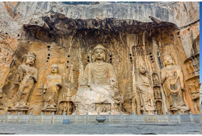
(Very) Recent charm results at Belle II experiment

李龙科 （湖南师范大学）
lilongke@mail.ustc.edu.cn

第六届粒子物理天问论坛
2024年11月9日于洛阳






Outline

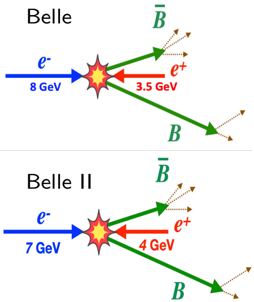
1. Charm sample available
2. First charm CPV results at Belle II
   - $D^0 \to K_S^0 K_S^0$
   - $D^+_{(s)} \to K_S^0 K^- \pi^+ \pi^+$
3. D^0-$\bar{D}^0$ mixing in $D^0 \to K_S^0 \pi^+ \pi^-$ (model-independent)
4. Study of hadronic decays of charmed baryons
   - $\Xi_c^0 \to \Xi^0 \pi^0, \Xi^0 \eta, \Xi^0 \eta'$
   - $\Xi_c^+ \to p K_S^0, \Lambda \pi^+, \Sigma^0 \pi^+$
5. Summary and Prospect

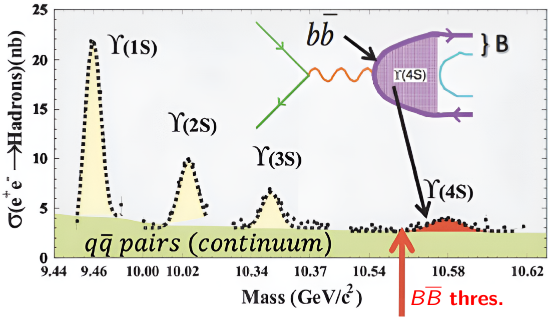
Outline

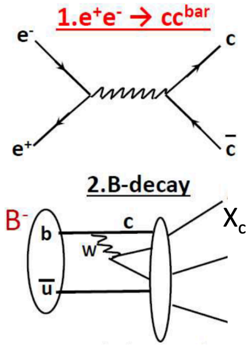
1. Charm sample available
2. First charm CPV results at Belle II
   - $D^0 \to K_S^0 K_S^0$
   - $D_{(s)}^+ \to K_S^0 K^- \pi^+ \pi^+$
3. D^0-$\bar{D}^0$ mixing in $D^0 \to K_S^0 \pi^+ \pi^-$ (model-independent)
4. Study of hadronic decays of charmed baryons
   - $\Xi_c^0 \to \Xi^0 \pi^0, \Xi^0 \eta, \Xi^0 \eta'$
   - $\Xi_c^+ \to p K_S^0, \Lambda \pi^+, \Sigma^0 \pi^+$
5. Summary and Prospect

Charm production at Belle and Belle II

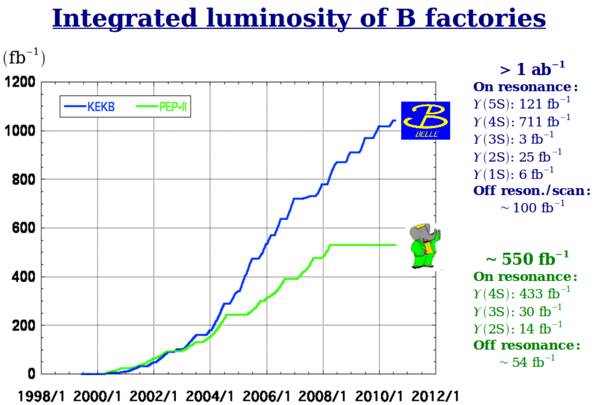
- At Belle (II), e^+e^- mainly collide at 10.58 GeV to make $\Upsilon(4S)$ resonance decaying into $B\bar{B}$ in 96% of the time.
- Meanwhile, continuum processes $e^+e^- \to q\bar{q}$ ($q = u, d, s, c$) have large cross sections.
- Two ways to produce the charm sample: $e^+e^- \to c\bar{c}$ ($\sigma = 1.3$ nb), and $B \to$ charm decays.



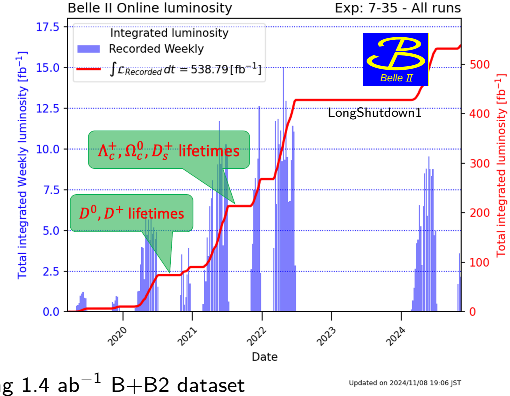




Luminosity at Belle and Belle II



First wave: charm lifetimes based on the early data set
PRL 127, 211801 (2021); PRL 131, 171803 (2023);
PRD 107, L031103 (2023); PRL 130, 071802 (2023).



New waves using 1.4 ab^{-1} B+B2 dataset

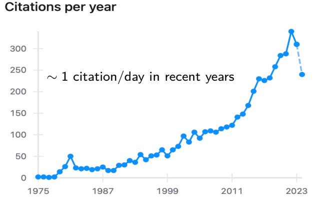
Charm results at Belle and Belle II in latest two years

中国组成员主导的分析占60%

- Charm lifetimes:
  - $\tau(D_s^+)$ [PRL 131, 171803 (2023)] / $\tau(\Lambda_c^+)$ [PRL 130, 071802 (2023)] / $\tau(\Omega_c^0)$ [PRD 107, L031103 (2023)]
- Charm *CP* violation:
  - $\mathcal{A}_{CP}^{\rm TP}(D^0 \to K_S^0 K_S^0 \pi^+ \pi^-)$ [PRD 107, 052001 (2023)] / $\mathcal{A}_{CP}^{\rm TP}(D_{(s)}^+ \to K^+ K_S^0 h^+ h^-)$ [PRD 108, L11102 (2023)] / $\mathcal{A}_{CP}^{\rm TP}(D_{(s)}^+ \to K h \pi^+ \pi^0)$ [arXiv:2305.12806] / $\mathcal{A}_{CP}^{\rm dir}, \mathcal{A}_{CP}^{\alpha}(\Lambda_c^+ \to \Lambda h^+, \Sigma^0 h^+)$ [Science Bulletin 68 (2023) 583] / $\mathcal{A}_{CP}^{X}(D_{(s)}^+ \to K_S^0 K^- \pi^+ \pi^+)$ [TP/QP, arXiv:2409.15777] / $A_{CP}(D^0 \to K_S^0 K_S^0)$ [arXiv:2411.00306]
- D^0-$\bar{D}^0$ mixing:
  - model-independent measurement of mixing parameter in $D^0 \to K_S^0 \pi^+ \pi^-$ [arXiv:2410.22961]
- $\mathcal{B}$ and α of hadronic decays:
  - $\mathcal{B}(D_{(s)}^+ \to K^+ h^- \pi^+ \pi^0)$ [PRD 107, 033003 (2023)] / $\mathcal{B}(\Xi_c^0 \to \Xi^0 \pi^0, \Xi^0 \eta, \Xi^0 \eta')$ and $\alpha(\Xi_c^0 \to \Xi^0 \pi^0)$ [JHEP 10 (2024) 045] / $\mathcal{B}(\Lambda_c^+ \to \Sigma^+ \pi^0, \Sigma^+ \eta, \Sigma^+ \eta')$ and $\alpha(\Lambda_c^+ \to \Sigma^+ \pi^0)$ [PRD 107, 032003 (2023)] / $\mathcal{B}(\Lambda_c^+ \to p K_S^0 K_S^0, p K_S^0 \eta)$ [PRD 107, 032004 (2023)] / $\mathcal{B}(\Omega_c^0 \to \Xi^- h^+, \Omega^- K^+)$ [JHEP 01 (2023) 055] / $\mathcal{B}(\Lambda_c^+ \to p K_S^0 \pi^0)$ [preliminary] / $\mathcal{B}(\Xi_c^+ \to p K_S^0, \Lambda \pi^+, \Sigma^0 \pi^+)$ [preliminary]
- Rare or forbidden decays:
  - $\Xi_c^0 \to \Xi^0 \ell^+ \ell^-$ [PRD 109, 052003 (2024)] / $D^0 \to p \ell$ [PRD 109, L031101 (2024)] / $D^0 \to h^- h^{(\prime)+} e^+ e^-$ [preliminary]
- Spectrum:
  - $\Lambda_c(2880, 2940)^+ \to p D^0$ [PRD 110, 032021 (2024)] / $\Lambda_c(2910)^+ \to \Sigma_c(2455)^0 \pi^+$ [PRL 130, 031901 (2023)] / $\Lambda_c(2625)^+ \to \Sigma_c^{0,++} \pi^{+,-}$ [PRD 107, 032008 (2023)] / $\Sigma(1435)^* \to \Lambda \pi^\pm$ in $\Lambda_c^+ \to \Lambda \pi^+ \pi^+ \pi^-$ [PRL 130, 151903 (2023)]

Why CPV and Charm CPV Special?

[A.D. Sakharov, Usp. Fiz. Nauk 161 (1991) 61]



- CPV is essential for elucidating the matter-antimatter asymmetry in the universe.
- Three necessary "Sakharov conditions" are:
  1) Baryon number violation; 2) C and CPV; 3) Interactions out of thermal equilibrium.
- The sole origin of CPV in Standard Model arising from the single complex phase of CKM matrix, is insufficient to account for the observed matter-antimatter asymmetry.
  $\Rightarrow$ we need to search for new CPV sources beyond SM (a lasting hot topic).
- Charm CPV effect is very small ($\mathcal{O}(10^{-3})$ or smaller [a b]). New Physics may enhance it [c d].
- In 2019, CP violation in D decays was found at LHCb [e]: $\Delta\mathcal{A}_{CP}(D^0 \to K^+K^-, \pi^+\pi^-) = (-15.4 \pm 2.9) \times 10^{-4}$ (5.3σ).
  Recently LHCb report the first evidence for direct CPV in a specific D decay [f]: $A^{\rm dir}_{\pi\pi} = (2.32 \pm 0.61) \times 10^{-3}$.
  $\Rightarrow$ to understand this CPV, study more channels and improve the precision on the existing measurements.
- CPV has been observed in all the open-flavored meson sector, but not yet established in the baryon sector.
  Baryogenesis, the process by which the baryon-antibaryon asymmetry of the universe developed, is directly related to baryon CPV [g].
  $\Rightarrow$ CPV search in charmed baryon is one of main targets of charm physics at Belle II.

