Symmetries in charm mesons and baryons from Belle and Belle II

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Belle at KEKB
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Selected studies of charm mesons
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Selected studies of charm baryons
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Charm results from Belle II
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Summary
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Outline

1. **Belle at KEKB**
2. **Selected studies of charm mesons at Belle**
   - $\mathcal{B}/A_{CP}$ for $D^0 \to h^+ h^- \eta$ ($h = K$, π) and $D^0 \to \phi\eta$
   - $\mathcal{B}/A_{CP}/a_{CP}^{T\text{-odd}}$ for $D^0 \to K_S^0 K_S^0 \pi^+ \pi^-$ and $D_{(s)}^+ \to K\pi\pi^+\pi^-$
3. **Selected studies of charm baryons at Belle**
   - $\mathcal{B}/A_{CP}/\alpha/A_{CP}^\alpha$ of $\Lambda_c^+ \to \Lambda h^+$, $\Sigma^0 h^+$
   - $\mathcal{B}/\alpha$ for $\Lambda_c^+ \to \Sigma^+ (\pi^0, \eta, \eta')$
4. **Charm results from Belle II**
   - Belle II and SuperKEKB
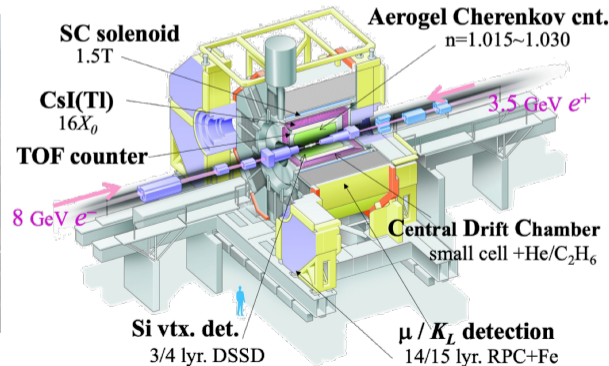   - Charm lifetimes from Belle II
5. **Summary**

Outline

Belle experiment at KEKB   (For more info, see Seema's talk yesterday.)

- KEKB is an asymmetric-energy e^+e^- collider operating near $\Upsilon(4S)$ mass peak (just above $B\bar{B}$ threshold).
- Belle detector: good performances on the momentum/vertex resolution and particle identification; $\sim 100\%$ trigger efficiency for hadronic events with uniform decay-time acceptance, etc. (upgraded to be Belle II now, see p.23.)
- Accumulated data set of ~ 1 ab^{-1}: not only a B-factory with large $B\bar{B}$ sample(772 millions), but also a tau-charm factory. $\Rightarrow$ a large charm sample from (1) $\sigma(e^+e^- \to c\bar{c}) = 1.3$ nb; (2) $b \to c$ in B decays, to study charm physics.

Recent Charm results at Belle

- Although 12 years have passed since Belle finished the final data set accumulation, we are lasting to produce fruitful Charm results. Here the charm results since 2021 (not covering charm spectroscopy results) are listed:

BF of $\Omega_c^0 \to \Xi^- \pi^+, \Xi^- K^+, \Omega^- K^+$	Preliminary result
BF/α of $\Lambda_c^+ \to \Sigma^+ (\pi^0, \eta, \eta')$	arXiv:2208.10825
BF/$A_{CP}^{\rm dir}/\alpha/A_{CP}^\alpha$ of $\Lambda_c^+ \to \Lambda h^+, \Sigma^0 h^+$	arXiv:2208.08695
BF/$a_{CP}^{T\text{-odd}}/A_{CP}$ of $D^0 \to K_S^0 K_S^0 \pi^+ \pi^-$	arXiv:2207.07555
BF of $D_{(s)}^+ \to K \pi \pi^+ \pi^0$	arXiv:2205.02018
BF of $D^+ \to K^- K_S^0 \pi^+ \pi^+ \pi^0$	arXiv:2207.06595
BF of $\Lambda_c^+ \to \Sigma^+ \gamma$ and $\Xi_c^0 \to \Xi^0 \gamma$	arXiv:2206.12517
BF of $\Xi_c^0 \to \Lambda_c^+ \pi^-$	arXiv:2206.08527
BF of $\Xi_c^0 \to \Lambda K_S^0, \Sigma^0 K_S^0$, and $\Sigma^+ K^-$	PRD **105**, L011102 (2022)
BF of $\Lambda_c^+ \to p \pi^0, p \eta, p \omega, p \eta'$	PRD **103**, 072004 (2021), PRD **104**, 072008 (2021), JHEP 03 (2022) 090
BF/A_{CP} in $D^0 \to \pi^+ \pi^- \eta, K^+ K^- \eta$, and $\phi \eta$	JHEP 09 (2021) 075
BF/$A_{CP}^{\rm dir}$ for $D_s^+ \to K^+ \pi^0, K^+ \eta, \pi^+ \pi^0$, and $\pi^+ \eta$	PRD **103**, 112005 (2021)
BF/α for $\Xi_c^0 \to \Lambda \bar{K}^{*0}, \Sigma^0 \bar{K}^{*0}$, and $\Sigma^+ K^{*-}$	JHEP 06 (2021) 160
BF of $\Xi_c^0 \to \Xi^- \ell^+ \nu_\ell$ and $\Omega_c^0 \to \Omega^- \ell^+ \nu_\ell$	PRL **127**, 121803 (2021), PRD **105**, L091101 (2022)
BF of $\Xi_c^0 \to \Xi^0 \phi$ and $\Xi_c^0 \to \Xi^0 K^+ K^-$	PRD **103**, 112002 (2021)
BF of $\Lambda_c^+ \to \Lambda \eta \pi^+, \Sigma^0 \eta \pi^+, \Lambda(1670)\pi^+, \eta\Sigma(1385)$	PRD **103**, 052005 (2021)
Search for $\Omega_c^0 \to \pi^+ \Omega(2012)^- \to \pi^+ (\bar{K}\Xi)^-$	PRD **104**, 052005 (2021)

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BF/A_{CP}^{dir} for $D_s^+ \to K^+ \pi^0, K^+ \eta, \pi^+ \pi^0$, and $\pi^+ \eta$	PRD **103**, 112005 (2021)
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$\Rightarrow$ BF of $\Xi_c^0 \to \Xi^- \ell^+ \nu_\ell$ and $\Omega_c^0 \to \Omega^- \ell^+ \nu_\ell$	PRL **127**, 121803 (2021), PRD **105**, L091101 (2022)
BF 0f $\Xi_c^0 \to \Xi^0 \phi$ and $\Xi_c^0 \to \Xi^0 K^+ K^-$	PRD **103**, 112002 (2021)
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- This talk covers above selected analyses on the branching fraction ($\mathcal{B}$), CP asymmetry (A_{CP}), and decay asymmetry parameters (α).

Outline

# $\mathcal{B}$ and A_{CP} of $D^0 \to h^+ h^- \eta$ ($h = K, \pi$) and $D^0 \to \phi\eta$ at Belle (JHEP 09 (2021) 075)

- The first and only observation of charm CP violation is achieved at LHCb: $\Delta A_{CP}(D^0 \to K^+ K^-, D^0 \to \pi^+\pi^-)^{[a]}$.
- Here we extend these singly Cabibbo-suppressed (SCS) decays with an additional η meson in the final state, to measure their time-integrated CP asymmetries and branching fractions ($\mathcal{B}$).
  - For $D^0 \to \pi^+\pi^-\eta$: $\delta\mathcal{B}/\mathcal{B} \sim 6\%^{[b, c]}$; $A_{CP} = (-9.6 \pm 5.7)\%^{[c]}$.
  - For $D^0 \to K^+K^-\eta$: no total $\mathcal{B}$ result; $\delta\mathcal{B}/\mathcal{B}(D^0 \to \eta(K^+K^-)_{\text{non}-\phi}) \sim 35\%^{[d]}$; $\delta\mathcal{B}/\mathcal{B}(D^0 \to \phi\eta) \sim 20\%^{[e, f]}$.
  - Reference Cabibbo-favored (CF) mode $D^0 \to K^-\pi^+\eta$ is well-measured with $\delta\mathcal{B}/\mathcal{B} \sim 2\%^{[g, d]}$ and Dalitz-plot analysis result$^{[g]}$.
- Based on 980 fb^{-1} data set, we fit the distributions of $Q = M(h^+h^-\eta\pi_s) - M(h^+h^-\eta) - m(\pi_s)$, to extract the signal yields for these decay channels and also for $D^0 \to \eta(K^+K^-)_{\phi-\text{excluded}}$ with $|M_{KK} - m_\phi| > 20$ MeV/c^2.
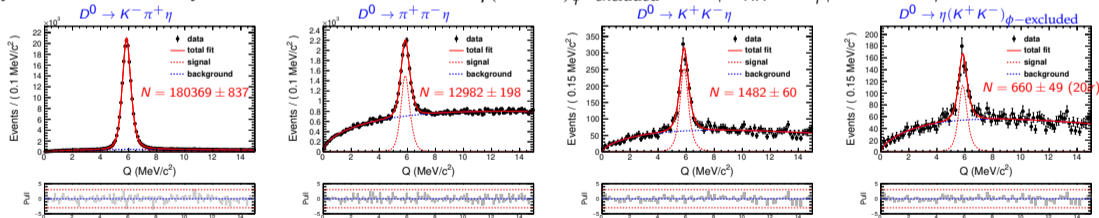
[a]LHCb, Phys. Rev. Lett. **122**, 211803 (2019)

