Laboratori Nazionali di Frascati

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G. Salvini, A. Turrin: THE γ RAY BEAM OF THE 25 GeV PROTON SYNCHROTRON. ON THE EXPERIMENTAL USE OF THE γ RAY'S RELATIVE POLARIZATION.

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G. Salvini and A. Turrin: THE γ-RAY BEAM OF THE 25 GeV PROTON SYNCHROTRON. ON THE EXPERIMENTAL USE OF THE γ-RAY'S RELATIVE POLARIZATION.

Summary: The possibility is considered of the experimental use of the γ-rays from a 25 GeV Proton Synchrotron like the one at CERN. The γ-rays take origin from the π^0's decay.

The energy and angular distribution of the photons from π^0's is given.

The experimental use of the fact that the two twin γ-rays from one π^0 are orthogonally polarized is examined, as a method to work with polarized photons.

The background due to the presence of neutrons is discussed: this could be in some experiments a major difficulty.

The measurement of the photon spectrum for getting the angular and energy distributions of the π^0's is considered.

§ 1) INTRODUCTION. ORIGIN OF THE PHOTONS

At the Venice Conference (1957) one of us proposed the use for experiments of the γ-rays from the CERN Proton Synchrotron. The possibility also was considered of making use of the relative polarization of the two photons from each π^o, for experiments with polarized photons. This paper is dedicated to these questions.

The main source of the photons is the decay of the π^o mesons produced in the collision of the accelerated protons against the nucleons of the internal target. Other sources of photons (apart from cascade multiplications) shall be the decay of heavy mesons and other less important phenomena: these sources will be disregarded in the present discussion. An estimate of the flux of particles from the P.S. is given in a paper by Citron and Hine[1].

The photon beam is taken in consideration here for two reasons:

a) its use for researches on photoproductions and on electromagnetic interactions

b) the study of its structure for getting the spectrum of the π^o mesons in the proton-nucleon collisions.

There is a definite relation (see §2) between the spectrum of the photons and the spectrum of the π^o's. The latter is still unknown, of course, and therefore in our calculations we have taken as a basis the π spectra proposed by two previous reports: One is the distribution estimated by the Monte Carlo method by Hagedòrn and Ce-

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1) - A. Citron and M.G.N. Hine; Supplemento al Nuovo Cimento Vol. II; 375 (1955).

rulus[2]).

The other is the total spectrum F_b as given by Sternheimer[3]. These two spectra are reported in our fig.1.

§ 2) ENERGY AND ANGULAR DISTRIBUTION OF GAMMA-RAYS FROM THE DECAY OF π° - MESONS.

Let $\Pi(\bar{E}_{\pi^\circ})d\bar{E}_{\pi^\circ}\frac{d\bar{\Omega}}{4\pi}$ represent the intensity of the π° - mesons of total energy $\bar{E}_{\pi^\circ}$ and angle $\bar{\theta}$ in the intervals $d\bar{E}_{\pi^\circ}$ and $d\bar{\Omega}$ in the center of mass system of the colliding nucleons, and let $\Gamma(\bar{\varepsilon})d\bar{\varepsilon}d\bar{\Omega}$ be the intensity of gamma-rays of energy $\bar{\varepsilon}$ and angle $\bar{\bar{\theta}}$ in the intervals $d\bar{\varepsilon}$ and $d\bar{\Omega}$ in the same c.m.s. Then one can show that $\Gamma(\bar{\varepsilon})d\bar{\varepsilon}d\bar{\Omega}$ is given by[4]

$$1) \quad \Gamma(\bar{\varepsilon})d\bar{\varepsilon}d\bar{\Omega} = \frac{1}{4\pi}d\bar{\varepsilon}d\bar{\Omega}\int_{\bar{\varepsilon}+\frac{(m_{\pi^\circ}c^2)^2}{4\bar{\varepsilon}}}^{\bar{E}_{\pi^\circ max}} \frac{\Pi(\bar{E}_{\pi^\circ})}{\bar{p}_{\pi^\circ}}\,d\bar{E}_{\pi^\circ}$$

Where

$$\bar{p}_{\pi^\circ} = \sqrt{\bar{E}^2_{\pi^\circ} - (m_{\pi^\circ}c^2)^2} \quad .$$

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2) - Hagedorn and Cerulus: High energy meson production at 25 GeV in Nucleon - Nucleon collision according to Fermi statistical theory. CERN Theory Division Internal Report.

3) - Sternheimer: 'Energy and angular distributions of particles produced by 25 BeV protons' - Brookhaven Internal Memo. ADD - RMS - 4, Nov. 21, 1957.

