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Inclusive η Production in τ Decays

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We have searched for inclusive eta production in tau decays using a sample of 2553 events of $e^+e^- \to \tau^+\tau^-$ in the one-three topology. The data were taken with the High Resolution Spectrometer at $\sqrt{s} = 29$ GeV Our results are based on an analysis of the $\pi^+\pi^-$ invariant mass spectrum to find the narrow peak resulting from the decay sequence $\tau \to \eta X$ and $\eta \to \pi^+\pi^-\pi^0$. No clear peak is observed and a 90% confidence upper limit on the process $\tau \to \eta X$ of 2.1% is found. For decays $\tau \to \eta\eta X$ the 90% confidence upper limit is 1.3%. Our best limit on $\tau \to \eta\eta X$ is obtained from tau decay to five charged particles with a 90% confidence level upper limit of 0.5%.

The observed properties of the tau lepton are generally in excellent agreement with it being a sequential lepton and its decays are well described by the standard model.[1] One outstanding problem however, is the discrepancy between the inclusive one prong branching ratio and the sum of measured exclusive modes.[2,3,4] Eta production has been proposed as a possible explanation of this discrepancy. Recently it has been shown, however, that the required level of eta production would not be consistent with low energy e^+e^- annihilation data and the predictions of the standard model.[5]

We have recently published evidence[6] for eta production in the channel $\tau \to \pi\eta\nu_\tau$ using the decay $\eta \to \gamma\gamma$. The $\pi\eta$ system has odd G parity and is in the J^P series 0^+, 1^- and is, therefore, not expected in the standard model. Since it would be produced by a second class current.[7] This observation was not a measurement of inclusive eta production since the decay channels involving additional neutral pions had too large a combinatorial background to separate the $\eta \to \gamma\gamma$ decay from the background.

In the present analysis, we have searched for inclusive eta production in tau decays by analysing the invariant mass distribution of the $\pi^+\pi^-$ system in three prong tau decays. The specific decay chain looked for is $\tau^\pm \to \pi^\pm\eta\, X^\circ$ ($\eta \to \pi^+\pi^-\pi^\circ$) where X° is one or more neutral particles. The data used for this were obtained at the PEP storage ring at a center of mass energy of 29 GeV using the High Resolution Spectrometer (HRS) detector. The total integrated luminosity is $300 pb^{-1}$.

A detailed description of the High Resolution Spectrometer can be found elsewhere.[8] For this analysis, the important elements were the central drift chamber of 15 layers and the outer drift chamber of two layers, which together give a momentum resolution of $\sigma_p/p = 2 \times 10^{-3}$ p (GeV/c) at high momentum. This tracking system was surrounded by a barrel shower counter system divided azimuthally into 40 modules, each consisting of 3 and 8 radiation lengths of leadscintillator sandwich, separated by a layer of proportional wire chambers. The resulting energy resolution is $\sigma^2_E/E^2 = 0.16^2/E + 0.06^2$ (E in GeV).

The cuts used to select $e^+e^- \to \tau^+\tau^-$ have been described previously[9] and resulted in a sample of 2553 events of the 1-3 topology in the solid angle region covered by the barrel shower counter system. The hadronic background in this sample is estimated to be 5.2 ± 1.0% based on an analysis of the 3 prong effective mass. In order to search for $\eta \to \pi^+\pi^-\pi^0$, we have utilized the fact that this decay results in a peak in the $\pi^+\pi^-$ mass distribution between .28 and .41 GeV with a width ~ 80 MeV. The actual $\pi^+\pi^-$ mass distribution depends on the square of the η matrix element which can be parameterized as $1 - a(3T_o/Q - 1)$ where T_o is the kinetic energy of the π^0 in the η rest frame and Q is the q value for the decay. We have used a = 1.07 as measured by Layter et al.[10] The resulting mass distribution for the $\pi^+\pi^-$ system is shown in Fig. 1 for generated η decays.

