Title
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# IMPACT PICTURE DESCRIPTION OF HIGH ENERGY ELASTIC PROTON-PROTON POLARIZATION

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ABSTRACT

A model of rotating matter inside the proton was recently proposed to explain the low and high-energy proton-proton elastic scattering. Predictions were made for the polarization at high-energy and recent experiments at CERN and Fermilab support this concept of matter current inside a hadron.

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High energy experiments performed in the past at CERN-ISR and Fermilab have proven to be of great interest in hadron physics for spin independent cross-sections. Although the behaviour of proton-proton cross-section was guessed on the theoretical level, the new experimental results have brought more precise information on the most difficult particle exchange to understand, namely the Pomeron. It was also expected that at high energy where the Regge background becomes negligible, the spin observables would vanish, and as a consequence one would not care about helicity flip amplitudes associated with the Pomeron.

Recently, experiments on p-p elastic scattering at CERN-SPS [1] and Fermilab [2,3], have revealed that polarization persists at energies up to 300 GeV/c. Remember that the present range of momentum tranfer (up to 3 $GeV^2$) covered by experiments corresponds to small angles scattering and if measurements at larger angles were available, perhaps one would observe more structure on the polarization as it has been observed at medium energy [4]. Elastic scattering is not the only domain where spin effects have been observed at high energy. The inclusive reactions provide even more striking results, the production of polarized hyperon shows important asymmetries in a range of energy including ISR [5].

Very few theoretical attempts [6] exist to interpret these elastic data, this is mainly due to the difficulty to understand the nature of the Pomeron helicity flip. Two years ago, some of us proposed [7] to describe proton-proton elastic scattering in a way compatible with the results of quantum field theory, namely, by including s-channel unitarity, t-channel unitarity, analyticity, and crossing symmetry. The spin dependence of the proton amplitude results from a simple physical picture of rotation of matter inside the proton, this concept of matter current inside a proton is due to Chou and Yang [8].

Results on total cross-section, differential cross-section, polarization and R parameter agree well with the existing data at the time, so in view of future experiments some predictions on observables were made [7], in particular on polarization. Now it turns out that these predictions are also in good agreement with the recent data of the CERN-SPS [1] and Fermilab [2,3]. In this short note we would like to report on these results and emphasize the validity of the concept of hadronic matter current.

In order to explain these results we summarize the main features of the model, for which a complete development is given in Ref. [7]. The proton-proton elastic amplitude in impact parameter representation reads as

$$M(s,t) = \frac{is}{2\pi} \int e^{-i\vec{q}\vec{b}}(1 - e^{-\Omega(s,\vec{b})})d\vec{b} \qquad (1)$$

where $\vec{q}$ is the momentum transfer ($t = -\vec{q}^2$), $\Omega(s, \vec{b})$ is defined to be the opaqueness at impact parameter $\vec{b}$ and at a given energy s. The total opaqueness $\Omega(s, \vec{b})$ is decomposed into a spin independent part $\Omega_0(s, \vec{b})$ and a spin dependent part $\Omega_1(s, \vec{b})$ such that

$$\Omega(s, \vec{b}) = \Omega_0(s, \vec{b}^2) \mp \Omega_1(s, \vec{b}^2)\hat{b}_x \qquad (2)$$



where $\mp$ refer to a target spin $\pm\frac{1}{2}$ along the z axis, $\hat{b}_x$ is a component of a unit vector $\hat{b} = \vec{b}/|\vec{b}|$.

i) The spin independent part is itself defined as the sum of two terms

$$\Omega_0(s, \vec{b}^2) = S_0(s)F(\vec{b}^2) + R_0(s, \vec{b}^2) \qquad (3)$$

the first term is associated to the "Pomeron" exchange, while the second term whose exact expression can be found in Ref. [7], is a Regge background which becomes negligible at high energy. The function $S_0(s)$ comes from the high energy behaviour of quantum field theory [9], and we shall take the crossing-symmetric expression

$$S_0(S) = \frac{s^c}{(\ell n s)^{c'}} + \frac{u^c}{(\ell n u)^{c'}} \qquad (4)$$

