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A Letter of Intent

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S P I N - T E N S O R

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Abstract

We propose to measure all components of the depolarization tensor D_{ik} in the elastic pp-scattering in the region of $|t|$~0.25 - 3.5 $(GeV/c)^2$ at the energies 150 GeV and 800 GeV at FNAL using polarized gas jet target and carbon polarimeter registering the polarization vector of the recoil protons. It is necessary that the vector of the target polarization has to be directed both along the normal to the reaction plane and along two axis in the reaction plane. The polarization of the beam particle is not needed to determine the depolarization tensor but will permit the additional characteristics of pp elastic scattering.

The measurement of the depolarization tensor D_{ik} at high energies has not been carried out yet. The information about the tensor D_{ik} is of much interest to verify different models of hadron interaction at high energy. Proposed experiment will enable one to determine spin-flip vertex of the pomeron in region of $|t|$~ 0.25-0.5 $(GeV/c)^2$ and to elucidate the role of the spin effects in the region of the second diffraction cone.

Introduction

Over the last years experimentalists have revealed quite a few interesting effects which demonstrate the significant role of the spin both in soft and hard processes in high energy collisions (see review [1]). One of the interesting observation was a discovery of the relatively large and slowly decreasing with energy polarization P_o in elastic pp-scattering for $|t|\leq 3$ $(GeV/c)^2$ in the interval of P_{lab}~100-400 GeV/c [2,3]. The parameter P_o coincides with the asymmetry A if we neglect the T-noninvariant effects. This fact is, perhaps, suggestive of the presence of the spin-flip components in the pp-scattering amplitude for the pomeron exchange. The existence of the pomeron spin-flip component has long been debated in the literature [4-11] but, nevertheless, the question is still far from being settled. In the case of the high p_T pp-scattering at the energies of 24 and 28 GeV [12,13] the asymmetry A also proved to be unexpectedly large. This result contradicts the helicity conservation in two-particle processes, predicted by the perturbative QCD [14]. In general, the situation with an understanding of the spin effects in high energy pp-collisions cannot now be declared as satisfactory. It is evident that further theoretical and experimental investigations are needed in this field.

The depolarization tensor D_{ik} possessing four independent components [15,16] has not been studied in detail in pp-collisions at high energies. Some components of D_{ik} were studied at P_{lab}=6 GeV/c [17-19] and P_{lab}=45 GeV/c [20] (one component). We propose to obtain information about the behavior of all four components of the depolarization tensor D_{ik} in the momentum transfer region $-t=0.25-3.5\ (GeV/c)^2$ at 150 GeV and 800 GeV at FNAL. The relations between this tensor and pp-scattering amplitudes are discussed in detail in our paper [21]. The measurement of the tensor D_{ik} is more difficult than one of the one-spin asymmetry A and the tensor A_{ij} but it may give new information about the role of the spin effects in high-energy pp-scattering.

Physics goal

Measurement of the components D_{xx} and D_{zz} at $|t|\sim 2-3.5\ (GeV/c)^2$ with accuracy ~0.1 will enable one to elucidate whether the mechanisms with the change of the protons helicities are dominant in the region of second diffraction cone [22]. There are different theoretical predictions for the sum of $D_{xx}+D_{zz}$ [21] in the model with odderon exchange [23-25]; in the "anomalon" model [26] and in the U-matrix model [27-28]. The predicted behavior of this sum is shown schematically on fig.1. One can see that the measurement of diagonal components of the depolarization tensor D_{ik} permits to verify these approaches to a description of the second diffraction cone in pp-scattering.

Measurement of the component D_{yy} of the depolarization tensor will permit the identification of the contribution provided to the pp-scattering cross section by amplitudes with nonnatural quantum numbers which at high energies can be connected with pomeron and pomeron-odderon cuts. It is of much interest to elucidation of the minimum in pp elastic cross section and to verification of phenomenological cut models [27-30].

The information about the polarization P_o and the component D_{zx} will enable one to determine the spin-flip pomeron-nucleon vertex with accuracy ~0.05 at $|t|$~0.25-0.5 $(GeV/c)^2$. This data can be compared with one obtained in the region of the Coulomb-nuclear interference [31]. It is of much interest in connection with the available theoretical prediction of the drastic t-dependence of this vertex in the region of -t~0.1 $(GeV/c)^2$ [9].

THE MEASUREMENT OF ALL COMPONENTS OF THE DEPOLARIZATION TENSOR

In the scattering on the polarized target the vector of the recoil proton polarization $\vec{P}_R$ can have components in the reaction plane. The expression for the vector $\vec{P}_R$ which relates it with the vector of the target polarization $\vec{P}_T$, the polarization parameter P_o and the depolarization tensor D_{ik} is of the form [15]:

$$P_{Rk} = \frac{P_o n_k + D_{ik} P_{Ti}}{1 + P_o(\vec{P}_T \vec{n})}$$

Here the subscripts of the depolarization tensor are arranged in the order accepted in the review [15] (the first index is for the target proton and the second - for the recoil proton), $\vec{n}$ is the normal to the reaction plane.

