Charm Physics at Belle (II)

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BESIII粲强子物理研讨会

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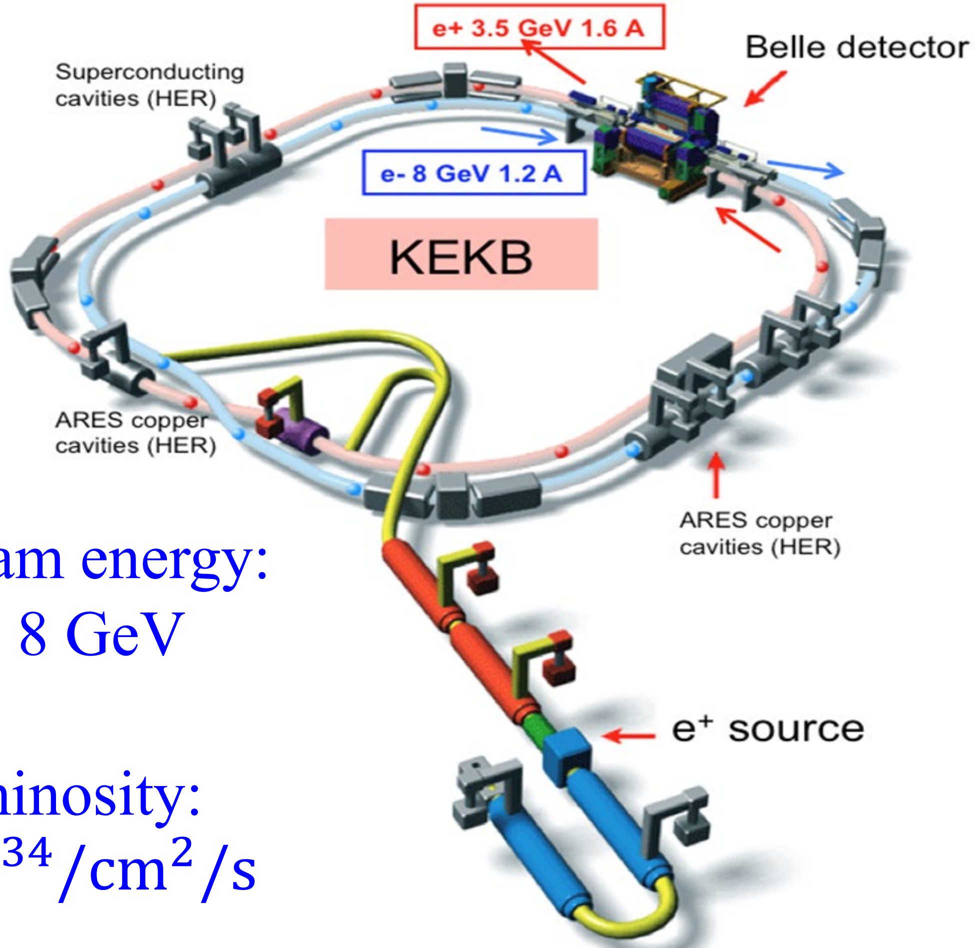
Outline

- Belle and Belle II experiments
- Charmed meson
  - Search for neutral $D \to p\ell$ — Belle [PRD 109, L031101 (2024)]
  - Search for $D^0 \to hh'e^+e^-$ — Belle [PRELIMINARY]
  - CPV in charm four-body decays — Belle [PRD 107, 052001 (2023); PRD 108, L111102 (2023); arXiv: 2305.12806]
- Charmed baryon
  - First search for $\Xi_c^0 \to \Xi^0 \ell^+ \ell^-$ — Belle [PRD 109, 052003 (2024)]
  - Study of $\Xi_c^0 \to \Xi^0 h^0$, $h^0 = \pi^0/\eta/\eta'$ — Belle + Belle II [PRELIMINARY]
- Charm lifetimes at Belle II — Belle II [PRL 131, 171803 (2023); PRD 107, L031103 (2023); PRL 130, 071802 (2023)]
- Summary

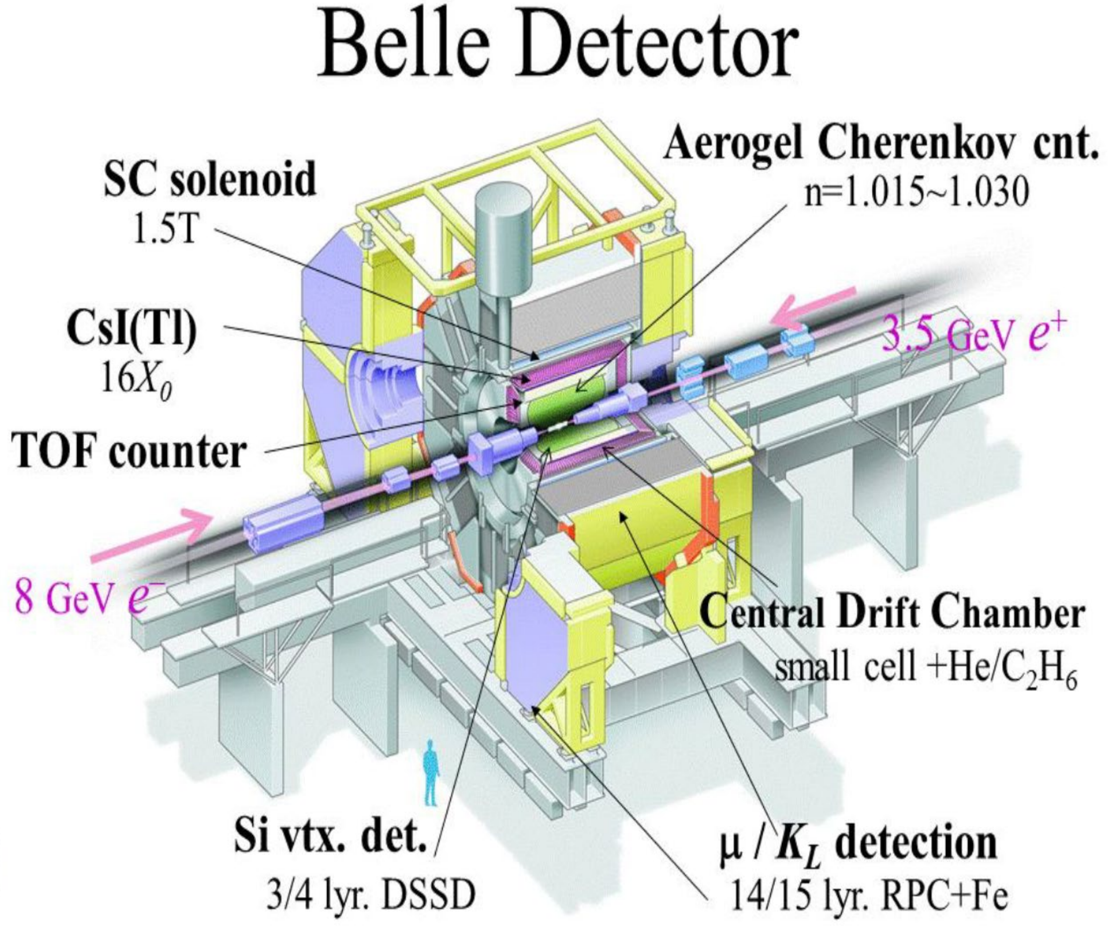
Belle experiment

- KEKB is an asymmetric-energy e^+e^- collider mainly operating near $\Upsilon(4S)$ resonance.
- Belle detector has good performances on momentum/vertex resolution, particle identification…



e^+e^- beam energy:
3.5×8 GeV

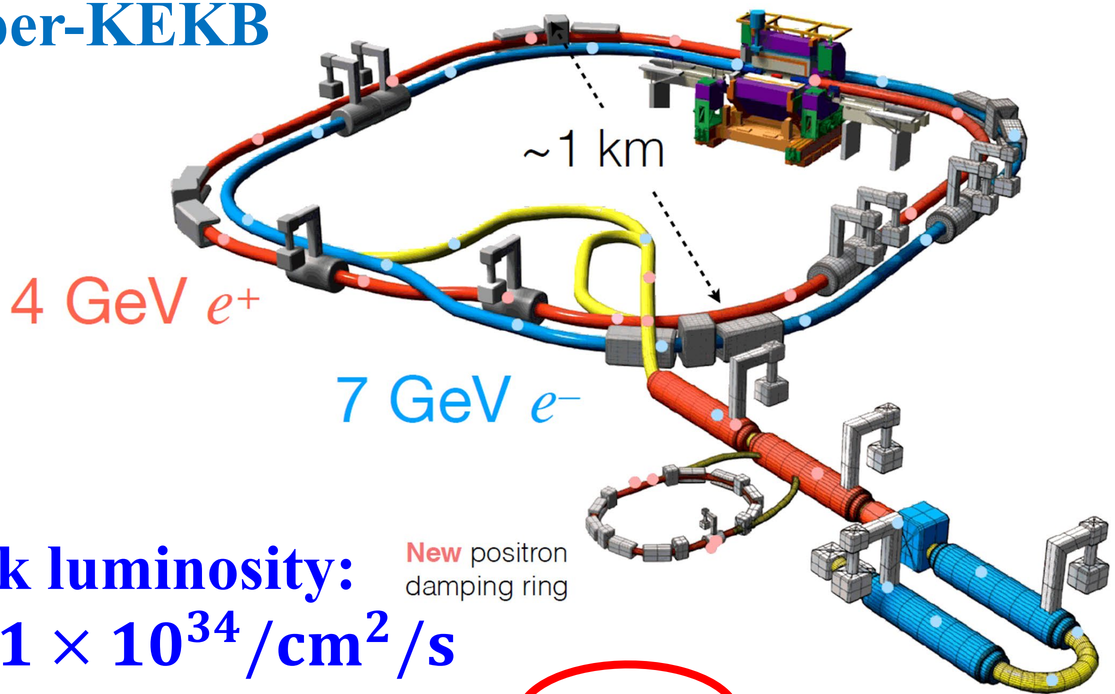
Peak luminosity:
$2.1 \times 10^{34}/\mathrm{cm}^2/\mathrm{s}$



$$u\bar{u}, d\bar{d}, s\bar{s}, c\bar{c}, \tau\bar{\tau} \leftarrow e^+ e^- \rightarrow \Upsilon(4S) \rightarrow B\bar{B}$$

Belle II experiment

Super-KEKB



Peak luminosity:
$4.71 \times 10^{34}/\mathrm{cm}^2/\mathrm{s}$
(June 22 2022)

