



Measurements of Charm hadrons in Belle & Belle II

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14th International Workshop
on e^+e^- collisions from Phi to Psi 2026

8-11 June 2026, Pisa, Italy

PhiPsi26

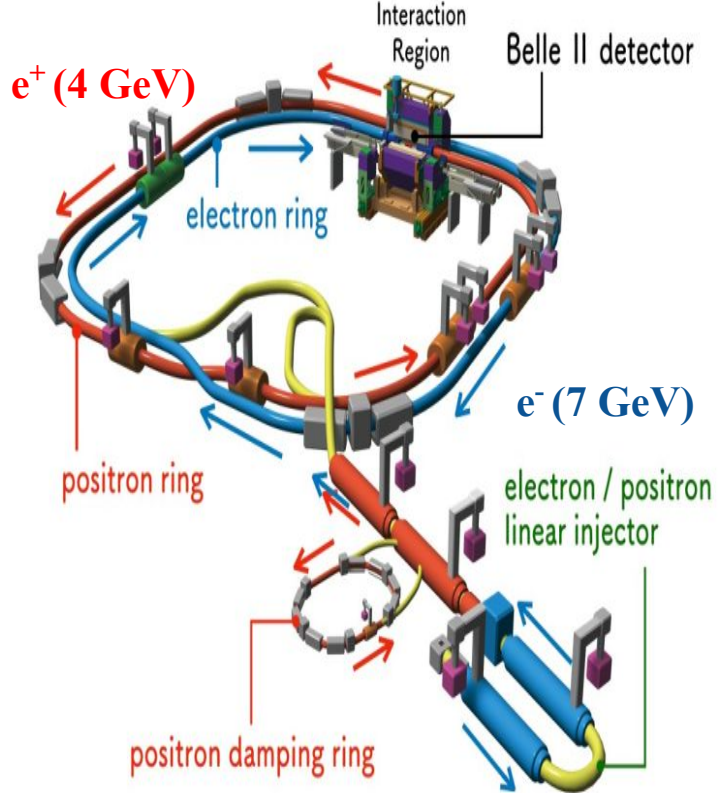


Outline

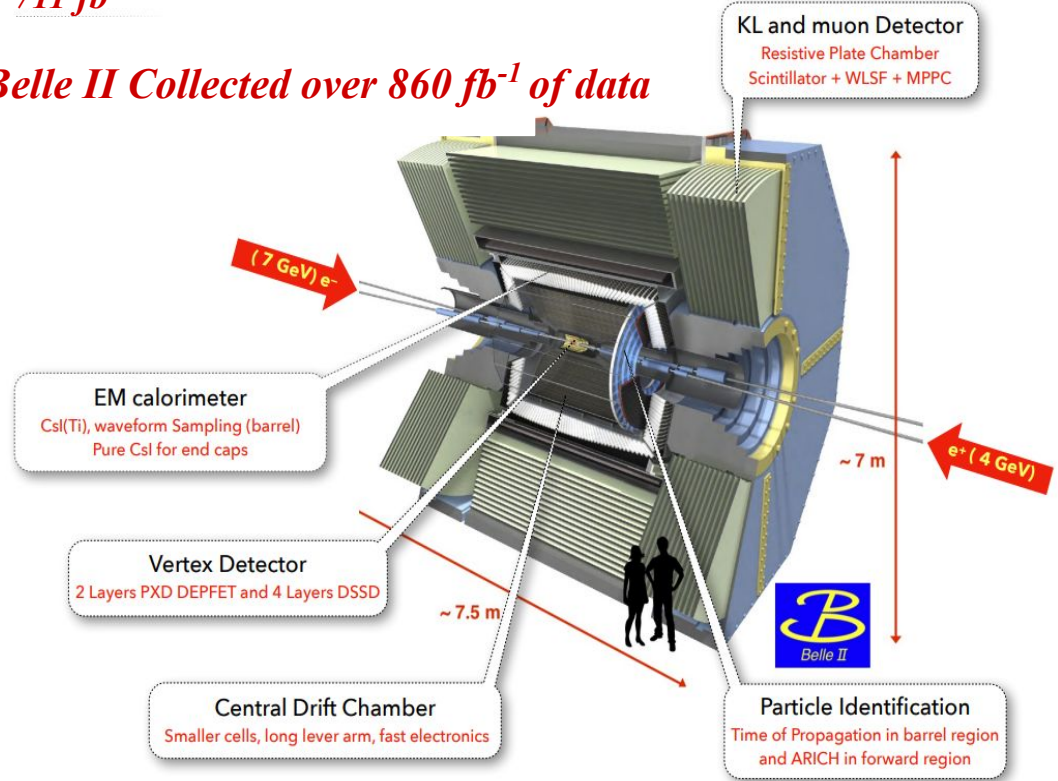
- Experimental Facility
- Belle II Charm Physics Program
- Charmed Baryon Decays and CP Violation
- Charm Meson CP Asymmetries
- Exotic Hadron Spectroscopy
- Summary

