



Hadron spectroscopy from BESIII and Belle II

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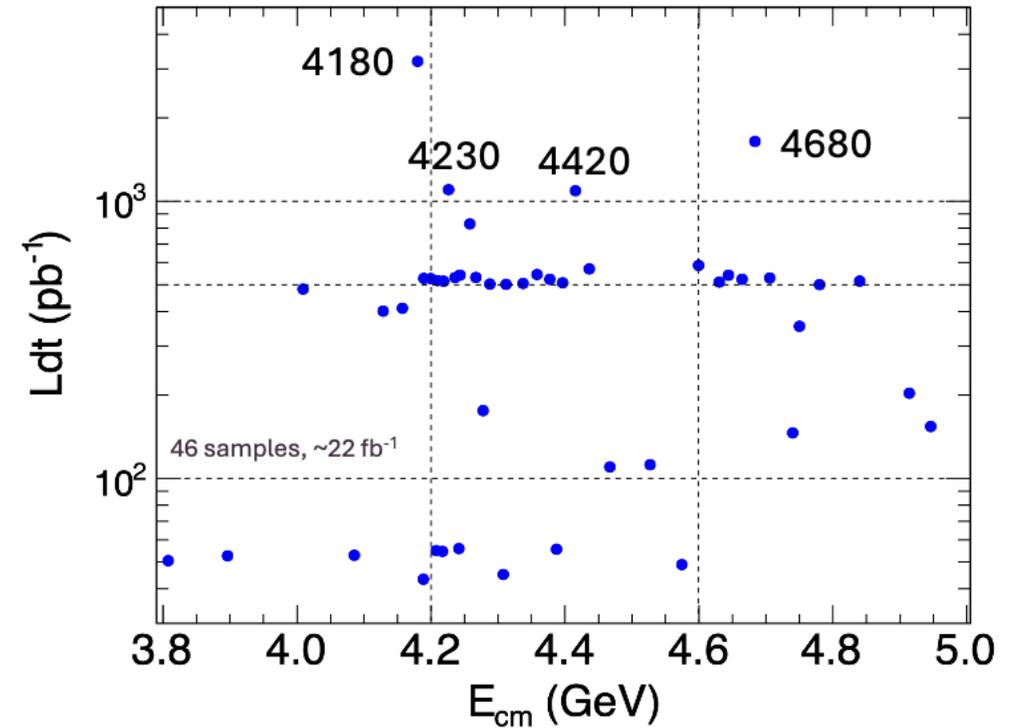
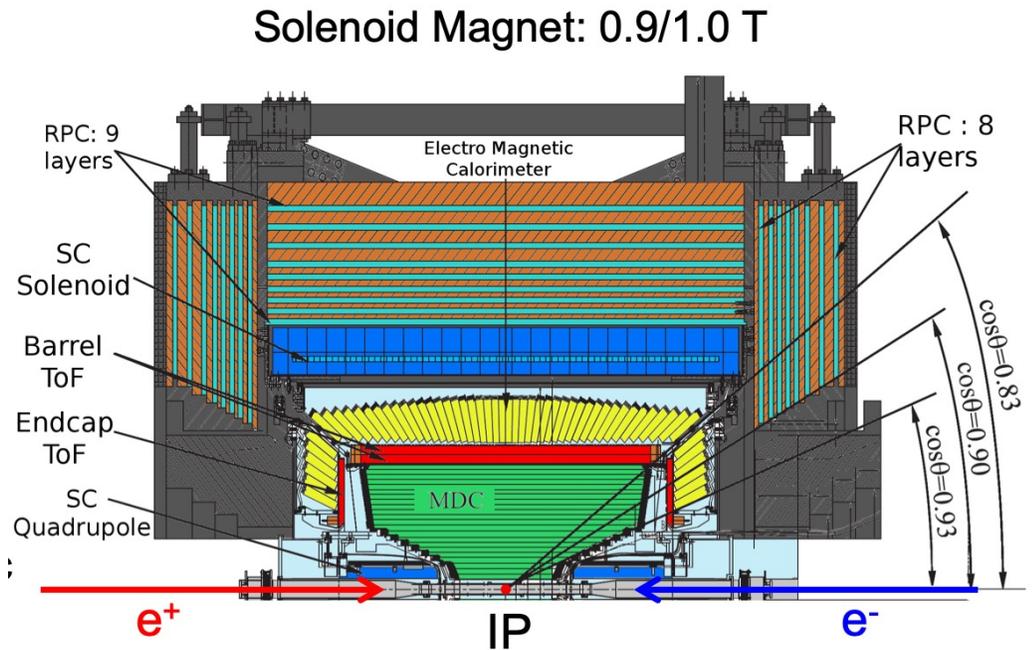
Southeast University

味物理前沿研讨会 暨味物理讲座100期特别活动

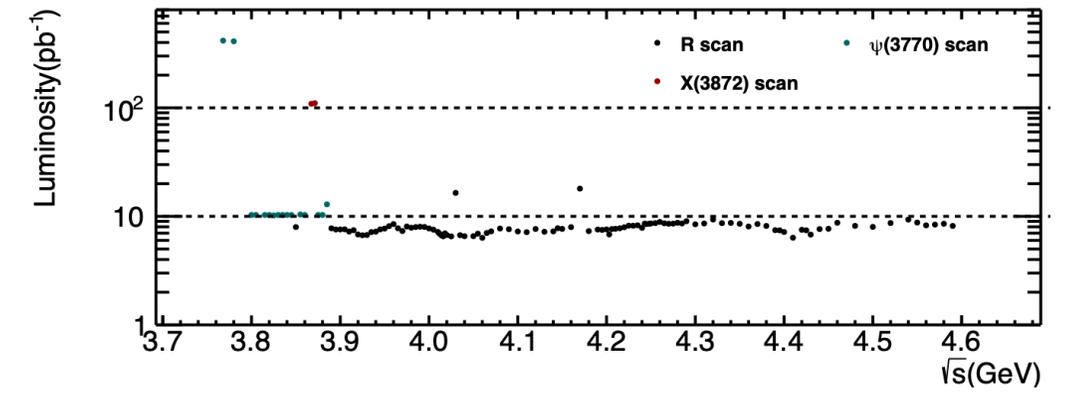
January 30 to February 4, 2026

BESIII detector and datasets

46 samples, $\sim 22 \text{ fb}^{-1}$



+ Small scan samples, 151 points from 3.8 to 4.6 GeV, $\sim 3.5 \text{ fb}^{-1}$

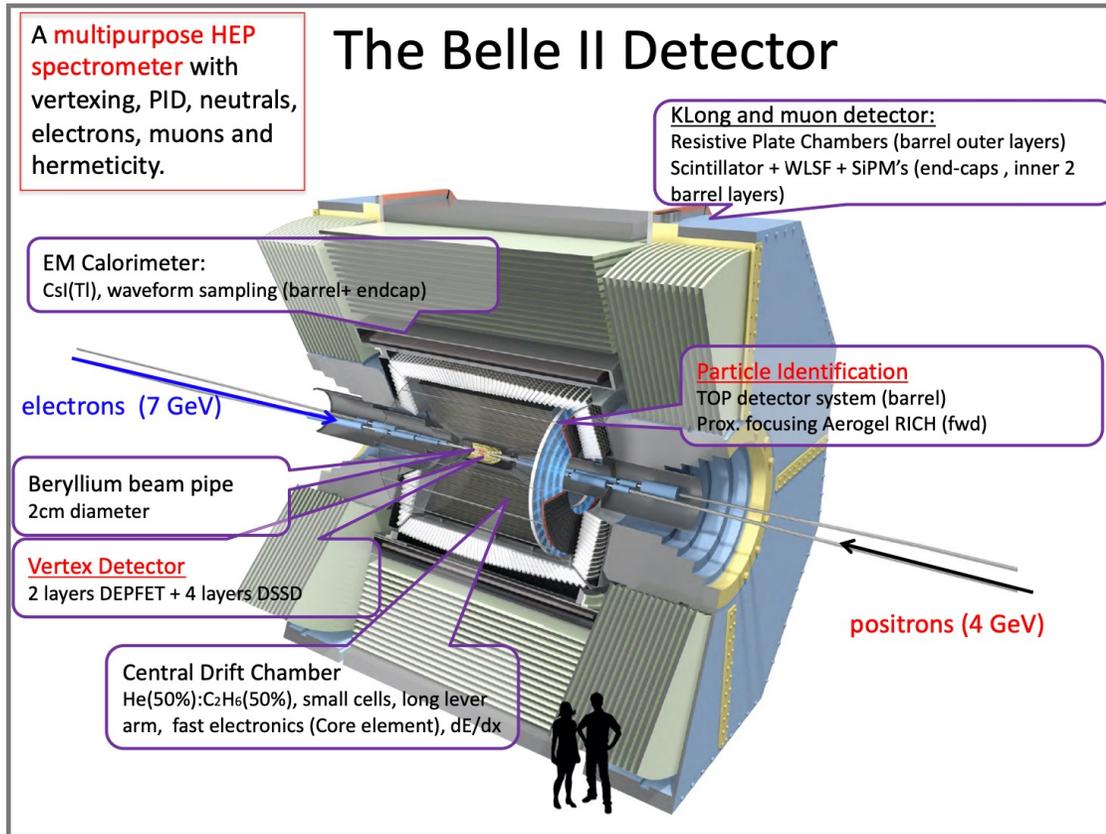


BEPCII: τ -charm factory
 Beam Energy: 0.92-2.45 GeV
 Lumi: $1.1 \times 10^{33} \text{ cm}^{-2} \text{ s}^{-1}$
 Data taking from 2009-

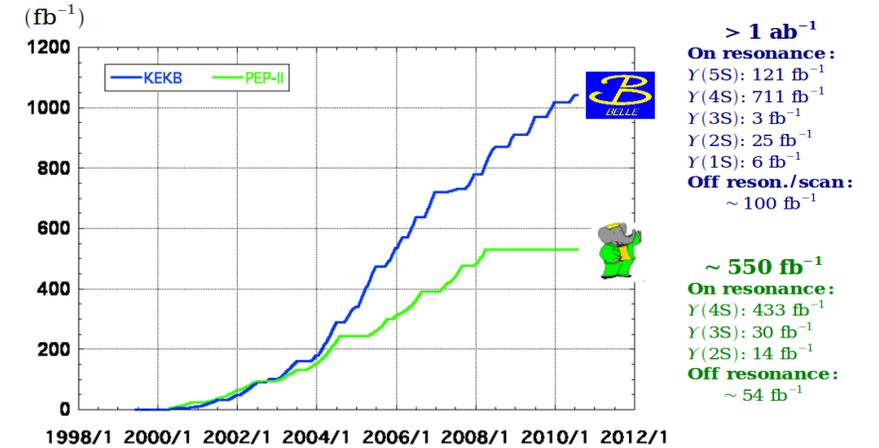
TOF	σ_T : 80 ps 110 ps (60 ps)	MUC $\sigma_{R\phi}$: 2 cm
MDC	dE/dx: 6% σ_p/p : 0.5% at 1GeV/c	EMC $\Delta E/E$: at 1GeV 2.5% 5.0% σ_z : 0.6 cm/ \sqrt{E}

Belle II detector and datasets

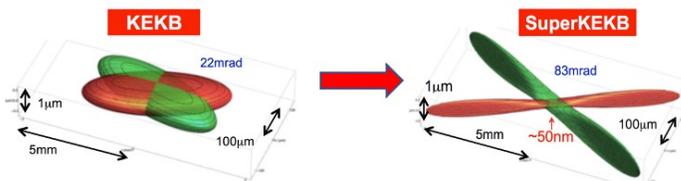
Belle + Belle II data: 1.6 ab^{-1}



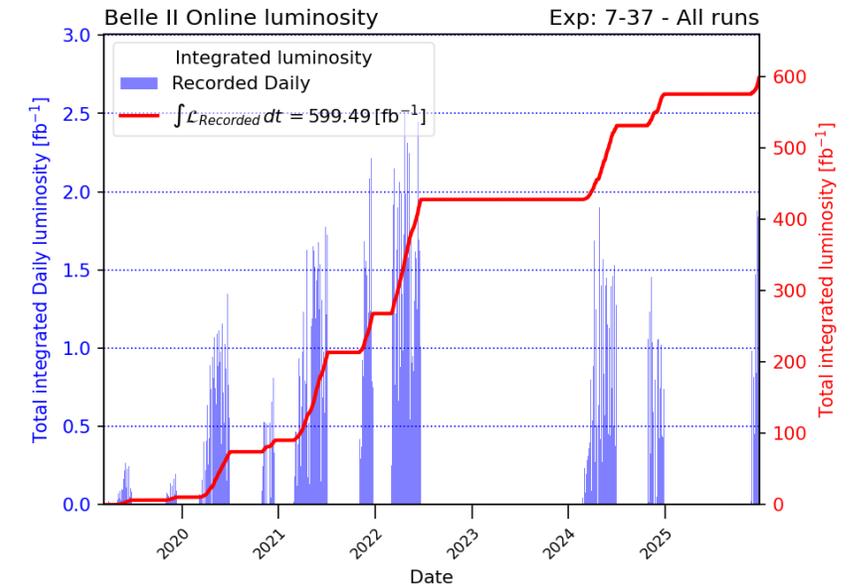
Integrated luminosity of B factories



Nano-beam design at Belle II:

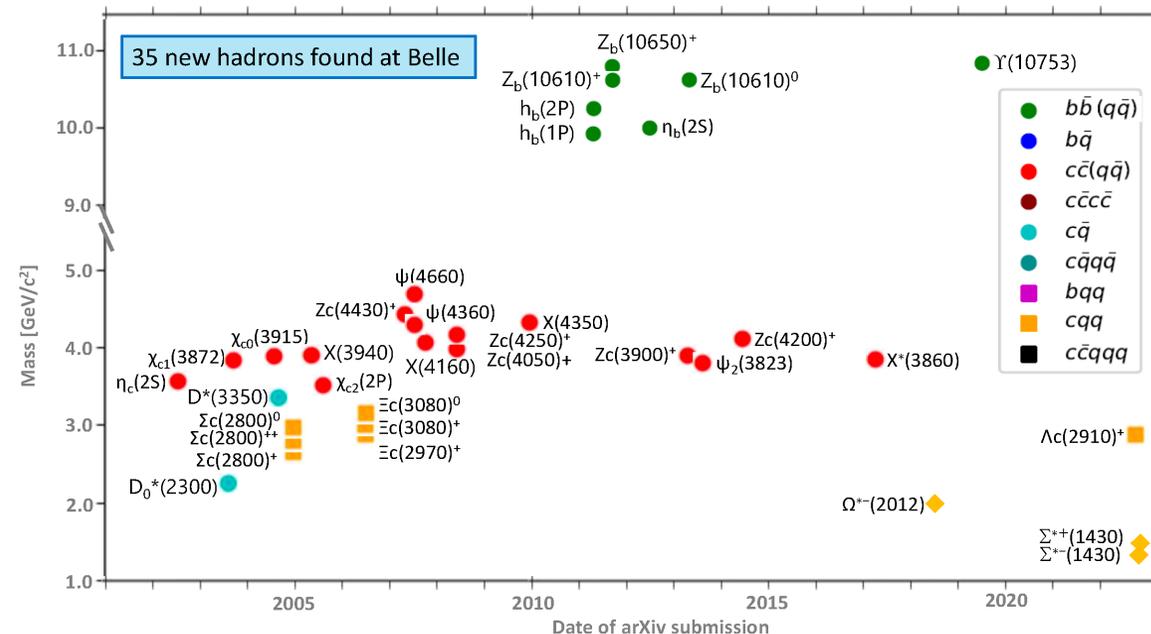
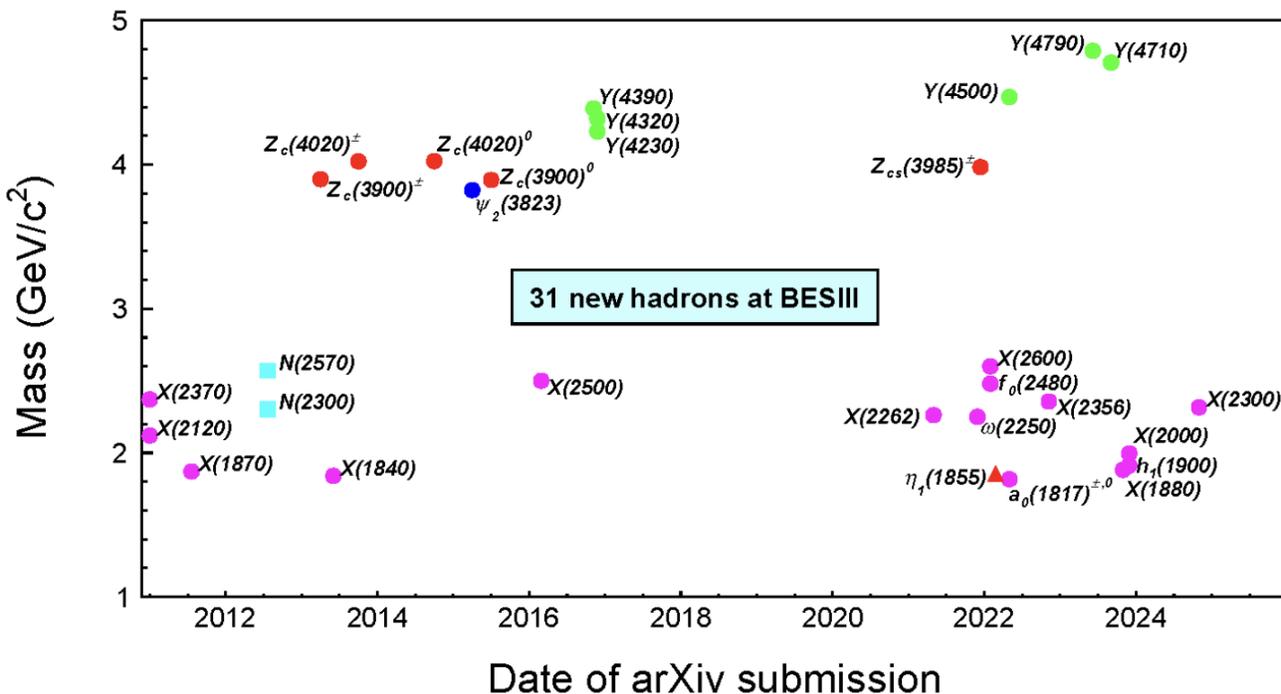


Nano-beam design:
Beam squeezing: $\times 20$ smaller;
Beam current: $\times 2$ larger
Target peak luminosity: **KEKB $\times 30$**



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

New hadrons found at BESIII and Belle (II)



Features of hadron spectroscopy studies at e⁺e⁻ colliders:

- Clean, low background, “energy conserving” environment, closed kinematics
- Production modes: e⁺e⁻ annihilations, B-decays, radiative and hadronic decays, ISR process, two-photon process, . . .
- Decay modes: hadronic, leptonic, neutral final states, . . .
- Compared to the LHC, the production cross sections are low.

Outline:

Spectroscopy results @BESIII:

1. PWA of $e^+e^- \rightarrow \pi^+\pi^-J/\psi$ (PRD 112, 092013 (2025))
2. $e^+e^- \rightarrow \pi^+\pi^-h_c(1P)$ (PRL 135, 071901 (2025))
3. $e^+e^- \rightarrow \eta h_c(1P)$ (PRD 111, L011101 (2025))
4. $e^+e^- \rightarrow K\bar{K}\psi(2S)$ and $K^0K^-\pi^-J/\psi$ (arXiv:2407.20009, JHEP 02 (2025) 120, arXiv:2510.13274)
5. $e^+e^- \rightarrow \Sigma_c\bar{\Sigma}_c, \Lambda_c^+\bar{\Sigma}_c^-,$ and $\pi^+H_c^-$ ($H_c^- \rightarrow \pi^-\Lambda_c^+\Lambda_c^-$) (arXiv:2508.16871, arXiv:2508.18594)

Charmonium(-like)
states

Spectroscopy results @BELLE II:

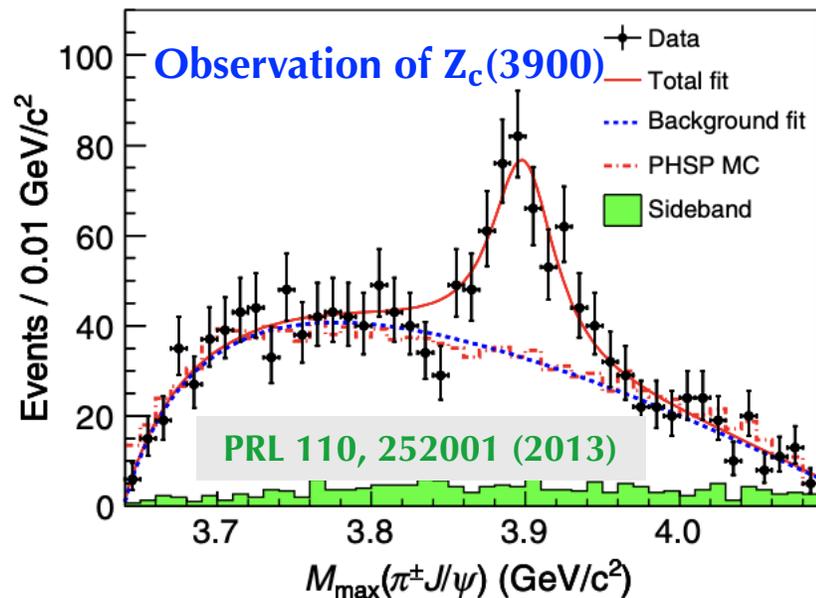
1. $D_{s0}^*(2317)^+ \rightarrow D_s^{*+}\gamma$ (arXiv:2510.27174)
2. $e^+e^- \rightarrow \omega\chi_{b1,b2}$ and $e^+e^- \rightarrow (\pi^+\pi^-\pi^0)_{\text{non-}\omega}\chi_{b1,b2}$ (arXiv:2510.25461)
3. $e^+e^- \rightarrow \eta Y(1S, 2S)$ (arXiv:2509.01917)
4. $e^+e^- \rightarrow \gamma\chi_{bJ}$ ($J = 0, 1, 2$) (arXiv:2508.16036)

