

Recent charmonium-like results at BESIII

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湖南 衡阳 25/10-29/10/2024

Outline

- Introduction

Two

- ~~Three~~ recent charmonium-like (XYZ) results at BESIII

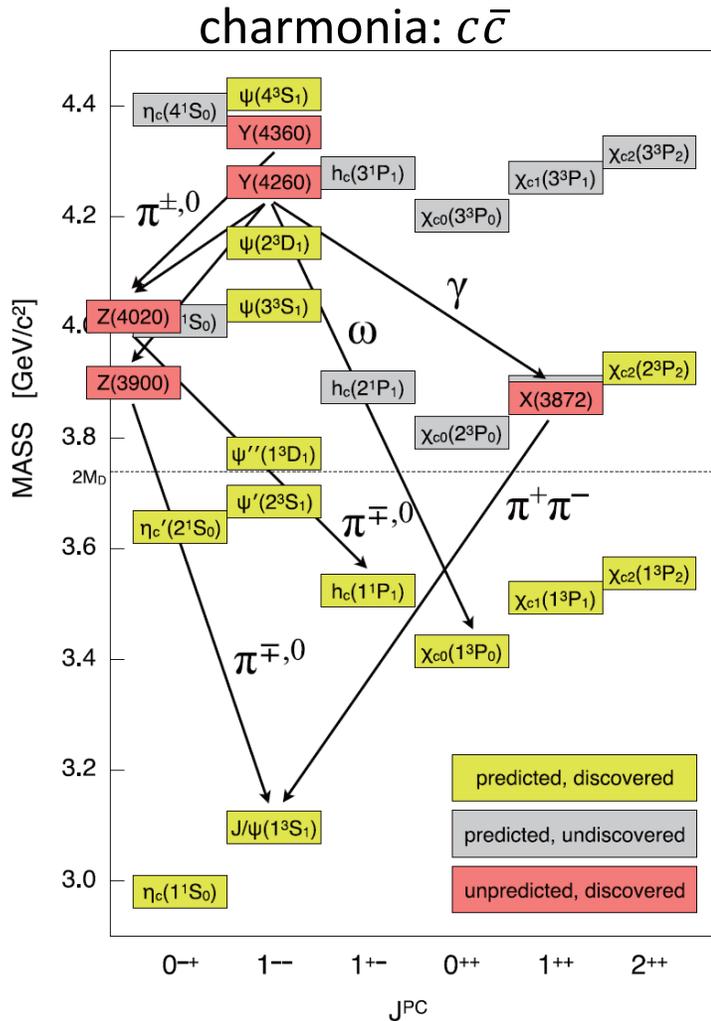
- ✓ $e^+e^- \rightarrow \phi X(3872)$ with $\phi \rightarrow K^+K^-$

- ✓ $e^+e^- \rightarrow K^+K^-\psi(2S)$

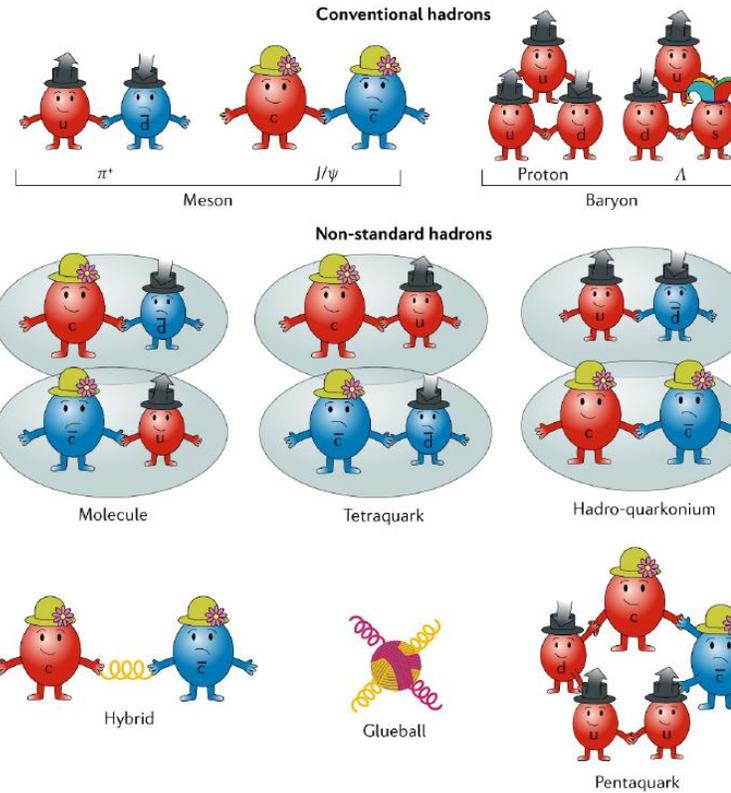
- ~~✓ $e^+e^- \rightarrow \phi\chi_{c0}/\phi\eta_{c2}(1D)$ with $\phi \rightarrow K^+K^-$~~

