

Recent Studies on Vector Charmonium(-like) States at BESIII

Yuping Guo on Behalf of BESIII Collaboration

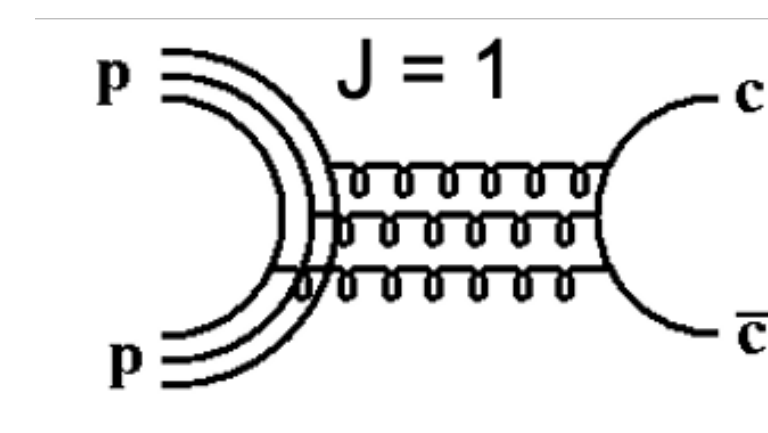
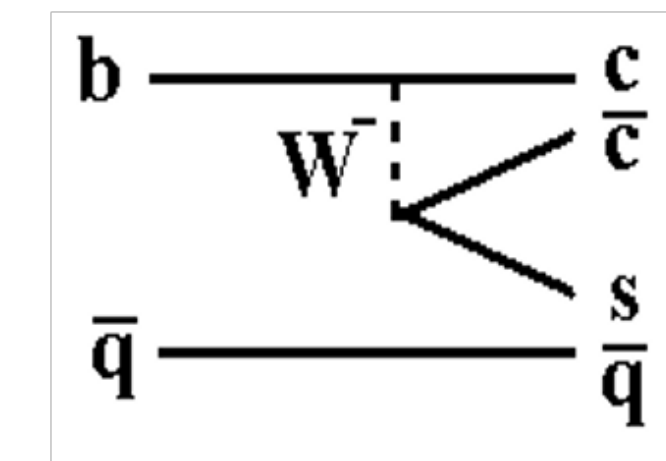
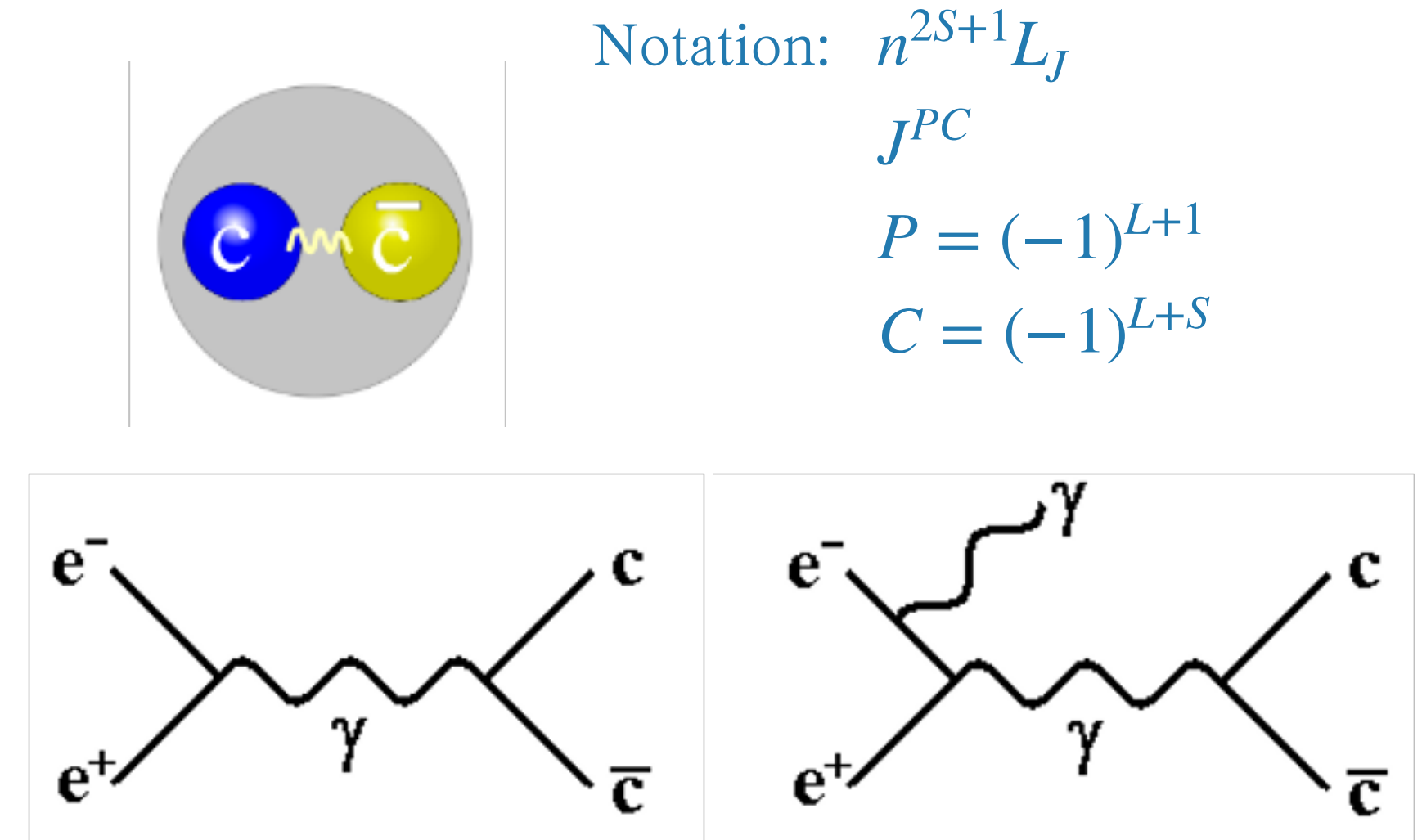
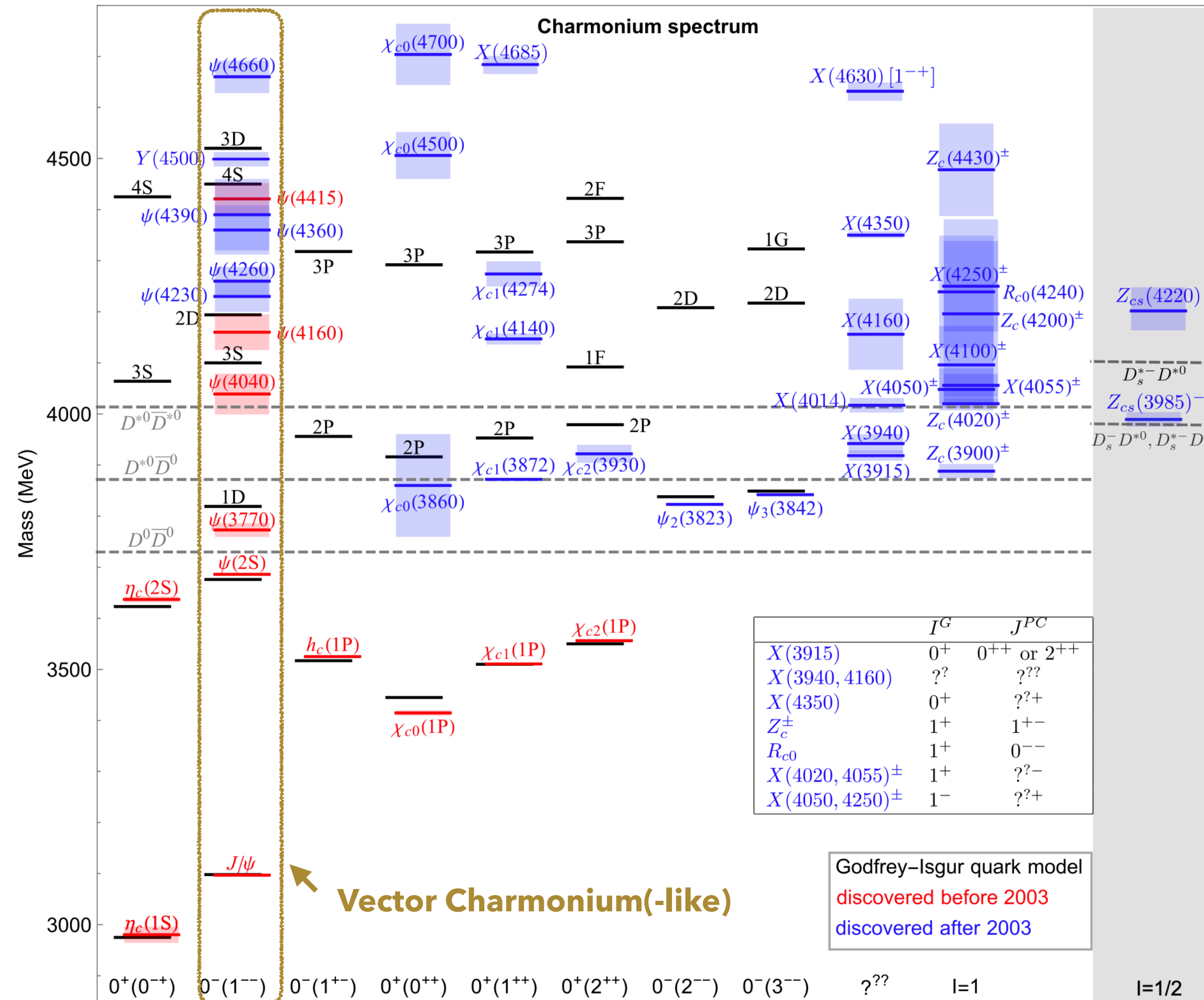
guoyp@fudan.edu.cn

A banner for the ICHEP 2024 conference in Prague, featuring a background image of a particle detector.

ICHEP 2024 | PRAGUE

Jul 17-24, 2024
Prague
Europe/Prague timezone

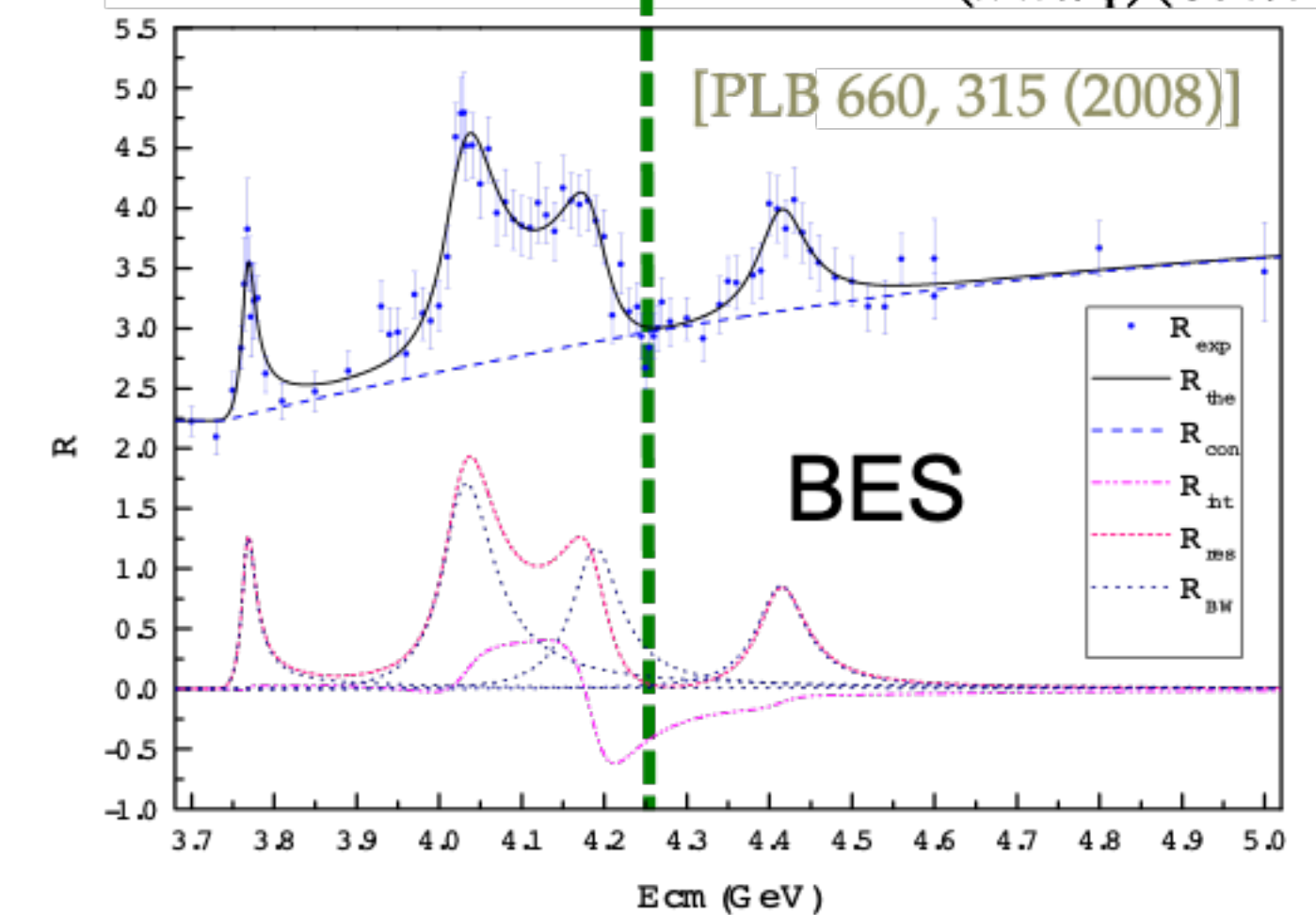
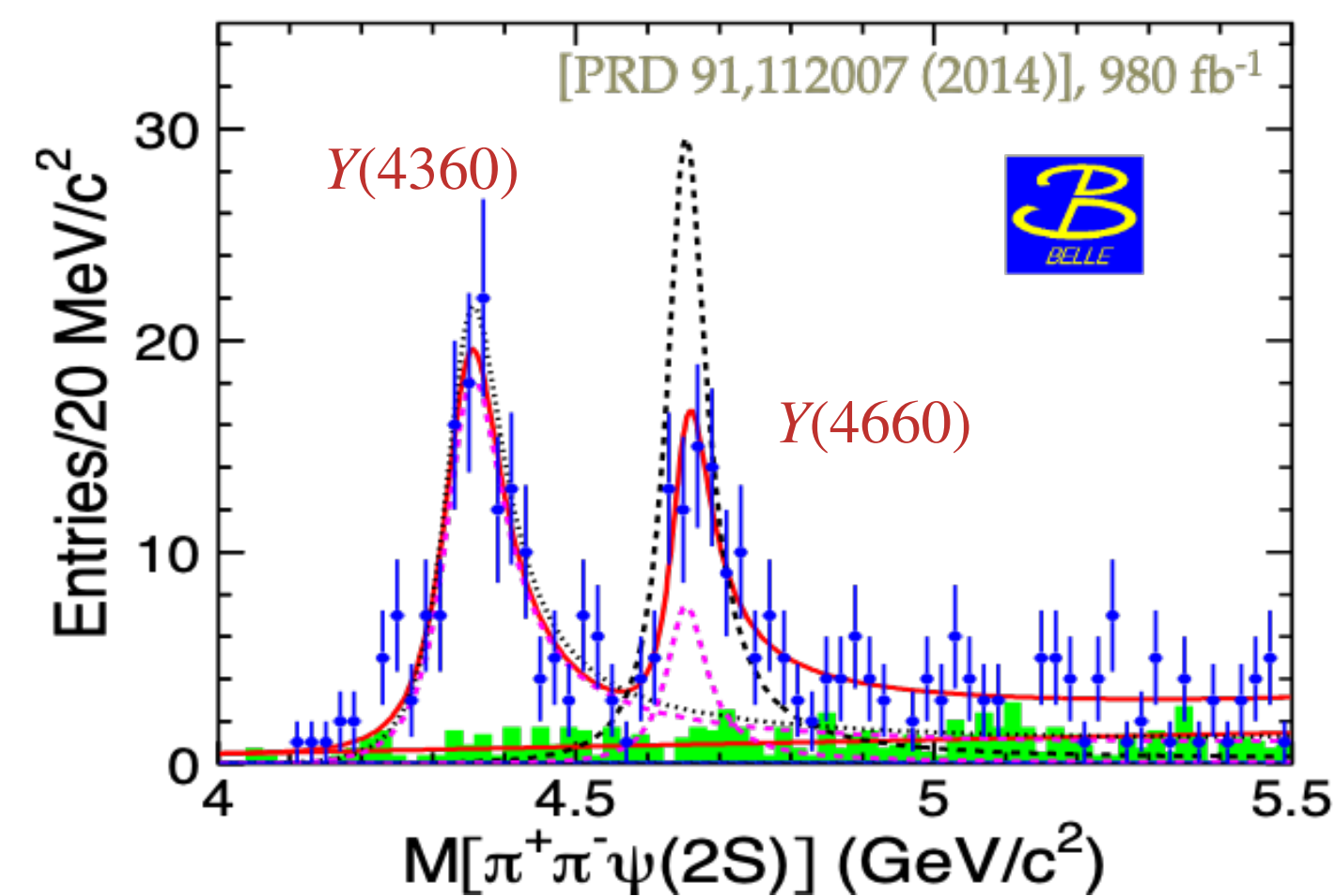
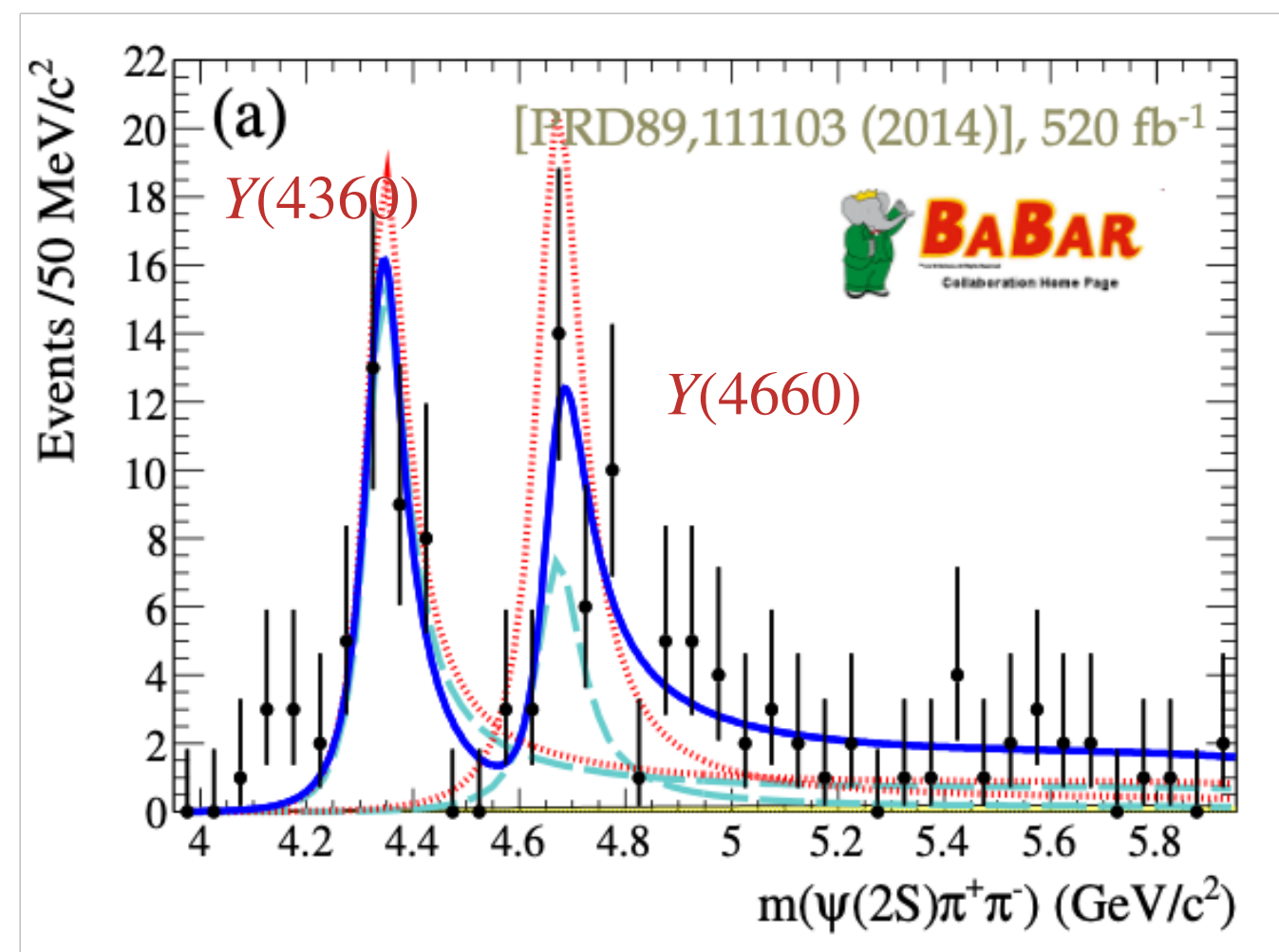
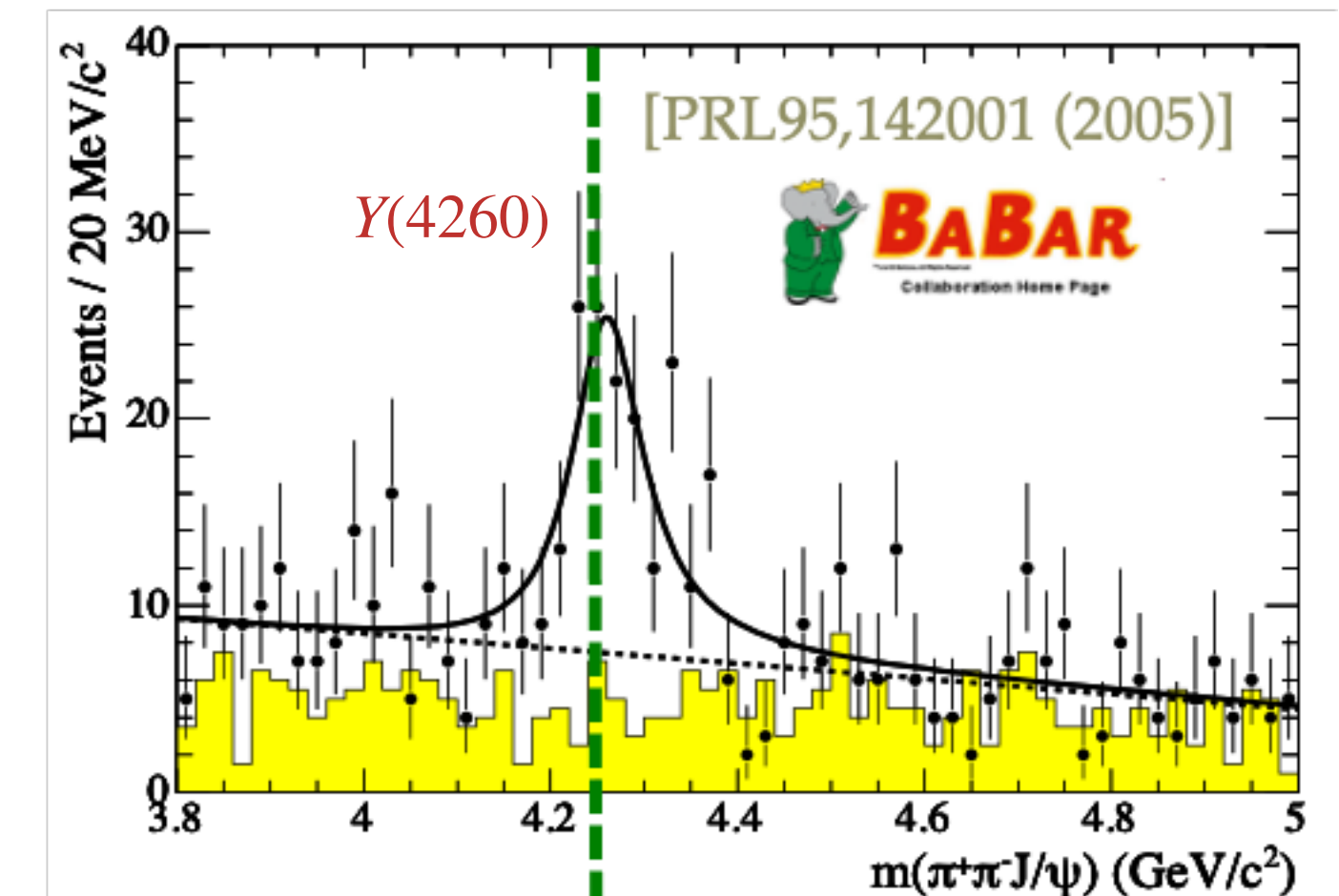
Charmonium Spectroscopy



