

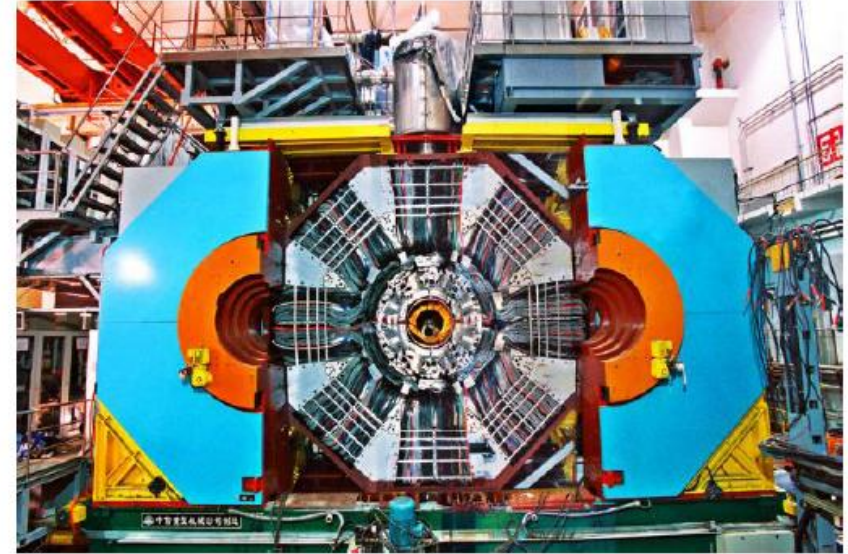
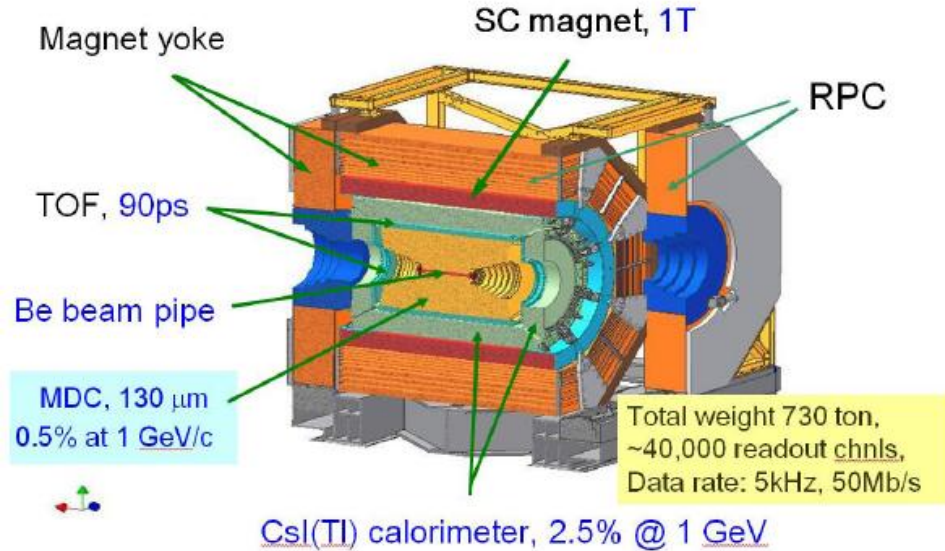
XYZ states at BESIII

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On behalf of BESIII collaboration

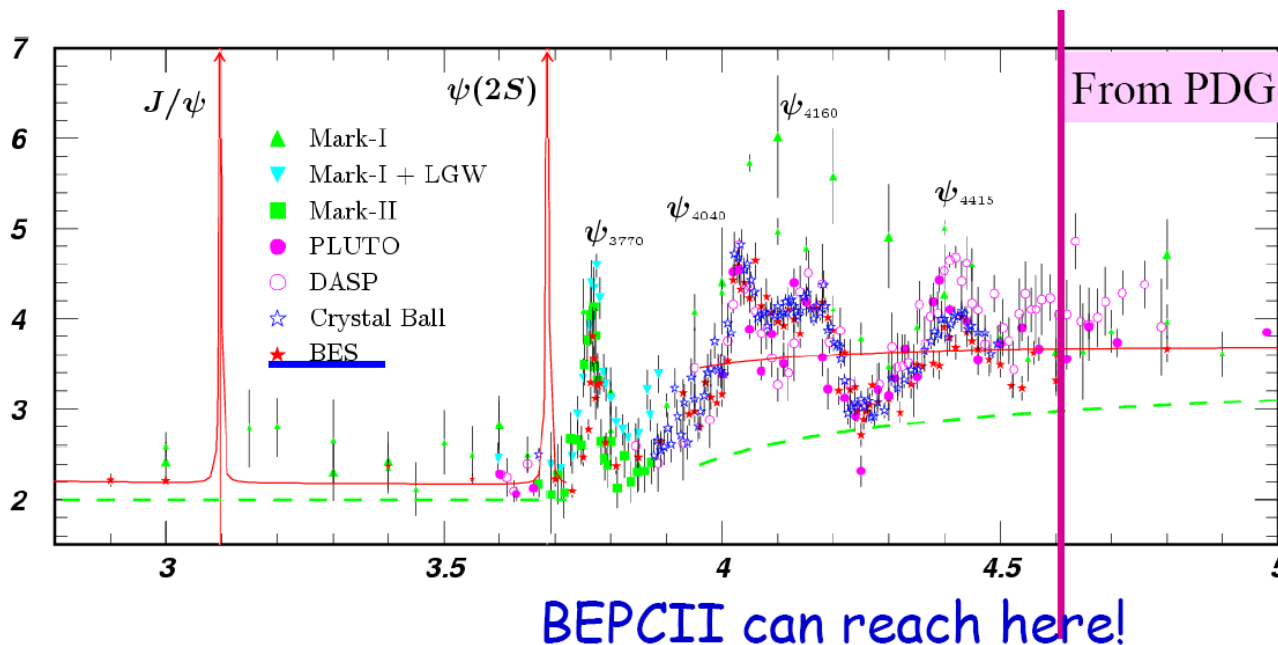
BESIII detector



Sub-detectors		Performance	
MDC	Momentum resolution	0.5% @ 1 GeV	
	dE/dx resolution	6%	
EMC	Energy resolution	2.5% @ 1 GeV	
	Spatial resolution	6 mm	
TOF	Time resolution	Barrel	80 ps (Bhabha)
		Endcap	110 ps (Di-muon)
MUC	9 layers RPC, 8 layers for endcap		

Charmonium-like state production at BESIII

- Vector ψ/Υ states can be produced directly
- C-even states can be produced from radiative transitions



$\psi(4040)$ @4.008GeV
 @4.23GeV
 $\Upsilon(4260)$ @4.26GeV
 $\Upsilon(4360)$ @ 4.36GeV
 $\psi(4415)$ @ 4.42GeV
 $\Upsilon(4660)$ @ 4.6GeV

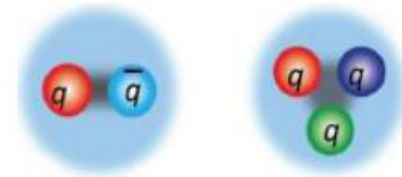
My talk based on these data samples

$\psi(4040)$	@4.009 GeV	0.5 fb ⁻¹
$\Upsilon(4260)$	@4.23,4.26 GeV	1.1+0.8 fb ⁻¹
$\Upsilon(4360)$	@4.36 GeV	0.5 fb ⁻¹
$\psi(4415)$	@4.42 GeV	1 fb ⁻¹
$\Upsilon(4660)$	@4.6 GeV	0.6 fb ⁻¹

Hadrons

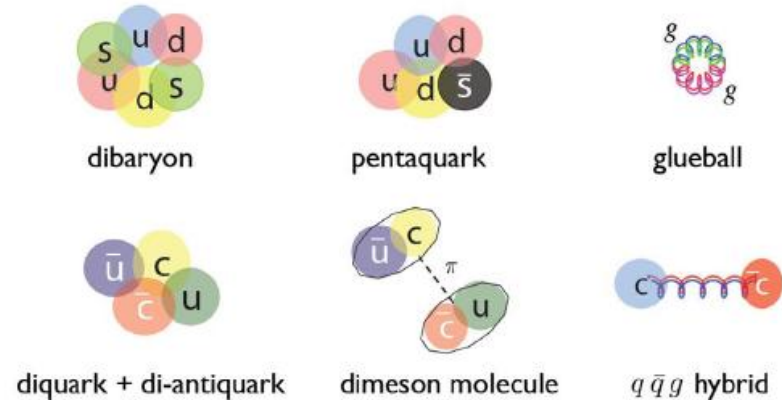
- **Hadrons:**

- ✓ 2 quarks (meson) or 3 quarks (baryon)
- ✓ described with quark model (QM)



