EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

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5 April, 1965

PROPOSAL FOR AN EXPERIMENTAL TEST OF TIME REVERSAL INVARIANCE IN LAMBDA DECAY

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RESUME

We propose to measure the β-parameter of the decay $\Lambda \to p + \pi^-$ to an accuracy which tests time reversal invarance to a higher precision than has been done in neutron decay. ($\Delta\beta \sim \pm 0.07$, corresponding to $\pm 6^\circ$ in the s-p phase difference). This is realized through a polarization analysis of the decay protons from polarized lambdas.

The apparatus consists of conventional scintillation counters, thin plate spark chambers, and a carbon plate spark chamber. Apart from an additional requirement on the trigger, which selects preferentially those events more useful for the determination of β, the experiment is similar to that of Cronin and Overseth.

To obtain the accuracy mentioned above, one needs to measure 5000 events for the determination of β and a similar number for calibrations and tests, all of which would be contained in approximately $3.5 \sim 10^5$ pictures if there is no major unforeseen background. To check estimates of the background, the first step will be a test with a part of the apparatus, which would be ready in three months. The total floor occupation needed is around $^3/_4$ year in a q-beam of which the actual data-taking time would be two weeks. The pictures will be made to be acceptable by Luciole, although the scanning and measuring is feasible on conventional scanning tables.

I. INTRODUCTION

The most general form for the effective Hamiltonian for the decay of the Λ into p and π^- is

$$H_I = (\bar{p}(A + B\gamma^5)\Lambda)\pi^+$$

in which A and B may be complex. The requirement of T invariance restricts the relative phase between A and B to an amount dictated by $\pi - p$ scattering. It is the purpose of the proposed experiment to measure this phase. The matrix element for the above process may be rewritten in terms of the more convenient quantities s and p, which signify the amount of s- and p - wave present. The quantities s and p are related through real constants to A and B. The parameters α, β and γ are related to s and p, and are given by

$$\alpha = 2\frac{\mathrm{Re}(s^* p)}{|s|^2 + |p|^2}$$

$$\beta = 2\frac{\mathrm{Im}(s^* p)}{|s|^2 + |p|^2}$$

$$\gamma = \frac{|s|^2 - |p|^2}{|s|^2 + |p|^2}$$

The polarization of the proton is specified by the quantities α, β, and γ :

$$\vec{\sigma}_p = [\ \vec{e}_q\,(\alpha + (1-\gamma)\ )\ \vec{\sigma}_\Lambda \cos\Theta + \gamma\,\vec{\sigma}_\Lambda + \beta\,(\vec{e}_q \times \vec{\sigma}_\Lambda)\ ]/\,\text{Norm.factor}$$

in which $\vec{\sigma}_\Lambda$ is the spin of the lambda and $\vec{e}_q$ is a vector in the direction of the momentum of the decay pion.

The measurement of β is the goal of this experiment. It is proportional to component of the transverse polarization of the proton in the Λ production plane. The best measurements of α, β, and γ were made by Cronin and Overseth[1], who obtained

$$\alpha = 0.62 \pm 0.07$$

$$\beta = 0.18 \pm 0.24$$

$$\gamma = 0.78 \pm 0.06 .$$

It should be noted that (assuming T invariance) the value of β from $\pi - p$ scattering data at 40 MeV is

$$\beta_{th} = - 0.08 \pm 0.1 .$$

A much more precise, but perhaps less reliable calculation of β can be made by extrapolating the data at 90 MeV, using dispersion theory. It seems feasible, however, to remeasure the $\pi - p$ phase shifts at 40 MeV to determine β_{th} to an accuracy of $\pm$ 0.01.[2]

II. PRINCIPLE OF THE EXPERIMENT

The polarization of the protons is to be measured by scattering on carbon. To obtain highest sensitivity to a transverse polarization, one must choose events in which a polarization which is transverse in the rest system of the Λ also appears as a transverse polarization in the laboratory. The component of the polarization which is proportional to β is maximum when the proton momentum is perpendicular to the Λ spin. For these two mesons, the most useful events for a determination of β are those in which the proton momentum is parallel or antiparallel to the Λ line of flight. For protons emitted parallel to the Λ line of flight, the decay pion goes backward in the laboratory system for Λ's with a momentum of less than 800 MeV/c.

