Exotic charmonium at BESIII

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On behalf of BESIII collaboration

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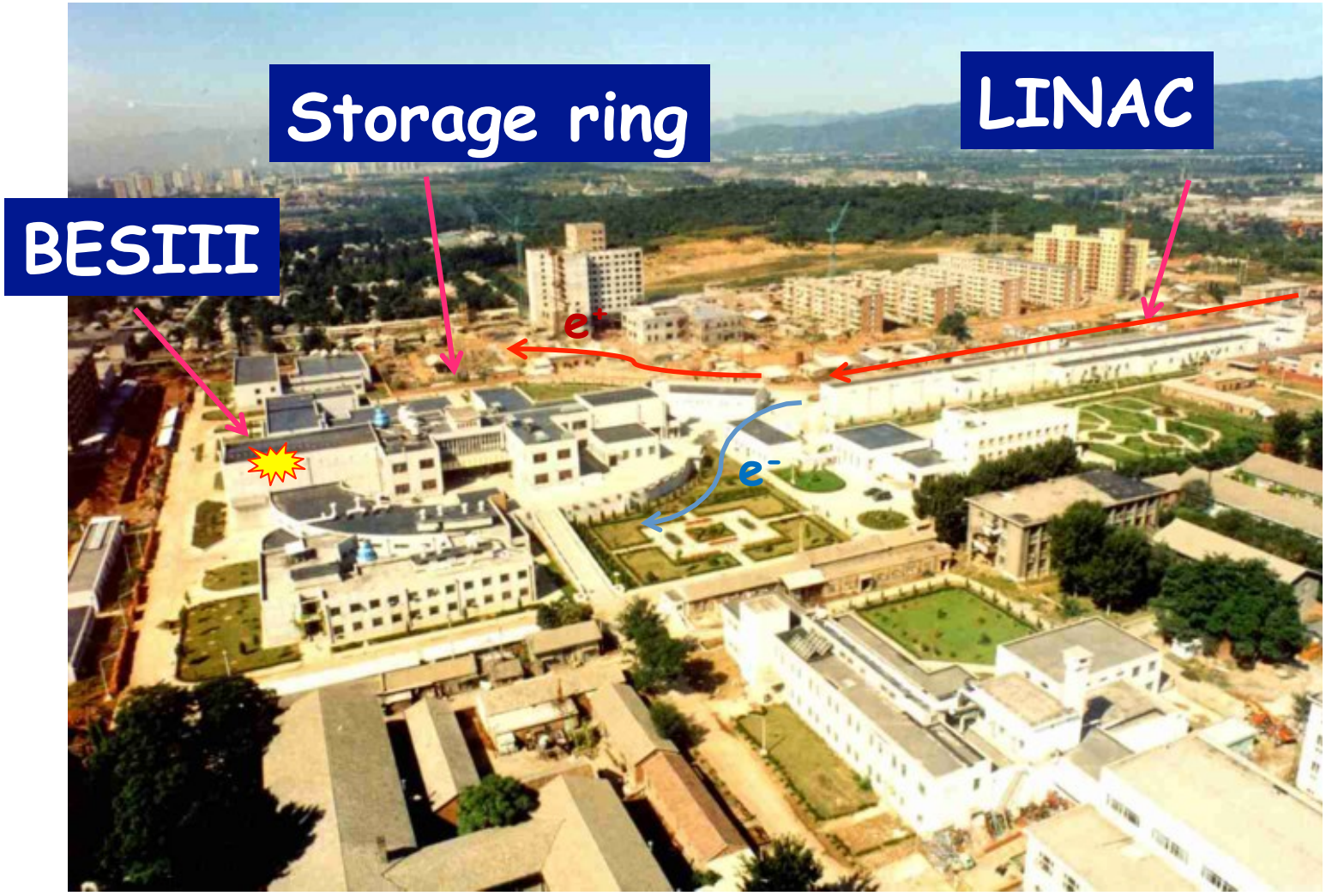
Outline

- ❑ Introduction
- ✓ BEPCII and BESIII
- ✓ BESIII data samples
- ✓ What's exotic states
- ❑ A quick view of the exotic in $Y(1^{--})$ states.
- ❑ The exotic Zc family.
- ✓ $Zc(3900)\rightarrow \pi J/\psi$, $Zc(3885)\rightarrow DD^*$
- ✓ $Zc(4020)\rightarrow \pi h_c$, $Zc(4025)\rightarrow D^*D^*$
- ❑ Observation $e^+e^-\rightarrow \gamma X(3872)$, $X(3872)\rightarrow \pi^+\pi^- J/\psi$

See Jiangming Bian's report at May 20 for the BES work about Y states and X states.

- ❑ Summary

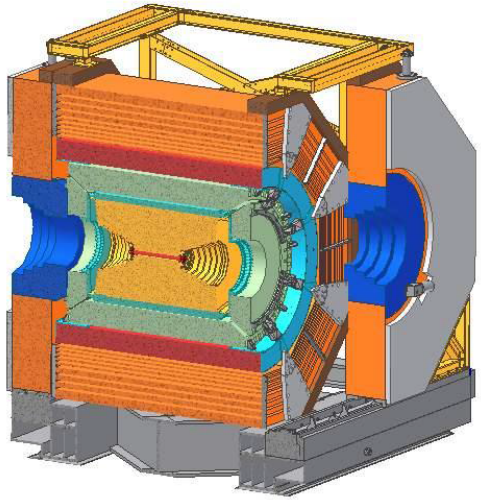
Beijing Electron and Positron Collider (BEPCII)

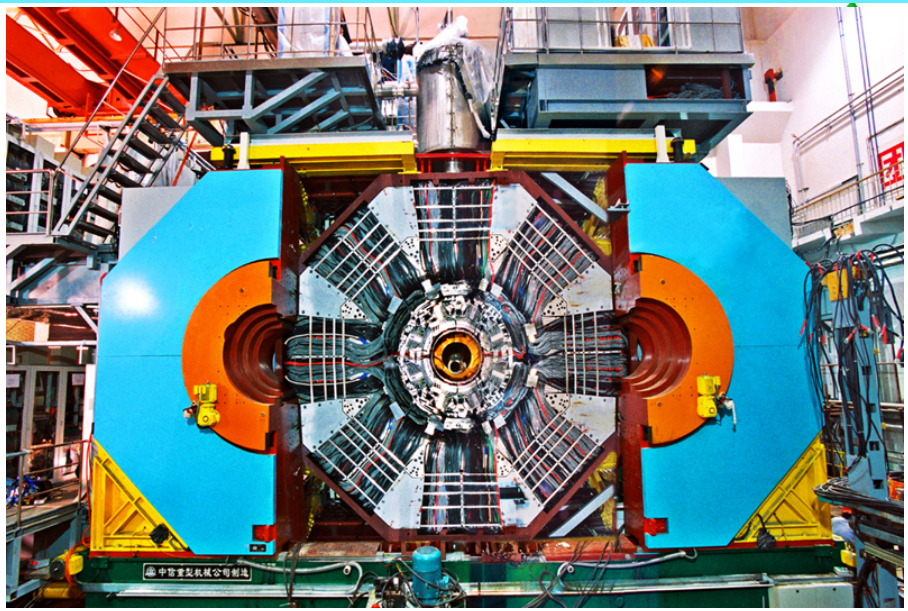


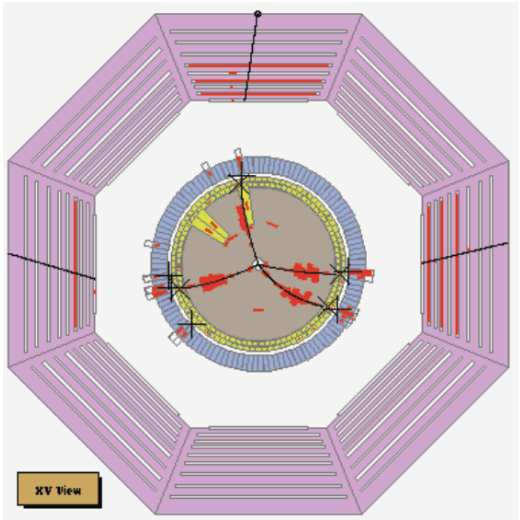
Beam energy: 1~2.3GeV, peaking Luminosity $0.853\times10^{33}cm^{-2}s^{-1}$

Beijing Spectrometer (BESIII)

