EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

Experimental Proposal
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PROPOSAL FOR MEASURING THE DIFFERENTIAL AND TOTAL CROSS SECTION OF THE REACTION $\pi^+ + d \rightarrow p + p$

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Introduction

The idea of searching for resonances of higher baryon numbers was first proposed by A.M. Wetherell[1]) and the idea of using the reaction $p + p \rightarrow \pi + d$ as a means of studying high momentum transfer processes (the nucleon pole) has been proposed by M.L. Perl et al[2]). A recent experiment by Cocconi et al[3]) on the reaction $p + p \rightarrow \pi^+ + d$ suggests a resonance-like behaviour of the differential cross section at a diproton mass of 2.87 Gev.

However, in that experiment only the differential cross sections at a fixed laboratory angle (60 mrad) were measured, therefore neither the behaviour of the total cross section of the reaction $p + p \rightarrow \pi^+ + d$ as a function of energy, nor the angular distribution of the differential cross section around the resonance region were measured. Since the knowledge of both are essential in determining the existence and some of the properties of this resonance, it is therefore interesting to perform a detailed study of the reaction $\pi^+ + d \rightarrow p + p$ around the c.m.energy of 2.87 Gev in the π d rest system.

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Purpose of the Experiment

A. It is intended in this experiment to carry out an accurate measurement, at various energies, of the differential and total cross sections of the reaction

$$\pi^{+} + d \rightarrow p + p \qquad (1)$$

The exact knowledge of both these quantities enables one to determine the existence and, possibly, the quantum number assignment of the resonance.

B. To fill in the gap in our present knowledge of the behaviour of reaction (1) at high energies.

C. This is an extremely simple experiment and it would therefore, from an experimental point of view, be fun to do it.

Kinematics

Before discussing the experimental set-up, it is important to observe the following kinematical facts which occur around the energy region in which we are interested.

A. To study reaction (1) around the centre of mass energy of 2.9 Gev, one needs an incident pion of 1.2 Gev and therefore the existing π^{+} beam of the PS (a_5) can be utilized.

B. The angular correlation of the two outgoing protons in the laboratory system (see Fig.1) of reaction (1) is sufficiently different ($(\Delta\Theta)_{min} \sim 2^{o}$) from that of other two-body final states that may occur in the $\pi^{+} + d$ system (i.e. $\pi^{+} + p \rightarrow \pi^{+} + p$, and $p + p \rightarrow p + p$; due to proton contamination in the π^{+} beam). This enables one to select reaction (1) from other two-body final states, by just using counters with angular resolutions $\Delta\Theta < 2^{o}$, and arrange the counters in coincidence according to angular correlation of reaction (1).

C. At given emission angles in the laboratory system, the momenta associated with the two protons are sufficiently different from the momenta of the products of other two-body reactions (see Fig.2).

Thus for a 5 m flight path, the difference in flight time between protons from reaction (1) and protons, pions and deuterons from other two-body reactions is of the order of 10 ns. This enables us to make a time-of-flight identification by using only the CERN standard fast coincidence circuits (± 5 ns resolution time).

Table 1 gives, as an example, at the incident pion momentum of 1.0 Gev/c, the angular correlations and flight times for 5 m flight path for protons from reaction (1) in comparison with particles from other two-body reactions. Note that the time-of-flight measurement is most efficient in rejecting other reactions with small angular separation and vice versa.

Experimental Procedure

A. Range of momenta of the incident beam.

In order to cover the region of the structure found in the reaction $p + p \rightarrow \pi^+ + d$, it is sufficient to run the present experiment at the following momenta:-

p_0(Gev/c) Incident π^+ momenta	$E^*_{c.m.}$ (Gev) Total energy in the c.m.s.
0.70	2.50
0.85	2.60
1.00	2.70
1.25	2.87
1.35	2.95
1.70	3.15
2.00	3.32

B. Beam characteristics.

It is intended to utilize the existing Lundby beam for this experiment. This beam yields an intensity of $10^6 \pi^+ / 10^{11}$ p in a momentum bite of ±2.5% at 1.5 Gev/c. Assuming an average intensity of the PS of $6 \cdot 10^{11}$ per burst, the experiment can be run as a parasite, using a spill on target 6 of 10% of the full intensity only.

