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STUDY OF THE K^* RESONANCE IN $(\bar{p}\ p)$ ANNIHILATIONS AT REST

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In the stopped antiproton experiment carried out at the CERN P.S. with the 81 cm. Saclay hydrogen bubble chamber, we are studying bumps in the $(K\pi)$ effective mass distributions. An annihilation is selected for analysis if at least one $K_1^o \to \pi^+ \pi^-$ decay appears associated with it.

Significant bumps corresponding to K^* - production are observed both in the three-body (i.e. $K_1^o\ K\pi$) and four-body (i.e. $K_1^o\ K\ \pi\pi$) annihilations. A detailed study of the three-body annihilations is now in progress. For the moment all that we can say about these is that, although there seems to be abundant K^* production in them, it is not possible to represent simply the observed effective mass-distributions in terms of a certain amount of K^* - production superimposed on a background that follows - more or less - the usual phase space expectations.

K^* - production occurs abundantly in the four-body annihilations. These constitute by far the most abundant group of fully classified events i.e. events in which the number and the nature of the particles produced in the annihilation can be unambiguously established. In a sample of 180×10^3 stopped $\bar{p}$'s, 2300 annihilations producing at least one $K_1^o \to \pi^+ \pi^-$ decay have been observed; 652 of these annihilations were unambiguously identified as $\bar{p} + p \to K_1^o\ K\pi\pi$.

The four effective $(K\pi)$-mass combinations which are obtained from each event are plotted in the histogram of fig. 1; for comparison the covariant phase space distribution - continuous smooth line - expected for the free production of the $(KK\pi\pi)$ final state is shown normalized to the total sample. A large peak in the K^* mass region shows up clearly. It has to be noticed that even if all four-body annihilations corresponded to $K^*\ K\pi$ - production, only 25 o/o of the combinations would appear in the peak. That this is not far from the reality is shown in the histogram of fig. 2. Here we have subtracted from the experimental results the phase space distribution - dotted curve of fig. 1 - that would apply to the three non-resonant $(K\ \pi)$ combinations obtained in the two-step process,

$$\bar{p} + p \longrightarrow K^{*}\ K\ \pi \longrightarrow (K\pi)\ K\pi.$$

The effective mass distribution remaining after subtracting the "background" fits reasonably well a Breit-Wigner curve characterized by:

$$M_{K^*} = 885 \text{ MeV}$$
$$\Gamma_{K^*} = 55 \text{ MeV},$$

where Γ_{K^*} is the total width at half-height after subtraction of the experimental resolution - about $\pm$ 5 MeV.

A more complete study of the four-body annihilations is under way: in the new analysis we are trying to establish, amongst other things, the possible existence of the annihilation mode: $\bar{p} + p \longrightarrow K^{*} + \bar{K}^{*}$. Preliminary results show that the values of M_{K^*} and Γ_{K^*} just given will not be much affected by the more detailed analysis. This arises from the fact that the background of events not leading to the production of at least one K^{*} is small and the mass and width of the K^{*}-resonance little affected by the relative proportions of $K^{*}\ K\ \pi$ and $K^{*}\bar{K}^{*}$ events.

Spin of K^{*}. No significant deviation from isotropy has been observed in the angular distribution of the decay products in the K^{*} rest system and, consequently, no conclusion can be derived from it about the K^{*} spin.

M. Schwartz[1] has proposed a method to obtain the spin of the K^{*} from the reaction,

$$\bar{p} + p \longrightarrow K^{o} + \bar{K}^{o*}\ (\bar{K}^{o} + K^{o*}) \qquad (1)$$

on the assumption that it proceeds from the S-state of protonium.

Briefly, the argument is the following:

If the spin of the K^{*} is zero, reaction (1) cannot be produced from capture in the $^{3}S_{1}$ state because of parity conservation: the parity of the initial state is odd while that of the final state is even (because angular momentum conservation requires that ℓ, the relative angular momentum between the K and K^{*}, be one and since, for K^{*} spin zero, the relative $(K\ K^{*})$ - parity is odd, the parity of the final state is given by $(-1)^{\ell + 1}$).

