R-measurement and XYZ physics at BESIII

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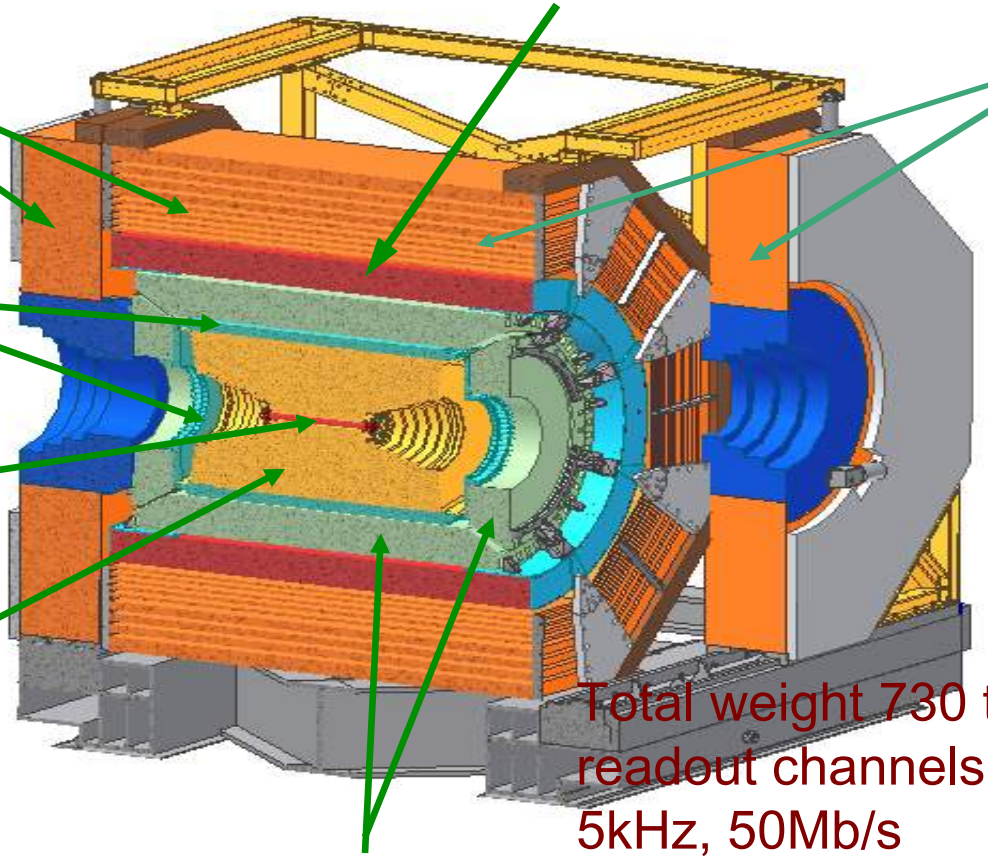
$(g-2)_\mu$: Quo vadis, 9th April, Mainz

Beijing Electron Positron Collider (BEPC II)

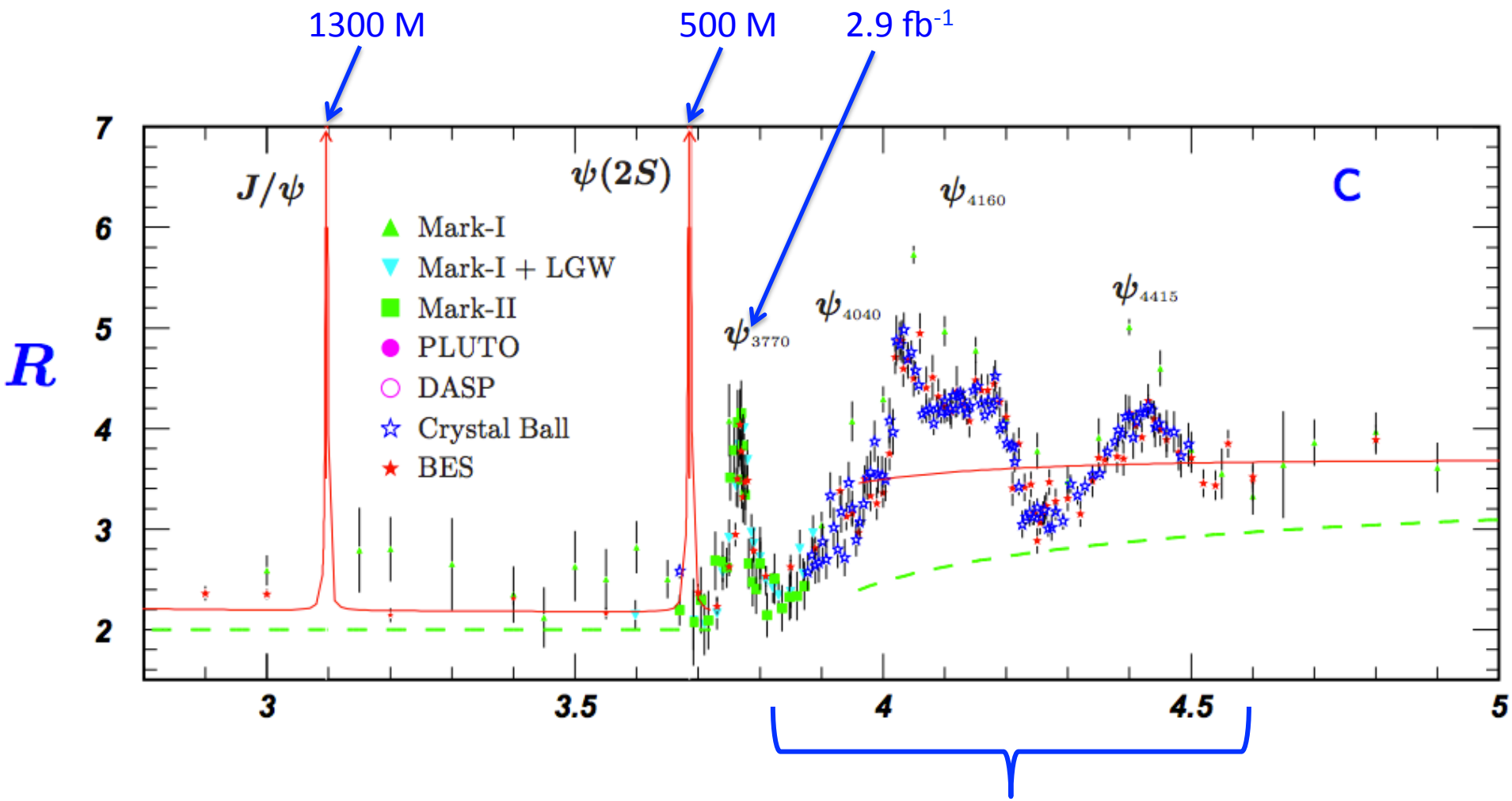
First physics run starts from 2009 !

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

BESIII Detector

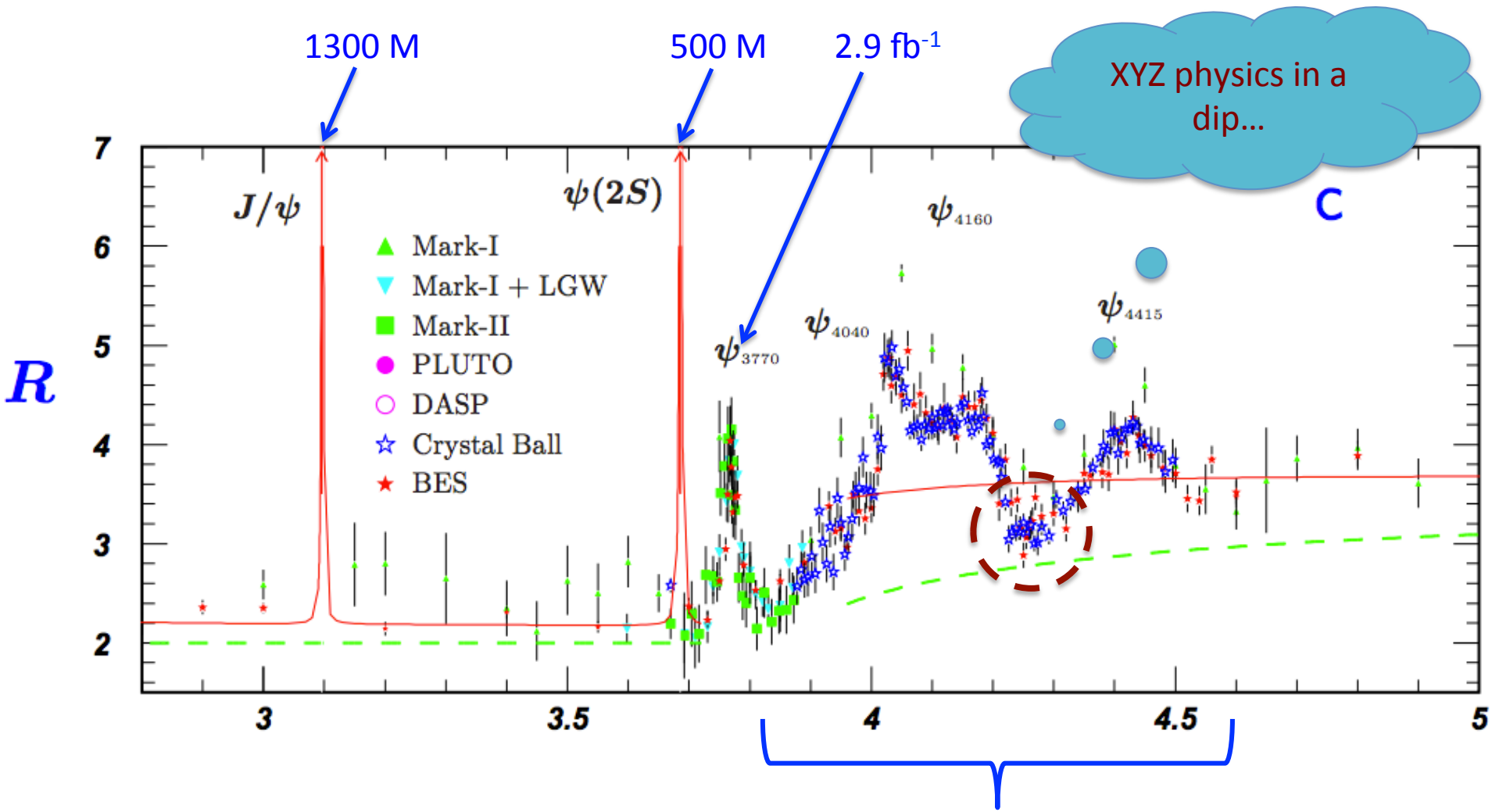


Physics covering at BESIII



Scan between 3.8 - 4.6 GeV with ~100 points (~10 MeV step, 6-8 pb^{-1})
See Guangshun's talk.

Physics covering at BESIII



Scan between 3.8 - 4.6 GeV with ~100 points (~10 MeV step, 6-8 pb^{-1})
See Guangshun's talk.

