XYZ states at BESIII

Zhentian Sun
Institute of High Energy Physics, China
On behalf of BESIII collaboration

PHIPSI2019, BINP, Novosibirsk, Russia,
Feb. 25-Mar. 2nd, 2019

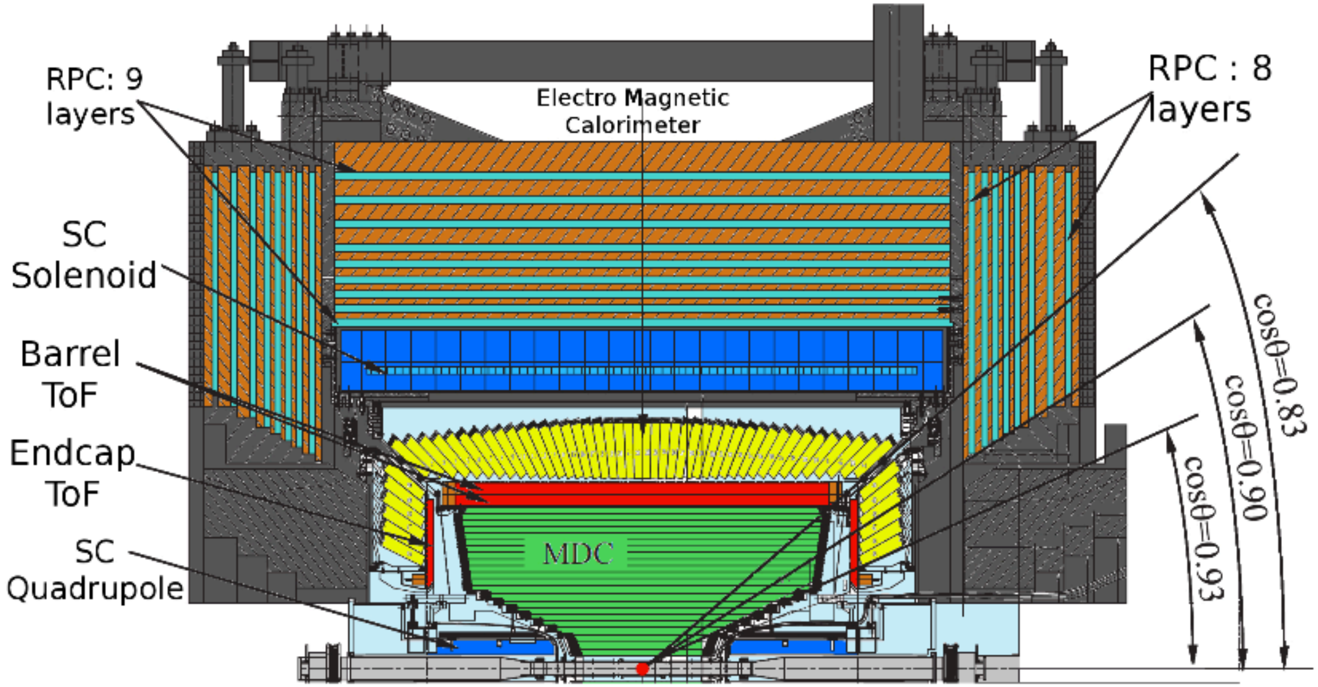
Outline

- Introduction
- $Y(1^{--})$ states
  - $Y \rightarrow \pi^+\pi^- J/\psi\ (\psi')$, $Y \rightarrow \pi^+\pi^- h_c$, $Y \rightarrow \pi^+ D^0 D^{*-}$
  - $Y \rightarrow \omega\chi_{cJ}$,
  - $Y \rightarrow \Lambda_c^+ \bar{\Lambda}_c^-$
- A quick view of the Zc states in BESIII
  - Determination of J^P of Zc(3900)
  - Search for $Z_c^\pm \rightarrow \rho^\pm \eta_c$
- X states
  - Observation of $e^+e^- \rightarrow \gamma X(3872)$, $X(3872) \rightarrow \pi^+\pi^- J/\psi$
  - $e^+e^- \rightarrow \gamma X(3872)$, $X(3872) \rightarrow \omega J/\psi$
  - Observation of $X(3872) \rightarrow \pi^0 \chi_{c1}(1P)$
- Summary

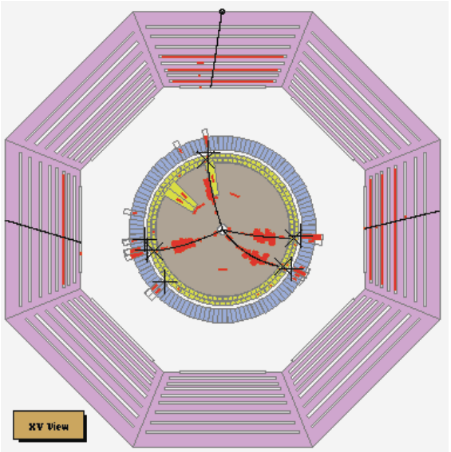
Beijing Electron and Positron Collider(BEPCII)

Beam energy: 1~2.3GeV
Ecms= 2~4.6 GeV

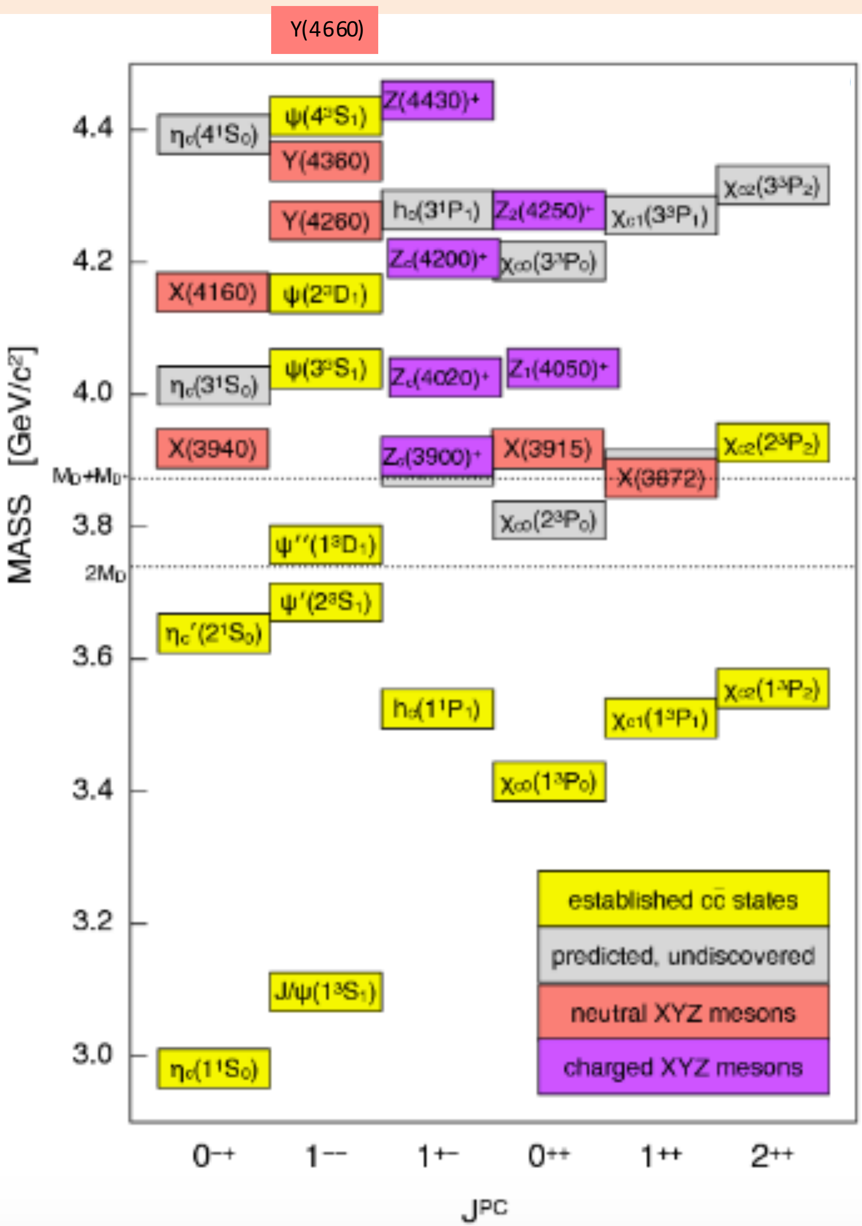
Beijing Spectrometer (BESIII)

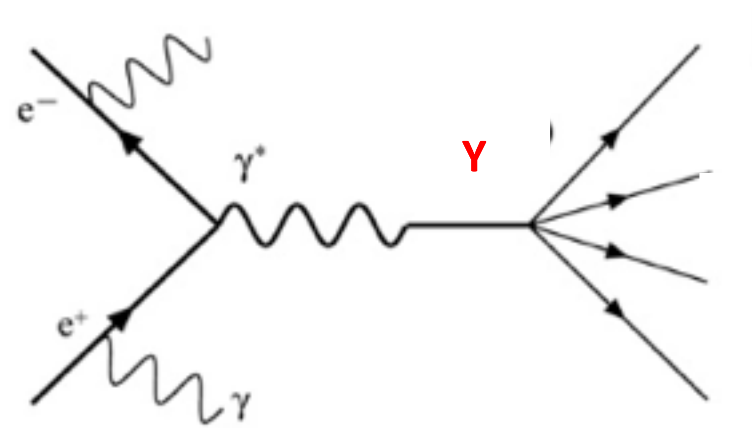


- **Inner to Outside：**
- ✓ **Main Drift chamber(MDC),**
- ✓ **Time of flight System(TOF),**
- ✓ **Electromagnetic Calorimeter(EMC),**
- ✓ **Solenoid super-conducting magnet(SSM),**
- ✓ **Muon chamber(MUC)**
- **Acceptance: 93% of 4π**



XYZ physics at BESIII

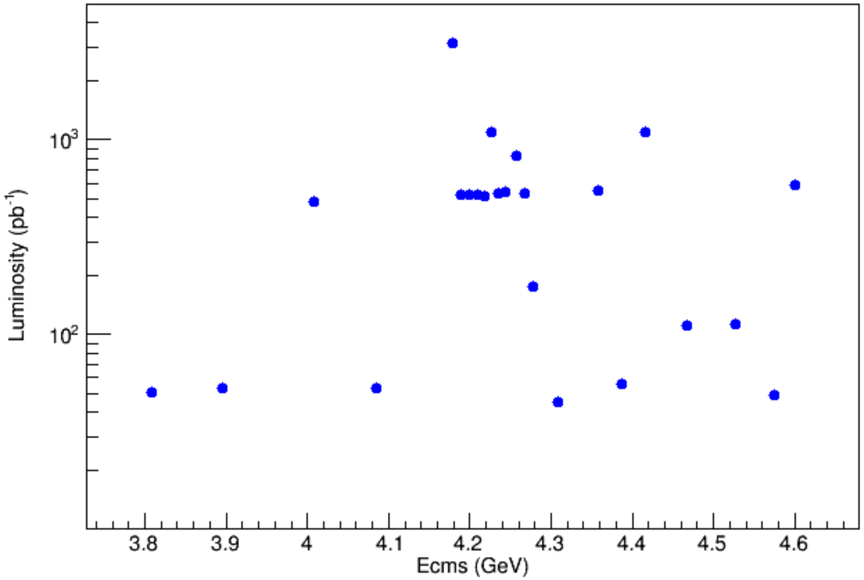




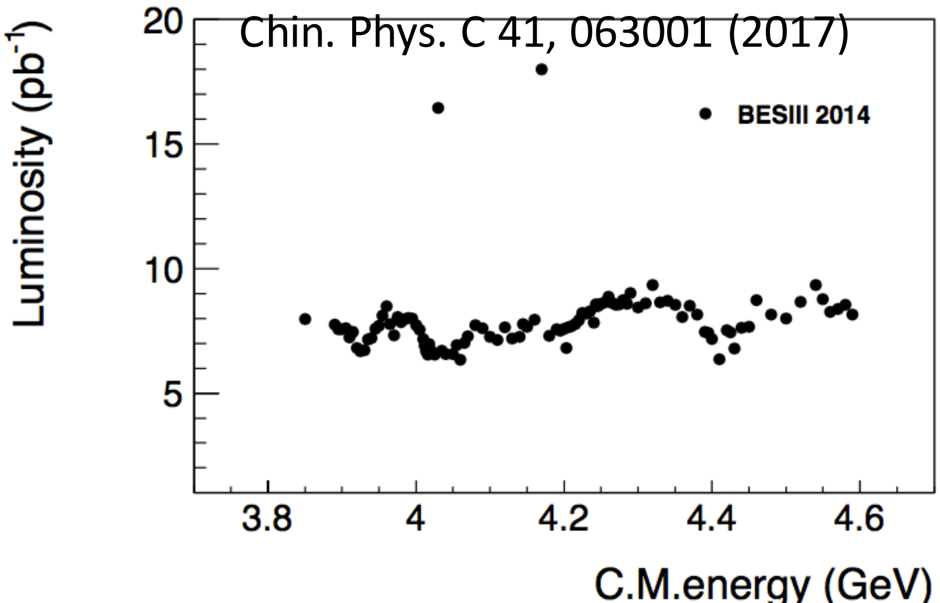
- ☐ A lot of states not well established in Open charm range

- ☐ BESIII can directly generate Y(1^{--})states by e^+e^- annihilation.
- ☐ Can also generate states with other J^{PC} with radiative decay or hadronic decay of ψ or Y.

