Recent results from Belle and Belle II

沈成平
复旦大学现代物理研究所

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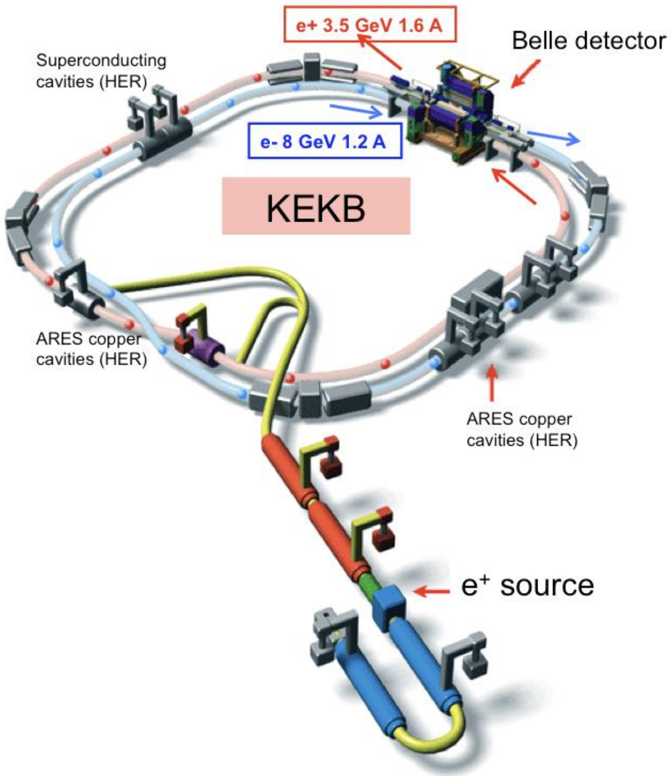
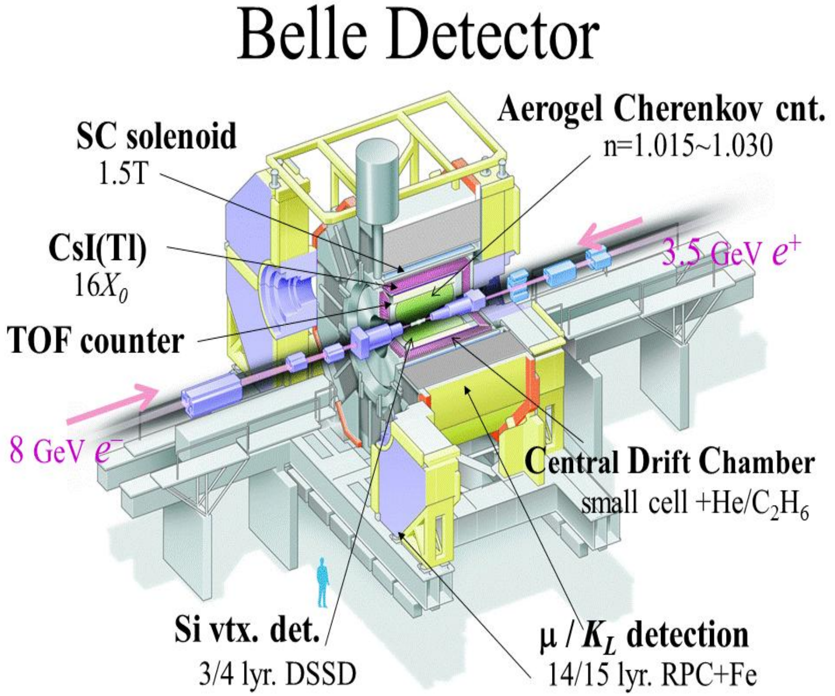
KEKB and Belle

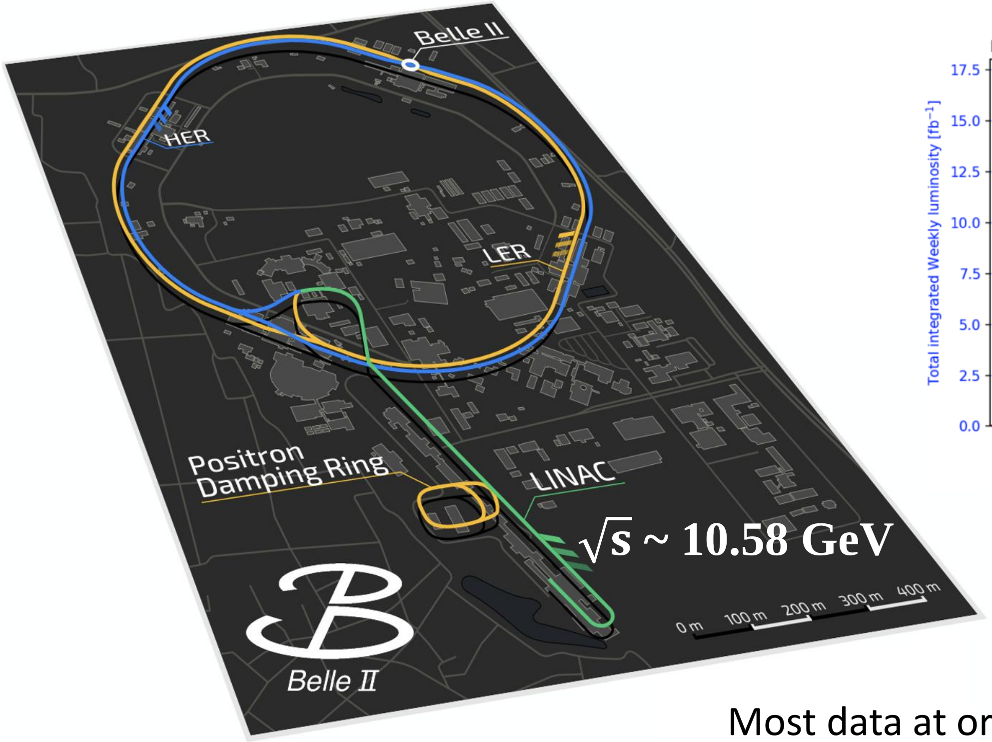
Peak luminosity: $2.11 \times 10^{34} \mathrm{cm}^{-1} \mathrm{s}^{-1}$
Integrated luminosity (~980 fb^{-1} in total):
$\Upsilon(5S)$: 121 fb^{-1}, $\Upsilon(4S)$: 711 fb^{-1}, $\Upsilon(3S)$: 3 fb^{-1},
$\Upsilon(2S)$: 25 fb^{-1}, $\Upsilon(1S)$: 6 fb^{-1}, continuum: 90 fb^{-1}

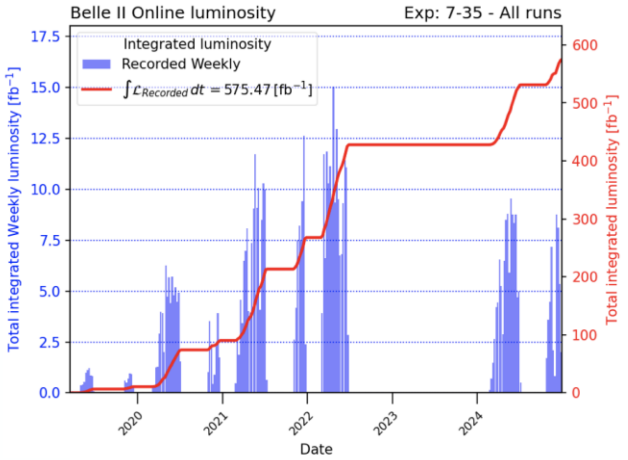
$\sqrt{s} \sim 10.6$ GeV

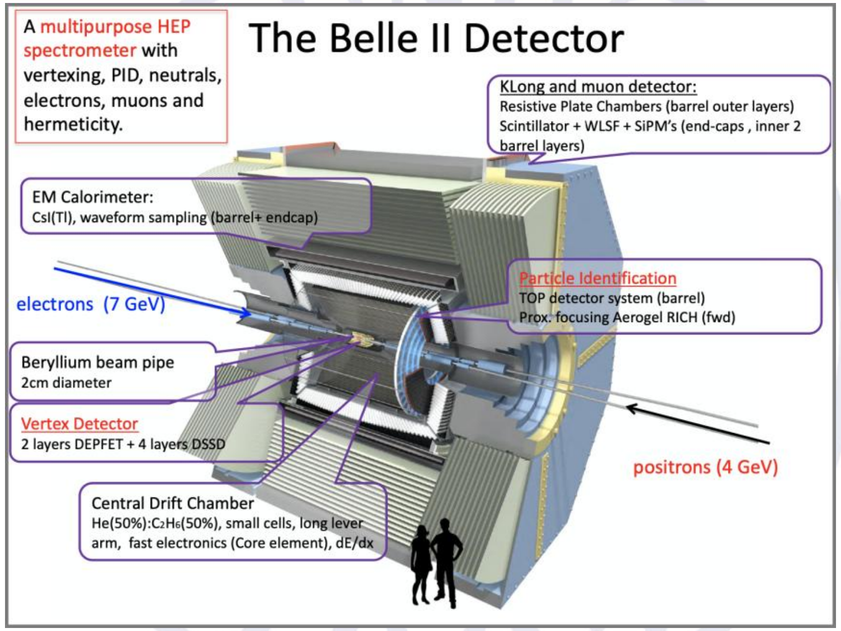




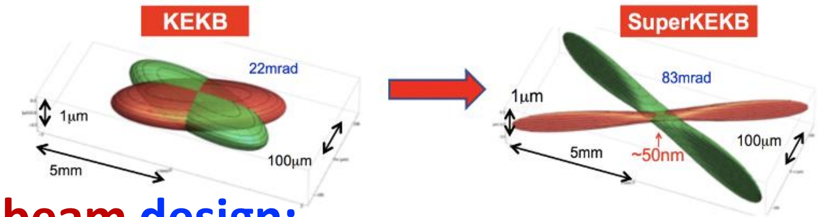
SuperKEKB and Belle II







Nano-beam design:



Most data at or near the $\Upsilon(4S)$ resonance, and 19.6 fb^{-1} near $\Upsilon(10753)$

In December 2024

WORLD RECORD: $5.1 \times 10^{34}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$

The Belle II experiment began collecting data on 18 November.

Nano-beam design:

Beam squeezing: ×20 smaller;

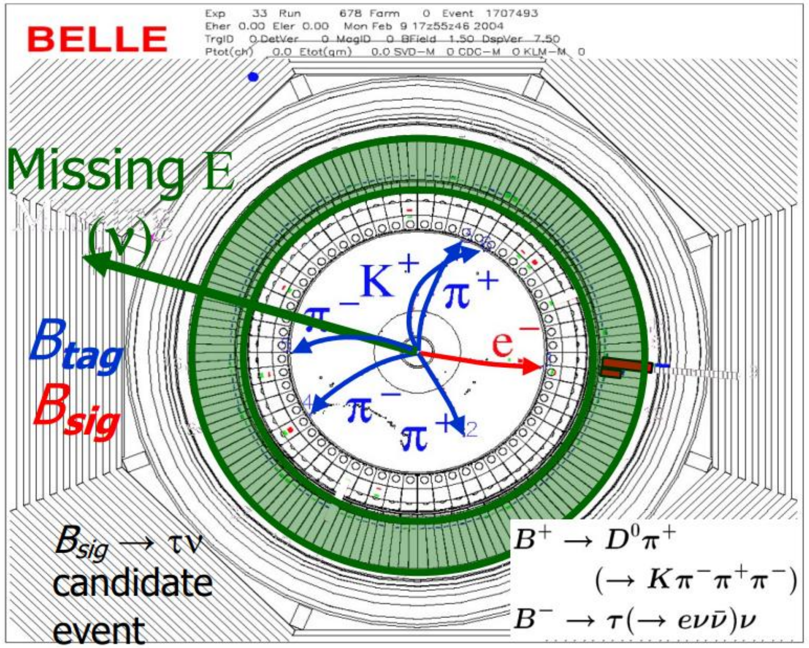
Beam current: ×2 larger

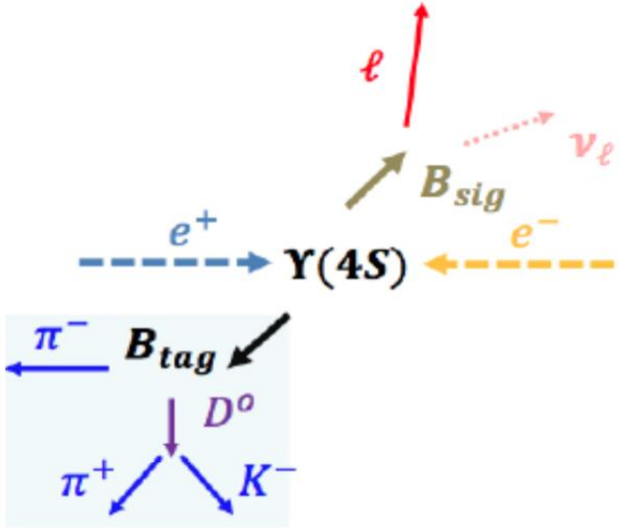
Target peak luminosity: KEKB×30

Unique capabilities of Belle/Belle II

- **Beam energy constraint**
- **Clean experimental environment:** high B, D, K, τ lepton reconstruction efficiency
- Long lived particles (e.g. $\mathbf{K_S}$), $\boldsymbol{\pi^0}$**s** and **photons** well reconstructed
- Capability of **inclusive measurements**
- **BB produced in quantum correlated state:** high flavour tagging effective efficiency (30% vs 5%@LHCb)
- The **full reconstruction of one B ($\mathbf{B_{tag}}$)** constraints the 4-momentum of the other B (B_{sig})
- Reconstruction of **channels with missing energy**

$$p_\nu = p_{e^+e^-} - p_{B_{tag}} - p_{B_{sig}}$$





Belle II国际合作组

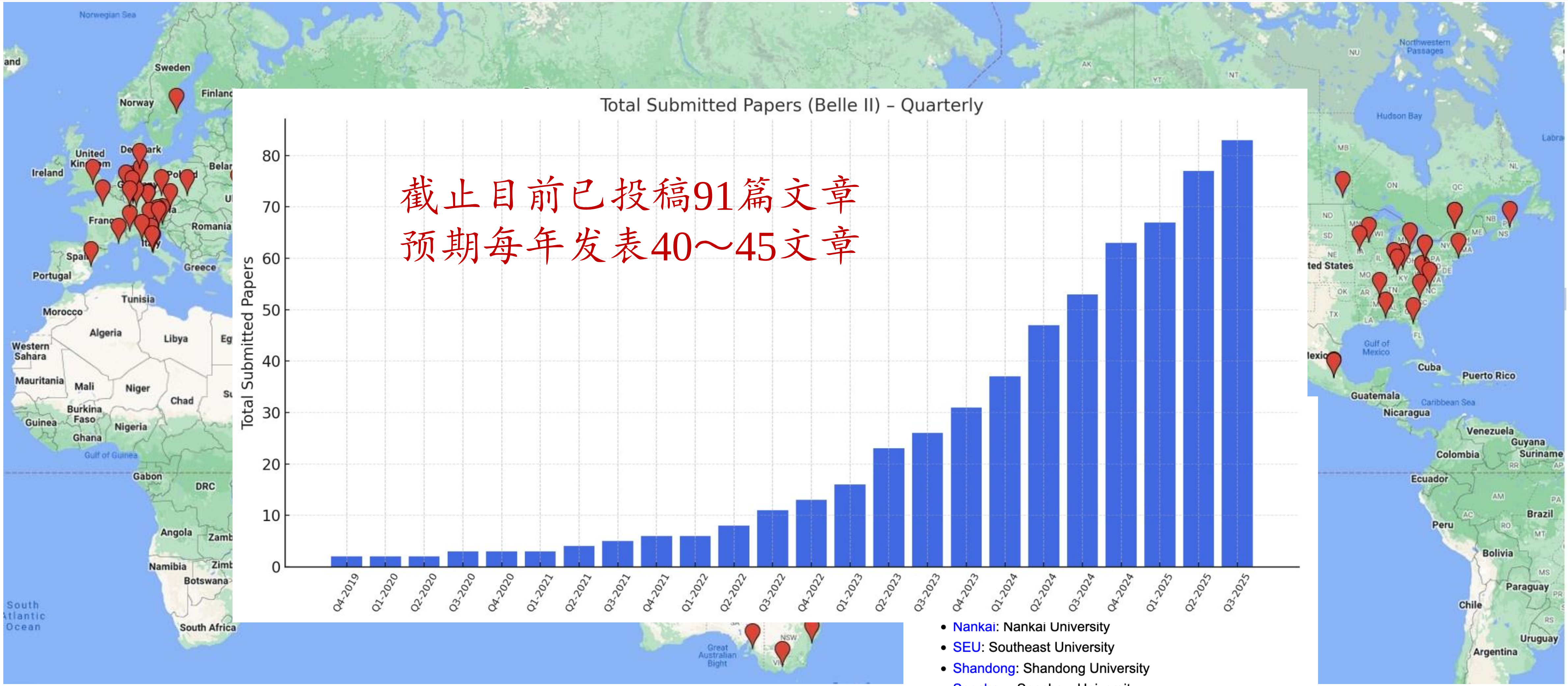
China

- Beihang: Beihang Univ.(BUAA)
- Fudan: Fudan Univ.
- HNU: Henan Normal University
- HUNNU: Hunan Normal University
- IHEP-China: Institute of High Energy Physics(IHEP)
- JLU: Jilin University
- LNNU: LiaoNing Normal University(LNNU)
- NNU: Nanjing Normal University
- Nankai: Nankai University
- SEU: Southeast University
- Shandong: Shandong University
- Soochow: Soochow University
- USTC: Univ. of Science and Technology of China(USTC)
- XJTU: Xi'an Jiaotong University
- ZZU: Zhengzhou University

Belle II合作组包括来自28个国家/地区702名成员组成

中国大陆：15家单位、142名成员，排名第三

Belle II国际合作组



- Nankai: Nankai University
- SEU: Southeast University
- Shandong: Shandong University
- Soochow: Soochow University
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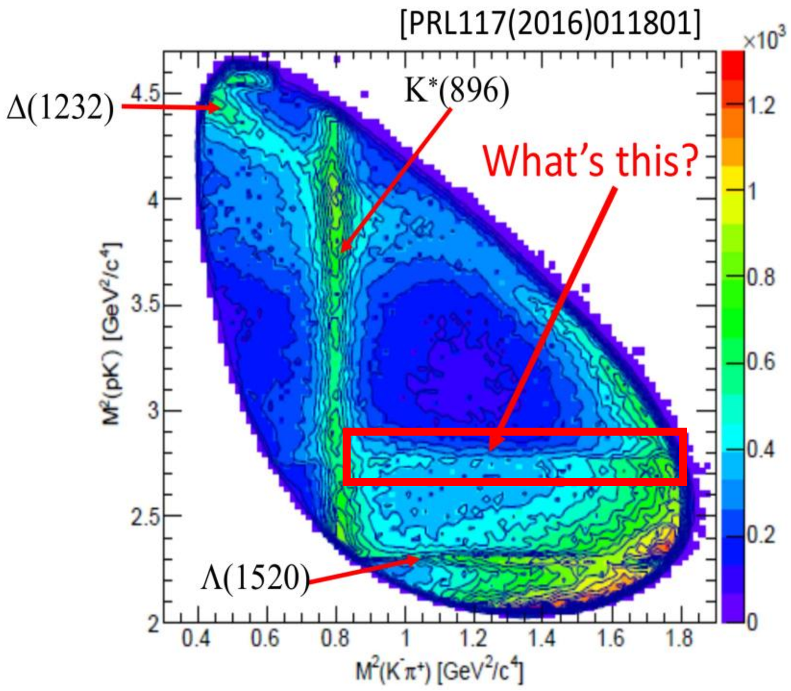
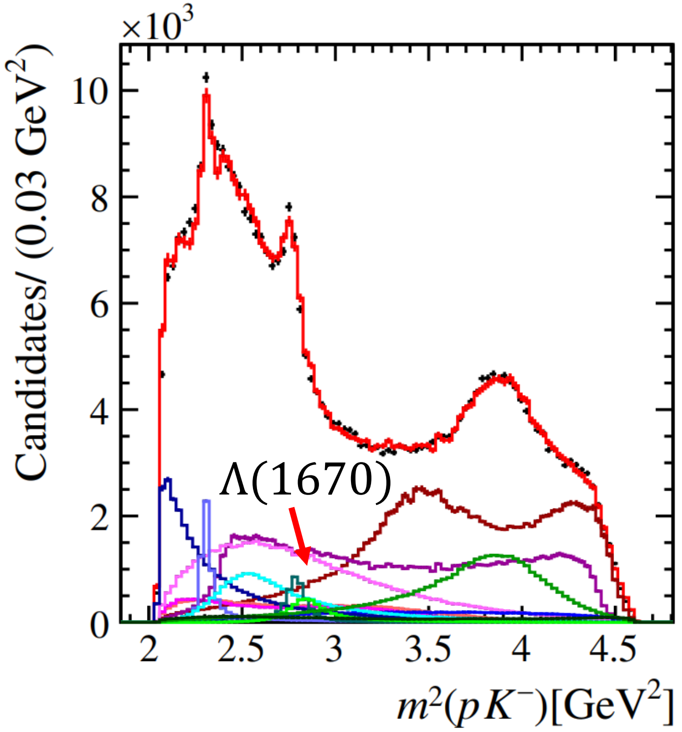
Light hadron

A peak at Λη threshold

- A trace of a peak structure is observed in the pK^- mass spectrum in the previous analysis of $\Lambda_c^+ \to pK^-\pi^+$ decay by the Belle. PRL, 117, 011801 (2016)
- LHCb performed an amplitude analysis of $\Lambda_c^+ \to pK^-\pi^+$. A similar structure is also seen. LHCb explained the structure using a BW form with fixed mass and width. PRD 108, 012023 (2023)





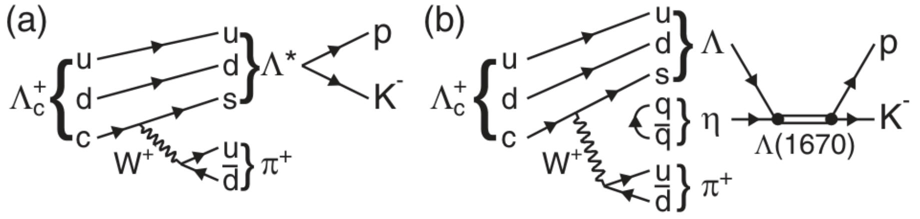


FIG. 1. Feynman diagrams for (a) a new Λ^* resonance and (b) a visible $\Lambda\eta$ threshold cusp enhanced by the $\Lambda(1670)$ pole in $\Lambda_c^+ \to pK^-\pi^+$ decay.

Two approach to describe this peak:

① **BW function**

② **Flatt´e function**

From the perspective of a new resonance

[PRD 108, L031104 (2023)]

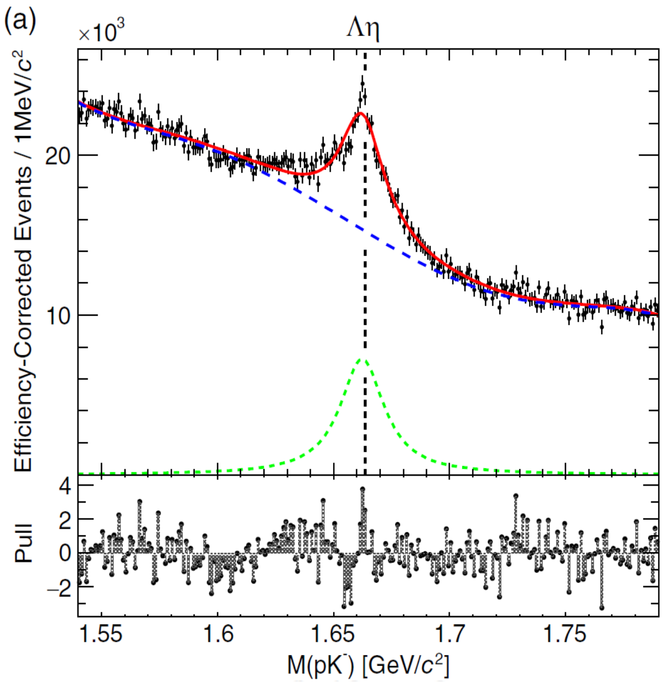
- We perform a binned least-χ^2 fit to the efficiency-corrected $M(pK^-)$distribution

- Fit to $M(pK^-)$ distribution using non-relativistic BW function.

$$\frac{dN}{dm} \propto |BW(m)|^2 = \left|\frac{1}{(m-m_0)+i\frac{\Gamma_0}{2}}\right|^2$$

$m_0 = (1662.4 \pm 0.3)$ MeV
$\Gamma_0 = (22.6 \pm 1.5)$ MeV

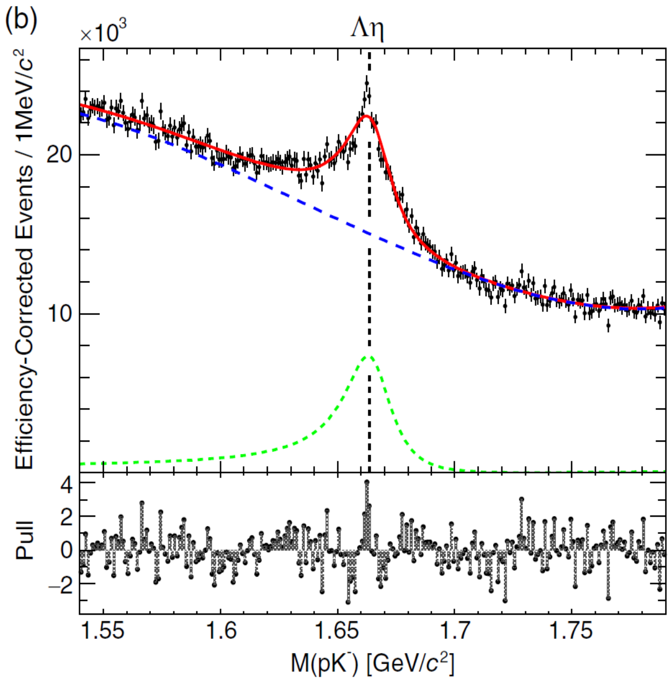
Reduced $\chi^2/\text{ndf} = 328/24$
$= 1.35$



- Not very good especially near the peak.

- Fit to $M(pK^-)$ using BW with complex constant added coherently, leading to constructive interference below the $\Lambda\eta$ threshold and destructive above that.

$$\frac{dN}{dm} \propto \left|BW(m) + re^{i\theta}\right|^2 = \left|\frac{1}{(m-m_0)+i\frac{\Gamma_0}{2}} + re^{i\theta}\right|^2$$



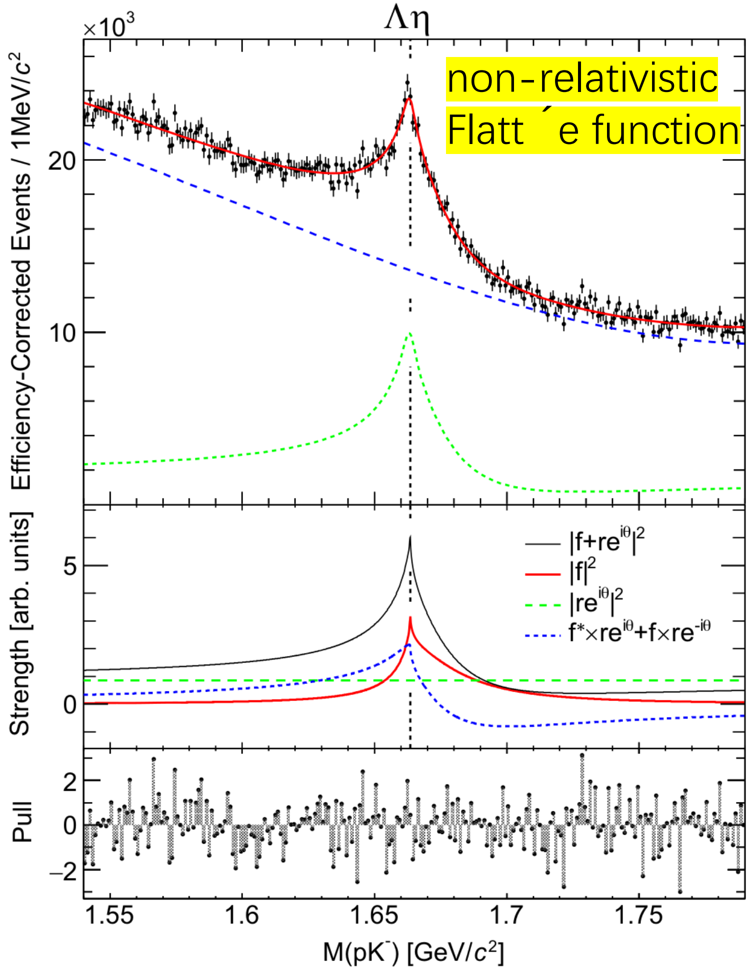
$m_0 = (1665.4 \pm 0.5)$ MeV
$\Gamma_0 = (23.8 \pm 1.2)$ MeV

Reduced $\chi^2/\text{ndf} = 308/243$
$= 1.27$

From the perspective of a cusp at $\Lambda\eta$

- Another possibility is that the peak structure is a cusp at the $\Lambda\eta$ threshold enhanced by the $\Lambda(1670)$ pole nearby.

$$\frac{dN}{dm} \propto |f(m)|^2 = \left| \frac{1}{m - m_f + \frac{i}{2}(\Gamma' + \bar{g}_{\Lambda\eta} k)} \right|^2$$



- The best fit with χ^2/ndf=1.06 (257/243) is obtained at m_f=1674.4 MeV/c^2.
- The measured: $\Gamma' = (27.2 \pm 1.9^{+5.0}_{-3.9})$ MeV, $\bar{g}_{\Lambda\eta} = (258 \pm 23^{+61}_{-75}) \times 10^{-3}$

	Our measurement	$\Lambda(1670)$ [PRD 103, 052005 (2021)]
mass	Fix m_f =1674.4 MeV/c^2	$(1674.3 \pm 0.8 \pm 4.9)$MeV/c^2
Total width	$(50.3 \pm 2.9^{+4.2}_{-4.0})$ MeV	$(36.1 \pm 2.4 \pm 4.8)$MeV

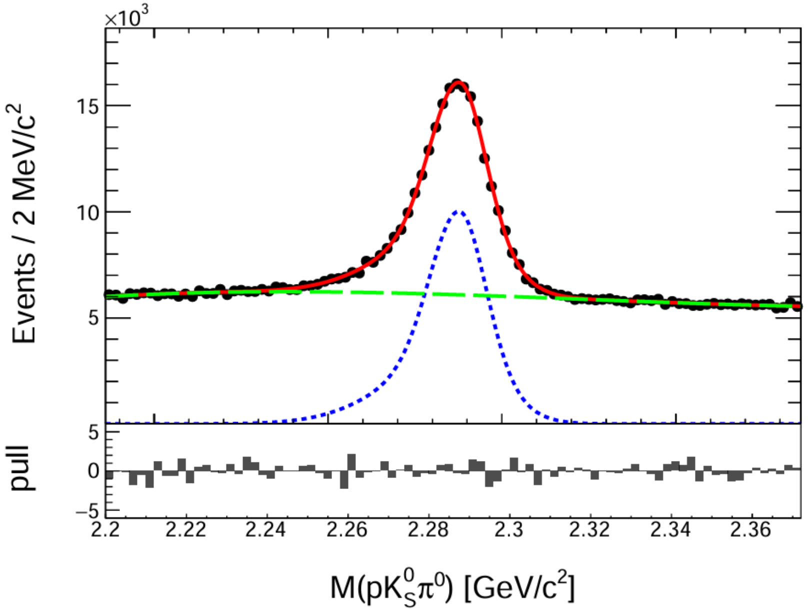
- The fit result with the Flatté function to which the constant is coherently added shows the best reduced χ^2/ndf of 1.06 (257/243, $p = 0.25$), while 1.27 (308/243, $p = 3.1 \times 10^{-3}$) from the best BW fit.