[b]CLEO, Phys. Rev. D **77**, 002003 (2008)

[c]BESIII, Phys. Rev. D **101**, 052009 (2020)

[d]BESIII, Phys. Rev. Lett. **124**, 241803 (2020)

[e]Belle, Phys. Rev. Lett. **92**, 101803 (2004)

[f]BESIII, Phys. Lett. B **798**, 134017 (2019)

[g]Belle, Phys. Rev. D **102**, 012002 (2020)

$\mathcal{B}/A_{CP}$ for $D^0 \to h^+h^-\eta$ ($h = K, \pi$) and $D^0 \to \phi\eta$

$\mathcal{B}$ and A_{CP} of $D^0 \to h^+h^-\eta$, and $D^0 \to \phi\eta$ at Belle (JHEP 09 (2021) 075)

- The efficiency-corrected yield on Dalitz-plot: $\boxed{N^{\mathrm{cor}} = \sum_i \dfrac{N_i^{\mathrm{tot}} - N^{\mathrm{bkg}} f_i^{\mathrm{bkg}}}{\varepsilon_i}}$ to consider bin-to-bin variations of ε,

  where ε_i is the efficiency in the ith-bin based on PHSP signal MC; N^{tot} is yield in Q signal region; and N^{bkg} is the fitted background yield in Q signal region; f_i^{bkg} is the fraction of background in the ith-bin, with $\sum_i f_i = 1$, obtaining from the Dalitz-plot in Q sideband.
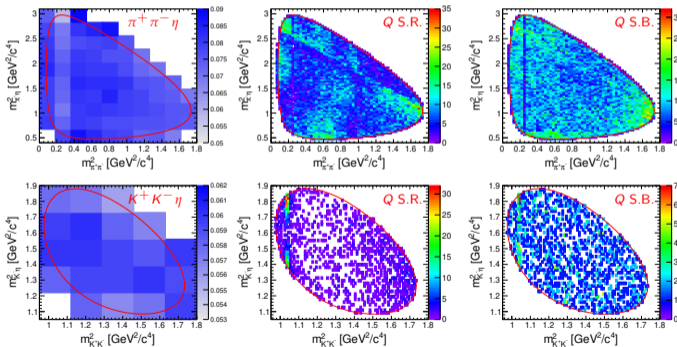
S.R. = signal region;
S.B. = sideband region

A very clear $\phi(1020)$ structure

Then we have $\boxed{\dfrac{\mathcal{B}(D^0 \to h^+h^-\eta)}{\mathcal{B}(D^0 \to K^-\pi^+\eta)} = \dfrac{N^{\mathrm{cor}}(D^0 \to h^+h^-\eta)}{N^{\mathrm{cor}}(D^0 \to K^-\pi^+\eta)}}$

$\dfrac{\mathcal{B}(D^0 \to \pi^+\pi^-\eta)}{\mathcal{B}(D^0 \to K^-\pi^+\eta)} = (6.49 \pm 0.09 \pm 0.12) \times 10^{-2}$

$\dfrac{\mathcal{B}(D^0 \to K^+K^-\eta)}{\mathcal{B}(D^0 \to K^-\pi^+\eta)} = (9.57^{+0.36}_{-0.33} \pm 0.20) \times 10^{-3}$

$\dfrac{\mathcal{B}(D^0 \to K^+K^-\eta)_{\mathrm{ex.}-\phi}}{\mathcal{B}(D^0 \to K^-\pi^+\eta)} = (5.26^{+0.45}_{-0.38} \pm 0.11) \times 10^{-3}$

Using the W.A. $\mathcal{B}(D^0 \to K^-\pi^+\eta)^{[g,d]}$, we have the absolute branching fractions:

$\mathcal{B}(D^0 \to \pi^+\pi^-\eta) = (1.22 \pm 0.02 \pm 0.02 \pm 0.02) \times 10^{-3}$

$\mathcal{B}(D^0 \to K^+K^-\eta) = (1.80^{+0.07}_{-0.06} \pm 0.04 \pm 0.03) \times 10^{-4}$

$\mathcal{B}(D^0 \to (K^+K^-)_{\mathrm{ex.}-\phi}\eta) = (0.99^{+0.08}_{-0.07} \pm 0.02 \pm 0.02) \times 10^{-4}$.

the last one is somewhat higher (but more precise) than a similar measurement by BESIII[d] $(0.59 \pm 0.19) \times 10^{-4}$.

Belle at KEKB
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Selected studies of charm mesons
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Selected studies of charm baryons
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Charm results from Belle II
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$\mathcal{B}/A_{CP}$ for $D^0 \to h^+h^-\eta$ ($h = K, \pi$) and $D^0 \to \phi\eta$

$\mathcal{B}$ and A_{CP} for $D^0 \to h^+h^-\eta$, and $D^0 \to \phi\eta$ at Belle (JHEP 09 (2021) 075)

- To extract the yield of this SCS and color-suppressed decay $D^0 \to \phi\eta$, we perform M_{KK}-Q 2D fit instead of Q 1D fit, considering there is a Q-peaking background from non-ϕ $D^0 \to K^+K^-\eta$ component.

- First observation with large statistical significance ($> 10\sigma$).

- Based on $N_{sig} = 600 \pm 29$ and $\varepsilon = (5.262 \pm 0.021)\%$ in signal region, the relative branching fraction is determined.
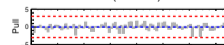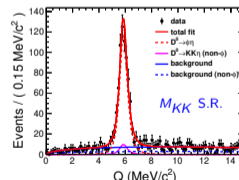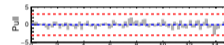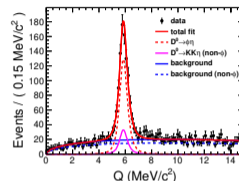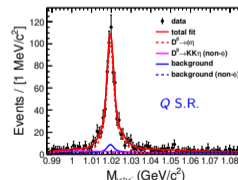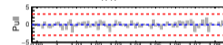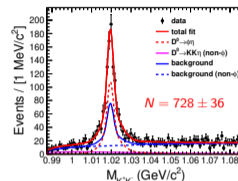
  $\frac{\mathcal{B}(D^0 \to \phi\eta, \phi \to K^+K^-)}{\mathcal{B}(D^0 \to K^-\pi^+\eta)} = [4.82 \pm 0.23\,(\text{stat}) \pm 0.16\,(\text{syst})] \times 10^{-3}$.

- using $\mathcal{B}(D^0 \to K^-\pi^+\eta)^{[g,d]}$ and $\mathcal{B}_{\text{PDG}}(\phi \to K^+K^-)$, we have

  $\mathcal{B}(D^0 \to \phi\eta) = [1.84 \pm 0.09\,(\text{stat}) \pm 0.06\,(\text{syst}) \pm 0.04\,(\mathcal{B}_{\text{ref}})] \times 10^{-4}$,

  which is consistent, but notably more precise than, previous results at Belle[e] and BESIII[f].

- As a consistency check, we calculate $\mathcal{B}(D^0 \to (K^+K^-)_{\text{non-}\phi}\eta)$ by $\mathcal{B}(D^0 \to K^+K^-\eta) - \mathcal{B}(D^0 \to \phi\eta, \phi \to K^+K^-) = (0.90 \pm 0.08) \times 10^{-4}$ which is very close to our measurement of $\mathcal{B}(D^0 \to K^+K^-\eta)_{\text{ex.-}\phi}$.
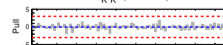
$\mathcal{B}/A_{CP}$ for $D^0 \to h^+ h^- \eta$ ($h = K, \pi$) and $D^0 \to \phi\eta$

$\mathcal{B}$ and A_{CP} for $D^0 \to h^+ h^- \eta$, and $D^0 \to \phi\eta$ at Belle (JHEP 09 (2021) 075)

- Time-integrated CP asymmetry for $D^0 \to f$ decays: $A_{CP} = \dfrac{\mathcal{B}(D^0 \to f) - \mathcal{B}(\overline{D}^0 \to \overline{f})}{\mathcal{B}(D^0 \to f) + \mathcal{B}(\overline{D}^0 \to \overline{f})}$

- Using D^{*+} tagged sample $e^+ e^- \to c\bar{c} \to D^{*+} X$, $D^{*+} \to [D^0 \to f]\pi_s^+$, the raw asymmetry includes several sources:

$$A_{\text{raw}} = \frac{N_{\text{rec}}(D^{*+}) - N_{\text{rec}}(D^{*-})}{N_{\text{rec}}(D^{*+}) + N_{\text{rec}}(D^{*-})} = A_{\text{FB}}^{D^{*+}} + A_{CP}^{D^0 \to f} + A_{\varepsilon}^f + A_{\varepsilon}^{\pi_s^+},$$

where forward-backward asymmetry A_{FB} is arising from γ-Z^0 interference and higher-order QED effects.

