$\bar{p}p$ ANNIHILATIONS INTO STRANGE PARTICLE FINAL STATES AT 700-750 MeV/c

M. Aguilar-Benitez, F. Barreiro, M. Cerrada, J. Diaz,
E. Fernández, R. Llosá and J.A. Rubio

Junta de Energia Nuclear, Madrid, Spain

B.S. Chaudhary, S.N. Ganguli, A. Gurtu, P.K. Malhotra,
U. Mehtani, R. Raghavan and A. Subramanian

Tata Institute of Fundamental Research, Bombay, India

A. Ferrando and L. Montanet

CERN, Geneva, Switzerland

Ch. d'Andlau, C. Defoix, L. Dobrzynski,
P. Ladrón de Guevara and R. Nacash

Collège de France, Paris, France

(Presented by J.A. Rubio)

In this review I am going to report about some preliminary results obtained in a $\bar{p}p$ 700 - 750 MeV/c experiment by the Bombay - CERN - College de France - Madrid collaboration.

The data for the analyses come from 1.7 x 10^6 pictures taken in the 80 cm Saclay hydrogen bubble chamber exposed to incident $\bar{p}$ beams of 700 and 750 MeV/c. A part of the experiment (3.5 x 10^5 pictures, 5 events/μb, 700 MeV/c $\bar{p}$ beam momentum) has already been analyzed by a CERN - College de France collaboration (1). The new part of the experiment corresponds to 1.35 x 10^6 pictures, ≈20 events/μb, at 750 MeV/c $\bar{p}$ momentum. The events used for this study have at least one visible K_1^o meson in the final state. At present we have 18223 events on DST which correspond to about 12 events/μb, and we hope to add the rest of the statistics in the near future. Using the above described sample, I am going to present the following preliminary results

1 - Measurements of the total and differential cross sections for the reactions $\bar{p}p \rightarrow K_1^o K_1^o$ and $\bar{p}p \rightarrow K_1^o K_2^o$ at 700 and 750 MeV/c. The results are discussed in connection with the ρ(1970) meson.

2 - Measurement of the $K^{*o}(890)$ - $K^{*\pm}(890)$ mass difference in the reactions $\bar{p}p \rightarrow K^{\pm}\pi^{\mp}K_1^o$.

3 - Observation of a $K_1^o K_1^o$ threshold enhancement in the reaction $\bar{p}p \rightarrow K_1^o K_1^o \pi^+\pi^-$ at 700 - 750 MeV/c.

1. $\bar{p}p \to K_1^oK_1^o$, $\bar{p}p \to K_1^oK_2^o$

In a recent formation experiment (2), the behaviour of the cross section and angular distribution for the reaction $\bar{p}p \to K_1^oK_2^o$ was taken as significant evidence for a new vector meson with mass ∿1968, width ∿35 MeV and $J^{PC} = 1^{--}$. The conclusions were drawn from a sample of 71 $K_1^oK_2^o$ events and 1 $K_1^oK_1^o$ event distributed in 7 momentum intervals.

Two other groups have reported on these annihilation processes in the same energy region. The analysis of Carson et al (3), based on 69 events in 5 momentum bins, did not show clear indication for a resonant state. The results were consistent with an almost constant cross section of aproximately 40 μbarns. A College de France - Pisa collaboration (4) has presented data, based on 120 events in 6 intervals of momentum, on the angular distribution and no narrow and significant structures were observed.

We have 2252 and 707 events in the 0prong + 1V° and 0prong + 2V° topologies respectively. After the kinematic analysis was performed we assigned 19 events to the $K_1^oK_1^o$ reaction and 289 to the $K_1^o(K^o)$. The possible misidentification in the selection procedure was estimated to be of the order of 1 event.

In our study the cross sections were obtained using the formula

$$\sigma_{K\bar{K}} = \sigma_{TOTAL} \frac{N_{\bar{K}K}}{N_{TOTAL}}$$

where the total cross section at 700 and 750 MeV/c were calculated interpolating with the function $\sigma = Ap^{-N}$ the values taken from a compilation of $N\bar{N}$ data (5). This procedure implies a small renormalization of our measured total cross sections (140.9 ± 2.4 mb and 134 ± 4 mb) to the values 141.5 mb and 135.5 mb respectively. The results are displayed in the following table

	$\sigma(K_1^oK_1^o)$	$\sigma(K_1^oK_2^o)$
700 MeV/c	1.7±1.1 μb	44.±7. μb
750 MeV/c	6.3±2.0 μb	39.±5. μb

The $K_1^oK_2^o$ cross sections are in good agreement with the values of Ref. 3. In the $K_1^oK_1^o$ process our results seems to indicate a fast increase in the cross section in this momentum range. We note that at the higher momentum the cross section is similar to the values obtained by R.R. Burns et al (6) and J. Barlow et al (7).

The angular distributions for the reactions

$$\bar{p}p \rightarrow K_1^oK_1^o$$
$$\bar{p}p \rightarrow K_1^oK_2^o$$
$$\bar{p}p \rightarrow K_1^o(K^o)$$

are shown in Fig. 1 for the 700 and 750 MeV/c data. For the $K_1^oK_2^o$ process the angular distribution was obtained substracting the two other distributions.

The $K_1^oK_2^o$ unfolded angular distribution was fitted to the expansion

$$\sum_{l=0}^{L} A_l \; P_l(\cos\theta)$$

As expected, the odd coefficients were found compatible with zero. The results of the fits to the folded angular distribution are shown in table 1 and Fig. 1. We observed that the values of the ratios A_2/A_o, A_4/A_o and A_6/A_o do not change significantly in this momentum region and are compatible with the values found at higher momentum.

