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An On-Line Longitudinal Vertex and Bunch Spectrum Monitor for RHIC

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An on-line Longitudinal Vertex and Bunch Spectrum Monitor for RHIC*

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Abstract

The longitudinal bunch profile acquisition system at RHIC was recently upgraded to allow on-line measurements of the bunch spectrum, and collision vertex location and shape. The system allows monitoring the evolution of these properties along the ramp, at transition and rebucketing, and at store conditions. We describe some of the hardware and software changes, and show some applications of the system.

WALL CURRENT MONITOR SYSTEM

Hardware and Front-End software

The wall-current-monitor(wcm) pickups, hardware and system setup is described in [1]. Since that time the system has been upgraded with the addition of a second oscilloscope, and for reduced signal jitter, the trigger system was updated to allow for smart-triggers using the RHIC 28 Mhz signal zero crossing.

For the purpose of vertex monitoring the system was upgraded to allow for the signals of both rings to be digitized by the same oscilloscope, giving time correlated signals. Figure 1 shows the signal paths from pickup, through the oscilloscopes, to the front-end software, and data delivery.

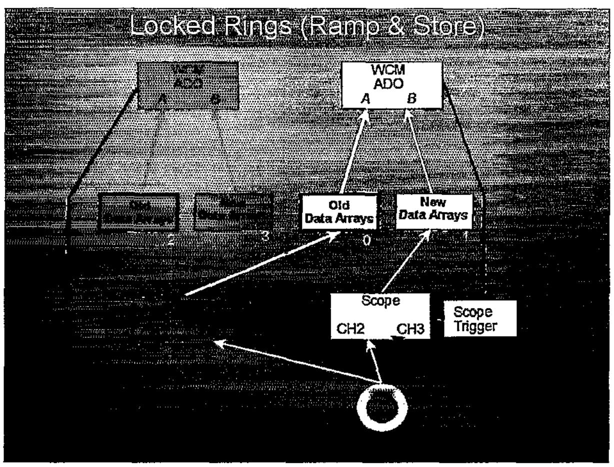

Figure 1: Blue and yellow wcm signal connections

Modes

The high-level server [2] organizes the data from the front-end into known 'modes', which include transition and rebucketing, where we digitize several bunches for thousands of turns, and the default ring fill-pattern mode where we digitize all bunches in one full turn for each ring. The data associated with these states is presented to on-line displays (see Figure 2). For the 'Fill Pattern' mode a buffer is maintained for approx. 1 hour of beam time.

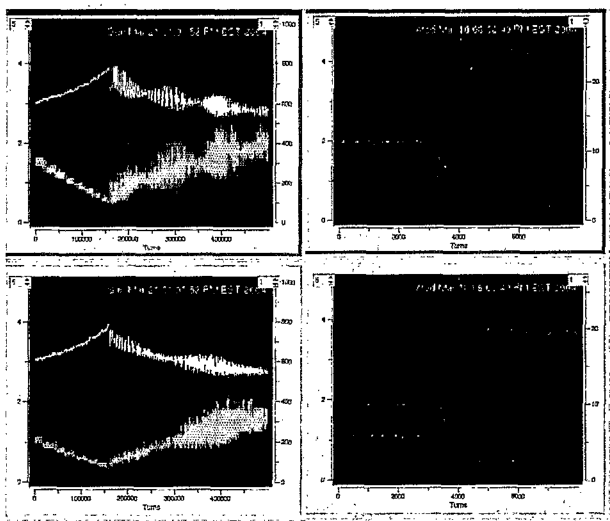

Figure 2: Bunch width (Green) and amplitude (White) in both rings during transition, and rebucketing.

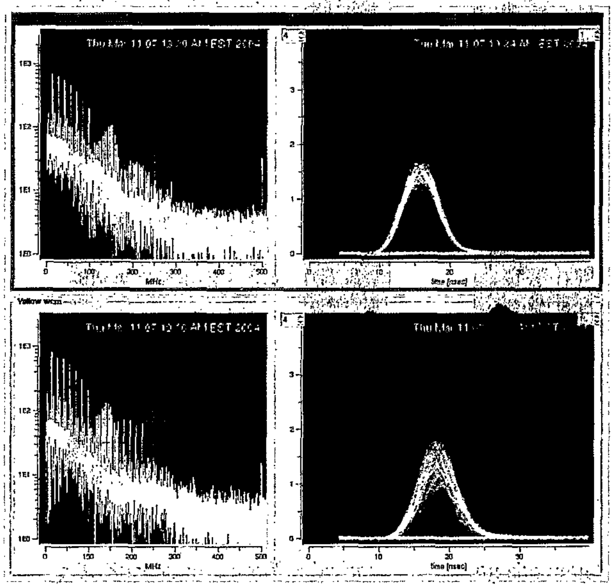

Figure 3: Spectra and profiles before rebucketing showing the effect of the Landau cavities.