- we weight events to correct the slow pion detection asymmetry: $w_{D^0, \overline{D}^0} = 1 \mp A_{\varepsilon}^{\pi_s^+}[\cos\theta(\pi_s^+), p_T(\pi_s^+)]$.

- In our decays ($A_{\varepsilon}^f = 0$), the weighted samples have the corrected raw asymmetry: $\boxed{A_{\text{corr}} = A_{CP}^{D^0 \to f} + A_{\text{FB}}(\cos\theta^*)}$.

- Considering $A_{CP}^{D^0 \to f}$ is independent on $\cos\theta^*$, and $A_{\text{FB}}(\cos\theta^*) = -A_{\text{FB}}(-\cos\theta^*)$, we determine the asymmetries in multiple symmetric bins of $\cos\theta^*$:

$$\boxed{A_{CP}^{D^0 \to f} = \frac{A_{\text{corr}}(\cos\theta^*) + A_{\text{corr}}(-\cos\theta^*)}{2}} \qquad \boxed{A_{\text{FB}} = \frac{A_{\text{corr}}(\cos\theta^*) - A_{\text{corr}}(-\cos\theta^*)}{2}}$$

Finally, fitting these $A_{CP}^{D^0 \to f}$ values to a constant gives the final measurement of $A_{CP}^{D^0 \to f}$ that we are interested in.

Belle at KEKB
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$\mathcal{B}/A_{CP}$ for $D^0 \to h^+ h^- \eta$ ($h = K, \pi$) and $D^0 \to \phi\eta$

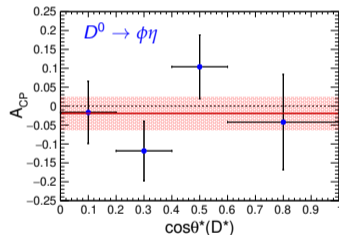## $\mathcal{B}$ and A_{CP} for $D^0 \to h^+ h^- \eta$, and $D^0 \to \phi\eta$ at Belle (JHEP 09 (2021) 075)

- We perform a simultaneous fit on the Q or M_{KK}-Q distributions for D^0 and $\bar{D}^0$ samples in each $\cos\theta^*$ bin, to extract the corrected raw asymmetry A_{corr}: $N_{sig}(D^0, \bar{D}^0) = N_{sig}/2 \cdot (1 \pm A_{corr})$.
- obtain the A_{CP} values in four pairs of symmetric bins and calculate their averages.
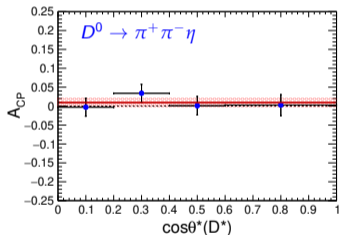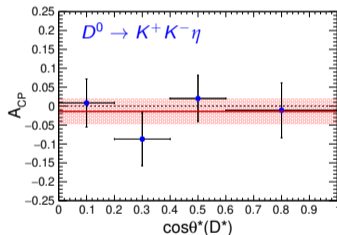
$A_{CP} = (0.9 \pm 1.2 \pm 0.5)\%$ $A_{CP} = (-1.4 \pm 3.3 \pm 1.1)\%$ $A_{CP} = (-1.9 \pm 4.4 \pm 0.6)\%$

- for $D^0 \to \pi^+\pi^-\eta$: much preciser than previous result[c] at BESIII; for other results: first such measurements.
- No evidence for CP violation is found in these decays.

Belle at KEKB   **Selected studies of charm mesons**   Selected studies of charm baryons   Charm results from Belle II   Summary

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$\mathcal{B}/a_{CP}^{T\text{-odd}}$ for $D^0 \to K_S^0 K_S^0 \pi^+ \pi^-$ and $D_{(s)}^+ \to K \pi \pi^+ \pi^-$

$\mathcal{B}/A_{CP}/a_{CP}^{T\text{-odd}}$ of $D^0 \to K_S^0 K_S^0 \pi^+ \pi^-$ at Belle (arXiv:2207.07555)

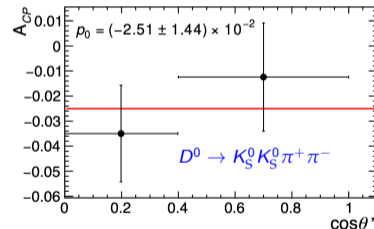- We measure the $\mathcal{B}$ (relative to reference mode $D^0 \to K_S^0 \pi^+ \pi^-$) and its time-integrated A_{CP} for $D^0 \to K_S^0 K_S^0 \pi^+ \pi^-$.

$$\mathcal{B}(D^0 \to K_S^0 K_S^0 \pi^+ \pi^-) = \frac{N_{K_S^0 K_S^0 \pi^+ \pi^-}/\varepsilon_{K_S^0 K_S^0 \pi^+ \pi^-}}{N_{K_S^0 \pi^+ \pi^-}/\varepsilon_{K_S^0 \pi^+ \pi^-}} \frac{\mathcal{B}(D^0 \to K_S^0 \pi^+ \pi^-)}{\mathcal{B}(K_S^0 \to \pi^+ \pi^-)}$$
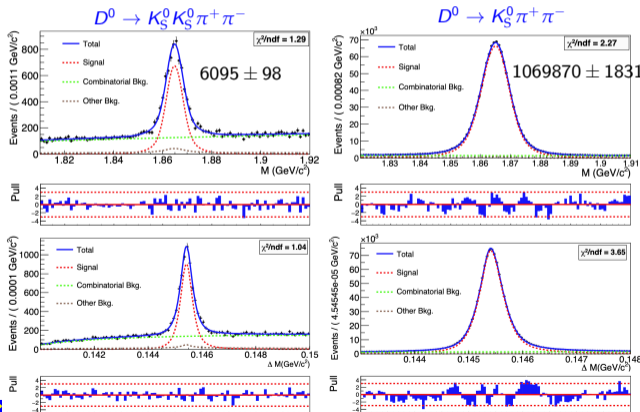
▶ Self-conjugated decay, using same method in previous analysis] Extract signal yield on the weighted sample ($w = 1 \mp A_\varepsilon^{\pi_s}$) in four bins of $\cos \theta^*$ distribution.

$$A_{CP} = (A_{corr}(\cos \theta^*) + A_{corr}(-\cos \theta^*))/2.$$

▶ we obtain the most precise $\mathcal{B}$ and the first A_{CP} result for $D^0 \to K_S^0 K_S^0 \pi^+ \pi^-$:

⇒ $\mathcal{B} = (4.82 \pm 0.08^{+0.10}_{-0.11} \pm 0.31) \times 10^{-4}$

⇒ $A_{CP} = (-2.51 \pm 1.44^{+0.35}_{-0.52})\%$

$\mathcal{B}/A_{CP}/a_{CP}^{T\text{-odd}}$ of $D^0 \to K_S^0 K_S^0 \pi^+ \pi^-$ at Belle (arXiv:2207.07555)

▶ T-odd correlations provides a powerful tool to indirectly search for CP violation under CPT symmetry conservation:

▶ C_T observable defined by triple mixed product of three momenta in the mother rest frame: $C_T = (\vec{p}_1 \times \vec{p}_2) \cdot \vec{p}_3$

$$A_T = \frac{\Gamma(C_T > 0) - \Gamma(C_T < 0)}{\Gamma(C_T > 0) + \Gamma(C_T < 0)} \qquad \overline{A}_T = \frac{\Gamma(-\overline{C}_T > 0) - \Gamma(-\overline{C}_T < 0)}{\Gamma(-\overline{C}_T > 0) + \Gamma(-\overline{C}_T < 0)}$$

▶ T-odd asymmetry definition to veto FSI effects:

$$\boxed{a_{CP}^{T\text{-odd}} = \frac{1}{2}\left(A_T - \overline{A}_T\right)}$$ can be nonzero if CPV

$\mathbf{M} \to \mathbf{P_1 P_2 P_3 P_4}$
in mother M rest frame

▶ Status of $a_{CP}^{T\text{-odd}}$ measurements in charmed mesons decay-rates:

$D^0 \to K_S^0 \pi^+ \pi^- \pi^0$	$a_{CP}^{T\text{-odd}} = (-0.28 \pm 1.38^{+0.23}_{-0.76}) \times 10^{-3}$	Belle[1]
$D^0 \to K^+ K^- \pi^+ \pi^-$	$a_{CP}^{T\text{-odd}} = (+1.7 \pm 2.7) \times 10^{-3}$	LHCb[2], BaBar[3], Focus[4]
$D^+ \to K_S^0 K^+ \pi^+ \pi^-$	$a_{CP}^{T\text{-odd}} = (-1.10 \pm 1.09) \times 10^{-2}$	BaBar[5], Focus[4]
$D_s^+ \to K_S^0 K^+ \pi^+ \pi^-$	$a_{CP}^{T\text{-odd}} = (-1.39 \pm 0.84) \times 10^{-2}$	BaBar[5], Focus[4]
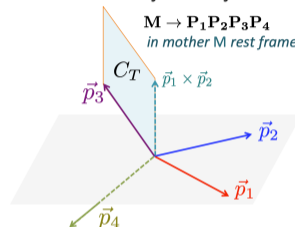
[1] K. Prasanth *et al.*(Belle Collab.), Phys. Rev. D **95**, 091101(R) (2017)
[2] R. Aaij *et al.*(LHCb Collab.), JHEP **10**, 5 (2014)
[3] P. del Amo Sanchez *et al.*(BaBar Collab.), Phys. Rev. D **81**, 111103(R) (2010)
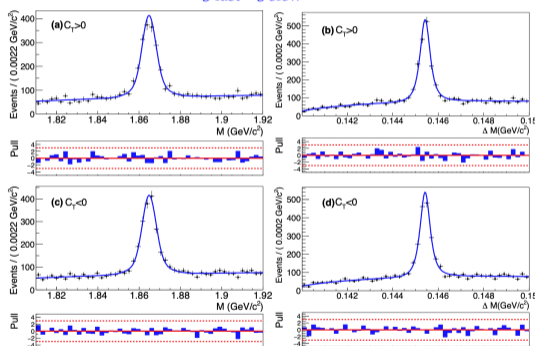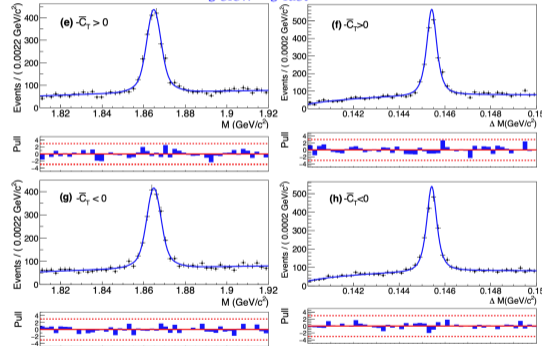[4] J.M. Link *et al.*(FOCUS Collab.), Phys. Lett. B **622**, 239 (2005)
[5] J.P. Lees *et al.*(BaBar Collab.), Phys. Rev. D **84**, 031103(R) (2011)

Belle and Belle II could improve these $a_{CP}^{T\text{-odd}}$ results or obtain the precise $a_{CP}^{T\text{-odd}}$ results in more channels benefited from the increasing dataset.

$\mathcal{B}/A_{CP}/a_{CP}^{T\text{-odd}}$ of $D^0 \to K_S^0 K_S^0 \pi^+ \pi^-$ at Belle   (arXiv:2207.07555)

- We divide the data into four subsamples (D flavor, C_T sign), and perform a simultaneous fit to extract $a_{CP}^{T\text{-odd}}$.

$$D^0 \to K_{S\,\text{fast}}^0 K_{S\,\text{slow}}^0 \pi^+ \pi^- \qquad\qquad \bar{D}^0 \to K_{S\,\text{slow}}^0 K_{S\,\text{fast}}^0 \pi^- \pi^+$$

- Finally we have $a_{CP}^{T\text{-odd}}(D^0 \to K_S^0 K_S^0 \pi^+ \pi^-) = (-1.95 \pm 1.42^{+0.14}_{-0.12})\%$ for the first time.
- Similar measurements of charged D decays, e.g $D_{(s)}^+ \to K\pi\pi^+\pi^-$, are in back-up or on the road.

Outline

$\mathcal{B}/A_{CP}^{\text{dir}}/\alpha/A_{CP}^{\alpha}$ of $\Lambda_c^+ \to \Lambda h^+$, $\Sigma^0 h^+$ at Belle (arXiv:2208.08695)

- To date, CPV has been observed in the open-flavored meson sector (i.e. K, D and B mesons), but not yet established in the baryon sector. While, Baryogenesis, the process by which the baryon-antibaryon asymmetry of the universe developed, is directly related to baryon CPV.

- Experimentally, no direct CPV searches in two-body SCS decays of charm baryons have been made to date.

- $A_{\text{raw}}^{\text{corr}}(\Lambda_c^+ \to \Lambda K^+) - A_{\text{raw}}^{\text{corr}}(\Lambda_c^+ \to \Lambda \pi^+) = A_{CP}^{\text{dir}}(\Lambda_c^+ \to \Lambda K^+) - A_{CP}^{\text{dir}}(\Lambda_c^+ \to \Lambda \pi^+)$. The reference mode $\Lambda_c^+ \to \Lambda \pi^+$ and signal mode have nearly the same Λ kinematic distributions, including the Λ decay length, the polar angle with respect to the direction opposite the positron beam and the momentum of the proton and pion in the laboratory reference frame.

- Measure $\mathcal{B}$ with $\mathcal{B}_{\text{sig}} = \mathcal{B}_{\text{ref}} \cdot (N_{\text{sig}}/\varepsilon_{\text{sig}})/(N_{\text{ref}}/\varepsilon_{\text{ref}})$.

- For $\Lambda_c^+ \to \Lambda h^+$ decays, the differential decay rate depends on α parameters and one helicity angle as: $\boxed{\dfrac{dN(\Lambda_c^+ \to \Lambda h^+)}{d\cos\theta_\Lambda} \propto 1 + \alpha_{\Lambda_c^+}\alpha_-\cos\theta_\Lambda}$

- For $\Lambda_c^+ \to \Sigma^0 h^+$ decays, considering $\alpha(\Sigma^0 \to \gamma\Lambda)$ is zero due to parity conservation for an electromagnetic decay, the differential decay rate related to the α parameters and helicity angles is given by

$\boxed{\dfrac{dN(\Lambda_c^+ \to \Sigma^0 h^+)}{d\cos\theta_{\Sigma^0}\, d\cos\theta_\Lambda} \propto 1 - \alpha_{\Lambda_c^+}\alpha_-\cos\theta_{\Sigma^0}\cos\theta_\Lambda}$
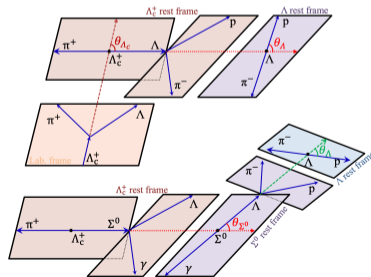
$\mathcal{B}/A_{CP}/\alpha/A_{CP}^{\alpha}$ of $\Lambda_c^+ \to \Lambda h^+, \Sigma^0 h^+$

## $\mathcal{B}/A_{CP}^{\mathrm{dir}}/\alpha/A_{CP}^{\alpha}$ of $\Lambda_c^+ \to \Lambda h^+, \Sigma^0 h^+$ at Belle (arXiv:2208.08695)
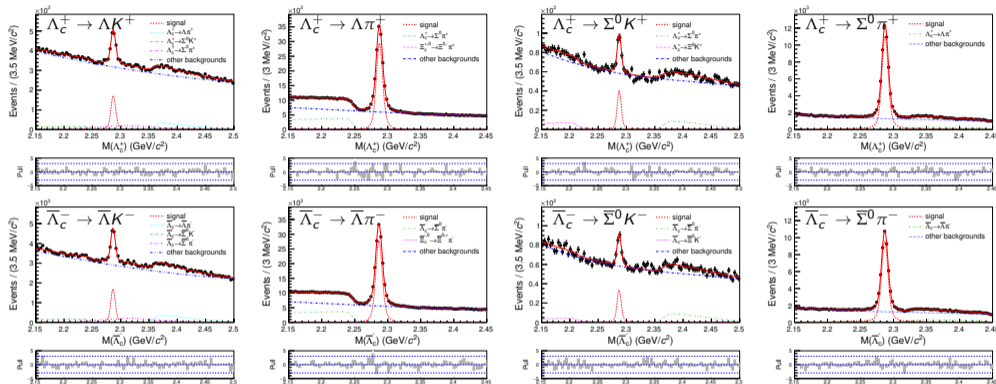
- We have $A_{CP}^{\mathrm{dir}}(\Lambda_c^+ \to \Lambda K^+) = (+2.1 \pm 2.6 \pm 0.1)\%$ and $A_{CP}^{\mathrm{dir}}(\Lambda_c^+ \to \Sigma^0 K^+) = (+2.5 \pm 5.4 \pm 0.4)\%$

- Based on the $M(\Lambda_c^+)$ fits on the combined Λ_c^+ and $\overline{\Lambda}_c^-$ samples and the W.A. $\mathcal{B}(\Lambda_c^+ \to (\Lambda, \Sigma^0)\pi^+)$, we have $\mathcal{B}(\Lambda_c^+ \to \Lambda K^+) = (6.57 \pm 0.17 \pm 0.11 \pm 0.35) \times 10^{-4}$ and $\mathcal{B}(\Lambda_c^+ \to \Sigma^0 K^+) = (3.58 \pm 0.19 \pm 0.06 \pm 0.19) \times 10^{-4}$.

