MULTIHADRON PRODUCTION AT ADONE

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SUMMARY

A short review of recent experimental results obtained at Adone, on multihadronic e^+e^- annihilation is given.

Results and comments concern:
1) R values, compared QCD and EVMD predictions;
2) Charged and neutral multiplicities, threshold for "energy crisis", G parities and SU_3 checks;
3) $\sigma(2\pi^+, 2\pi^-)$: evidence for a large $\varrho''(1600)$;
4) $\sigma(\pi^+\pi^- 2\pi^0)$: lack of evidence for a $\varrho'(1250)$;
5) $\sigma(2\pi^+, 2\pi^-, n\pi^0)$: possible interpretation of the 1.82 GeV structure.

INTRODUCTION

The results I'll report about are some of the latest results from the Frascati e^+e^- storage ring Adone. Recently interesting results have been obtained on QED tests, search for a heavy electron, $\gamma\gamma$ interactions. I'll concentrate only on results on multihadronic e^+e^- annihilation, mainly coming from the $\gamma\gamma 2$ experiment. Results on total cross sections and two body reactions will be available also from MEA and $B\overline{B}$ experiments in the next months.

Adone is an e^+e^- storage ring covering the interval $1.4 \leq W \leq 3.1$ GeV with a typical luminosity $L \sim 3 \times 10^{29}$ $cm^{-2}\,sec^{-1}$ at W = 3 GeV, which drops down to $L \sim 2 \times 10^{28}$ at W = 1.5 GeV.

Three of the four interaction regions of Adone are equipped with experimental set-ups; in the fourth a small angle (3^o - 6^o) Bhabha scattering detector, which serves as a high rate luminosity monitor, is installed. The luminosity used by the experiments is directly measured by counting wide angle electron pairs detected in each apparatus.

The three set-ups are somewhat complementary since MEA has magnetic analysis ($\Delta\Omega$ = 40%), $\gamma\gamma 2$ is oriented toward γ detection ($\Delta\Omega_\pi$ 90%, $\Delta\Omega_\gamma$ 66%) and $B\overline{B}$ uses calorimetric information from large liquid scintillators ($\Delta\Omega$ = 70%). They are described in detail in refs. (2, 3, 4) respectively. The three experiments ran at Adone up to June 1978.

NARROW RESONANCES

All data have been collected in scanning mode. As first, combining all the results of the three Adone experiments, we obtain for the J/ψ-like particle existence, in the full energy range ($1.42 \leq W \leq 3.1$ GeV) an upper-limit of ~ 0.05 $\Gamma_{ee}(J/\psi)$ with 90% C.L..

R VALUES

In order to obtain R, multiplicities and exclusive cross sections, using the standard likelihood method, the following assumptions were made:

a) all particles in the final states are π;
b) invariant phase space (IPS) momenta distributions;
c) isospin relation $\langle n^{\pm}\rangle = 2\,\langle n^o\rangle$ for $n^{\pm} + n^o = 5$;
d) maximum multiplicity $n^{\pm} + n^o = 6$ up to 2 GeV and $n^{\pm} + n^o = 8$ up to 3.1 GeV.

The first assumption is reasonable especially at lower energies. In a more quantitative way the MEA [5] group has measured the percentage of kaons respect to the total prongs in a given momentum window (see Fig. 1). This K fraction is lower than 20%.

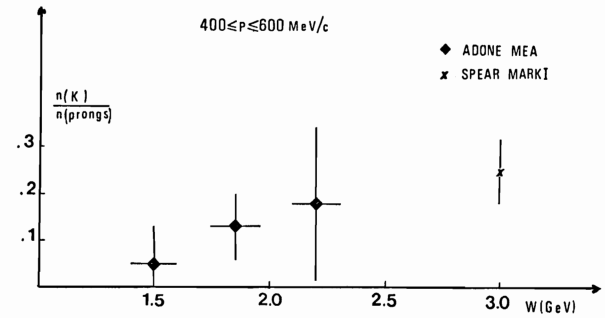

Fig. 1. Ratio between the numbers of K and prongs whose momentum falls in the range $400 \leq p \leq 600$ MeV/c.

