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MEASUREMENT OF THE DIFFERENTIAL CROSS SECTION AND OF THE POLARIZATION PARAMETER

IN pp ELASTIC SCATTERING AT 200 GeV/c

G. Fidecaro, M. Fidecaro, L. Lancieri^{†)}, S. Nurushev^{o)}, L. Piemontese^{*)},

V. Solovianov^{o)} and A. Vascotto

CERN, Geneva, Switzerland

F. Gasparini, A. Meneguzzo, M. Posocco, P. Sartori and C. Voci

Istituto di Fisica dell'Università and INFN, Padova, Italy

R. Birsa, F. Bradamante, M. Giorgi, A. Penzo, P. Schiavon and A. Villari

Istituto di Fisica dell'Università and INFN, Trieste, Italy

W. Bartl, R. Frühwirth, Ch. Gottfried, G. Leder, W. Majerotto,

G. Neuhofer, M. Pernicka, Ch. Poyer, M. Regler, M. Steuer and H. Stradner

Inst. f. Hochenergiephysik^{o)}, Österreich. Akad. Wissenschaften, Vienna, Austria

ABSTRACT

Data are given for the polarization parameter and for the differential cross-section in pp elastic scattering at 200 GeV/c, in the range $0.5 \leq -t \leq 4.0 \text{ GeV}^2$. The polarization changes sign in the dip region, as already observed at 150 GeV/c.

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o) Visitor from the Institute for High Energy Physics, Serpukhov, USSR.

*) On leave from INFN, Trieste, Italy.

†) Present address: INFN, Trieste, Italy.

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As a part of the WA6 experimental programme at the CERN Super Proton Synchrotron (SPS) we have measured the polarization parameter and the differential cross-section in pp elastic scattering at an incident beam momentum of 200 GeV/c, in the four-momentum transfer range $0.5 \leq -t \leq 4.0 \text{ GeV}^2$, using a polarized proton target.

1. APPARATUS AND DATA TAKING

The experimental layout is shown in Fig. 1. It is much the same as the one used in the measurement we made at 150 GeV/c¹⁾, so for a detailed description of the apparatus we refer to our previous paper. However, three modifications have been applied:

- i) A new target is used. It is made up of one section (PT) consisting of a 10 cm long, 2 cm diameter cell, filled by pentanol beads, $\text{C}_5\text{H}_{11}(\text{OH})$. The free hydrogen nuclei (14% of all nucleons) are polarized to 75% with an absolute calibration uncertainty of 4%. One centimetre down the beam line the PT is followed by a 4 cm long, 2 cm diameter unpolarized polyethylene disk target (DT). In this way we monitor the variation of the efficiency of the apparatus by using elastic events produced inside the cryostat on unpolarized protons, adding an independent check to the usual monitor, i.e. quasi-elastic events produced on the bound protons of the PT. For a fraction of time, this assembly is replaced by the carbon target (CT) of Ref. 1, containing a comparable number of bound nucleons as PT and DT, but hydrogen-free.
- ii) To increase the highest accepted $|t|$ -value to 4 GeV^2 , the forward spectrometer is moved perpendicular to the beam-axis in the scattering plane while the backward counter hodoscope is rotated to form an angle of 11.8° with the beam line.
- iii) An additional differential (CEDAR) Čerenkov counter tags the pions in the incident beam ($\sim 1\% \pi^+$ in 5×10^7 protons/burst) to improve the rejection of elastic π^+p events, which is particularly important in the dip region of the pp cross-section. Incident protons are required to have no signal in any of the three Čerenkov counters; the corresponding inefficiency is about 1-2%.

A total of 630 runs, corresponding to $\sim 16 \times 10^6$ triggers, have been collected during two periods of running time, in November 1979 and in April 1980. Out of these 92 runs ($\sim 15\%$) have been thrown away on the basis of stability checks of the complete set-up.

2. ANALYSIS

Events surviving the track finding procedure and the geometrical reconstruction (typically $\sim 35\%$) enter the geometrical fit of tracks which searches for a common interaction vertex of the forward and backward track (for details see Ref. 1).