Related to $Y(10753)$

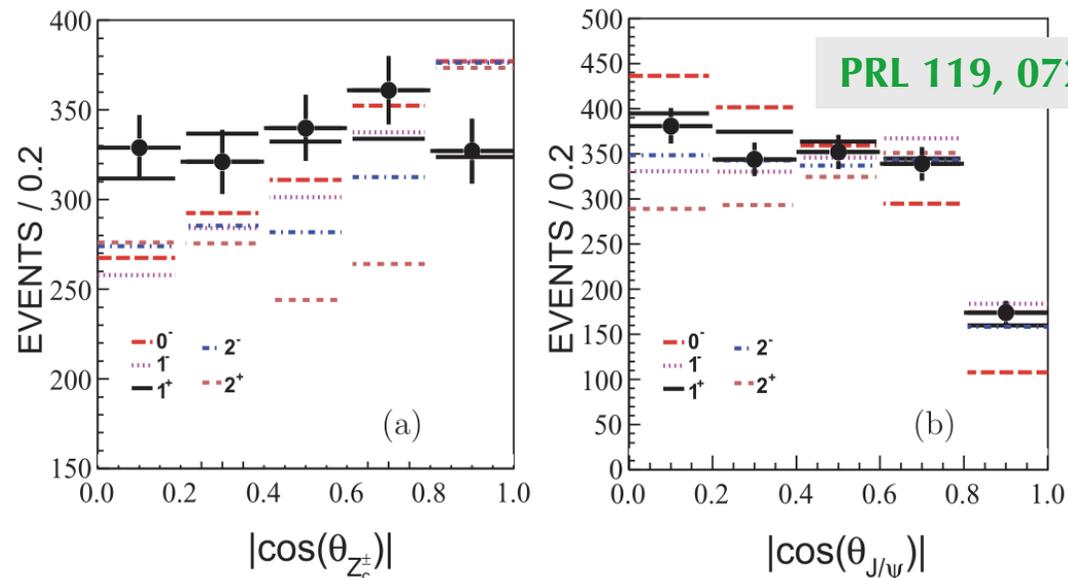
Spectroscopy results @BESIII

PWA of $e^+e^- \rightarrow \pi^+\pi^-J/\psi$

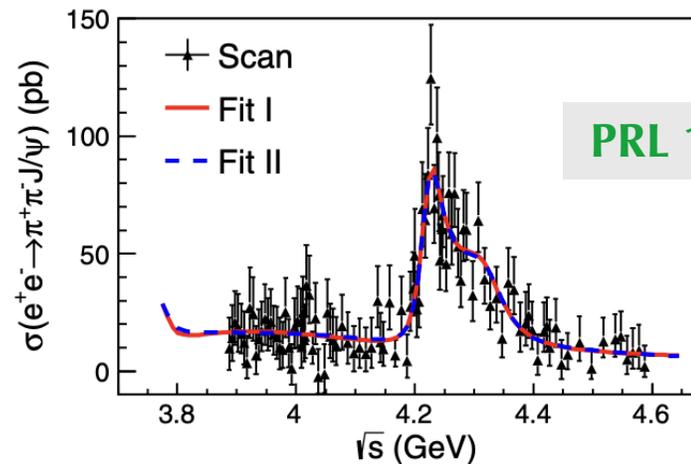
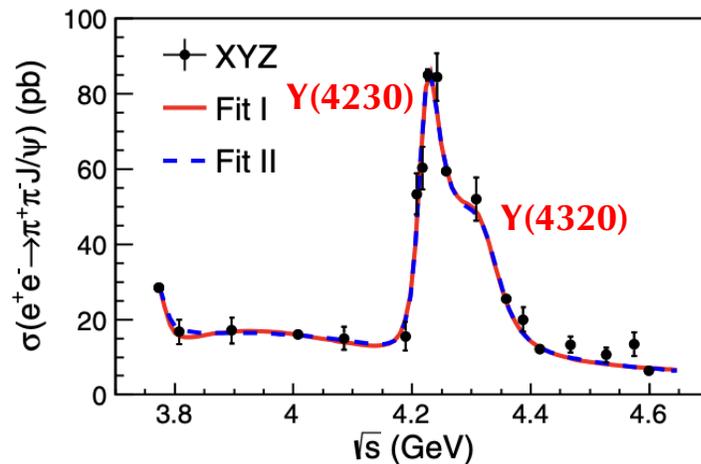
Previous studies on the $e^+e^- \rightarrow \pi^+\pi^-J/\psi$:



Determination of J^P for $Z_c(3900)$



Precise cross section measurement for $e^+e^- \rightarrow \pi^+\pi^-J/\psi$

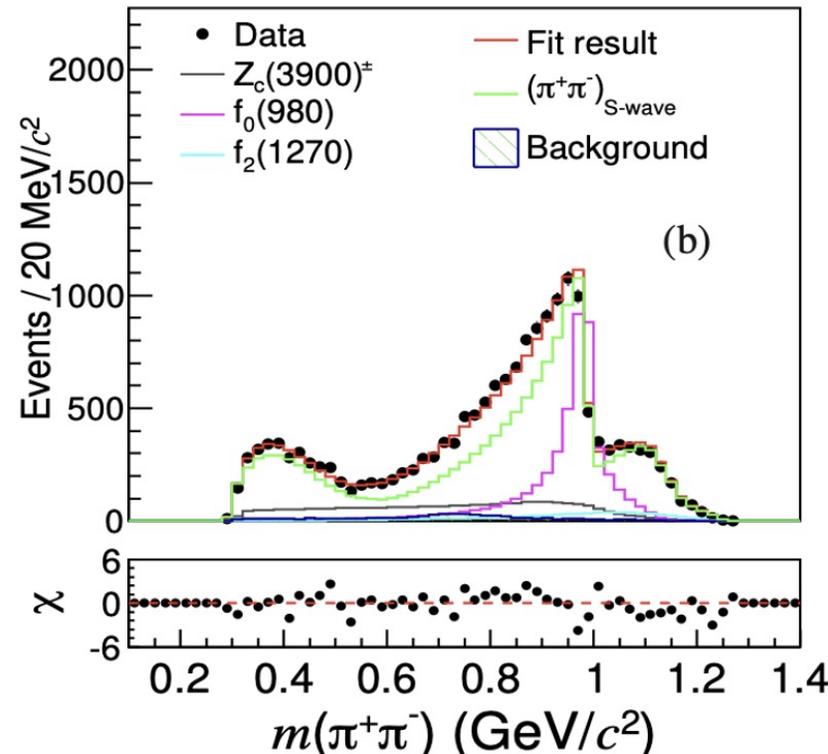
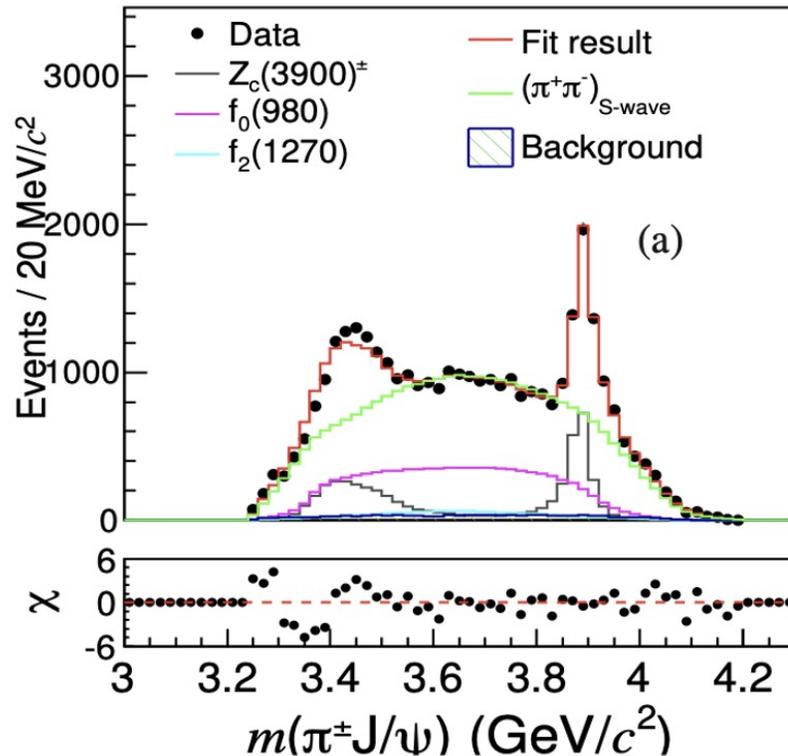


PWA of $e^+e^- \rightarrow \pi^+\pi^-J/\psi$

PRD 112, 092013 (2025)

- Partial Wave Analysis based on helicity formalism is performed on 17 energy points
- $M(\pi^\pm J/\psi)$: the $Z_c(3900)$ parameterized by Breit-Wigner function
- $M(\pi^+\pi^-)$: relativistic BW functions for $f_0(980)$ and $f_0(1270)$; K-matrix parameterization for $(\pi^+\pi^-)_{S\text{-wave}}$ also tested.

PWA projection at 4.178 GeV:



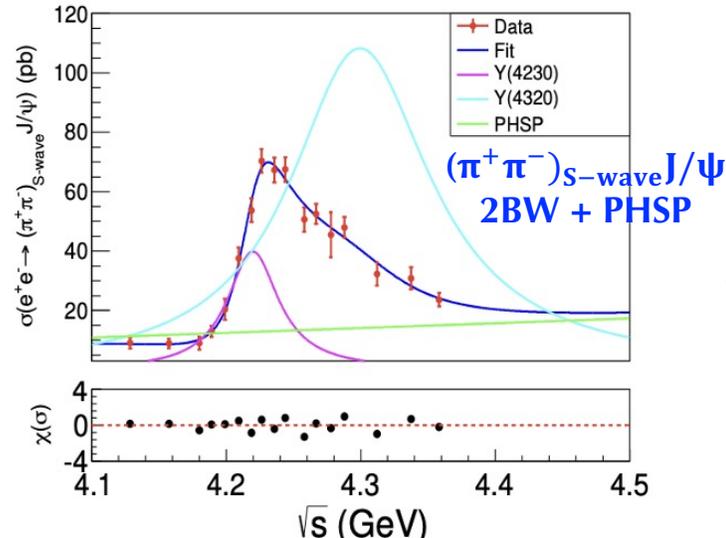
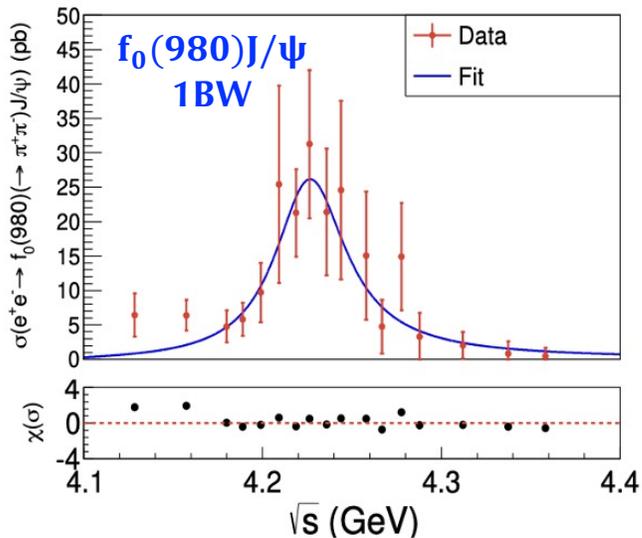
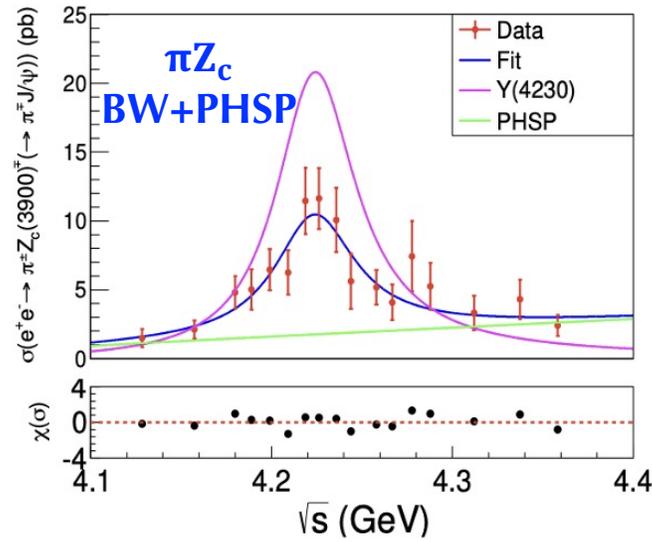
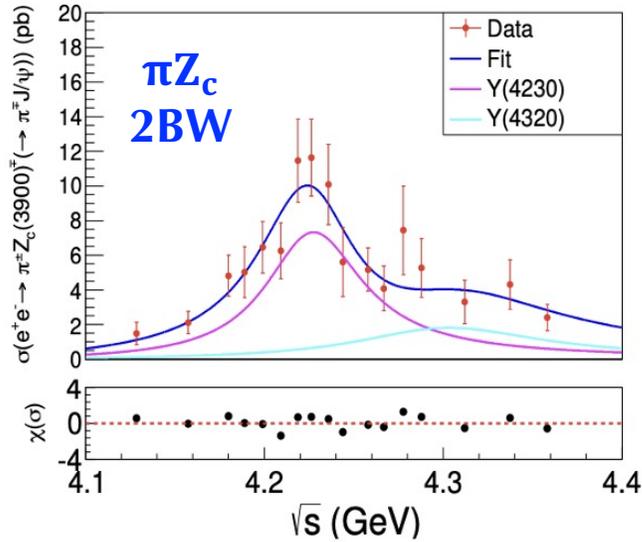
The mass and width of $Z_c(3900)$:

Mass (MeV/c^2)	$3884.6 \pm 0.7 \pm 3.3$
Width (MeV)	$37.2 \pm 1.3 \pm 6.6$

The mass and width of $Z_c(3900)$ are generally stable with C.M. energy rising.

PWA of $e^+e^- \rightarrow \pi^+\pi^-J/\psi$

PRD 112, 092013 (2025)



Process	Y(4220)		Y(4320)
	M (MeV/c ²)	Γ (MeV)	Significance
$\pi^\pm Z_c(3900)^\mp$ (model I)	$4225.7 \pm 6.8 \pm 6.8$	$66.5 \pm 16.1 \pm 24.1$	2.1σ
$\pi^\pm Z_c(3900)^\mp$ (model II)	$4223.1 \pm 6.4 \pm 0.6$	$53.8 \pm 19.1 \pm 0.3$	2.0σ
$f_0(980)J/\psi$ (model III)	$4225.6 \pm 4.5 \pm 0.6$	$48.4 \pm 9.8 \pm 0.2$	0.5σ
$(\pi^+\pi^-)_{S\text{-wave}}J/\psi$ (model IV)	$4218.8 \pm 3.4 \pm 3.7$	$43.5 \pm 5.3 \pm 5.0$	11.7σ
Y(4220) ^{ave}	$4225.7 \pm 4.1 \pm 3.4$	$57.5 \pm 9.4 \pm 12.1$	

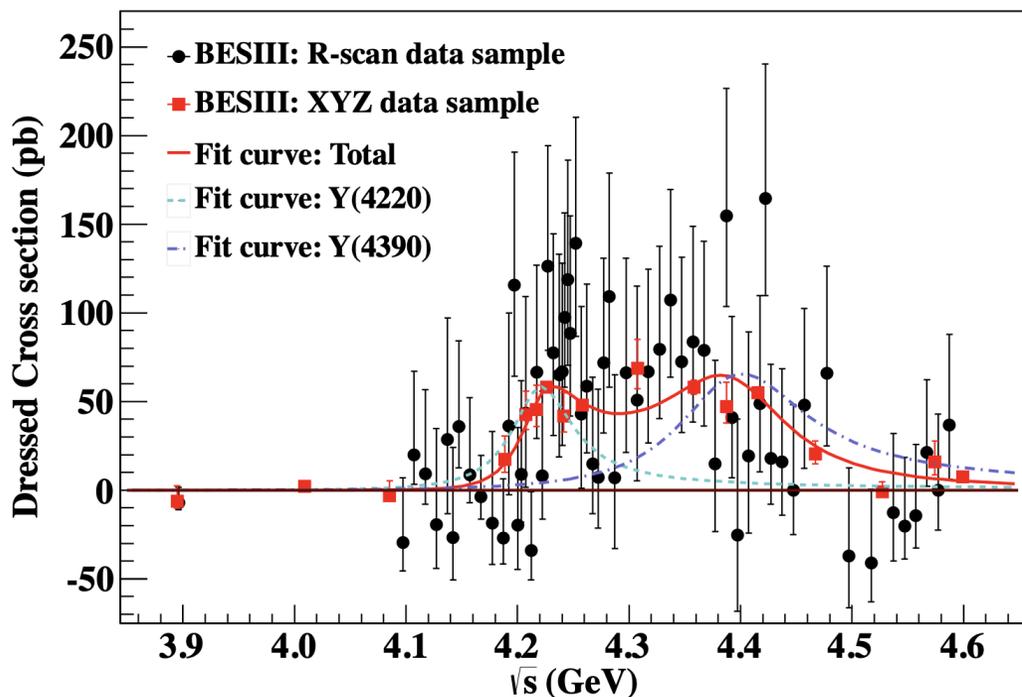
- Y(4220) are significant at each distribution
- Y(4320) are significant only in $(\pi^+\pi^-)_{S\text{-wave}}J/\psi$

The background subtracted & efficiency corrected plots of $M(\pi^\pm J/\psi)$ and $M(\pi^+\pi^-)$ at each energy point were given in the paper. Hepdata was also [uploaded](#).

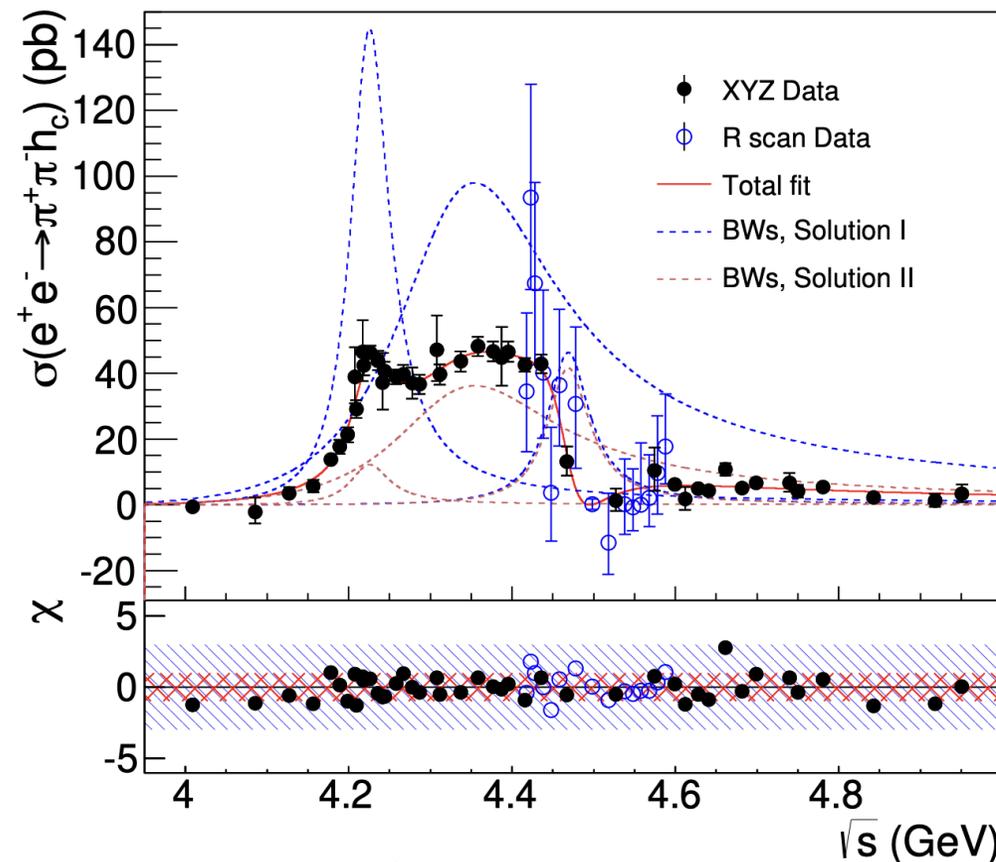
$e^+e^- \rightarrow \pi^+\pi^-h_c(1P)$

PRL 135, 071901 (2025)

PRL 118, 092002 (2017)



$$|BW_1(\sqrt{s}) + e^{i\phi_2}BW_2(\sqrt{s}) + e^{i\phi_3}BW_3(\sqrt{s})|^2$$

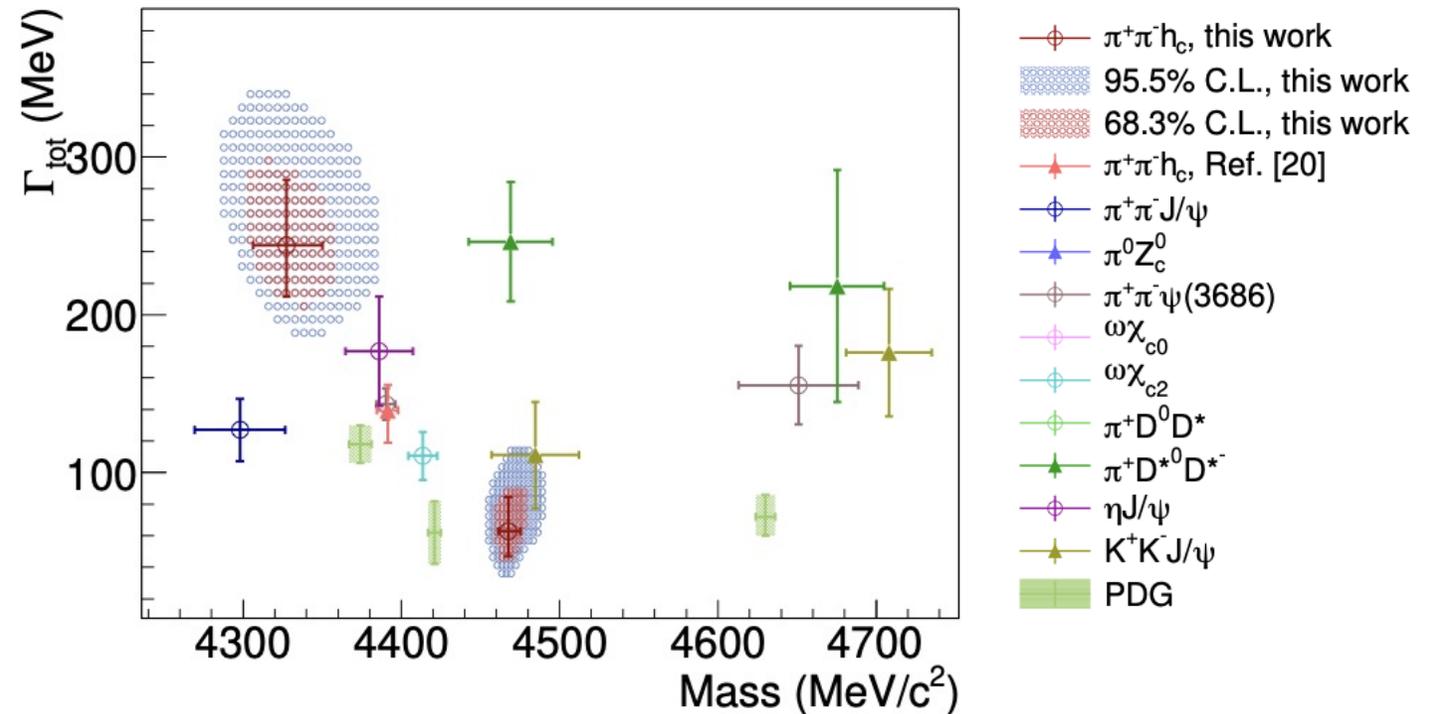
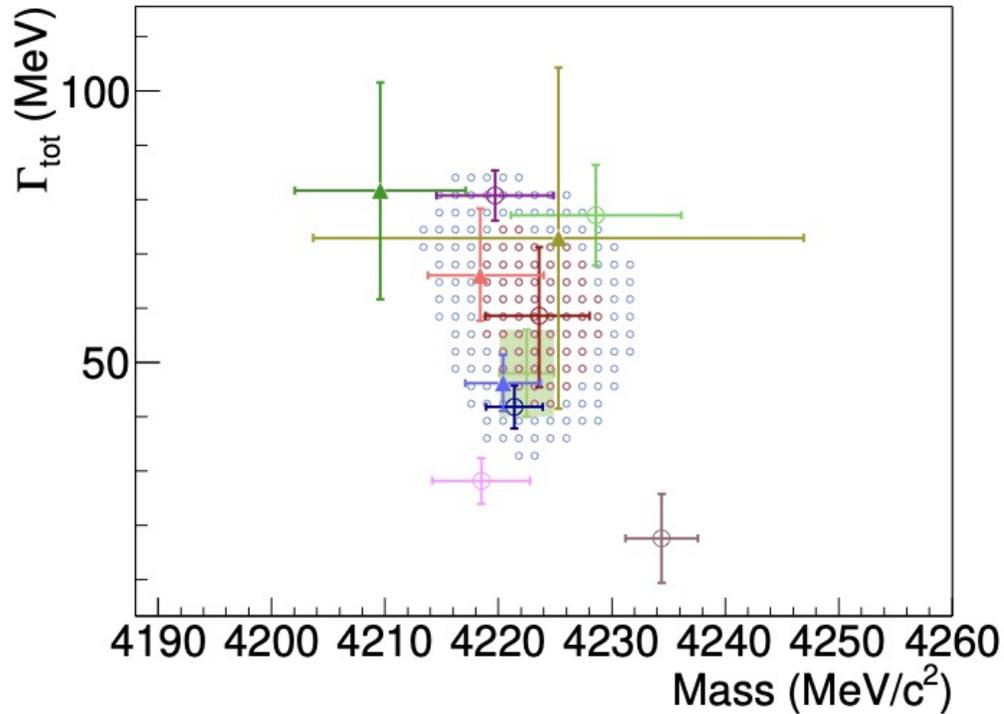


Parameter	R_1	R_2	R_3
M (MeV/ c^2)	$4223.6^{+3.6+2.6}_{-3.7-2.9}$	$4327.4^{+20.1+10.7}_{-18.8-9.3}$	$4467.4^{+7.2+3.2}_{-5.4-2.7}$
Γ (MeV)	$58.5^{+10.8+6.7}_{-11.4-6.5}$	$244.1^{+34.0+24.2}_{-27.1-18.3}$	$62.8^{+19.2+9.9}_{-14.4-7.0}$
$\Gamma_{ee} \cdot \mathcal{B}(R \rightarrow \pi^+\pi^-h_c)$ (eV)	$10.2^{+1.2+1.4}_{-1.5-1.4} (0.9^{+0.4+0.3}_{-0.4-0.2})$	$29.1^{+5.7+4.4}_{-3.9-3.4} (10.8^{+2.5+1.9}_{-1.8-1.5})$	$3.9^{+3.5+1.7}_{-1.7-0.5} (3.5^{+3.0+1.5}_{-1.6-0.7})$
ϕ (rad)	...	$3.6^{+0.1+0.1}_{-0.1-0.1} (0.7^{+0.3+0.2}_{-0.3-0.2})$	$0.7^{+0.3+0.1}_{-0.3-0.2} (-2.2^{+0.3+0.2}_{-0.3-0.1})$

The significance of 3rd state is 5.4σ .

