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Observation of Ξ^- Production in e^+e^- Annihilation at 29 GeV*

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ABSTRACT

Inclusive Ξ^- production in e^+e^- annihilation at 29 GeV has been measured with the Mark II detector. From an integrated luminosity of 207 pb^{-1}, we determine a production rate of $0.017 \pm 0.004 \pm 0.004$ $\Xi^- + \overline{\Xi^-}$ per hadronic event. A search for Ξ^{*0} (1530) $\rightarrow$ Ξ^- π^+ leads to an upper limit of $N(\Xi^{*0})/N(\Xi^-) < 0.35$ at a 90% confidence level.

Measurement of inclusive baryon production can provide important information as to the nature of the parton fragmentation process. In particular, comparison of production rates of baryons of different strangeness number can reveal details of the baryon production mechanism.[1-4] We present here a measurement of Ξ^- and $\overline{\Xi^-}$ production in e^+e^-collisions at a center of mass energy E_{cm} of 29 GeV. In the following, we refer to both Ξ^- and $\overline{\Xi^-}$ as Ξ^- unless stated otherwise.

The measurement is based on an integrated luminosity of 207 ± 8 pb^{-1} accumulated over a period of three years by the Mark II detector at the PEP storage ring. The detector is described elsewhere.[5] Charged particles are tracked in a 16 layer cylindrical drift chamber and a 7 layer precision drift chamber in a 2.3 kG magnetic field. Tracks are found and reconstructed independently of their distance of closest approach to the beam. Momenta p (GeV/c) are measured with a resolution of $\delta p/p = [(0.010p)^2 + (0.025)^2]^{1/2}$. The drift chamber is surrounded by 48 plastic scintillators instrumented with phototubes which provide time-of-flight information for charged particles over 75% of 4π sr.

Hadronic events are selected by a loose set of cuts. Only events with at least 4 reconstructed charged particles with a total measured energy of at least 8 GeV are used in the analysis. The sample contains some contamination from $\tau^+\tau^-$ pair production, two-photon processes, and beam-gas interactions. However, Ξ^- production from these sources is expected to be negligible.

Tracks used in the Ξ^- search are required to meet the following quality and acceptance defining criteria: a momentum transverse to the beam of at least 70 MeV/c, a polar angle θ with $|\cos\theta| < 0.80$, at least 9 hits in the tracking chambers, and a track fit χ^2 per degree of freedom less than 12.

Oppositely charged track pairs which are consistent with γ conversions to e^+e^- pairs are removed.[6]

Ξ^- candidates are found by searching for the decay chain $\Xi^- \rightarrow \Lambda\pi^-$, $\Lambda \rightarrow p\,\pi^-$. Λ candidates are selected by finding vertices for all oppositely charged track pairs in the plane perpendicular to the beam (the x-y plane). The higher momentum particle in each pair is assumed to be the proton. This assignment is always correct for Λ with momenta over 250 MeV/c. Pairs which meet the following requirements are considered to be Λ candidates:

1. The distance from the reconstructed vertex to the center of the interaction region in the x-y plane must be greater than 15 mm. This would be a tight cut in a search for directly produced Λ; it is much looser in a search for Λ from Ξ^- decay.

2. The π must have a distance of closest approach to the center of the interaction region of greater than 2 mm. This requirement reduces combinatorial backgrounds.

3. At the x-y vertex, the two tracks must have a z difference of less than 6 cm.

4. The angle between the Λ momentum vector and the line between the reconstructed Λ decay point and the interaction region in the x-y plane must be less than 6^0. For secondary Λ from Ξ^- decays, this angle is a few degrees, because the primary decay effectively puts a kink in the track.

5. Λ candidates with momenta less than 400 MeV/c are eliminated. Kinematics requires that all Λ from Ξ^- decays above 750 MeV/c (as required below) must have momenta above 400 MeV/c.

6. If good quality time-of-flight information is available for the proton track, the measured flight time is required to be within 720 psec (roughly 2 σ) of the predicted proton flight time.