BESIII data sets for XYZ study



Chin. Phys. C 41, 063001 (2017)



XYZ data

- **~12 fb^{-1} e^+e^- collision data event in open charm region from 3.8-4.6GeV.**
- **Massive events on several special energy points: Such as 4.26GeV, and 4.36GeV**

R-scan data

- **Dozens of energy points with luminosity < 20 pb^{-1}**
- **Initially taken for R study, can also help the XYZ study**

Part I:

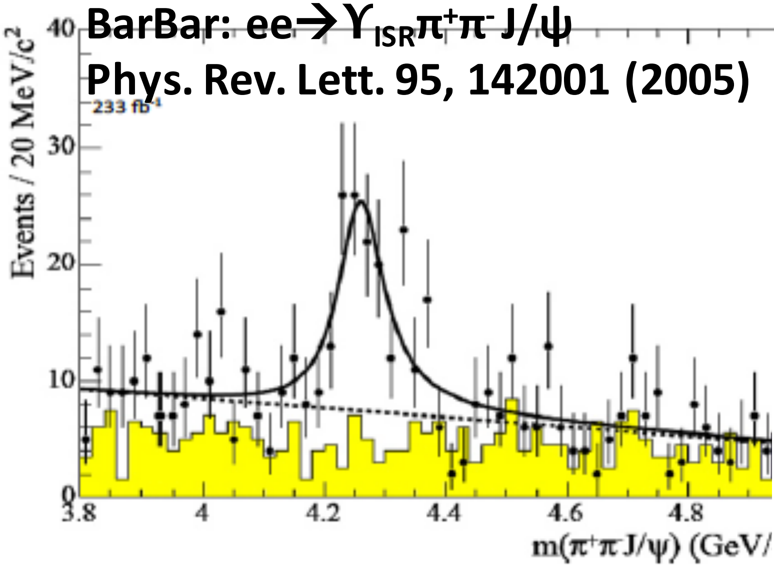
$e^+e^- \rightarrow \psi(1^{--})$ (well estabilished) $\rightarrow$...

or

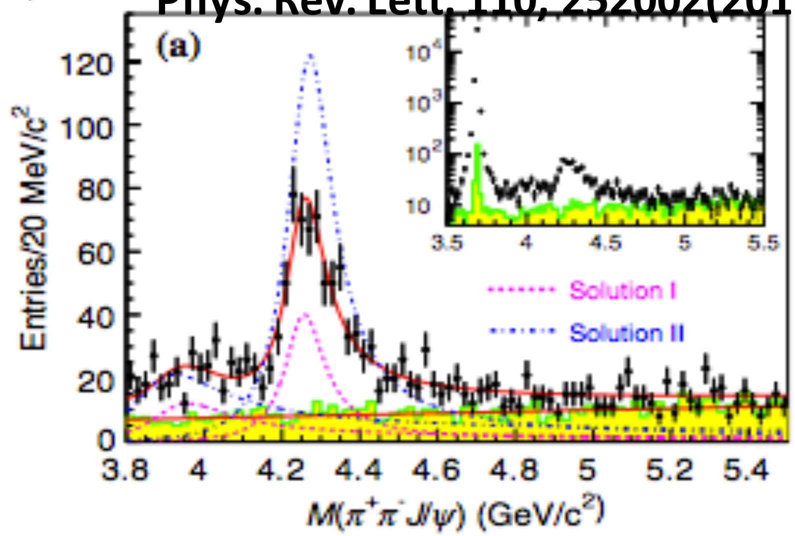
$e^+e^- \rightarrow \Upsilon(1^{--})$ (not so well estabilished) $\rightarrow$...

Y(4260),Y(4360),Y(4660): some history

BarBar: ee→$\Upsilon_{ISR}\pi^+\pi^- J/\psi$
Phys. Rev. Lett. 95, 142001 (2005)

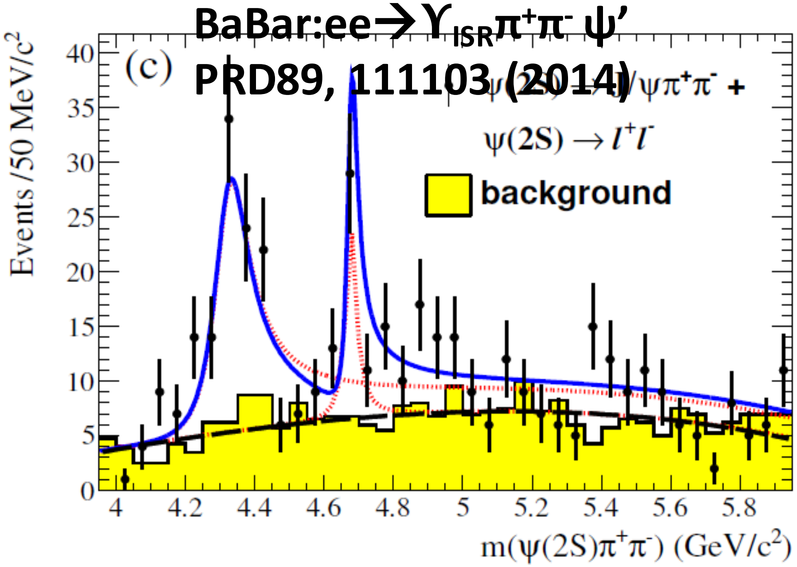


Belle: ee→$\Upsilon_{ISR}\pi^+\pi^- J/\psi$
Phys. Rev. Lett. 110, 252002(2013)

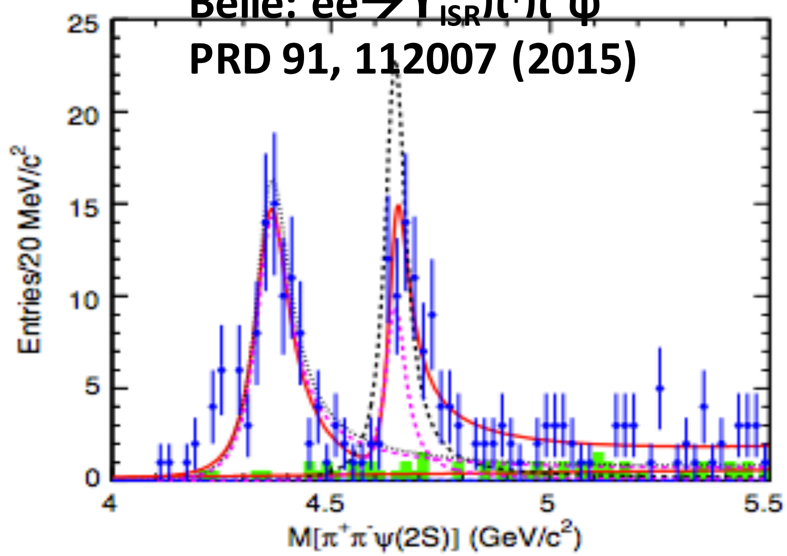


Y(4260)
PDG value
Without BES
Result:
Mass=
4251±9 MeV
width=
120±12 MeV

BaBar:ee→$\Upsilon_{ISR}\pi^+\pi^- \psi'$
PRD89, 111103 (2014)



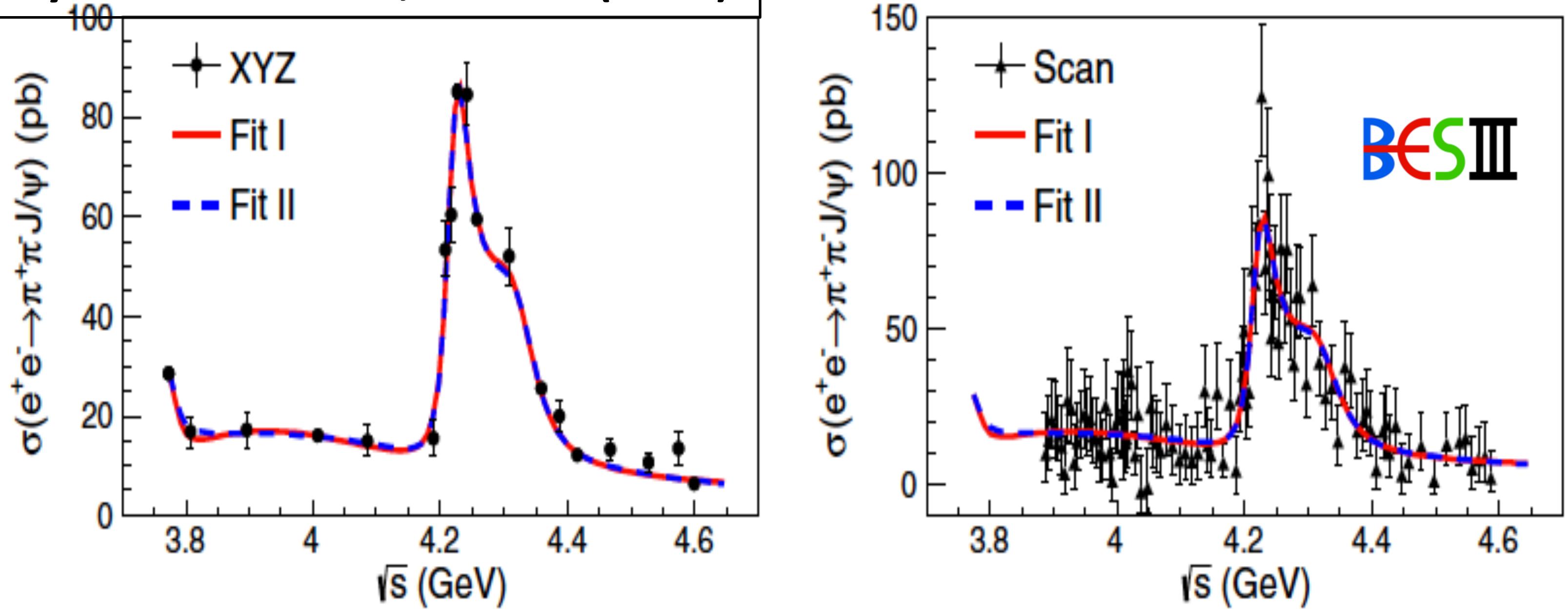
Belle: ee→$\Upsilon_{ISR}\pi^+\pi^- \psi'$
PRD 91, 112007 (2015)



Y(4360)
PDG mass
4346±6 MeV
PDG width
102±10 MeV

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

Phys. Rev. Lett. 118, 092001 (2017)



- ❑Simultaneous fit to XYZ data(left) and R-scan data (right)
- ❑Coherent sum of two Breit-Wigner like structure plus one incoherent ψ(3770)
  - ➢M = (4222.0±3.1±1.4) MeV, Γ = (44.1±4.3±2.0) MeV ,

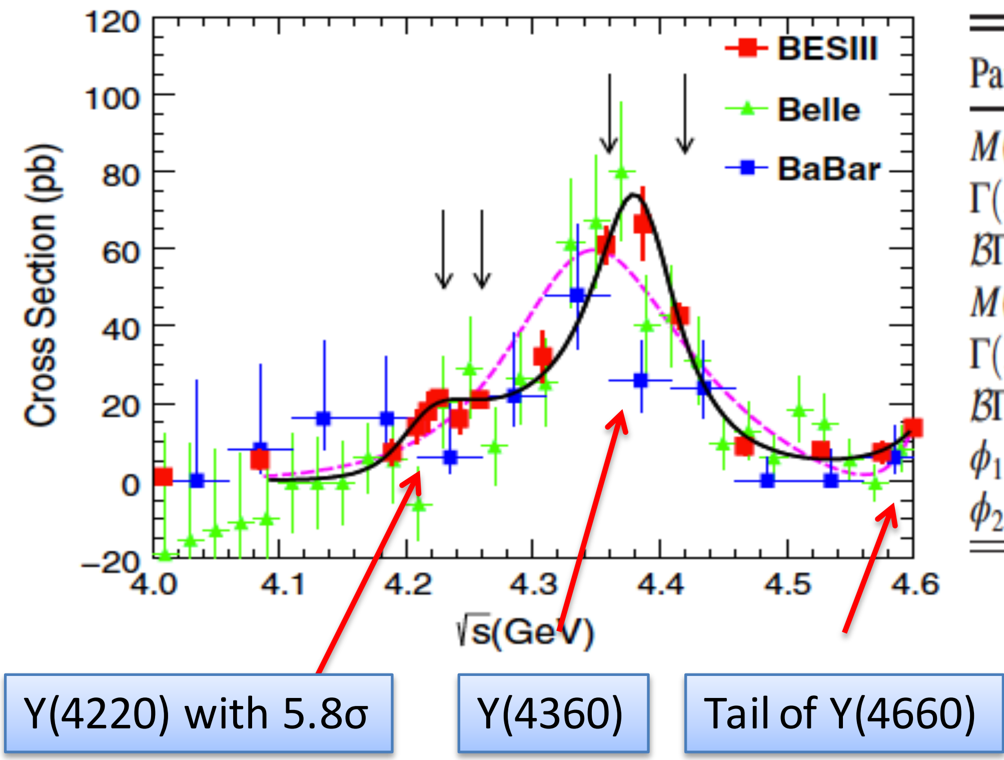
    Lower and narrower than previous Y(4260) PDG value

