

# Vector charmonium(-like) states at BESIII



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on behalf of BESIII Collaboration

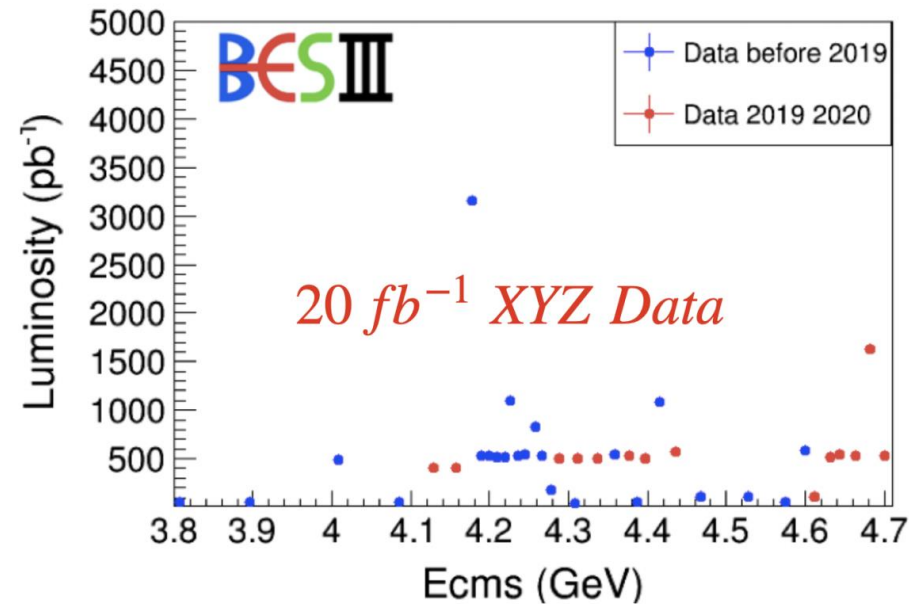
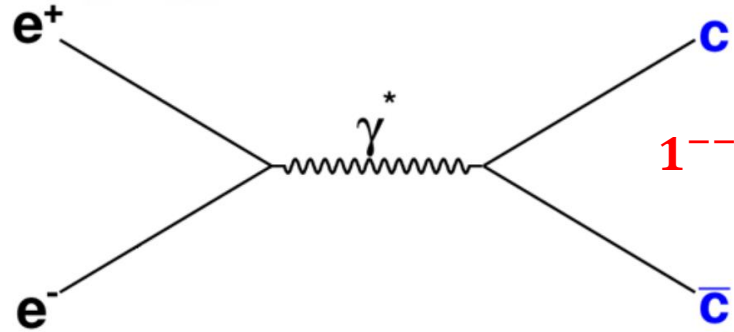
2021/8/16

# Outline

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- Introduction;
- Recent vector charmonium(-like) results at BESIII:
  1.  $e^+e^- \rightarrow \gamma + \chi_{cJ}$ ;
  2.  $e^+e^- \rightarrow X + J/\psi$ ;
  3.  $e^+e^- \rightarrow X + \eta_c$ ;
  4.  $e^+e^- \rightarrow X + \psi(2S)$ ;
  5.  $e^+e^- \rightarrow \textit{Light hadrons}$ ;
  6.  $e^+e^- \rightarrow \text{open charm}$ ;
- Summary;

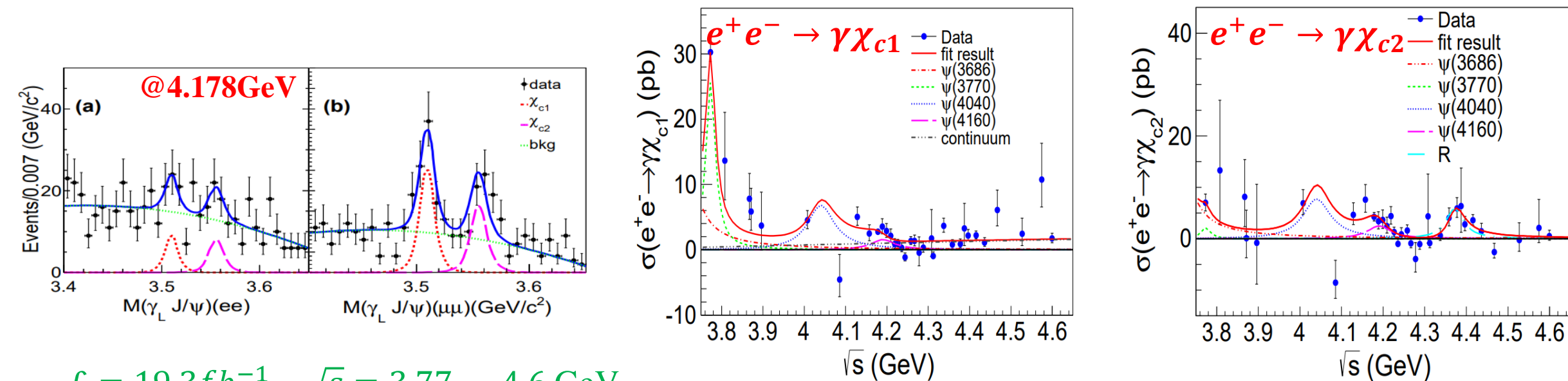
# Introduction



- Vector Charmonium(-like) States can be produced directly by electron-positron annihilation;
- Including the data collected in the recent two years, there are a total of  $\sim 20 \text{ fb}^{-1}$  from 3.8 ~ 4.7 GeV;
- Method of studying vector Charmonium(-like) States at BESIII: measured cross section line-shape, search for structures;
- Search for more decay modes will be helpful to understand their properties;