Using a special category of events the $\gamma\gamma$ group has also estimated an upper limit at 1.5 GeV for KK^* production of 8 nb (95% c.l.), that is 20% of the total cross section[6].

The DCI-DM1 experiment[7] gives also the ratio $\sigma(K\overline{K}X)/\sigma_{TOT} \approx 20\text{-}30\%$. In conclusion this assumption leads to a systematic error on R of 10-20% at the lowest energies, that becomes negligible at higher energies.

The rationale for the second assumption can be found in the energy distribution of produced hadrons (Fig. 2) well fitted by a thermodynamical spectrum with

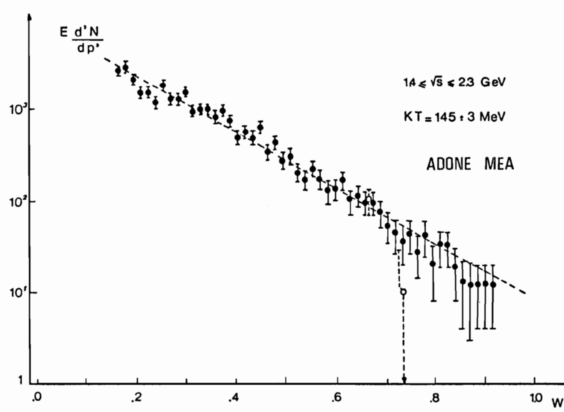

Fig. 2. Invariant distribution for π and K as function of the total energy of the particle.

KT = 145 ± 3 MeV. This distribution can be independently reproduced summing the IPS momentum distributions for each channel weighted with their own exclusive cross sections we will see after.

The values of R for at least 3π in the final states are reported in Fig. 3 together with a large panorama of already published values[8-13]. The values of VEPP2M are calculated summing the two most important cross sections that are $\sigma(2\pi^{\pm}, 2\pi^{0})$ and $\sigma(4\pi^{\pm})$. The agreement between all the machines is very good.

of R, calculated by formula $R = 16\pi^2/\Delta m_\rho^2 f_\rho^2 \simeq 2.5$[16] fits very well the value of R above 2.4 GeV.

The same contradictory situation comes from QCD corrections[17] to the asymptotic value $R = 3\Sigma_q Q_q^2 = 2$ which gives a $R \simeq 2.3$ between 2.4 and 3.6 GeV.

