

XYZ spectroscopy at BESIII

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(on the behalf of BESIII collaboration)

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Outline

■ Introduction

- Hadrons and XYZ states

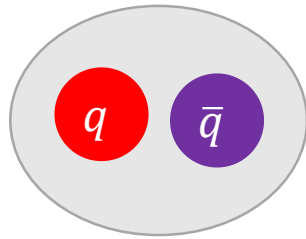
■ XYZ spectroscopy at BESIII

- BESIII data samples for XYZ study
- The XYZ states
 - ✓ $X(3872), X(3823)$
 - ✓ Abundant structures above 4GeV
 - ✓ $Z_c(3900)/Z_c(3885), Z_c(4020)/Z_c(4025)$

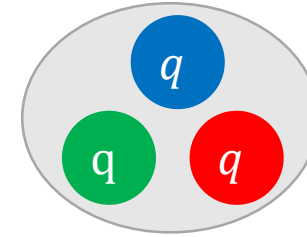
■ Summary

Constitution of hadrons in QCD

- Quark Model

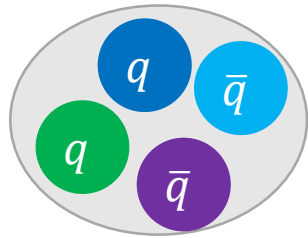


Mesons
Color-anticolor pairs

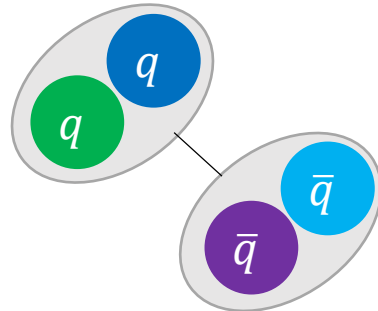


Baryons
Red-blue-green triplets

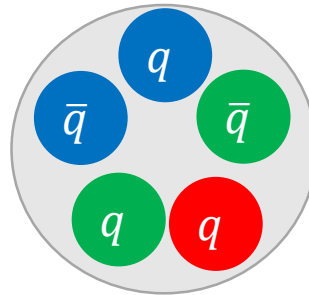
- Exotic states predicted by QCD



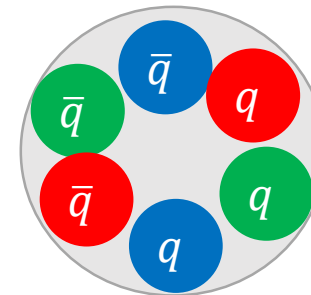
Tetraquark
Tightly bound
diquark&anti-diquark



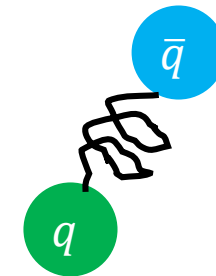
Molecule
Loosely bound
meson&anti-meson



Pentaquark
S=+1



Six-quark state
Tightly bound
6 quarks



Hybrid
More than 2
quarks and gluon

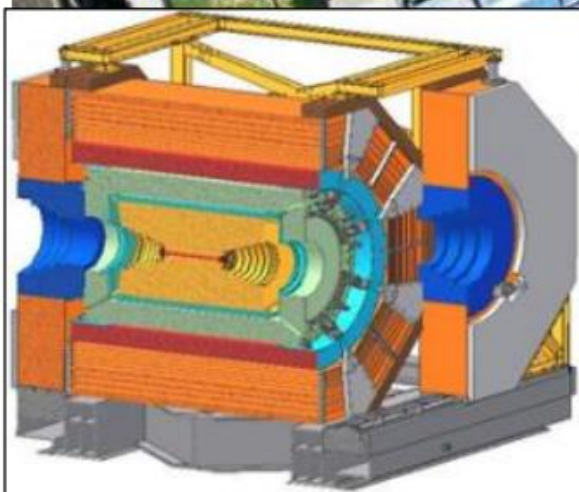
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BEPCII and BESIII

First physics run starts from 2009!

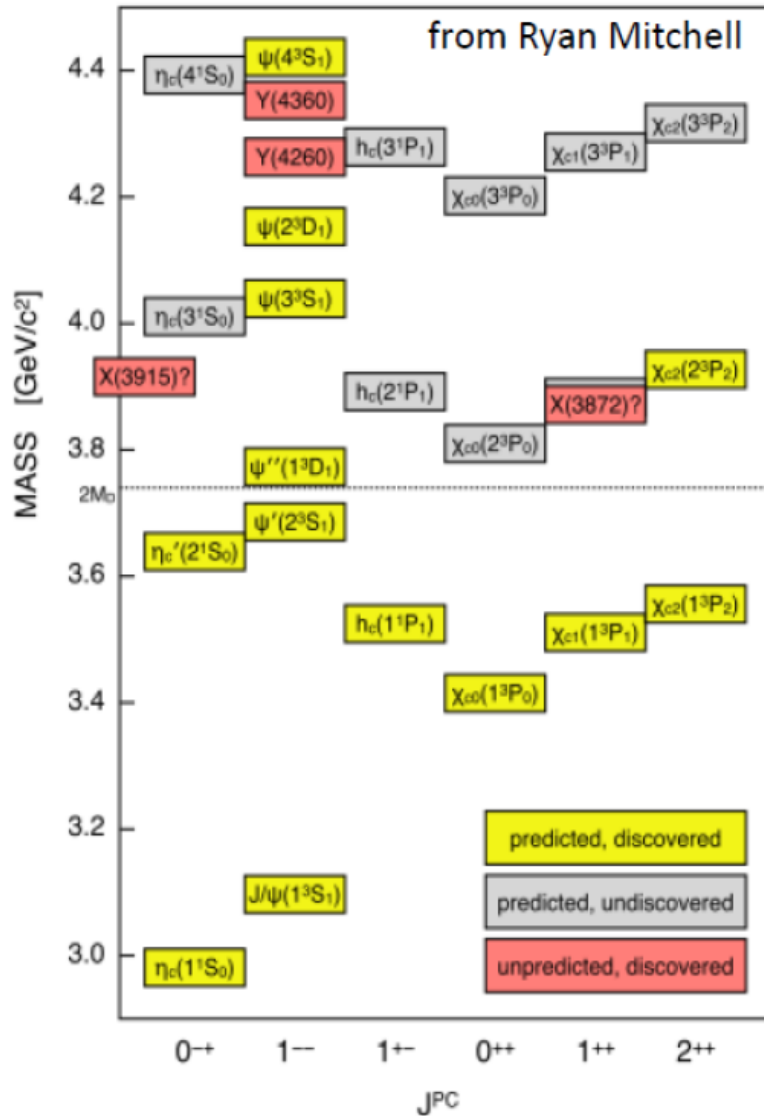
Linac

BESIII



Double ring:
Symmetric collider
CMS energy:
2.0~4.6 GeV
Design Luminosity @ $\psi(3770)$
 $1 \times 10^{33} \text{cm}^{-2}\text{s}^{-1}$
(70% achieved, $\sim 20 \text{pb}^{-1}/\text{day}$)

