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ELASTIC pp - SCATTERING FOR ANALYZING OF PROTON POLARIZATION IN COULOMB - NUCLEAR INTERFERENCE REGION

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ELASTIC pp-SCATTERING FOR ANALYSING OF PROTON POLARIZATION IN COULOMB-NUCLEAR INTERFERENCE REGION

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ABSTRACT

In the frame of the model with supercritical Pomeron the differential cross section and spin-dependent observables of the polarized pp-scattering are calculated in the kinematical region of Coulomb-nuclear interference at $\sqrt{s} = 500$ GeV. It is appeared that the analysing power of the polarized protons scattering gains a factor two in comparison with the process of the proton scattering on unpolarized target. A method is proposed to measure the proton beam polarization.

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INTRODUCTION

Recent technical developments involving polarized beams and targets will allow spin-dependence of the fundamental interactions to be measured in wide kinematic regions. A number of laboratories assign now a high priority to comprehensive experimental programs aimed at answering the many questions about the parton structure functions, including their spin dependence [1].

The use of the polarized beams assumes a proper and accurate measurements and control of the beam polarization during the experiment. Polarimeters for the polarized beams usually relied on the analyzing power in pp elastic scattering at small $|t|$. So it is necessary to have theoretical models for its calculation which will allow experimenters to assess the precision required to extract the desired information. As it is known the analyzing power becomes very small for higher energies at $|t|\leq 0.3$ (GeV/c), but it is possible to produce appreciable polarizations by magnetic interference effects of the hadronic and Coulomb interactions.

The conventional description of soft high energy hadronic reactions is in terms of Regge exchanges. The version of a supercritical Pomeron with $\alpha_P(t)=1+\epsilon+\alpha' t$, $\epsilon=0.05-0.1$, $\alpha'= 0.2-0.25$ $(\mathrm{Gev/c})^{-2}$ describes simultaneously the rising total cross sections, the t-dependence of the elastic scattering cross section $d\sigma/dt$ and the phenomenology of diffraction dissociation [2]. Though the proper unitarization schemes of the theory now exist we do not follow them in this paper. Rather we try to investigate how the model with a supercritical Pomeron can simulate the results of a more complete theory. The advantage of such a simplification is the very economical and transparent description of the various spin correlation phenomena.

As concerns the treatment of electromagnetic-hadronic interference we follow here Buttimore et al. paper [3] where a comprehensive study of elastic spin1/2-spin1/2 scattering at high energies in the electromagnetic-hadronic interference region has been undertaken.

DETAILS AND SIGNIFICANT FEATURES OF MODEL.

We now proceed to review the basic equations of our version of the model. As in the most of the theoretical works we shall use the helicity representation of the high energy nucleon-nucleon scattering amplitude due to its relatively simple behaviour under Lorentz transformations and crossing symmetry. Moreover the observable quantities are simply expressed via helicity amplitudes.

It is known that application of P and T invariance, and particle-exchange symmetry to the scattering matrix M for proton-proton scattering lead to results that only five amplitude are independent. These are the non-helicity-flip amplitudes $\phi_1=\langle ++|M|++\rangle$ and $\phi_3=\langle +-|M|+-\rangle$, the double-flip amplitudes $\phi_2=\langle ++|M|--\rangle$ and $\phi_4=\langle +-|M|-+\rangle$, and the single-flip amplitude $\phi_5=\langle ++|M+-\rangle$. We shall take for normalization that

$$\sigma = \frac{d\sigma}{dt} = \frac{2\pi}{s(s-4m^2)}\left(|\phi_1|^2+|\phi_2|^2+|\phi_3|^2+|\phi_4|^2+4|\phi_5|^2\right). \qquad (1)$$

Here and then we use the Mandelstam variables

$$s=4(p^2+m^2)=2m(m+E),$$
$$t=-2p^2(1-\cos\theta), \qquad (2)$$

where p is the center-of-mass (c.m.) momentum of one of the protons, θ is the scattering angle in the c.m. system, and E is the total energy of the incident proton in the laboratory system.