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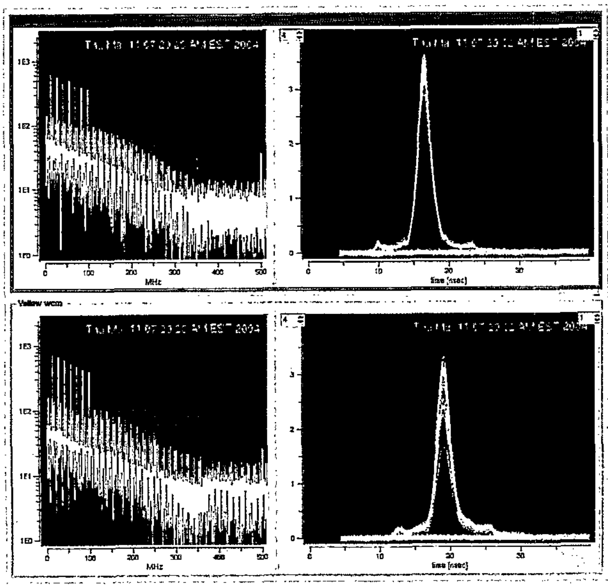

Figure 4: Spectra and profiles after rebucketing.

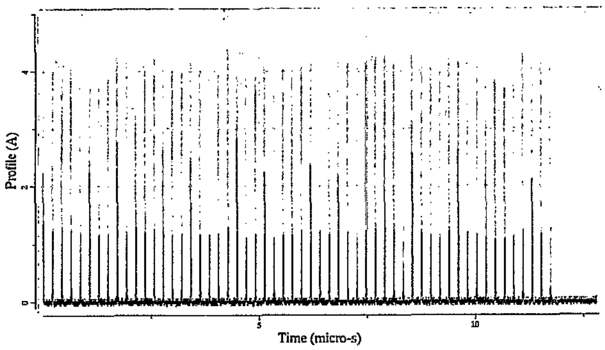

Figure 5: Longitudinal profiles along the Blue run after rebucketing (Orange), and at the end of store (Blue), showing a typical 56 bunch fill pattern and the abort gap.

VERTEX CALCULATION

The discrete correlation of two periodic functions g_k and h_k is defined by

$$\mathrm{C}(g,h)_j = \sum_{k=0}^{N-1} g_{j+k} h_k = G_k H_k^* \qquad (1)$$

where G and H are the Fourier transforms of g and h.

For use in the correlation calculation the signal from the wall-current-monitor is re-sampled as a periodic signal of length $N = 2^n$. Typically the digitizer is set up to run at 4 G/s, and one turn at 78 kHz revolution frequency is re-sampled to 2^{16} points. Higher resolution is possible by interleaving multiple turns. However, this requires the use of an external highly stable time base which was not implemented in this system for the FY04 run.

The vertex distributions at other interaction regions are retrieved from $\mathrm{C}(g,h)$ by shifting the index, i.e. the IR 6 vertex is

$$\sum_{k=0}^{N-1} g_{k+2N/3} h_{k+N/3} = \sum_{k=0}^{N-1} g_{k+N/3} h_k = \mathrm{C}_{N/3} \qquad (2)$$

since the signal has to travel $2/3$ of the blue ring, and $1/3$ of the yellow ring to reach the wcm pickup at IR 2. Table 1 gives the index for each interaction region.

IR		Blue	Yellow	Index
2	Brahms	0	0	C_0
4		5/6 N	1/6 N	$\mathrm{C}_{-N/3}$
6	Star	2/3 N	1/3 N	$\mathrm{C}_{N/3}$
8	Phenix	1/2 N	1/2 N	C_0
10	Phobos	1/3 N	2/3 N	$\mathrm{C}_{-N/3}$
12		1/6 N	5/6 N	$\mathrm{C}_{N/3}$

Table 1: Beam distance from each IR to wcm pickup, and associated index in correlation vector.

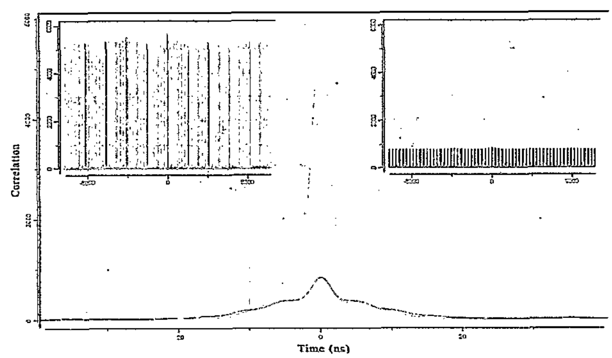

Figure 6: Correlation along the ring with 56 bunches injected, and the vertex for interaction region IR 2, after rebucketing at the start of store 4829 (Orange), and after 7 hours (Blue). The ratio between IR's can substantially deviate from the expected 52/56 ratio due to non-uniform filling of the rings.