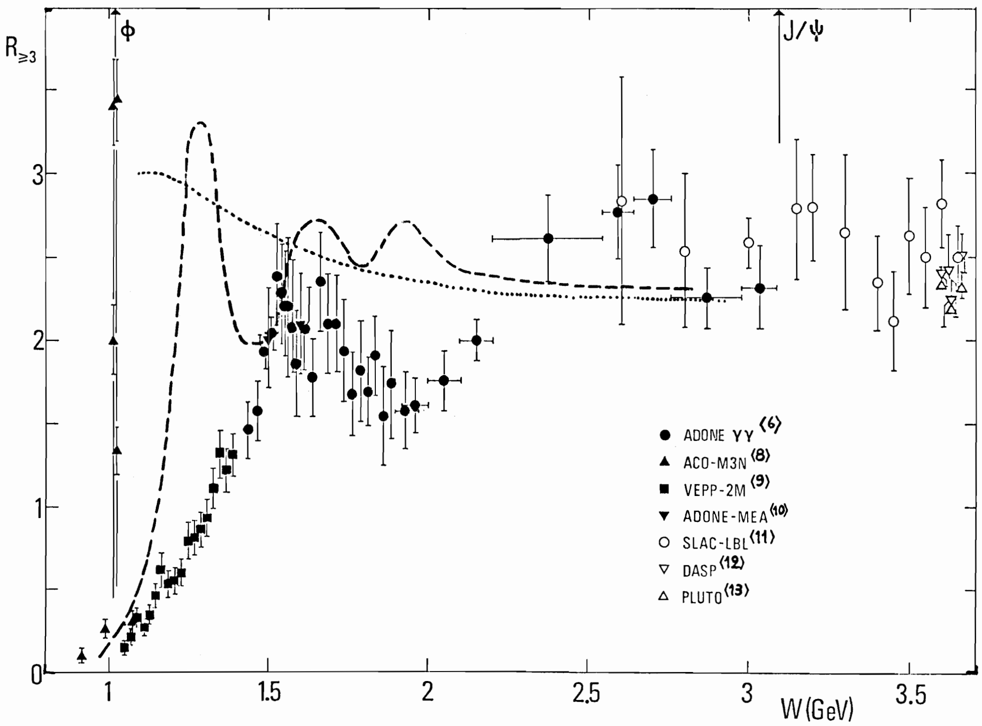

Fig. 3. R versus total energy. The dotted and dashed lines represent the QCD and EVMD expectations respectively.

The quoted errors are statistical only while the systematical ones on $\gamma\gamma$ group data are $\sim 20\%$ (due to luminosity, efficiencies, K presence).

Data from DCI-M3N[14], not quoted, are in general good agreement with the Adone $\gamma\gamma$ data.

The energy behaviour of the ratio R is now rather well established above 1 GeV.

In the low energy region after the ϕ, there is a sharp rise whose pattern is typical of the opening of new channels. In this behaviour the more important contribution comes from $\sigma(4\pi^{\pm})$ as we will see later.

Theoretical calculations give good asymptotic values but are not able to reproduce the low energy behaviour. The asymptotic value is expected to be reached from above at the lowest energies where, on the contrary, the measured R is growing. More precisely, the EVMD, with the help of the local duality[15], predicts, around the asymptotic value, a series of oscillations due to the vector meson recurrences. Using the mass formula $\Delta m_i^2 \approx 1$ GeV^2 and scaling Γ_{ee}^{-1} and Γ_{tot} with the masses the expected values of R do not fit the data concluding that, as we will see also later, some of these recurrences do not exist or have Γ_{ee} much smaller. On the contrary, the asymptotic value

MULTIPLICITIES, G-PARITIES

Mean charged and neutral multiplicities are reported in Fig. 4. New ln W fits are reported also.

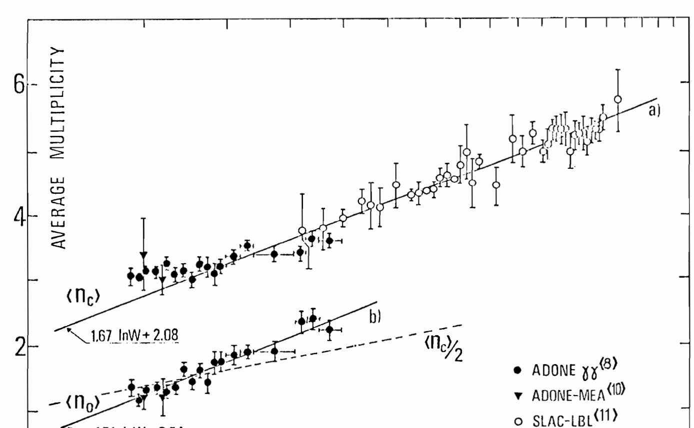

Fig. 4. Charged and neutral multiplicity.

Comparing neutral multiplicity with 1/2 of the charged multiplicity clearly the so called "energy crisis" appears starting from ~ 2 GeV. A possible interpretation for such a phenomenon is η's production.

Before considering the various reactions which contribute to the total cross section, let us divide them in two categories, according to the G-parities. The total cross section for even, G^+, and odd, G^-, number of pions are reported in Fig. 5 $(n \geq 3\pi)$. G^+ dominance is expected. Taking into account the quarks content of the ϱ-like and ω-like states, one finds:

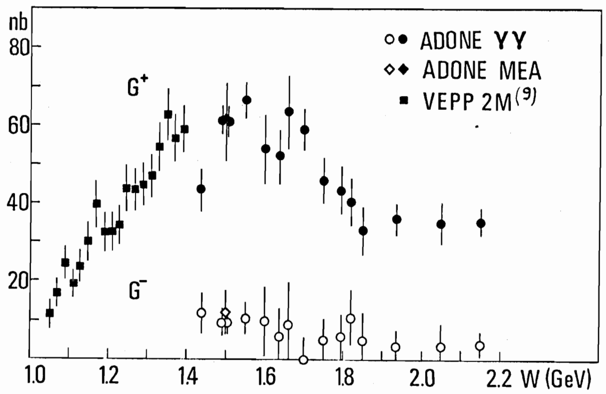

Fig. 5. G^+ (sum of $\sigma(n\pi)$ with n even) and G^- (sum of $\sigma(n\pi)$ with n odd) versus total energy.

