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PHYSICS I

ELECTRONICS EXPERIMENTS COMMITTEE

PROPOSAL

STUDY OF BARYONIC EXCHANGES WITH Ω APPARATUS

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Our aim is to study with the Omega the reactions $\pi^\pm$, $K^\pm$, $\bar{p}$-proton in which a fast proton is emitted forward. The trigger of the Ω optical chambers would be done using this proton alone. Such a trigger implies a fast analysis of momentum and the identification of the proton. It is selective and allows satisfactory use of the large solid angle offered by the Ω magnet. We are mainly interested by quasi-two-body reactions proceeding through baryon exchange mechanism: in such reactions a baryon (proton, hyperon, resonance) is emitted forward and its decay provides the fast proton required to trigger the chambers. The large Ω apparatus allows the detection and momentum analysis, with minimal biases, of all charged particles coming from the decay of both the baryon and the associated meson or antibaryon. Furthermore, we think that the reactions leading to a fast nucleon without being quasi-two-body are nevertheless very interesting and must not be considered as mere background.

1. KINEMATICS AND CHOICE OF THE TRIGGER ACCEPTANCE

Two factors govern the emission angle and momentum of the fast proton: firstly the quadritransfer $\sqrt{u}$ given to the baryon in the quasi-two-body reaction, secondly the parameters of its decay. The emission angle of the proton is always close to the baryon angle: for instance at 10 GeV/c there is at most 1.4° between a Σ^+ and its decay proton. So the maximum angular acceptance needed is given by the maximum transfer momentum required. $\sqrt{u}$ goes like $\sim p_{inc}\ \theta$.

If u_{max} is fixed by physical considerations, then the angular acceptance is determined by the lowest incident momentum which will be used.

In order to describe the backward peaks down to p_{inc} = 7 GeV/c, we adopt $|u_{max}|$ (7 GeV/c) $\sim$ 1(GeV/c)^2: this requires an angular acceptance of 0.143 rad or 8.1°. $|u_{max}|$ increases like $(p_{inc}/7)^2$.

Figure 1 shows, for several reactions, the minimum proton momentum one must accept to be able to detect in any case the proton from the baryon, within the previously defined angular limit. These reactions can be classified according to the momentum acceptance they require: this is done in Table 1 and one can see that an acceptance

(p_{inc}, 0.5 p_{inc}) allows the study of the four groups of reactions which have been distinguished. One can also see that if one wants to isolate, say, the reactions of group 1, a good resolution of a few per cent is required from the fast momentum analysis. We shall make this statement more precise below.

Within these kinematical limits we must identify the proton among a fairly large number of energetic π and K. This will be achieved by Čerenkov effect. Details are given in Section 3.

2. THE INTEREST OF THESE PHYSICS

The trigger parameters being now determined, we may look at the physics offered by such a trigger. We shall retain the following points:

a) Among the reactions of group 1 a limiting case is backward elastic scattering. In two cases (K^- and $\bar{p}$) this reaction is, in principle, forbidden. Nevertheless it has been observed very clearly with 5 GeV/c K^- [1]. It will be interesting to follow the evolution of this cross-section as a function of energy. However, for these reactions, the luminosity of the proposed apparatus in Ω will be of the same order as the one we have now in our present design[1], i.e. insufficient if the cross-sections decrease quickly as a function of energy.

b) In the same group, the backward production of ρ, A_2, R has already been measured[2] but the decay of the meson was not observed. Some predictions on its density matrix elements have been proposed[3]. Their experimental determination would be very useful to determine the properties of baryonic trajectories.

c) When both the meson and the baryon have non-zero spin and are unstable ($\pi^- p \to \Lambda^0 K^{*0}$, $N^{*0} \rho^0$, etc.) the measurement of both polarizations is very interesting. In particular one could test some hypothesis according to which combinations of density matrix elements could be oscillating functions of the incident energy[4].

d) Many tests of internal symmetries are possible. For instance, SU_3 predicts the equality of backward cross-sections for $K^- p \to \Sigma^+ \pi^-$ and $\pi^- p \to p \pi^-$. SU_6 predicts that the reaction $K^- p \to \Lambda\phi$ cannot occur in backward direction, etc.

e) It has been argued[5] that exotic mesons, if any, should be preferentially produced in reactions proceeding through an allowed baryonic exchange. The backward reactions

$$\pi^+ p \to \Lambda^0 M^{++}_{strange}$$

$$\to N^{*0} M^{++}$$

are examples of such processes.