A kinematical 4C-fit then defines out of a total of 4.7×10^6 remaining candidates the elastic events (EF) on hydrogen nuclei and the quasi-elastic events on bound nucleons (QF). In both cases the probability of the fit must be greater than 6%.

We evaluate the background for each t-bin (t given by the EF of each event) from the carbon target events ($\sim 12\%$ of the total) which are analysed in exactly the same way as the PT events:

$$BG = (EF)_{CT} \frac{(QF)_{PT}}{(QF)_{CT}}.$$

This background is mainly due to quasi-elastic events, since the inelastic background turns out to be less than 2%. The relative background contamination of the EF sample, $\rho = BG/(EF)_{PT}$, can be seen in Fig. 2. Particular care has been taken to avoid contamination of the QF sample by elastic events. Therefore we select QF candidates which have a probability less than 0.1% of fitting the elastic hypothesis.

The total number of $(EF)_{PT}$ events is $\sim 1.43 \times 10^6$. A detailed description of the methods employed in data reduction and analysis is found in Ref. 1. The geometrical acceptance $E(t)$ of the apparatus (Fig. 3) has been evaluated by Monte Carlo methods using the program GEANT⁵).

3. RESULTS

a) The polarization parameter

The polarization parameter P is calculated for each t-bin using the expression:

$$P(t) = \left(\frac{N^-(t)}{M^-} - \frac{N^+(t)}{M^+} \right) / \left[\langle P_T^+ \rangle \left(\frac{N^-(t)}{M^-} \right) + \langle P_T^- \rangle \left(\frac{N^+(t)}{M^+} \right) \right] \quad (1)$$

where $N^\pm(t) = (EF)_{PT}^\pm(t) [1 - \rho^\pm(t)]$. $M^\pm$ are the monitors for runs with positive and negative target polarization. They are defined as $M^\pm = \sum_{t\text{-bins}} (QF)_{PT}^\pm$. $\langle P_T^\pm \rangle$ and $\langle P_T^+ \rangle$ are the corresponding average values of $\langle P_T \cdot \cos \phi \rangle$, properly weighted by the corresponding number of events used (ϕ is the angle between the normal to the scattering plane and the target polarization $\vec{P}_T$). The asymmetry sign follows the Basel Convention²).

Table 1 lists the results for the polarization parameter in the t -range from -0.45 to -4.0 GeV^2 together with the number of elastic PT events used. The errors quoted include statistical errors and an estimation of systematic errors as described in Ref. 1.

Figure 4 shows the polarization parameter as a function of t . The general behaviour is similar to that of our data at $150 \text{ GeV}/c$ ¹⁾ and of other high-energy measurements^{3,4)}. The negative trend of the polarization from low $|t|$ values up to $t \approx -1.35 \text{ GeV}^2$ is confirmed. Additional evidence is shown for a change in polarization sign at $-t \approx 1.5 \text{ GeV}^2$, corresponding to the marked dip in the differential cross-section. In the t -region from -1.6 to -3.5 GeV^2 the polarization parameter P stays positive with a confidence level of 98%.

b) The angular distribution

The differential cross-section $d\sigma/dt$ is evaluated according to the expression:

$$\frac{d\sigma}{dt} \propto N(t) = [N^-(t)/M^- + N^+(t)/M^+]/E(t) \quad (2)$$

with the same meaning of symbols as in formula (1).

In Table 2 and Fig. 5 values of $d\sigma/dt$ are displayed for $0.6 \leq -t \leq 4.0 \text{ GeV}^2$. The t -range is limited to the region where the acceptance is higher than $2/3$ of its maximal value. The dip in the cross-section at $t \approx -1.5 \text{ GeV}^2$ and the second maximum around $\sim -1.9 \text{ GeV}^2$ are more pronounced than in the lower energy measurement, in agreement with other results at the same and higher energies at FNAL^{3,6)} and ISR⁷⁾. The quoted errors are statistical only. The absolute normalization of the differential cross-section is obtained by taking $d\sigma/dt$ to be $137 \text{ } \mu\text{b}/\text{GeV}^2$ at $t = -0.6 \text{ GeV}^2$, as measured by Rusack et al.⁸⁾.

