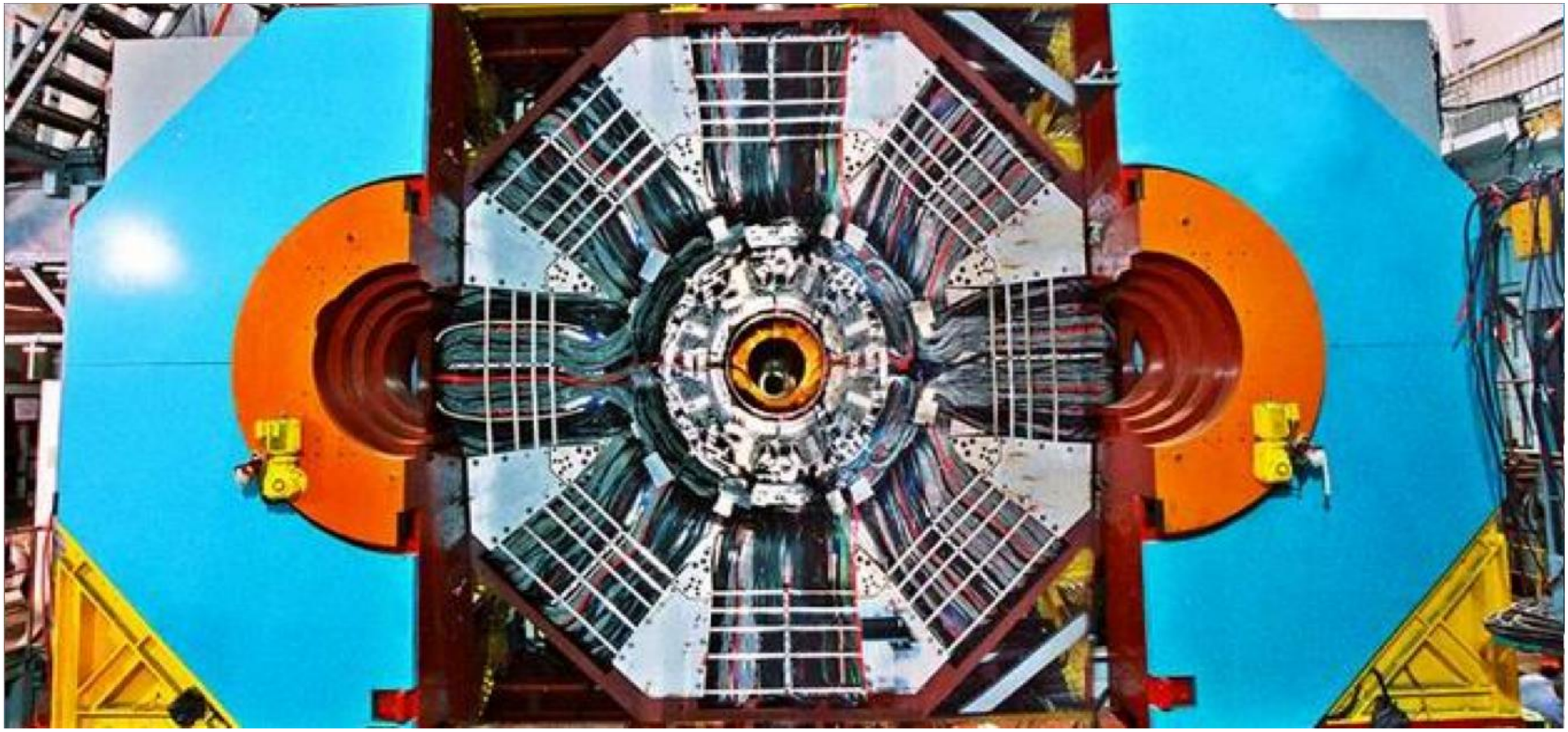

Hadronic transitions above 4GeV at BESIII

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University of Chinese Academy of Sciences (UCAS), Beijing

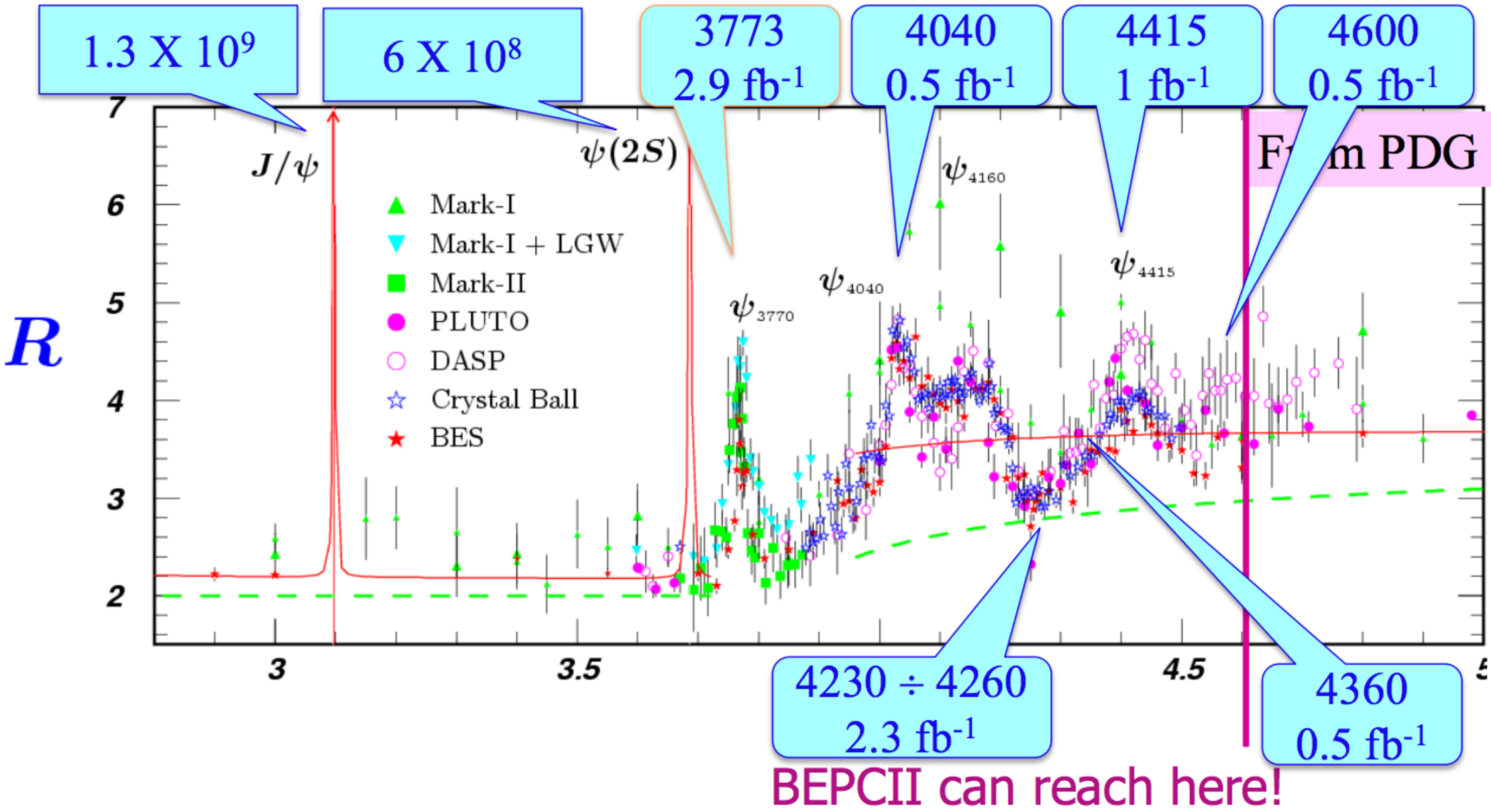
(On behalf of the BESIII collaboration)

Charm 2015, WSU, USA

Outline

- **Introduction**
- **Physics processes reported above 4GeV**
  - ✓ $e^+e^- \rightarrow \pi^+\pi^- X(3823)$
  - ✓ $e^+e^- \rightarrow \pi^+\pi^- J/\psi$, $\pi^0\pi^0 J/\psi$
  - ✓ $e^+e^- \rightarrow \pi^+\pi^- h_c(1P)$, $\pi^0\pi^0 h_c(1P)$
  - ✓ $e^+e^- \rightarrow \omega\chi_{c0}$, $\omega\chi_{c1}$, $\omega\chi_{c2}$
  - ✓ $e^+e^- \rightarrow \pi^0 J/\psi$, $\eta J/\psi$, $\eta' J/\psi$
  - ✓ $e^+e^- \rightarrow \eta\pi^0 J/\psi$
- **Summary**

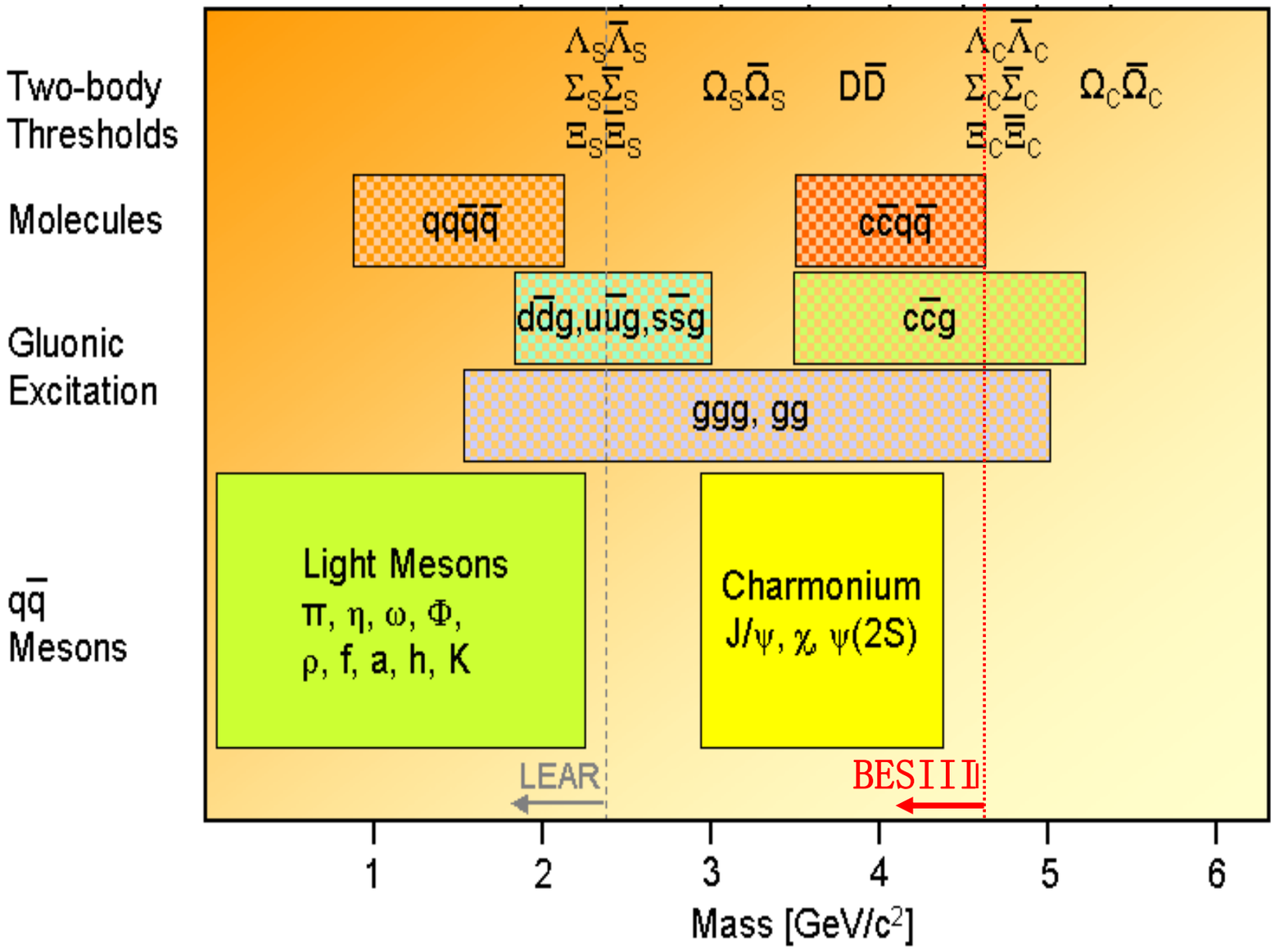
BESIII data samples above 4GeV



- 4100~4400 MeV: 0.5/fb coarse scan
- 3850~4590 MeV: 0.5/fb fine scan

Machine luminosity is optimal near ψ'' peak

Hadron Landscape



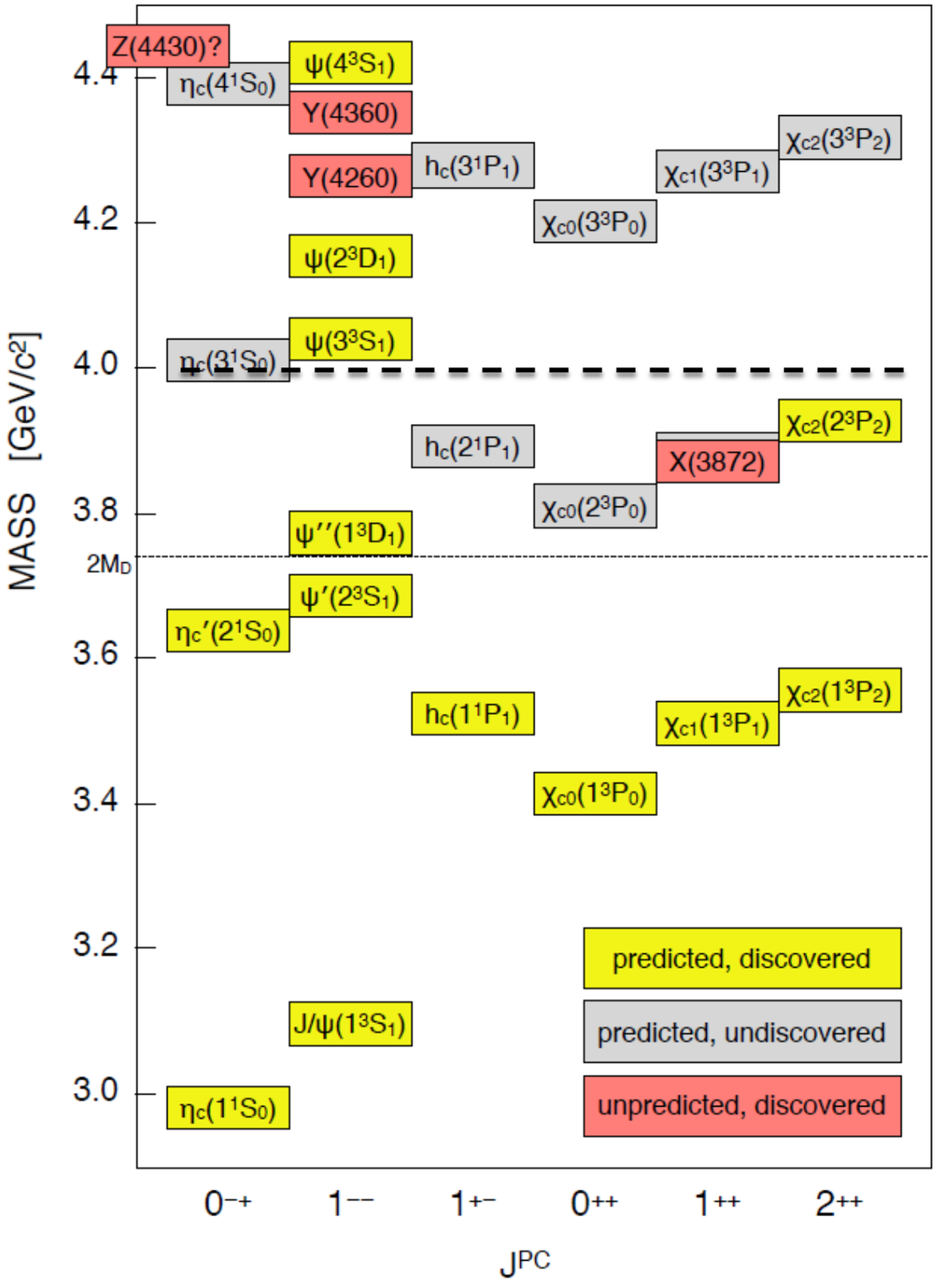
Hadron-physics challenges:

- Understanding of established states: precision spectroscopy
- Nature of exotic states: search and spectroscopy of unexpected states

At BESIII, two golden measures to study hadron spectroscopy

- Light hadrons: charmonium radiative decays (act as spin filter)
- Heavy hadrons: direct production, radiative and hadronic transitions

Charmonium Spectrum



Hidden-charm region of the spectrum is well understood,

however,

in the open-charm region there are predicted states, but not yet seen...

Moreover...