    Y(4260)→Y(4220)？
  - ➢M = (4320.0±10.4±7) MeV, Γ = (101.4±25±10) MeV ,

    a little bit lower than Y(4360) PDG
- ❑Compare with one Breit-Wigner fit, the significance of the second Breit-wigner is 7.6σ
- ❑Is this Y(4260) + Y(4360) ? The first observation of Y(4360)→$\pi^+\pi^- J/\psi$?
- ❑Y(4008) is not confirmed

$e^+e^- \rightarrow \pi^+\pi^-\psi'$

PRD 96, 032004 (2017)

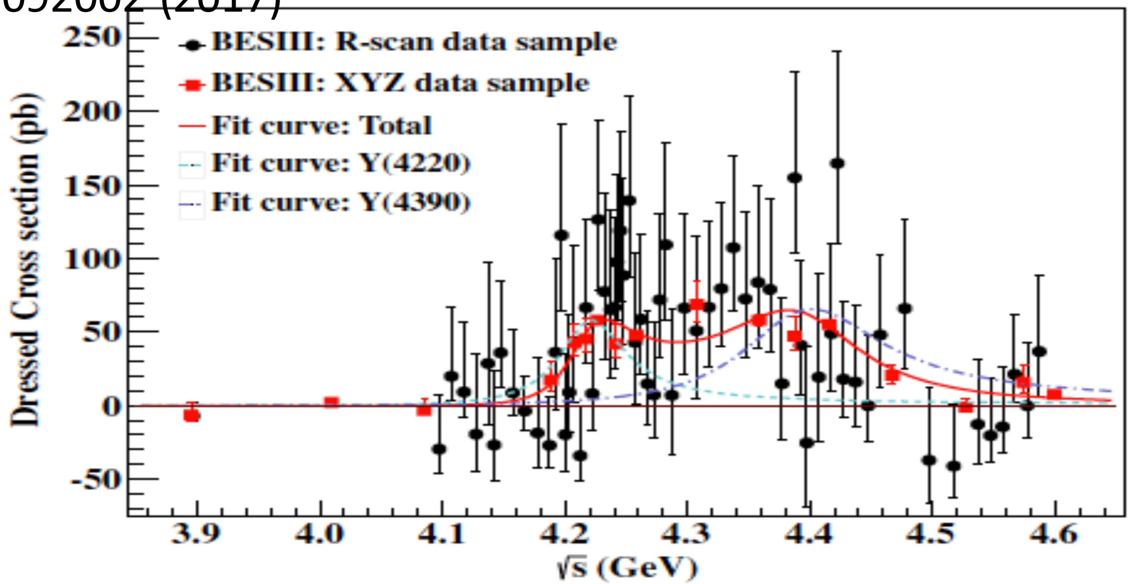


Parameters	Solution I	Solution II
$M(Y4220)$ (MeV/c^2)	4209.5 ± 7.4	
$\Gamma(Y(4220))$ (MeV)	80.1 ± 24.6	
$\mathcal{B}\Gamma^{e^+e^-}(Y(4220))$ (eV)	1.61 ± 1.27	1.80 ± 1.41
$M(Y4390)$ (MeV/c^2)	4383.8 ± 4.2	
$\Gamma(Y(4390))$ (MeV)	84.2 ± 12.5	
$\mathcal{B}\Gamma^{e^+e^-}(Y(4390))$ (eV)	7.25 ± 2.8	10.96 ± 3.8
ϕ_1 (rad)	3.3 ± 1.0	2.8 ± 0.4
ϕ_2 (rad)	0.8 ± 0.9	4.7 ± 0.1

- **Cross section of $e^+e^- \rightarrow \pi^+\pi^-\psi(3686)$ has been measured at 16 energy points from 4.008 to 4.600 GeV.**
- **Y(4220) is needed(5.8σ)**

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

PRL 118, 092002 (2017)

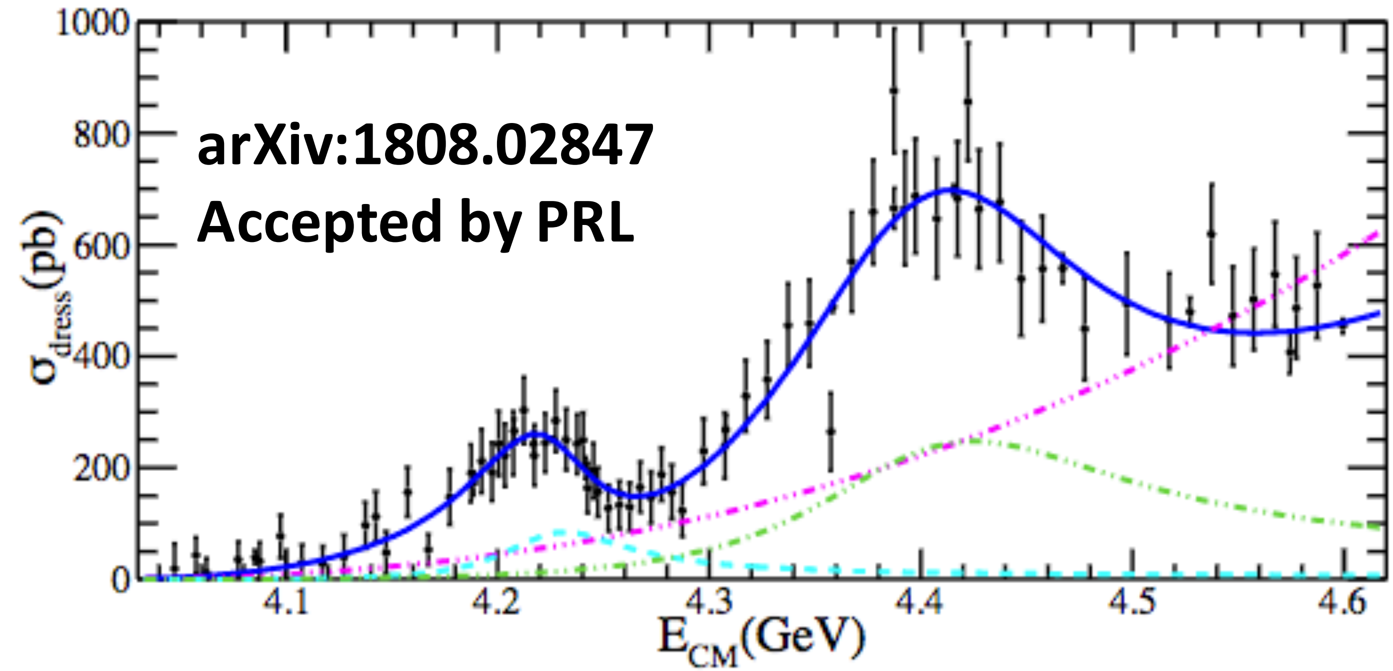


- Fitted with coherent sum of two Breit-Wigner like structue
  - $M_1 = 4218.4^{+5.5}_{-4.5} \pm 0.9\ \mathrm{MeV}/c^2$, $\Gamma_1 = 66.0^{+12.3}_{-8.3} \pm 0.4\ \mathrm{MeV}$ → Y(4220)
  - $M_2 = 4391.5^{+6.3}_{-6.8} \pm 1.0\ \mathrm{MeV}/c^2$, $\Gamma_2 = 139.5^{+16.2}_{-20.6} \pm 0.6\ \mathrm{MeV}$ → Y(4390)
- The Y(4220) here is consistent with the states observed in $\pi^+\pi^- J/\psi$ around 4222MeV

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

$$\sigma_{dress} = \frac{N^{obs}}{\mathcal{L}(1+\delta^r)B(D^0 \to K^-\pi^+)\varepsilon}$$

$$\sigma_{\rm dress}(m) = |c \cdot \sqrt{P(m)} + e^{i\phi_1} B_1(m)\sqrt{\frac{P(m)}{P(M_1)}} + e^{i\phi_2} B_2(m)\sqrt{\frac{P(m)}{P(M_2)}}|^2$$

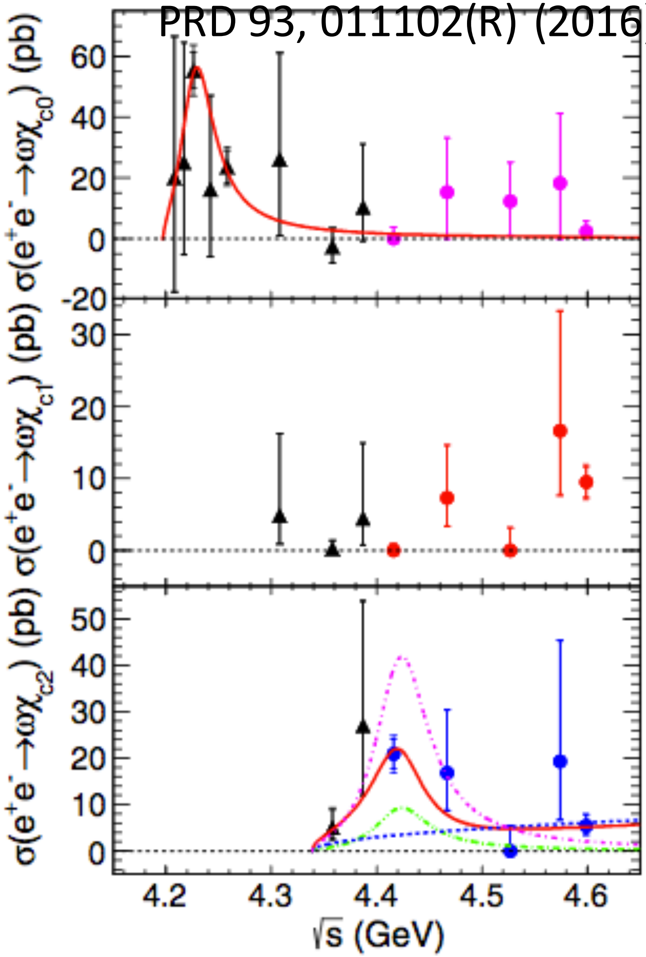


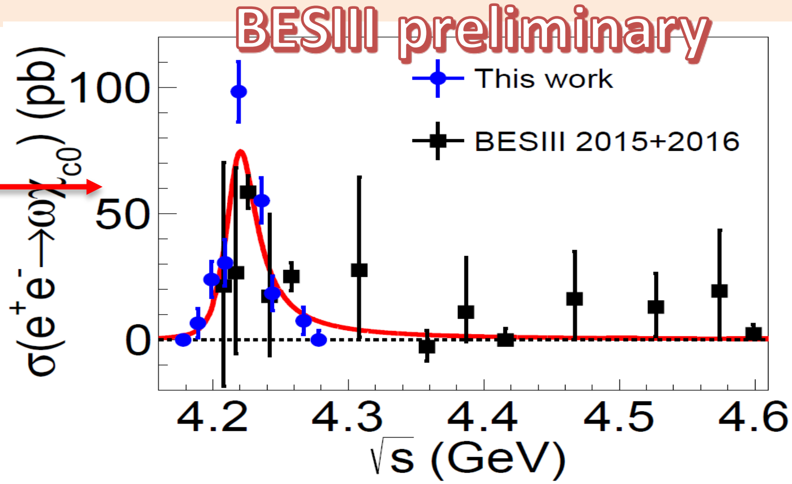
Fit with a three body phase space term (pink dashed line) and two relativistic BW functions (green dashed double-dot line and aqua dashed line).

$$M(Y(4220)) = (4228.6 \pm 4.1 \pm 5.9)\mathrm{MeV}/c^2$$
$$\Gamma(Y(4220)) = (77.1 \pm 6.8 \pm 6.9)\mathrm{MeV}/c^2$$

$e^+e^- \rightarrow \omega\chi_{cJ}$

PRL 114, 092003 (2015)
PRD 93, 011102(R) (2016)





- The process $e^+e^- \rightarrow \omega\chi_{cJ}$ (J=0, 1, 2 are observed).
- The cross section of $e^+e^- \rightarrow \omega\chi_{c0}$ is fitted with Breit-wigner

$$\sigma(\sqrt{s}) = \frac{12\pi\Gamma_{ee}\mathcal{B}(\omega\chi_{c0})\Gamma}{(s-M^2)^2+M^2\Gamma^2} \times \frac{\Phi(\sqrt{s})}{\Phi(M)}$$

