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LNF-74/66(P)
9 Dicembre 1974

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EXPERIMENTAL RESULTS ON THE PRODUCTION AND DECAY MODES OF THE 3101 MeV RESONANCE AT ADONE.

The first indications obtained at Adone about the recently discovered(1, 2) narrow resonance of 3101 MeV mass have been already published(3) in a very concise way. Here we present the results of a more extended, but still preliminary, analysis performed on part of the experimental data so far collected on the reactions :

(1) $e^+e^- \longrightarrow$ many hadrons ;

(2) $e^+e^- \longrightarrow \mu^+\mu^-$;

(3) $e^+e^- \longrightarrow e^+e^-$.

These data refer to a small energy region around the resonance ranging from 3085 to 3112 MeV. A clear peak is observed in all channels (1), (2) and (3) at a total c.m. energy of (3101 ± 2) MeV. The corresponding cross sections have been measured and the decay partial widths evaluated.

EXPERIMENTAL APPARATUS. -

The experimental set-up is schematically shown in Fig. 1. It consists of a main system of coaxial cylindrical detectors (KSC, SD, ISC) (scintillation counters and optical spark chambers with various

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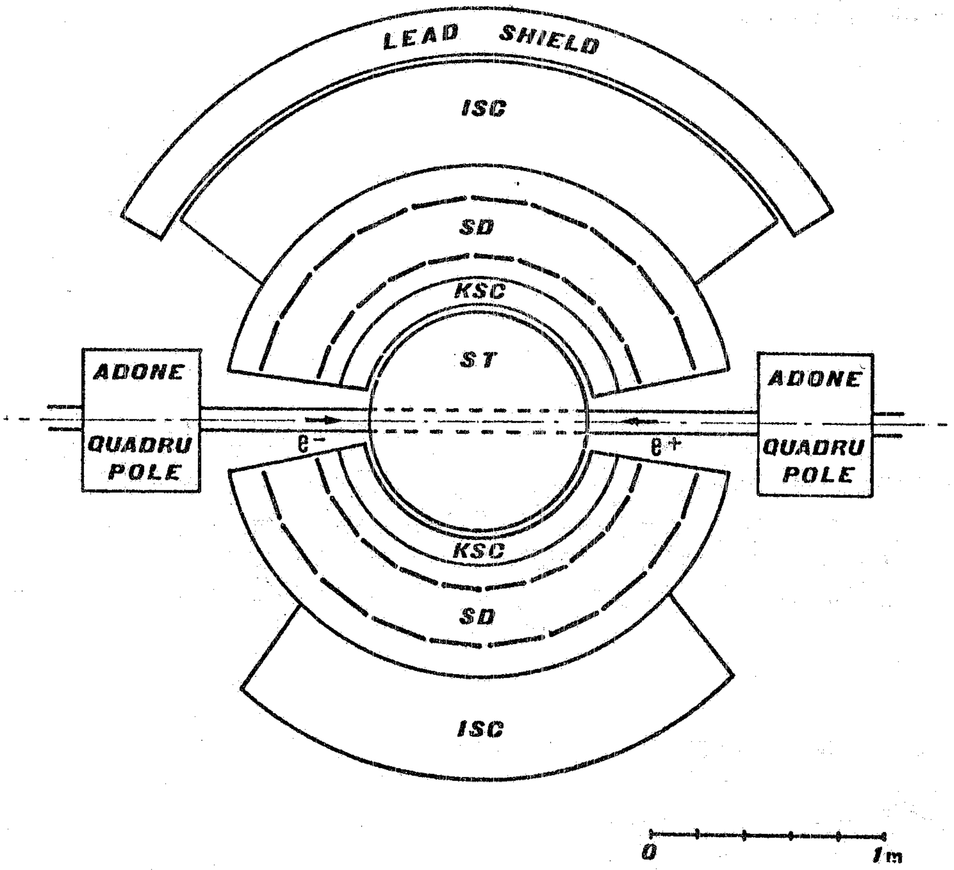

