Charm physics and Charmed-baryon decays at Belle II

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Belle and Belle II Experiments

- Asymmetric e^+e^- colliders
- Collisions mainly at 10.58 GeV , i.e at $\Upsilon(4S)$ resonance

KEKB

1999-2010

- e^+ (3.5 GeV) e^-(8 GeV)
- L_{peak}: $2.1 \times 10^{34}\ cm^{-2}s^{-1}$ [achieved]

SuperKEKB

2019-current

- e^+ (4 GeV) e^-(7 GeV)

Target:

$\int Ldt = 50\ ab^{-1}$

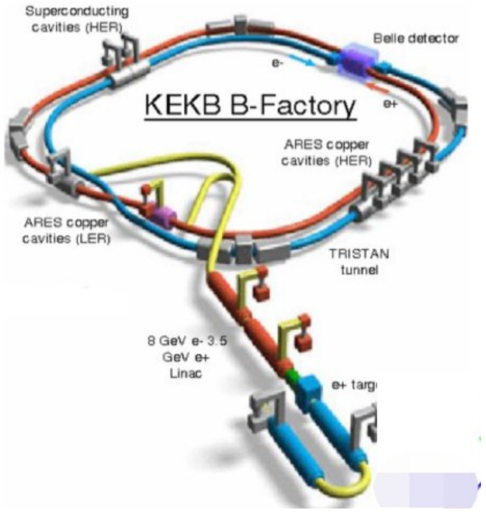
$L_{peak} = 6 \times 10^{35}\ cm^{-2}s^{-1}$

Achieved:

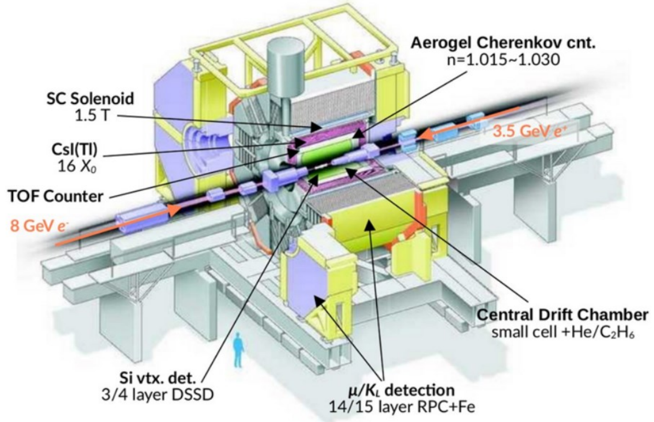
$\int Ldt > 530\ fb^{-1}$

$L_{peak} = 4.7 \times 10^{34}\ cm^{-2}s^{-1}$

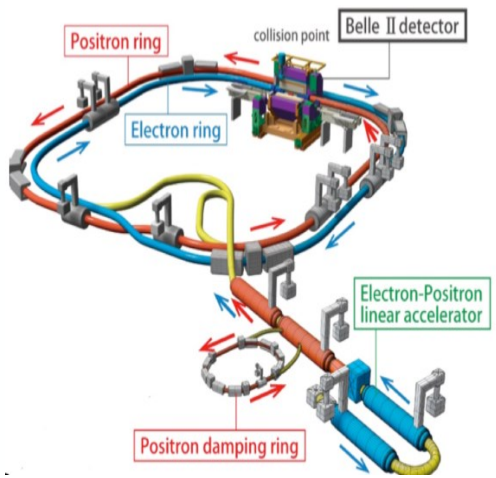
Current world record

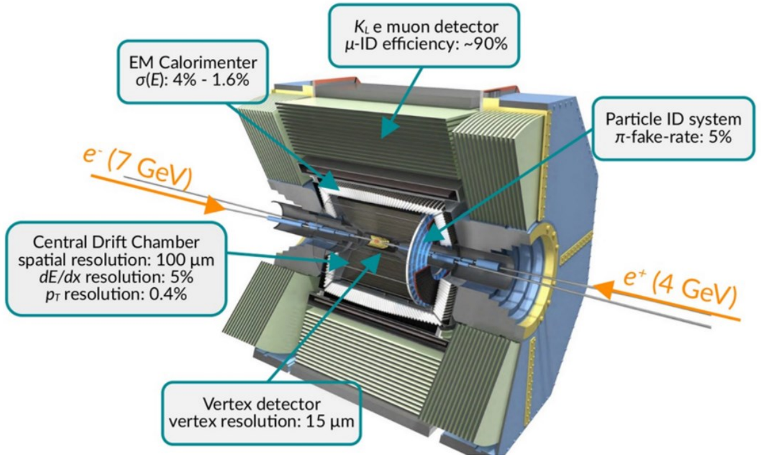


BELLE @ KEKB



Belle II @ SuperKEKB





Charm physics at Belle and Belle II

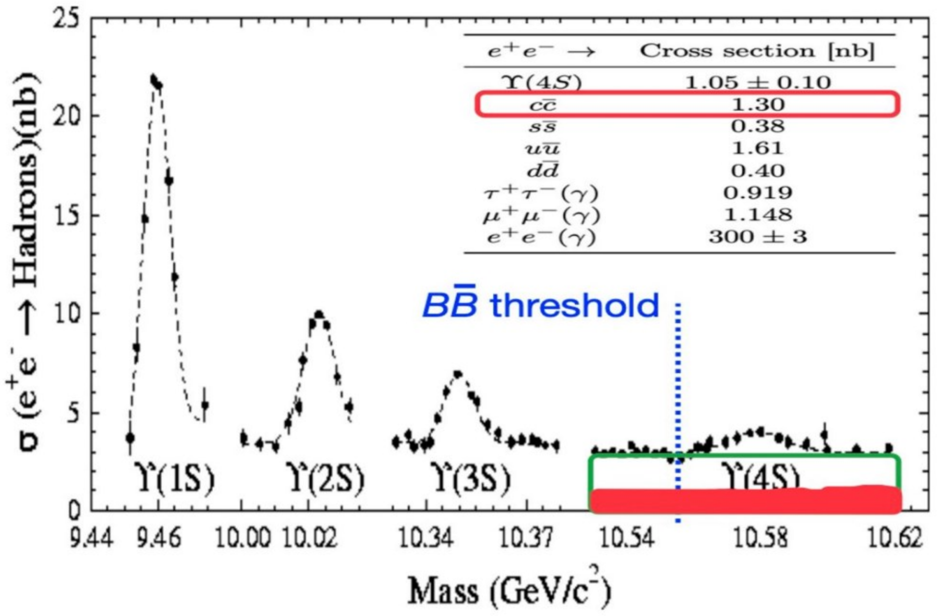
Two primary mechanisms for charm production at Belle/Belle II:

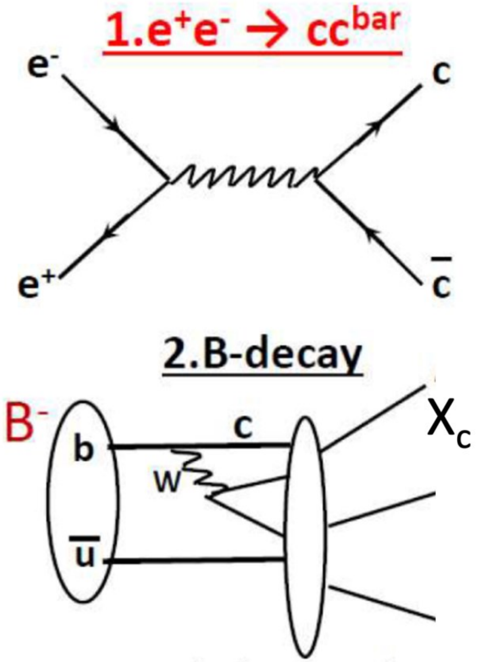
1. $e^+e^- \to c\bar{c} \to X_c$

- Absolute measurements not possible without reference
- Used for most analyses due to its simplicity compared to $B\bar{B}$ processes

2. $e^+e^- \to \Upsilon(4S) \to B\bar{B} \to X_c$

- Precise $B\bar{B}$ cross section allows for absolute measurements





CPV in Charm

CPV in $D \to \pi\pi$

- **$D^0 \to \pi^+\pi^-$:**
  - the only channel with > 3σ evidence of CPV in charm.
  - The SM generates CPV through interference of a tree-level and suppressed QCD loop amplitude $\Delta I = 1/2$ (I = isospin) [*Pys. Rev.D 85, 114036 (2012)*].

- **$D^+ \to \pi^+\pi^0$:**
  - I= 2 and can be reached from the I= 1/2 initial state only via a $\Delta I = 3/2$ transition.
  - Therefore, any observation will confirm New Physics.

- **$D^0 \to \pi^0\pi^0$:**
  - Can have I=0 or I=2 and hence can have nonzero direct CP asymmetries in SM.
  - Isospin sum rule:

$$R = \frac{a_{CP}(\pi^+\pi^-)}{1 + \frac{\tau_{D^0}}{\mathcal{B}_{+-}}\left(\frac{\mathcal{B}_{00}}{\tau_{D^0}} - \frac{2}{3}\frac{\mathcal{B}_{+0}}{\tau_{D^+}}\right)} + \frac{a_{CP}(\pi^0\pi^0)}{1 + \frac{\tau_{D^0}}{\mathcal{B}_{00}}\left(\frac{\mathcal{B}_{+-}}{\tau_{D^0}} - \frac{2}{3}\frac{\mathcal{B}_{+0}}{\tau_{D^+}}\right)} + \frac{a_{CP}(\pi^+\pi^0)}{1 - \frac{3}{2}\frac{\tau_{D^+}}{\mathcal{B}_{+0}}\left(\frac{\mathcal{B}_{00}}{\tau_{D^0}} + \frac{\mathcal{B}_{+-}}{\tau_{D^0}}\right)}$$

  - *$a_{CP} \neq 0$, $R=0$:* CP violation from the $\Delta I = 3/2$ amplitude (New Physics!!)
  - $R = (0.93 \pm 3.1) \times 10^{-3}$, uncertainty is dominated by the $\pi^0\pi^0$ mode *HFLAV*

CP asymmetry in $D^+ \to \pi^+\pi^0$

PRD 112, L031101 (2025)

- The physics variable that we are interested is $A_{CP}(D^+ \to \pi^+\pi^0) = \frac{\Gamma(D^+\to\pi^+\pi^0)-\Gamma(D^-\to\pi^-\pi^0)}{\Gamma(D^+\to\pi^+\pi^0)+\Gamma(D^-\to\pi^-\pi^0)}$

- But the variable easily accessed in exp is $A_{raw}^{\pi\pi} = \frac{N(D^+\to\pi^+\pi^0)-N(D^-\to\pi^-\pi^0)}{N(D^+\to\pi^+\pi^0)+N(D^-\to\pi^-\pi^0)}$

- $A_{raw}^{\pi\pi}$ is related by $A_{CP}^{\pi\pi} = A_{raw}^{\pi\pi} - \boxed{(A_{prod}^{D} + A_{\epsilon}^{\pi})} \rightarrow$ **nuisance asymmetries**

A_{prod}^{D}: forward-backward asymmetric production in e^+e^- collisions of charm hadrons, due to $\gamma^* - Z^0$ interference and higher-order QED effects, is an odd function of $\cos\theta_{CM}(D^\pm)$.

$A_{\epsilon}^{\pi^\pm}$: detection asymmetry of the low-momentum tagging pions.

use $D^+ \to \pi^+ K_S^0$ as a control mode to estimate this

$D^+ \to \pi^+ K_S^0$ $(Br = (1.562 \pm 0.031)\,\%$, Cabibbo-favored)

$A_{raw}^{\pi K_S} = A_{K_S} + \boxed{A_{prod}^{D} + A_{\epsilon}^{\pi^\pm}}$

$\sim -0.4\,\%$

Control mode

$\boxed{A_{CP}^{\pi\pi} = A_{raw}^{\pi\pi} - A_{raw}^{\pi K_S} + A_{K_S}}$

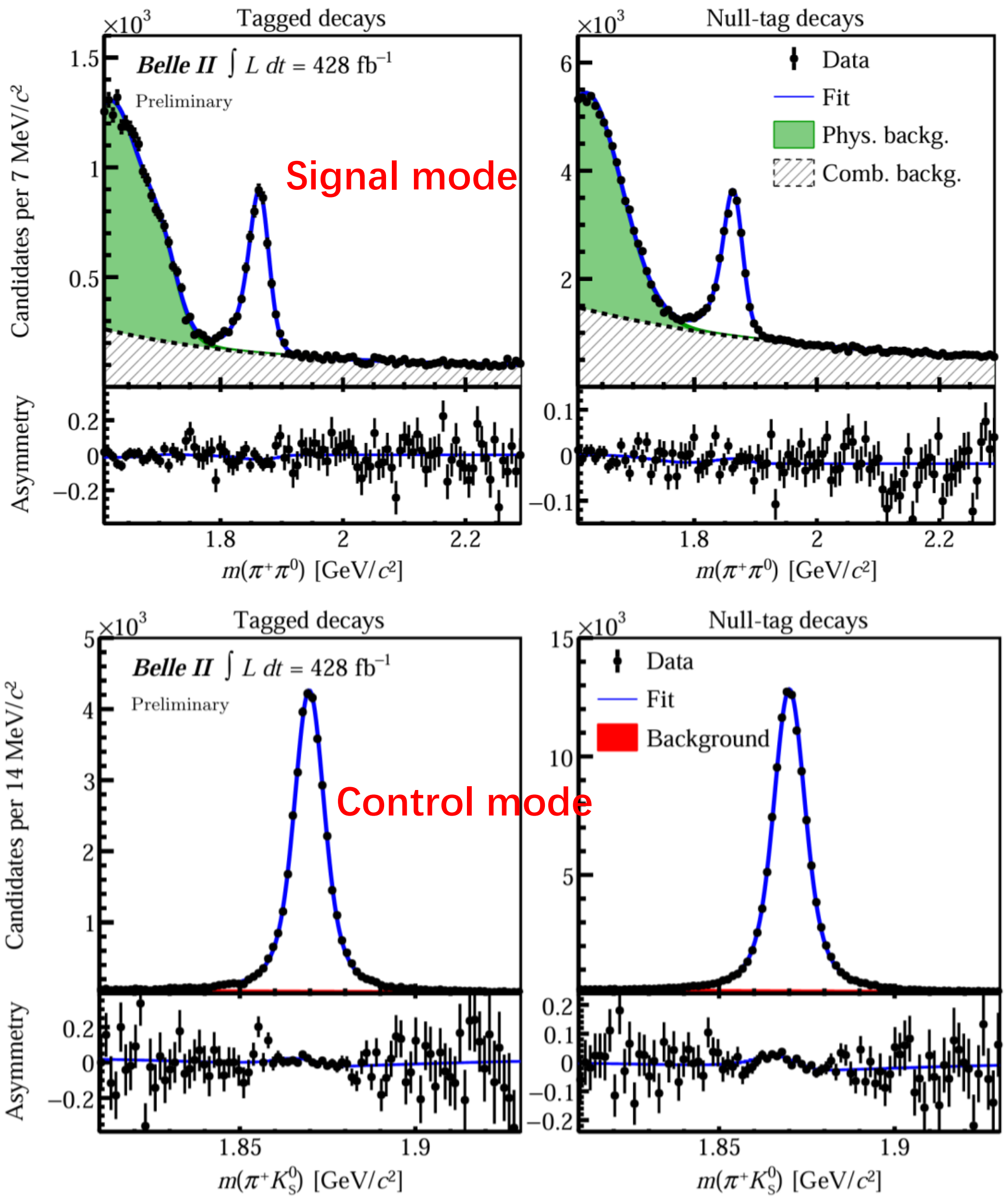
Signal mode

$A_{K_S^0}$: 1, CP-violation in the K^0-$\bar{K}^0$ system.