The dependence upon the impact parameter is contained in the function $F(\vec{b}^2)$, whose Fourier transform is proportional to the square of an approximate parametrization of the proton form factor

$$\tilde{F}(t) = f\left[\frac{1}{(1-\frac{t}{m_1^2})(1-\frac{t}{m_2^2})}\right]^2 \frac{a^2+t}{a^2-t} \qquad (5)$$

All the parameters have been adjusted by fitting the $\bar{p}$-p total-cross-section data and the elastic pp data on $\sigma_{tot}$, $\rho = \mathrm{Re}a_0/\mathrm{Im}a_0$, and $d\sigma/dt$, they have the following values:

$$c = 0.151,\quad c' = 0.756,\quad m_1 = 0.619\ \mathrm{GeV},\quad m_2 = 1.587\ \mathrm{GeV}$$

$$a = 2.257\ \mathrm{GeV},\quad f = 8.125 \qquad (6)$$

This is all that is needed to calculate the spin-independent amplitude

$$a_0(s, t) = is \int_0^\infty J_0(b\sqrt{-t})(1 - e^{-\Omega_0(s, \vec{b}^2)})\, bdb \qquad (7)$$

ii) The spin dependence of the amplitude originates from the idea that the matter inside a proton is subject to a movement due to the presence of a current. This concept of matter current inside a polarized hadron was first proposed by Chou and Yang [8], and complements nicely the notion of hadronic matter density. These two concepts result from the analogy with the electromagnetic charge and current densities. We are fully aware that the analogy is not exact, however it has been proven to be of interest when describing the p-p elastic $d\sigma/dt$, and as we shall see below for the polarization.

We suppose that the collision between two protons occur in the x-y plane, and the direction of the incident proton is along the y-axis. Let us call $v_y$ the y component of the velocity of a small region of the target in the c.m. system. The effective energy of the projectile in the rest-system region of the target is in the first order:

$$s_{eff} = s(1 - v_y) \qquad (8)$$

Taking into account $s_{eff}$, the energy dependence of the Pomeron exchange is modified according to

$$S_0(s) \to S(s, \vec{b}) = S_0(s_{eff}) \sim S_0(s) - s\, v_y \frac{\partial}{\partial y} S_0(s)$$

$$S(s, \vec{b}) = S_0(s) - v_y\, S_1(s) \qquad (9)$$



with

$$S_1(s) = \frac{s^c}{(\ell n s)^{c'}}\left(c - \frac{c'}{\ell n s}\right) + \frac{u^c}{(\ell n u)^{c'}}\left(c - \frac{c'}{\ell n u}\right) \qquad (10)$$

If we set

$$v_y = \omega(b^2)\, \hat{b}_x b \qquad (11)$$

we get

$$\Omega_1(s, \vec{b}^2) = F_s(\vec{b}^2) S_1(s) + R_1(s, b) \qquad (12)$$

$$F_s(\vec{b}^2) = b\omega(b^2) F(\vec{b}^2) \qquad (13)$$

where $F(b^2)$ is the Fourier transform of Eq. 5, $\omega(b^2)$ is an unknown function for the moment, and $R_1(s, b)$ is a spin dependent Regge background. Inserting Eq. 12 into Eq. 2, the total amplitude defined by Eq. 1 takes the form

$$M(s, t) = a_0(s, t) + i\vec{\sigma}\cdot\vec{n}\, a_1(s, t) \qquad (14)$$

$\vec{n}$ being a unit vector normal to the scattering plane and $a_1(s, t)$ the spin dependent amplitude

$$a_1(s, t) = is \int_0^\infty J_1(b\sqrt{-t})\Omega_1(s, \vec{b}^2) e^{-\Omega_0(s, \vec{b}^2)}\, bdb \qquad (15)$$

Once the function $\omega(b^2)$ is specified, we are able to calculate the polarization P in the laboratory system produced by the scattering of a proton on a polarized target.

$$\sigma_0 P = 2\, \mathrm{Im}\, (a_0 a_1^*)$$

$$\sigma_0 = |a_0|^2 + |a_1|^2 \qquad (16)$$

The hadronic matter velocity inside a proton defined by Eq. 11 cannot be estimated on a pure theoretical basis. So as a first guess we choose to take the simplest assumption $\omega(b^2) = \omega =$ constant, which corresponds to a rigid rotation of angular velocity $\omega$. This assumption which was already ruled out by theoretical arguments Ref. [7] disagrees anyway with recent data [1,2].