4) - This kinematic problen has been already resolved in the case of the π°'s in cosmic rays by: A.G. Carlson; J.E. Hooper and D.T. King; Phil. Mag. 41, 701 (1950).

With the help of the equations

$$2) \quad \begin{cases} \sin\vartheta = \frac{\varepsilon}{\bar{\varepsilon}} \sin\theta \\ \bar{\varepsilon} = \gamma\varepsilon(1-\beta\cos\theta) \end{cases}$$

where

β_c = velocity of the c.m.s. of the colliding nucleons with respect to the Laboratory system;

$\gamma = \frac{1}{\sqrt{1-\beta^2}}$,

one obtains the intensity $\Gamma(\varepsilon,\theta)\,d\varepsilon\,d\Omega$ of gamma rays of energy ε and angle θ in the intervals $d\varepsilon$ and $d\Omega$ in the lab. system:

$$\Gamma(\varepsilon,\theta)\,d\varepsilon\,d\Omega = d\varepsilon\,\frac{d\Omega}{4\pi}\,\frac{1}{\gamma(1-\beta\cos\theta)} \times$$

$$3) \quad \times \int_{\gamma\varepsilon(1-\beta\cos\theta)+\frac{(m_{\pi^0}c^2)^2}{4\gamma\varepsilon(1-\beta\cos\theta)}}^{\bar{E}_{\pi^0 max}} \frac{\pi(\bar{E}_{\pi^0})}{\bar{p}_{\pi^0}}\,d\bar{E}_{\pi^0} \; .$$

Formula 3 has been applied to the c.m.s. π-spectrum of Sternheimer[3] (F_b distribution, Fig. 1) and also to the c.m.s. π spectrum resulting from Monte Carlo calculations[2].

The results are shown in Fig. 2 and 3, for different angles. We make the following remarks on the results:

i) In all cases the spectrum has a maximum, whose value is of the order of a few hundred MeV in the forward direction. This is an interesting point, considering the lar ge background of low energy photons in the usual bremsstrahlung beams from electron machines.

ii) The spectrum includes in an appreciable amount photons up to 8-10 GeV in the case of fig. 2, and 10-12 GeV in the case of fig. 3, at least in the forward direction (0° - 5°).

§ 3) COMPARISON OF THE PRESENT PHOTON BEAM WITH A BREMSSTRAHLUNG BEAM.

In fig. 3 we have reported, normalizing at 5 GeV, the Bremsstrahlung spectrum from a 6 GeV electron-synchrotron (dotted line).

We may try compare, in a first rough approximation, the two beams.

As far as the intensity is concerned, we can estimate that the total energy per second of the photon beam is about 10 times higher from an electron synchrotron than from the P.S.: this number is obtained under the hypothesis that the P.S. accelerates $10^{10} \frac{\text{protons}}{\text{sec}}$ (against for instance 3×10^9 electrons in an e.s.); the repetition rate is for the P.S. 1 every 6 seconds (against 20 per second); $\frac{1}{6}$ of the energy of each 25 GeV proton goes into γ-rays (against $\frac{1}{10}$ for each 6 GeV electron).

The PS beam has no low energy photons, while in the Bremsstrahlung spectrum there is an infinite contribute of low energy photons.

The use of hardeners like LiH cannot probably sweep off the low energy photons in the bremsstrahlung beam in a way comparable to the natural 25GeV P.S. photon beam.

Photons of energy larger than 6 GeV, as we already said, could be well represented in the P.S. spectrum.

The P.S. spectrum is different at different an gles and is distributed in a rather wide cone; the Bremss trahlung spectrum is a very thin cone with an aperture of the order $\sim \frac{m_e c^2}{E_{max}} \cong 10^{-4}$ radiants.

The wide cone and the energy dependence may be useful in chamber experiments: the bremsstrahlung spectrum shall in general be better for counter experiments.

One definite disadvantage of the PS photon beam may be the presence of neutrons (see § 4).

It is clear that we cannot expect that the photon beam from the 25 P.S. may run out of businnes the electron machines of many GeV.

§ 4) THE PRESENCE OF THE NEUTRONS TRAVELLING TOGETHER WITH THE PHOTONS.

It is difficult to estimate at present the function $N_n(E,\Theta)$, that is the energy and angular distribution of the neutrons. The ratio R_o = photons: neutrons in a given point shall be a function of the distance, and the angle.

In general the neutron beam should be wider in angle than the photon beam, and the total ~~number~~ of neutrons of high energy is expected smaller than the number of photons. This could make possible to find out regions with high value of $\bar{R}_o$ when the proper distance and angle are chosen.

