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Hyperon Production in Z Decays

The ALEPH Collaboration

ABSTRACT

Inclusive production of hyperons has been studied in 2.86 million hadronic events observed with the ALEPH detector at LEP. Large Ξ^-, $\Xi(1530)^0$, and $\Sigma(1385)^\pm$ signals are observed, from which the production rates and energy spectra have been measured. A small, but clean, Ω^- signal also is observed, giving a measurement of its production rate.

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Production of baryons in quark fragmentation is still a poorly understood phenomenon. To increase our understanding of this process, or at least to constrain better our fragmentation models, it is important to measure the production rates of the various baryon species in high-energy e^+e^- annihilation. In particular, it is interesting to measure the rates of production of hyperons in the SU(3) octet and decuplet representations, which provide information on the formation of baryons with one, two, or three strange quarks and with spin-1/2 or spin-3/2. In this paper we present a measurement by the ALEPH experiment at LEP of the production rates of Ξ, Ξ^*, Σ^* and Ω hyperons (where antiparticles are implied throughout this paper) in e^+e^- annihilation at the Z resonance.

This analysis relies on the tracking chambers of the ALEPH detector, which have been described in detail elsewhere [1]. A total of 2.86 million candidates for hadronic Z decays is selected by requiring at least five good charged tracks with a total of at least 10% of the center-of-mass energy. Ξ^-, Ξ^{*0},$\Sigma^{*\pm}$, and Ω^- candidates are tagged by the decays $\Xi^- \rightarrow \Lambda\pi^-$, $\Xi^{*0} \rightarrow \Xi^-\pi^+$, $\Sigma^{*\pm} \rightarrow \Lambda\pi^\pm$, and $\Omega^- \rightarrow \Lambda K^-$.

The Λ candidates are tagged by the decay $\Lambda \rightarrow p\pi^-$. The analysis begins with a search for vertices that are consistent with that decay, inconsistent with being γ conversions, and correspond to a decay length of at least 0.2 proper lifetimes. To further reduce background, the measured dE/dx of each track must be within 2σ of the expected value for p, and within 3σ for π. However, the dE/dx cut is made only if there are at least 50 ionization measurements (out of 338), and in the case of protons the dE/dx is not used if $p < 2.9\,\mathrm{GeV}/c$. This selection is identical to that used in Ref. 3, except that no cut is made on the Λ impact parameter, and no kinematic fitting is done. Only those candidates with a reconstructed mass lying within about two standard deviations of the Λ mass are used in the following analysis.

For the Ξ and Ω analyses the resulting neutral Λ track is vertexed with all remaining good tracks of the appropriate charge, and candidates are selected by requiring that the decay length measured from the beam spot be within the range of 0.2 to 5 proper lifetimes. In addition, the Λ decay length as measured between the two vertices is required to be in the range of 0.2 to 5 proper lifetimes, and each vertex fit is required to have a χ^2 of no greater than 6, with the reconstructed Ξ or Ω extrapolating to with 0.8 cm of the beam. Kaon candidates are rejected if there are less than 50 ionization measurements or if the measured dE/dx is not within 2σ of the expected value. Finally, for the Ω^- selection, candidates are rejected if they fall within $7.5\,\mathrm{MeV}/c^2$ of the Ξ^- mass.

The resulting Ξ^- signal is shown in Fig. 1.a. Depending on the Ξ momentum, the mass resolution varies between $2\,\mathrm{MeV}/c^2$ and $6\,\mathrm{MeV}/c^2$. The mass histogram for each $x_E = E/E_{\mathrm{beam}}$ bin is fit to a gaussian plus quadratic polynomial. Thus the sidebands, which agree well with the wrong-sign spectrum, are used to determine the background.

Fig. 1.b shows the ΛK^- mass spectrum, where a clear peak is seen at the

Ω^- mass, with a resolution consistent with that expected from the Monte Carlo simulation. The fit to a gaussian plus quadratic polynomial is used to estimate the background in the signal region, which is taken to be $\pm 6\,\mathrm{MeV}/c^2$ about the peak. The number of events above background in this region is 156 ± 17.