This experiment is similar in many respects to that of CO, with the additional requirement of a particle emitted in the backward hemisphere. A sketch of the apparatus is shown in Fig. 1. The Λ's are produced in the target in the reaction

$$\pi^- + p \rightarrow \Lambda^o + K^o .$$

The Λ's decay in the chamber ahead of the target. The backward pions are detected in C_1, which is 1 cm thick. The pions from Λ decay will stop in this counter, and the anticoincidence counter A_1 is used to reduce background. The two proton counters C_2 and C_3 are separated by three carbon plates to reduce background from neutron stars and to inject low energy protons. The anticoincidence A_3 removes the background from K_{01} decay in which a low energy pion stops in C_1. The target consists of a block of scintillator T surrounded by an anticoincidence cup A_2. The trigger coincidence is therefore $(\bar{A}_1\ C_1\ T\ \bar{A}_2\ C_3\ C_4\ \bar{A}_3)$.

The selection of low momentum lambdas results in an anisotropic distribution of the lambdas in the production centre-of-mass system. This distribution has been determined with a Monte Carlo calculation (in which the production is assumed to be isotropic), and the results are shown in Fig.2. Since the distribution is peaked near $\cos\vartheta = -1$, it is suspected that the Λ polarization may differ from that measured by CO, who accepted all values of the production angle. For this reason, it will be essential to conduct a test of the Λ polarization early in the experiment and also to measure the polarization for the some events which are used to determine β. The former can be done with asymmetry measurements, while the latter can be done by measuring the component of proton polarization along the Λ^o spin, which provides a measurement of $(\gamma\ P_\Lambda)$.

III. APPARATUS

A. Target.

The target will consist of a cylindrical block of plastic scintillator 3 cm × 2 cm diameter. Pulse height analysis of ± 10% will allow a determination of the interaction point to ± 3 mm. The polarization of the lambdas produced in plastic scintillator is expected to be about 10% lower than for those produced in polyethylene, of which the target of CO was made. If this is a problem, or if the pulse height analysis appears to be difficult, we could replace the scintillator with blocks of polyethylene sandwidched between thin scintillation counters. Since the kinematical reconstruction will be done with a one-constraint fit, the determination of the interaction point is probably not crucial.

B. Counters and Electronics

The counters needed for the proposed experiment are the following:

1) three scintillators 1 m × 1 m × 1 cm

2) one scintillator 3 mm × 12 cm diameter

3) one scintillator 3 mm × 16 cm diameter

4) target of scintillator and anticoincidence cup.

The electronics needed for the logic would be standard fast CERN circuitry.

C. Spark chambers

The spark chambers needed for the experiment consist of the following:

1) one thin plate chamber, 10 cm × 60 cm × 60 cm, consisting of twelve gaps

2) one thin plate chamber 3.2 cm × 1 m × 1 m, consisting of four gaps

3) beam chambers of small dimensions

4) one carbon plate spark chamber 1 m × 1 m × 60 cm, consisting of thirty gaps and thirty carbon plates 1 cm thick.

IV. EXPECTED RESULTS

A. Rate of Events

The calculation of the rate of events and the fraction of the transverse polarization which remains transverse has been calculated, using Monte Carlo generated events. The kinetic energy of the backward pion is, on the average, 8 MeV, and therefore we have demanded that for each accepted event, the pion must first traverse the material between the lambda vertex and the scintillation counter and have a residual kinetic energy of 2 MeV. The material through which the pion must pass is three mylar windows 0.2 mm thick, aluminium spark chamber plates 25 μ thick, a few centimetres of air, and a light shield on C_1 (10 μ of aluminium). About half of pions stop before the counter. The residual kinetic energy of the pions which reach the counter is plotted in Fig. 3 .

The probability for a proton to scatter in the carbon plate chamber was 2% for CO. A rough calculation of this quantity using the kinetic energy spectrum of the protons of the accepted events (see Fig. 4) leads us to expect a scattering probability of 1.8% . We assume the analysing power for these protons will be the same as that given by CO, since our proton kinetic energy spectrum is contained in the spectrum of CO.

The rate of triggers for good events is calculated to be :

$$\text{trigger rate} = 0.95 / \text{burst}$$

assuming a beam of 3×10^5 pions of 1 GeV/c momentum per burst. We wish to obtain 5000 pictures containing useful scatterings, so apart from background pictures, we will need to take 280,000 pictures.

B. Background

The rate given above corresponds to one trigger per 3×10^5 incident pions. In the experiment of CO, the corresponding number was one trigger per 1.8×10^4 pions, three out of four pictures did not contain lambdas. We have analysed the background of CO and have concluded that it will contribute negligibly to our picture taking rate. Two additional sources of background have been found :

1) Decays of the backward π^- in flight. This will happen in about 10% of the cases, and about half of these events will still be useful.

