EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

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PHYSICS I
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PROPOSAL

FOR A MEASUREMENT OF THE DIFFERENTIAL CROSS SECTION FOR $\bar{p}p \rightarrow \bar{p}p$, $\pi^+\pi^-$, K^+K^-, BETWEEN 0.6 AND 2.0 GeV/c

by

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PROPOSAL FOR AN EXPERIMENT ON CERN P.S.

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RHEL/QMC/DNPL/LIVERPOOL

PERSONNEL:

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TIME SCALE:

Equipment ready for set-up ~ July 1970.

I. INTRODUCTION

EXPERIMENTAL BACKGROUND

There are several indications that the $\bar{p}p$ system might yield considerable information on the higher mass boson states. The evidence is outlined in the following:

(a) The $\bar{p}N$ total cross-section measurements from 1.0 - 3.4 GeV/c of Abrams et al 1) produced evidence for structure with the properties given in Table I. One possible explanation of the peaks is that they correspond to high mass bosons in the s-channel. For comparison we show in Table I, the CERN "missing mass" data in this energy region from Focacci et al 2). The mass values agree rather well although the widths do not. (Note that an alternative explanation of the bump at 2190 MeV is the onset of isobar production).

(b) At lower $\bar{p}$ momenta, a very speculative examination of the $\bar{p}p$ total cross-section work of Amaldi et al 3) indicates a possible shoulder which would correspond in mass with the S-meson.

(c) Some evidence for the S-mesons is also indicated in the differential cross-section data of Conforto et al 4) ($\sim$1000 events, $-1.0 < \cos\theta^* < 1.0$, at each of 9 momenta between 0.35 and 0.55 GeV/c) when one examines the data at $\cos\theta^* < -0.8$.

(d) Cline et al 5) have recently published bubble chamber data on elastic $\bar{p}p$ scattering in the backward hemisphere ($\sim$4000 events, $-1.0 < \cos\theta^* < 0.0$, momenta between 0.3 and 0.7 GeV/c).
There is evidence for the S(1925) and in addition possible new states at 1945 MeV and $\sim$1975 MeV. The last region is not completely covered by the data so the mass is somewhat uncertain. See Figure (1).

PROPOSED EXPERIMENT

It is proposed to make measurements of the $\bar{p}p$ elastic differential cross-section over an angular range $-0.95 < \cos\theta^* < 0.95$ and a momentum range 0.6 GeV/c to 2.0 GeV/c. The lowest momentum is probably determined by the availability of anti-protons. This momentum range covers the 1975 bump of Cline et al 5) and extends beyond the mass of the U(2380). The data in the backward direction will generally have considerably better statistics than exists at the present. An analysis of the full angular distribution should enable a statement to be made about the probable angular momentum states involved.

We also propose to collect data simultaneously on the annihilation channels $\bar{p}p \rightarrow \pi^+\pi^-$, K^+K^- although the region $-0.2 < \cos\theta^* < 0.5$ is inaccessible to our present detection system for these processes. It is hoped that this data will complement the elastic data for the following reasons. The diffraction peak is absent in the annihilation processes and the bosons have zero spin; both factors simplify the analysis of the angular distribution in terms of resonant states.

THEORETICAL BACKGROUND

The theoretical background of this boson spectroscopy lies in the Quark model and the more recent Veneziano model.

On the basis of the Quark model 6) with L-excitation of the $q\bar{q}$ system one has four meson nonets corresponding to each L-value. The experimental evidence suggests that the mass splitting between nonets with different L-value is greater than that which exists between nonets with the same L-value. On this model the S, T and U mesons correspond to L-values of 3, 4 and 5 respectively. One would therefore expect clusters of resonances at each of these masses.

Barger and Cline 7) have discussed the application of the Veneziano model to the $\bar{p}p$ system. Their model implies "towers" of parity degenerate meson states as shown in Figure (2). These states would combine destructively in the backward direction, thereby explaining the absence of a backward peak at low momenta in $\bar{N}N$. The smoothness of the $\bar{N}N$ total cross section is presumed to occur through wide states in the tower, probably with low L.

Some experimental tests for the existence of towers are the following:

(a) A complete $\bar{N}N$ elastic phase shift analysis (unlikely in the near future).

(b) In the regions of the S, T and U, the values of L required to fit the angular distributions should be consistent with the J value at the top of the tower. This is so for the S-region where L = 3 is required.