Partity conservation allows reaction (1) from capture in the $^1S_0$ state, but since this state is even under charge conjugation the final state[++] must consist either of ($K_1^o\, K_1^o\, \pi^o$) or ($K_2^o\, K_2^o\, \pi^o$) but not ($K_1^o\, K_2^o\, \pi^o$).

If the spin of the K^{o*} ($\bar{K}^{o*}$) is one, reaction (1) can proceed both from the $^1S_0$ and $^3S_1$ states; the final state will then be an incoherent mixture of $K_1^o\, K_1^o\, \pi^o$ (or $K_2^o\, K_2^o\, \pi^o$) and $K_1^o\, K_2^o\, \pi^o$, respectively.

The statement can then be made: if reaction (1) occurs only from the S-state and if the spin of the K^{o*} is zero, the final state ($K_1^o\, K_2^o\, \pi^o$) should not be observed in events corresponding to the production $K_1^o + K^{o*}$ ($\bar{K}^{o*}$).

Fig. 3 shows the momentum histograms of the $K_1^o \rightarrow \pi^+ \pi^-$ appearing singly (histogram a) or in pairs (histogram b) in $\bar{p}$ p - annihilations leading to the production of only neutral mesons. The large peak in histogram a) at $P_{K_1^o}$ = 800 MeV/c has been discussed elsewhere at this Conference[(2)] and has been shown to constitute strong proof that the annihilations $\bar{p} + p \rightarrow K^o + \bar{K}^o$ proceeds overwhelmingly from the S-state of protonium. A second peak appears prominently in the neighbourhood of $P_{K_1^o}$ = 610 MeV/c in the annihilation $\bar{p} + p \rightarrow$ K_1^o + neutrals. This we interpret as due to

$$\bar{p} + p \rightarrow \bar{K}^o + K^{o*}\ (K^o + \bar{K}^{o*}) \qquad (1)$$

In terms of the K_1^o momentum, the values of M_{K^*} and $\Gamma/2$ found from the four-body events correspond to 610 MeV/c and 17 MeV/c. To the natural width, Γ, of the K^* we have to add an experimental resolution of $\pm$ 10.5 MeV/c, deduced from the observed width of events in reaction $\bar{p} + p \rightarrow K_1^o + K^o$. To estimate the number of events which in histogram a) correspond to reaction (1) we count i) the number of $K_1^o \rightarrow \pi^+ \pi^-$ decays with momenta $P_{K_1^o}$ defined by 590 MeV/c $\leqslant P_{K_1^o} \leqslant$ 630 MeV/c (36 events satisfy this condition) and ii) the number of K_1^o - events in a momentum band of the same width (40 MeV/c) below 590 MeV/c (11 events) and above 630 MeV/c (13 events). We then assume that the real K^* events have a distribution such that 70 o/o of them appear in the central band and 30 o/o in the two adjoining bands while the background events are assumed to have an uniform distribution. In this way we obtain (43 $\pm$ 14) events corresponding to reaction (1) leading to the observation of one single $K_1^o \rightarrow \pi^+ \pi^-$ decay. The non observation of the other K^o can be due to its having decayed via $K_1^o \rightarrow \pi^o\, \pi^o$ or to its K_2^o nature or a combination of the two possibilities. The number of

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++ The K^{o*} ($\bar{K}^{o*}$) can, of course, also decay via the mode $K^+\, \pi^-$ ($K^-\, \pi^+$), but we need not be concerned about this decay here.

