EUROPEAN ORGANIZATION FOR NUCLEAI

To Members of the
E.E.C.

PH/ I/COM-68/48
19 September 1968

PHYSICS I

ELECTRONICS EXPERIMENTS COMMITTEE

EXPERIMENTAL PROGRAM TO STUDY THE PRODUCTION OF NEUTRAL MESONIC RESONANCES IN $\pi^- p$ INTERACTIONS AT HIGH ENERGIES AND OF THEIR DECAY MODES IN NEUTRAL CHANNELS

E. Bertolucci, I. Mannelli, G. Pierazzini, A. Scribano,
F. Sergiampietri, L. Vincelli

Istituto di Fisica della Università di Pisa and INFN Sezione di Pisa

W. Deinet, A. Menzione, H. Müller, D. Schmitt++), H. Staudenmaier

Institut für Experimentelle Kernphysik
Universität und Kernforschungzentrum Karlsruhe

++) CERN visitor

INTRODUCTION

Studies of $\pi^- p$ interactions, with all neutral non strange particles in the final state, have been performed with heavy liquid bubble chambers, with spark chambers which detect only the decay products of the mesons, with neutron spectrometers or, in a few cases, with a combination of spark chambers for the γ rays and of scintillation counters for the neutron detection.

The information which have been obtained range from the determination of decay modes of known resonances (η, f^0, ω, X^0), to results about the possible existence of others (ϵ^0), to accurate measurements, over a wide interval of s and t, of some two-body processes ($\pi^- p \rightarrow \pi^0 n$, $\pi^- p \rightarrow \eta n$ and to a lesser extent $\pi^- p \rightarrow f^0 n$) including determination of the polarization parameter, to studies of the $\pi\pi$ interaction in states of even angular momentum etc.

We believe that presently a more accurate and systematic experimental study of this field should be undertaken. To be really meaningfull, in view of the complications which can be anticipated now that situations as the A_2 splitting are known to occur, it should include the most detailed possible measurements of the final states. For this purpose we propose to build an apparatus which includes:

a) a liquid hydrogen target with localization (to about ±3 cm over a total length of 40 cm) of the interaction point;

b) a spark chamber with high detection efficiency for γ rays (up to 6-8 γ) which can also provide, by spark counting, an estimate of their energies (to about ±25%);

c) a large size (8 counters $16 \times 16 \times 200$ cm^3 each) neutron spectrometer.

When all the γ rays produced are actually detected in such an apparatus, the events are kinematically overdetermined and the constraints can be used to strongly reduce the background and to improve the resolution in each individual channel. High detection efficiency for up to 6 γ's (this seems to be also the practical limit for unambiguous reconstruction) over a well specified solid angle can indeed be achieved in the region of the forward peak at high incident energies.

Further details of the experimental apparatus and of its predictable performance for the proposed use are given in paragraphs 2 and 3 respectively. Paragraph 1 contains a short review of problems of current interest in the field and paragraph 4 a possible time schedule.

Since it will take almost a year to build and test the whole apparatus, it seems necessary to obtain, as early as possible, the opinion of the E.E.C. on the experimental program that we are proposing.

1. SHORT REVIEW OF TOPICS OF CURRENT INTEREST

1.1 Search for new resonances

A number of recent experimental findings and theoretical speculations are strongly suggestive that several new mesonic resonances exist in the 1.2 - 1.5 GeV mass region.

The splitting of the A_2 is well established and there are indications for splitting of f^o 1) in its $\pi^+\pi^-$ decay mode.

i) The Gell-Mann Zweig model requires that also daughter trajectories are occupied by particles. The C quantum number of daughters has to be the same as that of the parents. This model implies that each 2^+ meson has a partner with $J^P = 1^-$. Similarly the B meson and the other members of the 1^+ nonet have 0^- partners with unnormal C parity.

ii) The partner of the A_2 is the lowest lying $q\bar{q}$ state with $l = 3$. The low mass value derives from the very strong l-S coupling. This model allows $J^P = 2^+$ for the A_2 partner. The 1^+ mesons have no partners with the same J^P, but the lowest mass values of the $l = 2$ mesons ($J^P = 1^-, 2^-, 3^-$) are supposed to extend also down to the $l = 1$ mesons ($0^+, 1^+, 2^+$).