Charmonium Spectroscopy



- **Below open charm threshold**

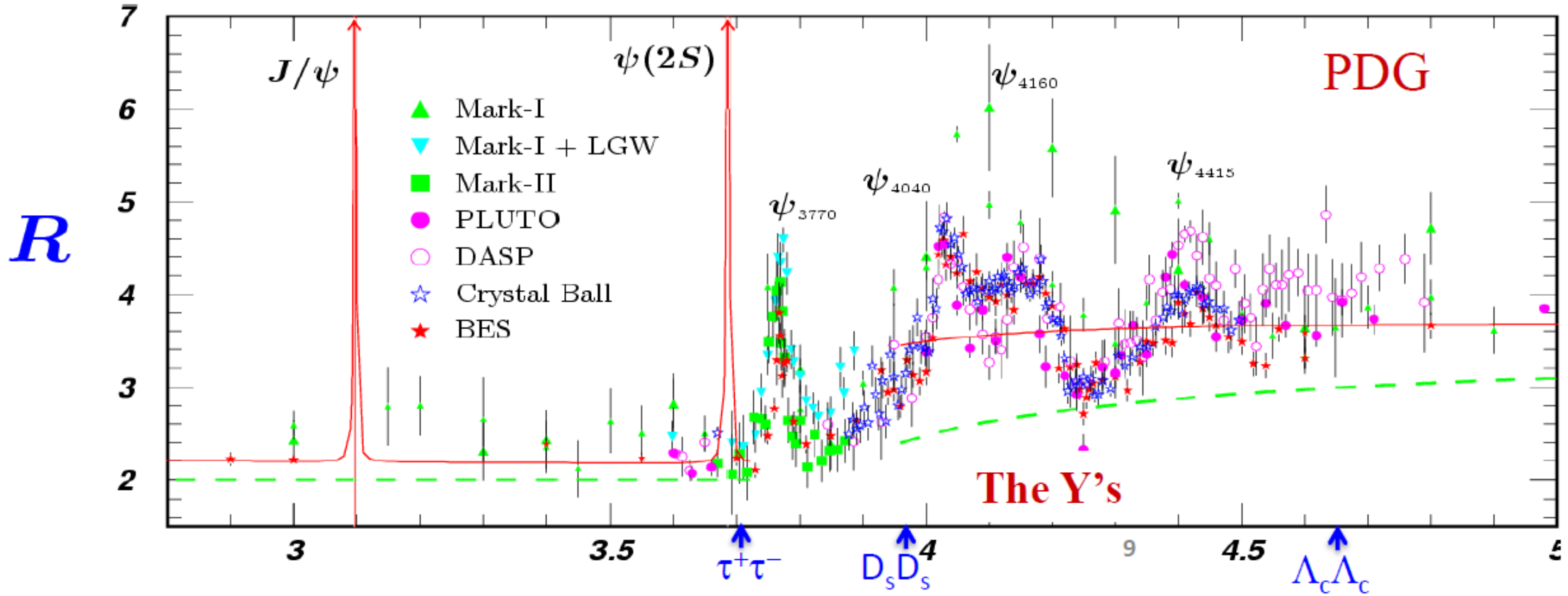
Good agreement between discovery and theoretical prediction.

- **Above open charm threshold**

Many expected states are not observed

Many unexpected states are observed: **XYZ** states

Data samples for XYZ states at BESIII



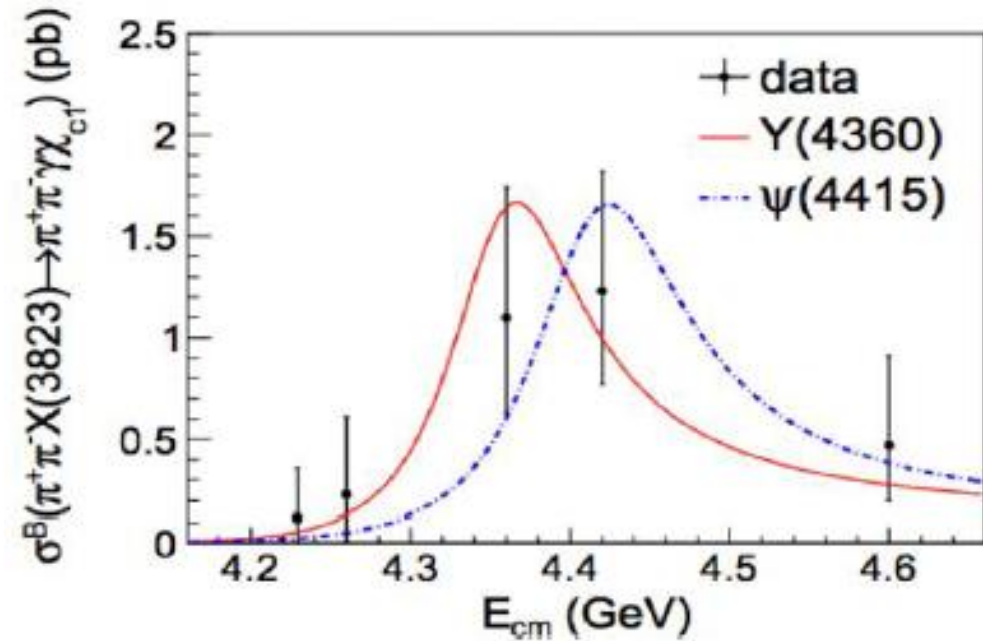
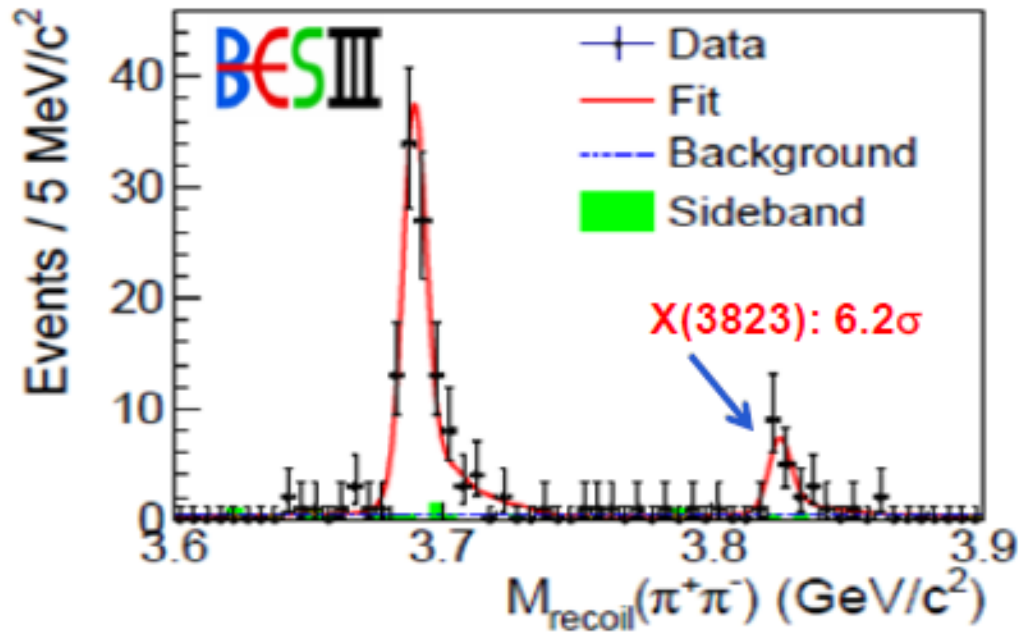
- Luminosity $\sim 5 \text{ fb}^{-1}$
- Large data samples around $\Psi(4040)$, $Y(4260)$, $Y(4360)$, $\Psi(4415)$ and $Y(4660)$

X(3823)/X(3872)

- X(3823) in $e^+e^- \rightarrow \pi^+\pi^- \gamma X_{c1}$ PRL 115,011803 (2015)
- X(3872) in $Y(4260) \rightarrow \gamma \pi^+\pi^- J/\psi$ PRL 112,092001 (2014)