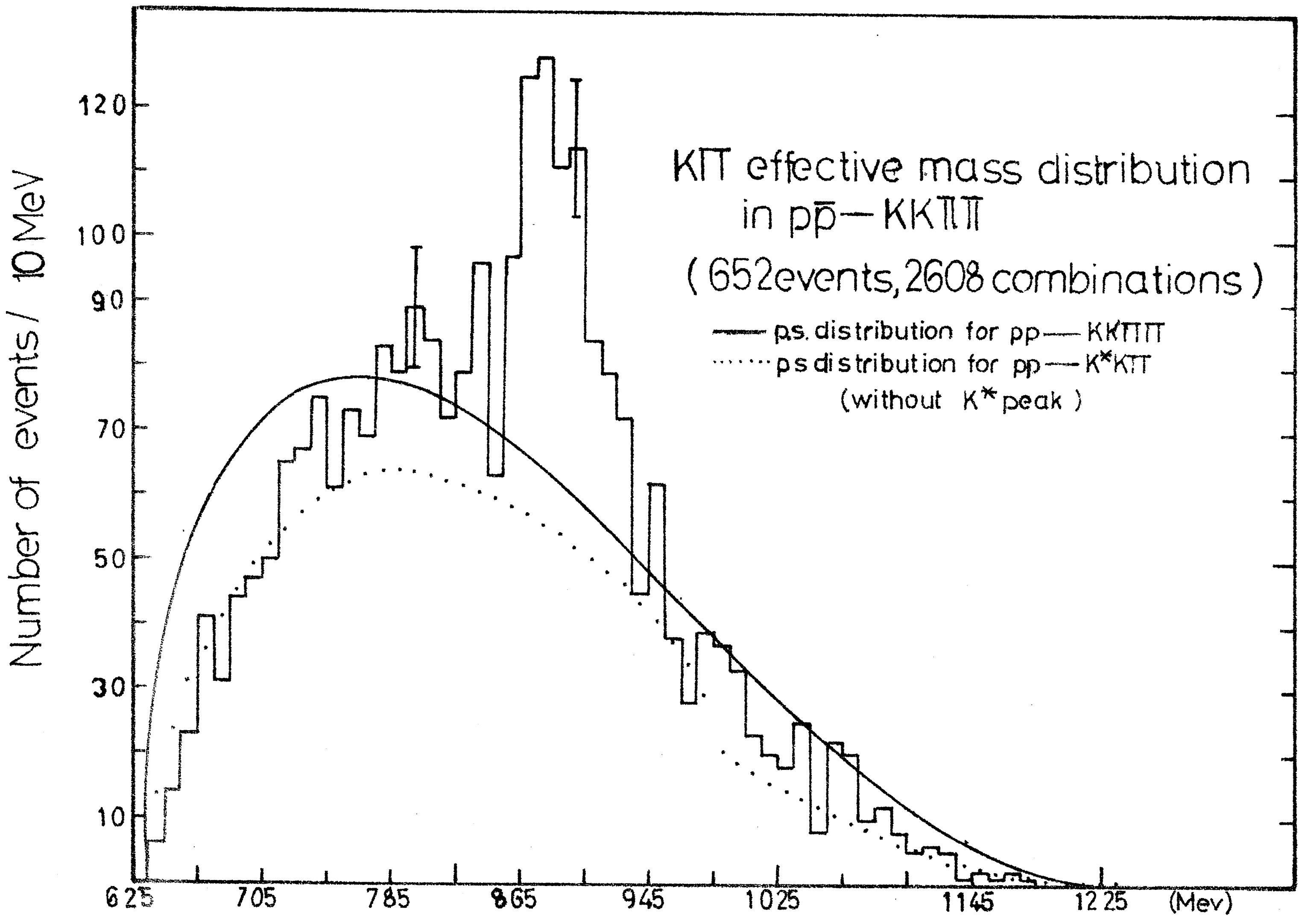
K_2^0's can be deduced from the number of events from reaction (1) leading to a $(K_1^0\ K_1^0\ \pi^0)$ final state. Proceeding in histogram b) in the same manner as we did in histogram a), the number of $(K_1^0\ K_1^0\ \pi^0)$ in the K^* region is found to be (13 $\pm$ 11). Because of the $\dfrac{K_1^0 \to \pi^+\ \pi^-}{K_1^0 \to \pi^0\ \pi^0} = 2$ branching ratio, (6.5 $\pm$ 5.5) events $(K_1^0\ K_1^0\ \pi^0)$ are expected to appear as $(K_1^0$ + neutrals) in the K^* region. The number observed is (43 $\pm$ 14) and we can therefore conclude that the number of events corresponding to reaction (1) and leading to a final state $(K_1^0\ K_2^0\ \pi^0)$ is (36.5 $\pm$ 15).

The final result is therefore that, if the annihilation is from an S-state as it was the case in the annihilation $\bar{p} + p \to K^0 + \bar{K}^0$, the spin of the K^* is not zero subject to the uncertainty implied in comparing (36.5 $\pm$ 15) events to zero.

