STUDY OF THE FRAGMENTATION p $\xrightarrow{K^-}$ Λ^0 AND K$^-$ $\xrightarrow{p}$ Λ^0 AT 4.2 GeV/c

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(Presented by S. Nilsson)

1. INTRODUCTION

The inclusive production of Λ^0 by kaons on protons has been investigated in a number of experiments in the momentum range 4-32 GeV/c[1].

In this paper we are mainly interested in the Λ^0 particles coming from target and beam fragmentation. The strangeness exchange and baryon exchange reactions respectively yield information on strangeness annihilation at the $K\bar{K}$ vertex and on $\bar{p}p$ annihilation at the $\bar{p}p$ vertex. It has been suggested by T. Inami and H. Miettinen[2] that the strangeness annihilation in the $\bar{K}K$ interaction may explain the experimentally observed rapid fall of the Λ^0-production in the beam fragmentation region.

In this spirit one should distinguish the reactions:

$$K^-p \rightarrow \Lambda + \text{pions} \tag{1}$$

and
$$K^-p \rightarrow \Lambda + K\bar{K} + \text{pions} \tag{2}$$

The cross section for these inclusive reactions is in the low missing mass region proportional to the forward Reggeon-particle amplitudes of the processes

$$'K^+' \; K^- \rightarrow \text{pions} \tag{3}$$

and
$$'K^+' \; K^- \rightarrow K\bar{K} + \text{pions} \tag{4}$$

where $'K^+'$ stands for a K^+ or $K^+(890)$ Regge trajectory.

Similarly in the beam fragmentation region the reaction

$$K^-p \rightarrow \Lambda + \text{mesons} \tag{5}$$

is related[3] to the antinucleon-nucleon annihilation process

$$'\bar{p}'p \rightarrow \text{mesons} \tag{6}$$

Definitions and the sample are presented in section 2, the missing mass distributions in the fragmentation regions in section 3. Fits to the distributions of crossing symmetric variables and interpretation in terms of trajectories are presented in section 4. Section 5 contains the multiplicity distributions of the residual pion system. Conclusions and discussion are presented in section 6.

2. DEFINITIONS AND SAMPLE

Variables and notations to be used in the study of the inclusive process

$$K^- p \to \Lambda^\circ X \qquad (7)$$

are illustrated in Fig. 1.

The t versus u scatter plot is a suitable representation for discussing contributions from different processes.

In our experiment $s = 9.1$ GeV^2 and $(M_X)_{max} = 1.90$ GeV/c^2. The variable $t + u$ is a linear function of M_X^2, so lines of $t + u$ = constant in Fig. 1 mean M_X = constant. The M_X^2 distribution is the projection of the $t - u$ plot onto the plane $t - u$ = constant. The variable $t - u$ is proportional to p_L or $\cos \theta_{cms}$. We define:

- target fragmentation region by $t > - 1.0$ (GeV/c)^2

- beam fragmentation region by $u > - 1.0$ (GeV/c)^2

There is no overlap between the regions. The selection is also illustrated in the $p_L - p_T$ plot, Fig. 2.

The sample consists of 30.000 events with seen Λ° in 4.2 GeV/c $K^- p$ interactions. The number of events in different channels are given in Table 1.

We want to study the processes with only pions produced in addition to the Λ°. Other reactions which contribute to our sample are:

$$K^- p \to \Sigma^\circ + \text{anything.} \qquad (8)$$

and
$$K^- p \to \Lambda + K\bar{K} + \text{anything.} \qquad (9)$$

Only the fitted events of reaction (8) have been identified. We estimate that 25% of our no fit events are due to reaction (8) and correct for this in an average sense by taking 75% of the cross section for the no fit channels. As for reaction (9), which contributes $\sim 10\%$ to the total sample, again only the fitted events have been well identified. Our estimate is, that the target fragmentation region contains $\sim 5\%$ of reaction (9) and in the beam fragmentation region reaction (9) will be absent. In the missing mass distributions reaction (9) will contribute to the mass region > 1.0 GeV/c^2.

3. MISSING MASS DISTRIBUTION

The distributions of missing mass are shown in Fig. 3 for the target fragmentation region (t > - 1) and in Fig. 4 for the beam fragmentation region (u > -1). A striking feature is immediately noticed: Below 1.1 GeV/c^2 in the t- and u-channels the missing mass distributions consist dominantly of single resonances. In the t-channel we find contributions from:

$$\Lambda^{\circ}\pi^{\circ}$$
$$\Lambda^{\circ}\eta(550)$$
$$\Lambda^{\circ}\rho(770)$$
$$\Lambda^{\circ}\omega(785)$$
$$\Lambda^{\circ}\eta'(960)$$
$$\Lambda^{\circ}\phi(1020)$$
$$\Lambda^{\circ}f(1270)$$

and
$$\Lambda^{\circ}A_2(1310)$$

The total resonance production for M_x < 1.1 GeV/c^2 is 60±10%. In the u-channel we find contributions from:

$$\Lambda^{\circ}\pi^{\circ}$$
$$\Lambda^{\circ}\eta(550)$$
$$\Lambda^{\circ}\rho(770)$$

and
$$\Lambda^{\circ}\omega(785)$$

and 30±5% resonance and π° production for M_x < 1.1 GeV/c^2.

