MEASUREMENT OF THE ANALYZING POWER OF PROTON-CARBON ELASTIC SCATTERING IN THE CNI REGION AT RHIC

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The single transverse spin asymmetry, A_N, of p-carbon elastic scattering process in the Coulomb Nuclear Interference (CNI) region at very low momentum transfer $-t$, was measured using the ultra thin carbon target and the proton beam in the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory (BNL). In 2004, data were collected to calibrate the p-carbon process at two RHIC energies (24 GeV, 100 GeV). A_N was obtained as a function of $-t$ over a wide region. The results were fit with theoretical models which allows us to assess the contribution from hadronic spin flip amplitude.

The elastic scattering process of polarized proton off the nucleus at RHIC energies $(24-250\text{ GeV})$ carries an interesting information on spin dependent hadronic spin-flip amplitude. In the Coulomb-Nuclear Interference (CNI) region, i.e. $0.005 < -t < 0.05$ $(\text{GeV/c})^2$ where $t = (p_{out} - p_{in})^2 \approx -2M_C T_{kin} < 0$, the single transverse spin asymmetry, A_N, of p-carbon elastic process is currently used for proton polarization measurement in RHIC. The data give a good opportunity to extract the physics information on the spin dependent hadronic contribution to the transverse asymmetry. At very small angle scattering, the elastic process dominates, and experimentally the elastic events are clearly identified by measuring the recoil carbons in the polar angles around $90°$ in the laboratory frame. In CNI region, the electromagnetic and hadronic helicity amplitudes become of comparable size. The A_N arises mainly from the interference between the coulomb spin-flip amplitude (which is caused by the anomalous magnetic moment of the proton) and the hadronic non spin-flip amplitude. This interference term, called 'pure CNI' is precisely determined from QED cal-

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culation. However, there is the other interference term having a contribution from the hadronic spin flip amplitude (coupling with the coulomb non spin-flip amplitude), which is described by the Regge poles exchange phenomenology[1]. Since this is about the nonperturbative QCD effect, experimental data is indispensable. Following the analogy to the helicity amplitude formalism of proton-proton elastic scattering, the pC process can be described by two amplitudes, spin non flip $F_{+0}(s,t)$, and spin flip amplitude $F_{-0}(s,t)$. The spin flip amplitude parameter $r_5^{pC}(t)$ is defined as, $r_5^{pC}(t) = mF_{-0}^h/(\sqrt{-t}\,\mathrm{Im}F_{+0}^h)$, where m is the proton mass, and $F_{\pm 0}^h$ is the hadronic element of the helicity amplitudes. This is translated to t independent parameter r_5 for pp with simple formula[7]. The AGS experiment E950[2] has been the only measurement of $A_N^{pC}(t)$ at 21.7 GeV/c. The r_5 result from E950 was $\mathrm{Re}r_5 = 0.088 \pm 0.058$ / $\mathrm{Im}r_5 = -0.161 \pm 0.226$ with a strong anti correlation between real and imaginaly parts. For the current experiment, the polarized proton beam passes through an ultra-thin carbon ribbon target (3.5-μg/cm^2 thick[3]), and carbon recoils from CNI scattering are observed in six silicon strip detectors placed at 90° to the beam direction, 15 cm away from the target. Each detector has 10×24mm^2 active area divided into 12 strips, each directed paralel to the beam line. The six detectors are mounted inside the vacuum chamber with readout preamplifier boards directly attached to the feed-through connector on the detector ports. Data acquisition is based on the waveform digitizer modules (WFD)[6]. The system reads out the data without deadtime to accommodate the very high event rates. The waveforms from strips are digitized, and energy (E) and time of flight (TOF) w.r.t. the RHIC rf clock are determined by on-board FPGA. Typically 2×10^7 samples of carbon events are stored in memory on board and readout after the measurement for the offline data analysis. Slow particles inside our kinematical acceptance follow the non-relativistic kinematics i.e., $TOF = \sqrt{\frac{M_C L^2}{2}}\frac{1}{\sqrt{E}}$, which is slightly deformed by energy loss correction in the inactive silicon surface. The size of deformation is used to estimate the thickness of the inactive layer[4]. The thickness is estimated to be $57 \pm 12\mu$g/cm^2. The invariant mass of the recoil particle is reconstructed with the time and energy information. The three standard deviation cut around the carbon peak is applied for the carbon identification. The cut clearly separates the carbon events (11.17GeV/c^2) from the dominating α background (3.7GeV/c^2). A raw asymmetry is calculated for carbon counts in left and right detectors using a square root formula, which takes advantage of the alternating spin patterns in RHIC[8]. Since each silicon strip can serve as an individual device measuring the asymmetry, the
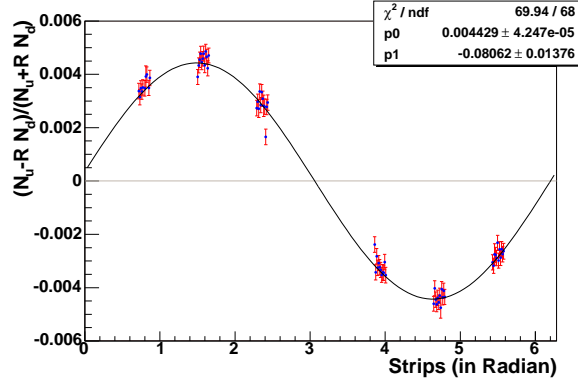
Figure 1.   Strip by strip asymmetry measurements. The raw up-down asymmetries are plotted as a function of strip location in radian. The curve is the best fit with the sine function allowing phase shift, i.e. $f(\phi) = P_0 \sin(\phi + P_1)$

