A MEASUREMENT OF STRANGE BARYON PRODUCTION WITH THE OPAL DETECTOR

J. R. Letts *
University of California, Riverside, CA 92521 USA

ABSTRACT
Production rates of $\Lambda$, $\Xi^-$, $\Sigma(1385)^\pm$, $\Xi(1530)^0$, and $\Omega^-$ baryons have been measured in a sample of 485,000 hadronic $Z^0$ decays. The differential cross section of $\Lambda$ baryons is found to be softer than those predicted by the JETSET and HERWIG Monte Carlo generators. Although the octet baryon rates could be reproduced by tuning JETSET, no tuning could be found in which all of the decuplet baryon rates were simultaneously described. The rapidity difference of $\Lambda\bar{\Lambda}$ pairs shows the correlations expected from models with a chain-like production of baryon-antibaryon pairs. The observed rapidity correlations are best described by JETSET with a dominant production chain of baryon-meson-antibaryon, the popcorn mechanism.

1. INTRODUCTION

Previous experiments at PETRA and PEP measured the production of various baryons in jets [1]. The differential momentum spectra of mesons and baryons were found to be very similar. Consequently it was assumed that baryons and mesons are produced by a similar mechanism during the fragmentation process. However, the observed production ratio of $\Xi^-$ to $\Lambda$ and the small rates of decuplet baryons required additional mechanisms to suppress the production of baryons with single and double strangeness and with spin 3/2.

The observed momentum spectra and the extra suppression factors can be described by the diquark model, the most common approach used to describe baryon production in jets. According to this model, quark-antiquark and diquark-antidiquark pairs are produced from the sea, and diquarks combine with single quarks to form baryons. A general assumption of jet hadronisation is a chain-like particle creation with local conservation of quantum numbers. Chain-like models of baryon production, such as implemented in JETSET [2] and HERWIG [3], predict a small rapidity difference between neighbouring particles in the chain. A variant of this model, in which the diquarks have the possibility to split into a meson and a diquark (the so-called popcorn mechanism), is implemented in JETSET [4].

Measurements of strange baryon production and correlations between strange baryon pairs can be used to test and constrain the parameters of the various Monte Carlo models. An outline of our recent work on this topic is presented below. Detailed descriptions of the cuts and analysis may be found in Refs. [5] and [6].

2. INCLUSIVE STRANGE BARYON PRODUCTION

The $\Lambda$, $\Xi^-$, and $\Omega^-$ can be identified by their decays into $p\pi^-$ (64.1%), $\Lambda\pi^-$ (100%), and $\Lambda K^-$ (67.8%), respectively, with the corresponding branching ratios given in parentheses. Due

\[ y = \frac{1}{2} \ln \left( \frac{E + p_\parallel}{E - p_\parallel} \right), \]

where $E$ is the energy and $p_\parallel$ is the momentum component parallel to the thrust axis.

*Present address: CERN, PPE Division, 1211 Genève 23, Switzerland

1The rapidity of a particle is defined as $y = \frac{1}{2} \ln \left( \frac{E + p_\parallel}{E - p_\parallel} \right)$, where $E$ is the energy and $p_\parallel$ is the momentum component parallel to the thrust axis.

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to the long lifetimes of these baryons, a strong rejection of the combinatorial background can be achieved by selecting track combinations with well displaced secondary vertices. The large OPAL central jet chamber is especially well suited to this purpose (for a detailed description of the OPAL detector see Ref. [7]). We also use the good dE/dx measurement in the central detector to reduce backgrounds still further [8]. The $\Sigma(1385)^\pm$ and $\Xi(1530)^0$ decay strongly with branching ratios of 88% to $\Lambda\pi^\pm$ and 67% to $\Xi^-\pi^+$, respectively. Because of the prompt decay, no secondary vertex cuts are possible to reduce the combinatoric background.

For the strange baryon analysis described below, the data from 1990 and 1991 were used, corresponding to 485,000 hadronic $Z^0$ decays, selected according to the criteria described in the OPAL line-shape analysis [9]. To determine selection efficiencies, we used a sample of 400,000 JETSET hadronic $Z^0$ decays which were passed through the full detector simulation of the OPAL experiment [10]. To date almost 1.3 million hadronic $Z^0$ decays have been recorded. The analysis of the 1992 data is in progress and will be completed soon [11].