2) Neutrons produced in the target may produce stars in the carbon plates which satisfy the other trigger requirements. This is a difficult background to estimate, and we wish to test for this with a set-up involving counters and one spark chamber.

C. Sensitivity of the Experiment

The improvement in sensitivity of this experiment to that of CO is illustrated in Fig. 5, in which is plotted the distribution of the fraction of the transverse polarization of the proton in the production plane which remains transverse in the laboratory. The mean r.m.s. value of this quantity is for the events of CO, 0.030, unlike for this experiment, it is 0.0513. This ratio enters linearly in the error on β .

D. Expected Error on β

Using likelihood function estimates, we have calculated the error on β to be

$$\delta\beta = \pm 0.07,$$

corresponding to a s - p phase difference of

$$\delta\varphi = \pm 6^{\circ} .$$

We have assumed the same analysing power and lambda polarization as given in CO. A check was made on the method of estimation by calculating the error given by CO, and perfect agreement was found.

This error corresponds to a measurement of an asymmetry to a precision of ± 1.2%. It does not seem likely that systematic effects will introduce errors comparable to the statistical error. In the experiment of CO , the asymmetry was measured to an accuracy of ± 1.8% in the measurement of α . This experiment is at present being improved by increasing the number of pictures by a factor of 4.

PS/4855/kl.

V. SUMMARY

For this experiment, the beam needed is an 1 GeV/c pion beam of intensity 3×10^5/burst. The first step in the experiment will be to test the set-up in the beam for background problems and to measure the polarization of the lambdas produced at large production angles with plastic scintillator as a target. We estimate that the floor occupation time will be roughtly $^3/_4$ year. The data handling problem will not be serious, since the pictures can be scanned rapidly. The pictures will contain the necessary requirements for measuring on Luciole, but it is entirely feasible to measure them on conventional scanning tables.

REFERENCES

1) J.W. Cronin and O.E. Overseth, Phys.Rev. 129, 1795 (1965), hereafter referred to as CO.

2) D. Amati, private communication.

FIGURE CAPTIONS

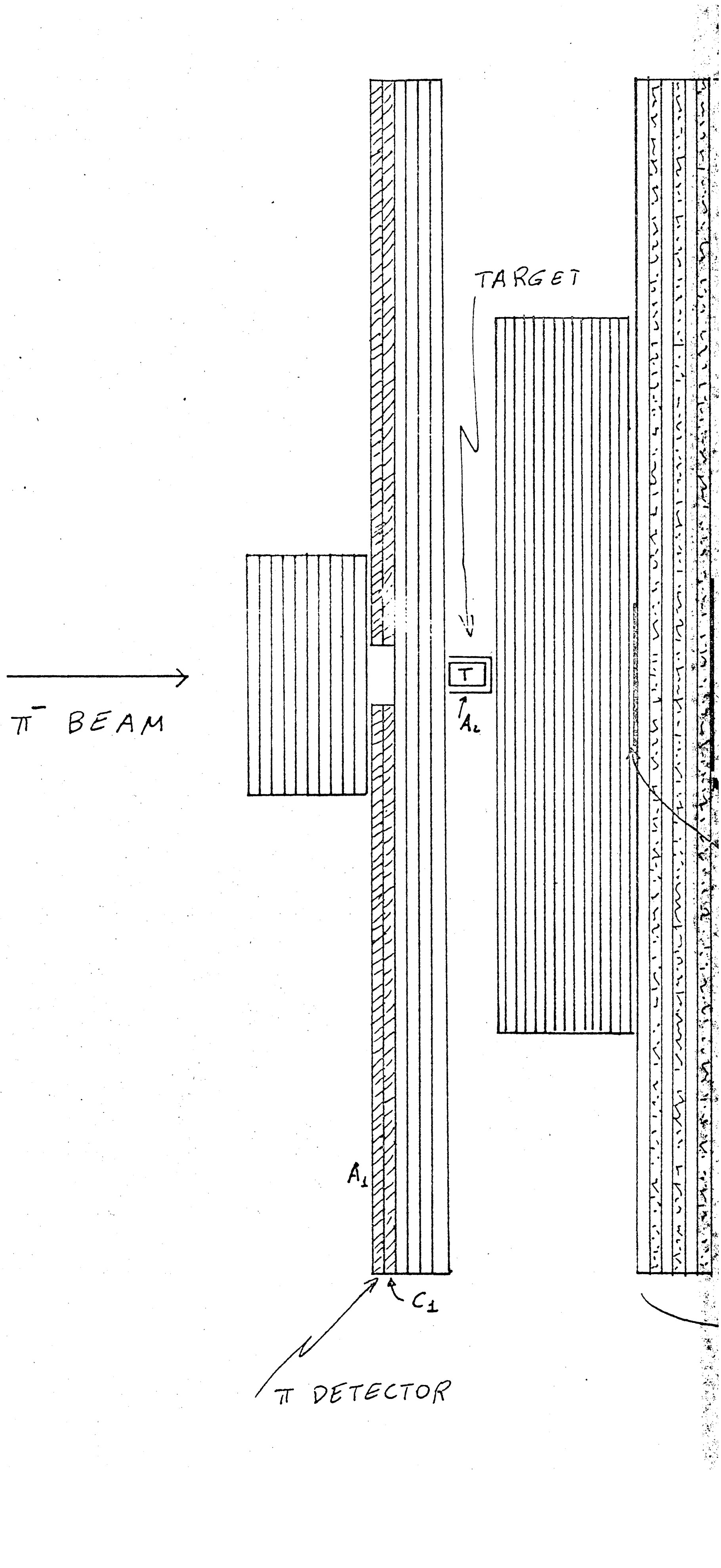
Fig. 1 : Experimental set-up .