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

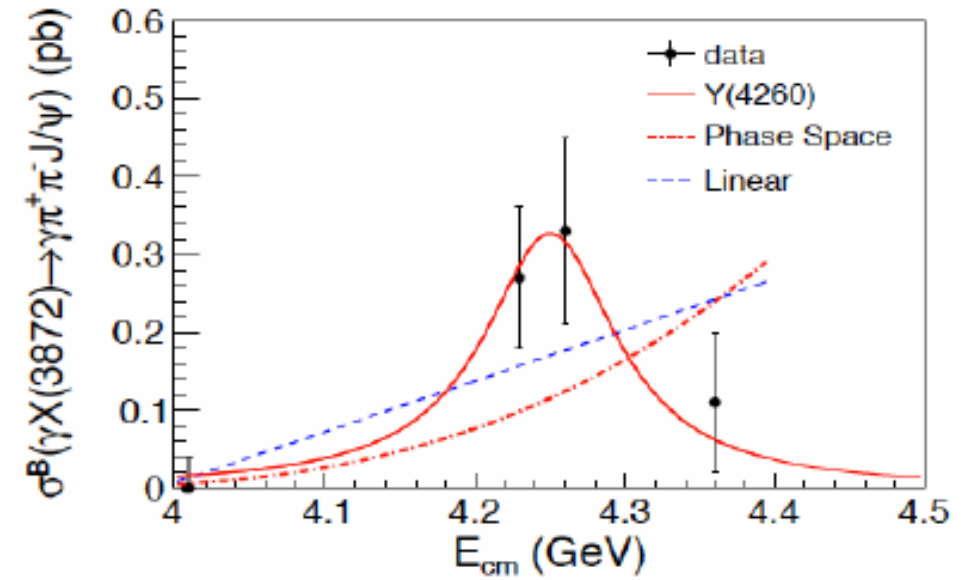
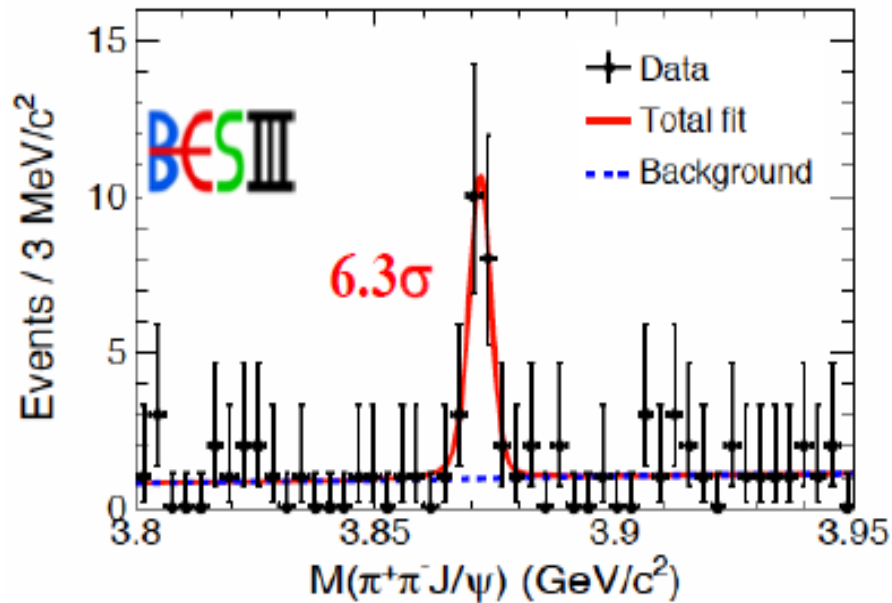
PRL 115,011803 (2015)



- Potential channel: $1^3D_2 \rightarrow \gamma \chi_{c1}, \gamma \chi_{c2}$ with large width.
- $M = 3821.7 \pm 1.3 \pm 0.7 \text{ MeV}$, $\Gamma < 16 \text{ MeV}$.
- Good candidate of $\Psi(1^3D_2)$.
- Both Y(4360) and $\Psi(4415)$ line shape give reasonable description.

$Y(4260) \rightarrow \gamma X(3872) \rightarrow \gamma \pi^+ \pi^- J/\psi$

PRL 112,092001 (2014)



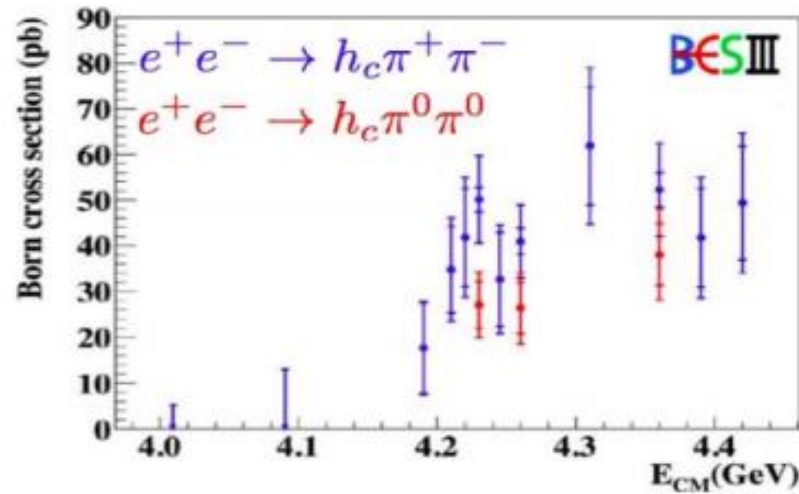
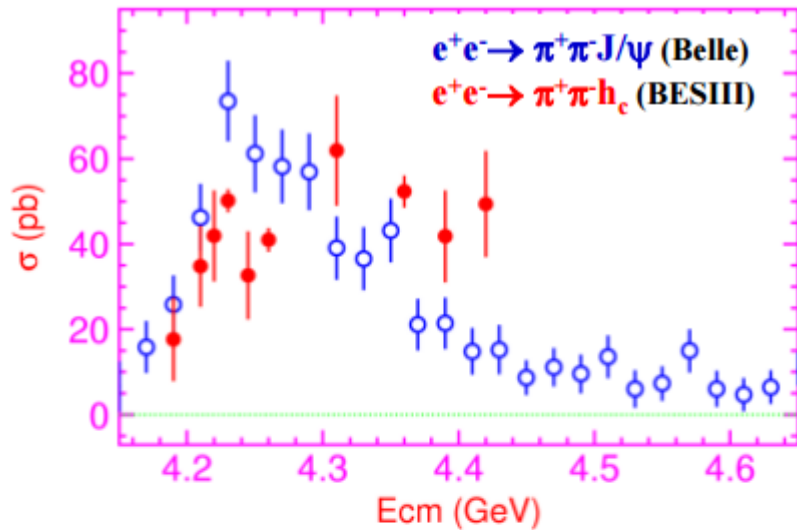
- $M = 3871.9 \pm 0.7 \pm 0.2 \text{ MeV}$, $\Gamma < 2.4 \text{ MeV}$.
- A new $Y(4260)$ decay mode and new $X(3872)$ production mode: $Y(4260) \rightarrow \gamma X(3872)$
- If we take $B(X(3872) \rightarrow \pi^+ \pi^- J/\psi) \sim 5\%$, ($> 2.6\%$ in PDG)

$$\frac{\sigma(e^+e^- \rightarrow \gamma X(3872))}{\sigma(e^+e^- \rightarrow \pi^+ \pi^- J/\psi)} \sim 11.2\% \text{ large transition ratio!}$$

Abundant structures above 4GeV

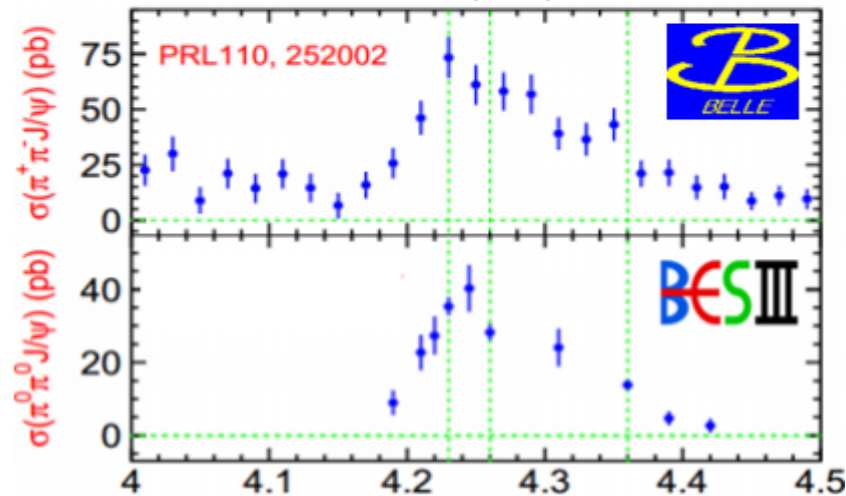
- Cross section of $e^+e^- \rightarrow \pi^+\pi^-J/\Psi(h_c)$ PRL 110, 252001(2013)
- Cross section of $e^+e^- \rightarrow \omega\chi_{c0}$ PRL 114, 092003(2015)
- Cross section of $e^+e^- \rightarrow \eta J/\Psi$ PRD 91,112005(2015)
- Cross section of $e^+e^- \rightarrow \eta' J/\Psi$ Preliminary