- Outlook

What are charmonium-like (XYZ) states



Exotic states with hidden charm



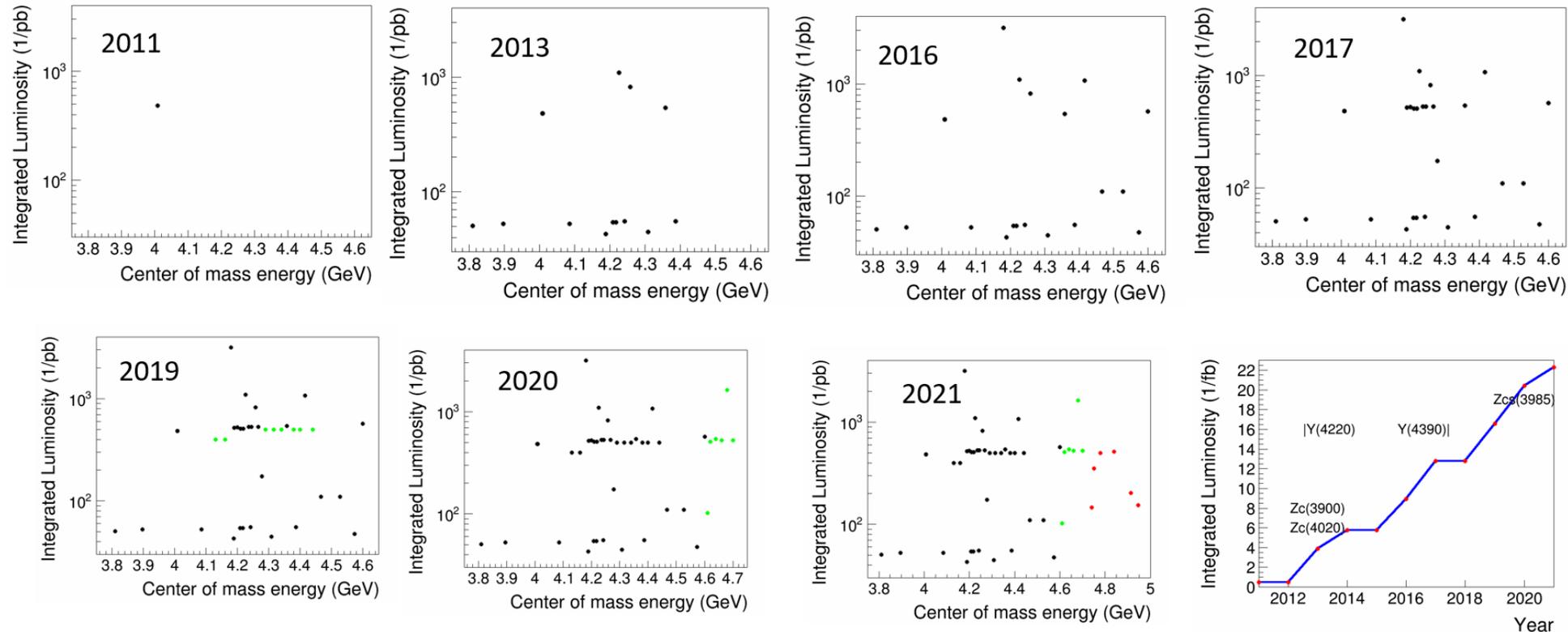
Y: vector states

Z: isospin $\neq 0$

X: remained

CZY & S. L. Olsen, *Nature Reviews Physics* **1**, 480 (2019)

How to study charmonium-like states at BESIII



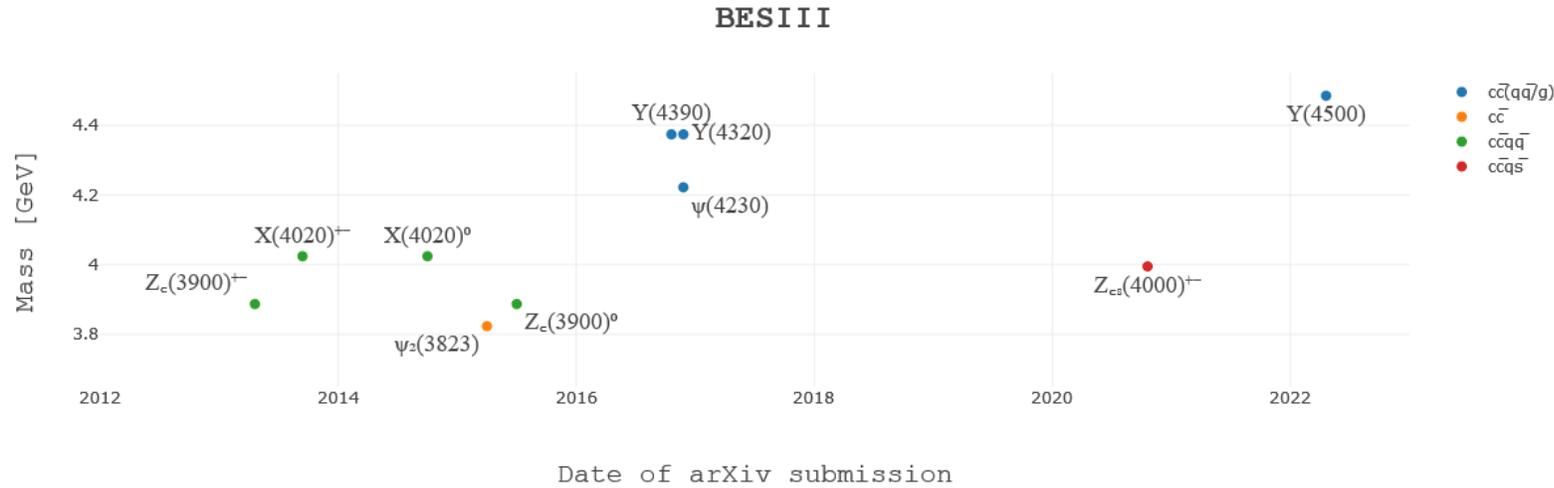
Data samples
accumulated at BESIII
among the years
 $22fb^{-1}$ above 4 GeV