---

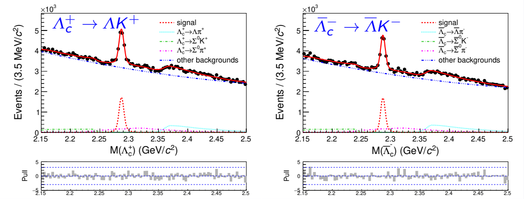
[a] H.-n. Li, C.-D. Lu, and F.-S. Yu, PRD 86, 036012 (2012)
[b] H.-Y. Cheng and C.-W. Chiang, PRD 104, 073003 (2021)
[c] A. Dery and Y. Nir, JHEP 12, 104 (2019)
[d] M. Saur and F.-S. Yu, Sci. Bull. 65, 1428 (2020)
[e] LHCb, PRL 122, 211803 (2019)
[f] LHCb, PRL 131, 091802 (2023)
[g] M.E. Shaposhnikov, NPB 287, 757 (1987)

(Belle) CPV searches in $\Lambda_c^+ \to \Lambda K^+, \Sigma^0 K^+$

L. K. Li *et al.* (Belle) Science Bulletin **68** (2023) 583

direct CPV in $\Lambda_c^+ \to \Lambda K^+, \Sigma^0 K^+$

- The sources of raw asymmetry of $\Lambda_c^+ \to \Lambda h^+$:
  $A_{\rm raw}(\Lambda_c^+ \to \Lambda K^+) \approx \mathcal{A}_{CP}^{\Lambda_c^+ \to \Lambda K^+} + \mathcal{A}_{CP}^{\Lambda \to p\pi^-} + A_\varepsilon^{\Lambda} + A_\varepsilon^{K^+} + A_{\rm FB}^{\Lambda_c^+}$
- Using (CF) $\Lambda_c^+ \to \Lambda \pi^+$, $\Sigma^0 \pi^+$ to remove common sources.

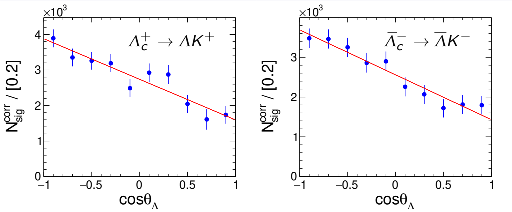


- $\mathcal{A}_{CP}^{\rm dir}(\Lambda_c^+ \to \Lambda K^+) = (+2.1 \pm 2.6 \pm 0.1)\%$
- $\mathcal{A}_{CP}^{\rm dir}(\Lambda_c^+ \to \Sigma^0 K^+) = (+2.5 \pm 5.4 \pm 0.4)\%$

First $\mathcal{A}_{CP}^{\rm dir}$ for SCS two-body decays of charmed baryons.

α-induced CPV in $\Lambda_c^+ \to \Lambda K^+, \Sigma^0 K^+$

- Measure $\alpha / \bar{\alpha}$ for the separate $\Lambda_c^+ / \bar{\Lambda}_c^-$ samples.
- Calculate $\mathcal{A}_{CP}^{\alpha} \equiv (\alpha_{\Lambda_c^+} + \alpha_{\bar{\Lambda}_c^-})/(\alpha_{\Lambda_c^+} - \alpha_{\bar{\Lambda}_c^-})$.



- $\mathcal{A}_{CP}^{\alpha}(\Lambda_c^+ \to \Lambda K^+) = -0.023 \pm 0.086 \pm 0.071$
- $\mathcal{A}_{CP}^{\alpha}(\Lambda_c^+ \to \Sigma^0 K^+) = +0.08 \pm 0.35 \pm 0.14$
  First $\mathcal{A}_{CP}^{\alpha}$ results for SCS decays of charmed baryons.
- No evidence of CPV is found.

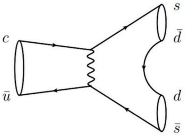
Outline

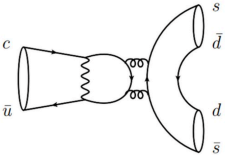
1. Charm sample available
2. First charm CPV results at Belle II
   - $D^0 \to K_S^0 K_S^0$
   - $D_{(s)}^+ \to K_S^0 K^- \pi^+ \pi^+$
3. D^0-$\bar{D}^0$ mixing in $D^0 \to K_S^0 \pi^+ \pi^-$ (model-independent)
4. Study of hadronic decays of charmed baryons
   - $\Xi_c^0 \to \Xi^0 \pi^0, \Xi^0 \eta, \Xi^0 \eta'$
   - $\Xi_c^+ \to p K_S^0, \Lambda \pi^+, \Sigma^0 \pi^+$
5. Summary and Prospect

Time-integrated CP asymmetry in $D^0 \to K_S^0 K_S^0$

arXiv:2411.00306, MNITJ/BNL 主导

- The time-integrated CP asymmetry $\mathcal{A}_{CP}(D^0 \to K_S^0 K_S^0) = \dfrac{\Gamma(D^0 \to K_S^0 K_S^0) - \Gamma(\bar{D}^0 \to K_S^0 K_S^0)}{\Gamma(D^0 \to K_S^0 K_S^0) + \Gamma(\bar{D}^0 \to K_S^0 K_S^0)}$.
- It may be enhanced to be an observable level (the 1% level) within the Standard Model, due to the interference of $c \to us\bar{s}$ and $c \to ud\bar{d}$ amplitudes. [PRD 99, 113001 (2019), PRD 86, 014023 (2012), PRD 92, 054036 (2015)]

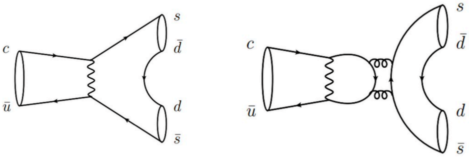




Time-integrated CP asymmetry in $D^0 \to K_S^0 K_S^0$

arXiv:2411.00306, MNITJ/BNL 主导

- The time-integrated CP asymmetry $\mathcal{A}_{CP}(D^0 \to K_S^0 K_S^0) = \dfrac{\Gamma(D^0 \to K_S^0 K_S^0) - \Gamma(\bar{D}^0 \to K_S^0 K_S^0)}{\Gamma(D^0 \to K_S^0 K_S^0) + \Gamma(\bar{D}^0 \to K_S^0 K_S^0)}$.
- It may be enhanced to be an observable level (the 1% level) within the Standard Model, due to the interference of $c \to us\bar{s}$ and $c \to ud\bar{d}$ amplitudes. [PRD 99, 113001 (2019), PRD 86, 014023 (2012), PRD 92, 054036 (2015)]



- World average: $A_{CP}(D^0 \to K_S^0 K_S^0) = (-1.9 \pm 1.0)\%$ is dominated by
  - Belle (921 fb^{-1}): $\mathcal{A}_{CP}^{K_S^0 K_S^0} = (-0.02 \pm 1.53 \pm 0.02 \pm 0.17)\%$ using $D^0 \to K_S^0 \pi^0$ as control mode [PRL 119, 171801 (2017)]
  - LHCb (6 fb^{-1}): $\mathcal{A}_{CP}^{K_S^0 K_S^0} = (-3.1 \pm 1.2 \pm 0.4 \pm 0.2)\%$ using $D^0 \to K^+ K^-$ as control mode [PRD 104, L031102 (2021)]
- $\mathcal{A}_{CP}(D^0 \to K^+ K^-)$: recently improved by LHCb, uncertainty $< 0.1\%$ [PRL 131, 091802 (2023)]
- Recently, CMS (42 fb^{-1}) reported $\mathcal{A}_{CP}^{K_S^0 K_S^0} = (6.2 \pm 3.0 \pm 0.2 \pm 0.8)\%$ [arXiv:2405.11606]

Time-integrated CP asymmetry in $D^0 \to K^0_S K^0_S$

arXiv:2411.00306, MNITJ/BNL 主导

- Measure $\mathcal{A}_{CP}(D^0 \to K^0_S K^0_S)$, using $D^0 \to K^+K^-$ as control mode, with $D^{*+} \to D^0 \pi_s^+$ sample at B+B2 (1.4 ab^{-1}).

$$A_{\rm raw}(D^0 \to f) = \frac{N(D^0) - N(\bar{D}^0)}{N(D^0) + N(\bar{D}^0)} = A_{\rm FB}^{D^{*+}} + A_{CP}^{D^0 \to f} + A_{\varepsilon}^{\pi_s}$$

- $\mathcal{A}_{CP}^{K^0_S K^0_S} = (A_{\rm raw}^{K^0_S K^0_S} - A_{\rm raw}^{K^+K^-}) + \mathcal{A}_{CP}^{K^+K^-}$ assuming that the nuisance asymmetries are identical between two decays, or that they can be made so by weighting the control sample.

Time-integrated CP asymmetry in $D^0 \to K_S^0 K_S^0$

arXiv:2411.00306, MNITJ/BNL 主导

- Measure $\mathcal{A}_{CP}(D^0 \to K_S^0 K_S^0)$, using $D^0 \to K^+K^-$ as control mode, with $D^{*+} \to D^0 \pi_s^+$ sample at B+B2 (1.4 ab^{-1}).

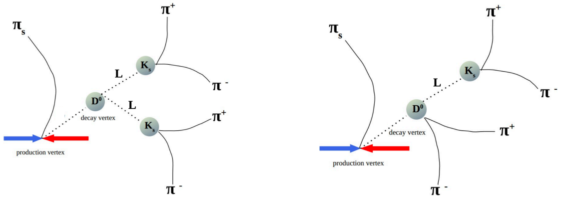
$$A_{\rm raw}(D^0 \to f) = \frac{N(D^0) - N(\bar{D}^0)}{N(D^0) + N(\bar{D}^0)} = A_{\rm FB}^{D^{*+}} + A_{CP}^{D^0 \to f} + A_{\varepsilon}^{\pi_s}$$

- $\mathcal{A}_{CP}^{K_S^0 K_S^0} = (A_{\rm raw}^{K_S^0 K_S^0} - A_{\rm raw}^{K^+K^-}) + \mathcal{A}_{CP}^{K^+K^-}$ assuming that the nuisance asymmetries are identical between two decays, or that they can be made so by weighting the control sample.
- $A_{CP}^{D^0 \to K^+K^-} = A_{CP}^{\rm dir}(D^0 \to K^+K^-) + \Delta Y = (6.7 \pm 5.4) \times 10^{-4}$ [PRL 131, 091802 (2023), PRD 104, 072010 (2021)]
  - $A_{CP}^{\rm dir}(D^0 \to K^+K^-) = (7.7 \pm 5.7) \times 10^{-4}$: direct CP asymmetry [PRL 131, 091802 (2023)]
  - $\Delta Y = (-1.0 \pm 1.1) \times 10^{-4}$: CPV in mixing and in the interference between mixing and decay [PRD 104, 072010 (2021)]

