COMMISSIONING SPIN ROTATORS IN RHIC*

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Abstract

During the summer of 2002, eight superconducting helical spin rotators were installed into RHIC in order to control the polarization directions independently at the STAR and PHENIX experiments. Without the rotators, the orientation of polarization at the interaction points would only be vertical. With four rotators around each of the two experiments, we can rotate either or both beams from vertical into the horizontal plane through the interaction region and then back to vertical on the other side. This allows independent control for each beam with vertical, longitudinal, or radial polarization at the experiment. In this paper, we present results from the first run using the new spin rotators at PHENIX.

INTRODUCTION

The Relativistic Heavy Ion Collider (RHIC) has the capability of colliding polarized protons[2, 3] in the energy range of $\sqrt{s}$ from 50 to 500 GeV. In each of the collider rings there are a pair of Siberian snakes to maintain polarization during the energy ramps. The stable spin direction in each ring is vertical with spin up between snakes in one half of the ring and spin down in the other half.

This year we have been running (Run 3) with 55 bunches of polarized protons in each ring at 100 GeV per beam. Individual bunches are injected with either spin-up $(+)$ or spin-down $(-)$. In one ring the pattern alternates $+-+-\cdots$, and in the other ring the pattern is $++--\cdots$ to allow for all four possible incident polarization combinations.

Each ring has a Coulomb Nuclear Interference (CNI) polarimeter which measures the transverse asymmetry of carbon nuclei recoiling from a thin carbon filament which can be moved into the beam.[4]. The asymmetry is due to an interference of the Coulomb and nuclear parts of the cross section. The STAR and PHENIX detectors are between snakes in the same half of the rings, and CNI polarimeters are in the opposite half; so for a bunch of protons with spin up as measured by the CNI polarimeter, STAR and PHENIX would measure spin down.

There are four spin rotators (Fig. 1) around each of the STAR and PHENIX interaction regions[3]. With the four rotators around each experiment we can rotate the polarization locally to obtain longitudinal and radial polarization at the collision point without affecting the spin dynamics in the rest of the rings. For longitudinal polarization the incoming rotator rotates the spin from vertical into the horizontal plane. Between the end of the rotator and the interaction point are two horizontal bends (D0 and DX) for bringing the beams into collision. There is an energy-dependent net rotation of the polarization about the vertical axis: about 10° at injection (24.3 GeV), 40° at 100 GeV, and 100° at full energy 250 GeV. On the outgoing side of the collision point, the DX, D0, and rotator magnets reverse the spin precession so that from rotator to rotator, the interaction region (IR) is transparent to spin.

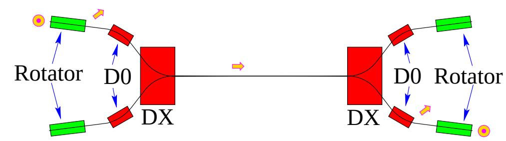

Figure 1: Layout of rotators around PHENIX (or STAR) interaction region.

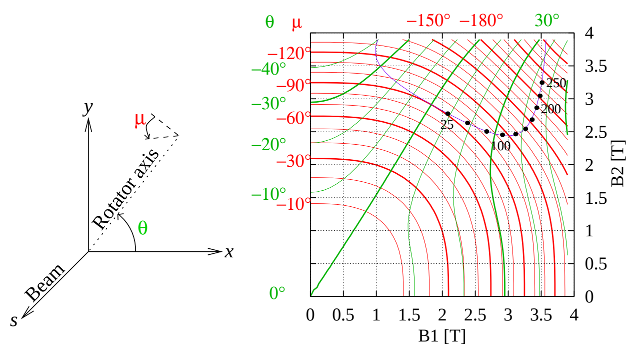

Figure 2: The helical rotators rotate the spin by an angle μ about an axis transverse to the beam as shown in the left diagram. The plot on the right shows contours of μ and θ, the angle of the rotation axis from the x-axis for various settings of fields in the inner and outer pairs of helices.

PHENIX LOCAL POLARIMETER

In order to have a verification of polarization direction at the experiments, both PHENIX and STAR developed local polarimeters for measuring transverse components of the polarization. When the polarization is longitudinal the local polarimeters show no transverse components while the CNI polarimeter measures a nonzero vertical component on the other side of the ring.

