Λ_c^+ PRODUCTION IN Z^0 DECAYS

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ABSTRACT

The production of Λ_c^+ baryons in Z^0 decays was measured using 1.72 million multihadronic events collected during 1991-93 with the OPAL detector at LEP. A sample of 423±71 Λ_c^+ candidates was obtained. By examining the energy spectrum of Λ_c^+ candidates, separation of Λ_c^+ from $Z^0 \to \bar{b}b \to \Lambda_c^+X$ and $Z^0 \to \bar{c}c \to \Lambda_c^+X$ sources was achieved, yielding production fraction times branching ratio:

$$\begin{aligned} f(b \to \Lambda_c^+X) \cdot Br(\Lambda_c^+ \to pK^-\pi^+) &= (0.48 \pm 0.12 \pm 0.05)\% \\ f(c \to \Lambda_c^+X) \cdot Br(\Lambda_c^+ \to pK^-\pi^+) &= (0.33 \pm 0.15 \pm 0.08)\% \end{aligned}$$

and the inclusive rate from Z^0 decays:

$$[\Gamma(Z^0 \to \Lambda_c^+X)/\Gamma_{had}] \cdot Br(\Lambda_c^+ \to pK^-\pi^+) = (0.322 \pm 0.049 \pm 0.038)\%$$

An excess of Λ_c^+ in $Z^0 \to \bar{b}b$ events is seen when compared with the rate measured at $\Upsilon(4S)$ energies, indicating the presence of b baryons decaying to Λ_c^+.

1. Introduction – Charmed Baryons at LEP

There are many measurements * of Λ_c^+ production from $c\bar{c}$ continuum and B meson decays (CLEO and ARGUS),[1] yet very few measurements have been performed at higher energies.[2] At LEP, it is interesting to examine inclusive Λ_c^+ production, as Λ_c^+ could also be produced in the decays of b baryons, which are not accessible at the lower energy $\Upsilon(4S)$ experiments.

2. The OPAL Detector

A complete description of the OPAL detector may be found elsewhere.[3] The crucial component of the detector in this analysis is the tracking system, which is immersed in a uniform .435 T magnetic field. The main tracking chamber is a jet-cell drift chamber, which provides particle identification via specific ionization (dE/dx) measurements, and together with the precision vertex drift chamber, tracks charged particles. The Silicon Microvertex detector[4] consists of 2 barrels of silicon wafers providing $r-\phi$ space point resolution of 9μm and an impact parameter resolution of 16μm for 45 GeV lepton pairs. In 1993, the silicon detector was upgraded and presently provides $r-\phi$ and z coordinate measurements.

3. Event Selection

This analysis used only events with Silicon Microvertex detector information available. The OPAL hadron selection[5] was applied and events which passed data quality and detector status were selected, leaving a sample of 1.72 million events.

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*Representing The OPAL Collaboration

*Throughout this note, whenever a specific particle or decay chain is specified, the conjugate particle or process is also implied.

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At this point, three prong vertices were formed. Only tracks with $|\cos\theta| < 0.85$ were considered. Silicon $r-\phi$ hits were matched to tracks when possible. Candidate Λ_c^+ vertices were formed in the r-ϕ plane, using all possible 3 track combinations for the decay $\Lambda_c^+ \rightarrow pK^-\pi^+$. A signed decay length was constructed using the position of the reconstructed vertex to average e^+e^- interaction point. At least 2 of the 3 tracks were required to have associated silicon hits, and the χ^2 probability of the vertex fit was required to be $> 1\%$. Particle identification cuts were then applied:

- $\pi^{\pm}$ candidates have $p >$ 1GeV/c and dE/dx π probability >1%
- p candidates have $p >$ 2GeV/c and dE/dx proton probability >1% (>3%) if below (above) the proton dE/dx expectation.
  The probability of the proton candidate being a pion must be $< 1\%$.
- K candidates have $p >$ 2GeV/c and dE/dx K probability >1% (>3%) if below (above) the kaon dE/dx expectation.
  The probability of the kaon candidate being a pion must be $< 1\%$.
- reject event if $K^- - p$ combination is consistent with being a ϕ when kaon mass hypotheses are assumed.

Finally, the large combinatorial background at low x_E was rejected by considering only Λ_c^+ candidates with $x_E > .15$ and applying the following cuts on decay length significance (L/σ) :

$$(L/\sigma) \quad \begin{array}{l} >4 \text{ for } .15 < x_E < .3 \\ >1 \text{ for } .3 < x_E < .6 \\ >0 \text{ for } .6 < x_E < 1.0 \end{array}$$

4. The $\Lambda_c^+ \rightarrow pK^-\pi^+$ Signal

The $pK^-\pi^+$ invariant mass distribution of all track combinations satisfying the selection criteria is shown in Figure 1. The line is a χ^2 fit to the Λ_c^+ spectrum, with a Gaussian signal and polynomial background.

