The XYZ States at BESIII

Xinping Xu

(For the BESIII Collaboration)

Soochow University, Suzhou, P.R. China

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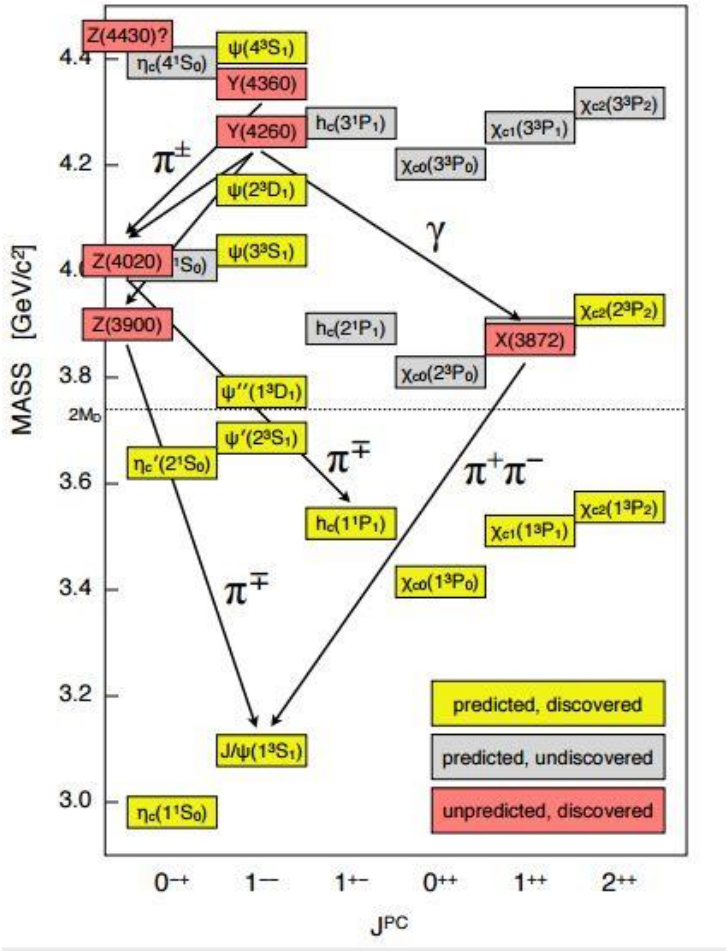
Outline

- Introduction
- X Y Z states at BESIII:
  - X states: X(3872), X(3823)
  - Y states: Cross sections of $e^+e^- \to \pi^+\pi^- J/\psi$, $\pi^+\pi^-\psi(2S)$, $\pi^+\pi^- h_c$, $\omega\chi_{cJ}$ *etc.*
  - Z_c states: $Z_c(3900)/Z_c(3885)$, $Z_c(4020)/Z_c(4025)$
- What's the nature of XYZ states?
- Summary

Charmonium & XYZ spectrum



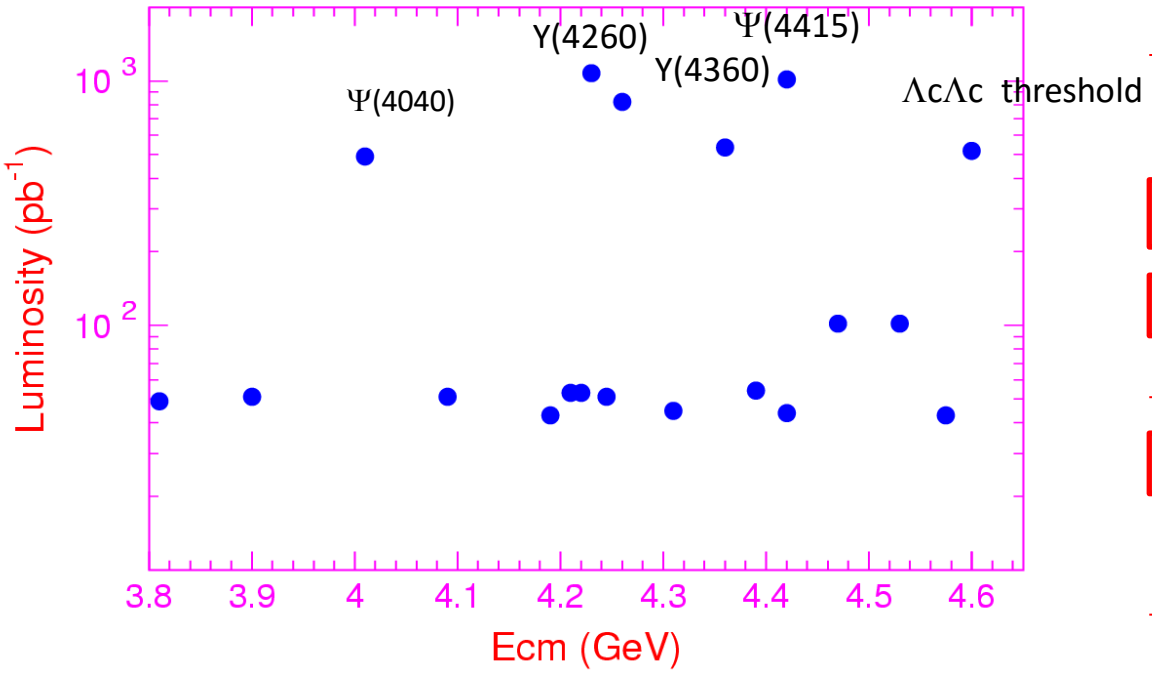
- ✓ Below open-charm threshold
- ✓ All the discoveries are in good agreement with theoretical prediction (Charmoium).
- ✓ Above open-charm threshold
- ✓ Some expected states have not been discovered
- ✓ Some unexpected states have been discovered: These unexpected states do not fit into the quark model, and can't be the conventional charmonium states(called charmonium-like or XYZ states)

X: $J^{PC} \neq 1^{--}$ X(3872); X(3823)…

Y: $J^{PC}=1^{--}$ produced in e^+e^- annihilation or initial state radiation(ISR)

Z: Z_c I=1 charmonium-like states

BESIII data samples for XYZ study (~5fb^{-1})



CM energy (GeV)	L (pb^{-1})
3.810	50.54±0.03
3.900	52.61±0.03
4.009	481.96±0.01
4.090	52.63±0.03
4.190	43.09±0.03
4.210	54.55±0.03
4.220	54.13±0.03
4.230[1]	44.40±0.03
4.230[2]	1047.34±0.14
4.245	55.59±0.04
4.260[1]	523.74±0.10
4.260[2]	301.93±0.08
4.310	44.90±0.03
4.360	539.84±0.10
4.390	55.18±0.04
4.420[1]	44.67±0.03
4.420[2]	1028.89±0.13
4.470	109.94±0.04
4.530	109.98±0.04
4.575	47.67±0.03
4.600	566.93±0.11

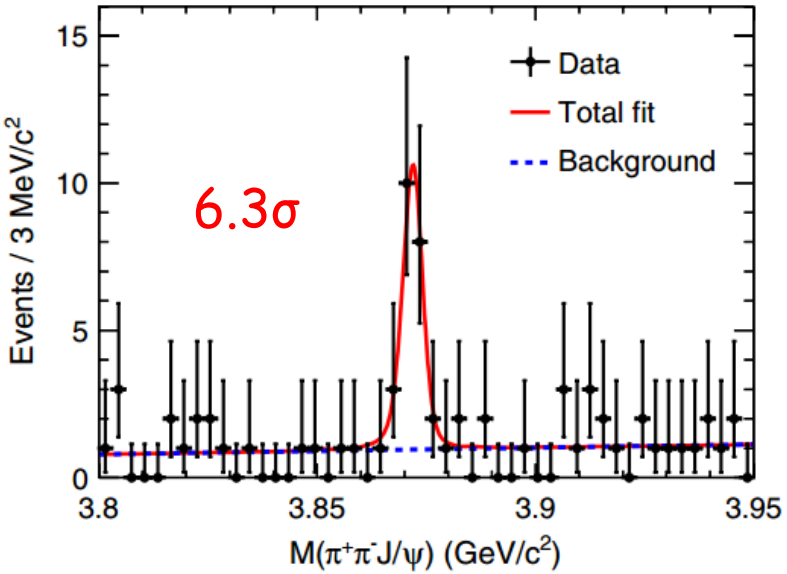
The c.m. Energy are ranged from 3.8 - 4.6 GeV

