XYZ STATES AT BESIII

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Institute of High Energy Physics, CAS
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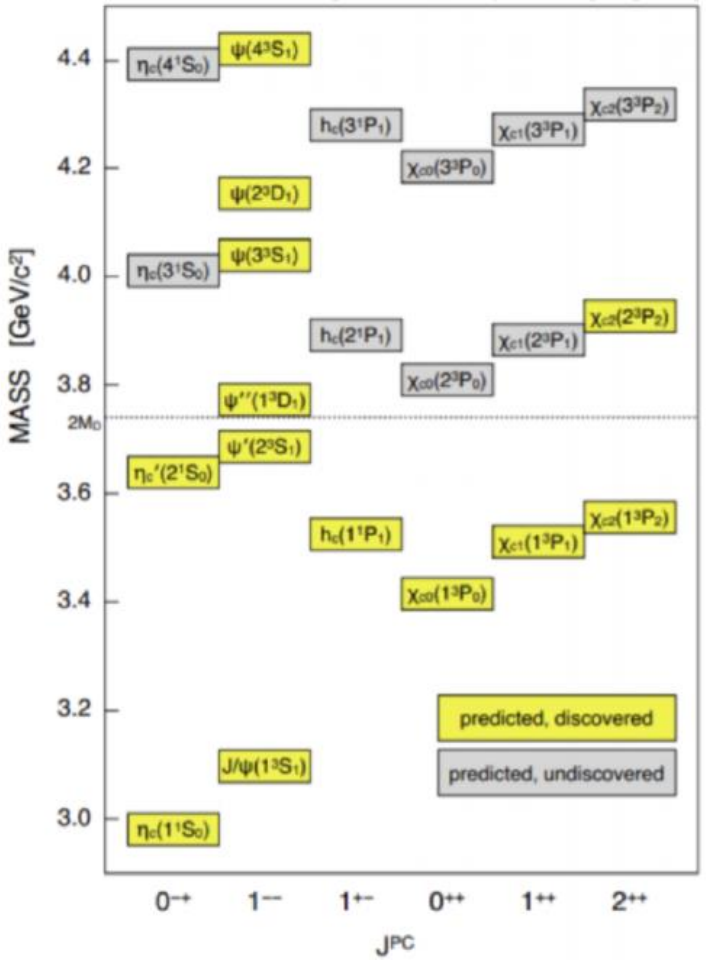
Outline

- Introduce to exotic states
- BESIII experimental results
  - Results on X states
  - Results on Y states
  - Results on Z states
- Summary and Outlook

Charmonium Spectroscopy

- Potential model works well in describing the higher quarkonia states.
  - Masses of the charmonium states below open-charm thresold matches predictions.
  - Many predicted states above the threshold but not discovered.



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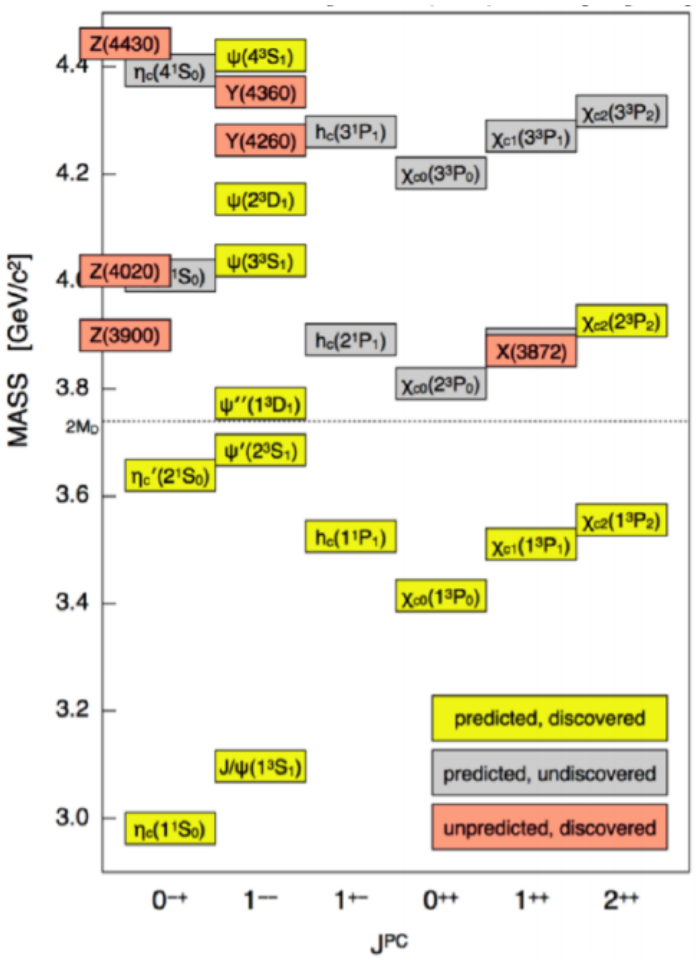

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  - Masses of the charmonium states below open-charm thresold matches predictions.
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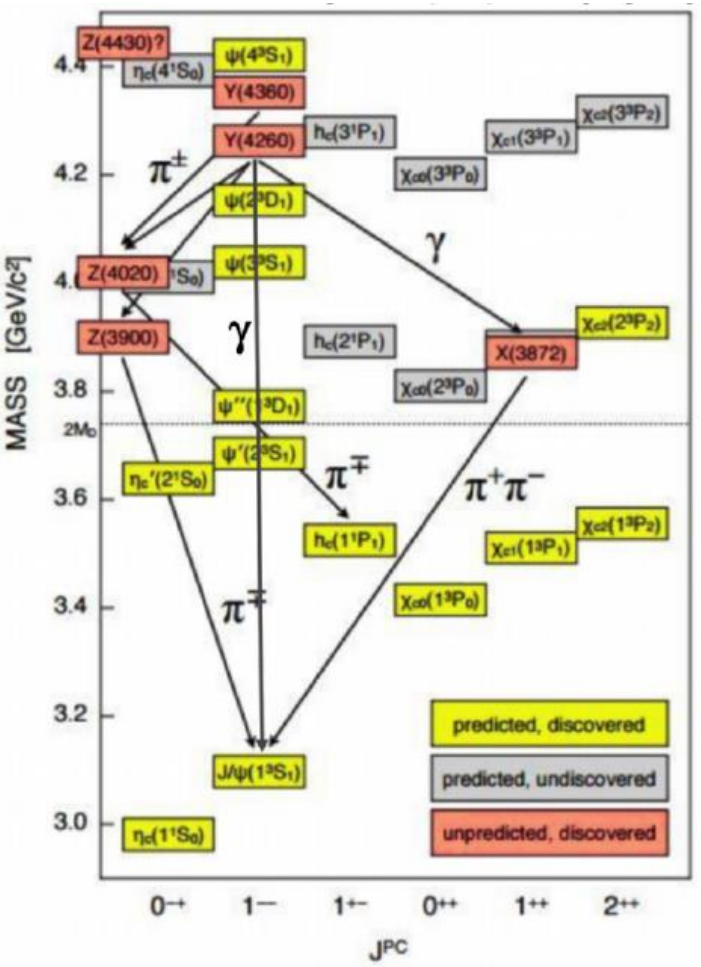
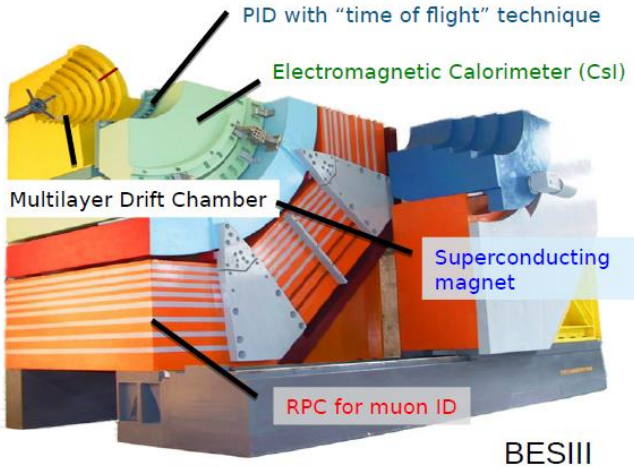
- An abundance of states discovered in recent years beyond prediction.
  - Transitions to $c\bar{c}$ final states
  - Charmonium-like or XYZ states

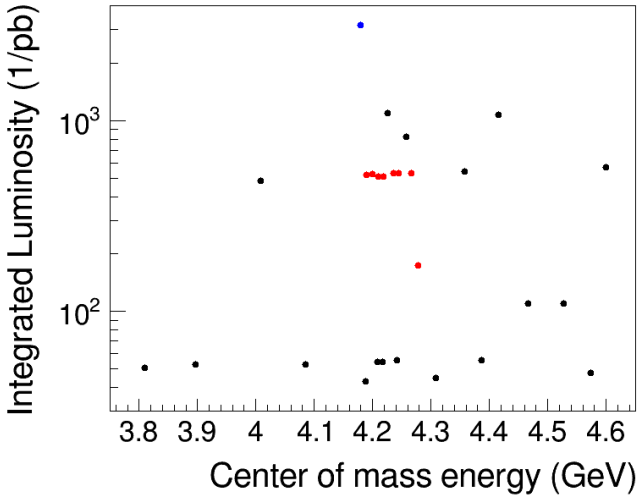


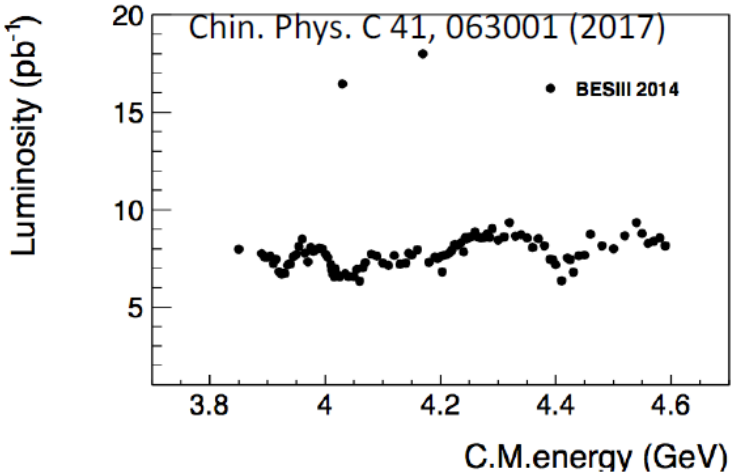
BEPCII & BESIII

- τ-charm factory
- $E_{cms} = 2 - 4.6$ GeV
- $\mathcal{L}_{max} = 10^{33}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$