2, different nuclear-interaction cross-sections for K^0 and $\bar{K}^0$ mesons with detector.

CP asymmetry in $D^+ \to \pi^+\pi^0$

PRD 112, L031101 (2025)



Signal mode

	Tagged	Null-tag
Yield	5130±110	18510±240
A_{raw}	(-2.9±1.8)%	(-0.4±1.0)%

Control mode

	Tagged	Null-tag
Yield	39630±300	123560±500
A_{raw}	(0.54±0.53)%	(0.33±0.30)%

- Using 428 /fb, Belle II obtain:

1. $A_{CP}(D^+ \to \pi^+\pi^0) = [-3.9 \pm 1.8(stat) \pm 0.2(syst)]\,\%$ for D^*-tagged sample;
2. $A_{CP}(D^+ \to \pi^+\pi^0) = [-1.1 \pm 1.0(stat) \pm 0.1(syst)]\,\%$ for null-tag sample.

- Combined:

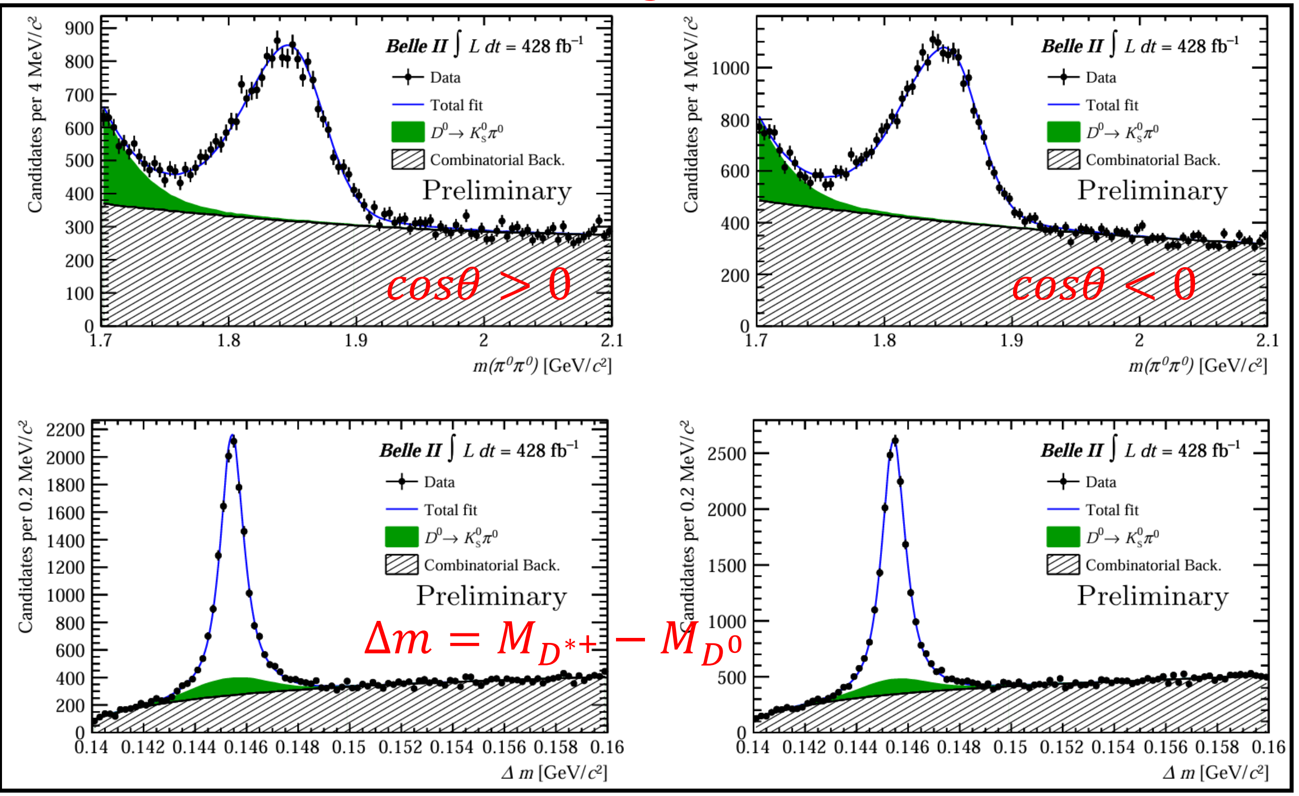
$A_{CP}(D^+ \to \pi^+\pi^0) = [-1.8 \pm 0.9(stat) \pm 0.1(syst)]\,\%$,

  - most precise measurement
  - improved precision compared to Belle's result: $(2.3 \pm 1.3 \pm 0.2)\%$ [*Phys. Rev. D 97, 011101 (2018)*]

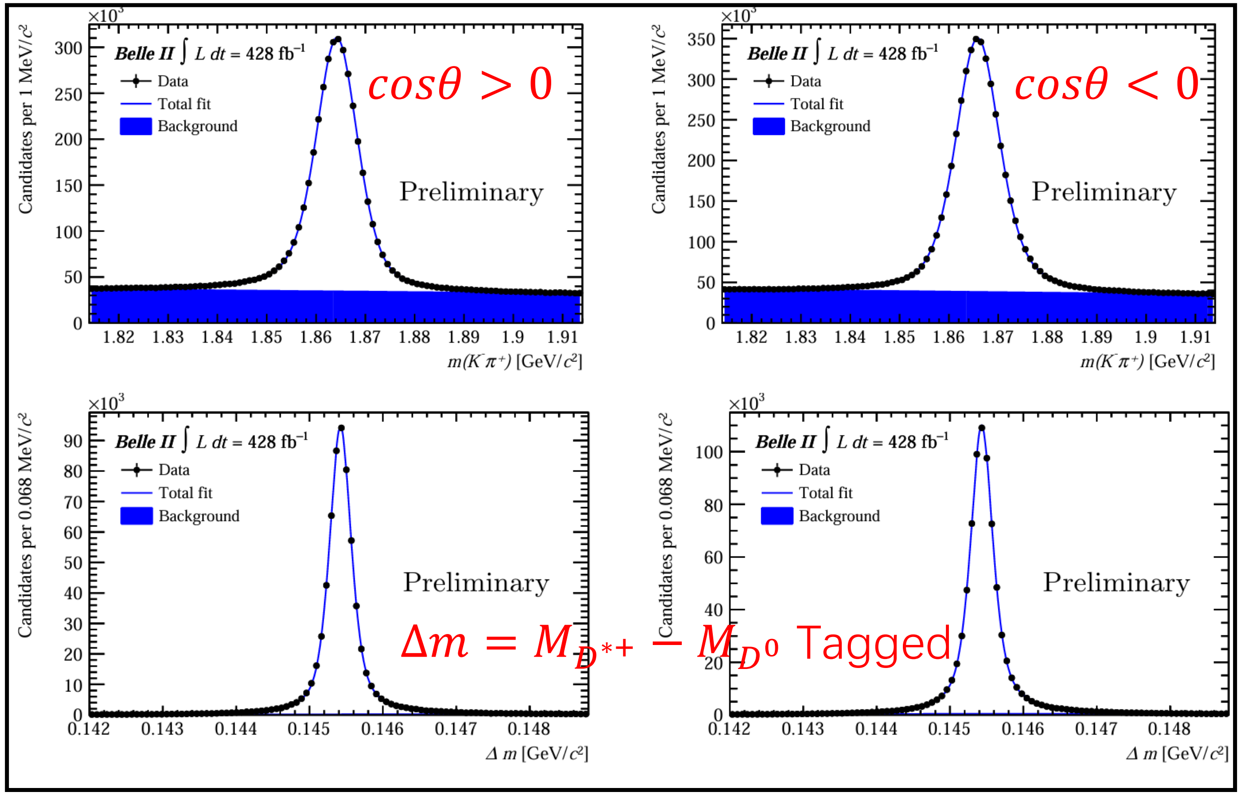
CP asymmetry in $D^0 \to \pi^0\pi^0$

PRD 112, 012006 (2025)

Signal mode



Control mode



- **A_{CP} ($D^0 \to \pi^0\pi^0$): $(0.30 \pm 0.72 \pm 0.20)$ %**
  - 15% less precise than the Belle measurement: $(0.030 \pm 0.64 \pm 0.10)$ % [*Phys. Rev. Lett. 112, 211601 (2014)*]
  - The improved precision per luminosity due to Belle II's better reconstruction π^0 .
- **R= $(1.5 \pm 2.5) \times 10^{-3}$**, 20% improved precision.

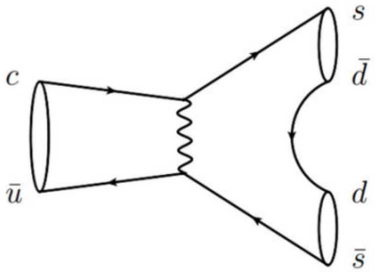
CP asymmetry in $D^0 \to K_S^0 K_S^0$

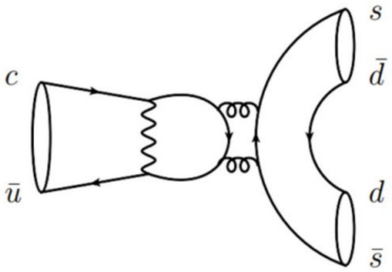
PRD 111, 012015 (2025)
PRD 112, 012017 (2025)

- The CP asymmetry (SCS)

$$A_{CP}(D^0 \to K_S^0 K_S^0) = \frac{\Gamma(D^0 \to K_S^0 K_S^0) - \Gamma(\bar{D}^0 \to K_S^0 K_S^0)}{\Gamma(D^0 \to K_S^0 K_S^0) + \Gamma(\bar{D}^0 \to K_S^0 K_S^0)},$$

- It may be enhanced to be an observable level (~1%) 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

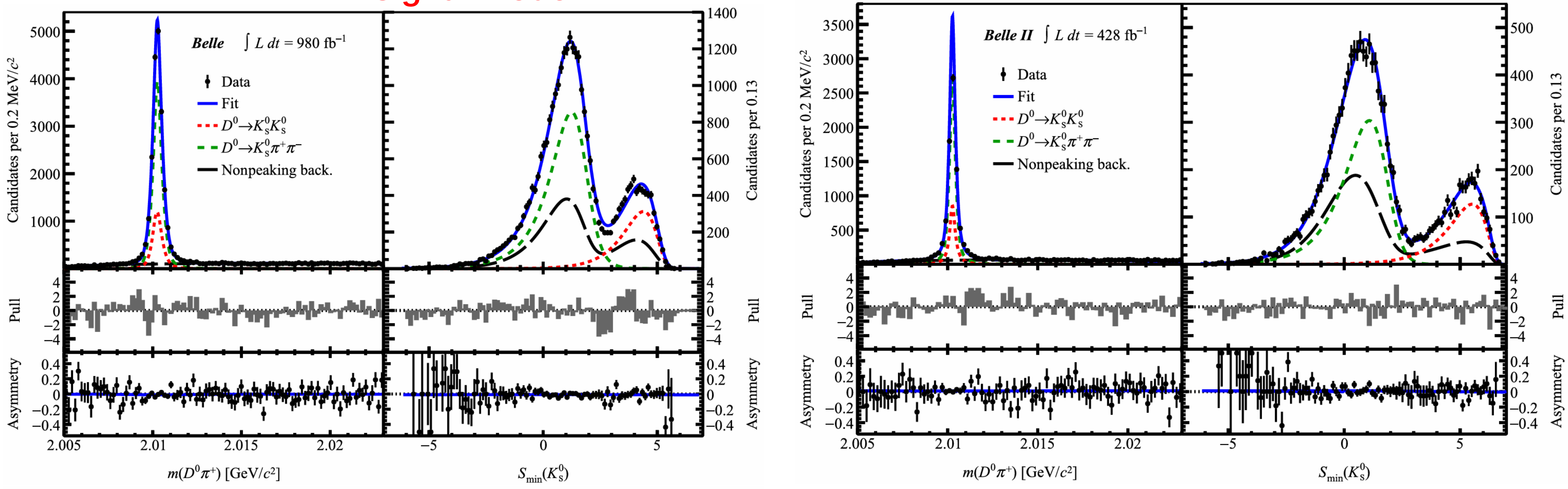
Belle (921 /fb): $A_{CP} = (-0.02 \pm 1.53 \pm 0.02 \pm 0.17)\,\%$, using $D^0 \to K_S^0 \pi^0$ as control mode. PRL 119, 171801 (2017)

LHCb (6 /fb): $A_{CP} = (-3.1 \pm 1.2 \pm 0.4 \pm 0.2)\,\%$, using $D^0 \to K^+ K^-$ as control mode. PRD 104, L031102 (2021)

CP asymmetry in $D^0 \to K_S^0 K_S^0$

PRD 111, 012015 (2025)

Signal mode



- Simultaneous 2D fit to $m(D^0\pi^+)$ and $S_{min}(K_S^0)$.

- Signal and Physics background ($D^0 \to K_S^0\pi^+\pi^-$) peak at the same position in $m(D^0\pi^+)$ but different in $S_{min}(K_S^0)$.