XYZ states

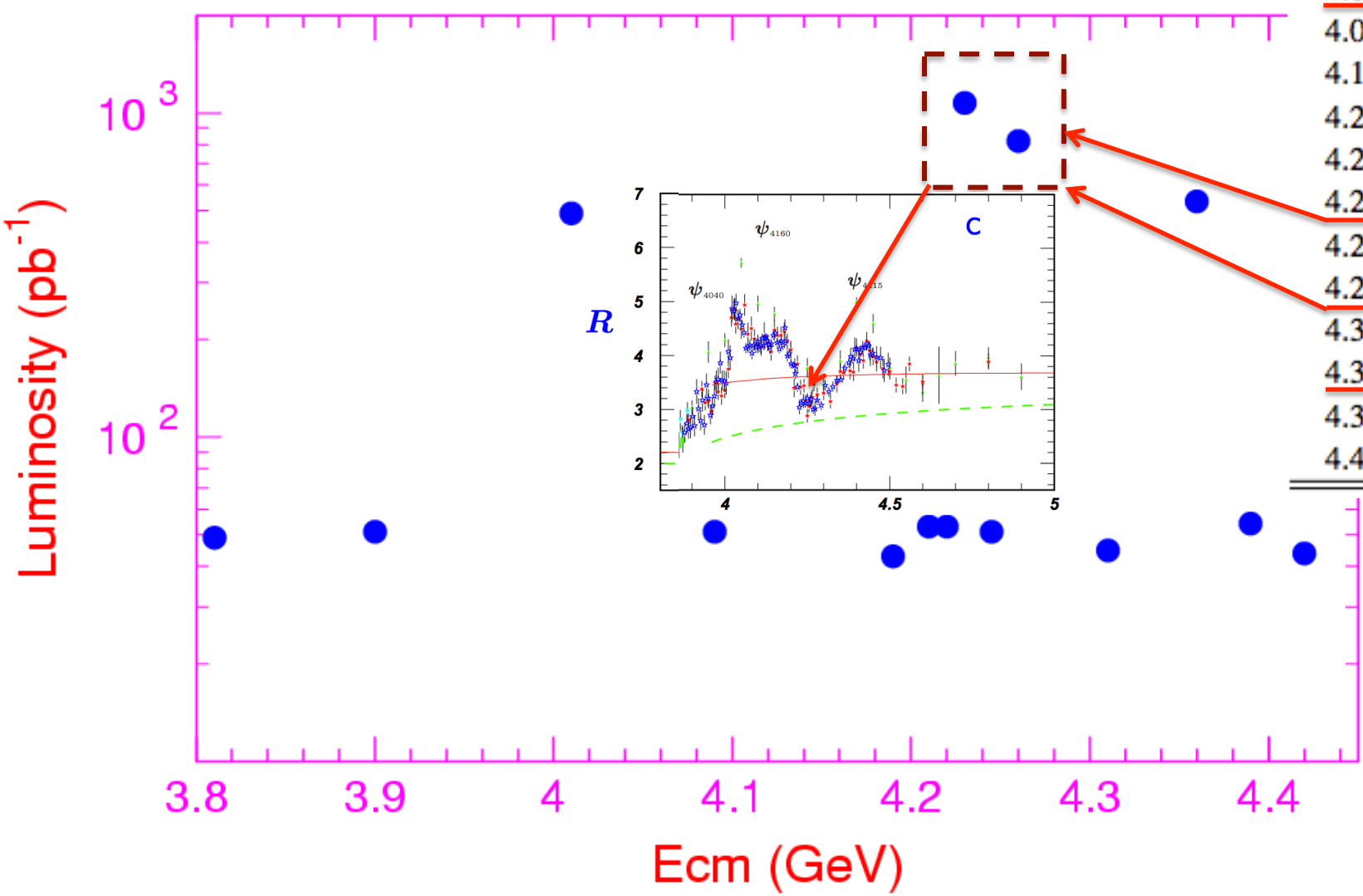
Not an obvious charmonium state, but charmonium in the final state. (charmoniumlike or XYZ).

What are they ?

X(3872)
Y(4260)
Y(4360)
$Z_c(3900)$
X(3915)
X(4160)
Y(4008)
Y(4140)
X(4350)
Y(4660)
XYZ(3940)
Z(4430)
Z(4250)
Z(4050)
...

Hybrid?
Tetraquark?
Molecule?
...

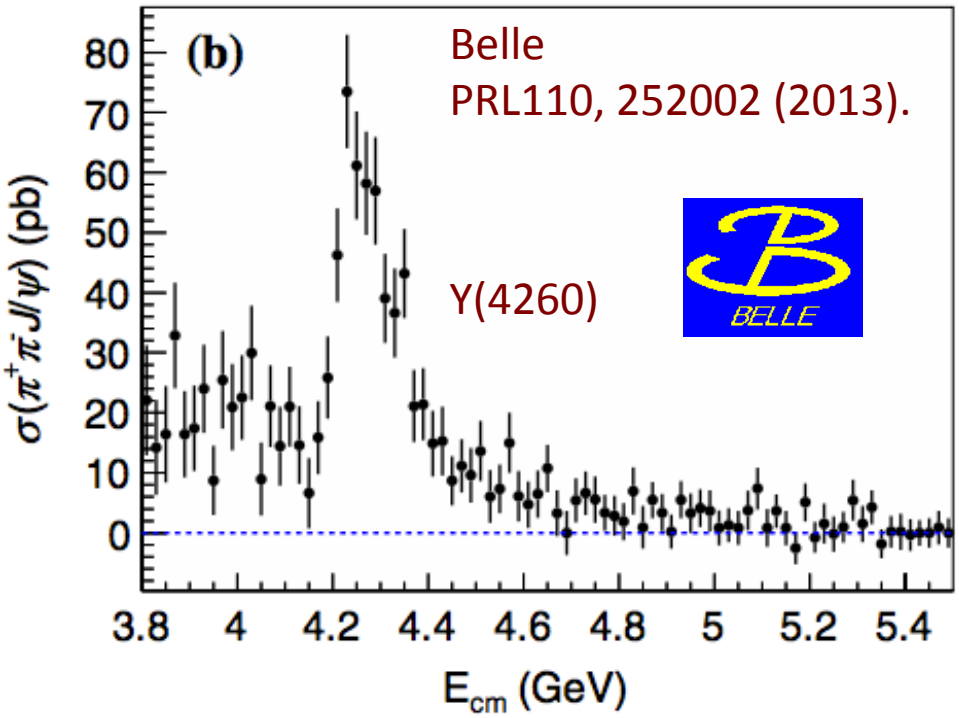
XYZ data at BESIII

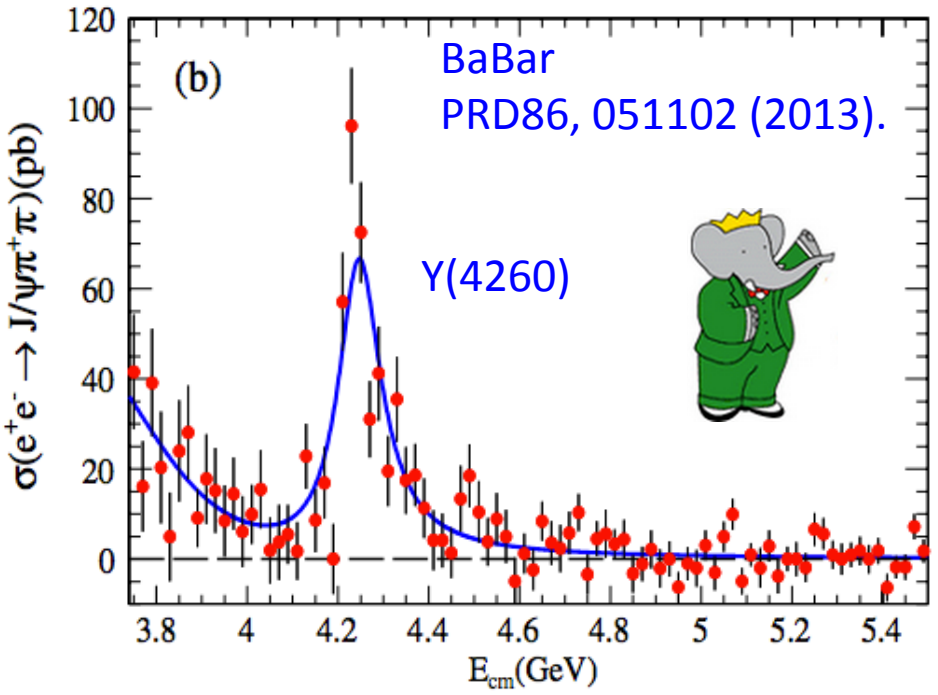


$\sqrt{s}$ (GeV)	$\mathcal{L}$ (pb^{-1})
3.900	52.8
4.009	482.0
4.090	51.0
4.190	43.0
4.210	54.7
4.220	54.6
4.230	1090.0
4.245	56.0
4.260	826.8
4.310	44.9
4.360	544.5
4.390	55.1
4.420	44.7

Discovery of $Z_c(3900)$

The Y(4260)→$\pi^+\pi^-$J/ψ

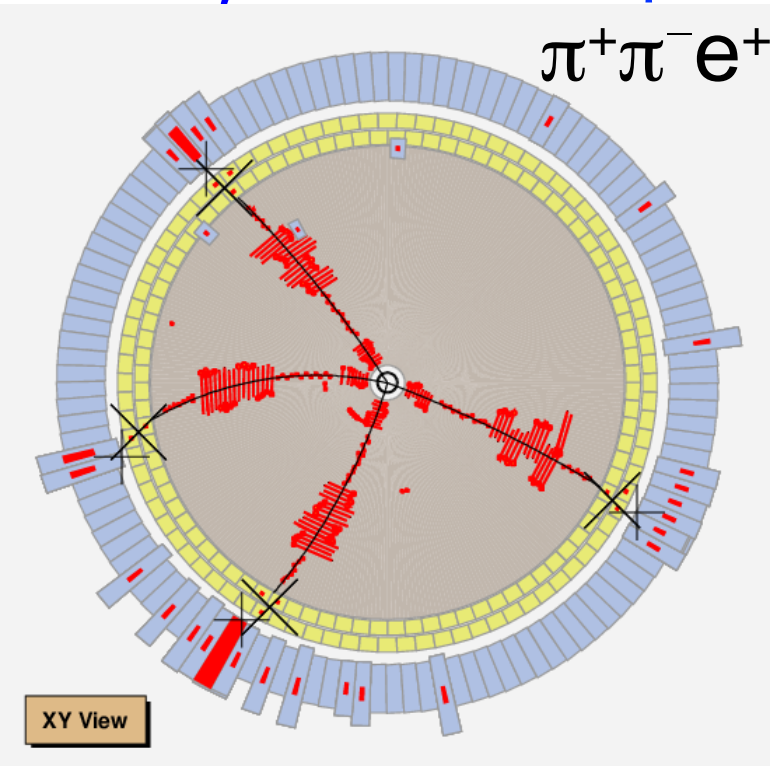


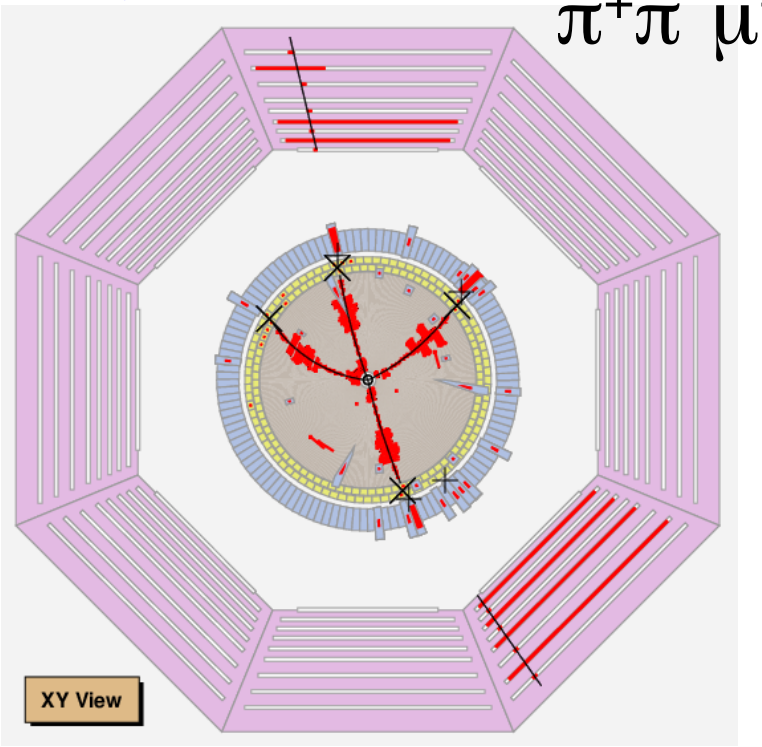


1. The Y(4260) resonance was observed by BABAR and Belle.
2. Based on data set ~10.58 GeV, using the initial-state-radiation (ISR) method.
3. The Y(4260) also interpreted to be an exotic hadron candidate.

