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THE SINGLE PHOTOPRODUCTION OF NEUTRAL PIONS IN HYDROGEN IN THE ENERGY RANGE 600 TO 800 MEV. USE OF THE SPARK CHAMBER TECHNIQUE

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(presented by R. QUERZOLI)

1 - INTRODUCTION -

Many attempts have been done in recent past [1] to make a phenomenological picture of the pion photoproduction in the region of the higher π-nucleon resonances. Valuable experimental informations have come from angular distributions [2] and polarization measurements [3,4] ; the shape of the cross section as a function of energy has also been measured with care in π^+ photoproduction.

From the point of view of a phenomenological approach, the knowledge of the differential cross section for π^0 photoproduction is another very important piece of information, even more important then the charged pions one, owing to the absence of the direct photoproduction term.

This cross section has been measured by many authors, but generally with a rather poor energy resolution. With standard counter technique, in fact the resolution cannot be pushed very far, if one wishes the convenient statistics in reasonable amount of time. Furthermore, the fact that one measures the value of $\left(\frac{d\sigma}{d\Omega}\right)$ point by point at different times, may be a source of instrumental errors, at least energy.

These difficulties are both resolved by using the spark chamber technique in the measurement of process :

$$\gamma + p \longrightarrow \pi^0 + p$$

In fact, it is possible by the spark chamber to collect at the same time events extending to a rather large energy and angular region, with the most detailed information on the energy and angle of each single event.

In figure 1 the resolution of the present experiment is shown.

2 - EXPERIMENTAL DISPOSITION -

The experimental set-up is shown in figure 2. The spark chamber is formed by 19 aluminium plates 6 mm thick, 20 × 28 cm^2 ; the width of the gaps between the plates is 6 mm. The useful volume is 16 × 16 × 20 cm^3. The chamber is filled with neon at ~ . 8 atmospheres ; this gas is continiously circulating through hot calcium by means of a thermosyphon system, and in this way is kept pure. The photographic camera sees, through a system of mirrors, two 90° views of the S.C. : in this way spacial reconstruction of the events is possible.

The high voltage pulse to the S.C. is supplied through a spark gap, which is triggered by the coincidence :

$$(S_0,\ S_1,\ S_2,\ S_3,\ \bar{C}). \tag{1}$$

S_0, S_1, S_2, S_3 are scintillation counters (S_0 is 3 mm thick, the other ones 1/2") ; $\bar{C}$ is a plexiglass Cerenkov counter, whose aim is to eliminate the relativistic particles and most part of the pions.

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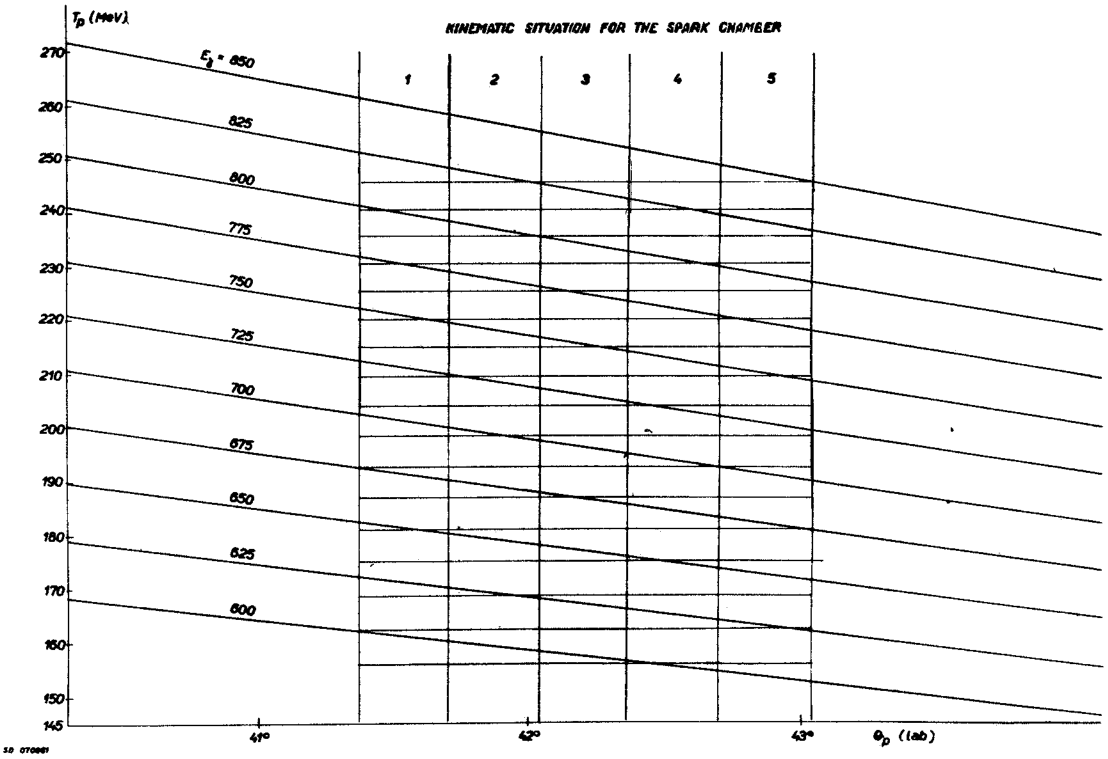