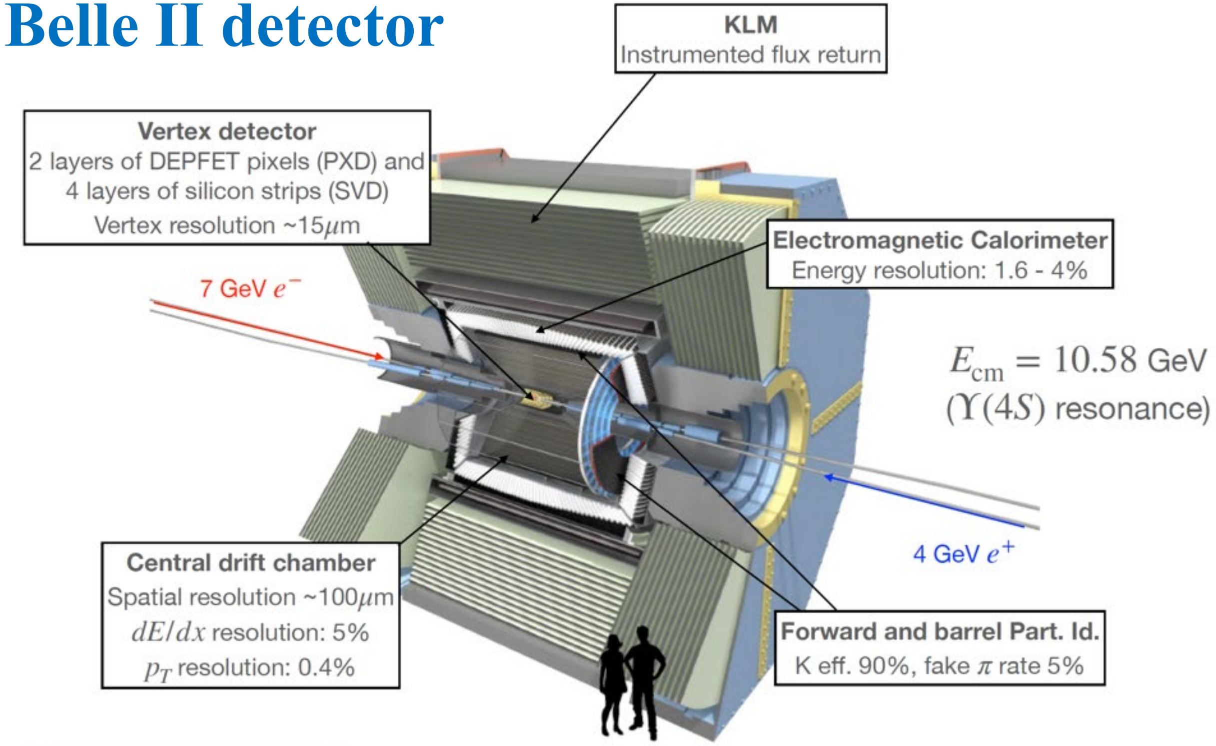
$\times \sim 1.5$

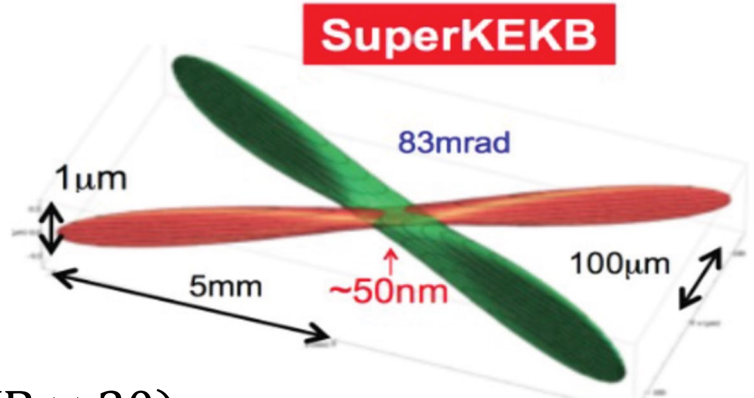
$$\mathcal{L} = \frac{\gamma_\pm}{2er_e}\left(1 + \frac{\sigma_y^*}{\sigma_x^*}\right)\frac{I_\pm \xi_{y\pm}}{\beta_{y\pm}^*}\left(\frac{R_{\mathcal{L}}}{R_{\xi_y}}\right)$$

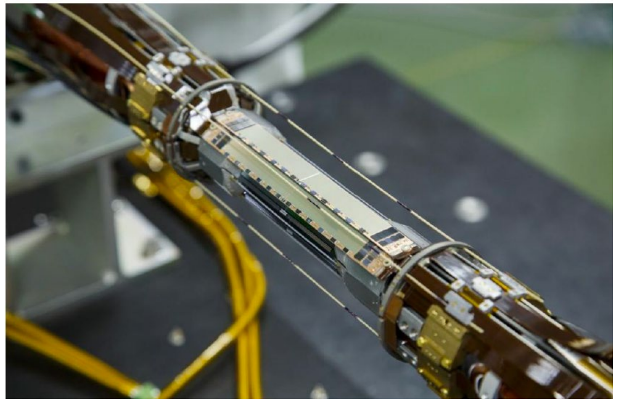
$\times \sim 1/20$

Target luminosity: $\sim 6 \times 10^{35}/\mathrm{cm}^2/\mathrm{s}$ (KEKB $\times$ 30)

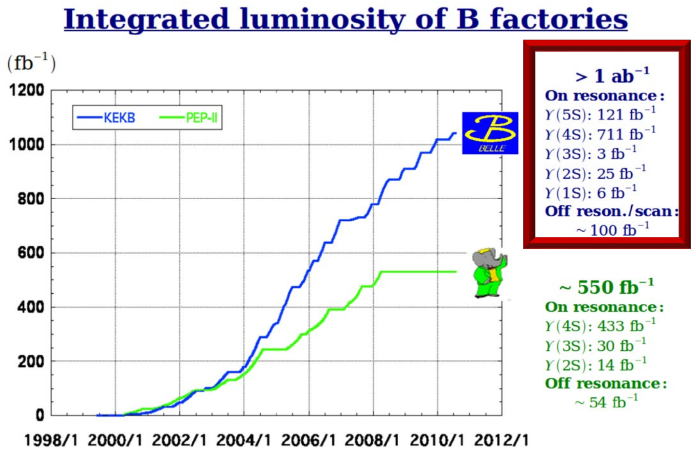
Belle II detector







Charm samples at Belle (II)



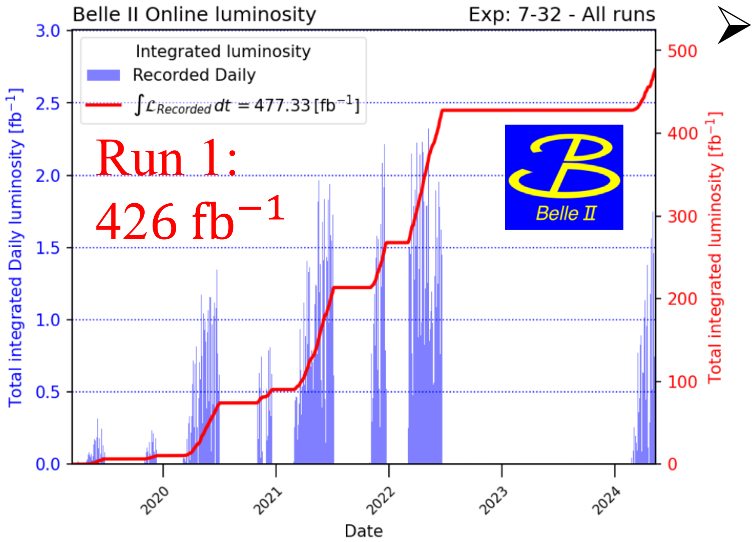
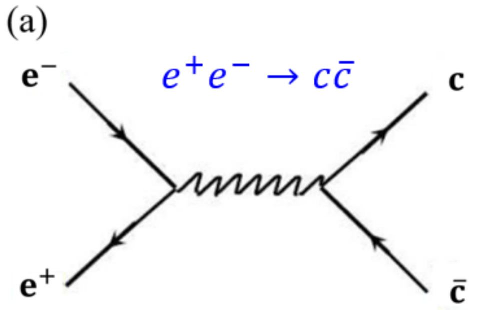


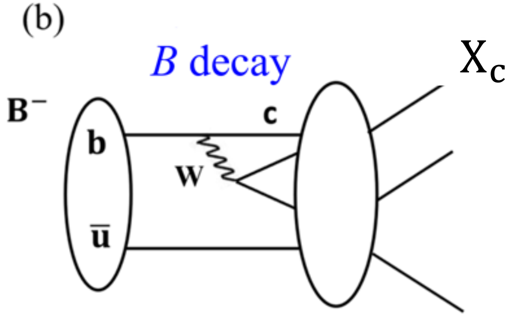
Table from Dr. Longke Li

➢ Two ways to produce charm samples at Belle (II)



$\sigma(e^+e^- \to c\bar{c}) \sim 1.33\,\mathrm{nb}$

$@\sqrt{s} = 10.58\ \mathrm{GeV}$



$\sigma(e^+e^- \to \Upsilon(4S)) \sim 1.05\,\mathrm{nb}$

$\mathcal{B}(\Upsilon(4S) \to B\bar{B}) \sim 96\%$

Experiment	Machine	Operation	C.M.	Luminosity	N_{prod}	Efficiency	Characters
BESIII	BEPC-II (e^+e^-)	2010-2011 (2021-) 2016-2019 2014+2020	3.77 GeV 4.18-4.23 GeV 4.6-4.7 GeV	2.9 (8 → 20) fb^{-1} 7.3 fb^{-1} 4.5 fb^{-1}	$D^{0,+}$: $10^7 (\to 10^8)$ D_s^+: 5×10^6 Λ_c^+: 0.8×10^6 ★☆	~ 10-30% ★★★	☺ extremely clean environment ☺ quantum coherence ☺ pure D-beam, almost no background ☹ no CM boost, no time-dept analyses
Belle II	SuperKEKB (e^+e^-)	2019-	10.58 GeV	0.4 (→ 50) ab^{-1}	D^0: 6×10^8 $(\to 10^{11})$ $D^+_{(s)}$: 10^8 $(\to 10^{10})$ Λ_c^+: 10^7 $(\to 10^9)$	$\mathcal{O}$(1-10%) ★★	☺ clear event environment ☺ high trigger efficiency ☺ good-efficiency detection of neutrals ☺ time-dependent analysis ☹ smaller cross-section than LHCb
BELLE	KEKB (e^+e^-)	1999-2010	10.58 GeV	1 ab^{-1}	D: 10^9 Λ_c^+: 10^8 ★★☆		
LHCb	LHC (pp)	2011,2012 2015-2018 (2022-2025,2029-)	7+8 TeV 13 TeV	1+2 fb^{-1} 6 fb^{-1} (→ 23 → 50)	5×10^{12} 10^{13} ★★★★	$\mathcal{O}$(0.1%) ★	☺ very large production cross-section ☺ large boost ☺ excellent time resolution ☹ dedicated trigger required

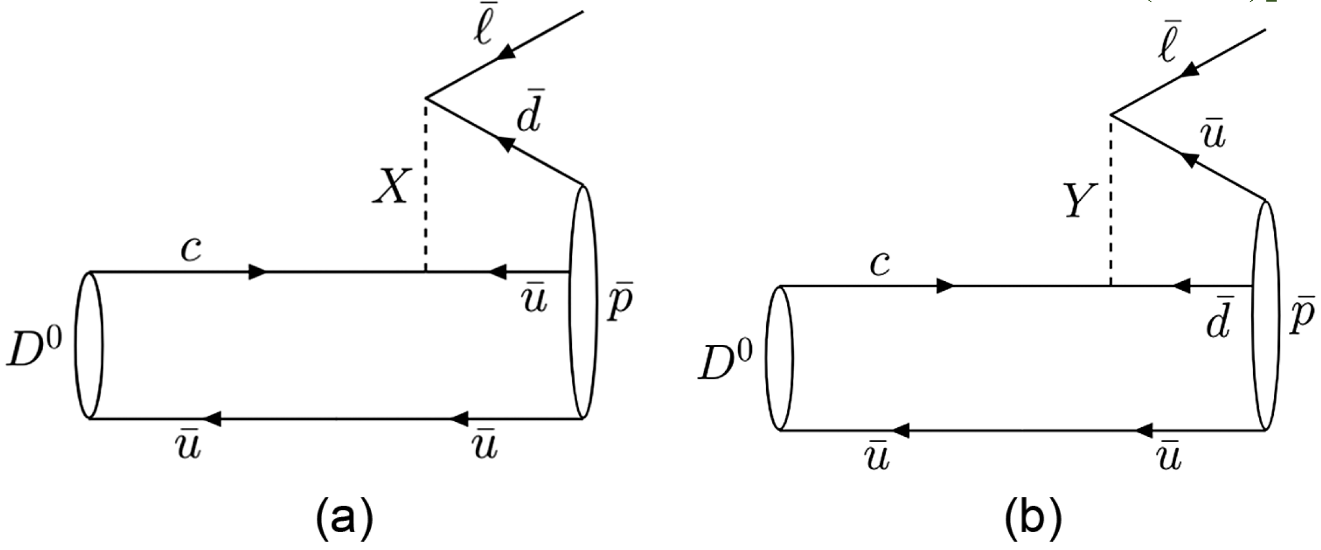
Search for neutral $D \to p\ell$

- Baryon number violation (BNV) is one of the crucial ingredients to create the matter-antimatter asymmetry as observed in the Universe. [JETP Lett. 5, 24 (1967)]
- Analogous to proton decays, the decays of $D^0 \to \bar{p}\ell^+$ can be explained using leptoquark couplings. [PRD 25, 266 (1982)]
- The branching fractions for $D^0 \to \bar{p}\ell^+$ are predicted to be of the order of $10^{-27}\sim10^{-39}$. [PRL 32, 438 (1974); PRD 72, 095001 (2005)]
- The decays $D \to p\ell$ simultaneously violate B and L but $\Delta(B - L) = 0$.
- BESIII searched for $D \to pe$ decay modes:

$$\mathcal{B}(D^0 \to \bar{p}e^+) < 1.2 \times 10^{-6}$$
$$\mathcal{B}(D^0 \to pe^-) < 2.2 \times 10^{-6}$$

[PRD 105, 032006 (2022)]

- We report a search for the D meson decay modes $D^0 \to p\ell^-$, $\bar{D}^0 \to p\ell^-$, $D^0 \to \bar{p}\ell^+$, $\bar{D}^0 \to \bar{p}\ell^+$, where ℓ is e or μ.