$$e^+e^- \rightarrow \gamma\chi_{c0,c1,c2}$$

arXiv: 2107.03604



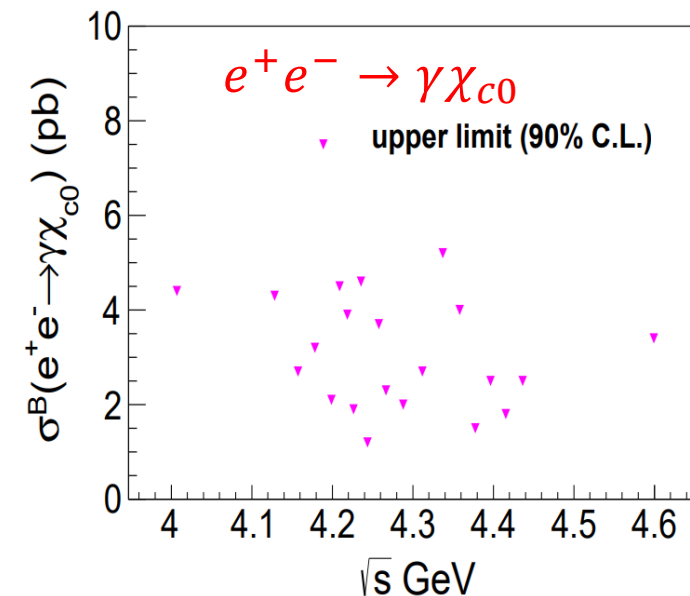
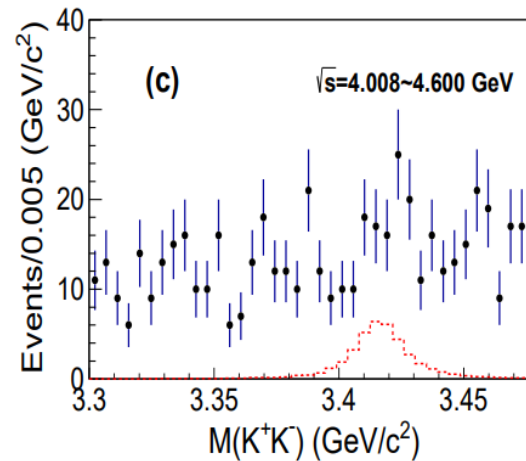
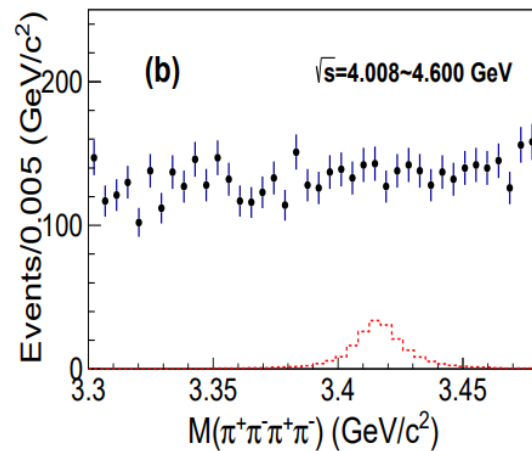
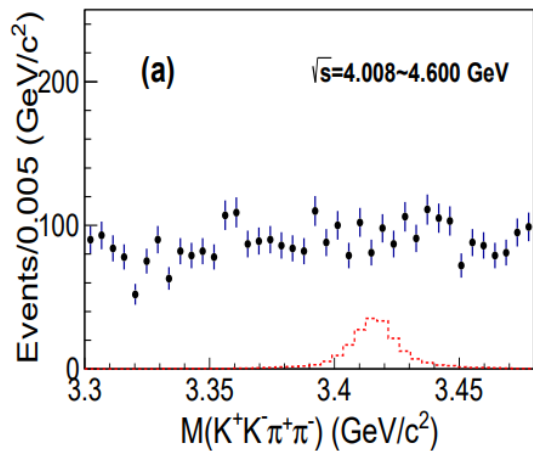
$$\mathcal{L} = 19.3 fb^{-1}, \sqrt{s} = 3.77 - 4.6 \text{ GeV}$$

- The processes of  $e^+e^- \rightarrow \gamma\chi_{c1,c2}$  are observed for the first time @ 4.178 GeV ( $7.6\sigma$  and  $6.0\sigma$ );
- Components in the cross section fit:
  - $e^+e^- \rightarrow \gamma\chi_{c1}$ :  $\psi(3686)$ ,  $\psi(3770)$ ,  $\psi(4040)$ ,  $\psi(4160)$  + continuum contribution;  $\psi(4040)$  ( $3.3\sigma$ ),  $\psi(4160)$  ( $3.7\sigma$ ), continuum ( $6.7\sigma$ );
  - $e^+e^- \rightarrow \gamma\chi_{c2}$ :  $\psi(3686)$ ,  $\psi(3770)$ ,  $\psi(4040)$ ,  $\psi(4160)$  +  $Y(4360)$ ;  $\psi(4040)$  ( $2.0\sigma$ ),  $\psi(4160)$  ( $4.6\sigma$ ),  $Y(4360)$  ( $5.8\sigma$ );
- The measured cross section are consistent with potential model predictions, except for  $B[\psi(4160) \rightarrow \gamma\chi_{c2}]$  is **three order of magnitude higher than** potential model predictions ( $\sim 10^{-7}$ );

$$e^+e^- \rightarrow \gamma\chi_{c0,c1,c2}$$

arXiv: 2107.03604

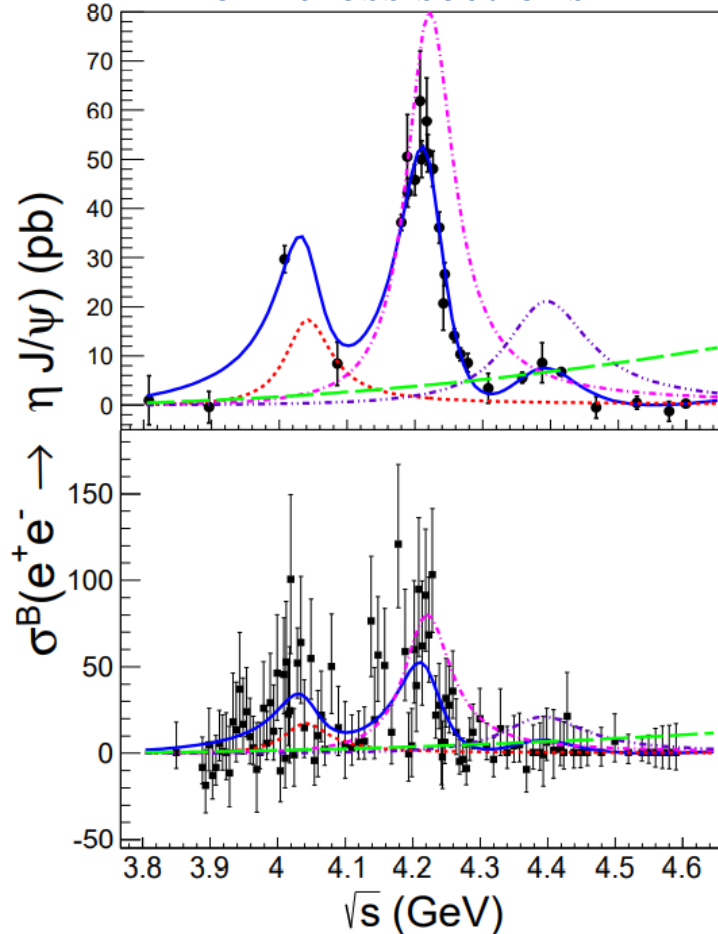
$$e^+e^- \rightarrow \gamma\chi_{c0}$$



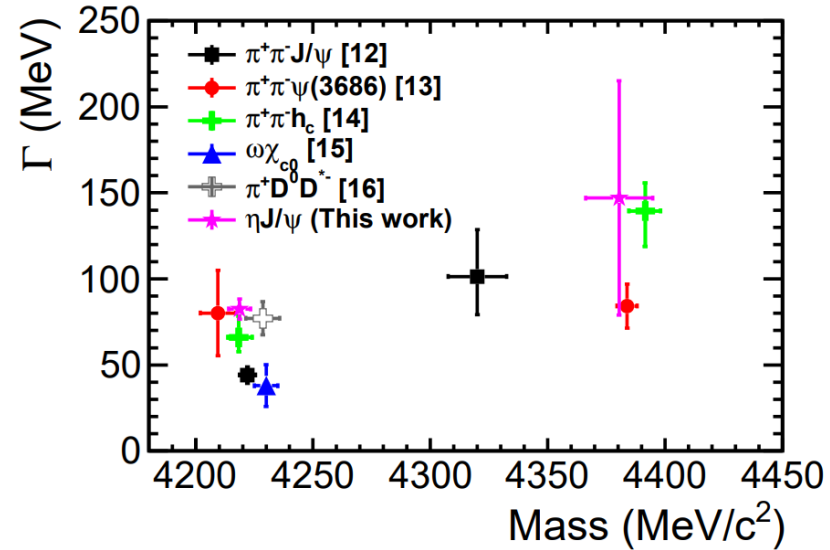
$$\mathcal{L} = 15 fb^{-1}, \sqrt{s} = 4.0 - 4.6 \text{ GeV}$$

- $\chi_{c0} \rightarrow K^+K^-\pi^+\pi^-/2(\pi^+\pi^-)/K^+K^-$ ;
- No obvious signal of  $e^+e^- \rightarrow \gamma\chi_{c0}$  ;
- The UL is consistent with potential model expectations;