The problem of reflection of hyperon resonances has been investigated. The hyperon resonances give in general rise to a smooth background or can be neglected in particular in the low mass region.

4. ANALYSIS OF THE INVARIANT CROSS-SECTION

The mass distributions vary as functions of t or u. Low masses populate the region t → 0. As t → -1 the low masses are depleted and the distribution peaks towards the kinematical limit. A smooth power law $(s_x/s)^{a(t)}$ describes the data at high masses.

We assume that the inclusive production of Λ° takes place by means of Regge trajectory exchange in the t- and u-channels. We assume furthermore that the processes can be parametrized by a triple Regge amplitude[4].

The corresponding graphs are shown in Fig. 5a) and b). The cross section then is

$$\frac{d^2\sigma}{dt\, d(s_x/s)} \propto f(s, s_x/s, t) \propto s^{\alpha_M(0)-1} (s_x/s)^{\alpha_M(0)-2\alpha(t)} \qquad (10)$$

The conditions for the validity of the formula are

$$s \to \infty, \quad s_x \gg 1, \quad s/s_x \gg 1 \text{ and fixed } t \text{ (u)}.$$

$\alpha_M(0)$ stands for the intercept of the trajectory in the forward scattering amplitude for $'K^+ K^- \to 'K^+ K^-$ or $'\bar{p}'p \to '\bar{p}'p$; $\alpha(t)$ is the trajectory in the t-channel or u-channel. Compared to the typical scale $s_0 \sim 1.$ (GeV)^2, $s = 9.1$ is $\gg 1$ and we choose in general $s/s_x > 4$ which is also $\gg 1$. The condition least fulfilled is $s_x \gg 1$ as $s_x \lesssim 2.3$. However it has been shown[5] that the Regge pole amplitude also describes the low s_x resonance region in an average sense, and therefore it may not bee too unreasonable to try to apply the cross-section parametrization (10) even at 4.2 GeV/c.

The variable s_x in formula (10) is an approximation of the crossing symmetric variables

$$\nu_t = s_x - t - m_k^2 \qquad (11)$$

$$\nu_u = s_x - u - m_p^2$$

The variable ν is negative in some cases. We replace ν_t/s by $\nu_t/s + 0.03$ and ν_u/s by $\nu_u/s + 0.10$ which corrects this. The distributions in s_x/s and ν/s have been fitted by a power law

$$(s_x/s)^{a(t)} \quad \text{or} \quad (\nu/s)^{a(t)}$$

for 10 bins in the interval $-1.0 < t < 0$, where $a(t)$ stands for:

$$a(t) = \alpha_M(0) - 2\,\alpha(t) \qquad (12)$$

The narrow and abundant resonances produced (section 3) make it difficult to fit the distributions directly. Instead we fit the first moment integrals as has been suggested by Chan Hong-Mo, H.I. Miettinen and R.G. Roberts[6]

$$I(X,t) = \int_0^X \frac{\nu}{s} f\left(\frac{\nu}{s}, t\right) d\left(\frac{\nu}{s}\right)$$

which gives

$$I(X,t) = G(t) \frac{X^{a(t)+2}}{a(t)+2} \qquad (13)$$

In order to interpret the results for $a(t)$ in (12) we need information from an s-dependent analysis in order to estimate $\alpha_M(0)$. We use the results

in the experiment of A. Borg et al.[7]. The cross sections at 3.93 and
14.3 GeV/c are given in the reference. The average ratio of the cross
sections for $K^-p \to \Lambda^\circ$ + pions and $-0.9 < x < -0.5$ and $0.5 < x < 0.9$ is
3.04 ± 0.31 and 2.81 ± 0.20 respectively, where x is the variable p_L/p_{LMAX}.
The ranges selected correspond roughly to target and beam fragmentation.
This implies for the intercepts that

$$\alpha_M(0) = 0.06 \pm 0.08 \quad \text{in the t-channel}$$

$$\alpha_E(0) = 0.13 \pm 0.06 \quad \text{in the u-channel}$$

The value for $\alpha_M(0)$ in the t-channel is in agreement with
the results of T. Inami and H. Miettinen[2] $\alpha_M(0) \sim 0$. The trajectory
for antiproton-proton annihilation is expected to be exotic[3]. The
result indicates that it is a low lying trajectory.

