COMITATO NAZIONALE PER L'ENERGIA NUCLEARE
Laboratori Nazionali di Frascati

LNF-75/15(R)
3 Aprile 1975

G. Penso and M. Piccolo: STATUS REPORT ON ψ(3.1 GeV) RESONANCE FROM ADONE.
(Presented at Xth Rencontre de Moriond - March 2-14, 1975)

Servizio Documentazione
dei Laboratori Nazionali di Frascati del CNEN
Casella Postale 70 - Frascati (Roma)

X[th] RENCONTRE DE MORIOND

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STATUS REPORT ON Ψ (3.1 GeV) RESONANCE FROM ADONE

presented by

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ABSTRACT

The present status of the Adone results on the Ψ (3.1 GeV) resonance is reported. Channels $e^+e^- \to$ multihadrons, e^+e^-, $\mu^+\mu^-$, $\pi^0\gamma$, $\eta\gamma$, $\gamma\gamma$ have been studied. Preliminary results are reported on a search for possible narrow resonance at lower energies.

RÉSUMÉ

Les résultats sur la résonance ψ (3.1 GeV) obtenus jusqu'à présent à Frascati sont passés en revue. Les réactions $e^+e^- \to$ $\to$ multihadrons, e^+e^-, $\mu^+\mu^-$, $\pi^0\gamma$, $\eta\gamma$, $\gamma\gamma$, ont été étudiées. Les résultats préliminaires sur la recherche d'éventuelles résonances étroites à plus basse énergie sont rapportés.

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STATUS REPORT ON ψ (3.1 GeV) RESONANCE FROM ADONE

The more recent results obtained at Adone are reported[(1÷4)]; they concern the study of the newly discovered ψ (3.1 GeV) particle and a first search for possible other new particles with lower mass.

We should begin by reminding the main parameters of Adone since the machine characteristics play an important role in many problems concerning the observation of this new kind of particle.

The energy range covered by Adone is $W = 2E = \sqrt{s} = 1.1 \div 3.0$ GeV. The machine group allowed experimentalists to work 100 MeV above the maximum design energy, in order to reach the ψ mass.

The luminosity, at maximum energy is $\sim 0.3\ \mu b^{-1}\ sec^{-1}$, measured by small angle ($\sim$ 70 mrad) Bhabha scattering, by single bremsstrahlung and by double bremsstrahlung.

The beams lifetime is typically 8 hours. Each beam consists of three bunches which cross in six regions of the machine: two of them are occupied by R.F. cavities, four are available for experiments.

The collision is an "head on" one and the source longitudinal density is gaussian-like with full width at half maximum of $(47 \pm 5)E^{3/2}$ cm (E in GeV). The radial and vertical dimensions of the source are 1 mm and 0.1 mm respectively (at 3.1 GeV).

The total c.m. energy spread Γ_W(FWHM) of the machine depends on the energy itself according to

$$\Gamma_W(\mathrm{MeV}) \simeq .31\ W^2\ (\mathrm{GeV}).$$

The reliability of the energy setting is of the order of 0.3 MeV. Recent calibration of Adone magnetic field, give for the ψ mass the value 3103 ± 6 MeV.

EXPERIMENTAL APPARATA -

Actually three of the four experimental crossing regions are occupied by the experimental set-up of:

i) $B\bar{B}$ group (Frascati, Napoli, Pisa collaboration)
ii) $\gamma\gamma$ group (Frascati, Roma collaboration)
iii) MEA group (Frascati, Napoli, Padova, Roma collaboration)

i) $B\bar{B}$ experiment. - The set up of the baryon-antibaryon group (Fig. 1) consists[(2)] of two symmetrical telescopes (six counters each).

Informations on the detected particles come from pulse height and timing analysis on the phototube signals.

Cosmic rays rejection is achieved hardware (time of flight between S_1 and S_2).

The collinearity of detected particles and the source point are determined by using measurement of the impact point on S_1 and S_2.

Electron identification is achieved by pulse height analysis on S_3.

The material between S_2 and S_3 is about 3.5 r.l. thick.

The angular region covered by this set up is : $\theta = 44^o \div 136^o$; $\Delta\varphi = 40^o$.

ii) <u>$\gamma\gamma$ experiment.</u> - This set up (Fig. 2) consists[3] of two kinematical spark chambers (KSC), two shower detectors (SD) sandwiches of spark chambers, plastic scintillators and lead converters, and two thick plate spark chambers (sandwiches of spark chambers and iron plates) (ISC). Two circular digitized side telescopes (ST) (magnetostrictive chambers and scintillation counters) complete the system. The total solid angle covered by the set up is for a point-like source $0.5 \times 4\pi$ sterad for the optical detection system and $0.15 \times 4\pi$ sterad for the side telescopes. The polar angle θ accepted by the set up ranges from 20^o to 160^o. The apparatus can be triggered by different configurations e.g.: two or more charged particles, at least one in the upper part and one in the lower part, or only photons in the upper and lower part of the apparatus. This last trigger is particularly suitable to look at the neutral decays of $\psi(3.1)$ particle. Time of flight technique is used for cosmic rays rejection. In this way the cosmic rays rate is lowered by a factor $\sim 10^3$.

iii) <u>MEA experiment.</u> - This set up[4] (Fig. 3) is a magnetic detector. The magnetic field is produced by a large (2 meters diameter, 2 meters length) solenoid, with Al coil: the axis is perpendicular to e^+e^- direction; the zero integral value of the magnetic field along the beam path is obtained by means of two compensator magnets. The maximum field available is 4.5 KG, but actually the running field was 2 KG. In this working condition the momentum resolution is $\sim$ 10% for 1 GeV/c particles.

A set of multiwire proportional chambers (MWPC) are placed above and below the crossing region. These chambers have wires parallel to the direction of the beam and are used both in the trigger system and in off-line reconstruction of the events.

A system of narrow and wide gap optical spark chambers is used to measure the emission angle and the momentum of the particles. The wide gaps are cylindrical and coaxial with the solenoid; the electrodes are made of wire in order to reduce multiple scattering and to simplify the optical system. In fact in this way a single photografic camera can give the reconstruction of the events in space.