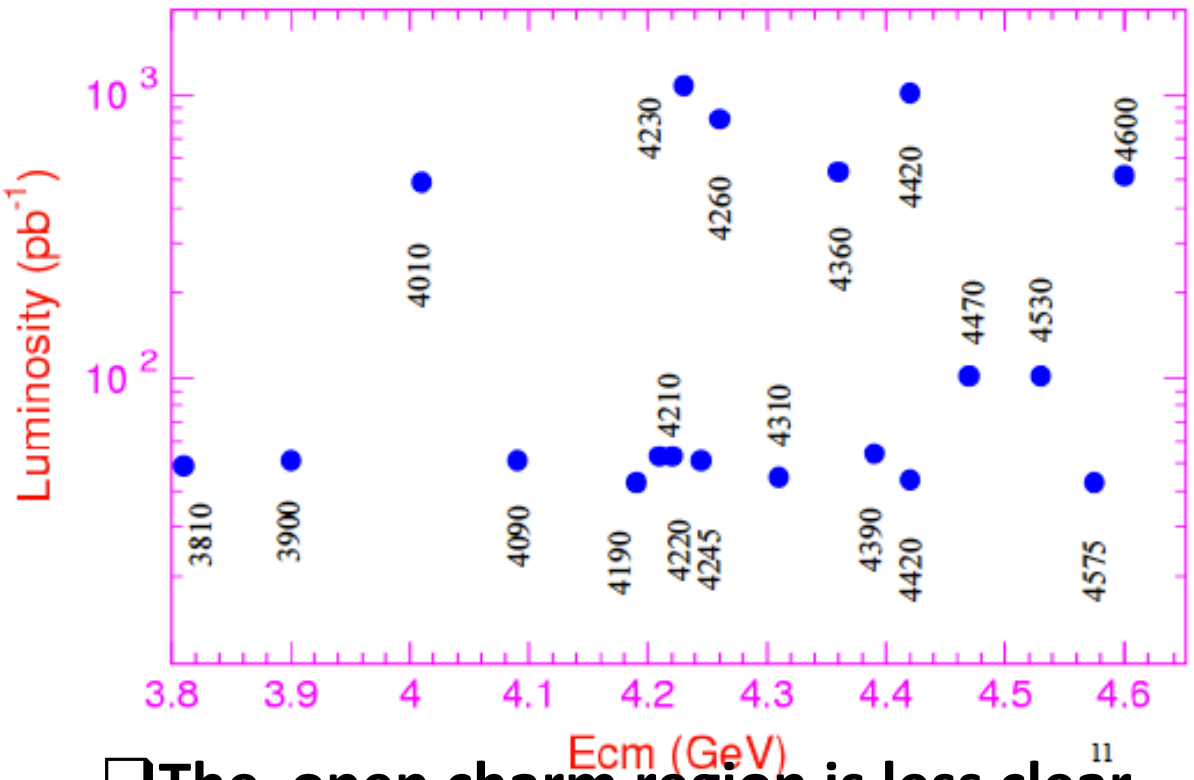
- Inner to Outside：
- ✓ Main Drift chamber(MDC),
- ✓ Time of flight System(TOF),
- ✓ Electromagnetic Calorimeter(EMC),
- ✓ Solenoid super-conducting magnet(SSM),
- ✓ Muon chamber(MUC)
- Acceptance: 93% of 4π

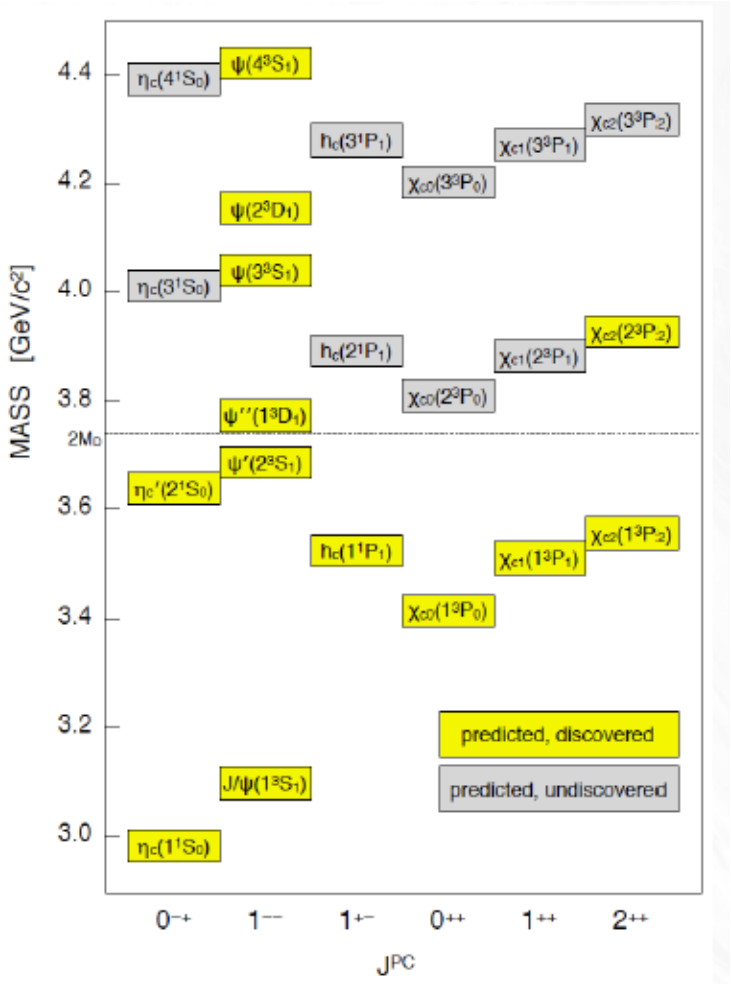






BESIII data sets for XYZ study

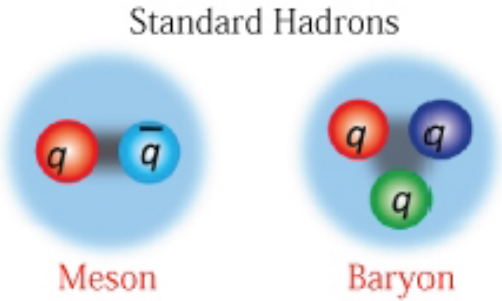




- The open charm region is less clear.
- BESIII has collected about 5 fb^{-1} e^+e^- collision data event in open charm region from 3.8-4.6GeV.
- We have massive events on several special energy points: Such as 4.26GeV, and 4.36GeV→The study of Y(4260) and Y4360.

What's the exotic states

- **The normal states from standard quark model meson(qq), baryon(qqq)**



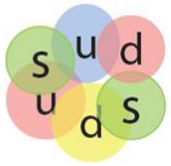
- **The QCD allow the existence of exotic states:**

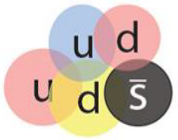
✓ **Glueball (gg, ggg…)**

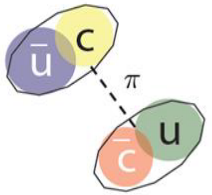
✓ **Multi-quark states (qqqq, qqqqq…)**

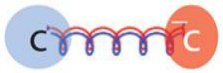
✓ **Molecular states (Bound states of normal hadrons)**

✓ **Hybrid (qqg)**

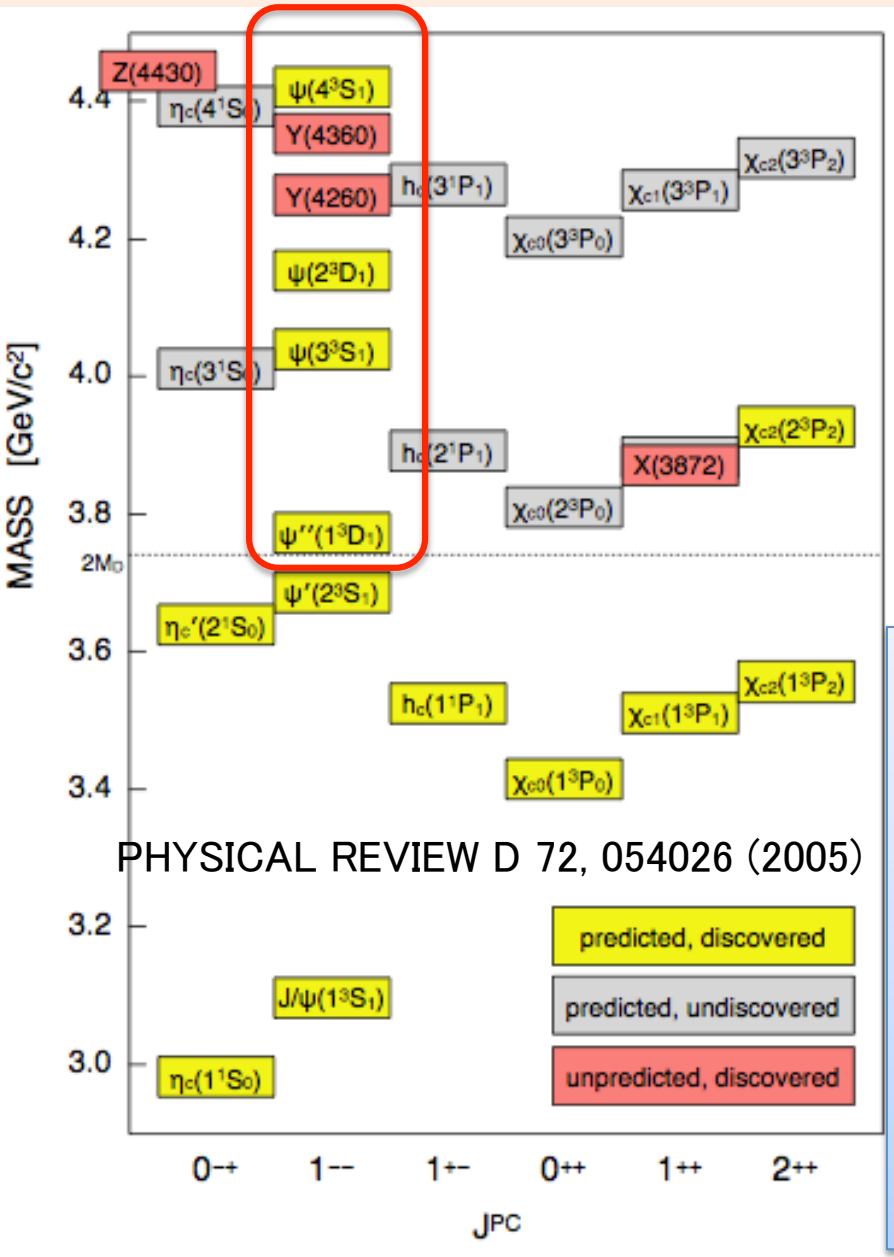








The exotics with Y(1^{--}) states

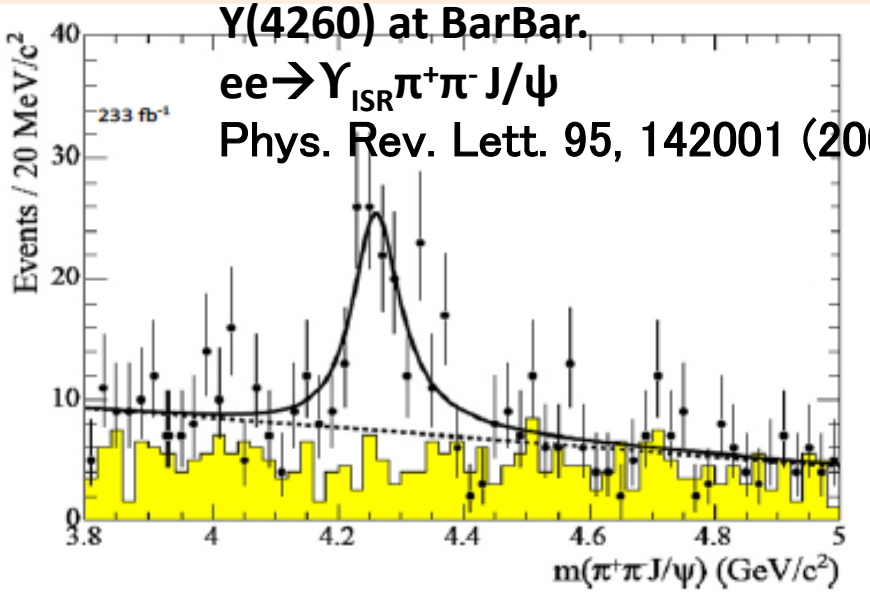


PHYSICAL REVIEW D 72, 054026 (2005)