$$\frac{|A(e^+e^- \to \omega\text{-like} \to G^-)|^2}{|A(e^+e^- \to \varrho\text{-like} \to G^+)|^2} = \frac{|Q_u + Q_d|^2}{|Q_u - Q_d|^2} = \frac{1}{9} =$$

$$= \frac{\Gamma_e(\omega\text{-like})}{\Gamma_e(\varrho\text{-like})} = \frac{\int_{M_\Phi}^{W} G^-(W)dW}{\int_{M_\Phi}^{W} G^+(W)dW}$$

being the Γ_e proportional to the integrated cross section over the resonance. Data have been collected at Adone in scanning mode, so a real energy integration can be done. The result is reported in Fig. 6.

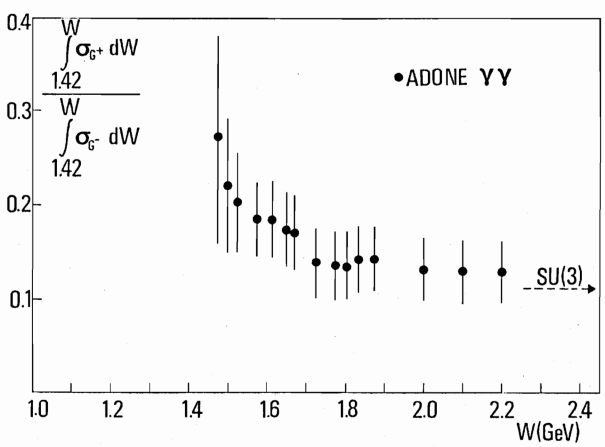

Fig. 6. Ratio between G^+ and G^- after the energy integration starting from W = 1.42 GeV.

Adone-$\gamma\gamma$ data are in fair agreement with SU_3 prediction, if no dramatic contribution to G^- is present for $M_\Phi < W < 1.42$ GeV.

EXCLUSIVE CROSS SECTIONS

$\sigma(\pi^+\pi^-\pi^+\pi^-)$.

The better established channel is the 4 charged pions. The $\gamma\gamma$ and MEA values are reported in Fig. 7

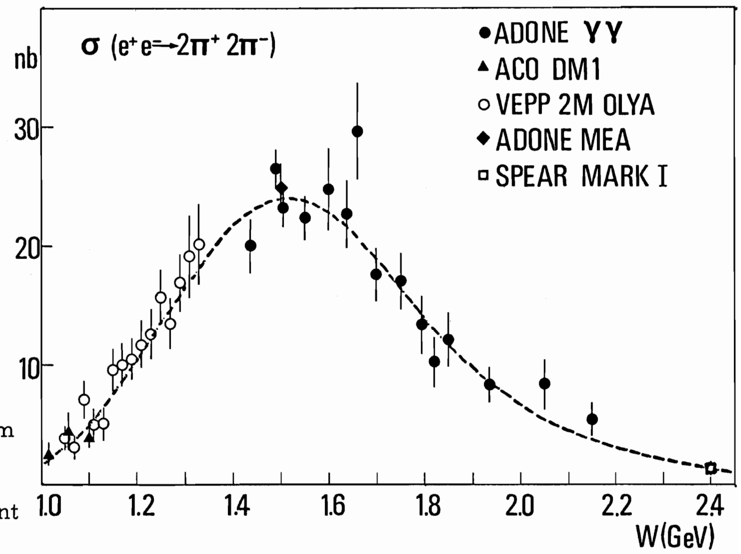

Fig. 7. $\sigma(\pi^+\pi^-\pi^+\pi^-)$. The dashed line represents the Breit-Wigner best fit.

