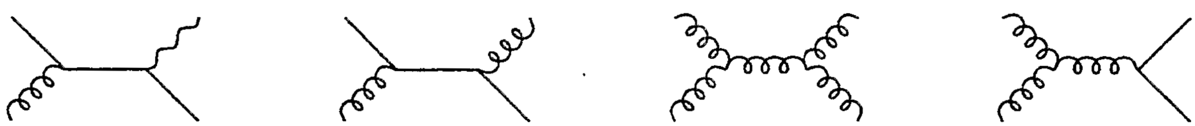
$$p_T^3 \frac{d\sigma}{dp_T} = \left| \quad \right|^2 + \mathcal{O}\left(\frac{\lambda}{p_T}\right)^n$$



$$p_T^3 \frac{d\sigma^{pp\to\pi X}}{dp_T} = \sum_{abc} \int dx_a\, dx_b\, dz_c\, f_a(x_a, \mu)\, f_b(x_b, \mu)\, D_c^\pi(z_c, \mu)$$
$$\times\, p_T^3 \frac{d\hat{\sigma}^{ab\to cX'}}{dp_T}(x_a P_a, x_b P_b, P^\pi/z_c, \mu) \quad + \quad \text{Power corr.}$$

at RHIC: Δg can be probed in *various* processes

$pp \to \gamma X$, $pp \to \text{jet}X$, $pp \to \pi X$, $pp \to (c\bar{c})X$, ...



Already in coming run : $\vec{p}\vec{p} \to \pi^0 X$

asymmetry $\quad A_{\rm LL}^\pi \equiv \dfrac{d\sigma^{pp\to\pi X'}(++) - d\sigma^{pp\to\pi X'}(+-)}{d\sigma^{pp\to\pi X'}(++) + d\sigma^{pp\to\pi X'}(+-)} \equiv \dfrac{\Delta\sigma}{\sigma}$

$$p_T^3 \frac{d\Delta\sigma^{pp\to\pi X}}{dp_T} = \sum_{abc} \int dx_a\, dx_b\, dz_c\, \Delta f_a(x_a, \mu)\, \Delta f_b(x_b, \mu)\, D_c^\pi(z_c, \mu)$$
$$\times\, p_T^3 \frac{d\Delta\hat{\sigma}^{ab\to cX'}}{dp_T}(x_a P_a, x_b P_b, P^\pi/z_c, \mu)$$

- partonic hard-scattering can be treated perturbatively :

$$\hat{\sigma} = \underbrace{\hat{\sigma}^0}_{\text{LO}} + \underbrace{\alpha_s \hat{\sigma}^1}_{\text{NLO}} + \ldots$$

- lowest order : good for qualitative descriptions
  "catches the most important effects"

- however, precise predictions afford higher-order (NLO) calculations :
  - may be sizeable, in particular in polarized case
  - reduction in scale dependence

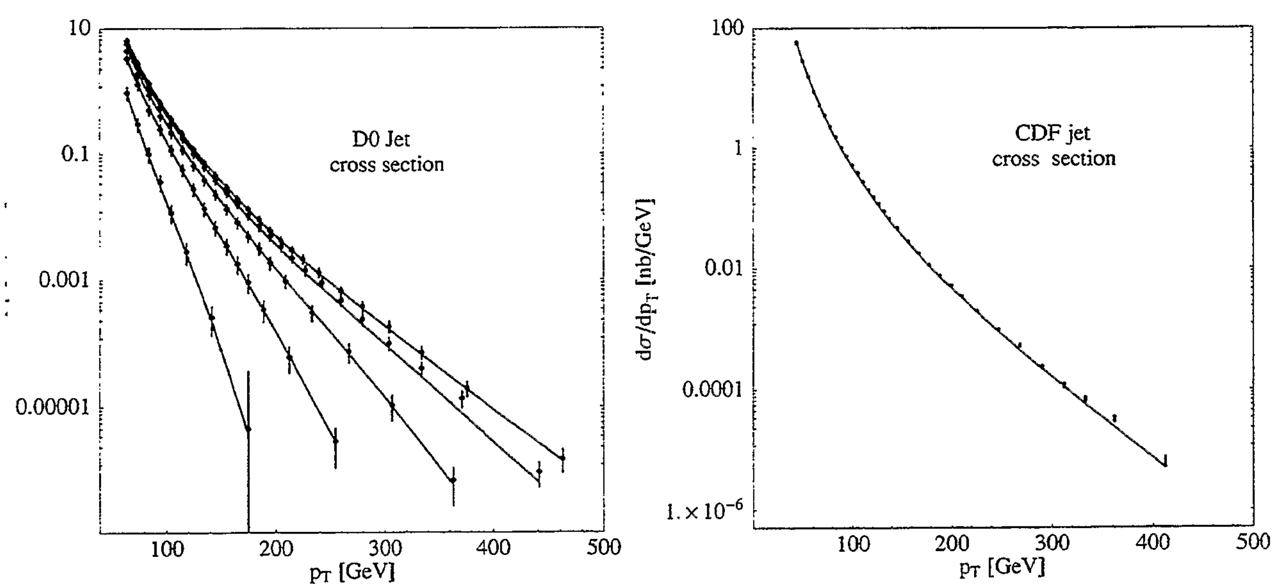
$$\mu \frac{\mathrm{d}}{\mathrm{d}\mu} d\sigma_{\text{phys}} = 0$$

$$\neq 0 \quad \text{in truncated perturbation theory}$$

  - sometimes, theory description becomes realistic only at NLO (jets !)

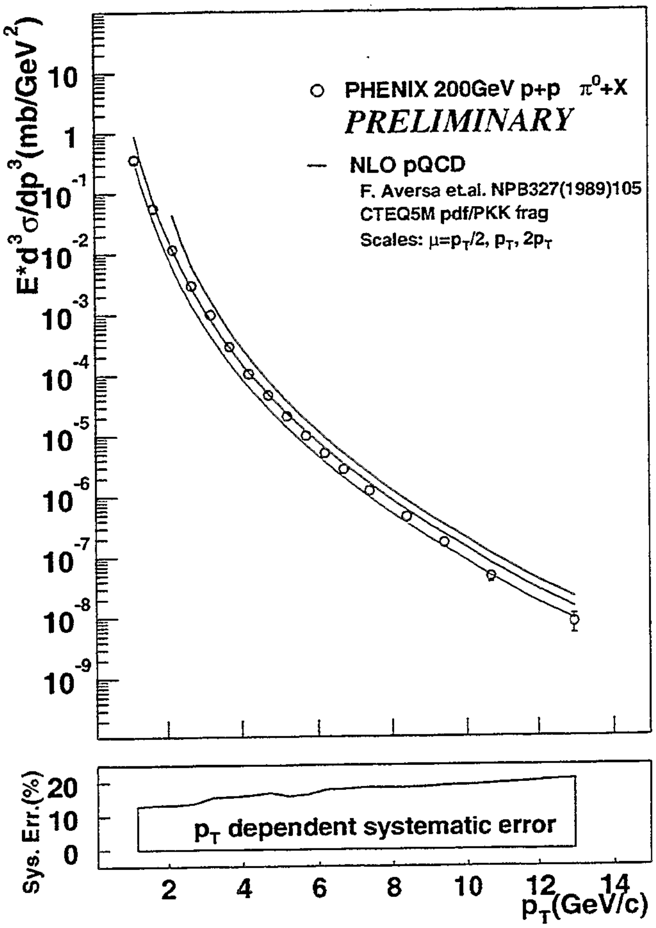
NLO pQCD hard scattering works well at colliders !

Example : High-p_T jets at the Tevatron :



AND :

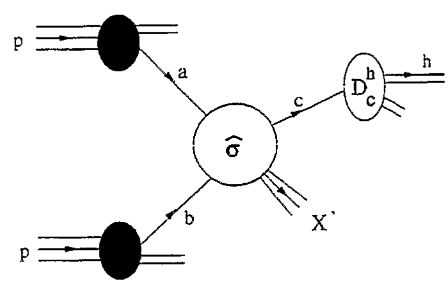
$pp \to \pi^0 X$ **by PHENIX**



(±30% normalization unc.)

NLO QCD corrections to A_{LL}^{π}

Jäger,Schäfer,Stratmann,WV



at $\mathcal{O}(\alpha_s^2)$ one has:

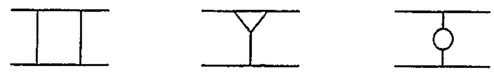
all LO $2 \to 2$ parton-parton scattering processes

unpol.: 4 processes $qq' \to qq'$, $qq \to qq$, $q\bar{q} \to gg$, $gg \to gg$

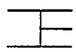
all other processes related by crossing

at $\mathcal{O}(\alpha_s^3)$ one has:

(1) 1-loop (virtual) corrections to all LO processes



'box' 'vertex' 'selfenergy'

(2) all $2 \to 3$  parton-parton scattering processes

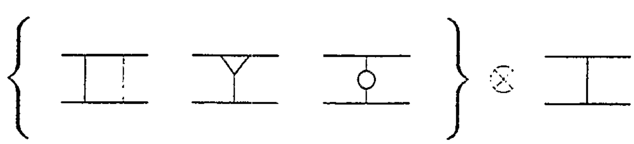
$qq' \to qq'g$, $q\bar{q} \to ggg$, $gg \to ggg$, etc.

important check: unpolarized matrix elements in Ellis, Sexton

all contributions individually singular $\Rightarrow$ choose $d = 4 - 2\epsilon$ dimensions

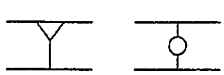
technical details (I) - 1-loop virtual corrections:

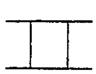
$\mathcal{O}(\alpha_s^3)$: only interference of 1-loop and Born amplitudes contributes:



can extensively make use of available results :

(1) renormalized propagators and vertices

 UV-divergent $\to$ tabulated in Nowak, Praszalowicz, Slominski

 UV-finite $\to$ calculate from scratch

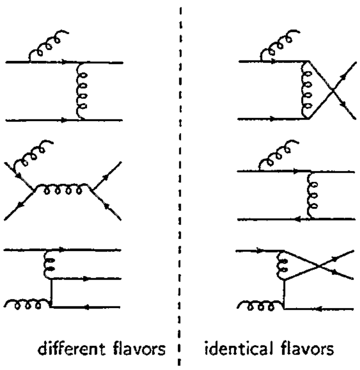
(2) one-loop renormalized helicity amplitudes Kunszt, Signer, Trocsanyi

some 'gymnastics' required to obtain desired results

✓ results for methods (1) and (2) fully agree

technical details (II) - $2 \to 3$ contributions:

some typical NLO $2 \to 3$ Feynman diagrams:

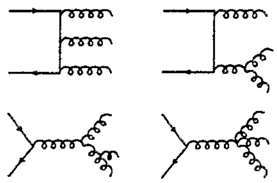


$q \neq q'$ $\quad$ $q = q'$

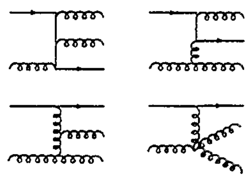
$qq' \to qq'g$

$q\bar{q} \to q'\bar{q}'g$

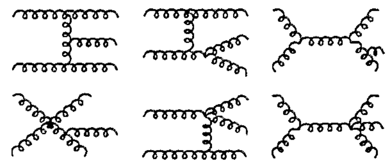
$qg \to qq'\bar{q}'$



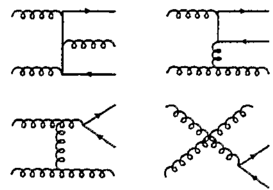
$q\bar{q} \to ggg$



$qg \to qgg$



$gg \to ggg$



$gg \to q\bar{q}g$

technical details (III) - cancellation of divergencies:

UV $1/\varepsilon$*-singularities*

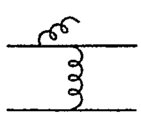
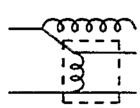
removed by renormalization of $\alpha_s \Rightarrow$ renormalization scale μ_r

IR singularities $(1/\varepsilon^2,\ 1/\varepsilon)$

cancel in sum of 1-loop and $2 \to 3$ contributions

collinear $1/\varepsilon$*-singularities*

removed by factorization $\Rightarrow$ factorization scale μ_f

e.g.:  $\to$  $\sim \frac{1}{\varepsilon} \int dx \Delta P_{qq}(x) \Delta\hat{\sigma}_{qq\to qq}$

final results (I) - $\mathcal{O}(\alpha_s^3)$ parton-parton processes:

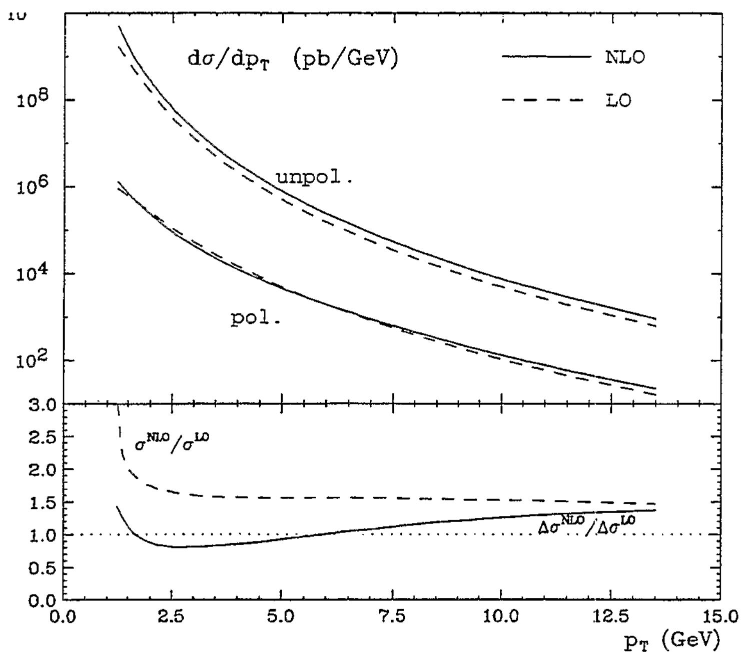
16 different inclusive cross sections contribute:

$$
\begin{array}{lll}
qq' & \to & q+X \\
 & \to & g+X \\
q\bar{q}' & \to & q+X \\
 & \to & g+X \\
q\bar{q} & \to & q'+X \\
 & \to & q+X \\
 & \to & g+X \\
qq & \to & q+X \\
 & \to & g+X
\end{array}
\qquad
\begin{array}{lll}
qg & \to & q'+X \\
 & \to & \bar{q}'+X \\
 & \to & \bar{q}+X \\
 & \to & q+X \\
 & \to & g+X \\
gg & \to & g+X \\
 & \to & q+X
\end{array}
$$

unpol. results all agree with Aversa et al.

final results (II) - importance of NLO corrections:

$\sqrt{S} = 200\,\mathrm{GeV}$

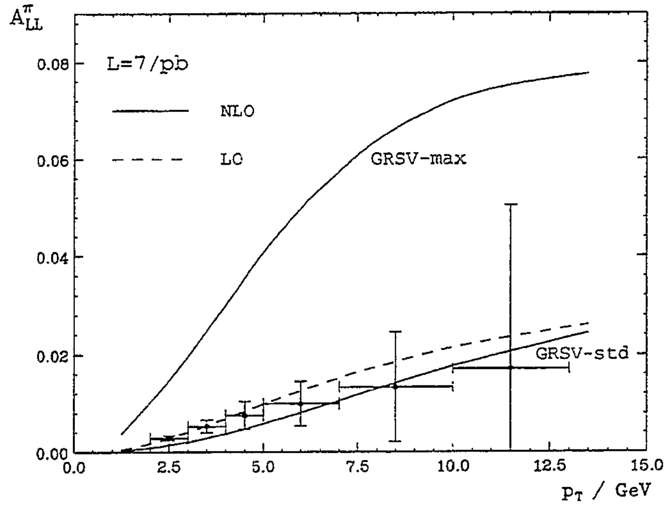


pdfs: CTEQ 5M (unpol.), GRSV std. (pol.)

frag. fcts: Kniehl et al.

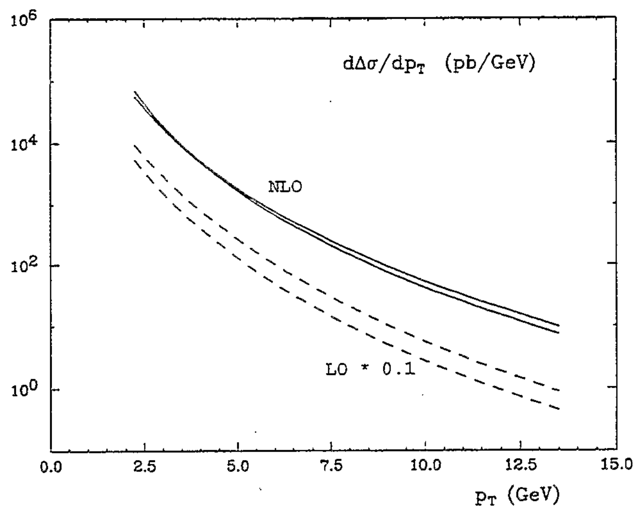
final results (III) - A_{LL}^{π} in NLO:

in coming run ! $\downarrow \sqrt{S} = 200\,\mathrm{GeV}$



good sensitivity to Δg even with $\mathcal{L} = 7/\mathrm{pb}$!

final results (IV) - scale dependence:



variation of scales: $\mu_f = \mu_r = p_T \ldots 2p_T$

$\Downarrow$

NLO results much more reliable

Investigation of Nuclear Matter In Extreme Conditions

Sangyong Jeon

Investigation of Matter in Extreme Conditions

- Event-by-Event Fluctuation
- η' as a gluon probe
- Energy loss of high p_T pions

Sangyong Jeon, RBRC & McGill

Event-by-event analysis

- An event = A single system in the ensemble
- Event average = Ensemble average

Previous Works

  * V.Koch and Jeon : Charge fluctuation as a signal of QGP
  * S.Pratt : Balance function width as a signal of QGP

- Relation? $\Longrightarrow$ Jeon and Pratt, Phys.Rev.C65:044902, 2002.

Balance Function and Charge Fluctuation

Jeon and Pratt, Phys.Rev.C65:044902, 2002

- Charge fluctuation: Measures $(+-)$ correlation globally. $\Longrightarrow$ Quantitative prediction of experimental result
- Balance function: Measures $(+-)$ correlation locally. $\Longrightarrow$ Qualitative prediction
- Relation:

$$\frac{\langle (Q - \langle Q \rangle)^2 \rangle}{\langle N_{\rm ch} \rangle} = 1 - \int_0^Y d\Delta y \; B(\Delta y | Y) + O\left(\frac{\langle Q \rangle}{\langle N_{\rm ch} \rangle} \right)$$

$Q = N_+ - N_-$

$N_{\rm ch} = N_+ + N_-$

The η' Meson

- The η' meson contains large glue (Half of its mass comes from glues) $\Longrightarrow$ Can probe gluon structure

- Effective vertex

  [Atwood and Soni, PLB 405, 150 (1997)]

$$\mathcal{L} = H_0 \, \epsilon_{\mu\nu\alpha\beta} \, \epsilon_p^\mu \epsilon_q^\nu \, p^\alpha q^\beta$$

  with $H_0 \approx 1.8\,\mathrm{GeV}^{-1}$

- Simple Matrix Element:

$$|T|^2_{\eta' \leftrightarrow gg} = 4|H_0|^2 M^2_{\eta'}$$

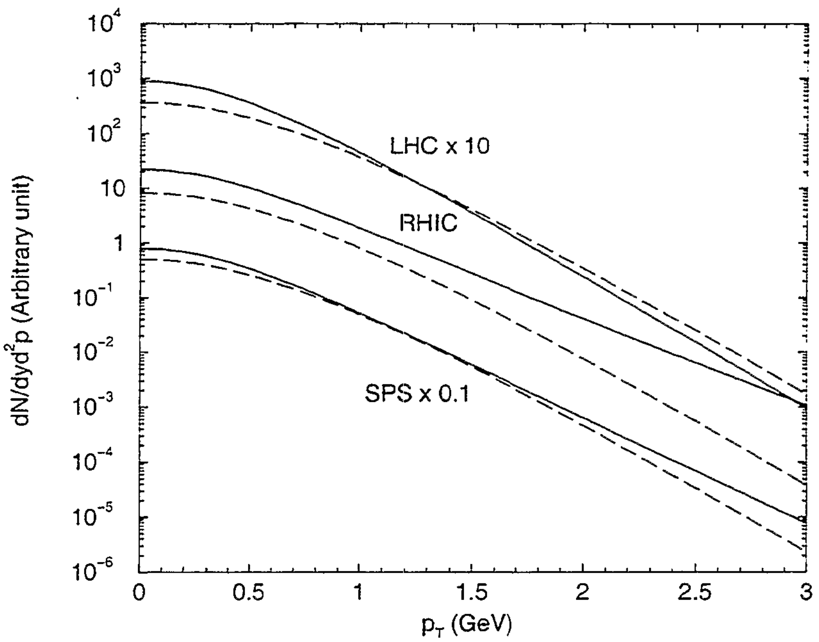
pp: Gluon polarization

$$\frac{d\sigma_{++} - d\sigma_{+-}}{d\sigma_{++} + d\sigma_{+-}} = \frac{\Delta G(x_+, Q^2)\, \Delta G(x_-, Q^2)}{G(x_+, Q^2)\, G(x_-, Q^2)}$$

pA: Gluon PDF

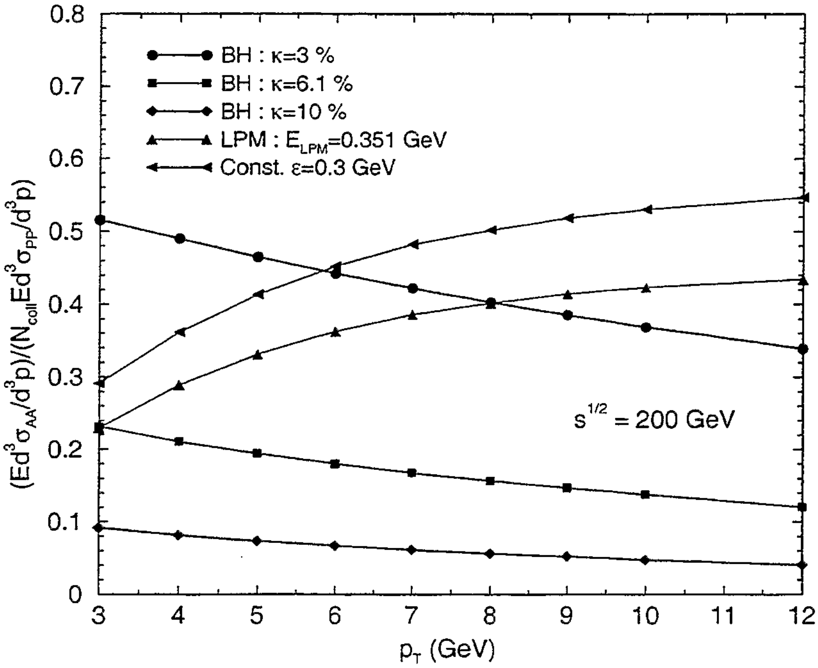
$$\frac{d\sigma^{pA\to\eta' X}}{dx_L} = \frac{\pi\, H_0^2}{64\, x_E}\, x_+ G^p(x_+, Q_f^2)\, x_- G^A(x_-, Q_f^2)$$

η' Enhancement in AA



Energy Loss

(with J.Jalilian-Marian, I.Sarcevic)



[Ratio of AA and PP π^0 cross-section at RHIC.]

- Recent PHENIX data is best explained with fractional energy loss, $-dE/dx \propto E$ (Bethe-Heitler)
- LPM effect, $-dE/dx \propto \sqrt{E}$, is not visible in the data.
- Why?

Outlook

- More fluctuation studies to come : How to beat b fluctuation, ...
- More η' studies to come : Higher order QCD correction, coherent production, ...
- More energy loss studies to come : LPM effect in QGP, ...
- In the works:
  * Vlasov equation description of thermalization of glue
  * Glueballs from Color Glass Condensate
  * ...

Recent Progress in Nuclear Effective Field Theory

Bira van Kolck

RBRC Review, Nov. 21-22, 2002

Recent Progress in Nuclear Effective Field Theory

Bira van Kolck

University of Arizona
and
RIKEN–BNL Research Center

- ◇ Goal and tool
- ◇ Previous developments
- ◇ Compton scattering
- ◇ Parity violation
- ◇ Halo nuclei
- ◇ Outlook

Supported in part by a DOE OJI Award and by a Sloan Fellowship

Goal

a QCD-based theory of nuclear matter in the hadronic phase

Tool

effective field theory for $Q < M_{QCD}$

=

most general dynamics with

- hadronic degrees of freedom (nucleons, pions, ...)
- symmetries of QCD (Lorentz, approximate chiral, ...)
- expansion in Q/M_{QCD},

$$T = \mathcal{N}(M_{QCD}) \sum_{\nu} \left(\frac{Q}{M_{QCD}}\right)^{\nu} \mathcal{F}_{\nu}(Q/m)$$

Previous developments

- $A = 2, 3$: *quantitative* description of strong interactions

  NN scattering $\leftarrow$ phase shifts

  deuteron $\leftarrow$ binding energy, form factors, various reactions

  Nd scattering $\leftarrow$ phase shifts, break-up diff cross sections

  triton $\leftarrow$ binding energy

- $A = 4$: in progress

- ...

- $A \to \infty$: finite T on the lattice

  toy model $\sim$ proof of concept

  EFT interactions $\sim$ in progress

Recently reviewed in
P. Bedaque and U. van Kolck, *Ann. Rev. Nucl. Part. Sci.* **52** (2002) 339
(nucl-th/0203055)

During last year:

- $A = 2$

  now a laboratory:

  $\rightarrow$ nucleon polarizabilities from Compton scattering

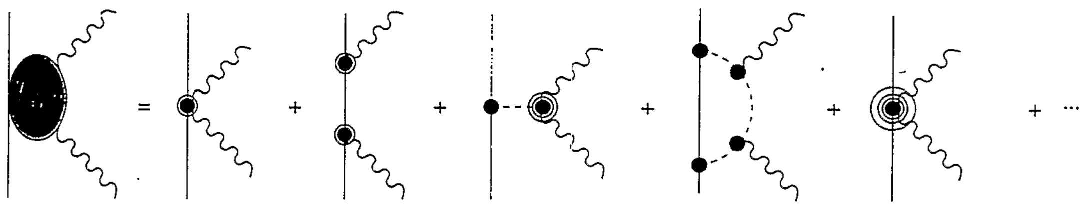
  $\rightarrow$ *weak* interactions

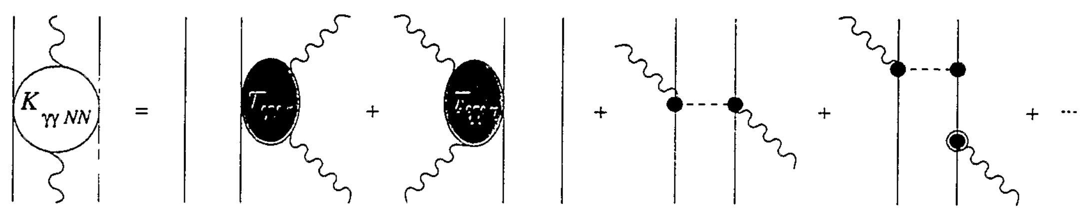
- $A = 5, 6, \ldots$

  new EFT for halo nuclei

Compton Scattering and Nucleon Polarizabilities

Beane, Malheiro, McGovern, Phillips + v.K., '02





$$T_{\gamma\gamma A} = \vec{\epsilon}\,' \cdot \vec{\epsilon}\left(-\frac{\mathcal{Z}_A{}^2 e^2}{m_A} + 4\pi\alpha_A\omega\omega'\right) + 4\pi\beta_A\,\vec{\epsilon}\,' \times \vec{k}' \cdot \vec{\epsilon} \times \vec{k} + \dots$$

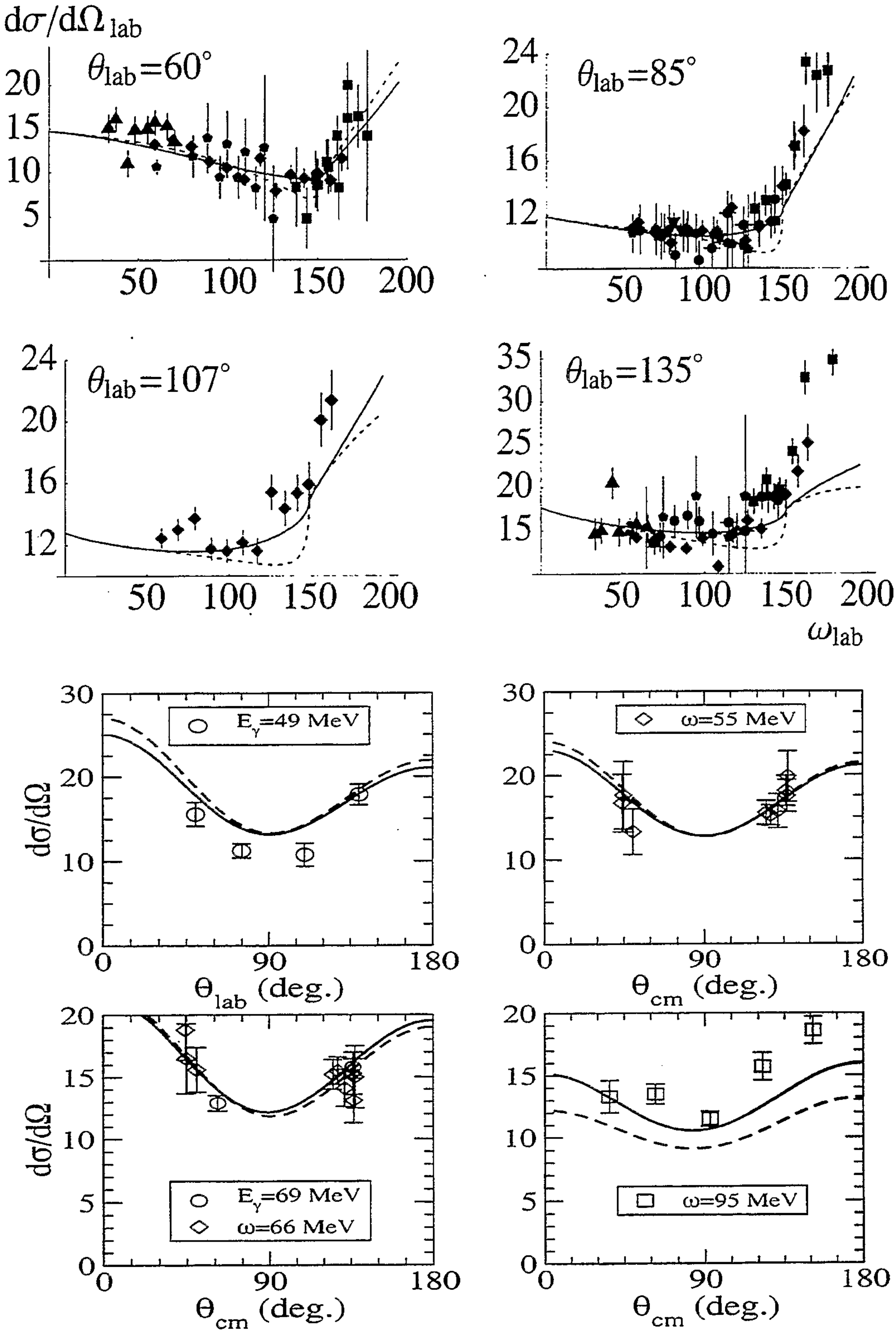
From fit to data,

$$\begin{aligned} \alpha_p &= (12.1 \pm 1.1)^{+0.5}_{-0.5} \times 10^{-4}\,\mathrm{fm}^3, \\ \beta_p &= (3.4 \pm 1.1)^{+0.1}_{-0.1} \times 10^{-4}\,\mathrm{fm}^3, \end{aligned}$$

$$\begin{aligned} \alpha_N &= (9.0 \pm 1.5)^{+3.6}_{-0.8} \times 10^{-4}\,\mathrm{fm}^3, \\ \beta_N &= (1.7 \pm 1.5)^{+1.4}_{-0.6} \times 10^{-4}\,\mathrm{fm}^3. \end{aligned}$$

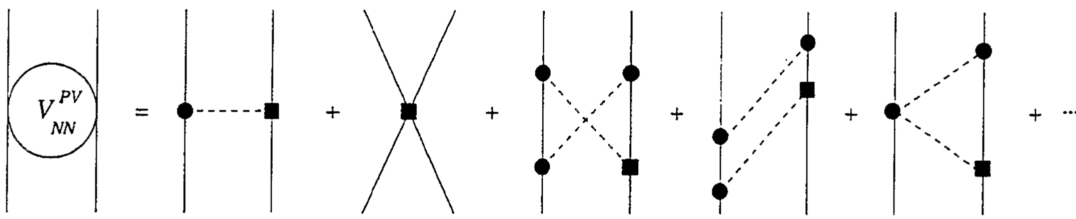
Compton Scattering on Proton and Deuteron to $O(Q^4)$

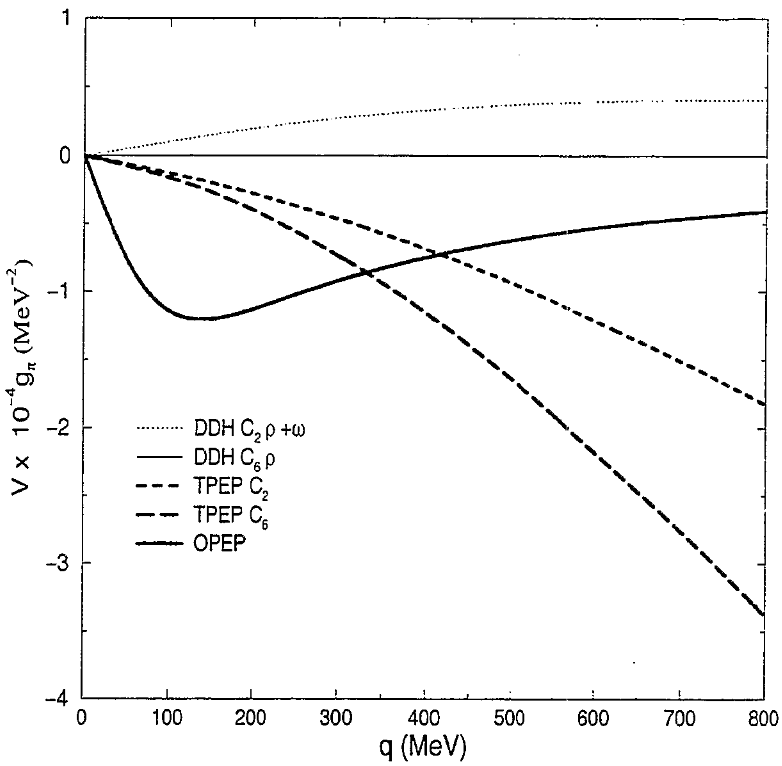
Beane, Malheiro, McGovern, Phillips + v.K., '02



Parity-Violating Nuclear Potential to $O(p)$

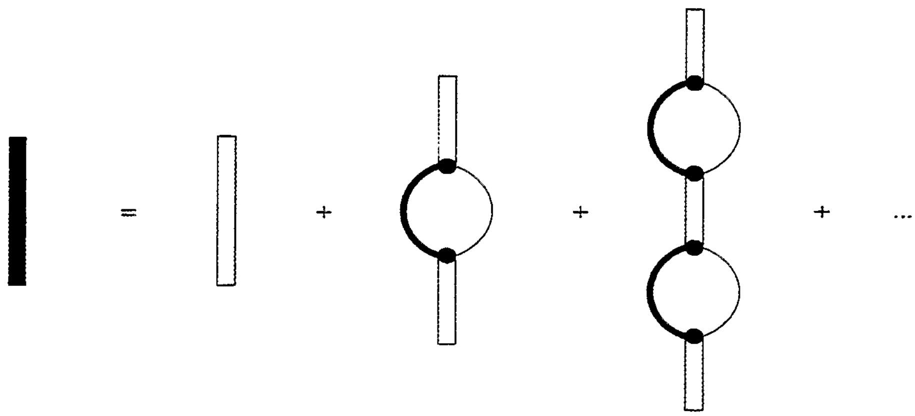
Zhu, Maekawa, Holstein, Ramsey-Musolf + v.K., in prep

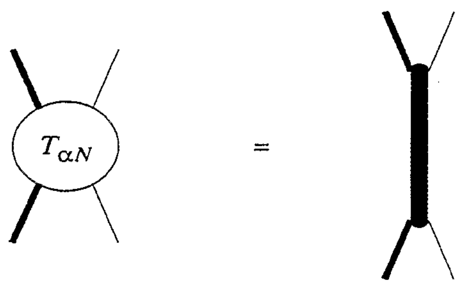




EFT for Halo Nuclei

Bertulani, Hammer + v.K., '02





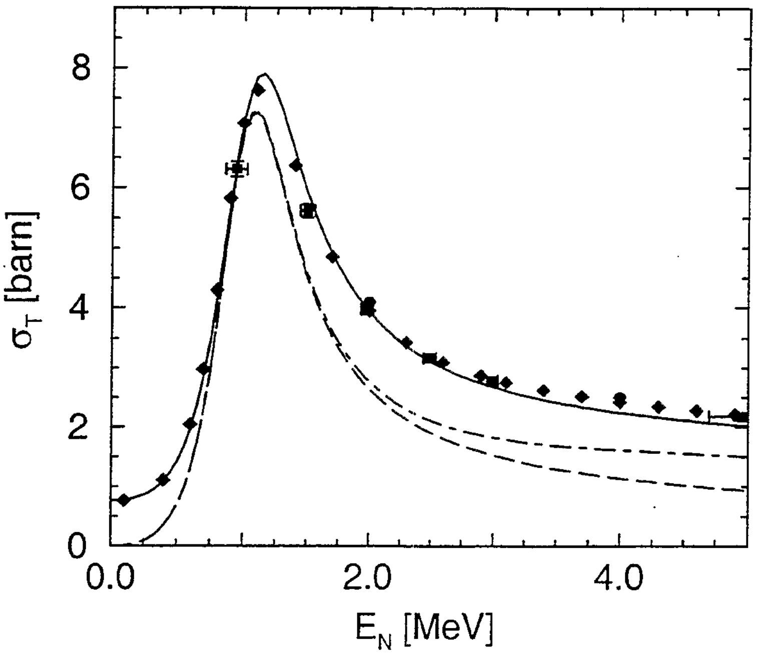
$$S_{\alpha N} = -\frac{E - E_0 - i\Gamma(E)/2}{E - E_0 + i\Gamma(E)/2}\,\frac{\sqrt{2\mu E} + i\gamma_1}{\sqrt{2\mu E} - i\gamma_1} + \ldots$$

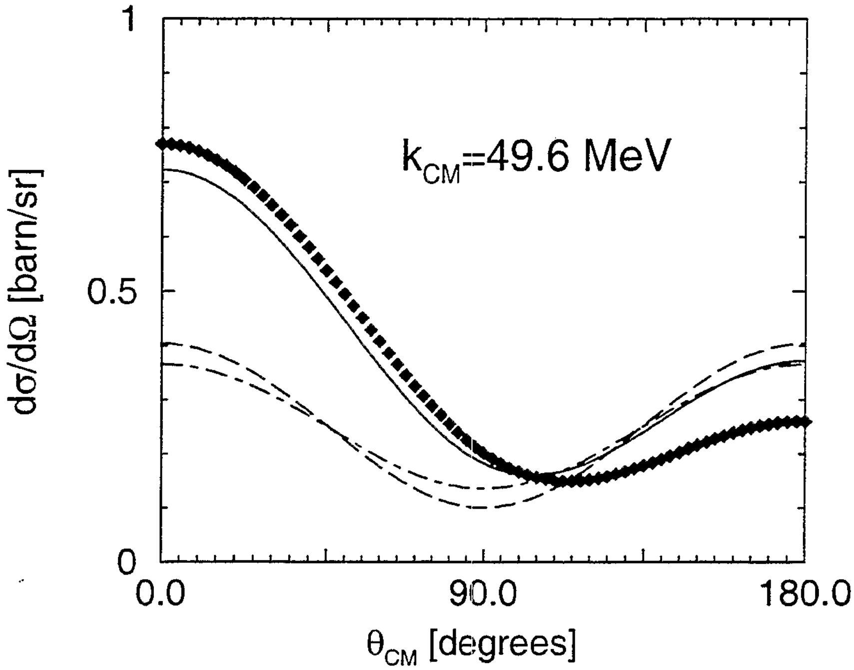
$$\left(E_0 = \frac{\gamma^2 + \tilde{\gamma}^2}{2\mu}, \quad \Gamma(E) = -4\gamma\sqrt{\frac{E}{2\mu}}\right)$$

$$\Rightarrow \quad \delta = \arctan\left(\frac{\Gamma(E)}{2(E_0 - E)}\right) + \delta_{\rm smooth}$$

$n\alpha$ Scattering at Low Energies

Bertulani, Hammer + v.K., '02





Outlook

- $A = 4$: strong interactions in leading orders

- $A \leq 5$: reanalysis of parity-violating experiments

- $A = 6, \ldots$: ^{6}He as an αnn bound state, other halos

- $A \to \infty$: strong interactions in leading orders (at $T \geq 0$)

(*i.e.*, still a lot do to!)

Fluctuations in Thermal QCD

Mikhail Stephanov

Motivation:

H.I.C. from SPS to RHIC — spectra and particle ratios — thermal.

$$\Downarrow$$

Final state (freezeout) thermodynamic.

$$\Downarrow$$

Q: What are the thermodynamic parameters: T and μ_B?
A: $T \sim 120 - 170$ MeV, $\mu_B = 50 - 600$ MeV (function of $\sqrt{s}$).

$$\Downarrow$$

Q: What are the thermodynamic properties (derivatives of thermodyn. functions) – susceptibilities, etc.?

$$\Downarrow$$

Fluctuations.

Naively:

$$\frac{\partial E}{\partial T} = -\frac{\partial^2 \mathcal{F}}{\partial T^2} = \frac{1}{T^2}\langle(\Delta E)^2\rangle,$$

$$\frac{\partial Q}{\partial \phi} = -\frac{\partial^2 \mathcal{F}}{\partial \phi^2} = \frac{1}{T}\langle(\Delta Q)^2\rangle$$

Caveat: not all d.o.f. are measured. $\Rightarrow$ More differential quantities have to be calculated in thermo QCD to compare to exps.

Two-particle correlator:

$$\langle \Delta n_p \Delta n_k \rangle$$

$\Delta n_p = n_p - \langle n_p \rangle$.

Example: $\Delta Q = \sum_{p.\alpha} q^\alpha \Delta n_p^\alpha$.

Task: calculate $\langle \Delta n_p \Delta n_k \rangle$.

Free gas (pions):

$$\langle N \rangle = -\frac{\partial \mathcal{F}}{\partial \mu}, \quad \text{and} \quad \langle (\Delta N)^2 \rangle = T \frac{\partial \langle N \rangle}{\partial \mu} = -T \frac{\partial^2 \mathcal{F}}{\partial \mu^2}.$$

Each mode p is independent: $\mathcal{F} = \Sigma_p \mathcal{F}_p$. Introduce μ_p: $\mu N = \mu \Sigma_p n_p \to \Sigma_p \mu_p n_p$. Then

$$\langle n_p \rangle = -\frac{\partial \mathcal{F}}{\partial \mu_p} = \frac{1}{e^{\beta \omega_p} - 1} \equiv f_p.$$

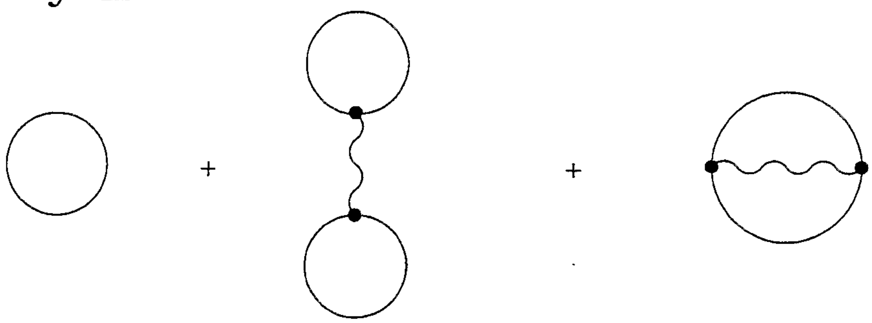
and

$$\langle \Delta n_p \Delta n_k \rangle = -T \frac{\partial^2 \mathcal{F}}{\partial \mu_p \partial \mu_k} = \delta_{pk} f_p (1 + f_p).$$

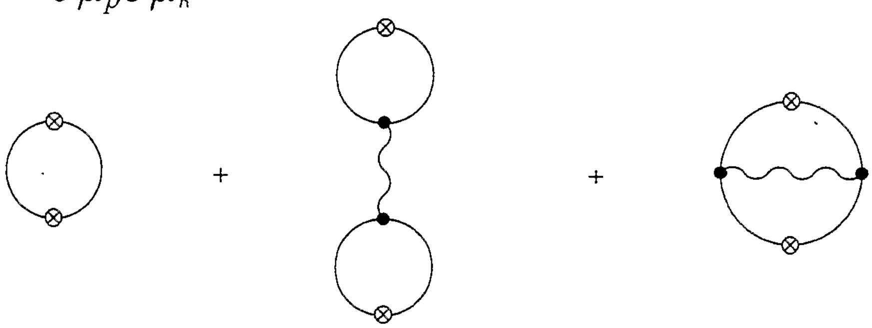
Interaction? $\mathcal{F} \neq \Sigma_p \mathcal{F}_p \Rightarrow$ correlations at $p \neq k$.

Interacting gas

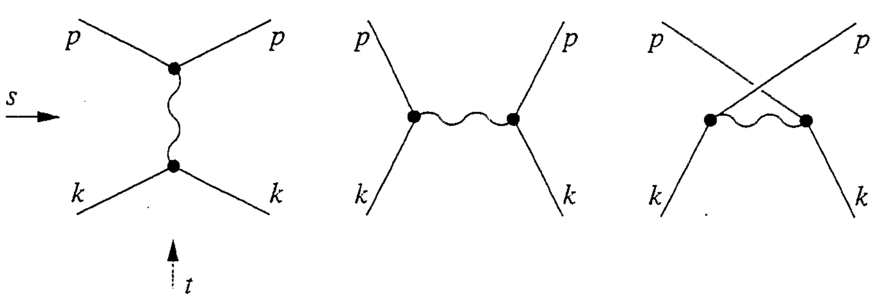
$\mathcal{F} =$



$$\frac{\partial^2 \mathcal{F}}{\partial \mu_p \partial \mu_k} =$$



$$\langle \Delta n_p \Delta n_k \rangle = -T \frac{\partial^2 \mathcal{F}}{\partial \mu_p \partial \mu_k} = \quad \text{(free)} \quad +$$



$$\langle \Delta n_p \Delta n_k \rangle_I = \beta \, \frac{f_p(1+f_p)}{\omega_p} \frac{f_k(1+f_k)}{\omega_k} \, \mathcal{A}_{pk\to pk}$$

Understanding this result:

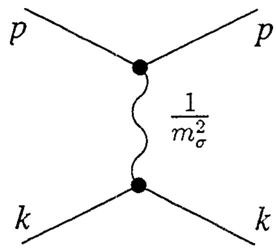
$$\langle n_p n_k \rangle - \langle n_p \rangle \langle n_k \rangle = f_2(p,k) - f_p f_k = f_p f_k (e^{-\beta E_I} - 1)$$

$$\approx f_p f_k(-\beta E_I) \sim f_p f_k \beta \, \mathcal{A}_{pk\to pk}.$$

(Born: $E_I = \langle pk | \mathcal{H}_I | pk \rangle \sim -\mathcal{A}_{pk\to pk}$).

Examples

σ - exchange. Near critical point $m_\sigma \to 0$. This diagram dominates:



$$\langle \Delta n_p^\alpha \Delta n_k^\beta \rangle_\sigma = \beta \, \frac{f_p' f_k'}{\omega_p \omega_k} \frac{G^2}{m_\sigma^2} \begin{pmatrix} 1 & 1 \\ 1 & 1 \end{pmatrix}^{\alpha\beta} .$$

$\alpha, \beta = \pi^+$ or π^-. No charge dependence – no contrib. to $\langle (\Delta Q)^2 \rangle = \Sigma_{\alpha\beta} q^\alpha q^\beta \langle \Delta n_p^\alpha \Delta n_k^\beta \rangle$.

ρ^0 - exchange. Charge dependence:
$\langle \Delta n_p^\alpha \Delta n_k^\beta \rangle_\rho \sim$

$$\frac{1}{m_\rho^2} \begin{pmatrix} -1 & 1 \\ 1 & -1 \end{pmatrix} + \frac{1}{m_\rho^2 - s} \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} + \frac{1}{m_\rho^2 - u} \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}$$

Negative contribution to $\langle (\Delta Q)^2 \rangle$.

Lattice Calculation of the Lowest Order Hadronic Contribution to the Anomalous Magnetic Moment of the Muon

Thomas Blum

Lattice calculation of hadronic contribution to the anomalous magnetic moment of the muon

Tom Blum

RIKEN BNL Research Center

Brookhaven National Laboratory

Classical interaction of particle with static magnetic field

$$V(\vec{x}) = -\mu \cdot \vec{B}$$

The magnetic moment μ is proportional to it's spin

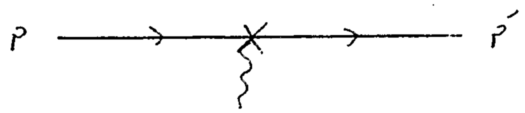
$$\vec{\mu} = g \left(\frac{e}{2m}\right) \vec{S}$$

The Landé g-factor is predicted from the Dirac eq. to be

$$g = 2$$

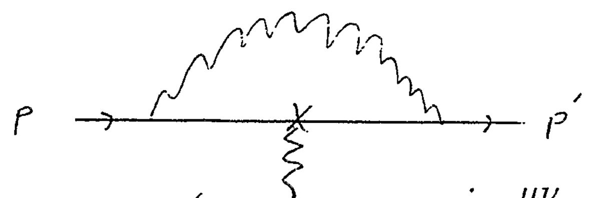
for elementary fermions

In the quantum theory this may change. At tree-level we have



$$\rightarrow \bar{u}(p')\,\gamma^\mu\, u(p)\,,$$

but radiative corrections modify this



$$\rightarrow \bar{u}(p')\,\Gamma^\mu\, u(p) \;=\; \bar{u(p')}\left(\gamma^\mu\, F_1(q^2) + \frac{i\,\sigma^{\mu\nu}\,q_\nu}{2m}\,F_2(q^2)\right)u(p)$$

Form factors F_1 and F_2 contain all information about muon's interaction with the electromagnetic field. In particular, it's charge and magnetic moment.