Total integrated luminosity~5fb^{-1}

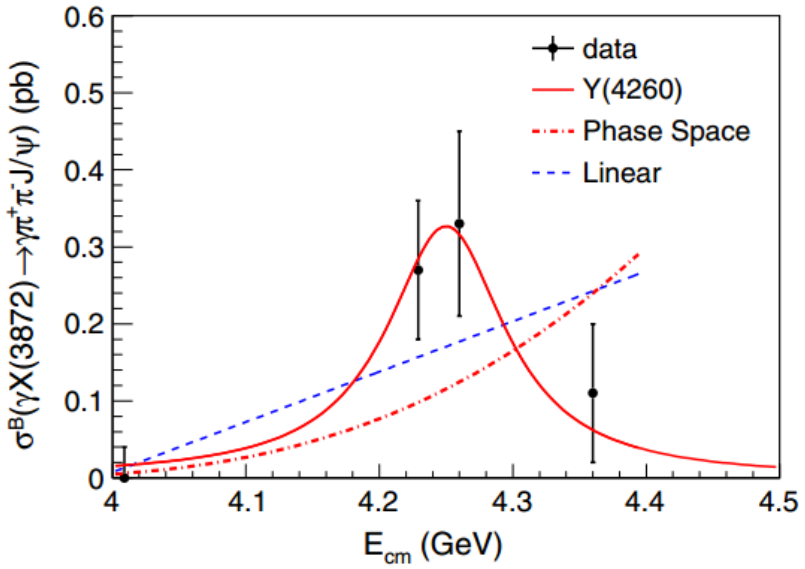
X States at BESIII

5

$e^+e^- \to \gamma X(3872) \to \gamma\pi^+\pi^- J/\psi$



M = (3871.9 ± 0.7 ± 0.2) MeV/c²



Suggestive of $Y(4260) \to \gamma X(3872)$

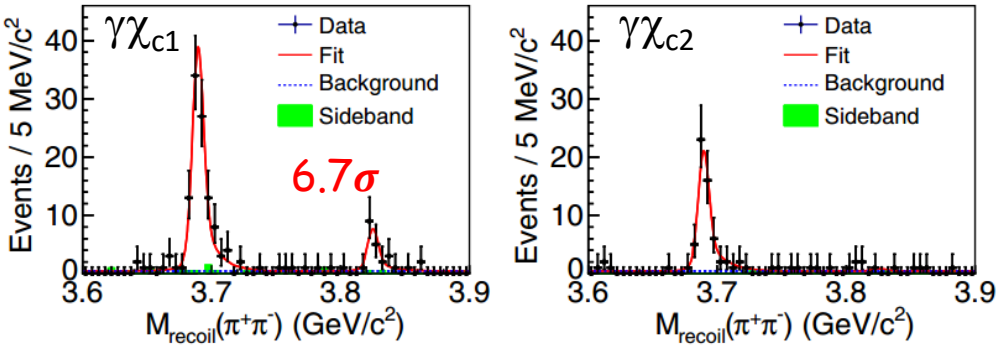
It is a narrow 1^{++} state and its mass is close to $\bar{D}^0 D^{*0}$ threshold

- $\bar{D}^0 D^{*0}$ molecule : loosely $\bar{D}^0 D^{*0}$ bound state
- Mixture of χ'_{c1} and $\bar{D}^0 D^{*0}$ bound state

Phys. Rev. Lett. **112**, 092001 (2014)

$e^+e^- \to \pi^+\pi^- X(3823) \to \gamma\pi^+\pi^-\chi_{c1}$

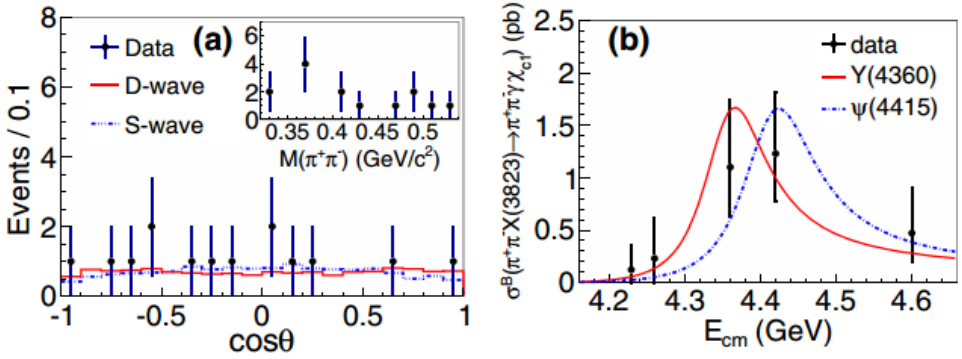
Phys. Rev. Lett. 115, 011803 (2015)



Good candidate of D-wave charmonium states : $\psi(1^3D_2)$

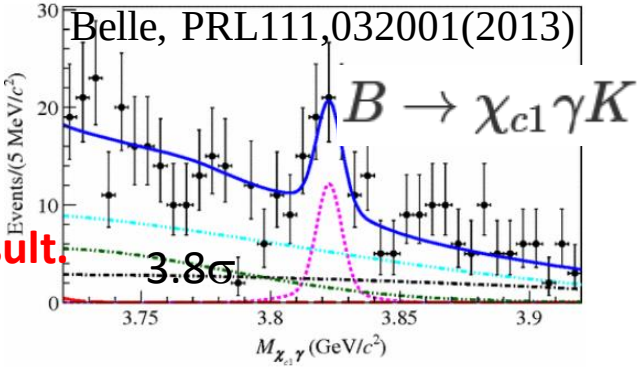
Mass expected to be ~3.82 - 3.85 GeV

Exclusions: $1^1D_2 \to \gamma\chi_{c1}$ forbidden; $1^3D_3 \to \gamma\chi_{c1}$ amplitude~small



(a) D wave expected, with limited statistics

(b) Both $Y(4360)$ and $\psi(4415)$ line shape give reasonable description



- M=(3821.7±1.3(stat.)±0.7(syst.))MeV/c²
- Narrow width Γ<16 MeV @ 90% C.L. **consistent with Belle's result.**

(Phys.Rev.Lett. **111**, 032001 (2013)

- $R=\frac{B(X(3823)\to\gamma\chi_{c2})}{B(X(3823)\to\gamma\chi_{c1})}$<0.43 @ 90% C.L. **agree with R~0.2 prediction.**

Y States at BESIII

Y states

The BESIII analyze the cross sections of exclusive process to study the Y states, including the following processes:

- Cross sections of $e^+e^-\to\pi^+\pi^- J/\psi$ to check Y(4260)
- Cross sections of $e^+e^-\to\pi^+\pi^-\psi(2S)$ to check Y(4360)
- Cross sections of $e^+e^-\to\pi^+\pi^- h_c$
- Cross sections of $e^+e^-\to\omega\chi_{cJ}$

  Phys. Rev. Lett **114**,092003(2015), Phys. Rev. D **93**, 011102 (2016)
- Cross sections of $e^+e^-\to\eta/\eta'\, J/\psi$

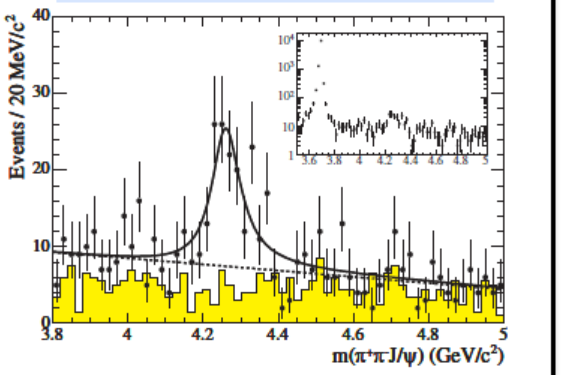
  Phys. Rev. D **91**,112005(2015); arXiv:1605.03256
- Cross sections of $e^+e^-\to\gamma\phi\, J/\psi$ Phys. Rev. D **91**,032002(2015)

These processes provide good chance to study the discovered Y states.

