SELEX: Recent Progress in the Analysis of Charm-Strange and Double-Charm Baryons

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New Results on the $\Omega_c^0$

DCB History, Features, Problems, Solutions
- The Discovery of Double Charm Baryons
- Features, Problems, and Solutions
- New Analysis Features within SELEX

First Observation of $\Xi_{cc}^+ \rightarrow \Xi_c^+ \pi^+ \pi^-$

Lifetime Determination of $\Xi_{cc}^+$

Summary
- Conclusions
- Future Work
$\Omega_c^0$ in Three Decay Modes

$\Omega_c^0 \rightarrow \Omega^- \pi^+$
Signal: $35 \pm 12$

$\Omega_c^0 \rightarrow \Omega^- \pi^+ \pi^+ \pi^-$
Signal: $44 \pm 14$

$\Omega_c^0 \rightarrow \Xi^- K^- \pi^+ \pi^+$
Signal: $28 \pm 12$

Total sample $107 \pm 22$ events (nearly half in $\Omega 3\pi$)
Working on systematics of Mass Measurement
**Calculate Reduced Proper Time:** 
\[ ct = L - N \sigma / \gamma \]
Here: \( N = 6 \)

- **Proper Time Resolution:** \( \sim 20 \text{ fs} \)

- **Maximize Likelihood for three exponentials (2 background)**

\[
N_s (1 - \alpha) f(t) \tau^{-1} e^{-t/\tau} + \alpha N_B (\beta \tau_1^{-1} e^{-t/\tau_1} + (1 - \beta) \tau_2^{-1} e^{-t/\tau_2})
\]

- **Fit parameters are** \( \tau, \alpha, \beta, \tau_1, \tau_2 \)

- **Use** \( \Omega_c^0 \rightarrow \Omega^- \pi^+, \Omega_c^0 \rightarrow \Omega^- \pi^+ \pi^+ \pi^- \)

- **First separate for each mode, then combined**
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$\Omega_c^0$ Lifetime

combined (SELEX Prelim.):

$\tau(\Omega_c^0) = 69 \pm 14 \pm 9 \text{ fs}$

PDG: $69 \pm 12 \text{ fs}$

(175 evts from 3 exper)

$$\frac{\tau(\Xi_c^0)}{\tau(\Omega_c^0)} = 1.5 \pm 0.3$$

Theory: $\sim 1$

$\Omega_c^0 \rightarrow \Omega^- \pi^+: 67.5 \pm 18.0 \text{ fs}$

$\Omega_c^0 \rightarrow \Omega^- \pi^+ \pi^+ \pi^- : 72.3 \pm 20.0 \text{ fs}$

Theory: $1.2 - 1.7$
An excited state and a pair of isodoublets?
Features and Problems in Original Analysis...

- All Signals have very low statistics
- There is nearly no background (→ difficult to determine)
- Entries in histograms only from baryon ($\Sigma^-$, proton) beams
- Other experiments do not see the states (but: nobody else has baryon beams...)
- Lifetime is short ($< 33$ fs)
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...and Possible Solutions

- Look for other decay modes to confirm DCB hypothesis
- Develop new method for background determination
- Include single-charm in vertex fit of double-charm vertex
- Redo full analysis chain to increase statistics
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Other Decay Modes of Double Charm Baryons

Cabibbo allowed decay of $\Xi_{cc}^+$:

In Final State:
- Baryon
- Quarks $csdu\bar{d}$
- Plus pairs from sea
- Cascaded decay chain

Easily accessible in SELEX:

$\Xi_{cc}^+ \rightarrow \Lambda_c^+ K^- \pi^+$
$\Xi_{cc}^+ \rightarrow pD^+ K^-$
$\Xi_{cc}^+ \rightarrow \Xi_c^+ \pi^- \pi^+$
$\Xi_{cc}^{++} \rightarrow \Lambda_c^+ K^- \pi^+ \pi^+$
$\Xi_{cc}^{++} \rightarrow pD^+ K^- \pi^+ \pi^+ \pi^-$
$\Xi_{cc}^{++} \rightarrow \Xi_c^+ \pi^+ \pi^- \pi^+$
$\Xi_{cc}^{++} \rightarrow \Xi_c^+ \pi^+ \pi^+ \pi^- \pi^+$

$\Omega_{cc}^+ \rightarrow \Xi_c^+ K^- \pi^+$
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```
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\text{In Final State:} \\
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\end{array}
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  $\Xi_{cc}^+ \rightarrow pD^+ K^-$
  
  $\Xi_{cc}^+ \rightarrow \Xi_c^+ \pi^- \pi^+$
  
  $\Xi_{cc}^{++} \rightarrow \Lambda_c^+ K^- \pi^+ \pi^+$
  
  $\Xi_{cc}^{++} \rightarrow pD^+ K^- \pi^+ (?)$

  $\Xi_{cc}^{++} \rightarrow \Xi_c^+ \pi^+$
  
  $\Xi_{cc}^{++} \rightarrow \Xi_c^+ \pi^+ \pi^+ \pi^-$

$\Omega_{cc}^{+} \rightarrow \Xi_c^+ K^- \pi^+$

$\Omega_{cc}^{+} \rightarrow \Xi_c^+ K^- \pi^+ \pi^- \pi^-$
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\[ W^+ \]
\[ c \quad s \quad d \quad c \quad d \]

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**Easily accessible in SELEX:**

