Universal Behavior of Charged Particle Production in Heavy Ion Collisions at RHIC Energies

Peter A. Steinberg[2] * for the PHOBOS collaboration

B.B.Back[1], M.D.Baker[2], D.S.Barton[2], R.R.Betts[6], M.Ballintijn[4], A.A.Bickley[7], R.Bindel[7], A.Budzanowski[3], W.Busza[4], A.Carroll[2], M.P.Decowski[4], E.García[6], N.George[1,2], K.Gulbrandsen[4], S.Gushue[2], C.Halliwell[6], J.Hamblen[8], G.A.Heintzelman[2], C.Henderson[4], D.J.Hofman[6], R.S.Hollis[6], R.Hołyński[3], B.Holzman[2], A.Iordanova[6], E.Johnson[8], J.L.Kane[4], J.Katzy[4,6], N.Khan[8], W.Kucewicz[6], P.Kulinich[4], C.M.Kuo[5], W.T.Lin[5], S.Manly[8], D.McLeod[6], J.Michałowski[3], A.C.Mignerey[7], R.Nouicer[6], A.Olszewski[3], R.Pak[2], I.C.Park[8], H.Pernegger[4], C.Reed[4], L.P.Remsberg[2], M.Reuter[6], C.Roland[4], G.Roland[4], L.Rosenberg[4], J.Sagerer[6], P.Sarin[4], P.Sawicki[3], W.Skulski[8], S.G.Steadman[4], P.Steinberg[2], G.S.F.Stephans[4], M.Stodulski[3], A.Sukhanov[2], J.-L.Tang[5], R.Teng[8], A.Trzupek[3], C.Vale[4], G.J.van Nieuwenhuizen[4], R.Verdier[4], B.Wadsworth[4], F.L.H.Wolfs[8], B.Wosiek[3], K.Woźniak[3], A.H.Wuosmaa[1], B.Wysłouch[4]

[1] Argonne National Laboratory, Argonne, IL 60439-4843, USA [2] Brookhaven National Laboratory, Upton, NY 11973-5000, USA [3] Institute of Nuclear Physics, Kraków, Poland [4] Massachusetts Institute of Technology, Cambridge, MA 02139-4307, USA [5] National Central University, Chung-Li, Taiwan [6] University of Illinois at Chicago, Chicago, IL 60607-7059, USA [7] University of Maryland, College Park, MD 20742, USA [8] University of Rochester, Rochester, NY 14627, USA

The PHOBOS experiment at RHIC has measured the multiplicity of primary charged particles as a function of centrality and pseudorapidity in Au+Au collisions at $\sqrt{s_{NN}} =$ 19.6, 130 and 200 GeV. Two kinds of universal behavior are observed in charged particle production in heavy ion collisions. The first is that forward particle production, over a range of energies, follows a universal limiting curve with a non-trivial centrality dependence. The second arises from comparisons with $pp/\overline{p}p$ and e^+e^- data. $\langle N_{ch}\rangle/\langle N_{part}/2\rangle$ in nuclear collisions at high energy scales with $\sqrt{s}$ in a similar way as N_{ch} in e^+e^- collisions and has a very weak centrality dependence. This feature may be related to a reduction in the leading particle effect due to the multiple collisions suffered per participant in heavy ion collisions.

1. Introduction

The PHOBOS experiment has measured $dN_{ch}/d\eta$ and the average multiplicity of charged particles $\langle N_{ch}\rangle$ produced in heavy ion collisions for center of mass energies in the nucleon-nucleon center of mass system, $\sqrt{s_{NN}}$, of 19.6, 130 and 200 GeV. The data is also binned as a function of event centrality (impact parameter) characterized by the number of participating nucleons, N_{part}, allowing comparisons to elementary systems, like $pp/\overline{p}p$ and $e^+e^- \rightarrow$ hadrons.

*Current address: Physics Department, University of Cape Town, South Africa

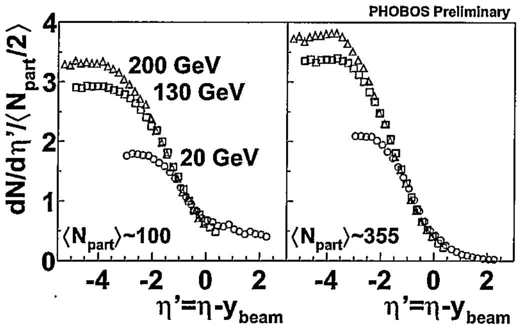

Figure 1. $dN/d\eta'/\langle N_{part}/2\rangle$ for peripheral ($\langle N_{part}\rangle \sim 100$) and central ($\langle N_{part}\rangle \sim 355$) events at three RHIC energies.