In the last decade there were found not-predicted charmonium-like states with unexpected properties

Many of these are observed through hadronic transitions

Evidence for the X(3823) at Belle

arXiv:1304.3975 (PRL111, 032001 (2013))

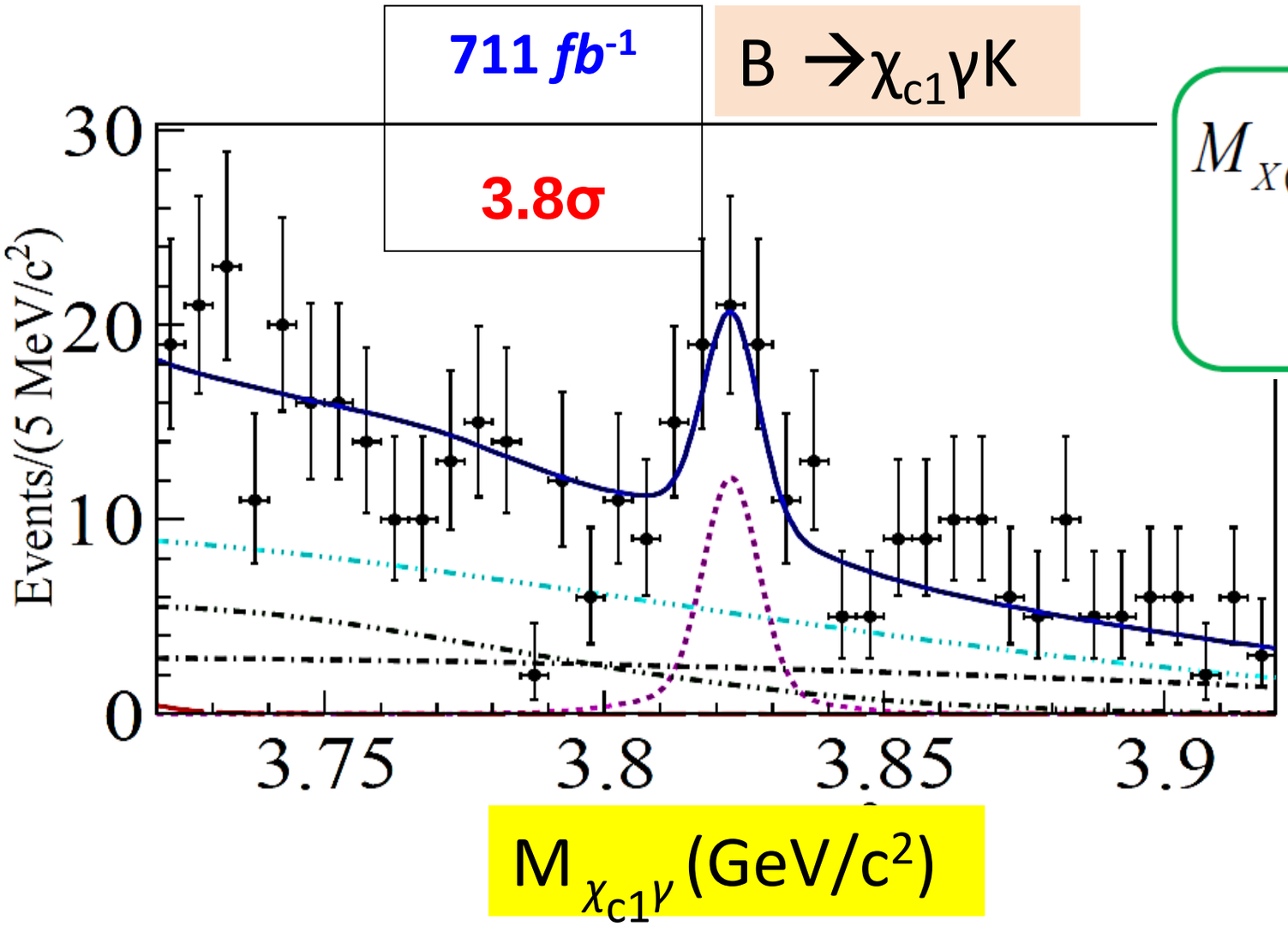


FIG. 4: 2D UML fit projection of $M_{\chi_{c1}\gamma}$ distribution for the simultaneous fit of $B^{\pm} \to (\chi_{c1}\gamma)K^{\pm}$ and $B^0 \to (\chi_{c1}\gamma)K^0_S$ decays for $M_{\rm bc} > 5.27$ GeV/c^2. The curves used in the fits are described in [31].

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

Γ[X(3823)] < 24 MeV

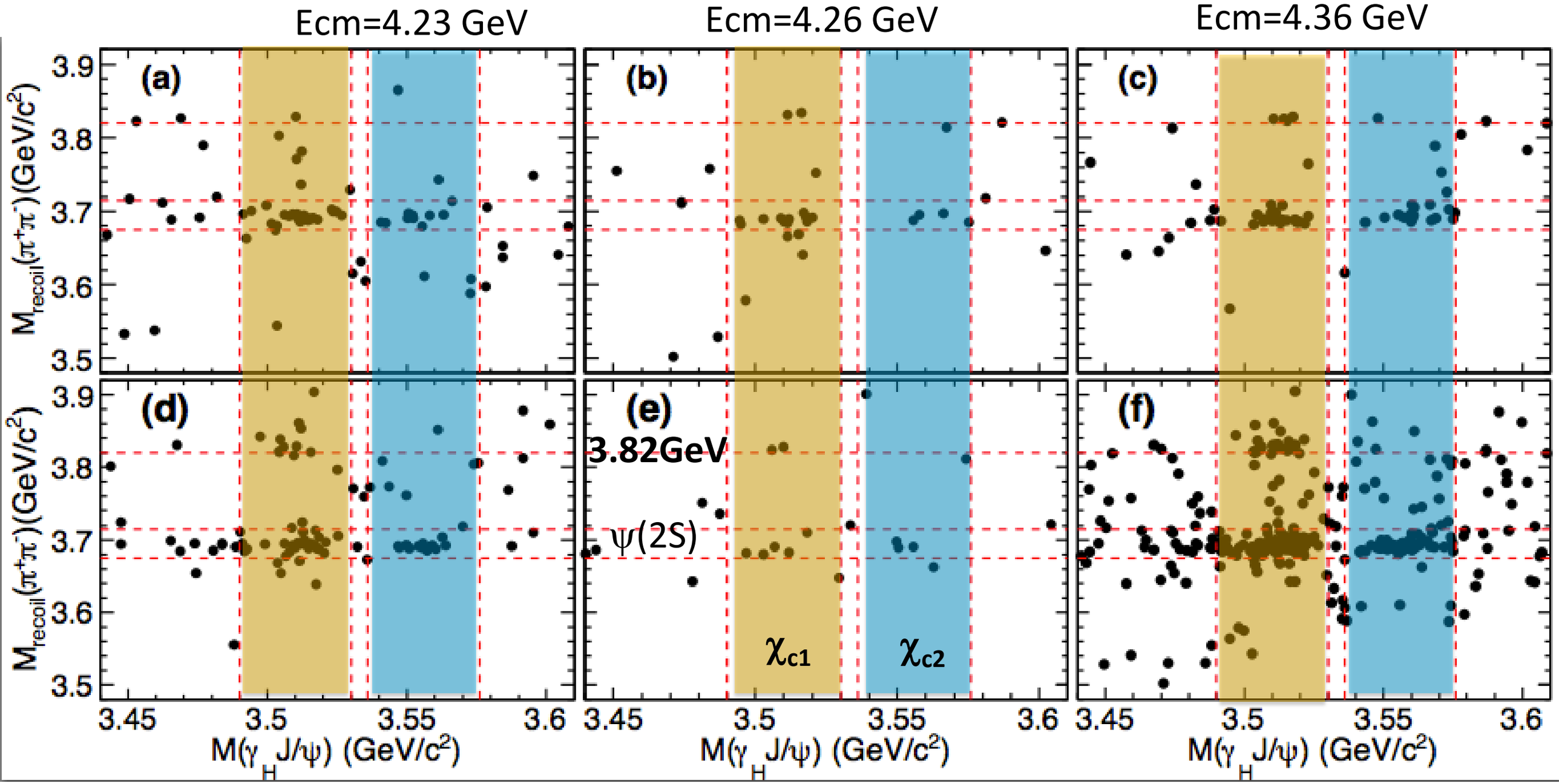
The measured mass and width are consistent with the missing $\Psi_2(1D)$ 2^{--} state

BESIII may search for it!

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

arXiv: 1503.08203

$\chi_{c1,2} \to \gamma J/\psi$, $J/\psi \to e^+e^-$ ($\mu^+\mu^-$)



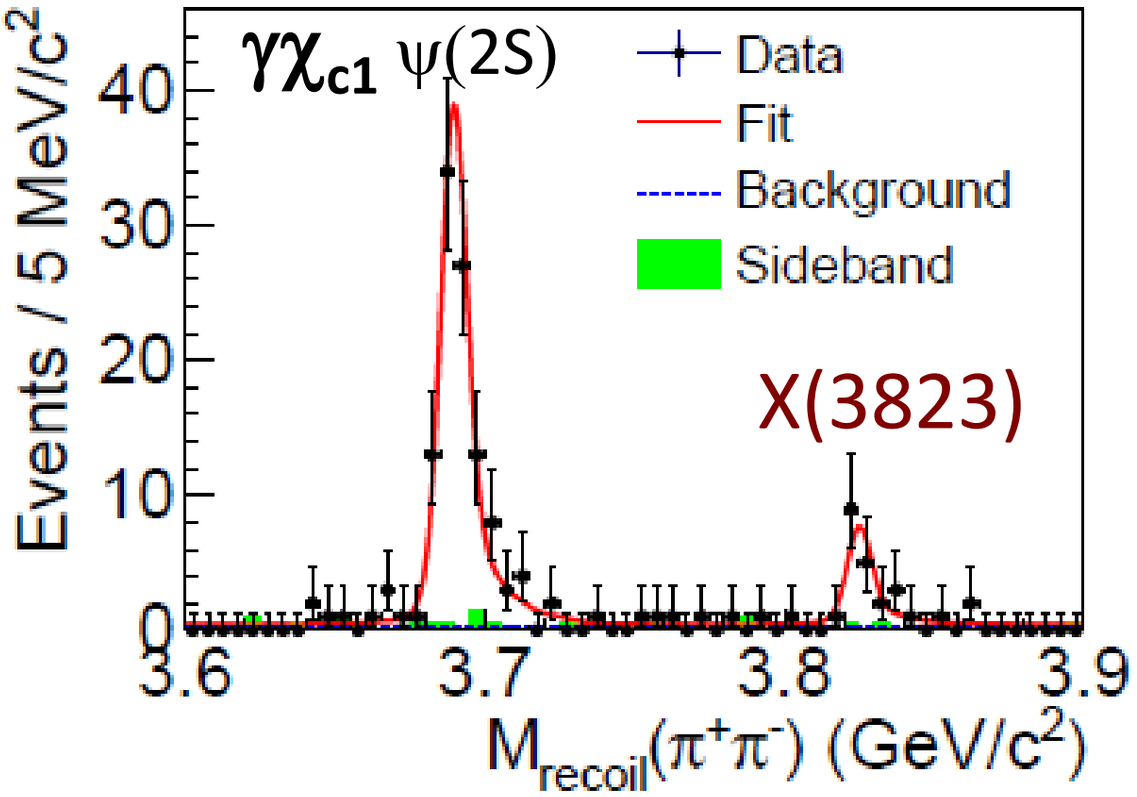
Ecm=4.42 GeV

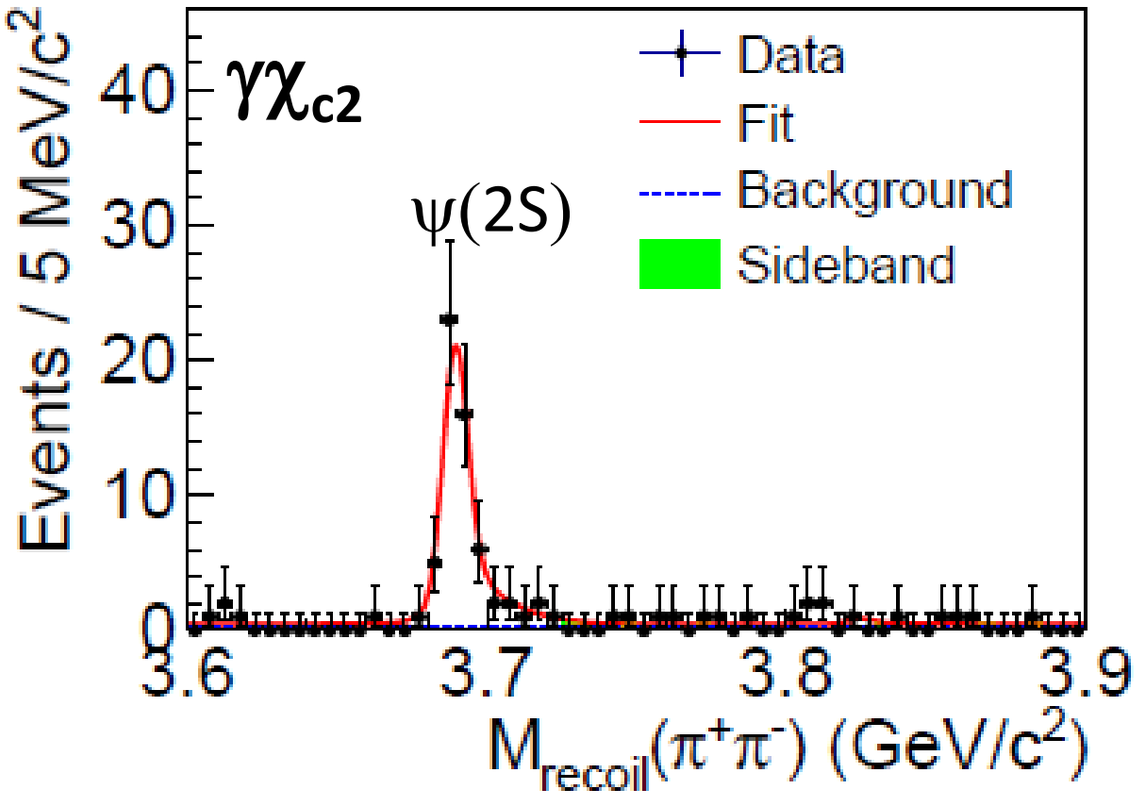
Ecm=4.60 GeV

The sum

Fit the $X(3823)$

arXiv: 1503.08203



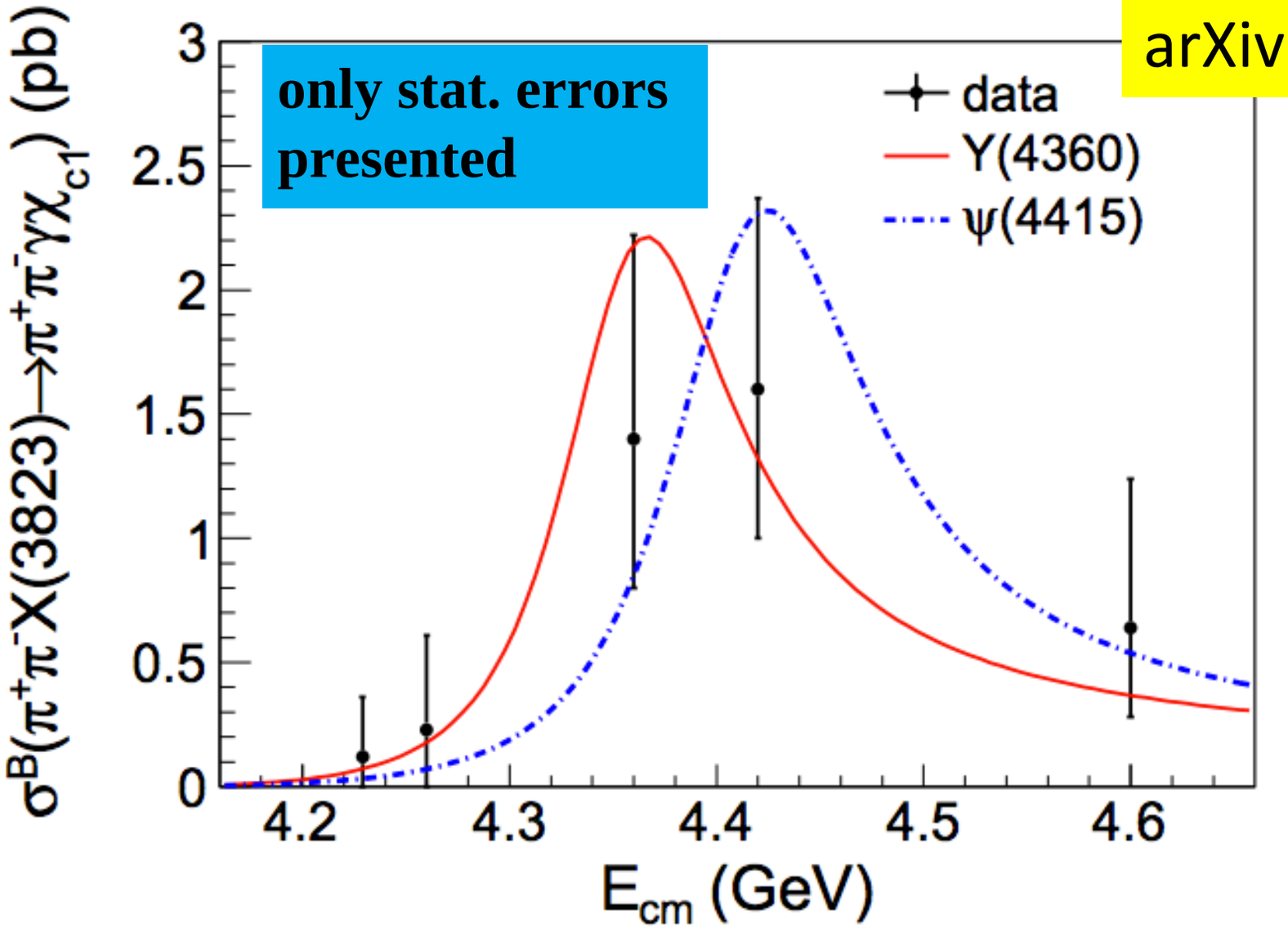


- Calibrate the mass position referring to $\psi(2S)$ peak
- **Signal**: MC simulated shape + **Background**: linear
- From the fit to $\gamma\chi_{c1}$ channel, we obtain
  M[X(3823)]=3821.7$\pm$1.3$\pm$0.7 MeV; Significance: > 5 σ, ***observation*** !
  Γ[X(3823)] < 16 MeV
- No X(3823) in $\gamma\chi_{c2}$ channel $\frac{\mathcal{B}[X(3823)\to\gamma\chi_{c2}]}{\mathcal{B}[X(3823)\to\gamma\chi_{c1}]} < 0.42$

BESIII measurement agrees with Belle's results

X(3823) production cross section

arXiv: 1503.08203



- Energy dependent cross sections of $e^+e^-\to\pi^+\pi^-X(3823)\to\pi^+\pi^-\gamma\chi_{c1}$.
- Both Y(4360) and ψ(4415) line shape give reasonable description.