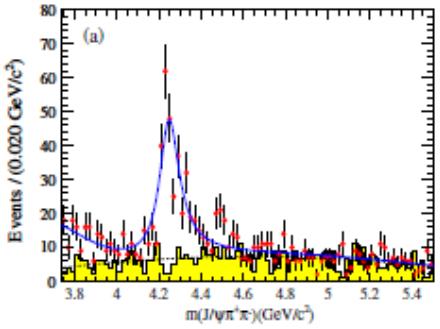
Cross sections of $e^+e^- \to \pi^+\pi^- J/\psi$

Discovery of the Y(4260):

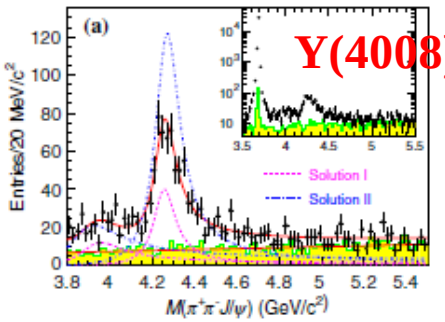
$e^+e^- \to \pi^+\pi^- J/\psi$ using ISR at BaBar
PRL 95, 142001 (2005)



$e^+e^- \to \pi^+\pi^- J/\psi$ using ISR at BaBar
PRD 86, 051102(R) (2012)

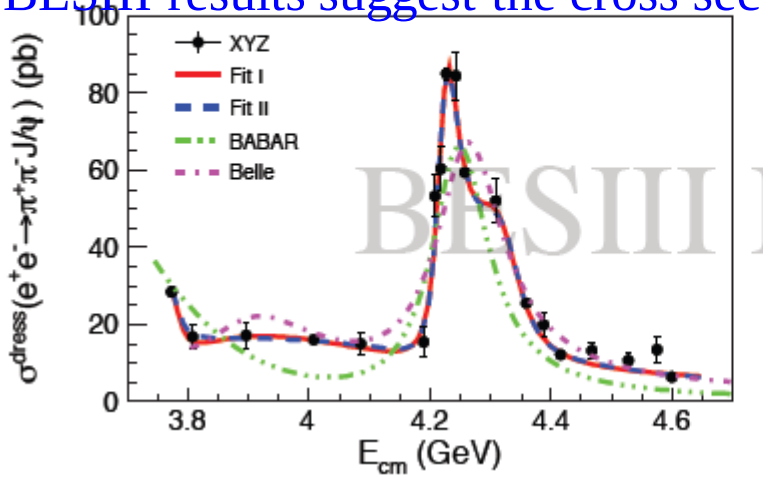


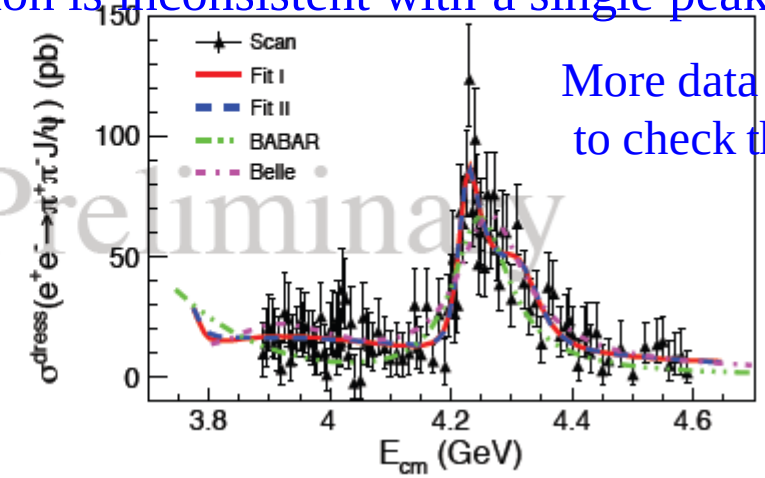
$e^+e^- \to \pi^+\pi^- J/\psi$ using ISR at Belle
PRL 110, 252002 (2013)



$e^+e^- \to \pi^+\pi^- J/\psi$ at BESIII (direct)
BESIII Preliminary (NEW!)

BESIII results suggest the cross section is inconsistent with a single peak for Y(4260)

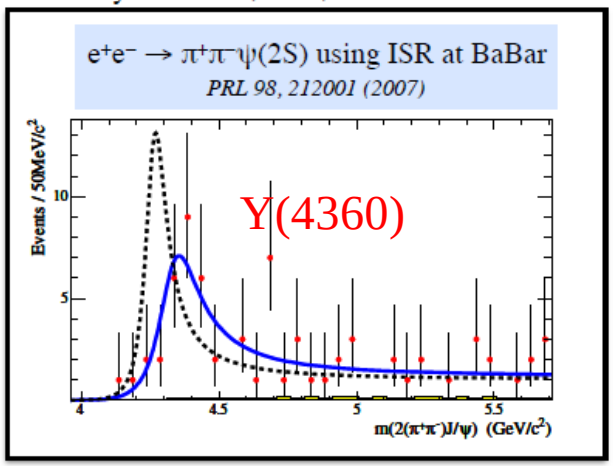


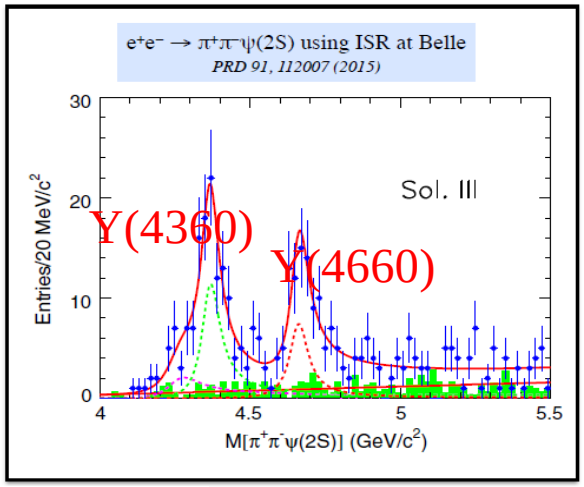


More data are needed to check the Y(4008)

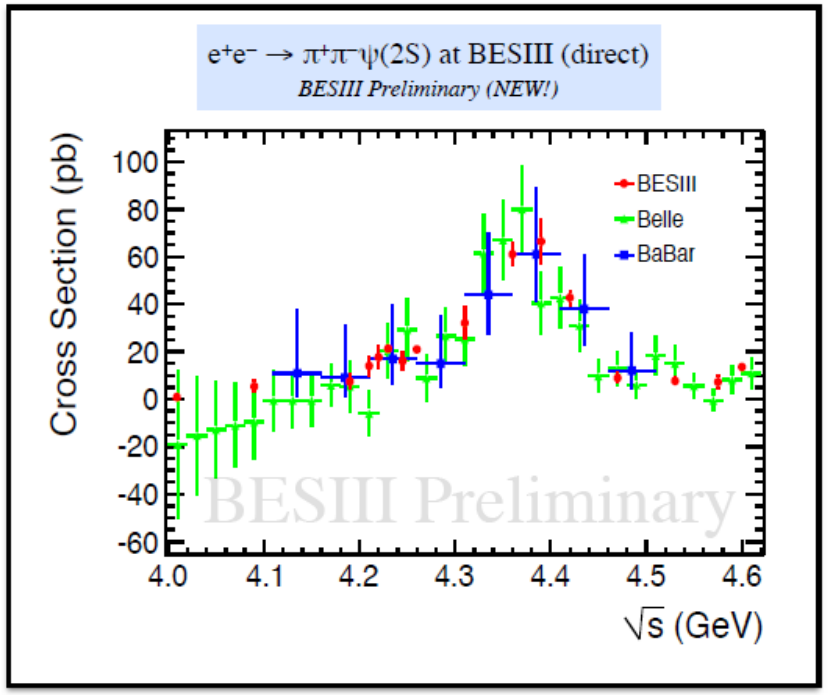
Cross sections of $e^+e^-\to\pi^+\pi^-\psi(2S)$

