Double Spin Asymmetries A_{NN} and A_{SS} at $\sqrt{s} = 200$ GeV in Polarized Proton-Proton Elastic Scattering at RHIC

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Abstract

We present the first measurements of the double spin asymmetries A_{NN} and A_{SS} at $\sqrt{s} = 200$ GeV, obtained by the pp2pp experiment using polarized proton beams at the Relativistic Heavy Ion Collider (RHIC). The data were collected in the four momentum transfer t range $0.01 \leq |t| \leq 0.03$ $(\text{GeV}/c)^2$. The measured asymmetries, which are consistent with zero, allow us to estimate upper limits on the double helicity-flip amplitudes ϕ_2 and ϕ_4 at small $|t|$ as well as on the difference $\Delta\sigma_T$ between the total cross sections for transversely polarized protons with antiparallel or parallel spin orientations.

PACS numbers: 13.85.Dz and 13.88.+e

I. INTRODUCTION

In this paper we present the first measurements of the double spin asymmetries A_{NN} and A_{SS} in elastic scattering of polarized protons at RHIC at $\sqrt{s} = 200$ GeV and low t-range $0.01 \leq |t| \leq 0.03$ (GeV/c)^2. The experiment was carried out by the pp2pp Collaboration at the RHIC-Spin complex as a part of the pp2pp experimental program [1–4]. The present results complement our previously published results on the analysing power A_N [4]. The center of mass energy exceeds by a factor of 10 the energies reached in previous measurements of the elastic scattering spin parameters [5–9].

The kinematic region of our experiment is suitable for an investigation of the spin dependence of diffractive scattering — the dominant mechanism at high energies. In particular, the physical motivation of the present experiment is connected with two long-standing questions. First, is s-channel helicity conserved in elastic scattering at asymptotic energies, which is directly related to the question if the Pomeron exchange contributes to the spin effects (ref. [10] and references therein)? Second, does the hypothetical Odderon exist [11]?

The double spin asymmetry A_{NN} is defined as the cross section asymmetry,

$$A_{NN} = \frac{\sigma^{\uparrow\uparrow+\downarrow\downarrow} - \sigma^{\uparrow\downarrow+\downarrow\uparrow}}{\sigma^{\uparrow\uparrow+\downarrow\downarrow} + \sigma^{\uparrow\downarrow+\downarrow\uparrow}}\,, \tag{1}$$

for both beams fully polarized along the unit vector $\hat{n}$ normal to the scattering plane. The asymmetry A_{SS} is defined analogously, but for both beams fully polarized along the unit vector $\hat{s}$ in the scattering plane and normal to the beam. Elastic pp-scattering is described by five independent helicity amplitudes: two helicity conserving ones ϕ_1 and ϕ_3, two double helicity-flip ones ϕ_2 and ϕ_4, and one single helicity-flip amplitude ϕ_5 (see Ref. [10] for definitions). Each amplitude consists of hadronic and electromagnetic parts; $\phi_i = \phi_i^{em} + \phi_i^{had}$. The double spin asymmetries and $\Delta\sigma_T = \sigma^{\uparrow\downarrow} - \sigma^{\uparrow\uparrow}$, which are the subject of this paper, relate to the helicity amplitudes as follows [10]

$$\begin{aligned} A_{NN}\cdot\frac{d\sigma}{dt} &= \frac{4\pi}{s^2}\{2|\phi_5|^2 + \mathrm{Re}(\phi_1^*\cdot\phi_2 - \phi_3^*\cdot\phi_4)\}\,, \\ A_{SS}\cdot\frac{d\sigma}{dt} &= \frac{4\pi}{s^2}\mathrm{Re}(\phi_1^*\cdot\phi_2 + \phi_3^*\cdot\phi_4)\,, \\ \Delta\sigma_T &= \frac{8\pi}{s}\mathrm{Im}(\phi_2)_{t=0}\,. \end{aligned} \tag{2}$$

In the small t region the parameters A_{NN} and A_{SS} are sensitive to the interference between hadronic spin-flip amplitudes ϕ_2^{had} and ϕ_4^{had}, and the electromagnetic non-flip amplitude. This provides a sensitive tool to study the spin dependence of diffractive scattering at asymptotic energies and to search of the hypothetical Odderon exchange [11]. Because Pomeron and Odderon have opposite C-parities, it is expected in leading order, that if Pomeron and Odderon have the same asymptotic behaviour, up to logarithms, they are out of phase by approximately 90° [12]. Therefore, if they couple to spin, their interference with the electromagnetic non-flip amplitude will result in different t dependences of the double spin asymmetries (for a more detailed discussion of the A_{NN} case see [11]).

