Measurement of proton beam polarization at RHIC in Run 11

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Abstract

At the Relativistic Heavy Ion Collider the measurement of the proton beam polarization is based on the observation of the azimuthal asymmetry of recoil products in elastic proton-proton and proton-carbon scattering processes. For the high energy beams (E = 24–250 GeV) scattered on a fixed target the asymmetry is maximal when induced by the coulomb-nuclear interference at a small momentum transfer squared $-t$. Fast measurements of the beam polarization are carried out few times during an accelerator store by the p-Carbon polarimeters utilizing a carbon filament as a target while the absolute polarization is provided by the H-jet polarimeter with a polarized hydrogen jet target. Recoil particles are detected by microstrip silicon detectors. For the 2011 run the readout system of the p-Carbon polarimeters was upgraded to cope with the increased beam intensity. We report the average beam polarization and discuss the systematic uncertainties associated with the measurement.

1 Introduction

At the Relativistic Heavy Ion Collider (RHIC) the polarization of the proton beams is measured by detecting recoil products from the elastic proton-proton ($pp \to pp$) and proton-Carbon ($pC \to pC$) scattering reactions on a fixed target. The beam polarization P is a statistical quantity defined as a fraction of the expected spin-dependent asymmetry $A_N = \frac{\sigma_\uparrow - \sigma_\downarrow}{\sigma_\uparrow + \sigma_\downarrow}$ measured in the experiment, i.e. $P = \varepsilon / A_N$ where ε and A_N are the observed and predicted asymmetries respectively. In general, the scattering cross section of particles with determined spin orientation $\sigma_{\uparrow/\downarrow}$ can be described by five independent helicity amplitudes corresponding to double-, single-, or no-spin flips between the initial and final states [1]. Each of the helicity amplitudes has an electromagnetic and hadronic part hence, making A_N dependent on contributions from both electromagnetic and strong interactions as well as their superposition. The asymmetry A_N, also known as the analyzing power, cannot be calculated exactly due to lack of precise theoretical framework for the strong force at smaller values of momentum transfer squared $-t$. However, with the assumption of negligible contribution from the hadronic spin-flip amplitude the analyzing power can be calculated exactly for a wide range of $-t$. It has been shown [2] that A_N has a maximum value of approximately 4–5% at $-t \approx 0.003$ GeV^2 and decreases with increasing $-t$. The kinematic region around the maximum is called the Coulomb Nuclear Interference (CNI) region, and corresponds to where the electromagnetic and strong forces become similar in strength and interfere with each other.

The measurements over the last decade demonstrated that the assumption of a small contribution of the hadronic spin-flip amplitude holds true within experimental uncertainties for the pp interactions at $\sqrt{s} \gtrsim 10$ GeV [3] whereas the same contribution at lower energies and in pC interactions may be non-zero [4, 5].

2 Experimental Setup

Precise knowledge of the beam polarization is essential for the spin physics program at BNL. To meet the program goals the RHIC utilizes two kinds of polarimeters. The first type includes the H-jet polarimeter that consists of a polarized atomic hydrogen jet target with a known polarization measured by a Breit-Rabi polarimeter [3]. It is located at one of the collision points and measures the kinematics of the protons recoiled from the vertical jet target. Both RHIC beams traverse the target simultaneously but do not interact with each other as they are vertically separated by ≈ 4 mm. The transverse size of the hydrogen jet is ≈ 6 mm which is wide enough to probe the entire cross section of the beam. The second type includes the p-Carbon polarimeters which operate by inserting an ultra-thin carbon ribbon target into the beam. A typical target size is $2.5 \text{ cm} \times 10\ \mu\text{m} \times 25$ nm. The high event rate and the small width of the targets allows one to measure polarization at different positions across the beam, i.e. a polarization profile. Since 2009 the RHIC has two independent p-Carbon polarimeters installed in each ring. Each polarimeter of this kind employs a set of six vertical and horizontal targets.