3. DETAILS OF THE TRIGGER

a) We think that the magnetic field of the Ω magnet is reasonably used if it gives a deflection of $\sim$ 100 mrad to the particles of momentum p_{inc}. This requires the maximum possible field for $p_{inc} \sim 16$ GeV/c, with the geometry shown in Fig. 2. Then the particles of momentum 0.5 p_{inc} are deflected by 200 mrad.

Another possibility which consists in using the maximum field at any incident momentum, will also be considered.

b) The fast momentum analysis. This will consist of two planes of proportional wires located at the end of Ω spark chambers and about 2 m apart from each other (Fig. 2). The principle of the analysis is simple: a particle emitted from a given point of the target and crossing H_1 in a point M of abscissa x hits H_2 in different points according to its momentum. The desired momentum range determines in H_2 a segment $M'M''$. The selection is made by asking a fast coincidence between the point M and the segment $M'M''$.

With the geometry proposed in Fig. 2 we have between H_1 and H_2 abscissae the approximate relation:

$$y = 1.8\,x + 1.25\,\delta\ , \qquad x,y \text{ in m}\ , \qquad \delta \text{ in rad.}$$

where $\delta(p)$ is the deflection angle in the magnet. This formula shows that, for a given value of x and $\delta = 0.15$, the position of arrival in H_2, y, changes by 1.9 mm when the momentum is varied by one per cent.

Obviously the ideal case described above is an approximation because of:

i) The length of the target: with the deflection we have chosen and tor $x = 0.35$ m, a point close to the middle of H_1, a target length of 1 cm is equivalent to an uncertainty of 1% on the momentum. So a target of 20 cm forbids a momentum resolution at the stage of the fast analysis better than ±10%. The resolution is obviously improved when one goes closer to the beam line.

ii) The diameter of the beam: a 1 cm radius is equivalent to an uncertainty of ±3% on the momentum. We need a well focused beam.

iii) The finite size of "counters" in H_1 and H_2: with a wire spacing of 2 mm, this uncertainty is smaller than the previous ones.

iv) The flight of hyperons: in such a case the proton is not emitted from the target. A 10 GeV Λ^0 has a decay length of ∿ 70 cm. The main effect is that the proton sees a shorter length of magnetic field and appears as being more energetic.

So we would say that without any special care and with a 20 cm H_2 target the momentum resolution of the fast analysis is limited to ±13% if we are far from the beam line. This resolution is improved at smaller angles. The momentum resolution can be improved by using a smaller target, a narrower beam, and, at low momenta, by increasing the deflection in the magnet above the adopted values. This last possibility would require a lateral move of H_1, H_2, and the Čerenkov counters and ask for a larger angular acceptance of these counters. Obviously this lack of resolution is only at the trigger stage: a posteriori measurements will reduce it to ∿ 0.40%, thus giving very good missing-mass determinations.

The logic of coincidence between H_1 and H_2 is now under study. The examination of Figs. 2 and 3 show that H_1 and H_2 would be made of ∿ 400 and ∿ 800 wires, respectively. A 400 × 800 matrix seems cumbersome and costly. One can probably use the fact that it is only used in a quasi-diagonal way to limit oneself to a single smaller matrix 56 × 56. Such a 56 × 56 matrix has already been built and will be operated in our next experiment.

c) The identification of the proton. This will be identified by an absence of signal in gas Čerenkov counters. In particular we found it necessary to distinguish between K and p. One would desire that the momentum selection ($p > p_0/2$) and the selection by Čerenkov effect (the kaon giving a signal and not the proton) could complement one another: so one asks that the threshold of Cerenkov effect for K be reached at $p_0/2$. This implies a high pressure Čerenkov counter called C_1.