The sample of 2553 three prong tau decays was divided into events with neutral energy in the shower counter and those with no neutral energy. For this analysis since the $\eta \to \pi^+\pi^-\pi^0$ contains a pi zero and our shower counter system is very efficient, we expect η production to be confined to those events with neutral energy. For each 3 prong τ decay, we have assumed that the charged particles are pions and computed the three possible di-pion effective masses. This gives two $\pi^+\pi^-$ mass combinations and one charge two $\pi\pi$ mass combination. For most processes contributing to τ decay, for example ρ, ω and η production it is expected that the charge two $\pi\pi$ distribution is identical to the distribution for one of the $\pi^+\pi^-$ combinations. A subtraction of the charge two distribution from the total $\pi^+\pi^-$ mass spectrum will therefore yield the true $\pi^+\pi^-$ distribution resulting from decays of resonances. Using this technique we have analysed the $\pi^+\pi^-$ mass distribution for the sample with no neutral energy and it is seen to be dominated by $\tau \to A_1 \nu \to \rho^0\pi\nu$ as observed by other authors[11] with only a few events in the eta region below $M\pi\pi < .41$ GeV. The total $\pi^+\pi^-$ mass distribution for the sample with neutral energy is shown in Fig. 2a and the corresponding charge two distribution in Fig. 2b. In order to determine the magnitude of η production, we have fitted the spectrum shown in Fig. 2a with contributions from the η, ω, ρ and a smooth background. We use a general parameterization for the smooth background which gives an excellent fit to the charge two mass spectrum as shown in Fig. 2b. In all the actual fits to the $\pi^+\pi^-$ mass distribution the parameters of the background are free. The actual shape of the eta and omega have been determined using Monte Carlo events of tau decays involving eta and omega using a full detector simulation.[12]

The fit to the data shown in Fig. 3a is the best fit obtained with all parameters free, except the ω fraction which is fixed corresponding to a $\tau \to \omega$ branching ratio of 1.75%.[13] Only a small eta contribution is found in this fit. To determine an upper limit on eta production we now fix eta production at various values still leaving the parameters of the background free. Using the increase in χ^2 the 90% upper limit on eta production is found and this fit is shown in Fig. 3b. Taking this fit to the data, correcting for the eta branching ratio, correcting for all acceptances and normalizing to the world average for B_3 of 13.2 $\pm$ 0.3%[3] yields an upper limit on the branching ratio of $\tau \to \eta X$, that is on inclusive eta production of 2.1% at the 90% confidence level.

There is not a unique way of performing the fit to the $\pi^+\pi^-$ distribution since, for example, the exact form of the background is unknown. We have therefore, tried a variety of fits to determine the maximum amount of eta that could be accommodated in our data. We have also done fits subtracting the charge two spectrum and fitting the resulting spectrum to $\rho + \omega + \eta$ + smooth background. For various values of omega production and background, we can achieve "best fits" corresponding to a branching ratio of $\tau \to \eta X$ of $1.0 \to 1.5\%$. These fits, however, still yield an upper limit consistent with 2.1%. As an absolute upper limit, if we assume 1.75% ω and that after the charge two subtraction all remaining events in the region $.28 < M_{\pi\pi} < .41$ GeV are eta, we obtain a 90% upper limit of 3.4%. This results in an uncorrelated $\pi^+\pi^-$ background which begins abruptly at .41 GeV and does not appear to be a reasonable interpretation of the data. We have also used samples of Monte Carlo events with varying percentages of eta as a cross check of our ability to find eta production with this technique. The low mass peak is clearly seen in the Monte Carlo for a $\tau \to \eta X$ branching ratio of 2% and is found by a similar fit to that performed on the data.

We should note that the largest contribution for inclusive eta production allowed within the current constraints of experimental data and the standard model involve tau decays to two eta's.[5] Our 90% upper limit on $\tau \to \eta\eta X$ is 1.3%. Our best limit on $\tau \to \eta\eta X$ is obtained from five prong tau decays[14] by taking all events which have two $\pi^+\pi^-$ mass combinations with $M < .41$ GeV. This gives a 90% upper limit of 0.5%.

The limit of 2.1% is not in agreement with our previously published result of (5.1 ± 1.5)% for the branching ratio of the $\tau^- \to \pi^-\eta\nu$ decay. As stated in our previous paper however, a fit assuming no eta and a smooth background had a χ^2 of 26.7 of which the η region contributed 10.9 which corresponds to a 3.3 standard deviation effect. It appears, therefore, that our previous result is most probably due to a statistical fluctuation.