$e^+e^- \rightarrow \pi^+\pi^-h_c(1P)$

PRL 135, 071901 (2025)

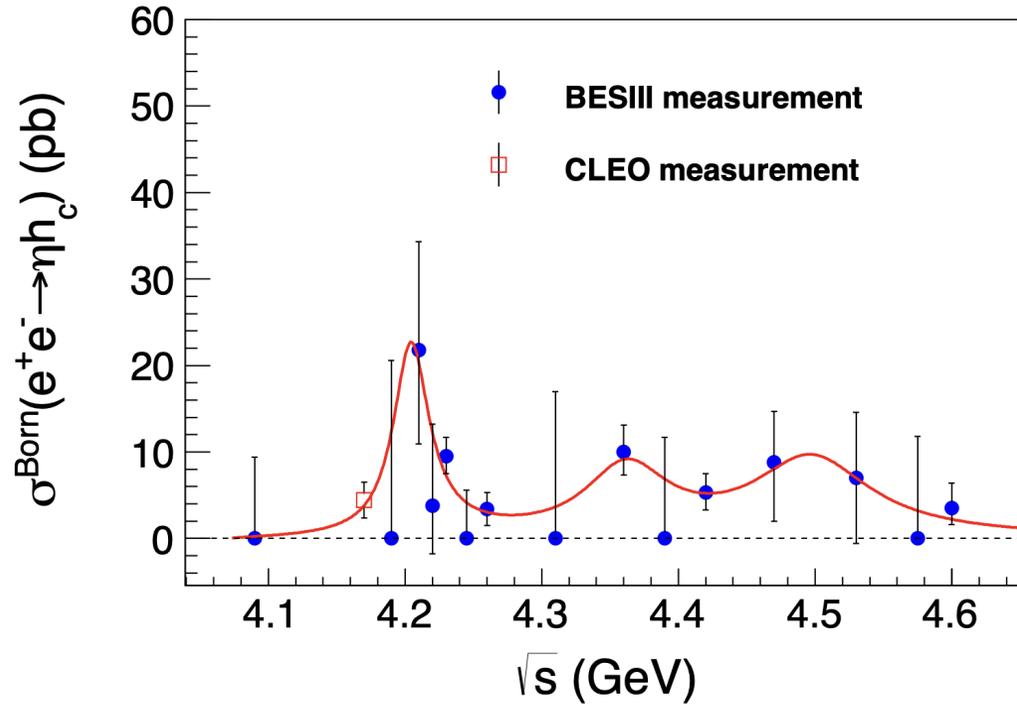


- The parameters for $\psi(4230)$ are generally consistent with each other.
- The mass of the second resonance is consistent with $\psi(4360)$, but the width is about 100 MeV larger.
- The parameters of the third resonance is consistent with the $\psi(4500)$ that observed in $e^+e^- \rightarrow K\bar{K}J/\psi$ [PRL 131, 211902 (2023)].
- In general, there are overpopulated states in this region, which need careful classification.

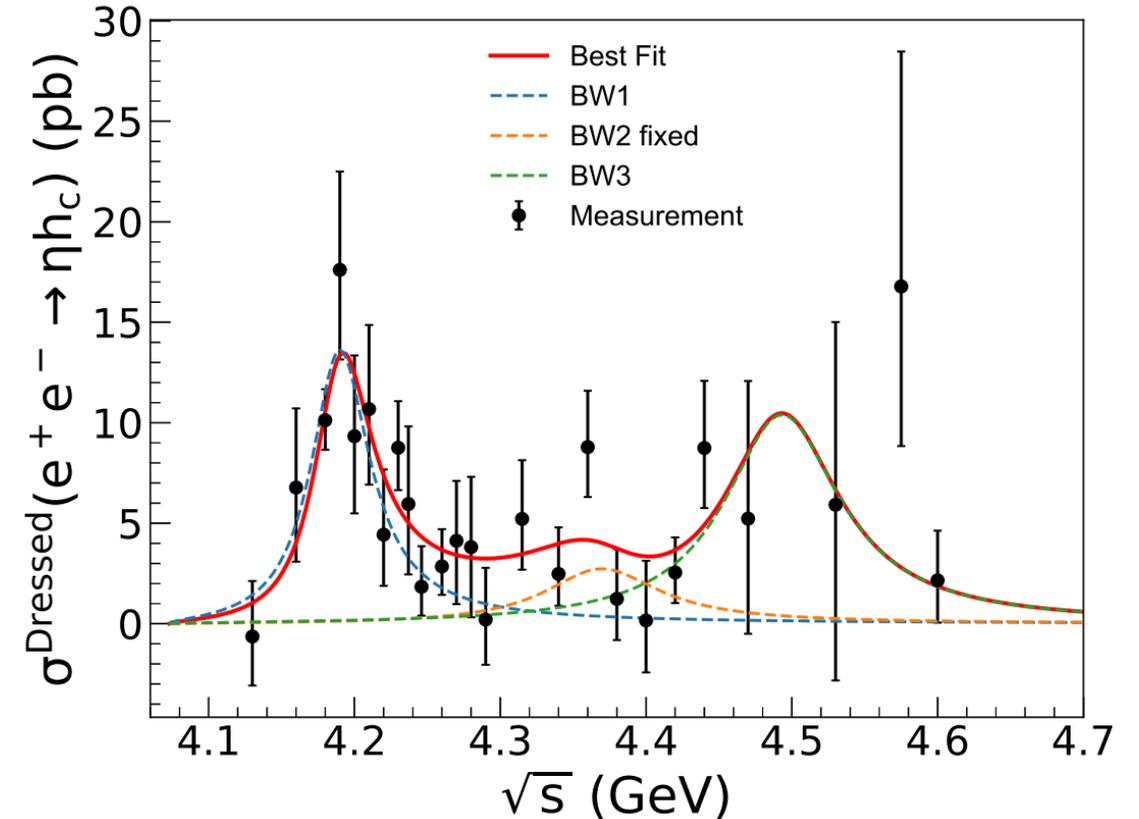
$e^+e^- \rightarrow \eta h_c(1P)$

PRD 111, L011101 (2025)

PRD 96, 012001 (2017)



$$\sigma^{\text{Dressed}}(s) = |\text{BW}_1(s) + \text{BW}_2(s)e^{i\phi}|^2 + |\text{BW}_3(s)|^2$$

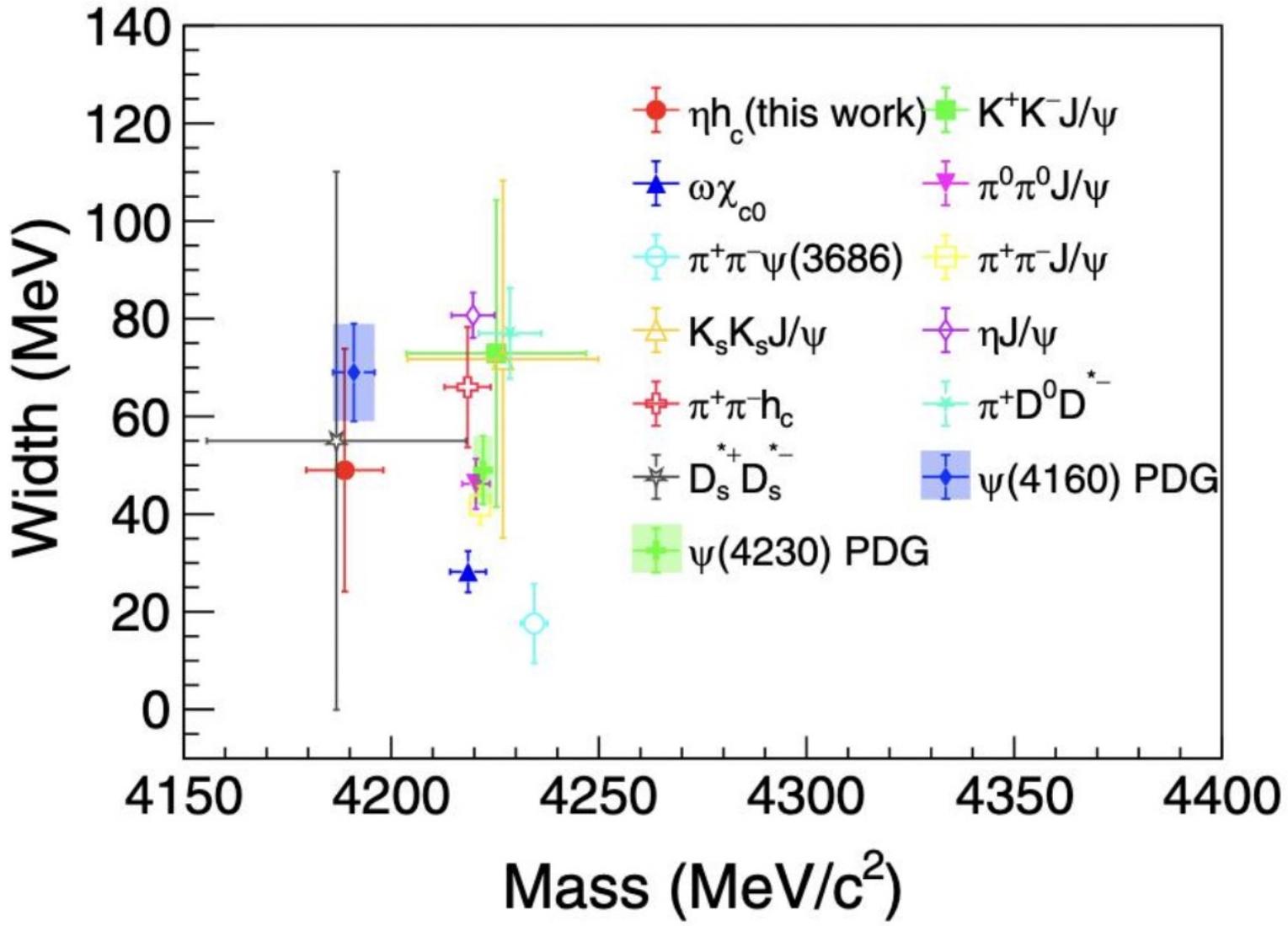


In right plot, the parameters of the second state are fixed to $\psi(4360)$, and the parameters for the other two states are free. The interference between BW2 and BW3 is not considered.

The first state:

$\Gamma_{ee}\mathcal{B}$ (eV)	M (MeV/ c^2)	Γ_{tot} (MeV)
$0.80 \pm 0.19 \pm 0.45$	$4188.8 \pm 4.7 \pm 8.0$	$49 \pm 16 \pm 19$

$e^+e^- \rightarrow \eta h_c(1P)$



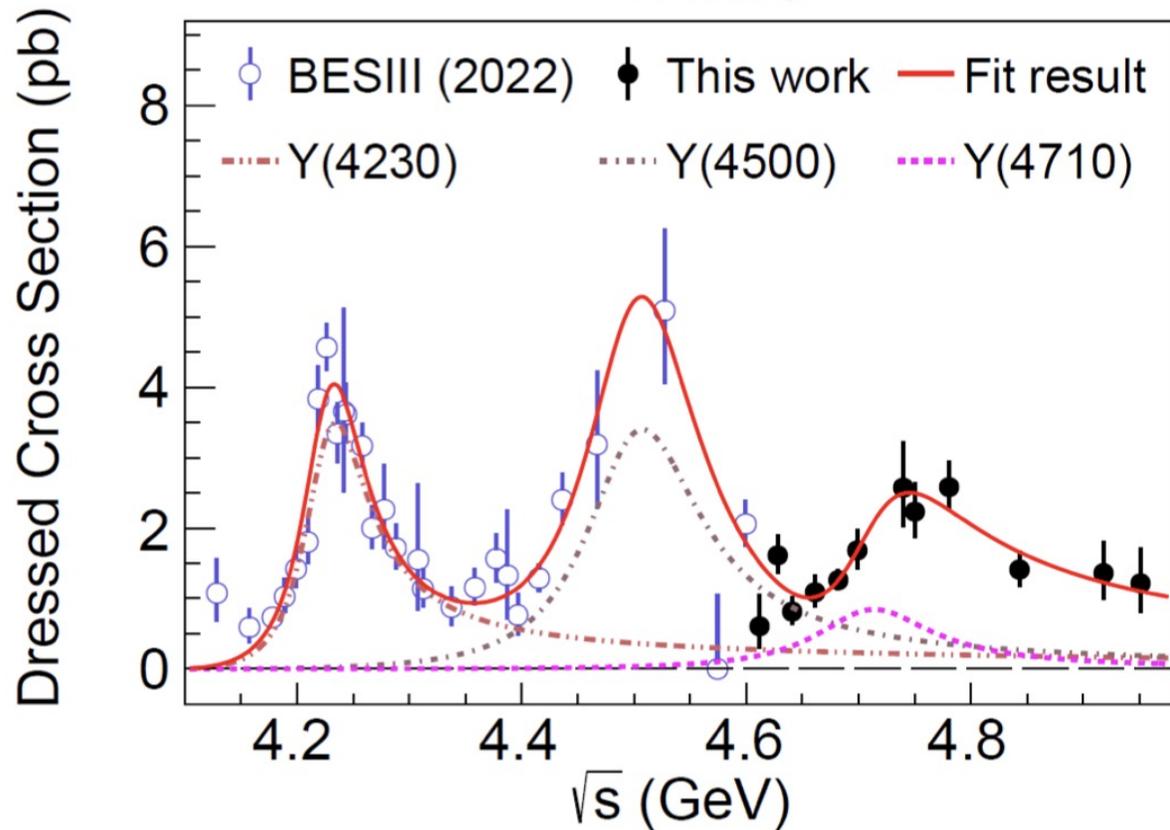
- The parameters of the first state are **consistent with $\psi(4160)$'s PDG value**
- Its mass is **lower than $\psi(4230)$** that was measured in other processes.
- The mass of the first state is consistent the that of **the 1^{--} hybrid charmonium state** predicted using nonrelativistic EFT [PRD 92, 114019 (2015)].

$e^+e^- \rightarrow K\bar{K}\psi(2S)$

Previous studies on the $K\bar{K}J/\psi$:

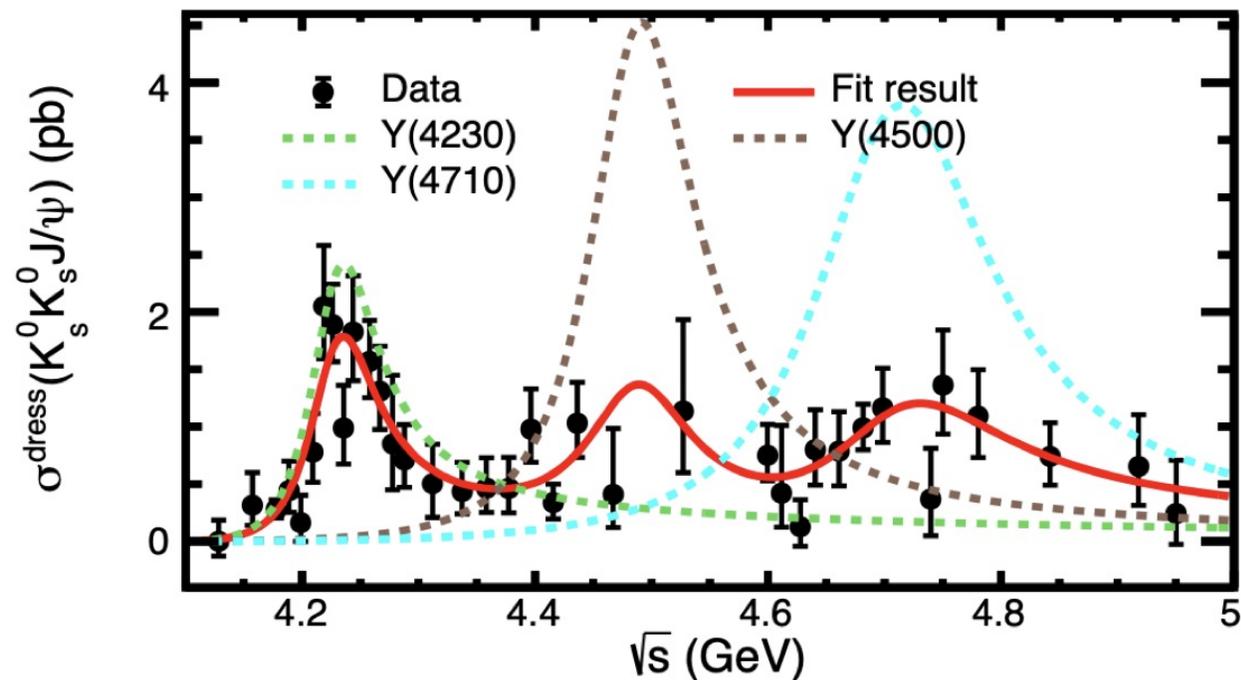
CPC46, 111002 (2022) & PRL131, 211902 (2023) & PRD107, 092005 (2023)

$e^+e^- \rightarrow K^+K^-J/\psi$



- ✓ Significance of the $Y(4500) > 8\sigma$
- ✓ Significance of the $Y(4710) > 5\sigma$

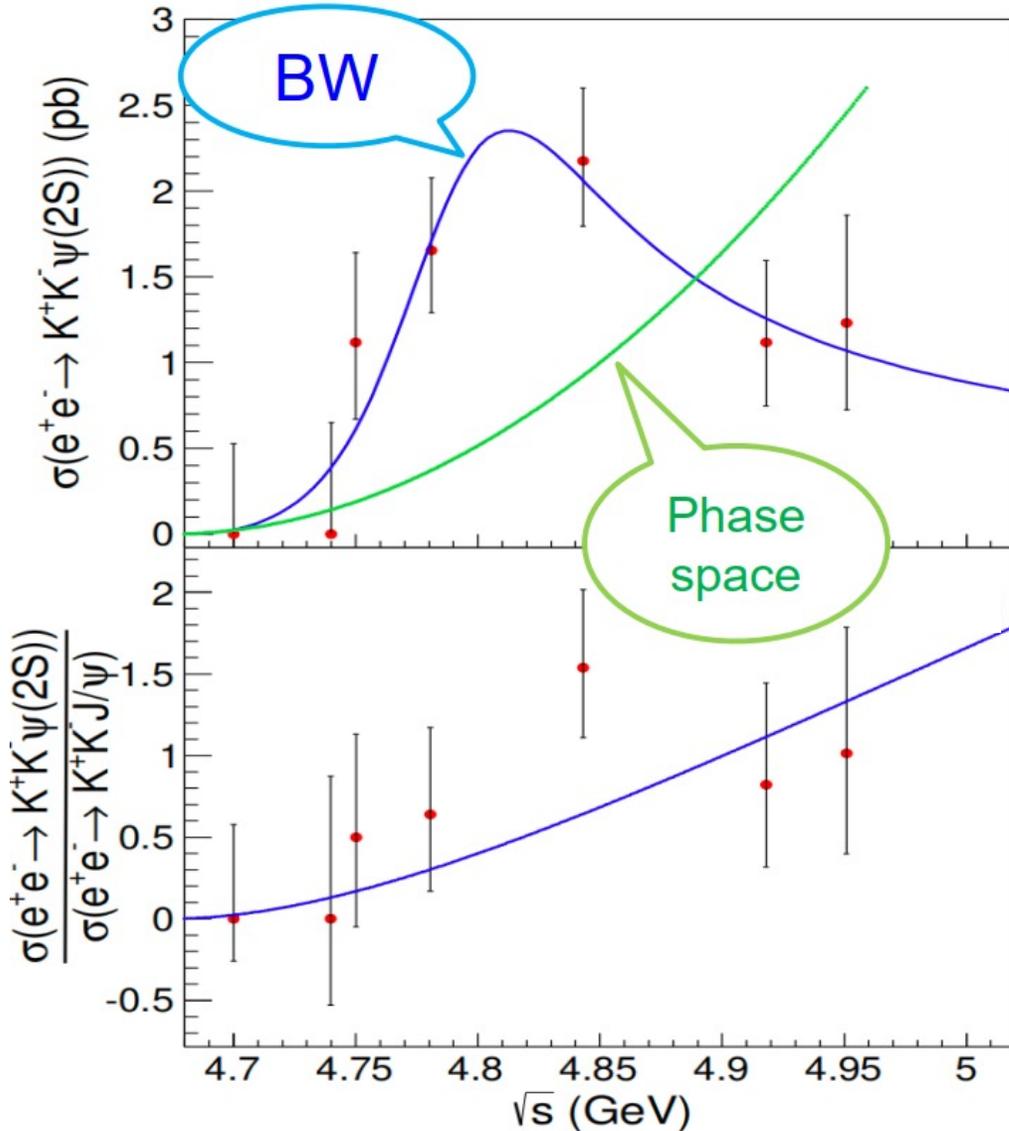
$e^+e^- \rightarrow K_S K_S J/\psi$



Resonance	Mass (MeV)	Width (MeV)
Y(4500)	$4485 \pm 13 \pm 24$	$111 \pm 30 \pm 15$
Y(4710)	$4708^{+17}_{-15} \pm 21$	$126^{+27}_{-23} \pm 30$