We can now obtain the values for the trajectories $\alpha(t)$ and $\alpha(u)$. The
results are shown in Figs 6a, and 6b, for $\alpha(t)$ and $\alpha(u)$ respectively.
Straight trajectories with slope 1 are drawn through the points $\alpha(m^2_{K(494)})=0.$,
$\alpha(m^2_{K(890)})=1$ and $\alpha(m^2_p)=0.5$ to guide the eye.

A fit to the points gives

$$\alpha(t) = (-0.05 \pm 0.04) + (1.02 \pm 0.02)t$$

and $$\alpha(u) = (-0.36 \pm 0.06) + (0.98 \pm 0.07)u$$

The measured points in the t-channel are between the K and K(890) trajectories.
This is in agreement with earlier published data[8] from this experiment, which
gave evidence for both K and K(890) exchange in this region. The trajectory in
the u-channel is in excellent agreement with an anti-nucleon trajectory.

Our analysis may be compared to a similar experiment at 14.3 GeV/c[9],
where the reaction (7) has been studied. In view of the limited statistics
at 14.3 GeV, the larger contribution from $K\bar{K}$ states and the different choices
of parameters the results are in fair agreement.

5. MULTIPLICITIES OF THE RESIDUAL SYSTEM

The number of π° produced in the states with missing mass will be
estimated. It can be done in two ways, either we use

$$<n_{\pi^\circ}> = \frac{<E_{MM}>}{<E_{\pi^\pm}>}$$

where $<E_{MM}>$ and $<E_{\pi^\pm}>$ are the average total energies computed in the same

final state or take $\langle E_\pi \rangle$ from events with known number of pions and vary $\langle n_{\pi O} \rangle$ until the relation is satisfied. The total energies are computed in the CMS.

Both ways agree very well. The results are:

$$\Lambda^O MM \qquad \langle n_{\pi O} \rangle = 2.9 \pm 0.1$$
$$\Lambda^O \pi^+ \pi^- MM \qquad \langle n_{\pi O} \rangle = 2.2 \pm 0.1$$
$$\Lambda^O 2\pi^+ 2\pi^- MM \qquad \langle n_{\pi O} \rangle = 2.0 \pm 0.1$$

The multiplicities might be slightly underestimated as the events with missing mass contain $\sim 25\% \Sigma^O \pi^+ \pi^- \ldots$. The total energy of the photon is not, however, very different from that of the pion.

The average charged and total pion multiplicities are plotted as functions of s_x in Figs. 7 and 8. Fits give

$$\langle n_{CH} \rangle = (1.29 \pm 0.04) + (0.42 \pm 0.02) s_x$$
$$\langle n_\pi \rangle = (2.44 \pm 0.03) + (0.53 \pm 0.02) s_x$$

in the t-channel and

$$\langle n_{CH} \rangle = (1.34 \pm 0.02) + (0.47 \pm 0.01) s_x$$

$$\langle n_\pi \rangle = (2.35 \pm 0.04) + (0.62 \pm 0.02) s_x$$

in the u-channel.

Interpolating $\langle n \rangle$ in the u channel one obtains

$$\langle n_{CH} \rangle = 3.00 \pm 0.02$$
and $\qquad \langle n_\pi \rangle = 4.54 \pm 0.05$

at $s_x = (2m_p)^2$, in excellent agreement with the results from $\bar{p}p$ annihilation at rest [10]:

$$\langle n_{CH} \rangle = 3.07 \pm 0.06$$
$$\langle n_\pi \rangle = 4.9 \pm 0.10$$

Several properties of the off-mass-shell multiplicity distributions emerge. The standard deviation D is plotted as function of $\langle n_{CH} \rangle$ in Fig.9. The Mueller moment $f_2 = D^2 - \langle n \rangle$ is large and negative as can be inferred from the plot.

6. CONCLUSIONS AND DISCUSSION.

We have studied target and beam fragmentation processes in $K^- p \rightarrow \Lambda +$ pions reactions at 4.2 GeV/c. The total sample consisted of 70.000 events

with measured Λ^o. 20664 events had t > - 1 and 9068 events had u > -1

The main results are:

i) The target fragmentation is dominated by resonance and particle formation for M_x < 1.1 GeV/c^2. States with Λ^o and π^o, $\eta(550)$, $\rho(770)$, $\omega(785)$, $\eta'(960)$, $\phi(1020)$, $f(1270)$ and $A_2(1310)$ make up $60\pm10\%$ of the cross section.

ii) In the beam fragmentation region Λ^o and π^o, $\eta(550)$, $\rho(770)$ and $\omega(785)$ contribute $30\pm5\%$ to the cross section for M_x < 1.1 GeV/c^2.

iii) In a Regge particle exchange model a K^+ (K^+ (890)) trajectory can be exchanged in the t-channel and an antinucleon trajectory in the u-channel. The result (i) is a confirmation of the prediction that the annihilation 'K^+' $K^- \to$ pions should proceed via intermediate resonances only.