The most favourable gas is freon 13 B1 (CF_3Br) which can be used up to 12 atm at 20°: in such conditions the threshold for kaons is 3.5 GeV/c and a 4 GeV/c kaon gives 160 γ *) on a length of 1.5 m, which is still usable. This means that down to $p_{inc} \sim 8$ GeV/c both selections are complementary. Under 8 GeV/c there will exist a range of momentum for which the kaons are not rejected.

Roughly speaking the numbers of fast π/K/p will be like 1000/100/1. To get in the trigger an equal number of π, K and p we need a rejection of 99.9% of the pions and a rejection of 99% of the kaons. To build a counter achieving 99.9% rejection is a difficult task[6] and a failure is possible, but 99% is certainly feasible.

A better solution for the π is to use two Čerenkov counters: an uncorrelated lack of efficiency of 3% in each would still allow the required rejection. This possible scheme is shown in Fig. 2. A high pressure Čerenkov counter C_1 is set between H_1 and H_2 as close as possible from the target. The pressure vessel is a truncated cone of $d_1 = 1.5$ m, $d_2 = 1$ m and $\ell = 2$ m. The total quantity of matter introduced along the particle path can be less than 10% of an interaction length for hadrons.

In order to detect correctly π and K between p_{inc} and $p_{inc}/2$ the optical acceptance **) of this counter must be large ($\sim \pm 150$ mrad). One can find in literature[7] the description and performances of such a big counter achieving a still larger acceptance with 99% efficiency. The size of this counter is such that a 0.5 geometrical acceptance is a achieved up to a production angle of 8° if the deflection for top momentum

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*) We used: $dn_\gamma = 500 \sin^2 \theta \, dx_{cm}$.

**) By optical acceptance we mean the angular range of light rays impinging on a point of the mirrors and being transmitted to photomultipliers.

p_{inc} is maintained to 100 mrad. Buf if the deflection is increased one can see in Fig. 3 that this is no more true: the geometrical acceptance is smaller, but still quite acceptable.

A problem arises from the pions emitted by hyperons or N^*: if they cross the Čerenkov counter they can suppress interesting events. One can see from Fig. 2 that negative pions are not dangerous in this respect if some shielding (a few W or U blocks) is set at 1.5 or 2 m from the target outside from the proton channel. But positive pions (from N^{*++} for instance) require an optical division of C_1 in two parts: roughly, if the proton crosses part I the pion can only be in part II and if the proton crosses part II the pion cannot cross the Cerenkov counter.

Each of the four cells of C_1 (we also divide it in the vertical plane) will be of the focusing type with a single mirror. Appropriate light funnels[8)] will allow to remove the photomultipliers far from the horizontal median plane, in a region where the fringing field is low and can be compensated by coils.

Delta-rays from protons may cause a loss of a few per cent of good events, but this effect will probably be greatly reduced by the strong fringing field.

Another very large Čerenkov counter C_2 of the focusing type working at atmospheric pressure, will be set after H_2.

If the inefficiency of the Čerenkov counters leaves a noticeable contamination by events with a fast π or K, then the off-line analysis will certainly permit to sort them out at least in the class of interactions with no neutral particle production.

d) The detection of decay products. The chambers located in the Ω magnet should allow the detection of all charged particles. The particles coming from the baryon are always emitted at forward angles (4.6°_{max} between the Λ and its decay π at 10 GeV/c). They will be well analysed by the Ω magnetic field and well seen in the forward chambers perpendicular to the beam.

For the decay products of the backward meson, the situation is less clear: at $u \sim 0$, the meson can be considered as being at rest, its decay is isotropic; but at $u \sim u_{max} \sim 1$ GeV/c, the meson and products are emitted preferentially at large angles with respect to the beam line, and in spite of the curvature of their trajectories in the magnetic field, chambers parallel to the beam are preferable near the target.

Detailed computations are being made on this problem. Whatever the configuration of optical chambers, there is a dead angle around the direction of the magnetic field, leading to a loss of at least one third of azimuthal acceptance: this problem can be solved by using solenoidal digitized chambers around the target.