A further increase could come from the use of proper absorbers. After an absorber of x gr/cm^2 the ratio R becomes

$$R = R_o \exp[x(\lambda_\gamma - \lambda_n)/\lambda_\gamma \lambda_n]$$

where $\lambda_\gamma, \lambda_n$ are the mean free paths.

In table I we give the values of λ_γ, λ_n and $\frac{\lambda_n \lambda_\gamma}{\lambda_\gamma - \lambda_n}$.

λ_n is given not including the diffraction scattering. Anyway this scattering could help for the low energy neu trons.

Table I.

	$\lambda_\gamma \left(\frac{gr}{cm^2}\right)$	$\lambda_n \left(\frac{gr}{cm^2}\right)$	$\frac{\lambda_n \lambda_\gamma}{\lambda_\gamma - \lambda_n} \left(\frac{gr}{cm^2}\right)$
H_2	83.5	26.4	38.5
D_2	167	33.2	41.3
L_i	122	50.4	85.4
B_e	130	55	95.3

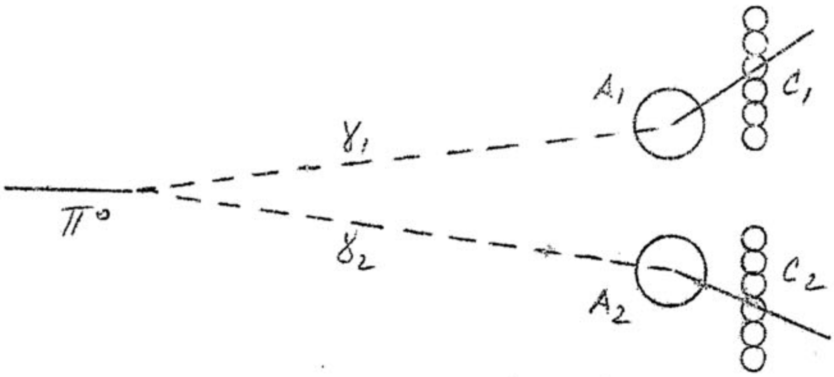
§ 5) ON THE POSSIBILITY OF MAKING USE OF THE RELATIVE POLARIZATION OF THE TWO DECAY PHOTONS.

Can one make experimental use of the relative polarization of the two photons emitted from the π^0's?

As known, the two decay photons are orthogonally polarized, one respect to the other (5). It would be therefore of interest to make experiments with the photon beam where the interactions of the two photons from the same π^0 are compared. This can give us informations on the dependence of the observed phenomena on the state of polarisation of the photon, and it is like making experiments with polarized photons.

In the figure below we give an example of what we mean:

(5) - C.N. Yang; Phys. Rev. 77, 242 (1950)



Let's assume γ_1, γ_2 are twin photons (orthogonally polarized); A_1, A_2 are two visualizing detectors (bubble chambers, cloud chambers?) flashed only when the two group of counters C_1, C_2, indicate a coincidence inside say 10^{-9} sec.

Let's suppose that we observe two events E_1, E_2 produced by photons γ_1, γ_2. Once we have at disposal a series of pairs of events E_1, E_2, we can know how the collision phenomena we are observing depend on the state of polarization of the photons. In fact let's suppose that events in detector A_1 are devided in different groups a_1, b_1, c_1 ...., according to some physical parameter under examination. If events E_2 are equally classified into a_2, b_2, c_2 ...., then the discussed parameter depends on the polarization of the γ if the events in the channel 2 are associated with different distributions to each groups a_1, b_1, c_1, ...

The situation may be considered in a different way too: suppose channel 2 is prepared for an interaction of the photons which allows one to know with a probability p the plane of polarization of the photon 2 (and from this of the photon 1). This interaction could be for instance a Compton effect or a cascade shower in a controlled chamber or in a counter telescope. Then the beam of channel 1 is in many respects equivalent to a beam of polarized photons, for we can assign for each event the most probable polarization plane of the photon.

Then the problem is: is it possible to pick up the two twin photons in a jungle of many photons? There is any hope of a reasonable intensity?

Let's call:

a, the area of two detectors of photons (total area 2 a);

ℓ, the distance of these detectors from the target where the π^o mesons are created;

τ, the time resolving power of a coincidence among the two detectors.

α, the average angle among the photons.

Then, the maximum flux N_γ of photons per sec per cm^2 which still allows to find out the twins with a say 90% certainty against the spurious double coincidences is:

$$N_\gamma \cong \frac{1}{10\,\pi\,\ell^2\alpha^2\tau} \quad .$$

This limiting flux is independent (in practice not strongly dependent) from the area a. If we assume: $\tau = 10^{-9}\,sec$; $\alpha = 2\cdot10^{-2}\,rad$; $\ell = 2\cdot10^{3}\,cm$, we have $N_\gamma = \sim 2 \times 10^4$; in the time of a pulse from the P.S., say 10^{-1} sec, we have a flux per pulse of 2.10^3 photons/cm^2; therefore it seems possible to pick up the two twin photons also in a large population of photons.