In summary, we have set a 90% confidence level upper limit[15] on inclusive eta production in tau decays of 2.1% and for decays involving two eta's of 0.5%. This result is in agreement with the standard model predictions and is consistent with low energy e^+e^- annihilation. It also means that η production cannot explain the discrepancies between the sum of exclusive one prong decays and the inclusive one prong branching ratio. The current world average for B_1 is 86.6 ± 0.3% and measured exclusive channels leave ~ 7% unaccounted for.[16] Our current limit would correspond to a one prong contribution of < 1.5% for channels involving η production.

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13) Omega Production has been measured in the Channel $\tau^- \rightarrow \omega\pi^-\nu$ to be $1.5 \pm 0.3 \pm 0.3\%$ by H. Albrecht et al., Phys. Lett. 185B, (1987) 223. We have chosen 1.75% as the inclusive branching ratio, however, the results presented in this paper are not sensitive to changes in this number over a wide range.

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15) The 95% confidence level limits are 2.3% and 0.6%.

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FIGURE CAPTIONS

1) Effective mass of the $\pi^+\pi^-$ system for $\eta \to \pi^+\pi^-\pi^\circ$ from Monte Carlo generated tau events including full detector simulation.

2a) Observed $\pi^+\pi^-$ mass distribution for three prong tau decays with additional neutral energy.

2b) Observed Charge two $\pi\pi$ mass distribution for three prong tau decays with additional neutral energy.

3a) Observed $\pi^+\pi^-$ mass distribution. The line is the best fit fixing the $\tau \to \omega$ to be 1.75%. The inset curves show the fitted contribution from η, ω and the background.

3b) Observed $\pi^+\pi^-$ mass distribution. The line is the 90% upper limit fit with $\tau \to \eta$ equal to 2.1%. The inset curves show the fitted contribution from η, ω and the background.