A fit to the data is obtained by parametrizing the differential cross-section with two interfering amplitudes, depending on five parameters⁹⁾:

$$\frac{d\sigma}{dt} = A |e^{b(t-t_0)/2} + e^{d(t-t_0)/2+i\phi}|^2 \quad (3)$$

Table 3 gives the parameter values for a fit in two ranges $0.8 \leq -t \leq 3 \text{ GeV}^2$ and $1.05 \leq -t \leq 2.5 \text{ GeV}^2$. The experimental t -resolution δ is taken into account by folding expression (3) with a Gaussian error distribution before fitting the data. The relative resolution increases linearly with $|t|$, according to the expression: $\delta/|t| = 0.015 \cdot |t|$ (t in GeV^2), and is similar to the one at $150 \text{ GeV}/c$ ¹⁾. For this fit the events are binned in t -steps of 0.025 GeV^2 .

4. CONCLUSIONS

The polarization parameter in elastic pp scattering at 200 GeV/c has been shown to have a t -dependence similar to the one we have measured at 150 GeV/c. In particular, with a larger statistical significance the polarization at $|t|$ values larger than 1.5 GeV^2 is positive, providing additional evidence for a change of sign at the dip region. The differential cross-section, computed with the same data, shows a dip much more pronounced than the one at 150 GeV/c, in agreement with the trend of existing higher energy data.

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Table 1

Polarization parameter P in pp elastic scattering at 200 GeV/c

$ t $ interval (GeV ²)	P	(EF) _{PT} ⁻	(EF) _{PT} ⁺
0.450 - 0.475	0.0103 ± 0.0113	30090	29912
0.475 - 0.500	-0.0026 ± 0.0087	56126	56769
0.500 - 0.525	0.0012 ± 0.0078	79700	80197
0.525 - 0.550	-0.0019 ± 0.0075	87847	88767
0.550 - 0.575	-0.0030 ± 0.0077	82555	83547
0.575 - 0.600	0.0013 ± 0.0081	71317	71744
0.600 - 0.625	-0.0094 ± 0.0085	59898	61158
0.625 - 0.650	0.0028 ± 0.0091	48775	48966
0.650 - 0.675	0.0240 ± 0.0095	39174	38192
0.675 - 0.700	-0.0016 ± 0.0099	31497	31816
0.700 - 0.800	-0.0239 ± 0.0076	73383	76451
0.800 - 0.900	-0.0155 ± 0.0089	30315	31214
0.900 - 1.000	-0.028 ± 0.023	12200	12777
1.000 - 1.150	-0.060 ± 0.025	5603	6129
1.150 - 1.300	-0.068 ± 0.038	1192	1312
1.300 - 1.450	-0.167 ± 0.081	195	242
1.450 - 1.600	0.19 ± 0.15	78	63
1.600 - 1.800	0.16 ± 0.10	138	113
1.800 - 2.000	0.04 ± 0.08	181	174
2.000 - 2.500	0.04 ± 0.06	342	328
2.500 - 3.000	0.15 ± 0.08	182	149
3.000 - 3.500	0.13 ± 0.14	63	53
3.500 - 4.000	-0.14 ± 0.21	23	28

