RESULTS FROM VERNIER SCANS AT RHIC DURING THE PP RUN 2001-2002*

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Abstract

Using the Vernier Scan or Van der Meer Scan technique, where one beam is swept stepwise across the other while measuring the collision rate as a function of beam displacement, the transverse beam profiles, the luminosity and the cross section can be measured. Data and results from the polarized proton run in the year 2001/02 are presented.

INTRODUCTION

The cross section observed by the experimental trigger counters is one of the necessary ingredients to absolutely normalize experimental data in heavy ion and proton collisions such as data on π° production. During the Au-Au runs ZDCs [1] are used for minimum bias triggering because of their large cross section. The ZDCs are common to all experiments . During pp runs, however, those detectors are not suitable for triggering because of their small cross section when protons collide. Instead, experiments use individual beam beam counters (BBC), which are of different type, shape, location and acceptance. In general, a BBC consists of two identical parts at a certain distance on either side of the vertex location at an Interaction Point (IP). Collision rates are typically measured by a coincidence of particle detection on both sides. In order to determine the cross section observed by those detectors, Vernier Scans at the individual IPs were performed collecting data from the local BBCs. In this report, we describe the method of Vernier Scans to measure the absolute cross section of pp collisions at $\sqrt{s_{NN}} = 200$ GeV at the STAR and PHENIX experiment at the Relativistic Heavy Ion Collider (RHIC).

VERNIER SCANS

The Vernier Scan technique was invented by S. van der Meer in 1968[2] who showed that it is possible to measure the effective height h_e of the colliding ISR beams by observing the counting rate R in a suitable monitor system while sweeping the two beams vertically through each other. A Gauss-shaped curve results with its maximum at zero displacement. The interaction rate observed by a BBC detector, R_{BBC}, is defined as the total number of beam particles (N_{blu} and N_{yel}) going through each other in some area A with cross section σ_{BBC}:

$$R_{BBC} = \frac{Nt_{blu} Nt_{yel}}{A} \sigma = \mathcal{L} \sigma_{BBC} \quad (1)$$

For two beams with Gaussian distribution in both, horizontal and vertical directions, the luminosity is given by [3]:

$$\mathcal{L} = \frac{k_b f_{rev} N_1 N_2}{2\pi \sqrt{(\sigma_{x1}^2 + \sigma_{x2}^2)(\sigma_{y1}^2 + \sigma_{y2}^2)}}. \quad (2)$$

with i=1,2 for blue and yellow beams respectively and N_i the number of particles per bunch assuming all bunches in one beam are of the same intensity. Bunch-to-bunch variations will be discussed below. In the case of non-centered beams, consider the case of one beam displaced by d, the luminosity $\mathcal{L}(d)$ as a function of d is:

$$\mathcal{L}(d) = \frac{k_b f_{rev} N_1 N_2 \exp\left[-d^2/2(\sigma_{x1}^2 + \sigma_{x2}^2)\right]}{2\pi \sqrt{(\sigma_{x1}^2 + \sigma_{x2}^2)(\sigma_{y1}^2 + \sigma_{y2}^2)}} \quad (3)$$

The terms $\sqrt{\sigma_{i1}^2 + \sigma_{i2}^2}$, where $i = x, y$, in Eq.3 and Eq.2 correspond to the beam profile derived from the width of the distribution measured by the Vernier Scan. The result for the horizontal plane is:

$$\sigma_{Vx} = \sqrt{\sigma_{x1}^2 + \sigma_{x2}^2}. \quad (4)$$

Vernier Scans measure the effective beam profile over the whole longitudinal interaction area between the two halfs of a BBC, i.e. approximately +/- 0.75 m (PHENIX) and +/- 3.5 m (STAR), instead of measuring the beam transverse size at the center of the IP only. However, the collision rates we get from those detectors do correspond to the number of events originating from the entire effective beam area as well. Therefore, applying a Gauss-fit+constant to the normalized collision rate = $R_{BBC}/Nt_{blu}Nt_{yel}$ as a function of beam displacement yields the effective beam size as well as the maximum achievable normalized rate R_{max}, the optimal position and the background. Fig. 1 shows an example of a typical data set and the applied Gauss fit. From this

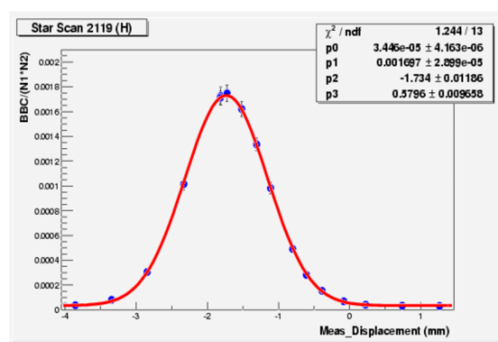

Figure 1: *Vernier Scan in STAR in the horizontal plane.*

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the cross section σ_{BBC} can be derived:

$$\sigma_{BBC} = 2\pi \; R_{max} \; \sigma_{Vx} \; \sigma_{Vy} \; k_b / f_{rev} \qquad (5)$$

where f_{rev} is the revolution frequency and k_b the number of bunches per ring.

