7. 9. 64 EEC 9

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

S31

NP Division
Technical Memo MM- 30
4 September, 1964

NOT TO BE CIRCULATED

ONLY FOR EEC

NEUTRON MISSING MASS SPECTROMETER FOR HEAVY NEUTRAL MESONS

W. Kienzle, R. Blieden, L. Dubal, D. Freytag,
F. Lefebvres, B. Levrat, B. Maglic

(Proposal for an experiment)

* * *

I. INTRODUCTION

We propose here a counter experiment to investigate the spectrum of heavy neutral mesons (I-spin 0) in the so far rather unexplored mass region between 1 and 3 GeV. The proposed reaction is

$$\pi^- + P \rightarrow N + X^0 \qquad (1)$$

where the neutral mesons X^0 are possible higher mass members of the well-known I-spin 0 sequence $\eta, \omega, \varphi, f^0$.

The experimental method to measure X^0 is based on the proton "Jacobian peak missing-mass spectrometer" [1,2], i.e. the purpose of this experiment is to measure the missing mass of the recoil neutron N in reaction (1). The kinematics of reaction (1) are completely analogous to the reaction

$$\pi^- + P \rightarrow P + X^- \;,^{1,2)} \qquad (2)$$

therefore, we do not repeat here at large the kinematic question, but discuss only the more experimental aspects of the problem, i.e. how to detect the

9519/p/cm

angular and momentum distribution of the neutrons in reaction (1). This can be justified by the fact that with protons the missing-mass method has recently given the expected results.

II. AIMS

With the missing-mass method it should be possible to cover the mass range

$$0.5 \leqq M_X \leqq 3.0 \text{ GeV}$$

using incident pion momenta in the range

$$5 \leqq p_1 \leqq 15 \text{ GeV/c}$$

where the momentum transfer p_3 to the recoil neutron covers the range

$$0.02 \leqq \Delta^2 \leqq 1.0 \ (\text{GeV/c})^2 \ ,$$

i.e. the recoil proton momentum is in the limit

$$0.15 \leqq p_3 \leqq 1.0 \text{ GeV/c}$$

Such a low limit in momentum transfer is a peculiar feature of the neutron missing-mass spectrometer, where the problem of multiple scattering (which limits the range of a proton missing-mass spectrometer) does not exist. Therefore, a neutron missing-mass spectrometer is of special interest for investigations of resonances produced in a peripheral mechanism, i.e. at very low momentum transfer, as for instance, the neutral ρ meson, where the production cross-sections are high, especially for neutral meson states.

The reaction rate is expected to be one detected neutron per 1 mb cross-section per burst of the PS (i.e. per 10^5 pions) using a hydrogen target of 10 cm length.

The resolution ΔM_X of the meson mass M_X is $\Delta M_X = \pm 20$ MeV at $M_X = 750$ MeV (= ρ mass) and $\Delta M_X = \pm 30$ MeV at $M_X = 1500$ MeV. This uncertainty in mass is mainly due to the finite angular resolution of the set-up which could be further improved, by at least a factor of two, in the second stage of the experiment; for instance, by shifting the hodoscope by a half-width of one element. In this case we expect to have $\Delta M = \pm 12$ and ± 18 MeV for $M_X = 750$ MeV and 1500 MeV, respectively.

The background problem is less serious in the case of neutrons than in the present proton experiment, because all charged background can be easily removed by shielding with anticounters; γ background can be removed with converters. Therefore one is essentially left with neutron background coming from N^+ production.

Further numbers concerning reaction rate, mass resolution and background will be given below.

It may be of interest to point out, that in the first part of the N experiment it should be possible to parasite on the present proton missing-mass experiment, i.e. to use the same beam and target and, even the same vertex analyser.