A scintillation counter system ($S_1 \div S_4$, $S'_1 \div S'_3$) is used for triggering. The trigger request is at least one particle with a minimum energy of 130 MeV (if pion) in the upper part ($S_1S_2S_3S_4$) and one particle of 110 MeV (if pion) in the lower part ($S'_1S'_2S'_3$). To reduce machine background, events with all particles at small angle with respect to the beam are rejected. The solid angle covered by the set up for point-like source is $\Delta\Omega_m = 0.4 \times 4\pi$ sterad ($40^o \lesssim \theta \lesssim 140^o$) for momentum analysis; $\Delta\Omega_i = 0.27 \times 4\pi$ sterad for particles identification (chambers C_3 C'_3). The effect of the extended source is to lower $\Delta\Omega_m$ to $\sim 0.09 \times 4\pi$ sterad at 3.1 GeV.

Cosmic rays background is rejected by time of flight measurement, by requiring correct timing with bunch-bunch collision and by requesting that radial position of the source lies within $\pm$ 5 cm from the beam line (fast logic of MWPC). With such requirements the cosmic ray rate is reduced by a factor $\sim 10^4$.

EXPERIMENTAL RESULTS -

The reactions we are studing around 3.1 GeV are:

(1) $e^+e^- \to$ many hadrons ($\gamma\gamma$, MEA)

(2) $e^+e^- \to e^+e^-$ ($B\bar{B}$, $\gamma\gamma$, MEA)

(3) $e^+e^- \to \mu^+\mu^-$ ($B\bar{B}$, $\gamma\gamma$, MEA)

(4) $e^+e^- \to$ neutrals ($\gamma\gamma$)

Reaction (1) has also been studied in the total c.m. energy range 1.9 $\div$ $\div$ 3.1 GeV in fine steps.

The identification criteria for the various channels are:

Channel 1 - 2 non collinear tracks or more than two tracks, coming from interaction region and having correct timing with beam-beam interaction (MEA).
- 2 tracks (one in each part of the apparatus) plus anything. ($\gamma\gamma$)

Channel 2 - 2 collinear tracks with proper: timing with the beam; source position; time of flight in both side of the apparata; furthermore:
- showering in the external spark chamber. (MEA).
- showering in the shower detector ($\gamma\gamma$)
- ionizing $\gtrsim$ 2 times minimum after 3.5 r.l. ($B\bar{B}$).

Channel 3 - The $\mu^+\mu^-$ events have to satisfy the same collinearity requirements as the e^+e^- events and are caracterized by:
- absence of e.m. showers (B$\bar{B}$, $\gamma\gamma$, MEA)
- absence of nuclear interactions in thick plates spark chamber ($\gamma\gamma$, MEA)
- correct momentum within $\pm$ 20% (MEA).

The B$\bar{B}$ set up cannot at present, distinguish between $\mu^+\mu^-$ pairs and hadrons pairs.

Channel 4 - No charged particle should be present but only photons coming from interaction region, having correct timing with the beam-beam interaction and showering in the shower detector ($\gamma\gamma$).

To extract from experimental data the resonance parameters, e.g. the width Γ_i, in this case ($\Gamma_i \ll \Delta W$ = c.m. energy spread of the machine) the simplest procedure is to integrate the resonant cross-section over ΔW ; one obtains for $J^P = 1^-$:

(5)
$$\int_{\Delta W} \sigma(e^+e^- \rightarrow \text{had})dW = \frac{6\pi^2}{M_\psi^2} \frac{\Gamma_{e^+e^-}\Gamma_{had}}{\Gamma_{tot}}$$

(6)
$$\int_{\Delta W} \left[\sigma(e^+e^- \rightarrow e^+e^-) - \sigma(e^+e^- \rightarrow e^+e^-)_{QED}\right] dW = \frac{6\pi^2}{M_\psi^2} \frac{\Gamma^2_{e^+e^-}}{\Gamma_{tot}}$$

(7)
$$\int_{\Delta W} \left[\sigma(e^+e^- \rightarrow \mu^+\mu^-) - \sigma(e^+e^- \rightarrow \mu^+\mu^-)_{QED}\right] dW = \frac{6\pi^2}{M_\psi^2} \frac{\Gamma_{e^+e^-}\Gamma_{\mu^+\mu^-}}{\Gamma_{tot}}$$

In expression (6) and (7), we have assumed that the interference term, integrated over the machine resolution is negligible.

The above integrals do not depend on the machine resolution.

To deduce the width from the experimental data, radiative corrections have to be taken into account.

$e^+e^- \to$ many hadrons. -

In Fig. 4 is reported the experimental total cross section for $e^+e^- \to$ many hadrons ($\gamma\gamma$ experiment), together with the theoretical curve calculated by taking into account radiative corrections[5] and machine energy spread.

The experimental results for multihadronic channel are:

$$\int_{\Delta W} \sigma\,(e^+e^- \to \text{had})\, dW = \begin{cases} (6.7 \pm 2.4)\ \text{nb x GeV} (\gamma\gamma) \\ (7.0 \pm 1.8)\ \text{nb x GeV (MEA)} \end{cases}$$

Here and in the following, the quoted errors include also uncertainties on detection efficiencies, and on luminosity measurement.

This corresponds to (without radiative corrections):

$$\frac{\Gamma_{e^+e^-}\ \Gamma_{had}}{\Gamma_{tot}} = \begin{cases} (2.8 \pm 0.9)\ \text{KeV} (\gamma\gamma) \\ (2.9 \pm 0.7)\ \text{KeV (MEA)} \end{cases}$$

Applying radiative corrections[5] we obtain

$$\frac{\Gamma_{e^+e^-}\ \Gamma_{had}}{\Gamma_{tot}} = \begin{cases} (3.8 \pm 1.3)\ \text{KeV} (\gamma\gamma) \\ (4.1 \pm 1.1)\ \text{KeV (MEA)} \end{cases}$$

In Fig. 5 are shown the charged, neutral and total multiplicity distributions of the detected multihadron events as obtained by $\gamma\gamma$ experiment.

The average charged multiplicity observed in the MEA set up is $\langle N_c \rangle = 3.3 \pm 0.3$; lower limits for high multiplicity channels turn out to be:

$$\frac{N_{\geqslant 6}}{N} \geqslant (0.13 \pm 0.02)\ \text{(MEA)}$$

$$\frac{N_{\geqslant 8}}{N} \geqslant (0.02 \pm 0.01)\ \text{(MEA)}$$

where $N_{\geqslant 6}$, $N_{\geqslant 8}$ and N are respectively the number of events with at least 6 or 8 charged particles, and the total number of events.

$e^+e^- \rightarrow e^+e^-$. -

For the channel $e^+e^- \rightarrow e^+e^-$ the resonance contribution is of the same order of magnitude as the QED.

