The Beam-Beam Counter: A Local Polarimeter at STAR

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Abstract. At the Brookhaven National Laboratory (BNL) Relativistic Heavy Ion Collider (RHIC) the Beam-Beam Counter (BBC) array for the Solenodial Tracker at RHIC (STAR) is a very versatile tool for polarized proton beam diagnostics. The BBC setup provides an excellent minimum bias trigger; and for hits on the inner annuli of six hexagonal scintillator tiles the BBC coincidence trigger with a suitable algorithm has a quite large single spin analyzing power $\sim 8\times 10^{-3}$ for 100 GeV polarized proton – 100 GeV polarized proton collisions. The STAR BBC is a very effective local polarimeter at these energies. For 100 GeV $\vec{p}$ -100 GeV $\vec{p}$ running in 2006 the BBC measured single spin asymmetries to a statistical accuracy of better than 2% for a data run of 20-30 minutes; and these measurements were quite robust. For fills with a duration of at least six hours these STAR BBC asymmetry measurements were used to study the time dependence of the polarization for 100 GeV proton beams in the RHIC rings. The decrease of the polarization is quite small, $\leq 0.01 P_B$ per hour .

Keywords: Polarization, RHIC, Polarimeter, Polarimetry
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INTRODUCTION

Through the initiative and management of Les Bland and Akio Agawa a local polarimeter for polarized proton beams, the Beam-Beam Counter (BBC), has been constructed and commissioned for the Solenoidal Tracker at RHIC (STAR) detector. The analyses presented in this paper of the BBC data for 2006 100 GeV $\vec{p}$ – 100 GeV $\vec{p}$ RHIC running, were performed by Joanna Kiryluk and Ernest Sichtermann. The BBC has been discussed in a set of previous publications.[1,2,3]

THE BBC LOCAL POLARIMTER

The BBC detector is a set of scintillator annuli installed around the RHIC beam pipe on the EAST and WEST pole tips of the STAR magnet. Figure 1 presents a schematic side view of the BBÇ EAST and BBC WEST detector arrays in relation to the STAR Magnet and Time Projection Chamber (TPC). Both BBC EAST and BBC WEST are 3.75 meters from the center of the STAR interaction region. The counter configurations for the BBC annuli are presented in Figure 2. A total BBC consists of two annuli; and each annulus is made-up of close packed hexagonal detectors in two rings: the inner ring has six tiles; while the outer ring has twelve tiles. These

scintillator tiles are 1cm. thick. Scintillation signals are transmitted by four optical fibers embedded in each tile to an individual, magnetically shielded photomultiplier placed on the outer rim of the STAR Magnet poletip. An average photomultiplier input signal of 15 photoelectrons is obtained for a minimally ionizing particle transversing a scintillator tile. For the operation of the BBC detector as a local polarimeter signals are used only from the 18 tiles of the inner annulus of BBC EAST and BBC WEST. These eighteen tiles subtend a range of pseudorapidity η from 3.4 to 5.0. A BBC trigger corresponds to a prompt coincidence between at least one (out of eighteen total) tile firing in both BBC EAST and BBC WEST; and these prompt coincidences originate from relativistic, high η particles produced by p-p collisions in the STAR interaction region. Note that a halo particle takes ~25 ns to travel between the two tile arrays; and such correlated BBC EAST - BBC WEST fires are easily distinguished from the prompt coincidences defining the BBC trigger. This BBC trigger defines a minimum bias trigger corresponding to a p-p cross section of $\cong$ 26 mb, 87% of the p-p inelastic total cross section excluding single diffraction processes.

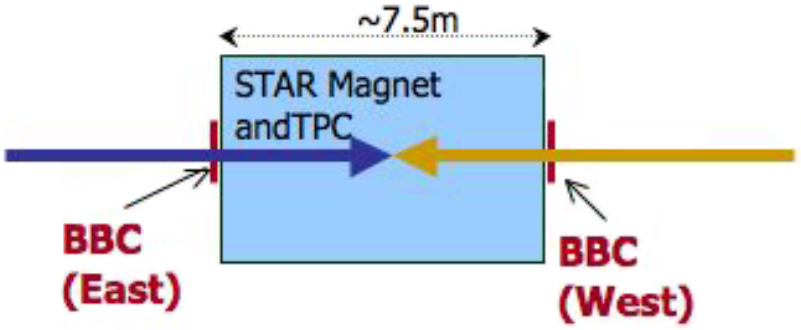

FIGURE 1. Schematic side view of BBC positions.

