Recent results of charmed baryon decays at Belle

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Outline:

• Observation of DCS decay $\Lambda_c^+ \rightarrow K^+ \pi^- p$
• Search for $\Lambda_c^+ \rightarrow \phi p \pi^0$ decays (hidden-strangeness penta-quark search)
• Branching fraction measurement of $\Lambda_c^+ \rightarrow K^- \pi^+ p \pi^0$ decays
The Belle experiment runs at KEKB

\[ e^- \rightarrow (\ast) \leftarrow e^+ \]

- Charmed hadrons are mainly produced via

- Total integrated luminosity \( \sim 1000/\text{fb} \)
- Most of the data was taken at the \( \Upsilon(4S) \) energy.

On resonance:
- \( \Upsilon(5S) : 121\ f\text{b}^{-1} \)
- \( \Upsilon(4S) : 711\ f\text{b}^{-1} \)
- \( \Upsilon(3S) : 3\ f\text{b}^{-1} \)
- \( \Upsilon(2S) : 25\ f\text{b}^{-1} \)
- \( \Upsilon(1S) : 6\ f\text{b}^{-1} \)

Off resonance/scan: \( \sim 100\ f\text{b}^{-1} \)
Double Cabibbo-suppressed (DCS) decays seen in charm mesons, but not previously in baryons.

One trial so far: \( \frac{B(\Lambda_c^+ \rightarrow p K^+ \pi^-)}{B(\Lambda_c^+ \rightarrow p K^- \pi^+)} < 4.6 \times 10^{-3} \) at 90% CL by FOCUS [PLB 624, 166 (2005)]

Naïve expectation: \( \frac{B(DCS)}{B(CF)} = \tan^4 \theta_c = 0.285\% \)

Since W-exchange diagram is absent in DCS decay, \( \frac{B(DCS)}{B(CF)} \) may be smaller than the naïve expectation.

This analysis uses the entire Belle Data.
DCS $\Lambda_c^+ \rightarrow pK^-\pi^+$ decays

- $\Lambda_c^+ \rightarrow \Lambda(\rightarrow p\pi^-)K^+$ is a singly Cabibbo-suppressed (SCS) decay having the same final state as the DCS decays.
- Most of the SCS decays are suppressed by vertex cut. We estimate the contamination of the remaining SCS decays using $\frac{N(\text{SCS})}{N(\text{CF})} = \frac{\varepsilon(\text{SCS})}{\varepsilon(\text{CF})}$ $\times$ $\frac{B(\text{SCS})}{B(\text{CF})}$.
- After subtraction, we observed $3379 \pm 380 \pm 78$ DCS events with a significance $> 9\sigma$.

Residuals of the data with respect to fitted the combinatorial background

$B(\Lambda_c^+ \rightarrow pK^+\pi^-) \over B(\Lambda_c^+ \rightarrow pK^-\pi^+) = (2.35 \pm 0.27 \pm 0.21) \times 10^{-3}$

$= (0.82 \pm 0.12) \tan^4 \theta_c$

(consistent within $1.5\sigma$ with the naïve expectation)

Absolute branching fraction

$B(\Lambda_c^+ \rightarrow pK^+\pi^-) = (1.61 \pm 0.23^{+0.07}_{-0.08}) \times 10^{-4}$

After subtracting the contribution $\Lambda^* (1520)$ and $\Delta$ isobar intermediates, which only contribute to CF decay, the revised ratio

$\frac{B(\Lambda_c^+ \rightarrow pK^+\pi^-)}{B(\Lambda_c^+ \rightarrow pK^-\pi^+)} = (1.10 \pm 0.17) \tan^4 \theta_c$

compatible with naïve expectation (within $1.0\sigma$): no large $W$-exchange contribution in CF decay.