The PHENIX Local Polarimeter was based on experi-

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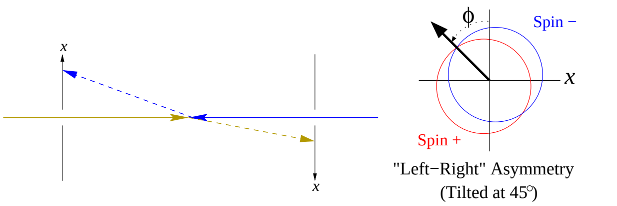

Figure 3: Left: Layout of the local PHENIX polarimeters around the interaction region. The y-axis (vertical) is out of the page; each local polarimeter has a right-handed Cartesian system with z-axis pointing along the corresponding beam direction. Right: definition of the left-right asymmetry indicating a polarization tipped away from the vertical axis by an angle ϕ.

mental evidence from a test experiment performed at IP12 in Run 2[5] which showed that there is a left-right asymmetry in very forward neutron production from collisions of protons with one transversely polarized beam.

Each PHENIX local polarimeter consists of the Zero Degree Calorimeters (ZDC) and a Shower Maximum Detectors (SMD) inserted between the first and the second modules of the three-module ZDC units on both sides of the PHENIX IR. The ZDCs sampled the neutron energy through the hadronic shower development within its volume. The SMDs consist of 8 horizontal and 7 vertical 1.5 cm strips of plastic scintillator read by a 16 channel photomultiplier tube (Hamamatsu M16). Based on the energy observed in each strip, we reconstructed the energy-deposited profile, and hence deduced the hit position of the neutron which was then used to reconstruct the left-right and up-down asymmetries. Both these types of asymmetries were further combined to show a ϕ distribution of asymmetry (defined in Fig. 3), $\phi = 0$ starting from the vertical direction, increasing in the counter-clockwise direction. To minimize the effect of different bunch intensities, the asymmetry was calculated by the formula

$$A_{\rm LR} = \frac{\sqrt{L^+R^-} - \sqrt{L^-R^+}}{\sqrt{L^+R^-} + \sqrt{L^-R^+}}, \qquad (1)$$

where $L^{\pm}$ corresponds to the number of neutrons detected to the left of the ϕ-line, and a $R^{\pm}$ the number on the right for spin-up $(+)$ and spin-down $(-)$ bunches.

ROTATOR CALIBRATION

Fig. 4 shows the asymmetry measured by the local polarimeters at PHENIX for both rings with the rotators turned off. The phase of the cosine distribution indicates vertical polarization (spin-down) opposite to the CNI polarimeter measurement (spin-up) on the other side of the snakes.

Each rotator consists of four superconducting helical dipole magnets – alternating right and left-handed helices[2]. The outer pair of helices are connected in series to one power supply, and the inner pair to a second. With the two snakes at full strength in a given ring at 100 GeV, longitudinal polarization is obtained when $I_{\rm in} = 184$ A and $I_{\rm out} = 221$ A. Fig. 5 shows the sensitivity of transverse polarization components to changes in rotator currents at 100 GeV.

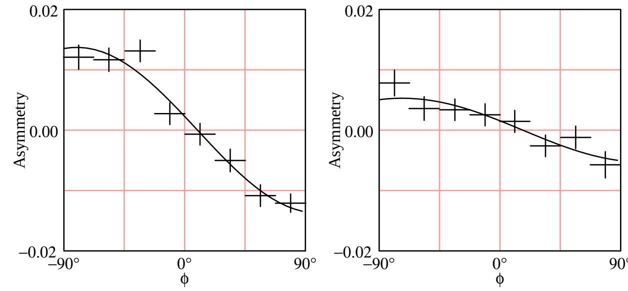

Figure 4: PHENIX local polarimeter measured asymmetries with the rotators off: left is for the Blue ring, and right is for the yellow ring. The curves are fits of a cosine function to the measured asymmetries. The positive peak at $\phi = -\pi/2$ corresponds to a spin-down polarization.

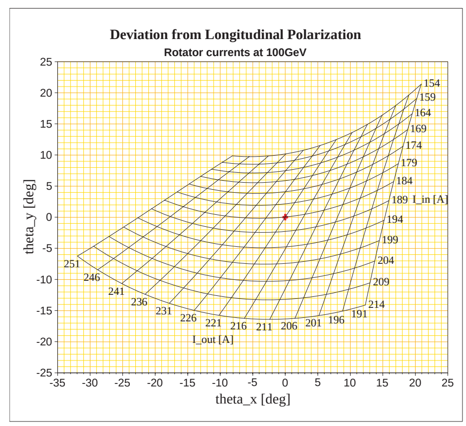

Figure 5: Sensitivity of polarization direction to rotator settings at 100 GeV. The angles θ_x and θ_y are defined in terms of the polarization components by the equations $\tan\theta_x = P_x/P_z$ for horizontal and $\tan\theta_y = P_y/P_z$ for vertical.