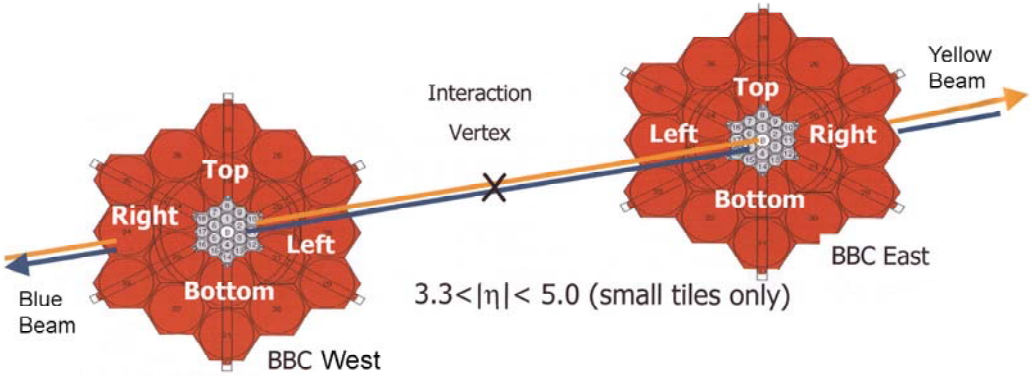

FIGURE 2. Setup of inner and outer hexagonal tile annuli for BBC East and BBC West.

The Blue and Yellow polarized proton beams at RHIC consist of bunches with either polarization $(\uparrow)$ or polarization down $(\downarrow)$ The bunch-bunch $\vec{p}-\vec{p}$ collisions in the STAR interaction region used by the local BBC polarimeter for asymmetry measurement are $B\uparrow Y\uparrow$,$B\uparrow Y\downarrow$, $B\downarrow Y\uparrow$, and $B\downarrow Y\downarrow$. BBC asymmetry measurements for the BLUE polarized proton sum the BBC triggers from the bunch-bunch collisions $B\uparrow Y\uparrow$ and $B\uparrow Y\downarrow$for BLUE beam "up" and the BBC triggers from the bunch-bunch

collisions $B\downarrow Y\uparrow$ and $B\downarrow Y\downarrow$ for BLUE beam "down". The measured BLUE beam asymmetry is then defined by left-right scattering for the particle firing the BBC WEST detector (see figure 2):

$$\varepsilon_{BBC}^{BLUE} = \frac{\sqrt{N_L\uparrow N_R\downarrow} - \sqrt{N_L\downarrow N_R\uparrow}}{\sqrt{N_L\uparrow N_R\downarrow} + \sqrt{N_L\downarrow N_R\uparrow}} \cong A_N P_B^{BLUE} \qquad (1)$$

where the ↑,↓ arrow refers to the BLUE polarized beam; and there is a similar equation for the asymmetry of the yellow beam for scattered particles into the BBC EAST detector. Not all BBC triggers are useful for asymmetry measurements. More than half of the p-p collisions giving a minimum bias BBC trigger produce at least one particle both left and right into a BBC detector array. Thus one must use an algorithm to define left-right scattering. This algorithm is presented in Figure 3. For the Blue beam this represents conditions on fires in BBC WEST; and at least one of any of the eighteen tiles in BBC EAST must fire. For a recorded $3.9 < \eta < 5.0$ right scattering at least one of the inner two right tiles must fire, none of the outer three right tiles or any of the inner and outer five left tiles can fire and the eight up/down tiles can fire. For a recorded $3.4 < \eta < 3.9$ right scattering at least one of the outer three right tiles must fire, none of the inner two right tiles or any of the inner and outer five left tiles can fire and the eight up/down tiles can fire. Now it has been determined empirically that ε_{BBC} for the $3.9 < \eta < 5.0$ algorithm is quite large while ε_{BBC} for the $3.4 < \eta < 3.9$ algorithm is consistent with zero. Thus the algorithm $3.9 < \eta < 5.0$ is used for BBC local polarimetry. For $100\ \text{GeV}\ \vec{p} - 100\ \text{GeV}\ \vec{p}$ collisions in the STAR interaction region about 20% of the BBC minimum bias triggers satisfy the $3.9 < \eta < 5.0$ algorithm.