Discovery of the Y(4360):



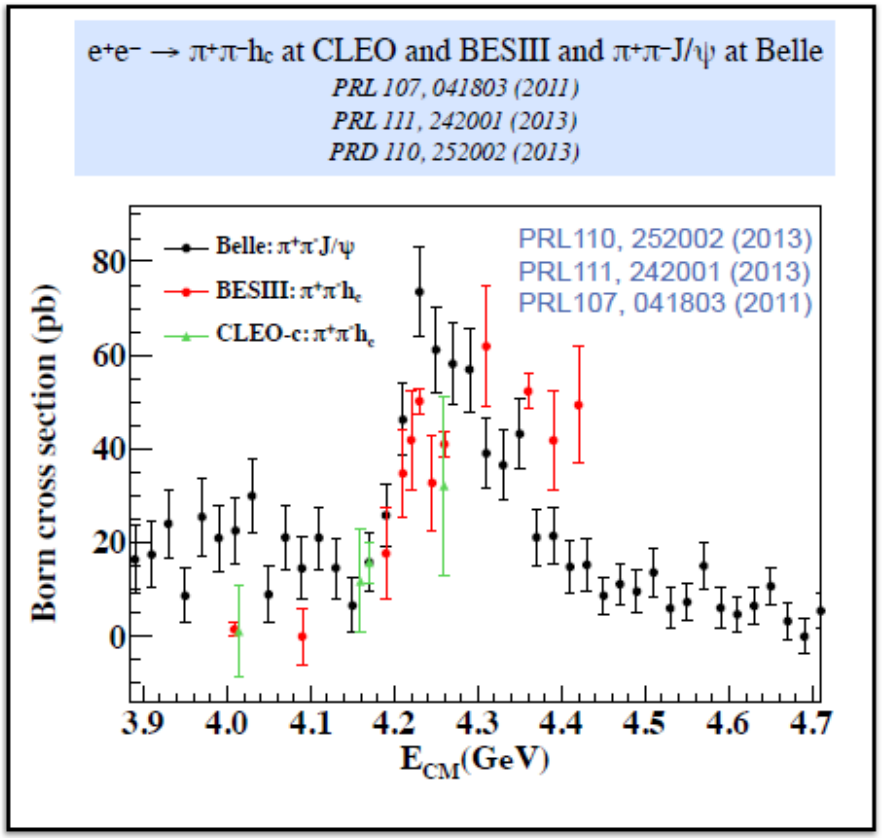


No evidence for $Y(4260)\to\pi^+\pi^-\psi(2S)$

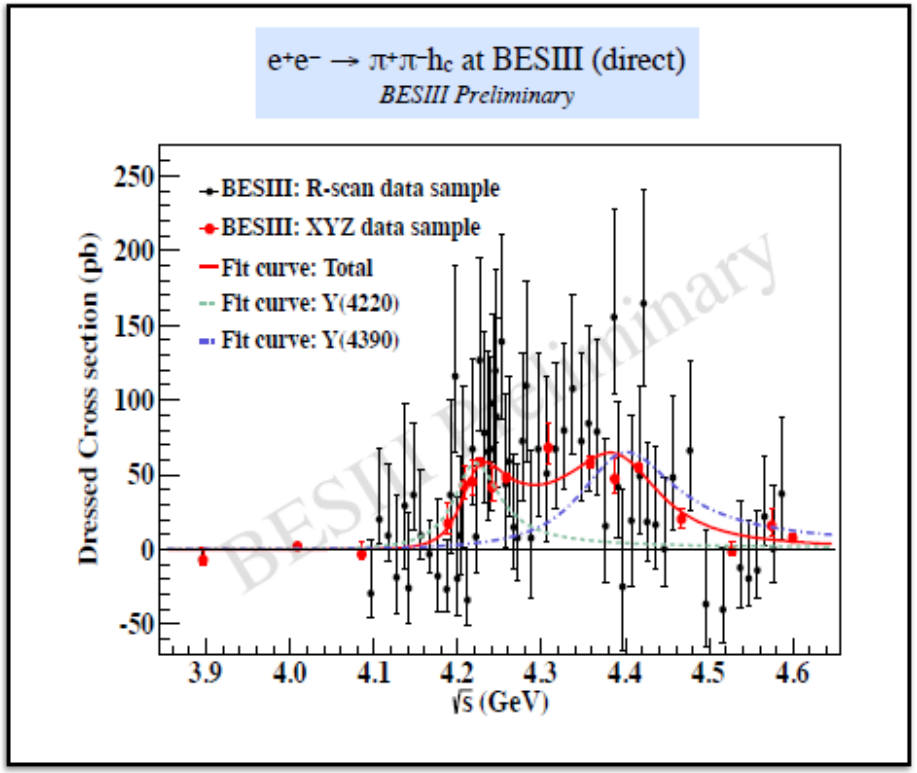


- BESIII confirms the lineshape for the Y(4360).
- More data will be taken soon to thoroughly study the region between 4.2 and 4.3 GeV.
- An analysis of the $\pi^\pm\psi(2S)$ substructure will be released soon.

Cross sections of $e^+e^-\to\pi^+\pi^-h_c$



The $\pi^+\pi^-h_c$ shape is clearly different from the $\pi^+\pi^-J/\psi$ shape.

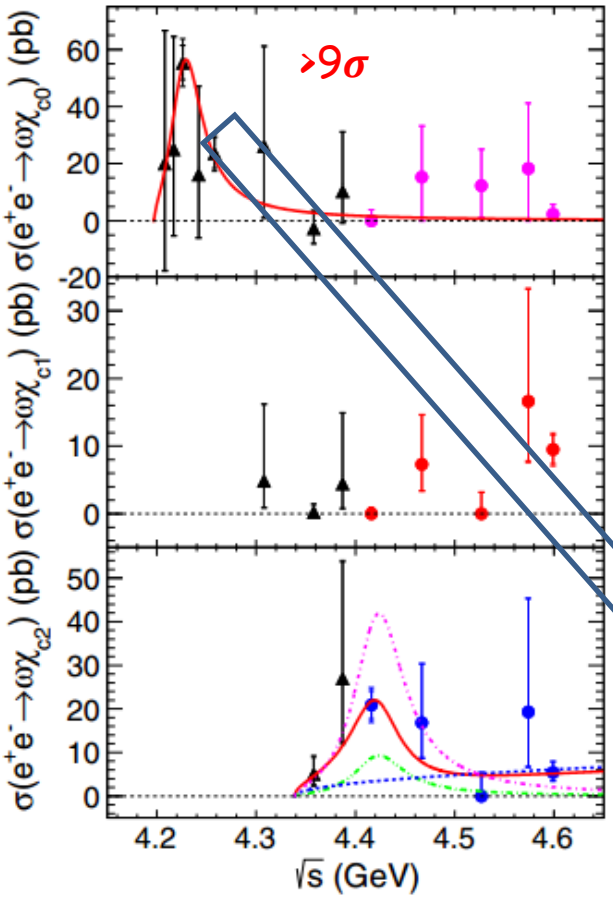


With more data, the $\pi^+\pi^-h_c$ shape appears to be consistent with two peaks:

M (MeV)	Γ_{tot} (MeV)
4218.4±4.0±0.9	66.0±9.0±0.4
4391.6±6.3±1.0	139.5±16.1±0.6

More work is needed to sort out these exclusive cross sections…

Cross sections of $e^+e^- \to \omega\chi_{cJ}$ (J=0,1,2)



Using scan data over 4.21 and 4.42 GeV, $e^+e^- \to \omega\chi_{c0}$ are significant @ E_{cm}=4.23 & 4.26 GeV.
Cross section peak near 4.23 GeV
Fit with a single BW
Mass=(4230±8±6) MeV, Width=(38±12±2) MeV.

- A new structure?
- ψ(4S) EPJC 74:3208 (2014)
- Tetraquark? Phys.Rev.D91, 117501 (2015)
- Threshold effect?

