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S. Focardi, G. Giacomelli, L. Monari and P. Serra: PROTON POLARIZATION IN $\pi^- + p$ ELASTIC SCATTERING AT 8.5 GeV/c. -

ABSTRACT. -

This paper describes an experiment on proton polarization in $\pi^- + p$ elastic scattering at 8.5 GeV/c. The experiment was performed using the spark chamber technique. In the four-momentum transfer interval $0.15 \leq t \leq 0.8\ (\mathrm{GeV}/c)^2$ the polarization found is $P = 0.33 \pm 0.15$.

I. - INTRODUCTION.

We report some experimental results on the proton polarization in $\pi^- + p$ elastic scattering at 8.5 GeV/c in the diffraction region.

This experiment was performed with the equipment used for an experiment on $\pi^\pm p$ and pp elastic scattering carried out at the CERN Proton Synchrotron(1). The polarization of the recoil proton was detected by means of a second scattering in a carbon target. At the moment, no data are available on the recoil proton polarization in $\pi + p$ elastic scattering at high energy.

II. - EXPERIMENTAL APPARATUS.

As shown in fig. 1, four spark chambers S_1, S_2, S_3 and S_4 detected the incident pion, and, the following chambers S_5, S_6, S_7 and S_8 the scattered one. A carbon plate was placed between spark chambers S_9 and S_{10}. The plate was either one, or two cm thick. The trigger consisted of a triple coincidence of the incident, scattered and recoil particles, in addition to a number of anticoincidences.

The incident pion was defined by counters C_1, C_3, C_4, the Cerenkov counter C_2 and the anticounter A_1 which limited the transverse dimen

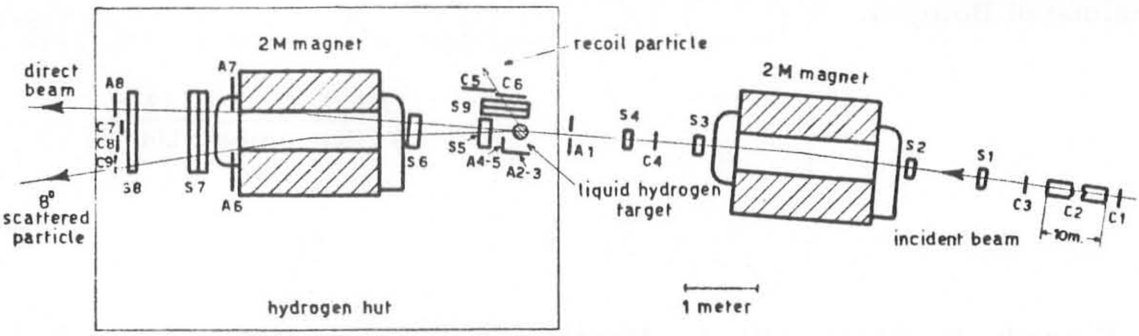

Fig. 1 - Layout of the experiment.

sions of the beam to 5 cm horizontal and 2. 5 cm vertical. The scattered pion was detected by one of the counters C_7, C_8 or C_9; the recoil proton by one of the counters C_5 or C_6. The anticoincidences $A_2 - A_5$ reduced the number of triggers caused by inelastic events. The incident beam had a momentum spread of $\pm$ 2. 5%. The momenta of incident and scattered particles were determined by magnetic deflection to an accuracy of $\pm$1. 5%.

The hydrogen target was a cylinder, 20 cm in diameter with 0. 25 mm thick mylar walls. A system of 38 plane mirrors gave the horizontal and vertical views of each spark chamber on a single frame of 35 mm films.

III. - PICTURE ANALYSIS.

18. 000 pictures with a 2 cm carbon target and 14. 600 with a 1 cm carbon target were taken. The whole film was scanned twice and the following criteria were used:

a) Presence of a proton-carbon scattering: this means that the proton track in at least one of the two views of chambers S_9 and S_{10} did not lie in the same straight line.

b) Horizontal and vertical projections of the two proton tracks in S_9 and S_{10} crossed in a point of the carbon target.

c) Events with more than one track in chambers S_1, S_2, S_3 and S_4 were rejected.

d) Inelastic events in the first pion proton scattering were also obviously rejected. This happened for pictures with more than one track in S_5 - S_6 or, if the angular correlation of the outgoing pion and proton was clearly inconsistent with the elastic scattering correlation.

e) In the horizontal and vertical projections, the angles which the scattered proton made with the incident proton, were evaluated at the scanning table. To avoid scanning bias and multiple Coulomb scattering, events were accepted, for which, at least one of these angles was larger than 4°.

