Recent results of hadrons at Belle (II)

贾森 (东南大学)
on behalf of the Belle and Belle II Collaboration

第六届重味物理与量子色动力学研讨会
2024年4月19 – 23日, 青岛

Outline

- Search for $P_c^+ \to pJ/\psi$ in $\Upsilon(1S, 2S)$ decays [arXiv:2403.04340]
- Search for $T_{cc}(3875)^+ \to D^0 D^{*+}$ [Preliminary results]
- Evidence of $h_b(2P) \to \Upsilon(1S)\eta$ decay and search for $h_b(1P, 2P) \to \Upsilon(1S)\pi^0$ [Preliminary results]
- $\Upsilon(10753) \to \pi^+\pi^-\Upsilon(nS)$ $(n = 1, 2, 3)$ [arXiv: 2401.12021]
- $\Xi_c^0 \to \Xi^0 h^0$ $(h^0 = \pi^0, \eta, \eta')$ [Preliminary results]

Search for $P_c^+ \to pJ/\psi$

Motivation

- LHCb discovered $P_c(4312)^+$, $P_c(4440)^+$, and $P_c(4457)^+$ decaying into pJ/ψ in the process $\Lambda_b^+ \to KpJ/\psi$ [PRL 122, 222001 (2019)].
- The $\Upsilon(1S, 2S, 3S)$ decay into three gluons (ggg) or two gluons plus a photon (γgg) with large branching fractions, providing an entry to many potential final states, including glueballs, light Higgs bosons, and states made of light quarks.

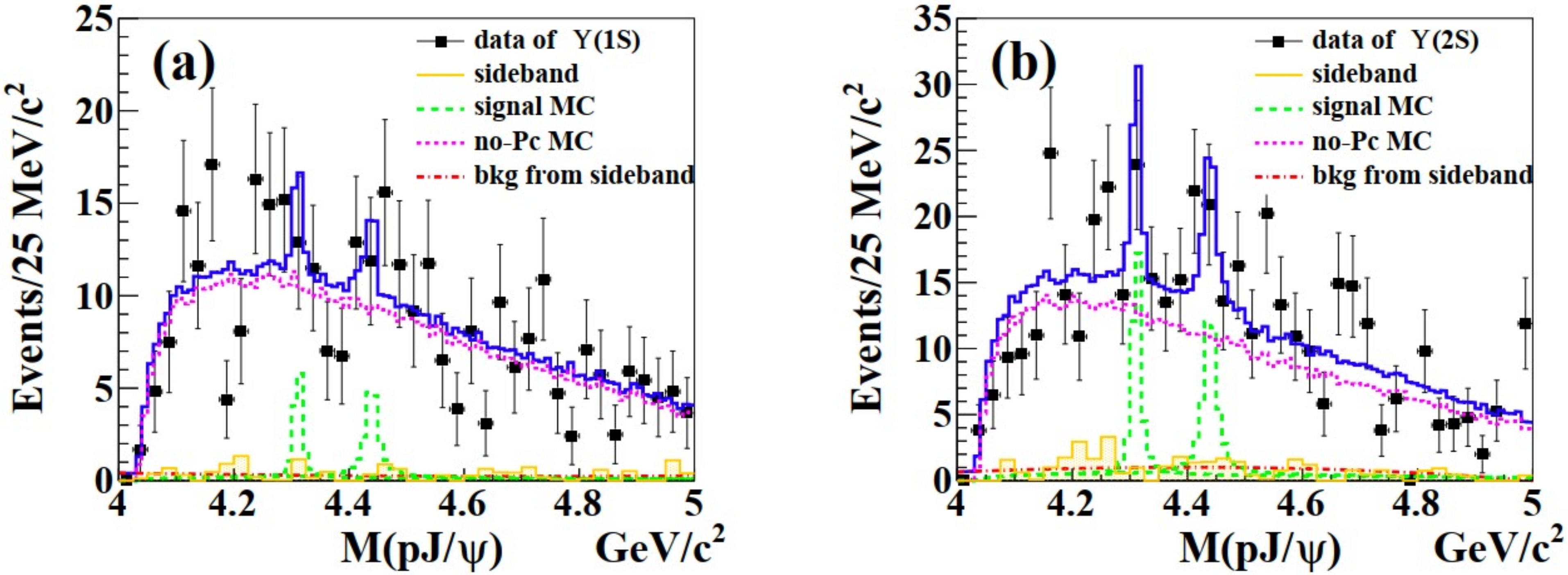
$\Upsilon(1S,2S,3S)$ datasets at e^+e^- colliders:

Experiment	$\Upsilon(1S)$		$\Upsilon(2S)$		$\Upsilon(3S)$	
	fb^{-1}	10^6	fb^{-1}	10^6	fb^{-1}	10^6
CLEO	1.2	21	1.2	10	1.2	5
BaBar	—	—	14	99	30	122
Belle	6	102	25	158	3	12

Search for $P_c^+ \to pJ/\psi$

[arXiv:2403.04340]
submitted to PRD

■Results



Belle
Υ (1S,2S)
dataset

$\mathcal{B}^{UL}$ is the upper limit on $\mathcal{B}(\Upsilon \to P_c^+ + \text{anything}) \cdot \mathcal{B}(P_c^+ \to pJ/\psi)$ at 90% C.L.

Yield / UL	Υ(1S) inclusive decay			Υ(2S) inclusive decay		
P_c state	$P_c(4312)^+$	$P_c(4440)^+$	$P_c(4457)^+$	$P_c(4312)^+$	$P_c(4440)^+$	$P_c(4457)^+$
N^{fit}	10 ± 8	14 ± 12	-3 ± 9	30 ± 16	33 ± 15	0 ± 3
N^{UL}	26	37	14	52	60	6
$\mathcal{B}^{UL}$ $(\times10^{-6})$	4.5	6.8	4.9	5.3	7.2	2.4

Search for $T_{cc}(3875)^+ \to D^0D^{*+}$

[Preliminary results]

Motivation:

The $T_{cc}(3875)^+ \to D^0D^0\pi^+$ was first observed by LHCb [Nature Phys. 18 (2022) 7, 751-754].

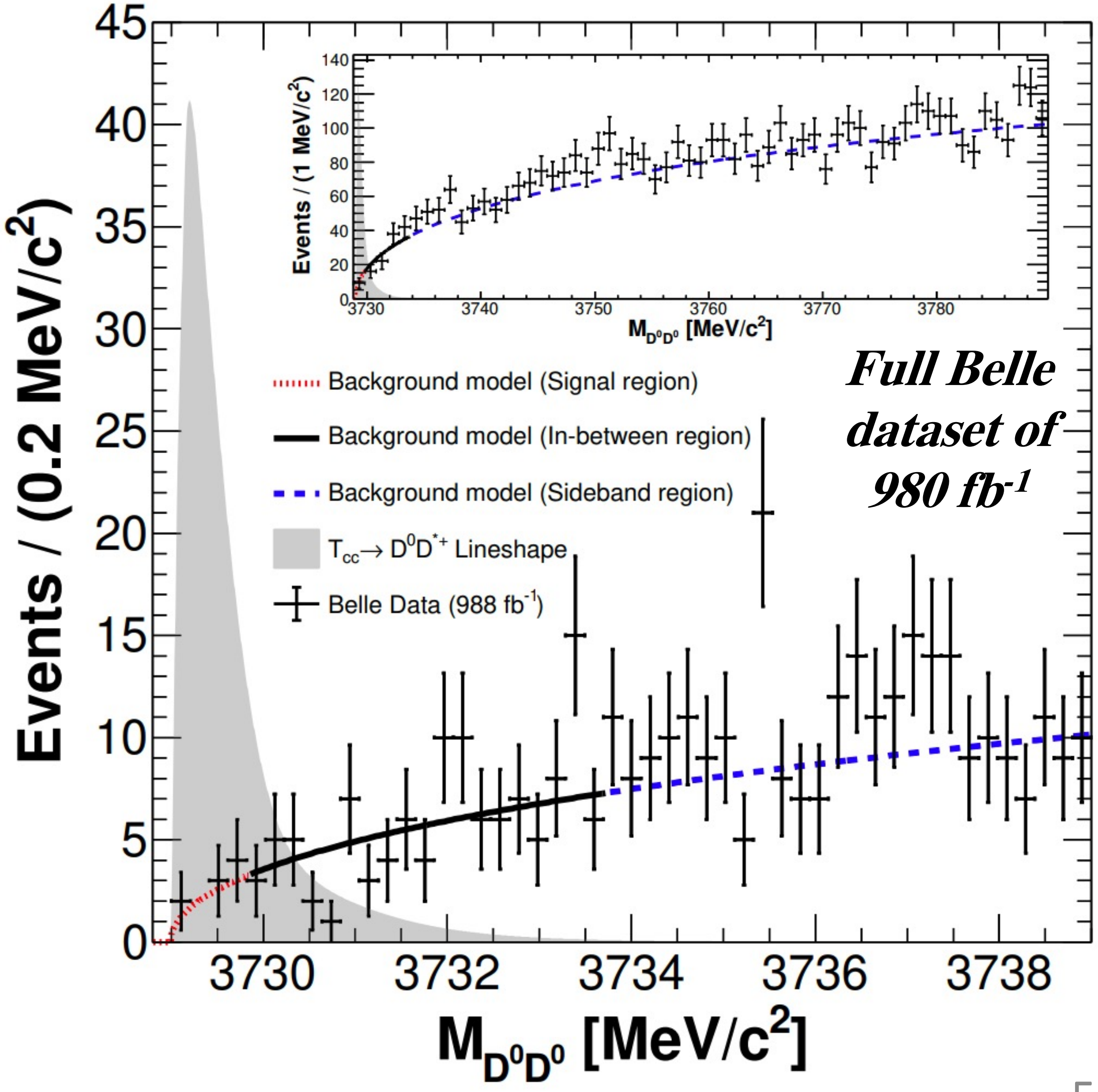
Analysis strategy:

Partially reconstruction using two $D^0 \to K^-\pi^+$ to increase the efficiency and improve signal resolution

Results:

$N^{obs} = 9$ and $N^{bkg} = 9.38^{+0.58}_{-0.44}$

$\sigma(e^+e^- \to T_{cc}(3875)^+ + \text{anything})\mathcal{B}(T_{cc}(3875)^+ \to D^0D^{*+}) < 38.7$ fb at 90% C.L.

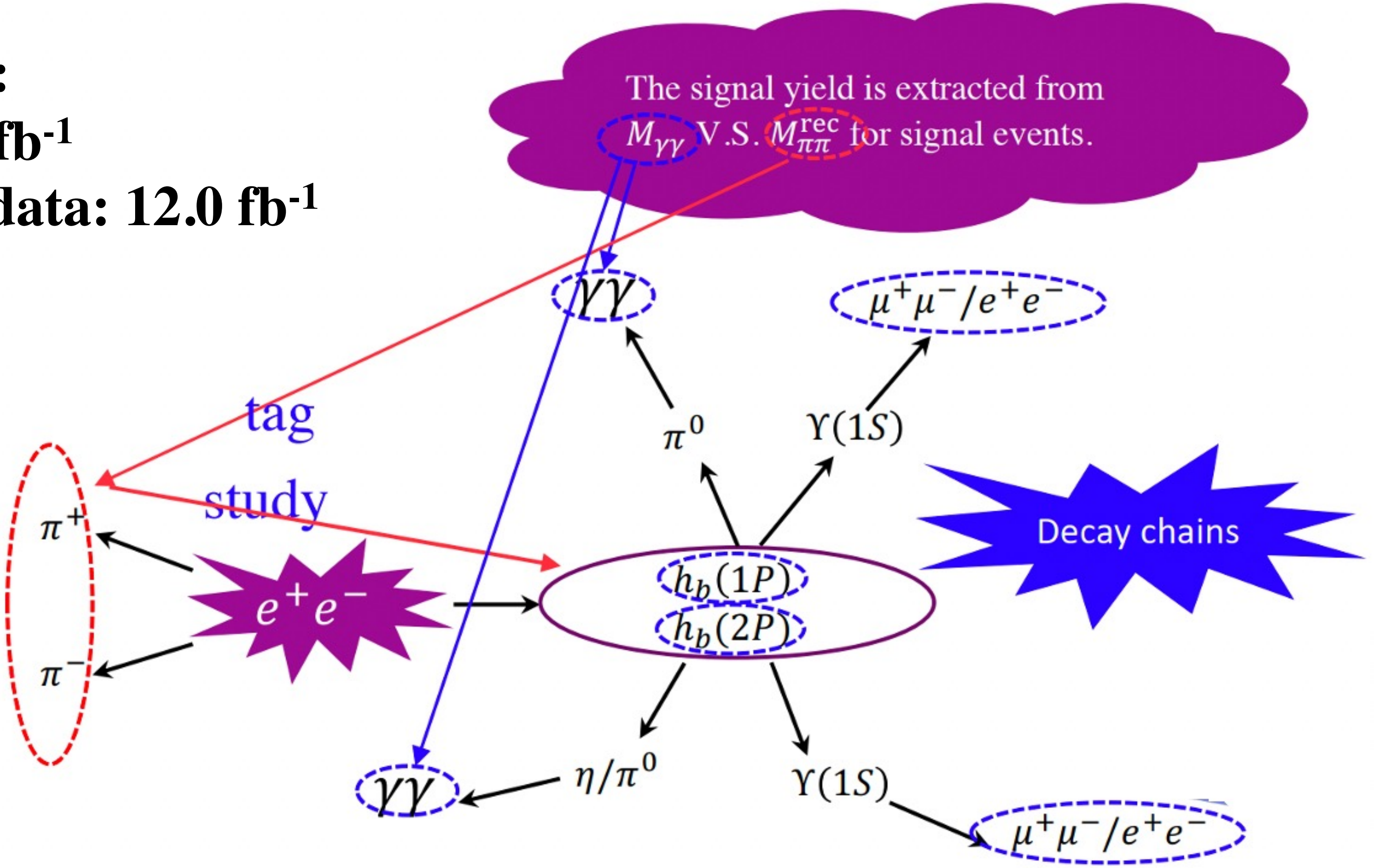


Evidence of $h_b(2P) \to \Upsilon(1S)\eta$ decay and search for $h_b(1P, 2P) \to \Upsilon(1S)\pi^0$

Motivation:

Based on the QCD multipole expansion [NPB 154, 365 (1979)], $h_b(2P) \to \Upsilon(1S)\eta$ decay is of great interest as its rate is suppressed by the heavy quark spin symmetry.