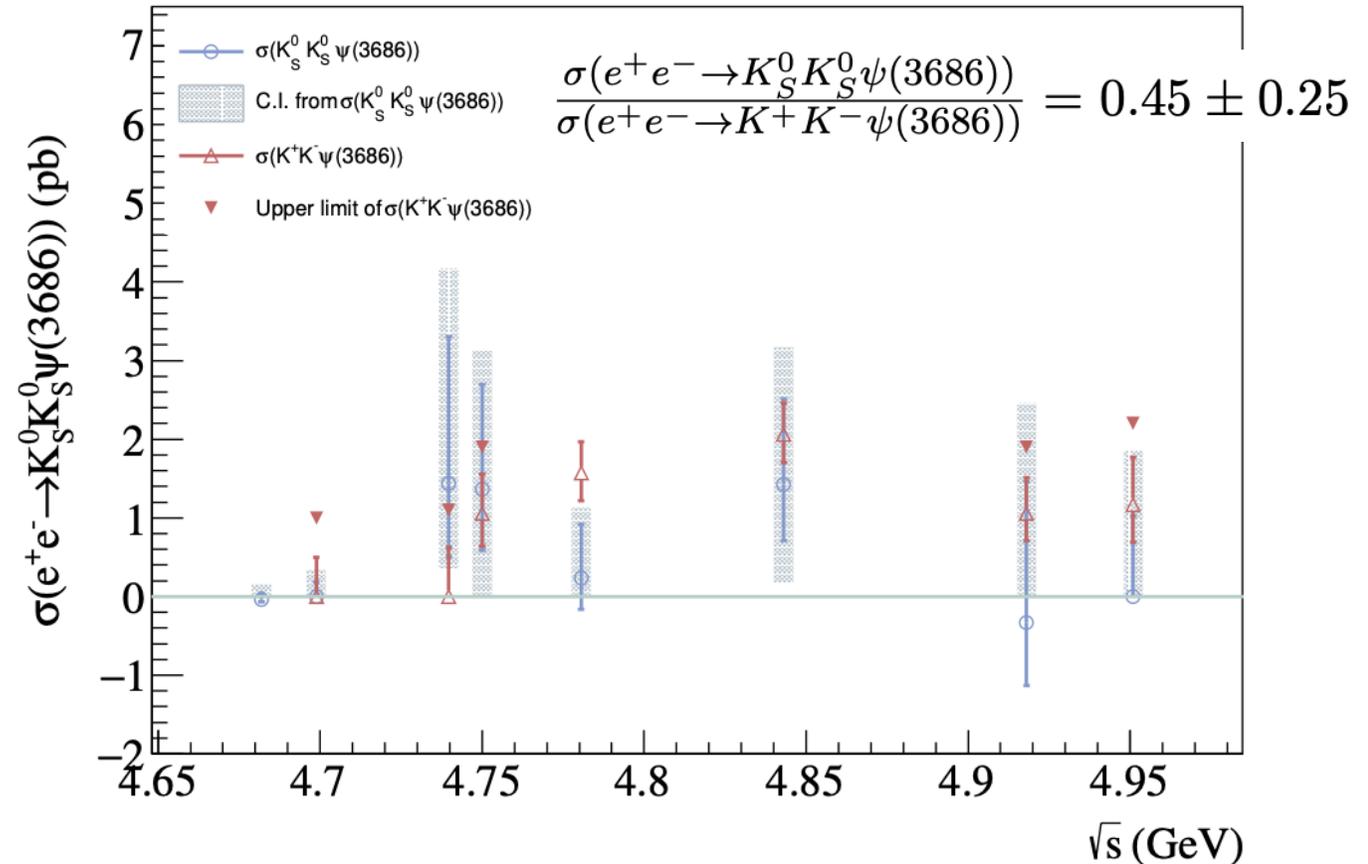
Cross section of $e^+e^- \rightarrow K\bar{K}\psi(2S)$

arXiv: 2407.20009
JHEP 02 (2025) 120



BW fit yields:

Mass: 4788 ± 18 MeV, Width: 110 ± 34 MeV

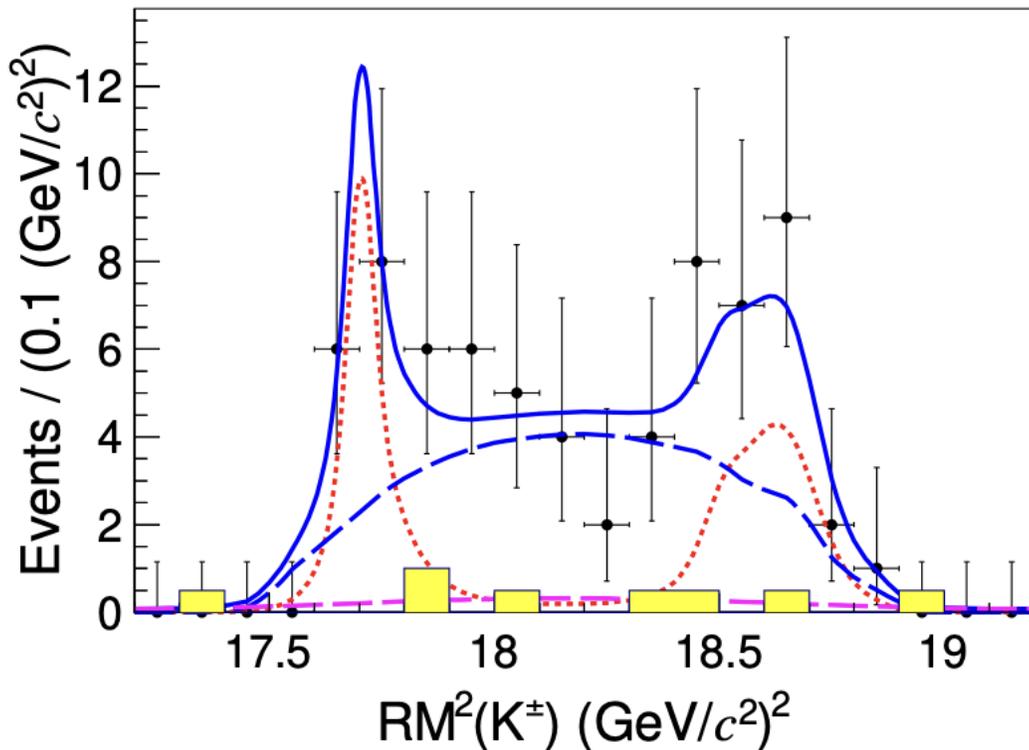


Intermediate states in $e^+e^- \rightarrow K^+K^-\psi(2S)$

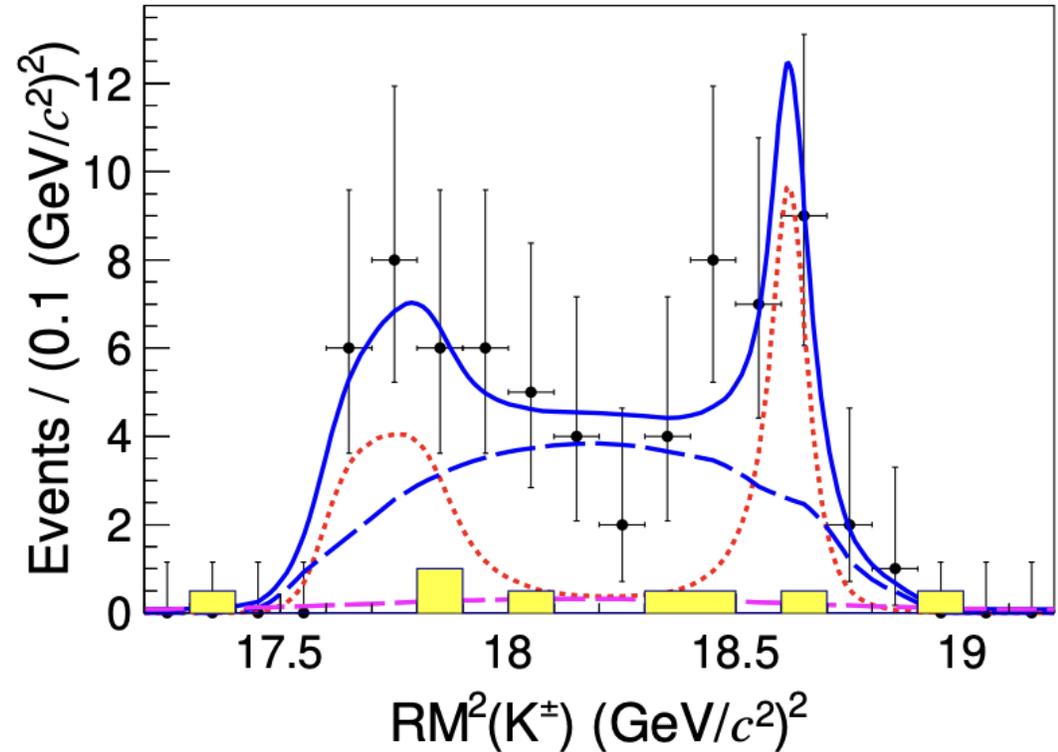
arXiv: 2407.20009

$\sqrt{s} = 4.843$ GeV, 34 events ($\sim 90\%$ purity). No significant Z_{cs} signals.

Fit I:



Fit II:



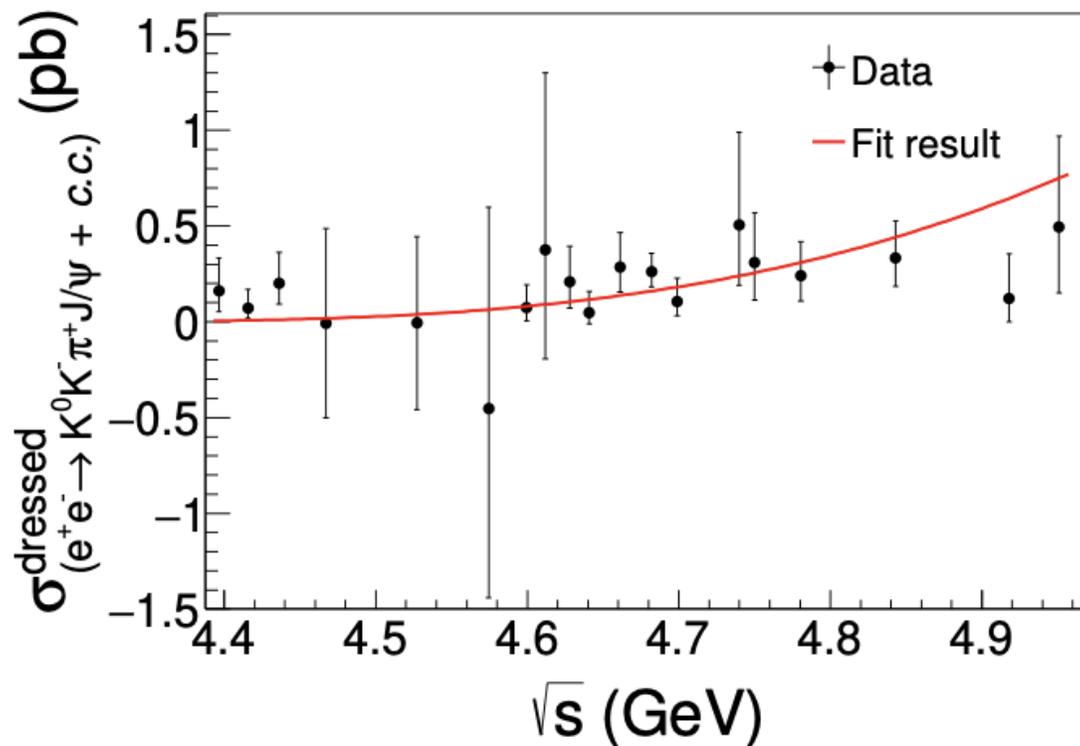
Fit I: $M = (4208.4 \pm 3.1)$ MeV/ c^2 and $\Gamma = (6.1 \pm 5.7)$ MeV; global significance of 1.2σ .

Fit II: $M = (4316.0 \pm 2.7)$ MeV/ c^2 and $\Gamma = (9.0 \pm 8.6)$ MeV; global significance of 1.1σ .

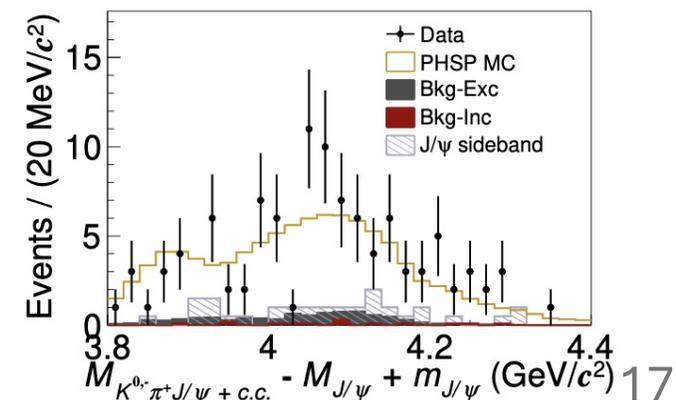
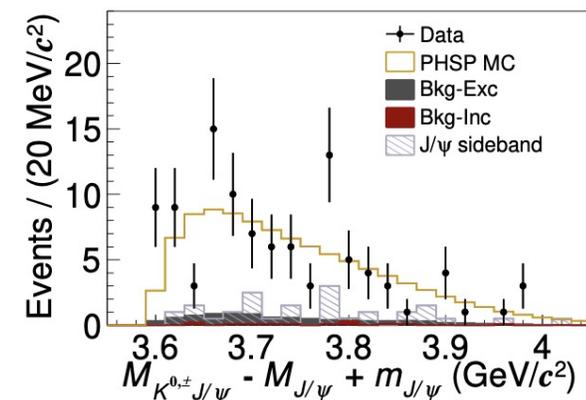
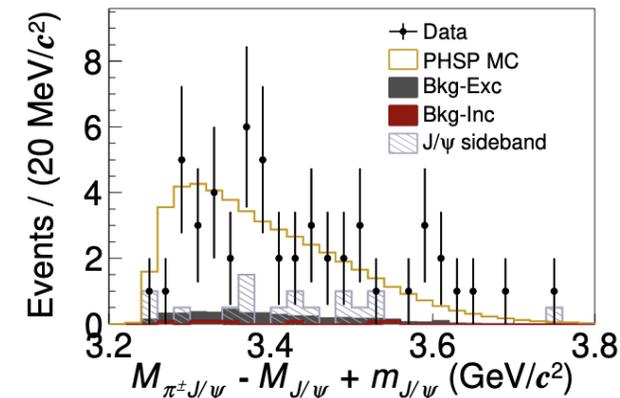
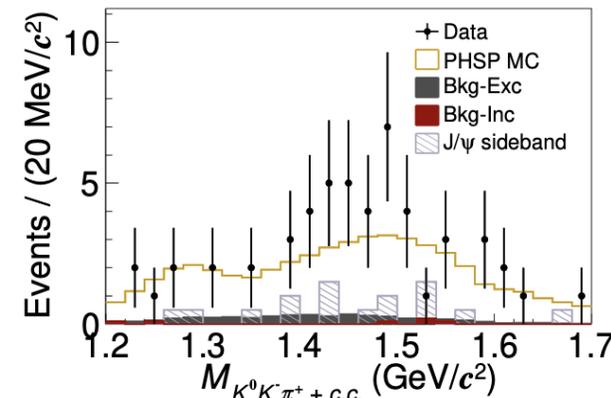
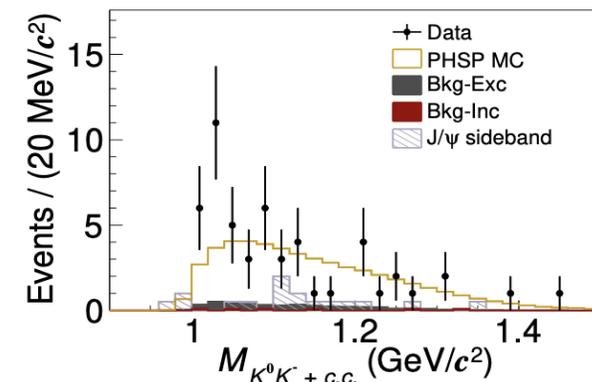
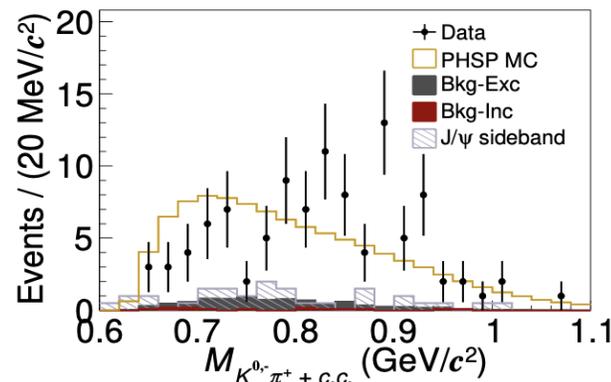
Intermediate states in $e^+e^- \rightarrow K^0 K^- \pi^- J/\psi$

arXiv: 2510.13274

1. Search for $Y \rightarrow K^0 K^- \pi^- J/\psi$
2. Search for $Z_c \rightarrow \pi J/\psi$, $Z_{cs} \rightarrow K J/\psi$ and $K^*(4307) \rightarrow K^* J/\psi$ [arXiv: 1912.04697]



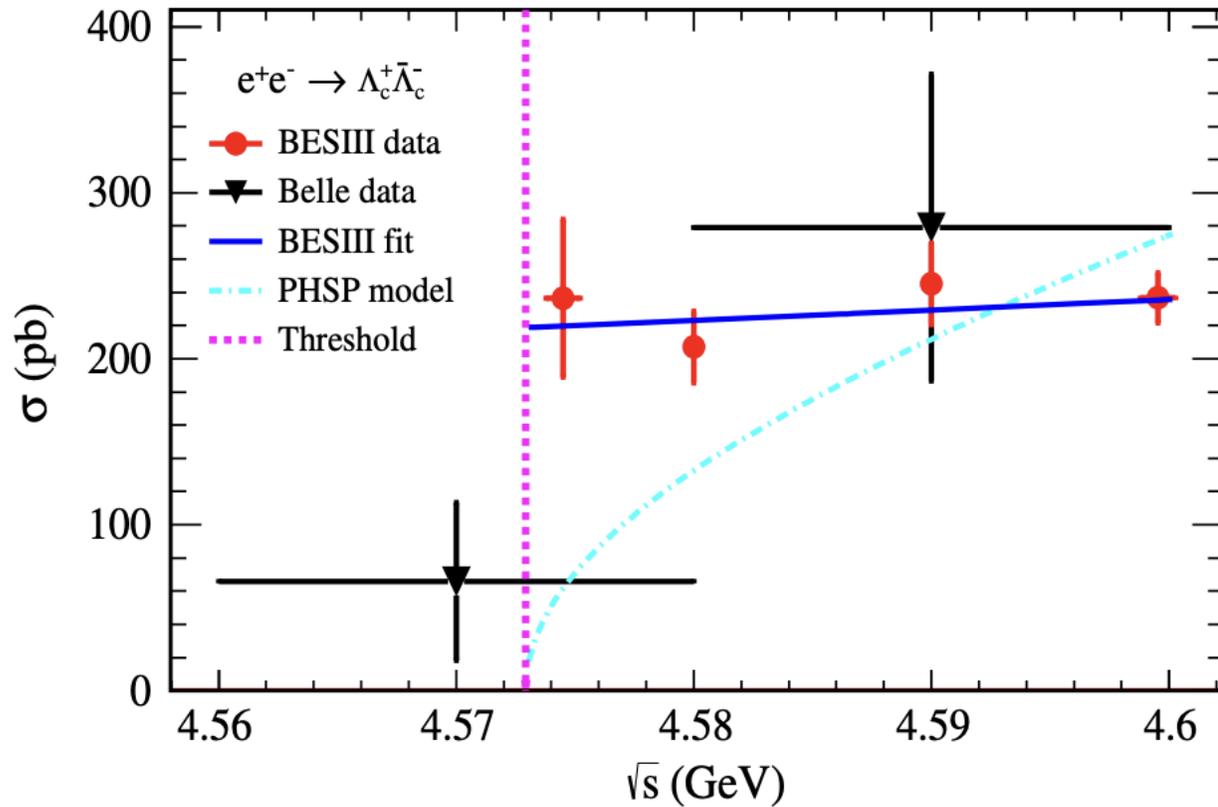
No significant vector structures nor any intermediate states of $\pi J/\psi$, $K J/\psi$, $K^* J/\psi$ are seen.



$e^+e^- \rightarrow \Sigma_c \bar{\Sigma}_c$ and $\Lambda_c^+ \bar{\Sigma}_c^-$

Previous studies on the $\Lambda_c^+ \Lambda_c^-$:

PRL 120, 132001 (2018)



Belle: peak (Y(4660)?);
BESIII: plateau.

Spin-1/2 baryons pairs ($B\bar{B}$) at threshold production.

- ✓ help understand the **internal structure of baryons**.
- ✓ probe the understanding of **strong interaction**.