- These A_{CP}^{dir}'s are the first results for SCS two-body decays of charm baryons. Both $\mathcal{B}$'s are most precise to date.

Belle at KEKB   Selected studies of charm mesons   **Selected studies of charm baryons**   Charm results from Belle II   Summary

$\mathcal{B}/A_{CP}/\alpha/A_{CP}^{\alpha}$ of $\Lambda_c^+ \to \Lambda h^+$, $\Sigma^0 h^+$

$\mathcal{B}/A_{CP}^{\text{dir}}/\alpha/A_{CP}^{\alpha}$ of $\Lambda_c^+ \to \Lambda h^+$, $\Sigma^0 h^+$ at Belle   (arXiv:2208.08695)

▶ $\cos\theta_\Lambda$ distributions of $\Lambda_c^+ \to \Lambda h^+$ after efficiency correction, fitted with formula on p.13

▶ $(\cos\theta_\Lambda, \cos\theta_{\Sigma^0})$ 2D distributions of $\Lambda_c^+ \to \Sigma^0 h^+$ after efficiency correction, fitted with formula on p.13
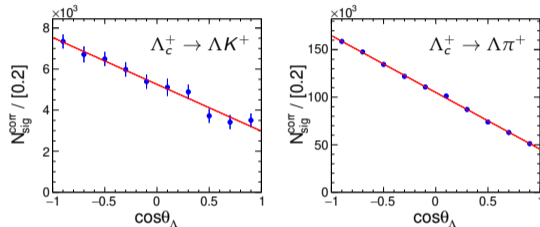
▶ Using the fitted slope factors and the average α_-, we have

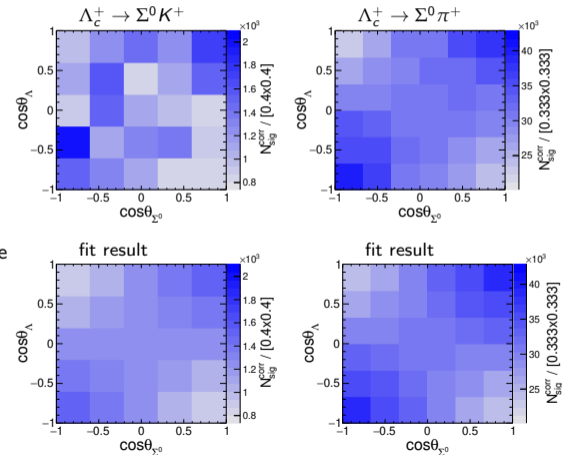$\alpha_{\text{avg}}(\Lambda_c^+ \to \Lambda K^+) = -0.585 \pm 0.049 \pm 0.018$
$\alpha_{\text{avg}}(\Lambda_c^+ \to \Lambda \pi^+) = -0.755 \pm 0.005 \pm 0.003$
$\alpha_{\text{avg}}(\Lambda_c^+ \to \Sigma^0 K^+) = -0.55 \ \pm 0.18 \ \pm 0.09$
$\alpha_{\text{avg}}(\Lambda_c^+ \to \Sigma^0 \pi^+) = -0.463 \pm 0.016 \pm 0.008$

▶ First α results of SCS decays of charm baryons; and significantly improved $\alpha_{\text{avg}}(\Lambda_c^+ \to \Lambda \pi^+, \Sigma^0 \pi^+)$.
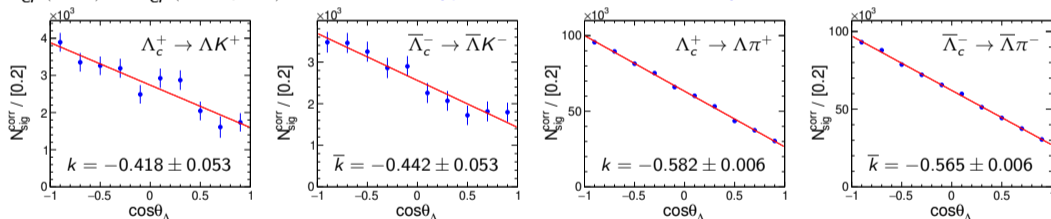
Belle at KEKB   Selected studies of charm mesons   **Selected studies of charm baryons**   Charm results from Belle II   Summary

$\mathcal{B}/A_{CP}/\alpha/A_{CP}^{\alpha}$ of $\Lambda_c^+ \to \Lambda h^+, \Sigma^0 h^+$

$\mathcal{B}/A_{CP}^{\mathrm{dir}}/\alpha/A_{CP}^{\alpha}$ of $\Lambda_c^+ \to \Lambda h^+, \Sigma^0 h^+$ at Belle (arXiv:2208.08695)

- The α-induced CP asymmetry: $A_{CP}^{\alpha} \equiv \frac{\alpha_{\Lambda_c^+} - \widehat{CP}\alpha_{\Lambda_c^+}\widehat{CP}^{\dagger}}{\alpha_{\Lambda_c^+} + \widehat{CP}\alpha_{\Lambda_c^+}\widehat{CP}^{\dagger}} = \frac{\alpha_{\Lambda_c^+} + \alpha_{\overline{\Lambda_c}}}{\alpha_{\Lambda_c^+} - \alpha_{\overline{\Lambda_c}}}$. In the case that A_{CP}^{dir} is zero, A_{CP}^{α} is given by the

  CPV in $\mathrm{Re}(S^*P)$. Therefore, A_{CP}^{α} provides an observable complementary to the A_{CP}^{dir} induced by decay widths.

- For our CF Λ_c^+ decay chains, $A_{CP}^{\alpha}(\text{total}) \equiv \frac{\alpha_{\Lambda_c^+}\alpha_- - \alpha_{\overline{\Lambda_c}}\alpha_+}{\alpha_{\Lambda_c^+}\alpha_- + \alpha_{\overline{\Lambda_c}}\alpha_+}$. Under the SM with $\alpha_{\Lambda_c^+} = -\alpha_{\overline{\Lambda_c}}$ for these CF Λ_c^+ decays,

  $A_{CP}^{\alpha}(\text{total}) = A_{CP}^{\alpha}(\Lambda \to p\pi^-)$. $\Rightarrow$ search for hyperon CPV in charm CF decays for the first time.

Channel	$k = \alpha_{\Lambda_c^\pm}\alpha_-$	$\bar{k} = \alpha_{\Lambda_c^-}\alpha_+$	$\alpha_{\Lambda_c^\pm}$	$\alpha_{\overline{\Lambda_c}}$	A_{CP}^{α}	W.A. A_{CP}^{α}	our $A_{CP}^{\alpha}(\Lambda \to p\pi^-)$
$\Lambda_c^+ \to \Lambda K^+$	-0.418 ± 0.053	-0.442 ± 0.053	$-0.566 \pm 0.071 \pm 0.028$	$0.592 \pm 0.070 \pm 0.079$	$-0.023 \pm 0.086 \pm 0.071$	–	–
$\Lambda_c^+ \to \Lambda \pi^+$	-0.582 ± 0.006	-0.565 ± 0.006	$-0.784 \pm 0.008 \pm 0.006$	$0.754 \pm 0.008 \pm 0.018$	$+0.020 \pm 0.007 \pm 0.013$	-0.07 ± 0.22	$+0.017 \pm 0.007 \pm 0.012$
$\Lambda_c^+ \to \Sigma^0 K^+$	-0.43 ± 0.18	-0.37 ± 0.21	$-0.58 \pm 0.24 \pm 0.09$	$0.49 \pm 0.28 \pm 0.14$	$+0.08 \pm 0.35 \pm 0.14$	–	–
$\Lambda_c^+ \to \Sigma^0 \pi^+$	-0.340 ± 0.016	-0.358 ± 0.017	$-0.452 \pm 0.022 \pm 0.023$	$0.473 \pm 0.023 \pm 0.035$	$-0.023 \pm 0.034 \pm 0.030$	–	$-0.026 \pm 0.034 \pm 0.030$

▶ The first or most precise α and A_{CP}^{α} results. No evidence of baryon CPV is found. combined: $+0.013 \pm 0.007 \pm 0.011$

Belle at KEKB · Selected studies of charm mesons · **Selected studies of charm baryons** · Charm results from Belle II · Summary

$\mathcal{B}/\alpha$ for $\Lambda_c^+ \to \Sigma^+(\pi^0, \eta, \eta')$

$\mathcal{B}$ and α of $\Lambda_c^+ \to \Sigma^+(\pi^0, \eta, \eta')$ at Belle (arXiv:2208.10825)

- Theoretical predictions by various models vs. experimental results:

Decay	Körner [a]	Ivanov [b]	Piotr [c]	Sharma [d]	Zou [e]	Geng [f]	Experiment
$\mathcal{B}(\Lambda_c^+ \to \Sigma^+ \eta)(\%)$	0.16	0.11	0.90	0.57	0.74	0.32 ± 0.13	0.44 ± 0.20
$\mathcal{B}(\Lambda_c^+ \to \Sigma^+ \eta')(\%)$	1.28	0.12	0.11	0.10	–	1.44 ± 0.56	1.5 ± 0.6
$\alpha(\Lambda_c^+ \to \Sigma^+ \pi^0)$	0.70	0.43	0.39	-0.31	-0.76	-0.35 ± 0.27	-0.55 ± 0.11
$\alpha(\Lambda_c^+ \to \Sigma^+ \eta)$	0.33	0.55	0.00	-0.91	-0.95	-0.40 ± 0.47	–
$\alpha(\Lambda_c^+ \to \Sigma^+ \eta')$	-0.45	-0.05	-0.91	0.78	–	$1.00^{+0.00}_{-0.17}$	–

- $\Lambda_c^+ \to \Sigma^+(\eta, \eta')$ are totally contributed by the nonfactorizable diagrams.