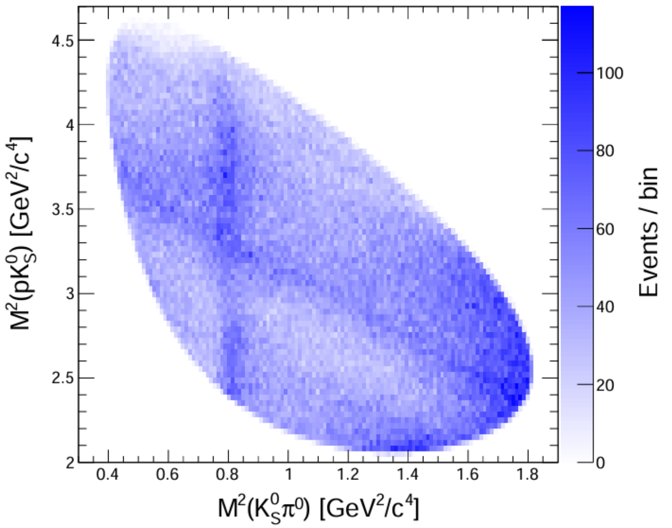
- The best fit explains the structure as a cusp at the $\Lambda\eta$ threshold.
- The obtained parameters are consistent with the known properties of $\Lambda(1670)$.

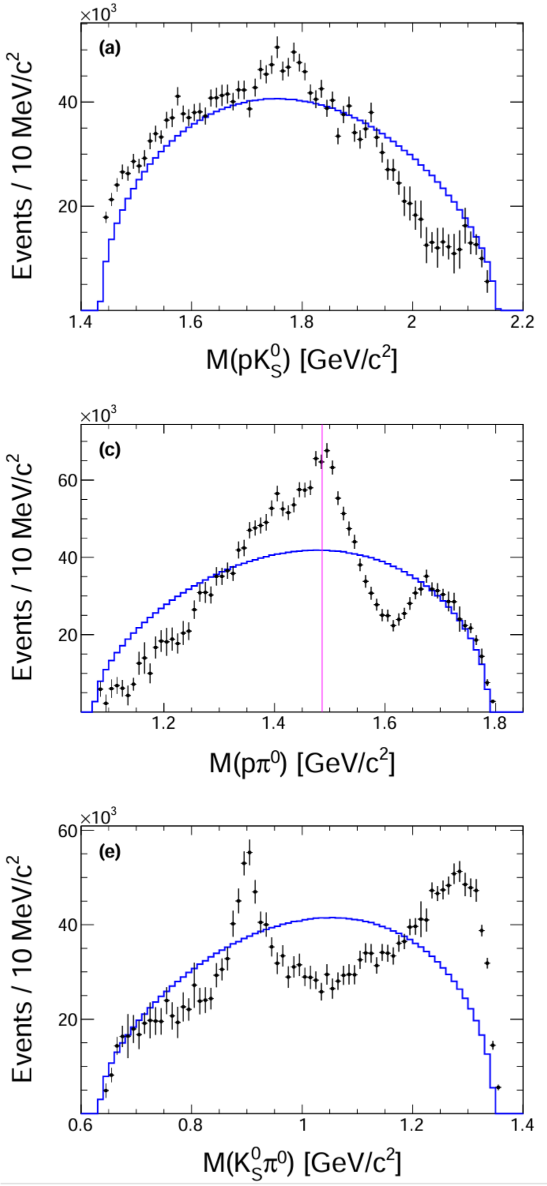
First identification of a threshold cusp in hadrons from the spectrum shape

(See Duan, Bayar and Oset for a theoretical interpretation of this result. Phys. Lett. B 857 (2024), 139003)

Peak at $p\eta$ threshold in $\Lambda_c^+ \to pK_S^0\pi^0$ arXiv:2503.04371



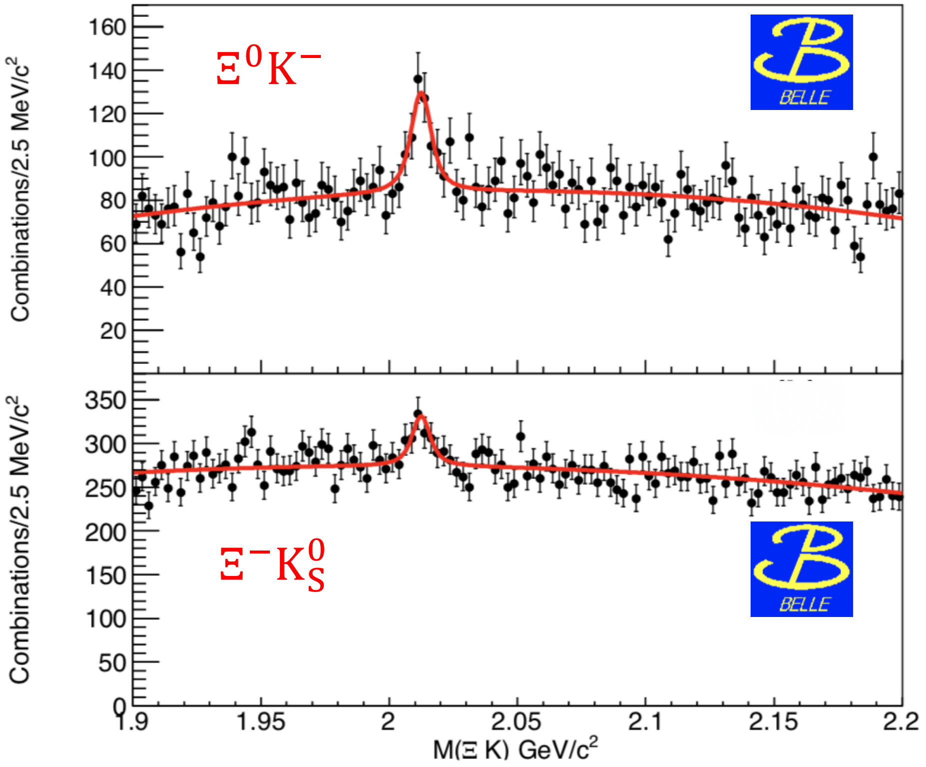




- A clear **peaking structure near the $p\eta$ mass threshold** is evident in the $M(p\pi^0)$ distribution.
- The same effect was observed in the $\Lambda_c^+ \to pK_S^0\eta$ study
- The similarity of this effect and the $\Lambda\eta$ threshold cusp, which was found to be amplified by the $\Lambda(1670)$ in the pK^- system
- Suggesting that the peak near the $p\eta$ threshold may also **be attributed to a threshold cusp enhanced by the N(1535)$^+$.**
- **A further analysis is planned for the near future**

The $\Omega(2012)^-$ baryon

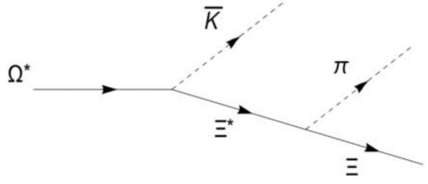
The $\Omega(2012)$ was first observed by Belle in $\Xi\bar{K}$ final states in $\Upsilon(1S, 2S, 3S)$ decays [PRL 121, 052003 (2018)].



The $\Omega(2012)^-$ was interpreted as a standard baryon or a $\Xi(1530)\bar{K}$ molecule.

Model	Comments	References
Standard baryon	The $\Omega(2012)^-$ decays dominantly to $\Xi\bar{K}$.	PRD 98, 034004 (2018), EPJC 78, 894 (2018), PRD 98, 114023 (2018), PRD 101, 016002 (2020), PRD 105, 094006 (2022), PRC 103, 025202 (2021), PRD 98, 014031 (2018), PRD 107, 034015 (2023), PRD 98, 014031 (2018), CPC 47, 063104 (2023), PRD 107, 014025 (2023)
$\Xi(1530)\bar{K}$ molecule	The $\Omega(2012)^-$ decays equally to $\Xi\bar{K}$ and $\Xi(1530)\bar{K}$. Or the $\Xi(1530)\bar{K}$ decay mode is dominant.	PRD 98, 054009 (2018), EPJC 78, 857 (2018), PRD 98, 076012 (2018), JPG 48, 025001 (2021), PRD 98, 056013 (2018), PRD 101, 094016 (2020), EPJC 80, 361 (2020), PRD 102, 074025 (2020), PRD 106, 034022 (2022), Few Body Syst. 64, 55 (2023).

$\Omega(2012)^- \to \Xi(1530)\bar{K}$

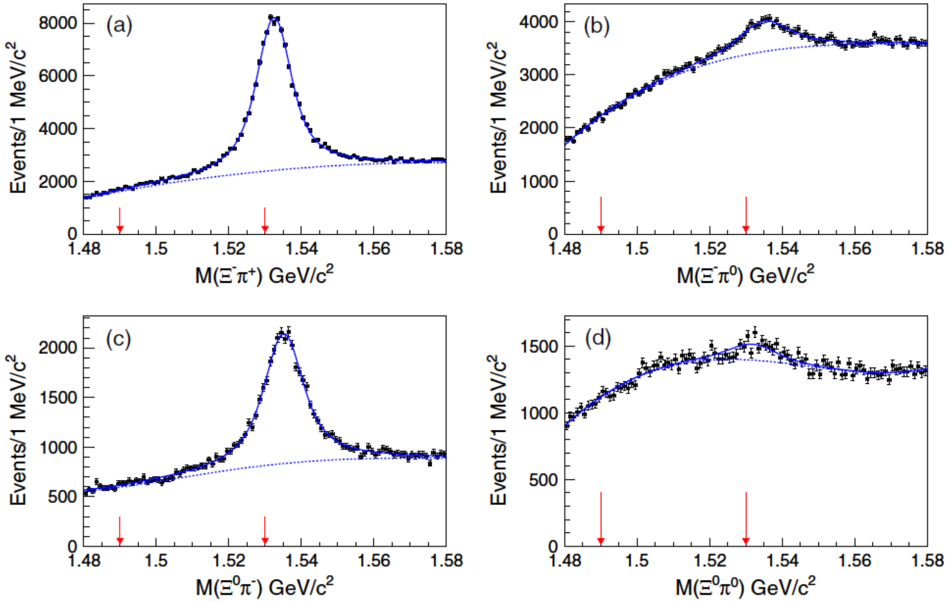


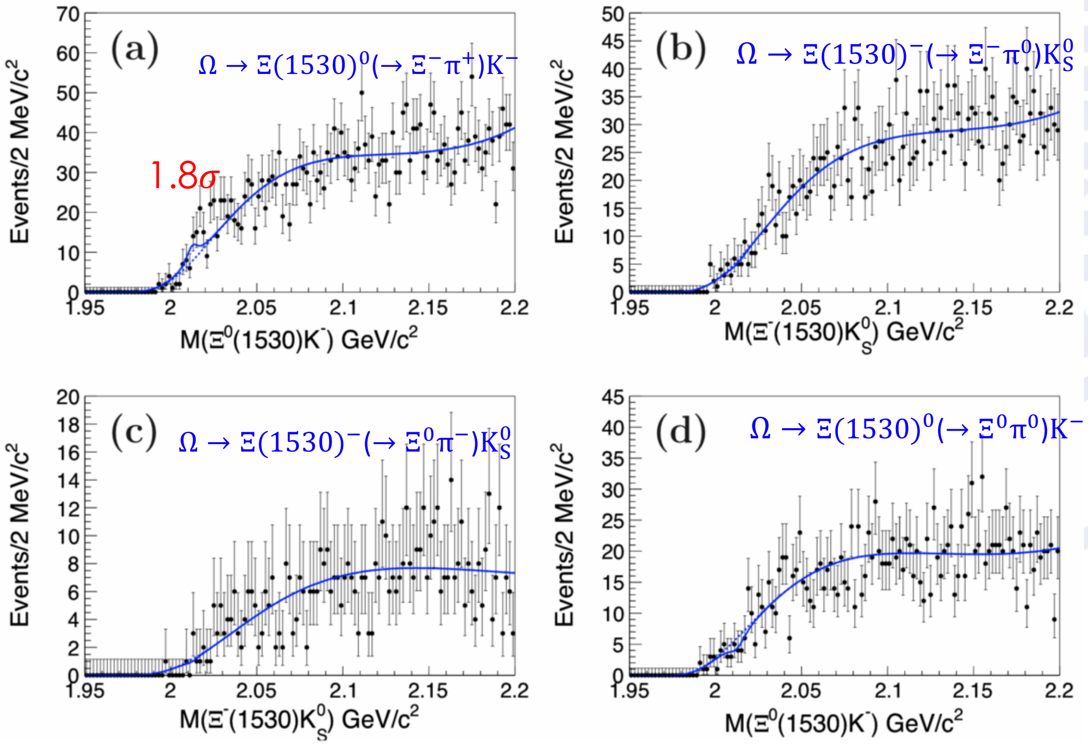
Measurement of the branching fraction for $\Omega(2012)^- \to \Xi(1530)\bar{K}$ is crucial to distinguish the nature of the $\Omega(2012)$!

Search for $\Omega(2012) \to K\Xi(1530) \to K\pi\Xi$

PRD 100, 032006 (2019)

We use the same data samples to search for $\Omega(2012) \to K\Xi(1530) \to K\pi\Xi$ in the decay of the narrow resonances $\Upsilon(1S)$, $\Upsilon(2S)$, and $\Upsilon(3S)$.





No clear $\Omega(2012)$ signals are observed.
We give the upper limit on the ratio of the branching fractions at 90% C.L.

$$R^{\Xi\pi K}_{\Xi K} = \frac{\mathcal{B}(\Omega\to\Xi(1530)(\to\Xi\pi)K)}{\mathcal{B}(\Omega\to\Xi K)} = (6.0\pm3.7(\text{stat.})\pm1.3(\text{syst.}))\%$$

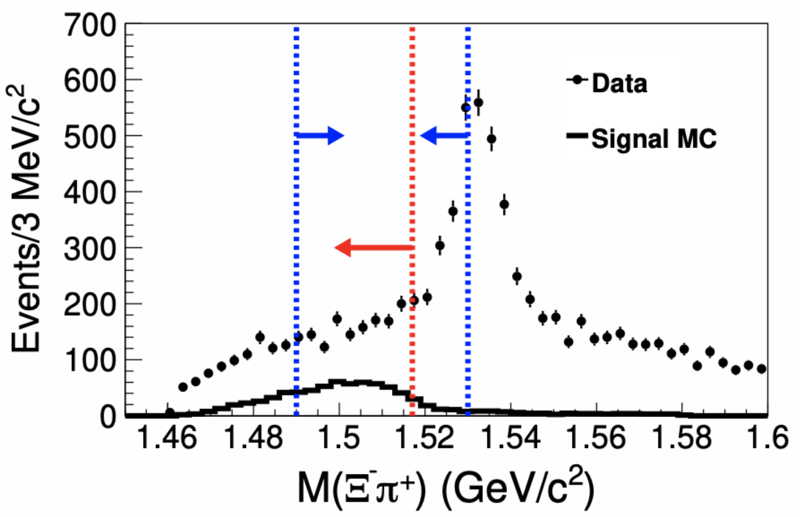
$$R^{\Xi\pi K}_{\Xi K} = \frac{\mathcal{B}(\Omega\to\Xi(1530)(\to\Xi\pi)K)}{\mathcal{B}(\Omega\to\Xi K)} < 11.9\% \text{ at } 90\% \text{ C.L.}$$

Revisit $\Omega(2012)^- \to \Xi(1530)\bar{K} \to \Xi\pi\bar{K}$

PLB 860, 139224 (2025)

The comparisons between the previous analysis [PRD 100, 032006 (2019)] and this work.

Analysis strategy	The previous analysis [40]	This work
The requirement of $M(\Xi\pi)$	$1.49 < M(\Xi\pi) < 1.53$ GeV/c^2	$M(\Xi\pi) < 1.517$ GeV/c^2
The signal shape of $\Omega(2012)^-$	A Breit-Wigner function	A Flatté-like function [41]
ϕ-induced backgrounds	No requirement	$\lvert M(K^-K^+) - m_\phi\rvert > 10$ MeV/c^2



The Flatté-like function [PRD 81, 094028 (2010)]

$$T_n(M) = \frac{g_n k_n(M_n)}{|M_n - m_{\Omega(2012)} + \frac{1}{2}\sum_{j=2,3} g_j[\kappa_j(M_j) + ik_j(M_j)]|^2}$$

- g_n is the effective coupling of to the n–body final state.
- k_n and κ_n parameterize the real and imaginary parts of the $\Omega(2012)^-$self-energy.

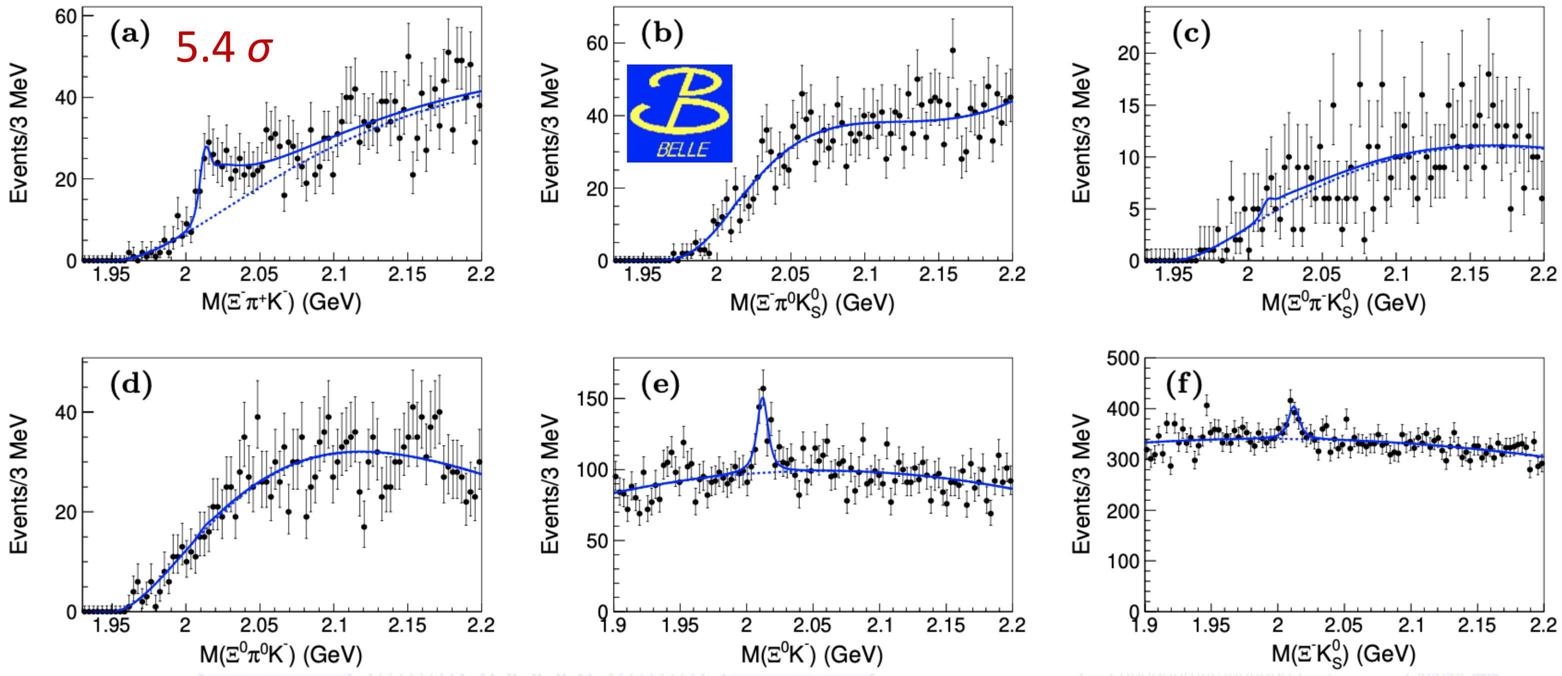
Above 2.02 GeV, the phase space k_3 increases sharply to cover more signal candidates.

The red arrow for this updated work; The blue arrow for the previous analysis.

Revisit $\Omega(2012)^- \to \Xi(1530)\bar{K} \to \Xi\pi\bar{K}$

PLB 860, 139224 (2025)

We fit simultaneously to the binned $\Xi^-\pi^+K^-$, $\Xi^-\pi^0K^0_S$, $\Xi^0\pi^-K^0_S$, $\Xi^0\pi^0K^-$, Ξ^0K^- and $\Xi^-K^0_S$ mass distributions from Υ(1S,2S,3S) data samples.



The mass and effective couplings :

$\Omega(2012)^-$ mass	(2012.5±0.7±0.5) MeV
The coupling to $\Xi\bar{K}$	$(1.7\pm0.3\pm0.3)\times10^{-2}$
The coupling to $\Xi(1530)\bar{K}$	$(39^{+31}_{-39}\pm9)\times10^{-2}$

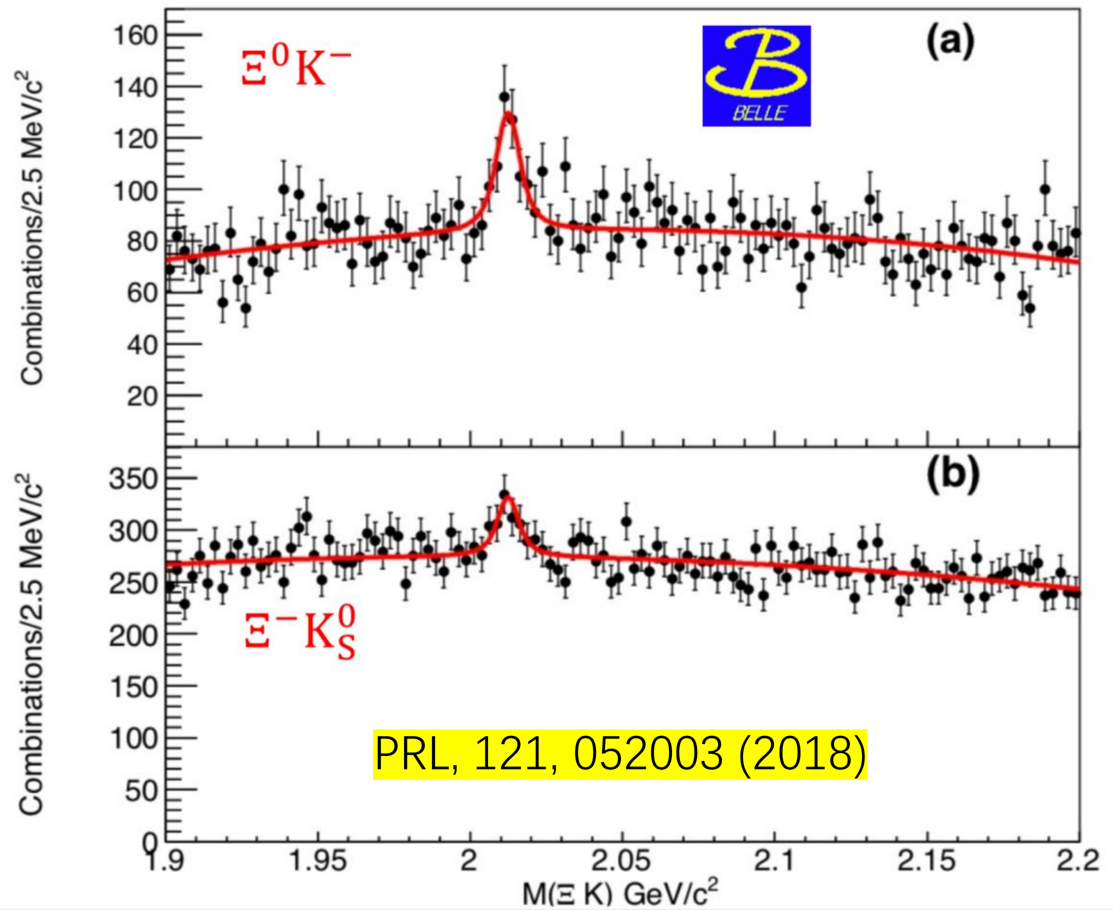
$$\mathcal{R}^{\Xi\pi\bar{K}}_{\Xi\bar{K}} = \frac{\mathcal{B}(\Omega(2012)^- \to \Xi(1530)\bar{K} \to \Xi\pi\bar{K})}{\mathcal{B}(\Omega(2012)^- \to \Xi\bar{K})}$$

0.99±0.26(stat.)±0.06(syst.)

Our result is consistent with the molecular model of $\Omega(2012)^-$, which predicts comparable rates for $\Omega(2012)^-$ decay to $\Xi(1530)\bar{K}$ and $\Xi\bar{K}$.

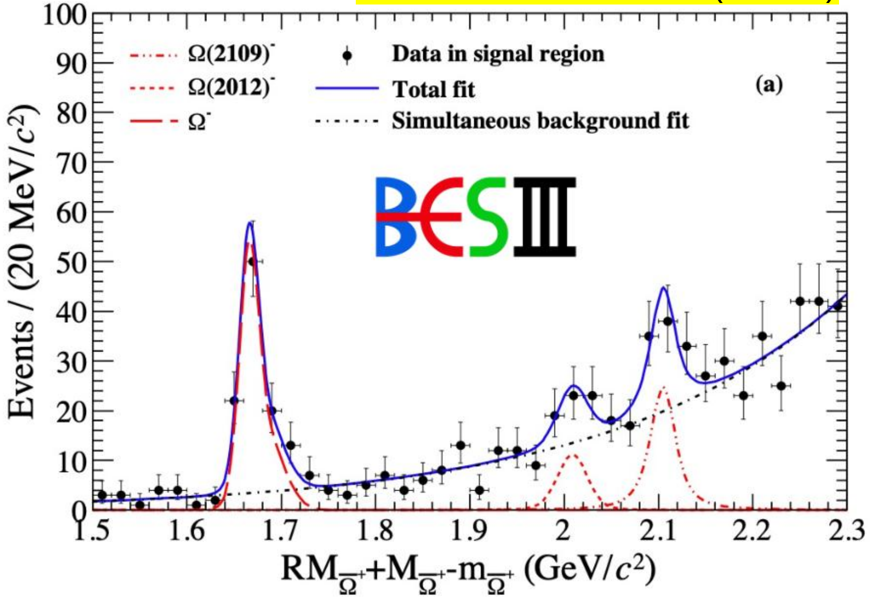
Discovery of $\Omega(2012)^-$

$\Omega(2012)$ was first observed by Belle in two-body (ΞK) decays,
Confirmed by BESIII (low statistics) and ALICE (15σ).

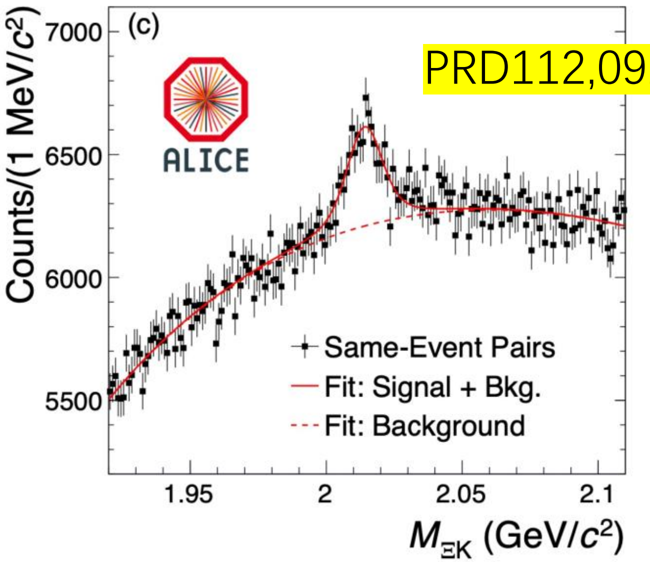


PRL, 121, 052003 (2018)

PRL 134, 131903 (2025)



PRD112,092002(2025)

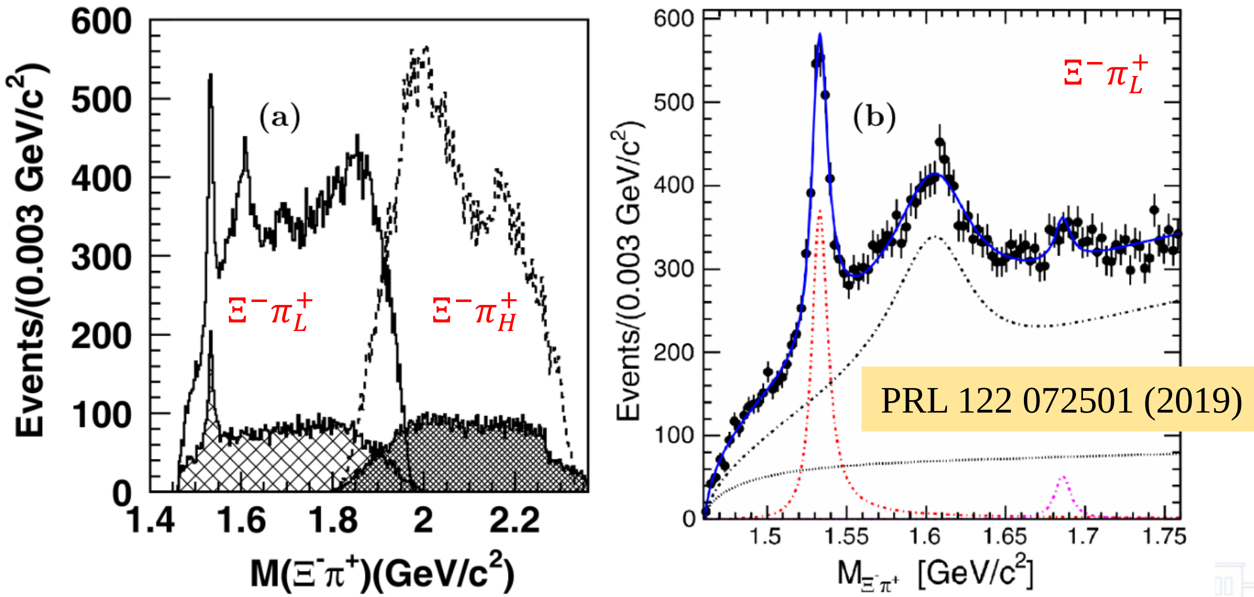


The $\Omega(2012)$ was interpreted as **a $\Xi(1530)\bar{K}$ molecule**.

MC-based PWA of $\Xi_c^+ \to \Xi^-\pi^+\pi^+$

PRD 111, 074039 (2025)

- $\Xi_c^+ \to \Xi^-\pi^+\pi^+$ is a golden channel to study properties of the Ξ^* excited baryons.