iii) The partner of the A_2 is a radially excited state. The allowed quantum numbers are then $J^P = 1^-$ or 0^-. Here one has already another candidate: the E(1420) for which 0^- is highly favoured.

iv) The $0^+, 1^+, 1^+, 2^+$ meson are considered as $q\bar{q}q\bar{q}$ states. This model has already been discussed by Dalitz in his review talk at the Berkeley Conference. It allows two systems of $0^+, 1^+, 1^+, 2^+$ resonances. The exotic ones (I = 2 or 3/2) may have escaped observation because their production could be inhibited.

In conclusion more resonances are expected than are currently known and since it is essential to determine quantum numbers the experimental task is not only to find bumps but it must include a complete analysis of the final states.

1.2 Electromagnetic decay modes in neutral channels

Up to now these decay modes have been observed only for π^0, η, ω, X^0. It is clear that the observation of a final state with a given number of γ rays directly establishes the C quantum number of the parent resonance and puts restriction on its spin. It is also of interest to verify the specific predictions about the branching ratios which are made by the quark and vector dominance models.

1.3 $\pi\pi$ interaction in states of even angular momentum

Indirect information about $\pi\pi$ s-wave interaction comes from studies of the decay asymmetry of the neutral ρ. It is restricted to the mass interval 600 - 900 MeV and moreover it suffers from ambiguity; one possibility is to explain the results in term of a s-wave resonance, with width and position similar to those of the ρ, the second possibility corresponds to a s-wave phase shift which stays near 90° over the whole region, i.e. a resonance several hundreds MeV wide. Such a broad resonance gives a $\pi^0\pi^0$ mass spectrum which looks very much like phase space. The best way to get quantitative informations consists in performing a $2\pi^0$ production experiment, with absolute determination of cross-section and sufficient statistical accuracy to allow a reliable Chew-Low extrapolation.

2. EXPERIMENTAL APPARATUS AND METHOD ANALYSIS

A typical layout is sketched in Fig. 1. The negative pion beam (4 to 12 GeV/c; 5×10^4 to $10^5 \pi^-$/pulse) is focussed onto the 40 cm long liquid hydrogen target, with localization of the interaction point by Čerenkov effect[2)]. The γ rays, emitted in the forward direction within a 30° cone, are detected in the 12 conversion lengths spark chamber. The scintillation counter spectrometer measures the time of flight and the position of the recoil neutrons. A beam hodoscope and a few light plates spark chamber modules can be added for possible measurements of $K_s K_s$ final states.

For the standard trigger it will be required that an incoming π^- is absorbed in the target and no signal is given by any of the anticoincidence counters, while a neutron is detected within a suitable time interval.

We now give further details about the proposed apparatus and a brief outline of the method of analysis.

2.1 Liquid hydrogen target

We have recently tested at the PS[2)] a hydrogen target with good collection efficiency for the Čerenkov light produced in the liquid by high energy pions. When the final state consists of only neutral particles, the amount of light emitted depends on the length of the pion path from the entrance window to the interaction point. A measurement of the light gives therefore a direct information about the location of the interaction along the target.

The result of the calibration for a 20 cm long cell is an almost constant resolution of about ±1.5 cm. We are now designing a 40 cm target for which we expect a resolution better than ±3 cm. This is a good match to the precision in position which can be achieved for neutrons with scintillation counters.

Since in the region of the jacobian peak the resolution in missing mass is determined mainly by the precision in the measurement of the neutron polar angle, it is evident that the adoption of such a target allows an increase of almost an order of magnitude in the usable target length. Other advantages, for checking and intercalibration purposes, are the facts that:

i) a given reaction, at fixed momentum transfer, produces neutrons which go in different portions of the spectrometer;

ii) neutron recoils of the same energy, but corresponding to different mesonic masses and interaction points, can reach the detector in the same spot.

A continuous monitor of the target performance is provided by the pulse height spectrum associated with straight-through particles.

In the design of the target particular care is taken in minimizing the average γ conversion probability in the walls. This is an important requisite in order to be able to detect multi γ final states with good efficiency.