In order to determine fully the tensor D_{ik} it is sufficient to measure in the lab system the components D_{SS}, D_{NN}, D_{LL} and D_{LS} or D_{SL} (the coordinate system is shown on fig.2). These quantities can be determined from a knowledge of the vector of the recoil proton polarization at different vectors of the target polarization, for example

$$D_{SS} = \frac{(\vec{P}_R \vec{e}^{\,S}_R)}{P_T}, \qquad \vec{P}_T = \vec{e}^{\,S}_T P_T$$

$$D_{LL} = \frac{(\vec{P}_R \vec{e}^{\,L}_R)}{P_T}, \qquad \vec{P}_T = \vec{e}^{\,L}_T P_T$$

$$D_{LS} = \frac{(\vec{P}_R \vec{e}^{\,S}_R)}{P_T}, \qquad \vec{P}_T = \vec{e}^{\,L}_T P_T$$

$$D_{NN} = P_o(\vec{P}_R \vec{n}) + \frac{(\vec{P}_R \vec{n}) - P_o}{P_T}, \qquad \vec{P}^S_T = \vec{e}_T P_T$$

The rotation of the vector of the proton spin in the passage through the magnetic field enables one to determine both the components P^L_R and P^S_R despite the fact that the proton rescatteringin the polarimeter is insensitive to the longitudinal component of the polarization vector. It is possible if measurements are carried out with two (for example, opposite in sign) values of the spectrometer magnetic field. Let $\Delta\varphi$ denote the angle of rotation of the proton spin with reference to the proton direction in the passage through the spectrometer. The estimation of this quantity at the magnetic field integral equal to 1 Tm shows that $\Delta\varphi$ ~ 0.6-1.1 in the region $|t|\leq 3.5$ $(GeV/c)^2$. For these values of $\Delta\varphi$ the accuracy of determination of the vector of the recoil proton polarization is close to the accuracy of measurement of the normal components of polarization vector in the polarimeter.

THE EXPERIMENTAL SETUP

The spectrometer is similar to the spectrometer-polarimeter arm of the NEPTUN experimental setup [32]. The experimental setup consist of a microstrip telescope with a strip step of 200 μm, blocks of proportional chambers, with a wire-to-wire step of 2 mm, placed behind and in front of the magnet with the path length of 1 m and the field of 10^4 gauss and a polarimeter consisting of the same blocks of proportional chambers interleaved with carbon plates (see fig.3). The thickness of carbon is changed from 1-2 cm for measurements at the region of small $|t|\leq 0.5$ $(GeV/c)^2$ to 20-25 cm at the region of large $|t|$. The setup, as a whole, can rotate about the axis passing through the target and is placed at an angle of $30°$-$75°$ to the beam axis. The angular aperture of the arm is about 0.1x0.1 rad^2 and it is determined by the necessity of existence in the polarimeter chambers of reserve regions for detecting the proton scattered on carbon. The distance between the target and the last chamber is about 5-7 meters.

Table 1, taken from ref [32], gives the values of the resolutions for the azimuthal $\Delta\theta$ and polar $\Delta\phi$ angles of scattering of a primary proton, for the momentum transfer Δt and the square of the missing mass ΔM^2 in different angular ranges of the system with respect to the beam direction which correspond to the intervals of

$-t$ from 0.25 GeV^2 to 3.5 GeV^2. Table 1 gives also the error in determination of the angles θ^{pC} and ϕ^{pC} of the analyzing pC-scattering and the efficiency of the polarimeter - the ratio of the number of registered analyzing interactions to the number of incident protons.

Table 1.

Errors in determination of the parameters of a recoil track and an analizing pC-interaction.

interval θ	interval $-t$ GeV^2	$\Delta\theta$ mrad	$\Delta\phi$ mrad	Δt GeV^2	ΔM^2 $(GeV/c^2)^2$	$\Delta\theta^{pC}$ mrad	$\Delta\phi^{pC}$ rad	N^{pC}/N_p %
45°-50°	2.5-3.5	1.8	2.5	0.050	9.0	8.6	0.12	20.
50°-55°	1.7-2.5	2.1	2.8	0.045	7.6	9.5	0.12	20.
55°-60°	1.2-1.7	2.6	3.2	0.035	6.1	10.	0.13	20.
60°-65°	0.8-1.2	3.2	4.0	0.023	4.3	17.	0.13	15.
65°-70°	0.5-0.8	4.4	5.0	0.013	3.6	20.	0.14	3.
70°-75°	0.25-0.5	5.7	6.3	0.006	3.0	29.	0.16	0.5

To identify elastic events in the region of the second maximum and, especially, in the region of the minimum in the elastic cross section, it is necessary to involve the information about the leading track in the event. To measure the leading track parameters we plan to use a microstrip or scintillator hodoscope placed near the beam and possessing the resolution less than the beam angular spread.