Belle has reported a research on this process. They reported:

- first observation of $\Xi(1620)^0$
- 4.0σ evidence of the $\Xi(1690)^0$
- An unknown structure in the range 1.8–2.1 GeV/c^2, expected to be due to resonances such as $\Xi(1820)^0$, $\Xi(1950)^0$, and $\Xi(2030)^0$.

- **The spin-parities of $\Xi(1620)^0$, $\Xi(1950)^0$, and $\Xi(2030)^0$ have not been determined yet.**
- **PWA is one of the best techniques to study the internal dynamics of three-body decays and the large statistic of $\Xi_c^+ \to \Xi^-\pi^+\pi^-$ in Belle (II) makes the PWA possible.**

MC-based PWA of $\Xi_c^+ \to \Xi^-\pi^+\pi^+$

PRD 111, 074039 (2025)

- In this work, we demonstrate the reliability of PWA method for analyzing the $\Xi_c^+ \to \Xi^-\pi^+\pi^+$ decay using the toy MC simulations.

- Decay amplitude of $\Xi_c^+ \to \Xi^*\pi^+, \Xi^* \to \Xi^-\pi^+$ is constructed using the covariant tensor formalism, expressed as:

$$M_i = \bar{u} V_{\Xi^* \to \Xi^-\pi^+} G_{\Xi^*}^{(J^P)} V_{\Xi_c^+ \to \Xi^*\pi^+} u$$

$u(\bar{u})$ is the spinor for a baryon, V is the effective vertex, G is the propagator of the Ξ^* resonance.

- The total decay amplitude of $\Xi_c^+ \to \Xi^-\pi^+\pi^+$ is

$$M = \sum_i c_i M_i$$

- Use maximum likelihood fit. The joint probability density is

$$L = \prod_{i=1}^{N} P(x_i) = \prod_{i=1}^{N} \frac{\omega(x_i)}{\int \omega(x) d\Phi}$$

The differential cross section is given by $\omega(x) = |\sum_i c_i M_i|^2$

We generate a set of toy MC samples using the properties:

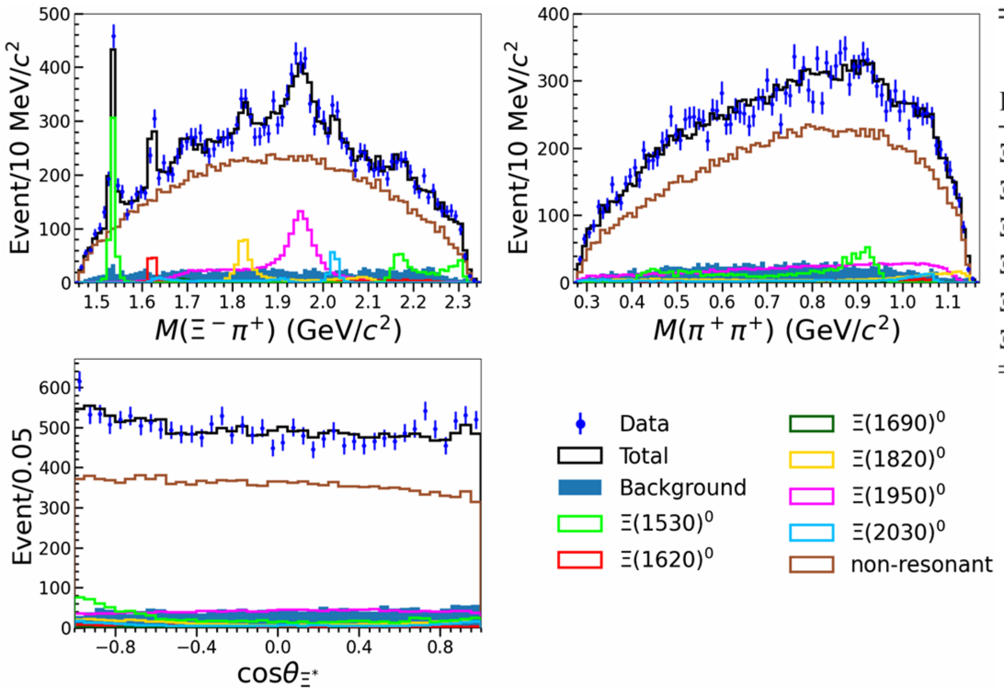
Resonance	Mass (MeV/c^2)	Width (MeV)	J^P
$\Xi(1530)^0$	1531.8	9.1	$\frac{3}{2}^+$
$\Xi(1620)^0$	1620.0	32.0	$\frac{1}{2}^-$
$\Xi(1690)^0$	1690.0	20.0	$\frac{1}{2}^-$
$\Xi(1820)^0$	1823.0	24.0	$\frac{3}{2}^-$
$\Xi(1950)^0$	1950.0	60.0	$\frac{1}{2}^-$
$\Xi(2030)^0$	2025.0	20.0	$\frac{5}{2}^-$

Ratio	$\Xi(1530)^0$	$\Xi(1620)^0$	$\Xi(1690)^0$	$\Xi(1820)^0$	$\Xi(1950)^0$	$\Xi(2030)^0$	non-resonance
$\Xi(1530)^0$	5.4	0.0	0.0	0.0	0.0	0.1	−0.2
$\Xi(1620)^0$		1.3	0.1	0.0	−0.1	0.0	1.4
$\Xi(1690)^0$			0.7	0.0	0.0	0.0	1.1
$\Xi(1820)^0$				2.8	−0.6	0.0	0.1
$\Xi(1950)^0$					9.0	0.0	−0.8
$\Xi(2030)^0$						1.5	0.0
Non-resonance							79.3

MC-based PWA of $\Xi_c^+ \to \Xi^- \pi^+ \pi^+$

PRD 111, 074039 (2025)

Best fit results to toy MC sample



Significances of rejection of alternative J^P_{alt} over favored J^P_{fav}

Resonance	$J^P_{\rm fav}$	$J^P_{\rm alt}$: $\frac{1}{2}^-$	$\frac{1}{2}^+$	$\frac{3}{2}^-$	$\frac{3}{2}^+$	$\frac{5}{2}^-$	$\frac{5}{2}^+$	$\frac{7}{2}^-$	$\frac{7}{2}^+$
$\Xi(1530)^0$	$\frac{3}{2}^+$	10.0σ	9.0σ	2.0σ	...	5.8σ	6.6σ	...	...
$\Xi(1620)^0$	$\frac{1}{2}^-$	...	3.9σ	22.4σ	24.5σ	...	...	...	...
$\Xi(1690)^0$	$\frac{1}{2}^-$	...	1.8σ	24.3σ	22.1σ	...	...	...	...
$\Xi(1820)^0$	$\frac{3}{2}^-$	28.0σ	26.5σ	...	2.8σ	5.8σ	5.7σ	...	...
$\Xi(1950)^0$	$\frac{1}{2}^-$	...	3.2σ	23.3σ	23.8σ	...	...	...	...
$\Xi(2030)^0$	$\frac{5}{2}^-$	...	...	6.3σ	6.0σ	...	2.9σ	11.6σ	8.7σ

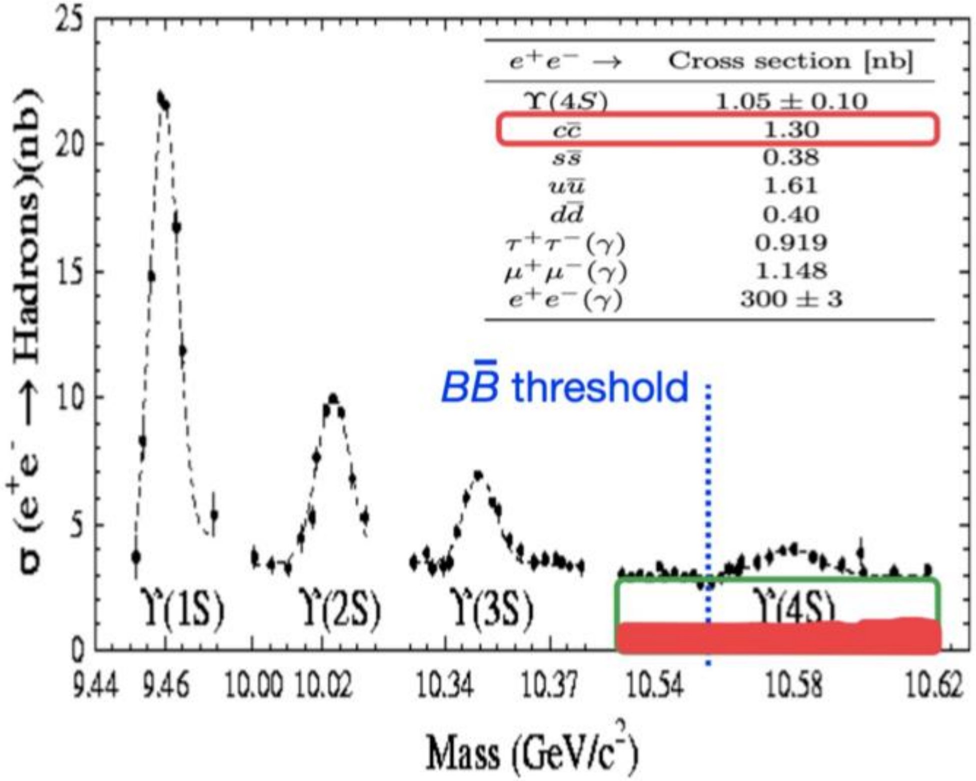
- Based on the current Belle integrated luminosity, the rejection significance of J^P_{alt} over J^P_{fav} is strong for different spins, but weak for different parities.

Further data collection is needed to improve the sensitivity of parity determination in the future, e.g., Belle II.

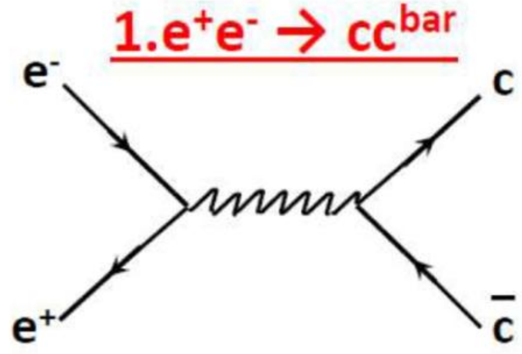
Charm

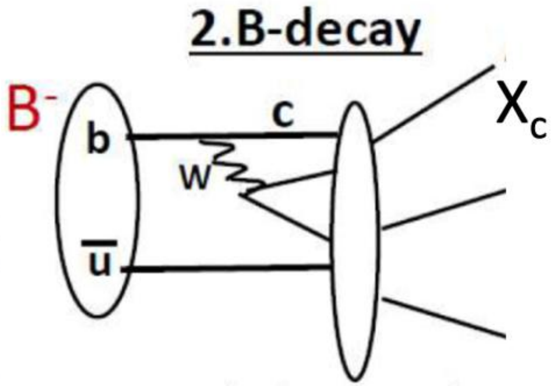
Charm production at Belle II

- At Belle II, e^+e^- mainly collide at 10.58 GeV to make $\Upsilon(4S)$ resonance mainly decaying into $B\bar{B}$.
- Meanwhile, **continuum processes $e^+e^- \to q\bar{q}$ (q = u, d, s, c) have large cross sections**.
- Two ways to produce charm samples: **1) $e^+e^- \to c\bar{c}$, and 2) B → charm decays**.



$e^+e^- \to$	Cross section [nb]
$\Upsilon(4S)$	1.05 ± 0.10
$c\bar{c}$	1.30
$s\bar{s}$	0.38
$u\bar{u}$	1.61
$d\bar{d}$	0.40
$\tau^+\tau^-(\gamma)$	0.919
$\mu^+\mu^-(\gamma)$	1.148
$e^+e^-(\gamma)$	300 ± 3





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 ΔI = 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 ΔI = 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 ΔI= 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 $A_{CP}^{\pi\pi} = A_{raw}^{\pi\pi} - (A_{prod}^{D} + A_{\epsilon}^{\pi})$ → **nuisance asymmetries**

A^D_{prod}: 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 $\cos\theta_{CM}(D^\pm)$.

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

↓ **use $D^+ \to \pi^+ K^0_S$ as a control mode to estimate this**

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

Control mode

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

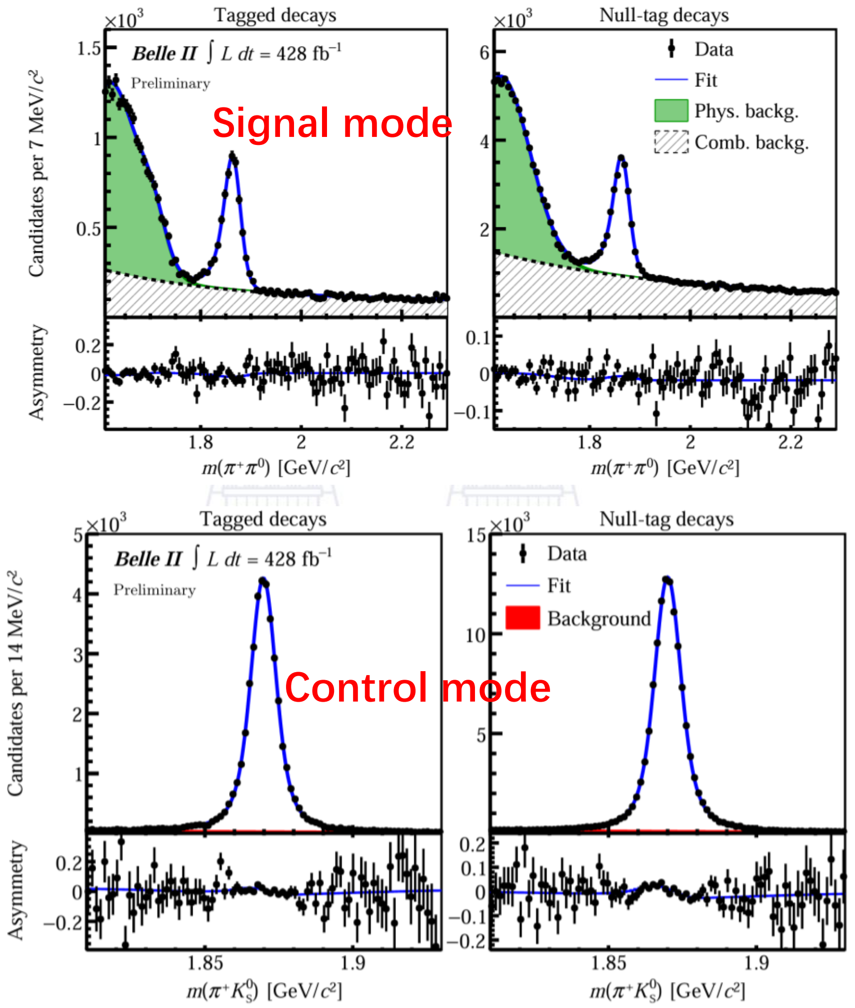
Signal mode

$A_{raw}^{\pi K_S} = A_{K_S} + A^D_{prod} + A^{\pi^\pm}_{\epsilon}$

A_{K_S} → $\sim -0.4\,\%$

$A_{K^0_S}$: 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 $D^+ \to \pi^+\pi^0$



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)%

PRD 112, L031101 (2025)

- 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:

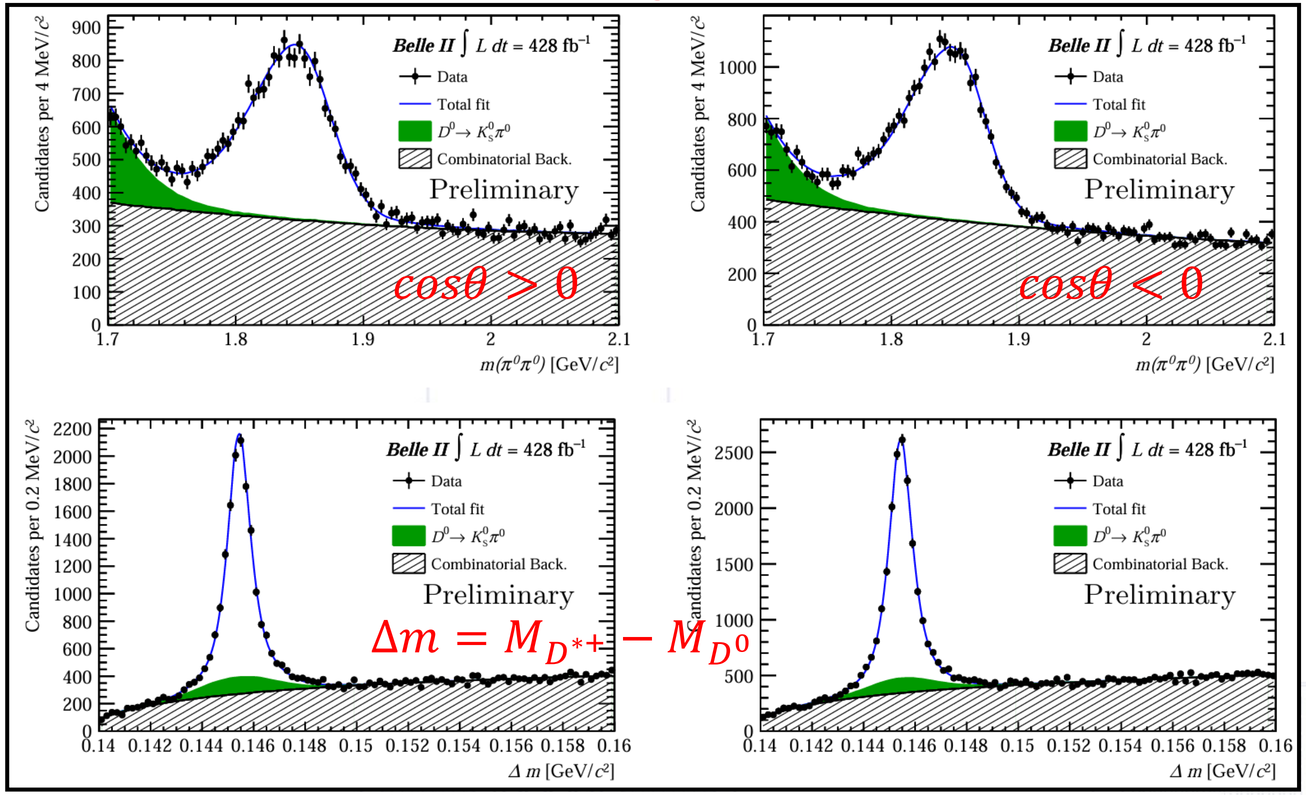
$$A_{CP}(D^+ \to \pi^+\pi^0) = [-1.8 \pm 0.9(stat) \pm 0.1(syst)]\,\%,$$

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

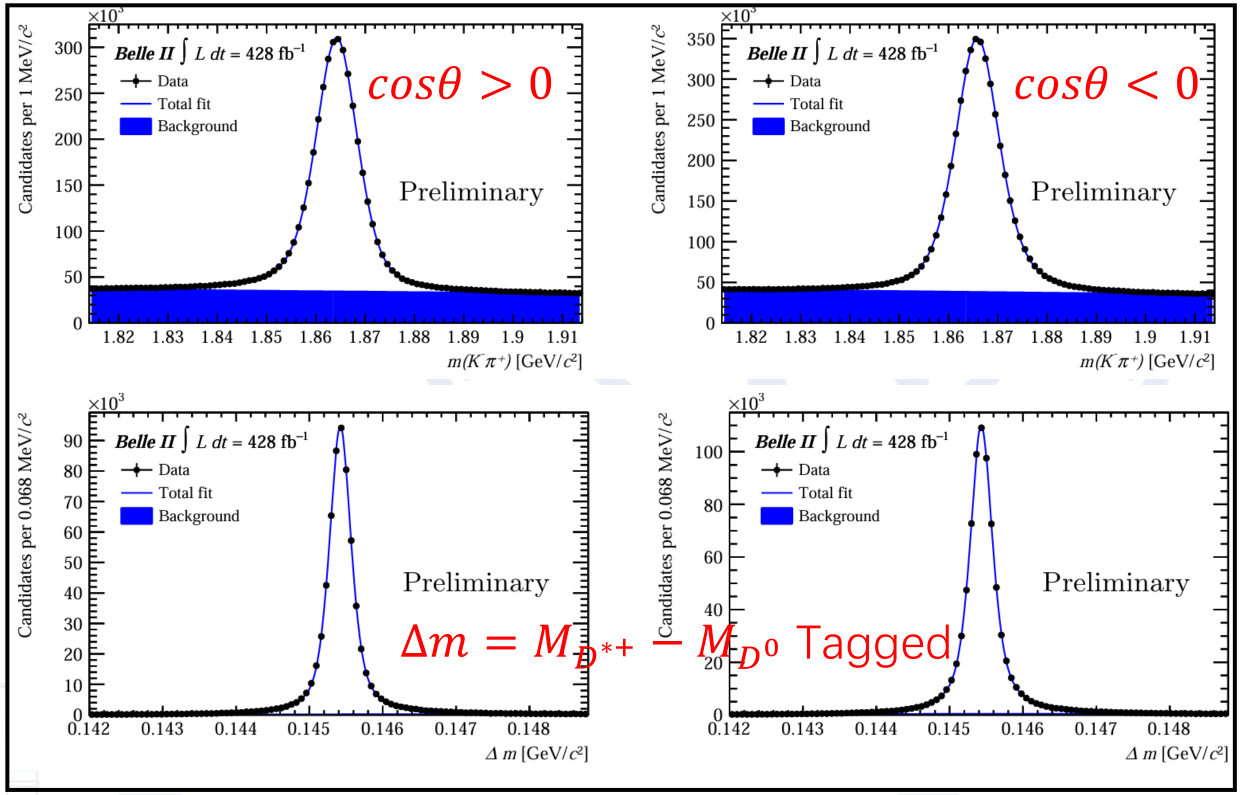
CP asymmetry in $D^0 \to \pi^0\pi^0$

PRD 112, 012006 (2025)

Signal mode



Control mode



- A_{CP} ($D^0 \to \pi^0\pi^0$): (0.30 ± 0.72 ± 0.20) %
  - 15% less precise than the Belle measurement: (0.030 ± 0.64 ± 0.10) % [*Phys. Rev. Lett. 112, 211601 (2014)*]

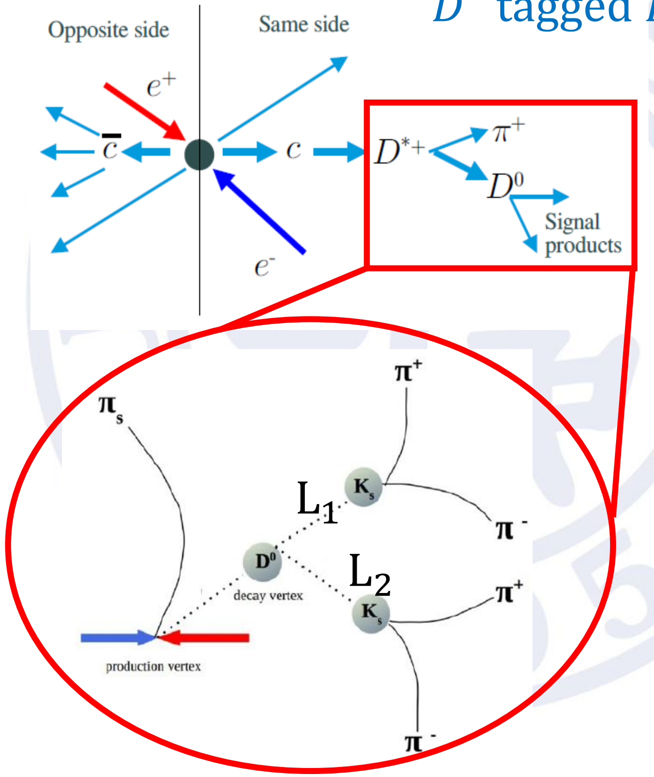
- R= (1.5 ± 2.5) × 10^{-3}, 20% improved precision.
  - The improved precision per luminosity due to Belle II's better reconstruction π^0 .

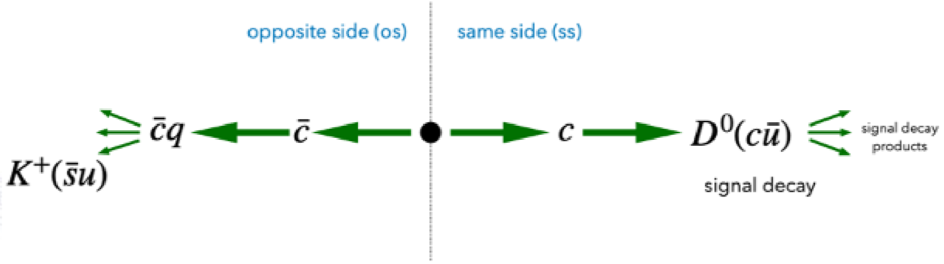
Time-integrated CP asymmetry in $D^0 \to K_S^0 K_S^0$

- Proceeds through color- and Cabibbo-suppressed transition
- Involves the interference between $c \to us\bar{s}$ and $c \to ud\bar{d}$ amplitudes
- Expected CP asymmetry of 1%
- World average:

  $A_{CP}\left(D^0 \to K_S^0 K_S^0\right) = (-1.9 \pm 1.0)\%$, is limited by statistics.
- Belle (980 fb^{-1}) + Belle II (428 fb^{-1}) data are used
- $A_{CP}(D^0 \to K_S^0 K_S^0) = \frac{\Gamma(D^0 \to K_S^0 K_S^0) - \Gamma(\bar{D}^0 \to K_S^0 K_S^0)}{\Gamma(D^0 \to K_S^0 K_S^0) + \Gamma(\bar{D}^0 \to K_S^0 K_S^0)}$
- Two independent measurements:
  - D^* tagged D^0 [Phys.Rev.D 111 (2025) 1, 012015]
    - Important definition: $S_{min}(K_S^0) = \log[\min\left(L_1/\sigma_{L_1}, L_2/\sigma_{L_2}\right)]$
  - Opposite-side flavor tagged D^0 [Phys.Rev.D 112 (2025) 1, 012017]
    - Flavor $q = +1$ for D^0, $q = -1$ for $\bar{D}^0$
    - Dilution factor $r = 1 - 2\omega$ (ω is the mistag probability)

D^* tagged D^0





Opposite-side flavor tagged D^0

Time-integrated CP asymmetry in $D^0 \to K_S^0 K_S^0$ (D^* tagged D^0)

Phys.Rev.D 111 (2025) 1, 012015

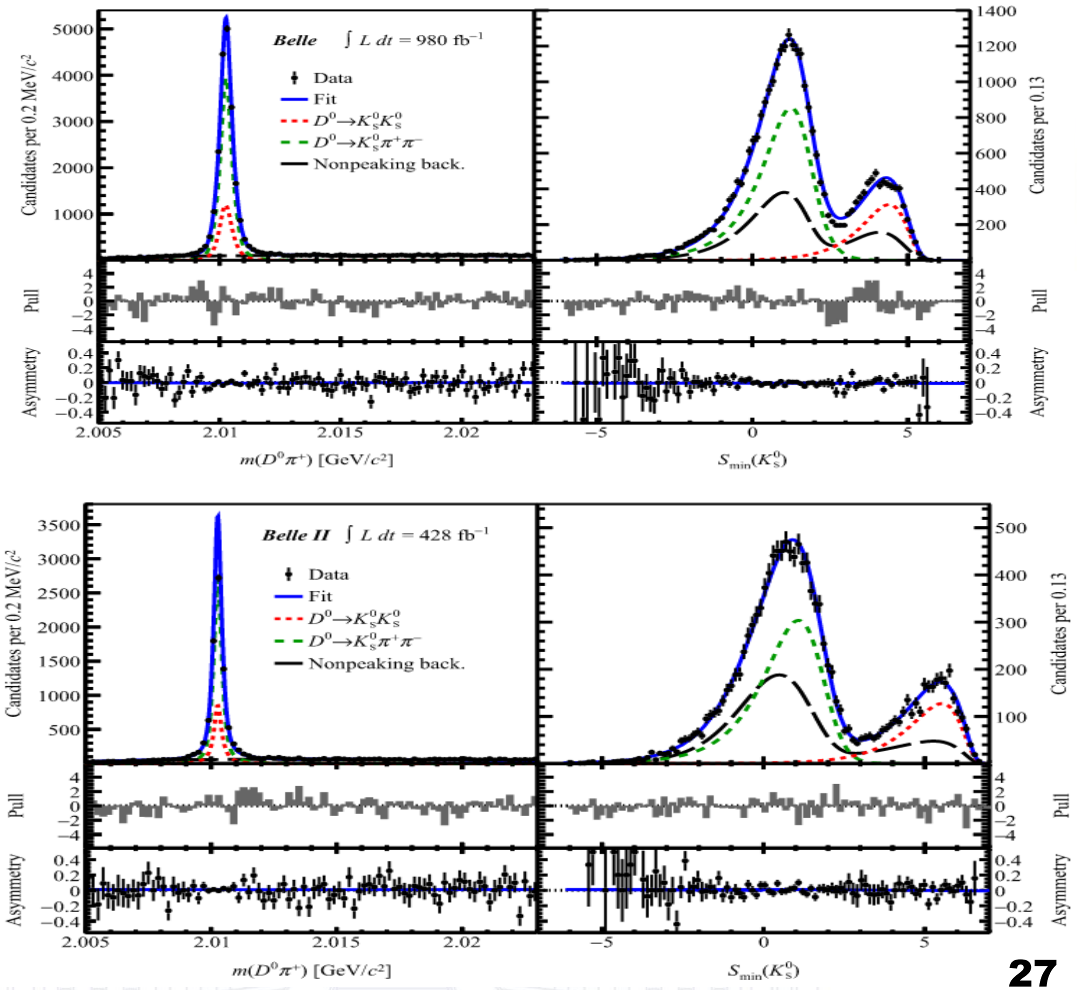
D^* tagged D^0

- Use $D^{*+} \to D^0\pi^+$ to tag flavor
- Determine production and detection asymmetries using $D^0 \to K^+K^-$

$$A_{raw}^{K_S^0K_S^0} = \frac{N(D^0 \to K_S^0K_S^0) - N(\overline{D}^0 \to K_S^0K_S^0)}{N(D^0 \to K_S^0k_S^0) + N(\overline{D}^0 \to K_S^0K_S^0)}$$
$$= A_{CP} + A_P^D + A_\epsilon^{\pi_s}$$

$$A_{CP}(D^0 \to K_S^0K_S^0) = A_{raw}^{K_S^0K_S^0} - A_{raw}^{K^+K^-} + A_{CP}(D^0 \to K^+K^-)$$

- Main background: $D^0 \to K_S^0\pi^+\pi^-$, separated by S_{min}
- 2D extended UML fit to $m(D^0\pi^+)$ and $S_{min}(K_S^0)$
- Belle: $A_{CP} = (-1.1 \pm 1.6(\text{stat.}) \pm 0.1(\text{syst.}))\%$
- Belle II: $A_{CP} = (-2.2 \pm 2.3(\text{stat.}) \pm 0.1(\text{syst.}))\%$
- Belle + Belle II: $A_{CP} = (-1.4 \pm 1.3(\text{stat.}) \pm 0.1(\text{syst.}))\%$



Time-integrated CP asymmetry in $D^0 \to K_S^0 K_S^0$ (Opposite-side flavor tagged D^0)

Phys.Rev.D 112 (2025) 1, 012017

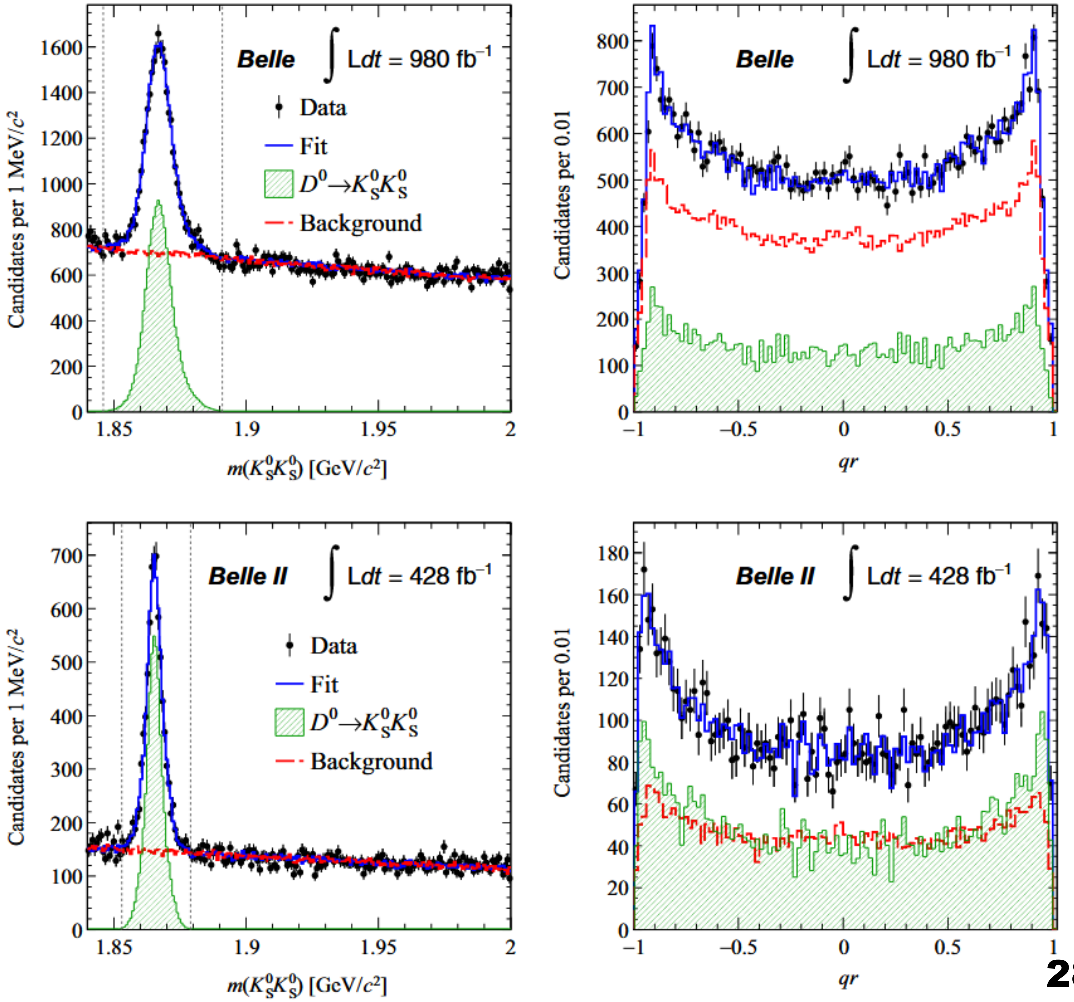
Opposite-side flavor tagged D^0

- Use information from the other tracks in the event to tag flavor
- Remove all the candidates in used in the D^* tagged measurement
- Background from partially reconstructed $D_s^+ \to K_S^0 K_S^0 \pi^+$ (peak at lower mass values)
- 2D extended UML fit to $m(K_S^0 K_S^0)$ and qr
- Belle: $A_{CP} = (2.5 \pm 2.7(\text{stat.}) \pm 0.4(\text{syst.}))\%$
- Belle II: $A_{CP} = (-0.1 \pm 3.0(\text{stat.}) \pm 0.3(\text{syst.}))\%$
- Belle + Belle II: $A_{CP} = (1.3 \pm 2.0(\text{stat.}) \pm 0.2(\text{syst.}))\%$
- Combined two tag methods:

$$A_{CP} = (-0.6 \pm 1.1(\text{stat.}) \pm 0.1(\text{syst.}))\%$$

The most precise determination to the date.