C. Counters and Target.

A 10 cm long and 2.0 cm diameter liquid deuterium target (see Fig.3). Six pairs of plastic scintillation counters F_1 ... F_6 (10 cm × 100 cm × 1 cm) and B_1 ... B_6 (40 cm × 100 cm × 1 cm) arranged in double coincidence according to the angular correlation of reaction (1) and in triple coincidence with the beam defining counter S_2 so as to measure the flight time of the secondaries from the target.

Fig.3 shows, as an example, the arrangement of counters for the incident pion momentum of 1.0 Gev/c. The angular correlation of counters BiFi (i = 1, ... 6) is determined according to Table 1.

D. Resolution

a) Angular resolution: The combined uncertainty due to beam divergence, multiple scattering in the beam counters S_1, S_2 and in the target, and from the finite sizes of the counters Bi Fi gives an overall spread of $\Delta\Theta = \pm 1.3^\circ$.

b) Coplanarity angle resolution: The coplanarity angle resolution is determined mainly by the size of the counters Bi Fi and the distance they are placed from the target. In the present case we have $\Delta\varphi \approx \pm 6^\circ$.

E. Solid angle of acceptance: $\Delta\Omega = 4 \times 10^{-3}$ sterad.

F. Background: The event/background ratio with the present resolutions is estimated to be of the order of 10^2. It will be determined by uncorrelated counter pairs.

G. Counting rate:

Assume an average differential cross section of 50 μb/sterad (see Appendix 1) and 10% of the PS intensity on target 6. One gets 0.4 events per burst per six pairs of counters, or 4×10^3 events per shift or approximately $0.7 \cdot 10^3$ counts per angle.

H. Running time required:

Assume a safety factor due to time required to adjust counters for each energy, and errors in the estimation of beam intensity and cross sections. Then, for the seven energies we are interested in, we estimate 30-40 shifts of parasitic running.

I. Time schedule:

Since no other claim has been put forward on the Lundby beam, and only standard equipment is used, we think to be able to run the experiment in December 1963.

ACKNOWLEDGEMENT

We wish to acknowledge the encouragement of Professor G. Cocconi, and the discussions with him and the members of his group.

TABLE 1

$\cos_{C.M.} \theta_p$	$\pi^+ + D \to P + P$				$\pi^+ + P \to \pi^+ + P$				$\pi^+ + D \to \pi^+ + D$			
	θ_p°	$t_p^{(NS)}$	θ_p°	$t_p^{(NS)}$	θ_π°	$t_\pi^{(NS)}$	θ_p°	$t_p^{(NS)}$	θ_π°	$t_\pi^{(NS)}$	θ_D°	$t_D^{(NS)}$
0.990	5.14	19.7	165.43	33.4	5.14	16.0	84.23	210.0	5.14	18.9	86.00	320.0
					165.43	18.3	3.48	20.6	166.4	17.4	5.14	27.0
					150.00	18.3	5.14	20.6	164.7	17.4	5.14	27.0
0.950	11.57	19.7	148.02	32.1	11.57	16.9	77.6	69.5	11.57	16.9	81.00	139.0
					148.02	18.1	7.82	20.8	148.02	17.4	10.40	27.3
					134.00	18.1	11.57	20.8	145.00	17.4	11.57	27.8
0.800	23.72	19.9	119.55	28.8	23.72	16.9	64.60	42.0	23.72	16.9	72.00	83.5
					119.55	18.0	15.96	21.7	119.55	17.4	20.60	28.8
					95.00	17.6	23.60	21.1	112.00	17.4	23.72	28.8
0.600	34.77	20.0	99.01	26.1	34.77	16.9	57.01	34.8	34.77	19.6	64.06	59.5
					99.01	17.6	22.00	21.7	99.01	17.2	29.00	29.9
					68.23	17.1	35.02	23.5	86.00	17.0	34.77	31.6
0.300	48.89	21.2	78.57	23.5	48.89	17.0	46.13	28.0	48.89	16.9	56.06	44.0
					78.57	17.4	30.33	22.4	78.57	16.9	38.00	32.0
					46.06	17.0	48.89	28.0	49.50	16.9	48.89	39.0
					11.00	16.8	78.57	90.0	15.43	16.9	78.57	119.0
0.00	62.85	22.3	62.85	22.3	62.85	17.0	38.43	23.8	62.85	16.9	47.21	37.0
					28.00	16.9	62.85	39.0	37.13	16.9	62.85	54.0