FIG. 1 - Front view of the experimental set-up. KSC = kinematical spark chambers ; SD = shower detectors ; ISC = Iron spark chambers ; ST = side telescopes.

absorbers in between) with the axis horizontal and perpendicular to the beam line. In addition, a pair of circular digitized side telescopes (ST) (magnetostrictive chambers and scintillation counters) complement the system in order to cover as much solid angle as possible. The total solid angle covered by the set-up for a point-like source is about 0.50 x 4π sterad for the optical detection system and 0.15 x 4π sterad for the side telescopes (ST). The minimum polar angle θ accepted by the set-up is 20^o. Because of the finite bunch length, the source point of the events produced at Adone, has a gaussian distribution, along the beam direction, with a width of $(47 \pm 5) E^{3/2}_{GeV}$ cm (FWHM). The transverse dimensions are of the order of 1 mm.

A particle produced in the interaction region traverses along its path through the optical detectors :

i) The doughnut wall (1.1 mm stainless steel) ;

ii) A scintillation counter close to the doughnut ;

iii) A thin plate 6-gaps kinematical spark chamber (KSC) which measures the direction of the charged particles and is used as a veto for the photons ;

iv) A shower detector (SD) consisting of 7 spark chambers (18 gaps) with 90^o stereoscopic view, 7 lead radiators (each 4 mm thick) and 5 layers of scintillation counters. Two of these layers consist of 10 different counters (see Fig. 1) in order to form a rough polar hodoscope. The total thickness of the shower detector is 5.5 r.l. (47 g/cm^2 equivalent of Fe);

v) A set of 8 bigap spark chambers sandwiched between 9 Iron layers 1.5 cm thick. This unit (ISC) which covers $\Delta\Omega \simeq 0.25 \times 4\pi$ sterad, helps to distinguish between muons and strongly interacting particles, by looking at their nuclear interactions.

Each side telescope (ST) is made up of 3 scintillation counters and 3 magnetostrictive spark chambers with lead converters interposed in between.

The trigger logic accepts several possible particle configurations. In particular the results presented here are obtained by requiring at least one charged particle in both the upper and lower telescopes. If only one charged particle is present in a telescope, the energy threshold for triggering is 140 MeV (for pions). However, if photons accompany the charged particle the energy threshold for this one may be as low as 25 MeV. It has to be remarked that in this trigger configuration, about 10% of the produced photons, which convert in the material in front of the kinematical spark chambers can simulate a charged particle. Single penetrating cosmic rays passing through the apparatus are reduced by a factor of $\sim 10^3$ by time of flight selection and by requiring the correct timing with the bunch collisions.

The wide angle ($30^o < \theta < 150^o$) Bhabha scattering detected in the apparatus has generally been used as an absolute luminosity monitor, outside the resonance. Beside this low rate "internal" monitor, high rate monitors (Bhabha scattering at small angles ($3^o - 6^o$) and double bremsstrahlung) are continuously provided by the Adone machine group with a monitoring apparatus installed in a different interaction region. The information of these monitors has been used to obtain the relative luminosity for the runs at the 3101 MeV resonance.

The experimental results on reactions (1), (2) and (3) will be now separately discussed.

(1) - $e^+e^- \longrightarrow$ many hadrons.

A relevant fraction of the decays of the 3101 MeV particle lead to multi-hadron final states. In order to minimize the number of events due to beam-gas interactions, only events of the type "2 tracks + anything" in the optical spark chambers have been considered. A track is defined as a non showering prong whose minimum penetration is about 40 MeV (for pion), and "anything" means at least one object charged or neutral (photon). The excitation curve for these events is shown in

Fig. 2, referring to a sample of about 1050 events. The width and the shape of this curve is compatible with a zero width resonance with its radiative correction tail, with the c.m. energy spread of the machine