(c) The cancellation of the contribution from each member of the tower is not likely to be exact over the backward hemisphere in $\bar{N}N$ scattering, so fluctuations should exist in the angular distribution as a function of energy (see Cline et al 5) and Figure (1)).

(d) The lower L-value of a tower may be more apparent in the di-boson channel since the angular momentum barrier factor would tend to favour this decay mode for the lower values of L.

II. THE BEAM

INTENSITY

The data of Duboc et al 8) may be used to get an idea of the fluxes of antiprotons which may be achieved at the P.S.. The yields quoted are for the following conditions:- 38 mm of Be, production angle 15°, proton momentum 19.2 GeV/c, $\Delta p/p = \pm 1\%$, $\Delta\Omega = .5 \times 10^{-3}$ sr. An increase in the acceptance to 1.5 msr and raising the momentum bite to ± 2.5% should give the following fluxes:

$\bar{p}$ momentum GeV/c	P.S. protons on target ∽ 19 GeV/c	$\bar{p}$s/PS pulse
.6	6×10^{11}	80
1.0	3×10^{11}	1500
1.2	3×10^{11}	4500

It would prove easier to attain the larger acceptance from a target in an external beam. However the length of target required to give comparable yields for the same incident flux may make this solution prohibitive.

The average P.S. target efficiency (20 mm x 1 mm ∅ Be) at ~20 GeV is ~60% i.e. ~40% of the incident protons undergo some nuclear reaction. For the same Be target this figure becomes 4% in an external beam (λ tot Be = 56.6 gm/cm^2). A target 20 cm long would create problems with beam optics and probably make target sharing difficult. Also if the low yields of very low momentum anti-protons are due to reabsorption in the target, a short target is preferable.

SEPARATION

The data of Amaldi et al [9)] give a $\bar{p}/\pi^-$ ratio at .6 GeV/c (27 GeV ~11° production, Be target) of $\sim 5 \times 10^{-5}$ at the production target. An intensity of ~ 100 $\bar{p}$s/pulse would mean a beam of $\sim 2 \times 10^6$ particles/pulse. A separation factor of 200 gives $\sim 10^4$ particles/pulse which combined with an effective spill of ~200 m secs gives a rate of $\sim 5 \times 10^4$ per sec which should be acceptable in the spark chambers. Any gain from pion decay has been ignored.

At 1.0 GeV/c the $\bar{p}/\pi^-$ ratio is $\sim 3 \times 10^{-3}$ therefore 1500 $\bar{p}$s/pulse give rise to 5×10^5 particles per pulse. A separation factor of 50 and an effective spill of 200 m sec give an instantaneous rate of $\sim 5 \times 10^4$ per sec.

PURIFICATION

The identification of the anti-protons may be achieved by time of flight, $\frac{dE}{dx}$ at low momenta, and a Cerenkov to veto pions at $\gtrsim 1$ GeV/c. The separation in time for a flight path of 10 mts at .6 GeV/c is $\bar{p}$-K ~19 n secs $\bar{p}$-π ~28 n secs. In order to accommodate the time spread introduced by the $\pm 2\frac{1}{2}\%$ $\Delta p/p$ a gate ~6 n secs is required, with the above separation factor of 200 at .6 GeV/c there would be 1.5% misidentified pions. These could easily be cleaned out with a $(\frac{dE}{dx})$ requirement. At 1 GeV/c and 10 mts path the timing separations are $\bar{p}$-K

8 n secs, $\bar{p}\pi \sim 12$ n secs, the random pion contamination in the time gate is .4%.

SPOT SIZE

A beam spot at the hydrogen target within the limits 4 cms x 4 cms would be acceptable.

III. EXPERIMENTAL SET-UP

GENERAL

The layout of the apparatus is shown in Figure (3). It consists of a spectrometer magnet and six spark chamber arrays, each with its associated set of triggering counters placed around a long liquid hydrogen target.

The incoming anti-proton is momentum analysed and its direction into the target defined by arrays 1 and 2. The direction and momentum of one of the secondary particles are measured using arrays 3 and 4 in conjunction with the spectrometer magnet. For the annihilation channels ($\pi^+\pi^-$, K^+K^-) and for 50 - 80 % of the angular range of the elastic channel, the other secondary is detected in arrays 5 and 6. This kinematic information should allow an identifiaction of the three channels we propose to measure. Time of flight in the spectrometer arm and information from water Cerenkov counters placed behind hodoscope 4 will allow additional cuts to be made where necessary.