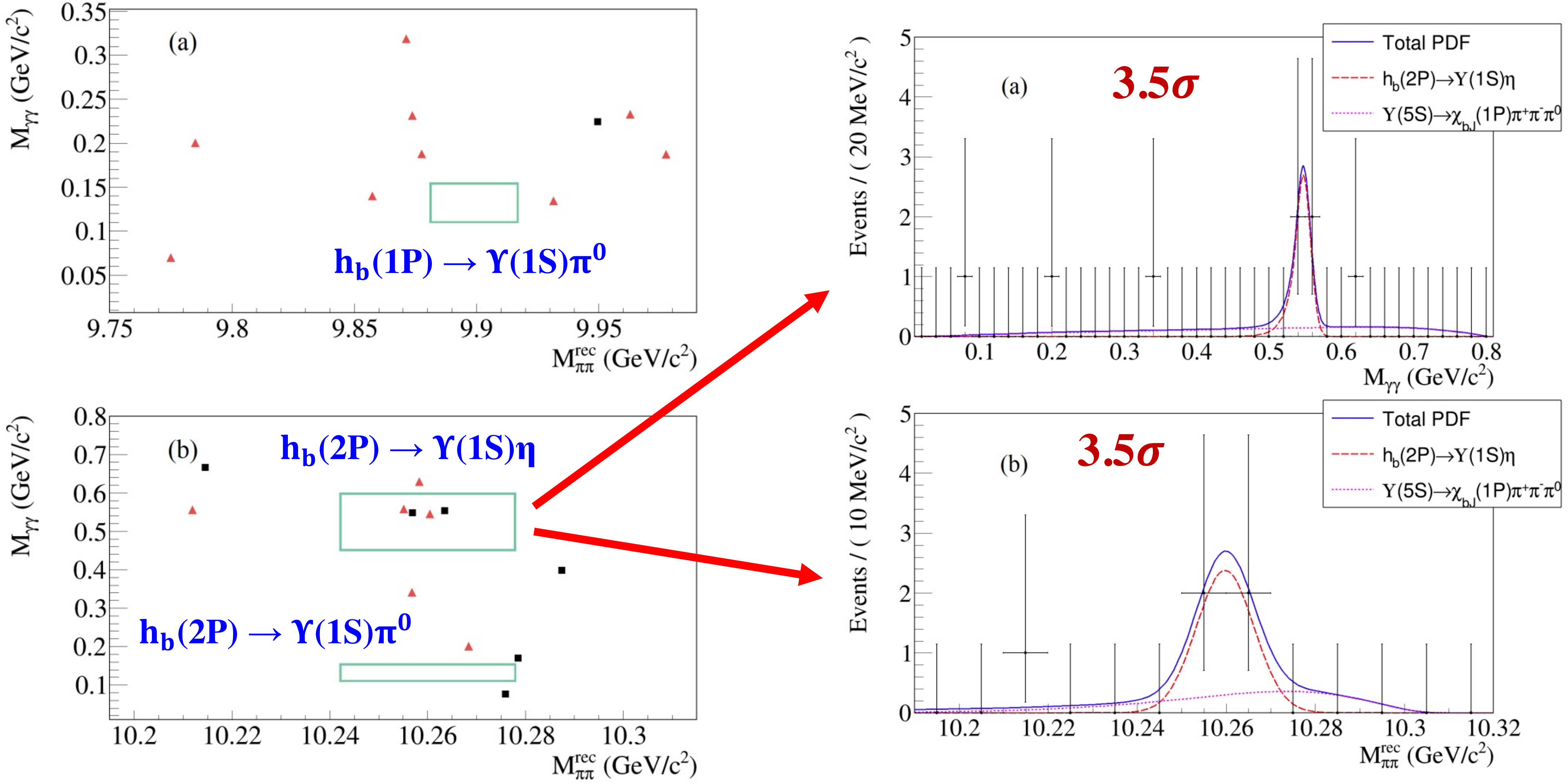
Data samples:
$\Upsilon(5S)$: 121.4 fb^{-1}
Energy-scan data: 12.0 fb^{-1}



Evidence of $h_b(2P) \to \Upsilon(1S)\eta$ decay and search for $h_b(1P, 2P) \to \Upsilon(1S)\pi^0$

Results:

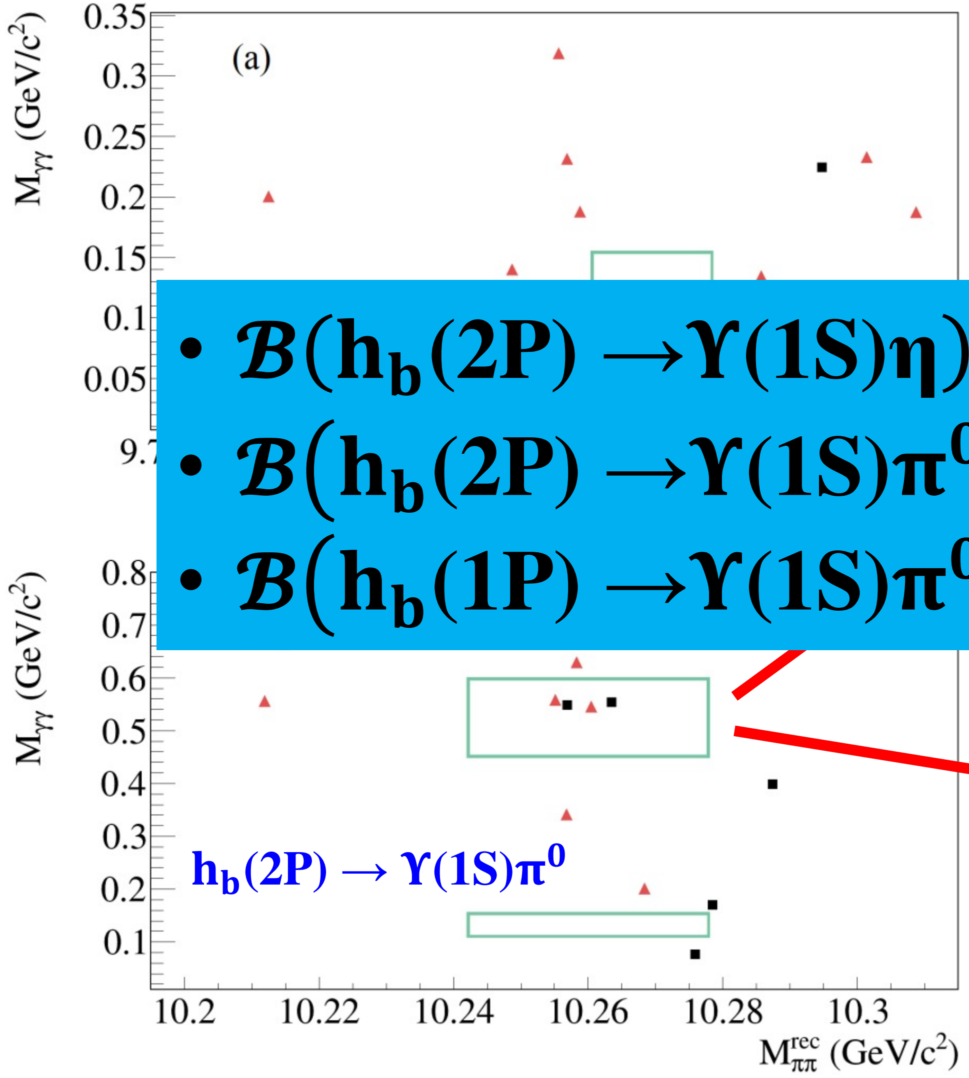
[Preliminary results]

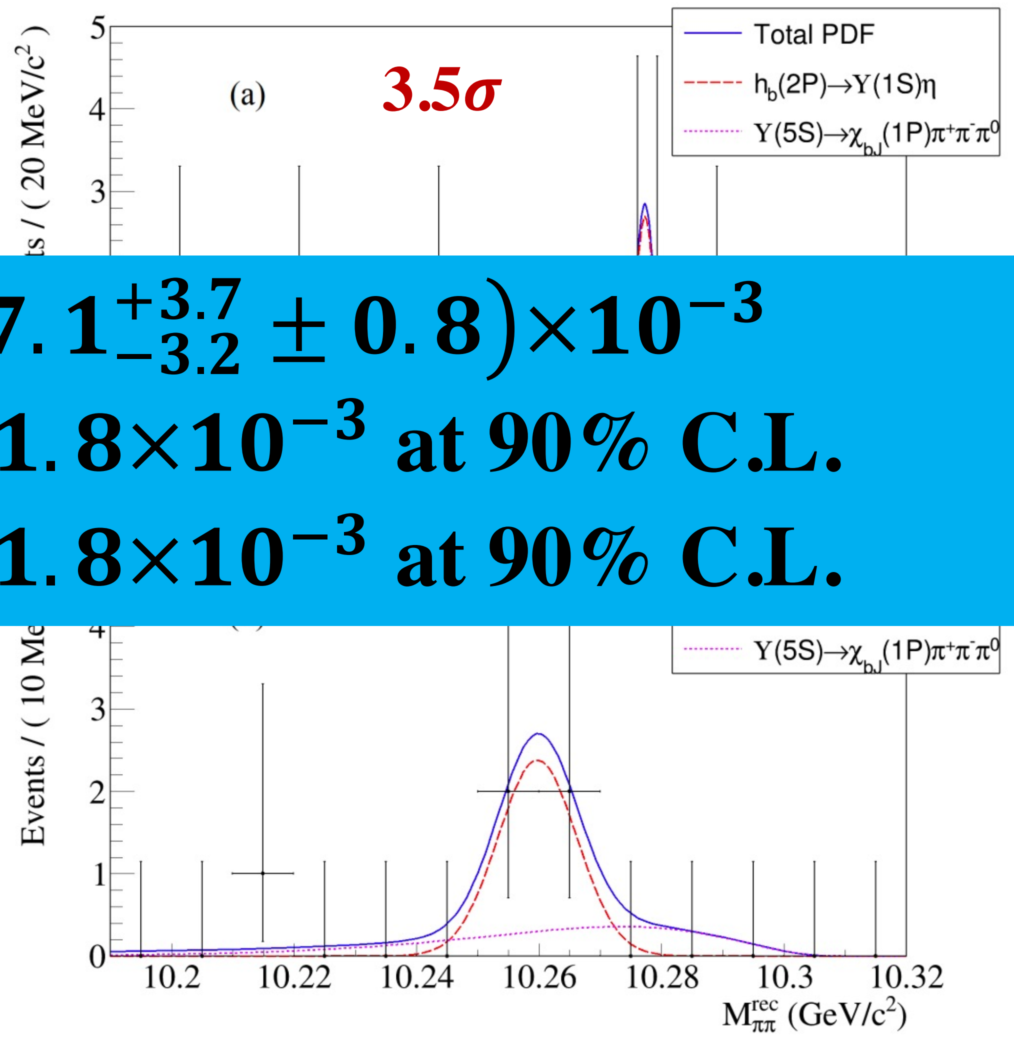


Evidence of $h_b(2P) \to \Upsilon(1S)\eta$ decay and search for $h_b(1P, 2P) \to \Upsilon(1S)\pi^0$