The laboratory spin-dependent observables I (beam, target;scattered,recoil) for pp→pp are defined [4] with respect to a frame for each particle such that $\hat{n}$ is along the normal to the scattering plane, $\hat{l}$ is along the direction of motion, and $\hat{s} = [\hat{n}\times\hat{l}]$ is in the scattering plane. All of them are given in terms of the helicity amplitudes:

$$I(0,0;0,0) = \sigma_0,$$

$$I(0,n;0,0) = P\sigma_0 = -\frac{4\pi}{s(s-4m^2)}\,\mathrm{Im}\left(\phi_5^*(\phi_1+\phi_2+\phi_3-\phi_4)\right),$$

$$I(n,n;0,0) = A_{NN}\sigma_0 = \frac{4\pi}{s(s-4m^2)} [\mathrm{Re}(\phi_1{}^*\phi_2 - \phi_3{}^*\phi_4) + 2|\phi_5|^2],$$

$$I(s,s;0,0) = A_{SS}\sigma_0 = \frac{4\pi}{s(s-4m^2)} \mathrm{Re}(\phi_1\phi_2{}^* + \phi_3\phi_4{}^*), \quad (3)$$

$$I(s,l;0,0) = A_{SL}\sigma_0 = \frac{4\pi}{s(s-4m^2)} \mathrm{Re}[\phi_5{}^*(\phi_1+\phi_2-\phi_3+\phi_4)],$$

$$I(l,l;0,0) = A_{LL}\sigma_0 = \frac{2\pi}{s(s-4m^2)} (|\phi_1|^2+|\phi_2|^2-|\phi_3|^2-|\phi_4|^2).$$

Within the electromagnetic-hadronic interference region each of the helicity amplitudes are to be written as [3]

$$\phi_i = \phi^h{}_i + \phi^{em}{}_i, \quad (4)$$

where hadronic part $\phi^h{}_i$ must include inside itself all manner of electromagnetic contributions, and

$$\phi^{em}{}_i = \varphi^{em}{}_i \exp(-i\alpha \log|t|).$$

Here α is the fine-structure constant and $\varphi^{em}{}_i$ denotes the one-photon approximation to the electromagnetic interaction of two protons, which leading terms at high energies have the form

$$\varphi^{em}{}_1 = \varphi^{em}{}_3 = \frac{\alpha s}{t} F_1{}^2(t),$$

$$\varphi^{em}{}_2 = -\varphi^{em}{}_4 = \frac{\alpha s}{4m^2} F_2{}^2(t), \quad (5)$$

$$\varphi^{em}{}_5 = -\frac{\alpha s}{\sqrt{-t}} \frac{1}{2m} F_1(t)F_2(t),$$

in which $F_i(t)$ are Dirac form-factors of the proton

$$F_1(t) = \frac{4m^2 - t(1+\varkappa)}{4m^2 - t} G_D,$$

$$F_2(t) = \frac{4m^2\varkappa}{4m^2 - t} G_D, \quad (6)$$

$$G_D = (1-t/0.71)^{-2},$$

and $\varkappa$ is the anomalous magnetic moment of the proton.

We assume that the pure nuclear amplitude is slightly contaminated by electromagnetic effects and use for it Donnachie and Landshoff model [5]. Their starting point is the description of elastic and total (anti-)proton-proton cross sections within the picture of Pomeron and Reggeon exchanges. Then they assume that the Pomeron is an isolated Regge pole and couples to single quarks like a C=+1 isoscalar photon through a simple γ_μ coupling, so its contribution to the proton-proton elastic amplitude has the form

$$i[3\beta F_1(t)]^2 \exp((\alpha_P(t)-1)(\log\frac{s}{m^2} -i\frac{\pi}{2}))(\bar{u}_3\gamma^\mu u_1)(\bar{u}_4\gamma_\mu u_2), \quad (7)$$

where the Regge scale parameter m^2 is taken to be equal to the square of the nucleon mass and $\beta^2= 2.0(\mathrm{mb})^{1/2}(\mathrm{GeV})^{-1}$ describes the Pomeron coupling to quarks. The linear trajectory $\alpha_P(t)=1+\varepsilon+\alpha' t$ is used and its slope $\alpha' = 0.25(\mathrm{GeV}/c)^{-2}$ is determined from the expe- riment. The $\varepsilon = 0.08$ in accordance with the observed rise of the proton-antiproton total cross section and takes into account effectively the combined effect of the multiple Pomeron exchanges.