Efficiencies were determined using a full simulation of the OPAL detector.[7] The JETSET 7.3 event generator was used, with heavy flavour branching ratios from EURODEC 205. This combination reproduces the CLEO Br($\overline{B} \rightarrow \Lambda_c^+ X$) very well. The Peterson fragmentation scheme in JETSET was used for heavy charm and beauty quarks, with parameters $\epsilon_b = 0.0055$ and $\epsilon_c = 0.050$. The OPAL measurements for b hadron lifetimes were used,[6] and the Z^0 widths used were $\Gamma_{\overline{b}b} : \Gamma_{\overline{c}c} = 17.2 : 21.7$.[8] Extra smearing on track parameters in the Monte Carlo was applied in order to get good agreement between data and Monte Carlo for tracking resolution.

The Λ_c^+ energy spectrum from Monte Carlo generator is shown in Figure 2. It is evident that the Λ_c^+ spectra from primary $Z^0 \rightarrow \overline{b}b$ and primary $Z^0 \rightarrow \overline{c}c$ quarks differ sufficiently to allow separation of Λ_c^+ into the two sources. The full Monte Carlo was then used to obtain acceptances as function of Λ_c^+ decay length and Λ_c^+ energy. The acceptances are low, due to the severity of the dE/dx and decay length significance cuts for Λ_c^+'s at low x_E.

5. Measurement of $b \rightarrow \Lambda_c^+ X$, $c \rightarrow \Lambda_c^+ X$ rates

The Λ_c^+ candidate events were divided into four ranges of the scaled energy variable x_E. Signal and backgrounds were fit as previously, and each x_E range was corrected for efficiencies.

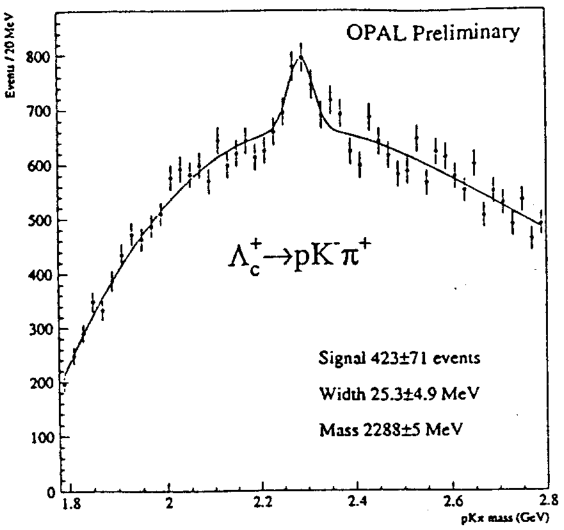

Figure 1. Invariant mass of $pK^-\pi^+$ combinations passing selection criteria described in Section 3.

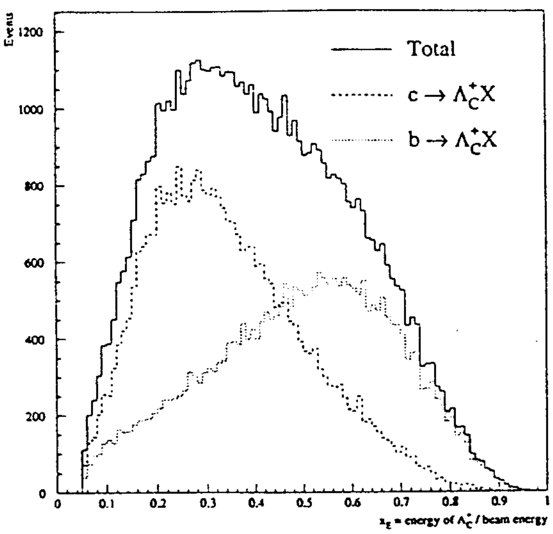

Figure 2. Monte Carlo simulation of the Λ_c^+ energy spectrum, showing contributions from $c \to \Lambda_c^+ X$ and $b \to \Lambda_c^+ X$.

5.1. *Systematic Uncertainties*

The dominant systematic uncertainties arise from the physics input to Monte Carlo generators and from the simulation of the detector.

The b hadron lifetimes from OPAL were varied over a 1 σ range of the OPAL measurements,[6] and the variation in the Λ_c^+ lifetime is taken from the Particle Data Group, over a 1σ range. The Peterson fragmentation parameters were varied over the ranges: $\epsilon_b = 0.0055^{+0.0045}_{-0.0035}$, $\epsilon_c = 0.050 \pm 0.020$, corresponding to the ranges for x_E: $\langle x_E \rangle_b = 0.70 \mp 0.02$, $\langle x_E \rangle_c = 0.51 \mp 0.02$.