from F. K. Guo

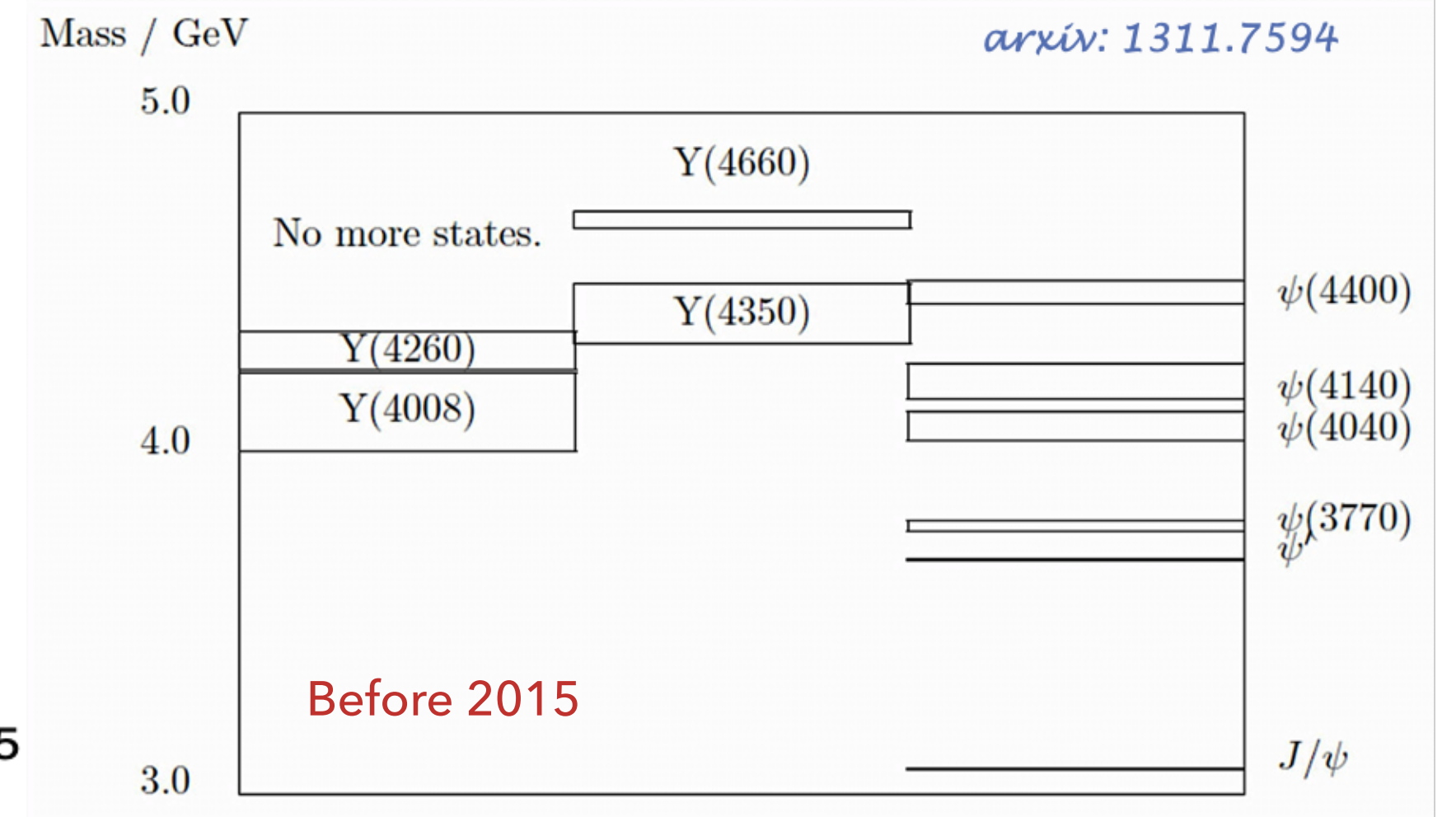
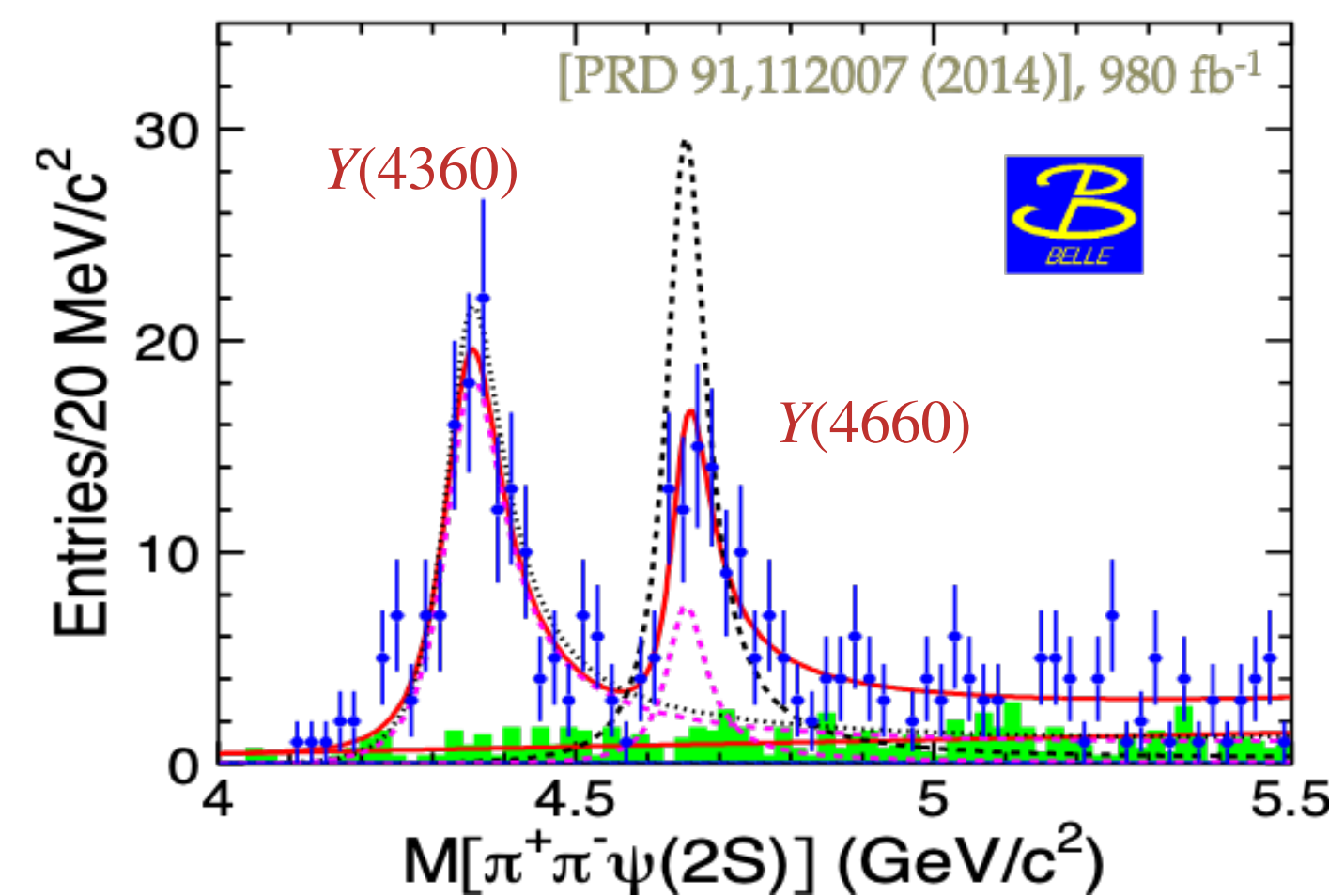
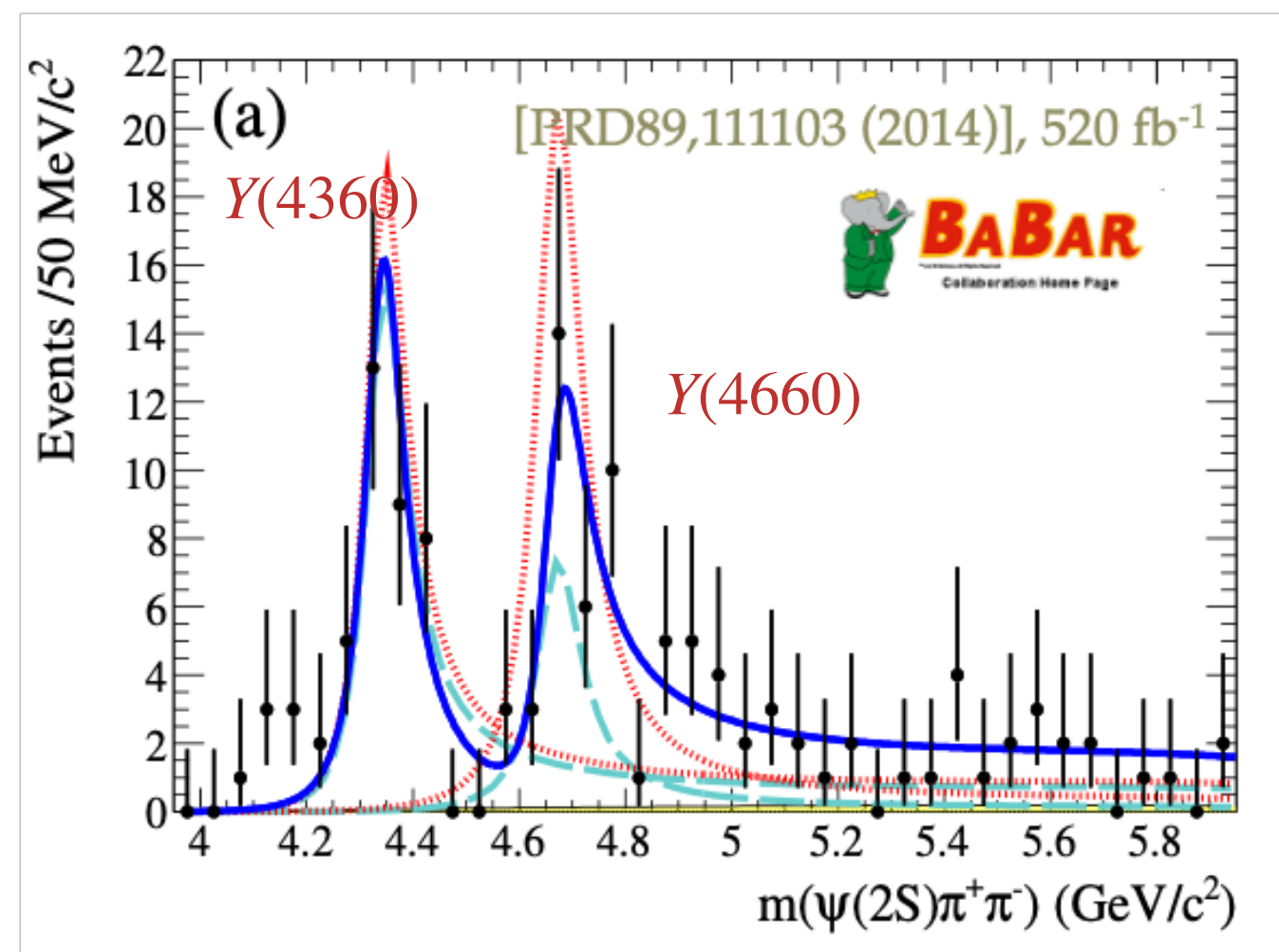
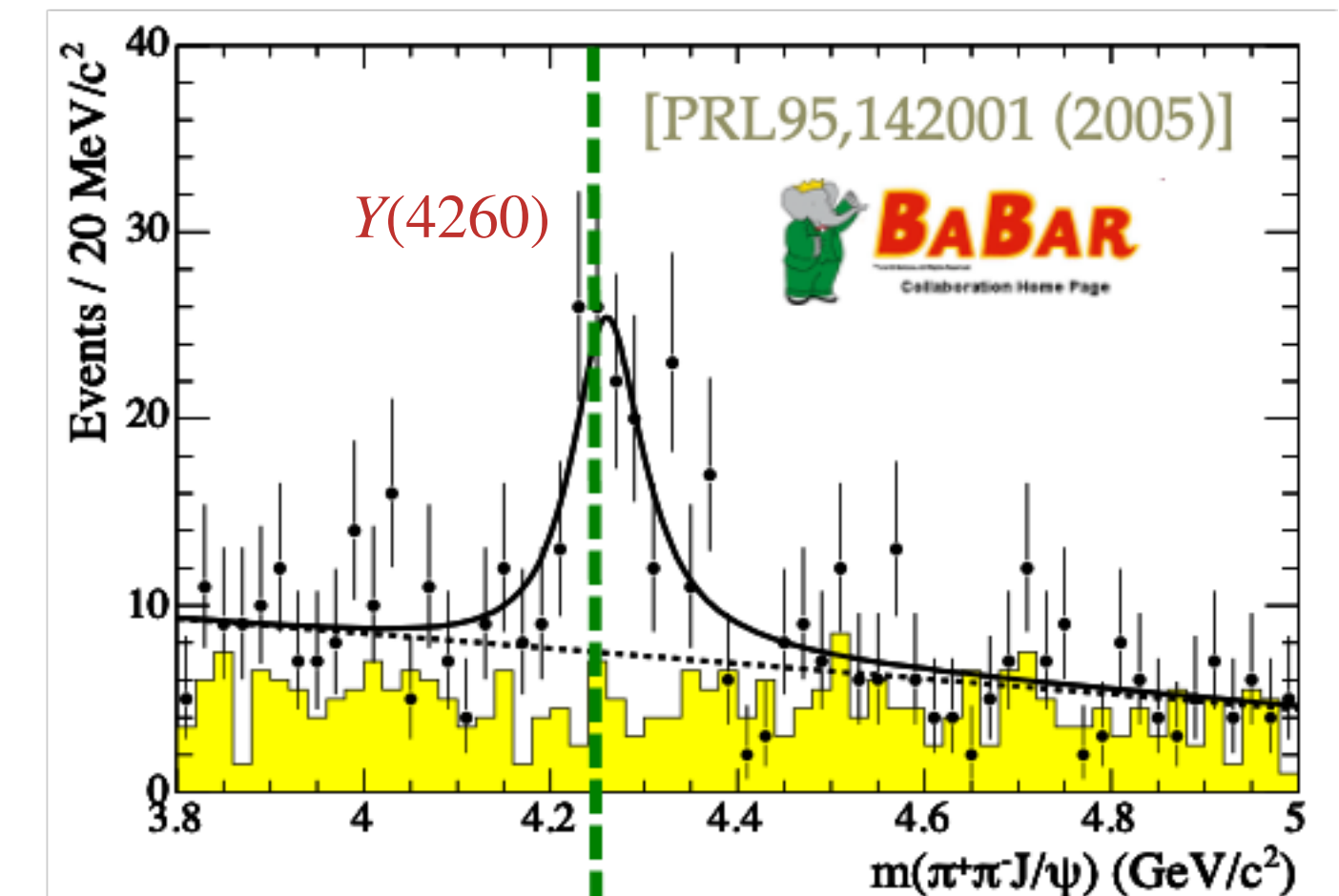
Discovery of Y States

- $Y(4260)$, discovered in ISR process at BaBar, $e^+e^- \rightarrow \gamma_{\text{ISR}}\pi^+\pi^-J/\psi$
 - Confirmed by CLEO and Belle
 - Mass > 4 GeV, above $D\bar{D}$ threshold
 - Not observed in inclusive hadron cross section
 - Not observed in open charm pair cross section
- Later, $Y(4360)$ was discovered at BaBar, $Y(4660)$ was discovered at Belle, both in $e^+e^- \rightarrow \gamma_{\text{ISR}}\pi^+\pi^-\psi(2S)$ process

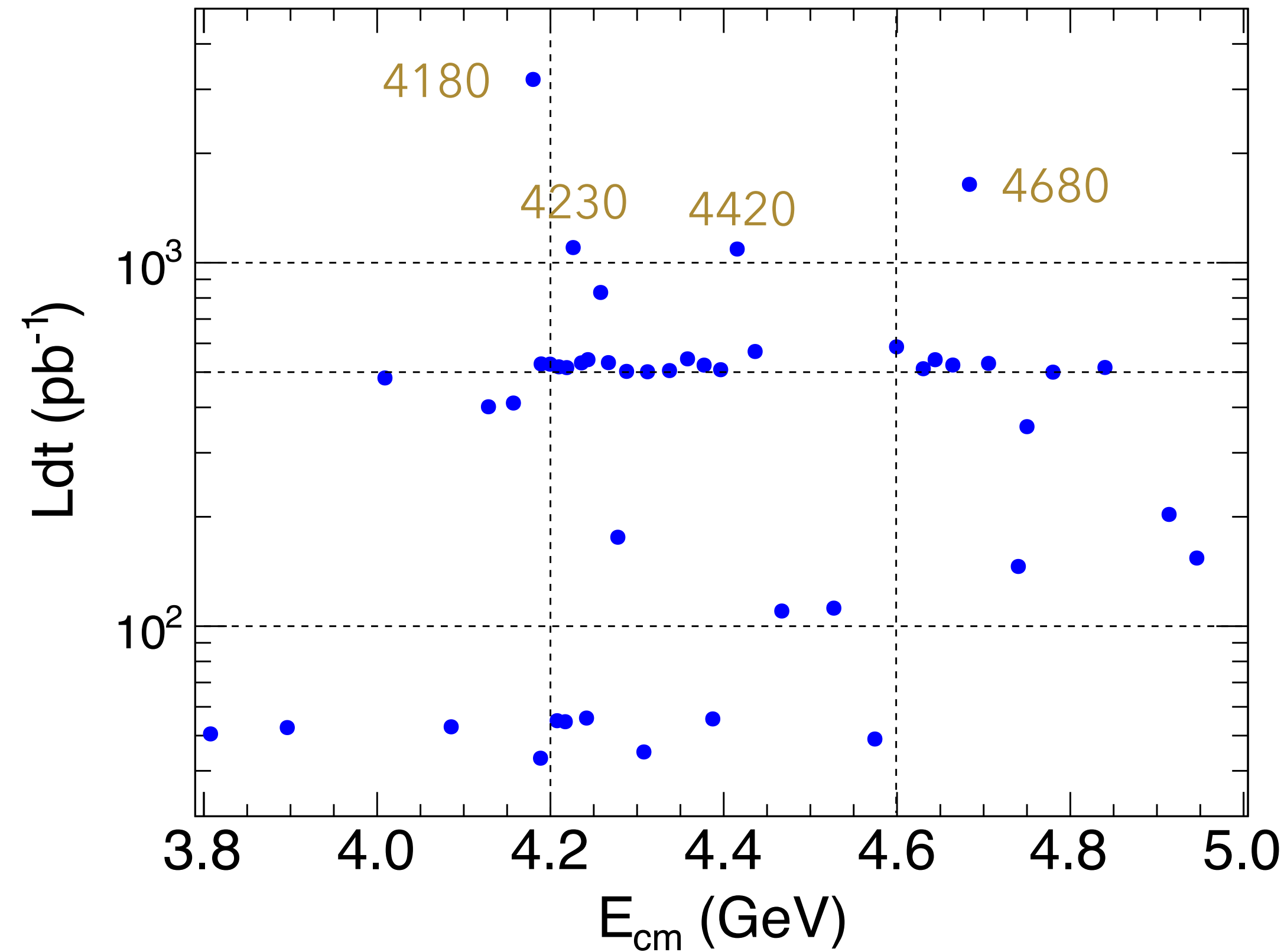


Discovery of Y States

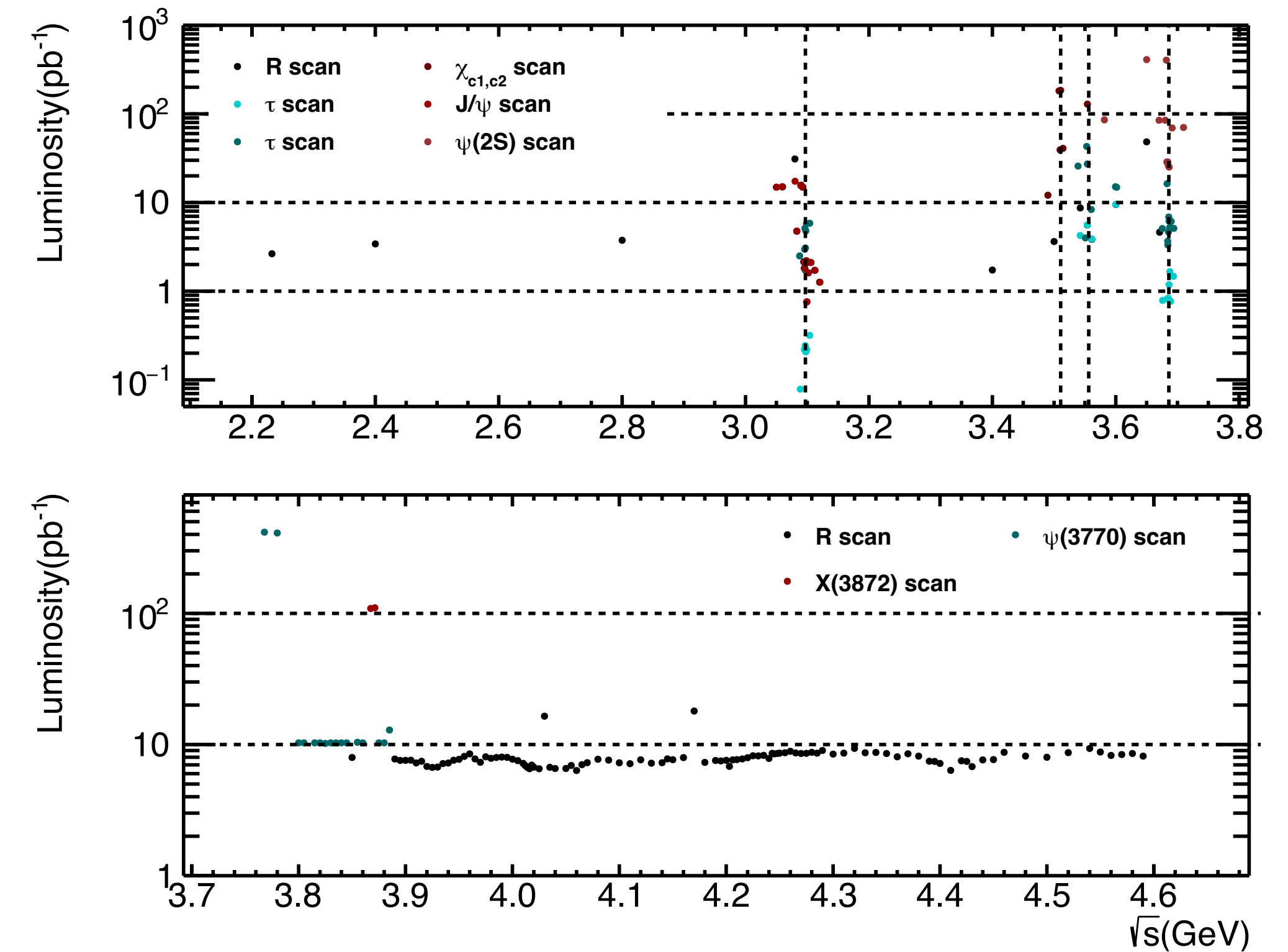
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BESIII Data Samples



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



+ Small scan sample, $\sim 3.5 \text{ fb}^{-1}$

Can measure $\sigma[e^+e^- \rightarrow h_i]$ (CS) with high precision using direct e^+e^- annihilation data at BESIII

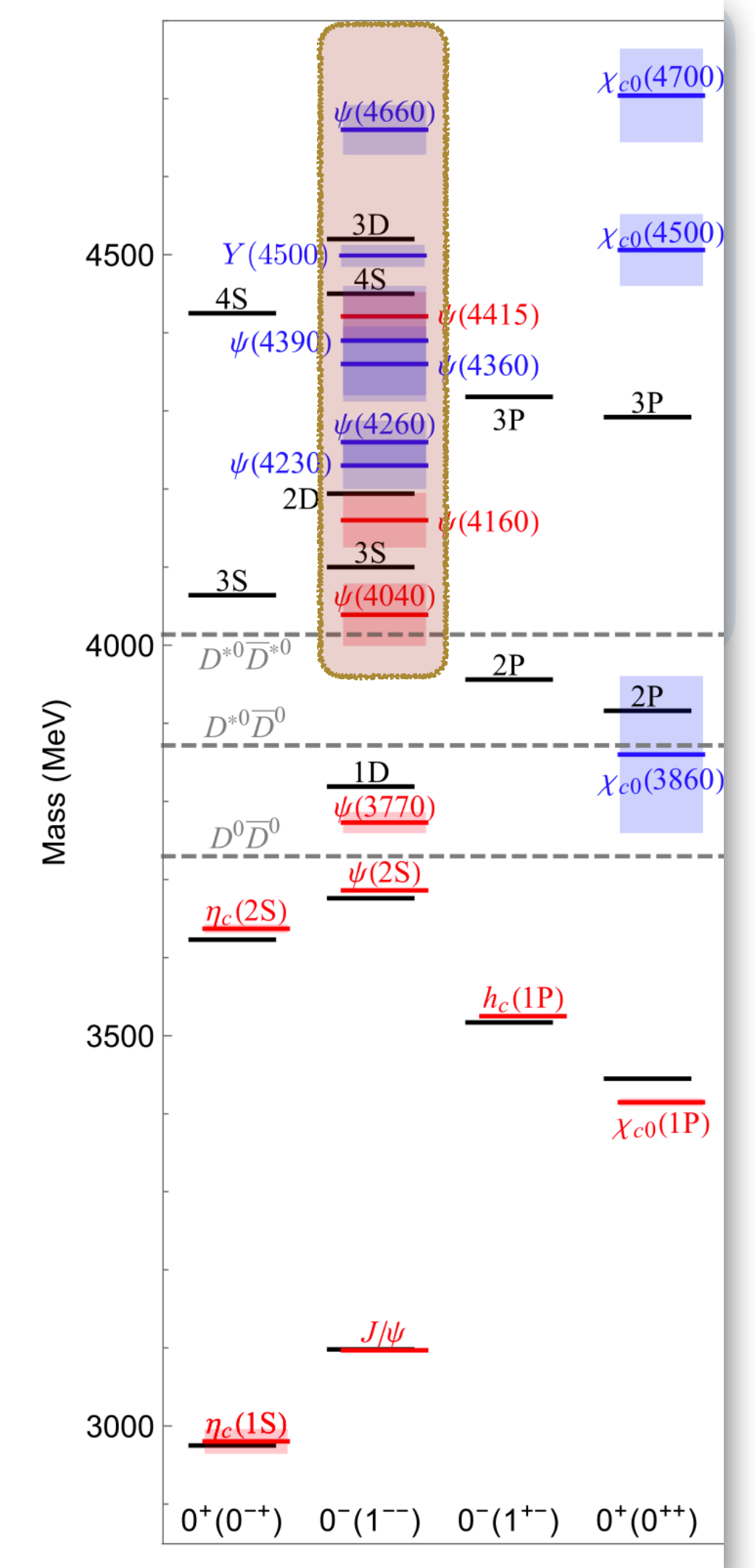
Selected Results

This talk

- Precise measurement of Born cross sections for $e^+e^- \rightarrow D\bar{D}$ *arXiv:2402.03829, submitted to PRL*
- Precise measurement of the $e^+e^- \rightarrow D_s^+D_s^-$ cross sections *arXiv: 2403.14998, submitted to PRL*
- Study of the decay and production properties of $D_{s1}(2536)$ and $D_{s2}^*(2573)$ *arXiv:2407.07651, submitted to PRL*
- Measurement of the Born cross section for $e^+e^- \rightarrow \eta h_c$ *arXiv:2404.06718, submitted to PRL*
- Observation of structures in the processes $e^+e^- \rightarrow \omega\chi_{c1}$ and $\omega\chi_{c2}$ *PRL 132, 161901 (2024)*
- Observation of a vector charmoniumlike state at 4.7 GeV/c² in $e^+e^- \rightarrow K^+K^-J/\psi$ *PRL131, 211902 (2023)*
- Precise measurement of the $e^+e^- \rightarrow D_s^{*+}D_s^{*-}$ cross sections *PRL131, 151903 (2023)*
- Observation of three charmoniumlike states with $J^{PC} = 1^{--}$ in $e^+e^- \rightarrow D^{*0}D^{*-}\pi^+$ *PRL130, 121901 (2023)*
- Observation of the $Y(4230)$ and evidence for $Y(4710)$ in $e^+e^- \rightarrow K_S^0K_S^0J/\psi$ *PRD 107, 092005 (2023)*
- Observation of $\psi(3770) \rightarrow \eta J/\psi$ *PRD107, L091101 (2023)*
- Observation of a new $X(3872)$ production process $e^+e^- \rightarrow \omega X(3872)$ *PRL 130, 151904 (2023)*
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Selected Results