iv) The ν_t/s and ν_u/s distributions have been fitted in order to obtain the effective trajectories in a triple Regge pole model. The resulting trajectory in the t-channel has slope and intercept between the expected K^+ and K^+(890) trajectories. The trajectory in the u-channel agrees with the nucleon trajectory.

v) The average charged and total pion multiplicities as a function of missing mass squared can be extrapolated to $s_x = (2m_p)^2$ and agree perfectly with the results from $\bar{p}p$ annihilations at rest. It lends further support to the interpretation of the exchange particle as an antinucleon trajectory.

vi) The average multiplicities for 'K^+' $K^- \to$ pions show the same s_x dependence as the '$\bar{p}$'p annihilations.

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TABLE 1: Sample of events in the fragmentation regions [a]

Final state	t > -1.0	u > -1.0
$\Lambda\pi^0$	1212	204
ΛMM	3143	979
$\Lambda\pi^+\pi^-$	2584	814
$\Lambda\pi^+\pi^-\pi^0$	6200	2978
$\Lambda\pi^+\pi^-$MM	4816	2262
$\Lambda 2\pi^+ 2\pi^-$	822	682
$\Lambda 2\pi^+ 2\pi^-\pi^0$	1385	915
$\Lambda 2\pi^+ 2\pi^-$MM	502	234
Total	20664	9068

a) Corrected for decay probabilities and ambiguous hypotheses. 4-c events are required to have P > 1%, 1-c events P > 5% in the selection. Correction factor for events with missing mass is 0.70 to account for Σ^0, $K\bar{K}$ etc.

FIGURE CAPTIONS

(1) a) Notations for the inclusive reaction $K^-p \to \Lambda^O X$

   b) Boundaries in the t-u plane and definition of the target and beam fragmentation regions.

(2) Target and beam fragmentation boundaries in the p_T-p_L plane.

(3) Mass distribution M_X in the t-channel.

(4) Mass distribution M_X in the u-channel

(5) Tripple Regge pole graph for

   a) target fragmentation

   b) beam fragmentation

(6) Trajectories

   a) $\alpha(t)$ in the t-channel

   b) $\alpha(u)$ in the u-channel

   $\alpha_M(O) = 0.06$ and $\alpha_E(O) = 0.13$ have been obtained from ref. (7).

(7) Average number of pions as a function of s_X in the t-channel.

(8) Average number of pions as a function of s_X in the u-channel.

(9) Dispersion $D = <n^2> - <n>^2$ versus $<n>$. The full lines are smooth curves through the points.
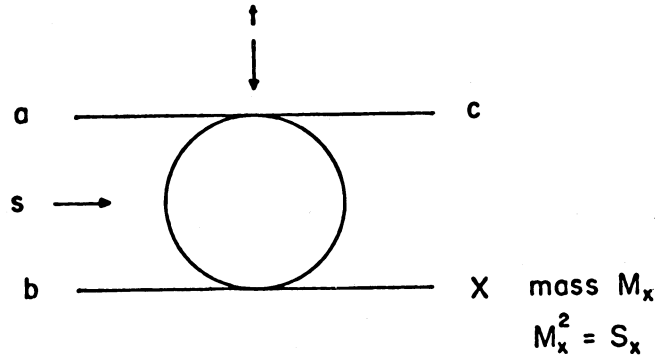
$$s = (p_a + p_b)^2$$

$$t = (p_a - p_c)^2$$

$$u = (p_b - p_c)^2$$

$$s_x = (p_a + p_b - p_c)^2$$

$$s + t + u = m_a^2 + m_b^2 + m_c^2 + s_x$$

a)