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

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

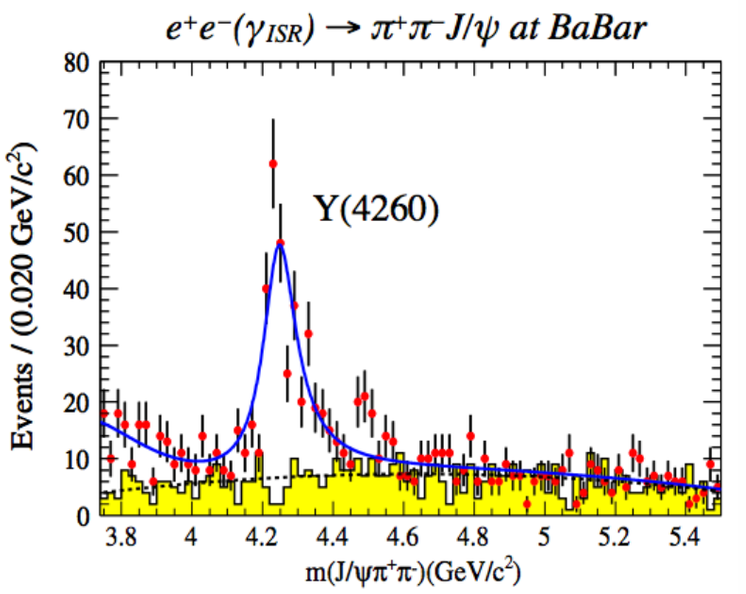
- Width: narrow
- X(3823) <16 MeV @ 90% C.L.).

- $\frac{\mathcal{B}[X(3823)\to\gamma\chi_{c2}]}{\mathcal{B}[X(3823)\to\gamma\chi_{c1}]} < 0.42$ agrees with prediction R~0.2.

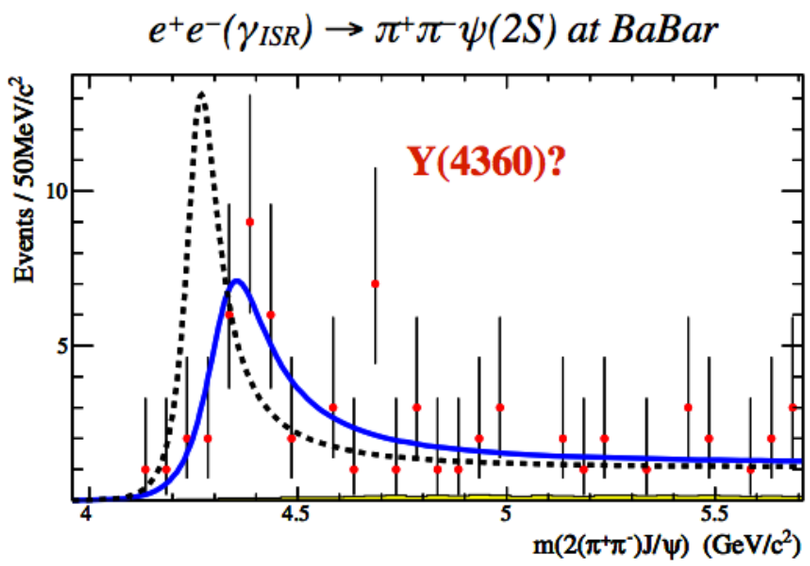
- Exclusions: $1^1D_2\to\gamma\chi_{c1}$ forbidden; $1^3D_3\to\gamma\chi_{c1}$ amplitude ~ 0.

Observed X(3823) is very likely $\psi(1^3D_2)$;
However, BESIII&Belle statistics hinder a sophisticated spin analysis.

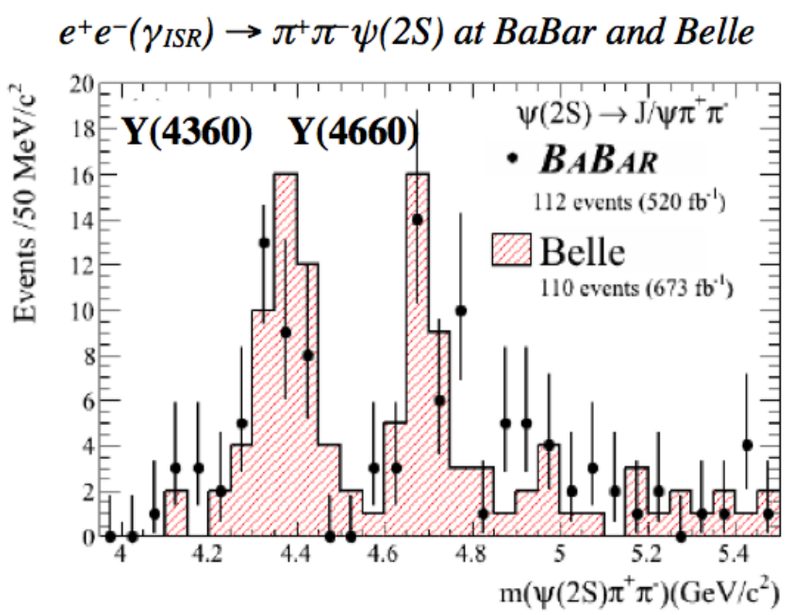
Y states
(vectors observed in Initial State Radiation)



PRD 86, 051102(R) (2012)



PRL 98, 212001 (2007)

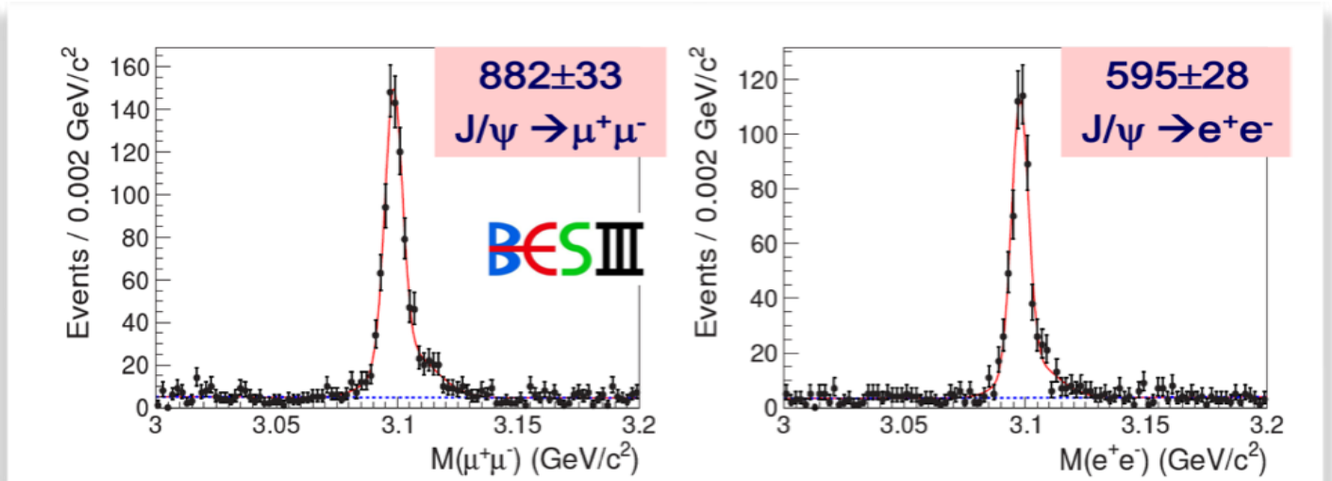


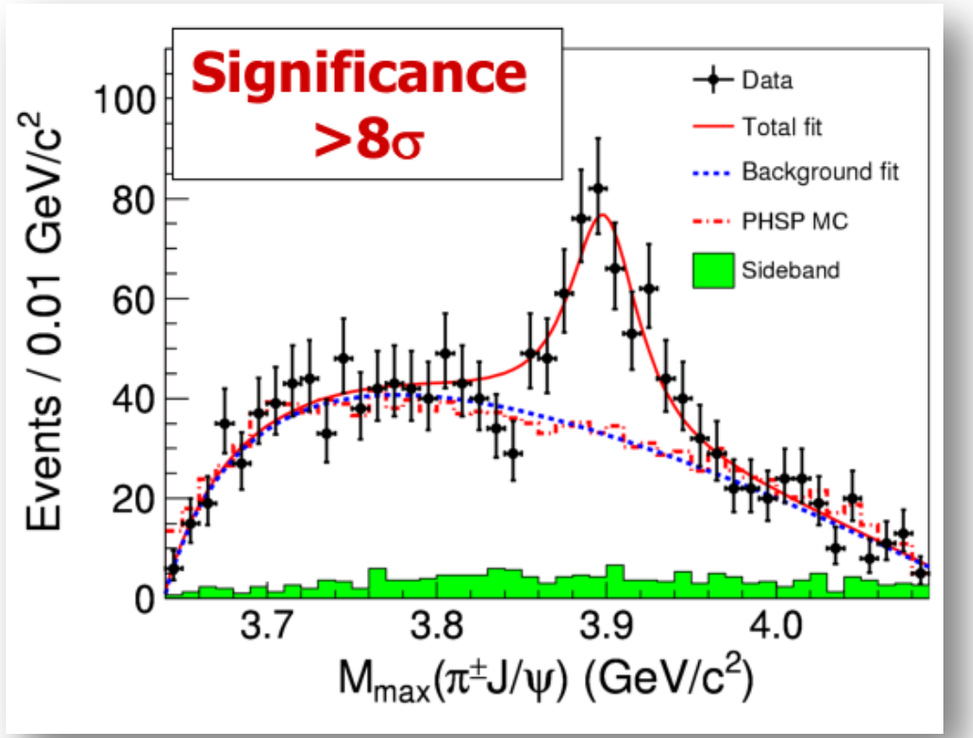
arXiv:1211.6271 and CHARM 2012

Study of $e^+e^- \to \pi^+\pi^- J/\psi$ at 4.26GeV

PRL110, 252001 (2013)

We observed $Zc(3900)^+ \to \pi^+ J/\psi$

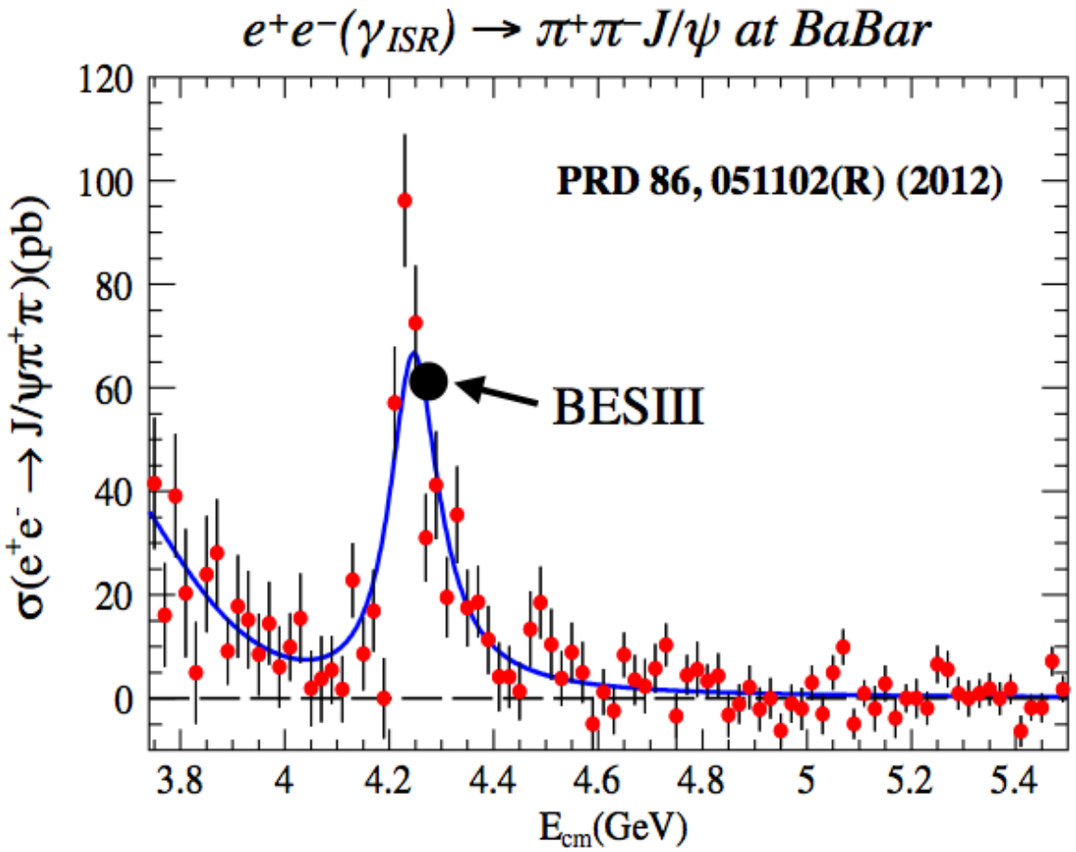


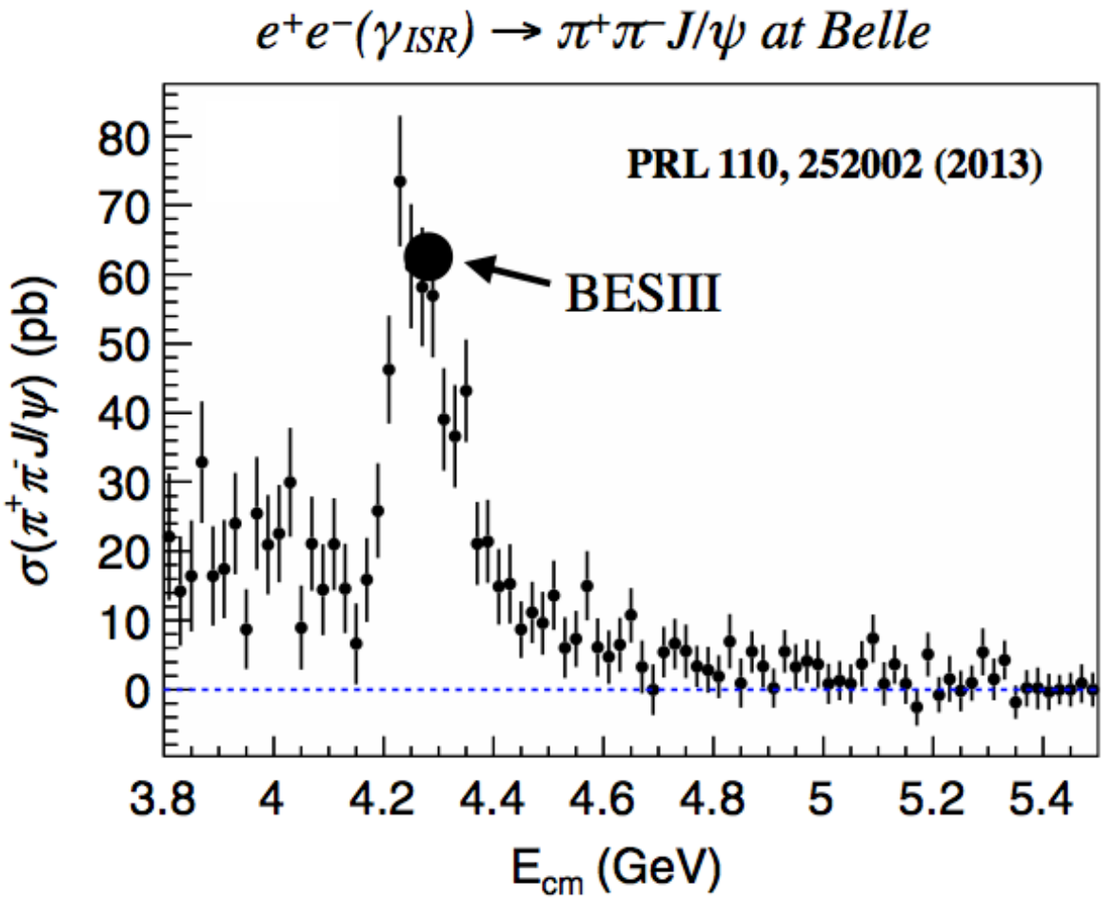


- Select 4 charged tracks and reconstruct J/ψ with lepton pair.
- Very clean sample, very high efficiency (~45%).
- $\sigma(e^+e^- \to \pi^+\pi^- J/\psi) = (62.9 \pm 1.9 \pm 3.7)$ pb