II. METHOD

In the centre of mass the recoil neutrons of the reaction

$$\underset{(1)}{\pi^-} + \underset{(2)}{P} \rightarrow \underset{(3)}{N} + \underset{(4)}{X^0} \qquad (1)$$

have a discrete momentum p_3^0 (or corresponding β_3^0) and a corresponding centre of mass angle Θ_3^0. Transformation to the laboratory system (Jacobian transformation) gives a broad distribution of the neutron momenta

$$p_3^{min} \leqq p_3 \leqq p_3^{max} , \qquad (3)$$

the minimum and maximum p_3 values being given by the incident pion momentum p_1, and the missing mass M_X. The corresponding angular distribution in the laboratory system is

$$\cos \Theta_3 = \frac{M_X^2 - m_1^2 + 2E_0 T_3}{2p_1 p_3} \qquad (4)$$

with $E_0 = E_1 + m_2$. If the centre of mass moves faster than the recoil neutron in centre of mass, i.e. if

$$\beta_{c.m.} > \beta_3^0$$

there exists a maximum angle Θ_3^{max} of neutron emission in the laboratory system

$$\cos \Theta_3^{max} = \frac{1}{2 m_3 p_1} (M_X^2 - m_1^2)(4 m_3 E_0 - M_X^2 + m_1^2)^{1/2} . \qquad (5)$$

This is the angle of the so-called "Jacobian peak".

A graphical method to construct the transformation is illustrated in Fig. 1.

The missing mass of the neutron, i.e. the meson mass M_X

$$M_X^2 = (E_1 + m_2 - E_3)^2 - p_1^2 - p_3^2 + 2 p_1 p_3 \cos \Theta_3 \qquad (6)$$

can be found in the laboratory system by measuring simultaneously two quantities: the neutron angle Θ_3 and the neutron momentum p_3. For a given M_X, pairs of corresponding values of p_3 and Θ_3, populate a curved line ("mass line") in the $\cos \Theta_3$, p_3 plane, as shown for example, in Fig. 2. The aim of the experiment is to find such mass lines in the $\cos \Theta_3$, p_3 plane.

"Non-resonating" pions produced in π-P collisions in the target contribute an uncorrelated background.

IV. JACOBIAN PEAK METHOD

It is now of great importance that the existence of a meson mass M_X can already be established by measuring only one quantity, namely the neutron angle Θ_3 (instead of both angle and momentum), if the accepted p_3 momentum band is experimentally chosen, such that it is narrow enough and, that it is centred at the maximum angle Θ_3^{max} of the mass line (i.e. minima in Fig. 2). In this case the existence of a discrete meson mass will manifest itself as a peak in the angular distribution of the recoil neutrons, as is illustrated in Fig. 3 ("Jacobian peaks"). The percentage of neutrons going into the Jacobian peak direction depends strongly on the centre of mass angular distribution, i.e. on the reaction mechanism, and generally increases with increased incident pion momentum p_1.

Two-parameter-analysis, i.e. measuring simultaneously cos Θ_3 and p_3, may however, in general, be of advantage in view of the fact that it is difficult to estimate in advance how the cross-section for X^0 production behaves along the mass line. If it is smooth or centred at Θ_3^{max}, the Jacobian peak method alone is already very effective.

V. EXPERIMENTAL PROCEDURE

The experimental arrangement to measure the angular and momentum distribution of the recoil neutrons in reaction (1) is shown in Fig. 4.

Incoming pions π^- interacting with the protons in the H_2 target are detected by the fast coincidence (T1, T2, $\overline{\overline{T3}}$) in C01. The signature for X^0 decay consists of 2n charged pions (n = 1,2,3 ...) emitted in a forward direction and detected by the vertex counter V, and, in addition, no charged particle leaving the target sideways, i.e. anticounter A in anticoincidence. γ's from π^0 decay are eliminated after conversion in C by anticounter A, so the complete coincidence requirement in C01 for meson X^0 production is (T1 T2 $\overline{\overline{T3}}$ V$\bar{A}$).

The neutron detector N consists of 24 slabs of plastic scintillator ($80 \times 15 \times 10$ cm^3), set up as a fence around the target at a distance of four metres. Each slab is viewed by a small phototube, their outputs going to a 24 channel pattern unit for encoding the angular positions, i.e. the pattern unit information gives the neutron angular distribution. The neutron time-of-flight (TOF) is measured by three large area phototubes, each viewing one of three batteries of eight scintillator slabs; the long sides of the scintillators of each battery are open for light, only towards their common big tube; each TOF unit is contained within a light-tight housing. The TOF start signal comes from T2, the stop from the mixed TOF tube output.

Fast anticounters A1′, A2′, A3′ shield the neutron counter N against general charged background.

"Good" neutrons correlated with "good" C01 events are finally selected by the coincidence C03. The complete requirement is $(T1\ T2\ \overline{T3}\ V\ \bar{A}\ N)$. The C03 output then opens the gates for TOF and for the pattern unit. Time-of-flight and PU information are fed into an online computer or into a magnetic tape.