### Born cross sections



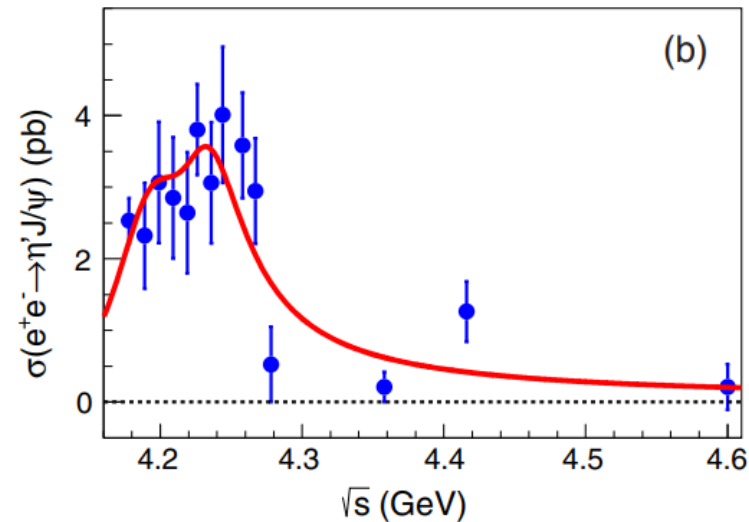
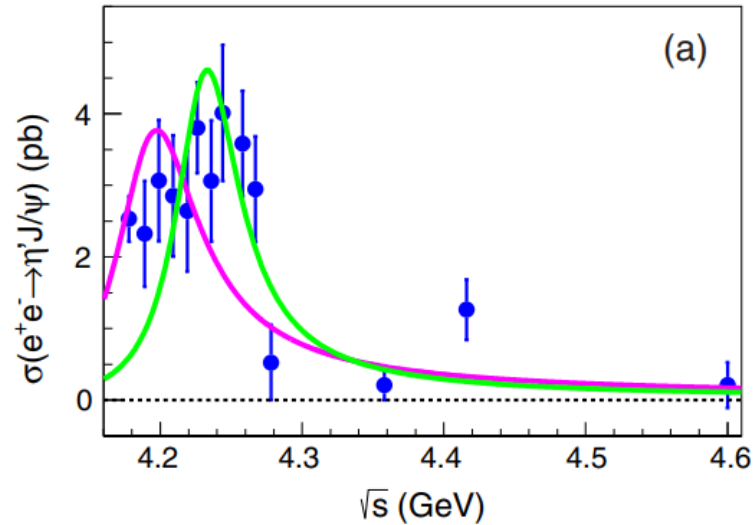
$$\sigma^B(\sqrt{s}) = |C_0 \sqrt{\Phi(\sqrt{s})} + e^{i\phi_1} B_1(\sqrt{s}) + e^{i\phi_2} B_2(\sqrt{s}) + e^{i\phi_3} B_3(\sqrt{s})|^2,$$



$$\mathcal{L} = 13.1 \text{ fb}^{-1}, \sqrt{s} = 3.8 - 4.6 \text{ GeV}$$

- Three structures : 4.04 GeV( $\psi(4040)$ ), 4.22GeV and 4.36GeV;
- The measured resonant parameters are consistent with  $Y(4220)$ ,  $Y(4360)$ ;
- Observation of  $Y(4220) \rightarrow \eta J/\psi$ , significantly higher than the  $\psi(4160) \rightarrow \eta J/\psi$  ( $8.1\sigma$ );
- Observation of  $Y(4360) \rightarrow \eta J/\psi$  with significance of  $6.0\sigma$ ;

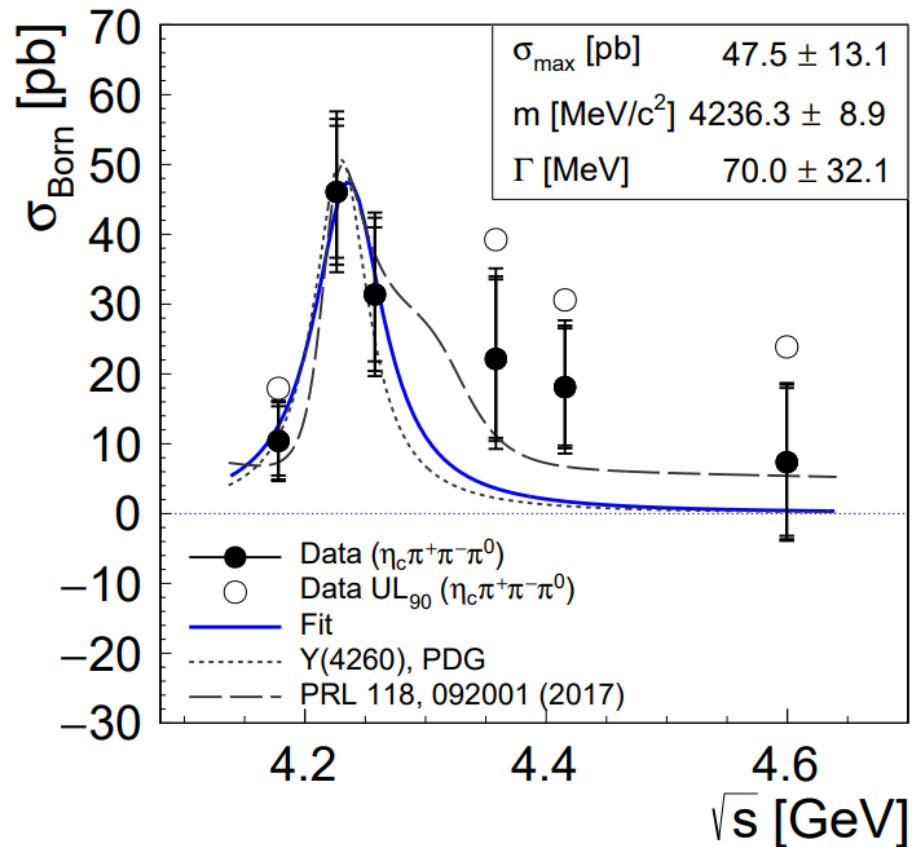
### Dressed cross sections



$\mathcal{L} = 11 \text{ fb}^{-1}$ ,  $\sqrt{s} = 4.18 - 4.6 \text{ GeV}$

- The  $e^+e^- \rightarrow \eta' J/\psi$  cross section **cannot be** properly described by **a single  $\psi(4160)$  or  $\psi(4260)$**  resonance (confidence level of  $2.9 \times 10^{-4} / 1.5 \times 10^{-8}$ );
- While a coherent sum of  $\psi(4160)$  and  $\psi(4260)$  offers **a better description**(confidence level of 6.1%);
- The significances for the  $\psi(4160)$  and  $\psi(4260)$  are  **$6.3\sigma$  and  $4.0\sigma$** .
- The cross section of  $e^+e^- \rightarrow \eta' J/\psi$  is about **an order of magnitude lower** than that of  $e^+e^- \rightarrow \eta J/\psi$ ;