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



$\sigma(\pi^0\pi^0 J/\psi)$ arXiv:1506.06018
 $\sigma(\pi^+\pi^- h_c)$ PRL 111,242001 (2013)
 $\sigma(\pi^0\pi^0 h_c)$ PRL 113,212002 (2014)

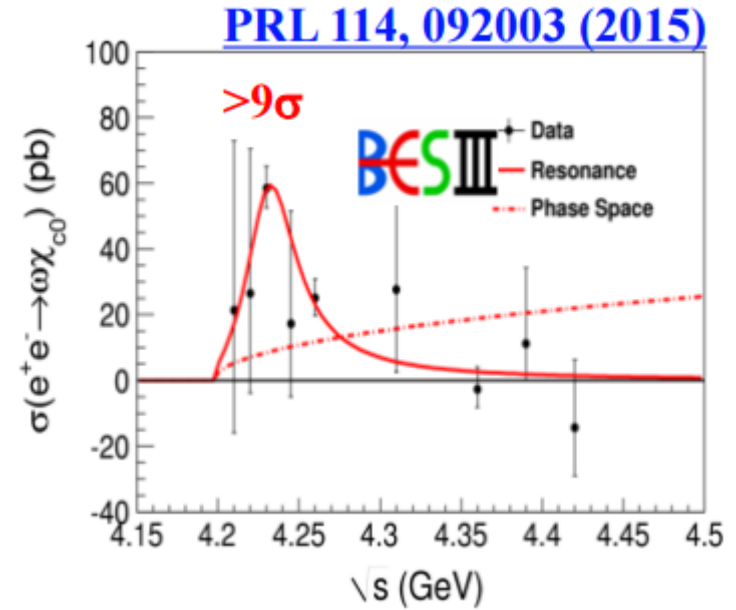
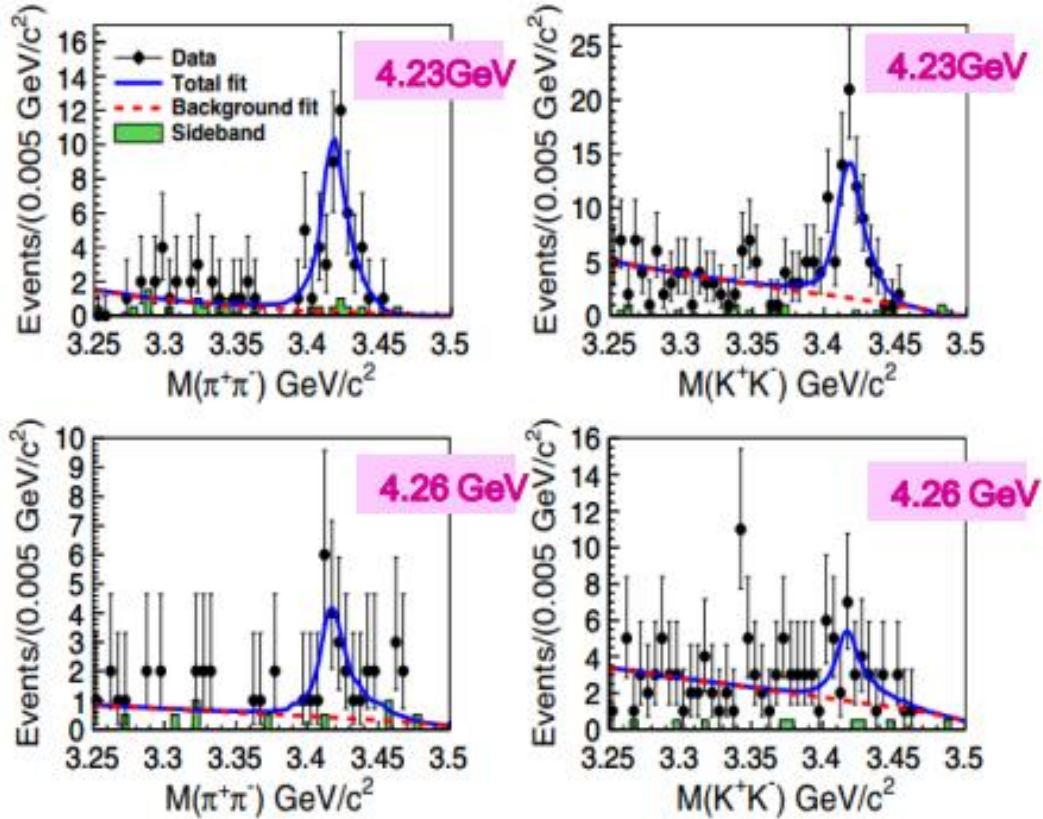
$$\sigma(\pi^0\pi^0 h_c)/\sigma(\pi^+\pi^- h_c) = 0.63 \pm 0.09$$



$$\sigma(\pi^0\pi^0 J/\psi)/\sigma(\pi^+\pi^- J/\psi) \sim 0.5$$

- $\sigma(\pi^+\pi^- h_c) \sim \sigma(\pi^+\pi^- J/\psi)$ different line shape
- A possible structure near 4.23 GeV for $\sigma(\pi^+\pi^- h_c)$
- No large iso-spin violation in $\sigma(\pi\pi h_c)$ and $\sigma(\pi\pi J/\psi)$

Observation of $e^+e^- \rightarrow \omega\chi_{c0}$

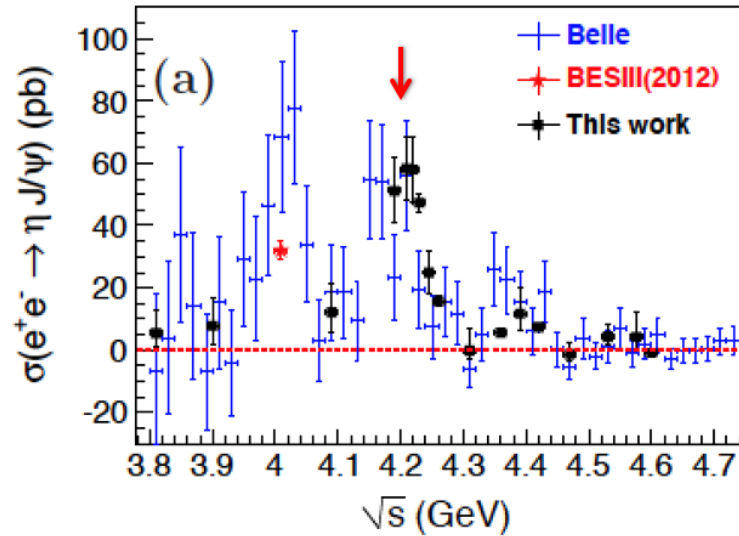


- A tetraquark? PRD 91,117501 (2015)
- $\Psi(4S)$? EPJC 74:3208 (2014)
- Threshold effect?
-