Study of $e^+e^- \to \pi^+\pi^- J/\psi$ at 4.26GeV

PRL110, 252001 (2013)



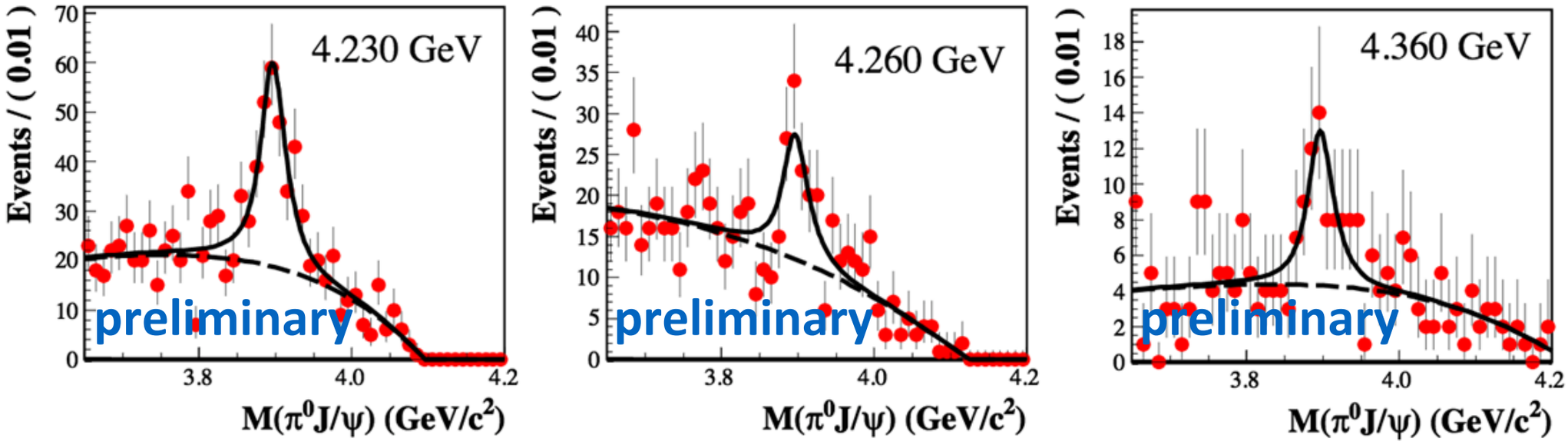


BESIII is measuring cross sections at more energy points.

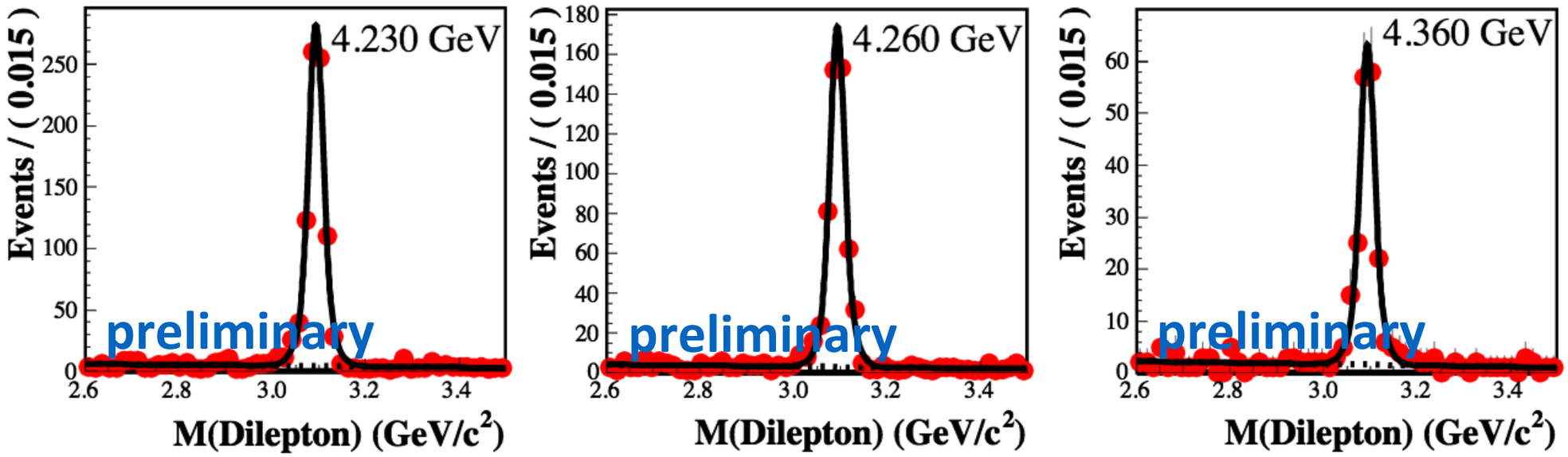
BESIII: $\sigma(e^+e^- \to \pi^+\pi^- J/\psi)$
= (62.9±1.9±3.7) pb
Agree with BaBar & Belle!
Best precision!

Study of $e^+e^- \rightarrow \pi^0\pi^0 J/\psi$

We observed $Zc(3900)^0 \rightarrow \pi^0 J/\psi$

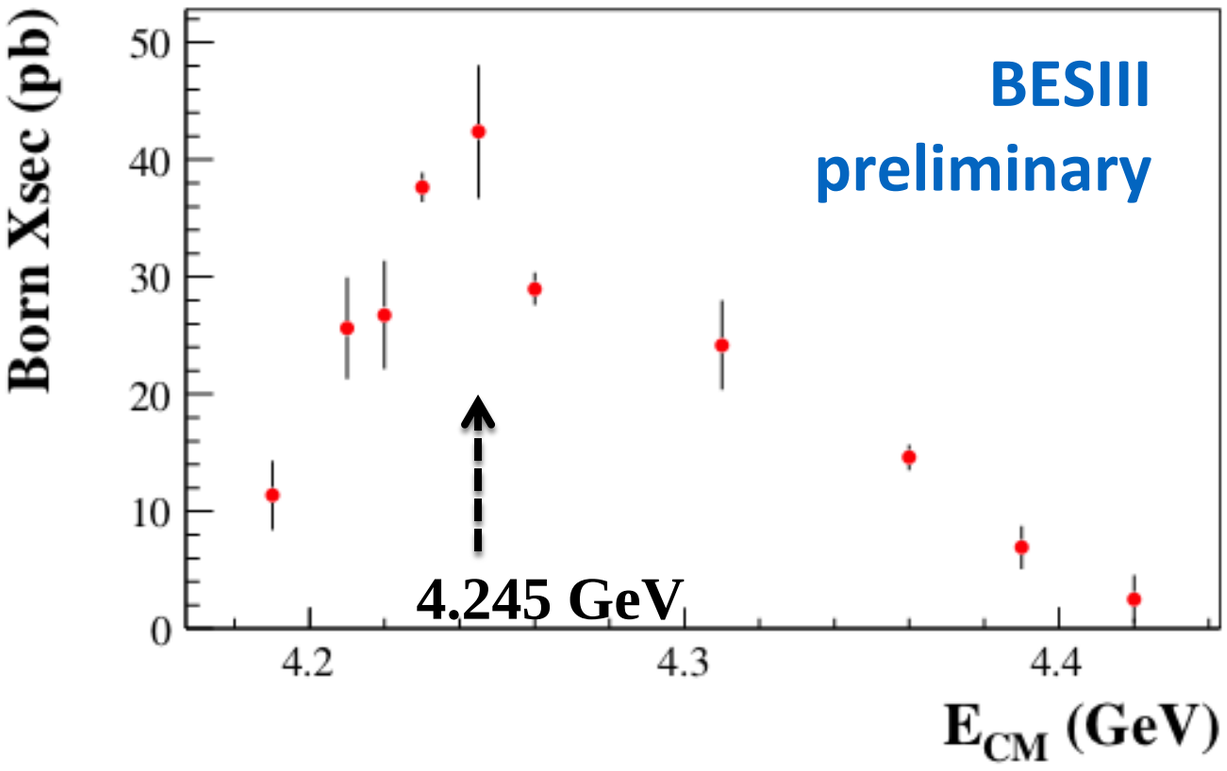


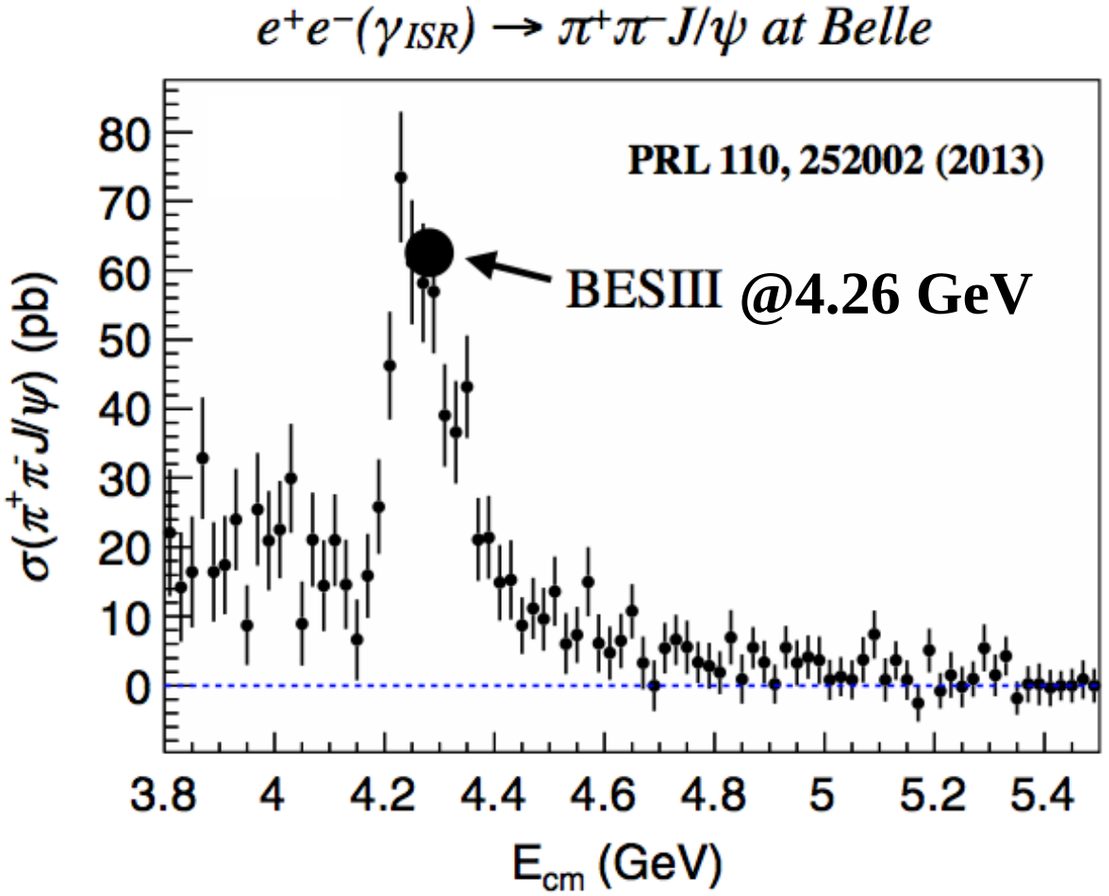
We also measured $\pi^0\pi^0 J/\psi$ cross sections