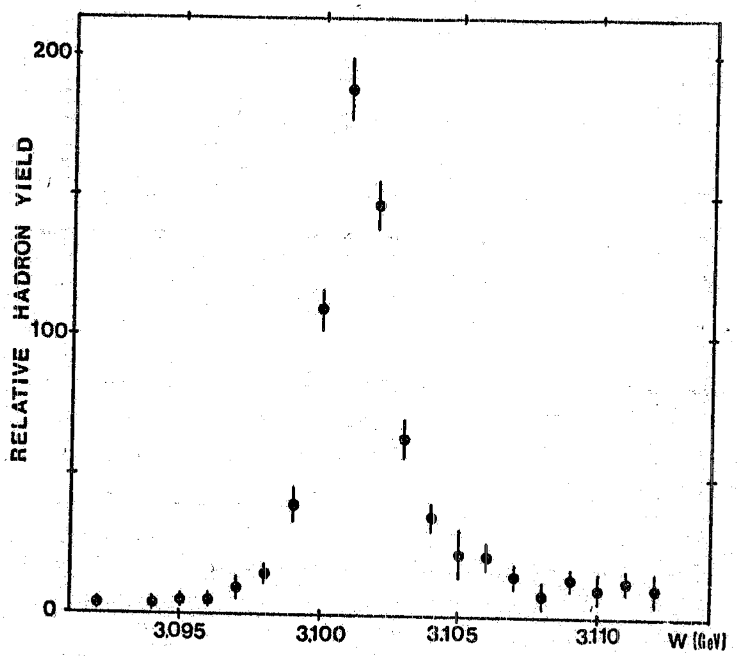

FIG. 2 - $e^+e^- \longrightarrow$ many hadrons excitation curve : the relative yield of the "2 tracks + anything" events is reported as a function of the total c.m. energy W.

($\sim$3 MeV FWHM)$^{(4)}$ folded in. From the analysis of part of the collected events at the peak energy, the charged and neutral multiplicities as observed in the main telescopes, have been deduced and are reported in Fig. 3. The angular distribution of the detected prongs (both charged and neutral) is shown in Fig. 4.

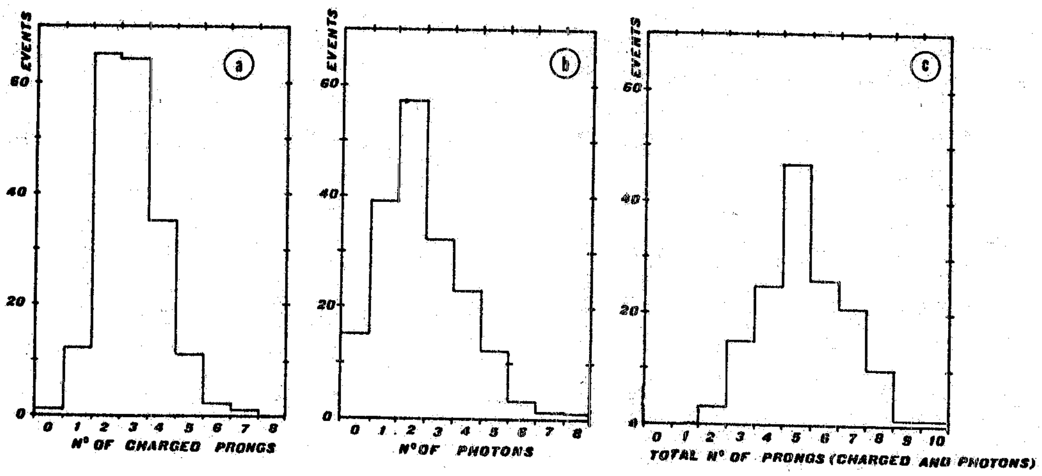

FIG. 3 - Experimental multiplicities at W = 3101 MeV as detected in the upper and lower telescopes. a) Charged prong multiplicity; b) Photon multiplicity; c) total (charged + photons) multiplicity.

