Charmonium-like states at BESIII

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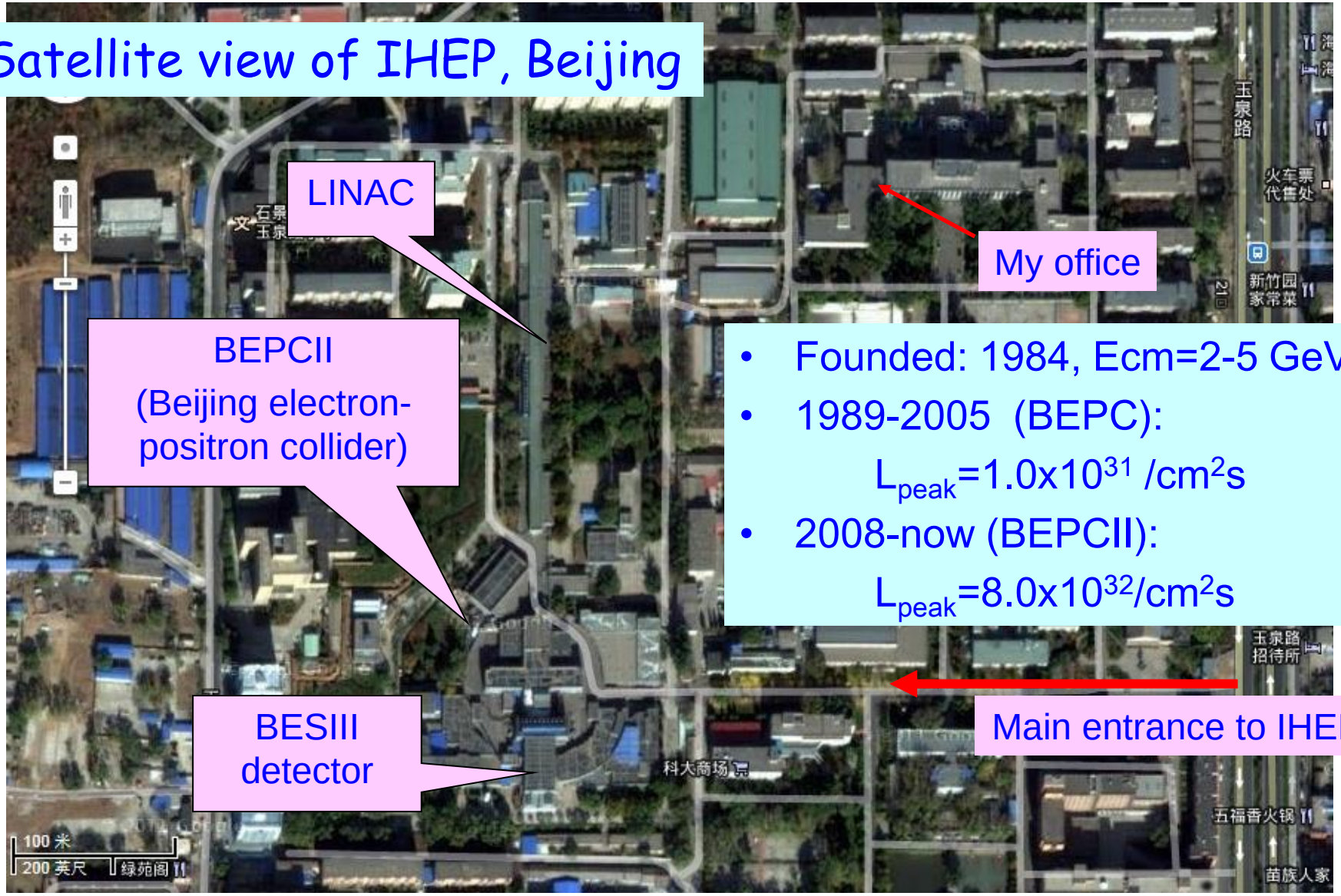
Outline

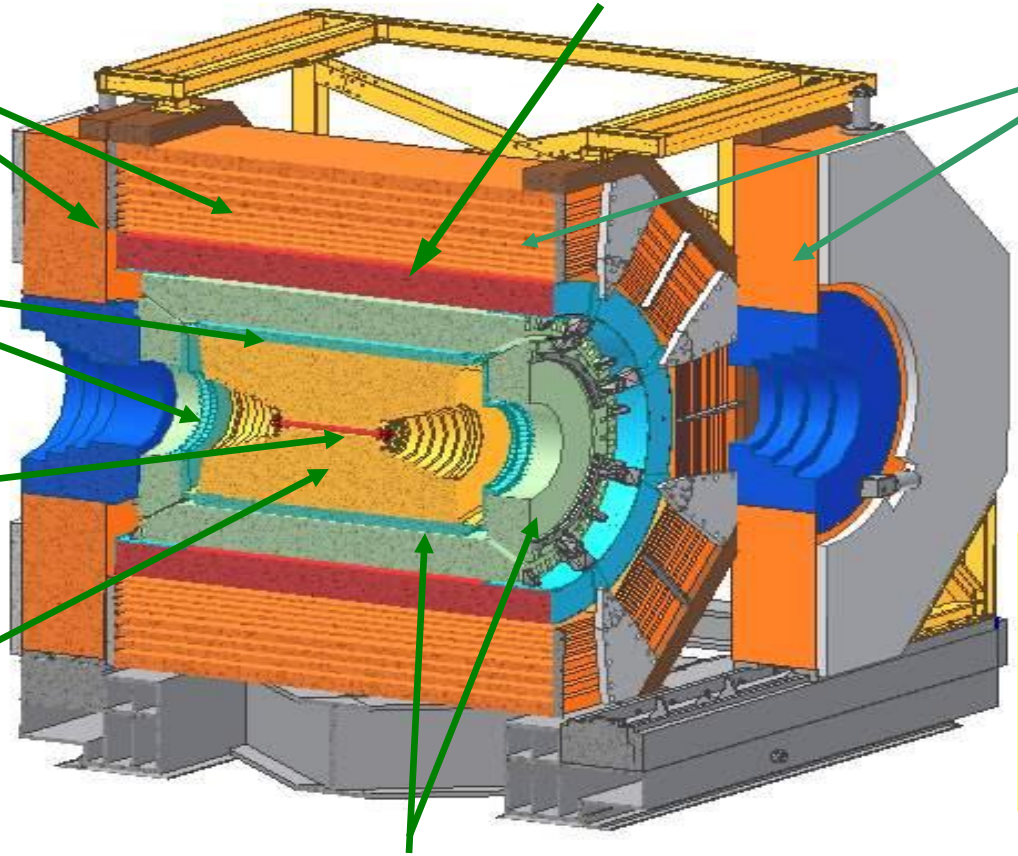
- The BESIII experiment
- The X states
- The Y states
- The Z_c states
- Summary & Outlook

Beijing Electron Positron Collider (BEPC)



- Founded: 1984, Ecm=2-5 GeV
- 1989-2005 (BEPC):
  $L_{peak}=1.0\times10^{31}$ /cm^{2}s
- 2008-now (BEPCII):
  $L_{peak}=8.0\times10^{32}$/cm^{2}s

The BESIII Detector



A total weight of 730t, ~40,000 readout channels, data rate 6,000Hz ~50Mb/s

BESIII Collaboration

US (5)

Univ. of Hawaii
Carnegie Mellon Univ.
Univ. of Minnesota
Univ. of Rochester
Univ. of Indiana

Europe (13)

Germany: Univ. of Bochum,
Univ. of Giessen, GSI
Univ. of Johannes Gutenberg
Helmholtz Ins. In Mainz
Russia: JINR Dubna; BINP Novosibirsk
Italy: Univ. of Torino, Univ. of Ferrara, Frascati Lab
Netherland : KVI/Univ. of Groningen
Sweden: Uppsala Univ.
Turkey: Turkey Accelerator Center

Korea (1)

Seoul Nat. Univ.

Japan (1)

Tokyo Univ.

Pakistan (2)

Univ. of Punjab
COMSAT CIIT

China(31)

IHEP, CCAST, GUCAS, Shandong Univ.,
Univ. of Sci. and Tech. of China
Zhejiang Univ., Huangshan Coll.
Huazhong Normal Univ., Wuhan Univ.
Zhengzhou Univ., Henan Normal Univ.
Peking Univ., Tsinghua Univ. ,
Zhongshan Univ.,Nankai Univ.
Shanxi Univ., Sichuan Univ., Univ. of South China
Hunan Univ., Liaoning Univ.
Nanjing Univ., Nanjing Normal Univ.
Guangxi Normal Univ., Guangxi Univ.
Suzhou Univ., Hangzhou Normal Univ.
Lanzhou Univ., Henan Sci. and Tech. Univ.
Beihang Univ., Beijing Petrol Chemical Univ.

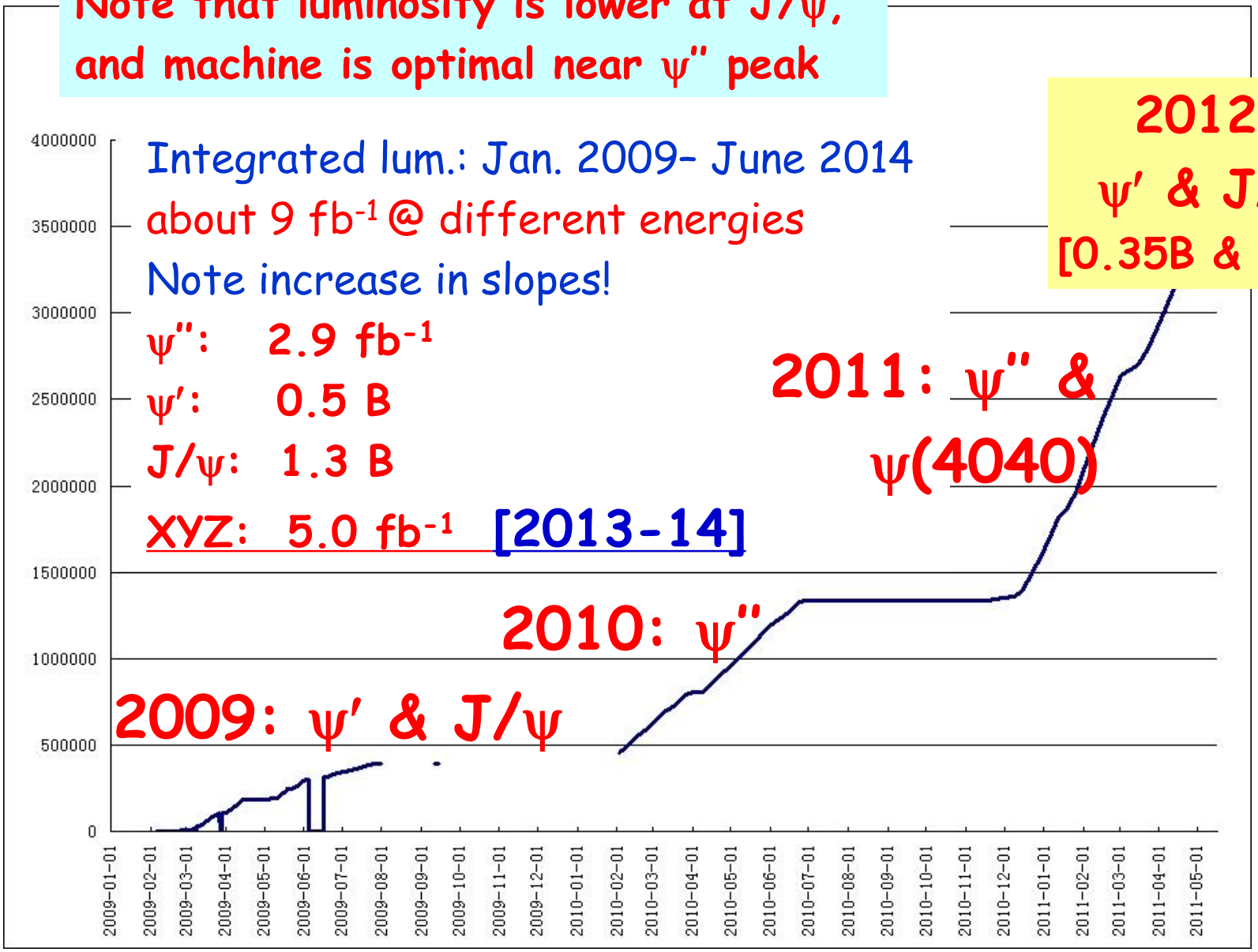
~400 members
53 institutions from 11 countries

BESIII Collaborators

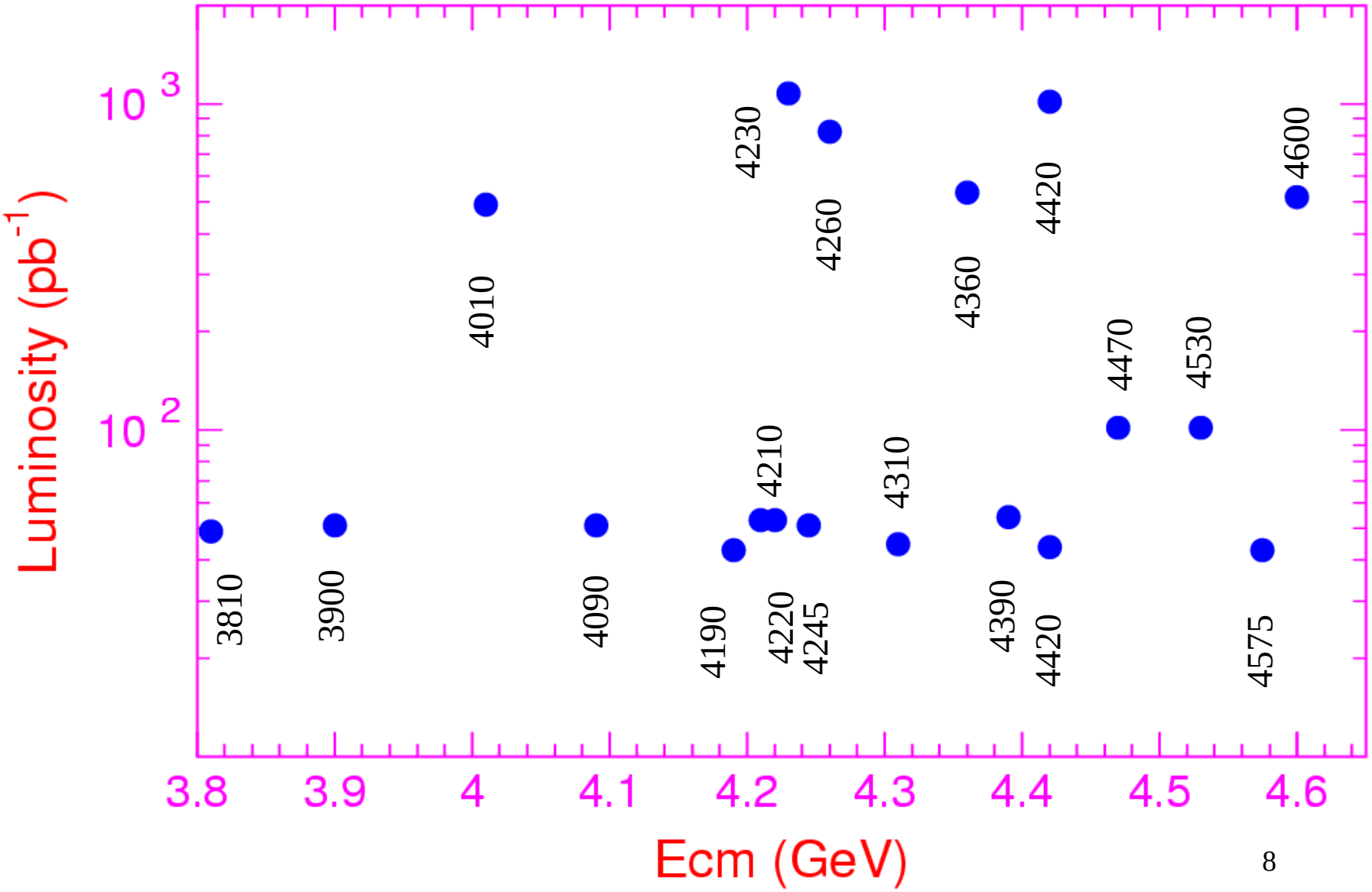
… about half of the BESIIIers!

BESIII data samples

Note that luminosity is lower at J/ψ, and machine is optimal near ψ'' peak



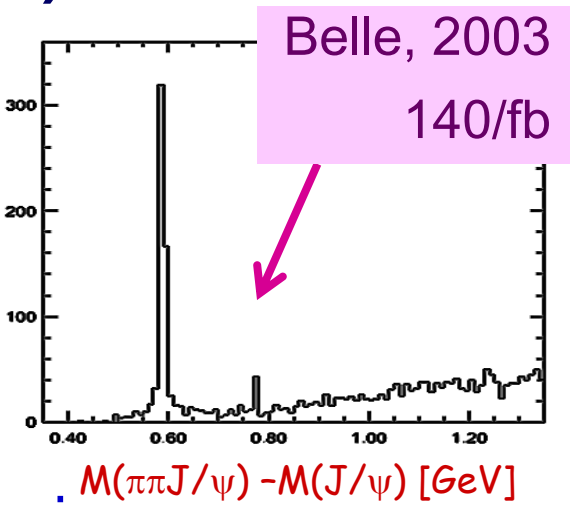
BESIII data samples for XYZ study (5/fb)



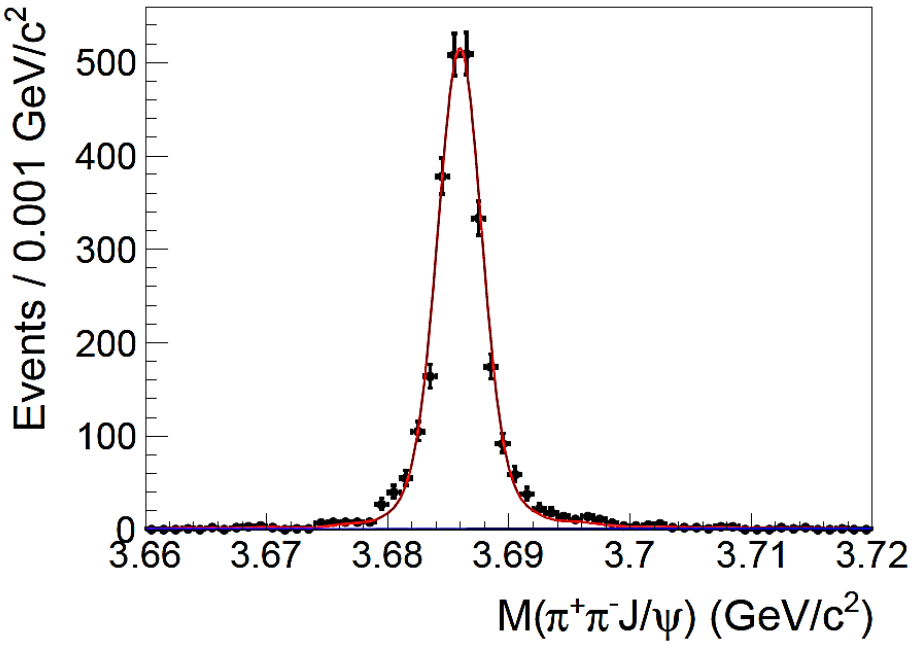
The X states

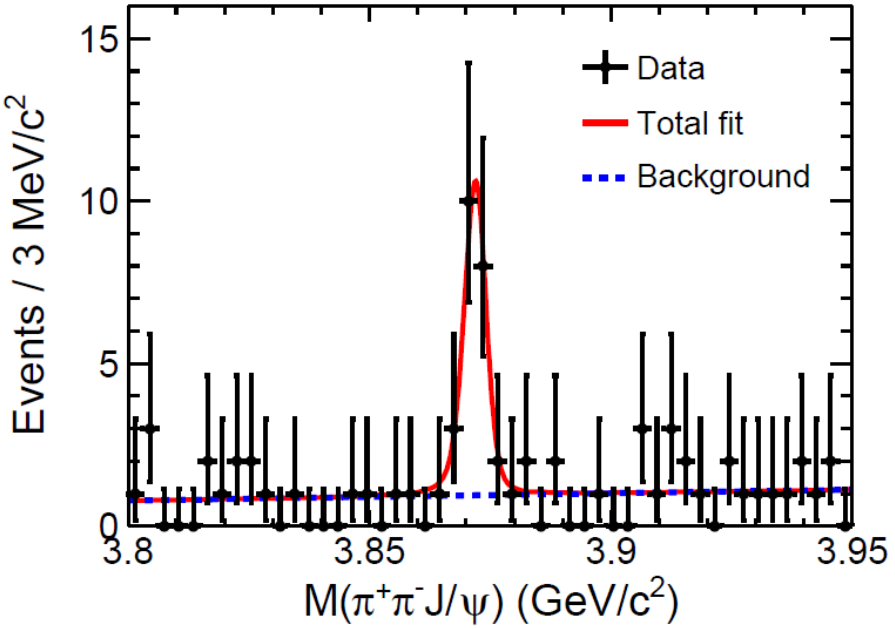
What is the X(3872)?