- $\Xi_{cc}^+ \rightarrow \Lambda_c^+ K^- \pi^+$
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- $\Xi_{cc}^+ \rightarrow \Xi_c^+ \pi^- \pi^+$
- $\Xi_{cc}^{++} \rightarrow \Lambda_c^+ K^- \pi^+ \pi^+$
- $\Xi_{cc}^{++} \rightarrow pD^+ K^- \pi^+ \pi^- (?)$
- $\Xi_{cc}^{++} \rightarrow \Xi_c^+ \pi^+$,
- $\Xi_{cc}^{++} \rightarrow \Xi_c^+ \pi^+ \pi^+ \pi^-$
- $\Omega_{cc}^+ \rightarrow \Xi_c^+ K^- \pi^+$,
- $\Omega_{cc}^+ \rightarrow \Xi_c^+ K^- \pi^+ \pi^+ \pi^-$
The Discovery of Double Charm Baryons
Features, Problems, and Solutions

**Summary**

The Discovery of Double Charm Baryons

**New Analysis Features within SELEX**

**Lifetime Determination of \( \Xi_{cc}^+ \)**

**First Observation of \( \Xi_{cc}^+ \rightarrow \Xi_c^{+} \pi^+ \pi^- \)**

**Features, Problems, and Solutions**

**New Results on the \( \Omega_c^0 \)**

**Lifetime Determination of \( \Xi_{cc}^+ \)**

**Jürgen Engelfried**

**SELEX Charm-Strange and Double-Charm Baryons**
Background Determination: Event Mixing

- First decay vertex close to primary vertex: assume all bkgd is combinatoric
- Make combinatoric bkgd by taking first decay vertex from one event, second from other
- Use each single-charm event 25 times to increase statistics

Resulting combinatoric bkgd is absolutely normalized ⇒ Bkgd shape known

![Decay Schematic](image)

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![Plot](image)

**Jürgen Engelfried**

SELEX Charm-Strange and Double-Charm Baryons 20/30
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$\Xi_{cc}^+ \rightarrow \Lambda_c^+ K^- \pi^+ – \text{New Analysis}$

Re-analysis of full data set ⇒ More $\Lambda_c$ cands (1630 → 2450)

- Refit $\Xi_{cc}^+$ vertex using $\vec{p}_{\Lambda_c^+}$ together with $K^- \pi^+$ tracks ⇒ Better $L1$ resolution
- Use event mixing for background
New Results on the $\Omega_c^0$
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Summary

$\Xi_{cc}^+ \rightarrow \Lambda_C^+K^--\pi^+$, $\Lambda_C^+ \rightarrow pK^-\pi^+$ – New Analysis

\begin{align*}
\text{Mass } & \Lambda_c^+K^-\pi^+ [\text{GeV/c}^2] \\
\text{Entries per } 5\text{MeV/c}^2 & \\
\text{SELEX Preliminary}
\end{align*}
Features of new Analysis

- **Re-Analysis and Relaxing Cuts on Single Charm:**
  - some more background, but shape is well understood from combinatoric analysis
  - more signal

- **Improved sec. vertex resolution:**
  - Cleaner Signals, access to other modes
  - Possibility (but challenging) to measure lifetime (is around 1 $\sigma$)
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The Discovery of Double Charm Baryons
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$$\Xi_{cc}(3780)^{++} \rightarrow \Lambda_c^+ K^- \pi^+ \pi^+$$

- Re-Analyzed Data
- Restrict to $\Sigma^-$ Beam
- Peak wider than Resolution
- Half decay to $\Xi_{cc}(3520)$
- Still working on Details

Re-Analyzed Data

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$\Xi_{cc}^+ \rightarrow \Xi_c^+ \pi^+ \pi^-$ – First Observation

**FIRST OBSERVATION:** $\Xi_{cc}^+ \rightarrow \Xi_c^+ \pi^+ \pi^-$, $\Xi_c^+ \rightarrow pK^- \pi^+$
Comparing the Mass of the Three Decay Modes

$\Lambda_c^+ K^+ L/\sigma_1 > 1.8$

Mass $3521.8 \pm 1.7 \text{ MeV}/c^2$

$\Xi_c^+ K^+ L/\sigma_1 > 0.$

$p D^+ K L/\sigma_1 > 1.$
Lifetime of $\Xi_{cc}^+$

SELEX Preliminary Results

uncorrected: $30\pm10$ fs
Cuts loose events at small $ct$
Use MC to correct for this effect
Uncorrected Lifetime: $(30 \pm 10 \text{ fs})$
Corrected Lifetime: $(15^{+10}_{-??} \pm ??) \text{ fs}$
Conclusions

- SELEX is still the only experiment observing Double Charm Baryons
- Published results on
  - $\Xi_{cc}^+ \rightarrow \Lambda_c^+ K^- \pi^+$ (PRL86 (2002) 5243)
  - $\Xi_{cc}^+ \rightarrow pD^+ K^-$ (PLB628 (2005) 18)
- SELEX is re-analyzing the data, with improved efficiency
- Presented $\Xi_{cc}^+ \rightarrow \Lambda_c^+ K^- \pi^+$
- $\Xi_{cc}(3780)^{++}$ is still there
- First Observation of $\Xi_{cc}^+ \rightarrow \Xi_c^+ \pi^- \pi^+$
- Determination of the $\Xi_{cc}^+$ Lifetime
Future Work

- Finishing re-analysis of $\Xi_{cc}^+ \rightarrow \Lambda_c^+ K^- \pi^+$
- Finishing analysis of $\Xi_{cc}^+ \rightarrow \Xi_c^+ \pi^- \pi^+$
- Finishing lifetime analysis
- Finishing $\Xi_{cc}(3780)^{++}$
- Working on re-analysis of $\Xi_{cc}^+ \rightarrow pD^+ K^-$
- Search for $\Omega_{cc}^+$
- Look for $\Xi_{cc}^{++}$ in all corresponding decay modes around 3500 MeV/$c^2$

STAY TUNED!