Energy threshold:

- $\Sigma_c \bar{\Sigma}_c$: **4.91 GeV**
- $\Lambda_c^+ \bar{\Sigma}_c^-$: **4.74 GeV**

New data @BESIII:

\sqrt{s} (MeV)	Luminosity (pb^{-1})
4750.05 ± 0.31	366.55 ± 1.95
4780.54 ± 0.32	511.47 ± 2.72
4843.07 ± 0.44	525.16 ± 2.79
4918.02 ± 0.48	207.82 ± 1.10
4950.93 ± 0.52	159.28 ± 0.85

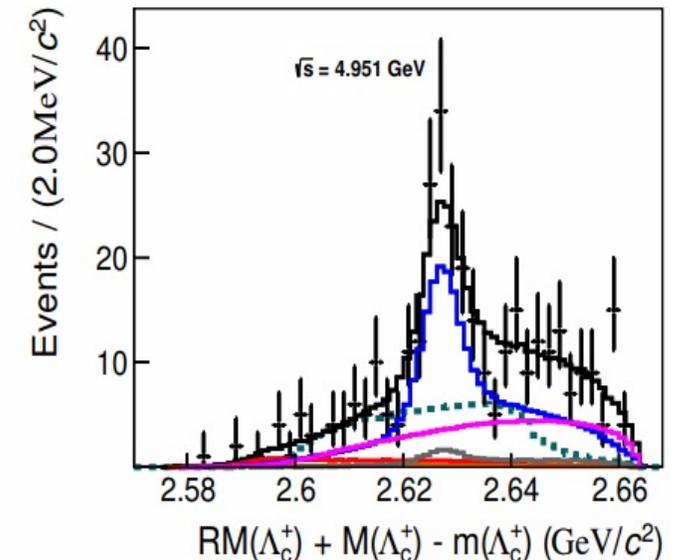
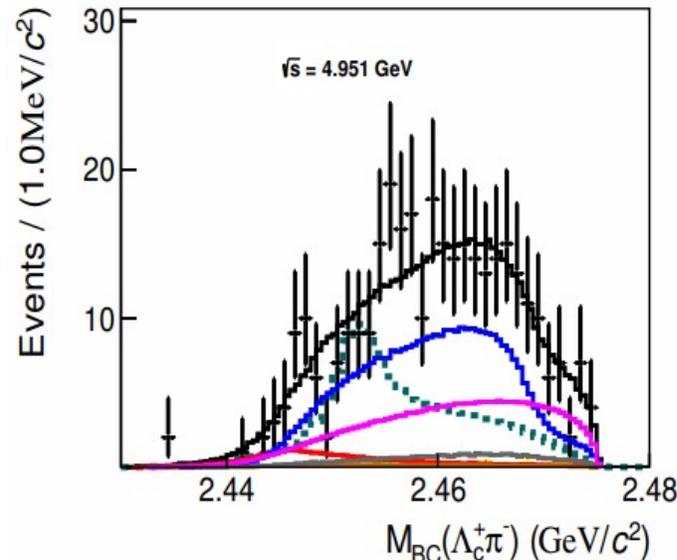
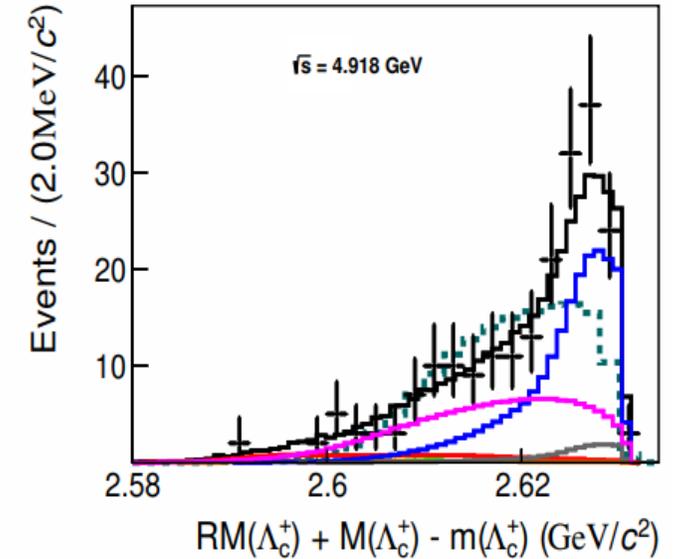
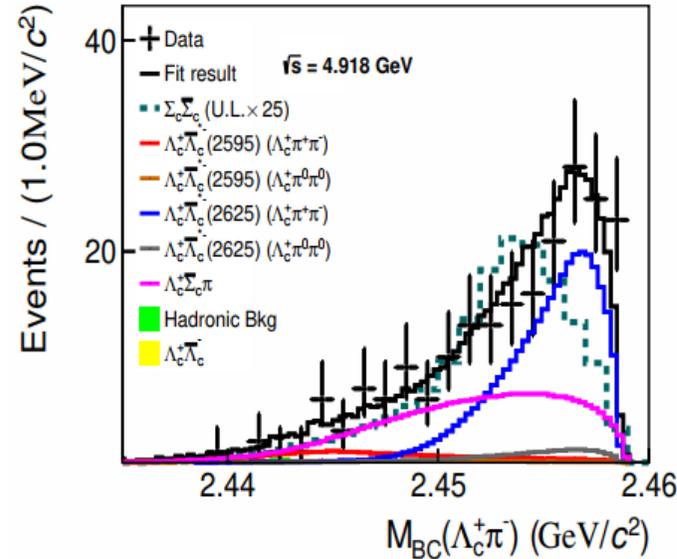
$e^+e^- \rightarrow \Sigma_c \bar{\Sigma}_c$

- The “Tag $\Lambda_c^+ \pi^-$ ”, “Tag $\Lambda_c^+ \pi^0$ ”, “Tag $\Lambda_c^+ \pi^+$ ”, “Tag $\Lambda_c^+ \pi^+ \pi^+$ ”, and “Tag $\Lambda_c^+ \pi^0 \pi^0$ ” method is applied.
- Dominant backgrounds from $\Lambda_c^+ \bar{\Lambda}_c^-$ (2595, 2625) and $\Lambda_c^+ \bar{\Sigma}_c \pi$
- Two-dimensional fits to $M_{BC}(\Sigma_c)$ and $RM(\Lambda_c^+) + M(\Lambda_c^+) - m(\Lambda_c^+)$
- No significant signals were observed, and the upper limits at 90% C.L. were set.

$\sqrt{s} =$	4.918 GeV	4.951 GeV
$\sigma_{\text{Born}}(e^+e^- \rightarrow \Lambda_c^+ \Lambda_c^-)$	$(96 \pm 5) \text{ pb}$	$(88 \pm 5) \text{ pb}$
$\sigma_{\text{Born}}^{\text{UL}}(e^+e^- \rightarrow \Sigma_c \bar{\Sigma}_c)$	$< 0.96 \text{ pb}$	$< 0.74 \text{ pb}$

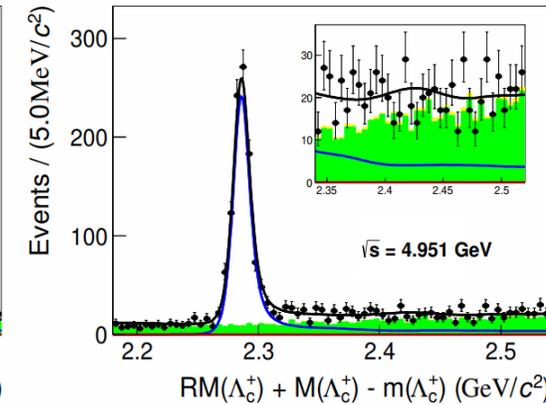
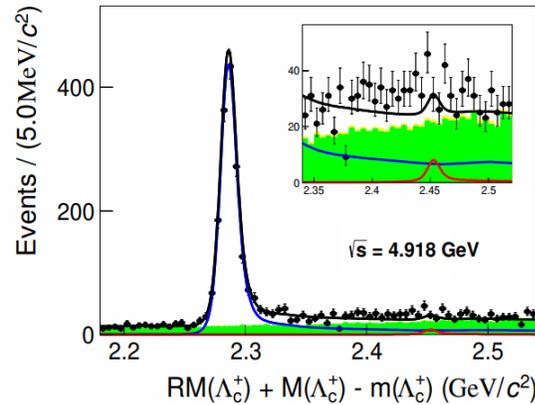
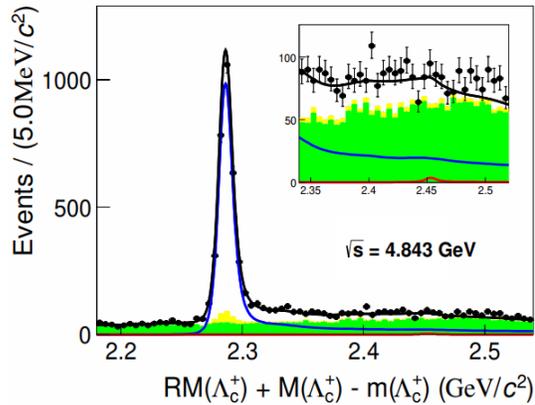
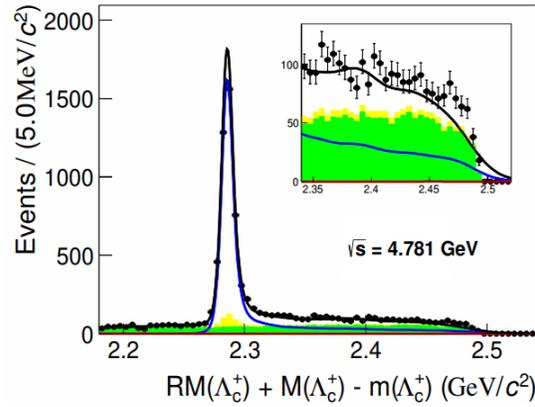
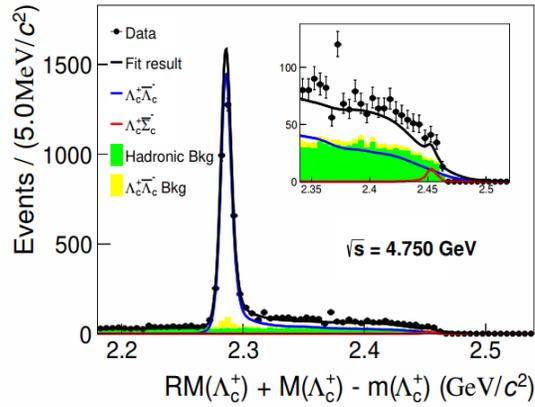
arXiv: 2508.16871

Tag $\Lambda_c^+ \pi^-$:



$$e^+ e^- \rightarrow \Lambda_c^+ \bar{\Sigma}_c^-$$

arXiv: 2508.16871



- The “Tag Λ_c^+ ” method is applied.
- No significant signals were observed, and the upper limits at 90% C.L. were set.

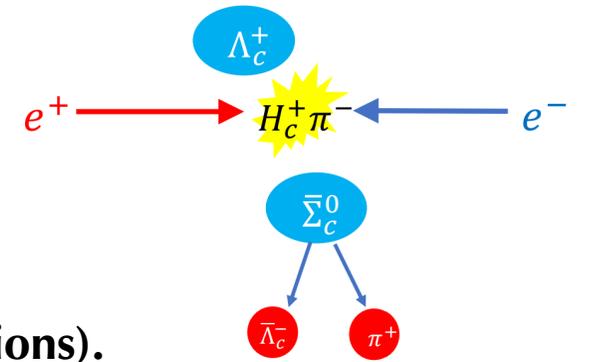
- The strong suppressions were observed in $e^+ e^- \rightarrow \Sigma_c \bar{\Sigma}_c$ and $e^+ e^- \rightarrow \Lambda_c^+ \bar{\Sigma}_c^-$ in comparison with $e^+ e^- \rightarrow \Lambda_c^+ \Lambda_c^-$.
- Such suppression was not observed in hyperon pair production ($\Lambda\Lambda$ pair: ~ 90 pb, and $\Sigma^0 \Sigma^0$: ~ 30 pb).

\sqrt{s}	4.750 GeV	4.781 GeV	4.843 GeV	4.918 GeV	4.951 GeV
$R(\sigma)$ (%)	< 1.1	< 0.6	< 1.5	< 3.4	< 1.6
$\sigma_{\text{Born}}(e^+ e^- \rightarrow \Lambda_c^+ \bar{\Lambda}_c^-)$ (pb)	$134 \pm 3 \pm 4$	$127 \pm 2 \pm 4$	$83 \pm 2 \pm 3$	$96 \pm 3 \pm 4$	$88 \pm 4 \pm 3$
$\sigma_{\text{Born}}(e^+ e^- \rightarrow \Lambda_c^+ \bar{\Sigma}_c^-)$ (pb)	< 1.52	< 0.76	< 1.26	< 3.26	< 1.38

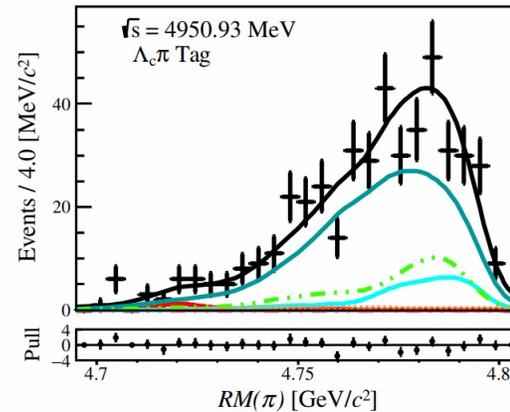
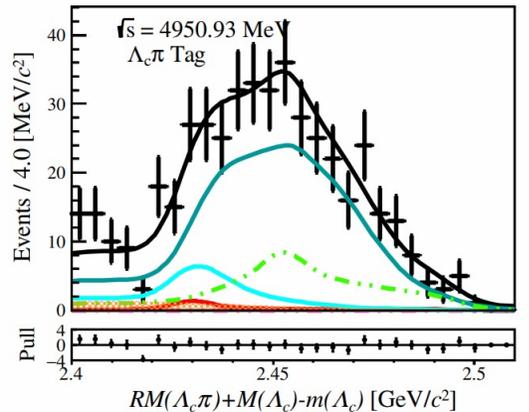
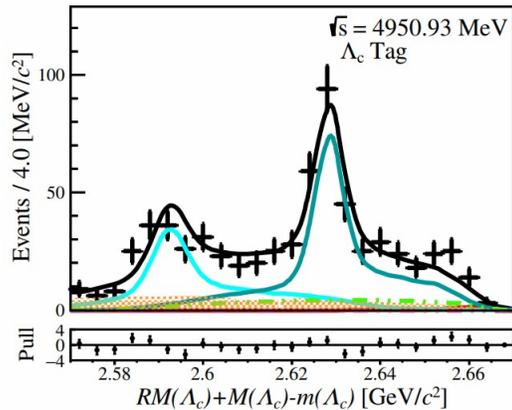
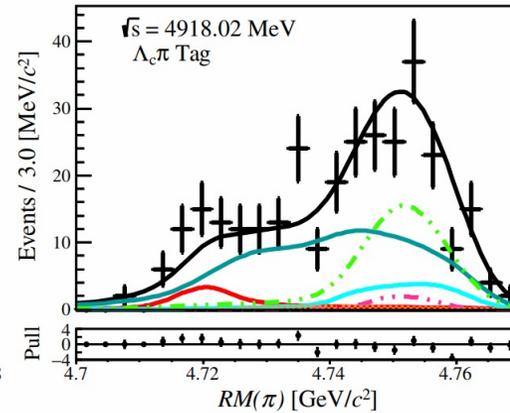
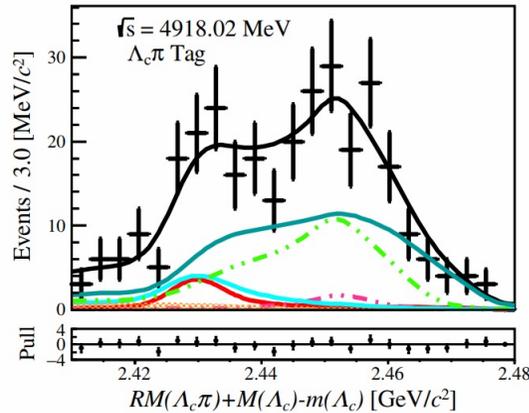
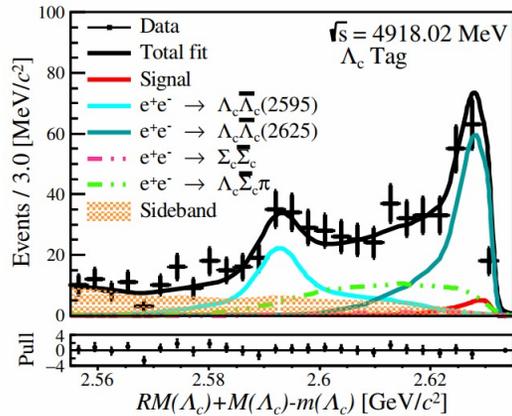
$$e^+e^- \rightarrow \pi^+ H_c^-, H_c^- \rightarrow \pi^- \Lambda_c^+ \Lambda_c^-$$

arXiv: 2508.18594

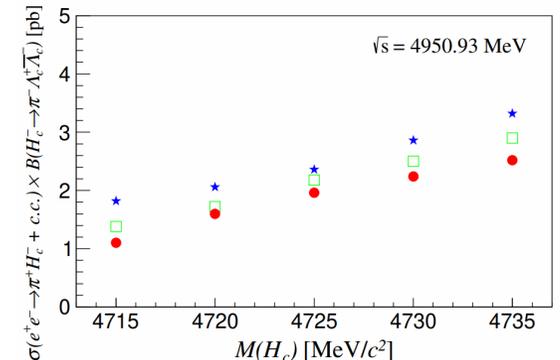
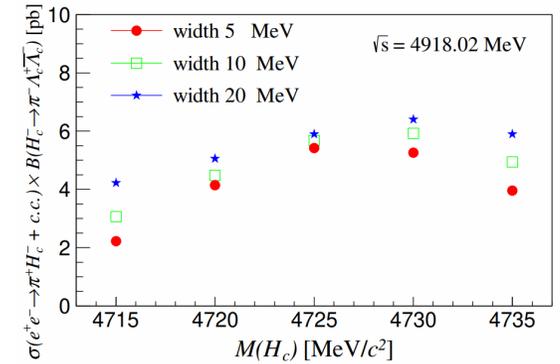
H_c^- : a $\Lambda_c \bar{\Sigma}_c$ bound state [Progr. Phys. 41 (2021) 65-93]



- Use “Tag Λ_c ” and “Tag $\Lambda_c \pi$ ” (two dimensional fits to $RM(\Lambda_c \pi)$ and $RM(\pi)$ distributions).
- Dominant backgrounds from $e^+e^- \rightarrow \Lambda_c^+ \bar{\Lambda}_c^-$ (2595, 2625), $\Lambda_c \bar{\Sigma}_c \pi$, and $\Sigma_c \bar{\Sigma}_c$



No clear signals, and **ULs at 90% C.L. were given for different H_c^- masses and widths at 4918.02 and 4950.93 MeV:**



Spectroscopy results @ Belle II

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

arXiv: 2510.27174

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

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

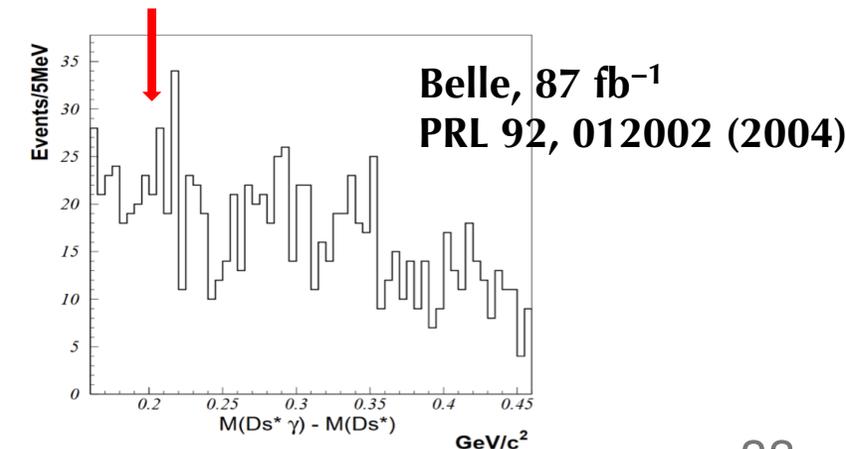
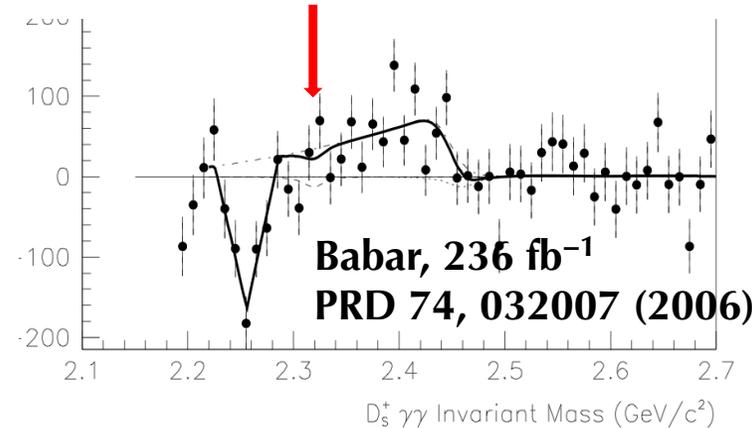
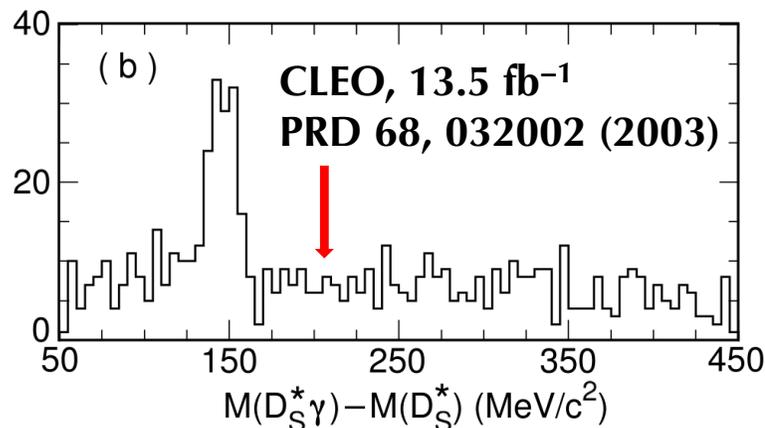
Mode	Fraction (Γ_i / Γ)	Scale Factor/ Conf. Level	P(MeV/c)
Γ_1 $D_s^+ \pi^0$	$(100_{-20}^{+0}) \%$		298
Γ_2 $D_s^+ \gamma$	<5 %	CL=90%	323
Γ_3 $D_s^*(2112)^+ \gamma$	<6 %	CL=90%	
Γ_4 $D_s^+ \gamma \gamma$	<18 %	CL=95%	323
Γ_5 $D_s^*(2112)^+ \pi^0$	<11 %	CL=90%	
Γ_6 $D_s^+ \pi^+ \pi^-$	$< 4 \times 10^{-3}$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

The nature of $D_{s0}^*(2317)^+$ was predicted to be

- 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 $D_{s0}^*(2317)^+ \rightarrow D_s^+ \pi^0$ was first observed by BaBar in 2006 [PRL 90, 242001 (2003)].
- The $D_{s0}^*(2317)^+ \rightarrow D_s^{*+} \gamma$ was searched for by CLEO, Belle, and BaBar, but no signals were found.