- Mass: Very close to $\bar{D}^0 D^{*0}$ threshold
- Width: Very narrow, < 1.2 MeV
- $J^{PC}=1^{++}$
- Production
  - in $\bar{p}p$/pp collison – rate similar to charmonia
  - In B decays – KX similar to $c\bar{c}$, K*X smaller than $c\bar{c}$
  - $Y(4260) \rightarrow \gamma + X(3872)$
- Decay BR: open charm ~ 50%, charmonium~O(%)
- Nature (very likely exotic)
  - Loosely $\bar{D}^0 D^{*0}$ bound state (like deuteron?)?
  - Mixture of excited χ_{c1} and $\bar{D}^0 D^{*0}$ bound state?
  - Many other possibilities (if it is not χ'_{c1}, where is χ'_{c1}?)



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





ISR ψ' signal is used for mass, and mass resolution calibration.

N=1818; ΔM=0.34±0.04 MeV; $\Delta\sigma_M$=1.14 ±0.07 MeV

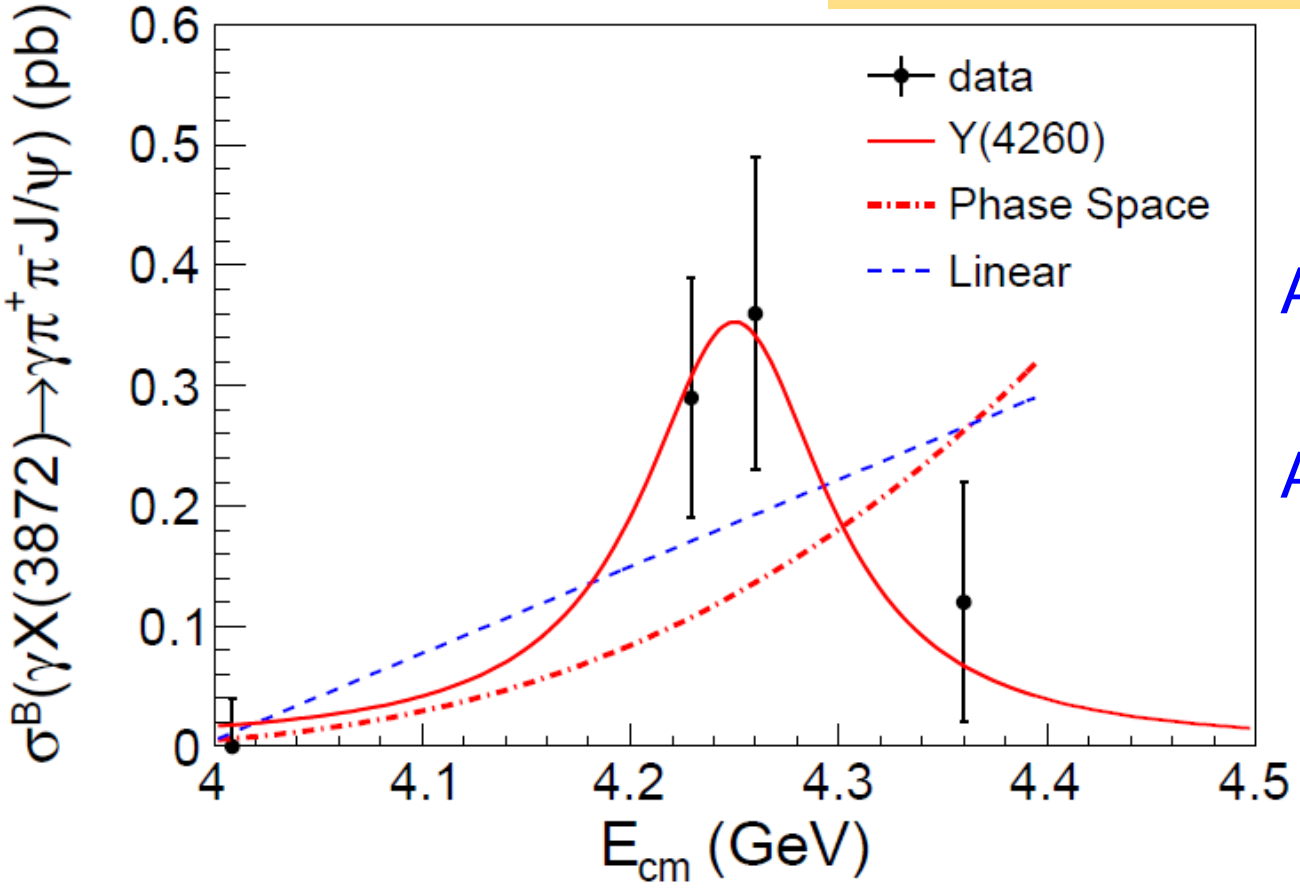
N(X(3872)) = 20.1±4.5 **6.3σ**

arXiv: 1310.4101,
PRL 112, 092001 (2014)

M(X(3872)) = 3871.9±0.7±0.2 MeV [PDG: 3871.68 ±0.17 MeV]

Observation of Y(4260)→γX(3872)

PRL 112, 092001 (2014)



A new Y(4260) decay mode

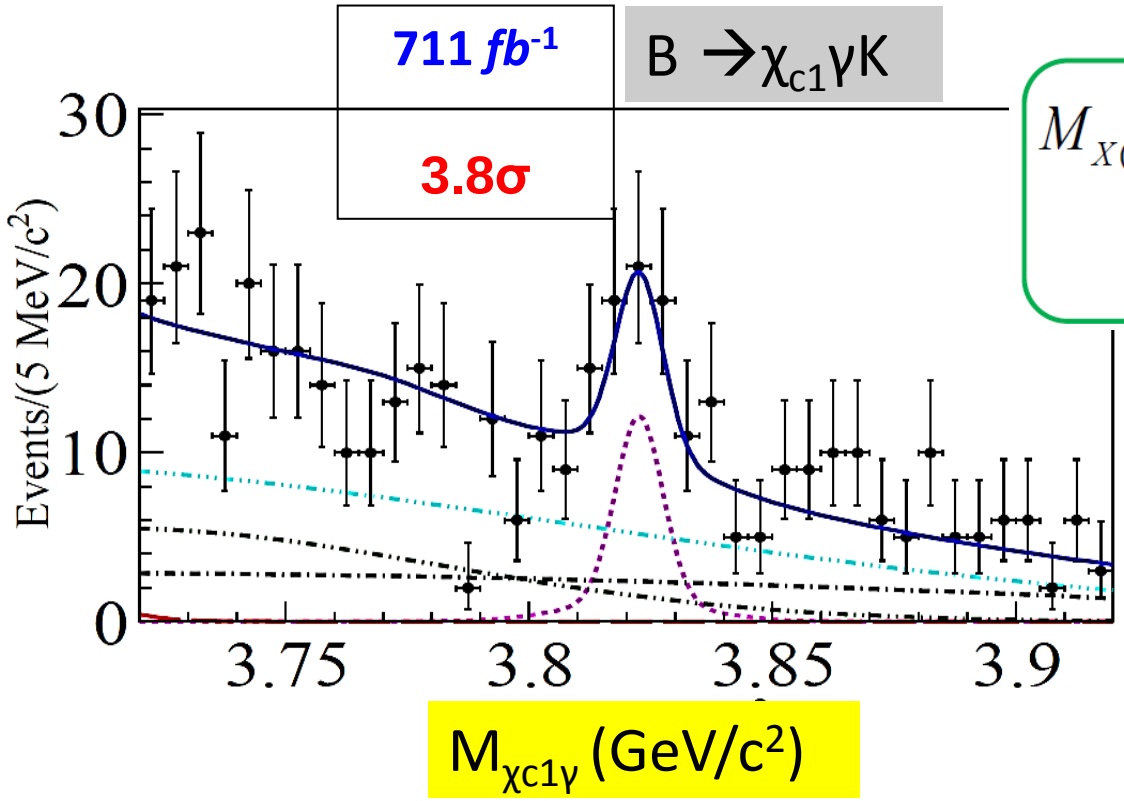
A new X(3872) production mode

If we take $\mathcal{B}(X(3872)\to\pi^+\pi^- J/\psi)\sim 5\%$, (>2.6% in PDG)

$\frac{\sigma(e^+e^-\to\gamma X(3872))}{\sigma(e^+e^-\to\pi^+\pi^- J/\psi)}\sim$ 10% Large transition ratio !

Evidence for the X(3823) at Belle

arXiv:1304.3975 (PRL111, 032001 (2013))



$$M_{X(3823)} = M^{meas}_{X(3823)} - M^{meas}_{\psi'} + M^{PDG}_{\psi'}$$
$$= 3823.1 \pm 1.8 \pm 0.7\, MeV$$

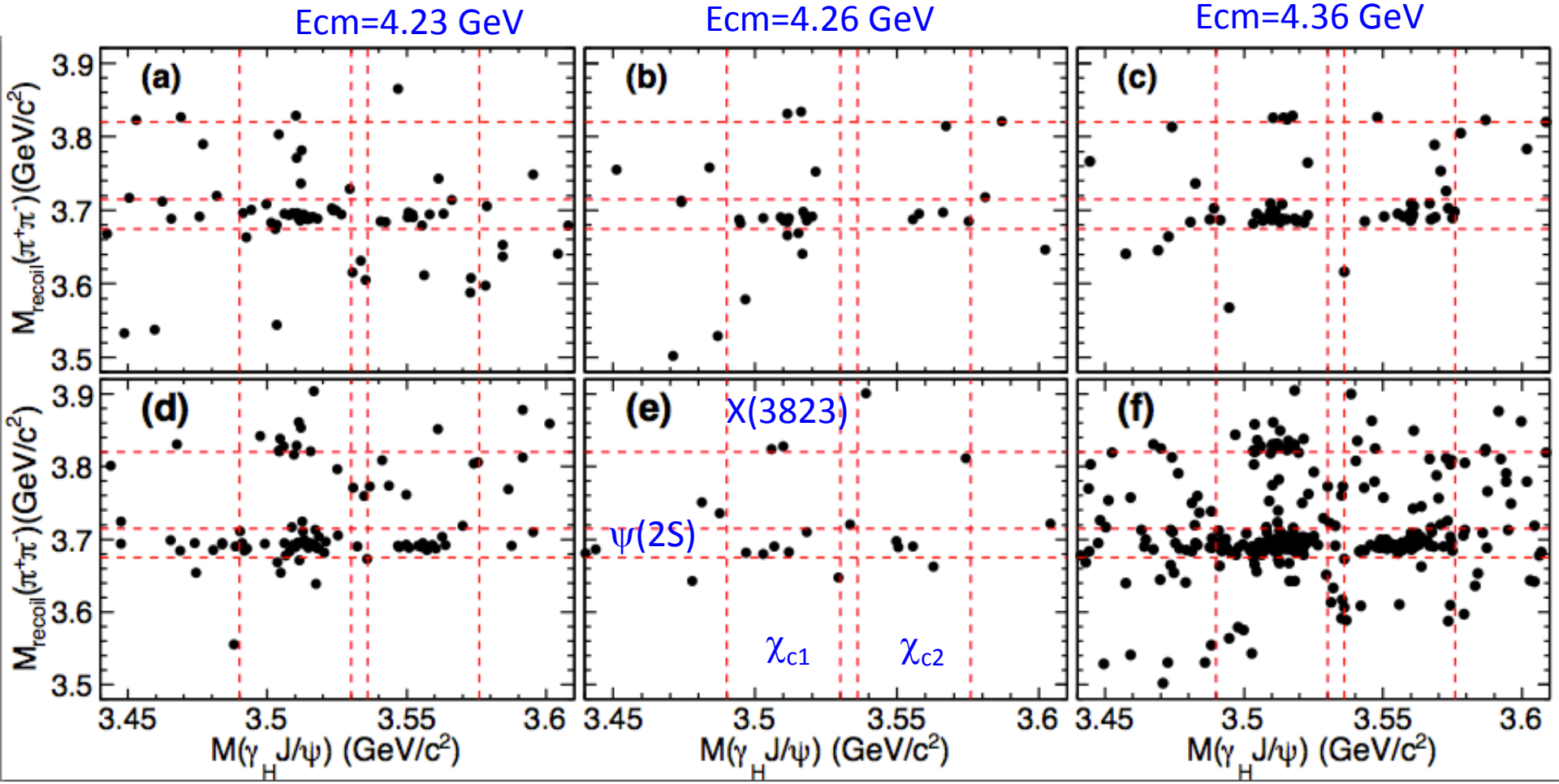
The measured mass and width are consistent with the missing Ψ_2(1D) state

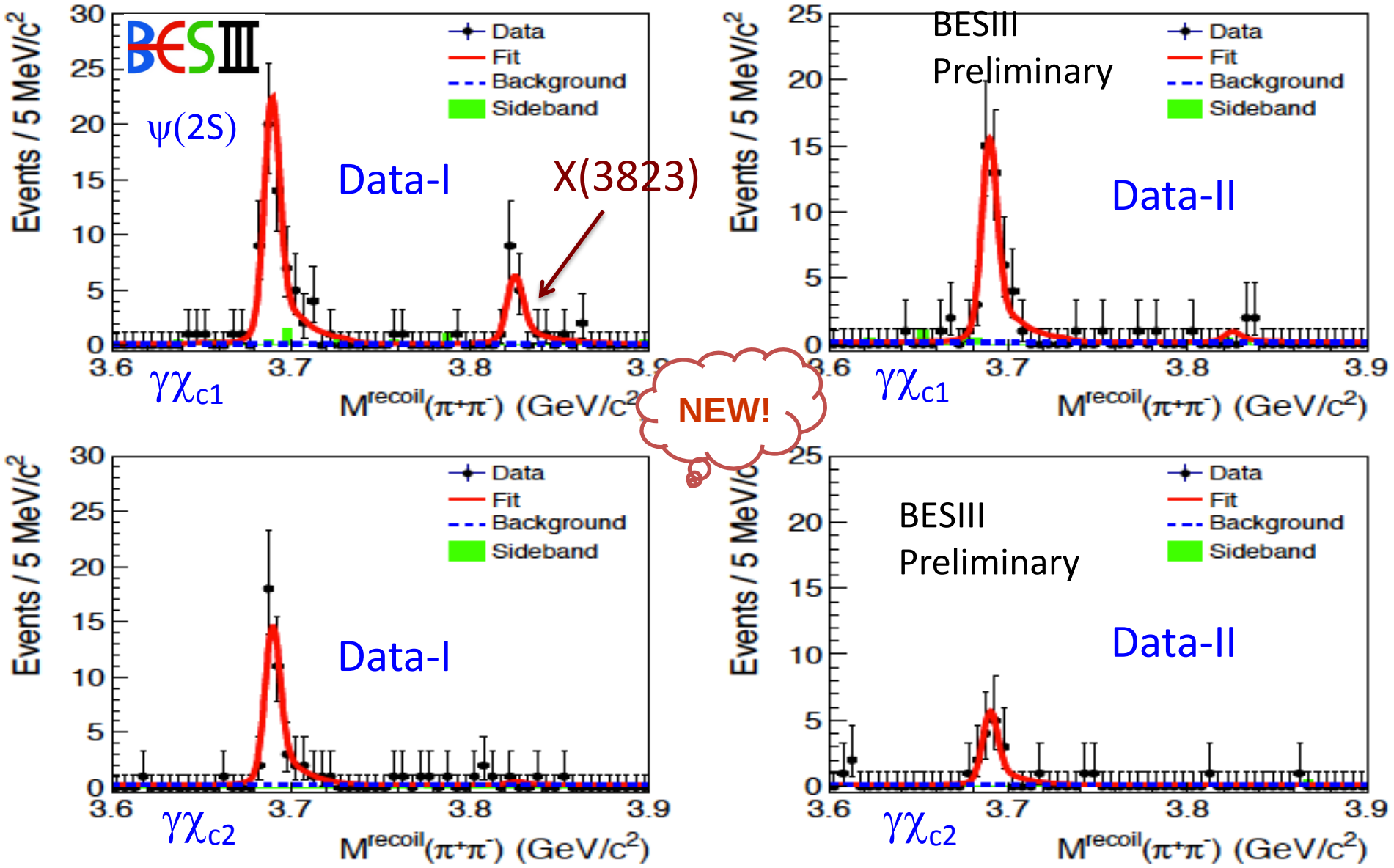
BESIII may search for it!

FIG. 4: 2D UML fit projection of $M_{\chi_{c1}\gamma}$ distribution for the simultaneous fit of $B^{\pm} \to (\chi_{c1}\gamma)K^{\pm}$ and $B^0 \to (\chi_{c1}\gamma)K^0_S$ decays for $M_{\rm bc} > 5.27$ GeV/c^2. The curves used in the fits are described in [31].

$e^+e^- \to \pi^+\pi^- X(3823) \to \pi^+\pi^- \gamma \chi_{c1}$

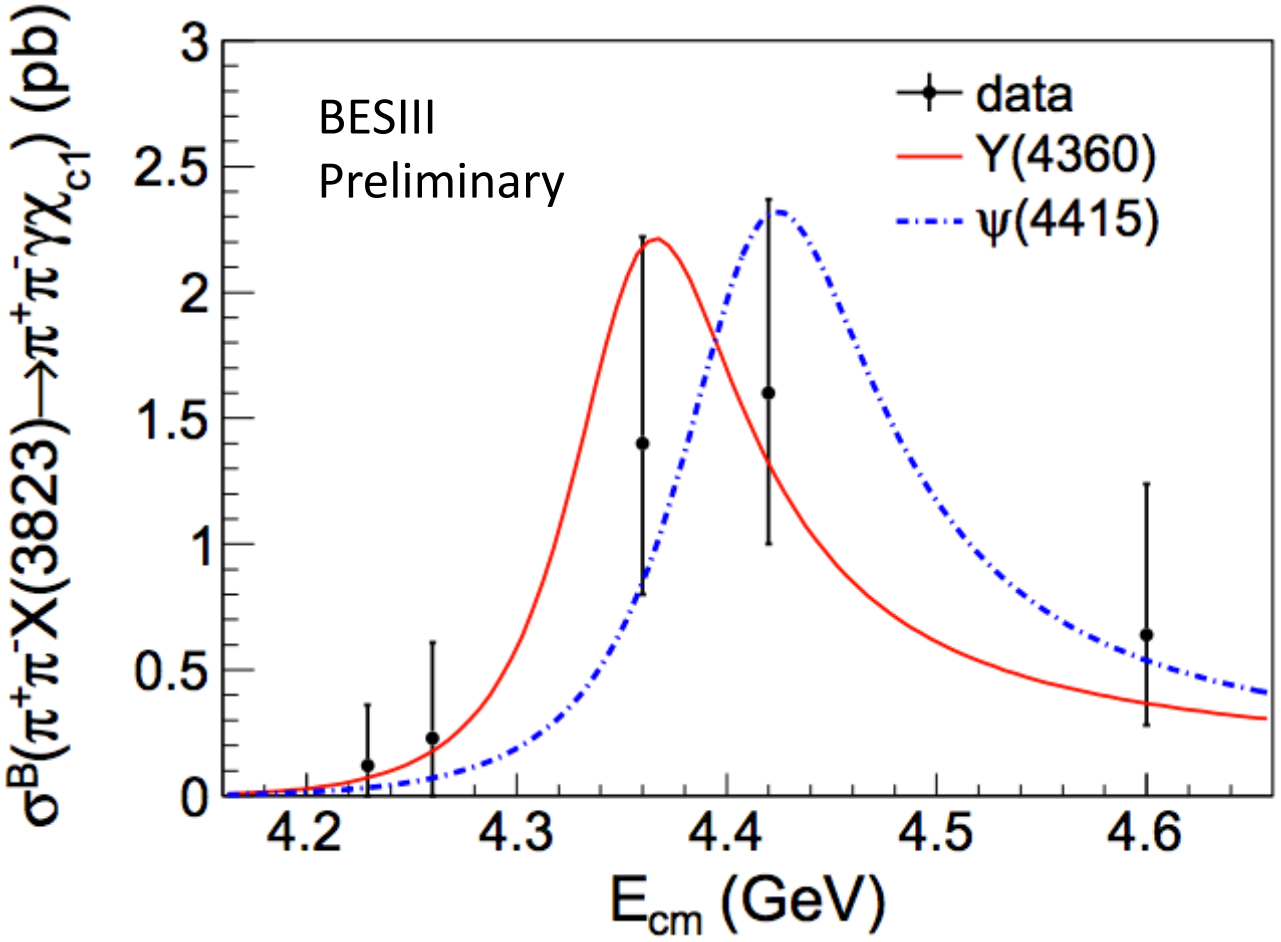
Preliminary





- Simultaneous fit: data-I (4.36, 4.42, 4.60 GeV) & data-II (4.23, 4.26 GeV)
- Signal: MC simulated shape + Background: linear
- M=3821.7$\pm$1.3$\pm$0.7 MeV; Significance: 6.7σ, observation !

Production cross section



NEW!

1. Energy dependent cross section of $e^+e^-\to\pi^+\pi^-X(3823)$.
2. Both Y(4360) and ψ(4415) line shape give reasonable description.

X(3823) as the $\psi(1^3D_2)$

- Mass: D-wave ~3.810-3.840 GeV by potential model.
- X(3823) mass agree with $\psi(1^3D_2)$ prediction.

- Width: narrow
- X(3823) should be narrow (<16 MeV @ 90% C.L.).