Line shapes of cross-sections for Y, whose (radiative & hadronic) transitions for X and Z

Previously discovered



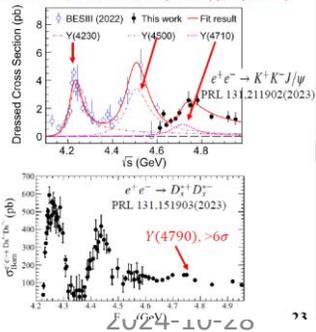
From QWG ExoticHub



From L. Y. Dong's talk @ this workshop

BESIII: a ψ/Y factory

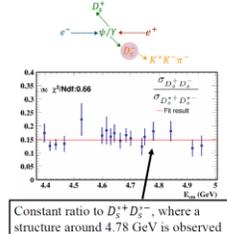
- Discovered $Y(4230)$ in >10 decay modes
- Discovered $Y(4500), Y(4710)/Y(4790)$



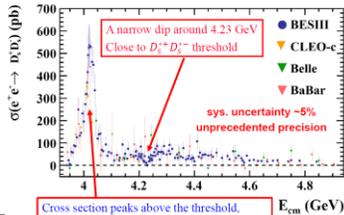
Precise Measurement of $\sigma[e^+e^- \rightarrow D_s^+ D_s^-]$

138 data samples with $\sim 22.9 \text{ fb}^{-1}$ at $\sqrt{s} = 3.94 - 4.95 \text{ GeV}$

Partial reconstruction



Constant ratio to $D_s^+ D_s^-$, where a structure around 4.78 GeV is observed

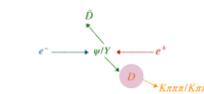


Cross section peaks above the threshold, → presence of a strong coupled channel effect
E. Eichten, et al., PRD 21, 203 (1980)

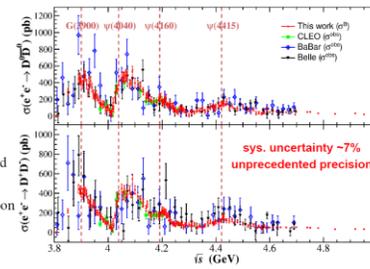
Precise Measurement of $\sigma[e^+e^- \rightarrow D\bar{D}]$

150 data samples with $\sim 20 \text{ fb}^{-1}$ at $\sqrt{s} = 3.8 - 4.95 \text{ GeV}$

Partial reconstruction



- Coupled channels analyses are desired to describe the cross-sections
- $e^+e^- \rightarrow DD^*, D_s D_s^*$ will be released soon

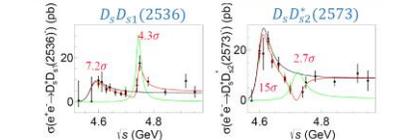
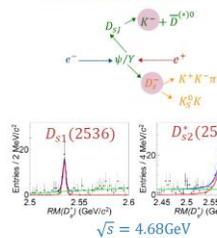


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Production Properties of $D_{s1}(2536)$ and $D_{s2}^*(2573)$

15 data samples with $\sim 6.6 \text{ fb}^{-1}$ at $\sqrt{s} = 4.53 - 4.95 \text{ GeV}$

Partial reconstruction



- Fit with $\sigma = |BW_0(\sqrt{s}) + BW_1(\sqrt{s})e^{i\phi}|^2$
- In both processes, the first resonance is $\sim 4.6 \text{ GeV}$, width $\sim 50 \text{ MeV}$ → first observation, consistent with $Y(4626)/Y(4620)$ (Inaba, 1993; 1111001 (2019); PRD 101, 091101 (2020))
- Second structure is $\sim 4.75 \text{ GeV}$, width $\sim 25 \text{ MeV}$ in $D_s^+ D_{s1}(2536)^-$ $\sim 4.72 \text{ GeV}$, width $\sim 50 \text{ MeV}$ in $D_s^+ D_{s2}^*(2573)^-$ → first evidence, could be $Y(4710)/Y(4790)$