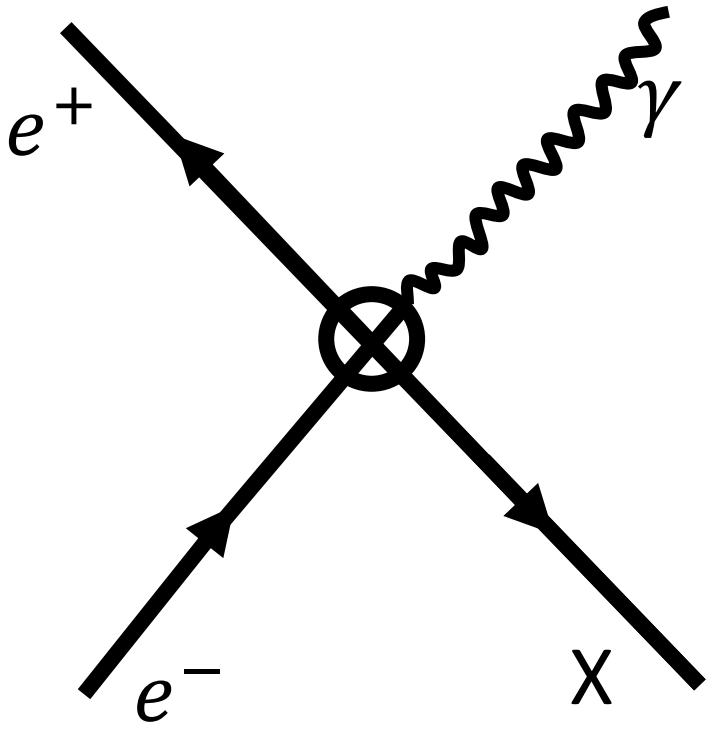
BESIII dataset for XYZ study





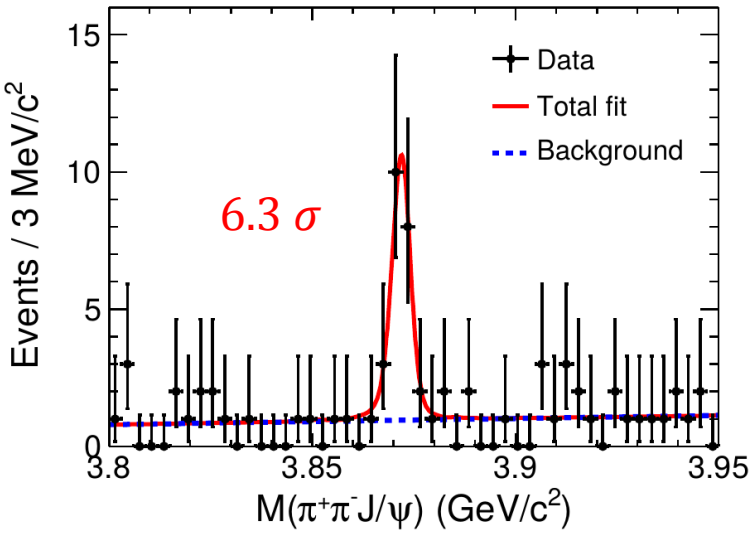
- XYZ data
  - ~12 fb^{-1} total
  - Massive sample collected around $4.260\ \mathrm{GeV}$
- R Scan data
  - $3.85 - 4.59\ \mathrm{GeV}$.
  - 104 points, ~$8\ \mathrm{pb}^{-1}$ each.

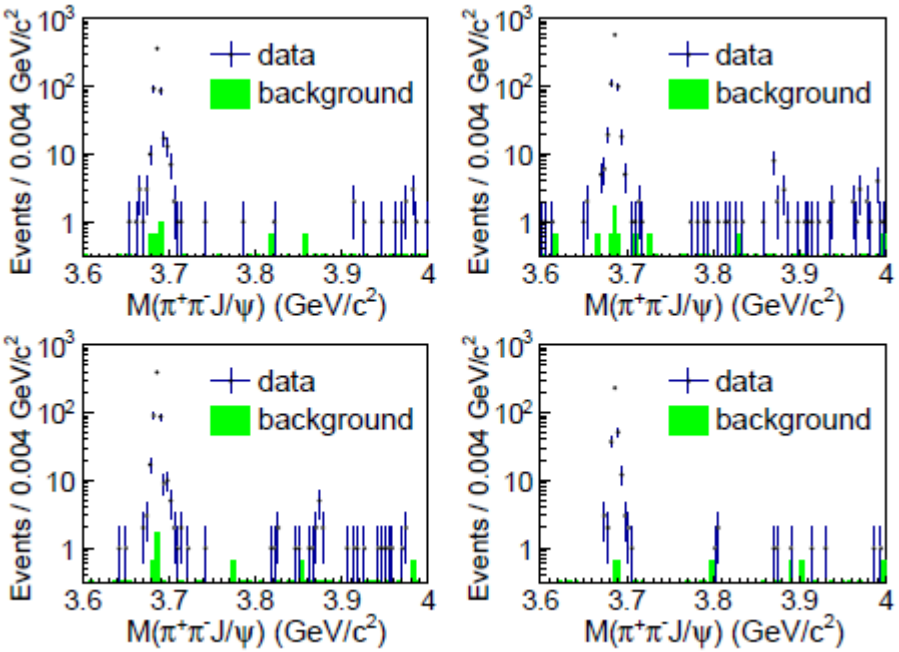
RESULTS ON



X States: $e^+e^- \to \gamma X(3872)$

PRL 112, 092001(2014)





Four energy points from 4.009 to 4.360 GeV

Calibrated by ψ', $M = \left(3871.9 \pm 0.7_{\text{stat.}} \pm 0.2_{\text{sys.}}\right)\ \text{MeV/c}^2$

$\Gamma < 2.4\ \text{MeV}\ (90\%\ \text{C. L.})$

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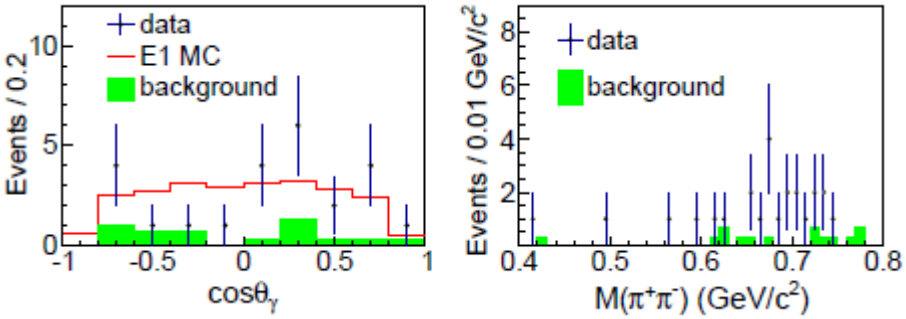
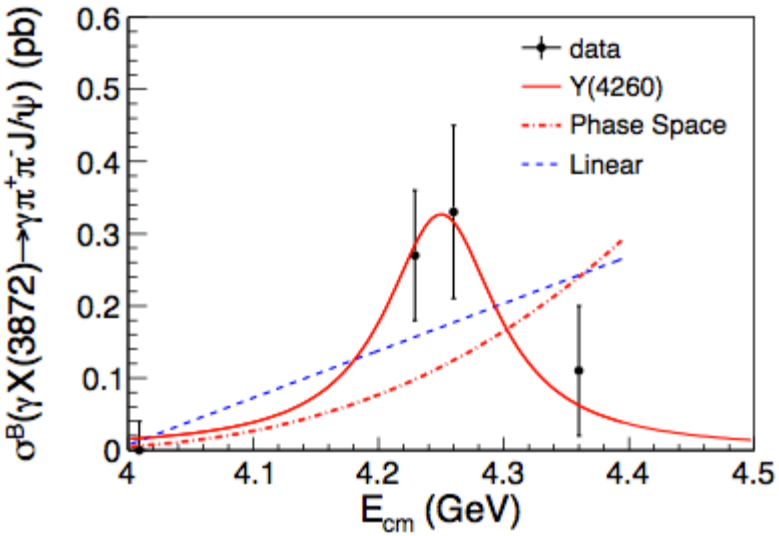


Angular distribution agree with $E1$ transition between $Y(4260)$ and $X(3872)$.
A dominant ρ^0 resonance contribution.



The $Y(4260)$ describes better than other two hypothesis.

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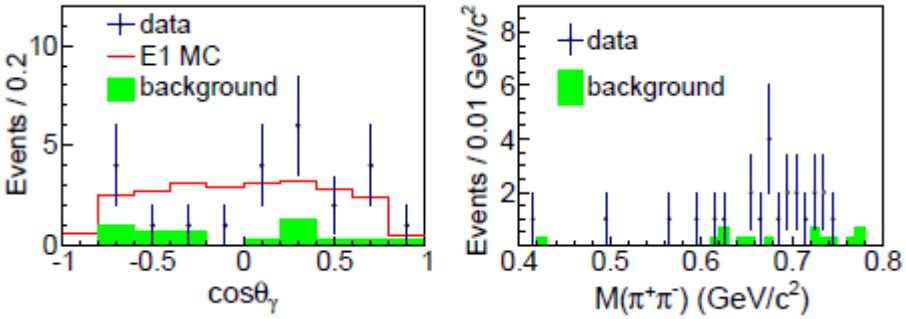

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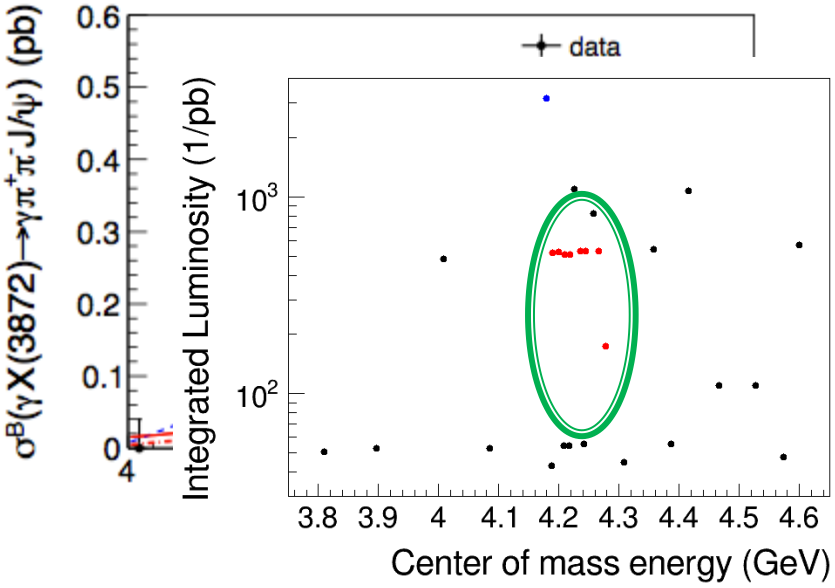


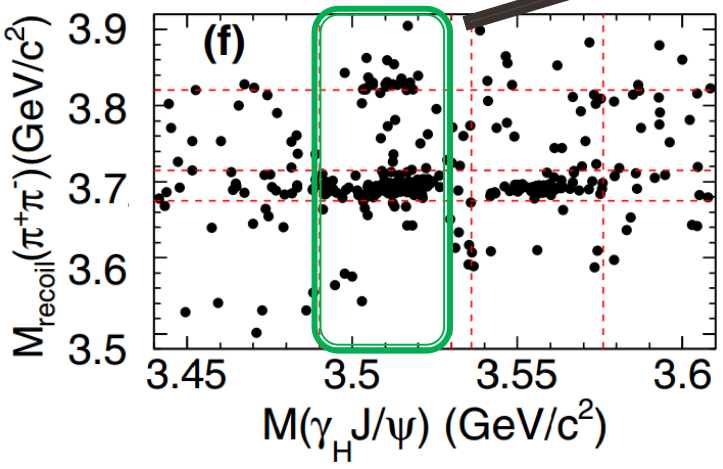
The $Y(4260)$ describes better than other two hypothesis.