These requirements are loose, and designed to maximize the yield of detected Λ from Ξ^- decay. The proton and π momenta are adjusted to compensate for dE/dx loss in the beam pipe. The two tracks are constrained in a full 3 dimensional vertex fit. The χ^2 of the fit is required to be less than 15 for 1 degree of freedom. Finally, for Λ candidates with momenta p_Λ less than 2 GeV/c, the calculated mass is required to be within 5 MeV/c^2 of the actual Λ mass. For candidates with momenta more than 2 GeV/c, the calculated mass is required to be within 4 MeV/c^2 + $0.5 p_\Lambda$ of the actual Λ mass, where p_Λ is in GeV/c. The resulting signal is 1688 $\pm$ 76 Λ over a background of 2059 $\pm$ 45. The peak is centered at the Λ mass and has a width of roughly 5 MeV/c^2.

Each Λ candidate is paired with every negatively charged track to make a Ξ^- candidate. A 2 dimensional line-circle intersection is made (the uncharged Λ travels in a straight line) in the x-y plane. For each Ξ^- candidate, the distance in the x-y plane from the reconstructed decay point to the center of the interaction region must be greater than 8 mm. At the x-y intersection point, the Λ and the π z coordinates must agree within 5 cm. Ξ^- candidates are required to have a momentum of at least 750 MeV/c. The angle between the Ξ^- track, the line between the reconstructed Ξ^- vertex and the center of the interaction region, and the Ξ^- momentum vector as projected back to the origin must be less than 5^0.

The masses of the resulting $\Lambda\ \pi$ combinations are shown in Fig. 1 , separately for right sign ($\Lambda\pi^-$, $\overline{\Lambda}\pi^+$) and wrong sign ($\Lambda\ \pi^+$, $\overline{\Lambda}\pi^-$) combinations. The narrow peak in the right sign distribution is centered at the Ξ^- mass, with a width of roughly 6 MeV/c^2, consistent with the Monte Carlo predictions. The small peak in the right sign plot at 1.28 GeV/c^2 is due to Λ decays where the proton combines with a random π track, to make a Λ candidate, then with the π from the Λ to form a Ξ^- candidate.

As with the Λ , the Ξ^- mass resolution is momentum dependent. For Ξ^- with momenta p less than 2 GeV/c, the mass is required to be within 6 MeV/c^2 of the actual Ξ^- mass. For Ξ^- with more than 2 GeV/c momenta, the mass is required to be within 5 MeV/c^2 + 0.5p of its nominal value, where p is in GeV/c. For each Ξ^- candidate, two background regions are chosen with widths dependent on the momentum of the candidate. For a given Ξ^- momentum, the background regions are centered at 40 MeV/c^2 above and below the nominal Ξ^- mass and are each twice as wide as the signal region. The total background region is four times as wide as the signal region, in order to reduce the statistical error on the background.

These cuts leave a signal of 41 $\pm$ 8 Ξ^- over a background of 14 $\pm$ 2 (statistical errors only). After subtraction of the roughly equal backgrounds, there are 29 Ξ^- and 12 $\overline{\Xi^-}$. We find no explanation for this apparent charge asymmetry; the Λ and $\overline{\Lambda}$ signals are roughly equal. Based on a study of the positions of the primary vertices in these events, beam gas production of Ξ^- appears to be negligible. The Ξ^- and $\overline{\Xi^-}$ momentum spectra are similar.

The efficiency for detecting Ξ^- decays is estimated by Monte Carlo simulation. The Monte Carlo includes the effects of multiple scattering, nuclear absorption and drift chamber inefficiency. At 750 MeV/c, the efficiency for Ξ^- detection is 3% , rising to 3.5% at 2-3 GeV/c, then dropping to 2% at 6 GeV/c. Above

7 GeV/c, the efficiency is very low, and this region is excluded from the analysis. At low momenta, the particles do not travel far enough to pass the minimum decay distance requirement, while at high momenta the three tracks are poorly separated, and the Λ may decay so far from the origin that its daughter particles cannot be tracked. Uncertainties in the Monte Carlo efficiency calculation are the dominant sources of systematic error. This calculation is dominated by the uncertainty in the track finding efficiency and the drift chamber efficiency during a period of time when it was operating at reduced voltage.

