Latest result on XYZ physics from BESIII

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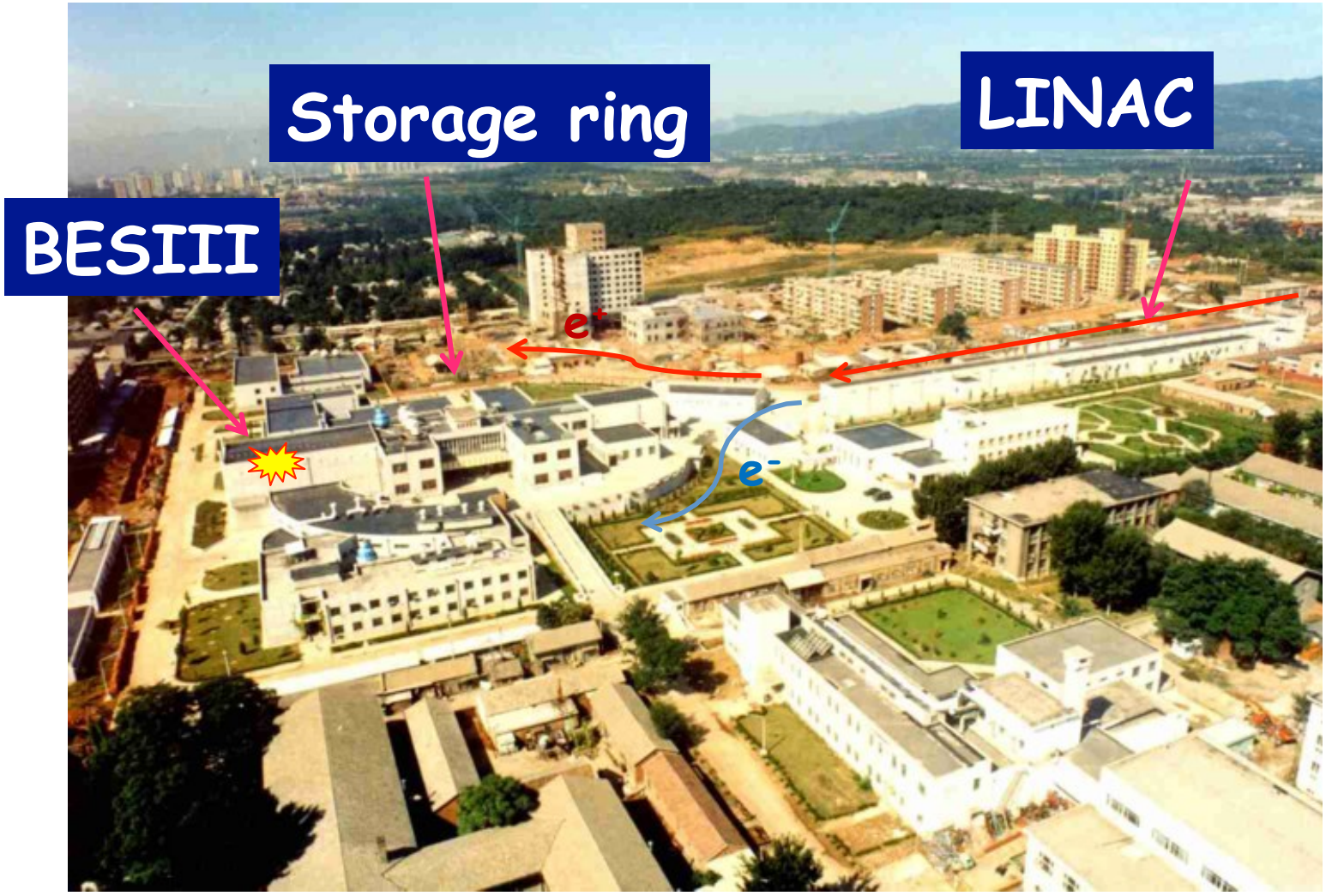
PHIPSI2017, Mainz, Germany, Jun. 26-29, 2017

Outline

- Introduction
  - BEPCII and BESIII
  - BESIII data samples
- Y(1^{--}) states
  - $Y \rightarrow \pi^+\pi^- J/\psi\ (\psi')$
  - $Y \rightarrow \pi^+\pi^- h_c$
  - $Y \rightarrow \omega\chi_{cJ}$
  - $Y \rightarrow \pi^+ D^0 D^{*-}$
- A quick view of the Zc states in BESIII
  - ✧ Determination of J^p of Zc(3900)
- Observation of $e^+e^- \rightarrow \gamma X(3872)$, $X(3872) \rightarrow \pi^+\pi^- J/\psi$
- Summary

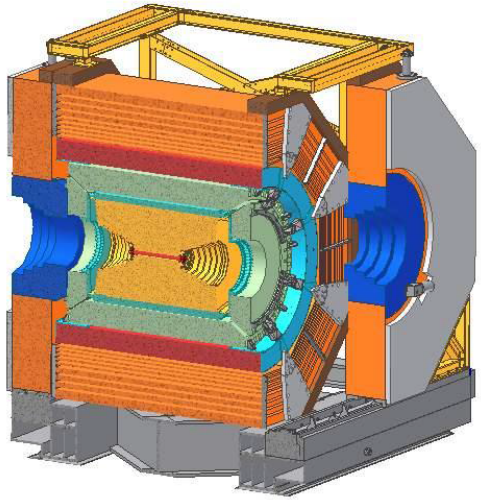
Beijing Electron and Positron Collider(BEPCII)

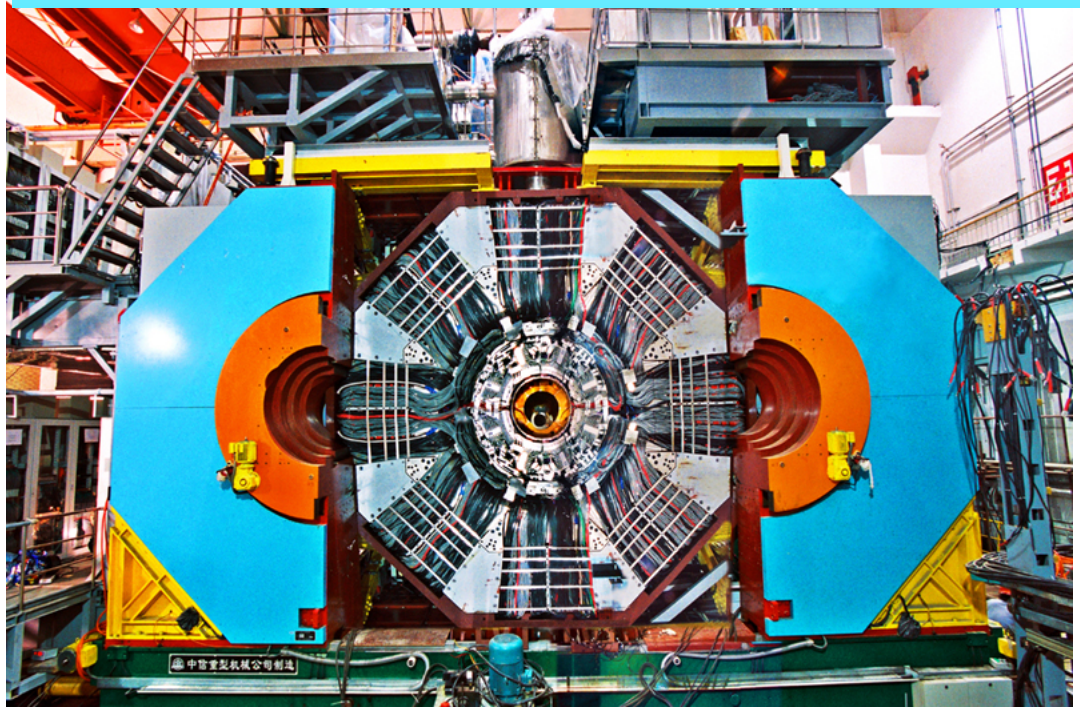


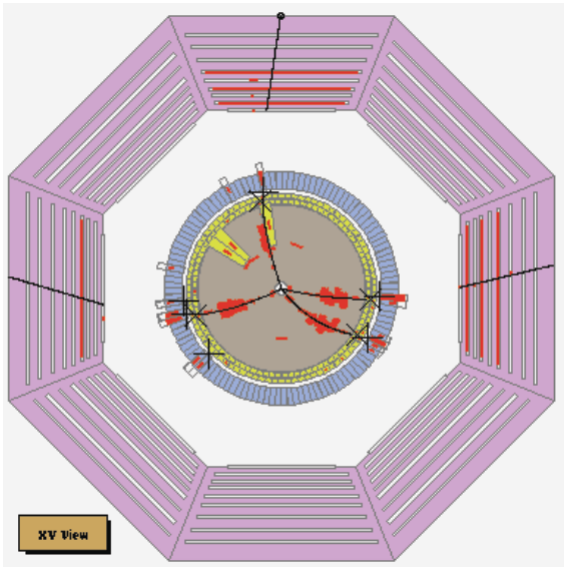
Beam energy: 1~2.3GeV

Beijing Spectrometer (BESIII)

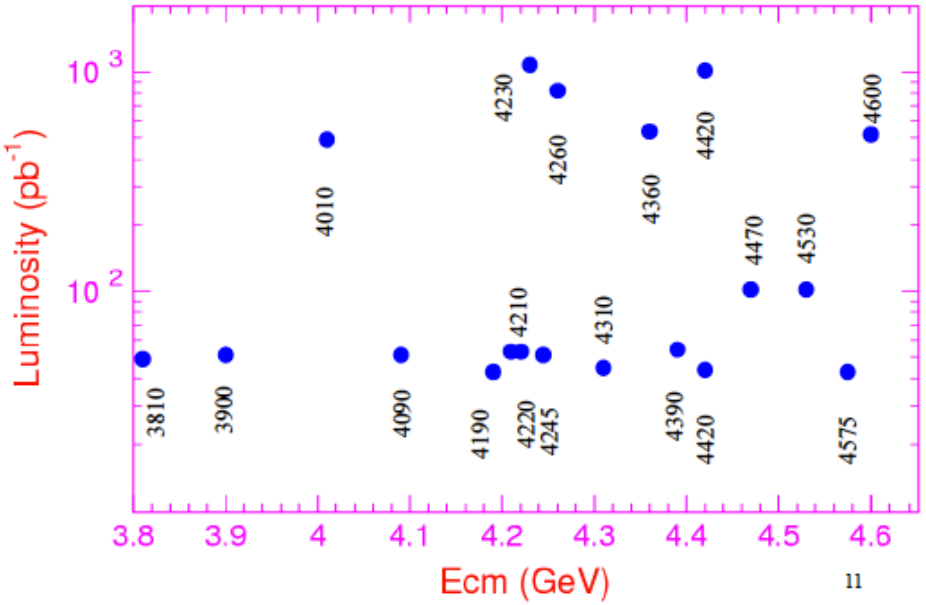
- Inner to Outside：
- ✓ Main Drift chamber(MDC),
- ✓ Time of flight System(TOF),
- ✓ Electromagnetic Calorimeter(EMC),
- ✓ Solenoid super-conducting magnet(SSM),
- ✓ Muon chamber(MUC)
- Acceptance: 93% of 4π