In Fig. 6 is reported the excitation curve for the reaction $e^+e^- \rightarrow e^+e^-$ ($B\bar{B}$ experiment).

In Fig. 7 the measured angular distribution is reported for the $B\bar{B}$ and MEA experiments.

From the integral (6) one obtains (without radiative corrections):

$$\frac{\Gamma^2_{e^+e^-}}{\Gamma_{tot}} = \begin{cases} (0.23 \pm 0.09)\,\text{KeV}\,(B\bar{B}) \\ (0.36 \pm 0.12)\,\text{KeV}\,(\gamma\gamma) \\ (0.21 \pm 0.07)\,\text{KeV})\,(\text{MEA}) \end{cases}$$

The above MEA value has been derived from back scattering ($\theta \gtrsim 90^o$) events for which QED background is lower.

After radiative corrections[5] have been applied these values become (not yet calculated for MEA results)

$$\frac{\Gamma^2_{e^+e^-}}{\Gamma_{tot}} = \begin{cases} (0.34 \pm 0.14)\,\text{KeV}\,(B\bar{B}) \\ (0.65 \pm 0.22)\,\text{KeV}\,(\gamma\gamma) \end{cases}$$

$e^+e^- \rightarrow \mu^+\mu^-$. -

In this channel the QED background is very small. In Fig. 8 the excitation curve for reaction $e^+e^- \rightarrow \mu^+\mu^-$ is reported (MEA experiment). From the integral (7) one obtains (without radiative corrections):

$$\frac{\Gamma_{e^+e^-}\,\Gamma_{\mu^+\mu^-}}{\Gamma_{tot}} = \begin{cases} (0.21 \pm 0.07)\,(B\bar{B}) \\ (0.26 \pm 0.09)\,(\gamma\gamma) \\ (0.24 \pm 0.04)\,(\text{MEA}) \end{cases}$$

By applying radiative correction:

$$\frac{\Gamma_{e^+e^-}\,\Gamma_{\mu^+\mu^-}}{\Gamma_{tot}} = 0.31 \pm 0.09 \quad (B\bar{B})$$

The radiative corrections have not been yet calculated for $\gamma\gamma$ and MEA results. It is important to notice that, within the experimental errors, $\Gamma_{e^+e^-} \simeq \Gamma_{\mu^+\mu^-}$ as expected from the μ-e universality.

$\mu^+\mu^-$ angular distribution (MEA experiment):

A possible forward-backward asymmetry in the $\mu^+\mu^-$ angular distribution has been investigated(6) by the MEA experiment; the asymmetry is defined by

$$\Sigma = \frac{N_F - N_B}{N_F + N_B}$$

where N_F is the number of the events in which the angle θ between e^+ and μ^+ directions is less than 85°, while N_B is the number of events in which θ is greater than 95°.

The measured Σ values averaged on the energy interval 3100.5 ÷ 3105.5 is consistent with zero: namely

$$\Sigma = \frac{49-53}{49+53} = -0.04 \pm 0.1$$

If further analysis is performed looking at the energy dependence of the asymmetry we find:

$$3100.5 \leq W \leq 3102.5 \ ; \quad \Sigma = \frac{32-16}{32+16} = 0.33 \pm 0.14$$

$$3103.5 \leq W \leq 3105.5 \ ; \quad \Sigma = \frac{12-28}{12+28} = -0.40 \pm 0.14$$

The errors are statistical only.

This result is quite difficult to explain; if it is not a statistical fluctuation, the energy spread of the machine should average any energy dependent asymmetry due to such a narrow resonance.

It is important to outline that, in the 1^- hypothesis, radiative corrections would generate(5) a forward-backward asymmetry in the angular distribution of the $\mu^+\mu^-$ pair of the order of + 5%.

Tests are in progress to check MEA apparatus symmetry: inversion of the magnetic field and of beam's direction.

$e^+e^- \rightarrow$ photons. -

The production of only photons at energies around the ψ (3,1 GeV) resonance has been studied by the $\gamma\gamma$ group, whose apparatus is particularly suitable for photon detection.

A sketch of the counters and converters arrangement in the shower detector SD is shown in Fig. 9.

A photon is defined by the coincidence $\overline{V}\cdot[(1\cdot 2\cdot 3)+(2\cdot 3\cdot 4)]$. The trigger efficiency is $\sim$ 75% for photon energies $E_\gamma \geqslant$ 500 MeV. Full tracking efficiency is reached in the shower detector for photon energies $E_\gamma \geqslant$ 200 MeV.

Experimental results. -

With this set-up three channels have been studied up to now[7]:

(8) $e^+e^- \rightarrow \gamma\gamma$

(9) $e^+e^- \rightarrow \pi^0\gamma$, $\pi^0 \rightarrow \gamma\gamma$

(10) $e^+e^- \rightarrow \eta\gamma$, $\eta \rightarrow \gamma\gamma$

In order to detect these reactions at least two photons are required one in the upper part and one in the lower part of the apparatus and no charged particles should be present either in the main telescopes or in the side telescopes.

A total luminosity of 19 nb^{-1} was collected at energies ranging from 3090 to 3110 MeV; 41 events were detected with two photons coplanar within $\pm$ 5° with the beam line. The collinearity distribution of these events is reported in Fig. 10. No three photons events were detected at the resonance energy.

A MonteCarlo calculation shows that for the reactions (9) and (10) the three photons configuration is favoured by a factor of $\sim$ 2÷3 with respect to the two photons configuration. More precisely the efficiencies for detection of $\pi^0\gamma$ and $\eta\gamma$ reaction in 2γ or 3γ configuration are:

$$\varepsilon_{2\gamma}(\pi^0\gamma) = (1.9 \pm 0.06)\% \qquad \varepsilon_{3\gamma}(\pi^0\gamma) = (5.7 \pm 0.1)\%$$

$$\varepsilon_{2\gamma}(\eta\gamma) = (2.9 \pm 0.1)\% \qquad \varepsilon_{3\gamma}(\eta\gamma) = (4.8 \pm 0.1)\%$$

Therefore the absence of three photon events allows to give the following upper limits for the cross sections for reaction (9) and (10), integrated over the energy spread of the machine, at the resonance energy

$$\int_{\Delta W} \sigma_{\pi^0\gamma}(w)dw < 27 \text{ nb} \cdot \text{MeV} \text{ (90\% c.l.)}$$

$$\int_{\Delta W} \sigma_{\eta\gamma}(w)dw < 89 \text{ nb} \cdot \text{MeV} \text{ (90\% c.l.)}$$

Radiative corrections have not yet been taken into account. In calculating the $\sigma_{\eta\gamma}$ upper limits the $\eta \rightarrow \gamma\gamma$ branching ratio has been used:

$$(\eta \rightarrow \gamma\gamma)/(\eta \rightarrow \text{all modes}) = 0.38$$

The above results correspond to the following upper limits for the partial width.

$$\frac{\Gamma_{\pi^o\gamma}}{\Gamma_{had}} < 0.5\% \quad (90\%\ \text{c.l.})$$

$$\frac{\Gamma_{\eta\gamma}}{\Gamma_{had}} < 1.6\% \quad (90\%\ \text{c.l.})$$

From these results it follows that the contribution from reaction (9) and (10) to the 41 two-photons events, is negligible. In order to study reaction (8) only 39 events out of the 41, have been selected by requiring the collinearity of the two photons within $\pm 15^o$.

