Charmed and Doubly Charmed Baryons
Recent Results from SELEX

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Introduction

Charm about 8-10 years ago:
- The “Traditional” Charm Experiments: E791, FOCUS, SELEX, (WA89, WA92), CLEO, H1/ZEUS
- “Traditional” Topics: Production, Lifetime, rare decays, resonances in decay, $D^0 - \overline{D^0}$ mixing
- Small number of theory and phenomenology papers

In the last 5 years or so:
- New players: BaBar and Belle, CDF, D0 (beauty)
- New charm states: double charm baryons, hidden double charm ($J/\psi c\bar{c}$), $D_s^*$, $X (Y, Z)$
- Penta-quark Euphoria
- Large number of “theory” papers: spectroscopy, production
- Shift of used words in papers: di-quark
Update on Double Charm Baryons

The Discovery of Double Charm Baryons

Features, Problems, and Solutions

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

Observation of $\Xi_{cc}^{++} \rightarrow \Lambda_{c}^{+} K^{-} \pi^{+} \pi^{+}, \Xi_{c}^{+} \pi^{-} \pi^{+} \pi^{+}$

My Personal List of Mysteries in Charm and Beauty

Other SELEX Charm Results

Hadro-Production of Charm

Cabibbo-Suppressed $\Xi_{c}^{+}$ Decays

$\Lambda_{c}^{+}$ Semi-leptonic Decay

Summary
Doubly Charmed Baryons

BARYONS WITH LOWEST SPIN ($J = \frac{1}{2}$)

BARYONS WITH HIGHEST SPIN ($J = \frac{3}{2}$)

SELEX candidates

not yet observed

ONE CHARM QUARK

TWO CHARM QUARKS

THREE CHARM QUARKS

NO CHARM QUARK

Observation of $\Xi_{cc}^{++} \rightarrow \Lambda_c^{+} K^- \pi^+ \pi^+, \Xi_c^+ \pi^- \pi^+ \pi^+$
Model Predictions for DCB Masses

- Several Authors (Bjorken 1986, Fleck & Richard 1989, Roncaglia 1995, Ellis 2002)
- Different models (Phenomenology, Bag, Quarkonium, Lattice)
- Masses (J=1/2): 3.516 – 3.66 GeV/c²
- Masses (J=3/2): 3.636 – 3.81 GeV/c²

Overall Features

- ground states near 3.6 GeV/c²
- ground states Isospin=1/2 multiplets degenerate
- Hyperfine splitting around 60 – 120 MeV/c²
- Most predict electromagnetic hyperfine transition (but some pionic)
- Model dependent predictions for orbital and radial excitations
The SELEX Collaboration

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Forward ($x_F > 0.1$) charm production

- $\Sigma^-$, $\pi^\pm$, $p$ beam at 600 GeV/$c$
- RICH PID above $\sim 22$ GeV/$c$
- 20 plane Si-Vertex.
- Data taken 1996/7
Vertex Spectrometer Performance

- transverse vtx resolution 8-15 μm
- 20 highly-efficient vertex planes over-determine tracks, reduce tracking confusion in high-multiplicity events
- target foils 0.8-2.2 mm thick with 1.5 cm spacing to localize primary interaction
- Lifetime resolution \( \sim 20 \text{ fs} \)
The Discovery of Double Charm Baryons
Features, Problems, and Solutions
Observation of $\Xi_{cc}^+ \rightarrow \Xi^-_c \pi^+ \pi^-$, $\Xi^+_{cc} \rightarrow \Lambda^+_c K^- \pi^+ \pi^+$, $\Xi^+_c \pi^- \pi^+ \pi^+$

Ring Imaging Cherenkov Counter Performance (1)
Ring Imaging Cherenkov Counter Performance (2)

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SELEX Single Charm Analysis

Charm Analysis Cuts

- Decay vertex separation significance $L/\sigma$
- Charm vector momentum points back to primary: cut on $(b/\sigma_b)^2$ (point-back cut)
- Decay vertex lies outside target material
- Proton and Kaon identified in RICH detector
SELEX Charm Selection Criteria

Charm Selection Cuts for single charm studies:

- secondary vertex significance:
  - $L/\sigma \geq 1$
    - short-lived states ($\Xi^0_c, \Omega^0_c$)
  - $L/\sigma \geq 8$
    - long-lived states ($\Lambda^+_c, D^+$)
- Pointback $\leq 4$ ($2\sigma_b$)
- second-largest miss significance among decay tracks $\geq 4$. 

