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A STUDY OF THE REACTION $\pi^- + p \rightarrow \Lambda + \bar{\Lambda} + n$ AT 7 AND 12 GeV/c *)

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ABSTRACT

Over 100 unambiguous events of the process $\pi^- + p \rightarrow \Lambda + \bar{\Lambda} + n$ have been observed in a magnet spark chamber. The data provide good evidence for peripheral production of $\Lambda\bar{\Lambda}$ and $n\bar{\Lambda}$ (via meson exchange) and against peripheral $n\Lambda$ (double baryon exchange). No resonances in the $\Lambda\bar{\Lambda}$ system are observed. Angular distributions and Λ ($\bar{\Lambda}$) polarizations are analysed.

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In this paper, we present results on the reaction $\pi^- + p \rightarrow \Lambda + \bar{\Lambda} + n$ at 7 and 12 GeV/c that have been extracted from the same set of magnet spark chamber pictures already analysed with respect to the K_1^0 K_1^0 n final state. For the experimental apparatus and the analysis procedure we refer to this previous letter$^{1)}$.

The $\Lambda\bar{\Lambda}n$ events are a small minority amongst the K_1^0 K_1^0 n final state (about 4% averaged over 7 and 12 GeV/c data) that have the same topology. Every V^0 has been tested for the decay hypotheses $K_1^0 \rightarrow \pi^+ \pi^-$, $\Lambda \rightarrow p \pi^-$, $\bar{\Lambda} \rightarrow \bar{p} \pi^+$, $\gamma + Z \rightarrow e^+ + e^- + Z$; γ conversion in the spark chamber material does not, however, produce any significant contamination. In Table 1 the sample is broken up according to possible decay hypotheses. From the number of unambiguous $(\Lambda\bar{\Lambda})$ and singly ambiguous events $[\Lambda(K + \bar{\Lambda})$ and $\bar{\Lambda}(K + \Lambda)]$ we can compute the expected number of double ambiguous events $[(\Lambda + K)\ (\bar{\Lambda} + K)]$. We observe 2 and 9 double ambiguous events in excess of the expected number at 7 and 12 GeV/c, respectively.

If these are really K_1^0 K_1^0 events, we expect to see the same number in the $(K + \Lambda)\ (K + \Lambda)$ and $(K + \bar{\Lambda})\ (K + \bar{\Lambda})$ fits combined. This is actually observed (three and eight at 7 and 12 GeV/c, respectively). The sample is therefore consistent with being pure when we exclude the double ambiguous events; furthermore, Table 1 shows that the analysis does not produce a significant number of spurious unambiguous fits. The analysis of the mass distribution of the missing neutron, of the χ^2 distribution of the decay fits, and of the Λ decay angular distribution provides further evidence for a pure $\Lambda\bar{\Lambda}$ sample.

We next turn to a contamination of $\Lambda(\bar{\Lambda})$ that are decay products of $\Sigma^0(\bar{\Sigma}^0)$. The associated γ rays are, in principle, detected in the counters surrounding the target. For the two γ rays from $\Sigma^0\bar{\Sigma}^0$ this detection efficiency is so high (> 96%) that we can neglect this type of background. For a single γ from a decaying $\Sigma^0(\bar{\Sigma}^0)$ from $\Sigma^0\bar{\Lambda}(\bar{\Sigma}^0\Lambda^0)$ (in the 12 GeV/c run) we estimate the inefficiency to be around 15%. Many of these events would also give a fit at the production vertex.

The loss of a γ tends to increase the observed missing mass of the neutron, resulting in a skew missing mass distribution. This is not observed; but within the statistical error we cannot exclude a contamination of 25% (at 12 GeV/c). On the other hand, we observe events that do not fit at production and have missing masses higher than the neutron mass. If we assume that they all are $\Sigma^0\bar{\Lambda}$ or $\Lambda\bar{\Sigma}^0$, an extrapolation of their distribution into the missing mass region where we expect them to fit indicates a contamination of 10 ± 5%. A $\Sigma^0(\bar{\Sigma}^0)$ contamination of 10 to 20% does not, however, affect any of the following conclusions.