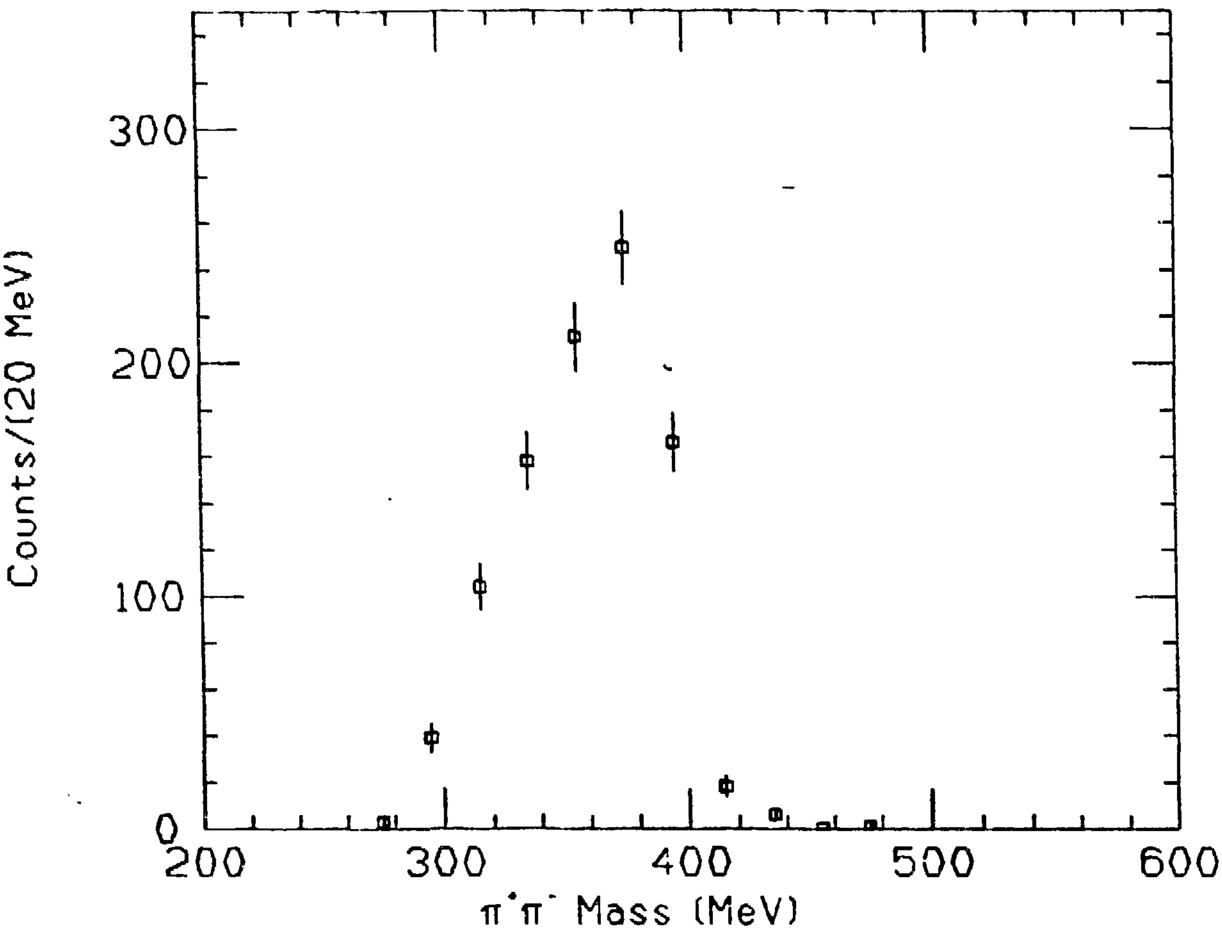

FIG1

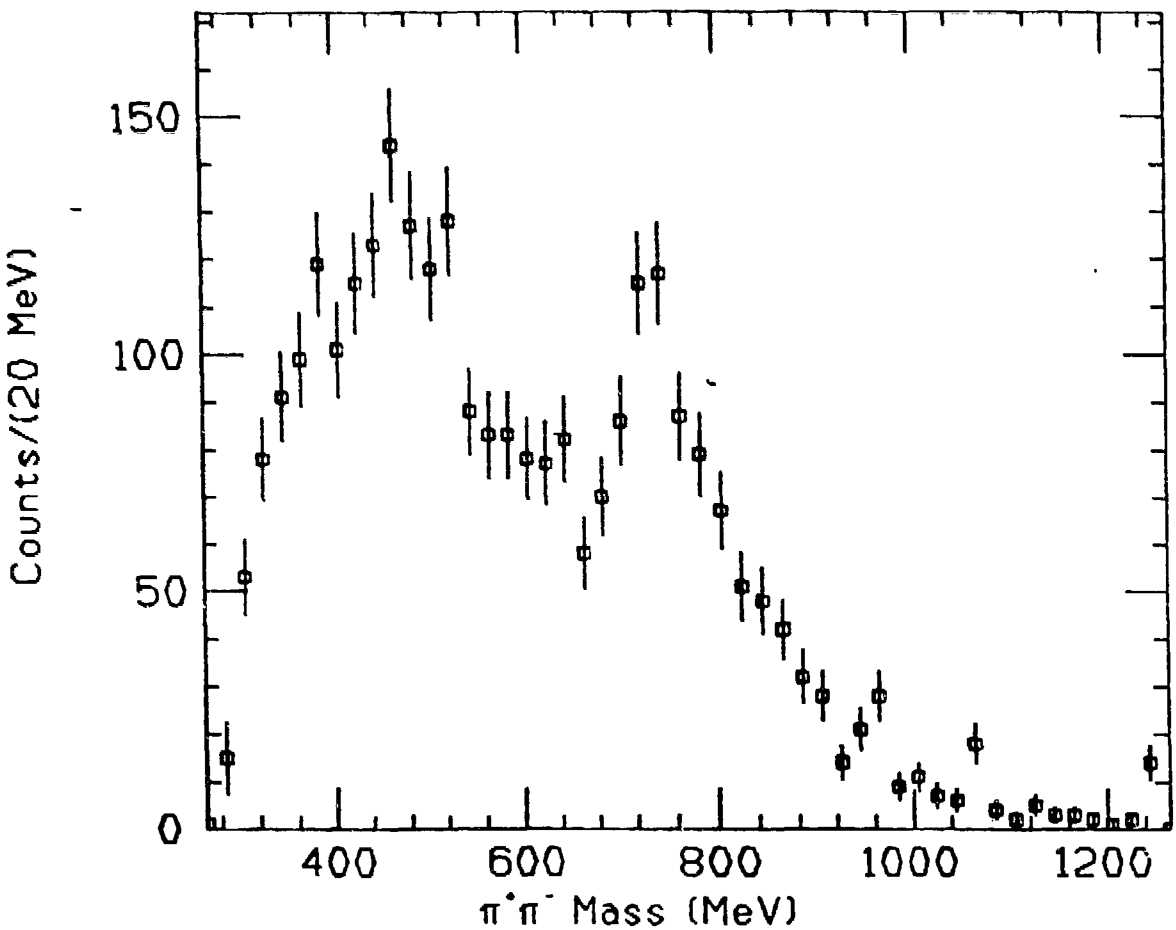

FIG2a

