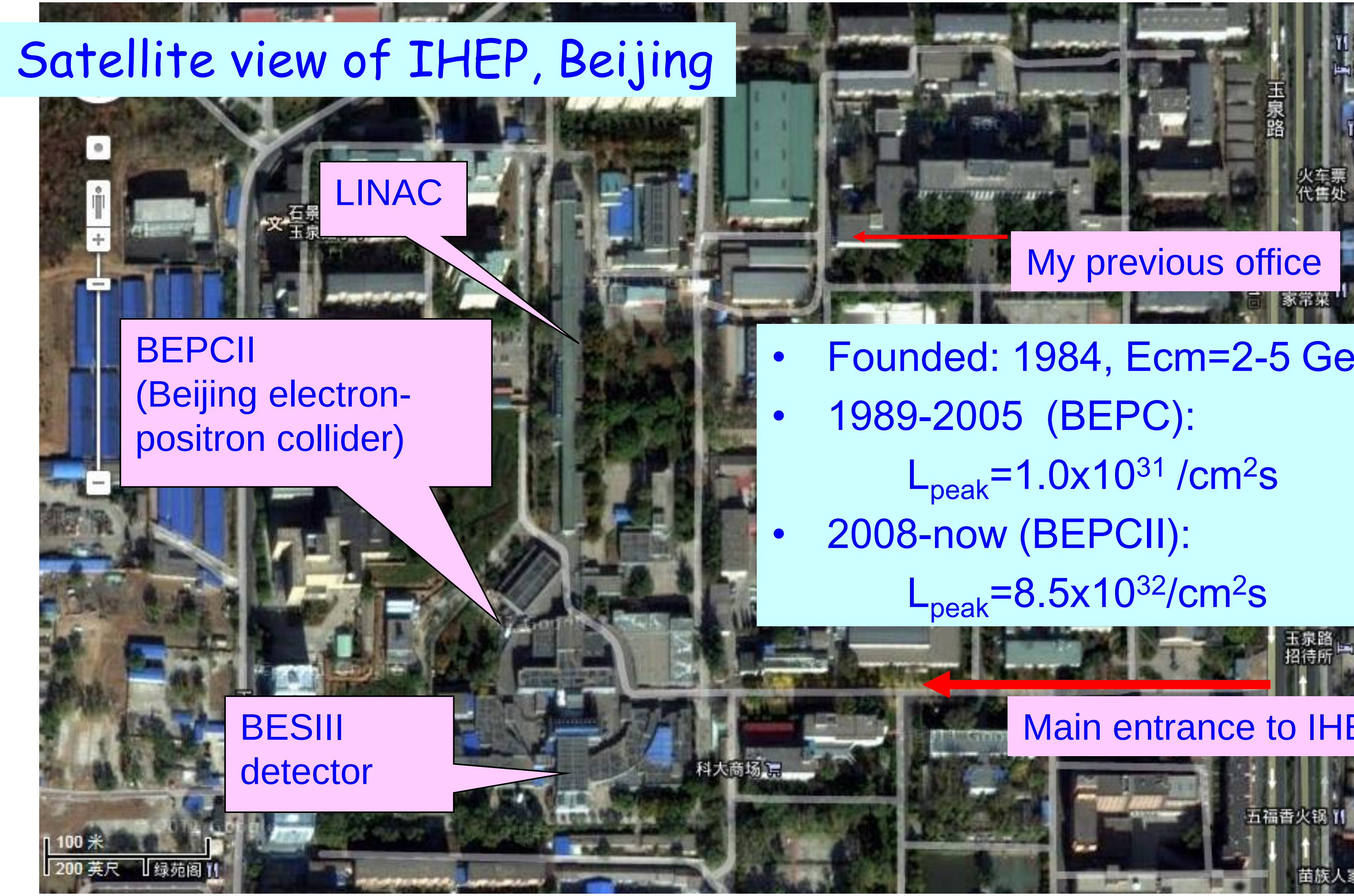
BESIII experimental status

Chengping Shen
(for the BESIII Collaboration)
Beihang University, Beijing

3rd BelleII Theory Interface Platform (B2TiP) Workshop

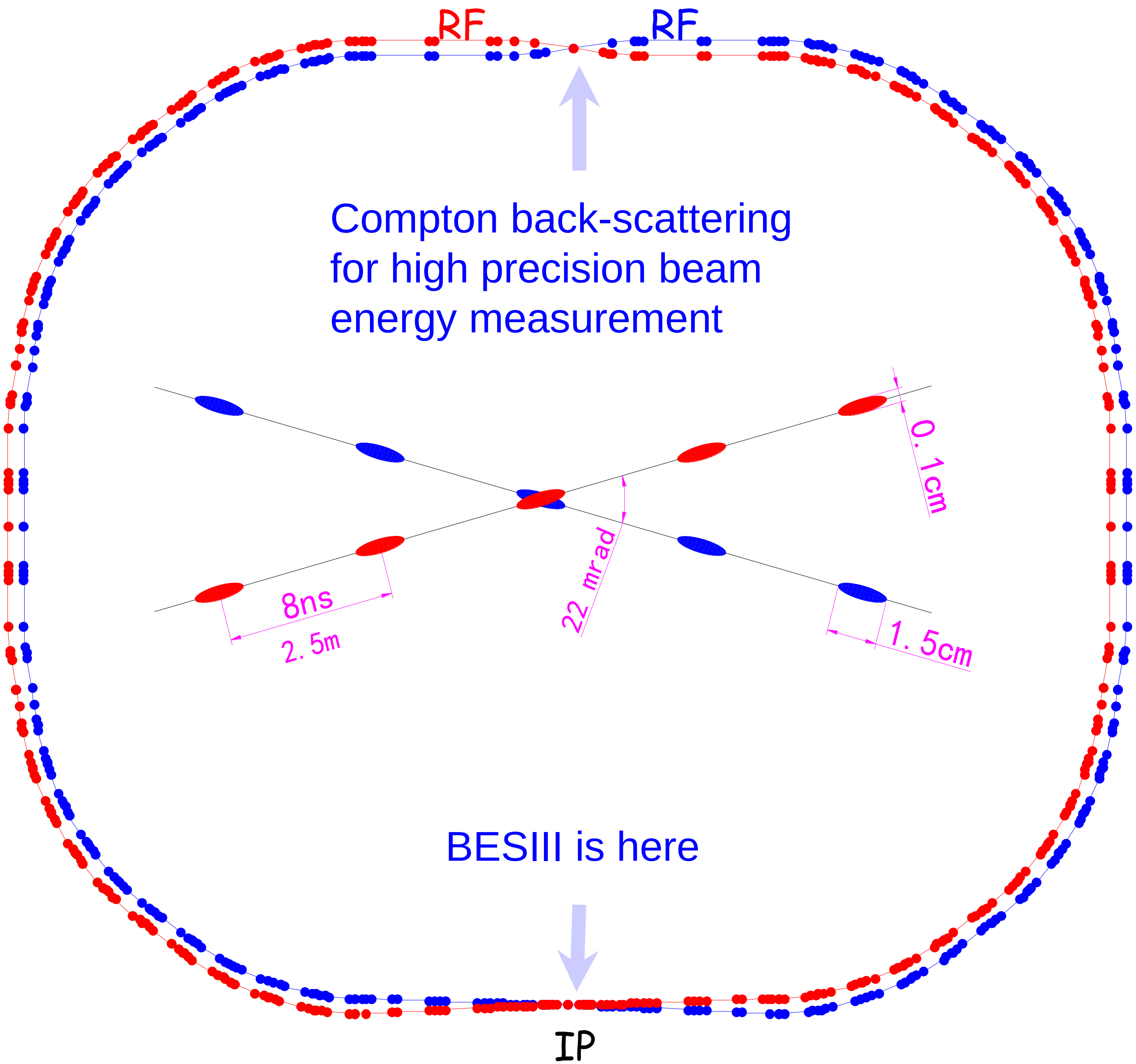
Oct. 28 – 29, 2015

Beijing Electron Positron Collider (BEPC)



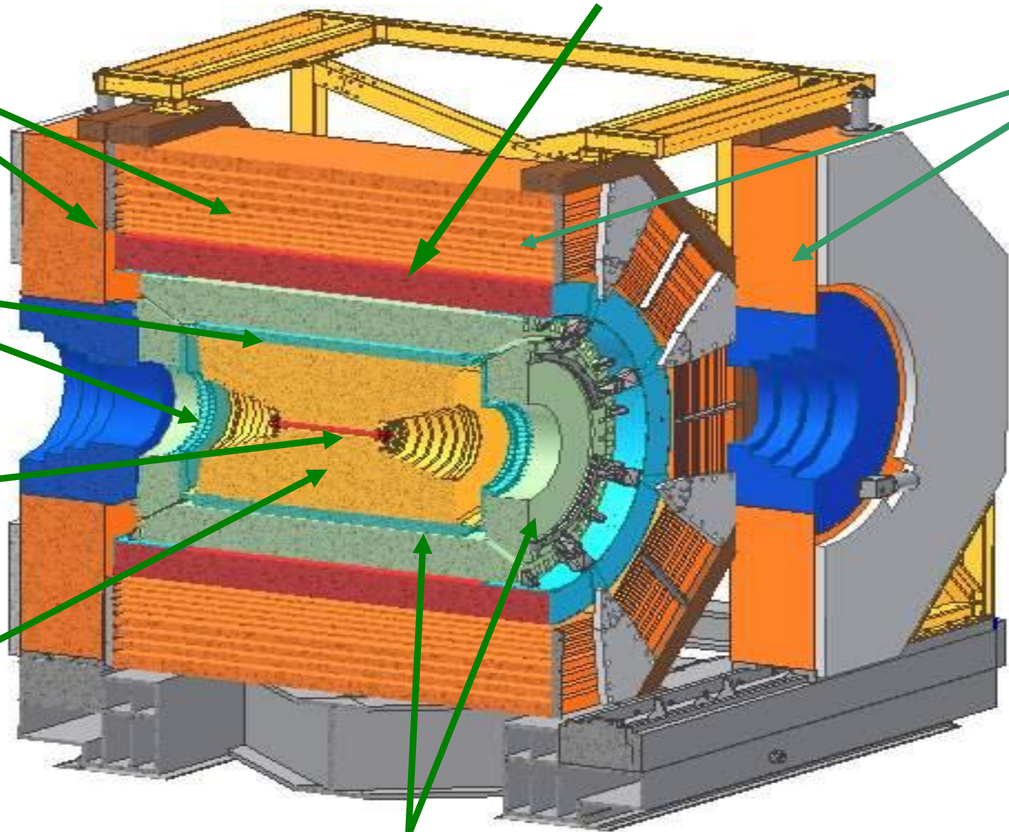
- Founded: 1984, Ecm=2-5 GeV
- 1989-2005 (BEPC):
  $L_{peak}=1.0\times10^{31}\ /cm^2s$
- 2008-now (BEPCII):
  $L_{peak}=8.5\times10^{32}/cm^2s$

BEPC II: a double-ring machine



Beam energy:
1-2.3 GeV
Luminosity:
1×10^{33} cm^{-2}s^{-1}
Optimum energy:
1.89 GeV
Energy spread:
5.16×10^{-4}
No. of bunches:
93
Bunch length:
1.5 cm
Total current:
0.91 A
SR mode:
0.25A @ 2.5 GeV

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.