2.2 Spark chamber for detection of the γ rays and measurement of their energy

With metal plates spark chambers and gaps of about 10 mm it is possible to obtain, from spark counting, an estimate of the energy, with resolution of the order of ±25%, for γ rays between ~100 MeV and several GeV.

Gaps of 20-30 mm give better multiple spark efficiency and the development of a shower is less affected by the possible presence of other showers in the same spark chamber. However, such fairly wide gaps have not been adopted due to the consequent increase in size for very large solid angle detectors.

A further improvement can be achieved by using plates with low surface conductivity[3)], at the expense however of a substantial loss in spark luminosity.

We are currently making tests with electrons at Frascati in order to optimize the design.

Indicatively the spark chamber will have a size of 150 × 150 × 80 cm^3 and 2 cm wide gaps. There will be 4 thin plates, 20 plates with .35 and 8 plates with .7 conversion lengths of lead. The typical distance of the spark chamber from the target will be 150 cm. The optics will use Plexiglass prisms and we will take 4 views in such a way that each shower will have a good chance to appear not overimposed to others in at least one view.

2.3 Neutron spectrometer

For the neutron detection we plan to use plastic scintillation counters which allow a resolution in position determination in the longitudinal direction of about ±3 cm. In order to be able to perform the exploration of a large missing mass interval, with good resolution and under uniform conditions, we have chosen counters with length of 200 cm and a 16 × 16 cm^2 cross-section. A group of 8 such counters, arranged differently according to the reactions on which the attention will be focussed during a given exposure, will generally allow to cover a sizable fraction of the azimuthal solid angle.

We expect to make absolute efficiency calibration to about ±5% as a function of the neutron energy and to establish a control procedure which will allow regular periodical checks.

The informations about the neutron position and time of flight will be recorded on magnetic tape together with the content of scalers and pattern units.

2.4 Reconstruction of the events

For the analysis we plan to scan the pictures visually and to measure on standard digitized tables the conversion points of the γ rays, choosing for each one the view in which the spark count can be carried out most easily. The result of this operation will be used as a guide for an HPD or LUCIOLE type machine which will perform the actual spark counting and geometrical measurements.

We have developed a reconstruction program which, on the basis of the above information from the spark chamber and according to various assumptions about the nature of the event, in a first step, classifies all possible combinations of γ rays in pairs, depending on the χ^2 relative to the condition imposed for the mass of each pair. In a subsequent step the same program makes use also of the neutron angle and energy determination to test a number of overall kinematical fits. A classification of the different combinations is finally performed and a data summary tape prepared for SUMX selection.

This whole procedure has been extensively tested using Monte Carlo simulated events in order to evaluate the reliability and efficiency of the reconstruction and selection criteria. By allowing for the foreseeable experimental uncertainties, the Monte Carlo simulation is also used to get estimates of effective resolution in various interesting quantities.

3. PROPOSED EXPERIMENTAL STUDY

From the analysis of the present experimental and theoretical situation, as briefly outlined in paragraph 1, and from an examination of the kinematical characteristics of production and decay in various channels, we have come to the conclusion that two runs should be made covering different mass regions.

3.1 Survey run in the mass region 900-1400 MeV with 6 GeV/c π^- incident momentum

The main purpose of this run would be to study systematically this region, by kinematically fitting events in the following channels: 2γ, $\pi^0\gamma$, $\underset{\hookrightarrow 2\gamma}{\eta}\gamma$, $\pi^0\pi^0$, $\underset{\hookrightarrow 2\gamma}{\eta}\pi^0$, $\underset{\hookrightarrow 2\gamma}{\eta}\;\underset{\hookrightarrow 2\gamma}{\eta}$, $\underset{\hookrightarrow \pi^0\gamma}{\omega}\pi^0$, $3\pi^0$ and, for channels with more than 6γ, simply by making missing mass plots for fixed numbers of γ's. It is clear that new resonances may be found in this way. In the following we will however limit ourselves to considerations about the already reported ones.