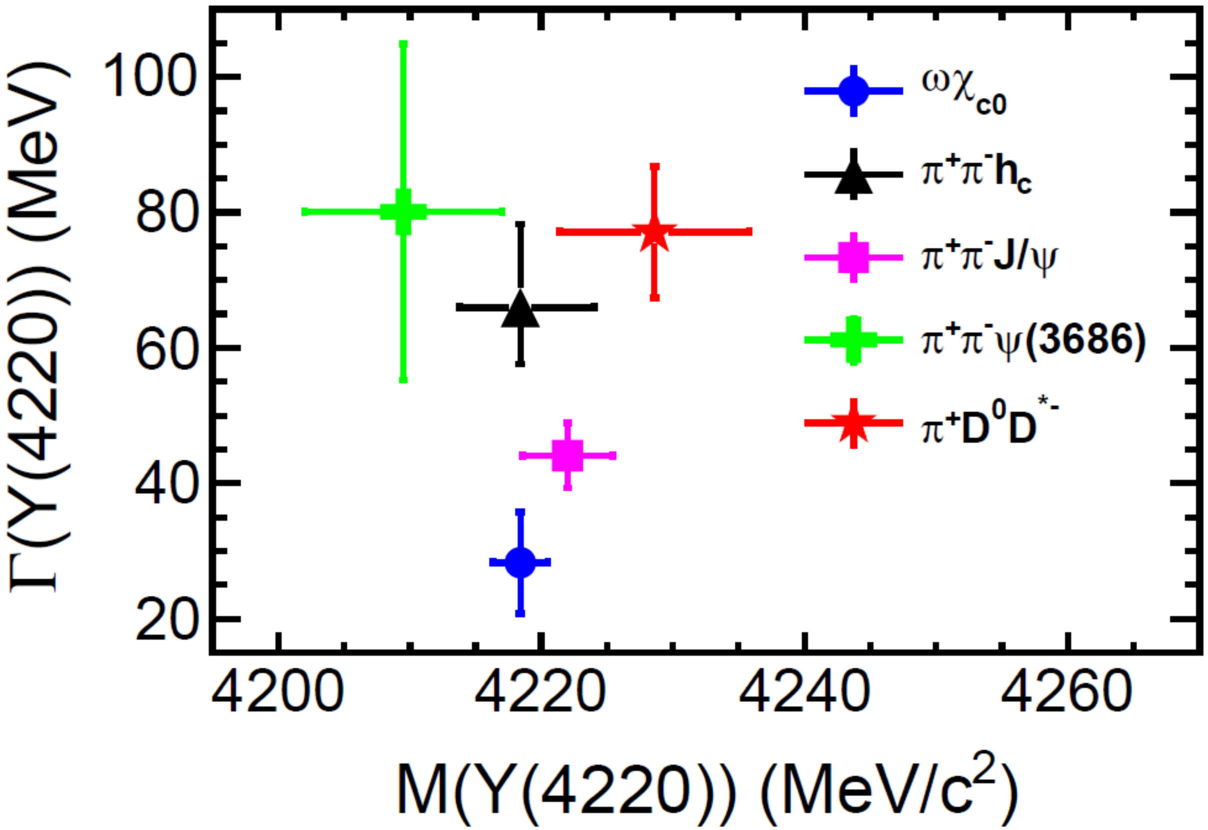
- The fitted parameters of Y(4220) is

$M = (4218.4 \pm 1.6 \pm 1.3)\ \mathrm{MeV}/c^2$

$\Gamma = (28.3 \pm 3.9 \pm 6.4)\ \mathrm{MeV}$

$\Gamma_{ee}\mathcal{B}(\omega\chi_{c0}) = (2.5 \pm 0.2 \pm 0.4)\ \mathrm{eV}$

Y(4260)→Y(4220)



The measured mass and width of $Y(4220)$ from the different processes.

$e^+e^- \rightarrow \Lambda_c^+ \bar{\Lambda}_c^-$ and Y(4660)

- **Using 10 decay processes to reconstruct Λ_c , $\sigma(e^+e^- \rightarrow \Lambda_c^+ \bar{\Lambda}_c^-)$ is measured at 4 energy points**

- Exotic?

$Y(4660) \rightarrow \pi^+\pi^-\psi'$, $\sigma_{peak} \sim 0.04\text{nb}$

$Y(4660) \rightarrow \Lambda_c^+ \bar{\Lambda}_c^-$, $\sigma_{peak} \sim 0.55\text{nb}$

Y(4660) baryonic coupling ≥ 10 mesonic coupling

Y(4660) is a charmed baryonium?

A charmed four quarks states decay by a light quark pair popping up from the vacuum and falling apart as a charmed baryon pair

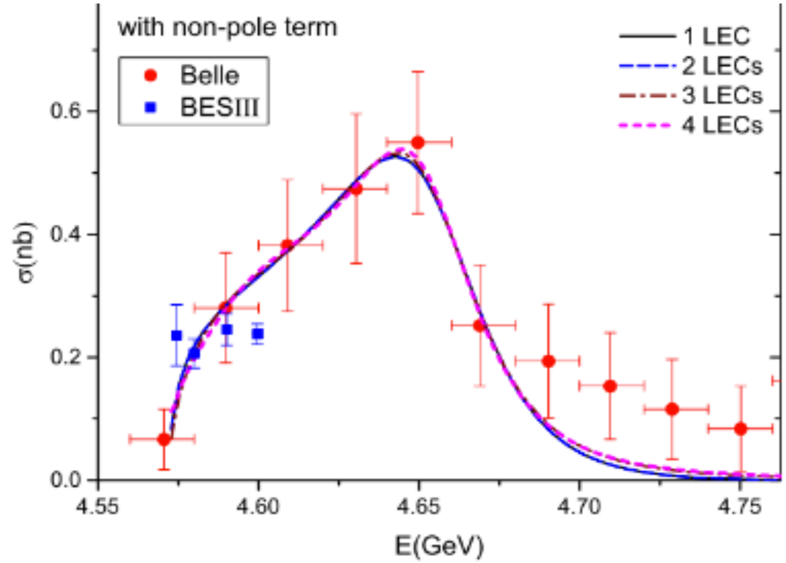
PRD 72, 031502(2005), L.Maiana et.al.

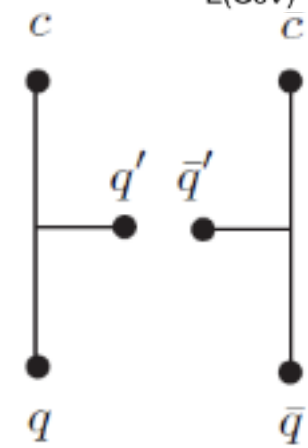
PRL104, 132005(2010), G. Cotugno et.al.

- **Currently, BESIII result and Belle result doesn't agree so well, data taking above 4.6 GeV by BESIII will help to clarify this.**

Belle PRL 101, 172001(2008)

BESIII PRL 120, 132001(2018)

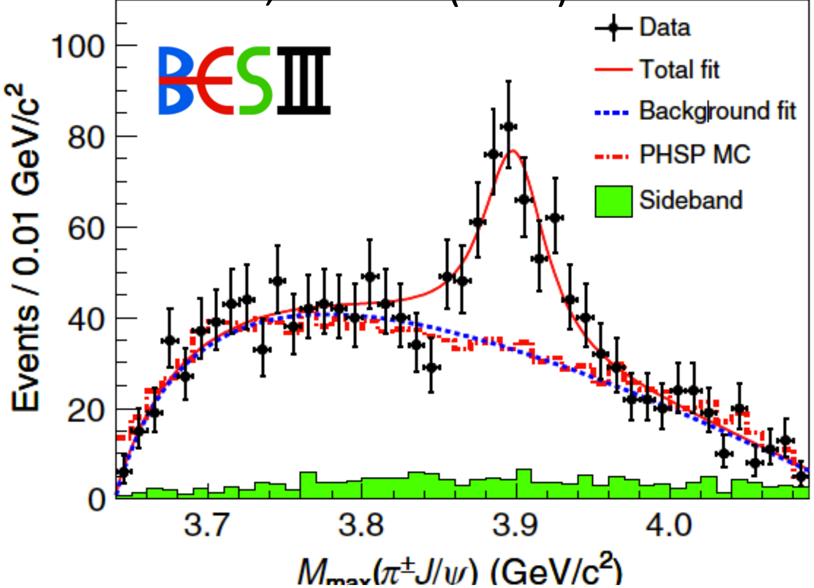




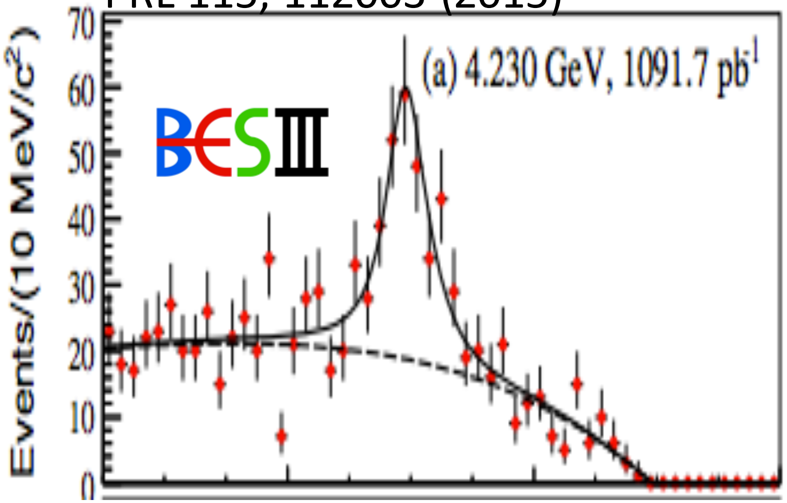
Part II: Zc states

Zc(3900)$^{\pm,0}$ in $\pi^+\pi^-$ J/ψ, $\pi^0\pi^0$ J/ψ

PRL 110, 252001 (2013)



PRL 115, 112003 (2015)



•The mass of Zc(3900) is in opencharm range and strongly coupled to charm → it should contain a (ccbar) pair.
•Zc(3900)$^{\pm}$ is charged → need at least two more quarks to form a charge unit.

Z$_c$(3900) is a four quark states?

❑**Tetraquark states?**

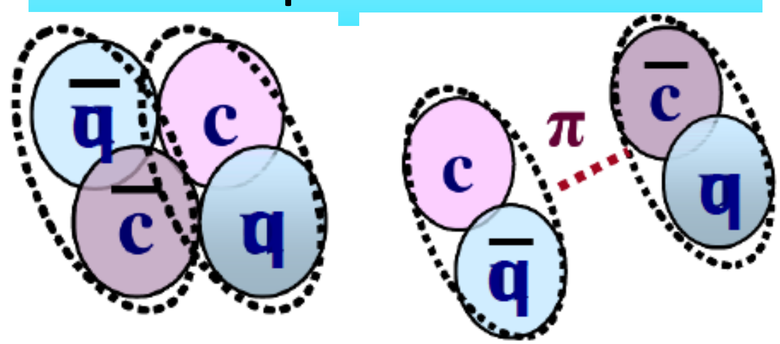
Phys. Rev. D89,054019(2014);

Phys. Rev. D90,054009(2014);