Two recent results

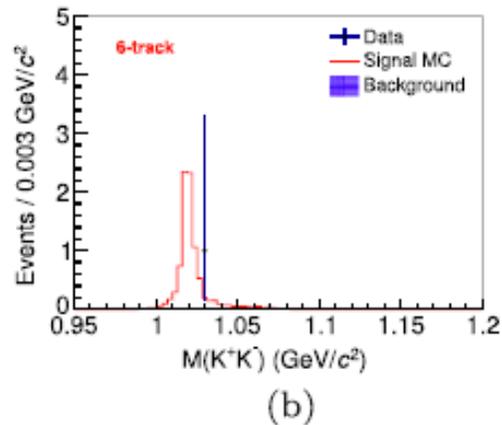
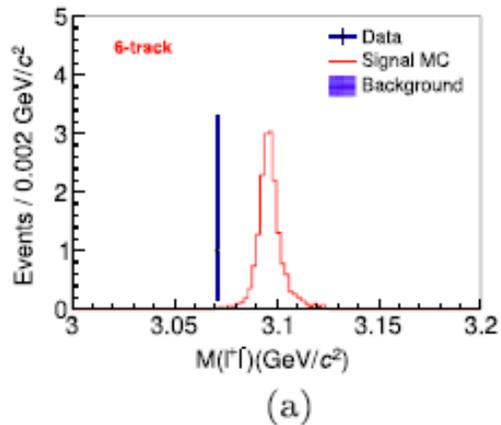
- $e^+e^- \rightarrow \phi X(3872)$ with $\phi \rightarrow K^+K^-$
- $e^+e^- \rightarrow K^+K^-\psi(2S)$

Search for new production mode of X(3872)

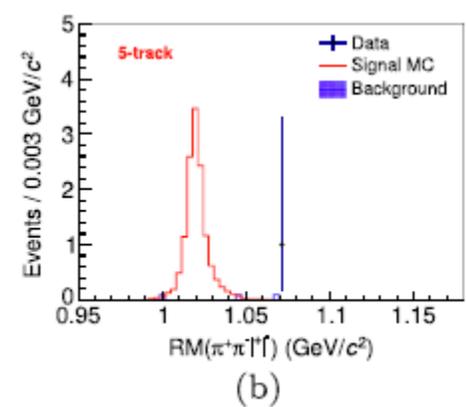
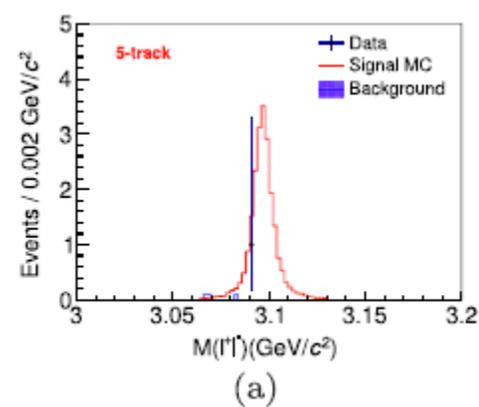
- X(3872): $J^{PC} = 1^{++}$, very narrow, mass quite near to DD^* threshold
- Known X production modes
 - B decays
 - Double $c\bar{c}$ productions
 - $\gamma\gamma$ collisions
 - Charmonium/Bottomonium(-like) decays
 - Prompt processes in pp collisions
- At BESIII
 - ✓ $e^+e^- \rightarrow Y \rightarrow \gamma X(3872)$ [PRL 112, 092001 (2014)]
 - ✓ $e^+e^- \rightarrow Y \rightarrow \omega X(3872)$ [PRL 130, 151904 (2023)]
 - ? $e^+e^- \rightarrow Y \rightarrow \phi X(3872)$

Analysis method

- $368.5 \text{ pb}^{-1} e^+ e^-$ colliding data at $\sqrt{s} = 4.914$ and 4.946 GeV
- $\phi \rightarrow K^+ K^-$, $X(3872) \rightarrow \pi^+ \pi^- J/\psi$, $J/\psi \rightarrow e^+ e^-$ or $\mu^+ \mu^-$
 - 6-track: 4C fit, ϕ and J/ψ mass windows of signal and sidebands
 - 5-track: missing one K, 1C fit, mass windows, and MUC for μ PID