Results:

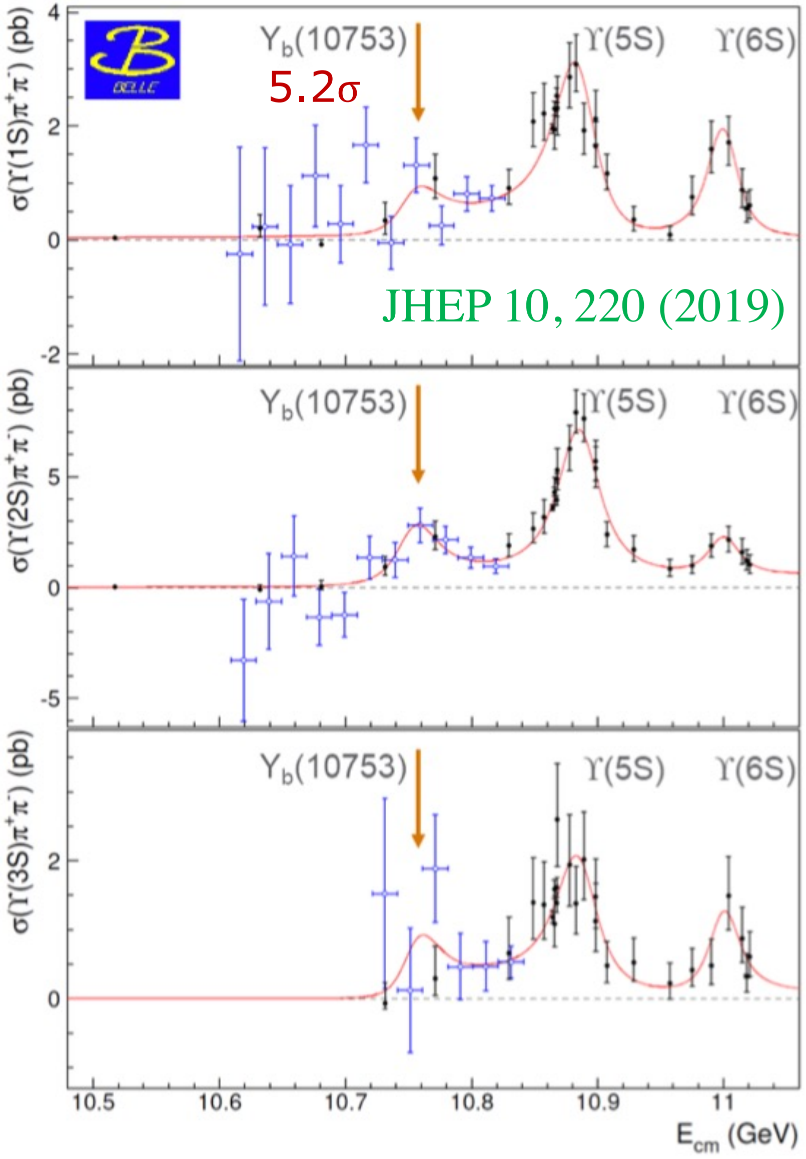
[Preliminary results]





- $\mathcal{B}(h_b(2P) \to \Upsilon(1S)\eta) = (7.1^{+3.7}_{-3.2} \pm 0.8)\times 10^{-3}$
- $\mathcal{B}(h_b(2P) \to \Upsilon(1S)\pi^0) < 1.8\times 10^{-3}$ at 90% C.L.
- $\mathcal{B}(h_b(1P) \to \Upsilon(1S)\pi^0) < 1.8\times 10^{-3}$ at 90% C.L.

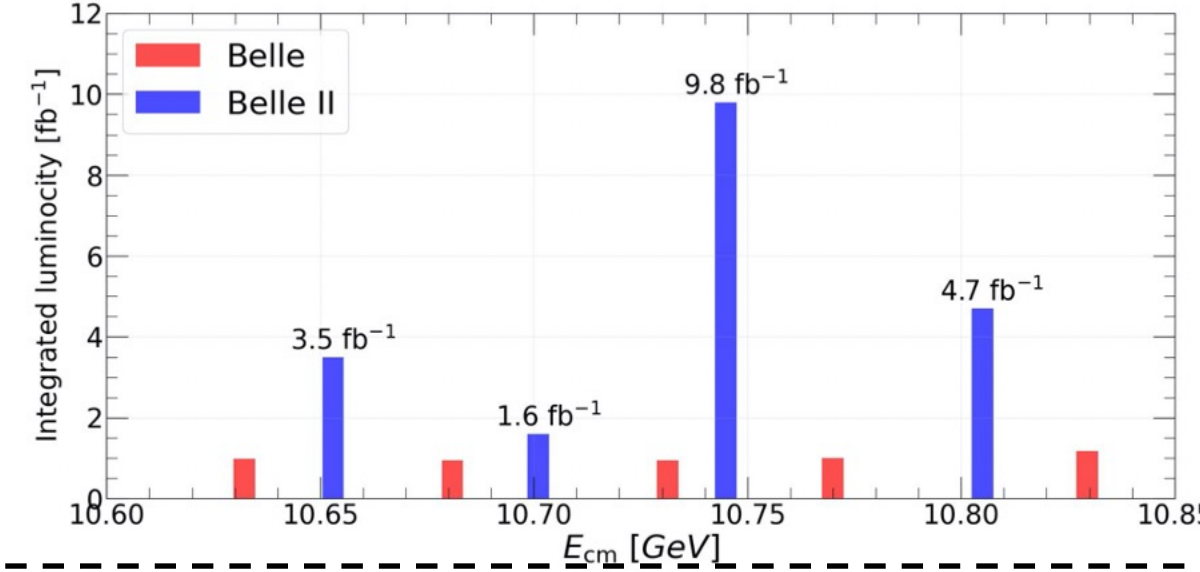
Discovery of Υ(10753)



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

	Υ(10860)	Υ(11020)	New structure
M (MeV/c²)	$10885.3 \pm 1.5\,^{+2.2}_{-0.9}$	$11000.0^{+4.0}_{-4.5}\,^{+1.0}_{-1.3}$	$10752.7 \pm 5.9\,^{+0.7}_{-1.1}$
Γ (MeV)	$36.6^{+4.5}_{-3.9}\,^{+0.5}_{-1.1}$	$23.8^{+8.0}_{-6.8}\,^{+0.7}_{-1.8}$	$35.5^{+17.6}_{-11.3}\,^{+3.9}_{-3.3}$