X   mass M_x

$$M_x^2 = S_x$$

4 GeV/c $K^- p \rightarrow \Lambda^0 X$
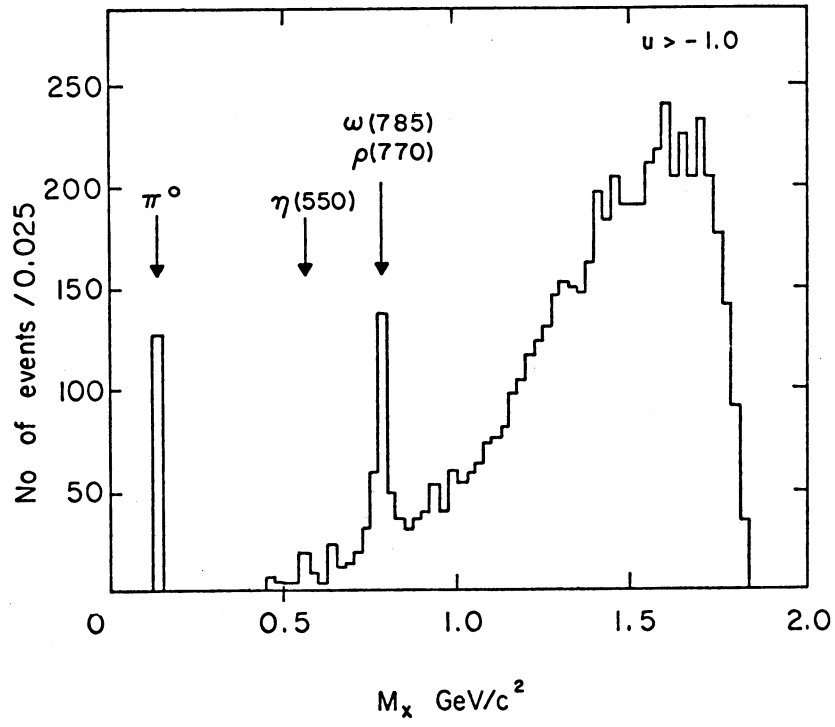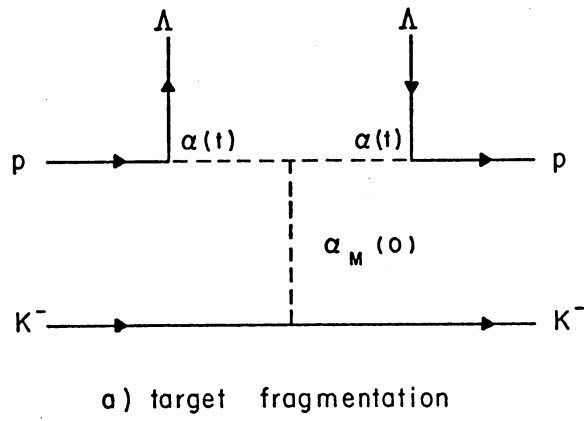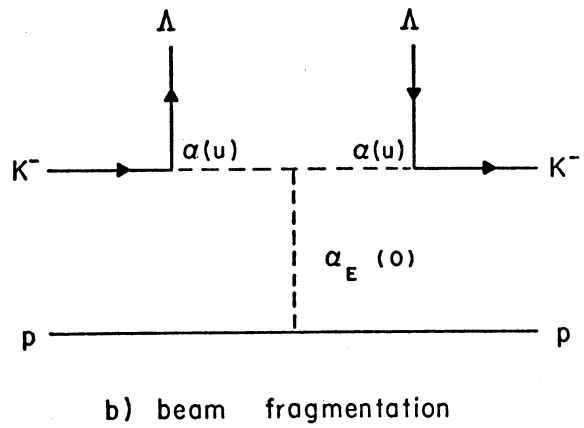
     b a   c