Taking all the values of the cross section for the channel $\bar{p}p \rightarrow K_1^oK_2^o$ (2), (3), (5), (6) and (7) we have fitted the following expression (Fig. 2)

$$\sigma = C_1 \; P_L^{-N} + C_2 \quad \frac{\Gamma}{(E-M)^2 + \Gamma^2/4}$$

including a P_L^{-N} dependence for the background and fixing the central mass of the Breit Wigner to M = 1968 MeV (2). We obtain a width (Γ) of 60 MeV but the description of the data is very bad (X^2 = 60 for ND = 16). Also, the width can appreciably change (40 MeV < Γ < 140 MeV) using or not some of the cross section measurements in the region of the 1968 meson.

Fig. 3 shows the behaviour of the A_2/A_o Legendre polynomial coefficient with the $\bar{p}$ laboratory momentum. Some broad structure in the region of the ρ(1968) meson could be present but it seems difficult to reconcile our results with a rapid variation of $\Gamma(K_1^o K_2^o)$ in the 700 - 750 MeV/c momentum region as would imply the fit of Benvenutti et al. (2).

2. $K^{*o} - K^{*\pm}$ mass difference

The advantages of using the reaction $\bar{p}p \rightarrow K_1^o K^{\pm}\pi^{\mp}$ to measure the mass difference of the two charged modes of the K*(890) was pointed out several years ago by N. Barash et al. (8). First, the charged and neutral K*s appear as prominent peaks above a relatively flat background. Second, both components of the K* are seen in the same reaction. This eliminates the possibility of systematic errors which may occur when two different channels are compared.

For our events, the (Kπ) mass spectra, Figs. 4,5 were fitted using a linear form in the mass as background and an energy dependent Breit-Wigner shape of the form

$$\frac{M_o \Gamma_o}{(M_o^2-M^2) - iM_o\Gamma} (q/q_o), \qquad \Gamma = \Gamma_o \left(\frac{M_o}{M}\right) (q/q_o)^3$$

The following results were obtained

	N. of events	M(MeV)	Γ(MeV)
K^{*o}, $\bar{K}^{*o}$	670 ± 58	898.9 ± 1.7	42.8 ± 5.2
K^{*+}, K^{*-}	902 ± 60	892.4 ± 1.5	45.3 ± 4.8

giving for the mass difference

$$\Delta M = 6.5 \pm 2.2 \text{ MeV}$$

The fit was repeated increasing the mass interval and/or using a different Breit-Wigner form. The lower and upper limits for the mass difference obtained with the various methods were

$$\Delta M^L = 4.4 \pm 2.0 \text{ MeV}$$

$$\Delta M^H = 7.6 \pm 2.4 \text{ MeV}$$

The systematic errors have been estimated to be less than .7 MeV. Finally we can compare our determination with the measurement of Ref (9), 5.7±1.7 MeV, and with the prediction of ≃4 MeV (10) obtained in the framework of the quark model. Excellent agreement is found.

3. $K_1^oK_1^o$ threshold enhancement as observed in $\bar{p}p \to K_1^oK_1^o\pi^+\pi^-$

Fig. 6 shows the $K_1^oK_1^o$ mass distribution for the reaction of interest. A narrow and significant enhancement near threshold is observed over a fairly large background. The general shape of the mass spectrum is similar to the one previously reported at .7 GeV/c and 1.2 GeV/c (11) (12). The enhancement seems to be produced with the ρ meson. Fig. 7 shows the $K_1^oK_1^o$ mass distribution for events with $\pi^+\pi^-$ effective mass in and out de ρ mass region. Similarly, Fig. 7 shows the $\pi^+\pi^-$ effective mass distribution for events with the $K_1^oK_1^o$ mass in and out of the $K_1^oK_1^o$ threshold region.

In the absence of any similar narrow effect in the $K_1^oK^\pm$ distribution, Fig 8, we assume the enhancement to be I = 0.

The folded helicity decay distribution for events in the region of interest ($M(K_1^oK_1^o) < 1.08$ GeV/c^2) is shown in Fig. 9a. The distribution for events in the same region but with at least one Kπ combination in the K* mass region (13) is shown in Fig. 9b. The same distribution for events with no Kπ mass combination in the K* region is shown in Fig. 1c, being compatible with isotropy. At the present level of statistics we have no evidence against the J = 0 assignment for the $K_1^oK_1^o$ signal.

The $K^o_1K^o_1$ mass spectrum have been parametrized with simple probability functions including smooth mass dependent forms for the background and describing the enhancement in the following ways,

a) S-wave Breit-Wigner

$$f(M)\ \frac{M_R^2\ \Gamma_o^2}{(M^2-M_R^2)^2+M_R^2\Gamma^2}\quad \text{with } \Gamma = \Gamma_o(q/q_o)$$

b) $f(M)\ \dfrac{a^2}{1+q^2a^2}$ where $f(M)$ is the background term.

c) Relating our observations with a narrow s-wave I = 0 resonance (S*) detected in detailed $\pi\pi$ phase shift analysis (14) (15). Using the Watson theorem for final states interactions we can write (16)

$$T^{\,I=0}_{\,J=0} = A_1\left\{ 1 + A_2\ \frac{q_{\pi\pi}}{m}\ f_o^{\bar{K}K\ \rightarrow\ \pi\pi} + A_3\ \frac{q_{\bar{K}K}}{m}\ f_o^{\bar{K}K\ \rightarrow\ \bar{K}K} \right\}$$

where $T^{\,I=0}_{\,J=0}$ is the amplitude for producing de S-wave, I = 0 resonance, A_1, A_2, A_3 are complex functions of m which for simplicity we will assume to be constant. $q^{\pi\pi}$, $q^{K\bar{K}}$ are the c. of m. momentum for the $\pi\pi$ or $K\bar{K}$ intermediate state, m is the mass of the $\bar{K}K$ system, $f_o^{\pi\pi\ \rightarrow\ \bar{K}K}$ and $f_o^{\bar{K}K\ \rightarrow\ \bar{K}K}$ are the partial wave amplitudes for the processes $\pi\pi \rightarrow \bar{K}K$ and $\bar{K}K \rightarrow \bar{K}K$ given in Ref. (14).