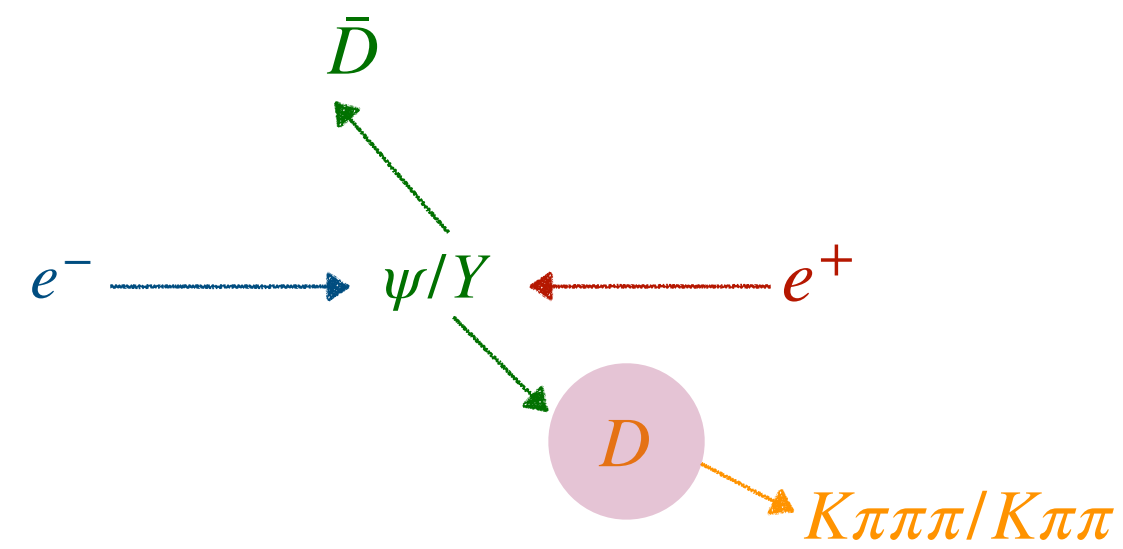
- Precise measurement of Born cross sections for $e^+e^- \rightarrow D\bar{D}$ [arXiv:2402.03829, submitted to PRL](#)
- Precise measurement of the $e^+e^- \rightarrow D_s^+D_s^-$ cross sections [arXiv: 2403.14998, submitted to PRL](#)
- Study of the decay and production properties of $D_{s1}(2536)$ and $D_{s2}^*(2573)$ [arXiv:2407.076](#)
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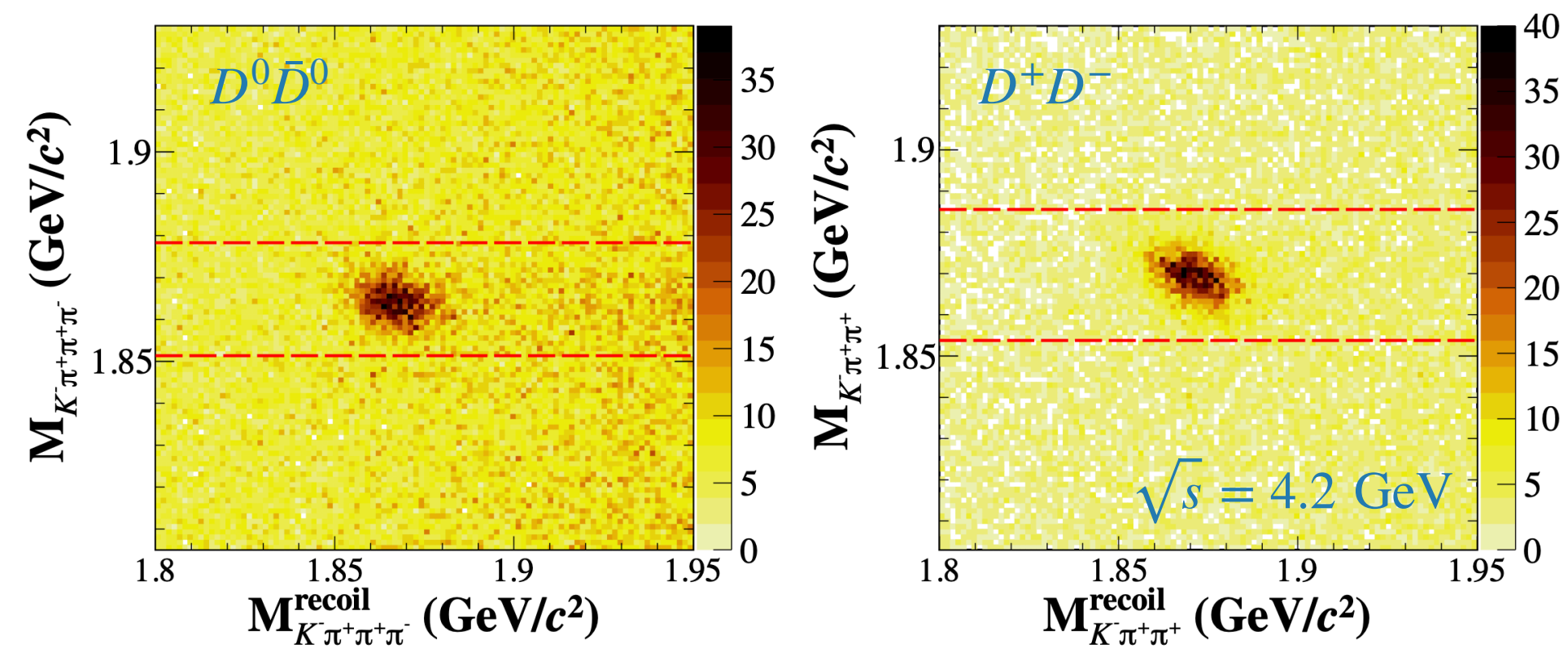
Precise Measurement of $\sigma[e^+e^- \rightarrow D\bar{D}]$

- 150 data samples corresponding to a total integrated lum. of 20 fb^{-1} from $\sqrt{s}=3.8$ to 4.95 GeV

Partial reconstruction



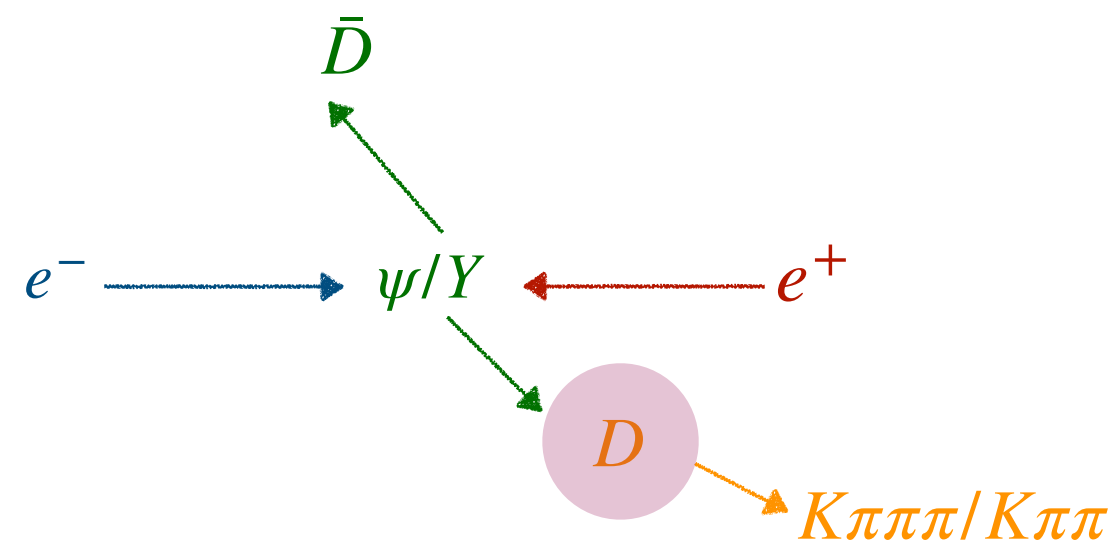
[arXiv:2402.03829](https://arxiv.org/abs/2402.03829)



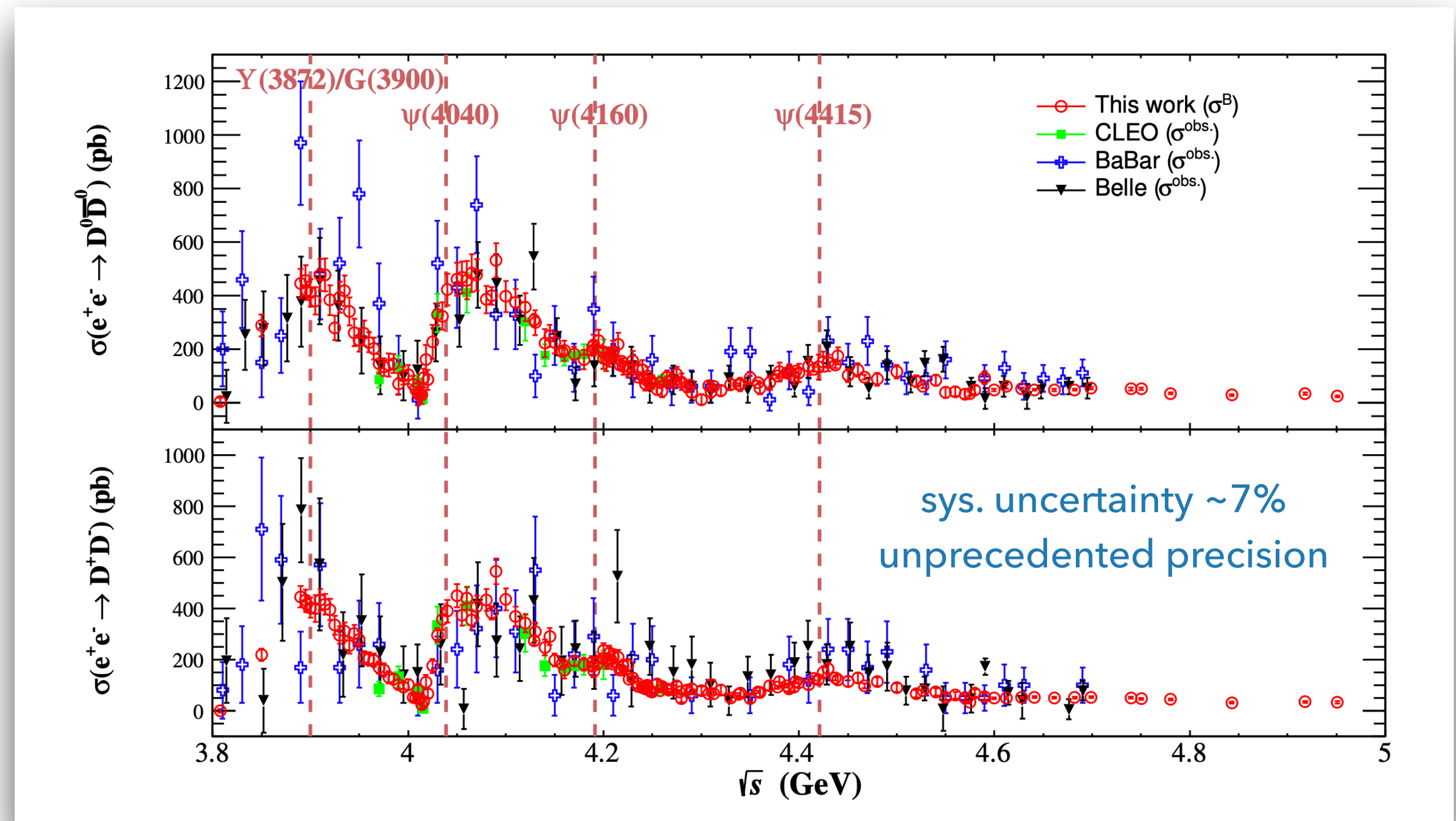
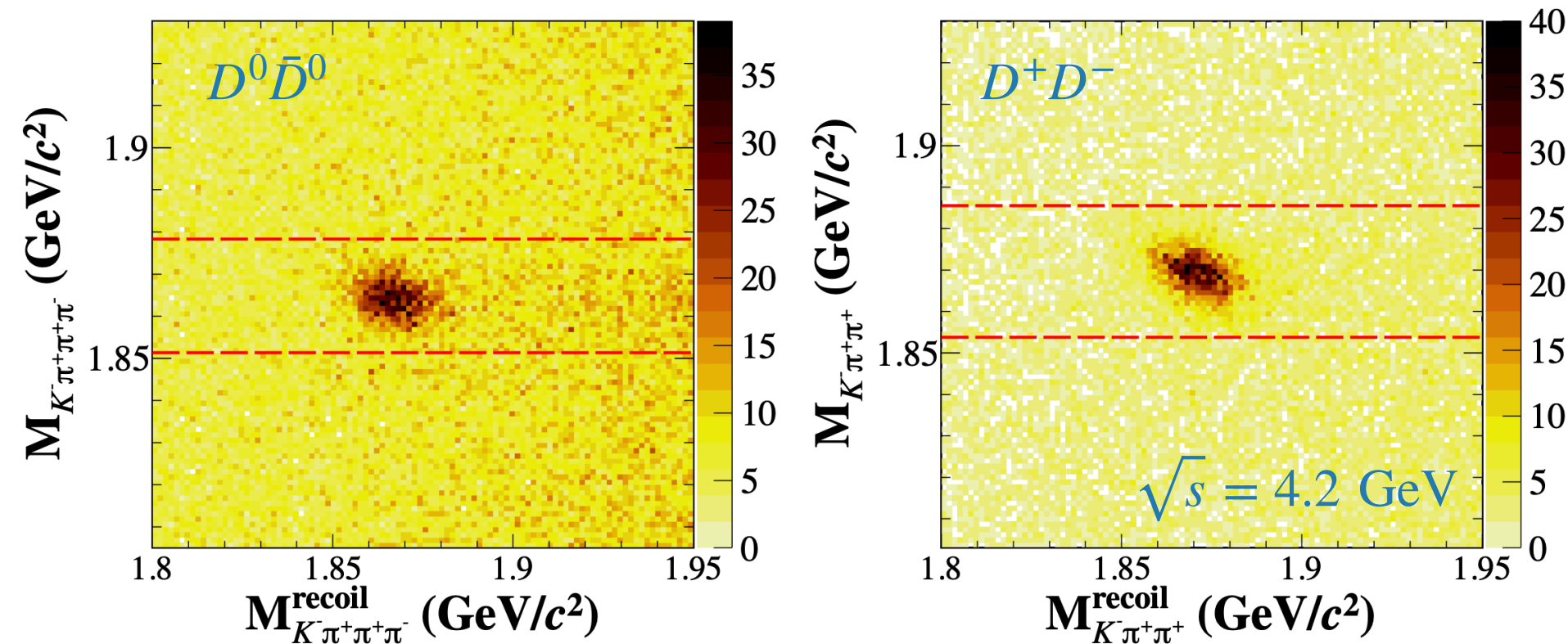
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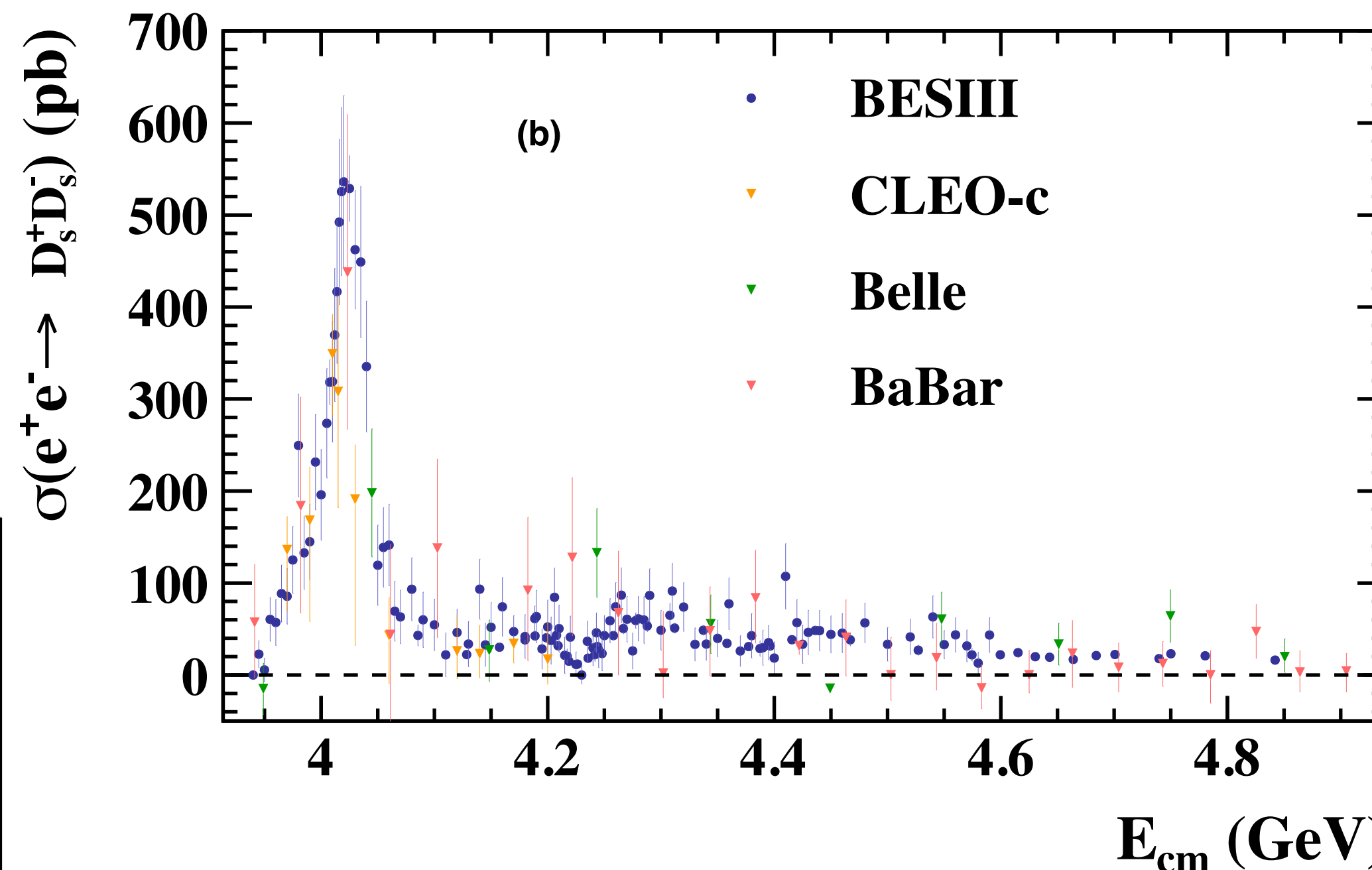
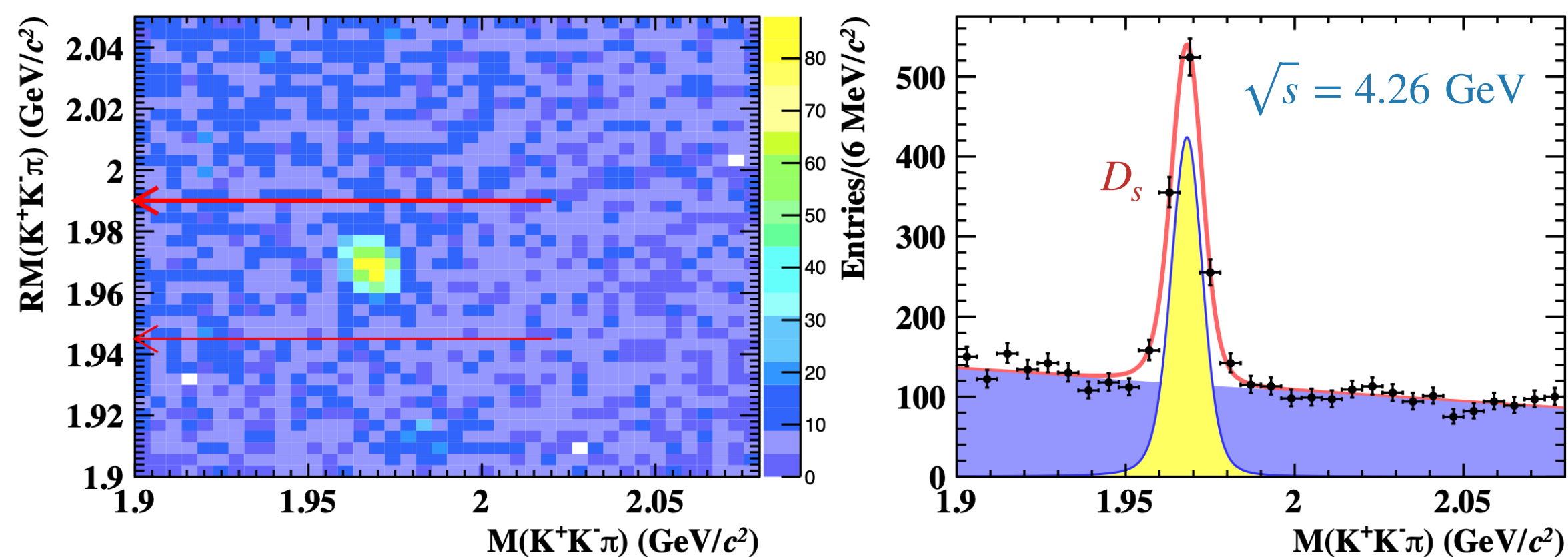
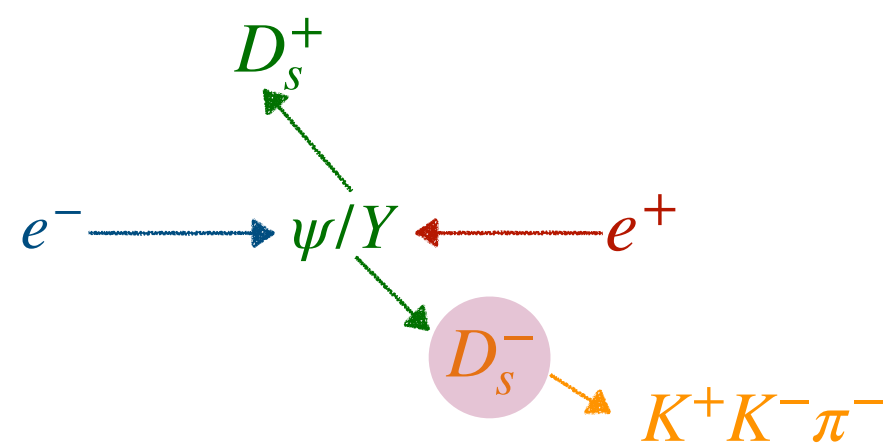
[arXiv:2402.03829](https://arxiv.org/abs/2402.03829)



Precise Measurement of $\sigma[e^+e^- \rightarrow D_s^+D_s^-]$

- 138 data samples corresponding to a total integrated lum. of 22.9 fb⁻¹ from $\sqrt{s}=3.94$ to 4.95 GeV