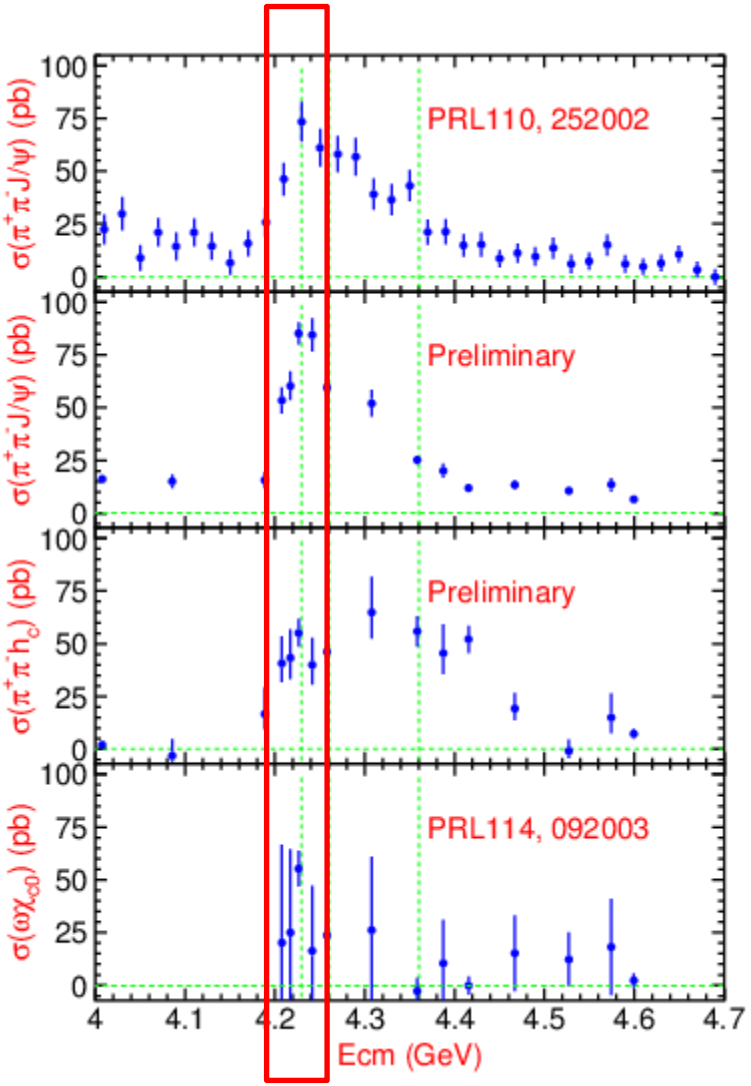
The Born cross section have been measured for
$e^+e^- \to \omega\chi_{c1,2}$
$\sigma(e^+e^- \to \omega\chi_{c2})$ is fitted with the coherent sum of the ψ(4415) BW function and a phase-space term.

However, the peak is not consistent with Y(4260)
The mass and width are smaller than Y(4260) .

The triangle black data points are from
Phys. Rev. Lett. 114,092003(2015)

Other data points are from
Phys. Rev. D93, 011102 (2016)

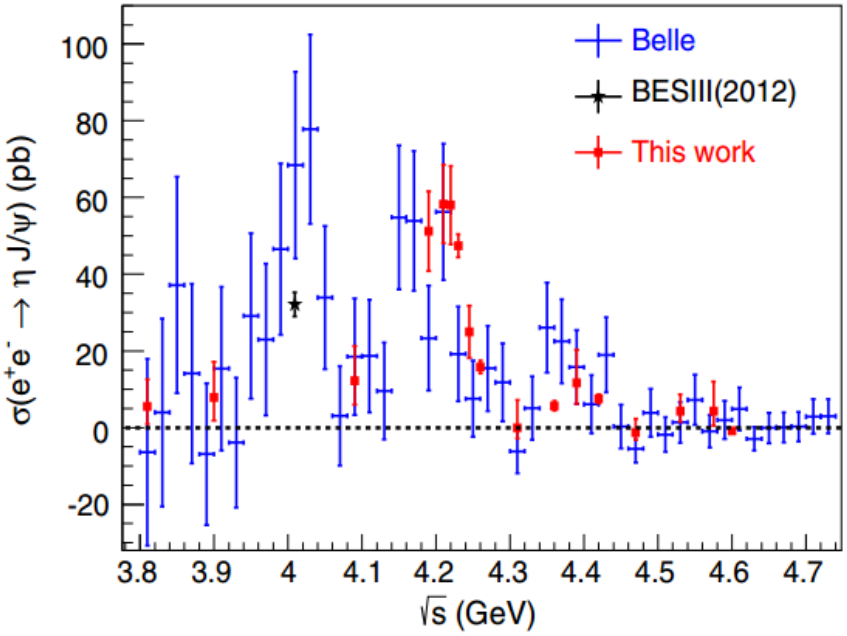
Comparison of the cross sections of $e^+e^-\to\pi^+\pi^- J/\psi, \pi^+\pi^- h_c, \omega\chi_{c0}$



From the line shapes of $\pi^+\pi^- J/\psi$, $\pi^+\pi^- h_c, \omega\chi_{c0}$ in the left plot, we may conclude the Y(4260) has a lower mass and width than previous measurements.

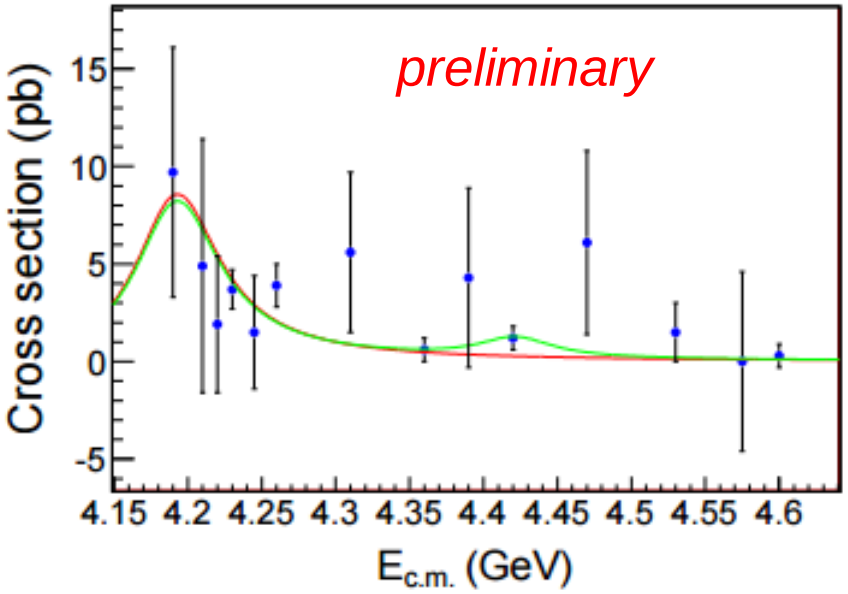
(See the events in the red box)

Cross sections of e^+e^-→ η/η'J/ψ



Phys. Rev. D 91, 112005 (2015)

- Agree with previous results with improved precision
- Structure around 4.2GeV possible from $\psi(4160) \rightarrow \eta\, J/\psi$?



arXiv:1605.03256

- Fit with ψ (4160) and ψ (4415) resonances
  ψ (4415) is not significant
- $\sigma(\eta' J/\psi)$ much lower than $\sigma(\eta\, J/\psi)$, lower than NRQCD calculation

Cross sections of $e^+e^- \to \gamma\phi\, J/\psi$

The X(4140) (or "Y(4140)") was recently confirmed at LHCb *(arXiv:1606.07898)* with $J^{PC} = 1^{++}$ in $B \to K(\phi J/\psi)$.

