

# Recent results from BESIII on heavy-flavour exotica

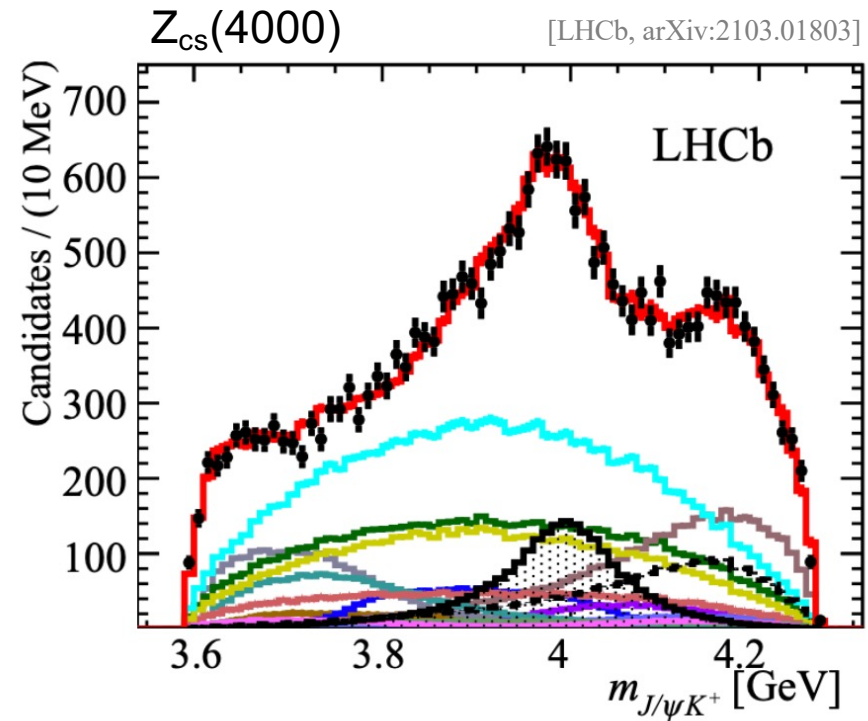
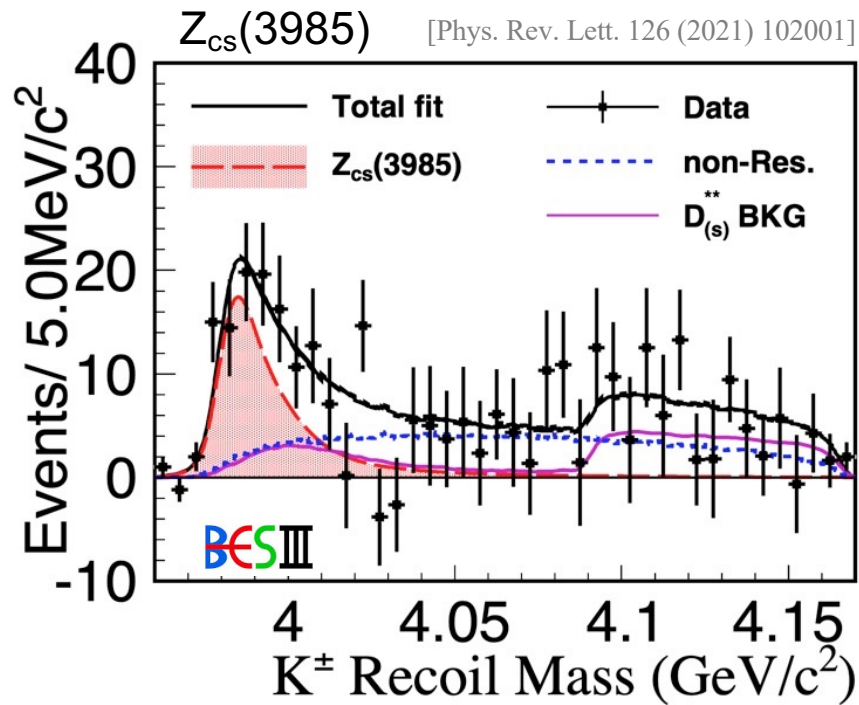
Frank Nerling  
HFHF, GSI & GU Frankfurt

4<sup>th</sup> Workshop on Anti-Matter, Hyper-Matter and Exotica Production  
at the LHC, February 13<sup>th</sup> - 17<sup>th</sup> 2023, Bologna

## Outline

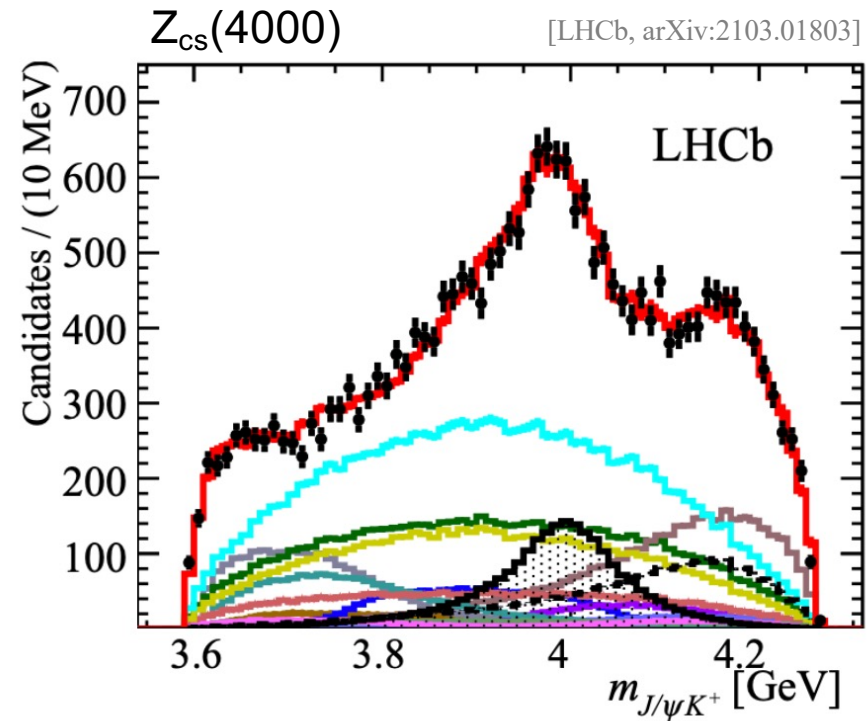
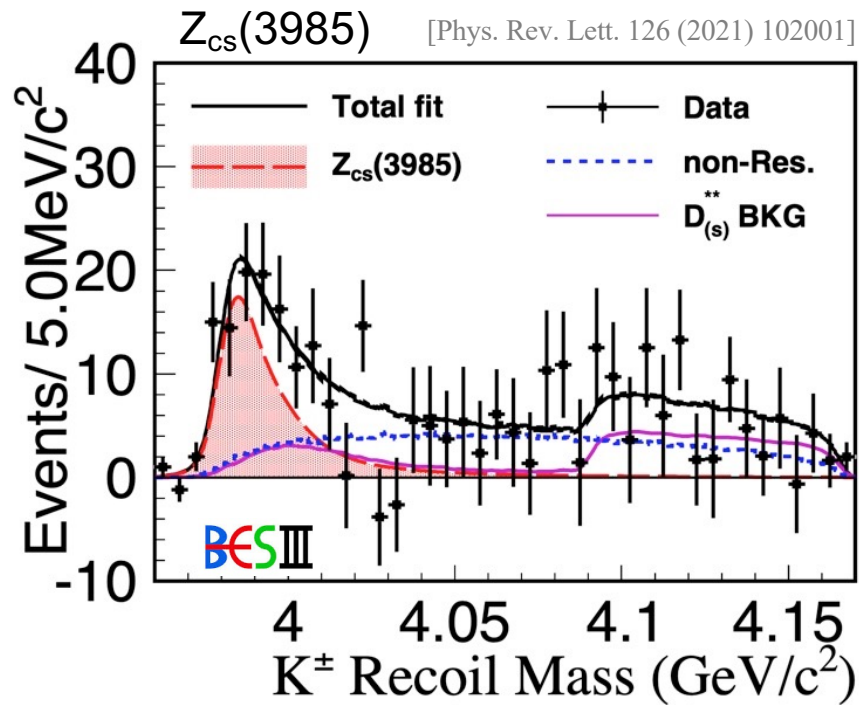
- Introduction
- The BESIII experiments and data sets
- A selection of recent results
  - Supernumerary vector  $Y$  states
  - Manifestly exotic  $Z_c$  states
  - The  $X(3872)$  and other  $X$  states
- Summary

## Hadron Spectroscopy

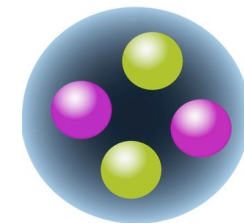


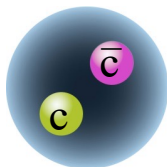
**Strange partner of the famous,  
unexpected, manifestly exotic  $Z_c(3900)$ ?**

## Hadron Spectroscopy



Strange partner of the famous,  
unexpected, manifestly exotic  $Z_c(3900)$ ?





### Potential model:

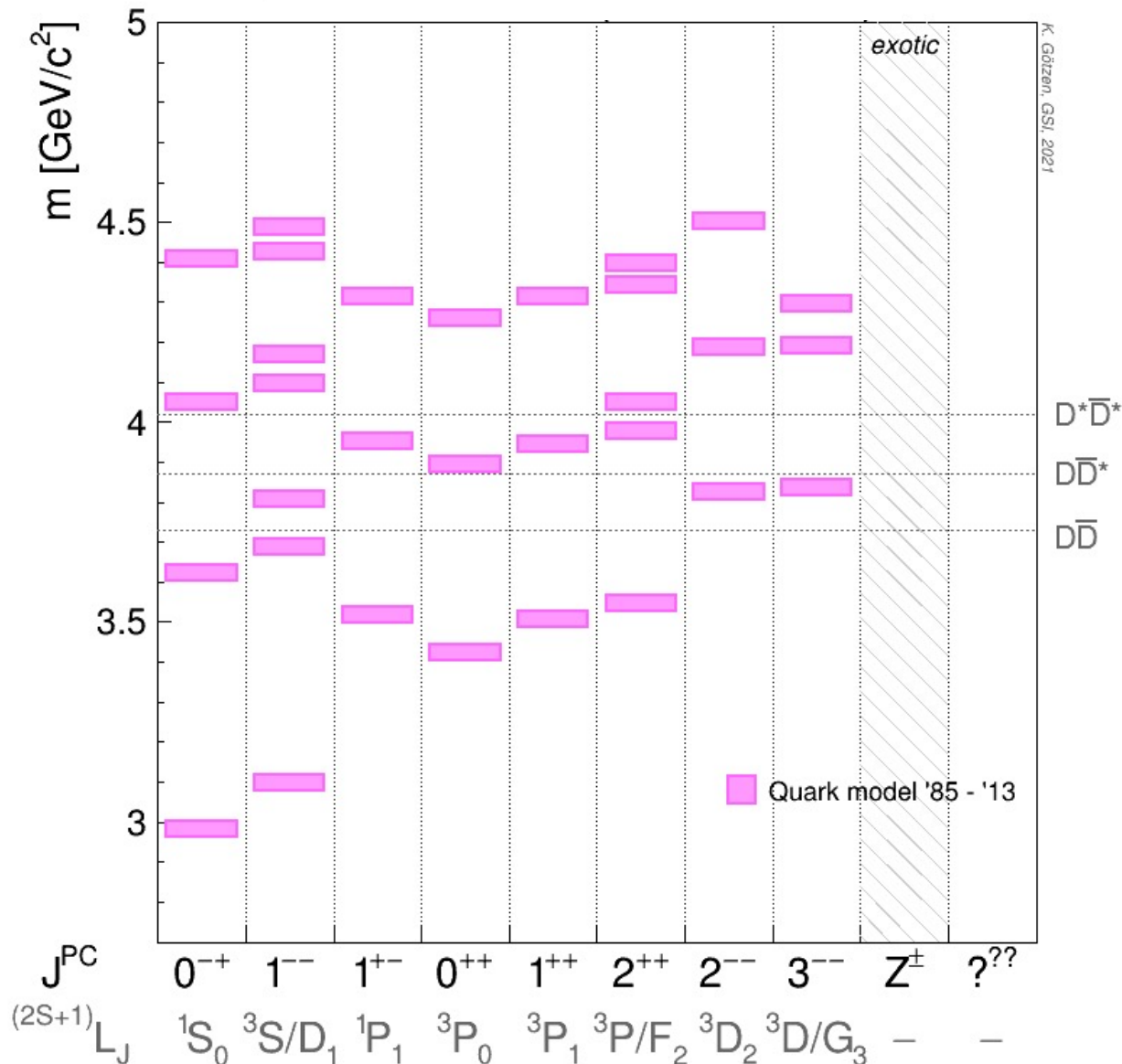
$$V_0^{c\bar{c}} = -\frac{4}{3} \frac{\alpha_s}{r} + br + \frac{32\pi\alpha_s}{9m_c^2} \delta(r) \vec{S}_c \vec{S}_{\bar{c}}$$

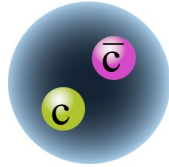
$$V_{\text{spin-dep.}} = \frac{1}{m_c^2} \left[ \left( \frac{2\alpha_s}{r^3} - \frac{b}{2r} \right) \vec{L} \cdot \vec{S} + \frac{4\alpha_s}{r^3} T \right]$$

+ relativistic corrections!

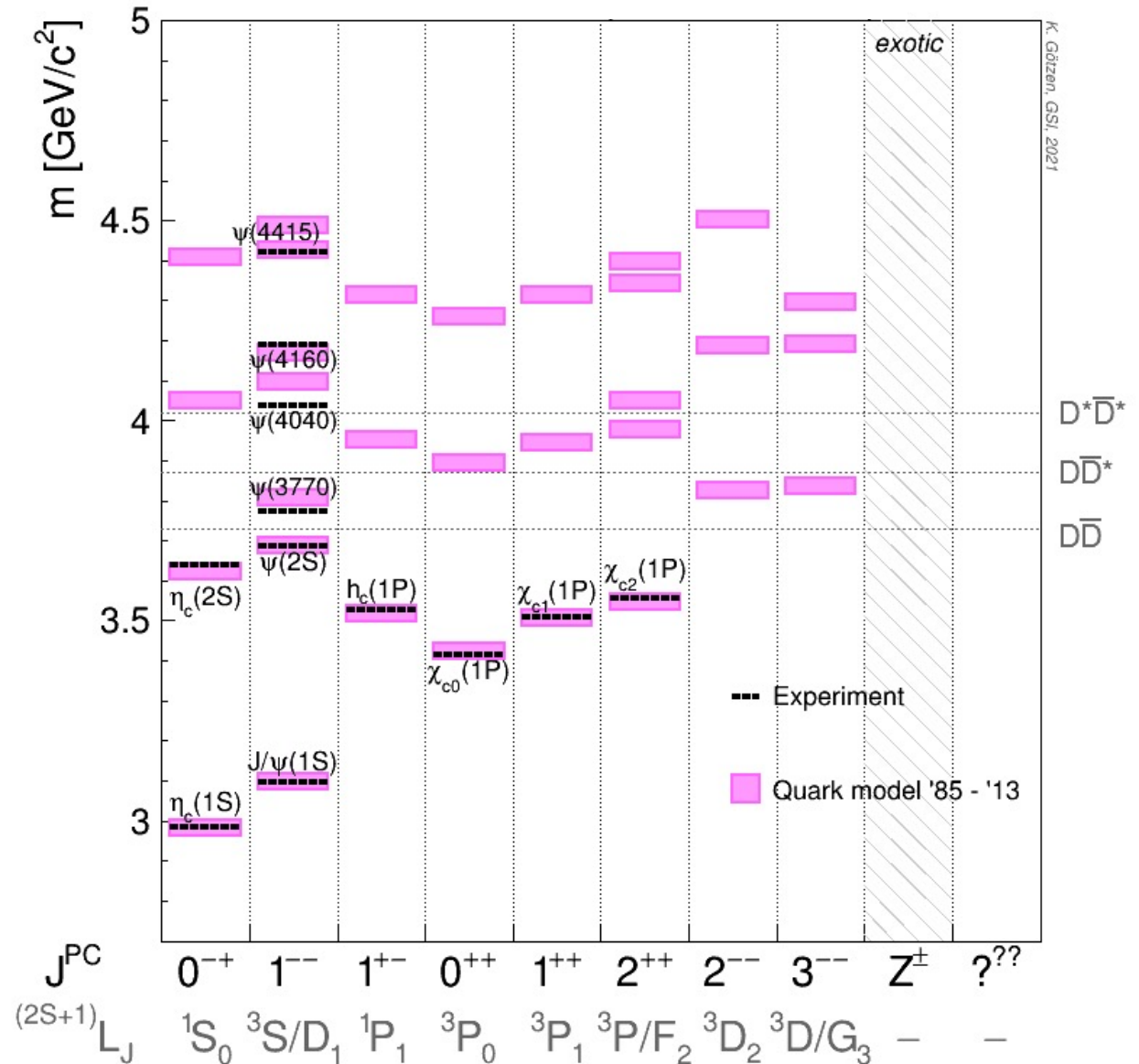
[Godfrey & Isgur, PRD 32 (1985) 189]

[Barnes, Godfrey & Swanson, PRD 72 (2005) 054026]





- Before 2003:
  - Good agreement between theory and experiment, particularly beneath open charm thresholds



