Laboratori Nazionali di Frascati

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A. Alberigi, C. Bernardini, R. Querzoli, G. Salvini, A. Silverman, G. Stoppini: SEARCH FOR A NEUTRAL MESON OF MASS BETWEEN 1.5 AND 3.5 PION MASSES (THE $\rho^0$ MESON).

## SUMMARY

A rather thin proton telescope at a given angle has been employed to observe the possible existence of neutral mesons like the so called $\rho^0$ meson. A straightforward argument based on the inspection of fig. 4 gives an upper limit to the cross section/steradiant for production of such a particle: $d\sigma/d\Omega \leq 6 \times 10^{-31}$ cm$^2$/sterad. If we take into account the possible contribute of the pair production in fig. 4, this upper limit may be reduced, for instance to $\frac{d\sigma}{d\Omega} \leq 2\text{-}3 \times 10^{-31}$ cm$^2$/sterad.

## § 1- Introduction

The method we describe is applicable to the search for any neutral meson of real (or almost real) existence (1). In particular it has been applied here to the search of a possible neutral meson (for instance the $\rho^0$ meson) of a mass between 1.5 and 3.5 $\pi$ masses.

Let's consider all possible processes of the type

1) $\gamma + p \rightarrow p + \ldots\ldots$

Some of them will end in a two body reaction, some in a 3 body etc. In the region of $\gamma$ energy between 500 and 1000 MeV the main known processes are:

2) $\gamma + p \rightarrow \pi^0 + p$

3) $\gamma + p \rightarrow \pi^+ + \pi^- + p$
$\searrow \pi^0 + \pi^0 + p$

Let's assume now the experimental disposition indicated in principle in fig. 1

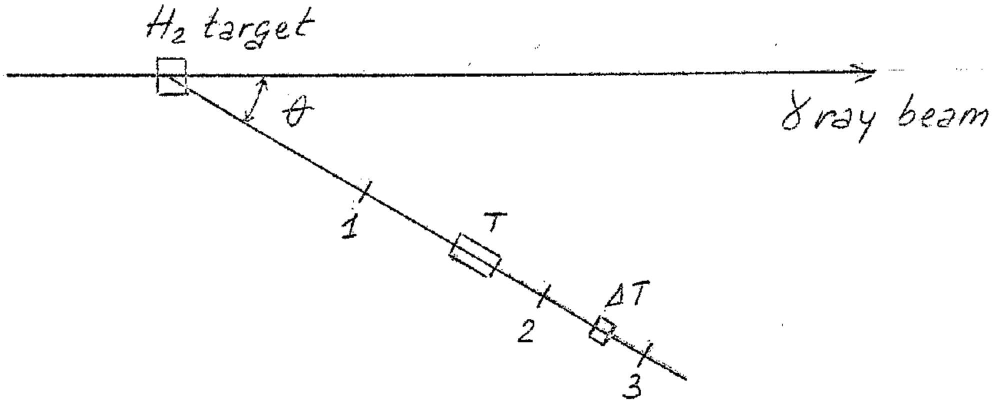

Fig. 1

The telescope indicated by counters 1, 2, 3 and abssorbers T, $\Delta$T (the experimental details are given in fig. 3) detects only the protons in the energy range $E \pm \Delta E$, emitted in an angle interval $\theta \pm \Delta\theta$.

Protons of energy E at the angle $\theta$ arising from any <u>two body reaction</u> are produced by $\gamma$-rays of a <u>definite energy</u> whereas for a reaction with more than two bodies in the final state, the protons can be produced by any $\gamma$-ray of an energy above a certain minimum. If how we measure the yield of protons per "equivalent Quanta" as a function of the peak energy of the Bremsstrahlung beam, we should obtain curves of type of fig. 2.