The number N_2 of pairs of twins per pulse is accordingly:

$$N_2 = a N_\gamma \frac{a}{\pi(\alpha\ell)^2} \times (0.1\,sec) \cong 0.4\,a^2$$

With $a = 4 \times 10^2\ cm^2$, we have $N_2 = 6 \times 10^4$. This is the number of twins observed per pulse by the two detectors of area a, in case the efficency of each of them is 1. It is worthwile to notice that the resulting value of the flux N_γ is of the order of magnitude expected from the Geneva P.S.

This possibility of making experiments with photons whose relative polarization is known, is being further analysed.

§ 6) DEDUCTION OF THE C.M.S. π^o SPECTRUM FROM THE γ-RAYS LAB SPECTRUM. PRELIMINARY PROPOSAL OF EXPERIMENT.

i) Relation between the π^o and the γ- spectrum

One significant point in the case of the 25 GeV P.S. is that the photons have in the Laboratory an angular distribution close to that of the π^o's. This comes from the fact that the angle between the two twin photons is appreciably smaller than the angle of the π^o's with respect to the producing proton. The general problem of getting $\Pi(\bar{E}_{\pi^o}, \bar{\vartheta})$ from $\Gamma(\varepsilon, \vartheta)$ has a long literature; we recall here that at Berkeley (6) nuclear plates have been exposed close to the internal target to deduce the angular distribution of the pions.

In order to obtain the function $\Pi(\bar{E}_{\pi^o}, \bar{\vartheta})$ one has in principle to know the function $\Gamma(\varepsilon, \vartheta)$.

The relation between $\Pi(\bar{E}_{\pi^o}, \bar{\vartheta})$ and $\Gamma(\varepsilon, \vartheta)$ may be in general very complicated. In the particular case that the π^o's are emitted isotropically in the C.M.S., then the relation is the equation 3 already given.

From a practical point of view, considering

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(6) - D.T. King. Phys. Rev. 109, 1344, (1958)

that the photon distribution, being obtained through an integration, tends to cancel the particularities of the π^{o}-spectrum, it may be more convenient to work by trial and error.

The experimental problem is therefore the complete measurement of the function $\Gamma(\varepsilon,\theta)$. This may be achieved by use of either some integral Cerenkov counters or a pair spectrometer.

ii) Measurement of the π^{o} spectrum by use of Cerenkov Counters.

The position and energy of the photons can be measured by use of Cerenkov counters, of the integral type. The energy of the photon is obtained by estimating the pulse size due to the Cerenkov light produced in the Cerenkov by the complete cascade development of the photon. The percentage precision in the measurement of the energy increases with the energy of the photon. A relative precision of 5 - 10% is possible.

The position of the photon could be localized within $\pm$ 5 cm at 20 meter (uncertainty in the angle of the photon of the order of 5×10^{-3} rad).

In this case we could have of the order of 10^{5} photons in 10^{-1} sec (lenght of the pulse) on the Cerenkov counter. A resolving time of a few 10^{-9} sec in the Cerenkov electronics could be required. The time for collecting the data does not seem a difficulty.

One difficulty is the distinction between a photon and a neutron. A neutron could simulate a photon (by emission of π^{o}'s, for instance) even in a Cerenkov counter. One obvious way is to make use of the very different Z - dependence of the absorption of the photons and the neutrons and to obtain the photons by difference.

May be it is quite possible to distinguish the photons by inspecting the cascade development in the Cerenkov at different stages. (See fig. 4).

iii) <u>On the use of a pair spectrometer for the same measurement.</u>

The pair spectrometer could give a more precise spectrum, and the distinction between photons and neutrons may become easier.

One possible spectrometer for our energies should have a gap of a lenght of about 3 meters, and its weight would be around 270 tons (see fig. 5).

We are grateful to proff. E. Amaldi, G. Bernardini and B. Touschek for discussions and comments.