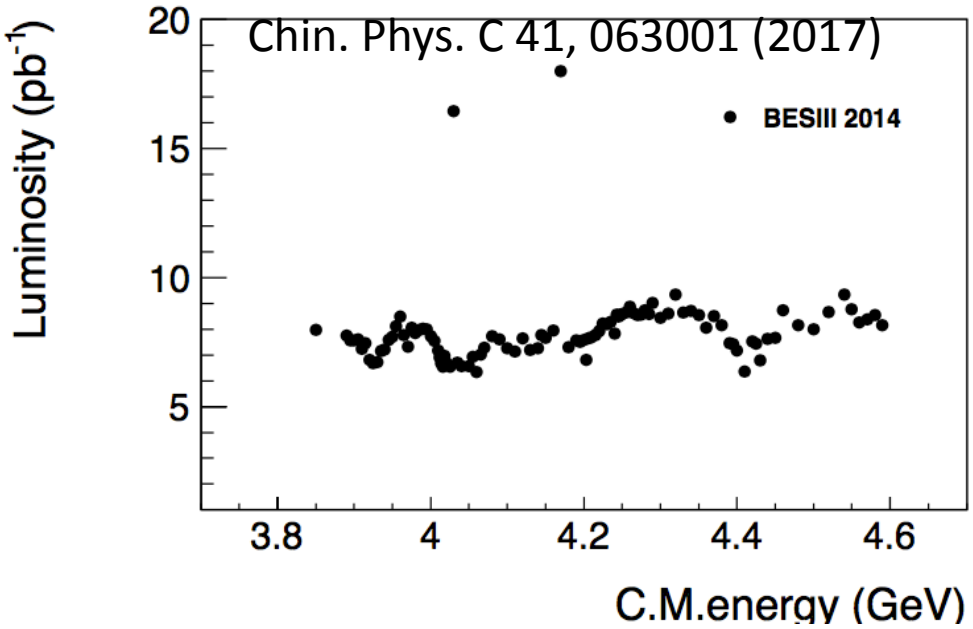






BESIII data sets for XYZ study





XYZ data

- 5 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:

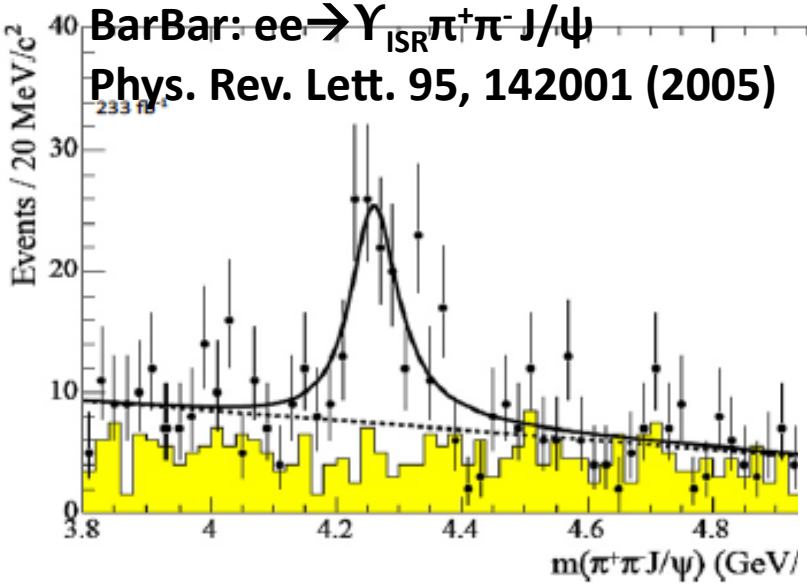
$e^+e^- \rightarrow \psi(1^{--})$ (well estabilished)→…

or

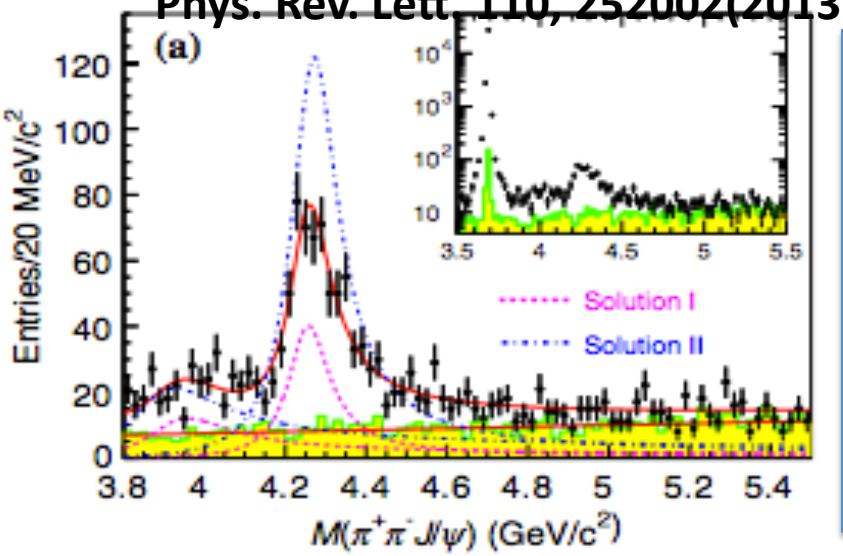
$e^+e^- \rightarrow Y(1^{--})$ (not so well estabilished)→…

Y(4260) & Y(4360): some history

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

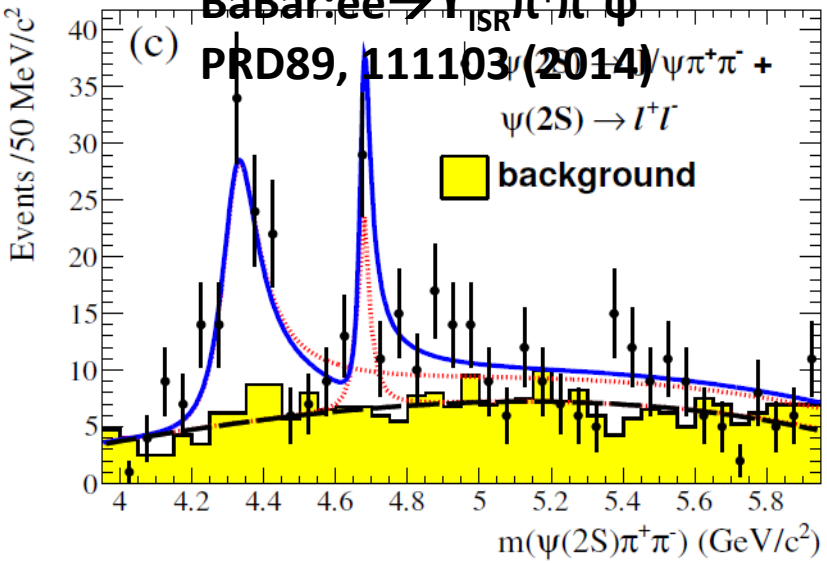


Belle: ee→$\Upsilon_{ISR}\pi^+\pi^-$ J/ψ
Phys. Rev. Lett. 110, 252002(2013)

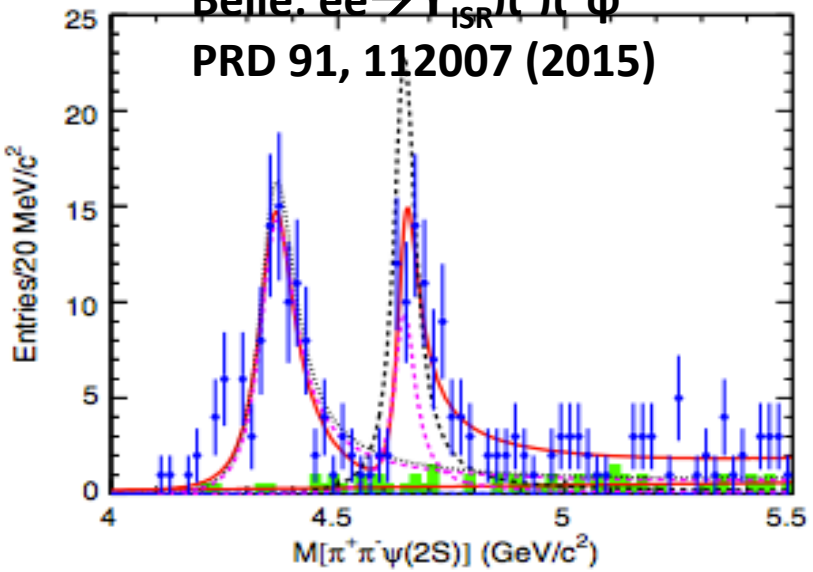


Y(4260)
PDG value
Without BES
Result:
Mass=
4251±9 MeV
width=
120±12 MeV

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



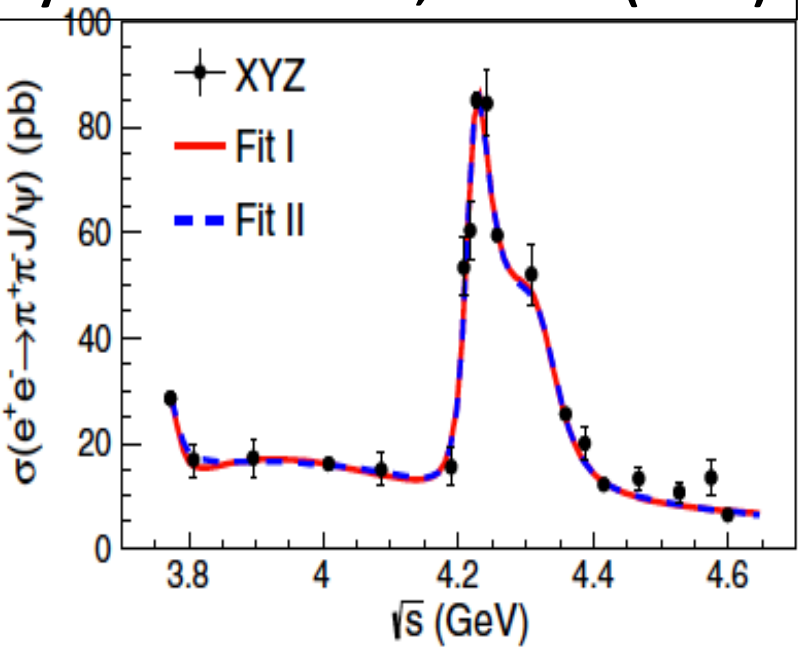
Belle: ee→$\Upsilon_{ISR}\pi^+\pi^-$ ψ'
PRD 91, 112007 (2015)

