Recent charmed baryon results at BESIII

Peirong Li (李培荣)

on behalf of BESIII collaboration

University of Chinese Academy of Sciences (UCAS), Beijing

QCD15, Montpellier, France
The BESIII experiment

\( \Lambda_c^+ \) decays at threshold
- \( \Lambda_c^+ \) hadronic decays
- \( \Lambda_c^+ \) semi-leptonic decays

Summary
Beijing Electron Positron Collider (BEPCII)

beam energy: 1.0 – 2.3 GeV

2004: started BEPCII upgrade, BESIII construction
2008: test run
2009 - now: BESIII physics run
The BESIII Detector @ BEPCII

Peak Luminosity:
0.85 \times 10^{33} \text{cm}^{-2}\text{s}^{-1} \text{ at } \psi(3770) \text{ in 2014}

Excellent tracking:
\delta p/p = 0.5\% @ 1\text{GeV}
dE/dx = 6\%

Shower reconstruction:
\delta E/E = 2.5\% @ 1\text{GeV}

Time resolution:
70\text{ps} @ BTOF
100\text{ps} @ ETOF
Rich of resonances: charmonia and charmed hadrons.

Threshold characteristic (pairs of $\tau$, $D$, $D_s$, $\Lambda_c$ ...).

Transition between smooth and resonances, perturbative and non-perturbative QCD.
New data taken for $\Lambda_c^+$ analysis

In 2014, BESIII took data above $\Lambda_c$ pair threshold and run machine at 4.6GeV with excellent performance!

Available data set for $\Lambda_c^+$ study

<table>
<thead>
<tr>
<th>Energy (GeV)</th>
<th>lum. (pb$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.575</td>
<td>~48</td>
</tr>
<tr>
<td>4.580</td>
<td>~8.5</td>
</tr>
<tr>
<td>4.590</td>
<td>~8.1</td>
</tr>
<tr>
<td>4.600</td>
<td>~567</td>
</tr>
</tbody>
</table>

First time to systematically study charmed baryon at threshold!

**FIG. 4:** The cross section for the exclusive process $e^+e^- \to \Lambda_c^+\Lambda_c^-$. 

**BELLE**

**PRL101 (2008) 172001**
Absolute BF of $Λ_c^+$ hadronic decays

- $Λ_c^+$ decay rates are still not well determined
  - BFs of most decay modes (~85%) are measured relative to $Λ_c^+ → pK^−π^+$
  - No completely model-independent measurements of the absolute BF of $Λ_c^+ → pK^−π^+$ (from Argus and CLEO very old results)
    - uncertainties of BFs are 25%~40% in PDG2014

- Belle’s first precision measurement:
  \[ B(Λ_c^+ → pK^−π^+) = (6.84 ± 0.24_{+0.21}^{−0.27})\% \]
  - precision reaches to 4.7%

- Measurement using the threshold pair-productions via $e^+e^-$ annihilations is unique:
  - the most simple and straightforward
  - kinematics does not allow additional particle produced along with the $Λ_c^+Λ_c^−$ pair
  - **Absolute measurement**: fully reconstruct the pairs and take ratios of DT yields and ST yields to measure the BFs
after adopting Belle’s
Detection of $\Lambda_c^+\Lambda_c^-$ pairs

12 modes

- $pK_S$
- $pK^-\pi^+$
- $pK_S\pi^0$
- $pK_S\pi^+\pi^-$
- $pK^-\pi^+\pi^0$
- $\Lambda\pi^+$
- $\Lambda\pi^+\pi^0$
- $\Lambda\pi^+\pi^-\pi^+$
- $\Sigma^0\pi^+$
- $\Sigma^+\pi^0$
- $\Sigma^+\pi^+\pi^-$
- $\Sigma^+\omega$

Constructing particles from final state particles:

- $K_S \rightarrow \pi^+\pi^-$
- $\pi^0 \rightarrow \gamma\gamma$
- $\Lambda \rightarrow p\pi^-$
- $\Sigma^0 \rightarrow \Lambda\gamma$
- $\Sigma^+ \rightarrow p\pi^0$
- $\omega \rightarrow \pi^+\pi^-\pi^0$

• Use energy difference ($\Delta E$) to improve S/B
• Extract signal yields in the beam-constrained mass ($M_{BC}$)

\[ \Delta E = E - E_{beam} \]

\[ M_{BC} = \sqrt{E_{beam}^2 - |\vec{p}_{\Lambda_c^-}|^2} \]

charge conjugate modes are implied in the following slides.
Estimation on the yields of the 12 modes

ST yields \( N_{i+}^{ST} = N_{\Lambda_c^+\Lambda_c^-} \cdot B_i \cdot \varepsilon_{i+}^{ST} \)

