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OBSERVATION OF Ξ^- PRODUCTION IN $p\bar{p}$ INTERACTIONS AT 540 GeV cms ENERGY

UA5 Collaboration

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Abstract

We have made the first observations of Ξ^- production in $p\bar{p}$ interactions at $\sqrt{s} = 540$ GeV. In a sample of 6964 non single - diffractive events we observe 17 Ξ^- decays with an estimated background of less than one event. This corresponds to 0.04 ± 0.01 Ξ^- per event in the transverse momentum range $p_t > 1.0$ GeV/c and in the pseudorapidity range $|\eta| < 3.5$. Assuming an exponential p_t distribution, we find $\langle p_t \rangle = 1.1^{+0.3}_{-0.2}$ GeV/c.

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1) Introduction

Measurements of doubly strange baryons and antibaryons are a useful factor in understanding the production of strange quarks in high energy hadronic processes, but very few data on the production of these particles exist. The production of Ξ^- and $\overline{\Xi^-}$ in the proton fragmentation region in p-nucleus collisions at a c.m. energy $\sqrt{s} = 21.2$ GeV has been measured [1], as well as the $\overline{\Xi^-}/\overline{\Lambda}$ ratio in the central region of pp collisions at $\sqrt{s} = 63$ GeV at the ISR [2]. Recently, the production of Ξ^- and $\overline{\Xi^-}$ in e^+e^- annihilations at $\sqrt{s} \sim 34$ GeV has been observed by the TASSO Collaboration [3]. In this paper we report the first measurement of strangeness 2 baryons at $\sqrt{s} = 540$ GeV, based on the observation of Ξ^- production in the UA5 streamer chamber detector at the CERN $p\bar{p}$ Collider.(*)

2) Data Analysis

The UA5 detector consists of two 6m x 1.25m x 0.5m streamer chambers, placed above and below the SPS beam pipe. Each chamber is viewed by 3 cameras, each camera recording a stereoscopic pair of views of the chamber. Large scintillation counter hodoscopes are used for triggering. Details of the apparatus can be found in ref [4], and of the normal data analysis procedures in ref [5].

We have already reported on neutral strange particle production, K^o_s and Λ, from the observation of V^o decays within the

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(*) Because there is no magnetic field in the UA5 streamer chambers, we are unable to distinguish between Ξ^- and $\overline{\Xi}^-$. The term Ξ^- indicates the sum of Ξ^- and $\overline{\Xi^-}$ cross-sections. Likewise Λ indicates the sum of Λ, $\overline{\Lambda}$, Σ^o and $\overline{\Sigma^o}$.

streamer chambers [6]. The cascade decay,

$$\begin{array}{l} \Xi^- \rightarrow \Lambda\pi^- \\ \qquad \lfloor\!\!\rightarrow p\pi^- \end{array} \qquad (1)$$

has a very clear signature in the streamer chamber: a V^o is seen to point back to a charged decay vertex ("kink") rather than to the primary event vertex. An example of such a cascade decay is shown in fig 1. We have scanned 6964 minimum bias events for cascade decays, and observe 17 candidates. For each event, measurements of the angles of all the tracks involved enable a kinematic fit with 3 degrees of freedom to be made to hypothesis (1). All 17 candidates give a good fit to the Ξ^- decay hypothesis. One of the events gives a better fit to the $\Omega^- \rightarrow \Lambda K^-$ decay hypothesis than to the Ξ^- hypothesis. However, the number of lifetimes survived as an Ω^- is 5.9, whereas the Ξ^- fit implies only 2.5 lifetimes. Thus, in the following we take all events to be Ξ^-.

To remove regions where the scanning efficiency is likely to be very low, we apply the following cuts to the data: the kink vertex must be at least 3cm in perpendicular distance from the chamber base; the kink angle and V^o opening angle must both be greater than 3°; the neutral particle path must be longer than 3cm. As in our recent K^o_s and Λ analysis [7], we also restrict ourselves to the pseudorapidity range $|\eta|<3.5$ ($\eta = -\ell n \tan \theta/2$). Of the 17 events 16 satisfy these cuts, and from independent scans we estimate our scanning efficiency for these events to be ~ 95%.