- **QCD suggests :**

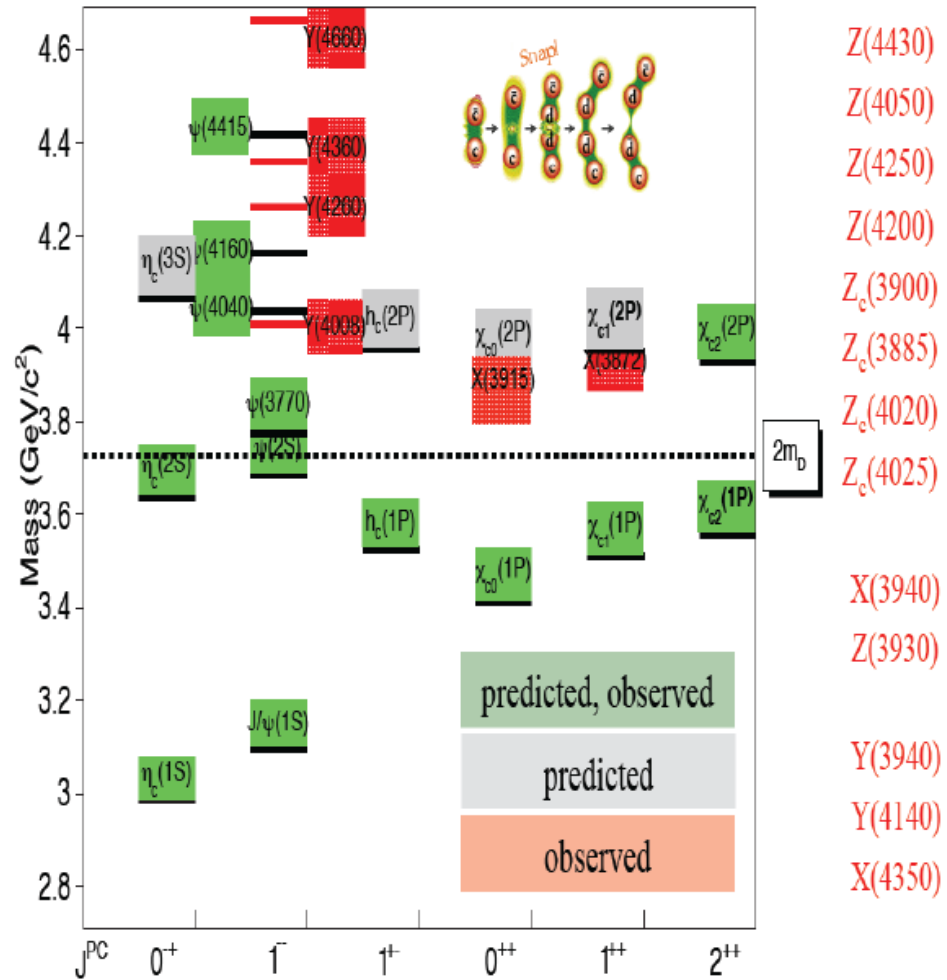
- ✓ **Molecule:** bound state of two hadrons
- ✓ **Multiquark state:** (qqqq, qqqqq, ...)
- ✓ **Glueball:** (gg, ggg, ...)
- ✓ **Hybrid:** (qqg, ...)



Search for these exotic hadrons

Charmonium spectroscopy

- Below charm threshold, all states have been observed
- Charm anti-charm potential model described spectrum very well
- Many missing states above charm threshold.
- A number of new states above charm threshold that do not fit into $c\bar{c}$ slots
 - ✓ Not all of them are charmonium
 - ✓ What are they ?

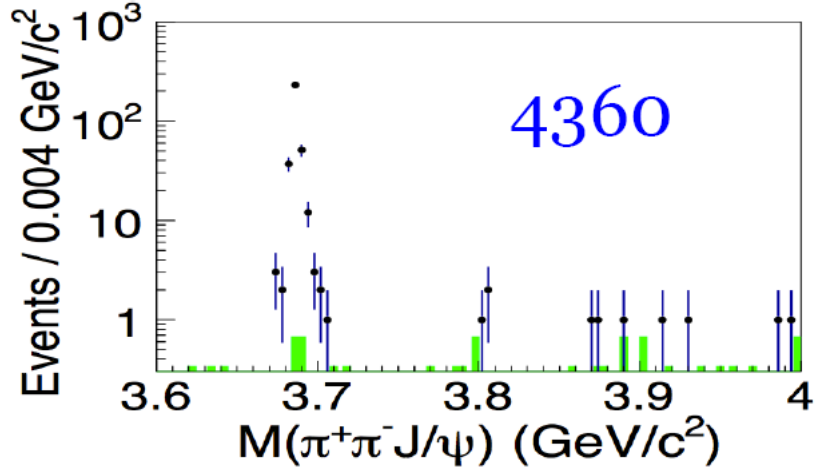
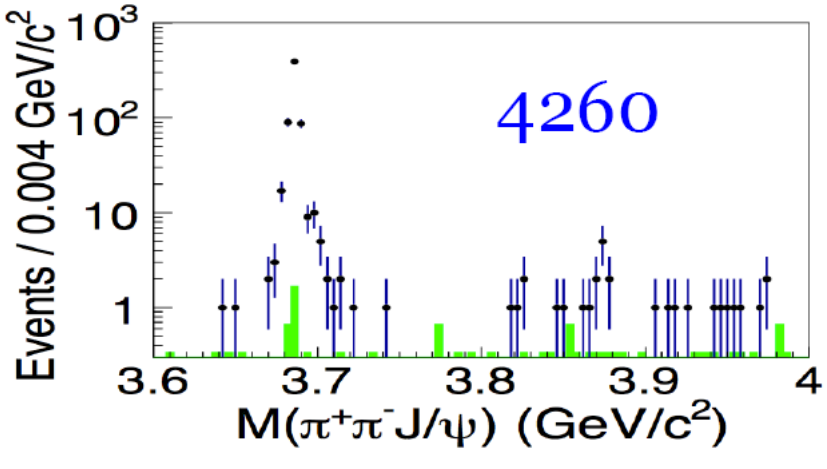
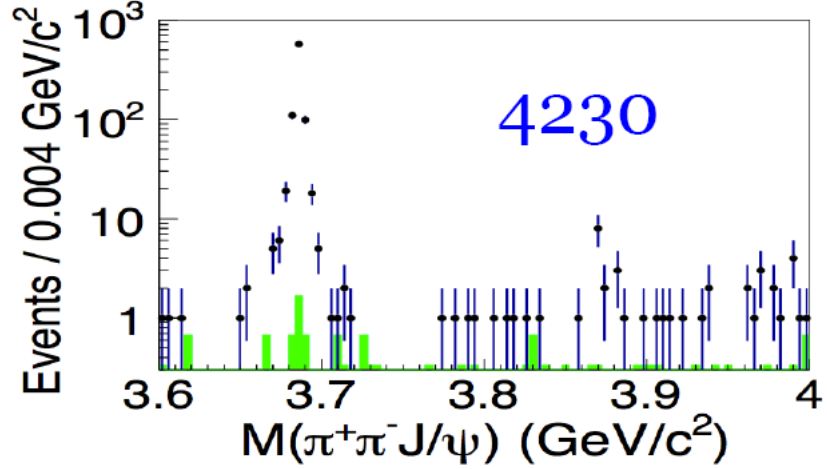
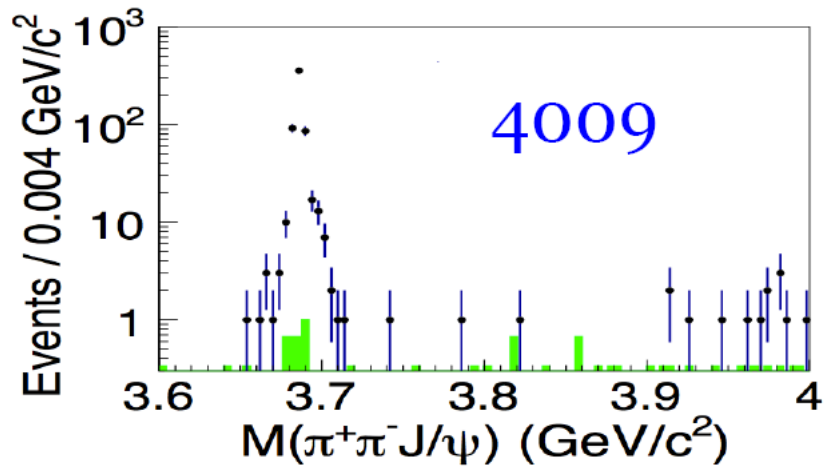


X(3872)