Details of the cuts used to identify $\Lambda$'s may be found in Ref. [5]. Only an outline of the method is presented here. To select $\Lambda$'s, all track combinations with opposite charges are examined, and the higher momentum track is assumed to be the proton. Relatively soft cuts on the dE/dx of the tracks are made to identify the proton and pion. Only track combinations with well-defined secondary vertices are retained. The invariant mass of all surviving $p\pi^-$ combinations is plotted in Fig. 1a. $\Lambda$ candidates whose reconstructed masses are within $\pm10$ MeV of the $\Lambda$ mass of 1115.63 MeV for $x_E(\equiv E_\Lambda/E_{\text{beam}})$ smaller than 0.2, and $\pm15$ MeV for higher energies, are used to search for the other baryon species. We find 30,041 $\Lambda$'s above a background of 16,016 in the mass region defined above.

To select $\Xi^-$ baryons, secondary vertices of the above $\Lambda$ candidates and additional charged tracks, assumed to be pions, are identified. Soft dE/dx cuts on the additional pion track are made as well. With our cuts a narrow $\Xi^-$ mass peak is observed in the $\Lambda\pi^-$ mass spectrum, as shown in Fig. 1b. Since there is no "$\Xi^+$", the $\Lambda\pi^+$ mass spectrum provides a good estimate of the background. In all we find 726$\pm38$ signal events above a background of 388 in a mass range of $\pm10$ MeV around the $\Xi^-$ mass of 1321.3 MeV.

The selection of $\Omega^-$ baryons is the same as for the $\Xi^-$, except that strong dE/dx cuts are used to positively identify the $K^-$ in the presence of a large $\pi^-$ background. The mass spectrum of selected $\Lambda K^-$ combinations is shown in Fig. 1c. A total of 47$\pm11$ $\Omega^-$ above a background of 42 is found. The dominant background is estimated from the wrong charge combination, $\Lambda K^+$. In addition, $\Xi^-$ decays with misidentified pions contribute to the background in the correct charge combination. The invariant $\Lambda K$ mass spectrum of such events does not show a peak in the $\Omega^-$ mass region and is separately shown as the shaded histogram.

$\Sigma(1385)^\pm$ and $\Xi(1530)^0$ are identified via their prompt decays into $\Lambda\pi^\pm$ and $\Xi^-\pi^+$, respectively. In these searches, no secondary vertex searches are possible. Only soft dE/dx cuts and a requirement that the additional track come from the primary event vertex are used. The resulting mass spectrum for $\Xi^-\pi^+$ is shown in Fig. 1d, where the background is obtained using wrong charge $\Lambda\pi^+$ combinations, assumed to have the $\Xi^-$ mass, combined with oppositely charged tracks. A total of 79$\pm13\Xi(1530)^0$ above a background of 83 is found.

The differential cross sections, $1/N_{\text{hadron}}dn/dx_E$, are plotted in Fig. 2a for $\Lambda$, $\Xi^-$, $\Sigma(1385)^\pm$, and $\Xi(1530)^0$ baryons, and are compared to the predicted cross sections from JETSET. The cross sections are found to be much softer in the data than in JETSET or HERWIG, which is very similar to JETSET. The inclusive rates are shown in Table 1, along with predictions from JETSET. Details of the systematic errors may be found in Ref. [5]. Although with the default parameters JETSET
does not agree with the data, with a small change in the strange diquark suppression parameter the $\Lambda$ and $\Xi^-$ rates are described.

Table 1

Inclusive particle yields measured by OPAL. The predictions are from JETSET with default parameters and JETSET with the extra strangeness suppression for diquarks changed to 0.3 from the default of 0.4.

<table>
<thead>
<tr>
<th>Baryon</th>
<th>N/event</th>
<th>JETSET default</th>
<th>JETSET tuned</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Lambda$</td>
<td>$0.351 \pm 0.003$ (stat.) $\pm 0.019$ (syst.)</td>
<td>0.383</td>
<td>0.351</td>
</tr>
<tr>
<td>$\Xi^-$</td>
<td>$0.0206 \pm 0.0011$ (stat.) $\pm 0.0019$ (syst.)</td>
<td>0.027</td>
<td>0.021</td>
</tr>
<tr>
<td>$\Sigma(1385)^\pm$</td>
<td>$0.0380 \pm 0.0038$ (stat.) $\pm 0.0049$ (syst.)</td>
<td>0.074</td>
<td>0.068</td>
</tr>
<tr>
<td>$\Xi(1530)^0$</td>
<td>$0.0063 \pm 0.0010$ (stat.) $\pm 0.0010$ (syst.)</td>
<td>0.0053</td>
<td>0.0048</td>
</tr>
<tr>
<td>$\Omega^-$</td>
<td>$0.0050 \pm 0.0012$ (stat.) $\pm 0.0009$ (syst.)</td>
<td>0.0007</td>
<td>0.0004</td>
</tr>
</tbody>
</table>

However, in trying to tune JETSET to the decuplet baryon yields, it was found that only one of the three ($\Sigma(1385)^\pm$, $\Xi(1530)^0$, or $\Omega^-$) could be described by tuning diquark parameters such that the $\Lambda$ and $\Xi^-$ rates were also correct. This is demonstrated in Fig. 2b, which plots the ratio of the decuplet baryons $\Xi(1530)^0/\Sigma(1385)^\pm$ versus the ratio of the octet baryons $\Xi^-/\Lambda$. It was found that these ratios can not be varied independently within the current model. For all parameters studied, the ratios obtained from the JETSET all fall within the hatched band in Fig. 2b and are in disagreement with the data.