b)
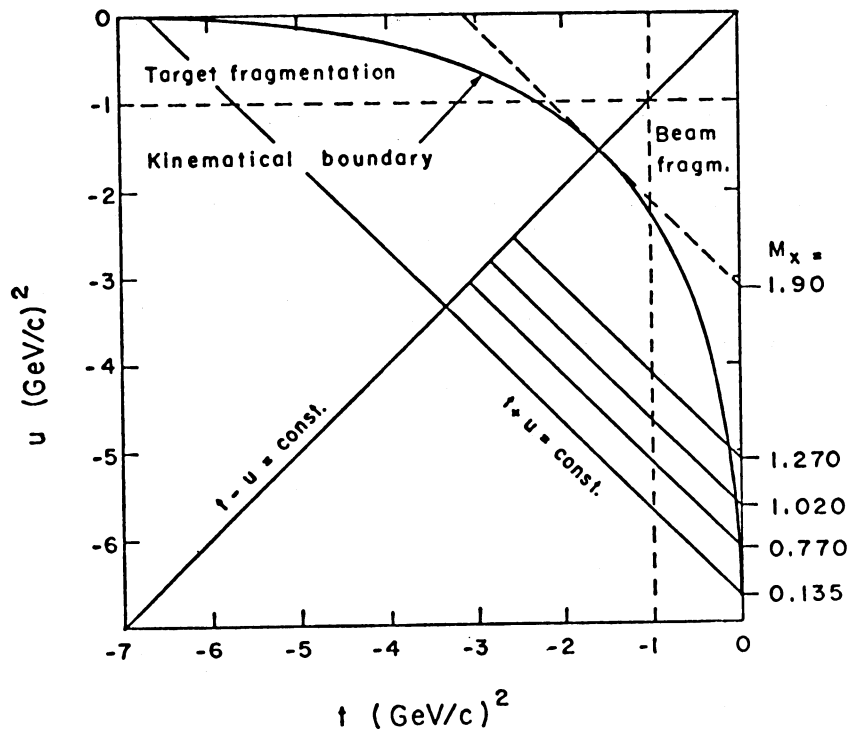
Fig. 1
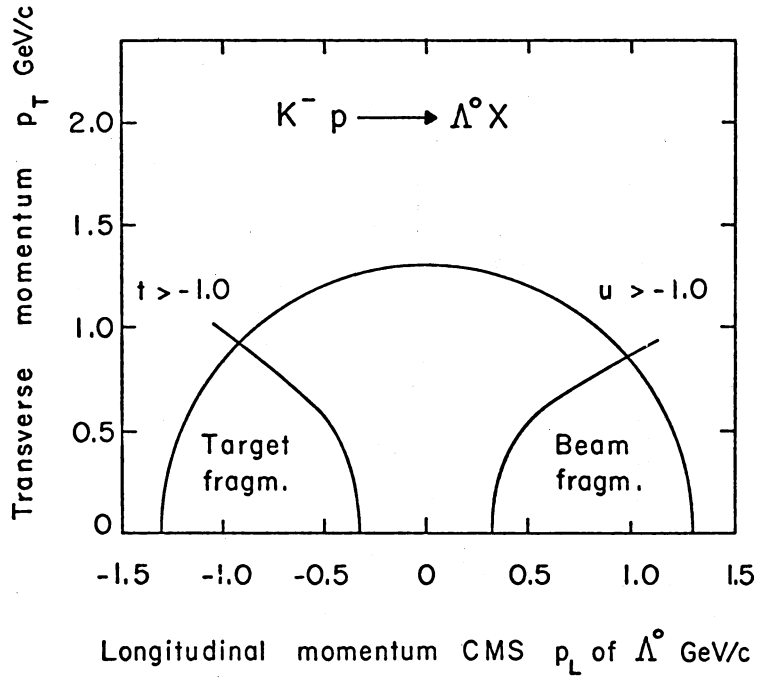
Fig. 2
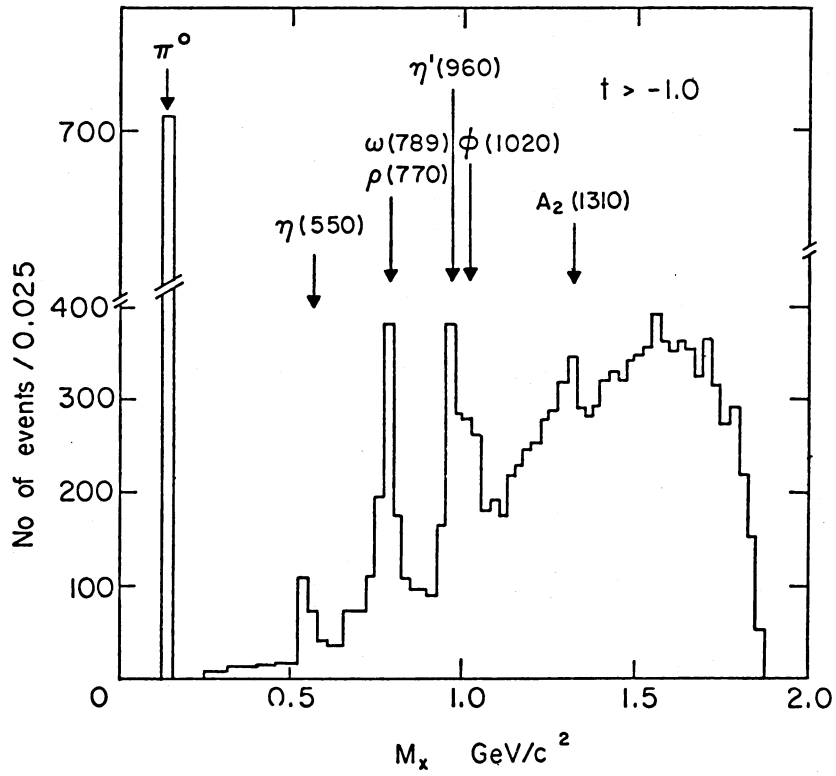
Fig. 3