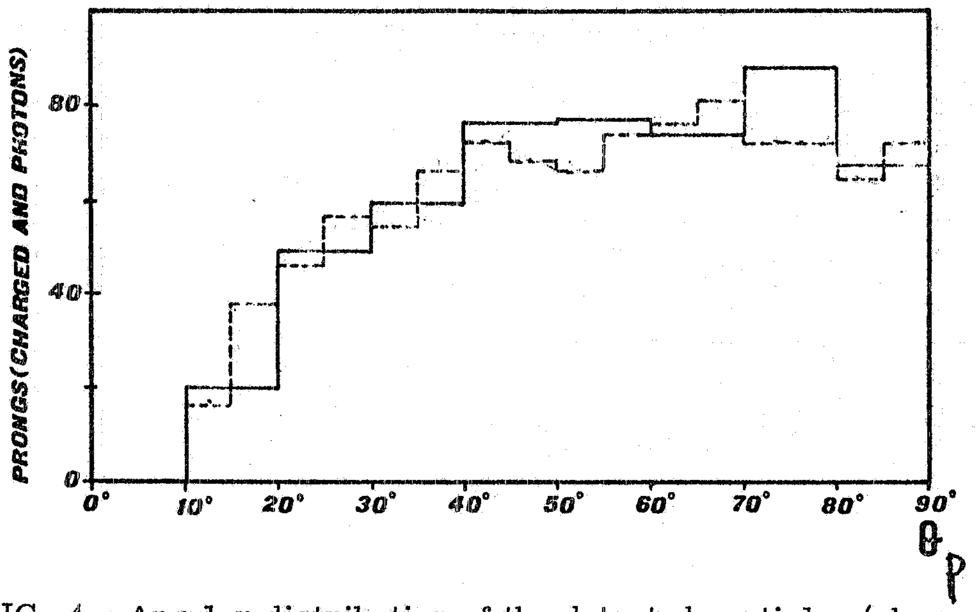

FIG. 4 - Angular distribution of the detected particles (charged or photons). In abscissa the production angle with respect to the beam line projected on a vertical plane is reported. The dashed line is the calculated distribution according to our Monte Carlo program.

In order to evaluate the cross section, the overall detection efficiency of the apparatus has been calculated under the hypothesis that all the produced particles are pions with an invariant phase-space momentum distribution. The relative weights of the possible decay channels have been chosen in such a way as to roughly reproduce the detected charged multiplicity. Within the limits of this preliminary calculation the lack of knowledge of the number of produced π^0's does not affect too much the overall efficiency which turns out to be about 25%. The energy integrated hadronic cross section $\sigma_H(W)$ in the resonance region is estimated to be

$$\int_{3097}^{3111} \sigma_H(W)\,dW = 6.7 \pm 2.4 \text{ nb GeV} \tag{4}$$

where the quoted error includes also a reasonable estimate of the uncertainties connected with the detection efficiency calculation.

(2) - $e^+e^- \to \mu^+\mu^-$.

This reaction has been studied only at the energies of 3100, 3101, 3102 MeV corresponding to the top of the resonance. A set of events with two colinear non showering tracks in the spark chambers was selected. It was also required that these tracks would not exhibit nuclear interactions in the shower detectors (SD). In order to reject the residual cosmic muons accepted by the trigger, more strin gent selection on the time of flight (measured over a basis of ~ 1 m in the upper telescope) and on the geometrical reconstruction of the source were applied. The source position distribution projected on a horizontal axis (x axis) perpendicular to the beam direction, is shown in Fig. 5. Around the interaction region $(x = 0)$, a clear peak emerges over a smooth background due to the residual cosmic muons. By interpolating the background under the peak, the number of colinear events from e^+e^- interactions turns out to be 84 ± 12.