Time-integrated CP asymmetry in $D^0 \to K_S^0 K_S^0$

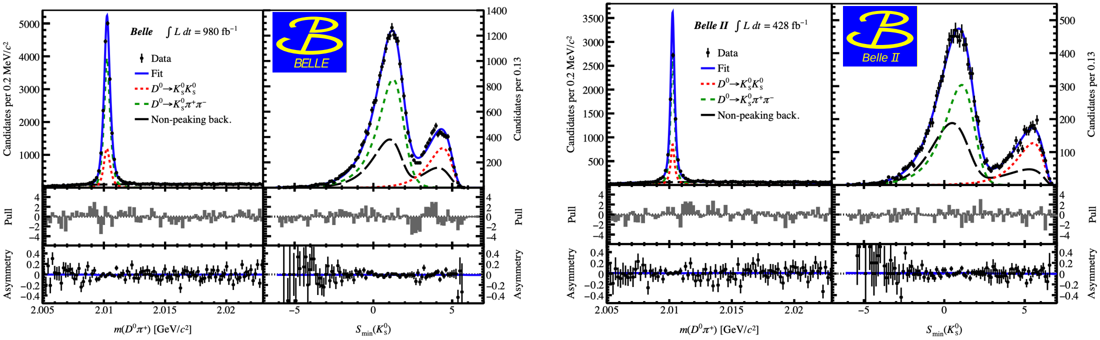
arXiv:2411.00306, MNITJ/BNL 主导

- Measure $\mathcal{A}_{CP}(D^0 \to K_S^0 K_S^0)$, using $D^0 \to K^+K^-$ as control mode, with $D^{*+} \to D^0 \pi_s^+$ sample at B+B2 (1.4 ab^{-1}).
  $$A_{\rm raw}(D^0 \to f) = \frac{N(D^0) - N(\bar{D}^0)}{N(D^0) + N(\bar{D}^0)} = A_{\rm FB}^{D^{*+}} + A_{CP}^{D^0 \to f} + A_{\varepsilon}^{\pi_s}$$
- $\mathcal{A}_{CP}^{K_S^0 K_S^0} = (A_{\rm raw}^{K_S^0 K_S^0} - A_{\rm raw}^{K^+K^-}) + \mathcal{A}_{CP}^{K^+K^-}$ assuming that the nuisance asymmetries are identical between two decays, or that they can be made so by weighting the control sample.
- $A_{CP}^{D^0 \to K^+K^-} = A_{CP}^{\rm dir}(D^0 \to K^+K^-) + \Delta Y = (6.7 \pm 5.4) \times 10^{-4}$ [PRL 131, 091802 (2023), PRD 104, 072010 (2021)]
  - $A_{CP}^{\rm dir}(D^0 \to K^+K^-) = (7.7 \pm 5.7) \times 10^{-4}$: direct CP asymmetry [PRL 131, 091802 (2023)]
  - $\Delta Y = (-1.0 \pm 1.1) \times 10^{-4}$: CPV in mixing and in the interference between mixing and decay [PRD 104, 072010 (2021)]
- Unbinned fit to $(m(D^0\pi_s), S_{\rm min})$ of D^0 and $\bar{D}^0$ candidates for $D^0 \to K_S^0 K_S^0$ decays.
  - Flight significance variable $S_{\rm min} = \log(\min(L_i/\sigma_i))$: separate the peaking background $D^0 \to K_S^0 \pi^+\pi^-$.



Time-integrated CP asymmetry in $D^0 \to K_S^0 K_S^0$

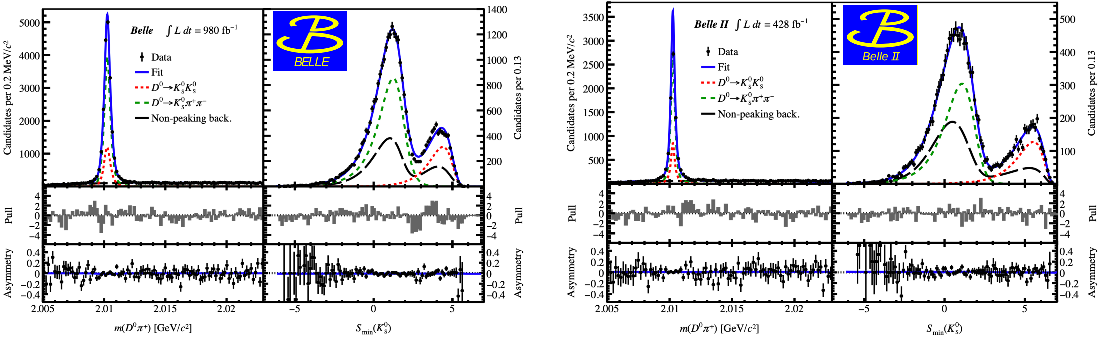
arXiv:2411.00306, MNITJ/BNL 主导



- Belle: $A_{CP}(D^0 \to K_S^0 K_S^0) = (-1.1 \pm 1.6 \pm 0.1)\%$ Belle II: $A_{CP}(D^0 \to K_S^0 K_S^0) = (-2.2 \pm 2.3 \pm 0.1)\%$
- Combined $A_{CP}(D^0 \to K_S^0 K_S^0) = (-1.4 \pm 1.3 \pm 0.1)\%$: comparable to the world-best result: $\sigma_{\text{LHCb}} = 1.3\%$

Time-integrated CP asymmetry in $D^0 \to K_S^0 K_S^0$

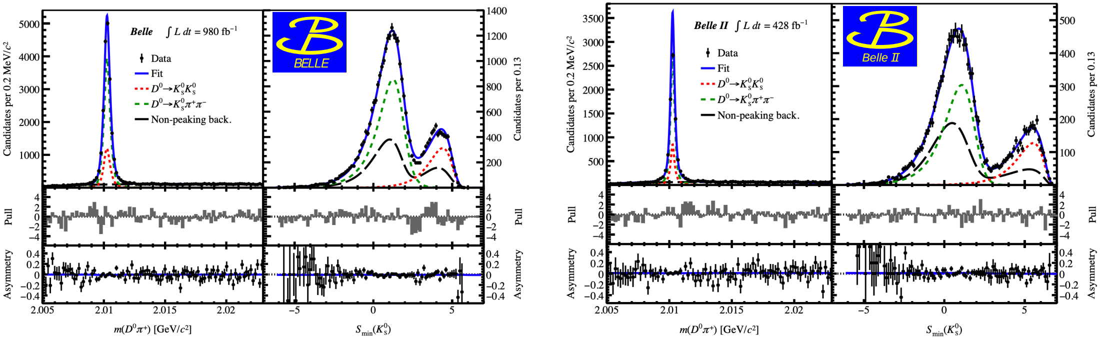
arXiv:2411.00306, MNITJ/BNL 主导



- Belle: $A_{CP}(D^0 \to K_S^0 K_S^0) = (-1.1 \pm 1.6 \pm 0.1)\%$ Belle II: $A_{CP}(D^0 \to K_S^0 K_S^0) = (-2.2 \pm 2.3 \pm 0.1)\%$
- Combined $A_{CP}(D^0 \to K_S^0 K_S^0) = (-1.4 \pm 1.3 \pm 0.1)\%$: comparable to the world-best result: $\sigma_{\text{LHCb}} = 1.3\%$
- Belle(II)+LHCb average: $(-2.3 \pm 0.9)\%$ vs. CMS: $(6.2 \pm 3.1)\%$: 2.6σ diff. $\Rightarrow$ preciser result needed

Time-integrated CP asymmetry in $D^0 \to K_S^0 K_S^0$

arXiv:2411.00306, MNITJ/BNL 主导

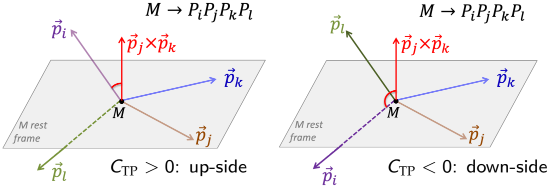


- Belle: $A_{CP}(D^0 \to K_S^0 K_S^0) = (-1.1 \pm 1.6 \pm 0.1)\%$ Belle II: $A_{CP}(D^0 \to K_S^0 K_S^0) = (-2.2 \pm 2.3 \pm 0.1)\%$
- Combined $A_{CP}(D^0 \to K_S^0 K_S^0) = (-1.4 \pm 1.3 \pm 0.1)\%$: comparable to the world-best result: $\sigma_{\text{LHCb}} = 1.3\%$
- Belle(II)+LHCb average: $(-2.3 \pm 0.9)\%$ vs. CMS: $(6.2 \pm 3.1)\%$: 2.6σ diff. $\Rightarrow$ preciser result needed
- Next results of CPV in D decays on the road:
  - $A_{CP}(D^0 \to K_S^0 K_S^0)$ using the non-D^{*+} sample (CFT method); more channels (e.g $D^{+,0} \to \pi^{+,0}\pi^0$ etc.)

CPV searches using triple-product correlations

arXiv:2409.15777，湖南师大/UC 主导

- CPV searches in several four-body D-decays at FOCUS, BABAR, LHCb and Belle using the triple-product (TP): $C_{\rm TP} = \vec{p}_i \cdot (\vec{p}_j \times \vec{p}_k)$.

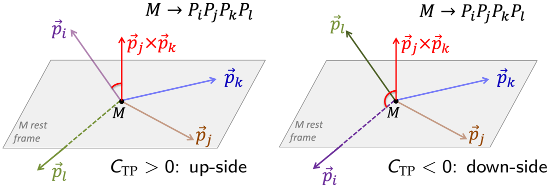


$C_{\rm TP}$ asymmetry: so-called 'up-down asymmetry'

CPV searches using triple-product correlations

arXiv:2409.15777, 湖南师大/UC 主导

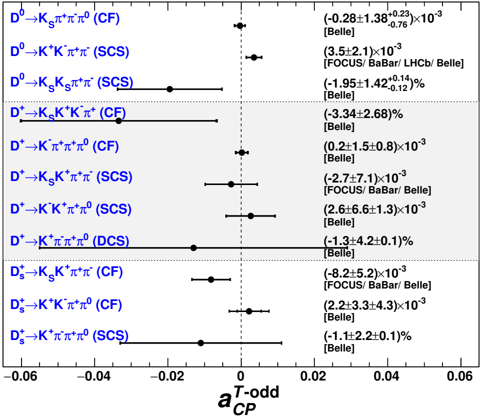
- CPV searches in several four-body D-decays at FOCUS, BABAR, LHCb and Belle using the triple-product (TP): $C_{\rm TP} = \vec{p}_i \cdot (\vec{p}_j \times \vec{p}_k)$.



$C_{\rm TP}$ asymmetry: so-called 'up-down asymmetry'

- CPV in $D^+_{(s)} \to K^0_S K^- \pi^+ \pi^+$: never been searched. They have large branching fractions $\mathcal{B} = 0.23\% (1.53\%)$ $\Rightarrow \mathcal{O}(10^5)$ signals expected, inspiring us to obtain their precise $a_{CP}^{T\text{-odd}}$ results for the first time.