For this run we propose to put the eight $16 \times 16 \times 200$ cm^3 counters at 5 meters from the target, covering the 45° to 68° range for the neutron polar angle and about 5% of the total azimuthal angle. With 40 cm long target, 5×10^4 π^-/pulse, 1,500 pulses/h and 12% efficiency for the detection of neutrons which reach the counters, the number of events per hour of useful running time is

$$N_{ev}/h = 7 \times 10^{29} \times \epsilon_\gamma \times \int_{t_{min}}^{t_{max}} \frac{d\sigma}{dt}\, dt$$

where ϵ_γ is the probability that all γ's are detected in the spark chamber and $d\sigma/dt$ $[\mathrm{cm}^2/(\mathrm{GeV}/c)^2]$ the differential cross-section for the process under consideration. At 6 GeV/c ϵ_γ (for 4γ's) is between 0.3 and 0.7 according to the mass and decay mode. We plan to accept the range of momentum transfers $0.04 \leq |t| \leq 0.5$ $(\mathrm{GeV}/c)^2$ which normally includes ~2/3 of the total cross sections at this energy [slope between 4 and 10 $(\mathrm{GeV}/c)^2$].

The kinematics is illustrated in Fig. 2. The resolution in missing mass is typically 35 MeV fwhm. This we consider adequate in most cases and although it may be not sufficient to see double peaks it should allow to analyse the two halves for spin and parity.

The total cross-section for $\pi^- p \to \underset{\to 2\pi^0}{f^0} n$ is ~120 μb, for $\pi^- p \to \underset{\hookrightarrow \underset{\hookrightarrow 2\gamma}{\eta}\pi^0}{A_2^0} n$ is ~8 μb. Consequently we expect respectively ~1700 and ~140 useful events per week (100 hours of effective running time) with a total average triggering rate of less than 1 per pulse.

We now give a brief description of what can be done in the various channels.

i) $\pi^0\pi^0$ $(\eta\eta)$ system for mass $\gtrsim 0.9$ GeV

The quantum numbers allowed are only $I = 0, 2$ ($I = 0$ for $\eta\eta$) and $J^P = 0^+, 2^+, 4^+ \dots$

The problem of highest interest in this channel is the possible splitting of the f^0 [1]. As already mentioned a critical test of the Gell-Mann Zweig generalized quark model is the prediction that the partner of the normal 2^+ mesons should have $J^P = 1^-$. In this case both f^0 partners could decay in $\pi^+\pi^-$ but only the 2^+ partner in $\pi^0\pi^0$. The width observed in the $\pi^0\pi^0$ spectrum should hence be narrower (and the peak shifted) in respect to that of $\pi^+\pi^-$.

A narrow $I = 0$ $\pi^+\pi^-$ resonance at 1050 MeV has been reported at the Vienna Conference[4]. The angular distribution favours $l = 2$, thus it cannot be the K_sK_s (1070). If the effect is real it should appear more clearly in $\pi^0\pi^0$ since there is no ρ background contribution.

A narrow peak has been reported at 940 MeV for $\pi^+\pi^-$ [5] produced in $\pi^-p \rightarrow \pi^+\pi^-n$ at 11.2 GeV/c, with no indication about quantum numbers. It seems of some interest to look for it in $\pi^0\pi^0$.

ii) $\eta\pi^0$ system

The quantum numbers allowed are $I^G = 1^-$ and $J^P = 0^+, 1^-, 2^+, \dots$ We can expect to see this mode for the $\delta(960)$ and for the A_2.

The $\delta(960)$ has been established in the decay $\eta\pi^\pm$. Quantum numbers are $I^G = 1^-$ and probably $J^P = 0^+$. The observation for

$$\pi^-p \rightarrow \delta^0 n, \quad \delta^0 \rightarrow \eta\pi^0, \quad \eta \rightarrow 2\gamma$$

would represent further confirmation.

In the case of the A_2 the $\eta\pi$ mode has been observed in bubble chamber as a single low statistics peak, with very little background. This channel is not allowed for $J^P = 1^+$ but both 2^+ and 1^- quantum numbers are possible. So the angular momentum analysis of the upper and lower A_2 mass region is of extreme interest. Also there is no Deck effect background in this case.