The detection efficiency of our apparatus has been taken into account by assigning to each event a weight which is the expected number of events produced in the target for one observed event of a given configuration. It turns out that at 12 GeV/c most events have a nearly constant weight 3, except for a group of seven events whose weights cluster around 25. We have verified, with a Monte Carlo computation, that these weights are characteristic for the final-state configurations observed, and that the gap between the groups is not simulated by a vanishing detection efficiency.

We present the angular distribution of the three final particles in Fig. 1, a scatter plot of $t(p \to \bar{\Lambda})$ versus $t(p \to \Lambda)$ weighted with the detection efficiency. This plot has the following properties:

i) the detection efficiency is symmetrical with respect to the 45° line from the origin;

ii) for a distribution governed by phase space, the density in the plot is slowly varying;

iii) the third invariant momentum transfer $t(p \to n)$ is proportional to the distance from the base of the "triangle".

At 7 GeV/c we observe some clustering around minimal $t(p \to n)$ values superposed on a rather uniform distribution. Note that 7 GeV/c is not a high energy for this final state of three heavy particles (Q-value = 0.72 GeV).

At 12 GeV/c the situation has changed: two groups of events are observed, characterized by low $t(p \to n)$ and $t(p \to \Lambda)$ values, respectively. The distribution of $t(p \to n)$, i.e. the momentum transfer in $\Lambda\bar{\Lambda}$ production by π^- on protons, is well fitted by an exponential $e^{-b|t|}$, $b = 2.05 \pm 0.25\ (\mathrm{GeV}/c)^{-2}$ in the range $-0.2 > t > 2.0\ (\mathrm{GeV}/c)^2$. This region may be explained by a peripheral interaction with exchange of a non-strange meson; the region of low $t(p \to \Lambda)$ by exchange of a strange meson. The absence of events in the region of low $t(p \to \bar{\Lambda})$ is another piece of evidence against peripheral processes with "impossible" exchange quantum numbers, baryon number = 2 in this case.

We next turn to the possibility of observing meson resonances in the $\Lambda\bar{\Lambda}$ system. This rather uncommon decay channel for meson resonances of high mass -- indications of such objects have been seen[2,3] -- would present definite advantages:

- A two-body channel of pure $I = 0$ accessible to almost all quantum numbers J^{PG} (exception 0^{+-}).
- Possibility to measure spin-parity by observing the Λ and $\bar{\Lambda}$ polarization through their weak decays.

In Fig. 2 we have plotted the invariant mass distribution of the $\Lambda\bar{\Lambda}$ system. No structure is evident except for a general enhancement in the low mass region, a consequence of the peripheral production mechanism. Figure 2d shows the close grouping of the seven events with peripheral $n\bar{\Lambda}$ production.

In the following analysis we consider only the events with low $t(p \rightarrow n)$ at 12 GeV/c. Since $\Lambda\bar{\Lambda}$ is an isospin 0 state, it follows that $C = G$. Its charge conjugation is therefore determined by the G parity of the t-channel; namely, $C = +1$ for $G = -1$ (e.g. π exchange), and $C = -1$ for $G = +1$ (e.g. ρ exchange). If only one C-state is present, the angular distribution of Λ and $\bar{\Lambda}$, in their centre-of-mass system and with respect to the incident π^- direction, must be symmetric around 90°. This is not observed experimentally; we have to assume interference between states of different C. The following states, in spectroscopic notation, could interfere: $^1S_0$ with $^1P_0$, and $^3S_1$ with ^3P, when we restrict the orbital angular momentum to 0 and 1. Therefore, we fit the Jackson angular distribution with $a_0 + a_1 \cos\vartheta + a_2 \cos^2\vartheta$, and the Treiman-Yang angular distribution with $b_0 + b_1 \cos\varphi + + b_2 \cos 2\varphi$, the terms with $\cos\vartheta$ and $\cos\varphi$ being due to interference. The fit to the distributions is shown in Fig. 3. If we normalize the parameters $a_0 = b_0 = 1$ we find $a_1 = 0.97 \pm 0.32$, $a_2 = 2.59 \pm 0.95$, $b_1 = 0.48 \pm 0.20$, $b_2 = 0.33 \pm 0.18$.

We have also tested for higher order terms ($\ell = 2$) and found them not to be significant.