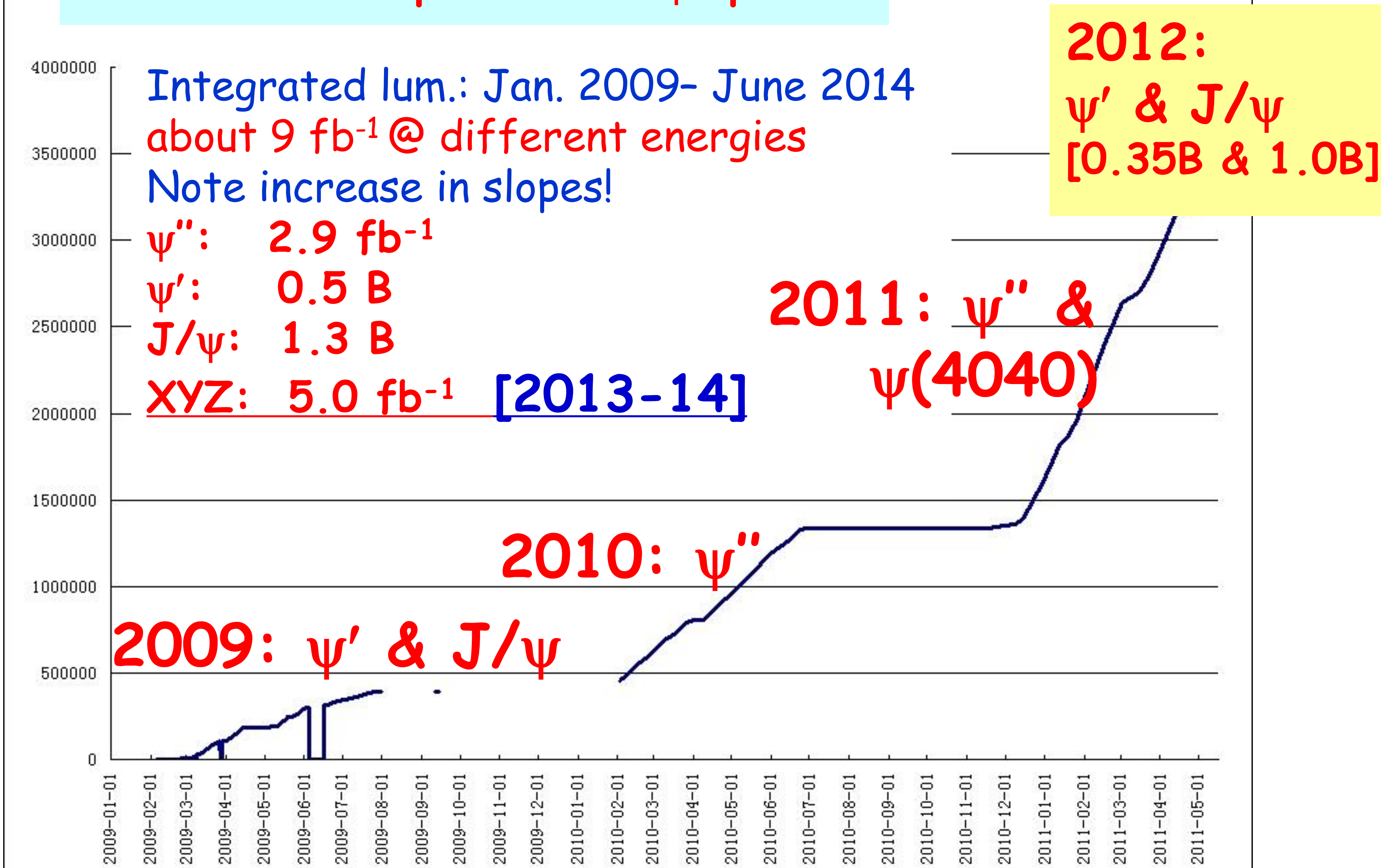
~400 members
53 institutions from 11 countries

BESIII Collaborators

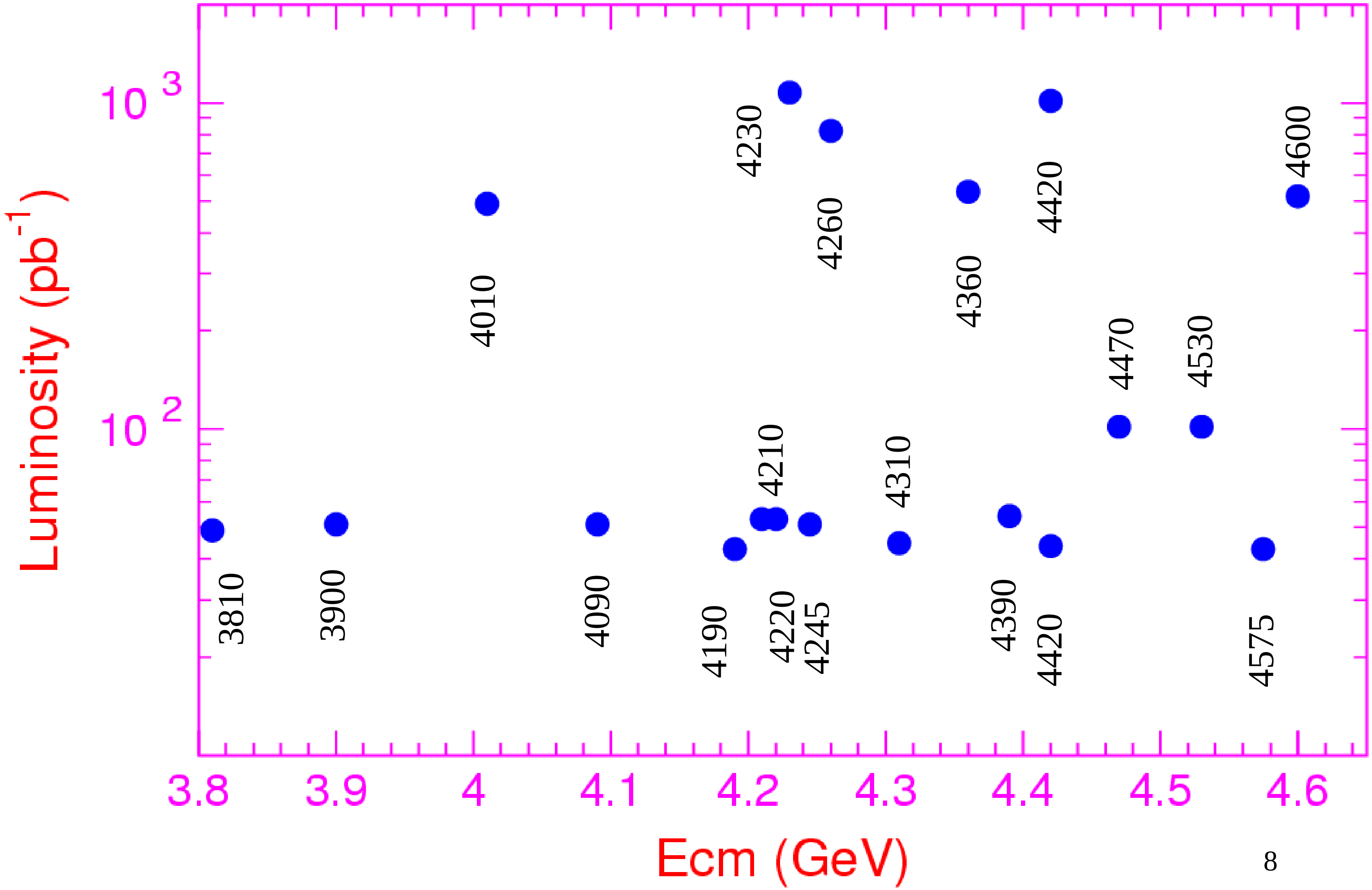
… a photo I can find myself in 10s!

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)