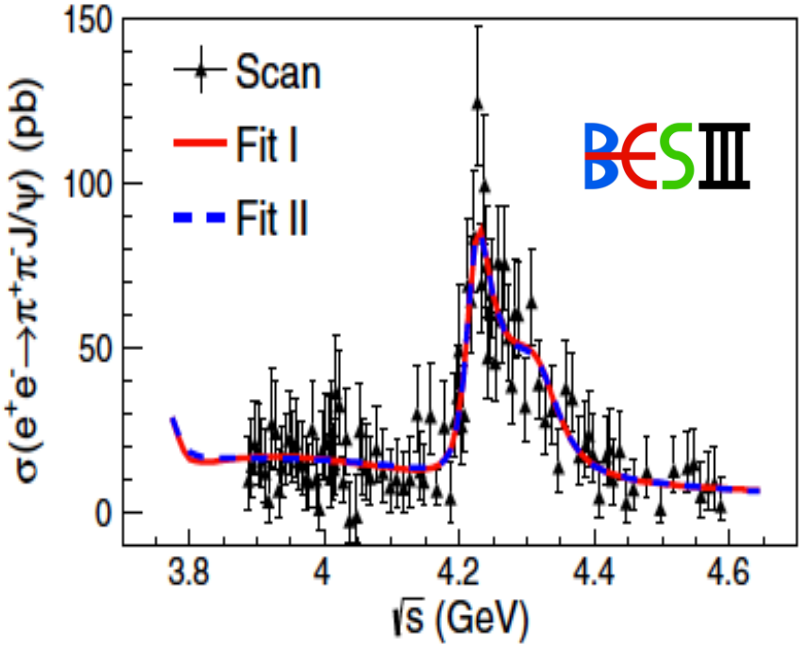


Y(4360)
PDG mass
4346±6 MeV
PDG width
102±10 MeV

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

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

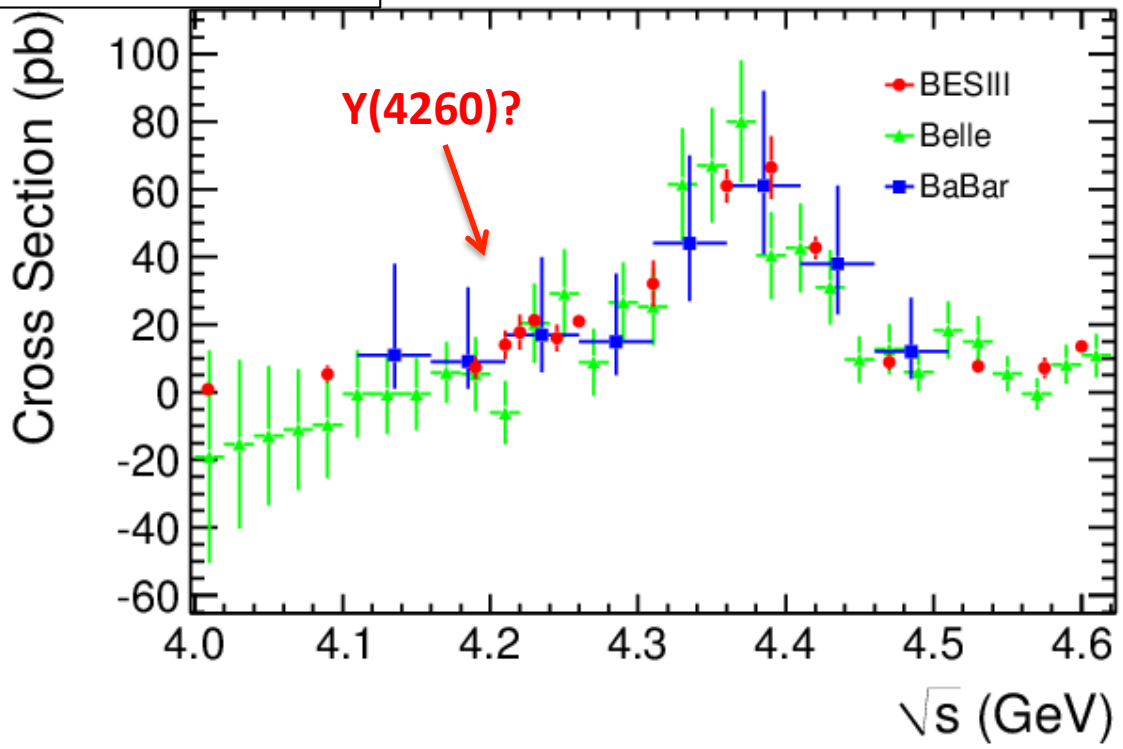




- Simultaneous fit to XYZ data (left) and R-scan data (right)
- Coherent sum of two Breit-Wigner like structure plus one incoherent ψ(3770)
  - M = (4222.0±3.1±1.4) MeV, Γ = (44.1±4.3±2.0) MeV ,
    Lower and narrower than previous Y(4260) PDG value
  - M = (4320.0±10.4±7) MeV, Γ = (101.4±25±10) MeV ,
    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 $Y(4360)\rightarrow\pi^+\pi^- J/\psi$?
- Y(4008) is not confirmed

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

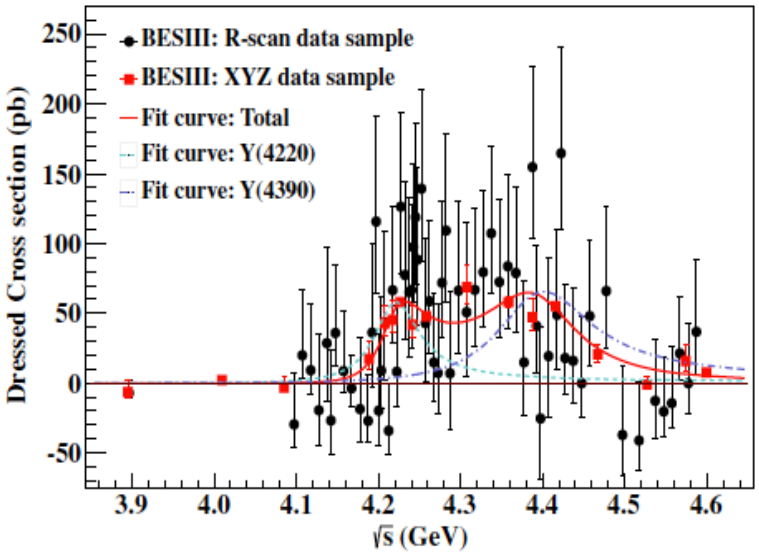
arXiv:1703.08787v1

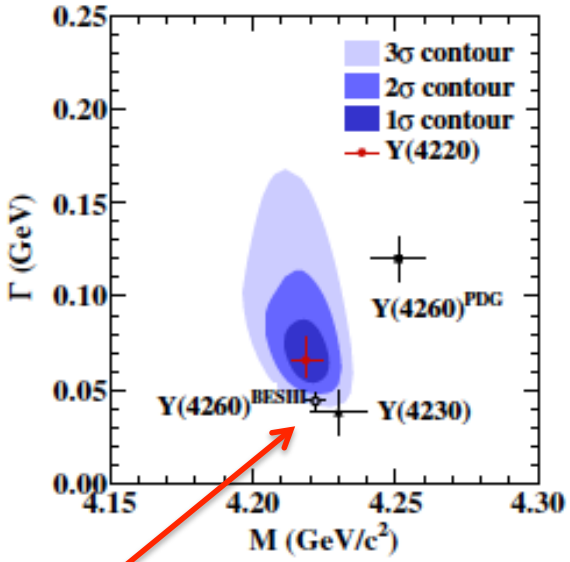


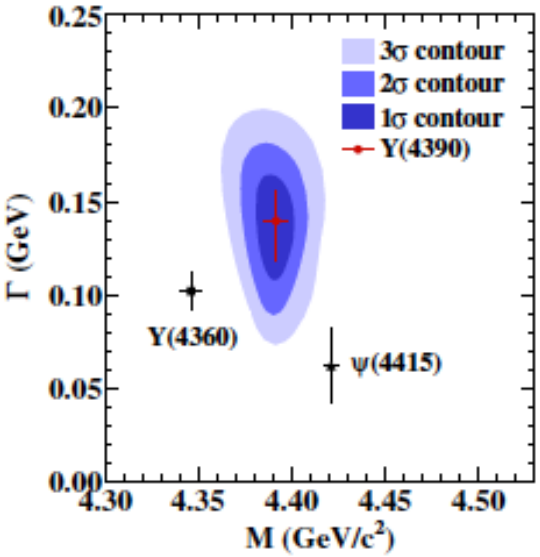
- Cross section of $e^+e^- \rightarrow \pi^+\pi^-\psi(3686)$ has been measured at 16 energy points from 4.008 to 4.600 GeV.
- A clear peak around Y(4360), consistent with Belle&BaBar's results, but with much improved precision
- A fitting on the cross sections is ongoing

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

PRL 118, 092002 (2017)



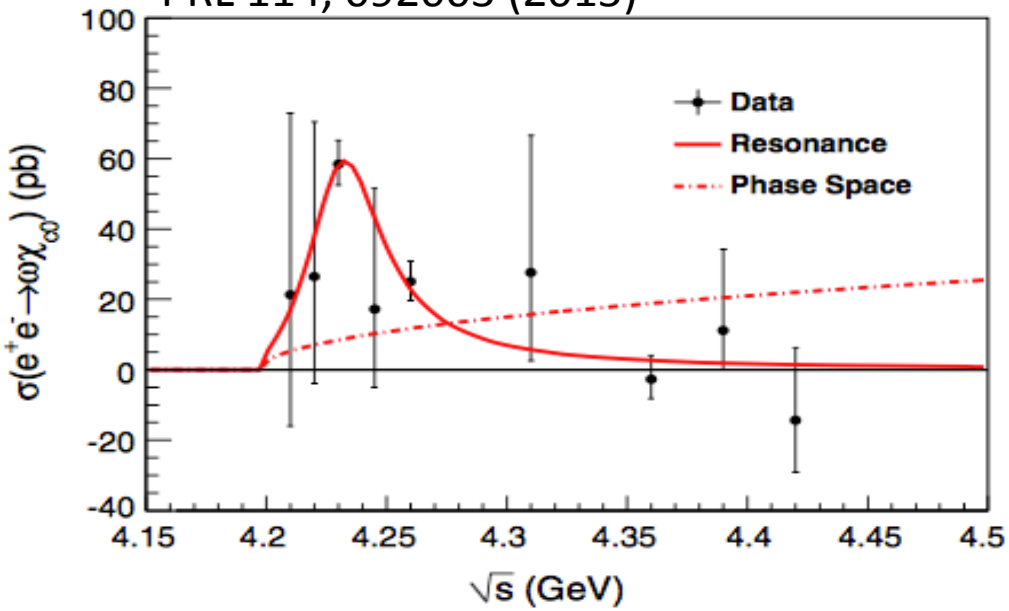


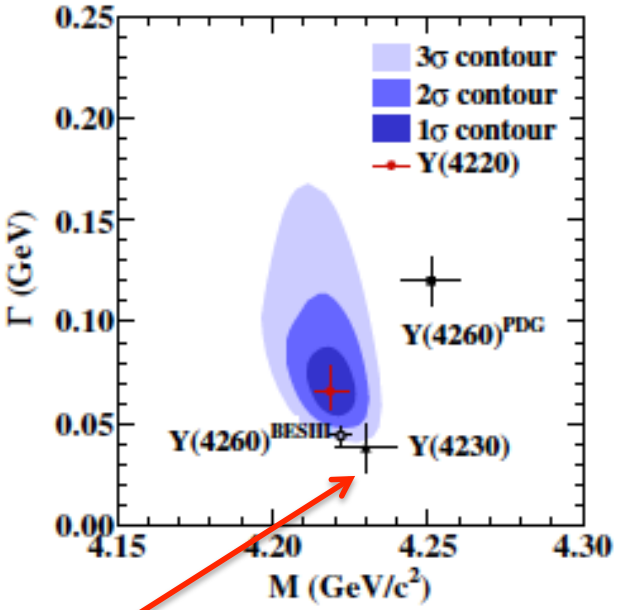


- Fitted with coherent sum of two Breit-Wigner like structue
  - $M_1=4218.4^{+5.5}_{-4.5}\pm0.9$ MeV/c^2, $\Gamma_1=66.0^{+12.3}_{-8.3}\pm0.4$ MeV → Y(4220)
  - $M_2=4391.5^{+6.3}_{-6.8}\pm1.0$ MeV/c^2, $\Gamma_2=139.5^{+16.2}_{-20.6}\pm0.6$ MeV → Y(4390)
- The Y(4220) here is consistent with the states observed in $\pi^+\pi^- J/\psi$ around 4222MeV