- Production ratio:
- $R=B[X(3823)\rightarrow\gamma\chi_{c2}]/B[X(3823)\rightarrow\gamma\chi_{c1}]<0.43$ @ 90% C.L.
- Agree with prediction R~0.2.

- Exclusions: $1^1D_2\rightarrow\gamma\chi_{c1}$ forbidden; $1^3D_3\rightarrow\gamma\chi_{c1}$ amplitude=0.

The Y states

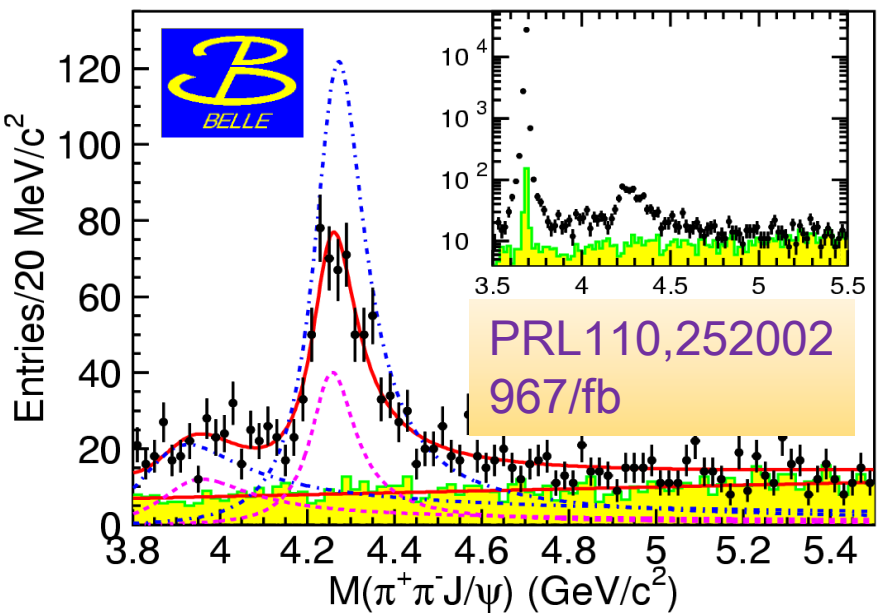
(vectors)

measurements of more final states for the

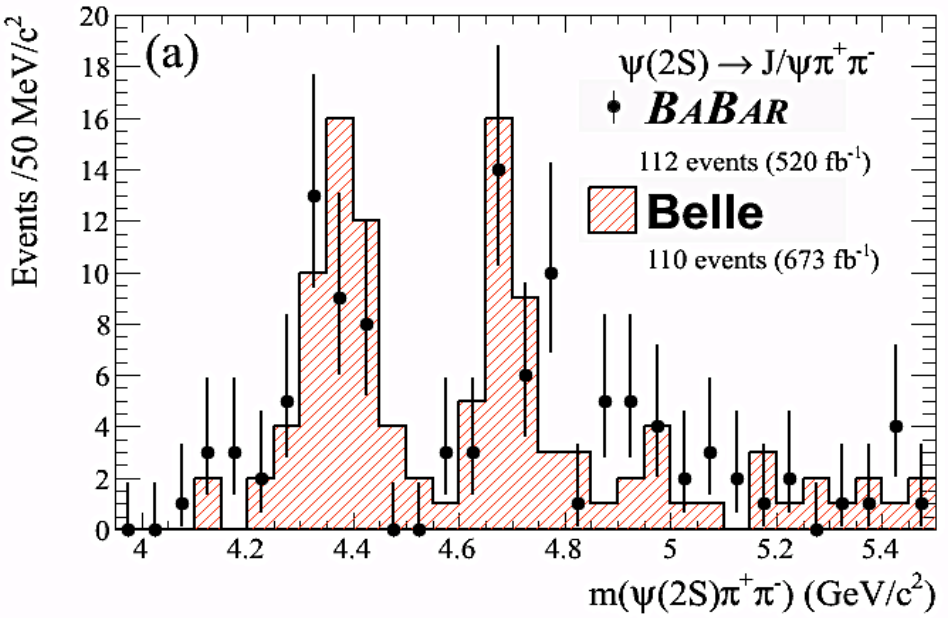
Y and ψ states

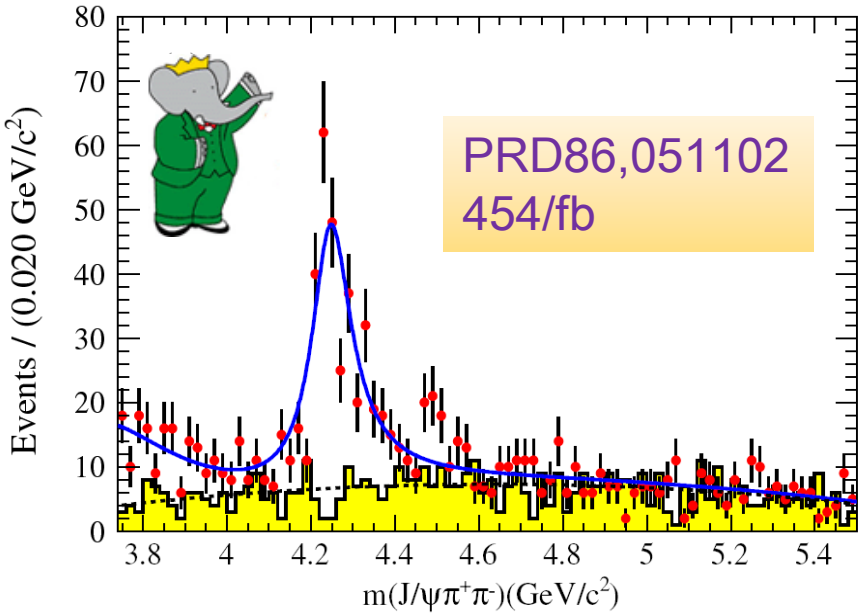
The Y states

Belle: PRL99,142002, 670/fb
BaBar: arXiv1211.6271, 520/fb

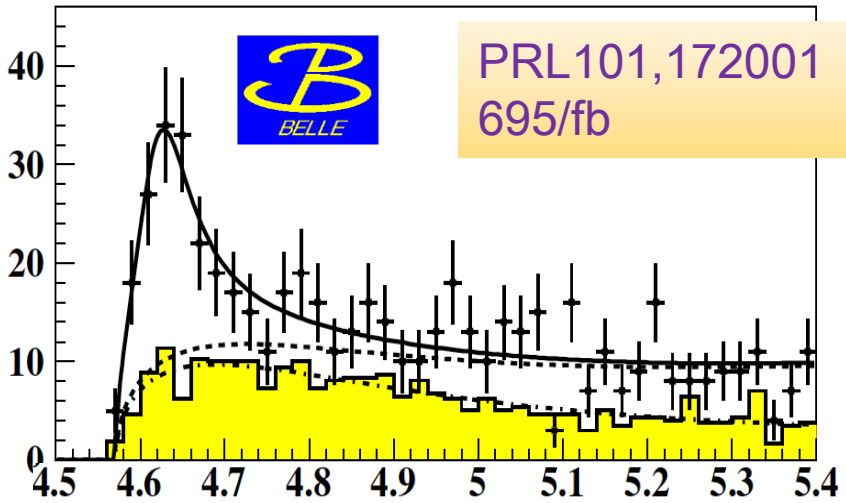


PRL110,252002
967/fb





PRD86,051102
454/fb



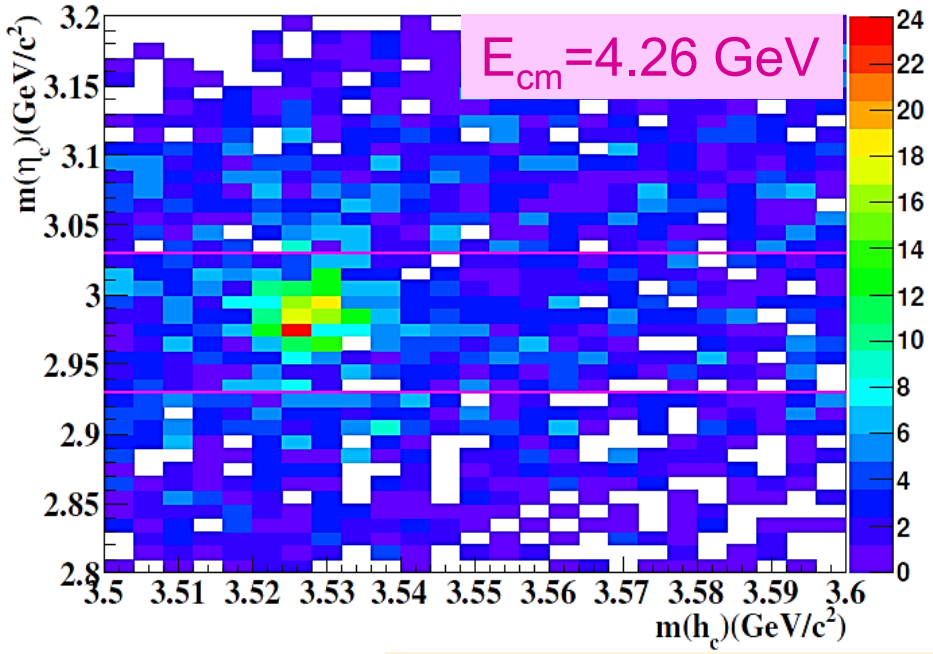
PRL101,172001
695/fb

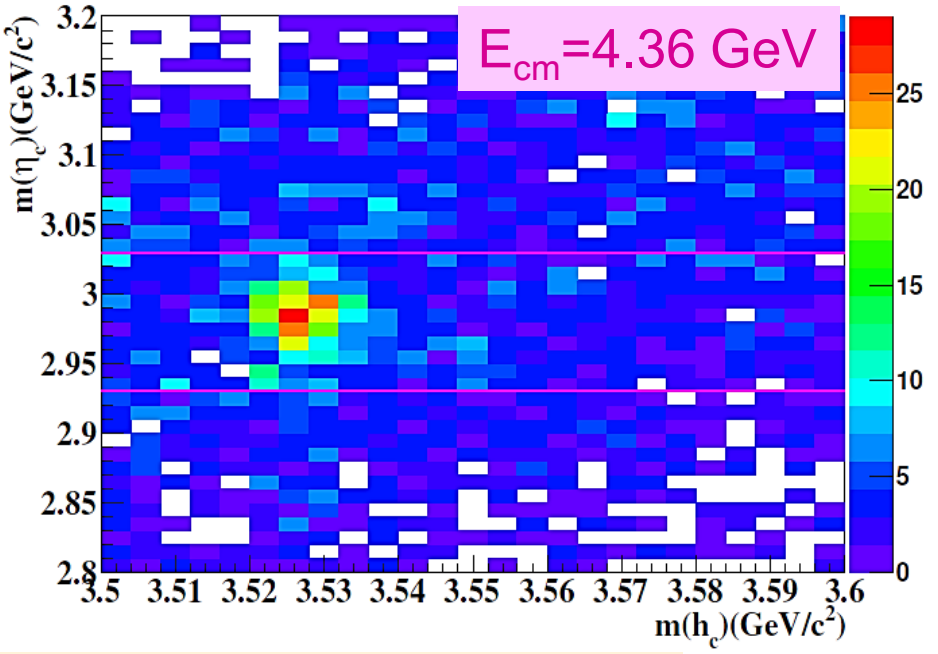
M($\Lambda_c^+\Lambda_c^-$)

May BESIII help?

$e^+e^- \to \pi^+\pi^- h_c(1P)$ at BESIII

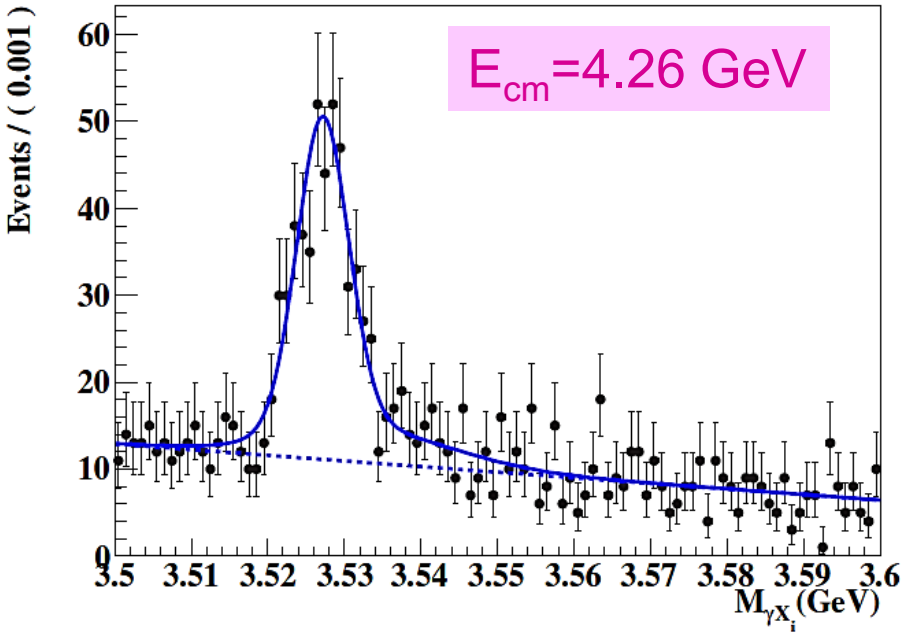
- $h_c \to \gamma\eta_c$, $\eta_c \to$hadrons [16 exclusive decay modes]
  - $p\bar{p}$, $\pi^+\pi^- K^+K^-$, $\pi^+\pi^- p\bar{p}$, $2(K^+K^-)$, $2(\pi^+\pi^-)$, $3(\pi^+\pi^-)$
  - $2(\pi^+\pi^-)K^+K^-$, $K_S^0K^+\pi^-$+c.c., $K_S^0K^+\pi^-\pi^+\pi^-$+c.c., $K^+K^-\pi^0$
  - $p\bar{p}\pi^0$, $K^+K^-\eta$, $\pi^+\pi^-\eta$, $\pi^+\pi^-\pi^0\pi^0$, $2(\pi^+\pi^-)\eta$, $2(\pi^+\pi^-\pi^0)$

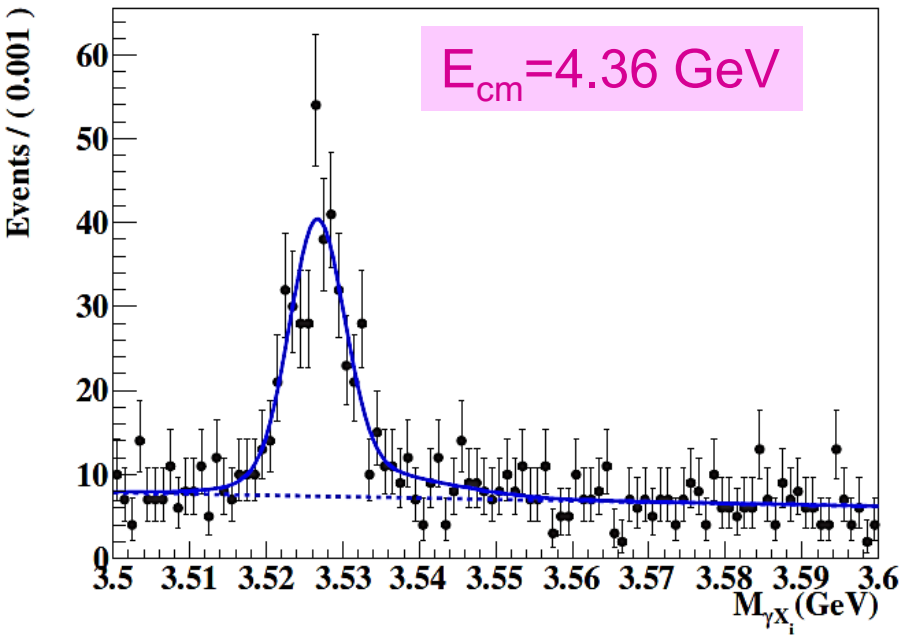




BESIII: arXiv:1309.1896, PRL111, 242001

Observation of $e^+e^- \to \pi^+\pi^- h_c(1P)$





$N(h_c)$=416±28

Lum=827/pb

σ^B= 41.0±2.8±7.4 pb

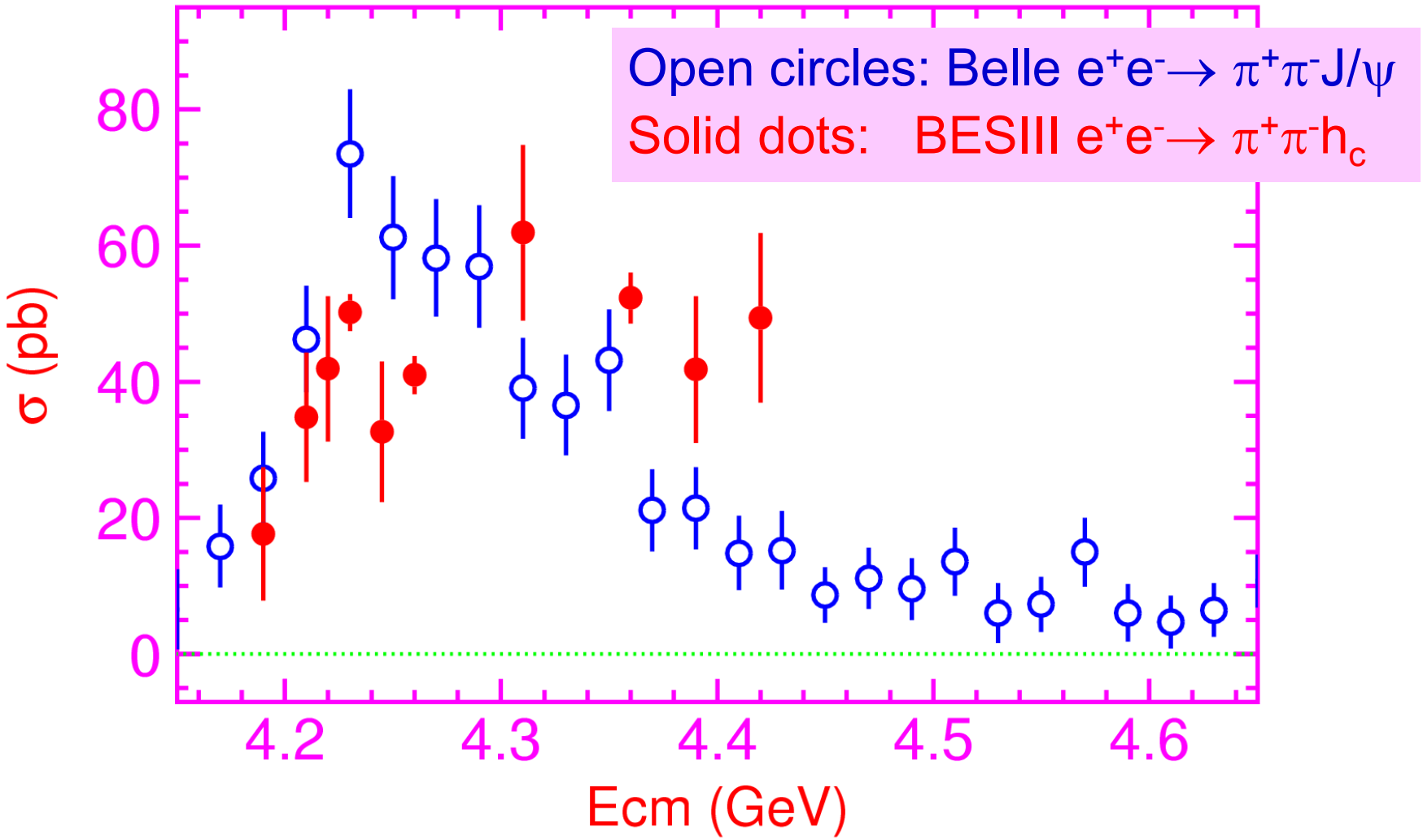
$N(h_c)$=357±25

Lum=544/pb

σ^B= 52.3±3.7±9.2 pb

BESIII: arXiv:1309.1896, PRL111, 242001

Comparison of $e^+e^- \to \pi^+\pi^- h_c$ and $\pi^+\pi^- J/\psi$



Broad structure at high energy region? Need more data at high energies to complete the line shape measurement.