together with those already published[10, 18, 19, 20]. The general behaviour shows a broad resonance centered at 1.5 GeV interpreted as the ϱ-recurrence $\varrho''(1.6)$. The dashed line represents a best fit over all the values with only one relativistic Breit-Wigner with an energy dependent width for threshold effect (for sake of simplicity assumed as a simple function of the IPS of $\varrho''(1.6) \to \varrho\pi\pi$ in S wave) according to the following formulas:

$$\sigma = \frac{12\pi}{s} \frac{M_v^2 \Gamma_v \Gamma_{ee}}{(s-M_v^2)^2 + M_v^2 \Gamma_v^2}, \quad \Gamma_v = \Gamma_o \frac{\alpha K}{1+\alpha K}$$

where K = IPS$(\varrho\pi\pi)/s$ and α a free parameter.

The result of the fit gives the following parameters:

$$M_v = 1650 \pm 20 \text{ MeV},$$

$$\Gamma_v(M_v) = 710 \pm 160 \text{ MeV},$$

$$\Gamma_{ee} = 2.8 \pm 0.2 \text{ keV}.$$

All these parameters are in a rather good agreement with those known of the $\varrho''(1.6)$. The Γ_e value expected by local duality is $\Gamma_e \simeq 3.1$.

Dynamical correlations in the final state have been investigated by the MEA group[10].

Selecting the 4 prongs events the corresponding Dalitz plot is shown in Fig. 8.

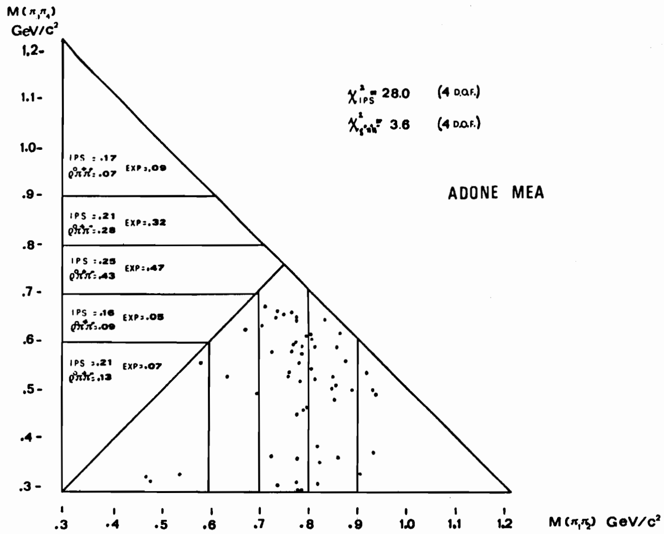

Fig. 8. Scatter plot of the invariant mass of oppositely charged pion pairs, $M(\pi_1\pi_2)$ vs the invariant mass of the remaining pair $M(\pi_3\pi_4)$.

The result largely favours a $\varrho\pi\pi$ intermediate state with the two pions in S-wave.

$\sigma(\pi^+\pi^-\pi^o\pi^o)$.

Another important channel in the total cross section is that with 2 charged plus 2 neutral pions in the final state. The $\gamma\gamma$ and MEA values are reported in Fig. 9 together with those from VEPP2-M[9]. This cross section shows a rather different behaviour respect to the $\sigma(4\pi^{\pm})$.

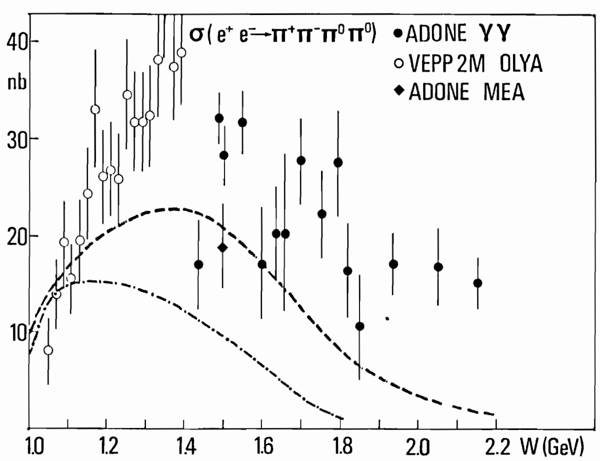

Fig. 9. $\sigma(\pi^+\pi^-\pi^o\pi^o)$. The dashed-dotted line is the calculation of the $\varrho_{TAIL} \rightarrow \omega\pi^o$. The dashed line is the incoherent sum of the $\varrho_{TAIL} \longrightarrow \omega\pi^o$ and the $\varrho''(1.6) \rightarrow \varrho^o\pi^o\pi^o$.