- Observed by Belle in $B^\pm \rightarrow K^\pm \pi^+ \pi^- J/\psi$ [PRL91,262001(2003)]
- Close to $D^0 \bar{D}^{*0}$ mass threshold, narrow peak
- $J^{PC}=1^{++}$ [CDF (PRL98,132002) $1^{++}/2^{--}$; LHCb (EPJC72,1972) 1^{++}]
- Nature unclear:
 - $D^0 \bar{D}^{*0}$ bound state?
 - Mixture of $\chi_{c1}(2P)$ and $D^0 \bar{D}^{*0}$ bound state?
 - Conventional charmonium $\chi_{c1}(2P)$? tetraquark? hybrid?...
- Production
 - pp collision; B decays;
 - $Y(4260) \rightarrow \gamma X(3872)$ [BESIII, PRL112, 092001 (2014)]
- Decay: $\pi^+ \pi^- J/\psi$, $\pi^+ \pi^- \pi^0 J/\psi$, $D^0 \bar{D}^0 \pi^0$, $D^0 \bar{D}^{*0}$, $\gamma J/\psi$, $\gamma \psi'$

Observation of $e^+e^- \rightarrow \gamma X(3872)$

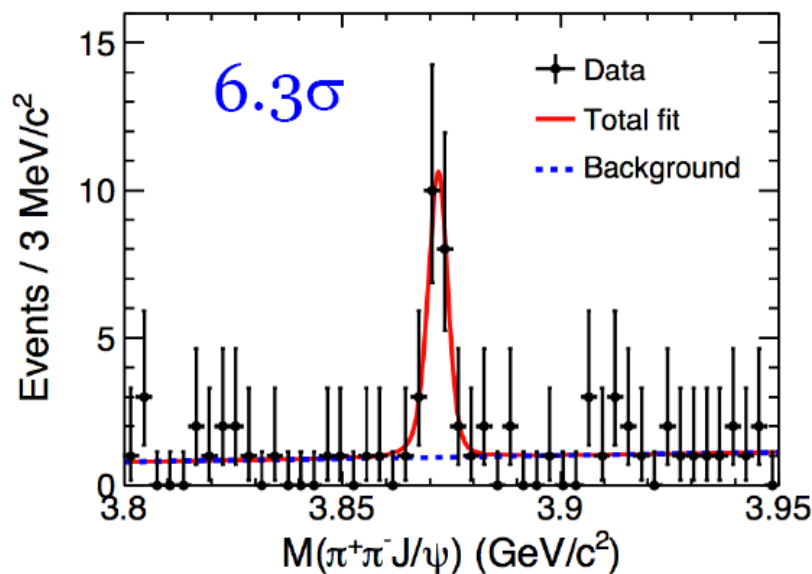
BESIII, PRL112, 092001 (2014)



Clear ISR ψ' signal for data validation; X(3872) signal at around 4.23-4.26 GeV

Observation of $e^+e^- \rightarrow \gamma X(3872)$

[PRL112, 092001 (2014)]

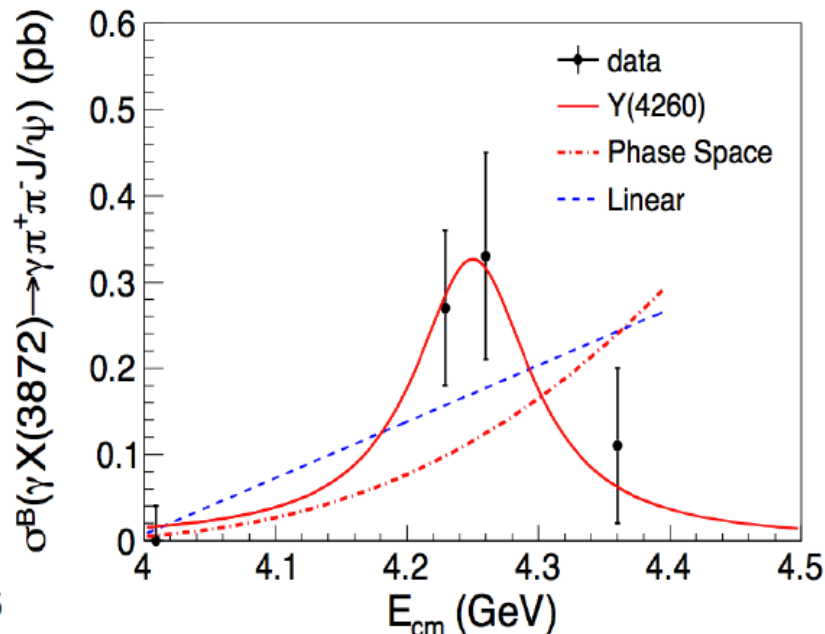


Obvious $X(3872)$ signal through radiative decay

$$N = 20.1 \pm 4.5;$$

$$M = 3871.9 \pm 0.7 \pm 0.2 \text{ MeV}$$

$$[\text{PDG} = 3871.68 \pm 0.17 \text{ MeV}]$$



- Seems from $Y(4260)$ decays
- $\sigma(e^+e^- \rightarrow \pi^+\pi^-J/\psi) = (62.9 \pm 1.9 \pm 3.7) \text{ pb}$;
 $B(X(3872) \rightarrow \pi^+\pi^-J/\psi) = 5\%$

$$\frac{\sigma(e^+e^- \rightarrow \gamma X(3872))}{\sigma(e^+e^- \rightarrow \pi^+\pi^-J/\psi)} \sim 11\%$$

Y states

- Mainly from B factories through ISR processes
 - $Y(4260): e^+e^- \rightarrow \gamma_{\text{ISR}}\pi^+\pi^-J/\psi$
 - Observed by BaBar, confirmed by CLEO and Belle
 - $Y(4008): e^+e^- \rightarrow \gamma_{\text{ISR}}\pi^+\pi^-J/\psi$ [PRL95,142001(2005)], 273 fb⁻¹
 [PRD74,091104(R)(2006)], 13.3 fb⁻¹
 [PRL99,182004(2007)], 548 fb⁻¹
 - Only in Belle data
 - $Y(4360): e^+e^- \rightarrow \gamma_{\text{ISR}}\pi^+\pi^-\psi(2S)$
 - Observed by BaBar, confirmed by Belle
 - $Y(4660): e^+e^- \rightarrow \gamma_{\text{ISR}}\pi^+\pi^-\psi(2S)$
 - Observed by Belle, confirmed by BaBar updated analysis
 [PRL98,212001(2007)], 298 fb⁻¹
 [PRL99,142002(2007)], 670 fb⁻¹
 - $Y(4630): e^+e^- \rightarrow \Lambda_c^+\Lambda_c^-$
 - Observed by Belle [PRL101,172001(2008)], 695 fb⁻¹

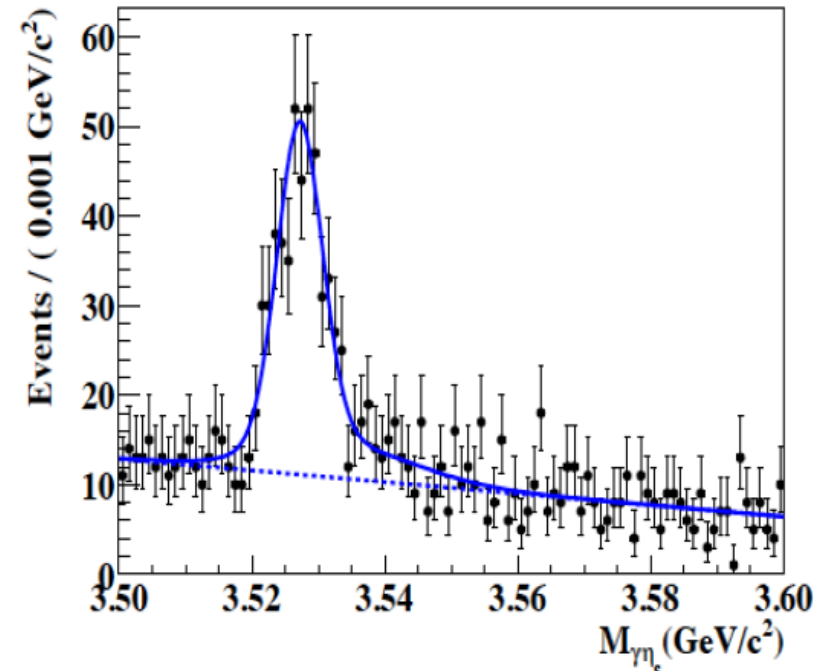
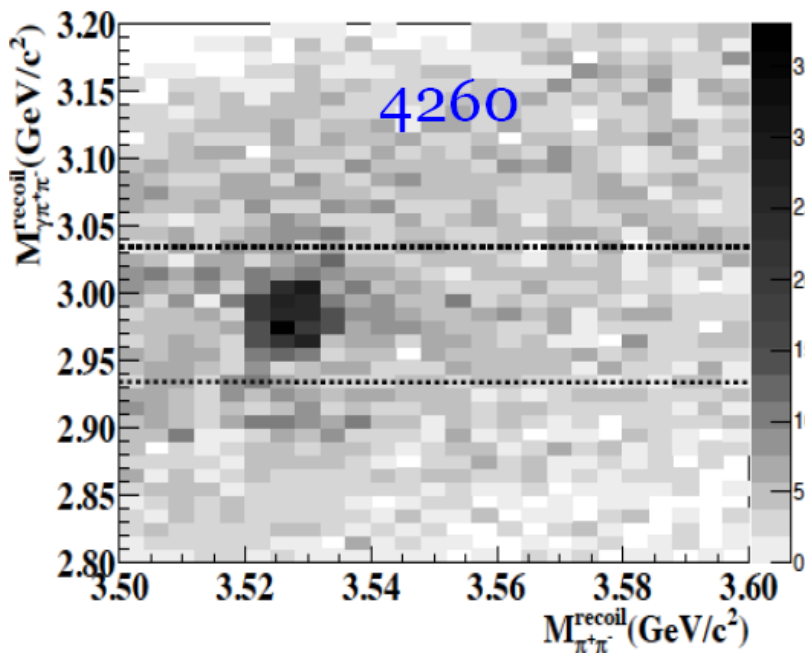
Observation of $e^+e^- \rightarrow \pi^+\pi^-h_c$