The acceptance of the streamer chambers for Ξ^- decays is low, because the fiducial region starts 8cm away from the beam axis whereas Ξ^- has a lifetime $c\tau$ = 4.92cm. The acceptance is thus strongly dependent on

p_t of the Ξ^-. We have estimated the acceptance using a Monte-Carlo program, in which Ξ^- are generated with a flat or gaussian rapidity distribution and with an exponential p_t distribution with a slope given below. The same cuts are applied to the Ξ^- decay products as to the data. The efficiency for detecting Ξ^- decays is effectively zero for $p_t \lesssim 0.5$ GeV/c, and rises to ~ 12% at $p_t \sim 2$ GeV/c, as shown in fig 2(a).

We have estimated backgrounds to the Ξ^- sample from the following sources:

i) K_s^o or Λ from $\pi^\pm$, $K^\pm$ one-prong interactions in the streamer chamber gas. The expected number of these is $\lesssim 1.4$ events.

ii) Photons from $K^\pm \rightarrow \pi^\pm\pi^o$ and $\Sigma^+ \rightarrow p\pi^o$ decays, which then convert in the streamer chamber gas; we estimate $\lesssim 0.1$ events from this source.

iii) Random association of a V^o from the primary vertex to a kink vertex. For the Ξ^- candidates the Ξ^- track and the V^o lie extremely close in both rapidity and azimuth (ϕ): in fact all the observed events have $|\Delta\eta| < 0.1$ and $|\Delta\phi| < 3°$. A study of events scanned for all V^o's and charged kinks leads to an estimate of 0.05 events from random associations.

iv) Photon conversions from $\pi^\pm$ one-prong interactions in the streamer-chamber gas: ~ 0.03 events.

The total background from all these sources is estimated to be $\lesssim 1.5$ events; it is unlikely that these backgrounds would all give a good kinematic fit to the Ξ^- decay hypothesis, so this estimate is an upper limit. In 10,000 events generated with the UA5 Monte-Carlo including all particle ratios and correlations as determined by this experiment [8,9], no background event of types i)-iv) above was found which gave a kinematic fit to the cascade decay hypothesis. We conclude that the background in our data sample is at most one event.

Figure 2(b) shows the distribution in the z coordinate of observed kink vertices (z is perpendicular to the beam axis and the base of the chamber). The events are seen to be clustered near the base of the chamber, as expected for short-lived particles. The curve is the distribution expected from a Monte-Carlo calculation with $\langle p_t \rangle$ = 1.1 GeV/c (see below). In Fig 2(c)-(d) we show the cms decay angular distributions for the $\Xi^- \rightarrow \Lambda$ decay and $\Lambda \rightarrow p$ decay respectively, and in fig 3(a)-(b) the distributions of proper lifetimes for the Ξ^- and Λ, measured from the production point of each hyperon to its decay point. The curves are again the distributions expected from the Monte-Carlo, and are seen to be consistent with the data. As a further check, we show in fig 3(c) the distribution of proper time measured between entering the fiducial volume and the decay point for Ξ^-'s. It shows the expected exponential behaviour, and yields an average lifetime for the Ξ^- of $(1.7 \pm 0.4) \times 10^{-10}$s, in good agreement with the accepted value [10] of 1.64×10^{-10}s.

3. Results

In figs 4(a) and (b) we show the rapidity and pseudorapidity distributions respectively of the observed Ξ^-'s and in fig 4(c) the p_t distribution. The curves are again the distributions expected from the Monte-Carlo with $\langle p_t \rangle = 1.1$ GeV/c. The observed Ξ^-'s, all of $p_t > 0.7$ GeV/c, tend to be fairly central in rapidity. The p_t distribution corrected for detection efficiency is shown in fig 4(d).

Correcting for the detection efficiency and Λ branching ratio, we find a mean number of Ξ^- per event in the range $|\eta| < 3.5$ and $p_t > 1.0$ GeV/c of 0.04 ± 0.01, where the error is statistical only. In this p_t range the detection efficiency is reasonably good, and the error is dominated by statistics. Uncertainties in the p_t and rapidity distributions assumed lead to a systematic error of about half the statistical error. Using the Λ's found on the same sample of film [7], we find a Ξ^-/Λ ratio of 0.35 ± 0.11 in the range $p_t > 1.0$ GeV/c. In calculating the ratio, Λ's from unseen Ξ^- and Ξ^0 decays have not been subtracted from the Λ cross-section. This value is considerably higher than the value of 0.06 ± 0.02 found for the $\overline{\Xi^-}/\overline{\Lambda}$ ratio at the ISR [2], in a similar p_t range ($1.2 < p_t < 2.4$ GeV/c), and also higher than the Ξ^-/Λ ratio observed in e^+e^- annihilations at $\sqrt{s} \sim 34$ GeV [3], namely $0.09 \pm 0.03 \pm 0.03$ (last error systematic).

