Measurement of transverse spin asymmetries in the elastic proton-proton scattering in the CNI region at STAR

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Abstract. Elastic scattering of polarized protons at small four momentum transfer squared $t$ is described by interference of Coulomb and nuclear amplitudes. The Coulomb amplitude is well calculable by QED and such interference provides a unique opportunity to study the nuclear amplitude. At high energies this amplitude is believed to be dominated by Pomeron exchange. Measurement of asymmetries can provide evidence for contribution of other Reggeons, including the hypothetical Odderon. The polarized proton collider RHIC is a perfect place for such experiment. A one week dedicated run with special beam optics in June 2009 allowed us to collect statistics of more than 30 million of elastic triggers with transversely polarized beams in the $t$ range $0.005 - 0.035$ (GeV/c)$^2$ at $\sqrt{s} = 200$ GeV. In this paper we present preliminary results of single and double spin asymmetries.

1. Introduction and formalism

Elastic pp-scattering at very small angles provides a unique tool to study dynamics of the strong interaction in the nonperturbative region. The total cross section was measured up to a very high energy and turned out to be in good agreement with a description using Regge pole exchange. At ultra relativistic energies the main contribution comes from Pomeron or, in modern terms, multigluon exchange [1]. Most of the previous experiments were done with unpolarized beams and targets. The first measurement with polarized protons at high energies in the Coulomb nuclear interference (CNI) region ($\sqrt{s} = 19.4$ GeV) was done by the E704 experiment [2] with a moderate precision. RHIC with its polarized beams [3] published a number of accurate measurements with $\sqrt{s} = 6.8 - 21.7$ GeV [4, 5] in last few years. But only one measurement with limited statistics exists so far in the collider energy range [6].

Elastic scattering of two identical particles with spin 1/2 is described by 5 helicity amplitudes [7, 8]. Two amplitudes $\phi_1(s,t) = <++|M|++>$ and $\phi_3(s,t) = <+-|M|+->$ produce no spin flip, two other $\phi_2(s,t) = <++|M|-->$ and $\phi_4(s,t) = <+-|M|-->$ produce double spin flip and the last $\phi_5(s,t) = <++|M|+->$ produces single spin flip. Each of the amplitudes can be written as a sum of hadron and Coulomb amplitudes $\phi_i = \phi_i^{em} + \phi_i^{h}$. The electromagnetic part is well calculable from QED. The total cross section is related to the non-flip amplitudes through the optical theorem: $\sigma_{tot} = \frac{4\pi}{s} Im(\phi_1 + \phi_3)|_{t=0}$. Other hadron amplitudes are expected
to be small and are parametrized in terms of $Im \phi_+ = Im(\phi_1 + \phi_3)/2$:

$$\phi_2 = 2r_2 Im \phi_+, \quad \phi_4 = -\frac{t}{m^2} r_4 Im \phi_+, \quad \phi_5 = \frac{\sqrt{-t}}{m} r_5 Im \phi_+.$$  (1)

The differential cross section and asymmetries can be written in terms of the amplitudes:

$$\frac{d\sigma}{dt} = \frac{2\pi s^2}{t} (|\phi_1|^2 + |\phi_2|^2 + |\phi_3|^2 + |\phi_4|^2 + 4|\phi_5|^2),$$  (2)

$$A_N \frac{d\sigma}{dt} = -\frac{4\pi}{s^2} Im \{\phi_5^* (\phi_1 + \phi_2 + \phi_3 - \phi_4)\},$$  (3)

$$A_{NN} \frac{d\sigma}{dt} = \frac{4\pi}{s^2} \{2|\phi_3|^2 + Re(\phi_1^* \phi_2^* - \phi_3^* \phi_4^*)\},$$  (4)

$$A_{SS} \frac{d\sigma}{dt} = \frac{4\pi}{s^2} \{Re(\phi_1 \phi_2^* + \phi_3 \phi_4^*)\}.$$  (5)

2. Experiment

The layout of the experiment is shown in fig. 1. The protons scattered at very small angles at the interaction point (IP) travel close to the beams within the beam pipe till they reach Roman Pot (RP) detectors located in the RHIC tunnel on both sides of the STAR detector. Each RP contains four silicon microstrip detectors and a trigger scintillation counter. The Roman Pot design allows to insert detectors very close to the beam without violation of the high accelerator vacuum [10]. Two RP stations with detectors inserted horizontally (at 55.5 m from IP) and vertically (at 58.5 m) were used on each side of IP. More details of the detectors can be found in [11]. The trigger for elastic events requires hits in the matching scintillator counters on both sides of the IP as well as no simultaneous hits in the scintillators of the same RP station. The coordinates measured by the detectors are related to the scattering angles at IP by the transport matrix:

$$\begin{pmatrix} x \\ y \end{pmatrix}_{RP} = T_{RP} \cdot \begin{pmatrix} \theta_x \\ \theta_y \end{pmatrix}_{IP},$$  (6)

where index $RP$ denotes a particular Roman Pot. The position of the RPs was selected so that the error introduced by the unknown position of the interaction point was minimal. More details on the detector layout, alignment and performance can be found at [12].