The $\Sigma(1385)^\pm$ is reconstructed by pairing the Λ candidates with tracks of $p > 200\,\mathrm{MeV}/c$ that pass within 0.2 cm of the beam and which are no more than 60° in angle from the Λ momentum vector. The large combinatorial background is fit to a function of the form

$$N \cdot (x - x_0)^P \cdot \exp(c_1(x - x_0) + c_2(x - x_0)^2)$$

while the signal is taken to be a relativistic Breit-Wigner shape with a mass-dependent width [2]:

$$\Gamma = \Gamma_0 \left(\frac{q}{q_0}\right)\left(\frac{m_0}{m}\right)$$

where $q(q_0)$ is the momentum of the Λ in the Σ^* rest frame for invariant mass $m(m_0)$ and m_0, Γ_0 are fixed to the known value. The decay sequence $\Sigma^* \rightarrow \Sigma^0\pi^\pm$, with $\Sigma^0 \rightarrow \Lambda\gamma$, is accounted for by an additional signal of the same shape shifted downward and broadened to account for the missing γ, by amounts determined from Monte Carlo simulation. Finally, a gaussian peak at the Ξ^- mass is included to account for that background. The data, including the entire range in x_E, and associated fit are shown in Fig. 1.c.

For the $\Xi(1530)^0$ analysis, all Ξ^- candidates within $6.4\,\mathrm{MeV}/c^2$ of the Ξ^- mass are paired with all remaining good tracks of $p > 300\,\mathrm{MeV}/c$ and of the appropriate charge which extrapolate to within 0.8 cm of the beam. The cosine of the angle between the pion candidate and the $\Xi(1530)$ momentum, measured in the $\Xi(1530)$ rest frame must be less than 0.85. The measured $\Xi^-\pi^-$ spectrum is used to fix the shape, but not normalization, of the background, by fitting it to the same function as used for the Σ^* background. The $\Xi^-\pi^+$ mass spectrum then is fit to a convolution of a Breit-Wigner, with fixed width, and gaussian plus the background shape, as shown in Fig. 1.d for the full x_E range.

For each of the analyses, the efficiencies were calculated by Monte Carlo simulation, in which the simulated events were treated the same as data, the methods of background subtraction included. The inclusive spectra for Σ^*, Ξ^-, and Ξ^* data are shown corrected for efficiency and background in bins of x_E in Fig. 2. As a cross check, the $c\tau$ of the Λ and Ξ^- were measured to be in good agreement with the accepted values. The Ξ^- polarization was measured to be 0.04 ± 0.06, consistent with zero, and an uncertainty of ± 0.06 in the polarization introduces a negligible systematic error into the efficiency.

The JETSET 7.3 model [4] was used to extrapolate the results over the unmeasured regions at low x_E to obtain the overall multiplicities:

$$\begin{aligned}
\langle N_{\Xi^-}\rangle + \langle N_{\bar{\Xi}^+}\rangle &= 0.0285 \pm 0.0007 \pm 0.0020, \\
\langle N_{\Xi(1530)^0}\rangle + \langle N_{\bar{\Xi}(1530)^0}\rangle &= 0.0072 \pm 0.0004 \pm 0.0006, \\
\langle N_{\Sigma(1385)^\pm}\rangle + \langle N_{\bar{\Sigma}(1385)^\pm}\rangle &= 0.065 \pm 0.004 \pm 0.009, \\
\langle N_{\Omega^-}\rangle + \langle N_{\bar{\Omega}^+}\rangle &= 0.0010 \pm 0.0002 \pm 0.0002,
\end{aligned}$$

where in each case the first uncertainty is statistical and the second is systematic. The systematic errors include a common 4% uncertainty in the efficiency of Λ reconstruction, as discussed in more detail in Ref 3. Distributions of all variables used to isolate the signals were compared between data and simulation, and those small differences which were found were considered in evaluating the systematic error in the efficiency. In addition, for each analysis, the effects of changing assumptions in the background subtraction were investigated. This was especially significant for the Σ^*, because of its large natural width and proximity to the threshold.