To estimate the total number of Ξ^- per event, we need to extrapolate to the region $p_t < 1.0$ GeV/c, where our detection efficiency is low. We have therefore made a maximum likelihood fit to the p_t distribution. Assuming a form $d\sigma/dp_t^2 = A\, e^{-bp_t}$ we obtain $\langle p_t \rangle = 1.1^{+0.3}_{-0.2}$ GeV/c. For comparison, the value found for Λ production in this experiment was 0.67 ± 0.20 GeV/c [6]. It should be noted that the Ξ^- value is determined from events in the p_t range 0.7 - 3.7 GeV/c. If the p_t distribution deviates from an exponential form, as is observed for pions [11,12], the value of $\langle p_t \rangle$ for the full distribution would probably be lower.

The total number of Ξ^- per event is very sensitive to the value of $\langle p_t \rangle$, which is quite poorly determined with our statistics. Figure 5 shows how the number of Ξ^- per event varies with mean p_t. Using our maximum likelihood estimate of $\langle p_t \rangle$, the total number of Ξ^- per event is $0.08^{+0.03}_{-0.02}$ (statistical error only).

If the probability of producing a Ξ^- were proportional to the total charged multiplicity of an event, as is observed for kaon and lambda production [6], we would expect the mean observed multiplicity of the events with a Ξ^- to be $\langle n_{obs}{}^2 \rangle / \langle n_{obs} \rangle = 31.3$. This is consistent with the observed value of 34.7 ± 4.3.

4. Summary

We have observed 17 examples of $\Xi^- \rightarrow \Lambda\pi^-$ decay in 6964 $\bar{p}p$ minimum bias events at $\sqrt{s} = 540$ GeV. The mean number of Ξ^- per event is 0.04 ± 0.01 for $|\eta| < 3.5$ and $p_t > 1.0$ GeV/c, corresponding to a Ξ^-/Λ ratio of 0.35 ± 0.11 in this kinematic region. Assuming a p_t spectrum of the form e^{-bp_t}, a maximum likelihood fit gives $\langle p_t \rangle = 1.1^{+0.3}_{-0.2}$ GeV/c.

Acknowledgements

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Figure Captions

Fig.1 An example of the cascade decay $\Xi^- \to \Lambda\pi^-$ as observed in the UA5 streamer chamber.

$$\Xi^- \to \Lambda\pi^-, \quad \Lambda \hookrightarrow p\pi^-$$

Fig.2 (a) Detection efficiency for Ξ^- decays as a function of p_t. Note that this efficiency has to be further corrected for the Λ branching ratio.

(b) Distribution of the z coordinate of the observed Ξ^- decay vertices. The fiducial volume of the chamber extends from $|z| = 8$cm to $|z| = 55$cm.

(c) $\mathrm{Cos}\theta^*$ distribution for $\Xi^- \to \Lambda$ decays.

(d) $\mathrm{Cos}\theta^*$ distribution for $\Lambda \to p$ decays.

In (b)-(d) the curves are the result of a Monte-Carlo simulation assuming the Ξ^-'s have $\langle p_t \rangle = 1.1$ GeV/c.

Fig.3 (a) Distribution of proper time from the production point to decay point for Ξ^-.

(b) Distribution of proper time from the production point to decay point for Λ from Ξ^- decays.

(c) Distribution of proper time between entering the fiducial volume and the decay point for Ξ^-.

In (a) and (b) the curves are the results of a Monte-Carlo simulation assuming the Ξ^-'s have $\langle p_t \rangle = 1.1$ GeV/c.

Fig.4 (a) Rapidity distribution of observed Ξ^-.

(b) Pseudorapidity distribution of observed Ξ^-.