Y(4260) at BarBar.

ee→$Y_{ISR}\pi^+\pi^-$ J/ψ

Phys. Rev. Lett. 95, 142001 (2005)



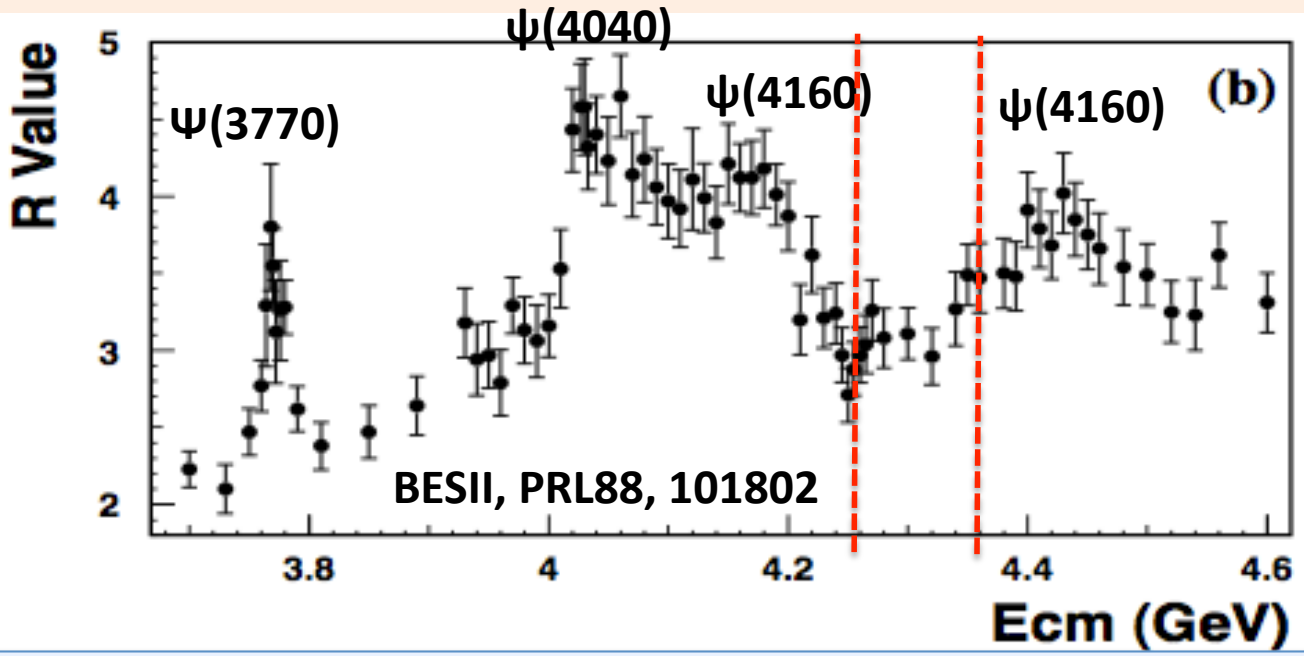
❑Y(4260), Y(4360) are not predicted by the Potential theory:

"Y" are observed in the ISR process, they should be 1^{--} states.

All the predicted 1^{--} charmonium are already discovered (ψ(4040), ψ(4160), ψ(4415).

→No place for Y(4260), Y(4360). Some of them might not be charmonium.

The exotics with Y(1^{--}) states



- Y(4260), Y(4360) doesn't correspond to a peak in R scan spectrum.
- Y(4260) has much smaller coupling to open charm compare with observed ψ.

$\Gamma(D\overline{D})/\Gamma(J/\psi\pi^+\pi^-)$ Y(4260) PDG Γ_{23}/Γ_2

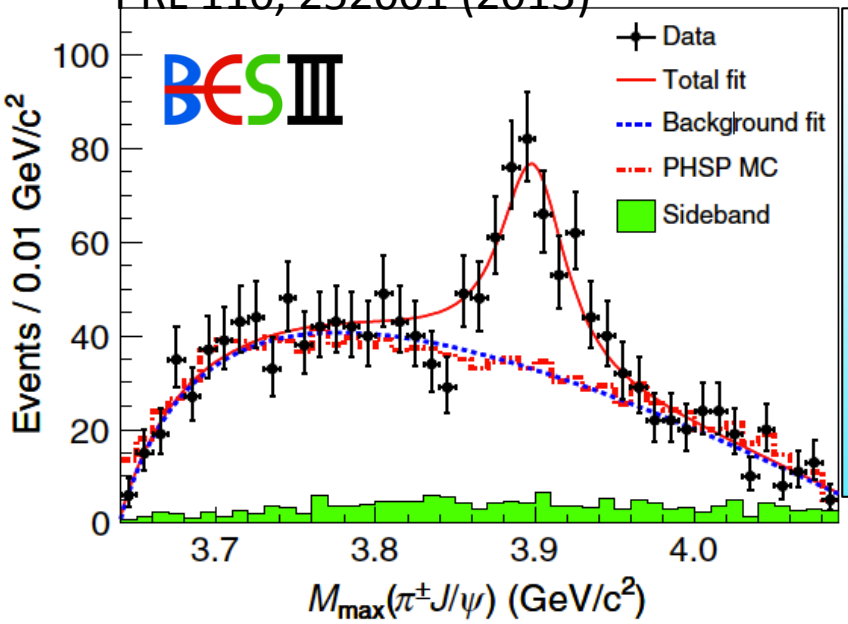
VALUE	CL%	DOCUMENT ID		TECN	COMMENT
<1.0	90	[1] AUBERT	07BE	BABR	$e^+e^- \to D\overline{D}\gamma$

For ψ(3770), Γ(DD)/Γ($\pi^+\pi^-$ J/ψ) ~ 500

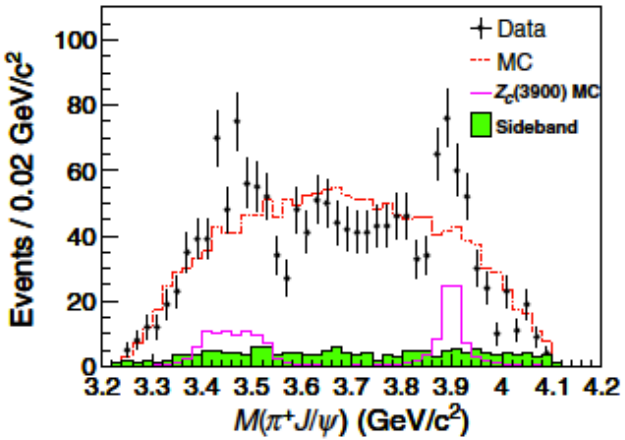
See Jiangming Bian's report at May 20 for the BES work about Y states.

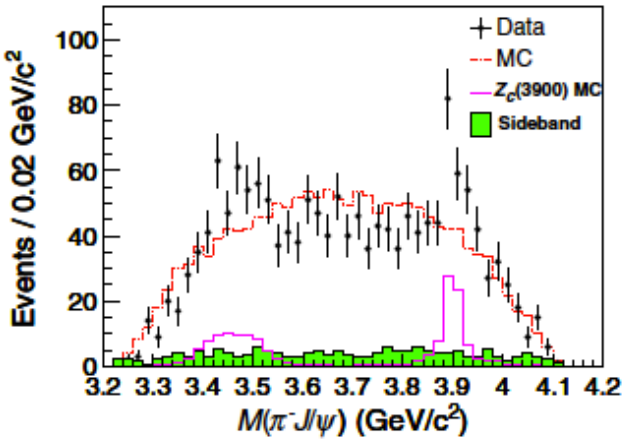
$Zc(3900)^{\pm}$ observed in $e^+e^- \rightarrow \pi^+\pi^- J/\psi$

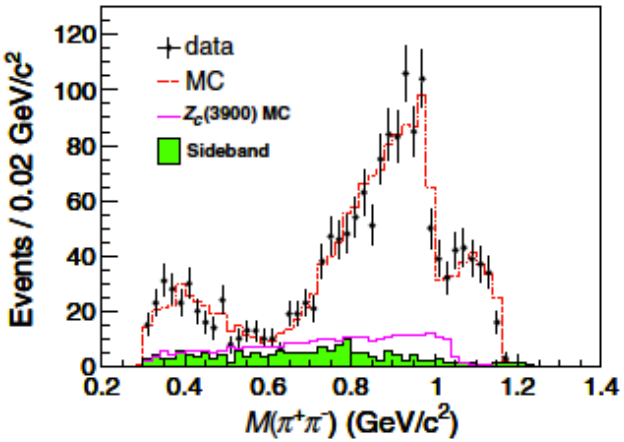
PRL 110, 252001 (2013)



- Measured with 525pb^{-1} data at E_{cms}=4.26GeV
- The peak is not a kinematic reflection of $\pi^+\pi^-$ system
- Zc(3900) parameters, S-wave BW
  M=(3899.0±3.6±4.9) MeV, Γ=(46±10±20)MeV
- Significance > 8σ