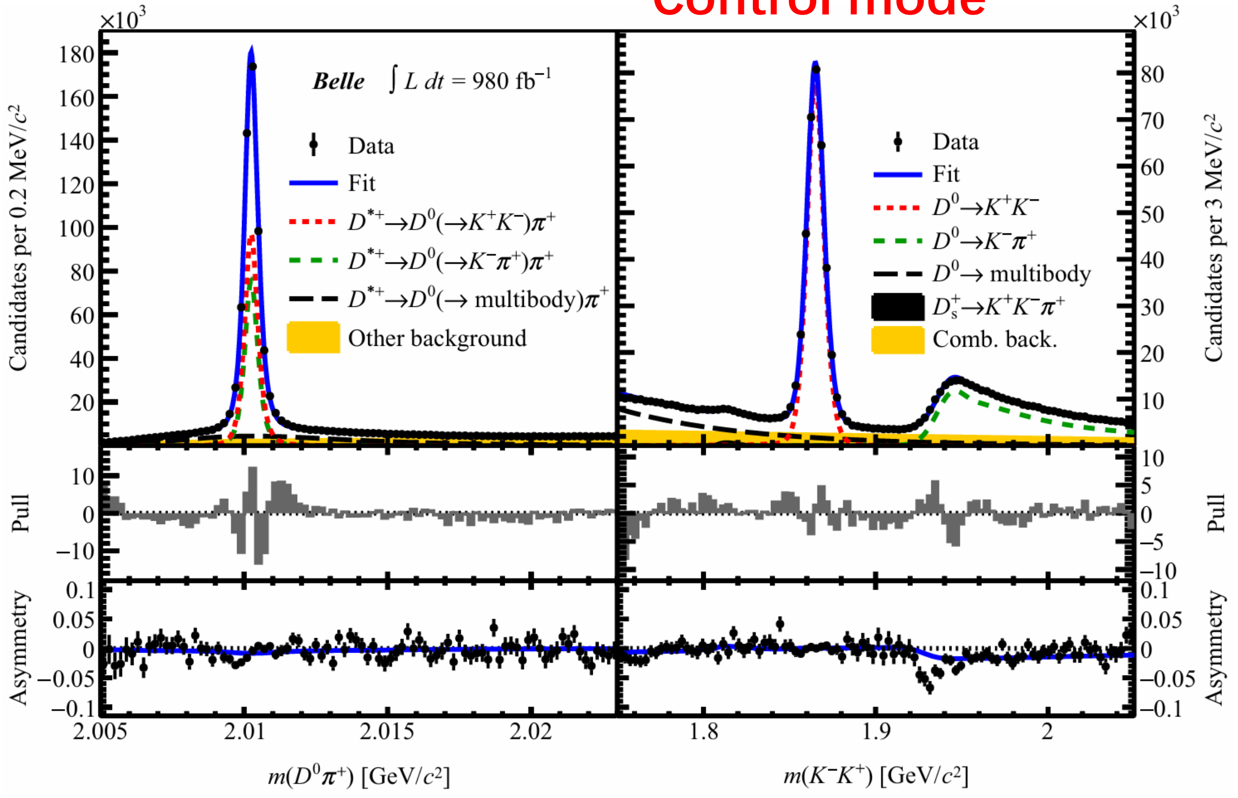
Using D^* tag method

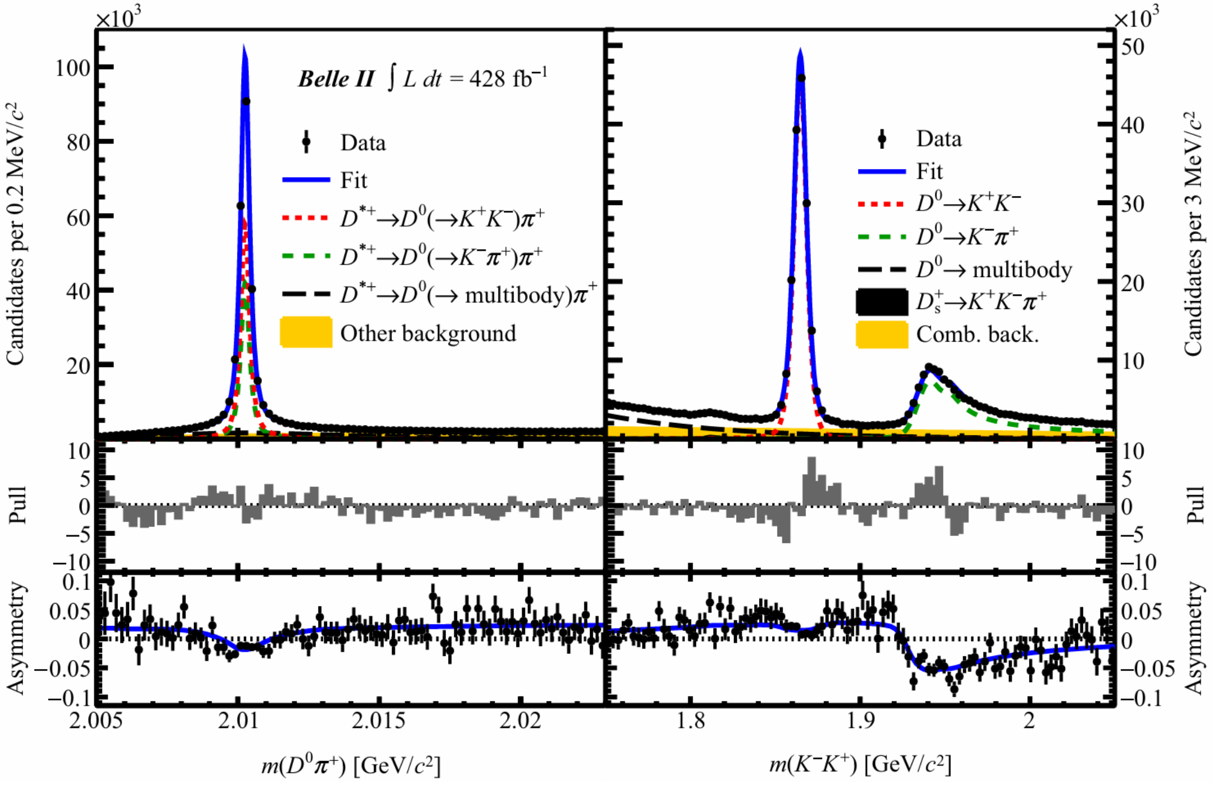
$$A_{raw}^{K_S^0K_S^0} = (-1.0 \pm 1.6)\,\% \text{ in Belle; } A_{raw}^{K_S^0K_S^0} = (-0.6 \pm 2.3)\,\% \text{ in Belle II.}$$

CP asymmetry in $D^0 \to K_S^0 K_S^0$

PRD 111, 012015 (2025)

Control mode





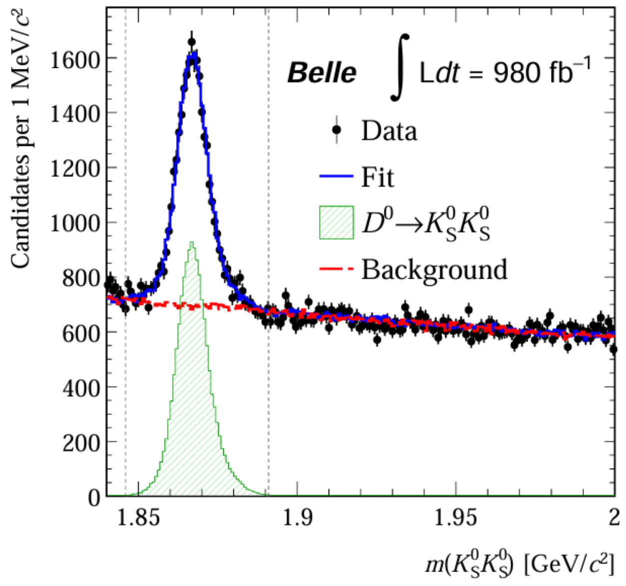
$A_{raw}^{K^+K^-} = (0.17 \pm 0.19)\,\%$ in Belle; $A_{raw}^{K^+K^-} = (1.61 \pm 0.27)\,\%$ in Belle II.

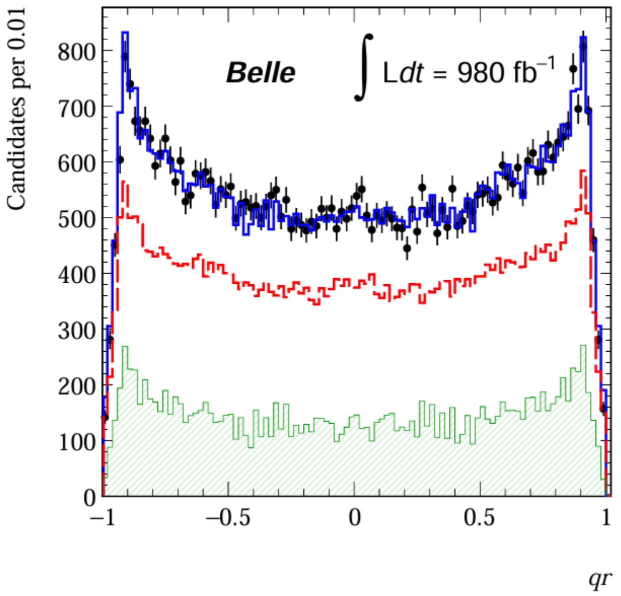
- Combined Belle and Belle II (1.4 /ab), $A_{CP}(D^0 \to K_S^0 K_S^0) = (-1.4 \pm 1.3 \pm 0.1)\,\%$, comparable to the best existing measurement (LHCb).
  - Factor of two smaller systematic uncertainty as compared to Belle result: (-0.02± 1.53 ± 0.02±0.17) % [*Phys. Rev. Lett. 119, 171801 (2017)*]
  - Comparable with world's best measurement by LHCb: (-3.1± 1.2 ± 0.4±0.2) % [*Phys. Rev. D 104, L031102 (2021)*].

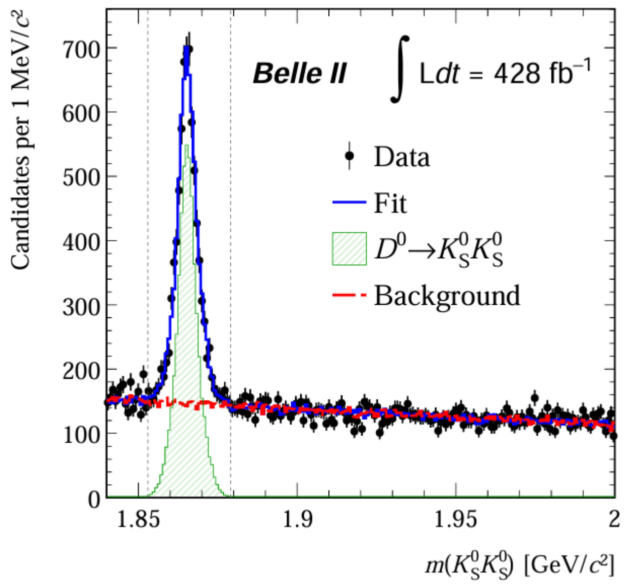
CP asymmetry in $D^0 \to K_S^0 K_S^0$

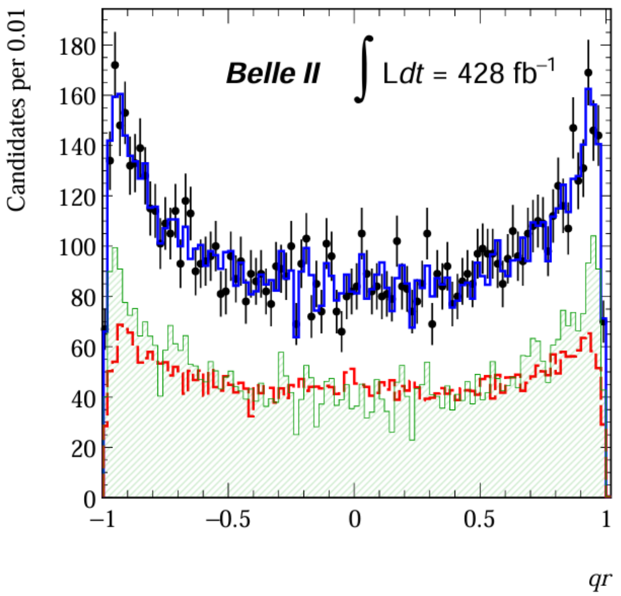
PRD 112, 012017 (2025)

Using charm flavor tagger









- Events used in the previous analysis are removed.
- $D^0 \to K_S \pi^+ \pi^-$ suppressed using $S_{min}(K_S)$.

Combine Belle and Belle II:

$$A_{CP}(D^0 \to K_S^0 K_S^0) = (1.3 \pm 2.0 \pm 0.3)\%$$

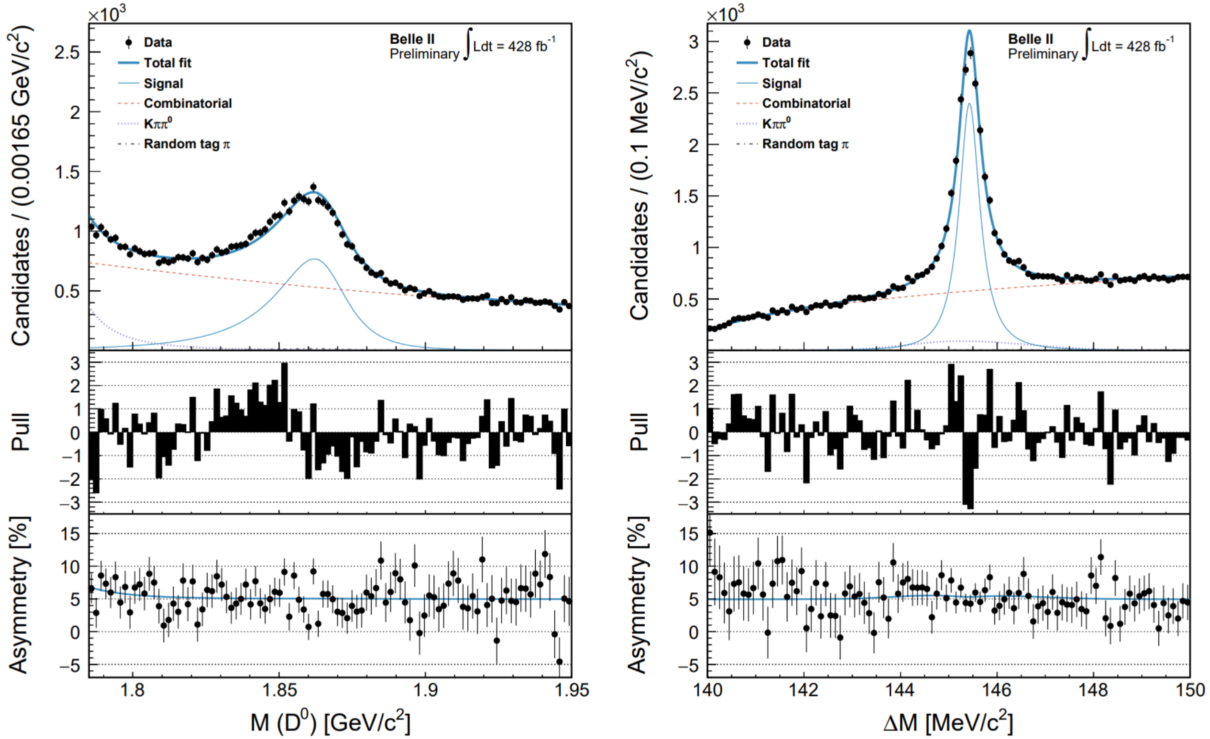
Method	A_{CP} [%]
D^*-tag	-1.4 ± 1.3 ± 0.1
CFT-tag	1.3 ± 2.0 ± 0.3
Combination	**-0.6 ± 1.1 ± 0.1**

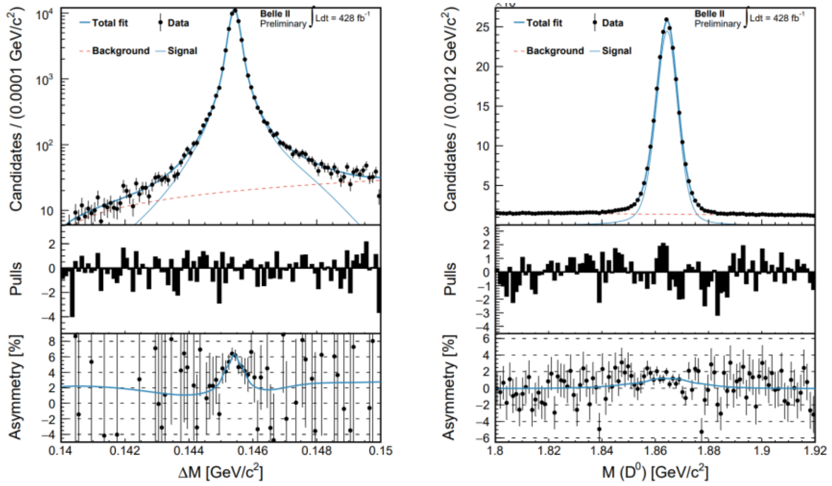
- Most precise determination till date.