$F_1(0) = 1$ is charge of the muon in units of e. Since $F_1^{\text{tree}}(0) = 1$, all radiative corrections vanish (W-T identity).

There is no F_2 term at tree level. In general,

$$g \;=\; 2(F_1(0) + F_2(0))$$
$$F_2(0) \;=\; \frac{g-2}{2} \equiv a_\mu$$

and corrections start at $\mathcal{O}(\alpha)$.

Theory and Experiment status

[illegible]

[illegible]

- QED. $$a_\mu^{QED} = \sum C_n(\alpha/\pi)^n \quad (n = \text{1-5})$$

$$C_1 = 1/2 \text{ (Schwinger term (1948) } \alpha/(2\pi) = .00116\ 14\text{...)}$$

$$a_\mu^{\text{QED}}(\text{total}) = 11\,658\,470.57(0.29) \times 10^{-10}$$

- Hadronic. $$a_\mu^{\text{had}}(\text{4th ord.}) = 692(6) \times 10^{-10}$$

$$a_\mu^{\text{had}}(\text{6th ord.}) = -10.0(0.6) \times 10^{-10}$$

$$a_\mu^{\text{had}}(\text{light} - \text{light}) = 8.6(3.2) \times 10^{-10}$$

$$a_\mu^{\text{had}}(\text{total}) = 690.4(7) \times 10^{-10}$$

- Electroweak. $$a_\mu^{\text{EW}}(\text{total}) = 15.1(0.4) \times 10^{-10}$$

- Theory total: $$a_\mu^{\text{Theory}}(\text{total}) = 11\,659\,177(7) \times 10^{-10}$$

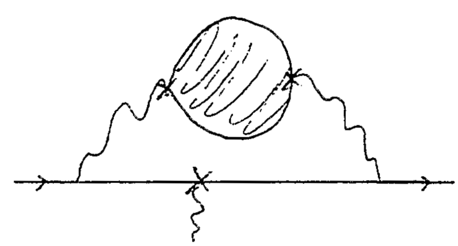
- Experimental value (Muon (g-2) Collab., BNL 2002):

$$a_\mu^{\text{Exp}} = 11\,659\,204(7)(5) \times 10^{-10}$$

- 2.6 σ discrepancy: $$a_\mu^{\text{Theory}} - a_\mu^{\text{Exp}} \approx -27(11) \times 10^{-10}$$

Focus on the lowest order in α hadronic contribution, the vacuum polarization.

$$\Pi^{\mu\nu}(q) = \int \mathrm{d}^4x\, \mathrm{e}^{i\,q\,(x-y)} \langle J^\mu(x) J^\nu(y)\rangle$$
$$= (q^\mu q^\nu - q^2 g^{\mu\nu})\Pi(q^2)$$



In the lattice regularization using domain wall fermions (DWF), current conservation is given by

$$\Delta^\mu J^\mu(x) = 0$$

where Δ^μ is the backward difference operator and

$$J^\mu(x) = \sum_s \frac{1}{2}\left(\bar\psi(x+\hat\mu,s)U^\dagger(x)(1+\gamma^\mu)\psi(x,s) - \bar\psi(x,s)U(x)(1-\gamma^\mu)\psi(x+\hat\mu,s)\right)$$

For the two-point function this yields

$$\begin{aligned}
&\Delta^\mu J^\mu(x)\,(J^\nu(y))^\dagger = \\
&- \sum_s \delta(x-y)\frac{1}{2}\left(\bar\psi(y+\hat\nu,s)U^\dagger(y)(1-\gamma^\nu)\psi(y,s) + \bar\psi(y,s)U(y)(1+\gamma^\nu)\psi(y+\hat\nu,s)\right) \\
&+ \delta(x-y-\hat\nu)\frac{1}{2}\left(\bar\psi(y+\hat\nu,s)U^\dagger(y)(1-\gamma^\nu)\psi(y,s) + \bar\psi(y,s)U(y)(1+\gamma^\nu)\psi(y+\hat\nu,s)\right),
\end{aligned}$$

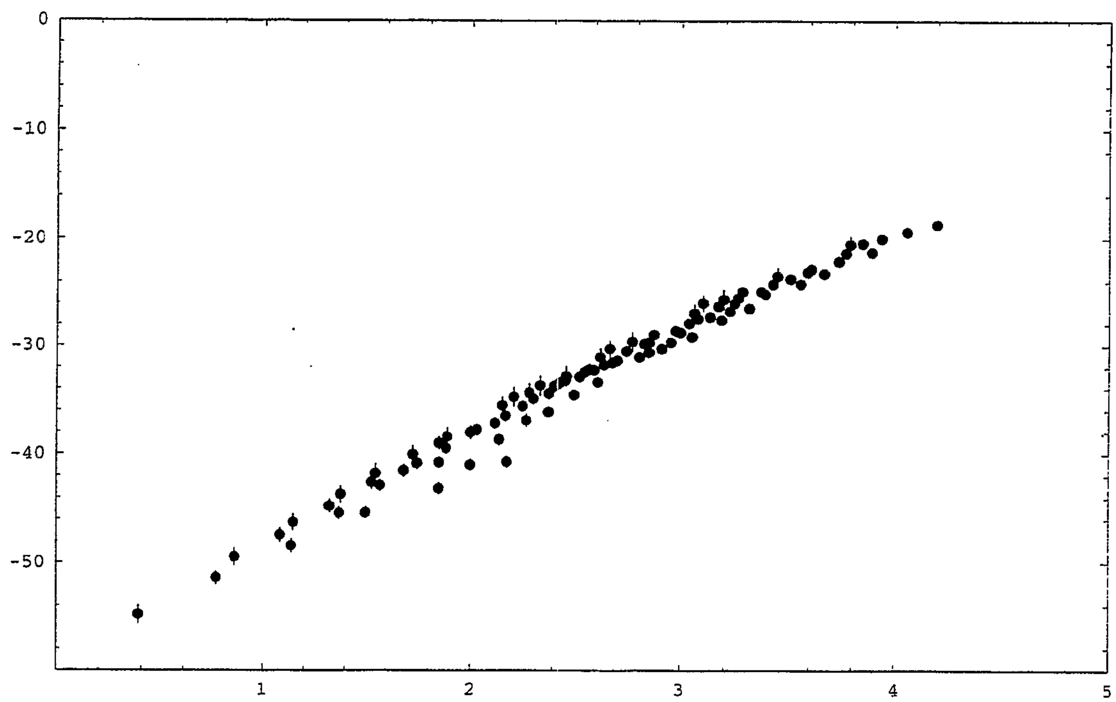
which is valid on any gauge-field configuration. After subtracting

$$\delta^{\mu\nu}\sum_s \frac{1}{2}\left(\,\bar\psi(y+\hat\nu,s)U^\dagger(y)(1-\gamma^\nu)\psi(y,s) + \bar\psi(y,s)U(y)(1+\gamma^\nu)\psi(y+\hat\nu,s)\,\right)$$

to cancel the contact terms, Fourier transformation of the two point functions yields the usual W-T Ident.

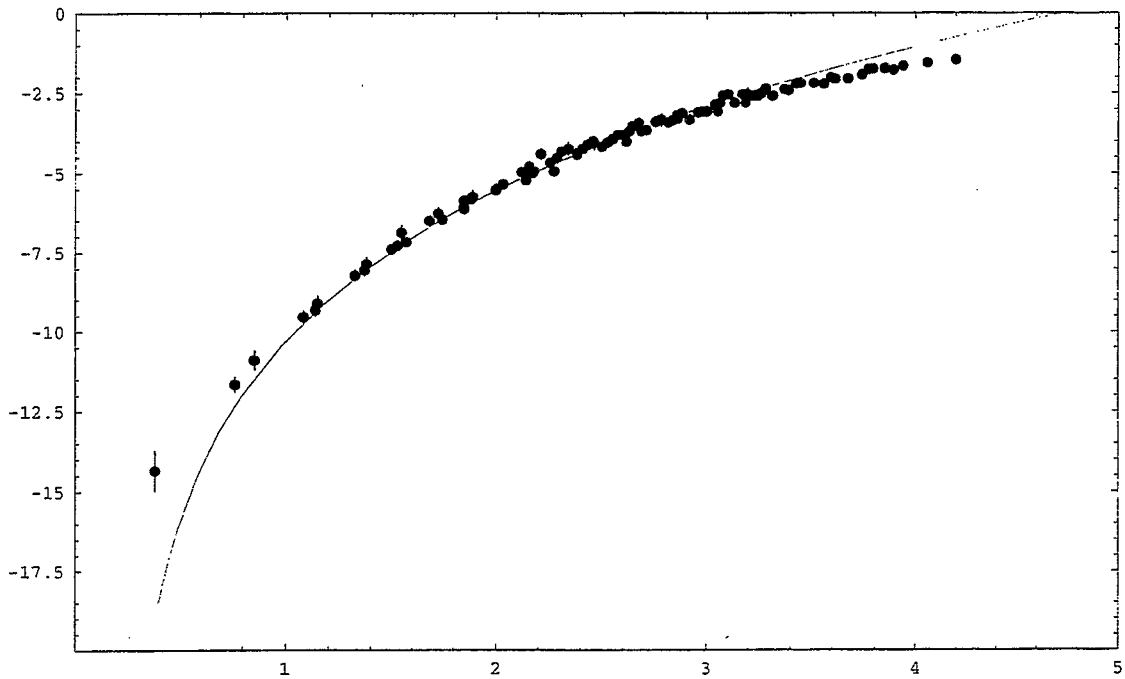
$$\hat q^\mu \Pi^{\mu\nu}(\hat q^2) = 0 \qquad (\hat q^\mu = 2\sin(\pi\,\mathsf{n}/L_\mu),\ \mathsf{n} = 0,\ldots,L_\mu - 1)$$

Need one more subtraction since we are using DWF, the subtraction of the heavy $5d$ bulk modes.



Note large $\mathcal{O}(a)$ and $\mathcal{O}(a^2)$ errors. As $L_s \to \infty$, heavy modes dominate.

After subtraction $\mathcal{O}(a)$ eliminated and $\mathcal{O}(a^2)$ errors reduced.



Points: DWF+DBW2 gauge action, $1/a \approx 2$ GeV, $m_f = 0.04$

Solid curve: 3-loop perturbation theory ($\overline{MS}$, $\mu = 1/a = 2$ GeV) [Chetyrkin, et al (1996)]

Proton Decay Matrix Elements with Domain-Wall Fermions

Yasumichi Aoki

Proton Decay Matrix Elements with Domain-Wall Fermions

Yasumichi Aoki for RBC collaboration

RIKEN BNL Research Center

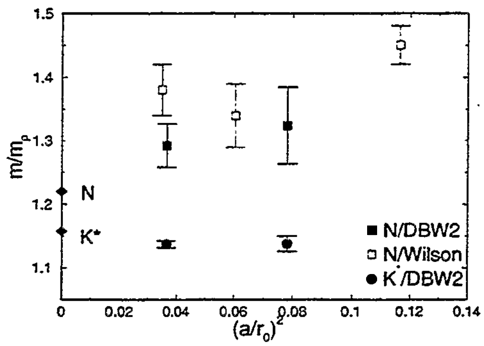
Nov. 21, 2002 (Scientific Review Committee Meeting)

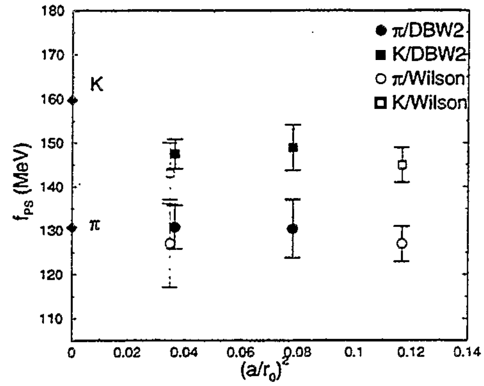
Introduction

- Proton (nucleon) decay.
  - Prediction from GUT. Not observed yet.
  - Lifetime of proton: given a GUT, one needs to know the hadronic matrix element.
  - Some old calculations for the chiral Lagrangian parameter.
  - Direct calculation by Gavela et al (1988), JLQCD (2000): Wilson fermion, $\beta = 6$, perturbative renormalization.
- Interesting to work with DWF because:
  - Small scaling violation to give reliable continuum extrapolation.
  - Good environment for NPR.
  - Eliminate mixing between operators which have different chirality.

Scaling property of DWF

DBW2+DWF, $L_s = 16$ [RBC, hep-lat/0211023].





DBW2 gauge action: T. Takaishi, PRD54 (96) 1050;
P. de Forcrand et al., NPB 577 (00) 263.

2

Chiral Lagrangian parameter of Proton Decay

$$\mathcal{O}_{RL}^{udu} \equiv \varepsilon_{ijk}(u^{iT}CP_R d^j)P_L u^k, \tag{1}$$
$$\mathcal{O}_{LL}^{udu} \equiv \varepsilon_{ijk}(u^{iT}CP_L d^j)P_L u^k. \tag{2}$$

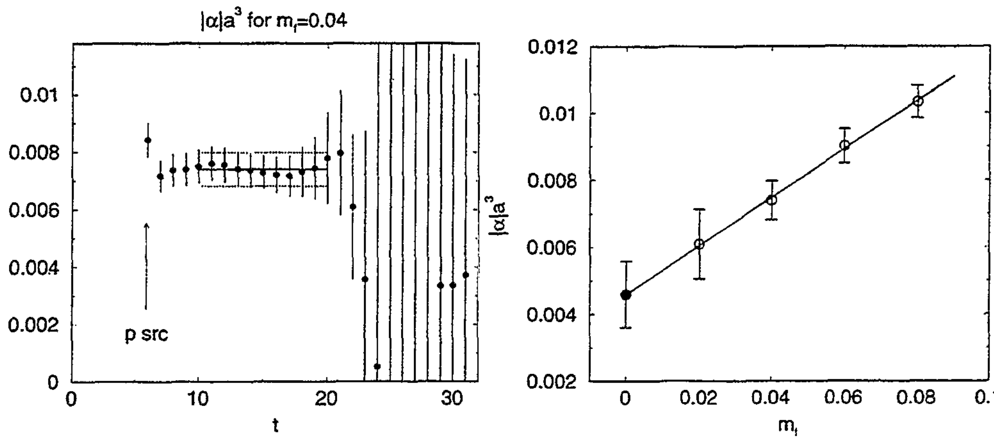
$$\langle 0|\mathcal{O}_{RL}^{udu}|p\rangle = \alpha P_L u_p, \tag{3}$$
$$\langle 0|\mathcal{O}_{LL}^{udu}|p\rangle = \beta P_L u_p. \tag{4}$$

χ PT (Claudson et al., NPB 195 (82) 297):

$$\langle \pi^0|\mathcal{O}_{RL}^{udu}|p\rangle \leftarrow \alpha\frac{1+(D+F)}{\sqrt{2}f}P_L u_p, \tag{5}$$
$$\langle \pi^0|\mathcal{O}_{LL}^{udu}|p\rangle \leftarrow \beta\frac{1+(D+F)}{\sqrt{2}f}P_L u_p, \tag{6}$$
$$D+F = 1.27. \tag{7}$$

$$R^{\alpha/\beta}(t,t_0) = \frac{\sum_{\vec{x}}\langle \mathcal{O}_{R/L\,L}^{udu}(\vec{x},t)\bar{J}_p(t_0)\rangle}{\sum_{\vec{x}}\langle J_p(\vec{x},t)\bar{J}_p(t_0)\rangle}\sqrt{Z_p}, \tag{8}$$

Results of Chiral Lagrangian parameter of Proton Decay



- $|\alpha|a^3$=0.0046(10).
- $|\beta|a^3$=0.0056(11).

4

Proton Decay Matrix Element with Direct Method

$$\langle \pi^0 | \varepsilon_{ijk} (u^{iT} C P_{R/L} d^j) P_L u^k | p \rangle = P_L \left[W_0(q^2) - W_q(q^2) i\not{q} \right] u_p, \tag{9}$$

where q is the momentum transfer of $p \to \pi^0$. We need to extract W_0, because $i\not{q}\nu_e = m_e \nu_e$ and $m_e \simeq 0$. But W_0 is always mixed with W_q, since we need to project + parity to drop the signal of parity partner of the proton,

$$\mathrm{tr}\left(P_L \left[W_0 - W_q i\not{q} \right] \left(\frac{\mathbb{1} + \gamma_4}{2} \right) \right) = W_0 - i q_4 W_q. \tag{10}$$

We can pick up W_q by

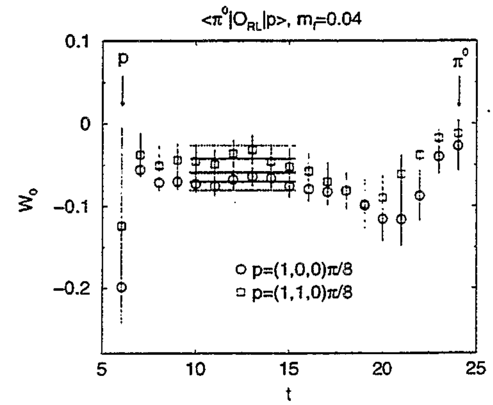
$$\mathrm{tr}\left(P_L \left[W_0 - W_q i\not{q} \right] \left(\frac{1 + \gamma_4}{2} \right) i\gamma_j \right) = q_j W_q. \tag{11}$$

$\to$ needs momentum injection for the three point function.

JLQCD, PRD 62 (00) 014506.

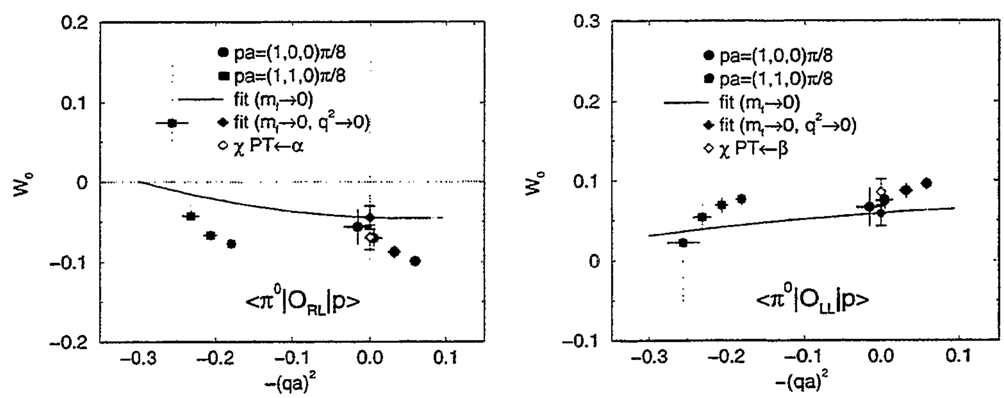
Ratio method for three and two point functions

$$
\begin{aligned}
R_{\vec{p}}(t',t,t_0) &= \frac{V_\sigma \sum_{\vec{x}',\vec{x}} e^{i\vec{p}\cdot(\vec{x}'-\vec{x})}\langle J_{\pi^0}(\vec{x}',t')\mathcal{O}^{udu}_{R/L;L}(\vec{x},t)\bar{J}_p(t_0)\rangle}{\sum_{\vec{x}',\vec{x}} e^{i\vec{p}\cdot(\vec{x}'-\vec{x})}\langle J_{\pi^0}(\vec{x}',t')J^{\dagger}_{\pi^0}(\vec{x},t)\rangle \sum_{\vec{x}}\langle J_p(\vec{x},t)\bar{J}_p(t_0)\rangle}\sqrt{Z_{\pi^0}}\sqrt{Z_p}, \\
&\to \left[W_0 - W_q i\not{q}\right]. \qquad (12)
\end{aligned}
$$



6

Results for Proton Decay Matrix Element



- Physical kinematics: $m_\pi \simeq m_e \simeq 0 : m_f \to 0, -q^2 \to 0$.
- No distinct difference between direct and χ PT, while JLQCD observed the difference.

Nucleon Matrix Elements with Domain Wall Fermions

Kostas Orginos

Nucleon matrix elements on the Lattice

Spin on the Lattice

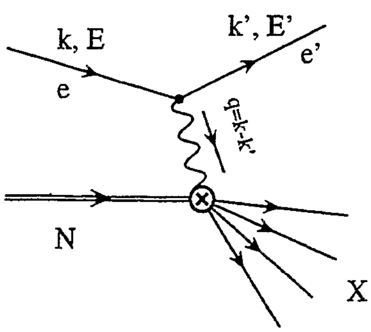
K. Orginos

RBC group

- Introduction and Motivation.
- What the Lattice can do / Review of Lattice results.
- RBC effort / Domain wall fermions.
- Preliminary results.
- Future work and Conclusions.

1

Introduction - Motivation



$$\left|\frac{\mathcal{A}}{4\pi}\right|^2 = \frac{\alpha^2}{Q^4} l^{\mu\nu} W_{\mu\nu}$$
$$W^{\mu\nu} = W^{[\mu\nu]} + W^{\{\mu\nu\}}$$

$$W^{\{\mu\nu\}}(x,Q^2) = \left(-g^{\mu\nu} + \frac{q^\mu q^\nu}{q^2}\right) F_1(x,Q^2) + \left(P^\mu - \frac{\nu}{q^2}q^\mu\right)\left(P^\nu - \frac{\nu}{q^2}q^\nu\right)\frac{F_2(x,Q^2)}{\nu}$$
$$W^{[\mu\nu]}(x,Q^2) = i\epsilon^{\mu\nu\rho\sigma} q_\rho \left(\frac{S_\sigma}{\nu}(g_1(x,Q^2) + g_2(x,Q^2)) - \frac{q\cdot SP_\sigma}{\nu^2} g_2(x,Q^2)\right)$$

with $\nu = q\cdot P$, $S^2 = -M^2$, $x = Q^2/2\nu$

- Calculate **non-perturbatively** Nucleon Structure Functions
  - Unpolarized: $F_1(x,Q^2)$, $F_2(x,Q^2)$
  - **Polarized:** $g_1(x,Q^2)$, $g_2(x,Q^2)$, $h_1(x,Q^2)$

Moments of Structure Functions

$$2\int_0^1 dx x^{n-1} F_1(x,Q^2) = \sum_{q=u,d} c_{1,n}^{(q)}(\mu^2/Q^2, g(\mu))\,\langle x^n\rangle_q(\mu) + \mathcal{O}(1/Q^2),$$

$$\int_0^1 dx x^{n-2} F_2(x,Q^2) = \sum_{f=u,d} c_{2,n}^{(q)}(\mu^2/Q^2, g(\mu))\,\langle x^n\rangle_q(\mu) + \mathcal{O}(1/Q^2),$$

$$2\int_0^1 dx x^{n} g_1(x,Q^2) = \sum_{q=u,d} e_{1,n}^{(q)}(\mu^2/Q^2, g(\mu))\,\langle x^n\rangle_{\Delta q}(\mu) + \mathcal{O}(1/Q^2),$$

$$2\int_0^1 dx x^{n} g_2(x,Q^2) = \frac{1}{2}\frac{n}{n+1} \sum_{q=u,d} [e_{2,n}^{q}(\mu^2/Q^2, g(\mu))\, d_n^q(\mu) - 2e_{1,n}^{q}(\mu^2/Q^2, g(\mu))\,\langle x^n\rangle_{\Delta q}(\mu)] + \mathcal{O}(1/Q^2)$$

- c_1, c_2 and e_1, e_2 are the Wilson coefficients ([illegible]),
- $\langle x^n\rangle_q(\mu)$, $\langle x^n\rangle_{\Delta q}(\mu)$ and d_n are forward nucleon matrix elements of certain local operators $\mathcal{O}$.

Method: Lattice QCD.

3

Lattice Operators

Unpolarized (F_1/F_2):

$$\frac{1}{2}\sum_s \langle P,S|\mathcal{O}^q_{\{\mu_1\mu_2\cdots\mu_n\}}|P,S\rangle = 2\langle x^{n-1}\rangle_q(\mu)[P_{\mu_1}P_{\mu_2}\cdots P_{\mu_n} + \cdots - trace]$$

$$\mathcal{O}^q_{\mu_1\mu_2\cdots\mu_n} = \overline{q}\left[\left(\frac{i}{2}\right)^{n-1}\gamma_{\mu_1}\overleftrightarrow{D}_{\mu_2}\cdots\overleftrightarrow{D}_{\mu_n} - trace\right] q$$

On the lattice we can measure: $\langle x\rangle_q$, $\langle x^2\rangle_q$ and $\langle x^3\rangle_q$

- Broken Lorentz symmetry $\Longrightarrow$ higher moment operators mix with **lower** dimensional operators. Operators belonging in irreducible representations of $O(4)$ transform reducibly under the lattice Hyper-cubic group.
- Only $\langle x\rangle_q$ can be measured with $\vec{P} = 0$

Polarized (g_1/g_2):

$$-\langle P,S|\mathcal{O}^{5q}_{\{\sigma\mu_1\mu_2\cdots\mu_n\}}|P,S\rangle = \frac{2}{n+1}\langle x^n\rangle_{\Delta q}(\mu)[S_\sigma P_{\mu_1}P_{\mu_2}\cdots P_{\mu_n}+\cdots-traces]$$

$$\mathcal{O}^{5q}_{\sigma\mu_1\mu_2\cdots\mu_n} = \overline{q}\left[\left(\frac{i}{2}\right)^n \gamma_5\gamma_\sigma \overleftrightarrow{D}_{\mu_1}\cdots\overleftrightarrow{D}_{\mu_n} - traces\right] q$$

$$\langle P,S|\mathcal{O}^{[5]q}_{[\sigma\{\mu_1]\mu_2\cdots\mu_n\}}|P,S\rangle = \frac{1}{n+1}d_n^q(\mu)[(S_\sigma P_{\mu_1}-S_{\mu_1}P_\sigma)P_{\mu_2}\cdots P_{\mu_n}+\cdots-traces]$$

$$\mathcal{O}^{[5]q}_{[\sigma\mu_1]\mu_2\cdots\mu_n} = \overline{q}\left[\left(\frac{i}{2}\right)^n \gamma_5\gamma_{[\sigma} \overleftrightarrow{D}_{\mu_1]}\cdots\overleftrightarrow{D}_{\mu_n} - traces\right] q$$

Transversity (h_1):

$$\langle P,S|\mathcal{O}^{\sigma q}_{\rho\nu\{\mu_1\mu_2\cdots\mu_n\}}|P,S\rangle = \frac{2}{m_N}\langle x^n\rangle_{\delta q}[(S_\rho P_\nu - S_\nu P_\rho)P_{\mu_1}P_{\mu_2}\cdots P_{\mu_n}+\cdots-traces]$$

$$\mathcal{O}^{\sigma q}_{\rho\nu\mu_1\mu_2\cdots\mu_n} = \overline{q}[\left(\frac{i}{2}\right)^n \gamma_5\sigma_{\rho\nu} \overleftrightarrow{D}_{\mu_1}\cdots\overleftrightarrow{D}_{\mu_n} - traces]q$$

On the lattice we can measure: $\langle 1\rangle_{\Delta q}$ (g_A), $\langle x\rangle_{\Delta q}$, $\langle x^2\rangle_{\Delta q}$, d_1, d_2, $\langle 1\rangle_{\delta q}$ and $\langle x\rangle_{\delta q}$. • Only $\langle 1\rangle_{\Delta q}$, $\langle x\rangle_{\Delta q}$, d_1, and $\langle 1\rangle_{\delta q}$ can be measured with $\vec{P}=0$

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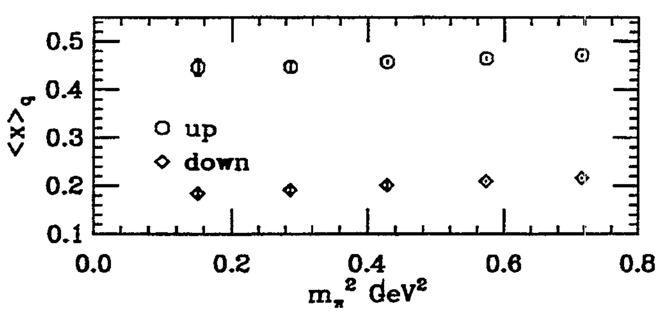
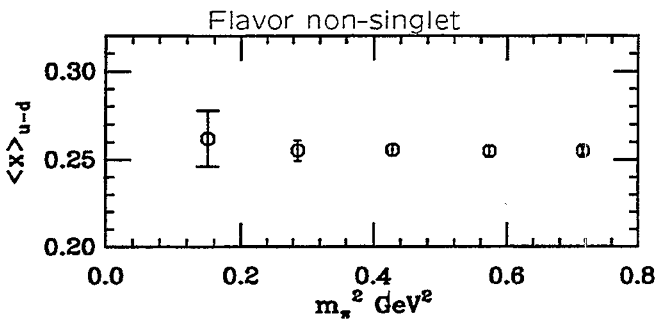




Quark density

$$\mathcal{O}_{44} = \overline{q}\left[\gamma_4 \overleftrightarrow{D}_4 - \frac{1}{3}\sum_{k=1}^{3}\gamma_k \overleftrightarrow{D}_k\right] q$$

- Hypercubic group rep. 3_1^+
- Momentum: $\vec{P}=0$
- Renormalization: Multiplicative

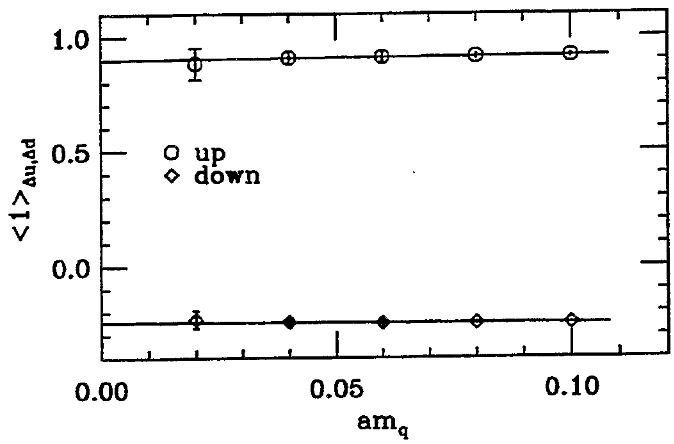
Note:

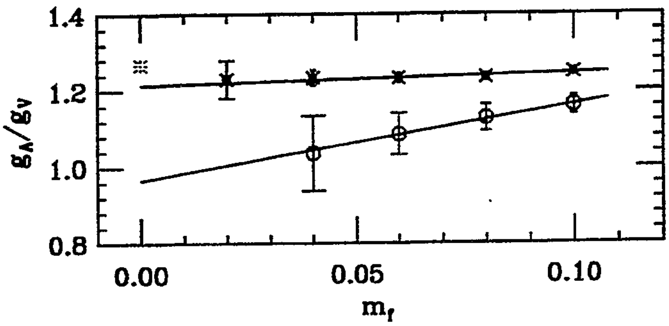
- Unrenormalized
- No Curvature in the chiral limit

$\frac{\langle x\rangle_u}{\langle x\rangle_d} = 2.41(4)$ at the chiral limit

plateaus

Helicity





Axial Charge

- Renormalization:

$$\langle A^{\cdots}\overline{q}\gamma_5 q\rangle = Z_A\langle A^{loc}\overline{q}\gamma_5 q\rangle$$

[Y. Aoki LAT01]

$$Z_A = 0.77759(45)$$

- Chiral limit ( ):

$$g_A = 1.21(2)$$

plateaus

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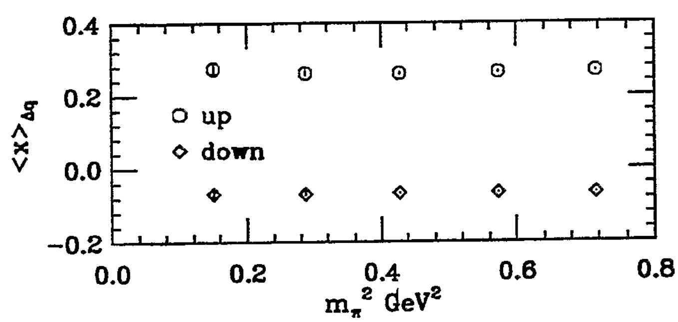
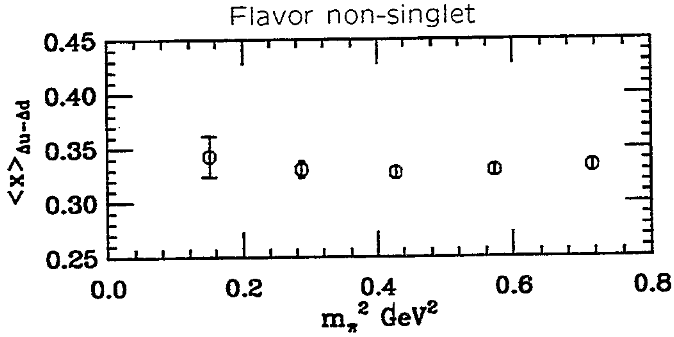


Flavor non-singlet



Measure:

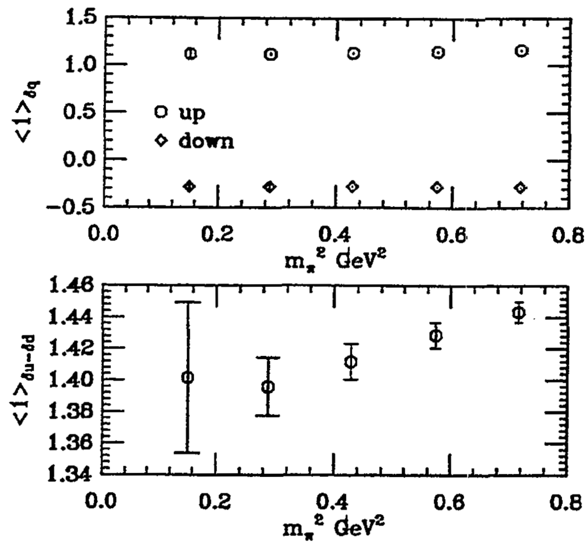
$$\mathcal{O}^{5}_{34} = \frac{1}{4}\overline{q}\gamma_5\left[\gamma_3 \overleftrightarrow{D}_4 + \gamma_4 \overleftrightarrow{D}_3\right] q$$

- Hypercubic group rep.: 6_3^-
- Momentum: $\vec{P} = 0$
- Renorm.: Multiplicative

Note:

- Unrenormalized
- No curvature in the chiral limit
- Light mass needs more statistics

plateaus



Transversity:

$$\mathcal{O}_{34}^{\sigma q} = \bar{q}\gamma_5\sigma_{34}q \quad \rightarrow \quad \langle 1 \rangle_{\delta q}$$

- Hyper-cubic group representation: $\mathbf{6}_1^+$
- Momentum: $\vec{P} = 0$
- Renorm.: Multiplicative

Note:

- Unrenormalized

  NPR has been done

  Result coming soon

  [C. Dawson LAT02]

QCDSF(quenched continuum):

$$\langle 1 \rangle_{\delta u - \delta_d} = 1.214(40)$$

plateaus

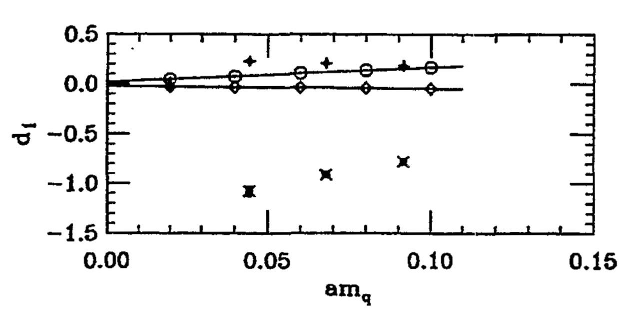
Twist Three

$$\mathcal{O}_{34}^{[5]q} = \frac{1}{4}\bar{q}\gamma_5\left[\gamma_3 \overleftrightarrow{D}_4 - \gamma_4 \overleftrightarrow{D}_3\right] q \quad \rightarrow \quad d_1^q$$

- Hyper-cubic group representation: $\mathbf{6}_1^+$
- Momentum: $\vec{P} = 0$
- Renormalization: Multiplicative (DWF Chiral symmetry)

  chiral symmetry breaking causes mixing with

  $\mathcal{O}_{34}^{\sigma q} = \bar{q}\gamma_5\sigma_{34}q$



Note:

- Unrenormalized
- Disagreement with the Wilson results

  Power divergent mixing

  [LHPC-SESAM: hep-lat/0201021]
- Small at chiral limit

Conclusions - Future

- Lattice QCD can compute non-perturbatively certain low moments of structure functions.
- Several systematic errors still need careful study:
  - Finite lattice spacing
  - Chiral limit
  - Finite volume
  - Quenching
- Started the calculation of Nucleon matrix elements with
  Domain wall fermions ... improved chirality.scaling
- Preliminary results look promising
  Simulation at light quark masses possible
- : Curvature in the chiral limit
- : Absence of power divergence mixing
  Small at the chiral limit

Future:

- Compute renormalization constants (NPR)
- Extend to higher moments (non-zero momentum)
- Disconnected contributions
- Form factor calculation
- Dynamical domain wall fermions

Calculation of Hadronic Matrix Elements for Kaon Decay in Quenched Domain-Wall QCD

Jun-Ichi Noaki

RIKEN Review, Nov. 2002

Calculation of Hadronic Matrix Elements for Kaon Decay in Quenched Domain-Wall QCD

Jun-Ichi Noaki

RIKEN BNL Reserch Center

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for RBC Collaboration

1. Introduction

- Physics in Kaon processes

indirect $\not{CP}$ $\Leftarrow K^0 - \overline{K^0}$ mixing : B_K

$\Delta I = 1/2$ rule, direct $\not{CP}$ $\Leftarrow K \to \pi\pi : \mathrm{Re}A_0/\mathrm{Re}A_2\ ,\ \ \varepsilon'/\varepsilon$

- Calculation in the lattice QCD

$$H_W^{\Delta S=2} = \frac{G_F^2}{16\pi^2} C(\mu) Q^{\Delta S=2}\ ,\ \ H_W^{\Delta S=1} = \frac{G_F}{\sqrt{2}} V_{\mathrm{us}} V_{\mathrm{ud}}^* \sum_i W_i(\mu) Q_i^{\Delta S=1}$$

$$\Rightarrow \left\langle \overline{K^0} \middle| Q^{\Delta S=2}(\mu) \middle| K^0 \right\rangle\ ,\ \ \left\langle \pi\pi \middle| Q^{\Delta S=1}(\mu) \middle| K^0 \right\rangle$$

Quenched calc. of ε'/ε: Pekurovsky & Kilcup, 1998 (Wilson gluon + staggerd quark)
CP-PACS Collab., 2001 (Iwasaki gluon + DW quark)
RBC Collab., 2001 (Wilson gluon + DW quark)

Inconsistent with experiments, many sources of the error

- Our new calculation

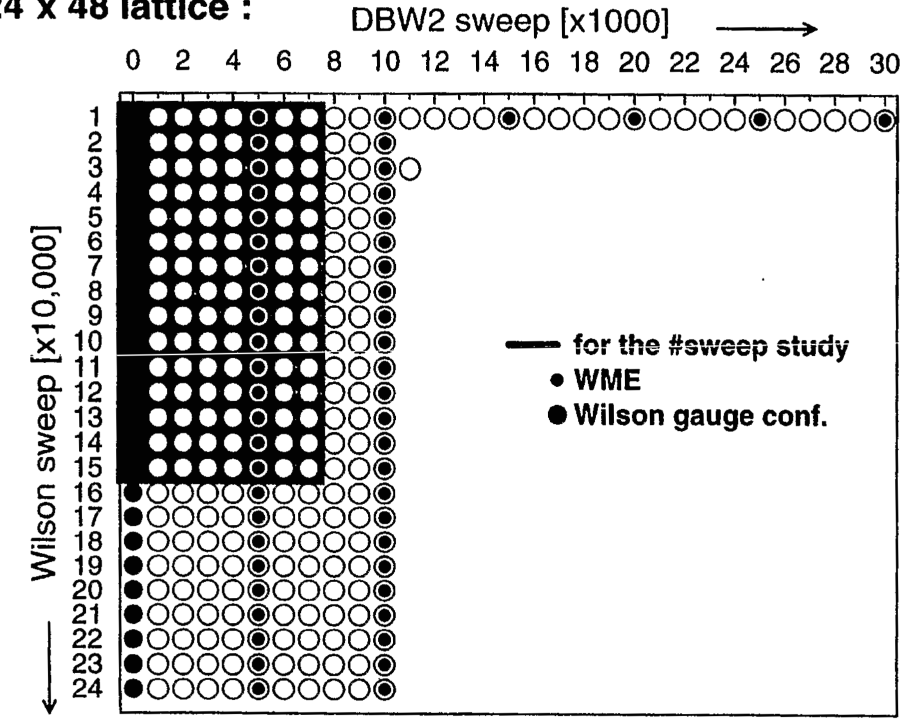
use of DBW2 gauge action + DWF: excellent chiral symm. on the lattice
scaling of lattice $a^{-1} \approx 3$ GeV : closer to the continuum limit
inclusion of charm quark : less systematic error

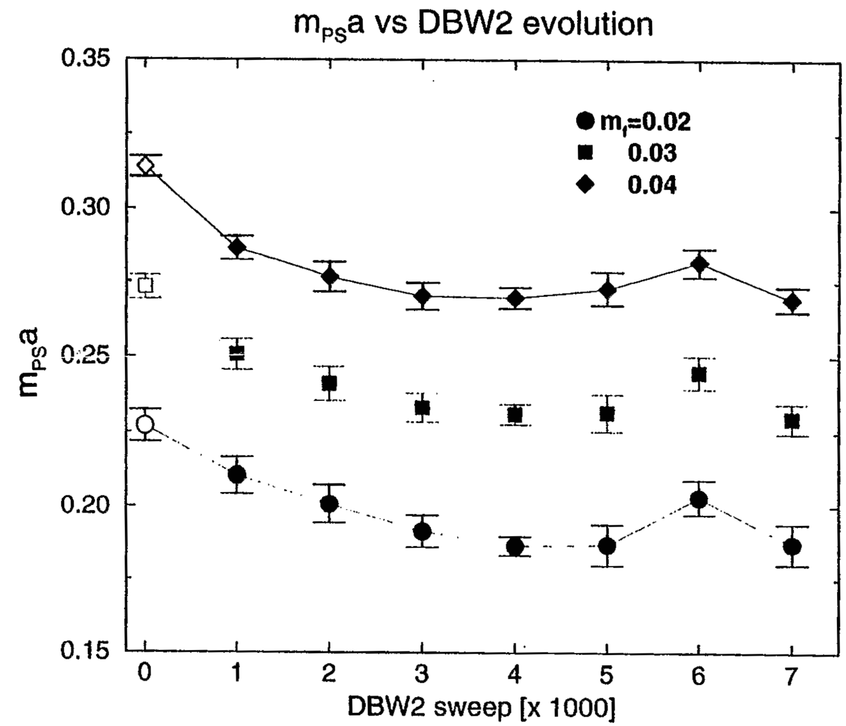
2. Gauge Configuration by DBW2 Action hep-lat/0211013

- **Strategy of gauge generation**

  DBW2 action hardly change the topological charge: $\langle Q_{\mathrm{top}} \rangle \neq 0$

24^3x 48 lattice :





natural Q_{top} distribution: $\langle Q_{\mathrm{top}} \rangle = -0.32 \pm 3.36$ over 50 Wilson gauge confs.
small chiral symm. breaking: $m_{\mathrm{res}} = 0.276(10)$ MeV with $L_s = 10$
$a^{-1} = 2.89(12)$ GeV $\Rightarrow$ phys. vol.$\approx$ 1.7 fm

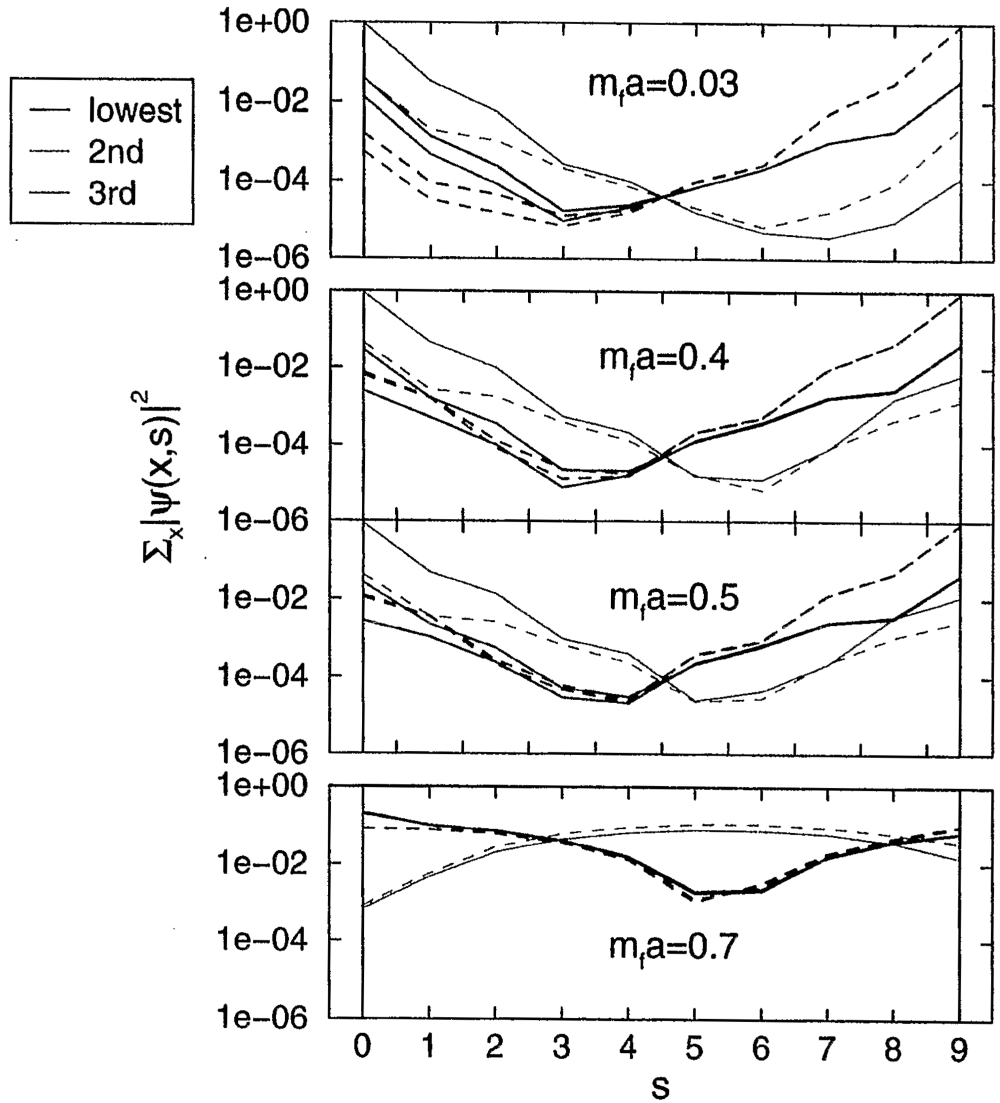
3. Inclusion of charm quark in the calc.

$$\langle \pi\pi | H_W^{\Delta S=1} | K \rangle$$
$$= \frac{G_F}{\sqrt{2}} V_{\rm us} V_{\rm ud}^* \sum_i W_i(\mu) \langle \pi\pi | Q_i^{\Delta S=1}(\mu) | K \rangle$$

- Matching at $\mu > m_c$
  $m_f a \to 1.0$: DWF fails to work.
  $a^{-1} \simeq 2.9$ GeV $\Rightarrow$ $m_c a \approx 0.44$

- Study of eigen vectors of $\gamma_5 D_W$

$$\Psi(x,s) \sim e^{ipx}[Ae^{\alpha s} + A' e^{-\alpha s}]$$

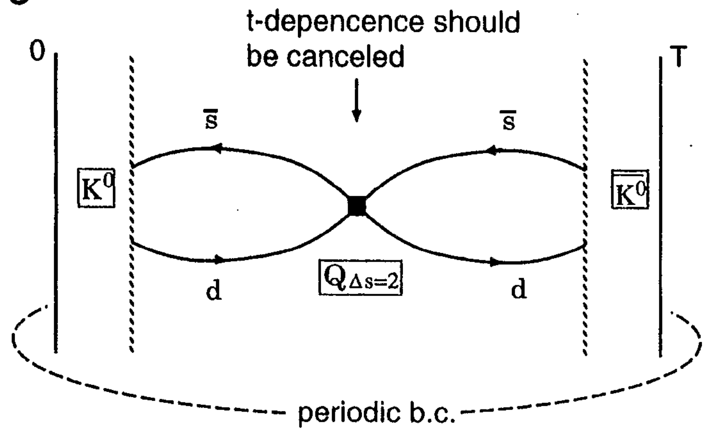


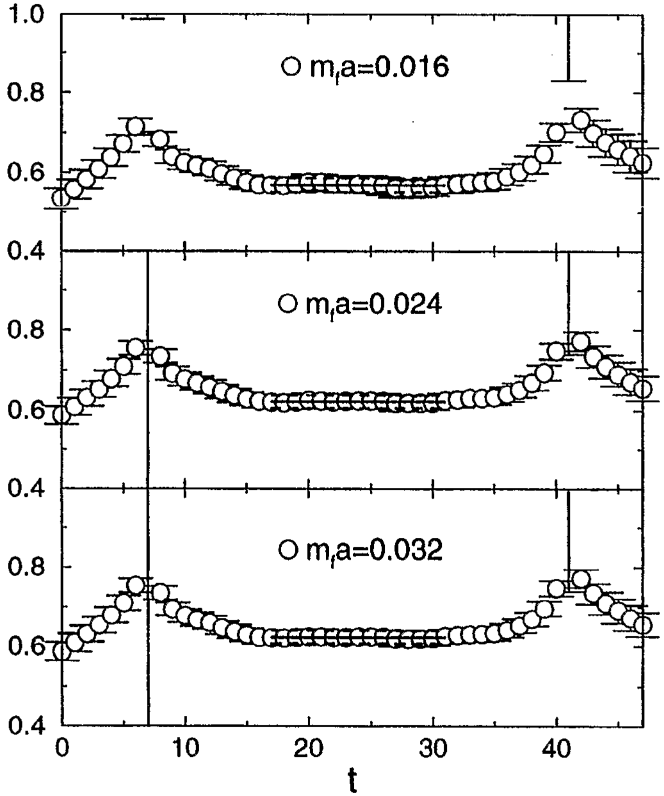
$m_c a \approx 0.44$ seems to work.