Fig. 2 : Lambda angular distribution in the production centre-of-mass system for events accepted by this apparatus.

Fig. 3 : Residual kinetic energy of the pions from lambda decay that reach the backward counter.

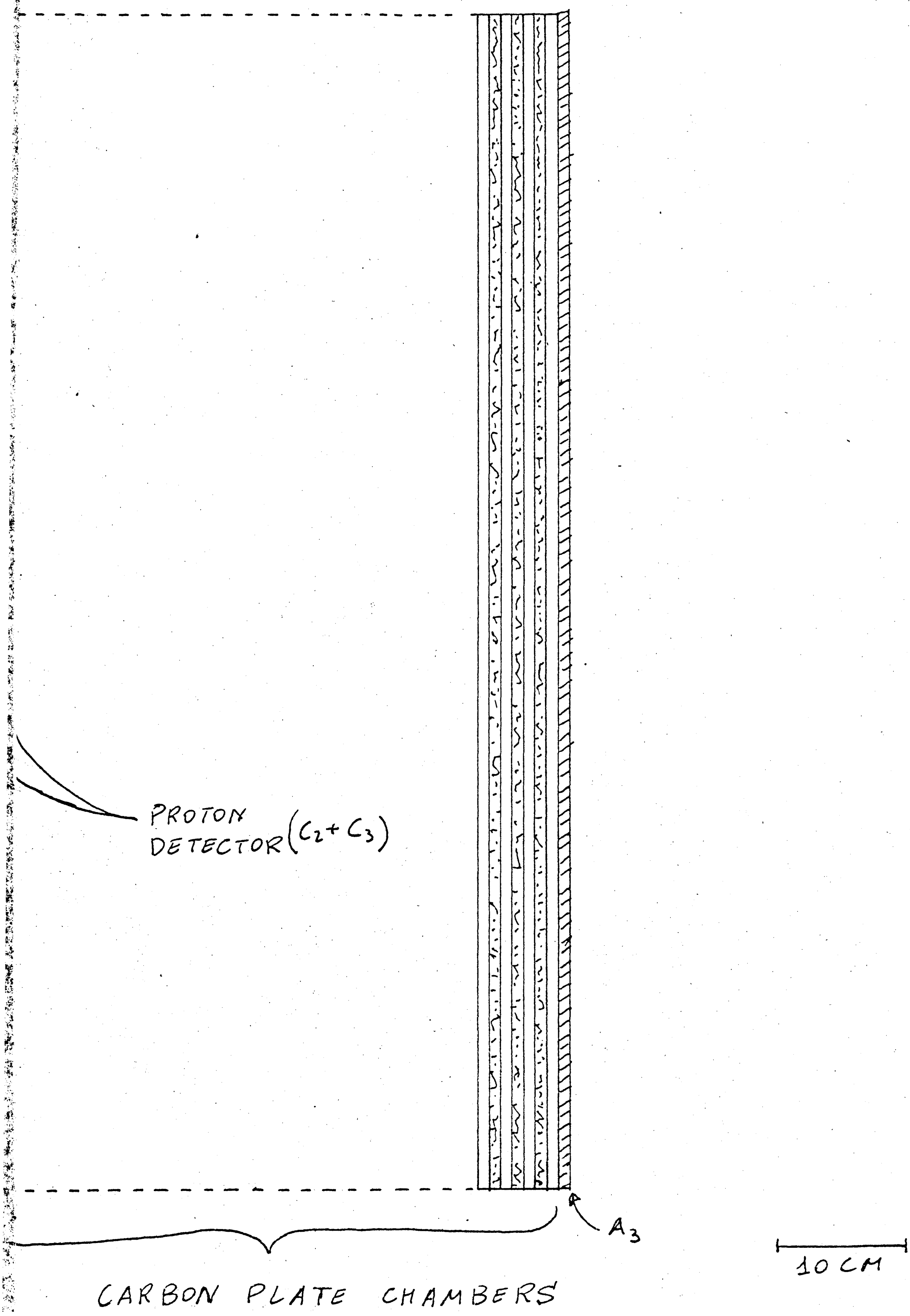
Fig. 4 : Kinetic energy spectrum of the protons for the events accepted by this apparatus.