- We choose $\Lambda_c^+ \to \Sigma^+ \pi^0$ ($\mathcal{B} = (1.25 \pm 0.10)\%$) as reference mode.
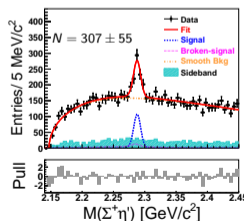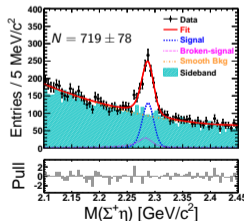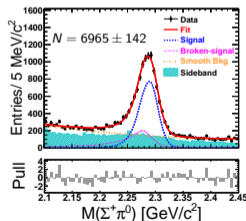
[a] ZPC **55**, 659 (1992)
[b] PRD **57**, 5632 (1998)
[c] PRD **50**, 5787 (1994)
[d] EPJC **7**, 217 (1999)
[e] PRD **49**, 3417 (1994)
[f] PLB **794**, 19 (2019)

▶ BESIII reported [CPC **43**, 083002 (2019)]

$$\frac{\mathcal{B}(\Lambda_c^+ \to \Sigma^+ \eta')}{\mathcal{B}(\Lambda_c^+ \to \Sigma^+ \eta)} = 3.5 \pm 2.1 \pm 0.4$$

▶ The isospin symmetry demands $\mathcal{B}$ and α of $\Lambda_c^+ \to \Sigma^+ \pi^0$ and $\Lambda_c^+ \to \Sigma^0 \pi^+$ shall be equal. [PLB **794**, 19 (2019)]

Based on full Belle data, we have

$$\frac{\mathcal{B}(\Lambda_c^+ \to \Sigma^+ \eta)}{\mathcal{B}(\Lambda_c^+ \to \Sigma^+ \pi^0)} = 0.25 \pm 0.03 \pm 0.01$$

$$\frac{\mathcal{B}(\Lambda_c^+ \to \Sigma^+ \eta')}{\mathcal{B}(\Lambda_c^+ \to \Sigma^+ \pi^0)} = 0.33 \pm 0.06 \pm 0.02$$

$$\frac{\mathcal{B}(\Lambda_c^+ \to \Sigma^+ \eta')}{\mathcal{B}(\Lambda_c^+ \to \Sigma^+ \eta)} = 1.34 \pm 0.28 \pm 0.06$$

▶ Using $\mathcal{B}$ of reference mode, we have

$\mathcal{B}(\Lambda_c^+ \to \Sigma^+ \eta) = (3.14 \pm 0.35 \pm 0.11 \pm 0.25) \times 10^{-3}$
$\mathcal{B}(\Lambda_c^+ \to \Sigma^+ \eta') = (4.16 \pm 0.75 \pm 0.21 \pm 0.33) \times 10^{-3}$
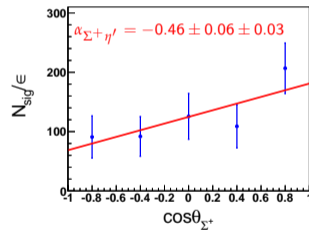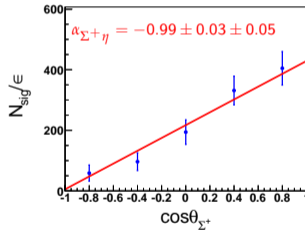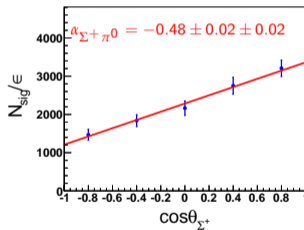which are the most precise results to date.

$\mathcal{B}/\alpha$ for $\Lambda_c^+ \to \Sigma^+ (\pi^0, \eta, \eta')$

$\mathcal{B}$ and α of $\Lambda_c^+ \to \Sigma^+ (\pi^0, \eta, \eta')$ at Belle   (arXiv:2208.10825)

- The differential decay rate depends on the decay asymmetry parameter $\alpha_{\Sigma^+ h^0}$ and the helicity angle of Σ^+.

$$\frac{dN(\Lambda_c^+ \to \Sigma^+ h^0)}{d\cos\theta_{\Sigma^+}} \propto 1 + \alpha_{\Sigma^+ h^0} \alpha_{p\pi^0} \cos\theta_{\Sigma^+}$$

- We perform $M(\Lambda_c^+)$ fits in five bins of $\cos\theta_{\Sigma^+}$ distribution individually, then plot and fit the efficiency-corrected $\cos\theta_{\Sigma^+}$ distributions.

- This $\alpha_{\Sigma^+ \pi^0}$ agrees with W.A. but with precision improved by threefold; the other two measured for the first time.
- Comparing with $\alpha_{\Sigma^0 \pi^+} = -0.463 \pm 0.016 \pm 0.008$ as aforementioned, their agreement within 1σ shows consistency with the prediction from the isospin symmetry [PLB **794**, 19 (2019)].
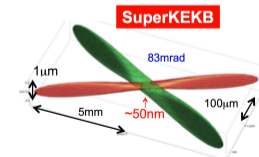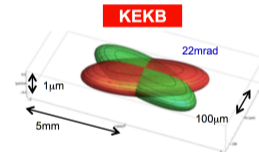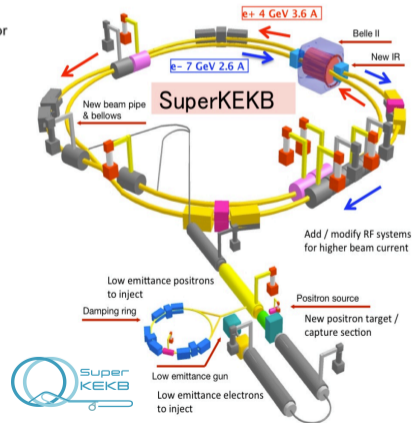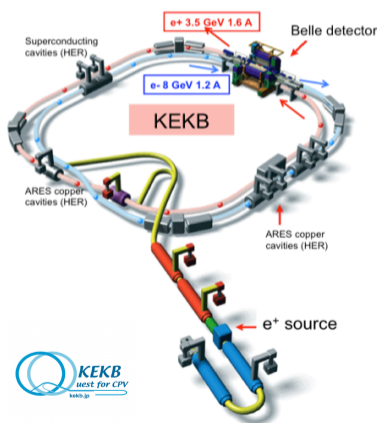- ...... more α-results, e.g. for Ξ_c^0 decaying to a hyperon and a vector... (see back up)

Outline

Belle II and SuperKEKB

from KEKB to SuperKEKB   (For more info, see Seema's talk yesterday.)

▶ As 1st and 2nd generation B-factories, KEKB and SuperKEKB have many similarities, and more differences:
- Damping ring added to have low emittance positrons / use 'Nano-beam' scheme by squeezing the beta function at the IP.
- beam energy: admit lower asymmetry to mitigate Touschek effects / beam current: ×2 to contribute to higher luminosity.
- SuperKEKB achieved the luminosity record of $4.7 \times 10^{34}\ cm^{-2}s^{-1}$.