The results of the fits are shown in table II. They favour the Breit-Wigner description for the signal, although the parametrization (c) reproduces the data reasonably well. The scattering length hypothesis is statistically very improbable and the percentage of background contribution in this case is unrealisticaly small.

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TABLE 1

Results of the fits to the folded differential cross sections $\bar{p}p \to K_1^0 K_2^0$ using the expansion $\sum_{l=0}^{L} A_{2l} P_{2l} (\cos \theta)$

700 MeV/c	750 MeV/c
$\frac{A_2}{A_o} = 0.84 \pm 0.18$ ND = 11 $\chi^2 = 16.7$	$\frac{A_2}{A_o} = 0.66 \pm 0.13$ ND = 13 $\chi^2 = 119.8$
$\frac{A_2}{A_o} = 0.76 \pm 0.18$ $\frac{A_4}{A_o} = -0.70 \pm 0.26$ ND = 10 $\chi^2 = 9.8$	$\frac{A_2}{A_o} = 0.88 \pm 0.13$ $\frac{A_4}{A_o} = -1.85 \pm 0.18$ ND = 12 $\chi^2 = 22.9$
$\frac{A_2}{A_o} = 0.72 \pm 0.21$ $\frac{A_4}{A_o} = -0.93 \pm 0.32$ $\frac{A_6}{A_o} = -0.85 \pm 0.47$ ND = 9 $\chi^2 = 5.8$	$\frac{A_2}{A_o} = 1.11 \pm 0.18$ $\frac{A_4}{A_o} = -1.85 \pm 0.23$ $\frac{A_6}{A_o} = -1.64 \pm 0.51$ ND = 11 $\chi^2 = 7.6$

TABLE 2

Results of the fits to the $K_1^oK_1^o$ mass spectrum with the parametrizations a, b, c described in the text

Fits	Values of parameters	χ^2	ND
a	M_R = 1040 ± 4 MeV Γ = 52 ± 10 MeV	8	11
b	a = 1.24 ± 0.32 fm	16.7	11
c		12.11	10

Figure Captions

Fig. 1.- Folded angular distributions in the $\bar{p}p$ center of mass system. The solid curves show the result of the fits 3.a and 3.b of TABLE 1.

Fig. 2.- $\bar{p}p \rightarrow K_1^o K_1^o$ and $\bar{p}p \rightarrow K_1^o K_2^o$ cross sections as a function of the $\bar{p}$ laboratory momentum.

Fig. 3.- A_2/A_o Legendre coefficient as a function of the $\bar{p}$ laboratory momentum.

Fig. 4.- $K^{\pm}\pi^{\mp}$ effective mass distribution for the reaction $\bar{p}p \rightarrow K_1^o K^{\pm}\pi^{\mp}$. The solid line is the result of the fit described in the text.

Fig. 5.- $K_1^o\pi^{\mp}$ effective mass distribution for the reaction $\bar{p}p \rightarrow K_1^o K^{\pm}\pi^{\mp}$. The solid line is the result of the fit described in the text.

Fig. 6.- $K_1^o K_1^o$ effective mass distribution for the process $\bar{p}p \rightarrow K_1^o K_1^o \pi^+\pi^-$.

Fig. 7.- $K_1^o K_1^o$ and $\pi^+\pi^-$ effective mass distributions for the process $\bar{p}p \rightarrow K_1^o K_1^o \pi^+\pi^-$. The selection used for every histogram is written on the corresponding figure.

Fig. 8.- $K_1^o K^{\pm}$ mass distribution for the process $\bar{p}p \rightarrow K_1^o K^{\pm}\pi^{\mp}\pi^o$. The selection used for every histogram is written on the corresponding figure.

Fig. 9.- Helicity angular distributions. The selection used for every histogram is written on the corresponding figure.

Fig.10.- $K_1^o K_1^o$ mass distribution. The solid lines are the result of the fits a, b, c described in the text. The dotted lines show the contribution of the different terms involved in the parametrizations.