We find more suitable to assume that $\omega(\vec{b}^2) \to 0$ when $\vec{b}^2 \to \infty$, such matter motion will be refered to as soft rotation. Our present theoretical knowledge does not allow a precise determination of the function $\omega(\vec{b}^2)$, therefore we choose arbitrarily a Gaussian form

$$\omega(b^2) = \omega_0 e^{-\vec{b}^2/b_0^2} \tag{17}$$

The fit of low energy data between 17-100 GeV/c shows that the value of the parameters are $\omega_0 = -0.06$ GeV, $b_0 = 3.75$ GeV$^{-1}$. Our predicted values of the polarization above 100 GeV/c are displayed on Fig. 1 for the CERN experiment [1] at 150 GeV/c, and on Fig. 2 for the FNAL data at 300 GeV/c. On Fig. 3 we show the comparison of the model with the results of different experiments [10] including new Fermilab data [2] with different bins of momentum transfer [11].

We notice that Coulomb amplitudes in one photon exchange approximation are included in the calculation of the polarization [12]. We would like to stress that Coulomb interference is generally believed to be important only at very small momentum transfer and negligible for larger values. This is certainly true when the measured polarization is important, however at high energy where the polarization is of the order of few percents for $t < 1$ GeV$^2$, Coulomb interference cannot be neglected in interpreting the data [13].



The good agreement of our curves with these recent data supports the concept of matter current inside a hadron and indicates that the picture of soft matter rotation in a proton is realistic. We expect further confirmation when measurements of the R parameter, whose predictions are given in Ref. [7], will become available.

ACKNOWLEDGEMENTS

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[11]. In Ref. [2] (curve c of Figs. 12-15) the comparison of the results of Ref. [7] was not correctly transcribed.

[12]. The fact that both the Coulomb effect and the hadronic effect contribute to the calculation of the polarization is not clearly stated in Ref. [2] section V. A. 3.

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# FIGURE CAPTIONS.

Figure 1. Elastic proton polarization at $p_{lab}$ = 150 GeV/c (data from Ref. [1]). The curve is a prediction of the soft rotation model.

Figure 2. Elastic proton polarization at $p_{lab}$ = 300 GeV/c (data from Ref. [3]). The curve is a prediction of the soft rotation model.

Figure 3. Elastic proton polarization as a function of s for different t values (data from Ref. [1, 2, 10]). The curves are a prediction of the soft rotation model.