All events satisfying these scanning criteria were measured by lines, using a digitized table. This was possible because the axis of every spark chamber pair (1,2) (3,4), (5,6), (7,8), was aligned with good accuracy on the photograph, so that it was possible to perform the measurement, superimposing a fine line scratched on a plexiglas ruler, on the parts of each track in the various chamber pairs. The measuring machine is such that two points belonging to the line (which obviously are not always the same) are bound to move following two parallel rails. These points are connected with two wires parallel to the rails and the lengths of the two wires are expressed in digital form, and punched on cards by a 026 IBM puncher[2]. Figure 2 shows a picture of the digitized table.

A geometrical reconstruction programme for the IBM 650 computer calculated, for all the measured events, the momenta of the incident (p_1) and scattered (p_2) pion, the angles Θ_π and Θ_p of the outgoing pion and proton, with respect to the incident pion, the direction cosines of every track and the coordinates for the two interactions in the laboratory system. We accepted as elastic, the events satisfying the following requirements:

a) The incident pion, the scattered pion and the recoil proton were on the same plane.

b) p_2, Θ_π and Θ_p were consistent with the expected values for elastic scattering.

c) The vertex of the (π, p) interaction was in the volume occupied by H_2.

Moreover, the incident pion momentum had to be between the limits of 7.9 and 8.9 GeV/c. All the events, which, even after a second measurement did not satisfy the above criteria, were rejected.

For all the elastic events with the (p-C) interaction vertex contained in the carbon plate, we evaluated, by means of an IBM 650 computer, α, φ and T, where α is the angle between the incident and the outgoing proton; in the carbon scattering φ is the angle between the (π^-p) scattering plane and the plane of the two protons, and T is the kinetic energy of the proton before the scattering in the carbon target.

IV. - POLARIZATION ANALYSIS.

The expected number of events at the angles α, φ within a solid angle $d\Omega$, and for a particular value of the polarization P, is given by:

$$dN = \frac{1}{K} \epsilon(\alpha, \varphi)\, \sigma(\alpha, T)\left[1 + PA(\alpha, T) \cos\varphi\right] d\Omega \qquad (1)$$

where $\sigma(\alpha, T)$ is the (p-C) cross-section for a non-polarized proton beam. $A(\alpha, T)$ is the analysability corresponding to (p-C) scattering, $\epsilon(\alpha, \varphi)$ is the geometrical efficiency of the apparatus for revealing the proton after the second scattering; K is a normalizing factor. A computation of the geometrical efficiency showed that $\epsilon(\alpha, \varphi)$ in the region between 0 and π is symmetric, with respect to $\varphi = \pi/2$, and, between π and 2π, with respect to $\varphi = 3/2\,\pi$.

Starting from the coordinates in the carbon target and the α for each measured event, fictitious scattered protons were constructed with different values of φ, equally spaced from 0 to 2π. For each value of α we defined $\epsilon(\alpha, \varphi)$ as the ratio between the number of intersections of these fictitious protons with the proton counters $C_5\ C_6$, and the number of φ trials. The normalization factor K, which may be obtained by $\int_\Omega dN = N$, is independent of P because $\epsilon(\alpha, \varphi)$ is symmetric. Using the maximum likelihood method[3] this allows us to search for the value of P which maximizes the function

$$(2) \qquad L = \prod_{i=1}^{N} \left[I + PA(\alpha_i, T_i) \cos \varphi_i \right]$$

where N is the total number of events.

The value $P = \bar{P}$ for which L is maximum, was found looking for the value of P satisfying the condition

$$(3) \qquad \left(\frac{d(\ln L)}{dP} \right)_{P=\bar{P}} = \sum_{i=1}^{N} \frac{A(\alpha_i, T_i) \cos \varphi_i}{I + \bar{P}A(\alpha_i, T_i) \cos \varphi_i} = 0 .$$

$A(\alpha_i, T_i)$ was determined using the analyzing power including inelastic scattering up to 50 MeV energy loss, as given by Peterson[4]. We plotted L and $d(\ln L)/dP$ versus P, for P ranging between - 1 and + 1. The errors $\Delta\bar{P}$ reported later on, are defined from

$$(4) \qquad L(\bar{P} \pm \Delta\bar{P}) = L(\bar{P})\, e^{-1/2} .$$

They do not take into account the errors $\Delta\alpha_i$, $\Delta\varphi_i$, ΔT_i and $\Delta[A(\alpha_i, T_i)]$. Figure 3 shows the plots of L and $d(\ln L)/dP$ versus P for all the events. A first analysis was made including all the events. Afterwards, the events were divided into three samples, according to different values of t, the four-momentum transfer squared. The results are reported in Table I.