SuperKEKB & Belle II Detector

Belle @ KEKB (1999-2010): 980 fb⁻¹, Y(4S) dataset: 711 fb⁻¹



Belle II Collected over 860 fb⁻¹ of data

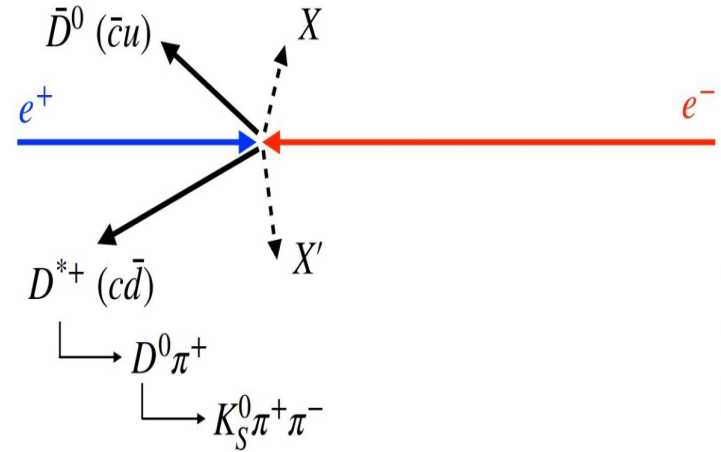


 **WORLD RECORD: $5.281 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$**

Largest Y(4S) dataset: 757 fb⁻¹

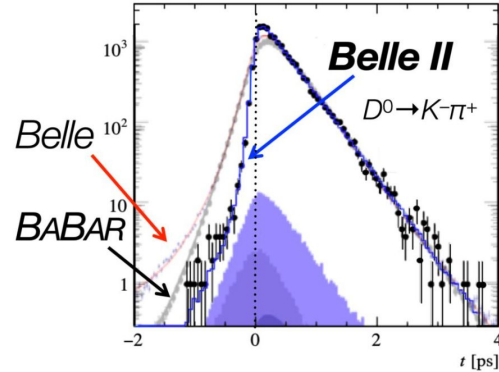
Charm production and reconstruction at Belle II

- $e^+e^- \rightarrow c\bar{c} \rightarrow D_{\text{tag}} X_{\text{frag}} D_{\text{sig}}$ ($\sigma = 1.3 \text{ nb}$)
- Typically only reconstruct the signal channel
- Also provides access to charmed baryons
- Flavour tagging using:
 - $D^{*+} \rightarrow D^0\pi^+$
 - Novel Charm Flavour Tagger, [PRD107\(2023\)112010](#):
 - exploits the correlation between the flavor of a reconstructed neutral D meson (signal D meson) and the electric charges of particles reconstructed in the rest of the event



Charm physics program at Belle II

- **Precision measurements:**
Charm lifetimes:



World's highest precision:

D^0, D^+ : [PRL127\(2021\)211801](#)

D_s^+ : [PRL131\(2023\)17180](#)

A_c^+ : [PRL130\(2023\)071802](#)

Ω_c^0 : [PRD107\(2023\)L031103](#)