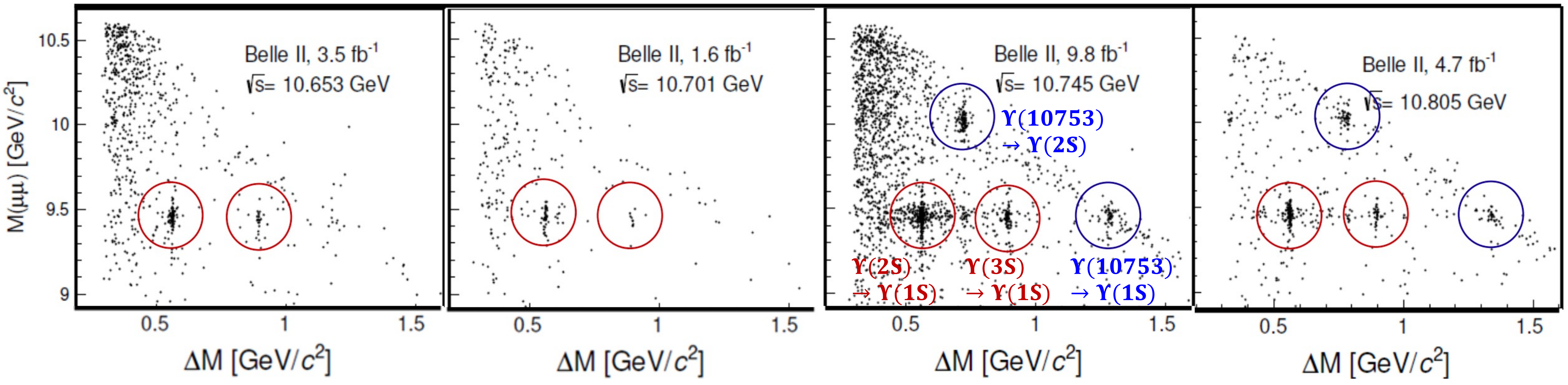
Unique scan data near $\sqrt{s}$ = 10.75 GeV at Belle II



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

[arXiv: 2401.12021]
submitted to JHEP

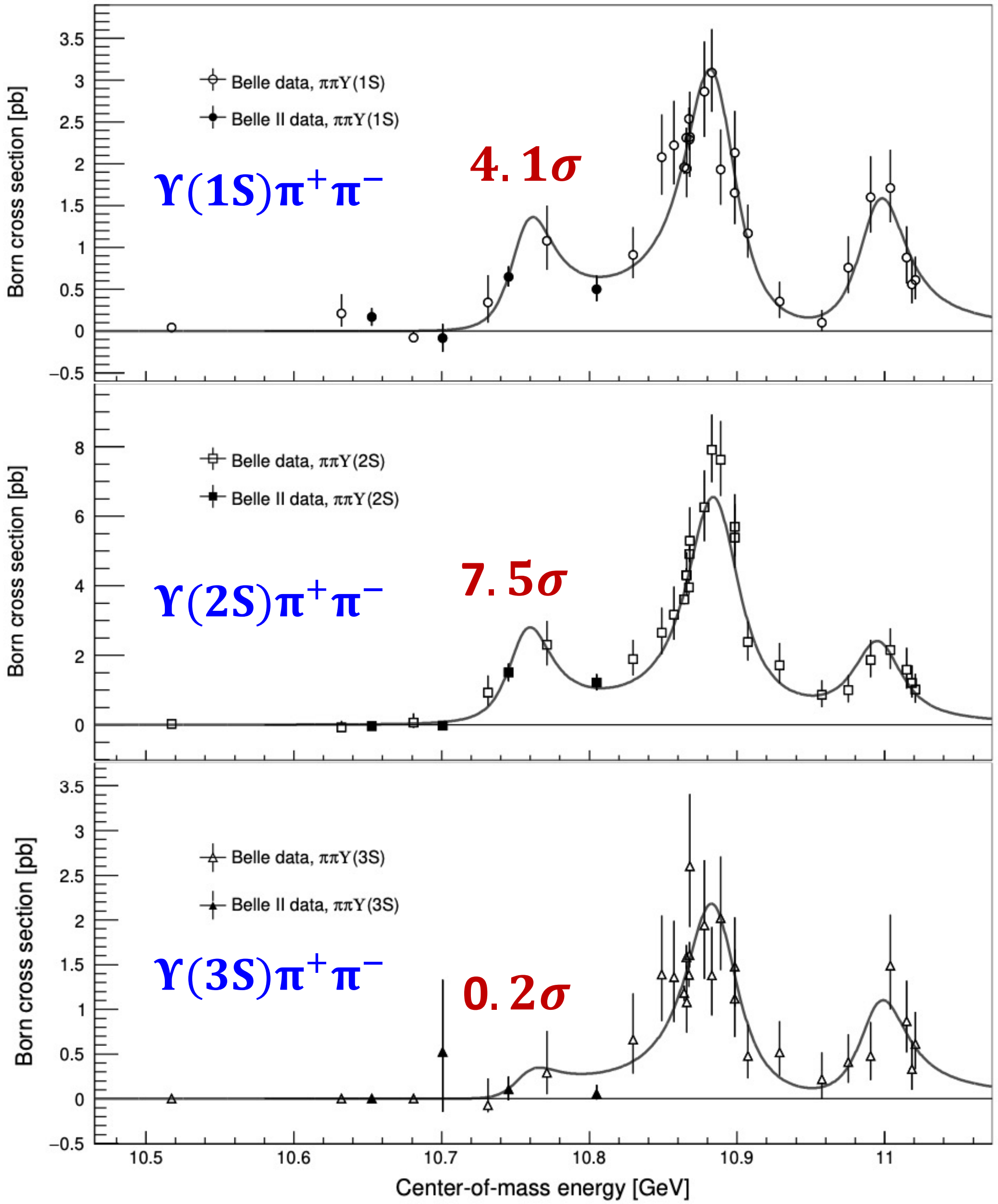
- The full reconstruction: $e^+e^- \to [\Upsilon(nS) \to \mu^+\mu^-]\pi^+\pi^-$
- $\Delta M = M(\mu^+\mu^-\pi^+\pi^-) - M(\mu^+\mu^-)$



ISR $\Upsilon(2S,3S) \to \Upsilon(1S)\pi^+\pi^-$ **Signal: $e^+e^- \to [\Upsilon(nS) \to \mu^+\mu^-]\pi^+\pi^-$**

If we require $p^*(\pi^+\pi^-\mu^+\mu^-) < 100$ MeV/c, the background from non-prompt production of the $\Upsilon(10753)$ is suppressed.