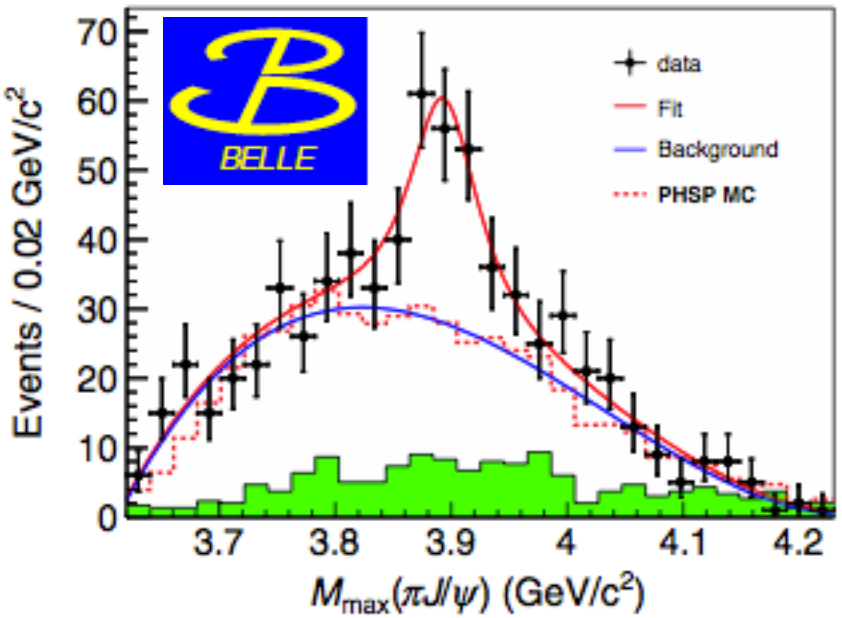




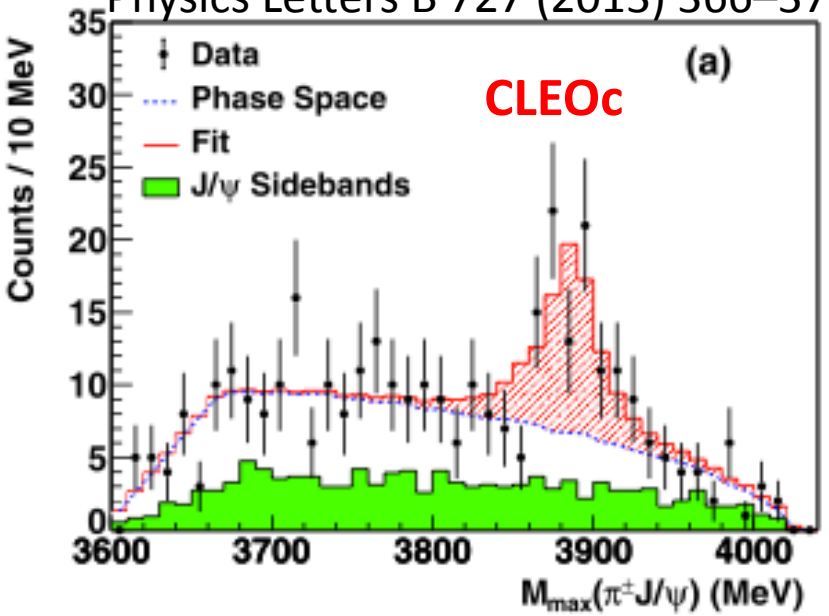


$Zc(3900)^{\pm}$ is also observed in other experiment

PRL 110, 252002 (2013)

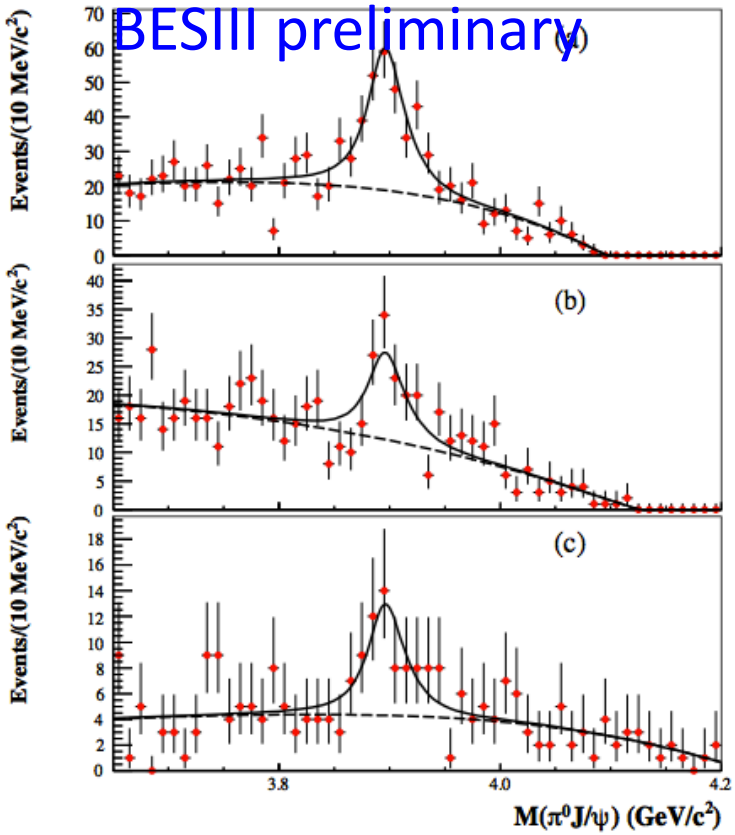


Physics Letters B 727 (2013) 366–370



	Mass	Width	significance
BESIII	3899.0±3.6±4.9	46±10±20	>8.0σ
BELLE	3894.5±6.6±4.5	63±24±26	5.2σ
Cleo-c	3886±4±2	37±4±8	>5σ

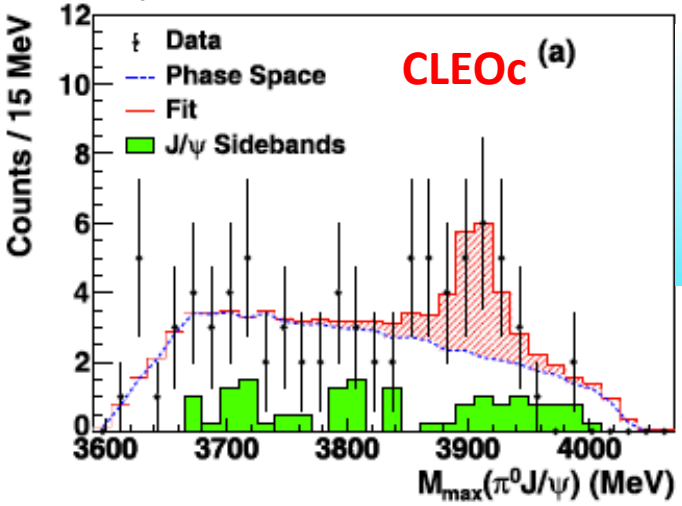
$Zc(3900)^0$ observed in $ee \rightarrow \pi^0\pi^0 J/\psi$



A simultaneous fit to data at E_{cms} of 4.23GeV, 4.26GeV and 4.36GeV

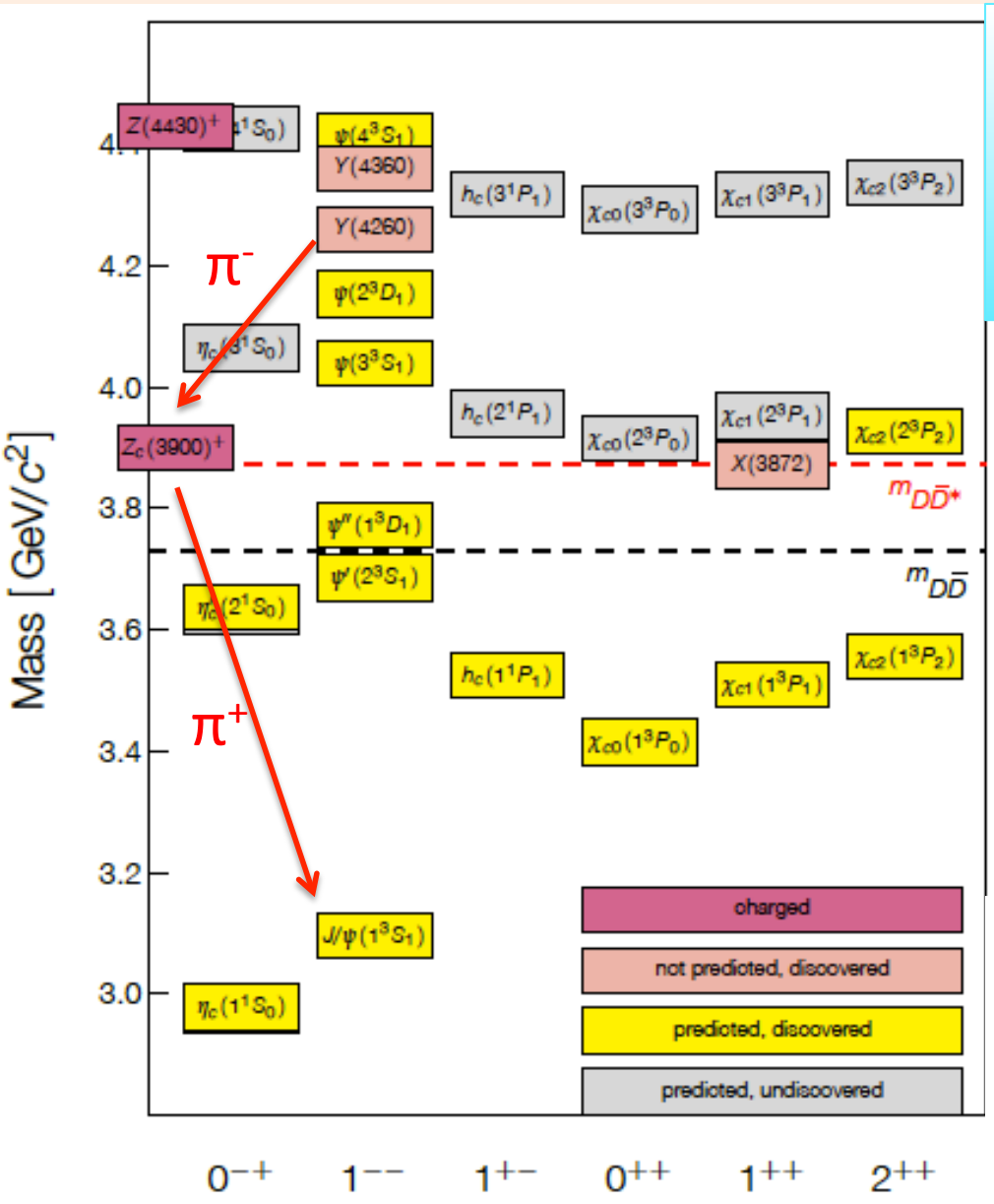
- **Significance=10.4σ**
- **M=3894.8±2.3±2.7 MeV, Γ=29.6±8.2±8.2 MeV**
- **IsoSpin triplet.**
- **$Zc(3900)^0 \rightarrow \pi^0 J/\psi$, C parity of Zc^0=-1**