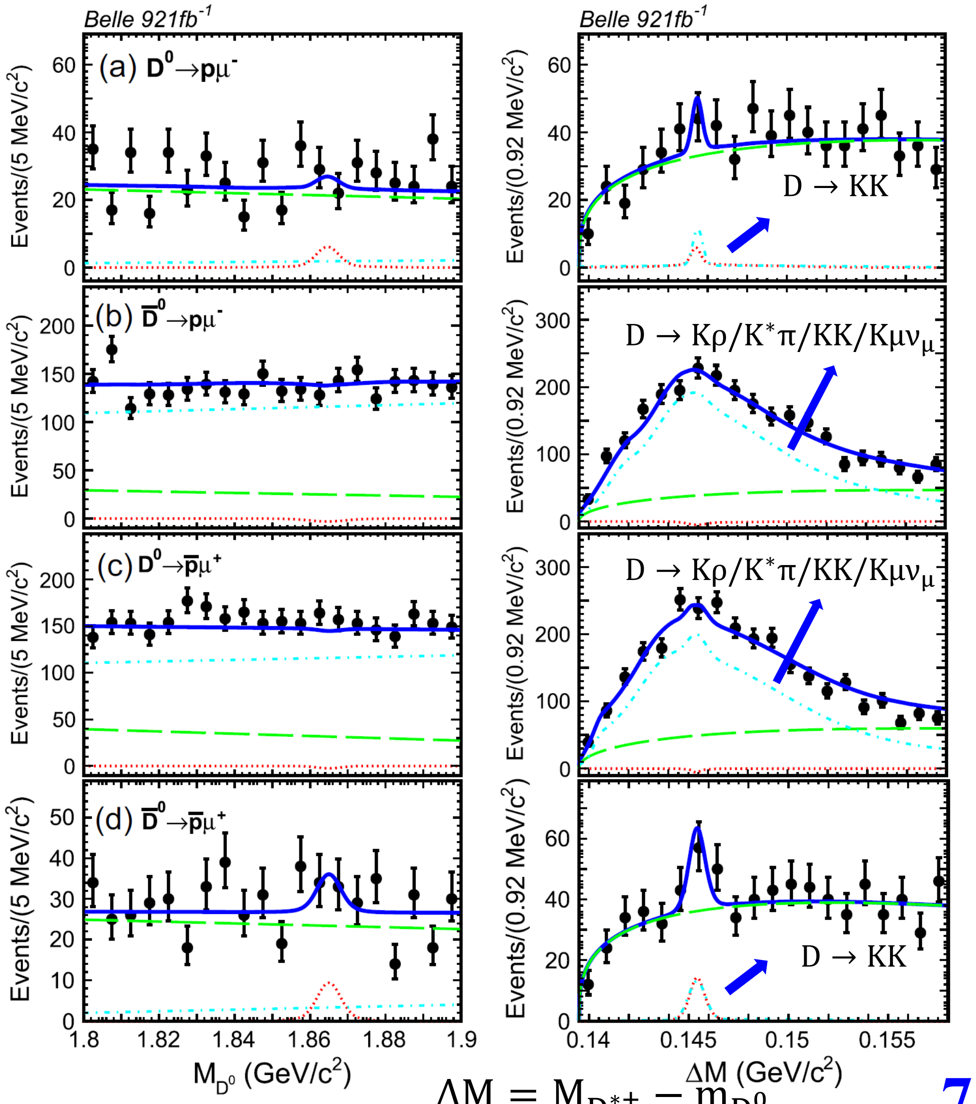
Feynman diagrams for the decays $D^0 \to \bar{p}\ell^+$ with non-SM gauge bosons (a) X and (b) Y.

Search for neutral D → pℓ

Belle 921/fb [PRD 109, L031101 (2024)]

- No signal observed, set upper limits on the branching fractions at 90% CL.
- Most stringent limit to date for the electron channels
- First measurement for the muon channels

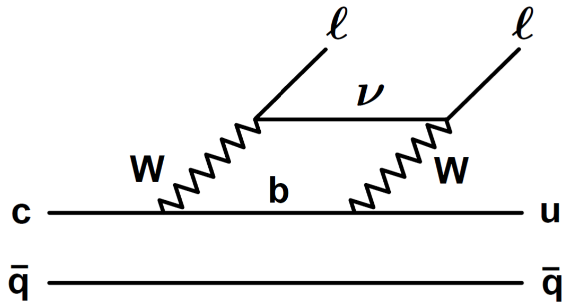
Decay mode	ϵ (%)	N_S	$\mathcal{S}$ (σ)	N^{UL}_{pl}	$\mathcal{B} \times 10^{-7}$
$D^0 \to pe^-$	10.2	-6.4 ± 8.5		17.5	< 5.5
$\bar{D}^0 \to pe^-$	10.2	-18.4 ± 23.0		22.0	< 6.9
$D^0 \to \bar{p}e^+$	09.7	-4.7 ± 23.0		22.0	< 7.2
$\bar{D}^0 \to \bar{p}e^+$	09.6	7.1 ± 9.0	0.6	23.0	< 7.6
$D^0 \to p\mu^-$	10.7	11.0 ± 23.0	0.9	17.1	< 5.1
$\bar{D}^0 \to p\mu^-$	10.7	-10.8 ± 27.0		21.8	< 6.5
$D^0 \to \bar{p}\mu^+$	10.5	-4.5 ± 14.0		21.1	< 6.3
$\bar{D}^0 \to \bar{p}\mu^+$	10.4	16.7 ± 8.8	1.6	21.4	< 6.5



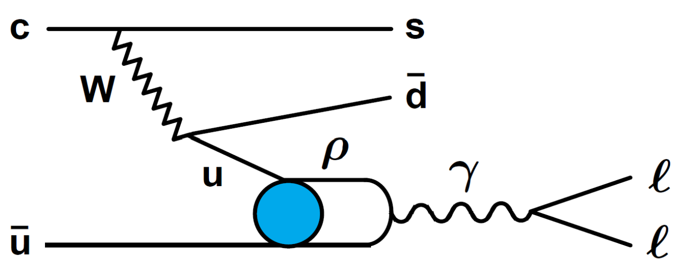
$\Delta M = M_{D^{*+}} - m_{D^0}$

Search for $D^0 \to hh'e^+e^-$

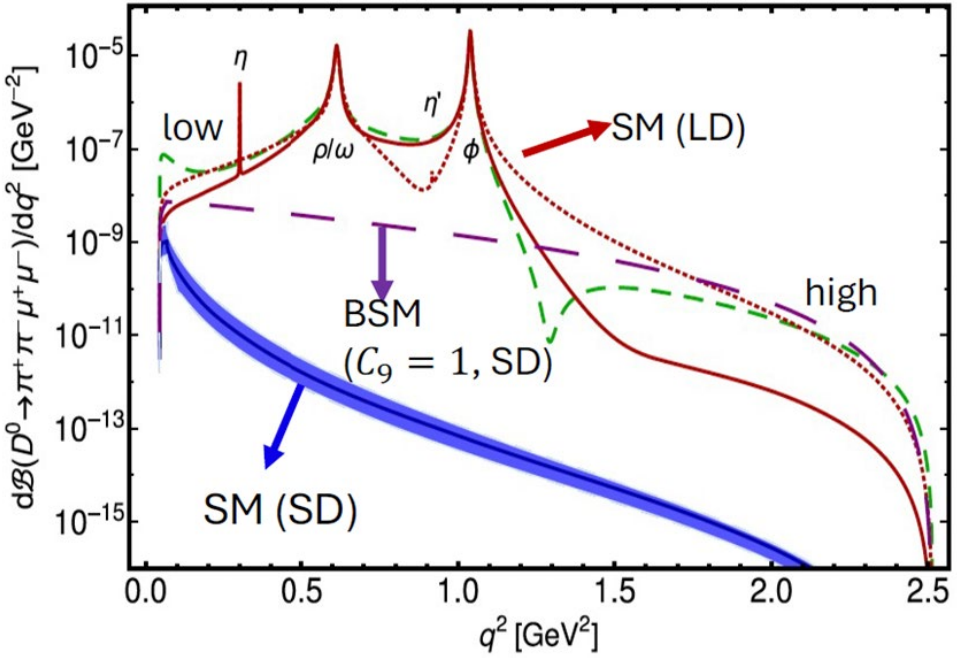
- FCNC $c \to u\ell\ell$ are suppressed processes in the SM, interesting place to look for NP.
- The $D^0 \to X^0\ell^+\ell^-$ can have contributions from both short-distance (SD) and long distance (LD) amplitudes.
  - SM long-distance contributions dominate, especially near resonances.
  - BSM contributions maybe visible far from resonances. [PRD 98, 035041 (2018)]



SD contribution



LD contribution



Measured BFs and ULs @ 90% CL [$\times 10^{-7}$]

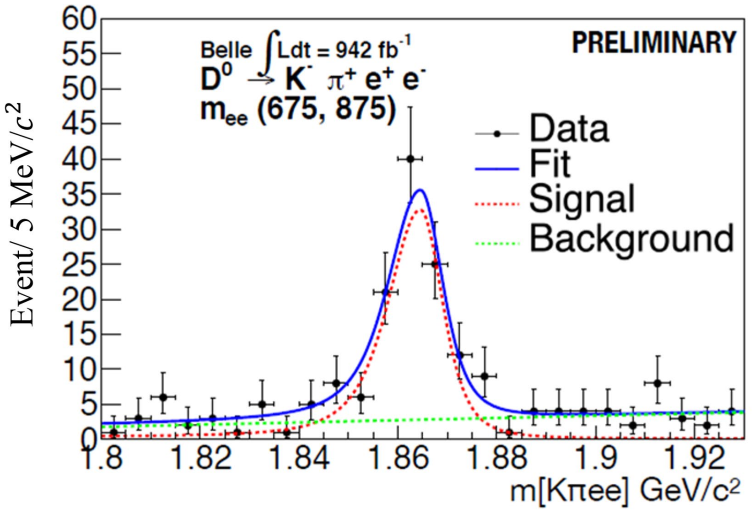
Experiment	$K^-K^+e^+e^-$	$\pi^-\pi^+e^+e^-$	$K^-\pi^+e^+e^-$
Babar (2019)			$40.0 \pm 5.0 \pm 2.3$ (ρ^0/ω) stat syst
BESIII (2019)	< 110	< 70	< 410
	$K^-K^+\mu^+\mu^-$	$\pi^-\pi^+\mu^+\mu^-$	$K^-\pi^+\mu^+\mu^-$
LHCb (2016-2017)	$1.54 \pm 0.27 \pm 0.19$	$9.64 \pm 0.48 \pm 1.10$	$4.17 \pm 0.12 \pm 0.40$ (ρ^0/ω)

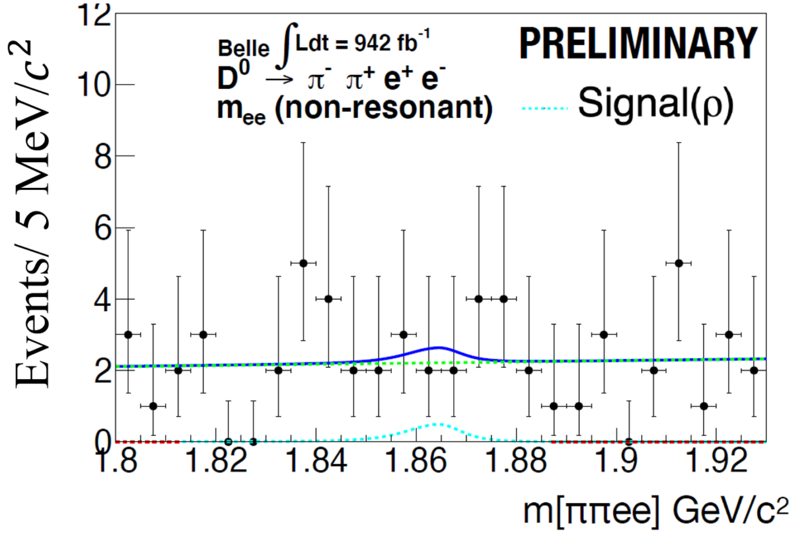
Babar: PRL 122, 081802 (2019)
BESIII: PRD 97, 072015 (2019)
LHCb: PLB517, 558(2016); PRL 119, 181805 (2017)