VI. EVENT RATE AND BACKGROUND

We expect one event per PS burst under the following conditions:

cross-section for X^0 production	= 1 mb	
target length	= 10 cm	
number of pions per burst	= 10^5	($\Delta p_1/p_1$ = 2% half width)
neutron-detection efficiency	= 25%	(at 300 MeV/c) .

The background problem is less serious than in the proton missing-mass spectrometer due to the possibility of eliminating charged particles by anticounters. The main contribution to neutron background will probably come from the reaction

$$\pi^- + P \rightarrow N + n\pi \quad (\sigma_{total} = 8 \text{ mb}) .$$

This gives four neutrons per burst into the detection system, so that a signal to noise ratio of about ¼ is expected. Therefore, the machine time requirement is roughly the same as in the proton proposal[2)]: four weeks PS time = 76 shifts.

VII. MASS RESOLUTION

The determination of M_X is affected by the precision with which the quantities p_1, p_3 and Θ_3 are measured. Here, we give the separate influences of errors in p_1, p_3 and Θ_3 on the missing mass M_X :

$$\Gamma^{p_1}_{exp} \cong \frac{p_3 \cos \Theta_3 - \beta_1 T_3}{M_X} \Delta p_1 \qquad (7)$$

$$\Gamma^{p_3}_{exp} \cong \frac{p_1 \cos \Theta_3 - \beta_3 E_0}{M_X} \Delta p_3 \qquad (8)$$

$$\Gamma^{\Theta_3}_{exp} \cong \frac{p_1 p_3 \sin \Theta_3}{M_X} \Delta \Theta_3 \quad . \qquad (9)$$

For a fairly monoenergetic incident pion beam ($\Delta p_1/p_1$ = 1 - 2% half width) and neutron momenta p_3 in the region of the Jacobian peak, the main contribution to an error Γ_{exp} in M_X comes from the angular uncertainty $\Delta\Theta_3$. In the neutron missing-mass spectrometer $\Delta\Theta_3$ is given purely by geometrical angular resolution, i.e. by the finite size of the target and the neutron detector elements; this angular resolution is therefore independent of the neutron momentum, contrary to the proton missing-mass spectrometer, where the mass resolution is limited towards low momentum transfer by multiple scattering, as already pointed out above.

Here, we give two representative figures for the mass resolution Γ_{exp} of the proposed neutron spectrometer:

Γ_{exp} = ± 33 MeV for p_1 = 10 GeV/c incident pion momentum
p_3 = 500 MeV/c neutron recoil momentum
M_X = 1.5 GeV meson mass

Γ_{exp} = ± 21 MeV for p_1 = 5 GeV/c
p_3 = 250 MeV/c Ditto
M_X = 0.750 MeV (= ρ)

assuming an angular resolution of $\Delta\Theta_3 = \pm 1^\circ$ according to the proposed set-up (Fig. 4), and a momentum spread of the incident pion beam of $\Delta p_1/p_1$ = 2% (half width).

The simultaneously covered mass range of the spectrometer is ΔM_X = 1.5 GeV at p_1 = 10 GeV/c, according to a range in neutron angle Θ_3 of $\Delta\Theta_3 = 36^\circ$.

Finally, it is of interest to note that a more sophisticated vertex analyser would make the reconstruction of the vertex inside the H_2 target possible. In this case even in the neutron missing-mass spectrometer a large target (i.e. high event rate) could be used.

The limits of application of the neutron missing-mass spectrometer towards low neutron momenta are at about p_3 = 150 MeV/c, given by the detection threshold of the neutron counter. The upper p_3 limit of about 1 GeV/c is set by time-of-flight uncertainties. The highest detectable mass M_X should therefore be M_X = 3 GeV (at 15 GeV/c incident pion momentum).

REFERENCES

1) B. Maglic, G. Costa, R. Blieden, F. Lefebvres, D. Freytag, C. Iselin, H. Slettenhaar and B. Levrat, "Missing-mass spectrometer with online computer", Dubna International Conference on High-Energy Physics (1964).

2) B. Maglic and G. Costa, "Missing-mass spectrometer for heavy mesons", proposal for an experiment, CERN NP Division, Technical Memo MM- 1, May (1963).