The part of the proton-proton elastic amplitude from Reggeon exchange was written as

$$i[3\beta F_1(t)]^2(A+iB)\exp((\alpha_R(t)-1)(\log \frac{s}{m^2}-i\frac{\pi}{2}))(\bar{u}_3\gamma^\mu u_1)(\bar{u}_4\gamma_\mu u_2) \quad (8)$$

with A=7.8 and B=2.1 and the linear trajectory $\alpha_R(t)= 0.44 + \alpha'_R t$, $\alpha'_R=0.93(\mathrm{Gev})^{-2}$ corresponds to the exchange-degenerate ρ, ω, f_2 and A_2 trajectories. Its intercept has been deduced from the data-table values of the masses of the particles on the trajectory.

In Figs.1-2 the predictions of the model are represented for $d\sigma/dt$ and analyzing power of elastic pp-scattering at $\sqrt{s}$=500 GeV. The other spin correlation parameters are compared with zero in the kinematical region under consideration (the largest of them A_{NN} is of order $3\ 10^{-4}$ in the range $0.001\leqslant|t|\leqslant 0.01$ $(\mathrm{GeV}/c)^2$). As far as in case of polarized along the normal to the scattering plane proton beam and target the differential cross section equals

$$\sigma_{NN}=\sigma_0\ [1 + \dot{P}(P_1+P_2) + \dot{A}_{NN}P_1P_2], \quad (9)$$

it follows, that if $\vec{P}_1$ is parallel to $\vec{P}_2$ the analysing power A_N is defined by twice P. The curves on Fig.3 give the possibility to estimate an excess of the yield of the reaction with polarized protons above unpolarized ones within the same momentum transfer kinematical region as above.

A POSSIBLE IMPLEMENTATION OF POLARIMETER.

The advantage of the process under consideration as a proton polarisation analyzer is that the analyzing power A of the polarized protons scattering gains a factor two in comparison with the process of the proton scattering on unpolarized target.

The method to be used for polarization measurements is essentially similar to the one used in the series of experiments for investigation of small angle pp-scattering carried out by the CERN-Rome group /6/, for example.

As the basic elements of a polarimeter the proton coordinate detectors of the "Roman pots" type can be used. The elastic pp-scattering is recorded by two coordinate detectors installed symmetrically about the interaction point. To define the proton polarization it is necessary to measure the difference of the yields of the elastic scattered protons in the Coulomb- nuclear interference region at parallel and antiparallel colliding beams spin orientations. The monitoring can be carried out by the same process of the elastic pp-scattering in $|t|\approx 1$ $(GeV/c)^2$ region where cross section is practically independent on polarization.

So the polarimeter must overlap the range of the momentum transfer from 0.001 to 1 $(GeV/c)^2$.

We take into account the RHIC lattice parameters /7/ to calculate the effective distance L_{eff}

$$L_{eff} = \sqrt{\beta_0 \beta}\ \sin\,(\,\phi - \phi_0\,), \qquad (10)$$

where β_0 , β and ϕ_0 , ϕ are the betatron function and phase at interaction point and at chosen point. Also we calculated the displacement d of a proton in the chosen point from the nominal beam orbit for particle starting at the interaction point (IP) with fixed angle and displacement and the deviation of proton D after scattering with angle θ_{CNI}

$$D = L_{eff} \sin \theta_{CNI}$$

For the calculation we used the following parameters:

normalized emittance $\varepsilon_N = 20\pi$ mm mrad;

betatron function $\beta = 200$ m

The results are shown at fig.4. One may conclude that CNI region in pp-scattering with $\sqrt{S} = 500$ GeV can be reached easily.