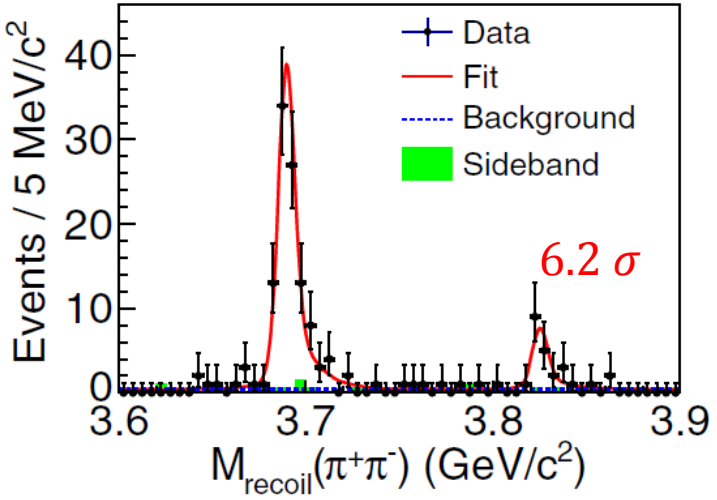
With more data taken in last year, we can investigate more on the relation between the exotic $X(3872)$ and $Y(4260)$.

X States: $e^+e^- \to \pi\pi X(3823)$

$\mathcal{L} = 4.67\ \mathrm{fb}^{-1}$

Reconstructed with $\gamma\chi_{c1,2}$





A good candidate for $\psi(1^3D_2)$!

- $M = (3821.7 \pm 1.3 \pm 0.7)\ \mathrm{MeV}/c^2$
- $\Gamma < 16\ \mathrm{MeV}$ (90% C. L.)

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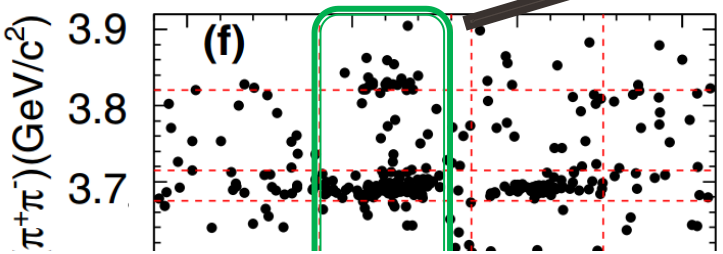

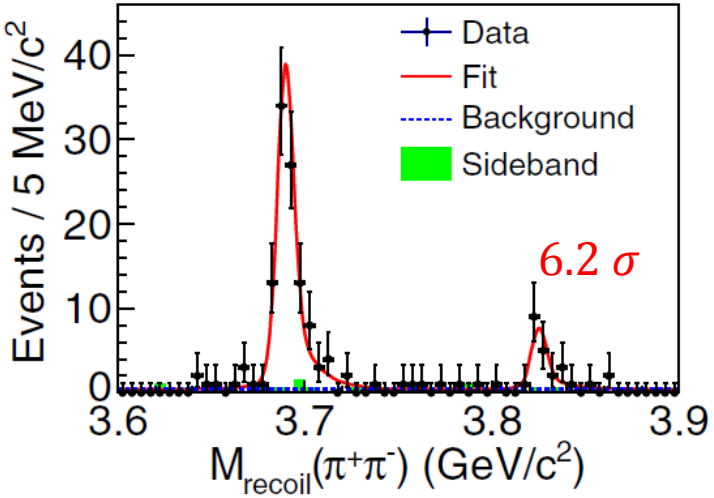

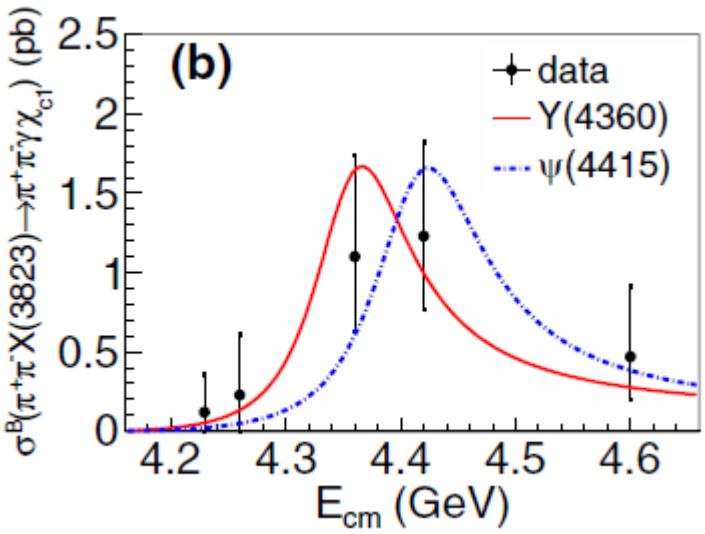

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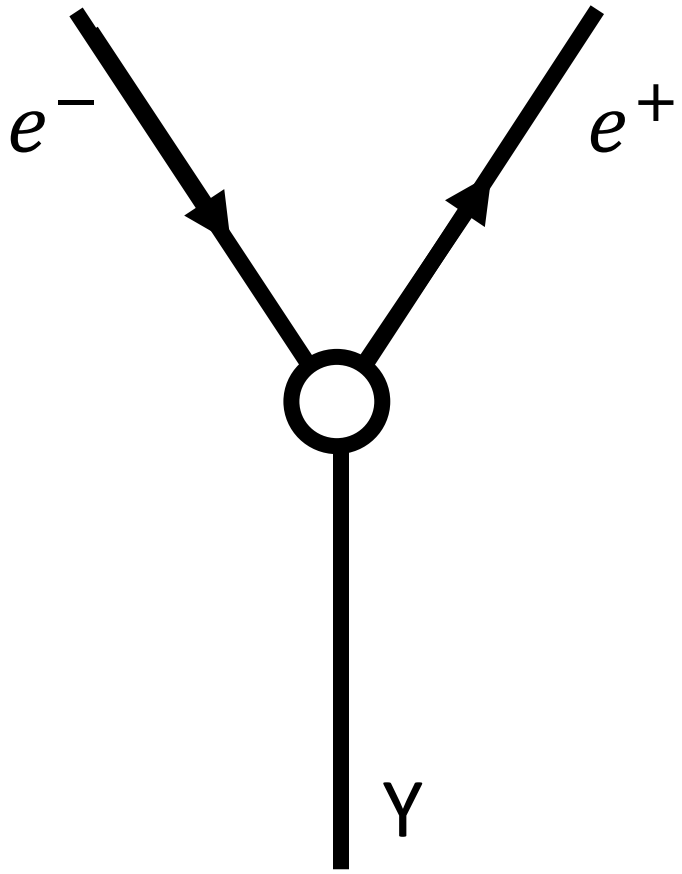
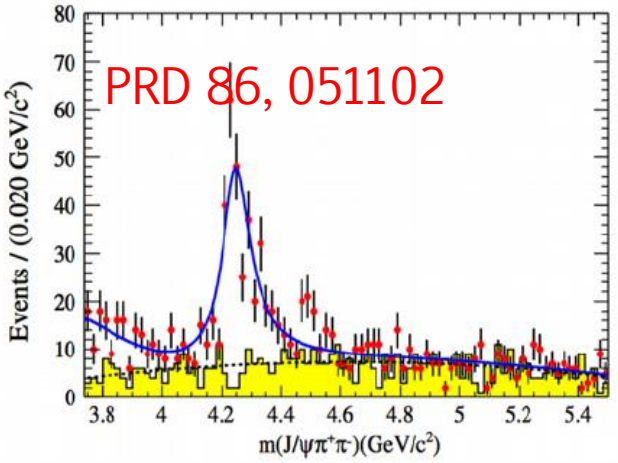
- $M = (3821.7 \pm 1.3 \pm 0.7)\ \mathrm{MeV/c^2}$
- $\Gamma < 16\ \mathrm{MeV}\ (90\%\ \mathrm{C.L.})$
- Both $Y(4260)$ and $\psi(4415)$ give reasonable description.

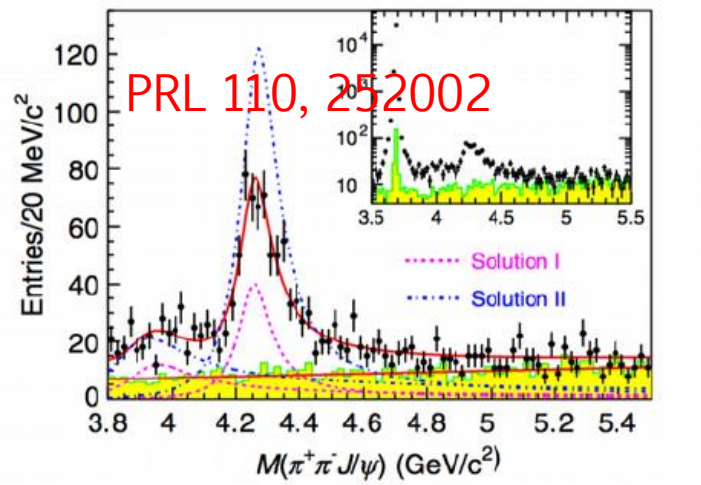
Provide another route to access XYZ states.

