EVIDENCE FOR SPIN EFFECTS IN pp ELASTIC SCATTERING AT 150 GeV/c

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ABSTRACT

Proton elastic scattering off a polarized proton target has been measured at 150 GeV/c, in the $|t|$ -range 0.2 - 3.0 GeV². The results on polarization and differential cross-section are presented.

Geneva - 21 March 1978
(Submitted to Physics Letters B)

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CM-P00063917

1. INTRODUCTION

We report here the results of a ten-day run at the CERN SPS to measure the polarization parameter $P(t)$ in pp elastic scattering at 150 GeV/c for momentum transfers $0.2 \leq -t \leq 3 \text{ GeV}^2$, in a t -region where a dip in the cross-section for elastic proton-proton scattering has been observed at the ISR energies. The results from a previous, much smaller, sample of data were reported at the Budapest Conference¹⁾.

The differential cross-section spans five orders of magnitude in the accepted t -range, going down to $\sim 10 \text{ nb/GeV}^2$ at $t = -3 \text{ GeV}^2$. To get reasonable statistics at the highest t -values we used an intense beam and a long polarized proton target (PT). To have a good background rejection, we needed precise measurements and redundancy in the determination of the kinematics of the reaction. This was achieved with a well collimated beam and by measuring momentum and direction of both outgoing particles in two spectrometers equipped with MWPCs and scintillator hodoscopes. Figure 1 shows the layout of the apparatus.

2. BEAM

The protons were provided by the H3 beam, a high-energy, high resolution beam from the target T5 ($0.4 \times 0.4 \times 50 \text{ cm}^3 \text{ Be}$) at a production angle of 0.5 mrad. The beam momentum was 151.6 GeV/c with $\sigma = 1.8 \text{ GeV/c}$. The divergencies were $\sigma_{\text{hor}} = 0.16 \text{ mrad}$ and $\sigma_{\text{ver}} = 0.20 \text{ mrad}$, with a beam spot of $\sigma_x = 2.5 \text{ mm}$ and $\sigma_y = 1.1 \text{ mm}$.

These quantities were monitored by two sets of charge integrating MWPCs located 3.4 m upstream and 49 m downstream of the PT. The intensity was on an average 2.5×10^7 protons per burst of $\sim 1 \text{ sec}$ effective spill time and was monitored by two threshold Čerenkov counters (8 and 10 m long), tuned on pions ($\sim 4\%$ of the beam).

Information on the beam incident on the production target, on the angles and divergencies at the PT (from the beam MWPCs), and on collimator setting was regularly transferred to tape.

3. THE APPARATUS

The incoming beam particles reached the PT through a hole in the yoke of the PT magnet. The PT consisted of a 14 cm long, 2.2 cm diameter propanediol sample kept at the temperature of $\sim 0.5^\circ$ K in a magnetic field of 2.502 T. The average polarization P_T was 90%. A "dummy" target DT, consisting of 2.2 cm diameter, 1 cm thick polyethylene (CH_2) disc, was located 4 cm downstream of the PT end. Its purpose was to act as an unpolarized source of elastic scattering events, thus providing a value for the normalization factor between "PT up" and "PT down" runs.

The scattered proton was detected by the counter S ($18 \times 8 \times 0.5 \text{ cm}^3$) and by the two scintillator hodoscopes FV (16 vertical strips each 3 cm wide and 32 cm high) and FH (10 wedge shaped strips, covering a $\pm 15^\circ$ azimuthal angle around the horizontal plane), located 49 m downstream of the PT. The trajectory, bent by $\sim 13 \text{ mrad}$ by two magnets was measured before and after this deflection by two telescopes of MWPCs with a precision of $\pm 0.07 \text{ mrad}$. Each telescope consisted of 2 groups of 4 sense wire planes, measuring x (horizontal) and y (vertical) coordinates (chambers F1, F2, F3, F5, F7) and u ($+30^\circ$) and v (-60°) coordinates (chambers F4, F6, F8). The wire spacing was 2 mm.

The recoil proton was detected by the 5 mm thick counter T located alongside the PT cryostat, and, after a flight path of $\sim 3.8 \text{ m}$, by the two scintillation hodoscopes BH (16 horizontal strips, $110 \times 10 \times 1 \text{ cm}^3$) and BV (11 vertical strips, $10 \times 160 \times 1 \text{ cm}^3$). The time of flight (TOF) to BH and BV was measured. The cylindrical counter AT, surrounding the target, covered the solid angle complementary to the region of interest. The recoil proton trajectory was bent by the PT magnet, which was a modified spectrometer magnet. Its field had cylindrical symmetry with 0.9 T·m bending power from the centre outwards. The momentum was obtained by measuring the trajectory with four $1 \times 1 \text{ m}^2$ MWPCs (B3 to B6), each with

2 mm step horizontal and vertical wire planes, placed outside the field region, and with two MWPCs (B1 and B2) located between the magnet poles. Chamber B1 had three 1 mm step sense planes, measuring twice the z coordinate (parallel to the beam) and once the y; the cylindrical chamber B2 contained two arrays of 2 mm step vertical sense wires (α coordinate) and was located in such a position as to minimize the error in the momentum measurement. The relative error was 2% for low t and 2p%, where p is in GeV/c, for $-t \geq 0.8 \text{ GeV}^2$. The error in the measured recoil angle was mainly contributed by the momentum error through the deflection of the trajectory.

