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EVIDENCE FOR A $(K\pi\pi)$ RESONANCE WITH A MASS OF 1.230 GeV/$c^2$

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In exposures of the Saclay 81 cm HBC to beams of slow $\bar{p}$'s from the CERN PS, we have obtained about 770 events corresponding to the annihilation $(\bar{p}\, p)$ at rest via the channel:

$$\bar{p} + p \longrightarrow K_1^o + K_1^o + \pi^+ + \pi^- \qquad (1)$$

In all these events, the $(\pi^+ \pi^-)$ - decays of both $K_1^o$'s were observed in the chamber; thus the results of the normal fitting procedures eliminate unambiguously annihilations in flight or events with the production of an additional $\pi^o$.

The different two and three-particles effective-mass combinations in the final state of (1) have been studied with the following general results:

1) no $(K_1^o K_1^o)$ enhancement is seen anywhere; in particular there are no indications of an anomaly in the 1.020 GeV/$c^2$ region[(1)].

2) no significant $K^*(888)$ or $K^*(725)$ production is observed.

3) no $(K_1^o K_1^o \pi)$ enhancement[(2)] in the neighbourhood of 1.41 GeV/$c^2$ or elsewhere is observed.

4) the $(\pi^+ \pi^-)$ distribution deviates strongly from the expected phase space distribution: it indicates an abundant production of events with high $(\pi^+ \pi^-)$ effective mass[(3)].

5) the $(K_1^o \pi^+ \pi^-)$ distribution exhibits a pronounced enhancement in the neighbourhood of 1.230 GeV/$c^2$; the purpose of this letter is to discuss the reasons why we believe this enhancement is most simply explained as a $(K\,\pi\,\pi)$ resonant state.



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The histogram of fig. 1 shows the experimental $(K_1^o \pi^+ \pi^-)$ effective mass-squared distribution (two combinations per event); for comparison, we have superimposed on the histogram three smooth curves. Curve α corresponds to the (K π π) invariant phase-space in the $(K \bar{K} \pi \pi)$ final state; curve β gives the $(K \rho^o)$ invariant phase-space for a $(K \bar{K} \rho)$ final state and has been obtained by assuming a Breit-Wigner distribution for the ρ centered at 750 MeV/$c^2$ and with a width $\Gamma$ = 100 MeV/$c^2$. In the calculation of the smooth distributions care has been taken to include the limitations imposed by phase space. Clearly, neither curve α nor β fits the experimental distribution. In spite of remarks 1) - 3), attempts have been made to explain the observed (K π π) distribution on the assumption that the final state of equation (1) proceeds through known resonances such as $K^*$ or $K_1^o K_1^o$; although the results are not illustrated in fig. 1 we find, in all cases, violent disagreement with the experimental results.

We assume, therefore, that there exists a resonant (K π π) system - which we call C - with a mass between 1.220 and 1.240 GeV/$c^2$ and width between 60 and 100 MeV/$c^2$. To verify this assumption and to find better values for the mass and width of C, we proceed by trial and error and find that a reasonably good fit to the data is given by a smooth curve γ computed as follows:

1) reaction (1) goes uniquely via the two-body process:

$$\bar{p} + p \longrightarrow K_1^o + C \tag{2}$$

2) The C resonance decays into $K_1^o + \rho^o$. (Just from the point of view of the (K π π) histogram, the assumption $C \longrightarrow K_1^o + \pi^+ + \pi^-$ fits almost equaly well; the, at this point, seemingly arbitrary choice $C \longrightarrow K_1^o + \rho^o$ is explained below).

3) To compute the "direct" effect, that is the effective mass squared of the resonating K - (π π) combination, we have taken into account the phase space available in reaction (2) and assumed different Breit-Wigner distributions for C. For the "reflection" effect, that is the effective mass squared of the non-resonating K - (π π) combination, we have assumed that the angular distribution of the C decay into $K_1^o \rho^o$ was isotropic; we have taken into account the phase space available in the C system for this mode of desintegration, and assumed a Breit-Wigner distribution for the $\rho^o$ with M = 750 MeV/$c^2$, $\Gamma$ = 100 MeV/$c^2$.

Curve γ represents the sum of the two contributions (direct and reflection); the direct effect explains, of course, the enhancement at M = 1.230 GeV/$c^2$, the reflection accounts for the accumulation of events with high values of (K π π) effective mass squared.

