EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH



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# Memorandum

To : Members of EEC

From : Amblard, Autones, Cozzika, Deregel, Ducros, Hansroul, Lehar, de Lesquen, Merlo, Movchet, Raoul, Rieubland, van Rossum.

Subject : Extension of the measurements of spin rotation parameters.

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Within the time allocated until the 1969 shut-down we expect to complete measurements for $\pi^+P$ and $\pi^-P$ at 6 Gev/c, $\pi^-P$ at 16 Gev/c and PP at 6 Gev/c (simultaneously with $\pi^+$), with about $10^6$ triggers for each of the measurements $\pi P$.

1) Our preliminary results for $\pi^-P$ at 6 Gev/c show that A is close to 1, and that R is small and negatif. This is in qualitative agreement with the two recent models that have led to predictions for A and R (Regge poles plus absorption, by Cohen Tannoudji et al., and Regge poles plus constraints from F.E.S.R., by Barger and Phillips ). The comparaison of the two predictions shows that it would be interesting, at least at one energy, to reach in the region of $-t = .5$ $(\text{Gev/c})^2$ a statistical error for R, comparable to the precision that we expect to obtain at smaller momentum transfers (larger differential cross-section )with the present set of data.

We propose, therefore, to continue to take data for $\pi^+P$ at 6 Gev/c (most intense beam).

2) The experimental determination of the parameters A and R in proton-proton scattering represents for high energy models an interest that is comparable to the one of data on $\pi P$ scattering. We have already started taking data for R in PP at 6 Gev/c. Measurements at high energies would be of importance.

We propose to take data for PP at 18 Gev/c (upper limit of beam p3).

The apparatus, as it is running, and the beam are well suited for the supplementary programme presented here, without modifications. The measurements would require five weeks. We think that it would be regrettable not to make use of the existing installation to obtain rapidly these two additional experimental informations.

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# MEASUREMENT OF SPIN ROTATION PARAMETERS IN PION-NUCLEON SCATTERING AT HIGH ENERGY*)


B. Amblard,**), G. Cozzika, Y. Ducros, M. Hansroul, A. de Lesquen, J.P. Merlo, J. Movchet, and L. van Rossum

Département de Physique des Particules Elémentaires, Centre d'Etudes Nucléaires, Saclay, France.


## A B S T R A C T


The spin rotation parameters A and R have been measured in pion-nucleon scattering from 6 GeV/c to 16 GeV/c for $t$ ranging from -0.17 to -0.47 $(GeV/c)^2$. The experiment is being carried out at CERN.

The apparatus is composed of a LMN polarized target; the magnetic field is produced by two superconducting coils. The direction of the polarization is in the scattering plane.

A set of scintillation counter hodoscopes is connected to an electronics logic of integrated circuits, permitting the triggering of the spark chamber polarimeter mainly on elastic $\pi N$ collisions.

At this Conference we present the analysis of the first data concerning the $9 \times 10^5$ spark chamber triggers that have been registered in $\pi^- p$ at 6 GeV/c.



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*) R. Beurtey and F. Lehar (CEN Saclay), J. Deregel and J.M. Fontaine (Université de Caen) have contributed to this experiment.

**) On leave from Institut de Physique Nucléaire, Orsay, France.

## 1. INTRODUCTION

The purpose of this experiment is to determine the module and the relative phase of the scattering matrix elements in pion-nucleon scattering at high energies, by measuring the recoil proton polarization in scattering on a polarized target.

In order to define the quantities measured in the experiment, we shall use the representation of the Pauli spin matrices for which the scattering matrix M can be written as

$$M(s,t) = f(s,t) + i\, g(s,t)\, \vec{\sigma} \cdot \hat{n}$$

where f(s,t) and g(s,t) are the non-spin-flip and spin-flip amplitudes, respectively;

$$\hat{n} = \frac{\vec{k}_i \times \vec{k}_f}{|\vec{k}_i \times \vec{k}_f|} \ .$$