We observe the interference terms in both $(\cos\vartheta,\varphi)$ distributions that are statistically independent, but we cannot determine with this analysis which interfering states are present. For more information we have looked for Λ and $\bar{\Lambda}$ polarization in a coordinate system where the z-axis is normal to the $(\pi^-\Lambda\bar{\Lambda})$ plane in the $\Lambda\bar{\Lambda}$ rest frame, and the y-axis in the direction of the Λ.

We found $P_z(\Lambda) = -0.10 \pm 0.32$, $P_z(\bar{\Lambda}) = -0.84 \pm 0.32$, the other components being compatible with zero. Neither a single state nor the interference mentioned above can give rise to unequal polarizations of Λ and $\bar{\Lambda}$. In a polarization measurement, singlet and triplet interference may however be observed*). Since singlets and triplets have different CP eigenvalues, antiparallel polarization of Λ and $\bar{\Lambda}$ may result. This contribution to the total polarization may explain the observed inequality $P_z(\Lambda) \neq P_z(\bar{\Lambda})$. Assuming this inequality to be real and considering also the asymmetric angular distributions, we conclude that at least two singlet and one triplet (or one singlet and two triplet) states are populated by the production mechanism. This is a further argument against the assumption that $\Lambda\bar{\Lambda}$ production proceeds mainly via resonant states.

The cross-sections corrected for decay, absorption, exclusion of ambiguous events, etc., and for neutral decays of the Λ and $\bar{\Lambda}$, are given in Table 2. These cross-sections are more than 100 times lower than in the reaction $\pi^- p \to p\bar{p}n$ at 8 GeV/c 4), $\sigma = 97 \pm 26$ μb; they are still lower than $\sigma(K^+p \to \bar{\Lambda}pp + \bar{\Sigma}^0pp) = 11.4 \pm 2.3$ μb at 9 GeV/c 5), but comparable to $\sigma(K^-p \to \Lambda\Lambda\bar{\Lambda}) \sim 1$ μb at 10 GeV/c 6).

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Table 1

Decay fit combinations

Decay hypotheses	π^- momentum	
	7	12 GeV/c
$\Lambda\bar{\Lambda}$	16	50
$\Lambda(K + \bar{\Lambda})$	1	14
$\bar{\Lambda}(K + \Lambda)$	7	15
$(K + \Lambda)$ $(K + \bar{\Lambda})$ estimated*)	1	4
$(K + \Lambda)$ $(K + \bar{\Lambda})$ observed	3	13
$(K + \Lambda)$ $(K + \Lambda)$ and $(K + \bar{\Lambda})$ $(K + \bar{\Lambda})$ **)	3	8
$\Lambda\Lambda$ **)	0	1
$\bar{\Lambda}\bar{\Lambda}$ **)	0	0

*) Numbers estimated from the preceding three lines.

**) These events are not $\Lambda\bar{\Lambda}$; no Λ - $\bar{\Lambda}$ ambiguities occur.

Table 2

Cross-sections for $\pi^- + p \rightarrow \Lambda + \bar{\Lambda} + n$
corrected for neutral decays

Beam momentum	5	7	12 GeV/c
Events observed	1	24	79
Corrected for detection efficiency	25	195	469
Cross-section	~ 0.08	0.27 ± 0.07	0.32 ± 0.05 μb
Low $t(p \rightarrow \Lambda)$ events alone			0.06 ± 0.02 μb

Figure captions

Fig. 1 : Momentum transfer plots. The third invariant momentum transfer, $t(p \rightarrow n)$, is proportional to the distance from the base of the "triangle": a) 7 GeV/c, 24 events; b) 12 GeV/c, 79 events, density corrected for detection efficiency.

Fig. 2 : Invariant mass distributions (unweighted):

a) $\Lambda\bar{\Lambda}$ mass 7 GeV/c

b) $\Lambda\bar{\Lambda}$ mass 12 GeV/c with a cut on the momentum transfer $t(p \rightarrow n) > -2.5\ (\mathrm{GeV}/c)^2$

c) $\Lambda\bar{\Lambda}$ mass a) and b) combined

d) $n\bar{\Lambda}$ mass for $t(p \rightarrow \Lambda) > -1(\mathrm{GeV}/c)^2$

Fig. 3 : Angular distributions of $\Lambda\bar{\Lambda}$ in their centre-of-mass system for 12 GeV/c events selected for $t(p \rightarrow n) > -2.5(\mathrm{GeV}/c)^2$:

a) Jackson angular distribution

b) Treiman-Yang angular distribution. See text for the fit.