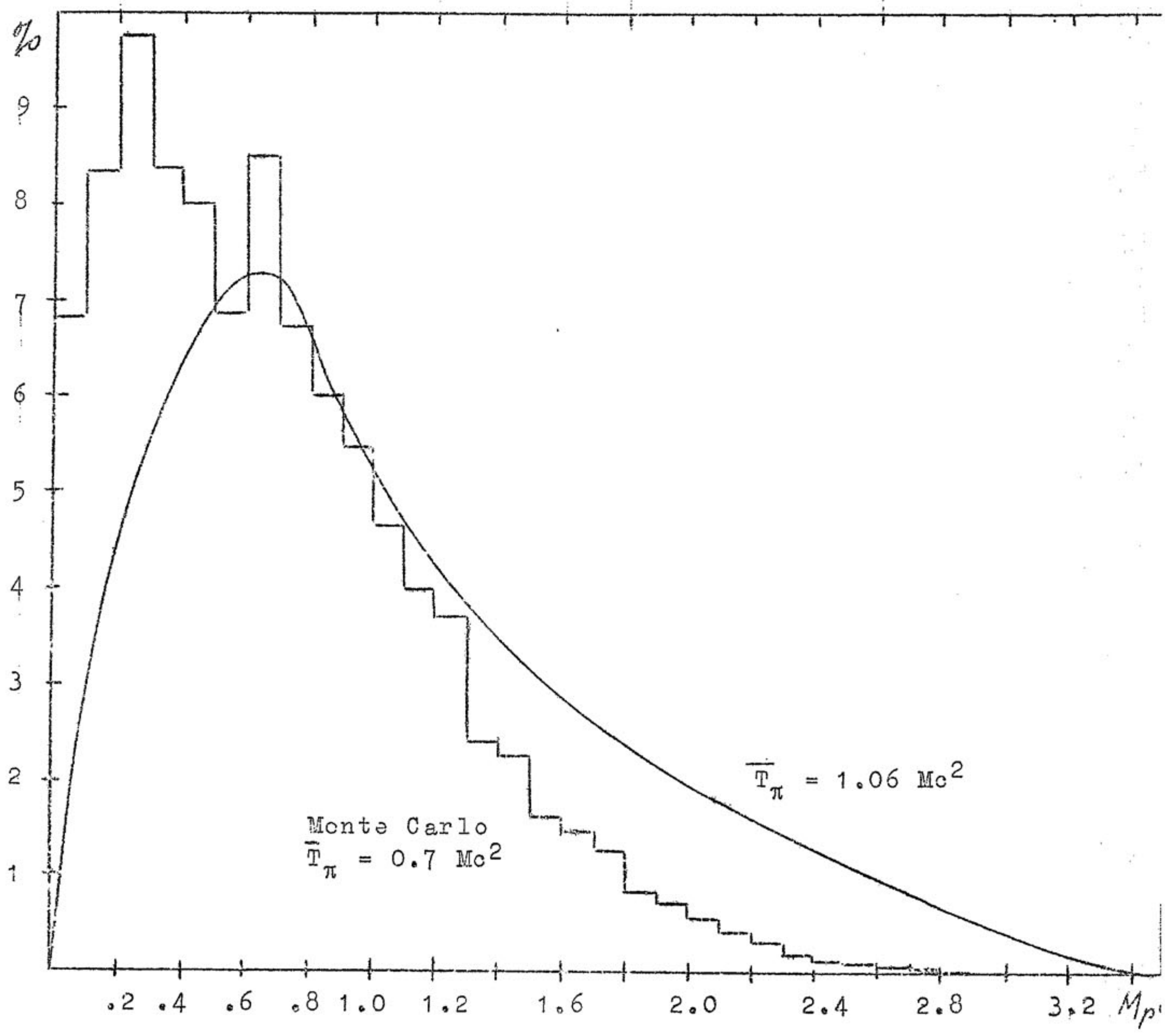

FIG. 1 - Spectrum of the π mesons in the c.m.s., used by us to obtain the energy and angle distribution of the photons.
Full line: ref. 3; Monte Carlo method: ref.2.
In the abscissa: energy of the π's in proton mass units.-