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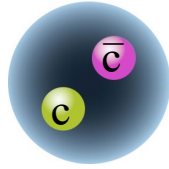
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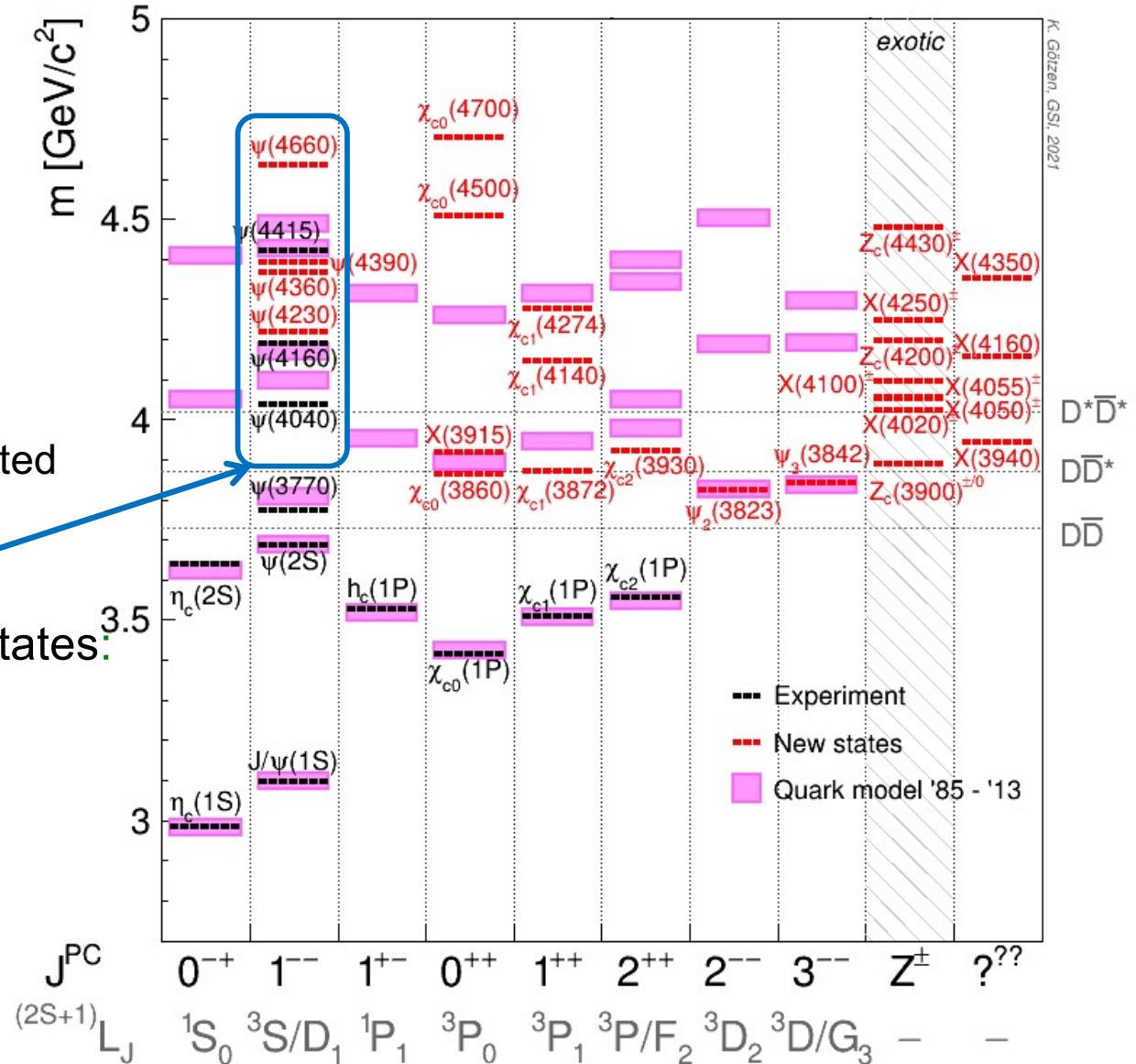
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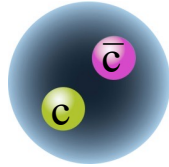




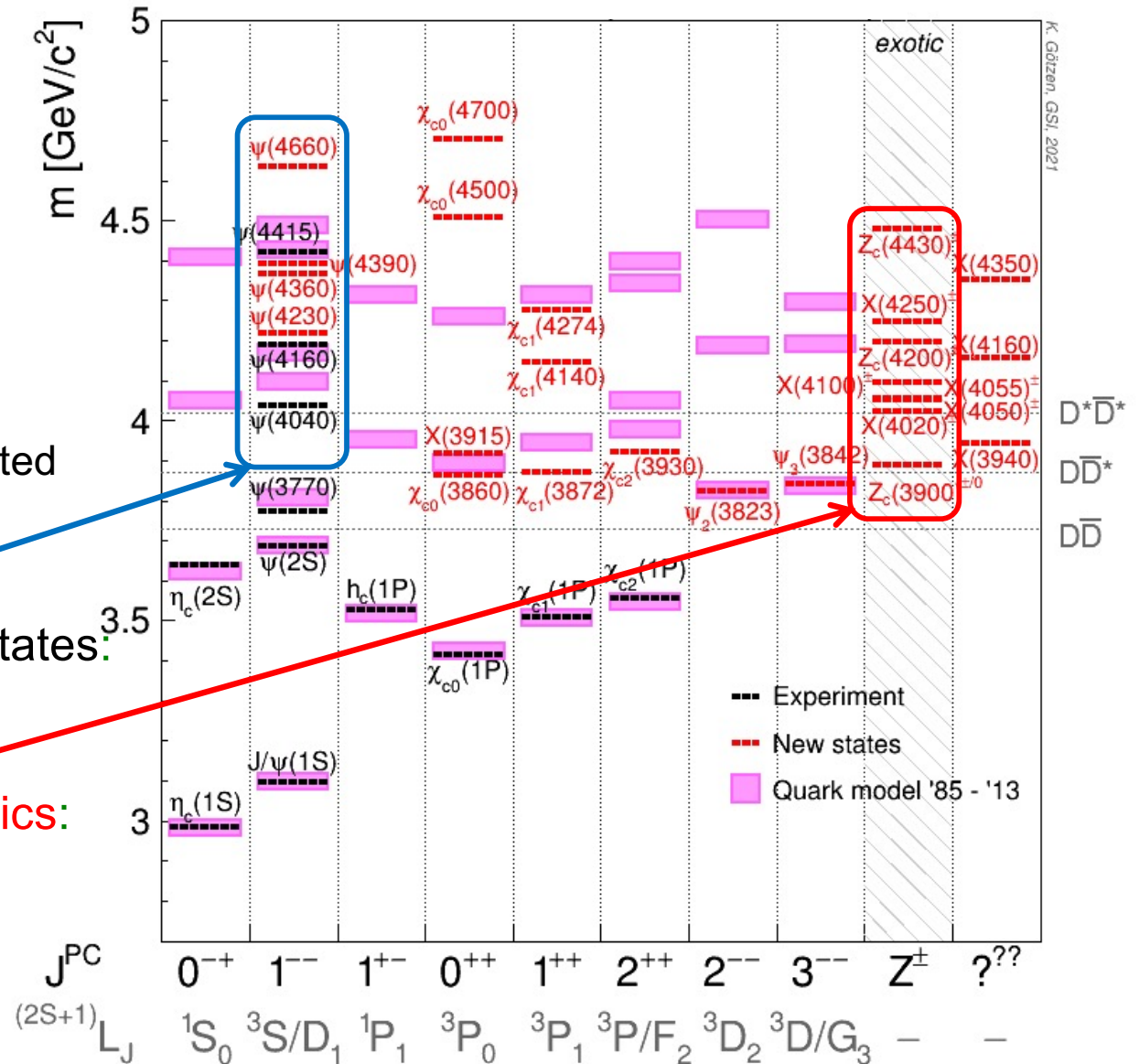
- Before 2003:
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- After 2003:
  - Severe mismatch between predicted and observed spectrum
- Several supernumerary vector states:  $Y(4260)$ , ...,  $Y(4660)$



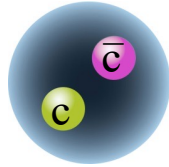
K. Götzen, GSI, 2021



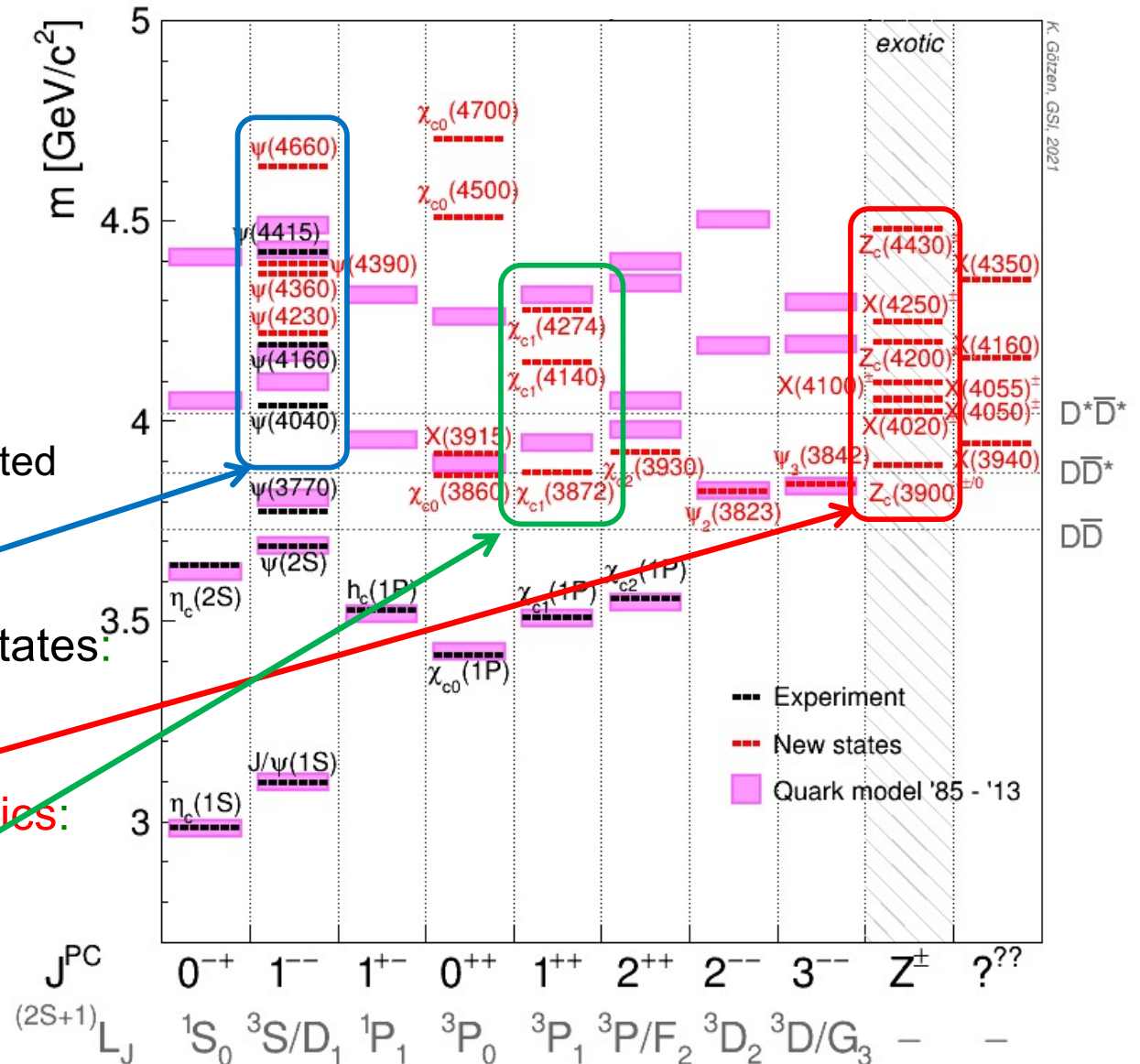
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- Several charged **manifestly exotics**:  $Z_c(3900)^{+/-}$ , ...,  $Z_c(4430)^{+/-}$





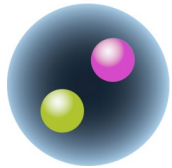


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- Several charged **manifestly exotics**:  $Z_c(3900)^{+/-}$ , ...,  $Z_c(4430)^{+/-}$
- The X states – the  $\chi_{c1}(3872)$  was the first observed in 2003



## Simple Quark model

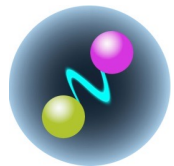
- Mesons: Color neutral  $q\bar{q}$  systems



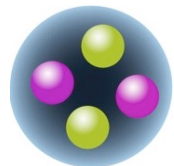
Conventional ( $q\bar{q}$ )

## QCD

- Meson states beyond  $q\bar{q}$



Hybrid ( $q\bar{q}$ )g

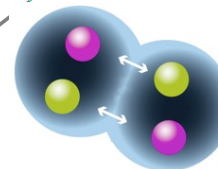


Tetraquark ( $q\bar{q}q\bar{q}$ )

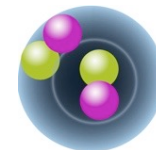


Glue-ball (gg) or (ggg)

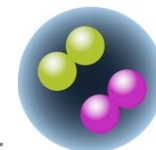
Alternative 4-quark configurations:



Molecule ( $q\bar{q}$ )( $q\bar{q}$ )



Hadro-quarkonium ( $Q\bar{Q}$ )( $q\bar{q}$ )



Di-quarkonium ( $qq$ )( $\bar{q}\bar{q}$ )

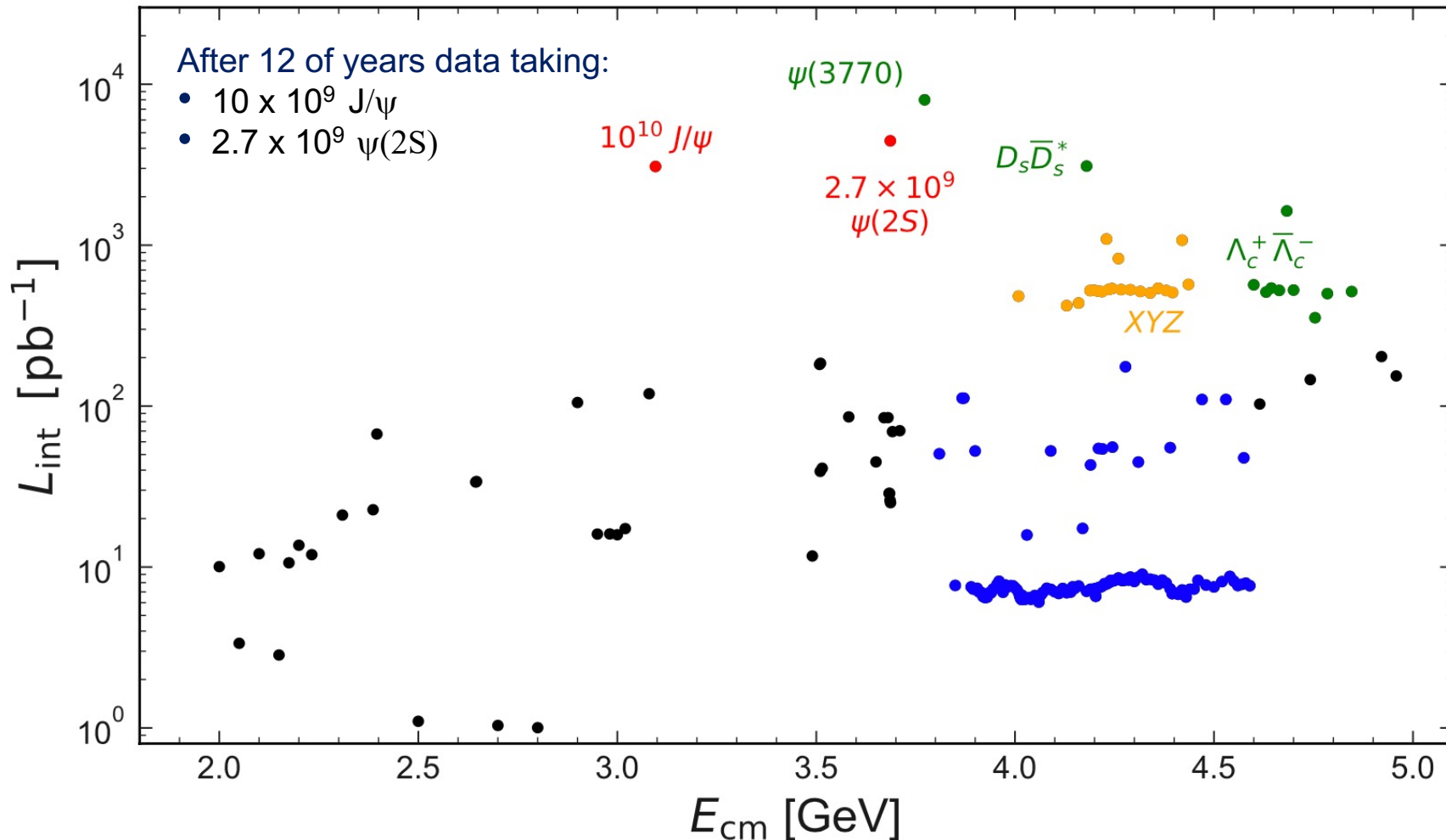


- Symmetric  $e^+e^-$  collider:
  - $\sqrt{s} = 2.0 - 4.6 \text{ GeV}$
- Design luminosity:
  - $1 \times 10^{33} \text{ cm}^{-2}\text{s}^{-1}$  (at  $\psi(3770)$ , achieved in 04/2016)



- Multi-purpose  $4\pi$  detector with
  - good tracking
  - calorimetry
  - PID and muon detection
- Operating since March 2008

# Unique BESIII data set (collected so far ...)



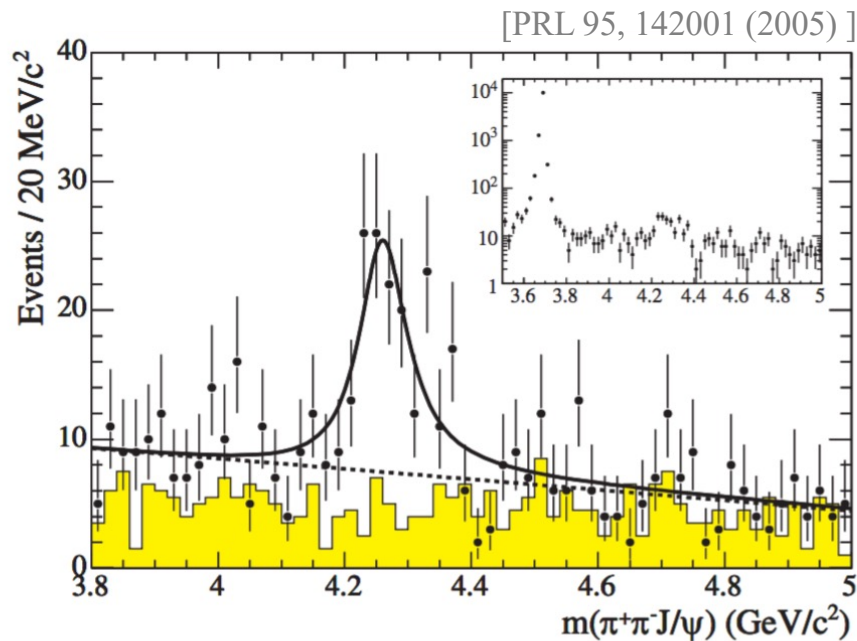
- XYZ region:  $> 3.8$  GeV, integrated luminosity:  $\sim 22 \text{ fb}^{-1}$
- 104 energy points between 3.85 and 4.59 GeV (*R scan*)
- $\sim 20$  energy points between 2.0 and 3.1 GeV

[Courtesy: W. Gradl]

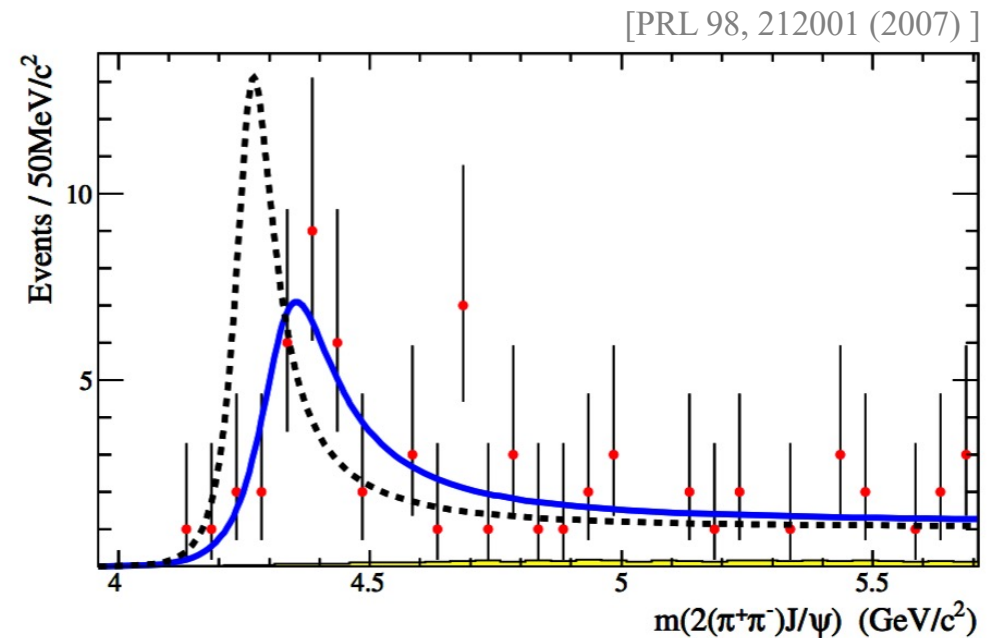
# The $Y(4260)$ and further supernumerary vector states