Study of $e^+e^- \to \pi^0\pi^0 J/\psi$

$\sigma(e^+e^- \to \pi^0\pi^0 J/\psi)$

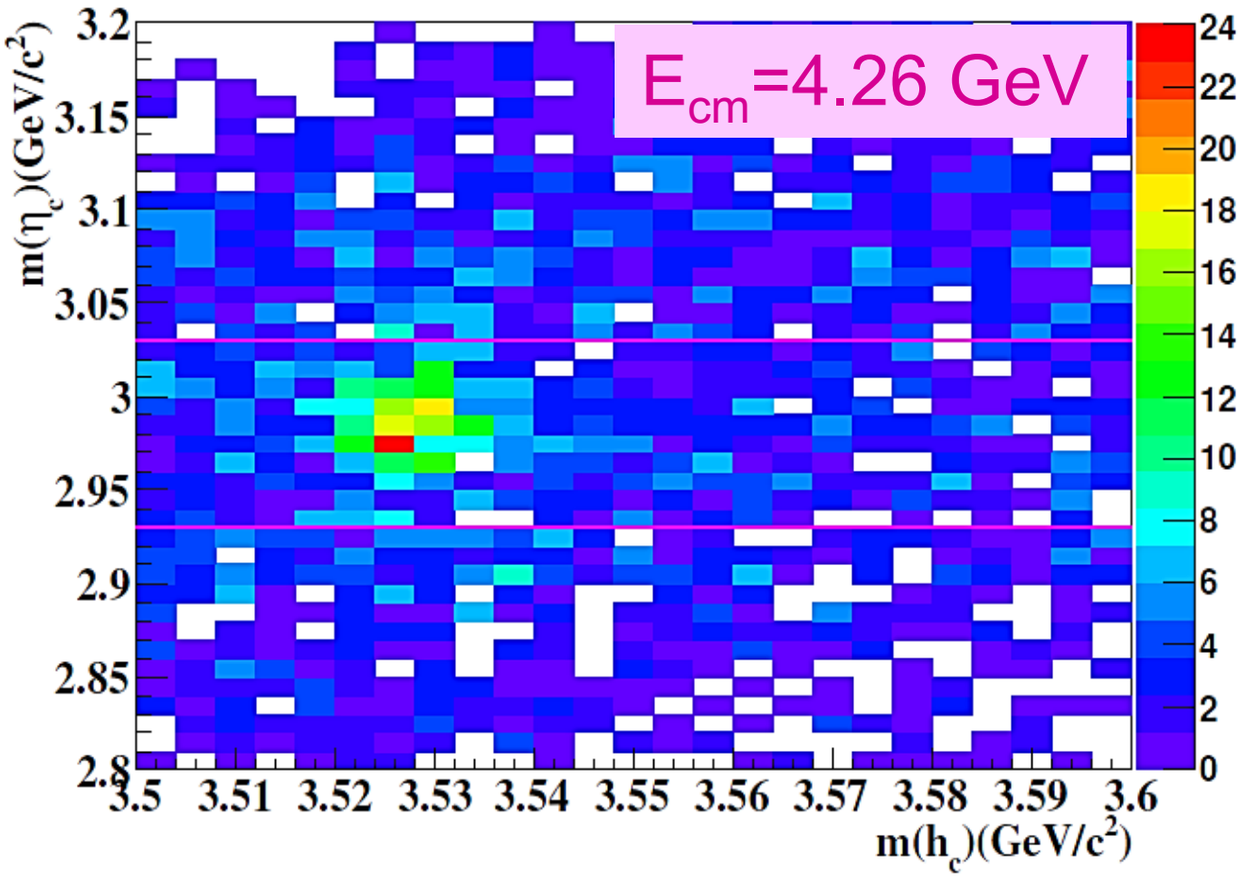


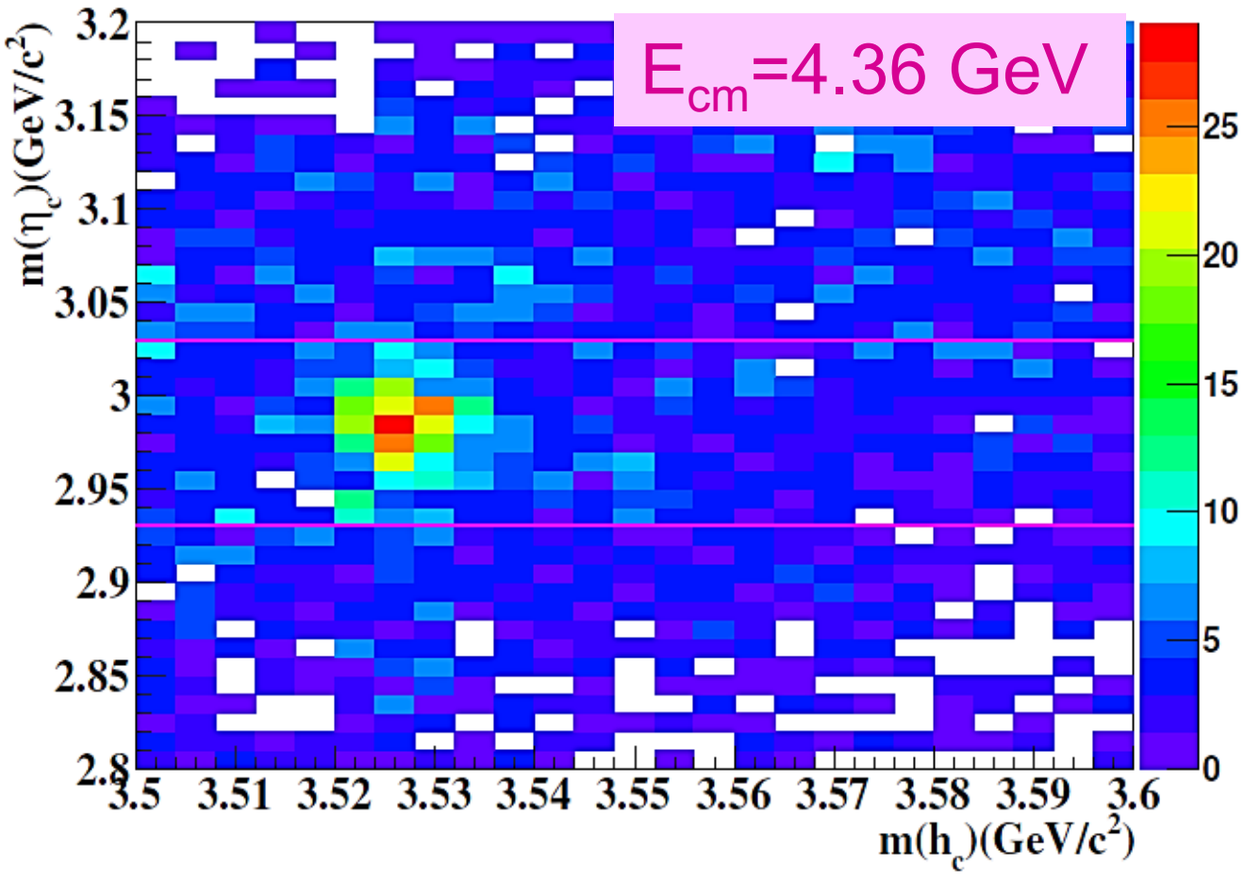


- Local maximum seems ~4.245GeV
- Cross sections of charged channel and netural channels are consistent under the isospin symmetry

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

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

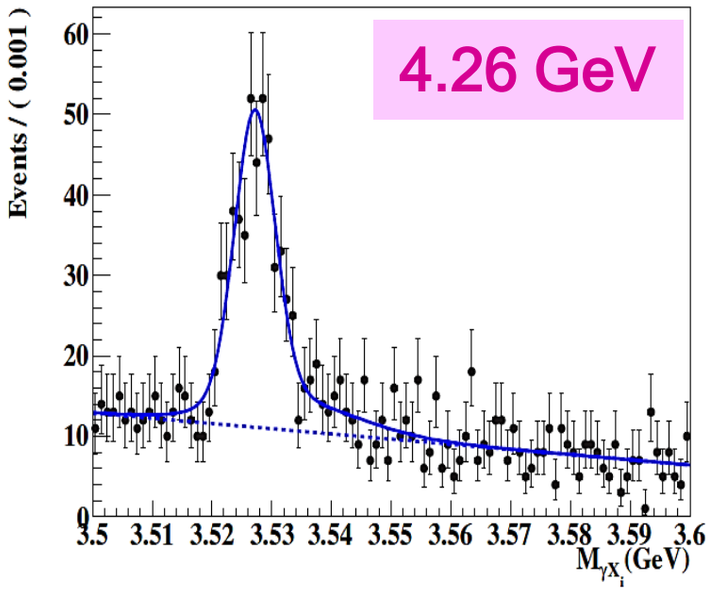


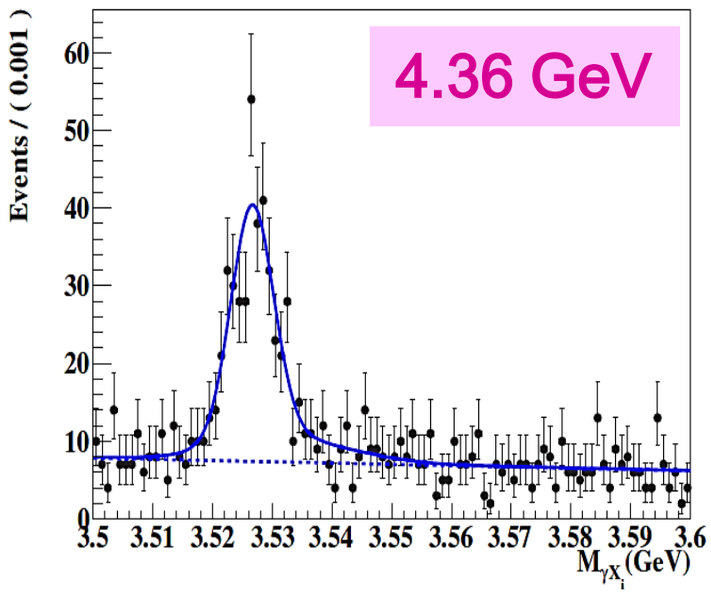


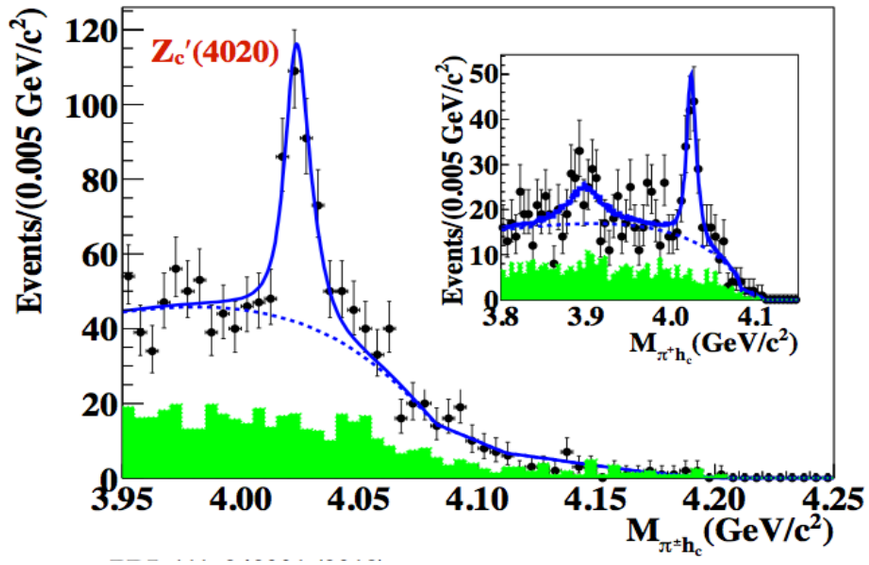
arXiv:1309.1896, PRL111, 242001

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

We observed $Zc(4020)^+ \to \pi^+ h_c(1P)$





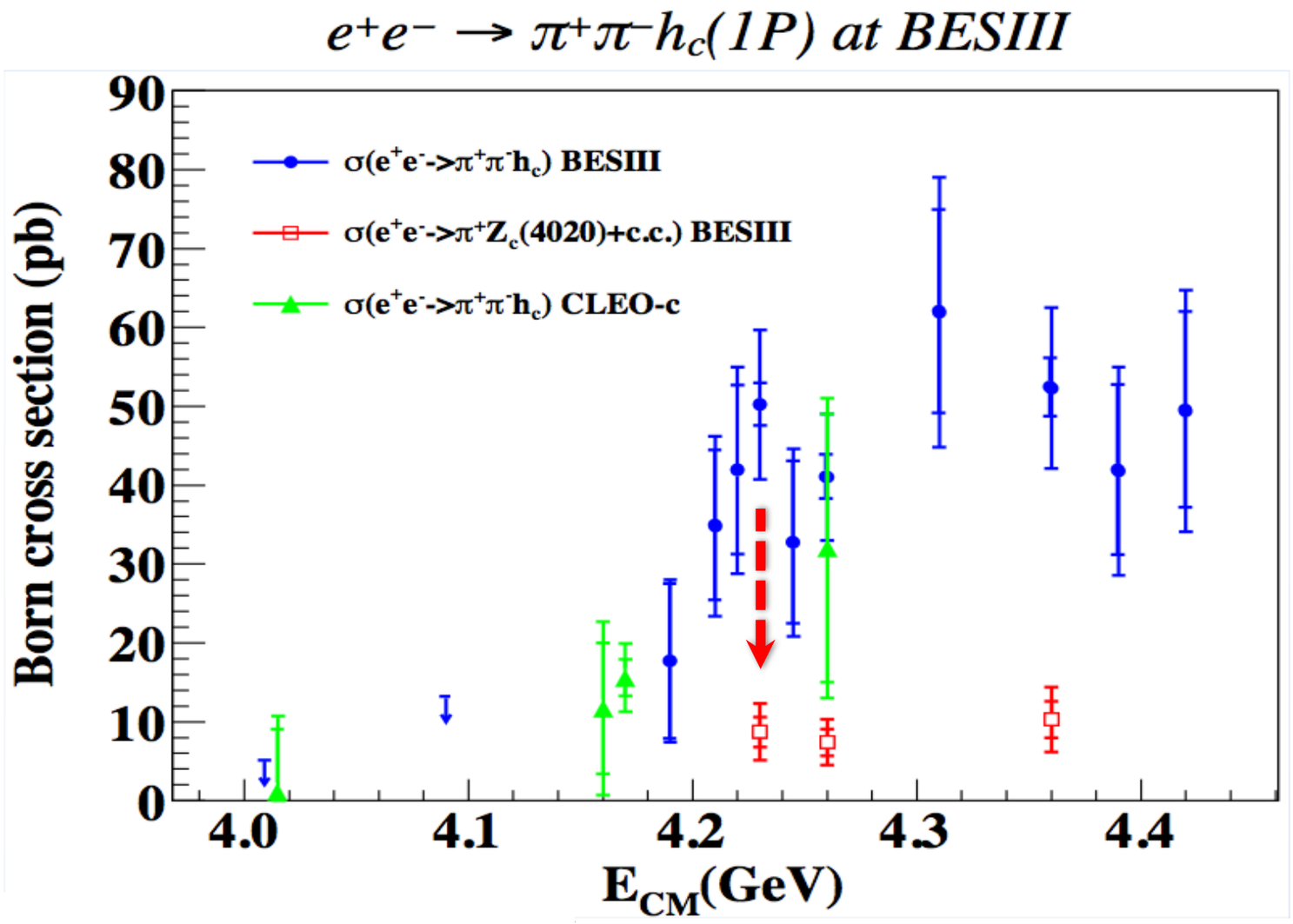


$N(h_c)$=416±28
Lum=827/pb
σ^B= 41.0±2.8±7.4 pb

$N(h_c)$=357±25
Lum=544/pb
σ^B= 52.3±3.7±9.2 pb

arXiv:1309.1896, PRL111, 242001

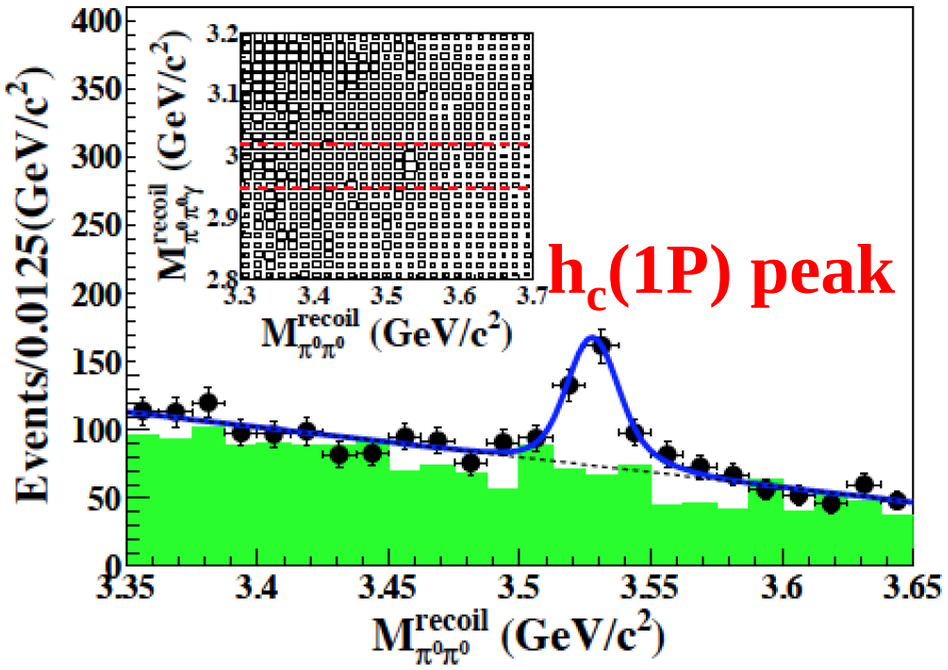
Observation of $e^+e^- \to \pi^+\pi^- h_c(1P)$