- primary vertex tagged by beam track
- secondary vertex must lie outside material
SELEX Search Strategy for Doubly-Charmed Baryons

- \( ccq \) decays to \( csqu\bar{d} \). Look for charm, strange and baryon in final state. SELEX started with \( \Lambda_c^+ K^- \pi^+ \).
- Look for new secondary vertex between primary and \( \Lambda_c^+ \)
- no RICH PID on new \( K^- \pi^+ \) tracks (too soft)
- All other cuts fixed from previous searches
SELEX: Experimental Evidence from 2002

SELEX reported 3 significant high mass peaks

SELEX argued that these states are doubly-charmed baryons
My Personal List of Mysteries in Charm and Beauty

Update on Double Charm Baryons

Jürgen Engelfried

Summary

Observation of Features, Problems, and Solutions

The Discovery of Double Charm Baryons

112001-1 0031-9007


(SELEX Collaboration)

First Observation of the Doubly Charmed Baryon $\Xi_{cc}^+$


(SELEX Collaboration)

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An exited 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 (Σ−, proton) beams
- Other experiments do not see the states (but: nobody else has baryon beams...)
- Lifetime is short (< 33 fs)
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Observation of $\Xi^{++}_{cc} \rightarrow \Xi^{+}_{c} \pi^+ \pi^-$

Observation of $\Xi^{++}_{cc} \rightarrow \Lambda^+_c K^- \pi^+ \pi^+$, $\Xi^{+}_{c} \pi^- \pi^+ \pi^+$
...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 $\Xi_{cc}^+$:

\[
\begin{align*}
\bar{d} & \quad u \\
W^+ & \quad \bar{d} \\
c & \quad s \\
c & \quad c \\
d & \quad d
\end{align*}
\]

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

Easily accessible in SELEX:

\[
\begin{align*}
\Xi_{cc}^+ & \rightarrow \Lambda_c^+ K^- \pi^+ \\
\Xi_{cc}^+ & \rightarrow \Lambda_c^+ K^- \pi^+ \pi^+ \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^+ (?) \\
\Xi_{cc}^{++} & \rightarrow \Xi_c^+ \pi^- \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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Other Decay Modes of Double Charm Baryons

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\Omega_{cc}^+ & \rightarrow \Xi_c^+ K^- \pi^+ \pi^+ \pi^- 
\end{align*}
\]
Other Decay Modes of Double Charm Baryons

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

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

Easily accessible in SELEX:

- $\Xi^{+}_{cc} \rightarrow \Lambda_{c}^{+} K^{-} \pi^{+}$
- $\Xi^{+}_{cc} \rightarrow \Lambda_{c}^{+} K^{-} \pi^{+} \pi^{+} \pi^{-}$
- $\Xi^{+}_{cc} \rightarrow pD^{+} K^{-}$
- $\Xi^{+}_{cc} \rightarrow \Xi_{c}^{+} \pi^{-} \pi^{+}$
- $\Xi^{++}_{cc} \rightarrow \Lambda_{c}^{+} K^{-} \pi^{+} \pi^{+}$
- $\Xi^{++}_{cc} \rightarrow pD^{+} K^{-} \pi^{+}$ (?)
- $\Xi^{++}_{cc} \rightarrow \Xi_{c}^{+} \pi^{+}$
- $\Xi^{++}_{cc} \rightarrow \Xi_{c}^{+} \pi^{+} \pi^{+} \pi^{-}$
- $\Omega^{+}_{cc} \rightarrow \Xi_{c}^{+} K^{-} \pi^{+}$
- $\Omega^{+}_{cc} \rightarrow \Xi_{c}^{+} K^{-} \pi^{+} \pi^{+} \pi^{-}$
Update on Double Charm Baryons
My Personal List of Mysteries in Charm and Beauty
Other SELEX Charm Results
Summary

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

$\Xi_{cc}^+ \rightarrow pD^+ K^-$ (PLB628 (2005) 18)
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
The Discovery of Double Charm Baryons

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Observation of $\Xi_{cc}^{++} \rightarrow \Lambda_c^+ K^- \pi^+ \pi^+$, $\Xi_c^+ \pi^- \pi^+ \pi^+$