Two contributions must be taken into account. First, the ϱ-tail going into $\omega\pi$, computed by Renard[22] starting from the $\omega \rightarrow \varrho\pi$ decay (dashed-dotted line). Second, the $\varrho''(1.6)$ decay via $\varrho^o\pi^o\pi^o$ whose cross section can be taken as $(\sigma(4\pi^{\pm}))/2$, if the two π are in S-wave. An incoherent sum of these two contributions is reported (dashed line) also in Fig. 9.

The measured values are systematically higher with respect to this curve so that other contributions should be present.

In the low energy region ($W \lesssim 1.5$ GeV) integrating the cross section exceeding the dashed line of Fig. 9, we get a value $\Gamma_e \leq 0.6$ keV. On the other hand around 1.25 GeV the first ϱ-recurrence is expected. Local duality, that works rather well on J/ψ and Υ families, gives[15]:

$$\left(\frac{m\,\Gamma_{ee}}{\Delta m^2}\right)_{\varrho} = \left(\frac{m\,\Gamma_{ee}}{\Delta m^2}\right)_{\varrho'} = \left(\frac{m\,\Gamma_{ee}}{\Delta m^2}\right)_{\varrho''} .$$

Applying this formula to the $\varrho''(1.6)$, we obtain, within a factor 2, the values quoted above.

For the $\varrho'(1.25)$ we obtain, using $\Delta m^2 \simeq 1$ GeV^2, $\Gamma_e \simeq 4$ keV that is far from the value $\Gamma_e \lesssim 0.6$ quoted above.

$\sigma(2\pi^+, 2\pi^-, 1\pi^o)$ and $\sigma(2\pi^+, 2\pi^-, 2\pi^o)$.

The separation between these two channels is a very critical one: it depends essentially on how well the photons detection efficiency is known. For the $\gamma\gamma$ apparatus this efficiency has been checked on the observed photons taking in account also the optical spark chamber efficiency for multisparks. However the sum of these two cross sections does not depend on the photon efficiency and is reported in Fig. 10. The high point at W = 1.82 GeV represents, integrated in energy, the resonance ($\Gamma \simeq 30$ MeV) already published by the 3 Adone experiments[23].

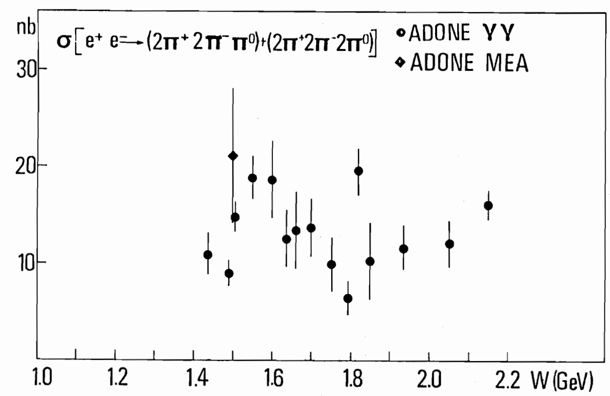

Fig. 10. Sum of $\sigma(2\pi^+, 2\pi^-, 2\pi^o)$ and $\sigma(2\pi^+, 2\pi^-, 1\pi^o)$.

A nice interpretation of this structure is a decay of a barionium state near $N\bar{N}$ threshold according to the following scheme:

$$\mathrm{Ba}(I=1) \rightarrow \mathrm{Ba}(I=0) + \pi^o$$
$$\hookrightarrow 2\pi^+\, 2\pi^-\, \pi^o .$$

The small value $\Gamma_e \simeq 60$ eV favours this interpretation instead of a standard vector meson recurrence.

Unfortunately, in separating these two channels the errors become larger (Figs. 11 and 12) so that it is impossible to determine the resonant channel.