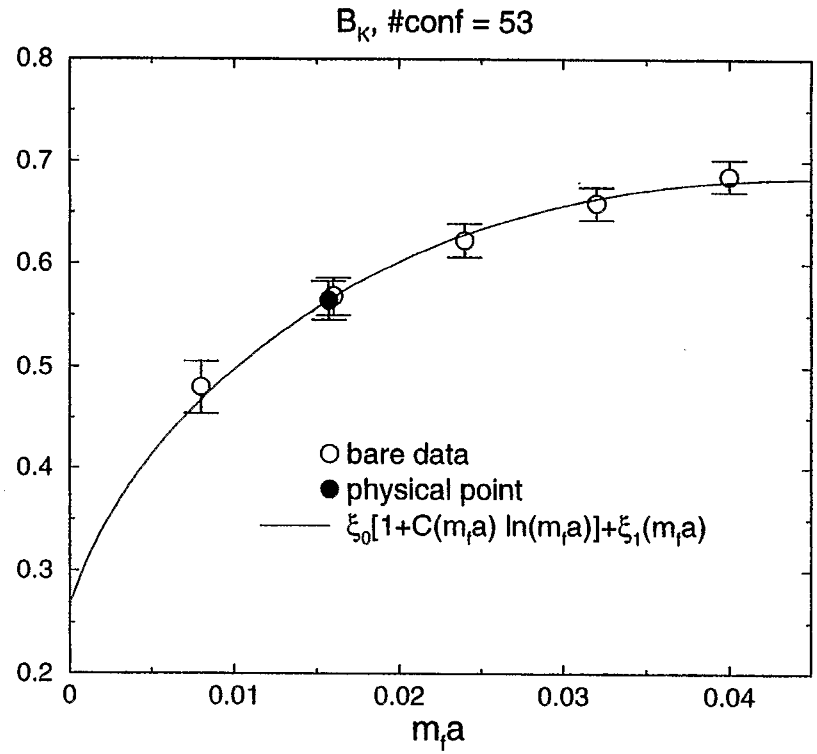
4. Kaon B-parameter hep-lat/0211013

$$B_K = \frac{\langle \overline{K} \,|\, Q^{\Delta S=2} \,|\, K \rangle}{\frac{8}{3} \langle \overline{K} \,|\bar{s}\gamma_4\gamma_5 d|\, 0 \rangle \langle 0 \,|\bar{s}\gamma_4\gamma_5 d|\, K \rangle}$$

$$Q^{\Delta S=2} = [\bar{s}\gamma_\mu(1-\gamma_5)d][\bar{s}\gamma_\mu(1-\gamma_5)d]$$







consistent with previous work (*eg.* CP-PACS Collab., 2001)
Calc. of ε'/ε is now going on.

Effective Theory for Polyakov Loops in Lattice QCD

Yukio Nemoto

Effective Theory for Polyakov Loops in Lattice QCD

(a test of multi-level algorithm)

Yukio Nemoto(RBRC)
(for RBC collaboration)

INTRODUCTION

Effective Theory for Polyakov Loops

- Critical Behavior in SU(N) Gauge Thory
  Effective Potential for Polyakov Loops
  → For 2 colors

$$\nu = -\frac{m_1^2}{2}\ell_1^2 + \frac{\lambda_1}{4}\ell_1^4$$

ℓ_1 : polyakov loop

$$\ell_1 = \frac{1}{N_C}\mathrm{Tr}(L), \qquad L = \mathrm{P}\exp(ig\int_0^{1/T} A_0(\vec{x},\tau)d\tau)$$

2-nd order phase transition implies

$$\left.\begin{array}{ll} m_1^2 > 0 & ,T < T_C \\ m_1^2 < 0 & ,T > T_C \ \text{(S.S.B)} \end{array}\right\}?$$

→ For 3 colors

$$\nu = -\frac{m_1^2}{2}|\ell_1|^2 + \frac{\kappa_1}{3}(\ell_1^3 + c.c) + \frac{\lambda_1}{4}(|\ell_1|^2)^2$$

weak 1-st order p.t. implies

$$\kappa_1 \ll 1?$$

Polyakov Loops with higher $Z(N)$-charge

Ordinary Pol. Loop ℓ_1 transforms as a field with charge-1 under a global $Z(N)$ transformation

$$\ell_1 \to e^{i\phi}\ell_1$$

A charge-two Pol. loop is defined by

$$\ell_2 = \frac{1}{N_C}\mathrm{Tr}(\tilde{L}^2) = \frac{1}{N_C}\mathrm{Tr}(L^2) - \frac{1}{N_C^2}(\mathrm{Tr}(L))^2$$

$$\tilde{L} = L - \ell_1 1$$

Under the $Z(N)$

$$\ell_2 \to e^{2i\phi}\ell_2$$

(see R.D.Pisarski,hep-ph/0112037,hep-ph/0203271)

Effective couplings of Polyakov loops

Deckert et.al.1987, Gonzalez-Arroyo el.al.1987

Precise Measurement of Polyakov Loop Correlation

We want to measure a set of physical quantities with as small statistical errors as possible.

Improved Estimator

When we measure an expectation value, $\langle A \rangle$, we can choose another one, $\langle A' \rangle$ with the same mean value $\langle A \rangle = \langle A' \rangle$, but the smaller error.

ex. multi-hit algorithm

$$U_4 \to \bar{U}_4 = \frac{\int dU U_4 e^{\beta S_4(U)}}{\int dU e^{\beta S_4(U)}}, \quad S_4 = \frac{1}{N_C}\mathrm{Tr}(U_4(n)F^\dagger(n))$$

$\to$ more efficient way to measure the correlation function

Multi-level algorithm

M.Lušcher and P.Weisz, JHEP 0109 (2001) 010

Consider measurement of 2 Polyakov loop correlation.

Define two-time link operator

$$T(t_0, r)_{\alpha\beta\gamma\delta} = U_4(n, t_0)_{\alpha\beta} U_4^\dagger(n + r, t_0)_{\gamma\delta}$$

The essence of the multi-level method is to take an average of T instead of T itself in the sublattice of the time-slice.

$$[T(t_0, r)_{\alpha\beta\gamma\delta}] = \frac{1}{Z_s}\int D[U]_s T(t_0, r) e^{-S[U]_s}$$

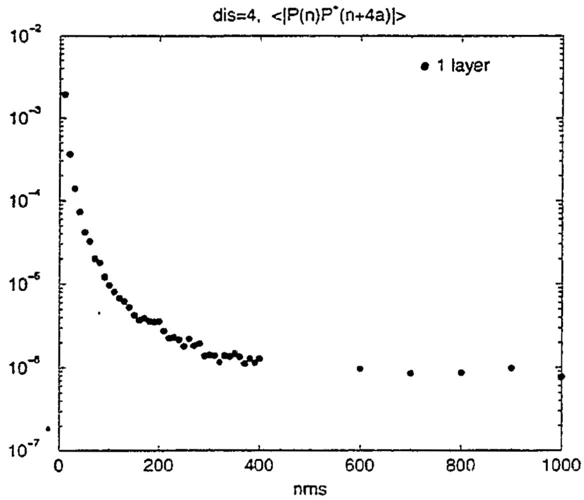
s: sublattice for each time-slice with boundary fixed

Test Simulation

1. 2 Polyakov loop correlation (T=0)

Lattice: 12^4 ($\beta = 5.7$), standard Wilson action

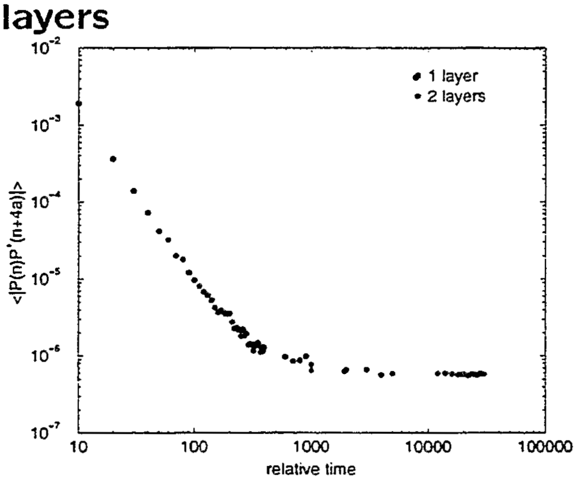
for 1 layer



$n_{\mathrm{ms}} = 1$ corresponds to usual measurement.

Computation time is proportional to n_{ms}.

for 1 and 2 layers



Outlook

Toward the measurement of Polyakov loop correlation at finite temperature, we have tried a new algorithm called the multi-level method as a test simulation.

- We have reproduced the 2 Polyakov loop correlation by Luscher and Weisz.

- 3 Polyakov loop correlation is also improved by the multi-level algorithm.

- Modified algorithm by ungauge-fixed summation (a la Kuramashi) seems to be ineffective because of rather large gauge noise.

The Color-flavor Transformation and Lattice QCD

Tilo Wettig

Color-flavor transformation for SU(N_c) and application to lattice QCD

Boris Schlittgen[1] and Tilo Wettig[1,2]

[1]Yale and [2]RBRC

Outline:

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1. Introduction and Motivation
2. Color-flavor transformation for SU(N_c)
3. Application to lattice QCD

References: Nucl. Phys. B 632 (2002) 155
math-ph/0209030 (J. Phys. A, in press)
hep-lat/0208044 (Lattice 2002 proceedings)

Introduction and Motivation

"color-flavor" transformation was first derived for U(N_c) by Zirnbauer (1996)
(motivation: disordered systems in condensed matter physics)

$$\int_{\mathrm{U}(N_c)} dU \ \exp\left(\bar{\psi}^i_{x+\hat{\mu},a} U^{ij} \psi^j_{x,a} + \bar{\psi}^j_{x,b} U^{\dagger ji} \psi^i_{x+\hat{\mu},b}\right)$$

color indices coupled,
flavor indices diagonal

$$= \int D\mu_{N_c}(Z,\tilde{Z}) \ \exp\left(\bar{\psi}^i_{x+\hat{\mu},a} Z_{ab} \psi^i_{x+\hat{\mu},b} + \bar{\psi}^i_{x,b} \tilde{Z}_{ba} \psi^i_{x,a}\right)$$

flavor indices coupled, color indices diagonal

(Z is a complex matrix in flavor space)

- integral over gauge field looks just like in lattice QCD (for a single link)
- on the RHS, fermion matrix becomes diagonal in configuration space
  $\longrightarrow$ promising new approach to fermion algorithms
- need the transformation for SU(N_c), with $N_c = 3$ in QCD
  (much more difficult mathematical problem)

Color-flavor transformation for SU(N_c)

$$\int_{\mathrm{SU}(N_c)} dU \exp\left(\bar{\psi}^i_a U^{ij} \psi^j_a + \bar{\varphi}^i_a U^{\dagger ij} \varphi^j_a\right) \qquad \begin{matrix} \bar{\psi} \mathrel{\widehat{=}} \bar{\psi}_{x+\hat{\mu}} & \psi \mathrel{\widehat{=}} \psi_x \\ \bar{\varphi} \mathrel{\widehat{=}} \bar{\psi}_x & \varphi \mathrel{\widehat{=}} \psi_{x+\hat{\mu}} \end{matrix}$$

$$= C_0 \int_{\mathrm{Gl}(N_f,\mathbb{C})} \frac{dZ dZ^\dagger}{\det(\mathbb{1} + ZZ^\dagger)^{2N_f+N_c}} \exp\left(\bar{\psi}^i_a Z_{ab} \varphi^i_b - \bar{\varphi}^i_a Z^\dagger_{ab} \psi^i_b\right) \sum_{Q=0}^{N_f} \chi_Q$$

where

$$\chi_0 = 1\,, \qquad \chi_{Q>0} = \mathcal{C}_Q \left[\det(\mathcal{M})^Q + \det(\mathcal{N})^Q\right] \qquad (Q \text{ baryons})$$

$$\mathcal{M}^{ij} = \bar{\psi}^i_a (\mathbb{1} + ZZ^\dagger)_{ab} \psi^j_b\;, \qquad \mathcal{N}^{ij} = \bar{\varphi}^i_a (\mathbb{1} + Z^\dagger Z)_{ab} \varphi^j_b$$

$$C_0 = \prod_{n=0}^{N_f-1} \frac{n!(N_c+N_f+n)!}{(N_c+n)!(N_f+n)!}\;, \qquad \mathcal{C}_Q = \frac{1}{(Q!)^{N_c}(N_c!)^Q} \prod_{n=0}^{Q-1} \frac{(N_c+n)!(N_f+n)!}{n!(N_c+N_f+n)!}$$

Z parameterizes the coset space $\mathrm{U}(2N_f)/[\mathrm{U}(N_f) \times \mathrm{U}(N_f)]$

B. Schlittgen and TW, Nucl. Phys. B 632 (2002) 155

Application to lattice QCD

- color-flavor transformed action does not include plaquette term
  $\longrightarrow$ can be generated by additional heavy fermions ("induced QCD")
  coupling $g^{-2} = 8N_h\kappa^4$ with $N_h \to \infty$, $\kappa \to 0$
- color-flavor transformation corresponds to a single link of the lattice
  $\longrightarrow$ apply it to all links
- after integrating out the fermions, one obtains an action which
  - in the $Q = 0$ sector is "diagonal" in coordinate space as for $\mathrm{U}(N_c)$
  - for $Q \neq 0$ gives rise to loops describing the propagation of Q baryons
- can derive set of rules for allowed loops and their weights in the partition function
- theory can be simulated by a random-walk algorithm that generates ensemble of allowed loops

$\longrightarrow$ reformulation of lattice QCD as a theory of baryonic loops in a mesonic background

details: hep-lat/0208044

Unfortunately, the color-flavor transformed action has a sign problem.

- this already shows up for $Q = 0$:

  weight function is $\prod_x \det\Big(\sum_\mu B_\mu(x)\Big)$ with

$$B_\mu(x)_{pq} = \frac{\delta_{pq}}{4\kappa_p} - [(1+\gamma_\mu)Z_\mu(x-\hat{\mu})]_{pq} + [(1-\gamma_\mu)Z^\dagger_\mu(x)]_{pq}$$

  $\longrightarrow$ not hermitian (Z is a general complex matrix)

- idea: write $Z = HU$ with H hermitian and U unitary
  - integrate out U analytically (before integrating over $\bar{\psi}$, ψ)
  - leads to complicated group integral (solved in math-ph/0209030)
  - idea worked for $N_f = 1$ but unfortunately not for $N_f \geq 2$
- no apparent physical reason for sign problem $\longrightarrow$ should be solvable
- work in progress (alternative parameterization of coset space?)

Light Quark Masses from Domain Wall Fermions

Chris Dawson

Light quark masses from Domain Wall Fermions

Chris Dawson, RIKEN BNL Research Center

[RBC Collaboration]

- at two lattice spacings $a^{-1} = 1.3\mathrm{GeV}$ and $a^{-1} = 2\mathrm{GeV}$
- with two *Gauge* actions (Wilson and DBW2).

Exracting the quark masses

- Use first order chiral perturbation theory for Pseudo-scalars

$$\begin{aligned} m_\pi^2 a^2 &= B_\pi a\overline{m} \\ m_K^2 a^2 &= B_\pi a(m_s + \overline{m})/2 \end{aligned}$$

with

$$\overline{m} = (m_u + m_d)/2$$

- And first order expansion in mass for Vectors

$$\begin{aligned} m_\rho a &= A_\rho + B_\rho a\overline{m} \\ m_{K^*} a &= A_\rho + B_\rho a(m_s + \overline{m})/2 \end{aligned}$$

- Extract B_π , A_ρ and B_ρ from the lattice.
- Solve for a , $\overline{m}$ and m_s using meson mass values from experiment.

- Convert the lattice mass to a renormalised mass using:
  1. Non-perturbative renormalisation :

     Lattice → Continuum (RI-scheme)

  2. Perturbative matching :

     RI-scheme → $\overline{MS}$

Simulation Parameters

- DBW2 gauge action at two couplings ;
  - $\beta = 0.80$ giving $a^{-1} \approx 2$ GeV .
  - $\beta = 1.04$ giving $a^{-1} \approx 1.3$ GeV .
  - ($a^{-1} \approx 3$GeV on the way) .

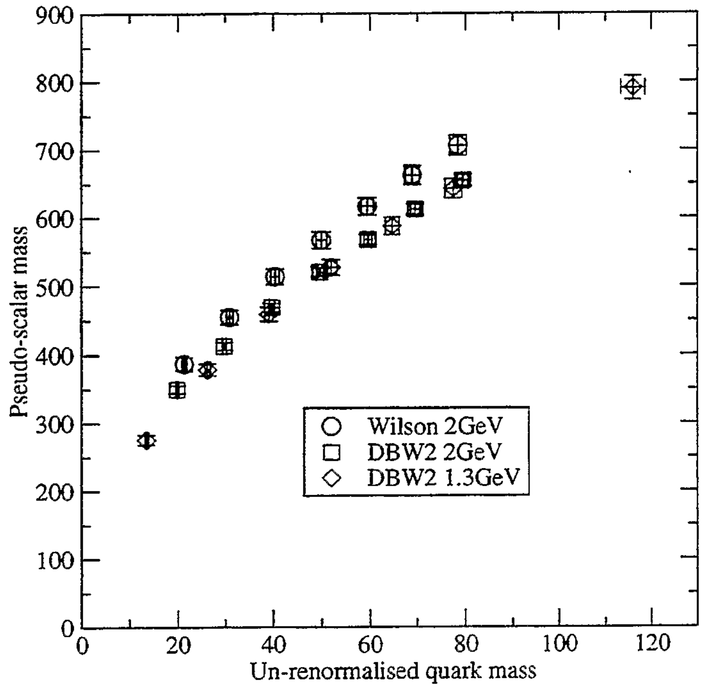
  a is the lattice spacing .

- Compare to existing Wilson gauge action, $\beta = 6.0$ ($a^{-1} \approx 2$ GeV)
  - [hep-lat/0007038] : Spectrum
  - [hep-lat/0102005] : NPR

- All calculations on a $16^3 \times 32$ lattice.
- Number of gauge configurations:

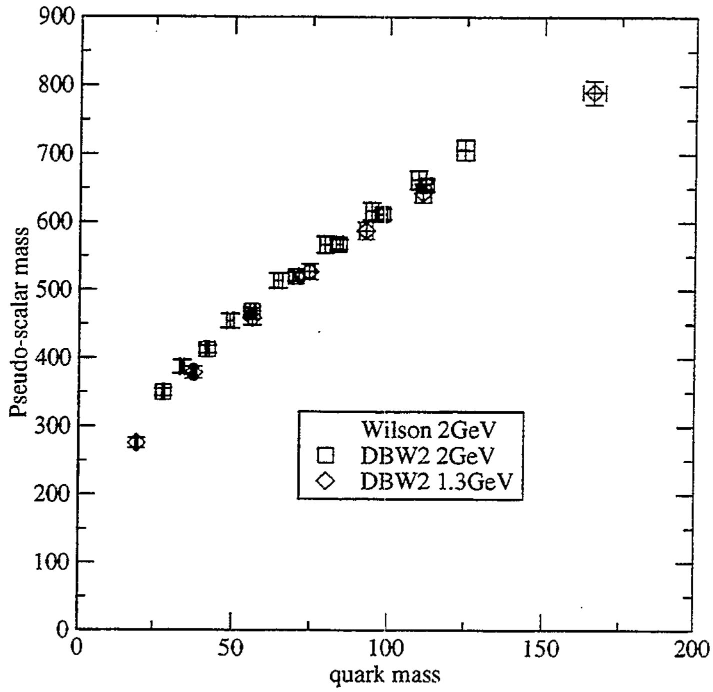
	Spectrum	NPR
DBW2 1.3 GeV	100	53
DBW2 2 GeV	405	51
Wilson 2 GeV	85	142

Spectrum: Pseudo-Scalar



- Quark mass shifted by m_{res}
- The only remaining difference should be
  - Lattice artifacts.
  - The mass renormalisation.
- Note: DBW2 2GeV and 1.3GeV very similar

Spectrum: Pseudo-Scalar vs Renormalised Mass



- Excellent agreement between:
  - DBW2 at both 1.3 and 2 GeV
  - Wilson and DBW2 actions at 2 GeV
- See no evidence for lattice artifacts with DBW2 or Wilson action.
- DBW2 allows simulations on realtively coarse lattices.

Summary

- Calculated values of the quark massed value of
  - $m_s \approx 130\mathrm{MeV}$
  - $\overline{m} \approx 5\mathrm{MeV}$

  in the $\overline{MS}$ scheme at 2 GeV .

- The DBW2 and Wilson gauge actions agree.
  Good check of validity of :
  - The non-perturbative renormalisation technique.
  - The unusual choice of gauge action.

- The DBW2 action shows no evidence of lattice artifacts even at a relatively large lattice spacing.

- In the (near) future:
  - $a^{-1} = 3\mathrm{GeV}$ DBW2 Quenched study.
  - $a^{-1} = 1.7\mathrm{GeV}$ DBW2 Dynamical study.

QCDSP/QCDOC: Physics Results and Prospects/ Project Status

Norman Christ
Robert Mawhinney

QCDOC Project
and
Physics Overview

2002 RBRC REVIEW

November 22, 2002

Norman H. Christ
Robert D. Mawhinney

OUTLINE

- **QCDOC Project: Hardware design, status and schedule.** [N. Christ]

- **QCDOC Project: BNL support, software design, implementation and benchmarks.** [R. Mawhinney]

- **QCDSP Physics.** [R. Mawhinney]
  - Overview of current projects.
  - Plans toward QCDOC.

- **New physics directions and conclusion.** [N. Christ]

QCDOC PROJECT

- <u>Physics:</u> QCD is a complete, fundamental theory. For many important problems the only significant errors are numerical: Immediate scientific reward from increased computer capability.

- <u>Architecture:</u>
  - Space-time homogeneity supports easy parallelization and a mesh network.
  - System-on-a-chip technology permits a highly scalable and cost-effective design:
    - Entire node (including interconnect logic) on a single chip.
    - The only extra components:
      Serial nearest-neighbor wires.
      Commercial Ethernet tree for booting, diagnostics and I/O.
  - Low power, compact design.

- <u>Goal:</u> 10 Teraflops QCDOC machine offers $20\times$ boost to RBRC physics.

COLLABORATION

Columbia (DOE): Norman Christ
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UKQCD (PPARC): Peter Boyle
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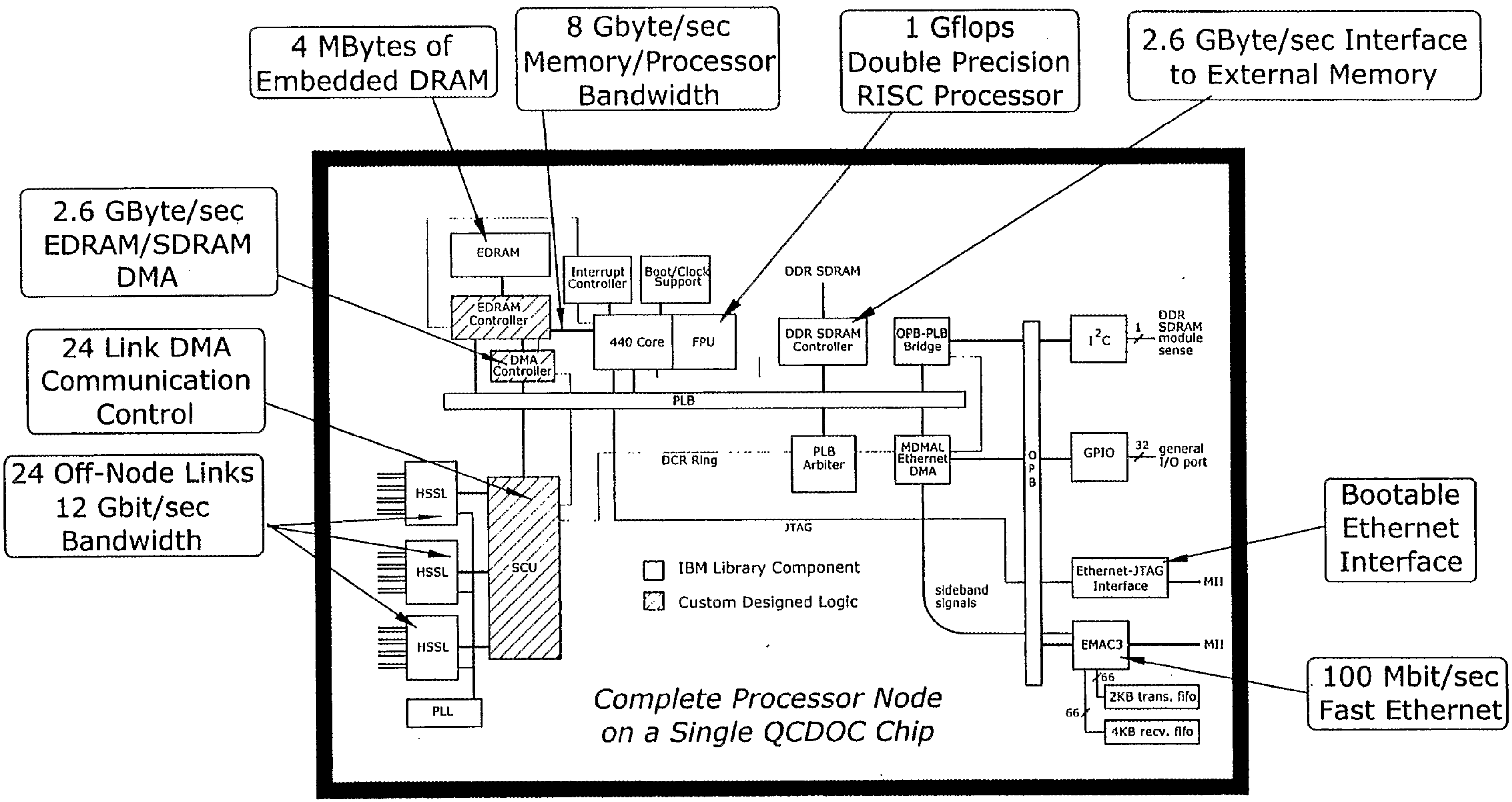
RBRC (RIKEN): Shigemi Ohta (KEK)
Tilo Wettig (Yale)

IBM: Dong Chen
Alan Gara
Design groups:
Yorktown Heights, NY;
Rochester, MN; Raleigh, NC

BNL (DOE): Dave Stampf
Robert Bennett

DESIGN

- IBM-fabricated, single-chip node.
  [50 million transistors. 1-2 Watt. 1.3cm×1.3cm die]
- PowerPC 32-bit processor
  - 1 Gflops, 64-bit IEEE FPU.
  - Memory management.
  - GNU and XLC compilers.
- 4 Mbyte on-chip memory and up to 2.0 Gbyte/node on DIMM card.
- 6-dim communications network:
  - Efficient for small packet sizes, ≈ 200ns latency.
  - Global sum/broadcast functionality.
  - Minimal processor overhead.
  - Lower dimensional machine partitions.
- 100 Mbit/sec, Fast Ethernet
  - JTAG/Ethernet boot hardware.
  - Host-node OS communication.
  - Disk I/O.
  - RISCWatch debugger.
- ≈ 5 Watt, 10 in^3 per node.

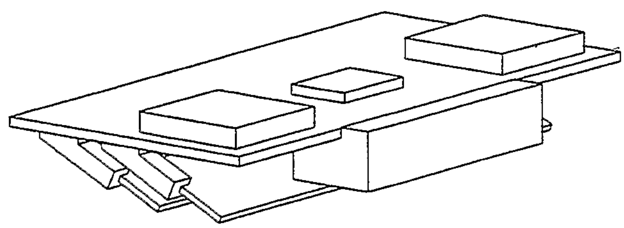

4 MBytes of Embedded DRAM
8 Gbyte/sec Memory/Processor Bandwidth
1 Gflops Double Precision RISC Processor
2.6 GByte/sec Interface to External Memory
2.6 GByte/sec EDRAM/SDRAM DMA
24 Link DMA Communication Control
24 Off-Node Links 12 Gbit/sec Bandwidth
Bootable Ethernet Interface
100 Mbit/sec Fast Ethernet
EDRAM
EDRAM Controller
DMA Controller
Interrupt Controller
Boot/Clock Support
440 Core
FPU
DDR SDRAM
DDR SDRAM Controller
OPB-PLB Bridge
I²C
DDR SDRAM module sense
PLB
DCR Ring
PLB Arbiter
MDMAL Ethernet DMA
OPB
GPIO
32
general I/O port
HSSL
HSSL
HSSL
SCU
JTAG
IBM Library Component
Custom Designed Logic
sideband signals
Ethernet-JTAG Interface
MII
EMAC3
MII
66
2KB trans. fifo
66
4KB recv. fifo
PLL
Complete Processor Node on a Single QCDOC Chip

STATUS

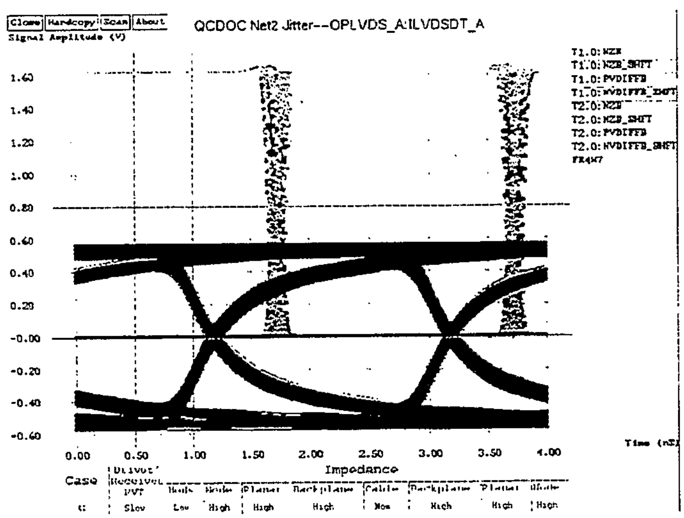
- ASIC Design
  - RTL design complete.
  - Floorplanning netlist accepted by IBM 8/16/02.
  - Preliminary netlist accepted by IBM 9/6/02.
  - Final netlist accepted by IBM 11/12/02.
  - Extensive testing ongoing:
    * Real code on full design simulation 100 applications of Dirac operator.
    * Two-node simulation:
      A sends Ethernet boot packets to B.
      B receives and executes boot code.
    * Testbenches for faster simulation of subcomponents.
    * Gate-level tests underway and formal verification of synthesis completed.
    * ≈ 18 CPU's: 24/7.

STATUS

- Board design
  - P.O. written for daughter board layout.



  - Connectors and cables simulated, AMP Z-Pack HM-Zd selected.

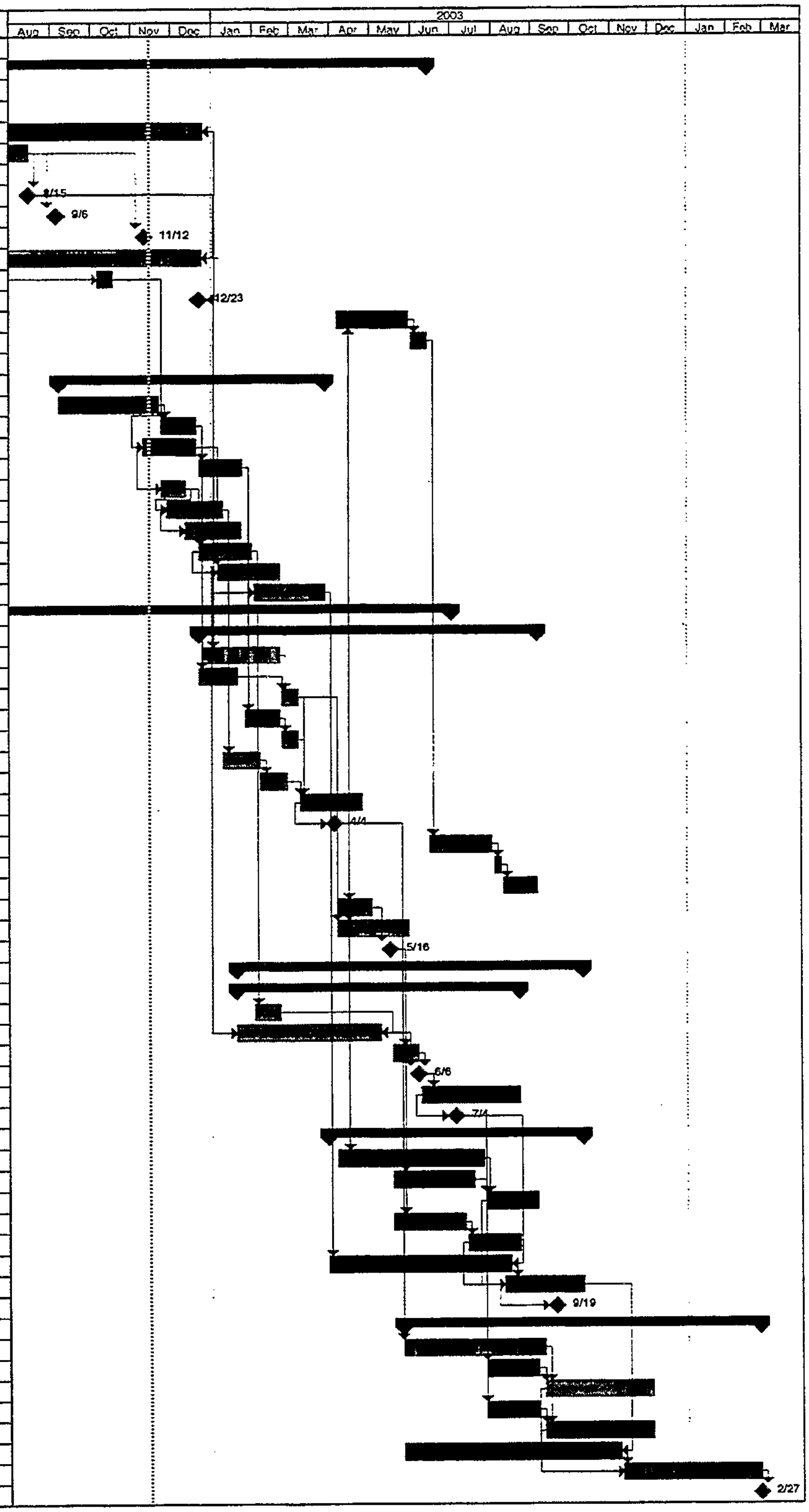


RELIABILITY

- ECC on external DIMM and EDRAM.
- Automatic recovery from single-bit communications errors.
- Running check sum on both ends of each serial channel.
- Number of components similar to QCDSP: 1-2 failures/week on 10K node machine.
- Soft error rate estimated at < 1/week on 10K nodes (low-α lead in solder balls).

QCDOC SCHEDULE

ID	Task Name
1	**Develop Architecture**
4	**Design ASIC chip**
5	VHDL behavioral design (w/o timing)
6	design/synthesis with timing
7	logical validation
8	timing validation
9	full analysis net list
10	floor planning net list
11	preliminary net list
12	final net list
13	IBM Physical Design
14	fix pin assignments
15	release to manufacture
16	design and verify respin
17	respin physical design
18	**IBM ASIC Support**
26	**Design printed circuit boards**
27	Specify daughter board
28	Design daughter board
29	Specify mother board
30	Design mother board
31	Specify single-slot backplane
32	Design single-slot backplane
33	Design single-slot module
34	Design full backplane
35	Design eight-slot crate
36	Design 16-motherboard cabinet
37	**QCDOC specific software**
45	**Construction, 128-node prototype**
46	fabricate ASIC
47	fabricate daughter boards
48	assemble daughter board
49	fabricate mother board
50	assemble mother board
51	fabricate single-slot backplane
52	assemble single-slot backplane
53	test daughter board
54	verify ASIC and daughter board
55	respin manufacture
56	assemble respin daughter board
57	verify respin
58	assemble 150 daughterboards
59	test mother board
60	verfiy mother board
61	**Phase I Construction (at Columbia)**
62	**Construction of 8-MBD Machine**
63	fabricate 8-slot backplane
64	fabricate crate
65	assemble printed circuit boards
66	complete 8-MBD machine
67	test 8-MDB machine
68	Verify 8-MBD machine
69	**Construction of 32-MBD Machine**
70	procure production ASICs
71	procure daughter board components
72	fabricate daughter boards
73	procure mother board components
74	fabricate mother boards
75	procure 8-slot backplanes/cabinets
76	assemble and test
77	verify production scale machine
78	**Phase II Construction, (at RBRC)**
79	procure production ASICS
80	procure daughter board components
81	fabricate daughter boards
82	procure mother board components
83	fabricate mother boards
84	procure backplanes/cabinets
85	assemble and test
86	complete 10 Tflops RBRC machine

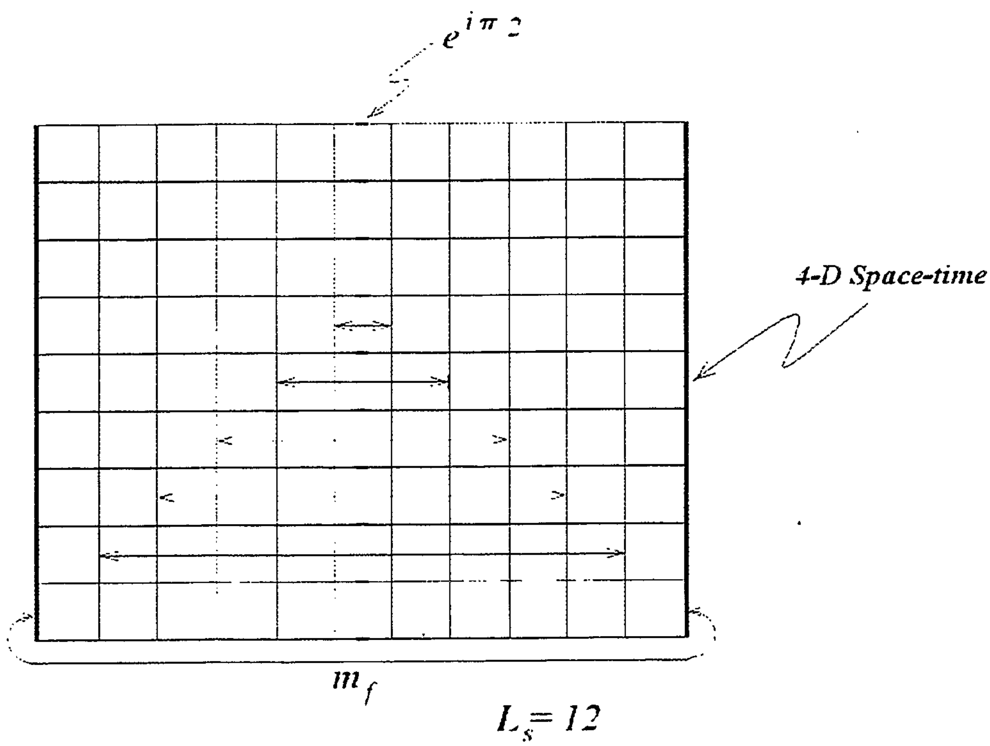


SCHEDULE SUMMARY

• Final net list	11/12/02
• Release to manufacturing	12/23/02
• Prototype chips available	02/25/03
• Verify ASIC and daughter board	Apr 03
• Verify motherboard (128 nodes)	May 03
• Verify 8 MBD machine (512 nodes)	Jul 03
• Verify 32 MBD machine (2,048 nodes)	Sep 03
• Complete 10 Tflops machine (10,240 nodes)	Feb 04

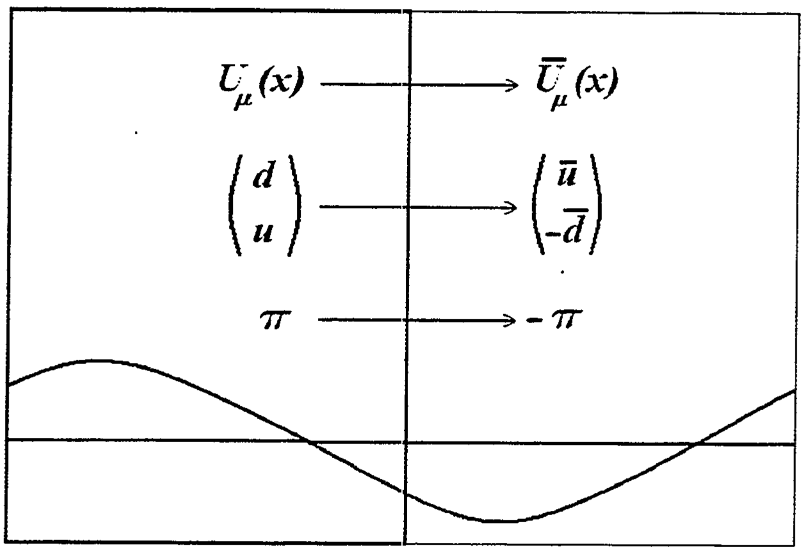
NEW PHYSICS DIRECTIONS

- **Heavy quarks**
  - Include charm quark in $K \to \pi\pi$ decays.
    - ∗ Develop a new DWF "twisted" mass term:



    - ∗ Simply adds a fermion mass—no effect on 5-D wave function.
    - ∗ Permits accurate GIM cancelation.
  - Exploring charm and bottom meson decay calculations. (Anisotropic lattices?)

- **Direct calculation of $K \to \pi\pi$ [C. Kim].**
  - Use Lellouch-Lüscher finite volume method.
  - Impose G-parity boundary conditions.



  - Now $\vec{p} \neq 0$ for ground state.
  - Gives on-shell $\Delta I = 3/2$ amplitude directly and $\Delta I = 1/2$ after vacuum subtraction.

CONCLUSION

- **Ongoing calculations of important quantities:**
  - Real and imaginary $K \to \pi\pi$ amplitudes, with smaller lattice spacing.
  - Proton decay amplitudes.
  - Low-order moments of nucleon structure functions.
  - Generation of configurations including sea quarks.

- **New methods and algorithms:**
  - Improved gauge actions (DBW2).
  - Non-degenerate quarks for $K \to \pi\pi$.
  - Enhanced dynamical DWF algorithm.
  - Heavy domain wall fermions.
  - Physical $\pi - \pi$ final states.

- **Next $\approx 20\times$ faster QCDOC machine:**
  - ASIC design complete.
  - Prototype hardware in February 2003.

QCDOC Software, Infrastructure and Physics

Robert D. Mawhinney
Columbia University

RBRC Scientific Review
Brookhaven National Laboratory
November 22, 2002

I. QCDOC Operating System

II. QCDOC performance benchmarks

III. BNL support for QCDOC

IV. Physics projects on QCDSP

V. Physics projects on QCDOC

Columbia University Designed Computers

Machine	Date	Processor (FPU precision)	Nodes	Speed (Gflops)	Memory (GBytes)
Previous:					
16-node	1985	286/TRW (22)	16	0.25	0.016
64-node	1987	286/Weitek (32)	64	1.0	0.128
256-node	1989	286/Weitek (64)	256	16.0	0.5
Current:					
CU QCDSP	1998	TI DSP (32)	8,192	400	16
RBRC QCDSP	1998	TI DSP (32)	12,288	600	24
Funded:					
RBRC QCDOC	2003	440 PPC (64)	10,000	10,000	1,280
UKQCD QCDOC	2003	440 PPC (64)	10,000	10,000	1,280
Proposed:					
CU QCDOC	2003	440 PPC (64)	3,000	3,000	381
US LGT QCDOC	2004	440 PPC (64)	10,000+	10,000+	1,280+

QCDOC Design Group

- Columbia:

  Faculty: Norman Christ, Robert Mawhinney

  Postdoc: Azusa Yamaguchi

  Staff researcher: Zhihua Dong

  Student: Saul Cohen, Calin Cristian, Changhoan Kim, Xiaodong Liao, Hueywen Lin, Guofeng Liu

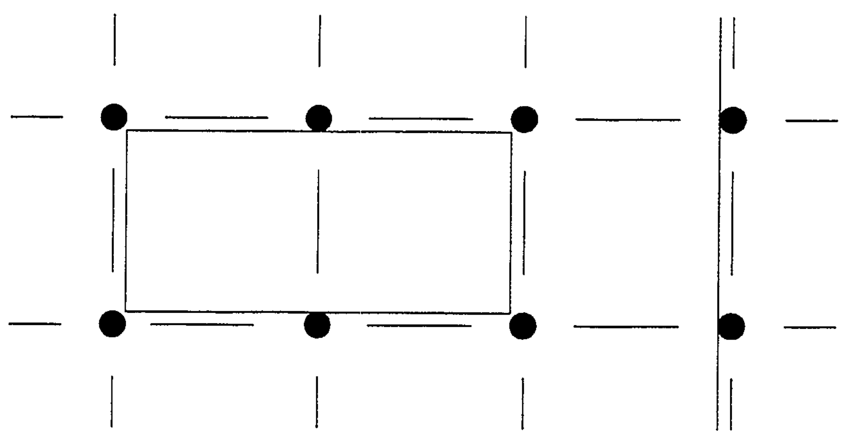
- IBM: Dong Chen, Alan Gara
- RBRC: Shigemi Ohta, Tilo Wettig
- UKQCD: Peter Boyle, Balint Joo

Additional Software Collaborators

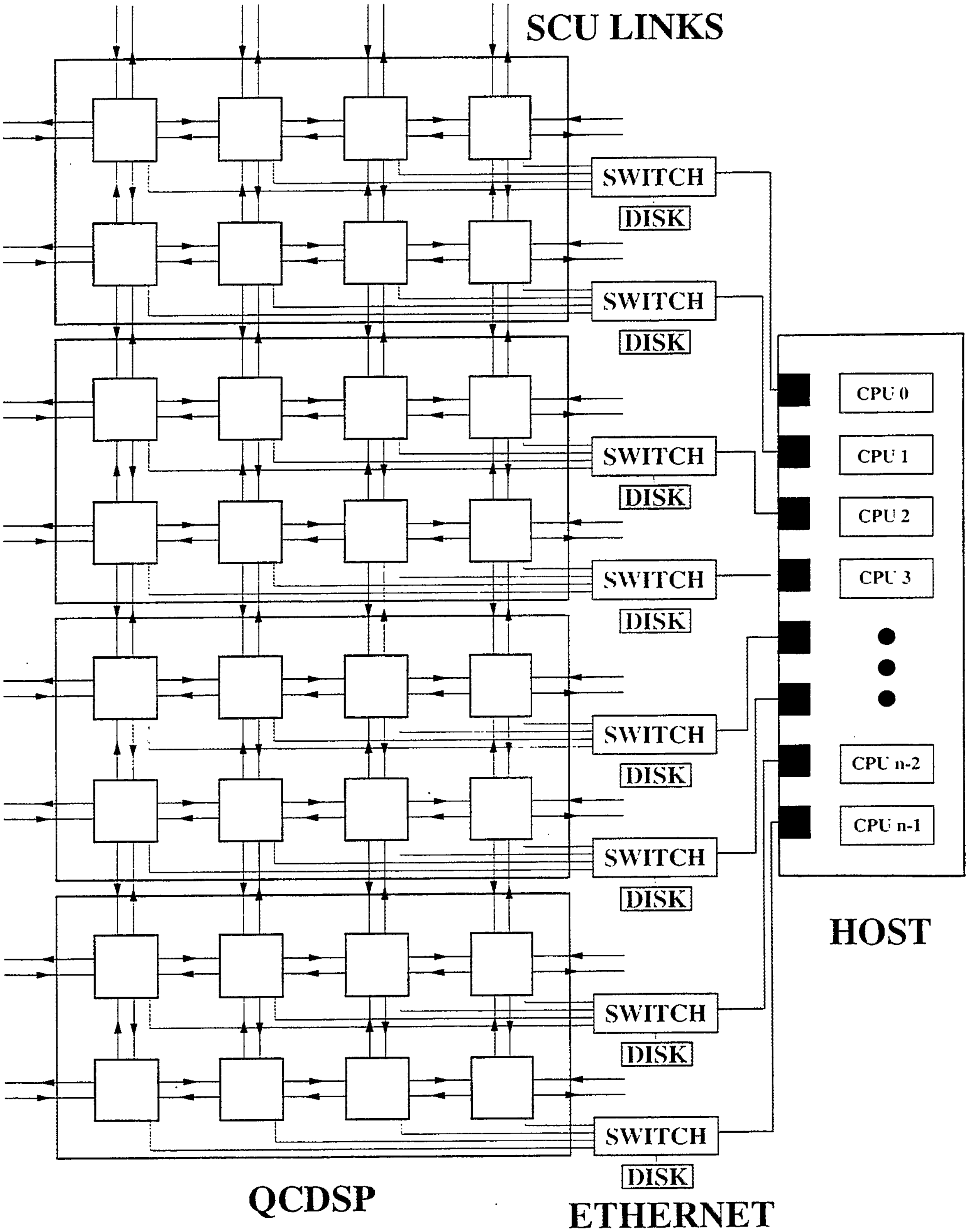
- BNL: Dave Stampf, Rob Bennett

QCDOC Overview

- Uses IBM's System-On-a-Chip Technology
- Industry standard, 64-bit, 1 Gflop Power PC processor with L1 instruction and data caches.
- 4 MBytes of embedded DRAM on chip
- Up to 0.5 Gbytes of DDR SDRAM per node
- 100 Mbit Ethernet connection to each node
- High-bandwidth, low-latency 6 dimensional nearest neighbor communications network.