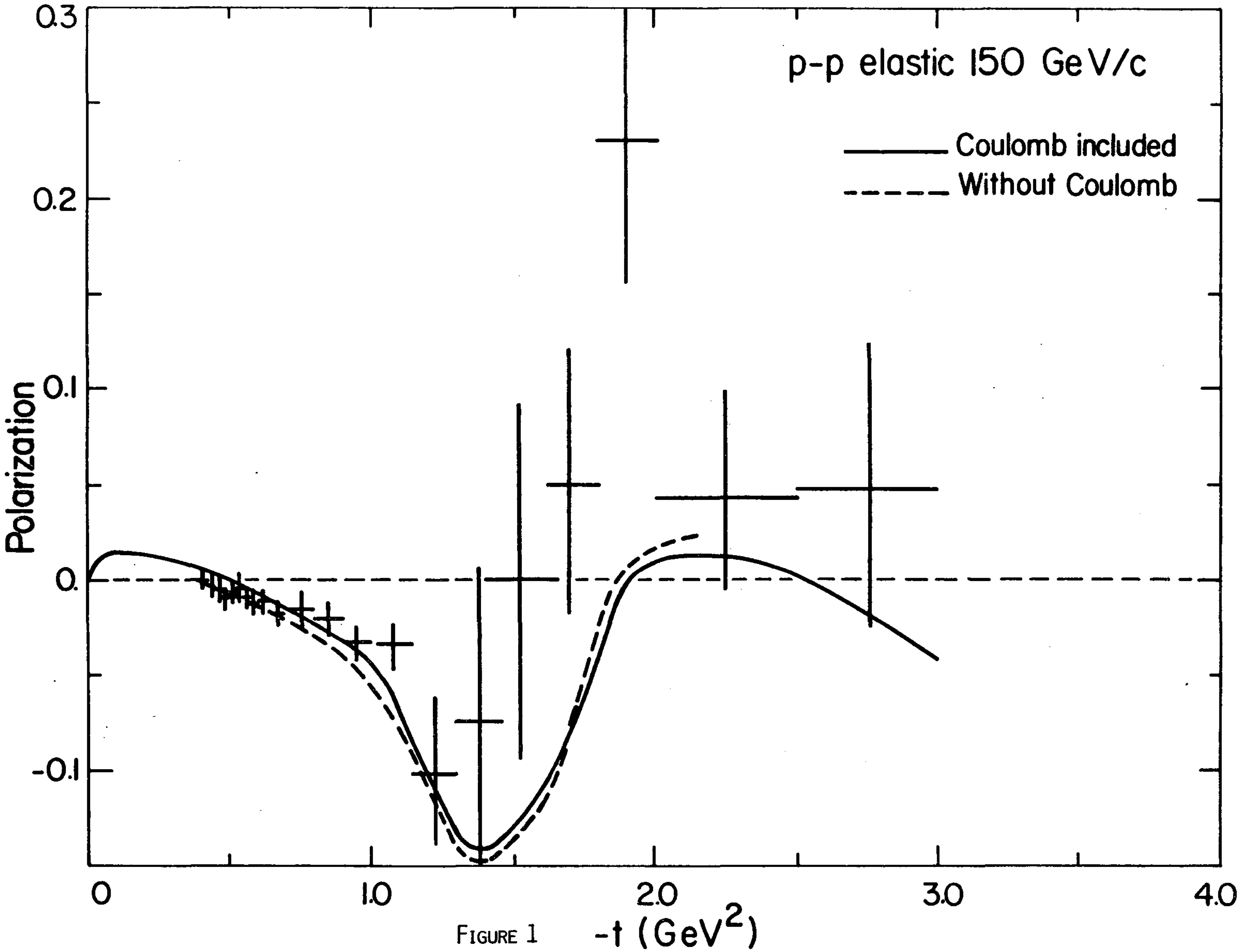
p-p elastic 150 GeV/c
Coulomb included
Without Coulomb
Polarization
0.3
0.2
0.1
0.
-0.1
0
1.0
2.0
3.0
4.0
-t (GeV$^2$)