PHYSICAL REVIEW D **91,** 032002 (2015)

Search for the $Y(4140)$ via $e^+e^- \to \gamma\phi J/\psi$ at $\sqrt{s} = 4.23$, 4.26 and 4.36 GeV

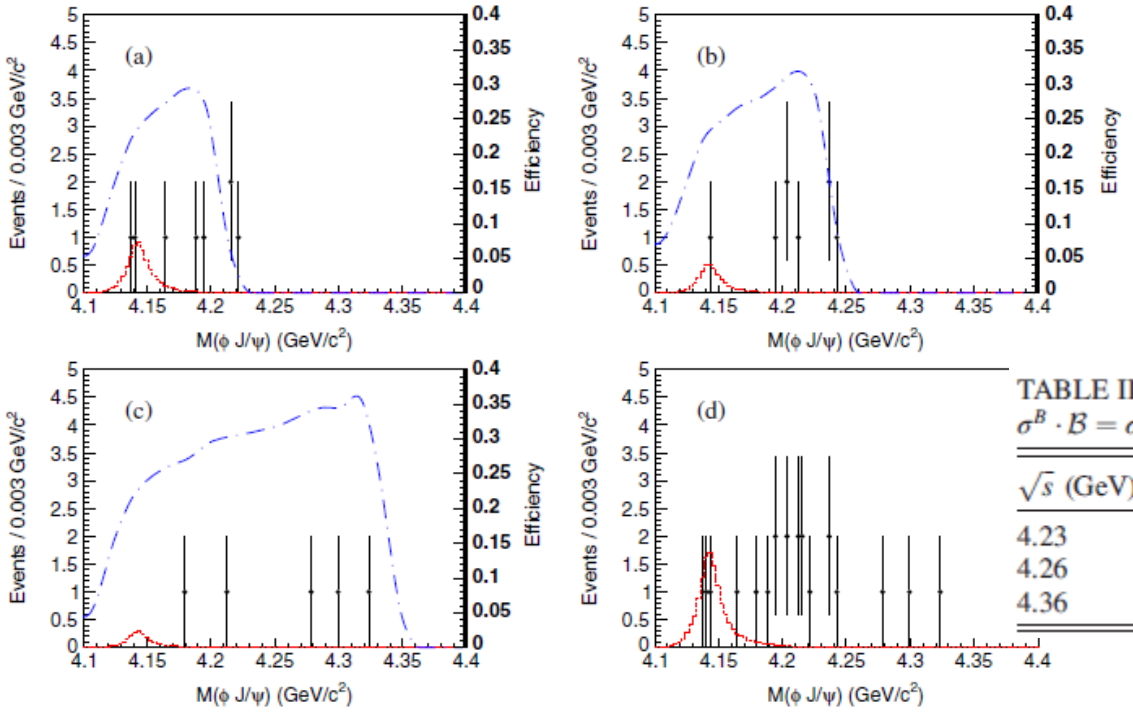


TABLE II. Upper limits at the 90% C.L. for measurements of $\sigma^B \cdot \mathcal{B} = \sigma(e^+e^- \to \gamma Y(4140)) \cdot \mathcal{B}(Y(4140) \to \phi J/\psi)$.

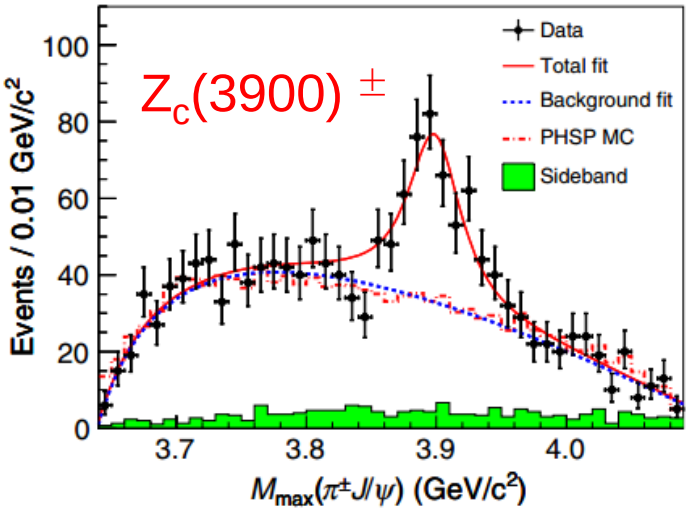
$\sqrt{s}$ (GeV)	Luminosity (pb^{-1})	$(1+\delta)$	$n^{\rm prod}$	$\sigma^B \cdot \mathcal{B}$ (pb)
4.23	1094	0.840	< 339	< 0.35
4.26	827	0.847	< 207	< 0.28
4.36	545	0.944	< 179	< 0.33

FIG. 7 (color online). Distribution of $M(\phi J/\psi)$ summed over all ϕ and J/ψ decay modes at $\sqrt{s}$ = (a) 4.23, (b) 4.26, (c) 4.36 GeV, and (d) the sum of three data samples. The red dashed histogram represents signal MC events scaled to our measured upper limit. The blue dashed-dot line shows the efficiency distribution.

No evidence for Y(4140) $\to \phi\, J/\psi$ using BESIII data

Z_c States at BESIII

Discovery of $Z_c(3900)^{\pm/0}$



$Z_c(3900)^{\pm}$

Phys. Rev. Lett. **110**, 252001 (2013)

Charged charmonium-like structure

- Decay to J/ψ → contains $c\bar{c}$
- Electric charge → contains $u\bar{d}$

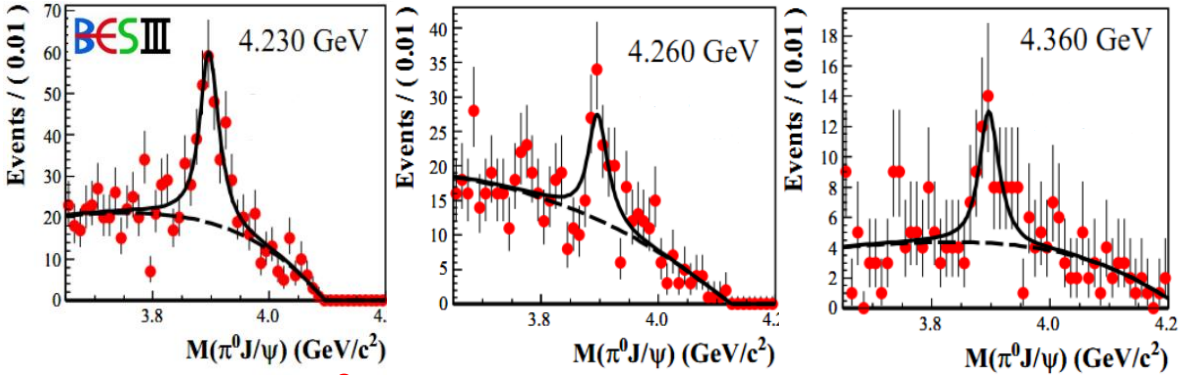
m = (3899.0 ± 3.6 ± 4.9) MeV/c²

Γ = (46 ± 10 ± 20) MeV

$\sigma[e^+e^- \to \pi^+\pi^- J/\psi]$ = (62.9 ± 1.9 ± 3.7) pb @4.26 GeV

$$\frac{\sigma[e^+e^- \to \pi^\pm Zc(3900)^\mp \to \pi^+\pi^- J/\psi]}{\sigma[e^+e^- \to \pi^+\pi^- J/\psi]} = (21.5 \pm 3.3 \pm 7.5)\%$$

It was also confirmed by Belle and CLEO-c data.