4. COUNTING RATE AND PROPOSED EXPERIMENT

With a H_2 target of 20 cm, $5 10^5$ particles in the beam, an acceptance of 0.5, we get 0.2 interaction per μb per burst. In Fig. 4 one can see the cross-section for reactions initiated by 11 GeV/c π^- and giving a forward proton of momentum $\geq p$, as obtained from bubble chamber data on 2, 4, and 6 prong events[9]. If, with incident π^-, all protons are detected down to $p_{inc}/2$ we get a cross-section of 250 μb corresponding to 50 triggers per burst. This is 10 times too much for the optical phase of Ω apparatus. This could be nearly registered with the plombicon device if its dead time is ~ 7 msec. Among these events only a few per cent are quasi-two-body reactions. From the same bubble chamber data one can see that the quasi-totality of these fast protons are emitted at very small angles (< 20 mrad for 11 GeV/c π^-). So we propose the following:

1) For incident K^- and $\bar{p}$ (say 2% of the negative beam) or incident K^+ we retain this type of trigger with a wide range of momentum (down to $p_{inc}/2$). So we register data on backward reactions induced by K and $\bar{p}$ in a way which can be considered as intermediate between the global registering of a bubble chamber and the precise trigger of a specific electronic experiment. We would say that such a trigger will give us ~ 1 trigger per burst.

2) For incident $\pi^{\pm}$ we avoid the very small angle region ($\lesssim$ 20 mrad) in normal conditions of run and we try to keep the previous triggering mode. A short period of run could be devoted to the small angle region. If it is still too much one can think of more specific triggers for the π:

a) by decreasing the momentum acceptance: for instance the interval (p_0, p_0 - 15%) includes the reactions

$$\pi^{\pm}p \rightarrow X^{\pm}p$$

where

$$X = \pi, \rho, A_2 \ldots .$$

b) by adding a small veto counter after the target to trigger only on a forward Λ (class 2). In fact such a trigger is simpler and does not require complicated equipment as the pressure Cerenkov counter and the wire planes. It can be considered as a safety trigger and is proposed elsewhere[10].

c) To decrease the rate of protons from non quasi-two-body reactions a possible way may consist in a fast estimation of the event multiplicity with proportional chambers, using, for instance, a cylindrical proportional chamber with wires parallel to the beam, around the target, and a plane of wires downstream. All events considered above lead to $n \leq 4$ charged particles in the final state and can be separated from higher multiplicities.

Even with a high rejection by the two Čerenkov and good performances of the momentum analysis device, the domain of physics envisaged here requires that we handle a very large amount of data. If we saturate the Ω capacity -- with the plombicon read-out system -- the number of triggers for 14 days of run will reach several million; we believe that we can cope with this load.

Table 1

I	$\pi^{\pm}p \to \pi^{\pm}p$ $\rho^{\pm}p$ $A_2^{\pm}p$ ⋮	$K^+p \to K^+p$ $K^{*+}p$ $\{K^-p \to K^-p\}$ $\{\quad \to K^{*-}p\}$	$\{\bar{p}p \to \bar{p}p\}$
II	$\pi^-p \to K^0\Lambda$ $K^{*0}\Lambda$ $\{\pi^+p \to M^{++}_{st}\Lambda\}$	$K^-p \to M^0\Lambda^0$	$\{\bar{p}p \to \bar{\Lambda}\Lambda\}$
III	$\pi^+p \to K^+\Sigma^+$ $K^*\Sigma$ KY^* ...	$K^-p \to \pi^-\Sigma^+$ π^-Y^{*+}	$\{\bar{p}p \to \overline{\Sigma^+}\Sigma^+\}$
IV	$\pi^-p \to M^0N^{*0}$ $\{\pi^+p \to M^{++}N^{*0}\}$ $\pi^+p \to M^0N^{*++}$ where $M^0 = \pi^0, \rho^0, \omega^0, (\phi)$	$\{K^-p \to \bar{K}^0N^{*0}\}$ $K^+p \to K^0N^{*++}$	$\{\bar{p}p \to \bar{N}^*p\}$

Exotic reactions are within brackets.