- **Mixing parameters:**

- In $D^0 \rightarrow K_S \pi^+ \pi^-$ [PRD111\(2025\)112011](#)

- **CP Asymmetries:**

- $D^+ \rightarrow \pi^+ \pi^0$: [PRD112\(2025\)L031101](#) (world's best)

- $D^0 \rightarrow \pi^0 \pi^0$: [PRD112\(2025\)012006](#)

- $D^0 \rightarrow K_S K_S$ [PRD111\(2025\)012015](#)

- $D^0 \rightarrow K_S K_S$ (with novel charm flavour tagger): [PRD112\(2025\)012017](#)

- $D^0 \rightarrow \pi^+ \pi^- \pi^0$ [PRD113\(2026\)052006](#) (world's best)

- **Charmed Baryons:**

- **CPV:** $\Xi_c^+ \rightarrow \Sigma^+ h^+ h^-, \Lambda_c^+ \rightarrow p h^+ h^-$ [PRD113\(2026\)032017](#)

- **First observations and branching fractions:**

- $\Xi_c^0 \rightarrow \Xi^0 h$ ($h = \pi^0, \eta, \eta'$): [JHEP10\(2024\)045](#)

- $\Xi_c^0 \rightarrow \Lambda h$ ($h = \pi^0, \eta, \eta'$): [PRD113\(2026\)032015](#)

- $\Xi_c^+ \rightarrow p K_S, \Lambda \pi^+, \Sigma^0 \pi^+$: [JHEP03\(2025\)061](#)

- $\Xi_c^+ \rightarrow \Sigma^+ K_S, \Xi^0 \pi^+, \Xi^0 K^+$: [JHEP08\(2025\)195](#)

- **Exotic hadrons:**

- $D_{s0}^*(2317)^+$ [arXiv:2510.27174](#) (accepted by PRL)

and many more...

Measurements of $\Xi_c^0 \rightarrow \Lambda h$ ($h = \eta, \eta', \pi^0$)

[PRD113\(2026\)032015](#)

- Charmed baryon spectroscopy:
 - probe light quarks dynamics in presence of heavy quarks,
 - Better understand decay dynamics
- Singly Cabibbo-suppressed (SCS) decays of anti triplet charmed baryons
- Control sample:
 - $\Xi_c^0 \rightarrow \Xi^- (\rightarrow \Lambda \pi^-) \pi^+$

- Absolute branching fractions for:

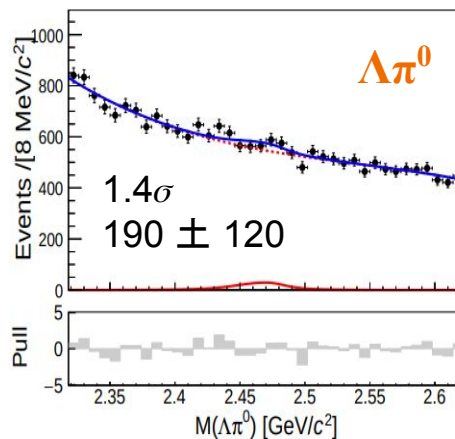
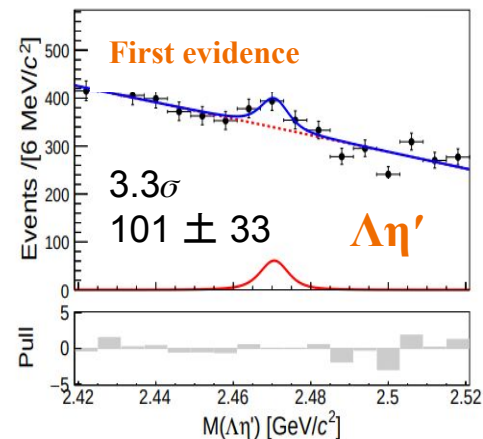
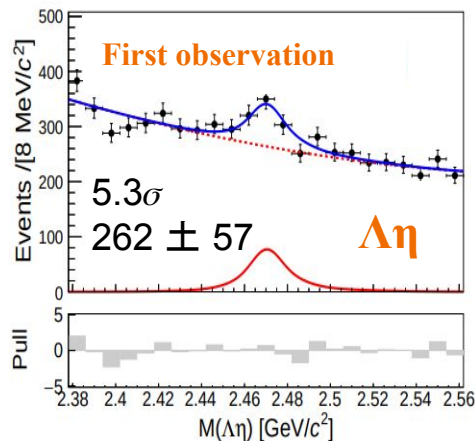
$$\mathcal{B}(\Xi_c^0 \rightarrow \Lambda \eta) = (5.95 \pm 1.30 \pm 0.32 \pm 1.13) \times 10^{-4}$$