The radiatively corrected inclusive cross section for Ξ^- production versus x is shown in Fig. 2 , where $x = 2E/E_{cm}$ and E is the baryon energy. The solid points show the data for Ξ^- , while the open circles are corresponding data for Λ production.[7] Above the Ξ^- threshold, the shapes of the two data sets are similar. The solid lines show the predictions of the Lund model,[8] which are in rough agreement with the data. The predictions of the Webber cluster model[9] are shown by the dotted lines. The Webber model predicts spectra similar to Lund and a comparable Λ production rate, but a higher Ξ^- production rate.

Measurement of the total cross section for Ξ^- production requires an extrapolation to Ξ^- momenta below 750 MeV/c and above 7 GeV/c. Since statistics do not permit a model independent fit, the Lund model is used to predict the spectrum. The Lund model indicates that 84% of all Ξ^- are produced with momenta in the 0.75 - 7.0 GeV/c range. With this extrapolation, the total radiatively corrected $\Xi^- + \overline{\Xi^-}$ production cross section is 7.0 ± 1.5 ± 1.5 pb. This translates to 0.017 ± 0.004 ± 0.004 Ξ^- per hadronic event, in agreement with the TASSO[1] and TPC[2] measurements of 0.026 ± 0.008 ± 0.009 and 0.020 ± 0.009 Ξ^- per hadronic event respectively. The Lund model agrees well with the data, predicting 0.014 Ξ^- per hadronic event. However, the cluster model predicts a higher rate, 0.037 Ξ^- per hadronic event.

The ratio of Ξ^- to Λ production is $0.08 \pm 0.02 \pm 0.02$. The Monte Carlo predictions are 0.07 for Lund and 0.15 for the Webber model. The measured Ξ^- to Λ ratio seems to require something more than the Webber cluster model phase space mass suppression.

An interesting application for this Ξ^- sample is a search for Ξ^{*0} (1530) production and decay via $\Xi^{*0} \rightarrow \Xi^- \pi^+$ and its conjugate reaction. The Ξ^- candidates are combined with all oppositely charged pions which pass the track quality requirements. The Ξ^{*0} candidates are not required to meet any other requirements. Fig. 3 shows the result of the search. The histogram is the data. The smooth curve shows the Lund Monte Carlo generated peak shape, normalized to correspond to the 90% confidence level upper limit. The peak shape is added to the measured background. The Monte Carlo includes the natural Ξ^{*0} width (9 MeV) and detector resolution. Based on the Monte Carlo, a signal region from 1.522 to 1.542 GeV/c^2 is chosen. There are six candidates in the signal region. Two background regions are chosen, one from 1.486 to 1.514 GeV/c^2 and the other from 1.550 to 1.598 GeV/c^2 , and contain 21 events in a region four times as wide as the signal region. The background regions have different widths because the Ξ^{*0} mass is near the $\Xi^- \pi^+$ kinematic threshold.

The small number of events necessitates the use of Poisson statistics for both signal and background. To find an upper limit, the probability of the signal plus background fluctuating to the measured signal region level times the probability of the background fluctuating to the measured background level is calculated for a matrix of possible mean signal and background levels. The probabilities are summed over all of the background levels for each signal level, giving the relative probability of each possible mean signal level fluctuating to the observed signal level, i.e. the probability that it is the true mean signal level. From this, the 90% confidence level upper limit of less than 5.8 Ξ^{*0} detected is established.