We would like to point out that the A_2 should also be seen in 8 shower events from both the $\underset{\hookrightarrow 3\pi^0}{\eta}\pi^0$ and $\underset{\hookrightarrow 2\pi^0}{K_S}\ \underset{\hookrightarrow 2\pi^0}{K_S}$ decay channels. Finally by using the thin foil chambers we can study the final state $\underset{\hookrightarrow \pi^+\pi^-}{K_S}\ \underset{\hookrightarrow \pi^+\pi^-}{K_S}$ with a sufficient number of constraints.

iii) $3\pi^0$ states

The quantum numbers are $C = +$, $I \neq 0$, $J^P \neq 0^+$.

The Deck mechanism should be equally important in $\pi^-p \to 3\pi^0 n$ as in $\pi^-p \to \pi^+\pi^-\pi^-p$. If the A_1 is observed strongly in $3\pi^0$ it would mean that the $\pi\rho$ decay mechanism is not dominant; in this case A_1 resonance is either mostly due to the Deck effect or proceeds via $\pi\sigma(\sim 700)$.

iv) Final states with odd number of γ rays

$C = -$; $J \neq 0$.

The $B \to \omega\pi$ meson is now well established. $J^P = 1^+$ is slightly favoured in respect to 2^+ or 3^-. We expect to see $B \to \underset{\hookrightarrow \pi^0\gamma}{\omega}\pi^0$ with an effective cross-section of about 10 μb. It would be interesting to measure the ratio $\frac{B \to \pi^0\gamma \text{ (or } \eta\gamma)}{B \to \omega\pi^0}$ and to contribute to determine the J^P value.

We point out that about 10 events of $\phi(1020) \to \eta\gamma$ can be expected during a one week run, assuming a production total cross section of 5 μb. It is not easy to predict whether the background will be small enough, after the kinematical fit, to allow a meaningful measurement.

3.2 Run covering the mass interval from $2\pi^0$ threshold to ~1 GeV

The main purpose of this run would be to study the $\pi\pi$ interaction in S and D waves. We propose to follow the Chew-Low prescription: This implies the extrapolation of $d^2\sigma/dt\,dm$ to the pion pole ($t = m_\pi^2$) from the -0.04 to -0.5 $(\mathrm{GeV}/c)^2$ t region which is actually measured. The extrapolation is more reliable in this case, than when the recoil is a proton, since in there is no multiple scattering. Of course for this run it is essential to have a good absolute calibration of the detection efficiency.

At the same time enough events would be collected in one to two weeks of running time to allow a very good determination of the $\pi^-p \to \underset{\hookrightarrow \pi^0\gamma}{\omega}n$ production cross section and of the $\frac{\eta \to \pi^0\gamma\gamma}{\eta \to \gamma\gamma}$ branching ratio.

4. PROPOSED TIME SCHEDULE AND PS TIME REQUEST

For building, calibrating and testing the apparatus it will take about one year. So we could be ready to install the equipment on the PS floor at the end of the summer 1969.

The d beam in the South Hall would be suitable for this experiment.

Some four to six weeks of parasitic beam will be necessary for the set up. Six weeks total running time should allow to perform the two proposed runs.