- 3.3 fb⁻¹ data at 13 energy points from 3900 MeV to 4420 MeV

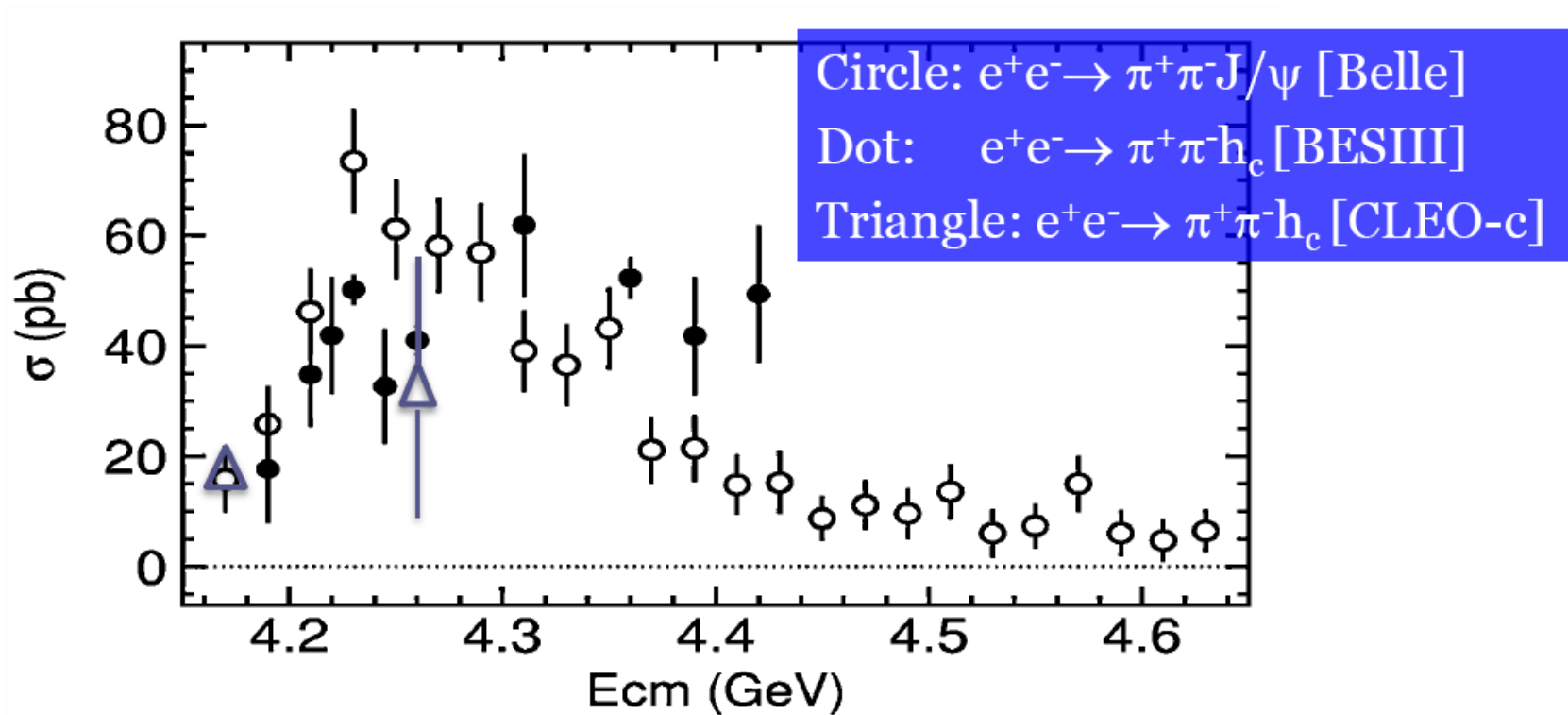
[PRL111,242001 (2013)]

- $h_c \rightarrow \gamma\eta_c$, $\eta_c \rightarrow \text{hadrons}$

[16 exclusive decay modes, ~35% of the η_c decays]

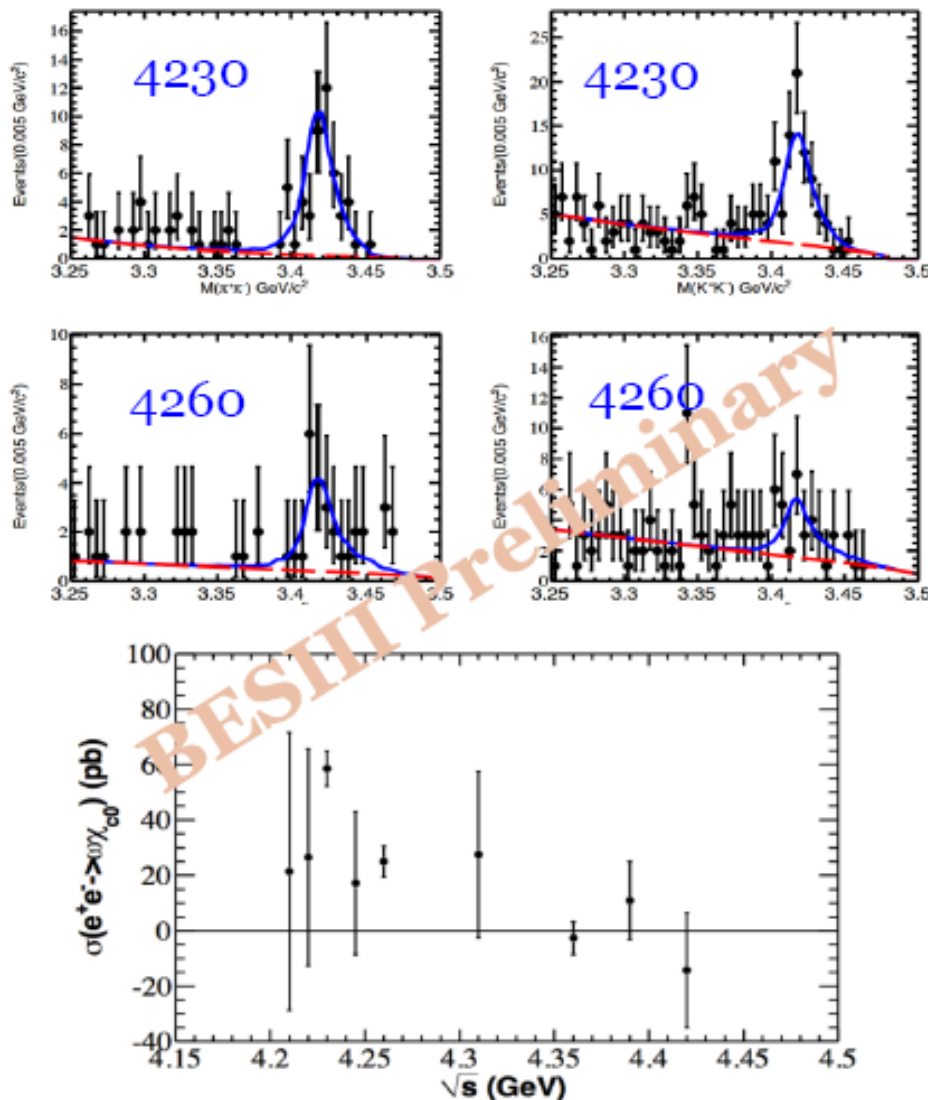


Comparison of cross section: $e^+e^- \rightarrow \pi^+\pi^-h_c$ and $\pi^+\pi^- J/\psi$