The different trials allow us to assign to the C resonance a mass $M = 1.230\ GeV/c^2$ with a width of 80 $MeV/c^2$, with errors which we estimate to be of the order of 10 $MeV/c^2$ in both cases. It is to be noted that the results are in good agreement with any distribution representing 60 to 100 o/o of C-resonance production.

To study the decay of the resonance, we have looked at the decay Dalitz plots for different narrow bands of $(K\ \pi\ \pi)$ mass. In fig. 2 two are shown; one (fig. 2a) centered at 1.230 $GeV/c^2$ and with a width of 40 $MeV/c^2$, another (fig. 2b) centered at 1.310 $GeV/c^2$ and with the same width. As expected (see Ref. 3), the plots are not uniformly populated and, by and large, show a tendency towards high $(\pi\ \pi)$ effective masses. That this effect is much more pronounced in the band where the effects of the resonance predominate is obvious and is, perhaps, more clearly illustrated by fig. 3, where the overall distribution of $M^2(\pi^+\ \pi^-)$ is shown together with the contribution from the events in the narrow resonance band.

A further experimental fact in favour of the hypothesis that the C-resonance decays abundantly into $K_1^o\ \rho^o$ is the following. If its decay were frequently into $(K\ \pi\ \pi)$ the decay mode $C \longrightarrow K\ \pi^o\ \pi^o$ (forbidden for $C \longrightarrow K\ \rho^o$) should be observed in the annihilations $\bar{p}\ p \longrightarrow K_1^o\ K_2^o\ \pi^o\ \pi^o$. Although the direct identification of this annihilation channel is not possible, its existence can be inferred by an appropriate subtraction of the $K_1^o$ momentum spectrum of events classified as $K_1^o\ K_1^o$ M from that of $K_1^o$ M events. We have made this subtraction and observed no enhancement whatsoever that can be attributed to the presence of the C-resonance in events that could belong to the channel $\bar{p}\ p \longrightarrow K_1^o\ K_2^o\ \pi^o\ \pi^o$.

Concerning the quantum numbers of the resonance we hope to publish soon the results of a full analysis now in progress. In the meanwhile, the following tentative remarks may be useful. The decay angular distributions of the $C \longrightarrow K_1^o\ \rho^o$ and associated $\rho^o \longrightarrow \pi^+\ \pi^-$ systems do not show striking deviations from isotropy. These results may be taken as an indication that production of the C and its decay into $K_1^o + \rho$ go via s waves if the annihilation channel (1) comes from the $^3S_1$-state. If this is the case, the C-state has spin-parity $1^+$.

It has not been possible to determine in this experiment the isospin (1/2 or 3/2) of the resonance; in particular, we have looked for evidence of the C-resonance in the channel $\bar{p} + p \longrightarrow K_1^o + K^{\pm} + \pi^{\mp} + \pi^o$, but are hindered by the fact that this channel is strongly dominated by $K^*(888)$-production.

To conclude, we believe these results show that an important fraction of reaction (1) proceeds via the production of a (K $\pi$ $\pi$) resonant state, which is characterized by a mass M = 1.230 GeV/$c^2$ and a width $\Gamma$ = 80 MeV/$c^2$, with errors of the order of 10 MeV/$c^2$ in both cases; the $C \rightsquigarrow K_1^0 \rho^0$ seems to be favoured.

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G. Alexander et al - PRL 9, p.460 (1962).

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3) Indeed, if we believe that the annihilation ($\bar{p}$ p) at rest occurs mainly in S-states, as it has been proved for annihilations into 2 body (K $\bar{K}$) final states[(4)], it is easy to see that reaction (1) cannot be produced with the ($\pi^+ \pi^-$) system in an S-state. Further experimental evidence is obtained from the study of annihilations of the type:

$$\bar{p} + p \longrightarrow K_1^o + K_1^o + M$$

where we write M for any missing particle(s); after elimination of possible $K_1^o K_1^o \pi^o$, $K_1^o K_1^o \eta^o$, $K_1^o K_1^o \omega^o$, events, we are left with a very small number of events which could be attributed to ($K_1^o K_1^o \pi^o \pi^o$) production; that is just what is expected if the annihilations occur mainly in S-states; the production of $K_1^o K_1^o \pi^o \pi^o$, which, under this assumption, can only come from $^1S_o$ initial state, is strongly suppressed by centrifugal barriers. In these conditions, it is probable that reaction (1) is mainly produced by annihilations of ($\bar{p}$ p) in the $^3S_1$ state, the ($\pi^+ \pi^-$) system having then an odd orbital angular momentum.