Agree with results from other experiments.



Charm CPV

Search for Charm CPV in following channels:

2025 Published and to be published!

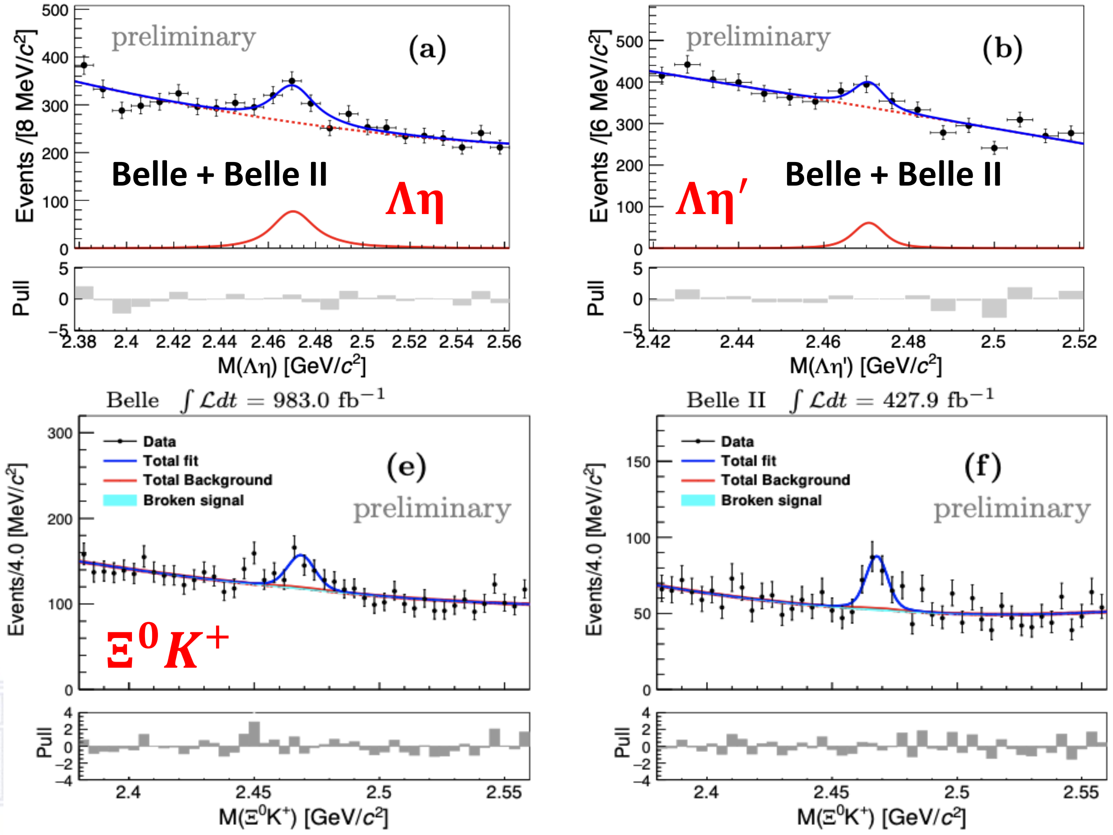
Channel	A_{CP}	References
$D^0 \to \pi^0\pi^0$	(+0.3±0.7±0.2)%	PRD 112, 012006 (2025)
$D^+ \to \pi^+\pi^0$	(−1.8±0.9±0.1)%	PRD 112, L031101 (2025)
$D^0 \to \pi^+\pi^-\pi^0$	(0.3±0.3±0.1)%	Preliminary result
$D^0 \to K_S^0K_S^0$	(−0.6±1.1±0.1)%	PRD 111, 012015 (2025), PRD 112, 012017 (2025)
$D^+, D_s^+ \to K_S^0K^-\pi^+\pi^+$	(+3.9±4.5±1.1)%, (−0.2±2.5±1.1)%	JHEP 04 (2025) 036
$\Lambda_c^+ \to \Lambda K^+, \Sigma^0K^+$	(+2.1±2.6±0.1)%, (+2.5±5.4±0.4)%	Sci. Bull. 68 (2023) 583
$\Lambda_c^+ \to pK^+K^-, p\pi^+\pi^-$	(+3.9±1.7±0.7)%, (+0.3±1.0±0.2)%	Preliminary result
$\Xi_c^+ \to \Sigma^+K^+K^-, \Sigma^+\pi^+\pi^-$	(+3.7±6.6±0.6)%, (+9.5±6.8±0.5)%	Preliminary result

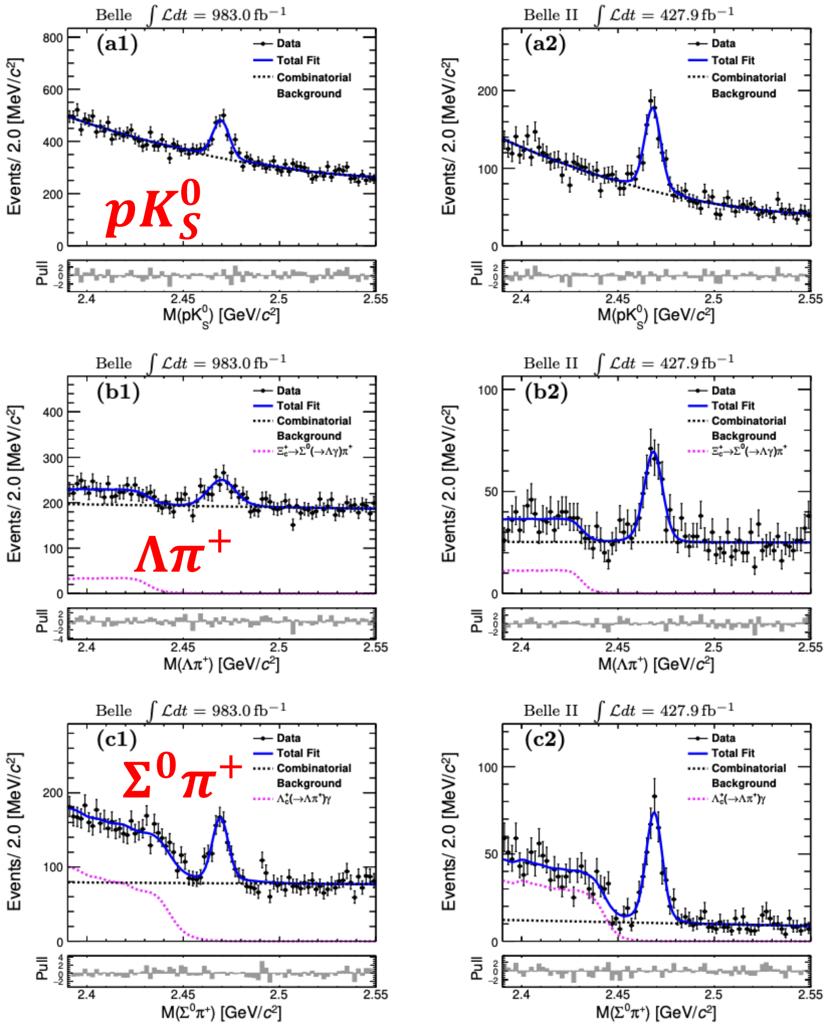
Ξ_c^+ and Ξ_c^0 decays

$e^+e^- \to \Xi_c^+/\Xi_c^0$ + anything

Reconstruct:

- $\Xi_c^0 \to \Lambda\eta$, $\Xi_c^0 \to \Lambda\eta'$ (singly Cabibbo-suppressed (SCS))
- $\Xi_c^+ \to \Xi^0 K^+$, $\Xi_c^+ \to pK_S^0$, $\Xi_c^+ \to \Lambda\pi^+$, $\Xi_c^+ \to \Sigma^0\pi^+$ (SCS)

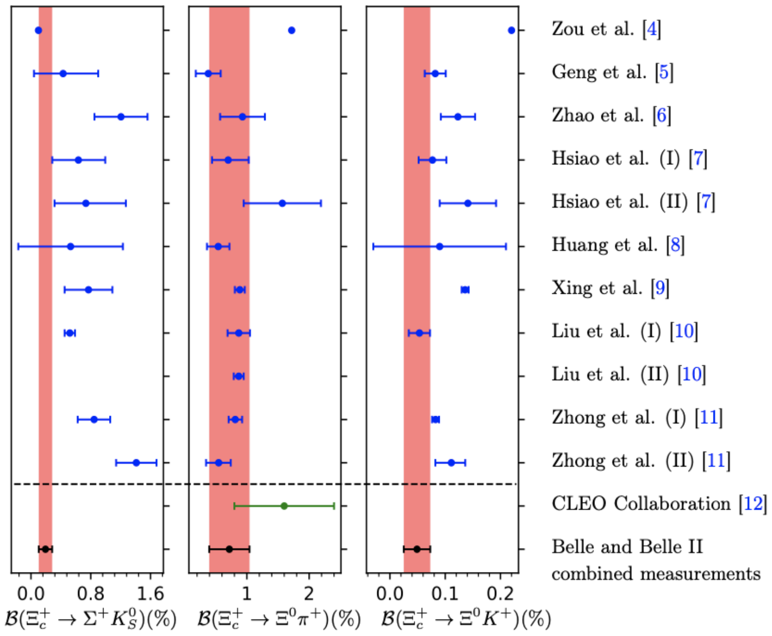




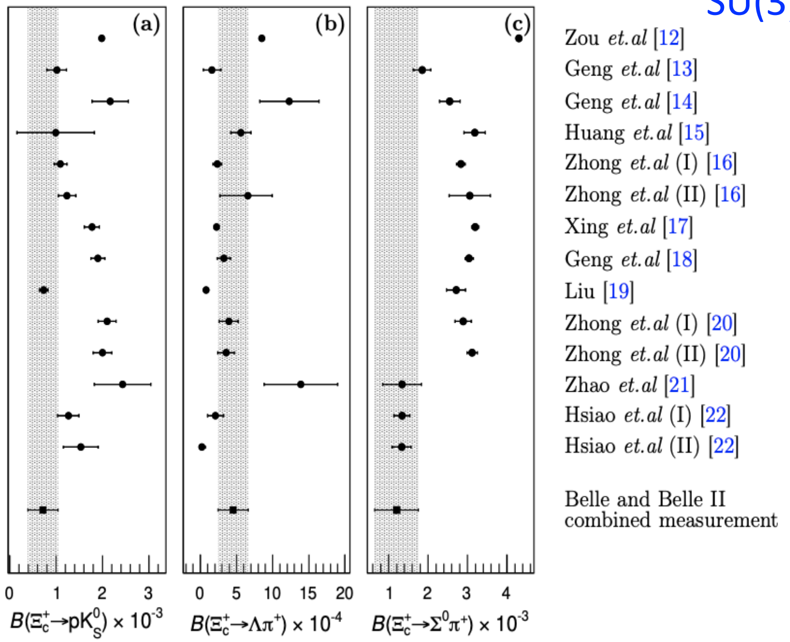
Branching fractions

First or most precise measurements!

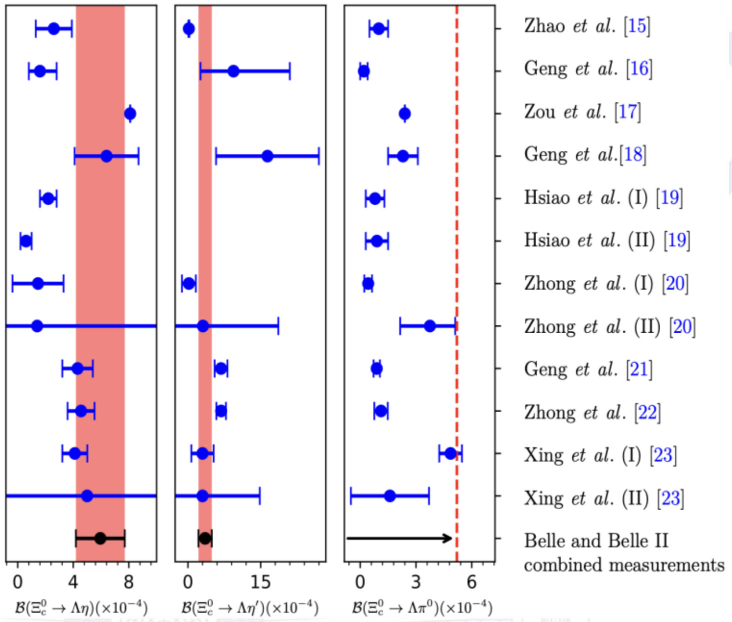
[JHEP 08 (2025) 195]



[JHEP 03 (2025) 061]



- [illegible] essential role and cannot be neglected.
- [illegible] model, the pole model (Pole), current algebra (CA), and, $SU(3)_F$ flavor symmetry.



Next steps: 1. Explore three-body decays; 2. Amplitude analyses to search for new intemediate states and identify J^P.

arXiv:2510.20882

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

arXiv:2509.25765

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}:

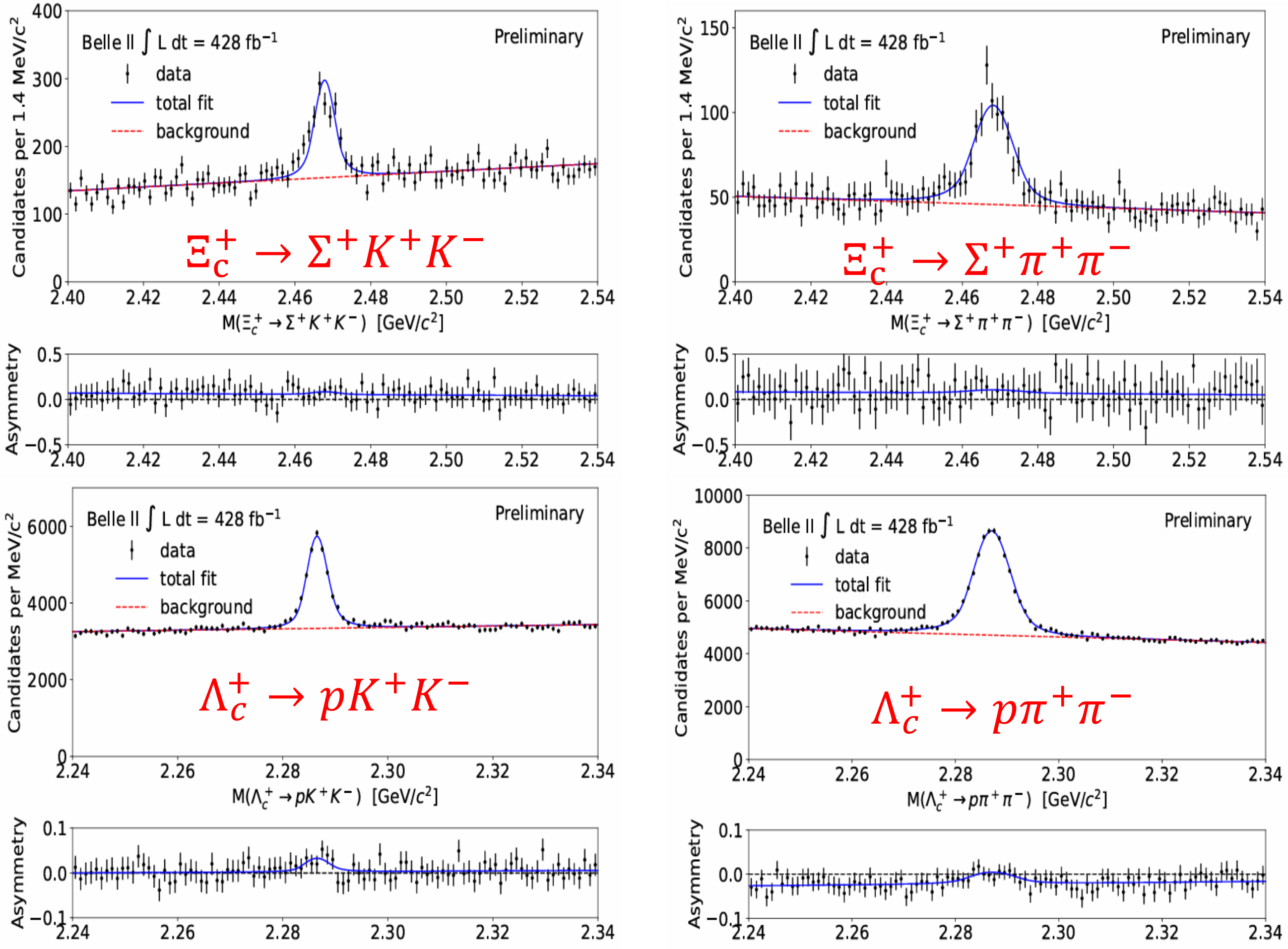
$$A_{CP}(\Xi_c^+ \to \Sigma^+ K^+ K^-) = (3.7 \pm 6.6 \pm 0.6)\%,$$
$$A_{CP}(\Xi_c^+ \to \Sigma^+ \pi^+ \pi^-) = (9.5 \pm 6.8 \pm 0.5)\%,$$
$$A_{CP}(\Lambda_c^+ \to p K^+ K^-) = (3.9 \pm 1.7 \pm 0.7)\%,$$
$$A_{CP}(\Lambda_c^+ \to p \pi^+ \pi^-) = (0.3 \pm 1.0 \pm 0.2)\%,$$

first A_{CP} for 3-body SCS

U-spin symmetry with 7% precision:

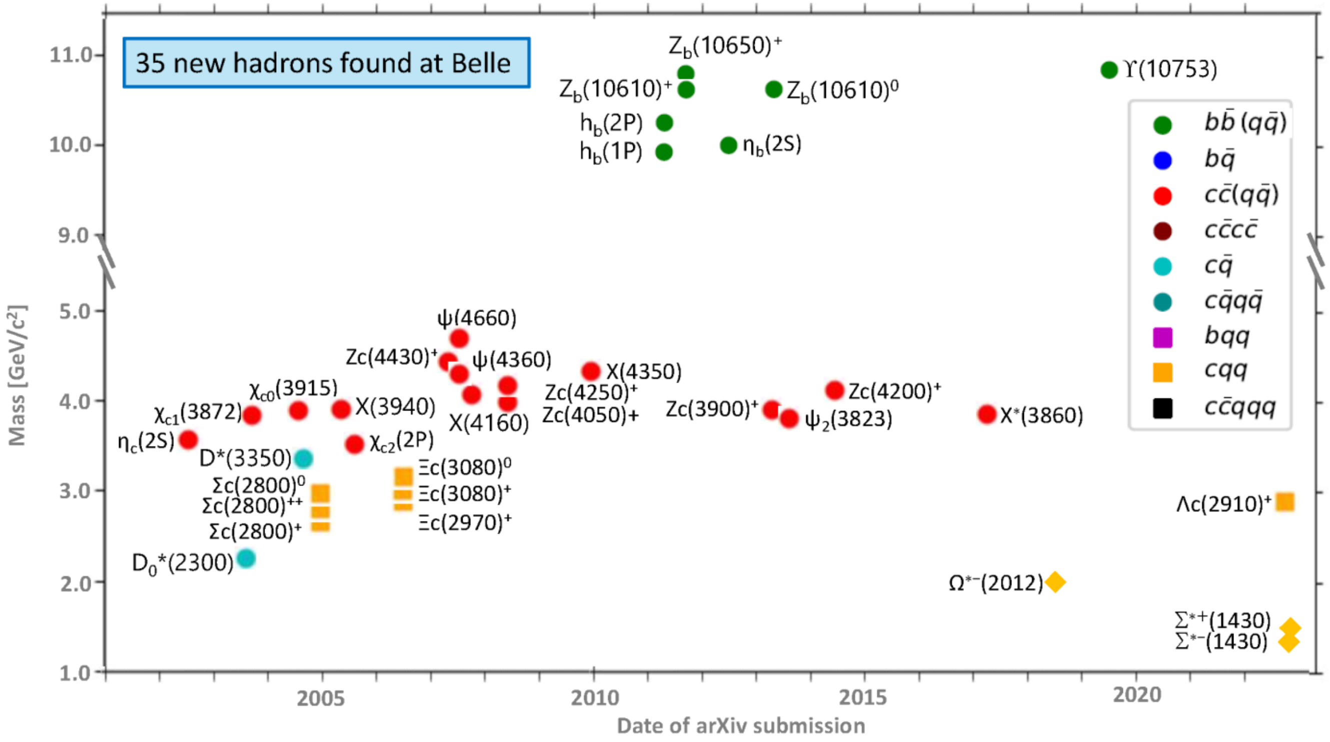
$$A_{CP}(\Xi_c^+ \to \Sigma^+ \pi^+ \pi^-) + A_{CP}(\Lambda_c^+ \to p K^+ K^-) = (13.4 \pm 7.0 \pm 0.9)\%,$$
$$A_{CP}(\Xi_c^+ \to \Sigma^+ K^+ K^-) + A_{CP}(\Lambda_c^+ \to p \pi^+ \pi^-) = (\ 4.0 \pm 6.6 \pm 0.7)\%,$$

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



Exotic states

New hadrons found at Belle(II)



Belle II has been designed to make precise measurements of **weak interaction parameters,** study exotic hadrons, and search for **new phenomena** beyond the Standard Model of particle physics.

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

$D_{s0}^{*}(2317)^{\pm}$ **DECAY MODES**

$D_{s0}^{*}(2317)^{-}$ modes are charge conjugates of modes below.

	Mode	Fraction (Γ_i/Γ)	Scale Factor/ Conf. Level	P(MeV/c)
Γ_1	$D_s^+\pi^0$	(100^{+0}_{-20}) %		298
Γ_2	$D_s^+\gamma$	<5 %	CL=90%	323
Γ_3	$D_s^*(2112)^+\gamma$	<6 %	CL=90%	
Γ_4	$D_s^+\gamma\gamma$	<18 %	CL=95%	323
Γ_5	$D_s^*(2112)^+\pi^0$	<11 %	CL=90%	
Γ_6	$D_s^+\pi^+\pi^-$	$< 4 \times 10^{-3}$	CL=90%	194
Γ_7	$D_s^+\pi^0\pi^0$	not seen		205

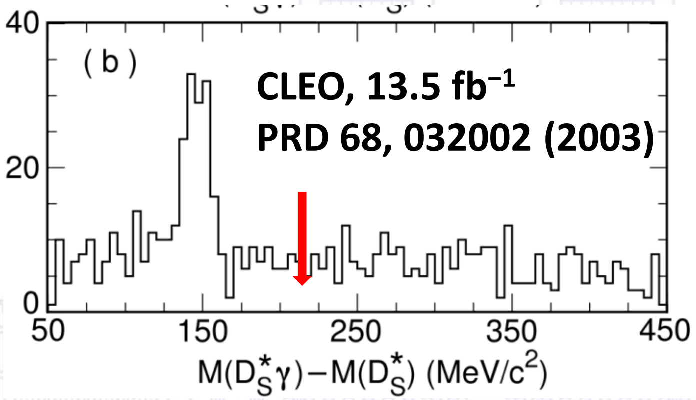
Mass of $D_{s0}^{*}(2317)^{+}$ is much lower than the quark model predictions of the lowest $c\bar{s}$ mesons with $J^P = 0^+$

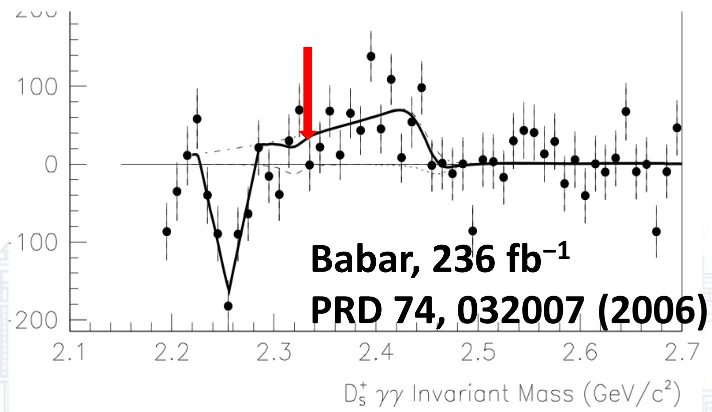
- **Modifying the $c\bar{s}$ quark model**
- **D^*K hadronic molecule**
- **Compact tetraquarks**
- **Chiral partners of the ground state D_s^* meson**

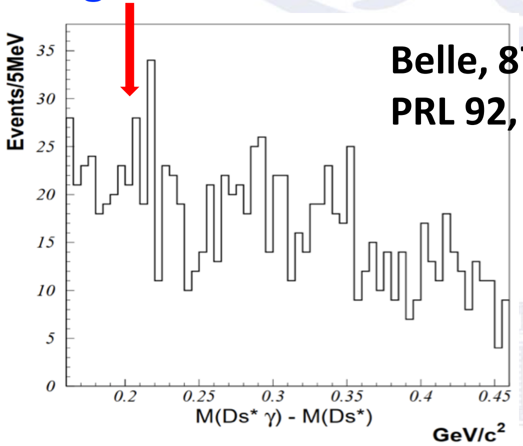
Partial decay widths:
unique in discriminating between various models

The $D_{s0}^{*}(2317)^{+} \to D_s^+\pi^0$ was first observed by BaBar in 2006 [PRL 90, 242001 (2003)].

The $D_{s0}^{*}(2317)^{+} \to D_s^{*+}\gamma$ was searched from by CLEO, Belle, and BaBar, but no signals were found.



