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Simultaneous measurements of spin observables $A_N$ and $A_{NN}$ in elastic $pp$ scattering (extension of the SPASCHARM program at U-70).

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Abstract. We propose to measure spin observables $A_N$ and $A_{NN}$ in elastic $pp$ scattering by using the transversely polarized proton beam and target at momenta $p = 12-45$ GeV/c. Existence of both polarized target and beam gives us unique possibility to measure $A_N$ simultaneously and independently for polarized beam ($A_B$) and target ($A_T$) to carry out and verify experimental measurements of single-spin and double-spin ($A_{NN}$) measurements in diffractive region.

1. Introduction
Spin correlation parameter $A_{NN}$ was measured earlier in diffractive region at the momentum less than 12 GeV/c [1,2,3]. We propose to measure analyzing power $A_N$ for both polarized beam and target and the initial state spin-spin correlation parameter $A_{NN}$ in proton-proton elastic scattering at $-t$ from 0.075 to 0.6 (GeV/c)$^2$ at the new IHEP beam line 24A in the momenta range 12-45 GeV/c [4].

The results of this experiment can be described by a set of spin parameters by the formula [5]:

$$
\frac{d\sigma}{d\Omega} = \frac{d\sigma}{d\Omega} \left[ 1 + P_B (j) A_B + P_T (j) A_T + P_B (j) P_T (j) A_{NN} \right]
$$

(1),

where $P_B$ and $P_T$ are the beam and target polarization, $A_B$ and $A_T$ are the beam and target analyzing powers. The $A_{NN}$, $A_B$, and $A_T$ can be expressed by equations (2-4), respectively:

$$
A_{NN} = \frac{1}{P_B P_T} \frac{N(\uparrow) - N(\downarrow)}{N(\uparrow) + N(\downarrow) + N(\uparrow)}
$$

(2),

$$
A_B = \frac{1}{P_B} \frac{N(\uparrow)}{N(\uparrow) + N(\downarrow) + N(\uparrow)}
$$

(3),

$$
A_T = \frac{1}{P_T} \frac{N(\downarrow)}{N(\uparrow) + N(\downarrow) + N(\downarrow)}
$$

(4),

1 $A_B$ and $A_T$ are the same values in the physical sense and corresponds to different polarized objects (beam or target).
where \( N(ij) \) is the number of events normalized to the incident proton flux with the beam's (i) and target's (j) spin direction up (↑) or down (↓). Our main goal is to determine the momentum dependence of the spin-correlation parameters in the range of 12-45 GeV/c in the diffractive kinematic region.

2. Existing experimental data of \( A_N \) and \( A_{NN} \) in proton-proton elastic scattering

\( A_N \) is fairly well measured at various energies (see figure 1 which was presented originally in Ref. [6]). The solid line is the fitting function with poles, suggested by the Regge model, namely, 
\[
A_N = a_1 + \frac{a_2}{\sqrt{p_{\text{beam}}} \, + \frac{a_3}{p_{\text{beam}}} \, [7].
\]

The measured value of \( A_N \) at 45 GeV/c is equal to \((2.3\pm0.2)\% [8]\), and this value is used here for estimating the required beam time. The experimental data on the spin correlation parameter \( A_{NN} \) in the diffractive region are very scarce. This parameter has been measured only at the momenta of 3.3; 6; 11.75 GeV/c [1,2,3] in laboratory system (see figure 2). The solid line presents the fit to experimental data with the function 
\[
A_{NN} = a (p/p_0)^b_{\text{beam}},
\]
where \( a=(57\pm23)\% \) and \( b=-0.86\pm0.33 \), and \( p_0=1 \) GeV/c. The expected value for \( A_{NN} \) at 45 GeV/c is \((2.2\pm1.1)\%\).

3. Beam characteristics and beam polarization measurement

The polarized proton and antiproton beams are described in detail in Ref. [9]. We plan to carry out these measurements at the polarized-proton beam at \( p_b=12-45 \) GeV/c with the narrowest possible momentum band \( \Delta p/p=1.2\% [9] \), striking the polarized target of a diameter 18 mm [10]. The beam properties are as follows [9]: an average beam polarization \( P_b=40\% \), transverse dimensions \( \sigma(x) \times \sigma(y) = 11 \times 8.7 \) mm\(^2\), angular divergences \( \sigma(x') \times \sigma(y') = 1.4 \times 1.7 \) mrad\(^2\), intensity \( I=5 \times 10^6 \) protons per cycle hitting the target.

The transverse polarization dependence on the beam-ray position along the vertical axis in the intermediate focus is presented in figure 3 [9]. It can be described by the function 
\[
\langle P_N \rangle = ay + by^3,
\]
where \( a=(0.025 \pm 0.027) \) mm\(^{-1}\), \( b=-(0.68 \pm 0.19) \times 10^{-5} \) mm\(^3\). The beam-tagging system will be used for measuring the momentum of each particle at the accuracy of about 1% and the polarization accuracy of few percent [11].

