PROTON POLARIMETRY AT RHIC

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Abstract. The techniques used to measure precisely the polarization of the proton beams at RHIC are presented and discussed. Fast polarization measurements are performed using polarimeters based on *pC* elastic scattering. The absolute normalization is provided by a polarized hydrogen gas jet target. During the 2004 polarized proton run a relative precision on the beam polarization $\Delta P_{beam}/P_{beam}$ of 6.6% has been achieved.

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INTRODUCTION AND METHOD

The RHIC Spin program [1] aims to determine the spin asymmetries with one or both beams polarized for a variety of processes with high precision, such to allow significant comparison with theoretical predictions and possibly unveil new physics. The proton polarimeters provide the normalization of the spin asymmetries measured by the RHIC experiments, and polarization measurements for the accelerator setup. A crucial requirement is the knowledge of the absolute polarization of the RHIC proton beams to 5% of its value and its constant monitoring.

The major requirements for a good and efficient polarimeter are a simple and well understood scattering process with a large cross section and known analyzing power A_N. The chosen *polarimetric* processes are *pC* and *pp* elastic scattering at very low momentum transfer t. The analyzing power A_N is defined as the left-right asymmetry of the cross section in the scattering plane normal to the beam polarization. Until recently, A_N^{pC} for *pC* scattering at RHIC energies was not well know. During the 2004 run a measurement and calibration of this process using a polarized hydrogen gas jet target has been performed to a precision better than 15%.

In high energy *pp* and *pA* elastic scattering at very low momentum transfer t, A_N originates from the interference between the real electromagnetic (Coulomb) spin-flip amplitude, which is generated by the proton's anomalous magnetic moment, and the imaginary hadronic (Nuclear) spin-nonflip amplitude (CNI = Coulomb Nuclear Interference), and thus provides important information on the spin dependence of the interaction. A_N has a maximum value of about 4-5% around $t \simeq -3 \times 10^{-3}$ $(\mathrm{GeV}/c)^2$ [2].

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PROTON-CARBON POLARIMETERS

Fast beam polarimetry at RHIC and AGS is based on *pC* elastic scattering at very small proton scattering angles. *pC* elastic scattering events are identified by detecting the recoil carbon ions. For very small angle scattering the elastic reaction dominates and the measurement of the recoil ions gives predominantly elastic events with very small backgrounds. Typical 4-momentum transfers squared are $-t \sim 0.01-0.02$ GeV$^2/c^2$, corresponding to recoil carbon ion kinetic energies of $T_R \sim 0.4-1$ MeV. In this t region the analyzing power for *pC* elastic scattering A_N^{pC} is small, around 1%. The figure of merit, however, is high, since the *pC* elastic cross section is very large. The small value of A_N^{pC} makes it necessary to collect large data samples, of the order of 2×10^7 events per measurement. Event rates are relatively high, of the order of 10^5 elastic events / polarimeter channel / sec. A typical measurement in RHIC lasts around 10 sec.

The slow recoil carbon nuclei emerge at almost 90° w.r.t. the incident beam and are detected with six silicon detectors at different azimuthal angles (see Figure 1), which provide energy and time of flight (ToF) information. Each silicon detector consists of 12 strips, for a total of 72. The strips are oriented along the beam direction, thus each strip covers the same polar angle and detects the same physical process in the same kinematical region. The detectors are located inside the accelerator vacuum system at $\sim$ 15 cm from the RHIC beam. On the basis of the T_R – ToF correlation, carbon recoils are identified and selected. Typical flight times are between 30 and 80 nsec. An ultra thin carbon ribbon of 3 – 5 μg/cm^2 and less than 10 μm wide is used as target and is inserted into the beam during the measurement. Two such devices are installed in RHIC for each beam, and one in AGS. The silicon detectors are readout with waveform digitizer, which provide a deadtimeless DAQ system with *on-board* event analysis, thus allowing us to handle the high rates. An algorithm in conjunction with on board FPGAs in the WFD units is used to extract energy and time information from the recorded waveforms.

Each detector channel covers a different azimuthal angle and can be viewed as an independent polarimeter. Figure 1 shows the asymmetry in the event yields for events from bunches with *up* polarization vs. bunches with *down* polarization, normalized with the relative luminosities, for each polarimeter channel. In Figure 1 these asymmetries are fitted with a sinusoidal function. The amplitude of this distribution, normalized with the corresponding A_N^{pC} gives P_{beam}. This is one method of extracting P_{beam}. These measurements are scattered around the fitted curve statistically. That indicates that all the measurements from each polarimeter channel are self consistent and that the systematic errors associated with each asymmetry measurement are small.

The largest systematical uncertainty in extracting P_{beam} comes from the absolute energy scale in determining the energy of the recoil carbon ions E_C. Since $A_N^{pC}(t)$ depends on E_C, an uncertainty is introduced in the extraction of P_{beam} from the measured asymmetries. The difficulty of the measurement resides in the fact that only a fraction of E_C is observed, part of this energy being deposited in the entrance window of the detector, and part being lost due to charge collection efficiencies. An energy correction term is estimated by requiring that the mass of the detected recoils correspond to the mass of carbon ions and is added to the measured energy on an event by event basis. At present this effect is estimated to be around 5% of the measured P_{beam} value.