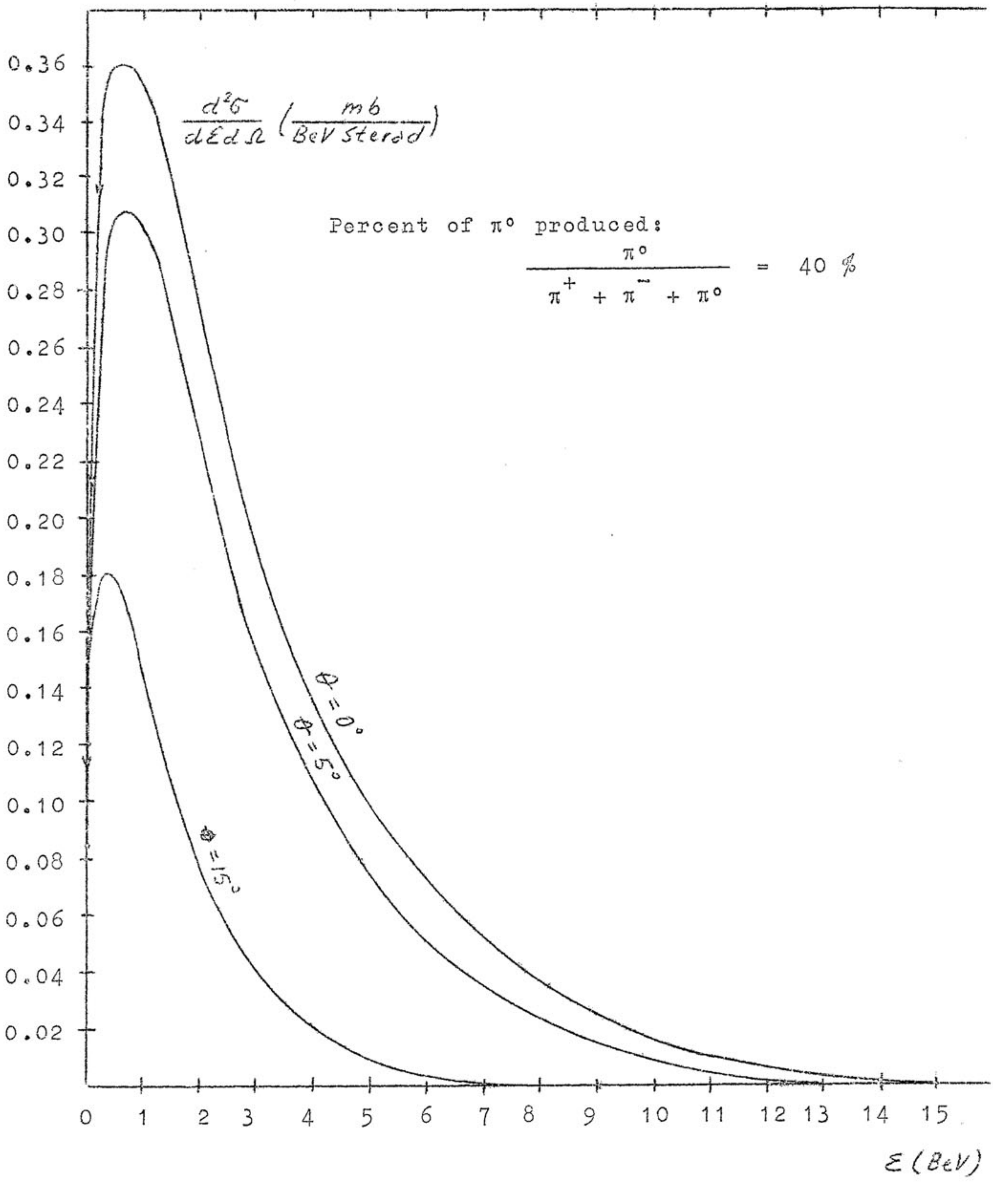

FIG. 2 - Lab photon spectrum as deduced from the π spectrum in the c. m. s. of Hagerdon and Cerulus (The photon cross section as if the π° as an intermediate step could be disregarded).-