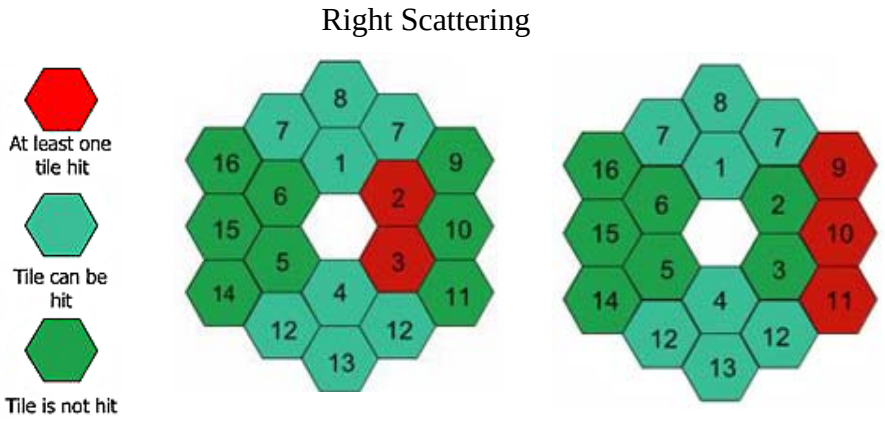

FIGURE 3. BBC event selection for asymmetry measurements (right scattering)
a) $3.9 < \eta < 5.0$ b) $3.4 < \eta < 3.9$

MEASUREMENTS USING THE BBC LOCAL POLARIMETER

A. Transverse and Radial Components for $\vec{P}_B$.

The BBC local polarimeter can be used to measure accurately both the normal (up-down) and radial (left-right) transverse components for the 100 GeV polarized proton beams at RHIC. Table 1 presents data from an ~5.5 hour fill on May 9, 2006. The $\varepsilon_{\mathrm{BBC}}$ L-R measurement and U-D measurements are proportional to the normal and radial transverse components for $\overrightarrow{\mathrm{P_B}}$, respectively. The quite small $\Delta\varepsilon_{\mathrm{BBC}}$ values follow from the very large number of recorded BBC coincidences in a given run. The value for $\Delta\varepsilon_{\mathrm{BBC}}$ is given statistically by:

$$\Delta\varepsilon_{\mathrm{BBC}} = (\mathrm{N_T})^{-1/2}$$
$$\text{where} \quad \mathrm{N_T} = N_L\uparrow + N_L\downarrow + N_R\uparrow + N_R\downarrow \qquad (2)$$

For a typical 21 minute, 1.27×10^3sec BBC run with a minimum bias rate of $440\times10^3\mathrm{sec}^{-1}$, $N_T = 440\times10^3\times1.27\times10^3\times0.20 = 1.12\times10^8$ and $\Delta\varepsilon_{BBC} = 9.5\times10^{-5}$. For the May, 2006 100 GeV $\vec{\mathrm{p}}$ – 100 GeV $\vec{\mathrm{p}}$ –running $\mathrm{P_B}$ (normal) was $\cong 0.60$ for both yellow and blue beams at RHIC. The Table 1 data indicates that the BBC local polarimeter can measure both normal and radial transverse components for the proton beam polarization to accuracies $\Delta\mathrm{P_B} \cong 0.015$ for runs lasting approximately twenty minutes. These BBC measurements greatly facilitate the production of almost pure longitudinal polarized beams at the STAR using Spin Rotators. BBC polarimetry allows fast and accurate tuning of the Spin Rotator system.