The measurement of the angular distribution determines $|f|^2 + |g|^2$, and the measurement of polarization normal to the scattering plane gives

$$P = \frac{2\, \mathrm{Im}\, (fg^*)}{|f|^2 + |g|^2}$$

When a polarized proton target of polarization $\vec{P}_i$ is used, the recoil proton polarization $\vec{P}_f$, measured in the laboratory reference system, can be expressed as a function of the amplitudes f and g, and of $\vec{P}_i$ in the reference frame formed by the normal $\hat{n}$, the recoil proton momentum $\vec{k}_p$, and the direction $\vec{k}_p \times \hat{n}$ (Fig. 1). The expressions of u, v, w in terms of f, g, and $\vec{P}_i$ are the following:

$$u = \frac{R\, \vec{P}_i \cdot (\hat{k}_i \times \hat{n}) - A\, \vec{P}_i \cdot \hat{k}_i}{1 + P\, \vec{P}_i \cdot \hat{n}}$$

$$v = \frac{R\, \vec{P}_i \cdot \hat{k}_i + A\, \vec{P}_i \cdot (\hat{k}_i \times \hat{n})}{1 + P\, \vec{P}_i \cdot \hat{n}}$$

$$w = \frac{P + \vec{P}_i \cdot \hat{n}}{1 + P\, \vec{P}_i \cdot \hat{n}}$$

with the definitions

$$R = \frac{|f|^2 - |g|^2}{|f| + |g|^2} \cos(\Theta - \Theta_L) + \frac{2\,\mathrm{Re}\,(fg^*)}{|f|^2 + |g|^2} \sin(\Theta - \Theta_L)$$

and

$$A = \frac{|f|^2 - |g|^2}{|f|^2 + |g|^2} \sin(\Theta - \Theta_L) - \frac{2\,\mathrm{Re}\,(fg^*)}{|f|^2 + |g|^2} \cos(\Theta - \Theta_L) .$$

where $\Theta_L$ and $\Theta$ are the angles between $\hat{k}_i$ and the recoil proton in the lab. and centre-of-mass frames, respectively. A and R are the Wolfenstein parameters and correspond to measurements of the component of the recoil proton polarization lying in the scattering plane with $\vec{P}_i$ directed along $-\hat{k}_i$ and along $\hat{k}_i \times \hat{n}$, respectively. The relation $A^2 + R^2 + P^2 = 1$ holds between A, R, and P.

## 2. EXPERIMENTAL APPARATUS

The experiment is being performed at the CERN Proton Synchroton. The apparatus has been designed in order to allow measurements between 4 GeV/c and 18 GeV/c for the incident pion momentum.

The measurement of the type A (target polarization at 18° with the beam axis) for $\pi^- p$ scattering at 6 GeV/c incident pion momentum was performed in a beam produced by an internal target, whereas the measurements of type R (target polarization at 87° with the beam axis), at the same energy, was performed in another beam produced by the extracted proton beam.

The experimental apparatus (Fig. 2) consists of a polarized proton target with its superconducting magnet[1], a carbon plates polarimeter, and scintillation counter hodoscopes. The polarized target magnet consists of two superconducting Helmholtz coils with a geometry giving a large angular opening necessary for the detection of the recoil protons. The polarimeter consists of 27 carbon plates sandwiched between wire spark chambers with magnetic wire read-out[2]. Six scintillation counter hodoscopes associated with a fast logic using integrated circuits[3)] select the triggering of the spark chambers on elastic scattering on free protons. For each event, the relevant information is recorded on magnetic tape by means of an on-line computer CAE 90-10. In addition, the computer performs various tasks of controlling the good running of the experiment. The target polarization was reversed about every four hours.

## 3. PRINCIPLE OF ANALYSIS

The magnetic tapes containing the data are treated off-line on a CDC 6600 computer. For a given orientation of the target polarization $\vec{P}_i$, the successive steps of the data handling programme are the following:

- Recognition of proton-carbon scatterings and calculation of the energy and angle of scattering by a least-squares-fit method.
- Check of the elasticity of the proton-carbon scattering using the residual range of the proton in the carbon.
- Calculation of the proton trajectory between the target and the polarimeter and of the relativistic rotation of its polarization vector in the magnetic field.