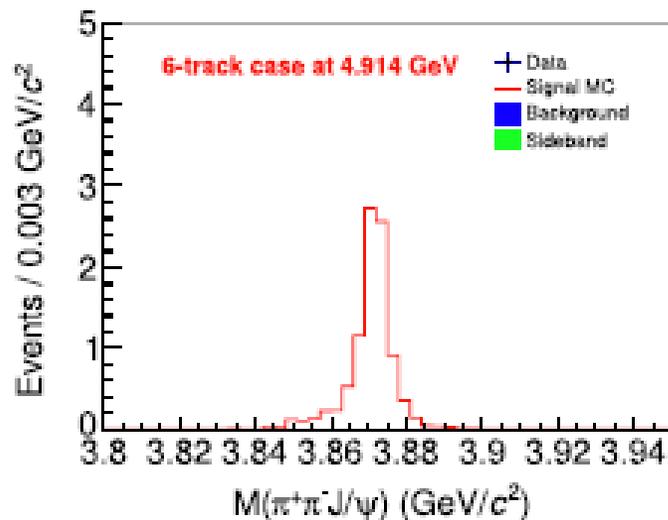
6-track



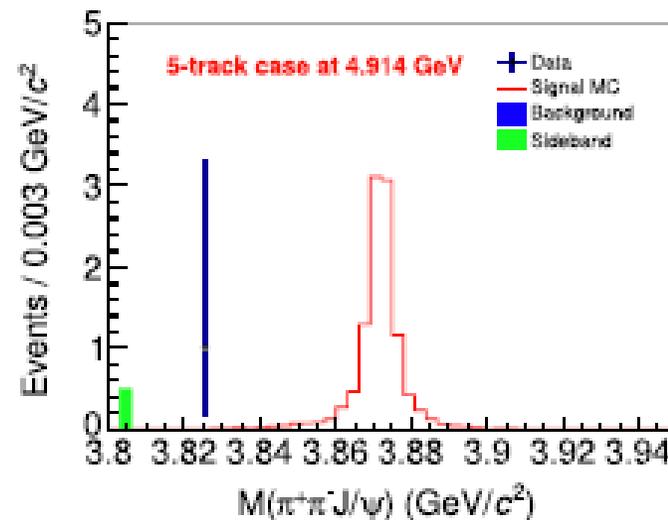
5-track

Results

Almost
no
signal

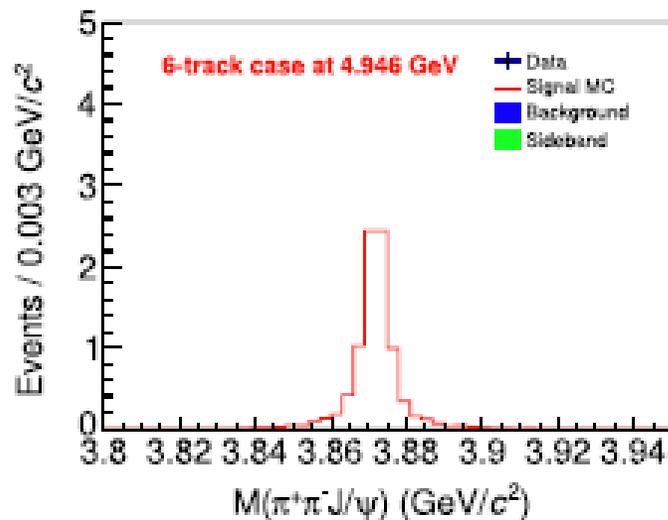


(a)

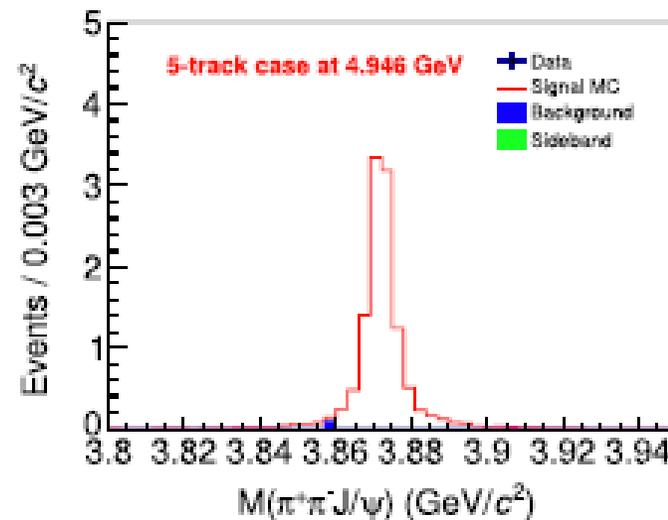


(b)

6-track



(c)



(d)

5-track

Upper limits of the cross sections

$$\sigma(e^+e^- \rightarrow \phi\chi_{c1}(3872)) \cdot \mathcal{B}[\chi_{c1}(3872) \rightarrow \pi^+\pi^-J/\psi]$$

$$= \frac{N_{\text{sig}}}{\mathcal{L}_{\text{int}}(1+\delta) \frac{1}{|1-\Pi|^2} \epsilon \mathcal{B}_{\text{sub}}},$$

[Phys. Rev. D 110, L031103 \(2024\)](#)