$$\mathcal{B}(\Xi_c^0 \rightarrow \Lambda \eta') = (3.55 \pm 1.17 \pm 0.17 \pm 0.68) \times 10^{-4}$$

- UL at 90% CL for

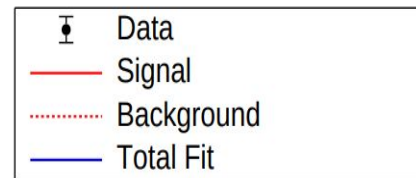
$$\mathcal{B}(\Xi_c^0 \rightarrow \Lambda \pi^0) < 5.2 \times 10^{-4}$$

- Consistent with theoretical predictions



$$\text{Belle} \quad \int L dt = 988.4 \text{ fb}^{-1}$$

$$\text{Belle II} \quad \int L dt = 427.9 \text{ fb}^{-1}$$



Intermediate states :

$$\Lambda \rightarrow p \pi, \eta \rightarrow \gamma \gamma, \eta \rightarrow \pi^+ \pi^- \pi^0$$

$$\eta' \rightarrow \pi^+ \pi^- \eta, \quad \eta' \rightarrow \pi^+ \pi^- \gamma,$$

$$\pi^0 \rightarrow \gamma \gamma$$

CP asymmetry in $\Xi_c^+ \rightarrow \Sigma^+ h^+ h^-$, $\Lambda_c^+ \rightarrow p h^+ h^-$ ($h=K, \pi$)

- Complementary information to that of mesons.
- Observation of CPV in b-baryon decays by LHCb $A_{CP}(\Lambda_b \rightarrow p K^- \pi^+ \pi^-)$: $(2.45 \pm 0.46 \pm 0.10) \%$
[Nature 643 \(2025\) 1223](#)
- There is a U-spin sum rule equivalent to the one that connects $D^0 \rightarrow KK, \pi\pi$, and links the SCS decays:
 $\Lambda_c^+ \rightarrow p h^+ h^-$, $\Xi_c^+ \rightarrow \Sigma^+ h^+ h^-$ [PRD99\(2019\)033005](#):

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

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

- Assuming U-spin symmetry:

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

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

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

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

CP asymmetry in $\Xi_c^+ \rightarrow \Sigma^+ h^+ h^-$, $\Lambda_c^+ \rightarrow p h^+ h^-$ ($h=K, \pi$)

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

$$A_{CP}(\Xi_c^+ \rightarrow \Sigma^+ K^- K^+) = (3.7 \pm 6.6(\text{stat}) \pm 0.6(\text{syst}))\%$$

$$A_{CP}(\Xi_c^+ \rightarrow \Sigma^+ \pi^- \pi^+) = (9.5 \pm 6.8(\text{stat}) \pm 0.5(\text{syst}))\%$$

$$A_{CP}(\Lambda_c^+ \rightarrow p K^- K^+) = (3.9 \pm 1.7(\text{stat}) \pm 0.7(\text{syst}))\%$$