The measurement of the transverse polarization of the recoil protons takes place at a distance of about two metres from the polarized proton target. Thus, the recoil protons have to pass through the magnetic field, which modifies their trajectories and rotates their polarization vector $\vec{P}_f$. In the non-relativistic approximation, the rotation angle of the proton spin is 2.8 times greater than that of the momentum having the same initial orientation. The programme selects the useful double scattering events, which represent a few per cent of triggers. These events are then used to determine, by a maximum likelihood method, the ratio of the magnitudes of the amplitudes f and g and their relative phase. The maximum likelihood function has the form

$$F(\vec{P}_i) = \sum_j q_j \log \left[1 + (1-\alpha)\, \vec{S} \cdot \hat{n}_2\, P_c + \alpha\vec{\omega} \cdot \hat{n}_2\, P_c\right]_j$$

where

$\vec{S}$ is the polarization vector $\vec{P}_f$ transformed by the magnetic field;

$\hat{n}_2$ is the normal to the proton-carbon scattering;

$P_c$ is the analysing power of the carbon;

$\alpha$ is the percentage of background remaining after all selection criteria have been applied;

$\vec{\omega}$ is the background polarization;

$q_j$ is a weighting factor for the $j^{th}$ event, $q_j = \overline{|P_i|}/|P_i(j)|N(\vec{P}_i)$ where $\overline{|P_i|}$ is the average value of $|P_i|$ for all the events and $N(\vec{P}_i)$ is the number of events with polarization $\vec{P}_i$.

The sum of $F(\vec{P}_i)$ and $F(-\vec{P}_i)$ allows elimination of the geometric biases and of the component of the background polarization which does not depend on $\vec{P}_i$, i.e. background coming from scatterings on bound protons of the polarized target.

In order to estimate the background, we have recorded data using a dummy target that simulates an LMN crystal without hydrogen. The analysis showed that after kinematic selection the background percentage $\alpha$ was less than 0.20. The contribution to the background from inelastic scattering of pions on polarized protons is one order of magnitude smaller than the background from bound protons. In order to reduce the contribution of inelastic collisions, the polarized target was surrounded by counters in anticoincidence. It was further reduced by anticoincidence counters covering all directions outside the useful regions.

In the usual double-scattering experiments, the polarization effect can be described, in the absence of a magnetic field, by the distribution of the number of double scatterings as a function of the angle $\xi$ between the normal $\hat{n}$ to the first scattering and the normal $\hat{n}_2$ to the second scattering. The distribution of events as a function of $\xi$ can then be written as

$$\frac{dN}{d\xi} = \frac{N}{2\pi}\left[1 + (u \sin\xi + w \cos\xi)\,\bar{P}_c\right],$$

where

$w = \vec{P}_f \cdot \hat{n}$

$u = \vec{P}_f \cdot (\hat{k}_p \times \hat{n})$

N is the total number of events, and $\bar{P}_c$ is the average analysing power of carbon.

The component u is present only in the case where the target protons are polarized in a direction $\hat{P}_i$ different from $\hat{n}$.

In the experiment described in this paper, we must define an angle $\xi$ that takes account of the effect of the magnetic field on the proton trajectories.

The angle $\xi$ is then the angle between $\hat{n}_2$ and the plane containing the polarization component $\vec{w}$, normal to the first scattering plane after rotation in the magnetic field and the momentum of the proton incident to the second scattering. Neglecting the relativistic correction and the effects of the stray field, the distribution of the number of double scatterings as a function of $\xi$ has the following form:

$$\frac{dN}{d\xi} \simeq \frac{N}{2\pi} \left[1 + (u \sin \xi + W(w,v) \cos \xi)\ \bar{P}_c\right],$$

where W(w,v) is a linear function of the polarization components v and w, deduced from the rotation of the polarization vector $\vec{P}_f$ in the magnetic field.

The change of the initial polarization from $\vec{P}_i$ to $-\vec{P}_i$ introduces a change of sign for u and v. This is a very sensitive effect in measurements of the type A, since A is close to one (Fig. 3).

## 4. RESULTS

Our preliminary results obtained by combination of the data for two signs and two directions of the initial polarization are shown on Fig. 4 and in Table 1. These results take into account the limitations of amplitudes f and g related to the value of the normal component of polarization at 6 GeV/c [4]. The mean value of A and R are in rather good agreement with theoretical predictions[5,6].

After kinematical constraints, about 6500 double scattering events are retained. The kinematical cuts are the following:

- kinetic energy of the incoming proton at the second scattering greater than 90 MeV;
- Angle of second scattering greater than 7°.

We hope to obtain a larger number of selected second scatterings by increasing the accuracy in the determination of the proton trajectory in the polarimeter.

TABLE I

Results of A and R measurements in $\pi^- p$ scattering at 6 GeV/c.