Some history:

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



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



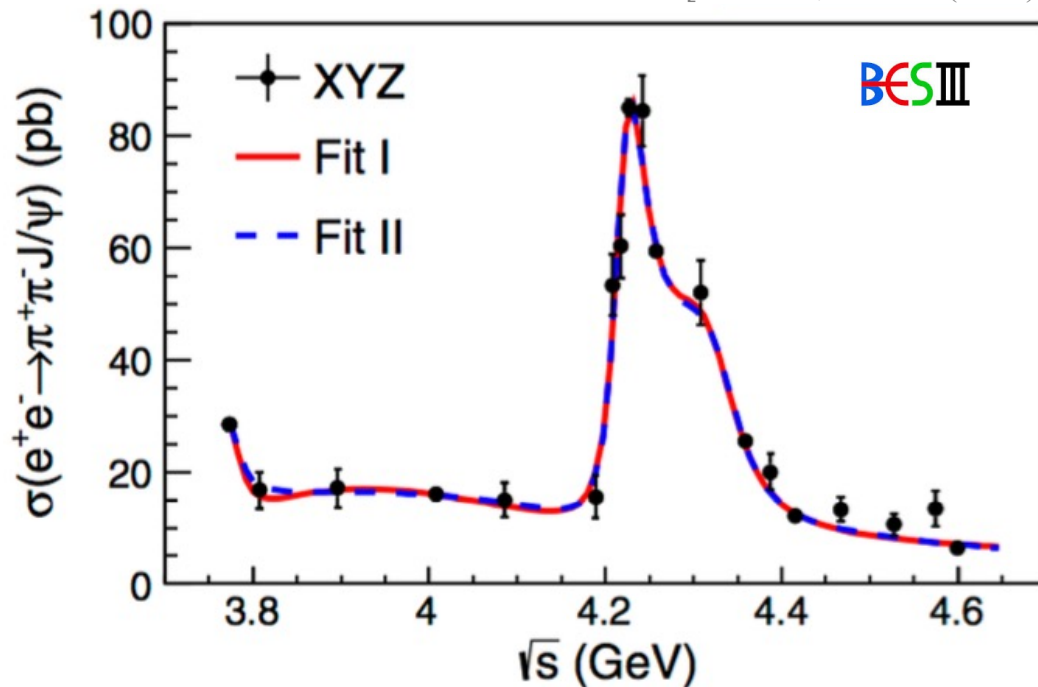
- Discovery of the Y(4260) using ISR by BaBar in  $J/\psi\pi^+\pi^-$

- Discovery of the Y(4360) using ISR by BaBar in  $\psi(2S)\pi^+\pi^-$

BESIII result, published

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

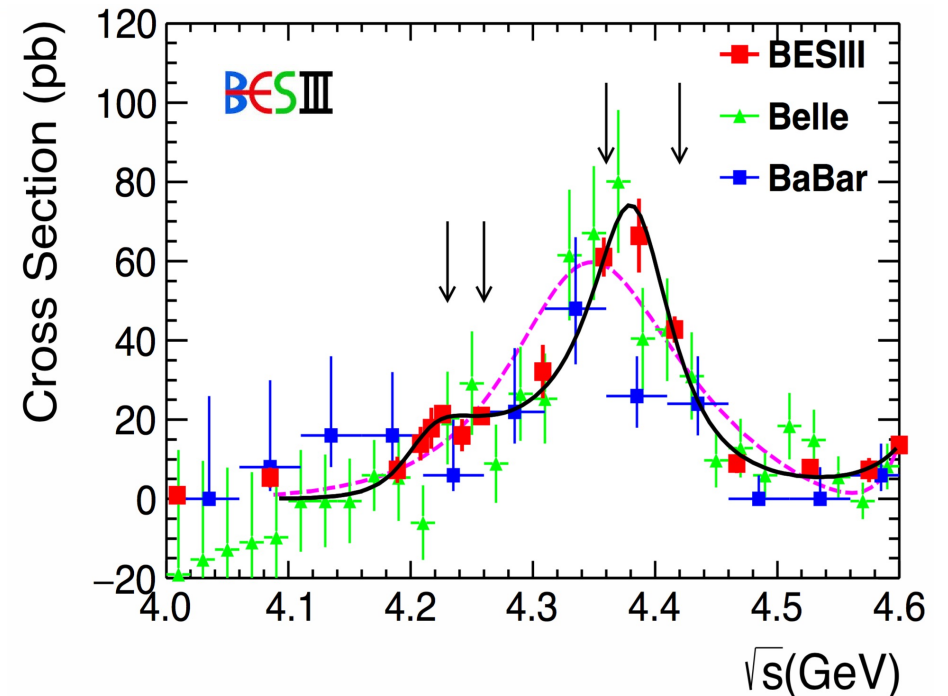
[PRL 118, 092001 (2017)]



- Cross-section inconsistent with the single resonance  $Y(4260)$ !
- Two favoured over one by  $>7\sigma$

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

[Phys. Rev. D 96, 032004 (2017)]

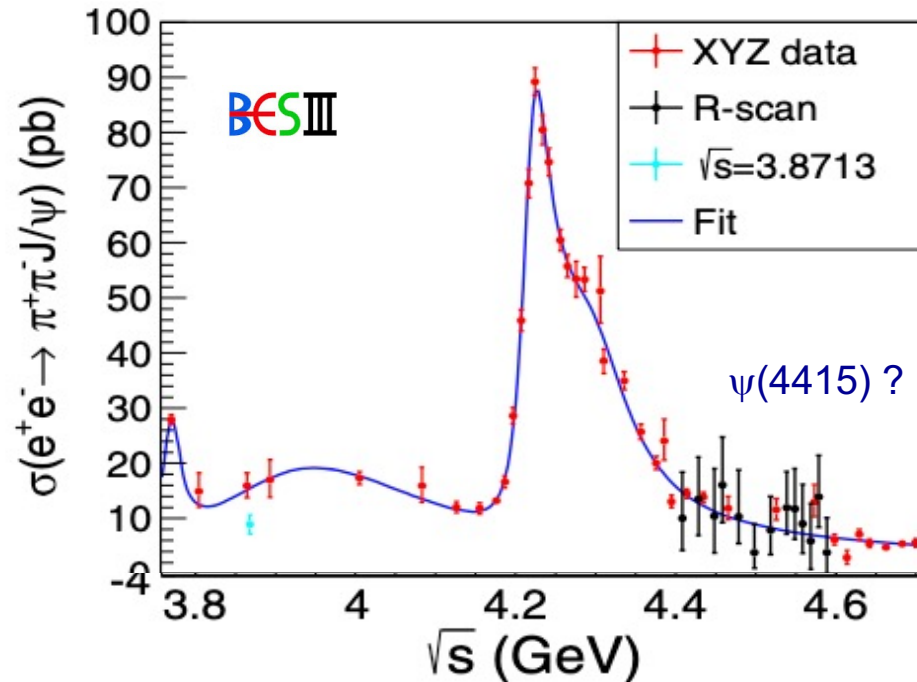


- BESIII: Much higher precision ( $5.8\sigma$ )
- Coherent BW fit:  $Y(4230)$  and  $Y(4360)$

BESIII result, published

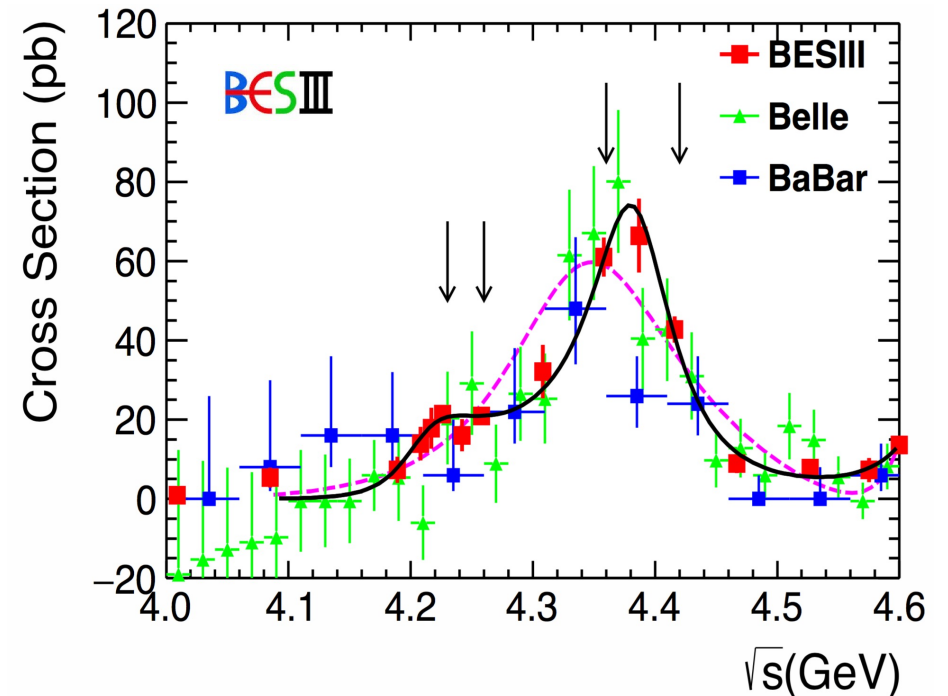
$$e^+e^- \rightarrow J/\psi\pi^+\pi^-$$

[Phys. Rev. D 106, 072001 (2022)]



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

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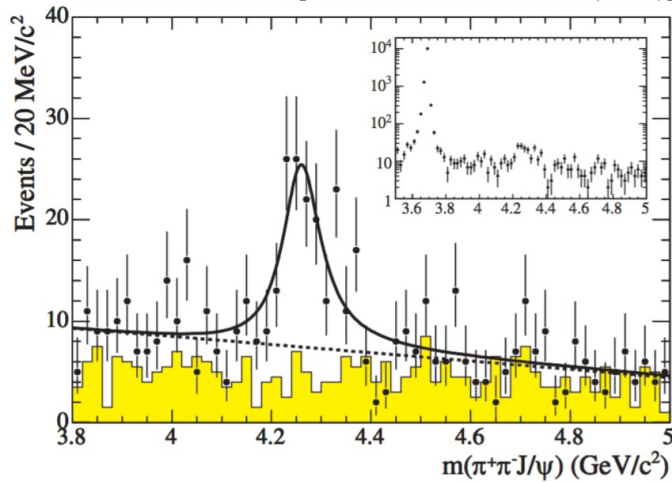
- Cross-section inconsistent with the single resonance  $Y(4260)$ 
  - Additional structure at  $\sim 4.5$  GeV needed (?), influences  $Y(4230)$  parameters

- BESIII: Much higher precision ( $5.8\sigma$ )
- Coherent BW fit:  $Y(4230)$  and  $Y(4360)$



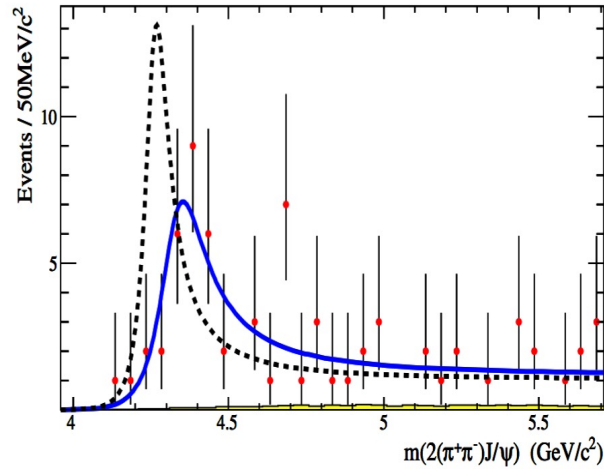
$$e^+e^- \rightarrow J/\psi\pi^+\pi^-$$

[BaBar, PRL 95, 142001 (2005)]

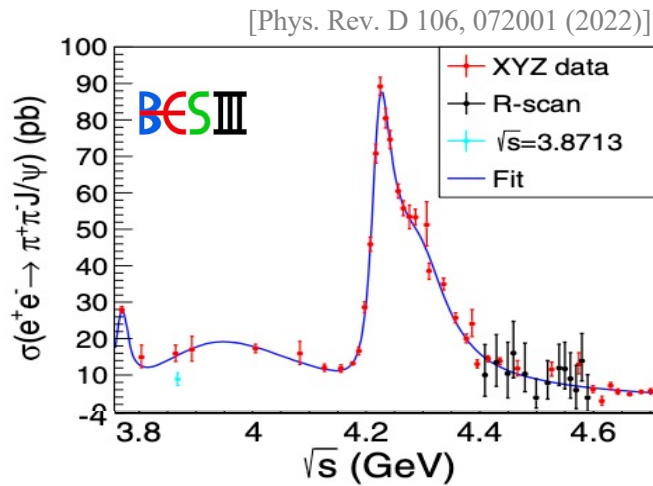
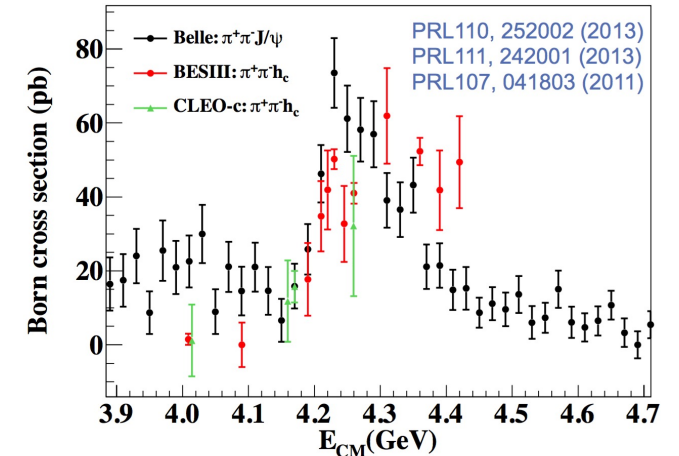


$$e^+e^- \rightarrow \psi(2S)\pi^+\pi^-$$

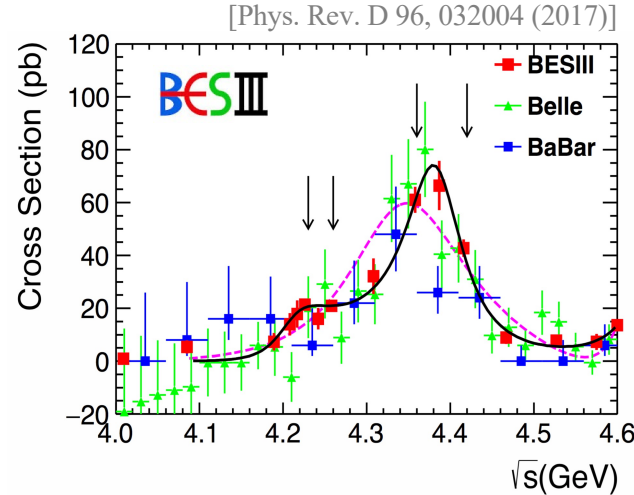
[BaBar, PRL 98, 212001 (2007)]



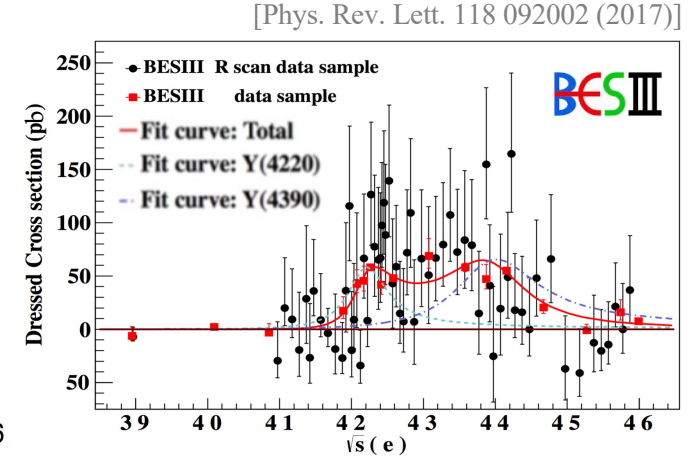
$$e^+e^- \rightarrow h_c\pi^+\pi^-$$



[Phys. Rev. D 106, 072001 (2022)]

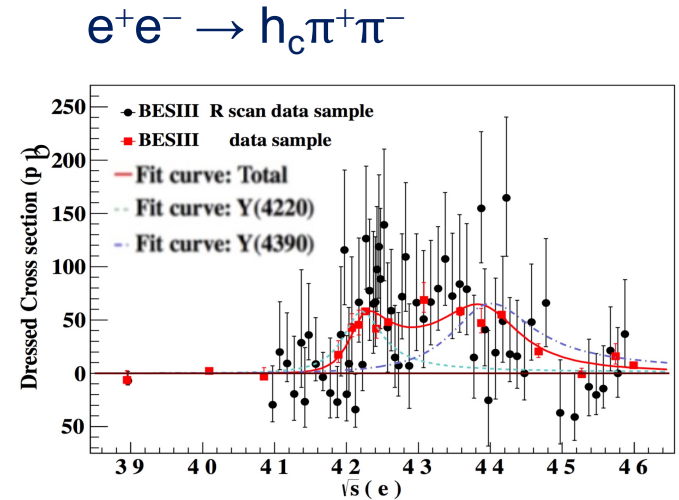
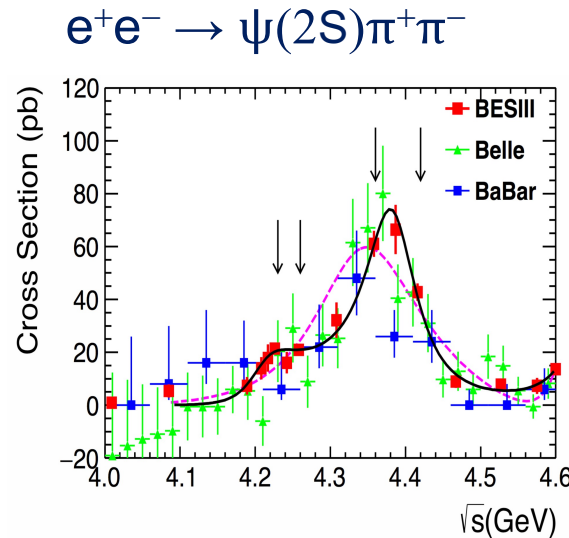
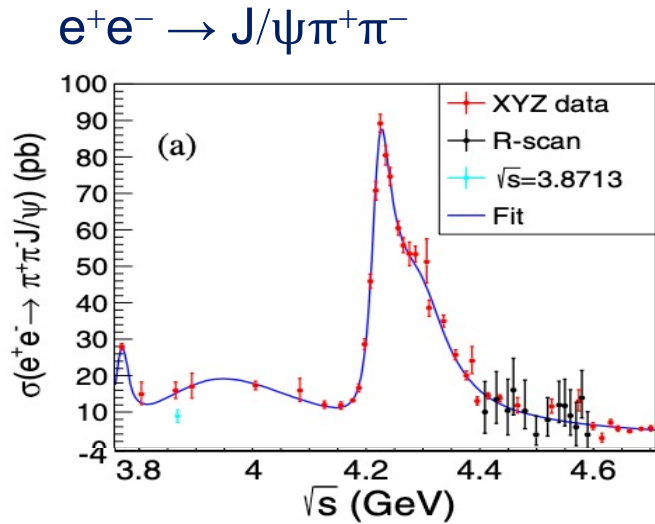