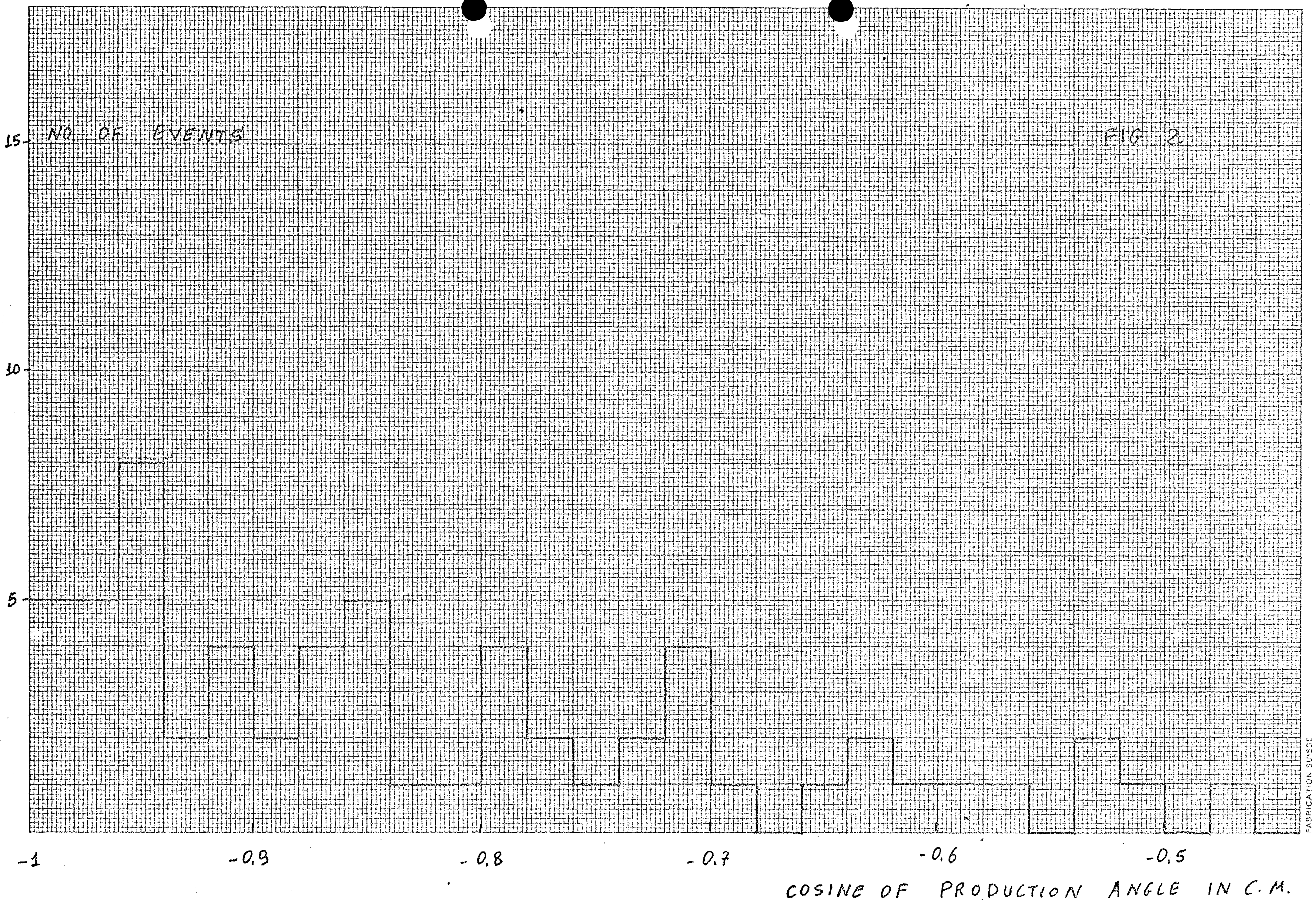
Fig. 5 : Fraction of the proton transverse polarization in the production plane which remains transverse in the laboratory.