$Z_c(3900)^0$

Phys. Rev. Lett. **115**, 112003 (2015)

Evidence with 3.7σ by using CLEO-c data @4.17GeV
Phys.Lett.B**727**, 366 (2013)

Study $e^+e^- \to \pi^0\pi^0 J/\psi$ at different E_{cm}

Simultaneous Fit:

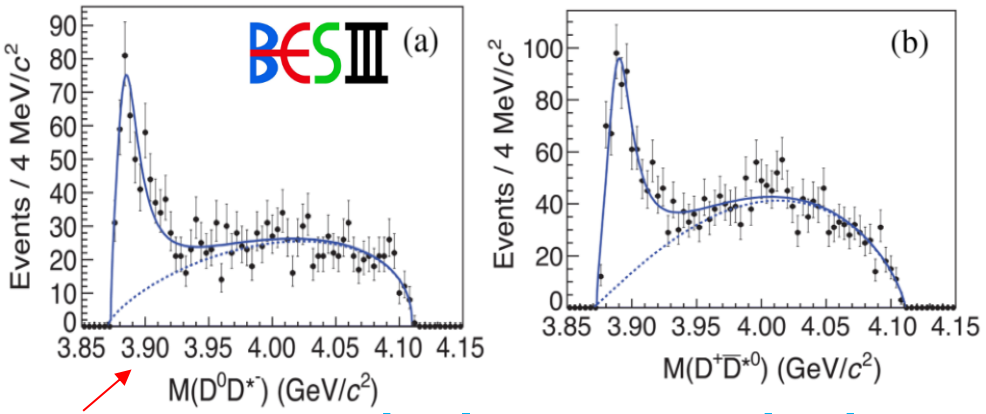
m = (3894.8 ± 2.3 ± 2.7) MeV/c²

Γ = (29.6 ± 8.2 ± 8.2) MeV

Significance: 10.4σ

Isospin triplet is established

Observation of $Z_c(3885)^{\pm/0}$ in $e^+e^- \to (D\bar{D}^*)\pi$

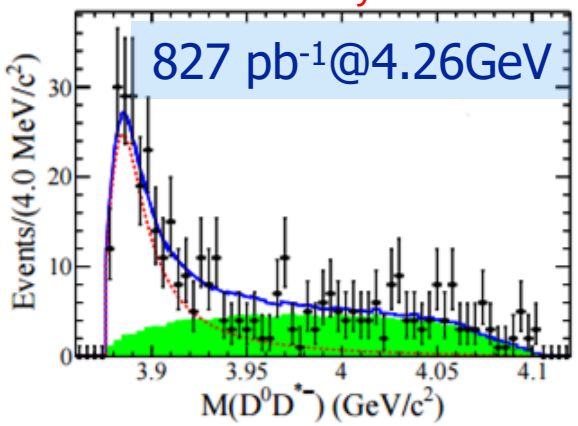


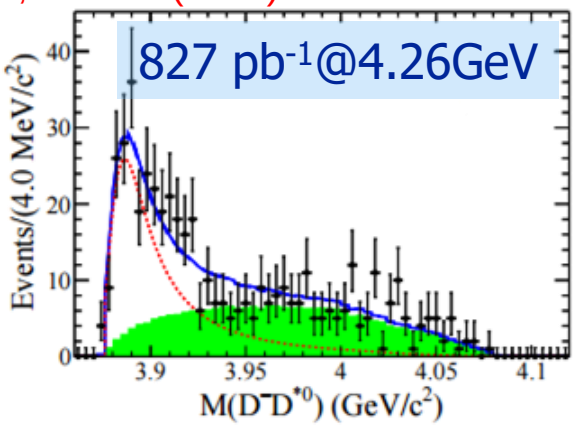
State	Mass (MeV/c^2)	Width (MeV)
$Z_c(3885)^{\pm}$	$3883.9 \pm 1.5 \pm 4.2$ Single D tag	$24.8 \pm 3.3 \pm 11.0$ Single D tag
	$3881.7 \pm 1.6 \pm 1.6$ Double D tag	$26.6 \pm 2.0 \pm 2.1$ Double D tag
$Z_c(3885)^0$	$3885.7^{+4.3}_{-5.7} \pm 8.4$	$35^{+11}_{-12} \pm 15$

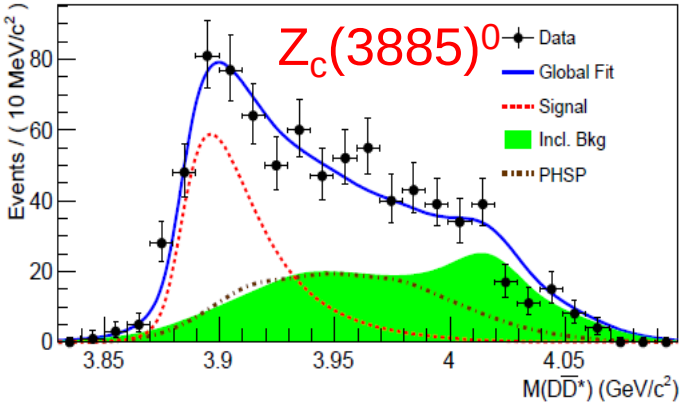
$Z_c(3885)^{\pm}$ **single D tag method**

Phys. Rev. Lett **112**, 022001 (2014)

Another Isospin triplet is established





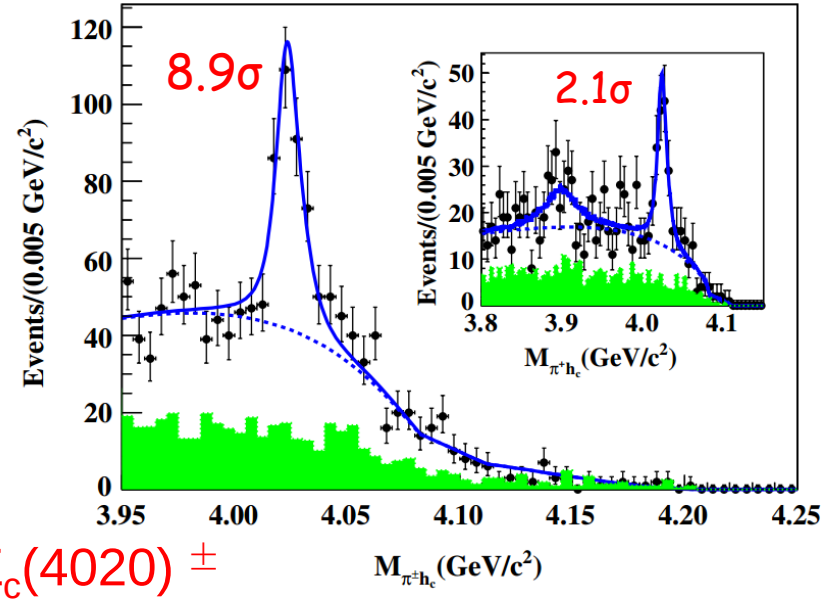


Double D tag method

Double D tag method

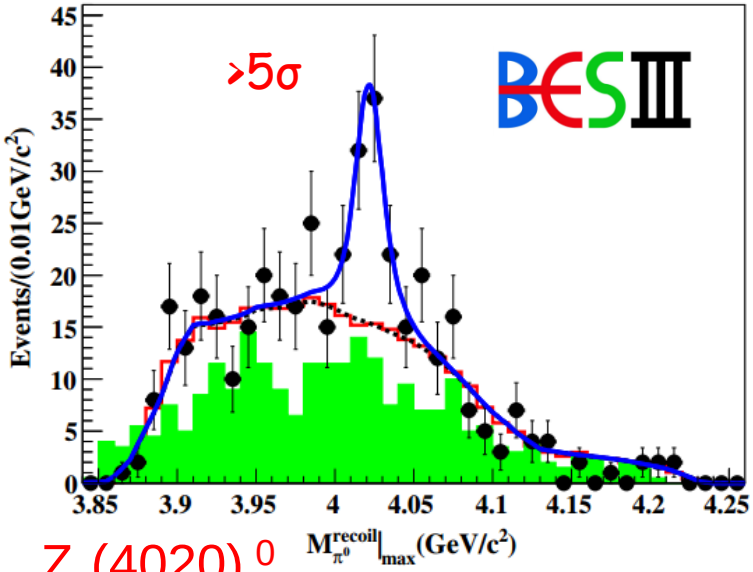
Phys. Rev. D **92**, 092006 (2015)

Observation of $Z_c(4020)^{\pm/0}$ in $e^+e^- \to \pi\pi h_c$



$Z_c(4020)^{\pm}$

Phys. Rev. Lett **111**, 242001 (2013)



$Z_c(4020)^{0}$

Phys. Rev. Lett **113**, 212002 (2014)

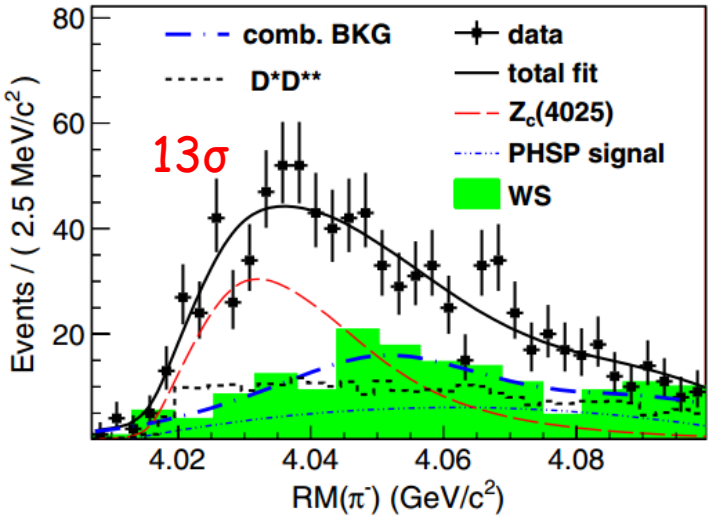
No significant $Z_c(3900)^{\pm} \to \pi^{\pm} h_c$ is observed.