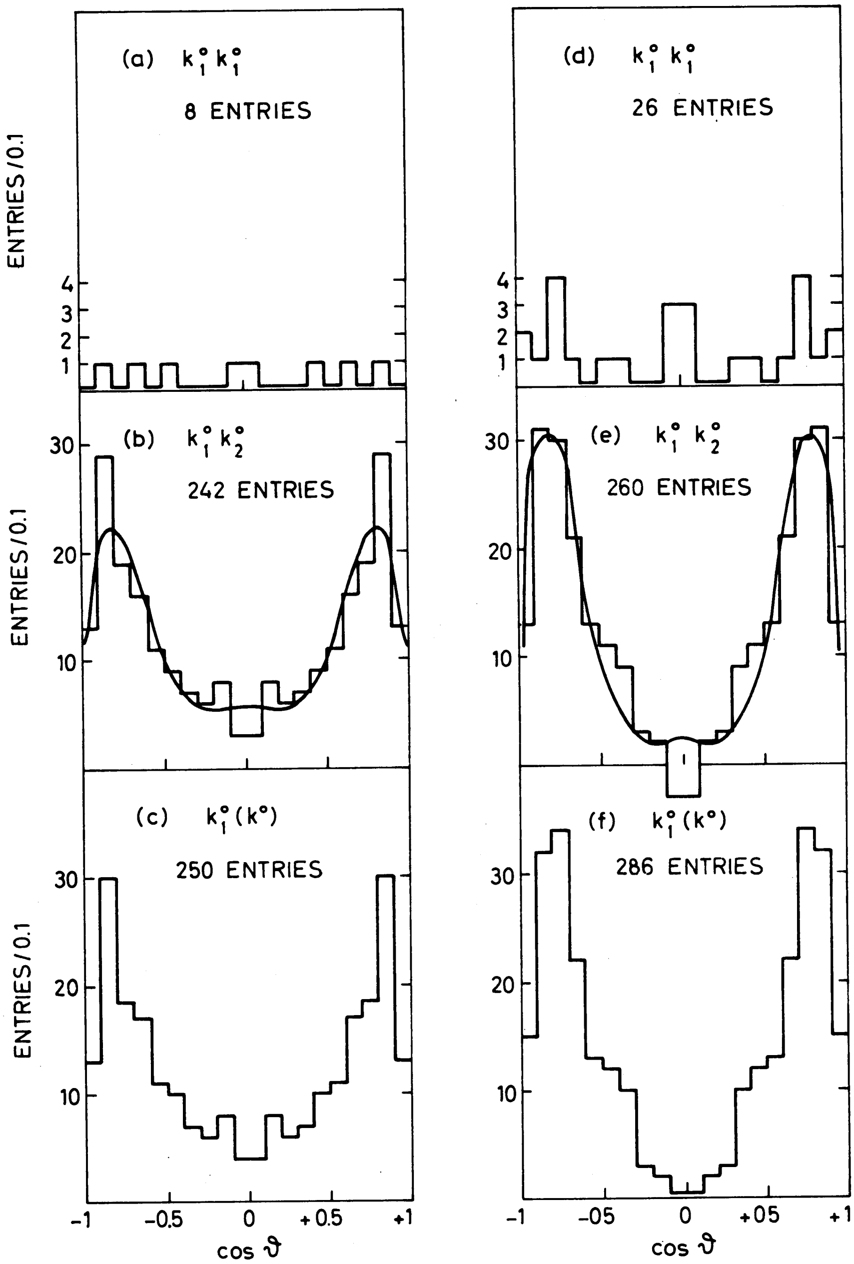

(a) $k_1^\circ k_1^\circ$
8 ENTRIES
(b) $k_1^\circ k_2^\circ$
242 ENTRIES
(c) $k_1^\circ (k^\circ)$
250 ENTRIES
(d) $k_1^\circ k_1^\circ$
26 ENTRIES
(e) $k_1^\circ k_2^\circ$
260 ENTRIES
(f) $k_1^\circ (k^\circ)$
286 ENTRIES
ENTRIES/0.1
1
2
3
4
10
20
30
-1
-0.5
0
+0.5
+1
-05
+05
cos ϑ

Fig. 1

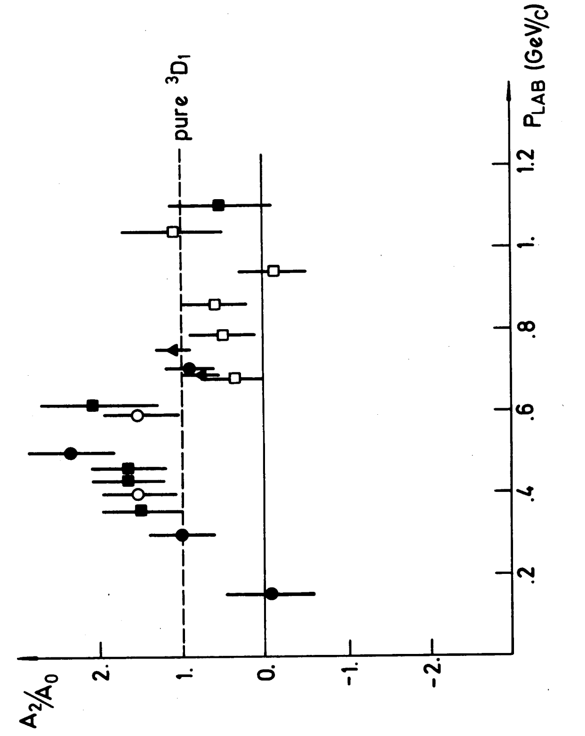

A. Benvenutti et al.
C. Defoix et al.
R.R. Burns et al.
R.G. Carson et al.
M. Aguilar-Benitez et al
A_2/A_0
pure $^3D_1$
P_{LAB} (GeV/c)
2.
1.
0.
-1.
-2.
.2
.4
.6
.8
1.
1.2