In fig. 2 we plot the number of the protons counted in the telescope versus the maximum energy of the $\gamma$-ray beam (to be exact: a point on the abscissa indicates the maximum energy of the bremsstrahlung beam)

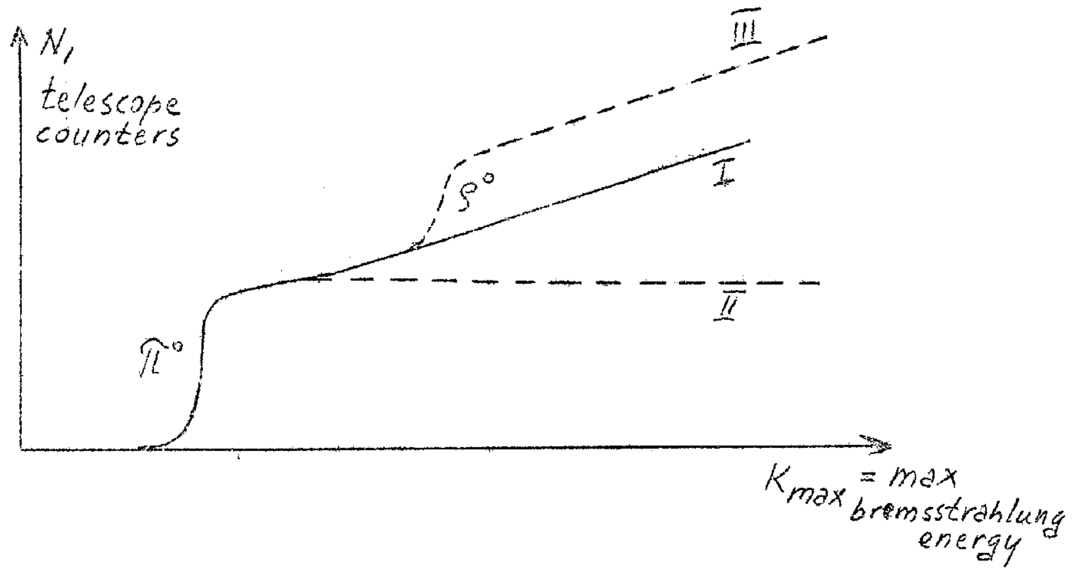

Fig. 2

A two body process shall then appear in fig. 2 as a vertical step (apart from the resolving power of the proton telescope), since the protons are produced by $\gamma$-rays of a unique energy. A typical one is the step due to the process $\gamma + p \rightarrow \pi^0 + p$, indicated with $\pi^0$ in fig. 2. The three and many body processes of type (3) shall give a smooth curve indicated in fig. 2 by the full line of curve I.

The possible existence of a new meson (i.e. of another two bodies process) should be put in evidence by another step (indicated by $\rho^0$ in curve III) which adds to the smooth many body curve, giving rise to curve III.

The flat curve II, parallel to the abscissa, is what we should have in case only process 2) exists.

A few comments on the method:

- the proton counts on the ordinates of fig. 2 are given at each abscissa for equal numbers of equivalent quanta's of the $\gamma$-ray beam: this means that the number of $\gamma$-rays in any energy interval remains constant while we change the beam maximum energy.
- the steps in the curve could indicate not only the existence of a new meson of a definite mass (a real particle) but also some particular correlation among the degrees of freedom of the pions in processes (3). In general we could say that a step in the curve of fig. 2 shall appear when in a reaction of the type

$$4) \quad \gamma + p \rightarrow p + m_1 + m_2 + \cdots\cdots m_n$$

the relation in the c.m. system holds:

$$5) \quad \left( \sum_1^n \frac{m_i}{\sqrt{1-\beta_i^2}} \right)^2 - p^2 = M^2 = const$$

with $M^2$ constant on a certain energy interval of the $\gamma$-ray energy. In relation (5) $\beta_i$ is the velocity of the particle of mass $m_i$ in the c.m. system and $p$ is the momentum of the proton (in the c.m. system); M is the mass of the equivalent two body process.