The estimate of statistical error can be done from the next assumptions. For CNI region where

$$-t \approx 2.\ 10^{-3}\ (\mathrm{GeV/c})^2\ ,$$
$$d\sigma/dt \approx 160\ \mathrm{mb}\ /(\mathrm{GeV/c})^2$$

we expect to get the counting rates about 3000 events /sec (if azimuthal acceptance is $\Delta\phi/2\pi = 0.2$, and luminosity is $L = 10^{32}$ cm^{-2}sec^{-1}). The time needed for gathering $N=10^5$ events is equal to 30 sec. With analyzing power $A = 2p \approx 10\%$ during this time one can reach the relative statistical error

$$\Delta_{stat} = (N\ A^2)^{-1} \approx 3\ \%\ .$$

We suppose that background contribution will be large and systematic errors will dominate therefore we should multiply this time by 10 for safety to estimate the time needful for measurement of proton polarization with error ≈ 3 % .

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Figure captions.

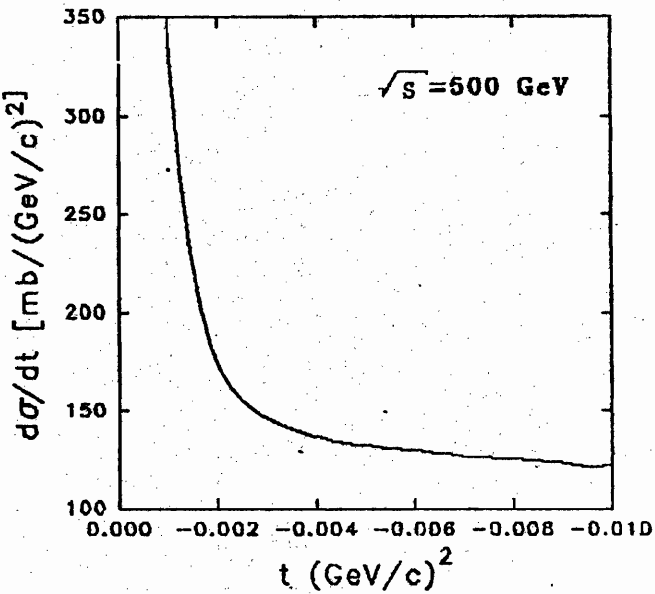
Fig.1 The model prediction of the pp differential cross section at $\sqrt{S}$=500 GeV.

Fig.2 The model prediction of the analysing power A_N=P in the Coulomb - nuclear interference region for unpolarized target.

Fig.3 The differential cross sections for unpolarized and polarized colliding beams at W=500 GeV.

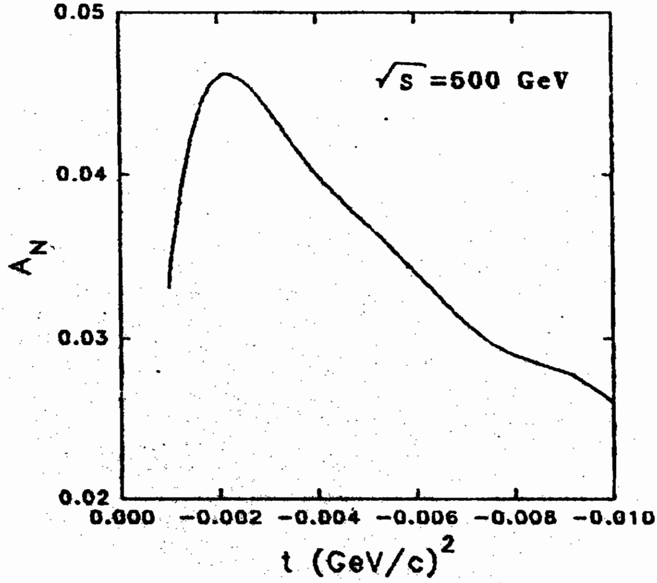
Fig.4 Displacement of particles of beam d and deviation of scattering protons D.