These results and errors take into account the limitations of amplitudes f and g related to the normal component of polarization [4] . Errors on R are the quadratic sum of statistical error and errors on initial polarization and analysing power of carbon ($\Delta P_i/P_i=0.05$ , $\Delta P_C/P_C=0.08$).

| $-t$ $(GeV/c)^2$ | A | R |
|---|---|---|
| $-0.236 \pm 0.029$ | $0.925 \pm 0.070$ | $-0.34 \pm 0.18$ |
| $-0.296 \pm 0.032$ | $0.920 \pm 0.060$ | $-0.37 \pm 0.19$ |
| $-0.361 \pm 0.035$ | $0.985 \pm 0.020$ | $-0.11 \pm 0.12$ |
| $-0.432 \pm 0.037$ | $0.995 \pm 0.020$ | $-0.08 \pm 0.17$ |

## REFERENCES

1) H. Desportes, 2nd Int. Conf. on Magnet Technology, Oxford 1967.

2) P. Autones, G. Cozzika, J.P. Merlo, J. Movchet and J.C. Raoul, International Seminar on Filmless Spark and Streamer Chambers, Dubna, April 1969.

3) J.C. Raoul, International Symposium on Nuclear Electronics, Versailles (France), September 1968, Volume III p.19-1.

4) M. Borghini, G. Coignet, L. Dick, K. Kuroda, L. Dilella, P.C. Macq, A. Michalowicz and J.C. Olivier, Phys. Letters 24 B, 77 (1967).

5) G. Cohen Tannoudji, A. Morel and H. Navelet, Nuovo Cimento 48 A, 1075 (1967).

6) V. Barger and R.J.N. Phillips, Rutherford High-Energy Laboratory, private communication.

## Figure captions

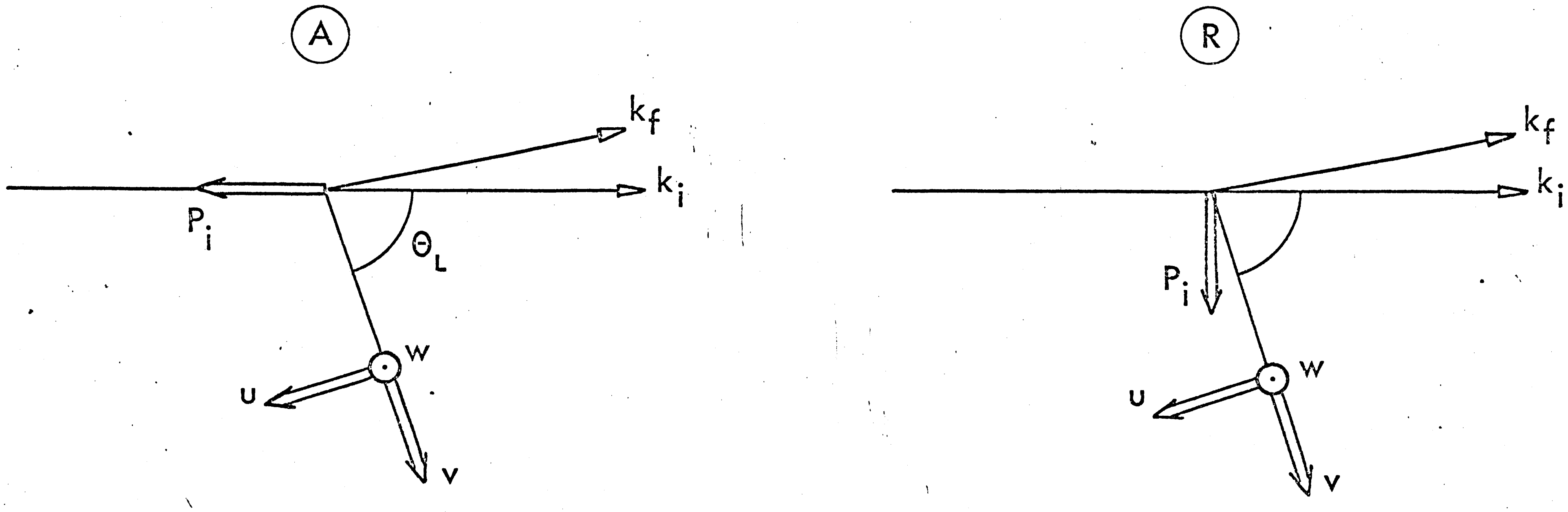
Fig. 1 : Definition of A and R measurements.

Fig. 2 : Experimental layout.