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

$\omega \rightarrow \pi^+\pi^-\pi^0$

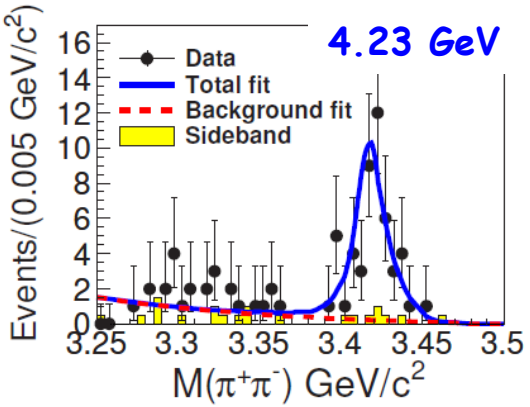
$\chi_{c0} \rightarrow \pi^+\pi^-$、 K^+K^-

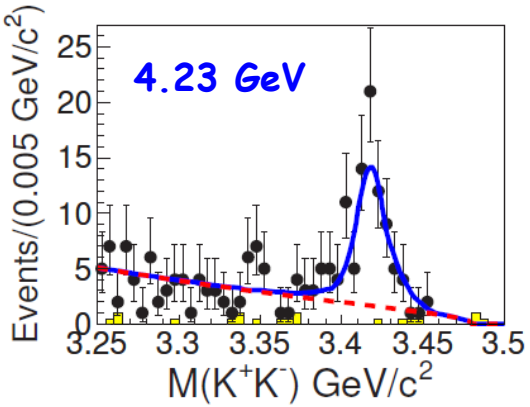
Fit with a single BW

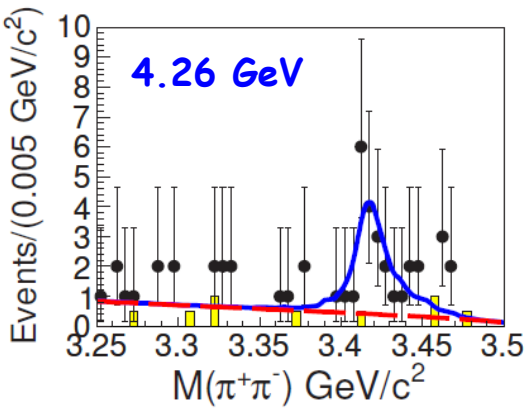
Mass = $4230 \pm 8 \pm 6$ MeV

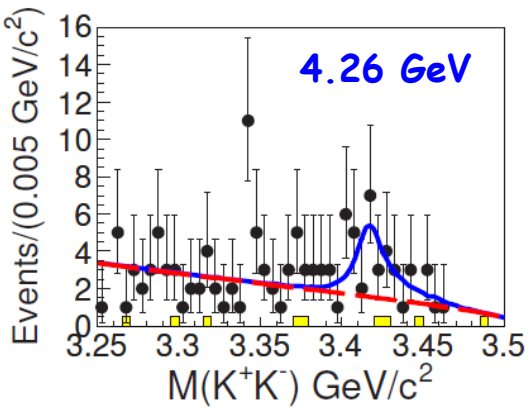
Width = $38 \pm 12 \pm 2$ MeV

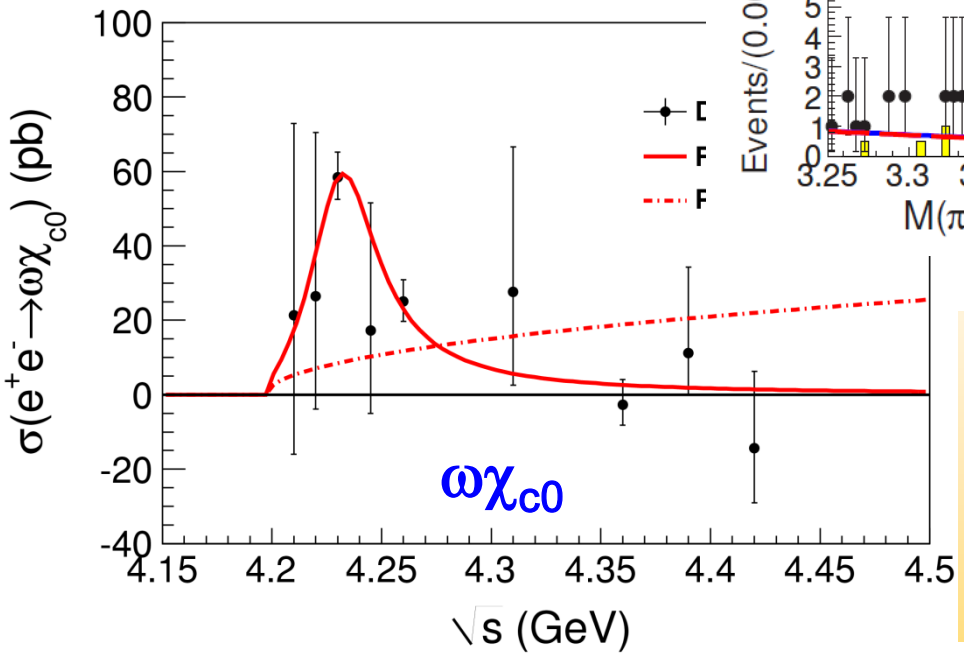
Significance $> 9\sigma$











A tetraquark? (arXiv: 1412.7196)

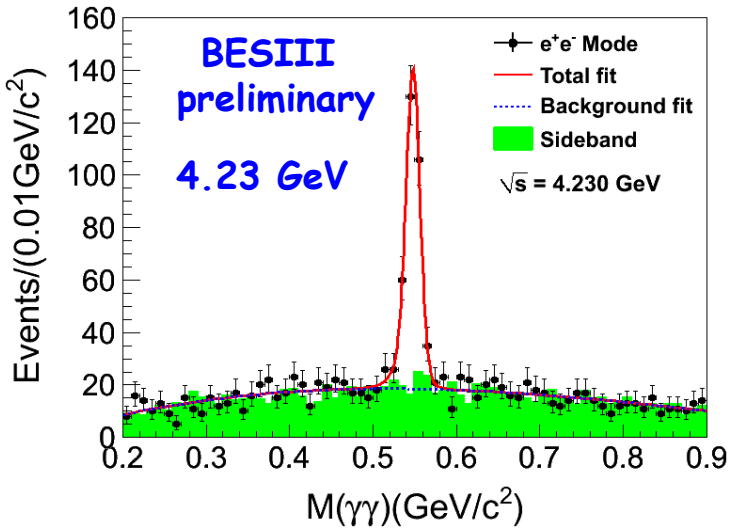
ψ(4S)? (arXiv: 1405.3831)

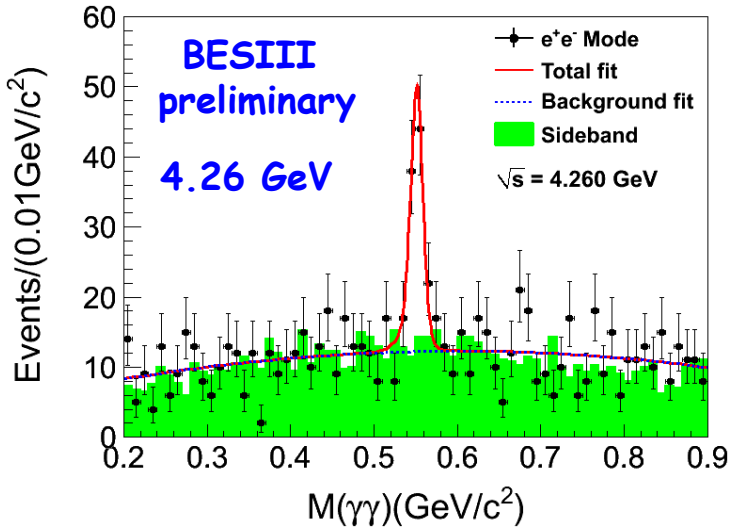
Threshold effect?

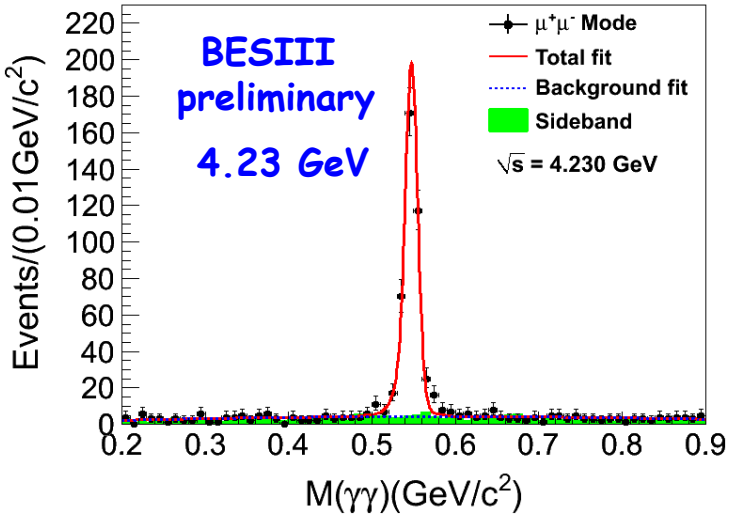
…

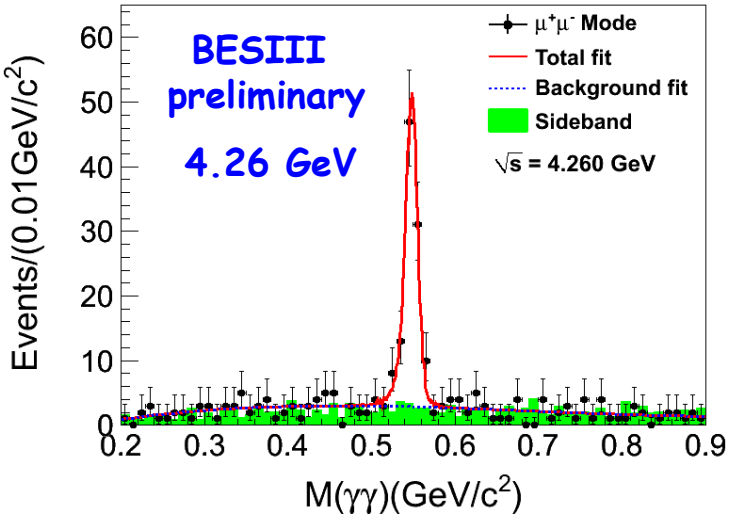
arXiv:1410.6538

Observation of $e^+e^- \rightarrow \eta J/\psi$

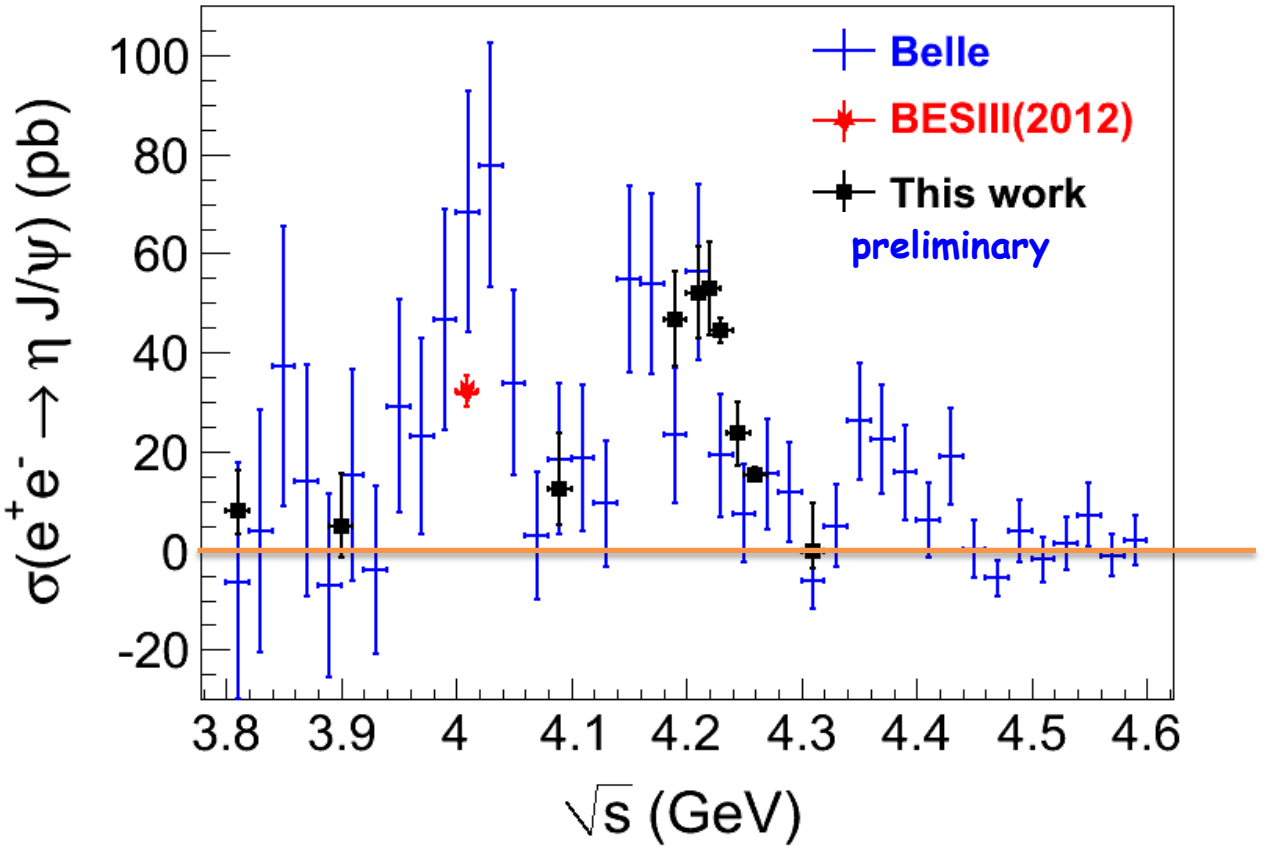






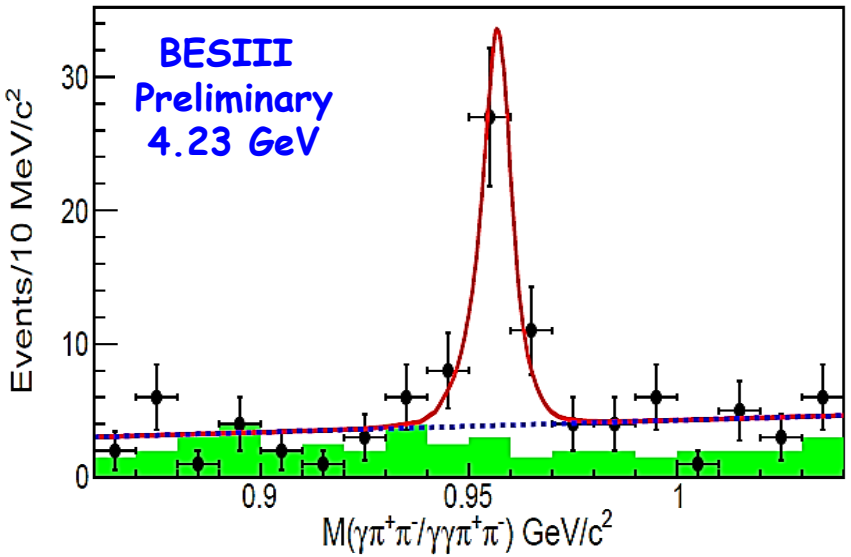


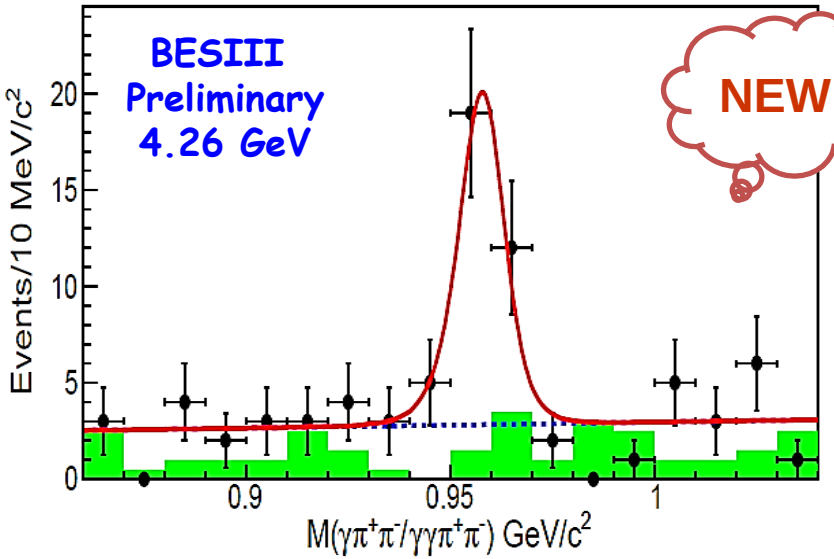
Observation of $e^+e^- \rightarrow \eta J/\psi$

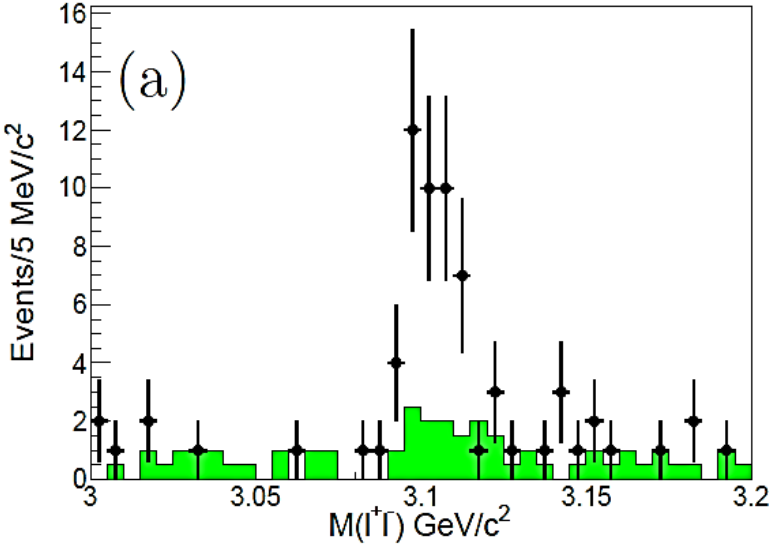


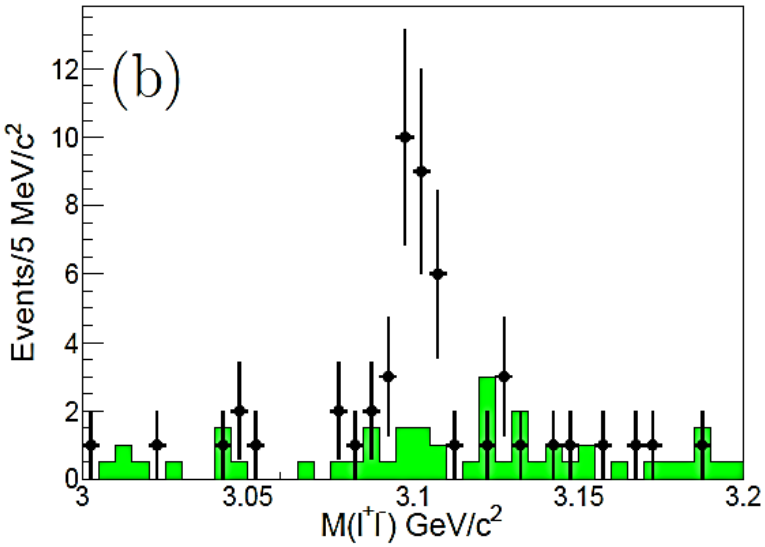
- Agree with previous results with improved precision
- The cross section peaks around 4.2 GeV
- Analysis of high energy points underway