References

1) M. Schwartz, Phys. Rev. Letters 6, 556, 1961

2) R. Armenteros et al. Communication by A. Shapira at this Conference.



Kπ effective mass distribution
in pp̄—KKππ
(652events, 2608 combinations)
p.s. distribution for pp — KKππ
p.s distribution for pp — K*Kπ
(without K* peak)
Number of events / 10 MeV
120
100
90
70
50
30
10
625
705
785
865
945
1025
1145
1225
(Mev)

Fig.1

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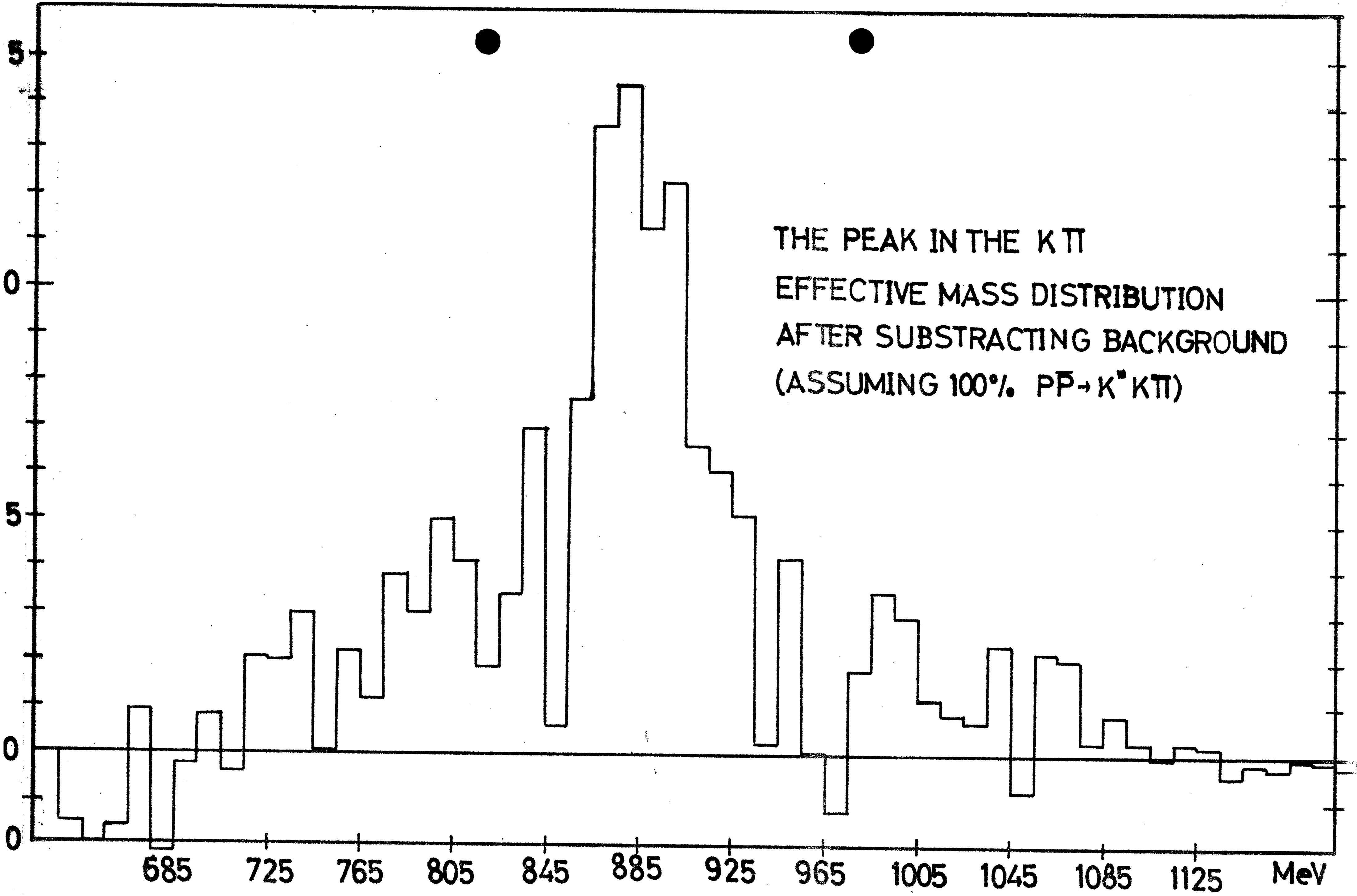
THE PEAK IN THE Kπ
EFFECTIVE MASS DISTRIBUTION
AFTER SUBSTRACTING BACKGROUND
(ASSUMING 100% $p\bar{p} \to K^* K \pi$)
5
0
5
0
0
685
725
765
805
845
885
925
965
1005
1045
1085
1125
MeV