FIGURE 1

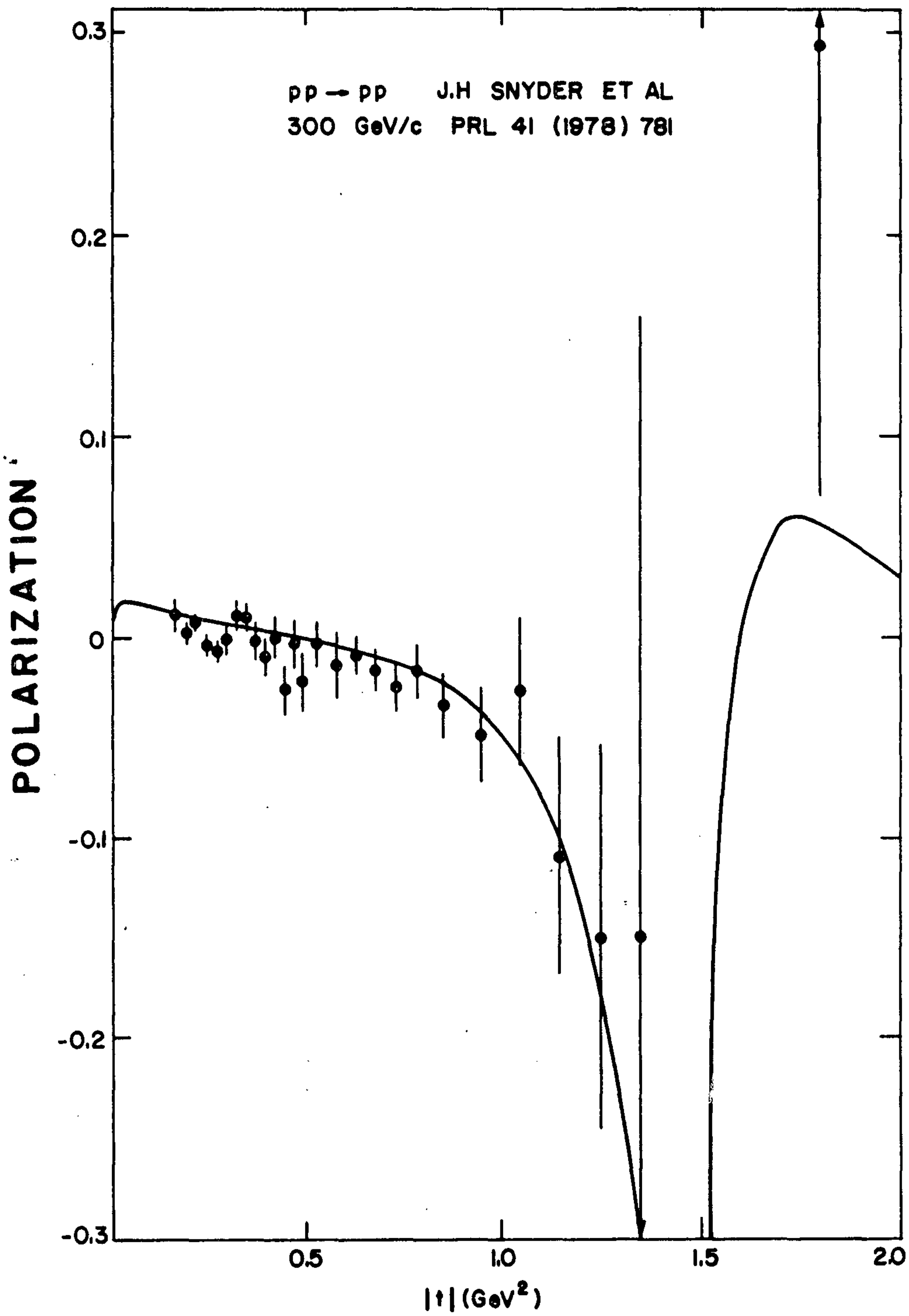
pp → pp J.H SNYDER ET AL
300 GeV/c PRL 41 (1978) 781
POLARIZATION
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
0.5
1.0
1.5
2.0
|t| (GeV²)

FIGURE 2

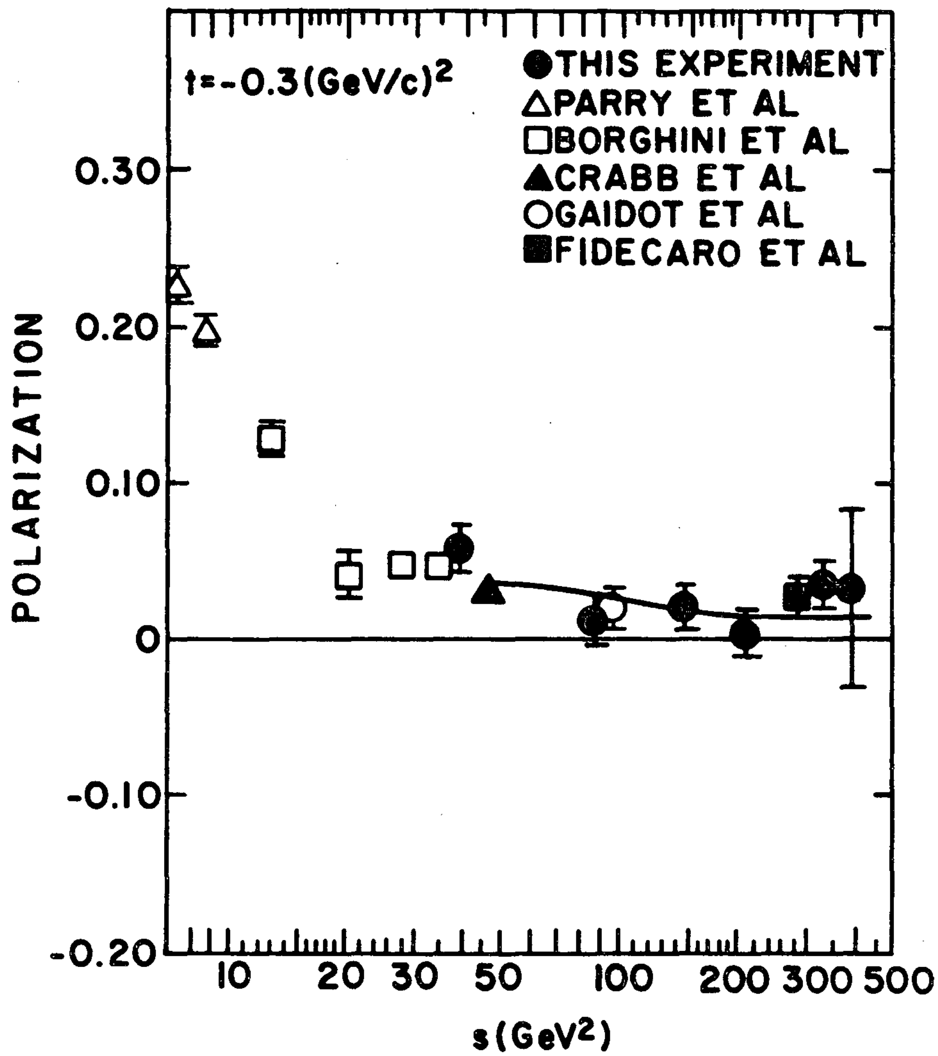
t=-0.3(GeV/c)$^2$
THIS EXPERIMENT
PARRY ET AL
BORGHINI ET AL
CRABB ET AL
GAIDOT ET AL
FIDECARO ET AL
POLARIZATION
0.30
0.20
0.10
0
-0.10
-0.20
10
20
30
50
100
200
300
500
s(GeV$^2$)