As can be seen in Fig. 2, the UCLA [5] and JETSET 7.3 [4] models are not far from agreeing with our measurements, in spite of the fact that no results from this analysis have been used to tune those models. Also, our measured rate for Ω^- production is only 40% higher than the value of 0.00071 given by the JETSET model. However, our measured rate for $\Sigma(1385)^\pm$ production is 1.7 time greater than what has been observed by the OPAL and DELPHI collaborations [6, 7], while the recently reported OPAL Ω^- rate is 2.8 times greater than what we have measured (the disagreement with the older published OPAL result is worse [8]). Our measured Ξ^- rate is also higher than that of the other two experiments, but only by 1.5 standard deviations, at most. The $\Xi(1530)^0$ rate is in good agreement between all three experiments. All of these ALEPH results are unpublished and preliminary.

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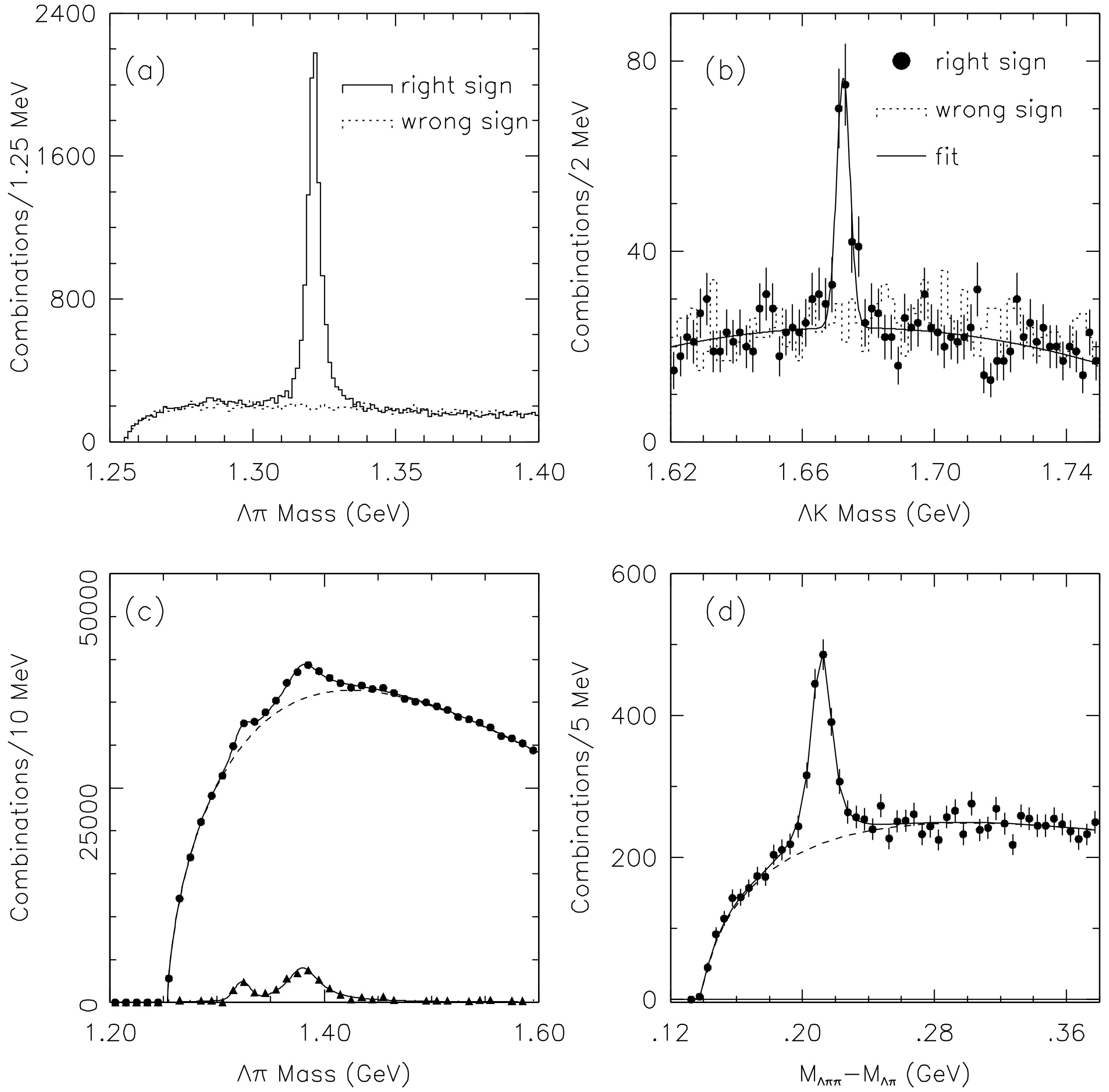