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Fig. 2

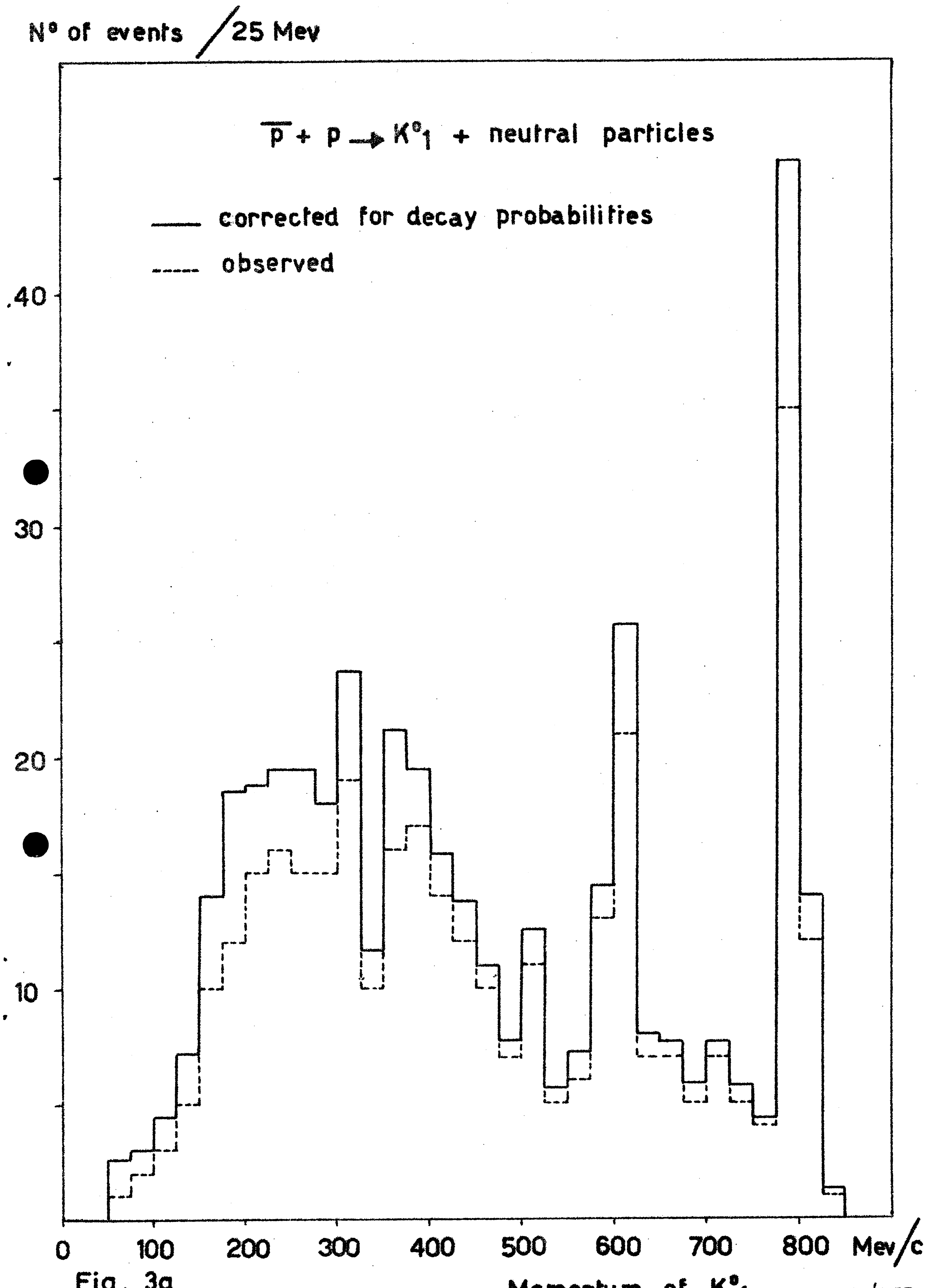

Fig. 3a

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