(c) P_t distribution of observed Ξ^-.

(d) p_t distribution for Ξ^- corrected for detection efficiency.

The curves in (a)-(c) are again the results of the Monte-Carlo simulation.

Fig.5 The dashed line shows the mean number of Ξ^- per event as a function of $\langle p_t \rangle$ assumed for the Ξ^-. Our best estimate is shown by the cross, with contours drawn at the 1σ and 2σ confidence levels.

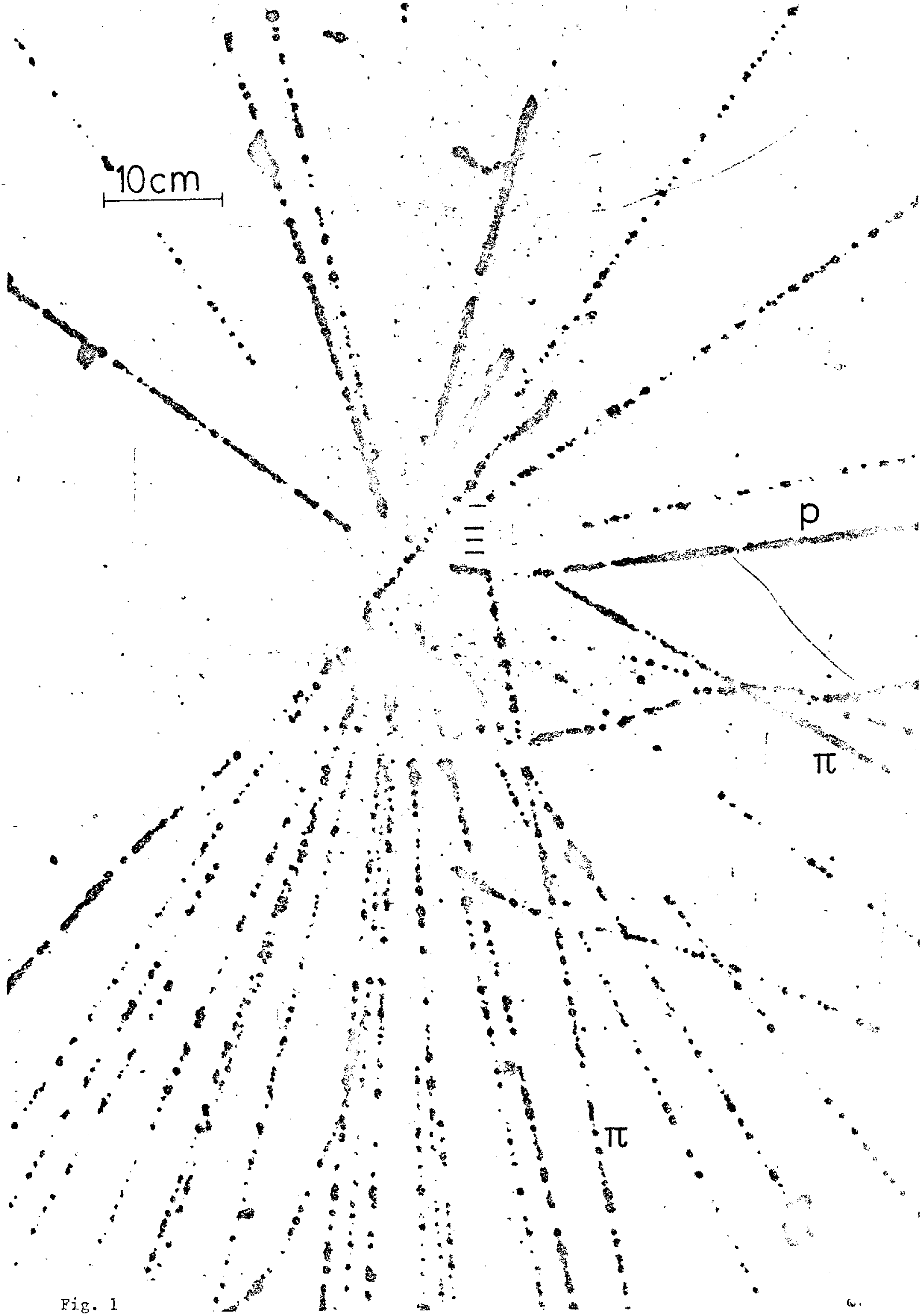


Fig. 1

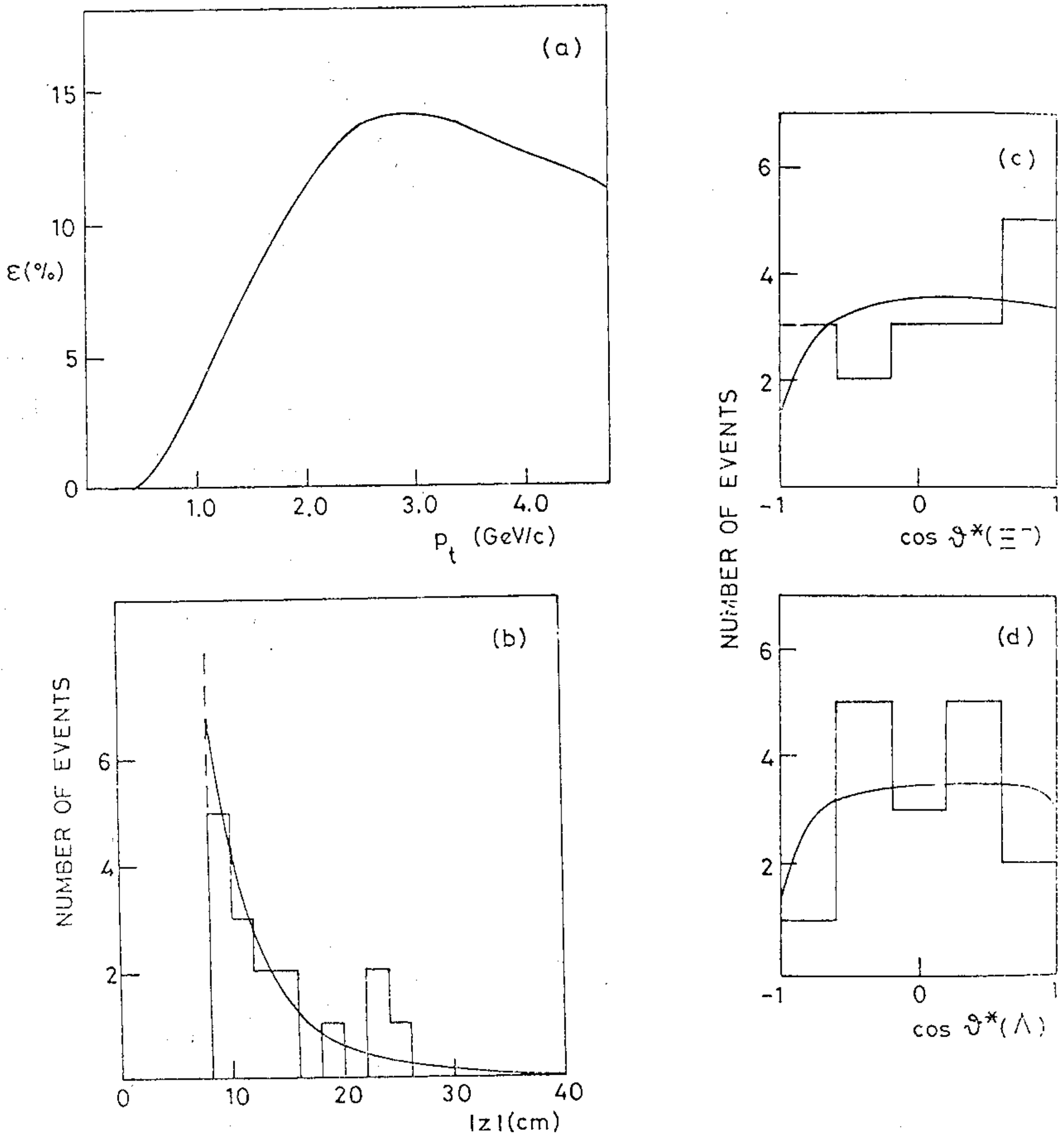

(a)
15
10
ε(%)
5
0
1.0
2.0
3.0
4.0
p_t (GeV/c)
(b)
NUMBER OF EVENTS
6
4
2
0
10
20
30
40
|z|(cm)
(c)
NUMBER OF EVENTS
6
4
2
-1
0
1
cos ϑ*(Ξ⁻)
(d)
6
4
2
-1
0
1
cos ϑ*(Λ)