Partial reconstruction

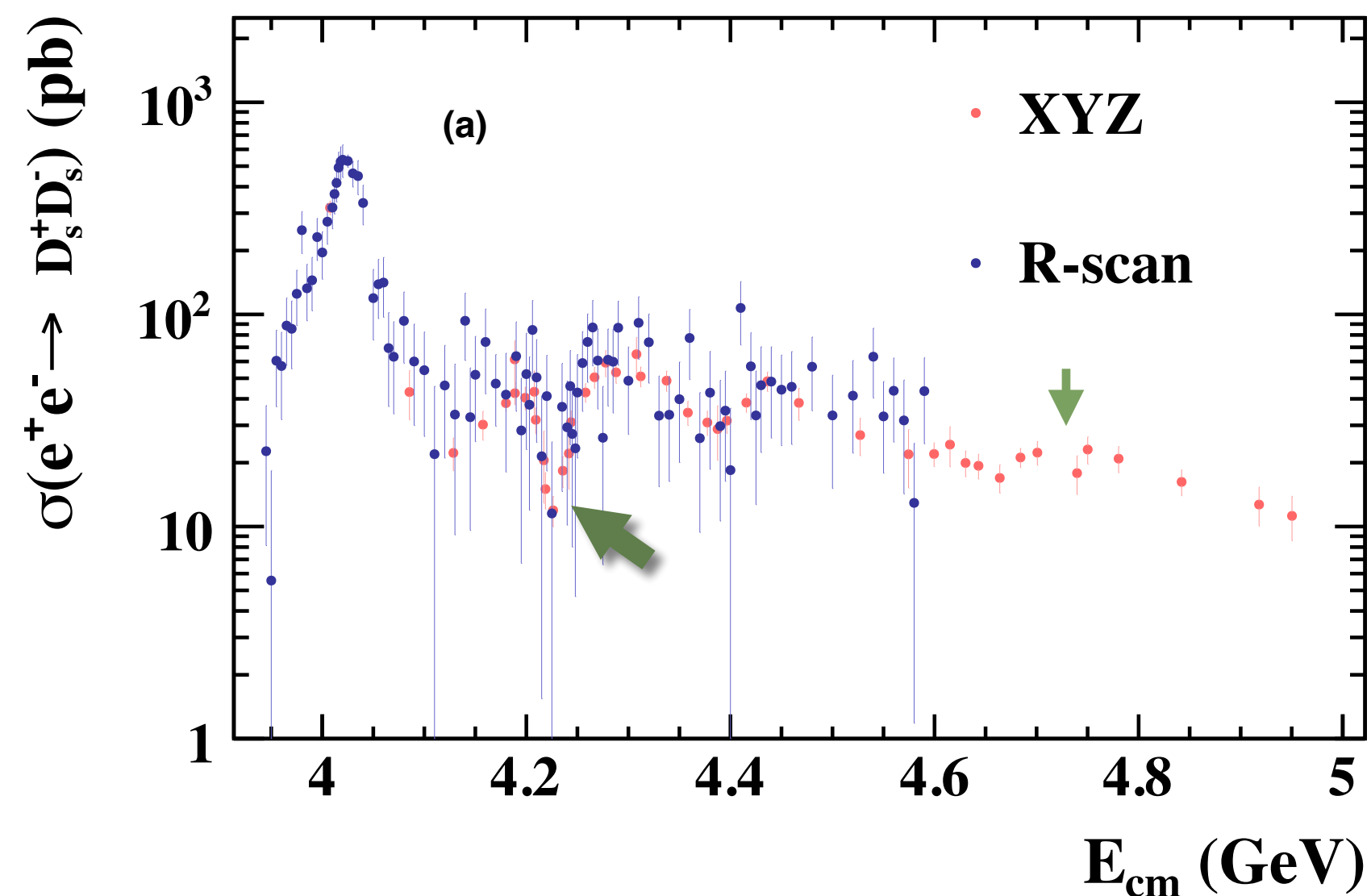


sys. uncertainty ~5%
unprecedented precision

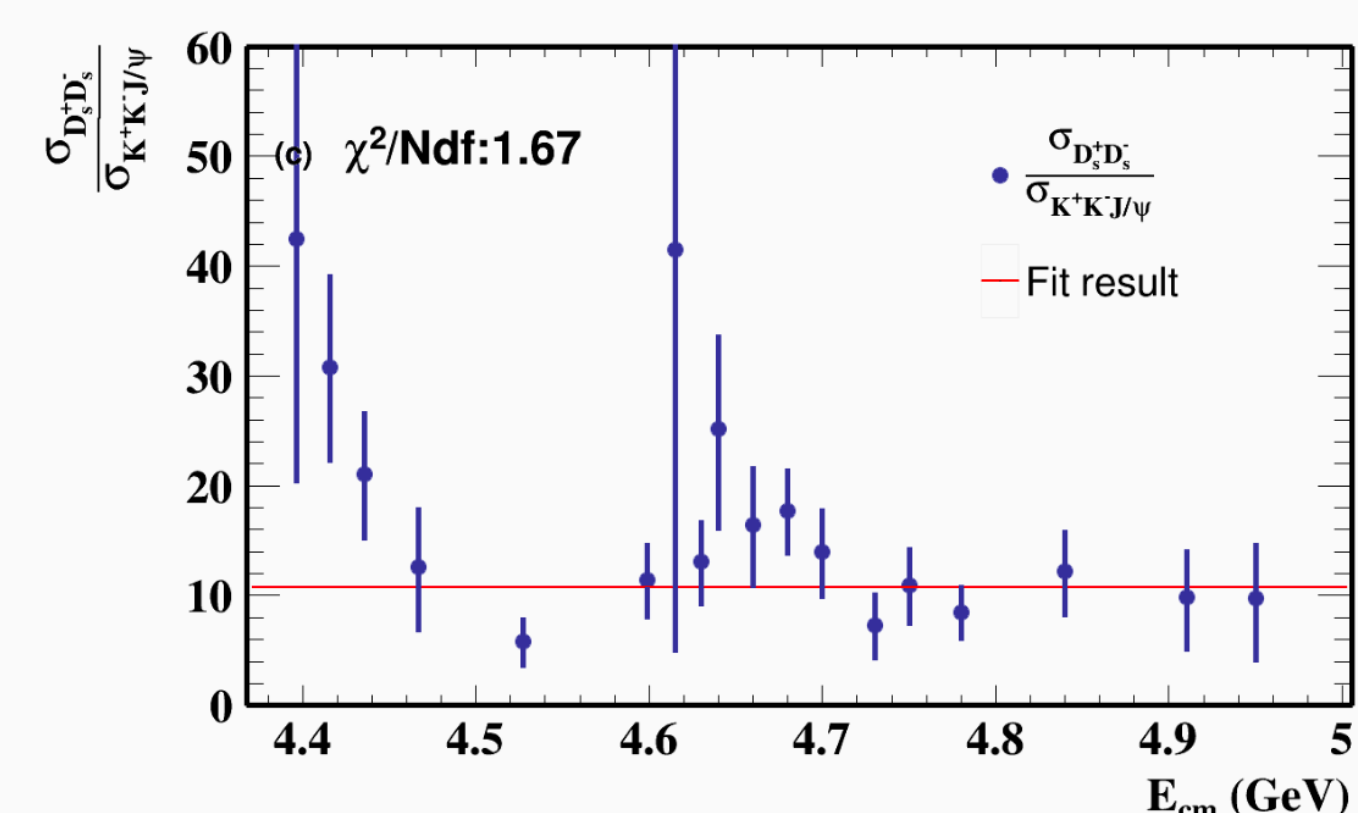
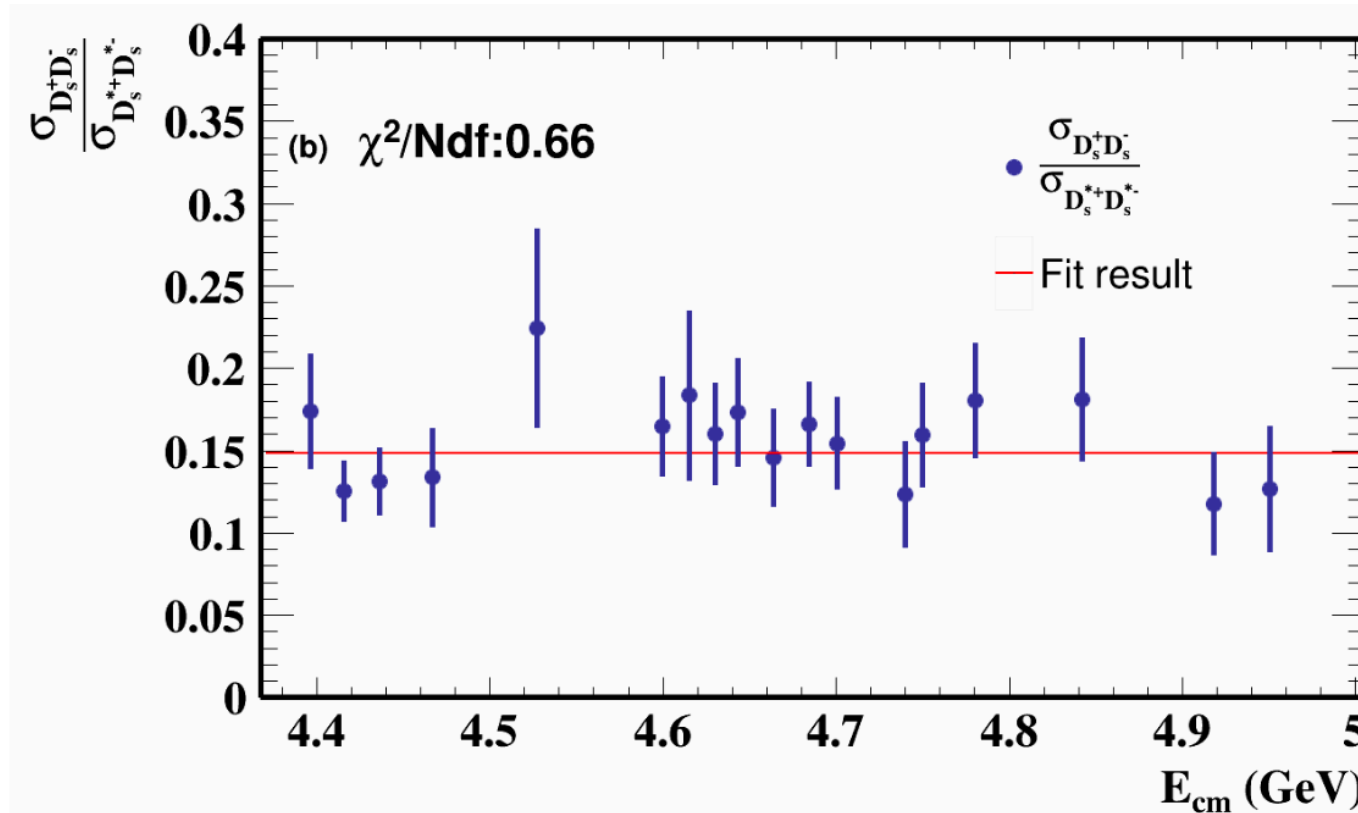
[arXiv:2403.14998](https://arxiv.org/abs/2403.14998)

Precise Measurement of $\sigma[e^+e^- \rightarrow D_s^+D_s^-]$

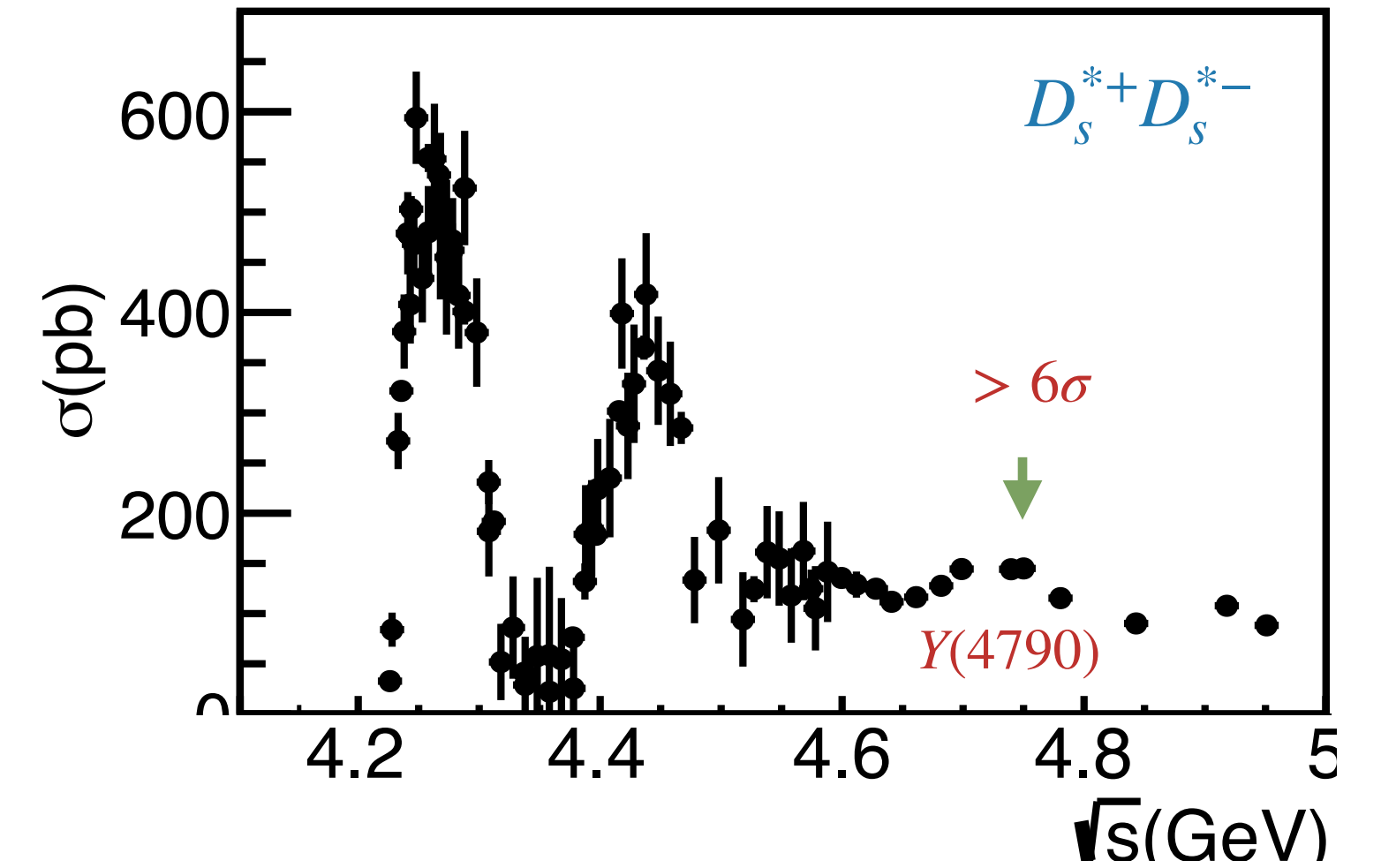
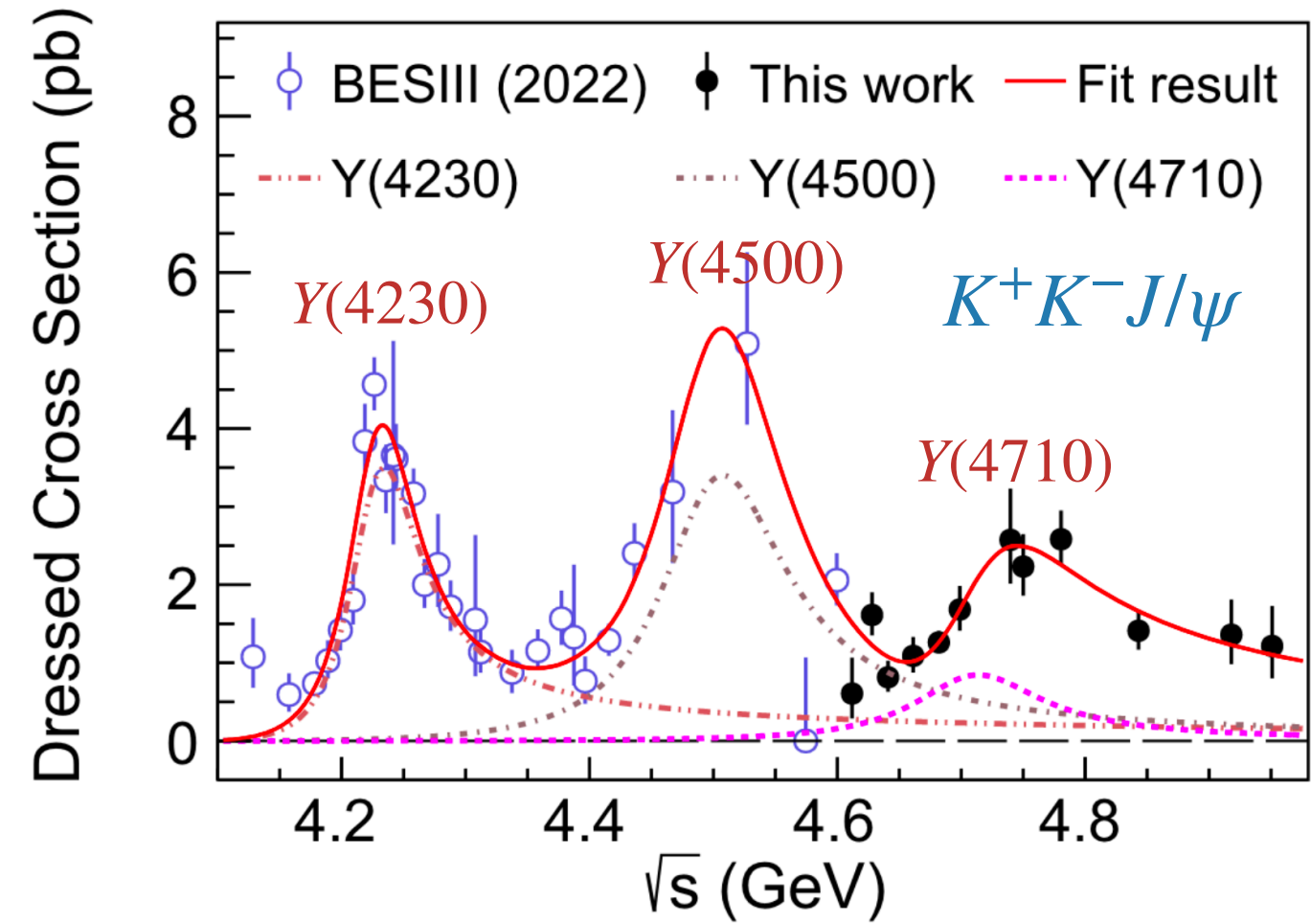
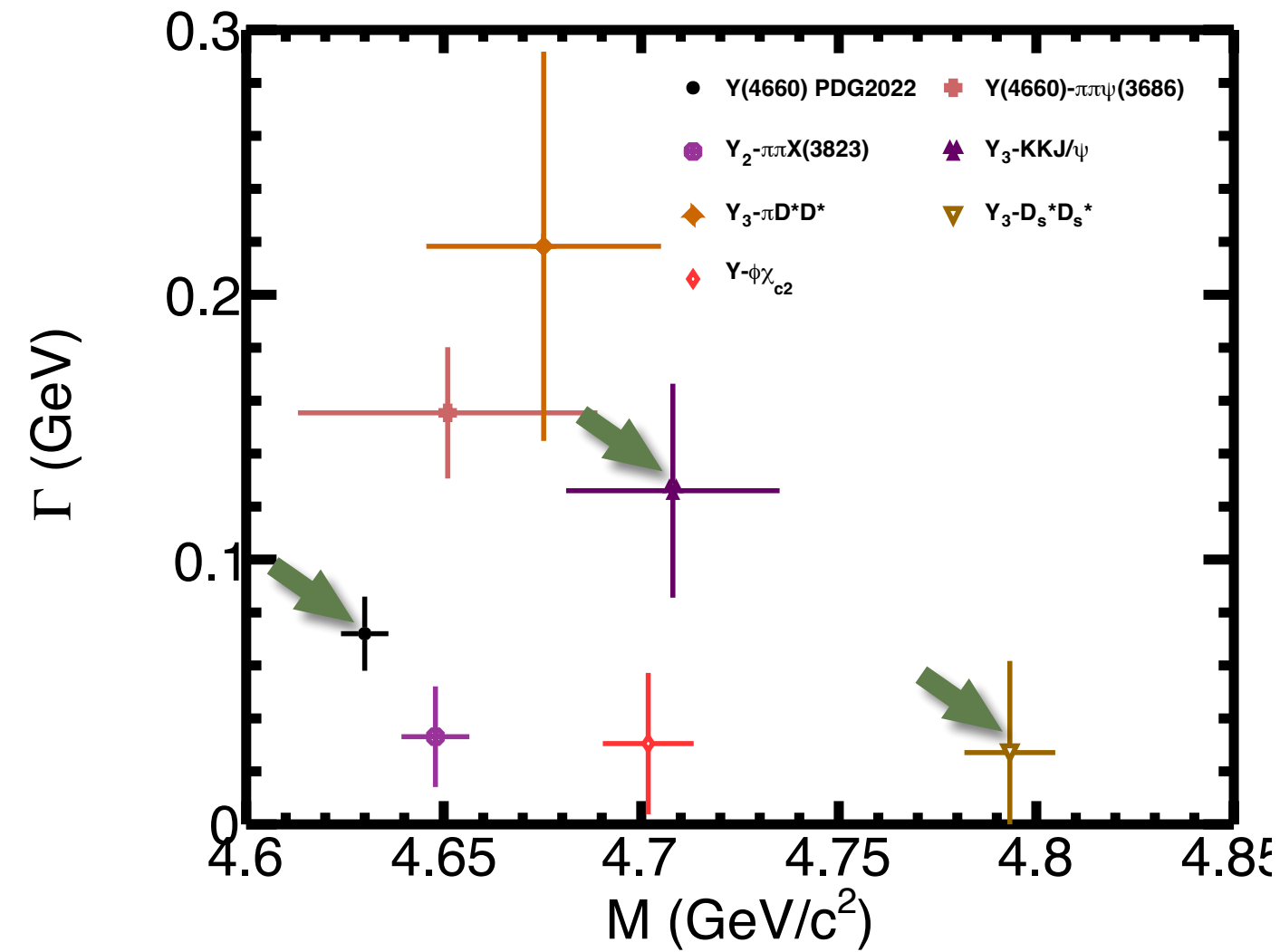
- Cross section peaks above the threshold, implies the presence of a strong coupled channel effect (*E. Eichten, K. Gottfried, T. Kinoshita, K. D. Lane, T. M. Yan, PRD21, 203 (1980)*)
- Maximum cross section around 4.02 GeV higher than previous studies using ISR method
- A narrow dip around 4.23 GeV, close to $D_s^{*+}D_s^{*-}$ threshold
- Constant ratio to $D_s^{*+}D_s^{*-}$, where a structure around 4.78 GeV is observed



[arXiv:2403.14998](https://arxiv.org/abs/2403.14998)



Production Properties of $D_{s1}(2536)$ and $D_{s2}^*(2573)$



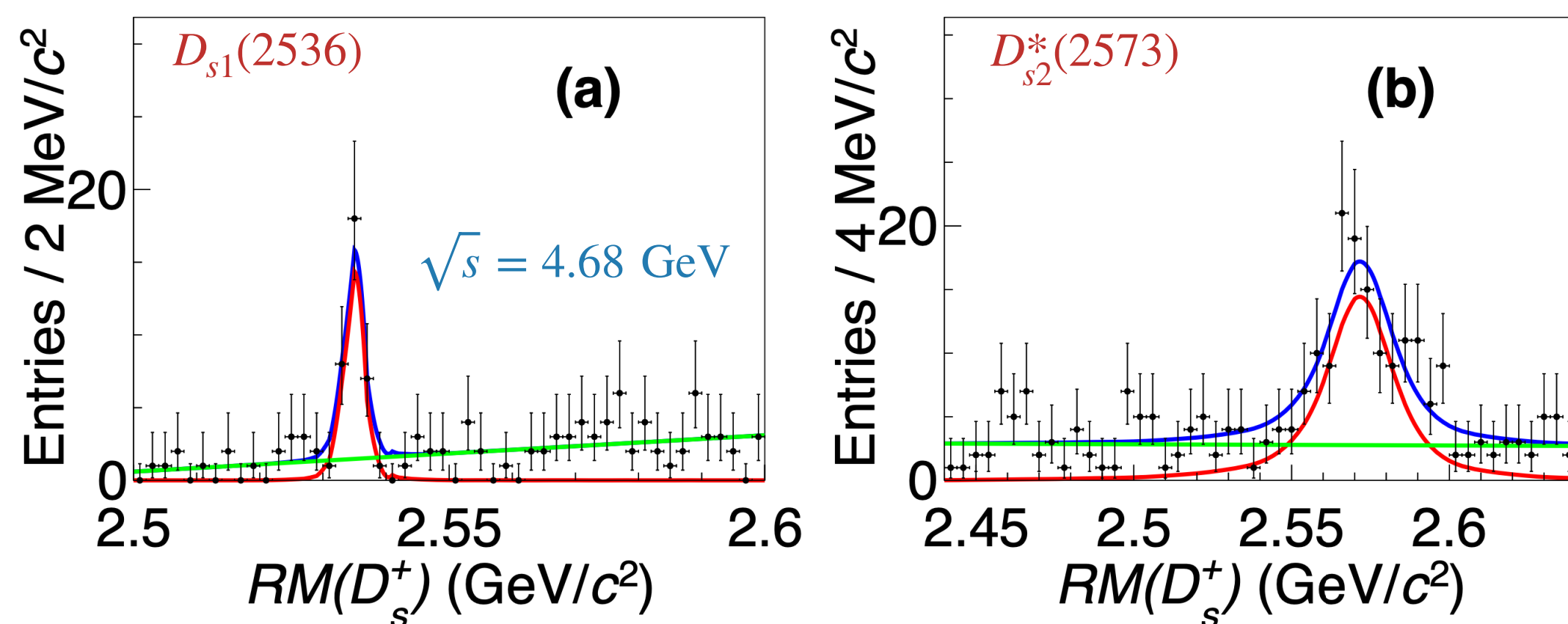
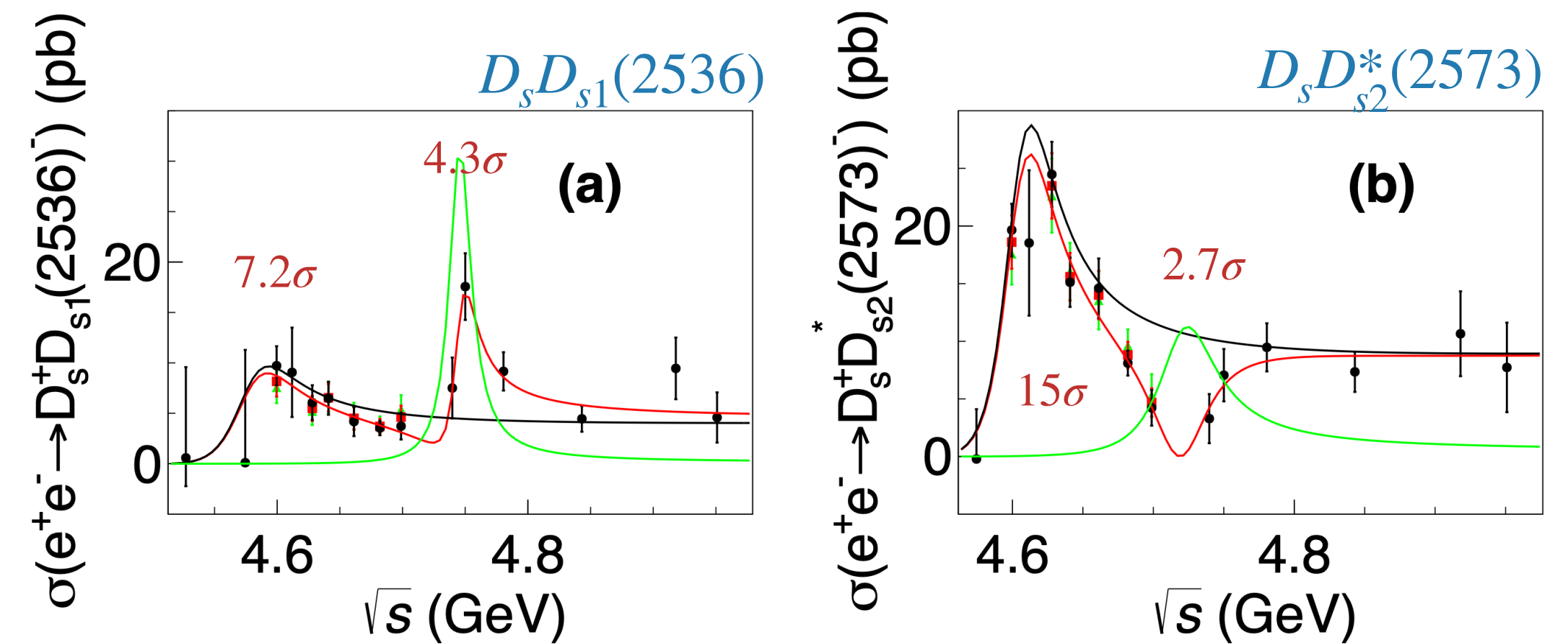
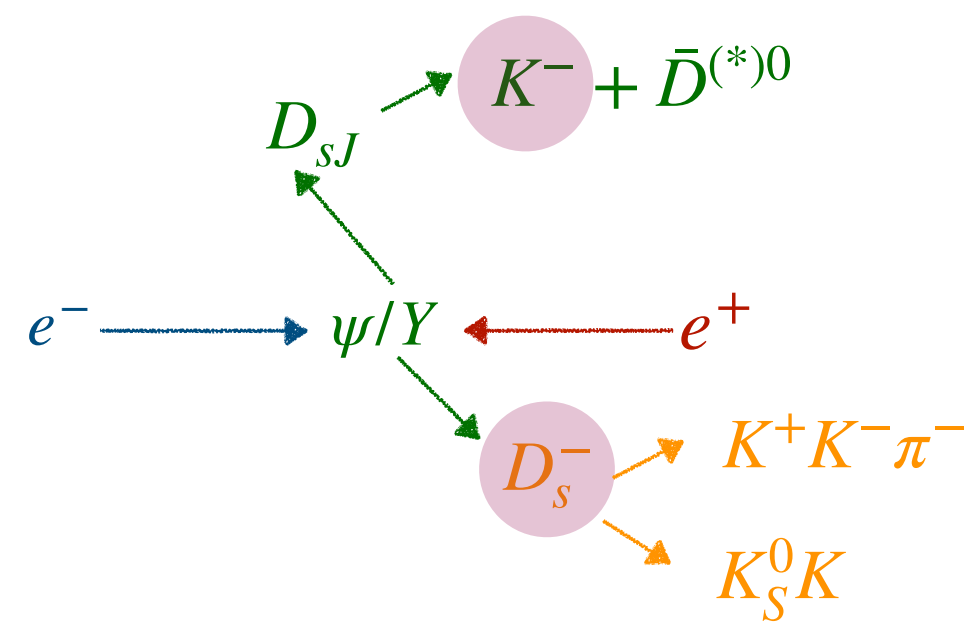
- $Y(4660)$ observed in $e^+e^- \rightarrow \gamma_{\text{ISR}}\pi^+\pi^-\psi(2S)$ by Belle Collaboration, confirmed by BaBar and BESIII experiments, $M(\pi^+\pi^-)$ tends to accumulate at the nominal mass of $f_0(980)$
- $Y(4710)$ observed in $e^+e^- \rightarrow K^+K^-J/\psi$ by BESIII experiment [PRL131, 211902 \(2023\)](#)
- $Y(4790)$ observed in $e^+e^- \rightarrow D_s^{*+}D_s^{*-}$ by BESIII experiment [PRL131, 151903 \(2023\)](#)
- $Y(4626)$ observed in $e^+e^- \rightarrow \gamma_{\text{ISR}}D_s^+D_{s1}(2536)^-$, and evidence of $Y(4620)$ in $e^+e^- \rightarrow \gamma_{\text{ISR}}D_s^+D_{s2}^*(2573)^-$ by Belle experiment [PRD100, 111103\(R\) \(2019\)](#), [PRD101, 091101\(R\) \(2020\)](#)