The excitation curve of these events is reported in Fig. 11. Within the present statistics no clear evidence appears for the existence of a peak in the cross section for reaction (8), at an energy corresponding to the mass of the ψ. An estimate of a possible enhancement of the cross section for reaction (8) around 3103 MeV is given by the ratio:

$$r = \frac{\gamma\gamma\ \text{yield}\ (3100 \leq W \leq 3106)}{\gamma\gamma\ \text{yield}\ (W < 3100;\ W > 3106)} = 1.6 \pm 0.6$$

Search for new resonances with masses below 3.1 GeV. -

Possible new resonances in the mass region 1.9 to 3.1 GeV are being searched for. The preliminary results from $\gamma\gamma$ group are now reported. Up to now, the following mass intervals have been explored: 1915 ÷ 2045 MeV and 2205 ÷ 2544 in steps of 1 MeV; and 2966 ÷ 3090 in steps of 2 MeV. The energy spread Γ_W (FWHM) of the total c.m. energy (W) of the beams depends on the energy itself, according to $\Gamma_W(\text{MeV}) \simeq 0.31\ W^2(\text{GeV})$. In the explored range of mass, Γ_W varies from 1.1 MeV to 3.0 MeV. Therefore the 1 or 2 MeV steps allow to detect also possible very narrow resonances.

Experimental results. -

For each energy value, the following luminosities were accumulated: 0.12 nb^{-1} for $1915 \leq W \leq 2045$ MeV; 0.066 nb^{-1} for $2205 \leq W \leq 2544$ MeV; 0.18 nb^{-1} for $2966 \leq W \leq 3090$ MeV. The multihadrons yield was recorded as a function of energy. The results are shown in Fig.12.

For comparison, the ψ (3.1 GeV) peak is reported on the same scale as the other experimental points. No statistically significant structures other than the ψ (3.1 GeV) seems to appear. In the multihadron channel an upper limit on experimental cross section of about 400 nb (90% c.l.) can be given for possible new narrow resonances.

The same conclusion can be deduced from the MEA data, although their statistics is lower by a factor $\sim$ 2. Work is in progress to increase the statistics and to complete the energy interval covered by Adone storage ring.

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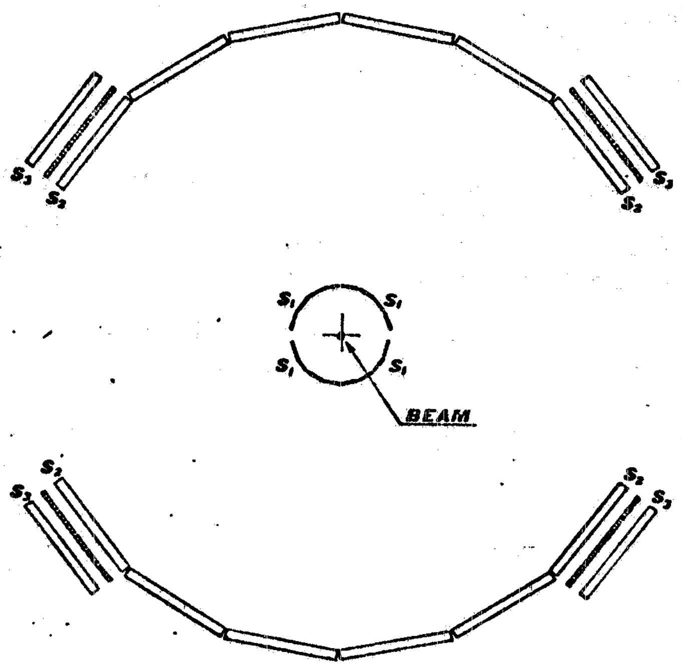

FIG. 1 - Experimental set-up of the $B\bar{B}$ experiment. S_1, S_2 and S_3 are scintillation counters.

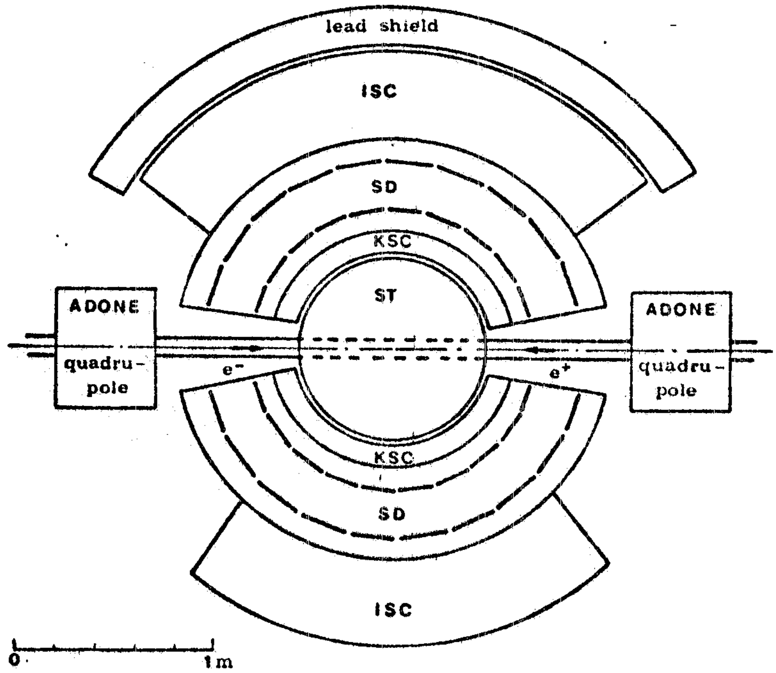

FIG. 2 - Experimental set-up of the $\gamma\gamma$ experiment.