RESULTS ON



Y State: some history





The $Y(4260)$ state is first observed by BaBar and confirmed by Belle in $\pi\pi J/\psi$ mass spectrum.

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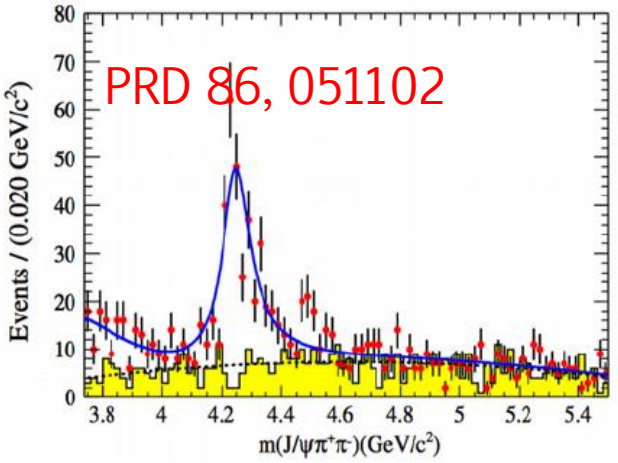

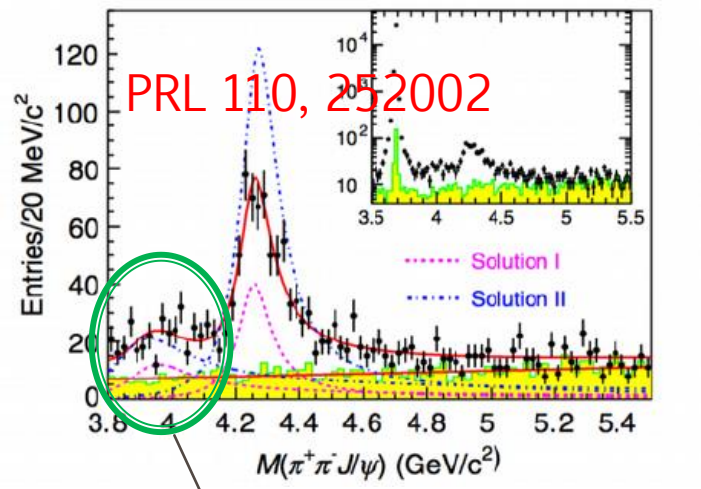

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$Y(4008)$?

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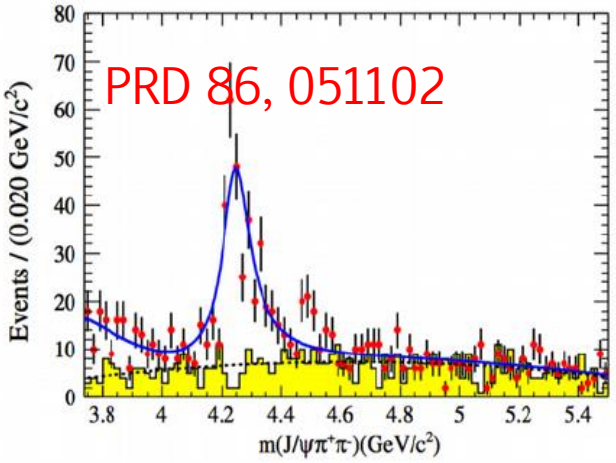

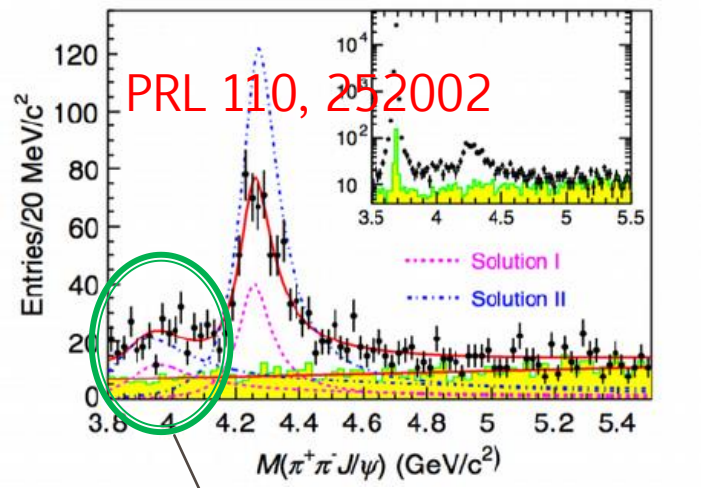

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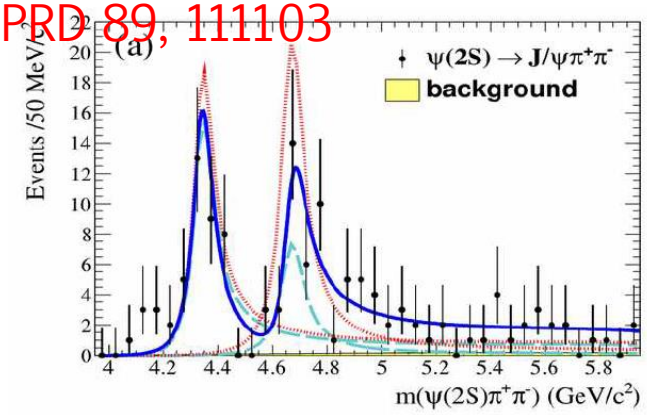
BaBar: PRD 89, 111103

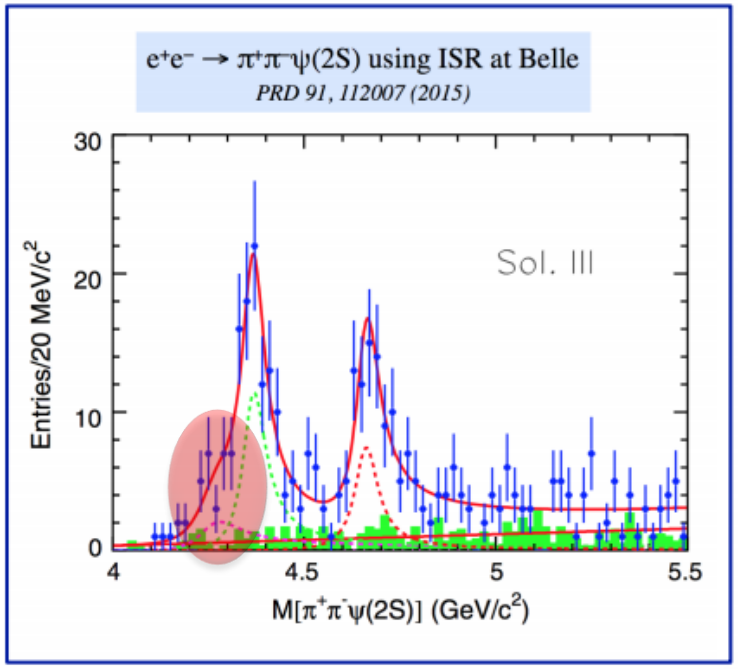


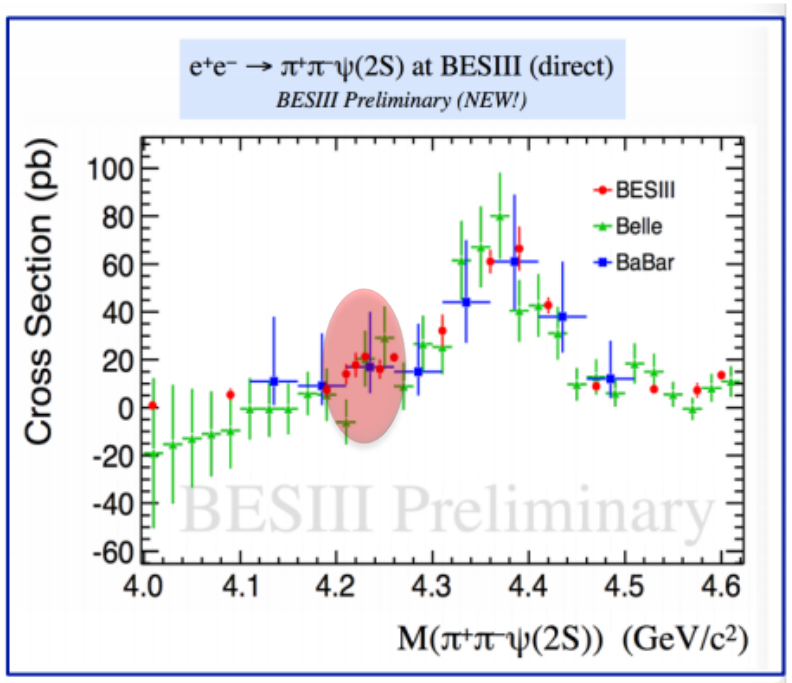
$Y(4008)$?

$Y(4360)$ and $Y(4660)$ are found in $\pi\pi\psi(2S)$ spectrum.