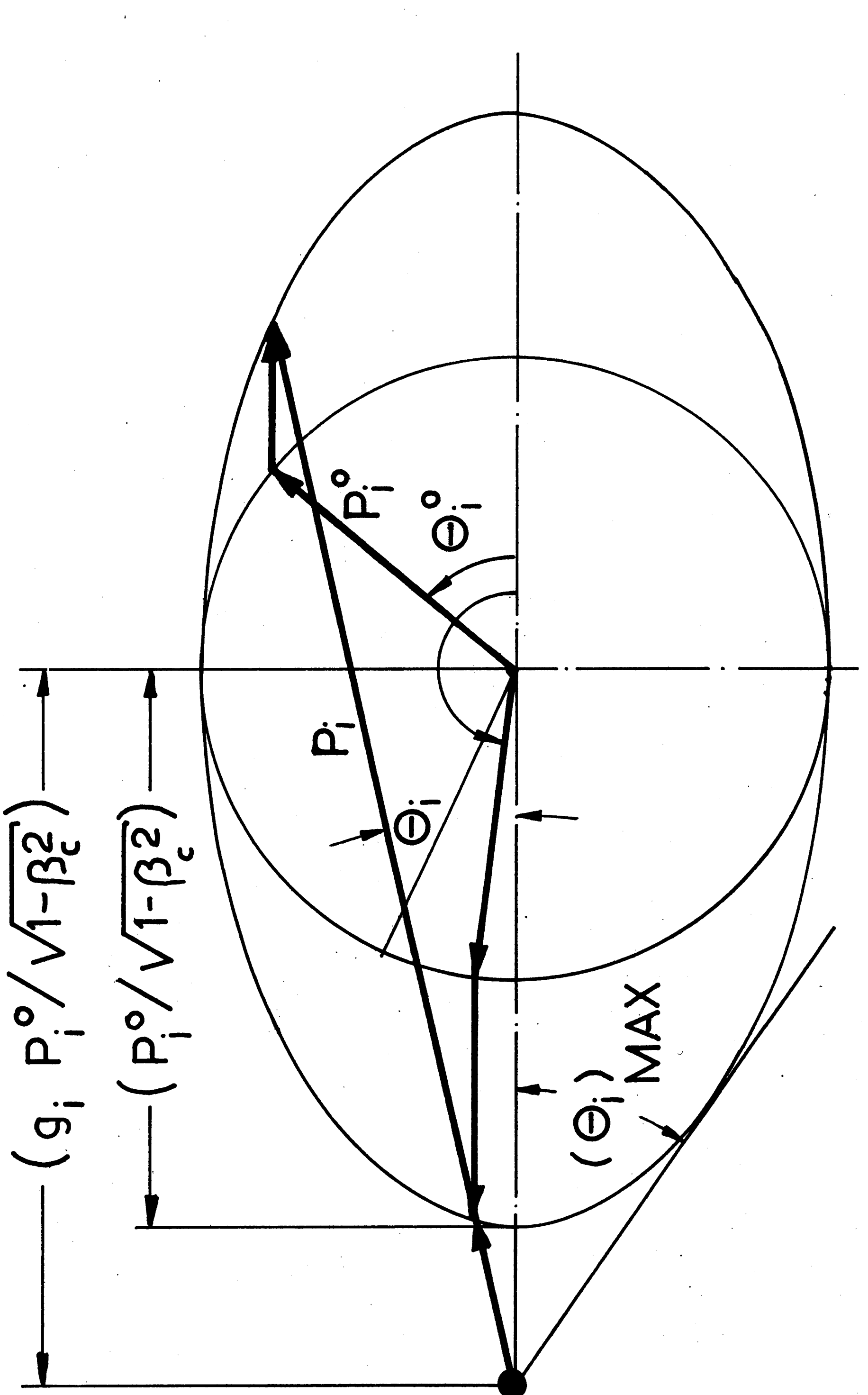
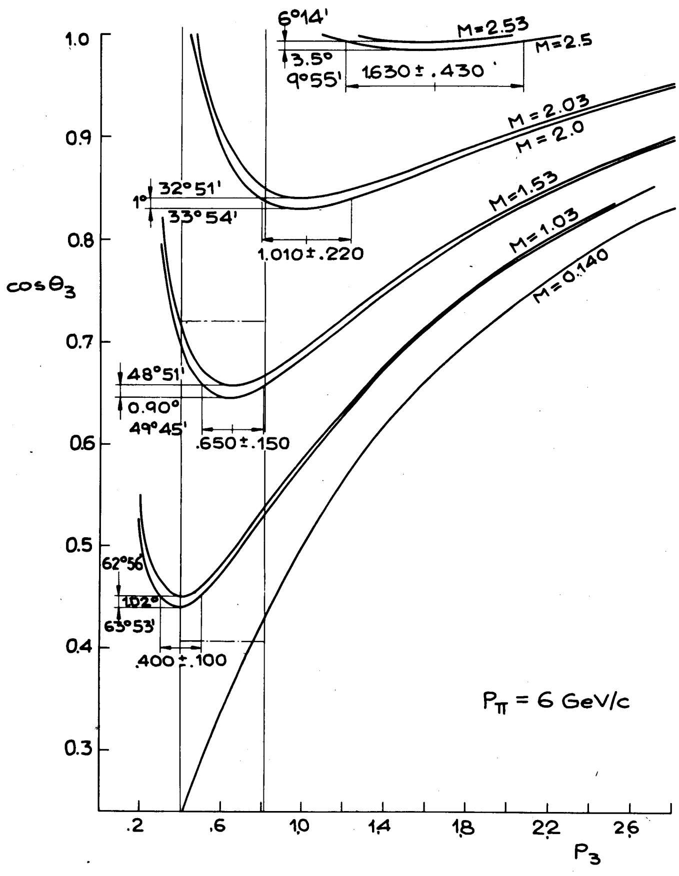