Study Y(4260) at BESIII

- Dec, 2012 to Jan, 2013, BESIII accumulated 525 pb^{-1} data @ 4.26 GeV, world's largest data set!
- Study $e^+e^- \to \pi^+\pi^- J/\psi$ exclusive process.

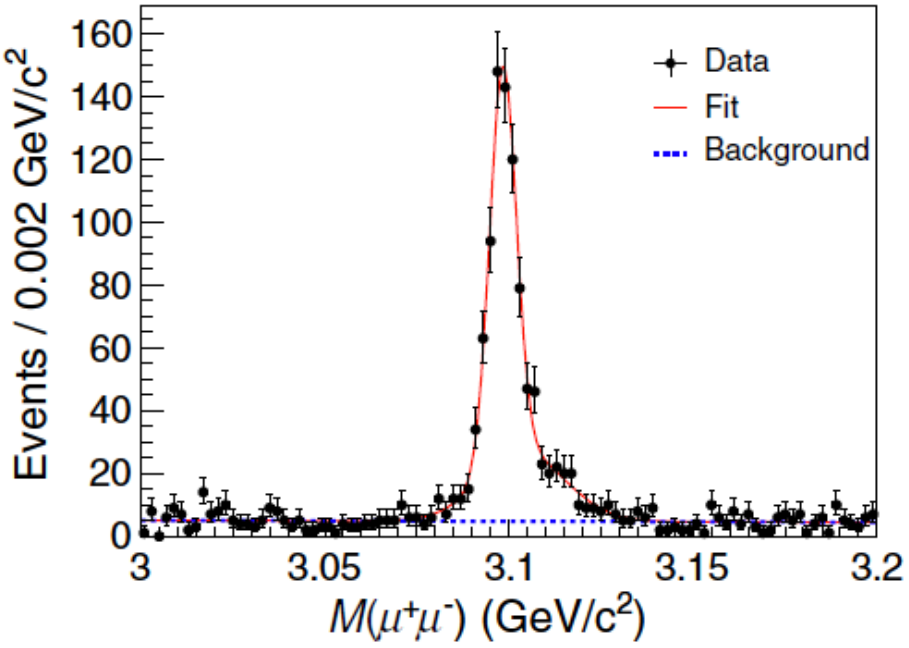


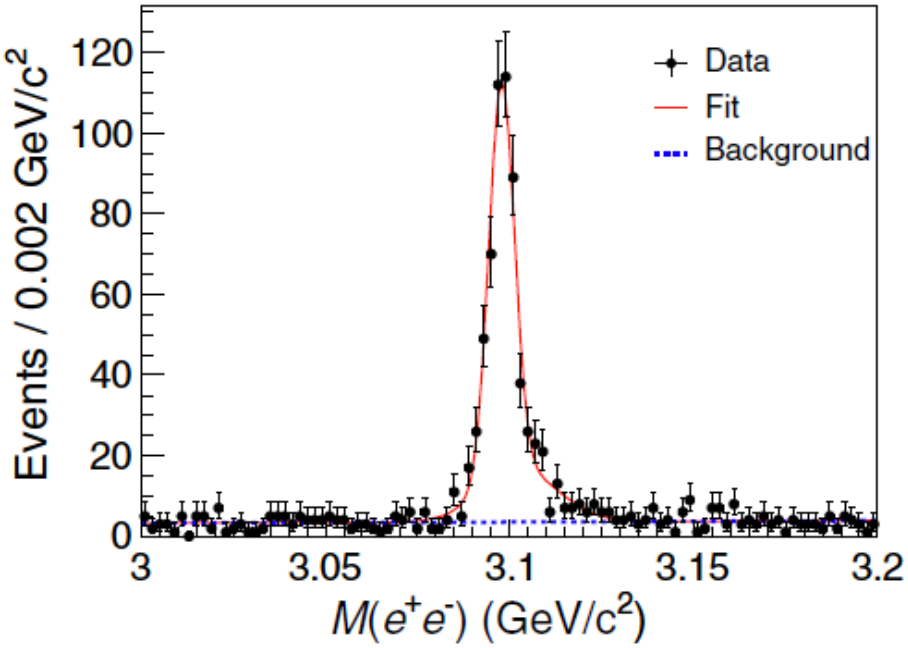


1. Very simple and straightforward analysis.
2. The produced vector charmonium(like) state almost in rest frame.
3. $Y(4260) \to \pi^+\pi^- J/\psi$, four charged track detected.

Cross Section at BESIII

PRL 110,252001 (2013).

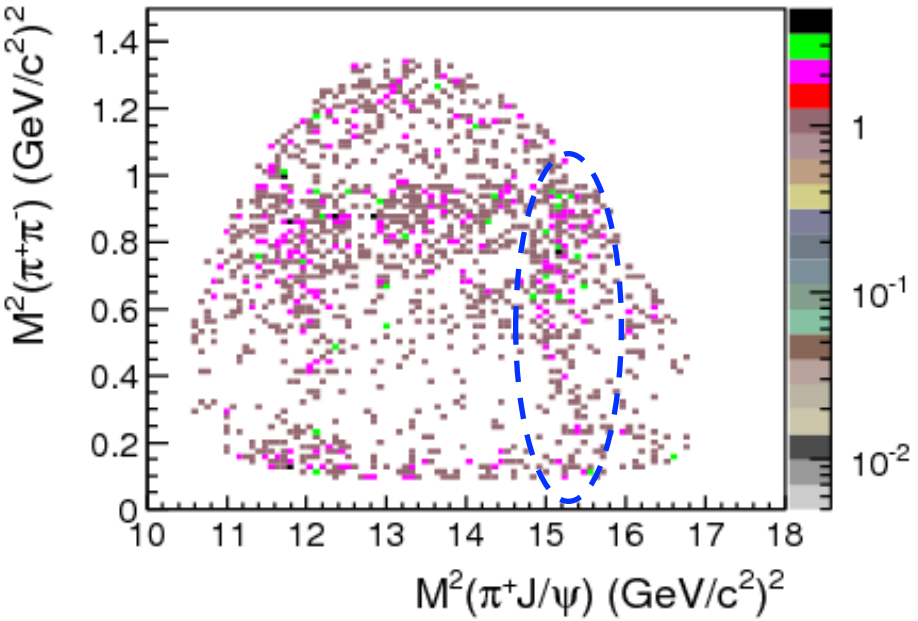


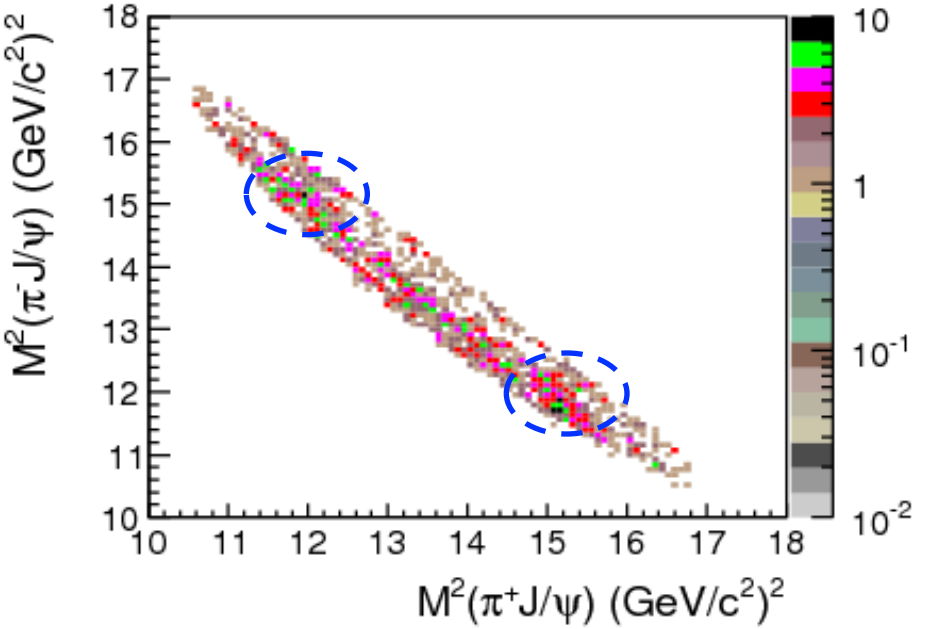


1. Lum=525 pb^{-1} @ BESIII
2. $N(\mu^+\mu^-)$=882±33; $N(e^+e^-)$=595±28.
3. Born cross section: σ^B=(62.9±1.9±3.7) pb @ BESIII.
4. Good agreement with Belle and BaBar.
5. Analysis is valid and unbiased.

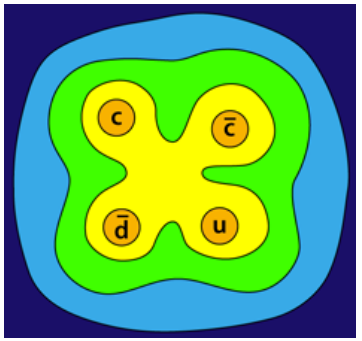
Intermediate state——$Z_c(3900)$

- Requiring J/ψ mass window: [3.08,3.12] GeV, we have 1595 signal events, with purity ~90%.