[Phys. Rev. D 96, 032004 (2017)]



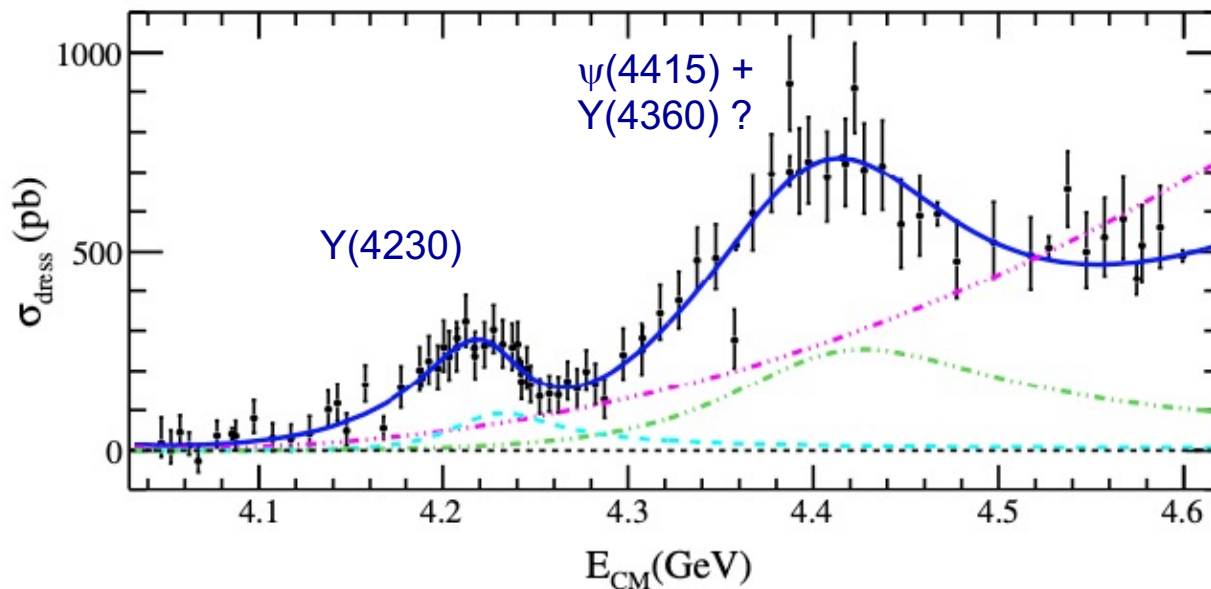
[Phys. Rev. Lett. 118 092002 (2017)]

Two structures now resolved:  $Y(4260) \rightarrow Y(4230)$ , and  $Y(4360)$



$e^+e^- \rightarrow D^0 D^{*-} \pi^+$

[PRL 122, 102002 (2019)]



### Y(4230):

- $M = (4228.6 \pm 4.1 \pm 6.3) \text{ MeV}/c^2$
- $\Gamma = (77.0 \pm 6.8 \pm 6.3) \text{ MeV}/c^2$

### Y state at about 4.40 GeV:

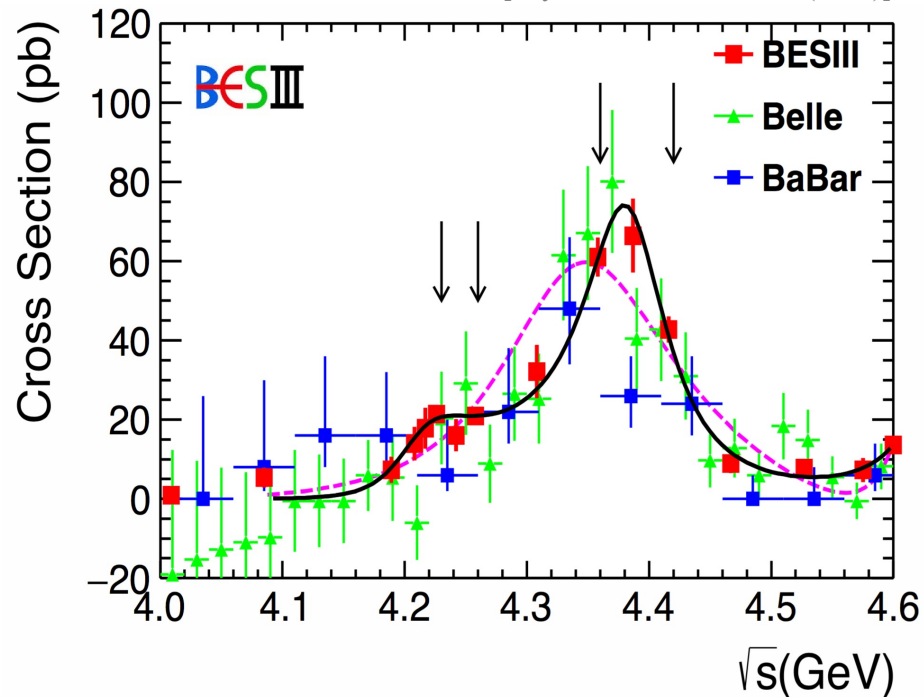
- strongly model dependent

- => First Y decays to open-charm
- => Consistency with structures in  $J/\psi / h_c / \psi(2S) \pi\pi$

# The Y states, $e^+e^-$ production of $J/\psi\pi\pi$ , $h_c\pi\pi$ and $\psi(2S)\pi\pi$

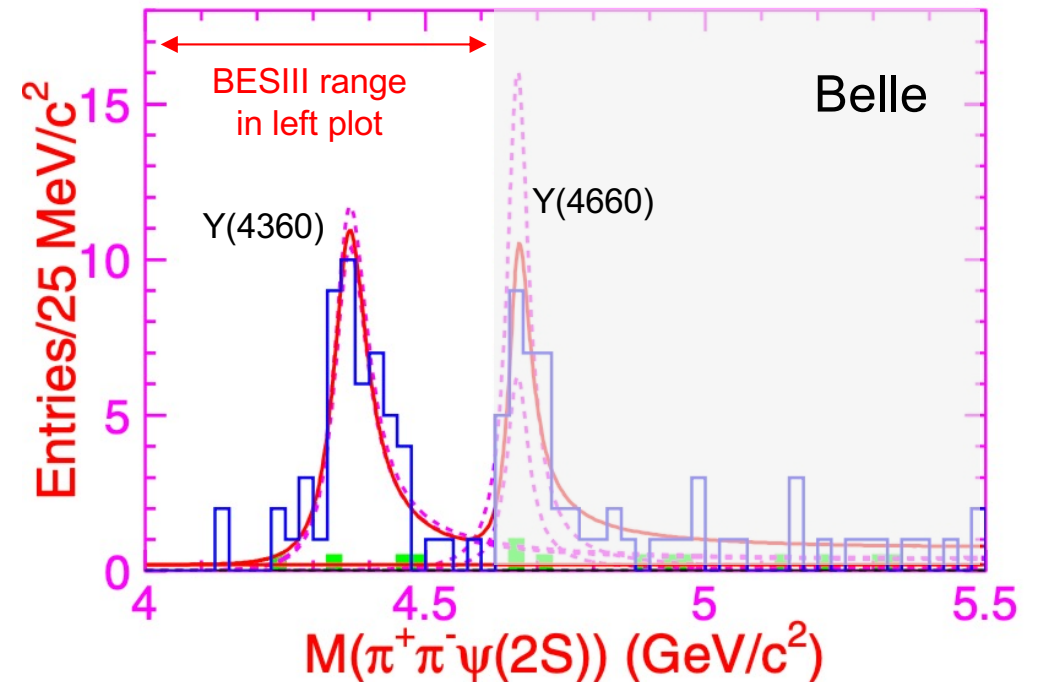
$$e^+e^- \rightarrow \psi(2S)\pi^+\pi^-$$

[Phys. Rev. D 96, 032004 (2017)]



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[PRL 99, 142002 (2007)]



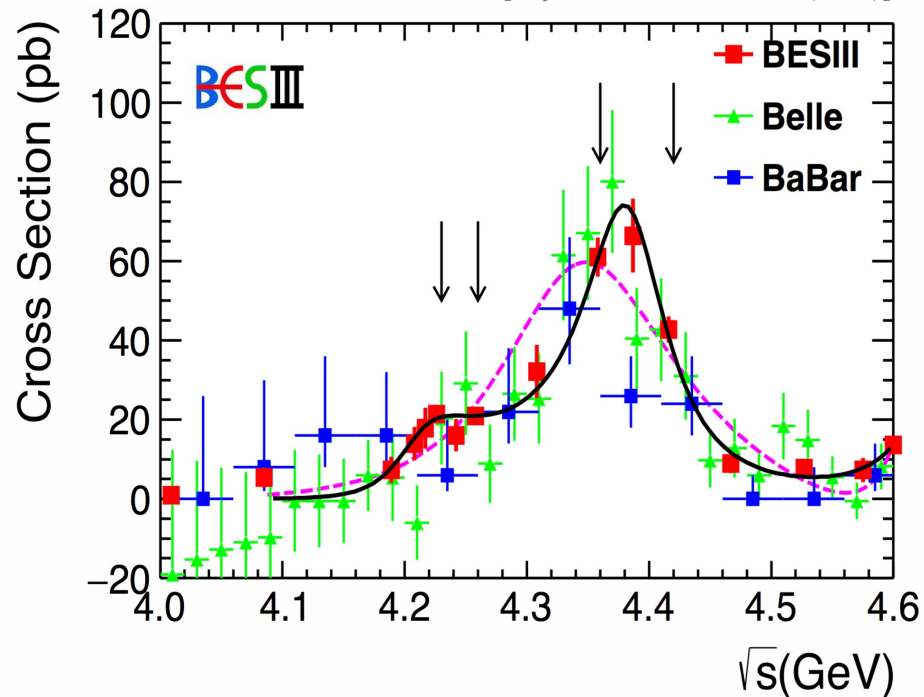
- BESIII: Much higher precision ( $5.8\sigma$ )
- Coherent BW fit: Y(4230) and Y(4360)

- Confirmation of the Y(4360) in  $\psi(2S)\pi^-\pi^+$  with a significance of  $8\sigma$
- First observation of Y(4660) with  $5.8\sigma$

# The Y states, $e^+e^-$ production of $J/\psi\pi\pi$ , $h_c\pi\pi$ and $\psi(2S)\pi\pi$

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

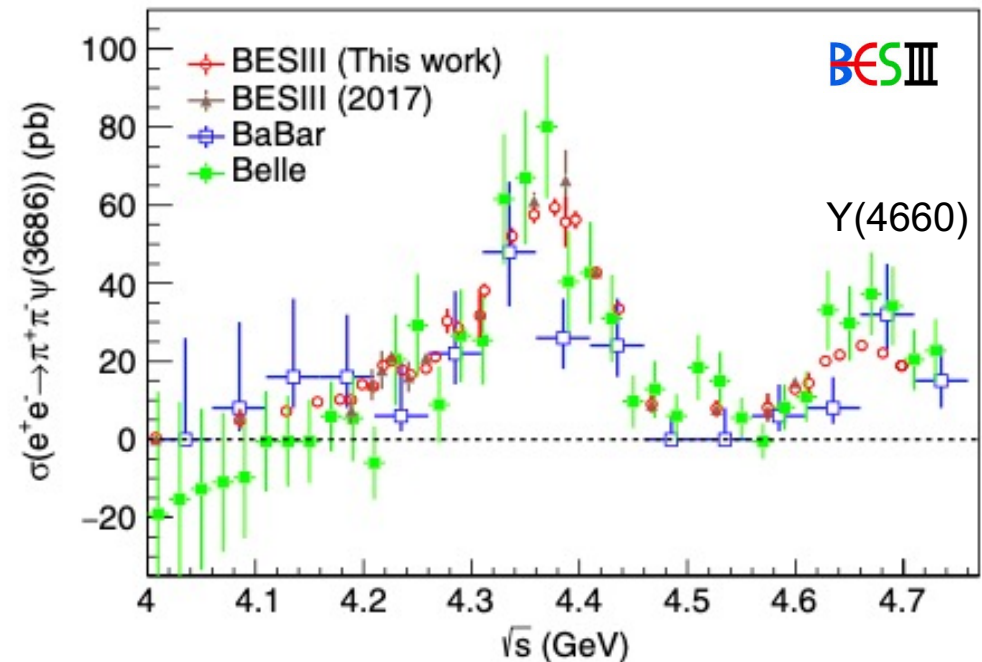
[Phys. Rev. D 96, 032004 (2017)]



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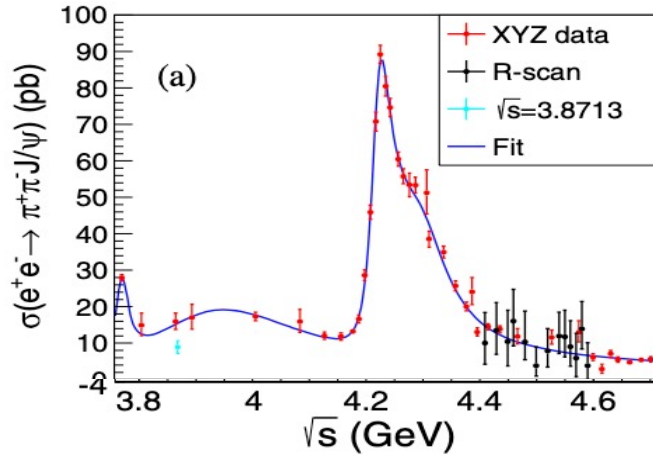
$$e^+e^- \rightarrow \psi(2S)\pi^+\pi^-$$

[PRD 104, 052012 (2021)]

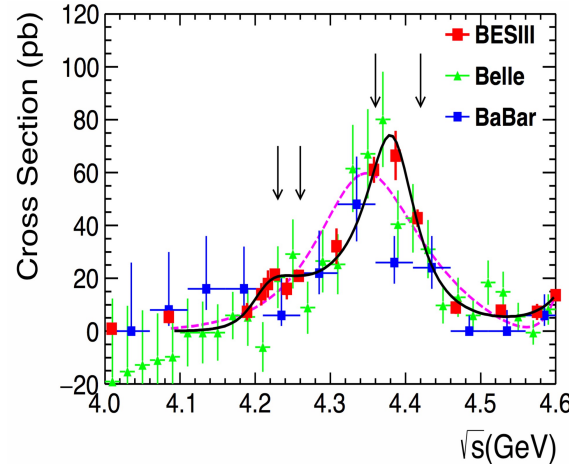


- Observation of  $Y(4660) \rightarrow \psi(2S)\pi^-\pi^+$  with a significance of  $8.1\sigma$
- First observation of Y(4660) at BESIII

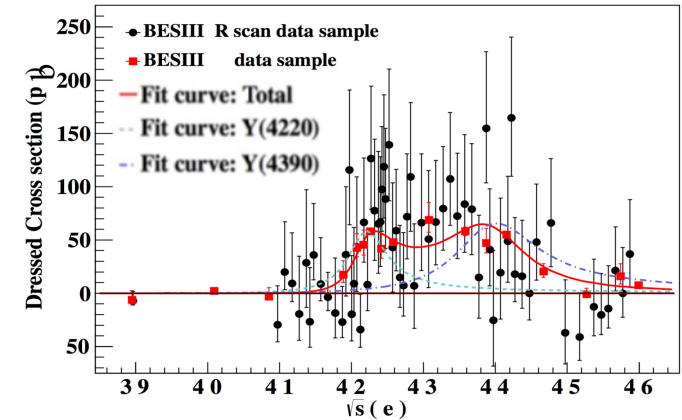
$$e^+e^- \rightarrow J/\psi \pi^+ \pi^-$$



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

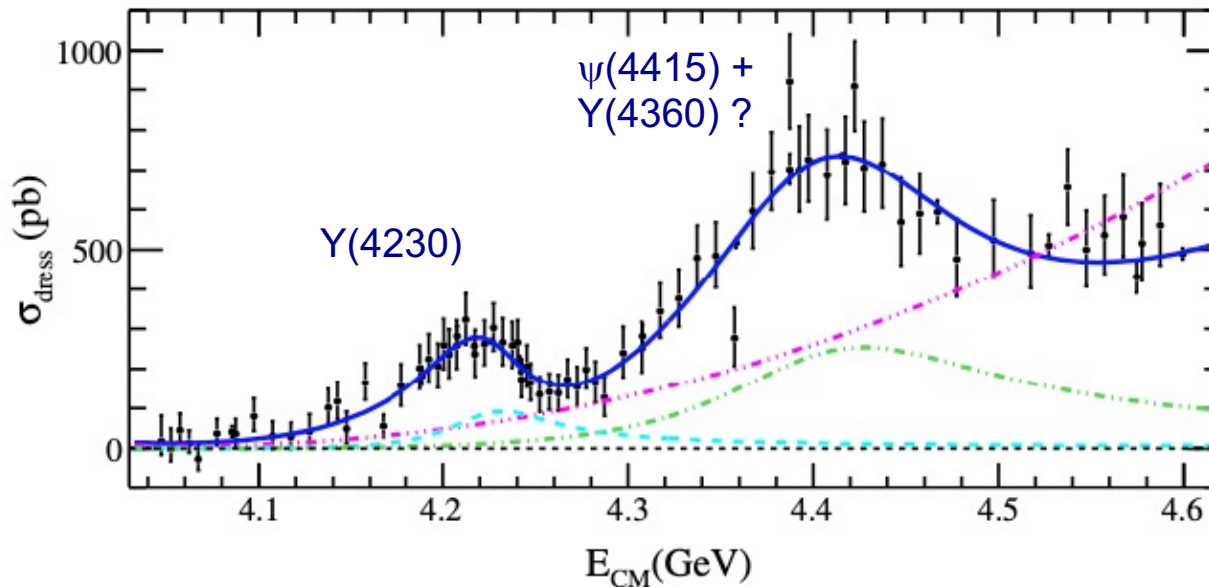


$$e^+e^- \rightarrow h_c \pi^+ \pi^-$$



$$e^+e^- \rightarrow D^0 D^{*-} \pi^+$$

[PRL 122, 102002 (2019)]