Fig. 3

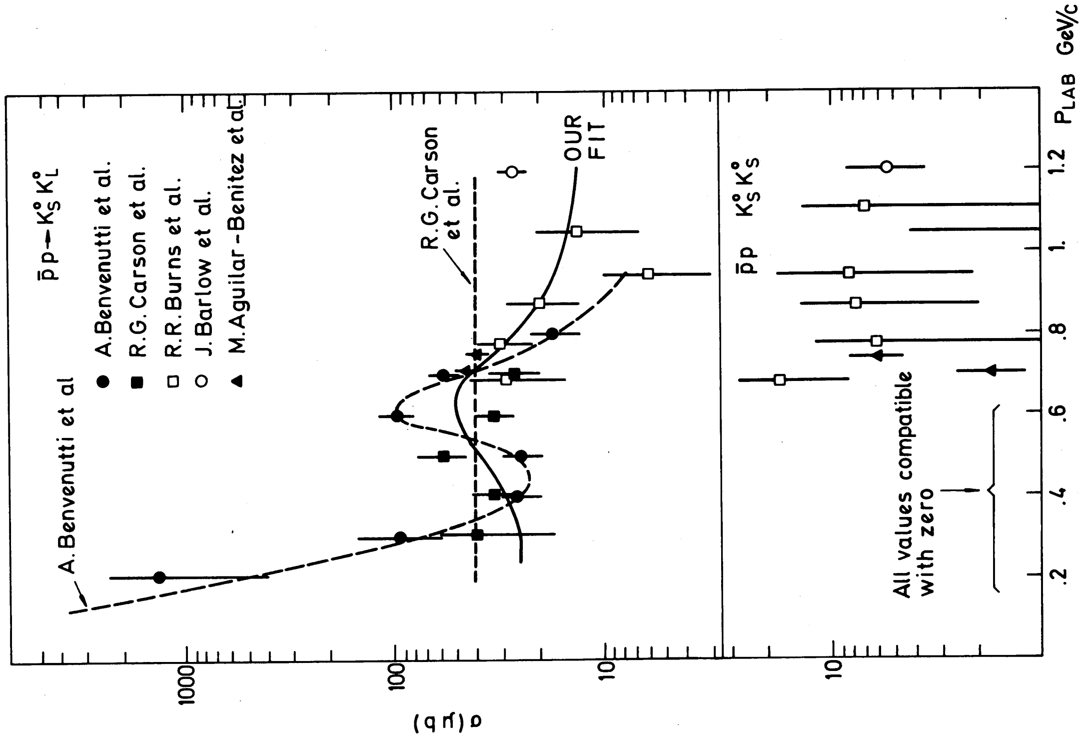

A. Benvenutti et al
$\bar{p}p \to K^0_S K^0_L$
A. Benvenutti et al.
R.G. Carson et al.
R.R. Burns et al.
J. Barlow et al.
M. Aguilar-Benitez et al.
R.G. Carson et al.
OUR FIT
$\bar{p}p$ $K^0_S K^0_S$
All values compatible with zero
σ(μb)
1000
100
10
10
.2
.4
.6
.8
1.
1.2
P_{LAB} GeV/c