Y State: $e^+e^- \to \pi\pi\psi(2S)$

NEW: BESIII preliminary result vs. Belle





- Clear indication of the Y(4360) and Y(4660) in $\psi(2S)\pi^-\pi^+$
- Significance of Y(4260) <3σ

- BESIII confirms Y(4360) lineshape
- More data for thourough study of mass region 4.2 - 4.3GeV *(current data taking)*

Y State: $e^+e^- \to \pi\pi\psi(2S)$

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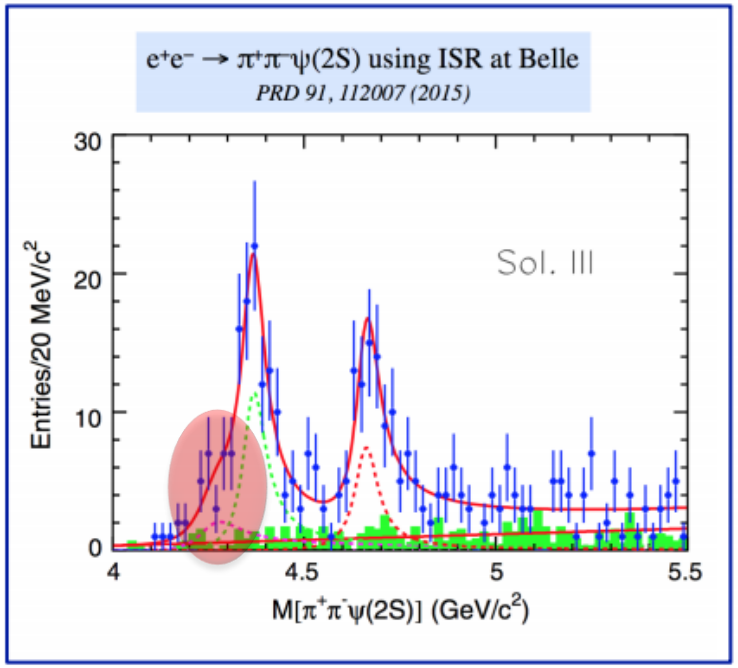

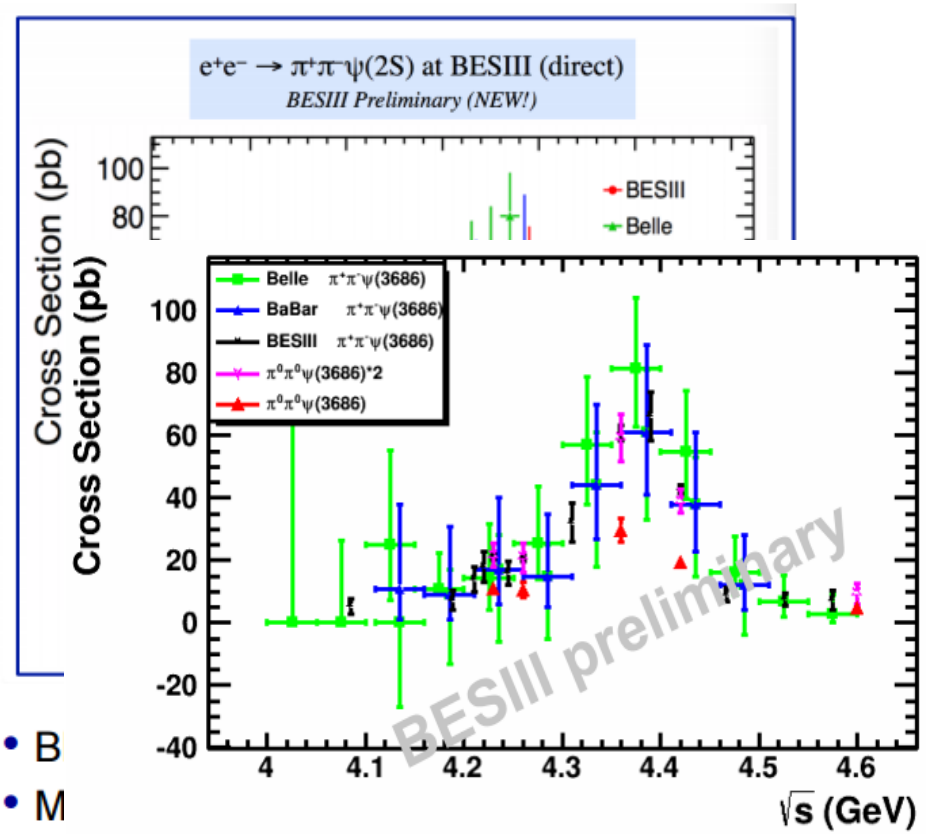

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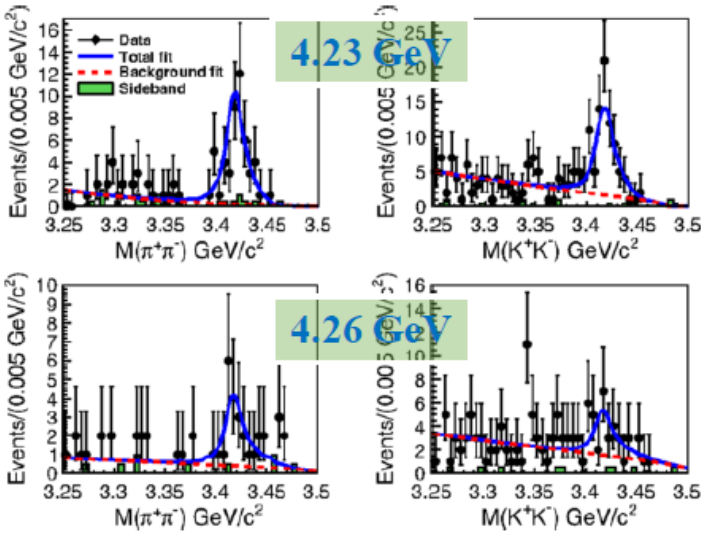
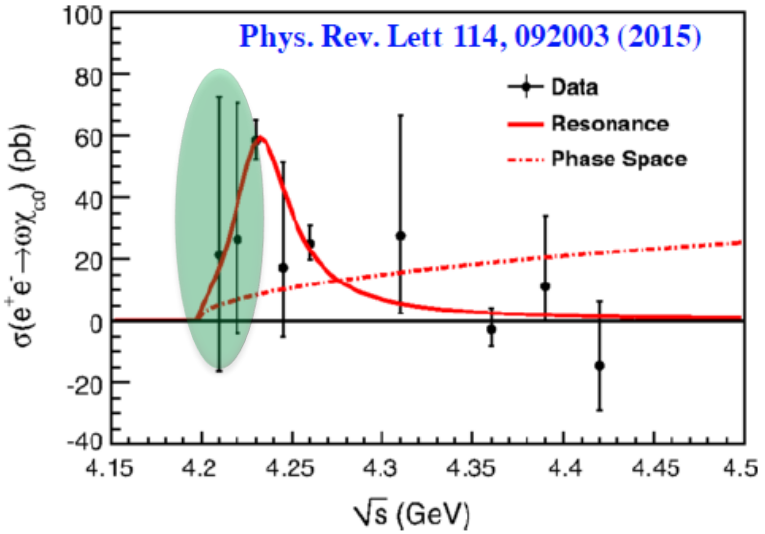
- B
- M

region 4.2 - 4.3GeV *(current data taking)*

Y State: $e^+e^- \to \omega\chi_{c0}$





9 energy points are used.

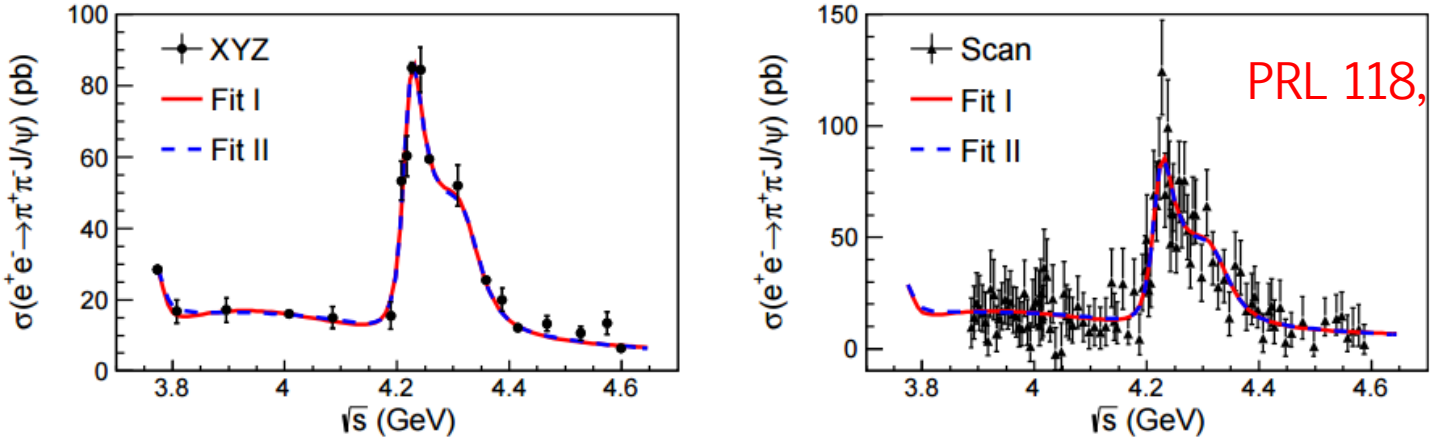
$e^+e^- \to \omega\chi_{c0}$ are observed at $\sqrt{s} = 4.23$ and $4.26\ \mathrm{GeV}$.

Lineshape in consistent with $Y(4260)$

$$M = 4230 \pm 8 \pm 6\ \mathrm{MeV/c^2}, \Gamma = 38 \pm 12 \pm 2\ \mathrm{MeV}$$

Limited by the statistics, it's difficult to tell $\omega\chi_{c0}$ comes from $Y(4260)$ or $\psi(4160)$.(**PRD91, 034004**)

Y State: $e^+e^- \to \pi\pi J/\psi$



PRL 118, 092001

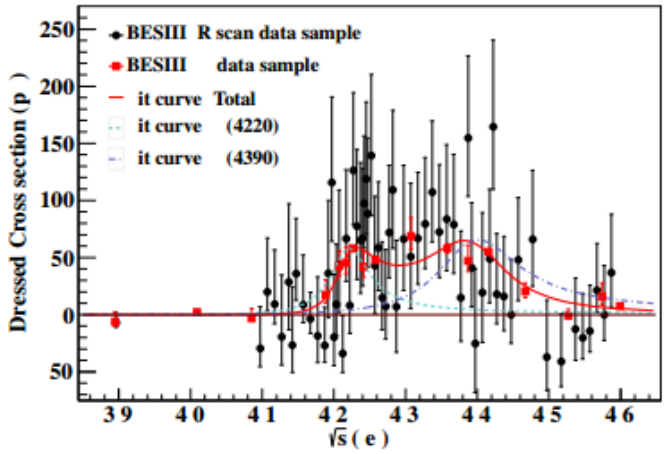
Performed with two data sets: XYZ data and R scan data;
Energy dependent cross sections are fitted simultaneously.

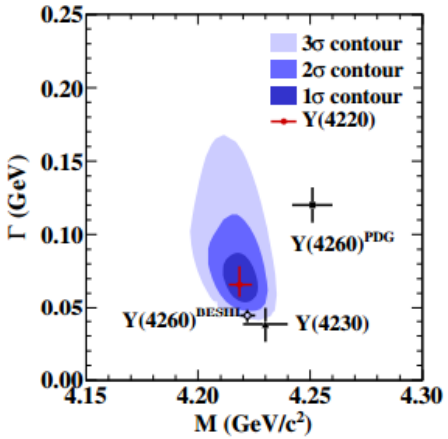
Two resonances are observed with $> 7.6\,\sigma$

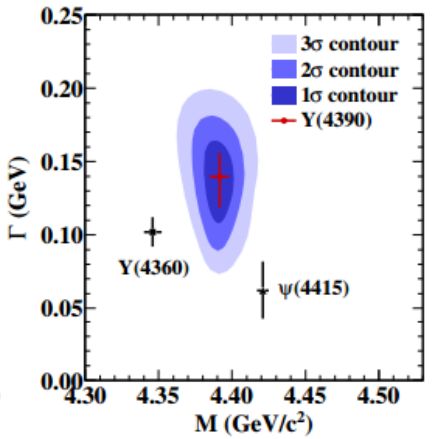
- $M_1 = 4222.0 \pm 3.1 \pm 1.4$ MeV, $\Gamma_1 = 44.1 \pm 4.3 \pm 2.0$ MeV
  - Agree with $Y(4260)$ but with much narrower width;
- $M_2 = 4320.0 \pm 10.4 \pm 7.0$ MeV, $\Gamma_2 = 101.4^{+25.3}_{-19.7} \pm 10.2$ MeV
  - Seen for the first time; A new decay mode if it is $Y(4360)$.