Figure 1 schematically illustrates the basic idea of the experimental setup for the RHIC polarimeters. A high energy polarized proton kicks a particle from the target which is then registered by a silicon strip detector. In the elastic CNI interaction the direction of the scattered proton does not change significantly while the recoil particle tends to stay in the plane perpendicular to the beam direction. In this optimal plane six detectors with 12 strips parallel to the beam line are installed as far as $\approx 18-19$ cm from the target at $\pm 45°$, $\pm 90°$, $\pm 135°$ w.r.t. the proton's spin direction in each of the p-Carbon polarimeters. Another set of six detectors is installed close to $\pm 90°$ at ≈ 80 cm from the jet target in the H-jet. All the detectors are mounted inside the vacuum chamber with readout preamplifier boards directly attached to the feed-through connector on the detector ports. The RHIC polarimeters employ a similar readout system based on the waveform digitizer modules. The data acquisition system provides timing and energy information for each event detected in the silicon detectors.

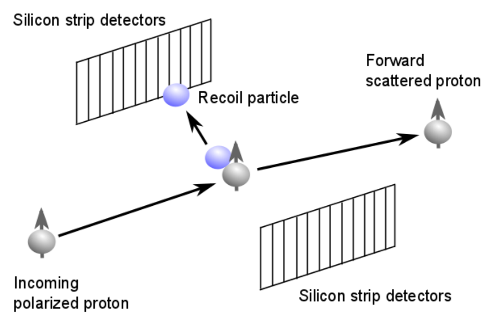
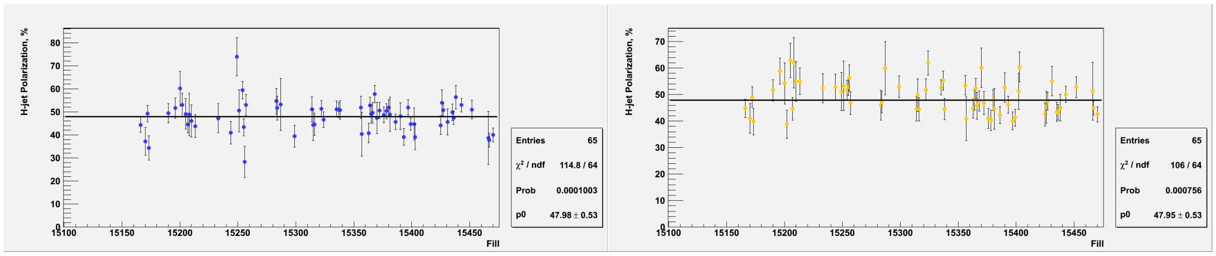


Figure 1: Schematic view of the RHIC polarimeters experimental setup. The shown direction of the silicon strips is typical for the H-jet polarimeter.

For the 2011 run the charge-sensitive preamplifiers in the p-Carbon polarimeters were replaced with current-sensitive ones. Due to this effort a significant reduction in the output signal length to ≈ 10 ns was achieved. The event pileup effects seen previously were minimized.



(a) (b)

Figure 2: Average polarization in a accelerator store as measured by the H-jet polarimeter in the blue (a) and yellow (b) rings.

3 Analysis and Results

The energy response of the silicon detectors is calibrated with α-sources installed inside the vacuum polarimeter chambers. Emitted α particles have energy of ~ 5 MeV and completely stop in the detectors. While most of the recoil protons and carbon ions are also stopped in the detectors the latter travel much shorter distance in silicon. The region close to the surface of a silicon detector is known to be under-depleted when a bias voltage applied. The energy lost in this dead region cannot be measured. To account for these extra energy losses E_{loss} we calibrate each channel by fitting elastic events with a non-relativistic equation relating the measured time of flight t_{meas} and the measured energy E_{meas} as: $E_{\text{meas}} + E_{\text{loss}} = \frac{m}{2} \times L^2/(t_{\text{meas}} + t_0)^2$, where m is the mass and L is the distance traveled by a recoil particle. An additional time of flight offset t_0 is also individually adjusted for each strip using the same data. Once the calibration parameters are identified the signal events are selected by applying a 3σ cut on the mass distribution. To further suppress the background we also constrain the kinematic energy range of recoil particles to be within a certain window. For thus defined elastic event dataset we define the yields according to the expected spin state of the incident beam particle and the left or right direction of the recoil particle with respect to the spin. These yields are plugged into the square root formula to calculate the asymmetry as: $\varepsilon = \left(\sqrt{N_L^{\uparrow} N_R^{\downarrow}} - \sqrt{N_L^{\downarrow} N_R^{\uparrow}}\right) \Big/ \left(\sqrt{N_L^{\uparrow} N_R^{\downarrow}} + \sqrt{N_L^{\downarrow} N_R^{\uparrow}}\right)$.