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

PRL 114, 092003 (2015)





- Only $\omega\chi_{c0}$ has significant signal
- The cross section is fitted with coherent sum of a Breit-Wigner and a phase space term

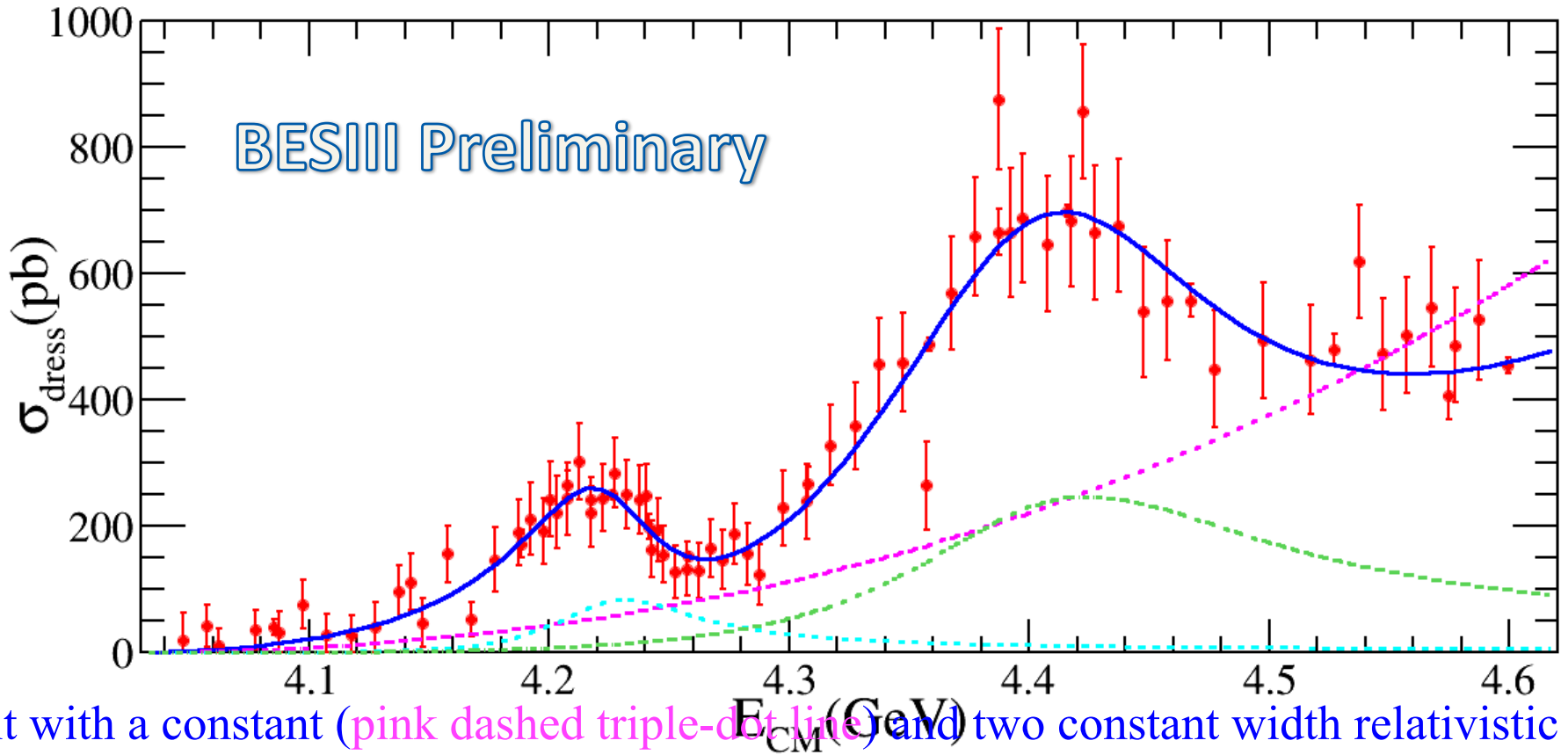
$$M = 4230 \pm 8 \pm 6 \text{ MeV}, \Gamma = 38 \pm 12 \pm 2 \text{ MeV}$$

- The mass and width here is compatible with the Y observed in $\pi^+\pi^- J/\psi$ and $e^+e^- \rightarrow \pi^+\pi^- h_c$

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

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

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



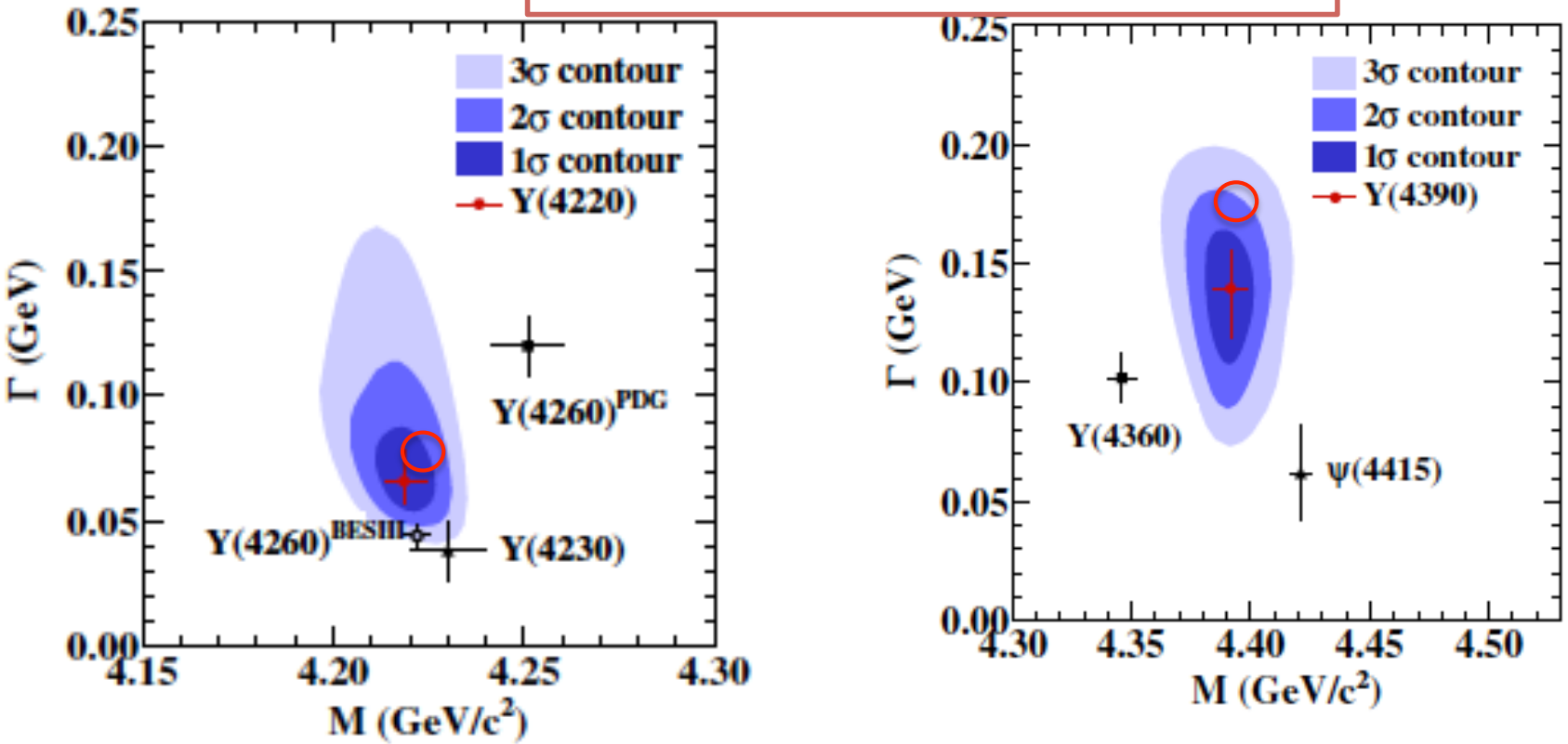
Fit with a constant (pink dashed triple-dot line) and two constant width relativistic BW functions (green dashed double-dot line and aqua dashed line).

$M(Y(4220)) = (4224.8 \pm 5.6 \pm 4.0)\,\text{MeV}/c^2$, $\Gamma(Y(4220)) = (72.3 \pm 9.1 \pm 0.9)\,\text{MeV}$.

$M(Y(4390)) = (4400.1 \pm 9.3 \pm 2.1)\,\text{MeV}/c^2$, $\Gamma(Y(4220)) = (181.7 \pm 16.9 \pm 7.4)\,\text{MeV}$.

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

Red circle is the result of $e^+e^- \rightarrow \pi^+D^0D^{*-}$



- The statistical significance of two resonances assumption over one resonance is greater than 10s.
- The resonant parameters of Y(4220) and Y(4390) states are consistent with the structures observed in $e^+e^- \rightarrow \pi^+\pi^- h_c$. The resonant parameters of Y(4220) are also consistent with those of the resonance observed in $e^+e^- \rightarrow \omega\chi_{c0}$ and $e^+e^- \rightarrow \pi^+\pi^- J/\psi$.

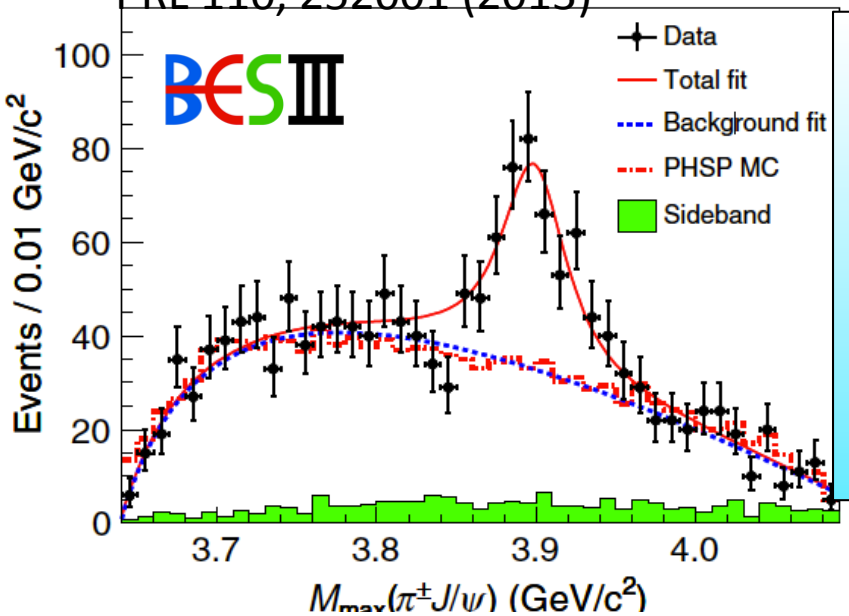
Part II: Zc states

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

$Z_c \rightarrow \pi(J/\psi, \psi', h_c)$ or $D^*D^{(*)}$

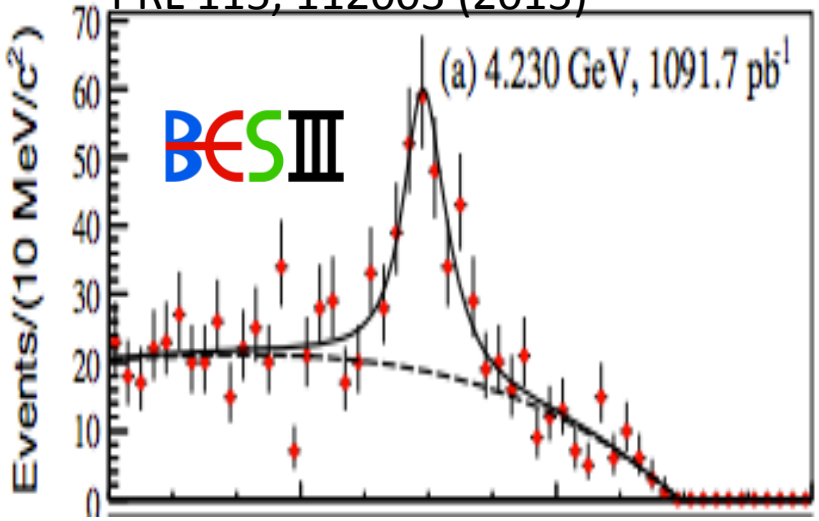
$Zc(3900)^{\pm,0}$ in $\pi^+\pi^-$ J/ψ, $\pi^0\pi^0$ J/ψ