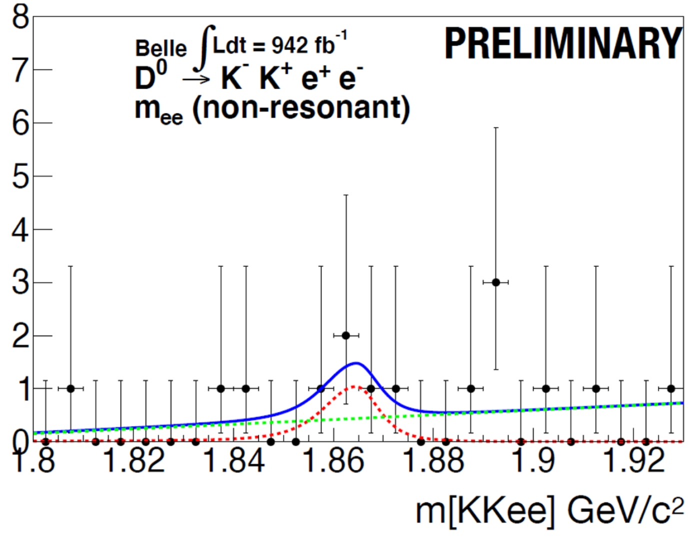
Search for $D^0 \to hh'e^+e^-$

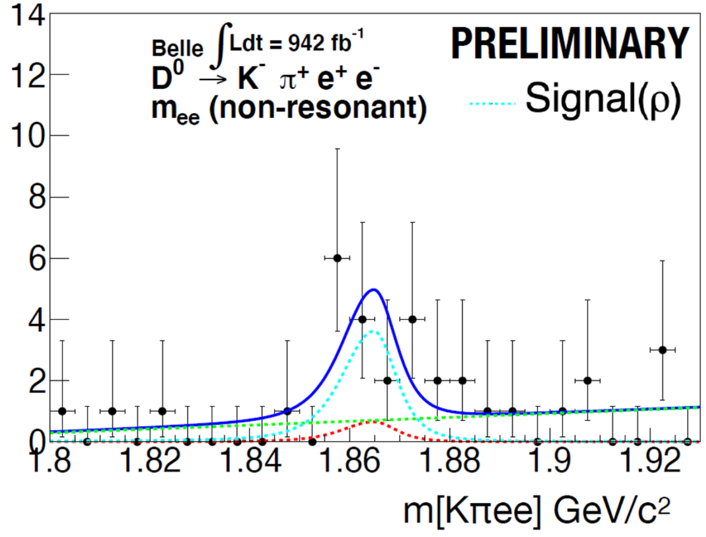
- Signal observed for $D^0 \to K^-\pi^+e^+e^-$ in ρ/ω region (11.8σ).
  - ✓ $\mathcal{B} = (39.6 \pm 4.5(\text{stat}) \pm 2.9(\text{syst})) \times 10^{-7}$.
  - ✓ compatible with Babar and with SM expectation
- No signal observed in other channels and regions.
  - ✓ set upper limits in $[2.3, 7.7]\times 10^{-7}$ at 90% CL.
  - ✓ significantly improved limits wrt BESIII and Babar.

Belle 942/fb PRELIMINARY









CPV in charm four-body decays

- Charge-parity violation (CPV) in charm decays is predicted to be very small $\leq \mathcal{O}(10^{-3})$.
- CPV in D four-body decay was searched with triple-product asymmetries by the FOCUS, Babar, LHCb, and Belle experiments. [PLB 622, 239 (2005); PRD 84, 031103 (2011); JHEP 10, 005 (2014)]
- Triple-product $C_T = \vec{p}_i \cdot (\vec{p}_j \times \vec{p}_k)$ is calculated in the mother's rest frame, satisfying $CP(C_T) = -C(C_T) = -\bar{C}_T$.

$M \rightarrow P_i P_j P_k P_l$

- The T-odd asymmetries are defined as:

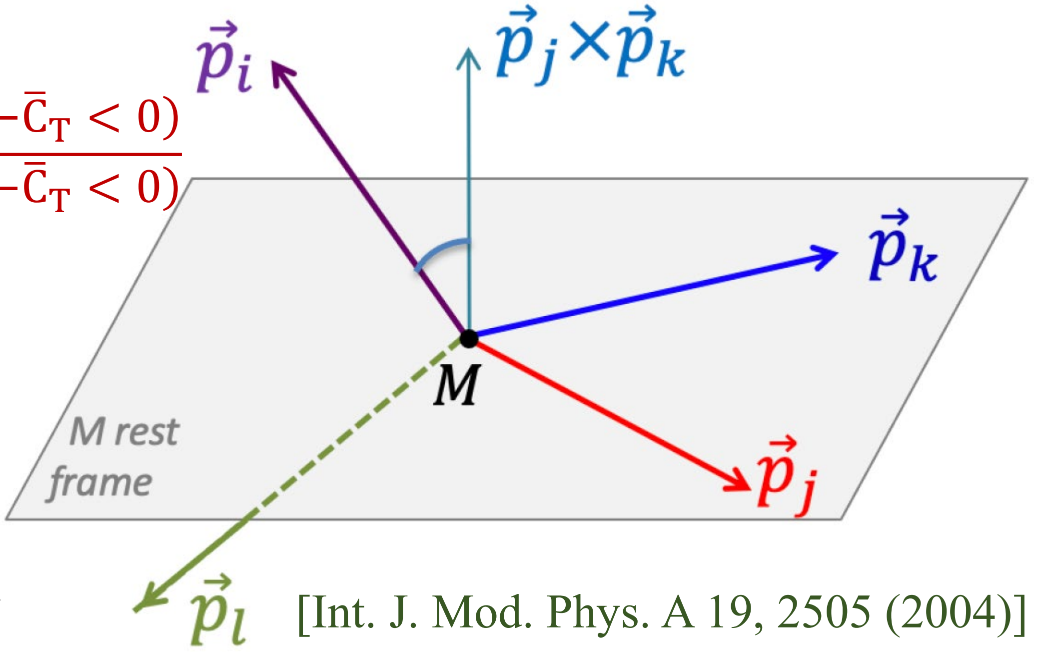
$$A_T(D^+) = \frac{N_+(C_T > 0) - N_+(C_T < 0)}{N_+(C_T > 0) + N_+(C_T < 0)} \qquad \bar{A}_T(D^-) = \frac{N_-(-\bar{C}_T > 0) - N_-(-\bar{C}_T < 0)}{N_-(-\bar{C}_T > 0) + N_-(-\bar{C}_T < 0)}$$

• $A_T(\bar{A}_T) \neq 0$ can also arise from final-state interaction.

- T-odd CP-asymmetry:

$$a_{CP}^{T-odd} = \frac{1}{2}(A_T - \bar{A}_T).$$

- a_{CP}^{T-odd} is unaffected by production and reconstruction asymmetries.
- $a_{CP}^{T-odd} \propto \sin\phi\cos\delta$ has largest value when $\delta = 0$ ($A_{CP}^{dir} \neq 0$ need $\delta \neq 0$).



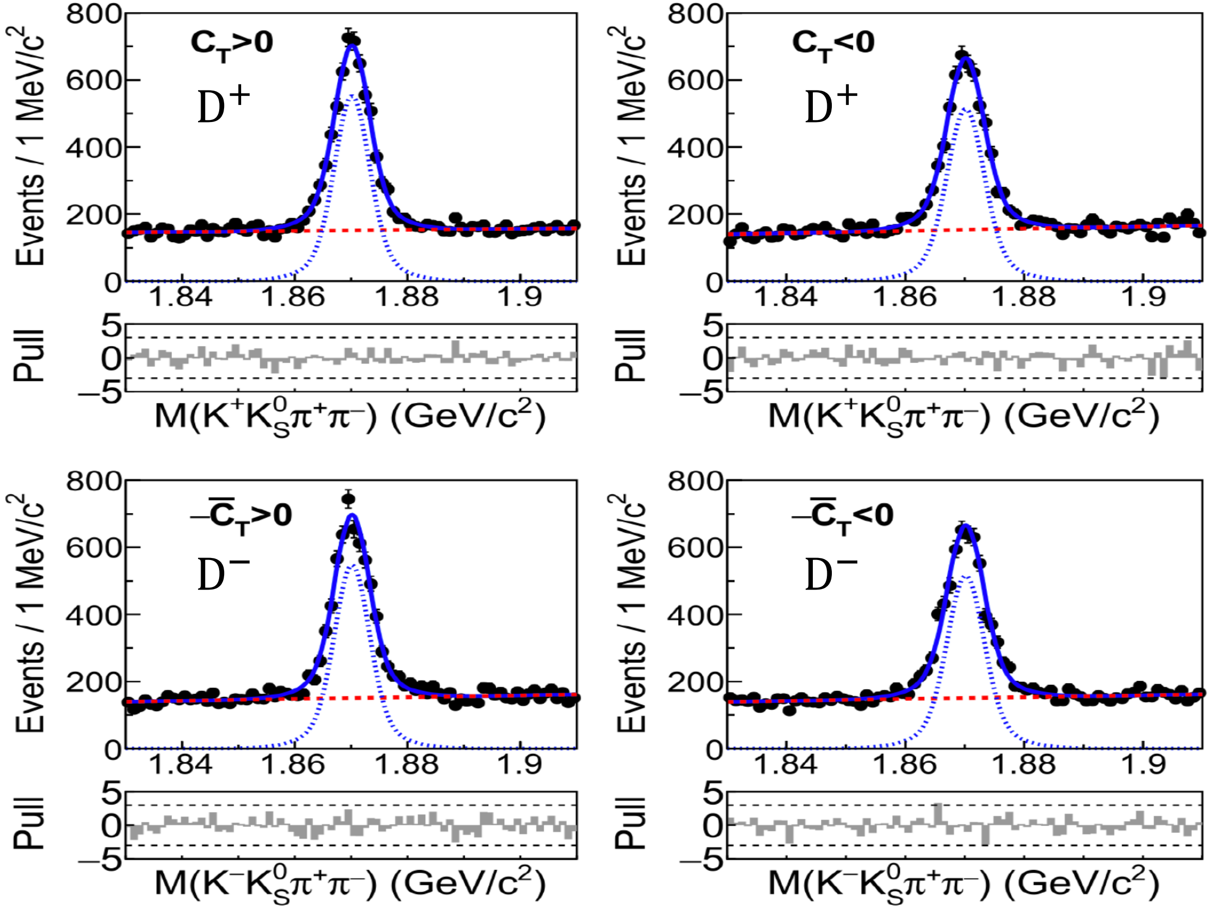
[Int. J. Mod. Phys. A 19, 2505 (2004)]