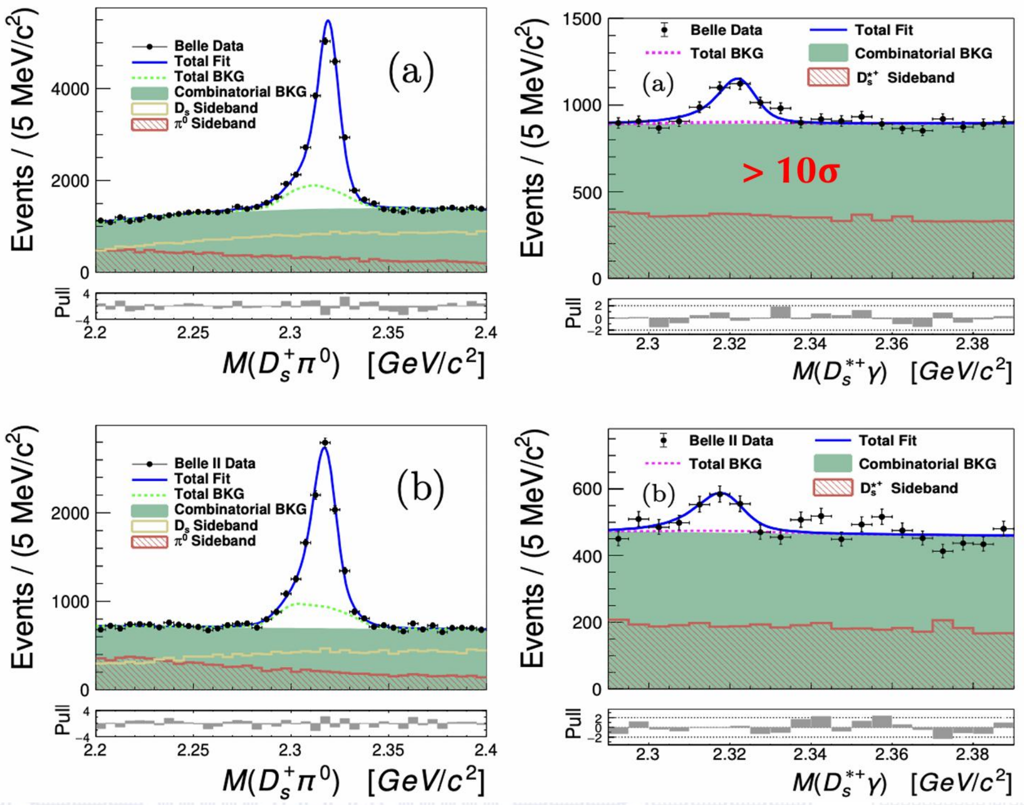




First observation of $D_{s0}^{*}(2317)^{+} \to D_s^{*+}\gamma$

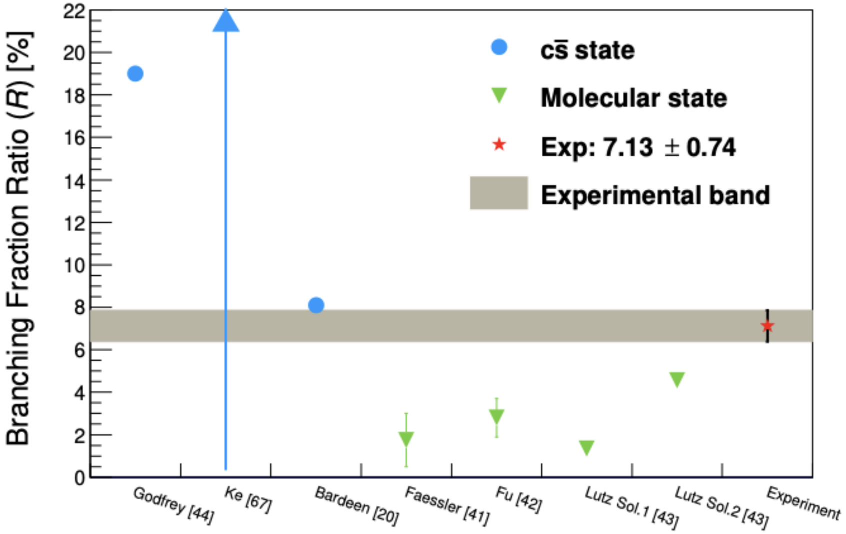
arXiv: 2510.27174

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



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

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



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

- Using all Belle data (983 fb^{-1}) and Belle II data (427 fb^{-1})

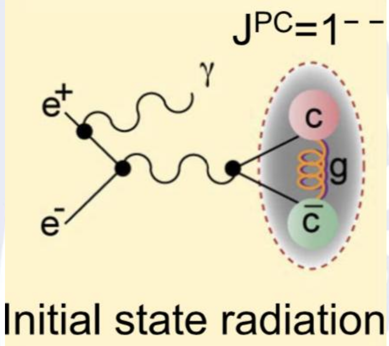
$e^+e^- \to h^+h^-J/\psi$ (h = π, K, p) via initial-state radiation (ISR) at Belle II

Adavantages of ISR:

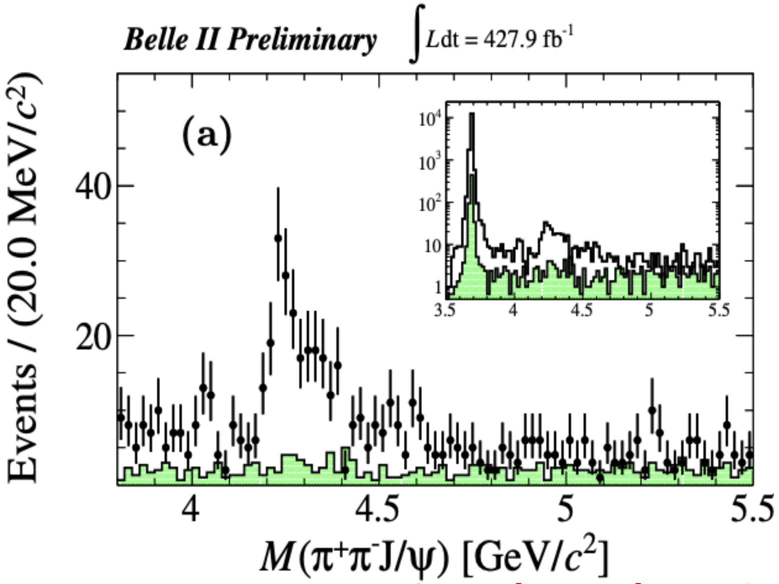
- Allows to study energies below $E_{c.m.}$
- Wide energy range available
- Measure more precisely the line-shapes

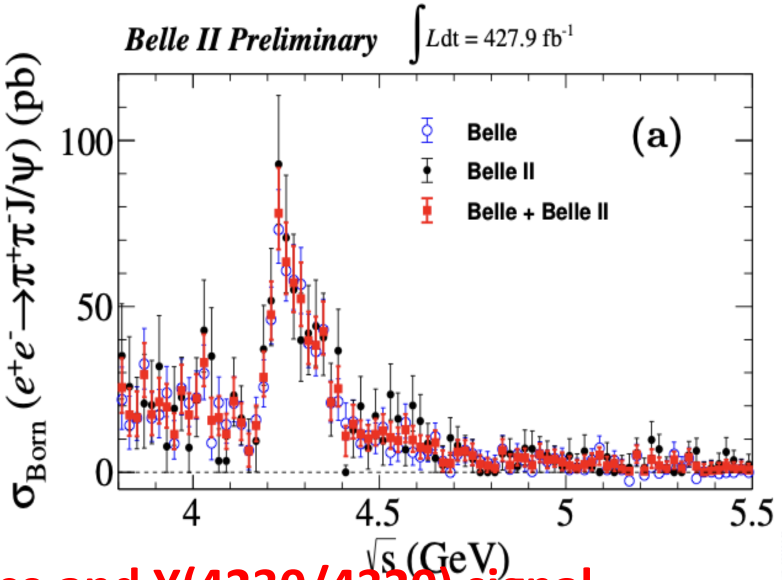
Disadvantages of ISR:

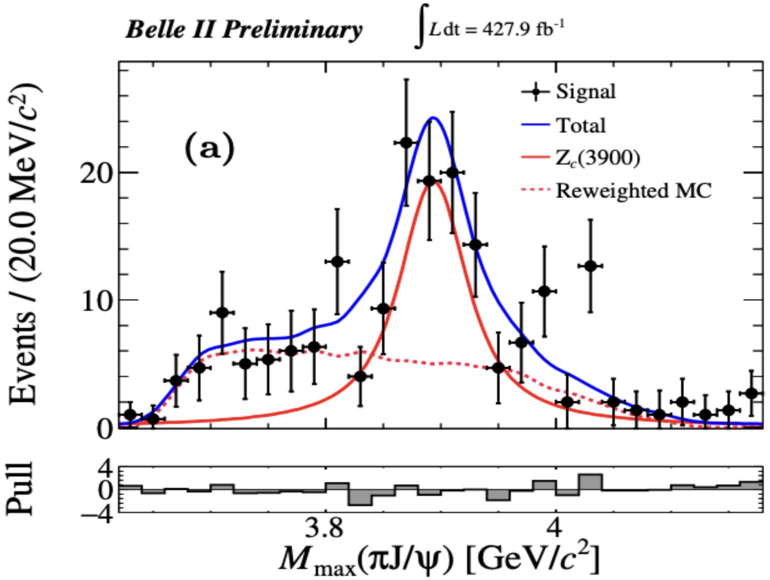
- The effective integrated luminosity decreases as the c.m. energy decreases
- The detection efficiency is also smaller



$e^+e^- \to \pi^+\pi^-J/\psi$ via ISR:

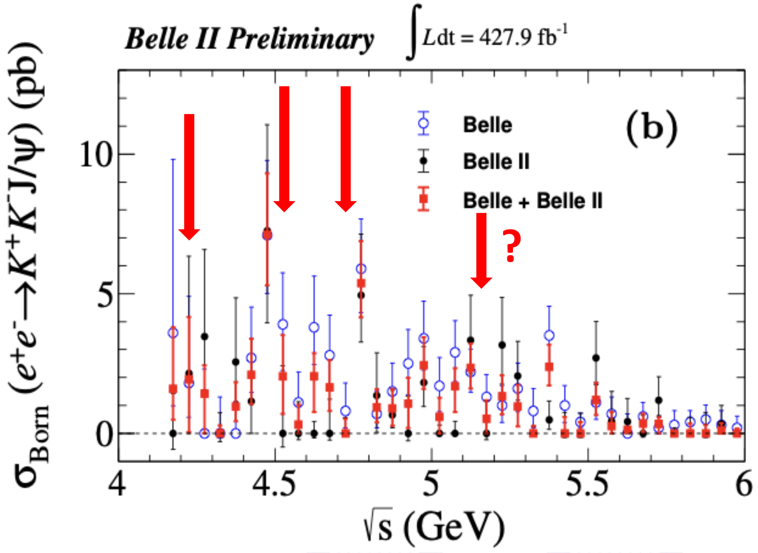




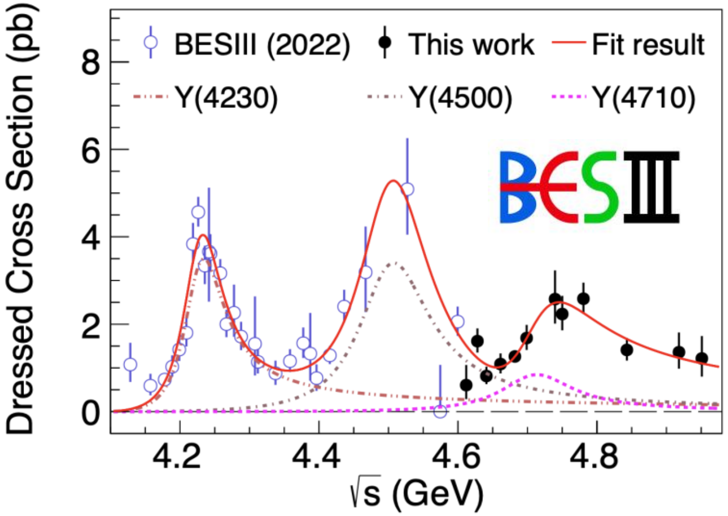


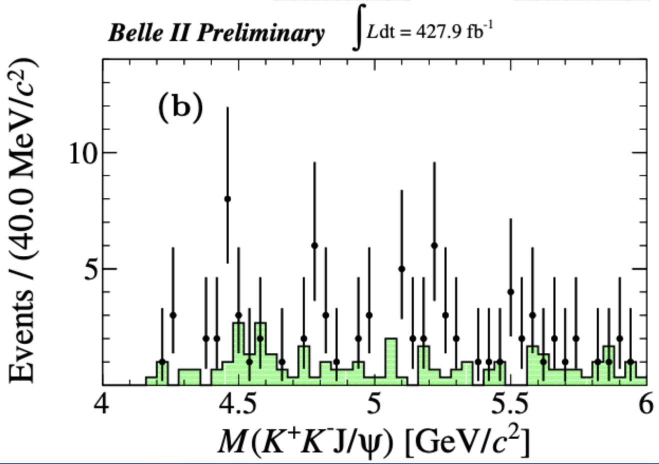
- **We can see the Y(4008) evidence and Y(4230/4320) signal.**
- **The significance of $Z_c(3900)$ is 5.3σ.**

$e^+e^- \to K^+K^-J/\psi$ via ISR:



PRL 131, 211902 (2023)

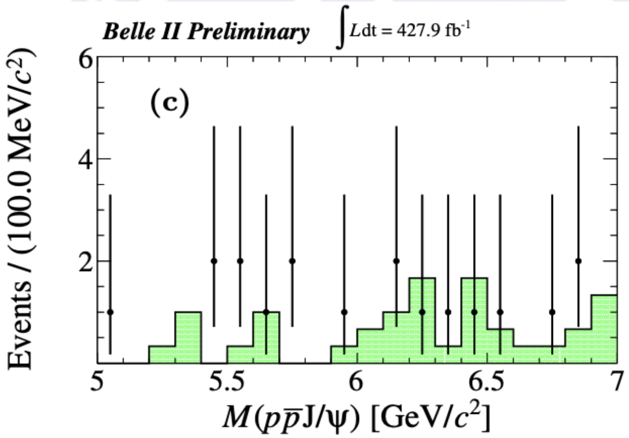


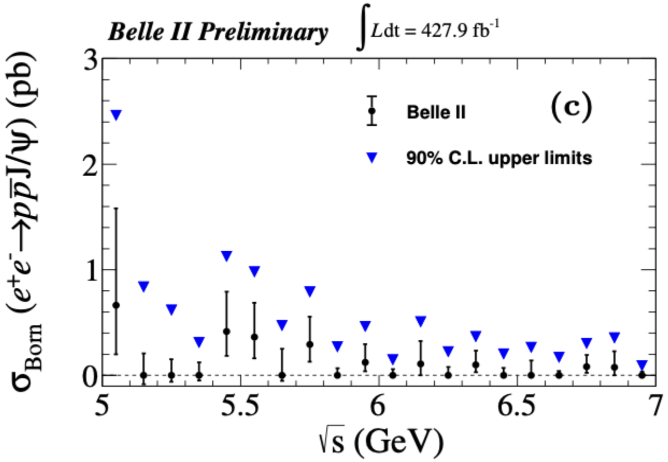


- No clear signals were observed at Belle II.
- More data are needed.

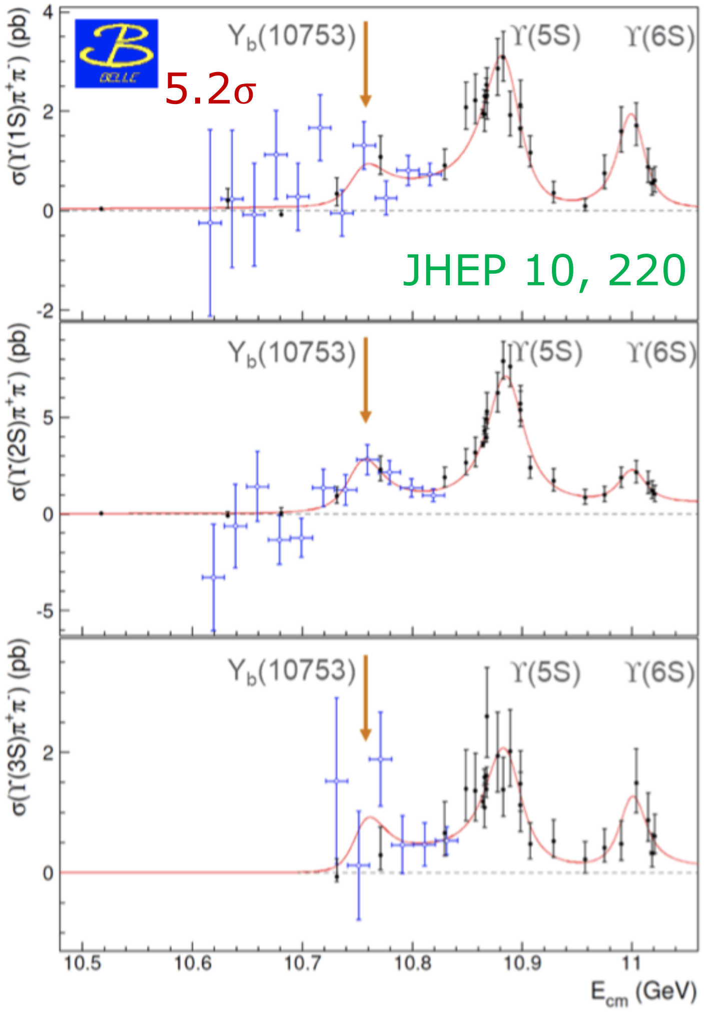
$e^+e^- \to p\bar{p}J/\psi$ via ISR:

The cross section for $e^+e^- \to P_c\bar{p}$ is estimated to be $\lesssim \mathcal{O}$(0.1 pb) [arXiv: 2508.08694].





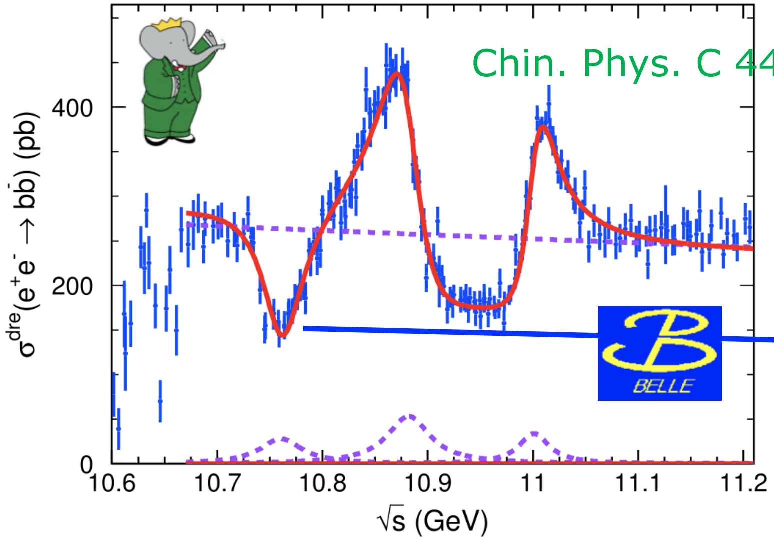
Discovery of $\Upsilon(10753)$



JHEP 10, 220 (2019)

- Belle: several ~$1fb^{-1}$ scan points below $\Upsilon(5S)$
- New structure observed in $\pi^+\pi^-\Upsilon(nS)$ transitions

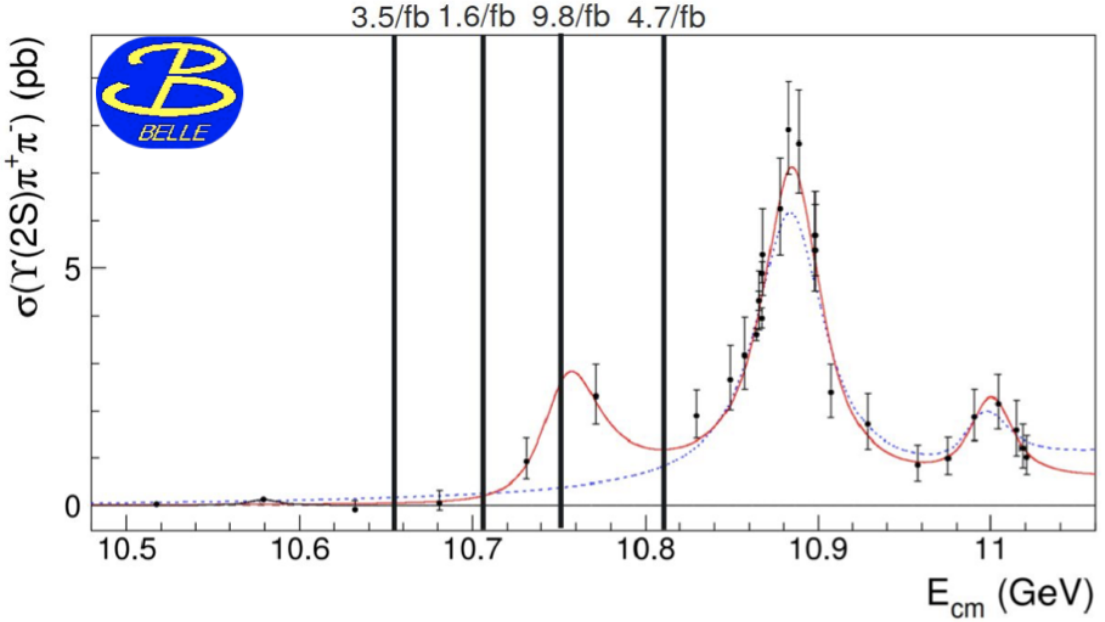
	$\Upsilon(10860)$	$\Upsilon(11020)$	New structure
M (MeV/c^2)	$10885.3 \pm 1.5 ^{+2.2}_{-0.9}$	$11000.0^{+4.0}_{-4.5}{}^{+1.0}_{-1.3}$	$10752.7 \pm 5.9 ^{+0.7}_{-1.1}$
Γ (MeV)	$36.6^{+4.5}_{-3.9}{}^{+0.5}_{-1.1}$	$23.8^{+8.0}_{-6.8}{}^{+0.7}_{-1.8}$	$35.5^{+17.6}_{-11.3}{}^{+3.9}_{-3.3}$

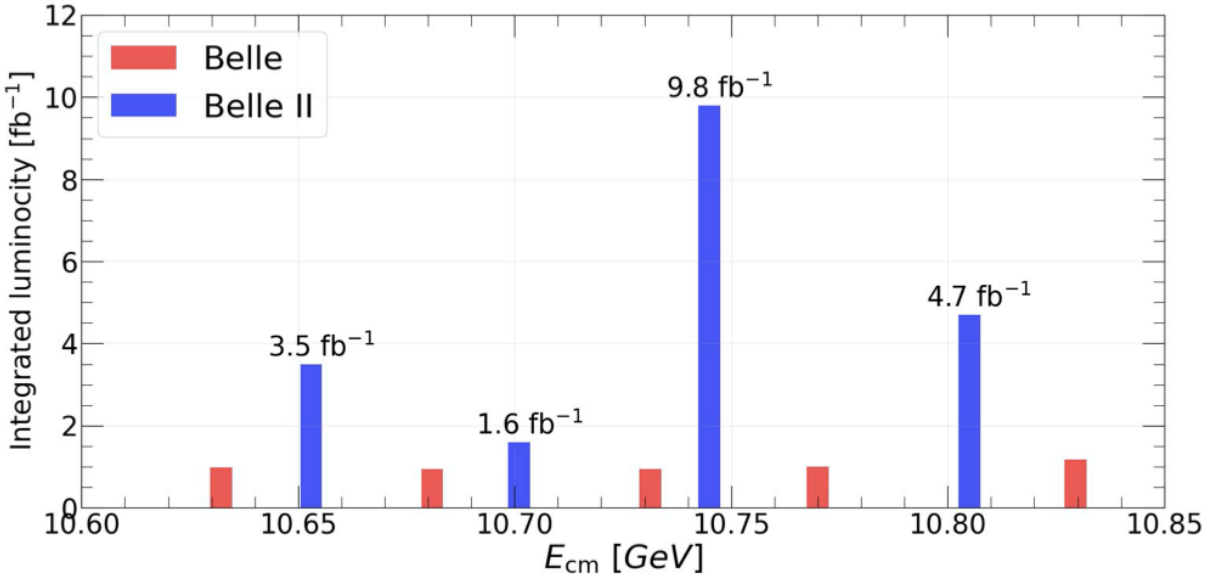


Chin. Phys. C 44 (2020) 8, 083001

A dip at 10.75 GeV may correspond to $\Upsilon(10753)$.

Unique scan data near $\sqrt{s}$ = 10.75 GeV

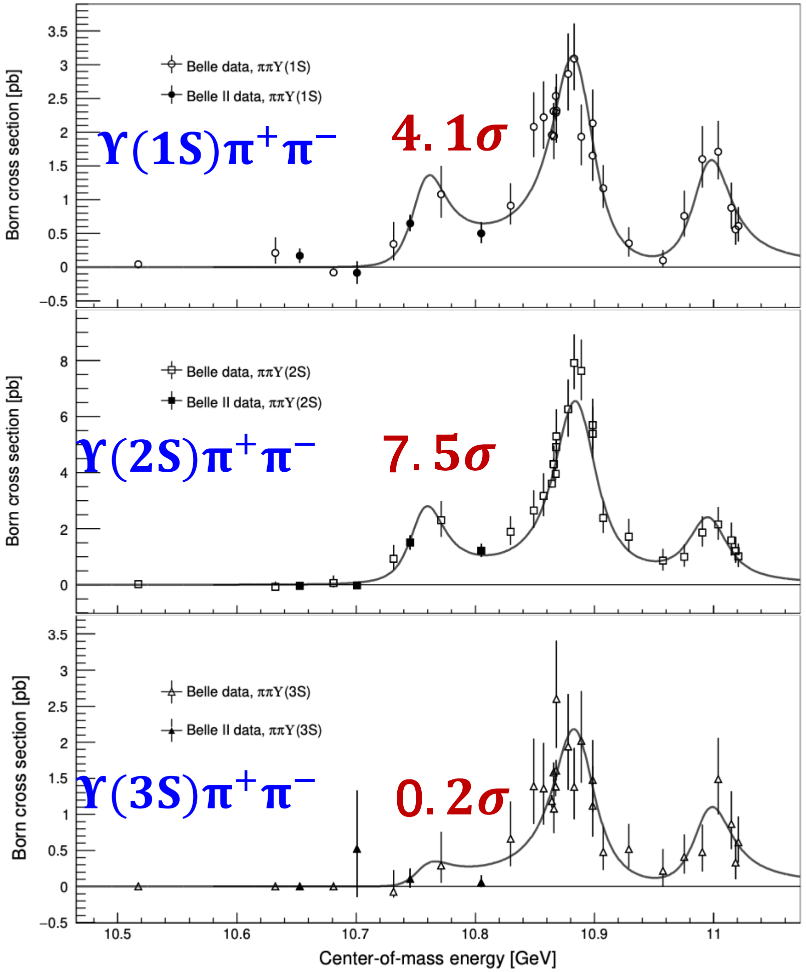




- In November 2021, Belle II collected 19 fb^{-1} of unique data at energies above the ϒ(4S): four energy scan points around 10.75 GeV.
- Belle II collected the data in the gaps between Belle energy scan points.
- Physics goal: understand the nature of the ϒ(10753) energy region.

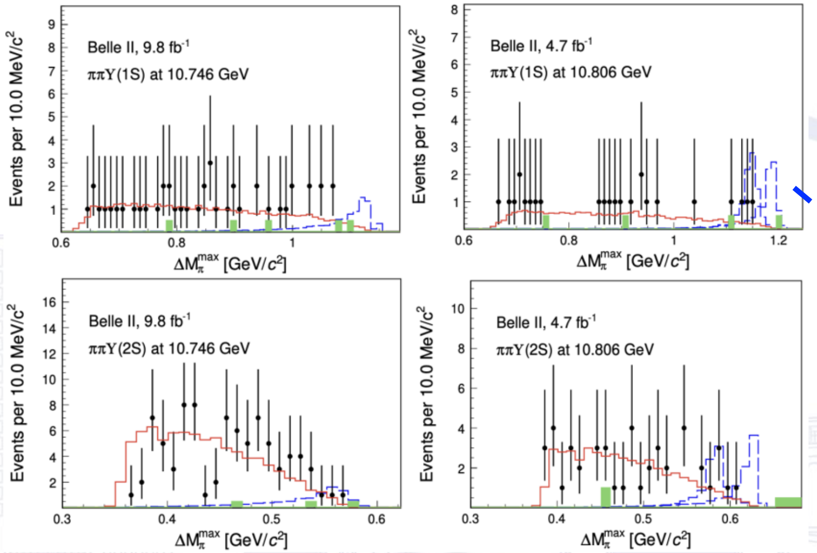
Measurement of $\Upsilon(10753) \to \pi^+\pi^-\Upsilon(nS)$ at Belle II

JHEP 07 **2024**, 116



Mass	$(10756.6 \pm 2.7 \pm 0.9)$ MeV/c^2
Width	$(29.0 \pm 8.8 \pm 1.2)$ MeV
$\mathcal{R}^{\Upsilon(10753)}_{\sigma(1S/2S)}$	$0.46^{+0.15}_{-0.12}$
$\mathcal{R}^{\Upsilon(10753)}_{\sigma(3S/2S)}$	$0.10^{+0.05}_{-0.04}$

- Search for $Z_b^\pm \to \pi^\pm\Upsilon(1S)$ with $\Delta M_\pi^{max} = M(\pi^\pm\mu^+\mu^-) - M(\mu^+\mu^-)$

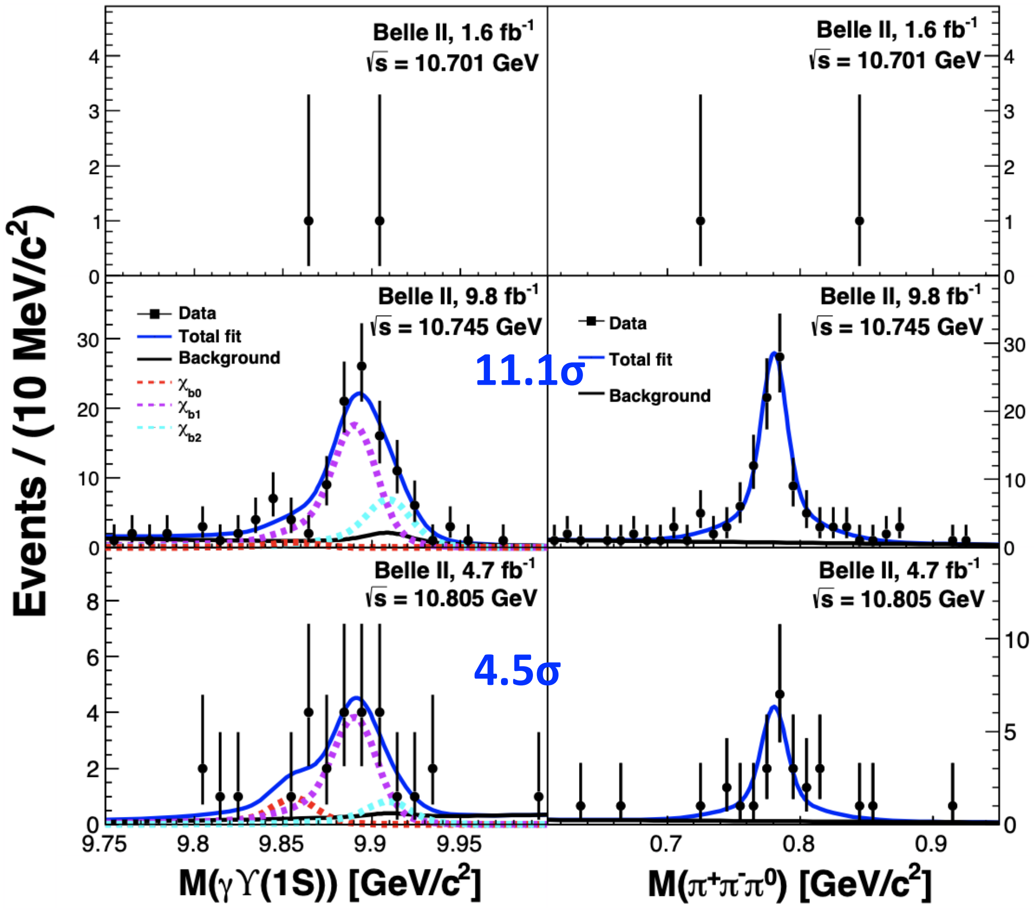


Simulated $Z_b^\pm$ events arbitrarily

Observation of $\Upsilon(10753) \to \omega\chi_{bJ}$

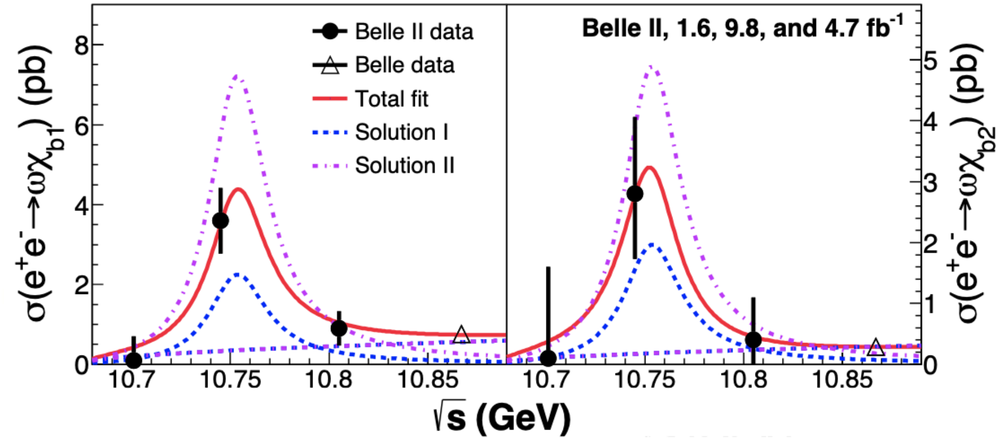
PRL 130, 091902 (2023)

Two dimensional unbinned maximum likelihood fits to the $M(\gamma\Upsilon(1S))$ and $M(\pi^+\pi^-\pi^0)$ distributions.