DT yields \( N_{i+j^-}^{DT} = N_{\Lambda_c^+\Lambda_c^-} \cdot B_i \cdot B_j \cdot \varepsilon_{i+j^-}^{DT} \)

\[ N_{-j}^{DT} = \sum_{i+ \neq j} N_{i+j^-}^{DT} + \sum_{i+ \neq j} N_{i-j+}^{DT} + N_{jj}^{DT} \]

<table>
<thead>
<tr>
<th>modes</th>
<th>( N_{ST} )</th>
<th>( N_{DT} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( pK_S )</td>
<td>1243 ± 37</td>
<td>89 ± 10</td>
</tr>
<tr>
<td>( pK^-\pi^+ )</td>
<td>6308 ± 88</td>
<td>390 ± 21</td>
</tr>
<tr>
<td>( pK_S\pi^0 )</td>
<td>558 ± 33</td>
<td>40 ± 7</td>
</tr>
<tr>
<td>( pK_S\pi^+\pi^- )</td>
<td>454 ± 28</td>
<td>29 ± 6</td>
</tr>
<tr>
<td>( pK^-\pi^+\pi^- )</td>
<td>1849 ± 71</td>
<td>148 ± 14</td>
</tr>
<tr>
<td>( \Lambda_c^+ )</td>
<td>706 ± 27</td>
<td>59 ± 8</td>
</tr>
<tr>
<td>( \Lambda^-\pi^0 )</td>
<td>1497 ± 52</td>
<td>89 ± 11</td>
</tr>
<tr>
<td>( \Lambda\pi^+\pi^- )</td>
<td>609 ± 31</td>
<td>53 ± 7</td>
</tr>
<tr>
<td>( \Sigma^0\pi^+ )</td>
<td>586 ± 32</td>
<td>39 ± 6</td>
</tr>
<tr>
<td>( \Sigma^+\pi^0 )</td>
<td>271 ± 25</td>
<td>20 ± 5</td>
</tr>
<tr>
<td>( \Sigma^+\pi^+\pi^- )</td>
<td>836 ± 43</td>
<td>56 ± 8</td>
</tr>
<tr>
<td>( \Sigma^+\omega )</td>
<td>157 ± 22</td>
<td>13 ± 3</td>
</tr>
</tbody>
</table>

- Dominated by \( \Lambda_c^+ \to pK^-\pi^+ \)
- Backgrounds are well controlled
Hadronic branching fraction results

- A least square global fitter: simultaneous fit to the all tag modes while constraining the total $\Lambda_{c}^{\pm}$ pair number, taking into account the correlations.

**BESIII prel.**

<table>
<thead>
<tr>
<th>Decay modes</th>
<th>Global fit $\mathcal{B}$</th>
<th>PDG $\mathcal{B}$</th>
<th>Belle $\mathcal{B}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$pK_{S}$</td>
<td>1.48 ± 0.08</td>
<td>1.15 ± 0.30</td>
<td>6.84 ± 0.24$^{+0.21}_{-0.27}$</td>
</tr>
<tr>
<td>$pK^{-}\pi^{+}$</td>
<td>5.77 ± 0.27</td>
<td>5.0 ± 1.3</td>
<td></td>
</tr>
<tr>
<td>$pK_{S}\pi^{0}$</td>
<td>1.77 ± 0.12</td>
<td>1.65 ± 0.50</td>
<td></td>
</tr>
<tr>
<td>$pK_{S}\pi^{+}\pi^{-}$</td>
<td>1.43 ± 0.10</td>
<td>1.30 ± 0.35</td>
<td></td>
</tr>
<tr>
<td>$pK^{-}\pi^{+}\pi^{0}$</td>
<td>4.25 ± 0.22</td>
<td>3.4 ± 1.0</td>
<td></td>
</tr>
<tr>
<td>$\Lambda\pi^{+}$</td>
<td>1.20 ± 0.07</td>
<td>1.07 ± 0.28</td>
<td></td>
</tr>
<tr>
<td>$\Lambda\pi^{+}\pi^{0}$</td>
<td>6.70 ± 0.35</td>
<td>3.6 ± 1.3</td>
<td></td>
</tr>
<tr>
<td>$\Lambda\pi^{+}\pi^{0}$</td>
<td>3.67 ± 0.23</td>
<td>2.6 ± 0.7</td>
<td></td>
</tr>
<tr>
<td>$\Sigma^{0}\pi^{+}$</td>
<td>1.28 ± 0.08</td>
<td>1.05 ± 0.28</td>
<td></td>
</tr>
<tr>
<td>$\Sigma^{+}\pi^{0}$</td>
<td>1.18 ± 0.11</td>
<td>1.00 ± 0.34</td>
<td></td>
</tr>
<tr>
<td>$\Sigma^{+}\pi^{+}\pi^{-}$</td>
<td>3.58 ± 0.22</td>
<td>3.6 ± 1.0</td>
<td></td>
</tr>
<tr>
<td>$\Sigma^{+}\omega$</td>
<td>1.47 ± 0.18</td>
<td>2.7 ± 1.0</td>
<td></td>
</tr>
</tbody>
</table>