- the limit of the method in searching for new neutral mesons ($\rho^\circ$ meson) is due to the limit of the statistics, to the error in the measurement of the $\gamma$-ray beam calibration and in the resolving power of the apparatus. The $\pi^\circ$ step divided by the maximum step which one can be able to observe in fig. II and multiplied by the ratio of solid angle in c.m. system will give the higher limit to the cross section for the $\rho^\circ$ production.
- a complete exploration should consider more than one value of $\theta$, to avoid the possibility of being in a minimum of the differential cross section.

## § 2- The experimental disposition

The preliminary result we report here has been obtained with the disposition of fig. 3.

The protons were counted in the telescope by the coincidences

$$(1 + 2) + (2 + 3 + 4 - 5)$$

The $H_2$ target was of the Cornell type. The results are given in fig. 4.

The counters were plastic scintillators of maximum dimensions 12.5 x 25 $cm^2$; the angle of the protons respect to the $\gamma$-ray beam was $\theta = 42° \pm 1.5°$; the energy of the counted protons was $E = 150 \pm 10$ MeV; the solid angle of the telescope was $3.75 \times 10^{-3}$ ster. The protons were separated from the $\pi$'s by discriminating the size of the pulse in counter 3.

An evident feature of the points in fig. 4 is the step due to the $\pi$'s . No other similar step appear at other $\gamma$-ray energies.

We have calculated the curve (dotted line in fig. 4) which should represent the single $\pi^0$ production contribution. The calculation has been done taking into account the angular and momentum spread of our telescope. The plateau of the curve was fitted with experimental counts. It is a good indication of the correctness of our measurements the fact that the plateau level corresponds to a correct value of the single $\pi^0$'s differential cross section. In fact the number of observed protons $N_0$ is given by:

$$(6) \quad N_0 = N_H \; N_\gamma \left(\frac{d\sigma}{d\Omega}\right)\left(\frac{d\Omega_{cm}}{d\Omega_L}\right) \quad \Delta\Omega_L$$

with $N_H$ = number of $H_2$ atoms per $cm^2$

$N_\gamma = Q \frac{\Delta k}{K}$ = number of photons

in the proper energy interval (the energy of the $\gamma$-rays produc ing our protons in process (2) is in our case k = 575 MeV).

The dotted curve agrees with the experimental points when a value of the differential cross section of process (2)

$$(7) \qquad \frac{d\sigma}{d\Omega} = 3.11 \times 10^{-30} \text{ cm}^2/\text{sterad.}$$

is assumed, and correction is made for nuclear interaction in the absorbers of the counter telescope.

As Table I indicates, this value agrees with the values given in the literature by different authors. $\vartheta^*$ is the angle of the $\pi^o$ in the c.m. system.

TABLE I

The experimental values of $(d\sigma/d\Omega)_{\pi^o}$ from different authors

| $\vartheta^*_{C.M.}$ | $\left(\frac{d\sigma}{d\Omega}\right)_{\pi^o}$ | k | Author |
|---|---|---|---|
| 90° | $3.3 \pm 0.4 \times 10^{-30}$ cm$^2$/sterad. | 600 MeV | DeWire & cont.(2) |
| 90° | $3.27 \pm 0.25$ | 579 | Vette (3) |
| 89° | $3.11 \pm 0.22$ | 580 | our result |

## § 3- Discussion of the results

A) The curve of fig. 4 does not seem to show any evident step beyond the $\pi^0$ step. The width of our vertical $\pi^0$ step is $\sim$ 70 MeV. We consider that an upper limit to the heavy neutral meson cross section can be put safely, assuming that the increasing of the curve of fig. 3 between two points 70 MeV apart is due to the $\rho^0$ production. The maximum increasing in 70 MeV is of the order of 23% of the $\pi^0$ step. Taking into account the solid angle transformation, we have an upper limit to the $\rho^0$ cross section

$$\frac{d\sigma}{d\Omega} \leq 6.10^{-31} \text{ cm}^2/\text{ster.} \qquad (8)$$

at the angle determined from our particular geometry. The argument is so elementary that the reader can derive his personal conclusions just by inspection of fig. 3.