Channel	$\sqrt{s}$ (GeV)	N^{sig}	$\sigma^{(UL)}_{Born}$ (pb)
$\omega\chi_{b1}$	10.745	$68.9^{+13.7}_{-13.5}$	$3.6^{+0.7}_{-0.7} \pm 0.4$
$\omega\chi_{b2}$		$27.6^{+11.6}_{-10.0}$	$2.8^{+1.2}_{-1.0} \pm 0.5$
$\omega\chi_{b1}$	10.805	$15.0^{+6.8}_{-6.2}$	1.6 @90% C.L.
$\omega\chi_{b2}$		$3.3^{+5.3}_{-3.8}$	1.5 @90% C.L.

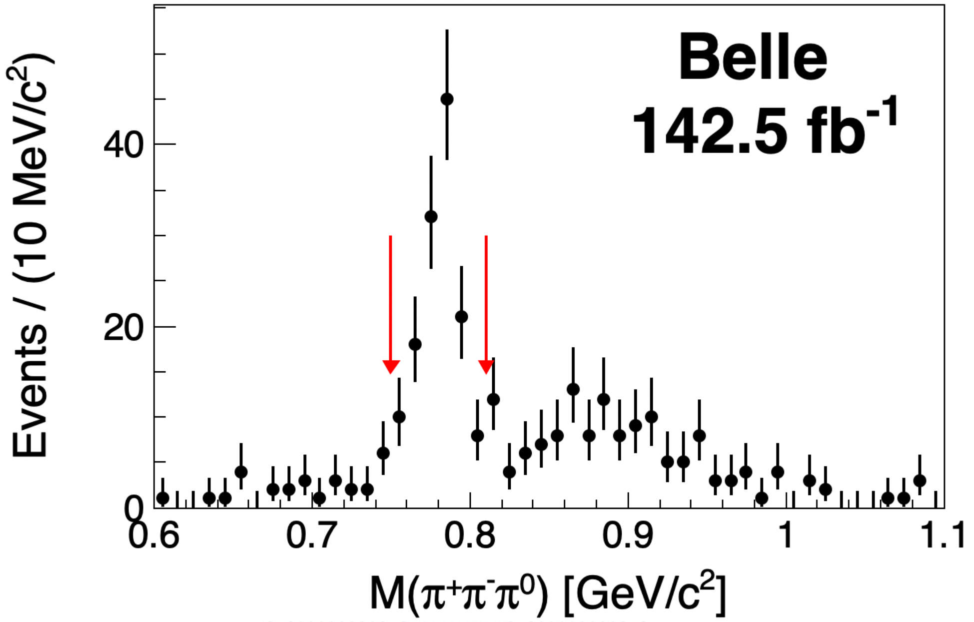
The $e^+e^- \to \omega\chi_{bJ}$ (J = 1, 2) cross sections peak at $\Upsilon(10753)$.



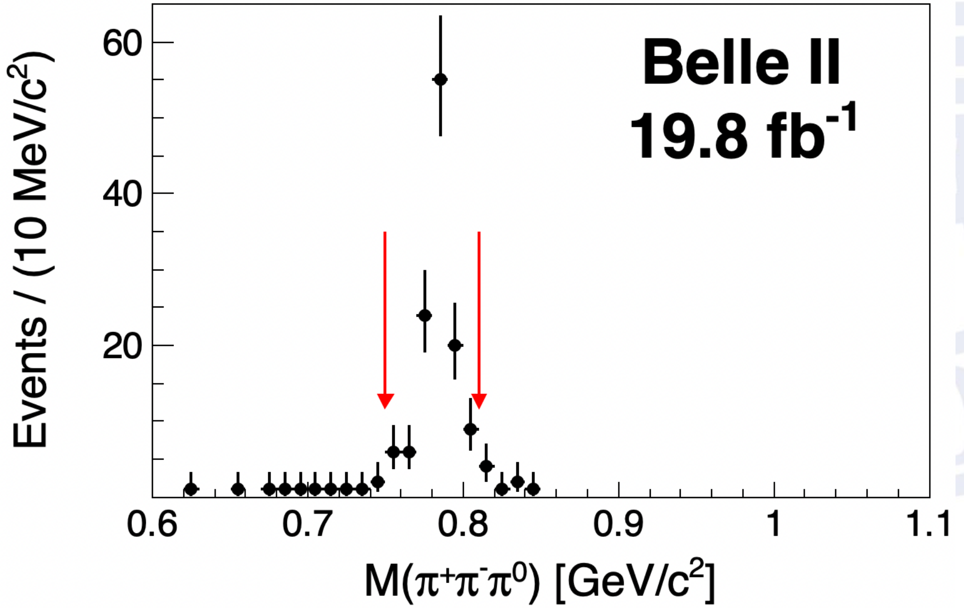
$e^+e^- \to \omega\chi_{bJ}$ and $e^+e^- \to (\pi^+\pi^-\pi^0)_{non-\omega}\chi_{bJ}$ at Belle and Belle II

arXiv: 2510.25461

$\sqrt{s} \in [10.73, 11.02]$ GeV



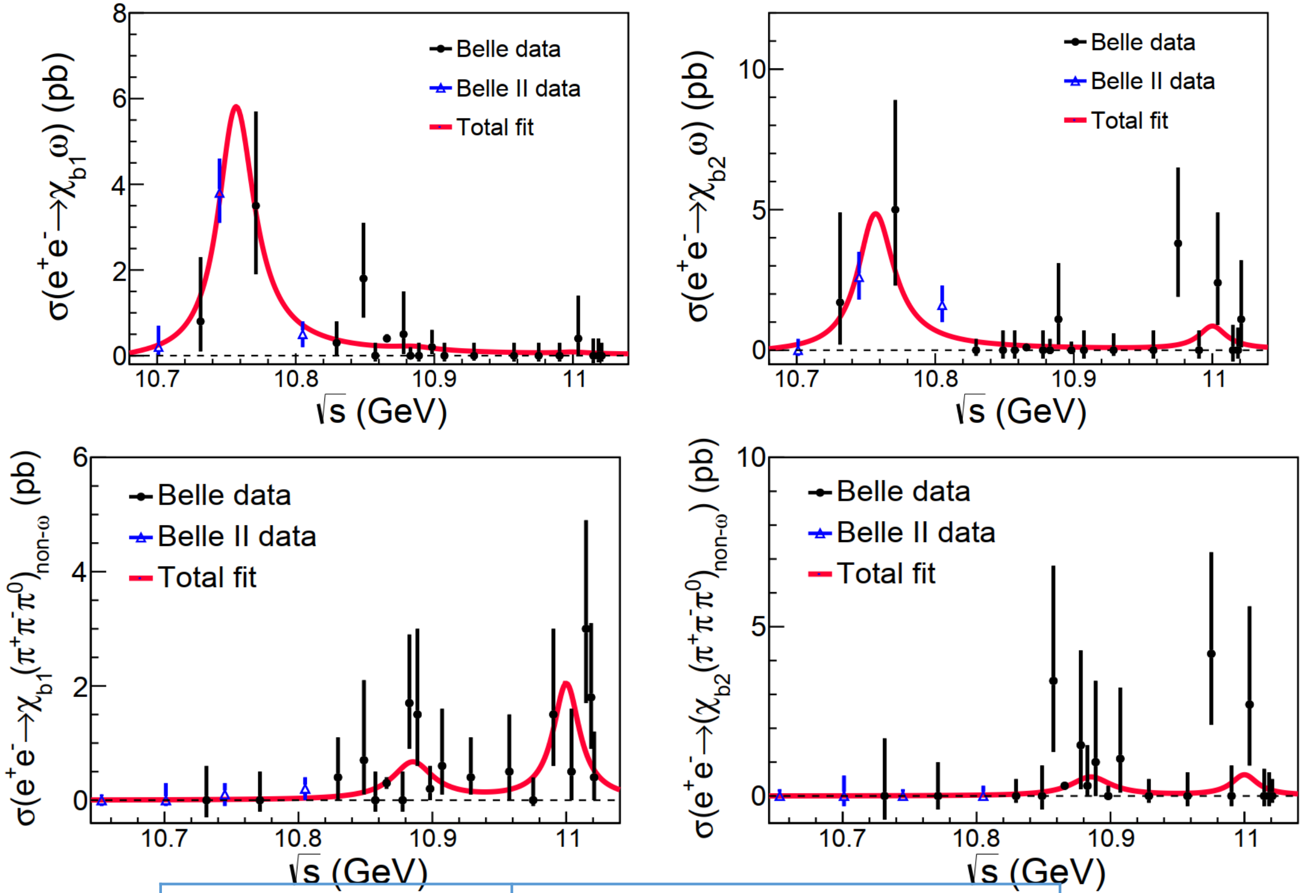
$\sqrt{s} \sim 10.75$ GeV



In addition to ω signal candidates, there are some events from non-resonant decays at Belle.

$e^+e^- \to \omega\chi_{bJ}$ and $e^+e^- \to (\pi^+\pi^-\pi^0)_{non-\omega}\chi_{bJ}$ at Belle and Belle II

arXiv: 2510.25461



$\Upsilon(10753)$ mass	(10756.1 ± 4.3) MeV/c^2
$\Upsilon(10753)$ width	(32.2 ± 18.7) MeV

$$\frac{\sigma(e^+e^-\to\chi_{bJ}(1P)\omega)}{\sigma(e^+e^-\to\Upsilon(nS)\pi^+\pi^-)}$$

1.5 at $\sqrt{s}\sim$ 10.75 GeV

0.15 at $\sqrt{s}\sim$ 10.867 GeV

This may indicate the difference in the internal structures of $\Upsilon(10753)$ and $\Upsilon(10860)$.

$\mathcal{B}(\Upsilon(10753)\to\chi_{b1}\,\omega)/\mathcal{B}(\Upsilon(10753)\to\chi_{b2}\,\omega)$

1.13±0.38±0.34

- The $(\pi^+\pi^-\pi^0)_{non-\omega}\chi_{bJ}$ excess maybe due the cascade decay of $\Upsilon(10860, 11020)\to Z_b\pi\to\chi_{bJ}\rho\pi$ [PRD 90, 014036 (2014)].

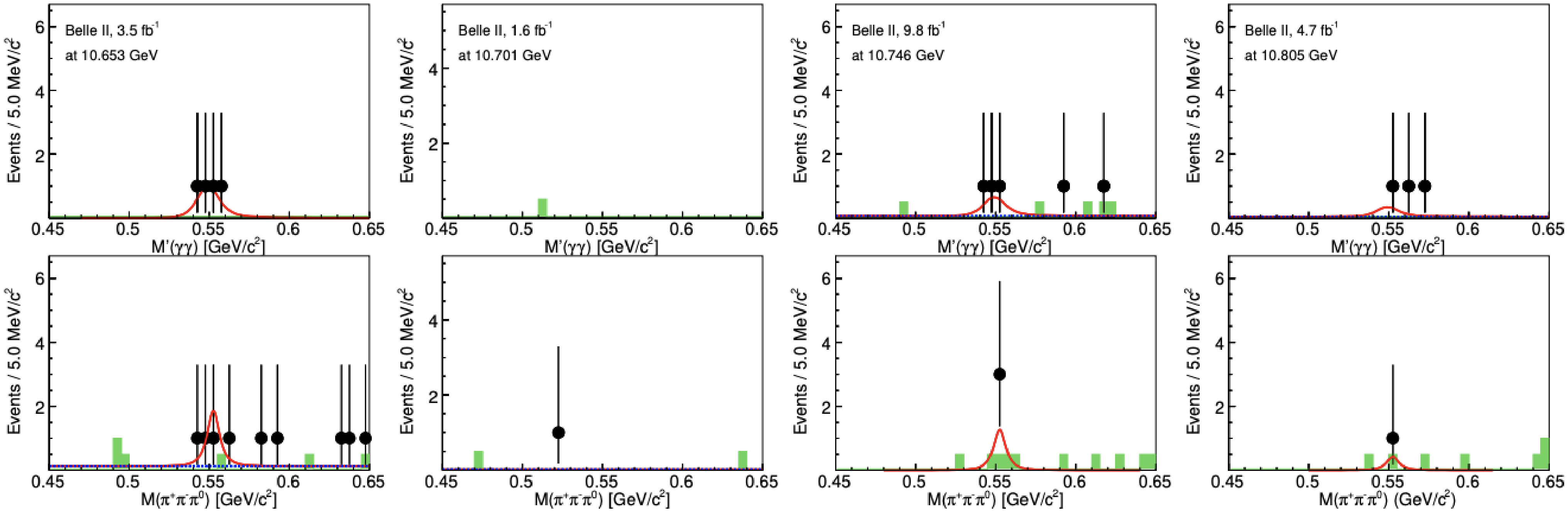
$e^+e^- \to \eta\Upsilon(1S, 2S)$

$\eta \to \gamma\gamma, \Upsilon(2S) \to \pi^+\pi^-\Upsilon(1S), \Upsilon(1S) \to \ell^+\ell^-$

$\eta \to \pi^+\pi^-\pi^0, \Upsilon(2S) \to \ell^+\ell^-$

arXiv: 2509.01917

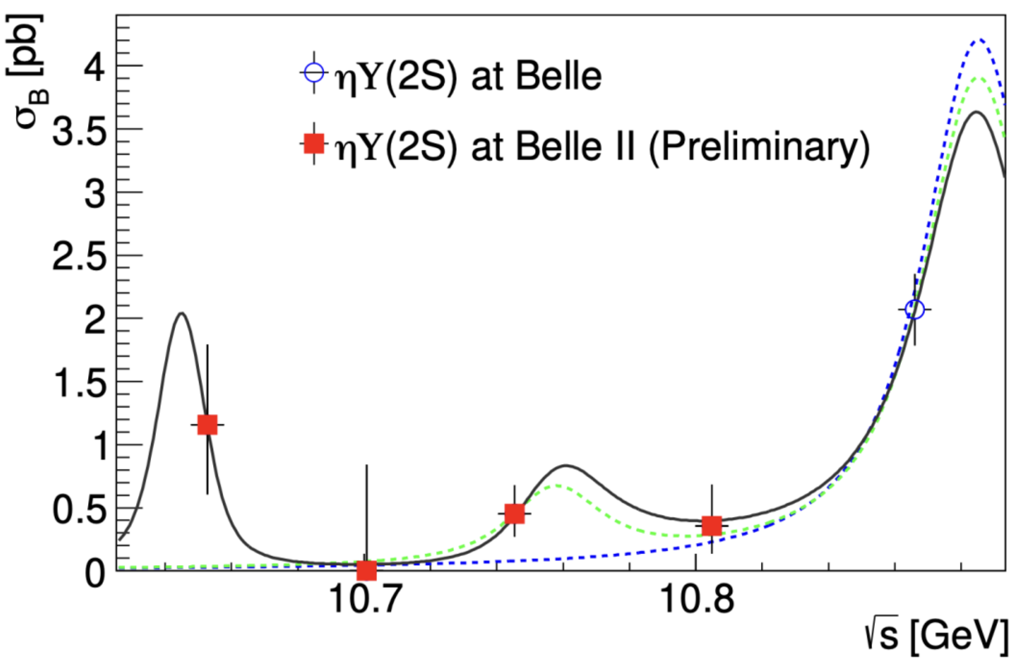
After requiring $\Upsilon(2S)$ signal region, simultaneous fit to $M(\gamma\gamma)$ and $M(\pi^+\pi^-\pi^0)$ for each energy point.



- Combining all of the energy points, the signal yields for $\eta \to \gamma\gamma$ and $\eta \to \pi^+\pi^-\pi^0$ are $6.0^{+1.7}_{-1.5}$ and $11.5^{+3.3}_{-2.8}$.
- The statistical significance is 6.4σ for $e^+e^- \to \eta\Upsilon(2S)$ at $\sqrt{s} \sim 10.75$ GeV.
- No clear signals were observed for $e^+e^- \to \eta\Upsilon(1S)$ at $\sqrt{s} \sim 10.75$ GeV.

$e^+e^- \to \eta\Upsilon(2S)$

arXiv: 2509.01917



Fit the with 3 different hypotheses:

H_1: only $\Upsilon(5S)$ [blue curve]

H_2: $\Upsilon(10753) + \Upsilon(5S)$ [Green curve]

H_3: $B^*\bar{B}^*$ bound state + $\Upsilon(10753) + \Upsilon(5S)$ [Black curve], the default fit.

The masses and widths of $B^*\bar{B}^*$ bound state, $\Upsilon(10753)$, and $\Upsilon(5S)$ are fixed.

The significance of $B^*\bar{B}^*$ bound state is larger than 3.2σ

1.The Born cross section of $e^+e^- \to \eta\Upsilon(2S)$ around $B^*\bar{B}^*$ mass is relatively large.

2. A rapid increase of $\sigma_{B*\bar{B}*}$ just above the threshold.

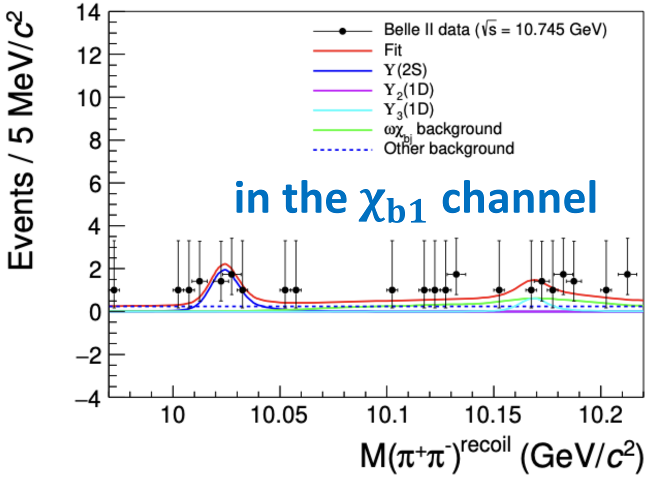
A new bottomonium-like state around $B^*\bar{B}^*$ threshold?

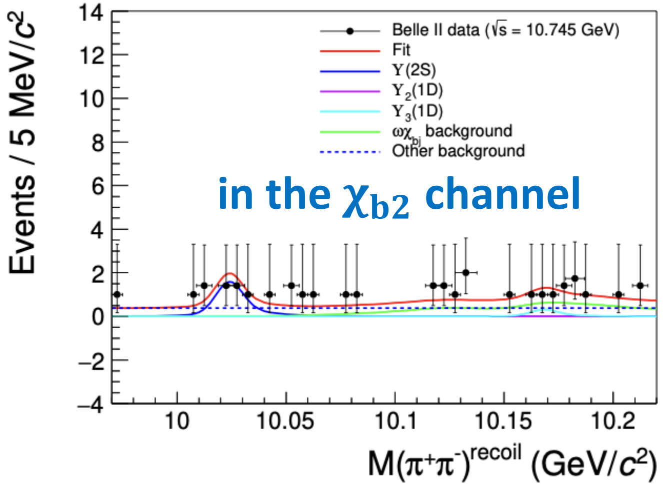
The $Y_b(10650)$ is predicted in Refs. [arXiv:2505.02742, arXiv:2508.11127, arXiv:2505.03647].

$e^+e^- \to \pi^+\pi^-\Upsilon_J(1D)$ $(J = 2, 3)$

$\Upsilon_{2,3}(1D) \to \gamma\chi_{b1,b2}, \chi_{b1,b2} \to \gamma\Upsilon(1S),$
$\Upsilon(1S) \to \ell^+\ell^-$

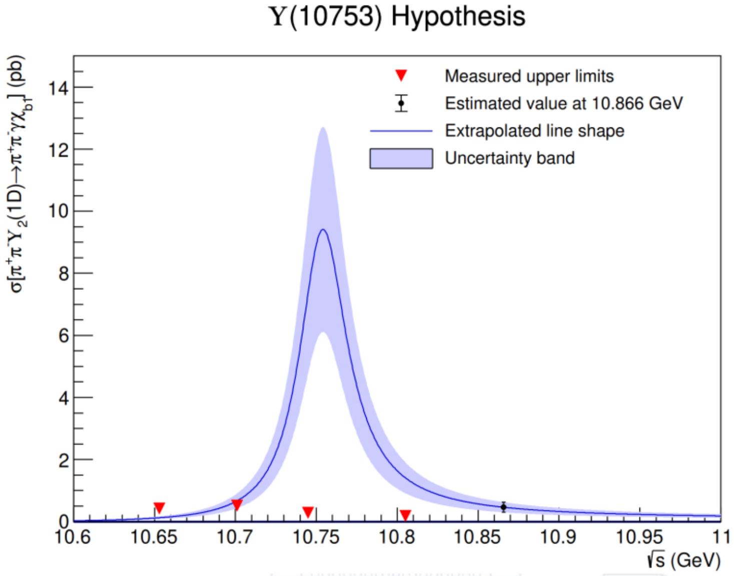
[Belle II Preliminary]

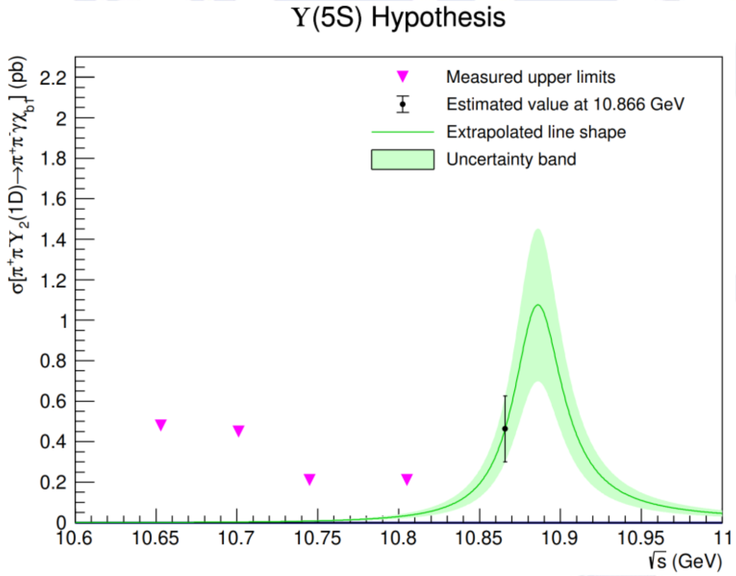




No significant $\Upsilon_J(1D)$ signal is observed.

Inverted triangles: the 90% C.L. upper limits on the product $\sigma(e^+e^- \to \pi^+\pi^-\Upsilon_2(1D))\mathcal{B}(\Upsilon_2(1D) \to \gamma\chi_{b1})$ as a function of C.M. energy.



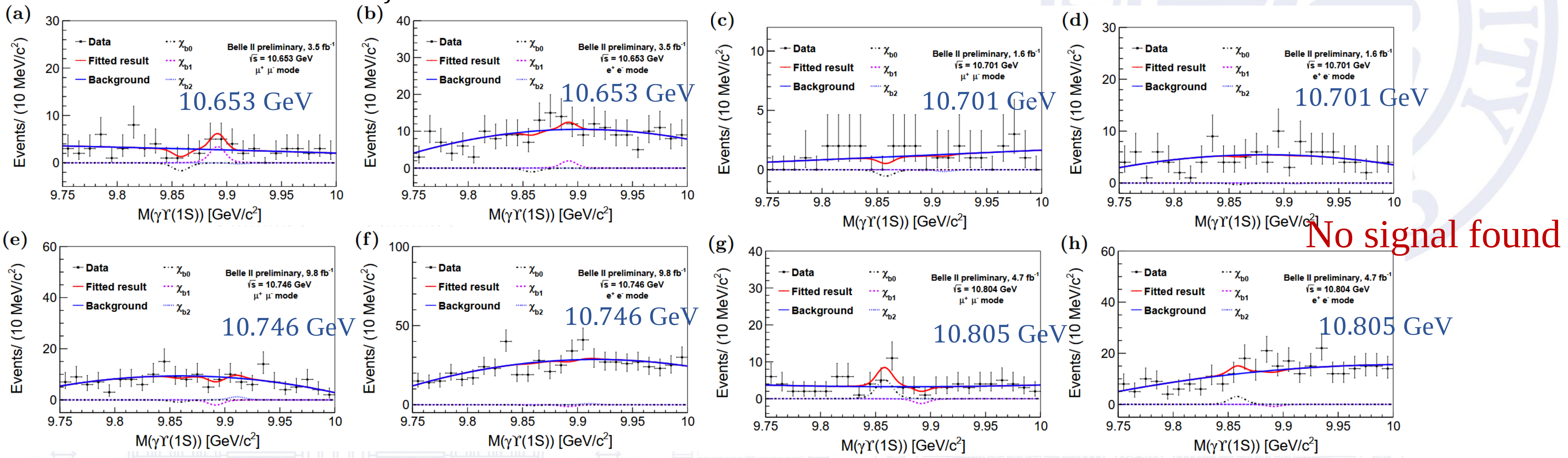


- A pronounced suppression in the coupling of the $\Upsilon(10753)$ resonance to $\Upsilon_J(1D)$ states via dipion transitions.
- The upper limits do not conflict with the $\Upsilon(10860)$ line shape.

Search for the radiative decay of $\Upsilon(10753)$

arXiv: 2508.16036

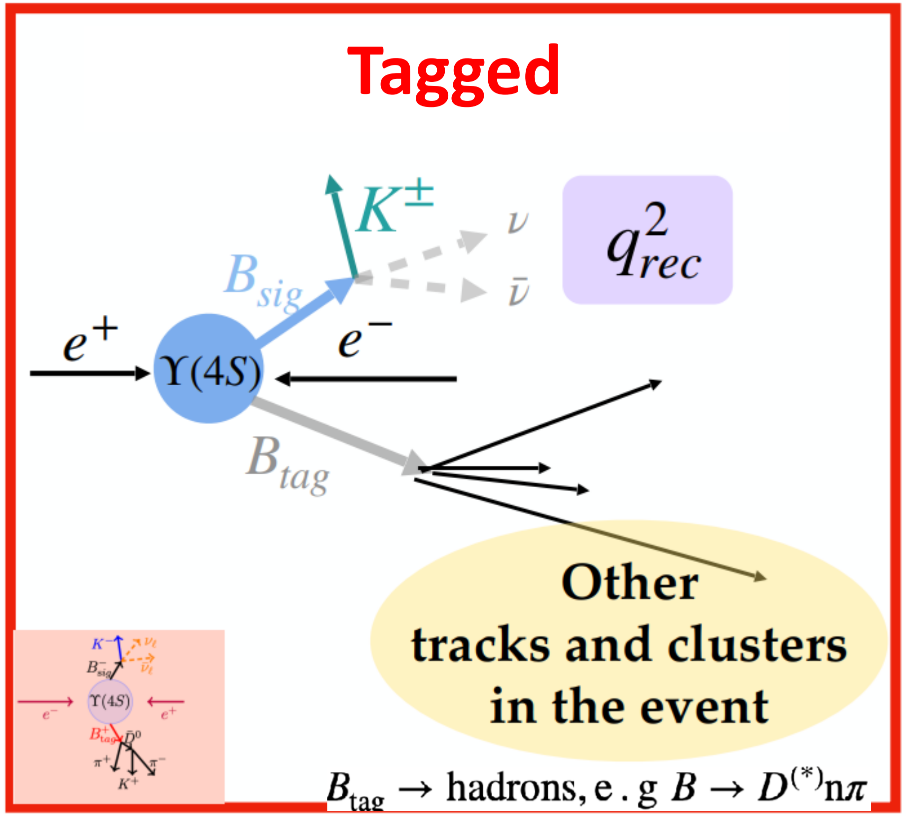
- The study of the radiative decay of $\Upsilon(10753)$ is helpful to understand its nature.
- If $\Upsilon(10753)$ is a pure 2D state, the BF for $\Upsilon(10753) \to \gamma\chi_{b1}$ can reach 12%[PRD 92,054034(2015), EPJC 78,915(2018)].
- We search for $e^+e^- \to \gamma\chi_{bJ}(J = 0,1,2)$ using 19.6 fb^{-1} Belle II data samples near $\sqrt{s}$ = 10.746 GeV.