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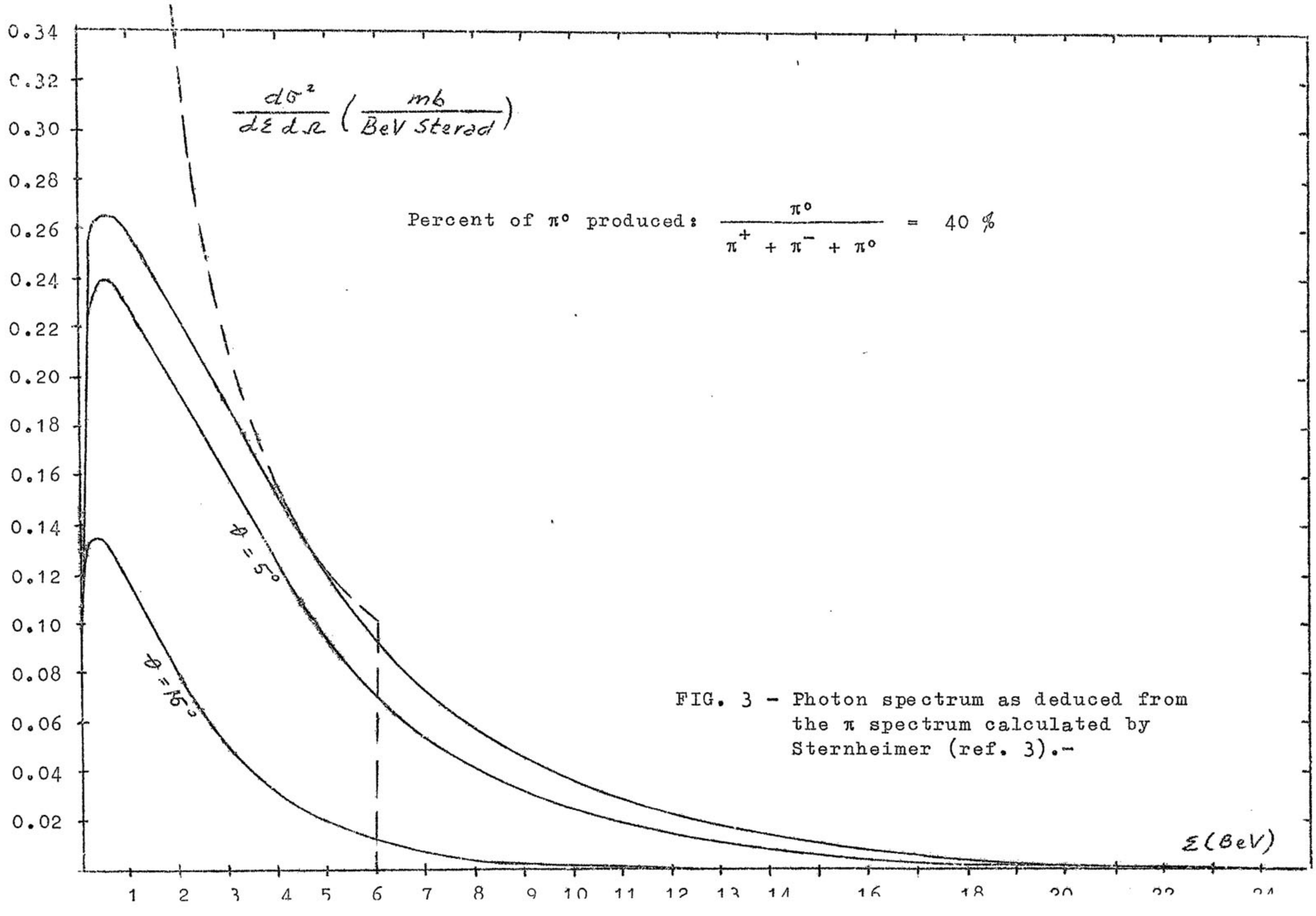

FIG. 3 - Photon spectrum as deduced from the π spectrum calculated by Sternheimer (ref. 3).-

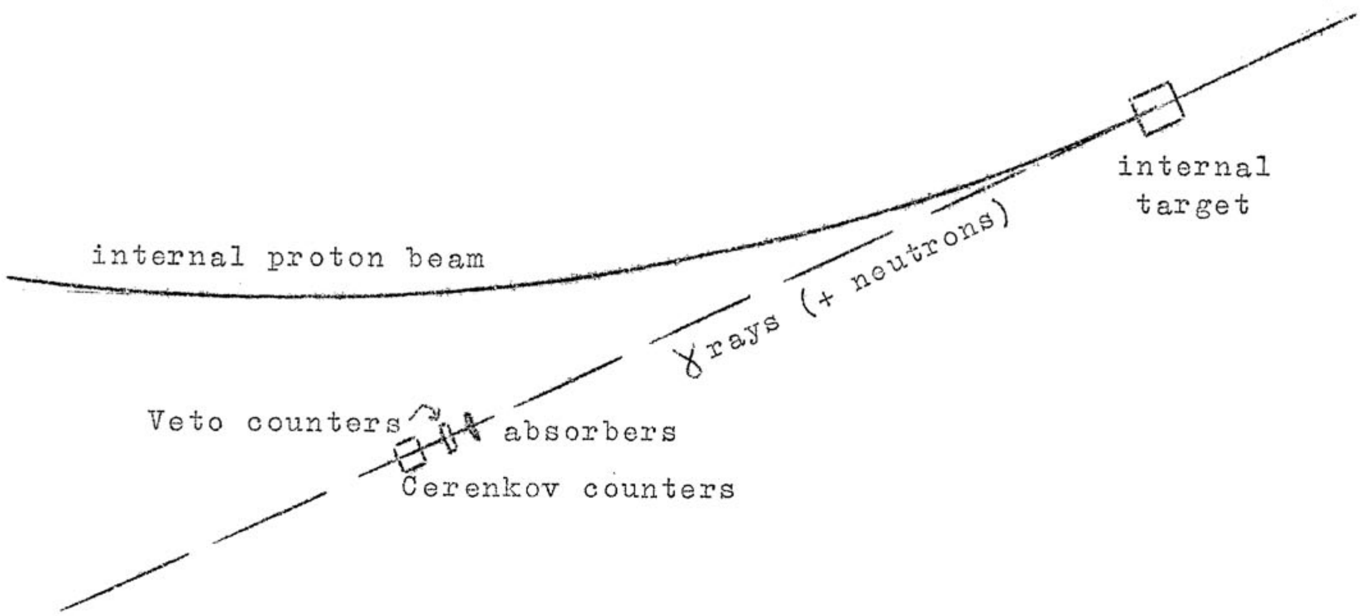

FIG. 4 - A rough sketch indicating the counter disposition in order to get the π^0 spectrum from the photon spectrum.-