Belle at KEKB
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Selected studies of charm mesons
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Selected studies of charm baryons
○○○○○○○

Charm results from Belle II
○○●○○

Summary
○○

Belle II and SuperKEKB

Detector: Belle II Vs. Belle

SVD: 4 lyrs → VXD=(PXD 2 lyrs + SVD 4 lyrs)
CDC: small cell, long lever arm
ACC+TOF → TOP+ARICH
ECL: waveform sampling
KLM: RPC → Scintillator + SiPM
         (endcaps, barrel inner 2 lyrs)

Belle at KEKB
○○○

Selected studies of charm mesons
○○○○○○○○○

Selected studies of charm baryons
○○○○○○○

Charm results from Belle II
○○○●○

Summary
○○
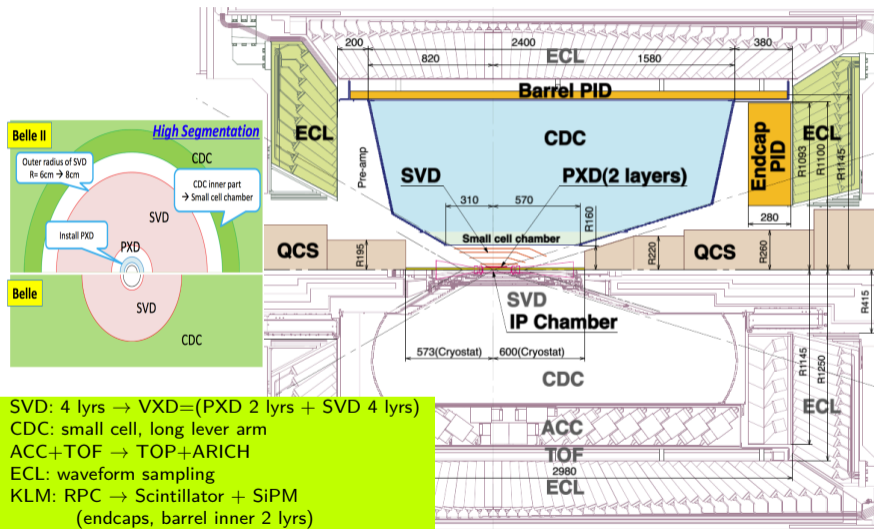
Charm lifetimes from Belle II
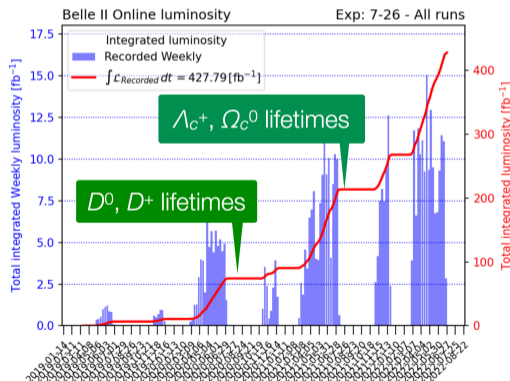
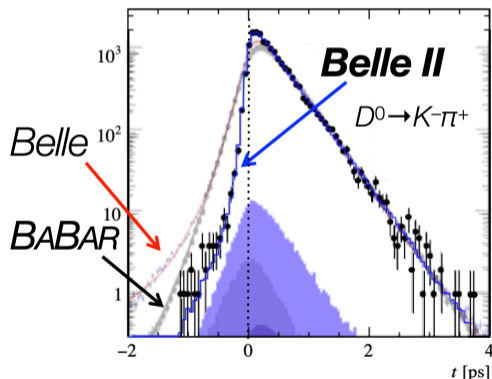# High precision vertex $\Rightarrow$ charm lifetimes at Belle II

- The impact parameter resolution is $\times 2$ better than Belle/BaBar, which shows up in decay-time distribution.
- Benefited from this, the charm lifetimes are measured using the early data set, as listed in luminosity plot.
- We (Belle II) totally have accumulated 428 fb^{-1} of data set in. Now we are under the long-shut one.

Belle at KEKB   Selected studies of charm mesons   Selected studies of charm baryons   **Charm results from Belle II**   Summary

Charm lifetimes from Belle II

charm lifetimes at Belle II (PRL 127, 211801 (2021), arXiv:2206.15227, arXiv:2208.08573)
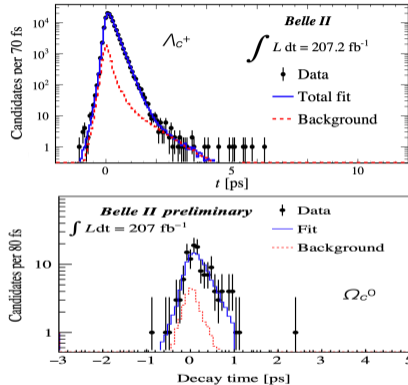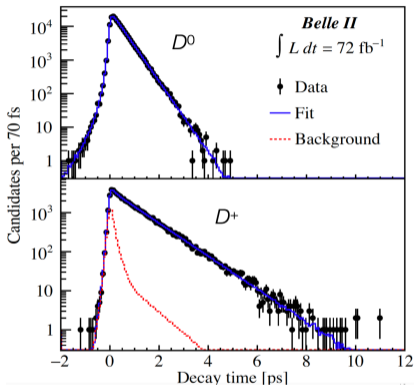
- We obtain the world-best charm lifetimes: $\tau(D^0) = 410.5 \pm 1.1 \pm 0.8$ fs, $\tau(D^+) = 1030.4 \pm 4.7 \pm 3.1$ fs, and $\tau(\Lambda_c^+) = 203.20 \pm 0.89 \pm 0.77$ fs (first Belle II precision measurements), Their tiny systematic uncertainties demonstrate the excellent performance and understanding of the Belle II detector.

- $\tau(\Omega_c^0)$ result, $243 \pm 48 \pm 11$ fs, is consistent with LHCb, inconsistent with pre-LHCb average at 3.4σ.
  $\Rightarrow$ the Ω_c^0 is not the shortest-lived weakly decaying charmed baryon.

Outline

1. Belle at KEKB

2. Selected studies of charm mesons at Belle
   - $\mathcal{B}/A_{CP}$ for $D^0 \to h^+ h^- \eta$ ($h = K$, π) and $D^0 \to \phi\eta$
   - $\mathcal{B}/A_{CP}/a_{CP}^{T\text{-odd}}$ for $D^0 \to K_S^0 K_S^0 \pi^+ \pi^-$ and $D_{(s)}^+ \to K\pi\pi^+\pi^-$

3. Selected studies of charm baryons at Belle
   - $\mathcal{B}/A_{CP}/\alpha/A_{CP}^\alpha$ of $\Lambda_c^+ \to \Lambda h^+$, $\Sigma^0 h^+$
   - $\mathcal{B}/\alpha$ for $\Lambda_c^+ \to \Sigma^+ (\pi^0, \eta, \eta')$

4. Charm results from Belle II
   - Belle II and SuperKEKB
   - Charm lifetimes from Belle II

5. Summary

Summary

- Belle are lasting to produce the fruitful charm results although its data taking finished 12 years ago. Here selected charm results in latest two years are presented.
  - charm mesons: $\mathcal{B}$, CP asymmetry, T-odd CP asymmetry, etc.
  - charm baryons: $\mathcal{B}$ of hadronic or semileptonic decays, direct CP asymmetry, α and A_{CP}^{α}, etc.

Belle at KEKB ○○○
Selected studies of charm mesons ○○○○○○○○○
Selected studies of charm baryons ○○○○○○○
Charm results from Belle II ○○○○○
Summary ○●

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- Some charm results from Belle are not covered, e.g. radiative decay, heavy-flavor-conserving decay, amplitude analysis of hadronic decays, etc. More results from Belle and Belle II are on the road.

Summary

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- Some charm results from Belle are not covered, e.g. radiative decay, heavy-flavor-conserving decay, amplitude analysis of hadronic decays, etc. More results from Belle and Belle II are on the road.

- Our beautiful world is charming due to the symmetries and asymmetries. And let us also admire the charm world from the view of Belle and Belle II.

Back up

Thank you for your attentions.

谢谢!

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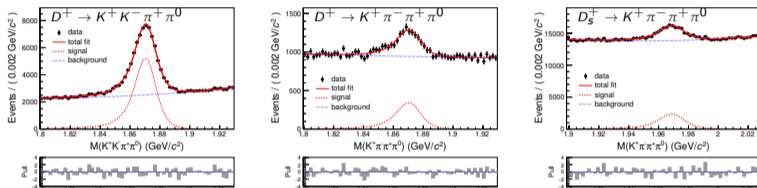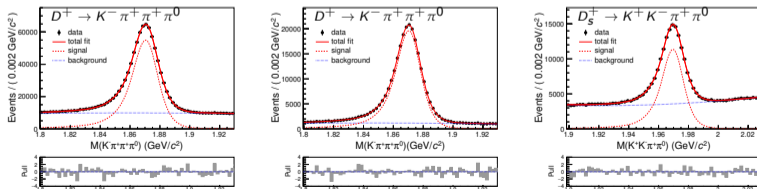lilongke@mail.ustc.edu.cn

$\mathcal{B}$ of $D^+_{(s)} \to K\pi\pi^+\pi^-$ at Belle (arXiv:2205.02018)

- The four-body decays of charged D mesons. e.g. three CS decays below


and their corresponding reference modes:

- Based on the efficiency-corrected yields and the W.A. $\mathcal{B}$ of reference mode, we have three most precise results: $\mathcal{B}(D^+ \to K^+K^-\pi^+\pi^0) = (7.08 \pm 0.08 \pm 0.16 \pm 0.20) \times 10^{-3}$, $\mathcal{B}(D^+ \to K^+\pi^-\pi^+\pi^0) = (1.05 \pm 0.07 \pm 0.02 \pm 0.03) \times 10^{-3}$, $\mathcal{B}(D_s^+ \to K^+\pi^-\pi^+\pi^0) = (9.44 \pm 0.34 \pm 0.28 \pm 0.32) \times 10^{-3}$.

- we obtain a DCS/CF ratio: $\frac{\mathcal{B}(D^+\to K^+\pi^-\pi^+\pi^0)}{\mathcal{B}(D^+\to K^-\pi^+\pi^+\pi^0)} = (1.68 \pm 0.11 \pm 0.03)\%$ which corresponds to $(5.83 \pm 0.42)\tan^4\theta_C$. This DCS/CF result is significantly larger than all other known DCS/CF ratios, so we confirm BESIII's discovery.