- Only stat. errors

- $B(pK^{-}\pi^{+})$: BESIII precision comparable with Belle’s result
- BESIII rate $B(pK^{-}\pi^{+})$ is smaller
- Precisions of the other 11 modes are also improved.
Absolute Measurement decay rate of $\Lambda_c^+ \rightarrow \Lambda e^+ \nu_e$

- $B(\Lambda_c^+ \rightarrow \Lambda e^+ \nu_e)$ will provide important experimental information
  - test the theoretical predictions (ranges from 1.4% to 9.2%)
  - calibrate the LQCD calculations
  - determining CKM matrix elements.

- No direct absolute measurement for $B(\Lambda_c^+ \rightarrow \Lambda e^+ \nu_e)$ available.
  - $B(\Lambda_c^+ \rightarrow \Lambda e^+ \nu_e)= (2.1 \pm 0.6)\%$ PDG2014
  - scaling to $(2.9 \pm 0.5)\%$, when taking the Belle’s $B(pK^- \pi^+)$

- Production at threshold has advantages on this type of decays with missing particle!
  - BESIII 567pb$^{-1}$ data @4.6GeV will provide the measurement up to precision of $\delta B/B \sim 10\%$ by using DT method
Candidate events for $\Lambda_c^+ \rightarrow \Lambda e^+ \nu_e$

- 11 ST modes are used, except $\Sigma^+ \omega$
- We detect $p, \pi^-, e^+$ among the remaining tracks form the ST $\Lambda_c^-$
- require $p$ and $\pi^-$ are from $\Lambda$

**BESIII preliminary**

**clean $\Lambda$ peak**

**signal region**

**sidebands**

**sidebands**
Semi-leptonic branching fraction results

✓ Fitting function:
  ➢ signals: Gaussian with two power law tails
  ➢ backgrounds: 1st order polynomial

BESIII preliminary

\[ U_{\text{miss}} = E_{\text{miss}} - c|\vec{p}_{\text{miss}}| \]
\[ E_{\text{miss}} = E_{\text{beam}} - E_{\Lambda} - E_{e^+} , \]
\[ \vec{p}_{\text{miss}} = \vec{p}_{\Lambda^0} - \vec{p}_{\Lambda} - \vec{p}_{e^+} . \]

- \(567\text{pb}^{-1}\) data @ 4.6 GeV

subtraction of backgrounds:
  • non-ST events: negligible
  • \(\Lambda\) sidebands: \(1.4 \pm 0.8\)
  • \(\Lambda\mu^+\nu + \Lambda\pi^+\pi^0 + \Lambda\pi^+ = 4.5 \pm 0.5\)

⇒ signal yields: \(103.5 \pm 10.9\)

BESIII Prel. : \(B(\Lambda_c^+ \to \Lambda e^+\nu_e) = (3.63 \pm 0.38 \pm 0.??)\%\)

scaled PDG: \((2.9 \pm 0.5)\%\)

◆ Statistics limited measurement.
  ➔ systematic error smaller than statistical
◆ Best precision to date
Summary

- BEPCII/BESIII accumulated 567pb⁻¹ data set @4.6GeV
- Open a door to study the lowest charmed baryon state $\Lambda_c^+$
  - low backgrounds and high detection efficiency
- Several physic potentials has been and is being explored
  - absolute BF of hadronic decays model-independent
  - $\Lambda_c$ Semi-leptonic decays

Thank you!
Backup slides
Basic global fit logical

\[ N_{i}^{ST} = N_{\Lambda_{c}^{+}\Lambda_{c}^{-}} \cdot B_{i} \cdot \varepsilon_{i}^{ST} \]

\[ N_{-j}^{DT} = N_{\Lambda_{c}^{+}\Lambda_{c}^{-}} \cdot \sum_{i} B_{i} \cdot B_{j} \cdot \varepsilon_{-j}^{DT} \]

The efficiencies-corrected yields, denoted by \( c = E^{-1} n \)

Based on the lease square principle, The \( \chi^{2} \) can be constructed as

\[ \chi^{2} \equiv (c - \tilde{c})^{T} V_{c}^{-1} (c - \tilde{c}) \]