- $\sigma(e^+e^- \rightarrow \pi^+\pi^-h_c) \sim \sigma(e^+e^- \rightarrow \pi^+\pi^-J/\psi)$ but line shape different
- Local maximum ~ 4.23 GeV, broad structure at ~ 4.4 GeV?
- Hint for a vector $c\bar{c}g$ hybrid? [PRD78, 056003 (Guo); 094504 (Dudek)]

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



- Data samples at 9 energy points from 4210 MeV to 4420 MeV
- $\omega \rightarrow \pi^+\pi^-\pi^0$;
 $\chi_{c0} \rightarrow \pi^+\pi^-/K^+K^-$
- Signal observed at 4230 MeV and 4260 MeV
- Simultaneous fit performed

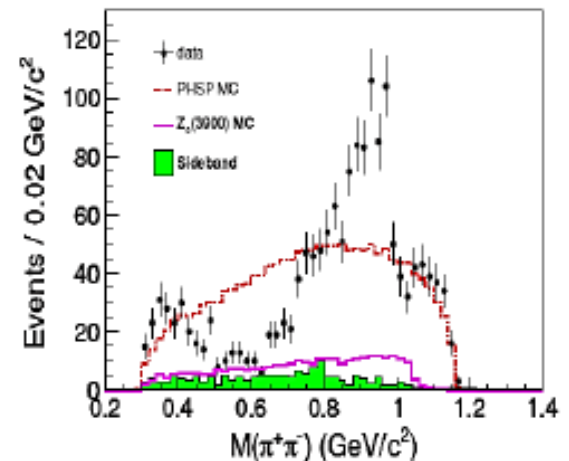
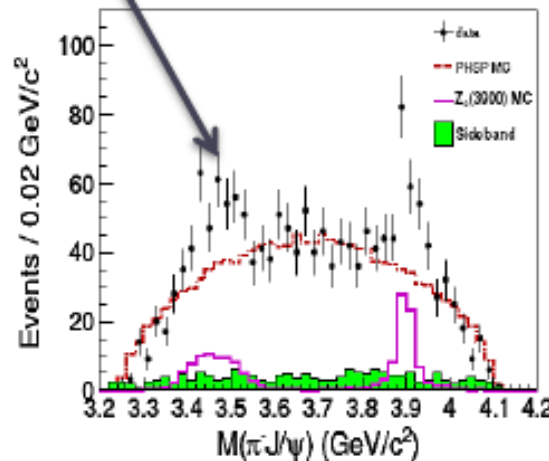
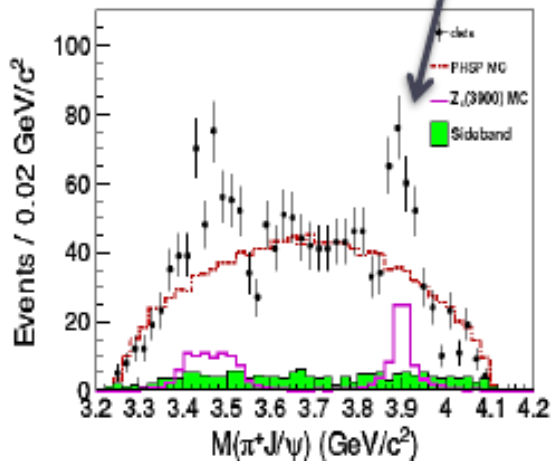
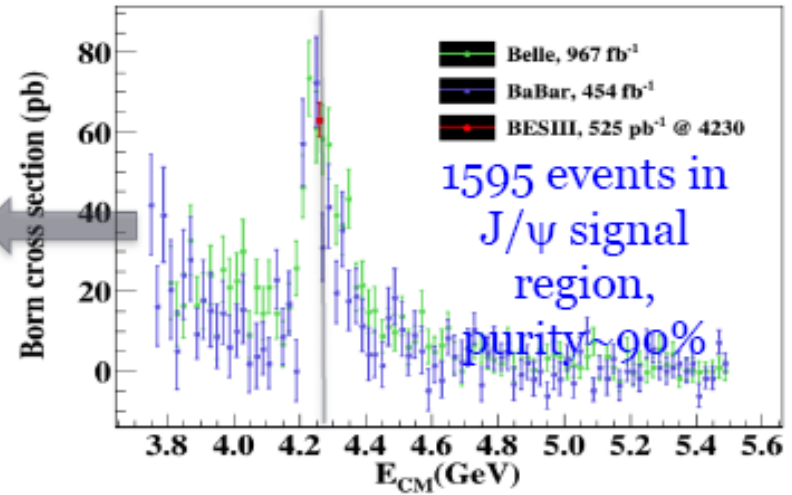
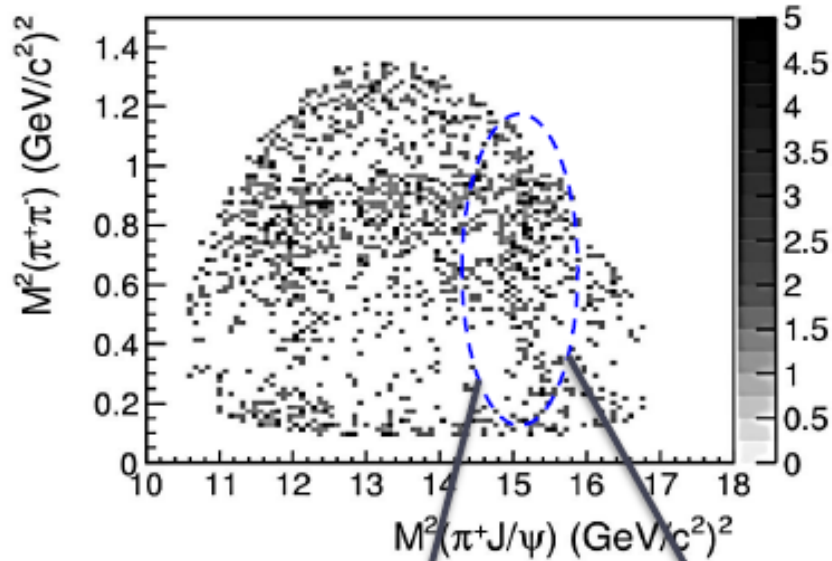
Cross section peaks
around 4230

- Decay into a charmonium, thus contains $c\bar{c}$
- Have electric charge, thus has two more light quarks
- Could exist in $\pi^\pm J/\psi$, $\pi^\pm \psi(2S)$, $\pi^\pm h_c$, $\pi^\pm \chi_{cJ}$, ...
- Experimental search:
 - BESIII/CLEO-c: $e^+e^- \rightarrow \pi^\pm$ exotics, ...
 - Belle/BaBar: $e^+e^- \rightarrow (\gamma_{\text{ISR}})\pi^\pm$ exotics, ...
 - Belle/BaBar/LHCb: $B \rightarrow K$ exotics, ...

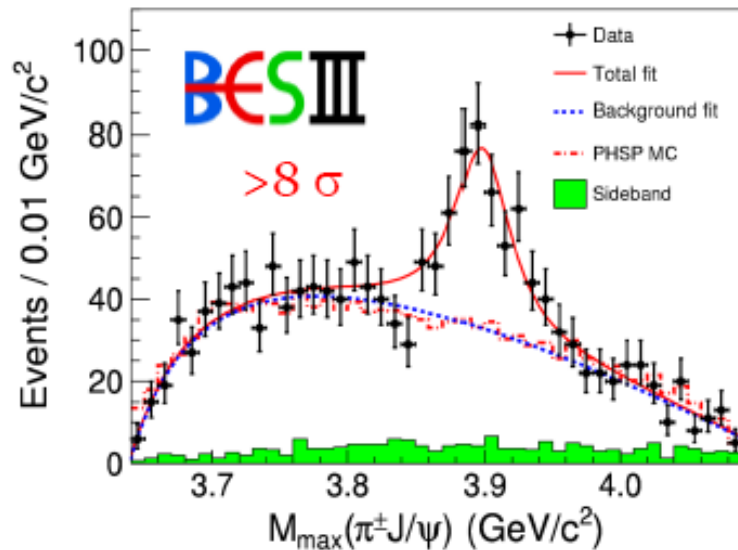
$$e^+e^- \rightarrow \pi^+\pi^-J/\psi$$

[PRL110, 252001(2013)]