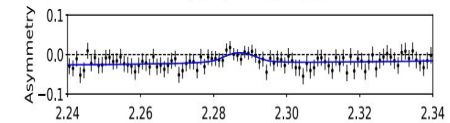
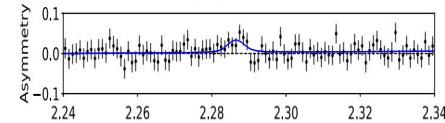
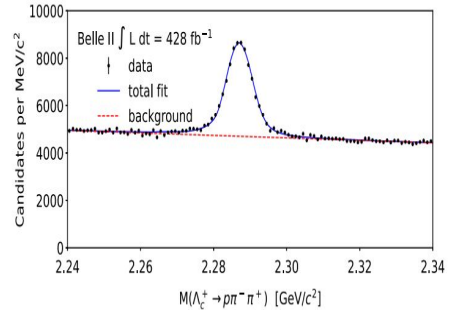
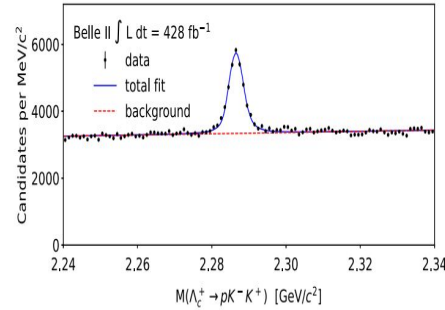
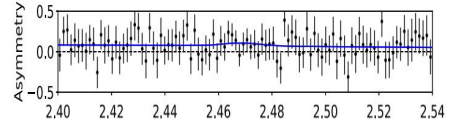
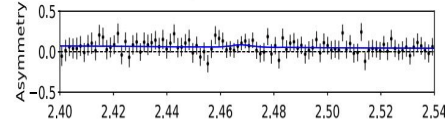
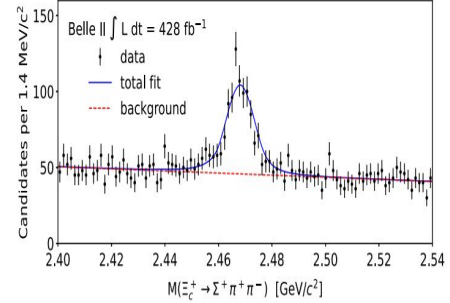
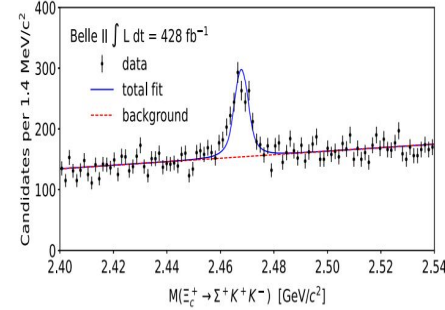
$$A_{CP}(\Lambda_c^+ \rightarrow p \pi^- \pi^+) = (0.3 \pm 1.0(\text{stat}) \pm 0.2(\text{syst}))\%$$

U-spin symmetry with 7% precision:

$$A_{CP}(\Lambda_c^+ \rightarrow p K^+ K^-) + A_{CP}(\Xi_c^+ \rightarrow \Sigma^+ \pi^+ \pi^-) = (13.4 \pm 7.0(\text{stat}) \pm 0.9(\text{syst}))\%$$

$$A_{CP}(\Lambda_c^+ \rightarrow p \pi^+ \pi^-) + A_{CP}(\Xi_c^+ \rightarrow \Sigma^+ K^+ K^-) = (4.0 \pm 6.6(\text{stat}) \pm 0.7(\text{syst}))\%$$

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



Observation of $D_{s_0}^{*+}(2317) \rightarrow D_s^{*+} \gamma$

- Exotic hadrons offer insight into nonperturbative QCD.
 - $D_{s_0}^{*+}(2317)$:discovered 20+ years ago, to $D_s^{*+} \pi^0$
 - Mass is much lower than quark model prediction
 - Nature: $c\bar{s}$ state, hadronic molecule, mixed configuration ??
- $D_{s_0}^{*+}(2317) \rightarrow D_s^{*+} \pi^0$ discovered by BESIII [PRD97\(2018\)051103](#)
 - Measured mass is in agreement with molecular picture, differs from $c\bar{s}$ hypothesis.