The efficiency is calculated using the Lund Monte Carlo, modified so that all produced diquarks are spin 1, composed of two s quarks. Most of the systematic errors are similar to those encountered in the Ξ^- analysis. However, the Ξ^{*0} spectrum comes directly from the Monte Carlo. The spectral uncertainty leads to an efficiency uncertainty which is a major source of systematic error. From this, we find $N(\Xi^{*0})/N(\Xi^-) < 0.35$ and $N(\Xi^{*0}) < 0.006$ per hadronic event, both at a 90% confidence level. This agrees with a recent TASSO measurement $N(\Xi^{*0})/N(\Xi^-) < 0.5$ at a 95% confidence level.[10] The Lund model is in agreement with the data, predicting 0.0028 Ξ^{*0} per hadronic event and $N(\Xi^{*0})/N(\Xi^-) = 0.20$. However, the cluster model predicts a much higher rate, 0.019 Ξ^{*0} per hadronic event and $N(\Xi^{*0})/N(\Xi^-) = 0.51$. Again, the Webber cluster phase space mass suppression seems inadequate to describe this data.

To summarize, we have measured $\Xi^- + \overline{\Xi^-}$ production in e^+e^-collisions at 29 GeV and observed a signal of 41 ± 8 events. The inclusive $\Xi^- + \overline{\Xi^-}$ production rate is $0.017 \pm 0.004 \pm 0.004$ Ξ^- or $\overline{\Xi^-}$ per hadronic event. At a 90% confidence level, the upper limit for $N(\Xi^{*0})/N(\Xi^-)$is 0.35.

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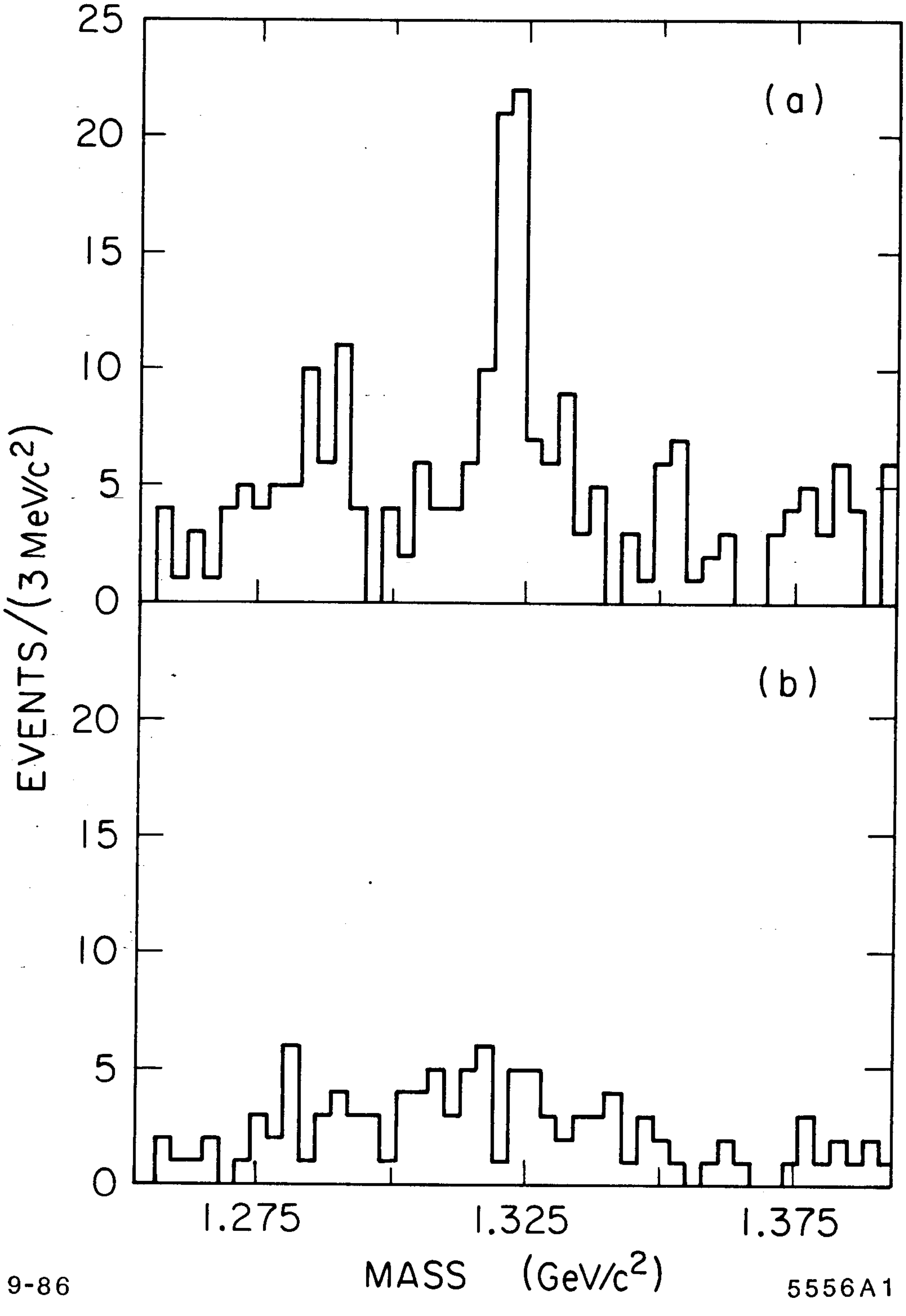
FIGURE CAPTIONS