Fig. 2

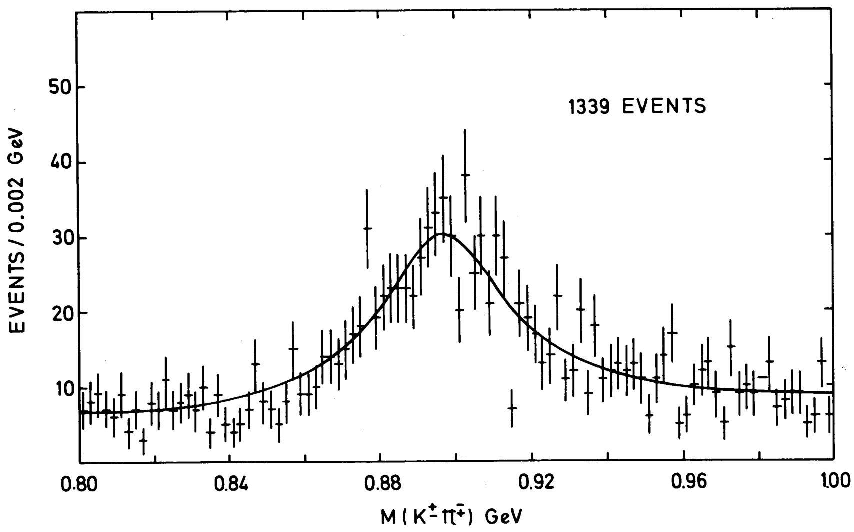


Fig. 4

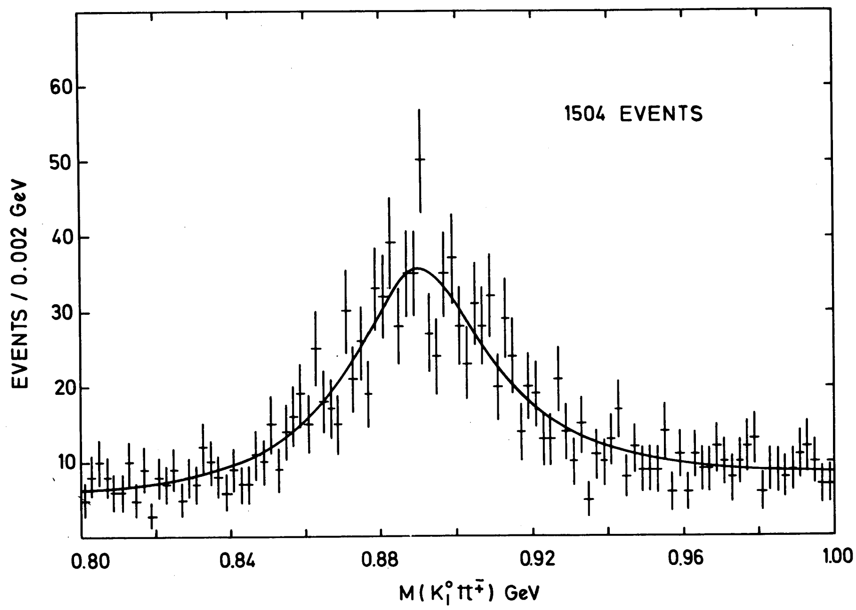


Fig. 5

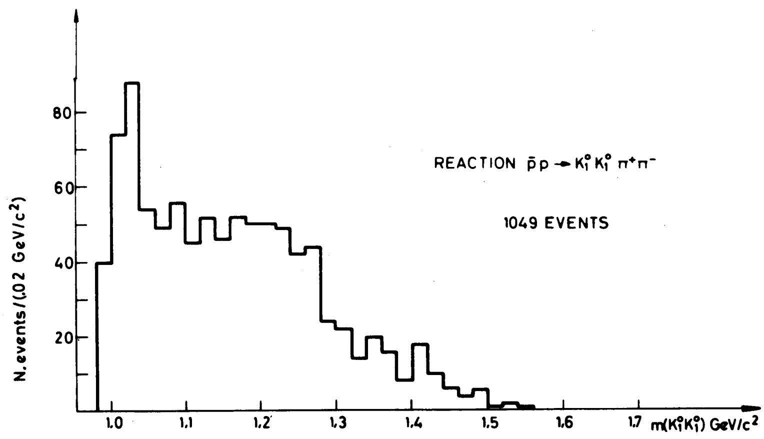


Fig. 6

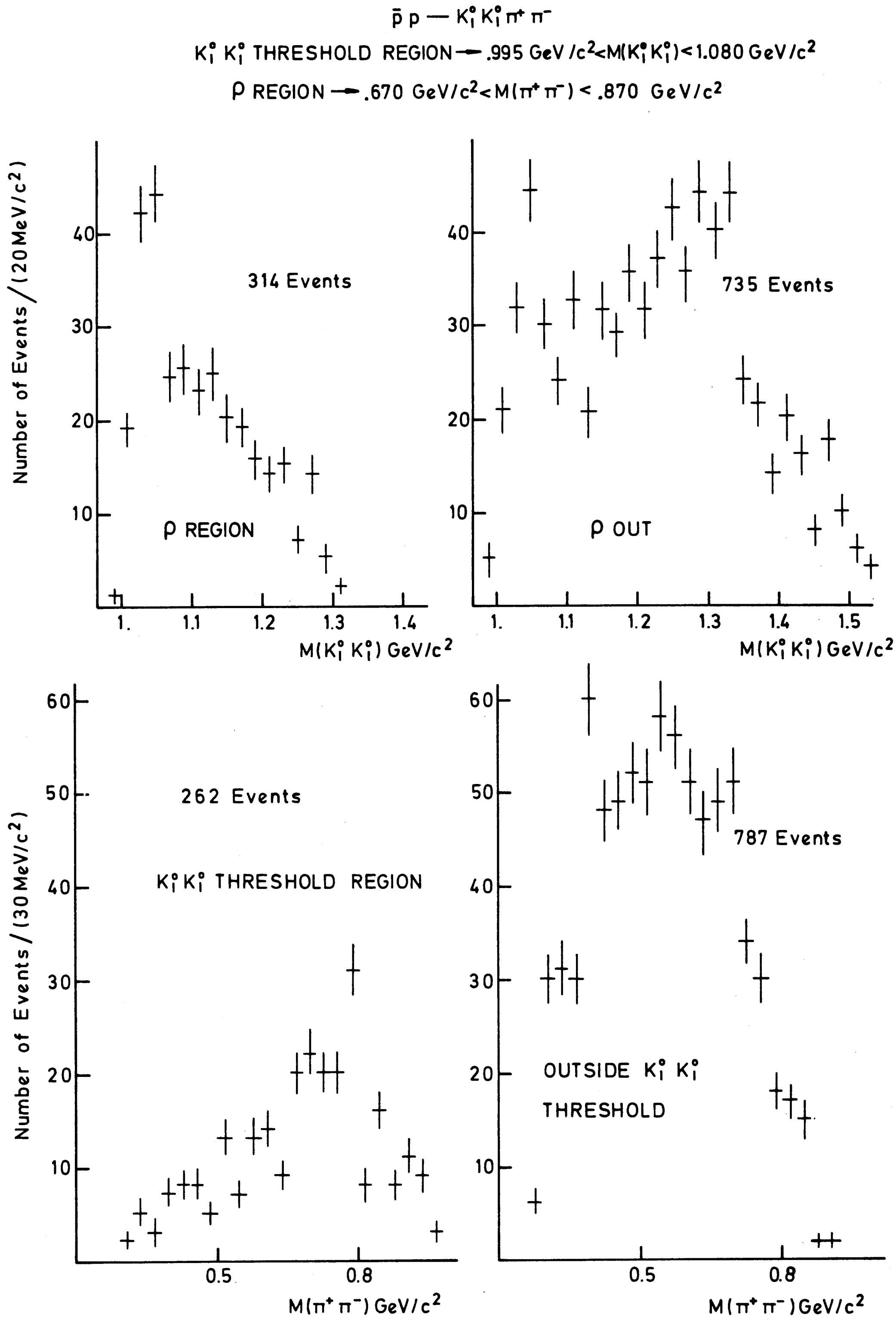
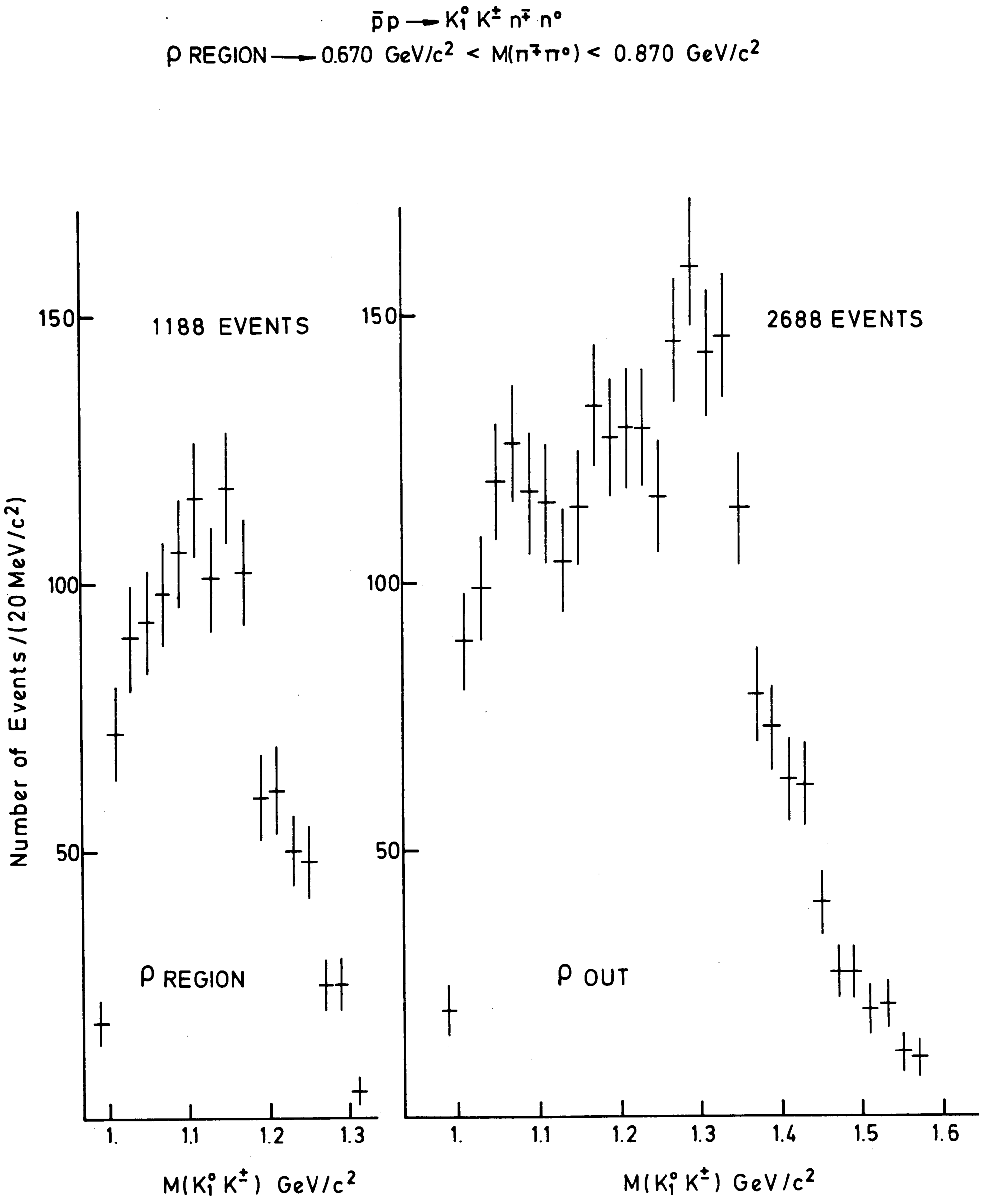