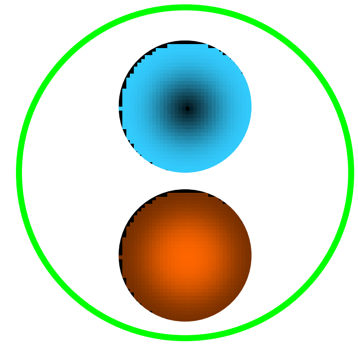


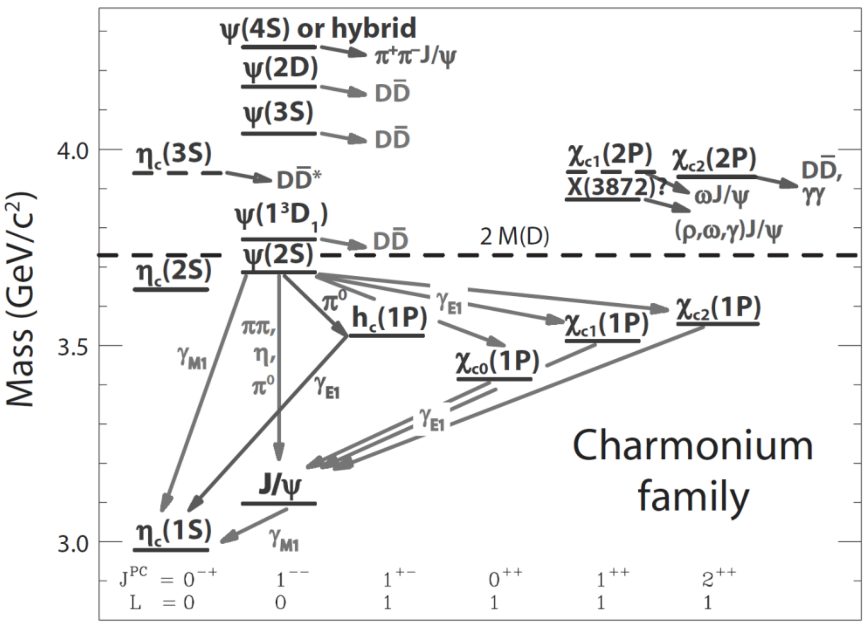
Outline

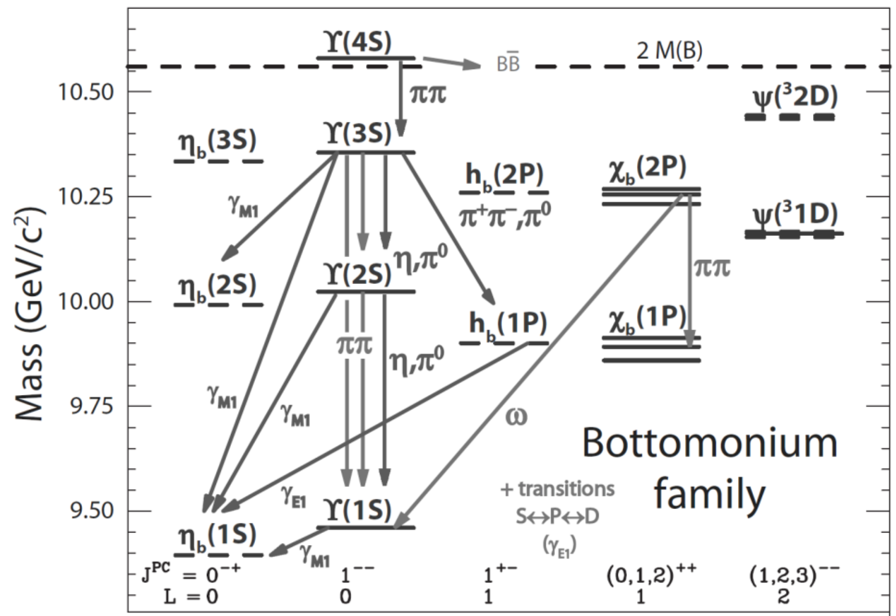
- Exotic states
- The X states
- The Y states
- The Z_c states
- Summary & Outlook

The heavy quarkonium system

- At short distance
  Cornell model works pretty well
  $V(r) = -4\alpha_s/3r+kr$







The quarkonium system

- When distance becomes larger
  - Theory 1: let there be screened potential
  - Theory 2: let there be hybrids with excited gluons
  - Theory 3: let there be tetraquark states
  - Theory 4: let there be meson molecules
  - Theory 5: let there be cusps
  - Theory 6: let there be final state interaction
  - Theory 7: let there be coupled-channel effect
  - Theory 8: let there be mixing
  - Theory 9: let there be mixture of all these effects
  - Theories …

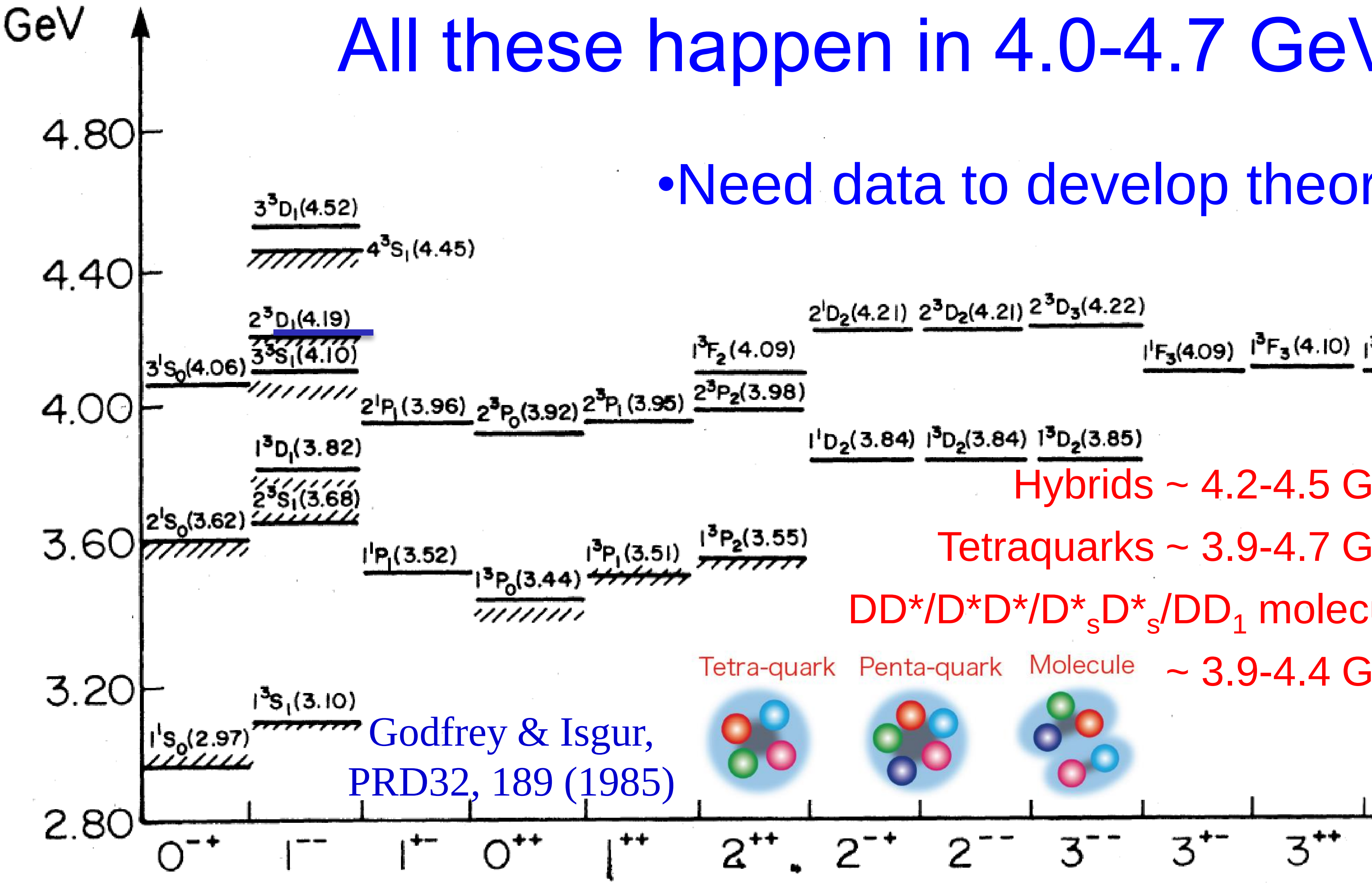
QCD is another least understood part of the SM.

"The absence of exotics is one of the most obvious features of QCD" – R. L. Jaffe, 2005

"The story of pentaquark shows how poorly we understand QCD" – F. Wilczek, 2005

All these happen in 4.0-4.7 GeV

- Need data to develop theory.



Godfrey & Isgur, PRD32, 189 (1985)

Hybrids ~ 4.2-4.5 GeV

Tetraquarks ~ 3.9-4.7 GeV

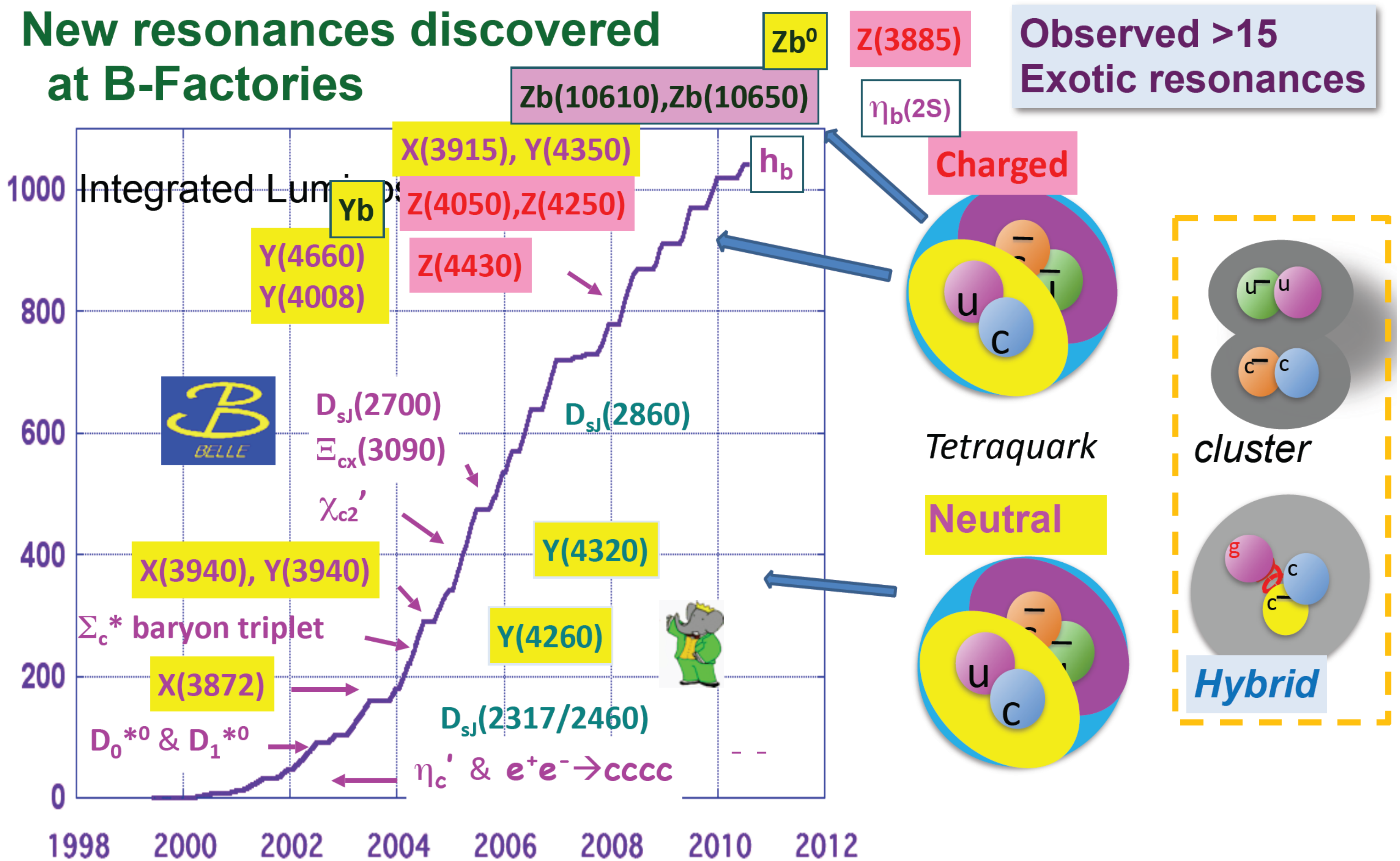
$DD^*/D^*D^*/D^*_sD^*_s/DD_1$ molecule ~ 3.9-4.4 GeV

QCD just require hadrons to be colorless, and allow exotics.