Production Properties of $D_{s1}(2536)$ and $D_{s2}^*(2573)$

- 15 data samples corresponding to a total integrated lum. of 6.6 fb^{-1} from $\sqrt{s}=4.53$ to 4.95 GeV

arXiv:2407.07651

Partial reconstruction

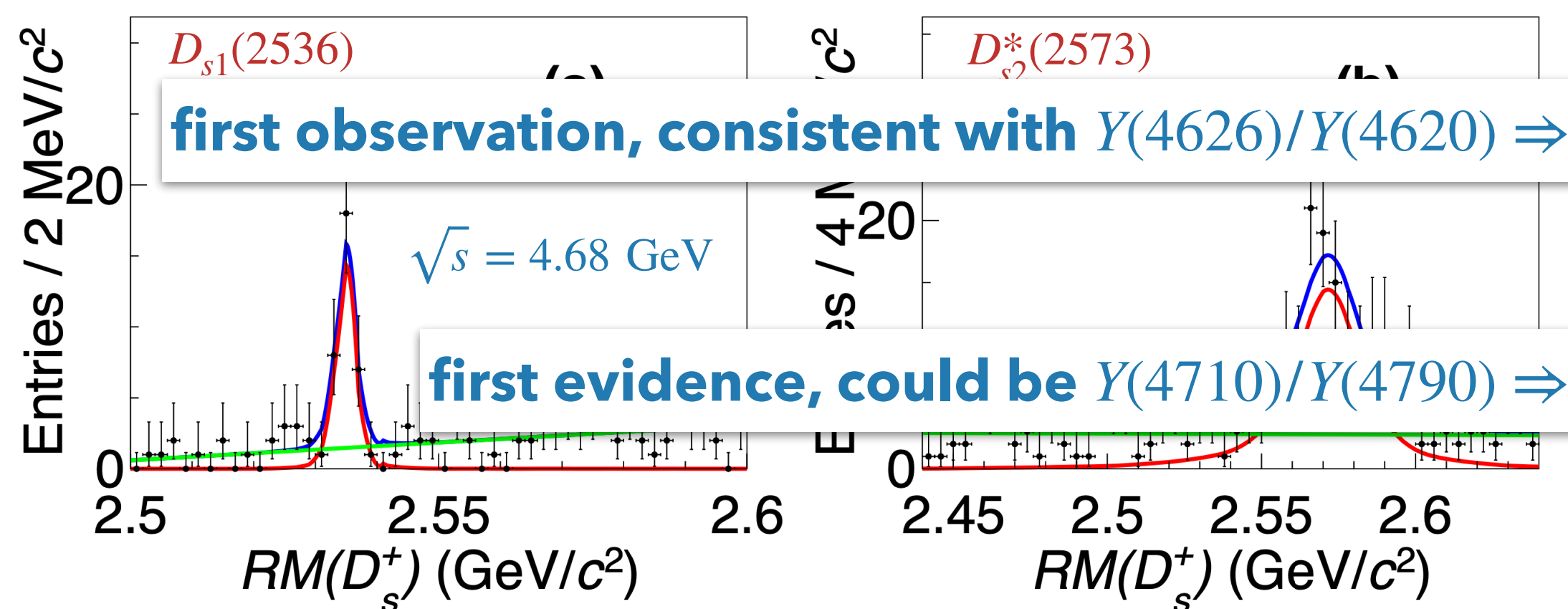
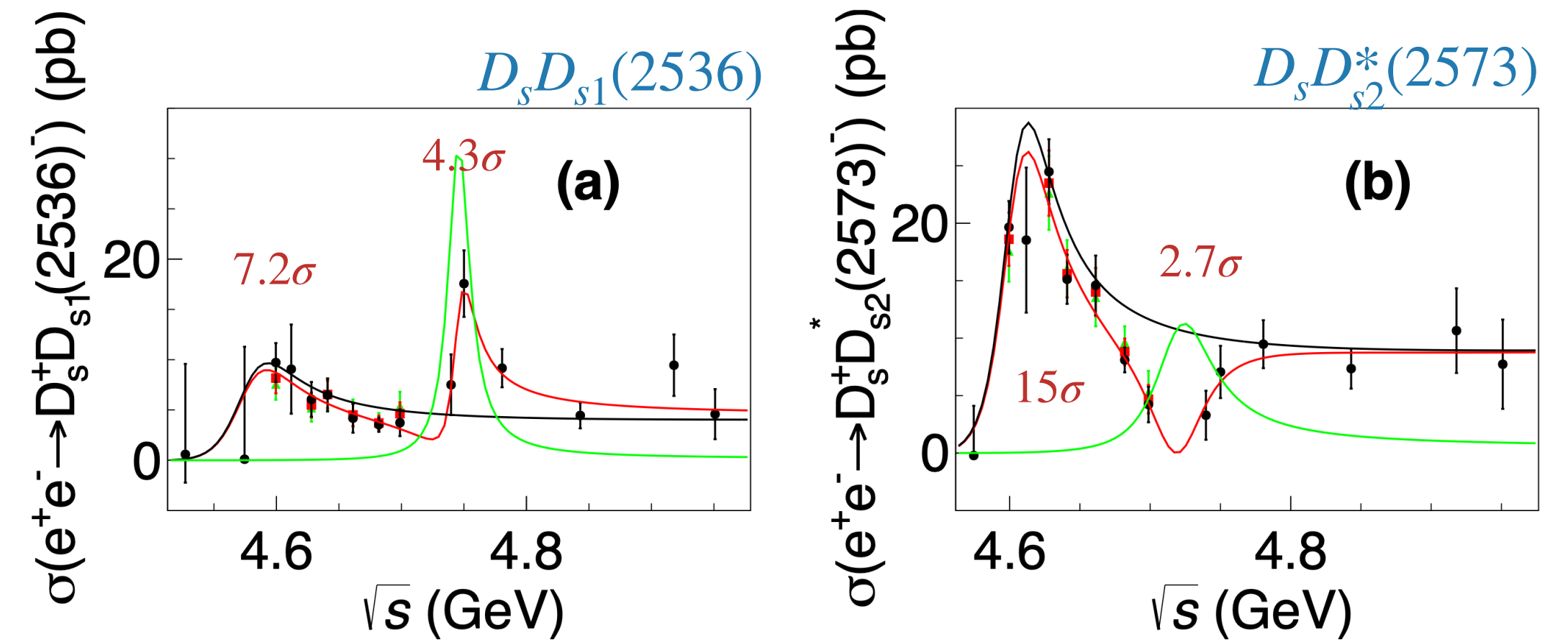
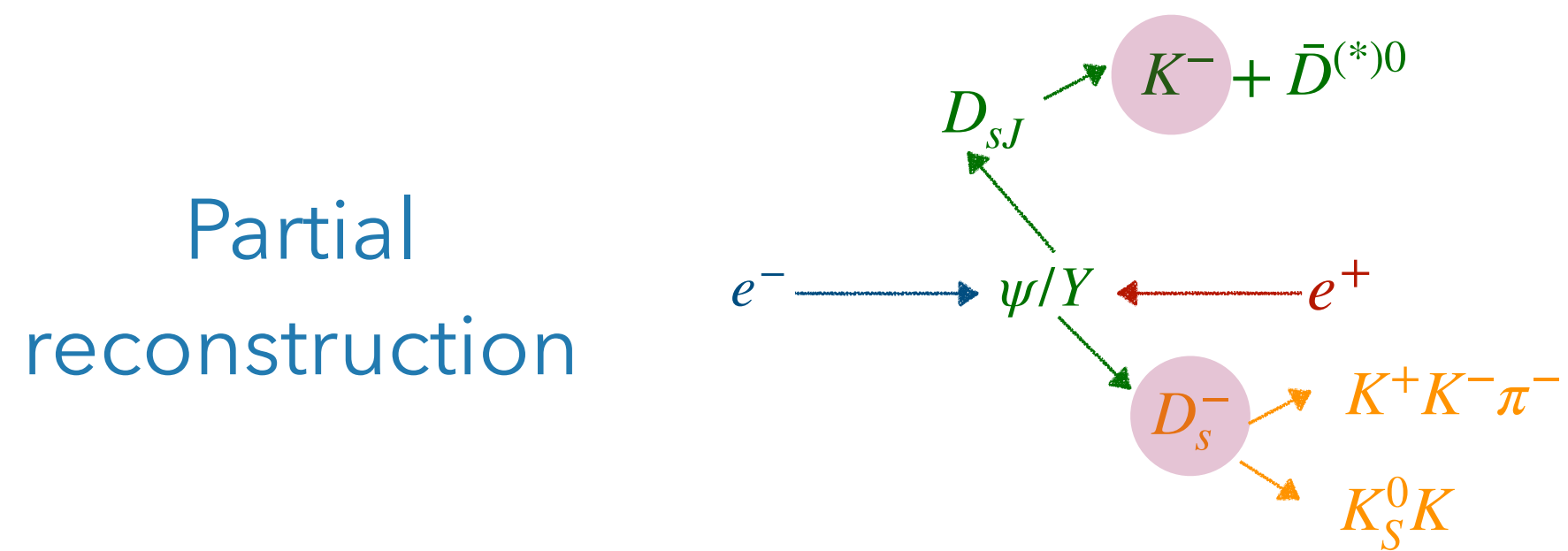


- Fit with $\sigma = |BW_0(\sqrt{s}) + BW_1(\sqrt{s})e^{i\phi_1}|^2$
- In both processes, the first resonance is around 4.6 GeV , with a width of 50 MeV
- Second structure is around 4.75 GeV with a width of 25 MeV in $D_s^+ D_{s1}(2536)^-$, around 4.72 GeV with a width of 50 MeV in $D_s^+ D_{s2}^*(2573)^-$

Production Properties of $D_{s1}(2536)$ and $D_{s2}^*(2573)$

- 15 data samples corresponding to a total integrated lum. of 6.6 fb^{-1} from $\sqrt{s}=4.53$ to 4.95 GeV

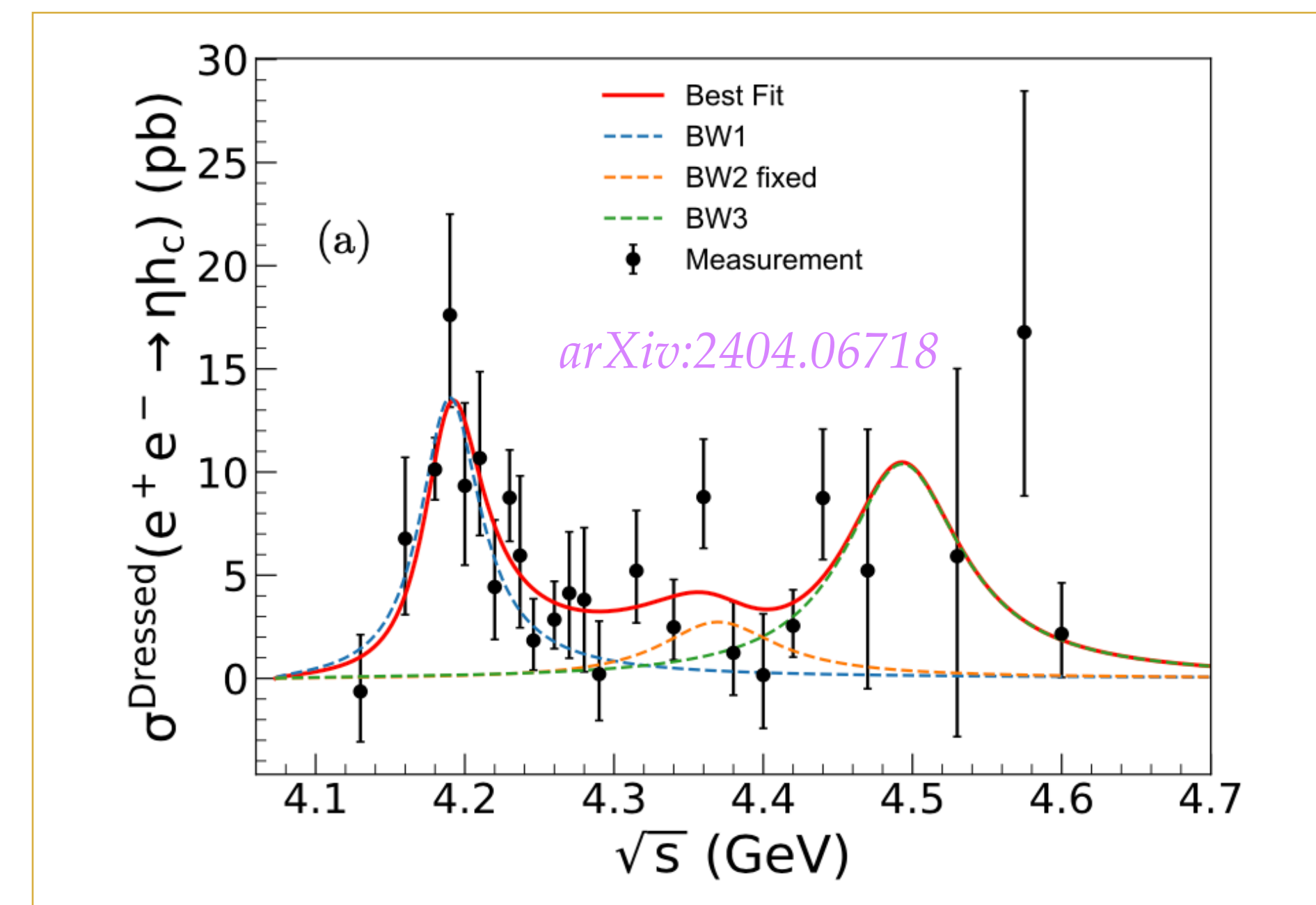
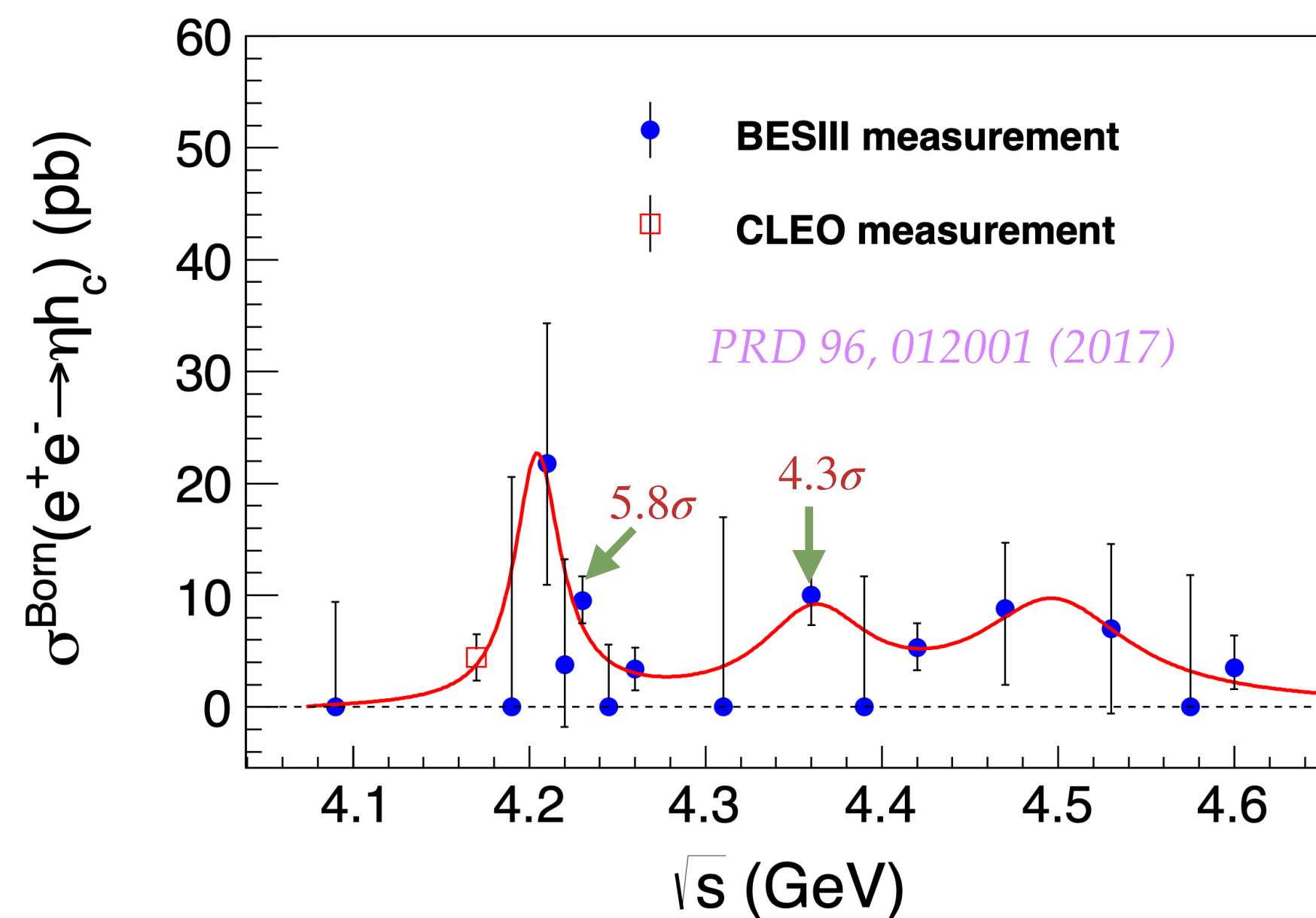
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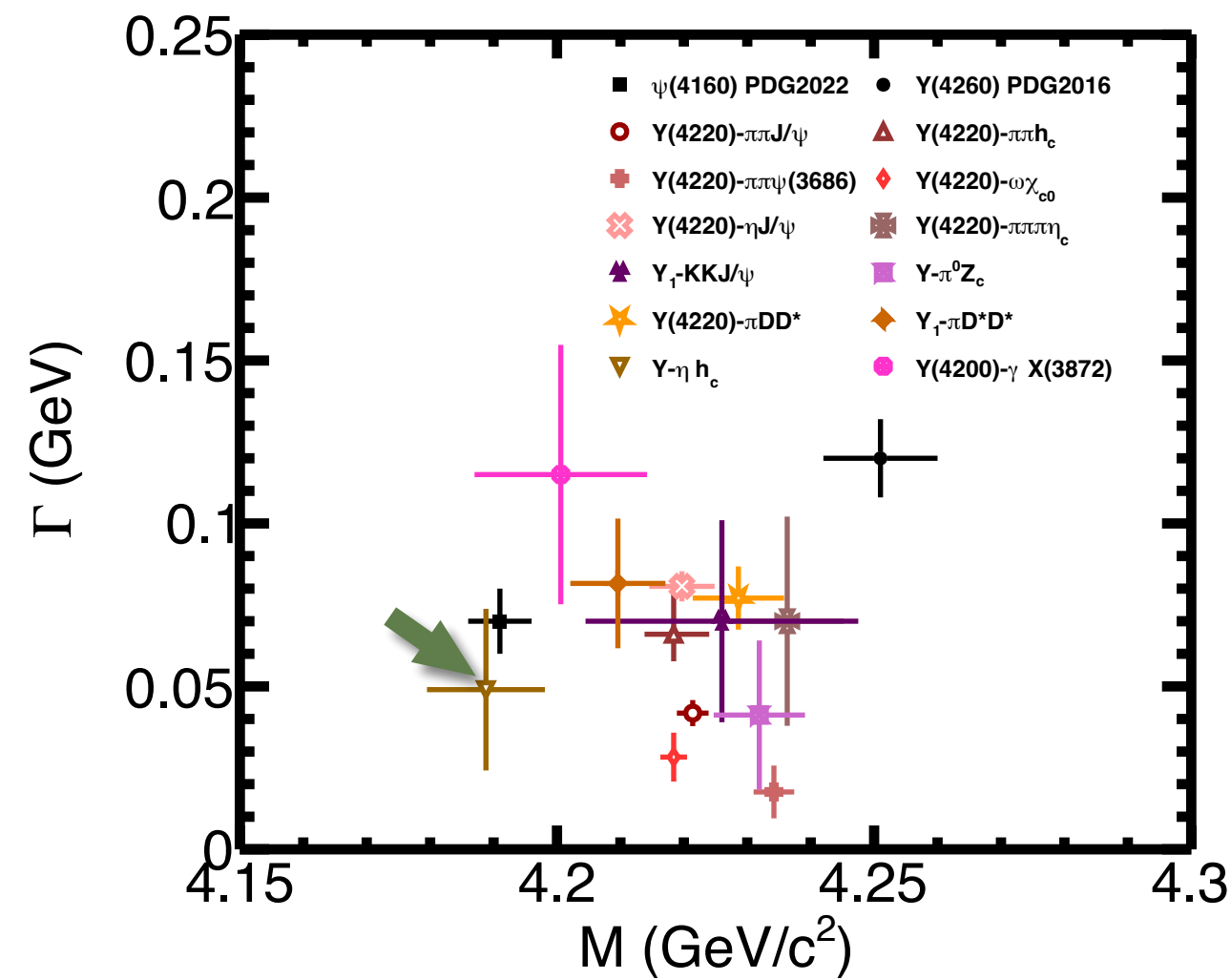
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Measurement of $\sigma[e^+e^- \rightarrow \eta h_c]$

- The first evidence of $e^+e^- \rightarrow \eta h_c$ was found by CLEO at $\sqrt{s}=4.17$ GeV [3σ] [PRL 107, 041803 \(2011\)](#)
- The process $e^+e^- \rightarrow \eta h_c$ was observed for the first time at $\sqrt{s}=4.226$ GeV by BESIII, a hint of a resonance around 4.2 GeV was observed [PRD 96, 012001 \(2017\)](#)
- New data (15 fb^{-1}) between $\sqrt{s}=4.13$ to 4.6 GeV has been collected by BESIII



Measurement of $\sigma[e^+e^- \rightarrow \eta h_c]$



- $\sigma^{\text{dressed}} = |BW_1 + BW_2 e^{i\phi}|^2 + |BW_3|^2$

- Mass and Width of BW_2 fixed to $Y(4360)$

- $M_1 = 4188.8 \pm 4.7 \pm 8.0 \text{ MeV}/c^2$

- $\Gamma_1 = 49 \pm 16 \pm 19 \text{ MeV}$

- $\Gamma_{ee} \mathcal{B} = 0.80 \pm 0.19 \pm 0.45 \text{ eV}$

- Alternative parameterizations:

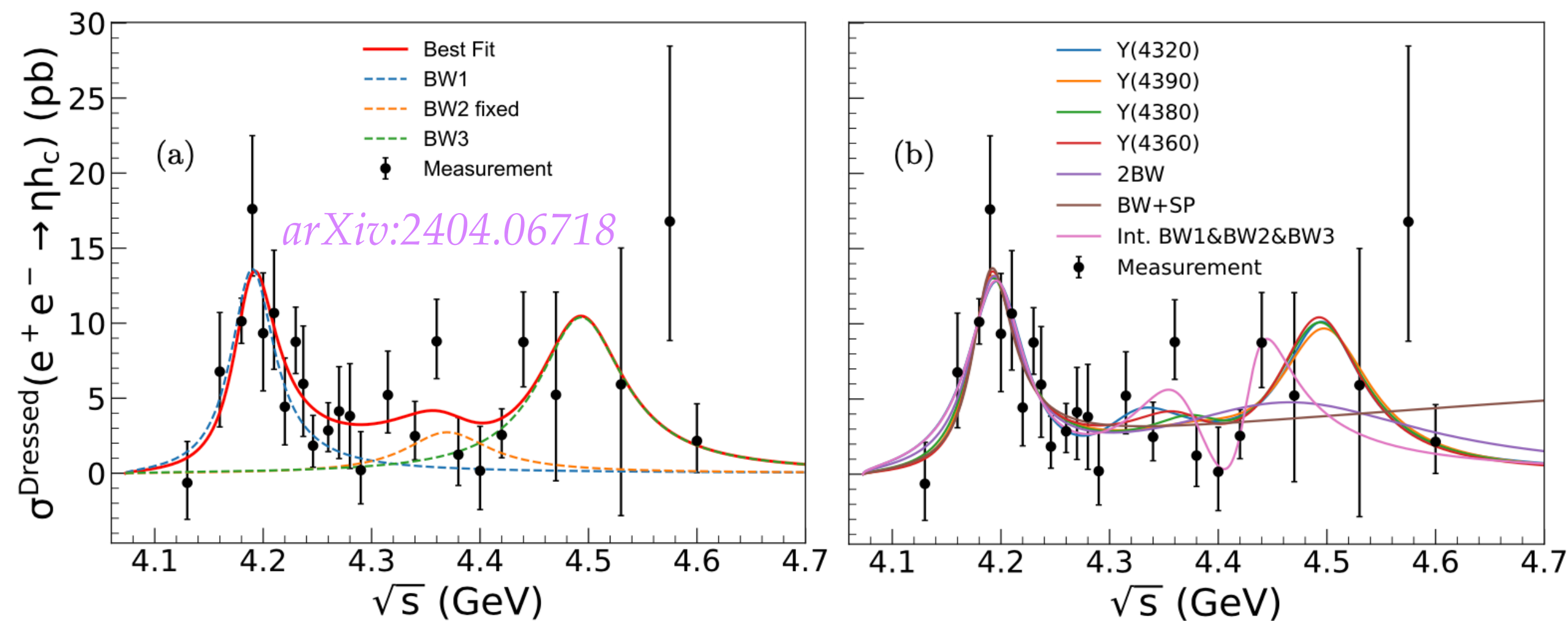
- Fix parameters of the second resonance to $Y(4320)/Y(4380)/Y(4390)$