p̄ p — $K_1^\circ K_1^\circ \pi^+ \pi^-$
$K_1^\circ K_1^\circ$ THRESHOLD REGION → .995 GeV/c² < M($K_1^\circ K_1^\circ$) < 1.080 GeV/c²
ρ REGION → .670 GeV/c² < M($\pi^+\pi^-$) < .870 GeV/c²
Number of Events/(20 MeV/c²)
314 Events
ρ REGION
735 Events
ρ OUT
M($K_1^\circ K_1^\circ$) GeV/c²
Number of Events/(30 MeV/c²)
262 Events
$K_1^\circ K_1^\circ$ THRESHOLD REGION
787 Events
OUTSIDE $K_1^\circ K_1^\circ$
THRESHOLD
M($\pi^+\pi^-$) GeV/c²

Fig. 7



$\bar{p}p \rightarrow K_1^0 K^{\pm} \pi^{\mp} \pi^0$
ρ REGION → 0.670 GeV/c² < M(π∓π°) < 0.870 GeV/c²
1188 EVENTS
2688 EVENTS
ρ REGION
ρ OUT
Number of Events /(20 MeV/c²)
150
100
50
1.
1.1
1.2
1.3
1.4
1.5
1.6
M(K₁° K±) GeV/c²
M(K₁° K±) GeV/c²