FIGURE 3A

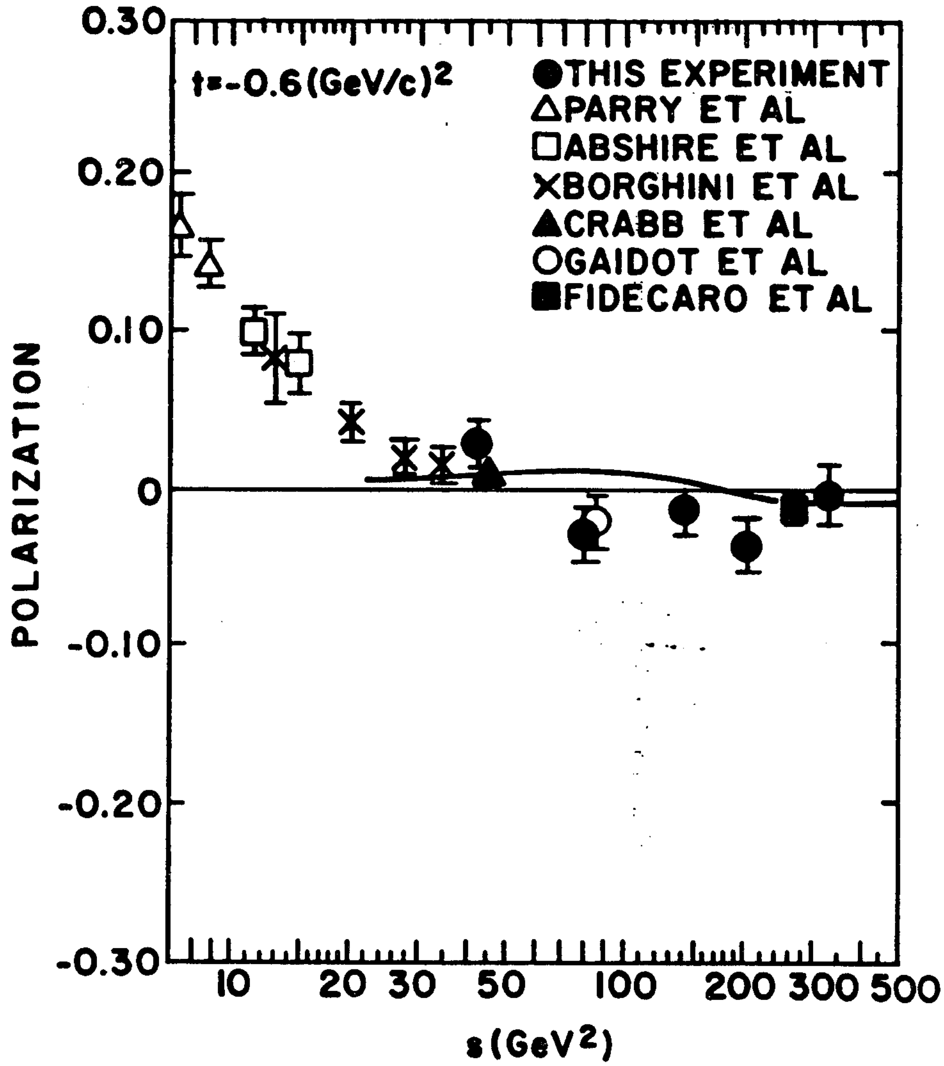
0.30
0.20
0.10
0
-0.10
-0.20
-0.30
POLARIZATION
t=-0.6(GeV/c)²
THIS EXPERIMENT
PARRY ET AL
ABSHIRE ET AL
BORGHINI ET AL
CRABB ET AL
GAIDOT ET AL
FIDECARO ET AL
10
20
30
50
100
200
300
500
s(GeV²)