BESIII

\sqrt{s}	\mathcal{L}_{int}	N_{obs}	N_{sdb}	$N_{\text{signal}}^{\text{up}}$	$(1+\delta)$	ϵ^5	ϵ^6	σ_B^{up}	
4.914	208.11	0	1	1.70	0.690	19.7	2.8	0.85	pb
4.946	160.37	0	0	2.00	0.755	20.8	7.0	0.96	pb

$$\sigma_{\phi\chi_{c1}(3872)} / \sigma_{\phi\chi_{c1}} < 9$$

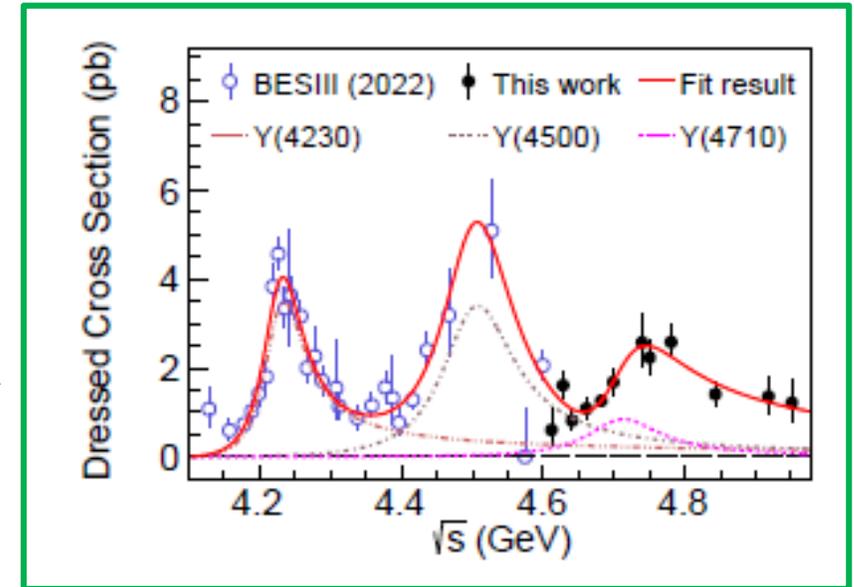
same order to

$$\sigma_{\omega\chi_{c1}(3872)} / \sigma_{\omega\chi_{c1}} \sim 5$$

Search for $e^+e^- \rightarrow K^+K^-\psi(2S)$

BESIII

- Y interest
 - $J^{PC} = 1^{--}$
 - Overpopulates the prediction of potential models
 - Not in the R-value structures, and *favor* hidden-charm final state
 - When strange-quark is involved



Extension from J/ψ to $\psi(2S)$?

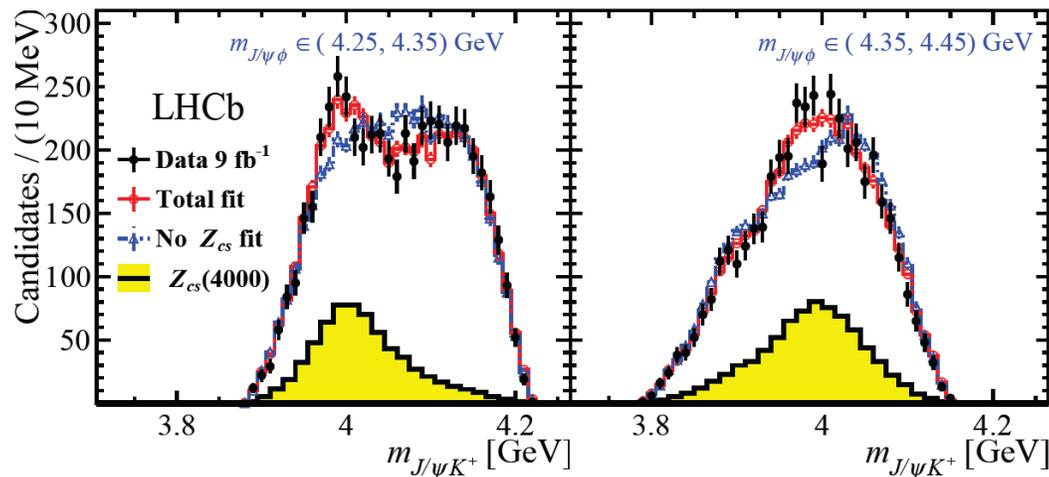
$e^+e^- \rightarrow K^+K^-J/\psi$

[CPC 46, 111002 \(2022\)](#)

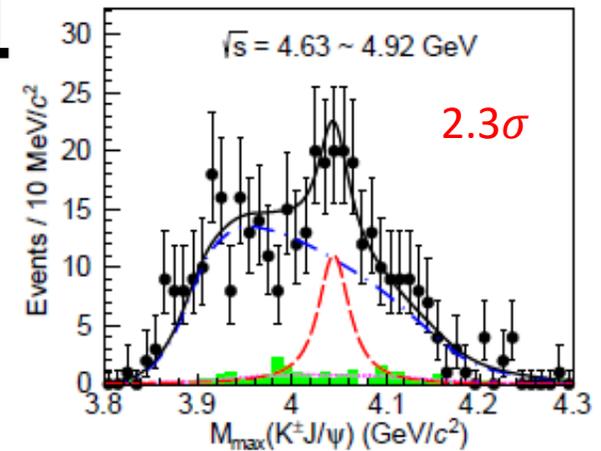
[PRL 131, 211902 \(2023\)](#)

Search for $e^+e^- \rightarrow K^+K^-\psi(2S)$ [cont']