Current world averages of all $a_{CP}^{T\text{-odd}}$ measurements:

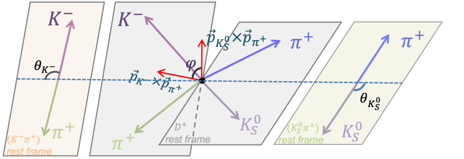


CPV searches using quadruple-product correlations

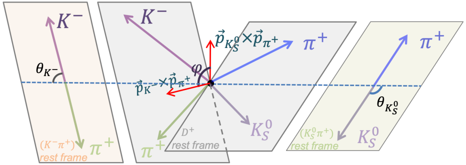
arXiv:2409.15777, 湖南师大/UC 主导

- We do the first CPV search with the quadruple-product (QP): in $D^+_{(s)} \to K^0_S K^- \pi^+ \pi^+$: $C_{\rm QP} = (\vec{p}_{K^-} \times \vec{p}_{\pi^+_h}) \cdot (\vec{p}_{K^0_S} \times \vec{p}_{\pi^+_l})$, where the subscripts ('h' and 'l') denote the π^+ with higher and lower momentum, respectively, of two identical π^+ in the final state.
- $D \to V_a V_b$ (e.g. $D^+_{(s)} \to \overline{K}^{*0} K^{*+}$ is a dominant process) amplitude involves terms of
  (1) $d^2_{1,0}(\theta_a) d^2_{1,0}(\theta_b) \sin\varphi \propto \sin(2\theta_a)\sin(2\theta_b)\sin\varphi$,
  (2) $d^2_{1,0}(\theta_a) d^2_{1,0}(\theta_b) \cos\varphi \propto \sin(2\theta_a)\sin(2\theta_b)\cos\varphi$.
- two more observables for CPV searches[a]:
  - $\cos\theta_{K^0_S}\cos\theta_{K^-} C_{\rm TP}$: same sign as $\cos\theta_{K^0_S}\cos\theta_{K^-}\sin\varphi$,
  - $\cos\theta_{K^0_S}\cos\theta_{K^-} C_{\rm QP}$: same sign as $\cos\theta_{K^0_S}\cos\theta_{K^-}\cos\varphi$.
- $\cos\theta_{K^0_S}\cos\theta_{K^-}$ is used for charm CPV searches; its asymmetry is the so-called 'two-fold forward-backward asymmetry'[b].

$C_{\rm QP} > 0$: $\vec{p}_{K^-}$ at left-side of $\vec{p}_{K^0_S\pi^+}(\vec{p}_{K^0_S} \times \vec{p}_{\pi^+})$ plane



$C_{\rm QP} < 0$: $\vec{p}_{K^-}$ at right-side of $\vec{p}_{K^0_S\pi^+}(\vec{p}_{K^0_S} \times \vec{p}_{\pi^+})$ plane



$C_{\rm QP}$ asymmetry: so-called 'left-right asymmetry'.

[a] G. Durieux and Y. Grossman, Phys. Rev. D **92**, 076013 (2015)

[b] Z.-H. Zhang, Phys. Rev. D **107**, L011301 (2023)

Signal yield extraction of $D^+_{(s)} \to K^0_S K^- \pi^+ \pi^+$

arXiv:2409.15777，湖南师大/UC 主导

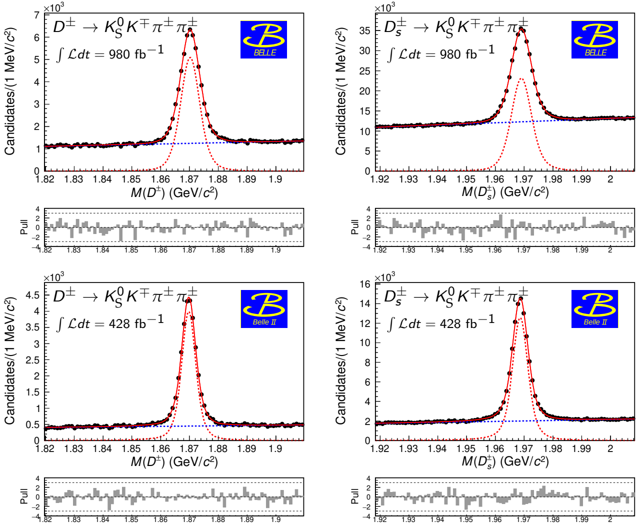


Table: Fitted signal and background yields in a window ± 10 MeV$/c^2$ around the nominal $D^+_{(s)}$ mass.

Component	$D^+ \to K^0_S K^- \pi^+ \pi^+$	
	Belle	Belle II
Signal (N_{sig})	44048 ± 288	26738 ± 199
Background (N_{bkg})	24844 ± 88	8964 ± 53
Ratio (N_{sig}/N_{bkg})	1.8	3.0
Component	**$D_s^+ \to K^0_S K^- \pi^+ \pi^+$**	
	Belle	Belle II
Signal (N_{sig})	210743 ± 780	92000 ± 393
Background (N_{bkg})	245285 ± 280	39997 ± 114
Ratio (N_{sig}/N_{bkg})	0.9	2.3

$\mathcal{A}^X_{CP}$ measurement in $D^+_{(s)} \to K^0_S K^- \pi^+ \pi^+$

arXiv:2409.15777, 湖南师大/UC 主导

- The sample is divided into four X-subsamples by the charm flavor and the sign of X-variables:

$$A_X(D^+_{(s)}) = \frac{N_+(X>0) - N_+(X<0)}{N_+(X>0) + N_+(X<0)}$$

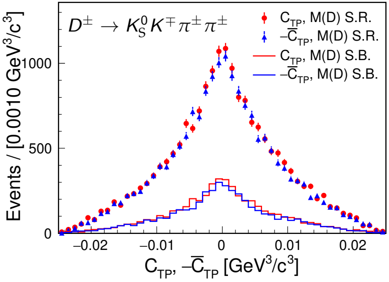
$$A_{\overline{X}}(D^-_{(s)}) = \frac{N_-(\overline{X}>0) - N_-(\overline{X}<0)}{N_-(\overline{X}>0) + N_-(\overline{X}<0)}$$

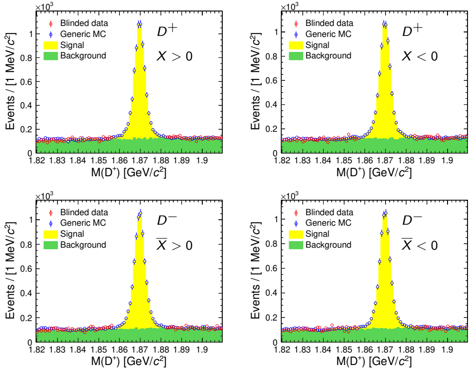
$$\mathcal{A}^X_{CP} = \frac{1}{2}(A_X(D^+_{(s)}) - A_{\overline{X}}(D^-_{(s)}))$$

$$N_D(X>0) = \frac{N_+}{2}(1+A_X) \qquad N_{D^-}(\overline{X}>0) = \frac{N_-}{2}(1+A_X-2\mathcal{A}^X_{CP})$$

$$N_{D^+}(X<0) = \frac{N_+}{2}(1-A_X) \qquad N_{D^-}(\overline{X}<0) = \frac{N_-}{2}(1-A_X+2\mathcal{A}^X_{CP})$$

Belle II data, $\int \mathcal{L}dt = 428\ \text{fb}^{-1}$





$\mathcal{A}_{CP}^{X}$ measurement in $D^+_{(s)} \to K^0_S K^- \pi^+ \pi^+$ arXiv:2409.15777, 湖南师大/UC 主导

- combining the results from Belle and Belle II experiments: $\mathcal{A}_{CP}^{X}(\mathrm{avg.}) = \frac{\mathcal{A}_{CP}^{B1}/\sigma_{B1}^2 + \mathcal{A}_{CP}^{B2}/\sigma_{B2}^2}{1/\sigma_{B1}^2 + 1/\sigma_{B2}^2}$, and its uncertainty $\sigma_{\mathcal{A}_{CP}^{X}(\mathrm{avg.})} = \frac{1}{\sqrt{1/\sigma_{B1}^2 + 1/\sigma_{B2}^2}}$, where σ_{B_1} and σ_{B_2} are the total uncertainties (i.e. $\sigma_{\mathrm{stat}} \oplus \sigma_{\mathrm{syst}}$) at Belle and Belle II.
- The $\mathcal{A}_{CP}^{X}$ results at Belle and Belle II and their combined results:

Decay	X	$\mathcal{A}_{CP}^{X}$ (10^{-3}) at Belle	$\mathcal{A}_{CP}^{X}$ (10^{-3}) at Belle II	Combined $\mathcal{A}_{CP}^{X}$ (10^{-3})	Significance
$D^+ \to K^0_S K^- \pi^+ \pi^+$	C_{TP}	$-4.0 \pm 5.9 \pm 3.0$	$-0.2 \pm 7.0 \pm 1.8$	$-2.3 \pm 4.5 \pm 1.5$	0.5σ
	C_{QP}	$-1.0 \pm 5.9 \pm 2.5$	$-0.4 \pm 7.0 \pm 2.4$	$-0.7 \pm 4.5 \pm 1.7$	0.2σ
	$C_{\mathrm{TP}} C_{\mathrm{QP}}$	$+6.4 \pm 5.9 \pm 2.2$	$+0.6 \pm 7.0 \pm 1.3$	$+3.9 \pm 4.5 \pm 1.1$	0.8σ
	$\cos\theta_{K^0_S} \cos\theta_{K^-}$	$-4.7 \pm 5.9 \pm 3.0$	$-0.6 \pm 6.9 \pm 3.0$	$-2.9 \pm 4.5 \pm 2.1$	0.6σ
	$\cos\theta_{K^0_S} \cos\theta_{K^-} C_{\mathrm{TP}}$	$+1.9 \pm 5.9 \pm 2.0$	$-0.2 \pm 7.0 \pm 1.9$	$+1.0 \pm 4.5 \pm 1.4$	0.2σ
	$\cos\theta_{K^0_S} \cos\theta_{K^-} C_{\mathrm{QP}}$	$+14.9 \pm 5.9 \pm 1.4$	$+7.0 \pm 7.0 \pm 1.6$	$+11.6 \pm 4.5 \pm 1.1$	2.5σ
$D_s^+ \to K^+ K^- \pi^+ \pi^0$	C_{TP}	$-0.3 \pm 3.1 \pm 1.3$	$+1.0 \pm 3.9 \pm 1.1$	$+0.2 \pm 2.4 \pm 0.8$	0.1σ
	C_{QP}	$+0.6 \pm 3.1 \pm 1.2$	$+2.0 \pm 3.9 \pm 1.4$	$+1.1 \pm 2.4 \pm 0.9$	0.4σ
	$C_{\mathrm{TP}} C_{\mathrm{QP}}$	$+1.5 \pm 3.2 \pm 1.4$	$-2.7 \pm 3.9 \pm 1.7$	$-0.2 \pm 2.5 \pm 1.1$	0.1σ
	$\cos\theta_{K^0_S} \cos\theta_{K^-}$	$-3.7 \pm 3.1 \pm 1.1$	$-6.3 \pm 3.9 \pm 1.2$	$-4.7 \pm 2.4 \pm 0.8$	1.8σ
	$\cos\theta_{K^0_S} \cos\theta_{K^-} C_{\mathrm{TP}}$	$-4.4 \pm 3.2 \pm 1.4$	$+0.8 \pm 3.9 \pm 1.4$	$-2.2 \pm 2.5 \pm 1.0$	0.8σ
	$\cos\theta_{K^0_S} \cos\theta_{K^-} C_{\mathrm{QP}}$	$-1.6 \pm 3.1 \pm 1.3$	$-0.0 \pm 3.9 \pm 1.7$	$-1.0 \pm 2.4 \pm 1.0$	0.4σ