TARGET
T
A2
π⁻ BEAM
A1
C1
π DETECTOR

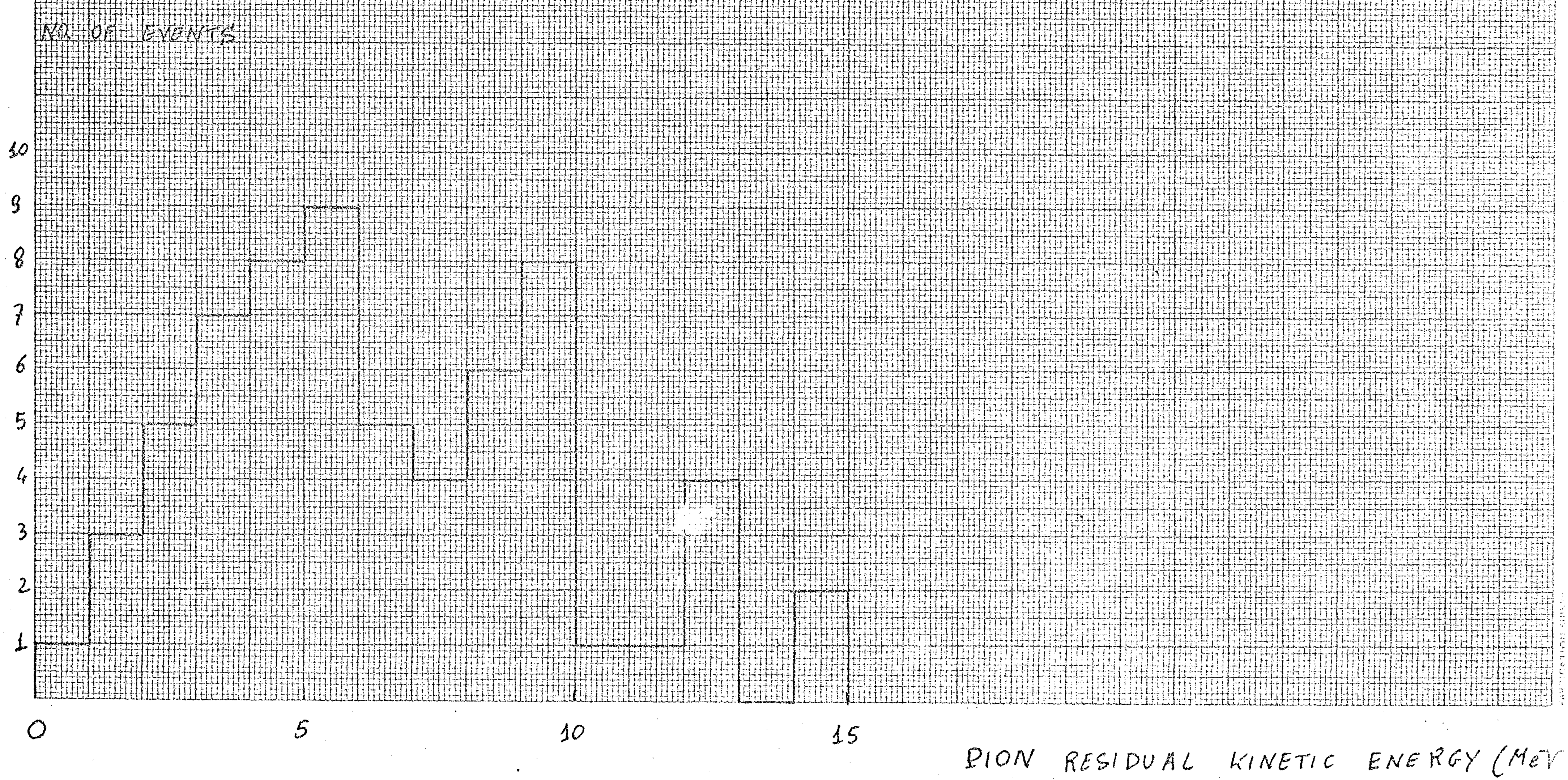
FIG. 1



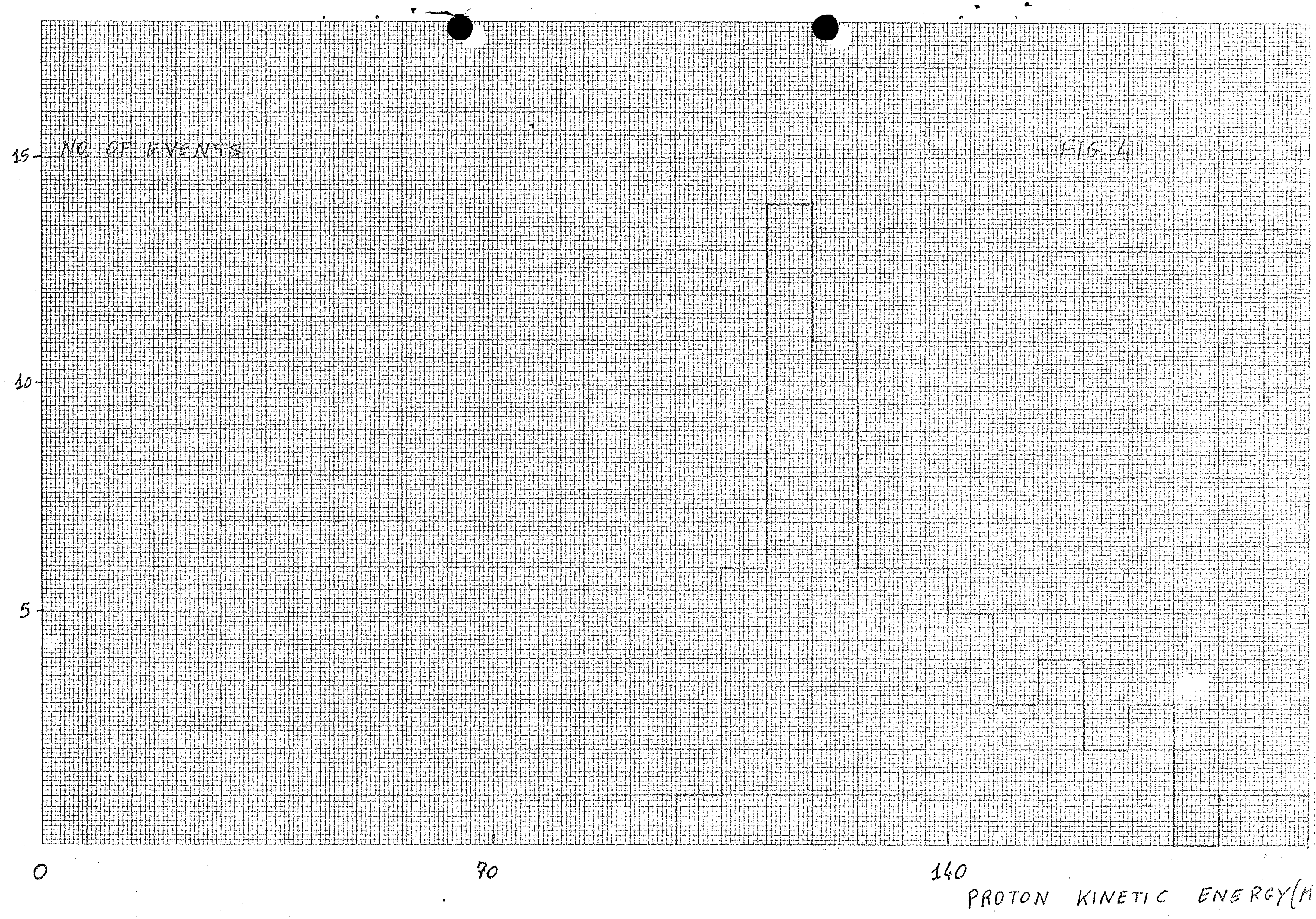


NO. OF EVENTS
FIG. 2
15
10
5
-1
-0.9
-0.8
-0.7