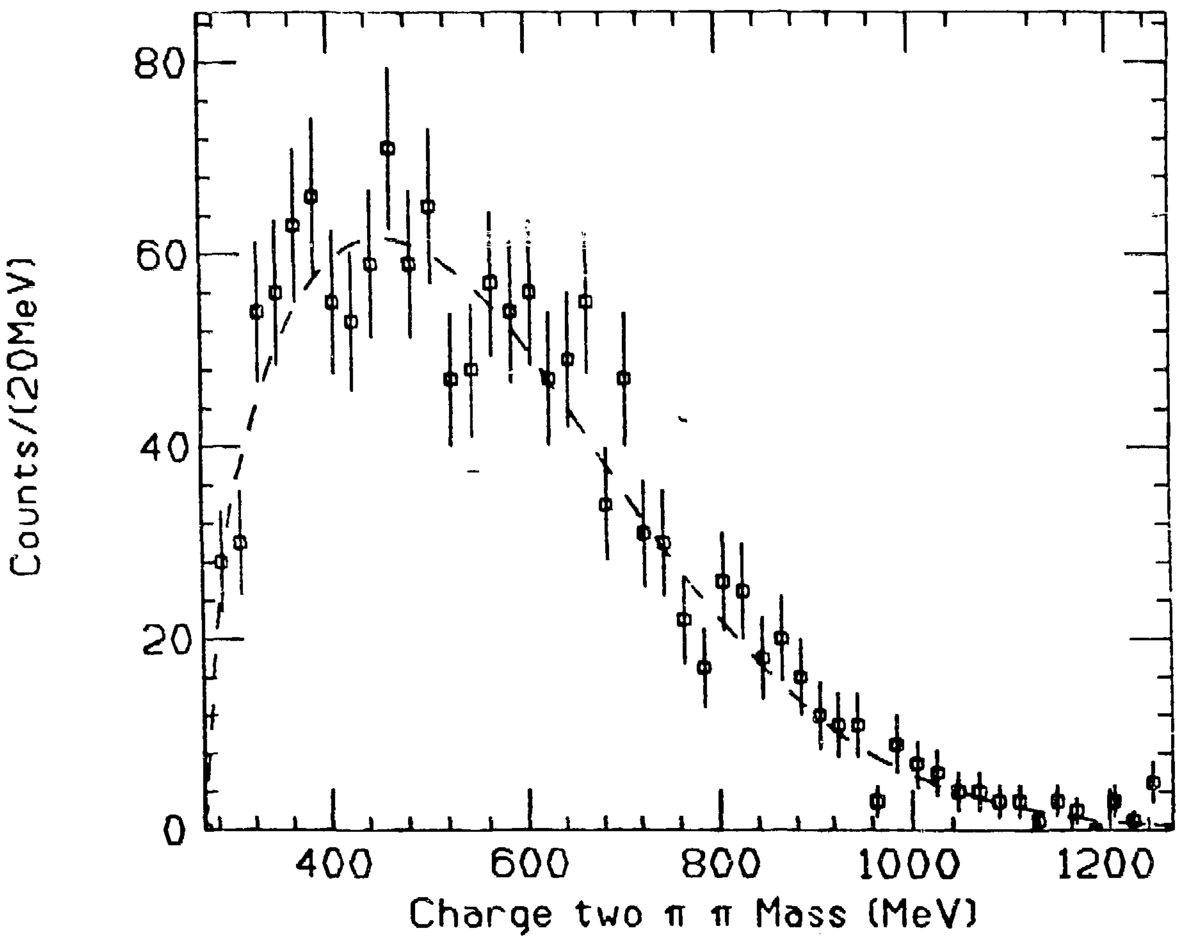
Counts/(20MeV)
0
20
40
60
80
400
600
800
1000
1200
Charge two π π Mass (MeV)