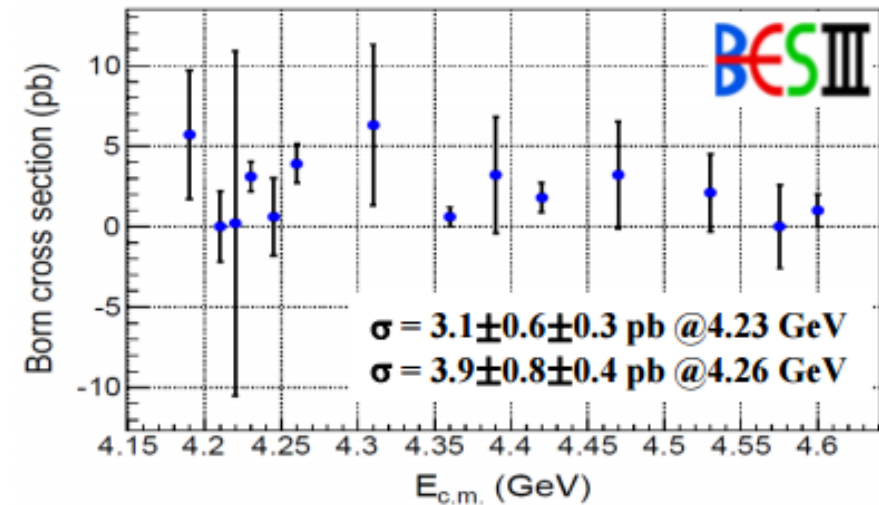
- Cross section peak near 4.23 GeV
- Fit with BW
 Mass = $4230 \pm 8 \pm 6$ MeV
 Width = $39 \pm 12 \pm 2$ MeV

Observation of $e^+e^- \rightarrow \eta J/\psi$ and $e^+e^- \rightarrow \eta' J/\psi$

PRD 91,112005 (2015)



BESIII Preliminary



- Agree with previous results with improved precision
- Structure near 4.2 GeV: $\Psi(4160) \rightarrow \eta J/\psi$

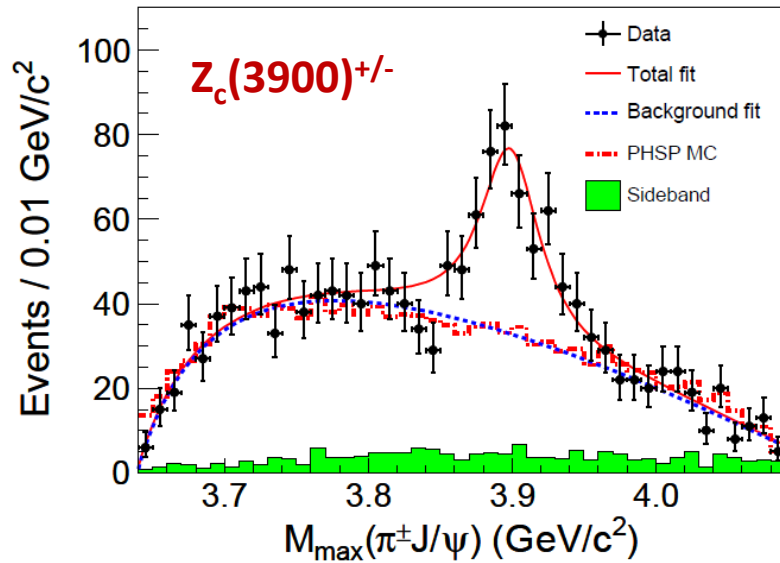
- First observation at 4.23 GeV and 4.26 GeV, couldn't tell the line-shape due to the statistics.
- $\sigma(\eta' J/\psi)$ is much lower than $\sigma(\eta J/\psi)$ which is in contradiction to the NRQCD calculation. PRD 89, 074006 (2014)

Z_c states at BESIII

- $Z_c(3900)^\pm$ in $e^+e^- \rightarrow \pi^+ \pi^- J/\psi$ PRL 110,252001 (2013)
- $Z_c(3900)^0$ in $e^+e^- \rightarrow \pi^0 \pi^0 J/\psi$ arXiv:1506.06018, accepted by PRL
- $Z_c(3885)^\pm$ in $e^+e^- \rightarrow \pi^+ (D\bar{D}^*)^-$ PRL 112, 022001 (2014)
- $Z_c(3885)^0$ in $e^+e^- \rightarrow \pi^0 (D\bar{D}^*)^0$ Preliminary
- $Z_c(4020)^\pm$ in $e^+e^- \rightarrow \pi^+ \pi^- h_c$ PRL 111.242001 (2013)
- $Z_c(4020)^0$ in $e^+e^- \rightarrow \pi^0 \pi^0 h_c$ PRL 113,212002 (2014)
- $Z_c(4025)^\pm$ in $e^+e^- \rightarrow \pi^+ (D^*\bar{D}^*)^-$ PRL 112,132001 (2013)
- $Z_c(4025)^0$ in $e^+e^- \rightarrow \pi^0 (D^*\bar{D}^*)^0$ arXiv:1507.02404

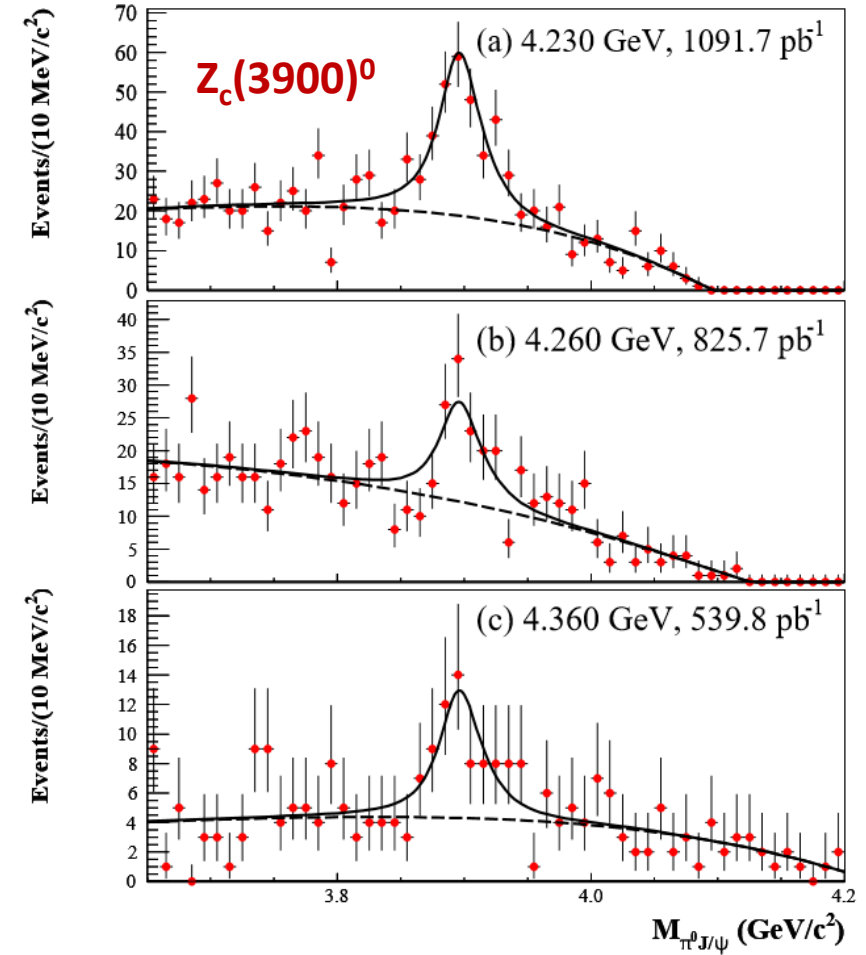
$e^+e^- \rightarrow \pi Z_c(3900) \rightarrow \pi \pi J/\psi$

PRL 110,252001 (2013)



- $Z_c(3900)^\pm$, observed by BESIII, confirmed by Bell and CLEO-c data.
- $Z_c(3900)^0$, evidence with 3.7σ at CLEO-c, observed by BESIII.