systematic error of the measurements are estimated from the size of fluctuation among the asymmetries for strips. Figure 1 shows the up-down asymmetry for the i-th $(i = 1 \cdots 72)$ strip $(\equiv (N_i^u - R \cdot N_i^d)/(N_i^d + R \cdot N_i^d)$ where R is the luminosity ratio of up/down spin bunches). By allowing the phase shift to the $\sin\phi$ fit (two parameters: amplitude, phase), the χ^2/ndf is reduced to 70/68, whereas it is 104/69 for one parameter fit. This χ^2/ndf value indicates there is a negligible systematic error in the measurement, and a possible spin tilt ($4 \sim 5$ degrees) from vertical. The A_N^{pC} is obtained from dividing the raw asymmetry of pC events by beam polarization obtained from the polarized Hydrogen gas jet target measurement[5], Figure 2 shows the obtained $A_N^{pC}(t)$ at 100GeV. P_{beam} used for the normalization is, $P_{beam} = 0.386 \pm 0.033$ [5]. The thin line on top of the data points is the best fit result with the model function which allows hadronic spin flip[1]. The error bars on the data points are statistical only. The size of systematic errors is shown with the shaded band. They are due to (i) the $-t$ ambiguity from the uncertainty in the inactive surface layer of the silicon, (ii) the error of the beam polarization measured with the jet. As shown in the fig. 2, r_5 value from the best fit results, Re $r_5 = 0.051 \pm 0.002$ and Im $r_5 = -0.012 \pm 0.009$. The uncertainty is actually large due to the two systematic error sources described above. The 1-σ error contour has a very stong anti correlation between real and imaginary part of r_5, starts from $(\mathrm{Re} r_5, \mathrm{Im} r_5) = (0.070, -0.16)$ to $(0.035, 0.110)$. For 24 GeV, even though the absolute scale of $A_N(t)$ is not available yet, the shape is obtained and com-
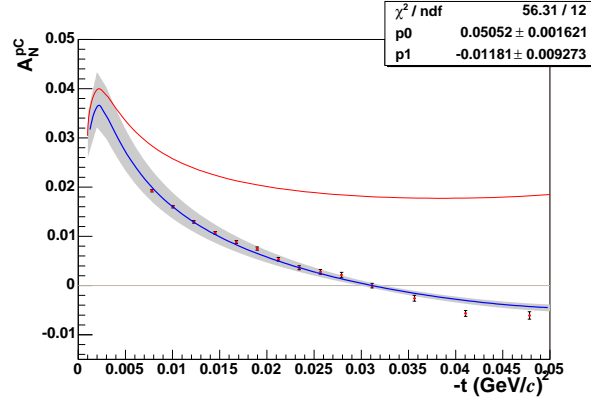
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Figure 2.   Measured $A_N(t)$ at 100GeV. The calibration is carried out with the polarization measured by the jet. The result for best fit using hadronic spin flip model is significantly different from the zero spin flip calculation (the top curve). The shaded band represents the systematic uncertainty of the measurement

pared with 100 GeV for the range, $0.008 < -t < 0.028 (\text{GeV/c})^2$. The slope of $A_N^{pC}(t)$ at 100 GeV is significantly steeper than 24 GeV. In summary, the measurement of $A_N(t)$ $(0.008 < -t < 0.05 \ (\text{GeV/c})^2)$ for proton-carbon at 100GeV was carried out, in conjunction with the beam polarization measurement by jet-target polarimeter. Also the shapes of $A_N(t)$ at 24GeV, 100GeV were compared, indicating a difference in slopes. The calibration of $A_N(t)$ at 24GeV is under analysis, we will obtain the new result from 24GeV fairly soon.

Acknowledgments

References

1. T.L. Trueman, *hep-ph/0305085* (2003).
2. J. Tojo et al. *Phys. Rev. Lett.* **89**, 052302 (2002).
3. W.R. Lozowski and J.D. Hudson, *NIM in Physics Research* **A334**, 173 (1993).
4. O. Jinnouchi et al. *RHIC/CAD Accelerator Physics Note 171* (2004).
5. H. Okada et al. these proceedings (2004).
6. D.N. Svirida et al. detail description is found in these proceedings (2004).

7. B.Z. Kopeliovich and T.L. Trueman, *Phys. Rev.* **D64**, 034004 (2001).
8. G.G. Ohlsen and P.W. Keaton, *NIM in Physics Research* **109**, 41 (1973).