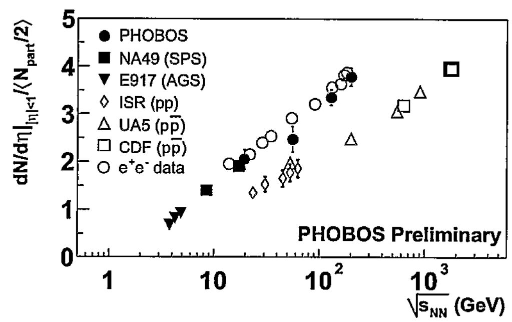

Figure 2. Particle density at midrapidity for A+A, $pp/\overline{p}p$ and e^+e^-

The PHOBOS multiplicity detector consists of several arrays of silicon detectors which cover nearly the full solid angle for collision events. The "Octagon" detector surrounds the interaction region with a cylindrical geometry below $|z| < 50$ cm, covering $|\eta| < 3.2$. Two sets of 3 "ring" detectors are placed far forward and backward of the interaction point and surround the beam pipe, covering $3 < |\eta| < 5.4$. The event centrality is characterized by the multiplicity of charged particles measured by two sets of 16 paddle counters covering $3 < |\eta| < 4.5$. The methods used for measuring the multiplicity of charged particles as well as for extracting $\langle N_{part}\rangle$ has been described in more detail in Ref. [1].

2. Limiting Behavior in Pseudorapidity Distributions

Fig. 1 shows $dN_{ch}/d\eta'/\langle N_{part}/2\rangle$ ($\eta' = \eta - y_{\rm beam}$) measured at three different RHIC energies for peripheral ($\langle N_{part}\rangle \sim 100$) and central events ($\langle N_{part}\rangle \sim 355$), in the left and right panels, respectively. These show a clear "limiting behavior" in the fragmentation region. That is, the distributions are independent of beam energy over a substantial range in η'. As the beam energy increases, $dN/d\eta'$ follows the universal trend until it reaches 85-90% of it's maximum value at midrapidity, at which point it stops following the trend. Similar behavior has been observed in elementary collisions as well, both in $\overline{p}p$ collisions [2] and in e^+e^- annihilation to hadrons [3].

The limiting curve constrains the energy dependence of the charged particle multiplicity. It also varies with centrality in such a way that the increases seen at low η' (which is midrapidity in η) as N_{part} increases, are accompanied by decreases near $\eta' \sim 0$ (forward rapidities), as seen in Fig. 1. It is not clear why this behavior occurs, e.g. whether it is from energy conservation or a true long-range correlation.

3. Comparison with Elementary Systems

Comparisons of the plateau height, $dN_{ch}/d\eta|_{|\eta|<1}/\langle N_{part}/2\rangle$, in heavy ion collisions with $\overline{p}p$ data have been made previously [4]. However, we can also include data from e^+e^-, presented as dN/dy_T, the rapidity density along the event thrust axis, calculated assuming the pion mass. JETSET calculations suggest that the difference between dN/dy_T and

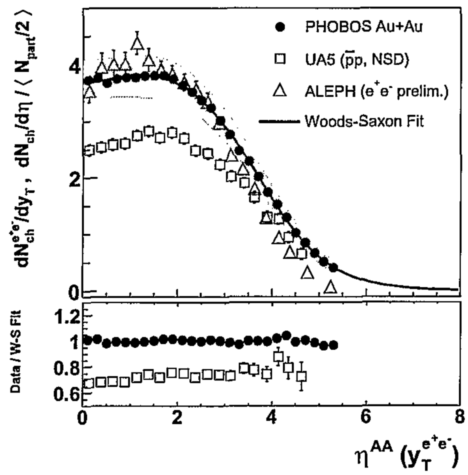

Figure 3. Top: $dN_{ch}/d\eta$ for central Au+Au and $\bar{p}p$ collisions compared with dN/dy_T for e^+e^- data, all at $\sqrt{s_{NN}} = 200$ GeV. Bottom: Au+Au and $\bar{p}p$ data divided by a Woods-Saxon fit to the Au+Au data.

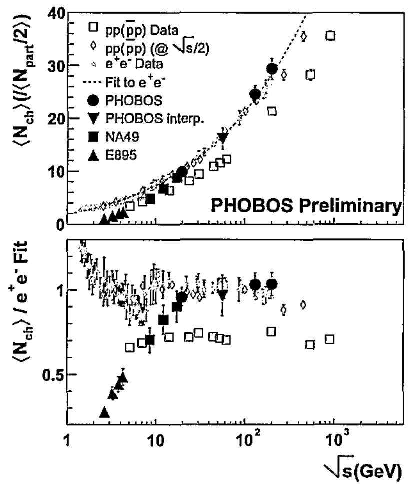

Figure 4. Comparison of $\langle N_{ch}\rangle/\langle N_{part}/2\rangle$ for A+A, $pp/\bar{p}p$, and e^+e^- data compared with a fit to the e^+e^- data.