FIG.2

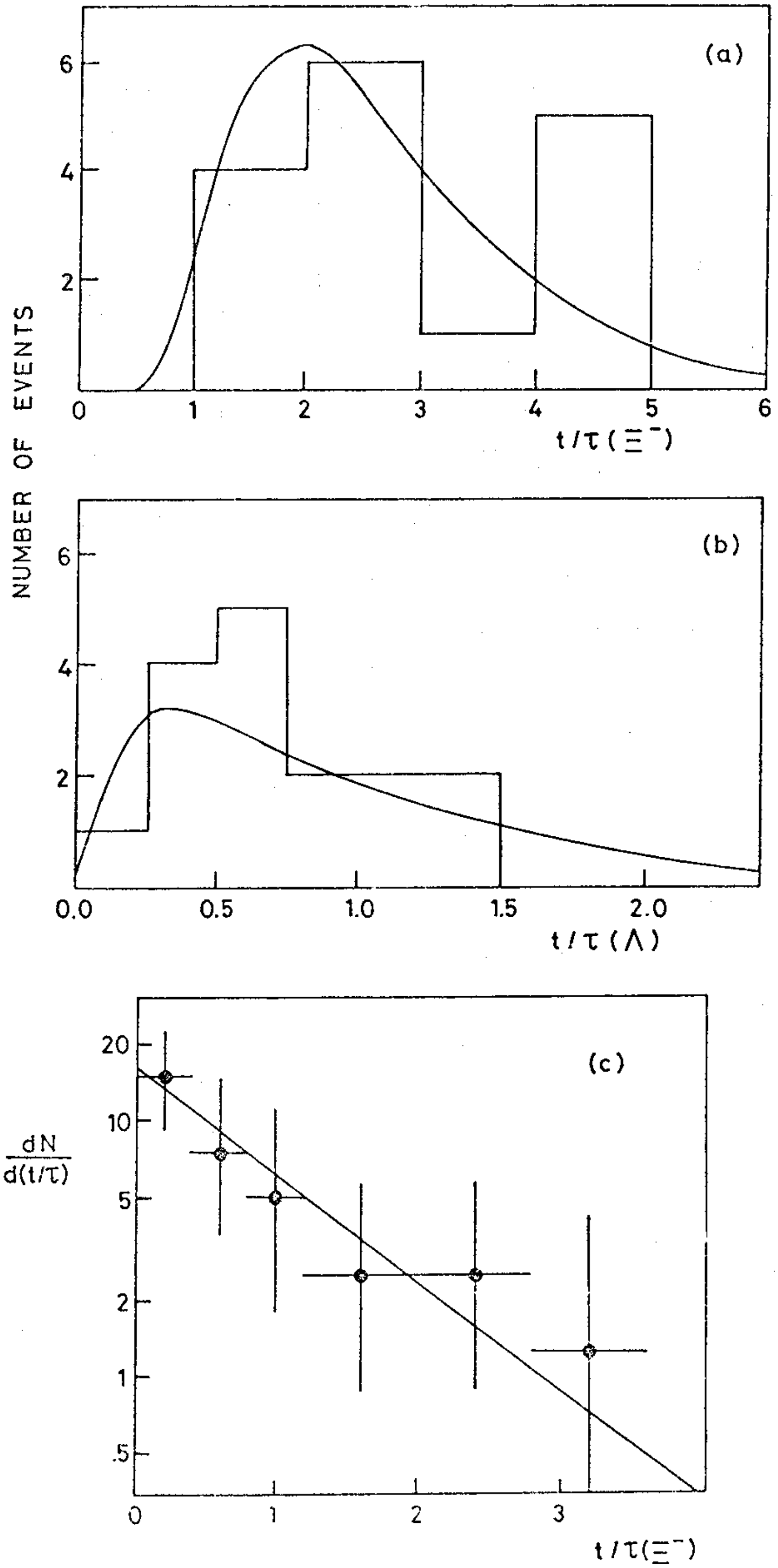