REFERENCES

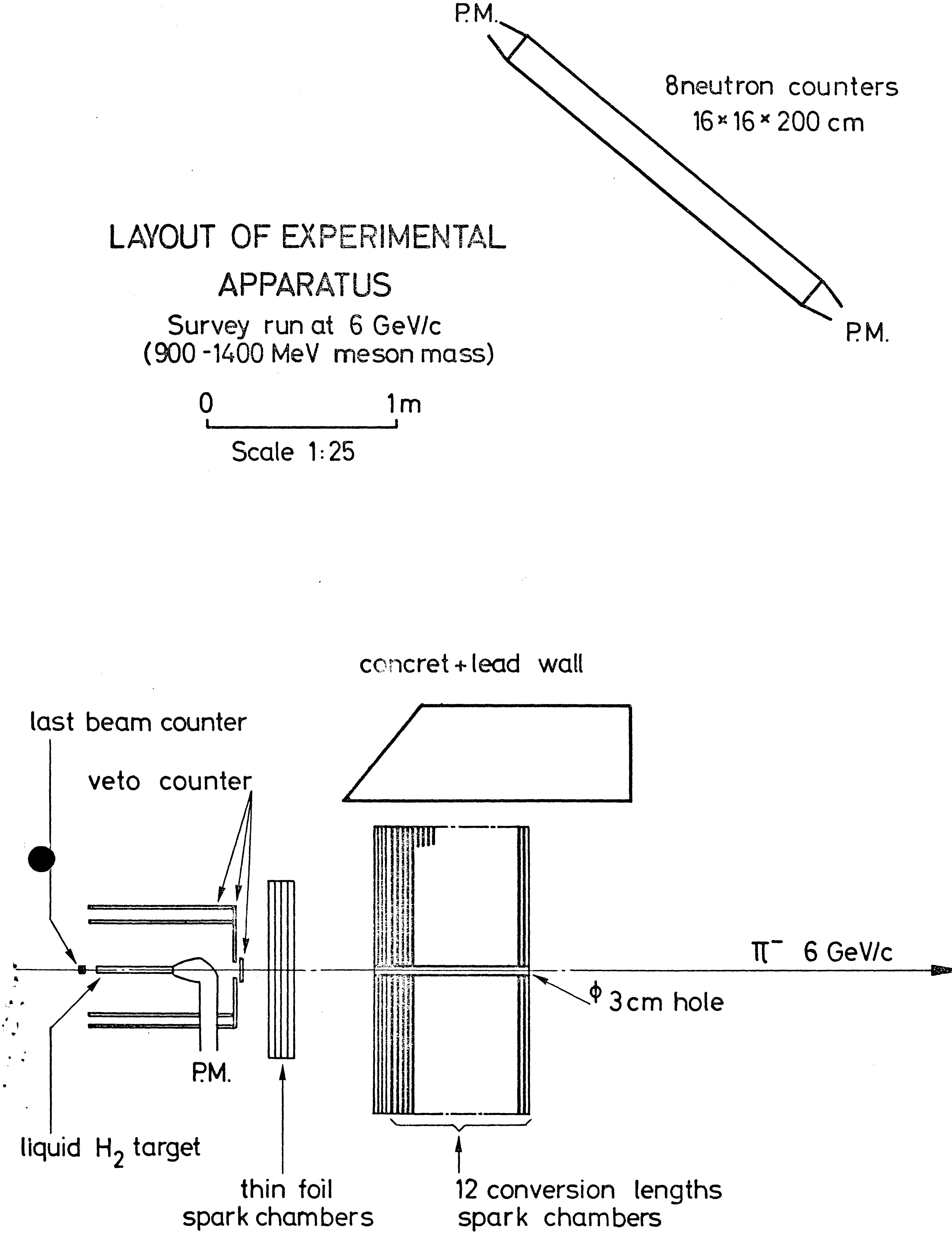
1) Search for a possible mass splitting in the f^0 region. V.P. Kenney et al., Contribution no. 21, Vienna Conference.

2) Liquid hydrogen target with interaction point localization by Cerenkov effect. E. Bertolucci et al., to be submitted to Nuclear Instruments and Methods.

3) Using metal plates covered with glass sheets, sparks wich are more than about 1 cm from each other develope quite independently. See R. Kajikawa, Journal of Physical Society of Japan 18, 1365 (1963).

4) Observation of an I = 0 $\pi^-\pi^+$ resonance at a mass of 1.05 GeV. D.H. Miller et al., Contribution 804, Vienna Conference.

5) The reactions $\pi^- p \to \rho^0 n$ and $K^- p \to K^{*0}(890)n$ at 11.2 GeV/c. B.D. Hyams et al., Contribution 765, Vienna Conference.