Figure 1

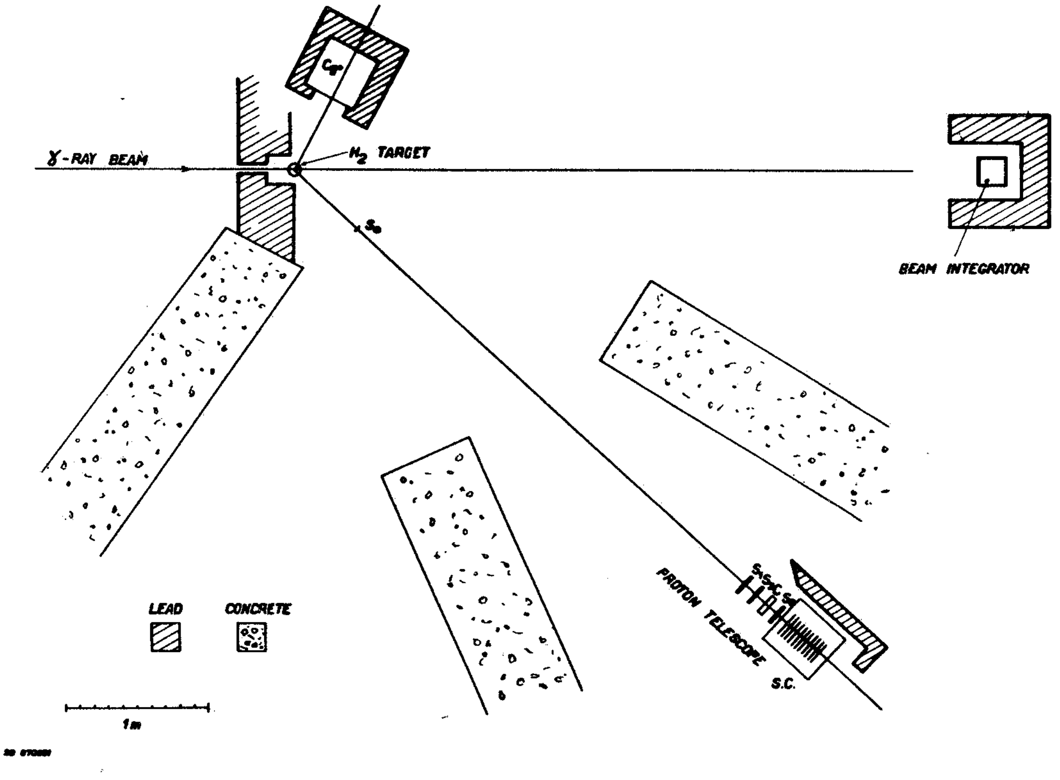

Figure 2

C_{π^0} is a total absorption lead glass Cerenkov counter to detect the π^0 ; if it give a pulse in coincidence with the coincidence (1), a neon lamp lights near the window of the S.C., and is photographed on the same slide with the particle track. This information is used as a subsidiary check, but is not included in the criteria of selection of the events, since the variations of the efficiency of C_{π^0} with energy could introduce a bias in the results.

Owing to counter S_0, our telescope does not see the walls of the hydrogen target ; in this way we can reduce the empty target background from $\sim 30\ \%$ to $3\ \%$. On counters S_1 and S_3, pulse height analysis is made : the height of the pulses is digitized in a 32-channel pulse height analyzer, and recorded on each photo in a binary form by means of neon lamps.

3 - DATA PROCESSING -

Each photo makes thus available to us the following informations about the concerned particle :

a) Angle of emission (directly related to the entrance point in the S.C.) ;

b) Range ;

c) Pulse height on counters S_1 and S_3 ;

d) If or not C_{π^0} gave a pulse in coincidence.

Information a) and b) give complete kinematical description of an event of single pion photoproduction. What we need is thus to know when the photographed particle is a proton ; in addition we have to evaluate the contribution of other photoproduction events with a secondary proton in the angular and energy region explored by the S.C.

i) Discrimination between protons and other kinds of particles.