Physics Letters B 727 (2013) 366–370



Cleo result give a Significance of $Zc(3900)^0$=3.7σ

Why is Zc(3900) exotic?



- **The mass of Zc(3900) is in opencharm range and strongly coupled to charm→it should contain a (ccbar) pair.**
- **Zc(3900) is charged→ need at least two more quarks to form a charge unit.**

Z_c(3900) is a four quark states?

❑Tetraquark states?

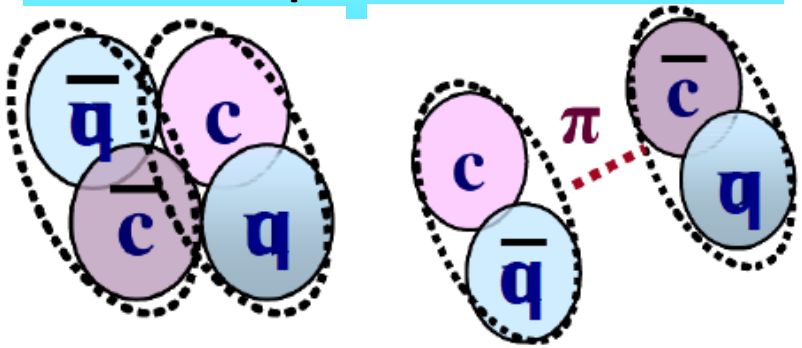
Phys. Rev. D89,054019(2014);

Phys. Rev. D90,054009(2014);

❑Zc(3900) is near the threshold of (DD*)→ A molecular states?

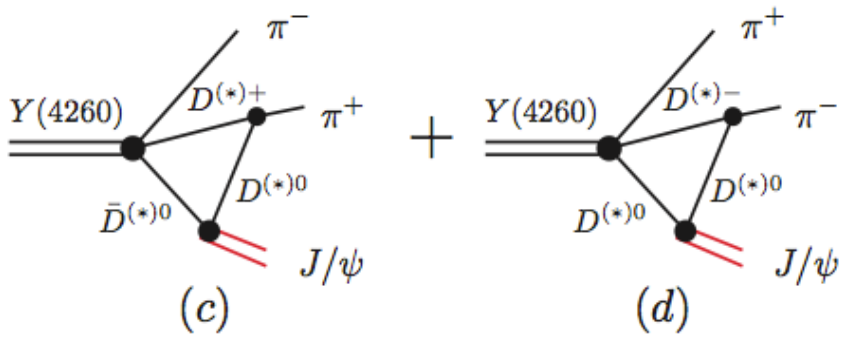
Arxiv:1303.6608, 1304.2882

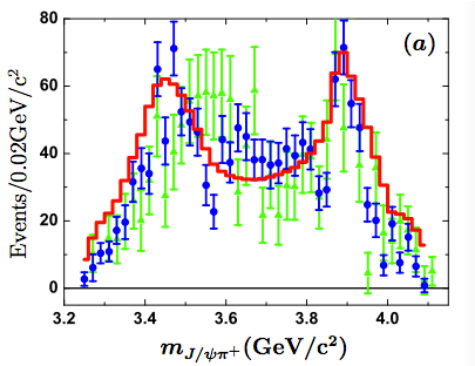
OR other explanation?



Other explanation of Zc(3900)

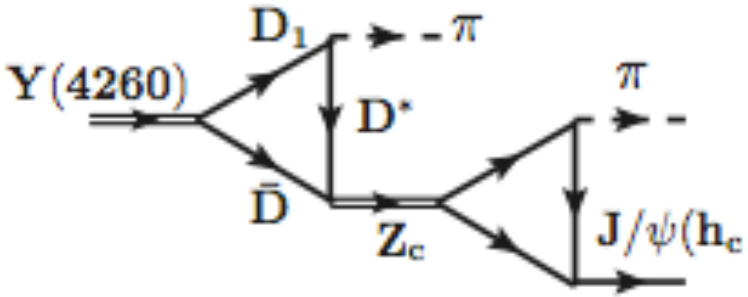
❑ ISPE(Initial single pion emission) model. (arxiv：1304.5845)

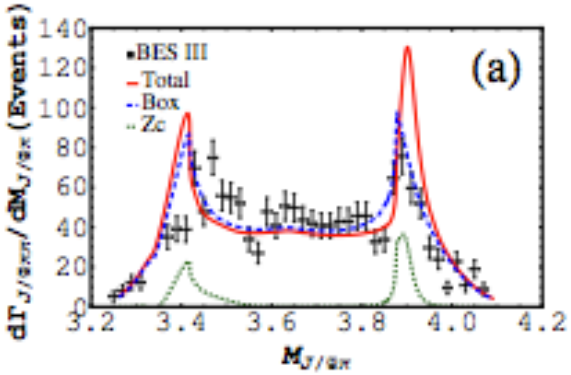




❑ Meson loop model. (Arxiv：1303.6355)

Based on the assumption that Y(4260) is (DD1) molecular states

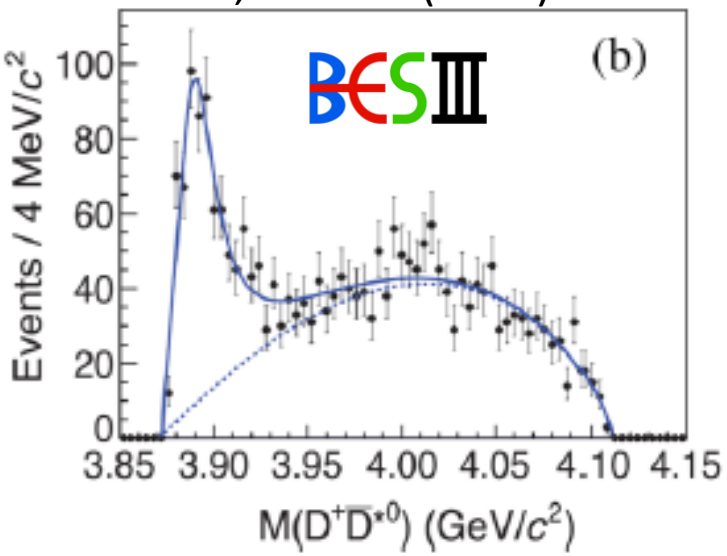


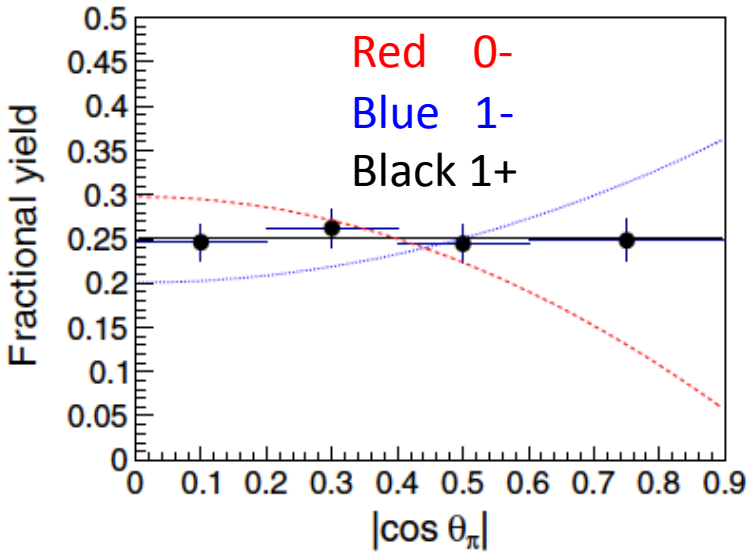


❑ …

Zc(3885)± observed in $e^+e^- \to \pi^\pm Z_c(3885)^\pm \to \pi^\pm (D\overline{D}^*)^\mp$

PRL 112, 022001 (2014)