$Y(4008)$ is not confirmed.

Y State: $e^+e^- \to \pi\pi h_c$





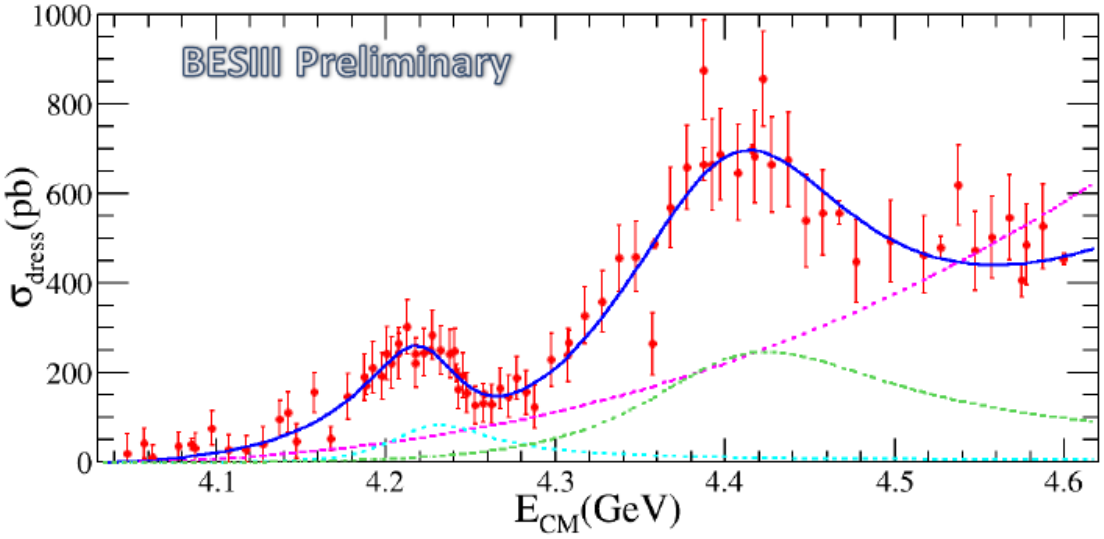


PRL 118, 092002

Energy dependent cross sections can not be fitted with a single peak.
Two resonances $> 10\ \sigma$.

- $M_1 = 4218.4^{+5.5}_{-4.5} \pm 0.9$ MeV, $\Gamma_1 = 66.0^{+16.2}_{-20.6} \pm 0.4$ MeV
  - Agree with $Y(4220)$ in $\pi\pi J/\psi$ analysis; quite different with $Y(4260)$ from PDG.
- $M_2 = 4391.5^{+6.3}_{-4.5} \pm 0.9$ MeV, $\Gamma_2 = 139.5^{+16.2}_{-20.6} \pm 0.4$ MeV

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

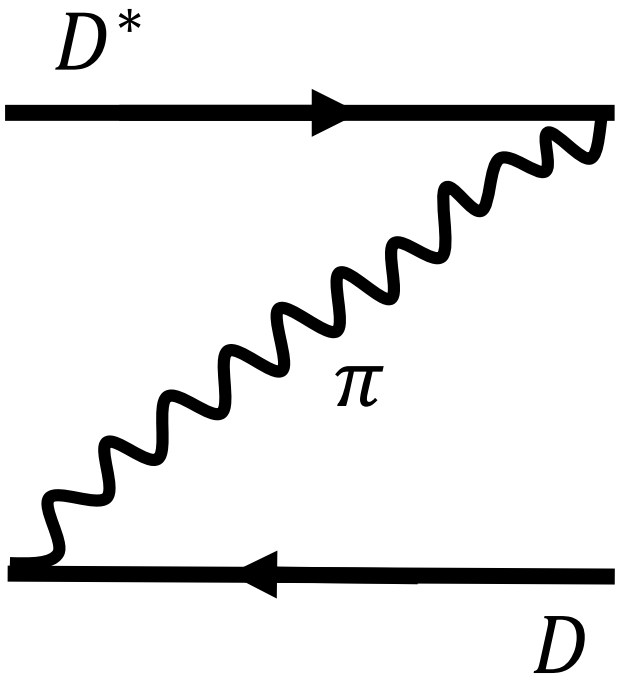


Two resonant structures are observed:

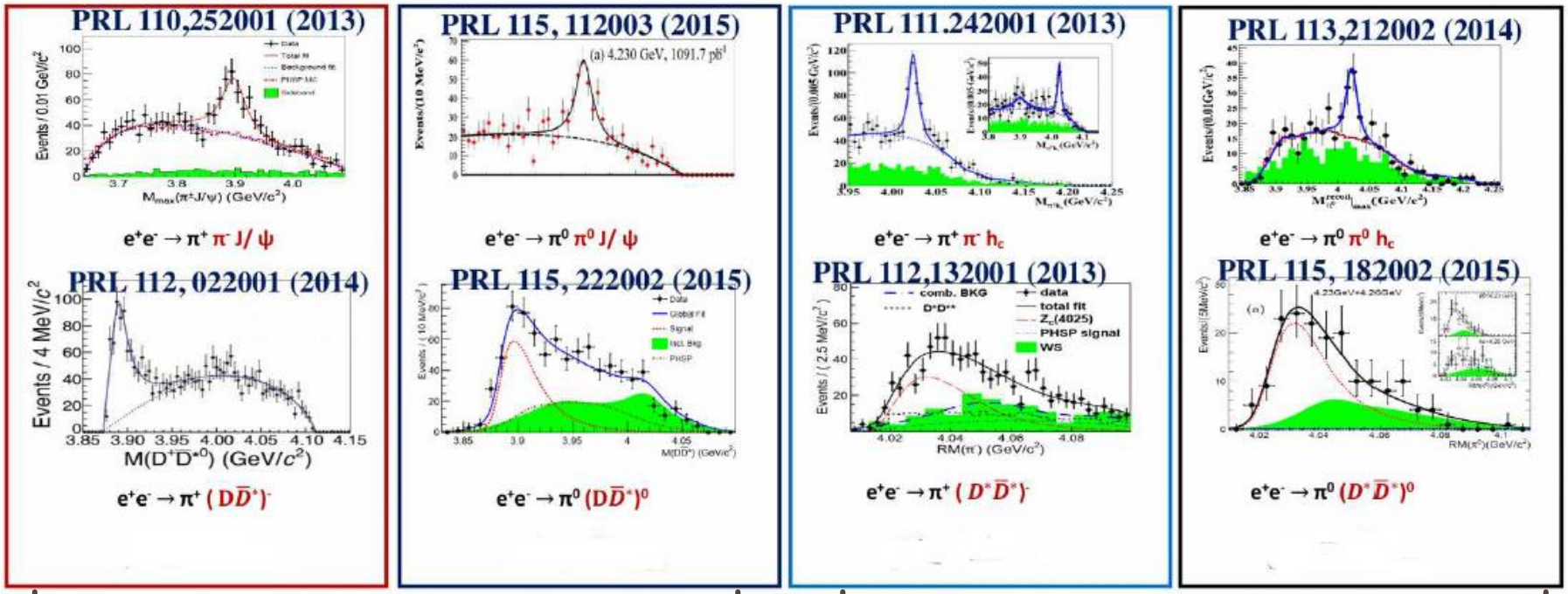
1. $M_1 = 4224.8 \pm 5.6 \pm 4.0$ MeV, $\Gamma_1 = 72.3 \pm 9.1 \pm 0.9$ MeV
   - Seen in $\pi\pi h_c, \pi\pi J/\psi, \omega\chi_{c0}$
2. $M = 4400.1 \pm 9.3 \pm 2.1$ MeV, $\Gamma = 181.7 \pm 16.9 \pm 7.4$ MeV
   - Seen in $\pi\pi h_c$

The mass of Y(4220) is 30 MeV lower than Y(4260), but consistent with $DD_1(2420)$ molecule interpretation within errors (PRD 90, 074039; PRD 73, 094510).

RESULTS ON



Z State: observed

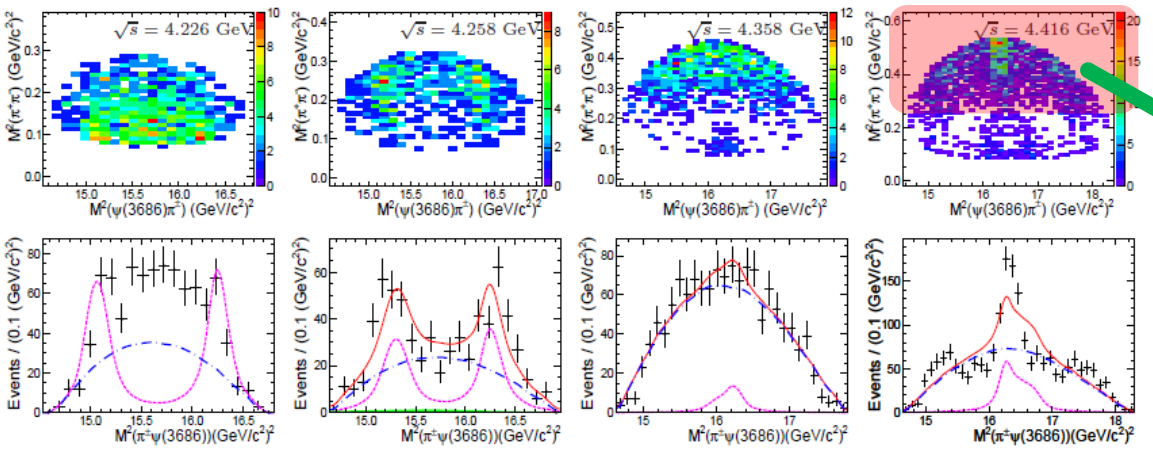


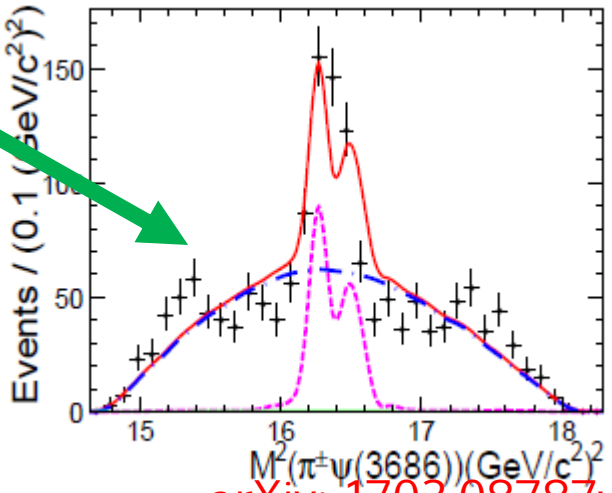
$Z_c(3900)^{\pm,0}$?