Such exotic states exist ?

Thanks B-factories !

- Discovery of X(3872) and other many XYZ states etc.
- Unexpected bonus of the B-factories

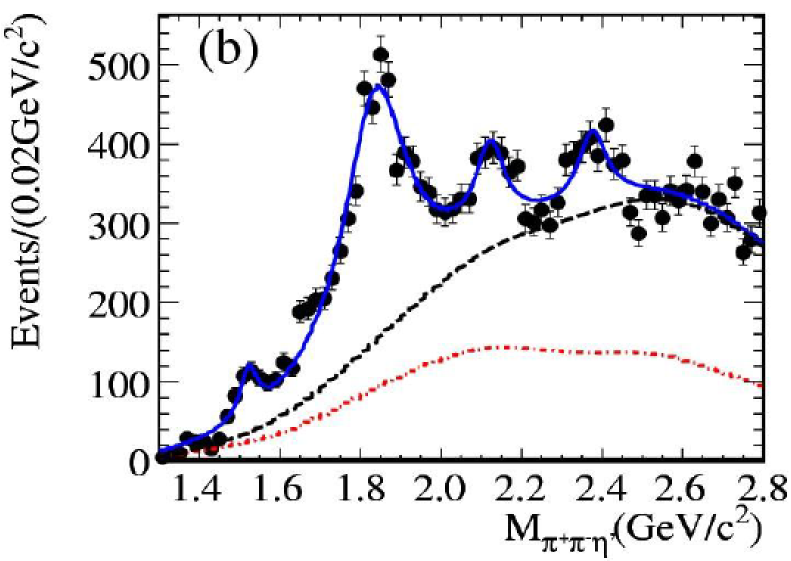


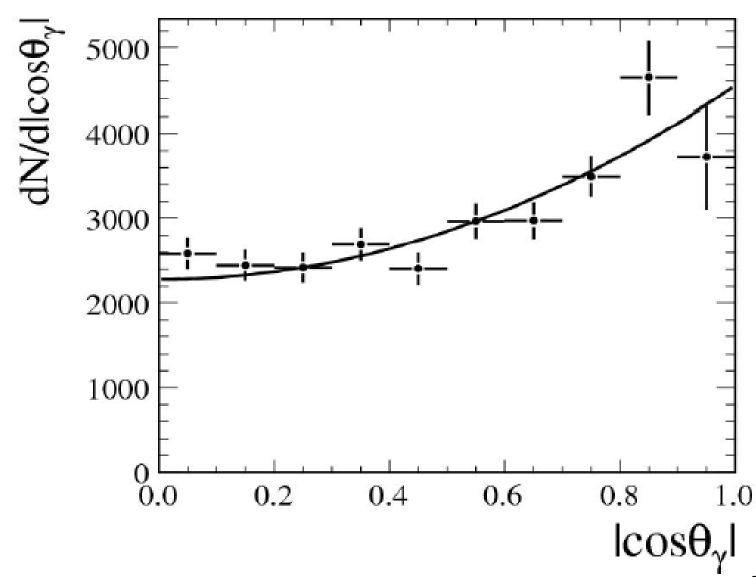
The X states

X(1835) review

- Observed in **$J/\psi \to \gamma\eta'\pi^+\pi^-$** at BESII in 2005
- Nature unclear, interpretations include $p\bar{p}$ bound state, excited η', glueball
- Confirmed in $J/\psi \to \gamma\eta'\pi^+\pi^-$ at BESIII
- Angular distribution consists with pseudoscalar, but other spin-parity assignments not excluded

225 million J/ψ events **PRL 106, 072002 (2011)**



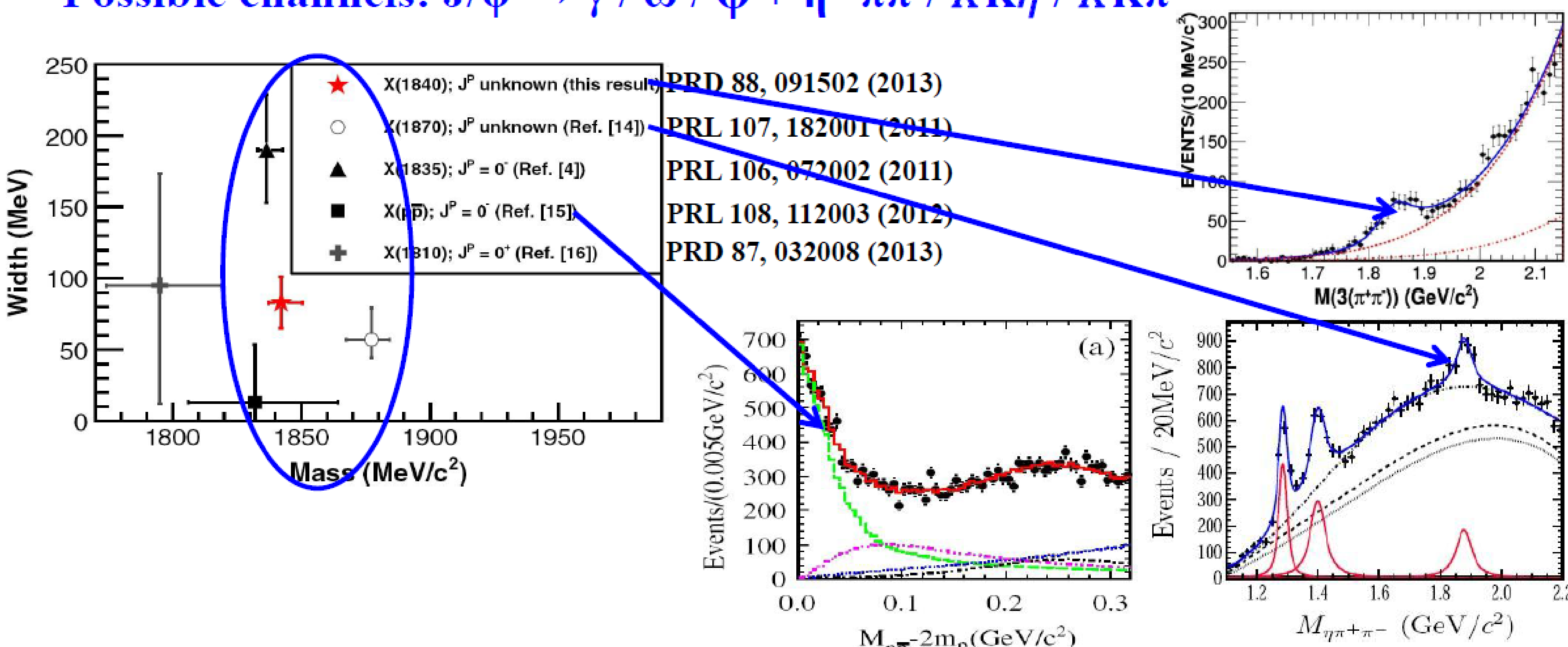


X(1835) review

- Simulated by $p\bar{p}$ threshold enhancement $X(p\bar{p})$ in $J/\psi \rightarrow \gamma p\bar{p}$
- Results in the observations of X(1870) in $J/\psi \rightarrow \omega(\eta\pi^+\pi^-)$ and X(1840) in $J/\psi \rightarrow \gamma 3(\pi^+\pi^-)$

- Are these states observed around 1.8 GeV/c^2 from the same origin?
- Further investigations on different production and decay mechanisms, precise physical parameters measurement are necessary

Possible channels: $J/\psi \rightarrow \gamma\ /\ \omega\ /\ \phi + \eta^{(\prime)}\pi\pi\ /\ K\bar{K}\eta\ /\ K\bar{K}\pi$



Observation of X(1835) in $J/\psi \rightarrow \gamma K_s K_s \eta$

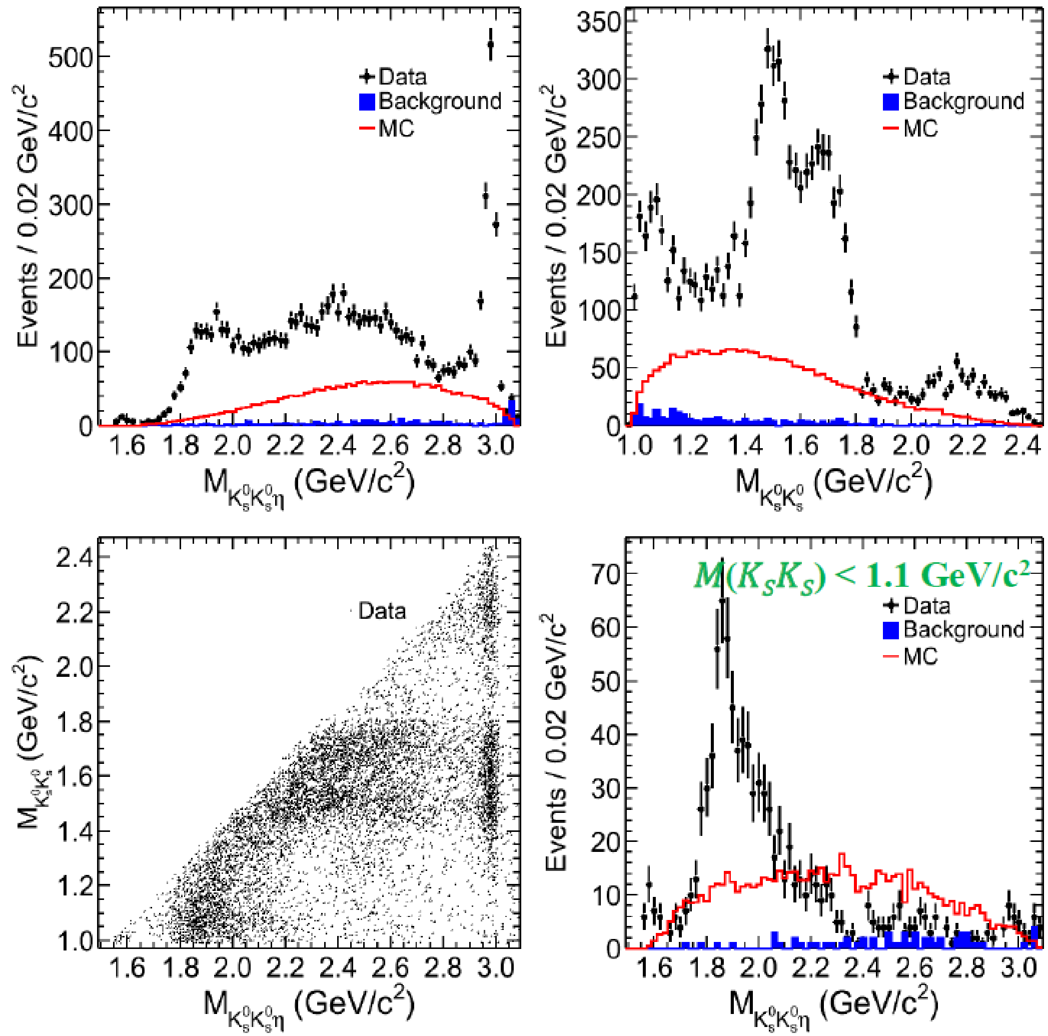
1.3 billion J/ψ events **PRL 115, 091803 (2015)**