Fig. 8

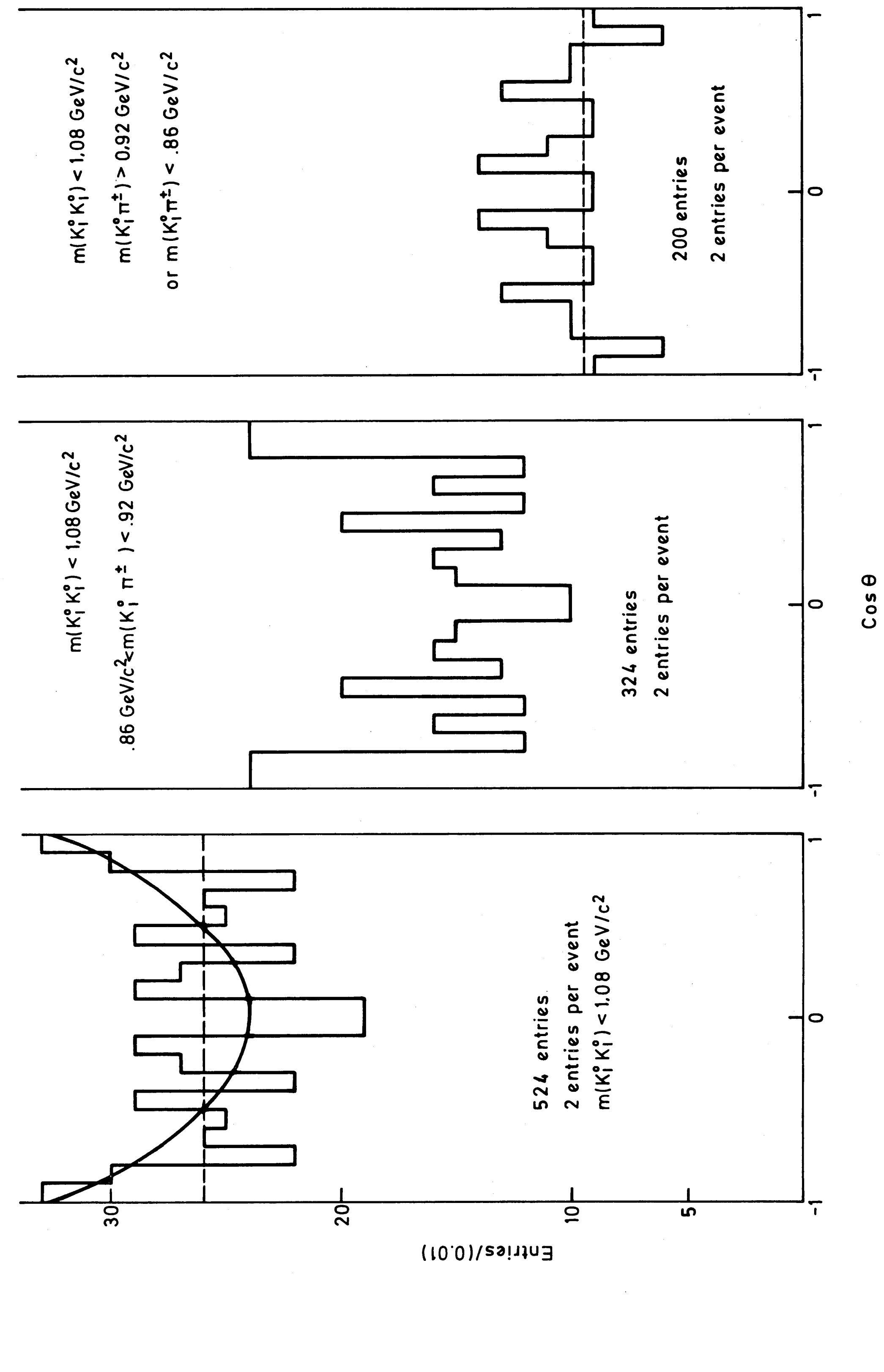

Entries/(0.01)
30
20
10
5
-1
0
1
Cos θ
524 entries
2 entries per event
m(K°₁K°₁) < 1.08 GeV/c²
324 entries
2 entries per event
m(K°₁K°₁) < 1.08 GeV/c²
.86 GeV/c² < m(K°₁ π±) < .92 GeV/c²
200 entries
2 entries per event
m(K°₁K°₁) < 1.08 GeV/c²
m(K°₁π±) > 0.92 GeV/c²
or m(K°₁π±) < .86 GeV/c²

Fig. 9

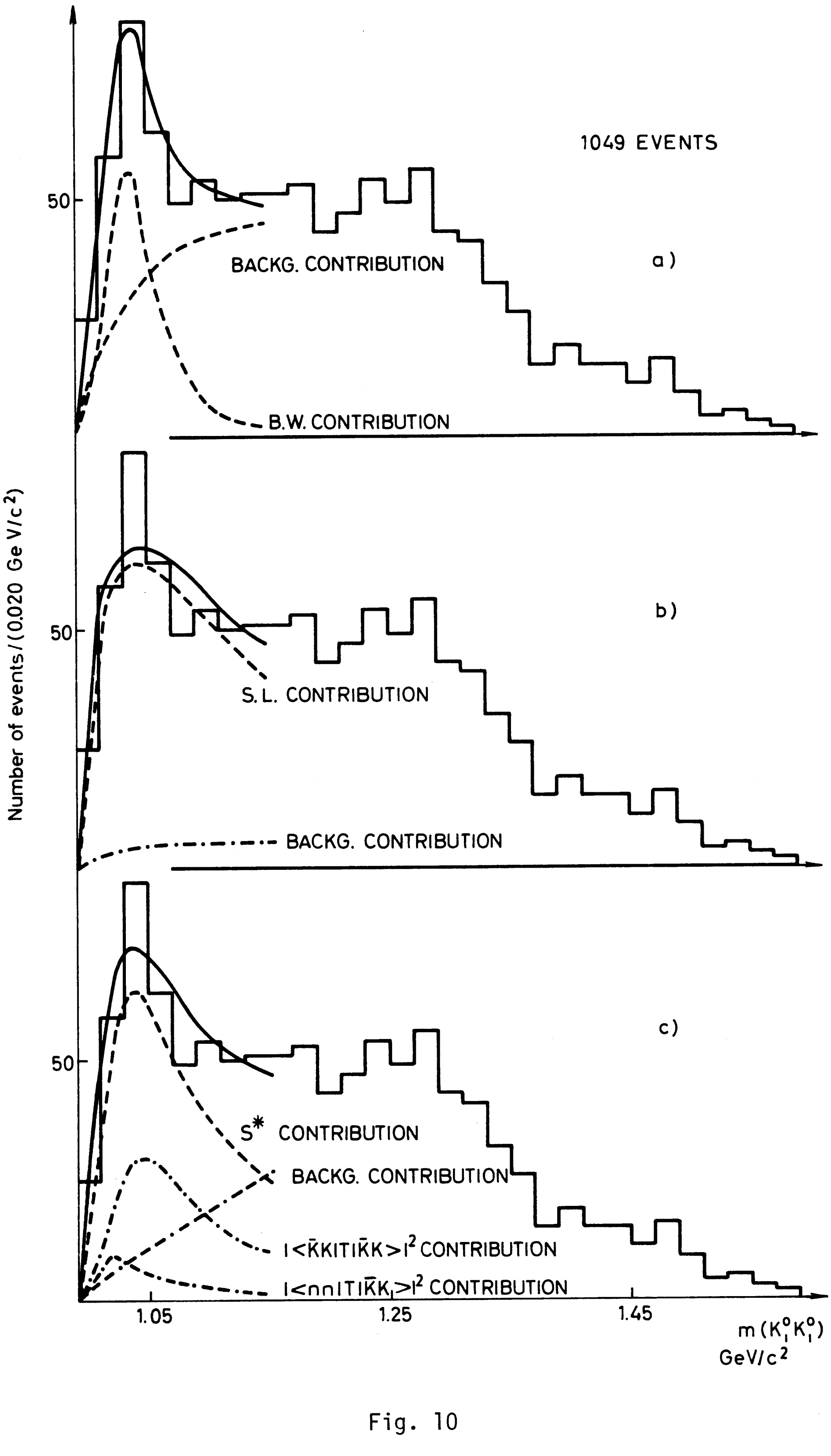

1049 EVENTS
a)
BACKG. CONTRIBUTION
B.W. CONTRIBUTION
b)
S.L. CONTRIBUTION
BACKG. CONTRIBUTION
c)
S* CONTRIBUTION
BACKG. CONTRIBUTION
|<K̄K|T|K̄K>|² CONTRIBUTION
|<nn|T|K̄K₁>|² CONTRIBUTION
50
50
50
1.05
1.25
1.45
Number of events/(0.020 GeV/c²)
m(K°₁K°₁) GeV/c²

Fig. 10

D I S C U S S I O N

- *Dao:*

There are some striking similarities between the resonance production in $p\bar{p}$ low energies and pp collisions at high energies at NAL. (The observation of $K_S^0 K_S^0$ enhancement near threshold is a good example of these similarities.) Is the $K\bar{K}$ enhancement you mentioned a resonance or just an enhancement or something else?

- *Rubio:*

It is most probably the same object as the S^* observed by Protopopescu et al. in $\pi N \to \pi\pi N$. Our data are consistent with the values quoted by Protopopescu et al.