APPENDIX 1

Estimation of the Average Cross Sections for the Reaction $\pi^+ + d \to p + p$ (1)

1) Total Cross Sections

For the reaction A + a → B + b and the inverse reaction B + b → A + a the relation between the total cross sections can be expressed as follows, (E. Fermi, Nuclear Physics, p. 146):

$$(2\,I_A + 1)\,(2\,I_a + 1)\,P_a^2\,\sigma_{(Aa \to Bb)} = (2\,I_B + 1)\,(2\,I_b + 1)\,P_b^2\,\sigma_{(Bb \to Aa)} \qquad (2)$$

where I_A, I_a, I_B, I_b are the spins of particle A,a,B,b and P_a, P_b are the c.m. momenta in the (A,a) and (B,b) system respectively.

For the reaction $p + p \leftrightarrows \pi + d$ at a c.m. energy of 2.9 Gev/c, one has

$I_A = I_a = ½$ $\qquad$ $I_B = 1 \quad I_b = 0$

$P_b = 0.69$ Gev/c $\qquad$ $P_a = 1.1$ Gev/c

$$\sigma_{(\pi d \to pp)} = 4/3 \times \left(\frac{1.1}{0.69}\right)^2 \sigma_{(pp \to \pi d)} \qquad (3)$$

or

$$\sigma_{(\pi d \to pp)} = 3.5 \qquad \sigma_{(pp \to \pi d)}$$

2. Differential Cross Sections

Assume at a given angle in the c.m.s. the differential cross sections for the reaction (1) also goes up by a factor 3.5 as determined from equation (3). Since we are detecting two identical particles at the same time, our rate, at a given angle should go up by a factor of 2.

However, the Jacobian of transformation from the c.m.s. to the laboratory system for the reaction (1) is of the order of 2.5, but instead, for the reaction $p + p \rightarrow \pi + d$ it is of the order of 20.

Therefore, the differential cross section for reaction (1) is

$$\left(\frac{d\sigma}{dn}\right)_{lab(\pi+d\rightarrow p+p)} = \frac{2.5\times 7}{20}\left(\frac{d\sigma}{dn}\right)_{lab(p+p\rightarrow \pi+d)} = \frac{9}{10}\left(\frac{d\sigma}{dn}\right)_{lab(p+p\rightarrow\pi+d)}$$

REFERENCES

1 A.M. Wetherell, CERN Memo, 1961, unpublished.

2 Perl, Jones, Overseth, B.N.L. proposal, and private communication. See also Perl, Jones, Ting, Technical Report No.9, University of Michigan, March, 1963. (To be published in Physical Review).

3 G. Cocconi, E. Lillethun, J.P. Scanlon, C.C. Ting, J. Walters and A.M. Wetherell, CERN Internal Report 14, August 1963, to be published.