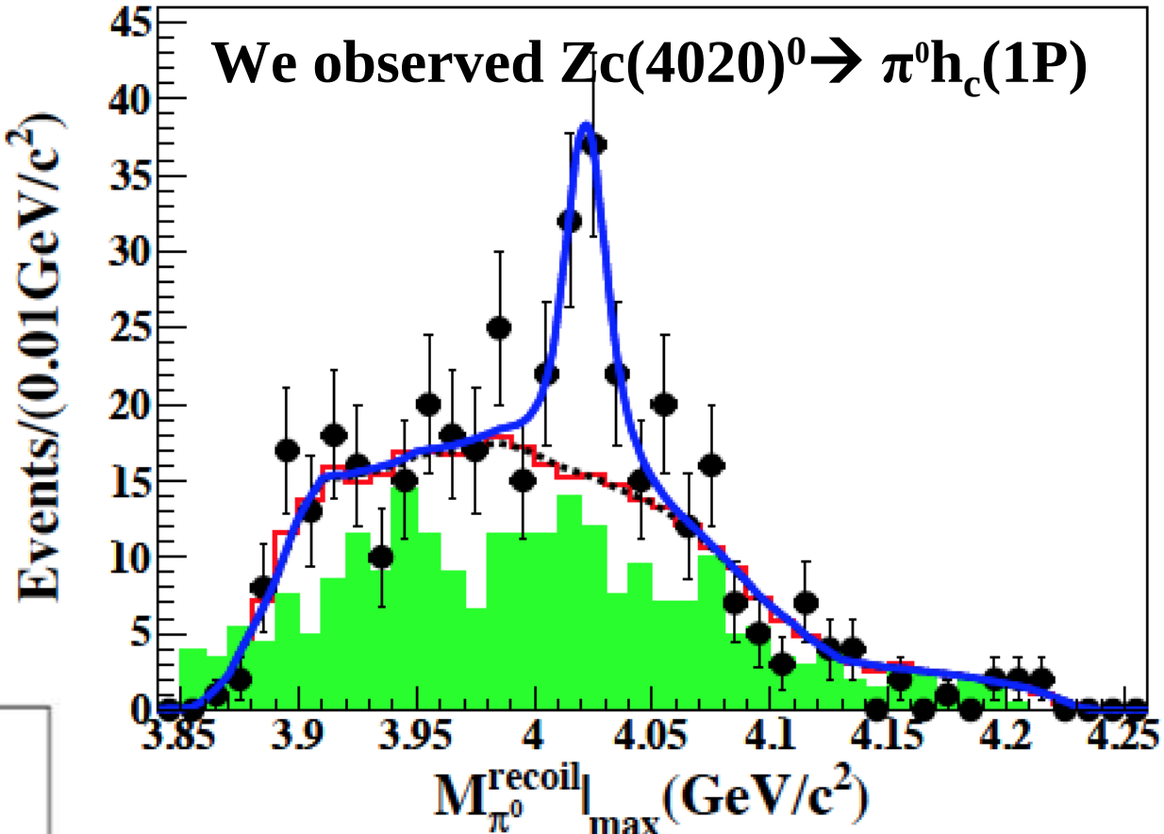


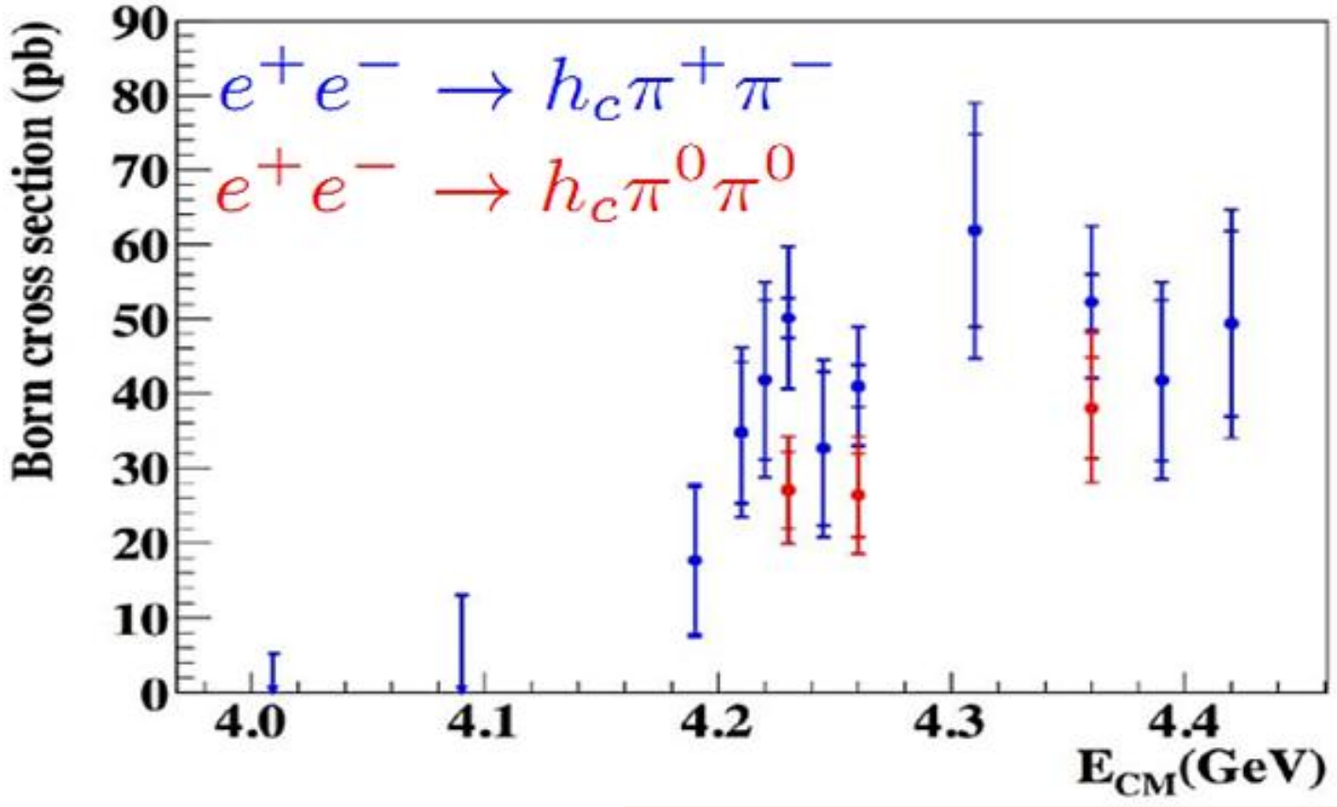
Local maximum ~ 4.23 GeV

arXiv:1309.1896, PRL111, 242001

Observation of $e^+e^- \to \pi^0\pi^0 h_c(1P)$



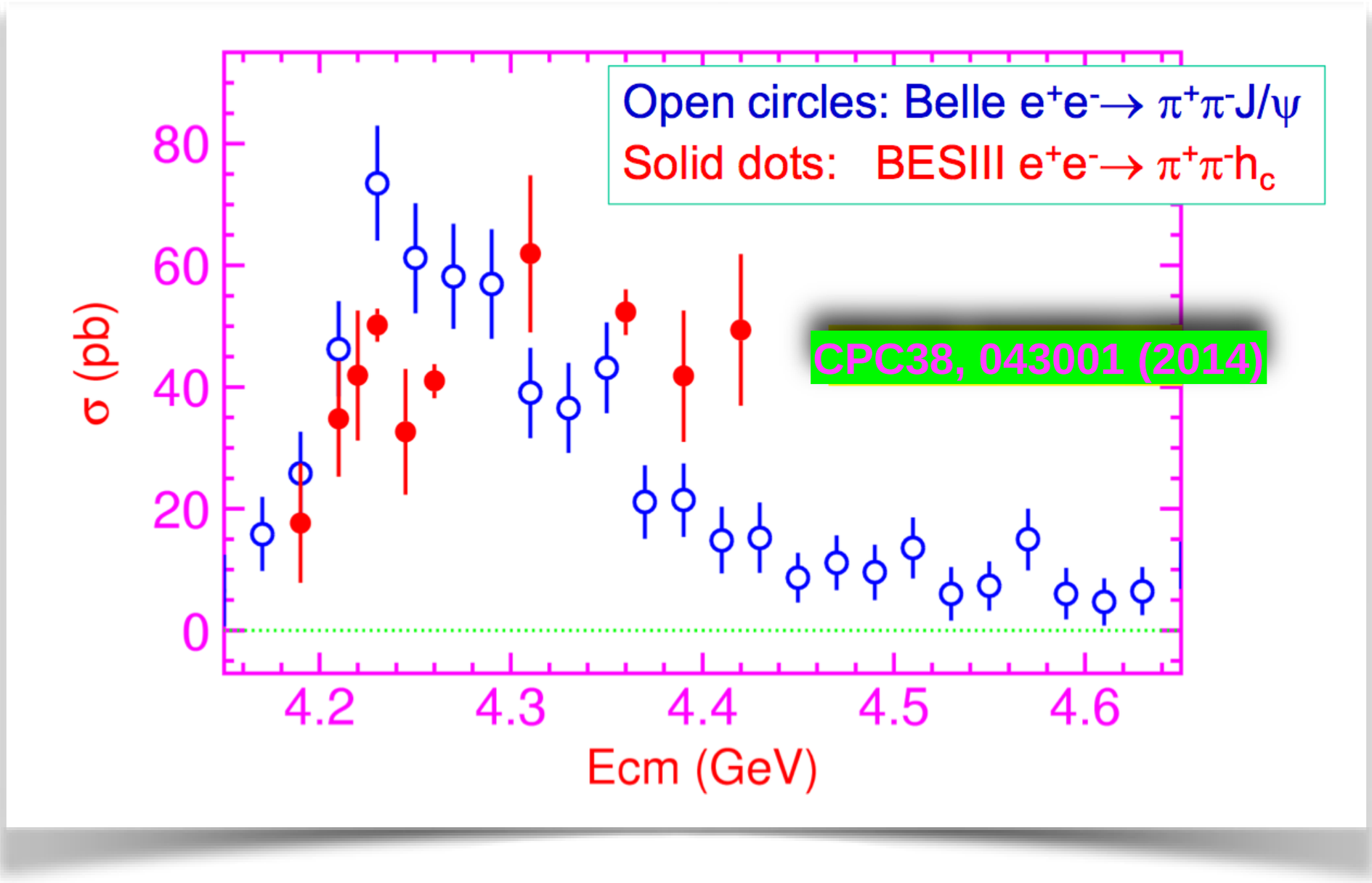




Cross sections for $e^+e^- \to h_c\pi^+\pi^-$ and $e^+e^- \to h_c\pi^0\pi^0$ are in agreement with isospin conservation

arXiv:1409.6577, PRL113,212002(2014)

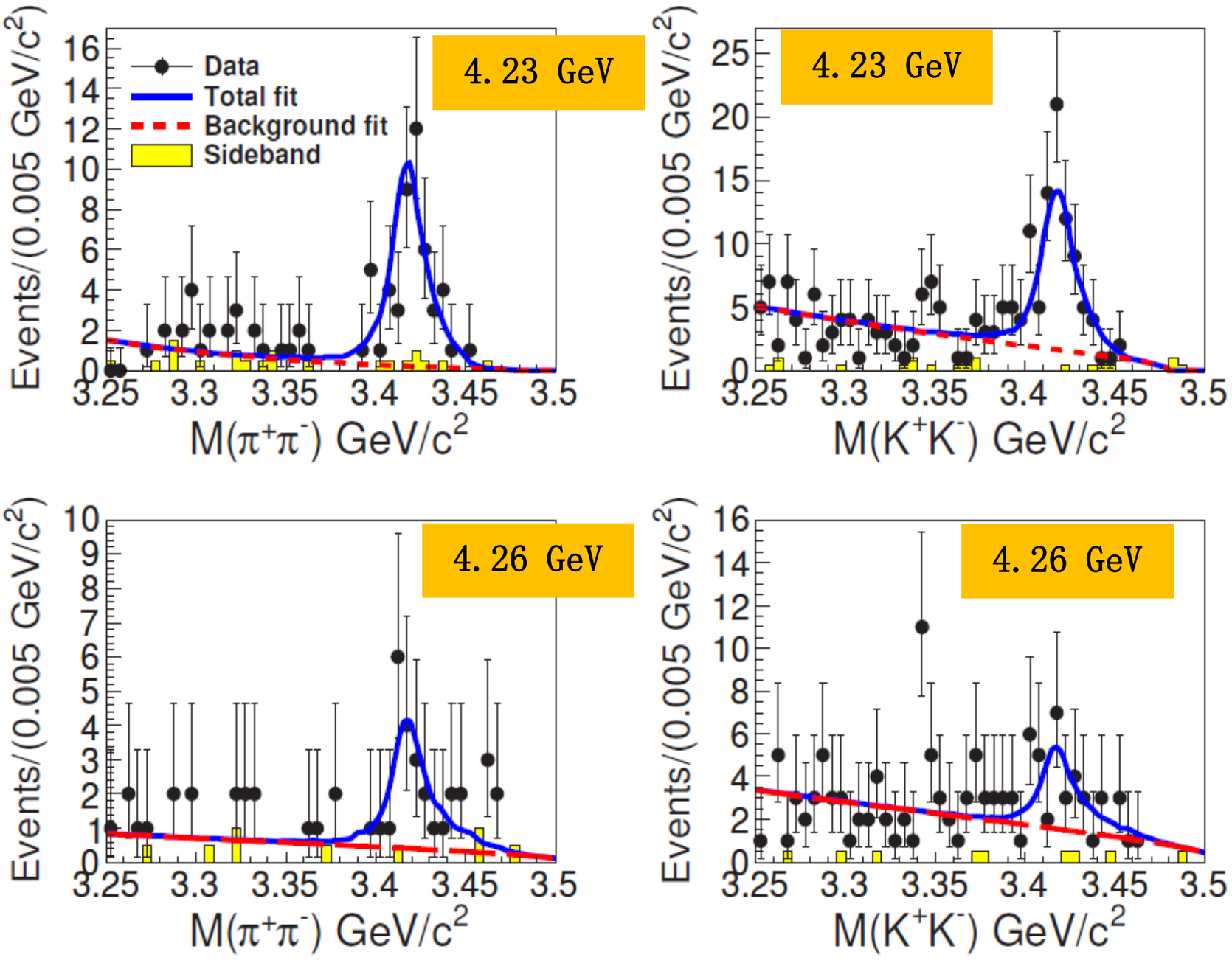
Comparison of $e^+e^- \to \pi^+\pi^- h_c$ and $\pi^+\pi^- J/\psi$



- $\sigma(e^+e^- \to \pi^+\pi^- h_c(1P) \sim \sigma(\pi^+\pi^- J/\psi)$; but lineshapes are different
- $\sigma(e^+e^- \to \pi^+\pi^- h_c(1P)$: is it a combination of **Y(4260)** and **Y(4360)**? or something completely different?
- Need more data to understand the shapes

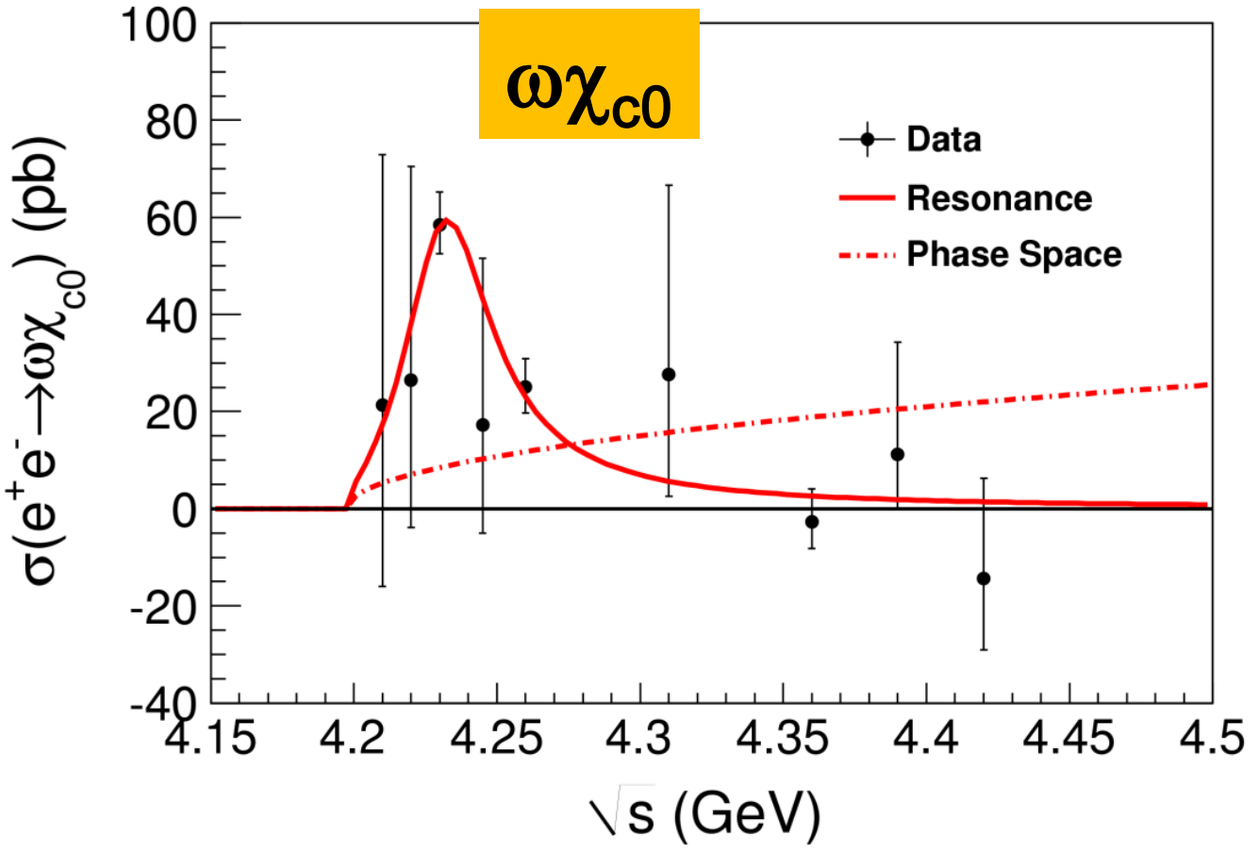
Observation of $e^+e^- \to \omega\chi_{c0}$

$\omega \to \pi^+\pi^-\pi^0$, $\chi_{c0} \to \pi^+\pi^-$、 K^+K^-



arXiv:1410.6538 PRL114.092003 (2015)