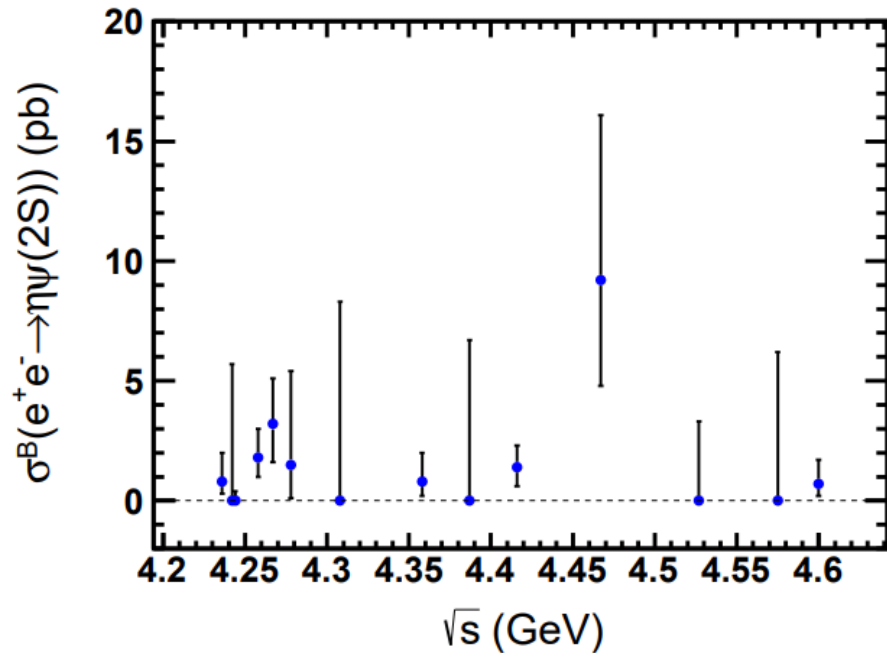
### Born cross sections



$$\mathcal{L} = 7.3 \text{ fb}^{-1}, \quad \sqrt{s} = 4.18 - 4.6 \text{ GeV};$$

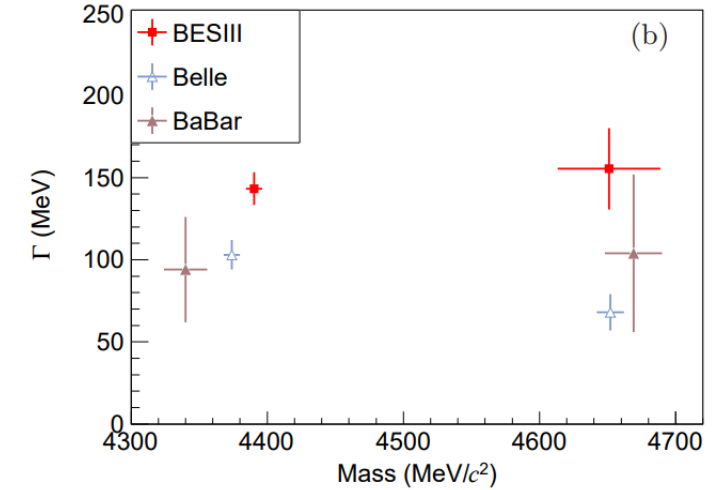
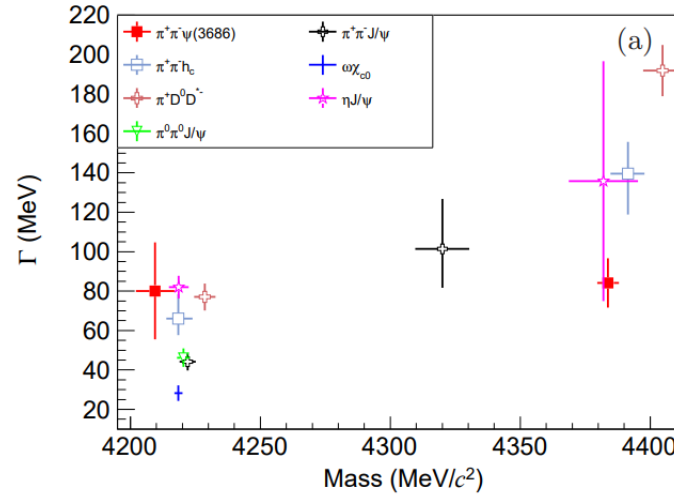
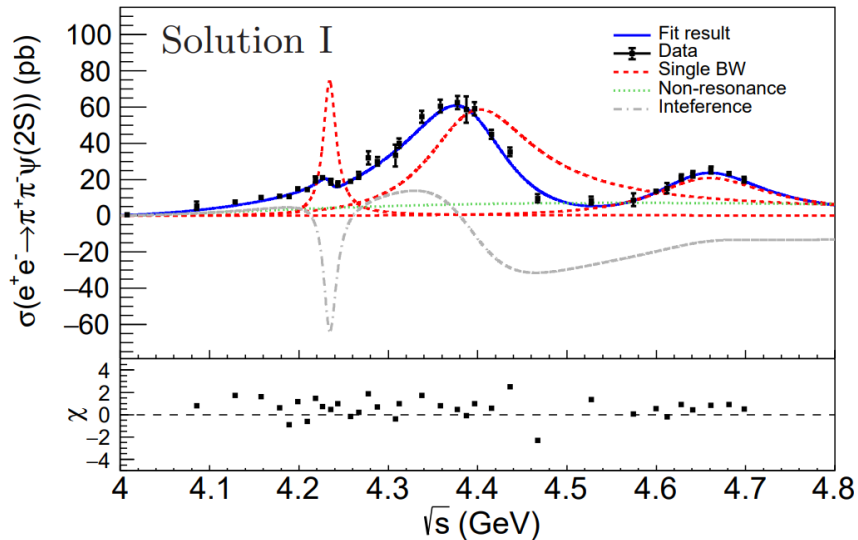
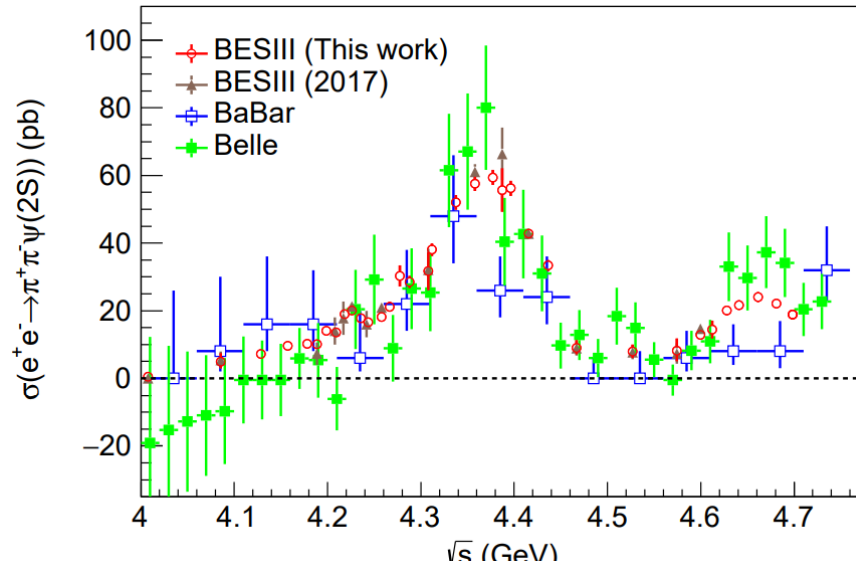
- The process  $e^+e^- \rightarrow \eta_c \pi^+ \pi^- \pi^0$  is **observed for the first time** with significance of  $5.2\sigma$ ;
- The energy-dependent Born cross section measured to be in agreement with the hypothesis of the production of  **$Y(4260) \rightarrow \eta_c \pi^+ \pi^- \pi^0$** ;
- While no signal is found for a charged  **$Z_c^\pm \rightarrow \eta_c \pi^\pm$**  state;

### Born cross sections



$$\mathcal{L} = 5.2 fb^{-1}, \sqrt{s} = 4.23 - 4.6 \text{ GeV}$$

- For the first times,  $e^+e^- \rightarrow \eta \psi(2S)$  are observed with a statistical significance of  $5\sigma$ ;
- Impossible to extract the couplings of the Y states to from a fit to the cross sections , due to the **limited statistics**;
- Further experimental studies with higher statistics are needed to draw a clear conclusion on the structure in  $e^+e^- \rightarrow \eta \psi(2S)$ ;