SPARK CHAMBERS

These will be wire chambers probably with capacity read out to allow operation in the magnet fringe field. Each array will contain four wire planes for each perpendicular projection with two additional planes of diagonal wires to remove ambiguities.

Some parameters of the arrays follow:

Array Number	Width cms	Height cms	Wires	Number of associated counters
1	20	20	1200	
2	20	20	1200	
3	100	50	4500	16
4	300	75	11000	32
5	150	50	5500	10
6	150	50	5500	10

HYDROGEN TARGET

In order to provide an acceptable event rate, particularly at low momenta, the target will be 50 cms long.

Although the energy loss in this target is as much as 70 MeV/c at 600 MeV/c, it is calculable to a few MeV/c for each event, given that the vertex can be located to a few cms. Because of absorption of the anti-protons, normalisation corrections of about 15% on the average will have to be applied to the data. For momenta above 1 GeV/c multiple scattering is of the same order as the angular resolution provided by the spark chambers, while below 1 GeV/c time of flight and the Cerenkov information remove the need for very good angular resolution.

The diamter of the target is limited to about 10 cms by the need to observe the low energy recoil protons or anti-protons.

SPECTROMETER MAGNET

The required gap is 260 cms wide by 50 cms high by 100 cms deep, with a maximum field of 18 KG. This requirement would be met by two CERN C-type spectrometer magnets mounted as shown. With such a magnet, and with the spark chamber array 4 having the dimensions shown in Figure (3) (300 cms long), the acceptance in the centre of mass for the processes to be studied are shown in Figure (4) at representative momenta. The limits on the acceptance correspond to the trajectories shown in Figure (3).

TRIGGER SYSTEM

The normal trigger for the spark chambers will be two-fold and are shown in a simplified form:-

$$\bar{p}p \rightarrow \bar{p}p\text{:- Beam x 3 x 4 x } \underset{\substack{\text{some}\\ \text{angles}}}{(5)} \text{ x } \underset{\substack{\text{some}\\ \text{momenta}}}{(\overline{\check{C}\ 4})}$$

$$\bar{p}p \rightarrow \pi^+\pi^-,\ K^+K^-\text{:- Beam x 3 x 4 x 6 x } \underset{\substack{\text{some}\\ \text{momenta}}}{(\check{C}\ 4)} \text{ x } \overline{\pi\ \text{Veto}}$$

In order to prevent many of the multi-particle annihilation events from triggering the system, it may be necessary to be able to distinguish a pion or kaon from a proton in the momentum arm (as indicated). This would allow the application of veto counters placed above and below the target for the d-boson events. (This veto cannot always be applied for the elastics because of the possiblitiy of annihilation of the recoil anti-proton).

IV. RUNNING TIME

In order to make an estimate of the running time required to collect data it has been assumed that we can achieve 100 $\bar{p}$s/pulse at .6 GeV/c and then the intensity scales up with momentum in the manner indicated by Duboc et al 8). At momenta 1 GeV/c the intensity is kept fixed at ~ 3000 $\bar{p}$s/pulse in order to keep the instantaneous rate in the chambers 5 x 10^4/sec.

A total of ~500 hours should allow data to be taken at $\gtrsim$ 15 momenta from .6 - 2.0 GeV/c with a typical statistical accuracy based on ~ 5% on 500 μb in a cos θ^* bin of .05. Approximately 1000 $\pi^+\pi^-$ events should be present at each momentum up to 1.0 GeV/c; above this the number falls to reach 200 at 2.0 GeV/c. The number of K^+K^- events is roughly a factor of 2 less than the ($\pi^+\pi^-$) channel

REFERENCES

1) Abrams et al., Phys. Rev. Letters 18, 1209 (1967).

2) Focacci et al., Phys. Rev. Letters 17, 890 (1966).

3) Amaldi et al., Nuovo Cimento 46, 171 (1966).

4) Conforto et al., Nuovo Cimento 54A, 441 (1968).

5) Cline et al., Phys. Rev. Letters 21, 1268 (1968).

6) Dalitz, Berkely Conference (1966).