Fig. 4
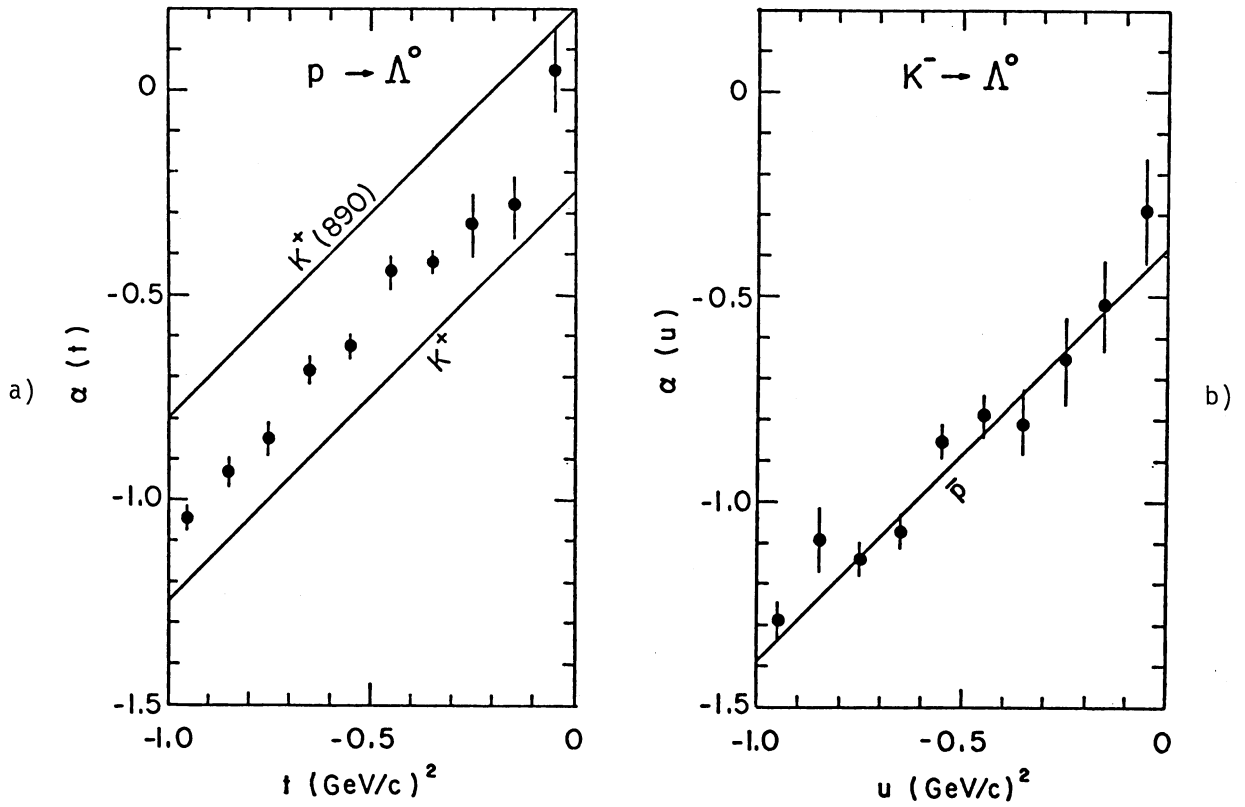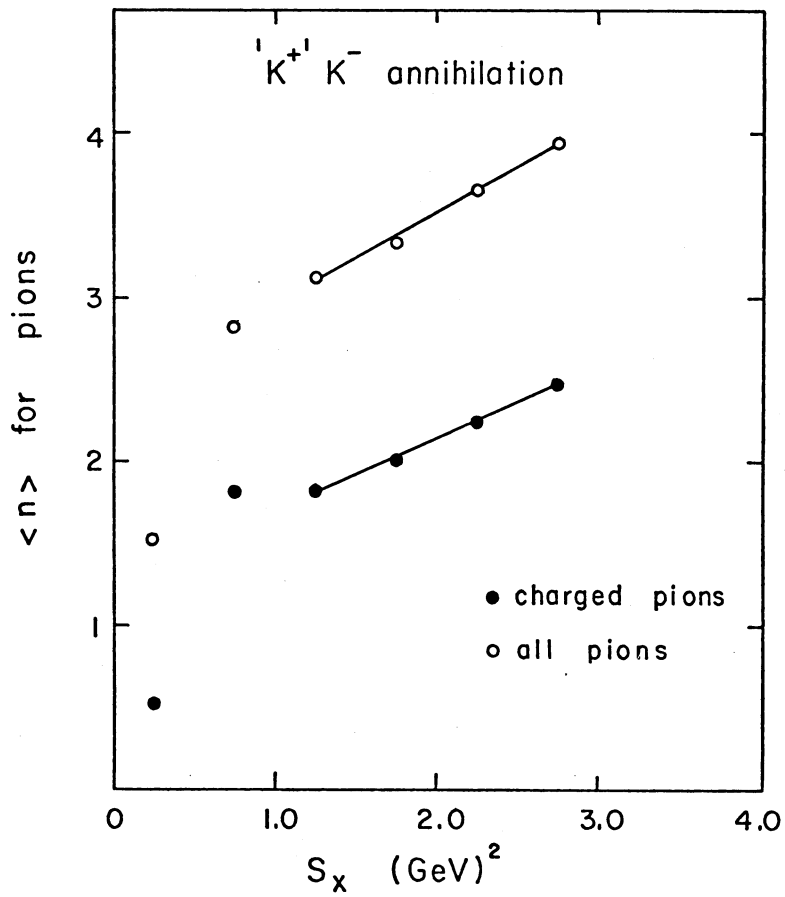