- Why this channel?
  - Unlike $J/\psi \rightarrow \gamma K^+ K^- \eta$, no background from two potential but forbidden channels of $J/\psi \rightarrow K_S K_S \eta$ and $J/\psi \rightarrow K_S K_S \eta \pi^0$

- Clear structure on mass spectrum of $K_s K_s \eta$ around 1.85 GeV/c²

- Strong correlation with the enhancement near $K_s K_s$ mass threshold (interpreted as $f_0(980)$)

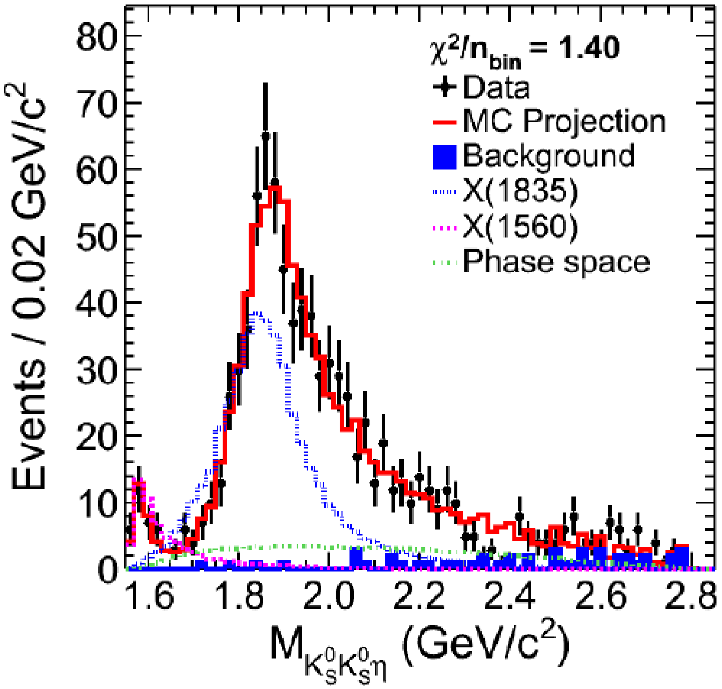
- Structure is enhanced for $M(K_S K_S) < 1.1$ GeV/c²



Observation of X(1835) in $J/\psi \to \gamma K_s K_s \eta$

- PWA for $M(K_S K_S) < 1.1$ GeV/c²
- Two resonant pseudoscalar components are required in nominal solution

PRL 115, 091803 (2015)



$X(1835) \to K_s K_s \eta$ ($> 12.9\,\sigma$)
dominated by $f_0(980)$ production

$m = 1844 \pm 9^{+16}_{-25}$ MeV/c²

$\Gamma = 192^{+20+62}_{-17-43}$ MeV

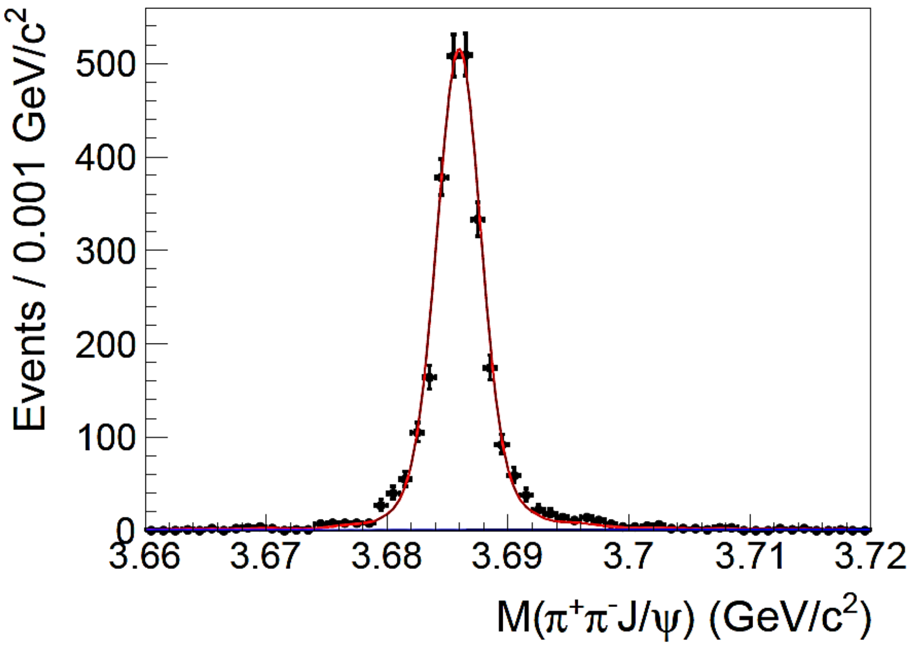
$\mathcal{B}(J/\psi \to \gamma X(1835)) * \mathcal{B}(X(1835) \to K_s K_s \eta)$
$= (3.31^{+0.33\,+1.96}_{-0.30\,-1.29}) * 10^{-5}$

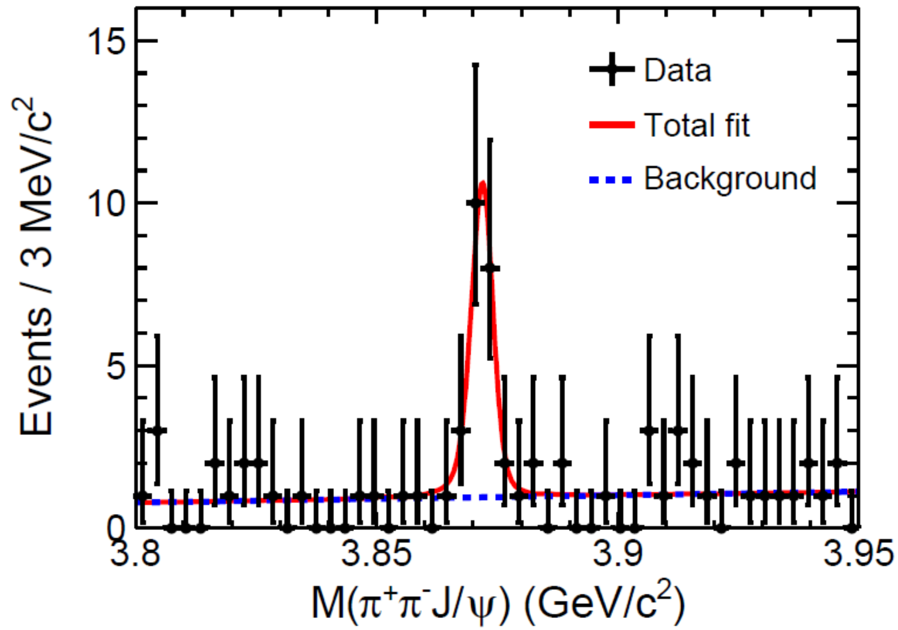
State	J^{PC}	Decay Mode	Mass (MeV/c²)	Width (MeV)	Product Branching Ratio	Significance
X(1835)	0^{-+}	$K_s K_s \eta$	$1844 \pm 9^{+16}_{-25}$	$192^{+20\,+62}_{-17\,-43}$	$(3.31^{+0.33\,+1.96}_{-0.30\,-1.29}) * 10^{-5}$	$> 12.9\,\sigma$
X(1835)	---	$\pi^+\pi^-\eta'$	$1836.5 \pm 3.0^{+5.6}_{-2.1}$	$190 \pm 9^{+38}_{-36}$	$(2.87 \pm 0.09^{+0.49}_{-0.52}) * 10^{-4}$	$> 20\,\sigma$
$X(p\bar{p})$	0^{-+}	$p\bar{p}$	$1832^{+19\,+18}_{-5\,-17} \pm 19$	<76@90%C.L.	$(9.0^{+0.4\,+1.5}_{-1.1\,-5.0} \pm 2.3) * 10^{-5}$	$> 30\,\sigma$

red: PRL 115, 091803 (2015) blue: PRL 106, 072002 (2011) black: PRL 108, 112003 (2012)