DATA ANALYSIS

Table 1 lists the available vernier scans from the pp_fy02 run at the STAR and PHENIX IRs respectively. The data

Table 1: *List of vernier scans performed at STAR and PHENIX during the year 2002 RHIC pp run. All scans were done at a β^* of 3m.*

fill	IP	beam	comment
2136	8	blue	$\sigma_{vtx} = 80cm$
2161	8	yellow	$\sigma_{vtx} = 80cm$
2277	8	yellow	$\sigma_{vtx} = 60cm$
2119	6	blue	1/2 scan
2161	6	yellow	
2193	6	yellow	no BPM
2277	6	yellow	

needs to be corrected for several effects: for the beam displacement in the other plane during a scan, for the actual bunch pairing at the given IR taking into account the bunch-to-bunch intensity variation and for the crossing angle between the two colliding beams (if any). The precision of the measured beam displacement and the bunched beam current add to the systematic errors.

Beam Position Measurements

When a vernier scan is performed, the beam displacements are not necessarily minimized. Thus the maximum achievable rate could be reduced by a certain amount depending on the offset from the optimal position in the other plane. In addition, beam position changes in one plane are induced by doing a scan in the other due to coupling. Therefore the beam position is recorded in both planes while doing a scan in one. The measured collision rates are then corrected for the deviation from the optimal position. Accurate beam position measurements (here from the BPMs at the DX magnets) are hence crucial to the procedure. Fig. 2 shows the RMS of the typically 14 beam position measurements per data point, corresponding to 60 sec of data taking per position. The average RMS is of the order of 5 μm but about a factor of 2 higher in the horizontal plane. The BPM scatter is taken into account by adding a 3% point-to-point systematic error. The uncertainty in the absolute scale of the BPM measurement [6] is considered by adding an absolute systematic error of 2%.

Fill Pattern

The collision rates during a scan is normalized by the total bunched beam current in the ring during the 60 seconds

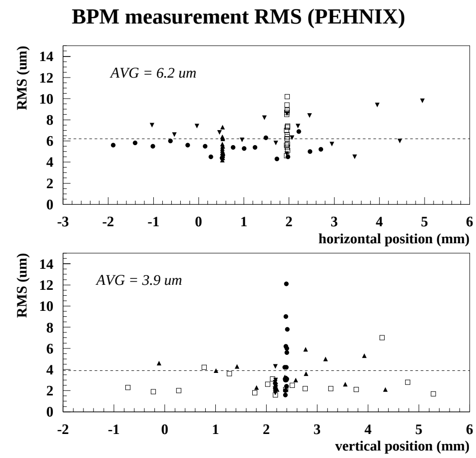

Figure 2: *RMS of beam position measurements from two vernier scans in PHENIX, 2136 and 2161.Each value corresponds to the RMS of 14 measurements which are included in one data point for the scans.*

of the data taking. The bunched current is measured by the Wall Current Monitor (WCM) [4]. The WCM readings are calibrated with the DCCT [5] measurements at the end of the ramp when only bunched current can be present. A systematic point-to-point error of 1-2% is assigned to the uncertainty of the WCM measurements after this calibration. Since bunch-to-bunch intensities vary and the colliding bunch pairs depend on the IR, the R_{max} value from the Gauss-fit has to be corrected for the actual measured intensity of colliding pairs. Fig. 3 shows the colliding blue-yellow pairs for the PHENIX vernier scans. Taking the fill

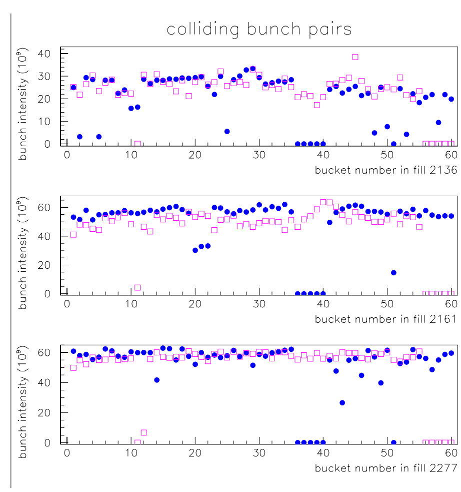

Figure 3: *Bunch intensity for blue and yellow beams as a function of bunch number during the PHENIX vernier scans. Note that blue bunches are shifted by +41 corresponding to actual pairing in PHENIX. The abort gap does not line up in PHENIX.*

pattern into account, the product of the total beam currents needs to be corrected by factors from 0.9 to 0.97, depending on IR and fill.