The simulation of the detector response is another source of systematic uncertainty. Track impact parameter and angular resolutions were varied by ± 15%.

The efficiency of matching silicon hits to tracks was studied using the decay $D^{*+} \to D^0\pi^+$, with $D^0 \to K^-\pi^+$, from which the single track matching efficiency was determined to be $90.6 \pm 0.9\%$, in excellent agreement with the Monte Carlo prediction.

The Monte Carlo simulation of the dE/dx response of the detector was studied using a sample of Λ^0 particles, decaying via $\Lambda^0 \to p\pi^-$. The dE/dx efficiency was measured as a function of proton momentum in both the data and the Monte Carlo simulation. The two were found to be in excellent agreement. Additionally, the kaon dE/dx simulation was checked using the decay chain $D^{*+} \to D^0\pi^+$, with $D^0 \to K^-\pi^+$. The measured efficiency of the dE/dx kaon identification cuts were found to agree excellently in the Monte Carlo and the data. Statistical uncertainties in the ratio of the data and Monte Carlo efficiencies were used to obtain the systematic uncertainty.

All systematic uncertainties are summarized in Table 1. A more detailed description of this analysis may be found elsewhere.[9]

6. Results and Conclusions

The OPAL detector was used to obtain the first inclusive measurements of Λ_c^+ in Z^0 decays:

$$\left[\Gamma\left(Z^0 \to \Lambda_c^+ X\right)/\Gamma_{had}\right] \cdot Br\left(\Lambda_c^+ \to pK^-\pi^+\right) = (0.322 \pm 0.049 \pm 0.038)\,\%$$

Quantity	$\Delta f(c \to \Lambda_c^+ X)\cdot$ Br	$\Delta f(b \to \Lambda_c^+ X)\cdot$ Br	$\Delta(\Gamma(Z^0 \to \Lambda_c^+ X)/\Gamma_{had})\cdot$ Br
τ_b	$\pm1.00\%$	∓4.62 %	∓2.68 %
τ_{Λ_c}	$\mp4.30\%$	±1.44 %	∓2.44 %
ϵ_b	$\pm11.2\%$	∓2.94 %	±5.80 %
ϵ_c	$\pm16.5\%$	∓4.83 %	±2.55 %
$\Gamma_{q\bar{q}}/\Gamma_{had}$	∓8.19 %	$\mp1.23\%$	–
Track Resolution	$\pm1.72\%$	±1.56 %	±1.10 %
p dE/dx	12.8%	6.24%	8.11%
K dE/dx	4.4%		
Silicon match	0.5%		
Total Syst. Err.	25.9%	10.9%	11.8%

Table 1. Summary of systematic uncertainties.

which may be separated into charm and beauty components:

$$f(b \to \Lambda_c^+ X) \cdot Br(\Lambda_c^+ \to pK^-\pi^+) \;=\; (0.48 \pm 0.12 \pm 0.05)\%$$

$$f(c \to \Lambda_c^+ X) \cdot Br(\Lambda_c^+ \to pK^-\pi^+) \;=\; (0.33 \pm 0.15 \pm 0.08)\%$$

These measurements may be combined with the ARGUS/CLEO average for $Br(\Lambda_c^+ \to pK^-\pi^+)$:

$$f(b \to \Lambda_c^+ X) \;=\; (11.1 \pm 4.0 \pm 1.2 \pm 2.8)\%$$

$$f(c \to \Lambda_c^+ X) \;=\; (7.6 \pm 4.1 \pm 2.0 \pm 1.9)\%$$

$$\Gamma(Z^0 \to \Lambda_c^+ X)/\Gamma_{had} \;=\; (7.5 \pm 2.2 \pm 0.9 \pm 1.9)\%$$

In conclusion, the $f(c \to \Lambda_c^+ X) \cdot Br(\Lambda_c^+ \to pK^-\pi^+)$ has been measured at $\sqrt{s} \sim 90$ GeV, and is compatible with measurements at $\sqrt{s} \sim 10$ GeV. b baryon decays to Λ_c^+ could produce an excess of Λ_c^+ over the number expected from B meson decays alone, and using the CLEO measurement of $\mathrm{Br}\left(\overline{B} \to \Lambda_c^+ X\right) \cdot Br\left(\Lambda_c^+ \to pK^-\pi^+\right) = (0.27 \pm 0.06)\%$, and the results of this analysis for $f(b \to \Lambda_c^+ X)$, one obtains

$$f(b \to Y) \cdot Br\left(Y \to \Lambda_c^+ X\right) \cdot Br\left(\Lambda_c^+ \to pK^-\pi^+\right) = (0.21 \pm 0.14)\%$$

where Y is a source of Λ_c^+ in $Z^0 \to \bar{b}b$ events other than B mesons. This may be interpreted as a 1.4σ excess of Λ_c^+production due to b baryon decays.

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