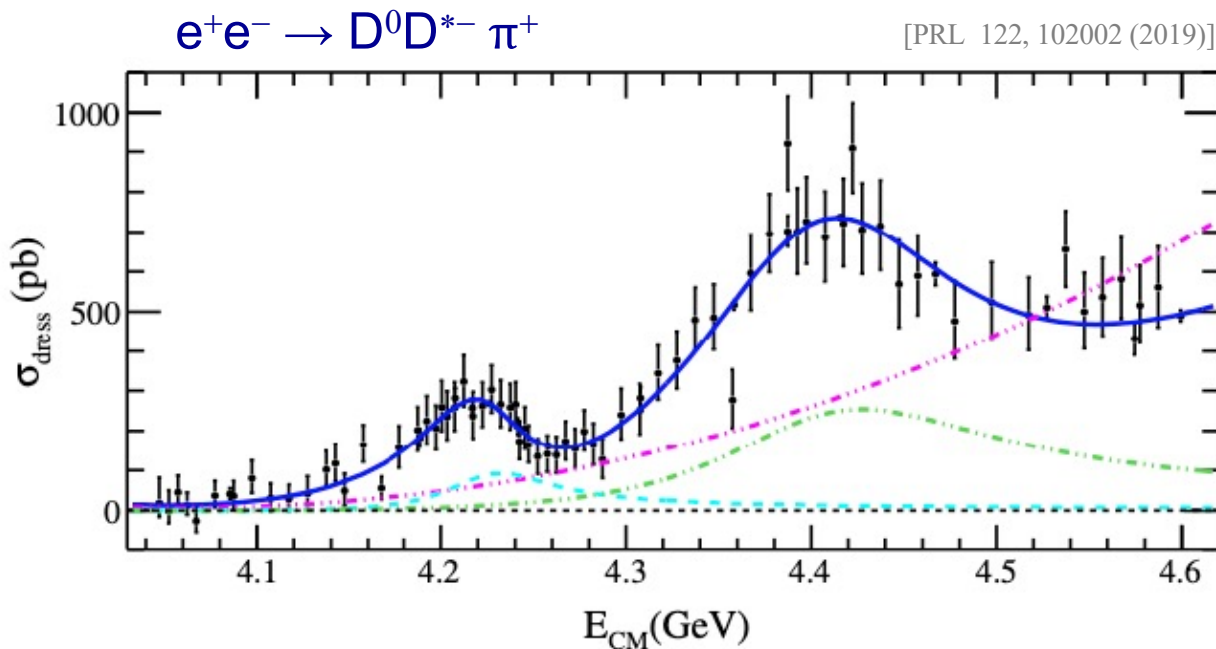
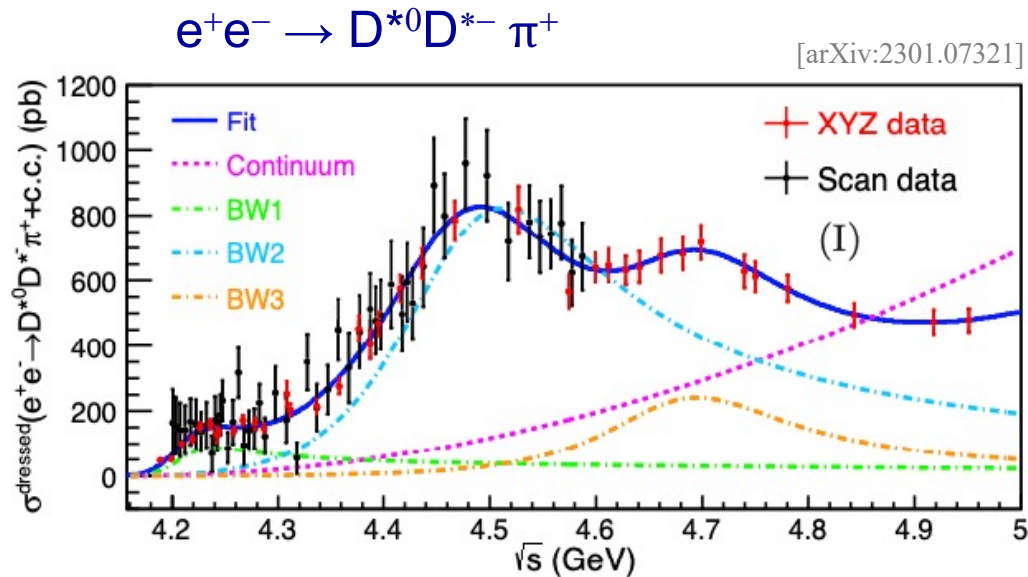
## Y(4230):

- $M = (4228.6 \pm 4.1 \pm 6.3) \text{ MeV}/c^2$
- $\Gamma = (77.0 \pm 6.8 \pm 6.3) \text{ MeV}/c^2$

## Y state at about 4.40 GeV:

- strongly model dependent

- => First Y decays to open-charm
- => Consistency with structures in  $J/\psi / h_c / \psi(2S) \pi\pi$



**Y(4230):**

- $M = (4209.6 \pm 4.7 \pm 5.9) \text{ MeV}/c^2$
- $\Gamma = (81.6 \pm 17.8 \pm 9.0) \text{ MeV}$

**Y(4500):**

- $M = (4469.1 \pm 26.2 \pm 3.6) \text{ MeV}/c^2$
- $\Gamma = (81.6 \pm 17.8 \pm 9.0) \text{ MeV}$

**Y(4660):**

- $M = (4675.3 \pm 29.5 \pm 3.5) \text{ MeV}/c^2$
- $\Gamma = (218.2 \pm 72.9 \pm 9.3) \text{ MeV}$

=> **Consistency** with structures in  $J/\psi / h_c / \psi(2S)\pi\pi$  &  $J/\psi KK$

**Y(4230):**

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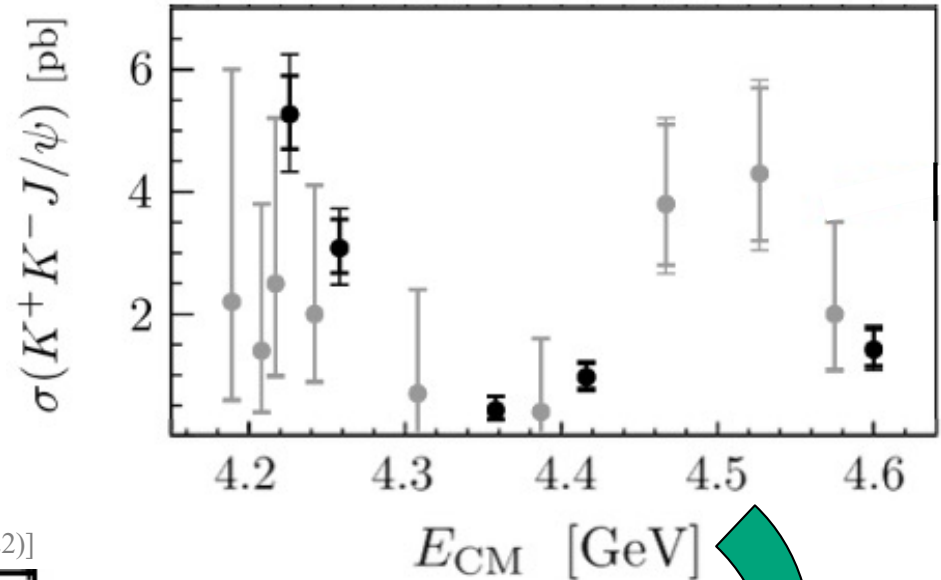
- strongly model dependent

=> **First Y** decays to **open-charm**  
 => **Consistency** with structures in  $J/\psi / h_c / \psi(2S) \pi\pi$

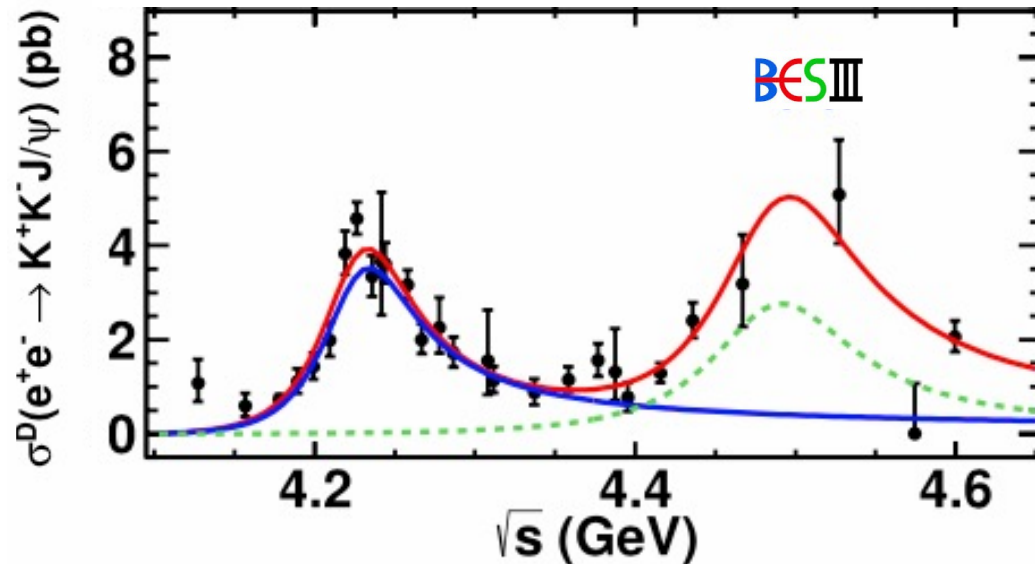
## The Y states, $e^+e^-$ production of $J/\psi\pi\pi$ , $h_c\pi\pi$ , $\psi(2S)\pi\pi$ and $J/\psi K^+K^-$

- Data samples from 4.13 to 4.60 GeV ( $15.6 \text{ fb}^{-1}$ )
- Dressed cross-section measurement of  $e^+e^- \rightarrow K^+K^- J/\psi$
- $Y(4230)$  and  $Y(4500)$  observed ( $29\sigma / 8\sigma$ )
  - $M = (4484.7 \pm 13.3 \pm 24.1) \text{ MeV}/c^2$
  - $\Gamma = (77.0 \pm 6.8 \pm 6.3) \text{ MeV}$

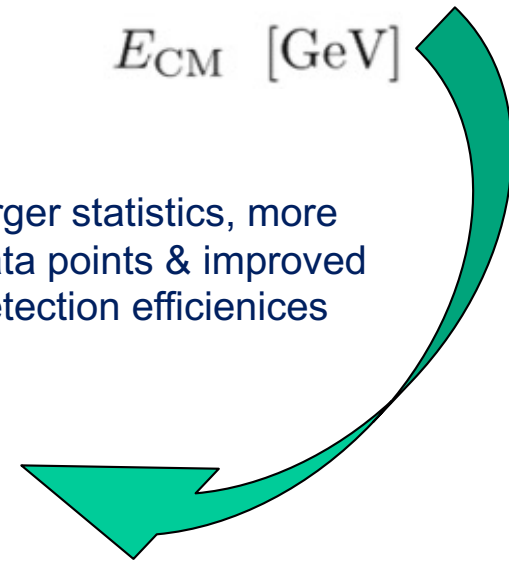
[PRD 97, 071101 (2018)]



[Chin. Phys. C 46, 111002 (2022)]

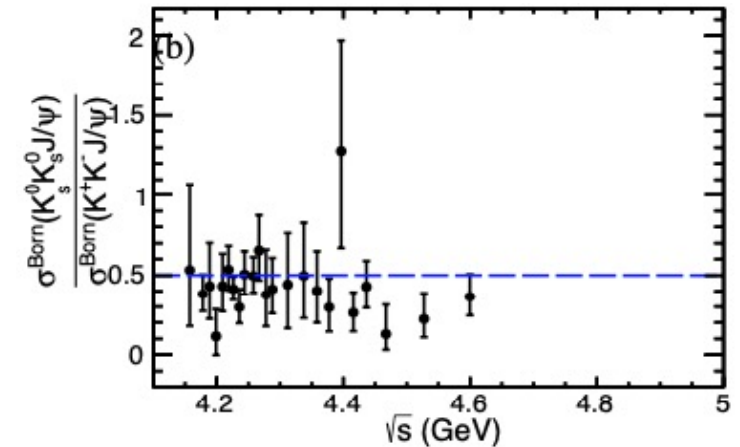
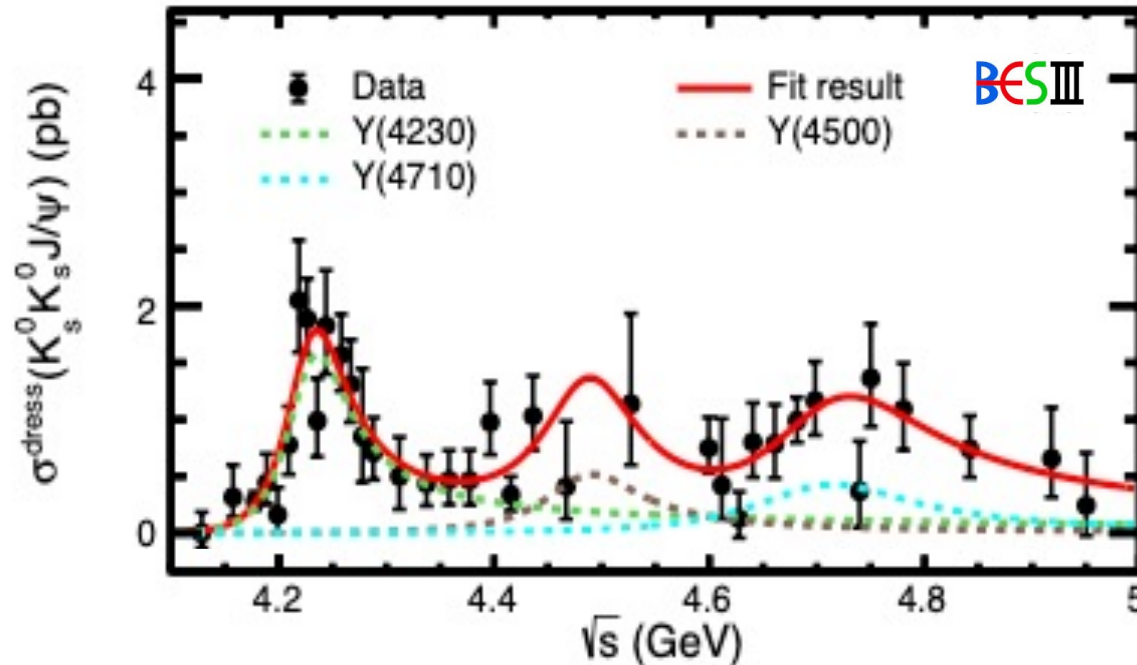


larger statistics, more data points & improved detection efficiencies



- Data samples from 4.13 to 4.95 GeV ( $21.2 \text{ fb}^{-1}$ )
- Dressed cross-section measurement of  $e^+e^- \rightarrow K_s^0 K_s^0 J/\psi$

[Chin. Phys. C 46, 111002 (2022)]

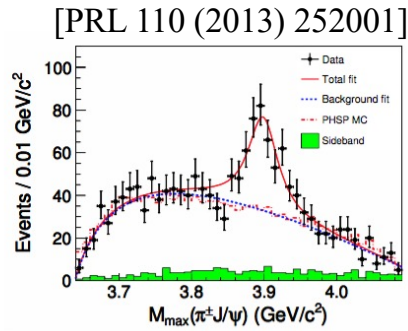


- Evidence for  $Y(4710) \rightarrow K_s^0 K_s^0 J/\psi$  ( $4.0\sigma$ )
  - $M = (4704.0 \pm 52.3 \pm 69.5) \text{ MeV}/c^2$
  - $\Gamma = (183.2 \pm 114.0 \pm 96.1) \text{ MeV}$
- $Y(4230) \rightarrow K_s^0 K_s^0 J/\psi$  observed for the first time ( $26\sigma$ )

$\Rightarrow$  consistent with isospin symmetry expectation of  $1/2$



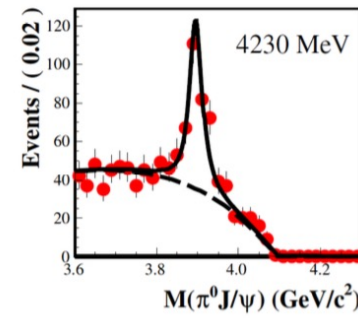
## The $Z(4430)$ and further (charged) $Z_c$ states



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

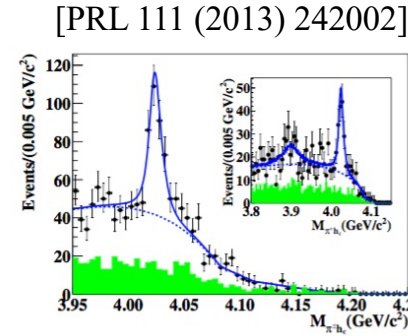
Charged

[PRL 115 (2015) 112003]



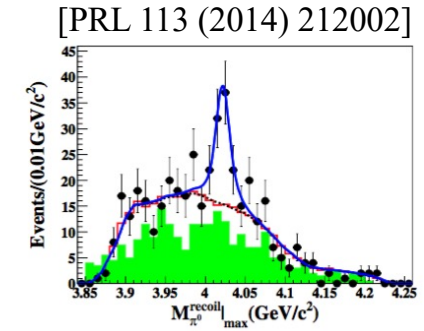
$$e^+e^- \rightarrow \pi^0 \pi^0 J/\psi$$

Neutral



$$e^+e^- \rightarrow \pi^- \pi^+ h_c$$

Charged



$$e^+e^- \rightarrow \pi^0 \pi^0 h_c$$

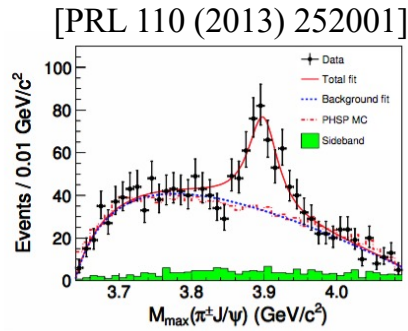
Neutral

$$Z_c(3900)^{\pm,0} \rightarrow J^P = 1^+$$

$$Z_c(4020)^{\pm,0} ?$$

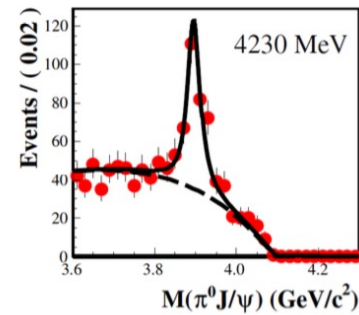
- Two isospin triplets of charmonium-like exotic states established

Hidden Charm



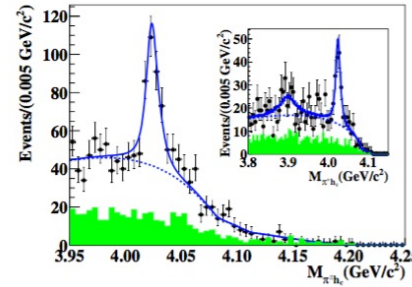
$$e^+e^- \rightarrow \pi^- \pi^+ J/\psi$$

[PRL 115 (2015) 112003]