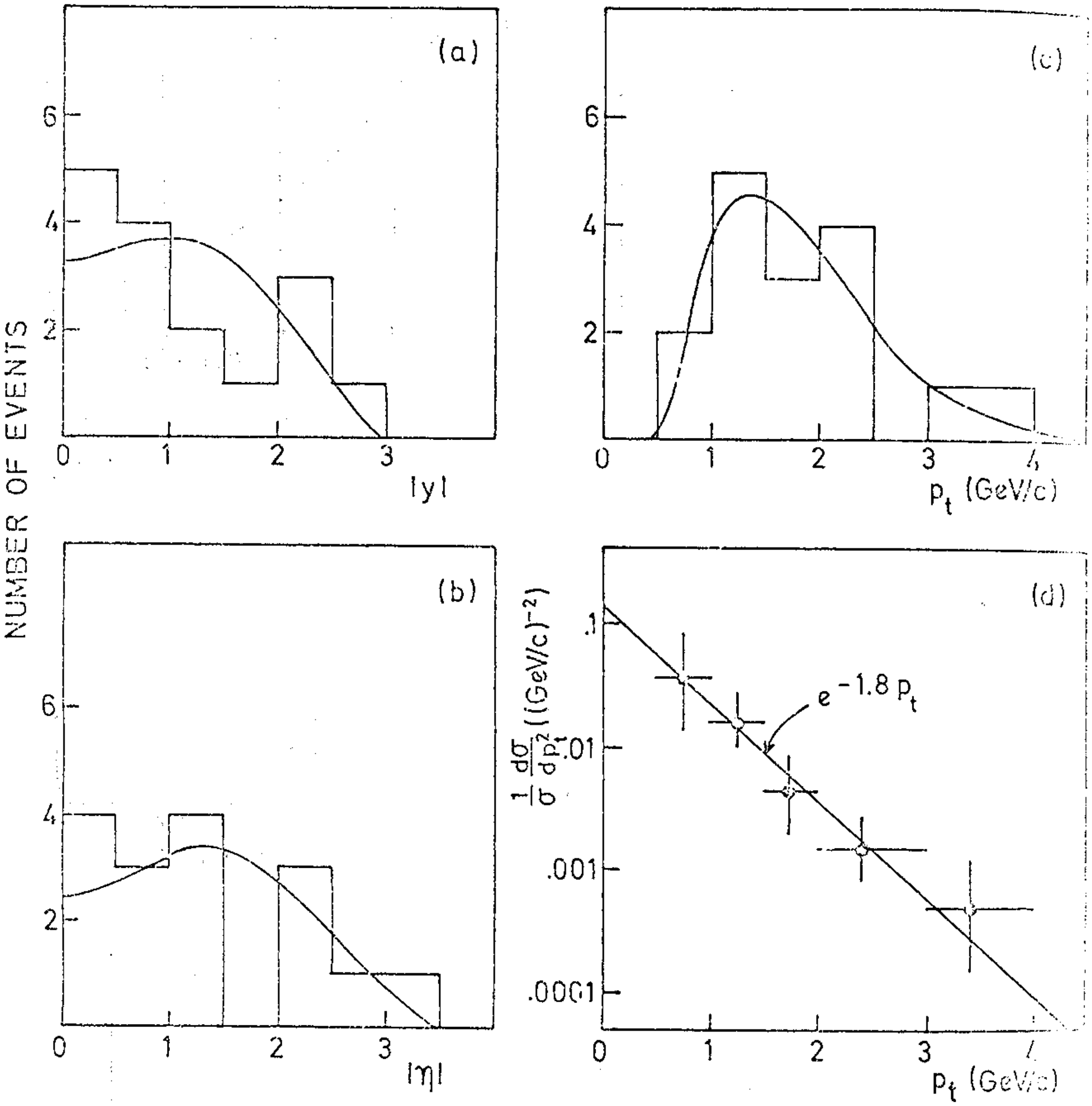