LAYOUT OF EXPERIMENTAL APPARATUS

Survey run at 6 GeV/c
(900 -1400 MeV meson mass)

FIG.1

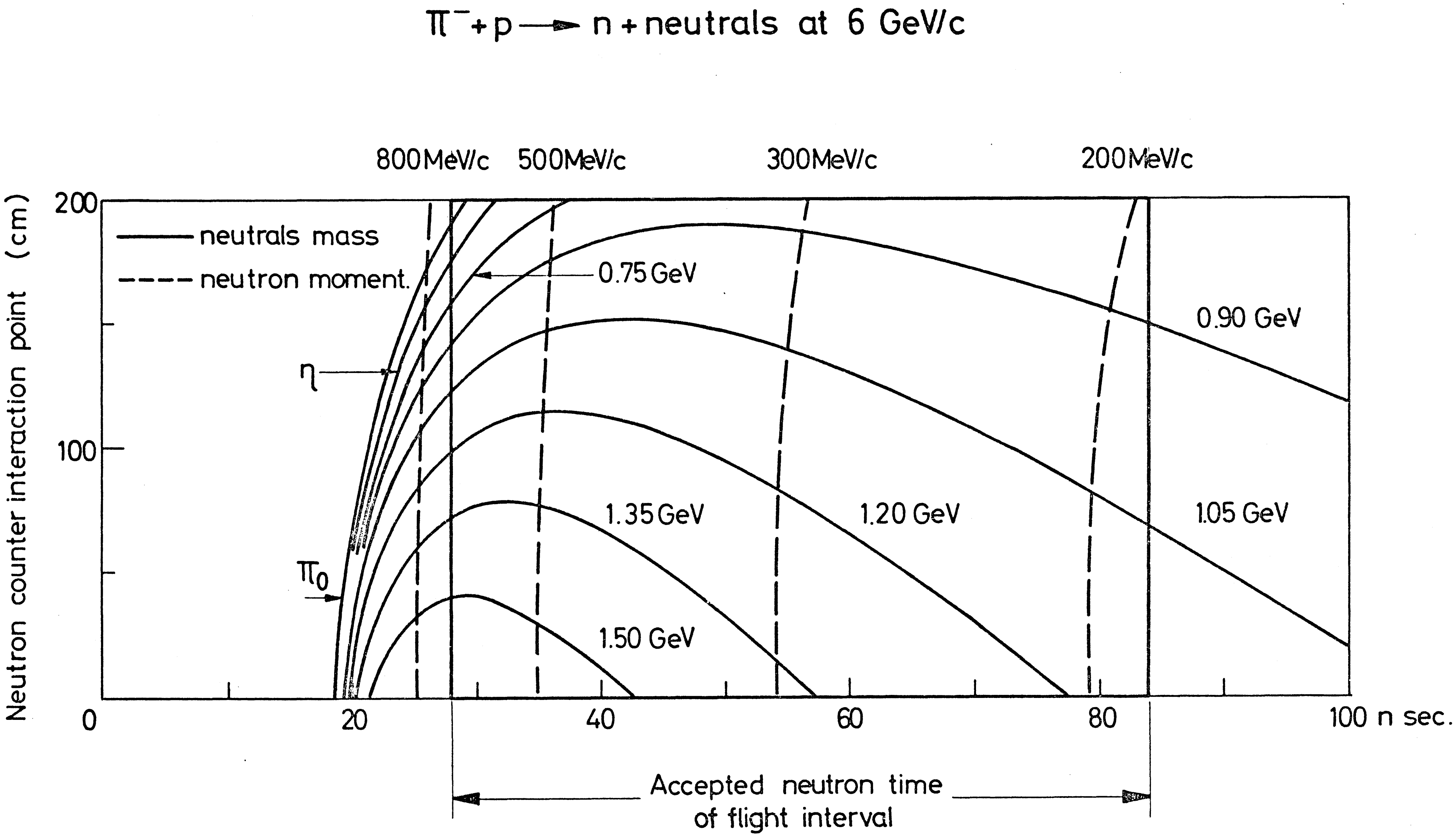

$\pi^- + p \longrightarrow n + \text{neutrals at } 6 \text{ GeV/c}$
800MeV/c
500MeV/c
300MeV/c
200MeV/c
neutrals mass
neutron moment.
0.75 GeV
0.90 GeV
1.05 GeV
1.20 GeV
1.35 GeV
1.50 GeV
η
π0
Neutron counter interaction point (cm)
200
100
0
20
40
60
80
100 n sec.
Accepted neutron time of flight interval

FIG. 2