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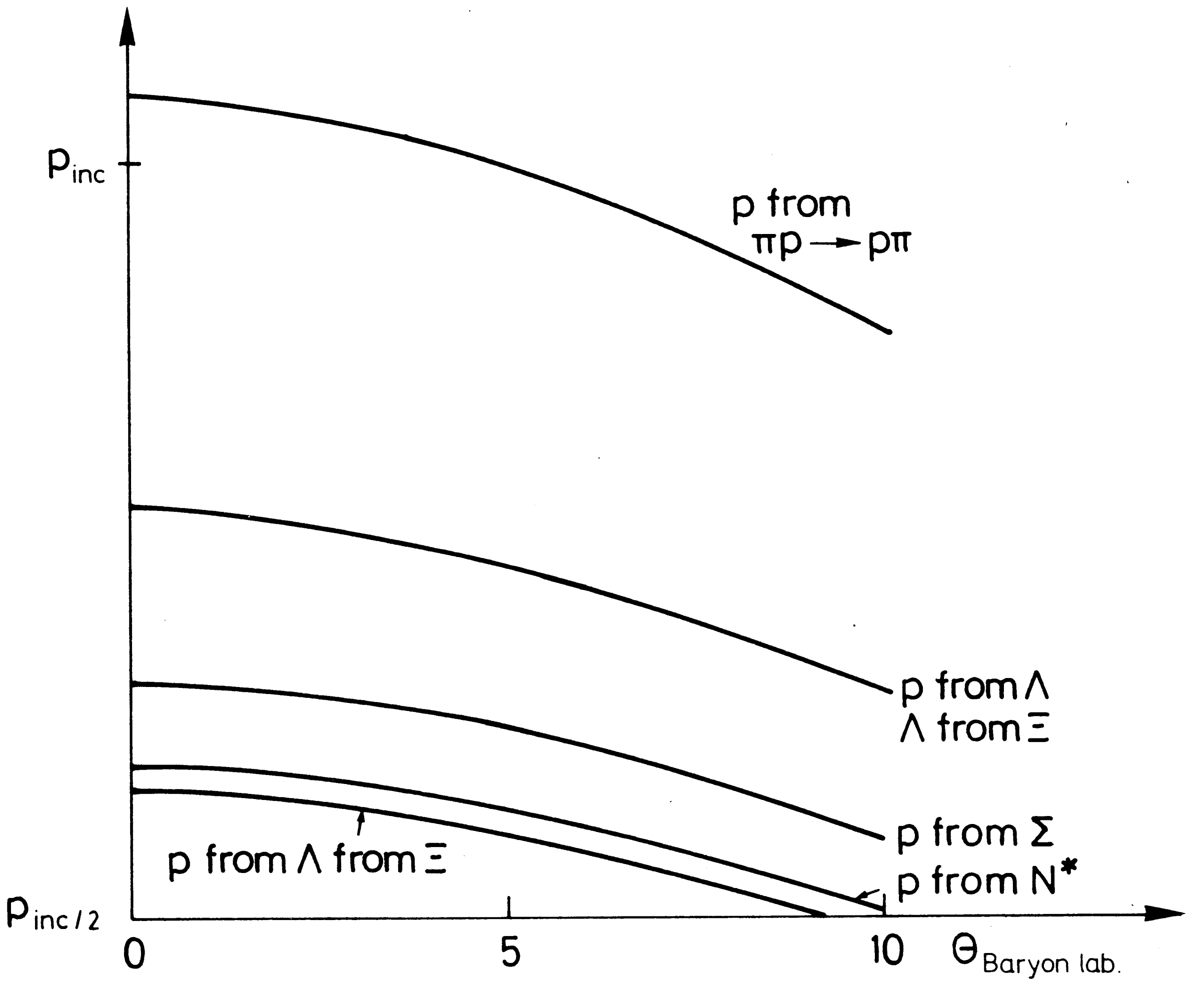
6) A. Muller, private communication.

7) H. Hinterberger et al., Rev. Sci. Instrum. 41, 413 (1970).

8) H. Hinterberger and R. Winston, Rev. Sci. Instrum. 37, 1094 (1966).