-0.6
-0.5
COSINE OF PRODUCTION ANGLE IN C.M.
FABRICATION SUISSE

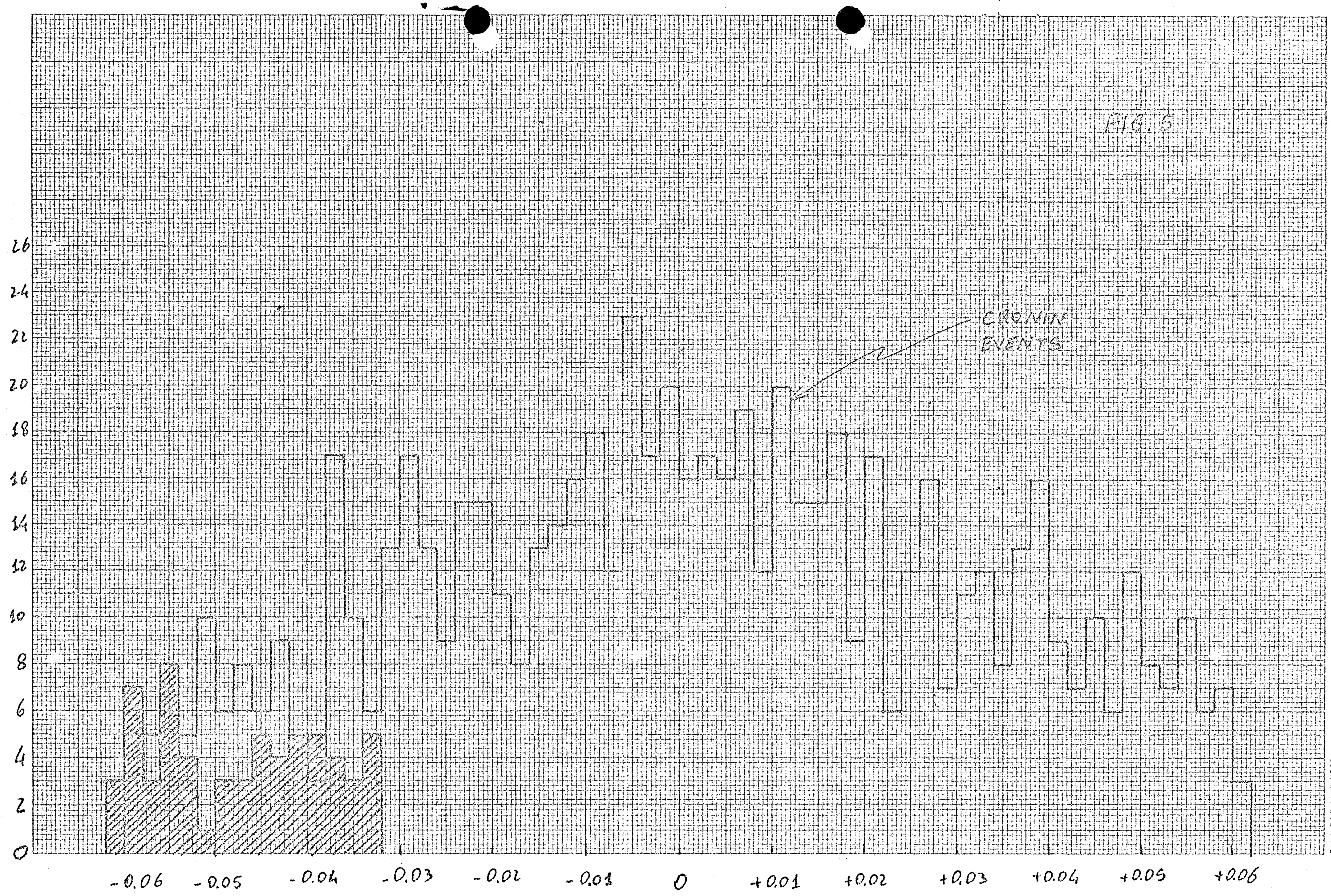
FIG 3



NO OF EVENTS
10
9
8
7
6
5
4
3
2
1
0
5
10
15
PION RESIDUAL KINETIC ENERGY (MeV



NO. OF EVENTS
FIG. 4
15
10
5
0
70
140
PROTON KINETIC ENERGY(M



CONTRIBUTION OF β TO THE TRANSVERSE POLARIZATION OF THE PROTON ($\beta = -0.08$)

FABRICATION SUISSE