- Low-electrical power allows dense packing
- Evolution of successful QCDSP architecture.
- 20,000+ processor machines planned



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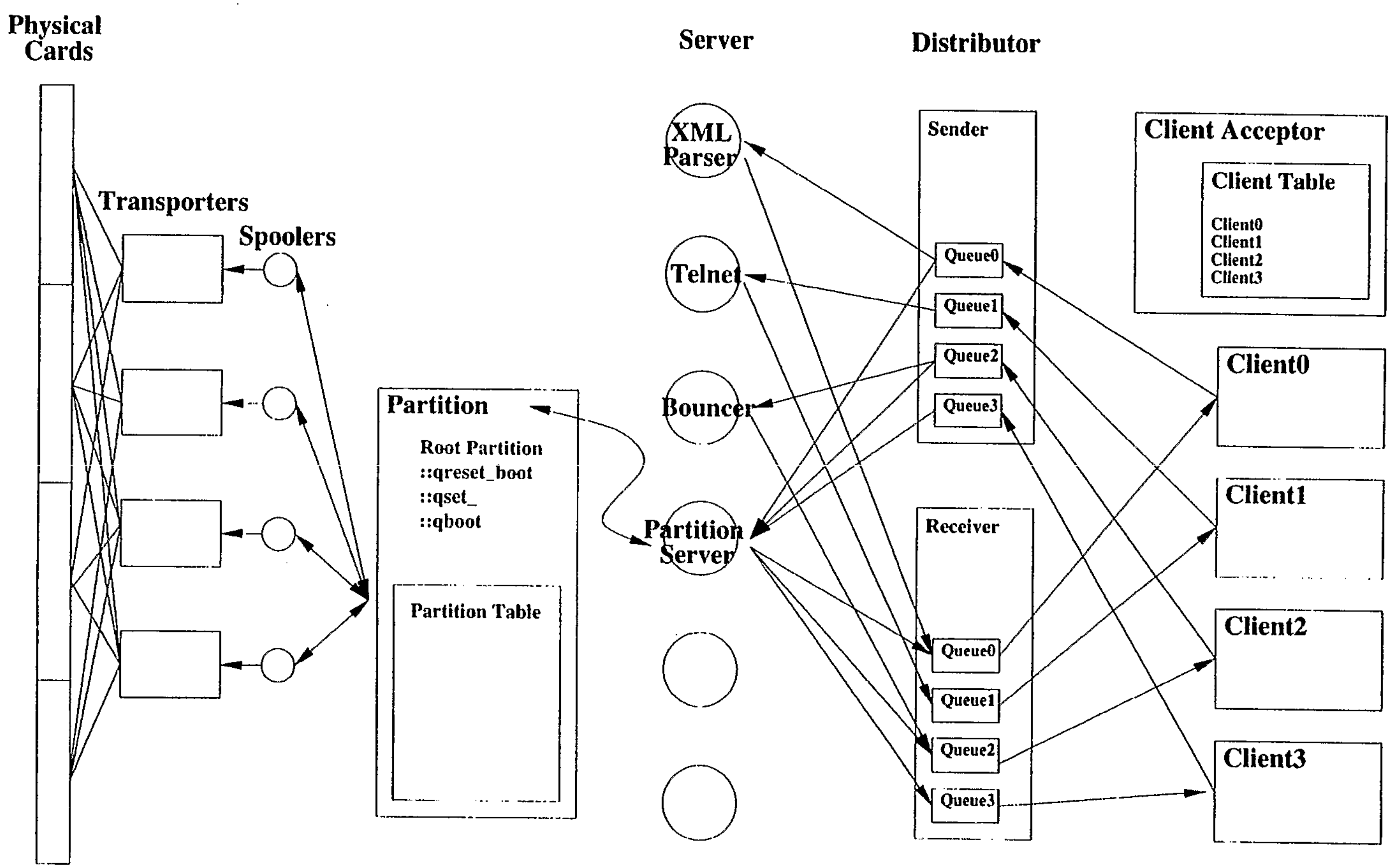
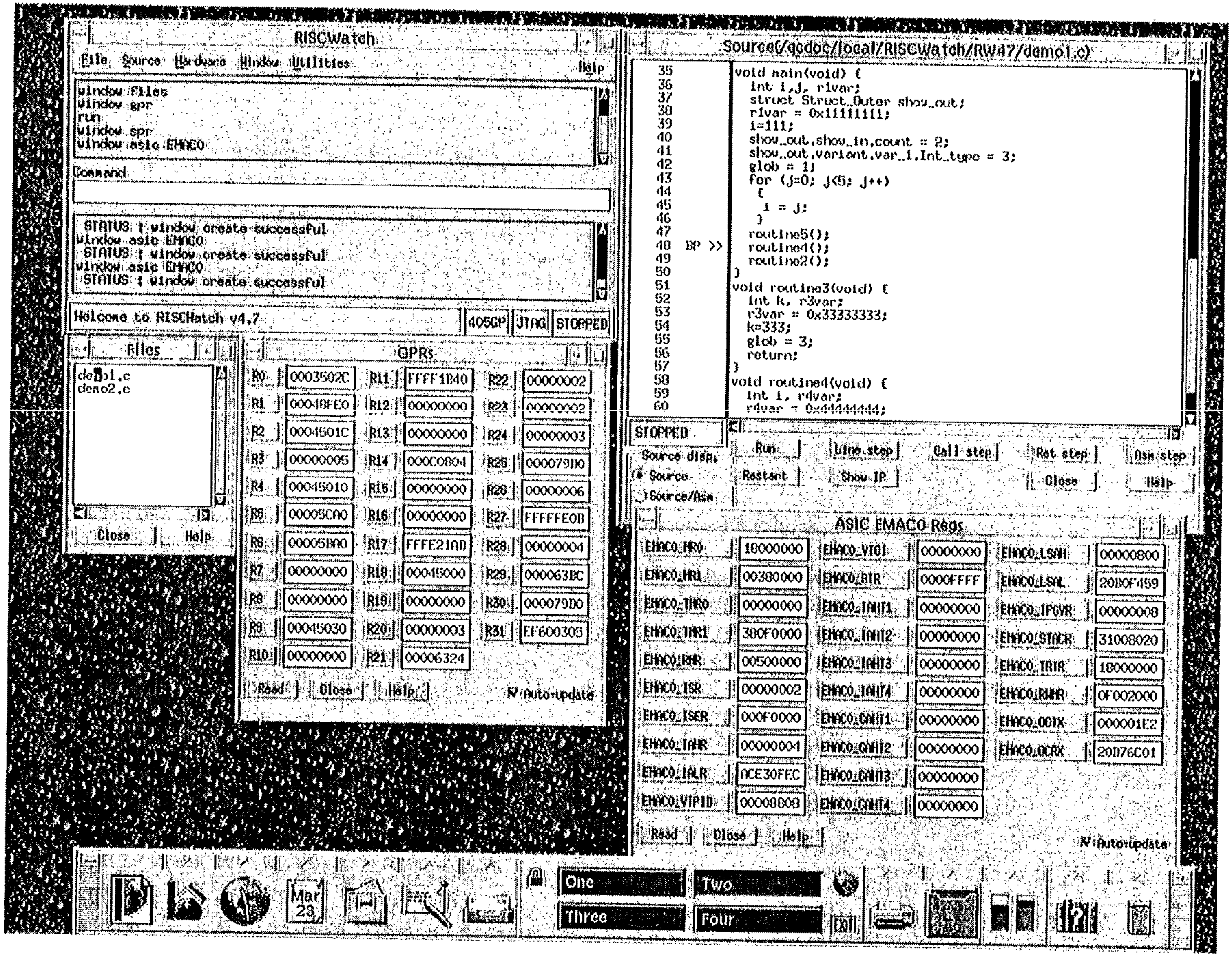
QCDOC Host OS



Operating System Goals for QCDOC

1. QOS must easily support hardware debugging of:
   - 10^4 nodes
   - 12×10^4 communications links
   - 10^6 MBytes of SDRAM
   - 100 to 1,000 disks
2. QOS must not hinder high performance code
3. QOS provides a standard, single execution thread application environment (real-time kernel)
   - Conventional C/C++ I/O function interfaces
   - Simple OS interface to special hardware features
     - QCDOC OS SCU calls (communications)
     - Processor location calls. global interrupts
4. QOS users see simple UNIX-like environment
   - Support for code development and debugging
   - Basic queueing system
   - Interaction via command line. perl, Web...
5. QOS interfaces to RISCwatch debugger for detailed information about any node

QCDOC and IBM RISCwatch debugger



Physics Software for QCDOC

1. Existing Columbia Physics System (CPS) is base
   - C++ for most lines of code
   - Assembly for high performance kernels
   - Data parallel programming style
2. CPS is actively evolving through ongoing RBRC/BNL/CU research
3. UKQCD Collaboration will also use CPS for their research.
   - Increased user base leverages effort
   - Will port to other platforms
4. SciDAC funding recieved for evolving CPS and QCDOC-OS to common community standards.
5. CPS goals are
   - Outstanding performance on QCDOC
   - Portability to other platforms for development
   - Consistency with evolving community standard

QCDOC Performance

From gate-level simulation of ASIC at "nominal" 500MHz speed. Communication, cache flush overhead and 20 ns pin-pin wire delay included.

Operation	Local Vol.	Perf/node (Mflops)
Wilson D_{eo}	2^4	470
Wilson D_{eo}	4^4	535
Clover D_{eo}	2^4	560
Clover D_{eo}	4^4	590
Staggered D_{eo}	2^4	370
Staggered D_{eo}	$2^2.4^2$	430
SU3-SU3	-	800
SU3-2spinor	-	780
DAXPY	-	190
ZAXPY	-	450
DAXPY-Norm	-	350
CloverTerm/asm	-	790
CloverTerm/gcc, no dcbt	-	150
CloverTerm/xlc, no dcbt	-	300

Peter Boyle, given at Lattice 2002

QCDOC Scalability

- **Global sum using store and forward hardware**

  4k nodes 10μs

  16k nodes 13μs

  32k nodes 15μs

- ***Estimate* for Wilson CG on** $32^3 \times 64$ **Lattice**

Nodes	$M^\dagger M$+linalg	Global Sum	Sust. Tflops
4096	2620μs	10 μs	2.15
8192	1310μs	11.5μs	4.2
16384	680 μs	13 μs	8.1
32768	340 μs	15 μs	15.6

- **Both Clover and DWF Dirac operators are *more* scalable than Wilson**

- **Most difficult type of scaling - more processing power on a physics problem of a fixed difficulty**

BNL GPP funds supporting QCDOC

$1.6 M GPP (General Plant Projects) grant for infrastructure to support:

1. Funded 10 Teraflops RBRC QCDOC
2. Proposed 20 Teraflops SciDAC QCDOC

Major infrastructure components to support both QCDOC machines:

- Provide UPS (uninterruptable power supply) power
- Cooling water and heat exchangers
- Dehumified air for cabinets
- Integen fire suppression system in cabinets
- Smoke and heat alarms
- Architectural improvements to room

Major Physics Projects on QCDSP

- Both quenched and full QCD simulations with DBW2 action
- A wide variety of observables being measured.
- Full QCD lattices to be analyzed on remaining machines
- Full QCD simulations have been sped up by $\approx 3\times$

Machines	a^{-1} (GeV)	L (fm)	N_f	m_f	L_s	$m_{\rm res}$
300 Gflops RBRC $225 + 3 \times 25$	2.9	1.6	0		10	$\approx m_s/300$
200 Gflops CU	1.7	1.9	2	$\approx m_s/2$	12	$\approx m_s/10$
100 Gflops CU	1.7	1.9	2	$\approx 3m_s/4$	12	$\approx m_s/10$
100 Gflops RBRC	1.3	2.5	2	$\approx m_s/2$	12	?

Major Physics Measurements with QCDSP

a^{-1} (GeV)	L (fm)	N_f	m_f	Observables
2.9	1.6	0		Hadron spectrum Weak matrix elements ∘ B_K, A_0, A_2 $\rightarrow$ ReA$_0$/ReA$_2$ $\rightarrow \epsilon'/\epsilon$ ∘ 3 flavor eff. theory ∘ 4 flavor eff. theory? Heavy quark physics?
1.7	1.9	2	$\approx m_s/2$ $\approx 3m_s/4$	Hadron spectrum Weak matrix elements Nucleon structure?
1.3	2.5	2	$\approx m_s/2$	Hadron spectrum Weak matrix elements Nucleon structure

Physics Projects on QCDOC

- Increasingly accurate full QCD simulations with DWF (or practical alternative)
  - With 200 Gflops QCDSP:
    * $\approx 5,000$ HMC trajectories/year
    * $m_f \approx m_s/2$, $L \sim 1.7$ fm
    * Need longer runs, lighter m_f, larger box
    * Quenched DWF shows good scaling with lattice spacing. May allow use of coarse dynamical lattices
  - With 2 Tflops QCDSP:
    * $\approx 50,000$ HMC trajectories/year
    * smaller m_f possible
    * larger physical volumes
- Move to 3-flavor simulations
  - Exact or inexact algorithms?
  - Contact with analytically predicted chiral behavior

- Major opportunites for QCD thermodynamics with DWF
  - Preliminary work done with QCDSP
  - For $N_t = 4$ lattices, $a^{-1} \sim 0.6$ GeV
    * DWF has large $m_{\rm res}$
    * Fallof of $m_{\rm res}$ with L_s very small
    * Gauge fields very rough
  - For $N_t = 8$ lattices, $a^{-1} \sim 1.2$ GeV
    * DBW2 DWF may work well
    * Current $a^{-1} \sim 1.3$ GeV runs for $T = 0$
    * Will know $m_{\rm res}$ soon
    * Additional optimizations with DWF possible
- Current quenched measurements easily replicated with dynamical lattices
- Improved lattice Dirac operators allow QCD simulations at finite lattice spacing with accurate control over symmetries of full QCD.

RESEARCH SUMMARY THEORY

The QCD critical-end/tricritical point and the quark number susceptibility

Takashi Ikeda

RIKEN BNL Research Center, Brookhaven National Laboratory, Upton, NY 11973

1 The QCD phase diagram

The vacuum of the quantum chromodynamics (QCD) is believed to undergo a phase transition from the hadronic phase to the quark-gluon plasma (QGP) at high temperature T and/or at high quark chemical potential μ. Such a new state of matter is expected to be produced in on-going heavy-ion collision experiments at Relativistic Heavy-Ion Collider (RHIC) and in the future Large Hadron Collider (LHC). This work focuses on the quark number susceptibility in the QCD phase diagram in the T-μ plane and its critical exponents at the QCD tricritical point (TCP) and the critical end point (CEP). In a recent paper [1], Hatta, and Ikeda pointed out the possibility that the hidden tricritical point affects the physics near the critical end point.

1.1 The critical end and tricritical points

There is a growing evidence that the phase diagram of QCD with massless 2-flavors has a tricritical point at which a second order phase transition line at lower μ's turns into a first order phase transition line at higher μ's. If the u, d-quark masses are increased from zero, a line of critical points (the wing critical line) emerges from TCP and the point which corresponds to the physical quark mass m_{phys} is called the QCD critical end-point because this is the point where the first order phase transition line terminates. This end point was found in several model calculations and recently in the lattice simulation with 2+1 flavors [2].

Second order phase transitions are characterized by the long-wavelength fluctuations of the order parameter. In the case of CEP, it is the sigma (σ) field. Then, it is expected that the fluctuations of the sigma field will be reflected in the event-by-event fluctuation of pion (π) observables due to the the $\pi - \sigma$ coupling. Based on this observation, possible observable signals associated with CEP have been studied in detail in relation to the relativistic heavy-ion collision experiments [3, 4].

1.2 Universality arguments

Our starting point is a simple question: "How large is the critical region?" The critical region is defined as the region where the mean field theory (or the Landau theory) of phase transitions breaks down and the true non-trivial critical exponents can be seen. Usually, one expects that the critical region is surrounded by the mean field region and the critical exponents change from the non-trivial values to the mean field values as one comes away from the critical point.

There is a well-known criterion which estimates the size of the critical region, the Ginzburg criterion which is based on the singular part of the thermodynamic potential Ω (the Landau-Ginzburg potential) for a second order phase transition. By using the Ginzburg criterion, we can obtain the radius of the critical region at CEP $\sim m^{\frac{4}{5}}$ (m is the quark mass). This gives a bound to the size of the critical region. It shrinks to zero as the quark mass decreases. If the quark mass is small, the critical region of CEP is small and we are naturally led to consider the mean field region around the critical region of CEP. In fact, there is a reason to expect that the critical region of CEP is small. This is because the QCD critical end point is a descendant of the tricritical point of the massless theory.

This observation led us to study the critical phenomena of both CEP and TCP simultaneously and their possible correlations. The central point is that if we consider the mean field region belonging to CEP, we should also consider the mean field region belonging to TCP. We made both qualitative and quantitative analyses of the physics near TCP and CEP with particular emphasis on the (singular) behavior of the quark number susceptibility χ_q. χ_q is a response of the quark number density to the variation of the quark chemical potential and is one of the key quantities characterizing the phase change from the hadronic matter to QGP [5, 6, 7, 8].

The lattice data tell us that, at $\mu = 0$, χ_q increases rapidly but smoothly near the critical temperature [9, 10, 11]. On the other hand, the universality argument predicts that it diverges at both TCP and CEP with certain critical exponents. Therefore, it would be important to study its critical behavior with and without the quark masses to see whether it can provide a new way of detecting the TCP/CEP on the lattice as well as in the heavy-ion collision experiments.

We analyzed the critical behavior of the quark number susceptibility at CEP/TCP based on the Landau-Ginzburg potential, and obtained the critical exponent $\epsilon = \frac{2}{3}$ at CEP and $\gamma_q = \frac{1}{2}$ at TCP in the mean field approximation. The tricritical point has, so to speak, a 'tricritical region' which is a sphere or an ellipsoid in the (T, μ, m) space centered at TCP. We pointed out interesting possibility that the critical point is inside the tricritical region and a crossover of different universality classes happens. Namely, as we approach CEP the critical exponents gradually change from those of the tricritical point to those of the 3D Ising model via those of CEP in the mean field approximation. However, the universality argument does not tell us whether the effect of TCP survives in the (T, μ) plane with the quark mass of, say, 5 MeV. In order to quantify the above ideas, a specific model must be resorted.

2 The gradual change of universality classes

2.1 CJT effective potential and the chiral phase transition

Hatta, and Ikeda examined the critical behavior of the quark number susceptibility quantitatively by employing the Cornwall-Jackiw-Tomboulis (CJT) effective potential [12] for 2-flavor QCD in the improved ladder approximation [13]. The parameters in this model are determined to reproduce the pion decay constant $f_\pi = 93$ MeV in the Pagels-Stokar formula [14] in the chiral limit.

At finite temperature and chemical potential, we use the imaginary time formalism. We have studied the chiral phase transition and the phase diagram by calculating the CJT effective potential at given T and μ and searching the value of the order parameter σ_0 which minimizes the potential. The location of the first order phase transition line is determined by finding a gap in σ_0. In the chiral limit, σ_0 goes to zero smoothly as the second order phase transition line is approached from below. With finite quark masses, there is no distinct border between the symmetric and broken phases, and σ_0 remains finite at all temperatures and chemical potentials.

The QCD phase diagram in this model has both the tricritical and the critical end points. The location of the tricritical point in the chiral limit is $T_t = 107$ MeV and $\mu_t = 209$ MeV, and the critical end point, for example, for $m(1\text{GeV}) = 5$ MeV locates at $T_c = 95$ MeV and $\mu_c = 279$ MeV. The distance between TCP and CEP approximately scales as $m^{\frac{2}{5}}$ up to $m \sim O(1)$ MeV, in agreement with the results of the universality arguments.

2.2 The quark number susceptibility and its critical exponent at CEP/TCP

The quark number susceptibility χ_q in the T-μ plane is obtained by taking the second derivative of the CJT effective potential with respect to μ numerically.

In both cases for the chiral limit and the finite quark mass, χ_q is suppressed far below the chiral phase transition line and enhanced near TCP or CEP. The region where χ_q is enhanced is elongated in the direction parallel to the first order phase transition line. This is because the critical exponent for this direction is larger than for other directions. We also found a jump in χ_q along the second order phase transition line. Inside the critical region, however, the jump must be replaced by a cusp with certain critical exponents. Our model can reproduce only the mean field behaviors.

The critical exponent for χ_q at CEP/TCP was calculated along the path parallel to the μ axis in the T-μ plane from lower μ towards CEP/TCP at fixed T_c or T_t.

We obtained the critical exponent $\gamma_q = 0.51 \pm 0.01$ in the chiral limit by using a linear logarithmic fitting numerically, which is consistent with the mean field theory.

For m=0.1 MeV, we obtained the critical exponent $\epsilon = 0.55 \pm 0.02$. This is significantly different from the prediction of the mean field theory $\epsilon = \frac{2}{3}$, which is a clear evidence of the effect of the tricritical point. It is expected that the exponent changes towards $\frac{2}{3}$ if we approach CEP much closer.

For m= 5 MeV, the slope of χ_q changes at around $|\mu - \mu_c| \sim 0.5$ MeV, and we obtained the critical exponent 0.68 ± 0.02 for $|\mu - \mu_c| < 0.3$ MeV and 0.57 ± 0.01 for $|\mu - \mu_c| > 1$ MeV. We interpret this change of the exponent as the crossover of different universality classes. Note that the purely mean field-like exponent is seen in a very small region $|\mu - \mu_c| < 0.3$ MeV from CEP. This result is somewhat surprising to the present authors because TCP is far away from CEP already for m= 5 MeV and the value of χ_q itself is unremarkable at (T_t, μ_t). It seems that, although the analysis based on the Landau-Ginzburg potential was made in the small quark mass limit, the effect of TCP is unexpectedly robust against the increase of the quark mass.

As a check, we also calculated the exponent for $m = 100$ MeV and obtained $\epsilon = 0.64 \pm 0.03$ which is consistent with the mean field value $\frac{2}{3}$. For such a large quark mass, we see no indication of a change in the slope. The effect of TCP has completely disappeared.

There are two important points in above results. First, if the quark mass is increased from zero, the critical exponent changes from $\frac{1}{2}$ to $\frac{2}{3}$. Second, even at fixed quark mass, the critical exponent changes from $\epsilon = \frac{2}{3}$ by the effect of the hidden TCP, as we draw away from CEP. This second point is very interesting because actually we can not change the quark mass, however this change of the critical exponent could be observed in the realistic quark mass.

Finally, we briefly comment on the implication of our results to heavy-ion experiments. The divergence of χ_q is directly related to an anomaly in the event-by-event fluctuation of baryon number B (divided by the entropy S) which was originally introduced in [8] to probe the deconfined phase. Although neutrons are not observed, we expect that the event-by-event fluctuation of the proton number is relatively enhanced for collisions which have passed 'near' CEP/TCP. Pion and diphoton observables are discussed in [3, 4, 15]. The critical exponents of the Ising model and the mean field theory are not so different numerically, therefore, the smallness of the critical region itself may not be an obstacle to the observability of critical phenomena in experiments. However, if we take the effect of TCP seriously either by assumption or stimulated by future lattice results, we must take into account the long-wavelength fluctuations of the pions as well as the sigma meson because the pions are no longer the environment but participate in the critical fluctuations around the trace of TCP.

ACKNOWLEDGMENTS

T. I. acknowledges RIKEN BNL Research Center for providing the facilities essential for the completion of this work. T. I. is supported by Special Postdoctoral Researchers Program of RIKEN.

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"Dense" matter in QCD

Progress report and research plan for RBRC Scientific Review Committee

Kazunori Itakura

Abstract

I review my past year's achievements in the physics of "dense" matter in QCD, by which I mean both gluonic and quark dense matter. Gluonic dense matter (Color Glass Condensate) is relevant at high energy processes and exhibits saturation. Quark dense matter shows color superconductivity at low temperature. I also discuss some future plans of my reseach.

1 Recent Progress

The problems I have been concerned about are extreme situations in QCD which may be called "dense" matter. Here I mean by "dense" matter both gluonic and quark dense matter. In the past few years, we have seen a very rapid progress in understanding the "dense" matter in QCD. Some of them can be treated with weak-coupling techniques but actually we need non-perturbative calculation such as resummation of log enhanced factors at high energy or the Cooper instability of the perturbative Fermi sphere. Notice that the current lattice simulations are not able to treat these situations, which makes our analyses very valuable.

1.1 Color Glass Condensate – Physics of Saturated Gluons

At very high energies, the cross-sections for hadronic processes are dominated by the small-x gluons in the hadron wavefunction. These gluons form a high density matter which is believed to reach saturation, and become a Color Glass Condensate. Roughly speaking, the saturation is realized under the balance between creation of small x gluons ("gain") and their recombination ("loss") which becomes significant at high density situation. This dense gluonic matter is relevant for various high energy processes such as the deep inelastic scattering (DIS) and the relativistic heavy ion collisions. We have provided two important things: natural interpretation of the new phenomena "geometric scaling" [1] and computation of the hadronic cross section at high energy [2].

1.1.1 Interpretaion of Geometric Scaling [1]

Geometric scaling is a novel scaling phenomenon in DIS at small x which was found by Staśto, Golec-Biernat and Kwieciński: The total virtual photon proton cross sections in DIS at $x < 0.01$, which are a priori functions of two independent variables — the photon virtuality Q^2 and the Bjorken variable x —, are consistent with scaling in terms of the variable: $\xi = Q^2R_0^2(x)$ where $R_0^2(x) = (x/x_0)^\lambda/Q_0^2$ with the parameters $\lambda = 0.3 \div 0.4$, $Q_0 = 1$ GeV, and $x_0 \sim 3 \times 10^{-4}$. This has been observed in the kinematical regime $0.045 < Q^2 < 450$ GeV^2.

At sufficiently low Q^2, below the saturation scale $Q_s^2(x)$ ($\sim$ a few GeV^2), this phenomenon finds a natural explanation as a property of the Color Glass Condensate. Indeed, in the saturation regime, the saturation momentum $Q_s(x)$ is the only one relevant scale, and any dimensionless quantities should be expressed as a function of $Q^2/Q_s^2(x)$. Therefore, this naturally leads to the identification between $Q_s^2(x)$ and the function $1/R_0^2(x)$.

However, we have to explain the reason why the geometric scaling holds even above the saturation scale. To explain the experimental observation of geometric scaling up to much higher values of Q^2, of the order of 100 GeV^2, we studied the solution to the BFKL equation subjected to a saturation boundary condition at $Q^2 \sim Q_s^2(x)$. We found that the scaling extends indeed above the saturation scale, within a window $1 \lesssim \ln(Q^2/Q_s^2) \ll \ln(Q_s^2/\Lambda_{\rm QCD}^2)$, or $Q^2 < Q_s^4/\Lambda_{\rm QCD}^2$ whose upper bound is consistent with phenomenology.

1.1.2 High Energy Behavior of Hadronic Cross Section – Froissart Bound [2]

Another important problem is to understand the high energy behavior of hadronic cross section. It is claimed that the linear evolution equation such as the BFKL equation violates the unitarity bound (so called "Froissart bound") and thus it is interesting how this can be cured from the viewpoint of gluon saturation.

We have demonstrated that the dipole-hadron cross-section computed from the non-linear evolution equation (the Balitsky-Kovchegov equation) for the Colour Glass Condensate indeed saturates the Froissart bound in the case of a fixed coupling and for a small dipole ($Q^2 \gg \Lambda_{\rm QCD}^2$). That is, the cross-section increases as ($\bar{\alpha}_s = \alpha_s N_c/\pi$, $\omega = 4\ln 2$)

$$\sigma \approx \frac{\pi}{2}\frac{(\omega\bar{\alpha}_s)^2}{m_\pi^2}\ln^2 s$$

The pion mass enters via the non-perturbative initial conditions at low energy. The BFKL equation emerges as a limit of the non-linear evolution equation valid in the tail of the hadron wavefunction. In Ref.[2], we provided a physical picture for the transverse expansion of the hadron with increasing energy, and emphasized the importance of the colour correlations among the saturated gluons in suppressing non-unitary contributions due to long-range Coulomb tails. We also presented the first calculation of the saturation scale including the impact parameter dependence.

1.2 Color Superconductivity – Physics of Paired Quarks [3]

Because of the asymptotic freedom and the Debye screening in QCD, deconfined quark matter is expected to be realized for baryon densities much larger than the normal nuclear matter density. Furthermore, any attractive quark-quark interaction in the cold quark matter causes an instability of the Fermi surface by the formation of Cooper pairs and leads to the color superconducting phase. Since the attractive interaction is effective for all of the quarks inside the Fermi sea, and it could be large at lower density, we can expect that color superconductivity at moderate density could be qualitatively different from the usual weak-coupling superconductivity in metal.

In order to study the difference from the usual BCS picture, we have investigated the two-flavor case over a wide range of baryon density with a single model [3]. In particular, we carefully looked at the *spatial*-structure of Cooper pairs. At extremely high baryon density ($\sim \mathcal{O}(10^{10}\rho_0)$ with ρ_0 being the normal nuclear matter density), our model becomes equivalent to the usual perturbative QCD treatment and the gap is shown to have a sharp peak near the Fermi surface due to the weak-coupling nature of QCD. This is consistent with the BCS picture. On the other hand, the gap is a smooth function of the momentum at lower densities ($\sim \mathcal{O}(10\rho_0)$) due to strong color magnetic and electric interactions. Through the analysis of quark correlation in the color superconductor, the size of the Cooper pair has turned out to become comparable to the averaged inter-quark distance at low densities. Also, effects of the momentum-dependent running coupling and the antiquark pairing, which are both small at high density, are shown to be non-negligible at low densities. These features are highly contrasted to the standard BCS superconductivity in metals, but are rather similar to the Bose-Einstein Condensate of Cooper pairs. We have also investigated the same problem in 2 color QCD [4] and found that a smooth transition from BCS to BEC really occurs as we go to lower densities.

2 Future Directions

So far, our application of the Color Glass Condensate has been focused on the deep inelastic scattering where the saturated gluon matter can be attributed only to one side of targets or projectiles. It is however very important to challenge the heavy ion collisions where we have two colliding saturated gluon matters. Several rough applications of the Color Glass Condensate have already succeeded in explaining various data from Au-Au collisions in RHIC at BNL. It is tempting to think that saturated gluon matter has been created in RHIC, but we have to analyze the data more carefully to be convinced of that.

The basic master equation, the Balitsky-Kovchegov (BK) equation is derived in the leading log resumed approximation with infinite number of colors N_c. Our understanding of the saturated gluon is mostly based on the analysis of the BK equation, but there are some cases where we have to consider the effects beyond the BK equation. This includes the analysis incorporating NLO contributions, effects of finite N_c. Also, it is interesting to consider the spin-dependent version of the BK equation, because it is claimed that the spin-dependent structure function will get $\alpha_s(\ln 1/x)^2$ enhancement instead of the usual single log enhancement $\alpha_s \ln 1/x$.

As for the dense quark matter, I think the most exciting field to work is the moderate density regime just above the chiral phase transition. In this regime, the QCD coupling is not so small and the diquark correlation is expected to be large as we already found in Ref. [3]. This strong correlation will add qualitatively new physics in this regime. One possibility is the realization of so called pseudo-gap phase in QCD, where diquarks form a bound state but do not condense. Also, even if the diquark pairs are formed, the interactions between Cooper pairs and between unpaired quark and the Cooper pairs will be strong. Thus we have to consider higher order correlations such as fluctuation effects beyond the mean field calculation. This problem is also related to the question how hadronization actually occurs in the presence of strong correlation between quarks. Deeper understanding of the consequence of strong diquark correlation will provide new physics for the dense quark matter in QCD.

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EXPERIMENTAL PRESENTATIONS

Introduction of Experimental Group

Hideto En'yo

Overview of
RBRC Experimental Group.

from organization point of view.

H. En'yo

Organization of RBRC activity

RHIC Machine Activity

Other Spin Experiment At RHIC

Group leaders

RICH fellow(half/half for 5 years)

Fellow(5 years)

Research Associates(2+1 years)

RIKEN Spin Program researchers

RIKEN Spin Program R.A.

PHENIX Activity

Students

RIKEN/Wako
KEK/Belle
Activity

RBRC experimental

RIKEN@RBRC

Atsushi Taketani
Yuji Goto
<u>Post N.Saito</u>
Kensuke Okada
Osamu Jin-nouchi

RBRC student

Hisayuki Torii
Hiroki Sato
Nob. Kamihara
Manabu Togawa
Victor Siegel
Takuma Horaguchi
Yoshi. Fukao

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Gerry Bunce

RBRC RHIC PHYSICS Fellow

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Douglas E. Fields

RBRC Fellow

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Brendan Fox
Federica Messer
Alexander Bazilevsky

RBRC Research Associate

Masashi Kaneta

RIKEN Special Postdoctoral fello

Hideyuki Kobayashi
T. Kawabata

BELLE(KEK)

Soeren Lange (VISITOR)
Akio Ogawa (VISITOR)
Kazumi Hasuko (RIKEN)

Upgrade @ CERN

Hiroaki Ohnishi
Johann Hauser

UPGRADE@WAKO

Kiyoshi Tanida
Rykov Vladimir
J.Tojo

WAKO/CCJ

Takashi Ichihara
Yasushi Watanabe
Satoshi Yokkaichi
Akio Kiyomichi

Since the last scientific review committee

- We had the first beam time of polarized proton collision at RHIC
  - excellent achievements but need more in pol and L

- Many have been promoted, 3 got tenure university positions, 2 got promoted in RIKEN/RBRC, 3 new comers. New students……

Member changes since last October

- K. Kurita (RBRC fellow) =>Associate Prof. of Rikkyo Univ.
- N. Saito (RIKEN tenure) => Associate Prof. of Kyoto Univ.
- J. Murata (RIKEN RSP RA) => RIKEN tenure (other lab)
- M. Perdekamp (RBRC fellow) => RHIC physics fellow(U.Illinois)
- Y.Goto (RBRC Fellow) => RIKEN tenure researcher
- A. Bazilevsky (RBRC RA) => RBRC fellow
- T. Kawabata(RCNP)=> RIKEN SPRA => CNS-U-Tokyo tenure post
- F. Messer (SUNY) => RBRC Fellow
- M. Kaneta (LBL) => RBRC R.A.
- ?????? (post Naohito Saito on going, for 1st March)
- Two new RIKEN R.A. is expected from 1st April
- K.Tanida (U.Tokyo) => RIKEN tenure researcher (PHENIX Upgrade)
- J. Tojo (RBRC student) => RIKEN special doctoral fellow (PHENIX Upgrade)
- V. Rykov (Wayne state) => RIKEN senior contract researcher (PHENIX upgrade)
- K. Hasuko (U.Tokyo) => RIKEN contract researcher (KEK/Belle)
- J. Hauser (SUNY) => RIKEN contract researcher (PHENIX Upgrade @ CERN)
- H.Ohnishi (BNL) => RIKEN contract researcher (PHENIX Upgrade @ CERN)
- Akio Kiyomichi(Tsukuba-U) => RIKEN contract researcher (CCJ)

! Students !

New scheme (RBRC young researcher)

Until last year, RIKEN(=RBRC) could support students only if they get salary, like JSPS fellow ship and RIKEN Junior Research Associate (JRA) . Otherwise students can stay at RBRC for only 1 month in a year. And limited only for Japanese University

Hisayuki Torii (Kyoto U) JRA => J-US (not supported by RIKEN now)
Hiroki Sato(Kyoto U) JRA=>JSPS
Junji Tojo (Kyoto U) JSPS, Nobuyuki Kamihara (T.I.Tech) JRA2
Manabu Togawa(Kyoto U) JRA2

This caused apparent limitation for students activity. New scheme uses BNL Technical collaborator system, and call it as RBRC young researcher. By doing so RBRC can support subsistence of students from anywhere in the world while they are at RBRC.

Victor Siegel (Heidelberg) , Takuma Horaguchi(T.I.Tech),
Yoshi. Fukao (Kyoto –U)

are appointed now. Thanks a lot to the review committee

- RHIC polarimeter worked excellently
  - Kazu => Osamu
- Collision point polarimeter(Local-pol) Super !
  - Yuji -> Abhey, Brendan -> Kyoto students (Manabu,Yoshi)
- Trigger: excellent achievement,
  - Yuji Brendan, Matthias -> Kensuke
- South Muon: well commissioned, North Muon ready
  - Doug + Hideyuki + Atsushi + Hiroki
- Analysis: On going..
  - Many + Federica, conducted by Brendan
- RIKEN/Wako activity
  - CCJ
  - Upgrade Si-Strip R&D @WAKO,Pixel R&D @CERN
- KEK/Belle activity
  - Matthias, Akio, Soeren + Victor,Kazumi

Introduction of Experimental Group

Gerry Bunce

21 November 2002
RBRC Review
G. Bunce

RBRC Experimental Group---a few remarks

Much to be proud of !

RBRC Workshops led to coordinated plan between experiments and accelerator which resulted in the September 2000 commissioning and the December 2001-January 2002 first spin run.

RBRC, with important collaborators, led the new RHIC polarimeter development and realization. These devices were invented for RHIC and work beautifully, measuring the polarization to 2% in one minute.

RBRC initiated and led design and realization of high rate event selection for spin for PHENIX. These triggers worked beautifully, increasing the number of events by x100 over min-bias.

RBRC designed and built additional beam-beam counters for pp for PHENIX. These worked well.

RBRC designed special electronics to keep track of luminosity for each crossing for PHENIX. This is necessary for spin and worked.

RBRC designed, built, calibrated (at Stanford), installed a photon detector for very forward polarization measurements. This worked and we observed very large online spin asymmetry for neutrons.

RBRC and collaborators led triggering for the PHENIX muon arm, and we expect to have cross sections and spin asymmetries for forward muons and pions. This was very successful.

RIKEN funded the Siberian Snakes for RHIC. This was a great success—the first time Snakes were used at high energy.

We took the first data ever at root(s)=200 GeV with colliding polarized protons, providing our first look at the spin structure of the proton using quark and gluon probes. We have beautiful data, and our sensitivity to transverse spin effects is 10x better than previous experiments, and at 10x the energy.

And, we should be very proud of our graduating class:

Naohito Saito, Kazu Kurita, Matthias Perdekamp, Yuji Goto

as well as our present members.

RHIC SPIN EXAMPLE RUN PLAN*

July, 2002

Year	Acceleration/ Polarimetry	P	Weeks Commiss./ Physics	root(s)	LT	Physics
2002	RHIC Snakes, CNI Polarimeters	20%	8 (5/3)	200 GeV	1/3 pb^-1	Transverse spin, systematic studies, start learning curve
2003	Spin Rotators, AGS CNI Polarim.	50%	8 (5/3)	200 GeV	6 pb^-1	A(LL), A(N), A(NN) STAR, PHENIX Gluon polarization? A(N),A(NN): pp2pp, BRAHMS
2004	Polarized Jet-- Absolute Polariz.	50%	8 (1/4)	200 GeV	80 pb^-1	Gluon polarization with jets Direct photon?
			(2/1)	500 GeV	20 pb^-1?	Parity violating W+?
2005	AGS Strong Snake	70%	10 (1/7)	200 GeV	140 pb^-1	Gluon polarization with direct gamma
			(1/2)	500 GeV	100 pb^-1	Begin W: antiquark pol.
2006		70%	10 (1/5)	200 GeV	100 pb^-1	Gluon pol.--direct gamma
			(1/3)	500 GeV	150 pb^-1	W parity violation
2007		70%	10 (1/9)	500 GeV	450 pb^-1	W parity violation

RHIC Spin Design Goals: 70% polarization, L = 2 x 10^32 cm^-2 s^-1 (root(s) = 500 GeV)

LT = 320 pb^-1 for root(s) = 200 GeV LT = 800 pb^-1 for root(s) = 500 GeV

The First RHIC Spin Run

Naohito Saito

PHYSICS of RHIC SPIN

- RIKEN and RBRC Activities-

RBRC Scientific Review
November 21-22, 2002

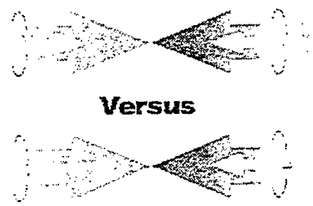
Naohito Saito

Kyoto U./ RIKEN / RIKEN BNL Research Center

RIKEN

Spin Physics at RHIC

- Measure Spin Asymmetries in *pp* collision to pin down
  - Spin Structure of the Nucleon
    - Proton Spin Sum Rule
    - Transversity Distributions
  - Spin Dependence of Fundamental Interactions
    - Parity Violating interaction
  - Spin Dependence of Fragmentation
    - E.g. Lambda fragmentation function
  - Spin Dependence in *pp* elastic scattering



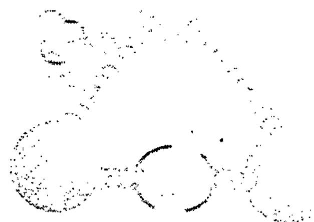
RIKEN

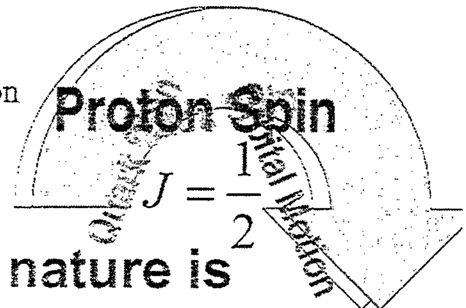
Why Spin Physics?

- "Spin" is a fundamental observable.

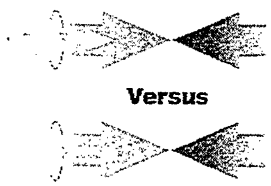
$$\Delta\Sigma = 0.1 \sim 0.2$$

Total fraction of the proton spin carried by the quark spin; Scheme dependent.





- *Axial vector* nature is useful in symmetry tests
  - Parity
  - Time Reversa



		$\mathcal{P}$	$\mathcal{T}$
position	x	$-x$	x
momentum	p	$-p$	$-p$
spin	σ	σ	$-\sigma$

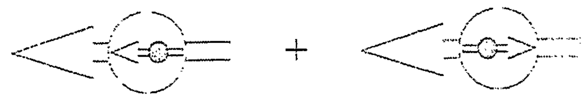
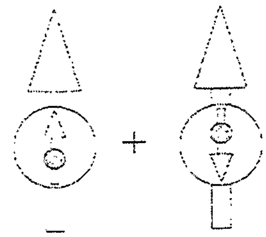
RIKEN

Parton Distribution Functions

RHIC

- **Quark Distributions**

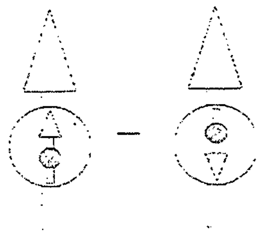
unpolarized distribution

$q(x,Q^2)=$  

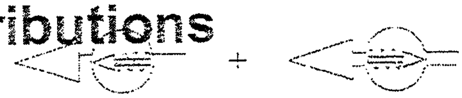
helicity distribution

$\Delta q(x,Q^2)=$ 

transversity distribution

$\delta q(x,Q^2)=$ 

- **Gluon Distributions**

$g(x,Q^2)=$ 

$\Delta g(x,Q^2)=$ 

No Transverse Gluon Distribution

RIKEN

RHIC Spin Structure Studies at a Glance

- **Dg measurements**

process	measure	PHENIX	STAR
$A_{LL}(pp\to\gamma(jet)X)$	$\Delta g\times A_1^p$	yes	yes
$A_{LL}(pp\to\pi X)$	$\Delta g\times(\Delta g+\Delta\Sigma)$	yes	yes
$A_{LL}(pp\to jet\ X)$	$\Delta g\times(\Delta g+\Delta\Sigma)$	no	yes
$A_{LL}(pp\to QQbar\ X)$	$\Delta g\times\Delta g$	yes	no
$A_{LL}(pp\to J/\psi\ X)$	$\Delta g\times\Delta g$	yes	no
$A_{LL}(pp\to\chi_2\ X)$ ✵	$\Delta g\times\Delta g$	yes?	no

- **Lepton, Photon, and Hadron**
- **Rare Process**
  - □ **Trigger**

- **Dq measurements**

process	measure	PHENIX	STAR
$A_L(pp\to W^+X)$	Δu, $\Delta dbar$	yes	yes
$A_L(pp\to W^-X)$	Δd, $\Delta ubar$	yes	yes
$A_{LL}(pp\to l^+l^-X)$	$\Delta q\ \times\Delta qbar$	yes	yes?
$A_L(pp\to WcX)$ ✵	Δs, $\Delta sbar$	yes	yes

- **dq measurements**

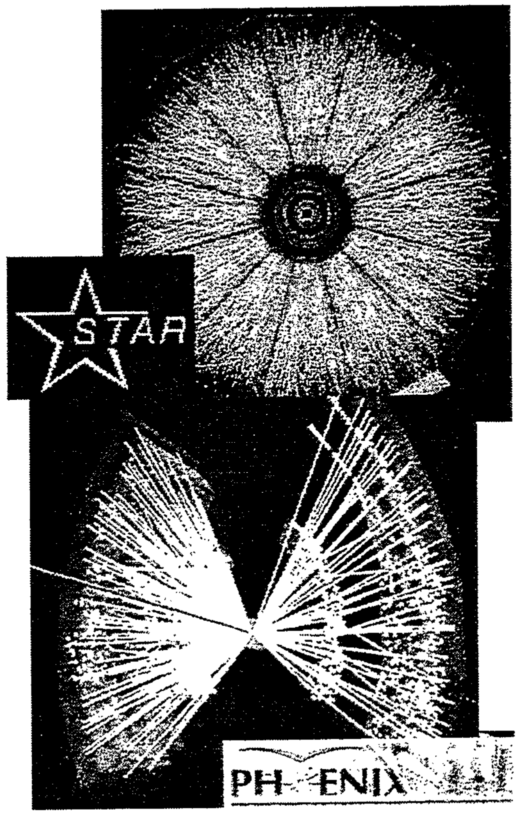
process	measure	PHENIX	STAR
$A_T(pp\to(\pi^+\pi^-)X)$	$\delta q\ \times D$	yes	yes
$A_{TT}(pp\to l^+l^-X)$	$\delta q\ \times\delta qbar$	yes	yes?
✵ $A_T(pp\to\gamma(\pi^+\pi^-)X)$	$\delta q\ \times D$	yes	yes

✵ *L/E* Upgrade desirable

RIKEN

RHIC Spin Run-1,2 and now Run-3

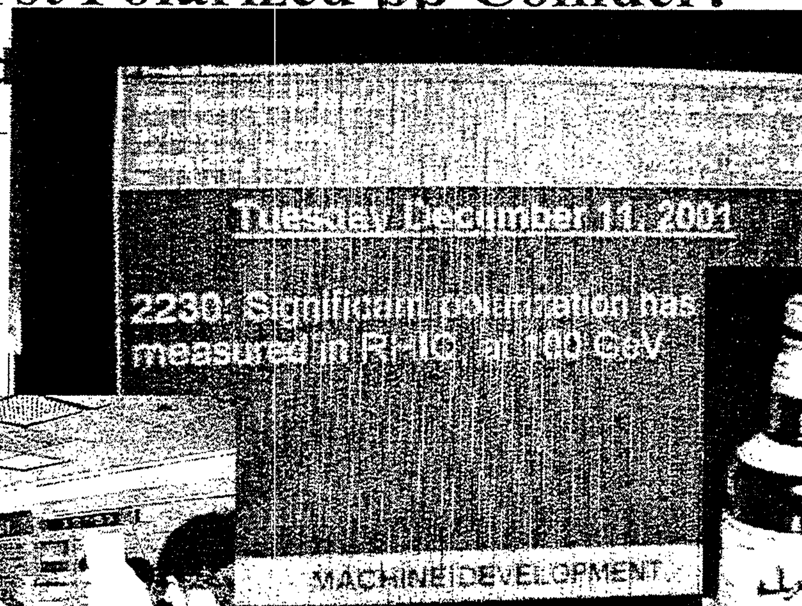
- Run-1
  - Successful Spin Commissioning in one ring!
- Run-2
  - First Polarized Proton Collision at 200 GeV Spin!
  - Spin Physics Run ~3 weeks
  - PHENIX has recorded ~150nb^{-1}
- Run-3
  - First Physics Run with Longitudinal Polarization



RIKEN

The First Polarized pp Collider!