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

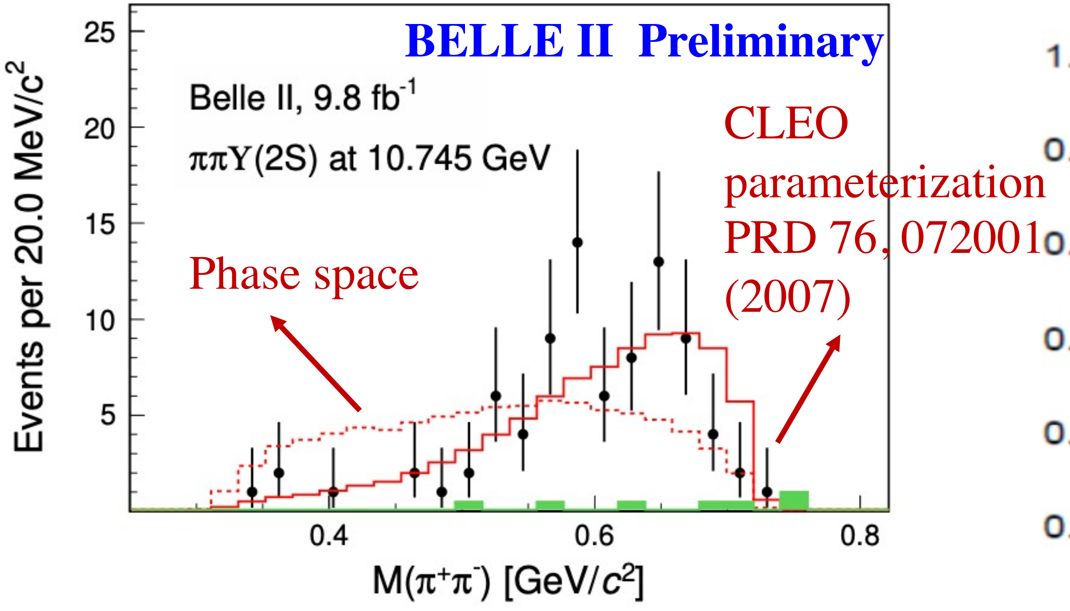


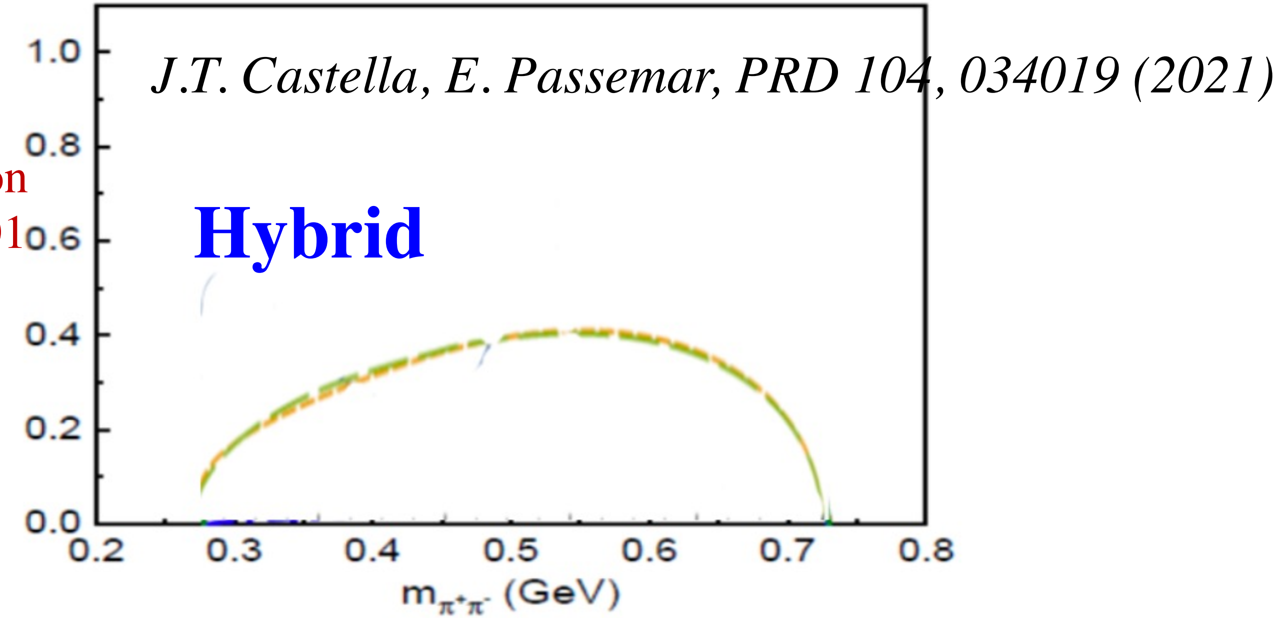
[arXiv: 2401.12021]
submitted to JHEP

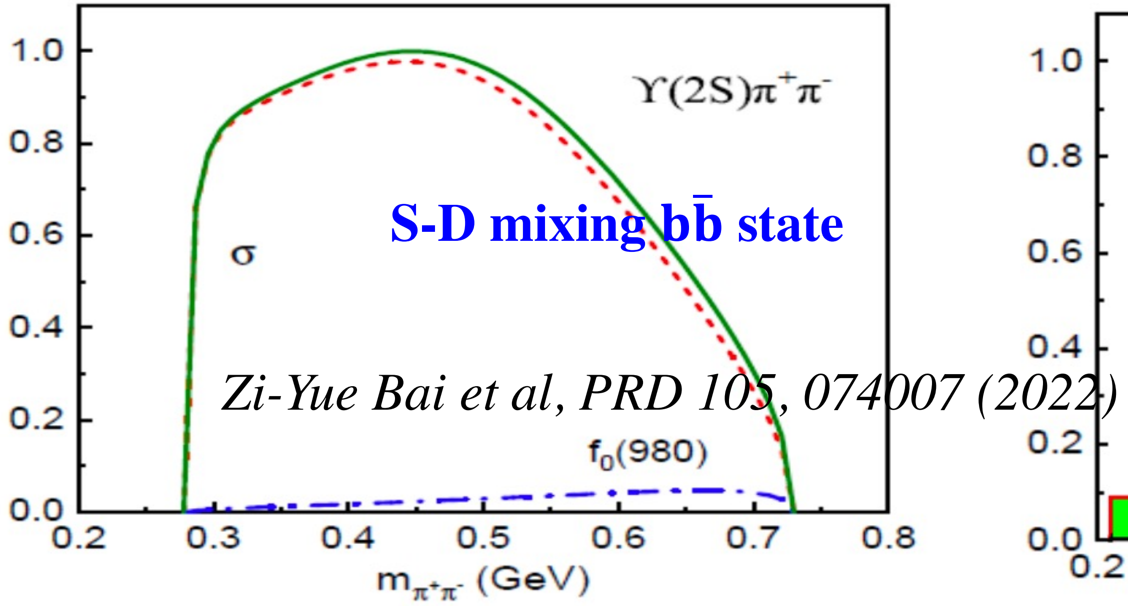
- New measurement confirms previous Belle result.
- Fit: Use coherent sum of Breit-Wigner amplitudes, convolve with a Gaussian to account for energy spread.

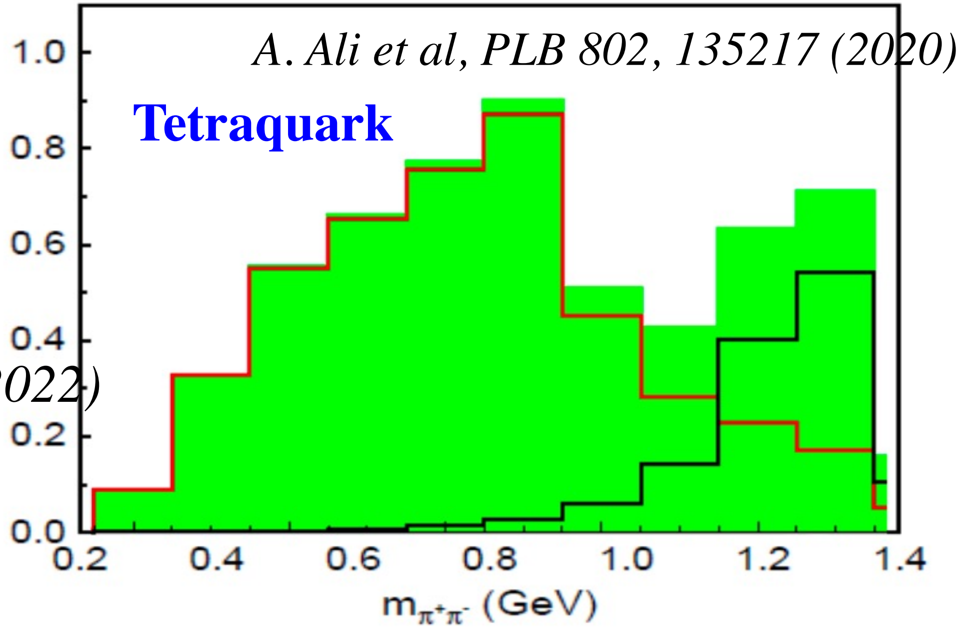
Mass	**$(10756.3 \pm 2.7 \pm 0.6)$ MeV/c^2**
Width	**$(29.7 \pm 8.5 \pm 1.1)$ MeV**
$\mathcal{R}_{\sigma(1S/2S)}^{\Upsilon(10753)}$	$0.46^{+0.15}_{-0.12}$
$\mathcal{R}_{\sigma(3S/2S)}^{\Upsilon(10753)}$	$0.10^{+0.05}_{-0.04}$