$dN/d\eta$ is less than $\pm 10\%$ for $|y| < 4$. In the comparison at midrapidity, shown in Fig. 2, we find two interesting features. First, the energy dependence of all of the systems is approximately logarithmic, at least below 200 GeV. Secondly, while it has been noticed that heavy ion data is 40-50% above $pp/\bar{p}p$ data, the e^+e^- data has the same trend and a similar magnitude (within 10%) over a large range in $\sqrt{s} = 14 - 183$ GeV [3]. This correspondence holds over the bulk of the angular distribution, as shown in Fig. 3, where central Au+Au (divided by $\langle N_{part}/2\rangle$), $\bar{p}p$ [2] and e^+e^- [5] data are compared, all at $\sqrt{s} = 200$ GeV. In the lower panel, we observe that the shapes of the Au+Au and $\bar{p}p$ distributions are also very similar over a large η range, but the integrals differ by $\sim 40\%$.

In Fig. 4, we compare $\langle N_{ch}\rangle/\langle N_{part}/2\rangle$ in heavy ion collisions [6] to e^+e^- and $pp/\bar{p}p$ data over a large range in $\sqrt{s}$ [7]. It is observed that $\langle N_{ch}\rangle/\langle N_{part}/2\rangle$ lies below pp at low energies, passes through the pp data around $\sqrt{s} \sim 10$ GeV, and then gradually joins with the e^+e^- trend above CERN SPS energies. These comparisons can be seen more clearly by dividing all of the data by a fit to the e^+e^- data [8].

The $pp/\bar{p}p$ data follows the same trend as e^+e^-, but it can be shown that it matches very well if the "effective energy" $\sqrt{s}_{\rm eff} = \sqrt{s}/2$ is used, which accounts for the leading particle effect seen in pp collisions [9]. Ref. [9] finds that bulk particle production in pp and e^+e^- data does not depend in detail on the collision system but rather the energy available for particle production. In this scenario, the Au+Au data suggests a substantially reduced leading particle effect in central collisions of heavy nuclei at high energy.

The alleviation of the leading particle effect might not be so surprising in nuclear collisions. Each participating nucleon is typically struck $\bar{\nu} > 3$ times on average as it passes through the oncoming gold nucleus for $N_{part} > 65$. One could speculate that the multiple collisions transfer much more of the initial longitudinal energy into particle production. This naturally leads to the scaling of total particle production in heavy ion collisions with N_{part}, as seen in Fig. 5, reminiscent of the "wounded nucleon model" [10] but with the scaling factor determined by e^+e^- rather than pp.

4. Conclusions

In conclusion, PHOBOS has observed two kinds of universal behavior. The first is an energy-independent, but centrality-dependent, universal limiting distribution of charged particle production away from midrapidity. The second is that the total charged particle multiplicity per participant pair in heavy ion collisions above CERN SPS energies scales with sqrt(s) in a similar way as e^+e^- collisions. These two kinds of universality strongly constrain the energy dependence of the total charged particle multiplicity and angular distributions, and may offer a new perspective on particle production in heavy ion collisions.

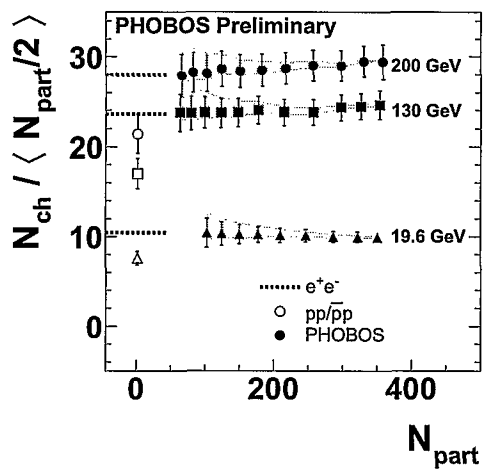

Figure 5: The total number of charged particles per participant pair shown as a function of N_{part} for $\sqrt{s_{NN}}$ = 19.6, 130, and 200 GeV.

5. Acknowledgements

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REFERENCES

1. B. B. Back *et al.*, submitted to Phys. Rev. Lett. (2002).
2. G. J. Alner *et al.*, Z. Phys. C **33**, 1 (1986).
3. P. Abreu *et al.*, Phys. Lett. B **459**, 397 (1999).
4. B. B. Back *et al.*, Phys. Rev. Lett. **88**, 022302 (2002). B. B. Back *et al.*, arXiv:nucl-ex/0201005 (2002).
5. H. Stenzel, ALEPH Collaboration, Contributed paper to ICHEP2000 (2000).
6. J. Klay, U.C. Davis PhD. Thesis (2001). S. V. Afanasiev *et al.*, arXiv:nucl-ex/0205002 (2002).
7. D. E. Groom *et al.*, Eur. Phys. J. C **15**, 1 (2000).
8. A. H. Mueller, Nucl. Phys. B **213**, 85 (1983).
9. M. Basile *et al.*, Phys. Lett. B **92**, 367 (1980). M. Basile *et al.*, Phys. Lett. B **95**, 311 (1980).
10. J. E. Elias *et al.* Phys. Rev. Lett. **41**, 285 (1978). A. Białas, B. Bleszyński and W. Czyż, Nucl. Phys. **B111**, 461 (1976).