Owing to the presence of the Cerenkov counter C in our counter telescope, most of the photographed particles are protons. There is however a contamination of pions, which some time do not

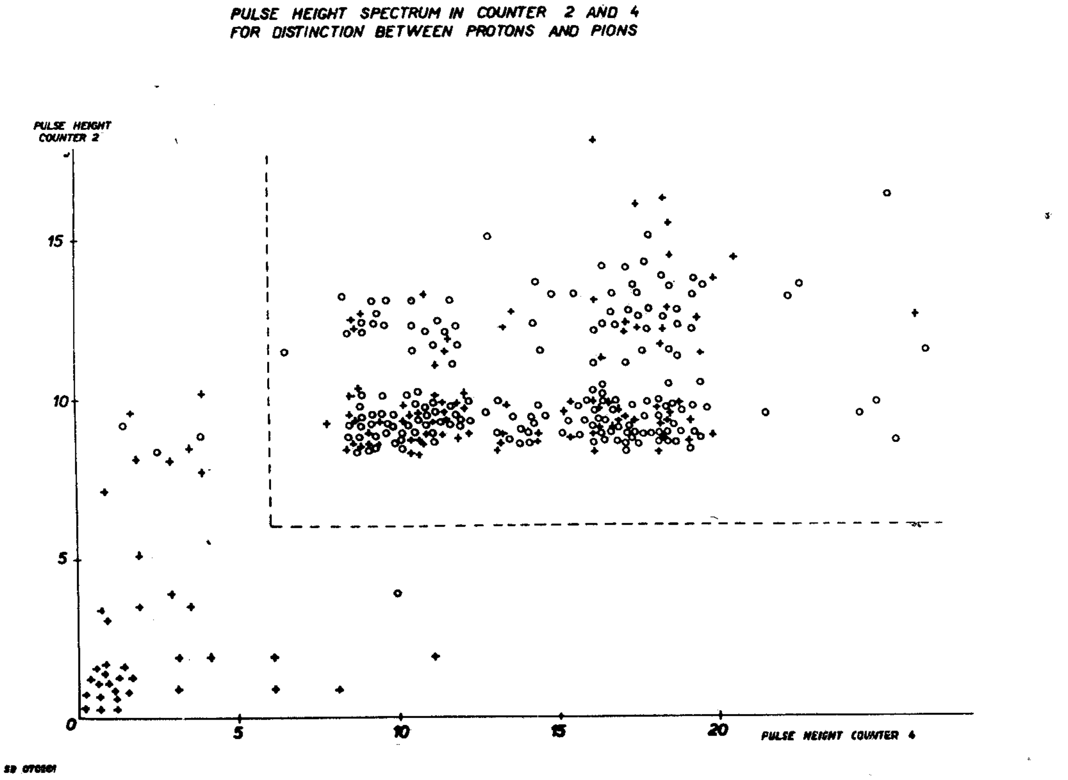

Figure 3

give a high enough pulse in C. For a given range, however, protons have a specific ionization about twice as large with respect to pions. Plotting in a two dimensional diagram the number of events with a fixed range as a function of pulse height in counters S_1 and S_3 (an example of such a diagram is given in figure 3), a clear separation between protons and pions is evident.

Particles which occured in coincidence with a pulse in C_{π^o} have systematically a pulse height corresponding to a proton, thus giving a further check of consistency. We make such a diagram for every roll of film (~ 400 protons, corresponding to about 40 minutes of machine time) ; in this way the distinction between protons and pions is not affected by possible drifts.

ii) Evaluation of the contribution of other kinds of processes.

Among the most important processes which give protons in the same angular and energy region as our process, we list :

$$\gamma + p \longrightarrow \pi^{o} + \pi^{o} + p$$

$$\longrightarrow \pi^{+} + \pi^{-} + p$$

$$\gamma + p \longrightarrow \gamma' + p \quad \text{(nuclear compton effect).}$$

On the basis of existing theories and experiments, we can estimate that the compton contribution is negligible (of the order of 2 %), and we do not make any correction.

In order to evaluate the double pion production contamination, we can : 1) change the maximum energy E^{o} of the machine and compare the statistics at the same gap of the S.C. for different values of E^{o} and 2) compare the apparent efficiency of C_{π^o} at each gap for different values of E^{o}. Considering that the double pion production starts to contribute at γ-ray energies 100 MeV at least lower than E^{o}, we can make a rather safe estimate of the double pion correction. This correction is in any case lower than 10 %.

iii) Normalizations and corrections.