Table 2

Differential cross-sections of elastic pp scattering at 200 GeV/c

$ t $ interval (GeV ²)	$d\sigma/dt$ ($\mu\text{b}\cdot\text{GeV}^{-2}$)	$ t $ interval (GeV ²)	$d\sigma/dt$ ($\mu\text{b}\cdot\text{GeV}^{-2}$)
0.600 - 0.625	$(1.21 \pm 0.05) \times 10^2$	1.20 - 1.30	$(2.65 \pm 0.11) \times 10^{-1}$
0.625 - 0.650	$(9.97 \pm 0.38) \times 10^1$	1.30 - 1.40	$(8.16 \pm 0.61) \times 10^{-2}$
0.650 - 0.675	$(7.48 \pm 0.28) \times 10^1$	1.40 - 1.50	$(1.81 \pm 0.44) \times 10^{-2}$
0.675 - 0.700	$(6.55 \pm 0.25) \times 10^1$	1.50 - 1.60	$(1.93 \pm 0.37) \times 10^{-2}$
0.700 - 0.725	$(4.91 \pm 0.18) \times 10^1$	1.60 - 1.70	$(2.05 \pm 0.32) \times 10^{-2}$
0.725 - 0.750	$(4.05 \pm 0.15) \times 10^1$	1.70 - 1.80	$(3.02 \pm 0.38) \times 10^{-2}$
0.750 - 0.775	$(3.21 \pm 0.12) \times 10^1$	1.80 - 2.00	$(3.84 \pm 0.29) \times 10^{-2}$
0.775 - 0.800	$(2.64 \pm 0.10) \times 10^1$	2.00 - 2.20	$(3.70 \pm 0.23) \times 10^{-2}$
0.800 - 0.850	$(1.87 \pm 0.05) \times 10^1$	2.20 - 2.40	$(2.53 \pm 0.23) \times 10^{-2}$
0.850 - 0.900	$(1.15 \pm 0.03) \times 10^1$	2.40 - 2.60	$(2.07 \pm 0.21) \times 10^{-2}$
0.900 - 0.950	(7.51 ± 0.21)	2.60 - 2.80	$(1.33 \pm 0.15) \times 10^{-2}$
0.950 - 1.00	(4.75 ± 0.14)	2.80 - 3.00	$(1.15 \pm 0.14) \times 10^{-2}$
1.00 - 1.05	(2.87 ± 0.08)	3.00 - 3.20	$(5.87 \pm 0.88) \times 10^{-3}$
1.05 - 1.10	(1.74 ± 0.06)	3.20 - 3.40	$(4.51 \pm 0.75) \times 10^{-3}$
1.10 - 1.15	(1.03 ± 0.04)	3.40 - 3.60	$(2.66 \pm 0.55) \times 10^{-3}$
1.15 - 1.20	$(5.90 \pm 0.28) \times 10^{-1}$	3.60 - 3.80	$(2.78 \pm 0.58) \times 10^{-3}$
		3.80 - 4.00	$(1.39 \pm 0.40) \times 10^{-3}$

Table 3

Parameters of Eq. (3) describing $d\sigma/dt$ with two amplitudes

	$0.8 < -t < 3.0 \text{ GeV}^2$	$1.05 < -t < 2.5 \text{ GeV}^2$
b	8.09 ± 0.08	$7.83 \pm 0.35 \text{ GeV}^{-2}$
d	1.79 ± 0.09	$1.80 \pm 0.26 \text{ GeV}^{-2}$
$-t_0$	1.468 ± 0.003	$1.472 \pm 0.005 \text{ GeV}^2$
$\cos \phi$	-0.944 ± 0.007	-0.954 ± 0.014
χ^2/DF	187/83	111/53
$-t_{\min}$	1.50 ± 0.01	$1.50 \pm 0.02 \text{ GeV}^2$
$-t_{\max}$	1.92 ± 0.01	$1.93 \pm 0.04 \text{ GeV}^2$
$\frac{d\sigma}{dt} \Big _{t_{\max}} / \frac{d\sigma}{dt} \Big _{t_{\min}}$	2.66 ± 0.48	2.94 ± 2.42

FIGURE CAPTIONS

Fig. 1: Layout of the apparatus: a) B3-6 and F1-8 are MWPCs; FV, FH, BV, and BH are scintillator hodoscopes; S1 and S2 are scintillation counters. The envelope of the forward and backward proton trajectories is also shown. b) Sketch of the forward arm showing the relative distances of the detectors.

Fig. 2: The relative background $BG/(EF)_{PT}$ of the elastic events, as a function of $-t$.

Fig. 3: Geometrical acceptance of the apparatus (normalized to its maximum value) as a function of $-t$.

Fig. 4: Results for the polarization parameter versus $-t$.

Fig. 5: Results for the differential cross-section versus $-t$.

(a)

(b)

Fig. 1

Fig. 2

Fig. 3

Fig. 4

Fig. 5