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

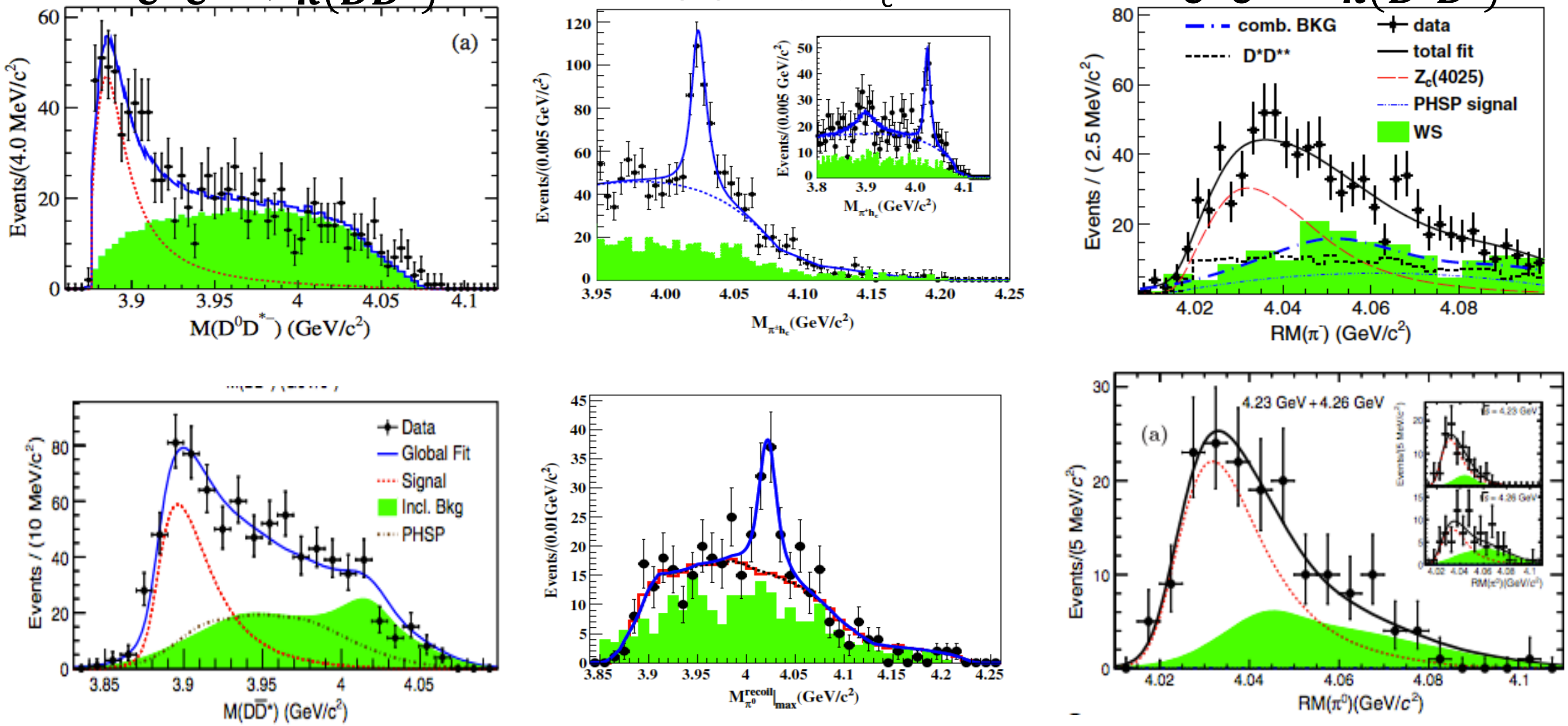
Arxiv:1303.6608, 1304.2882

OR other explanation?



Zc(3900)/(3885), Zc(4020)/(4025)

$e^+e^- \to \pi(D\bar{D}^*)$ | $e^+e^- \to \pi^+\pi^- h_c$ | $e^+e^- \to \pi(D^*\bar{D}^*)$



PRL 112, 022001 (2014)
PRD 92, 092006 (2015)
PRL115, 222002(2015)

PRL 111, 242001 (2013)
PRL 113, 212002 (2014)

PRL 112, 132001 (2014)
PRL 115, 182002 (2015)

The BESIII result for Zc family

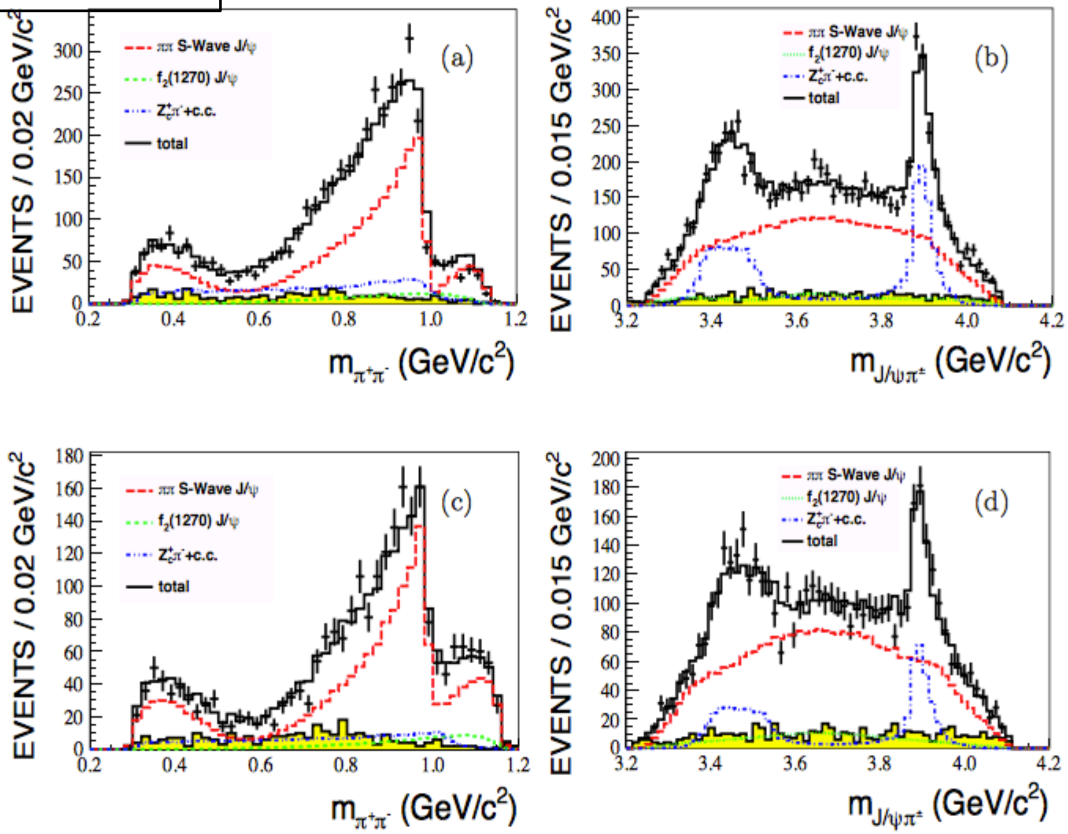
For reference: the mass threshold of m(DD*)~3875MeV, M(D*D*)~4014MeV

- 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	$(DD^*)^{\pm}$	3881.7±1.6±1.6	26.6±2.0±2.1	108.4±6.9±8.8
	Neutral	$(DD^*)^0$	$3885.7^{+4.3}_{-5.7} \pm 8.4$	$35^{+11}_{-12} \pm 15$	47±9±10
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

Determination of J^p of Zc(3900)

PRL 119, 072001 (2017)



√s=4.23GeV

√s=4.26GeV

- ❑Amplitude analysis with helicity formalism taking $\pi^+\pi^- J/\psi$ as final states
- ❑Simultaneous fit to data samples at 4.23GeV and 4.26GeV
- ❑$\pi^+\pi^-$ spectrum is parameterized with σ, $f_0(980)$, $f_2(1270)$ and $f_0(1370)$

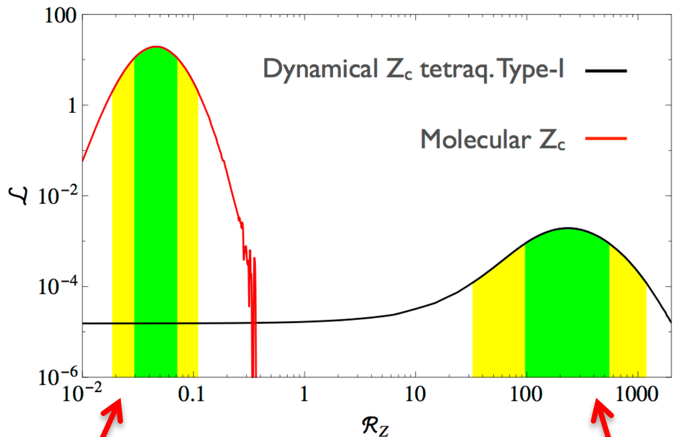
Determination of J^p of Zc(3900)

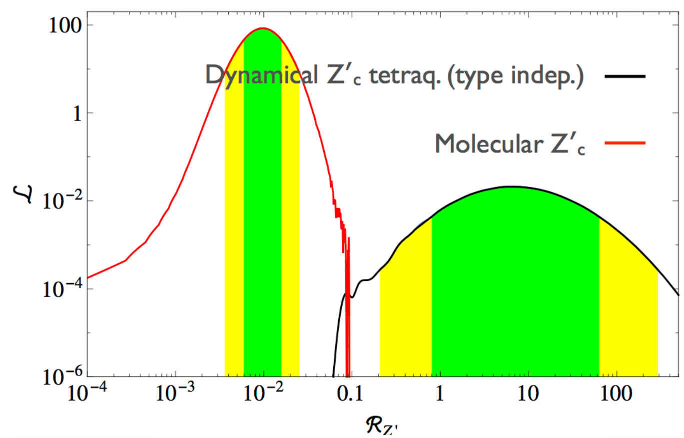
- **Zc is parameterized with Flatte formula**

$$BW(s, M, g_1', g_2') = \frac{1}{s - M^2 + i[g_1'\rho_1(s) + g_2'\rho_2(s)]}$$

- **M=(3901.5±2.7±38.0)MeV, g_1'=(0.075±0.006±0.025)GeV^2, g_2'/g_1'=27.1±2.0±1.9**
  Which corresponding to pole Mass= (3881.2±4.2±52.7)MeV, pole width=(51.8±4.6±36.0)MeV
- **J^p of Zc favor to be 1^+ with statistical significance larger than7σ over other quantum numbers**
- **The significance of Zc(4020) process is found to be 3σ**

Search for $e^+e^- \to \pi Z_c^{(\prime)}, Z_c^{(\prime)} \to \rho^\pm \eta_c$





$$R_z = \frac{Br(Z_c \to \rho\eta_c)}{Br(Z_c \to \pi J/\psi)}$$

$$R_{z'} = \frac{Br(Z_c' \to \rho\eta_c)}{Br(Z_c' \to \pi h_c)}$$

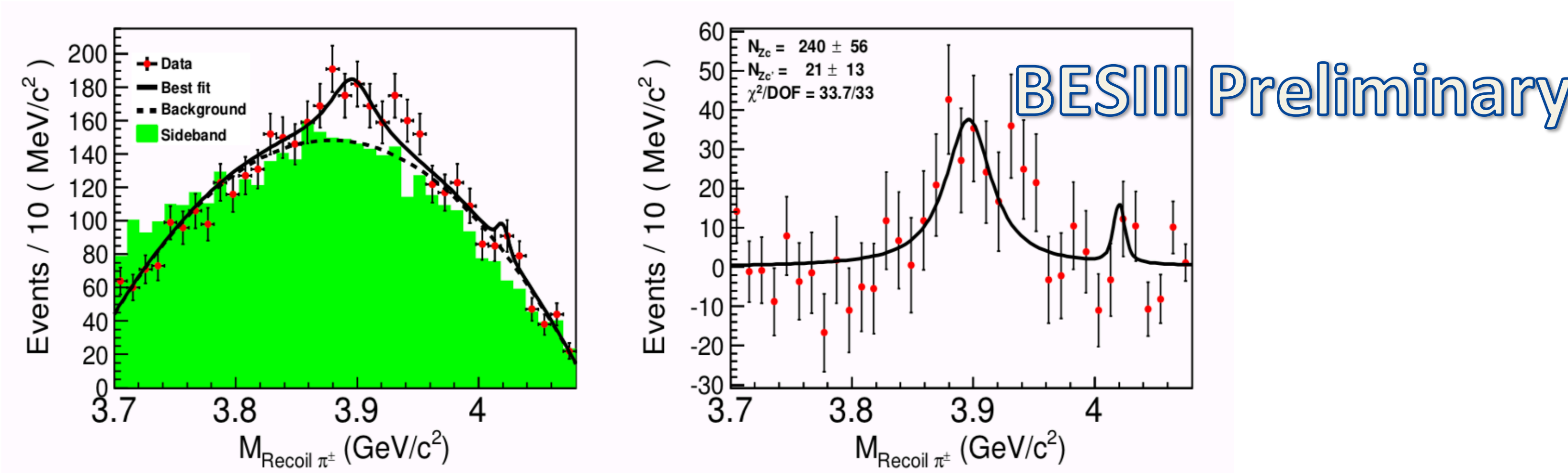
A.Esposito et.al., PLB 746(2015), 194-201

Molecular Zc

Tetraquak Type-1

- **This channel is important for the discrimination between different multi-quark schemes.**
- **The green band and yellow band show the 1σ and 2σ confidence range of the corresponding theoretical model.**

Search for $e^+e^- \to \pi Z_c^{(\prime)}, Z_c^{(\prime)} \to \rho^\pm \eta_c$

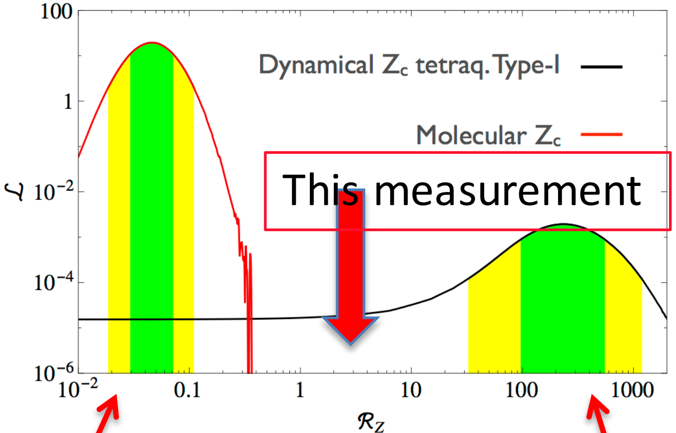


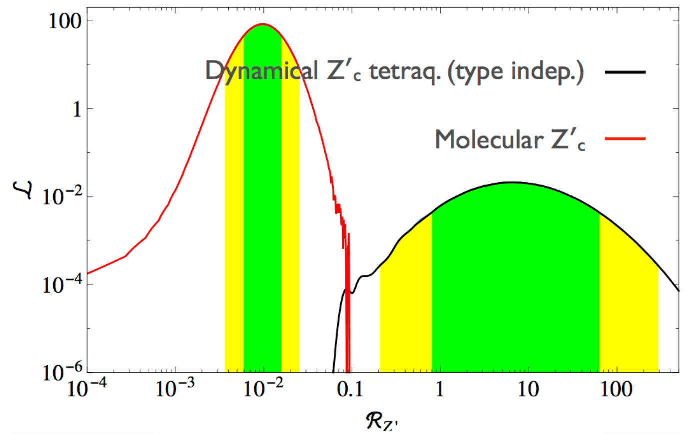
$e^+e^- \to \pi Z_c, Z_c \to \rho\eta_c$ @ 4.23 GeV

- ❑Nine η_c channels are used to reconstruct η_c.
- ❑After the η_c and ρ mass window, a hint of Z_c(3900) peak can be seen on the recoiled mass of the bachelor π.
- ❑The green histogram is η_c sideband. Z_c parameter are fixed to latest measurement.