Observation of $e^+e^- \rightarrow \eta' J/\psi$

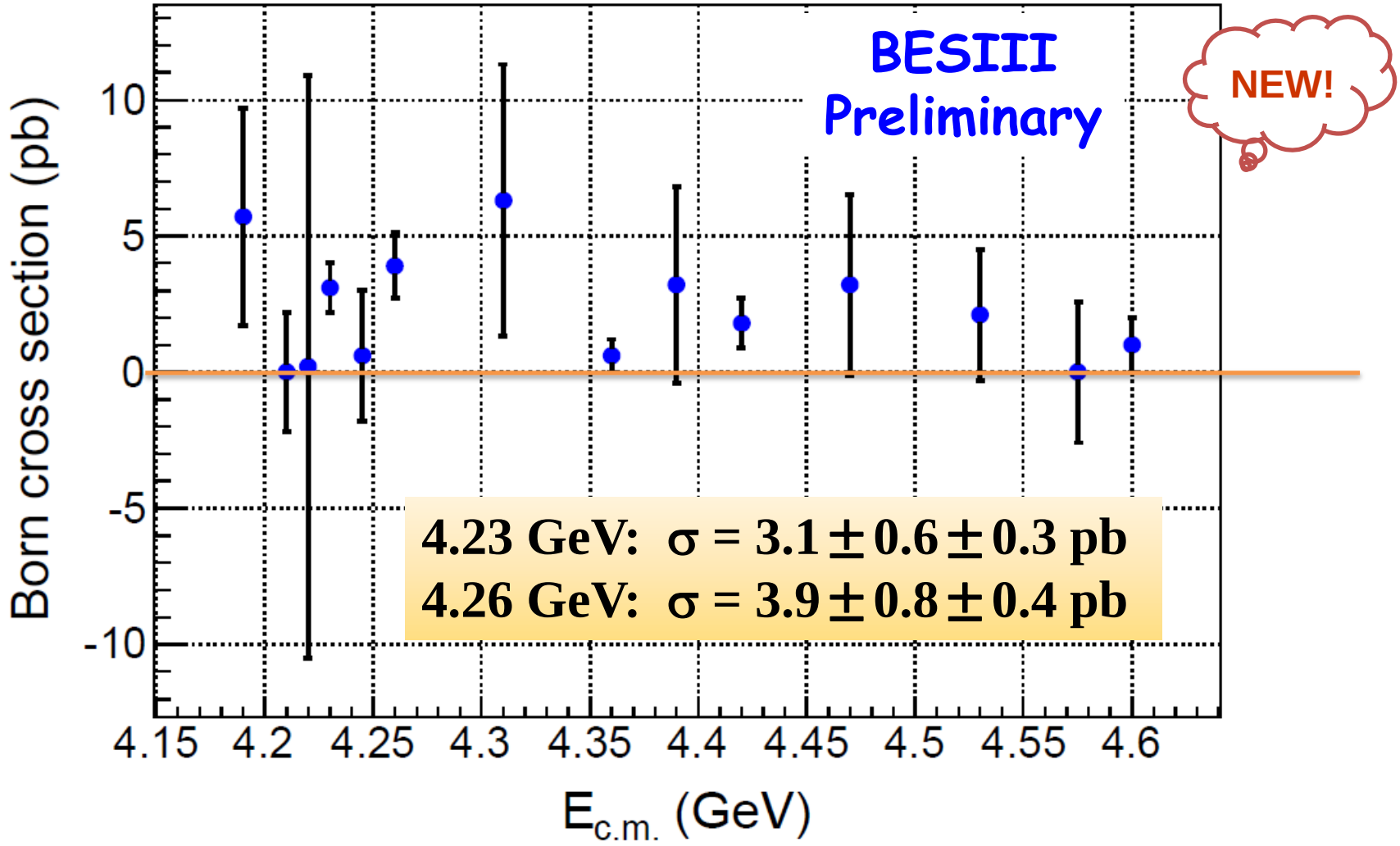








Observation of $e^+e^- \rightarrow \eta' J/\psi$

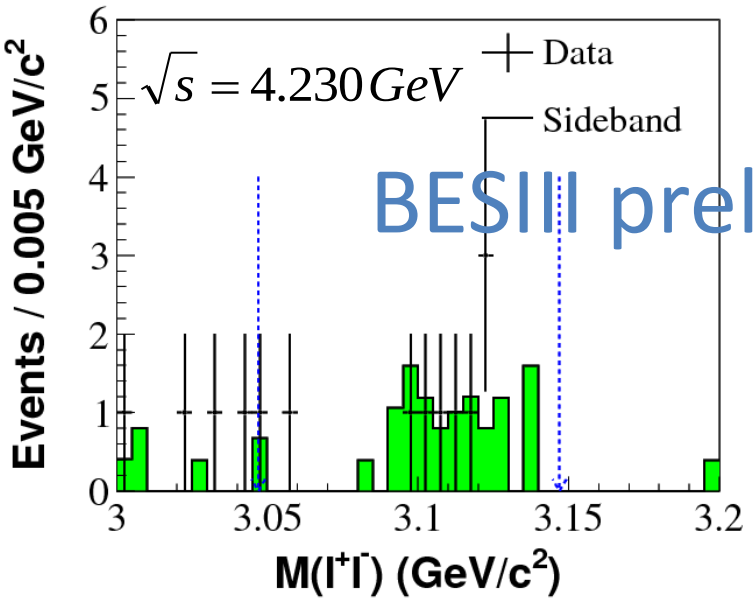


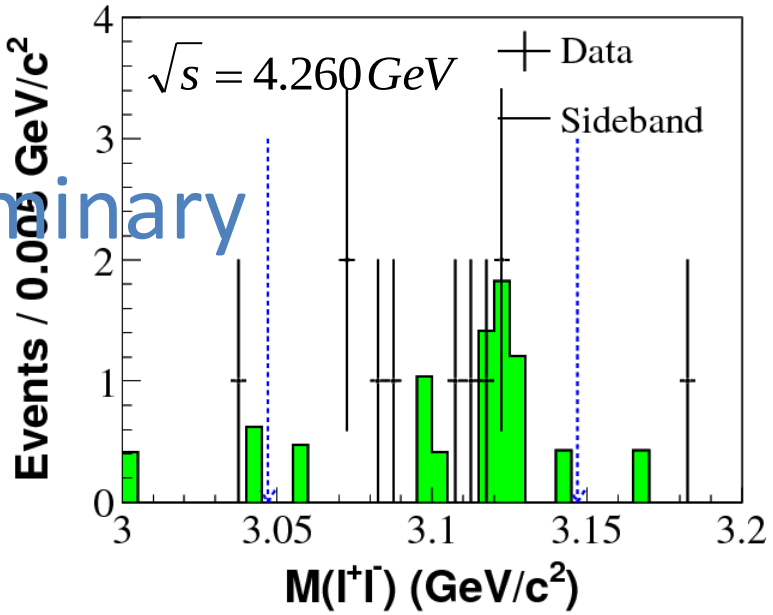
- First observation, cannot tell the line shape due to statistics

No significant $e^+e^- \rightarrow \eta\pi^0 J/\psi$

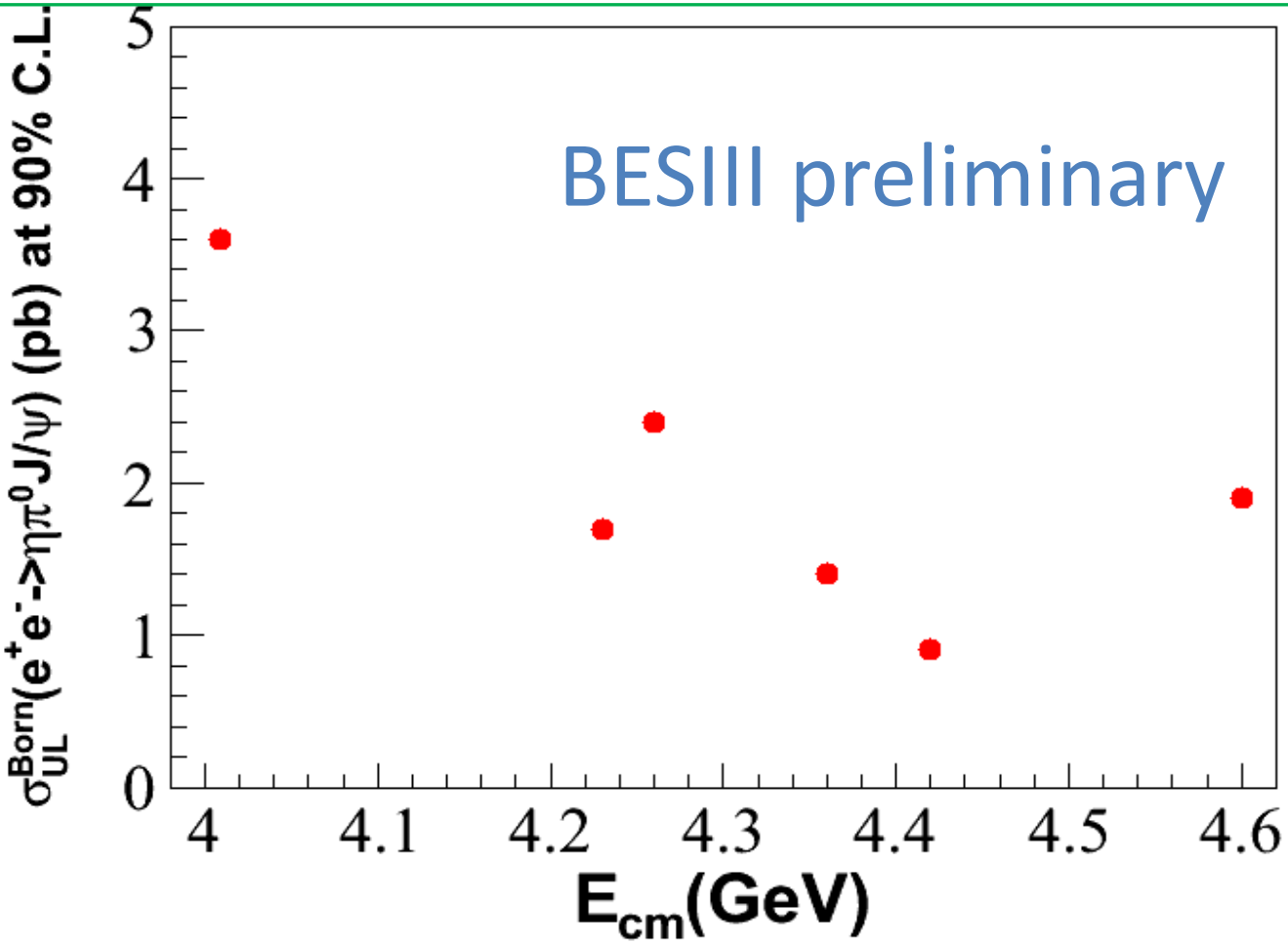
- Model predictions of $e^+e^- \rightarrow \eta\pi^0 J/\psi$
- Hadro-quarkonium/tetraquark of Z_b and Z_c:
  - M.Voloshin, PRD 86 034013
  - A. Ali et al., PRL 104 162001, PRL 106 092002
  - L. Maiani et al., PRD 87 111102
- Y(4260) as a D_1D molecule: X. Wu et al., PRD 89, 054038
- Select an η and a π^0, then check the J/ψ signal

NEW!





No Y(4260)→ $\eta\pi^0 J/\psi$



- Upper limits well above prediction of D_1D molecule model (0.05 pb at 4.290 GeV) [X. G. Wu et al., PRD 89, 054038]
- Need ~100 times more luminosity to reach the sensitivity

Evidence for $e^+e^- \to \gamma\chi_{cJ}$

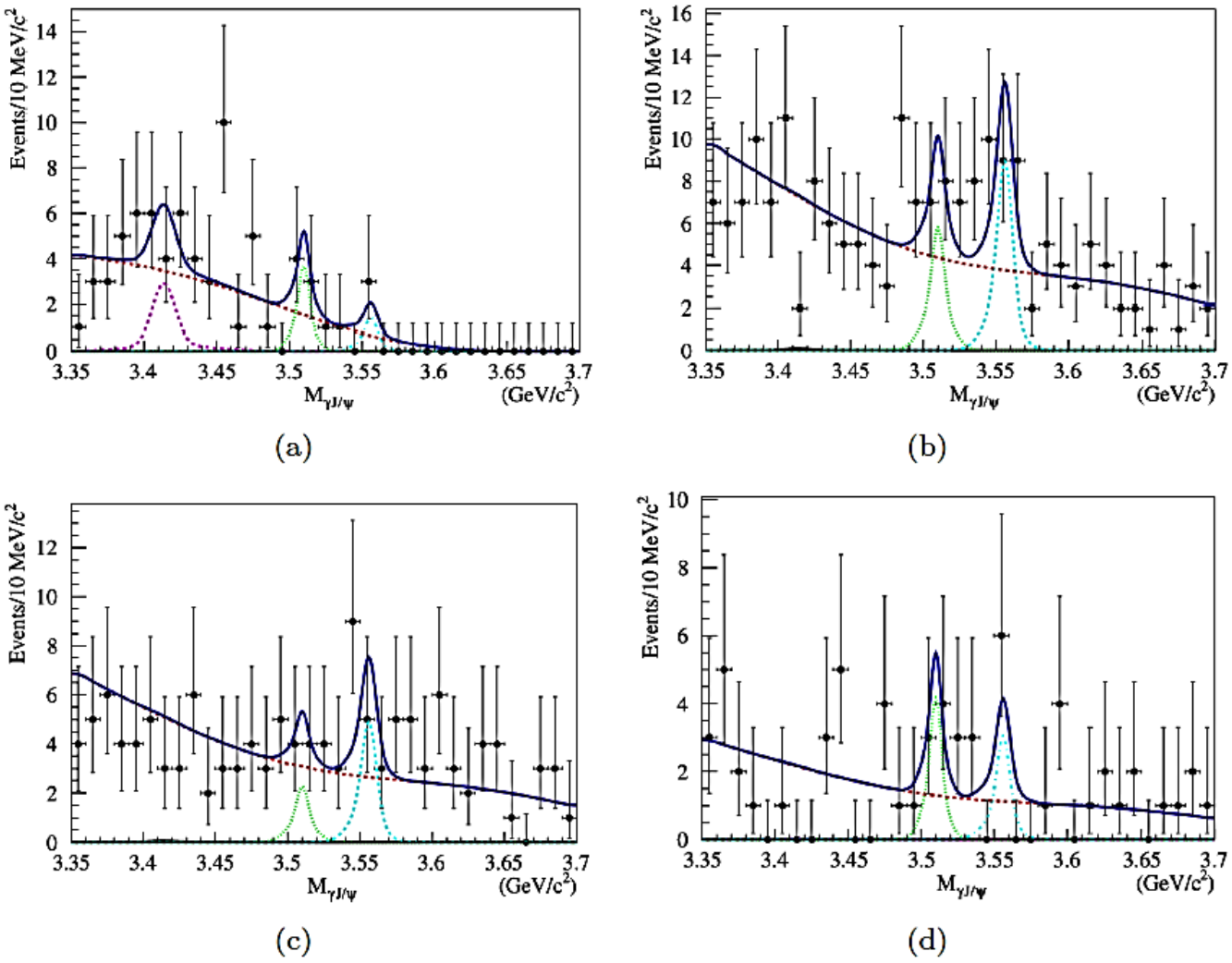
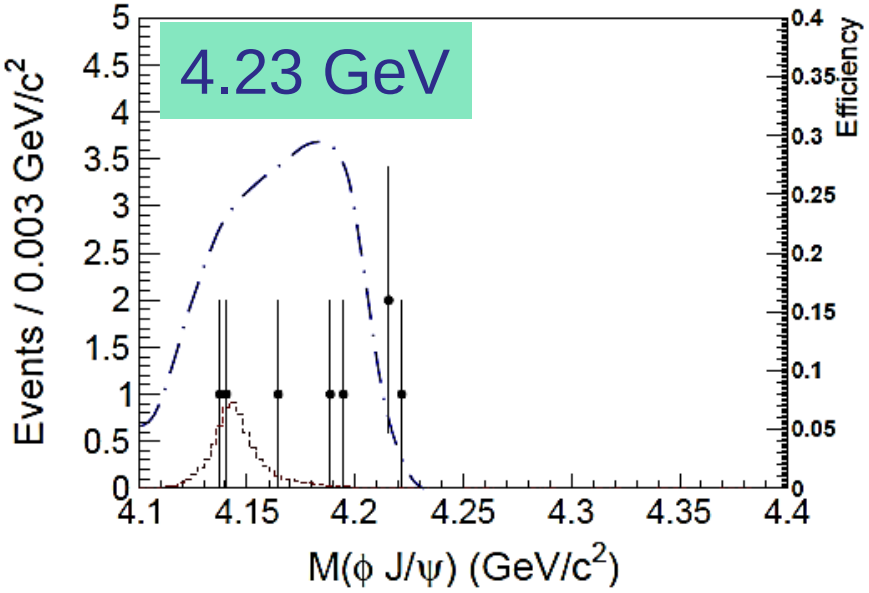
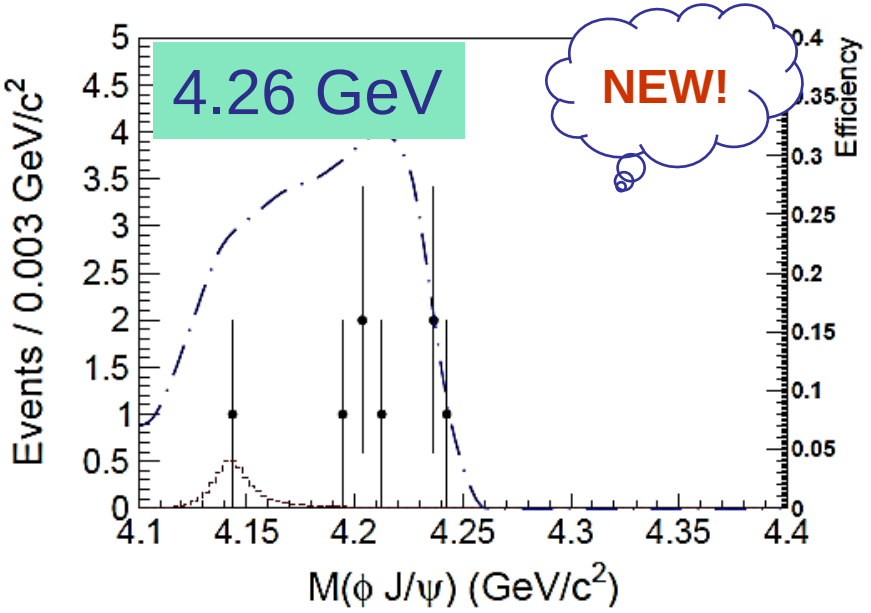


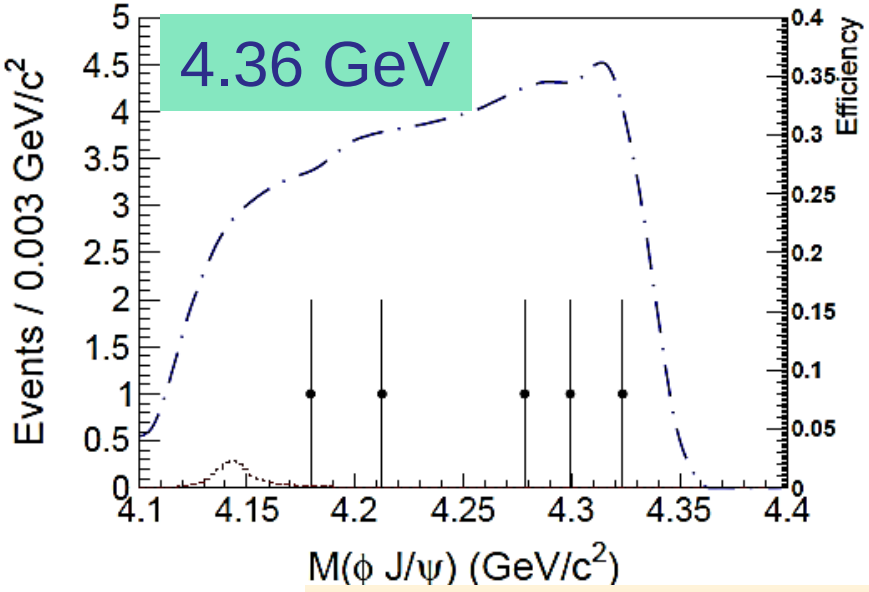
Fig. 2. The distribution of $\gamma J/\psi$ invariant mass, $M_{\gamma J/\psi}$, and fit results for data at $\sqrt{s} = 4.009$ (a), 4.230 (b), 4.260 (c) and 4.360 GeV (d). The solid lines show the total fit results. The χ_{cJ} signals are shown as dashed lines, dotted lines, and dash-dotted lines, for J = 0, 1, and 2, respectively. The backgrounds are indicated by red dashed lines.

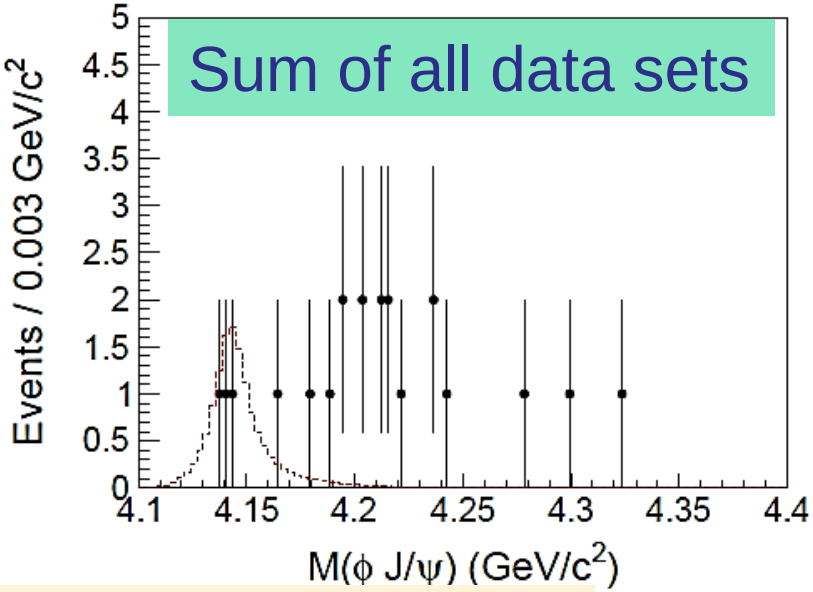
BESIII: arXiv:1411.6336, CPC (in press)

No significant e^+e^- → $\gamma Y(4140)$









BESIII: arXiv:1412.1867, PRD (in press)

No significant e^+e^- → $\gamma Y(4140)$

Upper limit at the 90% C.L. for $\sigma^B \cdot \mathcal{B} = \sigma^B(e^+e^- \to \gamma Y(4140)) \cdot \mathcal{B}(Y(4140) \to \phi J/\psi)$

$\sqrt{s}$ (GeV/c^2)	Luminosity (pb^{-1})	$(1+\delta)$	n^{prod}	$\sigma^B \cdot \mathcal{B}$ (pb)
4.23	1094	0.840	<339	<0.35
4.26	827	0.847	<207	<0.28
4.36	545	0.944	<179	<0.33

Systematic uncertainty is considered.