Outline

Model-independent measurement of D^0-$\bar{D}^0$ mixing

arXiv:2410.22961, 科大/BNL/湖南师大主导

- Open-flavor neutral meson transforms to its anti-meson and vice versa:

$$K^0 \Leftrightarrow \bar{K}^0,\ B_d^0 \Leftrightarrow \bar{B}^0,\ B_s^0 \Leftrightarrow \bar{B}_s,\ D^0 \Leftrightarrow \bar{D}^0$$

- D^0's unique: only the up-type meson for mixing

Model-independent measurement of D^0-$\bar{D}^0$ mixing

arXiv:2410.22961, 科大/BNL/湖南师大主导

- Open-flavor neutral meson transforms to its anti-meson and vice versa:

$$K^0 \Leftrightarrow \bar{K}^0,\ B_d^0 \Leftrightarrow \bar{B}^0,\ B_s^0 \Leftrightarrow \bar{B}_s,\ D^0 \Leftrightarrow \bar{D}^0$$

- D^0's unique: only the up-type meson for mixing
- Flavor eigenstate ($|D^0\rangle$, $|\bar{D}^0\rangle$) $\neq$ mass eigenstate $|D_{1,2}\rangle$ with $M_{1,2}$ and $\Gamma_{1,2}$);

$$|D_{1,2}\rangle \equiv p|D^0\rangle \pm q|\bar{D}^0\rangle \quad (\text{CPT: } p^2+q^2=1)$$

- D^0-$\bar{D}^0$ mixing parameters:

$$\boxed{\mathbf{x} \equiv \frac{M_1 - M_2}{\Gamma}, \quad \mathbf{y} \equiv \frac{\Gamma_1 - \Gamma_2}{2\Gamma}} \quad \Gamma \equiv \frac{\Gamma_1+\Gamma_2}{2} = 1/\tau$$

- under phase convention $CP|D^0\rangle = |\bar{D}^0\rangle$, $CP|\bar{D}^0\rangle = |D^0\rangle$
- with CP conservation ($q = p = 1/\sqrt{2}$): $|D_{1,2}\rangle = |D_{+,-}\rangle$ (CP eigenstates)

Model-independent measurement of D^0-$\bar{D}^0$ mixing

arXiv:2410.22961, 科大/BNL/湖南师大主导

- Open-flavor neutral meson transforms to its anti-meson and vice versa:

$$K^0 \Leftrightarrow \bar{K}^0,\ B_d^0 \Leftrightarrow \bar{B}^0,\ B_s^0 \Leftrightarrow \bar{B}_s,\ D^0 \Leftrightarrow \bar{D}^0$$

- D^0's unique: only the up-type meson for mixing
- Flavor eigenstate ($|D^0\rangle$, $|\bar{D}^0\rangle$) $\neq$ mass eigenstate $|D_{1,2}\rangle$ with $M_{1,2}$ and $\Gamma_{1,2}$);

$$|D_{1,2}\rangle \equiv p|D^0\rangle \pm q|\bar{D}^0\rangle \quad (\text{CPT: } p^2+q^2=1)$$

- D^0-$\bar{D}^0$ mixing parameters:

$$\mathbf{x} \equiv \frac{M_1 - M_2}{\Gamma}, \quad \mathbf{y} \equiv \frac{\Gamma_1 - \Gamma_2}{2\Gamma} \qquad \Gamma \equiv \frac{\Gamma_1+\Gamma_2}{2} = 1/\tau$$

- under phase convention $CP|D^0\rangle = |\bar{D}^0\rangle$, $CP|\bar{D}^0\rangle = |D^0\rangle$
- with CP conservation ($q = p = 1/\sqrt{2}$): $|D_{1,2}\rangle = |D_{+,-}\rangle$ (CP eigenstates)

- Time evolution of D^0-$\bar{D}^0$ system:

$$i\frac{\partial}{\partial t}\begin{pmatrix} D^0(t) \\ \bar{D}^0(t)\end{pmatrix} = (M - \tfrac{i}{2}\Gamma)\begin{pmatrix} D^0(t) \\ \bar{D}^0(t)\end{pmatrix}$$

- Time evolution related to (x,y) and (q/p)

$$|D^0(t)\rangle = g_+(t)|D^0\rangle + \tfrac{q}{p}g_-(t)|\bar{D}^0\rangle$$
$$|\bar{D}^0(t)\rangle = \tfrac{p}{q}g_-(t)|D^0\rangle + g_+(t)|\bar{D}^0\rangle$$
$$g_+(t) = e^{(-iM-\frac{1}{2}\Gamma)t}\cosh(-\tfrac{i\mathbf{x}+\mathbf{y}}{2}\Gamma t)$$
$$g_-(t) = e^{(-iM-\frac{1}{2}\Gamma)t}\sinh(-\tfrac{i\mathbf{x}+\mathbf{y}}{2}\Gamma t)$$

- Probability that the flavor is/is not changed at time t:

$$P_{D^0\to D^0}(t) = |\langle D^0|D^0(t)\rangle|^2 = \frac{1}{2}e^{-\Gamma t}(\cosh(y\Gamma t) + \cos(x\Gamma t))$$
$$P_{D^0\to \bar{D}^0}(t) = |\langle D^0|\bar{D}^0(t)\rangle|^2 = \frac{1}{2}\left|\frac{q}{p}\right|^2 e^{-\Gamma t}(\cosh(y\Gamma t) - \cos(x\Gamma t))$$

Model-independent measurement of D^0-$\bar{D}^0$ mixing

arXiv:2410.22961, 科大/BNL/湖南师大主导

- Open-flavor neutral meson transforms to its anti-meson and vice versa:

$$K^0 \Leftrightarrow \bar{K}^0,\ B_d^0 \Leftrightarrow \bar{B}^0,\ B_s^0 \Leftrightarrow \bar{B}_s,\ D^0 \Leftrightarrow \bar{D}^0$$

- D^0's unique: only the up-type meson for mixing
- Flavor eigenstate ($|D^0\rangle$, $|\bar{D}^0\rangle$) $\neq$ mass eigenstate $|D_{1,2}\rangle$ with $M_{1,2}$ and $\Gamma_{1,2}$);

$$|D_{1,2}\rangle \equiv p|D^0\rangle \pm q|\bar{D}^0\rangle \quad (\text{CPT: } p^2+q^2=1)$$

- D^0-$\bar{D}^0$ mixing parameters:

$$\mathbf{x} \equiv \frac{M_1 - M_2}{\Gamma}, \quad \mathbf{y} \equiv \frac{\Gamma_1 - \Gamma_2}{2\Gamma} \qquad \Gamma \equiv \frac{\Gamma_1+\Gamma_2}{2} = 1/\tau$$

- under phase convention $CP|D^0\rangle = |\bar{D}^0\rangle$, $CP|\bar{D}^0\rangle = |D^0\rangle$
- with CP conservation ($q = p = 1/\sqrt{2}$): $|D_{1,2}\rangle = |D_{+,-}\rangle$ (CP eigenstates)

- Time evolution of D^0-$\bar{D}^0$ system:

$$i\frac{\partial}{\partial t}\begin{pmatrix} D^0(t) \\ \bar{D}^0(t) \end{pmatrix} = \left(M - \frac{i}{2}\Gamma\right)\begin{pmatrix} D^0(t) \\ \bar{D}^0(t) \end{pmatrix}$$

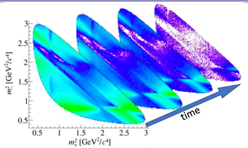
- Time evolution related to (x,y) and (q/p)

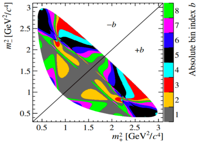
$$|D^0(t)\rangle = g_+(t)|D^0\rangle + \frac{q}{p}g_-(t)|\bar{D}^0\rangle$$
$$|\bar{D}^0(t)\rangle = \frac{p}{q}g_-(t)|D^0\rangle + g_+(t)|\bar{D}^0\rangle$$
$$g_+(t) = e^{(-iM-\frac{1}{2}\Gamma)t}\cosh\left(-\frac{i\mathbf{x}+\mathbf{y}}{2}\Gamma t\right)$$
$$g_-(t) = e^{(-iM-\frac{1}{2}\Gamma)t}\sinh\left(-\frac{i\mathbf{x}+\mathbf{y}}{2}\Gamma t\right)$$

- Probability that the flavor is/is not changed at time t:

$$P_{D^0\to D^0}(t) = |\langle D^0|D^0(t)\rangle|^2 = \frac{1}{2}e^{-\Gamma t}(\cosh(y\Gamma t) + \cos(x\Gamma t))$$
$$P_{D^0\to \bar{D}^0}(t) = |\langle D^0|\bar{D}^0(t)\rangle|^2 = \frac{1}{2}\left|\frac{q}{p}\right|^2 e^{-\Gamma t}(\cosh(y\Gamma t) - \cos(x\Gamma t))$$

- Time-dept. Dalitz-plot analysis in $D^0 \to K_S^0\pi^+\pi^-$:
  - 540 fb^{-1}: L.M. Zhang *et al.* (Belle), PRL 99, 131803 (2007)
  - 921 fb^{-1}: T. Peng *et al.* (Belle), PRD 89, 091103(R) (2014)





- **Model-dependent** measurement:
  - Isobar model to include quasi-two-body decays:
    $A(m_+^2, m_-^2) = \sum_r a_r e^{i\phi_r} \cdot A_r(m_+^2, m_-^2) + a_{\rm NR} e^{i\phi_{\rm NR}} \cdot A_{\rm NR}(m_+^2, m_-^2)$
    where $A_r = F_D \cdot F_r \cdot T_r \cdot W_r$: products of form factors and RBW/K-matrix.
  - Time-dept. DP amplitude: $|\langle f|D^0(t)\rangle|^2 = |A_f(m_+^2, m_-^2)g_+(t) + \overline{A}_f(m_+^2, m_-^2)\frac{q}{p}g_-(t)|^2$.
- **Model-independent** measurement:
  - strong phase difference over DP: Iso-$\Delta\delta$ scheme.
  - $p_b(t; D^0) \propto F_b g_+^2(t) + \overline{F}_{-b}|\frac{q}{p}|^2 g_-^2(t) + 2\sqrt{F_b\overline{F}_{-b}}\mathrm{Re}[X_b \frac{q}{p} g_+^*(t) g_-(t)]$
  - where $F_b = \int_b |A_f(m_+^2, m_-^2)|^2 dm_+^2 dm_-^2$, $\overline{F}_b = \int_b |\overline{A}_f(m_+^2, m_-^2)|^2 dm_+^2 dm_-^2$, and
    $X_b = \frac{1}{\sqrt{F_b\overline{F}_{-b}}} \int_b A_f^*(m_+^2, m_-^2)\overline{A}_f(m_-^2, m_+^2) dm_+^2 dm_-^2 = c_b - is_b$
    where (c_b, s_b) are determined by CLEO and BESIII [PRD 82, 112006 (2010), PRL 124, 241802 (2020)]