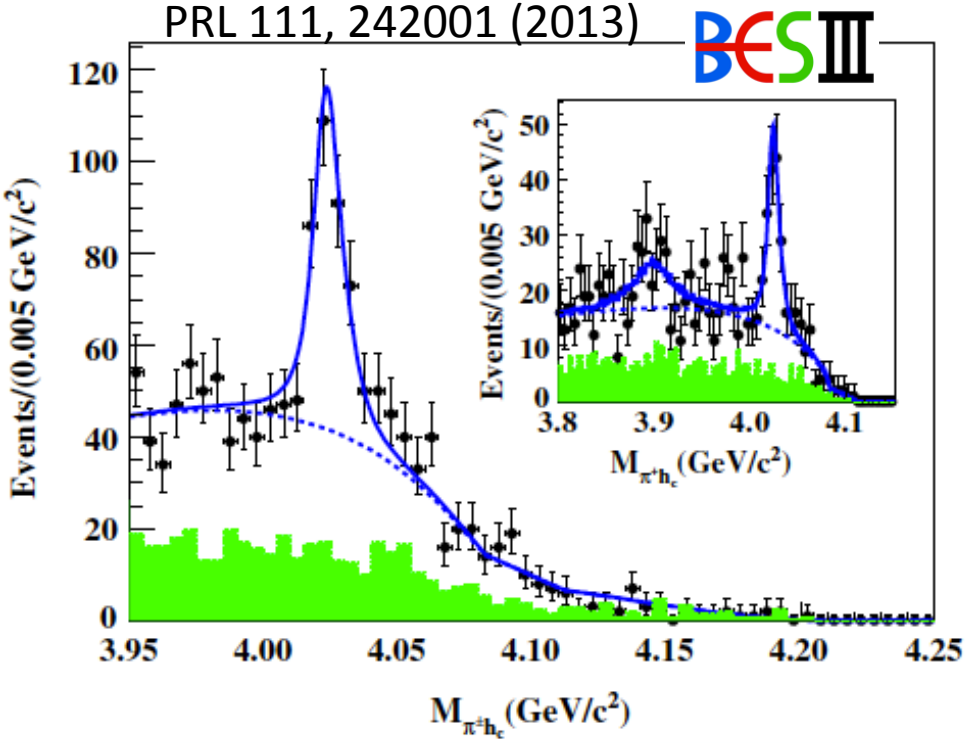
- M=3883.9±1.5±4.2 MeV, Γ=24.8±3.3±11.0 MeV
- $\sigma(e^+e^- \to \pi^\pm Z_c(3885)^\mp) \times B(Z_c(3885)^\mp \to (DD^*)^\mp)$
  $= (83.5 \pm 6.6 \pm 22.0)\,pb$
- Assmuing Zc(3885) and Zc(3900) are same states

$$\frac{\Gamma(Z_c(3885) \to D\overline{D}^*)}{\Gamma(Z_c(3900) \to \pi J/\psi)} = 6.2 \pm 1.1 \pm 2.7 \qquad \frac{\Gamma(\psi(4040) \to D^{(*)}\overline{D}^{(*)})}{\Gamma(\psi(4040) \to \eta J/\psi)} = 192 \pm 27$$

- The J^p of Zc(3885) favors to be 1^+, more work is needed

$Z_c(4020)^{\pm}$ observed in $e^+e^- \rightarrow \pi^+\pi^- h_c$

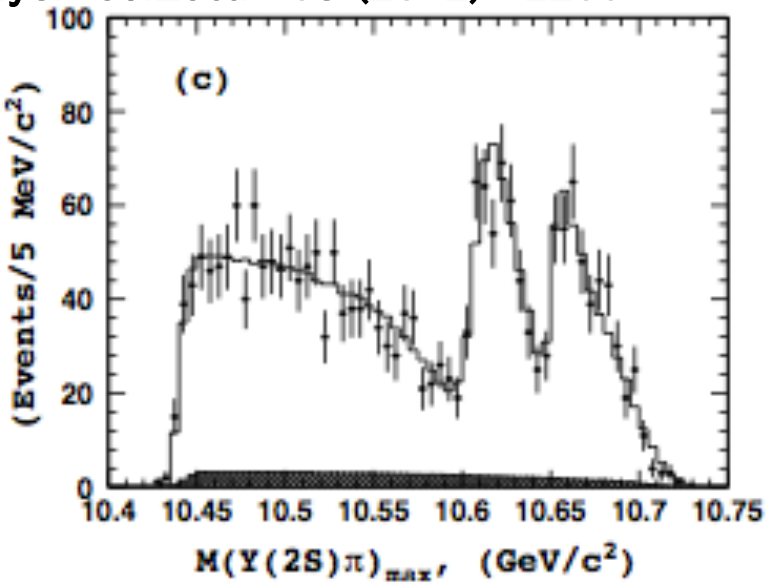
PRL 111, 242001 (2013)

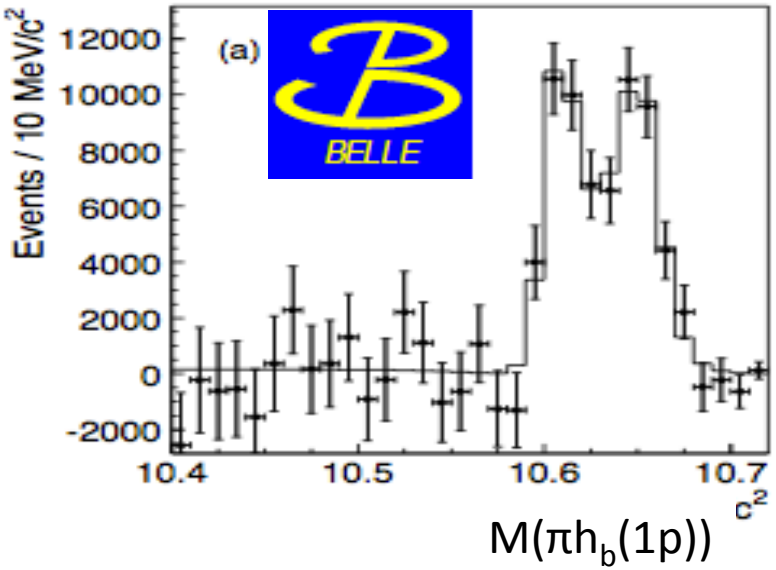


- The process used is $e^+e^- \rightarrow \pi^+\pi^- h_c$, $h_c \rightarrow \gamma\eta_c$, $\eta_c \rightarrow$ 16 exclusive modes.
- A simultaneous fit to the data at 4.23GeV, 4.26GeV and 4.36GeV gives
  - ✓ $M(Zc(4020)^{\pm})=4022.9\pm0.8\pm2.7$ MeV, $\Gamma(Zc(4020)^{\pm})=7.9\pm2.7\pm2.6$ MeV
  - ✓ significance of Zc(4020) >8.9σ, significance of Zc(3900) =2.1σ

$Z_c(4020)^{\pm}$ & Zc(3900)

Phys.Rev.Lett. 108 (2012) 122001

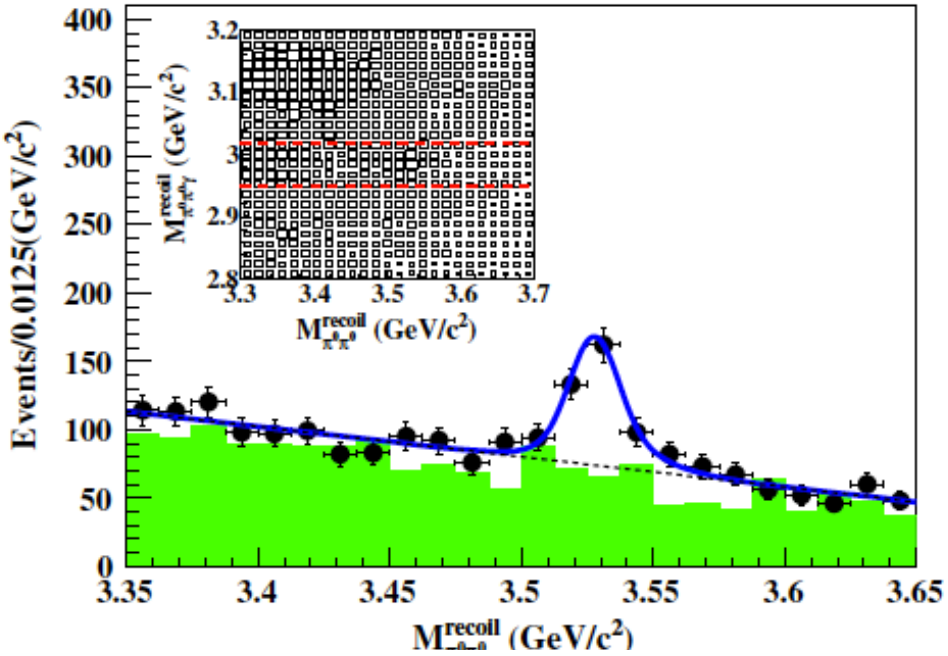


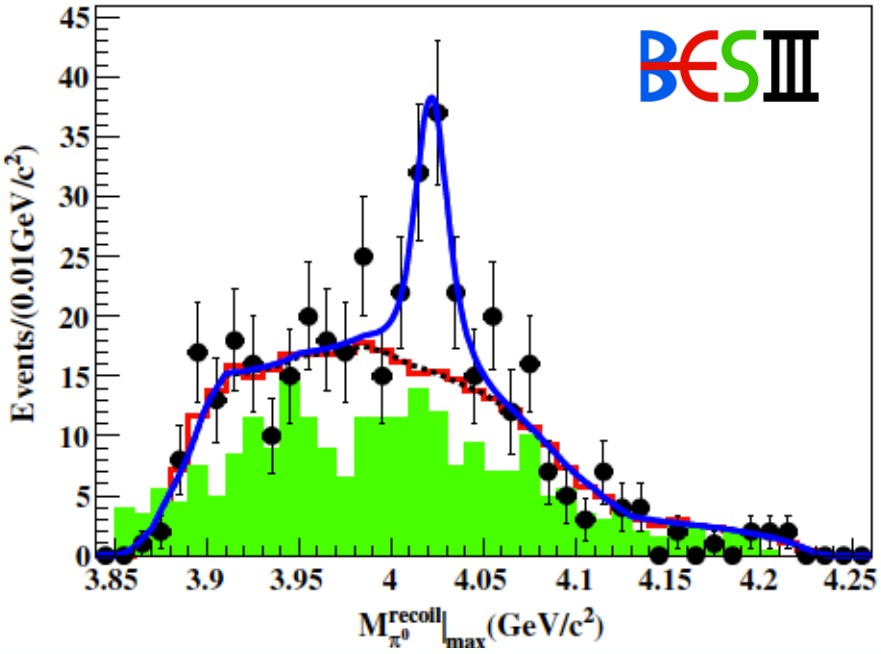


- $\sigma(e^+e^- \to \pi^{\pm}(Z_c(3900))^{\mp} \to \pi^{\pm}(\pi^{\mp}h_c)) =< 11pb \quad @4.26GeV$
- In Belle, two Z_b states are observed in all five modes of $\Upsilon(5S) \to \pi^+\pi^-\Upsilon(1S, 2S, 3S)$, and $\Upsilon(5S) \to \pi^+\pi^- h_b(1P, 2P)$.
- J^{pc} of h_c is 1^{+-}, J^{pc} of J/psi is 1^{--} .
- If Z_c is 1^+, $Z_c \to \pi J/\psi$ is dominated by S-Wave, $Z_c \to \pi h_c$ is P wave. Zc(3900)$\to \pi h_c$ might be suppressed by angular momentum barrier. More data is needed to use to search for Zc(3900)$\to \pi h_c$.