a) target fragmentation

b) beam fragmentation
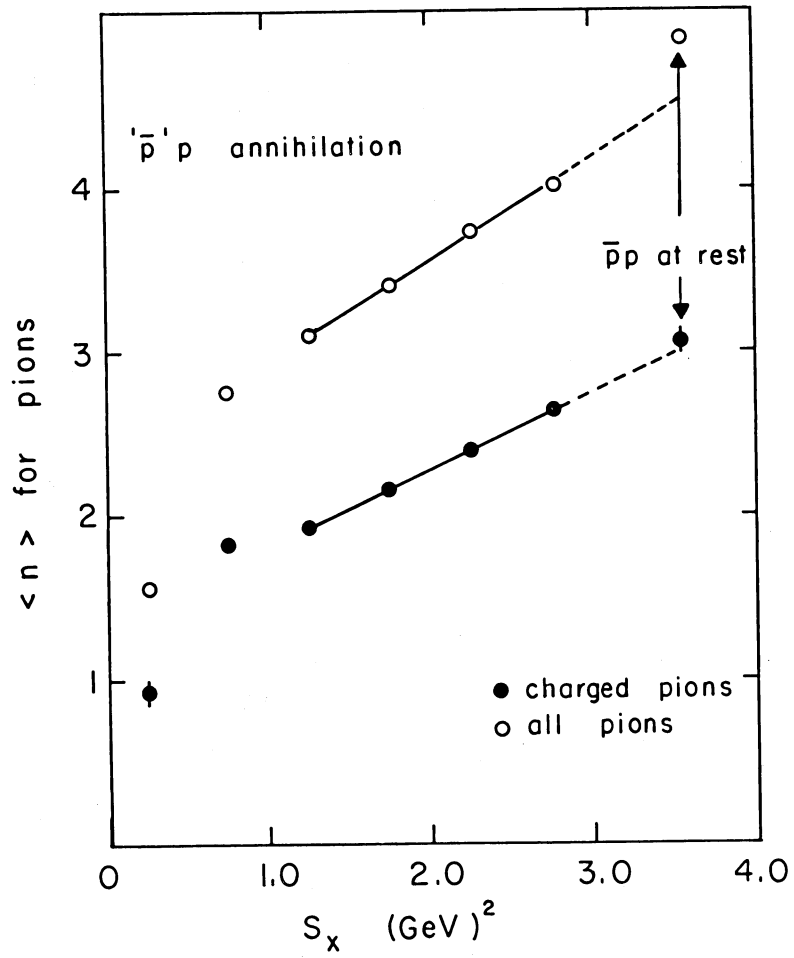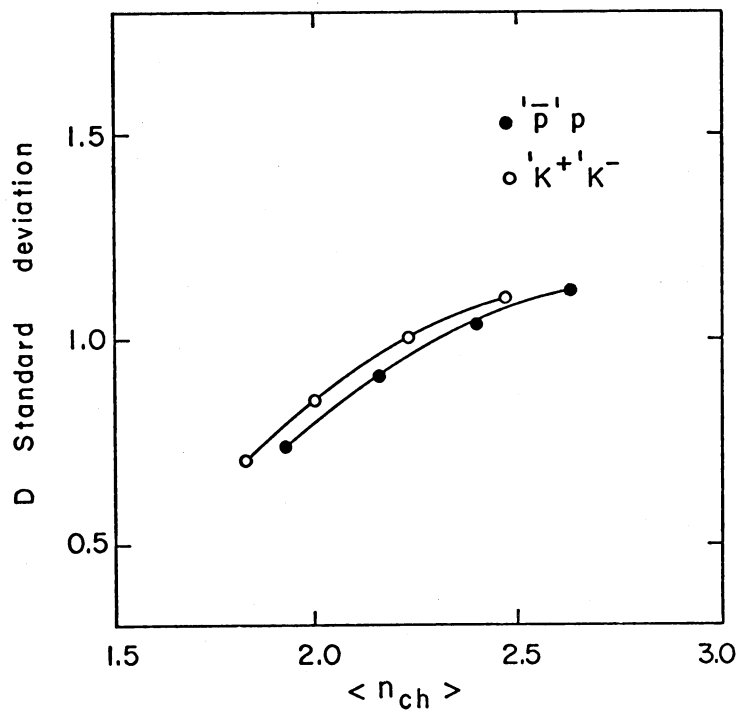
Fig. 5

Fig. 6

Fig. 7

Fig. 8

Fig. 9

DISCUSSION

- *Miettinen:*

One month ago we predicted [Takeo-Inami and H. Miettinen, Phys. Letters $\underline{B49}$, 67 (1974)] that below the $\bar{p}p$ threshold the resonances would be present. Moreover, we predicted no background under the low mass enhancements, in agreement with your experimental result. Your beautiful analysis shows a modern way of doing $\bar{p}p$ physics.