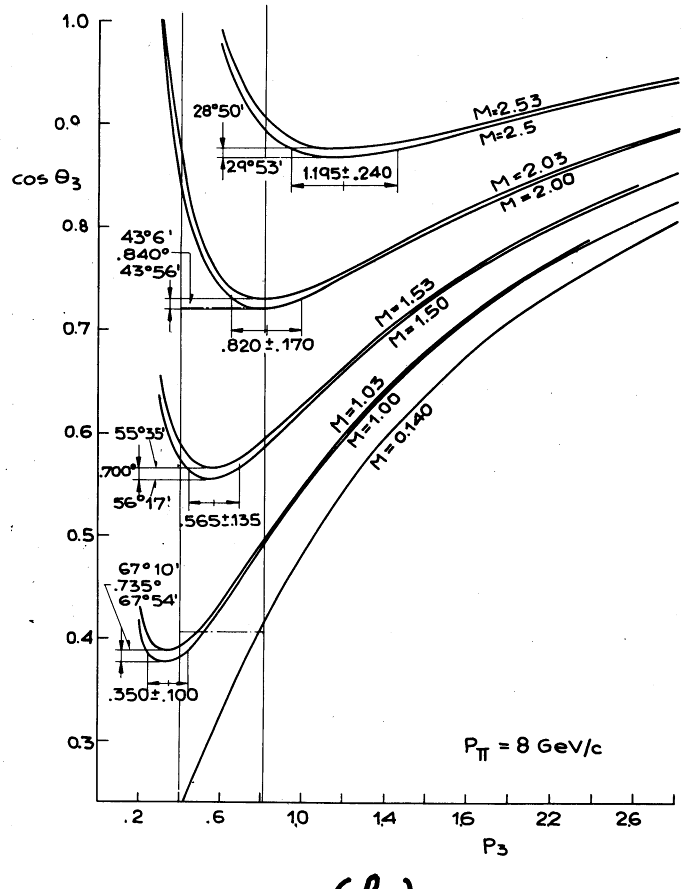