$Z_c(4020)^0$ observed in $e^+e^- \rightarrow \pi^0\pi^0 h_c$

PRL 113, 212002 (2014)

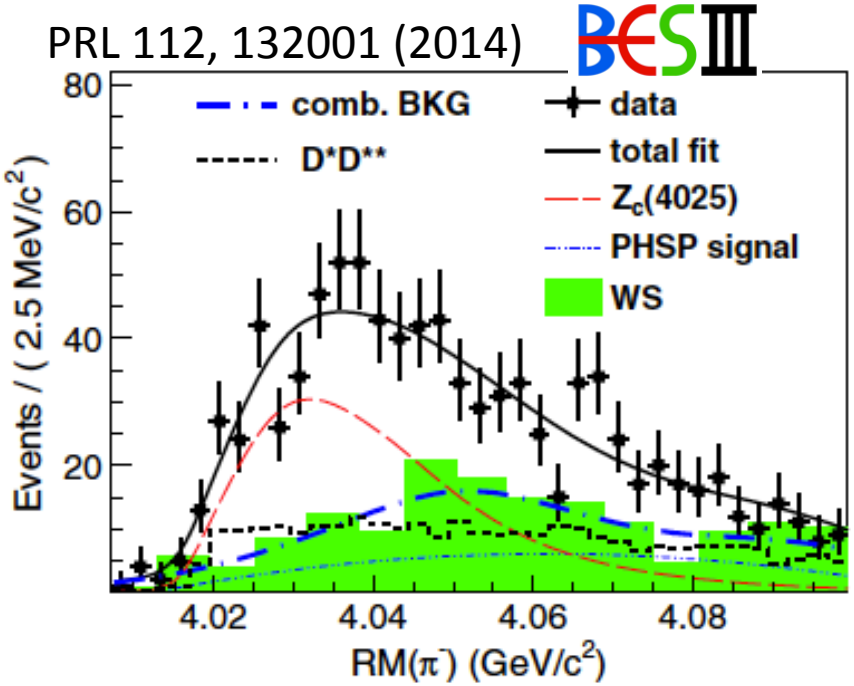




- A simultaneous fit to the data at 4.23GeV, 4.26GeV and 4.36GeV gives
- ✓M(Zc(4020))=4023.9±2.2±3.8 MeV, Width is fixed to Charged mode
- ✓significance of Zc(4020) >5σ
- Another Isospin-triplet.
- Zc(4020) is near the mass threshold of (D*D*). →next page

Zc(4025)$^{\pm}$ observed at the threshold of (D*D*) with $e^+e^- \to \pi^{\pm}(D^*\overline{D}^*)^{\mp}$

PRL 112, 132001 (2014)



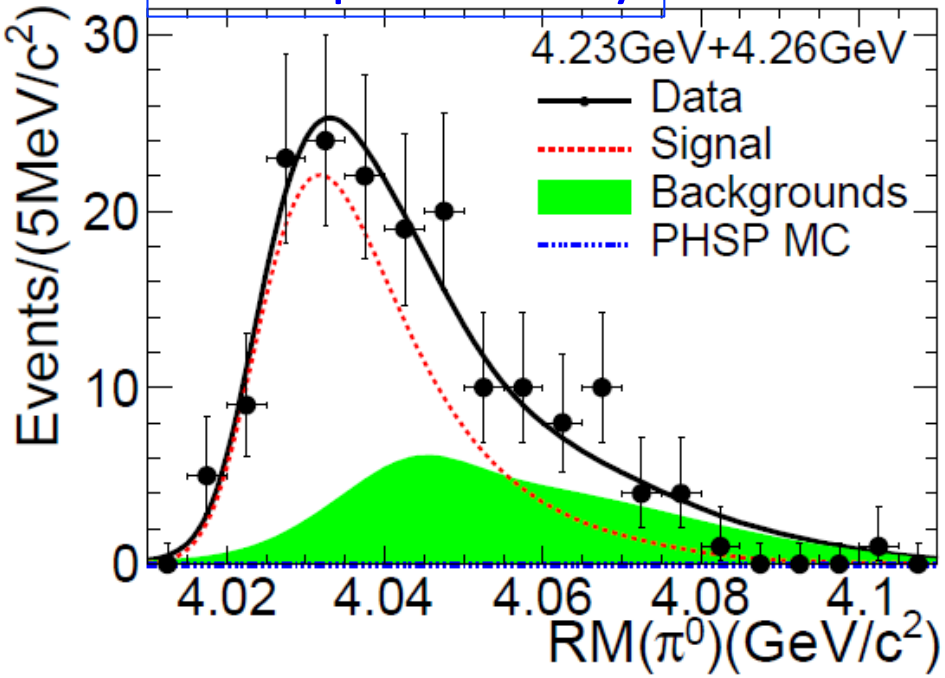
- Measured with 827pb^{-1} data at E_{cms}=4.26GeV
- Zc(4025)$^{\pm}$ parameters, S-wave BW
  M=(4026.3±2.6±3.7) MeV,
  Γ=(24.8±5.6±7.7)MeV
- Significance > 10σ

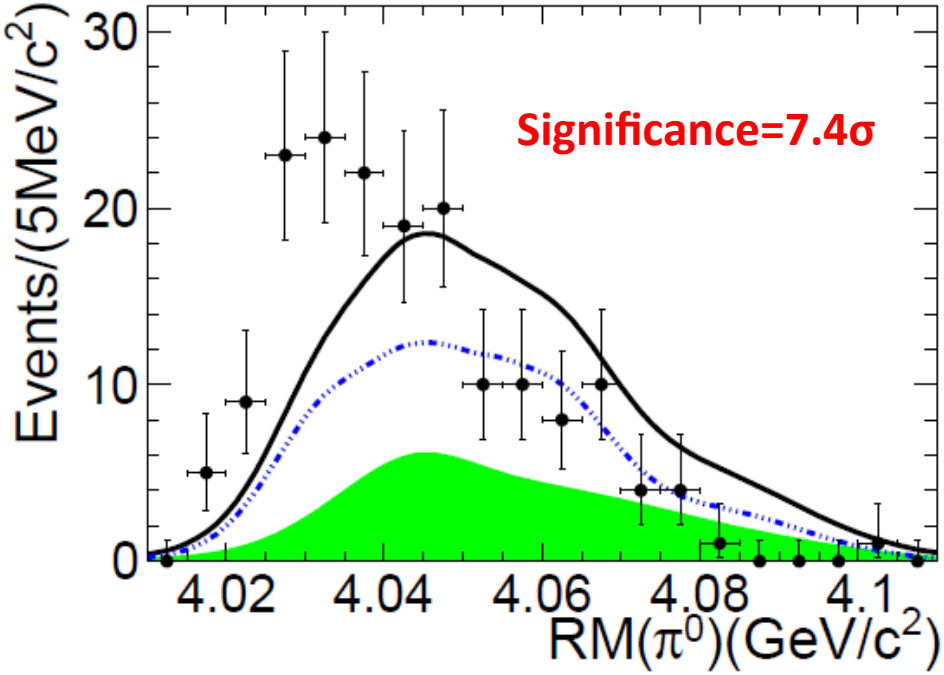
$$\sigma(e^+e^- \to \pi^{\pm}(D^*\overline{D^*})^{\mp}) = 137 \pm 9 \pm 15\,pb \quad @4.26GeV$$

$$\frac{\sigma(e^+e^- \to \pi^{\pm}(Z_c)^{\mp} \to \pi^{\pm}(D^*\overline{D^*})^{\mp})}{\sigma(e^+e^- \to \pi^{\pm}(D^*\overline{D^*})^{\mp})} = 0.65 \pm 0.09 \pm 0.06\,pb \quad @4.26GeV$$