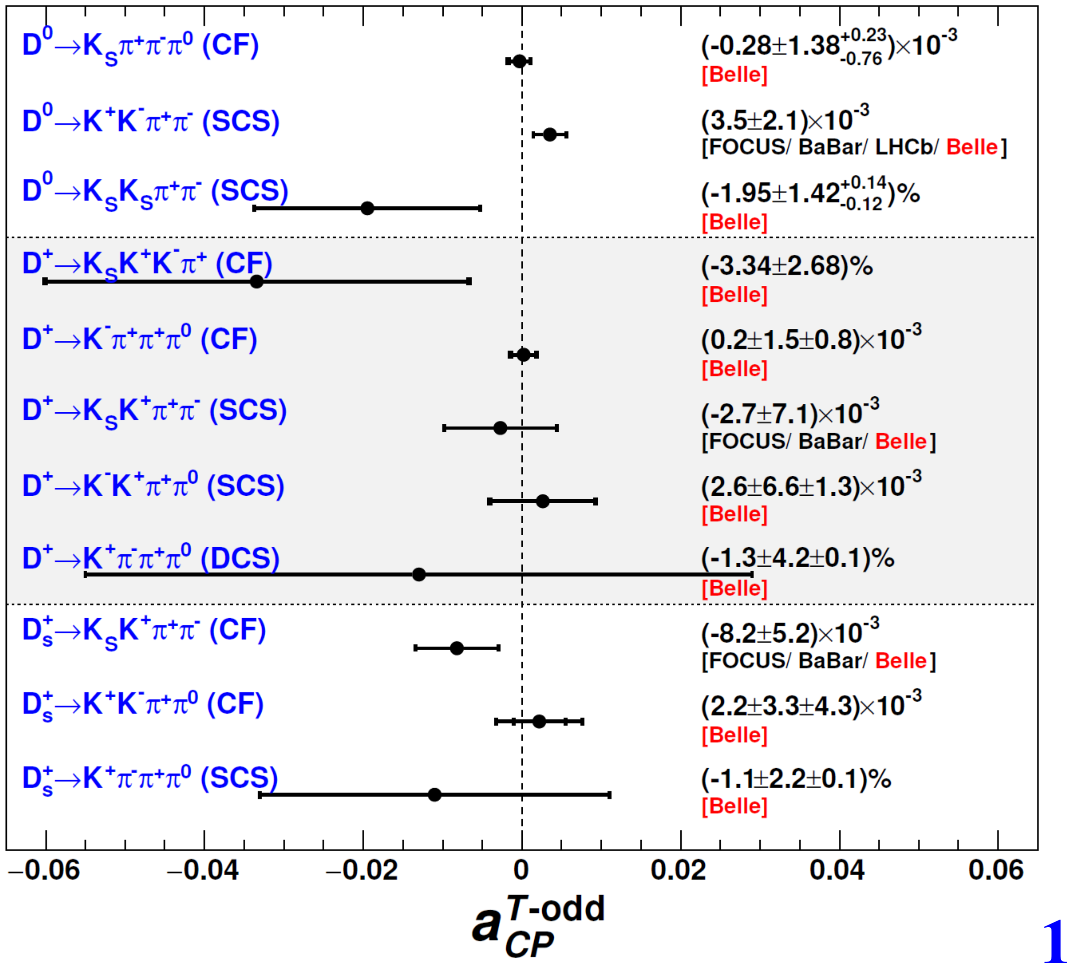
CPV in charm four-body decays

- Belle recently searched for CPV with T-odd correlations in decays of $D^0 \to K_S^0 K_S^0 \pi^+\pi^-$, $D^+_{(s)} \to K_S^0 h \pi^+\pi^-$, and $D^+_{(s)} \to K h \pi^+\pi^0$.

Belle [PRD 107, 052001 (2023); PRD 108, L111102 (2023); arXiv: 2305.12806]

- These a_{CP}^{T-odd} results mostly at first or most precise measurements.

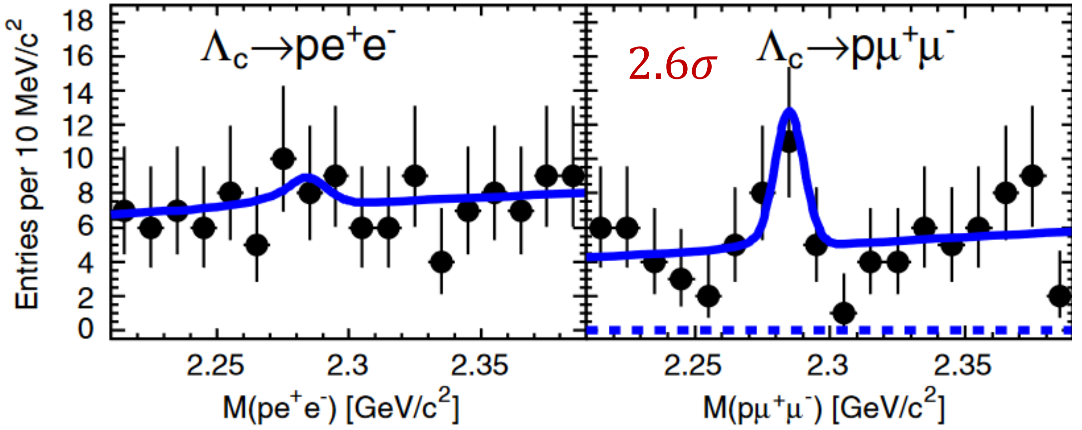




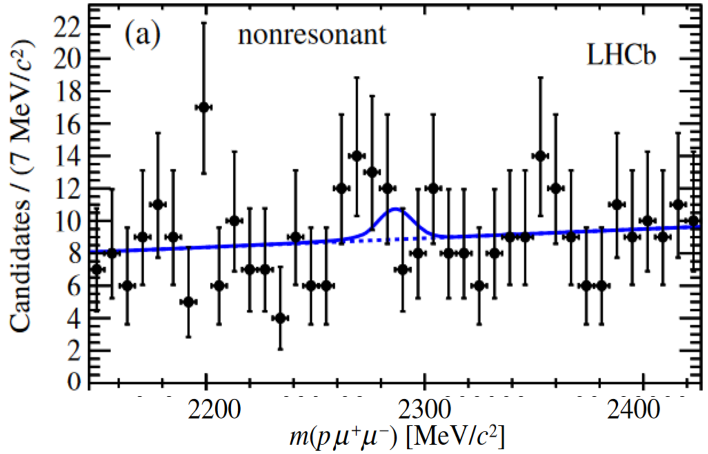
First search for $\Xi_c^0 \to \Xi^0 \ell^+ \ell^-$

- Semi-leptonic decay provides a test on Lepton Flavor Universality.
- Several baryonic neutrino-less semi-leptonic decays have been observed.

channels	Exp. results
$\mathcal{B}(\Xi^0 \to \Lambda e^+ e^-)$ [PLB 650, 1 (2007)]	$(7.6 \pm 0.6) \times 10^{-6}$
$\mathcal{B}(\Sigma^+ \to p\mu^+\mu^-)$ [PRL 94,021801(2005)]	$(8.6^{+8.6}_{-7.7}) \times 10^{-8}$
$\mathcal{B}(\Sigma^+ \to p\mu^+\mu^-)$ [PRL 120, 221803 (2018)]	$(2.2^{+1.7}_{-1.4}) \times 10^{-8}$
$\mathcal{B}(\Sigma^+ \to p\mu^+\mu^-)$ [ZPHY 228, 151 (1969)]	$< 7 \times 10^{-6}$, 90% CL
$\mathcal{B}(\Lambda_b \to \Lambda\mu^+\mu^-)$ [PRL 107,201802(2011)]	$(1.73 \pm 0.69) \times 10^{-6}$
$\mathcal{B}(\Lambda_b \to \Lambda\mu^+\mu^-)$[JHEP 06,115(2015)]	$(0.96 \pm 0.29) \times 10^{-6}$
$\mathcal{B}(\Lambda_c \to p e^+ e^-)$ [PRD 84,072006(2011)]	$< 5.5 \times 10^{-6}$, 90% CL
$\mathcal{B}(\Lambda_c \to p\mu^+ \mu^-)$ [PRD 84,072006(2011)]	$< 44 \times 10^{-6}$, 90% CL
$\mathcal{B}(\Lambda_c \to p\mu^+\mu^-)$[PRD 97,091101(2018)]	$< 7.7 \times 10^{-8}$, 90% CL



BaBar [PRD 84,072006(2011)]



LHCb [PRD 97,091101 (2018)]

- For charmed baryons, only $\Lambda_c^+ \to p\ell^+\ell^-$ were searched. There are no significant signals.
- The $\Lambda_c^+ \to p\ell^+\ell^-$ decays receive both W-exchange and FCNC process contributions.

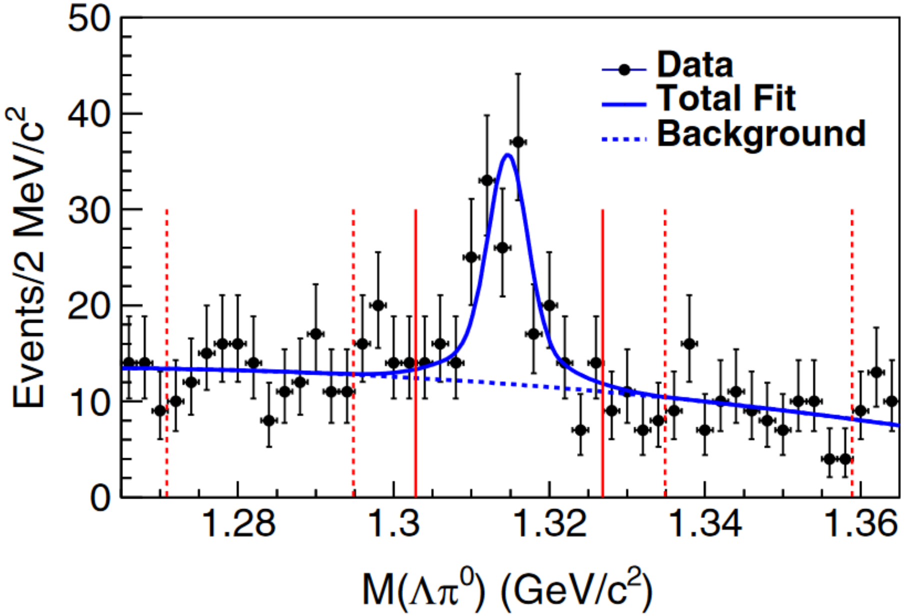
First search for $\Xi_c^0 \to \Xi^0 \ell^+ \ell^-$

- The Cabibbo-favored $\Xi_c^0 \to \Xi^0 \ell^+ \ell^-$ decay only receive the W-exchange contributions.
- If observed, the signal channels would allow to test LFU.

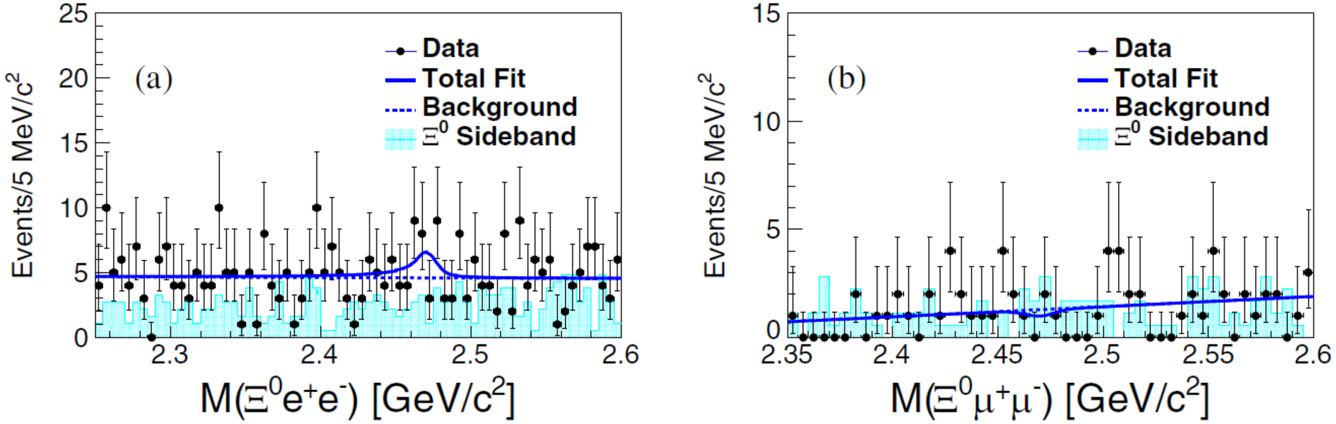
Belle 980/fb [PRD 109, 052003 (2024)]

- Fully reconstruct $\Xi_c^0 \to \Xi^0 \ell^+ \ell^-$ with $\Xi^0 \to \Lambda\pi^0$ in $e^+e^- \to c\bar{c}$ continuum process using all Belle data.
- Take $\Xi_c^0 \to \Xi^-\pi^+$ as normalization mode.

$\Xi^0 \to \Lambda\pi^0$ signals (~100)



- No significant signals observed in $M(\Xi^0 \ell^+ \ell^-)$.