$Z_c(4020)^{\pm,0}$?

Several Z_c states have been observed in $c\bar{c}$ and open charm states.

Z State: $Z_c \to \pi^{\pm,0}\psi(2S)$



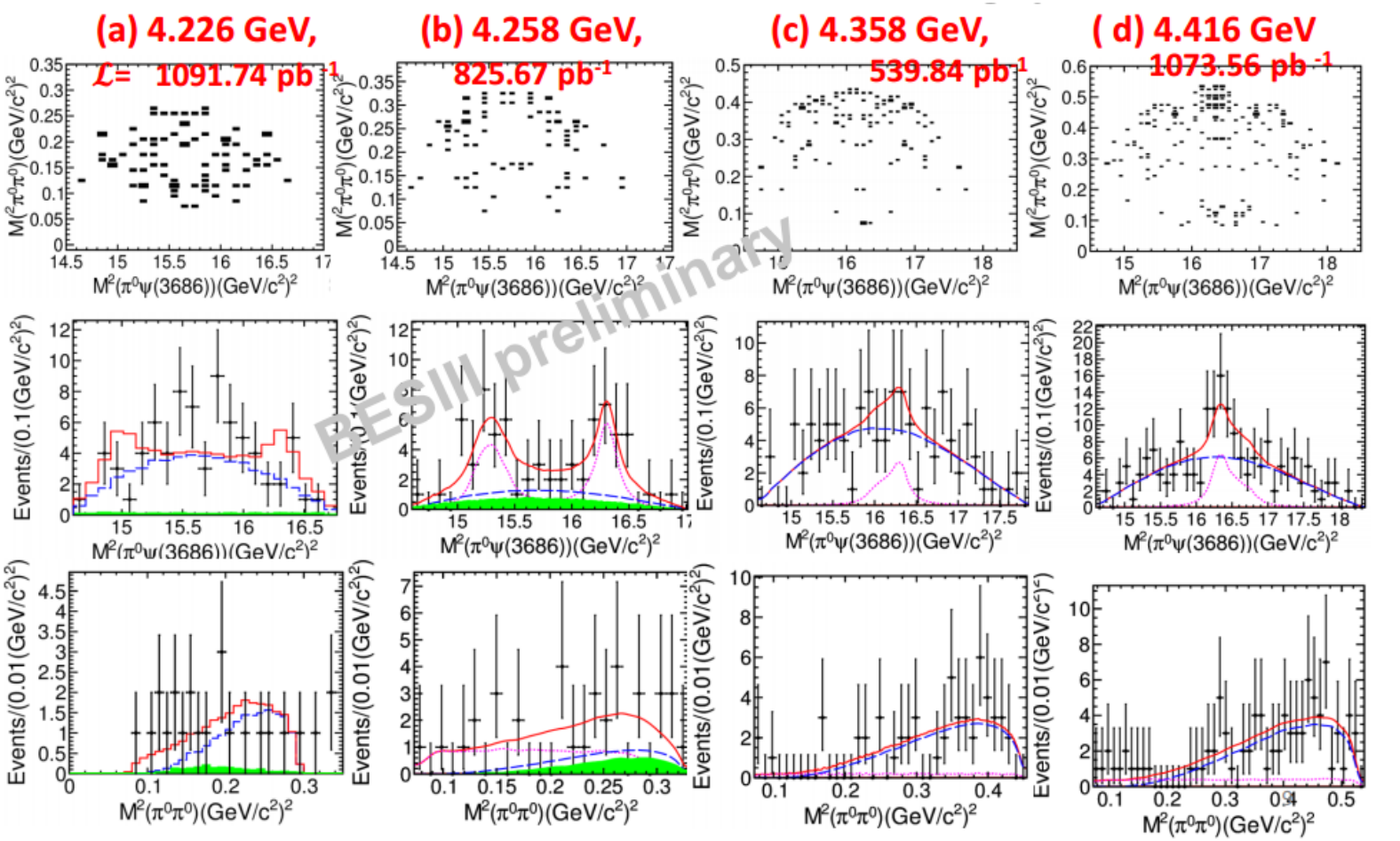


arXiv: 1703.08787v1

- A narrow structure is observed at $\sqrt{s} = 4.416$ GeV.
- But it looks much more complex looking at the Dalitz plots.

Larger datasets and additional theoretical input are necessary!

Z State: $Z_c \to \pi^{\pm,0}\psi(2S)$



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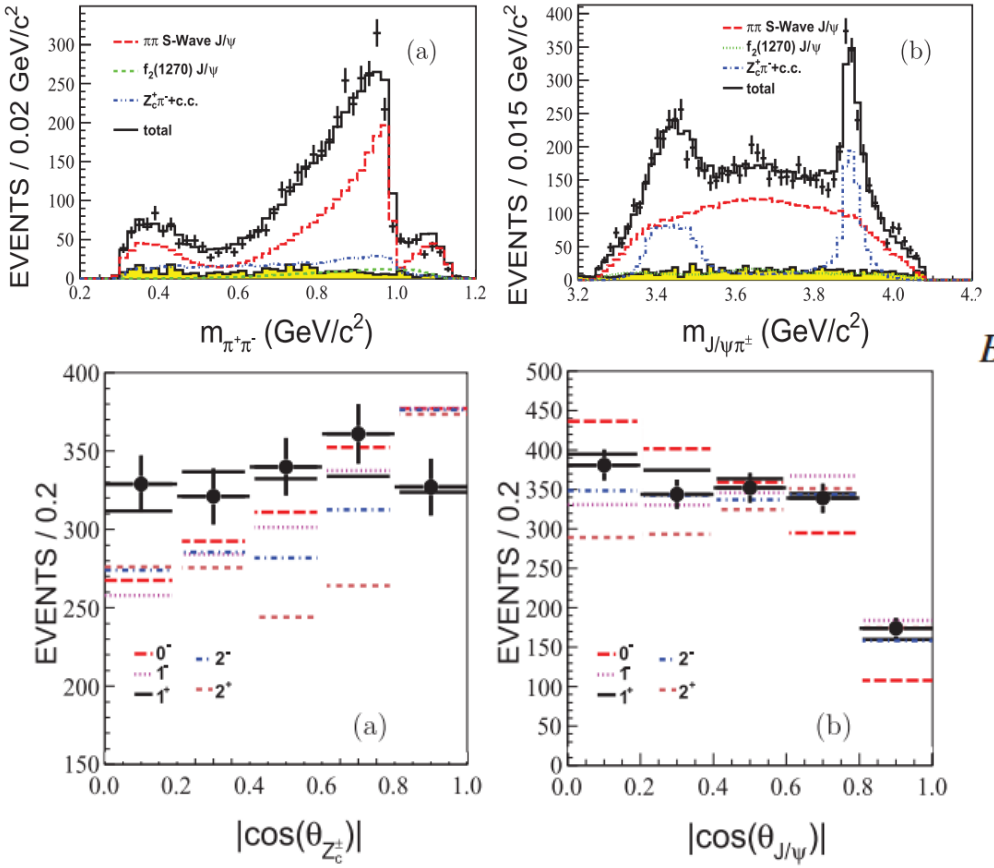
Z State: BESIII results for Z_c family

	C/N	Channel	Mass (MeV/c^2)	Width (MeV)	σ_{Born} @ 4260 (pb)
$Z_c(3900)$	Charged	$\pi^{\pm}J/\psi$	$3899.0 \pm 3.6 \pm 4.9$	$46 \pm 10 \pm 20$	13.5 ± 5.2
	Neutral	$\pi^0 J/\psi$	$3894.8 \pm 2.3 \pm 2.7$	$29.6 \pm 8.2 \pm 8.2$	4.0 ± 0.9
$Z_c(3885)$	Charged	$(D\bar{D}^*)^{\pm}$	$3881.7 \pm 1.6 \pm 1.6$	$26.6 \pm 2.0 \pm 2.1$	$108.4 \pm 6.9 \pm 8.8$
	Neutral	$(D\bar{D}^*)^0$	$3885.7^{+4.3}_{-5.7} \pm 8.4$	$35^{+11}_{-12} \pm 15$	$47 \pm 9 \pm 10$
$Z_c(4020)$	Charged	$\pi^{\pm}h_c$	$4022.9 \pm 0.8 \pm 2.7$	$7.9 \pm 2.7 \pm 2.6$	$7.4 \pm 1.7 \pm 2.1 \pm 1.2$
	Neutral	$\pi^0 h_c$	$4023.9 \pm 2.2 \pm 3.8$	Fixed	$8.5 \pm 2.9 \pm 1.1 \pm 1.3$
$Z_c(4025)$	Charged	$(D^*\bar{D}^*)^{\pm}$	$4026.3 \pm 2.6 \pm 3.7$	$24.8 \pm 5.6 \pm 7.7$	89.0 ± 18.7
	Neutral	$(D^*\bar{D}^*)^0$	$4025.5^{+2.0}_{-4.7} \pm 3.1$	$23.0 \pm 6.0 \pm 1.0$	$43.4 \pm 8.0 \pm 5.4$
$Z_c(4030)$	Charged	$\pi^{\pm}\psi(2S)$	4032.1 ± 2.4	26.1 ± 5.3	-
	Neutral	$\pi^0\psi(2S)$	4038.7 ± 6.5	-	-

Z State: Determination of J^P of $Z_c(3900)$

Amplitude of PWA:

$$A = |A(\sigma J/\psi) + A(f_0 J/\psi) + A(f_0(1370) J/\psi) + A(f_2(1270) J/\psi) + A(Z_c \pi)|$$