PRL 110, 252001 (2013)



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

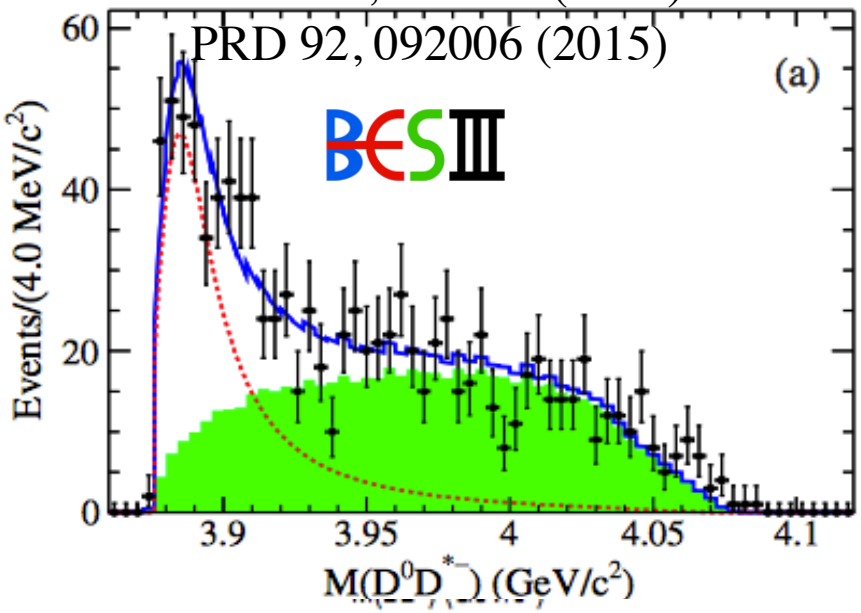
PRL 115, 112003 (2015)



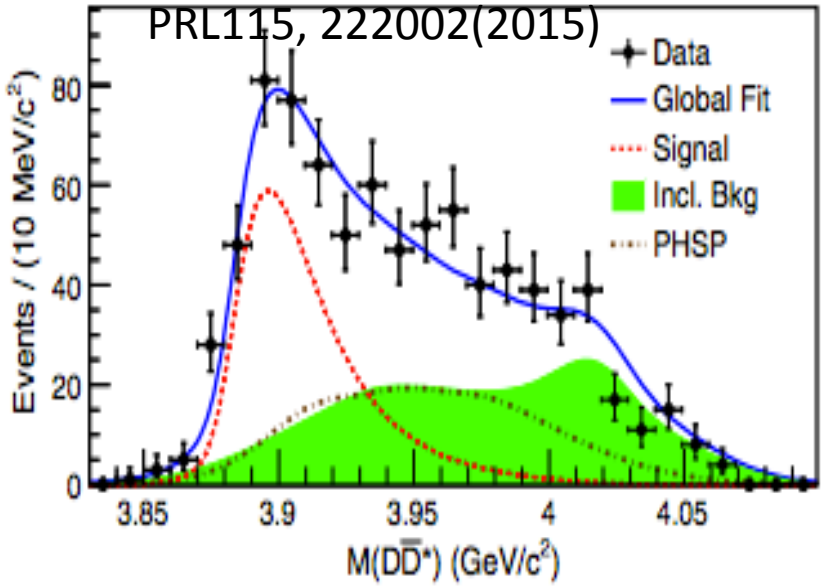
- $e^+e^- \rightarrow \pi^0\pi^0$ J/ψ
- M=3894.8±2.3±2.7 MeV,
  Γ=29.6±8.2±8.2 MeV
- IsoSpin triplet.
- $Zc(3900)^0 \rightarrow \pi^0$ J/ψ , C parity of Zc^0=-1

$Zc(3885)^{\pm,0}$ in $e^+e^- \to \pi(D\overline{D^*})$

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



PRL115, 222002(2015)



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

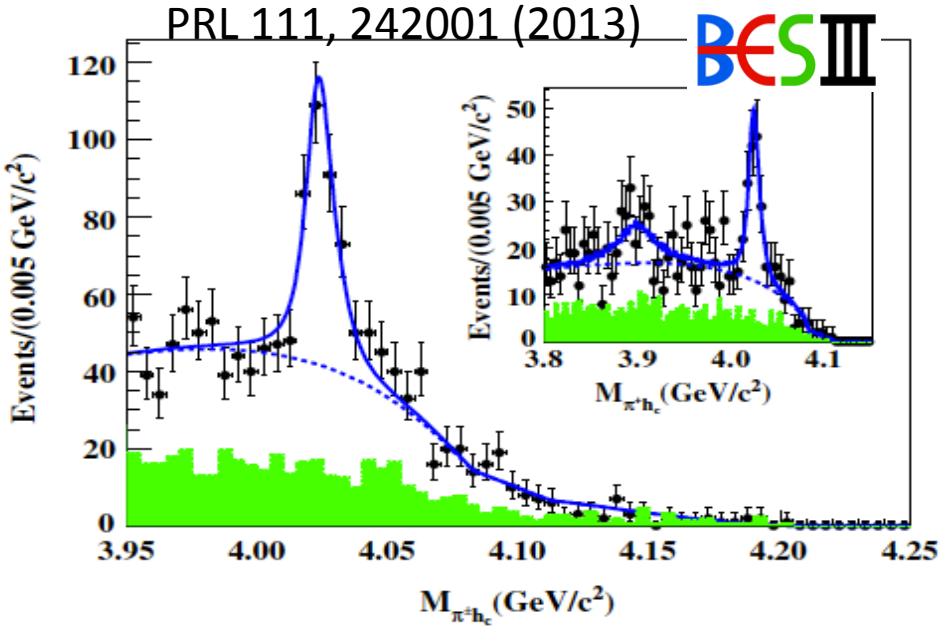
- M=3881.7±1.6±1.6 MeV,
  Γ=26.6±2.0±2.1 MeV
- The mass is close to the threshold of DD*

$e^+e^- \to \pi^0 Z_c(3885)^0 \to \pi^0 (D\overline{D^*})^0$

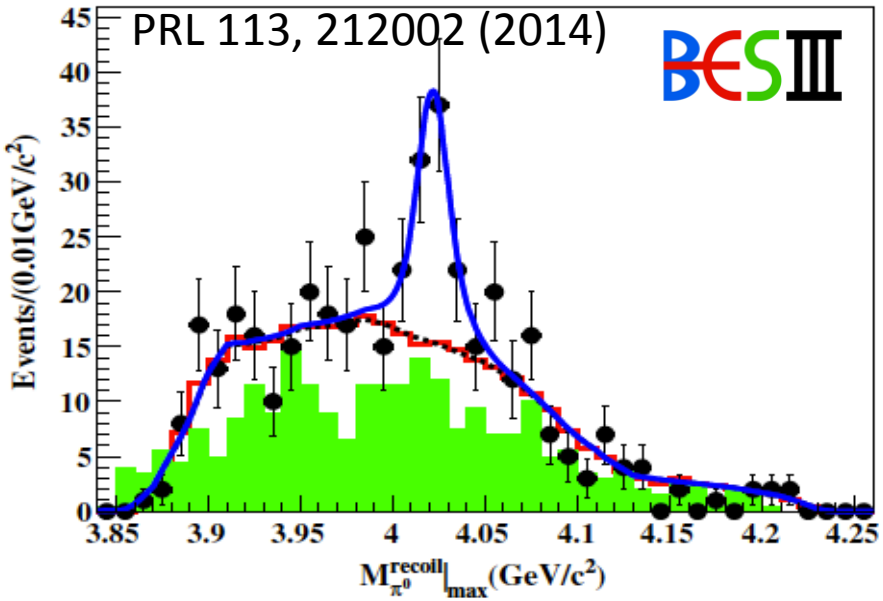
$M = 3885.7^{+4.3}_{-5.7} \pm 8.4 \quad MeV$

$\Gamma = 35^{+11}_{-12} \pm 15 \quad MeV$

$Z_c(4020)^{\pm,0}$ in $e^+e^- \to \pi^+\pi^- h_c$, $\pi^0\pi^0 h_c$



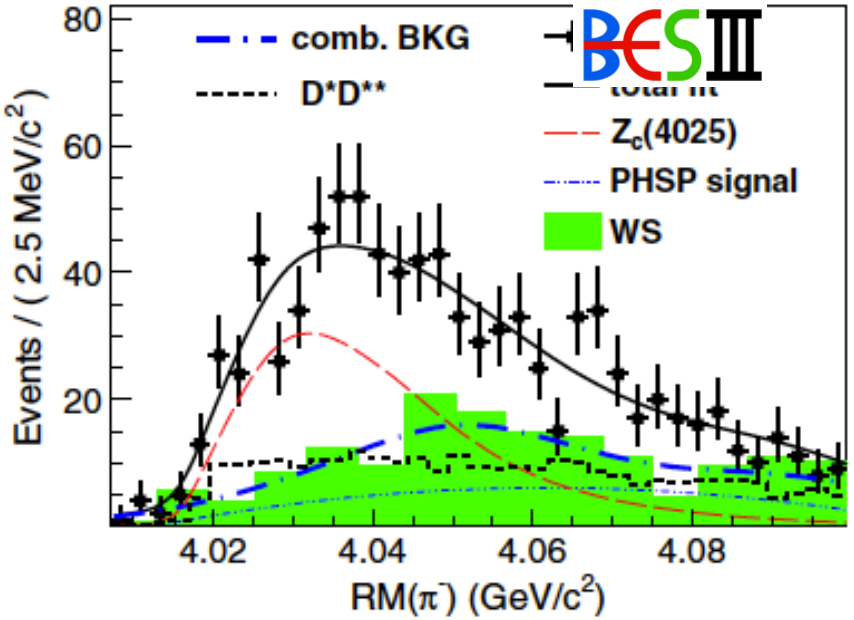
- $e^+e^- \to \pi^+\pi^- h_c$
- M=4022.9±0.8±2.7 MeV,
- Γ =7.9±2.7±2.6 MeV
- significance of Zc(4020) >8.9σ,
- significance of Zc(3900) =2.1σ



- $e^+e^- \to \pi^0\pi^0 h_c$
- Mass=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*)