BESIII

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





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

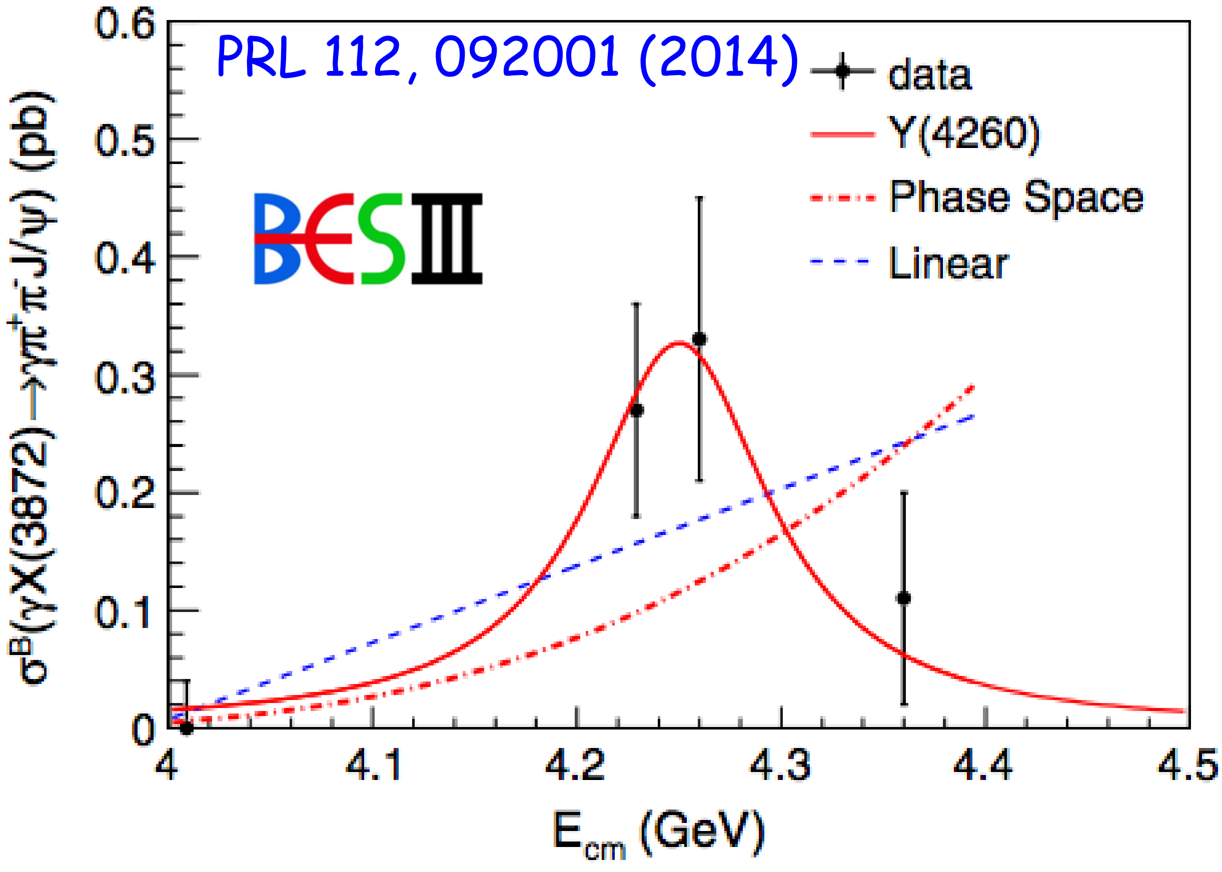
N=1818; ΔM=0.34±0.04 MeV; $\Delta\sigma_M$=1.14 ±0.07 MeV

N(X(3872)) = 20.1±4.5 **6.3σ**

PRL 112, 092001 (2014)

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

Production mechanics



Fit with different shapes

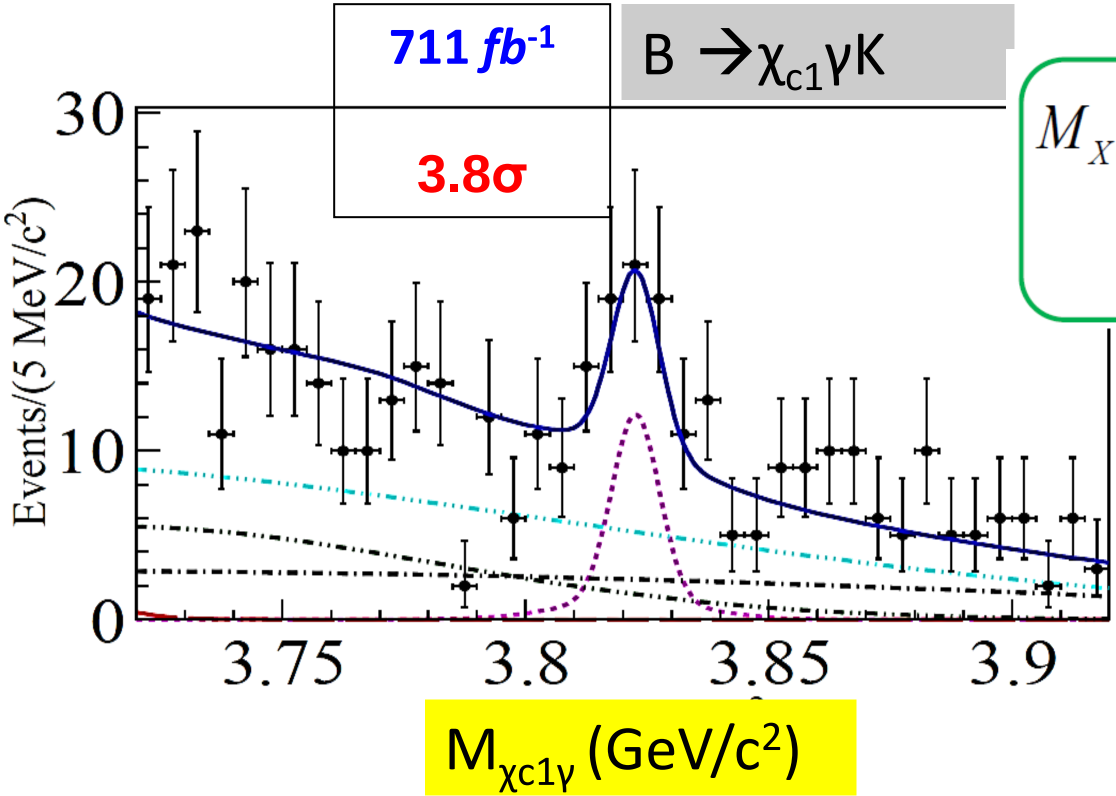
- Y(4260): χ^2/ndf=0.49/3
- E1 PHSP: χ^2/ndf=8.7/3
- Linear: χ^2/ndf=5.5/2

For the first time, bring connections between exotic hadrons (X and Y) !

- Central-of-mass energy dependent cross section peaks at 4.26 GeV
- Strongly suggest the decay Y(4260)→γX(3872)
- The ratio of B[Y(4260)→γX(3872)]~10%.

Evidence for the X(3823) at Belle

arXiv:1304.3975 (PRL111, 032001 (2013))



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

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 $M_{bc} > 5.27$ GeV$/c^2$. The curves used in the fits are described in [31].

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

BESIII may search for it!

Hunt D-wave charmonium at BESIII

1. Both E705 and Belle observed evidence.

[Phys. Rev. D 50, 4258 (1994); Phys. Rev. Lett. 111, 032001 (2013).]

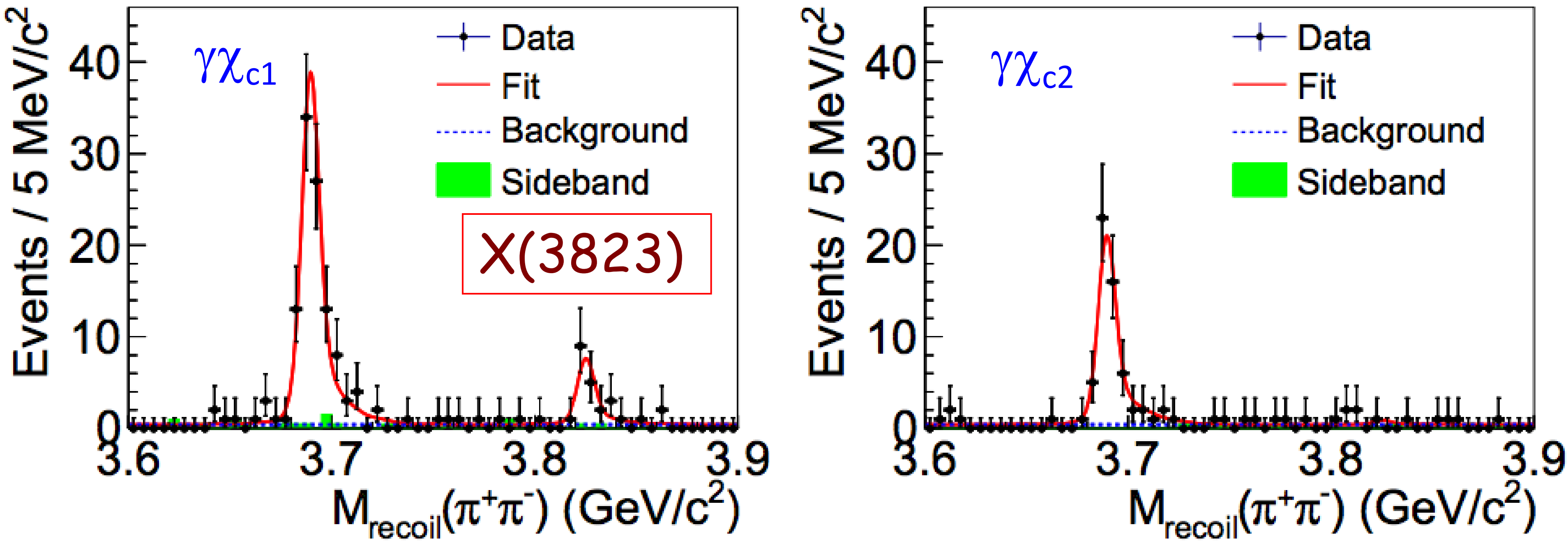
1. Potential model: $1^3D_2 \rightarrow \gamma\chi_{c1}, \gamma\chi_{c2}$ with large width.
2. Use $\pi^+\pi^-$ transition to produce 1^3D_2 with $J^{PC} = 2^{--}$; D-wave (L=2) transition is expected.

- Event Selection:
- Two charged pions and two leptons from J/ψ.
- Two photons from charmonium transitions.
- Using missing mass of $\pi^+\pi^-$ pair to identify signal (good resolution).

□ $\pi^+\pi^-\psi(2S)$ can be good reference channel.