Compared with $X(3872)$ production. PRL 112, 092001

$$\sigma^B(e^+e^- \to \gamma X(3872)) \cdot \mathcal{B}(X(3872) \to \pi^+\pi^- J/\psi)$$

= $0.27 \pm 0.09(\text{stat}) \pm 0.02(\text{syst})$ pb at $\sqrt{s}$= 4.23 GeV,

= $0.33 \pm 0.12(\text{stat}) \pm 0.02(\text{syst})$ pb at $\sqrt{s}$ = 4.26 GeV.

NEW!

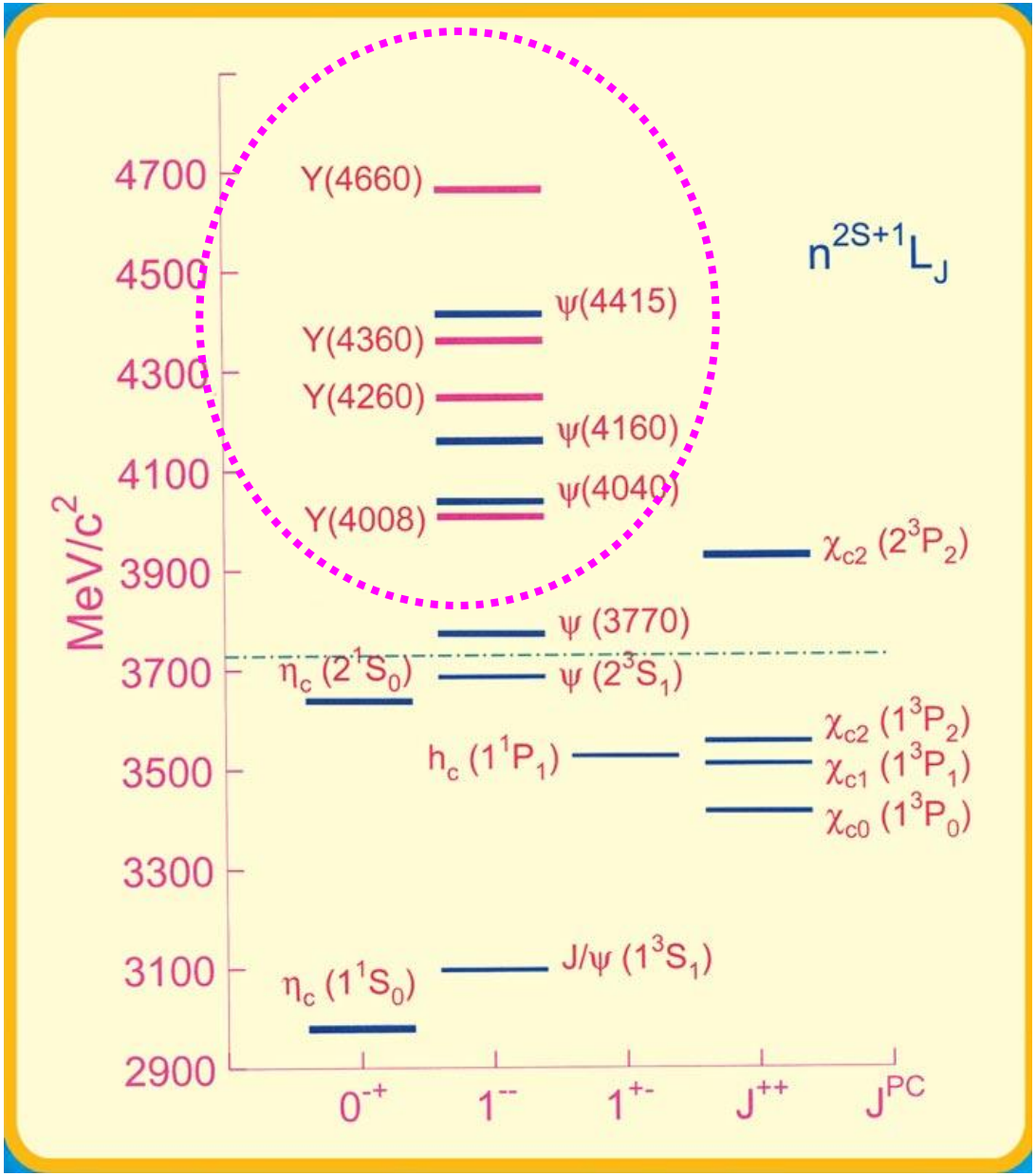
Take $\mathcal{B}(X(3872) \to \pi^+\pi^- J/\psi)$ = 5%. arXiv: 0910.3138

And $\mathcal{B}(Y(4140) \to \phi J/\psi)$ = 30%, molecular calculation, PRD 80, 054019.

$$\frac{\sigma^B(e^+e^- \to \gamma Y(4140))}{\sigma(e^+e^- \to \gamma X(3872))} \leq 0.1 \text{ at } \sqrt{s}=4.23 \text{ and } 4.26 \text{ GeV}.$$

BESIII: arXiv:1412.1867, PRD (in press)

What are the Y states?



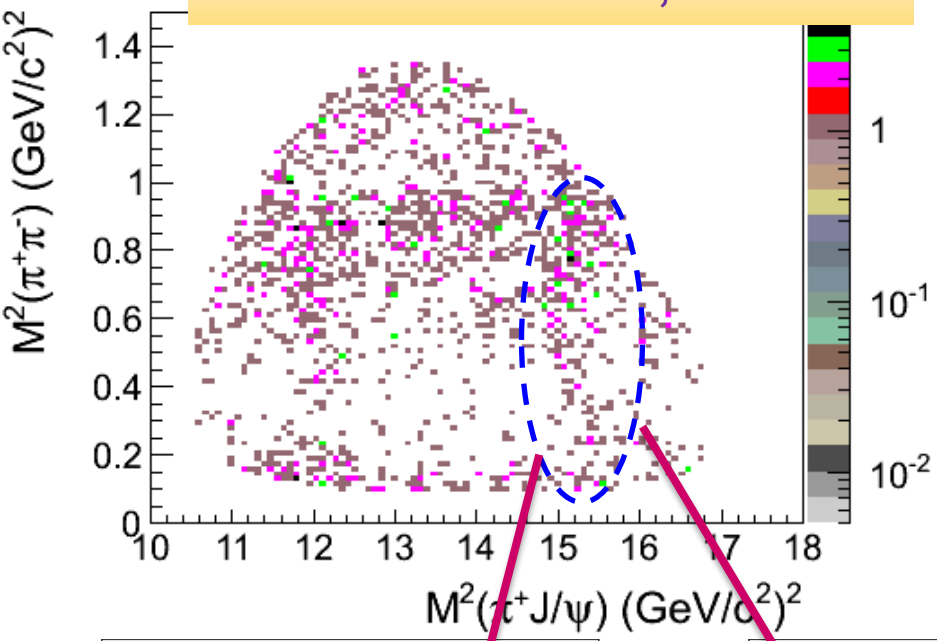
- Between 4 and 4.7 GeV, at most 5 states expected (3S, 2D, 4S, 3D, 5S), 7 observed
- Hybrids are expected in this mass region
- Molecular states?
- Cannot rule out threshold effect/FSI/…
- The Ys are all narrow and similar
- $\pi^+\pi^- h_c$, $\omega\chi_c$, … add complexity

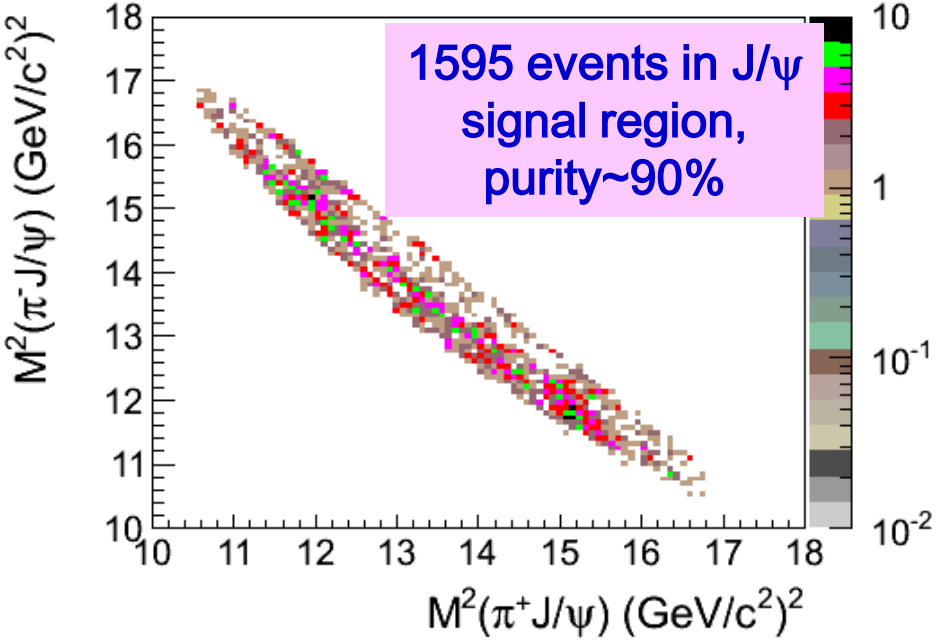
The Z_c states

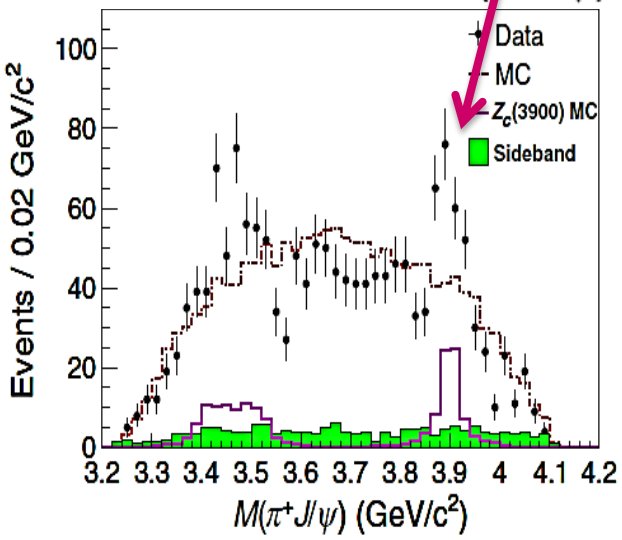
$e^+e^- \to \pi^+\pi^- J/\psi$ at E_{cm}=4.26 GeV

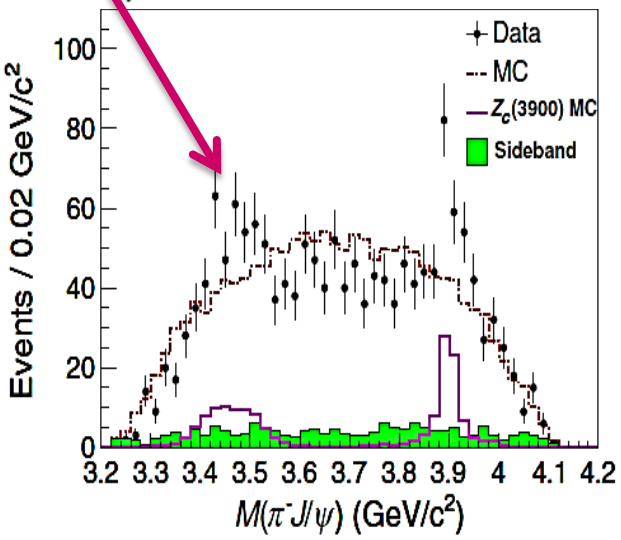
BESIII: PRL110,252001

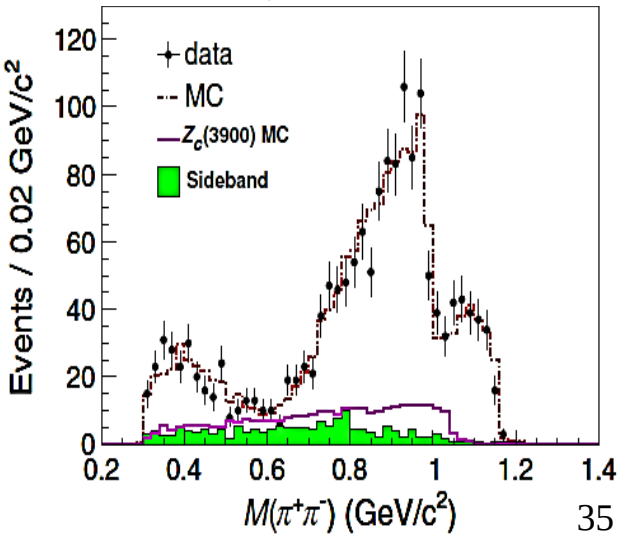
525 pb^{-1} data at 4.260 GeV











Discovery of $Z_c(3900)^{\pm}$

$Z_c(3900)^+$:

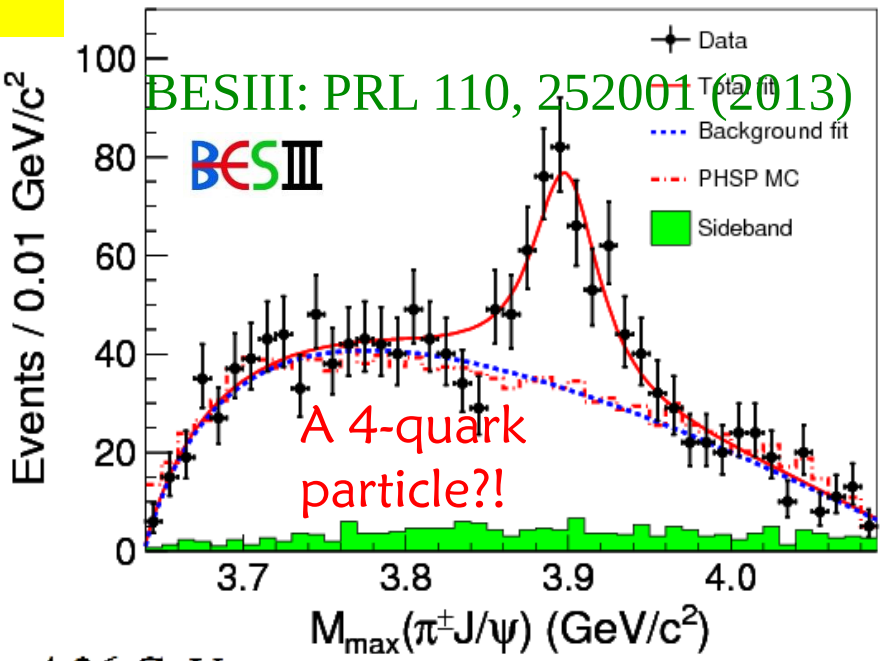
$m = (3899.0 \pm 3.6 \pm 4.9)\ \mathrm{MeV}/c^2$

$\Gamma = (46 \pm 10 \pm 20)\ \mathrm{MeV}$

Mass close to $D\bar{D}^*$ threshold

Decays to J/ψ → contains $c\bar{c}$
Electric charge → contains $u\bar{d}$

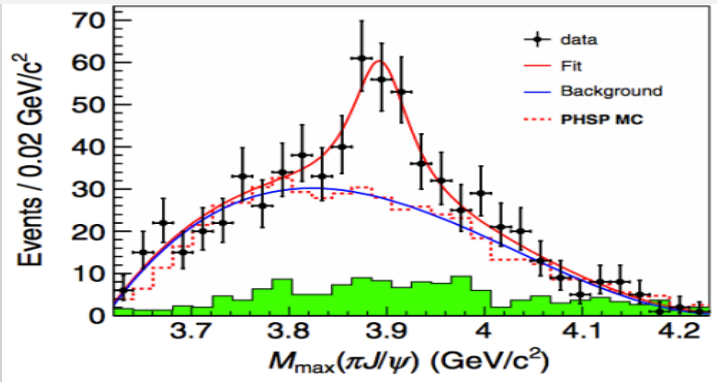
4260 MeV



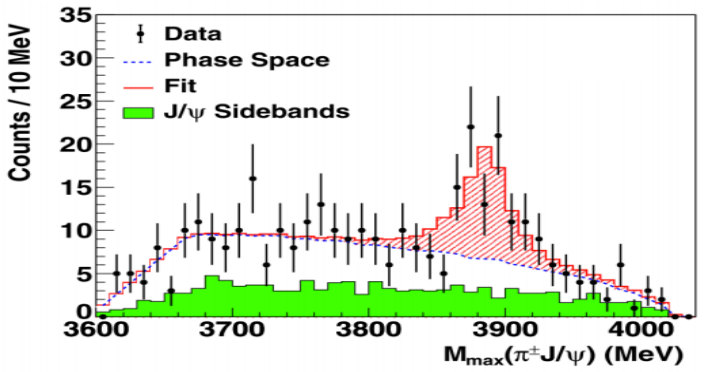
$$\sigma[e^+e^- \to \pi^+\pi^- J/\psi] = 62.9 \pm 1.9 \pm 3.7\ \mathrm{pb\ at\ 4.26\ GeV}$$

$$\frac{\sigma[e^+e^- \to \pi^\pm Z_c(3900)^\mp \to \pi^+\pi^- J/\psi]}{\sigma[e^+e^- \to \pi^+\pi^- J/\psi]} = (21.5 \pm 3.3 \pm 7.5)\%\ \mathrm{at\ 4.26\ GeV}$$

Belle with ISR data (PRL 110, 252002)

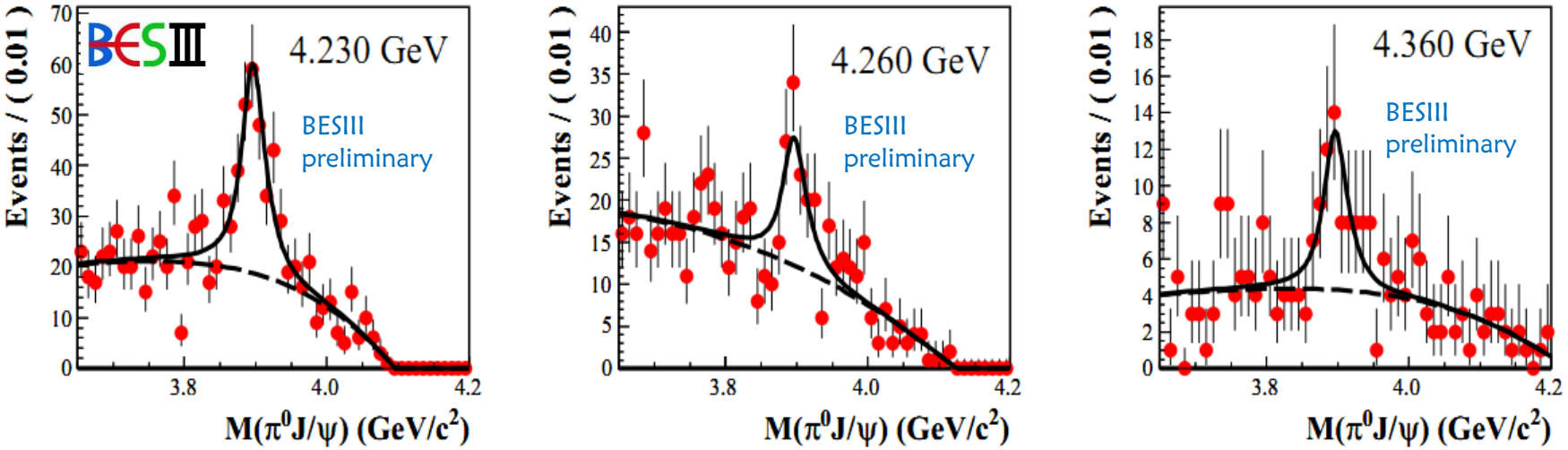


CLEOc data at 4.17 GeV (PLB 727, 366)



The neutral isospin partner: $Z_c(3900)^0$

Studying the $e^+e^- \to \pi^0\pi^0 J/\psi$ process

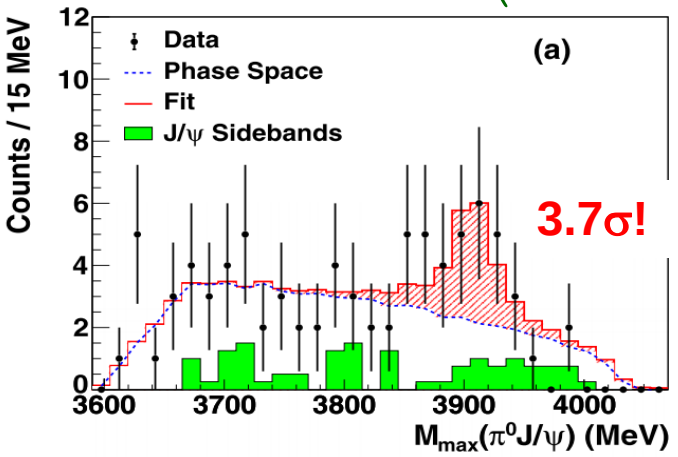


A structure on $\pi^0 J/\psi$ invariant mass spectrum can be observed:

Mass = $3894.8 \pm 2.3 \pm 2.7$ MeV
Width = $29.6 \pm 8.2 \pm 8.2$ MeV
Significance = 10.4 σ

Isospin triplet is established!