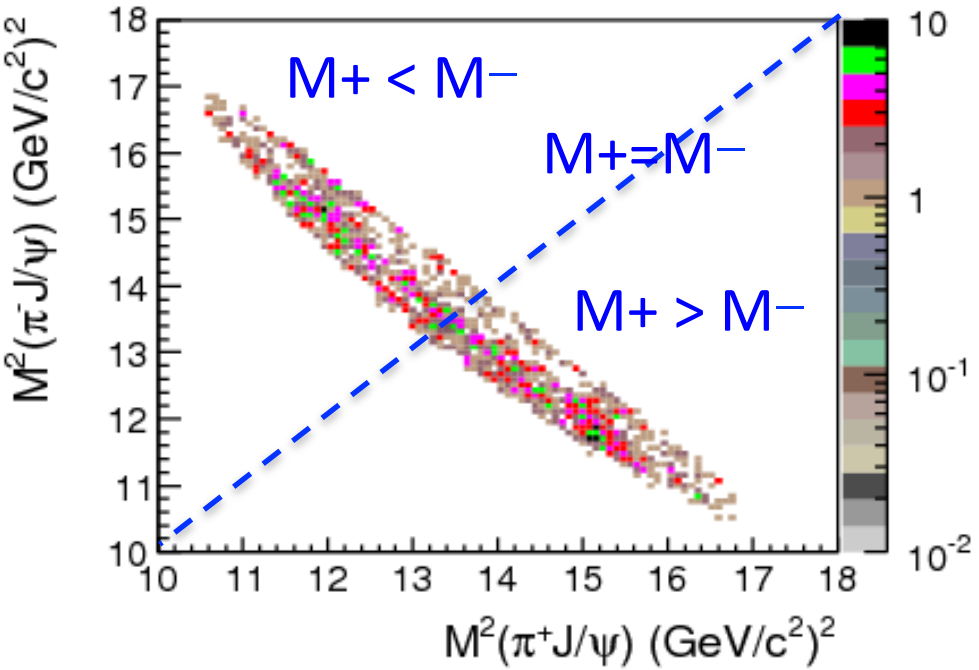


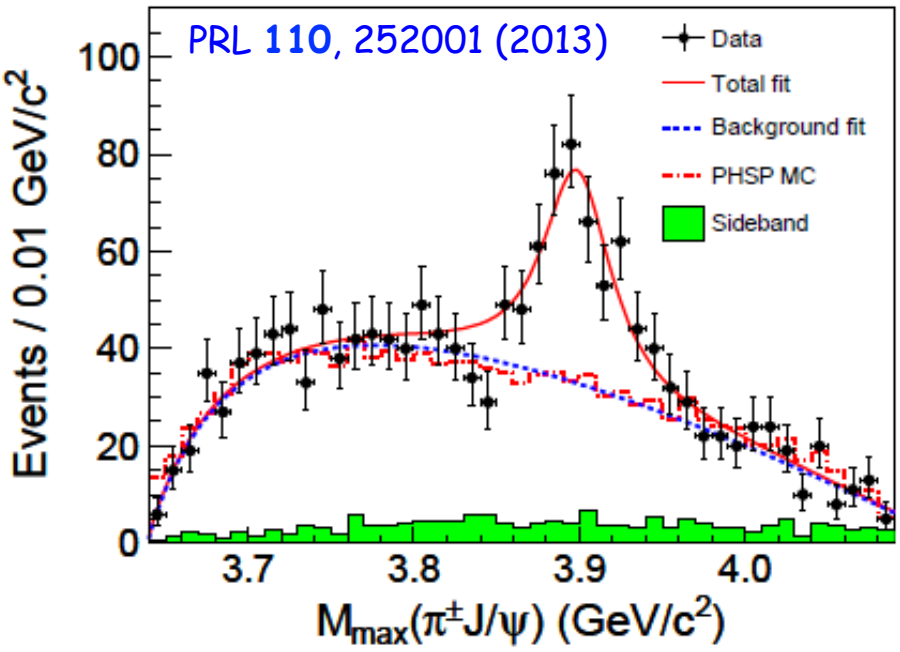


1. Intermediate states both in $M(\pi^+\pi^-)$ mass distribution and $M(\pi^\pm J/\psi)$ mass distribution.
2. A clear band in the $M(\pi^\pm J/\psi)$ invariant mass projection.
3. New charged resonance, exotic 4 quark hadron?



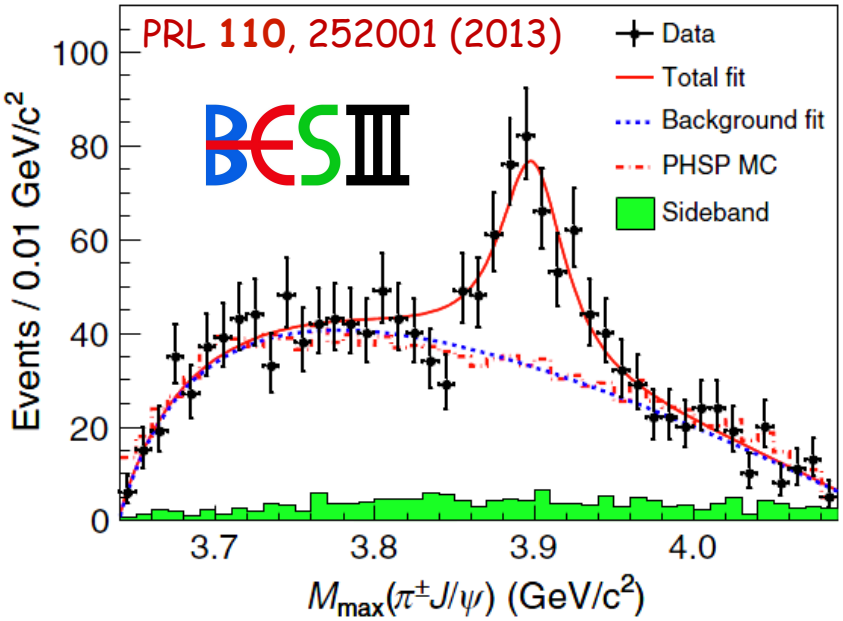
Intermediate state——$Z_c(3900)$

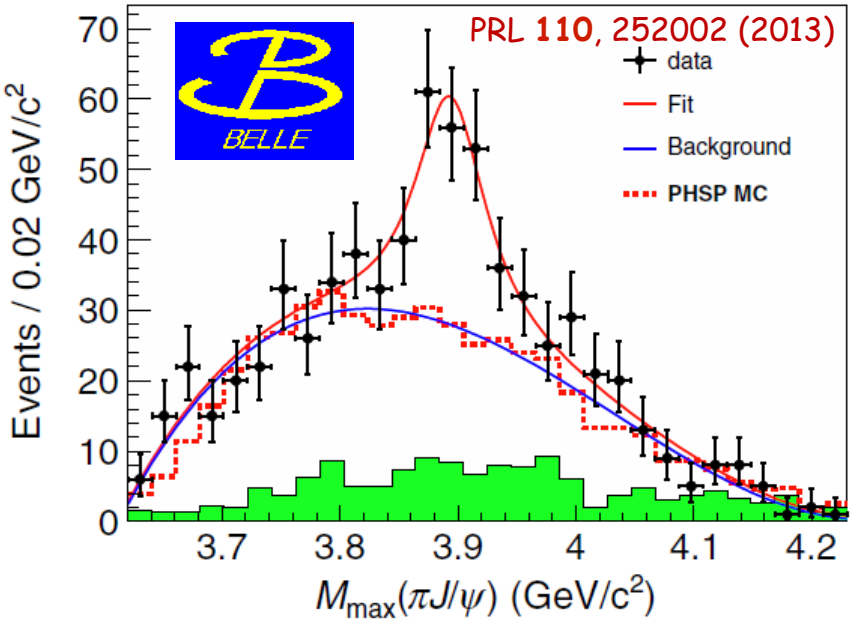


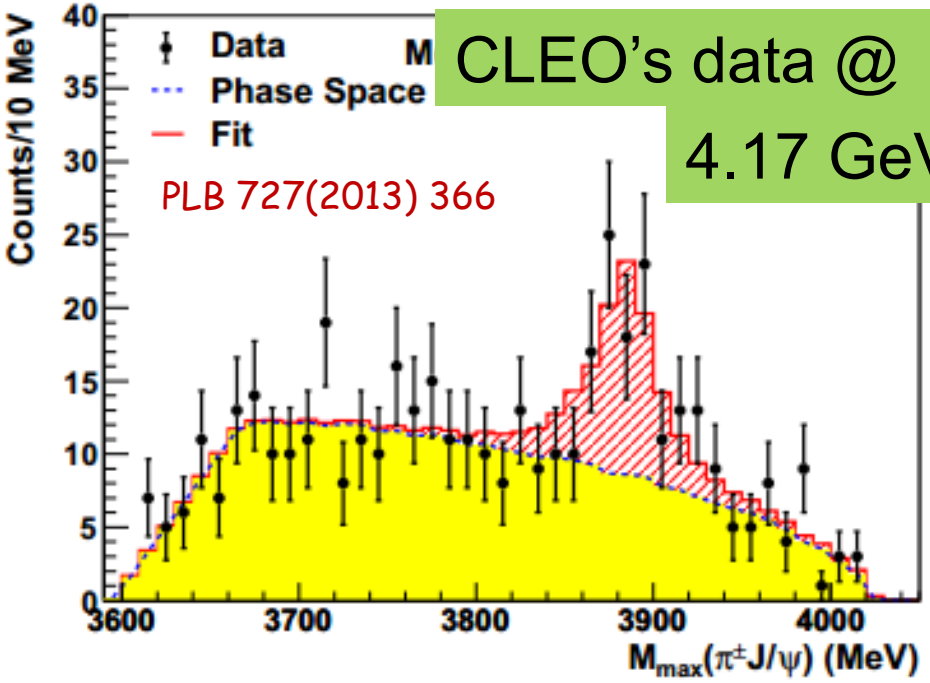


1. First stage, 1D fit to extract resonant parameters.
2. Divided by diagonal line of the Dalitz plot and fit $M_{max}(\pi^\pm J/\psi)$ mass distribution; best way to avoid cross counting.
3. S-Wave Breit Wigner; phase space factor; efficiency corrected.
4. M=(3899.0±3.6±4.9)MeV; Γ=(46±10±20)MeV.
5. Statistical significance: >8σ, discovery!

Good News





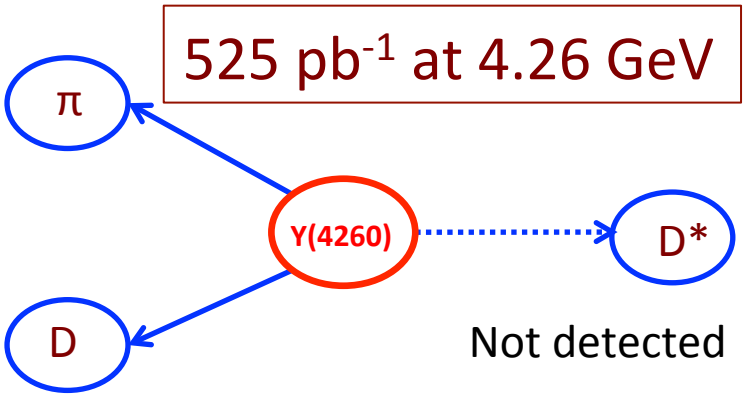


CLEO's data @ 4.17 GeV

1. CLEO's data: M=3886±6±4 MeV, Γ=33±6±7 MeV.
2. Belle: M=(3894.5±6.6±4.5) MeV; Γ=(63±24±26) MeV.
3. BESIII: M=(3899.0±3.6±4.9) MeV; Γ=(46±10±20)MeV
4. $Z_c(3900)=Z(3900)^{\pm}$.

$e^+e^- \rightarrow \pi^+(DD^*)^- + c.c.$

$e^+e^- \rightarrow \pi^+(DD^*)^-$



$\pi^{\pm}(DD^*)^{\mp}$ includes 4 decay modes:

1) $\pi^+D^0D^{*-}$+c.c., $D^{*-} \rightarrow \pi^0 D^-$

2) $\pi^+D^-D^{*0}$+c.c., $D^{*0} \rightarrow \gamma/\pi^0 D^0$

We only reconstruct the bachelor pion and a single D.

Type I: If we tag a π^+ and D^0, we select the events:

$\pi^+D^0D^{*-}$ and $\pi^+D^-D^{*0}$ ($D^{*0} \rightarrow \gamma/\pi^0 D^0$)

Type II: If we tag a π^+ and D^-, we select the events:

$\pi^+D^0D^{*-}$ ($D^{*-} \rightarrow \pi^0 D^-$) and $\pi^+D^-D^{*0}$ ($D^{*0} \rightarrow \gamma/\pi^0 D^0$)

- Sometimes there are cross feeding events, but it's OK.