4) R. Armenteros et al - 1962 International Conf. on High Energy Physics at CERN p. 351.

FIGURE CAPTIONS:

Fig. 1: Effective mass squared distribution of $(K_1^o \pi^+ \pi^-)$ in $(K_1^o K_1^o \pi^+\pi^-)$ events (Two combinations per event).

Curve $\alpha$ shows the $(K \pi \pi)$ phase space in $(K K \pi \pi)$ system.

Curve $\beta$ shows the $(K \rho)$ phase space in $(K \rho K)$ system.

Curve $\gamma$ : see the text.

Fig. 2: Dalitz-plot of the $(K \pi \pi)$ system in the band:

a) $1.210 < M (K \pi \pi) < 1.250$ GeV/c$^2$

b) $1.290 < M (K \pi \pi) < 1.330$ GeV/c$^2$

MM$(K \pi)$ are for the effective mass squared of the $(K \pi)$ in $(K \pi \pi)$.

Fig. 3: Effective mass squared distribution of the $(\pi \pi)$ system:

The continuous line shows the distribution of events in the band:

$$1.210 < M (K \pi \pi) < 1.250 \text{ GeV/c}^2$$

The dotted curve shows the complete distribution.

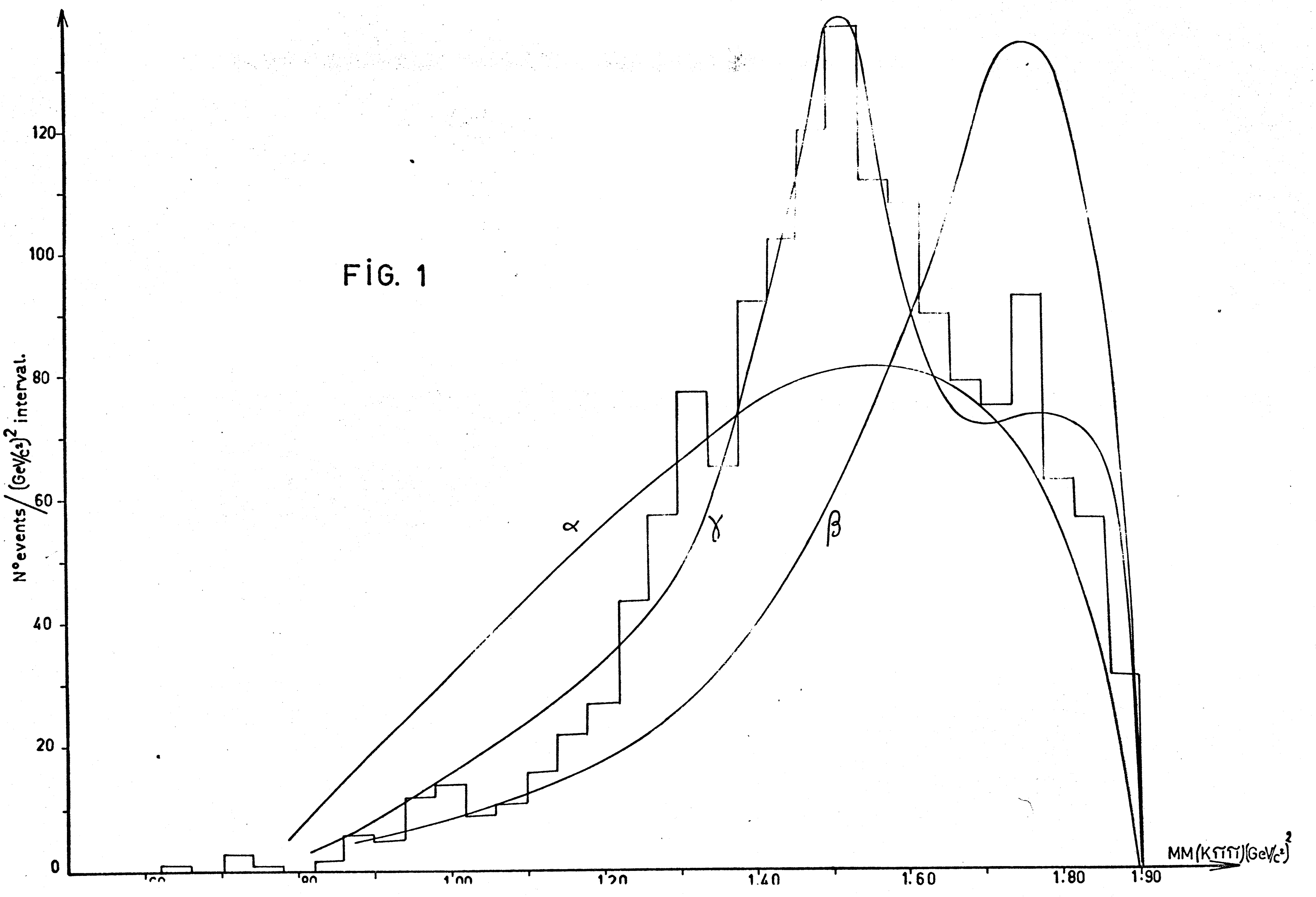


FIG. 1

DIA 20050

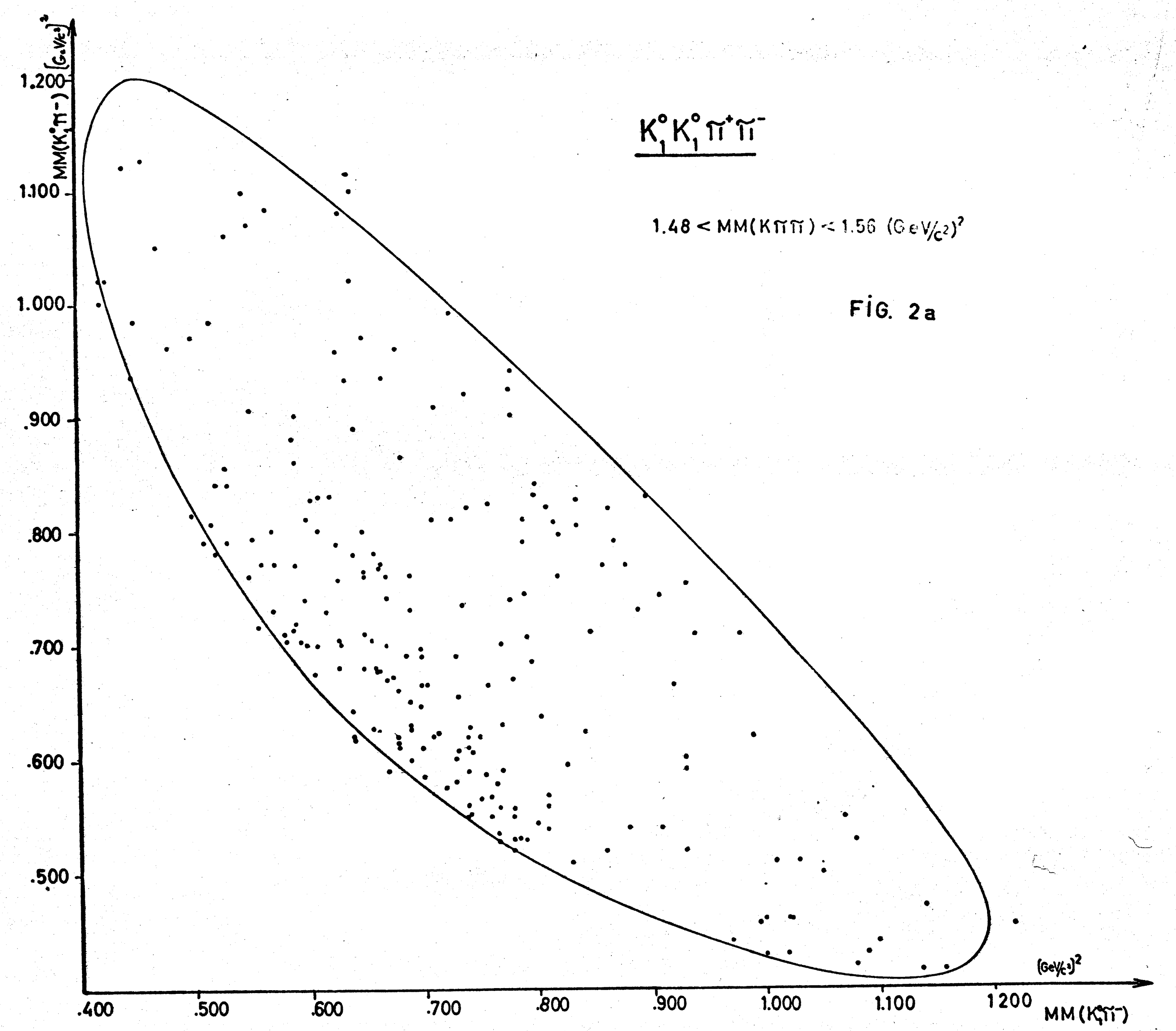


FIG. 2a

DIA 20051

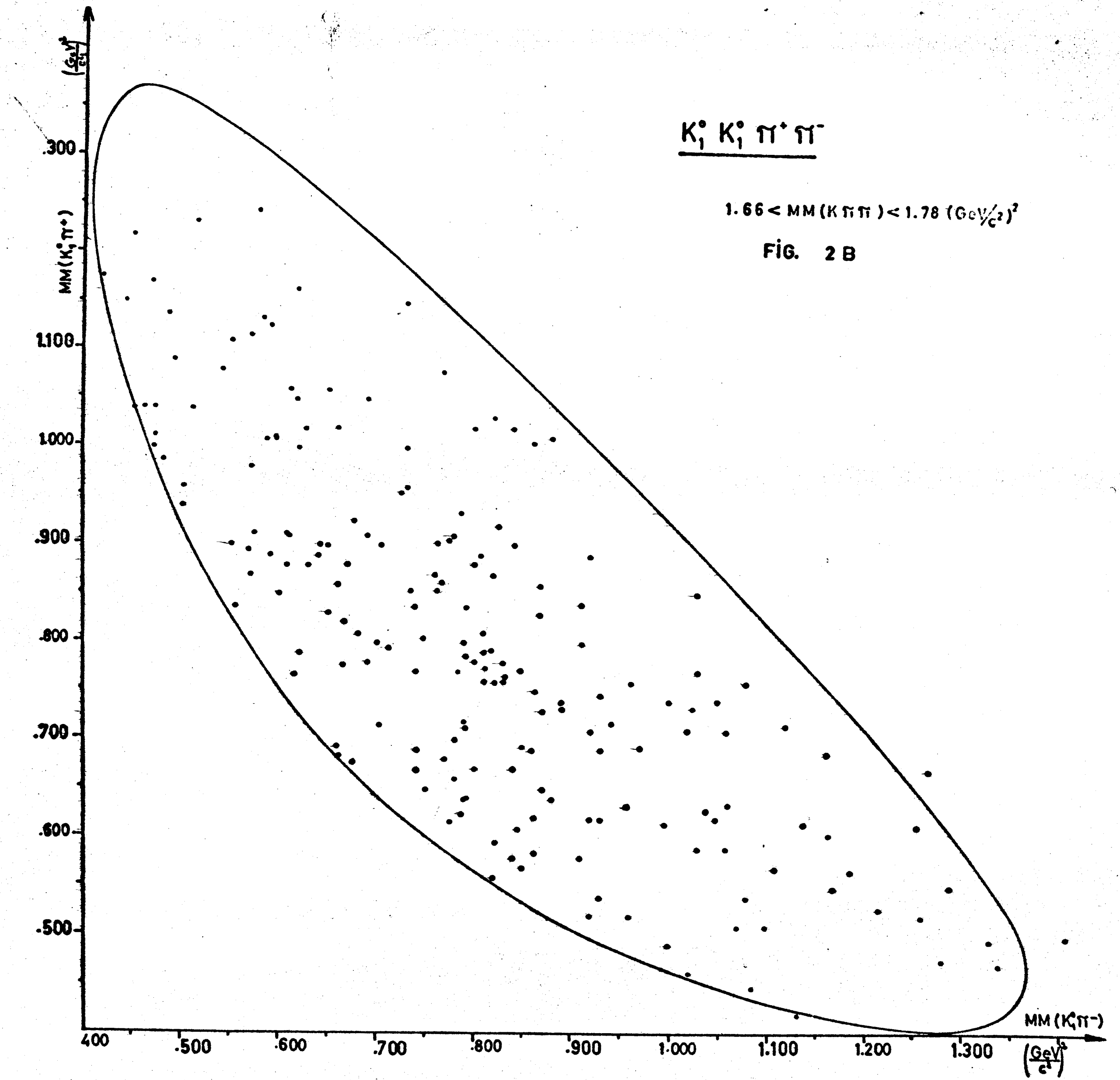


FIG. 2 B

DIA 20052

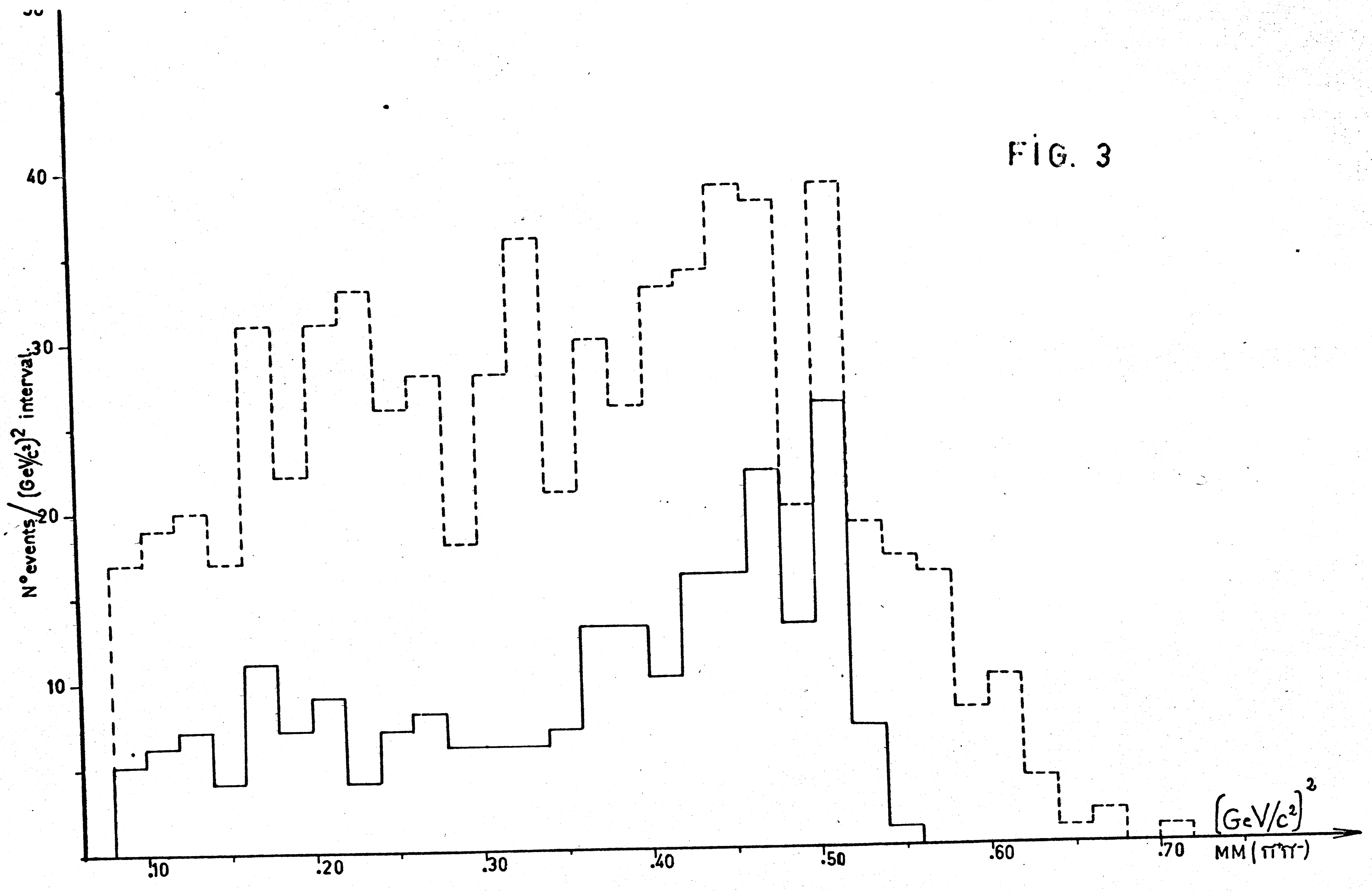


FIG. 3

DIA 20048