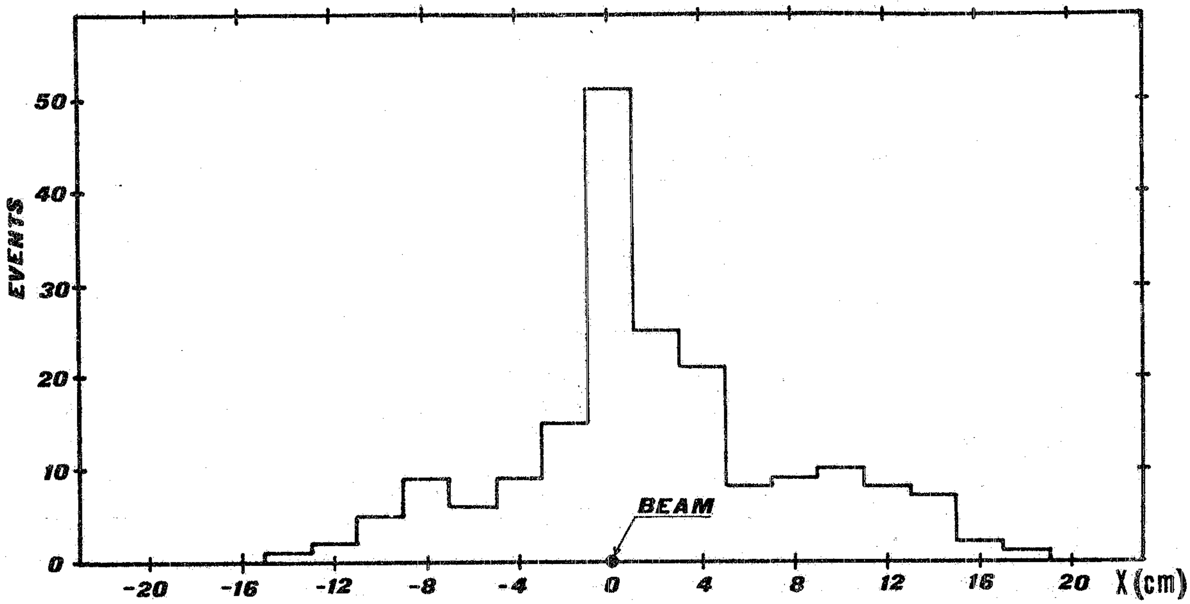

FIG. 5 - Radial distribution of the reconstructed e^+e^- interaction point for the colinear events. The beam line is perpendicular to the figure at the point $x = 0$.

In order to identify the nature of these particles (hadrons or muons), a subsample of events with both tracks in the ISC chambers (117 g/cm^2 of Iron) has been selected and their nuclear interactions (stops or scatterings with angles larger than 25°) looked for. The results of this analysis lead to the conclusion that the selected colinear events are mainly produced by reaction (2) and that an upper limit to possible hadron contamination is about 13%. The geometrical detection efficiency for process (2) is 20%, as estimated under the assumption that the angular distribution is of the $(1 + \cos^2\theta)$ type. The calculated cross section averaged in the energy interval 3100 - 3102 MeV is (146 ± 40) nb. The experimental angular distribution of the muon pairs is reported in Fig. 6 together with the Monte Carlo predictions. The data are consistent with the assumed distribution. It should be observed, however, that within the present statistical accuracy, the data could be well fitted also by different angular distributions. From the quoted value of the cross section at the peak and using the resonance shape as from the multihadron production, the following integral has been evaluated:

$$(5) \qquad \int \left[\sigma_{\mu\mu}(W) - \sigma_{\mu\mu}^{QED}(W) \right] dW = 0.61 \pm 0.18 \text{ nb GeV}.$$