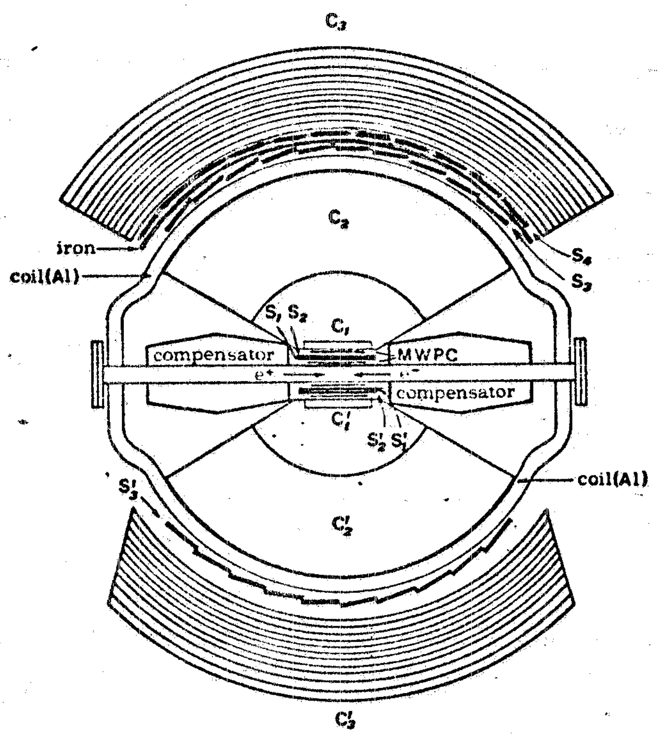

FIG. 3 - Experimental set-up of the MEA experiment. $S_1 \div S_4$, $S_1' \div S_3'$ are scintillator counters.

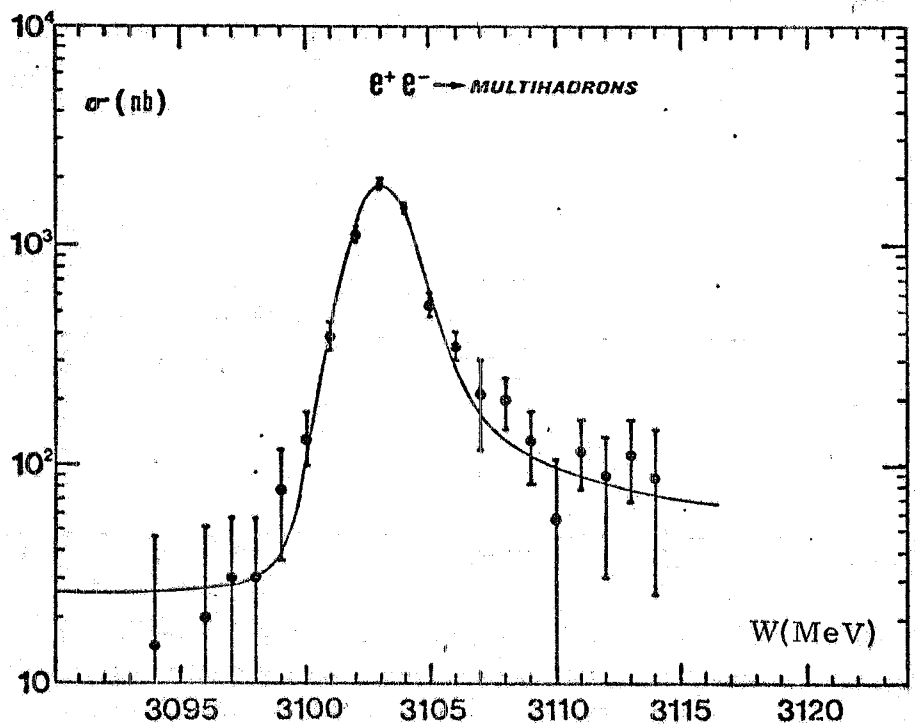

FIG. 4 - $e^+e^- \longrightarrow$ many hadrons total cross section ($\gamma\gamma$ experiment). The solid line is a fit of the experimental points withthe radiative cor rections formula of ref. (5), plus a constant background. The beam e nergy spread has been folded in. The errors are statistical only.

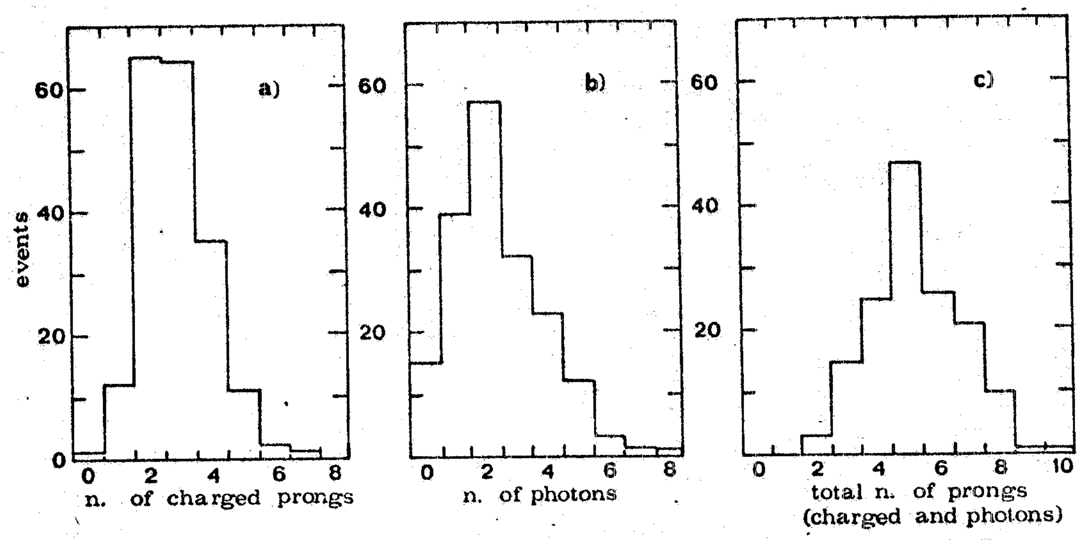

FIG. 5 - Multihadrons events multiplicities in the $\gamma\gamma$ experiment set-up. a) Charged prong multiplicity; b) Photon multiplicity; c) Total (charged + photons) multiplicity.