Crossing Angle

In case a crossing angle between the colliding beams in the horizontal plane is present the achievable luminosity has to be corrected by a factor R [7]:

$$R = \sqrt{1 + (\frac{\sigma_z}{\sigma_x^*} tan\phi)^2} \tag{6}$$

(vertical plane accordingly). For an average beam size of σ_x^* = 360 μm and a typical bunch length of about 1m, R amounts to 1% for an angle of $\phi = 0.1$ mrad and 4% for $\phi = 0.2$ mrad. From the BPM measurements we derived the crossing angles for the vernier scan fills (only PHENIX so far). Fig. 4 shows the extrapolated beam trajectory between the DX BPMS at +/- 8m. Since the data is taken

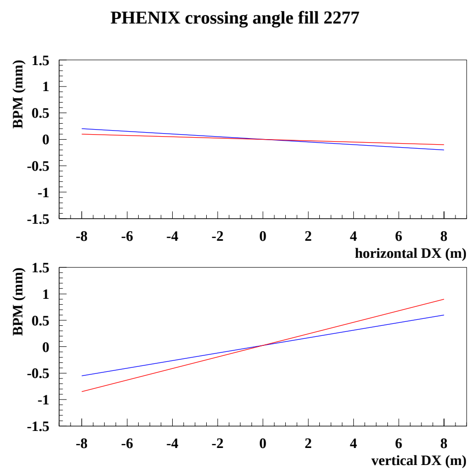

Figure 4: *Beam trajectories at IR8 in fill 2277 in the horizontal plane (top) and vertical plane (bottom). The angle between the two lines corresponds to the crossing angle ϕ.*

after a vernier scan no transverse offset between the beam is present. However, due to digital offsets in the electronics the BPM readings for the two beam were not identical although the DX BPM are recording positions for both beams. The two trajectories were vertically shifted by a few 100 μm so they would cross at 0. The angle between the trajectories reached 0.1 mrad in one case and was significantly smaller in all other. By applying the same shift on one side only one would create a larger angle ϕ. This value was found to be 0.1 mrad on average and used to determine a systematic point-to-point error of 1%.

SUMMARY

The cross sections and point-to-point errors are listed in tab. 2. A common absolute error for the uncertainty of the BPM scale of 2% and for the beam blow up due to the scan itself of 1% has to be added to the statistical and systematic errors. A weighted fit of the available measurements is shown in fig. 5. Thus the final value for the BBC cross section is found for
STAR: $\sigma_{BBC} = 21.6 \pm 0.2 \pm 1.0 \pm 0.8$ mbarn and for

Table 2: *Cross sections (Xsec) and statistical and systematic errors obtained from the individual vernier scans. All values are given in units of mbarn.*

fill	IP	Xsec	stat.	sys.
2136	8	12.3	0.2	1.3
2161	8	13.0	0.2	1.4
2277	8	12.8	0.1	1.0
2119	6	25.6	0.4	2.8
2161	6	27.5	0.5	1.8
2193	6	26.7	0.4	1.9
2277	6	24.6	0.4	1.5

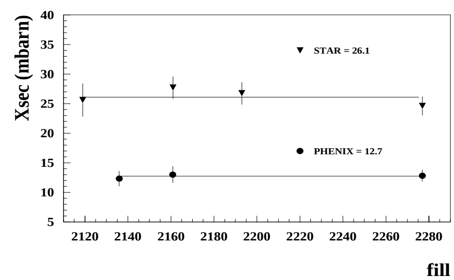

Figure 5: *Final cross sections of the STAR and PHENIX beam beam counters (BBC). Error bars include statistical and point-to-point systematic errors.*

PHENIX: $\sigma_{BBC} = 12.7 \pm 0.1 \pm 0.3 \pm 0.4$ mbarn.

Note that the PHENIX value is arbitrarily normalized to a vertex distribution σ_{vtx} of 80 cm and the third scan (2277) was scaled by the ratio $\frac{60cm}{80cm}$. In order to normalize the cross section to the entire interaction region, data from the PHENIX experiment is necessary, which was outside of the scope of this report. Since the STAR BBC covers the full interaction region, no further correction is necessary.

It could be shown that the Vernier Scan method is a powerful tool not only to determine the absolute instantaneous luminosity but also to provide the experiments with a valuable and independent measurement of the cross section seen by their BBC.

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