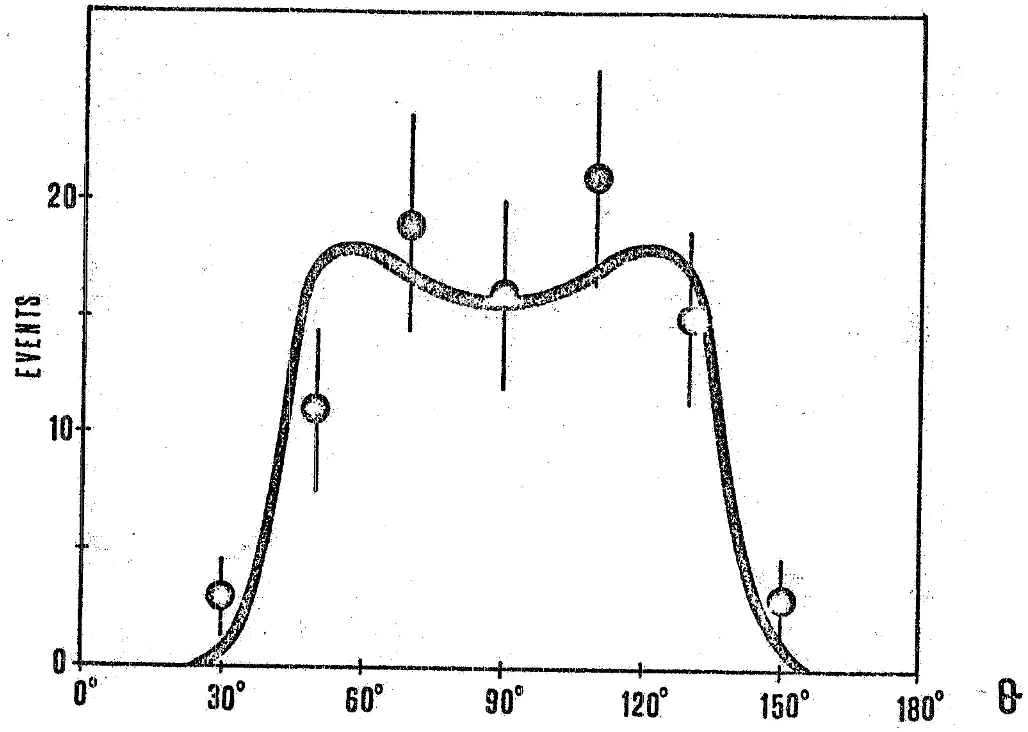

FIG. 6 - Angular distribution of the muon pairs. θ is the angle of the muons with respect to the beam line. The curve represents the Monte Carlo predictions assuming a $(1+\cos^2\theta)$ distribution.

(3) - $e^+e^- \rightarrow e^+e^-$ reaction.

At the energy of the resonance a clear peak appears also in the cross section for this process emerging by a factor more than 2 with respect to the Q.E.D. level. This is shown in Fig. 7 where the yield of e^+e^- events is reported as a function of the total c.m. energy. The quoted errors are statistical only and the dashed line represents the Bhabha scattering level outside the peak. The energy integrated cross section in the interval 3097 - 3105 MeV, with the Bhabha scattering level properly subtracted out, and under the assumption that the angular distribution for the e^+e^- pair from the resonance is of the $(1+\cos^2\theta)$ type turns out to be :

$$(6) \qquad \int_{3097}^{3105} \left[\sigma_{e^+e^-}(W) - \sigma_{e^+e^-}^{QED}(W) \right] dW = 0.88 \pm 0.30 \text{ nb GeV}.$$

The above mentioned Q.E.D. subtraction procedure has been performed considering that, within the limits of the present accuracy, the interrence term gives a negligible contribution to the integrated cross section.