Recoil mass of πD

I: π^+D^0 tagging method

Dots with error bars: Data
Solid: $e^+e^-\to\pi^+D^0D^{*-}$
Dash: $e^+e^-\to\pi^+D^-D^{*0}$, where DD* from Z_c
Hatch: Events from D^0 sideband

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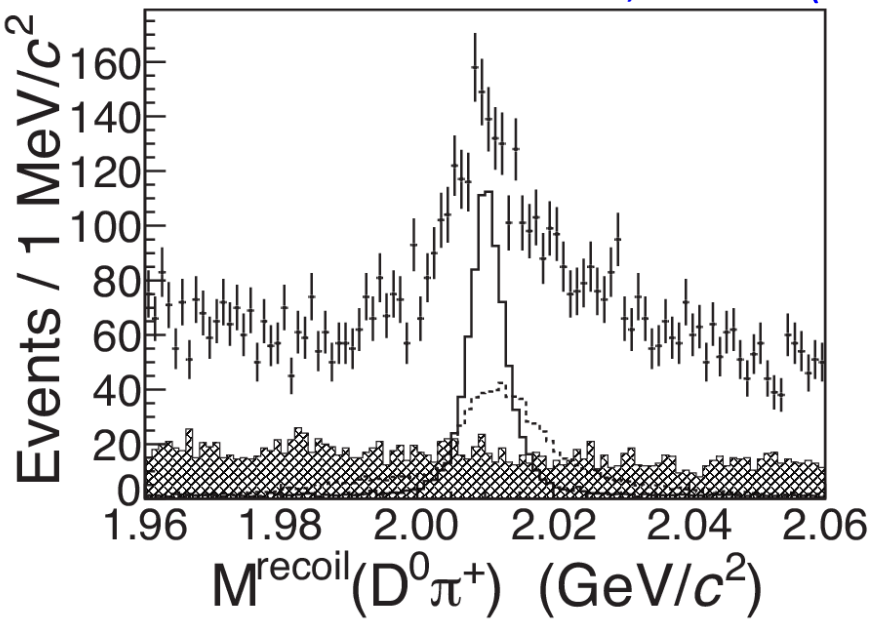
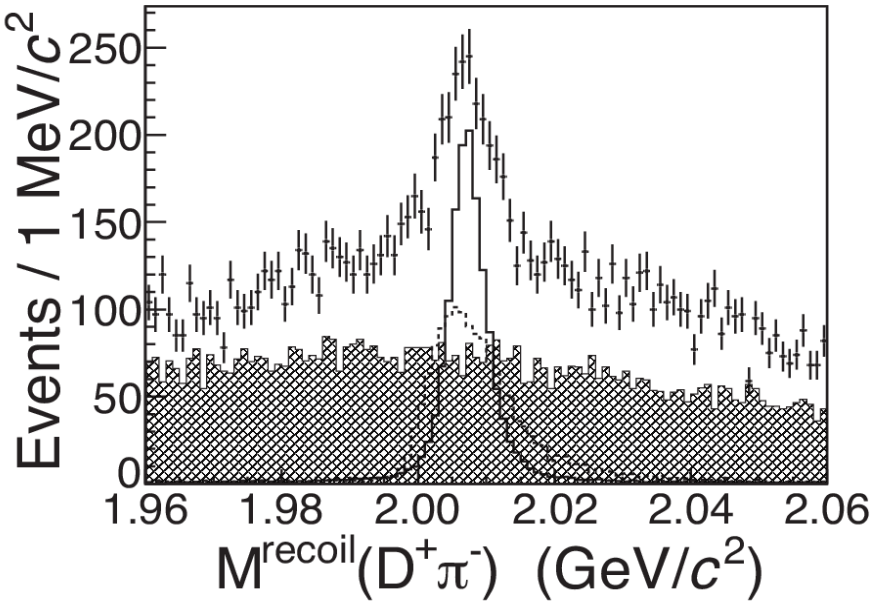


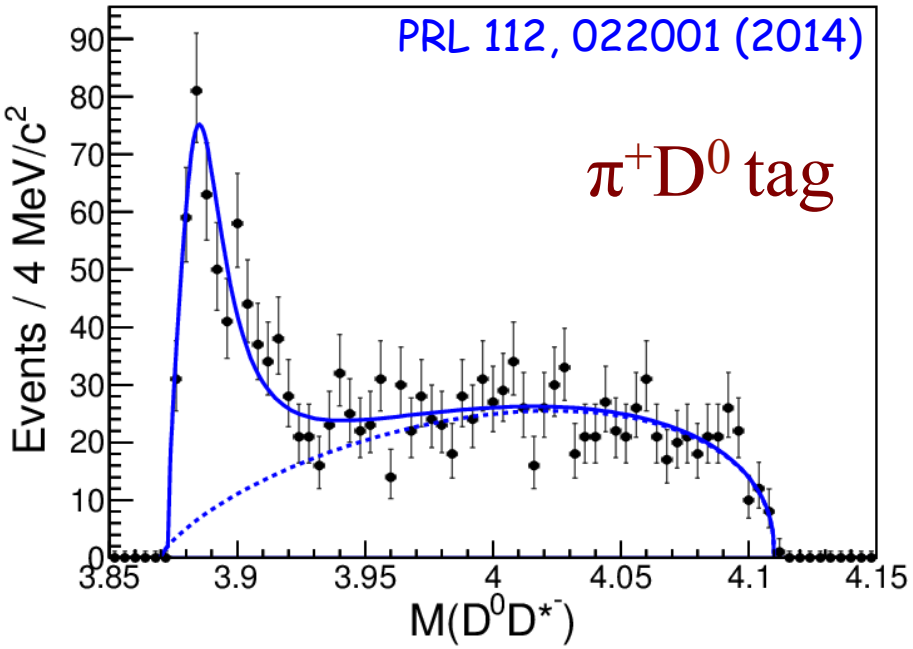
II: π^+D^- tagging method

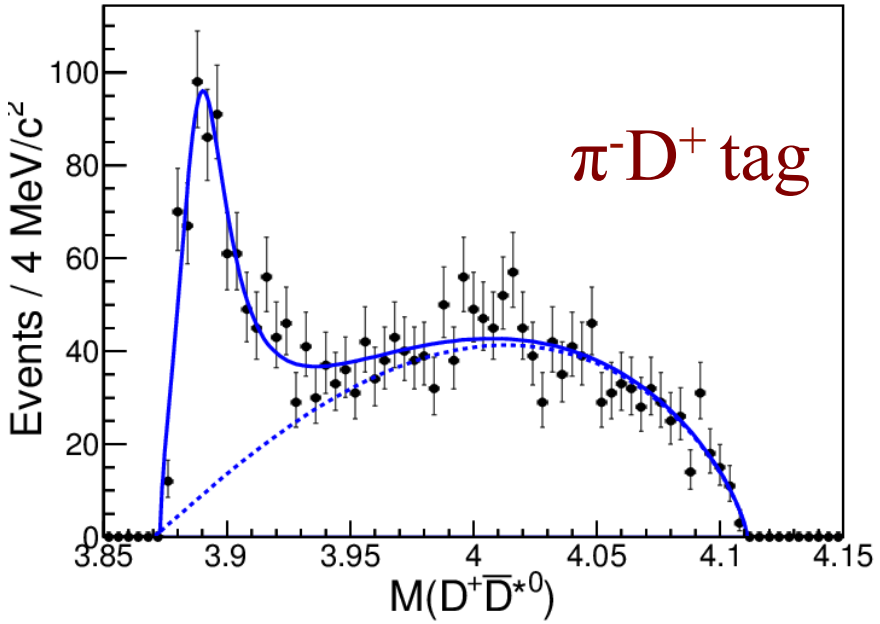
Dots with error bars: Data
Solid: $e^+e^-\to\pi^+D^-D^{*0}$
Dash: $e^+e^-\to\pi^+D^0D^{*-}$, where DD* from Z_c
Hatch: Events from D^- sideband



- Clear signal of D*
- Mass constraint to D*, $\chi^2<30$

Mass Spectrum by recoil π



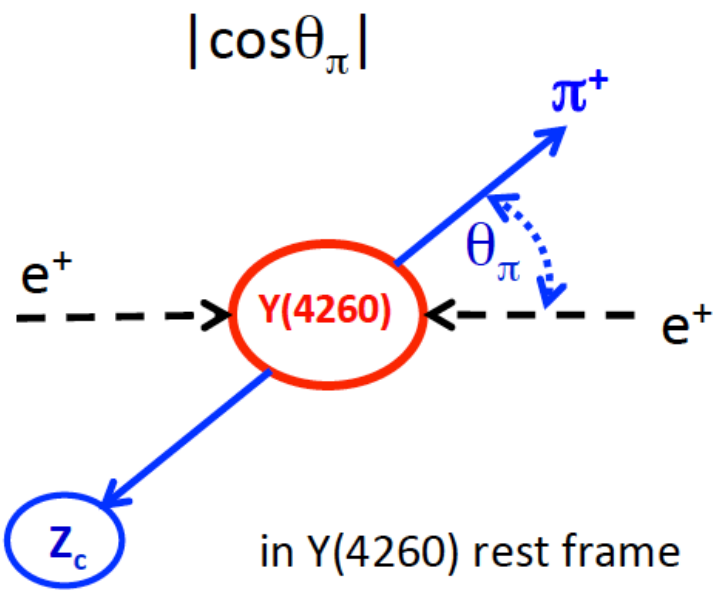


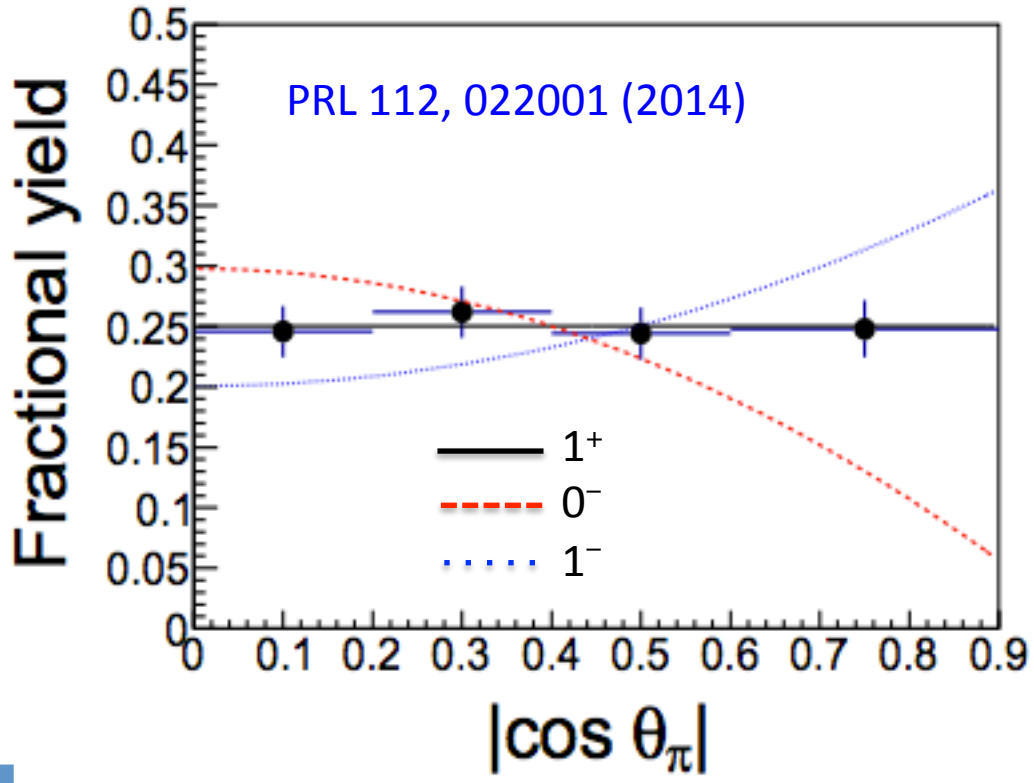
- Peak near threshold.
- Angular distribution (πD) disfavor DD_1 component.
- Fit with mass dependent BW, report pole position.
- Polynomial background.