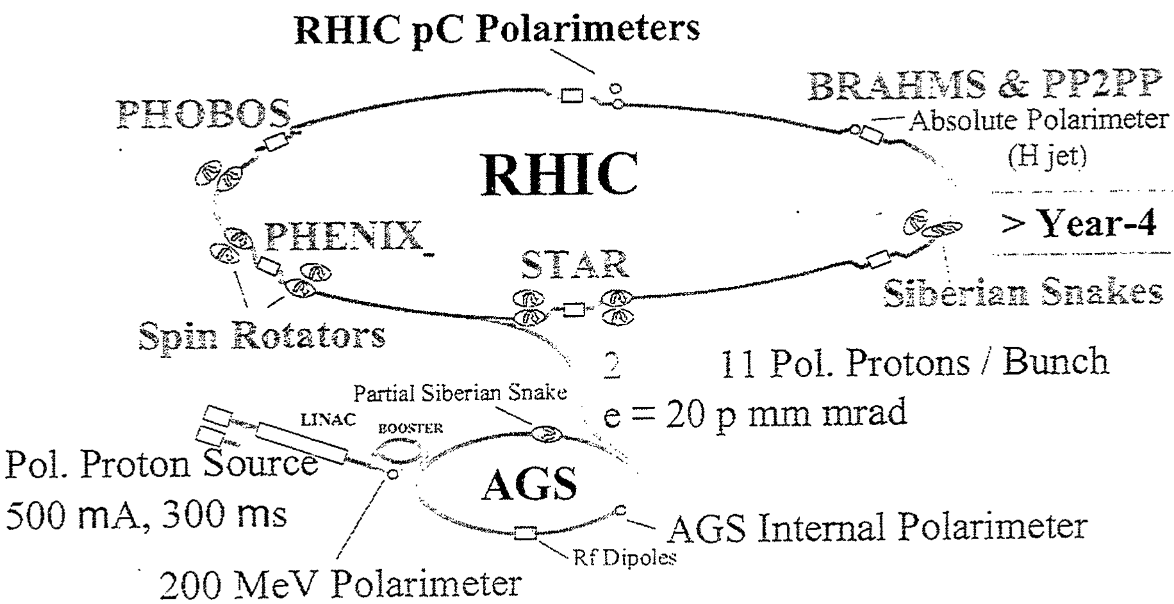
• Click to add



Participating Groups:
BNL
RIKEN, Japan and RBRC
ANL Indiana Kyoto
ITEP Moscow

RHIC Run-3 and Beyond

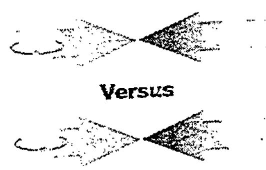
- Complete Polarized Collider



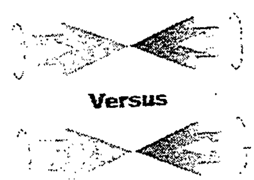
RIKEN

Goals of the 1st Spin Physics Run

- **Establish Stable Asymmetry Measurements**
  - Beam Polarization > 50%   15-20%
  - Luminosity ~5E30cm-2s-1 → 1E30cm-2s-1
- 1 week of transverse polarization (~0.75 pb-1)
  - AN ~ Higher Twist Effects



- 4 weeks of longitudinal polarization (~3 pb-1)
  - ALL for pion ~ Dg Measurements
  - ALL for J/y in muon Arm



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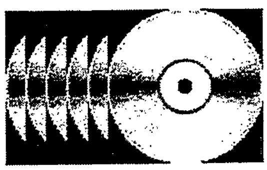
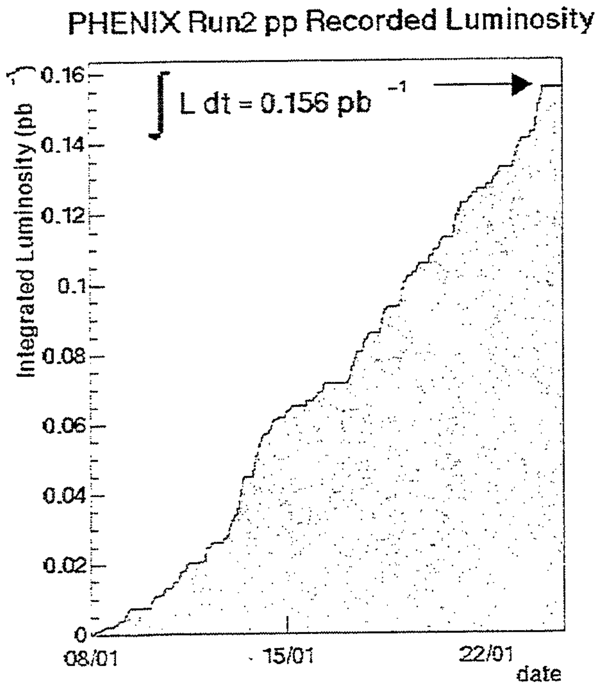
Luminosity Growth in Run-2 pp

- Delivered peak luminosity ~ $1x10^{30}cm^{-2} s^{-1}$
- Data Band Width ~ 60 MB/s = 6 CD's/min





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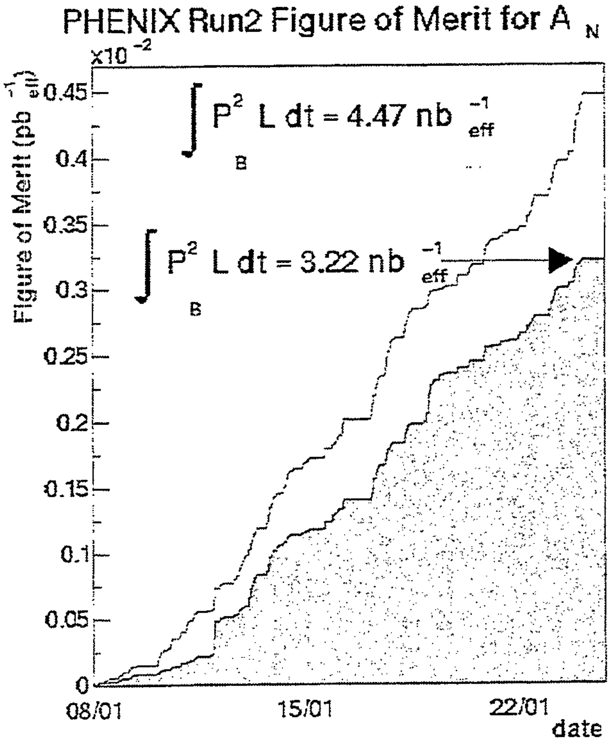
The Polarized Collider Performance in Run-2

- Beam Polarized Transversely
- Yellow > Blue
  - <Pyellow>=17%
  - <Pblue>=14%
    - Assumption: Analyzing Power is E-indep.
- Enough Statistics for first A_N physics



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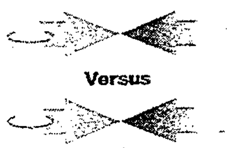
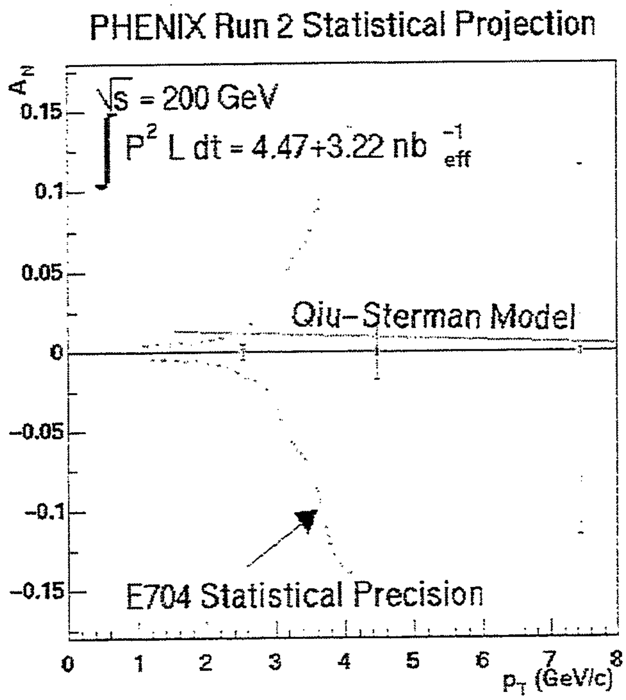
Run2 PHENIX Spin A_N Expectation

- Single Transverse Spin Asymmetry for Neutral Pion



- Statistical Significance of A_N ~ 10x E704



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RHIC Spin Plan (PHENIX and STAR)

Year	CM Energy	Weeks	Int. Lum.	Remarks
2003	200 GeV	3	3 pb^{-1}	Gluon pol. with pions / TT
2004	200 GeV	8	160 pb^{-1}	Gluon pol. with direct g , jets/ TT
	500 GeV	2	90 pb^{-1}	PV W production, u-quark pol.
2005	200 GeV	8	160 pb^{-1}	Gluon pol. with g + jet/ TT
	500 GeV	2	120 pb^{-1}	First ubar,dbar pol. meas..
2006	500 GeV	8	480 pb^{-1}	Gluon pol. with g+jet, g,jet+jet, heavy flavor, ubar, dbar pol.
	200 GeV	2	48 pb^{-1}	Gluon pol. with g, g+jet, heavy flavor/TT

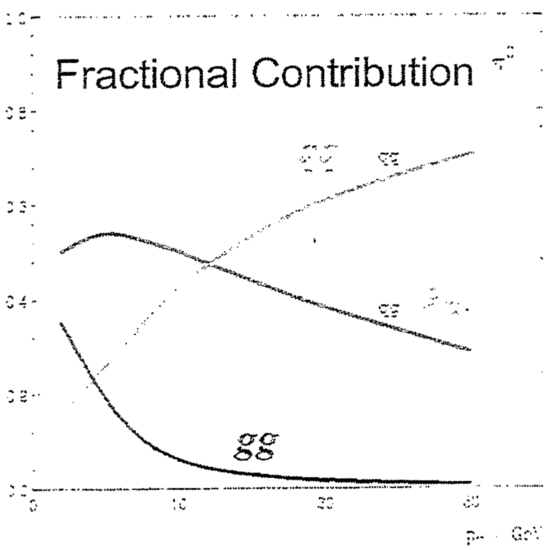
TT Transverse Spin Physics

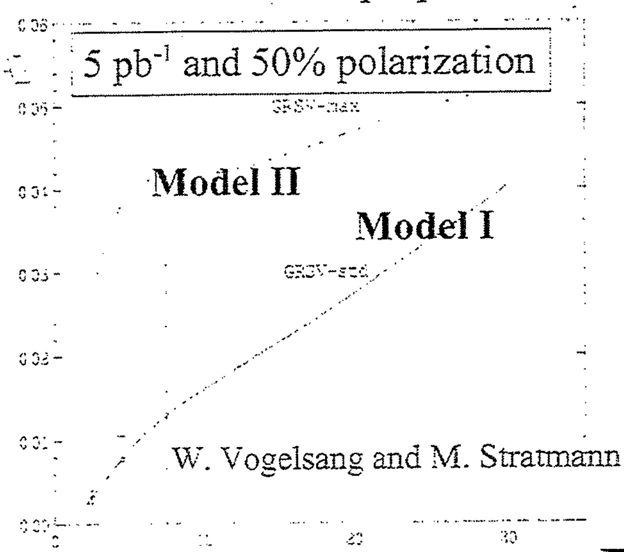
RIKEN

Run 3 Aims Dg with Pion

- Hi Statistics Pion Data! Sensitive to

$gg \rightarrow gg \quad \propto \frac{\Delta G}{G}\frac{\Delta G}{G}$ $\qquad gq \rightarrow gq \quad \propto \frac{\Delta q}{q}\frac{\Delta G}{G}$ $\qquad \propto \frac{\Delta q}{q}\frac{\Delta q}{q}$





RIKEN and RBRC Activities

- PHENIX Muon Arm Doug, Atsushi, Jiro, Hiroki, Mao, Hideyuki, Nobuyuki
- PHENIX EMCal
  - Analysis of Au-Au Data Sasha, Hisa
  - FEE QA Hisa, Yuji
  - High Energy Beam Test Yuji, Hisa and Naohito
- PHENIX Trigger
  - EMCal + RICH Matthias, Kensuke
  - Charged Hadron Trigger Yuji and Kensuke
  - MuID Hiroki
  - W Trigger Studies Abhay, Matthias, Brendan
- PHENIX NTC Brendan, Abhay
- PHENIX CC-J Takashi, Yasushi, Yuji, Satoshi, Osamu
- PHENIX Luminosity Monitor Gerry, Sasha, Yuji, Hiroki and Naohito
- Polarimeter
  - RHIC Polarimeter Kazu, Osamu, Junji, Doug, Gerry and Naohito
  - Local Polarimeter Brendan, Abhay, Yuji, Manabu, Yoshi, Yasushi, Kiyoshi, Gerry and Naohito
- Global Analysis of Polarized Data Yuji, Naohito, Hideyuki
- Fragmentation Functions Matthias
- PHENIX Si Upgrade Yuji, Junji, Manabu, Kiyoshi, Rykov, Johann, Hiroaki and many others
- PHENIX Drift Chamber Analysis Federica
- PHENIX Spin Analysis Brendan, Yuji, Sasha, Federica, Kensuke, Takuma, Hisa, Takahiro, Hiroki, Atsushi, and many others

RIKEN

Summary

- RIKEN and RBRC group are (still) growing
  - Thanks to our new boss ... Hideto
- Crucial Areas for Spin Physics are largely covered by this group

- Thanks:
  - Advisory Group:
    - T.D. Lee, N. Samios, T. Roser, Y. Makdisi. M. Tannenbaum and R.L. Jaffe
  - Strong Supports from Japan
    - RIKEN I. Tanihata and M. Ishihara
    - Kyoto University K. Imai
    - Tokyo Institute of Technology T.-A. Shibata

RIKEN

Luminosity for PHENIX—Absolute and Relative; A New Inner Detector for PHENIX

Yuji Goto

Luminosity for PHENIX

- Absolute luminosity
  - normalization in the cross section measurement
    - π^0, charged hadron, J/ψ, ...

$$E \cdot \frac{d^3\sigma(p_T)}{dp^3} = \frac{1}{2\pi \cdot p_T dp_T dy} \frac{N^{|z|<30cm}(p_T)}{L^{|z|<30cm}}$$

$$L^{|z|<30cm} = \frac{N_{BBC}^{|z|<30cm}}{\sigma_{pp} \cdot \varepsilon_{BBC}}$$

  - vernier scans

$$\sigma_{BBC}^{|z|<75cm} = \frac{N_{BBC}^{|z|<75cm}}{L} = \sigma_{pp} \cdot \varepsilon_{BBC}^{|z|<75cm}$$

We need to understand both ε_{BBC} and $\varepsilon_{BBC}^{|z|<75cm}$ to be consistent with $\sigma_{BBC}^{|z|<75cm}$ and σ_{pp}

Luminosity for PHENIX

- Absolute luminosity
  - Vernier scans
    - done by C-AD department (Angelika Drees et al.)

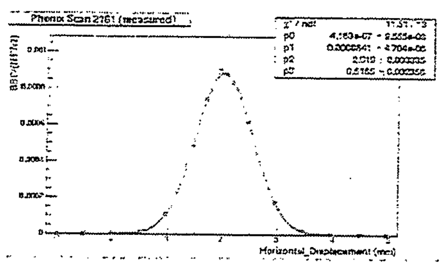
$$\sigma_{BBC}^{|z|<75cm} = \frac{N_{BBC}^{|z|<75cm}}{L} = \sigma_{pp} \cdot \varepsilon_{BBC}^{|z|<75cm}$$

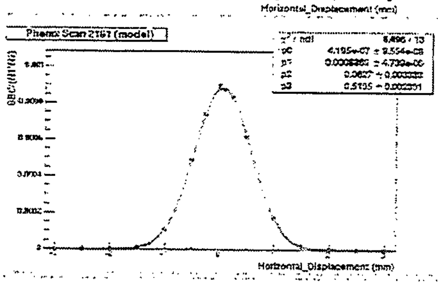
$\sigma_{BBC}^{|z|<75cm} = 12.6mb$: vernier scans

$\sigma_{pp} = 42mb$: interpolation of world data

$\varepsilon_{BBC}^{|z|<75cm}$: BBC efficiency

- BBC efficiency to be evaluated by dividing it:
  - BBC coincidence efficiency
  - BBC z-vertex cut efficiency





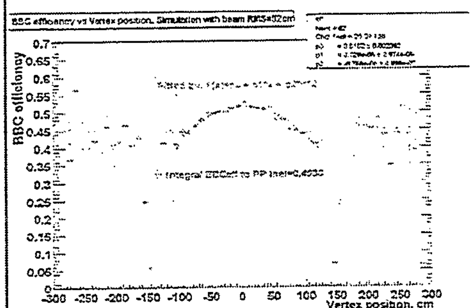
Luminosity for PHENIX

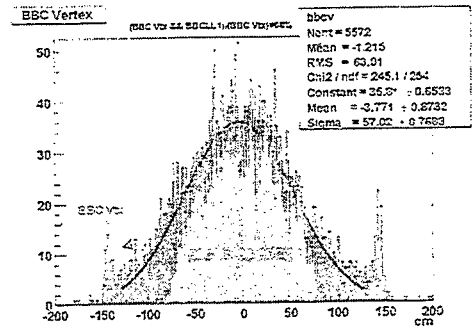
- Absolute luminosity
  - BBC efficiency $\varepsilon_{BBC}^{|z|<75cm} = \varepsilon_{BBCcoin} \cdot \varepsilon_{BBCcoin}^{|z|<75cm}$
    - BBC coincidence efficiency evaluated by MC simulation

$$\varepsilon_{BBC} = 51\% \quad \varepsilon_{BBCcoin} = 44\%$$

    - BBC z-vertex cut efficiency evaluated by real data analysis

$$\varepsilon_{BBCcoin}^{|z|<75cm} = 66\%$$





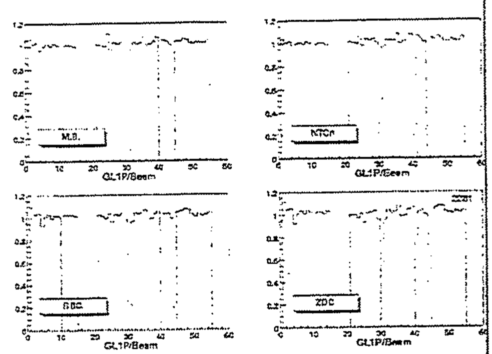
Luminosity for PHENIX

- Relative luminosity

$$A_{LL} = \frac{1}{P^2} \cdot \frac{N_{++} - R \cdot N_{+-}}{N_{++} + R \cdot N_{+-}}$$

$$R = \frac{L_{++}}{L_{+-}}$$

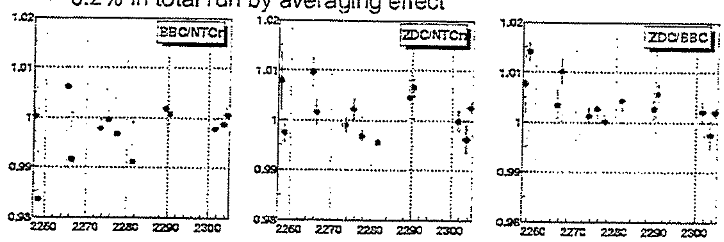
  - ΔA_{LL} < 0.3% measurement in 2002-2003 run requires ΔR < 0.1% measurement
  - Crossing-sorted scalers
    - 4 scalers × 120 crossings
      - Min.Bias = BBC ⊕ NTC
      - BBC
      - NTC
      - ZDC



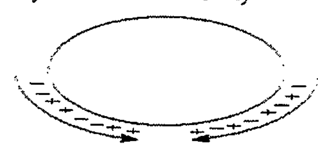
crossing-sorted specific luminosity = scaler / WCM blue / WCM yellow (WCM: wall current monitor)

Luminosity for PHENIX

- Relative luminosity
  - Crossing-sorted scalers
    - ΔR = 0.3% achieved in good fills (preliminary)
    - 0.2% in total run by averaging effect



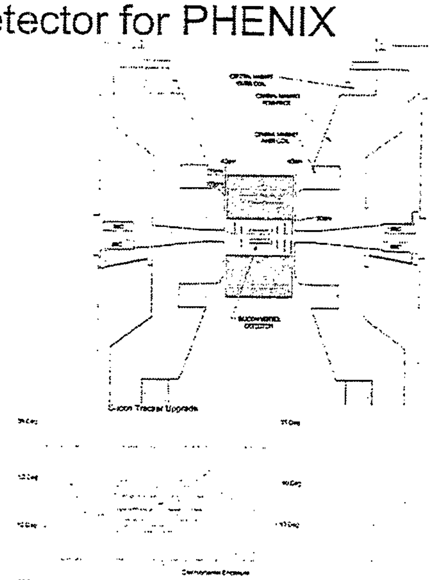
    - bunch-by-bunch characteristics make this systematic uncertainty
    - relation with accelerator parameters ??
  - 2002-2003 run
    - additional luminosity telescope
    - recogging / spin flip
    - → ~10-times better relative luminosity measurement expected



November 21, 2002 Yuji Goto (RIKEN/RBRC) 5

New Inner Detector for PHENIX

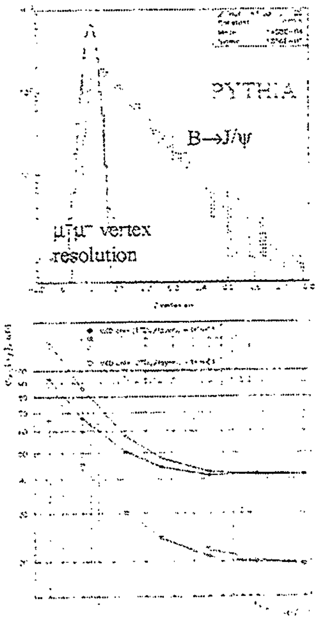
- 2004-2005 and beyond ...
  - full luminosity
    - 800pb^{-1} at $\sqrt{s}$=500GeV
    - 320pb^{-1} at $\sqrt{s}$=200GeV
  - A_{LL} of direct photon
  - A_{LL} of heavy flavor
- Silicon vertex tracker
  - straw-man design
  - barrel: 4 layers
    - $|\eta| < 1$ & $\Delta\phi \sim 2\pi$
    - 1 pixel layer + 3 strip layers (or 2 pixel layer + 2 strip layers)
  - endcap: 4 layers
    - to match with muon arms



November 21, 2002 Yuji Goto (RIKEN/RBRC) 6

New Inner Detector for PHENIX

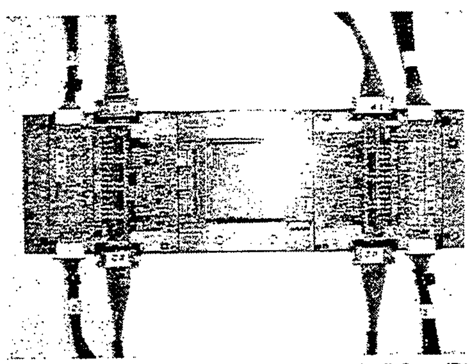
- Heavy flavor
  - identifying displaced vertex
    - muon displaced vertex: $\sigma_z \sim 100\ \mu m$
    - electron displaced vertex: $\sigma_{DCA} < 50\ \mu m$ (DCA: distance of the closest approach) at $p_T > 1$ GeV/c
  - open bottom $B \to J/\psi \to \mu^+\mu^-$
    $B \to J/\psi \to e^+e^-$
- Photon+jet
  - photon detected by EMCal: $|\eta| < 0.35$
  - jet detected by silicon tracker
    - $|\eta| < 1$ with barrel only
    ➔ wider with endcap, too ...
  - momentum resolution
    - ~10- 20 % at $p_T = 0.5 - 1$ GeV/c
    - ~50-100% at $p_T = 10$ GeV/c
    ➔ improves with TPC ...
  - optimizing to find jet axis well enough ...

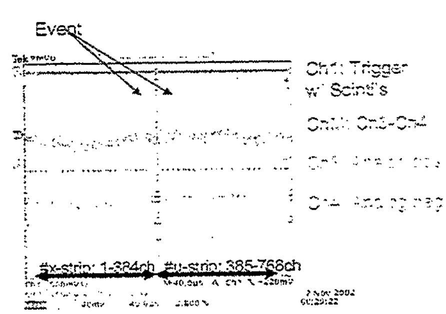


November 21, 2002 Yuji Goto (RIKEN/RBRC)

New Inner Detector for PHENIX

- Novel silicon microstrip detector
  - by Zheng Li (BNL instrumentation div.)
  - telescope with prototype sensor
    - cosmic-ray signal was observed !
    - beam test will be done at KEK in December !





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PHENIX Triggering and Belle Fragmentation Functions

Matthias Grosse Perdekamp

PHENIX Triggering and Belle Fragmentation Functions

Matthias Grosse Perdekamp, RBRC/UIUC

Trigger layout and organization

Physics and trigger channels for the 2003 PHENIX Run

Belle: Status of Fragmentation Analysis

PHENIX: Spin Trigger Needs

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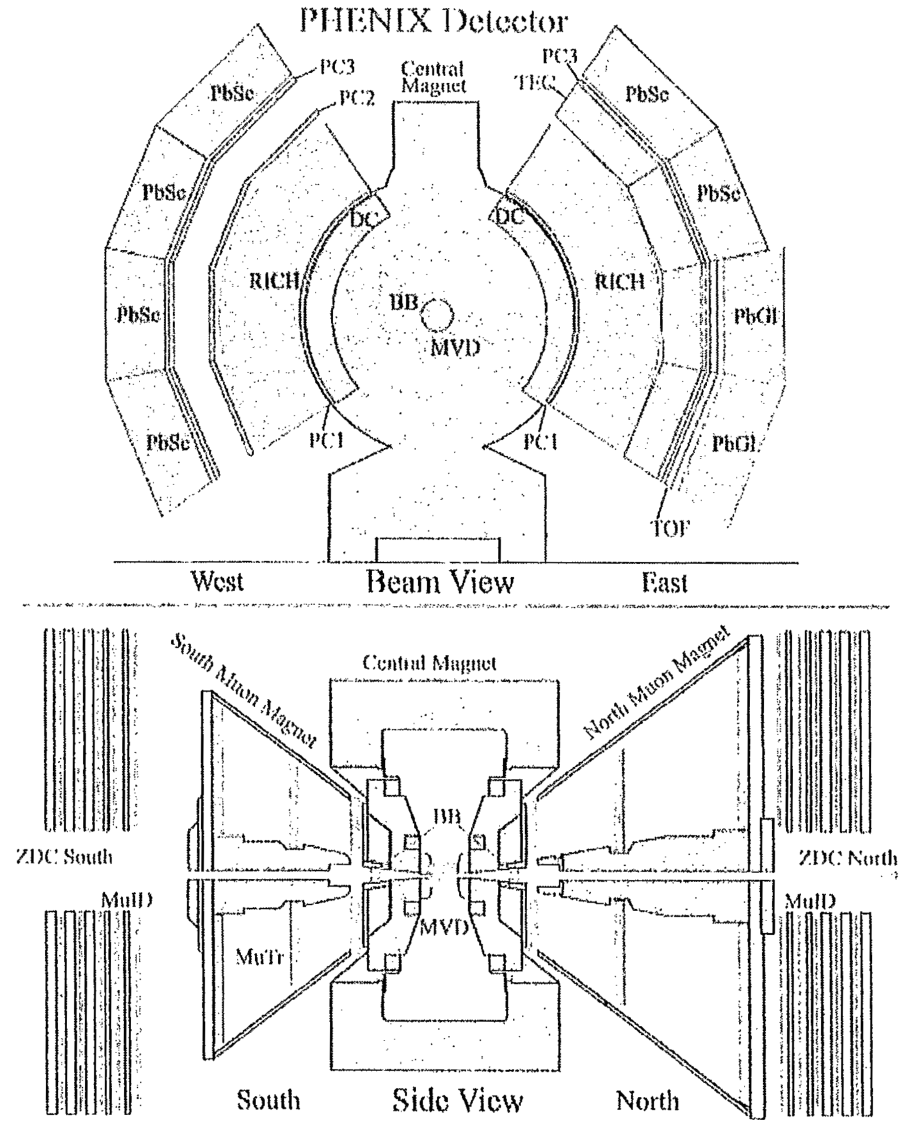
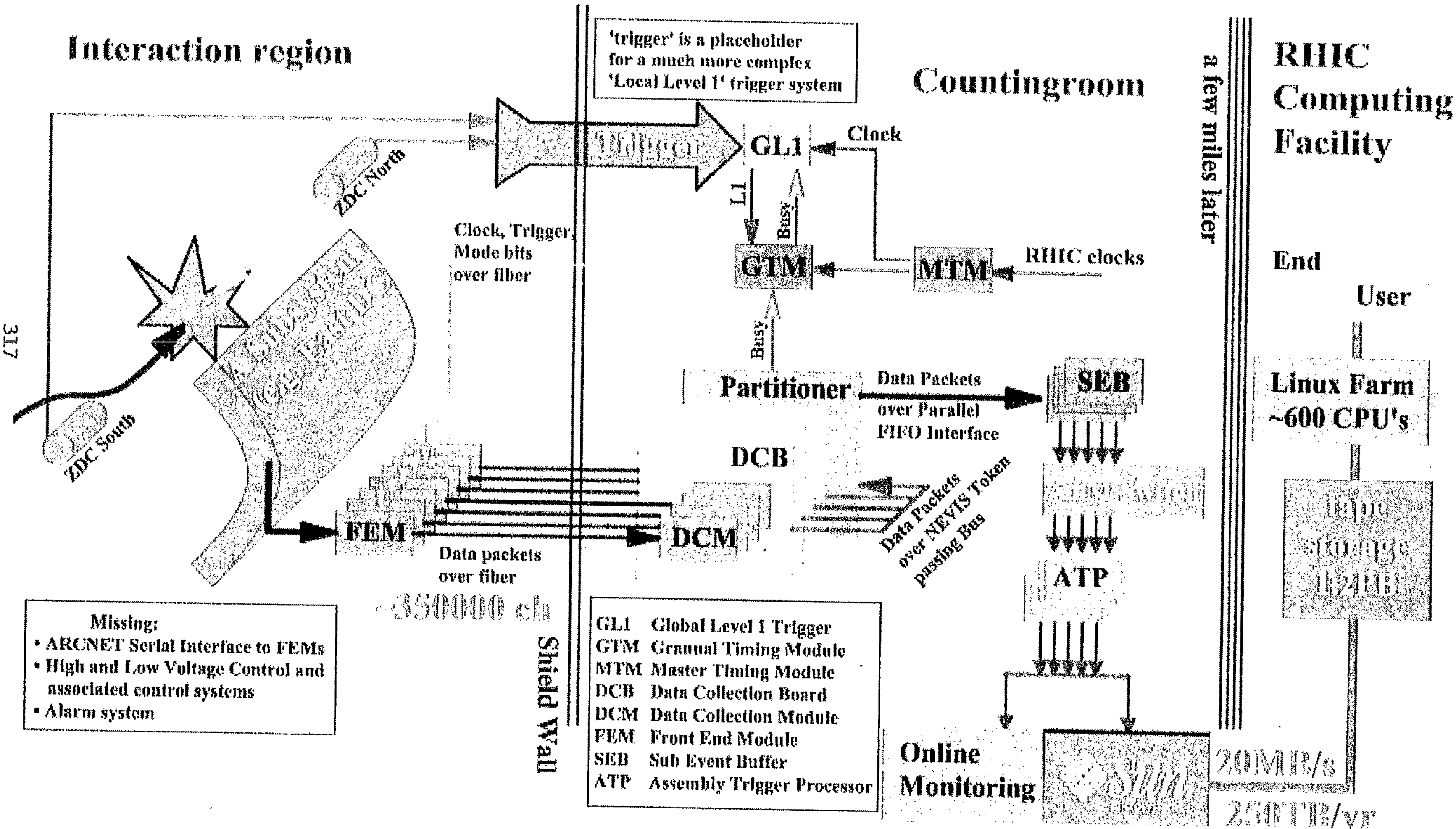
- Selective first Level Trigger
  Raw rate: up to 10 MHz
  Evt Bldr/Lvl 2 bandwidth:
  12kHz (for ~15 physics triggers)
  -> Rejection needed: 10^4

- Further reduction at level 2 to reduce data volume and Offline computing load: ~10



PHENIX DAQ and Trigger



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pp - Triggers for Run 03

Input Parameters

RHIC luminosities	proton-proton from Roser plan				
	L (average) [cm-2s-1]	L (peak) [cm-2s-1]	cross section [barns]	coll/sec (ave)	coll/sec (peak)
	1.00E+31	1.60E+31	4.20E-02	4.20E+05	6.72E+05
PHENIX limits	L1 accept rate	L1*L2 rate = archive			
	4.50E+03	1.20E+03			

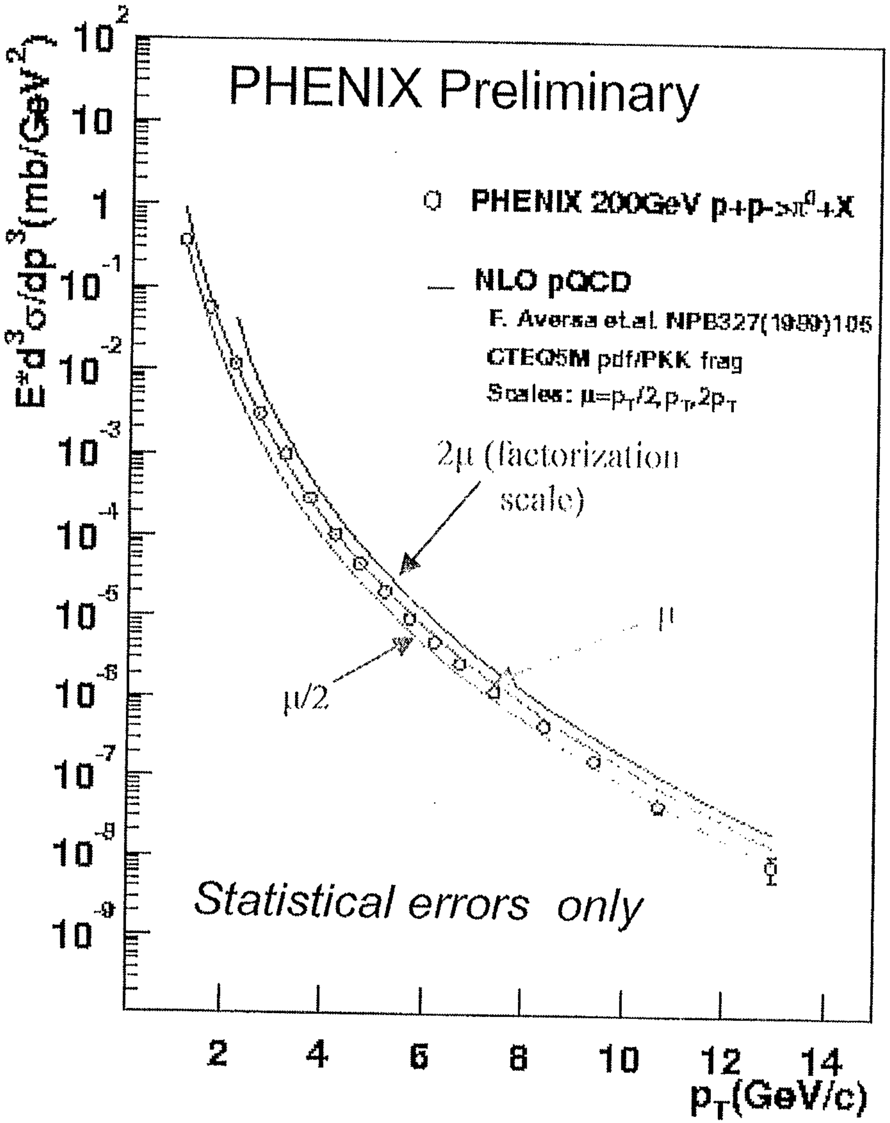
Assume an N week long data taking period, a 40% duty factor for RHIC (from Roser), and 50% duty factor from PHENIX.

Number of weeks	Seconds	Collisions in PHENIX	% of archive rate for MB	MB Collisions archived
3	1.81E+06	2.44E+11	0.2	8.71E+07

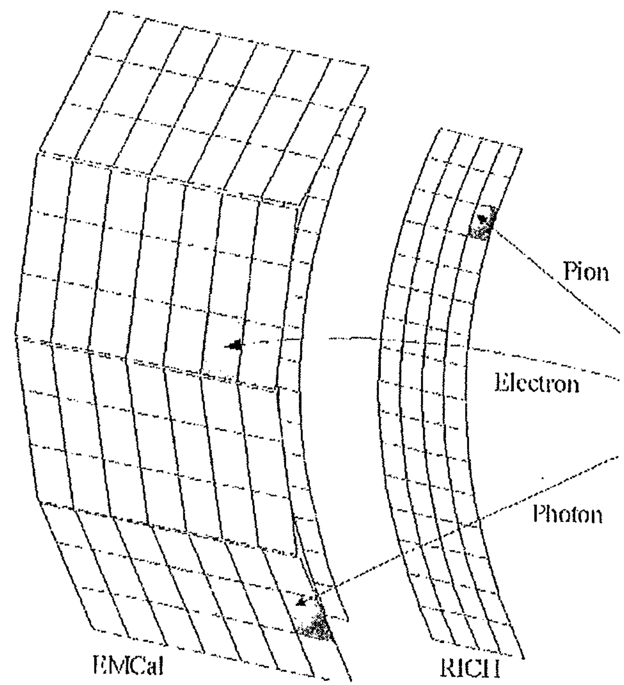
Lvl1 Trigger Index	Lvl1 Trigger Name	Expected Rejection	Lvl1 Prescale*	Rate at Average	Rate at Peak	Associated Lvl2
1	MB: BBCLL1	1	500	838	1341	
2	Clock*(Yfill+Bfill)	1	999999	0	1	
3	**MB && ZDCNS**	1	999999	0	1	
4	**ZDCNS**	1	999999	0	1	
5	MUID-S-LL1: 1 deep	240	0	1750	2800	L2 MUID-MUTR match
6	MUID-N-BLT: 1 deep	240	0	1750	2800	L2 MUID-MUTR match
7	MUID-S-LL1: 1 d, 1s	2400	0	175	280	
8	MUID-N-BLT: 1 d, 1 s	2400	0	175	280	
9	EMC 2x2: Thresh, 700	90	1	2333	3733	L2 2x2 Cleanup
10	EMC 4x4a	600	0	700	1120	L2 4x4a Cleanup
11	EMC 4x4b	1100	0	382	611	L2 4x4b Cleanup
12	ERT electron	1	999999	0	1	
13	ERT RICH pair	1	999999	0	1	
			Total ===>	8106	12969	

# MUST BE <	4.50E+03

I) EMC-RICH Trigger



Use and correlate information from the EMC and RICH to trigger on γ, (π^0), e and jets (multiplicity).



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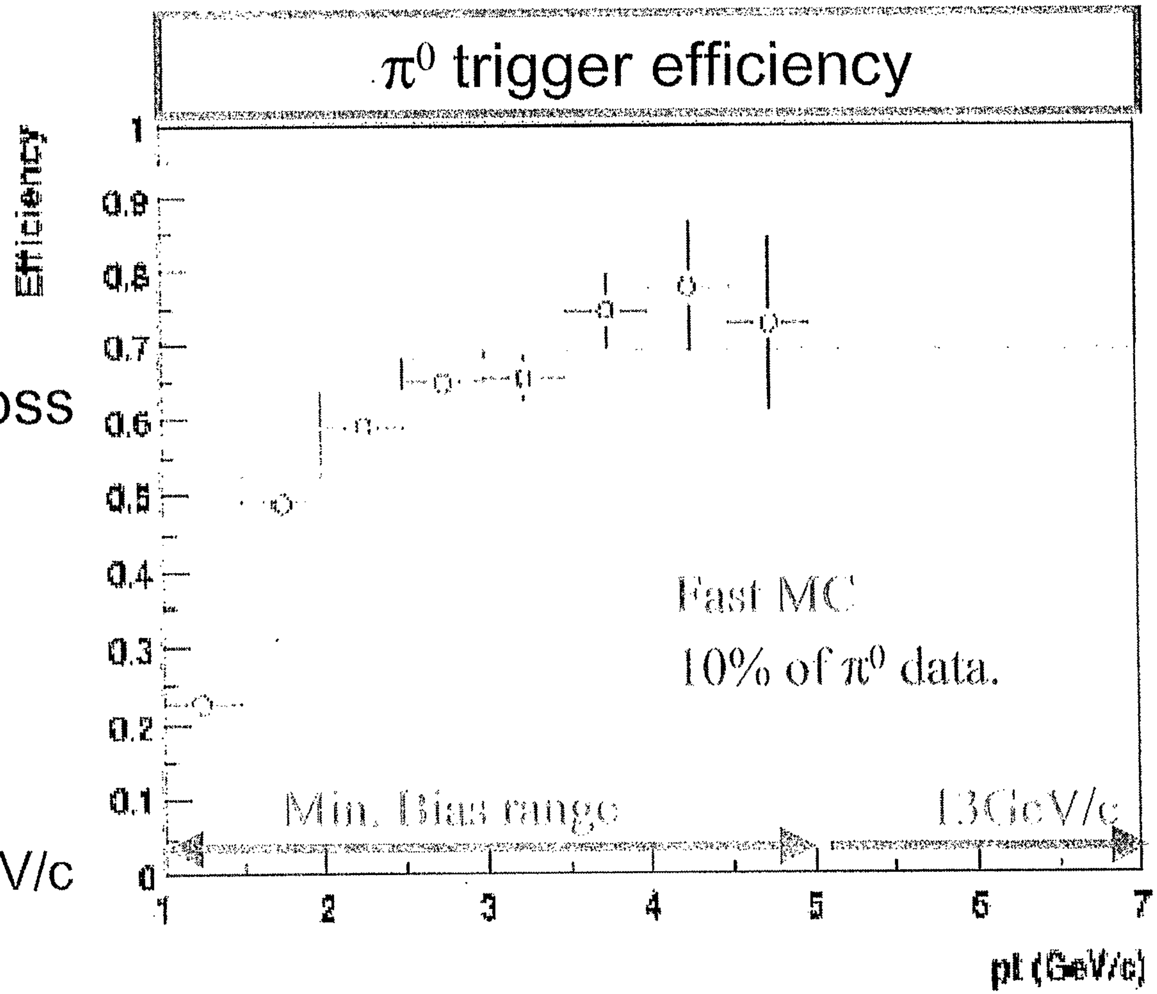
EMC Trigger Performance

- Efficiency

$$\varepsilon_{\pi 0}^{(High)} = \frac{N_{\pi 0}^{(2\times 2\& MB)}}{N_{\pi 0}^{(MB)}}$$

- They are uniform across the calorimeter <10%
- The trigger efficiency saturates at >3GeV/c
  - Min. Bias data for 1-5GeV/c
  - 2x2 trigger for 3-15GeV/c



The Level 1 in pp:

Level 1 Channel	Rates
electron trigger (EMCxRICH, E>1.5GeV)	4kHz R=3000
photon trigger (EMC>3GeV)	0.3kHz R=40000
Jet (EMC Multiplicity)	6kHz
single muon (muId deep muon)	17.6kHz R=570
Others	2kHz
Total	29.9kHz
PHENIX bandwidth	12kHz

Muon Trigger/Spectrometer Upgrade

W Production in pp

Measure quark and anti-quark polarizations in the proton :

$$\frac{\Delta u}{u}, \frac{\Delta \bar{u}}{\bar{u}}, \frac{\Delta d}{d}, \frac{\Delta \bar{d}}{\bar{d}}$$

$R_{raw} = 60\text{mb} \cdot 2 \cdot 10^{32}\,\text{cm}^{-2}\text{s}^{-1} = 12\text{MHz}$, bandwidth into DCMs $\approx$ 12 kHz for several rare event channels

$\Rightarrow$ Need Rejection of 10^4!

Gluon Saturation in dA

Measure the A-dependence of the gluon distribution at small x:

$$G_A(x)$$

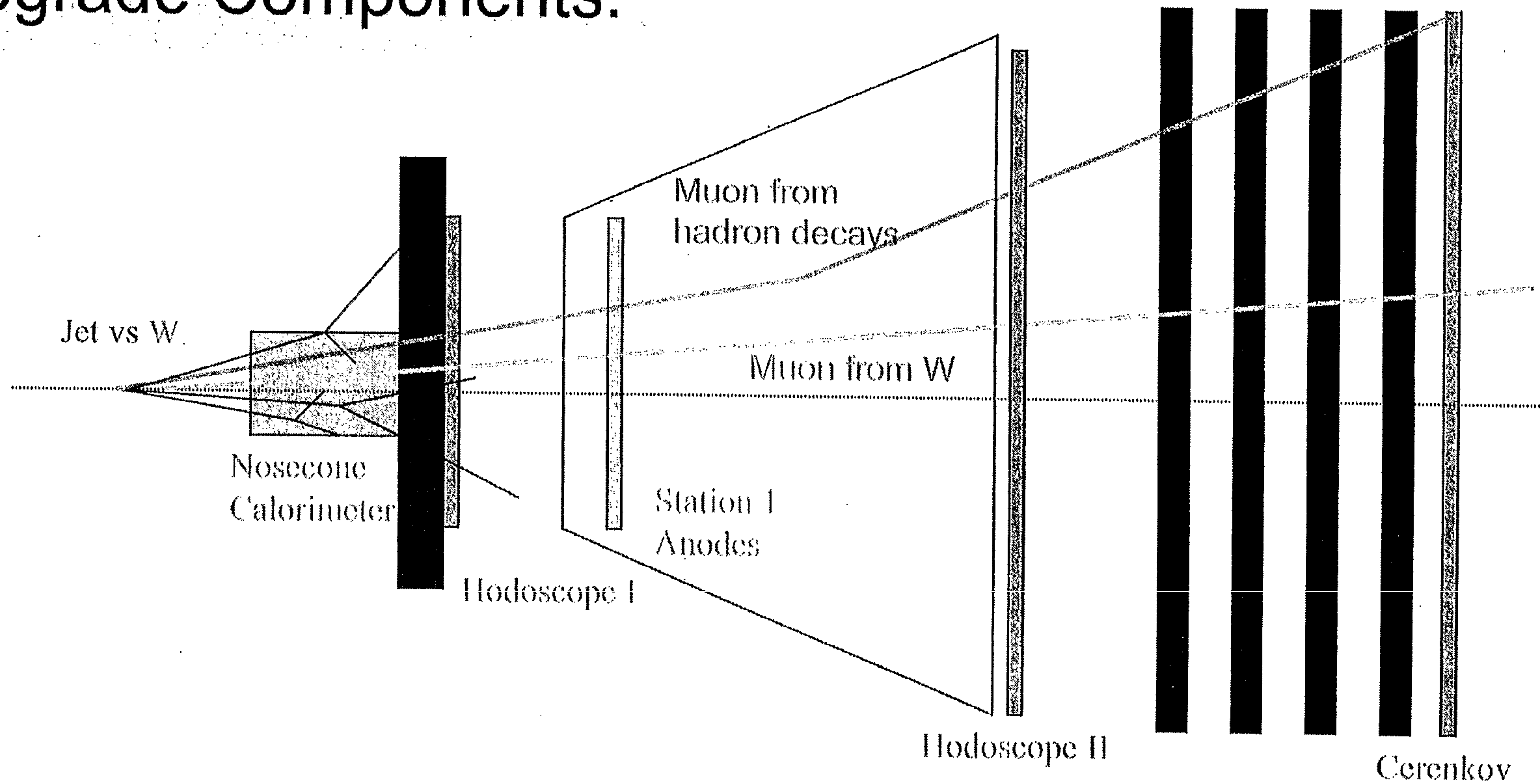
- o Survey the dependence of nucleon structure on the nuclear environment.
- o Search for gluon saturation at small x: 10-3<x<10-2
- o Survey initial state for HI high pT physics.

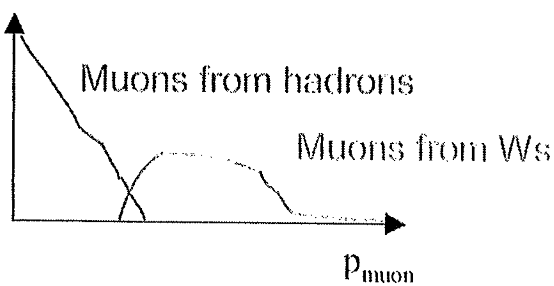
Υ Level 1 trigger in AA

Study color screening effects associated with QGP production in Υ quarkonium states:

The seperation of the Υ(1S) state from the Υ(2S) and Υ(3S) states requires good invariant mass resolution (100MeV) and requires long runs at as high as possible integrated luminosity.

Upgrade Components:





Nosecone calorimeter	-> dA: low x, pp: W-tag, b-tag
mu Tr anodes+uID	-> high mass di-lepton trigger for AA
hodoscopes+uID	-> pp: W-tag
Cerenkov+uID	-> AA: Υ trigger, beam gas rejection pp: W-tag

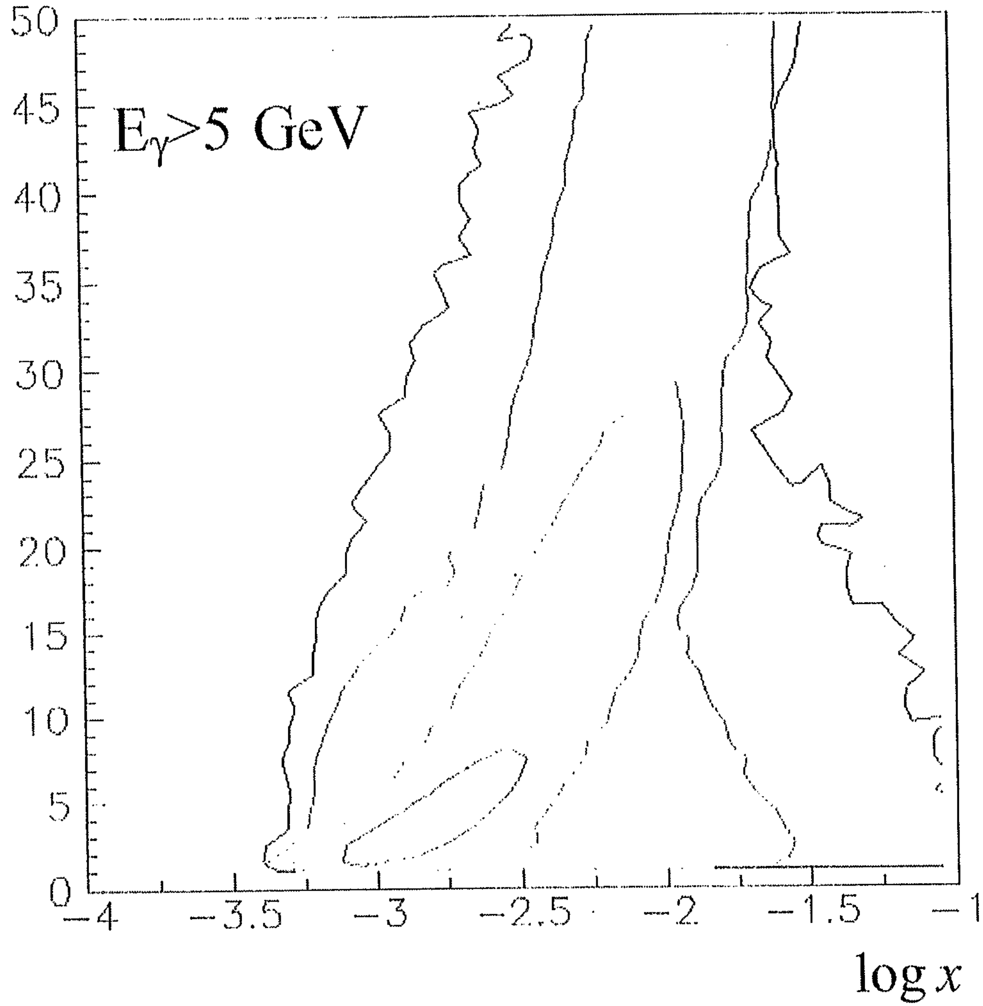
Example: N-EMC, kinematic coverage

More than 100 events
in bin width Δlogx=0.1

More than 10^3 events
in bin width Δlogx=0.1

More than 10^4 events
in bin width Δlogx=0.1

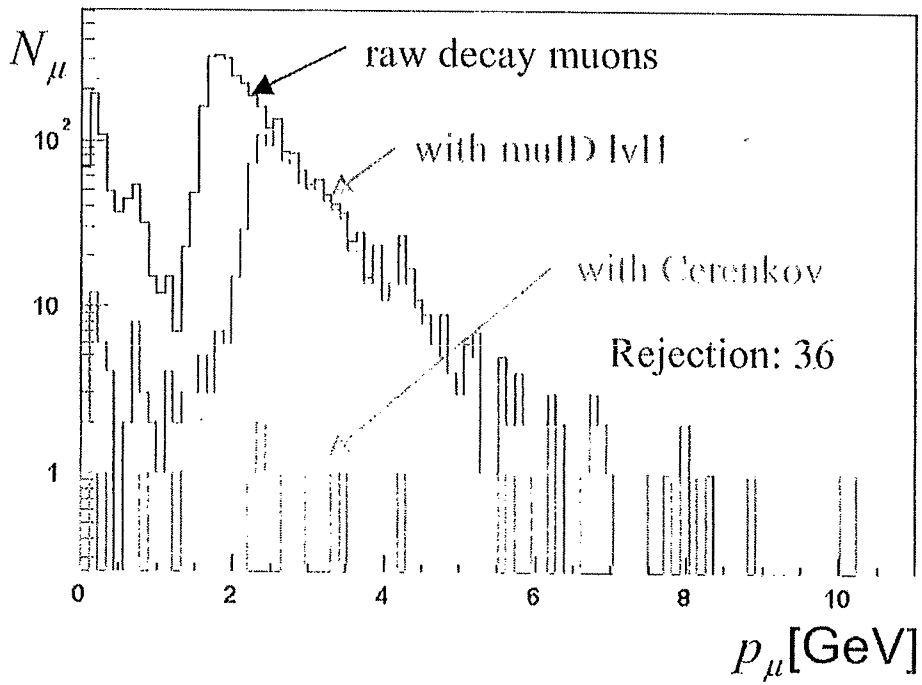
More than 10^5 events
in bin width Δlogx=0.1



Pythia simulation by Rich Seto

Example: Single Muon Trigger Rejection

Level 1 Threshold: Cerenkov + muID Road



Pythia and PISA simulation by Greg ver Steeg and Jennifer Hom

Plans:

(1) Staged approach: a) first 500 GeV run in 2004 : hodoscopes
b) max. Luminosity in 2006: full upgrade

(2) Maximal scope:
a) new LL1/L1.5 electronics
b) two tracking hodoscopes
c) instrument MuTr anodes
c) segmented nosecone calorimeter
d) Cerenkov

(3) Interested groups:
- o RBRC (B. Fox, A. Deshpande)
- o Kyoto (N. Saito+students)
- o RIKEN (A. Taketani)
- o Columbia (C. Chi)
- o UCR (K. Barish, R. Seto,1 postdoc + 1 summer student, shops)
- o UIUC (JCP, MGP + 1 post doc + 1 student, support from NPL)
- o Iowa (J. Lajoie , J. Hill+ 1 student, 2 engineers)
- o Ecole Polytechnique (M. Gonin, 2-3 engineers)
- o UNM (D. Fields+students, shop)
- o BNL (E. Kistenev)

(4) Funding: a) UIUC NSF + startup ($120k + $80k)
b) Kyoto (requested $300k)
c) RIKEN/RBRC ?
d) IN2P3 ?
b) NSF MRI grant: Consortium of UIUC, ISU and UCR ?