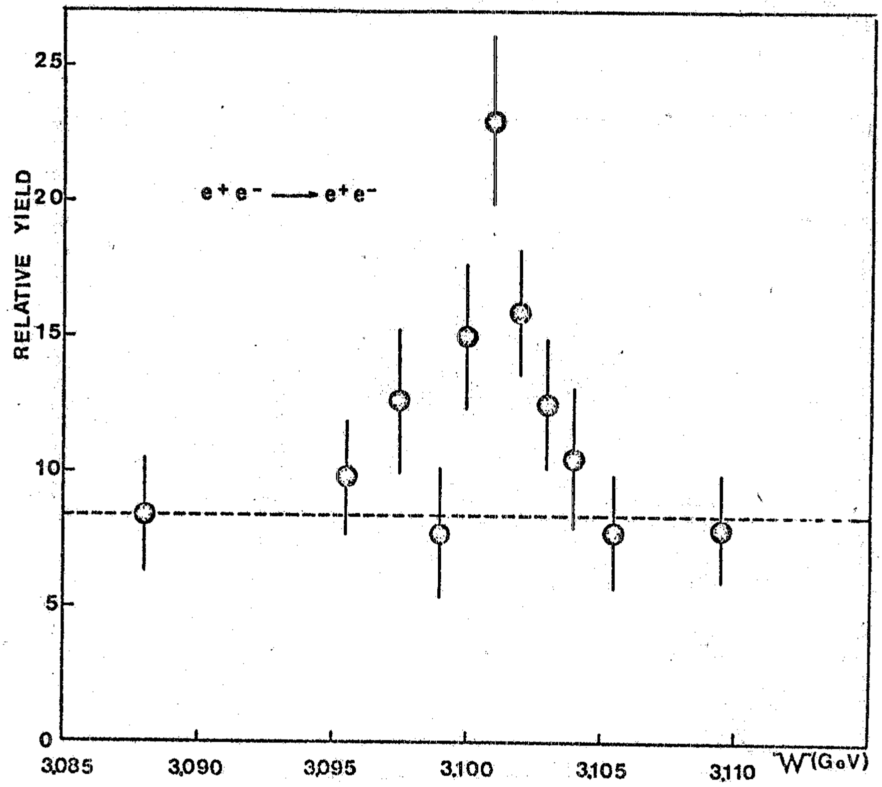

FIG. 7 - $e^+e^- \rightarrow e^+e^-$ excitation curve. The relative yield of the e^+e^- events is reported as a function of the total c. m. energy W. The dashed line is the average rate in the two regions $3082 \leq W \leq 3096$ (MeV) and $3105 \leq W \leq 3112$ (MeV), which is assumed to coincide with Bhabha scattering.

The values of the integrated cross section for processes (1), (2) and (3) reported in (4), (5) and (6) respectively, give information on the partial decay rates of the 3101 MeV resonance ; in particular from the ratio of the integrals (5) and (4) one finds :

$$\Gamma_\mu / \Gamma_H = (9 \pm 3)\% ,$$

and from the ratio of the integrals (6) and (4):

$$\Gamma_e / \Gamma_H = (13 \pm 4)\% ,$$

where Γ_H, Γ_e and Γ_μ are the partial widths for the decay in multihadrons, e^+e^- and $\mu^+\mu^-$ respectively.

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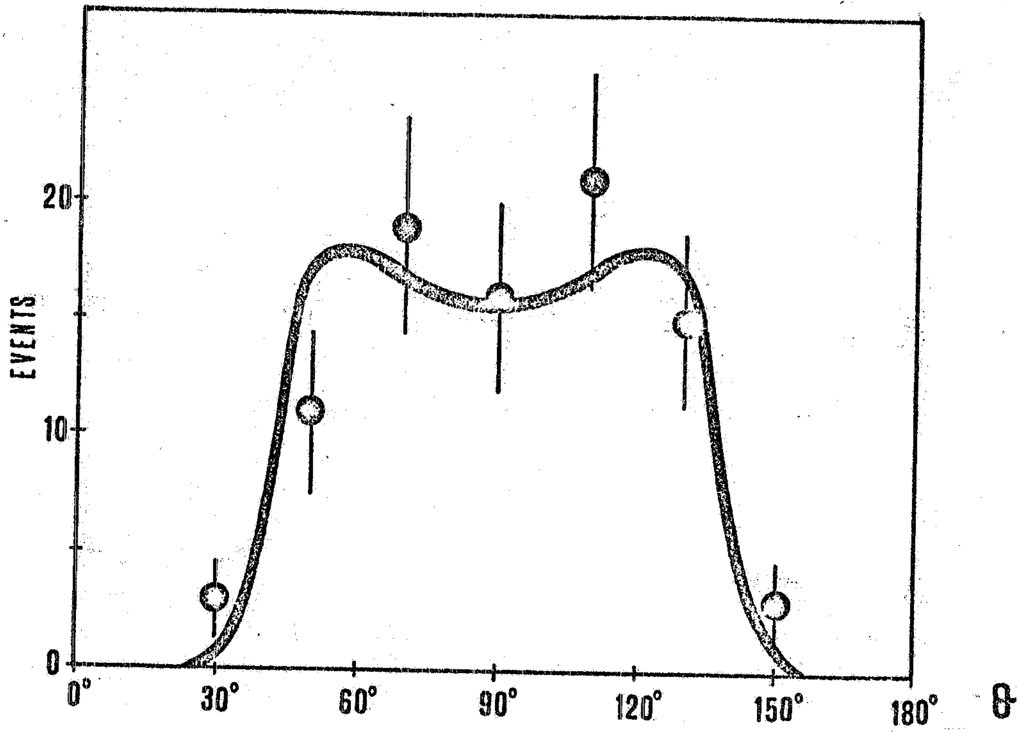