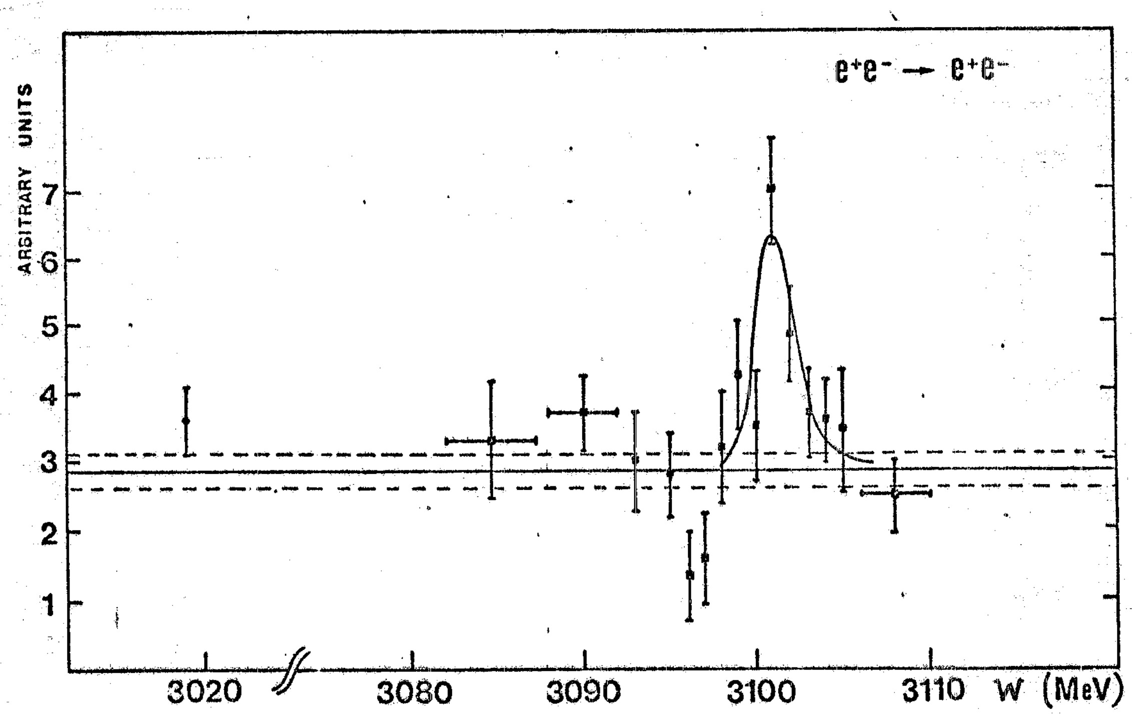

FIG. 6 - Excitation curve for $e^+e^- \rightarrow e^+e^-$ ($B\bar{B}$ experiment). The solid line is the average Bhabha level, measured outside the resonance. The dotted lines represent an estimate of uncertainties on this level. The errors are only statistical.

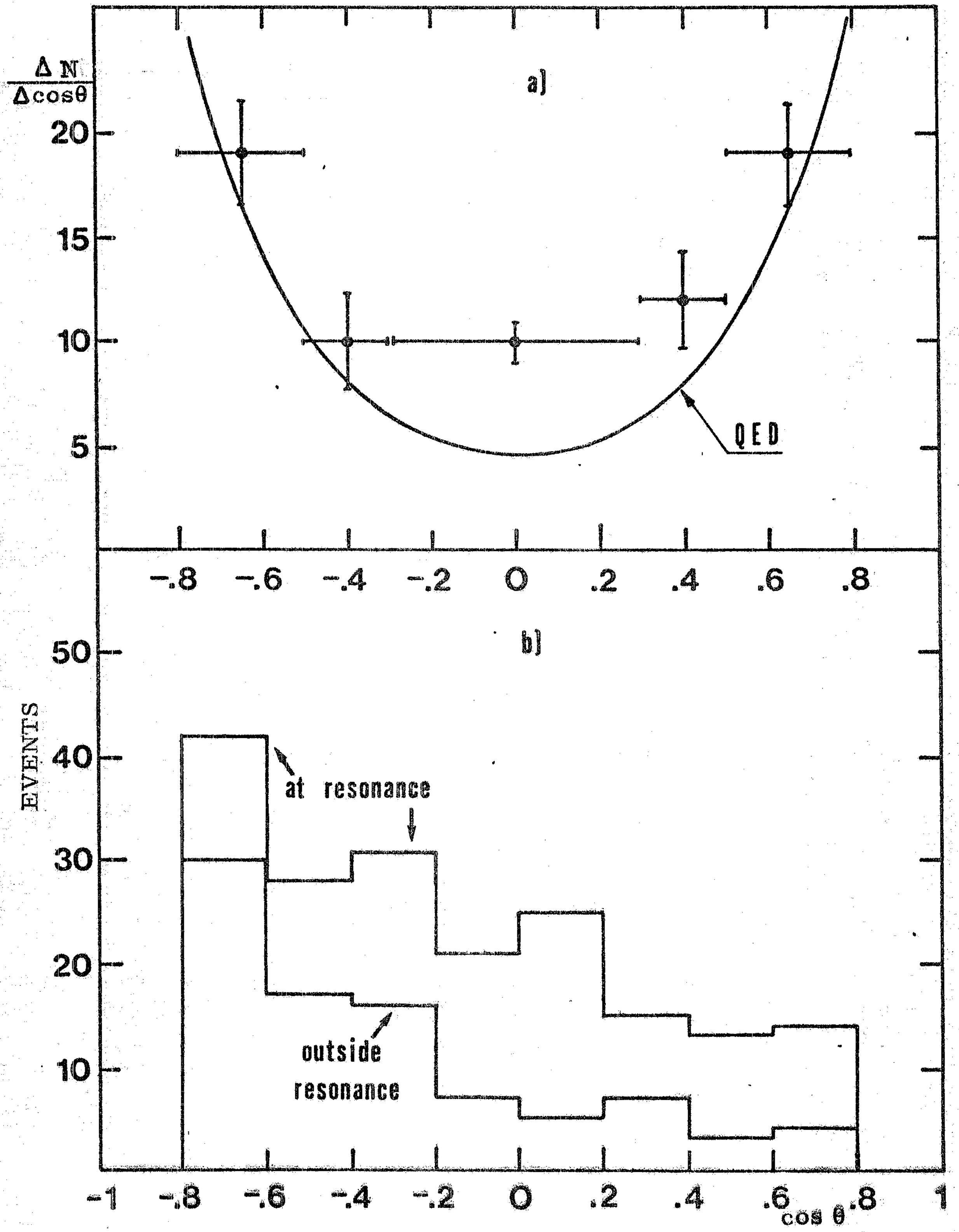

FIG. 7 - $e^+e^- \to e^+e^-$ Angular distribution: a) from the $B\bar{B}$ experiment. The solid line is the QED prediction. b) From the MEA experiment, inside and outside the resonance. The errors are statistical only.