FIGURE 3B

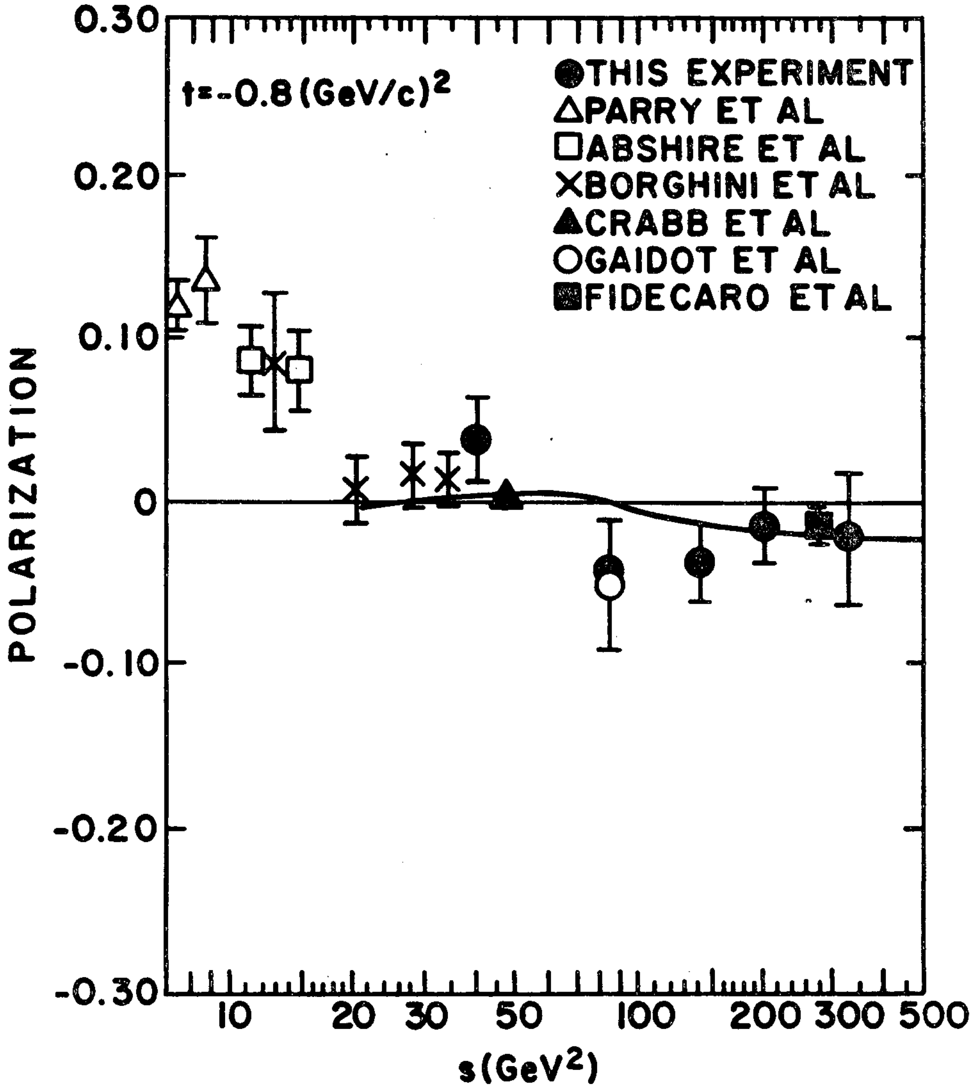
t=-0.8 (GeV/c)$^2$
THIS EXPERIMENT
PARRY ET AL
ABSHIRE ET AL
BORGHINI ET AL
CRABB ET AL
GAIDOT ET AL
FIDECARO ET AL
POLARIZATION
0.30
0.20
0.10
0
-0.10
-0.20
-0.30
10
20
30
50
100
200
300
500
s(GeV$^2$)