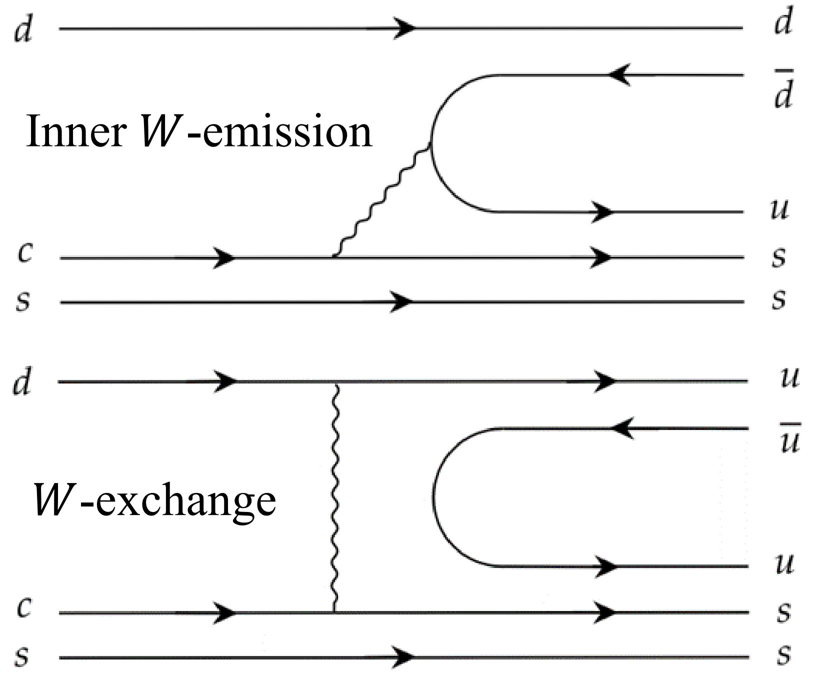
- Taking $\mathcal{B}(\Xi_c^0 \to \Xi^-\pi^+) = (1.43 \pm 0.32)\%$, we set upper limits at 90% CL

$$\mathcal{B}(\Xi_c^0 \to \Xi^0 e^+ e^-) < 9.9 \times 10^{-5}$$
$$\mathcal{B}(\Xi_c^0 \to \Xi^0 \mu^+ \mu^-) < 6.5 \times 10^{-5}$$

- Theoretical predictions under SU(3) symmetry give upper limits at $2.35\,(2.25) \times 10^{-6}$ for electron (muon) mode. [PRD 103, 013007 (2021)].

Study of $\Xi_c^0 \to \Xi^0 h^0$, $h^0 = \pi^0/\eta/\eta'$

- In hadronic weak decays of charmed baryons, nonfactorizable amplitudes play an essential role and lead to difficulties for theoretical predictions.
- The Cabibbo-favored $\Xi_c^0 \to \Xi^0 h^0$ decays only receive nonfactorizable contributions.
- Serval theoretical approaches developed to deal with nonfactorizable contributions, give various predictions on branching fractions (in unit of 10^{-3}) and decay asymmetry parameter.



Reference	Model	$\mathcal{B}(\Xi_c^0 \to \Xi^0\pi^0)$	$\mathcal{B}(\Xi_c^0 \to \Xi^0\eta)$	$\mathcal{B}(\Xi_c^0 \to \Xi^0\eta')$	$\alpha(\Xi_c^0 \to \Xi^0\pi^0)$
Körner, Krämer [5]	quark	0.5	3.2	11.6	0.92
Ivanov *et al.* [6]	quark	0.5	3.7	4.1	0.94
Xu, Kamal [7]	pole	7.7	-	-	0.92
Cheng, Tseng [8]	pole	3.8	-	-	-0.78
Żenczykowski [9]	pole	6.9	1.0	9.0	0.21
Zou *et al.* [10]	pole	18.2	26.7	-	-0.77
Sharma, Verma [11]	CA	-	-	-	-0.8
Cheng, Tseng [8]	CA	17.1	-	-	0.54
Geng *et al.* [12]	$SU(3)_F$	4.3 ± 0.9	$1.7^{+1.0}_{-1.7}$	$8.6^{+11.0}_{-6.3}$	-
Geng *et al.* [13]	$SU(3)_F$	7.6 ± 1.0	10.3 ± 2.0	9.1 ± 4.1	$-1.00^{+0.07}_{-0.00}$
Zhao *et al.* [14]	$SU(3)_F$	4.7 ± 0.9	8.3 ± 2.3	7.2 ± 1.9	-
Huang *et al.* [15]	$SU(3)_F$	2.56 ± 0.93	-	-	-0.23 ± 0.60
Hsiao *et al.* [16]	$SU(3)_F$	6.0 ± 1.2	$4.2^{+1.6}_{-1.3}$	-	-
Hsiao *et al.* [16]	$SU(3)_F$-breaking	3.6 ± 1.2	7.3 ± 3.2	-	-
Zhong *et al.* [17]	$SU(3)_F$	$1.13^{+0.59}_{-0.49}$	1.56 ± 1.92	$0.683^{+3.272}_{-3.268}$	$0.50^{+0.37}_{-0.35}$
Zhong *et al.* [17]	$SU(3)_F$-breaking	$7.74^{+2.52}_{-2.32}$	$2.43^{+2.79}_{-2.90}$	$1.63^{+5.09}_{-5.14}$	$-0.29^{+0.20}_{-0.17}$
Xing *et al.* [18]	$SU(3)_F$	1.30 ± 0.51	-	-	-0.28 ± 0.18

[5] Z. Phys. C 55, 659 (1992)
[6] PRD 57, 6532 (1998)
[7] PRD 46, 270 (1992)
[8] PRD 48, 4188 (1993)
[9] PRD 50, 5787 (1994)
[10] PRD 101, 014011 (2020)
[11] EPJC 7, 217 (1999)
[12] PRD 97, 073006 (2018)
[13] PLB 794, 19 (2019)
[14] JHEP 02, 165 (2020)
[15] JHEP 03, 143 (2022)
[16] JHEP 09, 35 (2022)
[17] JHEP 02, 235 (2023)
[18] PRD 108, 053004 (2023)

- Need experiment measurement to clarify the theoretical picture.
- First combined Belle and Belle II charm measurement!

Study of $\Xi_c^0 \to \Xi^0 h^0$, $h^0 = \pi^0/\eta/\eta'$

Belle + Belle II~1.4/ab PRELIMINARY

- First measurements of the branching fractions using combined data:

$\mathcal{B}(\Xi_c^0 \to \Xi^0\pi^0) = (6.9 \pm 0.3(\mathrm{stat.}) \pm 0.5(\mathrm{syst.}) \pm 1.5(\mathrm{norm.})) \times 10^{-3}$

$\mathcal{B}(\Xi_c^0 \to \Xi^0\eta) = (1.6 \pm 0.2(\mathrm{stat.}) \pm 0.2(\mathrm{syst.}) \pm 0.4(\mathrm{norm.})) \times 10^{-3}$

$\mathcal{B}(\Xi_c^0 \to \Xi^0\eta') = (1.2 \pm 0.3(\mathrm{stat.}) \pm 0.1(\mathrm{syst.}) \pm 0.3(\mathrm{norm.})) \times 10^{-3}$

- Taking $\Xi_c^0 \to \Xi^-\pi^+$ as reference mode; favoriting predictions in $SU(3)_F$-breaking model [JHEP 02, 235 (2023)].

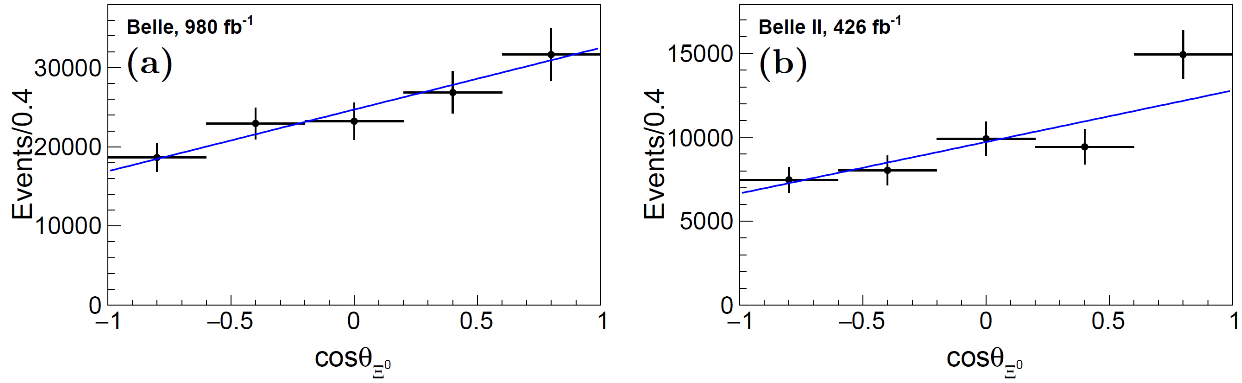
➢ First asymmetry parameter $\alpha(\Xi_c^0 \to \Xi^0\pi^0)$ measurement depending on

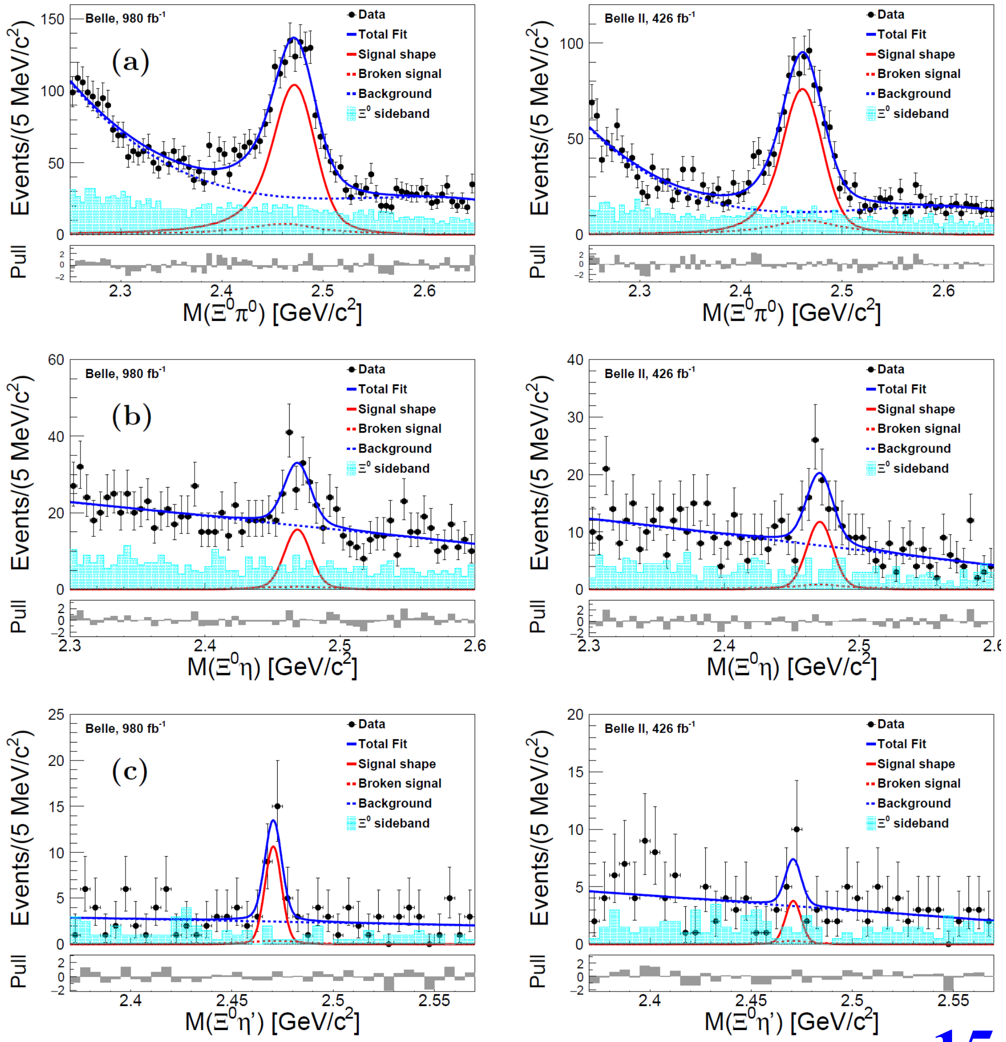
$$\frac{dN}{d\cos\theta_{\Xi^0}} \propto 1 + \alpha(\Xi_c^0 \to \Xi^0 h^0)\alpha(\Xi^0 \to \Lambda\pi^0)\cos\theta_{\Xi^0}$$

through a simultaneous fit to Belle and Belle II data samples

$$\alpha(\Xi_c^0 \to \Xi^0\pi^0) = -0.90 \pm 0.15(\mathrm{stat.}) \pm 0.23(\mathrm{syst.})$$

taking $\alpha(\Xi^0 \to \Lambda\pi^0) = -0.349 \pm 0.009$(PDG)