Observation of X(3823) at BESIII

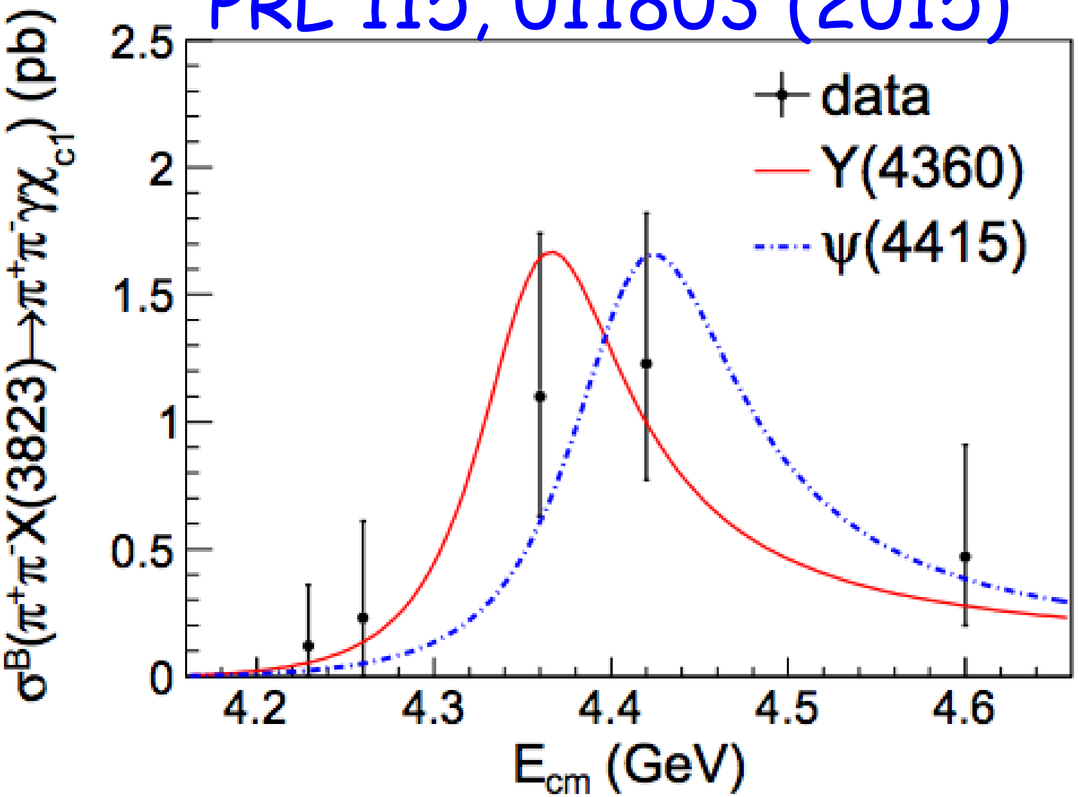
PRL 115, 011803 (2015)



- Simultaneous fit to data sets at different central-of-mass energies.
- M[X(3823)]=3821.7$\pm$1.3$\pm$0.7 MeV (calibrate by $\psi(2S)$).
- Statistical significance: 6.2σ (>5.9σ including sys.), observation!
- Good candidate of $\psi(1^3D_2)$, confirms X(3872)$\neq\psi(1^3D_2)$

Production mechanics of X(3823)

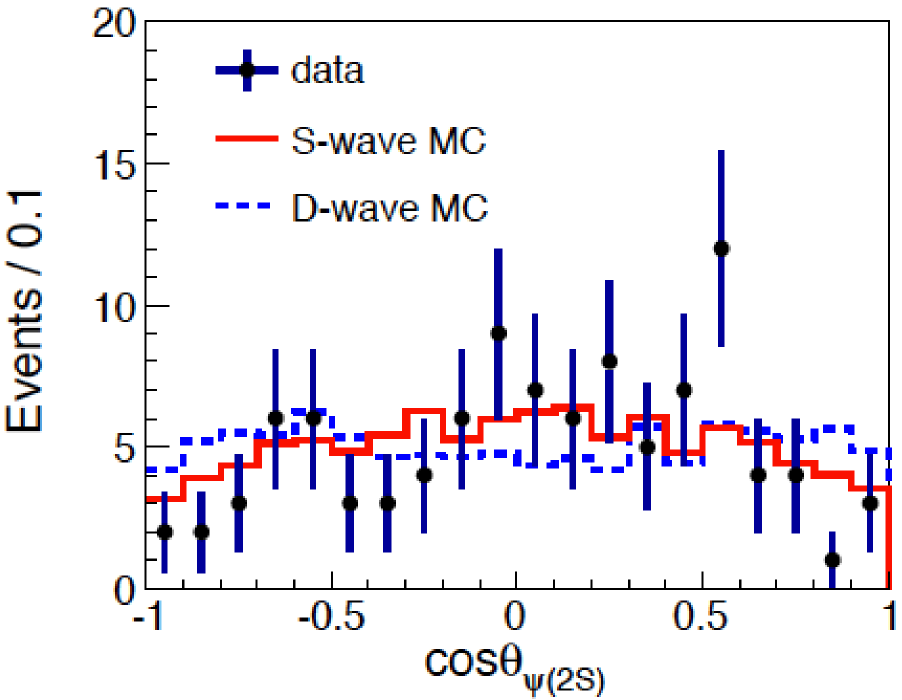
PRL 115, 011803 (2015)

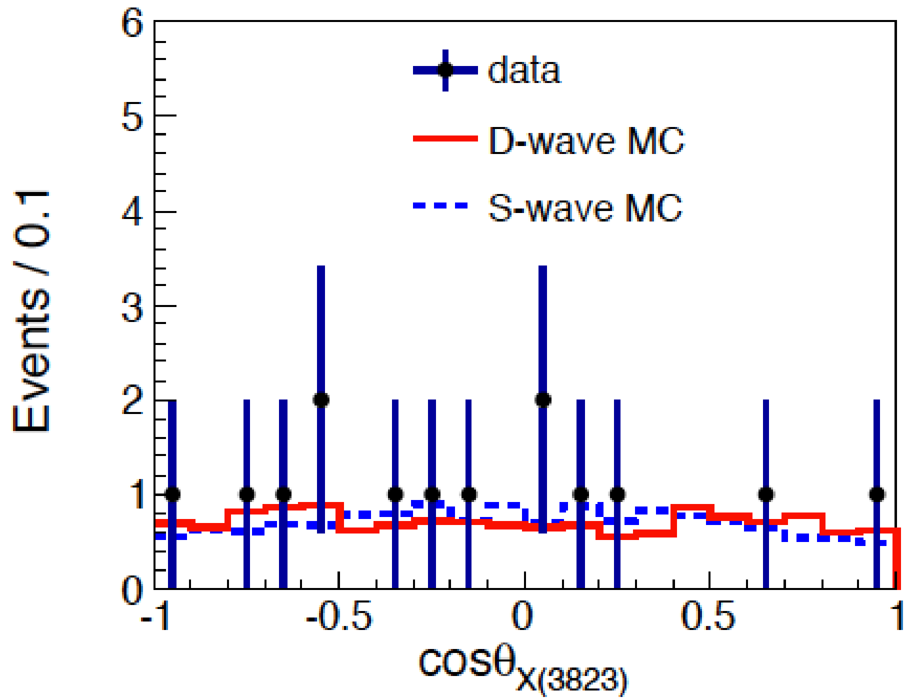


- Whether from Y(4360) or ψ(4415) decay
- Favor the Y(4360) ? [M. B. Voloshin, PRD 91, 114029 (2015)]
- Y(4360)→$\pi^+\pi^-$X(3823)? New decay model of Y(4360)?

$\sqrt{s}$ (GeV)	$\mathcal{L}$ (pb^{-1})	N^{obs}	ϵ	$1+\delta$	$\frac{1}{\vert 1-\Pi\vert^2}$	$\sigma_X^B \cdot \mathcal{B}_1$ (pb)	$\sigma_X^B \cdot \mathcal{B}_2$ (pb)	$\sigma_{\psi'}^B$ (pb)	$\mathcal{R}_{\psi'}$
4.230	1092	$0.7^{+1.4}_{-0.7}$ (< 3.7)	0.168	0.755	1.056	$0.12^{+0.24}_{-0.12} \pm 0.02$ (< 0.73)	-	$34.1 \pm 8.1 \pm 4.7$	-
4.260	826	$1.1^{+1.8}_{-1.2}$ (< 4.5)	0.178	0.751	1.054	$0.23^{+0.38}_{-0.24} \pm 0.04$ (< 1.11)	-	$25.9 \pm 8.1 \pm 3.6$	-
4.360	540	$3.9^{+2.3}_{-1.7}$ (< 7.9)	0.196	0.795	1.051	$1.10^{+0.64}_{-0.47} \pm 0.15$ (< 2.54)	(< 2.05)	$58.6 \pm 14.2 \pm 8.1$	$0.20^{+0.13}_{-0.10}$
4.420	1074	$7.5^{+3.6}_{-2.8}$ (< 12.9)	0.145	0.967	1.053	$1.23^{+0.59}_{-0.46} \pm 0.17$ (< 2.45)	(< 0.60)	$33.4 \pm 7.8 \pm 4.6$	$0.39^{+0.21}_{-0.17}$
4.600	567	$1.9^{+1.8}_{-1.1}$ (< 5.2)	0.157	1.075	1.055	$0.47^{+0.44}_{-0.27} \pm 0.07$ (< 1.48)	-	$10.4^{+6.4}_{-4.7} \pm 1.5$	-

Good candidate for $\psi(1^3D_2)$





1. Assume $\pi\pi$ system is dominant by $f_0(500)$
2. Scattering angle distribution of $\psi(2S)$ and X(3823) in e^+e^- CM frame.
3. Kolmogorov-Smirnov test p-value is given.
4. (Left) $\pi^+\pi^-\psi(2S)$: S-wave (p=0.791), D-wave (p=0.451)→S-wave seems to be better.
5. (right) $\pi^+\pi^-X(3823)$: S (p=0.928), D (p=0.978)→Can't distinguish

Good candidate for $\psi(1^3D_2)$

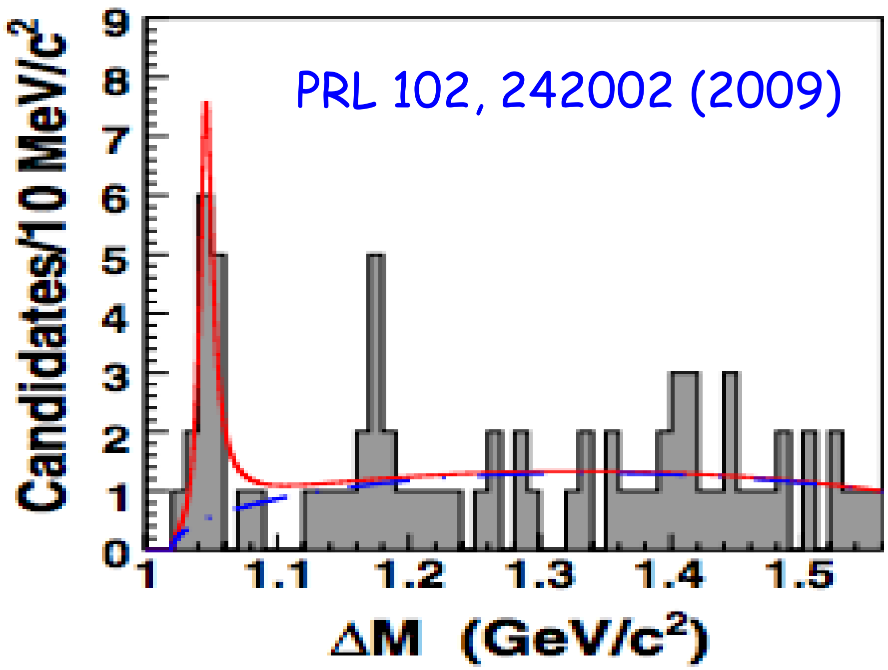
- Mass: D-wave ~3.810-3.840 GeV by potential model.
- X(3823) mass agree with $\psi(1^3D_2)$ prediction.