Q was calculated using formulae (2) and (3) where φ_i is now the angle between the plane of the two protons and the normal $\bar{n}$ to $(\pi^- p)$ scattering plane, $\bar{P}$ being replaced by $\bar{Q}$. $\Delta\bar{Q}$ was evaluated by means of equation (4), having substituted $\bar{P}$ by $\bar{Q}$ and $\Delta\bar{P}$ by $\Delta\bar{Q}$. We have computed $\bar{Q}$ as a test, because a value of $\bar{Q}$ different from zero would indicate an up-down asymmetric distribution of the scattered protons, with respect to $(\pi^- -p)$ scattering plane, which is forbidden, however, by parity conservation. In fact $\bar{Q}$ is zero within error. To exclude that the values different from zero were due to geometrical or scanning bias, several checks were performed.

a) Scanning efficiency.

A polarization different from zero, means that the number of protons scattered by carbon on the left, is different from the number scattered

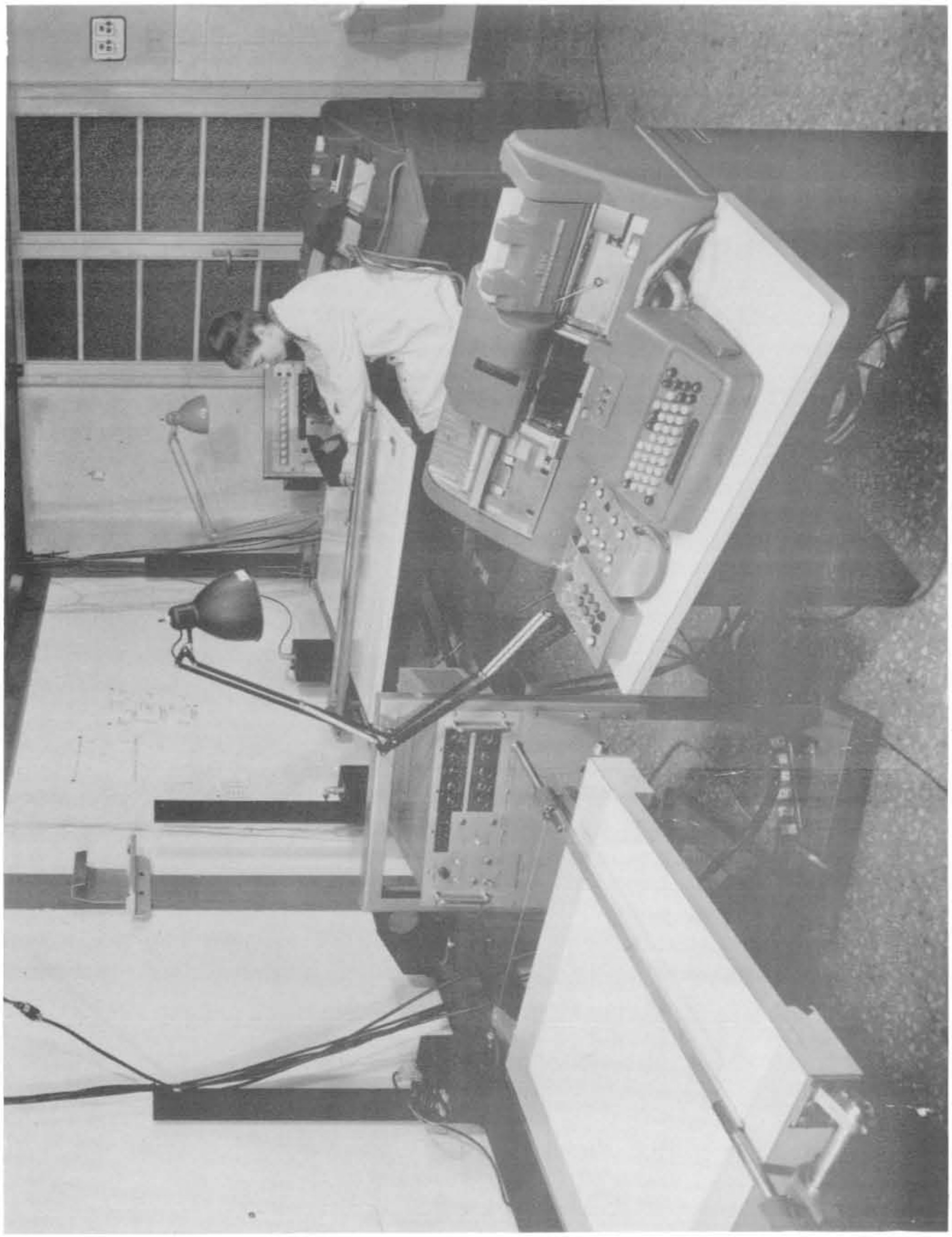

TABLE I

Results of the polarization measurements at 8. 5 GeV/c. P is the polarization derived from the left-right asymmetry; Q from the up-down asymmetry. The data refer to both the events with a 1 cm and 2 cm thick carbon plate.