II. THE EXPERIMENT

The experiment pp2pp is located at the "2 o'clock" position of the RHIC ring. The layout of the experiment is shown in Fig. 1. The two protons collide at the interaction point (IP) and since the scattering angles are small, the scattered protons stay within the beam pipe until they reach the detectors. The measured coordinates are related to the scattering angles by the beam transport matrix. The coordinates are measured by silicon microstrip detectors (SSD) positioned just above and below the beam orbits by insertion devices – Roman Pots (RP) [13]. Each RP contains four planes of SSDs (two vertical and two horizontal) to provide redundancy for the track reconstruction. High quality SSDs manufactured by Hamamatsu Photonics with sensitive area of 4.5×7.5 cm^2 and pitch of 100 μm were used. The identification of elastic events is based on the collinearity criterion, hence it requires the simultaneous detection of the scattered protons in a pair of RP detectors on either side of the IP. More details on the experiment and the technique used can be found in [2, 3].

In addition, the inelastic event rates were monitored by eight scintillation detectors, four on each side of the IP, positioned outside the beam pipe (cf. Fig. 1). To reduce background due to the beam halo the outer scintillators, labelled IP3, IP4 for the detectors on the side of the IP towards RP1, and IN3, IN4 on the opposite side, were used for this analysis. These detectors covered a pseudorapidity range of $4.2 < \eta < 5.3$. The inelastic trigger was defined as (IP3 OR IP4) AND (IN3 OR IN4) in coincidence with the beam crossing signal from RHIC.

In order to prevent inelastic events from dominating the event rate and causing excessive

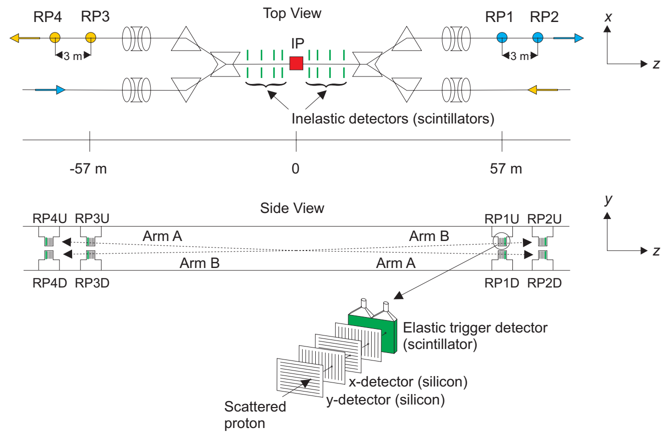

FIG. 1: Layout of the PP2PP experiment. Note the detector pairs RP1, RP2 and RP3, RP4 lie in different RHIC rings. Scattering is detected in either one of two arms: Arm A is formed from RP3U and RP1D. Conversely, Arm B is formed from RP3D and RP1U. The coordinate system is also shown.

dead time, the inelastic triggers were prescaled by a factor of 500. The data were recorded in an event-by-event mode, and broad offline cuts were made on the TDC and ADC to select events, yielding approximately 1400 inelastic events for each of 50 bunch-pair crossings.

Each bunch in one RHIC ring (B) collides with a bunch in the other ring (Y) to form different spin combinations. In this experiment, 13 different bunch-pairs yielded collisions with $B^{\uparrow}Y^{\uparrow}$ bunches, 13 yielded $B^{\uparrow}Y^{\downarrow}$ bunches, 11 yielded $B^{\downarrow}Y^{\downarrow}$, and 13 yielded $B^{\downarrow}Y^{\uparrow}$ combinations

The inelastic event rate was used as one of the two methods to monitor the relative luminosity for collisions of bunches with different polarizations. The product of intensities of colliding bunches was used in a second method to monitor the relative luminosity. Both methods are described and compared in Chapter IV.