Dataset: 4.23 & 4.26 GeV

Z_c is described better with a Flatte-like formula:

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

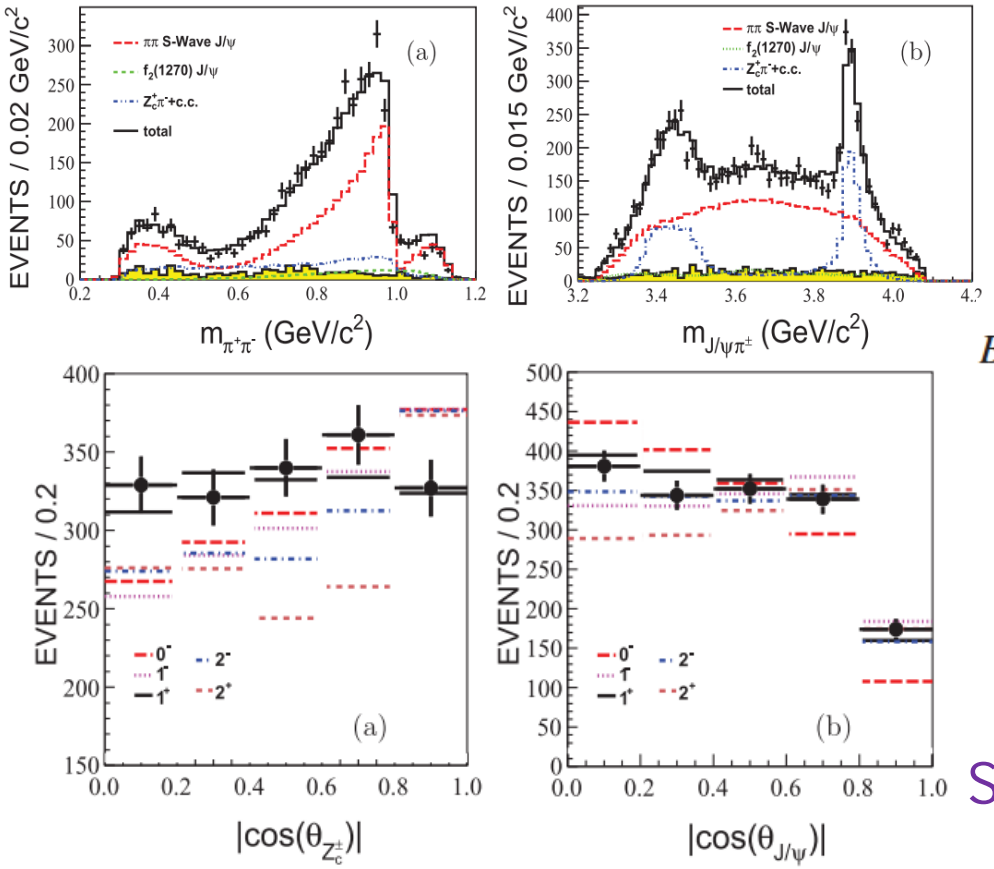
Hypothesis	$\Delta(-2\ln L)$	Δ(ndf)	Significance
1^+ over 0^-	94.0	13	7.6σ
1^+ over 1^-	158.3	13	10.8σ
1^+ over 2^-	151.9	13	10.5σ
1^+ over 2^+	96.0	13	7.7σ

arXiv: 1706.04100

Z State: Determination of J^P of $Z_c(3900)$

Amplitude of PWA:

$$A = |A(\sigma J/\psi) + A(f_0 J/\psi) + A(f_0(1370) J/\psi) + A(f_2(1270) J/\psi) + A(Z_c \pi)|$$



Dataset: 4.23 & 4.26 GeV

Z_c is descript better with a Flatte-like formula:

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Hypothesis	$\Delta(-2\ln L)$		Significance
1^+ over 0^-			7.6σ
1^+ over 1^-		13	10.8σ
1^+ over 2^-		13	10.5σ
1^+ over 2^+	96.0	13	7.7σ

$J^P(Z_c 3900) = 1^+$!

Strong proof to $Z_c(3900) = Z_c(3885)$

arXiv: 1706.04100

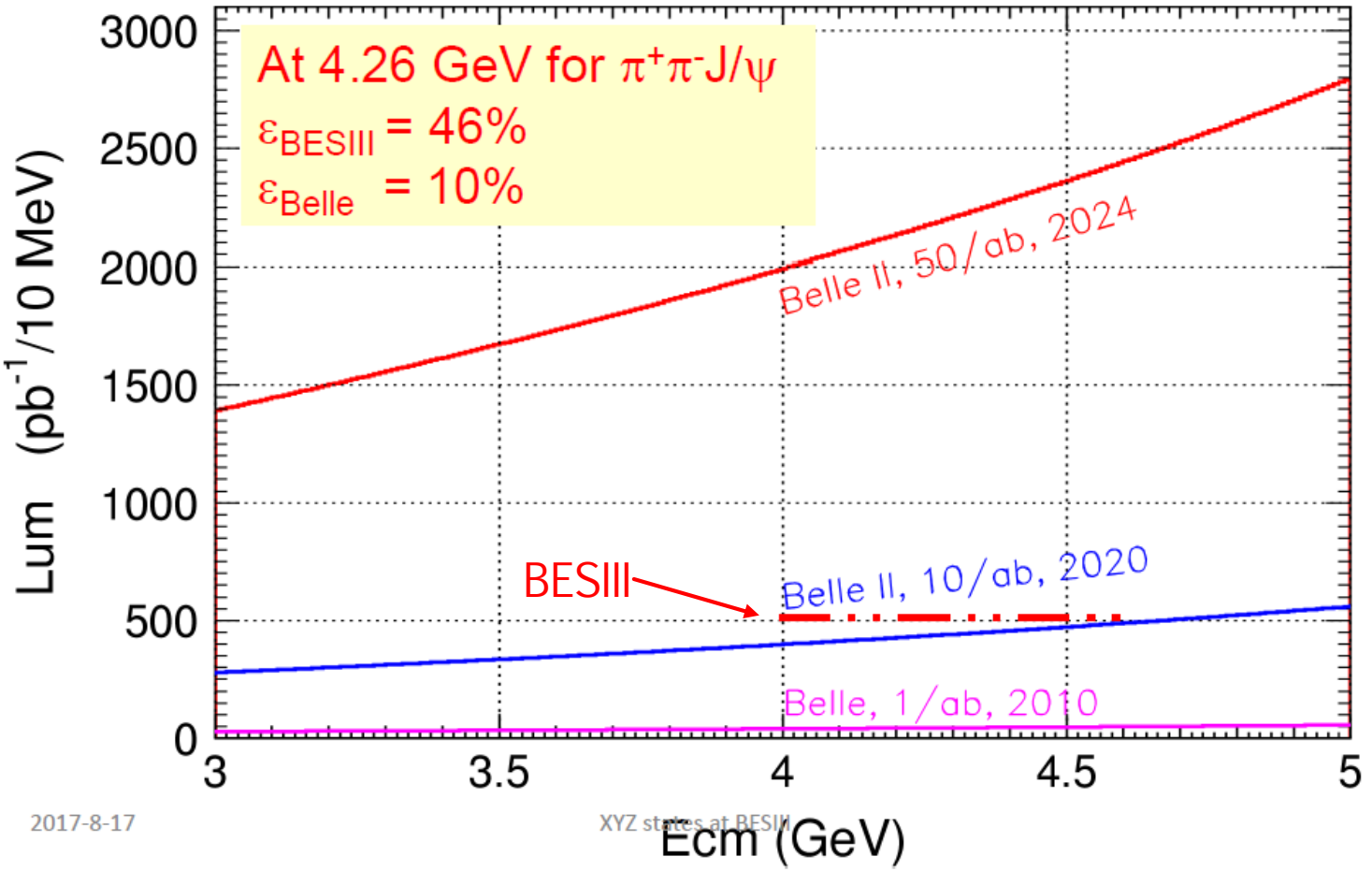
Summary & Outlook

- BESIII provide new route to access XYZ states by e^+e^- annihilation. Our understanding of XYZ has been significantly improved.
  - BESIII observe XYZ states, X(3823), Y(4220), Y(4390), Zc(3900)…
  - BESIII measure XYZ states, X(3872), Y(4360), J^P of Zc(3900)…
  - Two isospin triplet states $Zc(3900), Zc(4020)$ established.
- There are still puzzles.
  - Complex structures and difficult to describe; Even $Y(4260)$ in $\pi\pi J/\psi$ no longer looks like a simple peak.
  - Their nature is still unknown.
- More data taking is needed!

Thank you!

BACK UP

ISR @ Belle II vs. BESIII



Z State: BESIII results for Z_c family

	C/N	Channel	Mass (MeV/c^2)	Width (MeV)	$B_{relative}$ @ 4260 (%)
$Z_c(3900)$	Charged	$\pi^{\pm}J/\psi$	$3899.0 \pm 3.6 \pm 4.9$	$46 \pm 10 \pm 20$	7.8 ± 3.0
	Neutral	$\pi^0 J/\psi$	$3894.8 \pm 2.3 \pm 2.7$	$29.6 \pm 8.2 \pm 8.2$	2.3 ± 0.5
$Z_c(3885)$	Charged	$(D\bar{D}^*)^{\pm}$	$3881.7 \pm 1.6 \pm 1.6$	$26.6 \pm 2.0 \pm 2.1$	$\mathbf{62.7 \pm 6.5}$
	Neutral	$(D\bar{D}^*)^0$	$3885.7^{+4.3}_{-5.7} \pm 8.4$	$35^{+11}_{-12} \pm 15$	$\mathbf{27.2 \pm 7.8}$
$Z_c(4020)$	Charged	$\pi^{\pm}h_c$	$4022.9 \pm 0.8 \pm 2.7$	$7.9 \pm 2.7 \pm 2.6$	5.0 ± 2.0
	Neutral	$\pi^0 h_c$	$4023.9 \pm 2.2 \pm 3.8$	Fixed	5.7 ± 2.3
$Z_c(4025)$	Charged	$(D^*\bar{D}^*)^{\pm}$	$4026.3 \pm 2.6 \pm 3.7$	$24.8 \pm 5.6 \pm 7.7$	$\mathbf{60.0 \pm 12.6}$
	Neutral	$(D^*\bar{D}^*)^0$	$4025.5^{+2.0}_{-4.7} \pm 3.1$	$23.0 \pm 6.0 \pm 1.0$	$\mathbf{29.3 \pm 15.2}$
$Z_c(4030)$	Charged	$\pi^{\pm}\psi(2S)$	4032.1 ± 2.4	26.1 ± 5.3	-