4. THE TRIGGER

A first level Counter Trigger required: signals from T and S counters; no signal from AT; one and only one particle in BH and BV; one and only one particle in FH and FV; a TOF window which was set according to the FV strip hit (correlation between recoil proton energy and scattering angle); a signal from a Coincidence Matrix which imposed a correlation between the strips hit in FV and BV (rough angular correlation).

For events satisfying the counter trigger the chamber information was strobed into the read out system and a check was made by a specially built module (Decision Logic System) on the horizontal coordinates of B3 and B6 and of F5 and F7. The Logics correlated all pairs of hits in B3 and B6 to see if any would belong to a positive particle coming from the target, and all pairs of hits in F5 and F7 searching for pairs belonging to an $\sim 150 \text{ GeV/c}$ particle also coming from the target. The events which satisfied both conditions were written on tape. In order to keep the rate of data taking to a reasonable level over the whole t-range the low-t trigger was scaled down by a convenient factor. Two million events were recorded.

5. DATA ANALYSIS

The analysis and selection of events were done in three steps :

- i) The pattern recognition program searched for at least one track in both forward and backward arms checking the requirements of the Counter Trigger and the Decision Logic System and consistency with the geometrical limits. Approximately half of the events survived the cuts imposed by pattern recognition.

- ii) A geometrical fit program first fitted the backward and forward tracks and then required them to originate from a vertex. The vertex resolution was 1 mm in each coordinate. More than 90% of the events accepted by pattern recognition were also accepted by the geometrical fit program.
- iii) The beam parameters recorded on tape were checked for consistency with the data as seen from the output of the geometrical fit. Having adjusted these parameters for each partial run, a kinematical 4C-fit was applied testing the hypothesis of an elastic pp reaction. The resolution in four momentum transfer t ranges from $0.3 \times 10^{-2} \text{ GeV}^2$ at $-t = 0.3 \text{ GeV}^2$ to $8 \times 10^{-2} \text{ GeV}^2$ at $-t = 3 \text{ GeV}^2$.

The following selection criteria were applied : (i) unambiguous information from counters; (ii) vertex within a 1 cm radius around the PT axis; (iii) a 6% cut in the χ^2 probability of the kinematical fit. After all cuts had been applied, we were left with 400K events from the PT and 16K events from the DT. The latter sample has been used for the normalization.

From the shape of the χ^2 distribution and from an independent check via the kinematical fit with one constraint open, we evaluated the background to signal ratio ρ to range between 3% and 10%, according to the t -bin, with a 30% relative uncertainty. Further checks on coplanarity, and angular and momentum correlations supported this conclusion.

6. RESULTS

The polarization parameter P for pp elastic scattering has been computed as $P = [n^- - n^+] [(n^- + n^+)(1 - \rho)]^{-1}$, where n^- , n^+ are the number of selected events weighted with the PT polarization, and with the proper relative normalization, for PT "down" and "up", respectively.

The results are given in Table 1 and shown in Fig.2. The errors in the table are statistical only. The systematic error ΔP coming from the normalization and other sources was estimated to be less than ± 0.015 for $-t \leq 0.7 \text{ GeV}^2$ and ± 0.025 for the large $|t|$ -region. The contribution

to the measured asymmetry from a possible beam polarization (estimated to be consistent with zero) should be negligible.

The most interesting feature of these data is a sizeable negative polarization around $-t = 1 \text{ GeV}^2$. Moreover the t dependence is similar to the one indicated by the 45 GeV/c data ²⁾.

The differential cross-section has been obtained for $-t \geq 0.325 \text{ GeV}^2$ from the number N of selected events corrected for background and geometrical acceptance, summed over the "up" and "down" runs; the lower t -values were discarded because of a large variation in acceptance. The dN/dt distribution was extrapolated to $-t = 0.2 \text{ GeV}^2$ by fitting the first ten points with the function $A \exp(Bt)$, and normalized there with the fit of Fermilab cross-section data ³⁾ at 140 GeV/c. The results are given in Table 2 and shown in Fig. 3. The errors given in Table 2 include contributions from statistics, background subtraction and geometrical acceptance calculations. The distribution $A \exp(Bt)$ fits our data well down to $-t = 1.15 \text{ GeV}^2$; the fitted value for the slope parameter is $B = (9.53 \pm 0.03) \text{ GeV}^{-2}$.

ACKNOWLEDGEMENTS

The assistance of Mr. P. Dechelette and Mr. M. Renevey has been invaluable for the success of the experiment.

The authors gratefully acknowledge the enthusiastic support of the Experimental Areas Group, the EP Electronics Development Group, and the Polarized Target Group.

The Group from the Institut für Hochenergiephysik, Vienna, wishes to acknowledge the financial support from the Fonds zur Förderung der Wissenschaftlichen Forschung, Vienna, Austria.

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FIGURE CAPTIONS

Fig.1 Experiment layout.