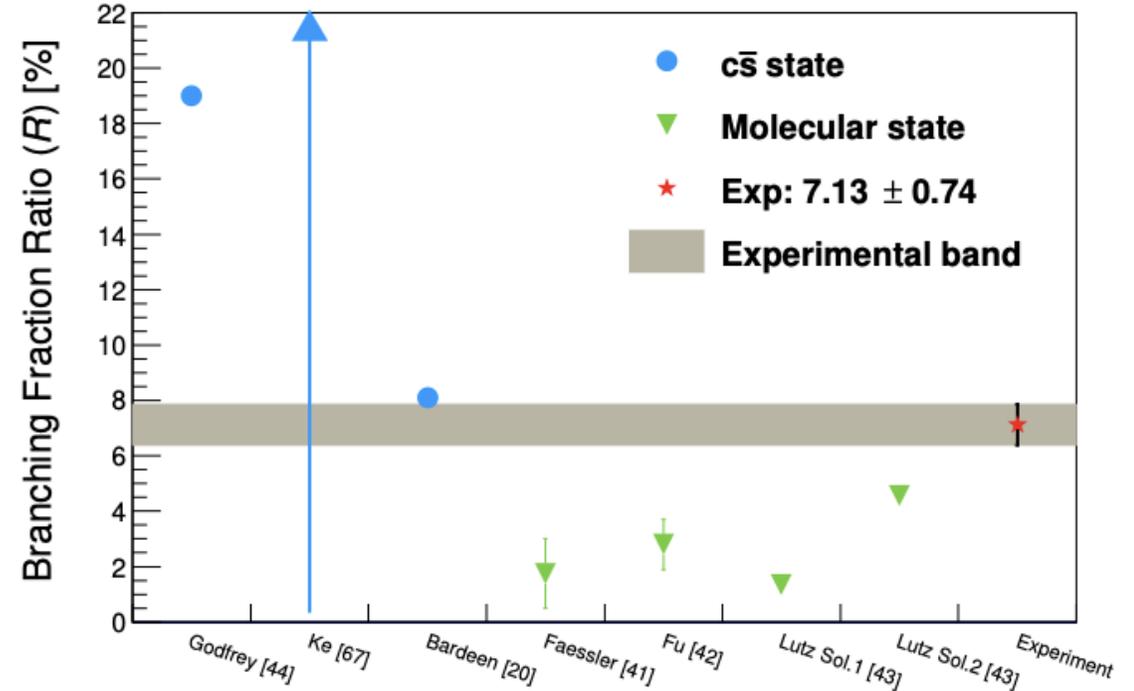
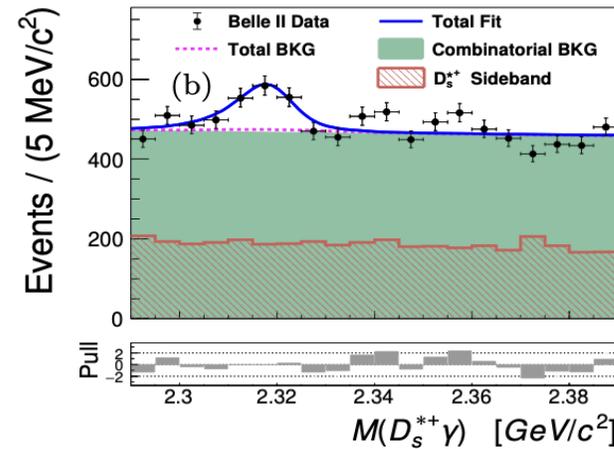
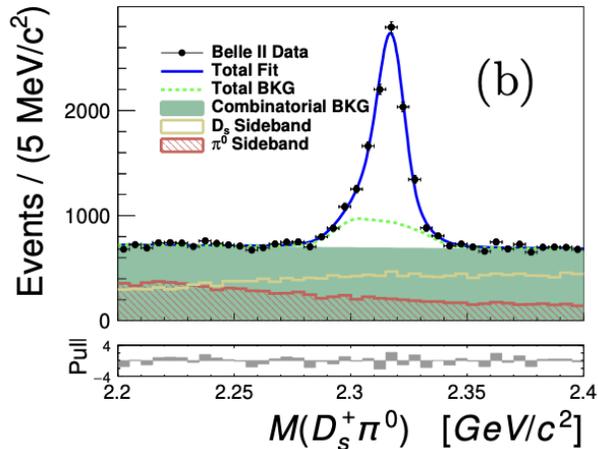
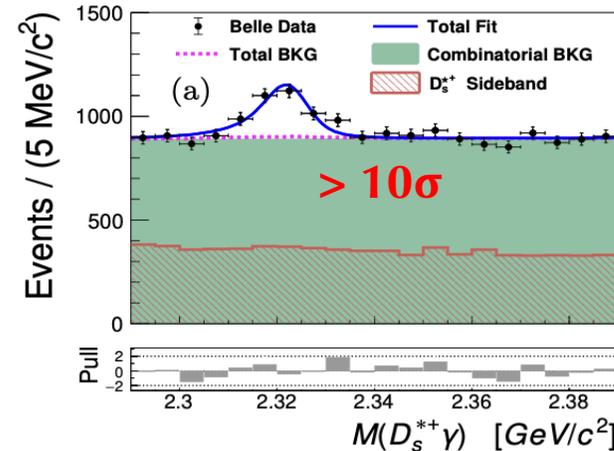
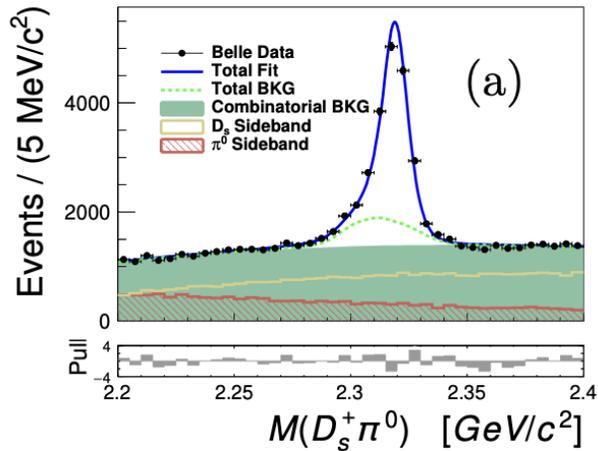
First observation of $D_{s0}^*(2317)^+ \rightarrow D_s^{*+} \gamma$

arXiv: 2510.27174

- Target: $D_{s0}^*(2317)^+ \rightarrow D_s^{*+} \gamma$
- Control channel: $D_{s0}^*(2317)^+ \rightarrow D_s^+ \pi^0$
- Using all Belle data (983 fb^{-1}) and Belle II data (427 fb^{-1})

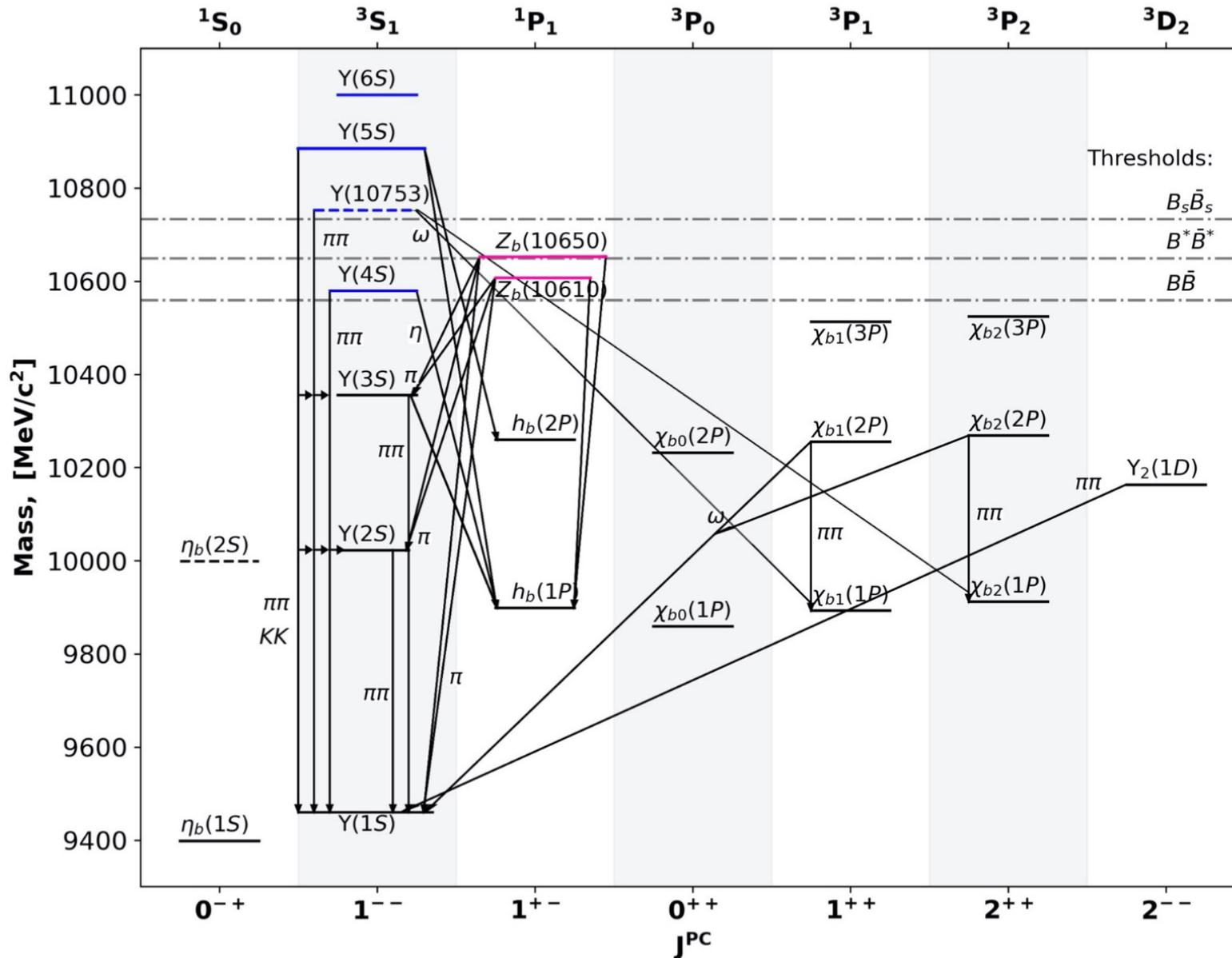
$$\mathcal{R} = \frac{\mathcal{B}(D_{s0}^*(2317)^+ \rightarrow D_s^{*+} \gamma)}{\mathcal{B}(D_{s0}^*(2317)^+ \rightarrow D_s^+ \pi^0)}$$

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



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

Bottomonium



- Conventional bottomonium (pure $b\bar{b}$ states)
- Bottomonium-like states (mix of $b\bar{b}$ and $B\bar{B}$)
- Exotic charged states (Z_b^+)

In 2019, the Y(10753) was first observed in $\pi^+\pi^-Y(nS)$ final states using Belle scan data [JHEP 10, 220 (2019)].

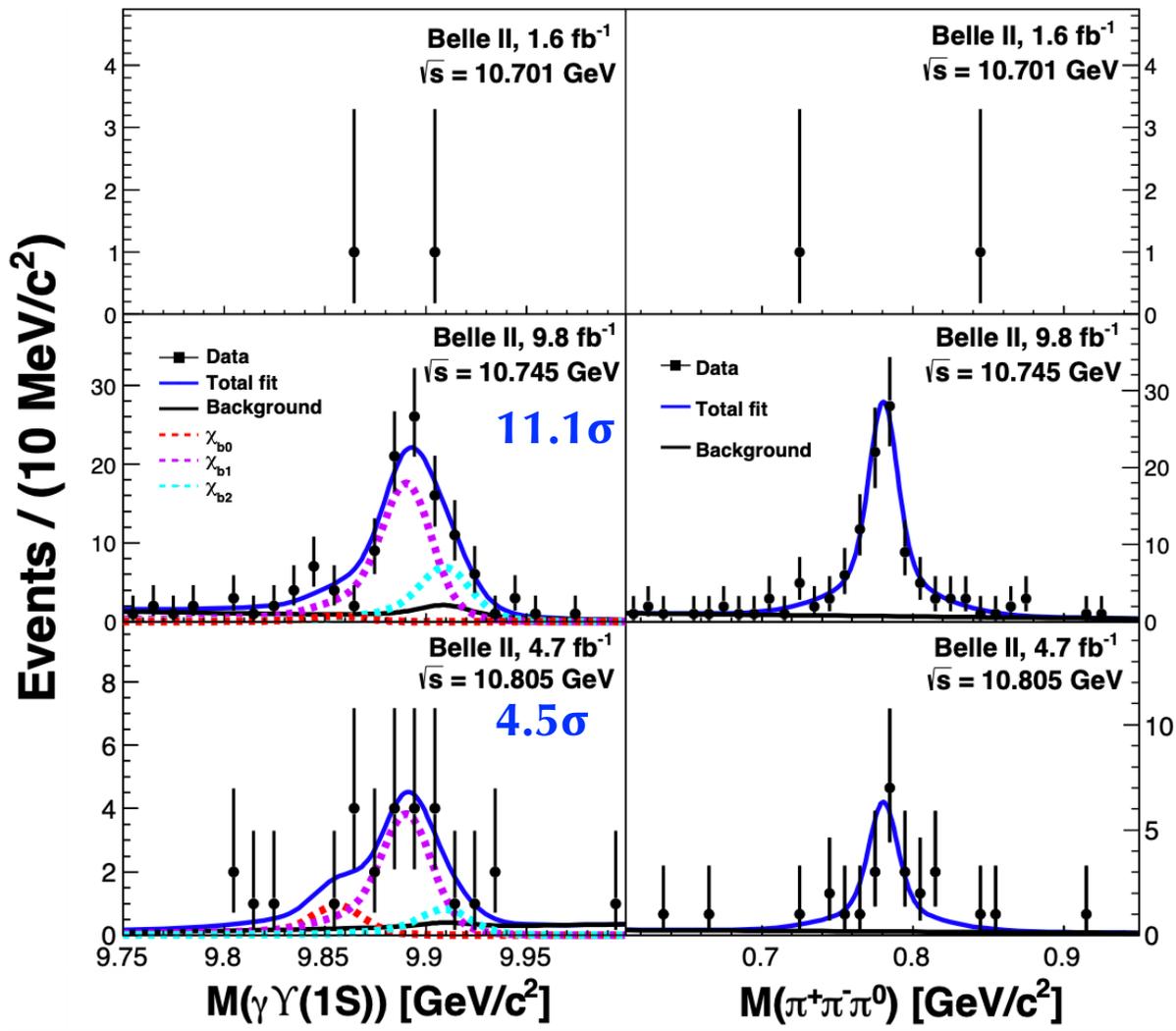
The Y(10753) was widely interpreted as conventional bottomonium, Tetraquark, or hybrid states.

Belle II collected the data of 19.8 fb⁻¹ at \sqrt{s} around 10.75 GeV to study the nature of the Y(10753).

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

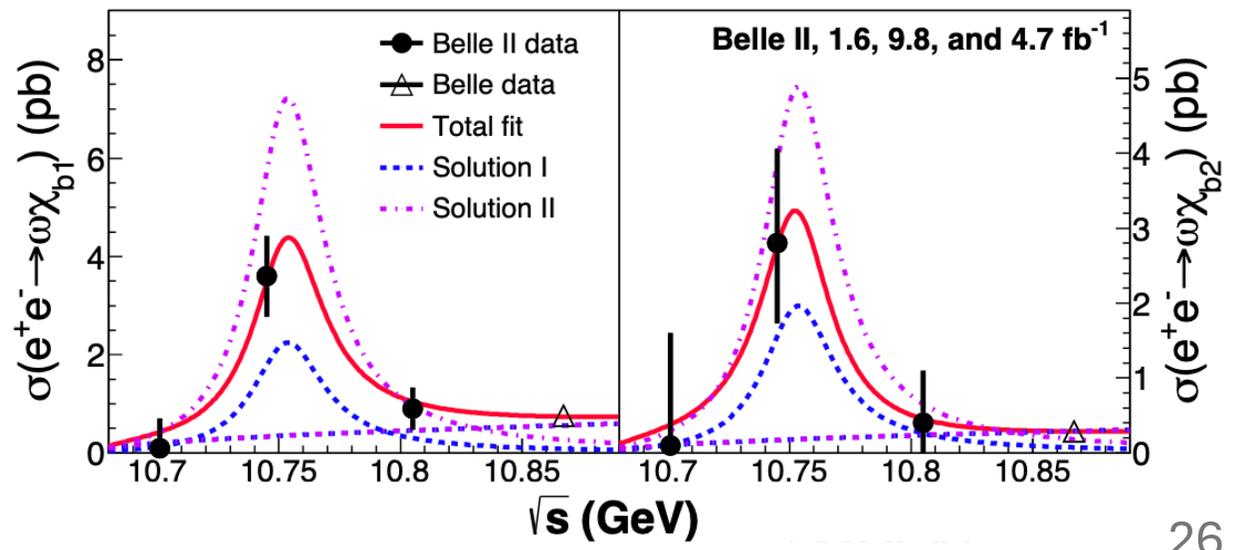
PRL 130, 091902 (2023)

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}	$\sigma_{\text{Born}}^{(\text{UL})}$ (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 $e^+e^- \rightarrow \omega\chi_{bJ}$ ($J = 1, 2$) cross sections peak at $\Upsilon(10753)$.

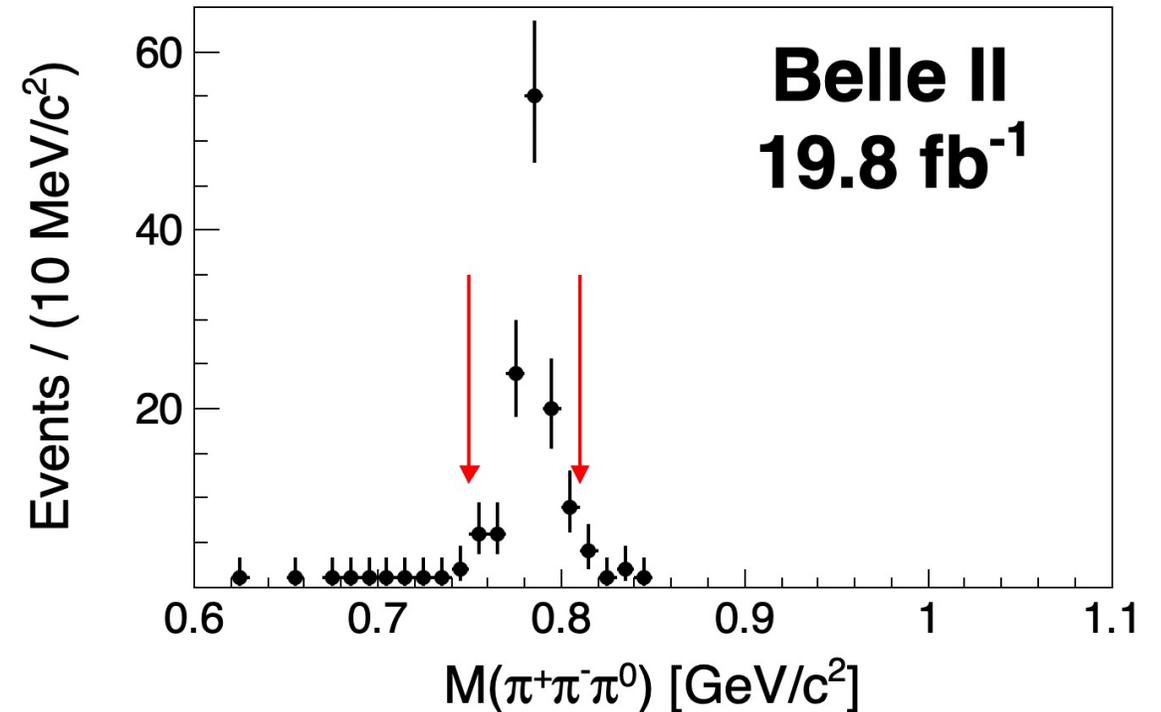
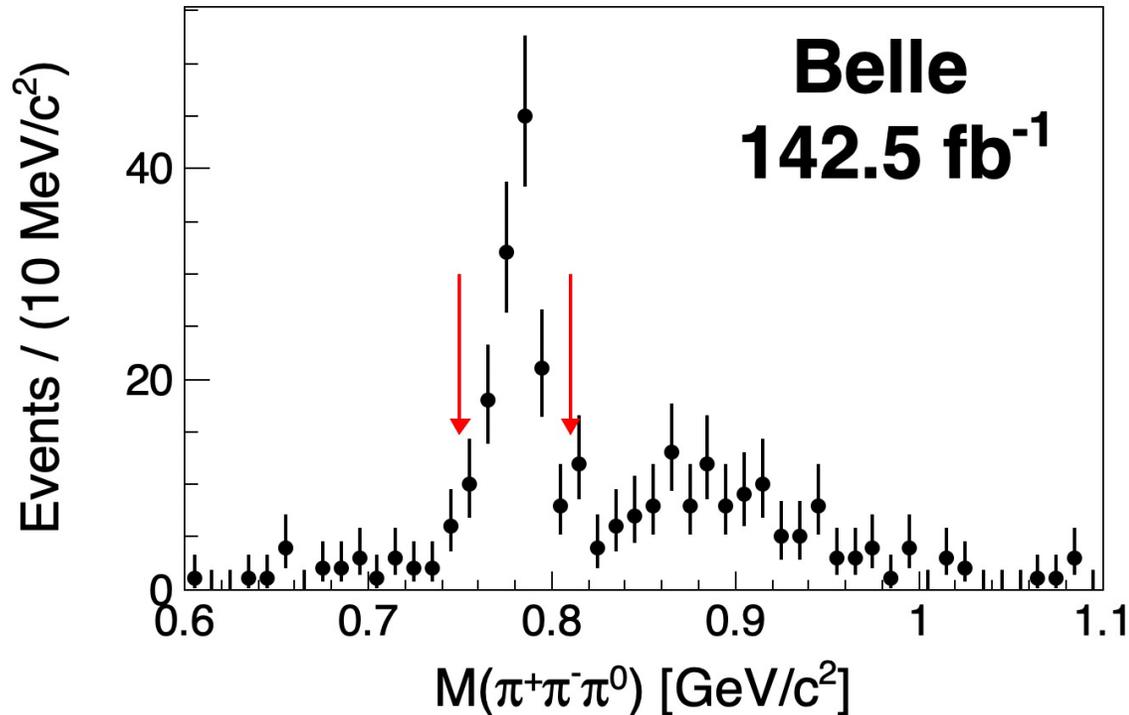