III. SELECTION OF ELASTIC EVENTS

Details on the identification of hits in the silicon detectors, hit clustering and selection of elastic events can be found in Ref. [4]. Because of the collinearity of the scattered protons a correlation between coordinates measured on each side of the IP is required. Hence, the main criterion to select the elastic scattering events was the hit coordinate correlation in the corresponding silicon detectors on the opposite sides of the IP. An example of the distribution

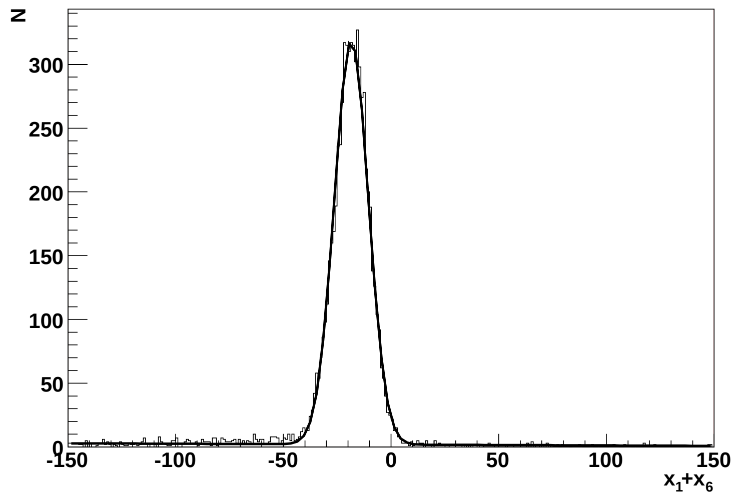

FIG. 2: Distribution of the sum of x-coordinates in a pair of silicon detectors on opposite sides of the IP. The coordinates are given in detector strip numbers.

of the sum of x-coordinates measured by a pair of detectors on both sides of the IP is shown in Fig. 2. One can observe that the background under the elastic peak is small. To select an elastic event, a match of hit coordinates (x,y) from detectors on the opposite sides of the IP was required to be within 3σ for x- and y-coordinates.

The average detector efficiency was 0.98, and the upper bound of the elastic events loss due to all criteria was $\leq 3.5\%$.

The background originates from particles of inelastic interactions, beam halo particles and products of beam-gas interactions. The estimated background fraction varies from 0.5% to 9% depending on the y-coordinate. Since in our analysis the coordinate area was essentially limited to $y > 30$ strips, the background in the final sample does not exceed 2%.

IV. DETERMINATION OF THE DOUBLE SPIN ASYMMETRIES

After the above cuts, a sample of 2.3 million elastic events was collected in the interval $0.010 \leq -t \leq 0.030$ (GeV/c)^2. The azimuthal angle dependence of the cross section for the elastic collision of the vertically polarized protons is given by

$$2\pi \frac{d^2\sigma}{dt d\phi} = \frac{d\sigma}{dt} \cdot (1 + (P_B + P_Y) A_N \cos\phi + P_B P_Y (A_{NN} \cos^2\phi + A_{SS} \sin^2\phi)) \,, \qquad (3)$$

where P_B and P_Y are the beam polarizations, A_{NN}, A_{SS} are the double spin asymmetries and A_N is the single spin asymmetry. The double spin raw asymmetry $\delta(\phi)$ is

$$\begin{aligned}\delta(\phi) &= P_B\, P_Y\, (A_{NN} \cos^2\phi + A_{SS} \sin^2\phi) \\ &= \frac{N^{\uparrow\uparrow}(\phi)/L^{\uparrow\uparrow} + N^{\downarrow\downarrow}(\phi)/L^{\downarrow\downarrow} - N^{\uparrow\downarrow}(\phi)/L^{\uparrow\downarrow} - N^{\downarrow\uparrow}(\phi)/L^{\downarrow\uparrow}}{N^{\uparrow\uparrow}(\phi)/L^{\uparrow\uparrow} + N^{\downarrow\downarrow}(\phi)/L^{\downarrow\downarrow} + N^{\uparrow\downarrow}(\phi)/L^{\uparrow\downarrow} + N^{\downarrow\uparrow}(\phi)/L^{\downarrow\uparrow}}\,,\end{aligned} \tag{4}$$

where $L^{i,j}$ is the relative luminosity for the sum of bunches with a given spin combination $\{i,j\} \in (\uparrow\uparrow, \uparrow\downarrow, \downarrow\uparrow, \downarrow\downarrow)$. The raw asymmetry δ was calculated as a function of the azimuthal angle ϕ using 5°-bins in the three t-intervals $0.010 \le -t < 0.015$, $0.015 \le -t < 0.020$, $0.020 \le -t \le 0.030$, as well as in the combined interval $0.010 \le -t \le 0.030$ (GeV/c)^2.