$\mathcal{L} = 20.1 fb^{-1}$ ,  $\sqrt{s} = 4.0 - 4.7$  GeV

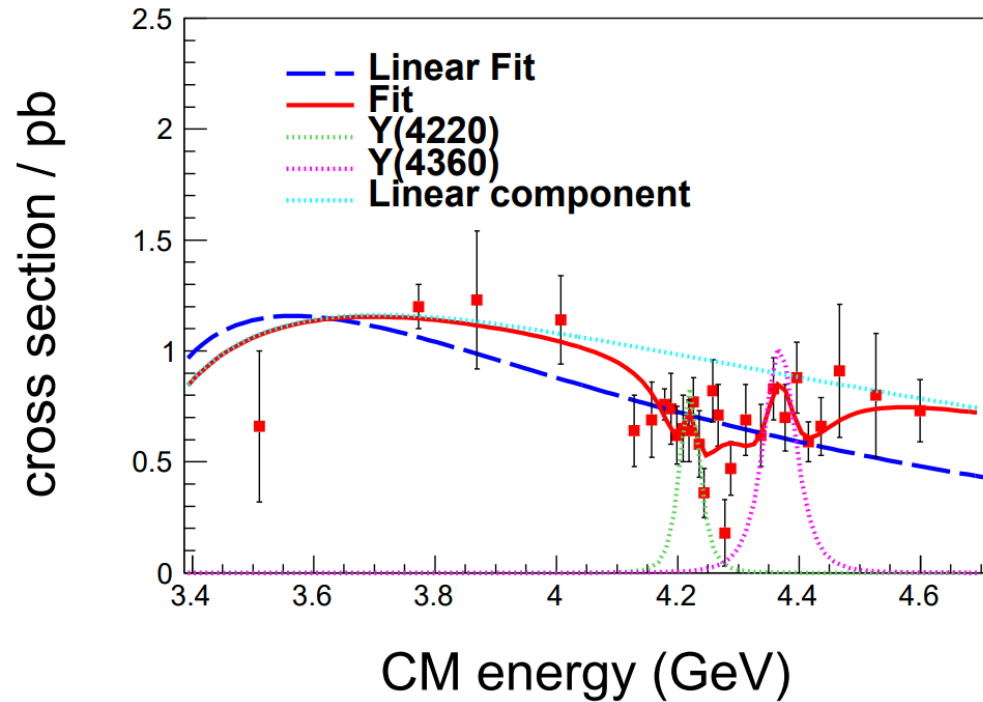
- The measured cross section is consistent with previous results, but with much improved precision;

- Fit function:  $\sigma^{\text{dressed}}(\sqrt{s}) = \left| \sum_k e^{i\phi_k} \cdot BW_k(s) + e^{i\phi_{\text{cont}}} \cdot \psi_{\text{cont}} \right|^2$

- **Y(4220), Y(4390), Y(4660) and a non-resonant contribution;**
- The fit results **confirm** the existence of four contributions;

$$e^+e^- \rightarrow \phi\Lambda\bar{\Lambda}$$

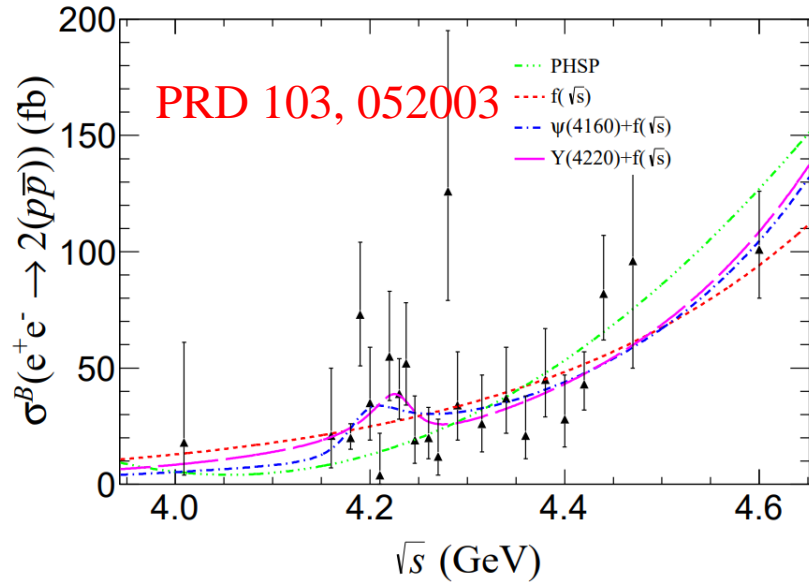
arXiv: 2104.08754



$$\mathcal{L} = 20 \text{ fb}^{-1}, \sqrt{s} = 3.5 - 4.6 \text{ GeV}$$

- It is clear that the lineshape **cannot be simply described with a continuum process** parameterized as  $1/s^n$  ( $n = 2.2 \pm 0.4$ );
- **Peaking structures** with statistical significances of  $4.2\sigma$  and  $3.1\sigma$  are seen around  $\sqrt{s} = 4.23$  and  $4.36$  GeV, respectively.

# $e^+e^- \rightarrow \text{Light hadrons}$

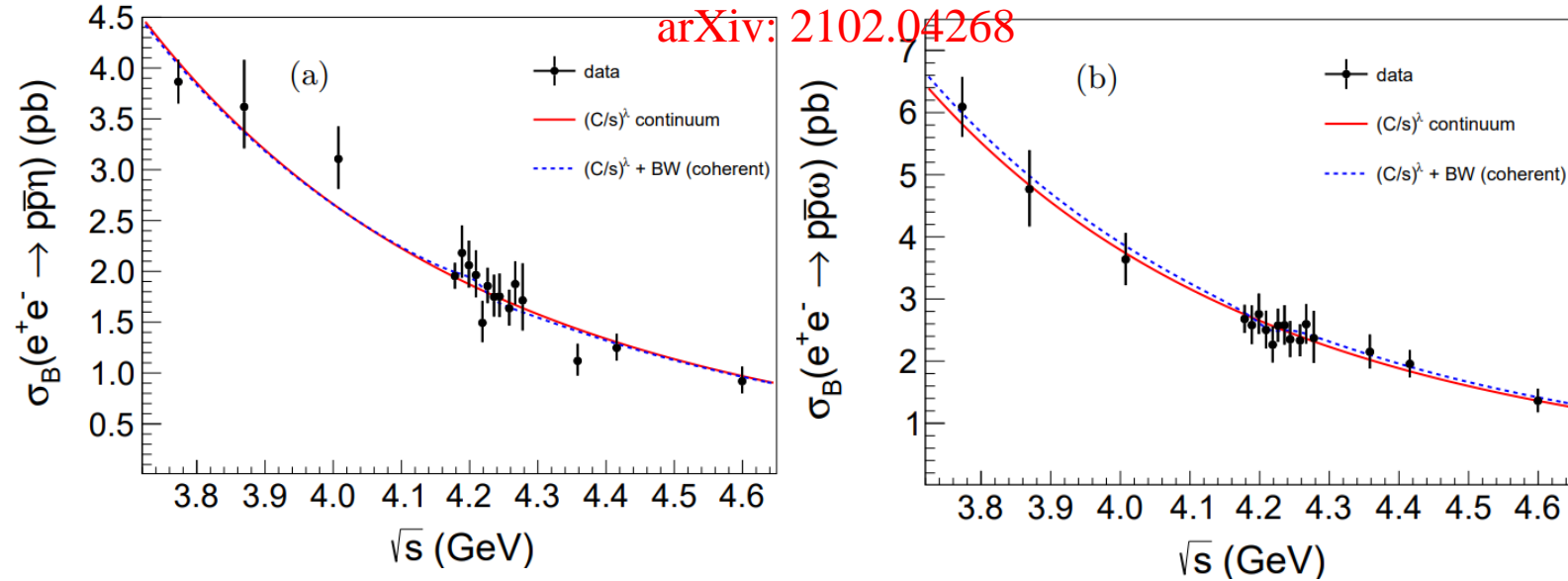


$$e^+e^- \rightarrow 2(p\bar{p})$$

$$\mathcal{L} = 15 \text{ fb}^{-1}, \sqrt{s} = 4.0 - 4.6 \text{ GeV}$$

Significances of  $\psi(4160)$  :  $0.8\sigma$ ;