$e^+e^- \rightarrow \omega\chi_{bJ}$ and $e^+e^- \rightarrow (\pi^+\pi^-\pi^0)_{\text{non-}\omega}\chi_{bJ}$ at Belle and Belle II

arXiv: 2510.25461

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

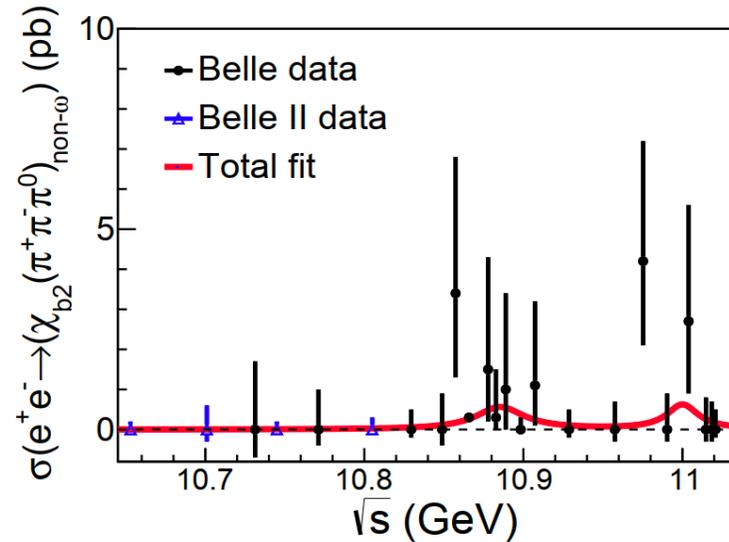
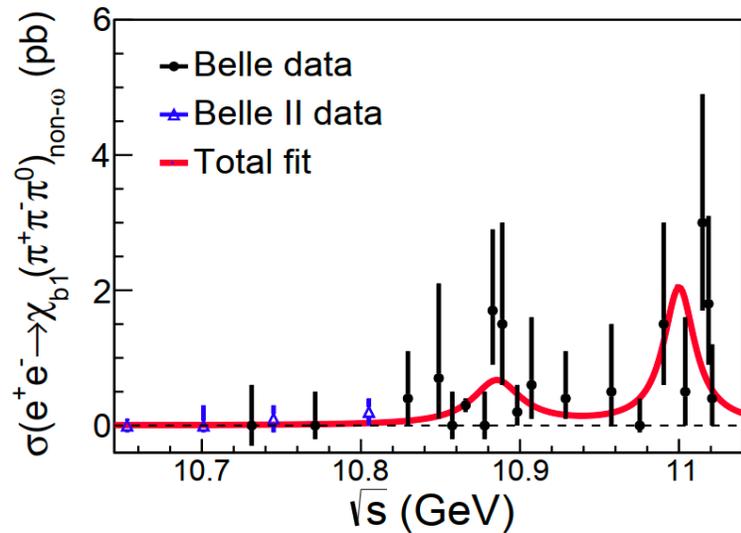
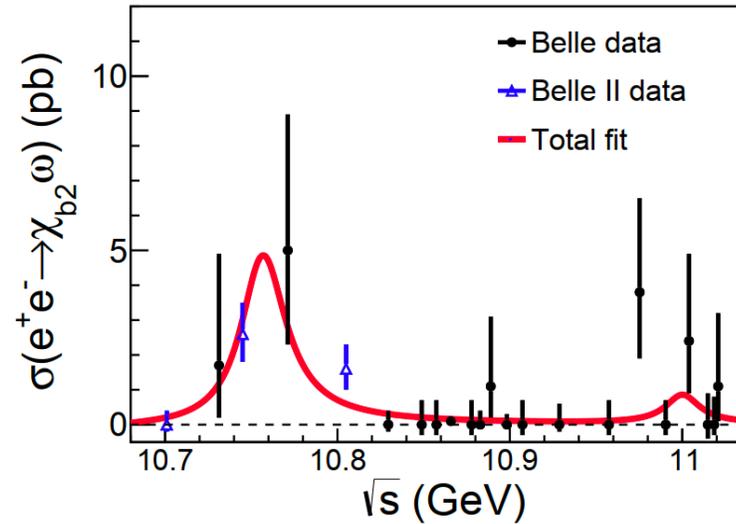
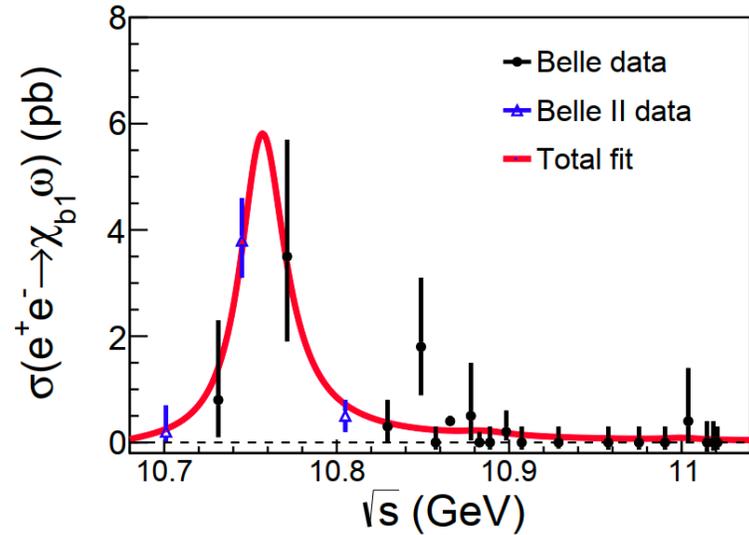
$\sqrt{s} \sim 10.75$ GeV



- In addition to ω signal candidates, there are some events from non- ω decays at Belle.
- We require $M(\pi^+\pi^-\pi^0) < 0.75$ GeV/c² and $M(\pi^+\pi^-\pi^0) > 0.81$ GeV/c² to select non- ω events.

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

arXiv: 2510.25461



$\Upsilon(10753)$ mass	$(10756.1 \pm 4.3) \text{ MeV}/c^2$
$\Upsilon(10753)$ width	$(32.2 \pm 18.7) \text{ MeV}$

- The mass and width are consistent with those from $e^+e^- \rightarrow \pi^+\pi^-\Upsilon(nS)$ measurement [JHEP 07, 116 (2024)].

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

↙ ↘

1.5 at $\sqrt{s} \sim 10.75 \text{ GeV}$ 0.15 at $\sqrt{s} \sim 10.867 \text{ GeV}$

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

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

↓

$1.13 \pm 0.38 \pm 0.34$

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

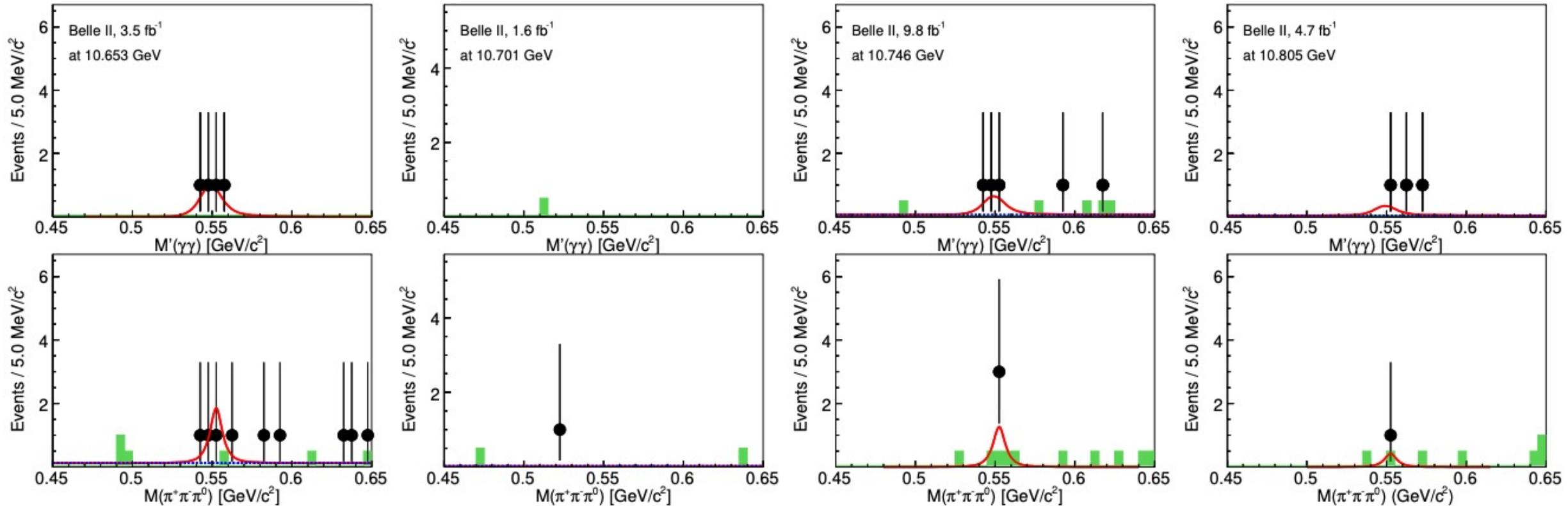
$$e^+e^- \rightarrow \eta\Upsilon(1S, 2S)$$

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

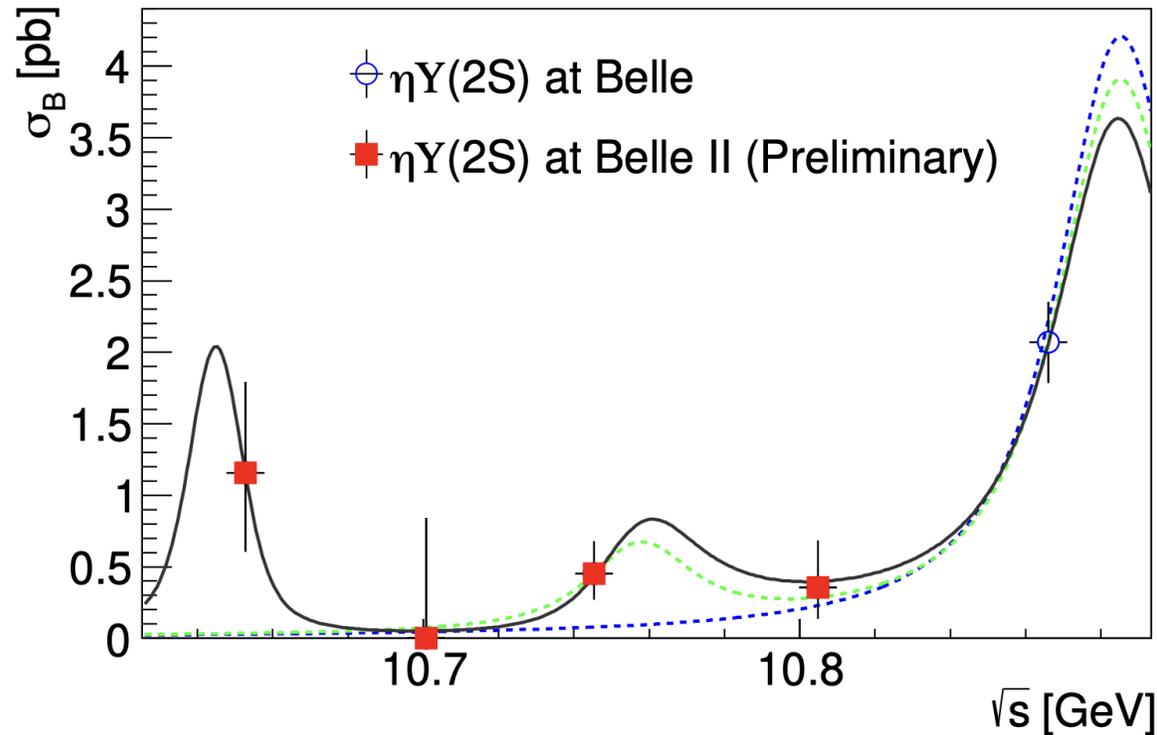
$$\eta \rightarrow \pi^+\pi^-\pi^0, \Upsilon(2S) \rightarrow \ell^+\ell^-$$

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



Fit the with 3 different hypotheses:

H₁: only $\Upsilon(5S)$ [blue curve]

H₂: $\Upsilon(10753)$ + $\Upsilon(5S)$ [Green curve]

H₃: $B^*\bar{B}^*$ 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 3.6σ

1. The Born cross section of $e^+e^- \rightarrow \eta\Upsilon(2S)$ around $B^*\bar{B}^*$ mass is relatively large.
2. A rapid increase of $\sigma_{B^*\bar{B}^*}$ just above the threshold [JHEP 10 (2024) 114].

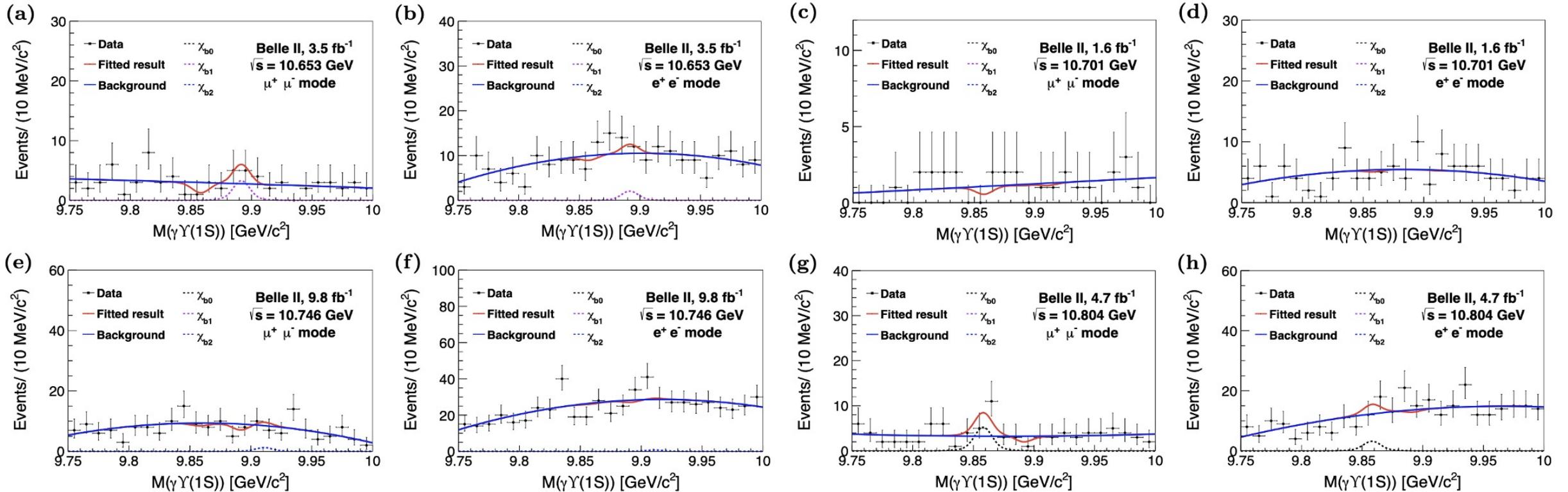
A new bottomonium-like state around $B^*\bar{B}^*$ threshold?

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

$e^+e^- \rightarrow \gamma\chi_{bJ} \ (J = 0, 1, 2)$

arXiv: 2508.16036

The radiative decay is enhanced if the D component is large [PRD 92, 054034 (2015), EPJC 78, 915 (2018)].



- No clear signal of $e^+e^- \rightarrow \gamma\chi_{bJ}$ can be seen.
- $\sigma_{\text{Born}}^{\text{UL}}(e^+e^- \rightarrow \gamma\chi_{b1})$ at $\sqrt{s} = 10.746$ GeV is 0.26 pb ($\mathcal{B}_{\text{Born}}^{\text{UL}}(e^+e^- \rightarrow \gamma\chi_{b1}) \sim 10^{-4}$), which is much smaller than the Born cross sections for $e^+e^- \rightarrow \omega\chi_{bJ}$ and $e^+e^- \rightarrow \pi^+\pi^-\Upsilon(nS)$.

A brief Summary for $Y(10753)$

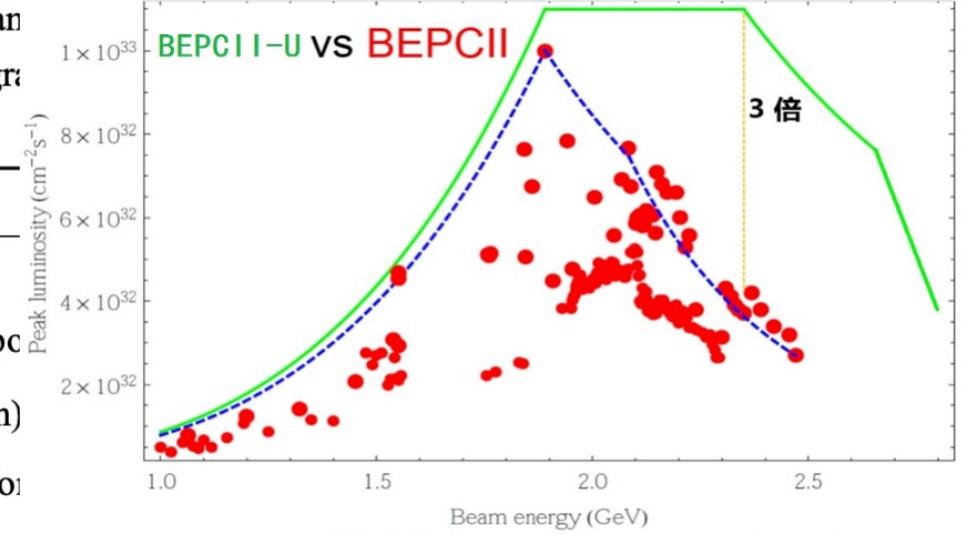
Channel	Results
$e^+e^- \rightarrow \omega\chi_{b1,b2}$	Large discrepancy of $\sigma(e^+e^- \rightarrow \chi_{bJ}(1P)\omega)/\sigma(e^+e^- \rightarrow Y(nS)\pi^+\pi^-)$ at $\sqrt{s} = 10.750$ and 10.867 GeV
	A prominent $Y(10753)$ signal, but no clear signals of $Y(10860)$ or $Y(11020)$
$e^+e^- \rightarrow (\pi^+\pi^-\pi^0)_{\text{non-}\omega}\chi_{b1,b2}$	Low-significance peaks for the $Y(10860)$ and $Y(11020)$, but no signal for the $Y(10753)$;
$e^+e^- \rightarrow \eta Y(2S)$	$\sigma(e^+e^- \rightarrow \eta Y(2S))$ around $B^*\bar{B}^*$ mass is relatively large; A new $Y_b(10650)$ around $B^*\bar{B}^*$ threshold?
$e^+e^- \rightarrow \gamma\chi_{bJ}$	$\sigma(e^+e^- \rightarrow \gamma\chi_{bJ})$ is much smaller than $\sigma(e^+e^- \rightarrow \omega\chi_{bJ})$ and $\sigma(e^+e^- \rightarrow \pi^+\pi^-Y(nS))$

Future prospects at BESIII

BEPChI finished upgrade, increase the luminosity at = 4.7 GeV by a factor of 3, and extend the up to 5.6 GeV starting from 2028.

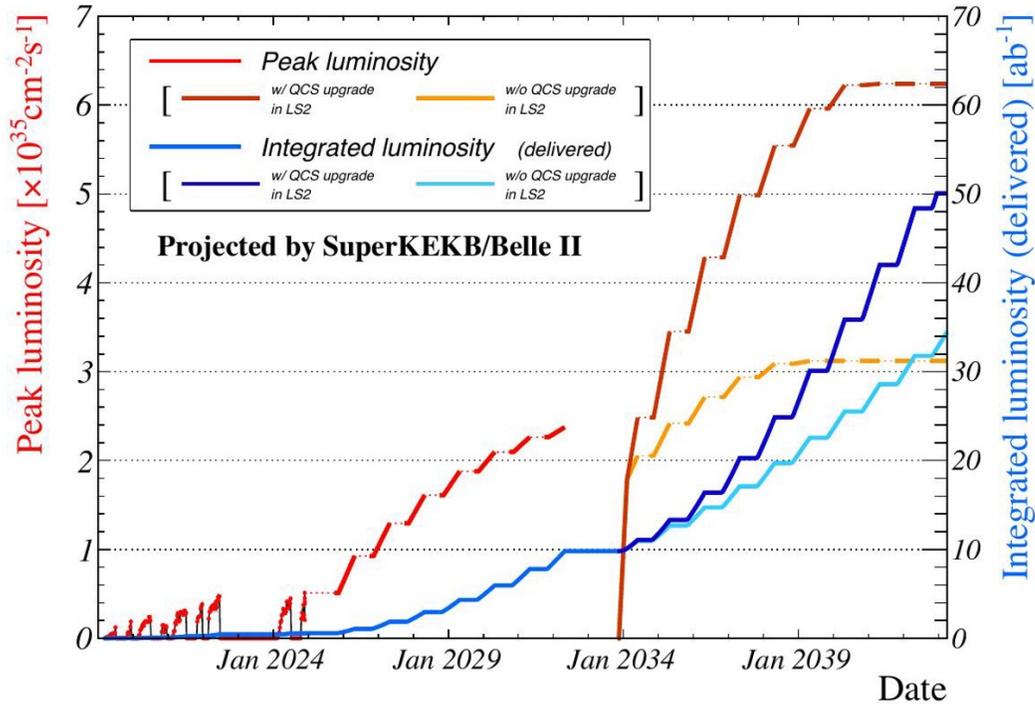
Table 7.1. List of data samples collected by BESIII/BEPCII up to 2019, and the proposed san most column shows the number of required data taking days with the current (T_C) and upgr implementation and beam current increase.

Energy	Physics motivations	Current data	Proposed data taking days	Proposed luminosity
1.8 - 2.0 GeV	R values Nucleon cross-sections	N/A		
2.0 - 3.1 GeV	R values Cross-sections	Fine scan (20 energy points)		
J/ψ peak	Light hadron & Glueball J/ψ decays	3.2 fb^{-1} (10 billion)		
$\psi(3686)$ peak	Light hadron & Glueball Charmonium decays	0.67 fb^{-1} (0.45 billion)		
$\psi(3770)$ peak	D^0/D^\pm decays	2.9 fb^{-1}	610/360 days	20.0 fb^{-1}
3.8 - 4.6 GeV	R values XYZ /Open charm	Fine scan (105 energy points)	N/A	No requirement
4.180 GeV	D_s decay XYZ /Open charm	3.2 fb^{-1}	140/50 days	6 fb^{-1}
4.0 - 4.6 GeV	XYZ /Open charm Higher charmonia cross-sections	16.0 fb^{-1} at different \sqrt{s}	770/310 days	30 fb^{-1} at different \sqrt{s}
4.6 - 4.9 GeV	Charmed baryon/ XYZ cross-sections	0.56 fb^{-1} at 4.6 GeV	1490/600 days	15 fb^{-1} at different \sqrt{s}
4.74 GeV	$\Sigma_c^+ \bar{\Lambda}_c^-$ cross-section	N/A	100/40 days	1.0 fb^{-1}
4.91 GeV	$\Sigma_c \bar{\Sigma}_c$ cross-section	N/A	120/50 days	1.0 fb^{-1}
4.95 GeV	Ξ_c decays	N/A	130/50 days	1.0 fb^{-1}



Future prospects at Belle II

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



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

Charmonium-like states:

➤ B decay ($B \rightarrow KX_{c\bar{c}}$)

$B \rightarrow KX(3872)$

➤ Initial-state radiation (ISR)

$e^+e^- \rightarrow Y(4260) \rightarrow \pi^+\pi^-J/\psi$ via ISR

➤ Two-photon process

$\gamma\gamma \rightarrow X(3915) \rightarrow \omega J/\psi$

➤ Double charmonium

$e^+e^- \rightarrow J/\psi X(3940)$

Need more data

Bottomonium-like states:

➤ Direct production via operation at center-of-mass energy

$e^+e^- \rightarrow Y(10753) \rightarrow \pi^+\pi^-Y(nS)$

➤ Decays of higher mass states

$Y(5S) \rightarrow \pi Z_b \rightarrow \pi\pi Y(nS)$

Need new collision energy points and more data

Summary

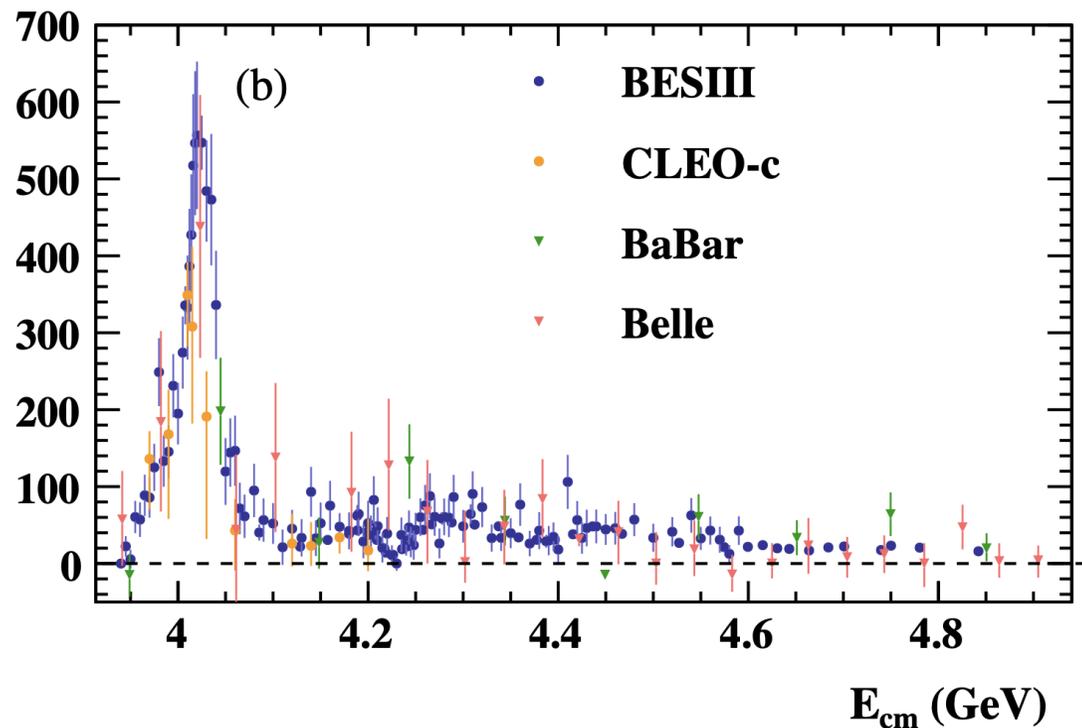
- **BESIII provides an ideal experimental platform for the charmonium(-like) spectroscopy.**
- **The data collected at Belle II can be used to study the bottomonium(-like) spectroscopy directly.**
- **More data will be obtained in a few years. Stay tuned for more exciting results from BESIII & Belle II.**

Thanks for your attention!