Fig.1



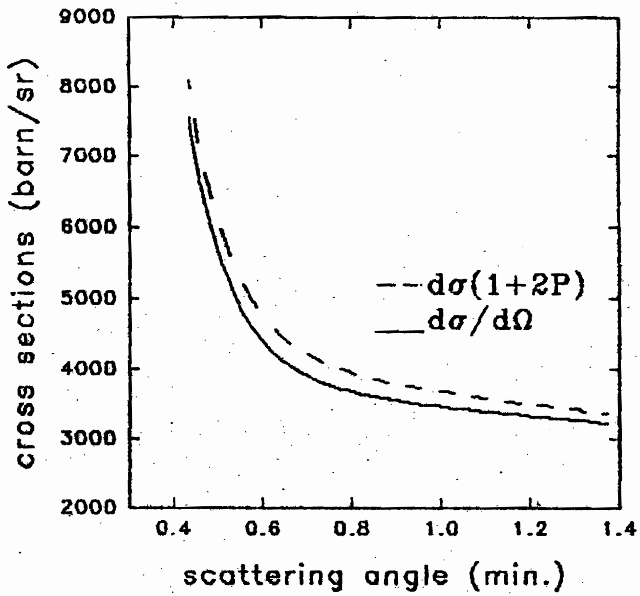
350
300
250
200
150
100
0.000
-0.002
-0.004
-0.006
-0.008
-0.010
$\sqrt{s}$=500 GeV
dσ/dt [mb/(GeV/c)^2]
t (GeV/c)^2

Fig.2



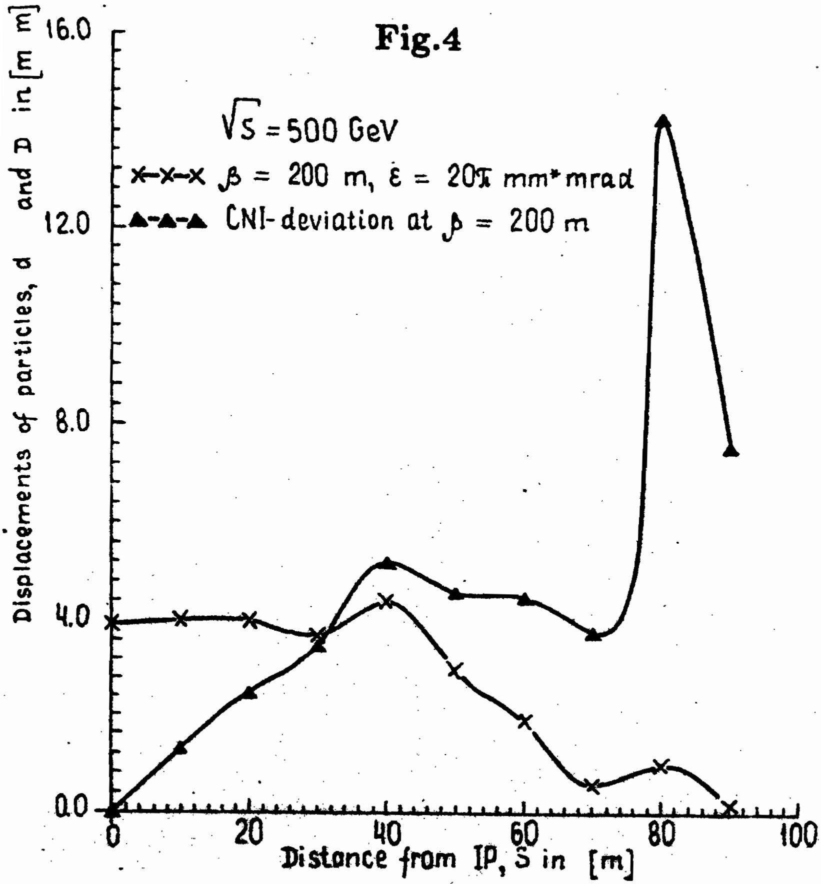
0.05
0.04
0.03
0.02
A_N
$\sqrt{s}$ =500 GeV
0.000
-0.002
-0.004
-0.006
-0.008
-0.010
t (GeV/c)^2

Fig.3



9000
8000
7000
6000
5000
4000
3000
2000
cross sections (barn/sr)
0.4
0.6
0.8
1.0
1.2
1.4
scattering angle (min.)
dσ(1+2P)
dσ/dΩ

Fig.4



$\sqrt{S}$ = 500 GeV
β = 200 m, ε = 20π mm*mrad
CNI-deviation at β = 200 m
Displacements of particles, d and D in [m m]
16.0
12.0
8.0
4.0
0.0
0
20
40
60
80
100
Distance from IP, S in [m]

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