MOMENTUM OF K°_{1}

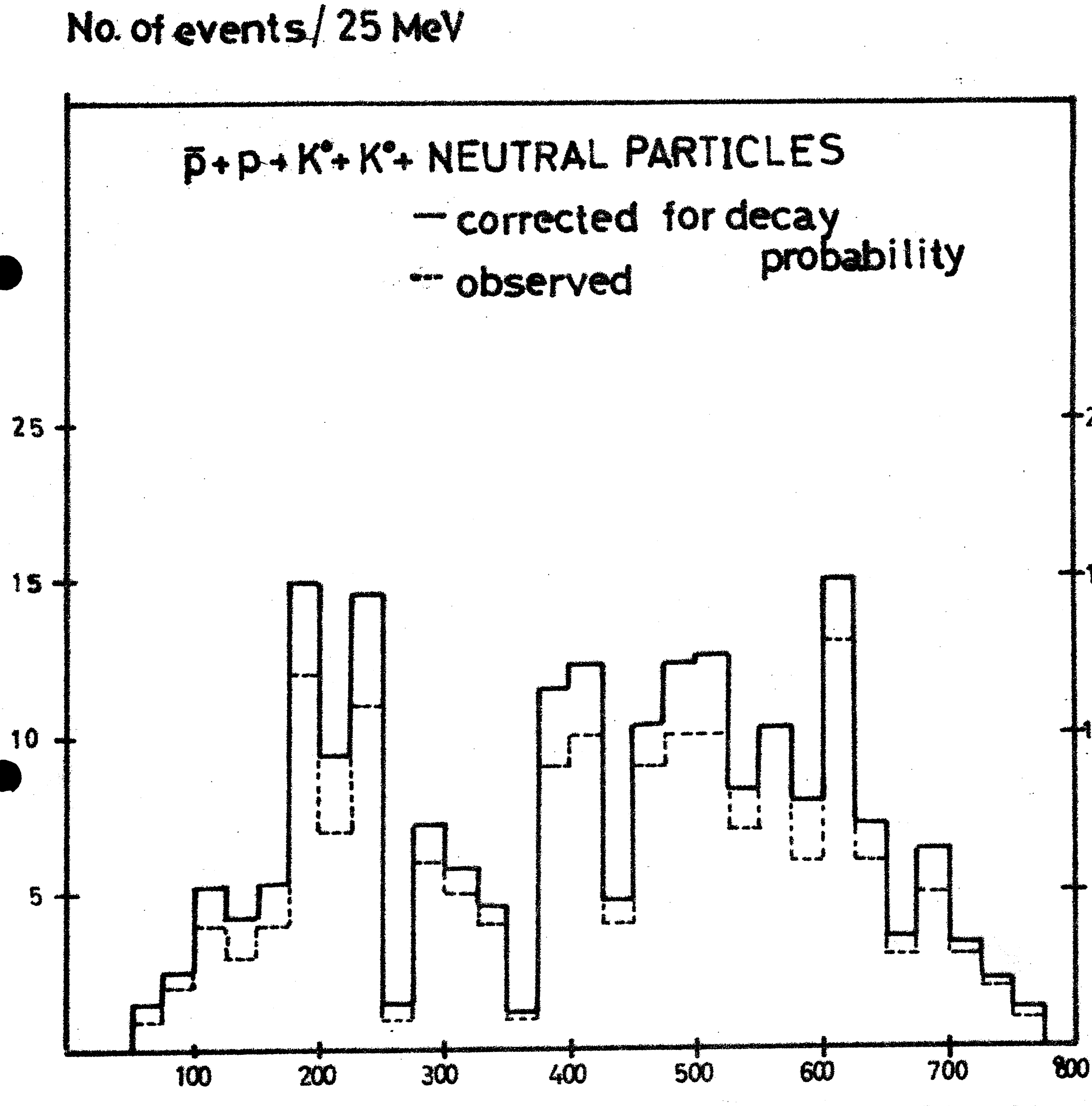

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Fig. 3b