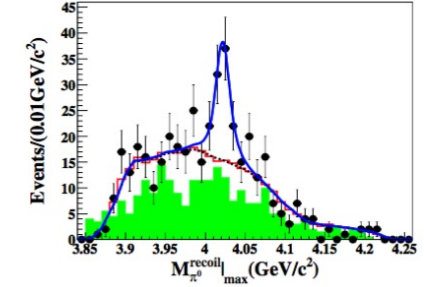
$$e^+e^- \rightarrow \pi^0 \pi^0 J/\psi$$

[PRL 111 (2013) 242002]



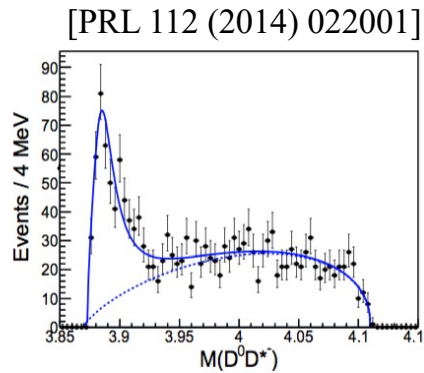
$$e^+e^- \rightarrow \pi^- \pi^+ h_c$$

[PRL 113 (2014) 212002]



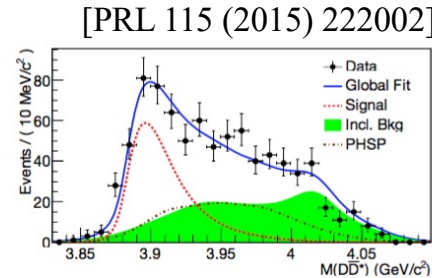
$$e^+e^- \rightarrow \pi^0 \pi^0 h_c$$

Open Charm



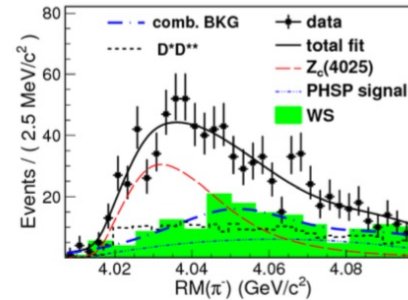
$$e^+e^- \rightarrow \pi^- (D\bar{D}^*)^+$$

Charged



Neutral

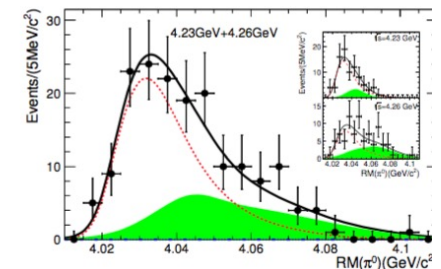
[PRL 112 (2013) 132001]



$$e^+e^- \rightarrow \pi^- (D^* \bar{D}^*)^+$$

Charged

[PRL 115 (2015) 182002]

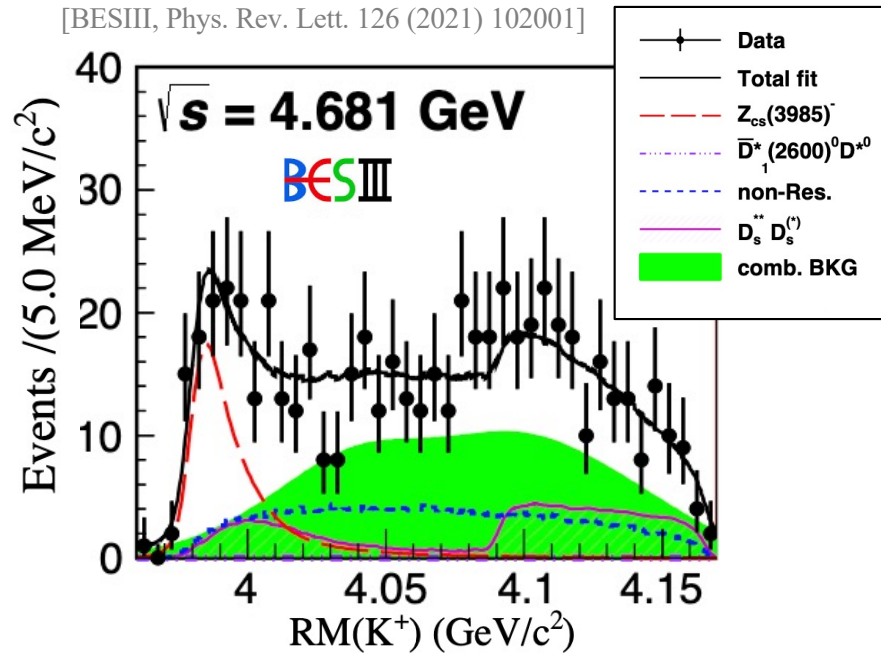


Neutral

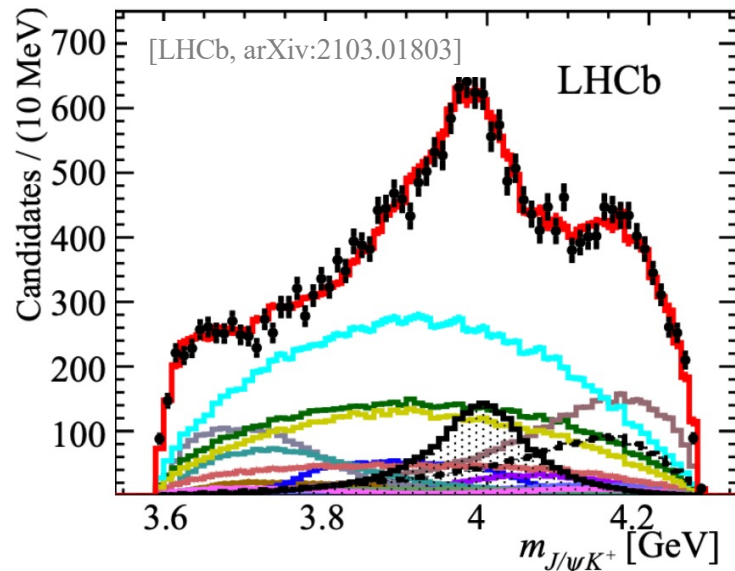
$$Z_c(3900)^{\pm,0} \rightarrow J^P = 1^+$$

$$Z_c(4020)^{\pm,0} ?$$

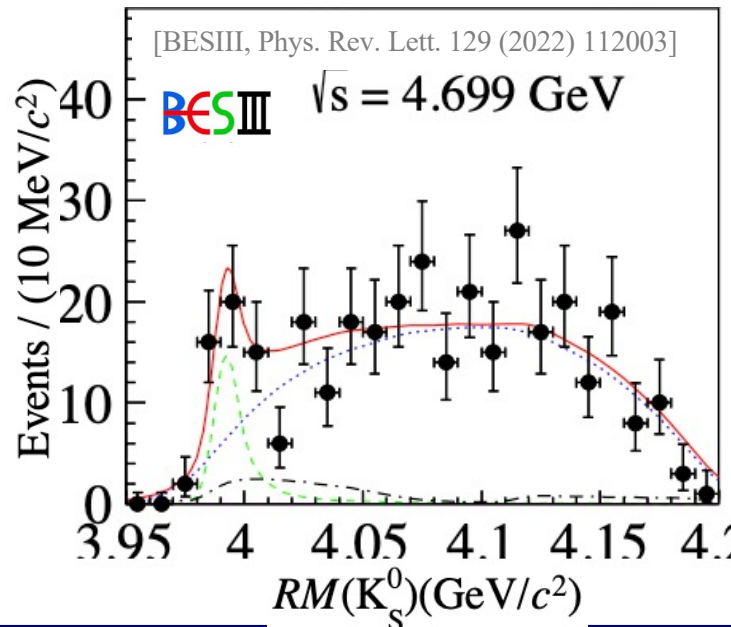
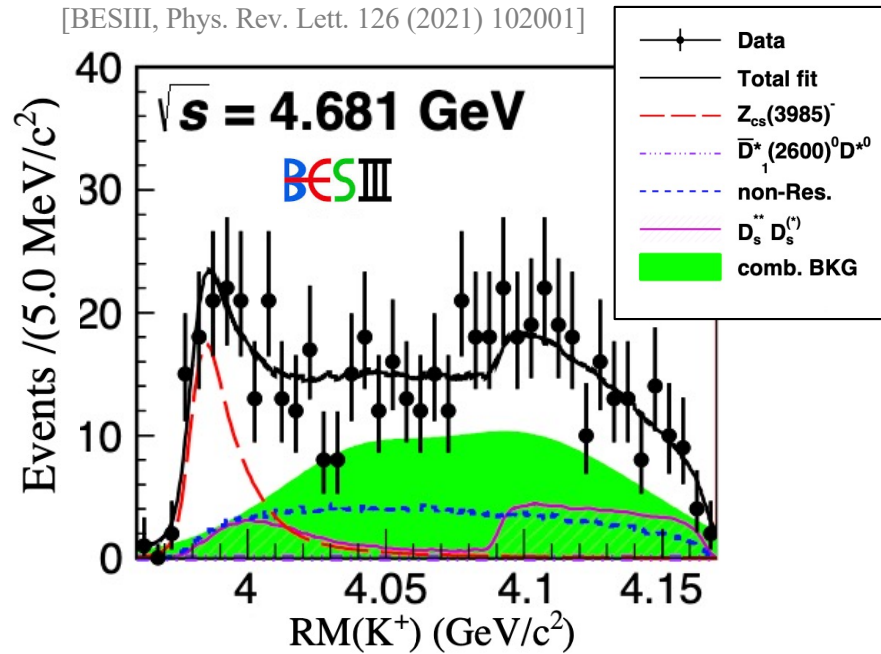
- Two isospin triplets of charmonium-like exotic states established
- Different decay modes (*hidden vs. open charm*) of same state observed?



- Search for **strange partner** of  $Z_c(3900)$ 
  - Containing s quark in open charm decay
  - $e^+e^- \rightarrow K^+(D_s D^*/D_s^* D)^-$
  - Narrow threshold enhancement ( $5.3\sigma$ )
  - $M = (3982.5_{-2.6}^{+1.8} \pm 2.1) \text{ MeV}/c^2$ ,
  - $\Gamma = (12.8_{-4.4}^{+5.3} \pm 3.0) \text{ MeV}$
- Manifestly exotic charged hidden-charm tetraquark candidate with strangeness
  - With a non-zero electric charge
  - Thus, minimal quark content  $\Rightarrow [c\bar{c}s\bar{u}]$

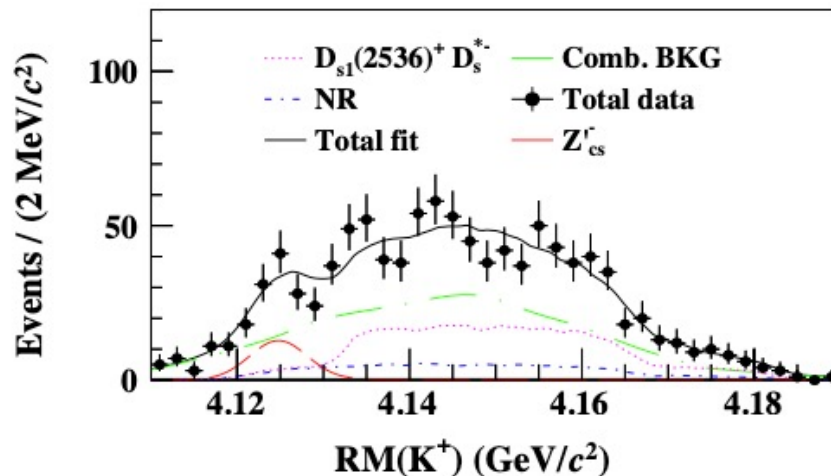
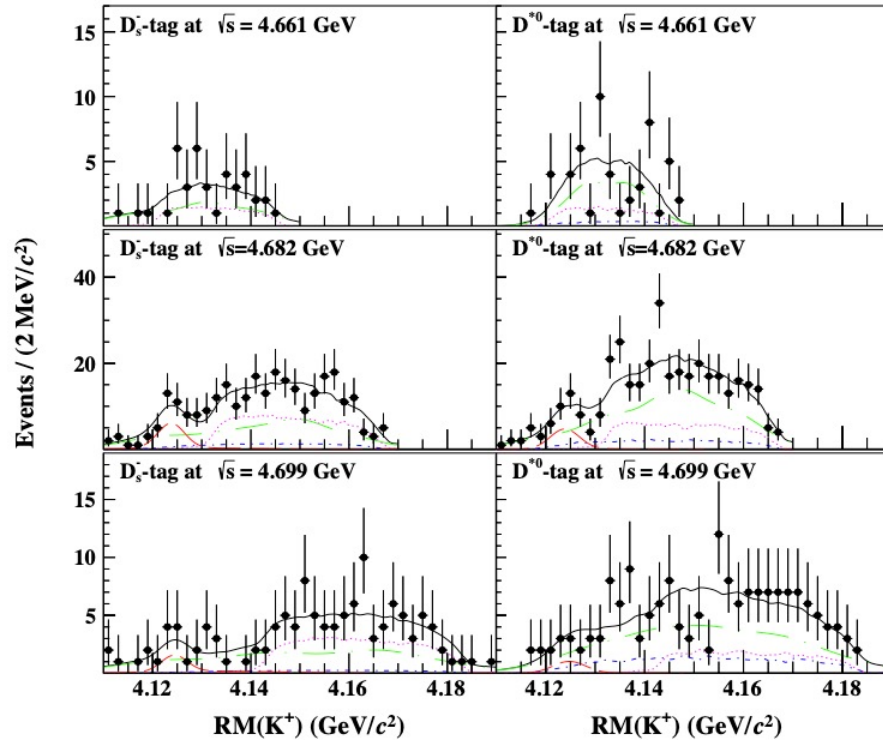


- LHCb reports a  $Z_{cs}(4000)$  in  $B \rightarrow \phi(J/\psi K^+)$ 
    - $M = (4000.3 \pm 6_{-14}^{+4}) \text{ MeV}/c^2$ ,
    - $\Gamma = (131 \pm 15 \pm 26) \text{ MeV}$
    - $J^P = 1^+$ , hidden charm final state
    - 10x broader ...
- $\Rightarrow$  Same state observed in different decays (open/hidden charm) at two experiments?



- Search for **strange partner** of  $Z_c(3900)$ 
    - Containing s quark in open charm decay
    - $e^+e^- \rightarrow K^+(D_s D^*/D_s^* D)^-$
    - Narrow threshold enhancement ( $5.3\sigma$ )
    - $M = (3982.5_{-2.6}^{+1.8} \pm 2.1) \text{ MeV}/c^2$ ,  
 $\Gamma = (12.8_{-4.4}^{+5.3} \pm 3.0) \text{ MeV}$
  - Manifestly exotic charged hidden-charm tetraquark candidate with strangeness
    - With a non-zero electric charge
    - Thus, minimal quark content =>  $[c\bar{c}s\bar{u}]$
  - Search for neutral partner of  $Z_{cs}(3985)$ 
    - Containing s quark in open charm decay
    - $e^+e^- \rightarrow K_S^0(D_s^+ D^{*-} + D_s^{*+} D^-)$
    - Narrow threshold enhancement ( $4.6\sigma$ )
    - $M = (3992.2 \pm 1.7 \pm 1.6) \text{ MeV}/c^2$   
 $\Gamma = (7.7_{-3.8}^{+4.1} \pm 4.3) \text{ MeV}$
- => Seem to be isospinpartners

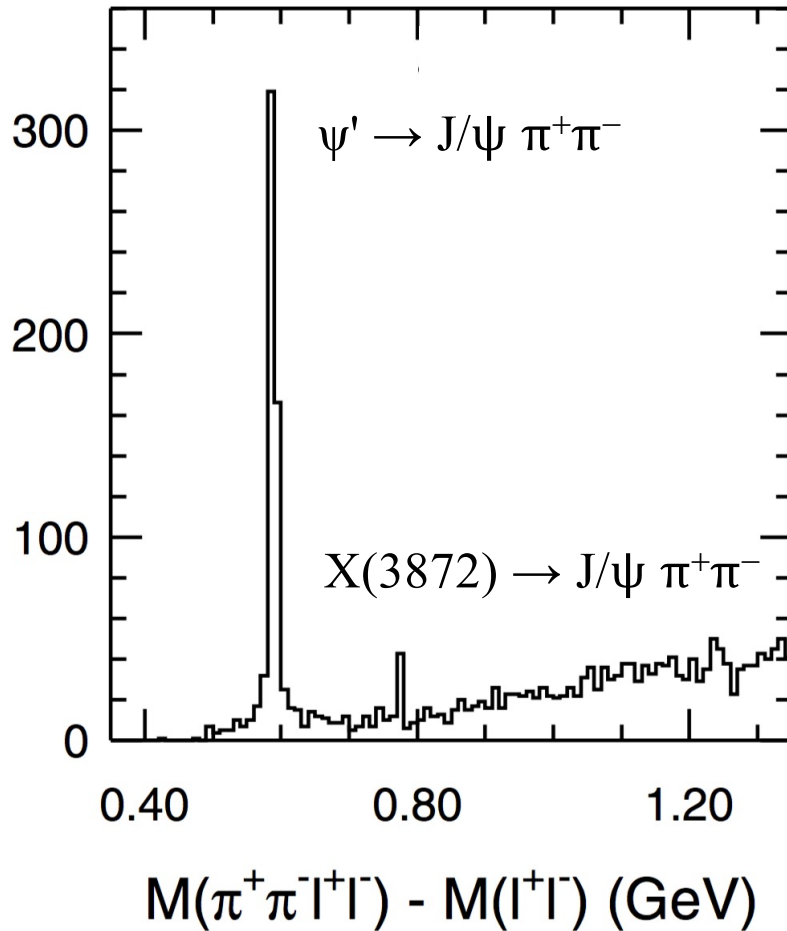
[Chin. Phys. C 47, 033001 (2023)]



- Search for **excited partner** of  $Z_{cs}(3985)$ 
    - 3 different data samples at  $\sqrt{s} = 4.661, 4.682$  and  $4.699$  GeV ( $2.7 \text{ fb}^{-1}$ )
    - $e^+e^- \rightarrow K^+ D_s^{*-} D^{*0} + c.c.$
    - two different tag-methods ( $D_s^-$ -/ $D^{*0}$ -tags)
  - Evidence for a  $Z_{cs}'$  state
    - $M = (4123.5 \pm 0.7) \text{ MeV}/c^2$
    - $2.1\sigma$  significance ( $3.9\sigma$  w/o systematics)
  - Statistics limited, test of decay width hypotheses, local statistical  $4.1\sigma$  for:  $(M_0, \Gamma_0) = (4124.1 \text{ MeV}/c^2, 10 \text{ MeV})$
  - Upper Limits (CL90) provided: on  $\sigma_{\text{Born}} \times \text{BR}$ :  $\mathcal{O}(1)$  pb
    - UL on  $\sigma_{\text{Born}} \times \text{BR}$ :  $\mathcal{O}(1)$  pb
    - at each  $\sqrt{s} = 4.661, 4.682$  and  $4.699$
- => More data will be taken