CP asymmetry in $D^0 \to \pi^+\pi^-\pi^0$

Preliminary result

- SCS three-body decay, interference of several amplitude
- Signal: D^{*+} tagged sample for $D^0 \to \pi^+\pi^-\pi^0$.
- Control mode: tagged and untagged $D^0 \to K^-\pi^+$
- Simultaneous fit to (Δm, $m(\pi^+\pi^-\pi^0)$) in 8 bins of $\cos\theta_{CM}$, averaged symmetrically around 0 to remove the production asymmetry
- **A_{CP} ($D^0 \to \pi^+\pi^-\pi^0$): (0.29 ± 0.27 ± 0.13) %**
    - Most precise measurement till date
    - 34% more precise than BABAR with just 10% more statistics





CP asymmetry in $\Xi_c^+ \to \Sigma^+ h^+ h^-$ and $\Lambda_c^+ \to p h^+ h^-$

Preliminary result

First measurement of A_{CP} in SCS three-body charm baryon decays.

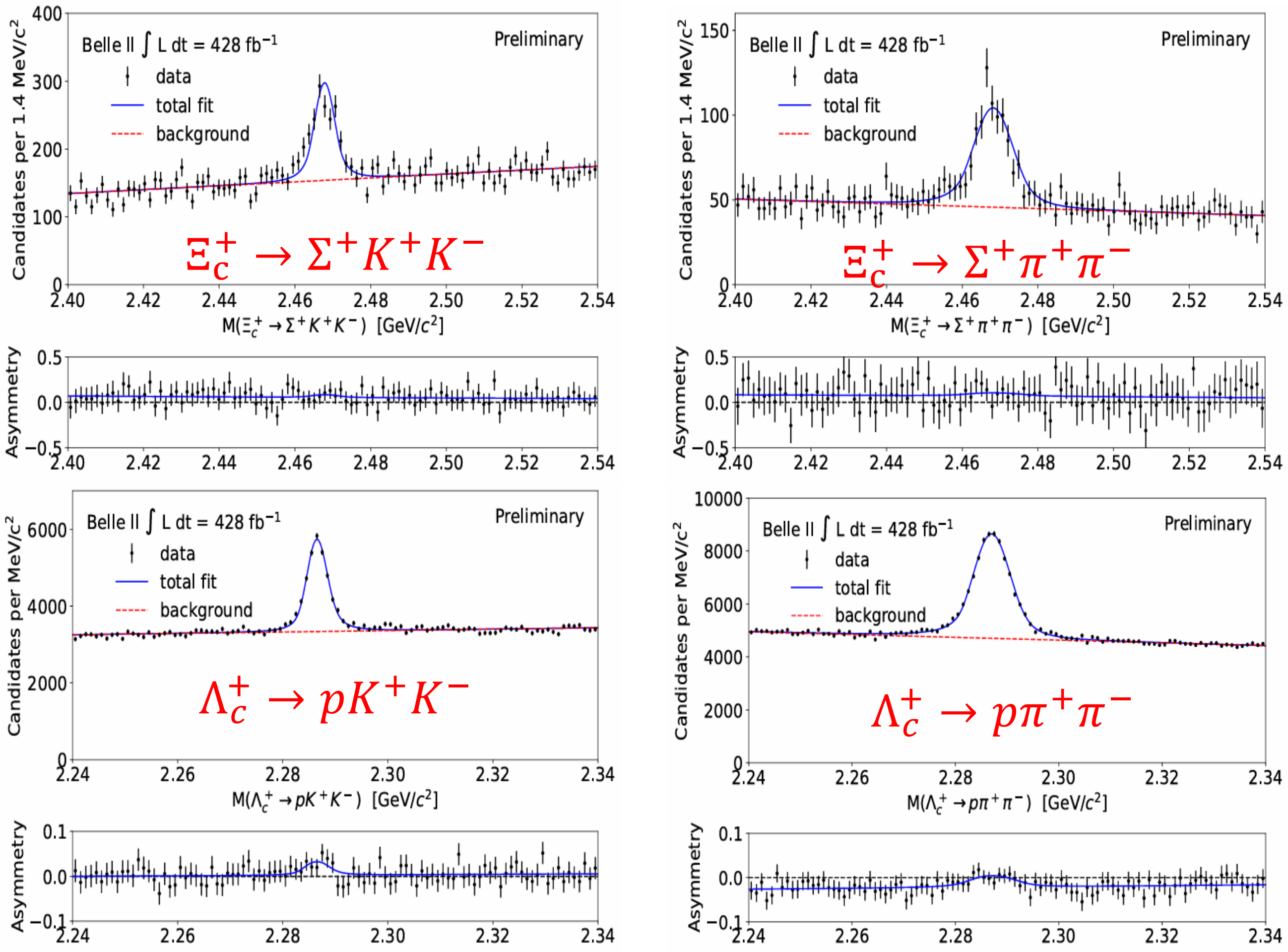
$$A_{CP}(X_c^+ \to f^+) \equiv \frac{\Gamma(X_c^+ \to f^+) - \Gamma(\bar{X}_c^- \to \bar{f}^-)}{\Gamma(X_c^+ \to f^+) + \Gamma(\bar{X}_c^- \to \bar{f}^-)}.$$

Measured A_{CP}:

$$A_{CP}(\Xi_c^+ \to \Sigma^+ K^+ K^-) = (3.7 \pm 6.6 \pm 0.6)\%,$$
$$A_{CP}(\Xi_c^+ \to \Sigma^+ \pi^+ \pi^-) = (9.5 \pm 6.8 \pm 0.5)\%,$$
$$A_{CP}(\Lambda_c^+ \to p K^+ K^-) = (3.9 \pm 1.7 \pm 0.7)\%,$$
$$A_{CP}(\Lambda_c^+ \to p \pi^+ \pi^-) = (0.3 \pm 1.0 \pm 0.2)\%,$$

U-spin symmetry with 7% precision:

$$A_{CP}(\Xi_c^+ \to \Sigma^+ \pi^+ \pi^-) + A_{CP}(\Lambda_c^+ \to p K^+ K^-) = (13.4 \pm 7.0 \pm 0.9)\%,$$
$$A_{CP}(\Xi_c^+ \to \Sigma^+ K^+ K^-) + A_{CP}(\Lambda_c^+ \to p \pi^+ \pi^-) = (4.0 \pm 6.6 \pm 0.7)\%,$$



- Their uncertainties are mainly statistical.
- Future measurements using more data collected by will be important for CP violation and testing U spin.

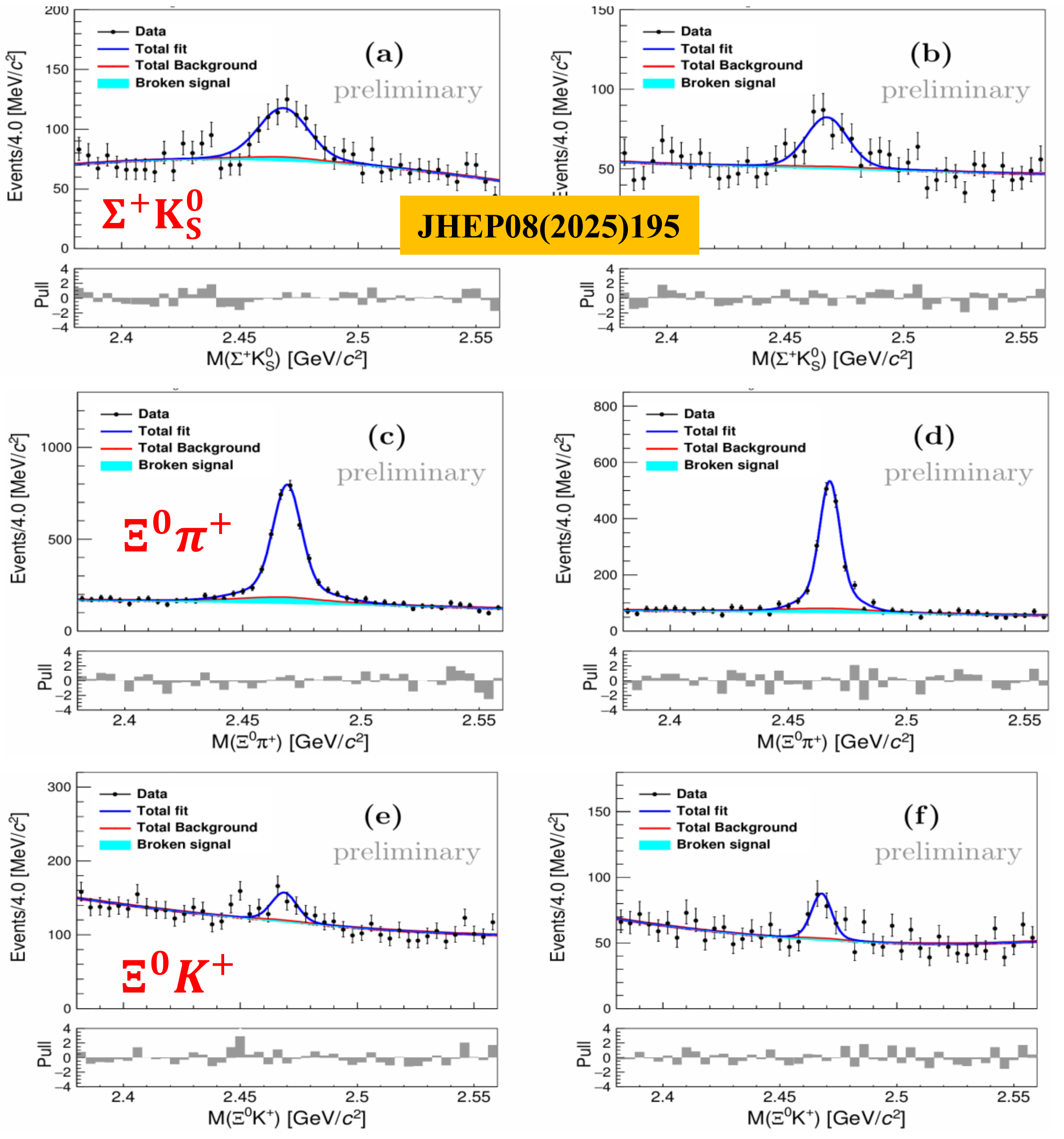
Summary of CPV in charm

Channel	A_{CP}	References
$D^0 \to \pi^0\pi^0$	$(+0.3\pm0.7\pm0.2)\%$	PRD 112, 012006 (2025)
$D^+ \to \pi^+\pi^0$	$(-1.8\pm0.9\pm0.1)\%$	PRD 112, L031101 (2025)
$D^0 \to \pi^+\pi^-\pi^0$	$(0.3\pm0.3\pm0.1)\%$	Preliminary result
$D^0 \to K_S^0K_S^0$	$(-0.6\pm1.1\pm0.1)\%$	PRD 111, 012015 (2025), PRD 112, 012017 (2025)
$D^+, D_s^+ \to K_S^0K^-\pi^+\pi^+$	$(+3.9\pm4.5\pm1.1)\%$, $(-0.2\pm2.5\pm1.1)\%$	JHEP 04 (2025) 036
$\Lambda_c^+ \to \Lambda K^+$, $\Sigma^0 K^+$	$(+2.1\pm2.6\pm0.1)\%$, $(+2.5\pm5.4\pm0.4)\%$	Sci. Bull. 68 (2023) 583
$\Lambda_c^+ \to pK^+K^-$, $p\pi^+\pi^-$	$(+3.9\pm1.7\pm0.7)\%$, $(+0.3\pm1.0\pm0.2)\%$	Preliminary result
$\Xi_c^+ \to \Sigma^+K^+K^-$, $\Sigma^+\pi^+\pi^-$	$(+3.7\pm6.6\pm0.6)\%$, $(+9.5\pm6.8\pm0.5)\%$	Preliminary result

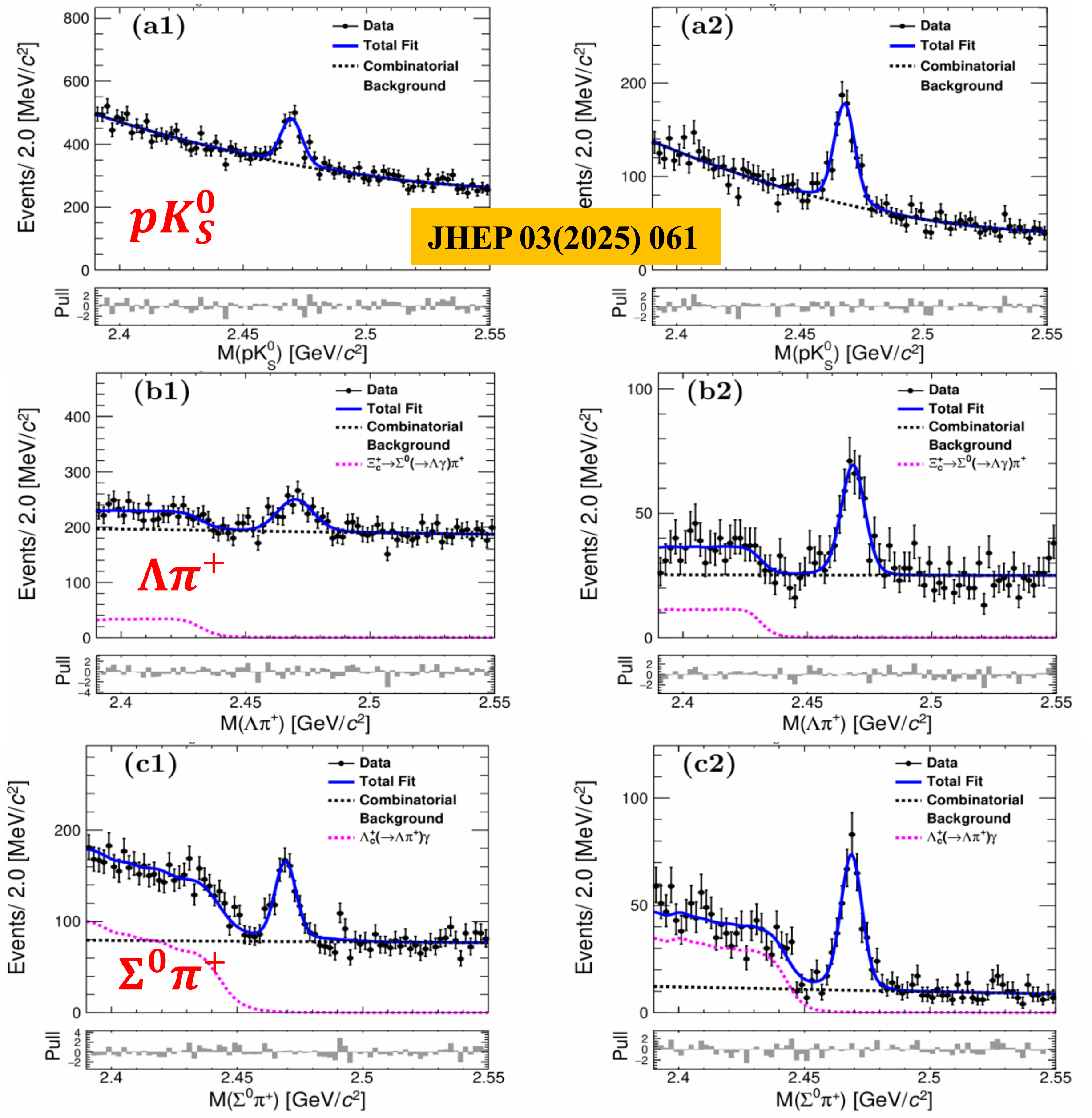
2025 Published and to be published!