- Z interest
 - Non-zero iso-spin, good tetra-quark candidate
 - From $Z_c (\pi J/\psi)$ to $Z_{cS} (K J/\psi)$



[PRL 127, 082001 \(2021\)](#)

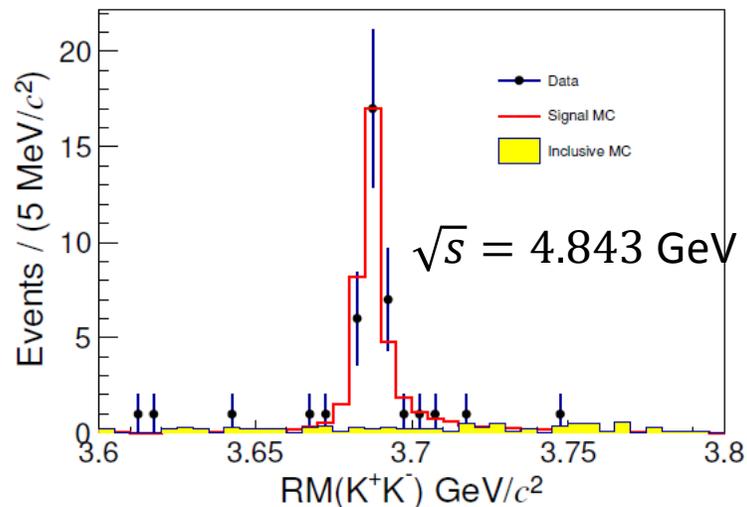


[PRL 131, 211902 \(2023\) 21](#)

Again, extension from J/ψ to $\psi(2S)$?

Analysis strategy

- Data sets: $\sqrt{s} = 4.699 - 4.951$ GeV, 2.5 fb^{-1}
- Various reconstructions
 - Approach (i): tag K^+ , K^- , and J/ψ from $\psi(2S) \rightarrow X J/\psi$
 - Approach (ii): tag K^+ or K^- , and $\psi(2S)$ with $\pi^+\pi^-J/\psi$, 1C
 - Approach (iii): tag K^+ , K^- , and $\psi(2S)$ with l^+l^-
 - Approach (iv): tag K^+ or K^- , and $\psi(2S)$ with l^+l^- , 1C

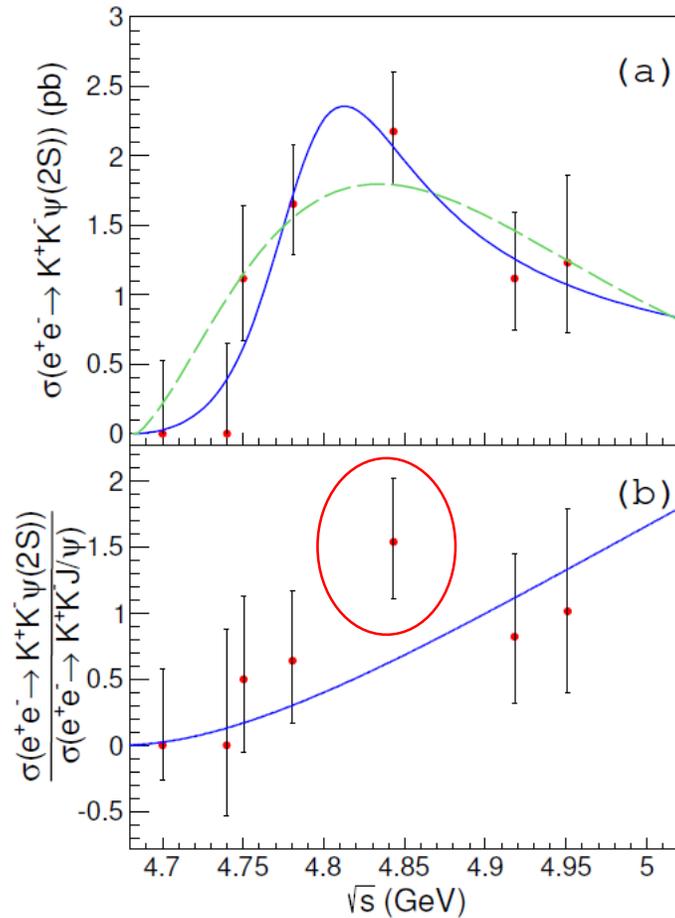


No peaking background from inclusive MC

Cross sections

$$\sigma^B = \frac{N_s}{\mathcal{L}_{\text{int}} \epsilon_r (1 + \delta) \frac{1}{|1 - \Pi|^2}}$$