- Remove BW_2

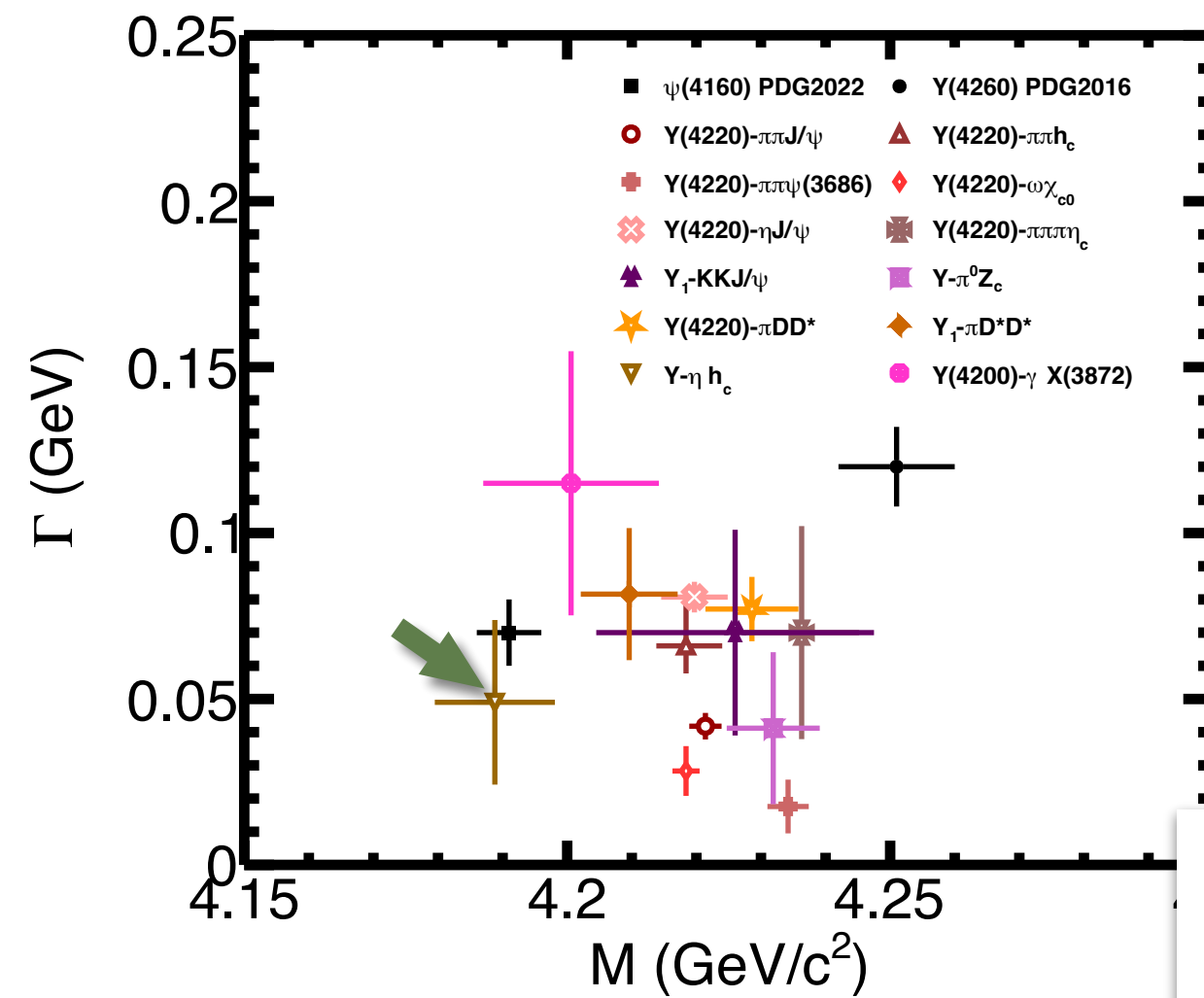
- Use sum of a BW and phase space

- Coherent sum of three BW s

- Statistical significance of BW_1 in all cases $> 7\sigma$



Measurement of $\sigma[e^+e^- \rightarrow \eta h_c]$



● $\sigma^{\text{dressed}} = |BW_1 + BW_2 e^{i\phi}|^2 + |BW_3|^2$

● Mass and Width of BW_2 fixed to $Y(4360)$

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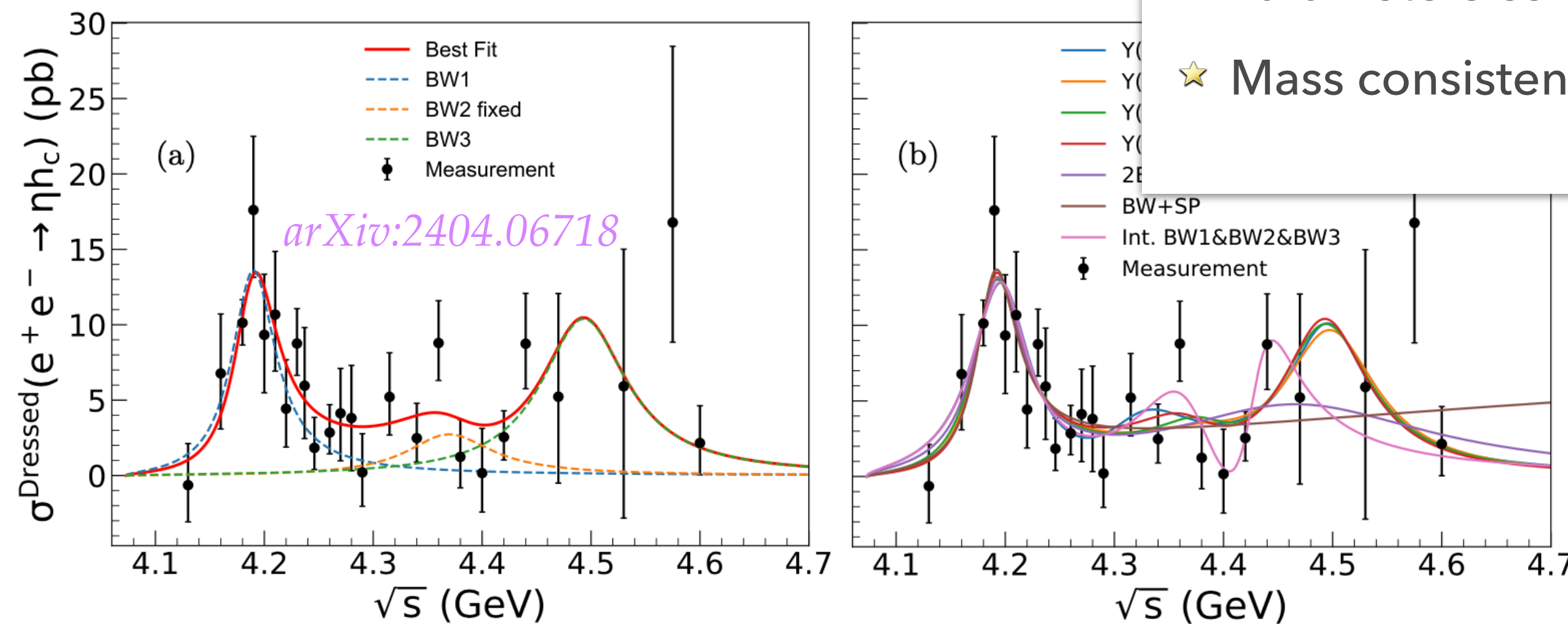
$\Gamma_{ee} \mathcal{B} = 0.80 \pm 0.19 \pm 0.45 \text{ eV}$

The first resonance:

★ Parameters consistent with $\psi(4160)$

★ Mass consistent with hybrid with a mass of $(4.15 \pm 0.15) \text{ GeV}/c^2$

PRD92, 114019 (2015)



● Remove BW_2

● Use sum of a BW and phase space

● Coherent sum of three BW s

● Statistical significance of BW_1 in all cases $> 7\sigma$

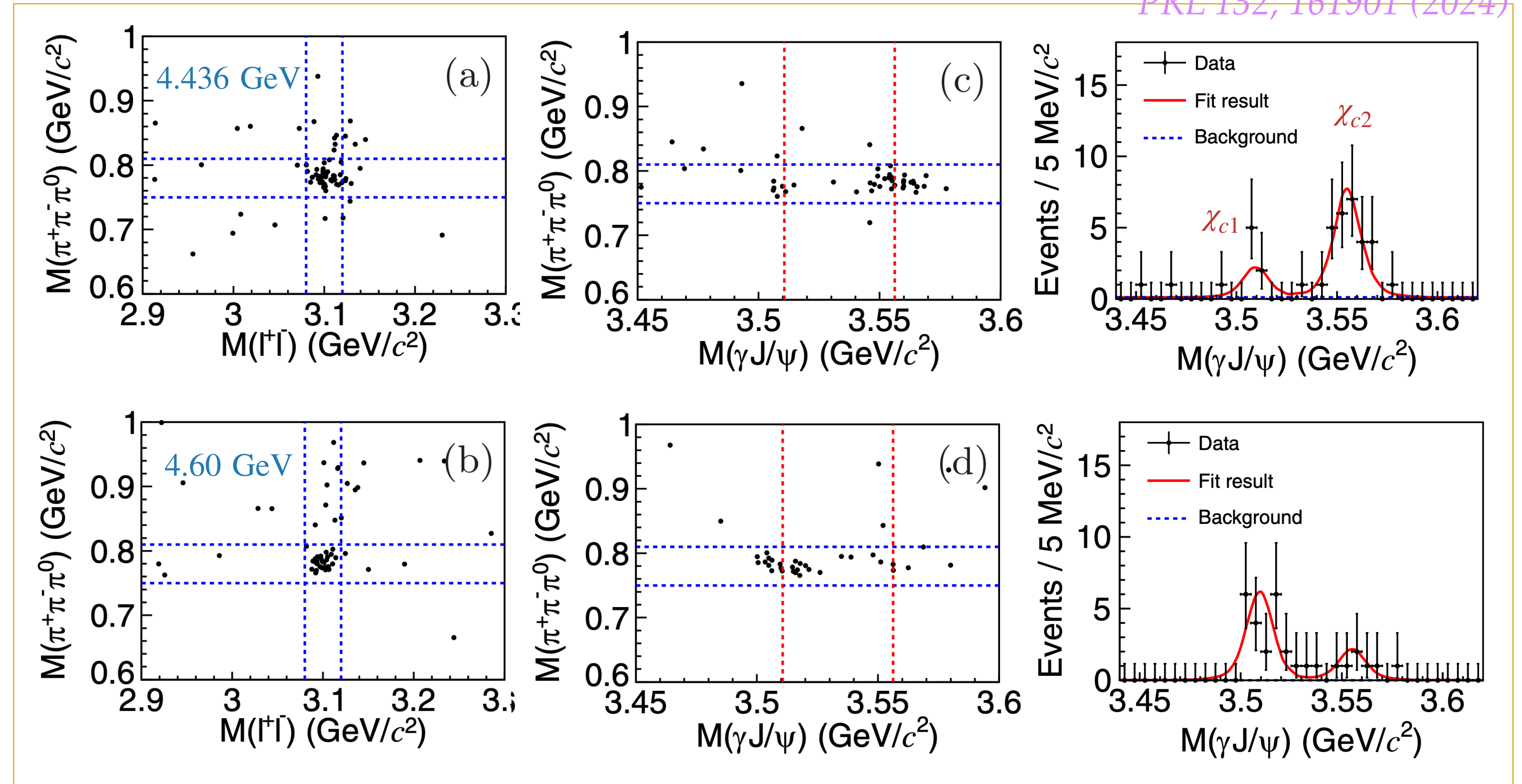
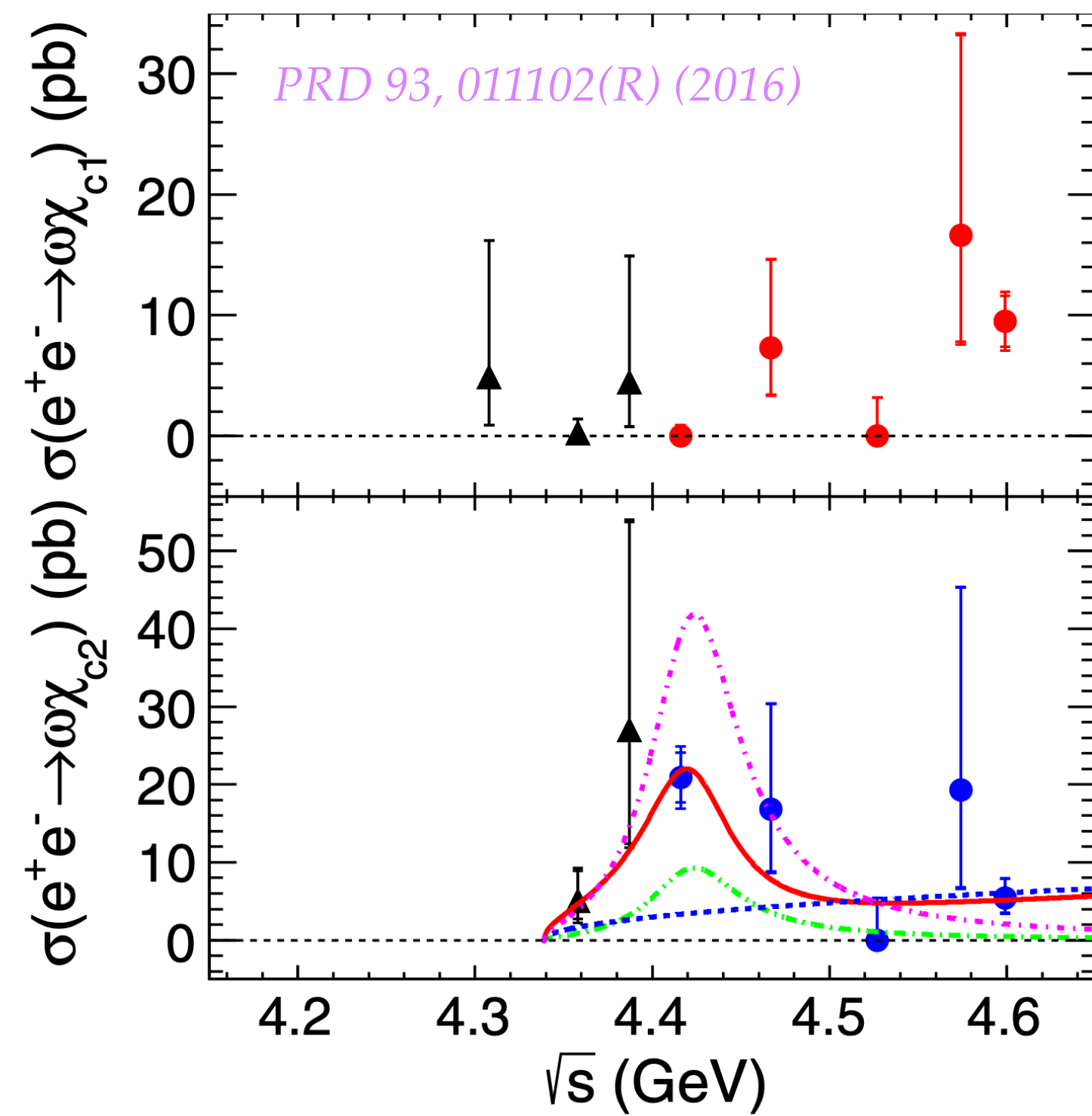
Measurement of $\sigma[e^+e^- \rightarrow \omega\chi_{c1,2}]$

- The process $e^+e^- \rightarrow \omega\chi_{c1,2}$ was observed for the first time at $\sqrt{s}=4.6$ GeV or 4.42 GeV by BESIII

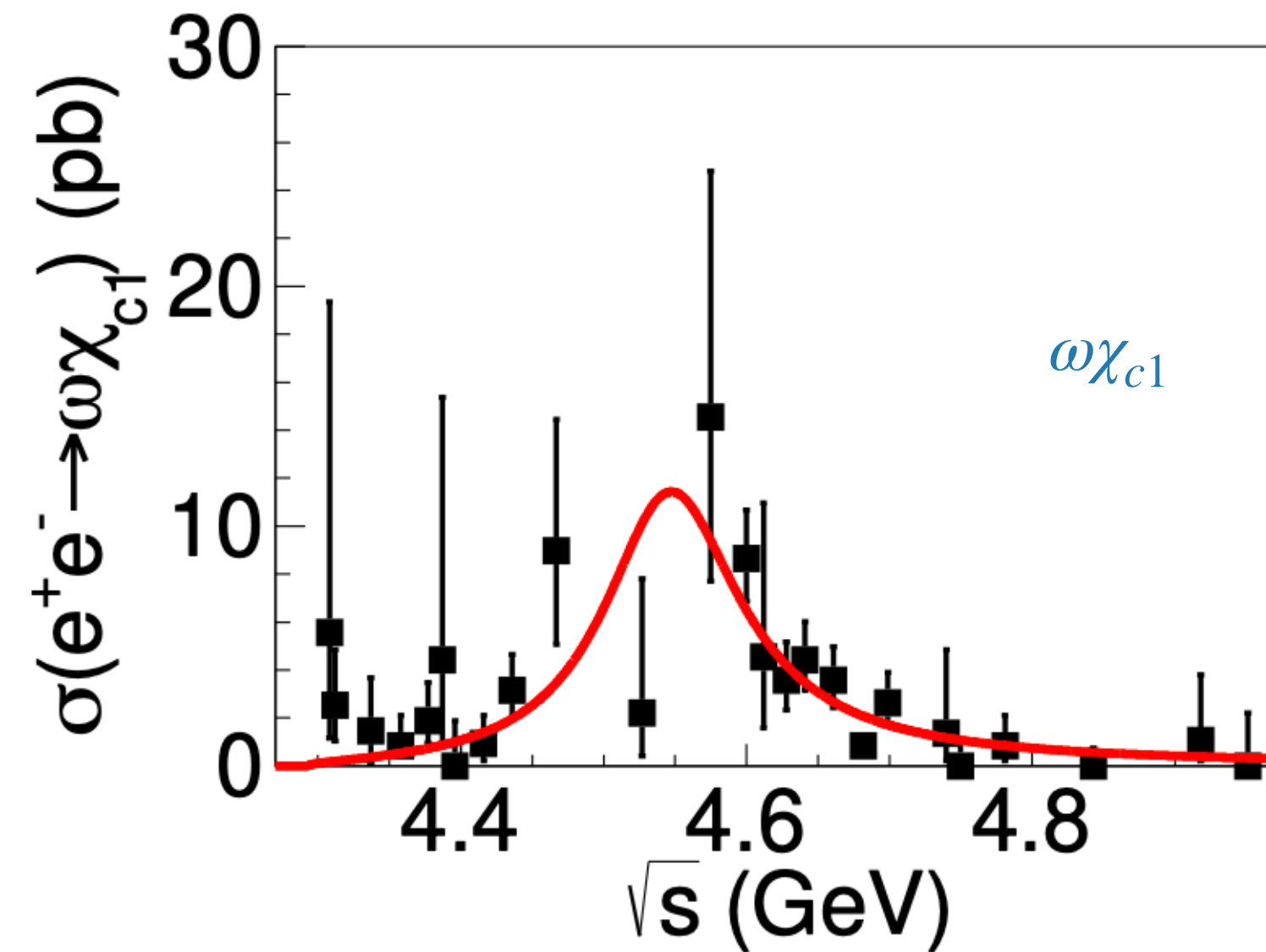
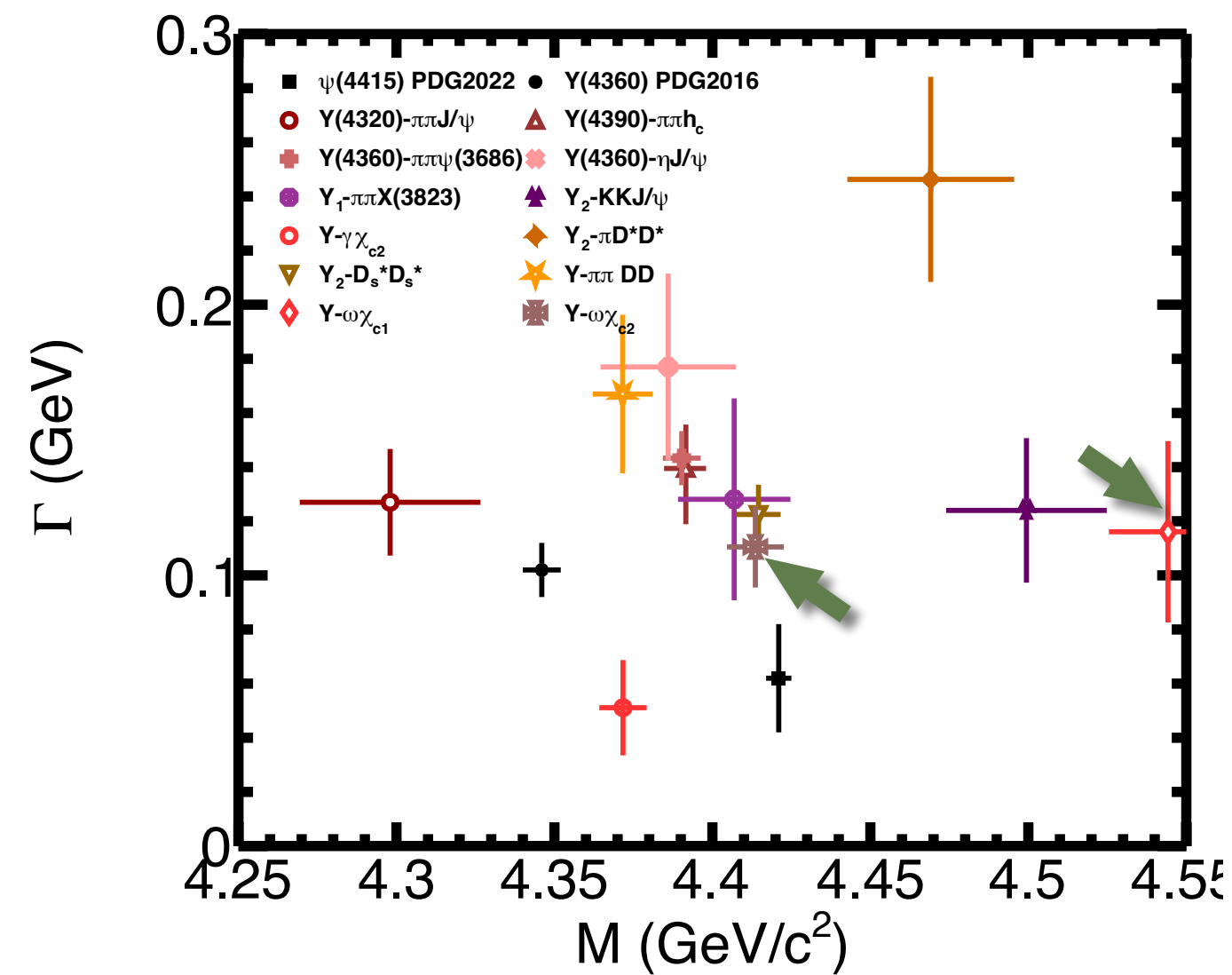
PRD 93, 011102(R) (2016)

- New data (11.0 fb⁻¹) between $\sqrt{s}=4.3$ to 4.95 GeV has been collected by BESIII