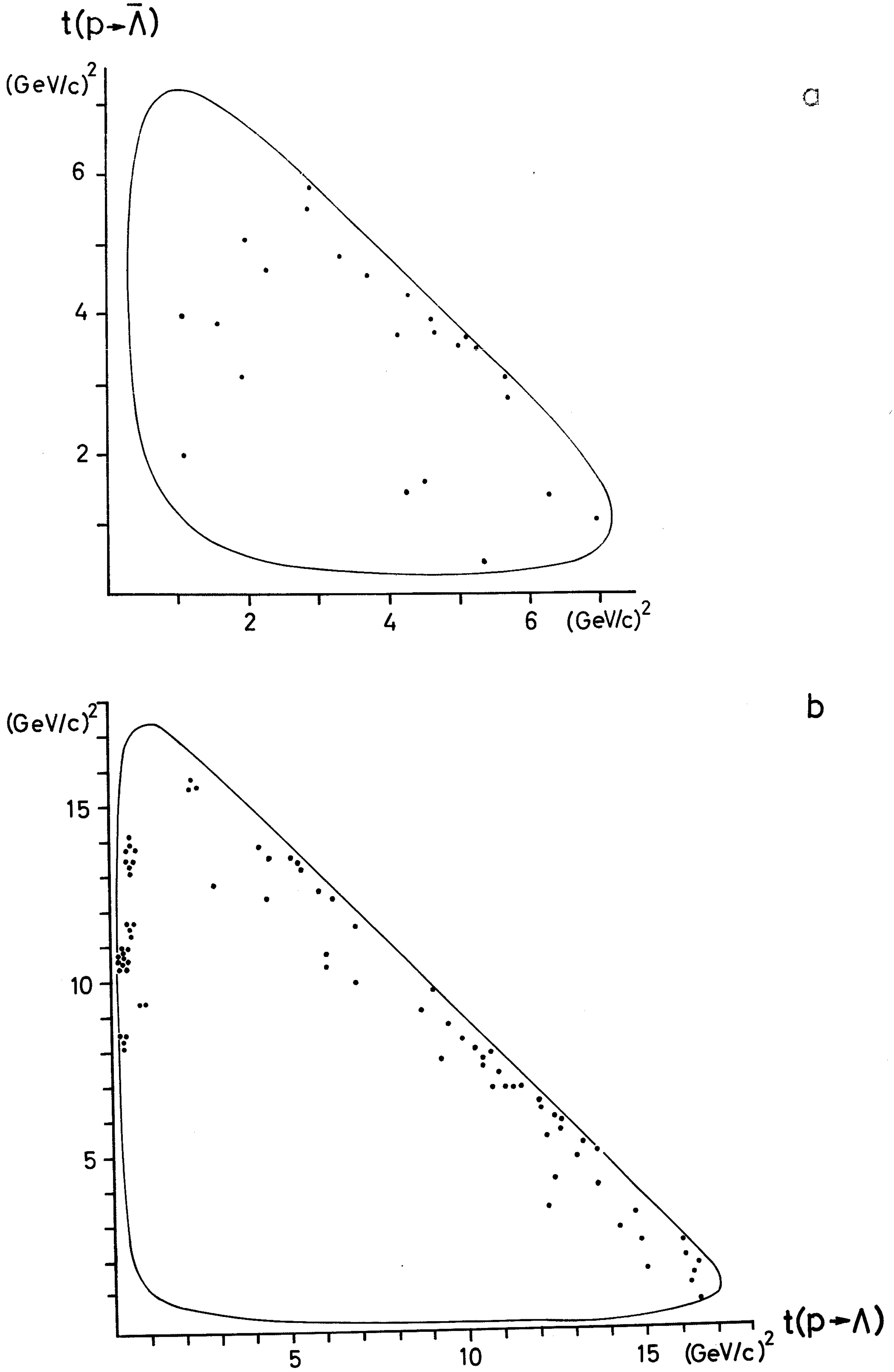

Fig.1

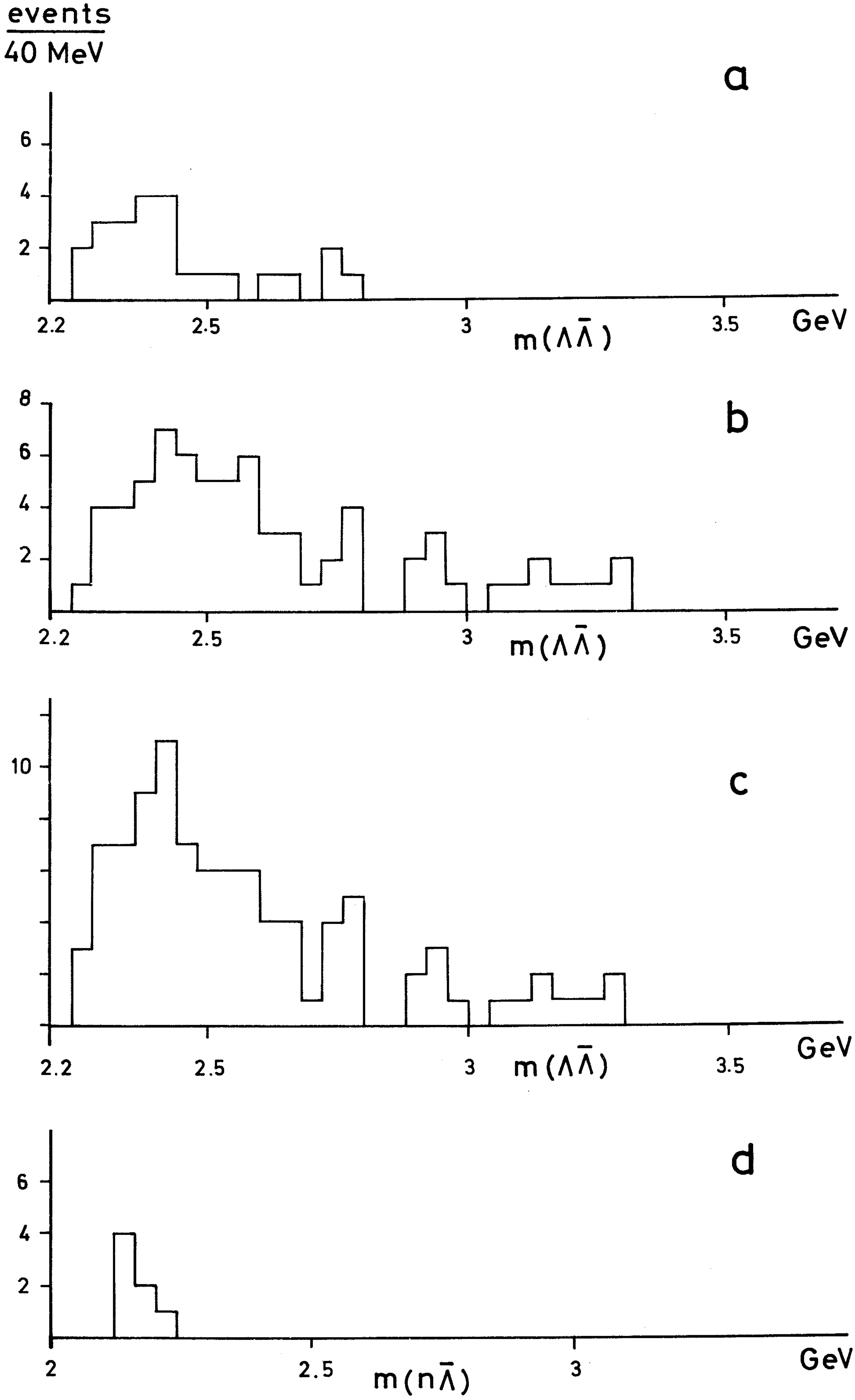
events
40 MeV
a
6
4
2
2.2
2.5
3
3.5
GeV
m(ΛΛ̄)
8
6
4
2
b
2.2
2.5
3
3.5
GeV
m(ΛΛ̄)
10
c
2.2
2.5
3
3.5
GeV
m(ΛΛ̄)
6
4
2
d
2
2.5
3
GeV
m(nΛ̄)