FIG2b

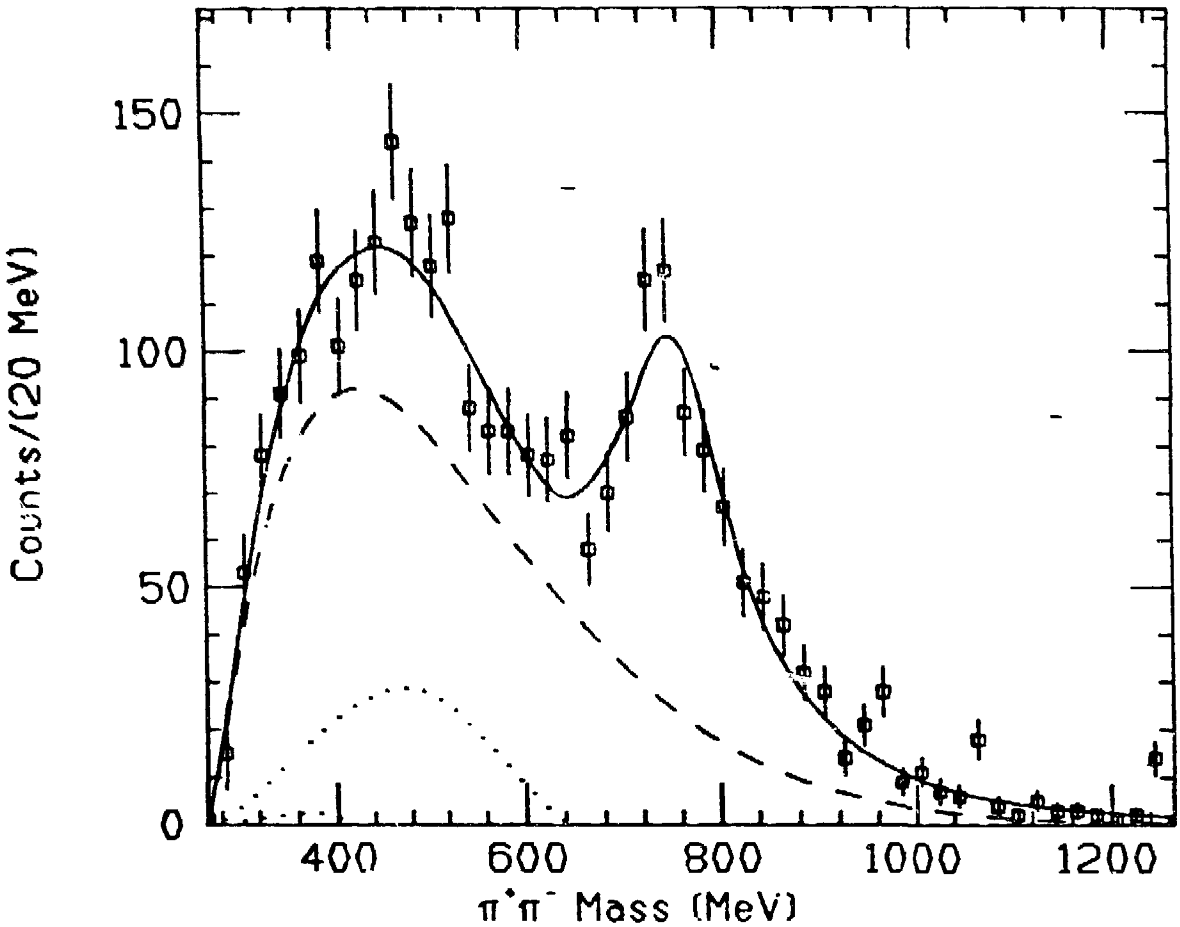