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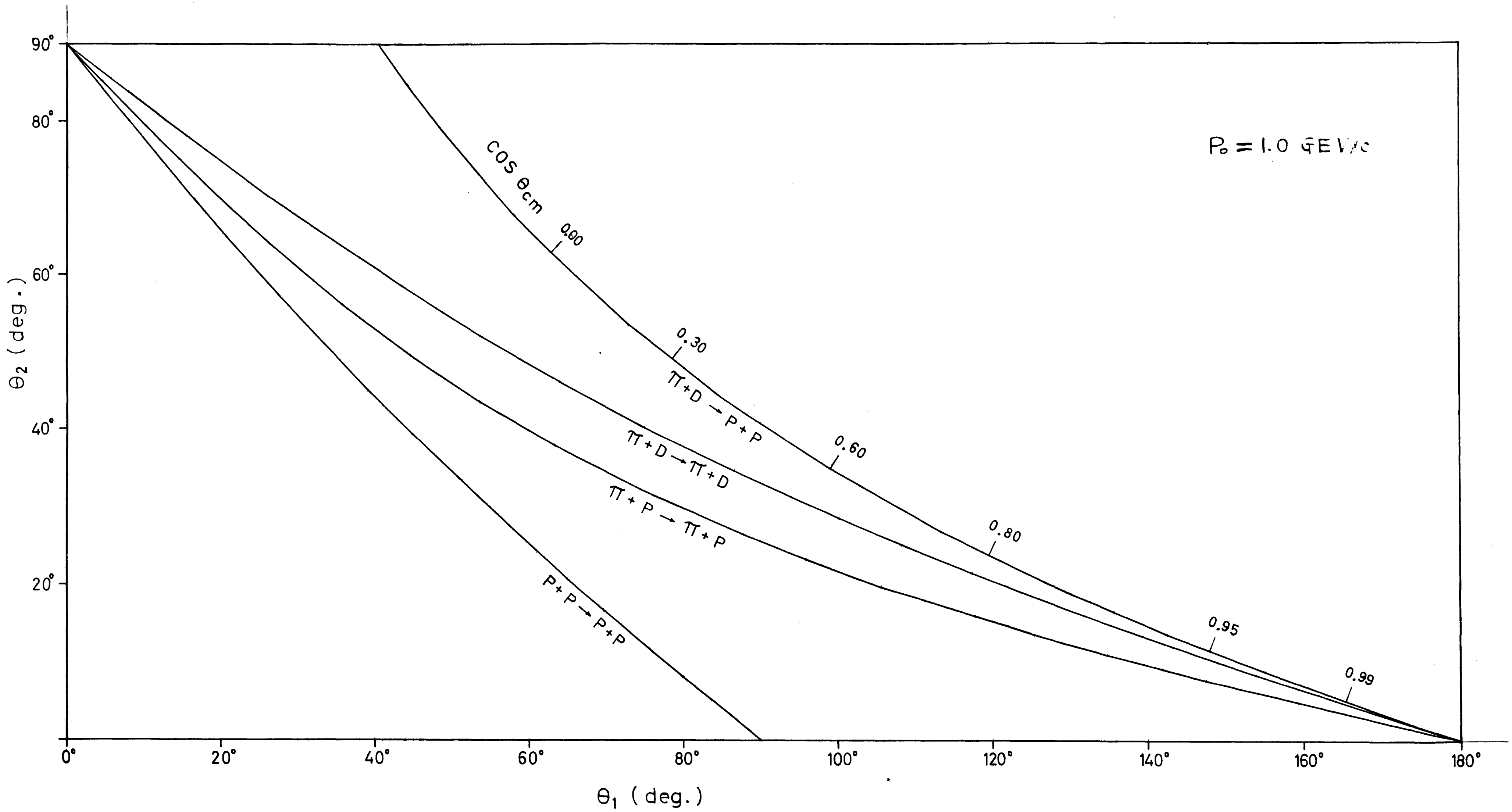
ADM 377



90°
80°
60°
40°
20°
θ_2 (deg.)
0°
20°
40°
60°
80°
100°
120°
140°
160°
180°
θ_1 (deg.)
P_0 = 1.0 GEV/c
COS θcm
0.00
0.30
0.60
0.80
0.95
0.99
π+D → P+P
π+D → π+D
π + P → π + P
P+P → P+P