arXiv:1506.06018



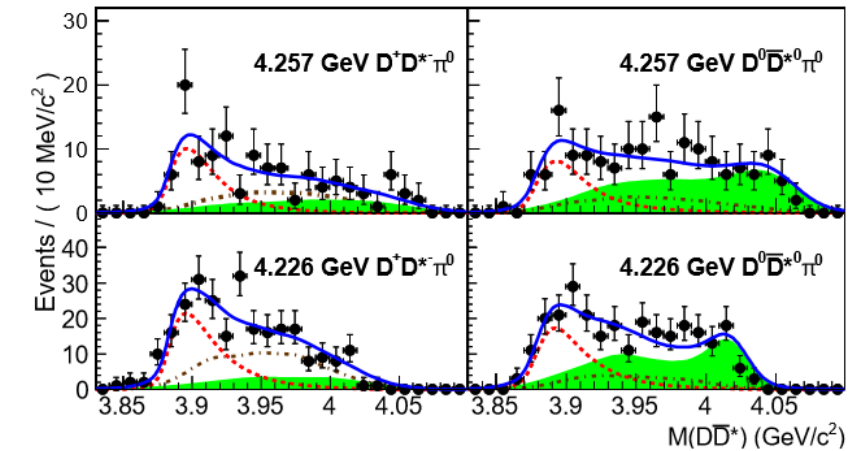
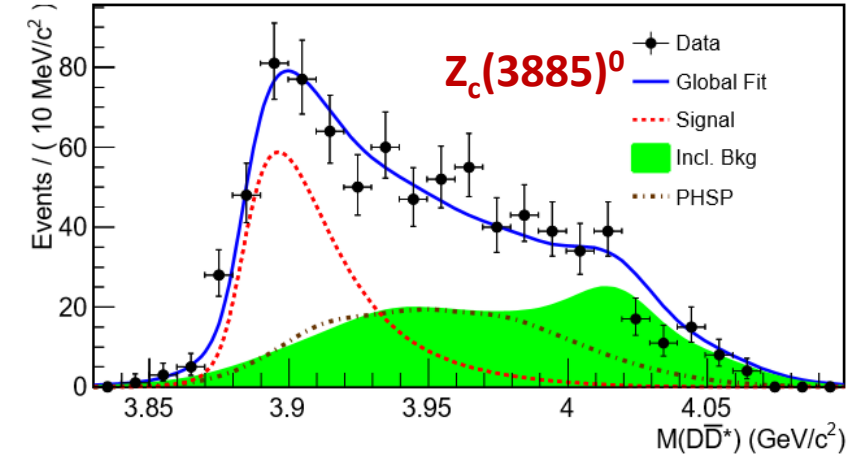
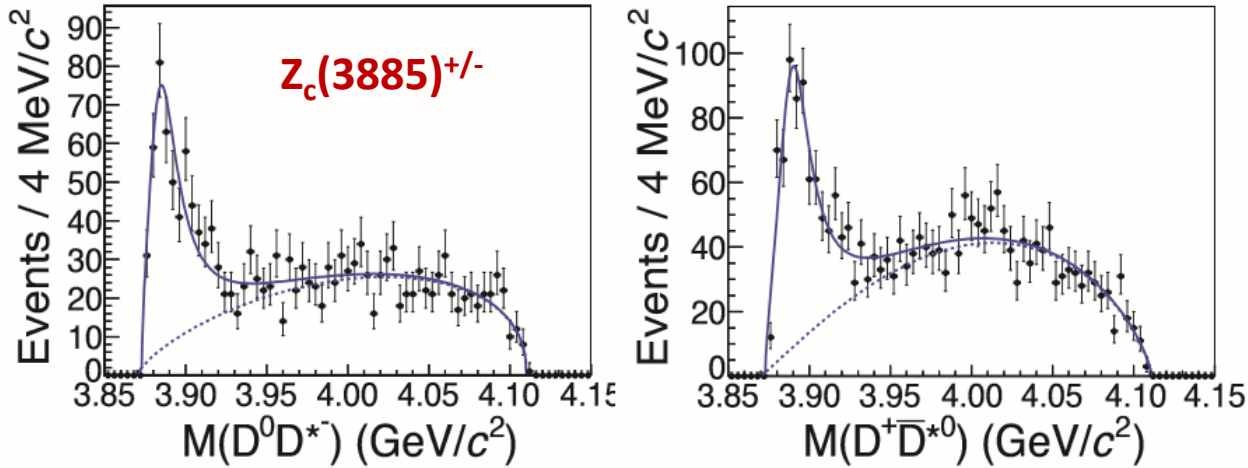
Iso-spin triplet is established!

$Z_c(3900)$	Mass(MeV)	Width(MeV)
$Z_c(3900)^\pm$	$3899.0 \pm 3.6 \pm 4.9$	$46 \pm 10 \pm 20$
$Z_c(3900)^0$	$3894.8 \pm 2.3 \pm 2.7$	$29.6 \pm 8.2 \pm 8.2$

$e^+e^- \rightarrow \pi Z_c(3885) \rightarrow \pi (D\bar{D}^*)$

PRL 112.022001 (2014)

preliminary



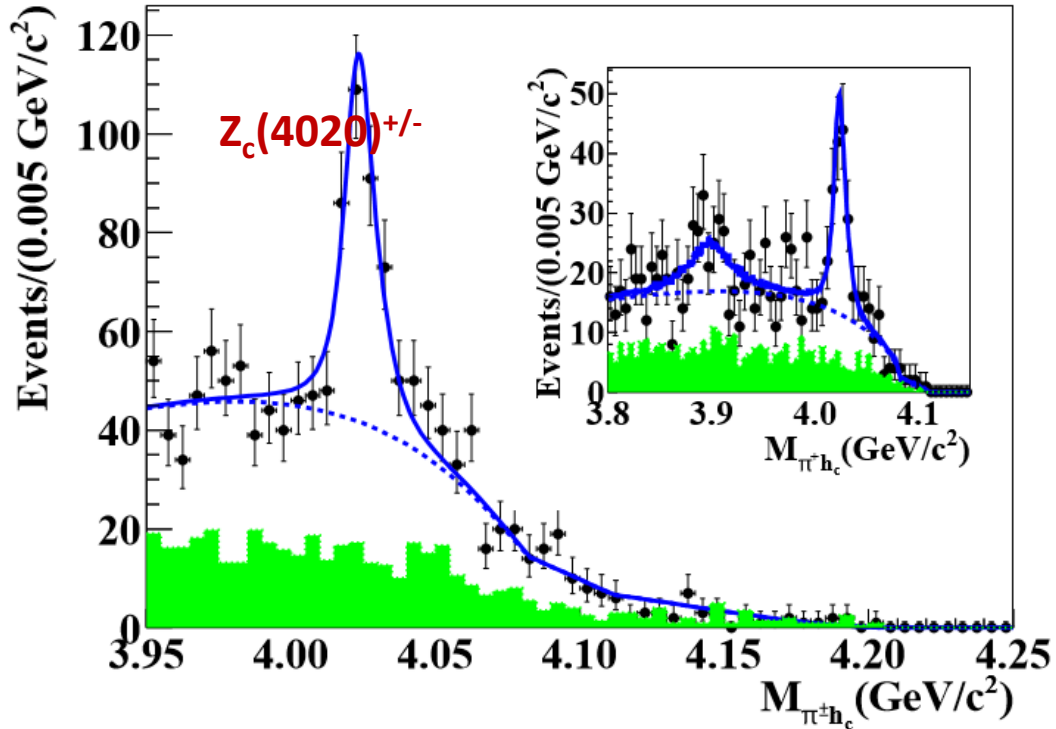
- $Z_c(3885)^\pm$, observed by BESIII.
- Have a mass and width close to $Z_c(3900)$.