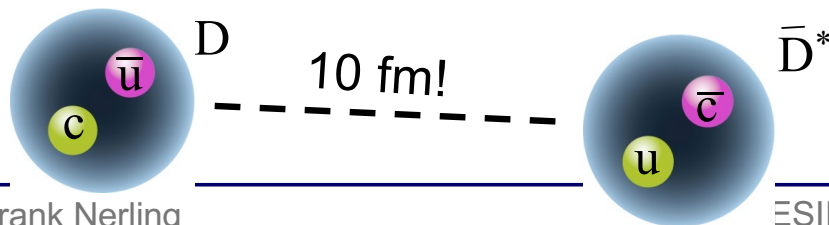
# The X(3872) and further X states

[Belle Collab., PRL 91 (2003) 262001]



- First observed by Belle in 2003
  - $X(3872) \rightarrow J/\psi \pi^+ \pi^-$
  - very narrow state with  $J^{PC} = 1^{++}$
  
- Belle & BaBar report signal in
  - $X(3872) \rightarrow D^0 \bar{D}^{*0}$
  
- Mass  $m[X(3872)] - m[D^{*0}] - m[D^0]$ 
  - =  $(-0.07 \pm 0.12) \text{ MeV}/c^2$  (LHCb 2020)
  
- Width measurement:
  - $\Gamma_{X(3872)} < 1.2 \text{ MeV}$  (2011, Belle)
  - $\Gamma_{X(3872)} = 1.13 \text{ MeV}$  (2020, LHCb)

Analogy to deuteron:

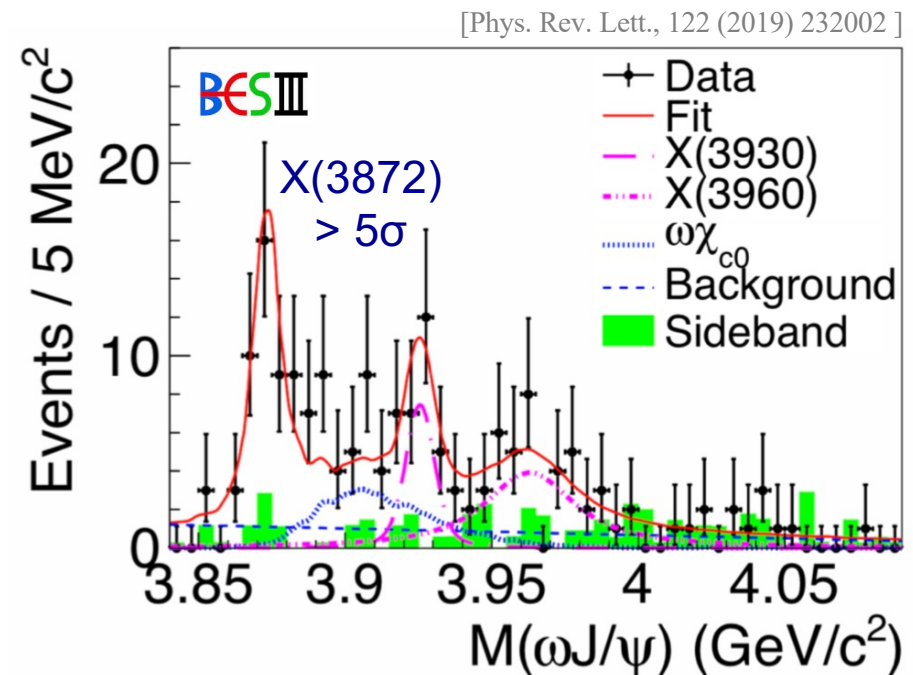
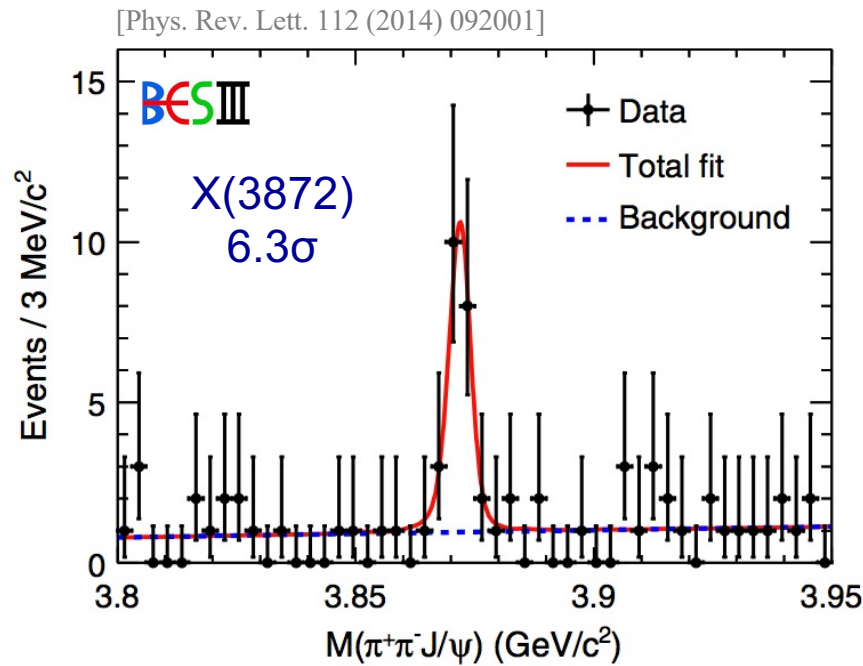


For clarification:

=> Precision measurement with sub-MeV resolution needed!



BESIII: First observation of  $e^+e^- \rightarrow \gamma X(3872) \rightarrow \gamma \pi^+ \pi^- J/\psi$   
 First observation of  $e^+e^- \rightarrow \gamma X(3872) \rightarrow \gamma \omega J/\psi$

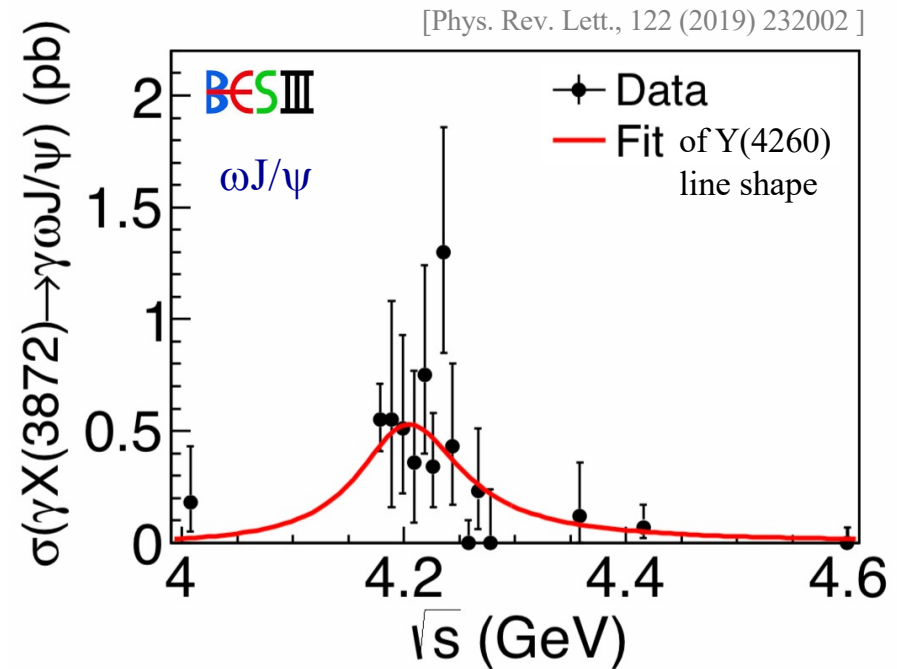
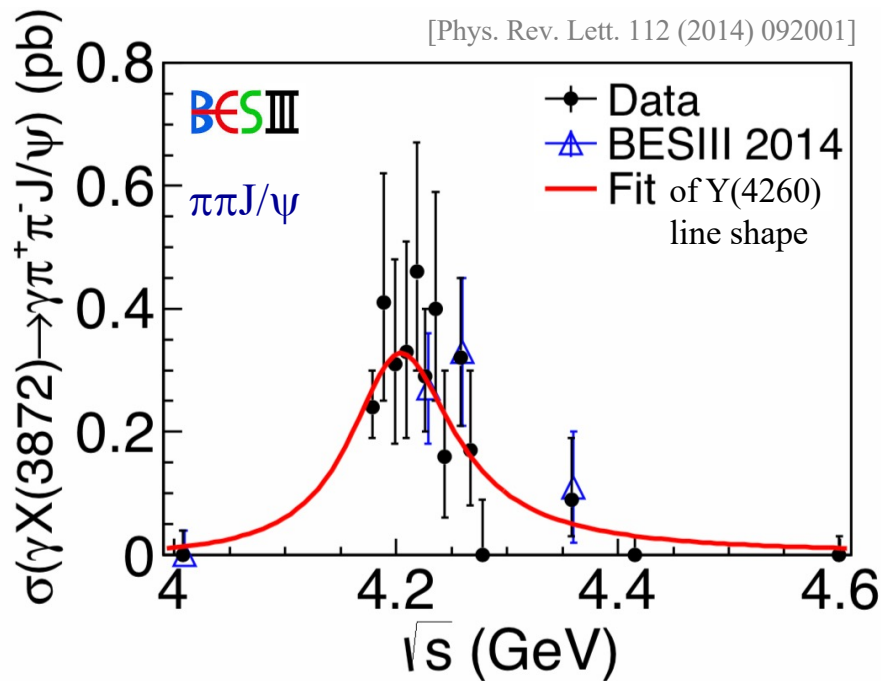


- $m = (3871.9 \pm 0.7 \pm 0.2) \text{ MeV}/c^2$
- $\Gamma < 2.4 \text{ MeV}$  (90% CL)

- Fit with three Breit-Wigner resonances  
 => Evidence for two more structures

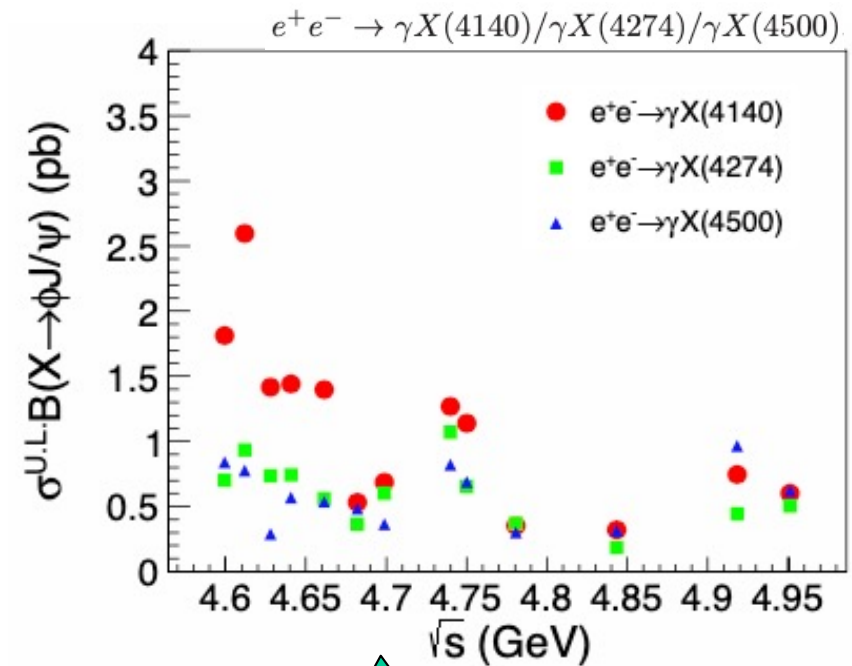
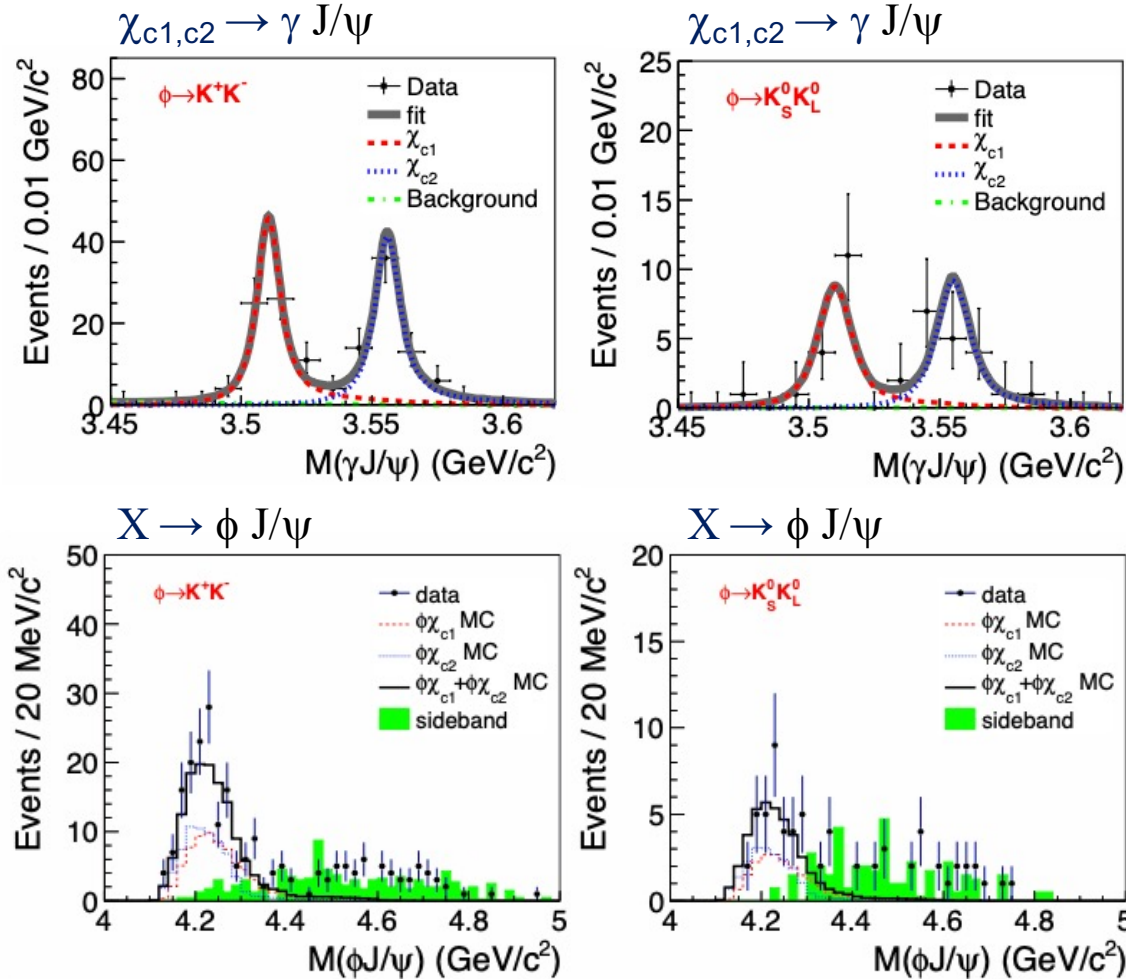
BESIII: First observation of  $e^+e^- \rightarrow Y(4260) \rightarrow \gamma X(3872) \rightarrow \gamma \omega J/\psi$   
 First observation of  $e^+e^- \rightarrow Y(4260) \rightarrow \gamma X(3872) \rightarrow \gamma \pi^+ \pi^- J/\psi$

cross section

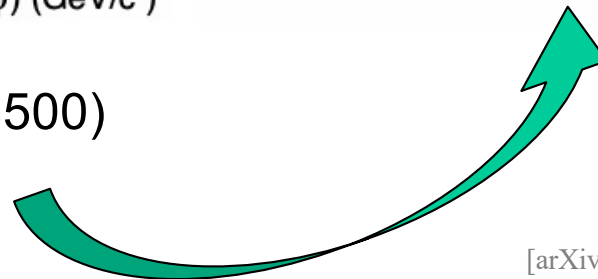


- $m = (4200.6^{+7.9}_{-13.3} \pm 3.0) \text{ MeV}/c^2$
- $\Gamma = (115^{+38}_{-26} \pm 12) \text{ MeV}/c^2$

- Shape consistent with production via a Y(4260) state

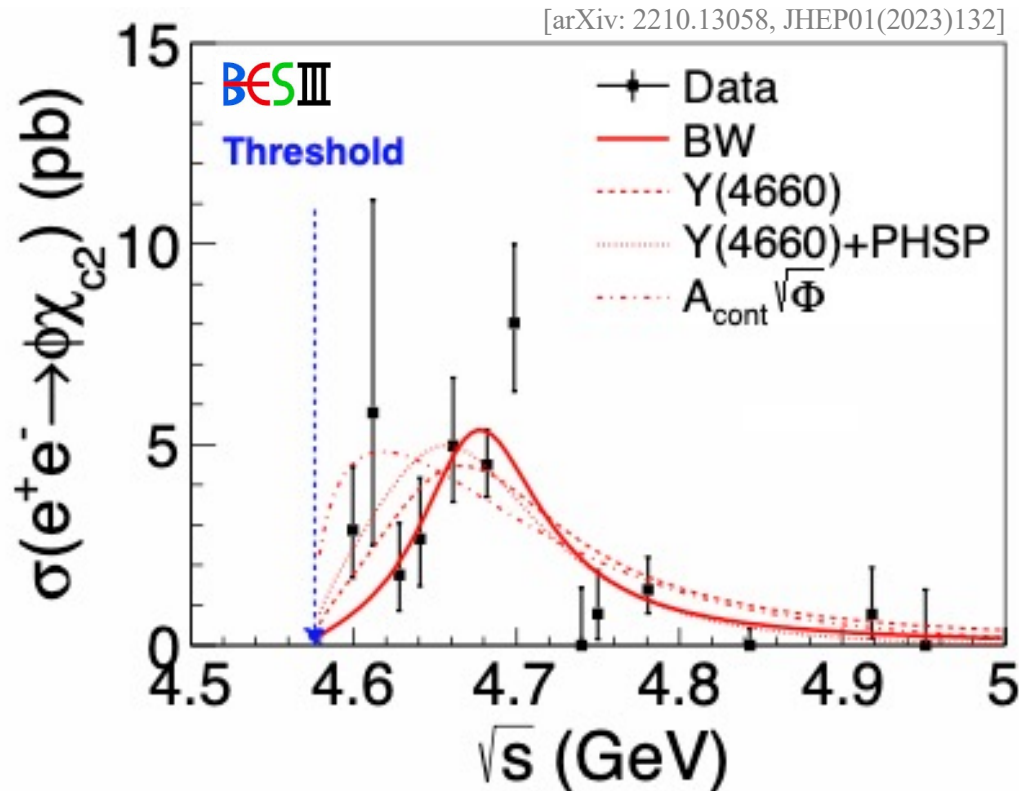


- No evidence for X(4140), X(4274), X(4500)
- CL90 Upper Limits provided, see plot



[arXiv: 2210.13058, JHEP01(2023)132]

$$e^+e^- \rightarrow \gamma \phi \chi_{c2}$$



- Cross section measurement:  
 $e^+e^- \rightarrow \phi \chi_{c2}$
- Evidence for  $Y(4660) \rightarrow \phi \chi_{c2}$
- Statistical significance of  $3.1\sigma$
- No signal for  $Y(4660) \rightarrow \phi \chi_{c1}$