PRL 117, 011801 (2016)
Search for $\Lambda_c^+ \rightarrow \phi p \pi^0$ decays

- The decay is similar to the decay of LHCb’s hidden-charm penta-quark ($P_c^+$) discovery channel $\Lambda_b \rightarrow J/\psi p K^-$. [PRL 115, 072001 (2015)]

- Hidden-strangeness penta-quark ($P_s^+$) may appear in the intermediate state of $\phi p$, assuming the underlying mechanism creating the $P_c^+$ also holds for $P_s^+$, independent of the flavor and mass of $P_s^+$ is smaller than 2.151 GeV. [PRD 92, 114030 (2015)]

- LEPS & CLAS collaborations observed a bump at $\sqrt{s} \approx 2.0$ GeV in $\phi$ photo-production. [PRL 95, 182001(2005); PRC 89, 055208(2014); PRC 90, 019901 (2014)]

- This analysis uses 915/fb of Belle data collected at and near $\Upsilon(4S)$ and $\Upsilon(5S)$ resonances.
Search for $\Lambda_c^+ \rightarrow \phi p \pi^0$ decays

- Two dimensional fit is performed to $K^+ K^- p \pi^0$ and $K^+ K^-$ invariant masses, in order to extract the $\Lambda_c^+$ signal yield.
- Cabibbo-favored $\Lambda_c^+ \rightarrow \phi \Sigma^+ (\rightarrow p \pi^0)$ decay has the same final state and is suppressed by rejecting the events in which $p \pi^0$ system has an invariant mass within 10 MeV of $\Sigma^+$ mass.
- Branching fraction is measured with respect to well measured CF decay $\Lambda_c^+ \rightarrow \pi^+ K^- p$

Combinatorial

$3$ components:
- $\phi p \pi^0$ signal $(148 \pm 62, 2.4\sigma)$
- $K^+ K^- p \pi^0$ NR $(76 \pm 85, 1.0\sigma)$

Normalization mode
- $1.46$ M events

90% CL Upper limits on branching fractions

$$B(\Lambda_c^+ \rightarrow \phi p \pi^0) < 15.3 \times 10^{-5},$$
$$B(\Lambda_c^+ \rightarrow K^+ K^- p \pi^0)_{\text{NR}} < 6.3 \times 10^{-5},$$

New
Search for hidden-strangeness pentaquark

- 2D fits (slide # 6) are performed in bins of $m(\phi p)$ for the background-subtracted $m(\phi p)$ distribution.
- The distribution is then fitted with a RBW for $P_s^+$ and a phase space contribution obtained from MC simulation.
- The data shows (no) clear evidence of a $P_s^+$ state

90% CL Upper limits on product branching fractions

$$B(\Lambda_c^+ \to P_s^+\pi^0) \times B(P_s^+ \to \phi p) < 8.3 \times 10^{-5}$$

This limit is a factor of 6 higher than the product branching measured by LHCb for an analogous hidden-charm pentaquark states $P_c^+(4450)$ [(1.3 ± 0.4)×10^{-5}]

$M = 2.025 \pm 0.005$ GeV
$\Gamma = 0.022 \pm 0.012$ GeV

arXiv:1707.00089[hep-ex]
Submitted to PRD(RC)
Branching fraction of $\Lambda_c^+ \rightarrow K^- \pi^+ p\pi^0$

- CF decay $\Lambda_c^+ \rightarrow K^- \pi^+ p\pi^0$ has the same final state topology and is used to adjust the MC-data differences in $\phi p\pi^0$ and $K^+ K^- p\pi^0$ decays.

$$\frac{\mathcal{B}(\Lambda_c^+ \rightarrow K^- \pi^+ p\pi^0)}{\mathcal{B}(\Lambda_c^+ \rightarrow K^- \pi^+ p)} = (0.685 \pm 0.007 \pm 0.018)$$

**Absolute branching fraction**

$$\mathcal{B}(\Lambda_c^+ \rightarrow K^- \pi^+ p\pi^0) = (4.42 \pm 0.05 \pm 0.12 \pm 0.16)\%$$

This is the most precise measurement to date.

New

arXiv:1707.00089[hep-ex]
Submitted to PRD(RC)
We have presented

- The first observation of DCS baryonic decay $\Lambda_c^+ \rightarrow K^+\pi^-p$
- The search for the decays $\Lambda_c^+ \rightarrow \phi p\pi^0$ and NR $\Lambda_c^+ \rightarrow K^+K^-p\pi^0$, no significant signal is observed for either decay mode and we set 90% CL upper limit on their branching fractions. These are the first such limit.
- The search for hidden-strangeness pentaquark decay $P_s^+ \rightarrow \phi p$, our data shows no clear evidence of this decay and we set an upper limit on product branching fraction. This is also first such search.
- The most precise measurement of $B(\Lambda_c^+ \rightarrow K^-\pi^+p\pi^0)$. 