Production rate are much higher than $\pi^{\pm}J/\psi$!

	$Z_c(3885) \to D\bar{D}^*$
Mass (MeV/c^2)	$3883.9 \pm 1.5 \pm 4.2$
Γ (MeV)	$24.8 \pm 3.3 \pm 11.0$
$\sigma \times \mathcal{B}$ (pb)	$83.5 \pm 6.6 \pm 22.0$

Spin-Parity of $(DD^*)^{\pm}$





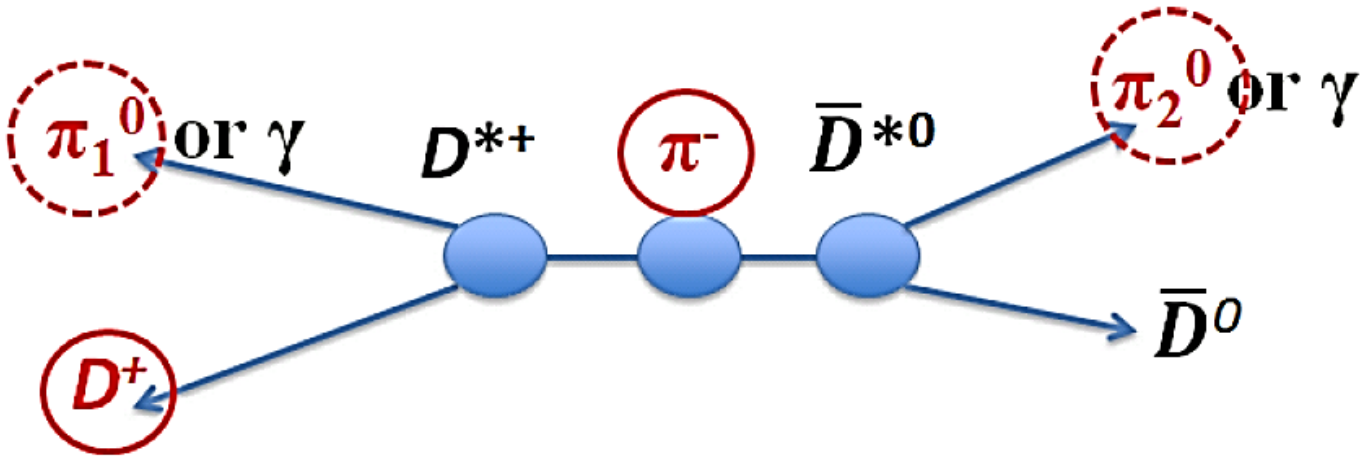
J^P	L	$dN/d|\cos\theta_\pi|$
1^+	S-wave	flat
0^-	P-wave	$\sin^2\theta_\pi$
1^-	P-wave	$1+\cos^2\theta_\pi$

Favor $J^P=1^+$

$Z_c(4025) \rightarrow (D^* D^*)^{\pm}$

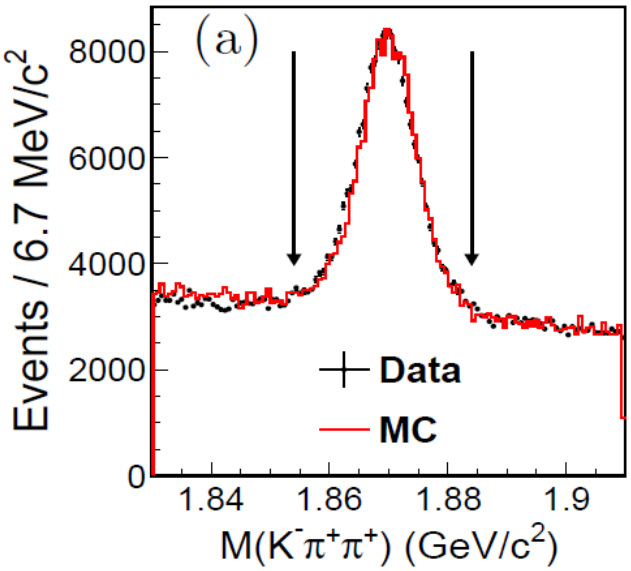
$e^+e^- \to \pi^- (D^*\bar{D}^*)^+ + c.c.$ at BESIII

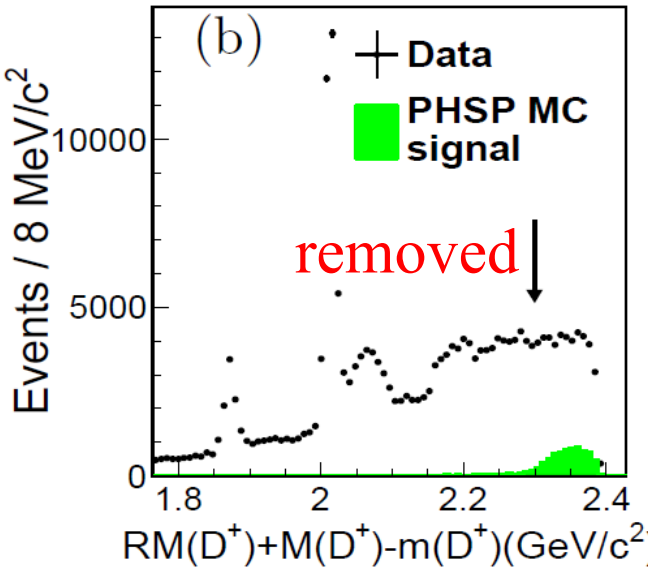
- 827 pb^{-1} data at E_{cm}=4.26 GeV
- Tag a D^+ and a bachelor π^-, reconstruct one π^0 to suppress the background.



Topology of the decays of the signal process. Thick line circled D^+ and π^- are detected in the final states and at least one of the dashed line circled π_1^0 or π_2^0 is tagged.

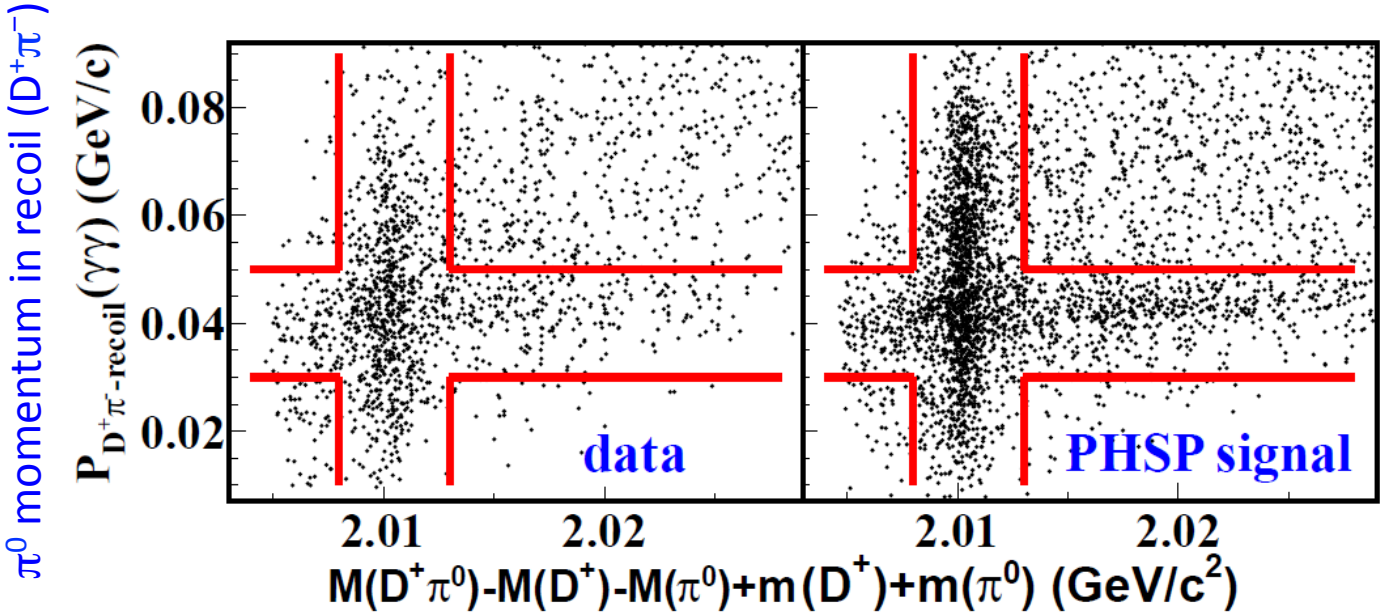
$e^+e^- \to \pi^- (D^*D^*)^+ + c.c.$ at BESIII