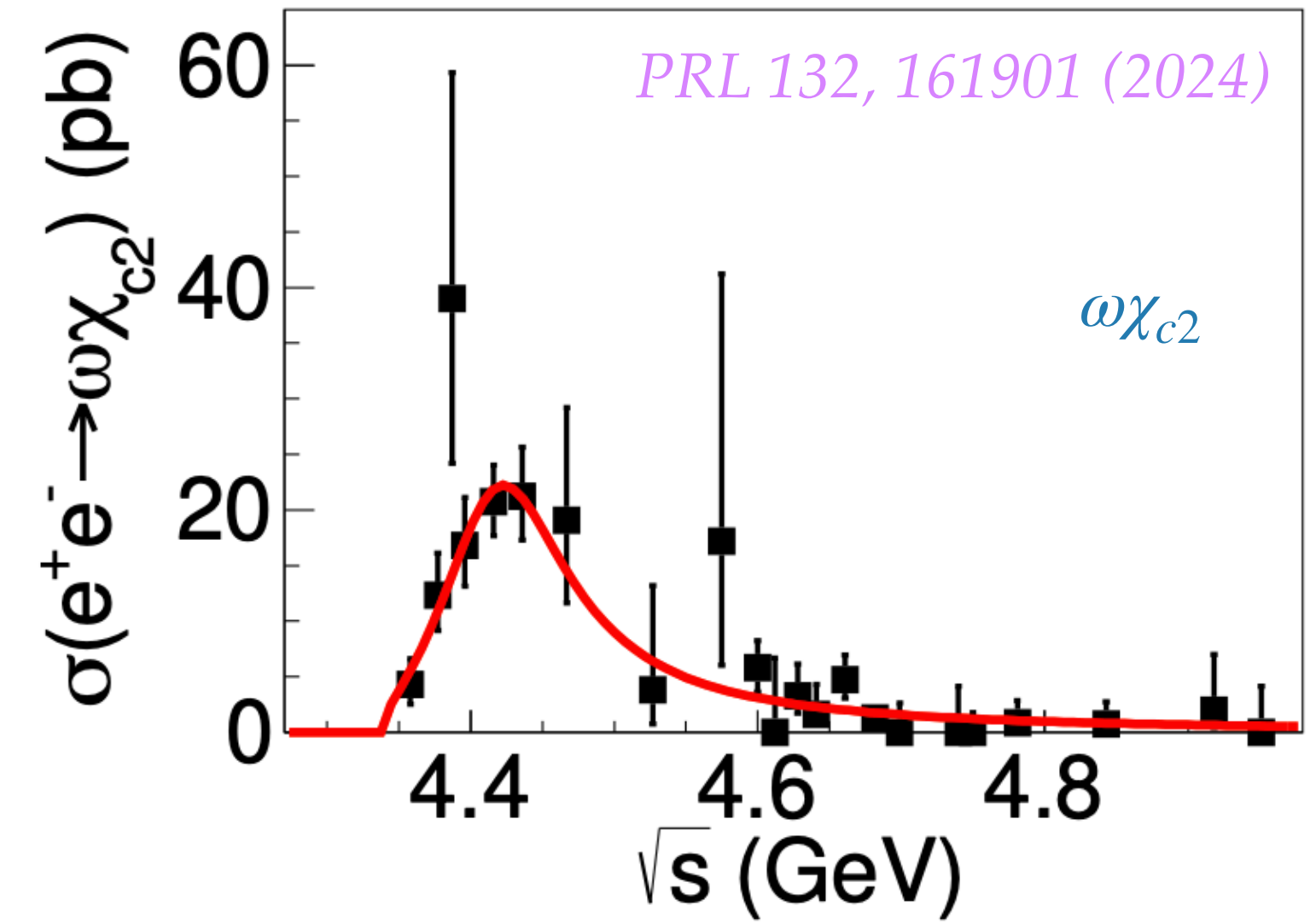
PRL 132, 161901 (2024)



Measurement of $\sigma[e^+e^- \rightarrow \omega\chi_{c1,2}]$



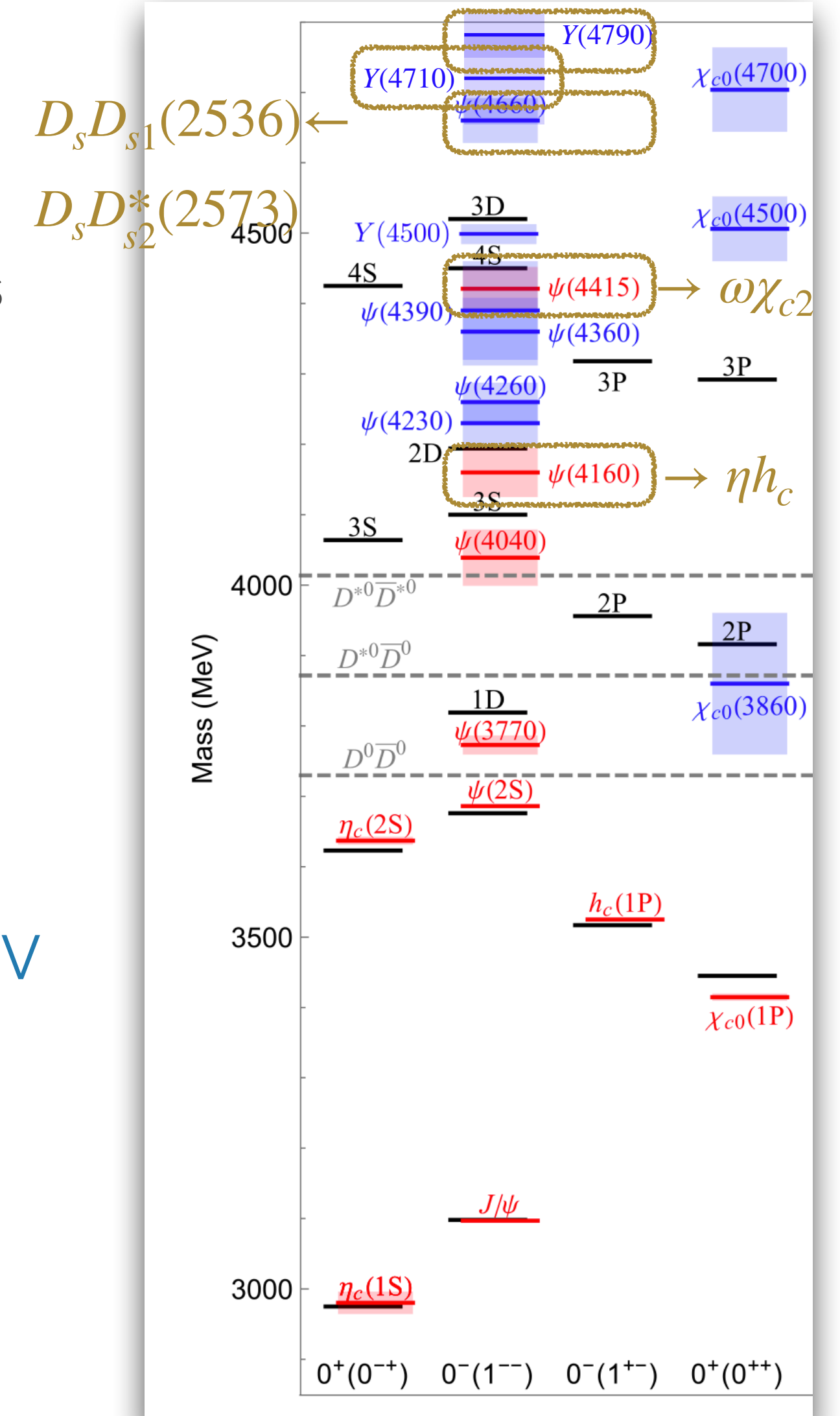
- $M = 4544.2 \pm 18.7 \pm 1.7 \text{ MeV}/c^2$
 $\Gamma = 116.1 \pm 33.5 \pm 1.7 \text{ MeV}$
- Significance over PHSP: 5.8σ
- Mass higher than structure seen in KKJ/ψ and $\pi D^* D^*$



- $M = 4413.6 \pm 9.0 \pm 0.8 \text{ MeV}/c^2$
 $\Gamma = 110.5 \pm 15.0 \pm 2.9 \text{ MeV}$
- Significance over PHSP: 10.7σ
- Parameters consistent with $\psi(4415)$, implying the existence of $\psi(4415) \rightarrow \omega\chi_{c2}$

Summary

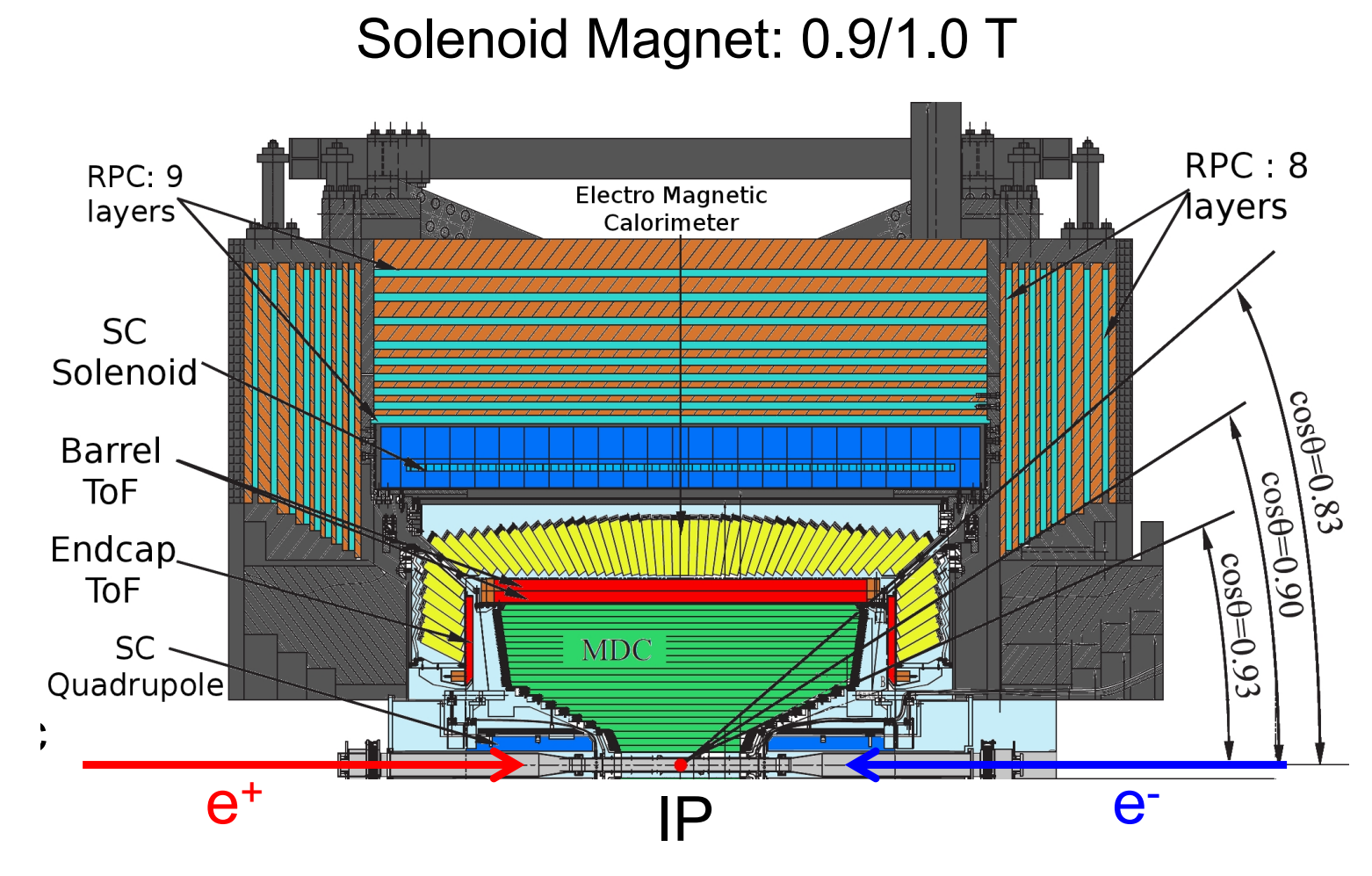
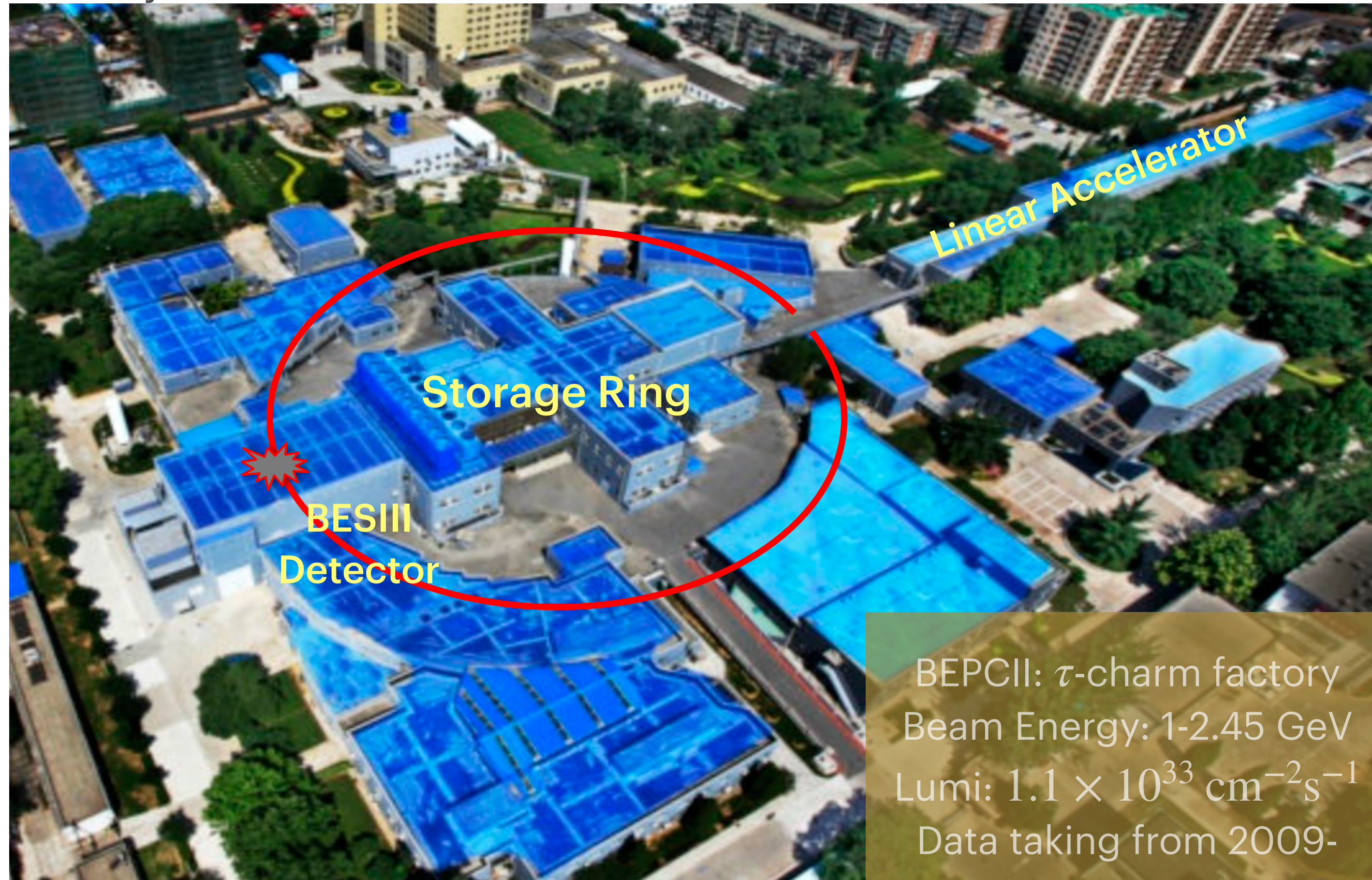
- Benefit from the fine scan data samples collected between $\sqrt{s}=3.8$ to 4.95 GeV, properties of vector charmonium(-like) states have been investigated in hidden charm, open charm, and light hadron processes
 - Discovered $Y(4230)$ in more than 10 decay modes
 - Discovered new charmonium-like states $Y(4500)$ and $Y(4710)/Y(4790)$
 - No evident structure is seen in light hadron processes
 - The cross-section line shapes are very complicated, more sophisticated analysis may determine the pole positions of these states better and help to understand their nature
- BEPCII will upgrade this summer, increase the luminosity at $\sqrt{s}=4.7$ GeV by a factor of 3, and extend the \sqrt{s} up to 5.6 GeV starting from 2028, more exciting results are expected!



Thank You!

Beijing Electron Positron Collider II and BESIII

- Body Level One



MUC $\sigma_{R\phi}$: 2 cm

TOF

σ_T : 80 ps
 110 ps (60 ps)