The values of $\sigma(2\pi^+, 2\pi^-, 1\pi^o)$ agree rather well with the DM1 data[21].

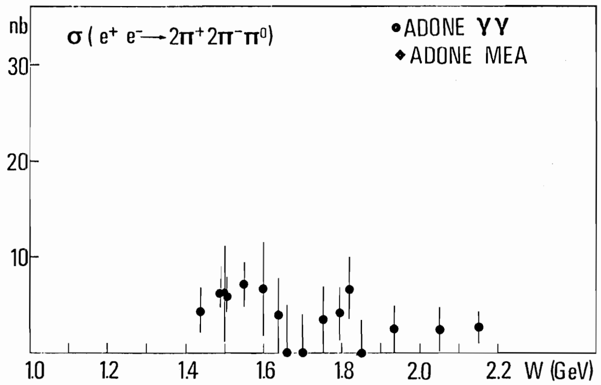

Fig. 11. $\sigma(2\pi^+, 2\pi^-, 1\pi^0)$.

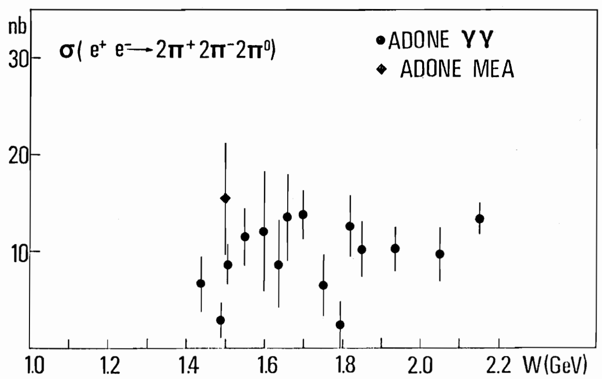

Fig. 12. $\sigma(2\pi^+, 2\pi^-, 2\pi^0)$.

$\sigma(\pi^+\pi^-\pi^0)$.

For completness in Fig. 13 the $\sigma(\pi^+\pi^-\pi^0)$ is reported.

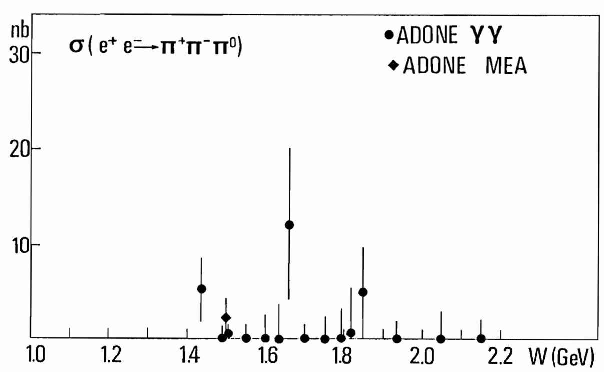

Fig. 13. $\sigma(\pi^+\pi^-\pi^0)$.

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DISCUSSION

Speaker: M. Spinetti

Question: R. Diebold, Argonne National Laboratory
Could you very briefly tell us what the plans are for future e^+e^- work at Frascati--the time scale?

Spinetti: At Frascati we are planning to build a new machine called ALLA that for economic reasons uses the old machine. The maximum energy of ALLA will be 2.4 GeV, but it will have a very high luminosity. The goal is $10^{31}cm^{-2}sec^{-1}$. It could be good to study very rare channels.

Diebold: How soon would that be operating then? How long will it take until one can take data?

Spinetti: It has been designed but we need financial support for this project.

Diebold: When is that being decided?

Spinetti: It will be decided in about six months.

Question: J. Perez, Orsay
How does your R value compare with the R value you measured at Orsay and reported at Tokyo one year ago?

Spinetti: The agreement is very good.

Perez: The agreement is good.

Spinetti: Yes.

Perez: Okay.

Perez: What is the final state of your 1.82 GeV resonance and why are you obliged to add one I = 0 and one I = 1 channel to observe it?

Spinetti: There are uncertainties separating the channel with one π^o and two π^o, so the evidence in each of these channels is not so strong. In fact, we say that the barionium interpretation is only possible--we cannot demonstrate it.