Charm baryon decays

$\Xi_c^+ \to \Sigma^+ K_S^0, \Xi^0\pi^+, \Xi^0 K^+, pK_S^0, \Lambda\pi^+, \Sigma^0\pi^+$



JHEP08(2025)195

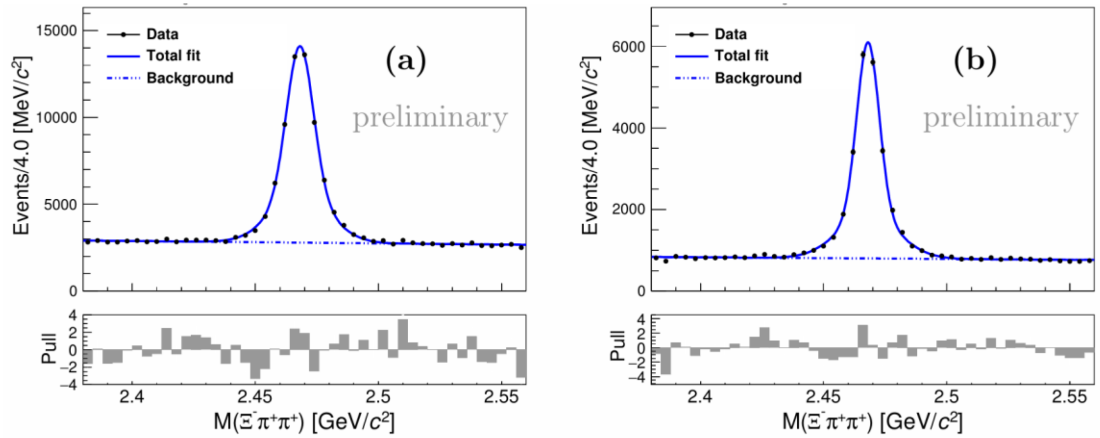


JHEP 03(2025) 061

$\Xi_c^+ \to \Sigma^+ K_S^0, \Xi^0\pi^+, \Xi^0 K^+, pK_S^0, \Lambda\pi^+, \Sigma^0\pi^+$

Ratio of BF between signal and reference mode: $\frac{B_{sig}}{B_{ref}} = \frac{y_{sig} \times B'_{sig}}{y_{ref} \times B'_{ref}}$

JHEP08(2025)195



$$\mathcal{B}(\Xi_c^+ \to \Sigma^+ K_S^0) = (0.194 \pm 0.021 \pm 0.009 \pm 0.087)\%,$$
$$\mathcal{B}(\Xi_c^+ \to \Xi^0 \pi^+) = (0.719 \pm 0.014 \pm 0.024 \pm 0.322)\%,$$
$$\mathcal{B}(\Xi_c^+ \to \Xi^0 K^+) = (0.049 \pm 0.007 \pm 0.002 \pm 0.022)\%,$$

Improved precision

For the first time

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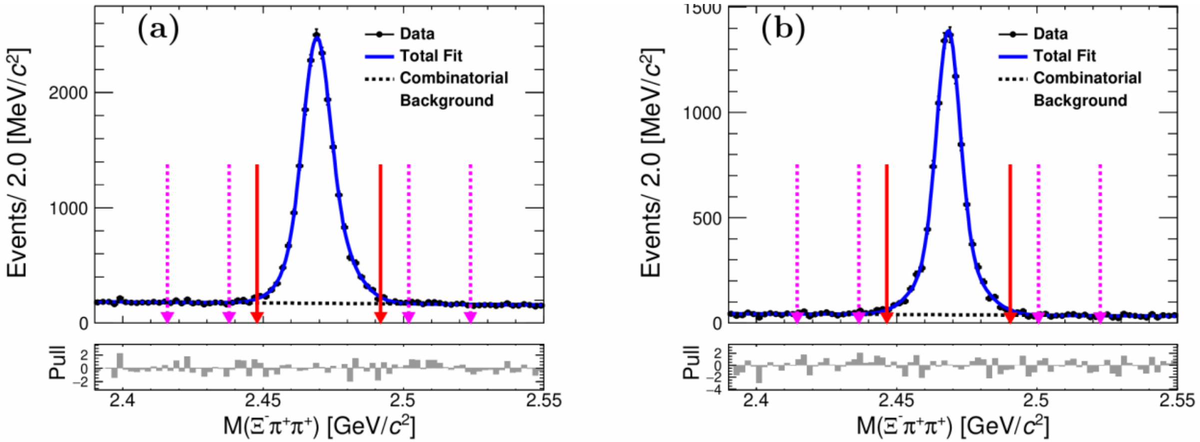


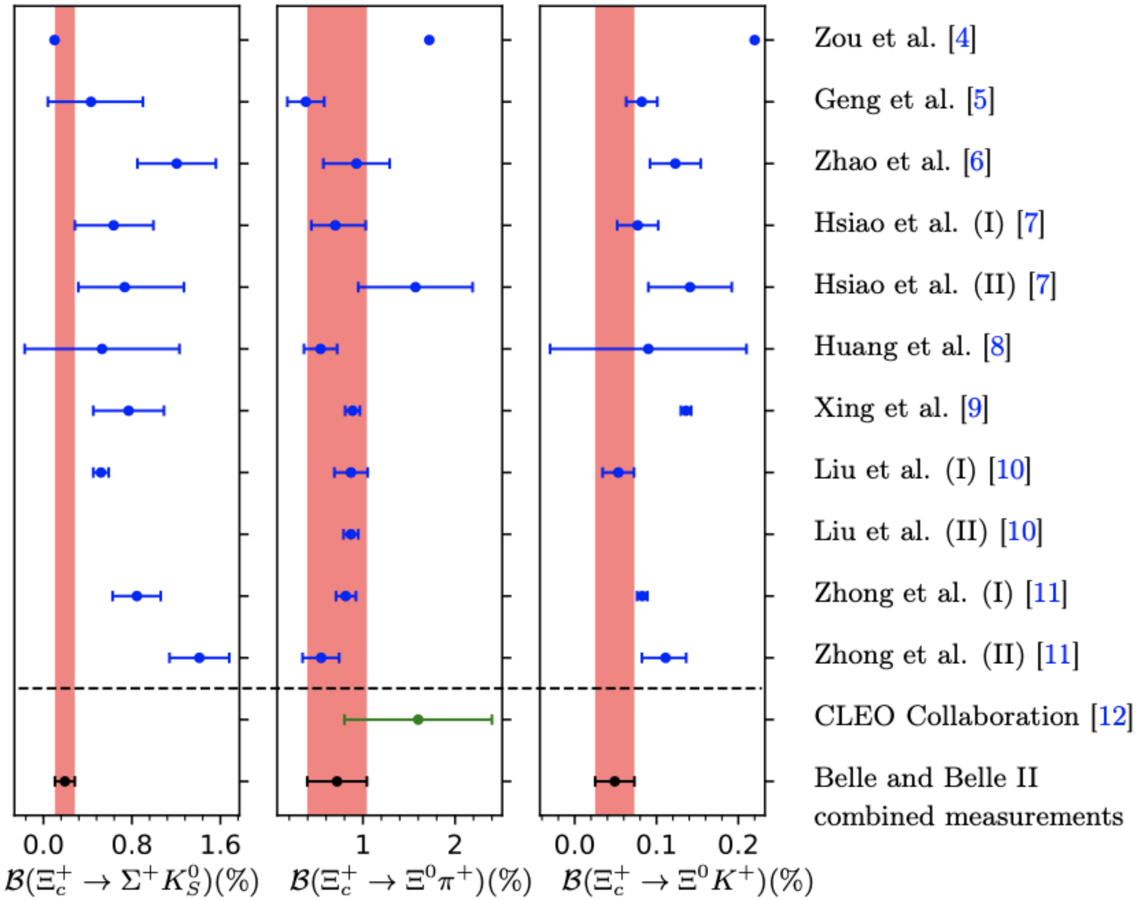
$$\mathcal{B}(\Xi_c^+ \to pK_S^0) = (7.16 \pm 0.46 \pm 0.20 \pm 3.21) \times 10^{-4},$$
$$\mathcal{B}(\Xi_c^+ \to \Lambda\pi^+) = (4.52 \pm 0.41 \pm 0.26 \pm 2.03) \times 10^{-4},$$
$$\mathcal{B}(\Xi_c^+ \to \Sigma^0\pi^+) = (1.20 \pm 0.08 \pm 0.07 \pm 0.54) \times 10^{-3},$$

For the first time

$\Xi_c^+ \to \Sigma^+ K_S^0, \Xi^0\pi^+, \Xi^0 K^+, pK_S^0, \Lambda\pi^+, \Sigma^0\pi^+$

First or most precise measurements! Consistent with different predictions.

JHEP08(2025)195



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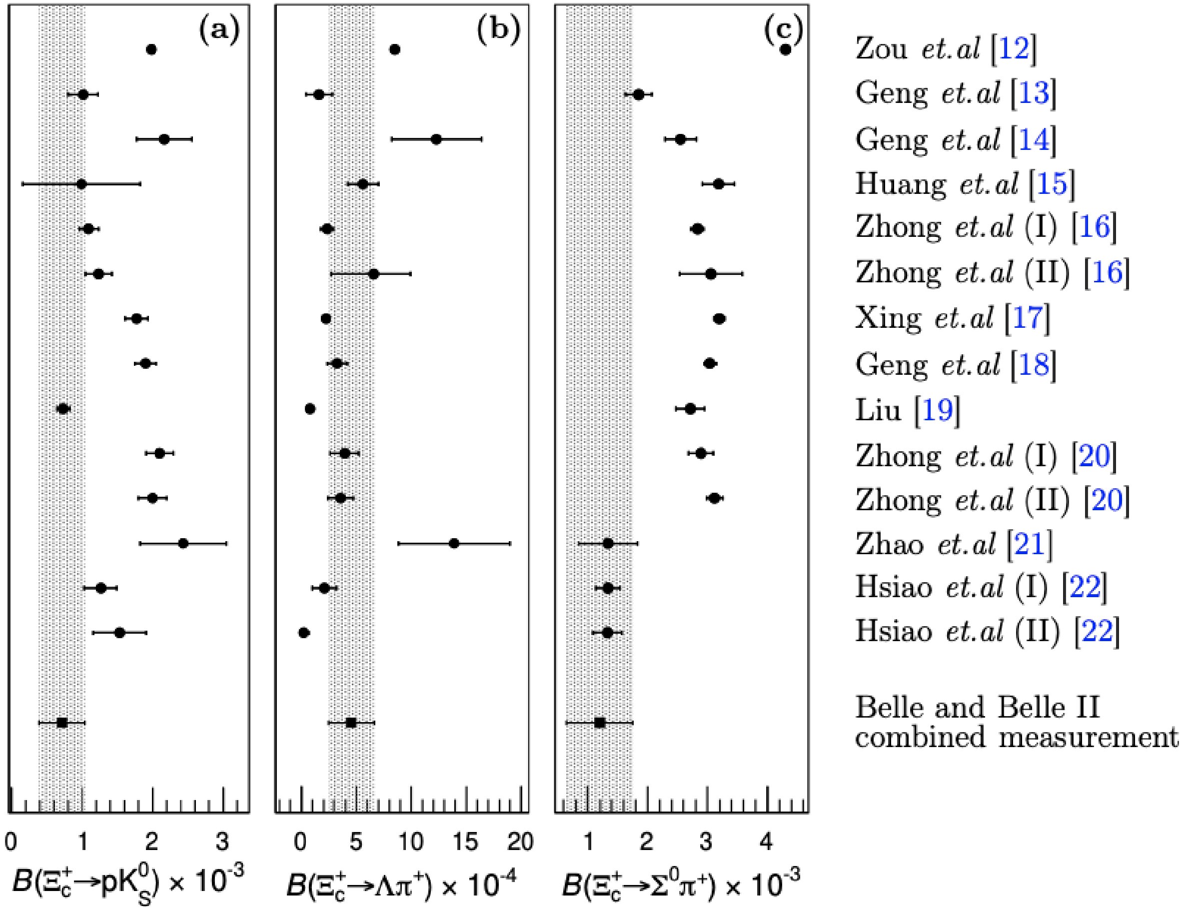
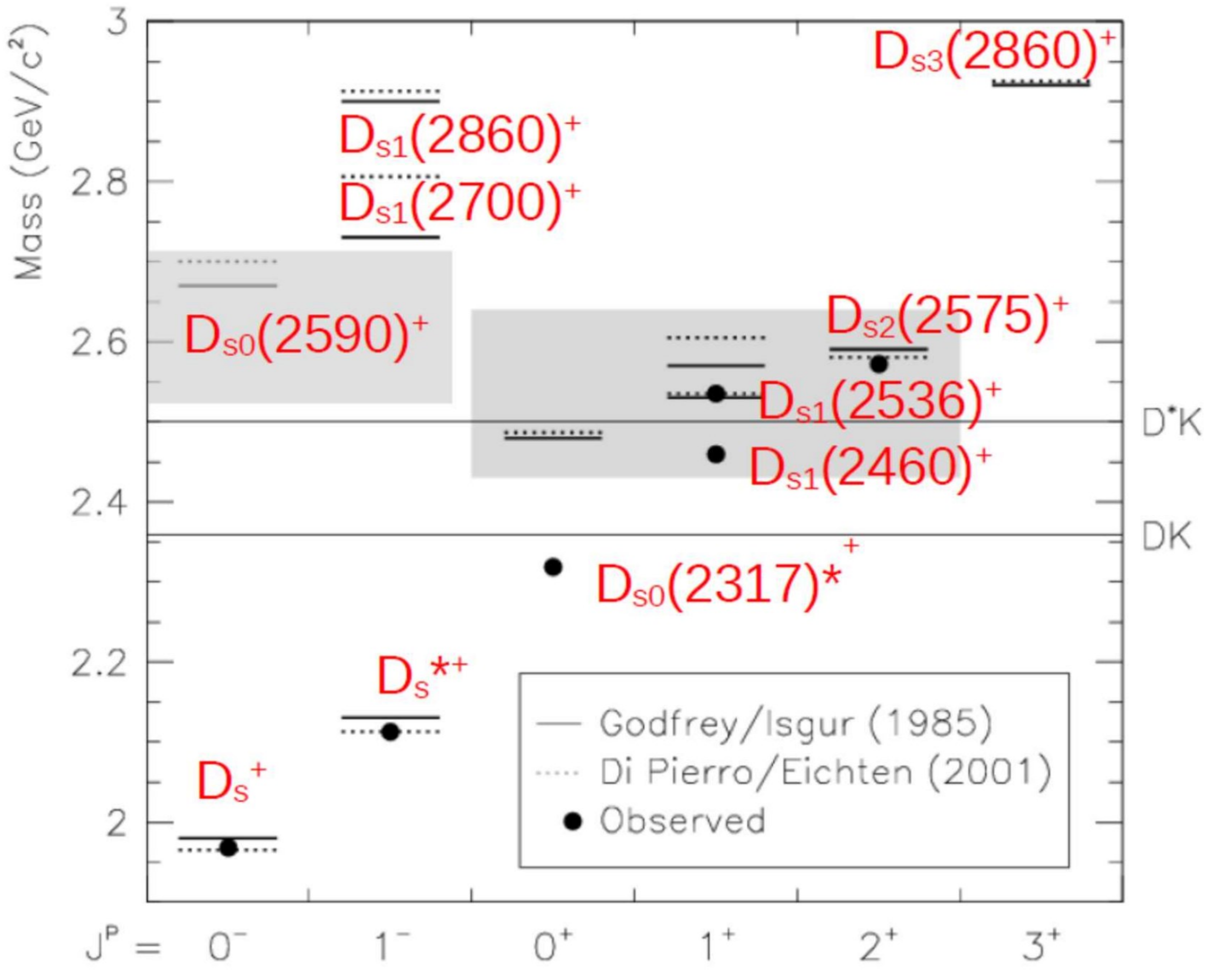