- ❑Strong evidence of Zc(3900) →ρη_c is observed at √s=4.23GeV, with statistical significance 4.3σ(3.9σ including systematic uncertainty)
- ❑No significant Zc'(4020)→ρη_c observed.

Comparison between measurement and prediction





$$R_z = \frac{Br(Z_c \to \rho\eta_c)}{Br(Z_c \to \pi J/\psi)}$$

$$R_{z'} = \frac{Br(Z'_c \to \rho\eta_c)}{Br(Z'_c \to \pi h_c)}$$

A.Esposito et.al., PLB 746(2015), 194-201

Molecular Zc

Tetraquak Type-1

- **The cross section measured at √s= 4.23GeV**

$$\sigma^B(e^+e^- \to \pi^+\pi^-\pi^0\eta_c) = (46 \pm 12 \pm 10\ )\text{pb}$$
$$\sigma^B(e^+e^- \to \pi Z_c, Z_c \to \rho\eta_c) = (47 \pm 11 \pm 11\ )\text{pb}$$

$$R_z = 2.1 \pm 0.8$$

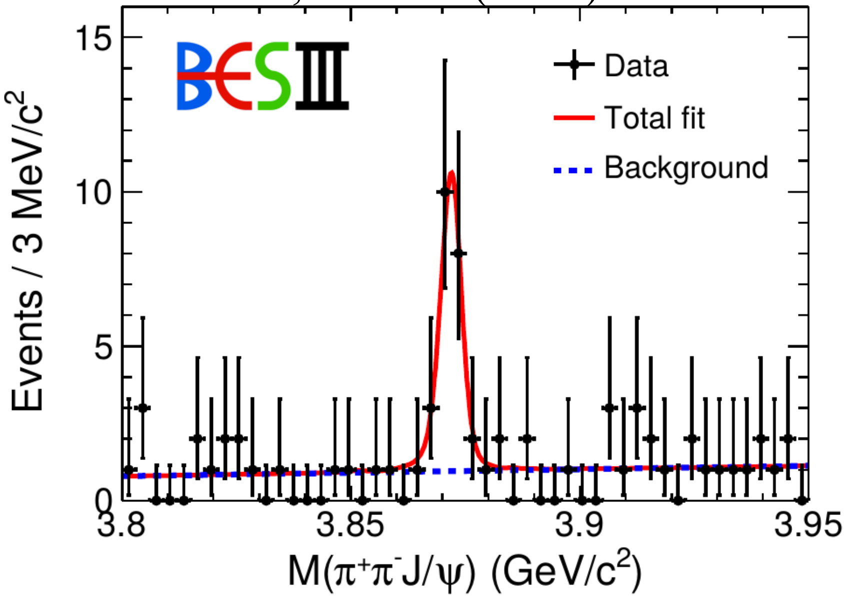
BESIII Preliminary

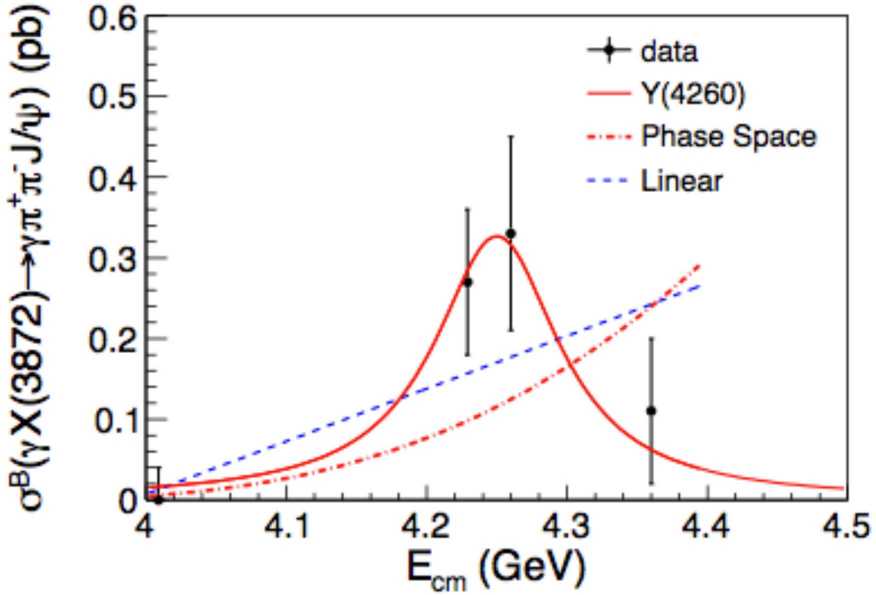
- **Our measurement doesn't agree with both molecular Zc and tetraquark Zc Type-1 assumptions**

Part III: X states

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

PRL 112, 092001 (2014)

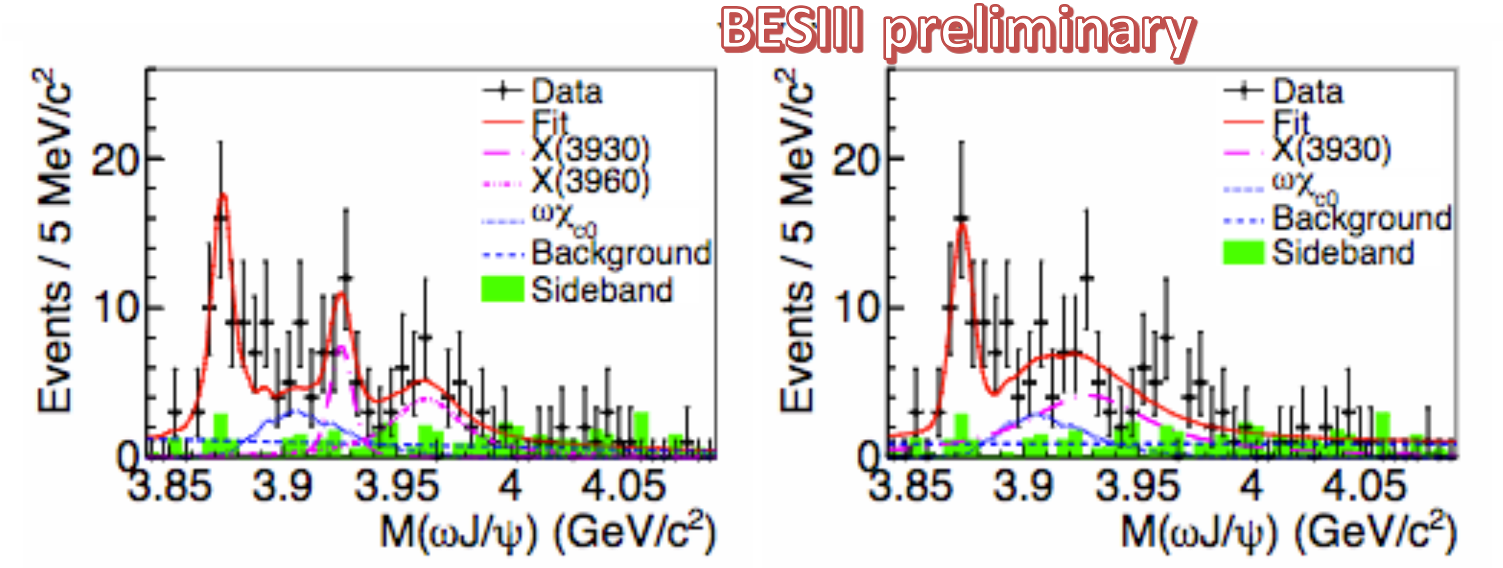




- X(3872) is sitting at the threshold of DD*.
- $J^{PC}=1^{++}$ *(CDF, LHCb)*
- X(3872) is candidate of exotic states for long time: molecular states, tetraquark states, Mixture of excited χ_{c1} and D^0D^{*0} bound state.

- 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 of $Y(4260)$

$e^+e^- \rightarrow \gamma X(3872) \rightarrow \gamma\omega J/\psi$



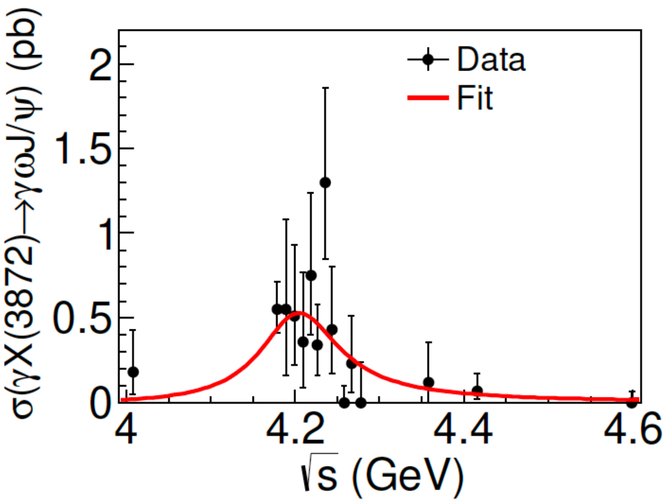
(1). Fit with X(3872), X(3915) and X(3960)
(2). Fit with X(3872) and X(3915)

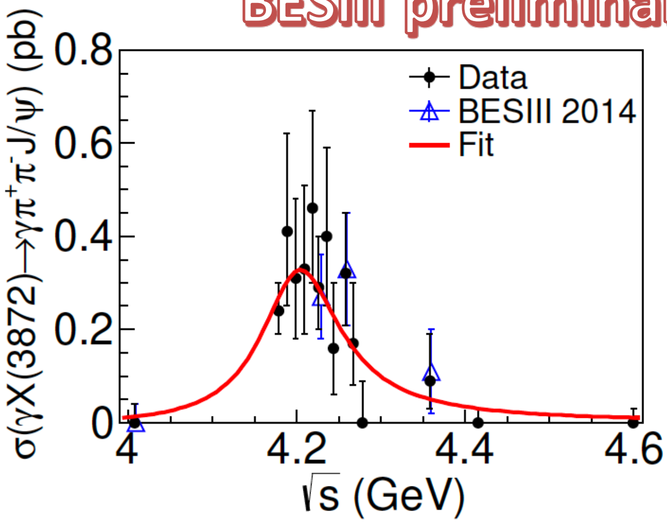
M[X(3872)]= $3873.3 \pm 1.1 \pm 1.0\ \mathrm{MeV}/c^2$

X(3872) signal significance >5.1σ, including systematic errors

$Y \rightarrow \gamma X(3872) \rightarrow \gamma\omega J/\psi$

BESIII preliminary





(1). Cross section measurement of $e^+e^- \rightarrow \gamma X(3872)$ for (left) $\omega J/\psi$ and (right) $\pi^+\pi^- J/\psi$ channel