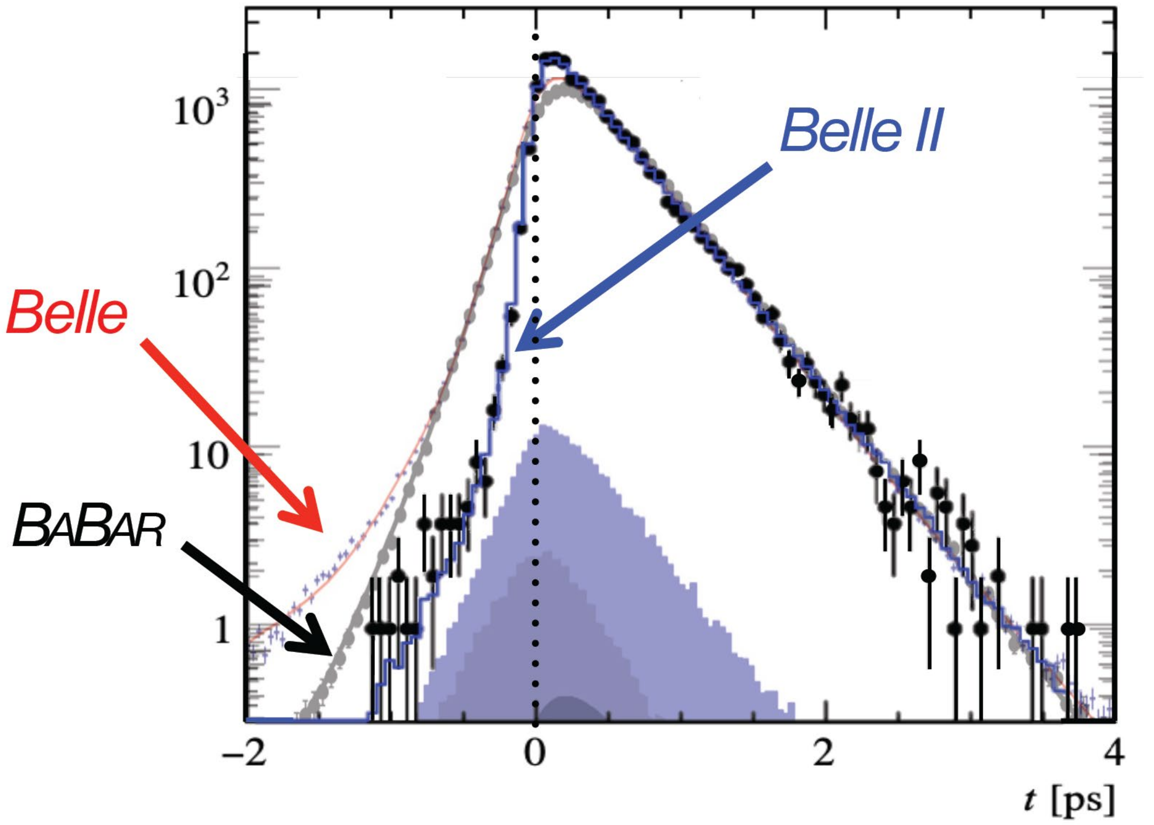


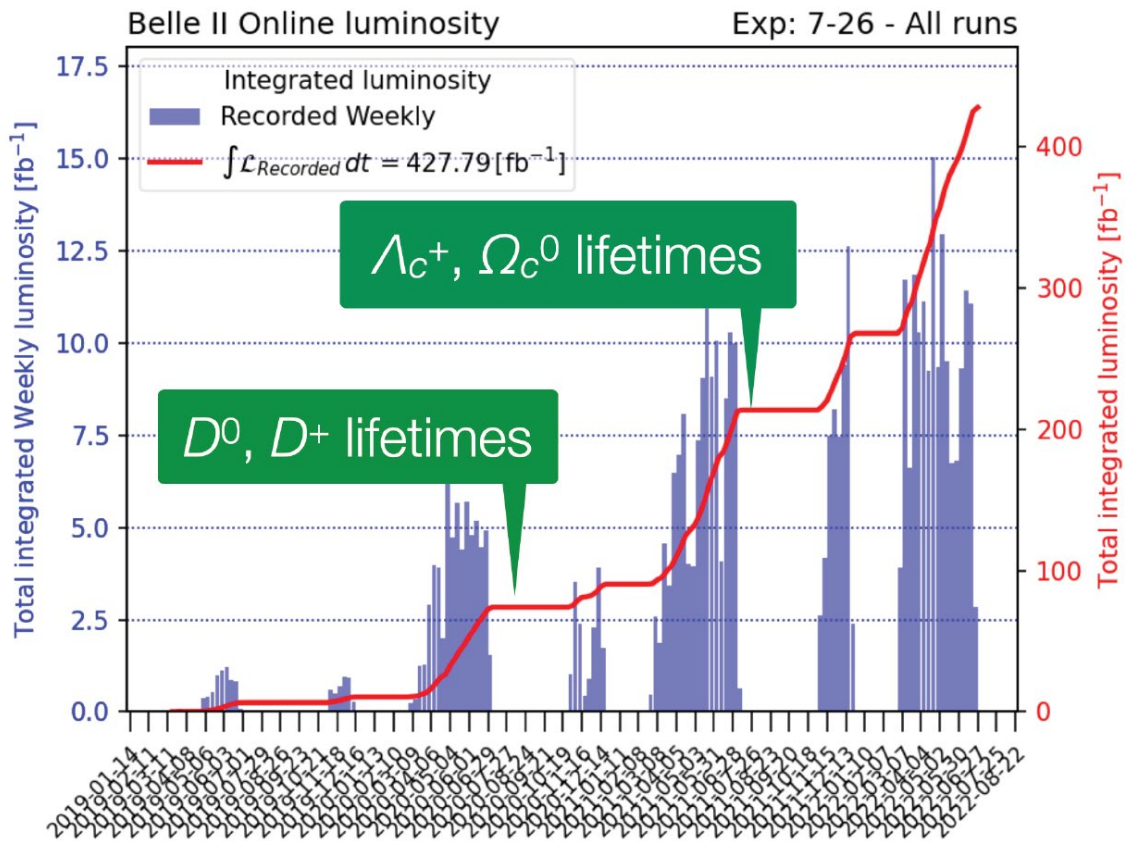


Charm lifetimes at Belle II

- At Belle II, the decay-time resolution is × 2 better than that at Belle/Babar.
- Based on the early Belle II dataset, the most precise charm lifetimes are measured: $\tau(D^0) = 410.5 \pm 1.1 \pm 0.8$ 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.

[PRL 127, 211801 (2021); PRL 130, 071802 (2023)]

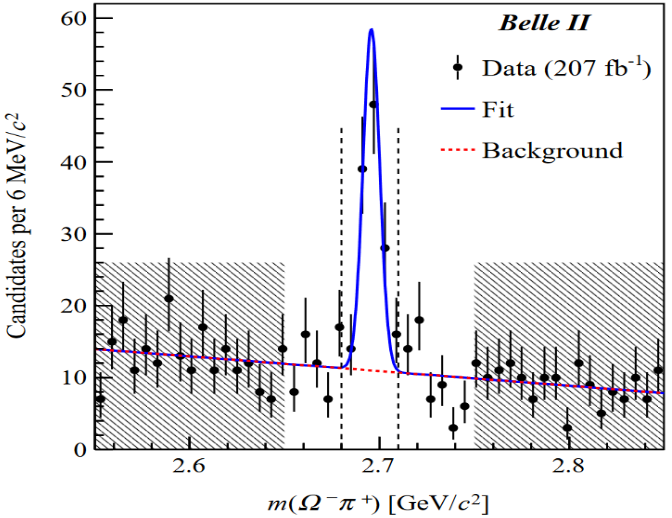


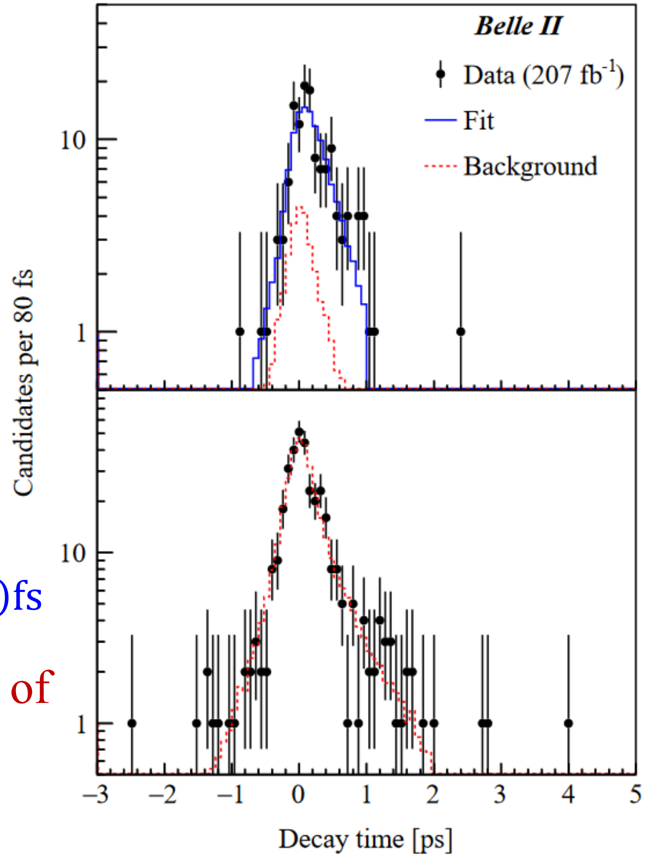


Charm lifetimes at Belle II

- Measurement of Ω_c^0 lifetime with $\Omega_c^0 \to \Omega^-\pi^+$ signals using 207 fb^{-1} data.

[PRD 107, L031103 (2023)]





$\tau(\Omega_c^0) = 243 \pm 48(\mathrm{stat.}) \pm 11(\mathrm{syst.})\,\mathrm{fs}$

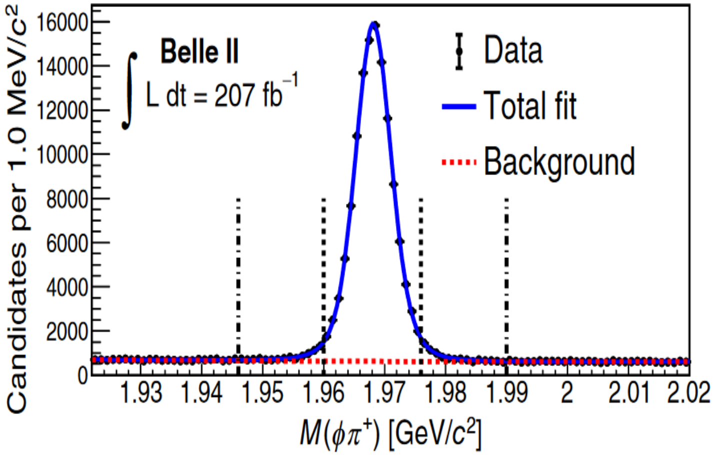
Consistent with the LHCb average of $\tau(\Omega_c^0) = (274.5 \pm 12.4)$ fs

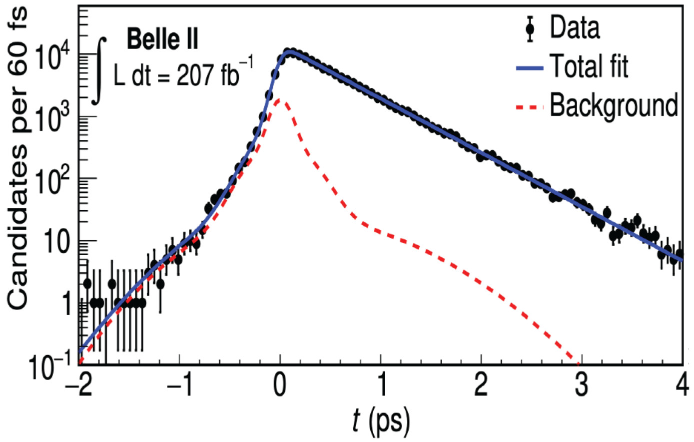
[Sci.Bull. 67 (2022) 5, 479]

$\tau(\Xi_c^+) > \tau(\Omega_c^0) > \tau(\Lambda_c^+) > \tau(\Xi_c^0)$

- Precise measurement of D_s^+ lifetime with 116K $D_s^+ \to \phi\pi^+$ signals using 207 fb^{-1} data.