TABLE 1. BBC measurements for both transverse components – normal and radial – for the polarization vectors of the RHIC proton beams at the STAR detector

Data for Fill 13 May 9, 2006

	BBC L-R measurements for the inner six BBC tiles		BBC U-D measurements for the inner six BBC tiles	
Time(hr.)	$\varepsilon_{\mathrm{BBC}}$ Yellow Beam (10^{-5})	$\varepsilon_{\mathrm{BBC}}$ BlueBeam (10^{-5})	$\varepsilon_{\mathrm{BBC}}$ Yellow Beam (10^{-5})	$\varepsilon_{\mathrm{BBC}}$ Blue Beam (10^{-5})
0	400±6	401±6	10±7	-4±7
0.8	392±6	378±6	18±7	5±7
2.2	383±6	388±6	22±8	15±8
2.9	391±7	376±7	13±8	4±8
4.0	385±6	376±6	37±8	-4±8
5.2	373±7	385±8	17±9	6±9

B. Time Dependence for $\overrightarrow{\mathrm{P_B}}$

For 100 GeV $\vec{\mathrm{p}}$ –100 GeV $\vec{\mathrm{p}}$ RHIC running in May 2006 $\varepsilon_{BBC} \cong 400\times10^{-5}$ for $\mathrm{P_B} \cong 60\%$ and $\Delta\varepsilon_{BBC} \cong 6-8\times10^{-5}$ for a run of ~20-30 minutes. Thus a group of five fills during the period from May 4, 2006 through May 7, 2006 was used to study the time dependence $P_B(t)$ through measurement of $\varepsilon_{BBC}(t)$. The following criteria were used:

i. BBC data for ε_{BBC} were taken for at least 5.5 hours during a given fill.

ii. The statistical accuracy for a given $\varepsilon_{BBC}(\mathrm{L}-\mathrm{R})$ measurement was <3%.

The $\varepsilon_{\mathrm{BBC}}(\mathrm{t}) \pm \Delta\varepsilon_{\mathrm{BBC}}$ measurements for a given fill were fit to the linear function $\varepsilon_{\mathrm{BBC}}(\mathrm{t}) = \varepsilon(0)(1-a\mathrm{t})$ and values for $\varepsilon(0), a, \Delta\varepsilon(0)$ and Δa were extracted. Figure 4 presents the data and linear fits for two fills while Table 2 presents the $a \pm \Delta a$ values determined for the five fills indicating a decrease of less than 0.01 $\mathrm{P_B\ hr^{-1}}$ in the normal component of the RHIC 100 GeV polarized proton beams.