525 pb⁻¹ data at 4.260 GeV



Observation of $Z_c(3900)$



BESIII: [PRL110, 252001(2013)]

$$M = 3899.0 \pm 3.6 \pm 4.9 \text{ MeV}$$

$$\Gamma = 46 \pm 10 \pm 20 \text{ MeV}$$

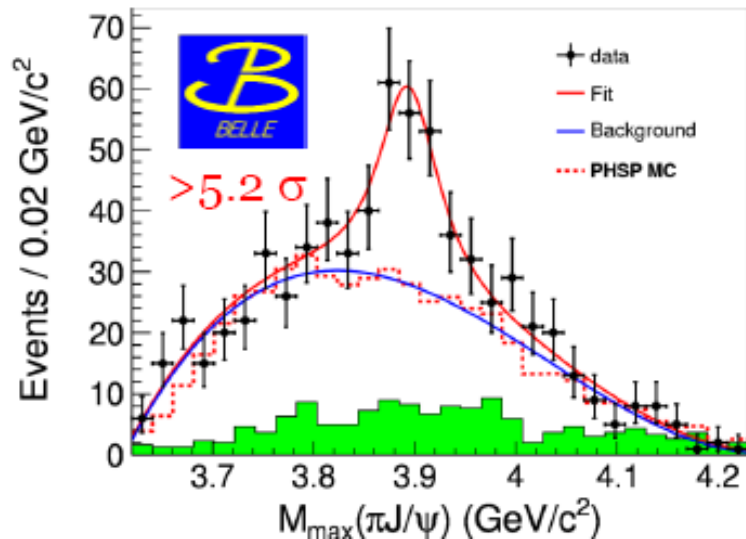
$$307 \pm 48 \text{ events}$$

BELLE: [PRL110, 252002 (2013)]

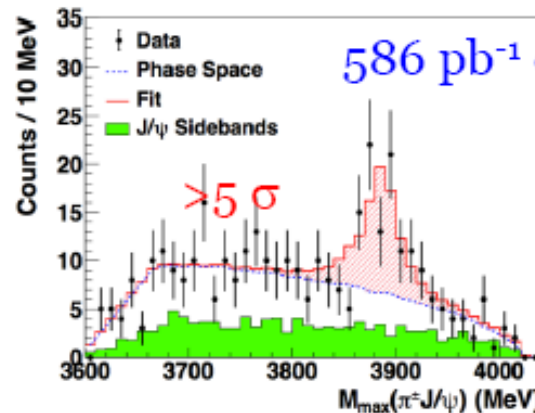
$$M = 3894.5 \pm 6.6 \pm 4.5 \text{ MeV}$$

$$\Gamma = 63 \pm 24 \pm 26 \text{ MeV}$$

$$159 \pm 49 \text{ events}$$



[PLB727, 366-370(2013)]



586 pb^{-1} data at 4.170 GeV

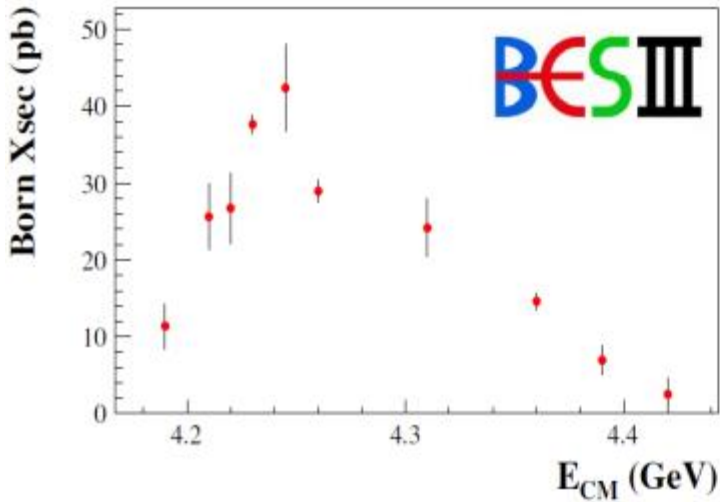
$$M = 3886 \pm 4 \pm 2 \text{ MeV}$$

$$\Gamma = 37 \pm 4 \pm 8 \text{ MeV}$$

$$81 \pm 16 \text{ events}$$

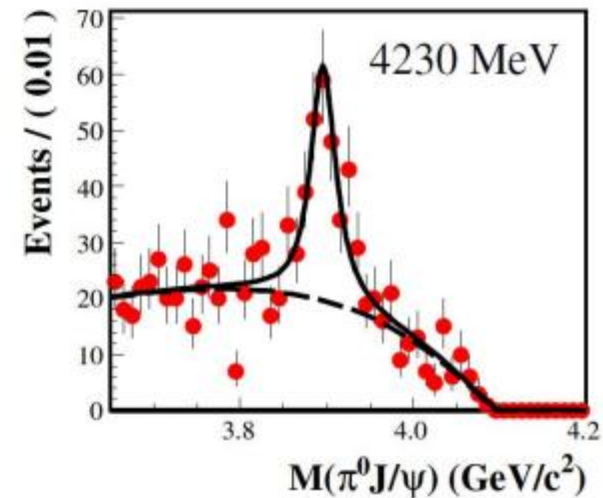
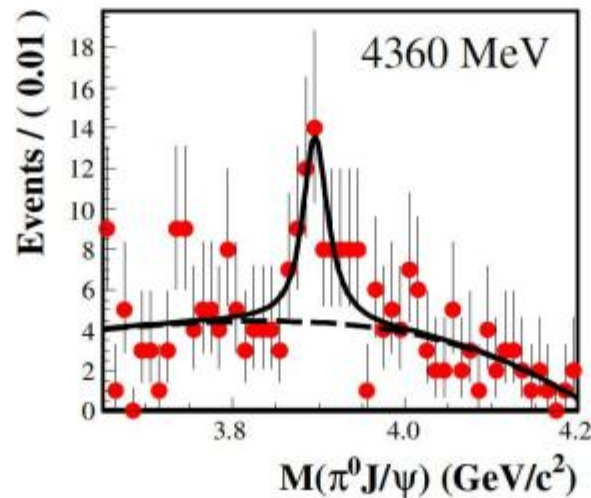
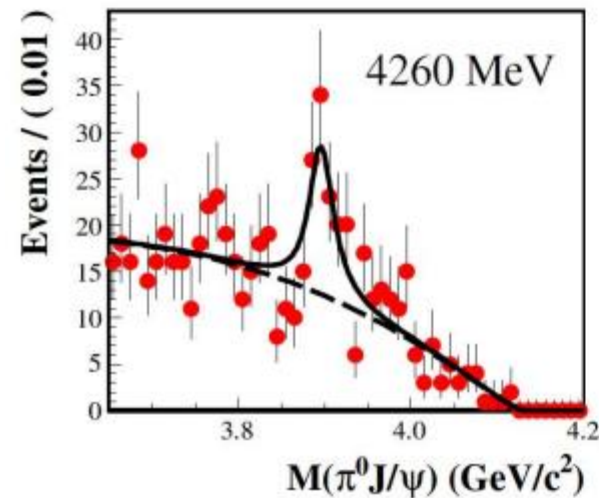
CLEOc data

Neutral partner of Zc(3900)



- 2.8fb^{-1} data at 10 energy points from 4260~4420 MeV
- $Z_c(3900)^0$ is observed clearly at $E_{\text{cm}} = 4230, 4260, 4360\text{MeV}$
- BESIII preliminary results :
 - $M = 3894.8 \pm 2.3 \text{ MeV}$, $\Gamma = 29.6 \pm 8.2 \text{ MeV}$
 - Significance = 10.4σ
- $R(Z_c^0/\pi^0\pi^0J/\psi) = N(Z_c^0(3900))/N(\pi^0\pi^0J/\psi)$, E_{cm} dependence

Neutral isospin partner, $Z_c(3900)^0$ observed



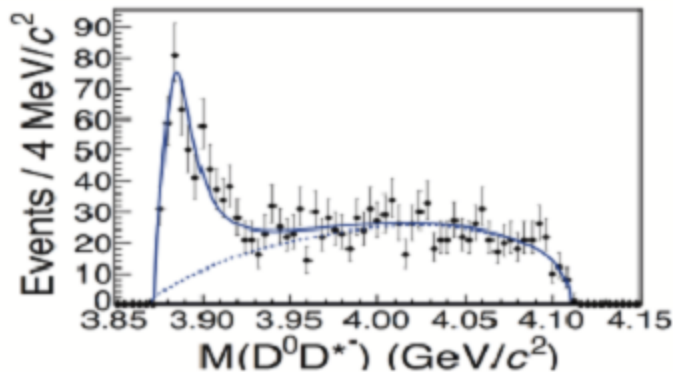
$$e^+e^- \rightarrow \pi^+ (D^* \bar{D})^- + c.c.$$

525 pb⁻¹ data at 4.260 GeV

[PRL112, 022001 (2014)]

Strategy:

- reconstruct $D^0 \rightarrow K^- \pi^+$ / $D^+ \rightarrow K^- \pi^+ \pi^+$; reconstruct “bachelor” π ; require D^* in the missing mass using kinematic fit; look at the recoil side of π