No signal found

W.T. Xiong, S. Jia, **C.P. Shen** *et.al* (Belle II Collaboration) arXiv:2508.16036

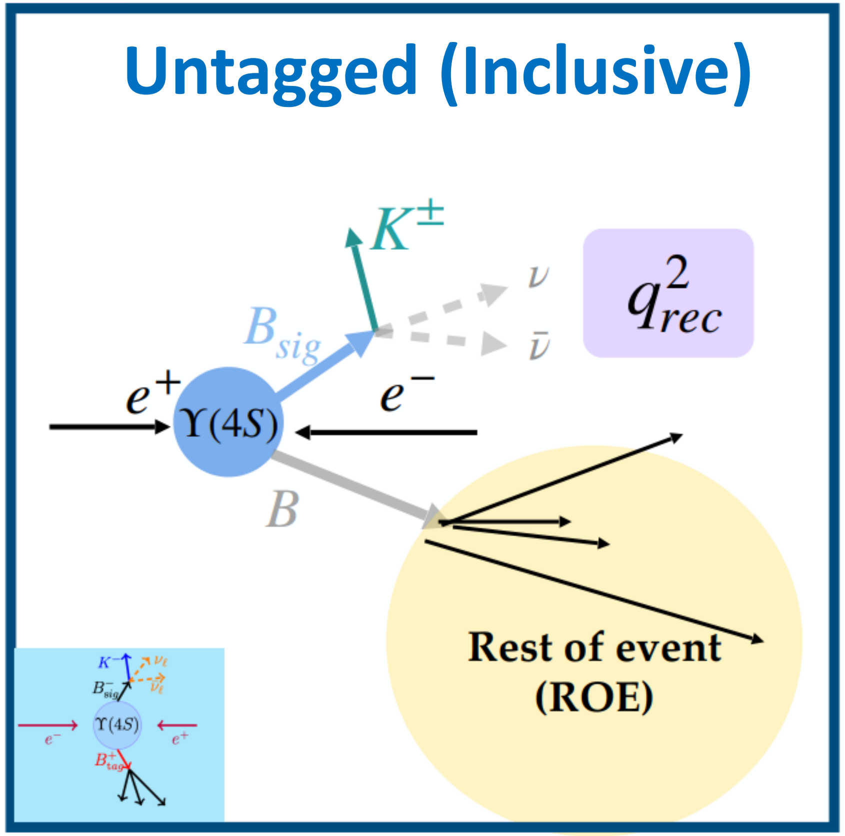
B decays



Efficiency →

q^2_{rec} : mass squared of the neutrino pair

← Purity, Resolution



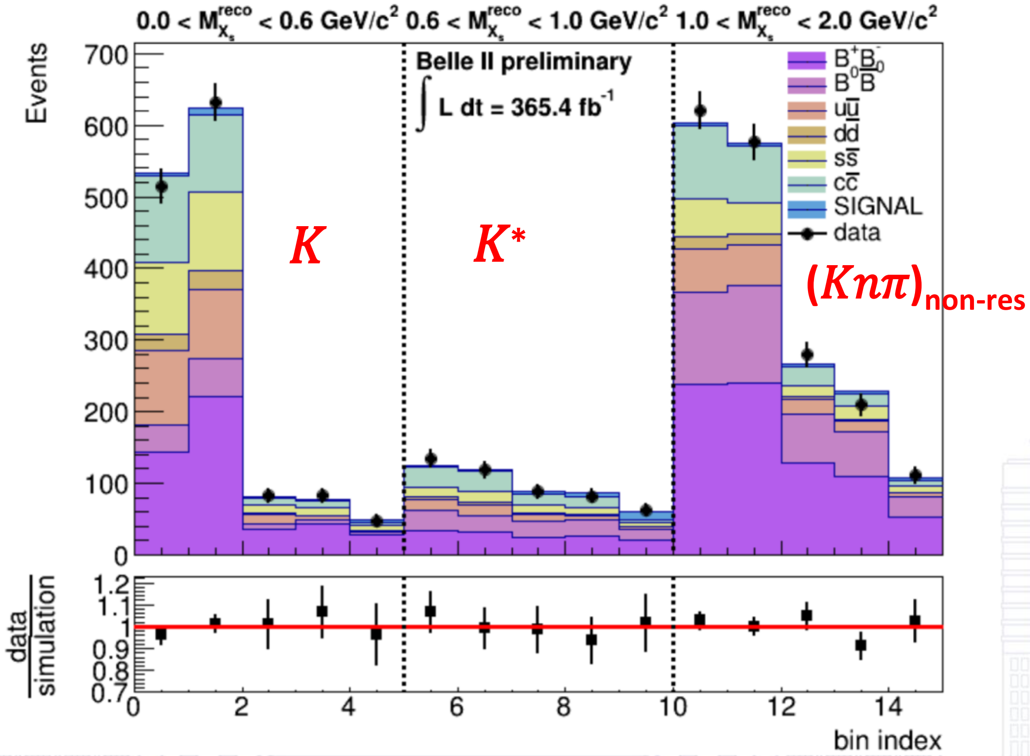
- **Tagging: Hadronic + Semileptonic**
- **Inclusive ROE (Rest of Event) (× 10 - 20 efficiency, but large backgrounds); add some ML/AI (boosted decision trees or BDTs) to help suppress the large backgrounds.**

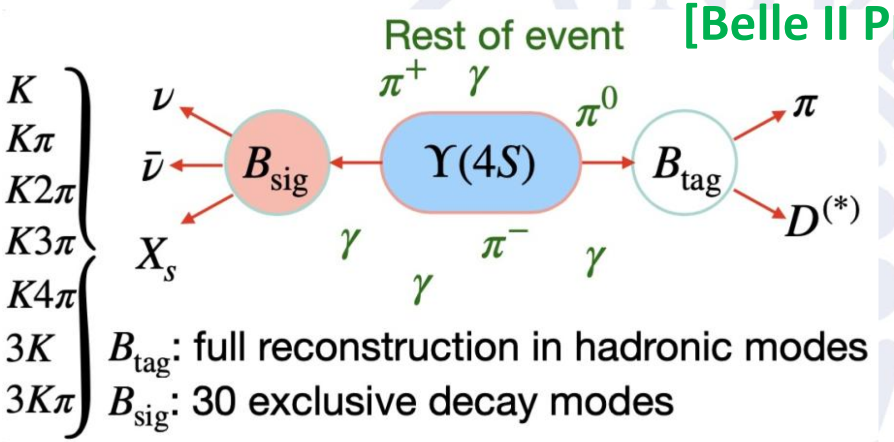
Inclusive $B \to X_s\nu\nu$ with hadronic tagging

[Belle II Preliminary]

- Probe flavor changing neutral currents (FCNC) in $b \to s\nu\nu$.
- The branching fraction for $B \to X_s\nu\nu$ is cleanly predicted to be $(2.9\pm0.3)\times10^{-5}$ in the SM [JHEP 02, 184 (2015)].

Maximum likelihood fit in $M_{X_s} \times \mathcal{O}_{\rm BDT}$ with 3 × 5 bins:





M_{X_s} [GeV/c^2]	ϵ	$N_{\rm sig}$	$\mathcal{B}$ [10^{-5}] Central value	$\mathcal{B}$ [10^{-5}] UL$_{\rm obs}$	$\mathcal{B}$ [10^{-5}] UL$_{\rm exp}$
[0, 0.6]	0.29%	6^{+18+19}_{-17-16}	$0.3^{+0.8+0.9}_{-0.8-0.7}$	2.2	2.0
[0.6, 1.0]	0.12%	36^{+27+31}_{-26-26}	$3.5^{+2.6+3.1}_{-2.5-2.6}$	9.5	6.6
[1.0, $M^{\rm max}_{X_s}$]	0.07%	24^{+44+62}_{-43-53}	$5.1^{+9.2+12.9}_{-8.8-11.0}$	31.2	26.7
Full range	0.10%	66^{+64+95}_{-62-81}	$8.8^{+8.5+12.6}_{-8.2-10.8}$	32.2	24.4

Full range: $\mathcal{B}(B \to X_s\nu\bar{\nu}) < 3.6 \times 10^{-4}$ (90 % CL)

Most stringent upper limit on the inclusive rate

$B^+ \to \mu^+ \nu_\mu$

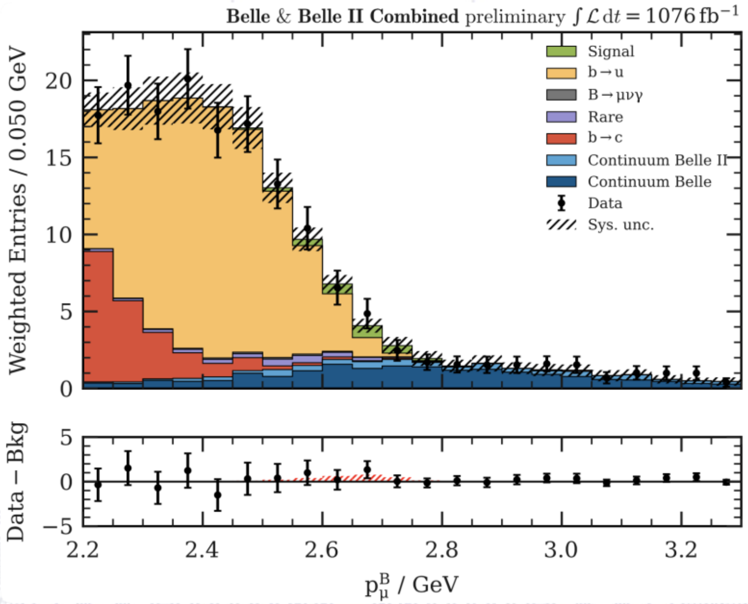
- SM branching fraction:

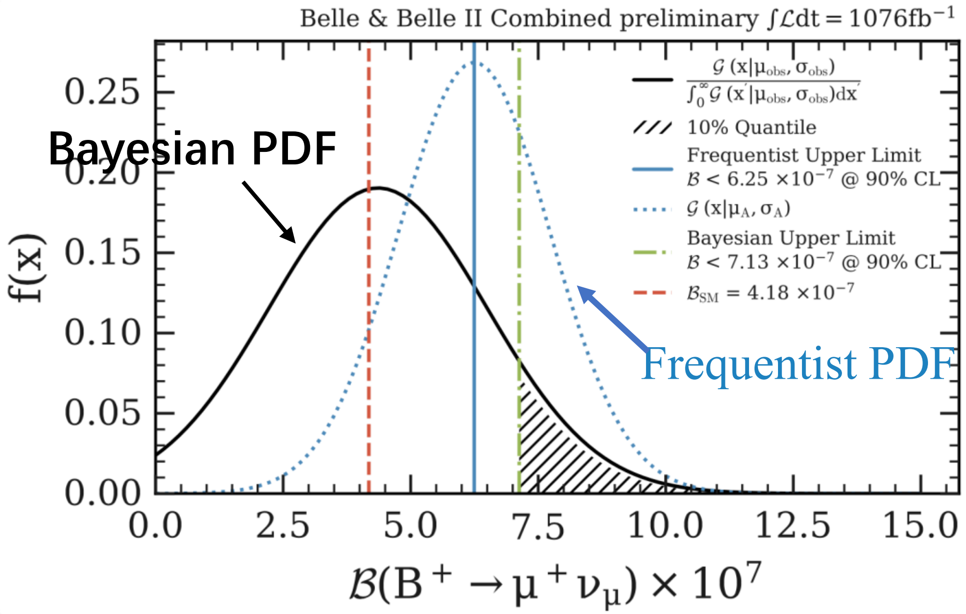
$$\mathcal{B}(B^+ \to \mu^+ \nu_\mu) = \frac{G_F^2 m_B m_\mu^2}{8\pi}\left(1 - \frac{m_\mu^2}{m_B^2}\right)^2 f_B^2 |V_{ub}|^2 \tau_{B^+},$$

- Belle + Belle II (1076/fb):
  - $B(B^+ \to \mu^+ \nu_\mu) = (4.36 \pm 1.89 \pm 1.01) \times 10^{-7}$ (2.35σ)

Preliminary result

- SM predicted: $B = (4.18 \pm 0.44) \times 10^{-7}$.
- Belle: $B = (5.3 \pm 2.0 \pm 0.9) \times 10^{-7}$ (2.8σ) (PRD 101 (2020) 032007)





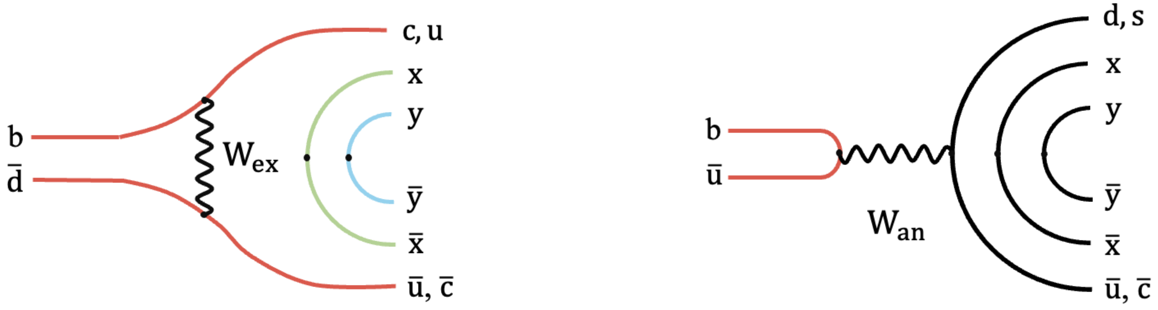
45页的文章！

These are the most stringent limits to date.

Observation of the decay $B \to \Sigma_c(2455)\bar{\Xi}_c$

PRD 112, L051101 (2025)

- The tree-level two-body baryonic B decays can proceed through W-exchange ($W_{\rm ex}$), W-annihilation ($W_{\rm an}$), and internal W-emission ($W_{\rm em}$) diagrams.

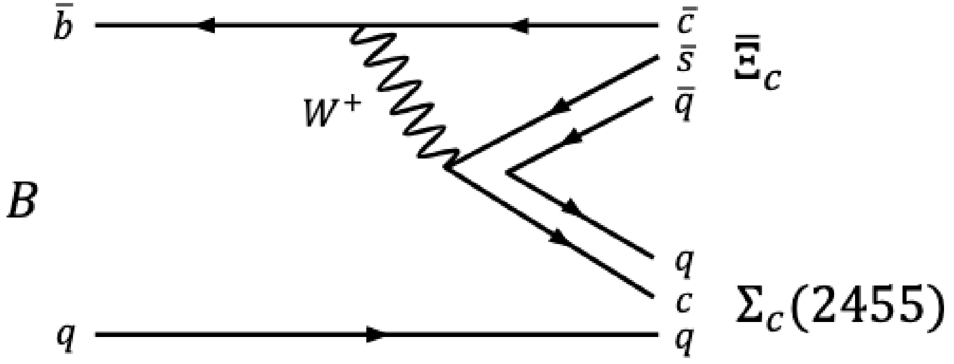


$W_{\rm ex}$ and $W_{\rm an}$: helicity suppressed

$W_{\rm em}$: nonfactorizable amplitude

- The decays $B \to \Sigma_c(2455)\bar{\Xi}_c$ proceed through a pure $W_{\rm em}$ diagram, providing a clean and ideal environment for studying nonfactorizable effects.

- The QCD sum rule predicts $\mathcal{B}(B \to \Sigma_c(2455)\bar{\Xi}_c) \sim 4 \times 10^{-3}$ [NPB 345 137 (1990)], while the diquark model estimates $\mathcal{B}(B \to \Sigma_c(2455)\bar{\Xi}_c)$ to be 30%–70% of $\mathcal{B}(B \to \Lambda_c\bar{\Xi}_c) \sim 10^{-3}$ [ZPC 51 445 (1991)].



$\Sigma_c(2455)$: a sextet of flavor-symmetric states $\bar{\Xi}_c$: an antitriplet of flavor-antisymmetric states

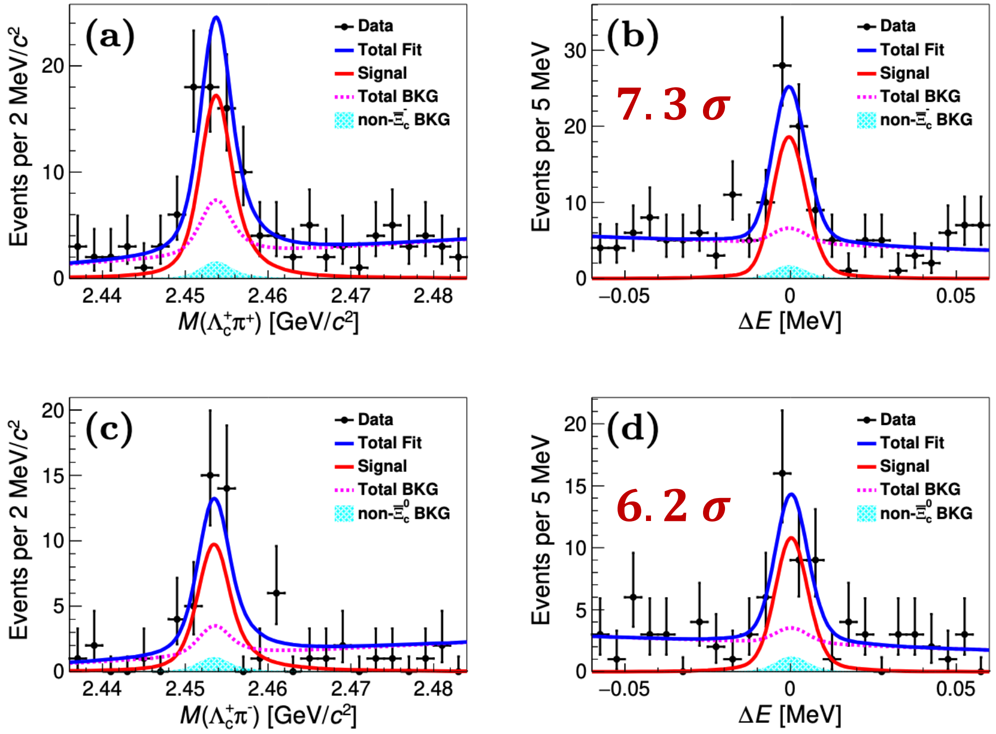
Observation of the decay $B \to \Sigma_c(2455)\bar{\Xi}_c$

PRD 112, L051101 (2025)

- We report the first observation of the decays $B^+ \to \Sigma_c(2455)^{++}\bar{\Xi}_c^-$ and $B^0 \to \Sigma_c(2455)^0\bar{\Xi}_c^0$, using the 772×10^6 and 387×10^6 $\Upsilon(4S)$ events collected by Belle and Belle II, respectively.
- We perform a 2D fit to the unbinned $M(\Lambda_c^+\pi^\pm)$ and ΔE distributions, simultaneously using four data sets: events from the signal and sideband regions of $M(\bar{\Xi}_c^{-,0})$.

B^+

B^0



$$\mathcal{B}(B^+ \to \Sigma_c(2455)^{++}\bar{\Xi}_c^-) = (5.74 \pm 1.11 \pm 0.42^{+2.47}_{-1.53}) \times 10^{-4}$$

$$\mathcal{B}(B^0 \to \Sigma_c(2455)^{0}\bar{\Xi}_c^0) = (4.83 \pm 1.12 \pm 0.37^{+0.72}_{-0.60}) \times 10^{-4}$$

- $\mathcal{B}(B \to \Sigma_c(2455)\bar{\Xi}_c)$ are larger than those of $B^+ \to \bar{\Sigma}_c(2455)^0 p$ and $B^0 \to \bar{\Sigma}_c(2455)^- p$:
  - Similar size of CKM matrix elements: $V_{bc} * V_{cs} \sim V_{bc} * V_{ud}$
  - Smaller phase-space [Int. J. Mod. Phys. A 21(2006) 4209]
- One possible mechanism is that hard gluons are not necessarily required for double-charm decays.

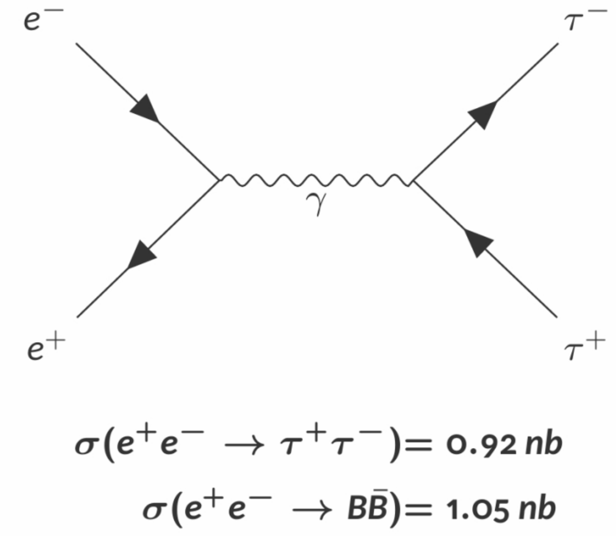
tau decays

τ physics

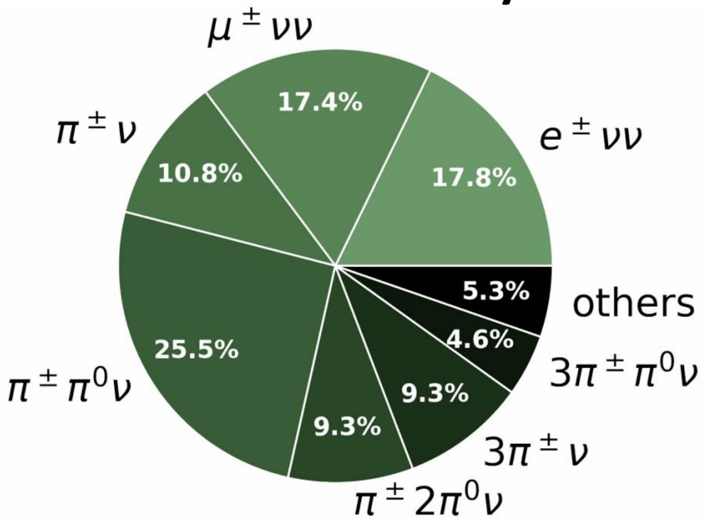
*SuperKEKB as a **τ factory***

» τ mass and lifetime, lepton flavor violation, CKM unitarity, CP violation, ...

- e^+e^- collider produce τ lepton pairs at high rate



τ decay modes



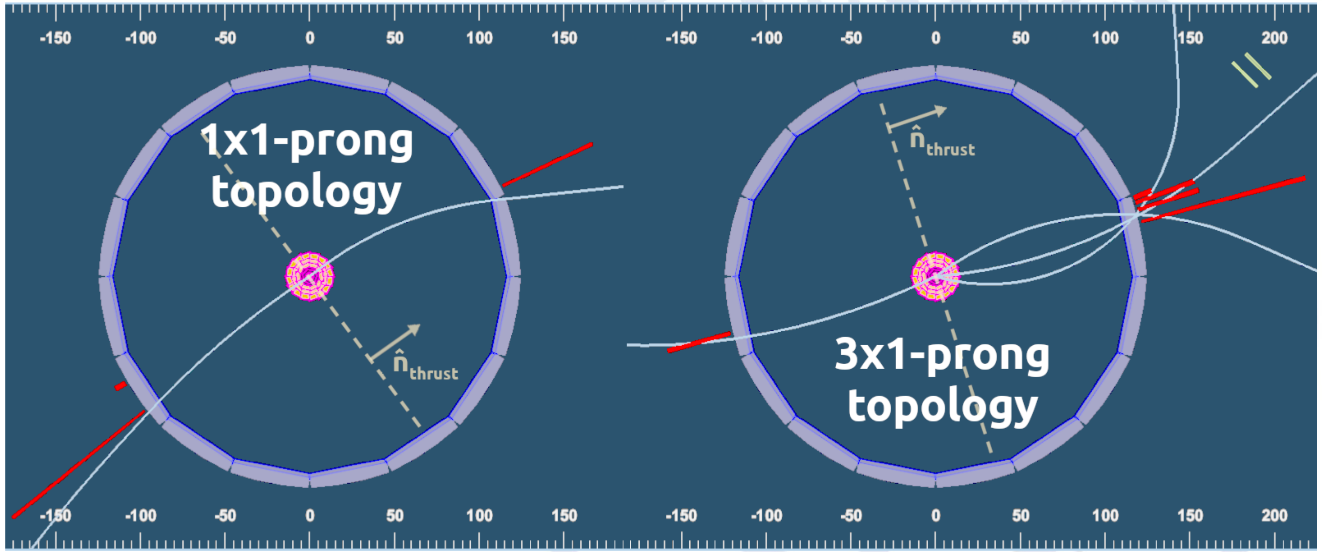
- The heaviest known lepton (heavier than proton)
- Very short lifetime (<300 fs)
- Decays mostly into one (1-prong) or three (3-prong) charged particles
- Can decay to lighter leptons but also hadrons (>200 channels)

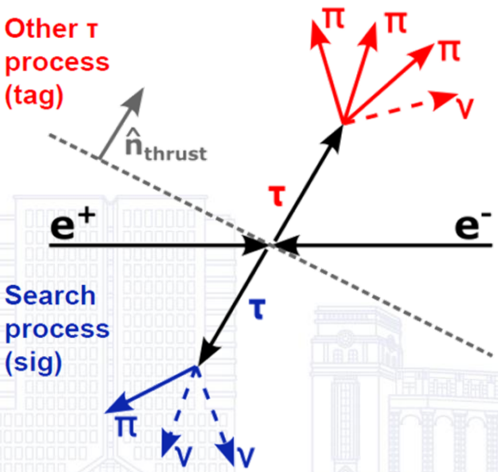
Advantages at Belle II:

✓ High luminosity
✓ Good vertexing and tracking capabilities
✓ Good trigger system and particle ID

Tau topologies and signatures

- Tau leptons in e^+e^- collisions are mostly produced in pairs, back to back, in center-of-mass system.
- At Belle II we mainly study 1×1 and 3×1-prong topologies.
- Separation into two hemispheres defined by the plane perpendicular to the thrust axis $\hat{n}_{thrtst}$.
- Use one tau to tag the event and reconstruct signal in the other hemisphere
- Even using new method: untagged





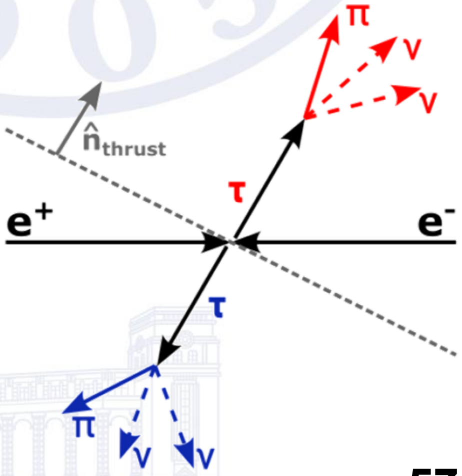
Use different topologies:

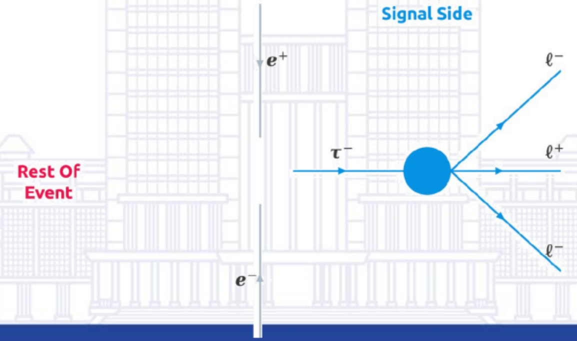
(1x3) vs (1x1)

Define best topologies for each analysis, e.g., to suppress background

$$T = \max_{\hat{n}_{thrust}} \left(\frac{\sum_i |p_i \cdot \hat{n}_{thrust}|}{\sum_i |p_i|} \right)$$

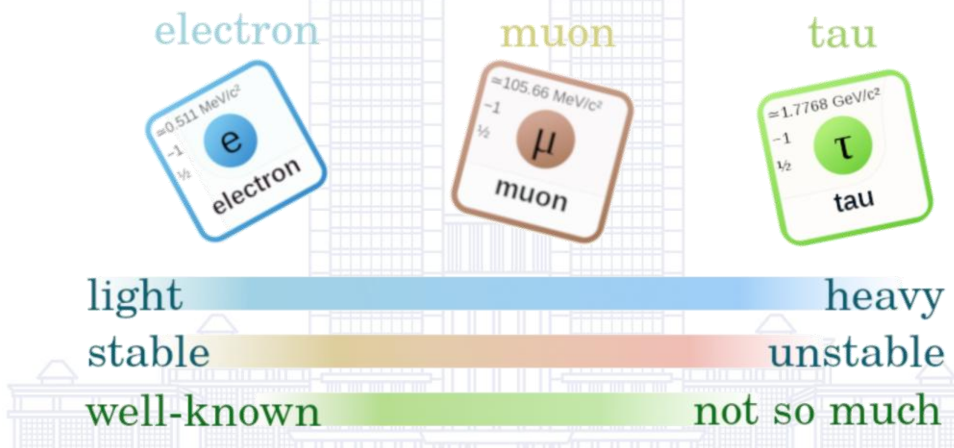
$\hat{n}_{thrust}$, the best approximation of the τ flight direction





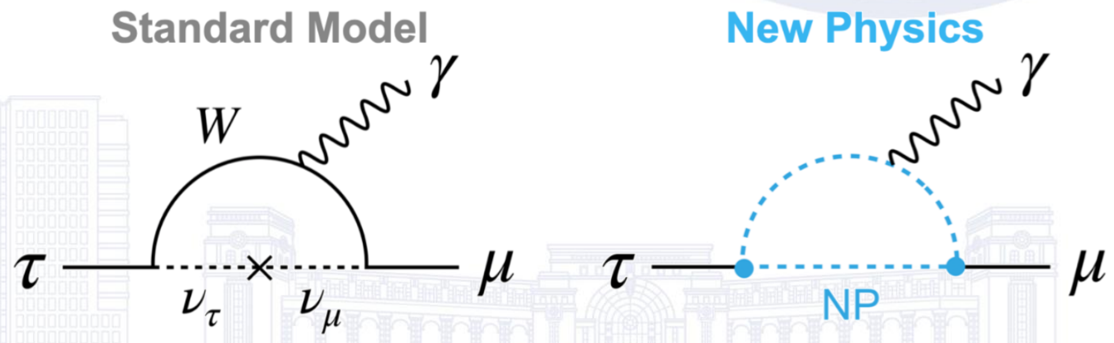
Precision SM measurements

- Tau properties are know with much worse precision compared to e and μ. (e.g. tau mass, lifetime, couplings, etc)
- Impact on the precision of SM parameters (e.g. test of LFU).
  - possible indirect hints of NP in deviations from the SM.