- Determination of R can constrain theoretical models

$$R = \frac{\mathcal{B}(D_{s_0}^{*+}(2317) \rightarrow D_s^{*+} \gamma)}{\mathcal{B}(D_{s_0}^{*+}(2317) \rightarrow D_s^{*+} \pi^0)}$$

- Best upper limit on R is $< 5.9\%$ at 90% CL [PRD68\(2003\)032002](#)

Observation of $D_{s0}^{*+}(2317) \rightarrow D_s^{*+} \gamma$

[arXiv:2510.27174](https://arxiv.org/abs/2510.27174) (Accepted by PRL)

- Belle (980 fb⁻¹) + Belle II (428 fb⁻¹) analysis:

- First observation

- Intermediate states:

- $D_s^{*+} \rightarrow D_s^+ \gamma$, $D_s^+ \rightarrow [\phi \rightarrow K^+ K^-] \pi^+$

- $D_s^+ \rightarrow [\bar{K}^{*0} \rightarrow K^- \pi^+] K^+$

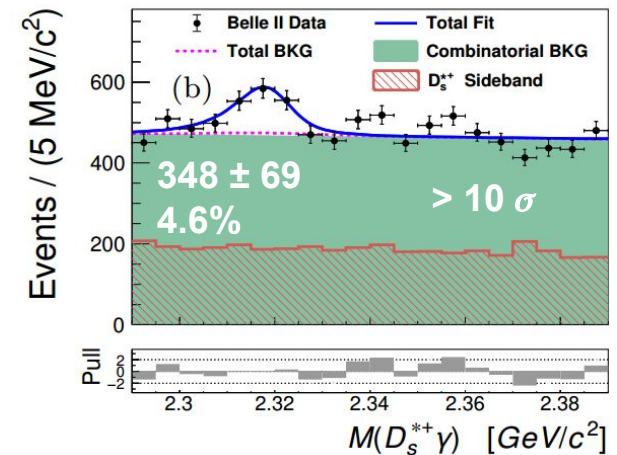
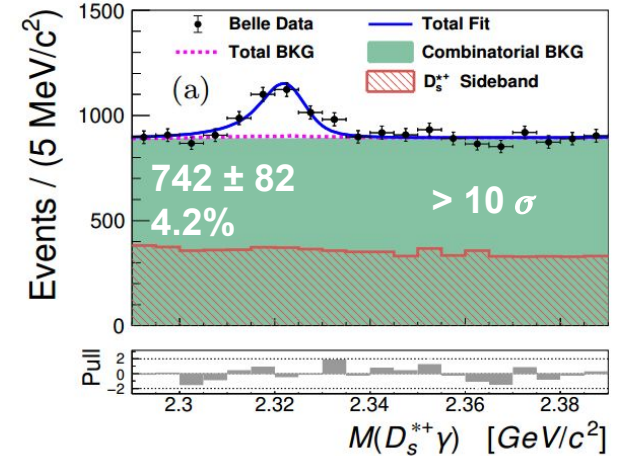
- $R = [7.14 \pm 0.70(\text{stat.}) \pm 0.23(\text{syst.})]$

- larger than theoretical predictions suggesting a molecular state

- Smaller than the $c\bar{s}$ state assumption

- predictions based on the light front quark model and chiral quark model are in agreement (pure $c\bar{s}$)

- *could be an admixture of pure $c\bar{s}$ and molecular state*



CP Asymmetry in $D^0 \rightarrow \pi^+ \pi^- \pi^0$

PRD113(2026)052006

- SCS three-body decay, interference of several amplitudes

$$\mathcal{A}_{\text{raw}}^{\pi\pi\pi^0} = \frac{N(D^0 \rightarrow \pi^+ \pi^- \pi^0) - N(\bar{D}^0 \rightarrow \pi^+ \pi^- \pi^0)}{N(D^0 \rightarrow \pi^+ \pi^- \pi^0) + N(\bar{D}^0 \rightarrow \pi^+ \pi^- \pi^0)}$$