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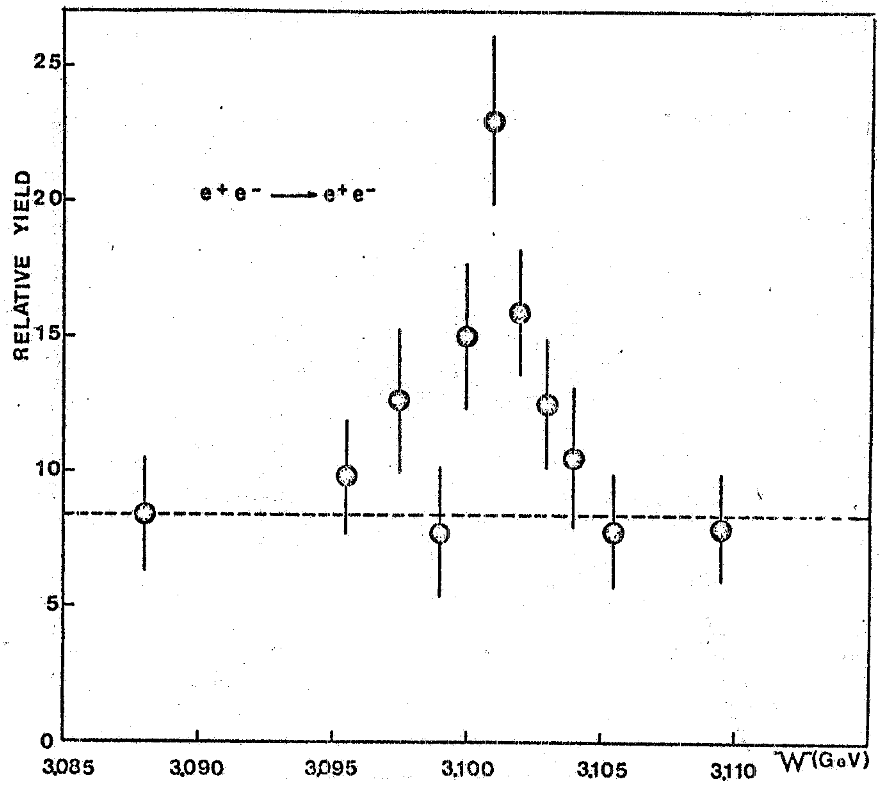

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It has to be recalled that the integrals (5) and (6) have been calculated assuming a $(1+\cos^2\theta)$ distribution for the decay of the re sonance, and integral (4) assuming an invariant phase space distribution.

Furthermore in the hypothesis of a spin 1 resonance with a total width Γ given by

$$\Gamma = \Gamma_H + \Gamma_e + \Gamma_\mu$$

we obtain from (4), (5) and (6):

$$\Gamma_H = 26 \pm 11 \text{ keV} , \tag{7}$$

$$\Gamma_e = 3.4 \pm 1.2 \text{ keV} , \tag{8}$$

$$\Gamma_\mu = 2.4 \pm 1.1 \text{ keV} . \tag{9}$$

The quoted errors take into account also a reasonable estimate of systematic uncertainties. Radiative corrections have not yet been applied.

This experiment was made possible by the unvaluable collaboration whole research and technical staff of the Adone group which was able to keep the machine operation extremely efficient. Particular thanks are due to G. Di Stefano and the other technicians of the Detector Workshop for their excellent work in designing and building the experimental set up. We warmly thank F. Cesaroni for his unvaluable role in building the analysis system of our spark chamber pictures. We are grateful to I. Bruno, M. Gillia, M. A. and F. Melorio for their continuous help in the various stages of the analysis procedure and to L. Di Virgilio for his collaboration in building the set up.

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