Summary

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

- Refit $\Xi_{cc}$ vertex using $\bar{p}_{\Lambda_c^+}$ together with $K^-\pi^+$ tracks
  $\Rightarrow$ Better $L_1$ resolution
- Use event mixing for background
The Discovery of Double Charm Baryons

Features, Problems, and Solutions

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

$\Xi_{cc}^+ \rightarrow \Lambda_C^+ K^- \pi^+$, $\Lambda_C^+ \rightarrow pK^- \pi^+$ – New Analysis
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 \( \sigma \))
FIRST OBSERVATION: $\Xi_{cc}^+ \rightarrow \Xi_c^+ \pi^+ \pi^-$, $\Xi_c^+ \rightarrow pK^- \pi^+$
Comparing the Mass of the Three Decay Modes

\[ \Lambda_c^+ K^+ L/\sigma > 1.8 \]

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

\[ \Xi_c^+ K^- \pi^+ L/\sigma > 0. \]

\[ p D^+ K^- L/\sigma > 1. \]
Observation of $\Xi_{cc}^{++} \rightarrow \Lambda_{c}^{+} K^{-} \pi^{+}\pi^{+}$

- If we have a ccd state ($\Xi_{cc}^{+}$), there has to be a ccu state as well ($\Xi_{cc}^{++}$)
- Look in $\Xi_{cc}^{++} \rightarrow \Lambda_{c}^{+} K^{-} \pi^{+}\pi^{+}$
- Use same cuts as before
  - Use same code
  - Just ask for one more $\pi^{+}$

Green: Absolutely-normalized background
Gaussian with fixed width (MC)

New $\Xi_{cc}^{++}$ at 3452!
Observation of $\Xi_{cc}^{++} \rightarrow \Xi_{c}^{+}\pi^{-}\pi^{+}\pi^{+}$

- Now look in $\Xi_{c}^{+}\pi^{-}\pi^{+}\pi^{+}$
- Same as before, ask for additional $\pi^{+}$
- Only use $\Xi_{c}^{+} \rightarrow pK^{-}\pi^{+}$

- Add data from both modes
- Significance 6.5 $\sigma$
- Mixed event background describes sidebands
Re-Analyzed Data
Restrict to $\Sigma^-$ Beam
Peak wider than Resolution
Half decay to $\Xi_{cc}^+(3520)$
Still working on Details

$\Xi_{cc}(3780)^{++} \rightarrow \Lambda_c^+ K^- \pi^+ \pi^+$
Why weakly decaying Doublet?

- If Excitation is Chromomagnetic:
  - Expect dominant E1 Dipole Transition (like in \( D^* \rightarrow D \gamma \))
  - Weak decay of Chromomagnetic Excited State Suppressed by \( \sim 6 \) orders of magnitude

- Bardeen, Eichten and Hill: spectroscopy of \( cc \) compared to \( c\bar{s} \) (PRD68 054024, hep-ph/0305049)

\[
\text{Ground State: } \quad J^P = \frac{1^+}{2} \left[ c \uparrow c \uparrow \ L = 0, \ J^P = 1^+ \right] q \downarrow
\]

\[
\text{Excited State: } \quad J^P = \frac{1^-}{2} \left[ c \uparrow c \downarrow \ L = 1, \ J^P = 1^- \right] q \downarrow
\]

- First excited state is \( L = 1 \) of heavy \( (cc) \) di-quark
- In at least one version of the model splitting is consistent with observed 78 MeV/\( c^2 \)
- First EM transition is M2.
Doubly Charmed Baryons Production

- **SELEX**: Dominantly produced by baryon beam.
- **E791** has looked in 250 GeV/c $\pi^-$ production
  - no signal
- **FOCUS** looked in 250 GeV/c photo-production
  - no signal
- **BaBar** looked:
  - no signal
- **Hadro-Production Theory/Phenomenology**:
  - Most just assume independent production
  - But: Are intrinsic components important?
My Personal List of Mysteries in Charm and Beauty

Mysteries: Observations which have no commonly accepted explanation within the usually accepted theory.
Charm Mysteries (1) – Discovery of the $\Xi^+_c$