BESIII



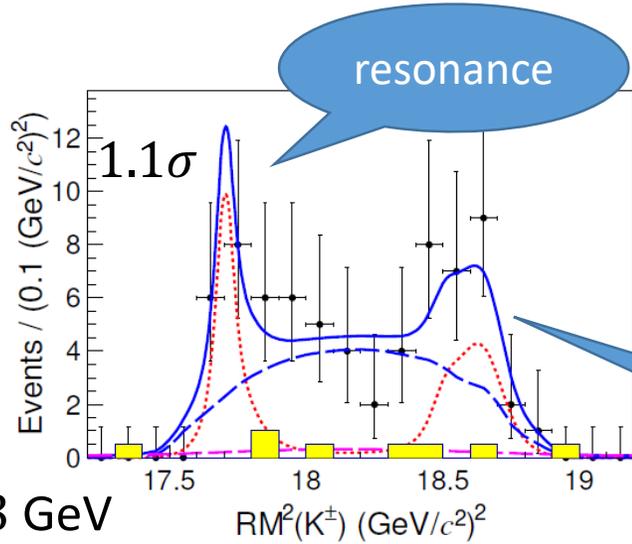
(a) Both BW and Expo functions can fit the data well
 $M = 4787.7 \pm 17.7 \text{ MeV}, \Gamma = 110.3 \pm 33.9 \text{ MeV}$
 $\Gamma^{ee} B(Y \rightarrow K^+ K^- \psi(2S)) = 0.13 \pm 0.02 \text{ eV}$

(b) Solid line represents PHSP, 2σ deviation at 4.845 GeV
 Indicate distinct production mechanism

[arXiv:2407.20009](https://arxiv.org/abs/2407.20009), submitted to [Phys. Rev. Lett.](https://arxiv.org/abs/2407.20009)

Search for $Z_{cs} \rightarrow K^\pm \psi(2S)$

BESIII



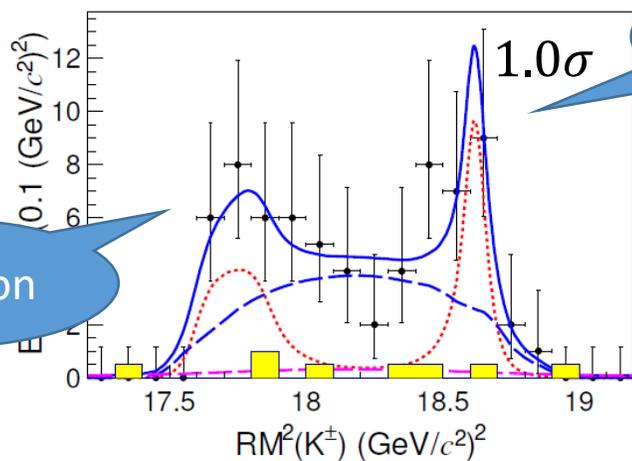
Two fit assumptions (interference is ignored)

I: low mass, high reflection

$$M = 4208.4 \pm 3.1 \text{ MeV}, \Gamma = 6.1 \pm 5.7 \text{ MeV}$$

reflection

$$\sqrt{s} = 4.843 \text{ GeV}$$



II: high mass, low reflection => 4.315 GeV

$$M = 4316.0 \pm 2.7 \text{ MeV}, \Gamma = 9.0 \pm 8.6 \text{ MeV}$$

reflection

[arXiv:2407.20009](https://arxiv.org/abs/2407.20009), submitted to [Phys. Rev. Lett.](https://arxiv.org/abs/2407.20009)

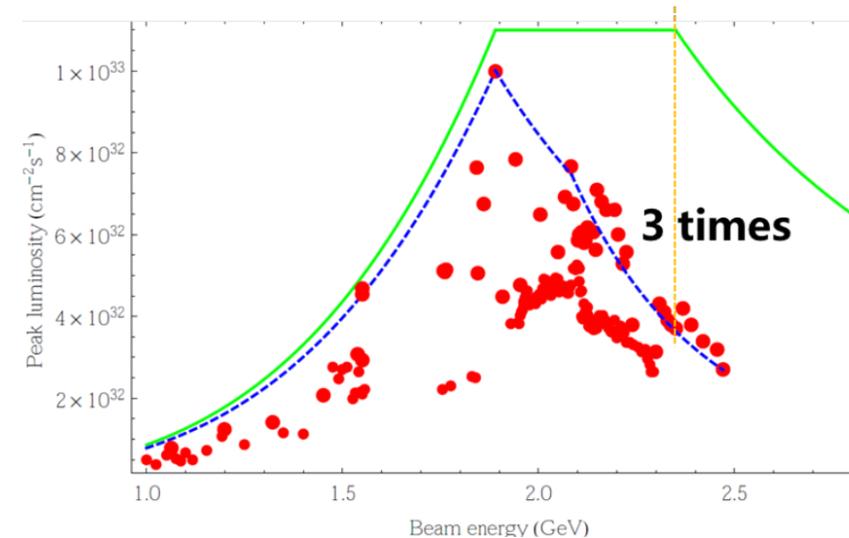
Summary and outlook

- Charmonium-like physics is still an active topic at BESIII
- Ways to beyond the limited statistics (analysis vs. data)

BEPCII will upgrade in both Lum. and Max. E

- Luminosity is increased by a factor 3 @ 2.35 GeV
- Maximun beam energy is increased up to 2.8 GeV

More data, more exciting results!



Thanks for your attention!