Fig.2 The polarization parameter P vs $-t$.

Fig.3 The differential cross-section $d\sigma/dt$ vs $-t$.

TABLE 1

POLARIZATION PARAMETER P IN PP ELASTIC SCATTERING AT 150 GeV/c

(The errors are statistical only)

$ t $ interval (GeV) ²	P	$ t $ interval (GeV) ²	P
.200 - .300	.0301 ± .0113	.60 - .65	-.0462 ± .0077
.300 - .325	.0179 ± .0082	.65 - .70	-.0392 ± .0092
.325 - .350	.0222 ± .0073	.70 - .80	-.0686 ± .0091
.350 - .375	.0141 ± .0071	.80 - .90	-.0775 ± .0147
.375 - .400	.0068 ± .0070	.90 - 1.00	-.126 ± .024
.400 - .425	.0076 ± .0073	1.00 - 1.15	-.144 ± .035
.425 - .450	.0007 ± .0077	1.15 - 1.30	-.133 ± .078
.450 - .475	.0081 ± .0080	1.30 - 1.45	-.011 ± .155
.475 - .500	-.0112 ± .0083	1.45 - 1.60	-.063 ± .166
.500 - .525	-.0192 ± .0087	1.60 - 1.80	.025 ± .174
.525 - .550	-.0197 ± .0094	1.80 - 2.00	.025 ± .228
.550 - .575	-.0200 ± .0099	2.00 - 2.50	.090 ± .160
.575 - .600	-.0394 ± .0101	2.50 - 3.00	.144 ± .263

TABLE 2

DIFFERENTIAL CROSS - SECTIONS OF ELASTIC pp - SCATTERING AT 150 GeV/c

$ t $ interval (GeV) ²	$d\sigma / dt$ mb / (GeV) ²	$ t $ interval (GeV) ²	$d\sigma / dt$ mb / (GeV) ²
.325 - .350	$2.105 \pm .185$	.80 - .85	$(20.66 \pm .47) \times 10^{-3}$
.350 - .375	$1.731 \pm .116$	.85 - .90	$(13.00 \pm .34) \times 10^{-3}$
.375 - .400	$1.388 \pm .068$	.90 - .95	$(7.88 \pm .24) \times 10^{-3}$
.400 - .425	$1.080 \pm .019$	.95 - 1.00	$(4.99 \pm .18) \times 10^{-3}$
.425 - .450	$(8.423 \pm .147) \times 10^{-1}$	1.00 - 1.05	$(2.954 \pm .131) \times 10^{-3}$
.450 - .475	$(6.524 \pm .115) \times 10^{-1}$	1.05 - 1.10	$(1.875 \pm .101) \times 10^{-3}$
.475 - .500	$(5.026 \pm .089) \times 10^{-1}$	1.10 - 1.15	$(1.231 \pm .080) \times 10^{-3}$
.500 - .525	$(3.970 \pm .071) \times 10^{-1}$	1.15 - 1.20	$(.564 \pm .053) \times 10^{-3}$
.525 - .550	$(3.071 \pm .055) \times 10^{-1}$	1.20 - 1.30	$(.334 \pm .029) \times 10^{-3}$
.550 - .575	$(2.404 \pm .044) \times 10^{-1}$	1.30 - 1.40	$(.132 \pm .018) \times 10^{-3}$
.575 - .600	$(1.933 \pm .036) \times 10^{-1}$	1.40 - 1.50	$(82.9 \pm 14.7) \times 10^{-6}$
.600 - .625	$(1.548 \pm .029) \times 10^{-1}$	1.50 - 1.60	$(89.6 \pm 15.9) \times 10^{-6}$
.625 - .650	$(1.212 \pm .023) \times 10^{-1}$	1.60 - 1.70	$(94.6 \pm 17.9) \times 10^{-6}$
.650 - .675	$(9.700 \pm .187) \times 10^{-2}$	1.70 - 1.80	$(58.6 \pm 15.0) \times 10^{-6}$
.675 - .700	$(7.476 \pm .149) \times 10^{-2}$	1.80 - 2.00	$(56.6 \pm 11.1) \times 10^{-6}$
.700 - .725	$(5.889 \pm .123) \times 10^{-2}$	2.00 - 2.20	$(33.8 \pm 7.3) \times 10^{-6}$
.725 - .750	$(4.730 \pm .104) \times 10^{-2}$	2.20 - 2.40	$(33.2 \pm 7.2) \times 10^{-6}$
.750 - .775	$(3.740 \pm .087) \times 10^{-2}$	2.40 - 2.60	$(26.2 \pm 6.4) \times 10^{-6}$
.775 - .800	$(2.981 \pm .074) \times 10^{-2}$	2.60 - 2.80	$(11.4 \pm 4.3) \times 10^{-6}$
		2.80 - 3.00	$(8.3 \pm 3.7) \times 10^{-6}$

B_i ($i=1, \dots, 6$) $\equiv$ MWPC
 F_i ($i=1, \dots, 8$) $\equiv$ MWPC

BH, BV, FH, FV $\equiv$ Hodoscopes

Fig. 1

Fig. 2

Fig. 3