Absolute Polarization Measurements at RHIC in the Coulomb Nuclear Interference Region

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Abstract. The Relativistic Heavy Ion Collider at Brookhaven National Laboratory provides polarized proton beams for the investigation of the nucleon spin structure. For polarimetry, carbon-proton and proton-proton scattering is used in the Coulomb nuclear interference region at small momentum transfer (−t). Fast polarization measurements of each beam are carried out with carbon fiber targets at several times during an accelerator store. A polarized hydrogen gas jet target is needed for absolute normalization over multiple stores, while the target polarization is constantly monitored in a Breit-Rabi polarimeter. In 2005, the jet polarimeter has been used with both RHIC beams. We present results from the jet polarimeter including a detailed analysis of background contributions to asymmetries and to the beam polarization.

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INTRODUCTION

Accurate knowledge of the beam polarization is essential in the spin program at the Relativistic Heavy Ion Collider (RHIC). Measurements of beam polarizations utilize scattering processes. Fast measurements are based on proton-carbon scattering off carbon fiber targets [1], for which the necessary normalization is provided from elastic proton-proton scattering with a polarized hydrogen gas jet target. At high energies, the asymmetries are driven by the electromagnetic spin-flip amplitude at small four-momentum transfer (10^{-3} < |−t| < 10^{-2}). Asymmetries are small (few percent) and contain unknown contributions from hadronic amplitudes in this so-called Coulomb nuclear interference region. The existing data, therefore, not only serve as a necessary input to other RHIC experiments, but on the other hand can also be used to further confine the helicity am-
FIGURE 1. Detector setup of the jet polarimeter at RHIC. The six detectors are centered with respect to the interaction point. In routine operation only one RHIC beam hits the target, while the other beam is displaced.

plitudes $\phi_1 - \phi_5$ and the hadronic spin-flip contribution in particular [2].

SETUP AND ANALYSIS

The jet polarimeter is located at one of the collision points in the RHIC accelerator and reflects the kinematics of elastic proton-proton scattering at small $| - t |$. It consists of a polarized hydrogen atomic jet target with a Breit-Rabi polarimeter [3] and a set of six separate detectors each of 16 silicon strips, see figure 1. The target polarization is prepared in an inhomogeneous magnetic field in combination with a radio-frequency transition unit and constantly monitored (not shown in the figure). The hydrogen molecular content has been determined and is corrected for. The effective polarization amounts to $P_{\text{target}} = (92.4 \pm 1.8)\%$.

The detectors are centered with respect to the interaction point of the proton beam with the target. In this geometry, eight downstream strips on each detector can detect elastically scattered recoil protons when one RHIC beam hits the target. In routine operation, one of the two RHIC beams is displaced, so the respective eight non-signal strips can be used to estimate the background fraction below the elastic signal peak.

The silicon detectors are read out with waveform digitizers (running at 420 MHz and synchronized with the RHIC clock) that send the pre-processed ADC spectra to the DAQ-PC. Two different $\alpha$-sources (Am and Gd) are used for energy calibration and estimation of the entrance window thickness of the detectors. Additional time of flight offsets are individually adjusted for each strip using the pronounced proton signal. Particle identification is based on time of flight and energy. Elastic scattering further correlates the detector geometry, i.e. the scattering angle, and the small recoil energy of the proton. A time-of-flight cut of a few ns removes the major part of prompt background events below 5 MeV.

In 2005, one of the two RHIC beams was centered on the jet target for several days to
accumulate enough statistics for a precise measurement of the beam polarization. Both beams have been measured repeatedly over the course of a few weeks.

For the determination of the RHIC beam polarization, a set of four different vertical polarization combinations of target and beam is used. The yields are then combined to separate asymmetries resulting from the beam and target polarizations. While a certain polarization direction would result in a specific left-right asymmetry in the detectors, respective yields can be coupled with their opposite polarization directions in order to remove detector acceptances and efficiencies and luminosity effects, [4]. The beam polarization $P_{\text{beam}}$ is then derived from the ratio of the measured asymmetries $\varepsilon_{\text{beam}}$ and $\varepsilon_{\text{target}}$ and the known target polarization $P_{\text{target}}$:

$$
P_{\text{beam}} = -\frac{\varepsilon_{\text{beam}}(T_R)}{\varepsilon_{\text{target}}(T_R)} \cdot P_{\text{target}}.
$$

The analyzing power $A_N = \varepsilon / P$ is not flat in the considered $t$-region and, therefore, the beam polarization was determined in separate steps of the recoil energy $T_R$ before calculating the weighted mean. Also, the kinematic correlation of the detector strip position and the recoil energy suppresses the background outside of the considered energy range, where no elastic signal is seen.

The ratio of asymmetries is very robust with regards to background contributions to the yields, as long as the background has no pronounced polarization dependence. Background fractions can be as large as 7% in certain energy ranges, which affect the beam polarization only in second order.
RESULTS

Target and beam asymmetries have been measured as functions of energy of the recoil proton. Figure 2 shows the typical peak of the asymmetries (and the analyzing power) at $T_R \approx 1.5$ MeV in the CNI region from a subset of the data. The asymmetry ratio between 1.0 and 4.0 MeV is used to determine the beam polarization. Lower and higher recoil energies are discarded due to increased acceptance asymmetries and highly increased background. Also, the asymmetries in figure 2 are compared to the expected shape of the analyzing power $A_N$ from a formal description in terms of helicity amplitudes [2] that has been scaled with the target and beam polarizations. The shown curves are neither fitted to the analyzed data, nor do they include contributions from hadronic spin-flip amplitudes.

In 2005, beam polarizations of nearly 50% have been measured in RHIC with good statistical accuracy. Systematic errors were estimated from the background yields from empty target measurements and subdivision with respect to separate proton bunches in the accelerator. Other checks included many thousand repetitions of random assignments to the polarization directions of bunches and calculating the resulting asymmetries.

Background contributions have been identified from molecular content in the jet target, from beam gas, and from the displaced beam that is threaded around the target. No significant beam or target polarization dependence has been observed in the background, which is uniformly distributed over the detector halves within the statistical uncertainties. The effect on the determination of the beam polarization has been estimated by purposefully widening the signal region on the detectors, this way increasing the background by factors of up to four and consecutively lowering the beam and target asymmetries. The ratio of asymmetries, on the other hand, is largely unaffected by the growing background and an upper limit of $\Delta P/P = 1.1\%$ has been assigned to the beam related background below the signal. The hydrogen molecular content of the target causes an additional uncertainty that is already taken into account in the target polarization error.

SUMMARY

Fast beam polarization measurements at RHIC are carried out with two carbon polarimeters [1]. Absolute polarization normalization is done alternatingly with a polarized hydrogen jet target. Beam polarizations of nearly 50% have been measured in the latter half of the 2005 run. Total uncertainties have reached the accuracy that experiments in the RHIC spin program have called for. The existing data, also, have been used to further constrain the knowledge of hadronic spin-flip amplitudes at $\sqrt{s} = 13.7$ and 6.9 GeV [2].

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