3. Analysis

Reconstruction of elastic events was performed in the following steps. Adjacent strips with charge values above 5$\sigma$ from their pedestal averages were found and combined into clusters. Very noisy

Figure 1. Layout of the setup for small-t measurements with the STAR detector.
and dead strips were rejected (total 5 out of \(\sim 14000\) in the active detector area). A threshold depending on the cluster width was applied to the total charge of the cluster thus achieving better signal to noise ratio for clusters of 3 and 4 strips, with wider clusters ignored. Clusters in the planes of the same coordinate in each RP were merged if closer than 200 \(\mu m\) or left separate, resulting in nearly 100 % detection efficiency. Clusters on each side of the IP were combined into track candidates; if there were more than one track candidate on a side, only those contributed by all 4 planes were used. Exactly one track candidate was required on each side with at least 6 silicon planes contributing to the whole event. Transport equation (6) was solved for each side. The corresponding distributions of angle differences between east and west sides are presented in fig. 2. The strongest criterion for the elastic event selection is the strict kinematic correlation: the scattering angles are required to be equal for both protons after interaction. The implementation of the selection was based on

\[
\chi^2 = \left( \frac{\theta_{west}^{x} - \theta_{east}^{x}}{\sigma_{x}} \right)^2 + \left( \frac{\theta_{west}^{y} - \theta_{east}^{y}}{\sigma_{y}} \right)^2,
\]

where \(\sigma_x = \sigma_y = 0.057\) mrad, and a strong cut \(\chi^2 < 5\) was used for this preliminary analysis (8.2% elastic event loss). As a result of all cuts \[19.3 \cdot 10^6\] events out of \[32.9 \cdot 10^6\] elastic triggers recorded during the run were selected for asymmetry calculations.

The single spin asymmetry \(A_N\) was calculated in 5 \(t\)-bins using the square root formula [13, 6] individually for each fill and then averaged. The raw asymmetry as function of azimuthal angle \(\phi\) for only ++ and −− bunch polarizations can be written as:

\[
\epsilon_N(\phi) = \frac{(P_B + P_Y)A_N \cos(\phi)}{1 + \delta(\phi)} = \frac{\sqrt{N^{++}(\phi)N^{--}(\pi + \phi)} - \sqrt{N^{--}(\phi)N^{++}(\pi + \phi)}}{\sqrt{N^{++}(\phi)N^{--}(\pi + \phi)} + \sqrt{N^{--}(\phi)N^{++}(\pi + \phi)}},
\]

(7)

where \(N^{ij}(\phi)\) - number of events with bunch polarization pattern \(ij\) at the azimuthal angle \(\phi\). \(P_B/Y\) are polarizations of blue and yellow beams, measured by HJET and pCarbon polarimeters [14]. The polarization values averaged for the time of our data taking were:

\[P_B + P_Y = 1.221 \pm 0.038, \quad P_B - P_Y = -0.016 \pm 0.038\] and \[P_B P_Y = 0.372 \pm 0.023\]. From double spin asymmetries measured by [6] we know that \(\delta(\phi) = P_B P_Y (A_{NN} \cos^2(\phi) + A_{SS} \sin^2(\phi))\) is less than 0.01. Using different bunch polarization combinations more raw asymmetries can be introduced similarly to (7): \(\epsilon_B(\phi) \sim A_N \cdot P_B, \epsilon_Y(\phi) \sim A_N \cdot P_Y\) and \(\epsilon'_N(\phi) \sim A_N \cdot (P_B - P_Y)\). \(\epsilon_N(\phi)\) and \(\epsilon'_N(\phi)\) are presented in fig. 3 for \(0.005 < |t| < 0.010\) (GeV/c)\(^2\) and all 4 fills.

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**Figure 2.** Elastic correlation — difference in scattering angles at IP for particles scattered to east and west in \(x\) (left) and \(y\) (right).
The double spin raw asymmetry is given by the equation:

$$
\delta(\phi) = P_B P_Y (A_{NN} \cos^2(\phi) + A_{SS} \sin^2(\phi)) = \frac{(N^{++} + N^{−−}) - (N^{++} + N^{−−})}{(N^{++} + N^{−−}) + (N^{++} + N^{−−})} + \frac{(N^{++} + N^{−−})}{(N^{++} + N^{−−})} .
$$

(8)

Here $L^{ij}$ are relative luminosities for the corresponding polarization pattern. For the preliminary results we used relative luminosities obtained from counts of inelastic triggers produced by the vertex position detector (VPD) and beam-beam counters (BBC). The systematic uncertainty in the normalization can be estimated by the difference between VPD and BBC normalizations which is 0.25%. We hope to reduce this uncertainty taking advantage of other normalization sources.

4. Results

The preliminary results on the single spin asymmetry are shown in fig. 4 in comparison with the theoretical curve without hadron spin-flip (black line) and with the best fit allowing non zero

![Figure 3. Raw single spin asymmetries $\epsilon_N$ (left) and $\epsilon'_N$ (right) for $0.005 < |t| < 0.010 \text{ (GeV/c)}^2$.](image1)

![Figure 4. Single spin asymmetry $A_N$, black curve $r_5 = 0$, green curve fitted $r_5$.](image2)

![Figure 5. Complex plane of parameter $r_5$ with contours of confidence level: 1, 2 and 3-$\sigma$.](image3)
hadron spin-flip (green line) (see [15] for formula). Fig. 5 shows fitted value of $r_5$ with contours showing confidence levels of 1, 2 and 3$\sigma$. No evidence for any contribution from hadron spin flip amplitude $\phi_5$ is seen.

The preliminary results on double spin asymmetries are shown in fig. 6. Though some effects of the order of $10^{-3}$ could be seen they are small and comparable with the normalization uncertainty. A careful study of systematic effects due to the normalization is in progress.

Our preliminary results agree with the hypothesis that only Pomeron exchange, which contributes only to spin-nonflip amplitudes $\phi_1$ and $\phi_3$, survives at high energies. As well as other cited measurements of the proton-proton elastic scattering with $\sqrt{s} > 10$ GeV we see no evidence of contribution of other amplitudes.

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