Fig. 3 : Distribution of the number of double scattering events versus angle $\xi$ between the normal to the second scattering $\hat{n}_2$ and the plane containing the vectors $\vec{K}_p$ and $\vec{N}_1$, $\vec{K}_p$ being the momentum of the incident proton to the second scattering and $\vec{N}_1$ being the polarization component $\vec{w}$ normal to the first scattering plane after rotation in the magnetic field.

Fig. 4 : Comparison of our preliminary results with those of the theoretical prediction of Ref. 5 (continuous line) and Ref. 6 (dotted line).

POLARIZATION MEASUREMENT IN THE LABORATORY REFERENCE SYSTEM




(A)

$u = A|P_i|$

$v = -R|P_i|$

$w = P$

(R)

$u = R|P_i|$

$v = A|P_i|$

$w = P$

FIGURE 1

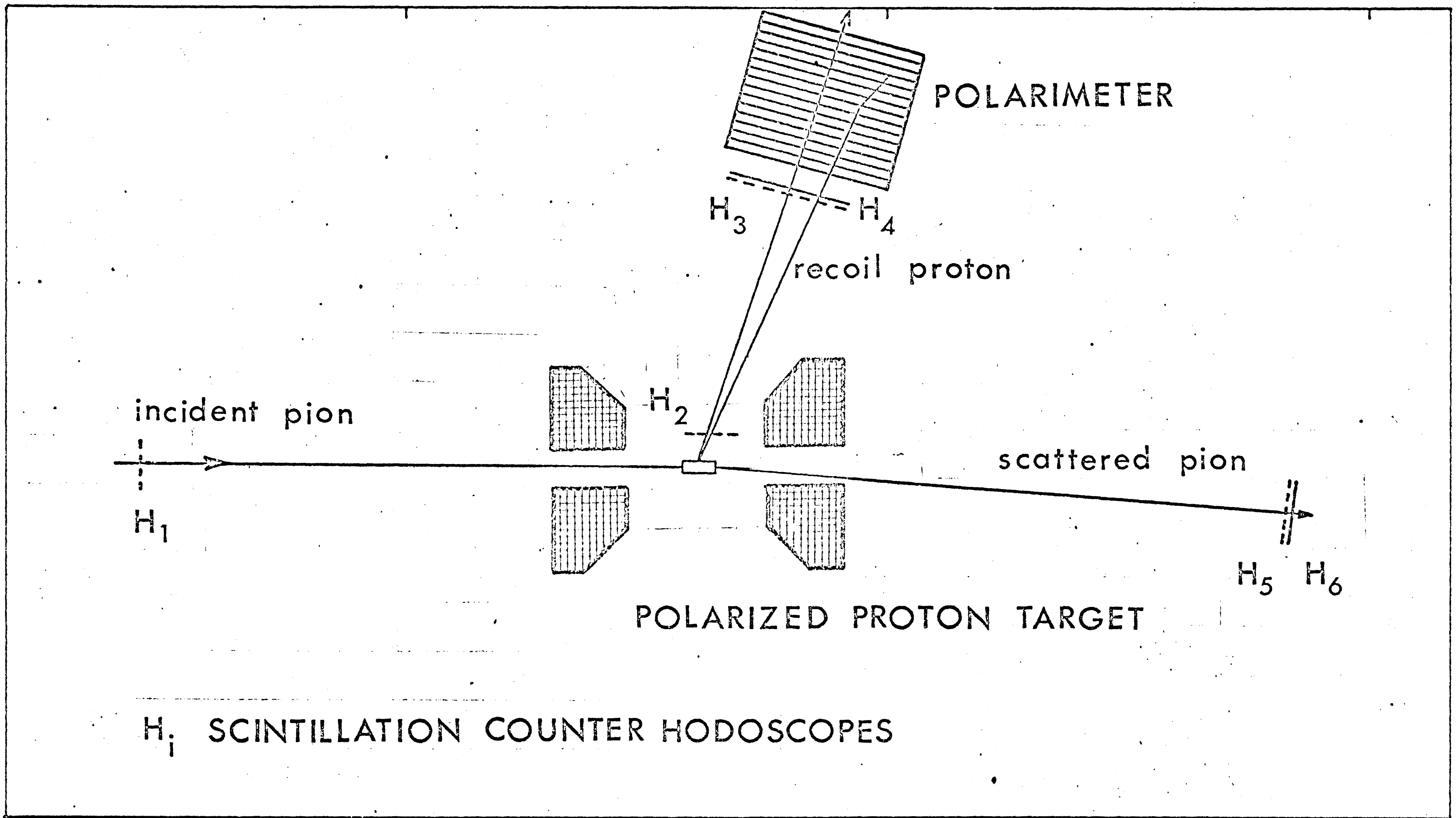

POLARIMETER
H3
H4
recoil proton
H2
incident pion
scattered pion
H1
H5
H6
POLARIZED PROTON TARGET
Hi SCINTILLATION COUNTER HODOSCOPES