Elastic rates

To estimate the event rate the experimental data at $\sqrt{s}$=30.5 GeV [33] was used and we assume that the luminosity is $L=3\cdot10^{32}$ cm^{-2}sec^{-1}. The observed values of the elastic cross sections in different $-t$-intervals are given in table 2. Using these values and efficiency of the polarimeter N^{pC}/N_p listed in table 1 one can calculate the event rate for analyzing pC-events:

$$\frac{\text{Events}}{\text{hour}} = L \cdot \sigma \cdot N^{PC}/N_p$$

To determine all four components of the tensor D_{ik} the measurement must be carried out with the vector of the target polarization directed along all three directions ($\vec{e}_N$, $\vec{e}_L$, $\vec{e}_S$) and with two values of the spectrometer magnetic field for the target polarization placed in the reaction plane. Thus, the total time needed to measure the tensor D_{ik} is five times greater then one required for the measurement of the normal component of the recoil proton polarization.

Table 2.

Estimates of the cross sections and the errors in determination of the components of the tensor D_{ik} at a given collection time of the statistics.

interval θ	interval $-t$ GeV^2	σ_{el} nb	$\frac{\text{Events}}{\text{hour}}$	hours	ΔD_{ik}
45^o-50^o	2.5-3.5	0.21	45	1000	0.10
50^o-55^o	1.7-2.5	0.46	100	500	0.10
55^o-60^o	1.2-1.7	0.47	100	500	0.10
60^o-65^o	0.8-1.2	43.0	$7 \cdot 10^3$	100	0.03
65^o-70^o	0.5-0.8	746.	$2 \cdot 10^4$	50	0.02
70^o-75^o	0.25-0.5	5830	$2 \cdot 10^4$	50	0.02

Table 2 gives the expected values of the statistical errors in determination of the components of D_{ik} for the indicated collection time of statistic and $-t$ intervals. The errors in D_{ik} are calculated assuming that the target polarization is 100%. It was assumed here that the system can record max. 10^3 events per second, that limits event rate for small $|t|$.

Thus, the determination of all four independent components of the tensor D_{ik} requires 2200 hours. During 1760 hours the vector of the target polarization must be placed into the reaction plane.

REQUEST FOR FUNDS

The detectors for the proposed spectrometer will be manufactured in Moscow State University. We intend to use the Michigan University polarized gas jet target at the same time with the high P_T-experiment of prof. A.D.Krisch. It is required that the FNAL gives the space for the spectrometer installation, the beam time (2200 hours) and places at our disposal the magnet with field 10^4 gauss, path length 1 m and aperture approximately 0.5x1 m. Six physicists from MSU will serve the apparatus during the data taking time. It is necessary to get the financial support for the visits of Russian physicists from the USA.

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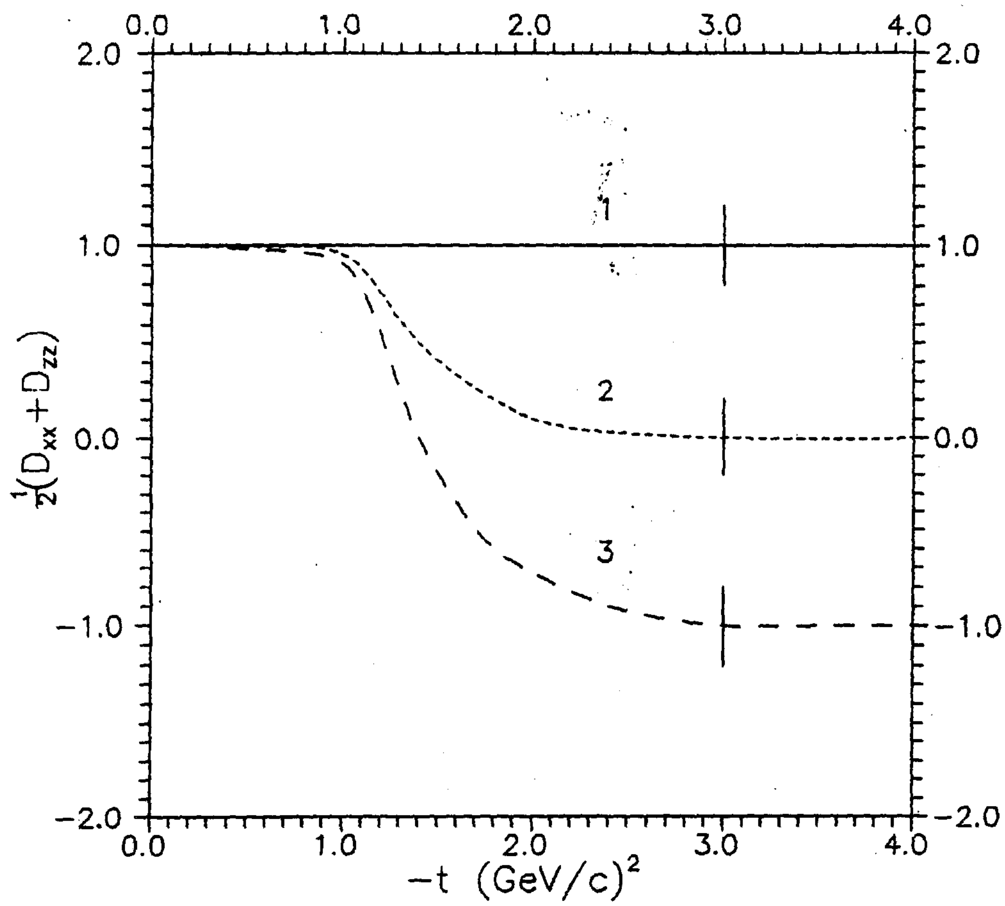