A
P_i
P_i^o
Θ_i
Θ_i^o
$(\Theta_i)_{MAX}$
$(g_i\ P_i^o/\sqrt{1-\beta_c^2})$
$(P_i^o/\sqrt{1-\beta_c^2})$

FIG.1



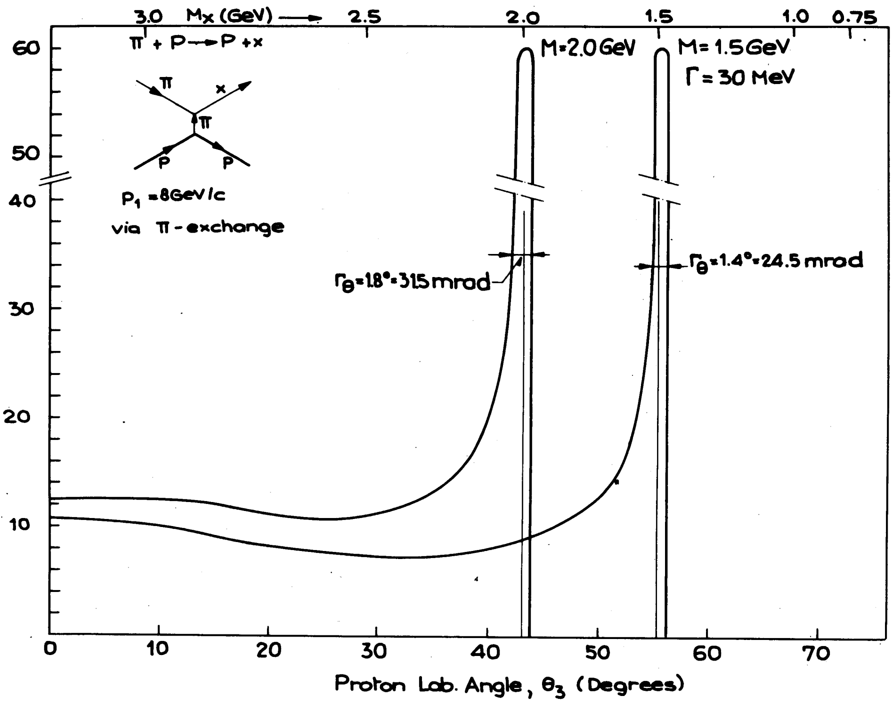
cos θ3
P3
M=2.53
M=2.5
M=2.03
M=2.0
M=1.53
M=1.03
M=0.140
6°14'
3.5°
9°55'
1.630 ± .430
32°51'
1°
33°54'
1.010 ± .220
48°51'
0.90°
49°45'
.650 ± .150
62°56'
1.02°
63°53'
.400 ± .100
Pπ = 6 GeV/c

(a)

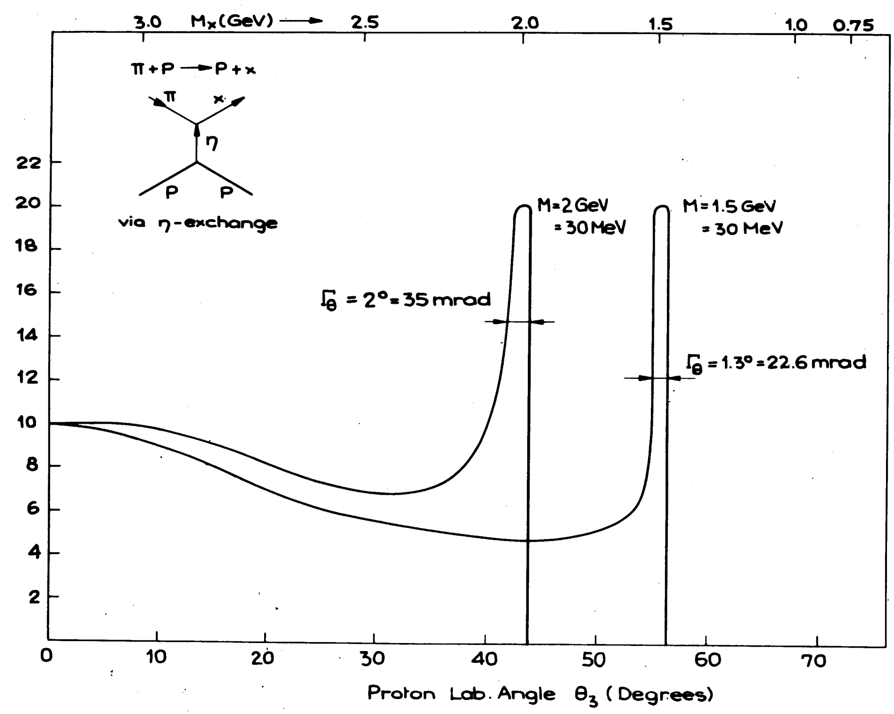


cos θ3
P3
M=2.53
M=2.5
M=2.03
M=2.00
M=1.53
M=1.50
M=1.03
M=1.00
M=0.140
28°50'
29°53'
1.195 ± .240
43°6'
.840°
43°56'
.820 ± .170
55°35'
.700°
56°17'
.565 ± .135
67°10'
.735°
67°54'
.350 ± .100
Pπ = 8 GeV/c