FIGURE 2

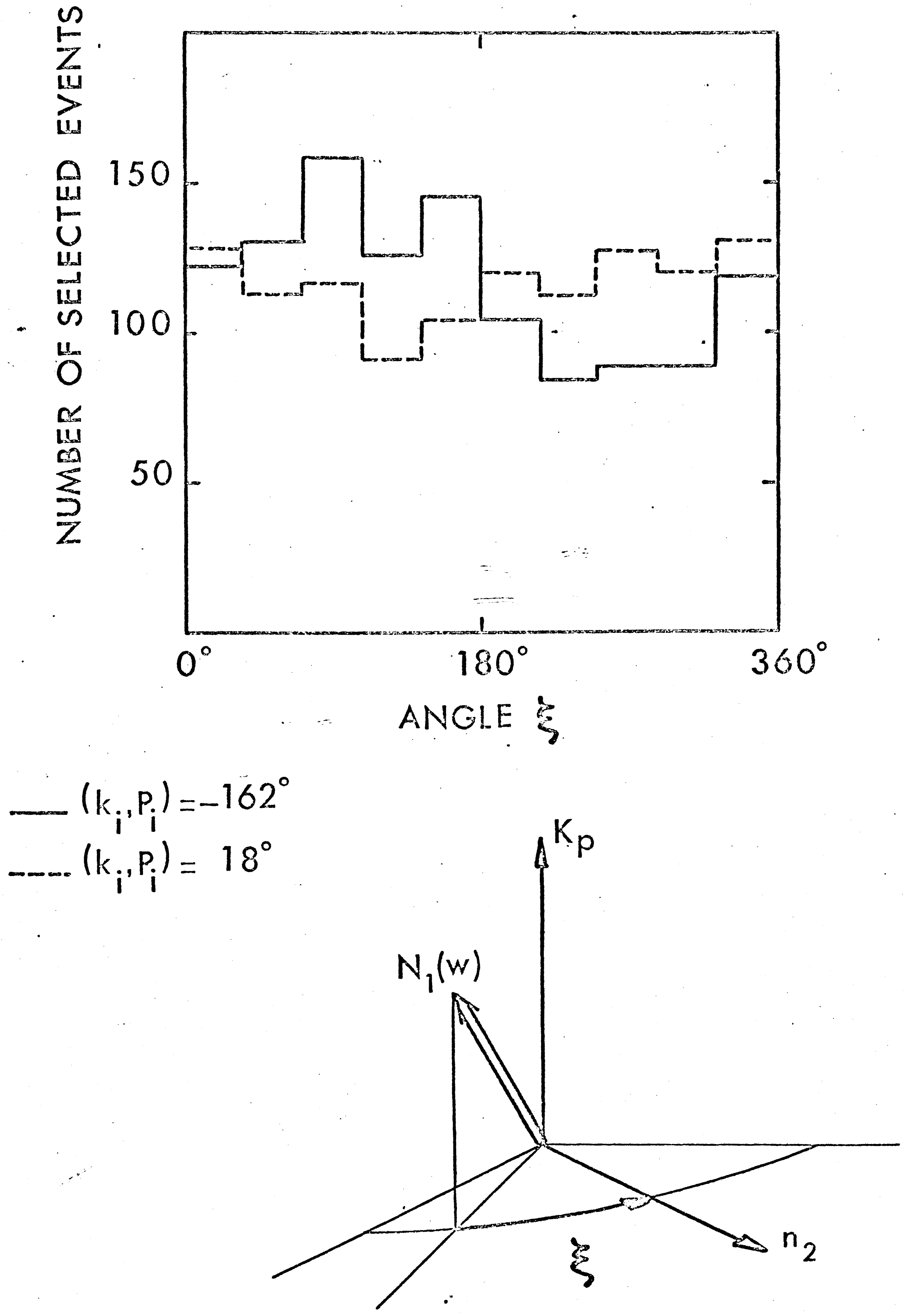

NUMBER OF SELECTED EVENTS
150
100
50
0°
180°
360°
ANGLE ξ
$(k_i, P_i) = -162°$
$(k_i, P_i) = 18°$
Kp
$N_1(w)$
$n_2$
ξ