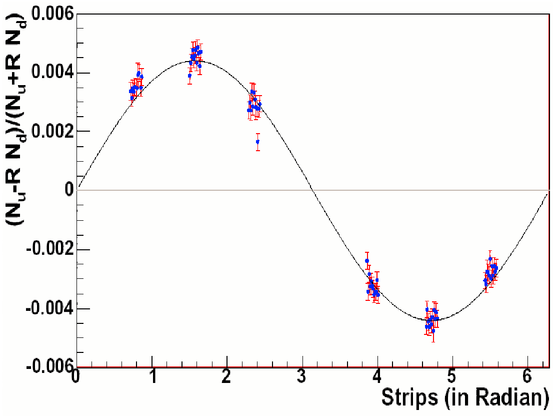

FIGURE 1. Asymmetry in the event yields for events from bunches with *up* polarization vs. bunches with *down* polarization, normalized with the relative luminosities, for each polarimeter channel. The amplitude of this distribution is directly related to P_{beam}. See text for more details.

THE POLARIZED GAS JET TARGET

An absolute polarimeter, based on *pp* elastic scattering, using a polarized hydrogen gas jet target, has been installed in 2004, and provides the absolute normalization for the fast *pC* polarimeters. The transverse spin asymmetry in *pp* elastic scattering of a polarized beam on an unpolarized target is identical to the unpolarized beam – polarized target one in the same kinematical region: $A_N^{p\uparrow p} = A_N^{pp\uparrow}$. This symmetry relation, which holds for the elastic scattering of spin 1/2 identical particles only, permits the direct transfer of the target polarization P_{target} to the beam polarization P_{beam}:

$$P_{beam} = P_{target} \times \frac{\varepsilon_{beam}}{\varepsilon_{target}} \quad , \tag{1}$$

where ε_{beam}, ε_{target} are the *left - right pp* scattering asymmetries obtained by averaging over the target polarization and beam polarization states, respectively (see Figure 2), using events from the same data set. This procedure is also referred to as the *self-calibration* method, and is independent of theoretical assumptions.

In the CNI region recoil protons from *pp* elastic scattering emerge close to 90° with respect to the incident beam direction. The recoil protons were detected using an array of silicon detectors. The scattered beam protons did not exit the beam pipe and they were not detected. In the covered t region, however, the elastic process is fully constrained by the recoil particle only, thus the detection of the scattered beam proton is not mandatory. Recoil protons were identified on the basis of the T_R – ToF non-relativistic relation $T_R = \frac{1}{2}M_p(\mathrm{dist}/\mathrm{ToF})^2$ and selected on the basis of the $\vartheta_R - T_R$ relation $T_R \simeq 2M_p\vartheta_R^2$ (ϑ_R is the polar angle). On the basis of the $\vartheta_R - T_R$ correlation one can reconstruct the mass of the scattered particle (so called missing mass M_X). For a *pp* elastic scattering process $M_X = M_p$. We found that $M_X \simeq M_p$ with little background below the elastic peak (figure not shown), confirming indeed that we were selecting *pp* elastic scattering events. The estimated background in the selected *pp* elastic scattering sample was less than 5%.

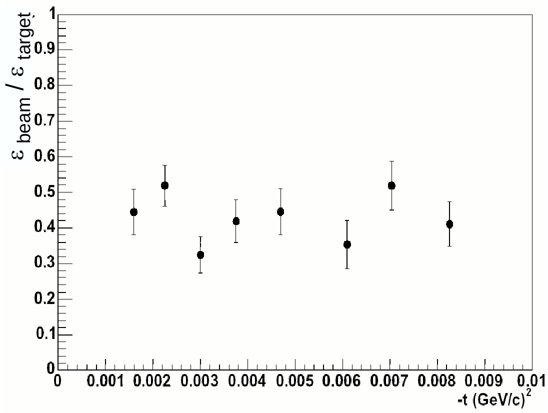

FIGURE 2. $\varepsilon_{beam}/\varepsilon_{target}$ as a function of t. For definitions see text.

The polarized hydrogen gas jet target crossed the RHIC beams from above with its polarization directed vertically. The polarized target is a free atomic beam jet. The state-of-the-art atomic polarized source delivered polarized protons with a polarization of 0.924 ± 0.018 (the dilution from molecular hydrogen is included in this figure), a density in excess of $10^{12}\ p/\mathrm{cm}^2$ in its center, and a FWHM profile of less than 6 mm. The target polarization was reversed every 5 to 10 minutes. The target polarization was constantly monitored with a Breit-Rabi polarimeter. For more details see [3].

During the 2004 polarized pp run, P_{beam} has been measured with an absolute precision of 2.7% using the *self-calibrating* method described above. The preliminary result on the average P_{beam} and the error from the past run is given here below:

$$P_{beam} = 0.392 + 0.021(\mathrm{stat}) + 0.008(\Delta P_{target}) + 0.014(\mathrm{sys}) \quad . \tag{2}$$

The second term in the systematic error comes mainly from backgrounds in the selected pp elastic sample. The relative precision of this measurement $\Delta P_{beam}/P_{beam}$ is 6.6%. For the 2005 polarized pp run a relative precision on P_{beam} better than 5% is expected.

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