$\|t\|$ $(GeV/c)^2$	Number of events	$\bar{P} \pm \Delta\bar{P}$	$\bar{Q} \pm \Delta\bar{Q}$
$0.15 \leq \|t\| \leq 0.8$	367	0.33 ± 0.15	0.04 ± 0.17
$0.15 \leq \|t\| < 0.3$	230	0.19 ± 0.22	0.07 ± 0.25
$0.3 \leq \|t\| < 0.45$	102	0.43 ± 0.23	0.04 ± 0.30
$0.45 \leq \|t\| \leq 0.8$	35	0.72 ± 0.55	-0.03 ± 0.40

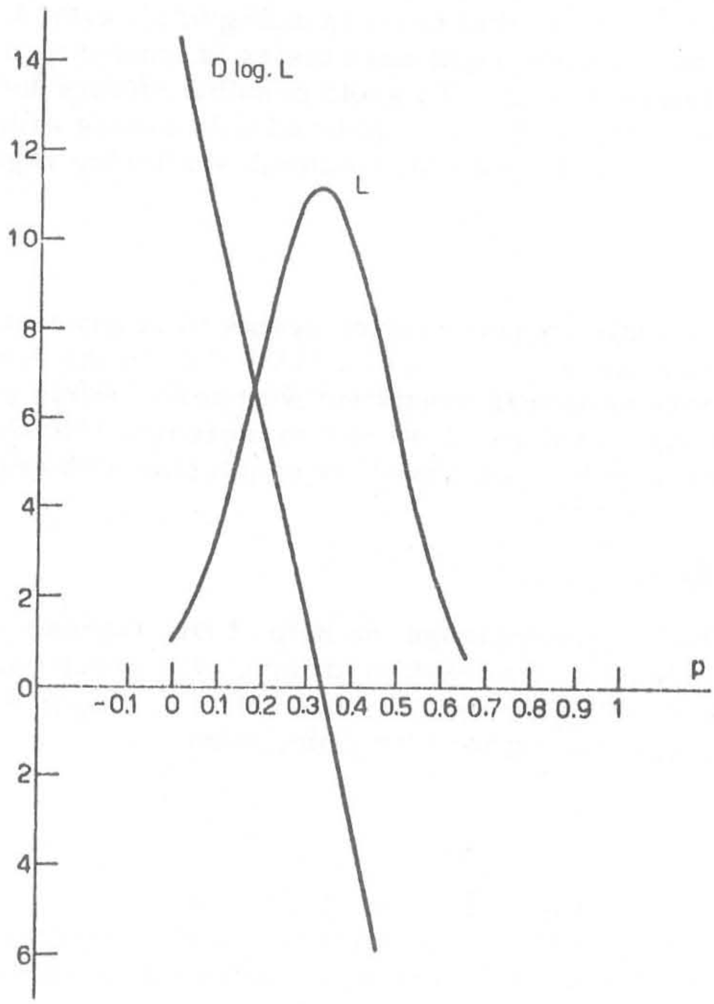

Fig. 3 - Plot of the likelihood function L and of d(ln L)/ dP versus the polarization P.

on the right. Left and right, are defined with respect to the plane containing the incident proton and parallel to the normal $\bar{n}$. We can exclude that the polarization effect is due to a scanning bias, because detection efficiency on the left and on the right, computed from scanning and rescanning, are equal and consistent to 100%.

b) Relative alignment of spark chambers S_9 and S_{10}.

The alignment of the horizontal and vertical projections of S_9 and S_{10} was checked by measuring the proton tracks in 200 pictures, which correspond to elastic events in a run without carbon plate, between S_9 and S_{10}. A misalignment both in the horizontal and vertical projections was found, corresponding to, at most, 0.3^o. This misalignment is almost an order of magnitude too small to produce the found asymmetry.

c) Eventual event loss.

We formed three samples of events according to the different values of α. The values of the polarization for the three samples are equal, within experimental error, to that corresponding to all events. This enables us to exclude that the left-right asymmetry is caused by a loss of events in a limited interval of α. To avoid possible effects due to the cut-off used during the scan, we have considered only events with $\alpha > 7^o$, and also in order to avoid the multiple Coulomb scattering region.

V. - CONCLUSION.

As shown in Table I a polarization seems to be present which is different from zero in the interval $0.15 \leq |t| \leq 0.8$. In the interval $0.15 \leq |t| < 0.3$, the polarization is consistent with zero, within experimental error, while for larger t values, P seems to increase. Our data do not have sufficient precision to draw any other conclusion with certainty.

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