1. Invariant mass spectra for (a) $\Lambda\pi^-$, $\overline{\Lambda}\ \pi^+$ (b) $\Lambda\ \pi^+$, $\overline{\Lambda}\pi^-$.
2. Inclusive cross section for $\Xi^- + \overline{\Xi^-}$. The solid points are the Ξ^- ; the open circles are the corresponding data for Λ production. The solid and dotted lines are the Lund string and Webber cluster model predictions, respectively.
3. Invariant $\Xi^-\ \pi^+$, $\overline{\Xi^-}\ \pi^-$ mass spectra. The histogram represents the data, while the curve shows the Monte Carlo predicted shape, normalized to 5.8 Ξ^{*0} (the 90% confidence level), added to the measured background.



25
20
15
10
5
0
(a)
(b)
EVENTS/(3 MeV/c2)
1.275
1.325
1.375
MASS (GeV/c2)
9-86
5556A1

Fig. 1

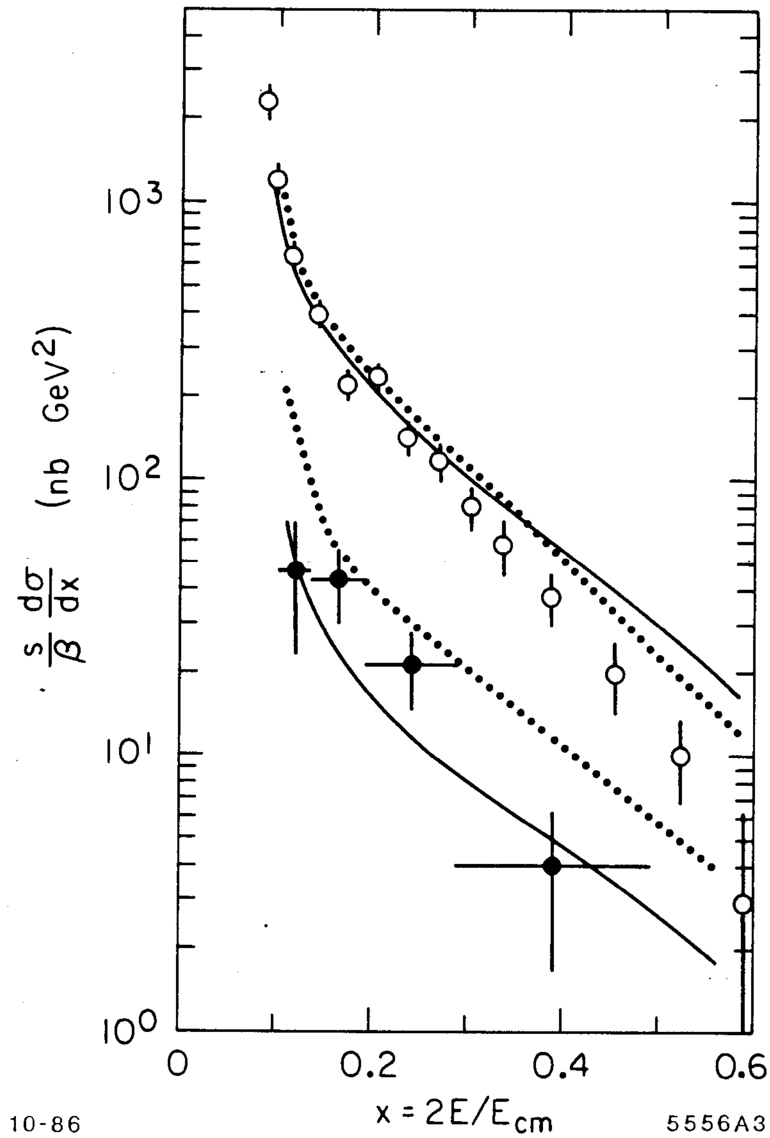

$\frac{s}{\beta}\frac{d\sigma}{dx}$ (nb GeV^2)
10^3
10^2
10^1
10^0
0
0.2
0.4
0.6
$x = 2E/E_{cm}$
10-86
5556A3

Fig. 2

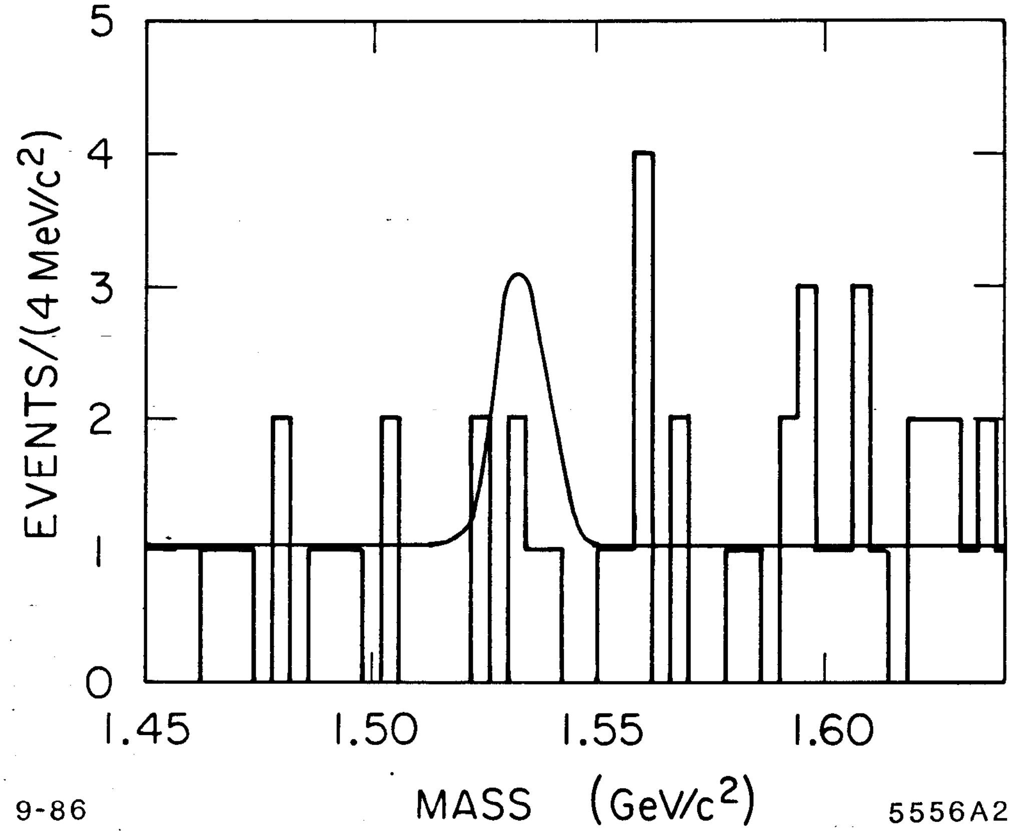


Fig. 3