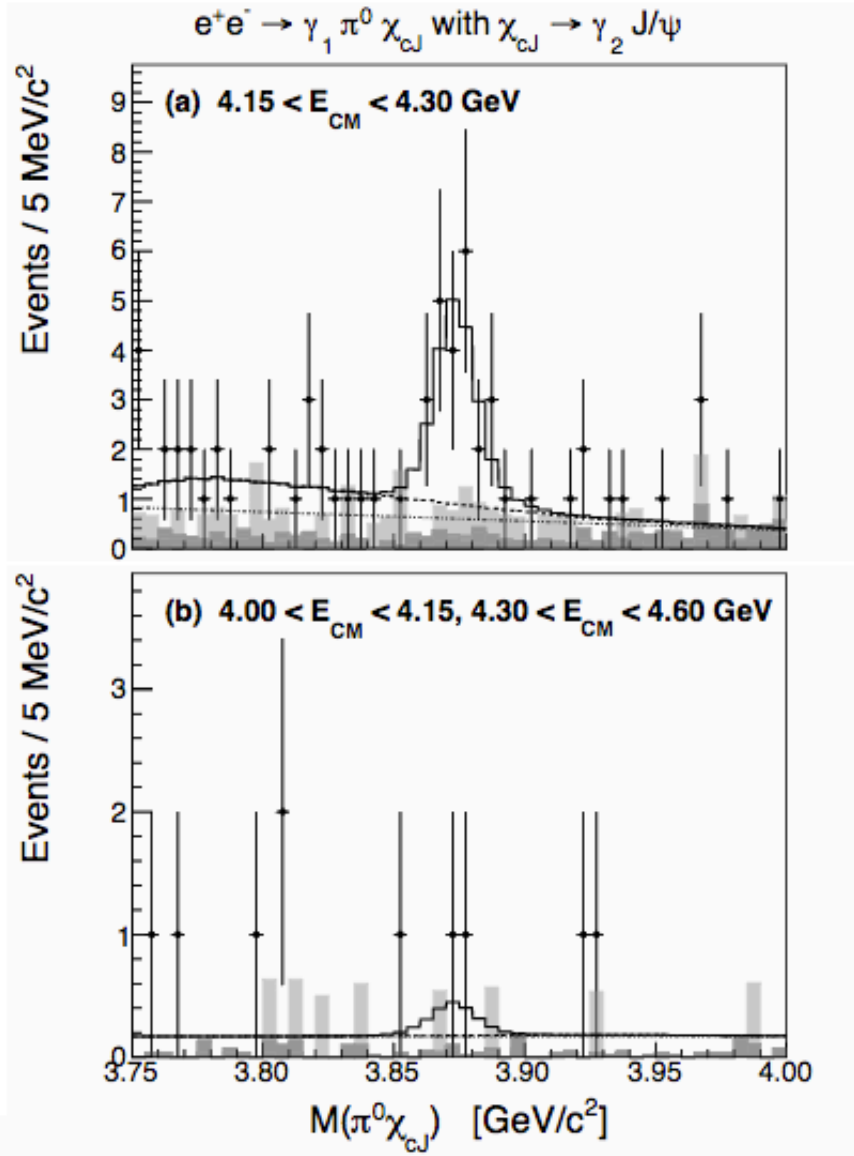
(2). Simultaneous fit to the cross section with a single Breit-Wigner resonance

$$M[Y(4200)] = 4200.6^{+7.9}_{-13.3} \pm 3.0 \text{ MeV}/c^2$$

$$\Gamma[Y(4200)] = 115^{+38}_{-26} \pm 12 \text{ MeV}$$

$$\mathcal{R} = \frac{\mathcal{B}[X(3872)\to\omega J/\psi]}{\mathcal{B}[X(3872)\to\pi^+\pi^- J/\psi]} = 1.6^{+0.4}_{-0.3} \pm 0.2$$

Observation of X(3872) →$\pi^0\chi_{c1}(1P)$



arXiv:1901.03992.

- **Data sets used:**

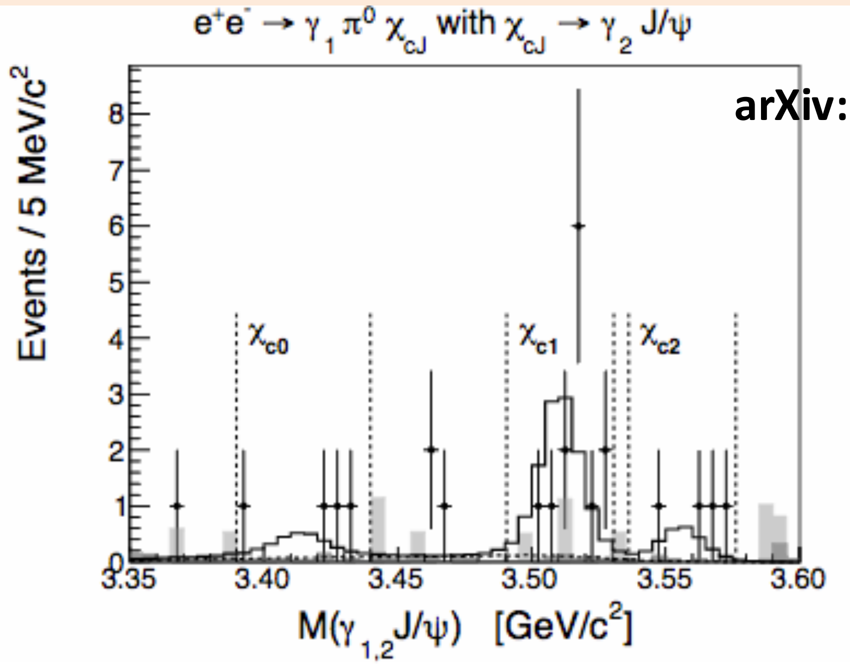
9.0fb^{-1} for 4.15<E$_{cm}$<4.30 GeV
0.7fb^{-1} for 4.00<E$_{cm}$<4.15 GeV
2.8fb^{-1} for 4.30<E$_{cm}$<4.60 GeV

- **With in range of 4.15<E$_{cm}$<4.30 GeV**

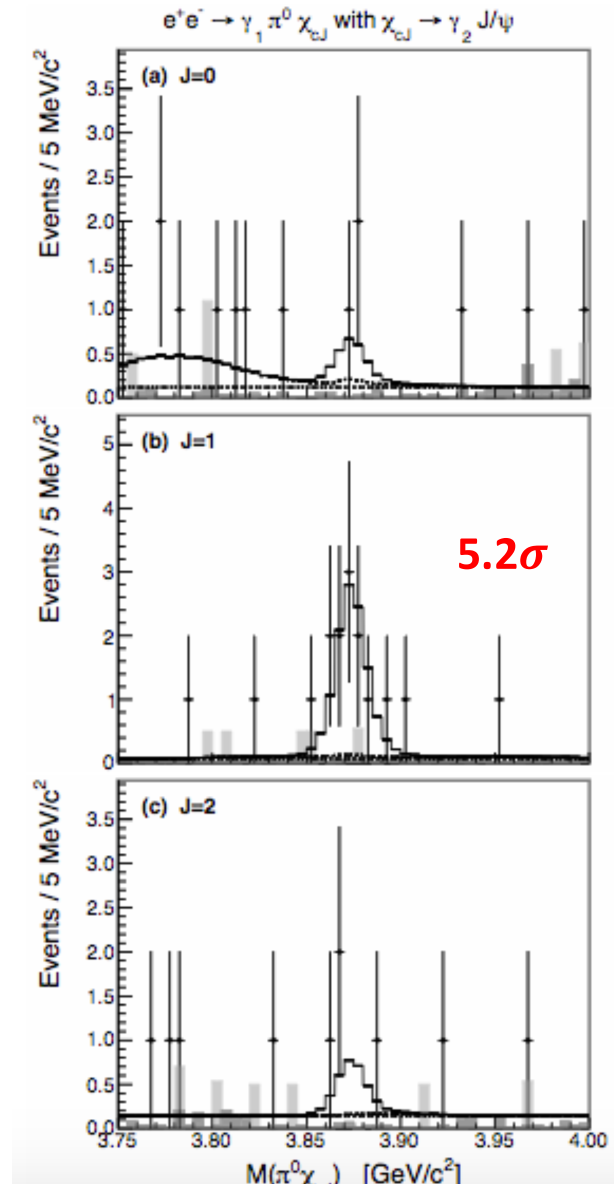
For the sum of events in all the three χ_{cJ} range, a clear X(3872) signal is seen with events number=$16.9^{+5.2}_{-4.5}$, and Significance= 4.8σ

- **No evidence of X(3872) in other E$_{cm}$**

Observation of X(3872) $\rightarrow \pi^0 \chi_{c1}(1P)$



arXiv:1901.03992.



- $10.8^{+3.8}_{-3.1}$ X(3872) signal observed in χ_{c1} range with statistical significance 5.2σ

- The branching ratio

$R_J = B(X \rightarrow \pi^0\chi_{c1})/B(X \rightarrow \pi^+\pi^- J/\psi)$

R_0<19 (90% U.L.)

$R_1=0.88^{+0.33}_{-0.27} \pm 0.10$

R_2<1.1 (90% U.L.)

Comparison between experiment and theory

- Using $Br(X(3872) \to \pi^+\pi^- J/\psi) > 3.2\%\ (PDG)$
And $Br(X(3872) \to \pi^+\pi^- J/\psi) < 6.4\%$
We get

$$Br\left(X(3872) \to \pi^0 \chi_{cJ}\right) \sim 3 - 6\%$$

- If X(3872) were the $\chi_{c1}(2p)$ state of charmonium, then
From the estimation of [Dubynskiy, Voloshin, PRD 77, 014013 (2008)],

$$\Gamma\left(X(3872) \to \pi^0 \chi_{cJ}\right) \sim 0.06 KeV$$

Which would imply an unrealistically small

$$\Gamma_{TOT}\left(X(3872)\right) \sim 0.5 - 1 KeV$$

- So this measurement disfavor the $\chi_{c1}(2p)$ interpretation of the X(3872).

Summary

- The ~~Y(4260)~~ Y(4220) are measured to be lower and narrower than previous PDG value with $\pi^+\pi^- J/\psi(\psi')$, $\pi^+\pi^- h_c$, $\omega\chi_{cJ}$ and $\pi^+ D^0 D^{*-}$
- $\sigma(e^+e^- \rightarrow \Lambda_c^+ \bar{\Lambda}_c^-)$ near threshold doesn't agree with Belle

- The J^p of $Z_c^{\pm}(3900)$ are determined to be 1^+
- Evidence for a new decay mode of $Z_c^{\pm}(3900) \rightarrow \rho^{\pm}\eta_c$

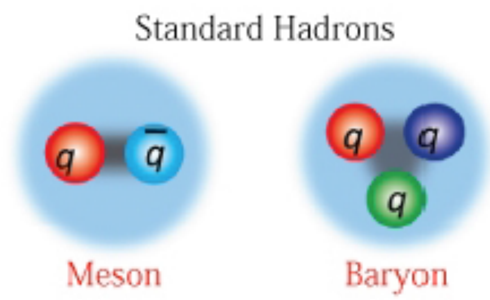
- $e^+e^- \rightarrow \gamma X(3872)$, $X(3872) \rightarrow \pi^+\pi^- J/\psi$, $\omega J/\psi$ are measured, and a sign of $Y(4220) \rightarrow \gamma X(3872)$
- A new decay mode of $X(3872) \rightarrow \pi^0 \chi_{c1}(1P)$ is observed

- More data from BESIII is on the way, and also plan to take data above 4.6GeV. More new result can be expected.

Backup

What’s the exotic states

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



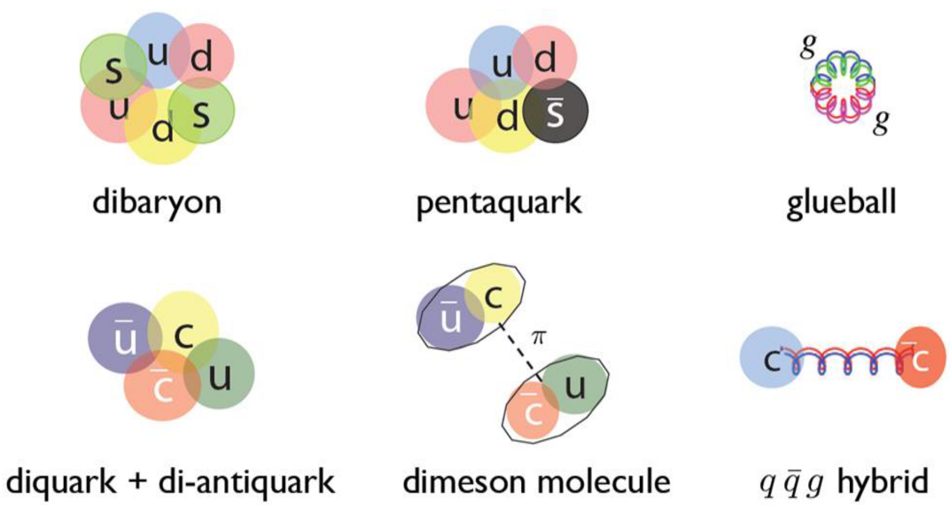
- **The QCD allow the existence of exotic states:**