When we first turned on the rotators around PHENIX the polarization measured by the local polarimeters showed nonzero zero asymmetries corresponding to a large negative radial component in both rings (see Fig. 6). The amount of precession through the D0 and DX magnets at 100 GeV is about 40° degrees. In our earlier calculations we inadvertently missed a sign, and had the power supplies to all rotators wired backwards. With the wrong polarity, the spin in the rotator is rotated by an angle $-\mu$ about the same axis so that after the rotator, the spin is rotated to the other side of the longitudinal by -40°. The additional precession through the D0 and DX magnets then rotates the polarization to -80° from the longitudinal. This was verified by spin tracking through all rotators in both rings. After correcting the polarity of the rotator power supplies, the

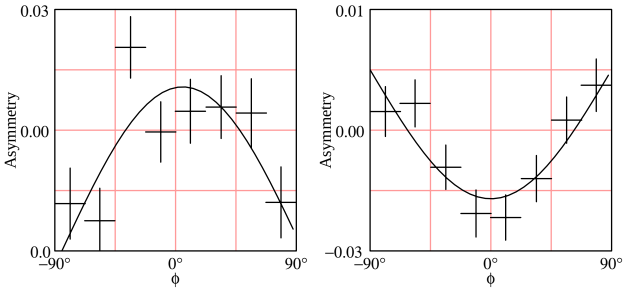

Figure 6: PHENIX asymmetries measured after first turning on the rotators at PHENIX with reversed currents ($I_{\rm in} = -184$ A and $I_{\rm out} = -221$ A): left is for the Blue ring, and right is for the Yellow ring.

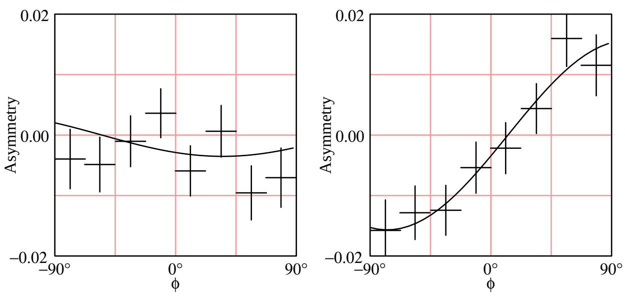

Figure 7: PHENIX asymmetries measured after correcting the polarities of the power supplies. Both sets of rotators were set to the currents: $I_{\rm in} = 184$ A and $I_{\rm out} = 221$ A. The negligible asymmetry in the Blue ring (left plot) is consistent with longitudinal polarization at PHENIX. The Yellow ring measurement (right plot) still shows a sizable vertical component due to the weak snake as discussed in the text.

measurements showed a negligible transverse component in the Blue ring (see Fig. 7).

During the initial startup a helical dipole in one of the snakes in the Yellow ring failed with an opening of the superconductor. We reconfigured this snake to run as a partial snake using a single pair of helices; the amount of spin rotation in this snake was only $158°$ rather than a full $180°$. We were able to operate the Yellow ring with one full snake and the weaker snake maintaining polarization by keeping the spin tune close to 0.5 during the ramps for energy, beta-squeezes, and rotators. With this weak snake the stable spin direction is not vertical, but tilts away from the vertical by about $11°$. This tilt is also translated through the rotators into a spin which is not quite longitudinal as shown in the right side of Fig. 7.

A correction may be made according to Fig. 5 from an estimate of the direction of the polarization away from the longitudinal and the orientation of the transverse components. From the Yellow ring measurements of the local polarimeter in Fig. 7 and the CNI polarimeter, a crude estimate determined that the spin was pointing as much as $40°$ away from the longitudinal with a transverse compo-

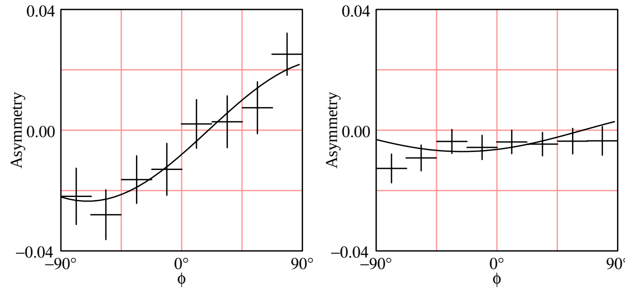

Figure 8: Further PHENIX asymmetries for the Yellow ring with rotator adjustments. A setting of $I_{\rm out} = 198$ A and $I_{\rm in} = 229$ A shown at left increased the transverse component. At right the setting with currents $I_{\rm out} = 244$ A and $I_{\rm in} = 138$ A eliminated the transverse component.

nent about $12°$ away from the vertical. A first estimate was made for the correction shown in the left of Fig. 8 went in the wrong direction. Compensating in the opposite (correct) direction (Fig. 8 right) nulled the transverse components to yield longitudinal polarization.

RHIC is now the first collider with longitudinal polarization in both beams. The STAR rotators were successfully commissioned later during the conference.

REFERENCES

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