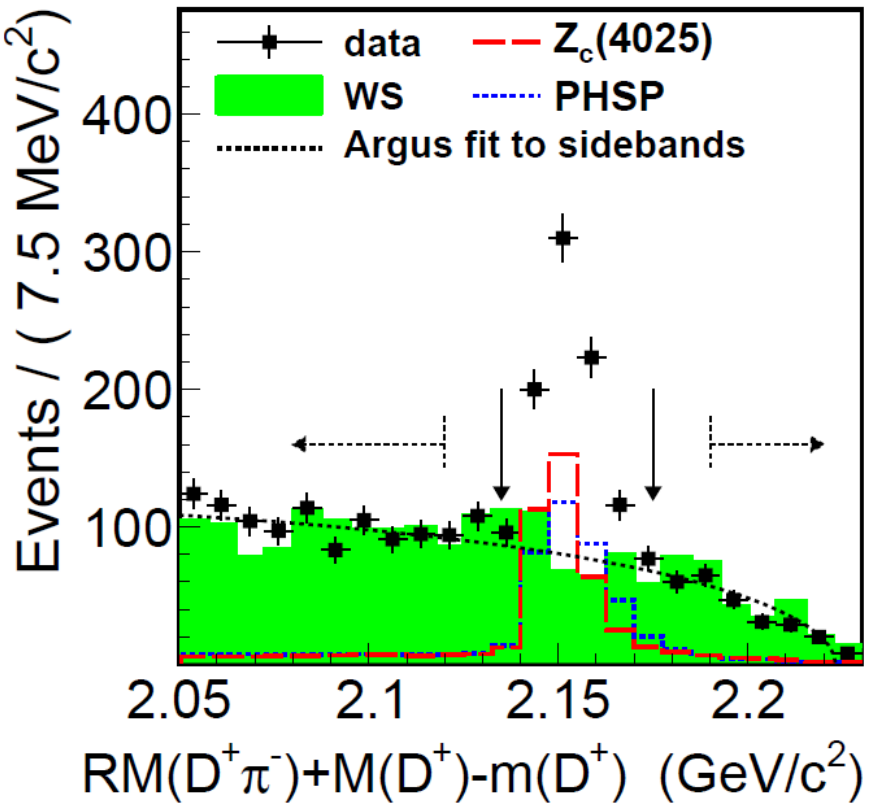


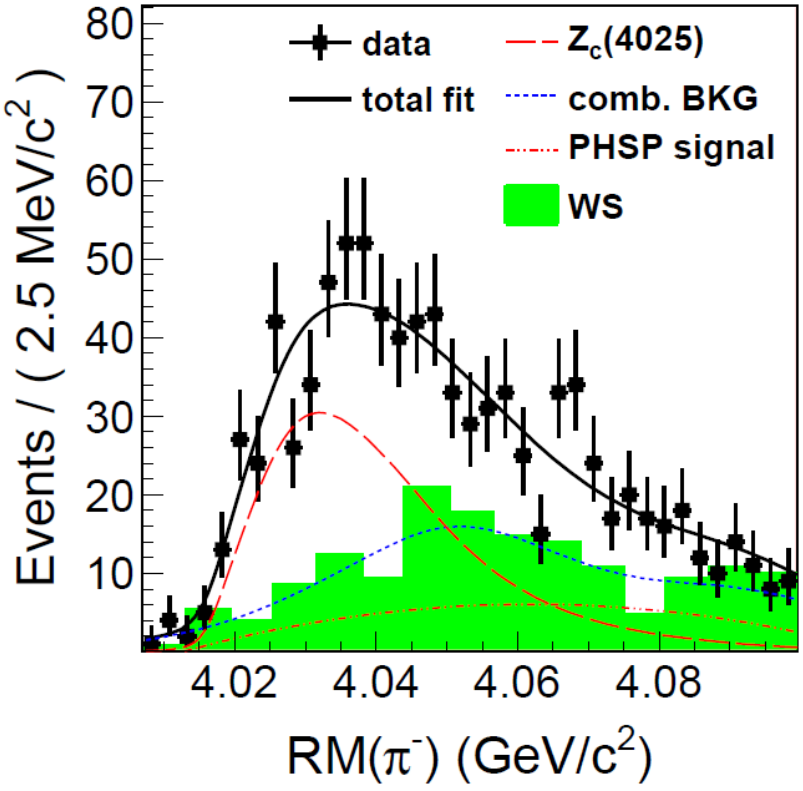
Remove DD, DD^*, D^*D^*, D_sD_s, …

RM=(Recoil Mass)



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





Fit to $\pi^\pm$ recoil mass (RM) yields 401±47 $Z_c(4025)$ events.

M[$Z_c(4025)$] =(4026.3±2.6±3.7) MeV; Γ[$Z_c(4025)$] =(24.8±5.6±7.7) MeV

$$\sigma(e^+e^- \to \pi^\pm (D^* \overline{D}^*)^\mp) = (137 \pm 9 \pm 15)\ \text{pb}$$

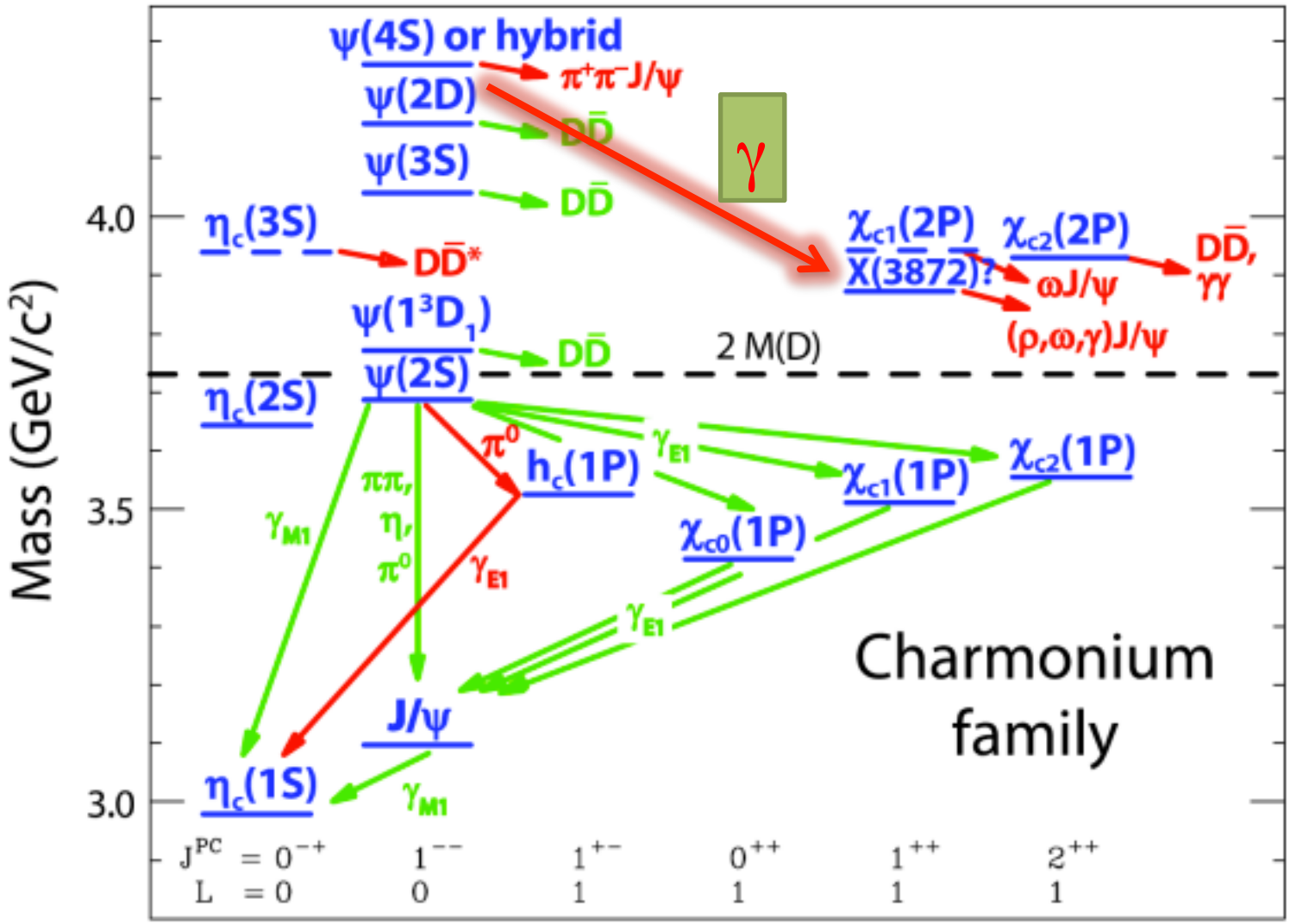
Significance >10σ

$$R = \frac{\sigma(e^+e^- \to \pi^\pm Z_c^\mp(4025) \to \pi^\pm (D^* \overline{D}^*)^\mp)}{\sigma(e^+e^- \to \pi^\pm (D^* \overline{D}^*)^\mp)} = (65 \pm 9 \pm 6)\%$$

PRL112,132001 (2014)

$Y(4260) \rightarrow \gamma X(3872)$

Produce X(3872) at BESIII

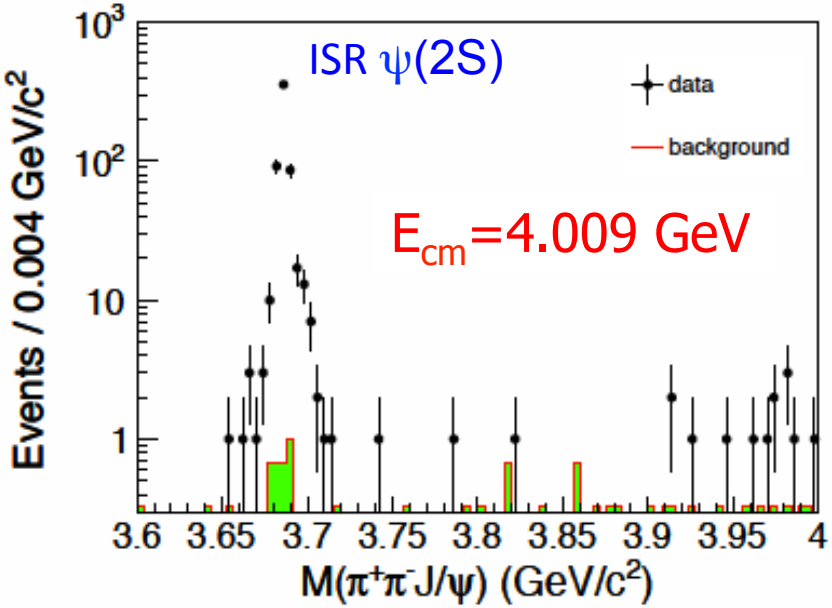


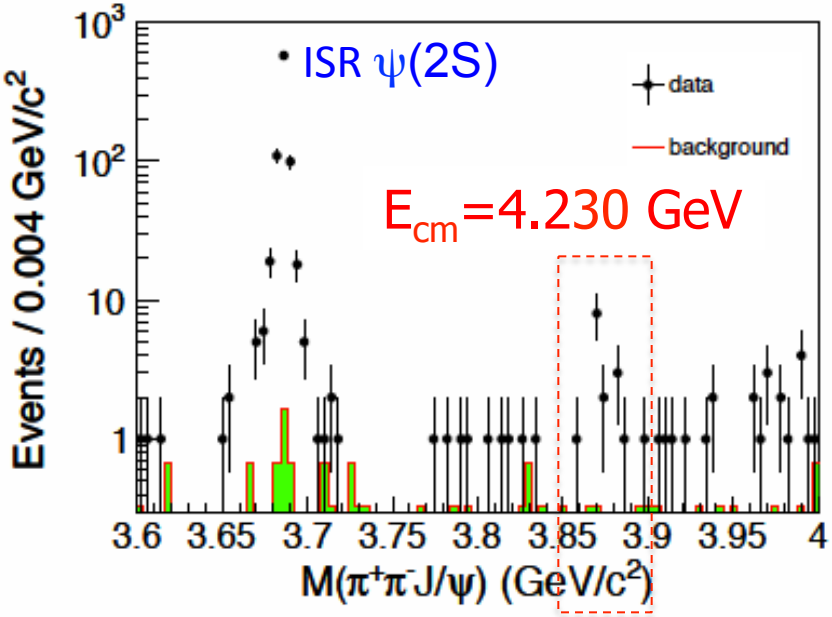
BESIII can produce lots of vector charmonium and charmoniumlike state.