(b) Fig. 2



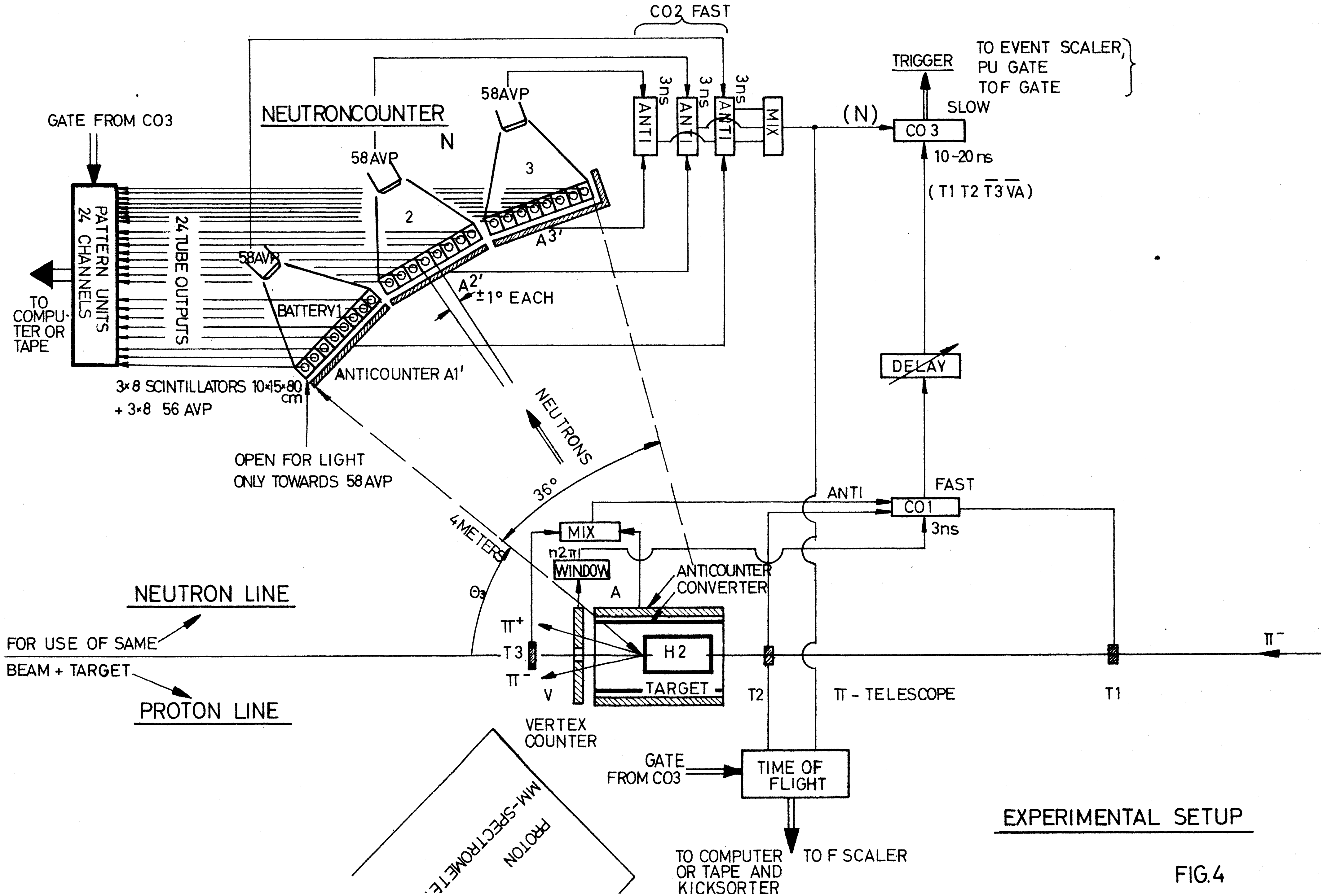
(a)



(b)

FIGURE 3

SIS/R/8955



EXPERIMENTAL SETUP

FIG.4