B) The slope of the curve of fig. 4 between 692 and 1000 MeV is probably mostly due to the $\pi$ pairs production (processes (3)). We develop here a more sophisticated argument which tends to reduce the limit on the possible $\rho^0$ cross section given in (8).

There is not at present sufficient experimental information which may allow a good calculation of the contribute of the pairs in the curve of fig. 4

Our estimate has been done on the basis of the following hypothesis:

a) the three particles (2 pions and the proton) are emitted isotropically in the c.m. system;

b) the total cross section for pair production $\sigma_p$ varies with the energy and in the interval 700 - 1000 MeV is given by

$$\sigma_p = (2.55 - 2.22 \times 10^{-3}\ k)\,\sigma_0$$

where k is the photon energy in MeV; $\sigma_0 = 5 \times 10^{-29}\ \mathrm{cm}^2$.

Hypothesis b) indicates a cross section not incompatible for instance with the results of Cocconi (4) on the charged pion pairs, but generally lower.

The number of protons per equivalent Quantum due to pair production and detected in our telescope is given by:

$$N_p = N_H \frac{\Delta\Omega_L}{4\pi} \int_{692}^{k} \frac{d\mathcal{E}_\gamma}{\mathcal{E}_\gamma}\, \sigma_p\, f(p)\, \Delta p\, \frac{d\Omega_{cm}}{d\Omega_L}$$

where:

- $\frac{d\mathcal{E}_\gamma}{\mathcal{E}_\gamma}$ is the photon spectrum
- $f(p)$ is the percent of phase space per momentum unit of the proton in the c.m. (°) system
- $\Delta p$ is the momentum interval of the proton in the c.m. system
- $\frac{d\Omega_{cm}}{d\Omega_L}$ is the solid angle transformation from the c.m. to the laboratory, for our protons (whose direction and energy in the laboratory is constant)

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(°) The phase space evaluation may be found in Franzinetti e Morpurgo - Supplemento a "Il Nuovo Cimento" - VI - 576 - 1957

The result of the calculation is reported in fig. 4. The solid line is the addition of the pair yield plus the $\pi^0$ contribution.

This result (which of course is not so clear an argument as that of point A) tendes to leave much less room to the possible existence of the $\rho^0$. On its basis we should conclude that the production cross section per steradian of the $\rho^0$ should be not larger than $\frac{d\sigma}{d\Omega} \leq$ 2-3 x $10^{-31}$ $cm^2$. As a possible remark on the solid curve of fig. 4 we observe that the result of our calculation is a little puzzling. In fact, in order to get an agreement of the mentioned calculated curve with the experimental points, we had to assume a charged pion pair total cross-section strongly decreasing with the $\gamma$-ray energy and a negligible contribution from the $\pi^0$-$\pi^0$ process. It has to be underlined, of course, that these conclusions might be dependent on the assumed isotropic angular distribution of the pions in the c.m. system. This hypothesis, somehow suggested by the Cocconi's results, should be checked with similar measurements at different angles.