7) Barger and Cline, "Meson Towers and the absence of Backward Peaks", Univ. Wisconsin Preprint (Jan. 1969).

8) Duboc et al., CERN 65/2.

9) Amaldi et al., Nuovo Cimento 30, 973 (1963).

TABLE I

PARAMETERS OF POSSIBLE BOSON STATES FROM $\bar{N}N$ TOTAL CROSS-SECTIONS AND FROM MISSING MASS EXPERIMENT

Lab Momentum $\bar{p}p$ GeV/c	Mass GeV/c		Full Width GeV/c^2	
	$\sigma_T(\bar{n}n)$	missing mass 2)	$\sigma_T(\bar{n}n)$	missing mass
.44	Possible 3) shoulder	S(1929 ± 14)	-	$\lesssim$ 35
1.32	2190 ± 5 1)	T(2195 ± 15)	85	$\lesssim$ 13
1.76	2345 ± 10 1)	U(2382 ± 24)	140	$\lesssim$ 30
1.86	2380 ± 10 1)	-	140	-

p̄p Backward Hemisphere Scattering
at Low Energy

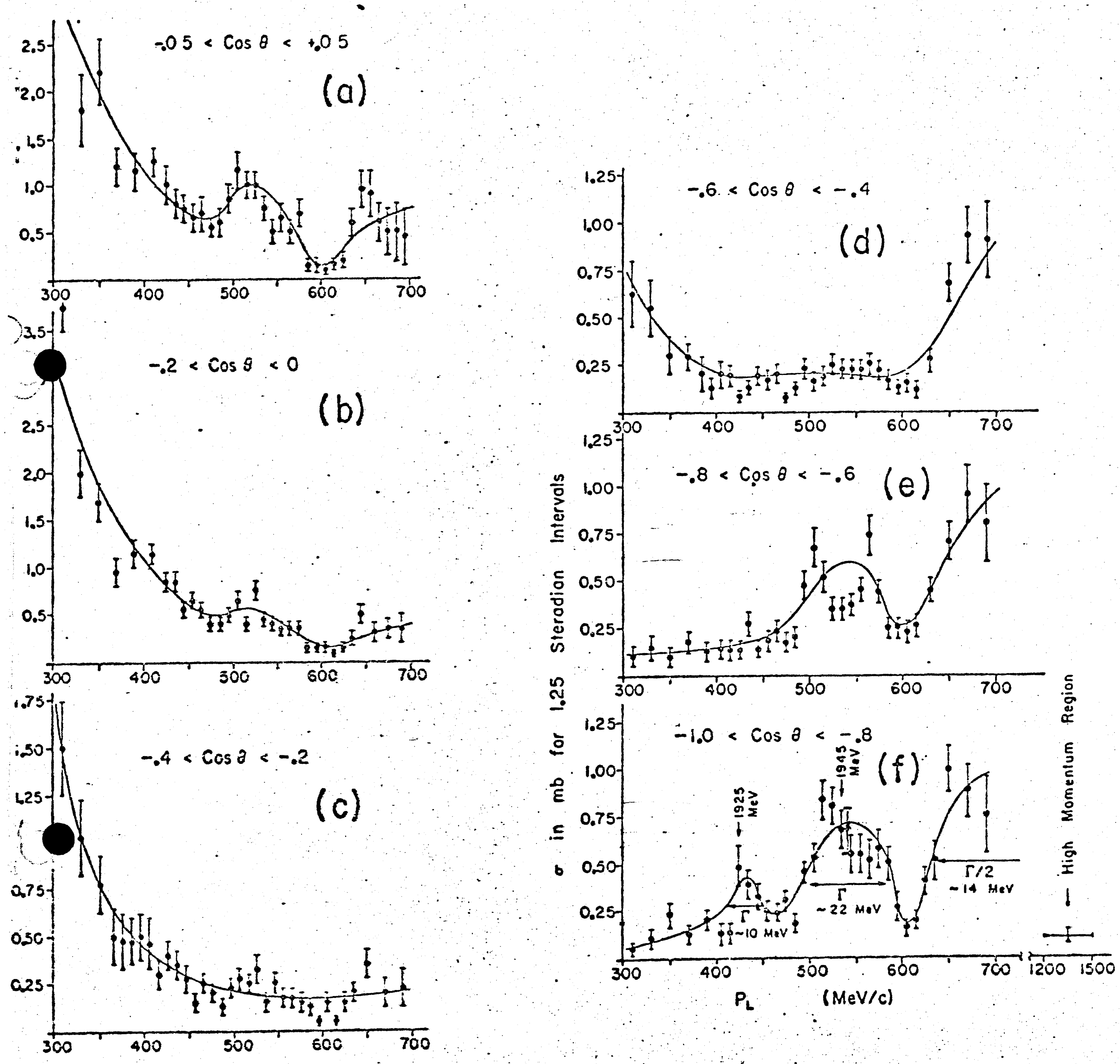


FIGURE 1 FROM REF 5

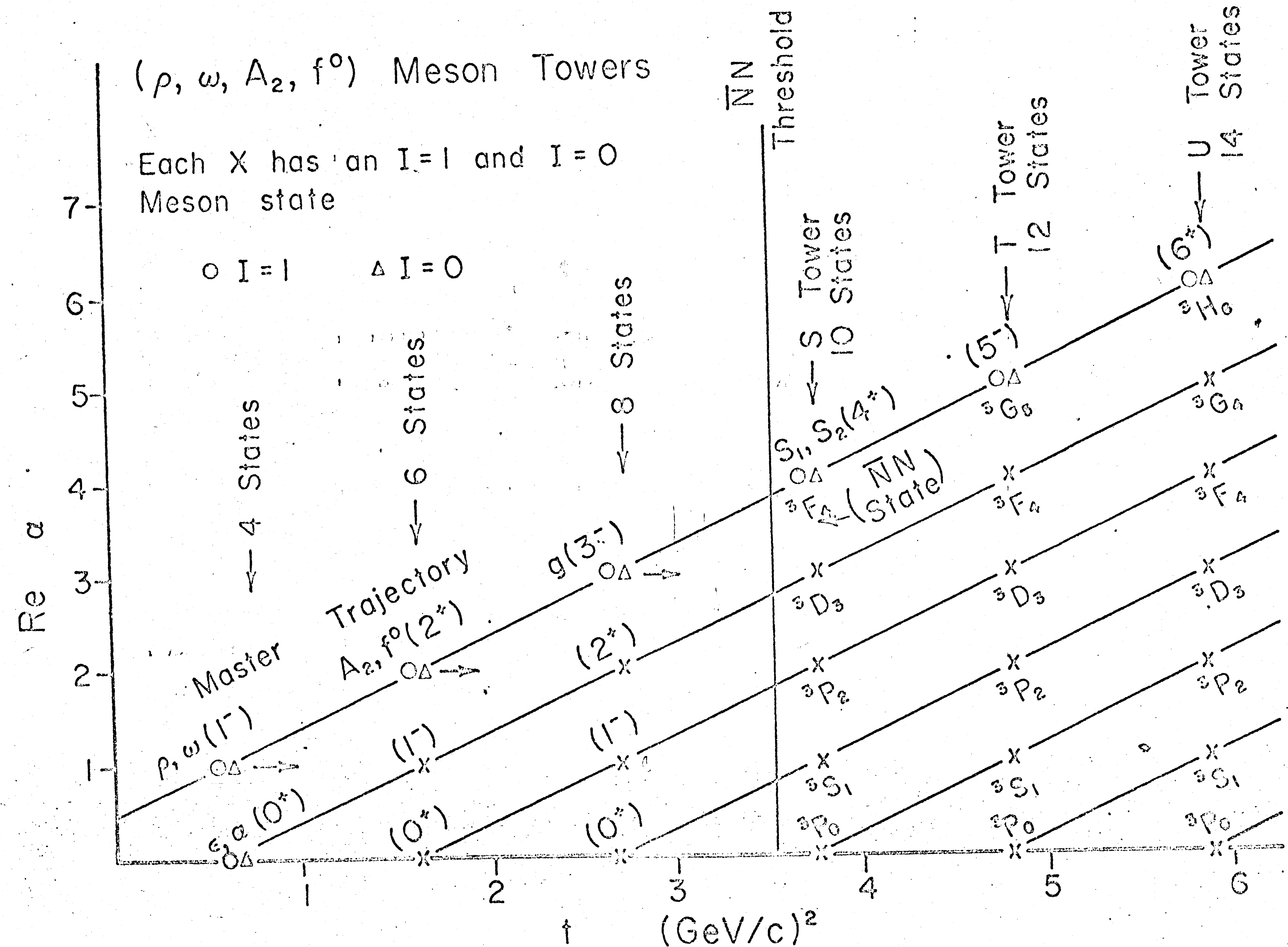


FIGURE 2 FROM REF. 7 [redacted]