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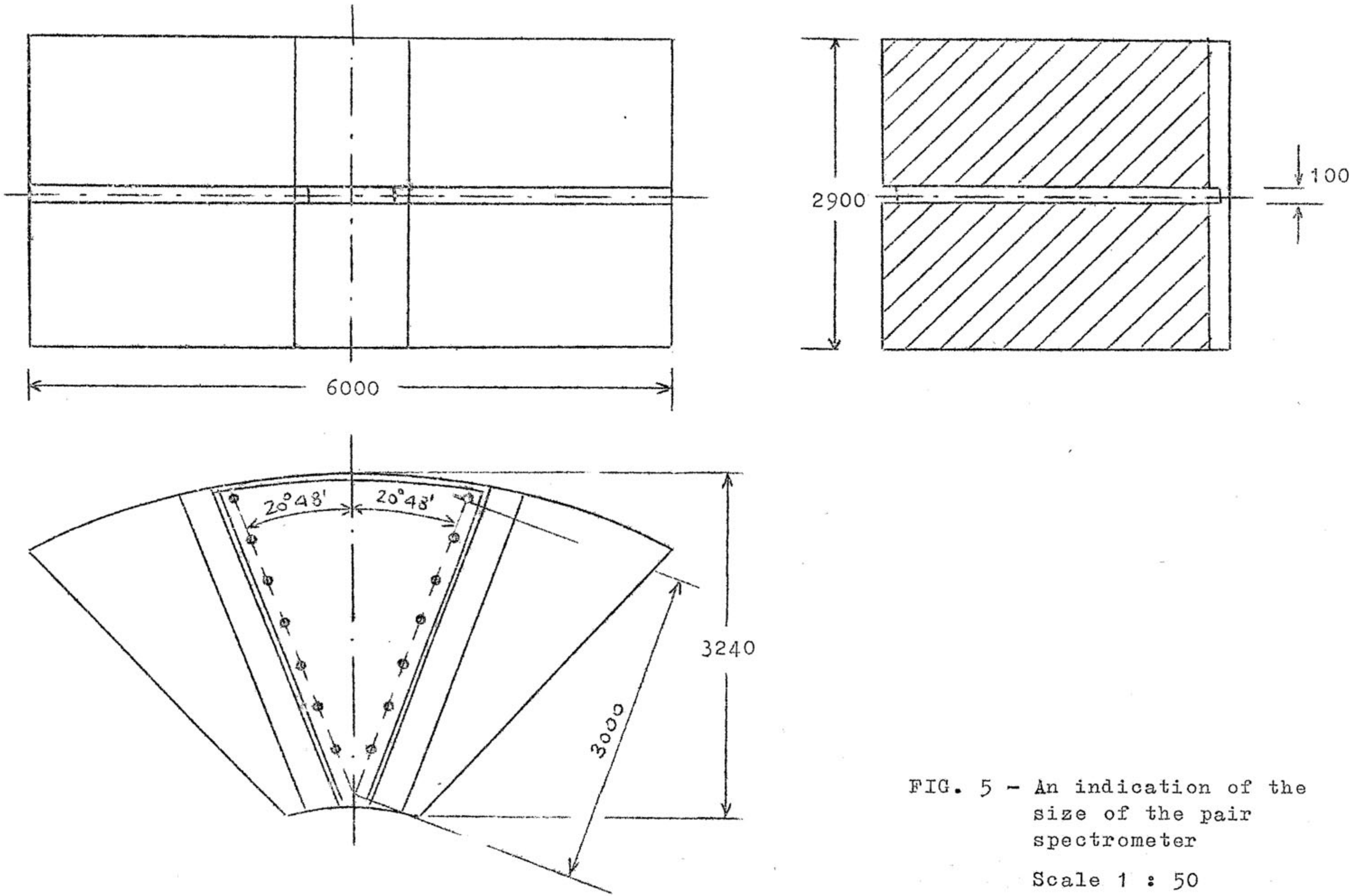

FIG. 5 - An indication of the size of the pair spectrometer

Scale 1 : 50