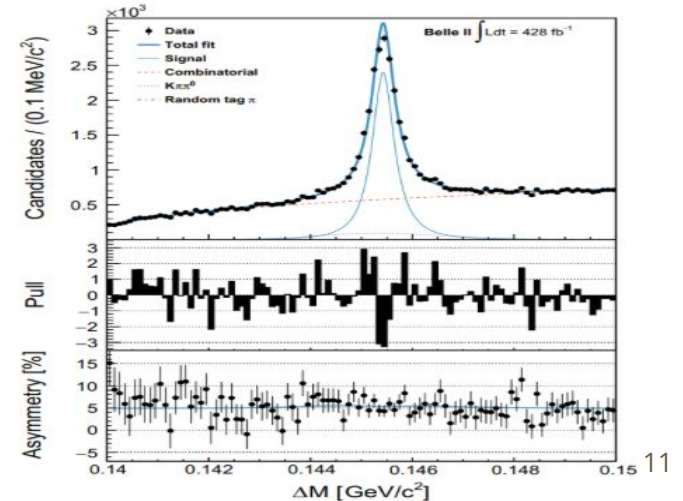
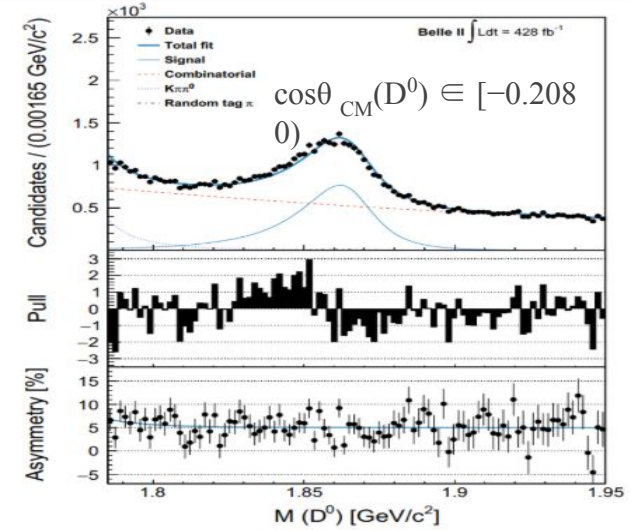
- Signal: D^{*+} tagged sample for $D^0 \rightarrow \pi^+ \pi^- \pi^0$.

$$\mathcal{A}_{\text{raw}}^{\pi\pi\pi^0} \simeq \mathcal{A}_{CP} + \mathcal{A}_{\text{prod}} + \mathcal{A}_{\varepsilon}^{\pi\pi\pi^0} + \mathcal{A}_{\varepsilon}^{\pi_{\text{tag}}}$$

- Control mode: tagged and untagged $D^0 \rightarrow K^- \pi^+$

$$\mathcal{A}_{\varepsilon}^{\pi_{\text{tag}}} = \mathcal{A}_{\text{raw}}^{\text{tagged}} - \mathcal{A}_{\text{raw}}^{\text{untagged}}$$

- Simultaneous fit to $(\Delta m, m(D^0 \rightarrow \pi^+ \pi^- \pi^0))$ in 8 bins of $\cos\theta_{\text{CM}}(D^0)$, averaged symmetrically around 0 to remove $\mathcal{A}_{\text{prod}}$
- $\mathcal{A}_{CP}(D^0 \rightarrow \pi^+ \pi^- \pi^0)$: $(0.29 \pm 0.27 \pm 0.13) \%$
 - Most precise measurement till date
 - 34% more precise than BABAR: $(0.31 \pm 0.41 \pm 0.17) \%$ At 385 fb^{-1}



Summary

- Belle II accumulated over 860 fb^{-1} of data, world record instantaneous luminosity by SuperKEKB
- First observation of $\Xi_c^0 \rightarrow \Lambda\eta$ and first evidence for $\Xi_c^0 \rightarrow \Lambda\eta'$, consistent with theoretical expectations.
- First measurement of CP asymmetries in SCS three-body charm baryon decays, consistent with CP symmetry
- Most precise measurements of A_{CP} in $D^0 \rightarrow \pi^+\pi^-\pi^0$, consistent with CP symmetry
- First observation of $D_{s0}^*(2317)^+ \rightarrow D_s^{*+}\gamma$, providing important constraints on the nature of the $D_{s0}^*(2317)^+$ state.

Stay tuned!!