Spectroscopy

First observation of $D_{s0}^*(2317)^+ \to D_s^{*+}\gamma$

Preliminary result

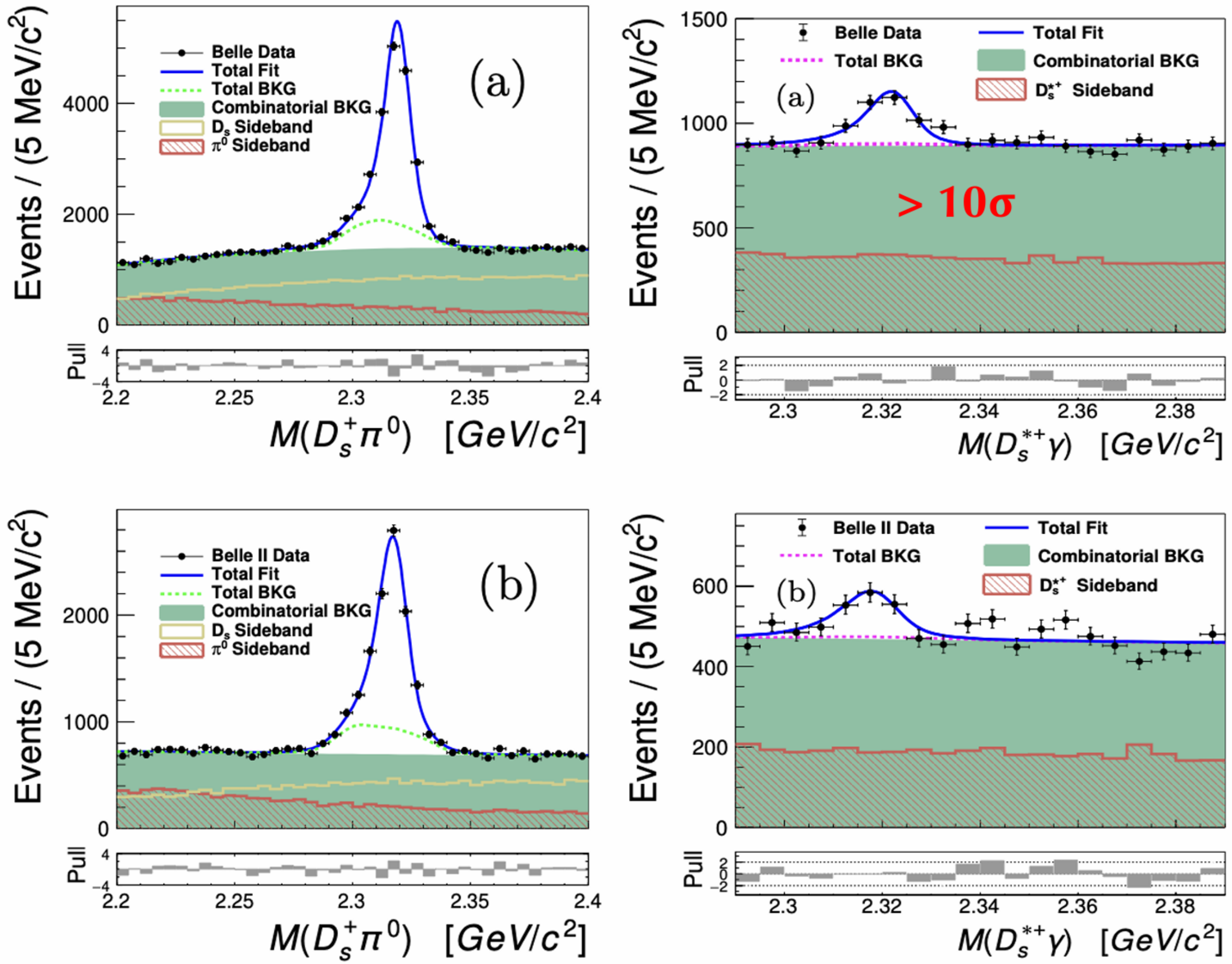


- $D_{s0}^*(2317)$ draws s significant attention as its mass significantly lower than expectation
- Its radiative transition will provide a direct experimental constraint on various theoretical models.

First observation of $D_{s0}^*(2317)^+ \to D_s^{*+}\gamma$

Preliminary result

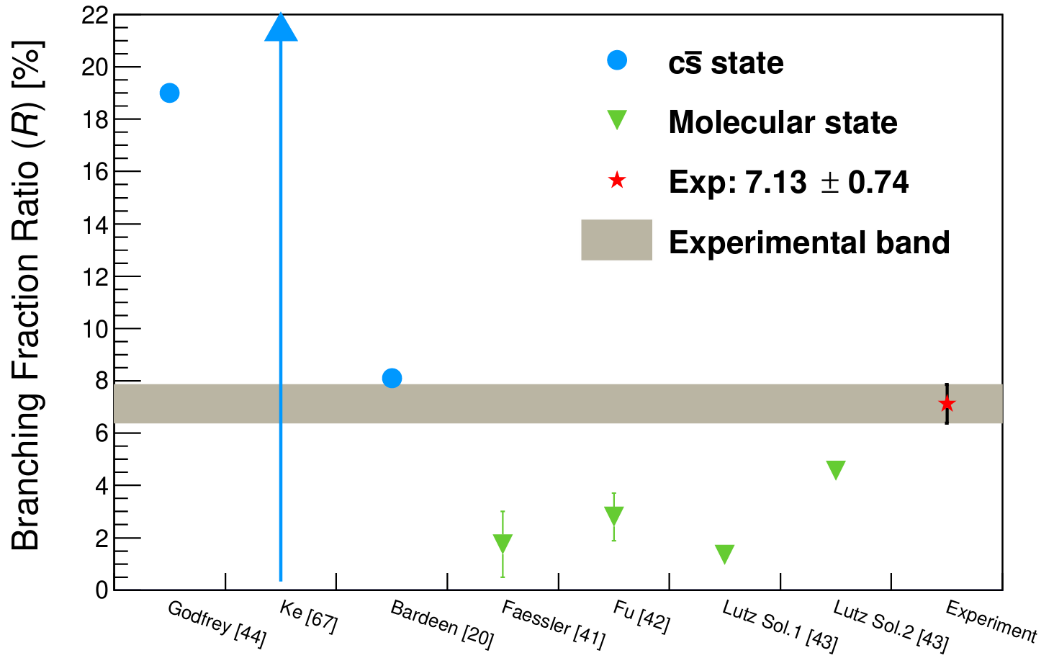
- **Target: $D_{s0}^*(2317)^+ \to D_s^{*+}\gamma$**
- **Control channel: $D_{s0}^*(2317)^+ \to D_s^+\pi^0$ (Br = $(100^{+0}_{-20})\%$)**



Partial decay widths:
unique in discriminating between various models

$$\mathcal{R} = \frac{\mathcal{B}(D_{s0}^*(2317)^+ \to D_s^{*+}\gamma)}{\mathcal{B}(D_{s0}^*(2317)^+ \to D_s^+\pi^0)}$$

$$= [7.14 \pm 0.70(\text{stat.}) \pm 0.23(\text{syst.})]\%$$



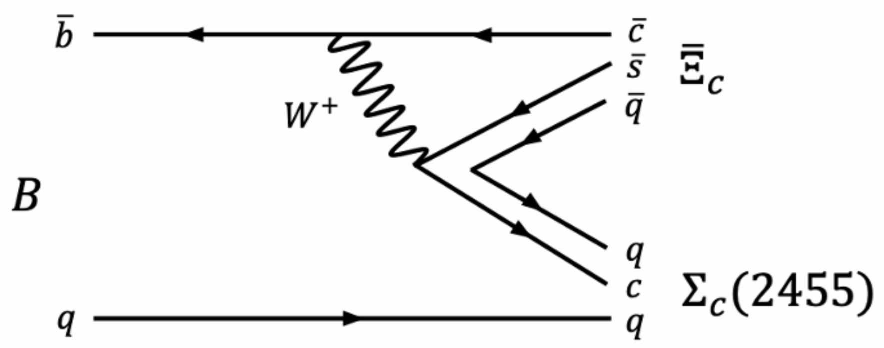
$D_{s0}(2317)^+$ could be the mixture state of pure $c\bar{s}$ state and molecular state.

BF of $B^{+,0} \to \Sigma_c(2455)^{++,0}\bar{\Xi}_c^{-,0}$

PRD 112 L051101 (2025)

- BF predicted to be 4×10^{-3} (sum rule) [NPB 345, 137 (1990)] or of the order 10^{-4} (di-quark model) [ZPC 51, 445 (1991)].

These two decays proceed through a purely internal W-emission:



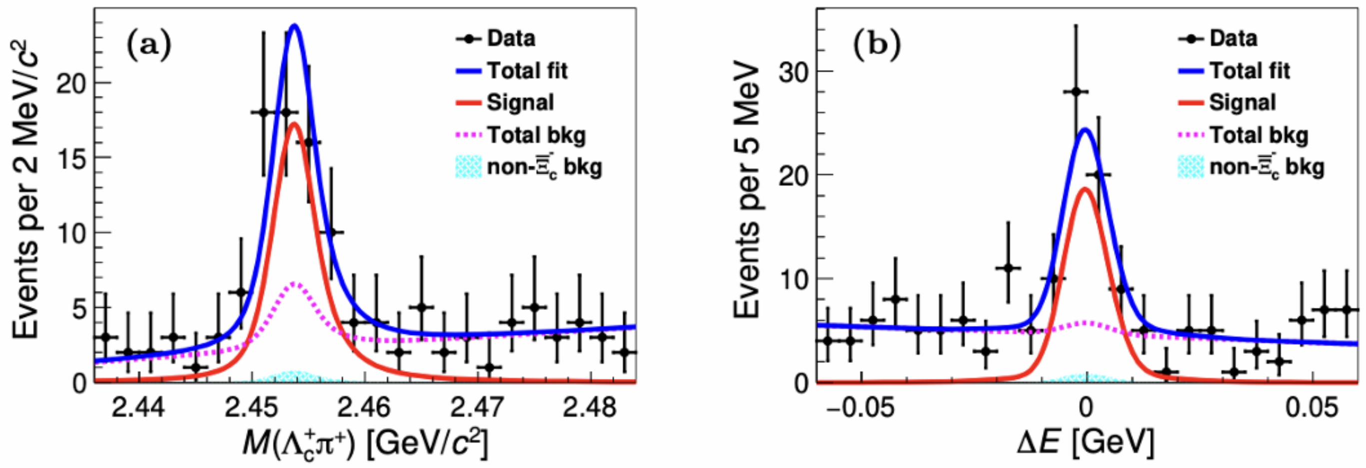
To date, no B decays into charmed baryon pairs containing both a sextet and an antitriplet have been observed.

$$\mathcal{B}(B^+ \to \Sigma_c^{++}\bar{\Xi}_c^-) = (5.74 \pm 1.11 \pm 0.42^{+2.47}_{-1.53}) \times 10^{-4}$$

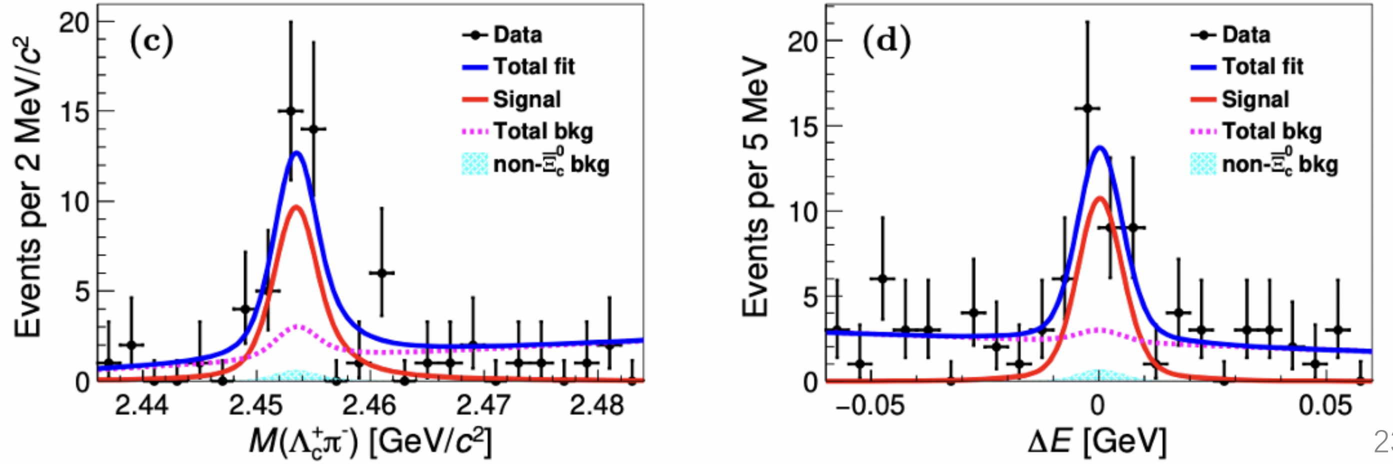
$$\mathcal{B}(B^0 \to \Sigma_c^{0}\bar{\Xi}_c^0) = (4.83 \pm 1.12 \pm 0.37^{+0.72}_{-0.60}) \times 10^{-4}$$

First observations!