4. Experimental setup

The design of the experimental setup is presented in figure 4. The main detectors to be used are the trigger scintillator counters (S1-S8) and hodoscopes (H1-H8).

The parameters for all hodoscopes are presented in table 1. The hodoscopes are constructed in such a manner that each scintillator strip overlaps its two adjacent neighbors by one-third of the width. This kind of overlapping arrangement provides twice as many of the spatial segments for the same number.
of channels of encoding electronics as for the edge-butted array. It also removed the loss of tracking efficiency by eliminating the inter-segment gaps.

Figure 3. Correlation between the average vertical transverse polarization of protons and the vertical ray coordinate \( y \) in the plane of intermediate focus.

Figure 4. Design of the experimental setup.

In order to suppress inelastic events, a special fast trigger will be organized on the base of coincidences between scattered and recoil protons in forward (H3-H4) and backward (H5-H8) detectors. It worth mentioning, that elastic scattering measurements can be carried out simultaneously with the inclusive double-spin studies, using the main detectors of SPASCHARM experiment.

Table 1. Design of the hodoscopes

| Hodoscope     | Distance from target ( mm) | Total dimensions (mm) | Dimension of scintillator strips: Width × Thickness × Length (mm³) | Numbers of channels |
|---------------|-----------------------------|-----------------------|-------------------------------------------------------------------|--------------------|
|               | X                           | Y                     | X                    | Y                  | X     | Y     |
| Beam Hodoscopes |                             |                       |                      |                    |       |       |
| H1            | -9000                       | 40 × 40               | 6 × 3 × 40           | 6 × 3 × 40         | 9     | 9     |
| H2            | -2800                       | 40 × 40               | 6 × 3 × 40           | 6 × 3 × 40         | 9     | 9     |
| Forward Hodoscopes |                         |                       |                      |                    |       |       |
| H3            | 850                         | 62 × 45               | 6 × 3 × 62           | 6 × 3 × 45         | 15    | 11    |
| H4            | 2850                        | 182 × 86              | 6 × 3 × 182          | 6 × 3 × 86         | 45    | 21    |
| Recoil Hodoscopes |                         |                       |                      |                    |       |       |
| H5 - H7       | 300                         | 322 × 228             | 9 × 5 × 322          | 9 × 5 × 228        | 51    | 37    |
| H6 - H8       | 600                         | 432 × 430             | 9 × 5 × 432          | 9 × 5 × 420        | 71    | 69    |

5. Beam time estimation

Numerical calculations for the number of elastic scattering events has been done at 45 Gev/c and for the worst case scenario, i.e. at the maximum value of \( |t| = 0.6 \text{ (GeV/c)}^2 \) and \( \Delta t = ±0.1 \text{ (GeV/c)}^2 \), where the cross-section is the smallest. For measuring the t-dependence of \( A_{NN} \), the following input parameters have been assumes in simulations: the main beam characteristics as they are described in Sec. 3, the beam duty factor \( \nu = 0.1 \), the polarized target proton density \( \rho = 0.12 \text{ g/sm}^3 \), the vertical component of magnetic field in the frozen polarized target zone 0.45 T, the target polarization \( P_T = (75±5) \% \). These correspond to the luminosity \( L = 10^{35} \text{ sm}^{-2} \text{s}^{-1} \) [9].
An event rate is defined as \( n = L \Delta t \frac{d\sigma}{dt} \Delta \phi/\phi \), where \( \frac{d\sigma}{dt} = 0.23 \text{ mb/(GeV/c)}^2 \) \(^{[12]}\) and \( \Delta \phi/\phi = 0.1 \).

Finally, at the assumptions above, the counting rate \( n = 0.04644 \text{ s}^{-1} \). In order to measure \( A_{NN} \) with the statistical error \( \Delta A_{NN} = A_{NN} \leq 2.2\% \), and taking into account both the beam and target polarizations and data taking inefficiency\(^2\), the required beam time would be about 10 days. The parameters \( A_B \) and \( A_T \) will be measured at the same time with the precision of \( \sim 50\% \) and 30\%, respectively, for the same \( |t| = 0.6 \text{ (GeV/c)}^2 \). The much better precisions for these observables are expected at the smaller \( |t| \) values.

6. Summary

We proposed the experiment which allows to measure simultaneously three spin observables in elastic pp scattering at 12-45 GeV/c in the \( |t| \) interval of 0.07÷0.60 (GeV/c)^2. 10 days are required for measuring the t-dependence of \( A_{NN} \) in order to reach the precision \( \Delta A_{NN} = A_{NN} \leq 2.2\% \) at maximum momentum value 45 GeV/c. The time required for measuring the \( A_N \) for both beam (\( A_B \)) and target (\( A_T \)) with \( \sim 10 \% \) relative error is significantly shorter at the smaller \( |t| \).

The momentum dependence of these parameters can be studied in wide momentum range from 12 to 45 GeV/c.

The work on estimations of the possibility to carry out similar measurements with the polarized-antiproton beam is in progress.

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\(^2\) Target polarization has to be changed at least each two days, which takes about 10 hours for each change of polarization sign