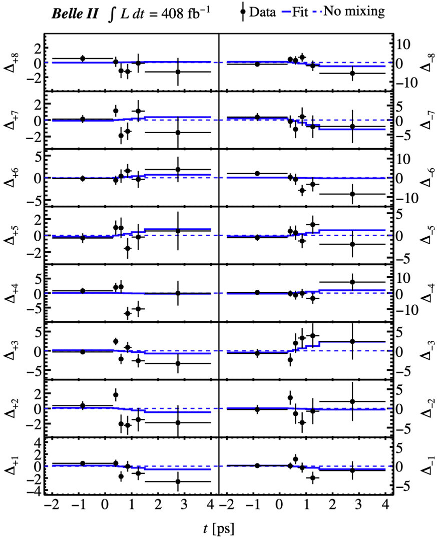
Model-dependent	Integrated luminosity	Signal yields	x [10^{-3}]	y [10^{-3}]	$\lvert q/p\rvert$	ϕ [°]
CLEO(2005) [38-39]	9.0 fb^{-1}	5299	$23^{+35}_{-34} \pm 4 \pm 4$	$-15^{+25}_{-24} \pm 8 \pm 4$	$\epsilon = 1.1 \pm 0.7 \pm 0.4 \pm 0.2$	$5.7 \pm 2.8 \pm 0.4 \pm 1.2$
Belle(2007) [40]	540 fb^{-1}	0.53×10^6	$8.1 \pm 3.0^{+1.0+0.9}_{-0.7-1.6}$	$3.7 \pm 2.5^{+0.7+0.7}_{-1.3-0.8}$	$0.86^{+0.30+0.06}_{-0.29-0.03} \pm 0.08$	$-14^{+16+5+2}_{-18-3-4}$
BaBar(2010) [41]	468.5 fb^{-1}	0.84×10^6	$1.6 \pm 2.3 \pm 1.2 \pm 0.8$	$5.7 \pm 2.0 \pm 1.3 \pm 0.7$	-	-
Belle(2014) [42]	921 fb^{-1}	1.23×10^6	$5.6 \pm 1.9^{+0.3+0.6}_{-0.9-0.9}$	$3.0 \pm 1.5^{+0.4+0.3}_{-0.5-0.6}$	$0.90^{+0.16+0.05+0.06}_{-0.15-0.04-0.05}$	$-6 \pm 11 \pm 3^{+3}_{-4}$
LHCb(2016) [43]	1.0 fb^{-1}	0.17×10^6	$-8.6 \pm 5.3 \pm 1.7$	$0.3 \pm 4.6 \pm 1.3$	-	-
LHCb(2019) [44]	3 fb^{-1}	2.3×10^6	$2.7^{1.7}_{1.5}$	7.4 ± 3.7	$1.05^{+0.22}_{-0.17}$	$5.2^{+6.3}_{-9.2}$
LHCb(2021) [45]	5.4 fb^{-1}	30.6×10^6	$3.98^{+0.56}_{-0.54}$	$4.6^{+1.5}_{-1.4}$	0.996 ± 0.052	$3.2^{+2.7}_{2.9}$
LHCb(2023) [46]	5.4 fb^{-1}	3.72×10^6	$4.29 \pm 1.48 \pm 0.26$	$12.61 \pm 3.21 \pm 0.83$	-	-

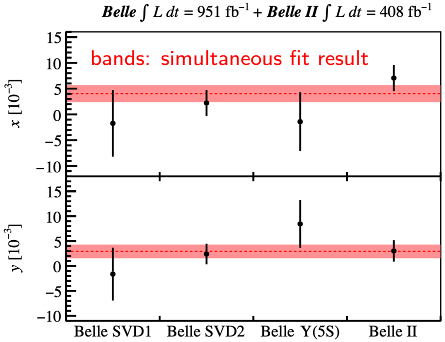
Model-independent

The model uncertainty is comparable to the total uncertainty.

Model-independent measurement of D^0-$\bar{D}^0$ mixing

arXiv:2410.22961, 科大/BNL/湖南师大主导





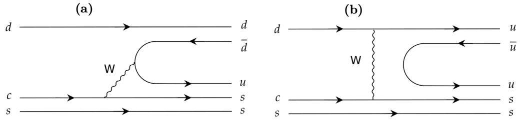
- Based on 2M signals from 951+408 fb^{-1} data at B1+B2: $x = (4.0 \pm 1.7 \pm 0.4) \times 10^{-3}$, $y = (2.9 \pm 1.4 \pm 0.3) \times 10^{-3}$
- the most precise result in e^+e^- collider experiments;
- having significantly smaller systematic uncertainties than the model-dependent Belle measurements.

Outline

Measurement of $\mathcal{B}(\Xi_c^0 \to \Xi^0\pi^0, \Xi^0\eta, \Xi^0\eta')$

JHEP 10 (2024) 045, 复旦/东南大学主导

- The internal W-emission and W-exchange amplitudes in $\Xi_c^0 \to \Xi^0 h^0$, to which only the nonfactorizable amplitude contribute.



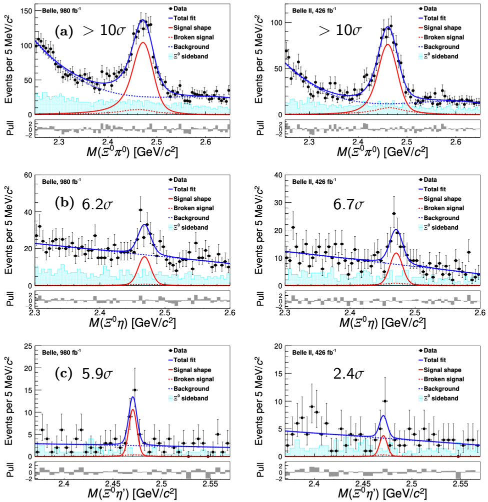
- Using $\Xi_c^0 \to \Xi^-\pi^+$ as normalization mode
- Combine $\mathcal{B}$-results at Belle/Belle II:

$$\frac{\mathcal{B}(\Xi_c^0\to\Xi^0\pi^0)}{\mathcal{B}(\Xi_c^0\to\Xi^-\pi^+)} = 0.48 \pm 0.02 \pm 0.03$$

$$\frac{\mathcal{B}(\Xi_c^0\to\Xi^0\eta)}{\mathcal{B}(\Xi_c^0\to\Xi^-\pi^+)} = 0.11 \pm 0.01 \pm 0.01$$

$$\frac{\mathcal{B}(\Xi_c^0\to\Xi^0\eta')}{\mathcal{B}(\Xi_c^0\to\Xi^-\pi^+)} = 0.08 \pm 0.02 \pm 0.01$$

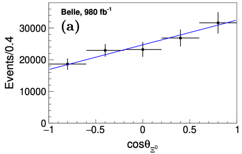
- Current $\mathcal{B}_{\rm PDG}(\Xi_c^0 \to \Xi^-\pi^+) = (1.43 \pm 0.32)\%$ to be improved.

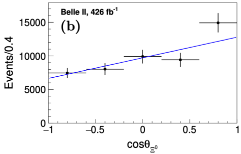


Measurement of $\alpha(\Xi_c^0 \to \Xi^0\pi^0)$

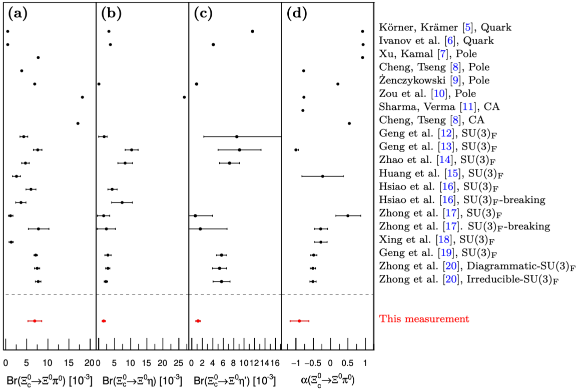
JHEP 10 (2024) 045, 复旦/东南大学主导

- In $1/2^+ \to 1/2^+ + 0^-$ decays, the decay asymmetry parameter:
  $$\alpha \equiv \frac{2\cdot \mathrm{Re}(S^*P)}{(|S|^2+|P|^2)}$$
  where S and P denote the parity-violating S-wave and parity-conserving P-wave amplitudes.
- The differential decay rate of $\Xi_c^0 \to \Xi^0 h^0$:
  $$\frac{dN}{d\cos\theta_{\Xi_c^0}} \propto 1+\alpha(\Xi_c^0\to\Xi^0 h^0)\alpha(\Xi^0\to\Lambda\pi^0)\cos\theta_{\Xi^0}$$
- Simultaneous fit result on B1+B2 data:
  $\alpha(\Xi_c^0\to\Xi^0\pi^0) = -0.90\pm0.15\pm0.23$





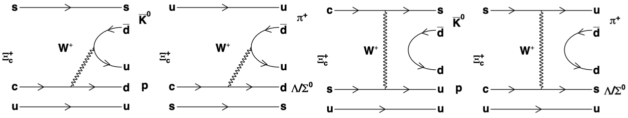
- Comparison results with predictions:



Observation of (SCS) $\Xi_c^+ \to pK_S^0, \Lambda\pi^+, \Sigma^0\pi^+$

Preliminary result, 复旦/吉大/湖南师大主导

- In hadronic decays of charmed baryons, nonfactorizable contributions from the internal W-emission and W-exchange diagrams play an essential role and cannot be neglected. e.g.



- SCS charm decays provide good probes for CP violation.

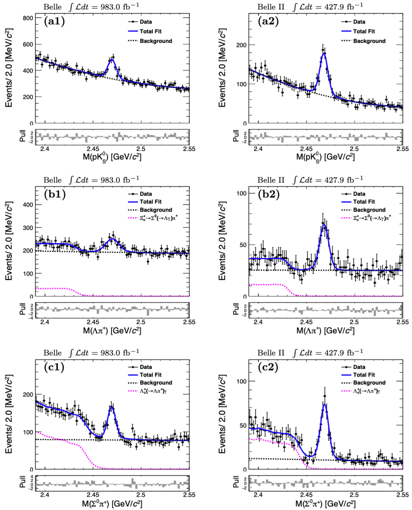
- First observation of three SCS decays of Ξ_c^+ using B+B2 data:

$$\frac{\mathcal{B}(\Xi_c^+ \to pK_S^0)}{\mathcal{B}(\Xi_c^+ \to \Xi^-\pi^+\pi^+)} = (2.47 \pm 0.16 \pm 0.07)\%$$

$$\frac{\mathcal{B}(\Xi_c^+ \to \Lambda\pi^+)}{\mathcal{B}(\Xi_c^+ \to \Xi^-\pi^+\pi^+)} = (1.56 \pm 0.14 \pm 0.09)\%$$

$$\frac{\mathcal{B}(\Xi_c^+ \to \Sigma^0\pi^+)}{\mathcal{B}(\Xi_c^+ \to \Xi^-\pi^+\pi^+)} = (4.13 \pm 0.26 \pm 0.22)\%$$

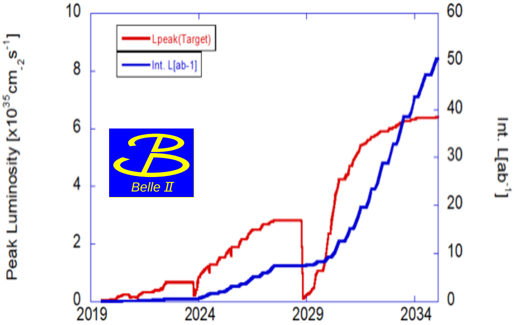
- Current $\mathcal{B}_{\rm PDG}(\Xi_c^+ \to \Xi^-\pi^+\pi^+) = (2.9 \pm 1.3)\%$ to be improved.