$B^+ \to \Sigma_c^{++}\bar{\Xi}_c^-$



$B^0 \to \Sigma_c^{0}\bar{\Xi}_c^0$



Summary

- Belle II collected 575 fb^{-1} of data + Belle 1 $ab^{-1} \approx 1.5\ ab^{-1}$
- Presented recent measurements of CP asymmetries in charm:
  - Consistent with CP symmetries.
  - Most precise measurement of $A_{CP}(D^0 \to K_S^0 K_S^0)$ and $A_{CP}(D^0 \to \pi^+\pi^-\pi^0)$
  - First measurement of A_{CP} in SCS three-body charm baryon decays
- Presented BF measurement of charmed baryons and study of the $D_{s0}^*(2317)$
- First observation of B meson decay to a sixtet and an antitriplet charmed baryon pair.
- Belle II resumes operations in November. Stay tuned for more results!!

Thanks for your attention!

Backup

Comparison of available charm samples

Experiment	Machine	C.M.	Luminosity	N_{prod}	Efficiency	Characters
BESIII	BEPC-II (e^+e^-)	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 ★☆	★★★	☺ extremely clean environment ☺ quantum coherence ☹ no boost, no time-dept analysis
Belle II	SuperKEKB (e^+e^-)	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 $(\to 10^9)$		☺ high-efficiency detection of neutrals ☺ good trigger efficiency ☺ time-dependent analysis ☹ smaller cross-section than LHCb
BELLE	KEKB (e^+e^-)	10.58 GeV	1 ab^{-1}	$D^{0,+}, D_s^+$: 10^9 Λ_c^+: 10^8 ★★☆	$\mathcal{O}$(1-10%) ★★	
LHCb	LHC (pp)	7+8 TeV 13 TeV	1+2 fb^{-1} 6 fb^{-1} (→ 23 → 50) fb^{-1}	5×10^{12} 10^{13} ★★★★	★	☺ very large production cross-section ☺ large boost, excellent time resolution ☹ dedicated trigger required

Here uses $\sigma(D^0\bar{D}^0@3.77\,\text{GeV})$=3.61 nb, $\sigma(D^+D^-@3.77\,\text{GeV})$=2.88 nb, $\sigma(D_s^*D_s@4.17\,\text{GeV})$=0.967 nb; $\sigma(c\bar{c}@10.58\,\text{GeV})$=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.
- They all are continuously collecting more datasets with increased luminosity in the foreseeable future.

CP asymmetry in $D^+ \to \pi^+\pi^0$

PRD 112, L031101 (2025)

- A 3.8σ CPV in the pionic mode $D^0 \to \pi^+\pi^-$.
  - Unclear if observed CP violation can be described by the SM or not, due to large hadronic uncertainties

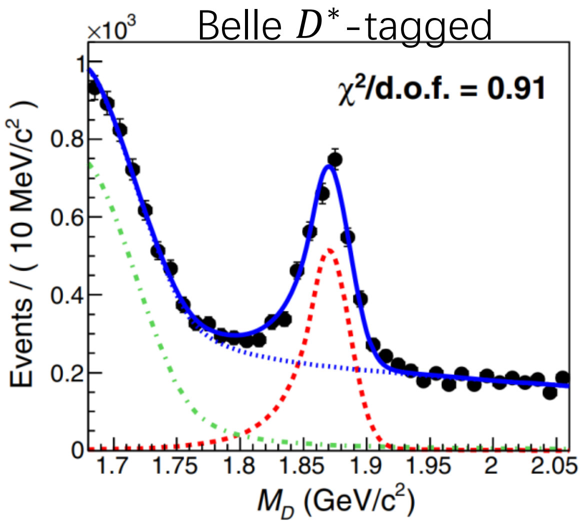
PRL 131, 051802 (2023) PRD 108, 036026 (2023) PRD 109, 033011 (2024)

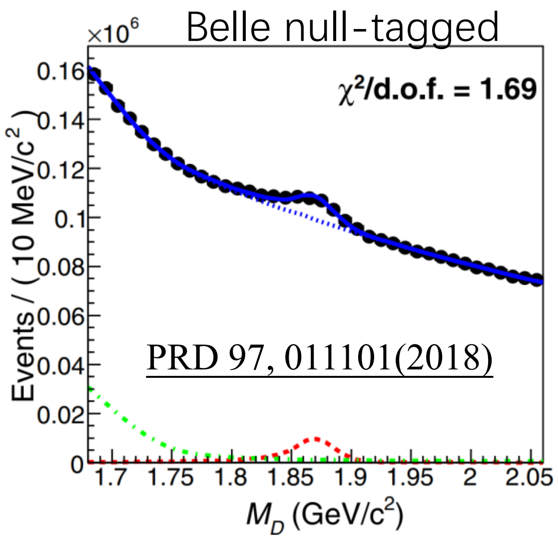
- Isospin-related modes $D^+ \to \pi^+\pi^0$ can reduce hadronic uncertainty.
- In addition, $D^+ \to \pi^+\pi^0$ $(I = 2)$ is expected to have no CPV in SM
  - since it does not receive QCD penguin $(\Delta I = 1/2)$ contribution and has suppressed electroweak penguin contribution.

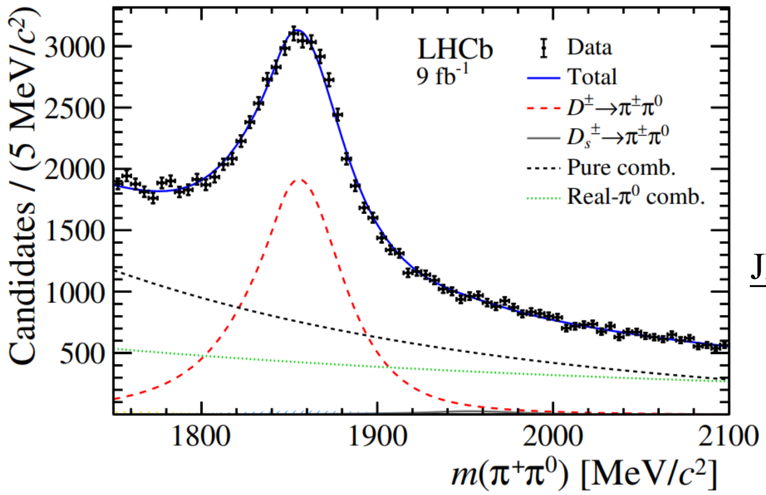
History of $A_{cp}(D^+ \to \pi^+\pi^0)$:

Belle: $A_{cp}(D^+ \to \pi^+\pi^0) = (2.31 \pm 1.24 \pm 0.23)\%$

LHCb: $A_{cp}(D^+ \to \pi^+\pi^0) = (-1.3 \pm 0.9 \pm 0.6)\%$





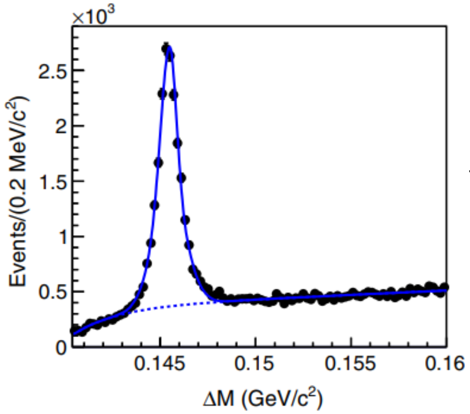


JHEP 06, 019 (2021)

CP asymmetry in $D^0 \to \pi^0\pi^0$

PRD 112, 012006 (2025)

- Belle reported $A_{CP}(D^0 \to \pi^0\pi^0) = (-0.03 \pm 0.64 \pm 0.10)\%$ using 980 fb^{-1} datasets.



PRL 112, 211601 (2014)

- Signal mode: $A_{raw}^{\pi^0\pi^0} = A_{CP}^{\pi^0\pi^0} + \boxed{A_{prod}^{D^*}} + A_{\epsilon}^{\pi_s}$; control modes: D^*-tagged $D^0 \to K^-\pi^+$, untagged $D^0 \to K^-\pi^+$.
- $A_{raw}^{K\pi,tag} = \boxed{A_{prod}^{D^{*+}}(D^0 \to K^-\pi^+)} + A_{\epsilon}^{\pi_s}(D^0 \to K^-\pi^+) + A_{\epsilon}^{K\pi}(D^0 \to K^-\pi^+)$
- $A_{raw}^{K\pi,untag} = \boxed{A_{prod}^{D^0}(D^0 \to K^-\pi^+)} + A_{\epsilon}^{K\pi}(D^0 \to K^-\pi^+)$
- Using $A'_{raw} = \dfrac{A_{raw}(cos\theta_{CM} < 0) + A_{raw}(cos\theta_{CM} > 0)}{2}$, the Production Asymmetry is averaged out.

(odd function of $cos\theta_{CM}$)

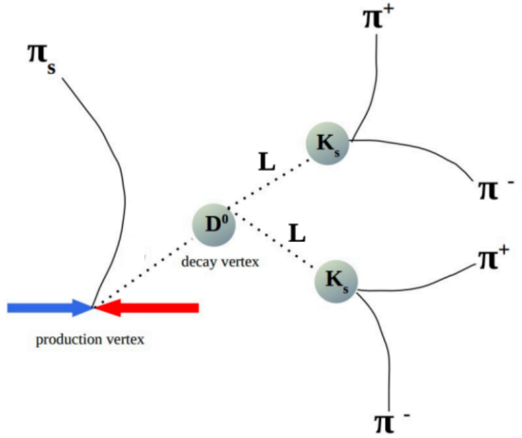
- $A_{CP}(D^0 \to \pi^0\pi^0) = A'^{\pi^0\pi^0}_{raw} - (A'^{K\pi,tag}_{raw} - A'^{K\pi,untag}_{raw})$

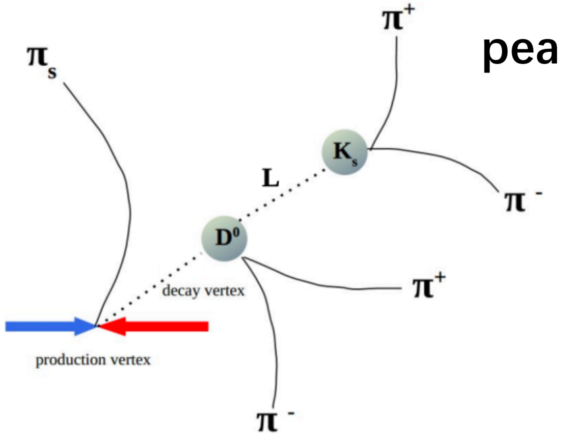
CP asymmetry in $D^0 \to K_S^0 K_S^0$

PRD 111, 012015 (2025)

$A_{CP}(D^0 \to K_S^0 K_S^0)$ using D^*-tagged sample

- Measure $A_{CP}(D^0 \to K_S^0 K_S^0)$ based on $D^{*+} \to D^0 \pi_s^+$ sample at Belle + Belle II (1.4 /ab).
- $A_{CP}^{K_S^0 K_S^0} = (A_{raw}^{K_S^0 K_S^0} - A_{raw}^{K^+K^-}) + A_{CP}^{K^+K^-}$ assuming nuisance asymmetries are made identical by kinematics weighting.
- Main background from same-final-state $D^0 \to K_S^0 \pi^+ \pi^-$ decays. Separate with K_S^0 flight distance significance L/σ: $S_{min}(K_S^0) = \log[\min(L1/\sigma1, L2/\sigma2)]$.





peaking background

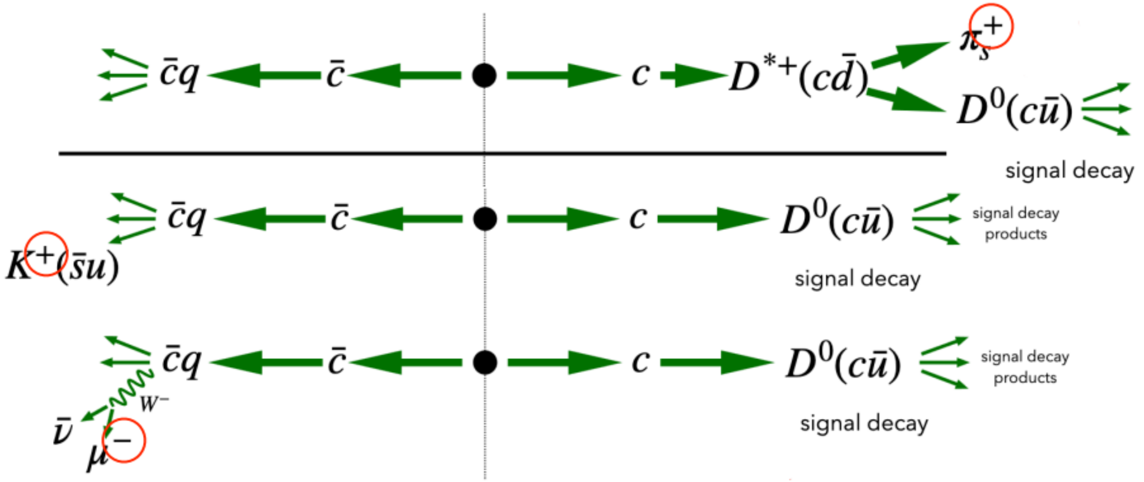
CP asymmetry in $D^0 \to K_S^0 K_S^0$

PRD 112, 012017 (2025)

$A_{CP}(D^0 \to K_S^0 K_S^0)$ using opposite side charm-flavor tagger

PRD 107, 112010 (2023)

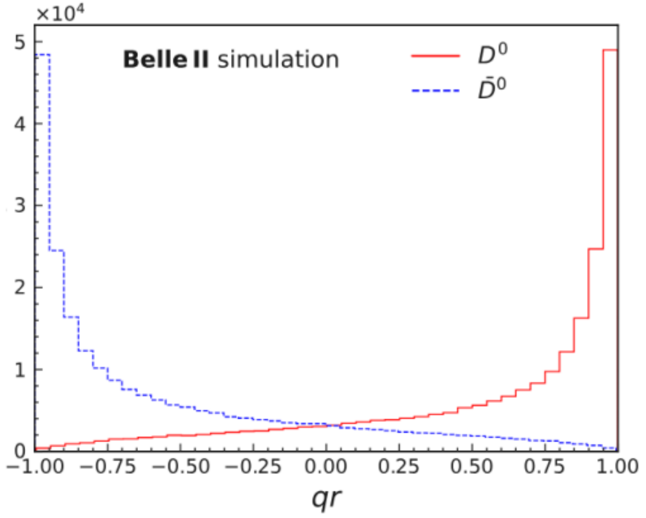
- Charm flavor tagger: novel method to tag flavor of D^0 meson from other collision products ($K^\pm/\mu^\pm$ from other charm hadron) → new CFT-tag independent sample.