$Zc(4025)^{\pm,0} \rightarrow (D^* \overline{D}^*)^{\mp,0}$

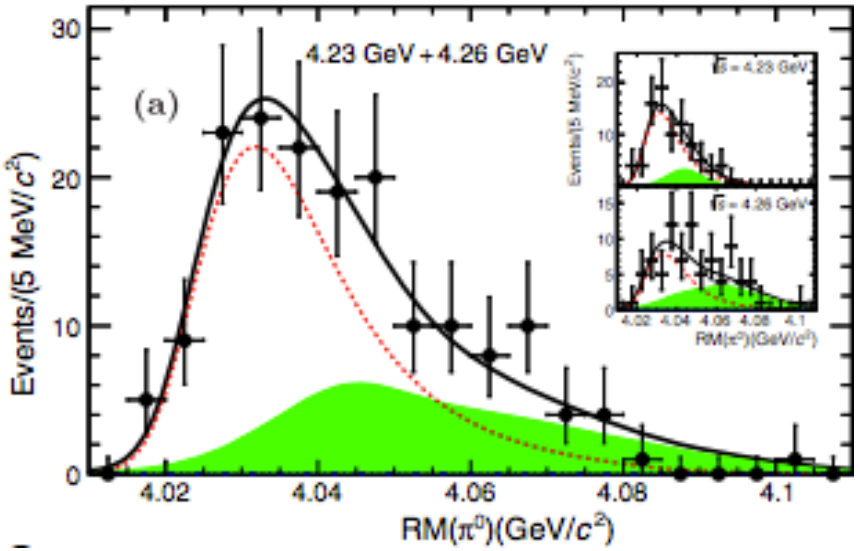
PRL 112, 132001 (2014)



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

- $Zc(4025)^\pm$ parameters, S-wave BW
  M=(4026.3±2.6±3.7) MeV,
  Γ=(24.8±5.6±7.7)MeV
- Significance > 10σ

PRL 115, 182002 (2015)



$$e^+e^- \rightarrow \pi^0 Z_c(4025)^0 \rightarrow \pi^0 (D^* \overline{D^*})^0$$

$$M = 4025.5^{+2.0}_{-4.7} \pm 3.1 \quad MeV$$

$$\Gamma = 23.0 \pm 6.0 \pm 1.0 \quad MeV$$

The BESIII result for Zc family

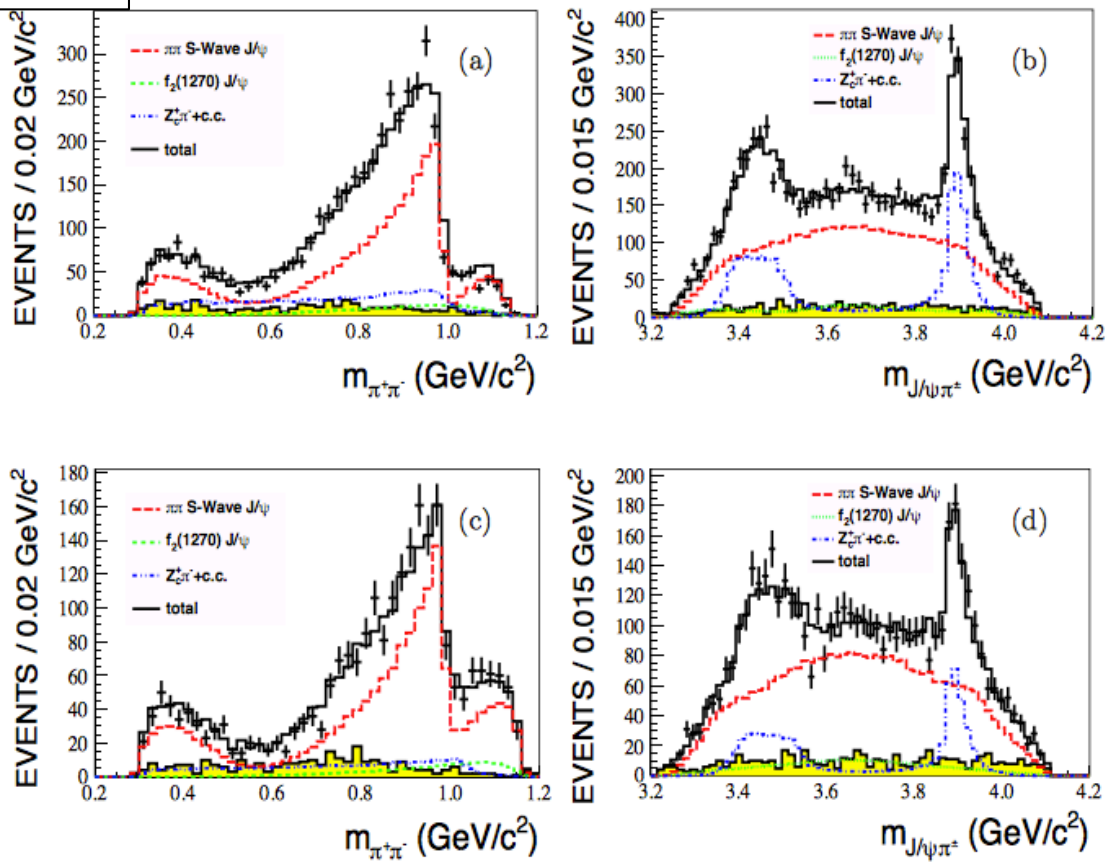
For reference: the mass threshold of m(DD*)~3875MeV, M(D*D*)~4014MeV

- **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)

arXiv:1706.04100v1



4.23GeV

4.26GeV

- Amplitude analysis with helicity formalism 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, f0(980), f2(1270) and f0(1370)

Determination of J^p of Zc(3900)

- **Zc is parameterized with Flatte formula**

$$BW(s) = \frac{1}{s - M^2 + i(g_1' \rho_{\pi J/\psi}(s) + g_2' \rho_{D^* D}(s))}$$

$g_2'/g_1' = 27.1 \pm 13.1$ according to the measurement

$\Gamma(Z_c^{\pm} \to (D\bar{D}^*)^{\pm})/\Gamma(Z_c^{\pm} \to J/\psi\pi^{\pm}) = 6.2 \pm 2.9$

The fitted mass, g_1', g_2'/g_1' and $-\ln L$ for the Z_c resonance.

$Z_c : J^P$	M (MeV)	g_1' (GeV^2)	g_2'/g_1'	$-\ln L$
1^+	3900.2 ± 1.5	0.075 ± 0.006	21.8 ± 1.7	-1569.8

Z_c pole mass and with:

$M_{\text{pole}} = 3887.0 \pm 0.8 \pm 10.0$ MeV, $\Gamma_{\text{pole}} = 45.2 \pm 4.8 \pm 16.8$ MeV

Determination of J^p of Zc(3900)

$Z_c : J^P$	M (MeV)	$g_1'(\mathrm{GeV}^2)$	g_2'/g_1'	$-\ln L$
0^-	3906.3 ± 2.3	0.079 ± 0.007	25.8 ± 2.9	-1528.8
1^-	3903.1 ± 1.9	0.063 ± 0.005	26.5 ± 2.6	-1457.7
1^+	3900.2 ± 1.5	0.075 ± 0.006	21.8 ± 1.7	-1569.8
2^-	3905.2 ± 2.1	0.060 ± 0.004	28.7 ± 2.7	-1516.5
2^+	3894.3 ± 1.9	0.051 ± 0.005	23.4 ± 3.3	-1316.2

- **J^p of Zc favor to be 1^+ with statistical significance larger than 7.3σ over other quantum numbers**

- Significance for $e^+e^- \to Z_c^+(4020)\ \pi^- + c.c \to \pi^+\pi^- J/\psi$ is ~3σ.

Upper limits at 90% C.L.:

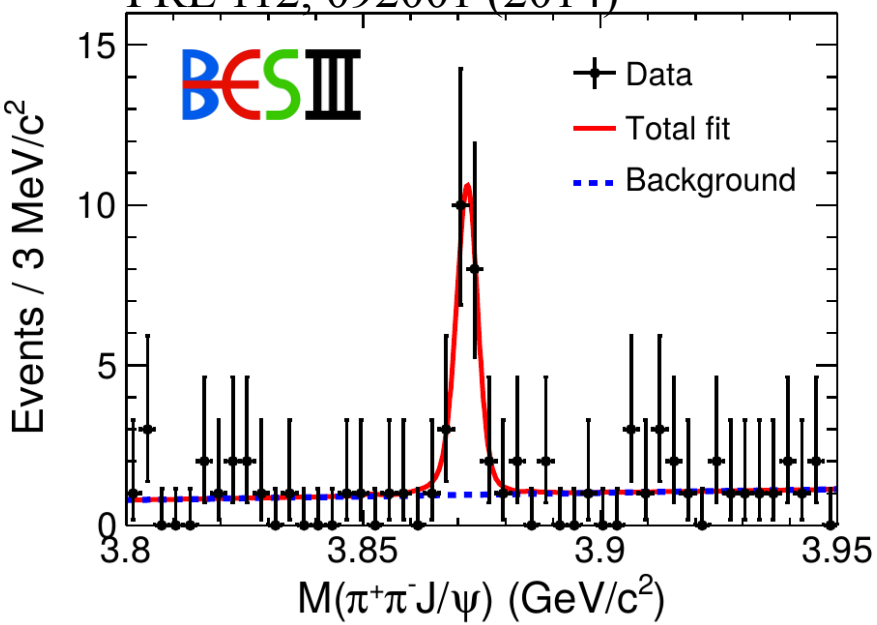
$$\frac{\sigma(e^+e^- \to Z_c^+(4020)\ \pi^- + c.c \to \pi^+\pi^- J/\psi)}{\sigma(e^+e^- \to Z_c^+(3900)\ \pi^- + c.c \to \pi^+\pi^- J/\psi)} < 3.3\% \text{ at } 4.23 \text{ GeV}$$

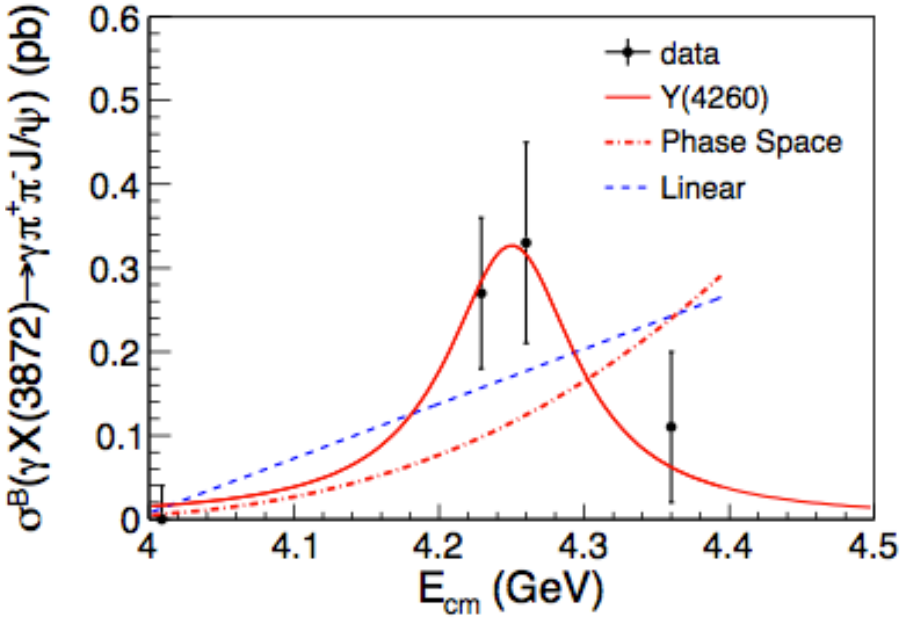
$$< 25.1\% \text{ at } 4.26 \text{ GeV}$$