(a)
NUMBER OF EVENTS
0
1
2
3
4
5
6
2
4
6
t / τ (Ξ⁻)
(b)
0.0
0.5
1.0
1.5
2.0
2
4
6
t / τ (Λ)
(c)
dN / d(t/τ)
20
10
5
2
1
.5
0
1
2
3
t / τ(Ξ⁻)

FIG. 3



NUMBER OF EVENTS
(a)
6
4
2
0
1
2
3
|y|
(b)
6
4
2
0
1
2
3
|η|
(c)
6
4
2
0
1
2
3
4
p_t (GeV/c)
(d)
$\frac{1}{\sigma}\frac{d\sigma}{dp_t^2}$ ((GeV/c)$^{-2}$)
.1
.01
.001
.0001
$e^{-1.8\,p_t}$
0
1
2
3
4
p_t (GeV/c)

FIG. 4

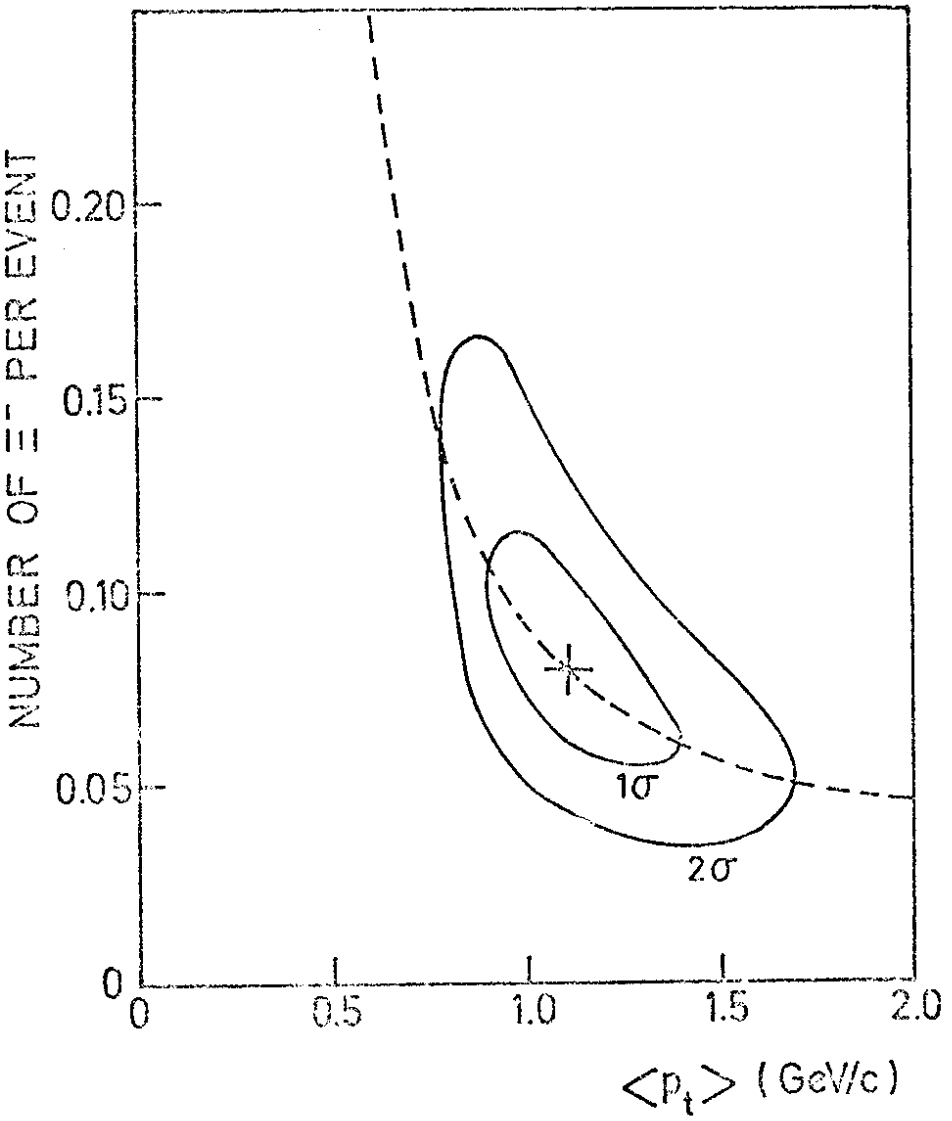

NUMBER OF Ξ⁻ PER EVENT
0.20
0.15
0.10
0.05
0
1σ
2σ
0
0.5
1.0
1.5
2.0
$\langle p_t \rangle$ (GeV/c)

FIG.5