Fit to $\sigma(e^+e^- \rightarrow \omega\chi_{c0})$

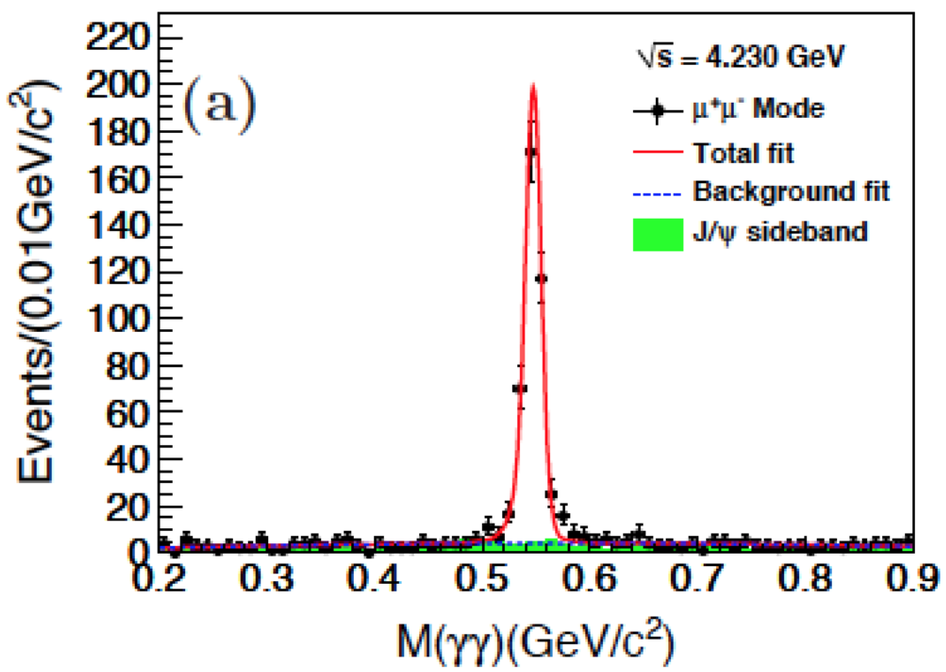


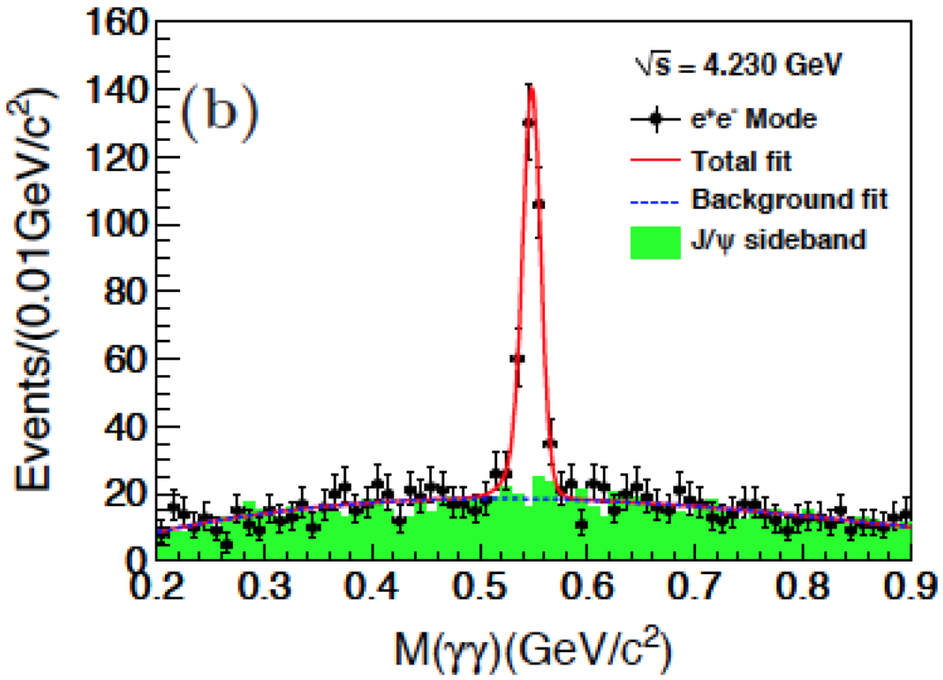
- We did not observe $e^+e^- \rightarrow \omega\chi_{c1,2}$ and set up limits of cross sections at pb level at these energy pionts.
- Analysis on the data set above 4.4GeV is ongoing.

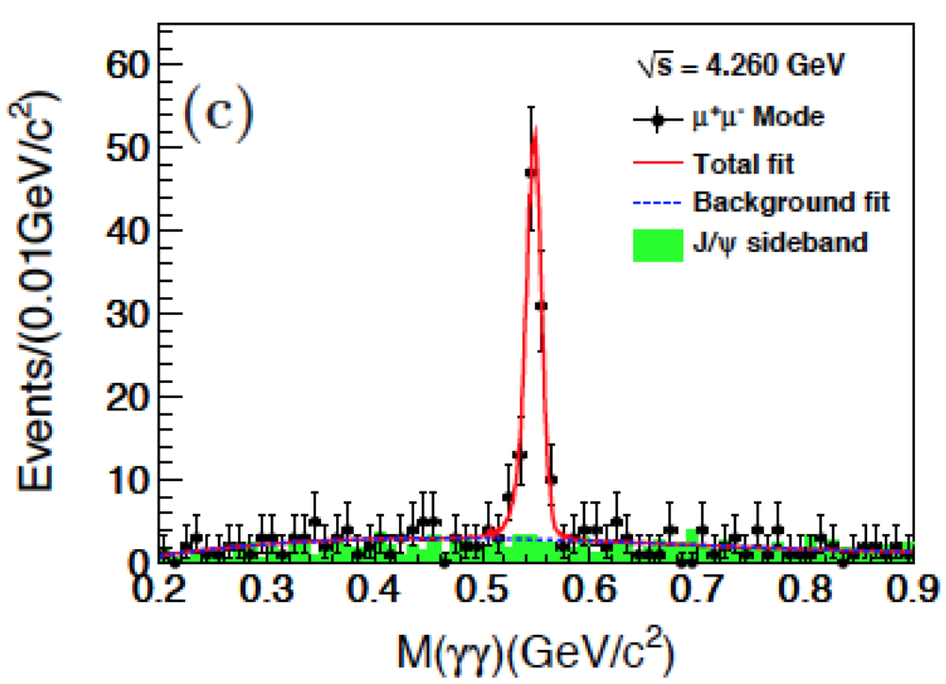
Fit with a single BW
Mass = $4230 \pm 8 \pm 6$ MeV
Width = $38 \pm 12 \pm 2$ MeV
Significance $> 9\sigma$

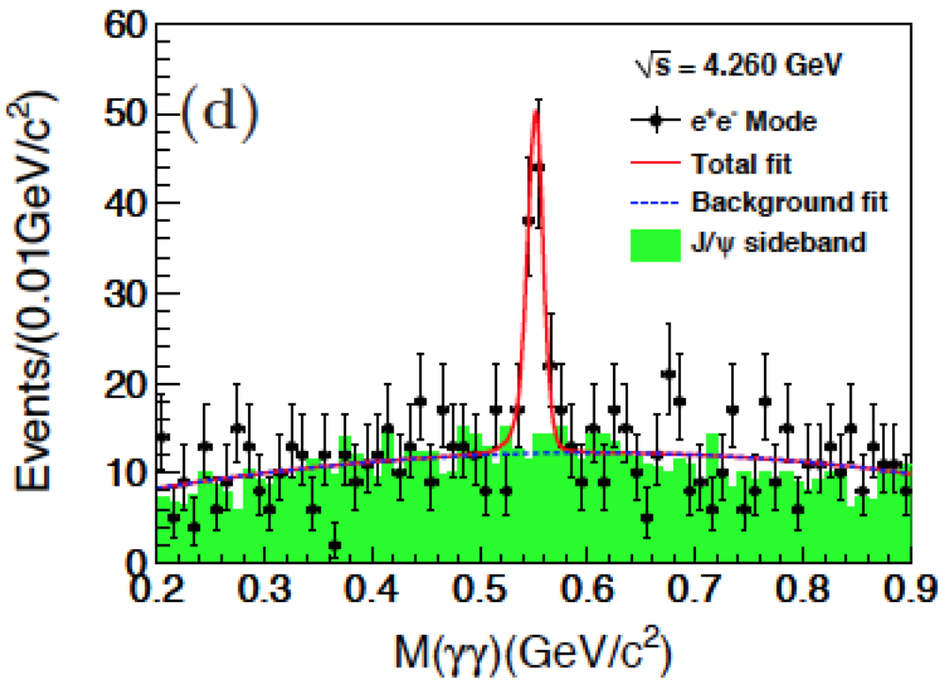
A tetraquark? (arXiv: 1412.7196)
ψ(4S)? (EPJC74,3208(2014))
Threshold effect?
…

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



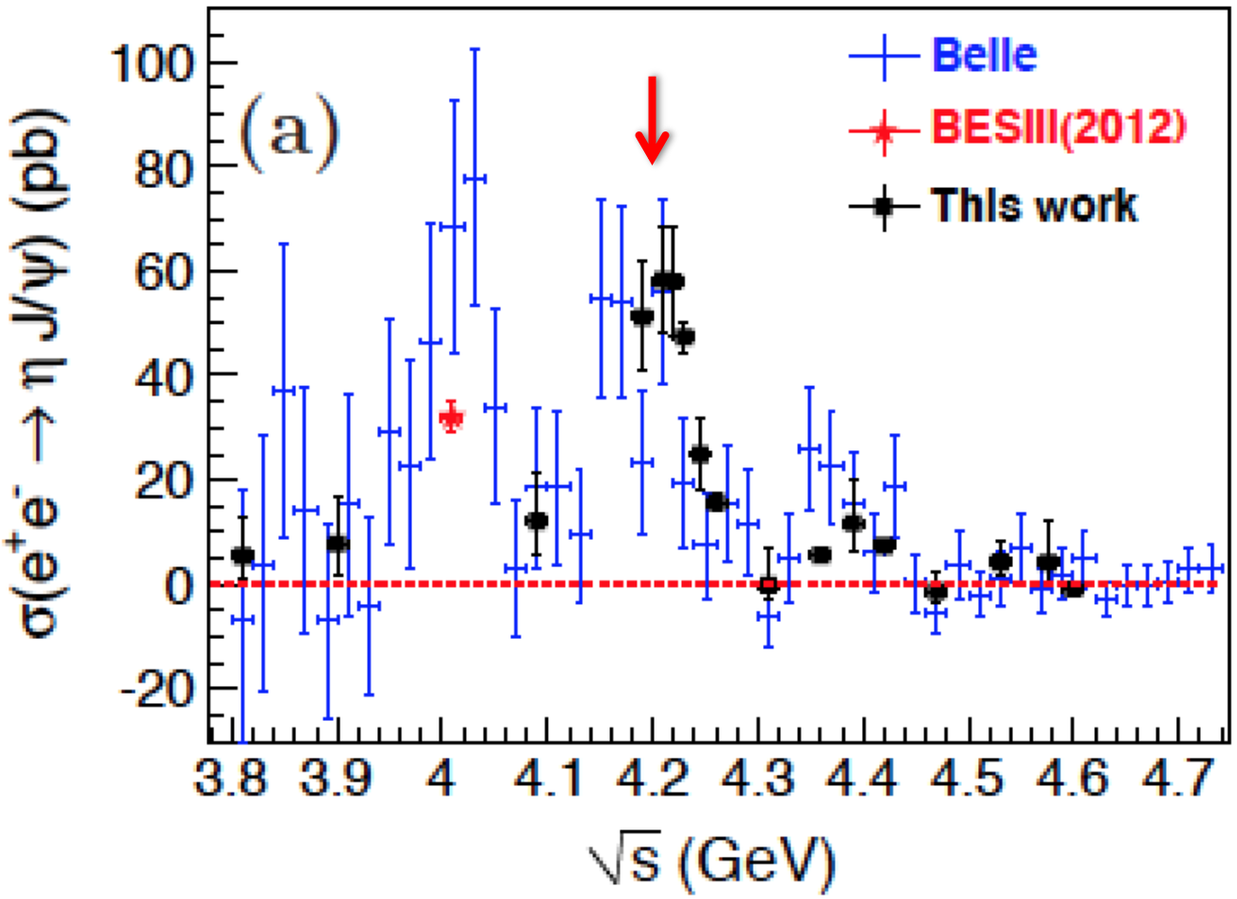


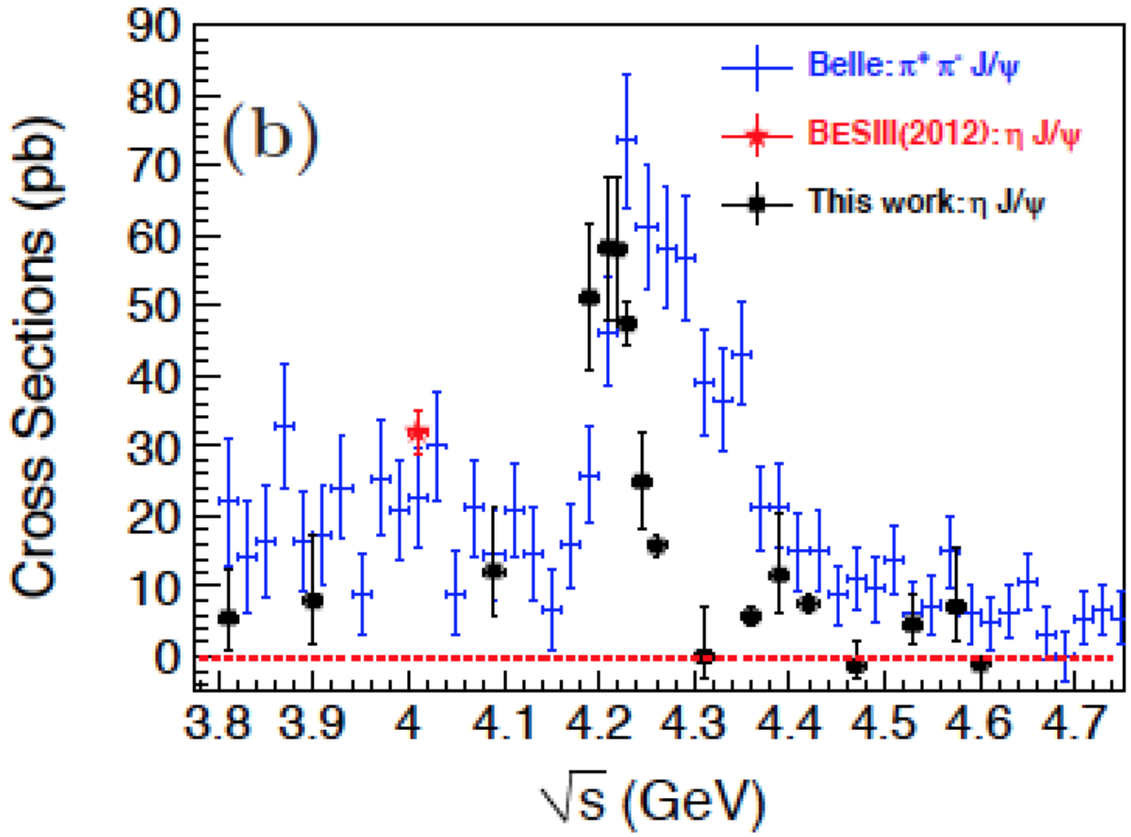




arXiv:1504.6644

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





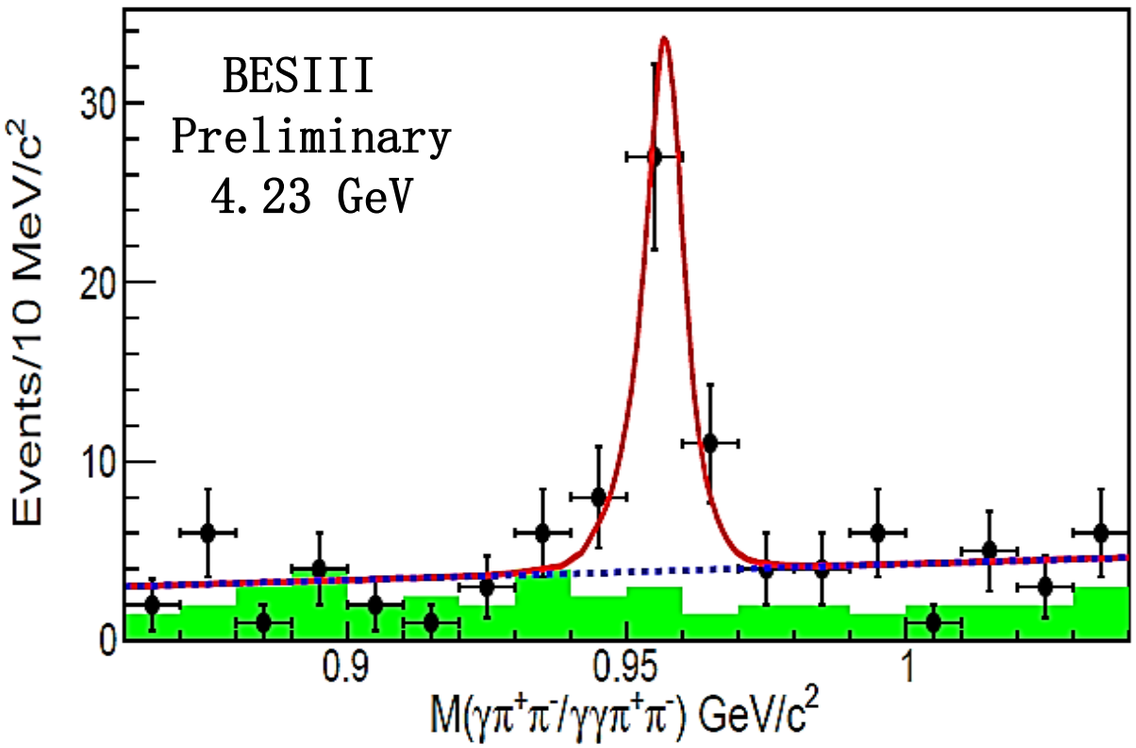
- Agree with previous results with improved precision
- The cross section peaks around 4.2 GeV
- Different line shape from $\pi^+\pi^- J/\psi$

We did not observe $e^+e^- \rightarrow \pi^0 J/\psi$ and set up limits of cross sections at pb level at above energy pionts.