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 $Y(4260)$

Summary

- **The Y(4260) are measured to be lower and narrower than previous PDG value with $\pi^+\pi^- J/\psi$, $\pi^+\pi^- h_c$, $\omega\chi_{cJ}$ and $\pi^+ D^0 D^{*-}$**

- **A new structure around 4.39GeV is observed in $\pi^+\pi^- h_c$ and $\pi^+ D^0 D^{*-}$**

- **Two possible sets of isospin triplet Zc(3900)/ Zc(4020) are observed.**

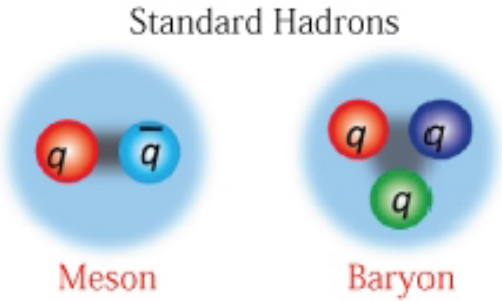
- **The J^P of $Z_c(3900)$ are determined to be 1^+**

- **$e^+e^- \rightarrow \gamma X(3872)$, $X(3872) \rightarrow \pi^+\pi^- J/\psi$ are observed, and a sign of $Y(4260) \rightarrow \gamma X(3872)$**

Backup

What's the exotic states

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



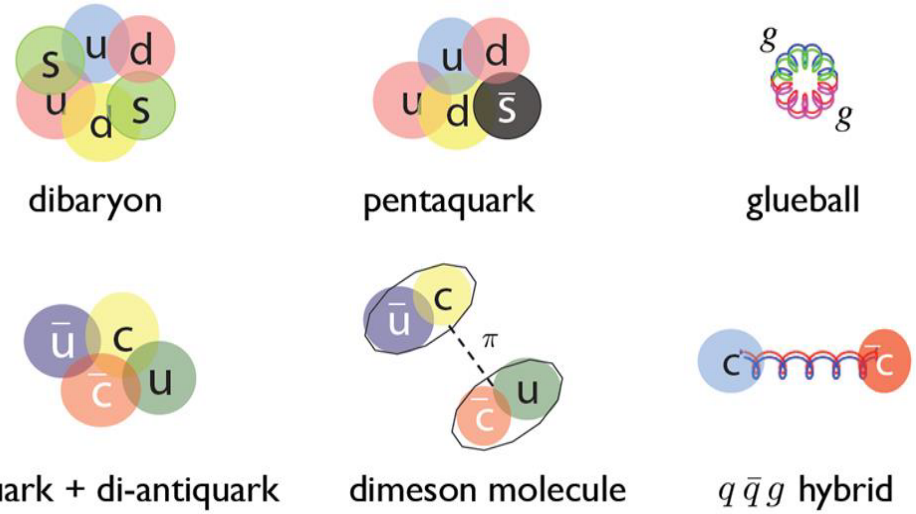
- **The QCD allow the existence of exotic states:**

✓ **Glueball (gg, ggg…)**

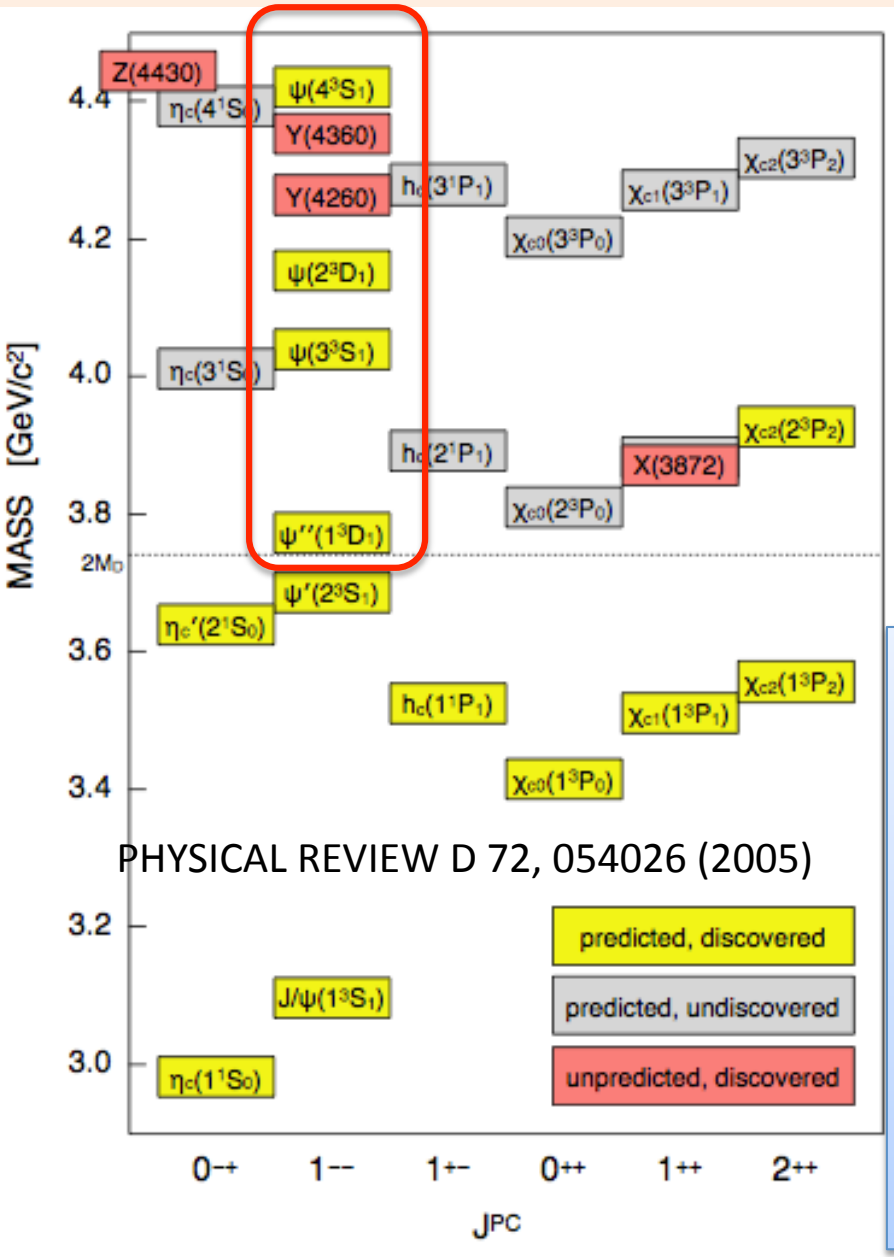
✓ **Multi-quark states (qqqq, qqqqq…)**

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

✓ **Hybrid (qqg)**



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

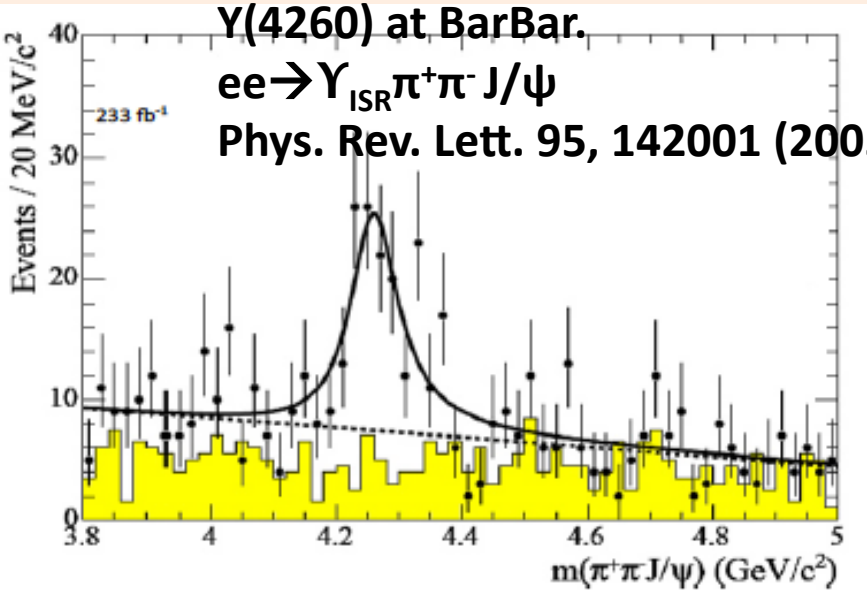


PHYSICAL REVIEW D 72, 054026 (2005)

Y(4260) at BarBar.

ee→$Y_{ISR}\pi^+\pi^-$ J/ψ

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



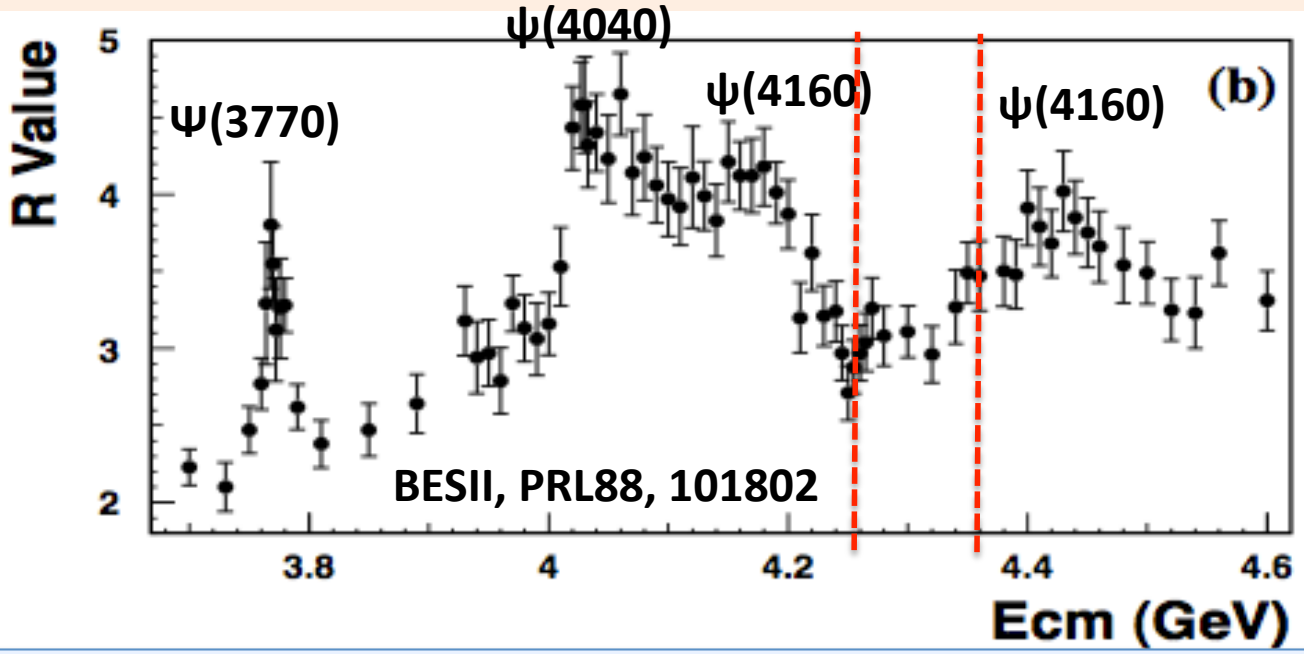
❑Y(4260), Y(4360) are not predicted by the Potential theory:

"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.