APPLICATIONS

Cogging

The system was used to determine non-optimized longitudinal cogging situations, several cases where the beam seemed to have jumped several buckets due to timing glitches were analyzed. Currently the quality of the beam cogging process is determined by looking at the signal from a single separate wall-current-monitor which samples both beams simultaneously. Minimizing this signal is complicated by different beam intensities in each ring. After calibration, the vertex monitor system will be used instead, where now the integrated vertex signal can be maximized by modifying the RF phase. This should give a more precise method to optimize the cogging. On the acceleration ramp the beams are intentionally anti-cogged to avoid beam-beam effects. However, this condition is not perfectly maintained and here the vertex location can be used to provide a metric for the longitudinal separation, and correlate with possible effects on the beam.

Irregular bunch patterns

In order to deal with pressure rise due to vacuum issues, non-regular bunch patterns were routinely used [3]. Fig. 7 gives the correlation of a 45x45 bunches fill. Together with the model predicted transverse lattice-functions, the integrated vertex ratios can be used to analyze discrepancies in luminosity ratios between different IR's.

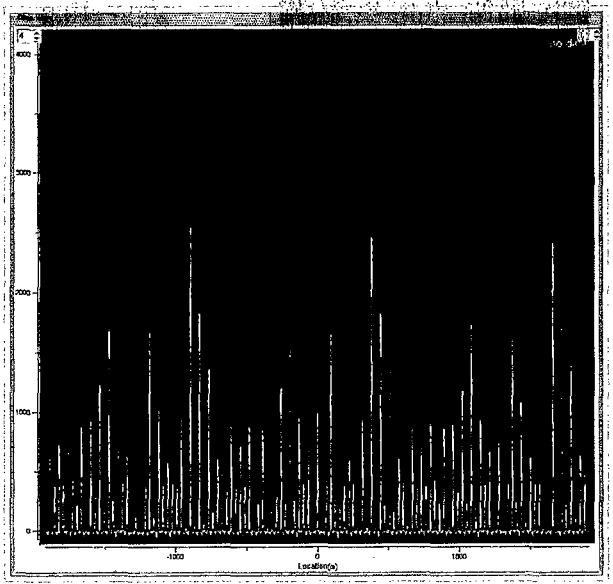

Figure 7: Vertex distribution for an irregular 45 bunch pattern. Horizontal scale is in meters. Peaks are at 0 m and at ±1/3 of the circumference of RHIC = ±1278m.

Relative emittance monitor

Assuming constant β^* and optimized steering [4], the collision rates are proportional to the integral of the vertex, and inversely proportional to the transverse emittance:

$$\text{collision rate} \approx 1/\epsilon \times \int_{\text{IR}} C(g,h)\text{d}t \qquad (3)$$

where the integral is taken over the time window of the measured vertex. Fig. 8 shows the evolution of these parameters for IR 8 (Phenix), normalized wrt. the start of the store. The deduced emittance increase is a factor of 1.8 over a 7 hour store. For FY05 this signal, and the time derivative, will be available each 4 seconds, aiding in the on-line analysis of luminosity rates during operations, and machine-experiments. Integration with the experimentally measured vertex diamond will be improved to allow verification of the measured signals.

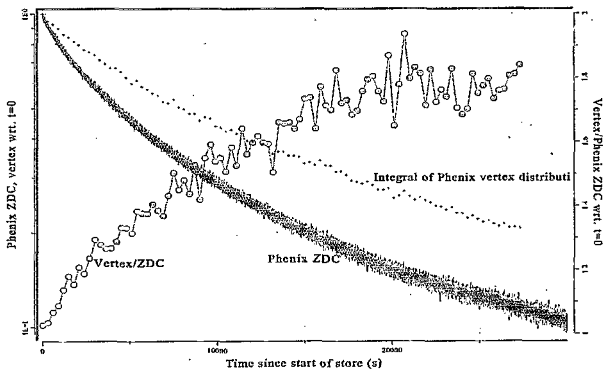

Figure 8: Phenix ZDC rates (Brown), and integral of vertex (Blue) normalized wrt. the start of store 4829, and deduced emittance increase (Red) as a function of time in store.

CONCLUSIONS AND PLANS FOR FY05

The wall-current-monitor system has proven to be very flexible, and has performed reliably at 0.25Hz for routine display of fill patterns, bunched beam intensities, bunch spectra, vertex location, and vertex shape. The special modes for Transition and Rebucketing have shown to be very useful for operational analysis. For FY05 we plan on adding the capability to catch many turns for each injected bunch. Also effort will be spend on bringing tomographic reconstruction of injected bunches, and the rebucketing process, to the on-line displays. For data interleaving, data throughput issues will need to be addressed to be able to deal with the increased data sizes.

ACKNOWLEDGEMENTS

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