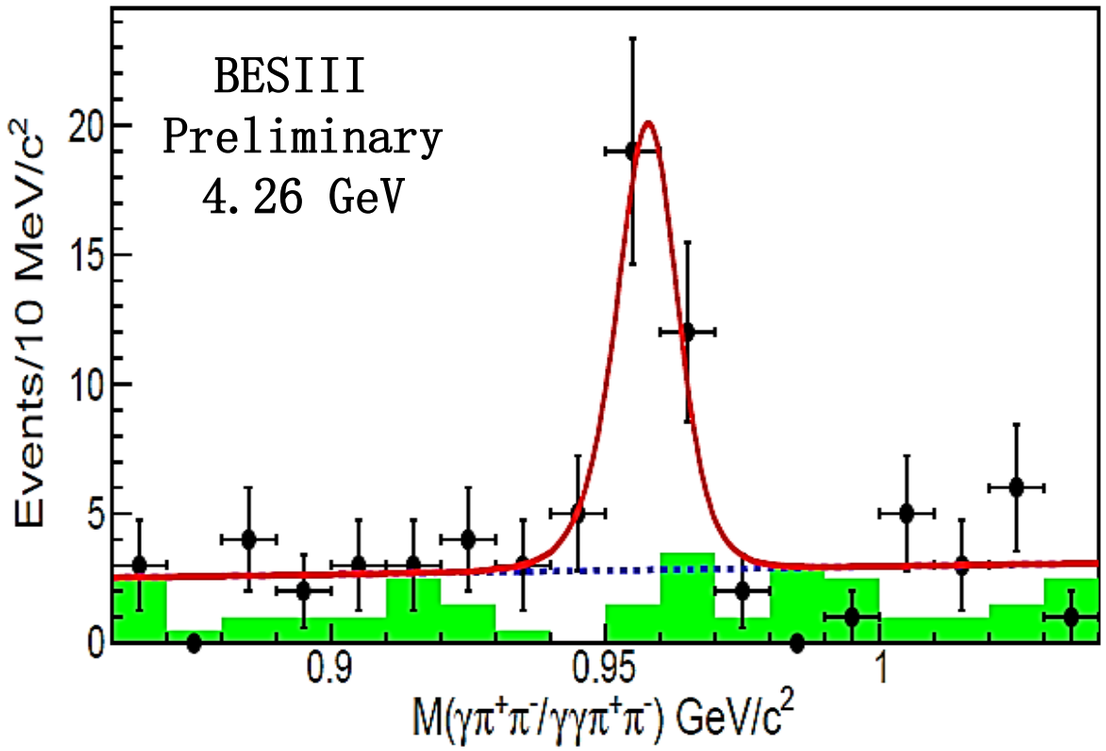
arXiv:1504.6644

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

$\eta' \to \gamma \pi^+\pi^-$
$\eta' \to \eta \pi^+\pi^-, \eta \to \gamma\gamma$

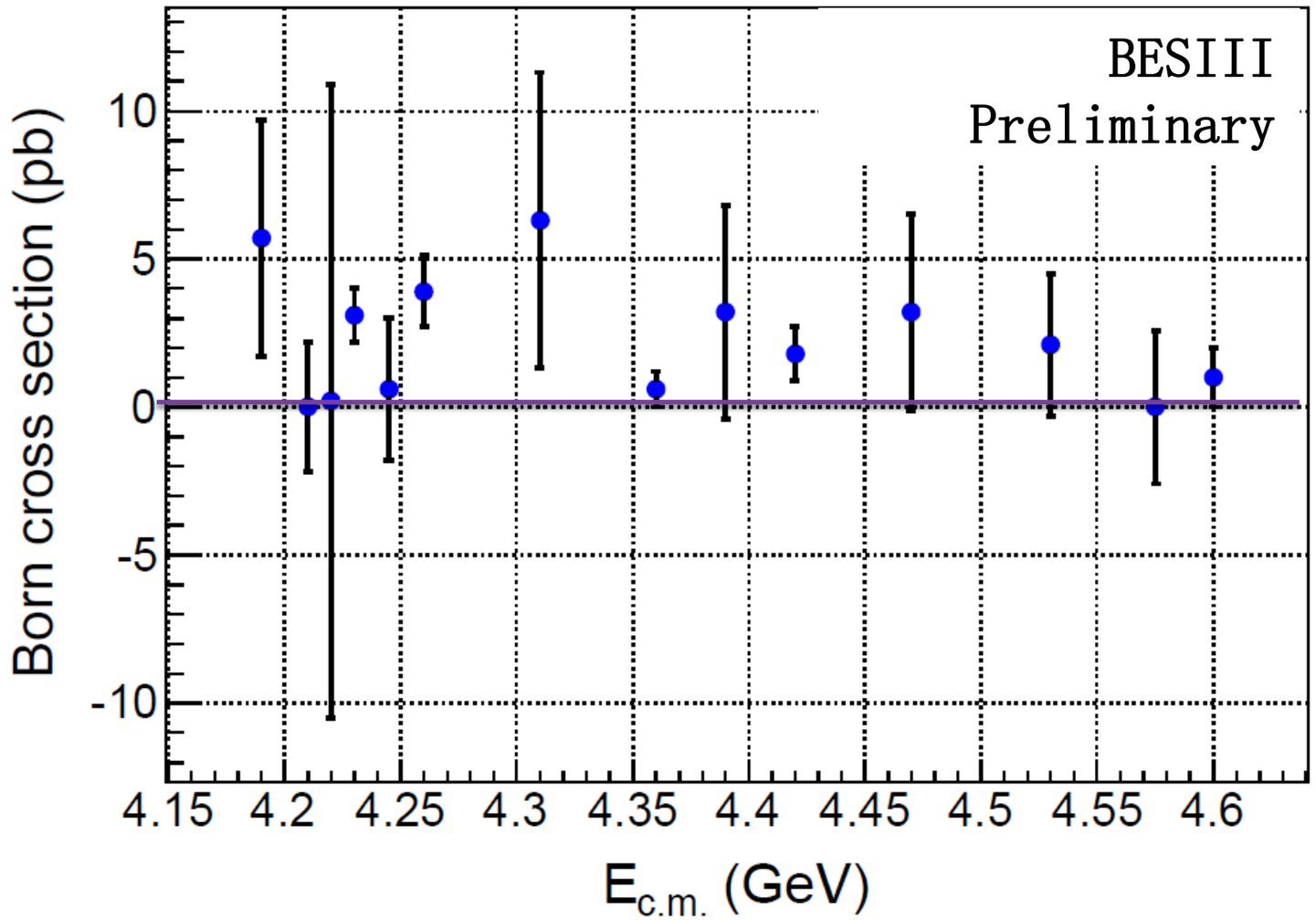


- Significance = 9.0σ
- $\sigma^B = 3.1 \pm 0.6(stat.) \pm 0.3(syst.)$ pb



- Significance = 7.7σ
- $\sigma^B = 3.9 \pm 0.8(stat.) \pm 0.4(syst.)$ pb

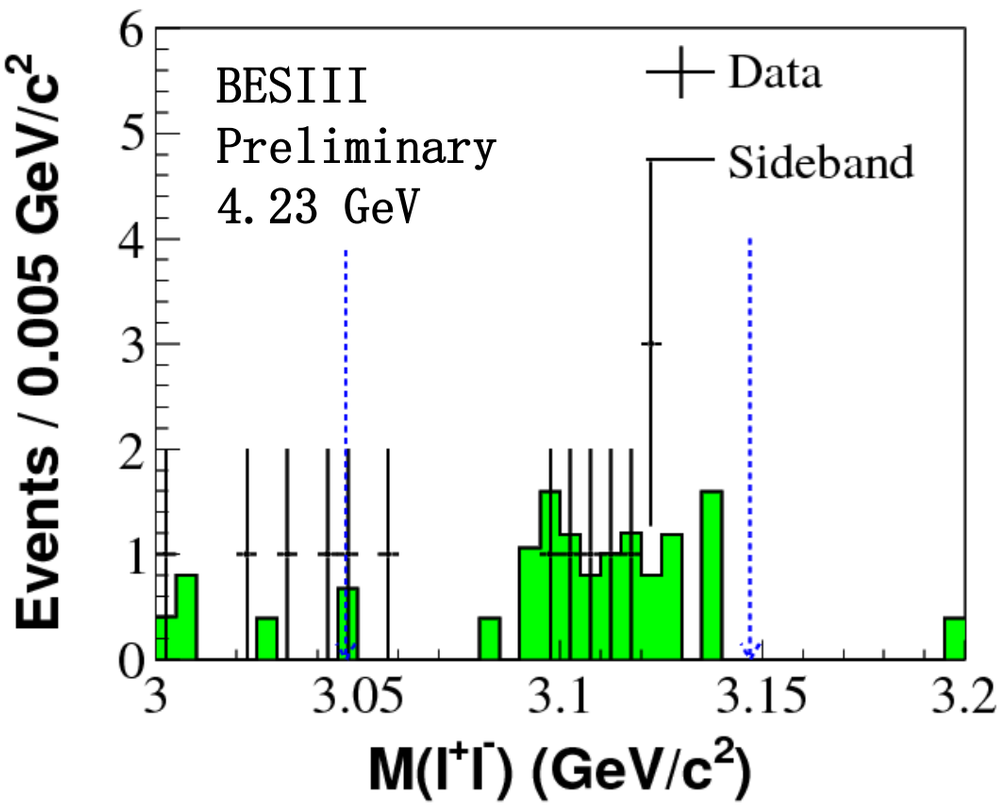
Observation of $e^+e^- \to \eta' J/\psi$

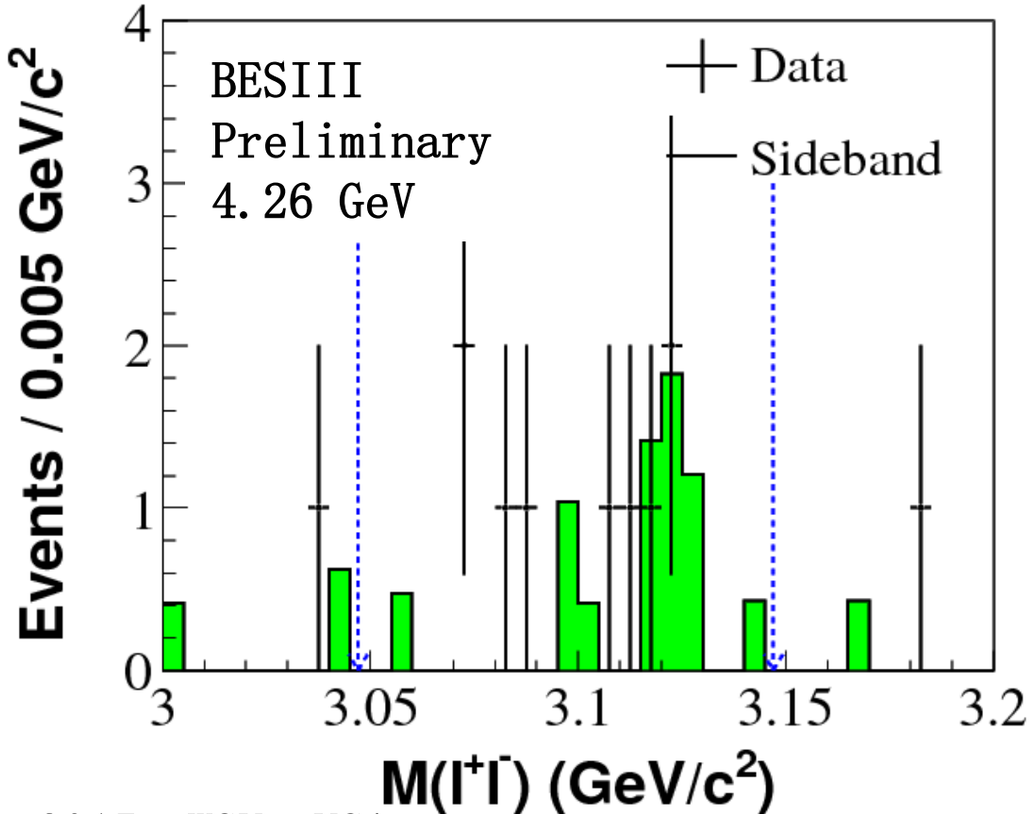


- First observation, cannot tell the line shape due to statistics
- Much lower than $\sigma(e^+e^- \to \eta' J/\psi)$
- Lower than theoretical calculations in the framework of NRQCD

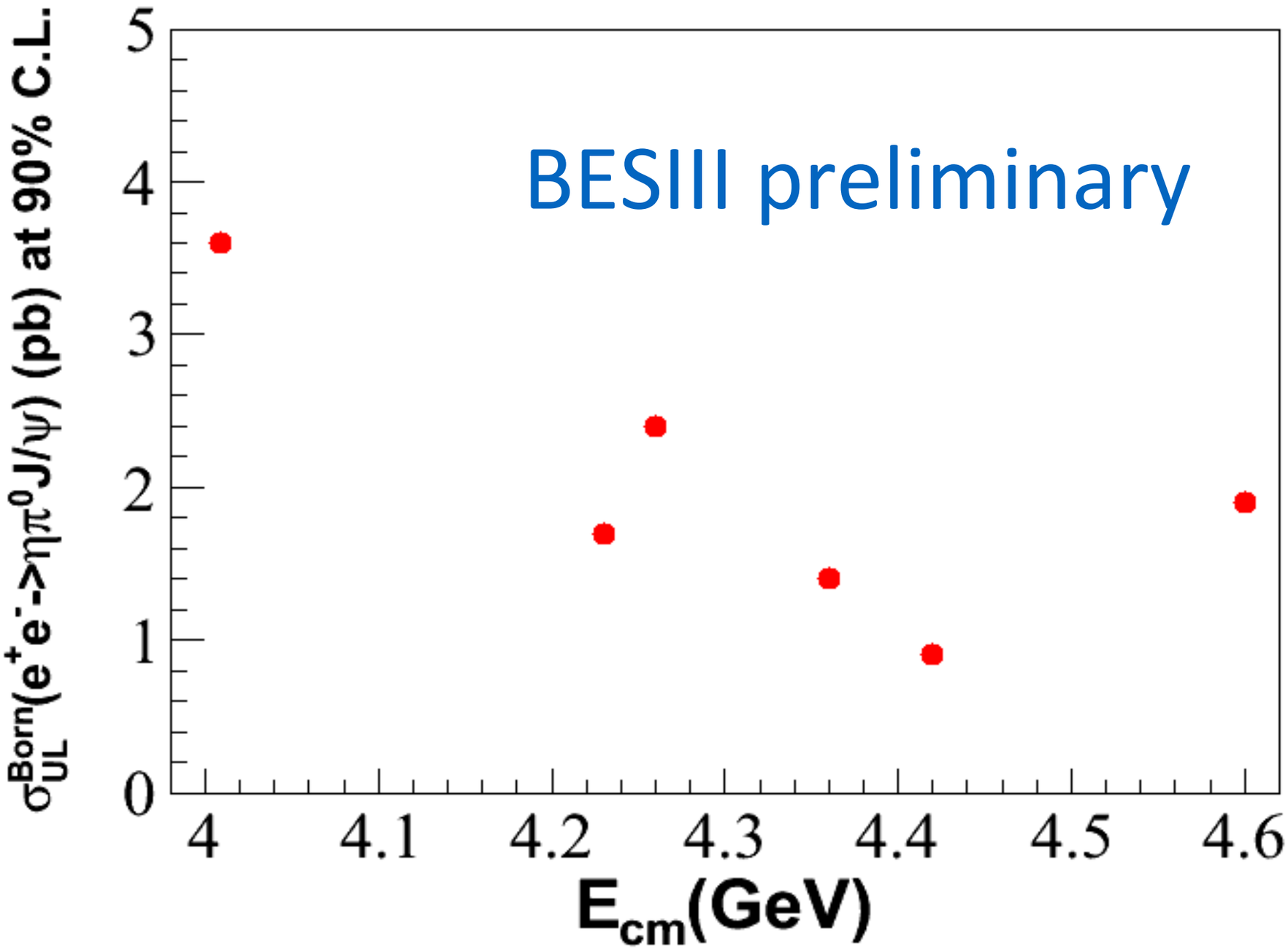
No significant $e^+e^- \rightarrow \eta\pi^0 J/\psi$

- 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





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

Summary & outlooks

- BESIII is scanning the processes of hadronic transitions to charmonia above 4 GeV.
- A few observations:
  - ✓ $e^+e^-\to\pi^+\pi^-X(3823)$
  - ✓ $e^+e^-\to\pi^+\pi^-J/\psi$, $\pi^0\pi^0J/\psi$
  - ✓ $e^+e^-\to\pi^+\pi^-h_c(1P)$, $\pi^0\pi^0h_c(1P)$
  - ✓ $e^+e^-\to\omega\chi_{c0}$
  - ✓ $e^+e^-\to\eta J/\psi$, $\eta' J/\psi$
- Searching for the missing charmonium states devours statistics
- We need machines beyond current to settle everything: Belle II, Panda, HIEPA …

Thank you!

谢谢！