$Z_c(3885)$	Mass(MeV)	Width(MeV)
$Z_c(3885)^\pm$	$3883.9 \pm 1.5 \pm 4.2$	$24.8 \pm 3.3 \pm 1.0$
$Z_c(3885)^0$	$3885.7^{+4.3}_{-5.7} \pm 8.4$	$35^{+11}_{-12} \pm 15$

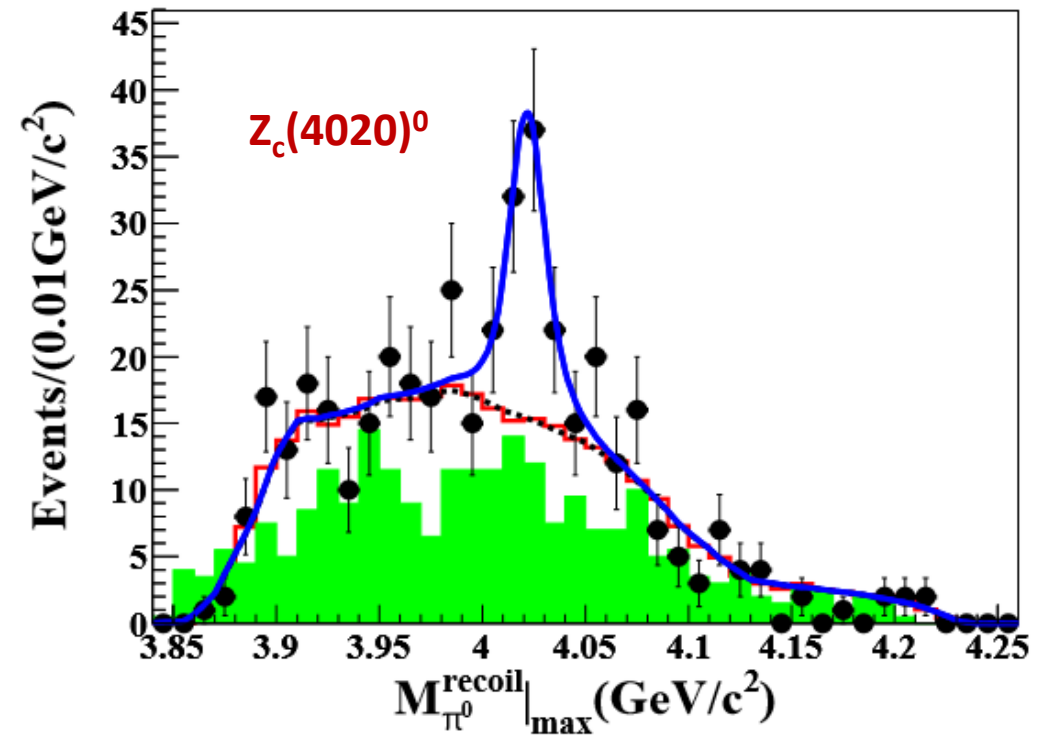
Iso-spin triplet is established!

$$e^+e^- \rightarrow \pi Z_c(4020) \rightarrow \pi \pi h_c$$

PRL 111,242001 (2013)



PRL 113,212002 (2014)



$Z_c(4020)$	Mass(MeV)	Width(MeV)
$Z_c(4020)^{+/-}$	$4022.9 \pm 0.8 \pm 2.7$	$7.9 \pm 2.7 \pm 2.6$
$Z_c(4020)^0$	$4023.8 \pm 2.2 \pm 3.8$	Fixed(=7.9)

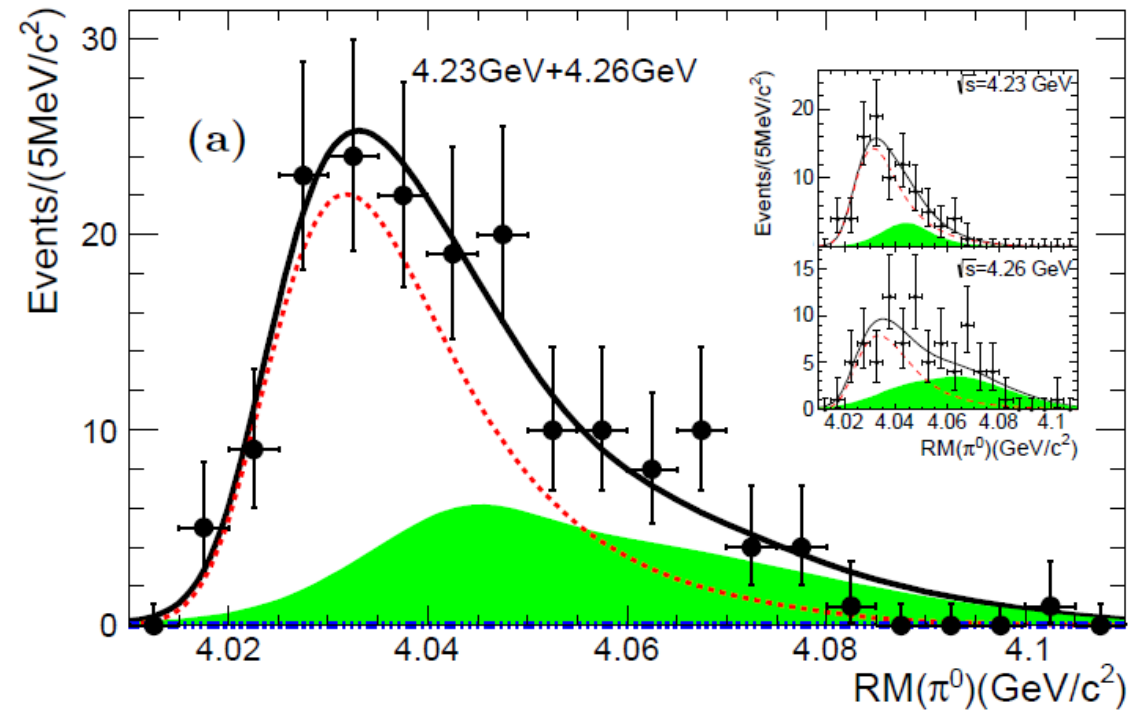
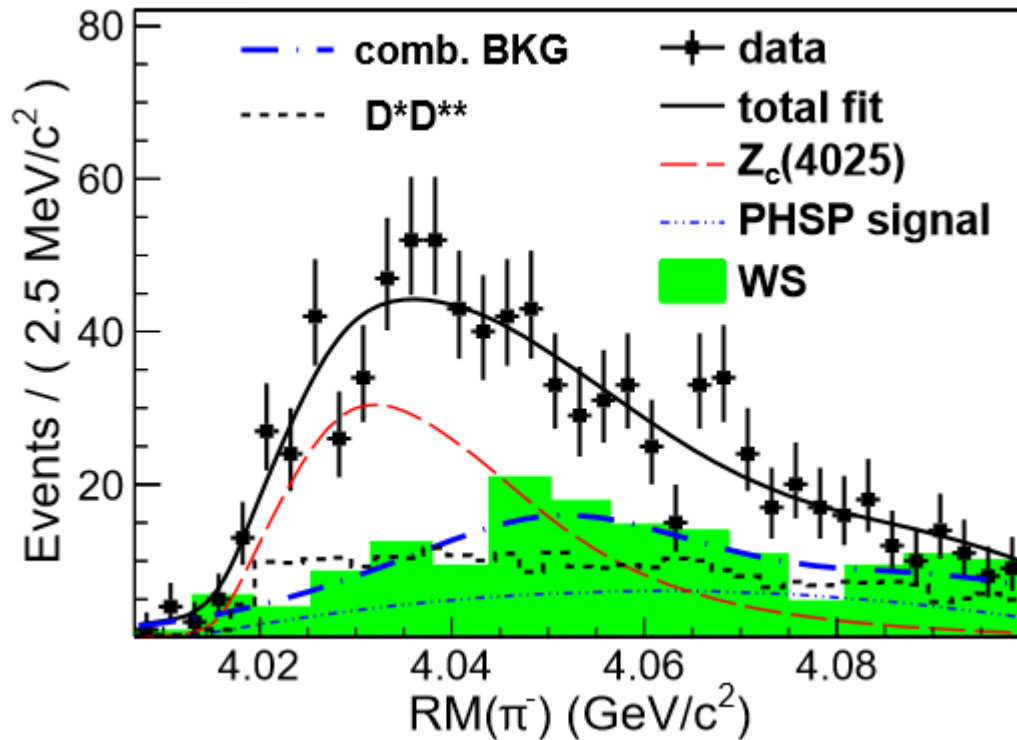
- $Z_c(4020)$, observed by BESIII.
- A hint for $Z_c(3900)^\pm \rightarrow \pi^\pm h_c$.
- $Z_c(4020)$, near the $D^* \bar{D}^*$ threshold.

Iso-spin triplet is established!