✓ **Glueball (gg, ggg…)**

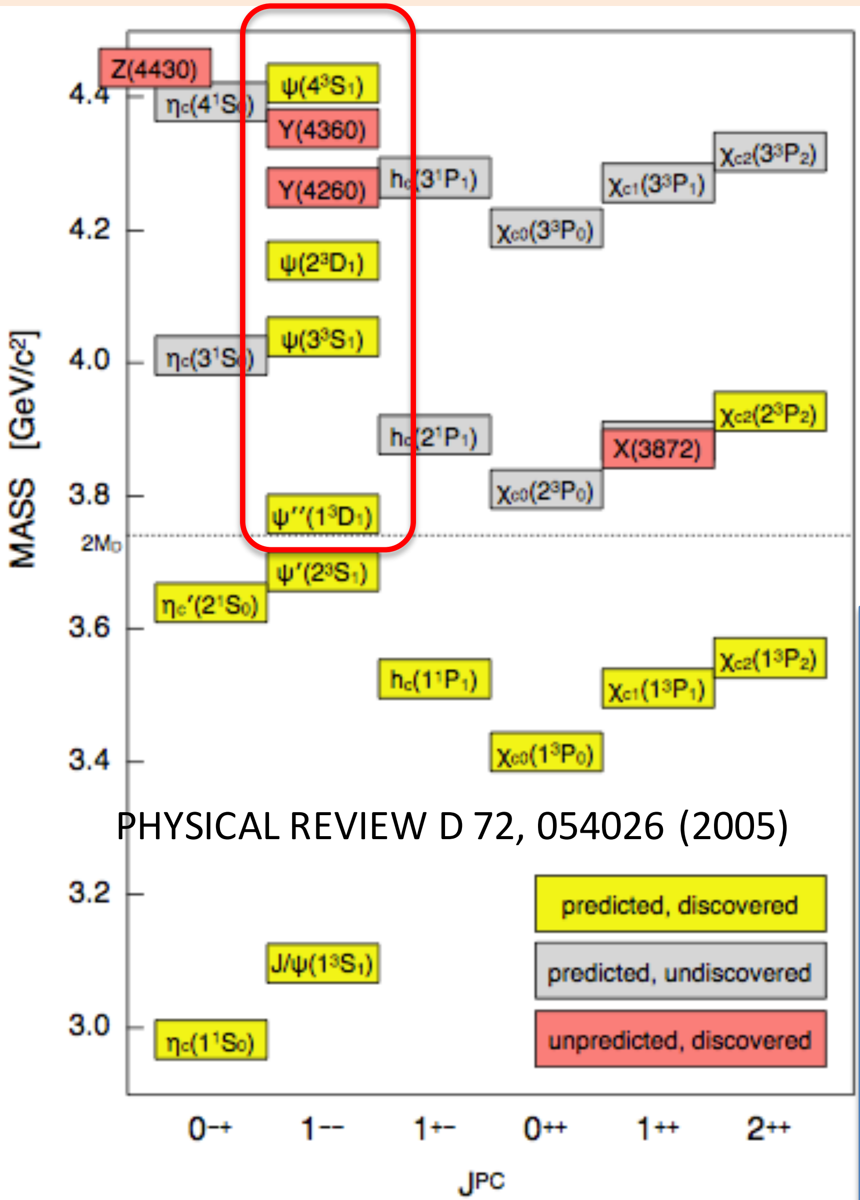
✓ **Multi-quark states (qqqq, qqqqq…)**

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

✓ **Hybrid (qqg)**

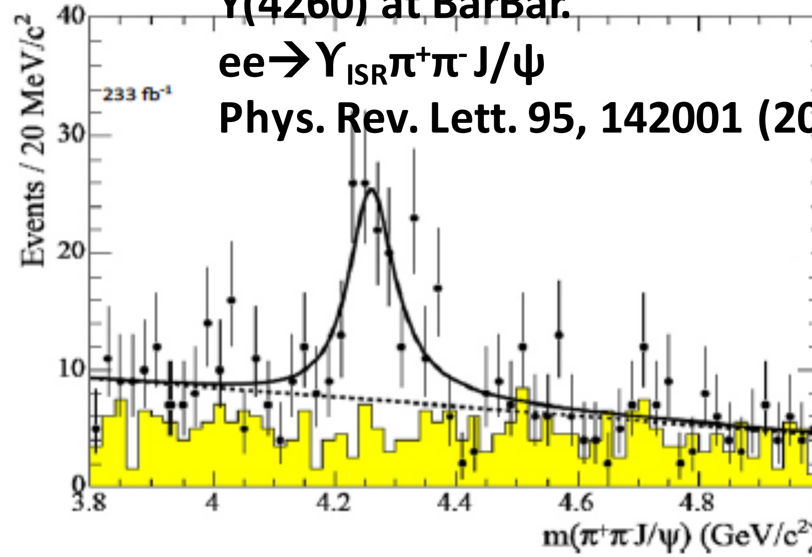


The exotics with Y(1^{--}) states



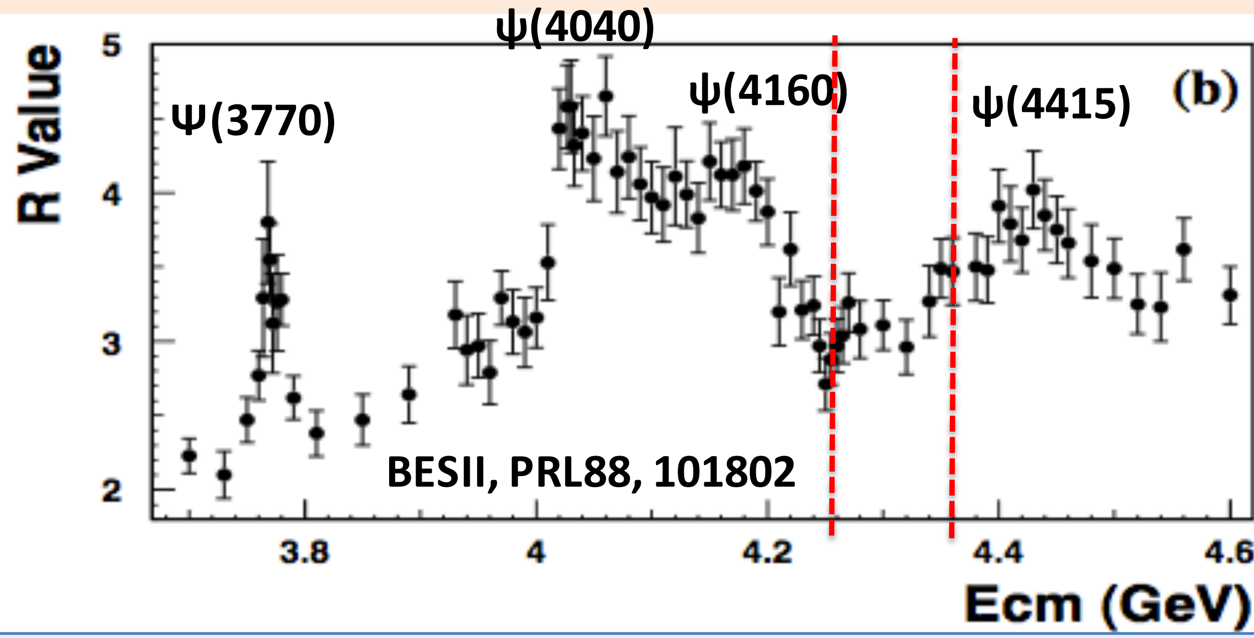
PHYSICAL REVIEW D 72, 054026 (2005)

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

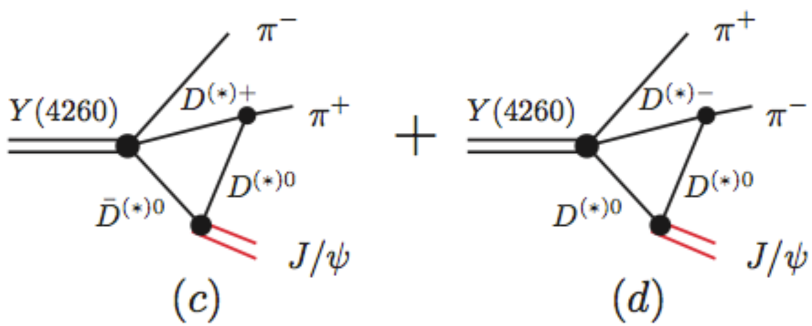
VALUE	CL%	DOCUMENT ID		TECN	COMMENT
<1.0	90	1 AUBERT	07BE	BABR	$e^+e^- \to D\overline{D}\gamma$

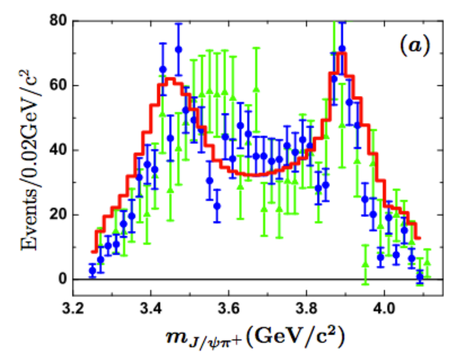
For ψ(3770), $\Gamma(DD)/\Gamma(\pi^+\pi^- J/\psi) \sim 500$

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

Other explanation of Zc(3900)

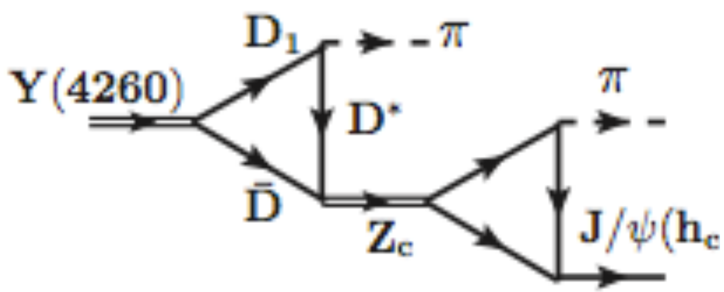
- ❑ ISPE(Initial single pion emission) model. (arxiv ： 1304.5845)

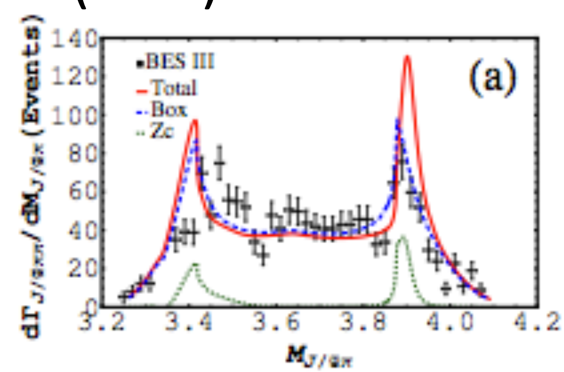




- ❑ Meson loop model. (Arxiv ： 1303.6355)

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





- ❑ …

Coupled channels fit

- The Y states in these channels

	$Y(4220)$		$Y(4320)/Y(4360)/Y(4390)$	
	M (MeV/c^2)	Γ (MeV)	M (MeV/c^2)	Γ (MeV)
$\omega\chi_{c0}$ [13]	$4226 \pm 8 \pm 6$	$39 \pm 12 \pm 2$		
$\pi^+\pi^- h_c$ [14]	$4218.4^{+5.5}_{-4.5} \pm 0.9$	$66.0^{+12.3}_{-8.3} \pm 0.4$	$4391.5^{+6.3}_{-6.8} \pm 1.0$	$139.5^{+16.2}_{-20.6} \pm 0.6$
$\pi^+\pi^- J/\psi$ [7]	$4222.0 \pm 3.1 \pm 1.4$	$44.1 \pm 4.3 \pm 2.0$	$4320.0 \pm 10.4 \pm 7.0$	$101.4^{+25.3}_{-19.7} \pm 10.2$
$\pi^+\pi^-\psi(3686)$ [11]	$4209.1 \pm 6.8 \pm 7.0$	$76.6 \pm 14.2 \pm 2.4$	$4383.7 \pm 2.9 \pm 6.2$	$94.2 \pm 7.3 \pm 2.0$
$\pi^+ D^0 D^{*-} + c.c.$ [15]	$4224.8 \pm 5.6 \pm 4.0$	$72.3 \pm 9.1 \pm 0.9$	$4400.1 \pm 9.3 \pm 2.1$	$181.7 \pm 16.9 \pm 7.4$

- Assume these two peaks structure are from same two states.
- Fit theses cross sections simultaneously with the interference between the Y states considered
- The result from CLEO, BaBar, Belle are also used
- The fit result gives:

Parameter	$Y(4220)$	$Y(4390)$	$Y(4660)$
M (MeV/c^2)	$4216.5 \pm 1.4 \pm 3.2$	$4383.5 \pm 1.9 \pm 6.0$	$4623.4 \pm 10.5 \pm 16.1$
Γ (MeV)	$61.1 \pm 2.3 \pm 3.1$	$114.5 \pm 5.4 \pm 9.9$	$106.1 \pm 16.2 \pm 17.5$

Coupled channels fit

arXiv:1805.03565

- The fit give $\chi^2/ndf=0.97$, which indicate that the two same states assumption is reasonable.

- There are multi-solution problem. Each column Corresponding to one solution.

→Ambiguity in couple fraction between Y states and these channels.

$e^+e^- \to \omega\chi_{cJ}$

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

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

$e^+e^- \to \pi^+\pi^- \psi'$

$e^+e^- \to \pi^+ D^0 D^{*-}$