Outline

总结和展望

- Belle II 已经加入“战场”，现可使用 (B+B2) 1.5 ab^{-1} 数据。
- 粲物理成果正在持续产生：继第一波结果：粲强子寿命的高精度测量后，我们迎来了多方位的下一波研究结果：
- D^0-$\bar{D}^0$ 混合参数的测量：模型无关的方法
- 粲介子 CP 破坏的寻找：Belle II 上首个粲 CPV 结果 新方法、新衰变道、新样本
- 粲重子 CP 破坏的寻找
- 粲强子衰变的分支比和角分布的研究
- 粲强子稀有或禁戒衰变的寻找
- 粲强子激发态的寻找和研究
- 粲强子衰变的振幅分析
- Belle II 探测器性能的提升，使其物理分析结果有显著改善。



- 从事 Belle II 粲物理分析的中国单位：复旦/湖南师大/西交/东大/科大/吉大/北航/辽宁师大等等
- Belle II 未来更多的数据，更多重要的“粲”结果。

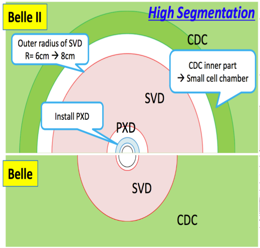
Back up

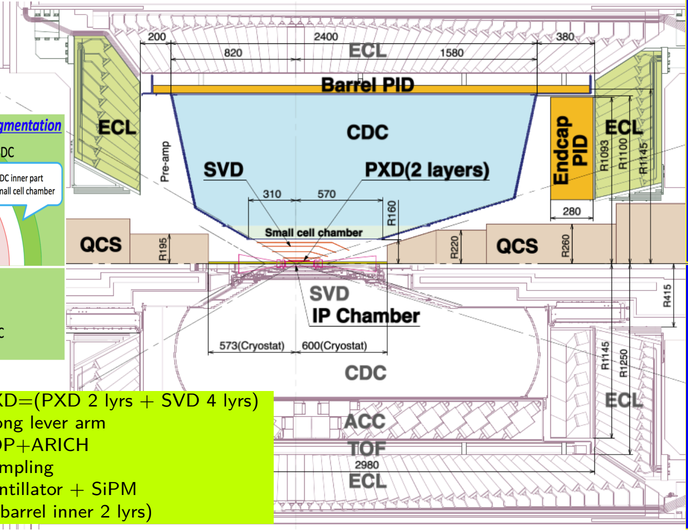
Thank you for your attention.

谢谢！

Dr. Longke LI (李龙科)
School of Physics and Electronics
Hunan Normal University
36 LuShan Road, YueLu District,
Changsha, 410081, P. R. China
lilongke_ustc
lilongke@mail.ustc.edu.cn

Detector: Belle II Vs. Belle

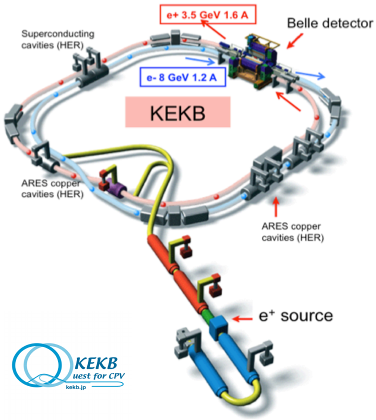


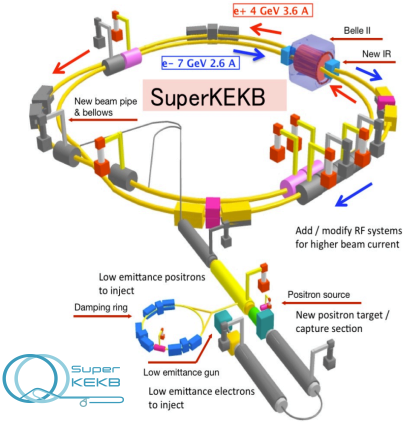


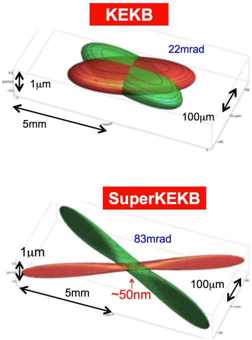
SVD: 4 lyrs → VXD=(PXD 2 lyrs + SVD 4 lyrs)
CDC: small cell, long lever arm
ACC+TOF → TOP+ARICH
ECL: waveform sampling
KLM: RPC → Scintillator + SiPM
(endcaps, barrel inner 2 lyrs)

from KEKB to SuperKEKB

- As 1^{st} and 2^{nd} 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: $\times 2$ to contribute to higher luminosity.
  - SuperKEKB achieved the luminosity record of $4.7 \times 10^{34}\ cm^{-2}s^{-1}$.







Comparison of available charm samples

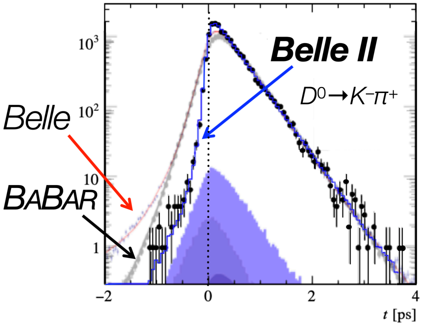
Experiment	Machine	C.M.	Luminosity(fb^{-1})	N_{prod}	Efficiency	Characters
BESIII	BEPC-II (e^+e^-)	3.77 GeV 4.18-4.23 GeV 4.6-4.7 GeV	20 7.3 4.5	$D^{0,+}$: 10^8 D_s^+: 5×10^6 Λ_c^+: 0.8×10^6 ★☆	$\sim$ 10-30% ★★★	☺ extremely clean environment ☺ quantum coherence ☹ no boost, no time-dept analysis
Belle II	SuperKEKB (e^+e^-)	10.58 GeV	500 ($\rightarrow$ 50000)	D^0: 10^9 ($\rightarrow 10^{11}$) $D^+_{(s)}$: 10^8 ($\rightarrow 10^{10}$) Λ_c^+: 10^7 ($\rightarrow 10^9$)	$\mathcal{O}$(1-10%) ★★	☺ high-efficiency detection of neutrals ☺ good trigger efficiency ☺ time-dependent analysis ☹ smaller cross-section than LHCb
BELLE	KEKB (e^+e^-)	10.58 GeV	1000	$D^{0,+}$, D_s^+: 10^9 Λ_c^+: 10^8 ★★☆		
LHCb	LHC (pp)	7+8 TeV 13 TeV	1+2 6+9 ($\rightarrow$ 23 $\rightarrow$ 50)	5×10^{12} 10^{13} ★★★★	$\mathcal{O}$(0.1%) ★	☺ very large production cross-section ☺ large boost, excellent time resolution ☺ more charm sources (e.g. $\Lambda_b\rightarrow\Lambda_c$) ☹ dedicated trigger required

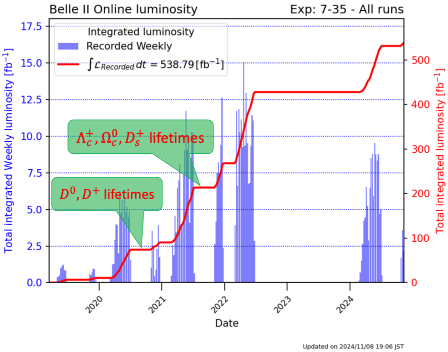
Here uses $\sigma(D^0\bar{D}^0@3.77\,\mathrm{GeV})$=3.61 nb, $\sigma(D^+D^-@3.77\,\mathrm{GeV})$=2.88 nb, $\sigma(D_s^*D_s@4.17\,\mathrm{GeV})$=0.967 nb; $\sigma(c\bar{c}@10.58\,\mathrm{GeV})$=1.3 nb where each $c\bar{c}$ event averagely has 1.1/0.6/0.3 $D^0/D^+/D_s^+$ yields; $\sigma(D^0@CDF)$=13.3 μb, and $\sigma(D^0@LHCb)$=1661 μb, mainly from *Int. J. Mod. Phys. A* **29** *(2014)24,14300518*.

- BESIII, Belle II, and LHCb experiments have their advantages for charm studies.

Charm lifetimes PRL 127, 211801 (2021); PRL 130, 071802 (2023); PRD 107, L031103 (2023); PRL 131, 171803 (2023

- Hadron lifetimes are difficult to calculate theoretically, as they depend on nonperturbative arising from QCD.
- Comparing calculated values with measured values improves our understanding of QCD. [(FLAG) EPJC 82, 869 (2022)]
- Belle II early dataset gave the most precise 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, $\tau_{D_s^+} = (499.5 \pm 1.7 \pm 0.9)$ fs, and $\tau(\Lambda_c^+) = 203.20 \pm 0.89 \pm 0.77$ fs.
- confirm the new charmed baryon lifetime hierarchy found by LHCb $\tau(\Omega_c^0)$ result.