Spin Dependent Fragmentation Functions from Belle

Belle:

8GeV+3.5GeV
94/fb: 10^8 hadronic events

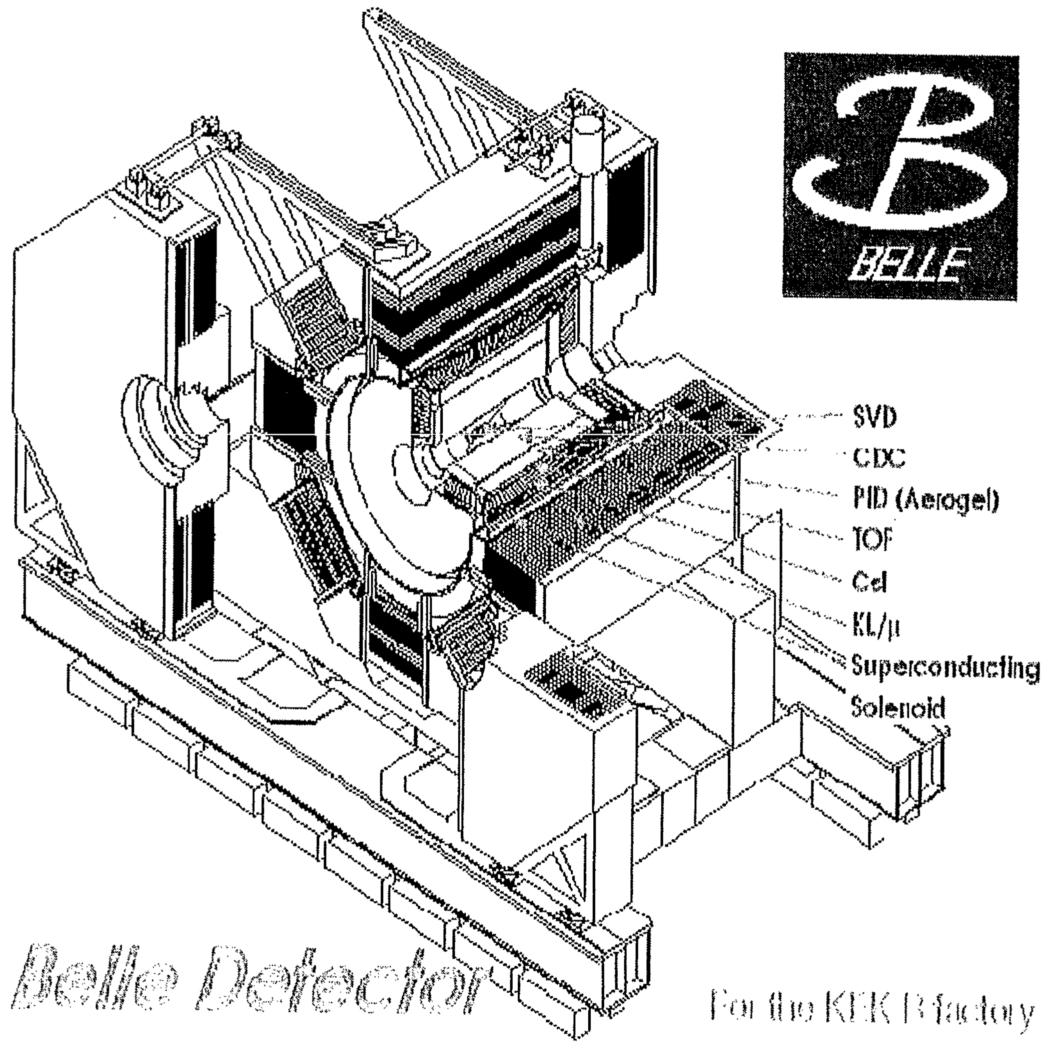
Almost hermetic collider detector with good PID: Measure FF to high z

Use 2-jet events to extract Observables: $H(z_1)*H(z_2)$

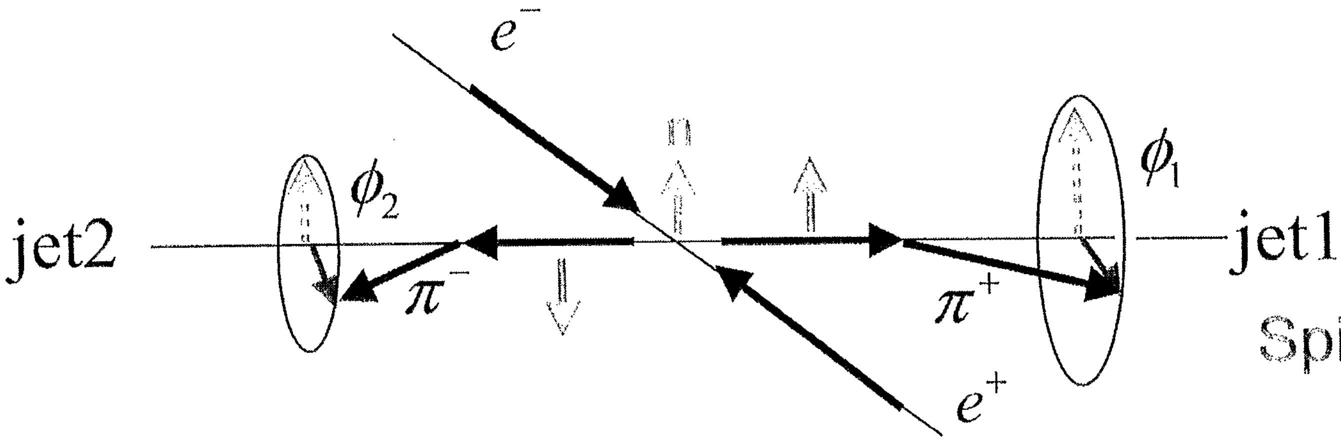
Scale s^2~100 GeV high enough to apply pQCD frame work
Avoid Z-interference

Analyzing power 4 larger than at LEP

Statistics 30 times larger than LEF



$$e^+e^- \rightarrow (\pi^+)_{jet1}(\pi^-)_{jet2}X$$



Spin of quarks are correlated!

$$A \propto H(z_1)H(z_2)\cos(\phi_1 + \phi_2)$$

Extracting the Collins Function

RBRC Activities in Belle

FF analysis

(Kazumi Hasuko, Viktor Siegle,
Akio Ogawa, Soeren Lange, MGP)

- o identify 2 jet events
- o charm suppression
- o study "hadron cuts":
- o reproduce spin average FF for charged hadrons
- o first look at asymmetries
- o expect first results on Collins FF next spring.

SVD-DAQ

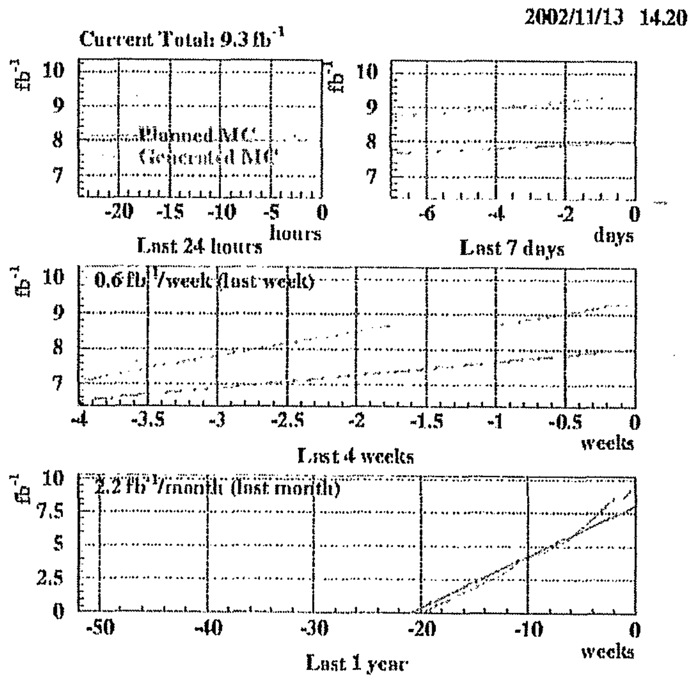
(Kazumi Hasuko)

Communication between Vienna FADC boards and commercial PCI based FPGA card.

MC-production

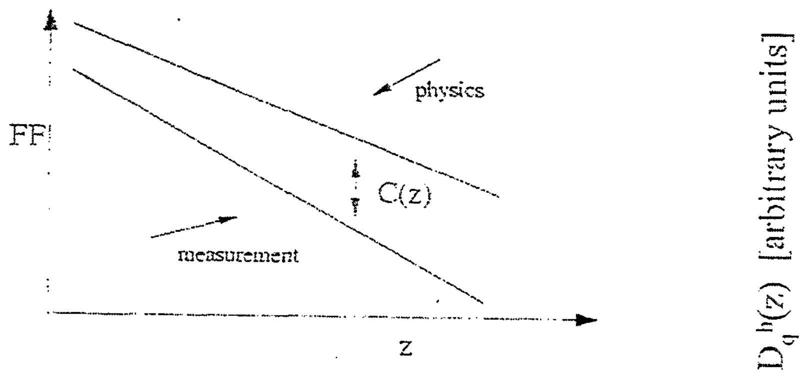
(Kazumi Hasuko, Viktor Siegle)

Total MC: 9.3fb^{-1}



Obtaining spinaveraged FFs

experiment: $\frac{d\sigma^h}{dz \cdot \sigma_{tot}} = \frac{dN^h}{dz \cdot N^h_{tot}} \cdot C(z)$



1. obtain $C(z)$ (hadronic efficiency&acceptance) from MC ($\frac{\#reconstructed}{\#generated}$)

2. obtain $\frac{dN^h}{dzN^h_{tot}}$ from data

3. correct sprectrum

November 21, 2002

Conclusions

PHENIX trigger development towards high pp luminosity continues:

- EMC-RICH to be completed in 2003
- Muon trigger upgrade to start in 2003

Belle FF analysis has started in the summer

- MC + MVD DAQ work are going well
- Reproduce spin averaged results
- First Results on Collins FF in spring 2003

Level 1 Triggering for the PHENIX Central Arms

Kensuke Okada

Level 1 Triggering for the PHENIX Central Arms

Kensuke Okada
(RIKEN Wako, Saitama, Japan)

EMCal-RICH trigger

Trigger for
high pT γs
$h^{\pm}$s
electrons

Physics

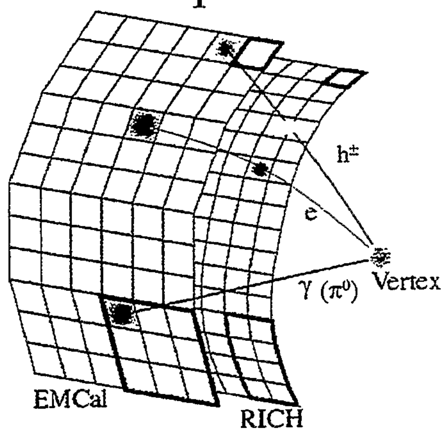
- ΔG from A_{LL} (of direct γ, $\pi^0 \to 2\gamma, h^{\pm}$)
- Δq/q with W production asymmetry (W→eν)
- ΔG from charm production asymmetry(charm→eνX)
- pQCD test through A_N ($\pi^0 \to 2\gamma, h^{\pm}$)
- Comparison data for Heavy Ion collision ($\pi^0 \to 2\gamma, h^{\pm}$, J/ψ →ee)

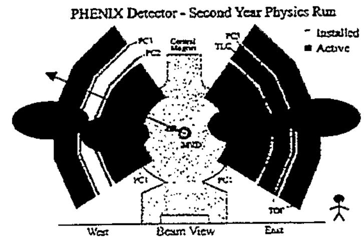
pp run in run2
('01Dec~'02Jan)

Rejection power requirement in run2

averaged trigger rate : ~20kHz (max 75kHz)
DAQ bandwidth : ~1kHz (200Hz assigned to this trigger)
→ factor 100 was needed

Concept of EMCal-RICH trigger

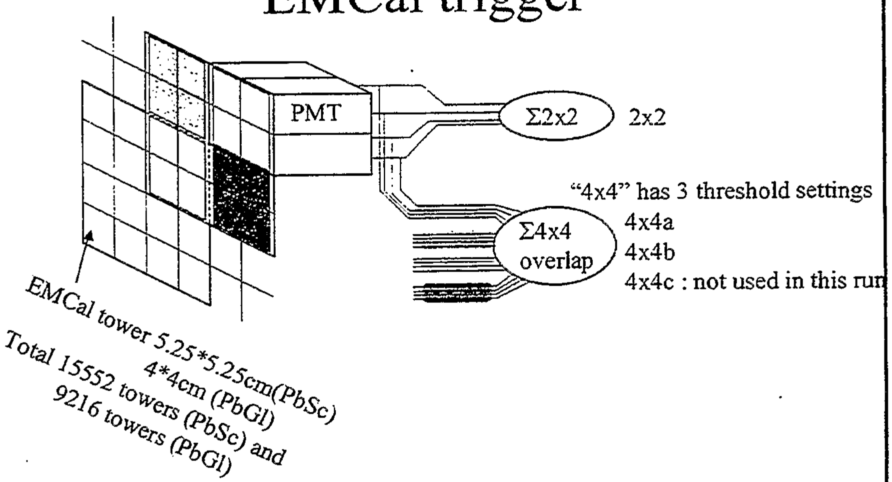




PHENIX central arm
2 types of EMCal (PbSc, PbGl)

$\gamma(\pi^0)$: EMCal
Electron : EMCal and RICH
$h^{\pm}$: EMCal and RICH (through hadronic interactions)

EMCal trigger

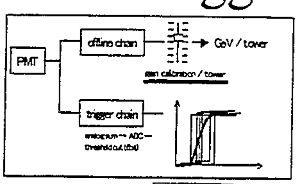


Trigger Performance Check

- Live channel ratio
  = ~75% due to hot channel mask

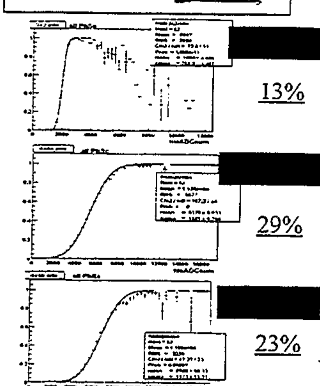
◆ Turn on curve
  (important for the rejection power)

Trigger Turn On Curve



Width= A ⊙ B
A: PMT gain variation = **18%** for PbSc
B: Trigger circuit "noise"

B

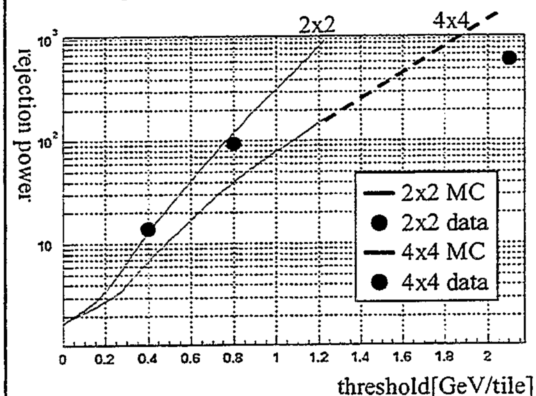


13% ⟶ Comparable to the gain variance

29%
23%
} ⟶ Dominant source of turn on width

Rejection Power of EMCal Trigger

compared to the MC simulation with sharp turn on.

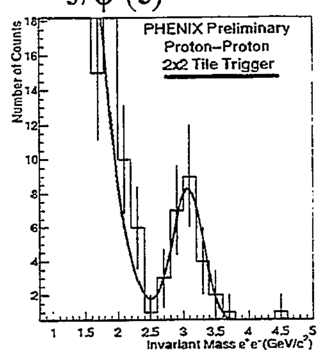


4x4 has low rejection power than expectation because of wide turn on curve.

Profits in Various Channels

from EMCal 2x2 trigger
~40nb^{-1}

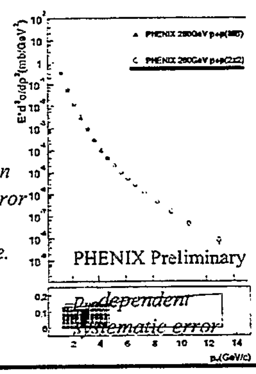
J/ψ (e)



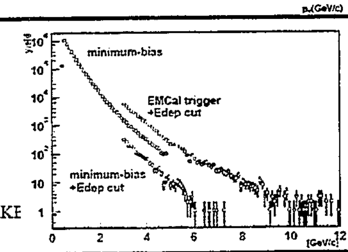
• Mass(ee)

π^0 (γ)

Normalization systematic error 30% is not included here.



h±



Summary

EMCal-RICH trigger was newly installed at PHENIX RUN2.

EMCal trigger

~75% worked properly

Turn on curve width came from PMT gain variance and trigger circuit.

Physics results on π^0, $h^{\pm}$, J/ψ, etc

RICH trigger

~15% of RICH trigger units worked properly.

For the next run (RUN3 January,2003) :

Luminosity : ~20× RUN2

DAQ ability : ~5×

We will be in severer condition.

- raise the live channel ratio (RICH part is already solved the problem. EMCal will be improved by some card replacements.)
- EMCal-RICH coincidence
- reduce the turn on width

RBRC Review Nov 21,2002 Kensuke Okada (RIKEN) 9

π^0 and ET Measurements at PHENIX

Alexander Bazilevsky

π^0 and E_T Measurements at PHENIX

Alexander Bazilevsky

RBRC Scientific Review Committee Meeting
November 21-22, 2001

Run-2 results

Polarized p-p at $\sqrt{s_{NN}}$=200 GeV

- π^0 cross section
  Provides a testing ground for pQCD
  Data baseline for heavy ion physics
- π^0 transverse asymmetry (A_N)
  Coming soon

Au-Au at $\sqrt{s_{NN}}$=200 GeV and 19 GeV
(and at $\sqrt{s_{NN}}$=130 GeV in Run-1)

- Energy density
  $dE_t/d\eta$
- Transverse energy scaling
  $dE_t/d\eta$ and $\langle E_t\rangle/\langle N_{ch}\rangle$ vs $\sqrt{s}$ and N_{part}

PHENIX Detector

PHENIX: Heavy Ion + Spin Programs

[illegible]

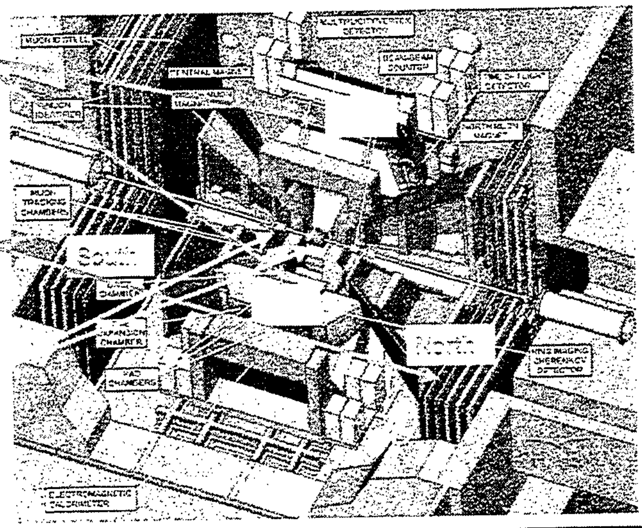
[illegible] and Spectrometers

[illegible]

Muon Tracking and Identification

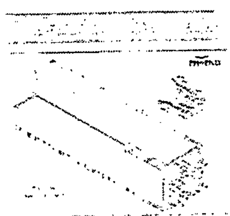
Global Detectors

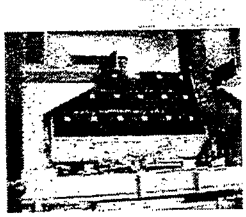
- Beam Beam Counter
- Zero Degree Calorimeter
- Multiplicity and Vertex Detector



PHENIX EMCal

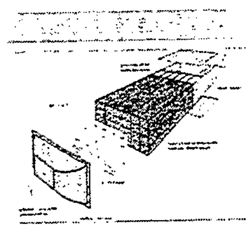
Basic device for π^0 and E_T measurements in PHENIX

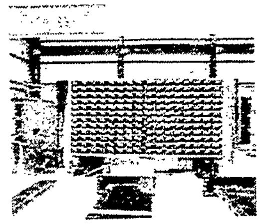




6 PbSc sectors (15,552 channels)
2 PbGl sectors (9,216 channels)
$\eta = \pm 0.38$ $\Delta\phi = 180°$

Granularity ($\delta\eta \times \delta\phi$)	
0.011×0.011	0.008×0.008
Energy resolution (%)	
$8.2/\sqrt{E} \oplus 2.1$	$5.8/\sqrt{E} \oplus 1$
Position resolution, orthog. imp. (mm)	
$5.9/\sqrt{E} + 1.4$	$\approx 6/\sqrt{E}$

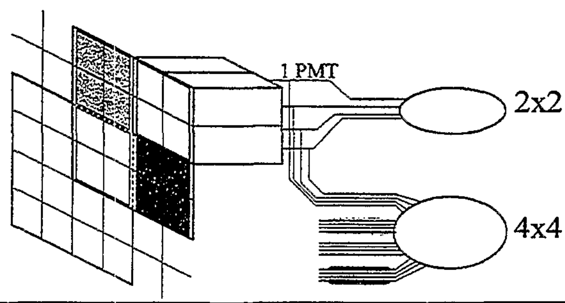




High p_t Photon Trigger

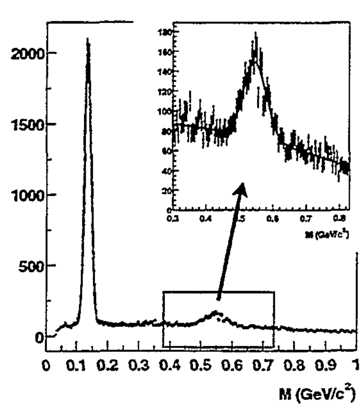
See talk by Kensuke Okada

- EMCal has two sums to collect photon shower
  - 2x2 towers non-overlapping sum (threshold at 0.8 GeV)
  - 4x4 towers overlapping sum (thresholds at 2 and 3 GeV)
- π^0 measurement w/**2x2 trigger** is shown in this talk
  - Enhances high-p_T π^0 by a factor of 90 over min-bias sample.



π0 Reconstruction in pp

$p_t(\gamma\gamma) > 3.5$ GeV/c



- RHIC run2002 proton-proton run
  - Integrated luminosity 0.15pb-1
  - Analyzed luminosity 0.03pb-1
    - half of runs are analyzed.
    - Vertex position cut +/-30cm
    - Sample Size: 140M events
- Analysis
  - 5 EMCal sectors (of 8) are used in this analysis
    - 1 PbSc needs fine tuning of calibration
    - 2 PbGl results coming soon

π0 Cross Section Measurements

$$\varepsilon^{(MB)}$$ 51%

Minimum Bias(MB) trigger efficiency
(Luminosity normalization)

$$\varepsilon_{\pi 0}^{(MB)}(p_T) = \frac{N_{\pi 0}^{(MB\&4\times4)}}{N_{\pi 0}^{(4\times4)}}$$

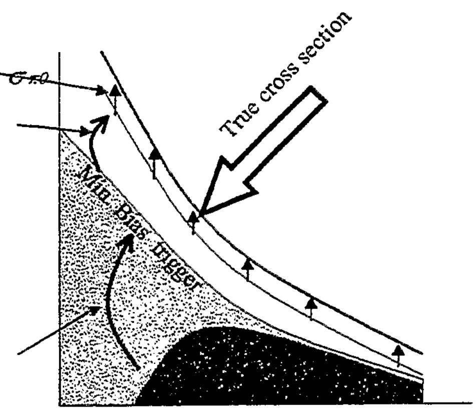
75% flat

π^0 efficiency in Min. Bias trigger
(Slope correction for Min. Bias trigger)

$$\varepsilon_{\pi 0}^{(2\times2)}(p_T) = \frac{N_{\pi 0}^{(2\times2\&MB)}}{N_{\pi 0}^{(MB)}}$$

80%, flat for p_T> 3GeV

π^0 efficiency in 2x2 trigger
("turn-on" curve for trigger)

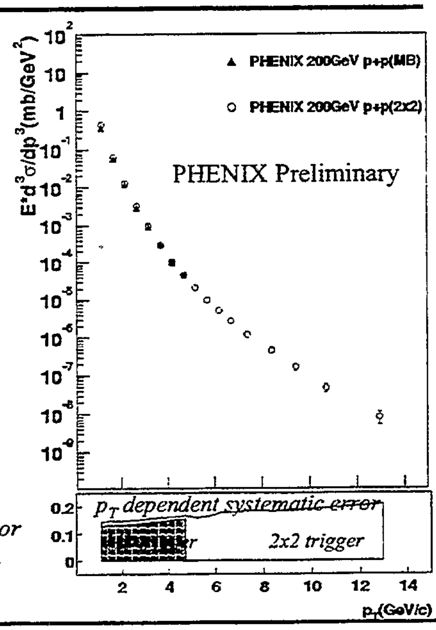


$$N_{\pi 0}^{raw}(p_T) \cdot C_{\pi 0}^{reco}(p_T)$$

Acceptance and efficiency corrections

π0 Cross Section

- Cross section measured over 8 orders of magnitude
  - 1-13GeV/c
- Two triggers
  - Minimum Bias(MB) trigger
  - 2x2 trigger
  - They are consistent within systematic error.

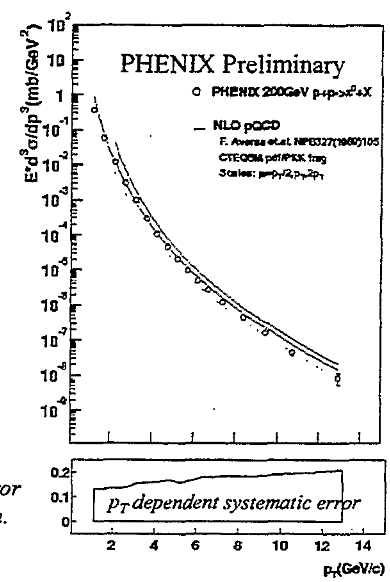


Normalization error of 30% not shown.

π0: Comparison with QCD Calculation

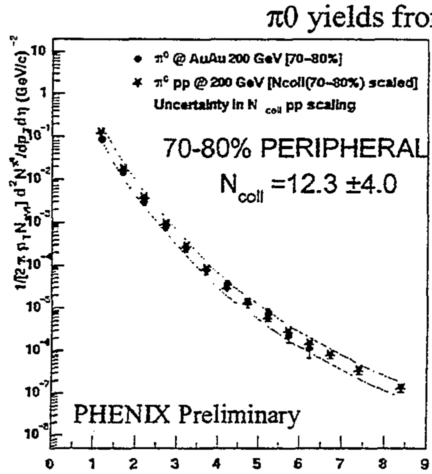
- NLO pQCD calculation
  - CTEQ5M pdf
  - Potter-Kniehl-Kramer fragmentation function
  - $\mu = p_T/2, p_T, 2p_T$
- Consistent with data within the scale dependence.

Normalization error of 30% not shown.

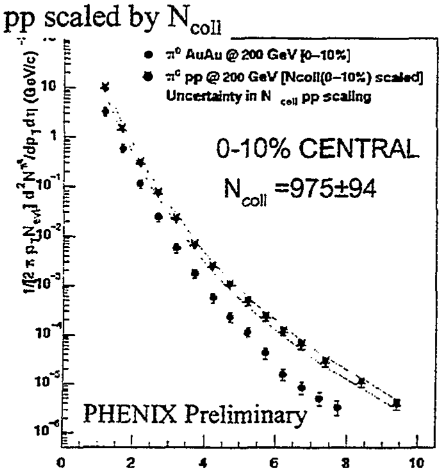


π0: pp vs AuAu (peripheral & central)

π0 yields from pp scaled by N_{coll}



Consistent with N_{coll} scaling



Large suppression (increasing with p_T)

Conclusion: π0 from pp

- π^0 cross section measured
  - ✓ p_t from 1 to 13 GeV/c, 8 orders of magnitude change
  - ✓ results from two triggers (Min. Bias and 2x2) are consistent within systematic error
- Comparison with NLO pQCD calculation
  - ✓ pQCD calculation agree with data
- Comparison to AuAu data
  - ✓ π0 yield in peripheral collisions consistent with N_{coll}-scaled *pp* results
  - ✓ High-p_t π0 strongly suppressed in central collisions compared N_{coll}-scaled *pp* results
- A_N results at low x_F / high p_t coming…
- A_{LL} (ΔG) in Run-3

Transverse Energy Measurements in Au-Au

EMCal is "almost" hadronic calorimeter:

$E_{EMC} = 1.0 \cdot E_{tot}$ for γ, π^0

$E_{EMC} = 0.7 \cdot E_{tot}$ for $\pi^{\pm}$

$E_{EMC} \rightarrow E_T$ transformation:

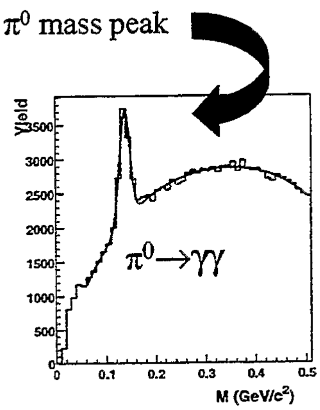
$E_T = 1.23 \cdot E_T^{EMC}$

EMCal absolute energy calibration

MIP (min. ioniz. part.) peak

E/p matching peak for $e^{\pm}$

π^0 mass peak

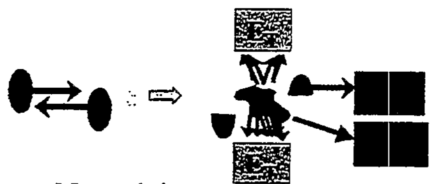


PHENIX

E_T vs Centrality at $\sqrt{s_{NN}}$=200 GeV

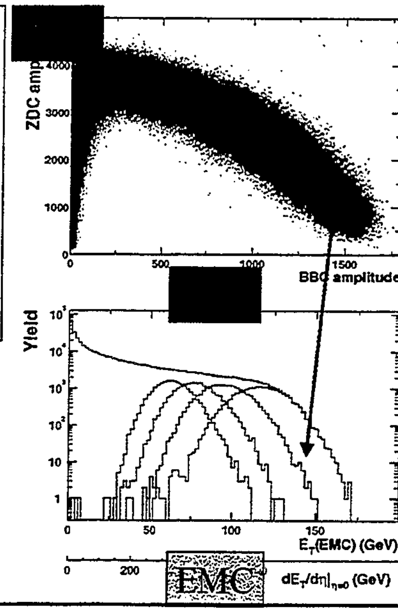
Define centrality classes

Zero Degree Cal. vs Beam Beam Counter



Extract N participants

Glauber model

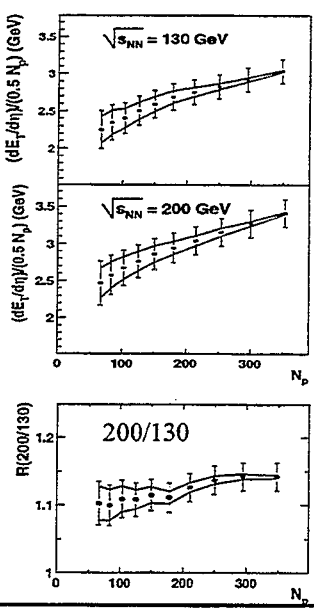


Energy density (Bjorken): $\varepsilon = \frac{1}{\pi R^2 \tau} \frac{dE_t}{dy}$

2% of most central collisions:

$\varepsilon \sim$ 5.5 GeV/fm³ ~1.9×CERN

E_T: $\sqrt{s_{NN}}$= 200 GeV vs 130 GeV



Fit: $dE_T/d\eta \propto N_{part}^{\alpha}$:

WA98 at $\sqrt{s_{NN}}$=17.2 GeV: α=1.08±0.06

PHENIX at $\sqrt{s_{NN}}$=130 GeV: α=1.18±0.05

PHENIX at $\sqrt{s_{NN}}$=200 GeV: α=1.19±0.05

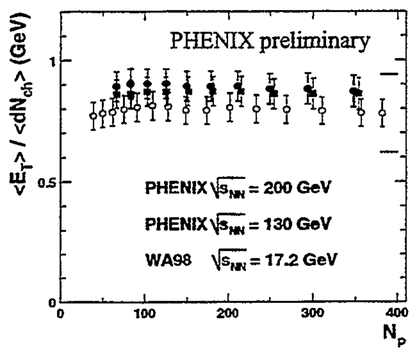
$dE_t/d\eta$ per participant increases with centrality, the increase is stronger than at SPS

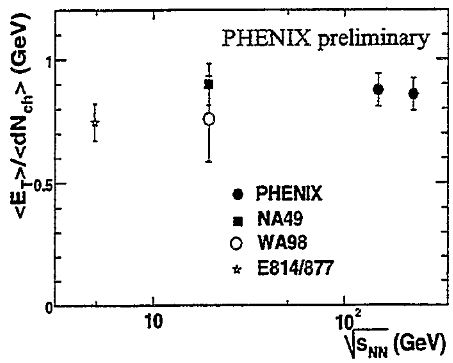
For the most central collisions:

$$\frac{E_T(200GeV)}{E_T(130GeV)} = 1.14 \pm 0.02$$

The ratio R(200/130) consistent with constant scaling vs N_{part}

$\langle E_T \rangle / \langle N_{ch} \rangle$





Independent from centrality

Independent from energy

Conclusion: E_T from AuAu

- Centrality dependence of particle $dE_T/d\eta$ have been measured at $\sqrt{s_{NN}}$ = 130 GeV and 200 GeV in Au+Au collisions
  - ✓ $\sqrt{s_{NN}}$ = 19 GeV results coming…
- $dE_t/d\eta$ per participant increase with centrality:
  - ✓ the increase is stronger than at SPS
- $\langle dE_T \rangle / \langle dN_{ch} \rangle$ is near independent of centrality and of $\sqrt{s_{NN}}$
- The ratio R(200/130) consistent with constant scaling vs N_{part}

Charged Particle Measurements at PHENIX

Federica Messer

Charged particle measurement in Phenix

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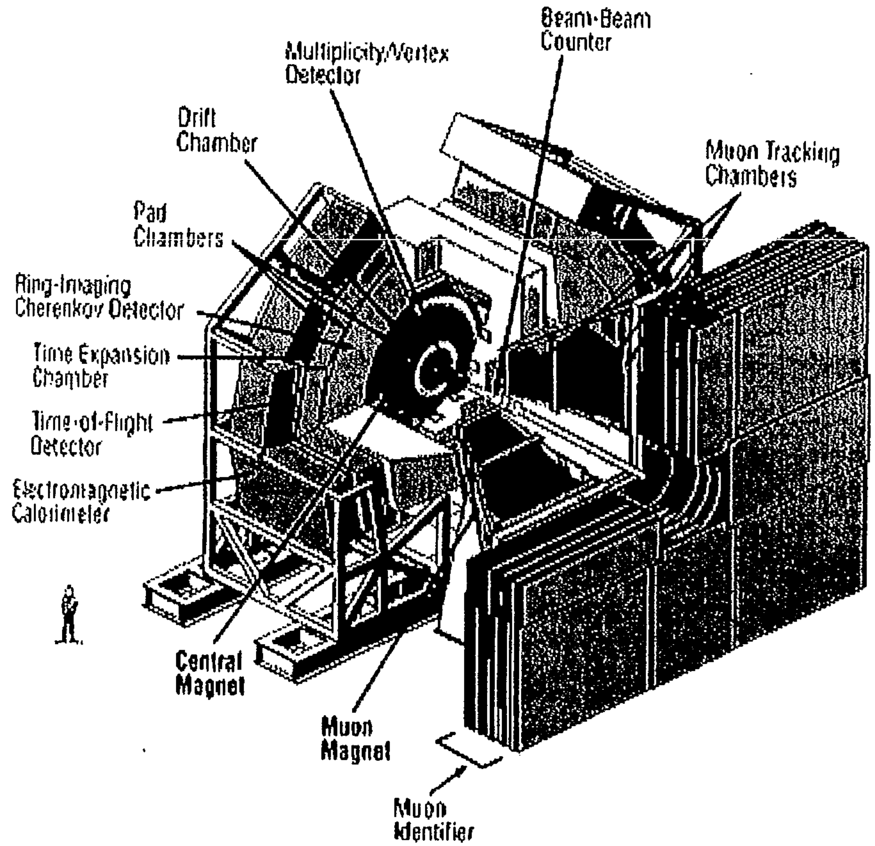
Experimental setup

- Complex multi-purpose experiment
  - 2 central arms
    - 0.7 units of pseudorapidity
    - 2x90 degree in phi
  - 2 muon arms
    - For- and back-ward rapid.
- Tracking performed outside the field by 2 drift chambers at 2m from vertex
- Good momentum resolution: ~1% p[GeV/c] in the high momentum limit

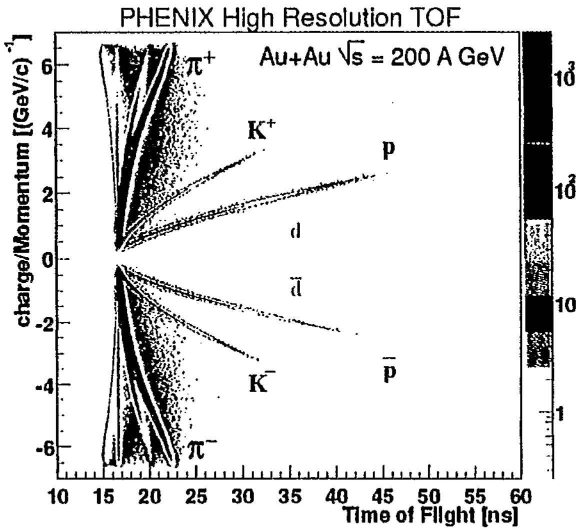


Particle identification

PHENIX has excellent PID capability:

- TOF : 110 ps time resolution
- EMC : 450 ps

- Allow to separate pion/kaons up to 2GeV/c and proton/kaon up to 4.5GeV



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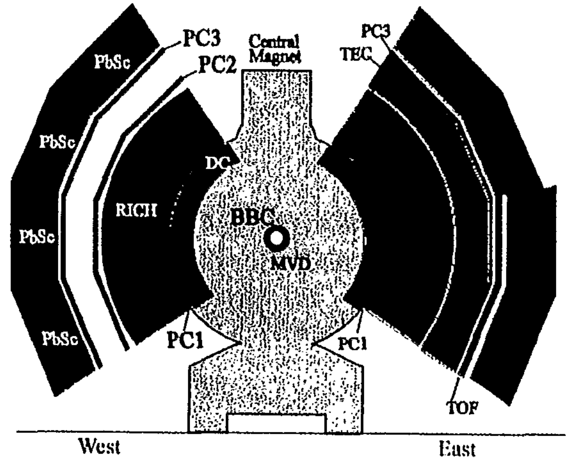
- 2 RICH detectors:
  - Mainly to perform electron/positron identification
  - Above p = 4.7 GeV/c, pions emit Cherenkov light
    - Identify charged pions over a wide range 5 to 15GeV/c (kaon threshold)
    - Granularity not good enough to reconstruct rings

Background

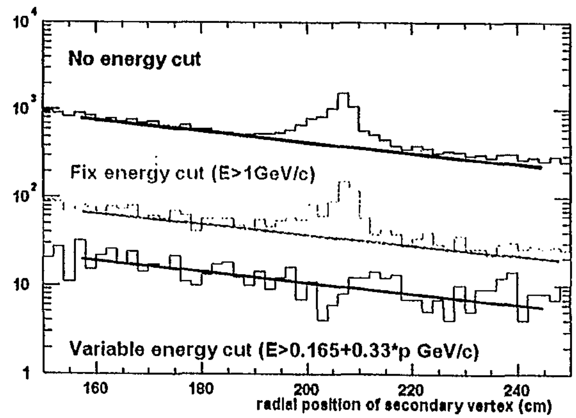


PHENIX background

- Since we track outside the field:
  - Momentum is represented by the angle of the track in respect to a trajectory coming from the vertex
  - All particle decays and photon conversions that happen just in front of the DC (small residual field) suffer a small deflection
  - Reconstructed as “fake” high momentum tracks.

Solution:

- Use the small residual field bending and
- Outer detectors (PC3 at ~5m) match
  - Up to 6 GeV on a track by track basis
  - Above 6 GeV to 10 GeV on a statistical basis.
- Use deposited energy in EMC

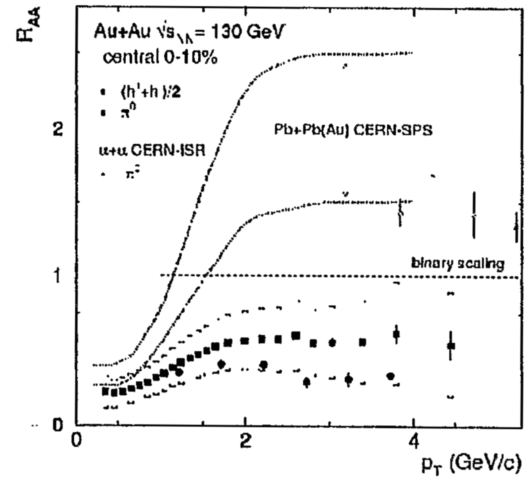


Not just talking …

Run 1:

Heavy Ion at 130GeV/c:

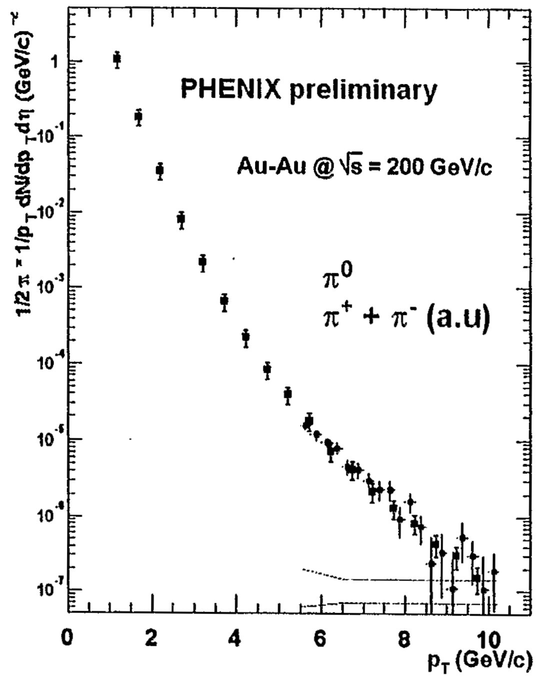
- Pioneered the charged particle analysis
- Developed tools and standards
  - QM01 talk and 2 papers :
    - * Suppression of hadron in central collisions (PRL)
    - * Centrality evolution of cross-section and suppression (server)
- Transfer of "know-how" to students



Run 2 :

Heavy Ion (still in S.B.) at 200 GeV/c:

- Charged particle analysis performed under my supervision by a Stony Brook student (J.Jia at QM02)
  - A paper is in preparation
- Pioneered the charged pion analysis at high transverse momentum using the PHENIX RICH.
  - Developed new tools to fight background (EMC)
  - Data presented at QM02



PP at 200 GeV/c :

- helped Kensuke in charged particle anal. (SPIN02)

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What's cooking ?

Last months have seen a lot of activity on data

- Cross-section measurement
  - Near to release the first data after:
    - * finalization of calibrations and corrections
  - fundamental measurement / reference for Heavy Ion (PHENIX)
- Proceed in the transverse asymmetry analysis:
  - Learn and develop the tools and technique for the future
  - Transfer of information and knowledge acquired in the past
  - Understanding of detector asymmetries
  - Heavy software developments needed

- Charged particles, charged pions, etc.. on the TO DO list
  - All depends on statistics
- Develop ideas to fight background on a track by track basis
  - New and simple detector

Soon will be time to eat

A new run is at the door,
we hope to have soon all the tools ready for a fast data analysis.

Students (Kensuke and Frank) and fellows (Brandon,Abhay, Yiji, myself, etc…) shared (and will continue to share) the work on charged particles analysis.

- discussing, suggesting and running code

We are tightly connected with the HI part of PHENIX and it is important to participate actively to analysis meetings and learning as much as possible about the technicality (hardware,software, calibrations, qa) such that the physic results can smoothly follow.