Zc(4025)^0 observed with $e^+e^- \to \pi^0(D^*\overline{D^*})^0$

BESIII preliminary

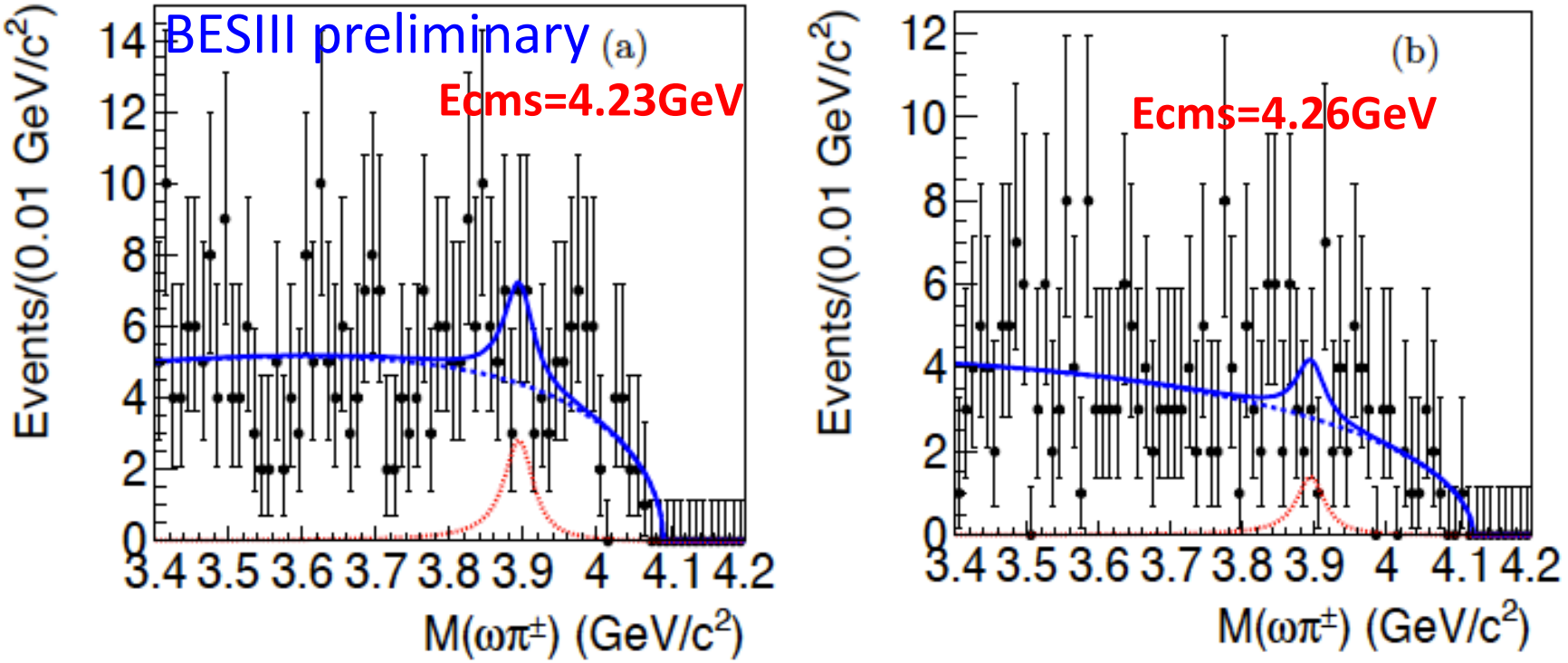




- Measured with data at Ecms=4.23GeV and 4.26GeV
- A simultaneous fit for two energy points gives

Data sample	Mass(MeV/c^2)	Width(MeV/c^2)	$\sigma(e^+e^- \to Z_c(4025)^0\pi^0 \to D^*\bar{D}^*\pi^0)$(pb)
@4.23GeV	$4025.5^{+2.0}_{-4.7}\pm3.1$	$23.0 \pm 6.0 \pm 1.0$	$61.6 \pm 8.2 \pm 9.0$
@4.26GeV			$43.4 \pm 8.0 \pm 5.4$

Search for Zc(3900)→π± ω with e^+e^-→$\pi^+\pi^-$ ω



- This channel doesn't contain charmonium final sates.
- The significance at Ecms=4.23GeV is 1.2σ,

$$\sigma(e^+e^- \to \pi^\pm Z_c(3900)^\mp, Z_c(3900)^\mp \to \omega\pi^\mp) < 0.26\,pb$$

- The significance at Ecms=4.26GeV is 0.1σ

$$\sigma(e^+e^- \to \pi^\pm Z_c(3900)^\mp, Z_c(3900)^\mp \to \omega\pi^\mp) < 0.18\,pb$$

The BESIII result for Zc family

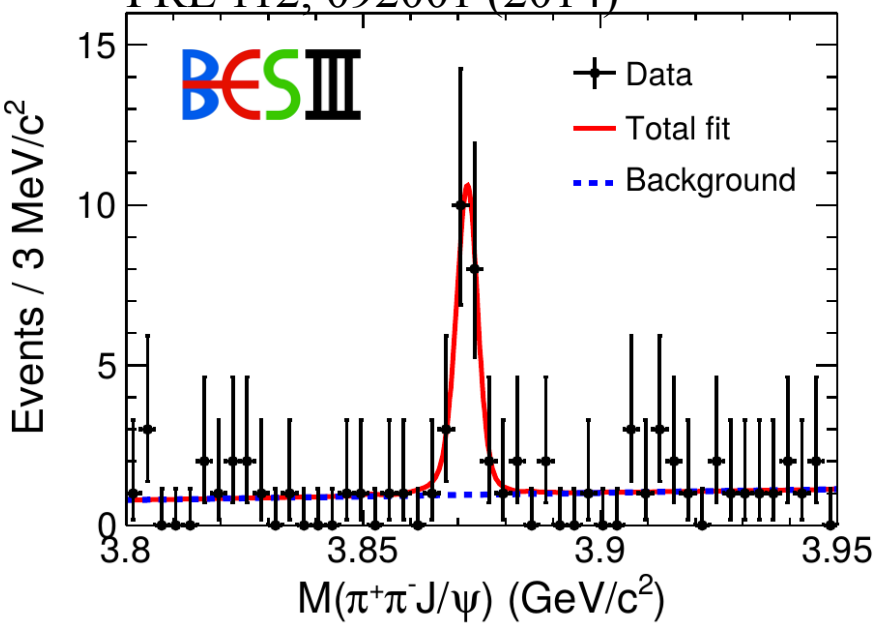
For reference: the mass threshold of m(DD*)~3875MeV, M(D*D*)~4014MeV

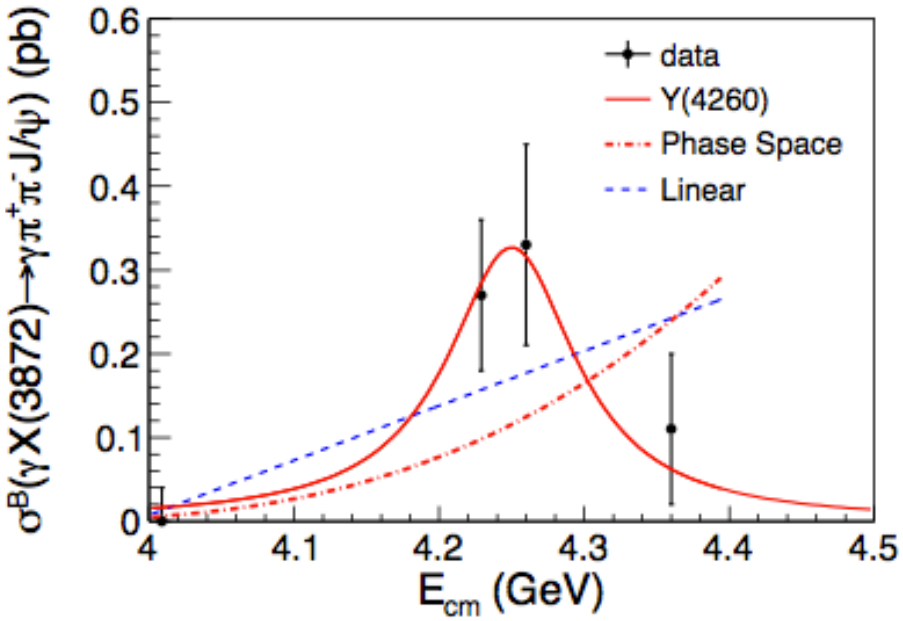
❑Is Zc(3900) and Zc(3885) same sates? Zc(4020) and Zc(4025)?

	C/N	channel	Mass (MeV)	Width (MeV)	σ(ee→πZc, Zc→...) @4.26GeV pb
Zc(3900)	charged	$\pi^{\pm} J/\psi$	3899.0±3.6±4.9	46±10±20	13.5±5.2
	Neutral	$\pi^{0} J/\psi$	3894.8±2.3±2.7	29.6±8.2±8.2	4.0±0.9
Zc(3885)	charged	$(DD^*)^{\pm}$	3883.9±1.5±4.2	24.8±3.3±11.0	83.5±6.6±22.0
	Neutral	NA			
Zc(4020)	Charged	$\pi^{\pm} h_c$	4022.9±0.8±2.7	7.9±2.7±2.6	7.4±1.7±2.1±1.2
	Neutral	$\pi^{0} h_c$	4023.9±2.2±3.8	Fixed	8.5±2.9±1.1±1.3
Zc(4025)	charged	$(D^*D^*)^{\pm}$	4026.3±2.6±3.7	24.8±5.6±7.7	89.0±18.7
	Neutral	$(D^*D^*)^{0}$	$4025.5^{+2.0}_{-4.7} \pm 3.1$	23.0±6.0±1.0	43.4±8.0±5.4
Zc(3900)	charged	$\pi^{\pm} \omega$			<0.18
Zc(3900)	Charged	$\pi^{\pm} h_c$			<11

Observation of a new production mode of X(3872)

PRL 112, 092001 (2014)





- X(3872) is sitting at the threshold of DD*.
- $J^{PC}=1^{++}$ *(CDF, LHCb)*
- X（3872） is candidate of exotic states for long time: molecular states, tetraquark states, Mixture of excited χ_{c1} and D^0D^{*0} bound state.

- BESIII observed $e^+e^- \rightarrow \gamma X(3872)$, $X(3872) \rightarrow \pi^+\pi J/\psi$.
- $e^+e^- \rightarrow \gamma X(3872)$ → Charge parity of X(3872)=+1.
- It seems that $X(3872)$ is from the radiative transition from $Y(4260)$

Summary

- Several Zc states are observed with different decay mode. They might contain at least four quarks. Some theories can also explain the structure without introducing exotic states.
- J^P of the Zc need to be determined, PWA works are ongoing.
- More decay modes of Z_c are needed.
- The decay Y→Zc+…, and Y→X(3872)+… show the relation between these exotic states. More scan data around Y(4260) and Y(4360) would help the analysis.
- Compare with the Z_b family observed in other experiments, can help us understand the nature of Zc and Y(4260), Y (4360)..