Significances of  $Y(4220)$  :  $1.7\sigma$ ;



$$e^+e^- \rightarrow p\bar{p}\eta/p\bar{p}\omega$$

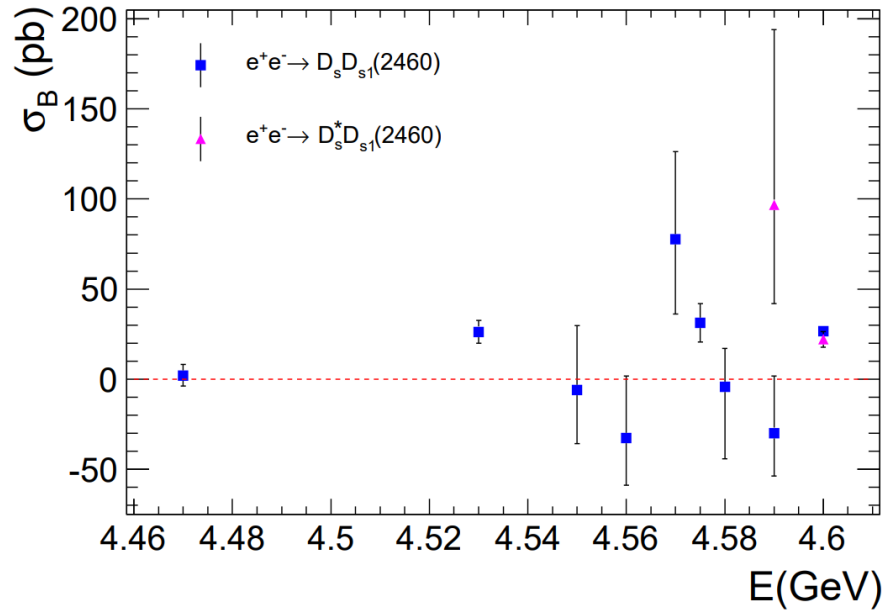
$$\mathcal{L} = 14.7 \text{ fb}^{-1}, \sqrt{s} = 3.77 - 4.6 \text{ GeV}$$

no evidence for a resonant contribution

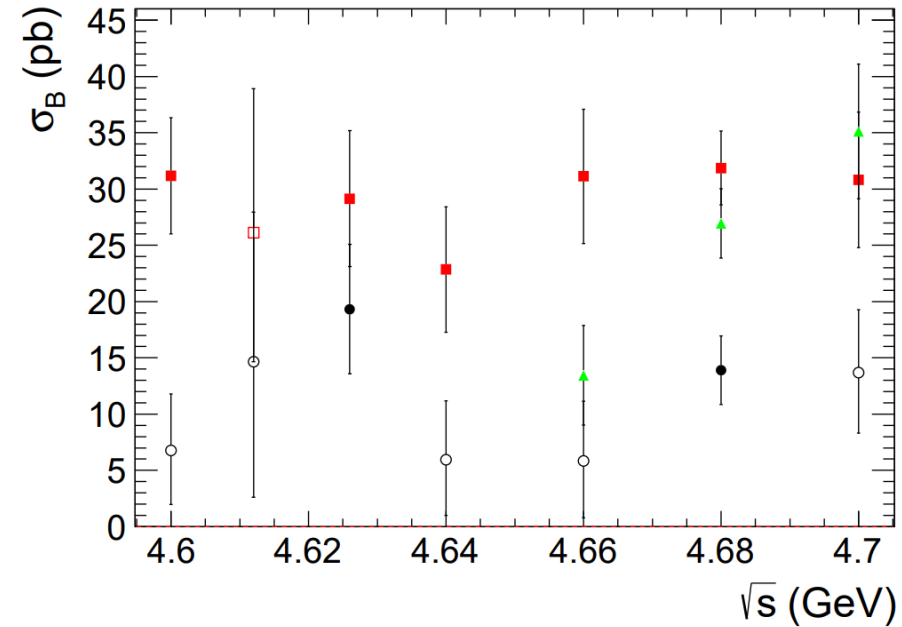
$Y/\psi \rightarrow p\bar{p}\eta/p\bar{p}\omega$ ;

# $e^+e^- \rightarrow \text{open charm}$

Phys. Rev. D 101, 112008 (2020)



arXiv:2106.02298



$$e^+e^- \rightarrow D_s^+ D_{s1}(2460)^- / D_s^{*+} D_{s1}(2460)^- + \text{c.c.}$$

$\mathcal{L} = 0.9/0.6 \text{ fb}^{-1}$ ,  $\sqrt{s} = 4.467/4.590 - 4.6 \text{ GeV}$

No obvious charmonium or charmonium-like structure is seen in the measured cross section;

$$e^+e^- \rightarrow D_s^{*+} D_{s0}(2317)^- / D_s^{*+} D_{s1}(2460)^- / D_s^{*+} D_{s1}(2536)^- + \text{c.c.}$$

$\mathcal{L} = 4.4/2.7 \text{ fb}^{-1}$ ,  $\sqrt{s} = 4.6/4.66 - 4.7 \text{ GeV}$

No structures are observed in cross-section distributions for any of the processes