FIGURE 3

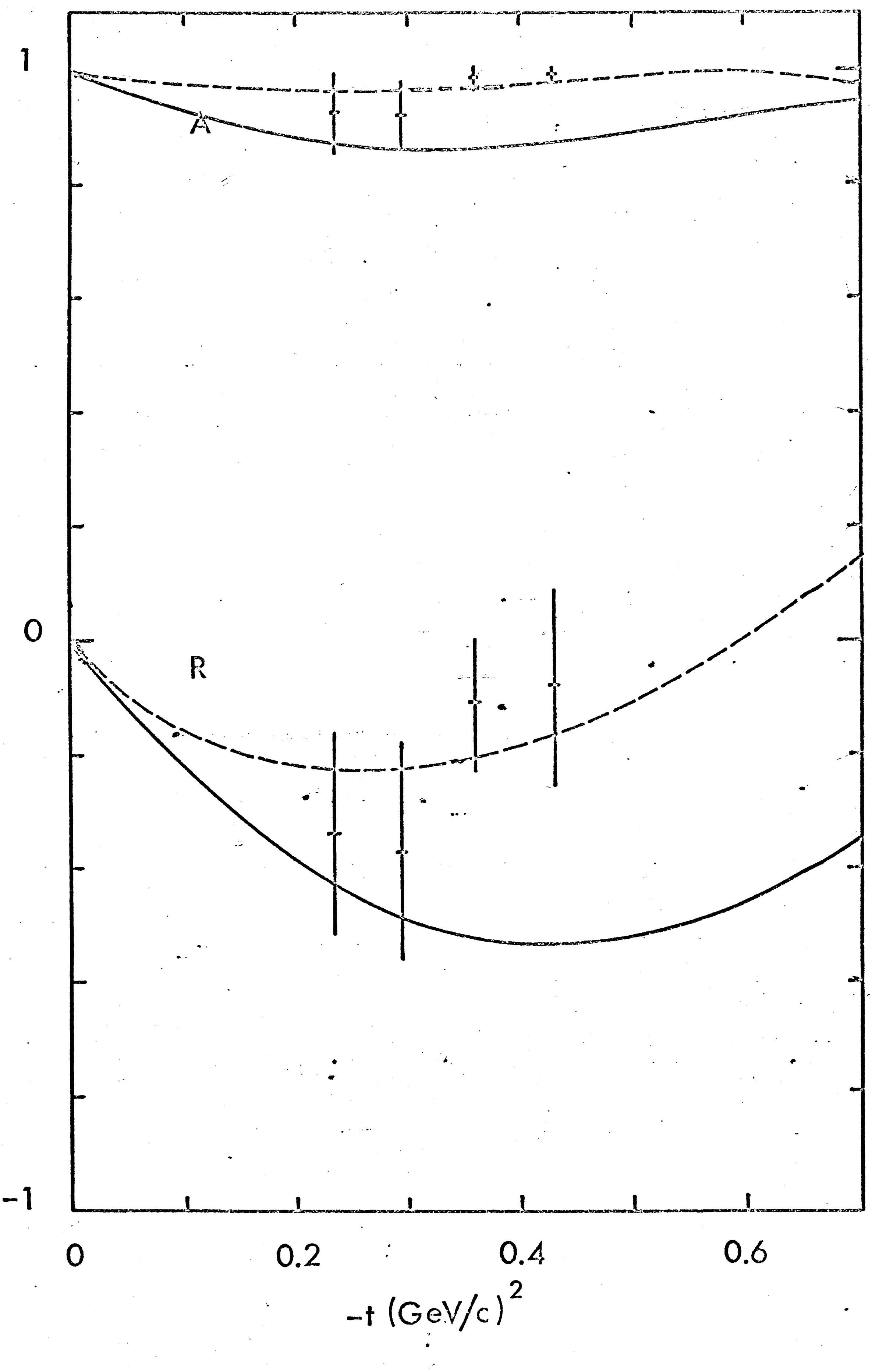



FIGURE 4