- Beam: 135 GeV/c $\Sigma^-$
- 3 weeks of running
- no silicon detectors

- 83 events $\Xi^+_c \rightarrow \Lambda K^- \pi^+ \pi^+$
- measured $\Xi^+_c$ lifetime correctly
Beauty Mysteries – $\Lambda_b$ in ISR

CERN-ISR R422 (Split Field Magnet), 1988/1991

$\Lambda_b^0 \rightarrow p D^0 \pi^-$

$\Lambda_b^0 \rightarrow \Lambda_c^+ \pi^+ \pi^- \pi^-$

Il Nuovo Cimento 104, 1787
(Double)-Charm Mysteries (2) – $J/\psi \eta_c$ Production

- Belle observed high double charm production in
  
  $e^+ e^- \rightarrow J/\psi c \bar{c}$,
  
  $e^+ e^- \rightarrow J/\psi \eta_c$

  (PRL 89 (2002) 142001)

- At publication, factor x40 higher cross section than theory.

- BaBar confirms a few years later

- Belle arXiv:0901.2775: still x10 higher
Charm Mysteries (3) – Narrow $D_S$ Resonances

BaBar, CLEO, Belle (2003)

$D_{sJ}^*(2315) \rightarrow D_S \pi^0$,
$D_{sJ}^*(2463) \rightarrow D_S \gamma \pi^0$

SELEX 2004

$D_{sJ}^*(2632) \rightarrow D_S^+ \eta$ and $D^0 K^+$

PRL90 (hep-ex/0304021);
PRD68;
PRL91 (hep-ex/0308019)

PRL 93, 242001 (hep-ex/0406045)
Charm Mysteries (4) – X, Y, Z

- Charmonium-like states
- Are they Charmonium? Are they Tetra-quark states?
- Do the charged states (observed by Belle) really exist?
Experiments at Jefferson Lab (and other places) search for Baryon Resonances

About half the states predicted by $SU(6)_{SF} \times SO(3)$ are missing

$SU(6)_{SF} \times SO(3)$ is non-relativistic, spin and angular momentum are separate.

Other schemes predicting the correct number of resonances exist (e.g. $SU(3)_F \times SO(3, 1)$, $SO(3, 1)$ is Lorentz-Group)
Hadro–Production Mysteries – Cronin Effect

- $p_t$ distributions depend on particle type and target material
- First Observations:
  - Cronin, Frisch, Shochet, et al.: *Production of Hadrons with Large Transverse Momentum at 200-GeV and 300-GeV*
- Another interpretation: $\alpha = \alpha(x_F, p_t)$
- Consequences for charm signature of Quark-Gluon-Plasma
- Not enough experimental data available over full range of kinematic variables
Other SELEX Charm Results

- Hadro-Production of Charm
- Cabibbo-Suppressed $\Xi_c^+$ Decays
- $\Lambda_c^+$ Semi-leptonic Decay
Hadro-Production of Charm

- Usual parametrization of material dependend cross section: $\sigma \propto A^\alpha$
- From $\Lambda$-Production: $\alpha = \alpha(x_F, p_t)$
- Charm: Published $\alpha$ vary between 2/3 and 1, different(?) for open and hidden charm.
- Usually experiments only give one $\alpha$ averaged over their $(x_F, p_t)$ acceptance
- No model on first principle exists, even less for double charm
- Still problems calculating double-double-charm production in $e^+ e^- \rightarrow J/\psi \eta_c$!!!
- Important input for other fields like Heavy-Ion and Cosmics
Hadro-Production of Charm in SELEX

- SELEX has charm signals with decent statistics in 14 particles and modes, in several $x_F$ and $p_t$ bins.
- $D^+, D^0, D_s^+, D^+(2010), \Lambda_c^+$, and charge-conjugate
- 2 Copper and 3 Carbon Targets
- 4 different beam particles: $\Sigma^-, \pi^-, \rho, \pi^+$
- Cross check results with $\Lambda$ and $K^0$ production
- Average results in different categories: beams, charm/anticharm, leading/nonleading

PhD Thesis E. Alejandro Blanco-Covarrubias
Hadro-Production of Charm (cont.)

No difference when separating in charm and anti-charm final states

(a) Averaged over all particles and beams

(b) Charm

AntiCharmp
Hadro-Production of Charm (cont.)