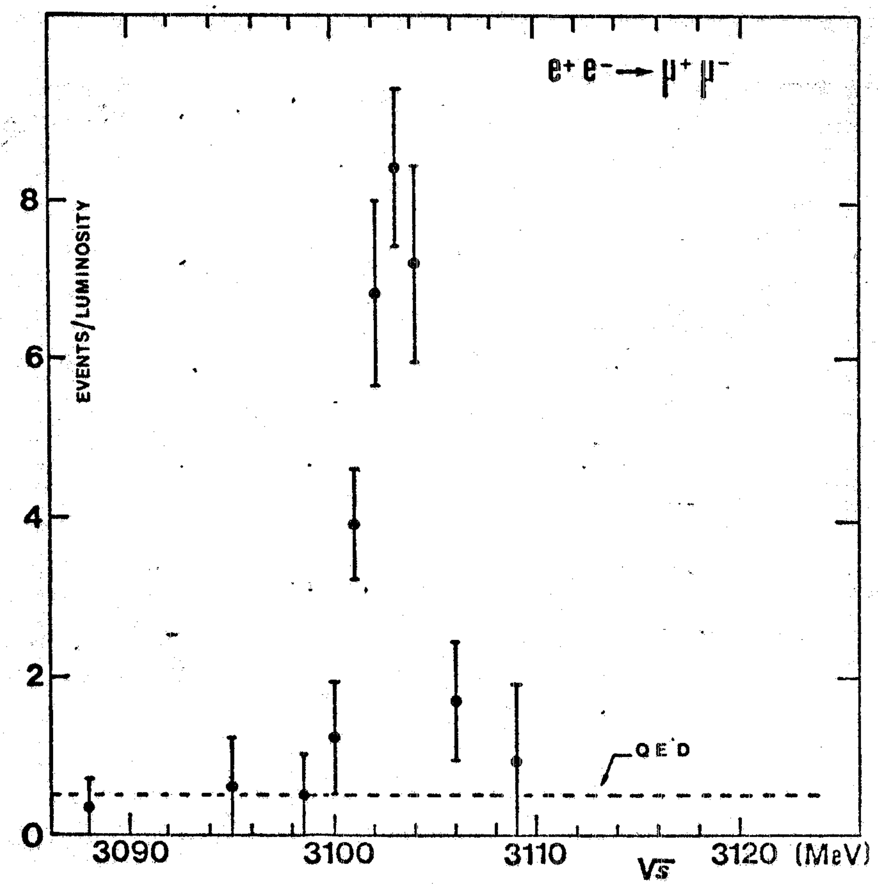

FIG. 8 - $e^+e^- \rightarrow \mu^+\mu^-$ excitation curve from MEA experiment. The errors are statistical only.

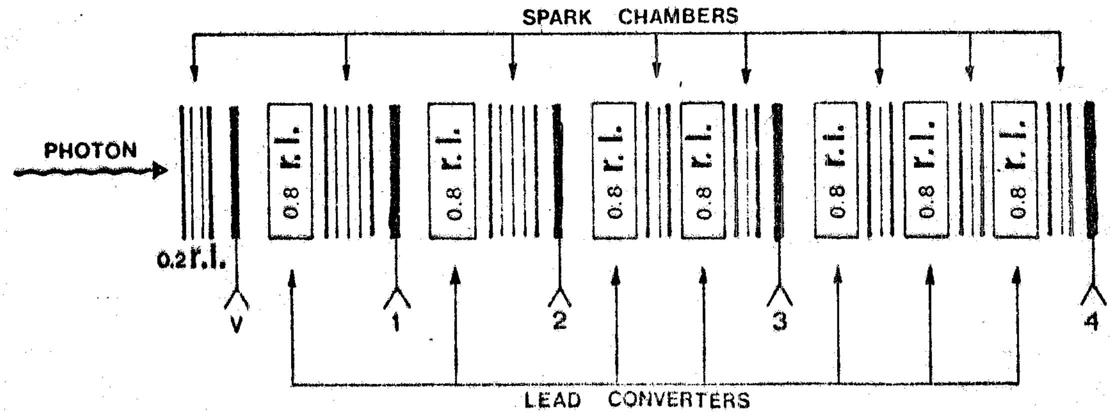

FIG. 9 - A sketch of one of the two main telescopes (SD) of the $\gamma\gamma$ apparatus. V, 1, 2, 3 and 4 are scintillation counters.

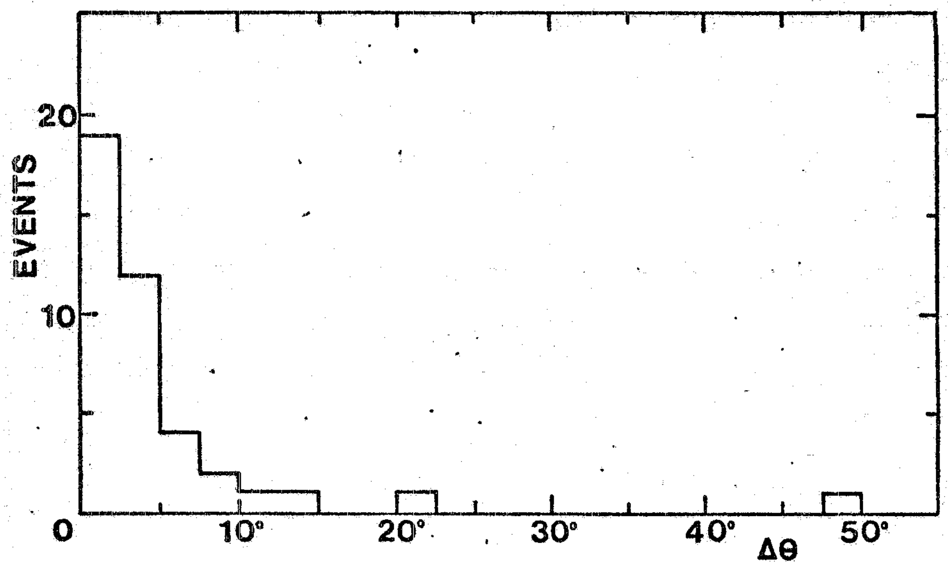

FIG. 10 - Collinearity distribution for two-photon events coplanar with the beam ($\gamma\gamma$ experiment).