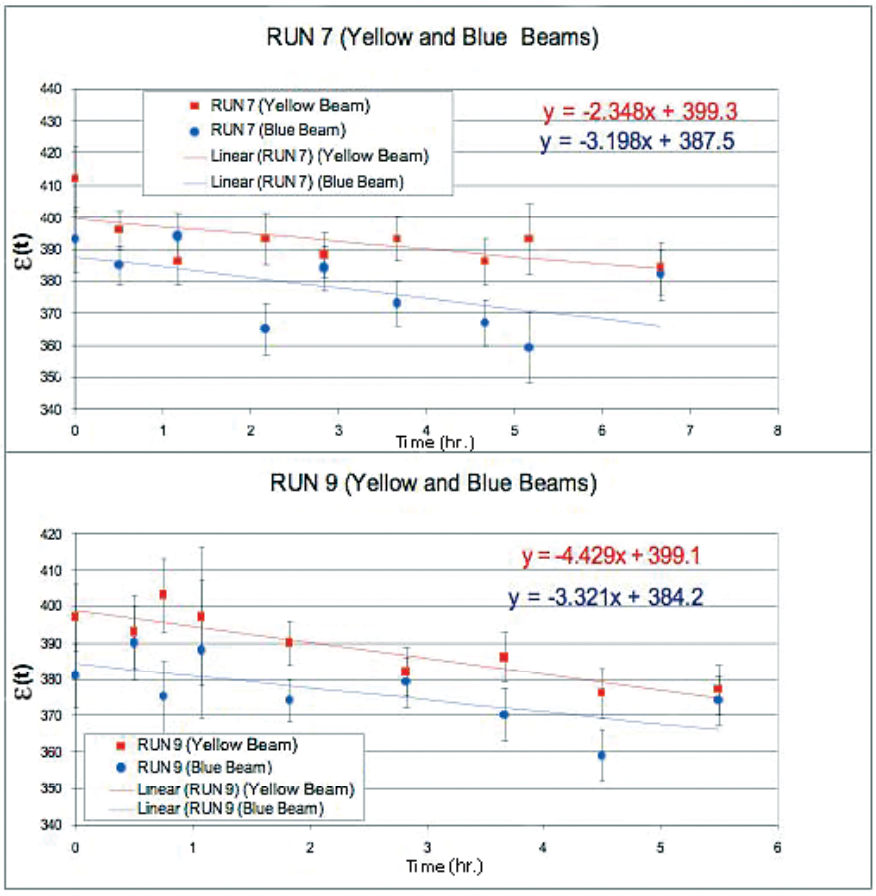

FIGURE 4. $\varepsilon_{BBC}(t)$ measurements for the yellow and blue 100 GeV polarized proton beams during two long ($\geq$ 6 hour) fills. These data are fit with linear time dependent curves.

TABLE 2. Analysis of $\varepsilon_{BBC}(t)$ from BBC measurements May 4 – May 7, 2006 $\varepsilon_{BBC}(t)$ data fit to function. $\varepsilon_{BBC}(t) = \varepsilon(0)(1-at)$

	Results	
Fill	Yellow Beam	Blue Beam
	a±Δa (10^{-3}/hr.)	a±Δa (10^{-3}/hr.)
4	5.6±3.4	7.3±3.6
5	12.5±3.7	11.0±3.0
6	5.7±2.7	6.4±2.7
7	5.8±3.0	8.2±3.3
9	11.1±3.7	8.6±3.9

At RHIC the polarizations for 100 GeV polarized proton beams (BLUE and YELLOW) are monitored both by the BBC local polarimeters discussed in this paper and by Coulomb-Nuclear Interference (CNI) polarimeters[4,5,6,7,] which use the asymmetry in $\vec{p}$–^{12}C elastic scattering at low four-momentum transfer, $t, \left(0.009 \le t \le 0.022 \ \ \mathrm{GeV}^2/c^2\right)$. Table 3 compares these two methods by determining a super ratio from the polarimetry measurements taken by both experimental methods for each proton beam during long fills. Here for a given fill $\langle \varepsilon_{BBC} \rangle$ is the average of all ε_{BBC} measurements with high statistical accuracy ($\le 3\%$); and $< P_B CNI >$ is the average of all the online CNI measurements. For a given beam (BLUE or YELLOW) the super ratio is consistent to $\le 2\%$ between fills indicating good consistency between the relative proton beam polarizations measured by these two methods.

TABLE 3. Comparison of STAR BBC polarimetry and RHIC CNI polarimetry

$$\text{Super Ratio} = \frac{\langle \epsilon_{\mathrm{BBC}} \rangle_{\mathrm{Fill}} \times 10^5}{\langle P_{\mathrm{B\ CNI}} \rangle_{\mathrm{Fill}}}$$

Fill	Super Ratio	
	Yellow Beam	Blue Beam
4	6.77	6.11
5	6.72	6.15
6	6.83	6.14
7	6.61	5.96
9	6.64	5.98

The effective analyzing power A_N for the 100 GeV $\vec{p}$ – 100 GeV $\vec{p}$ scattering processes defined by the $3.9 < \eta < 5.0$ algorithm can be estimated from the May 2006 measurements by:

$$A_N(3.9 < \eta < 5.0) = (\varepsilon_{BBC}/0.827)P_B$$
$$\cong \left(4.0 \times 10^{-3}/0.827\right)0.60$$
$$\cong 8.1 \times 10^{-3} \text{ to about } 10\%$$

Here the factor 0.827 corrects for the broad 120^o azimuthal angle coverage of the two left and two right inner tiles.

SUMMARY

1) The STAR BBC local polarimeter provides fast (~20 minute/measurement), accurate (<3% relative), and robust measurements for 100 GeV polarized proton beams.
2) The STAR BBC local polarimeter permits accurate tuning of the spin rotators which provide longitudinally polarized proton beams at the STAR interaction region; and it monitors reliably normal and radial transverse components during running with longitudinally polarized 100 GeV polarized proton beams at STAR.
3) As a function of time the decrease for the polarization of 100 GeV proton beams in the RHIC rings is small, $\leq$ 0.01 P_B per hour.

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