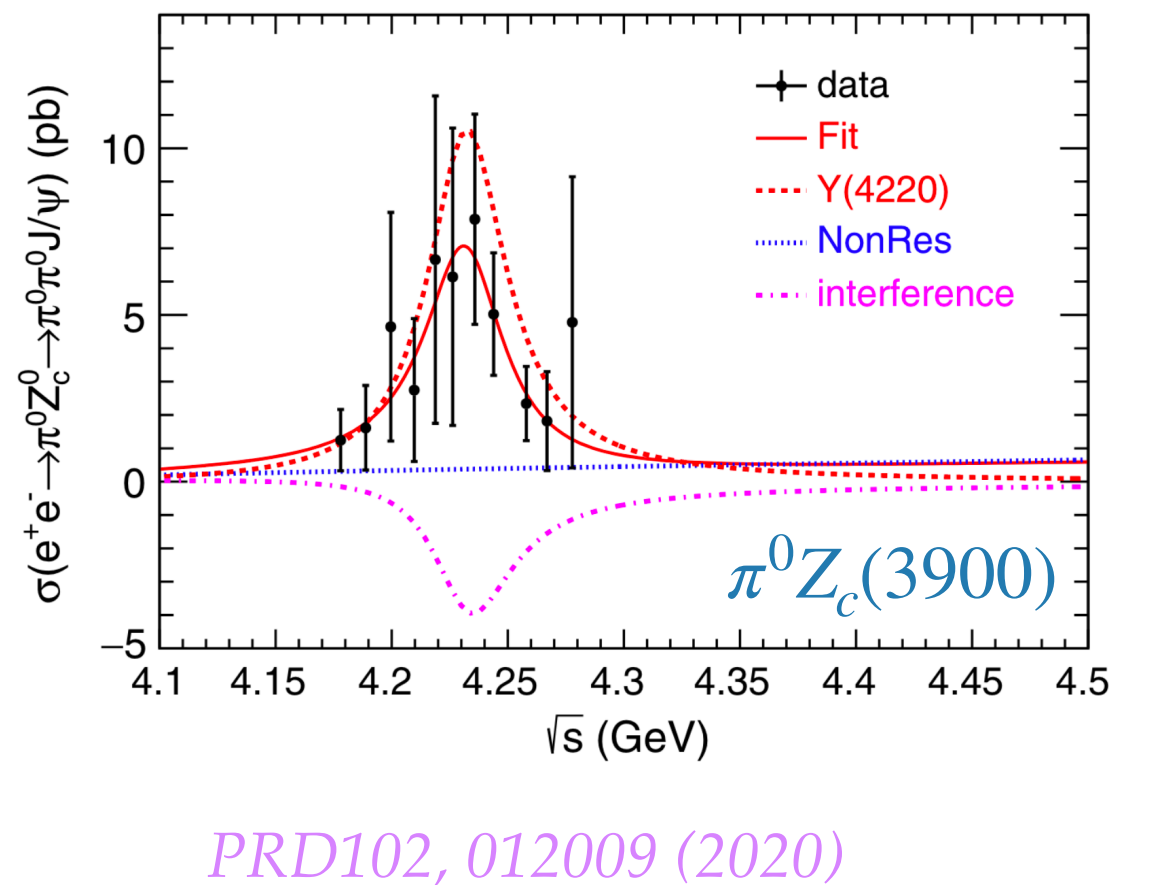
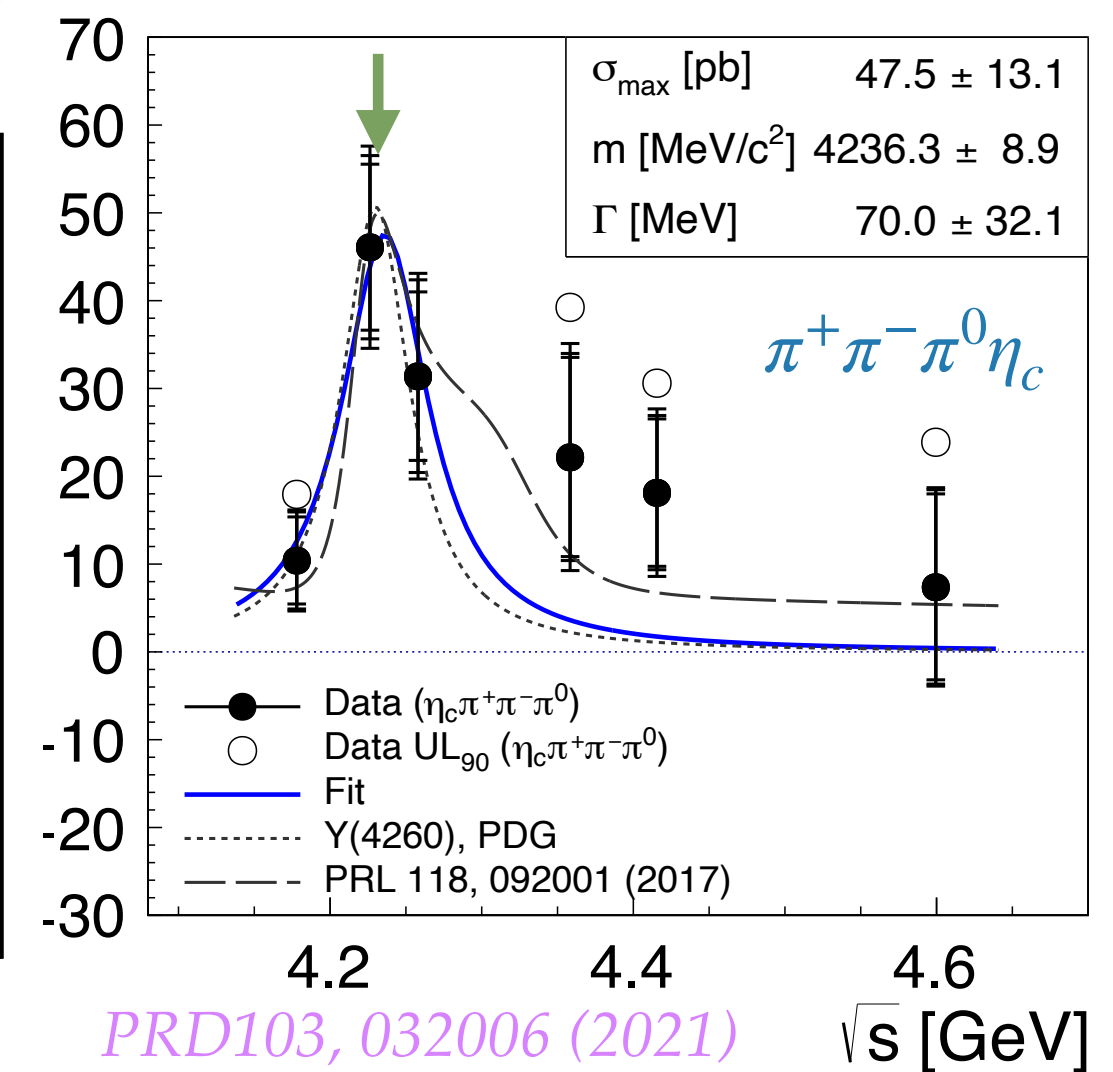
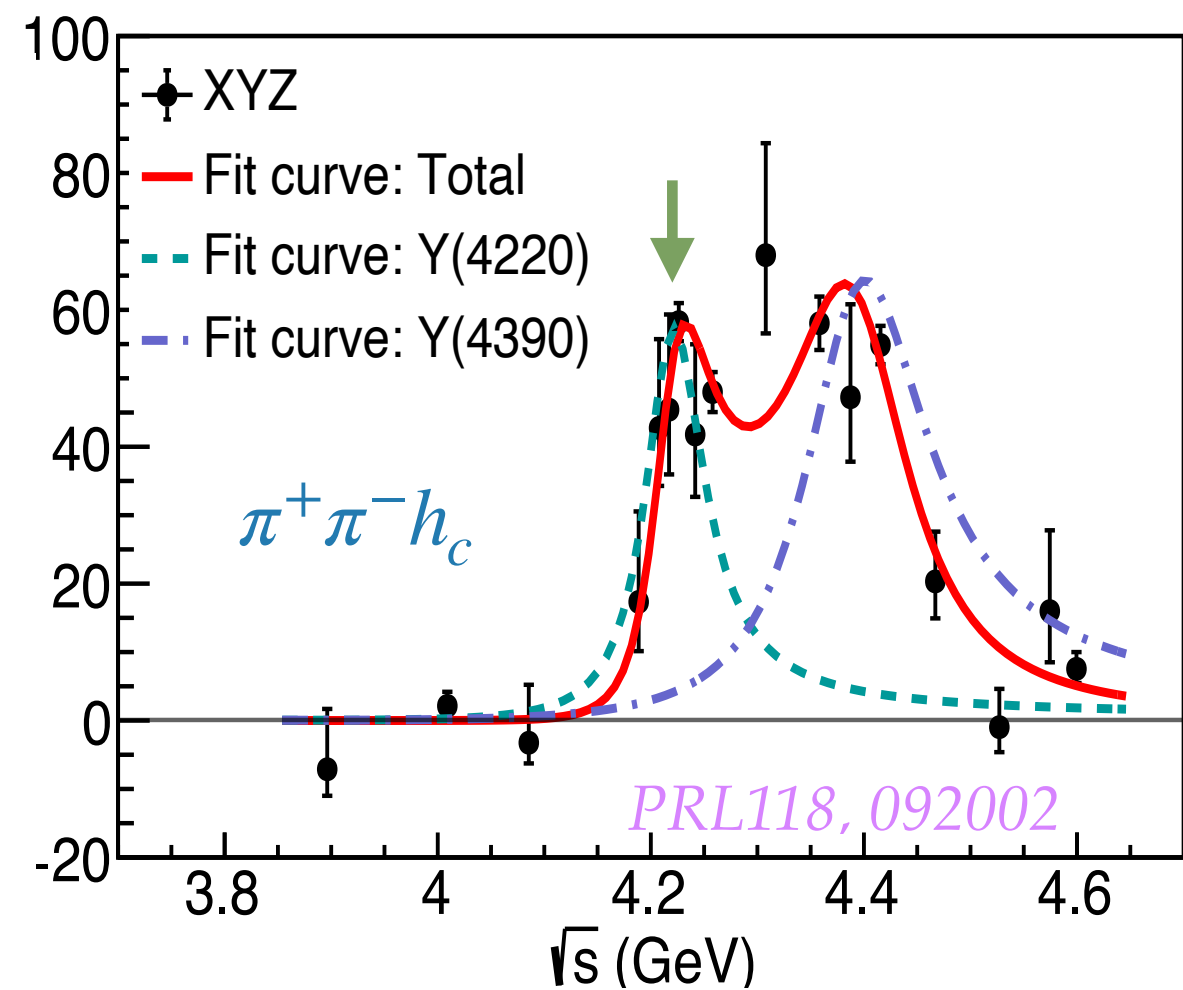
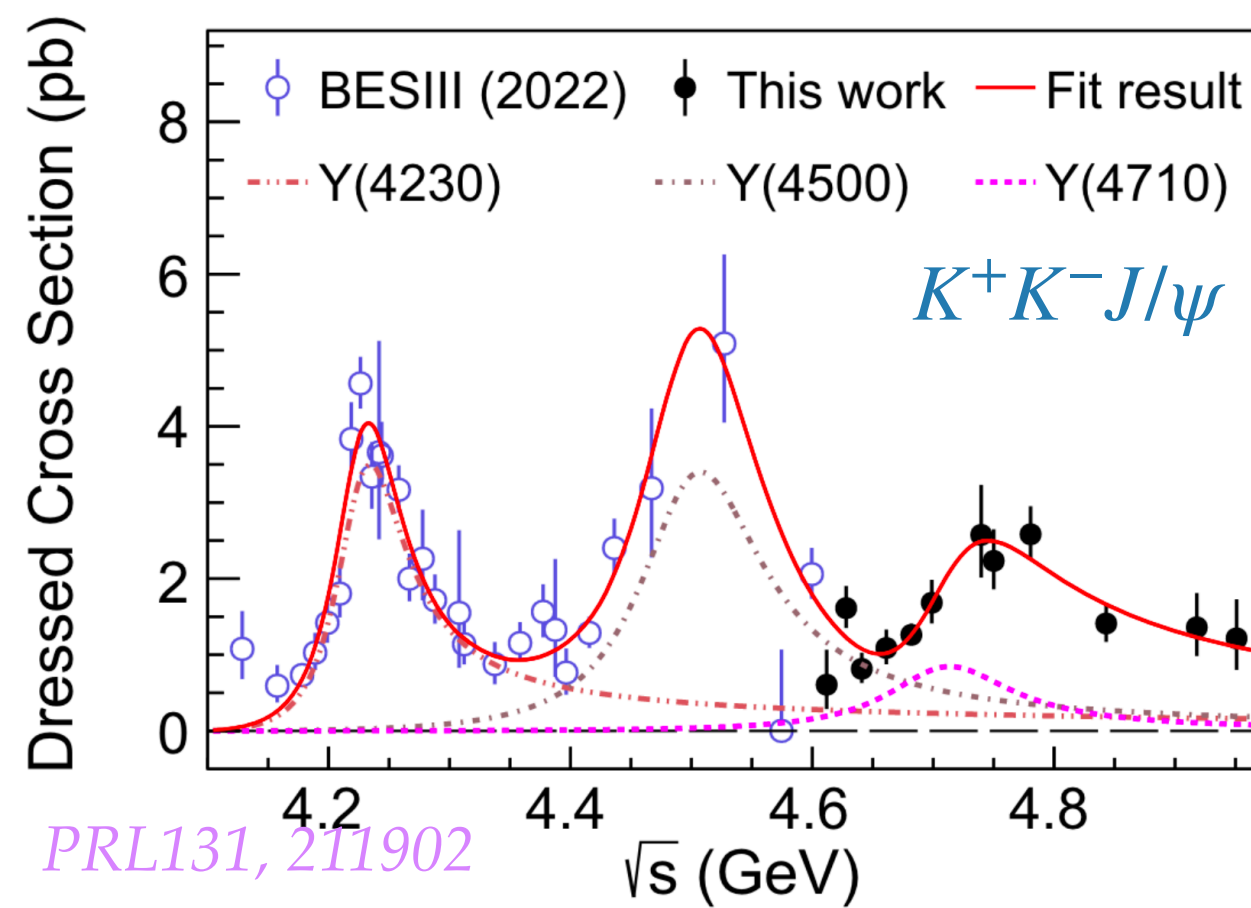
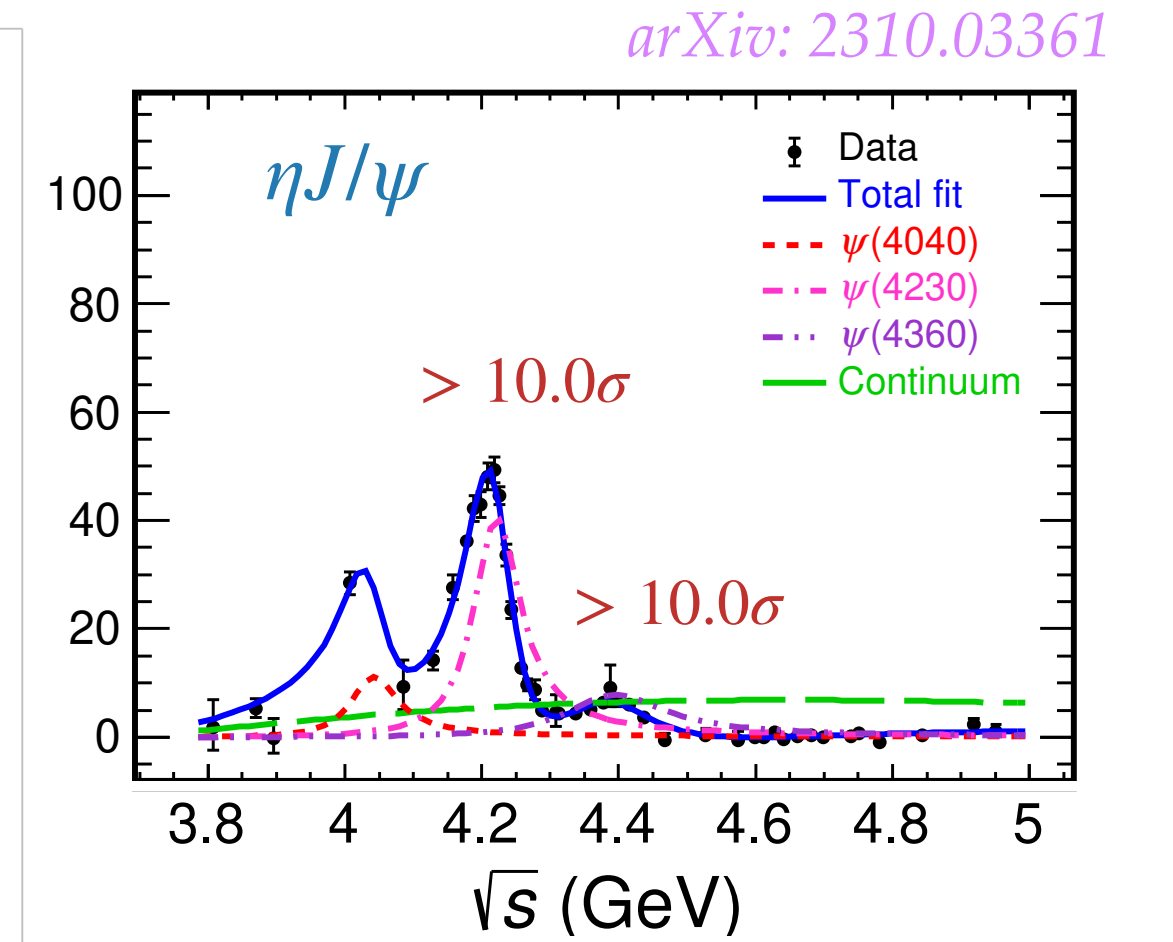
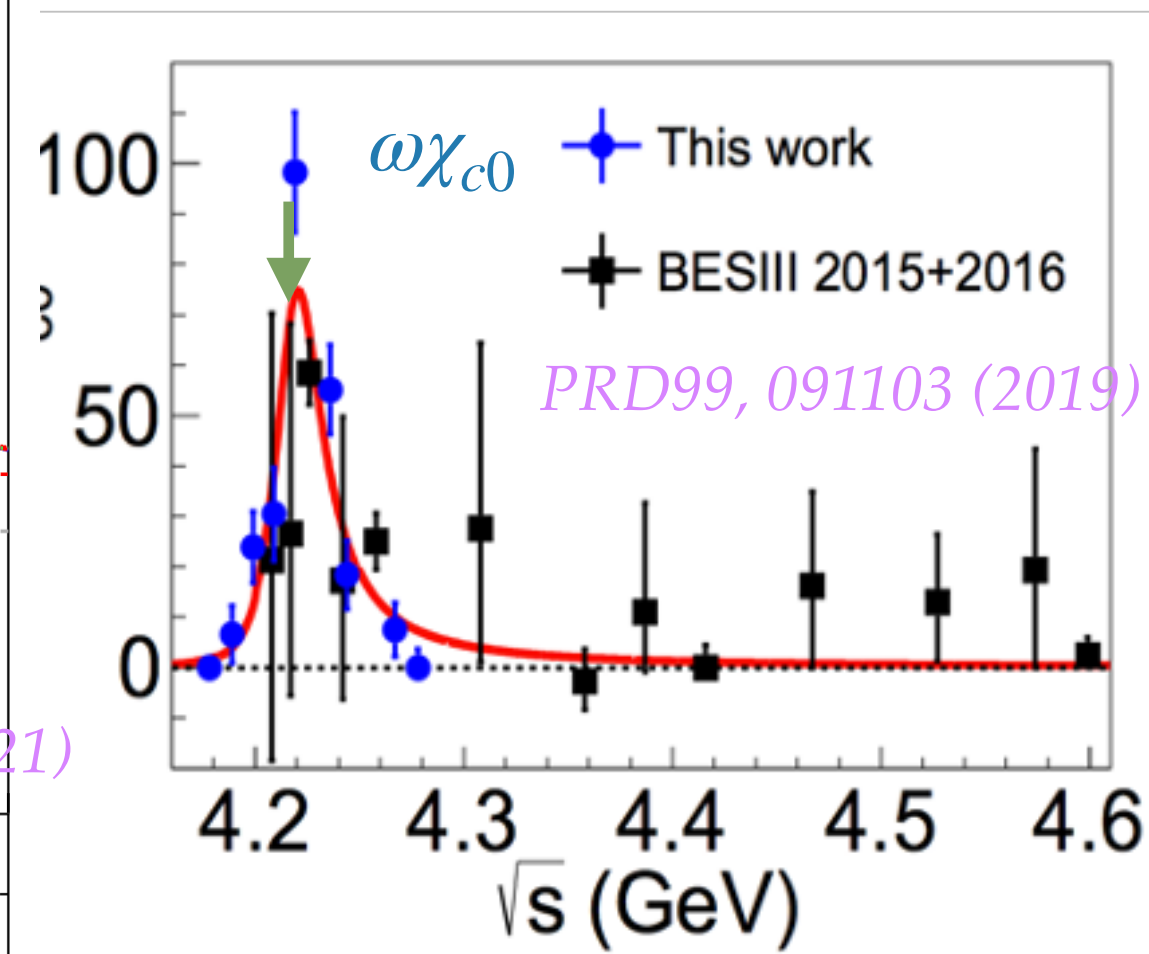
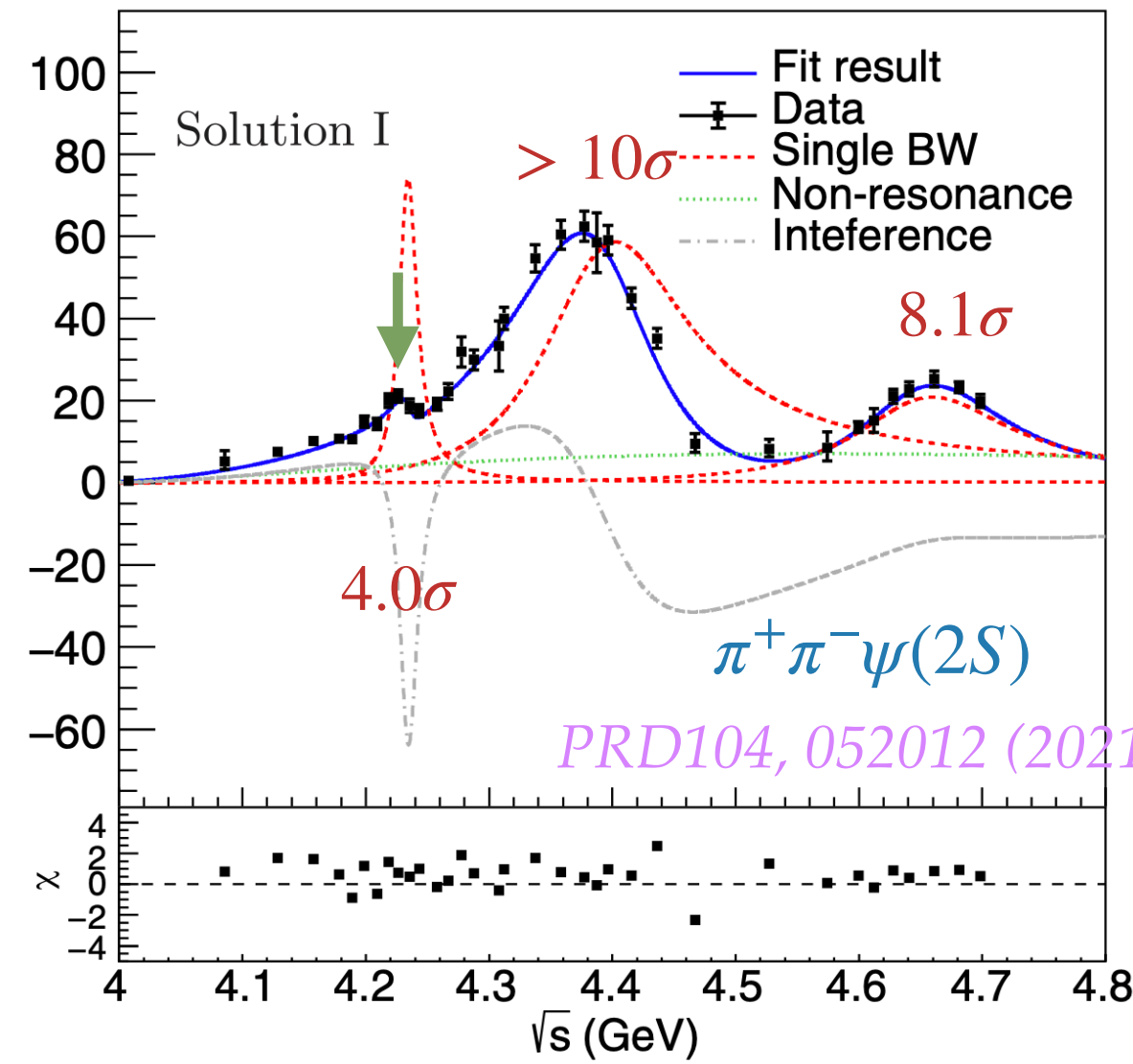
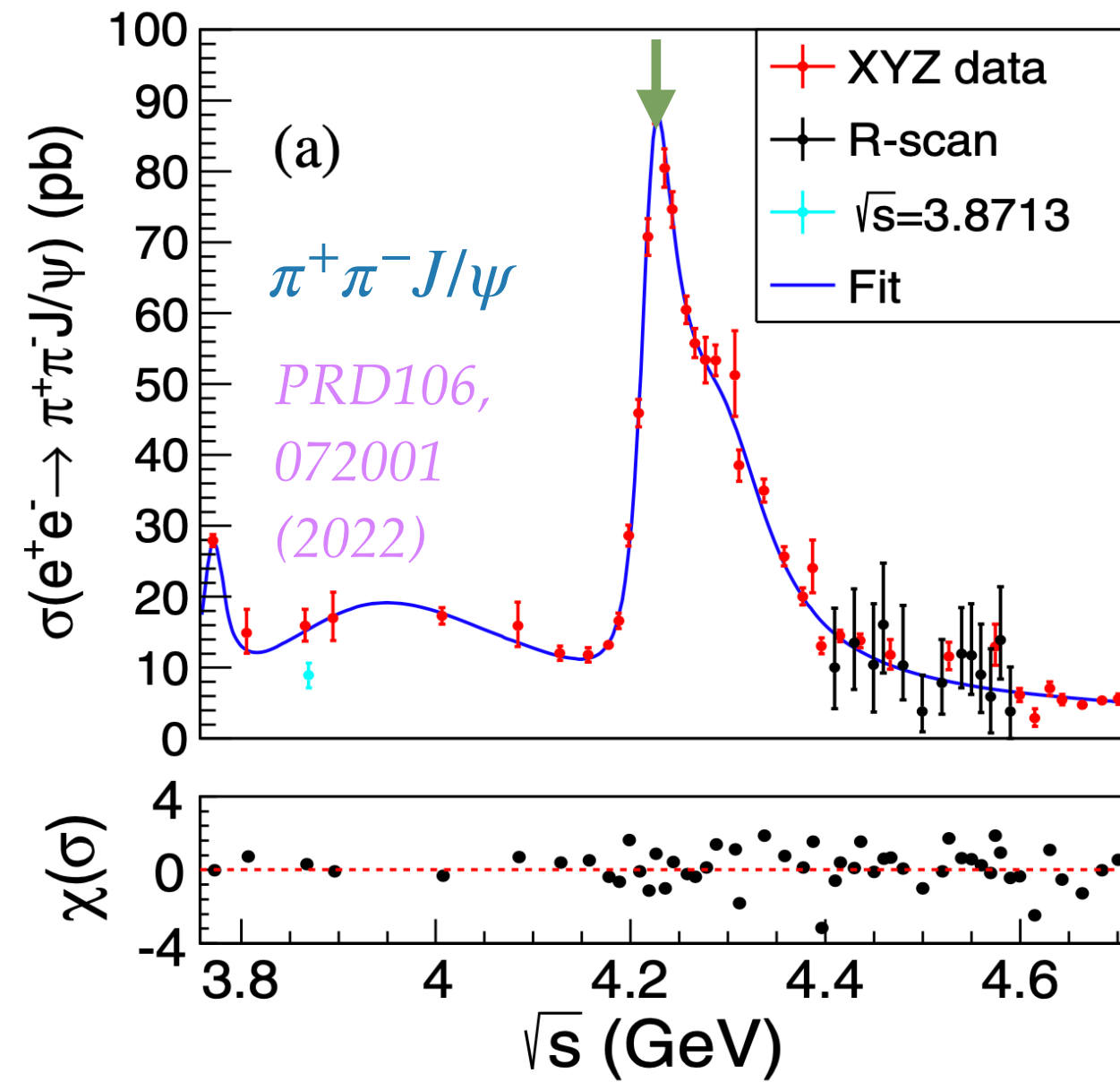
MDC

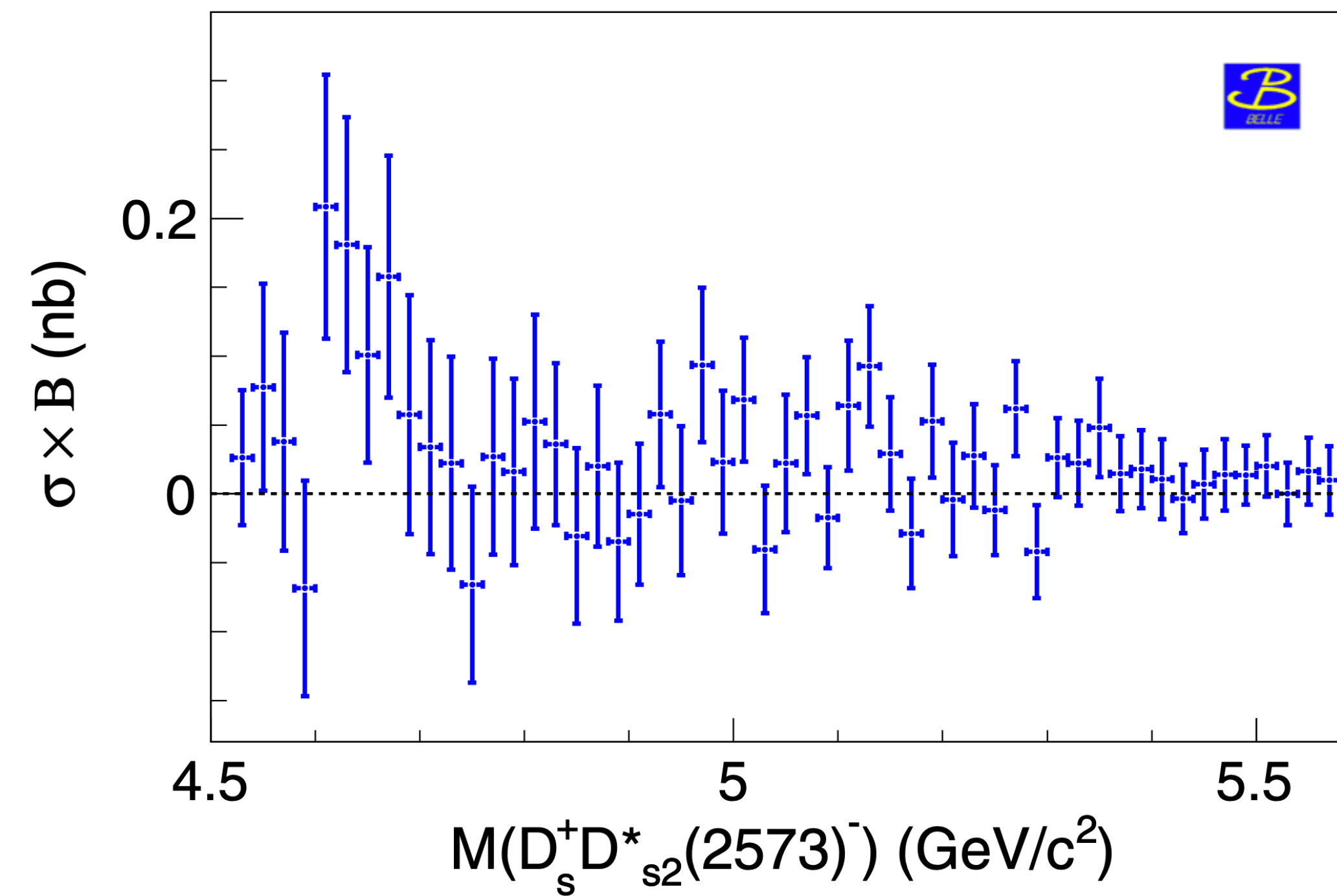
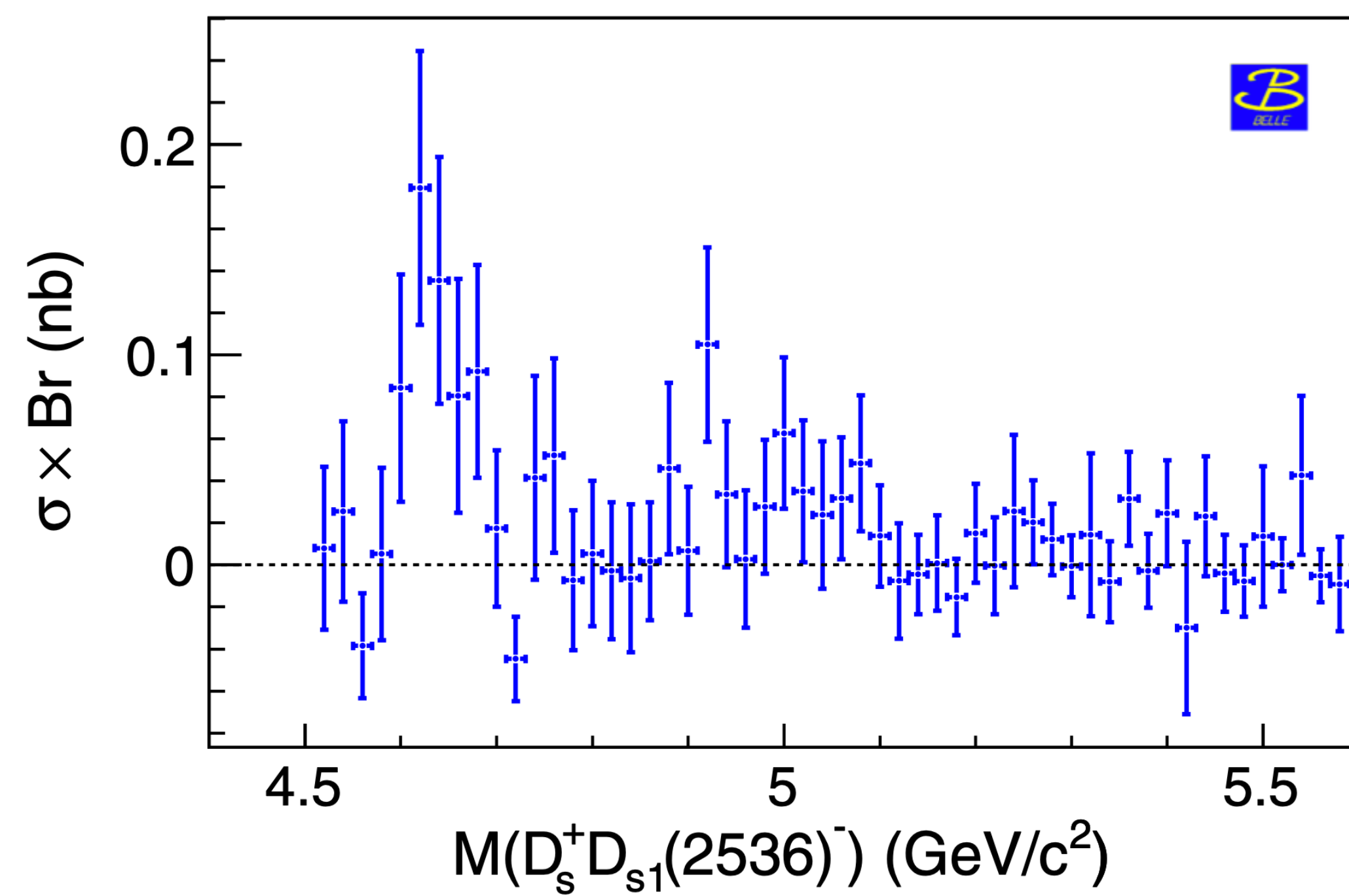
dE/dx: 6%
 σ_p/p : 0.5% at 1GeV/c

EMC

$\Delta E/E$: at 1GeV
 2.5%
 5.0%
 σ_Z : 0.6 cm/ \sqrt{E}

Y(4260) \Rightarrow Y(4230)





PRD100, 111103(R) (2019), PRD101, 091101(R) (2020)

Future Data Samples

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

| Energy | Physics motivations | Current data | Current data | Proposed data | Days |
|-------------------|---|--|--------------|--|---------------|
| 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} | | 20.0 fb^{-1} | 610/360 days |
| 3.8 - 4.6 GeV | R values XYZ /Open charm | Fine scan (105 energy points) | | No requirement | N/A |
| 4.180 GeV | D_s decay XYZ /Open charm | 3.2 fb^{-1} | | 6 fb^{-1} | 140/50 days |
| 4.0 - 4.6 GeV | XYZ /Open charm Higher charmonia cross-sections | 16.0 fb^{-1} at different \sqrt{s} | | 30 fb^{-1} at different \sqrt{s} | 770/310 days |
| 4.6 - 4.9 GeV | Charmed baryon/ XYZ cross-sections | 0.56 fb^{-1} at 4.6 GeV | | 15 fb^{-1} at different \sqrt{s} | 1490/600 days |
| 4.74 GeV | $\Sigma_c^+ \bar{\Lambda}_c^-$ cross-section | N/A | | 1.0 fb^{-1} | 100/40 days |
| 4.91 GeV | $\Sigma_c \bar{\Sigma}_c$ cross-section | N/A | | 1.0 fb^{-1} | 120/50 days |
| 4.95 GeV | Ξ_c decays | N/A | | 1.0 fb^{-1} | 130/50 days |