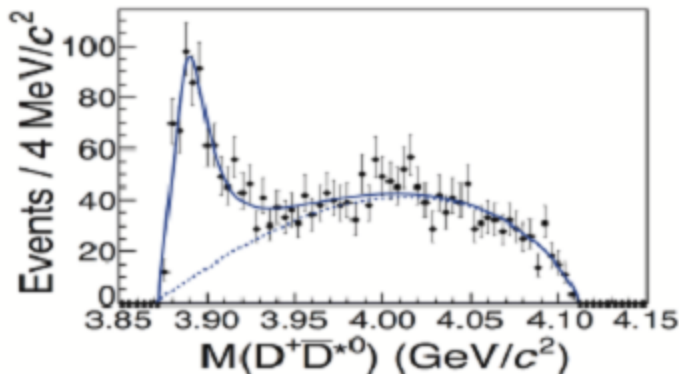


$$M = 3883.9 \pm 1.5 \pm 4.2 \text{ MeV}$$

$$\Gamma = 24.8 \pm 3.3 \pm 11.0 \text{ MeV}$$

$$\sigma \times B = 85.3 \pm 6.6 \pm 22.0 \text{ pb}$$

Assuming $Z_c(3885)$ is $Z_c(3900)$



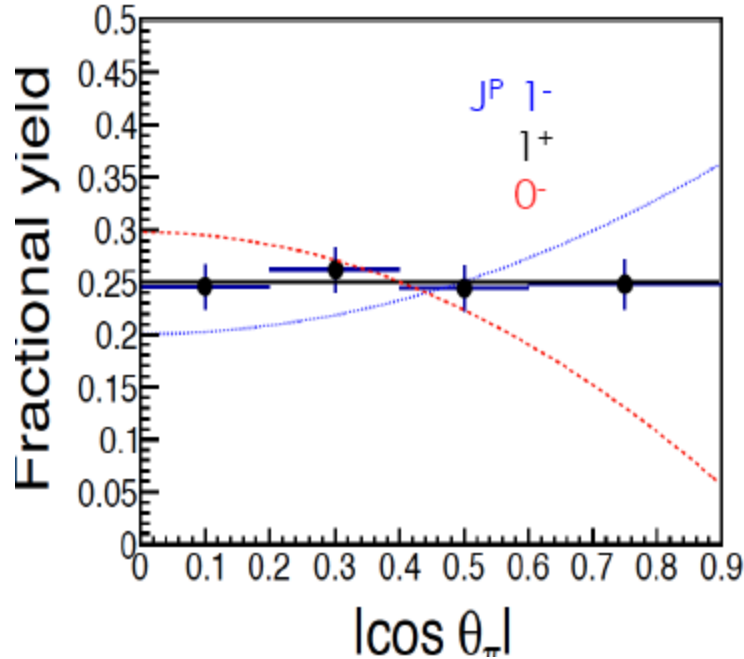
$$\frac{\Gamma(Z_c(3885) \rightarrow D \bar{D}^*)}{\Gamma(Z_c(3900) \rightarrow \pi J/\psi)} = 6.2 \pm 1.1 \pm 2.7$$

Large non- $D\bar{D}$ coupling

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

[PRL112, 022001 (2014)]

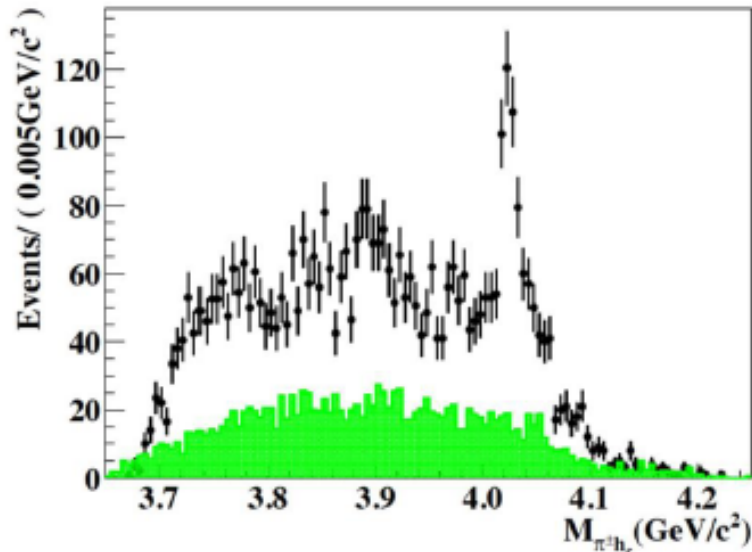
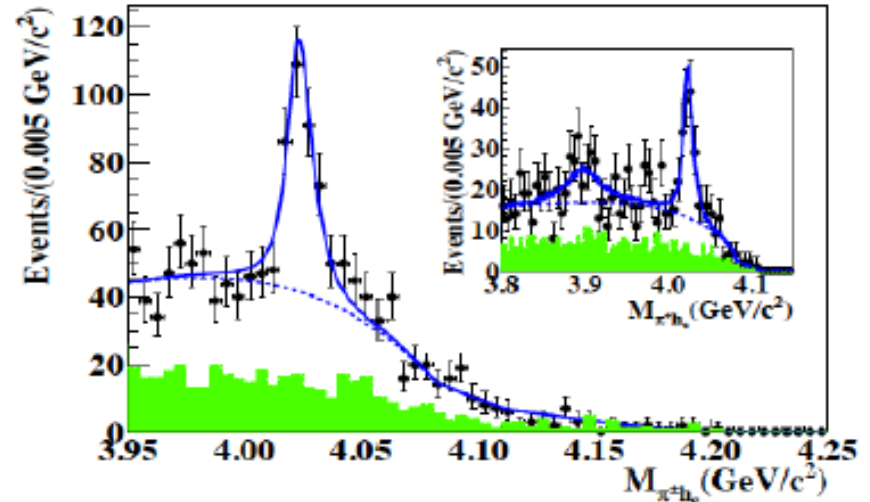
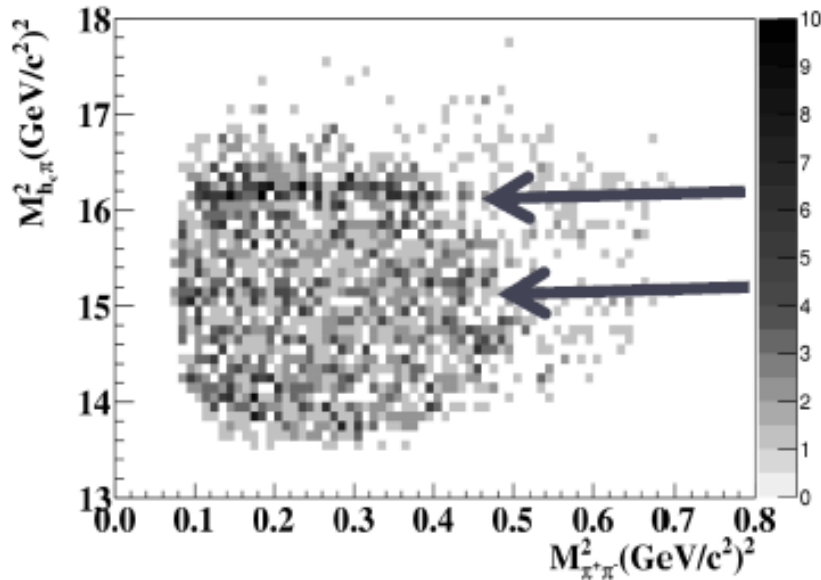
- $\cos\theta_\pi$:
- bachelor pion's pole angle (relative to beam direction) in the CMS



- 0^- : P-wave, with $J_Z = \pm 1$
 $\rightarrow \sin^2\theta_\pi$
 - 0^+ : parity conservation
 - 1^- : P-wave, $1 + \cos^2\theta_\pi$
 - 1^+ : S-wave/D-wave, D-wave small contribution
 \rightarrow flat distribution
- fits favor 1^+ assumption