FIG3a

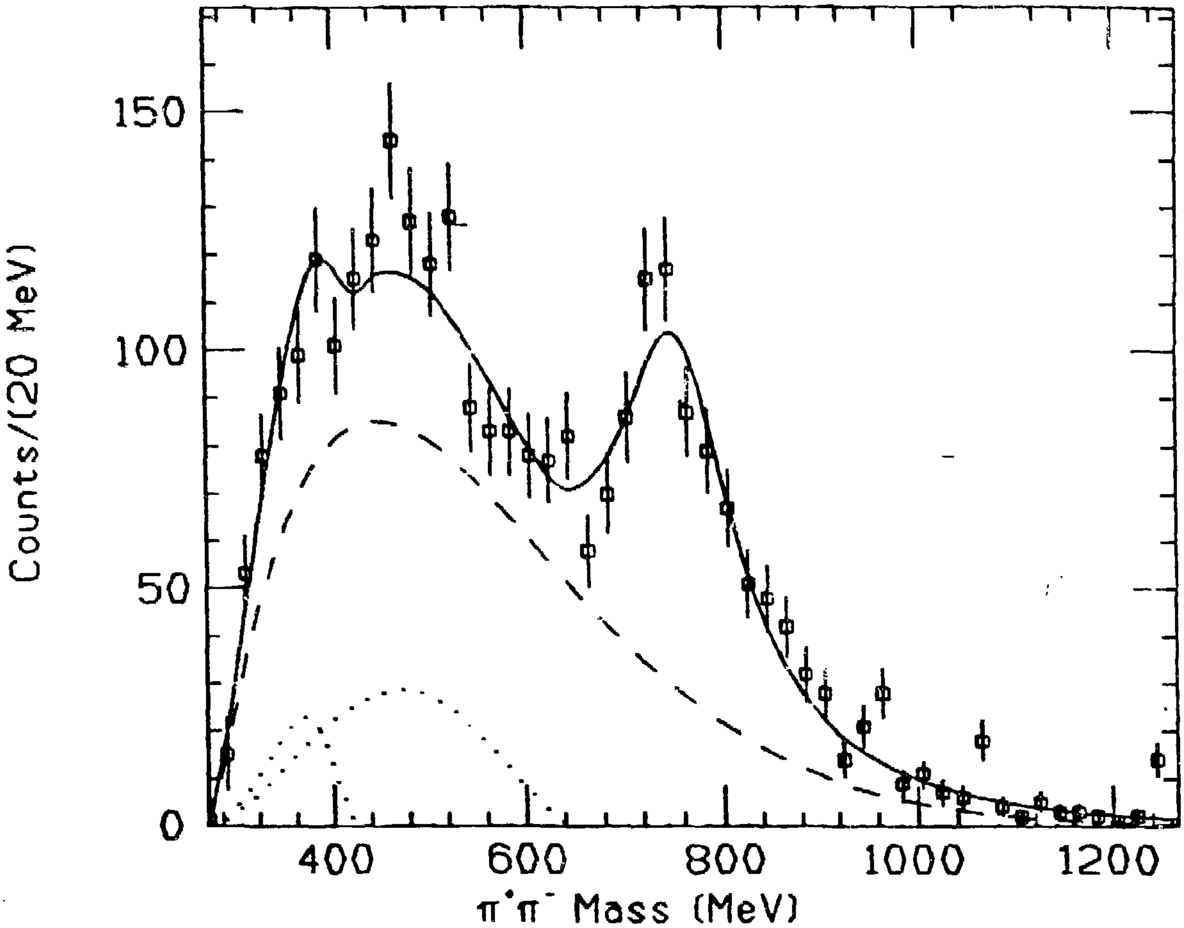

FIG 3b