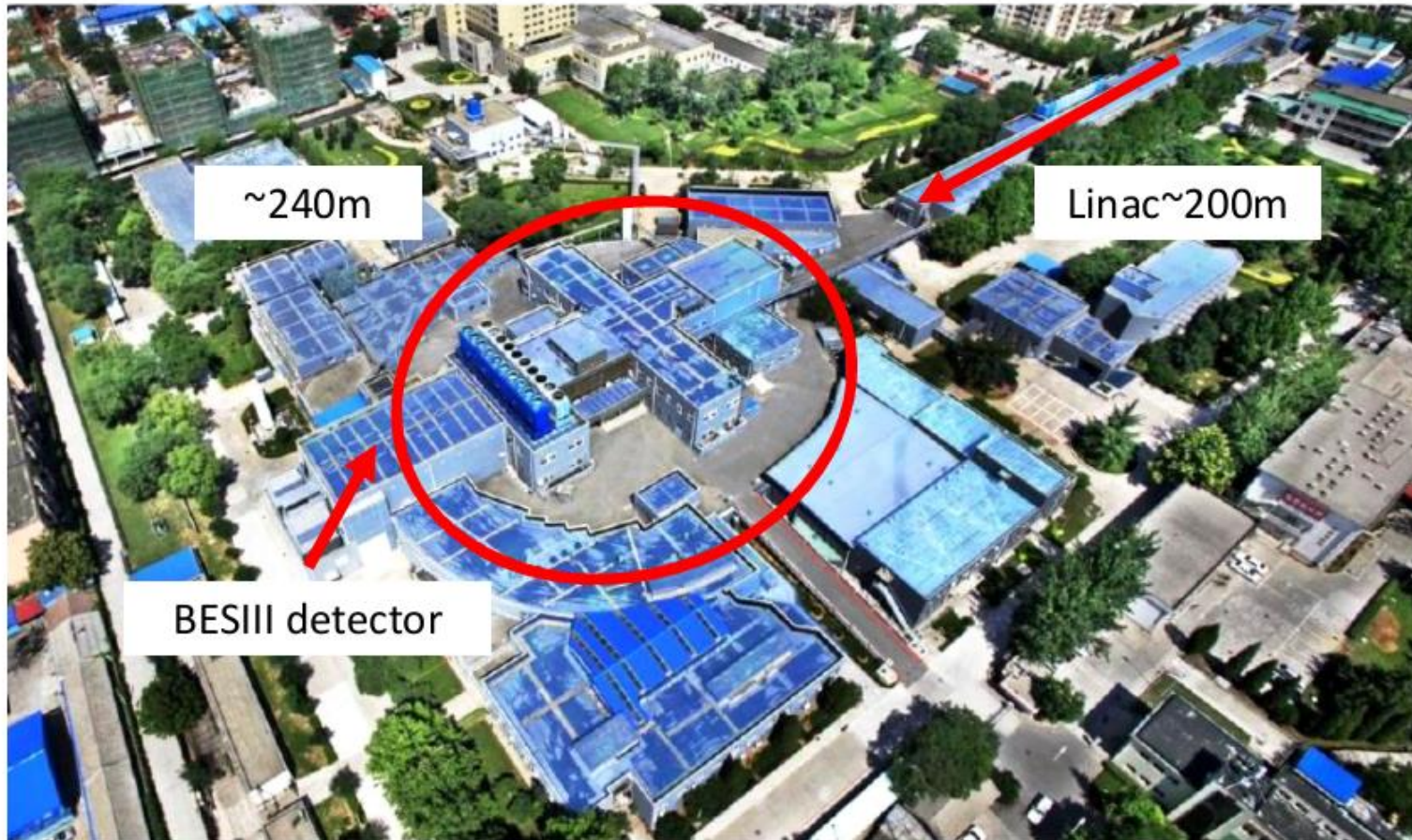
# Summary

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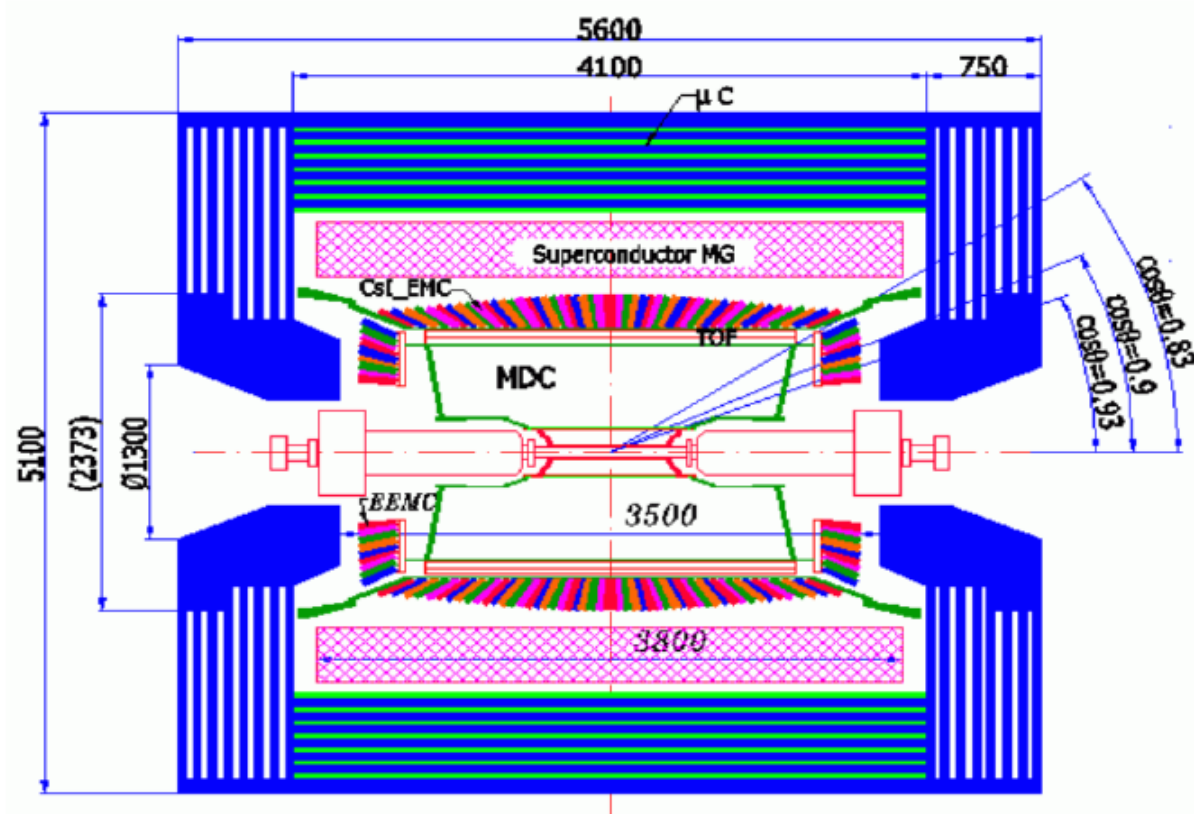
- A lot of progress in study of Vector Charmonium(-like) States in recent year at BESIII;
- Possible “new” decay modes of  $Y(4220)/Y(4360)/Y(4390)/Y(4660) - \psi(4040)/\psi(4160)$  are studied;
- More results about Vector Charmonium(-like) States will come soon!

*Thanks for your attention*

# Back Up



- Double rings;
- $E_{cm} = 2.0\text{--}4.6\text{ GeV}$  ( $2.0\text{--}4.9\text{ GeV}$  since 2019);
- Energy spread:  $\Delta E \approx 5 \times 10^{-4}\text{ GeV}$ ;
- Design luminosity @  $E_{cm} = 3.77\text{ GeV}$ :  $\sim 1 \times 10^{33}\text{ cm}^{-2}\text{ s}^{-1}$  (reached 2016);
- 2009~ today: BESIII physics runs;