To evaluate $\delta(\phi)$ two estimates of relative luminosities $L^{i,j}$ were used. For the first one the rates of 'inelastic' counters [2, 3], $N^{i,j}_{inel}$, summed over bunch crossings with a given spin combination were used, $L^{i,j}_{inel} \sim \sum N^{i,j}_{inel}$. As the second estimate the sums of the machine bunch intensities products for each spin combination $L^{i,j}_{bint} \sim \sum I^i_B \cdot I^j_Y$ were used. Because the relative statistical errors and relative errors on the luminosity are comparable, they have to be combined for the determination of errors of raw asymmetries.

An example of the double spin raw asymmetry $\delta(\phi)$ distribution for the whole $t-$interval is shown in Fig. 3 together with the fitted function $P_B\, P_Y\, (A_{NN} \cos^2\phi + A_{SS} \sin^2\phi)$. A_{NN} and A_{SS} are the fit parameters and $P_B \cdot P_Y = 0.198 \pm 0.064$. The displayed raw asymmetry was obtained using bunch intensities for an estimate of the relative luminosities.

In order to facilitate separation of contributions of the helicity amplitudes ϕ_2 and ϕ_4 to the double spin asymmetries (cf. Eqs 2), we performed also alternative fits to $\delta(\phi) = P_B\, P_Y\, (a_1 + a_2 \cos 2\phi)$ using $a_1 = (A_{NN} + A_{SS})/2$ and $a_2 = (A_{NN} - A_{SS})/2$ as fit parameters.

For a cross check the $\delta(\phi)$ distributions were obtained using each of the two methods to estimate relative luminisities and the results of the fits to the $\delta(\phi)$ distributions have been compared. Both methods gave consistent results, although with larger errors for normalization by the numbers of inelastic events. Thus from now on we only present results obtained by using the bunch intensities.

V. SYSTEMATIC ERRORS

A detailed study of the errors on the relative luminosity estimated using bunch intensities was carried out. In the first stage of data processing the stability of the normalization was

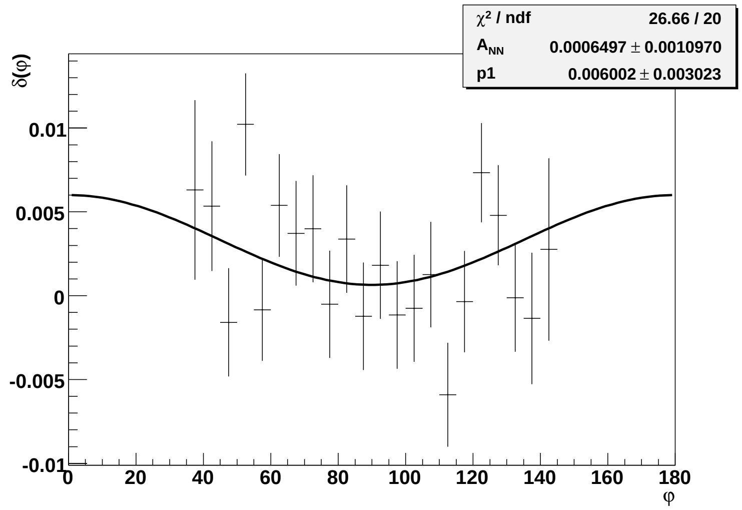

FIG. 3: The raw double spin asymmetry $\delta(\phi)$.

checked by inspecting for each spin state $\{i,j\}$ the ratio $N^{i,j}_{elast}/I^i_b \cdot I^j_Y$ as a function of the bunch crossing number. The bunch crossings for which a significant deviation of the ratio from the average was observed were excluded from the analysis. Next the $L^{i,j}_{bint} \sim I^{i,j} = \sum I^i_B {\cdot} I^j_Y$ summed over runs were evaluated for each position of detectors. The ratios between any pair of $I^{i,j}$'s are quite stable as a function of the position of detectors, at the level of $< 0.2\%$.

For the method using bunch intensities to be applicable, it is mandatory that $L^{i,j}_{bint} = k \cdot I^{i,j} = k \cdot \sum I^i_B \cdot I^j_Y$ and the coefficient k not to depend on the spin state. The stability of $N^{i,j}_{elast}/I^{i,j}$ was analysed on a bunch-by-bunch basis. The main result of this analysis is that the relative error on the normalization is equal to $\sigma(k)/k = 0.0124 \pm 0.0015$. From the analysis of the spread of k on a run-by-run basis we conclude that about half of the error on k is due to the accuracy of the intensity measurements.