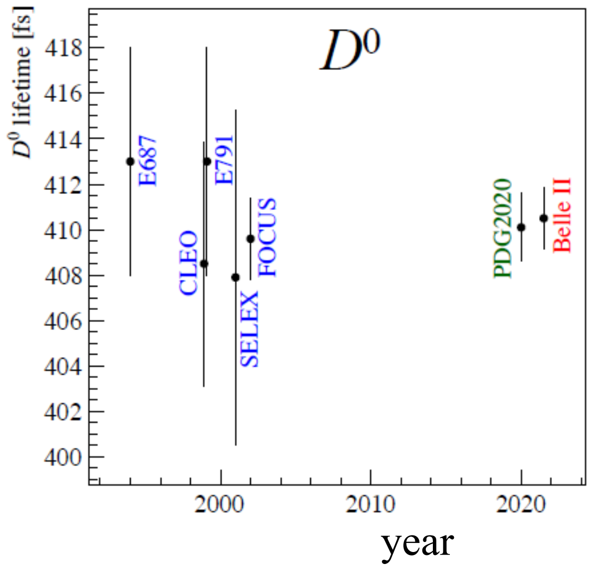
[PRL 131, 171803 (2023)]

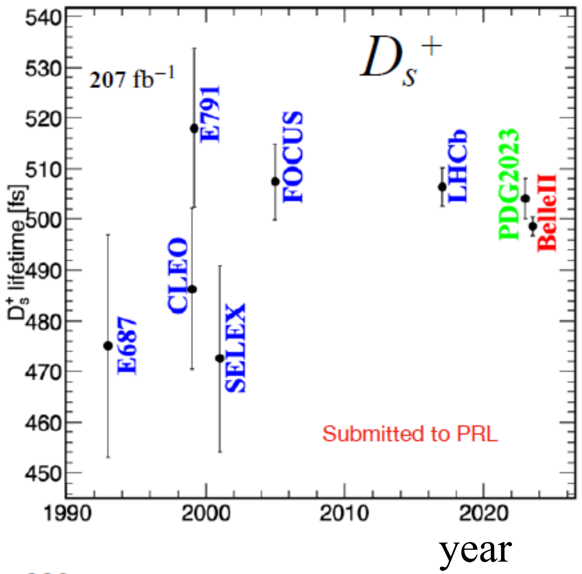


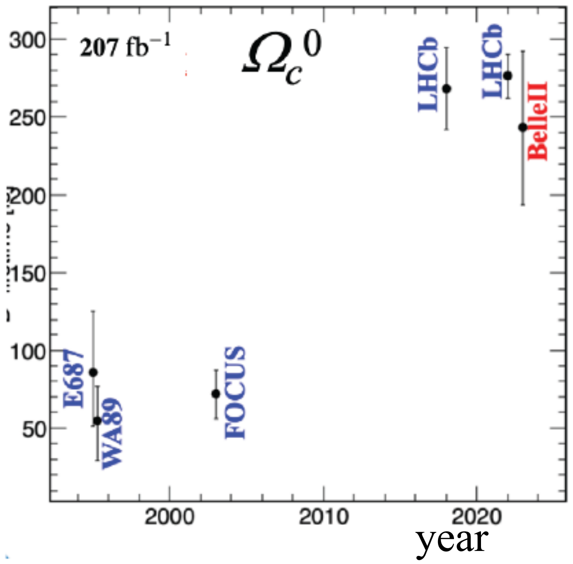


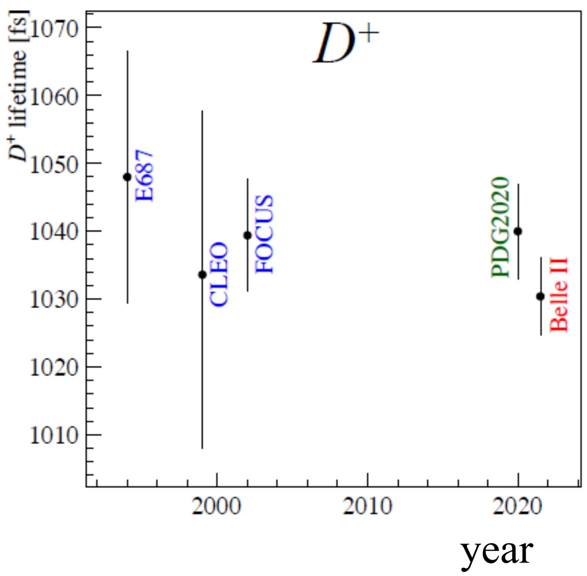
$\tau(D_s^+) = (203.20 \pm 0.89 \pm 0.77)$ fs

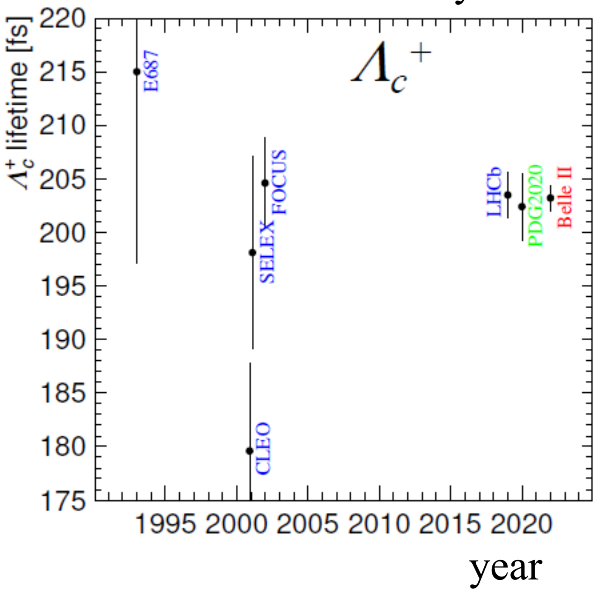
Charm lifetimes at Belle II







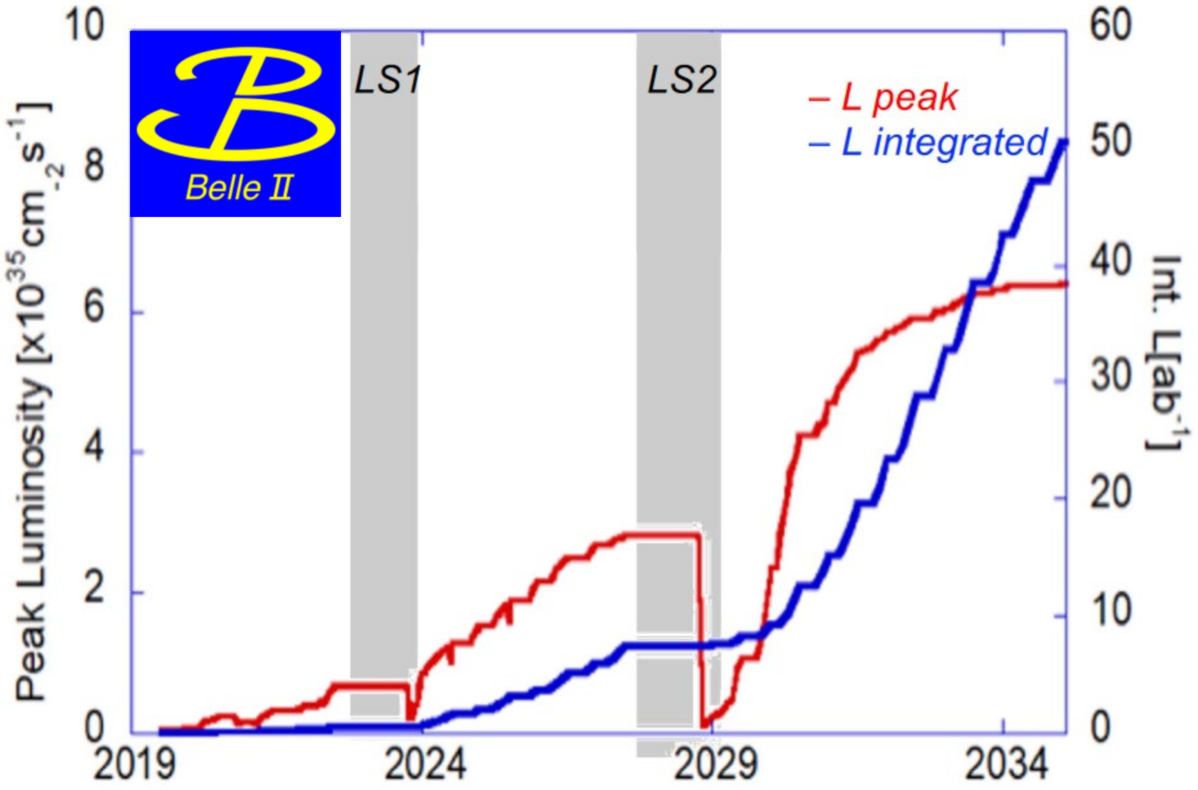




- In all cases except for Ω_c^0, Belle II has made the world's highest precision measurement (in some cases after 20 years).
- For Ω_c^0, the Belle II measurement confirms the longer lifetime measured by LHCb.

Summary

- Belle are lasting to produce the fruitful charm results although its data taking finished 14 years ago.
  - Search for $D \to p\ell / D^0 \to hh'e^+e^-$
  - CPV in charm four-body decays
  - Search for $\Xi_c^0 \to \Xi^0 \ell^+ \ell^-$
- Belle II has joined the game.
  - Study of $\Xi_c^0 \to \Xi^0\pi^0 / \Xi^0\eta / \Xi^0\eta'$
- Utilizing the early dataset, we obtain the world best $\tau(D^{0,+})$, $\tau(D_s^+)$, and $\tau(\Lambda_c^+)$ confirmation of LHCb $\tau(\Omega_c^0)$ result.



- More charm results utilizing 1.4 ab^{-1} of dataset at Belle and Belle II in 2024. Please stay tuned!

Thanks for your attention!

Backup

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TABLE I. $D^0 \to h^- h^{(\prime)+} e^+ e^-$ modes yields, significance, branching fractions, branching fraction upper limits, and the efficiencies of each m_{ee} region [$\times 10^{-7}$]. A fitted yield and a branching fraction are not reported for $K^- K^+ e^+ e^-$ mode with m_{ee} in the m_η region since only one event is observed, and the significance is determined from the CL$_s$ distribution.

m_{ee} region	[MeV/c^2]	Yield	Significance	$\mathcal{B}$	UL @ 90% CL	Efficiency
$K^- K^+ e^+ e^-$						
η	520-560	-	$< 0.1\sigma$	-	< 2.3	3.53 ± 0.04
ρ^0/ω	> 675	2.6 ± 1.8	2.0σ	$1.2 \pm 0.9 \pm 0.1$	< 3.0	6.00 ± 0.06
non-resonant	> 200 [a]	3.5 ± 3.3	1.5σ	$3.1 \pm 3.0 \pm 0.4$	< 7.7	3.19 ± 0.04
$\pi^- \pi^+ e^+ e^-$						
η	520-560	0.6 ± 2.3	0.3σ	$0.4 \pm 1.4 \pm 0.2$	< 3.2	5.31 ± 0.05
ρ^0/ω	675-875	3.7 ± 4.1	0.9σ	$2.0 \pm 2.2 \pm 0.8$	< 6.1	5.69 ± 0.05
ϕ	995-1035	3.6 ± 3.2	1.1σ	$1.1 \pm 1.1 \pm 0.2$	< 3.1	9.41 ± 0.06
non-resonant	> 200	-0.2 ± 4.1	$< 0.1\sigma$	$-0.2 \pm 3.4 \pm 0.9$	< 7.2	3.69 ± 0.04
$K^- \pi^+ e^+ e^-$						
η	520-560	4.0 ± 2.7	1.6σ	$2.2 \pm 1.5 \pm 0.5$	< 5.6	5.09 ± 0.04
ρ^0/ω	675-875	110 ± 13	11.8σ	$39.6 \pm 4.5 \pm 2.9$	-	8.01 ± 0.06
ϕ	990-1034	4.6 ± 2.4	2.5σ	$1.4 \pm 0.8 \pm 0.3$	< 2.9	9.19 ± 0.06
non-resonant	> 560	2.2 ± 4.2	0.4σ	$1.3 \pm 2.4 \pm 0.6$	< 6.5	4.89 ± 0.09

[a] Excluding resonance regions, which is same for all three modes.