3 $\sigma$ difference in production by baryon and meson beams
2.3 $\sigma$ difference when separating in leading and non-leading final states
Hadro-Production of Charm (cont.)

No difference for low/high $p_t^2$ production
Cabibbo-Suppressed Weak Decay of Charm

- Cabibbo-Suppressed weak decay of charm $(c \rightarrow s$ vs $c \rightarrow d)$:
  Expect (phase space corrected) ratio of $\sim \tan^2 \Theta_c = 0.05$ if rescattering effects are not important.

- Results from $D$ mesons: rescattering is important.

- Need to measure as many channels as possible to understand rescattering effects.
Cabibbo Suppression for Charmed Baryons

From PDG:
- $\Lambda_c^+$:
  - $\Lambda K^+/\Lambda \pi^+ = 0.047 \pm 0.009$
  - $\Sigma^+ K^+\pi^-/\Sigma^+\pi^+\pi^- = 0.047 \pm 0.015$
  - $p\pi^-\pi^+/pK^-\pi^+ = 0.07 \pm 0.04$
- $\Xi_c^+$:
  - $pK^-\pi^+/\Sigma^+K^-\pi^+ = 0.22 \pm 0.03$
  - $\Sigma^+ K^+ K^-/\Sigma^+\pi^+K^- = 0.16 \pm 0.06$
- Generally not close to 0.05
First Observation of $\Xi_c^+ \rightarrow \sum^+ \pi^- \pi^+$, $\Xi_c^+ \rightarrow \sum^- \pi^+ \pi^+$

Can cross check analysis method with $\Lambda_c^+$ modes

PhD Thesis Eric Vázquez-Jáurequi
### Branching Ratio Results:


<table>
<thead>
<tr>
<th>Branching Ratio</th>
<th>This Analysis</th>
<th>Other Measurements</th>
</tr>
</thead>
<tbody>
<tr>
<td>( B(\Xi_c^+ \to \Sigma^+\pi^-\pi^+) ) / ( B(\Xi_c^+ \to \Xi^-\pi^+\pi^+) )</td>
<td>0.48 ± 0.20 ( \alpha = 6.4 \pm 2.7 )</td>
<td>–</td>
</tr>
<tr>
<td>( B(\Xi_c^+ \to \Sigma^-\pi^+\pi^+) ) / ( B(\Xi_c^+ \to \Xi^-\pi^+\pi^+) )</td>
<td>0.18 ± 0.09 ( \alpha = 2.5 \pm 1.2 )</td>
<td>–</td>
</tr>
<tr>
<td>( B(\Xi_c^+ \to \Sigma^-\pi^+\pi^+) ) / ( B(\Xi_c^+ \to \Sigma^+\pi^-\pi^+) )</td>
<td>0.42 ± 0.24 ( \alpha = 0.43 \pm 0.25 )</td>
<td>–</td>
</tr>
<tr>
<td>( B(\Xi_c^+ \to pK^-\pi^+) ) / ( B(\Xi_c^+ \to \Xi^-\pi^+\pi^+) )</td>
<td>0.194 ± 0.054 ( \alpha = 2.6 \pm 0.7 )</td>
<td>0.234 ± 0.047 ± 0.022 ( 0.20 \pm 0.04 \pm 0.02 )</td>
</tr>
<tr>
<td>( B(\Lambda_c^+ \to \Sigma^-\pi^+\pi^+) ) / ( B(\Lambda_c^+ \to pK^-\pi^+) )</td>
<td>0.314 ± 0.067 ( \alpha = 0.30 \pm 0.07 )</td>
<td>–</td>
</tr>
<tr>
<td>( B(\Lambda_c^+ \to \Sigma^+\pi^-\pi^+) ) / ( B(\Lambda_c^+ \to pK^-\pi^+) )</td>
<td>0.72 ± 0.14 ( \alpha = 0.68 \pm 0.14 )</td>
<td>0.74 ± 0.07 ± 0.09 ( 0.54^{+0.18}_{-0.15} )</td>
</tr>
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<td>( B(\Lambda_c^+ \to \Sigma^-\pi^+\pi^+) ) / ( B(\Lambda_c^+ \to \Sigma^+\pi^-\pi^+) )</td>
<td>0.38 ± 0.10 ( \alpha = 0.39 \pm 0.11 )</td>
<td>0.53 ± 0.15 ± 0.07</td>
</tr>
</tbody>
</table>
**$\Lambda_c^+$ Semi-leptonic Decay**