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



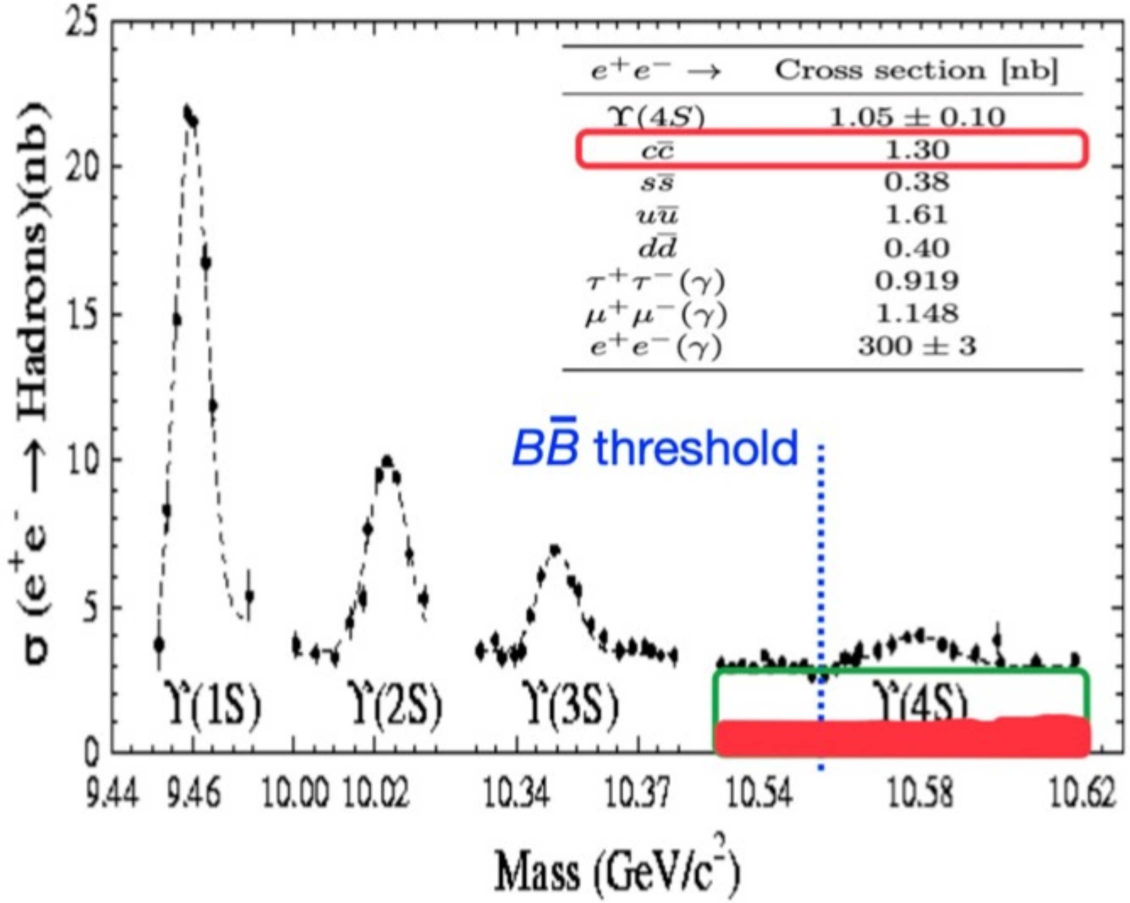


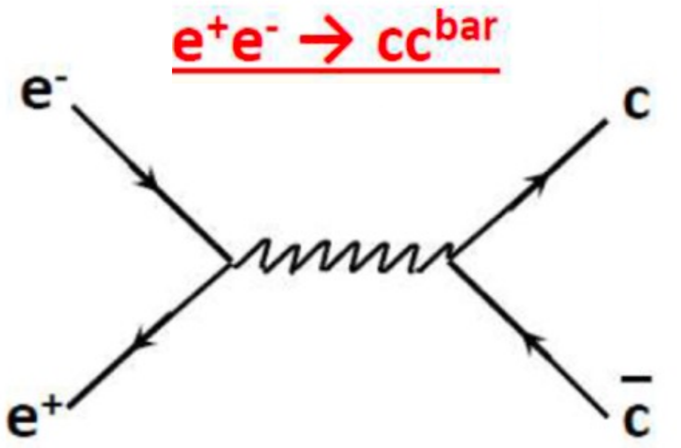




Dataset and charmed baryon production at Belle (II)

- In B-factories, e^+e^- collider at 10.58 GeV to make $\Upsilon(4S)$ resonance decaying into $B^0\bar{B}^0$ and B^+B^- in 96% of the time.
- Meanwhile, a large cross section for continuum processes $e^+e^- \to q\bar{q}$ $(q = u, d, s, c)$.





Datasets	Luminosity
Belle	980 fb^{-1}
Belle II	426 fb^{-1}

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

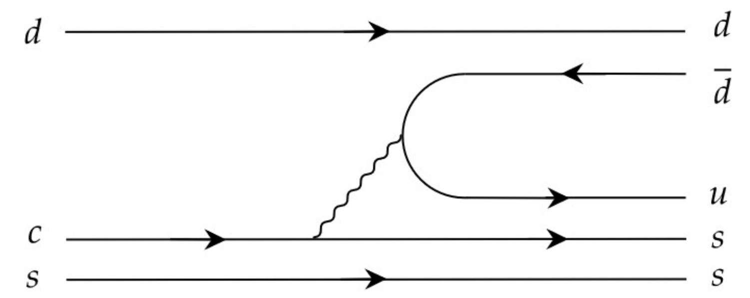
Motivation:

- Nonfactorizable amplitudes arising from internal W-emission and W-exchange lead to the difficulties for theoretical predictions in hadronic weak decay of charmed baryons.

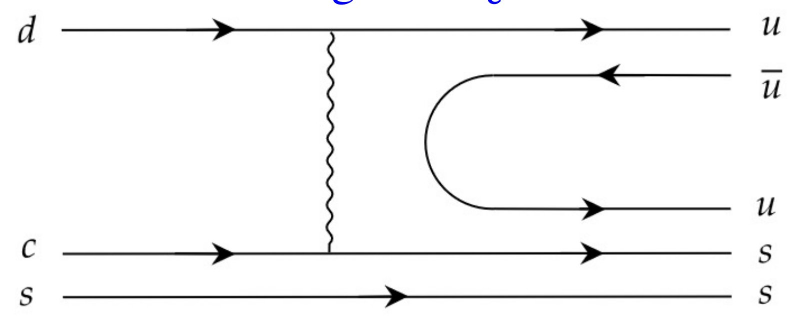
Theoretical predictions for branching fractions ($\times 10^{-3}$) and asymmetry parameters:

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

Internal W-emission for $\Xi_c^0 \to \Xi^0 h^0$



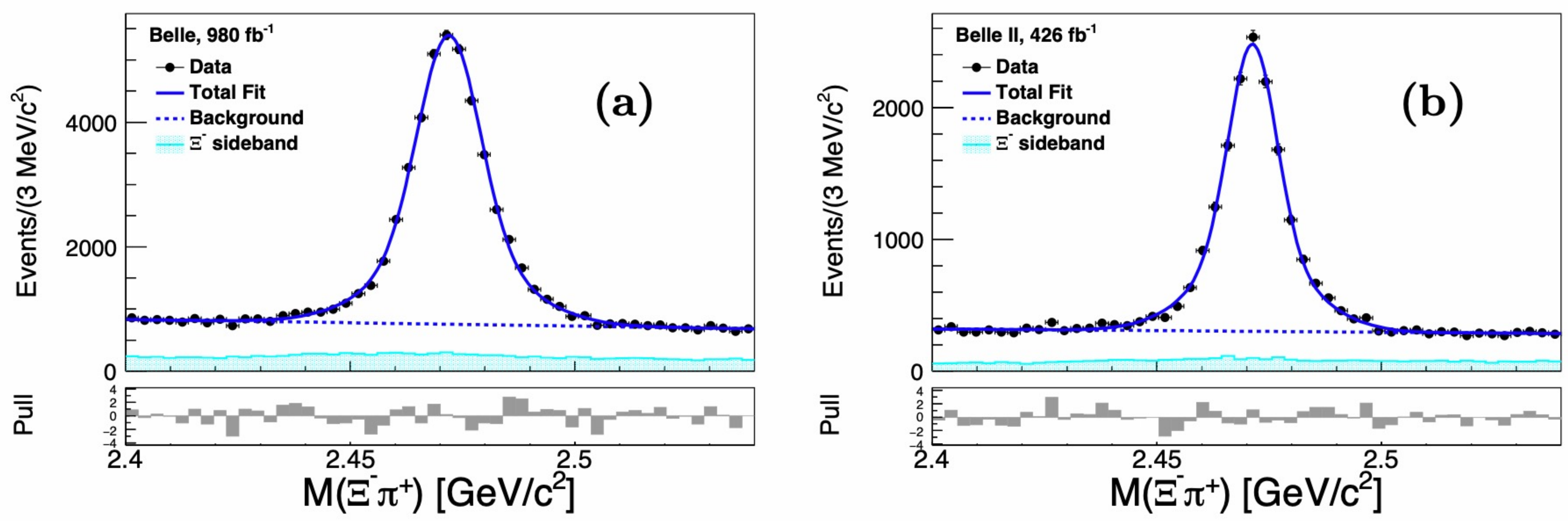
W-exchange for $\Xi_c^0 \to \Xi^0 h^0$



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

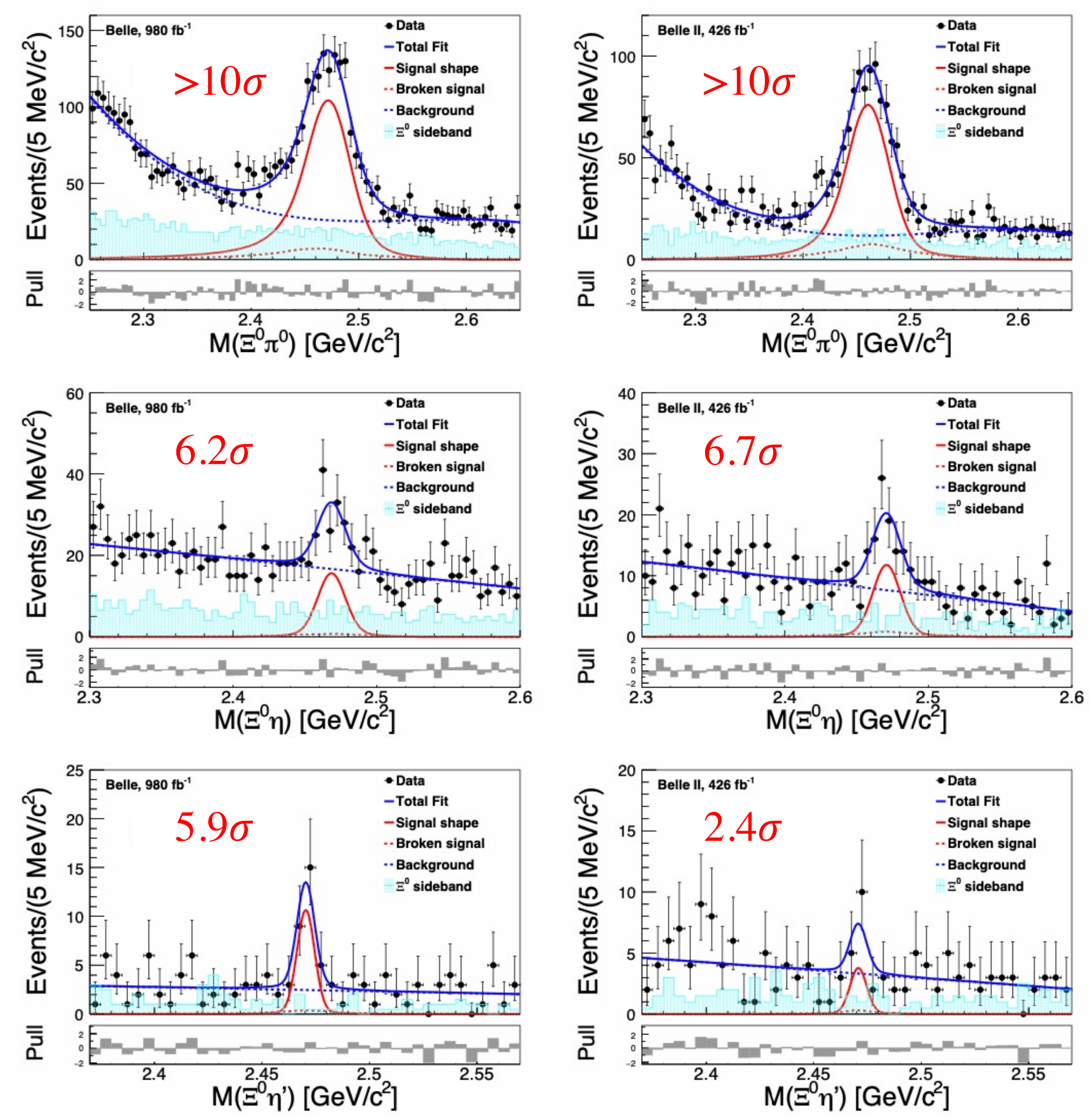
Reference mode of $\Xi_c^0 \to \Xi^-\pi^+$

First Belle + Belle II combined charm measurement.



Datasets	Signal yield
Belle	36340±348
Belle II	13719±184

Branching fractions for $\Xi_c^0 \to \Xi^0 h^0$ ($h^0 = \pi^0, \eta, \eta'$)



Preliminary results, will be submitted to JHEP

Signal yield:

Channel	Belle	Belle II
$\Xi_c^0 \to \Xi^0\pi^0$	1315±66	869±46
$\Xi_c^0 \to \Xi^0\eta$	81±15	60±11
$\Xi_c^0 \to \Xi^0\eta'$	23±6	8±4

First measurement of the following BRs:

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

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

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

They are compatible with theoretical prediction based on $SU(3)_F$-breaking [JHEP 02, 235 (2023)].

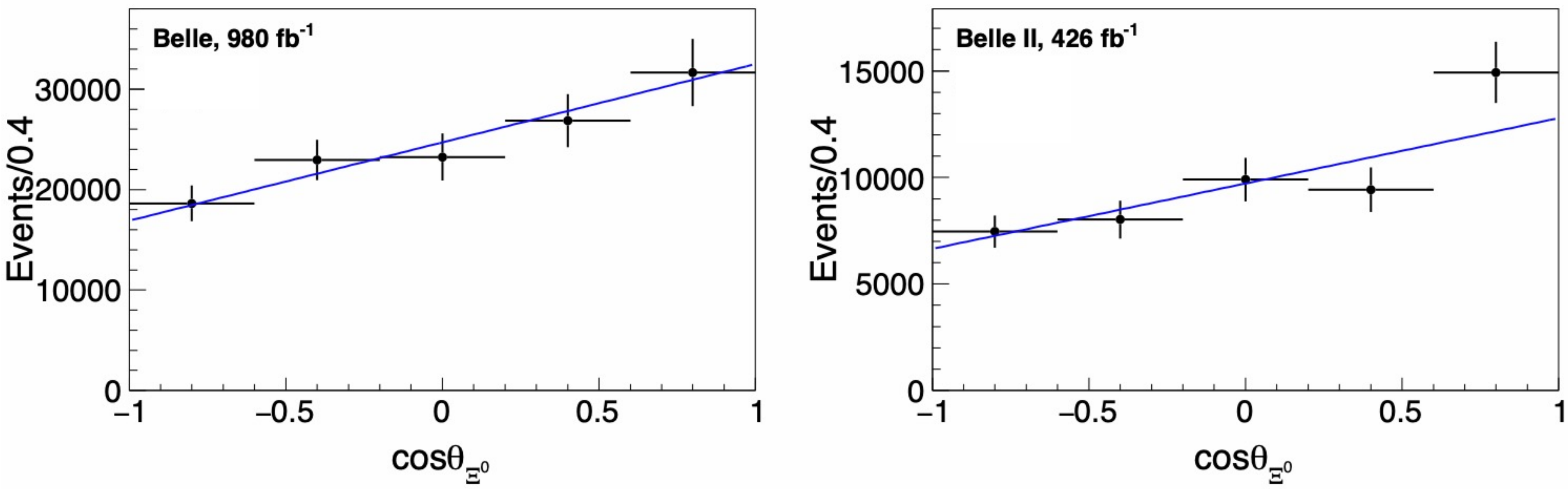
Asymmetry parameter for $\Xi_c^0 \to \Xi^0\pi^0$

The asymmetry parameter, related to P-violation, is measured through the differential decay rate:

[Preliminary results]

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

The $\cos\theta_{\Xi^0}$ is the angle between the Λ momentum vector and the opposite of the Ξ_c^0 momentum vector in the Ξ^0 rest frame.



The $\alpha(\Xi_c^0 \to \Xi^0\pi^0) = -0.90 \pm 0.15 \pm 0.23$, which is consistent with predictions based on the pole model [PRD 48 (1993) 4188, PRD 101 (2020) 014011], CA [EPJC 7 (1999) 217], and SU(3)$_F$ flavor symmetry [PLB 794 (2019) 19] approaches.

Summary

- Neither $P_c^+ \to pJ/\psi$ nor $T_{cc}(3875)^+ \to D^0 D^{*+}$ signals are found.
- **First evidence of $h_b(2P) \to \Upsilon(1S)\eta$.**
- Updated measurement of $\Upsilon(10753) \to \pi^+\pi^-\Upsilon(nS)$ **with improved precision**.
- **First observation of $\Xi_c^0 \to \Xi^0\pi^0/\Xi^0\eta/\Xi^0\eta'$** with combined Belle and Belle II data.

Thanks for your attentions!