Search for rare and forbidden processes

- Lepton Flavour Violating (LFV) tau decays
  - very little to no background
- Innovative approaches to set world-leading limits
  - High reconstruction efficiency, MVA techniques, inclusive tagging
  - Direct observation would be unambiguous sign of NP

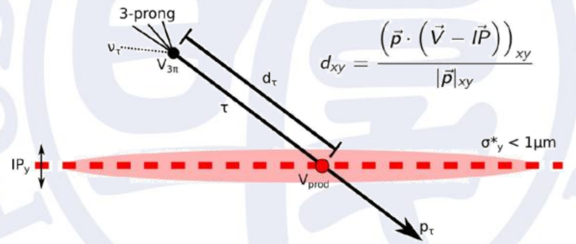


Tau lifetime: ongoing

- Measure using proper decay time relation to flight distance and momentum in lab frame.
- 3×1-prong topology ($\tau_{\text{sig}} \to 3\pi\nu$, $\tau_{\text{tag}} \to \rho\nu$).
- Reconstruct 3-prong vertex and estimate p_τ from decay produces.
- This method is possible exclusively at Belle II, due to the very high requirements for vertex detectors.
- $2 \times$ better proper decay time resolution in Belle II (Preliminary Study).

$$t = \frac{l_\tau}{\beta\gamma c} = m\frac{l_\tau}{p_\tau}$$

measure these

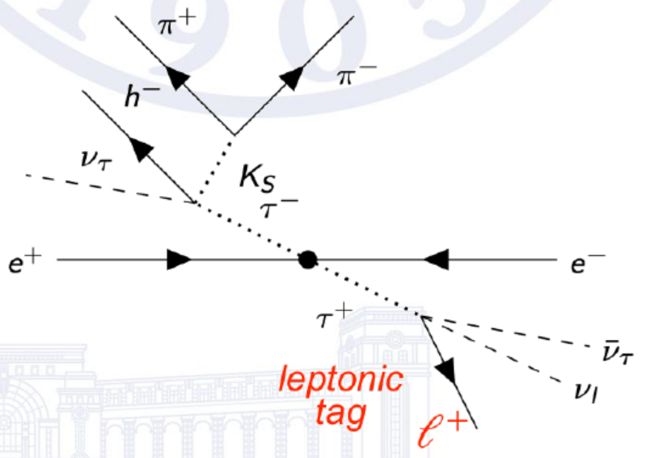


CPV test in kaon sector: ongoing

- Charge asymmetry in $\tau \to K_S\pi\nu$, CP violation in the kaon sector.

$$A_\tau = \frac{\Gamma(\tau^+ \to \pi^+ K_S^0 \bar{\nu}_\tau) - \Gamma(\tau^- \to \pi^- K_S^0 \nu_\tau)}{\Gamma(\tau^+ \to \pi^+ K_S^0 \bar{\nu}_\tau) + \Gamma(\tau^- \to \pi^- K_S^0 \nu_\tau)}$$

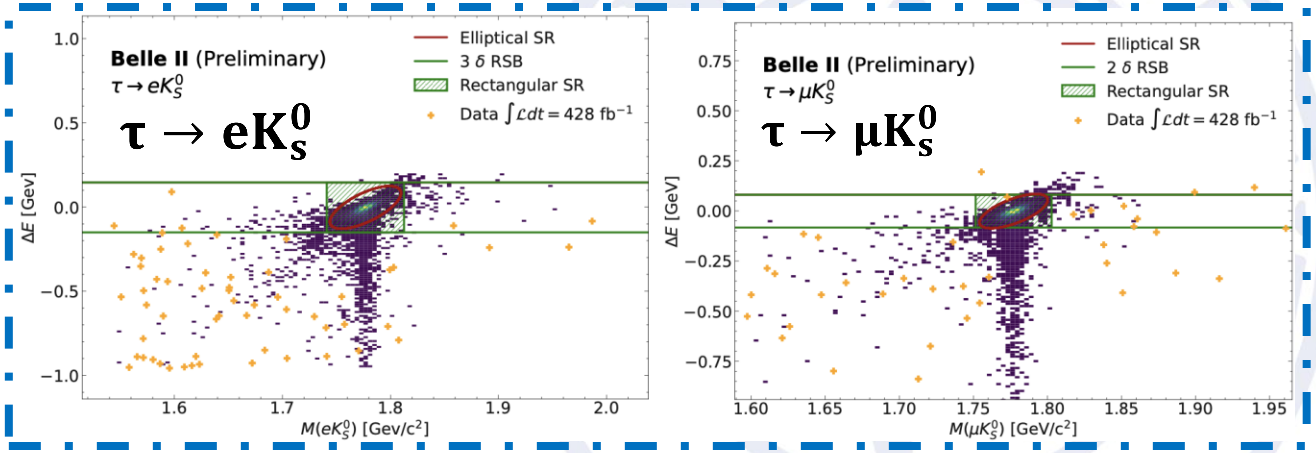
- SM prediction: $A_\tau^{\text{SM}} = (3.6 \pm 0.1) \times 10^{-3}$
- Current most precise result from BaBar: $A_\tau^{\text{BaBar}} = (-0.36 \pm 0.23 \pm 0.11) \times 10^{-3}$, 2.8σ deviation from the SM.
- An improved A_τ measurement is a priority at Belle II (Stay tuned).



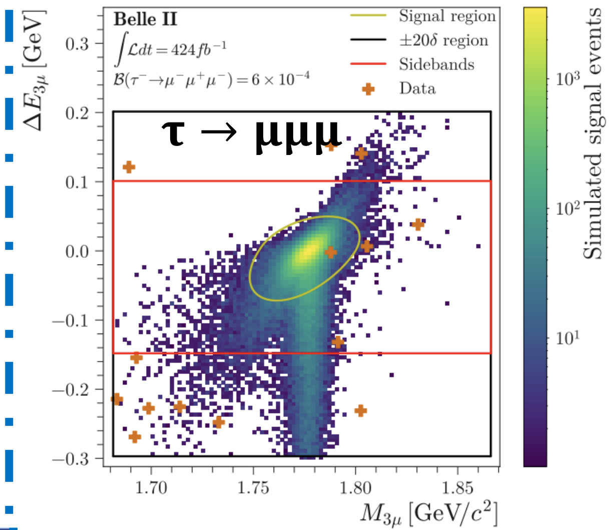
Lepton-flavor violation in τ physics

Lepton flavour violation is only allowed by:
- **Neutrino oscillations** $\mathcal{O}(10^{-55})$
far beyond current experimental sensitivities
- **New Physics models** $\mathcal{O}(10^{-8})$
e.g. Leptoquarks for $\tau^- \to \ell^- V^0$ deals with $R(K^{*0})$ anomalies

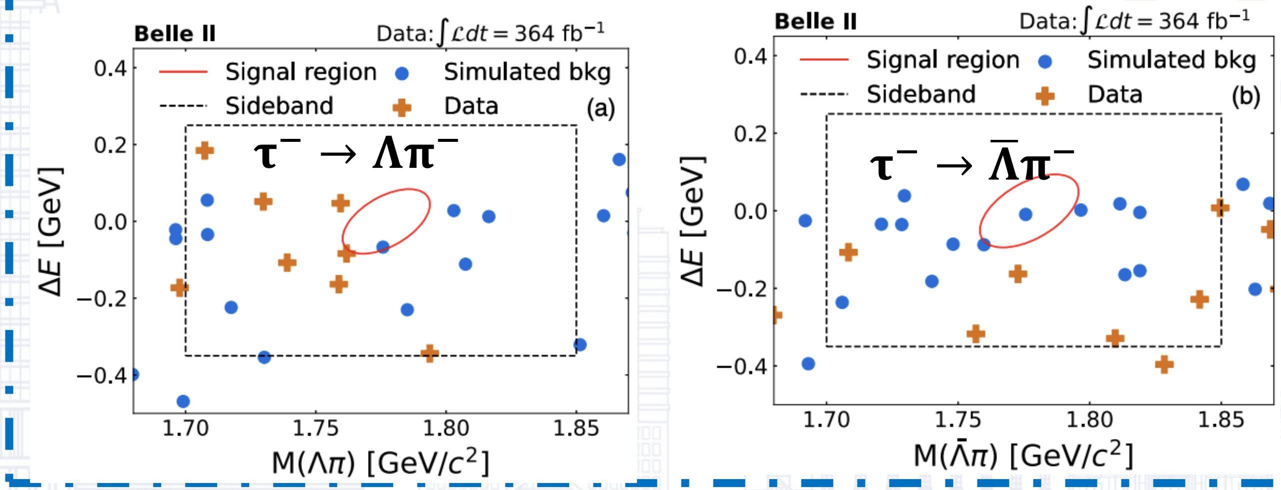
[JHEP 08 (2025) 092]



[JHEP 09 (2024) 062]



[PRD 110, 112003 (2024)]

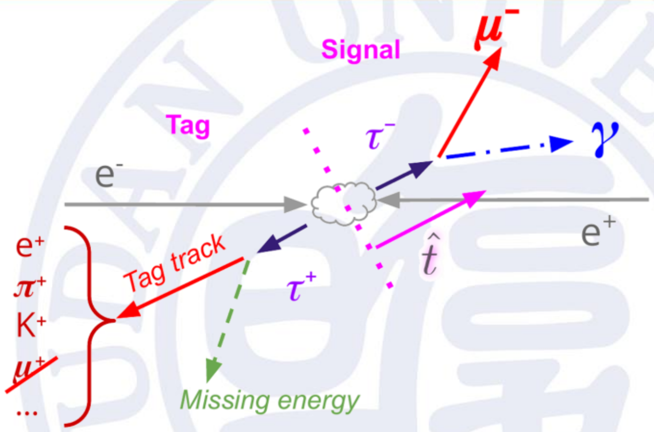


$\mathcal{B}^{UL}(\tau \to e(\mu)K_S^0) < 0.8(1.2) \times 10^{-8}$
$\mathcal{B}^{UL}(\tau \to \mu\mu\mu) < 1.9 \times 10^{-8}$
$\mathcal{B}^{UL}(\tau^- \to \Lambda\pi^-(\bar{\Lambda}\pi^-)) < 4.7(4.3) \times 10^{-8}$

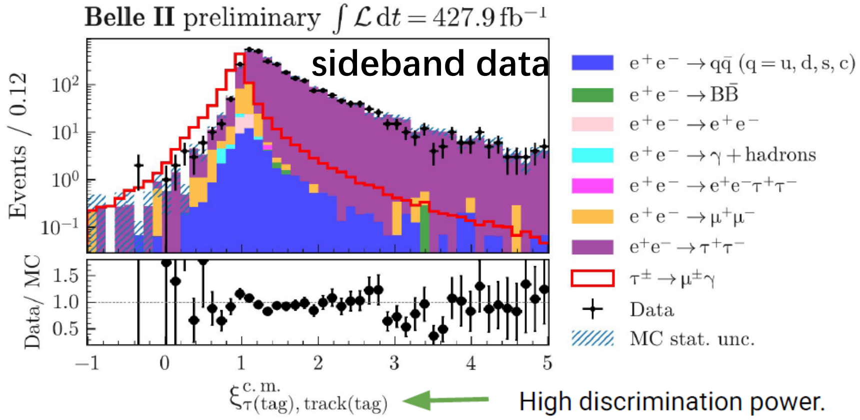
$$\Delta E_{3\mu} = E_\tau^* - \sqrt{s}/2$$

LFV decay $\tau \to \mu\gamma$: To be submitted to JHEP

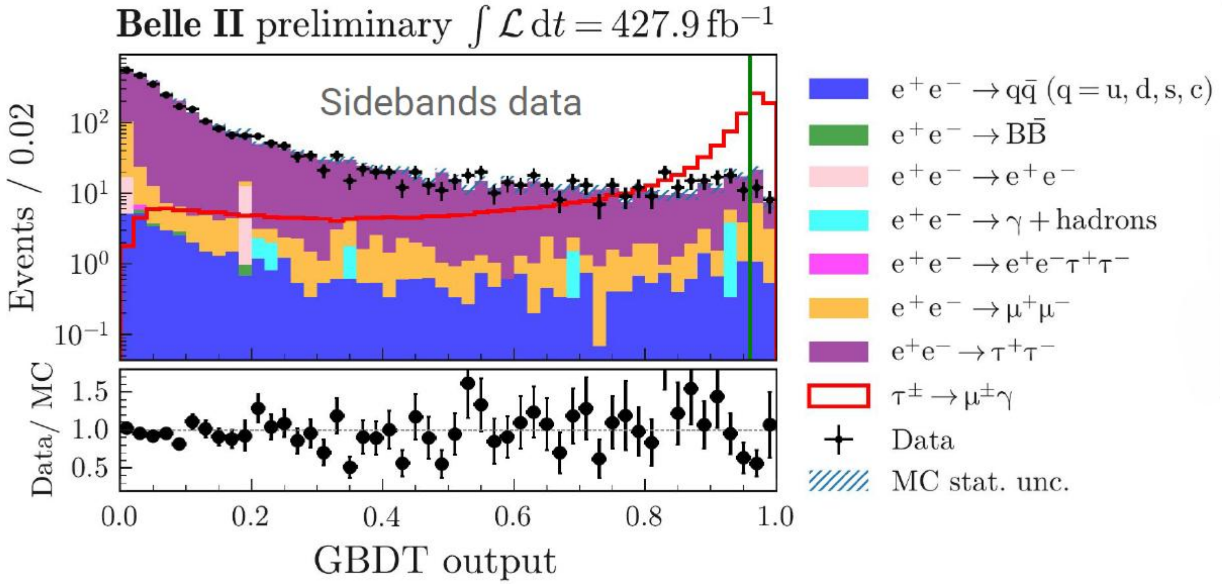
- Using 427.9 fb^{-1} data
- Require 2 charged particle with 0 net charge in 1×1-prong topology
  - Signal side: muID>0.95
  - Tag side: muID<0.1
- Cut-based preselection + BDT classifier
  - Data-driven pre-selection
  - Kinematic-based + Event-based selection
  - BDT trained using track kinematics and event shape variables $\xi^{\text{c.m.}}_{\tau(\text{tag}),\text{track(tag)}} = \frac{\vec{p}_{\tau(\text{tag})} \cdot \vec{p}_{\text{track(tag)}}}{|\vec{p}_{\tau(\text{tag})}||\vec{p}_{\text{track(tag)}}|}$.



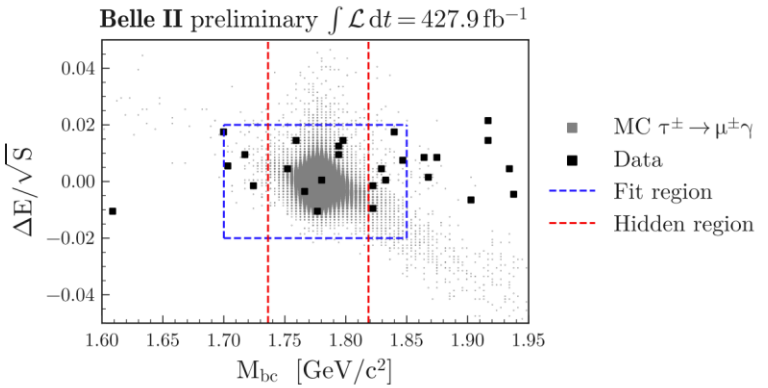
The sidebands consist of all data outside the signal region.



High discrimination power.

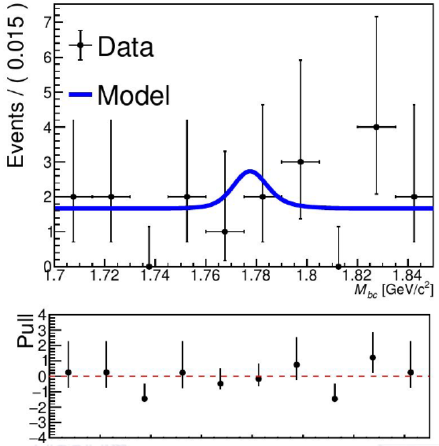


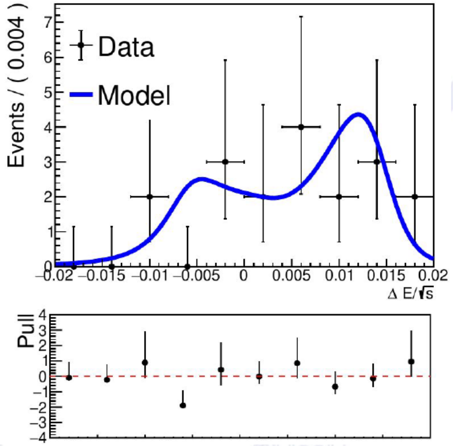
LFV decay $\tau \to \mu\gamma$: To be submitted to JHEP



- Signal efficiency 5.21%
- Signal from 2D fit ($M_{bc}, \Delta E/\sqrt{s}$)
  - Unbinned extended max. likelihood fit
  - Signal pdf: sum of two bifurcated Gaussian
  - Bkg pdf:the sum of the two main background components $e^+e^- \to \tau^+\tau^-$ and $\mu^+\mu^-$,
  - Use sidebands to extrapolate expected bkg yields

$$M_{\rm bc} = \sqrt{(E^{\rm c.m.}_{\rm beam})^2 - (|\vec{p}^{\,\rm c.m.}_{\mu\gamma}|)^2},$$
$$\Delta E/\sqrt{s} = (E^{\rm c.m.}_{\mu\gamma} - E^{\rm c.m.}_{\rm beam})/\sqrt{s}$$





- Fit result
  - Consistent with zero
  - 1.3 signal, 16.7 background
- **Upper limits computed with CLs technique**

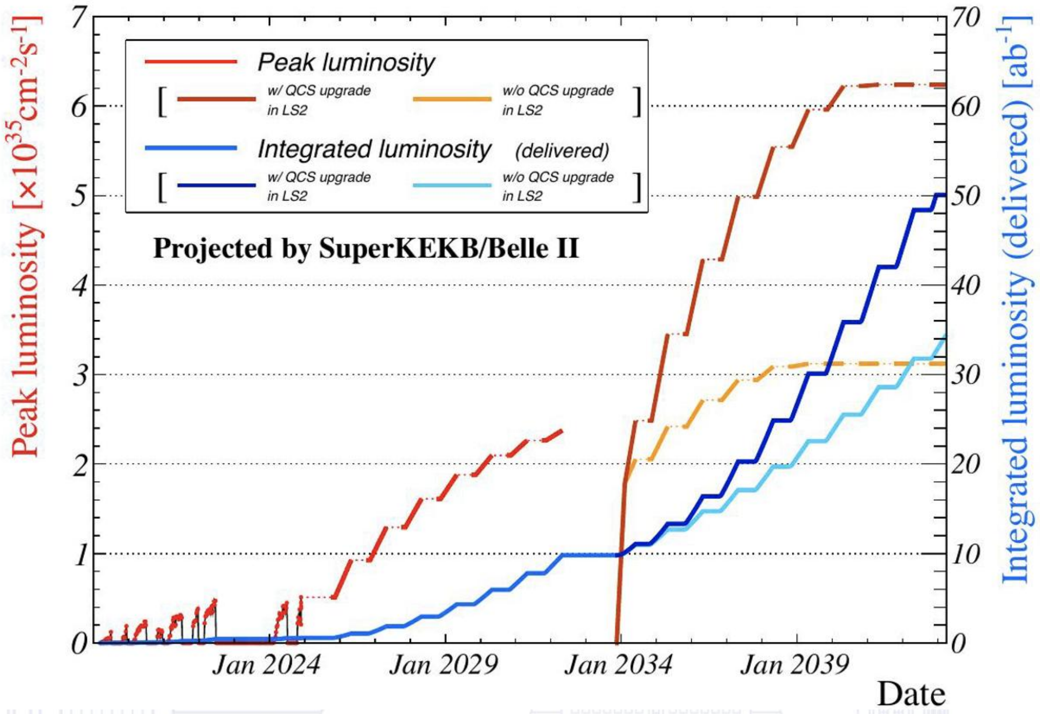
$$\mathcal{B}(\tau \to \mu\gamma)^{exp} < 5.8 \times 10^{-8}$$
$$\mathcal{B}(\tau \to \mu\gamma)^{obs} < 9.5 \times 10^{-8}$$

PDG: B($\tau \to \mu\gamma$)< 4.2×10^{-8}

- Belle II provides a unique environment for tau physics studies, providing world’s most precise measurements, as well as setting world-leading in LFV searches
- **Recent highlights from precision SM measurements and forbidden decay searches:**
  - Tau mass: [PRD 108, 032006]
  - LFU test: [JHEP 2024, 205]
  - $\tau \to l\alpha$: [PRL 130, 181803] + [JHEP 2025, 155]
  - $\tau \to \mu\mu\mu$: [JHEP 2024, 062]
  - $\tau \to e2l$: [arXiv:2507.18236]
  - $\tau \to lK_S^0$: [JHEP 2025, 092]
  - $\tau \to \Lambda(\bar{\Lambda})\pi$: [PRD 110, 112003]
  - $\tau \to \mu\gamma$: To be submitted to JHEP
  - And more to come!
  - Tau lifetime, CPV in kaon sector, LFU test and $\tau \to l\alpha$ search updates

Future prospects

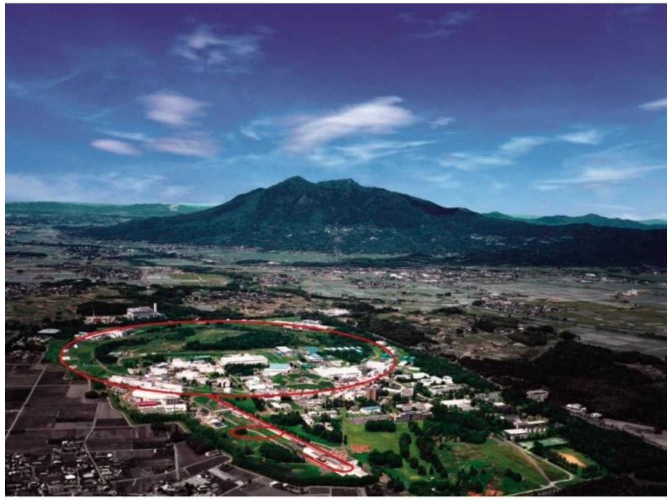
From https://www.belle2.org/research/luminosity/



- Until 2026, about 1 ab^{-1} data, comparable to Belle
- Until 2029, about 4 ab^{-1} data.

Summary

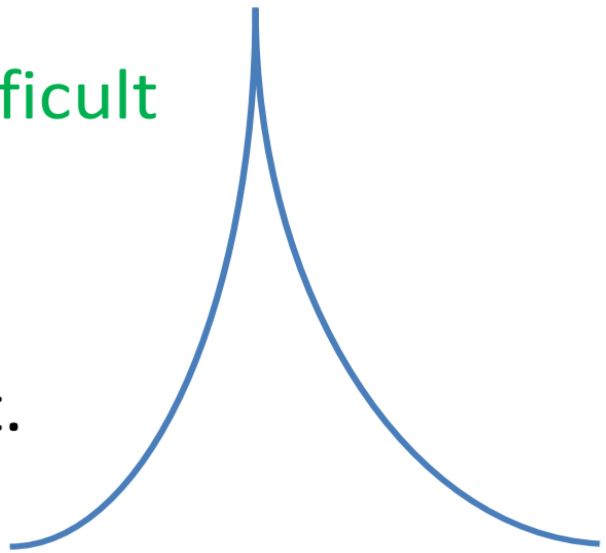
- Belle II and Belle hold a unique data sample. Some interesting measurements have been already performed
- Only ~1% of target luminosity collected so far. Stay tuned for more exciting results from Belle & Belle II.



Thanks for your attention!

Virtual state & threshold cusp

- Molecular type state -- when interaction is not strong enough to make a bound state, there would be a virtual state.
  - E < 0 (bound??), but in different Riemann sheet
  - Appears as threshold cusp instead of usual Breit-Wigner peak (in the narrow sense).
  - However, identification is rather difficult due to experimental resolution
- Are there really such states?
  - Pointing shape is not confirmed yet.



"threshold cusp" 指在物理过程的**能量阈值**（threshold）附近，某些观测量（如散射截面、衰变率、能谱分布等）出现**非解析的尖点状突变**（cusp）。这种现象通常源于新反应通道的打开或多粒子动力学的临界行为。

From the perspective of a cusp at $\Lambda\eta$ threshold

- Another possibility is that the peak structure is a cusp at the $\Lambda\eta$ threshold enhanced by the $\Lambda(1670)$ pole nearby.

- We fit the efficiency-corrected $M(pK^-)$distribution using a non-relativistic Flatté function [PLB, 63, 224 (1976), EPJA, 23, 523 (2005)]:

$$\frac{dN}{dm} \propto |f(m)|^2 = \left|\frac{1}{m - m_f + \frac{i}{2}(\Gamma' + \bar{g}_{\Lambda\eta} k)}\right|^2$$

- m_f is a parameter corresponding to the nominal mass of $\Lambda(1670)$.
- Γ' is a parameter for the sum of the partial widths of the decay modes other than $\Lambda\eta$, and is approximated as a constant.
- k is the decay momentum in the $\Lambda\eta$ channel, and $\bar{g}_{\Lambda\eta} k$ represents the partial decay width of the $\Lambda\eta$ channel.

- We fix m_f when we perform a fit and repeat the fit with various m_f values.

- We take into account an interference with another S-wave amplitude such as a tail of $\Lambda(1405)$. We perform a binned least-χ^2 fit with the combined function, $\frac{dN}{dm} \propto |f(m) + re^{i\theta}|^2$.

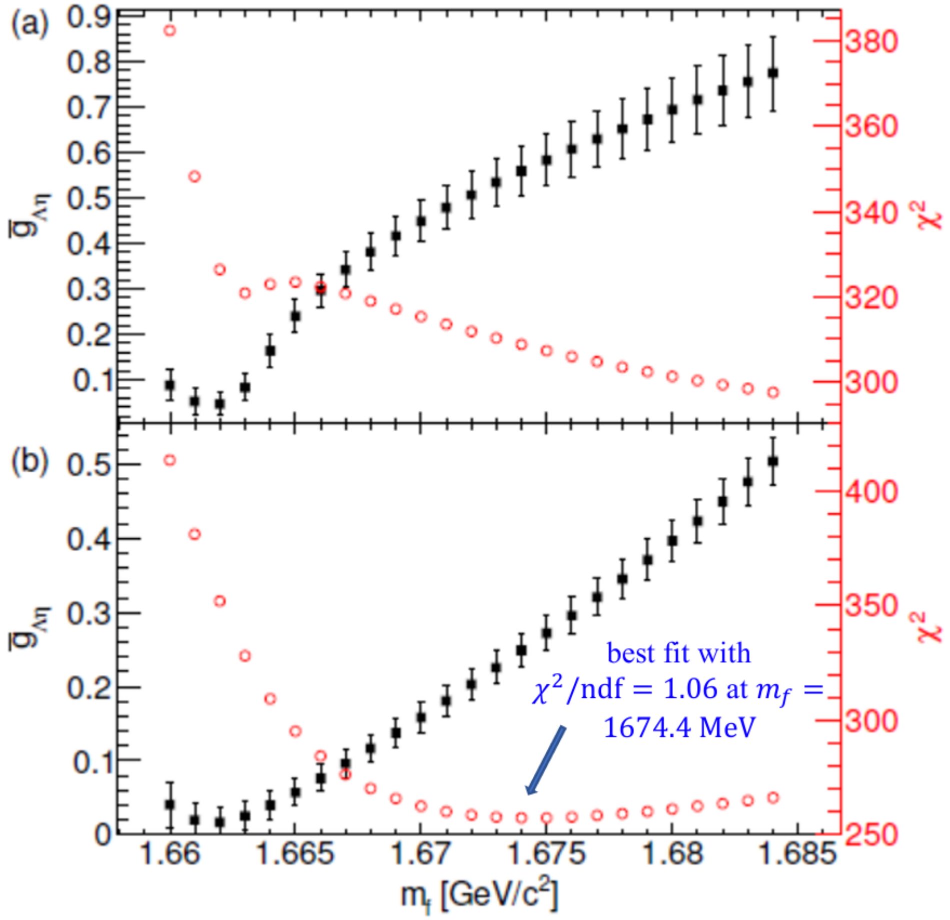


Figure :$\bar{g}_{\Lambda\eta}k$ and χ^2 from Flatté model (a) without and (b) with the interference as a function of fixed m_f .

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

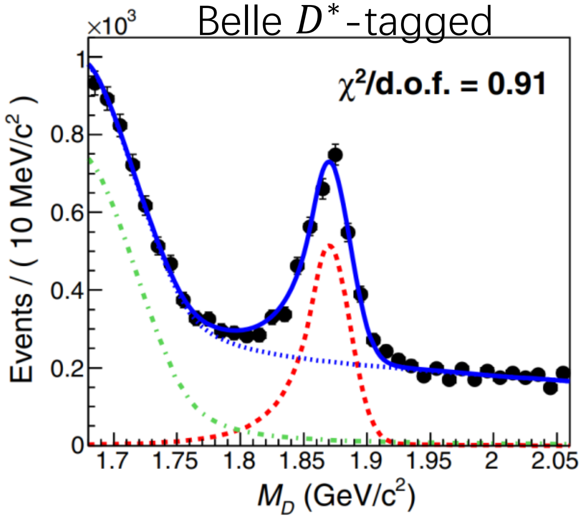
PRL 131, 051802 (2023)   PRD 108, 036026 (2023)   PRD 109, 033011 (2024)

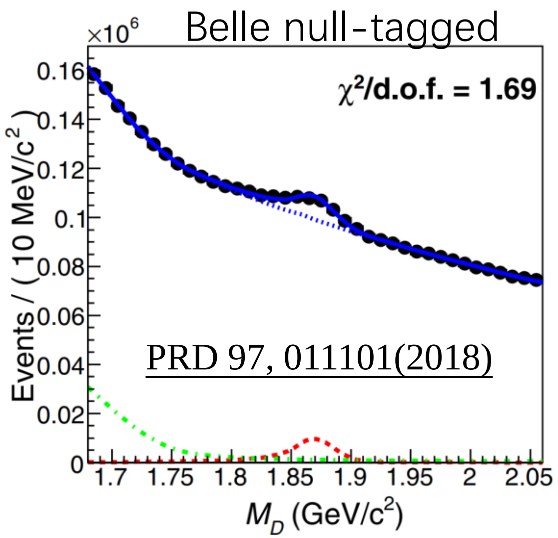
- Isospin-related modes $D^+ \to \pi^+\pi^0$ can reduce hadronic uncertainty.
- In addition, $D^+ \to \pi^+\pi^0$ $(I = 2)$ is expected to have no CPV in SM
  - since it does not receive QCD penguin $(\Delta I = 1/2)$ contribution and has suppressed electroweak penguin contribution.

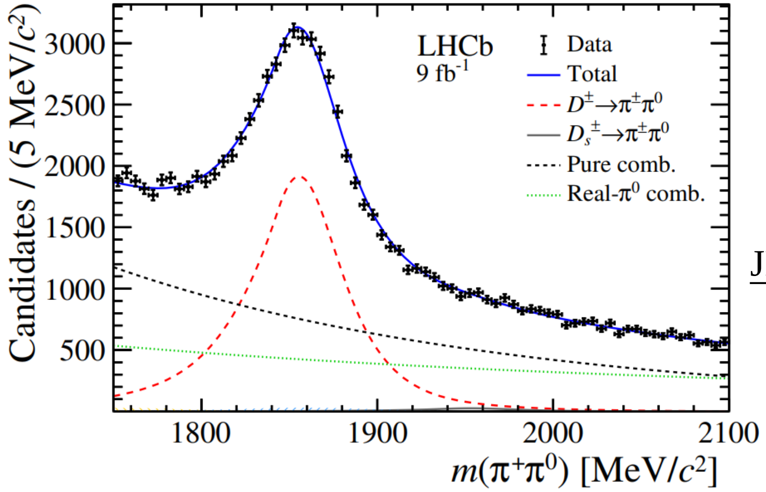
History of $A_{cp}(D^+ \to \pi^+\pi^0)$:

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

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





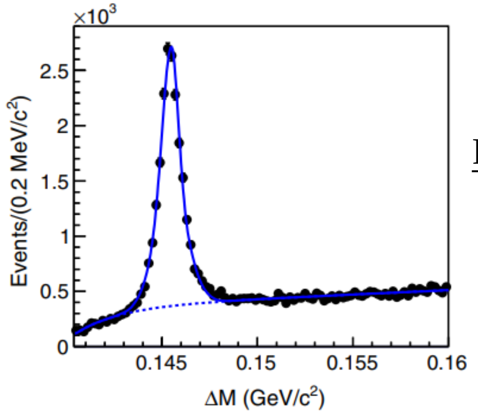


JHEP 06, 019 (2021)

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: $A_{raw}^{\pi^0\pi^0} = A_{CP}^{\pi^0\pi^0} + A_{prod}^{D^*} + A_{\epsilon}^{\pi_s}$; control modes: D^*-tagged $D^0 \to K^-\pi^+$, untagged $D^0 \to K^-\pi^+$.
- $A_{raw}^{K\pi,tag} = A_{prod}^{D^{*+}}(D^0 \to K^-\pi^+) + A_{\epsilon}^{\pi_s}(D^0 \to K^-\pi^+) + A_{\epsilon}^{K\pi}(D^0 \to K^-\pi^+)$
- $A_{raw}^{K\pi,untag} = A_{prod}^{D^0}(D^0 \to K^-\pi^+) + A_{\epsilon}^{K\pi}(D^0 \to K^-\pi^+)$

- 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 $\Xi_c^+ \to \Sigma^+ h^+ h^-$ 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]:

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