The systematic errors on the double spin asymmetries depend on the errors of the positions of the beams in the x and y planes and on the transport matrix elements, especially the effective lengths. The systematic errors due to these two effects were estimated using the experimental sample and assuming $\Delta x = 0.5$ mm, $\Delta y = 1.0$ mm, $\Delta L^x_{eff}/L^x_{eff} = 5\%$ and $\Delta L^y_{eff}/L^y_{eff} = 5\%$.

The effect of these two sources on the systematic error depends on a particular asymmetry; the uncertainty on the effective lengths is the dominant contribution to the systematic error of A_{NN} while the uncertainty on the beam coordinates is dominating the one for A_{SS}. The combined systematic errors for various double spin asymmetries are given in Table I. The systematic errors are about half of the statistcal errors (including the relative luminosity errors).

The polarization values of the proton beams were obtained from the accelerator polarimetry [14]. They were evaluated using A_N measurements for elastic proton-carbon (pC) scattering at small $|t|$-values, in the range $0.01 - 0.02$ (GeV/c)^2. The details are described in Ref. [9]. During the period in 2003 when the present data were taken the beam polarizations were $P_Y = 0.411 \pm 0.021$ and $P_B = 0.481 \pm 0.027$. These values correspond to the present analysis, which includes bunches with all spin combinations. The indicated errors are purely statistical. In addition there is a systematic uncertainty of 13%, due to the calibration of the pC polarimeter, which is correlated for both beams. This gives for the combined statistical and systematic errors of the measurement of the product of the polarizations $P_Y \cdot P_B = 0.198 \pm 0.064$. Thus, due to the uncertainties on the beam polarization the scale error on the measured asymmetries is equal to 32% .

VI. RESULTS AND CONCLUSIONS

The results on the double spin asymmetries for the whole t-interval $0.010 \leq -t \leq 0.030$ (GeV/c)^2, at an average $< -t >= 0.0185$ (GeV/c)^2, are presented in Table I. The most accurately determined asymmetry is $A_{SS} = 0.0035 \pm 0.0081$, which is consistent with zero at 1σ confidence level. The asymmetry $A_{NN} = 0.0298 \pm 0.0166$ as well as the combinations $(A_{NN} + A_{SS})/2 = 0.0167 \pm 0.0091$ and $(A_{NN} - A_{SS})/2 = 0.0131 \pm 0.0096$ are also small and consistent with zero.

At collider energies one expects [10] the two helicity conserving amplitudes ϕ_1 and ϕ_3 to be equal, $\phi_1 \approx \phi_3 \approx \phi_+ = (\phi_1 + \phi_3)/2$. In addition, if for simplicity one assumes the Coulomb amplitude to be pure real, $\phi_+^{em} = -\mathrm{Im}\, \phi_+^{had} \cdot t_c/t$, where at our energy $t_c = -0.0013$ (GeV/c)^2, the general formulae for the transverse double spin asymmetries (cf. Eq. 2)

TABLE I: Double spin asymmetries A_{NN}, A_{SS}, $(A_{NN}+A_{SS})/2$ and $(A_{NN}-A_{SS})/2$ for the t-interval $0.010 \le -t \le 0.030$ (GeV/c)^2 at $< -t >= 0.0185$ (GeV/c)^2.

	A_{NN}	A_{SS}	$(A_{NN}+A_{SS})/2$	$(A_{NN}-A_{SS})/2$
$Asym$	0.0298	0.0035	0.0167	0.0131
$\Delta Asym$ (stat.+norm.)	± 0.0166	± 0.0081	± 0.0091	± 0.0096
$\Delta Asym$ (syst.)	± 0.0045	± 0.0031	± 0.0034	± 0.0072
$\Delta Asym$ due to $\Delta(P_Y \cdot P_B)$	± 32.3 %			

reduce to approximate ones:

$$\begin{aligned}
A_{NN}\cdot \mathrm{Im}^2\phi_+ &= 2|\phi_5|^2 + \mathrm{Im}\,\phi_+\{\mathrm{Im}\,\phi_2 - \mathrm{Im}\,\phi_4 + (\rho - t_c/t)\cdot(\mathrm{Re}\,\phi_2 - \mathrm{Re}\,\phi_4)\}\,,\\
A_{SS}\cdot \mathrm{Im}^2\phi_+ &= \mathrm{Im}\,\phi_+\{\mathrm{Im}\,\phi_2 + \mathrm{Im}\,\phi_4 + (\rho - t_c/t)\cdot(\mathrm{Re}\,\phi_2 + \mathrm{Re}\,\phi_4)\}\,,\\
(A_{NN}+A_{SS})/2\cdot \mathrm{Im}^2\phi_+ &= |\phi_5|^2 + \mathrm{Im}\,\phi_+\{\mathrm{Im}\,\phi_2 + (\rho - t_c/t)\cdot\mathrm{Re}\,\phi_2\}\,,\\
(A_{NN}-A_{SS})/2\cdot \mathrm{Im}^2\phi_+ &= |\phi_5|^2 - \mathrm{Im}\,\phi_+\{\mathrm{Im}\,\phi_4 + (\rho - t_c/t)\cdot\mathrm{Re}\,\phi_4\}\,,
\end{aligned} \tag{5}$$

where $\rho = \mathrm{Re}\,\phi_+/\mathrm{Im}\,\phi_+$. For brevity, in Eqs 5 and in the following we omitted the superscripts 'had' for hadronic amplitudes.

As seen from the above formulae, taking $(A_{NN}+A_{SS})/2$ and $(A_{NN}-A_{SS})/2$ combinations allows one to select the amplitudes ϕ_2 and ϕ_4, respectively. Let us first assume that the phases of ϕ_2 and ϕ_4 are about the same as the phase of the non-flip amplitude ϕ_+. Then the last term in the brackets can be neglected and the 1σ upper limits for the imaginary parts of ϕ_2 and ϕ_4 at $t = -0.185$ (GeV/c)^2 are: $\mathrm{Im}\,\phi_2/\mathrm{Im}\,\phi_+ < 0.028$ and $-\mathrm{Im}\,\phi_4/\mathrm{Im}\,\phi_+ < 0.026$, or in terms of the conventional ratios $r_2 = \phi_2/(2\,\mathrm{Im}\,\phi_+)$ and $r_4 = -m^2\,\phi_4/(t\,\mathrm{Im}\,\phi_+)$ [10] they are $\mathrm{Im}\,r_2 < 0.014$ and $\mathrm{Im}\,r_4 < 1.25$.

A more precise limit on $\mathrm{Im}\,\phi_2$ at t close to zero and therefore on $\Delta\sigma_T = \sigma_{tot}^{\uparrow\downarrow} - \sigma_{tot}^{\uparrow\uparrow}$ can be obtained using the t-dependence of the asymmetry A_{SS} and extrapolating A_{SS} to $t = -0.01$ (GeV/c)^2 where the term containing the real parts of amplitudes vanishes. For that purpose the corresponding experimental distributions $\delta(\phi)$ in the three t-intervals were fitted with a function $P_B\,P_Y\,\{A_{SS} + (A_{NN} - A_{SS})\cos^2\phi\}$ with A_{SS} as a fit parameter. Here the term $A_{NN} - A_{SS}$ was not fitted, but calculated as a predefined function of t. At small $|t|$ this term is proportional to t, $A_{NN} - A_{SS} = C\cdot t$, because of the kinematical factors in ϕ_5 and ϕ_4

resulting from angular momentum conservation [10]. The constant C was calculated using the value of $A_{NN} - A_{SS}$ from the $\delta(\phi)$ fit for the combined t-interval (cf. Table I). The results of the fit of A_{SS} in bins of t are given in Table II.

TABLE II: Double spin asymmetry A_{SS} in different intervals of t.

$-t$ interval (GeV/c)^2	0.010 - 0.015	0.015 - 0.020	0.020 - 0.030
$-<t>$ (GeV/c)^2 interval	0.0127	0.0175	0.0236
A_{SS}	0.0005	0.0076	0.0015
ΔA_{SS} (stat.)	± 0.0071	± 0.0056	± 0.0061

With the linear extrapolation to $t_0 = -0.01$ (GeV/c)^2 we obtain $A_{SS}(t_0) = 0.0037 \pm 0.0104$. Neglecting the contribution of ϕ_4 to A_{SS} and the variation of ϕ_2 over the small range of t one obtains $\mathrm{Im}\,\phi_2/\mathrm{Im}\,\phi_+ = 0.0037 \pm 0.0104$, $\mathrm{Im}\,r_2 = 0.0019 \pm 0.0052$ and $\Delta\sigma_T = -0.19 \pm 0.53$ mb. The quoted errors are the quadratic sum of the statistical, normalization and systematic errors and the error due to the beam polarizations uncertainty.