Once we get the crude experimental distribution - as a function of the range - of the protons, a number of normalizations and corrections are to be applied in order to get the differential cross section as a function of the γ-ray energy.

A list of the corrections we have applied is given in the following.

a) The γ-ray energy interval corresponding to the protons stopping in a gap, is not a constant as a function of the gap. An obvious normalization is to be applied when plotting proton frequency as a function of the γ-ray energy.

b) The number of protons per unit interval of γ-ray energy has to be referred to the same number of photons (bremsstrahlung spectrum correction).

c) Nuclear interactions of the protons. This is quite a serious correction for our energy interval of the protons. Once we know the mean free path of the protons for nuclear interaction, the correction due to this effect at the i^{th} gap is given by the formula :

$$N(R_o)_{corr} = \frac{N(R_o)_{meas} - N(R)_{meas}\,[1 - e^{-\lambda\Delta R}]}{e^{-\lambda\Delta R_o}}$$

where λ is the mean free path for nuclear collisions, R_o is the range of the protons stopping at the i^{th} gap, R is the thickness of an aluminium plate, $N(R)_{meas}$ is the number of protons with a range $R > R_o$.

d) Coulomb scattering. Examination of our geometry indicates that the Coulomb scattering does not appreciably change our counting rate. As far as the shape of $\left(\frac{d\sigma}{d\Omega}\right)$ as a function of energy is concerned, Coulomb scattering is only a second order effect. For the determination of the absolute value of the cross section, our geometry was changed to a somewhat more compact disposition (see later) : in it, no correction due to Coulomb scattering was believed necessary.

4 - EXPERIMENTAL RESULTS -

The experimental results we are reporting here are the first part of a program mainly devoted to the study the shape and the absolute value of the cross section around the so called second resonance.

In our present experiment the c.m. angle of emission of the pion varies from 91.4° ± 1.5° for a γ-ray energy in the lab. of 600 MeV, to 92.4° ± 1.5° for a γ-ray energy of 800 MeV.

The γ-ray energy resolution of the points is ~ ± 10 MeV (85 % of the protons included).

The absolute value of $\frac{d\sigma}{d\Omega}$ could in principle have been determined by the S.C. statistics. We have however preferred to make an independent measurement of it choosing a simpler way, particularly to avoid those errors which easily arise in a complicated counter telescope, e.g. : Coulomb scattering of the protons, uncertainties on the perifery of the counters (expecially the smallest one S_0), dead time of the spark chamber, etc.

We measured therefore the absolute value of the cross section using the counter telescope $S_1 + S_2 + S_3 - C - S_4$, whose solid angle is well defined between S_3 and S_4 an aluminium absorber was placed, in order to detect protons in the energy range 188-216 MeV.

After the usual corrections of the type listed above, we obtain an average cross section :

$$\left(\frac{d\sigma}{d\Omega}\right)_{90^\circ} = 3.9 \times 10^{-30}\ \mathrm{cm}^2/\mathrm{ster} \pm 3\ \%$$

the average being extended from 680 to 750 MeV for the γ-ray energy. This average value has been used to report the spark chamber results (figure 4) in terms of the absolute cross section.