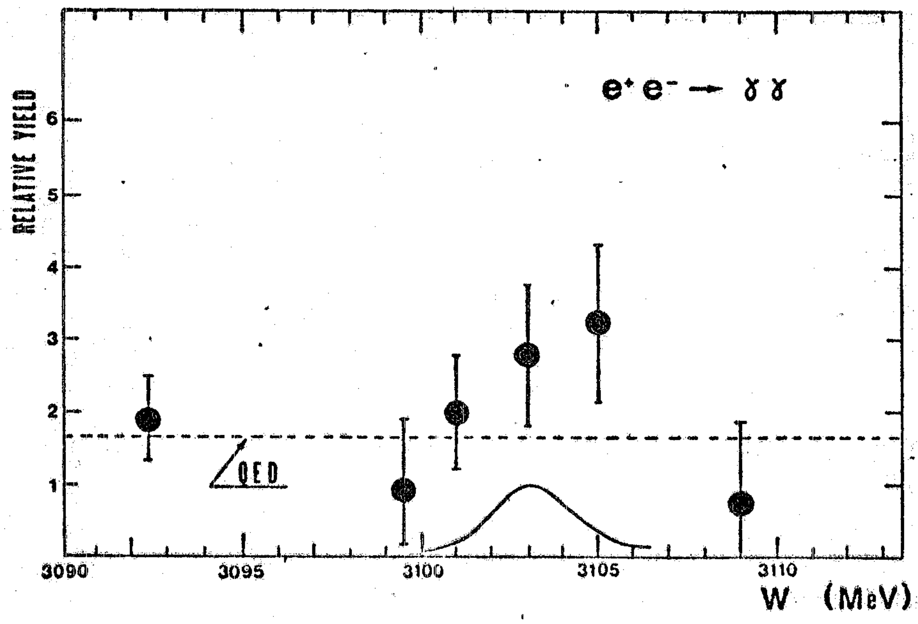

FIG. 11 - Relative yield for the production of collinear photon pairs as a function of the total c.m. energy. ($\gamma\gamma$ experiment) The horizontal dashed line represents the $e^+e^- \longrightarrow \gamma\gamma$ level as deduced by averaging the first and last point. The position and the shape of the ψ (3.1 GeV) resonance is shown.

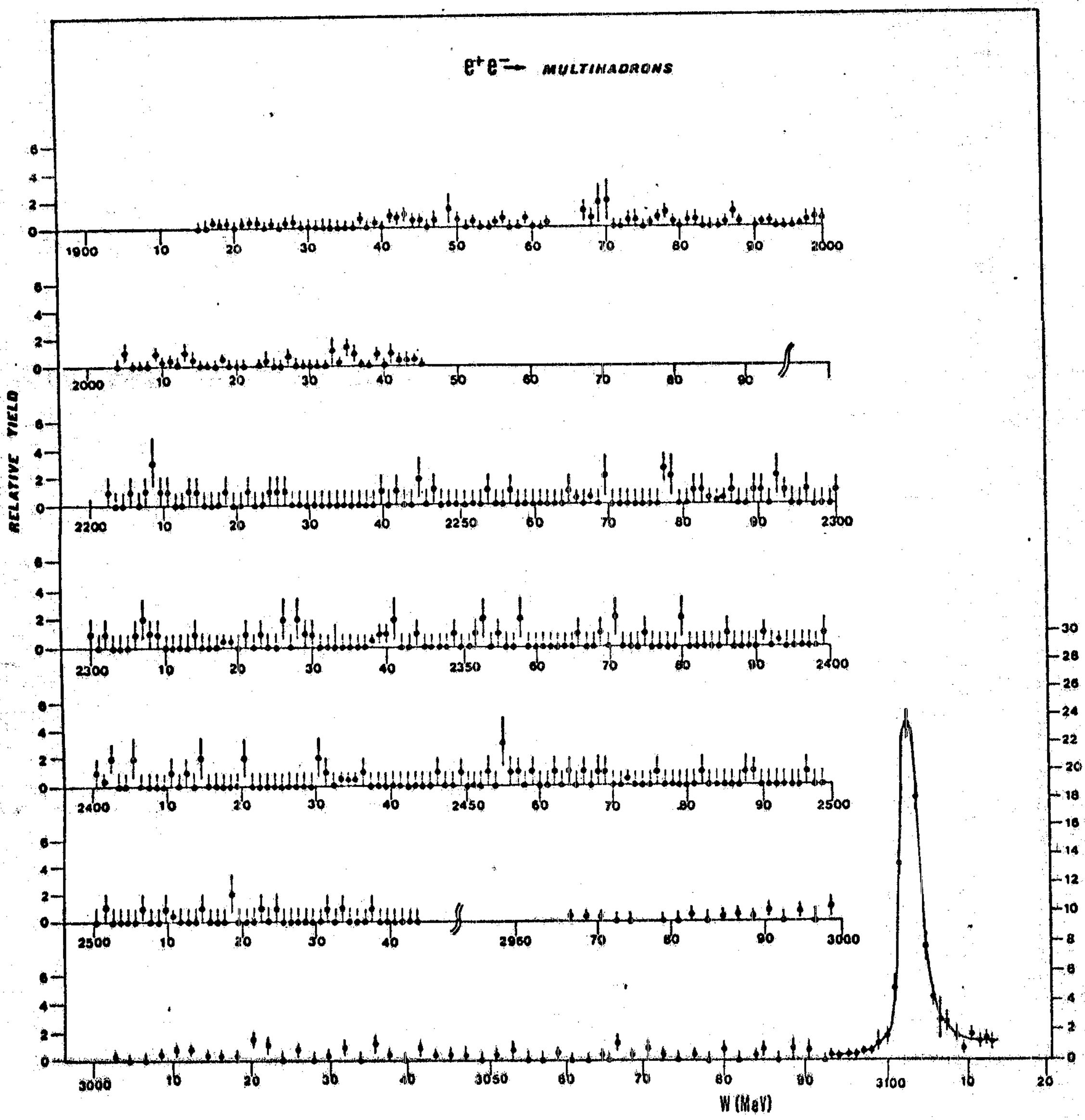

FIG. 12 - Multihadron relative yield ($\gamma\gamma$ experiment) as a function of total c.m. energy W. The ψ(3.1 GeV) is reported for comparison, on the same scale as the other points.