Fig. 2

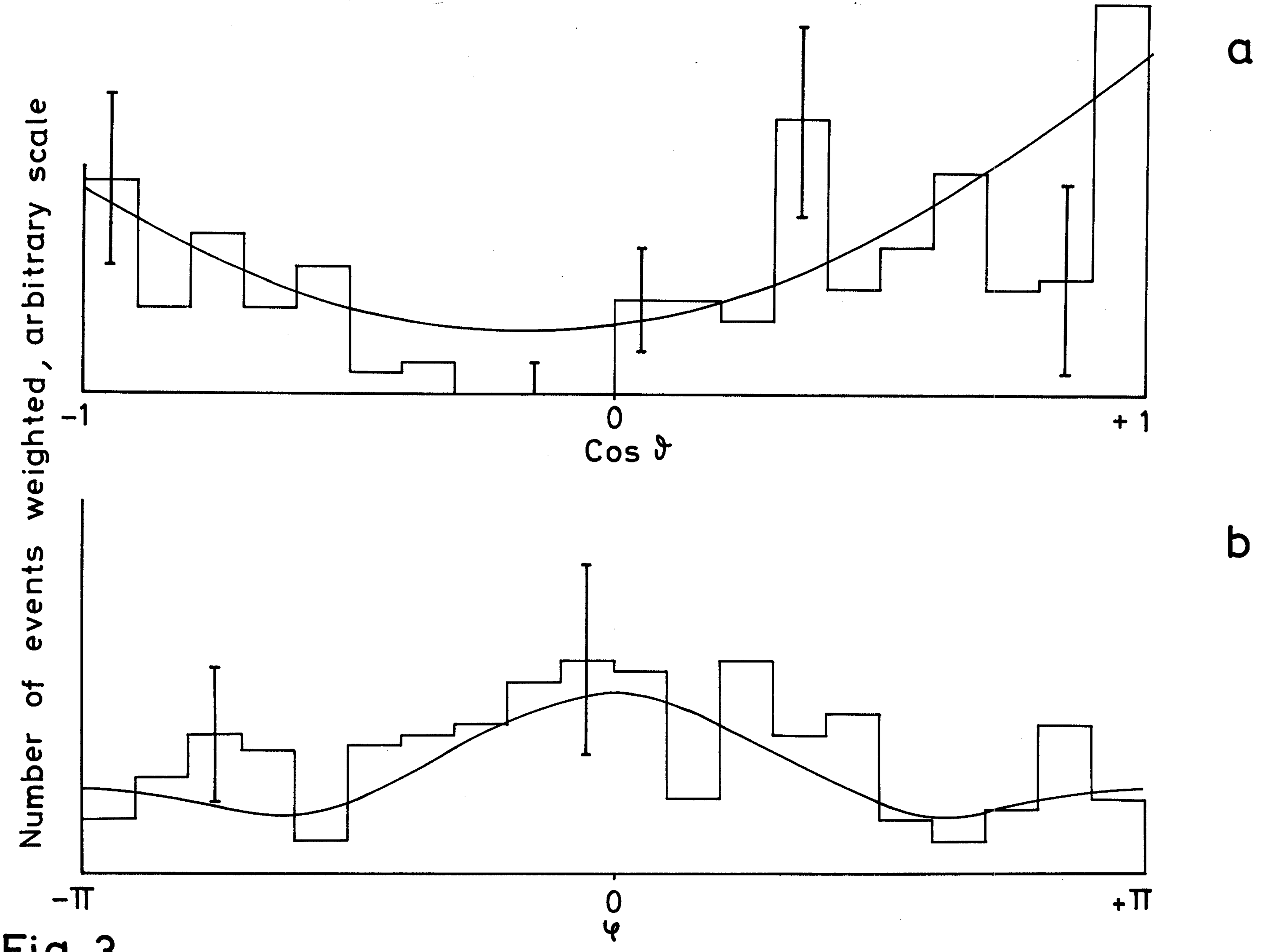

Fig.3