Fig.1. The behavior of the sum of the components $D_{xx}+D_{zz}$ in the different models; 1 – /23–25/, 2 – /26/, 3 – /27–28/.

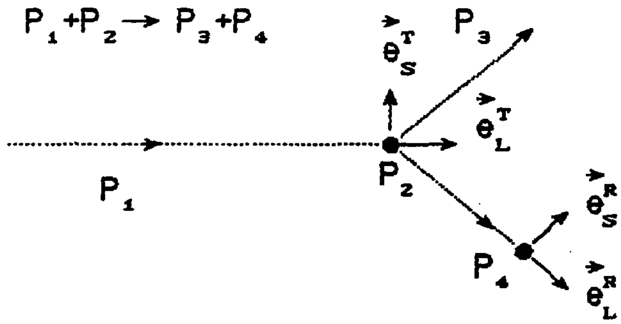

Fig.2. The coordinate systems in the lab. frame for target and recoil protons.

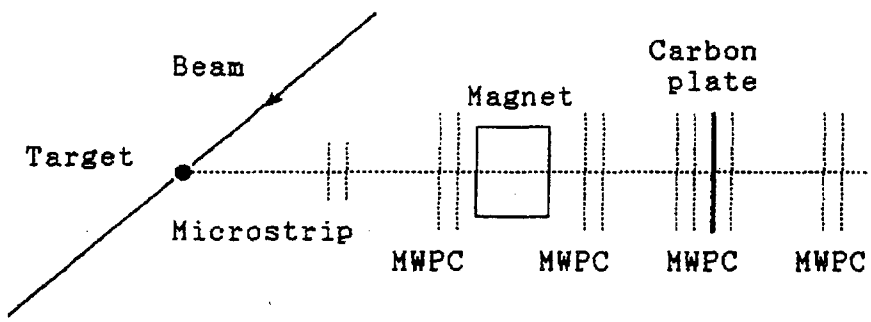

Fig.3. The scheme of the spectrometer.

Status of SPIN

Below we list the present status of the five conditions discussed in our 13 May 1991 Letter of Intent.

1. A significant group of Fermilab accelerator physicists should join in the polarized beam acceleration project.
   [*This condition has been met.*]
2. Several Fermilab experimenters should join in the large-$P_{\perp}^2$ elastic experiments.
   [*This is somewhat important, but we accept John Peoples' 23 July 1991 statement that this should await approval of the polarized beam project.*]
3. The Fermilab management should simultaneously make a serious commitment to both the experiment and the polarized beam.
   [*On 14 August 1991 John Peoples indicated that he plans to make this decision just after the June 1992 PAC meeting.*]
4. Appropriate funding for the project should be obtained in a timely way. The preliminary budget estimate is about $9.6 Million of US funding for the total project; perhaps about half of this could come from Fermilab's budget and about half directly to Michigan. Part of Michigan's budget could be used to help our foreign and US collaborators to provide some of the hardware.
   [*We are now reviewing this budget estimate in detail; so far it seems reasonable. (See page 16.) Providing this funding is of course the responsibility of DoE and possibly Fermilab.*]
5. The funding should begin in FY 1992 for the hardware modifications necessary to accelerate an 8 GeV polarized proton beam in the Booster with a target date of 1994 for 8 GeV beam.
   [*Fermilab provided $100,000 in September 1991; this allowed us to begin the polarized beam study last year.*]

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