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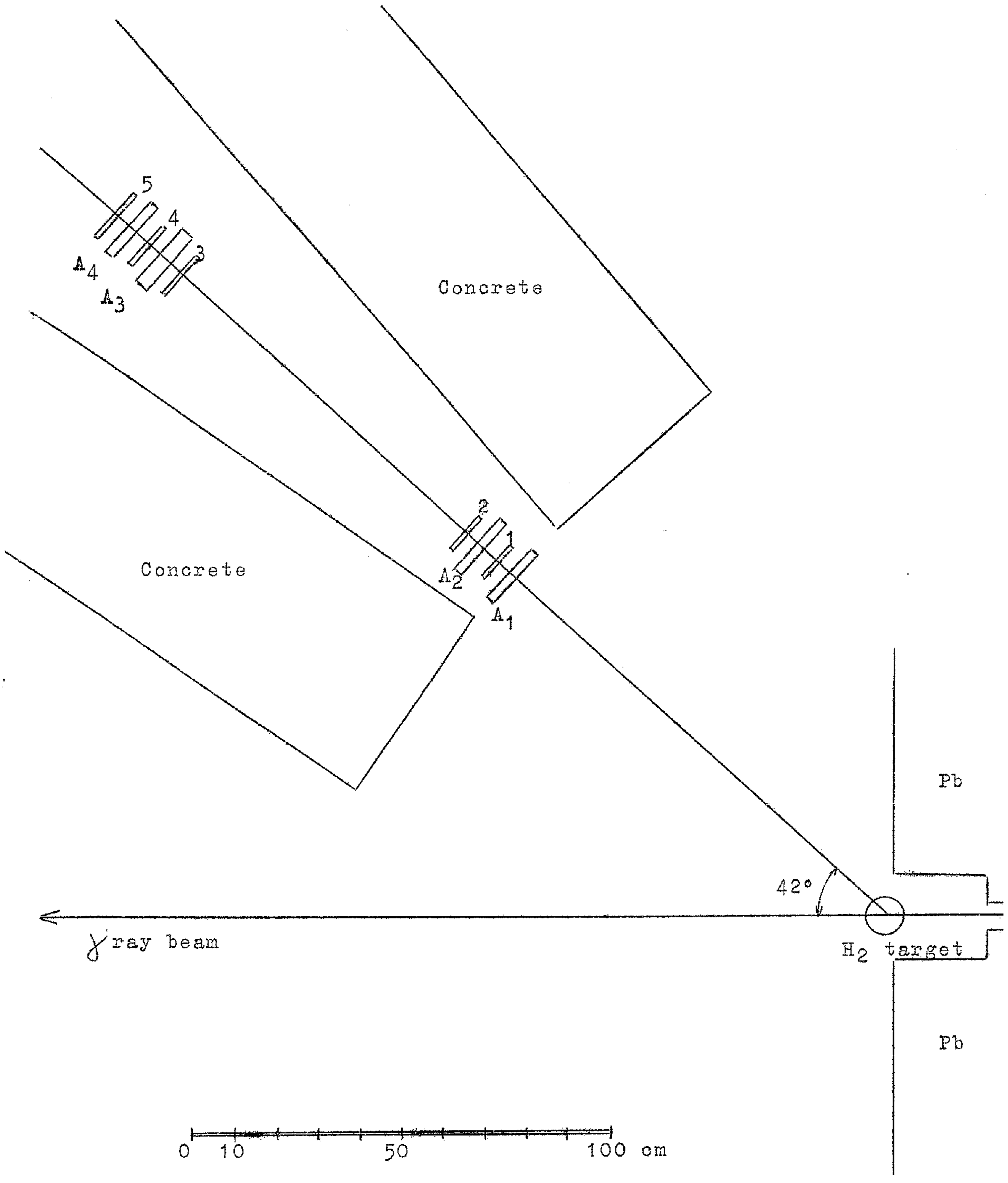

FIG.3 - Experimental disposition: the coincidences 1+2+3+4-5 were counted.-

Thickness of the absorbers: $A_1=A_2=4$mm Cu; $A_3=9$mm Cu; $A_4=4$mm Cu.