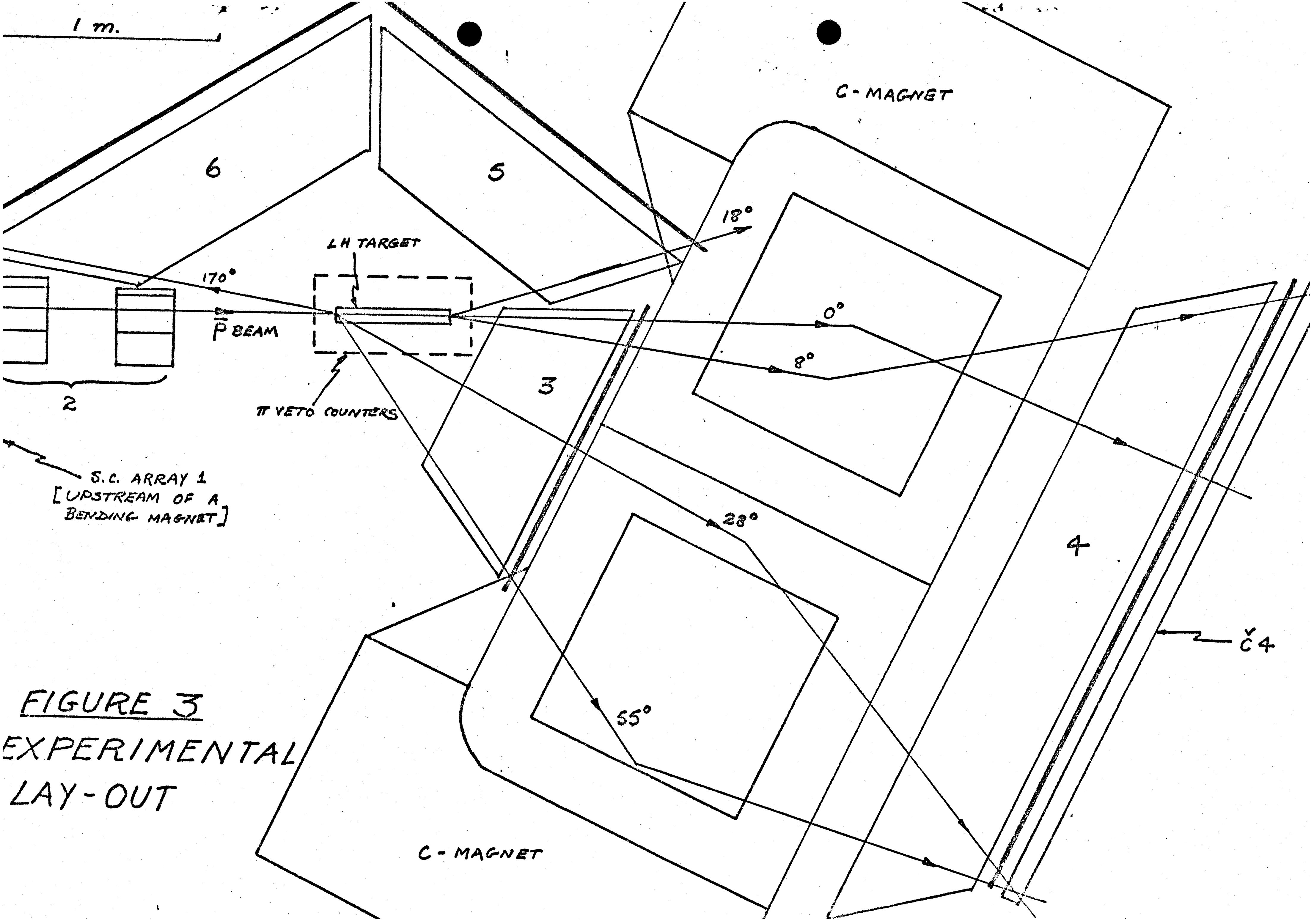
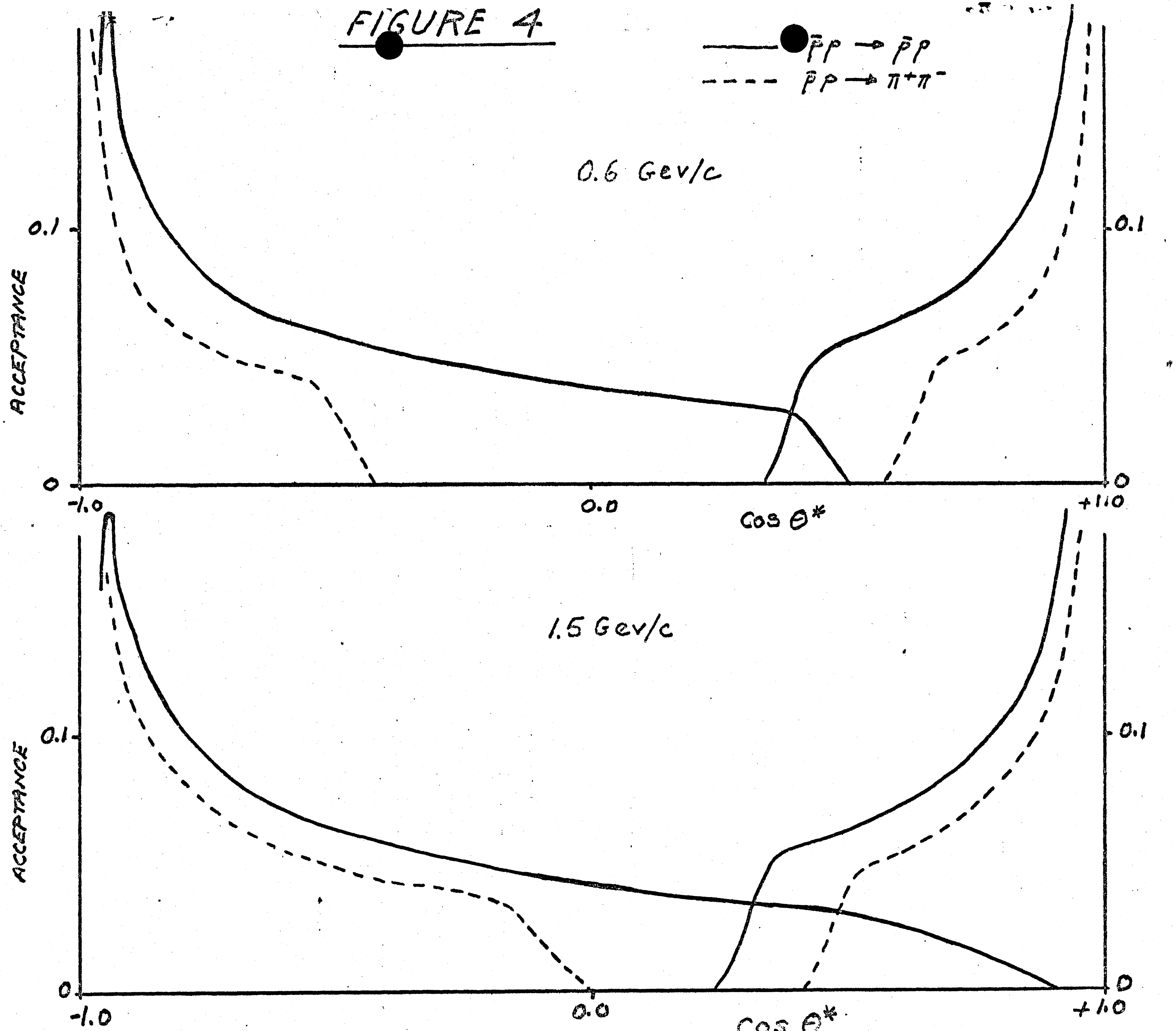


FIGURE 3
EXPERIMENTAL
LAY-OUT

FIGURE 4


$\bar{p}p \rightarrow \bar{p}p$
$\bar{p}p \rightarrow \pi^+\pi^-$
0.6 Gev/c
ACCEPTANCE
0.1
0
-1.0
0.0
+1.0
Cos θ*
1.5 Gev/c
ACCEPTANCE
0.1
0
-1.0
0.0
+1.0
Cos θ*