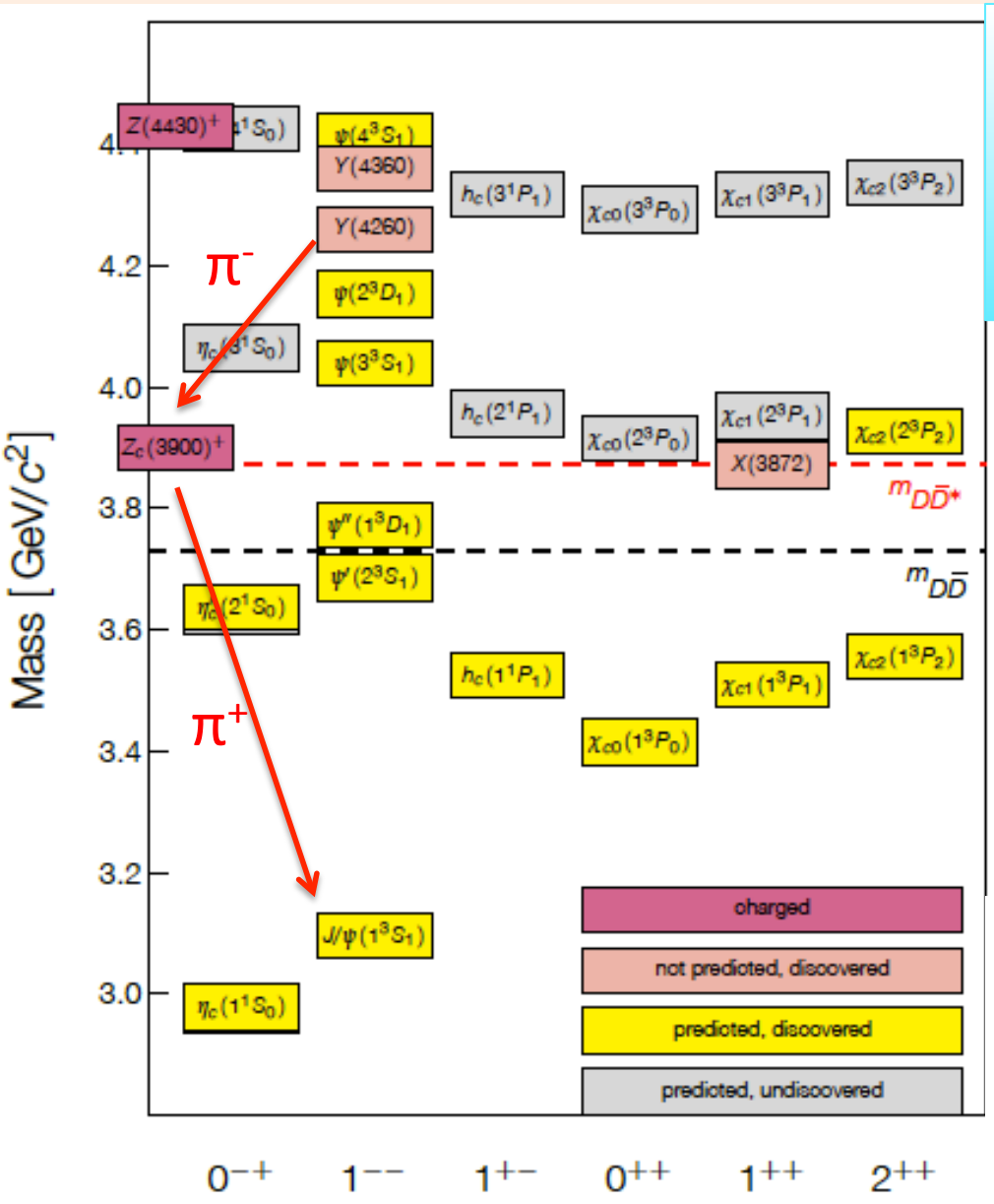
$\Gamma(D\overline{D})/\Gamma(J/\psi\pi^+\pi^-)$ Y(4260) PDG Γ_{23}/Γ_2

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

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

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

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?**

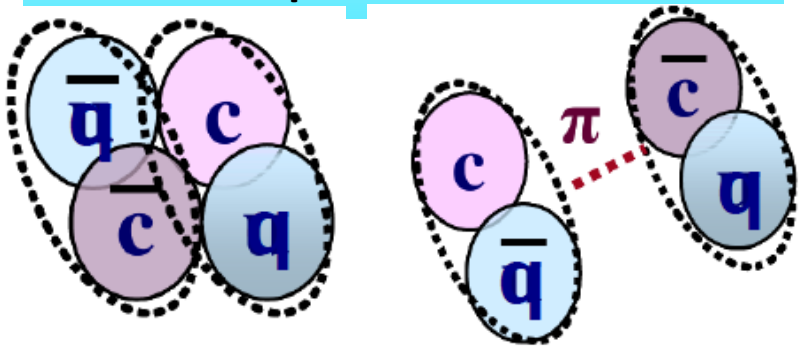
Phys. Rev. D89,054019(2014);

Phys. Rev. D90,054009(2014);

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

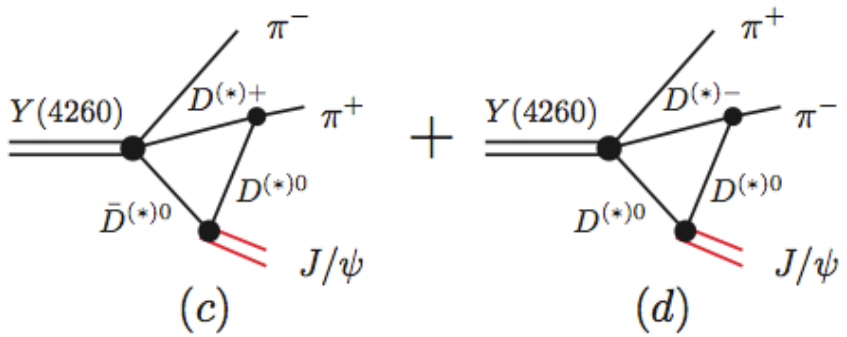
Arxiv:1303.6608, 1304.2882

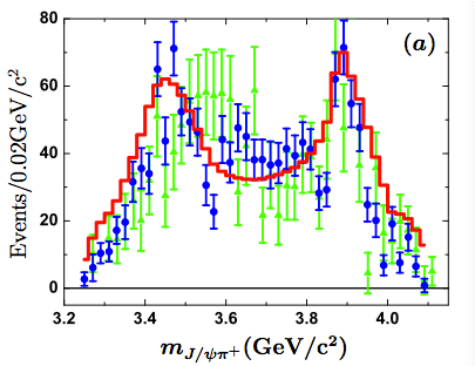
OR other explanation?



Other explanation of Zc(3900)

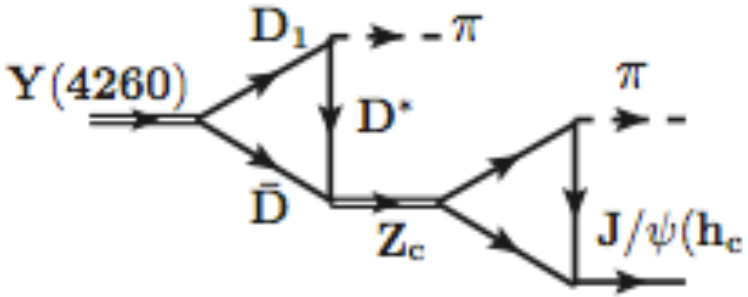
- ISPE(Initial single pion emission) model. (arxiv：1304.5845)

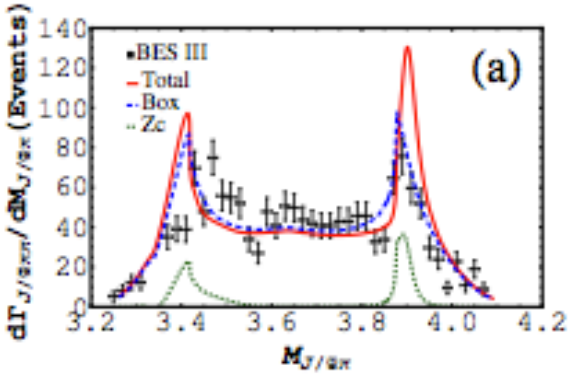




- Meson loop model. (Arxiv：1303.6355）

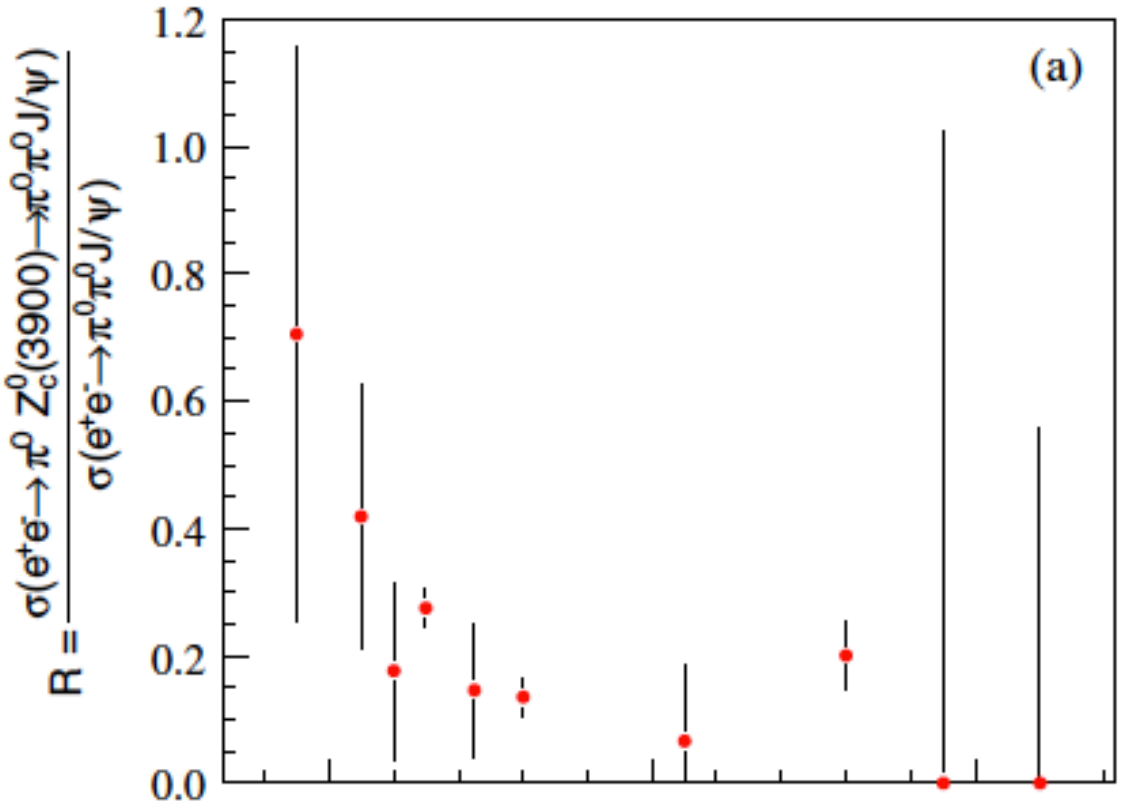
Based on the assumption that Y(4260) is (DD1) molecular states





- …

Relation between Y and Z



PRL 115, 112003 (2015)