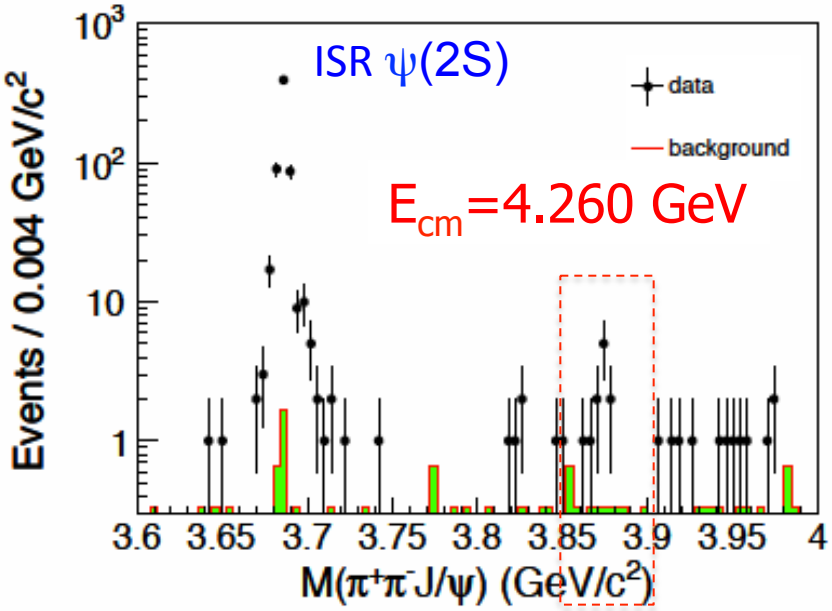
ψ(4040)
Y(4260)
Y(4360)
…

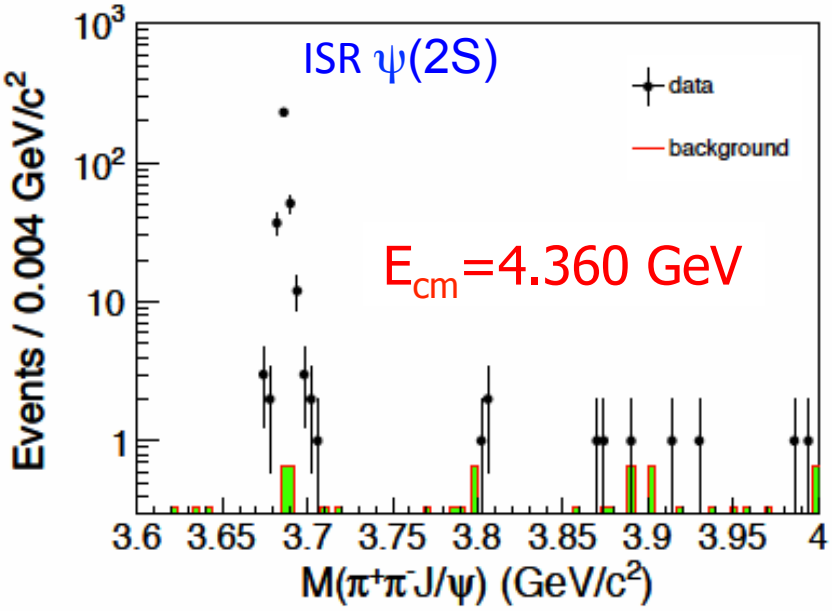
LHCb:
$J^{PC}=1^{++}$

$e^+e^- \rightarrow \gamma(\pi^+\pi^- J/\psi)$ at BESIII

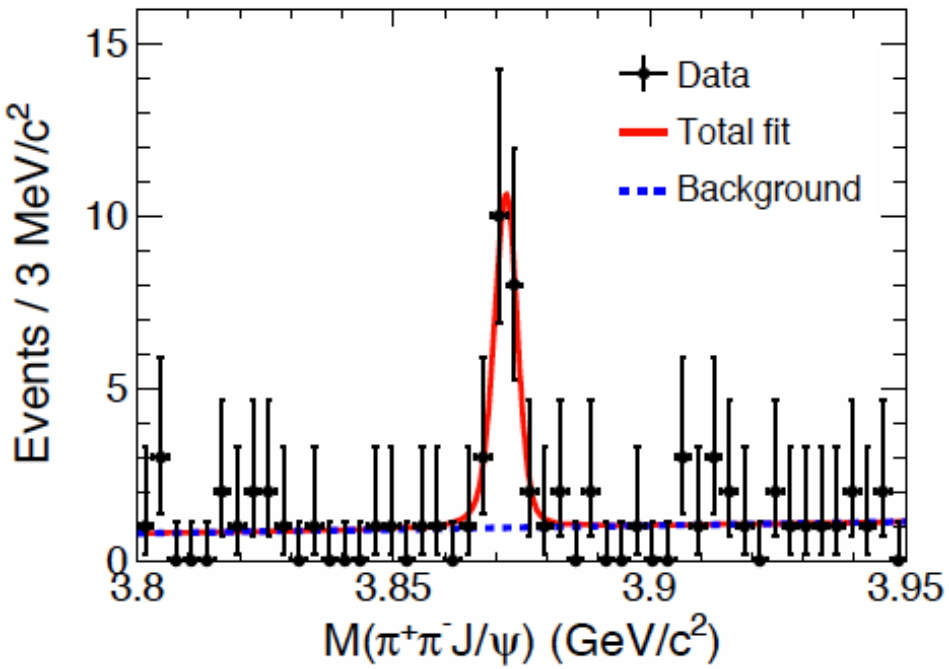


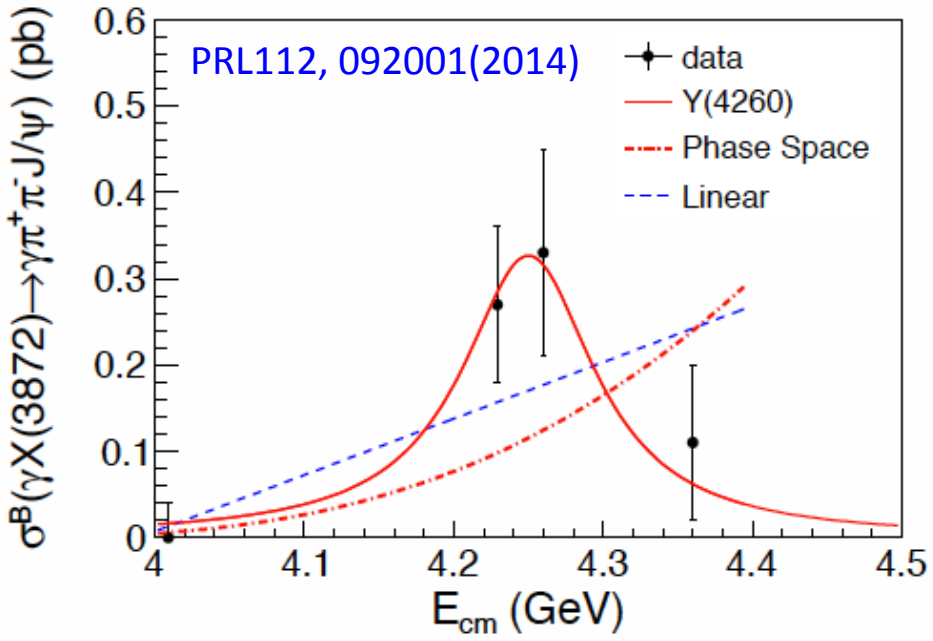






Y(4260)→γX(3872)





M=(3871.9±0.7±0.2) MeV

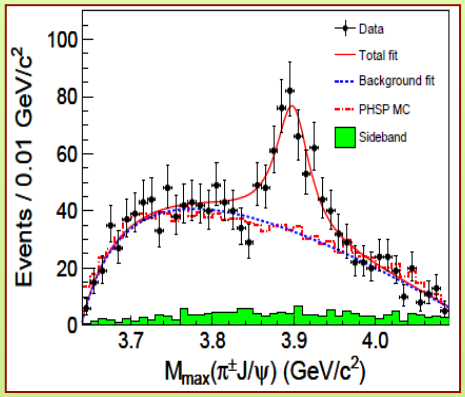
Γ<2.4 MeV

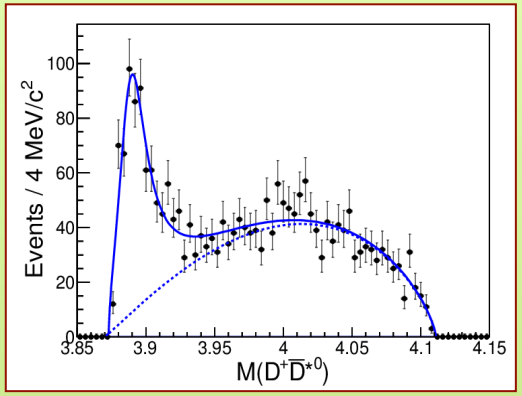
Significance: 6.3 σ

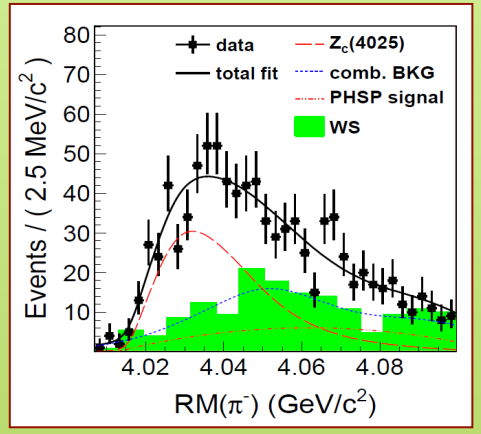
Fit with:

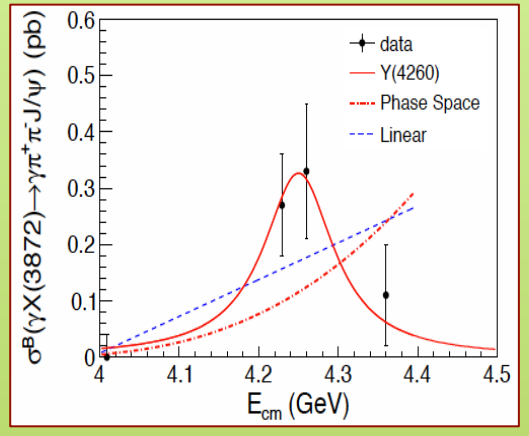
1. Y(4260): χ^2/ndf=0.49/3
2. E1 PHSP: χ^2/ndf=8.7/3
3. Linear: χ^2/ndf=5.5/2

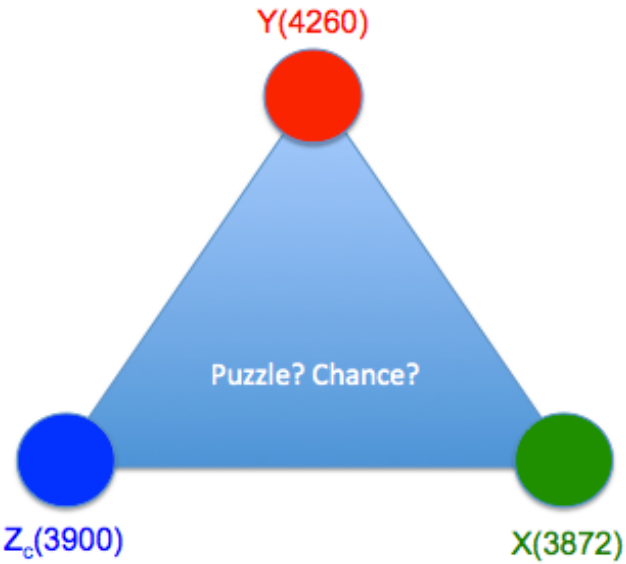
$$\frac{\mathcal{B}[Y(4260)\to\gamma X(3872)]}{\mathcal{B}(Y(4260)\to\pi^+\pi^- J/\psi)} = 0.1$$


Data
Total fit
Background fit
PHSP MC
Sideband
Events / 0.01 GeV/c²
M_max(π±J/ψ) (GeV/c²)


Events / 4 MeV/c²
M(D⁺D̄*⁰)


data
total fit
Z_c(4025)
comb. BKG
PHSP signal
WS
Events / (2.5 MeV/c²)
RM(π⁻) (GeV/c²)


data
Y(4260)
Phase Space
Linear
σ^B(γX(3872)→γπ⁺π⁻J/ψ) (pb)
E_cm (GeV)


Y(4260)
Puzzle? Chance?
Z_c(3900)
X(3872)

R
C
ψ4160
ψ4415
DASP
Crystal Ball
BES

Summary

- BESIII observed a charged Charmonium-like state $Z_c(3900)$, $Z_c(4025)$ @ 4.26 GeV
- $Y(4260) \rightarrow \gamma X(3872)$ radiative transition for the first time.
- Understand them with more data & effort.

Thank you (谢谢)！