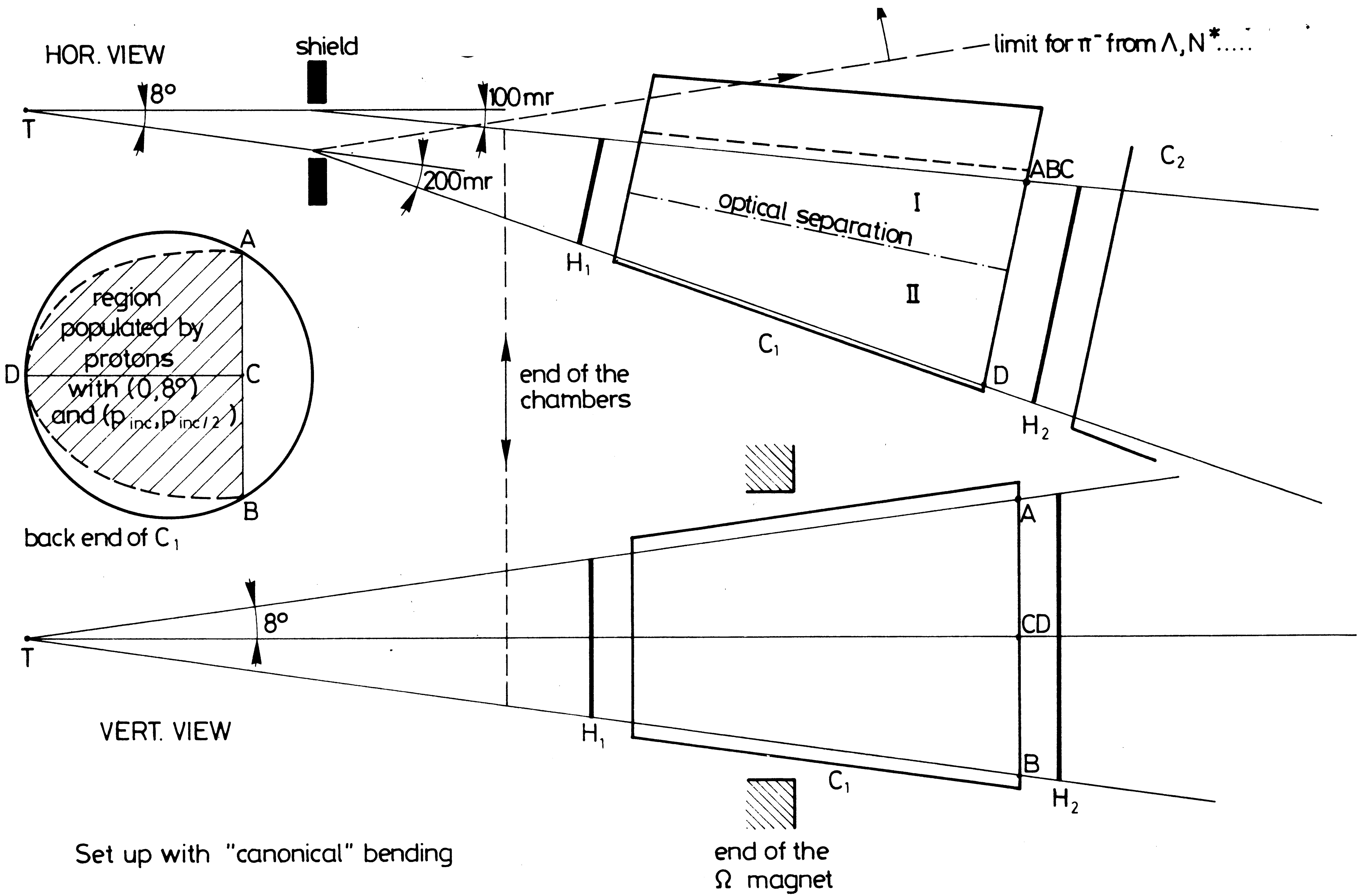
9) We thank Dr. H. Grote for communicating these results.

10) Proposal of a trigger on fast Λ for the Omega.