- Their $a_{CP}^{T\text{-odd}}$ results are on the road...

$\mathcal{B}$ of $\Xi_c^0 \to \Xi^- \ell^+ \nu_\ell$ and $\Omega_c^0 \to \Omega^- \ell^+ \nu_\ell$ at Belle (PRL **127**, 121803 (2021), PRD **105**, L091101 (2022))

- Semileptonic (SL) decay of charm baryons is an ideal test of QCD in transition region of (non-)perturbation; cleanest processes among charm decays; test lepton flavor universality (LFU).
- Currently experimental results (from BESIII, ARGUS, CLEO) have large uncertainties.
- We measure the $\mathcal{B}$ of $\Xi_c^0 \to \Xi^- \ell^+ \nu_\ell$ and $\Omega_c^0 \to \Omega^- \ell^+ \nu_\ell$ with detailed study of backgrounds by data-driven method.
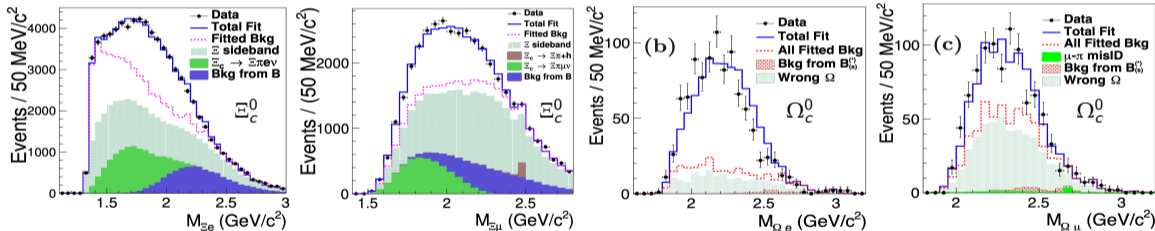
- ▶ $\mathcal{B}(\Xi_c^0 \to \Xi^- e^+ \nu_e) = (1.31 \pm 0.39)\%$, $\mathcal{B}(\Xi_c^0 \to \Xi^- \mu^+ \nu_\mu) = (1.27 \pm 0.39)\%$, and their ratio is $1.03 \pm 0.05 \pm 0.07$.

- ▶ $\frac{\mathcal{B}(\Omega_c^0 \to \Omega^- e^+ \nu_e)}{\mathcal{B}(\Omega_c^0 \to \Omega^- \pi^+)} = 1.98 \pm 0.13 \pm 0.08$, $\frac{\mathcal{B}(\Omega_c^0 \to \Omega^- \mu^+ \nu_\mu)}{\mathcal{B}(\Omega_c^0 \to \Omega^- \pi^+)} = 1.94 \pm 0.18 \pm 0.10$, and $\frac{\mathcal{B}(\Omega_c^0 \to \Omega^- e^+ \nu_e)}{\mathcal{B}(\Omega_c^0 \to \Omega^- \mu^+ \nu_\mu)} = 1.02 \pm 0.10 \pm 0.02$.

- ▶ Both ratios of SL decays are consistent with the expectation of lepton flavor universality.

$\mathcal{B}$ and α of $\Xi_c^0 \to (\Lambda, \Sigma^0) \overline{K}^{*0}$ and $\Sigma^+ K^{*-}$ at Belle (JHEP 06 (2021) 160)

- We measure $\mathcal{B}$ and α of three CF Ξ_c^0 decays of which the final state is a combination of a hyperon and a vector particle.

- The signal yields are extracted via $M_{\Xi_c^0}$-M_{K^*} 2D fit. See the figures with achieved signal yields.

- Then we have their $\mathcal{B}$'s relative to that of $\Xi_c^0 \to \Xi^- \pi^+$ after considering the efficiency.

  $\mathcal{B}(\Xi_c^0 \to \Lambda \overline{K}^{*0})/\mathcal{B}(\Xi_c^0 \to \Xi^- \pi^+) = 0.18 \pm 0.02 \pm 0.01$
  $\mathcal{B}(\Xi_c^0 \to \Sigma^0 \overline{K}^{*0})/\mathcal{B}(\Xi_c^0 \to \Xi^- \pi^+) = 0.69 \pm 0.03 \pm 0.03$
  $\mathcal{B}(\Xi_c^0 \to \Sigma^+ K^{*-})/\mathcal{B}(\Xi_c^0 \to \Xi^- \pi^+) = 0.34 \pm 0.06 \pm 0.02$

- Finally, using the W.A. $\mathcal{B}(\Xi_c^0 \to \Xi^- \pi^+)$, we have absolute $\mathcal{B}$'s below for the first time:

  $\mathcal{B}(\Xi_c^0 \to \Lambda \overline{K}^{*0}) = (3.3 \pm 0.3 \pm 0.2 \pm 1.0(\mathcal{B}_{\text{ref}})) \times 10^{-3}$
  $\mathcal{B}(\Xi_c^0 \to \Sigma^0 \overline{K}^{*0}) = (12.4 \pm 0.5 \pm 0.5 \pm 3.6(\mathcal{B}_{\text{ref}})) \times 10^{-3}$
  $\mathcal{B}(\Xi_c^0 \to \Sigma^+ K^{*-}) = (6.1 \pm 1.0 \pm 0.4 \pm 1.8(\mathcal{B}_{\text{ref}})) \times 10^{-3}$
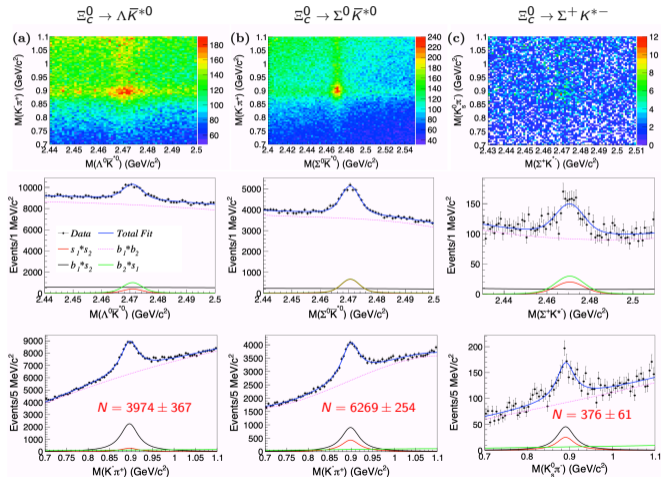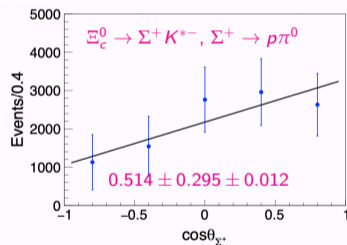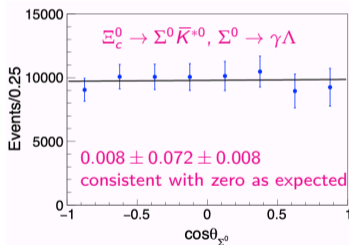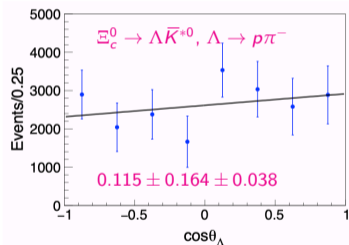
$\mathcal{B}$ and α of $\Xi_c^0 \to (\Lambda, \Sigma^0) \overline{K}^{*0}$ and $\Sigma^+ K^{*-}$ at Belle (JHEP 06 (2021) 160)

- Taking $\Xi_c^0 \to \Lambda \overline{K}^{*0}$ for example, the differential decay rate depends on decay asymmetry parameters and $\cos\theta_\Lambda$

$$\frac{dN}{d\cos\theta_\Lambda} \propto 1 + \alpha(\Xi_c^0 \to \Lambda \overline{K}^{*0})\alpha(\Lambda \to p\pi^-)\cos\theta_\Lambda$$

- We extract the $\alpha_{\Xi_c^0}\alpha_{(\Lambda, \Sigma^0, +)}$ via the fits on the efficiency-corrected $\cos\theta_\Lambda$ or $\cos\theta_\Sigma$ distributions:

- The $\alpha(\Xi_c^0 \to \Sigma^0 \overline{K}^{*0})$ can not be measured via 1D $\cos\theta_{\Sigma^0}$ distribution due to $\alpha(\Sigma^0 \to \gamma\Lambda) = 0$ in an electromagnetic decay.
- Using the W.A. $\alpha(\Lambda \to p\pi^-) = 0.747 \pm 0.010$ and $\alpha(\Sigma^+ \to p\pi^0) = -0.980 \pm 0.017$, we finally, for the first time, have
  $\alpha(\Xi_c^0 \to \Lambda \overline{K}^{*0}) = 0.15 \pm 0.22 \pm 0.05$ and $\alpha(\Xi_c^0 \to \Sigma^+ K^{*-}) = -0.52 \pm 0.30 \pm 0.02$.