CLEOc data at 4.17 GeV (PLB 727, 366)

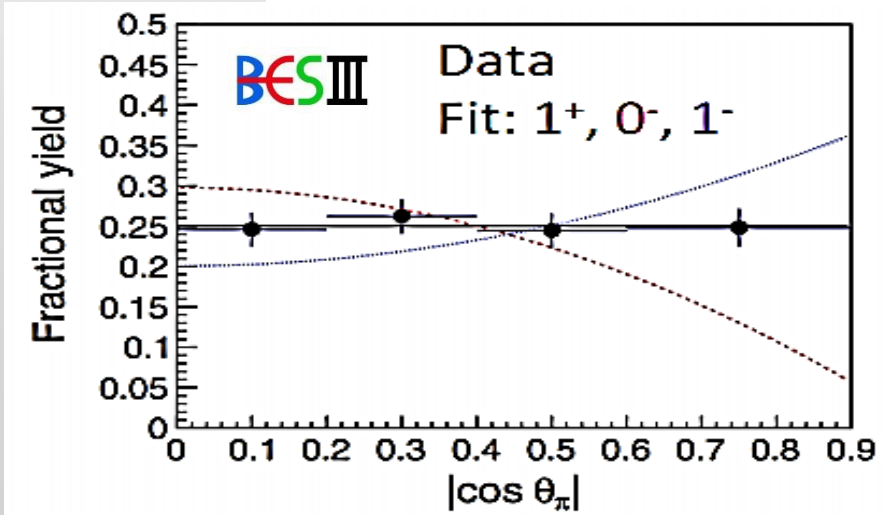


Observation of $Z_c(3885)^{\pm}$ in $e^+e^- \to \pi^{\pm}(D\bar{D}^*)^{\mp}$ at $\sqrt{s} = 4.26$GeV using single D tag method

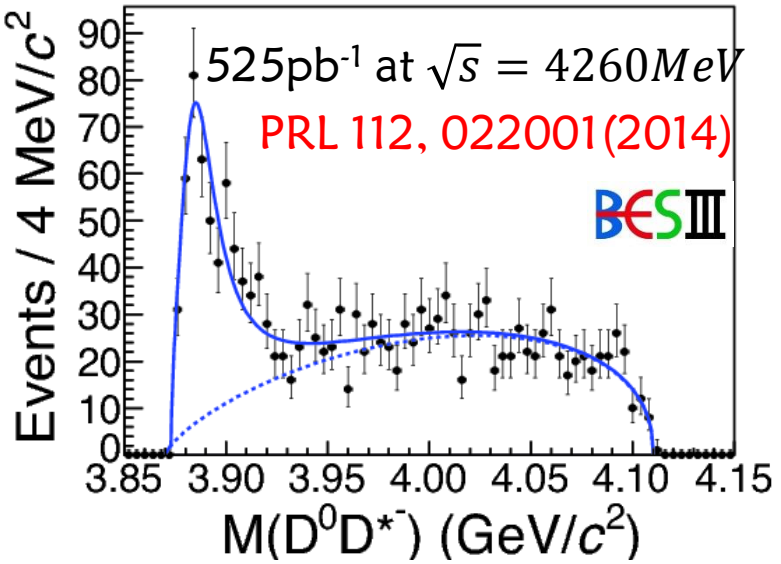
Reconstruct the π^+ and $D^0 \to K^-\pi^+$ and infer the D^{*-}.
(Also analyze $\pi^+D^-D^{*0}$ with the same method.)

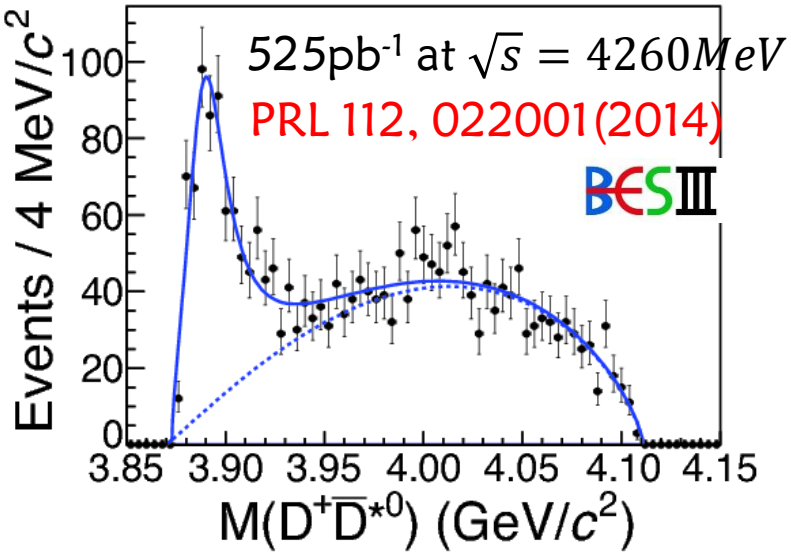
Enhancement at $D\bar{D}^*$ threshold in both channels ($Z_c(3885)^+$):

Mass = $3883.9 \pm 1.5 \pm 4.2$ MeV, (fit with BW function)
Width = $24.8 \pm 3.3 \pm 11.0$ MeV



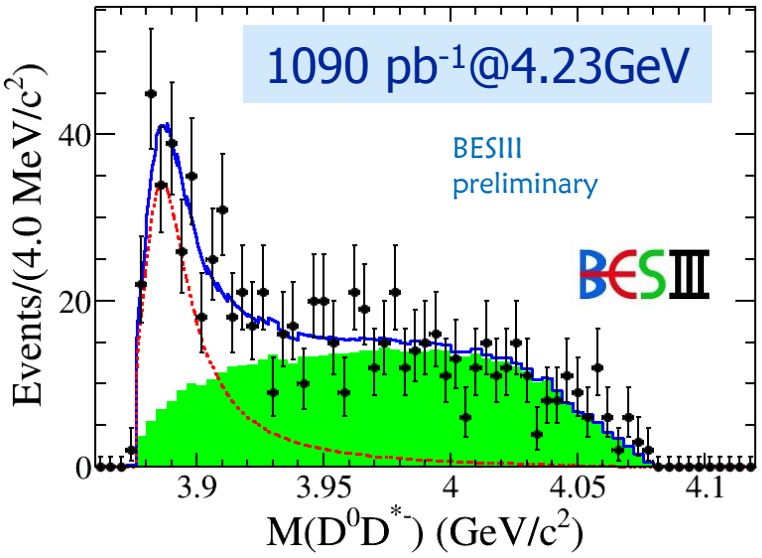
Fit to angular distribution favors $J^P = 1^+$ over 0^- and 1^-



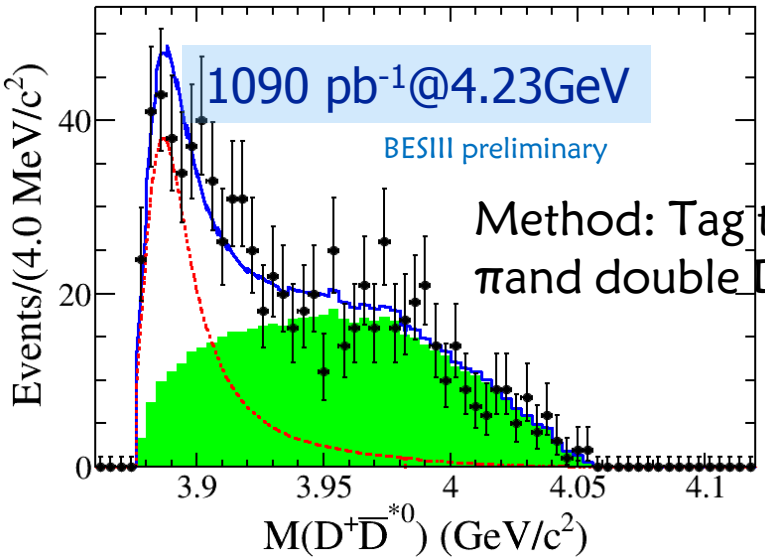


Confirmation of $Z_c(3885)^{\pm}$ in $e^+e^- \to \pi^{\pm}(D\bar{D}^*)^{\mp}$ using double D tag method

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

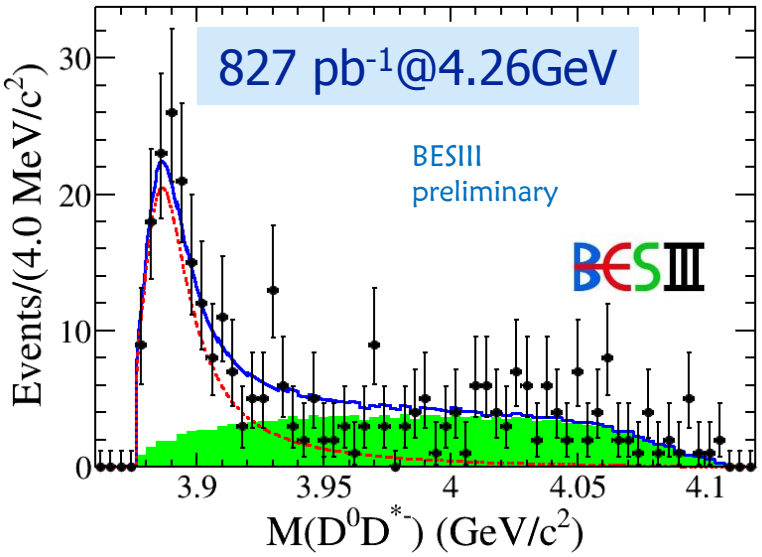


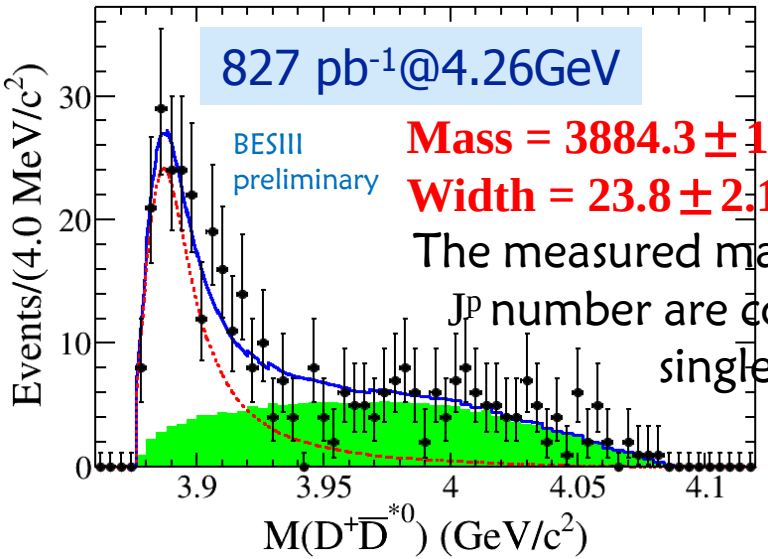
$e^+e^- \to \pi^+ D^- D^{*0}$



NEW!

Method: Tag the bachelor π and double D mesons





Mass = $3884.3 \pm 1.2 \pm 1.5$ MeV,
Width = $23.8 \pm 2.1 \pm 2.6$ MeV

The measured mass, width and J^P number are consistent with single D tag results.

Comparison between $Z_c(3885)^{\pm}$ and $Z_c(3900)^{\pm}$

Single D tag results,
PRL 112, 022001(2014)

	$Z_c(3885) \to D\bar{D}^*$	$Z_c(3900) \to \pi J/\psi$
Mass (MeV/c^2)	$3883.9 \pm 1.5 \pm 4.2$	$3899.0 \pm 3.6 \pm 4.9$
Γ (MeV)	$24.8 \pm 3.3 \pm 11.0$	$46 \pm 10 \pm 20$
$\sigma \times \mathcal{B}$ (pb)	$83.5 \pm 6.6 \pm 22.0$	$13.5 \pm 2.1 \pm 4.8$

- The mass and width are consistent within **2σ!**
- If this is $Z_c(3900)^+$, open charm decays are suppressed, since

$$\frac{\mathcal{B}(Z_c \to D^* \bar{D})}{\mathcal{B}(Z_c \to J/\psi \pi)} = 6.2 \pm 1.1 \pm 2.7$$

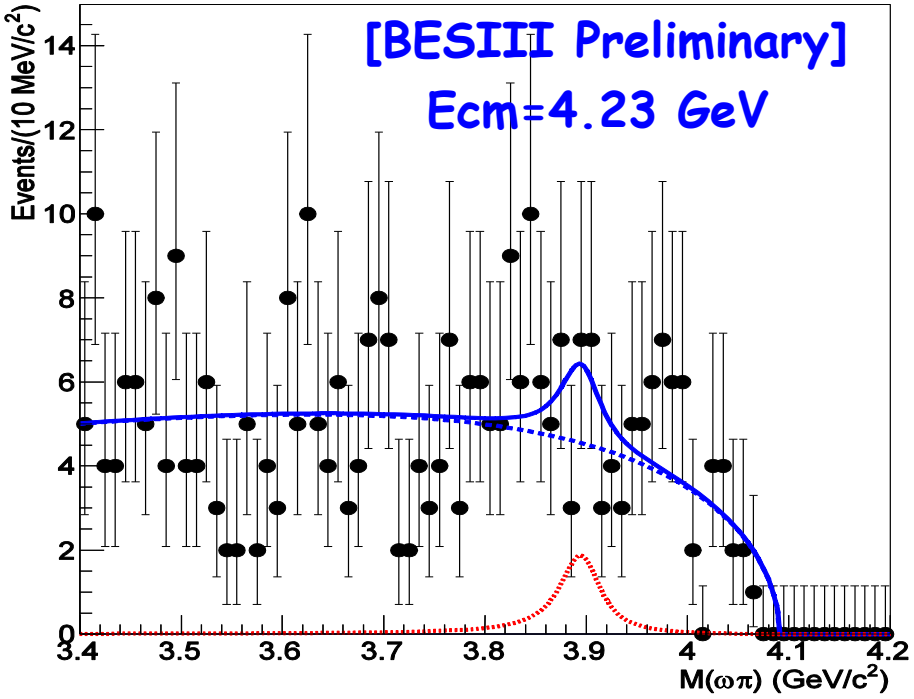
Compared to e.g.

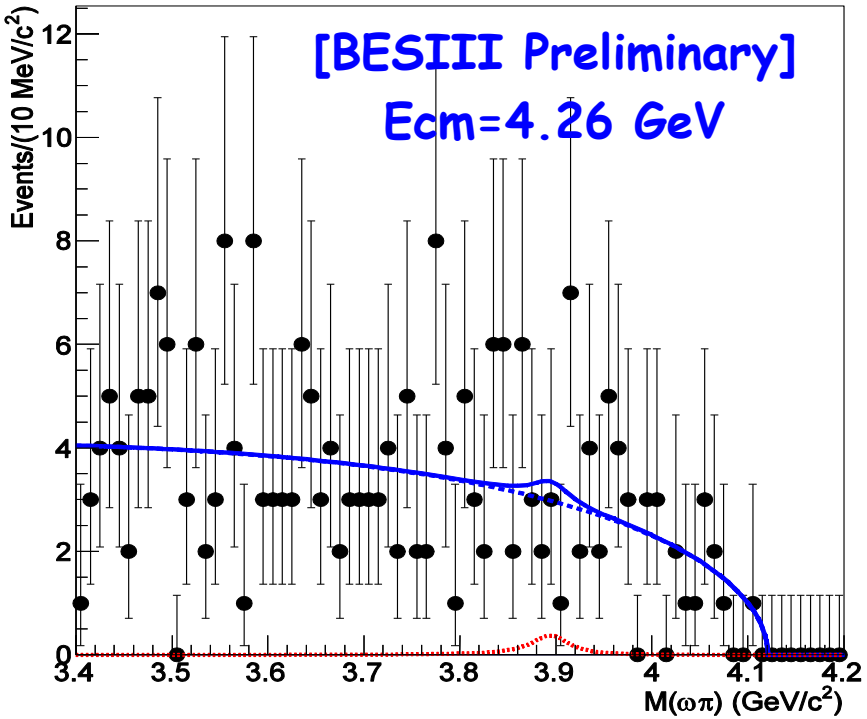
$$\frac{\mathcal{B}(\psi(4040) \to D^{(*)} \bar{D}^{(*)})}{\mathcal{B}(\psi(4040) \to J/\psi \eta)} = 192 \pm 27$$

Different dynamics in Y(4260)-Zc(3900) system!

No significant $Z_c \to \omega\pi$

NEW!





$\sigma(e^+e^- \to Z_c\pi^- + c.c., Z_c \to \omega\pi) < 0.27$ pb @ 4.23 GeV

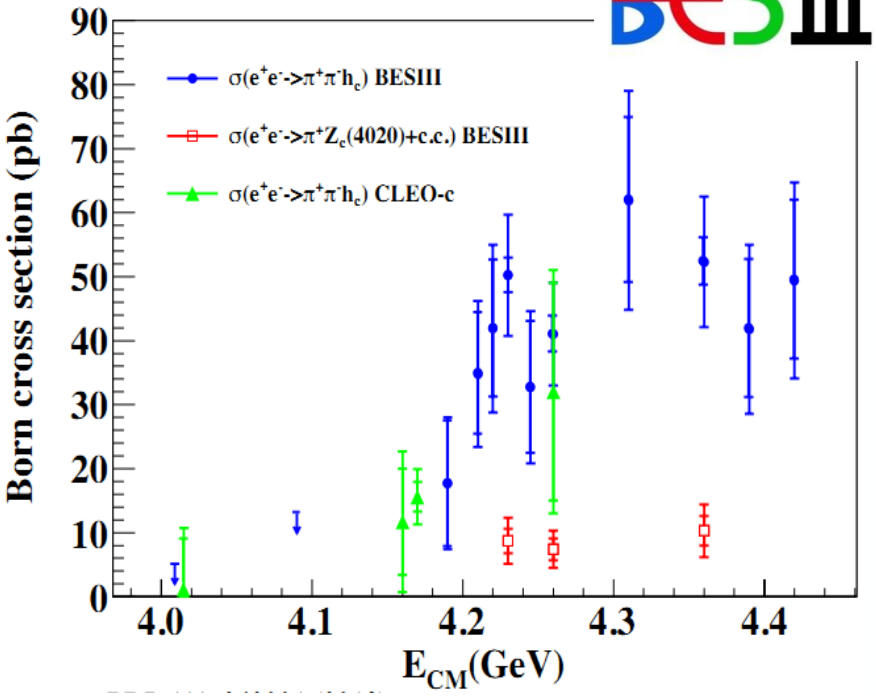
$\sigma(e^+e^- \to Z_c\pi^- + c.c., Z_c \to \omega\pi) < 0.18$ pb @ 4.26 GeV

$B(Z_c \to \omega\pi) < 0.2\%$ [or $\Gamma_{\omega\pi} < 70$ keV] @ 90% C.L.

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

PRL 111, 242001(2013)

$h_c \to \gamma\eta_c$,
$\eta_c \to$ 16 hadronic decay modes

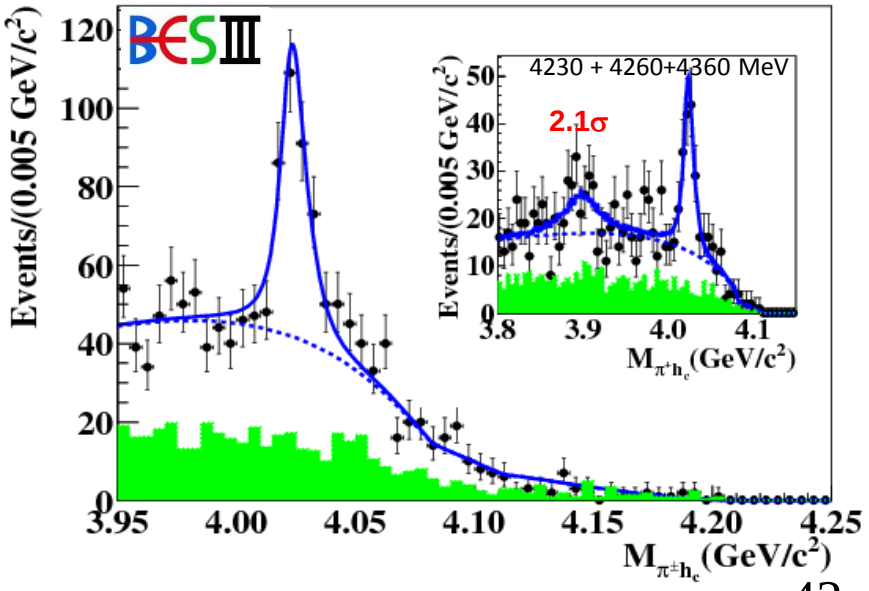


The cross section of $e^+e^- \to \pi^+\pi^- h_c$ is measured, and the shape is not trivial.

A structure, $Z_c(4020)^{\pm}$, is observed.