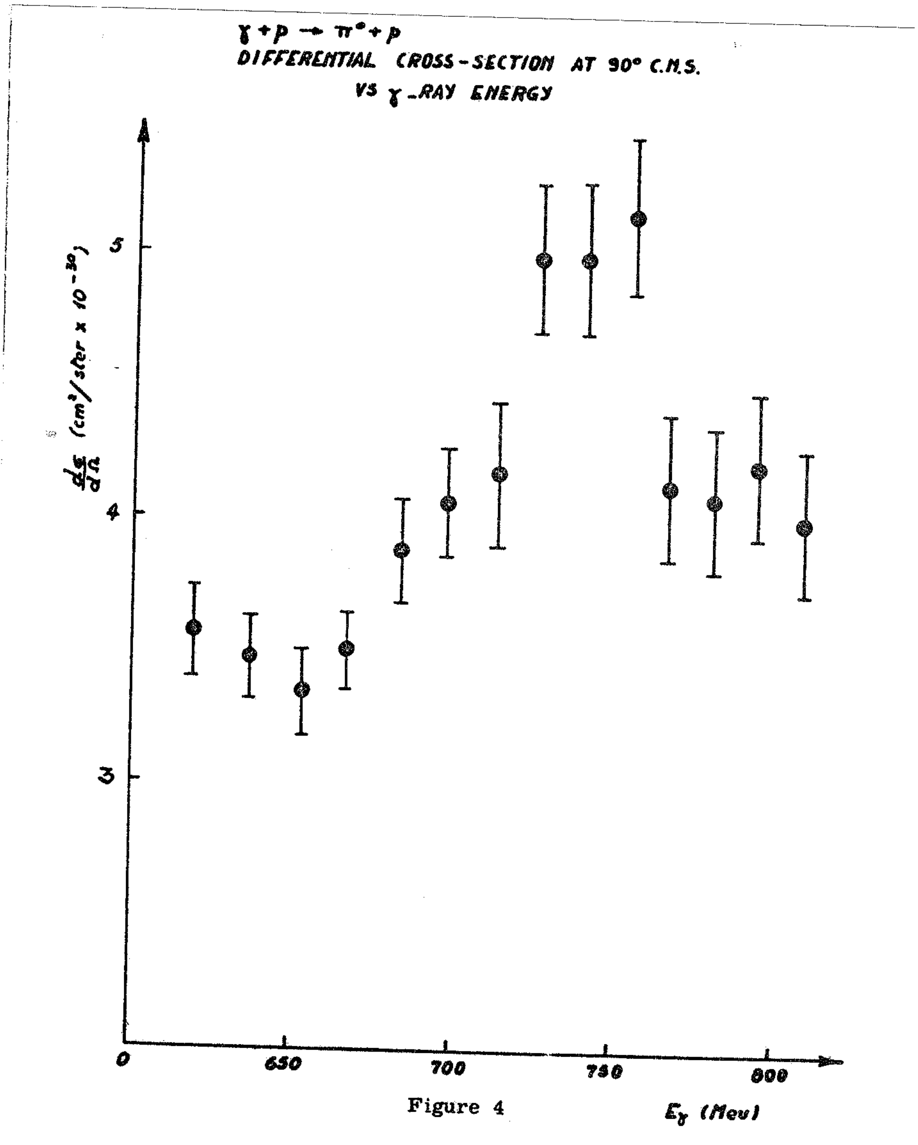

Figure 4

The estimate of $\frac{d\sigma}{d\Omega}$ from spark chamber statistics gave a more uncertain result in agreement with the result from counters.

5 - DISCUSSION -

In figure 4 we report our results. Keeping in mind the large difference in resolving power, our results do not disagree with the ones obtained by others authors. The second resonance appear to be at 90° c.m.s. a "bump" of the following caracteristics :

1/ the position of the peak is 740 ± 10 MeV ;

2/ the width of the peak is hard to define. Its value seems to be at most ± 30 MeV ;

3/ the ratio between the value of the cross section on the maximum and that at 650 MeV is about 1,6.

As well known, it is rather hopeless to try to obtain from the analysis of the experimental cross sections the amplitude and phases of each possible state contributing to the photoproduction. The procedure we can follow is to make some simplifying hypothesis and to check them. The simplest possible attempt in this direction has been done by Peierls [1] ; which tries to describe the neutral photoproduction in the 500-1 100 MeV energy interval of the γ-rays in terms of three resonant states.

We already followed the lines indicated by Peierls in the discussion of our results on the polarization of the recoil proton in neutral photoproduction [3], and we would able to confirm the state assigments for the second and the third resonances.

The discussion however stem on a rather uncertain experimental ground owing to the fact that the shape of the second resonance was measured with very poor resolution.

The present experiment was undertaken also to overcome this difficulty.

As matter of a fact, no essentially new element arises from the more detailed informations about the shape of the second resonance we get. From some preliminary calculations it seems that the Peierls hypothesis is stil compatible with the general experimental situation on π photoproduction. More detailed calculation are in progres at a computer.

Anyway, we think that further experimental work with good resolution and statistics on neutral pion photoproduction should be very important also to answer the following questions :

1/ From the experimental data available up to now, it is impossible in our opinion to decide even if at 740 MeV (the position of the so called second resonance) the phase of the $D_{3/2}$ state passes through 90°. To answer this question it is particularly important to determine the coefficient A_i in the expansion :

$$\frac{d\sigma}{d\Omega} = \sum_{i=0}^{n} A_i \cos^i (\vartheta)$$

2/ Looking at the results of the π° and π^+ photoproduction, and of the pion nucleon scattering one can see that the energy of the resonance is generally higher in pion scattering and π° photoproduction that in π^+ photoproduction. It is important however to keep in mind that this comparison should be made only looking at the total cross section to avoid interference terms. Furthermore in π^+ photoproduction the apparent position of the resonance can be shifted by the presence of the photoelectric term.

Anyway, if the resonance is so narrow as it seems to be, it looks rather difficult to explain in this way the scattering in the position of the maximum.

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