- $q = \pm 1$, the predicted flavor
- ω, per-event wrong-tag probability

- Define dilution r = 1-2ω. Use product qr to measure A_{CP}.
- Calibrate r value using self-tagged decays ($D^0 \to K^-\pi^+$) in data.

- Use Belle + Belle II data sets (1.4 /ab), excluding D^*-tagged sample.
- Larger background wrt D^*-tag: train BDT with kinematic information.
- Cut on BDT output and S_{min} reduce $D^0 \to K_S^0\pi^+\pi^-$ significantly.



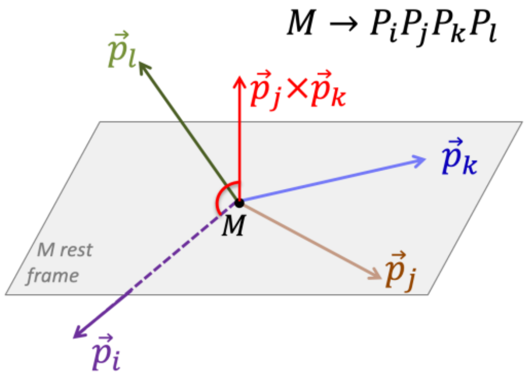
Search for CPV in $D^+_{(s)} \to K^0_S K^- \pi^+ \pi^+$

JHEP 04 (2025) 036

- $D^+_{(s)} \to K^0_S K^- \pi^+ \pi^+$ has a dominant intermediate process: $D^+_{(s)} \to \bar{K}^{*0} K^{*+}$ (tree, annihilation, penguin.)

These amplitudes interfere with one another, potentially giving rise to CPV

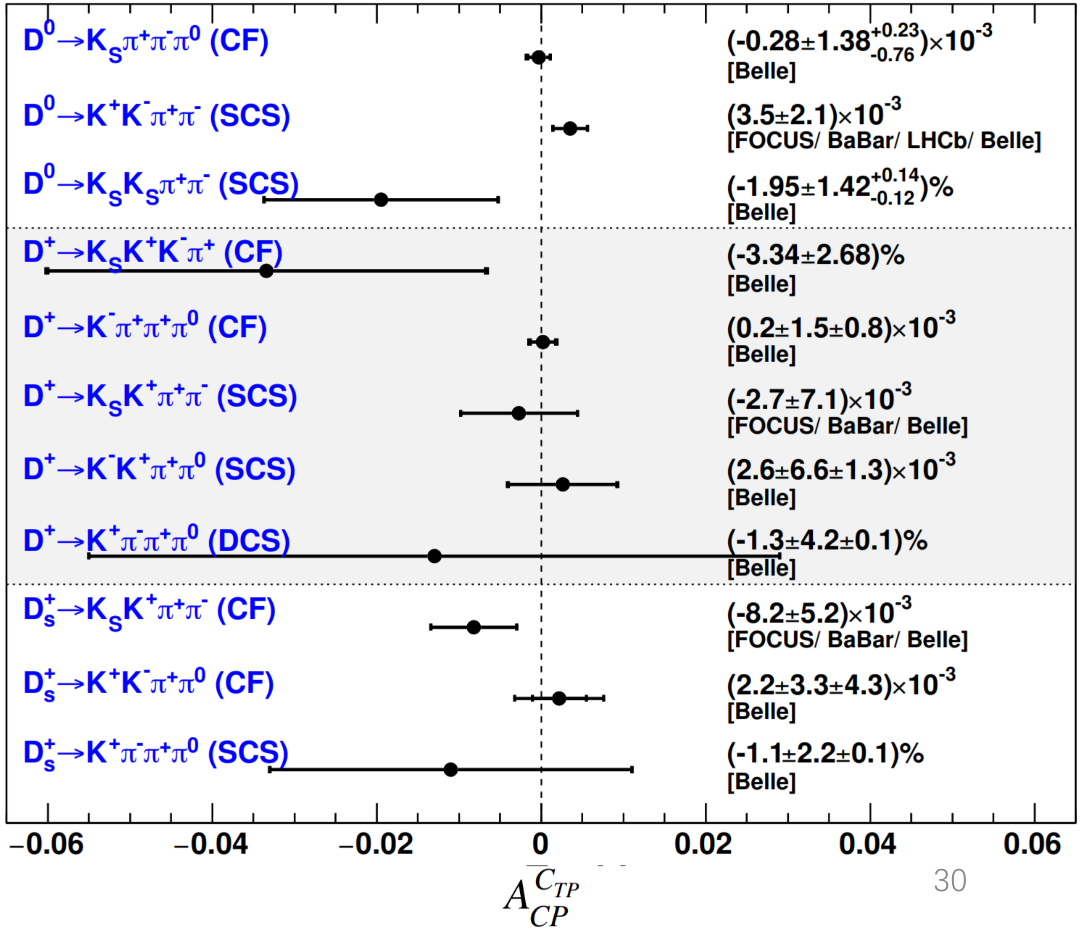
- Unlike time-integrated CPV, which is proportional to $sin\delta \cdot sin\phi$, CPV via kinematic observables (e.g. triple-product) is proportional to $cos\delta \cdot sin\phi$. (δ strong phase difference, ϕ weak phase difference)



$$X = C_{TP} \equiv (\vec{p}_j \times \vec{p}_k) \cdot \vec{p}_i$$

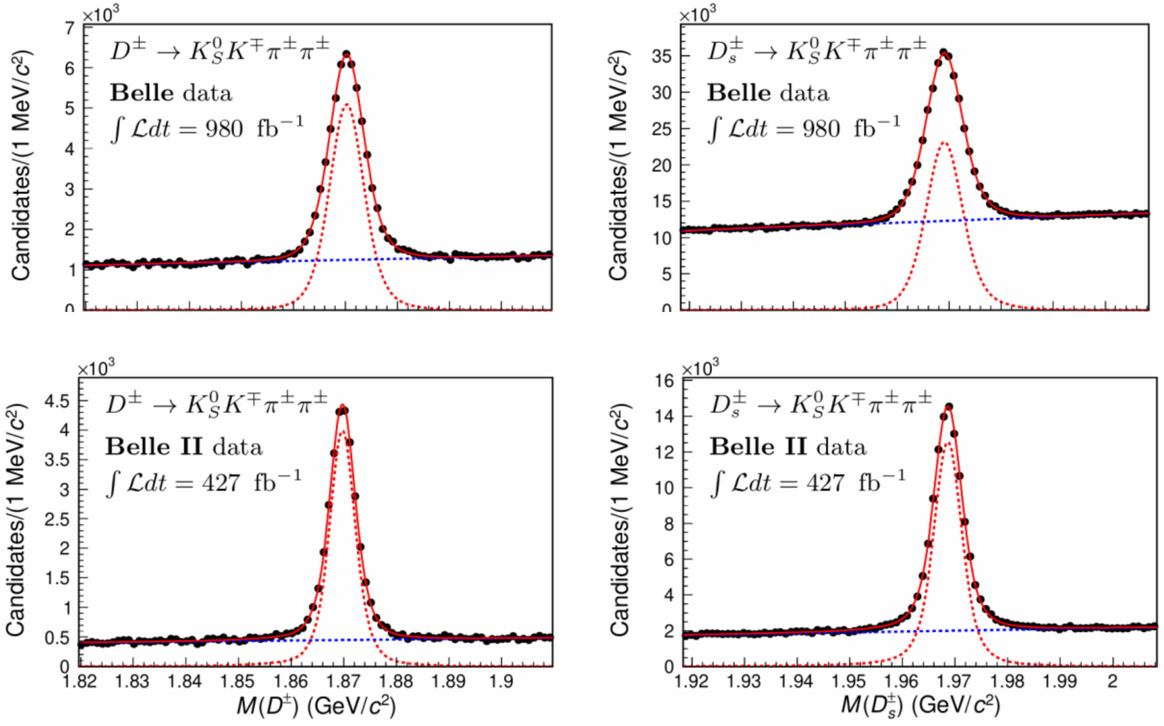
- $A_X(D^+_{(s)}) = \dfrac{N_+(X>0) - N_+(X<0)}{N_+(X>0) + N_+(X<0)}$; $A_{\bar{X}}(D^-_{(s)}) = \dfrac{N_-(\bar{X}>0) - N_-(\bar{X}<0)}{N_-(\bar{X}>0) + N_-(\bar{X}<0)}$
- N is obtained from fit. $\bar{X}$ is CP-conjugate of X
- $A^X_{CP} = \dfrac{1}{2}(A_X(D^+_{(s)}) - A_{\bar{X}}(D^-_{(s)}))$

- A couple of 4-body decays searched using this technique.
- First time on $D^+_{(s)} \to K^0_S K^- \pi^+ \pi^+$, whose $\mathscr{B} = 0.23\,\%\,(1.53\%)$.



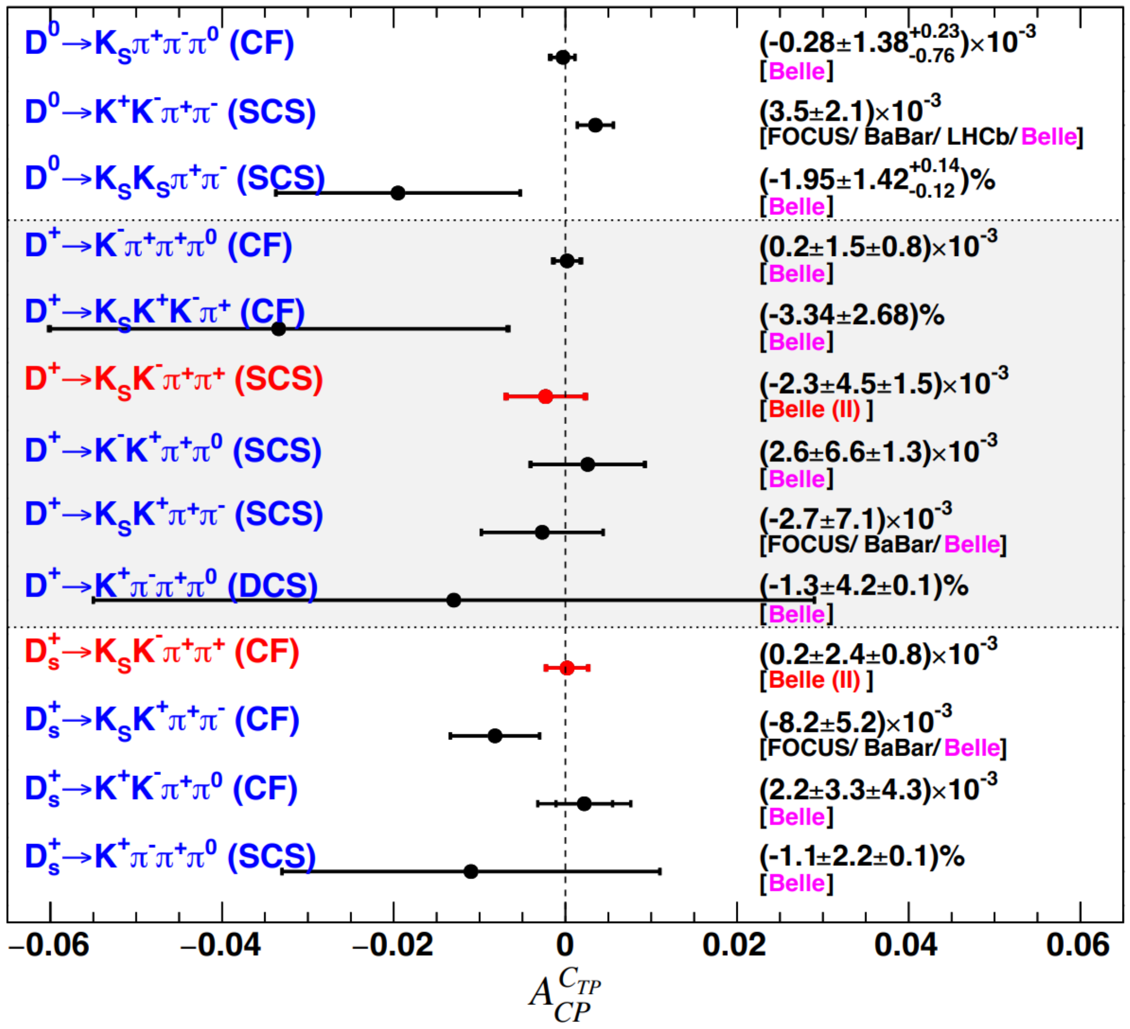
Search for CPV in $D^+_{(s)} \to K^0_S K^- \pi^+ \pi^+$

JHEP 04 (2025) 036



$$A^{C_{TP}}_{cp}(D^+) = (-2.3 \pm 4.5 \pm 1.5) \times 10^{-3}$$

$$A^{C_{TP}}_{cp}(D^+_s) = (0.2 \pm 2.4 \pm 0.8) \times 10^{-3}$$



No evidence for CPV found!

CP asymmetry in $\Xi_c^+ \to \Sigma^+ h^+ h^-$ and $\Lambda_c^+ \to p h^+ h^-$

Preliminary result

- There is a U-spin sum rule equivalent to the one that connects $D^0 \to KK, \pi\pi$, links the SCS decays $\Xi_c^+ \to \Sigma^+ h^+ h^-$ and $\Lambda_c^+ \to p h^+ h^-$ $(h = K, \pi)$ [PRD 99,032005(2019)]:

$$A_{CP}^{dir}(\Lambda_c^+ \to pK^+K^-) + A_{CP}^{dir}(\Xi_c^+ \to \Sigma^+\pi^+\pi^-) = 0$$
$$A_{CP}^{dir}(\Lambda_c^+ \to p\pi^+\pi^-) + A_{CP}^{dir}(\Xi_c^+ \to \Sigma^+K^+K^-) = 0$$

- Assuming U-spin symmetry:

$$A_{CP}(\Lambda_c^+ \to pK^+K^-) + A_{CP}(\Xi_c^+ \to \Sigma^+\pi^+\pi^-) = 0$$
$$A_{CP}(\Lambda_c^+ \to p\pi^+\pi^-) + A_{CP}(\Xi_c^+ \to \Sigma^+K^+K^-) = 0$$

- Measurement by LHCb [JHEP03(2018)182]:

$$\Delta A_{CP}^{wgt} = A_{CP}(pK^-K^+) - A_{CP}^{wgt}(p\pi^-\pi^+) = (0.30 \pm 0.91 \pm 0.61)$$