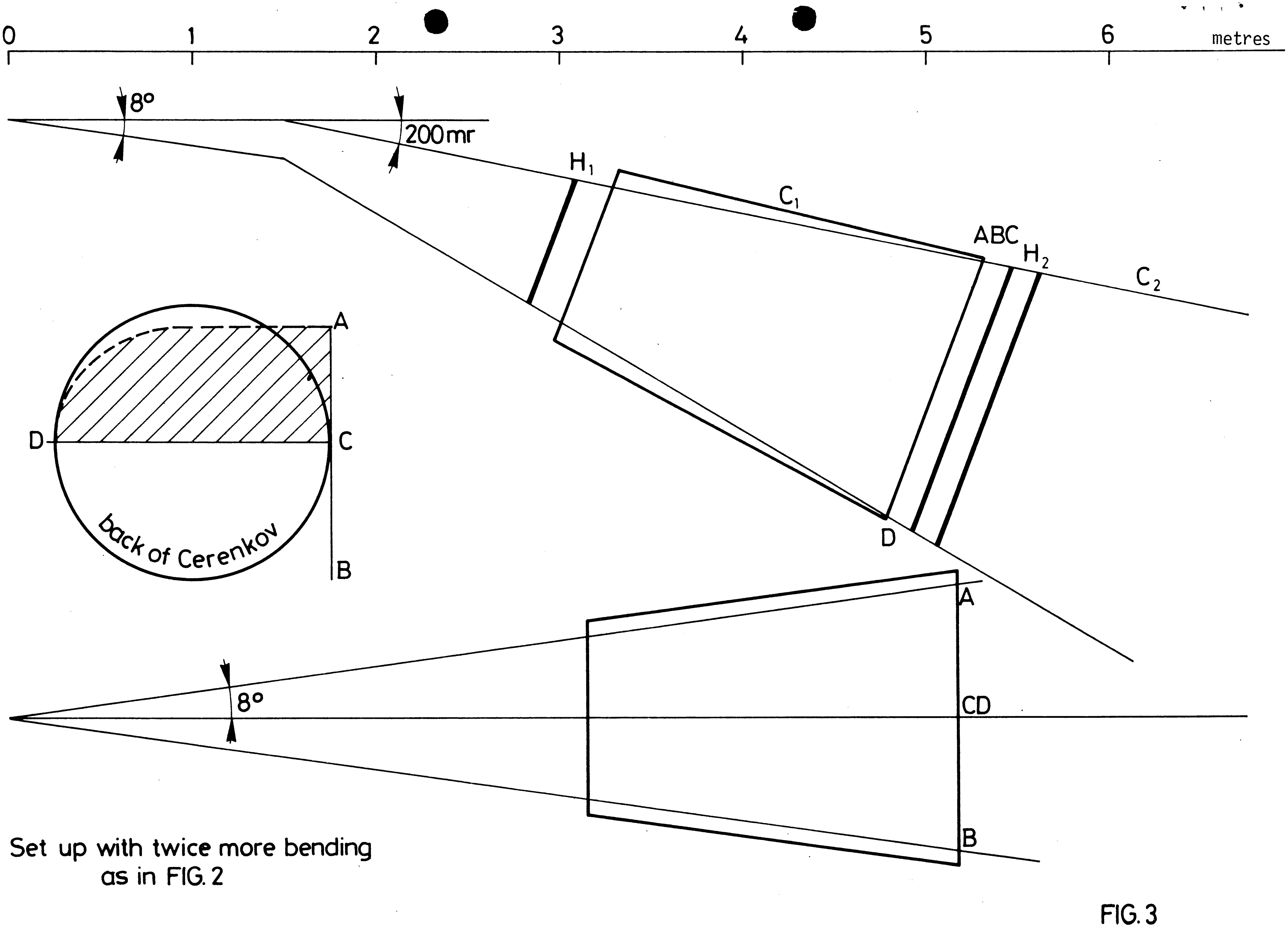
Lower momentum of the proton coming from various hyperons and N^* versus baryon emission angle in the quasi-two-body reaction