$e^+e^- \rightarrow \pi Z_c(4025) \rightarrow \pi (D^* \bar{D}^*)$

PRL 112,132001 (2013)

arXiv:1507.02404



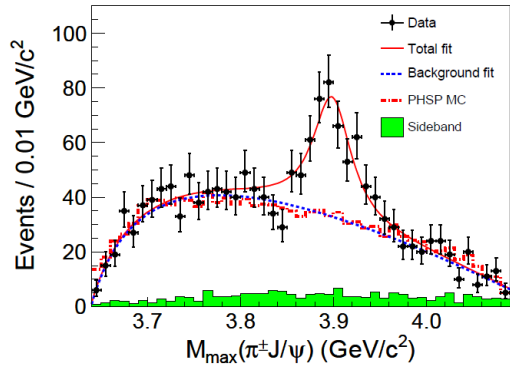
- $Z_c(4020)$, observed by BESIII.
- The $Z_c(4020)$ and $Z_c(4025)$ are consistent within 1.5σ .
- If they are the same state:

$$\frac{\Gamma(Z_c(4025) \rightarrow D^* \bar{D}^*)}{\Gamma(Z_c(4020) \rightarrow \pi h_c)} = 12 \pm 5$$

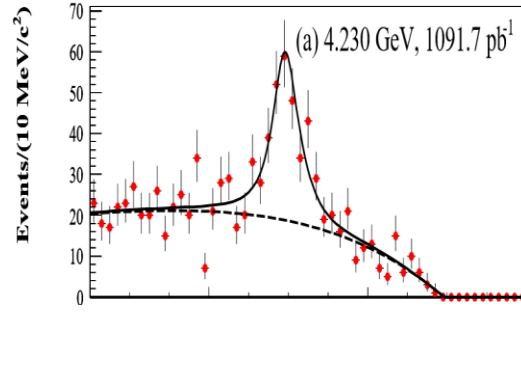
Iso-spin triplet is established!

$Z_c(4025)$	Mass(MeV)	Width(MeV)
$Z_c(4025)^\pm$	$4026.3 \pm 2.6 \pm 3.7$	$24.8 \pm 5.6 \pm 7.7$
$Z_c(4025)^0$	$4025.5 \pm 2.0 \pm 3.1$ -4.7	$23.0 \pm 6.0 \pm 1.0$

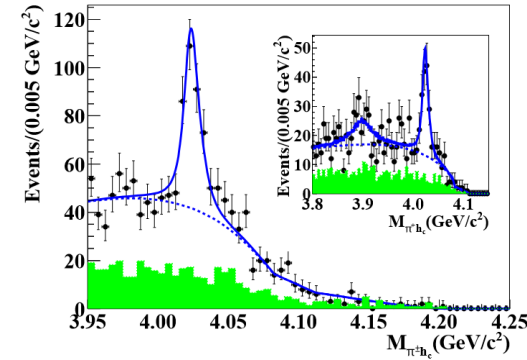
Summary of Z_c states at BESIII



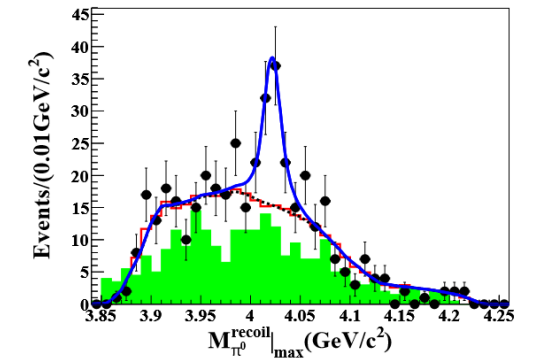
$$e^+e^- \rightarrow \pi^+ \pi^- J/\psi$$



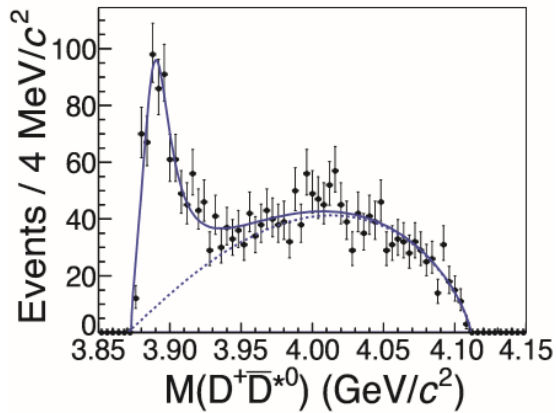
$$e^+e^- \rightarrow \pi^0 \pi^0 J/\psi$$



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

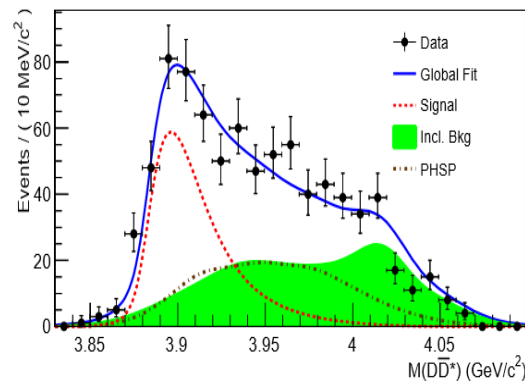


$$e^+e^- \rightarrow \pi^0 \pi^0 h_c$$



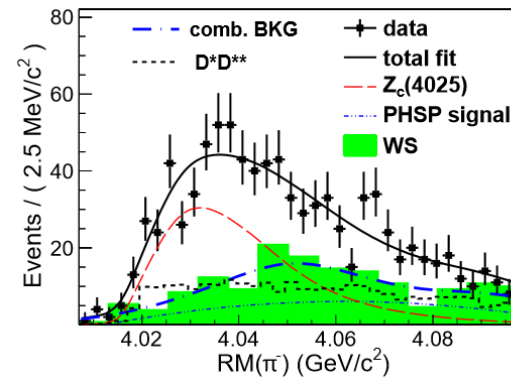
$$e^+e^- \rightarrow \pi^+ (D\bar{D}^*)^-$$

$$Z_c(3900)^\pm?$$



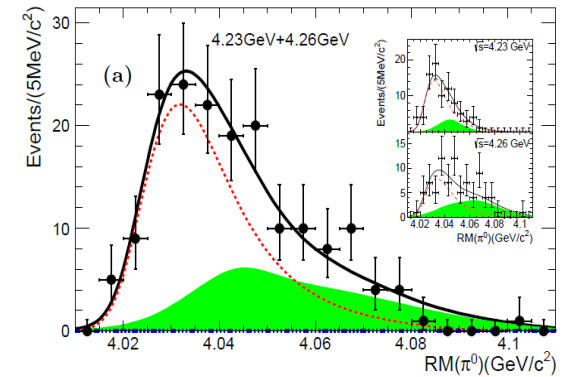
$$e^+e^- \rightarrow \pi^0 (D\bar{D}^*)^0$$

$$Z_c(3900)^0?$$



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

$$Z_c(4020)^\pm?$$

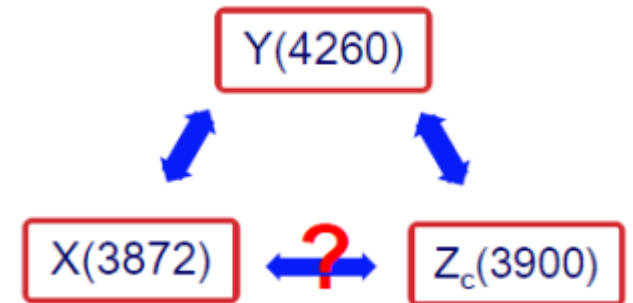


$$e^+e^- \rightarrow \pi^0 (D\bar{D}^*)^0$$

$$Z_c(4020)^0?$$

Summary

- Lots of progress in charmonium-like studies at BESIII recently.
- Observation of $e^+e^- \rightarrow \gamma X(3872)$ & $\pi^+\pi^- X(3823)$.
- Observation of Z_c states.
- Measurements of many hidden charm final states.
- X, Y, Z particles are correlated.
- BESIII will continue to study the XYZ states.



Thank you!