Chin.Phys.C 44 (2020) 4, 040001

## Main Drift Chamber

$$\sigma_p/p < 0.5\% \text{ (@1GeV) (1T)}$$

$$\sigma_{xy} \sim 120 \mu m$$

$$dE/dx \sim 6\%$$

## Time Of Flight

$$\sigma_t < 68 ps \text{ (barrel)}$$

$$\sigma_t < 70 ps \text{ (endcap MRPC)}$$

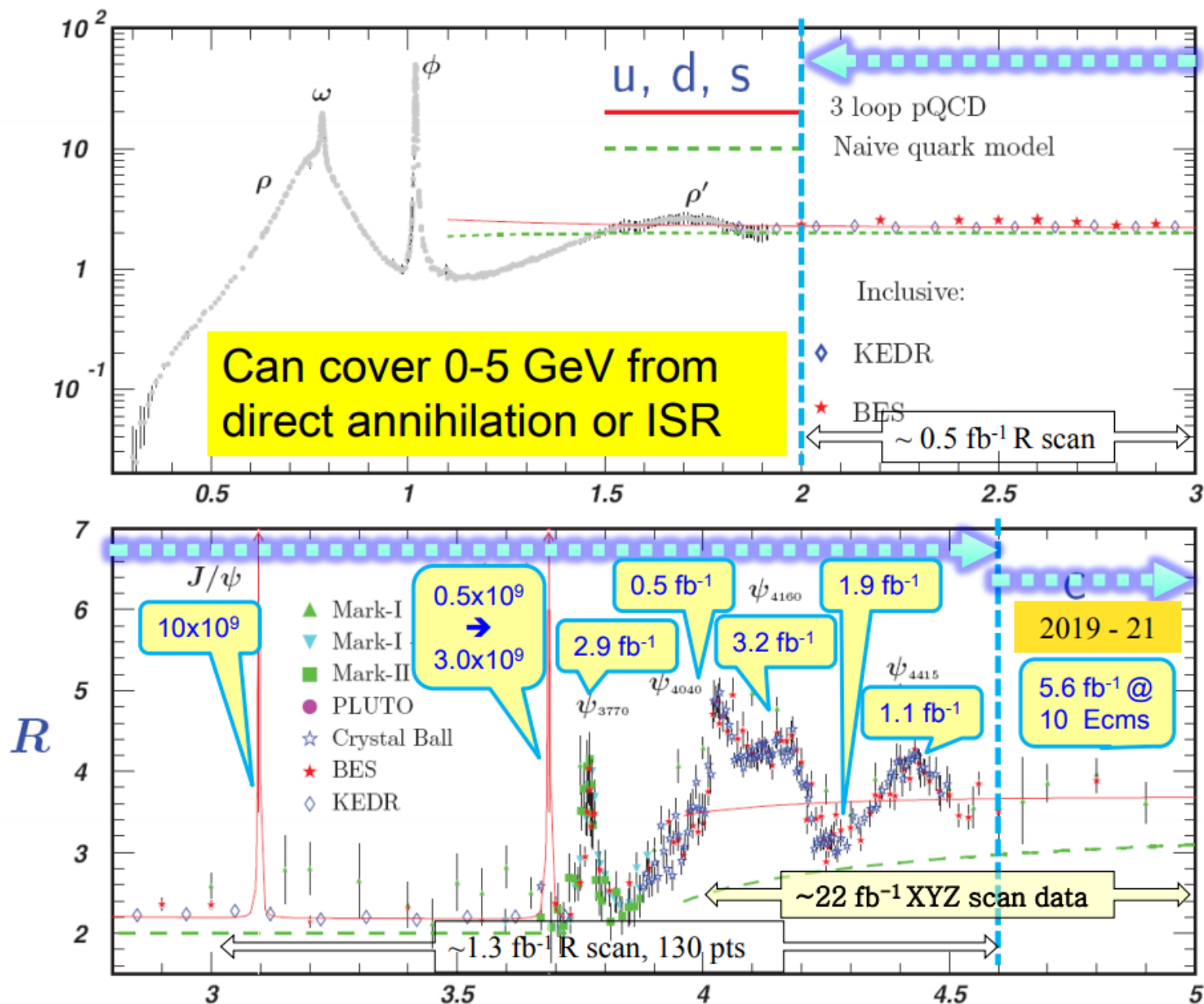
## Electromagnetic Calorimeter

$$\sigma_E/E < 2.5\% \text{ (@1GeV)}$$

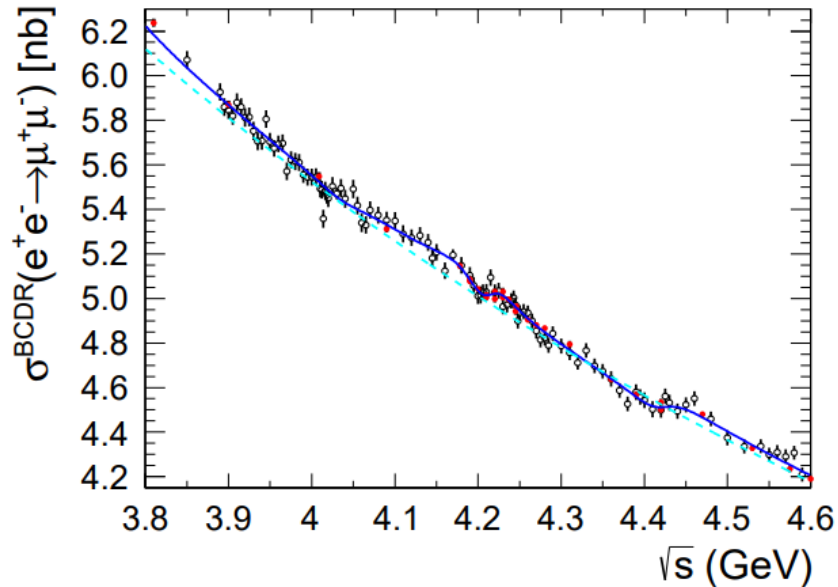
$$\sigma_{xy} \sim 6 mm \text{ (@1GeV)}$$

## Muon Counter

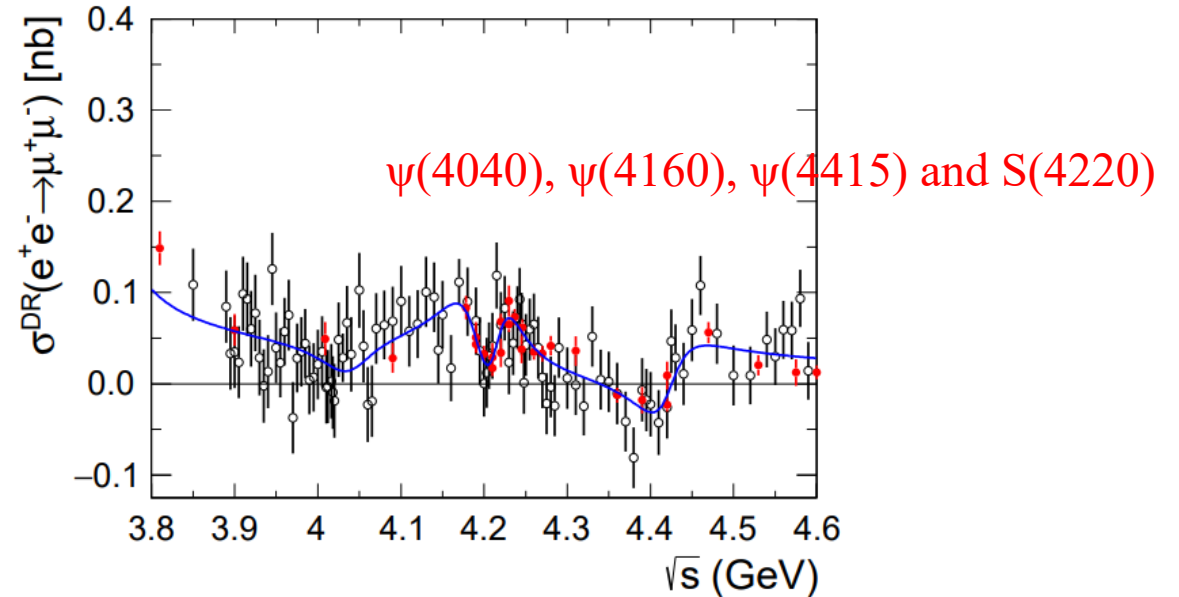
$$\sigma_{\text{spatial}} < 2 cm$$



Dressed cross section



subtracted both the continuum and  $\psi(3686) \rightarrow \mu^+\mu^-$



$$\sigma_{\mu^+\mu^-}^D(s(1-x)) = \left| A_{\text{cnt}} + \sum_{k=1}^9 e^{i\phi_{R_k}} A_{R_k} + e^{i\phi_S} A_S \right|^2$$

$\mathcal{L} = 13.2 fb^{-1}$ ,  $\sqrt{s} = 3.8 - 4.6$  GeV

- For the first times, directly measured the muonic widths, branching fractions and the phases of the decay amplitudes;
- A structure S(4220):  $M_{S(4220)} = 4216.7 \pm 8.9 \pm 4.1 \text{ MeV}/c^2$ ,  $\Gamma_{S(4220)}^{\text{tot}} = 47.2 \pm 22.8 \pm 10.5 \text{ MeV}$  with significance of  $3.9\sigma$ ;