FIG. 1



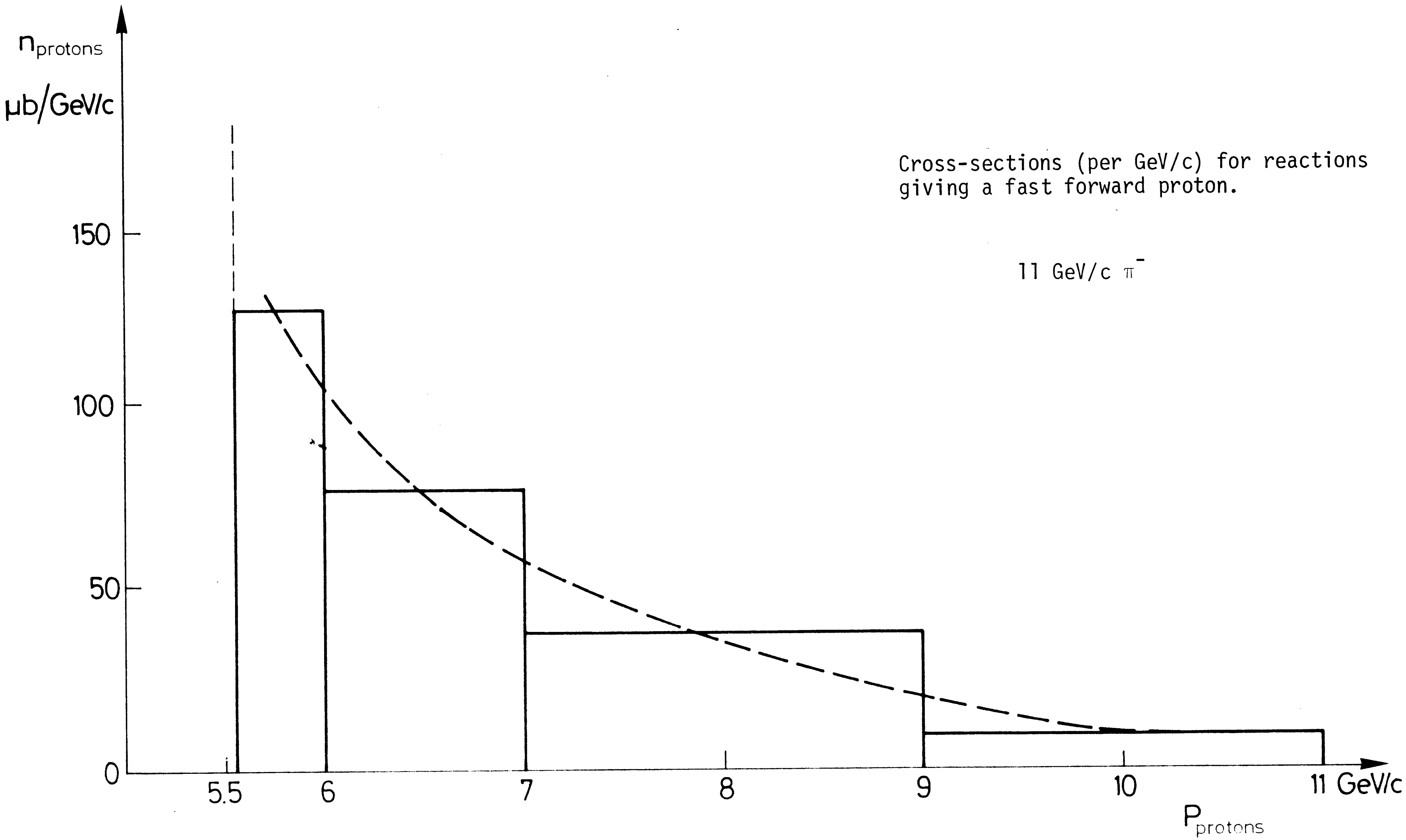
Set up with "canonical" bending

FIG. 2



Set up with twice more bending
as in FIG. 2

FIG. 3



n protons
μb/GeV/c
150
100
50
0
5.5
6
7
8
9
10
11 GeV/c
P protons
Cross-sections (per GeV/c) for reactions giving a fast forward proton.
11 GeV/c π⁻

FIG. 4