State	Mass (MeV/c²)	Width (MeV)
$Z_c(4020)^{\pm}$	$4022.9 \pm 0.8 \pm 2.7$	$7.9 \pm 2.7 \pm 2.6$
$Z_c(4020)^{0}$	$4023.9 \pm 2.2 \pm 3.8$	fixed

Isospin triplet is established

Observation of $Z_c(4025)^{\pm/0}$ in $e^+e^- \to (D^*\bar{D}^*)\pi$

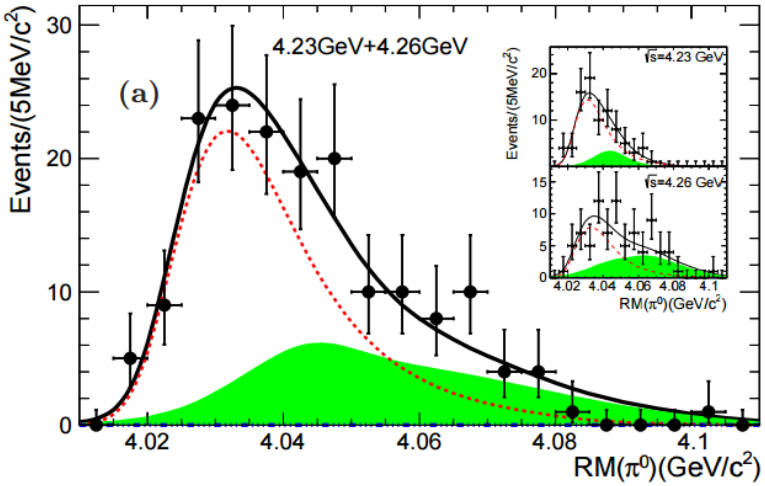
$Z_c(4025)^{\pm}$



single D tag method

Phys. Rev. Lett **112**, 132001 (2014)

$Z_c(4025)^{0}$



Double D tag method

Phys. Rev. Lett. **115**, 182002 (2015)

State	Mass (MeV/c^2)	Width (MeV)
$Z_c(4025)^{\pm}$	$4026.3 \pm 2.6 \pm 3.7$	$24.8 \pm 5.6 \pm 7.7$
$Z_c(4025)^0$	$4025.5^{+2.0}_{-4.7} \pm 3.1$	$23.0 \pm 6.0 \pm 1.0$

Another isospin triplet is established

If $Z_c(4025)$ and $Z_c(4020)$ are the same state, $\frac{\Gamma[Zc(4025)\to D\bar{D}^*]}{\Gamma[Zc(4020)\to \pi h_c]} = 12 \pm 5$

Comparison of Z_c states at BESIII

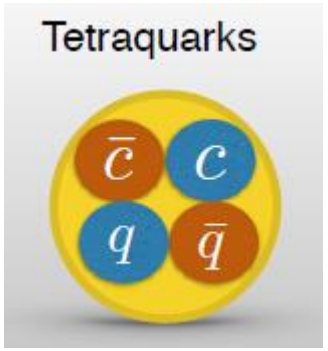
State	Mass (MeV/c^2)	Width (MeV)	Decay	Process
$Z_c(3900)^{\pm}$	$3899.0 \pm 3.6 \pm 4.9$	$46 \pm 10 \pm 20$	$\pi^{\pm} J/\psi$	$e^+e^- \to \pi^+\pi^- J/\psi$
$Z_c(3900)^0$	$3894.8 \pm 2.3 \pm 2.7$	$29.6 \pm 8.2 \pm 8.2$	$\pi^0 J/\psi$	$e^+e^- \to \pi^0\pi^0 J/\psi$
$Z_c(3885)^{\pm}$	$3883.9 \pm 1.5 \pm 4.2$ Single D tag	$24.8 \pm 3.3 \pm 11.0$ Single D tag	$(D\bar{D}^*)^{\pm}$	$e^+e^- \to (D\bar{D}^*)^{\pm}\pi^{\mp}$
	$3881.7 \pm 1.6 \pm 1.6$ Double D tag	$26.6 \pm 2.0 \pm 2.3$ Double D tag	$(D\bar{D}^*)^{\pm}$	$e^+e^- \to (D\bar{D}^*)^{\pm}\pi^{\mp}$
$Z_c(3885)^0$	$3885.7^{+4.3}_{-5.7} \pm 8.4$	$35^{+11}_{-12} \pm 15$	$(D\bar{D}^*)^0$	$e^+e^- \to (D\bar{D}^*)^0\pi^0$
$Z_c(4020)^{\pm}$	$4022.9 \pm 0.8 \pm 2.7$	$7.9 \pm 2.7 \pm 2.6$	$\pi^{\pm} h_c$	$e^+e^- \to \pi^+\pi^- h_c$
$Z_c(4020)^0$	$4023.9 \pm 2.2 \pm 3.8$	fixed	$\pi^0 h_c$	$e^+e^- \to \pi^0\pi^0 h_c$
$Z_c(4025)^{\pm}$	$4026.3 \pm 2.6 \pm 3.7$	$24.8 \pm 5.6 \pm 7.7$	$D^*\bar{D}^*$	$e^+e^- \to (D^*\bar{D}^*)^{\pm}\pi^{\mp}$
$Z_c(4025)^0$	$4025.5^{+2.0}_{-4.7} \pm 3.1$	$23.0 \pm 6.0 \pm 1.0$	$D^*\bar{D}^*$	$e^+e^- \to (D^*\bar{D}^*)^0\pi^0$

Are $Z_c(3900)^{\pm/0}$ and $Z_c(3885)^{\pm/0}$ the same state?

Are $Z_c(4025)^{\pm/0}$ and $Z_c(4020)^{\pm/0}$ the same state?

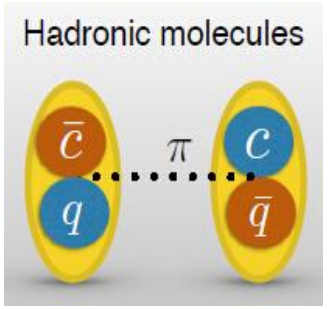
What's the nature of these states?

- At least 4 quarks, not a conventional meso
- Tetraquark state?



Phys. Rev. D87,125018(2013); Phys. Rev. D88, 074506(2013);
Phys. Rev. D89,054019(2014); Phys. Rev. D90,054009(2014); etc

- Molecule state?

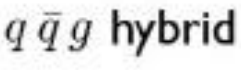


Phys. Rev. Lett. 111, 132003 (2013); Phys. Rev. D 89, 094026 (2014)
Phys. Rev. D 89, 074029 (2014); Phys. Rev. D 88, 074506 (2013) ;etc

- Charmonium hybrid?

Phys.Rev. D88 (2013) 045027; etc

- Kinematical effect (FSI? ISPE model? Cusp?



Phys. Rev. D 88, 014013 (2013); Phys. Rev. D 84, 034032 (2011);
Phys. Lett. B 725, 106 (2013); Phys. Rev. D 91, 034009(2015);

- ……

Summary & Outlook

- Recent results of XYZ states at BESIII are shown.
- The nature of XYZ states is not clear.
- The relations between XYZ states are not clear
- Great efforts are needed to understand these XYZ states.
- More data will be collected to study the XYZ states.
  (search for other decay modes, …)
- More exciting results of BESIII will be coming soon, wish we could understand them better.

Thank you!!