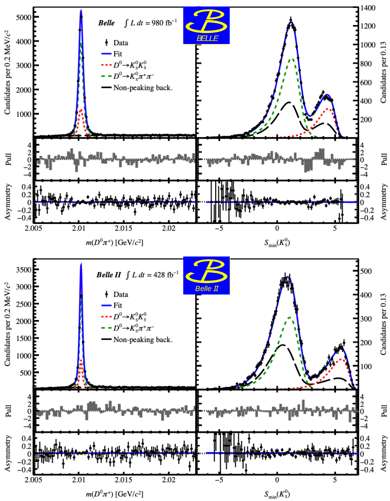




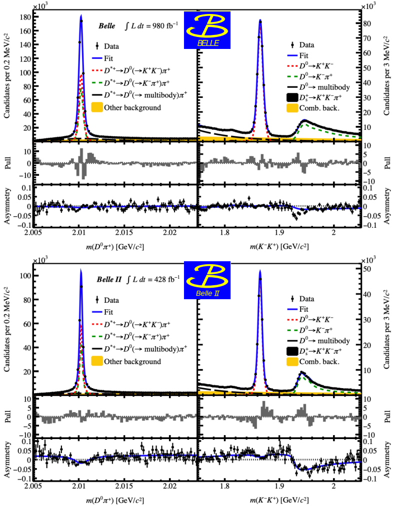
Time-integrated CP asymmetry in $D^0 \to K_S^0 K_S^0$

Preliminary, MNITJ/BNL 主导

$D^0 \to K_S^0 K_S^0$



$D^0 \to K^+ K^-$

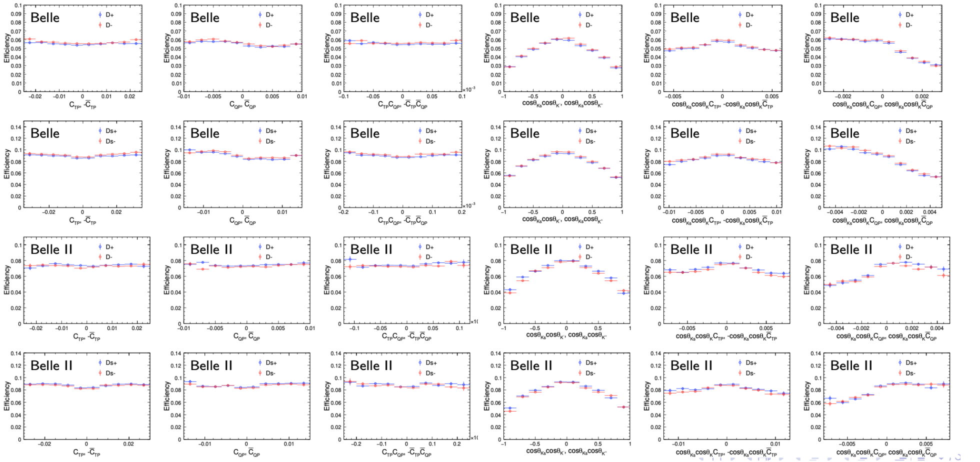


Preliminary results:

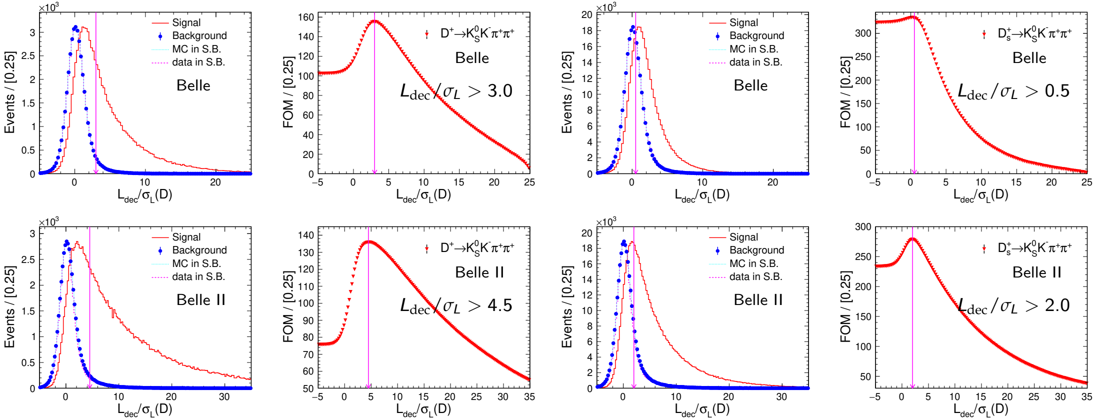
- $A_{\rm raw}(D^0 \to K_S^0 K_S^0)$:
  - Belle: $(-1.0 \pm 1.6)\%$
  - Belle II: $(-0.6 \pm 2.3)\%$
- $A_{\rm raw}(D^0 \to K^+ K^-)$:
  - Belle: $(0.17 \pm 0.19)\%$.
  - Belle II: $(1.61 \pm 0.27)\%$.
- final $A_{CP}(D^0 \to K_S^0 K_S^0)$:
  - Belle: $(-1.1 \pm 1.6 \pm 0.1)\%$).
  - Belle II: $(-2.2 \pm 2.3 \pm 0.1)\%$).
  - combined: $(-1.4 \pm 1.3 \pm 0.1)\%$.
- Comparable precision to the world-best measurement from LHCb (6 fb^{-1}): $\sigma = 1.3\%$.

X-dependent efficiency in $D^+_{(s)} \to K^0_S K^- \pi^+ \pi^+$

$$A_X(D^+_{(s)}) = \frac{N_+(X>0) - N_+(X<0)}{N_+(X>0) + N_+(X<0)} \quad A_{\overline{X}}(D^-_{(s)}) = \frac{N_-(\overline{X}>0) - N_-(\overline{X}<0)}{N_-(\overline{X}>0) + N_-(\overline{X}<0)} \quad \mathcal{A}^X_{CP} = \frac{1}{2}\left(A_X(D^+_{(s)}) - A_{\overline{X}}(D^-_{(s)})\right)$$



Event selection and optimization: $D^+_{(s)}$ flight significance $L_{\rm dec}/\sigma_L(D^+_{(s)})$



- This flight significance of D^+ is more efficient than D_s^+ due to longer lifetime in D^+;
- This flight significance is more efficient at Belle II than Belle because of an improved time resolution at Belle II.

direct CPV in $\Lambda_c^+ \to \Lambda K^+, \Sigma^0 K^+$

(Belle) Science Bulletin **68** (2023) 583

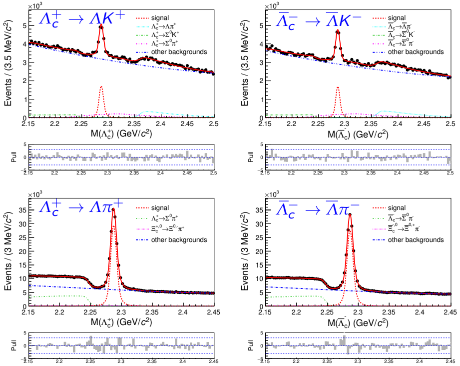
- The raw asymmetry of $\Lambda_c^+ \to \Lambda h^+$ includes several asymmetry sources:

$$A_{\rm raw}(\Lambda_c^+ \to \Lambda K^+) \approx A_{CP}^{\Lambda_c^+ \to \Lambda K^+} + A_{CP}^{\Lambda \to p\pi^-} + A_\varepsilon^{\Lambda} + A_\varepsilon^{K^+} + A_{\rm FB}^{\Lambda_c^+}$$

$$A_{\rm raw}(\Lambda_c^+ \to \Lambda \pi^+) \approx A_{CP}^{\Lambda_c^+ \to \Lambda \pi^+} + A_{CP}^{\Lambda \to p\pi^-} + A_\varepsilon^{\Lambda} + A_\varepsilon^{\pi^+} + A_{\rm FB}^{\Lambda_c^+}$$

  - $A_{CP}^{\Lambda_c^+ \to \Lambda h^+}$ ($A_{CP}^{\Lambda \to p\pi^-}$): CP asymmetry associated with Λ_c^+ (Λ) decay,
  - A_ε^{Λ}: detection asymmetry arising from efficiencies between Λ and $\bar{\Lambda}$.
  - $A_\varepsilon^{h^+}$: removed by widthing $w_{\Lambda_c^+, \bar{\Lambda}_c^-} = 1 \mp A_\varepsilon^{K^+}[\cos\theta, p_T]$
    - $A_\varepsilon^{K^+}$: $D^0 \to K^-\pi^+$ and $D_s^+ \to \phi\pi^+$
    - $A_\varepsilon^{\pi^+}$: $D^+ \to K^-\pi^+\pi^+$ and $D^0 \to K^-\pi^+\pi^0$
  - $A_{\rm FB}^{\Lambda_c^+}$ arises from the forward-backward asymmetry (FBA) of Λ_c^+ production due to γ-Z^0 interference and higher-order QED effects in $e^+e^- \to c\bar{c}$ collisions.

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



- $A_{CP}^{\rm dir}(\Lambda_c^+ \to \Lambda K^+) = (+2.1 \pm 2.6 \pm 0.1)\%$
- $A_{CP}^{\rm dir}(\Lambda_c^+ \to \Sigma^0 K^+) = (+2.5 \pm 5.4 \pm 0.4)\%$

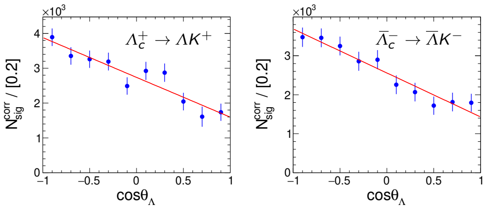
First $A_{CP}^{\rm dir}$ for SCS two-body decays of charmed baryons.

baryonic α-induced CPV in $\Lambda_c^+ \to \Lambda K^+, \Sigma^0 K^+$

(Belle) Science Bulletin **68** (2023) 583

(SCS) $\Lambda_c^+ \to \Lambda K^+, \Sigma^0 K^+$

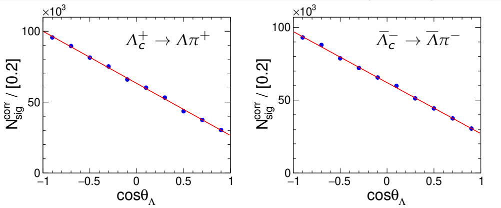
- Measure $\alpha/\bar{\alpha}$ for the separate $\Lambda_c^+/\overline{\Lambda}_c^-$ samples.
- Calculate $\mathcal{A}_{CP}^{\alpha} \equiv (\alpha_{\Lambda_c^+} + \alpha_{\overline{\Lambda}_c^-})/(\alpha_{\Lambda_c^+} - \alpha_{\overline{\Lambda}_c^-})$.



- Result: $\mathcal{A}_{CP}^{\alpha}(\Lambda_c^+ \to \Lambda K^+) = -0.023 \pm 0.086 \pm 0.071$
  $\mathcal{A}_{CP}^{\alpha}(\Lambda_c^+ \to \Sigma^0 K^+) = +0.08 \pm 0.35 \pm 0.14$
  First $\mathcal{A}_{CP}^{\alpha}$ results for charmed baryon SCS decays.
- No evidence of CPV is found.

(CF) $\Lambda_c^+ \to \Lambda \pi^+, \Sigma^0 \pi^+$

- Probe Λ-hyperon CPV in charmed baryon CF decays, inspired by PLB 849 (2024) 138460 (JP Wang, FS Yu).
- Under a reasonable assumption $\alpha_{\Lambda_c^+} = -\alpha_{\overline{\Lambda}_c^-}$ in CF decays, we have $\mathcal{A}_{CP}^{\alpha}(\Lambda \to p\pi^-) = \mathcal{A}_{CP}^{\alpha}(\text{total}) \equiv \frac{\alpha_{\Lambda_c^+}\alpha_- - \alpha_{\overline{\Lambda}_c^-}\alpha_+}{\alpha_{\Lambda_c^+}\alpha_- + \alpha_{\overline{\Lambda}_c^-}\alpha_+}$.



- Result: $\mathcal{A}_{CP}^{\alpha}(\Lambda \to p\pi^-) = +0.013 \pm 0.007 \pm 0.011$
  The first result of hyperon CPV in charm CF decays