FIGURE 3c

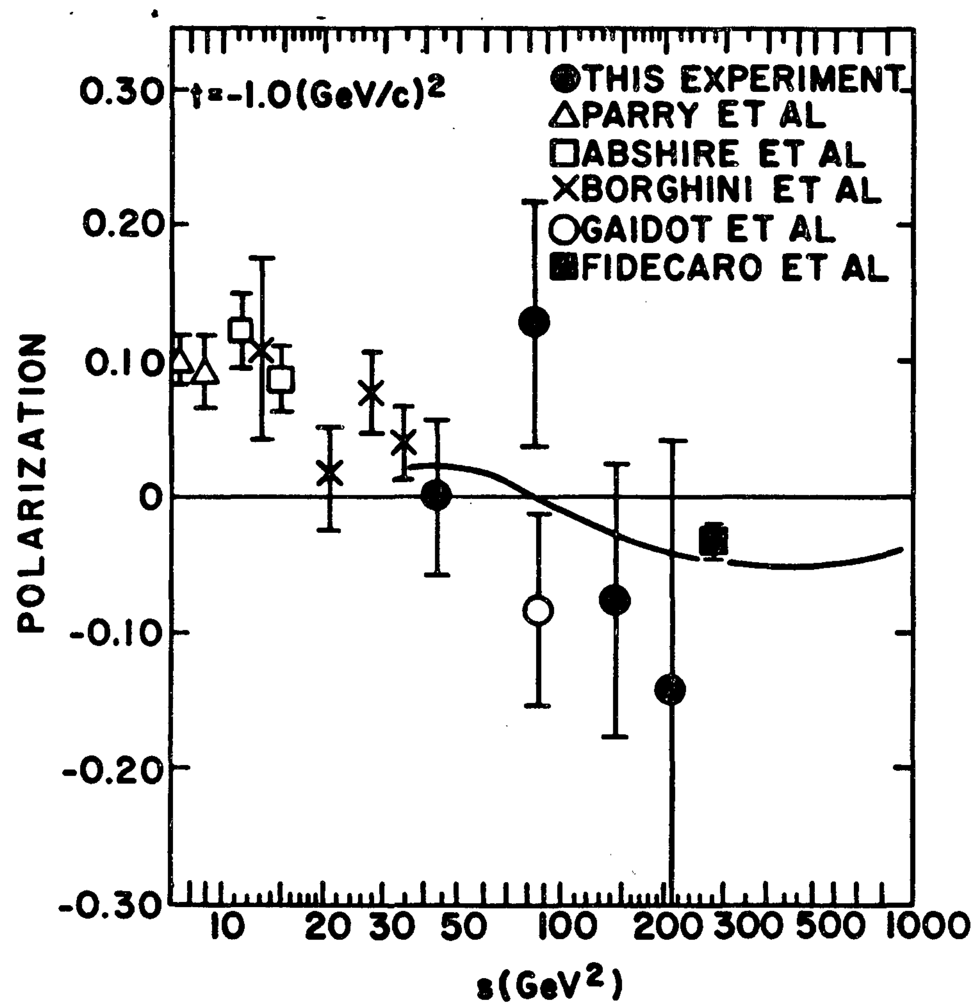
t=-1.0(GeV/c)²
THIS EXPERIMENT
PARRY ET AL
ABSHIRE ET AL
BORGHINI ET AL
GAIDOT ET AL
FIDECARO ET AL
POLARIZATION
0.30
0.20
0.10
0
-0.10
-0.20
-0.30
10
20
30
50
100
200
300
500
1000
s(GeV²)

FIGURE 3D

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