Figure 1: (a) The signal for $\Xi^- \rightarrow \Lambda\pi^-$. (b) The signal for $\Omega^- \rightarrow \Lambda K^-$. (c) The mass spectrum for $\Sigma(1385)^{\pm} \rightarrow \Lambda\pi^{\pm}$ candidates, fitted to a background shape, a Ξ^- contribution, plus a Breit-Wigner resonance. Also shown is the background-subtracted spectrum. (d) The mass-difference spectrum for $\Xi(1530)^0 \rightarrow \Xi^-\pi^+$ candidates, fitted to the background shape plus a Breit-Wigner resonance convolved with a gaussian.

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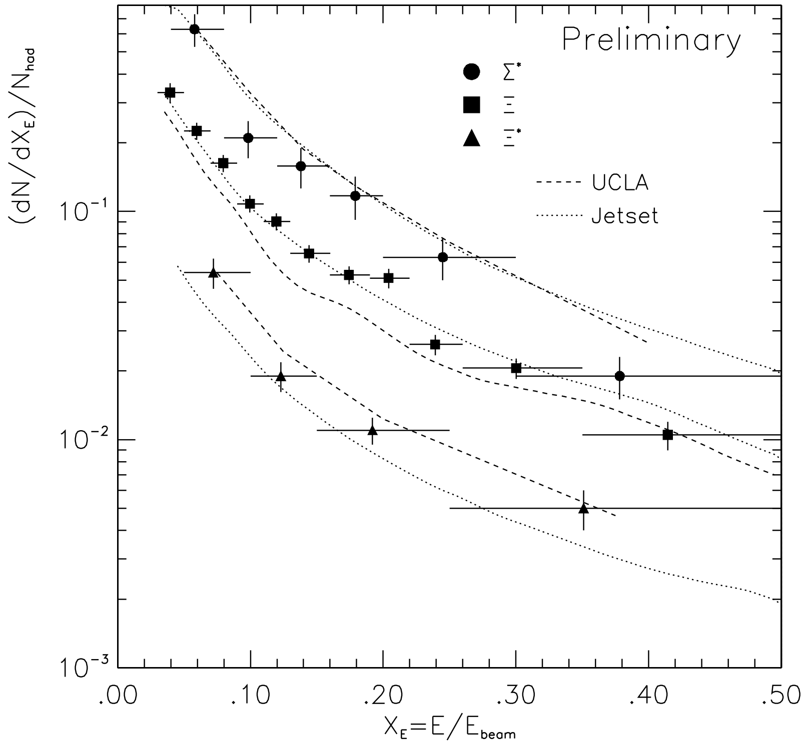

Figure 2: The measured x_E distributions for $\Sigma(1385)^{\pm}$, Ξ^{-}, and $\Xi(1530)^{0}$ (with antiparticles included), compared with predictions from the UCLA and JETSET 7.3 models. No results from this analysis were used to tune the models.