Buon Appetito !!
(Enjoy your lunch)

Polarimetry for RHIC

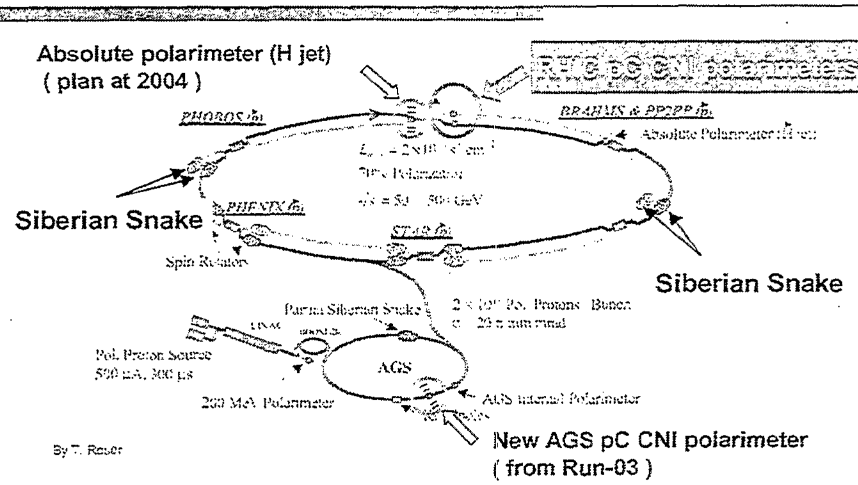
Osamu Jinnouchi

Polarimetry for RHIC

Osamu Jinnouchi, RIKEN

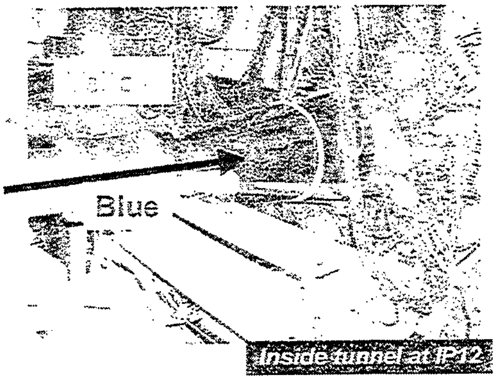
- Introduction
- Digest of the successful Run-02 performance
- Prospects for Run-03 and after

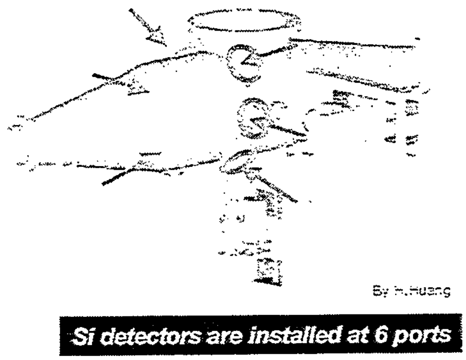
Polarimetry systems over RHIC facility



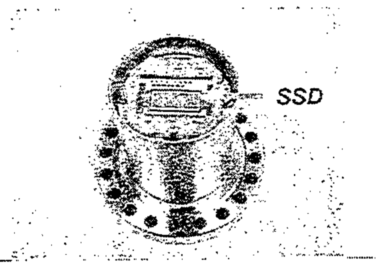
- In polarized proton run, polarimeters serve as,
  - Fast polarization monitor for accelerator
  - Primary polarimeter to normalize the physics asymmetries at experiments
- Fast (<1min) and reliable measurements are required

RHIC CNI polarimeter setup



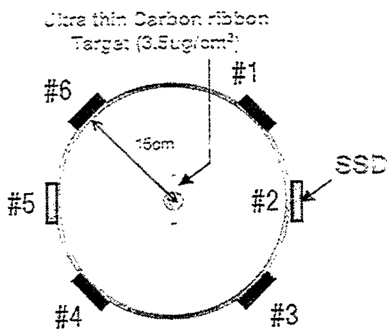


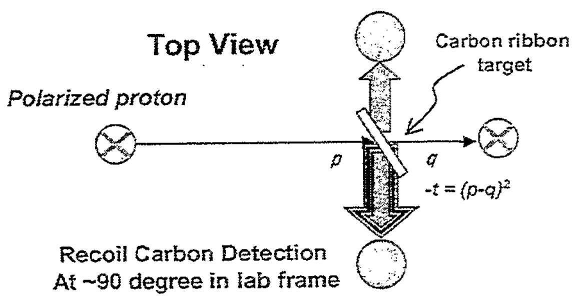
- Successful commissioning in Sep.2000
- Started operation on both rings from Run-02
- Silicon strip detectors (SSD) are installed at 6 ports on the vacuum chamber

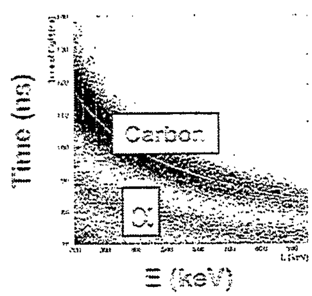


RHIC CNI polarimeter kinematics/setup

- Counting the recoil carbons at 90 degree in lab frame
- Calculate the left-right asymmetry of the counts
- Analyzing power is known from an AGS experiment (E950) ~ 1.3%





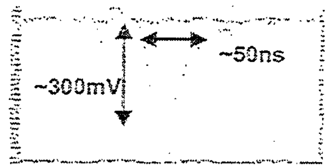


Wave Form Digitizer (WFD)

- New feature used from Run-02
- Dead time less readout system for a very high rate measurement
- Consist of high frequency video ADC chips and Xilinx FPGAs
- Wave form digitization every 2.4ns
- Time of flight and max pulse height are determined in real time
- Carbons are selected with look up memory table on board

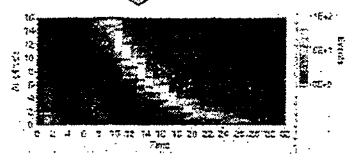
- ***20M events are obtained within 1minute***

Inside FPGA



WFD Signal

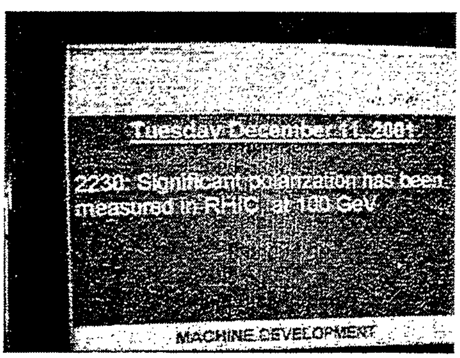
Time of flight (T)
Pulse Height (E)

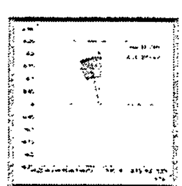


2D Memory map in WFD

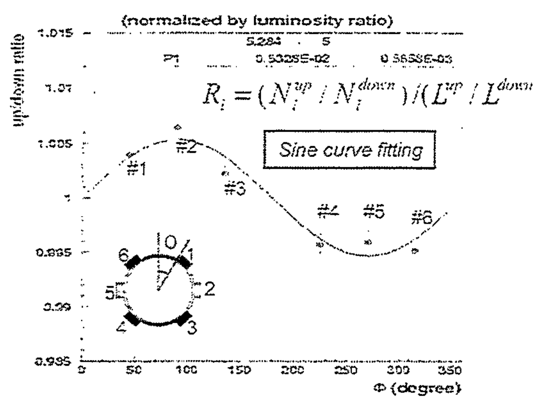
Carbon selection using Look Up Memory Table

First polarization at 100GeV / phi asymmetry



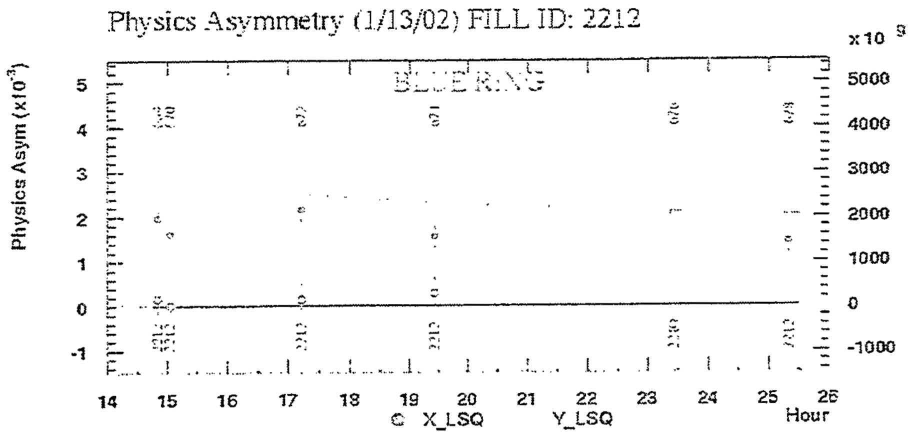


Polarization vectors for 3 successive runs at 100GeV



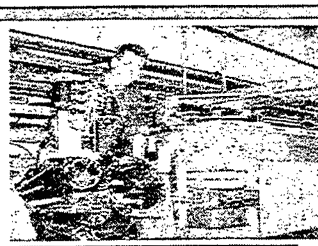
- Up/Down luminosity ratios for six detectors are fit with sine function
- Phi-asymmetry shows the clear angle dependence of analyzing power

Intensity vs. polarization



- X asymmetry (physics) and Y asymmetry (false) are plotted as a function of the beam lifetime
- Measurements are at injection, after acceleration, and two hours each at 100GeV
- Beam Intensity was lost, but the polarization kept stable

Plan for run-03 and after



AGS polarimeter in ring

AGS polarimeter at test bench

- Run-03
  - RHIC Down ramp for an analyzing power calibration at 100 GeV
  - AGS polarimeter for a fast feed-back to AGS operation
  - The first measurement at 250GeV
- After Run-04
  - Absolute calibration using the hydrogen jet target

Jet target design

Summary / Outlook

- RHIC polarimeter worked beautifully during the Run-02
- Two Siberian snakes worked, stable proton polarizations at 100GeV were measured

- Down ramp measurement is the key issue for Run-03
- New polarimeter for AGS, and the hydrogen gas-jet target are coming

Local Polarimetry for PHENIX

Brendan Fox

Measurement of single transverse-spin asymmetries in forward production of photons and neutrons in pp collisions at $\sqrt{s}$=200 GeV

Brendan Fox for the Local Polarimeter Collaboration

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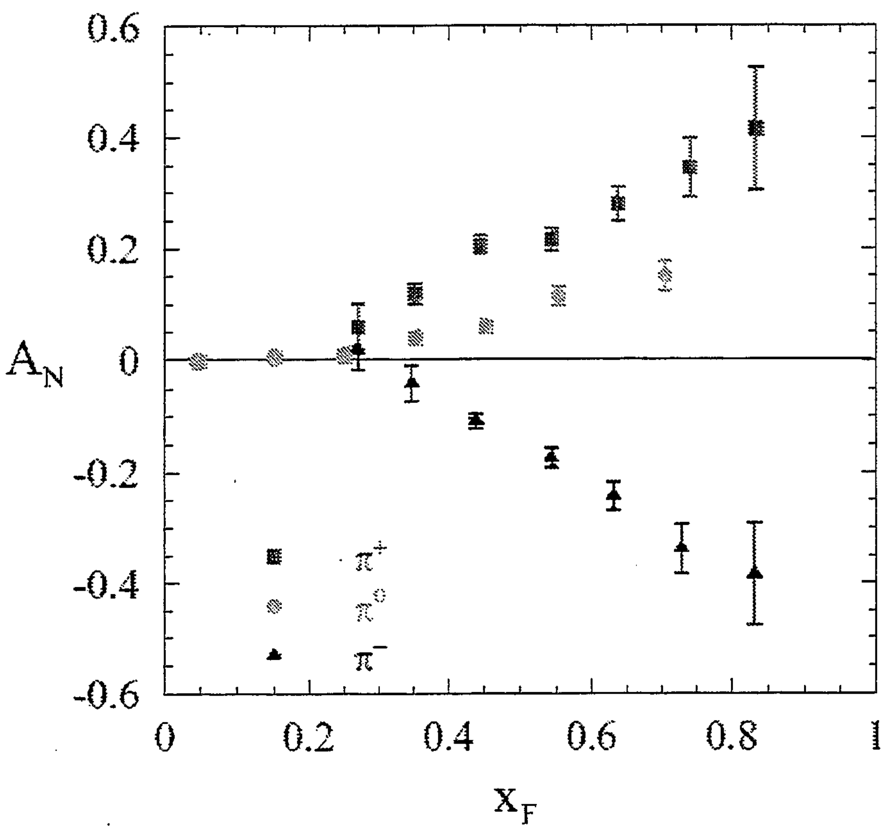
[d] Kyoto University, Kyoto 606-8502, Japan
[e] Los Alamos National Laboratory, Los Alamos, NM 87545
[f] Moscow Engineering Physics Institute (State University Russia)
[g] Institute for High Energy Physics Protovino (Russia)

Introduction

Motivation

Many interesting measurements of single transverse-spin asymmetries especially in forward region in lower energies;...

...would like to see if such effects persists at High Energy $\sqrt{s}$ =200 GeV.



The E704 experiment at Fermilab

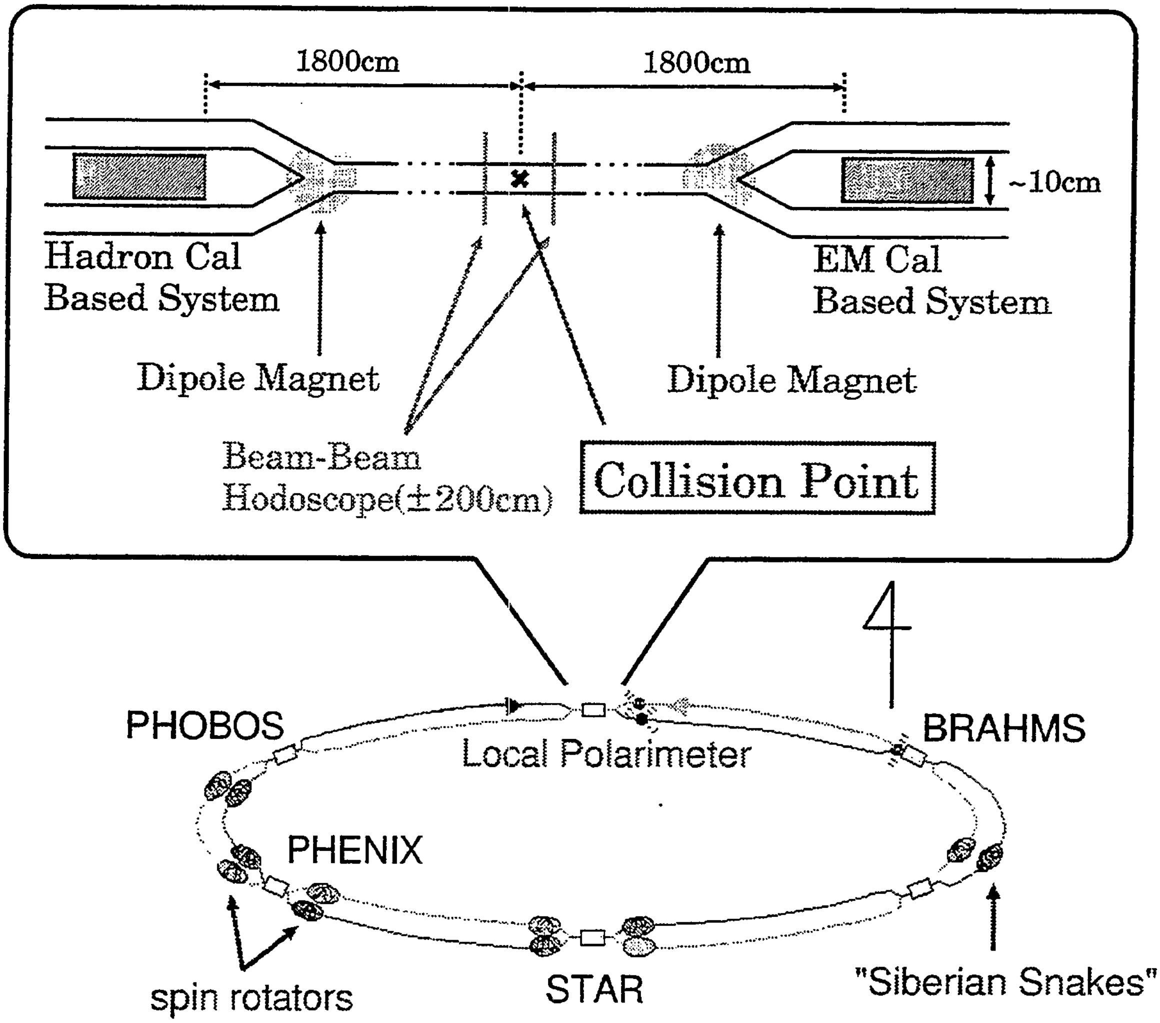
> pp -> $\pi^{\pm 0}$ X

> $\sqrt{s}$ = 19.4GeV

> p_T = 0.2~2.0 GeV/c

D.L. Adams *et al., Phys. Lett.* **B264** (1991) 462

Experimental Setup



$0<\theta_{Lab}<3$mrad　　$0<p_T<0.3$ GeV/c　　$0<x_F<1$

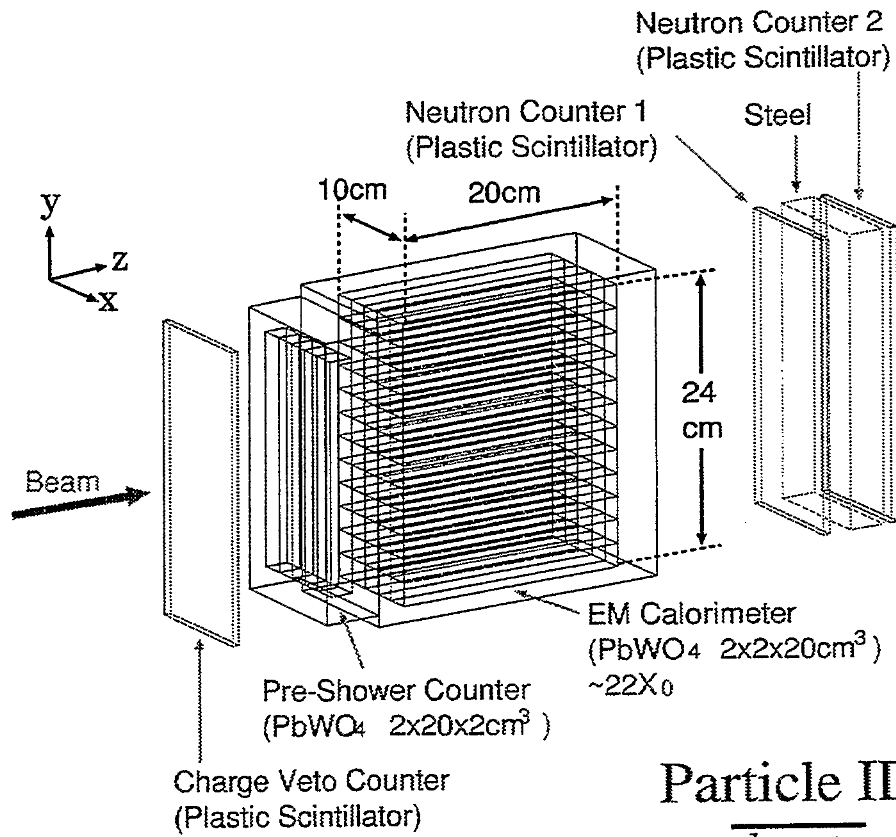
Detect neutral particle in forward region

>EM Cal-Based System —— Photon, π^0, Neutron

>Hadron Cal-Based System– Neutron

>Beam-Beam Hodoscope —— Separate beam collisions from beam gas events.

Experimental Setup
(EM Cal-Based System)



EM Cal Performance

Calibrated with
Beam Test at SLAC

$\Delta E/E \sim 10/\sqrt{E}$ %

noise~1.4GeV

$\Delta x = \Delta y \sim 0.15$cm ($\gamma$)

$\Delta x = \Delta y \sim 0.5$cm (n)
(simulation)

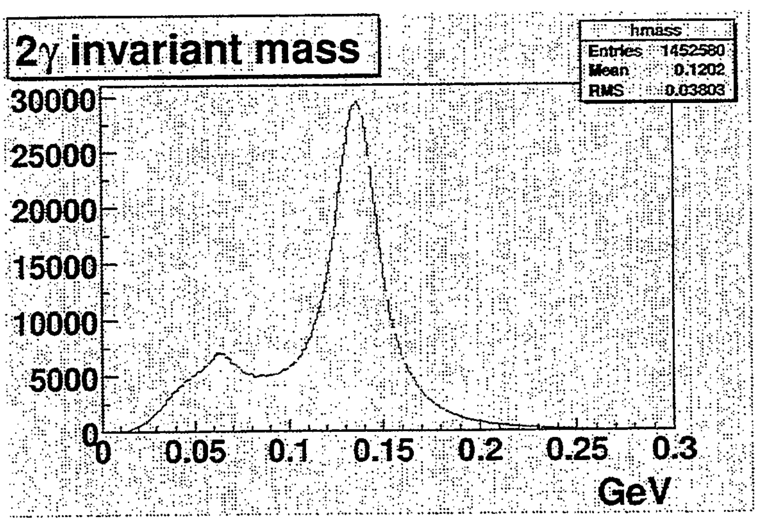
Particle ID Logic

$\gamma = \overline{\text{ch-veto}} \times \overline{\text{n-counter1}} \times \overline{\text{n-counter2}}$

Purity ~ 98%

$n = \overline{\text{ch-veto}} \times \text{n-counter1} \times \text{n-counter2}$

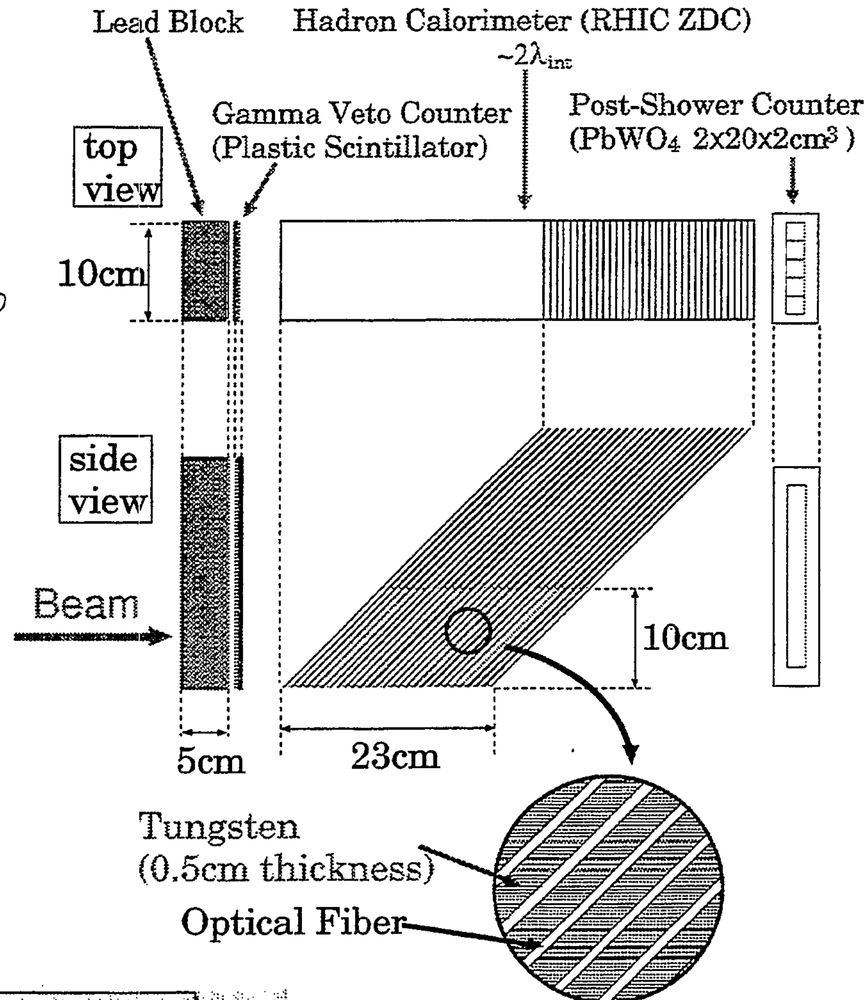
Purity ~ 89%



Succeed in
π^0 Reconstruction

$\Delta M/M = 9.3\%$

Experimental Setup
(Hadron Cal-Based System)



Performance

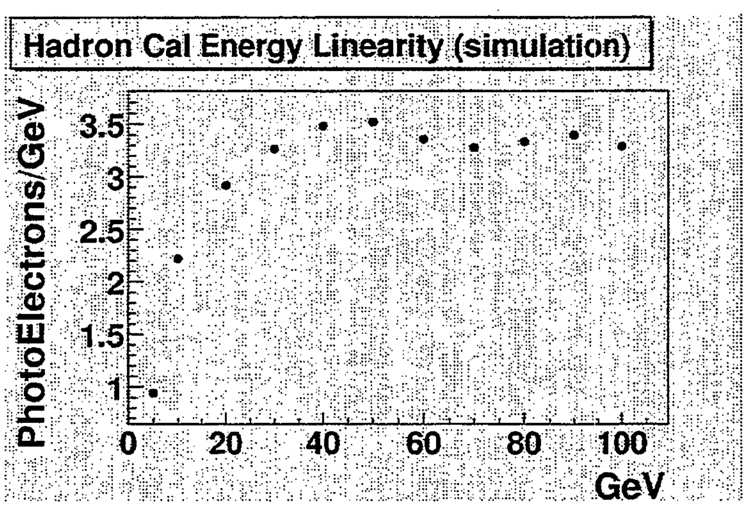
$\Delta E/E \sim 40\%$ to 50% at E>20GeV

$\Delta x \sim 3$ to 4cm (post-shower)

Particle ID

$n = \overline{\gamma\text{-veto}}$

purity~100%



Energy is calibrated by using cosmic-ray test and simulation

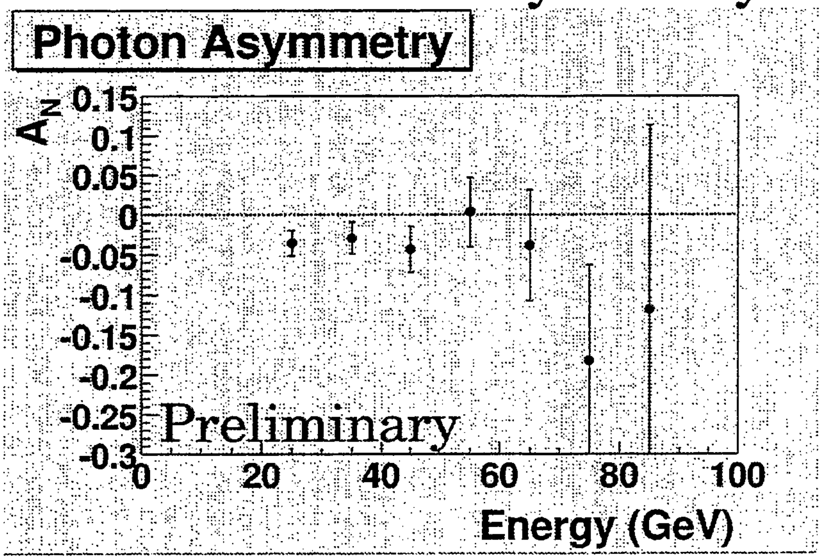
Flat Responce E>20 GeV

π^0 and Inclusive Photon Asymmetry

$$A_N = \frac{1}{P_B}\frac{\sqrt{N_{\uparrow L}N_{\downarrow R}} - \sqrt{N_{\uparrow R}N_{\downarrow L}}}{\sqrt{N_{\uparrow L}N_{\downarrow R}} + \sqrt{N_{\uparrow R}N_{\downarrow L}}}$$

calculated using square root formula

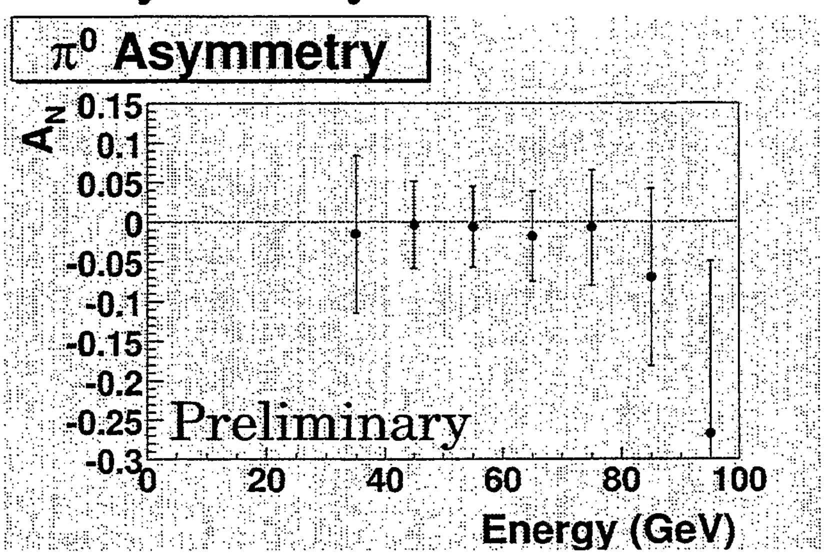
Inclusive Photon Asymmetry



Average beam polarization is
~11% for EM Cal
~18% for Hadron Cal

Analyzing Power is small.

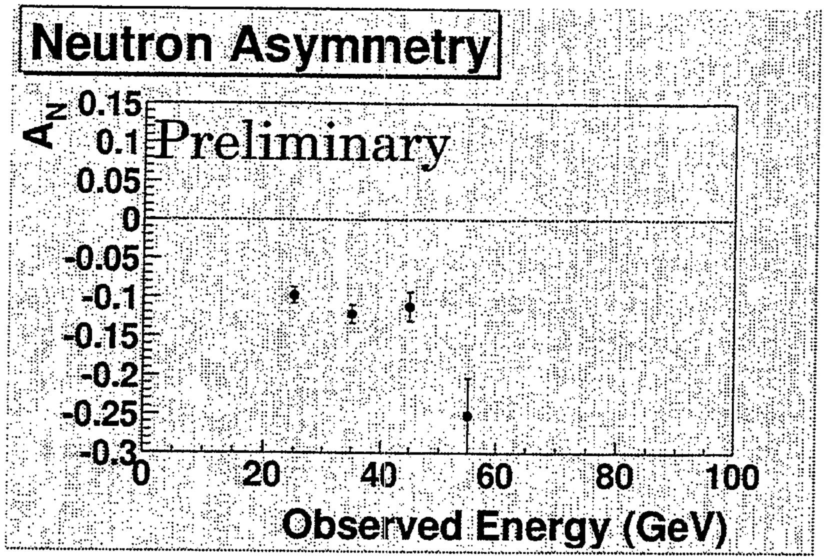
π^0 Asymmetry



Analyzing Power is consistent with 0

Neutron Asymmetry

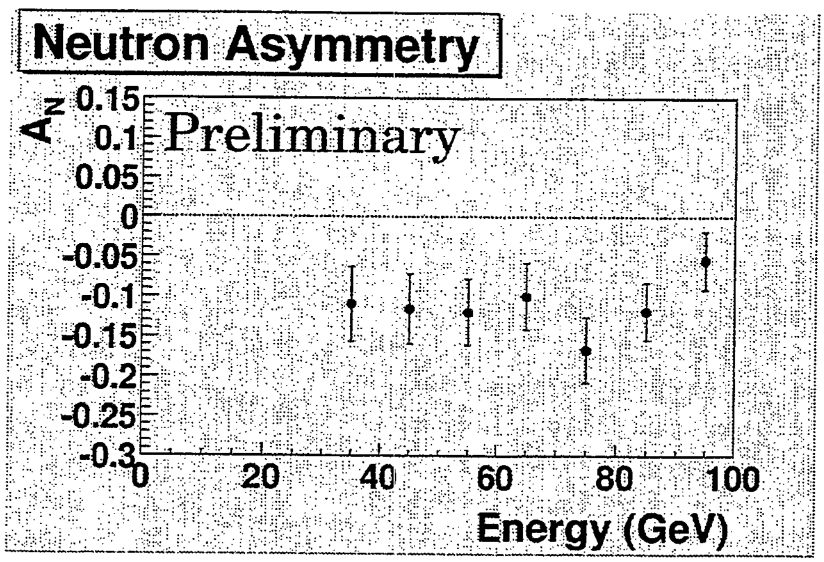
EM Cal



Calibrated for photon only

$\langle A_N \rangle = -0.109 \pm 0.0072$
additional scale error (due to beam pol error)

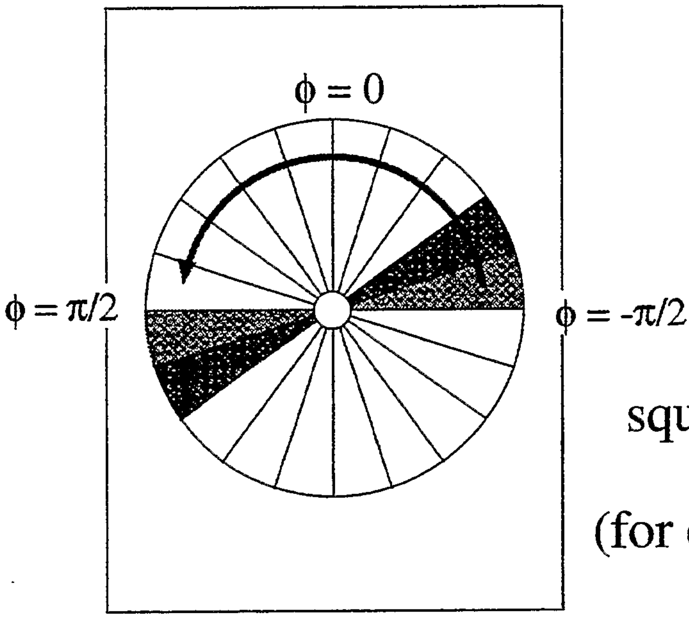
Hadron Cal



$\langle A_N \rangle = -0.110 \pm 0.015$
additional scale error

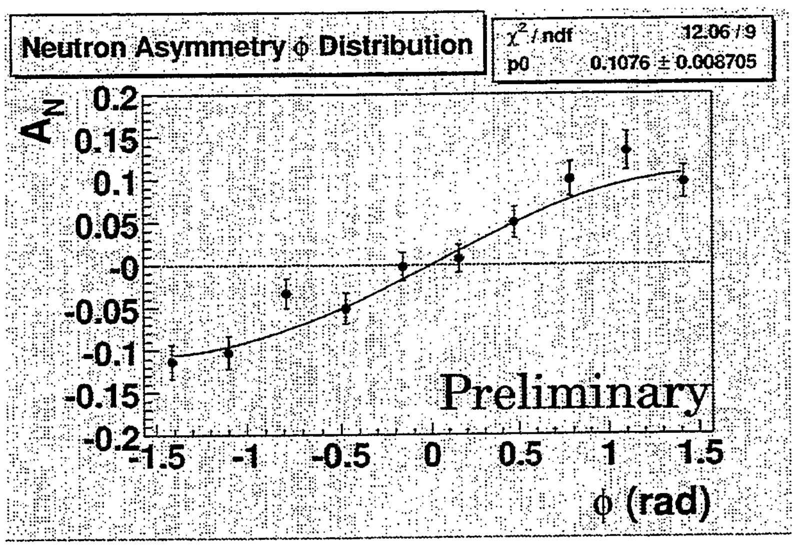
EM Cal and Hadron Cal are consistent

Neutron Asymmetry
ϕ distribution



square root formula is used for ϕ dependent asymmetry (for example red area, blue area)

EM Calorimeter



$\langle A_N \rangle = -0.108 \pm 0.0087$
additional scale-error

ϕ-dependence is consistent with sin ϕ

Summary

1) We measured single transverse-spin asymmetry in forward production of photons and neutrons in $\vec{p}p$ collision at $\sqrt{s} = 200$ GeV.

> π^0 Asymmetry : consistent with 0 within error.

> Inclusive photon Asymmetry : small.

> Neutron Asymmetry : observed and its analyzing power is
-0.109 ± 0.0072 for EM Cal
-0.110 ± 0.015 for Hadron Cal
(additional scale error).

2) Modified Hadron-Cal Based System will be installed at PHENIX Collision Point for Spin Rotater Commissioning.

South Muon Arm Operation in 2001/2 and North Muon Arm Construction

Douglas Fields

PHENIX South Muon Arm Performance and North Muon Arm Status

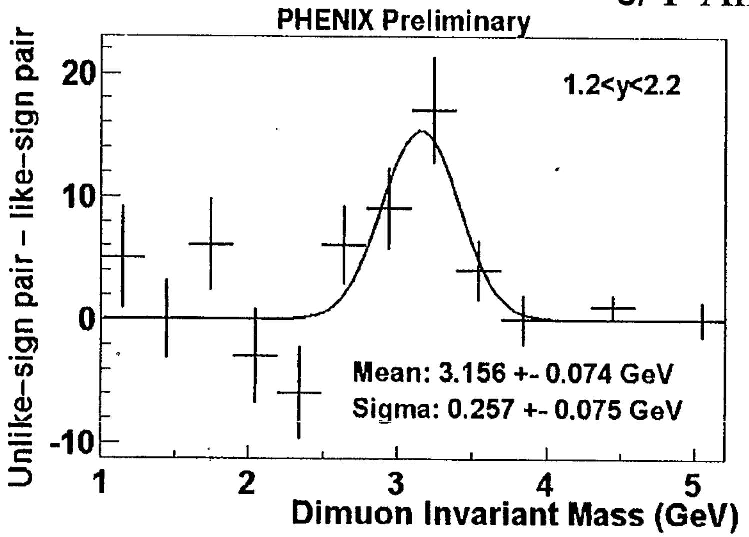
Douglas E. Fields
UNM/RBRC Fellow

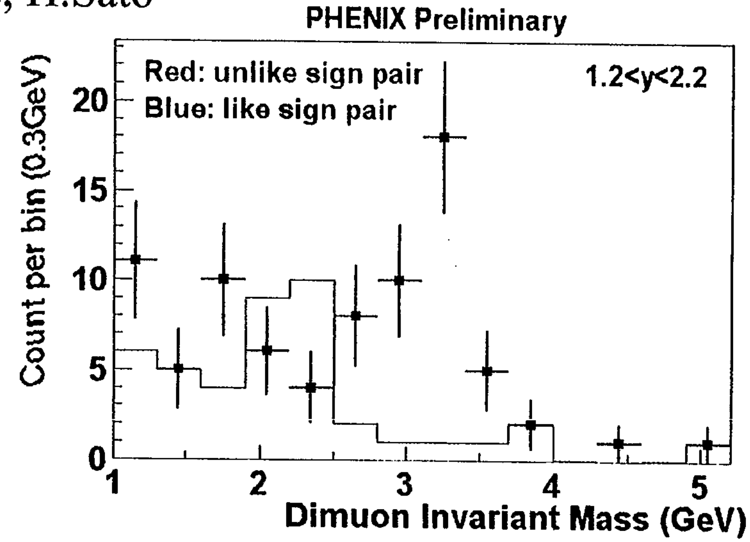
South Muon Arm Performance

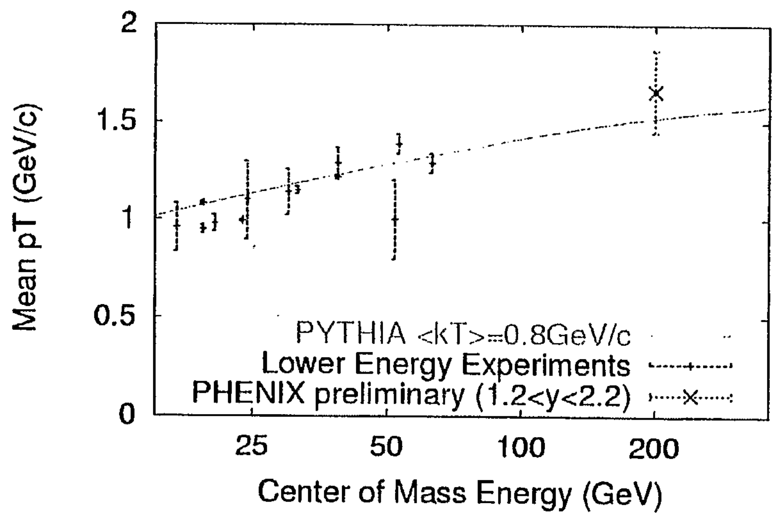
- Run-02
  - Some HV & Readout Problems
    - Repaired over last shutdown
  - Au-Au
    - PHENIX recorded 24 mb-1 of Au-Au data
  - polarized p-p
    - RHIC delivered 700nb-1 to PHENIX
    - After an online vertex cut, PHENIX recorded 150 nb-1
    - Present preliminary analysis used data from:
      81 nb-1 (1.7 x 109) μ+μ- (Hiroki Sato)

pp Run

J/Ψ Analysis, H.Sato

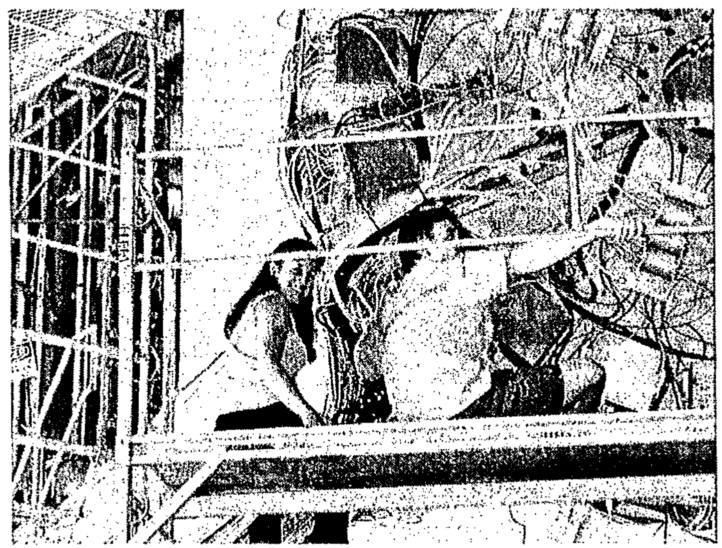






North Muon Arm Status

- Installation Complete.
- Noise Studies Successful.
- Cosmic Ray Calibration Soon.
- Ready for Run-03!



Summary

- South Arm performed well in Run-02
  - J/Ψ's in p-p data
  - Data analysis ongoing for Au-Au data
- North Arm ready for Run-03
  - Installed.
  - Commissioned
- Software status improving, ready for analysis.

Muon Arm Alignment for 2001/2 and Optical Alignment System Construction for the North Arm

Hideyuki Kobayashi

RBRC Review at BNL

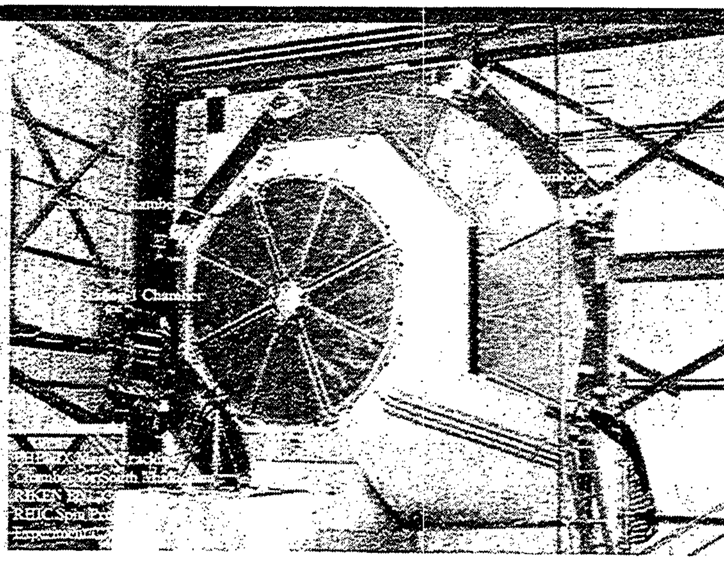
Muon tracker alignment in run 2001-2002 and optical alignment system construction for the north arm

- Muon Tracker overview
- Muon tracker alignment in year 2001-2002 (Run2)
- Construction of the optical alignment system for the north muon tracker

RBRC
Hideyuki Kobayashi

Hideyuki Kobayashi

Muon Tracker



Hideyuki Kobayashi 11/21/2002

Inter Station Alignment

Relative station alignment requirement < 25 um

- Initial alignment using zero field straight tracks
  - Cosmic ray data. – Not enoght statistics
  - p-p collision data. – Good statistics
  - Au-Au collision data. – Tracking code did not work

- Real time alignment
  - Optical alignment system

Hideyuki Kobayashi 11/21/2002

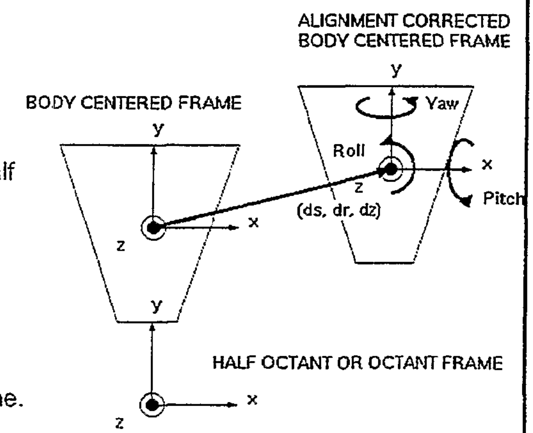
How to extract alignment constants

- Zero field pp data.
  - Run 40321, 40322, 36597 37576
  - 4800k triggered events.
  - 46k straight tracks (–1< Residual at Station-2 <1cm).
  - 2.4k straight tracks with MuID roads.
- Track candidates reconstructed by taking combination of Stubs from 3 stations in each octant.
- Look at Residuals
  - X-residual -> ds, Y-residual-> dr
  - Y-residual vs ySlope or X-residual vs xSlope -> dz
  - X-residual vs Y -> Roll
  - ...

Hideyuki Kobayashi 11/21/2002

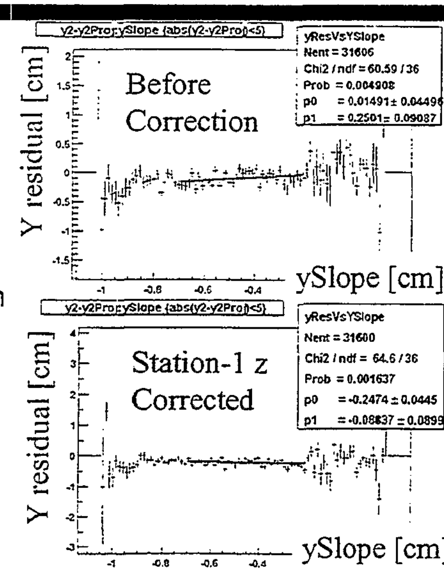
Alignment parameters

- Defined for each half-octant.
- Translation
  - (ds, dr, dz)
    - (dx,dy,dz) in the half octant or octant frame.
- Rotation.
  - (Roll, Pitch, Yaw)
    - (θx, θy, θz) in the body centered frame.



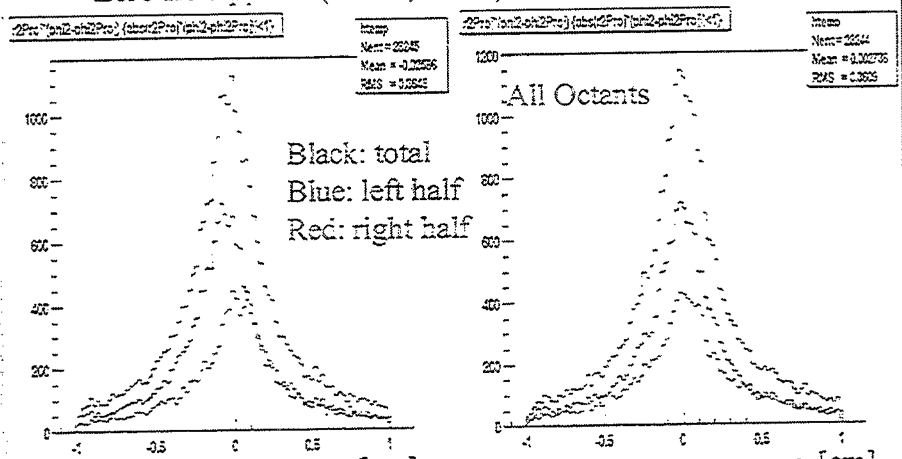
Station-1 z position correction

- Y-residual vs ySlope at station-2.
- Non-zero slope larger than 1mm/1m was found in all octants.
- 2mm z position mistake in the station-1 survey data in the libmut found.
- The database in the software was corrected on Apr/10/2002.



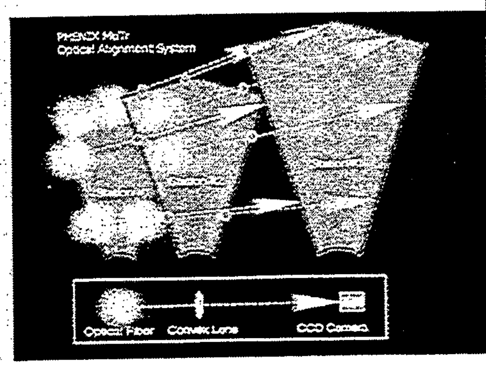
Half Octant ds Correction (all octants)

Zero field pp run (40321,40322) residual at Station-2

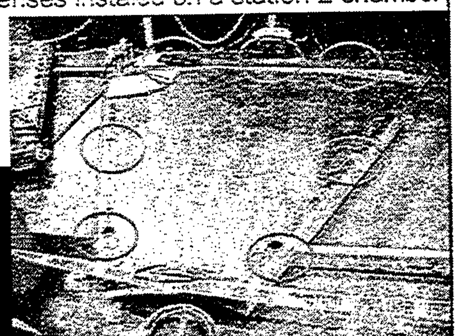


North Optical Alignment System

- Image capturing with a frame grabber.
- 11x13μm pixel CCD.
- 7 light beams per octant.



Lenses instaled on a station-2 chamber

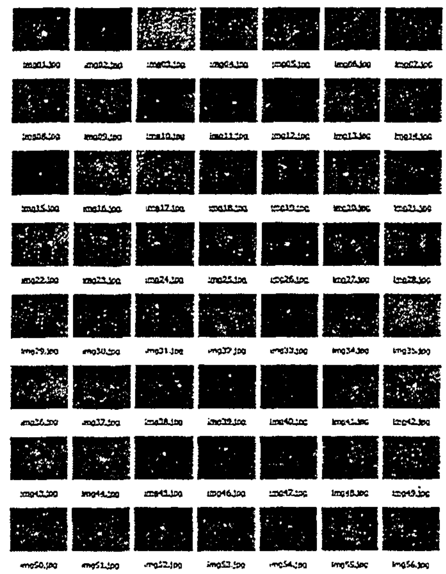


- Light source, fiber, lens, and Camera mechanical installation completed.
- Online software is ready.

North OASys First Data

- Installation of North optical alignment system was completed.
- Improved data taking control stability using the GPIB-ethernet adapter.
- Improved image shape with optimum focal length using custom lenses .
- Fibers for light beam 7, 14, 21, 35, 49 is broken. It is OK since there is a redundancy.

North OASys Oct 15-18:41



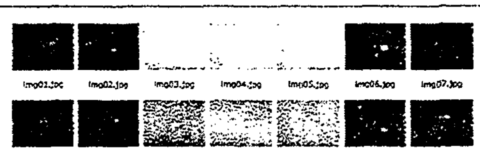
Hideyuki Kobayashi 11/21/2002

Alignment change during lampshade installation

1 or 2 mm alignment change observed in top octants

South OASys 2002-08-15 14:52

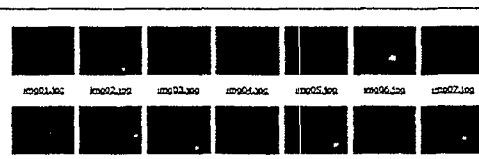
Octant1
Octant2



Just before lampshade panels installed

South OASys 2002-08-16 14:30

Octant1
Octant2



Just after lampshade panels installed

Hideyuki Kobayashi 11/21/2002

Summary

- Alignment of the muon tracker was looked at using 46k straight tracks out of 4800k triggered pp collision zero field data.
- Station-1 z-position was corrected for 2mm.
- Half octant correction to a zero field data improves residual distribution.
- Construction of the optical alignment system for the north was completed.
- Alignment change during installation of the south lampshade panels was observed with the optical alignment system.

Muon Measurements at PHENIX

Atsushi Taketani

Muon Measurements at PHENIX

Atsushi Taketani
RIKEN/RBRC

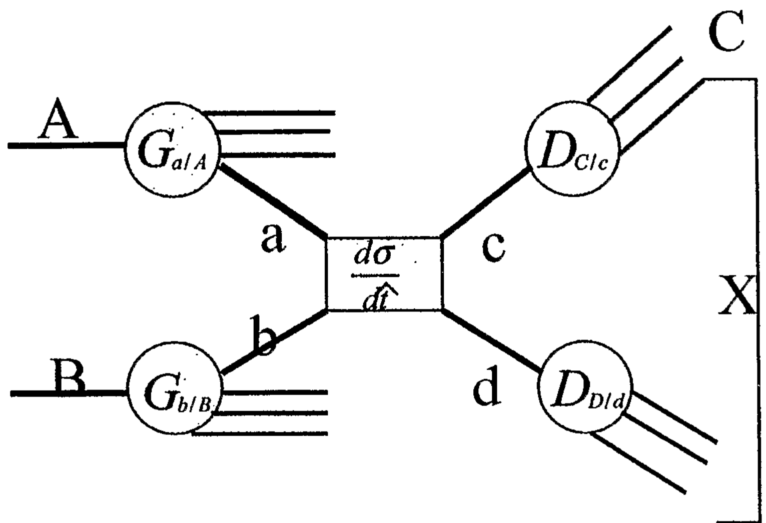
1. Motivation
2. PHENIX Muon Arm
3. Analysis
4. Summary

Spin Crisis and Nuclear Structure Function

Proton Spin

$1/2=(1/2)\Delta\Sigma+\Delta G+LQ+LG$

- $\Delta\Sigma$: quark spin ~ 0.2-0.3
- ΔG : gluon spin ~ 0-2±2
- LQ,LG : Orbital ~ ?