FIG. 1

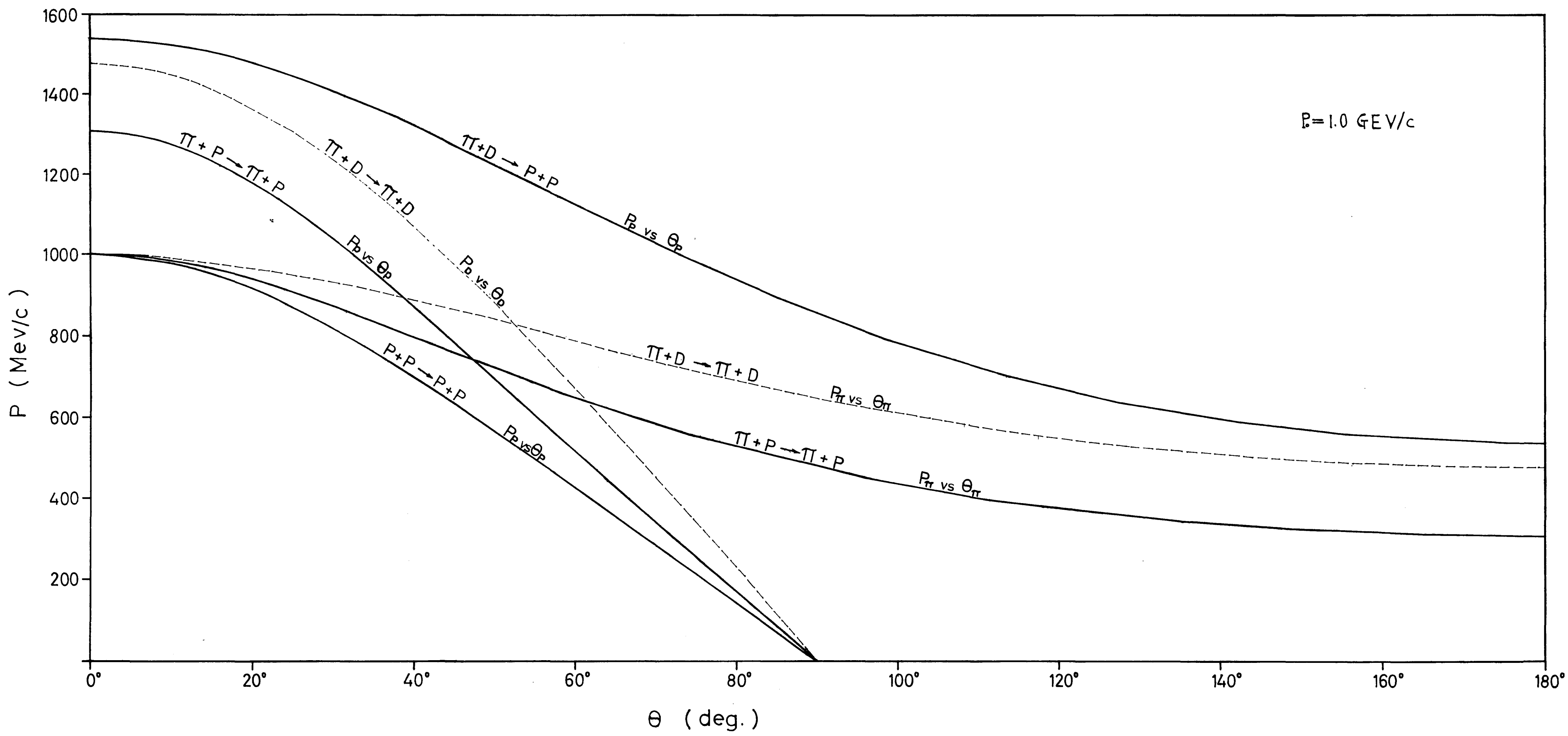
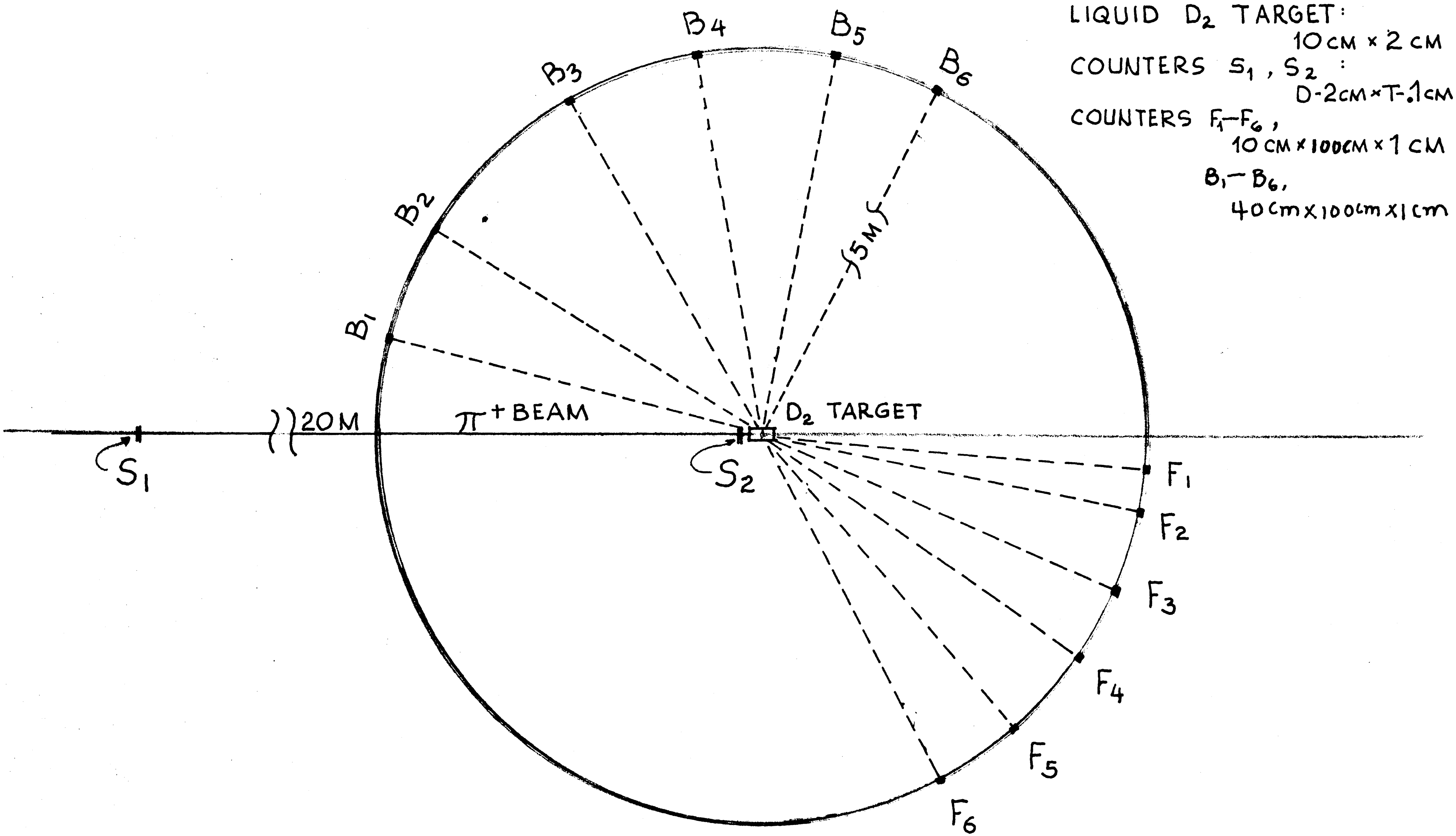

P (Mev/c)
1600
1400
1200
1000
800
600
400
200
0°
20°
40°
60°
80°
100°
120°
140°
160°
180°
θ (deg.)
P₀= 1.0 GEV/c
π+D → P+P
Pp vs θp
π+P → π+P
Pp vs θp
π+D → π+D
PD vs θD
P+P → P+P
Pp vs θp
π+D → π+D
Pπ vs θπ
π+P → π+P
Pπ vs θπ

FIG. 2



LIQUID D_2 TARGET:
10 CM × 2 CM
COUNTERS S_1, S_2:
D-2CM × T-.1CM
COUNTERS F_1–F_6,
10 CM × 100CM × 1 CM
B_1–B_6,
40CM × 100CM × 1CM
B1
B2
B3
B4
B5
B6
5M
D_2 TARGET
π^+ BEAM
20M
S_1
S_2
F_1
F_2
F_3
F_4
F_5
F_6

FIG. 3