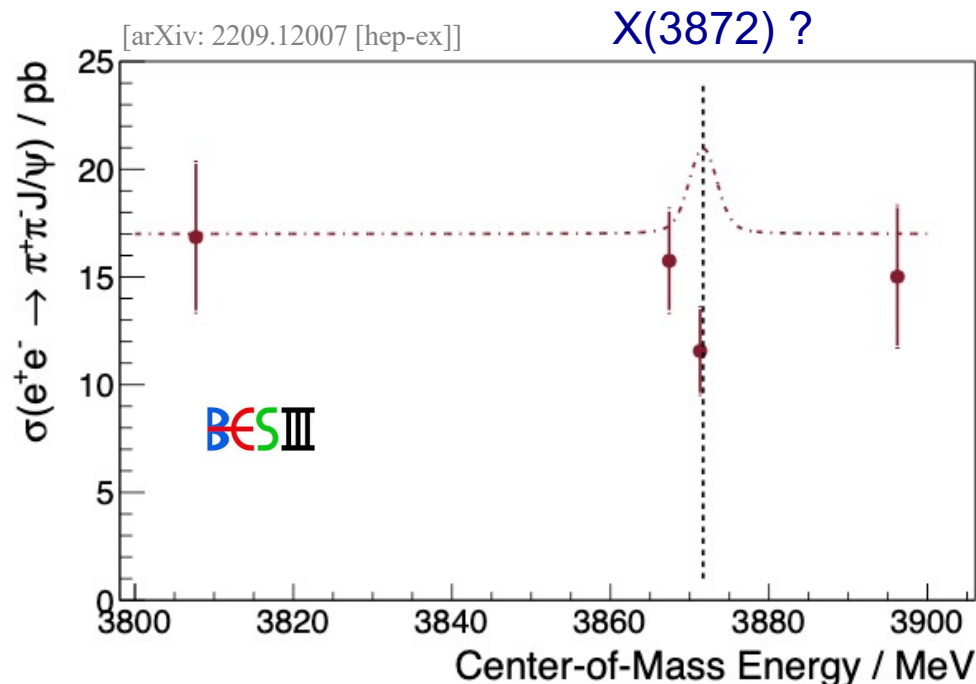
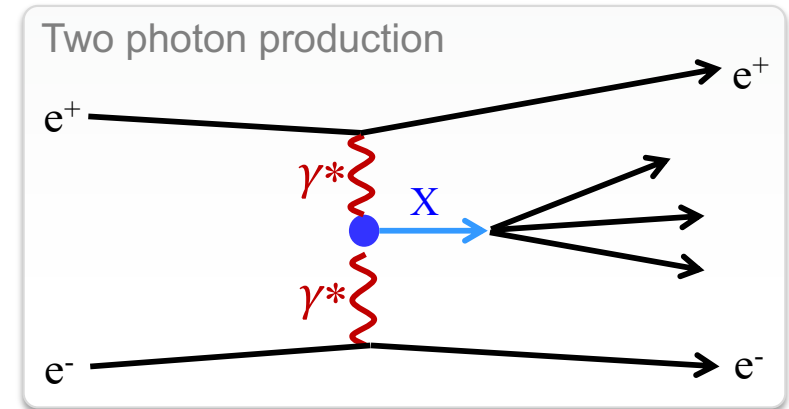
- Different fit models:
  - Single BW model (red line, a)

$$M = (4672.8 \pm 10.8 \pm 3.9) \text{ MeV}/c^2$$

$$\Gamma = (93.2 \pm 19.8 \pm 9.4) \text{ MeV}$$

## Production mechanisms

- B meson decays (*discovery by Belle, 2003*)
- Radiative transitions (*e.g. from Y(4230), BESIII*)
- Prompt production (*e.g. pp collisions, e.g. CMS*)
- Two-photon fusion (*evidence by Belle, 2021*)



## Two-photon fusion at BESIII

- VMD prediction:  $\Gamma_{ee} \gtrsim 0.036 \text{ eV}$   
[A.Denig et al. PLB 736 (2014) 221]
- After observation ( $5.1\sigma$ ) of  $e^+e^- \rightarrow \chi_{c1}$   
[BESIII, PRL 129 (2022) 122001]
- Search for  $e^+e^- \rightarrow X(3872)$ 
  - No enhancement observed in cross section
  - Provide UL(CL90) assuming average value:  
 $\Gamma_{\text{tot}} = 1.19 \text{ MeV}$

$$\Rightarrow \Gamma_{ee} \times \mathcal{B} < 7.5 \times 10^{-3} \text{ eV}$$

$$\Gamma_{ee}(X(3872)) < 0.32 \text{ eV}$$

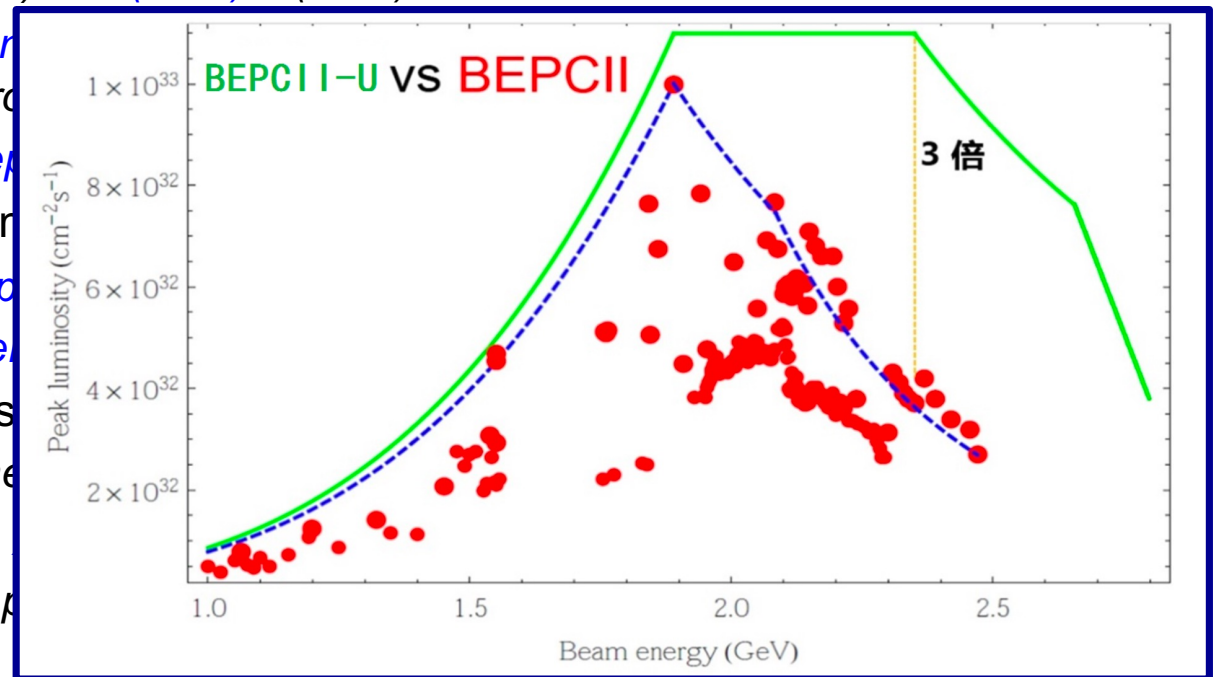
- BESIII successfully operating since 2008
  - World largest data sets in tau-charm mass region, unique XYZ data
  - Recent machine upgrade extends studies up to  $E_{\text{cms}} = \sim 4.9 \text{ GeV}$
  
- BESIII successfully operating since 2008
  - Supernumerary vector Y states consistently resolved (statistics)
    - $Y(4260)$  and  $Y(4360) \rightarrow Y(4230), Y(4360)$
    - *First decays to open charm, further new decay modes to  $c\bar{c}$  and/or light hadrons investigated*
    - *More candidates reported, especially  $Y(4500), Y(4710),$  and  $Y(4660)$*
  - Charged  $Z_c$  states are manifestly exotic states
    - *First complete isospin triplets established*
    - *First strange partner(s) reported, isospin triplet  $Z_{cs}(3895)$*
  - The first of these states discovered, the  $X(3872)$  still not understood
    - *Line shape to be measured precisely*
    - $X(4140, ), X(4274), X(4500) \rightarrow \phi J/\psi$  not seen
    - *Two-photon fusion process promising*
  
- Next machine upgrade planned (summer 2024)  $\Rightarrow E_{\text{cms}} > 5\text{GeV}$

- BESIII successfully operating since 2008
  - World largest data sets in tau-charm mass region, unique XYZ data
  - Recent machine upgrade extends studies up to  $E_{\text{cms}} = \sim 4.9 \text{ GeV}$

- BESIII successfully operating since 2008

- Supernumerary vector Y states consistently resolved (sta
  - $Y(4260)$  and  $Y(4360) \rightarrow Y(4230), Y(4360)$
  - First decays to open  $c\bar{c}$  and/or light hadrons
  - More candidates reported
- Charged  $Z_c$  states are now
  - First complete isospin multiplets
  - First strange partners
- The first of these states
  - Line shape to be measured
  - $X(4140), X(4274), X(4350)$
  - Two-photon fusion production

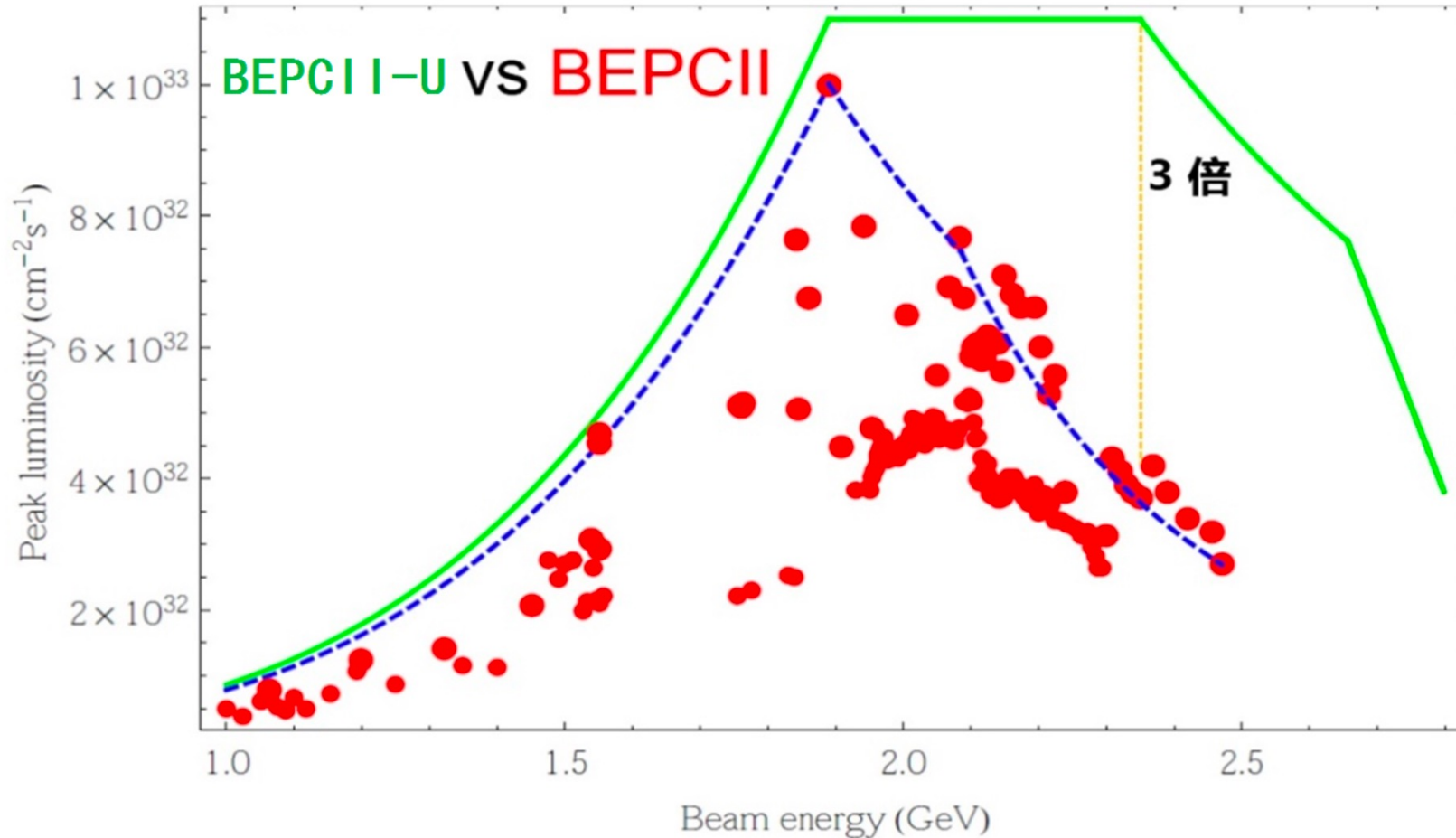
## Thank you!



- Next machine upgrade planned (summer 2024) =>  $E_{\text{cms}} > 5 \text{ GeV}$

# BEPCII Upgrade

(higher luminosity at higher energies)



- Machine upgrade: 2 new cavities (RF), higher currents
- Higher luminosities at higher energies, e.g. factor  $\sim 3$  at 2.3 GeV
- After shutdown collect more XYZ data at 4.6 – 5.5 GeV



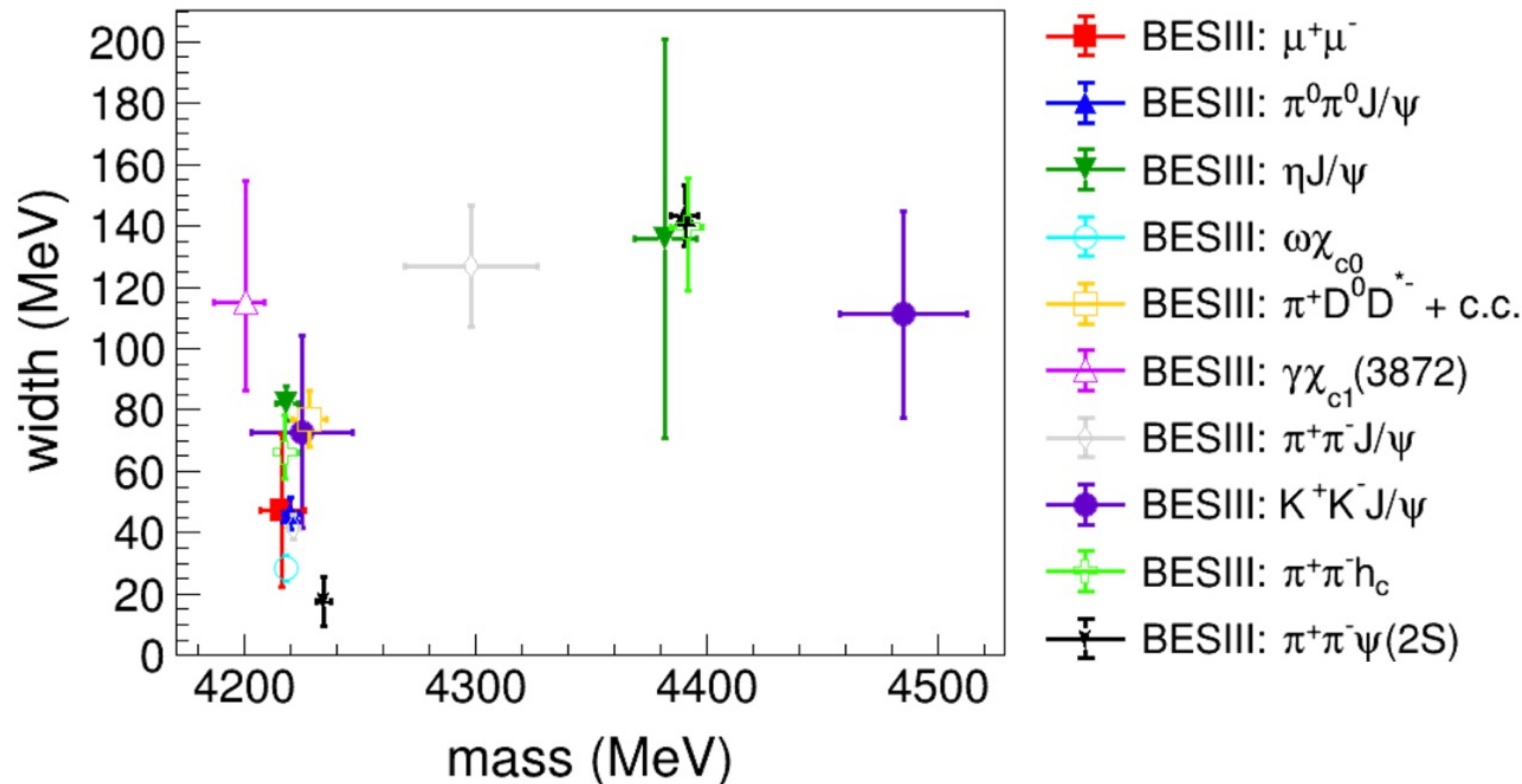
$c\bar{c}$  MESONS >  $\psi(4230)$  >  $\psi(4230)$  MASS

$\psi(4230)$  MASS INSPIRE

VALUE (MeV)	EVTS	DOCUMENT ID	TECN	COMMENT
<b>4222.7 ± 2.6</b>	<b>OUR AVERAGE</b>	Error includes scale factor of 1.7. See the ideogram below.		
4234.4 ± 3.2 ± 0.2		<sup>1</sup> ABLIKIM	2021AJ BES3	$e^+ e^- \rightarrow \pi^+ \pi^- \psi(2S)$
4216.7 ± 8.9 ± 4.1		<sup>2</sup> ABLIKIM	2020AG BES3	$e^+ e^- \rightarrow \mu^+ \mu^-$
4220.4 ± 2.4 ± 2.3		<sup>3</sup> ABLIKIM	2020N BES3	$e^+ e^- \rightarrow \pi^0 \pi^0 J/\psi$
4218.6 ± 3.8 ± 2.5		<sup>3</sup> ABLIKIM	2020O BES3	$e^+ e^- \rightarrow \eta J/\psi$
4218.5 ± 1.6 ± 4.0		<sup>4</sup> ABLIKIM	2019AI BES3	$e^+ e^- \rightarrow \omega \chi_{c0}$
4228.6 ± 4.1 ± 6.3		ABLIKIM	2019R BES3	$e^+ e^- \rightarrow \pi^+ D^0 D^{*-} + \text{c.c.}$
4200.6 $^{+7.9}_{-13.3}$ ± 3.0		<sup>5</sup> ABLIKIM	2019V BES3	$e^+ e^- \rightarrow \gamma \chi_{c1}(3872)$
4222.0 ± 3.1 ± 1.4		<sup>6</sup> ABLIKIM	2017B BES3	$e^+ e^- \rightarrow \pi^+ \pi^- J/\psi$
4218 $^{+5.5}_{-4.5}$ ± 0.9		ABLIKIM	2017G BES3	$e^+ e^- \rightarrow \pi^+ \pi^- h_c$

PDG calls the narrow structure meanwhile  $\psi(4230)$  — seen in many different decay modes, mainly charmonium + light meson(s)

- different channels show (slightly) different masses and widths



- coupled channel studies are needed!

PDG calls the narrow structure meanwhile  $\psi(4230)$  — seen in many different decay modes, mainly charmonium + light meson(s)