Mass = 4022.9±0.8 ±2.7 MeV,
Width = 7.9±2.7 ±2.6 MeV

A weak evidence for $Z_c(3900)^{\pm} \to \pi^{\pm} h_c$



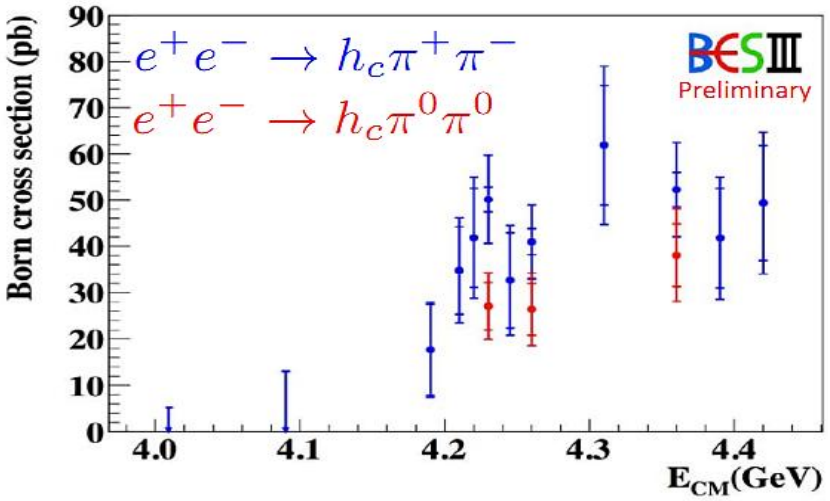
The neutral isospin partner: $Z_c(4020)^0$

Studying the $e^+e^- \to \pi^0\pi^0 h_c$ process

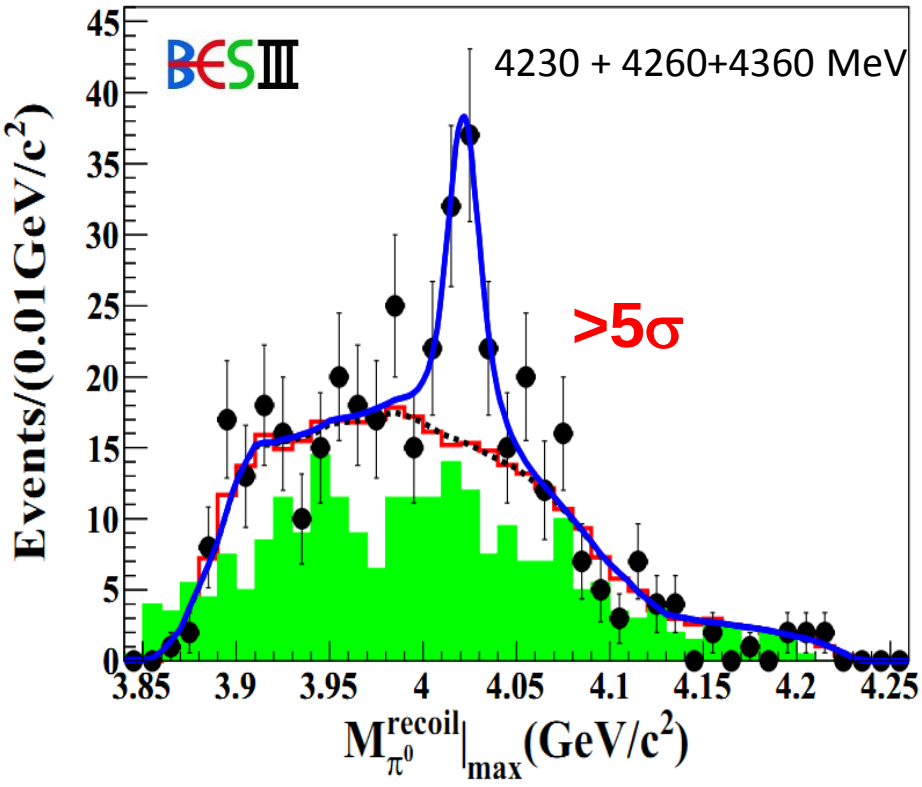
A structure on π^0 h_c invariant mass spectrum can be observed:

Mass = 4023.9±2.2 ±3.8 MeV, Width is fixed to be same as its charged partner.

Another isospin triplet is established!



arXiv: 1409.6577, PRL113,212002



Cross sections for $e^+e^- \to h_c\pi^+\pi^-$ and $e^+e^- \to h_c\pi^0\pi^0$ are in agreement with isospin conservation

Observation of $Z_c(4025)^{\pm}$

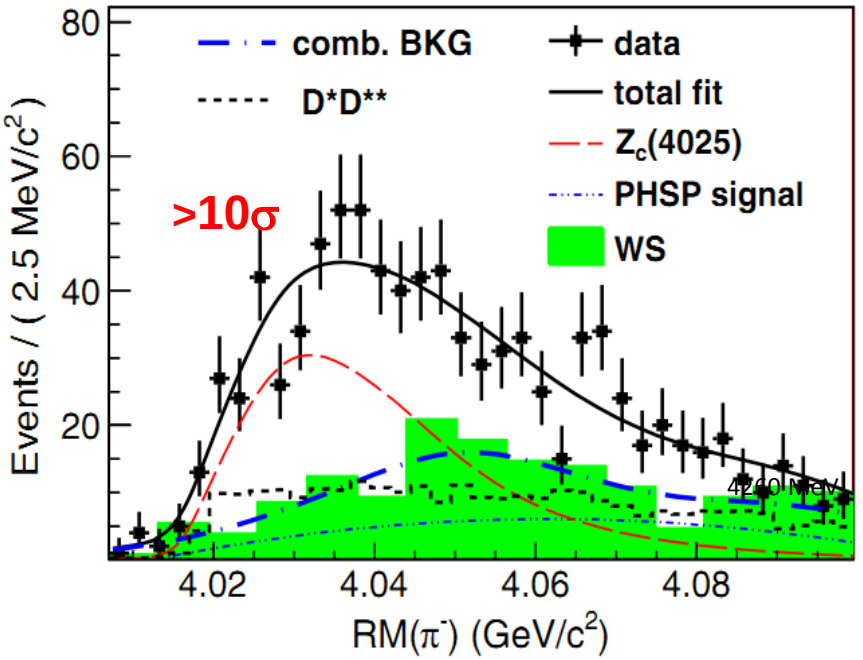
$e^+e^- \to \pi^{\pm}(D^*\bar{D}^*)^{\mp} at \sqrt{s} = 4.26 GeV$

PRL 112, 132001 (2014)

Tag a D^+ and a bachelor π^-, reconstruct one π^0 to suppress the background.

A structure, named as Zc(4025), can be observed in the recoil mass of the bachelor π^-.

$M(Z_c(4025)) = 4026.3 \pm 2.6 \pm 3.7$ MeV;
$\Gamma(Z_c(4025)) = 24.8 \pm 5.6 \pm 7.7$ MeV



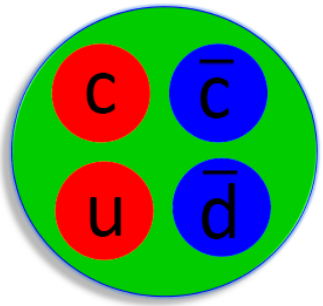
$$\sigma[e^+e^- \to (D^*\bar{D}^*)^{\pm}\pi^{\mp}] = 137 \pm 9 \pm 15 \text{ pb at } 4.26 \text{ GeV}$$

$$\frac{\sigma[e^+e^- \to \pi^{\pm}Z_c(4025)^{\mp} \to (D^*\bar{D}^*)^{\pm}\pi^{\mp}]}{\sigma[e^+e^- \to (D^*\bar{D}^*)^{\pm}\pi^{\mp}]} = 0.65 \pm 0.09 \pm 0.06 \text{ at } 4.26 \text{ GeV}$$

Coupling to $\bar{D}^*D^*$ is much larger than to πh_c if $Z_c(4025)$ and $Z_c(4020)$ are the same state.

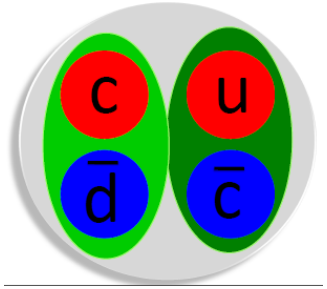
What's the nature of these Z_c states?

- At least 4 quarks, not a conventional mesor
- Tetraquark state?



Phys. Rev. D87,125018(2013); Phys. Rev. D88, 074506(2013);
Phys. Rev. D89,054019(2014); Phys. Rev. D90,054009(2014); etc

- $D^{(*)}\ \bar{D}^{(*)}$ molecule state?



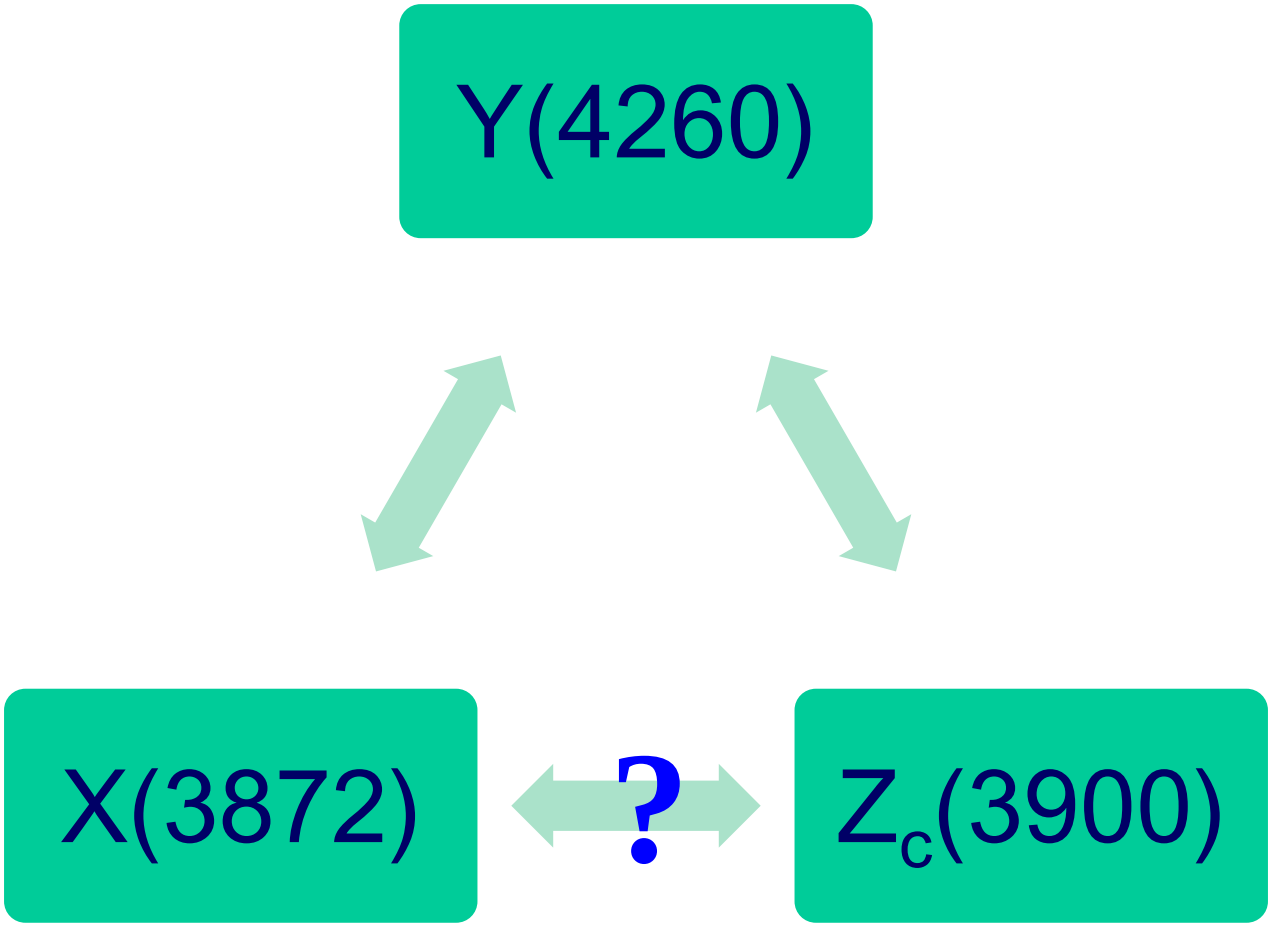
Phys. Rev. Lett. 111, 132003 (2013); Phys. Rev. D 89, 094026 (2014)
Phys. Rev. D 89, 074029 (2014); Phys. Rev. D 88, 074506 (2013); etc

- FSI?
- Cusp?
- …

I will leave the discussion to the other speakers.

X、Y、Z particles are correlated!

What are they? Are they all molecules/tetraquarks/…?



Summary & outlooks

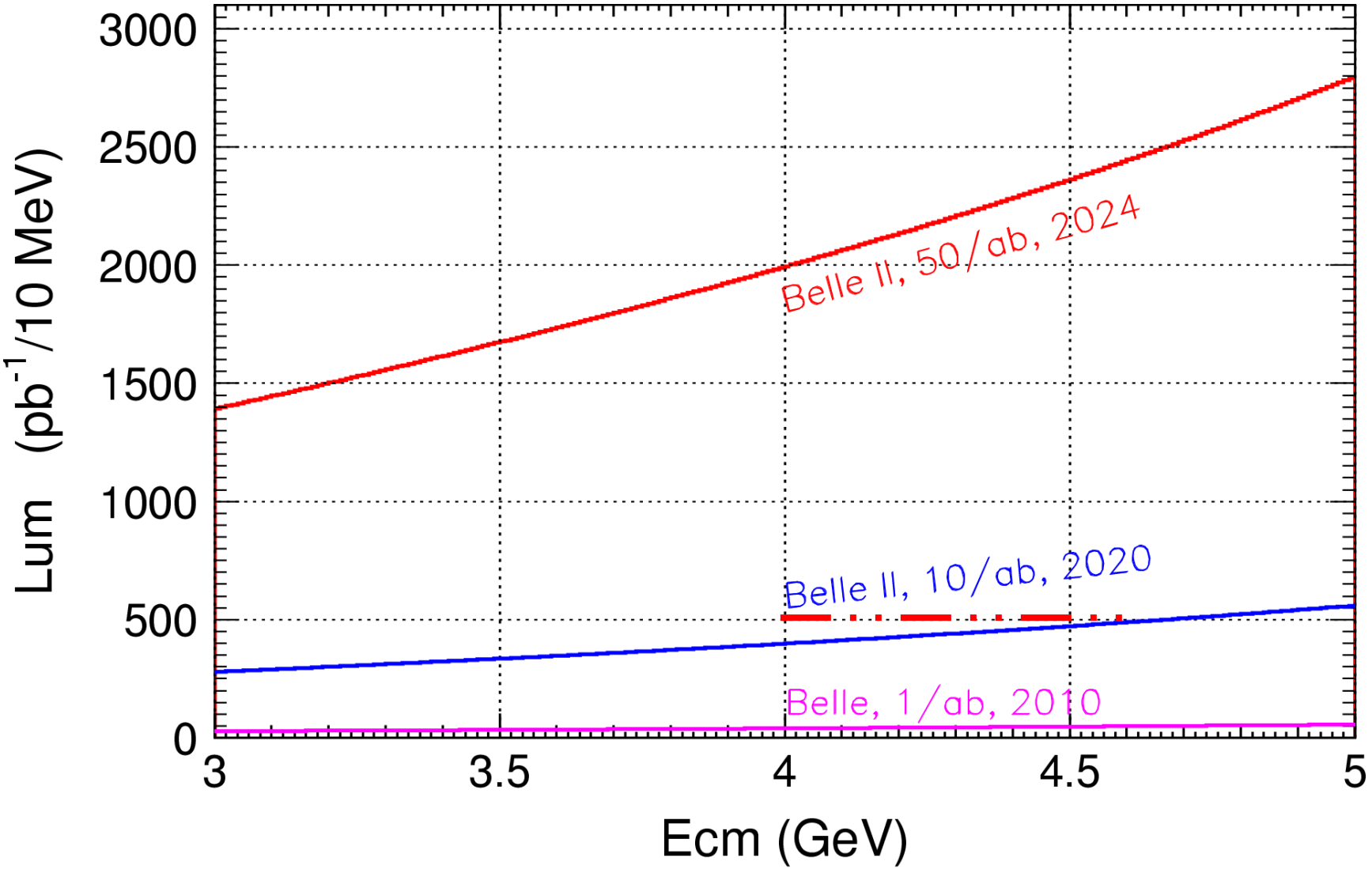
- Lots of progress in the study of charmoniumlike states at BESIII recently
- Observation of $e^+e^- \rightarrow \gamma X(3872)$ & $\pi^+\pi^- X(3823)$
- Measurements of many hidden charm final states
- Observation of Zc states
- BESIII may continue data taking until 2020-2022
- Belle II, Panda, HIEPA …

Thanks a lot!

谢谢！

ISR at Belle II vs. BESIII

ISR produces events at all CM energies BESIII can reach

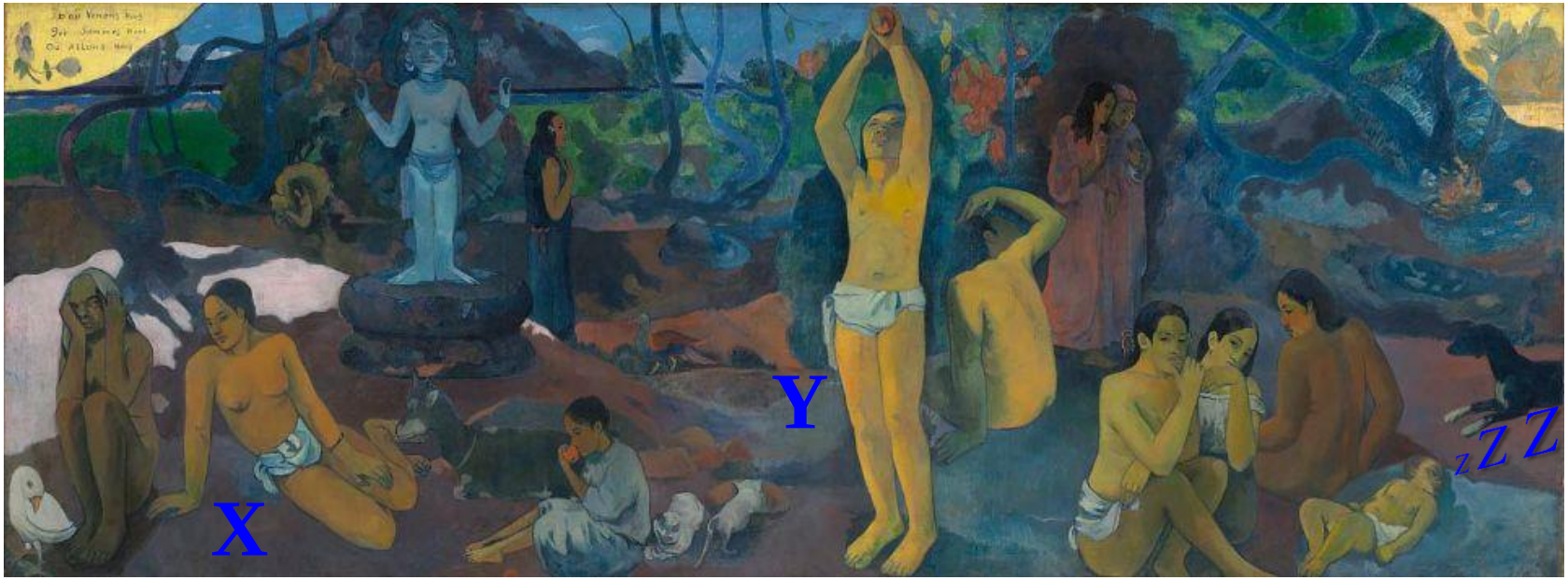


Who can answer?

"Where Do They Come From?

What Are They?

Where Are They Going?"



Summary on Z_c states

The BESIII experiment discovered several Z_c states.

State	Mass(MeV)	Width(MeV)	Decay mode	Process
$Z_c(3900)^{\pm}$	$3899.0 \pm 3.6 \pm 4.9$	$46 \pm 10 \pm 20$	$\pi^{\pm} J/\psi$	$e^+e^- \to \pi^+\pi^- J/\psi$
$Z_c(3900)^0$	$3894.8 \pm 2.3 \pm 2.7$	$29.6 \pm 8.2 \pm 8.2$	$\pi^0 J/\psi$	$e^+e^- \to \pi^0\pi^0 J/\psi$
$Z_c(3885)^{\pm}$	$3883.9 \pm 1.5 \pm 4.2$ [single D tag] $3884.3 \pm 1.2 \pm 1.5$ [double D tag]	$24.8 \pm 3.3 \pm 11.0$ [single D tag] $23.8 \pm 2.1 \pm 2.6$ [double D tag]	D^0D^{*-} D^-D^{*0}	$e^+e^- \to \pi^+D^0D^{*-}$ $e^+e^- \to \pi^+D^-D^{*0}$
$Z_c(4020)^{\pm}$	$4022.9 \pm 0.8 \pm 2.7$	$7.9 \pm 2.7 \pm 2.6$	$\pi^{\pm} h_c$	$e^+e^- \to \pi^+\pi^- h_c$
$Z_c(4020)^0$	$4023.9 \pm 2.2 \pm 3.8$	fixed	$\pi^0 h_c$	$e^+e^- \to \pi^0\pi^0 h_c$
$Z_c(4025)^{\pm}$	$4026.3 \pm 2.6 \pm 3.7$	$24.8 \pm 5.6 \pm 7.7$	$D^{*0}D^{*-}$	$e^+e^- \to \pi^+(D^* \bar{D}^*)^-$