Counter n° 3 biased to discriminate pions by protons.-

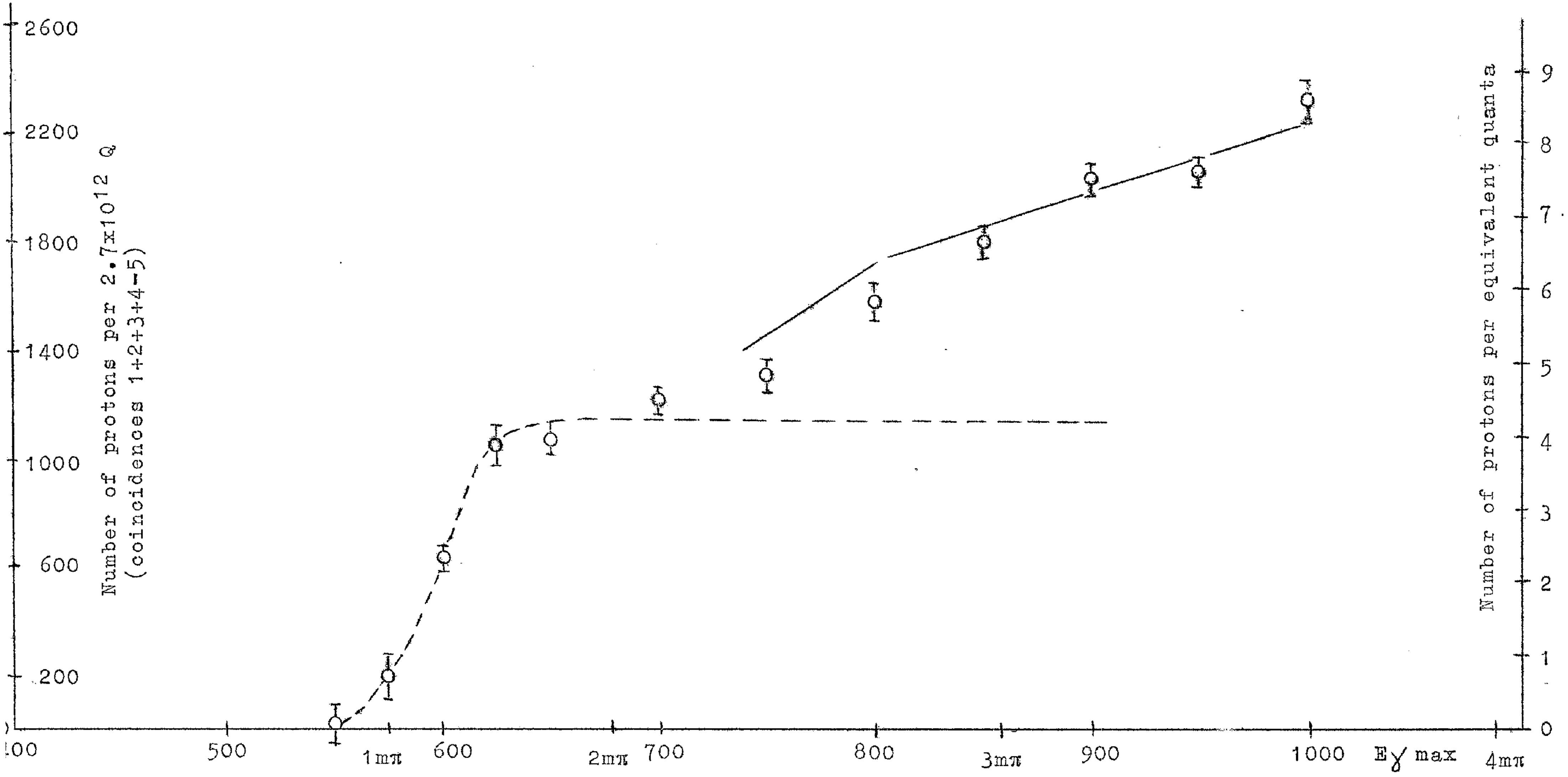

FIG.4 - Abscissa: maximum ray energy of the bremsstrahlung spectrum

Ordinates: number of protons in the telescope of fig.3 per 2.7x10$^{12}$ Eq. Quanta (left) and per Eq. Quanta (right).-

- - - - - - Contribution of the single $\pi^0$ production (calculated)

——— Calculated yield including pair production (see text)