Backup slides

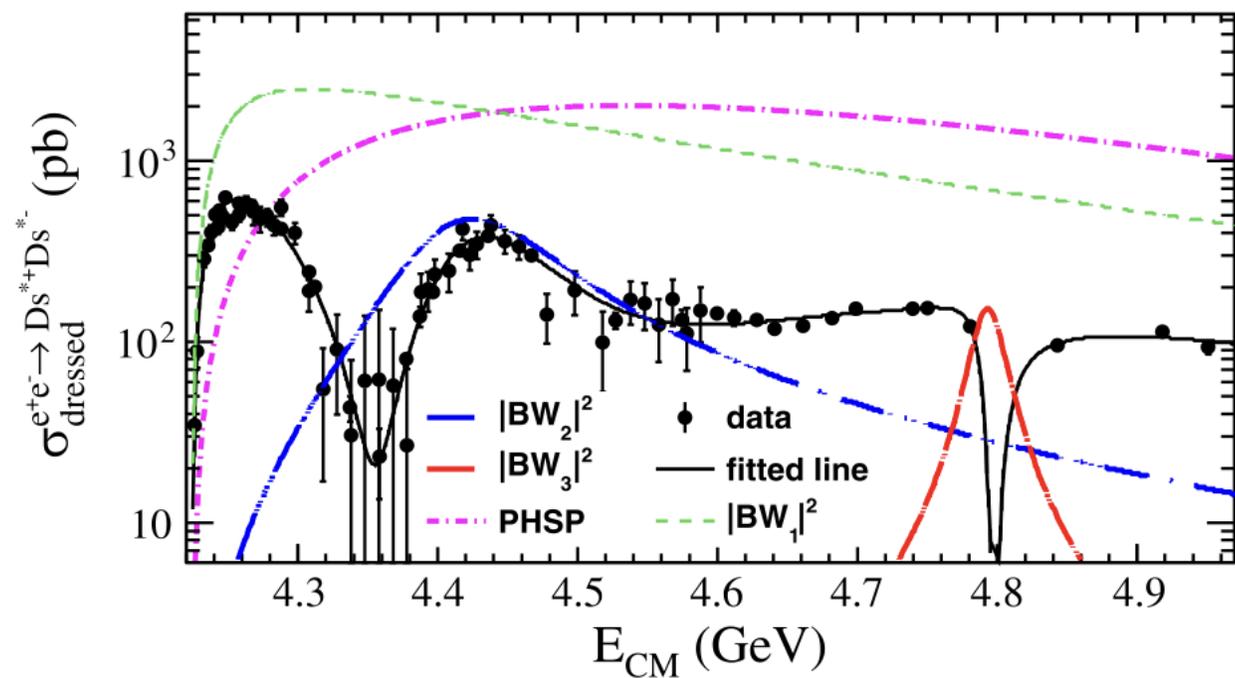
PHYSICAL REVIEW LETTERS 133, 261902 (2024)

$$e^+ e^- \rightarrow D_s^+ D_s^-$$



PHYSICAL REVIEW LETTERS 131, 151903 (2023)

$$e^+ e^- \rightarrow D_s^{*+} D_s^{*-}$$

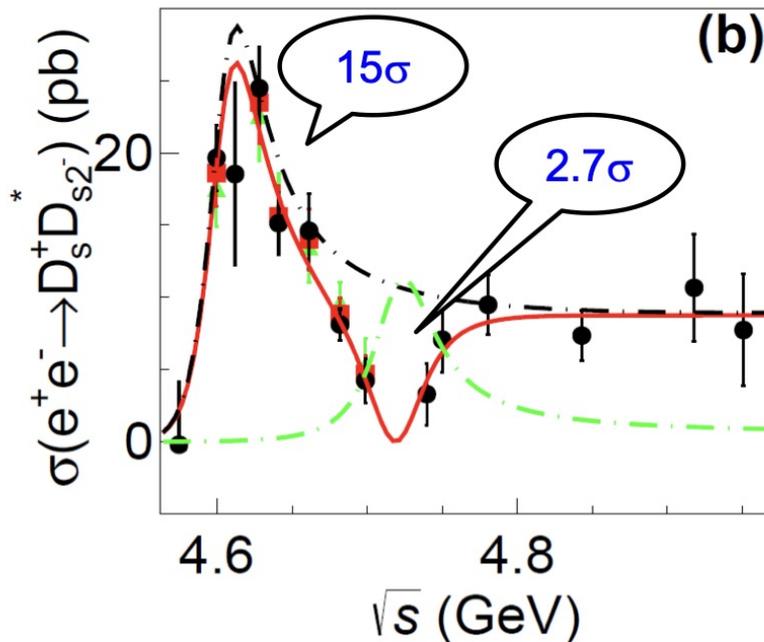
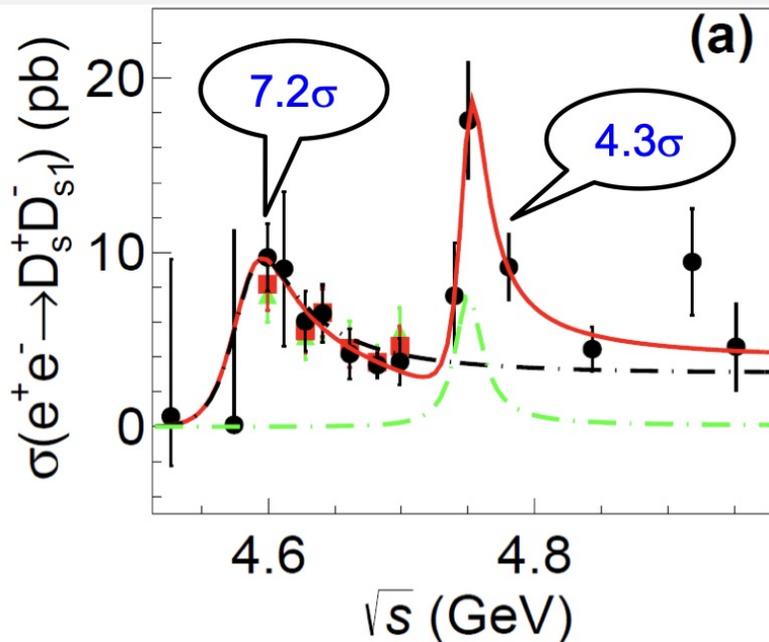


$e^+e^- \rightarrow D_s^+ D_{s1}^-$ and $D_s^+ D_{s2}^{*-}$

BESIII

Vectors in $c\bar{c} + s\bar{s}$ final states: two in $e^+e^- \rightarrow D_s^+ D_{s1}^-$ and $D_s^+ D_{s2}^{*-}$?

Phys. Rev. Lett. 133 (2024) 17, 171903 [arXiv: 2407.07651]



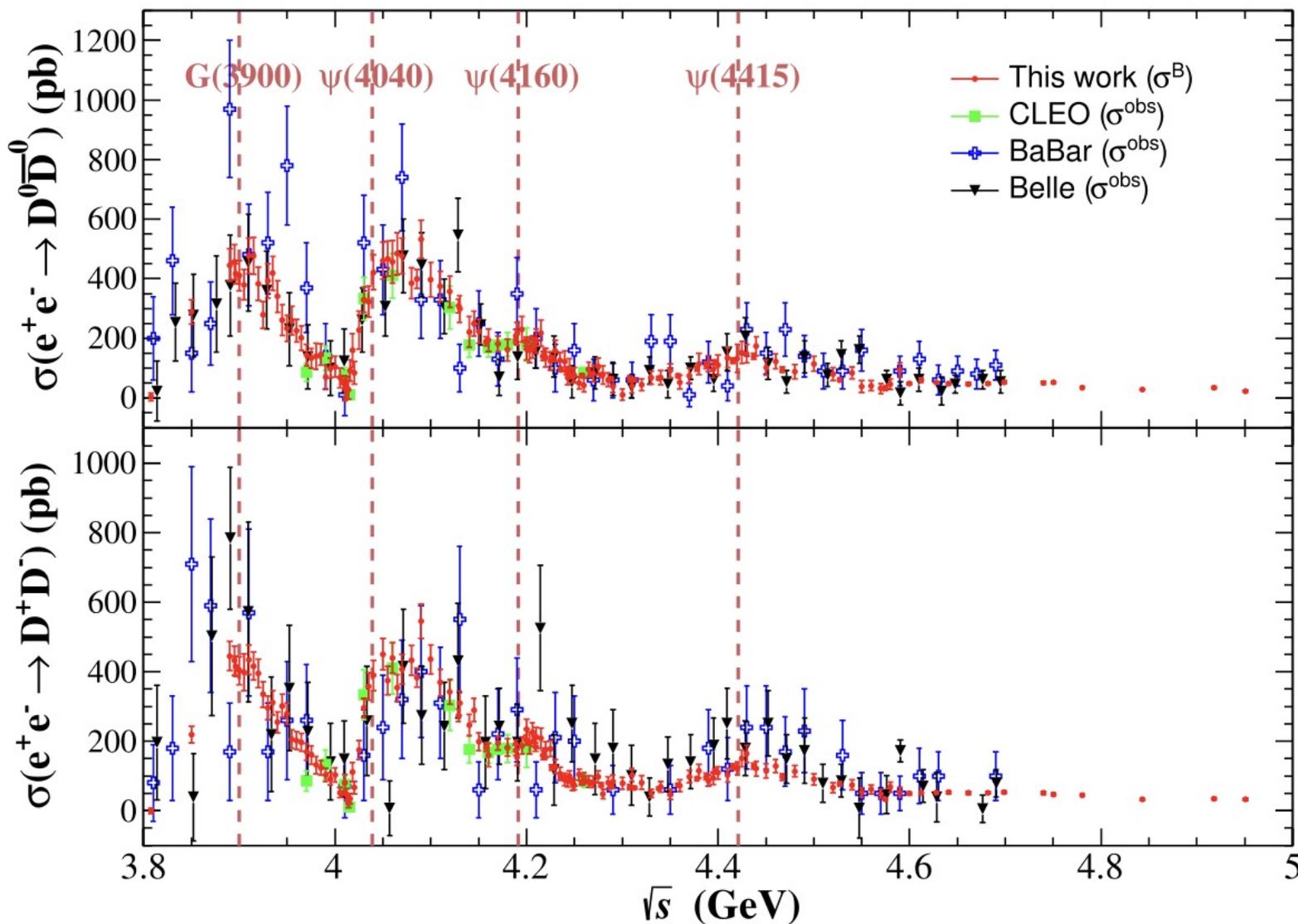
resonance	mass (MeV)	width (MeV)
R1	$4584 \pm 14 \pm 80$	$57 \pm 12 \pm 219$
R2	$4750 \pm 8 \pm 6$	$25 \pm 8 \pm 1$

resonance	mass (MeV)	width (MeV)
R1	$4603 \pm 4 \pm 1$	$45 \pm 6 \pm 1$
R2	$4720 \pm 13 \pm 2$	$50 \pm 12 \pm 1$

- Could the low mass structure be the $Y(4630)$?
- Could the high mass structure be the $Y(4710)$ in KKJ/ψ or $Y(4790)$ in $D_s^{*+} D_s^{*-}$?

$e^+e^- \rightarrow D^0\bar{D}^0$ and D^+D^-

PRL 133, 081901 (2024)



- **A single tag technique is employed to increase the statistics, and only one $D^0(D^+)$ meson is reconstructed using the $K^-\pi^+\pi^-\pi^+(K^-\pi^+\pi^-\pi^+)$ decay modes.**
- **The precision achieved in this study is high.**
- **Clear peaks of $G(3900)$, $\psi(4040)$, $\psi(4160)$, $\psi(4260)$, $\psi(4415)$, etc., can be seen.**
- **The comprehensive models to fit the cross section is necessary.**

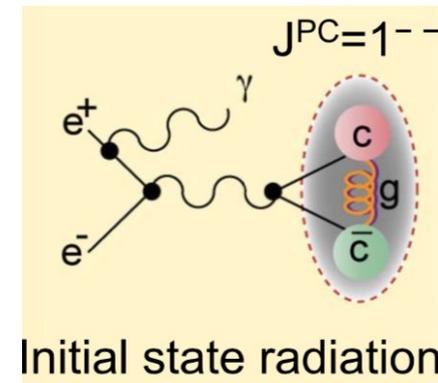
$e^+e^- \rightarrow h^+h^-J/\psi$ ($h = \pi, K, p$) via initial-state radiation (ISR) at Belle II

Advantages of ISR: 😊

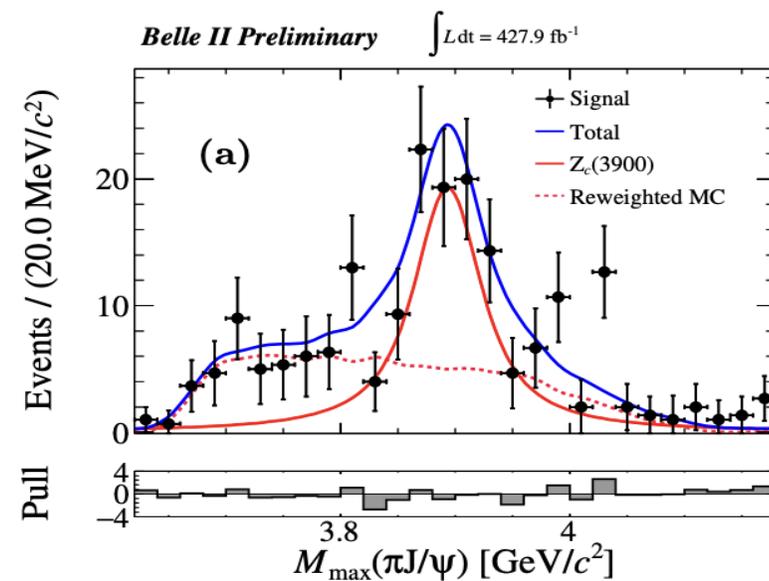
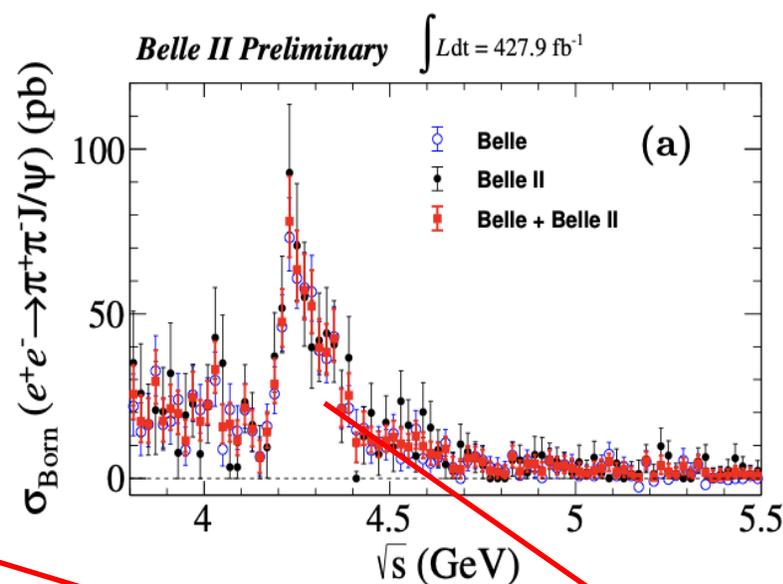
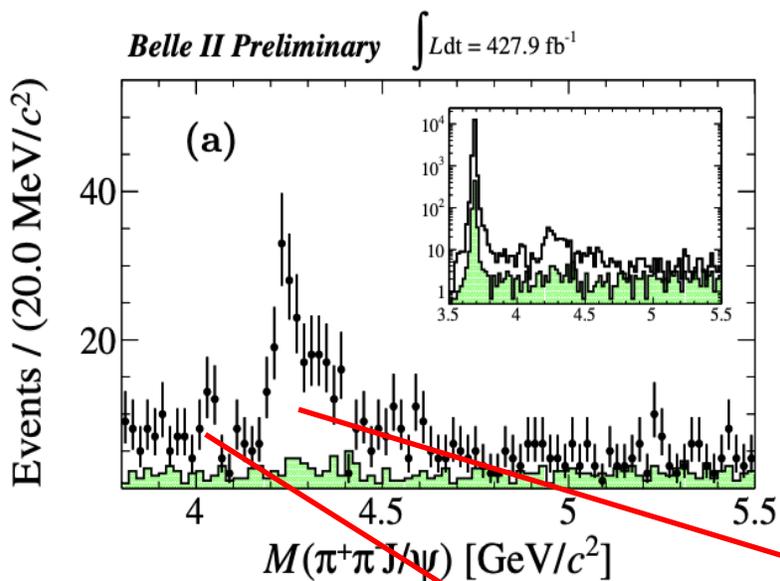
- Allows to study energies below $E_{c.m.}$
- Wide energy range available
- Measure more precisely the line-shapes

Disadvantages of ISR: 😞

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



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

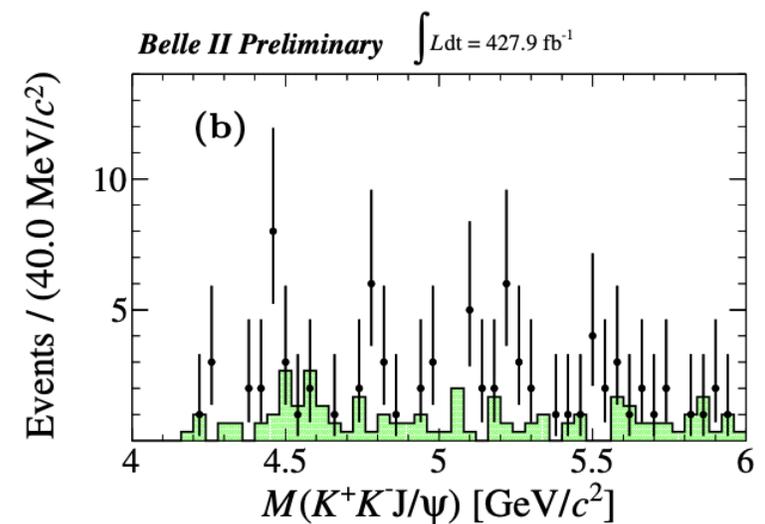
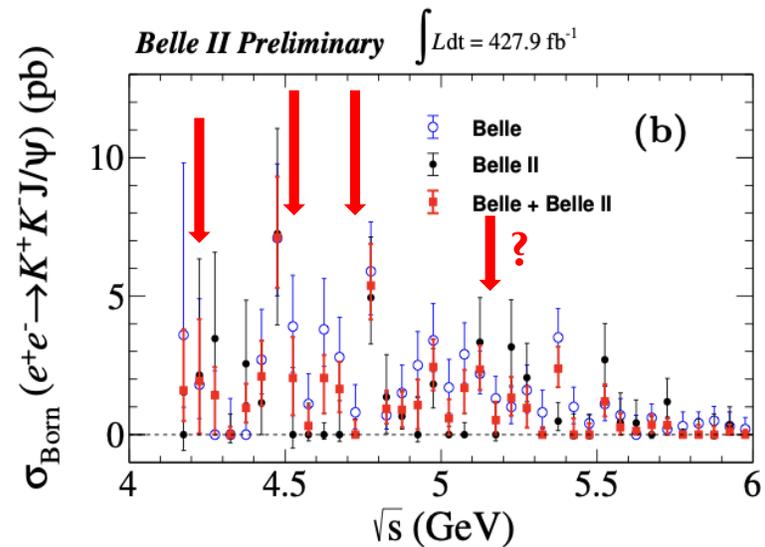


- We can see the $Y(4008)$ evidence and $Y(4260)$ signal.
- The significance of $Z_c(3900)$ is 5.3σ .

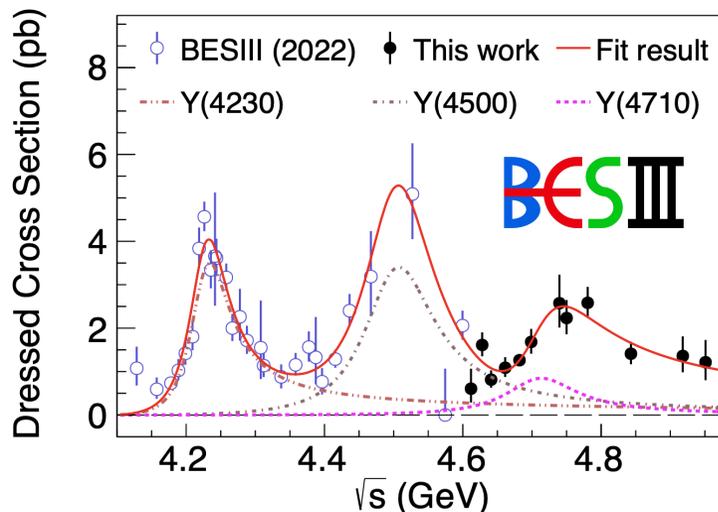
There seem to be two peaks ($Y(4230)$ and $Y(4320)$).

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

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



PRL 131, 211902 (2023)



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

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

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