3. CORRELATIONS BETWEEN STRANGE BARYON PAIRS

In a subsequent paper [6], using similar criteria to select $\Lambda$ and $\Xi^-$ baryons, we examine the dynamics of strange baryon pairs. After tagging on a $\Lambda$ or a $\Xi^-$ we look for additional $\Lambda$'s in the event. Large excesses of opposite baryon number pairs over same baryon number pairs are found, indicating a simultaneous conservation of strangeness and baryon number. In all we find 990$\pm$54 excess $\Lambda\bar{\Lambda}$ pairs, where the background of 945 is taken from the same baryon number pairs. Also, we find 61$\pm$12 excess $\Xi^-\bar{\Lambda}(\Xi^+\Lambda)$ pairs, over a background of 45. From these numbers we determine the following efficiency corrected pair rates:

- $[\Lambda\bar{\Lambda} - \Lambda\Lambda(\bar{\Lambda}\bar{\Lambda})]/\text{Event} = 0.0621 \pm 0.0034$ (stat.) $\pm 0.0084$ (syst.)
- $[\Xi^-\bar{\Lambda}(\Xi^+\Lambda) - \Xi^-\Lambda(\Xi^+\bar{\Lambda})]/\text{Event} = 0.0096 \pm 0.0019$ (stat.) $\pm 0.0013$ (syst.)

We also investigate rapidity correlations between $\Lambda\bar{\Lambda}$ pairs. For this measurement, the data are divided into five rapidity subsamples according to the rapidity of the tagging $\Lambda$. The rapidities of the two particles are then shifted such that the rapidity of the tagging particle is centered in the appropriate rapidity interval, while the rapidity difference remains unchanged. The rapidity distribution of the $\Lambda$ corrected for background and efficiency is shown in Fig. 3a for the five rapidity intervals of the tagging $\Lambda$ for the data and for JETSET with a production chain of
baryon-antibaryon. Strong rapidity correlations are clearly seen over the entire rapidity range, which is evidence for a chain-like production of baryon-antibaryon pairs.

The overall rapidity difference of $\Lambda\bar{\Lambda}$ pairs is shown in Fig. 3b, along with predictions from JETSET for various popcorn parameters. The rapidity difference distribution in JETSET was found to be sensitive only to the choice of the popcorn parameter, which enables the production of baryon-meson-antibaryon configurations. The observed rapidity difference is best described by a large popcorn probability.

4. SUMMARY AND CONCLUSIONS

In two publications we examine strange baryon production and correlations between strange baryon pairs. We find that diquark models of baryon production describe the general features of baryon production in jets, but fail to predict the large rates for decuplet baryons observed in the data. The differential cross sections predicted by the Monte Carlo models are also too hard.

The rapidity difference of $\Lambda\bar{\Lambda}$ pairs shows the correlations expected from models with a chain-like production of baryon-antibaryon pairs. The observed rapidity correlations are best described by JETSET with a dominant production chain of baryon-meson-antibaryon, the popcorn mechanism.

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REFERENCES


\(^{4}\) A popcorn parameter of zero is used.
Fig. 1: Mass spectra for (a) $p\pi^-$, (b) $\Lambda\pi^-$ (c) $\Lambda K^-$, and (d) $\Xi^-\pi^+$. 
Fig. 2: (a) Differential cross sections, \(1/N_{\text{hadron}} \, \frac{d\sigma}{dx_E}\), for \(\Lambda\), \(\Sigma(1385)^\pm\), \(\Xi^-\), and \(\Xi(1530)^0\). The curves show the respective Monte Carlo differential cross sections from JETSET. (b) The ratio of the decuplet baryons \(\Xi(1530)^0/\Sigma(1385)^\pm\) versus the ratio of the octet baryons \(\Xi^-/\Lambda\) for data (\(\ast\)) and JETSET (\(\bullet\)).

Fig. 3: (a) Rapidity distribution of \(\bar{\Lambda}\), corrected for background and efficiency, for various \(\Lambda\) tagging intervals (shown as solid boxes). The distributions from JETSET with a popcorn production of 0% are also shown. (b) Rapidity difference, corrected for background and efficiency, for all \(\Lambda\bar{\Lambda}\). The distributions from JETSET with a popcorn production of 0%, 80%, and 95% are also shown.