Observation of $Z_c(4020)$ in $\pi^+\pi^-h_c$

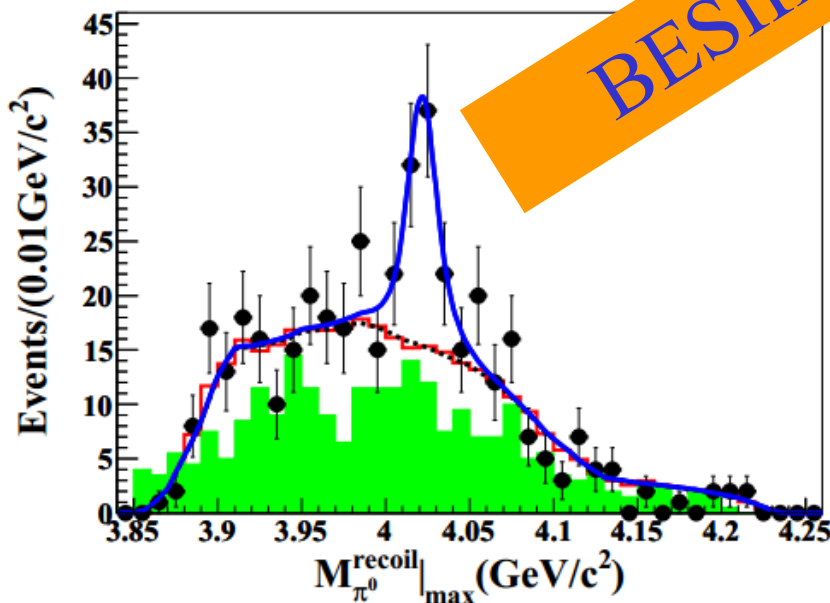
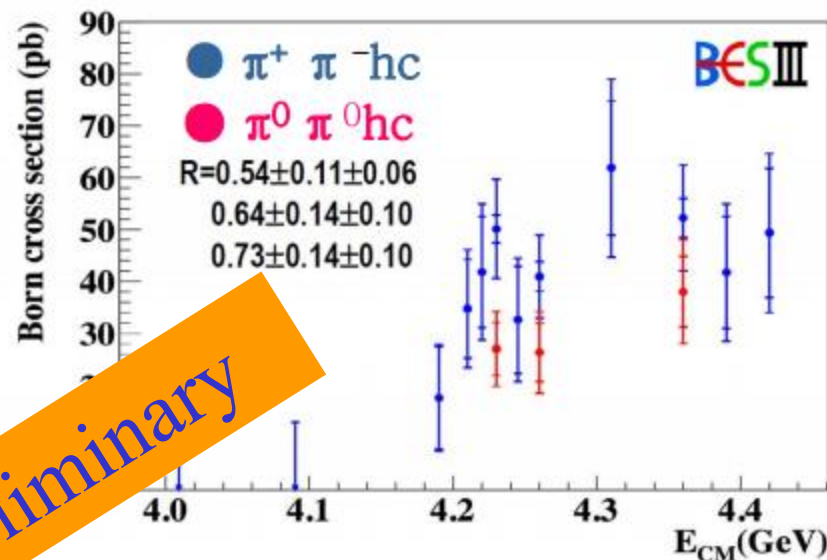
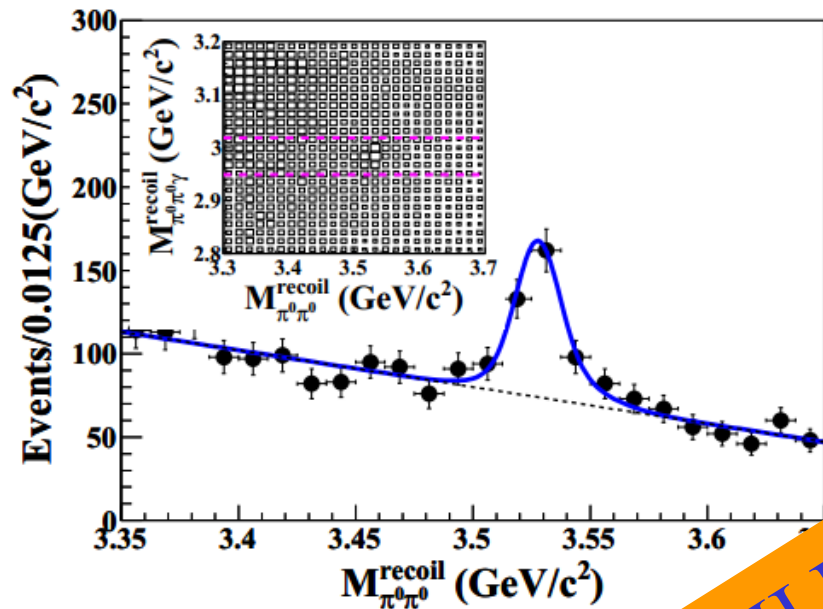
[PRL111, 242001 (2013)]



- Simultaneous fit to 4.23 /4.26/ 4.36 GeV data
- $M = 4022.9 \pm 0.8 \pm 2.7$ MeV;
- $\Gamma = 7.9 \pm 2.7 \pm 2.6$ MeV

$Z_c(4020)$: 8.9σ ; $Z_c(3900)$: 2.1σ

Neutral partner of $Z_c(4020)$ in $\pi^0\pi^0h_c$

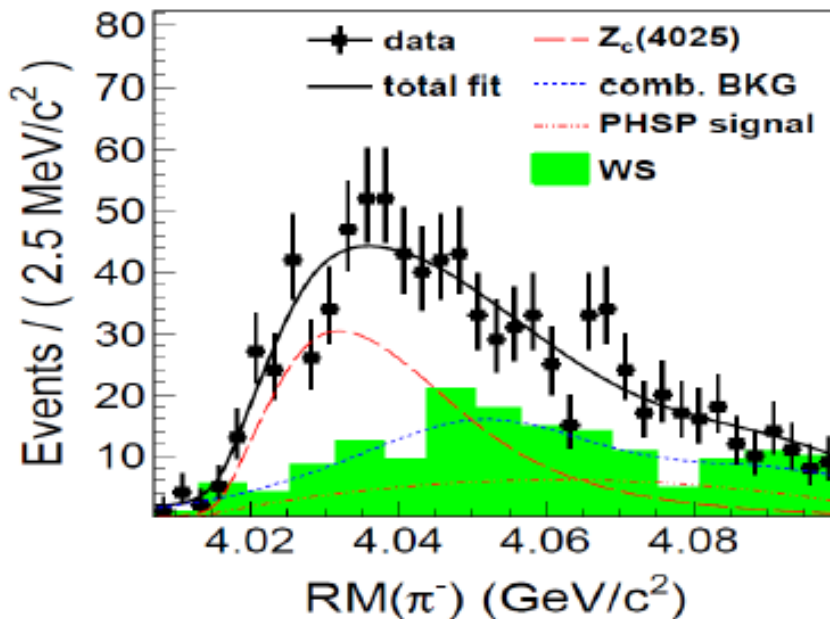
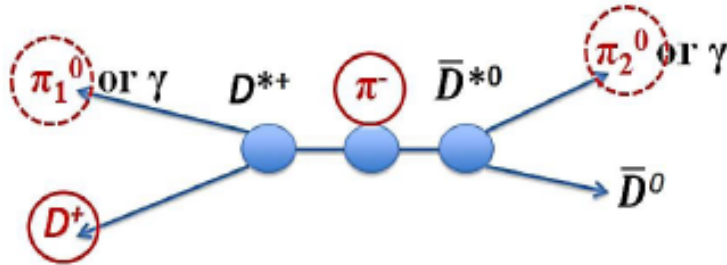


BESIII Preliminary

- Simultaneous fit to 4.23 / 4.26 / 4.36 GeV data
- Width fixed to charged $Z_c(4020)$
- Interference neglect
- $M = 4023.6 \pm 2.2 \pm 3.9$ MeV;
[$M = 4022.9 \pm 0.8 \pm 2.7$ MeV]

$Z_c(4025)$ in $D^*\bar{D}^*$ mode

Strategy:



827 pb⁻¹ data at 4.260 GeV

[PRL112, 132001 (2014)]

- Look at π^\pm recoil mass
- Events excess phase space could be described by a state decay into D^*D^*
- $N = 401 \pm 47$
- $M = 4026.3 \pm 2.6 \pm 3.7$ MeV;
 $\Gamma = 24.8 \pm 5.6 \pm 7.7$ MeV

Assuming $Z_c(4025)$ is $Z_c(4020)$

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

Summary Zc mass and widths

State	Mass (MeV/c ²)	Width (MeV)	Note
Z _c (3900) [±]	3899.0±3.6±4.9	46±10±20	BESIII
	3894.5±6.6±4.5	63±24±26	Belle
	3886±4±2	37±4±8	CLEO-c*
	3883.9±1.5±4.2	24.8±3.3±11.0	BESIII
	<u>3888.7±2.7</u>	<u>34.7±6.6</u>	<u>Average</u>
Z _c (4020) ^{±,0} BESIII	4022.9±0.8±2.7	7.9±2.7±2.6	π [±] h _c
	4026.3±2.6±2.7	24.8±5.6±7.7	D*D*
	4023.6±2.3±3.9	-	π ⁰ h _c
	<u>4023.8±2.1</u>	<u>10.2±3.5</u>	<u>Average</u>

More excited states?

Z_c(4430)

Belle, LHCb

PRD88, 074026 (2013)

arXiv1404.1903

Summary

- $e+e-\rightarrow\pi+\pi-h_c$ and $\omega\chi_{c0}$ are observed, and cross sections are measured by BESIII

Around 4.2 GeV, $\pi+\pi-h_c$ mode has large production of cross section, and different line shape observed at $\pi+\pi-h_c$ process, makes situation complicate

- X(3872) are observed in $Y(4260)\rightarrow\gamma X(3872)$
- Charged Z_c states:
 - Confirmed exotic state with at least four quarks, $Z_c(3900)$, at BESIII, Belle and CLEOc
 - Observation of charged and neutral Z_c' at BESIII
- More results will come soon