The existing experimental data on $\Delta\sigma_T$ at low energies were fairly well described by a Regge model with cuts [15]. Our result is consistent with the prediction of the model for $\Delta\sigma_T$ at $\sqrt{s} = 200$ GeV.

As seen from Eq. 5 the asymmetry A_{SS} depends on the sum of the amplitudes ϕ_2 and ϕ_4 and this sum does not couple to the leading and subleading Regge poles (Pomeron, Odderon, ρ, ω, f, a_2) [10]. Thus one can expect that at $\sqrt{s} = 200$ GeV only Regge cuts may contribute. We consider the effect on A_{SS} of a possible contribution of the Pomeron-Odderon cut exchange in the t-channel as discussed in Refs [11] and [16]. In case of such exchange the phase of the ϕ_2 amplitude is shifted by 90° relative to the amplitude ϕ_+, and $\mathrm{Im}\,\phi_2 = -\rho\,\mathrm{Re}\,\phi_2$ and thus $A_{SS} \approx -t_c/t \cdot \mathrm{Re}\,\phi_2/\mathrm{Im}\,\phi_+$. Using the A_{SS} value at $t = -0.185$ (GeV/c)^2 (Table I) one obtains $\mathrm{Re}\,\phi_2/\mathrm{Im}\,\phi_+ = -0.050 \pm 0.130$ or $\mathrm{Re}\,r_2 = -0.025 \pm 0.065$. Though this value is well consistent with zero it leaves wide room for a possible Pomeron-Odderon cut contribution.

Theoretical predictions for double-spin asymmetries in elastic proton-proton scattering at high energies and small momentum transfers have been recently presented in Ref. [16]. The magnitudes of A_{NN} and A_{SS} have been estimated using results from an earlier determination of the spin-couplings of the leading Regge poles [17] and the required Regge cuts were estimated using the absorptive Regge model. As the Odderon spin coupling is totally unknown, the predictions are given for various assumptions: (a) no Odderon, (b) weak Odderon spin coupling - equal to that of the Pomeron, (c) strong Odderon spin coupling - equal to the ρ Reggeon spin coupling. For none or a weak Odderon coupling the predicted values of the A_{NN} and A_{SS} asymmetries are very small. At $\sqrt{s} = 200$ GeV and $0.01 \le |t| \le 0.03$ $(\mathrm{GeV}/c)^2$ their values are in the range 0.001 - 0.002. On the contrary, for a strong Odderon spin coupling (like ρ) the double-spin asymmetries become significantly larger, at least by a factor of 10. Our results support predictions of Ref. [16] which assume none or a weak spin coupling of the Odderon.

In conclusion, these are the first measurements of the transverse double spin asymmetries and the first results on the double helicity-flip amplitudes in the small $|t|$ region in elastic pp scattering at collider energies. From the measured double spin asymmetries we determined the parameters $\mathrm{Im}\, r_2 = 0.0019 \pm 0.0053$ and $\Delta\sigma_T = -0.19 \pm 0.53$ mb, both being consistent with zero within errors. We also estimated the upper limit on $\mathrm{Im}\, r_4$ which is $\mathrm{Im}\, r_4 < 1.25$.

Assuming the Pomeron-Odderon cut exchange one finds $\mathrm{Re}\, r_2 = -0.025 \pm 0.065$. The signs and central values of the real and imaginary parts of r_2 agree with expectations for Pomeron-Odderon cut exchange. Their magnitudes are consistent with an assumption of about 5% ratio of the cut amplitude to the dominant one.

Acknowledgments

The research reported here has been performed in part under the US DOE contract DE-AC02-98CH10886, and was supported by the US National Science Foundation and the Polish Academy of Sciences. The authors are grateful for the help of N. Akchurin, D. Alburger, P. Draper, R. Fleysher, D. Morse, Y. Onel, A. Penzo, and P. Schiavon at various stages of the experiment and for the support of the BNL Physics Department, Instrumentation Division, and the Collider-Accelerator Department at the RHIC-AGS facility. We would also like to thank T. L. Trueman for useful discussions.

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