In order to take advantage of the higher statistics for the final polarization $P = \varepsilon / A_N$ we use the yields provided by the p-Carbon polarimeters. However, we choose not to rely on loose theoretical predictions for the pC analyzing power A_N but instead scale on average the final results to the polarization measured by the H-jet. The H-jet polarimeter provides an absolute measurement of the beam polarization. In fact, no knowledge about the pp A_N is required because the beam and the target are both protons, and the beam polarization is given by $P_{\text{beam}} = -(\varepsilon_{\text{beam}}/\varepsilon_{\text{target}}) \times P_{\text{target}}$. The beam polarization as measured by the H-jet is shown in Figure 2.

The strategy outlined above benefits from lower final statistical errors without introducing an additional systematic uncertainty due to poorly known A_N for pC interactions. However, the systematic uncertainties now include effects from both the p-Carbon and H-jet polarimeters. The global store-to-store correlated uncertainties include the normalization uncertainty (1.1–1.5%) and the uncertainty due to molecular background in the jet target ($\sim 2\%$). The store-to-store uncorrelated uncertainties decrease with the number of stores combined as $1/\sqrt{N}$ and are mainly defined by unstatistical fluctuations in the p-Carbon measurements. These are believed to be induced by unaccounted energy losses of the recoil carbon ions in the target due to presumably unstable angle between the target ribbon and the beam. The results for run 2011 are available online at [6, 7].

4 Summary

The RHIC polarimeters performed well during the 2011 run. In this run we measured the average beam polarization of about 48% in both collider rings with the total uncertainty consistent with the requirements set by the RHIC spin physics program. The higher than in the preceding run average beam polarization is due to a better control of the beam orbit achieved by the accelerator group and other tune-up of the accelerator complex [8]. A careful offline analysis showed that the store-to-store correlated systematic uncertainties reduced with respect to the previous run. The improvement is attributed to a number of reasons including the reduction of the event pile-up effects, thanks to shortened signal pulses from the current-sensitive preamplifiers, and the use of thinner carbon targets in the p-Carbon polarimeters. The stable performance of the H-jet during 2011 has assured a higher acquired statistics which, in turn, decreased the global uncertainty due to the overall normalization. We confirmed the good performance of the absolute polarimeter by comparing the asymmetry A_N in the pp interactions with the same measured in the 2009 run (Figure 3) and found them to be in a good agreement. The details and results of the offline analysis can be found online at [6, 7].

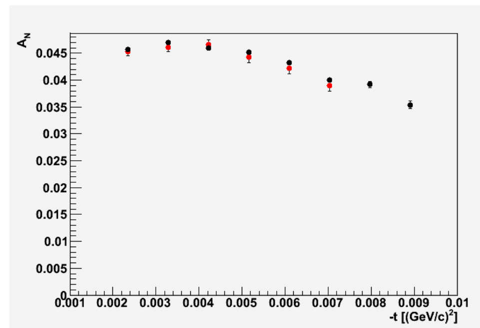


Figure 3: Analyzing power A_N for $pp \to pp$ scattering as a function of the momentum transfer $-t$. The 2011 and 2009 data is shown with black and red circles respectively.

References

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