Origin of nuclear Spin?

Unpol. case $\quad E\frac{d^3\sigma}{dp^3} \sim \sum_{abcd} G_{a/A}(x_a)\otimes G_{b/B}(x_b)\otimes \frac{d\sigma_{cd}^{ab}}{dt}\otimes D_{C/c}(z)$

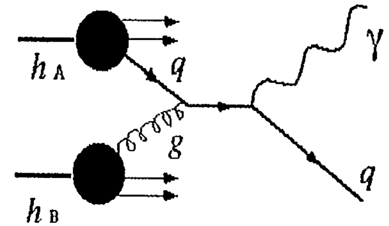
Pol. case $\quad A=\frac{Ed^3\Delta\sigma}{dp^3}\Big/\frac{Ed^3\sigma}{dp^3} \sim \frac{\Delta G_{a/A}(x_a)}{G_{a/A}(x_a)}\otimes\frac{\Delta G_{b/B}(x_b)}{G_{b/B}(x_b)}\otimes a_{LL}(ab\rightarrow cd)$

Measurement | PDF | pQCD | Fragmentation

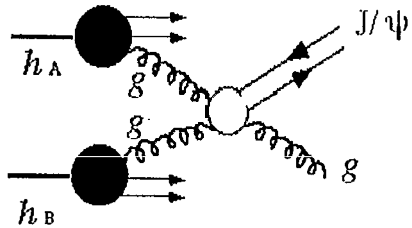
Atsushi Taketani RIKEN/RBRC

Major processes for probe

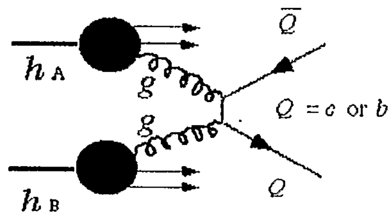
Process | **Signature**



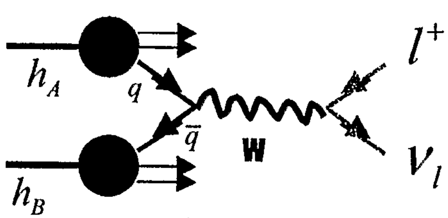
Gluon Compton — High-Pt prompt γ



Charmonium — e^+e^- $\mu^+\mu^-$



Open Heavy Quark
Light Flavor — e^+e^- $\mu^+\mu^-$ $e\mu$,
e, μ, **Charged Hadrons**, pi0



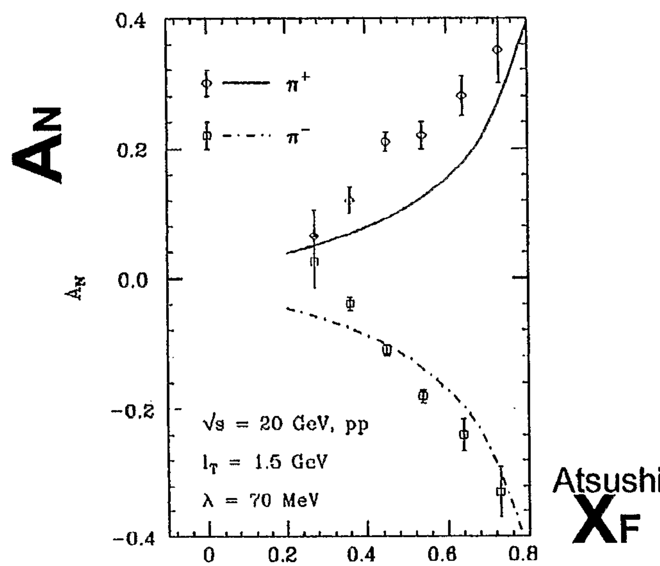
W boson (Z,Drell-Yan) — *High-Pt* μ *e,*
e^+e^- $\mu^+\mu^-$

Atsushi Taketani RIKEN/RBRC

- Physics of Single Mu (A_N)
  - LEFT-RIGHT asymmetry
    - Large asymmetry at high XF
    - Transversely polarized beam
  - Possible origins
    - Siverse Effect
    - Higher Twist
    - Final state fragmentation
      - Collins effect

400

FNAL E704 and Qiu-Sterman model



Physic of J/Y

Determination of Production Mechanism

- Color-Evaporation Model
- Color-Single Model
- Color-Octet Model

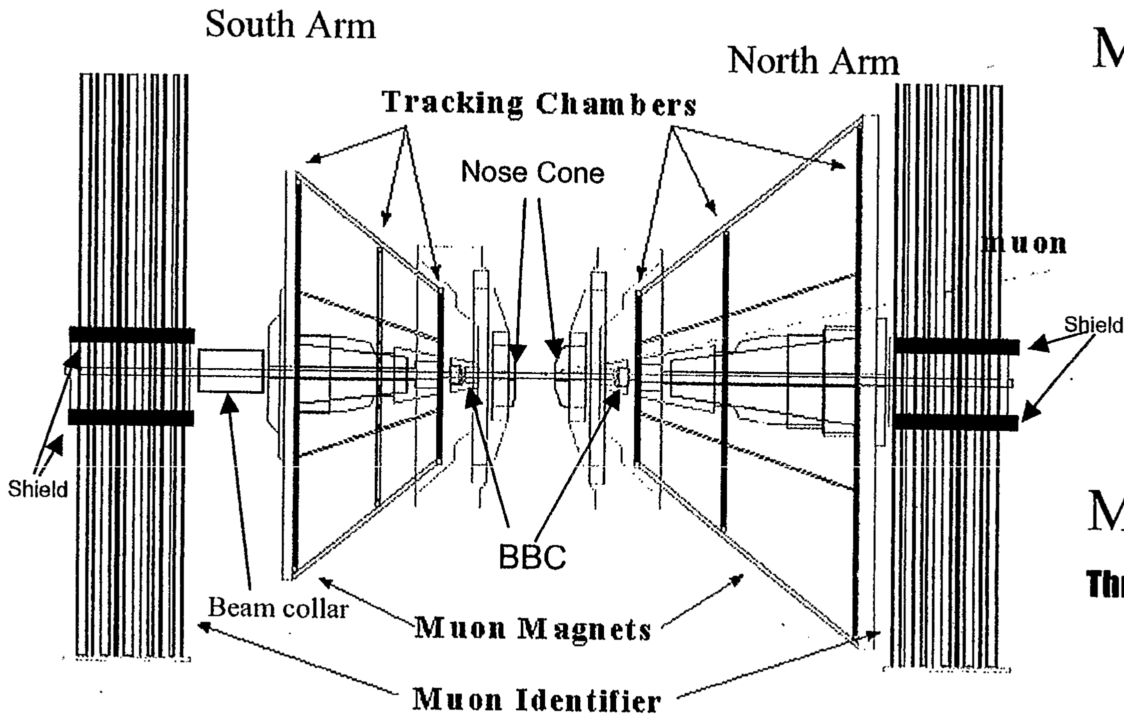
Gluon Polarization measurment

Longitudinally Pol. Beam ->Run03

Reference data for Heavy ion collision

Under going

PHENIX Muon Arm



Acceptance $1.2<|\eta|<2.4$

Muon Identifier

Five layers of steel absorber and detector

absorber~10 λ_{int}

P cut~2GeV/c

Used as Trigger counter

Muon Tracker

Three layers for Cathode readout chamber

–σ_x~100μm (as design)

→ $\Delta p/p$~3%@3~10GeV/c

South arm was operated in 2001/2002 run.

North Arm is just completed and under commissioned now for Run 3.

Atsushi Taketani RIKEN/RBRC

Data for Run2

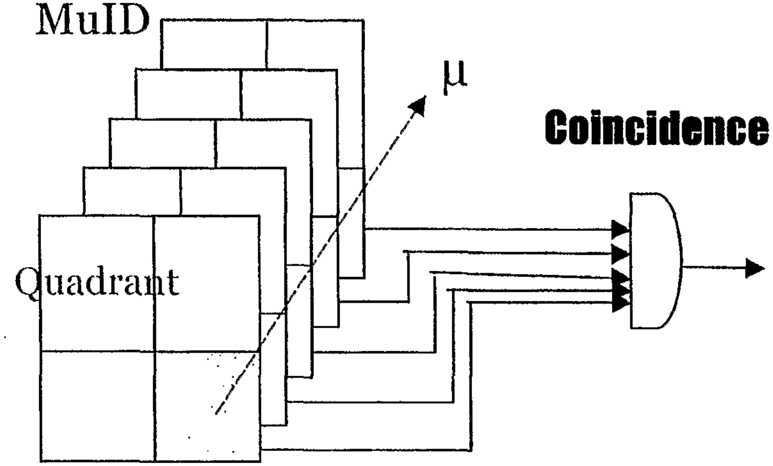
- **Intergrated luminosity**:
  0.15pb-1
- Beam polarization:
  15-17%, Both beams are transverse.
- **Total Triggered events**
  188 million events

Trigger

Z direction coincidence for MuID quadrant

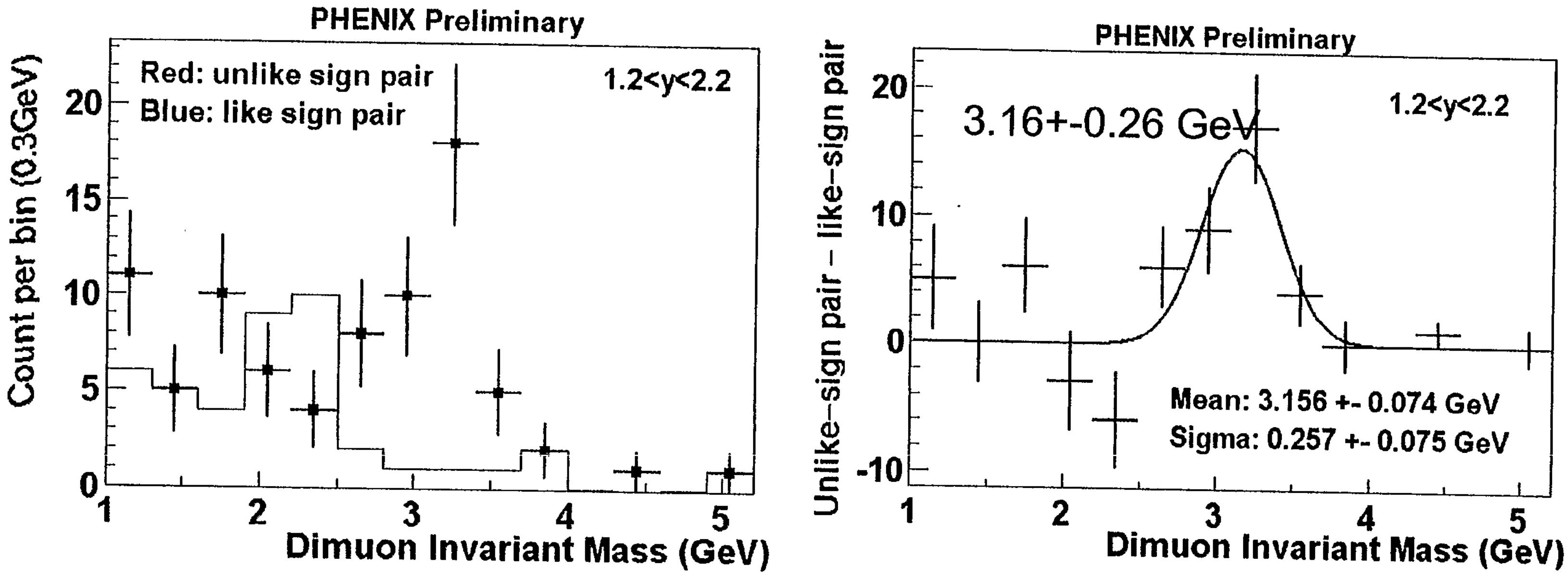
- **Single muon trigger >= 1**
- **Di-Muon Trigger>= 2**

Coincidence for 1/4



Atsushi Taketani RIKEN/RBRC

$J/\psi \rightarrow \mu^+\mu^-$ signal (By H. D. Sato)



- Using only unlike sign muon pairs
  Peak at (3156 ± 74 MeV) −>Mass of J/ψ
  Mass width (257 ± 75 MeV) −>Need to improve Momentum resolution (H.Kobayashi)
- $N_{J/\psi} = 36$ in 2.5<mass<3.7GeV, Estimated the number of background by counting like sign muon pairs.
- Systematic error by variation of mass cut is 10%.

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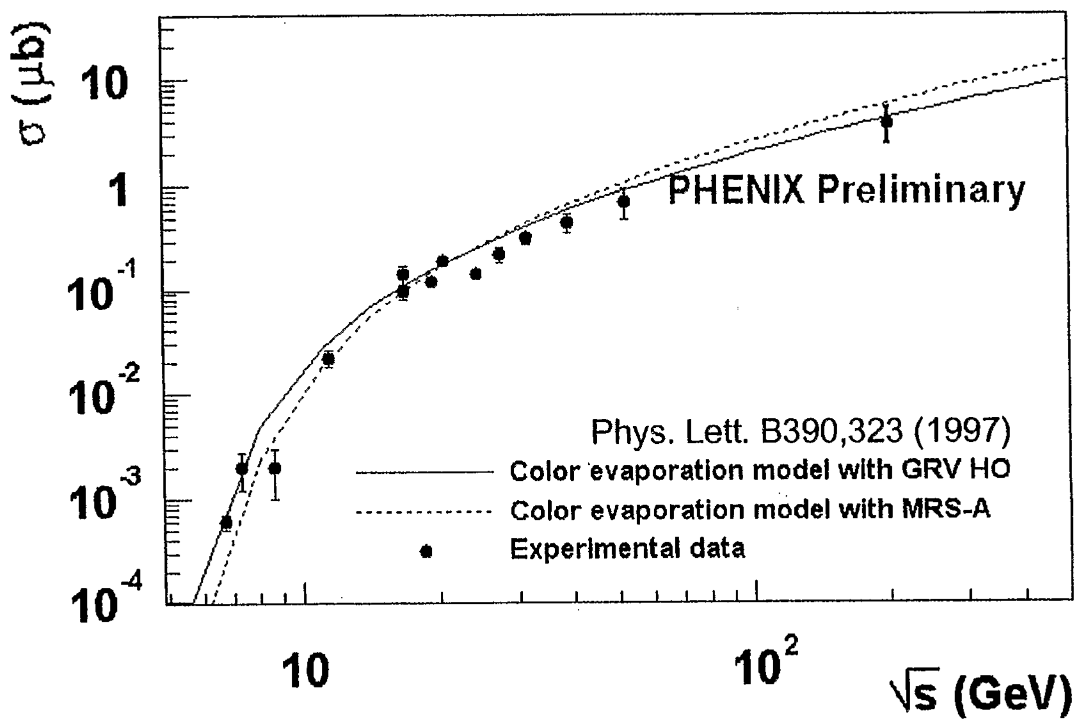
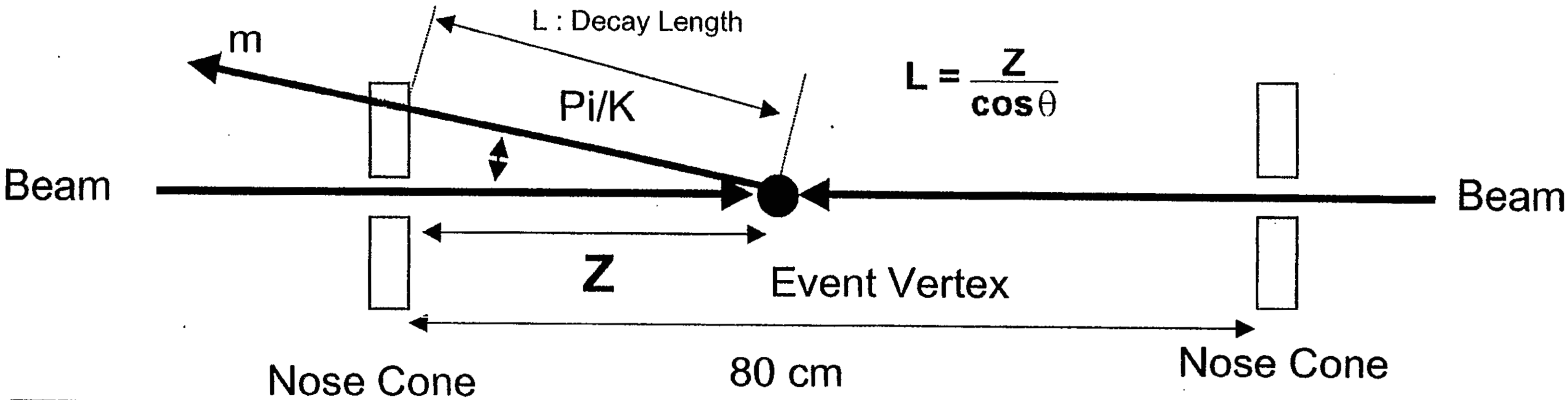
Color-Evaporation Model and Cross Section



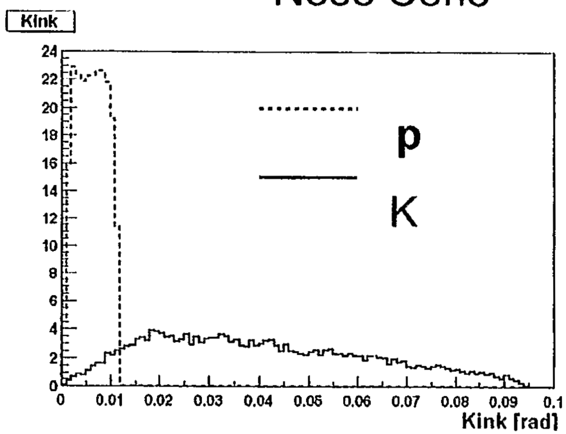
- CEM Parameters are fixed by fitting low energy data
- Our result agrees with the CEM prediction at $\sqrt{s}$=200 GeV

Single Muon Analysis

Most of the muon come from Pi/K decay.



$$L = \frac{Z}{\cos\theta}$$



Kink Angle [rad]

Kink are ignored

$$N_\pi(L) = N_\pi^0 e^{\frac{-L}{c\tau_\pi\gamma_\pi}}$$

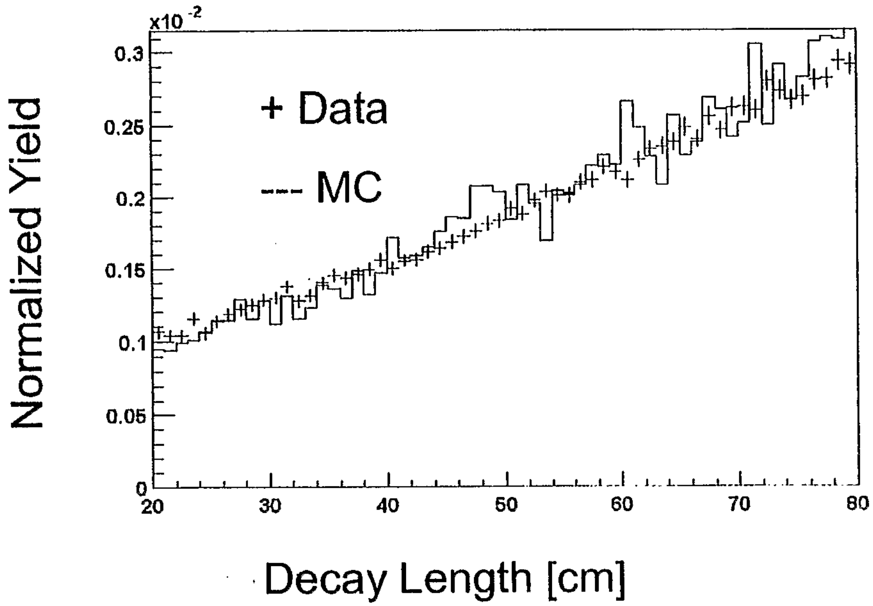
$$N_\mu(L) = N_\pi^0(1-e^{\frac{-L}{c\tau_\pi\gamma_\pi}}) + N_K^0(1-e^{\frac{-L}{c\tau_K\gamma_K}})$$

Thus $L << c\tau\gamma$

$$= L(\frac{N_\pi^0}{c\tau_\pi\gamma_\pi} + \frac{N_\pi^0}{c\tau_K\gamma_K})$$

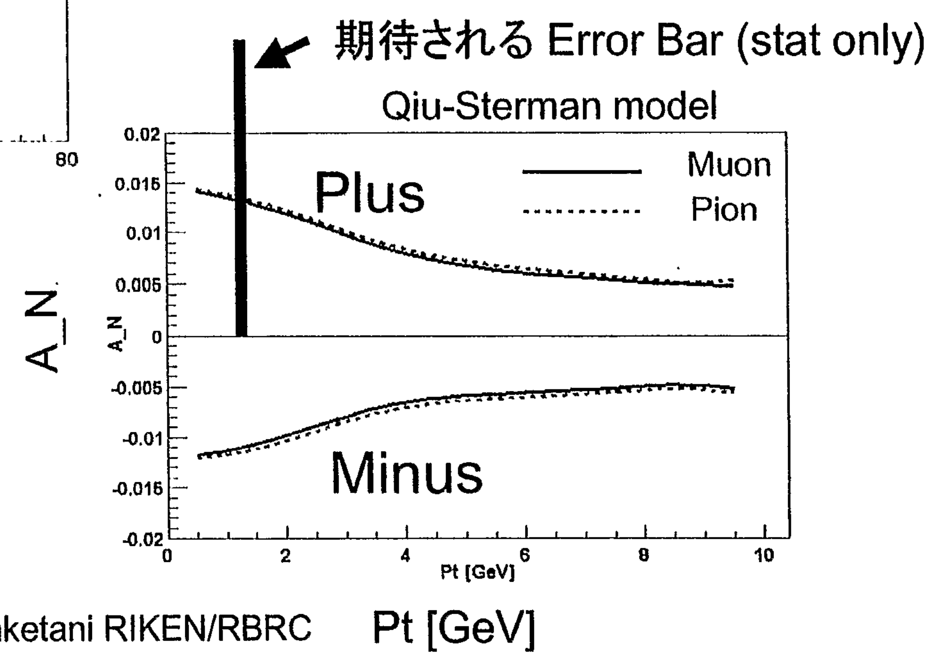
Atsushi Taketani RIKEN/RBRC

Single Muon Analysis



Plan

- Measurement of A_N and A_LL
- Measurement of Pt spectrum



Decay Length dependency agrees with Pi./K decay expectation.

Atsushi Taketani RIKEN/RBRC

Summary

- Analyzing the inclusive muon events for $\sqrt{s}$ = 200 GeV proton-proton collision.
- We measured production J/ψ production cross section by using $\mu^+\mu^-$ channel.

- 10-20 times higher integrated Luminosity, 50% longitudinally polarized beams are expected in coming Run3. Muon arm will be improved 2-4 times higher acceptance/efficiency.
  - J/ψ Polarization and A_{LL}
  - *Single Muon Pt spectrum and* A_{LL}

Atsushi Taketani RIKEN/RBRC

Computing at CC-J at RIKEN

Yuji Goto

CCJ status

Computing Center in Japan for spin physics at RHIC

T. Ichihara, Y. Watanabe, S. Yokkaichi, A. Kiyomichi,
O. Jinnouchi, H. En'yo, Y.Goto , H. Hamagaki[1]
RIKEN, RBRC, CNS[1]

Presented on 21th November 2002 at RBRC Review at BNL

RIKEN CCJ : Overview

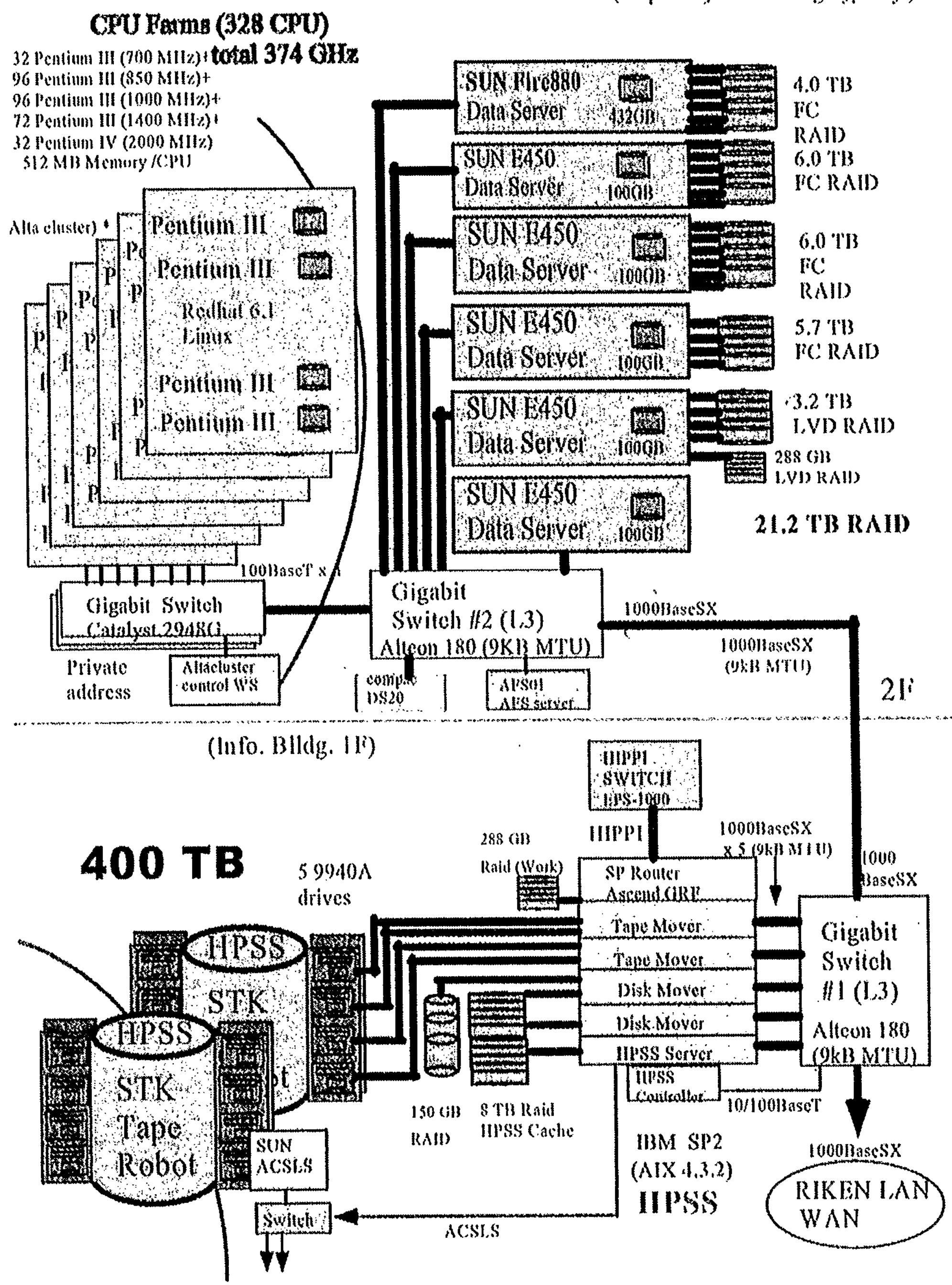
- Scope
  - Center for the analysis of **RHIC Spin Physics**
  - **Principal site of computing for PHENIX simulation**
    - PHENIX CC-J is aiming at covering **most of the simulation tasks of the whole PHENIX experiments**
  - **Regional Asia** computing center
- Size
  - Data amount: handing 225 TB /year
  - Disk Storage : ~ 20 TB, Tape Library: ~400 TB
  - CPU performance : 328 Pentium 3/4 CPU (Total: 374 GHz)

System upgrade since Nov. 2001

- CPU farms
  - 224 CPU -> 328 CPU (total: 374 GHz)
- Disk storage
  - Same (21 TB fiber channel Raid)
- Tape storage
  - 100 TB -> 150 TB (2500 cartridges)
  - 1 Dedicated Tape Silo (Full capacity: 400 TB)
- Data Servers
  - 5 SUN E450 servers -> 5 SUN E450 servers + 1 SUN Fire880 server
- Data Duplication Facility at RCF
  - Same (2 RedWood drives + IBM RS6000 F50)
- Bandwidth of RIKEN Wide Area Network
  - Same (50 Mbps)

RIKEN CC-J current system

(http://ccjsun.riken.go.jp/ccj/)



Analysis for the PHENIX experiment with CCJ

- DST Production
  - **~40TB of Raw Data (Year-2) was transferred via air plane (so called FedEXnet) from BNL to RIKEN**
  - **PHENIX official pp-DST production (A. Kiyomichi)**
    - **about 50% of DSTs produced at CCJ**
- Analysis
  - Fast analysis for spin – Y. Goto
  - electron/photon analysis - T.Hachiya, Y. Akiba
  - fluctuation analysis - T.Nakamura, K.Homma
  - BBC trigger study - K.Homma, T.Nakamura, T.Hachiya
  - pi0 analysis - K.Oyama
  - Photon polarimeter analysis – Y. Goto
  - Simulation for silicon vertex detector – K. Tanida
  - pp muon – H. Sato, H. Kobayashi
  - EMCal calibration – H. Torii
  - EMCal photon analysis - T.Sakaguchi
  - hadron analysis - A.Kiyomichi, T.Chujo
  - Lambda simulation – H. Ohnishi
  - Alignment study of muon arm – N. Kamihara

  - Belle simulation - K. Hasuko, A. Ogawa, M. G. Perdekamp

CCJ Operation

- Operation, maintenance and development of CC-J are carried out under the charge of the CCJ Planning and Coordinate Office (PCO).

CCJ Director (Chief Scientist of the Radiation Lab.)
H. En'yo

Planning and Coordination Office

manager	T. Ichihara	(RIKEN and RBRC)
technical manager	Y. Watanabe	(RIKEN and RBRC)
scientific programming coordinator		
	H. En'yo	(RIKEN and RBRC, PHENIX-EC)
	H. Hamagaki	(CNS-U-Tokyo, PHENIX-EC)
PHENIX Liaison	Y. Goto	(RIKEN and RBRC)
computer scientists		
	S. Yokkaichi	(RIKEN)
	O. Jinnouchi	(RIKEN)
	A. Kiyomichi	(RIKEN)

Technical Management Office

Manager, Data duplication	Y. Watanabe	(RIKEN and RBRC)
System engineer	T. Maeda	(IBM Japan)

RESEARCH SUMMARY EXPERIMENT

Statement of Research Activities

Abhay Deshpande
November 2002

Introduction:

This is a summary of my activities over the last one year at RIKEN BNL research center. The principle topics covered in document are:

1. The IP12 PHENIX Local Polarimeter test setup during the Run 2001-2002 (Construction and installation of this experiment was principally done with Brendan Fox and Yuji Goto, while the data analysis was performed with Yoshinori Fukao, Manabu Togawa & Naohito Satio)
2. The PHENIX muon trigger upgrade studies (Work done with: Gerry Bunce, Brendan Fox, Matthias Grosse-Perdekamp & Atsushi Taketani and four summer students.)
3. Towards the Electron Ion Collider (EIC) at BNL

Other studies I participated in include analysis of data on charged pion production in central rapidity region in pp scattering at PHENIX and issues regarding proton beam polarization, which will be covered in greater details in [1] and [2], respectively.

The IP12 PHENIX Local Polarimeter Test Setup during Run 2001-2002:

I was involved in the design, planning, and running of this experiment during the 2001-2002 RHIC run. After the run, I was involved in the data analysis performed with two students from Kyoto University. The preliminary results from this experiment were presented at PANIC'02[3], SPIN'02[4] and APS/DNP'02[5].

The spin rotators for the PHENIX (and for STAR) experiments were setup recently in the RHIC ring. It was anticipated that an experimental proof /measurements would be needed to confirm that the two spin rotators functioned properly during the collider experiment's operation. The stable spin direction of the protons in the RHIC ring being transverse (perpendicular to the proton orbit), the two rotators, each located on either side of the experiment, are expected to rotate the spin from transverse to longitudinal and back to transverse, so that the experiments can collide proton beams in longitudinal-longitudinal configuration needed for most of RHIC Spin measurements[6].

The design of the IP12 experiment was motivated by the E704 experiment's result [7] on observation of asymmetry in the forward π^0 production in transverse single spin pp scattering at Sqrt(s)~20 GeV. The idea behind the IP12 experiment was to explore the existence of such an asymmetry at RHIC energies, (including asymmetries in inclusive photons) using the transverse spin orientation (rotator off) of protons and then design a "null" experiment for the test of the spin rotators (when they are on). If the spin rotators functioned properly, there should be no asymmetry observed in the forward region in single longitudinal spin pp scattering. If there is any residual asymmetry, that would indicate non-longitudinal components of the proton spin component.

The East and West side of the IP12 experiment were instrumented with a Lead Tungstate Crystal Electromagnetic Calorimeter and a Zero Degree Calorimeter (ZDC) respectively. They were located about 18 meters from the IP. The location of our experiments makes us sensitive to measurements in low p_T (< 0.3 GeV) and high x_F (> 0.7) region. Further, the east arm was instrumented with a pre-shower detector, a charge veto counter, and two scintillators (N1,N2) located after the EMCal separated by a lead brick. The neutral particles (gammas and neutrons) exit the experimental area and enter the acceptance of our detectors. Based the signals from the preshower, the energy deposited in the EMCal on the east side of the experiment, and the N1 and N2 counters the particles were identified as being either gammas and neutrons. Extensive Monte Carlo studies including Pythia generator and GEANT detector response were made to understand the response of our detectors. Relative normalization of the EMCal towers was refined using the reconstructed π^0 mass in data and MC. Extensive studies were also performed on the West side for the ZDC, its pre and post shower detectors to understand its response to neutrons. Left right asymmetries were constructed out of the data for photons coming from pion decays even if one photon escaped detection, fully reconstructed pions (both photons detected), and the neutron on the East side, while only neutron asymmetries were measured for the West side.

Detailed results will be presented during this review[8]. The high lights of the results are summarized below:

1. We observe no asymmetries in the reconstructed π^0 sample.
2. We see a small asymmetry (< 3%) in the inclusive gamma data sample, but we can not rule out a small contamination from neutrons in this sample of photons.
3. We observe a large asymmetry/analyzing power in the neutron production. We confirmed this result with the result seen in the West side apparatus of ZDC.
    - The asymmetry plotted against the ϕ azimuthal angle clearly shows a $\sin(\phi)$ dependence
    - We see a clear correlation between the magnitude of asymmetry and the polarization of the on-coming beam.

In summary, we have observed an unexpected asymmetry/analyzing power in neutron production in pp scattering at Sqrt(s)=200 GeV. No asymmetry has been seen for photons (reconstructed pions or inclusive photons). Physical origin of this neutral analyzing power is unknown, although some candidate reactions are being explored for possible explanation. An experiment may be planned in PHENIX experimental area next year 2003-2004 to understand the physics process responsible.

Plans for Run 2002-2003:

The neutron asymmetry observed in the IP12 experiment last year will be exploited to check and study the operation of PHENIX spin rotators. Two shower max detectors (SMD) with a vertical and horizontal granularity are being inserted between the first and the second units of the Phenix Zero Degree Calorimeters. The SMDs are being constructed at BNL by the BNL Physics group (A. Denisev & S. White et al.). RIKEN has contributed towards the construction cost of the Front End Modules (FEMs) built at Columbia U. The FEMs are ready, the SMDs are expected to be ready in the next two to three weeks and will be installed in PHENIX by the early December. I will be

involved with the BNL & the RIKEN group to facilitate the use of these detectors for the spin rotator operations and associated tests during the upcoming RHIC run.

Muon Trigger Upgrade Studies:

Over the last few decades the spin structure of the nucleon has been explored using the technique of polarized Deep Inelastic Scattering (DIS). One of the limitations of the DIS technique is that the virtual photon can not distinguish between the quark and anti-quarks, nether can it distinguish between various quark flavors. Both these limitations could be overcome by using polarized pp scattering at PHENIX resulting in parity violating W+/- production and its subsequent decay in to the muons and neutrinos. It is essential however that the decay muons are tagged efficiently (since the neutrinos escape detection) and background muons from all sources are identified.

RHIC luminosity upgrades will require a substantial enhancement of the PHENIX muon trigger (a factor ~50 at RHIC II luminosities). At the L= $2x10^{32}$ $cm^{-2}sec^{-1}$ the first level trigger will fire at 21kHz. This rate is dominated by hadron decays in to muons and exceeds the available bandwidth of the single muon trigger channel by a factor ~20. An additional factor of 2-3 in rejection power is needed to compensate for the additional beam related backgrounds expected at high beam intensities.

We studied possible ways to get the required rejection in PHENIX to enable its W physics program. The proposed trigger upgrade exploits the difference in the muon momentum spectra from the background hadron decays and those originating in the pp collision via a $W^{+/-}$ decay. Three possible hardware components for the trigger upgrade were studied:

1. ***Addition of Scintillation Hodoscope:*** Measurement of momentum using new scintillator hodoscope upstream of the muon magnet along with anode read out from the upstream muon tracker station to be used in conjunction with the roads built in the present level 1 muon identifier trigger.
2. ***Addition of a threshold Cherenkov Counter:*** Matching threshold information from a segmented Cherenkov-counter to muon roads from muon identifier.
3. ***Addition of a Nosecone Calorimeter:*** Compare event topology differences between background jet production and direct muon signals.

All the above studies were performed using PYTHIA event generator and PISA simulation package for PHENIX. Preliminary studies indicate that rejection factors of ~4, ~30 and ~2-3 could be achieved by these new detectors, respectively. Detailed studies are underway. This is being written up as part of the PHENIX upgrade proposal [9]. The integration of the new trigger will require a new set of local level 1 processors. A new regional trigger processor will predigest information from these detector subcomponents before the information is passed on to PHENIX global level 1 trigger. Ideas for such a processor board are being discussed within PHENIX.

The Electron Ion Collider at BNL:

Addition of an electron beam facility to the RHIC accelerator complex enabling high intensity high energy electron beam to collide with one of the RHIC's existing heavy ion or polarized proton beam, will significantly enhance RHIC's ability to explore fundamental and universal aspects of QCD [10]. We propose to build a ~10 GeV polarized electron beam facility at RHIC which will allow collisions between polarized protons and electrons at Sqrt(s) =100 GeV and a luminosity of $L_{ep}= 10^{33}\ cm^{-2}sec^{-1}$. The same beam could provide a Sqrt(s) = 63 GeV when colliding with 100 GeV/A collisions with heavy ions. For the first time such DIS studies would be possible in a collider geometry and at high luminosities. This would allow detailed studies of many inclusive reactions as well as abundant rates of exclusive measurements in kinematic regions never before explored.

Many physics topics have been studied to make the physics case for this collider already[11]. They have mostly concentrated on inclusive or semi-inclusive physics measurements. New physics topics such as Deeply Virtual Compton Scattering (DVCS) and others, which may lead us to the generalized parton distributions (GPDs), are now being pursued and studied by various theoretical groups around the world. Early attempts to measure DVCS have been made at the ZEUS, H1 and HERMES experiments at DESY[12]. The biggest hurdle in the measurements seems to be the exclusive measurement of final states (particles). In DVCS, the final states are the scattered proton and a real photon. The kinematics of these interactions is such that very small deviations of the proton from the initial direction are expected. The photon comes out in all directions. I have starting studying this problem in collaboration with A. Sandacz(INP, Warsaw), D. Hasel(MIT/Bates) in detail with the aim to have an appropriate design for the detector components for this. One possible option we are pursuing presently is a roman pot detector (like the one from PP2PP) to detect the small angle scatter of the proton and a calorimeter to measure the photon. This is a typical study underway which eventually lead to aspects EIC detector design. Others physics studies will follow.

In addition to such topical studies I also serve presently as the EIC contact person and physics coordinator. While the Contact Person's responsibilities are mostly communications with non-EIC outsiders, as the Physics Coordinator I am organizing and enabling small working groups dedicated to detailed studies of physics processes to be studied at EIC. Conclusions from these working groups are communicated to the accelerator and IR design working group, which is presently formed between BNL/CAD and MIT/Bates. I try to keep the information exchange at its best so many issues crucial for the physics measurements at EIC do not get over looked during the ring and IR design.

References:

[1] F. Messer & K. Okada, RBRC review presentation, November 2002.
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[3] M. Togawa, *Phenix Local Polarimeter Experiment*, Proceedings of PANIC '02.

[4] Y. Fukao, *Measurement of Single Transverse-spin Asymmetries in Forward Production of Photons and Neutrons in pp collisions at Sqrt(s)=200 GeV*, Proceedings of the Spin Symposium at BNL, September 2002.
[5] B. Fox for A. Deshpande, *A Local Polarimeter for PHENIX*, APS Meeting of the DNP, October 2002.
[6] G. Bunce et al., *Prospects of Spin Physics at RHIC*, July 2002
[7] D. L. Adams et al., Phys. Lett. **B261**, 201 (1991); ibid Phys. Lett. **B264**, 462 (1991)
[8] B. Fox, RBRC review presentation, November 2002
[9] Phenix Detector Upgrade Proposal, Edited by A. Drees (to be released)
[10] The Spin Structure of the Proton & Polarized Collider Physics, Nucl. Phys. B. (Proc. Suppl.) **105** (2002) February 2002, Edited by S. Bass, A. De Roeck & A. Deshpande.
[11] The Electron Ion Collider, A high luminosity probe of the partonic substructure of nucleons and nuclei, BNL Report 68933, February 2002, Edited by S. Davis, A. Deshpande, R. Milner & R. Venugopalan
[12] H1 Collaboration, Phys. Lett. **B517** 47-58 (2001)
HERMES Collaboration, hep-ex 0106068
ZEUS collaboration, P. Saull, hep-ex/0003030

CURRICULA VITAE - SUMMARY

CURRICULA VITAE - SUMMARY
RBRC FELLOWS/RESEARCH ASSOCIATES/YOUNG RESEARCHERS

Yasumichi Aoki **Birthplace:** Gunma, Japan **DOB:** January 7, 1968
Ph.D. 1996, University of Tsukuba, Japan
Experience: COE Research Fellow at the Center for Computational Physics University of Tsukuba;
Assistant (3 year research position) at the Center for Computational Physics, University of Tsukuba
Research Associate, RIKEN BNL Research Center, May 1, 2000 - present

Steffen A. Bass **Birthplace:** Frankfurt, Germany **DOB:** May 17, 1968
Ph.D. 1997, J. W. Goethe Universität Frankfurt, Germany
Experience: Feodor Lynen Fellow and Research Associate, Duke University, 1998-99
Visiting Assistant Professor, Michigan State University, 1999
•RHIC Physics Fellow/Assistant Professor--RBRC/Duke, September 1, 2000 – present
Awards and Honors: W. E. -Heraeus-Award, W.E.-Heraeus Foundation, Germany, 1993
Feodor-Lynen Fellow, A. v. Humboldt Foundation, Germany, 1997

Alexander V. Bazilevsky **Birthplace**: Yaroslavl, Russia **DOB**: May 10, 1968
Ph.D. 1999, Institute for High Energy Physics, Protvino, Russia
Experience: Scientific Researcher, IHEP, Protvino, Russia
Research Collaborator, BNL PHENIX
Research Associate, BNL, RIKEN BNL Research Center, March 10, 1999 – March 9, 2002;
RIKEN BNL Fellow, March 10, 2002 - present
Awards and Honors: Soros Scholarship, 1996.

Thomas C. Blum **Birthplace**: USA **DOB**: December 27, 1962
Ph.D. 1995, University of Arizona, Tucson, AZ
Experience: Postdoctoral Fellow, High Energy Theory Group, BNL
RIKEN BNL Fellow, October 1, 1998 - present
Awards and Honors: DOE-GANN Fellowship: August 1990 - May 1993

Christopher Dawson **Birthplace**: Preston, Lancashire, UK **DOB**: July 6, 1973
Ph.D. 1998, University of Southampton, UK
Experience: Research Associate, High Energy Theory Group, BNL
RIKEN BNL Fellow, October 1, 2001 – present

Abhay L. Deshpande **Birthplace**: Mumbai/Bombay, India **DOB:** March 21, 1965
Ph.D. 1994, Yale University
Experience: Visiting Scientist, BNL, 1989-1994 (Member of the BNL-E851 Collaboration)
Visiting Scientist, CERN, 1994-1999 (Member of the SMC Collaboration)
Visiting Scientist, DESY, 1998-Present (Member of the ZEUS Collaboration)
Associate Research Scientist, Yale University, 1994-2000
RIKEN BNL Fellow, February 2000 - present
Awards and Honors: Gibbs Prize in Physics, University of Bombay, 1985.

Douglas Fields: **Birthplace**: U.S.A. **DOB**: July 2, 1963
Ph.D. 1991, Indiana University, Bloomington
Experience: Postdoctoral Research Associate, Los Alamos National Laboratory, 1992-1995
Research Associate Professor, University of New Mexico, 1995-2001
Member of the PHENIX Collaboration, BNL, 1995-present
•RHIC Physics Fellow/Assistant Professor—RBRC-E, University of New Mexico, September 1, 2001 – present

Brendan Fox **Birthplace**: U.S.A. DOB:
Ph.D. 1996, University of Illinois, Urbana,
Experience: Research Associate, University of Colorado, 1996-2001
RIKEN BNL Fellow, March 1, 2001 – present.

Yoshinori Fukao **Birthplace**: Aichi, Japan **DOB**: April 5, 1978
B.S. 2001, Kyoto University, Kyoto, Japan
Master Course Student, 2002 – present
Experience: RBRC Young Researcher, Experimental Group, 2002 – present.

Yuji Goto **Birthplace**: Shizuoka, Japan **DOB**: November 25, 1965
Ph.D 1996, Kyoto University, Kyoto, Japan
Experience: Research Fellow of the Japan Society for the Promotion of Science, 1994-1996
Postdoctoral Fellow, RIKEN, Japan, 1996-1999
RIKEN BNL Fellow, November 1999 – March 31, 2002
Scientist, RIKEN; RIKEN Spin Program Researcher, RBRC, April 1, 2002 – present.

Matthias Grosse-Perdekamp
Birthplace: Schwenningen, Germany **DOB:** December 1, 1963
Ph.D. 1995, University of California at Los Angeles
Experience: Associate Research Scientist, Yale University 1995-1998
Research Scientist, Mainz University, 1998-1999
RIKEN BNL Fellow, January 1999 – August 31, 2002.
Member of the PHENIX and BELLE Collaborations;
•RHIC Physics Fellow/Assistant Professor—RBRC-E; University of Illinois, Urbana Champaign, September 1, 2002 – present.
Awards and Honors: Foreign Scholar Award, UCLA, 1990; Gustav Mie Preis, Freiburg University, 1991.

Yoshitaka Hatta **Birthplace:** Kyoto, Japan **DOB:** August 5, 1976
Master Degree
Graduate School: 1999, Kyoto University, Department of Physics
Experience: RBRC Young Researcher, Theory Group, RBRC,
Spring 2002 – present

Takuma Horaguchi **Birthplace:** Iwate, Japan **DOB:** September 29, 1977
Graduate School: Tokyo University of Science, Japan
Experience: RBRC Young Researcher, Experimental Group, RBRC,
Spring 2002 – present.

Takashi Ichihara **Birthplace:** Japan **DOB:** February 22, 1958
Ph.D. 1987, Kyoto University, Japan
Experience: Research Scientist, RIKEN, Japan, 1987-1995
Senior Research Scientist, RIKEN, Japan, 1995-1998
Assistant Chief Scientist, RIKEN, Japan, 1998
Researcher, RBRC Experimental Group, 1998
RIKEN Spin Program Researcher, November 1999- present

Takashi Ikeda **Birthplace:** Saitama, Japan **DOB:** December 2, 1973
Ph.D. 2002, University of Tokyo, Japan
Experience: Special Postdoctoral Researcher, RIKEN;
RIKEN Spin Program Research Associate, Theory Group, RBRC,
Spring 2002 – present.

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Postdoctoral Fellow in Research Center for Nuclear Physics, Osaka University
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Ph.D. 1994, University of Washington, Seattle
Postdoctoral Research, University of Washington, Particle Theory Group,
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Atsushi Taketani **Birthplace**: Ako, Japan **DOB**: February 26, 1963
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Research Assistant Professor, Department of Physics, University of Washington, March 1996 to December 1997
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Awards and Honors: Fellowships: Fellow of the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq), Brazil, 1987-1992. Fellow of the Coordenadoria de Aperfeiçoamento de Pessoal de Nível Superior (CAPES), Brazil, 1985-1987; U.S. Department of Energy Division of Nuclear Physics Outstanding Junior Investigator Award, 2001; Alfred P. Sloan Fellowship, 2002.

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Research Assistant Professor and Danish Research Council Fellow, Niels Bohr Institute, Denmark, January 1997 -October 1998
Assistant Physicist, Physics Department, BNL - October 1998
Associate Physicist, Physics Department, BNL - Nov. 1999 – Oct. 2001
Physicist, Physics Department, BNL – Oct. 2001 – June 1, 2002
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Research Associate in Theory Group of the Rutherford Appleton Laboratory, Didcot, England, Oct. 1994-Dec. 1996
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29. C. Bernard, T. DeGrand, C. DeTar, Steven Gottlieb, Urs M. Heller, J.E. Hetrick, N. Ishizuka, C. McNeile, R. Sugar, D. Toussaint, and M. Wingate (MILC Collaboration), "Heavy-Light Decay Constants: Conclusions from the Wilson Action," [hep-lat/9809109] *Proc. of the XVI International Symposium on Lattice Field Theory, Lattice '98*, Boulder, Colorado, July 13-18, 1998, Eds. T. DeGrand, C. DeTar, R. Sugar and D. Toussaint; Nuclear Physics B (Proc. Suppl.) 73, 372-374 (1999).

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34. A. J. Baltz, "Exact Dirac Equation Calculation of Ionization Induced by Ultrarelativistic Heavy Ions, Phys. Rev. A 61, 042701 (2000).

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44. D. Kharzeev, "Quarkonium as a Probe of QCD Matter," to appear in *Proc. Intl. Phys. Conf.*, Paris, 1998, Nucl. Phys. A.

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55. R. L. Jaffe and D. Kharzeev, "X_2 Production in Polarized pp Collisions at RHIC: Measuring ΔG and Testing the Color Octet Model," [hep-ph/9903280], March 1999, Phys. Lett. B 455, 306-310 (1999).

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