**History:**

- **Mark II (1982):** $\Gamma(\Lambda_c^+ \to e^+ X)/\Gamma = (4.5 \pm 1.7)\%$
- **CLEO (1994):** $\Gamma(\Lambda_c^+ \to \Lambda e^+ \nu)/\Gamma(pK\pi) = 0.43 \pm 0.08$
- **PDG:** $\Gamma(\Lambda_c^+ \to pK^-\pi^+)/\Gamma = 5\%$

**What are the rest of the modes?**

- **$D$ mesons:** ground state and $p$-wave ($K^*(892)$)  
  $\sim 85\%$ of total semileptonic rate

**SELEX observed** $\Lambda_c^+ \to \Lambda(1520)e^+\nu$
Measure $\Gamma(\Lambda_c^+ \rightarrow \Lambda(1520)e^+\nu)/\Gamma(\Lambda_c^+ \rightarrow pK^-\pi^+)$

- Use all features of SELEX: tracking, RICH, eTRD, BTRD, Pb glass
- eTRD separates $e$ from $\pi$ up to 120 GeV/$c$, momentum dep. efficiency measured with Pb glass
- Look for 3-prong vertices, $pK^-e^+$, $pK^-\pi^+$, $L/\sigma > 8$, RICH id for $p$, $K^-$, $M(pKe) < M(\Lambda_c^+)$
- Combinatoric Background via event mixing

Jürgen Engelfried
The $pK^-$ Mass Spectrum from $pK^-e^+$ vertex

Fit to $\Lambda(1520)$ with fixed width (PDG) and MC resolution:

Yield: $132 \pm 26$

$pK^-\pi^+$ yield: $1544 \pm 34$
**$\Lambda_c^+$ Branching Ratios**

- correct for eTRD Efficiency ($\sim 93\%$), relative acceptance ($\sim 1.2$), $\Lambda(1520) \to pK^- \text{ BR}$

\[
\Gamma(\Lambda_c^+ \to \Lambda(1520)e^+\nu)/\Gamma(\Lambda_c^+ \to pK^-\pi^+) = 0.47 \pm 0.10
\]

SELEX Preliminary

- $\Gamma(\Lambda_c^+ \to pK^-\pi^+)/\Gamma = 0.05 \pm 0.013$ (PDG)
  (Can this be measured well by BES or Panda?)

\[
\Rightarrow (\Gamma(\Lambda e^+\nu) + \Gamma(\Lambda(1520)e^+\nu))/\Gamma = (4.5 \pm 1.3)\%
\]

- These two semileptonic modes saturate the Mark II measurement

PhD Thesis Jorge Amaro-Reyes
Conclusions – Double Charm Baryons

- SELEX is still the only experiment observing Double Charm Baryons (until LHCb trigger upgrade?)

- Published results on $\Xi_{cc}^+ \rightarrow \Lambda_c^+ K^- \pi^+$, $\Xi_{cc}^+ \rightarrow pD^+ K^-$

- SELEX is re-analyzing the data, with improved efficiency

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

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

- Working on determination of the $\Xi_{cc}$ Lifetime

- Searching for $\Omega_{cc}^+$
Conclusions

- Working on Double Charm Baryons
- Study of Charm Hadro-Production
- Preliminary result on semi-leptonic decay of $\Lambda_c^+$
- Study Cabibbo Suppressed Decays of charm baryons
  - First Observation of $\Xi_c^+ \rightarrow \Sigma^+ \pi^- \pi^+$, $\Xi_c^+ \rightarrow \Sigma^- \pi^+ \pi^+$
  - More modes to come...
My Personal Wishlist for Theory (and Phenomen.)

- What is the correct potential (model) for heavy-light systems?
- What is the correct potential in charmonium?
- How to transfer this to double-heavy baryons? \((c\bar{c} \rightarrow cc)\)
- Make a good pre(post)diction of the mass of the \(\Xi_{cc}\)
- What is the mass difference between \(\Xi_{cc}^{+}\) and \(\Xi_{cc}^{++}\) (including sign!)?
- What are the quantum numbers of the lowest exited state of the \(\Xi_{cc}\)?

- In this field, Experiments are Ahead!