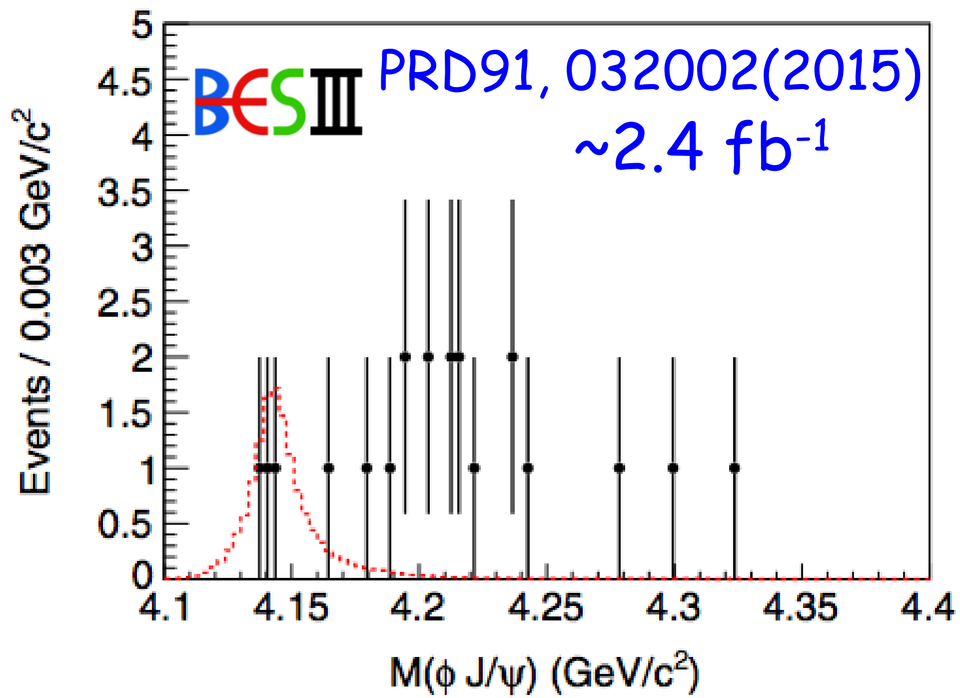
- Width: narrow
- X(3823) should be narrow (<16 MeV @ 90% C.L.).

- 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.

Search X(4140)→$\phi J/\psi$

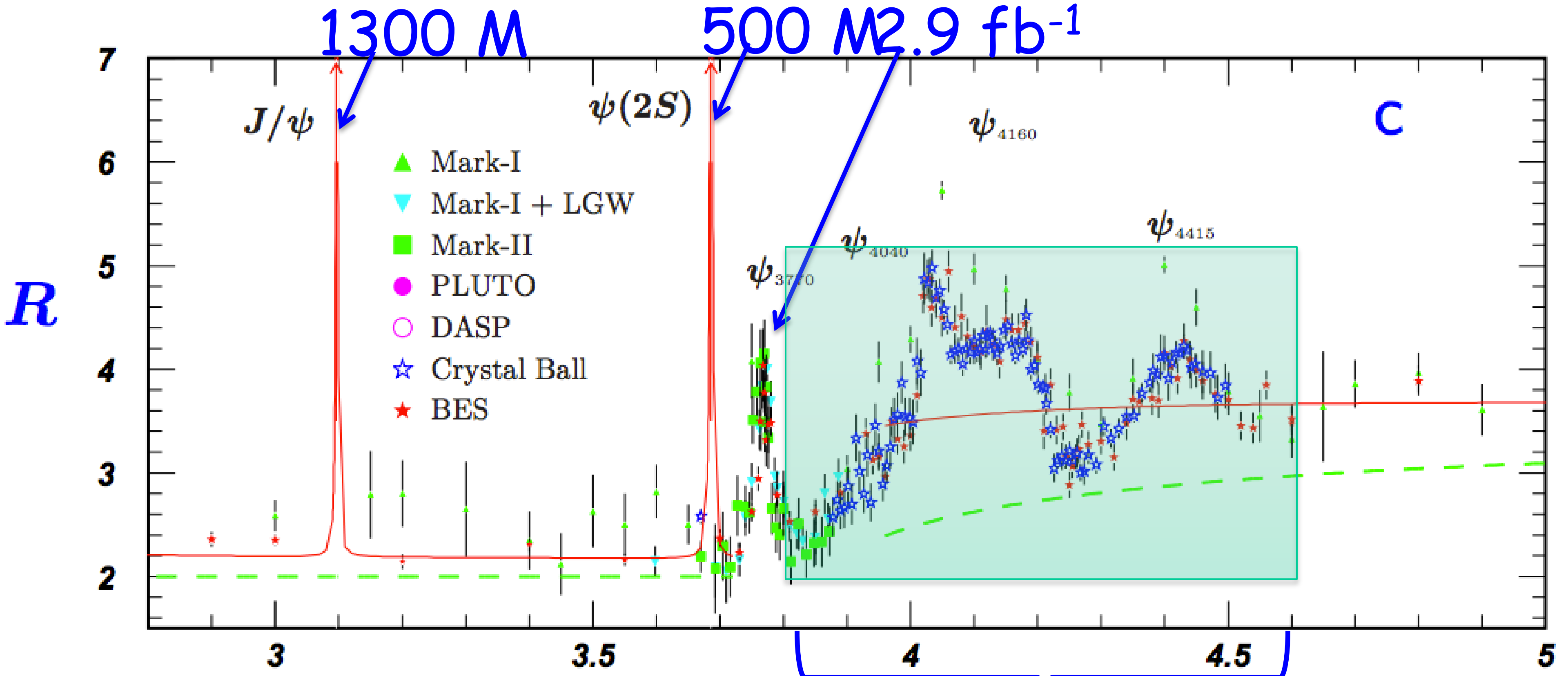




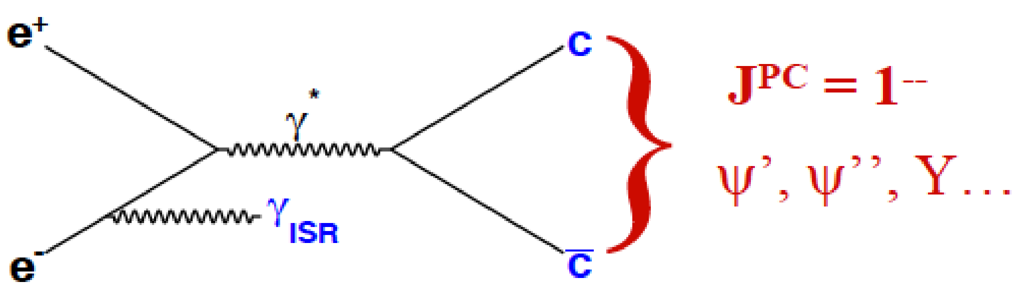
- The X(4140) was reported by CDF with Mass=(4143.0$\pm$2.9$\pm$1.2) MeV and Width=$11.7^{+8.3}_{-5.0}\pm3.7$ MeV
- Controversial: CMS (Yes), Belle (No), LHCb (No), BaBar (no)
- BESIII: different process $e^+e^-\to\gamma\phi J/\psi$
- No signal, cross section γX(4140)/γX(3872)<10%.

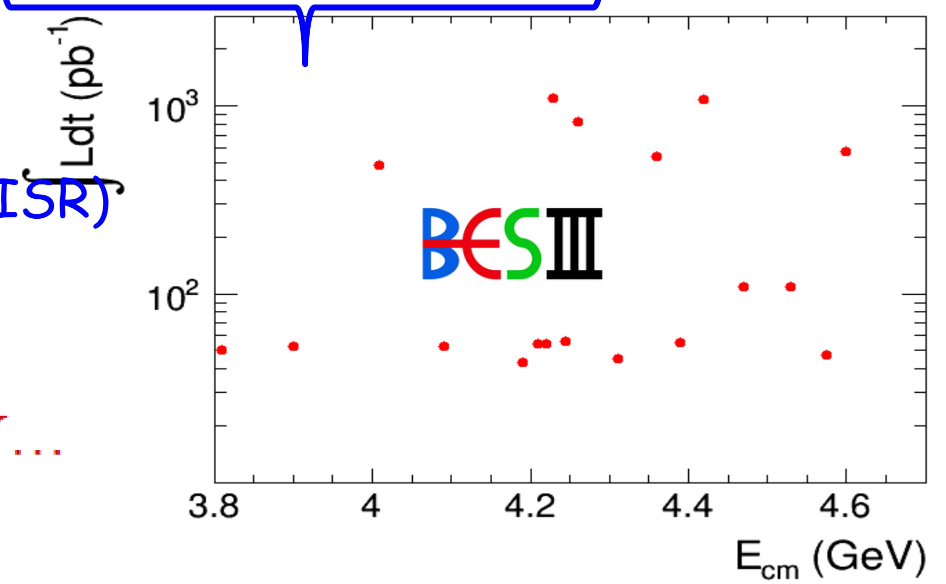
The Y states

(vectors)



BaBar+Belle: Initial-State-Radiation (ISR)

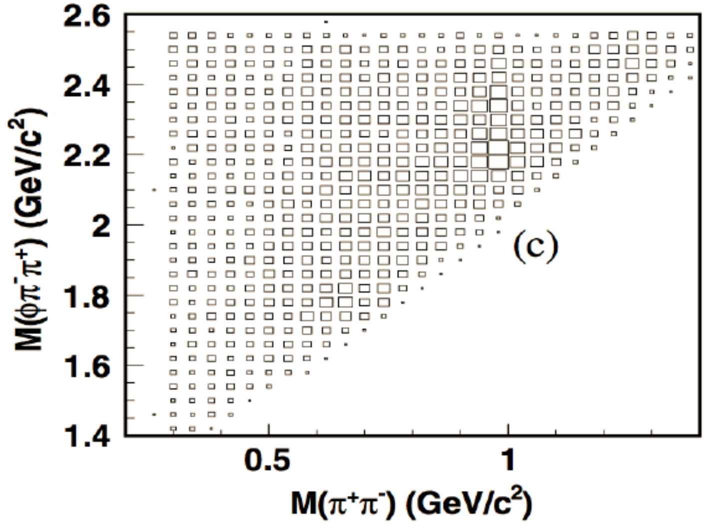




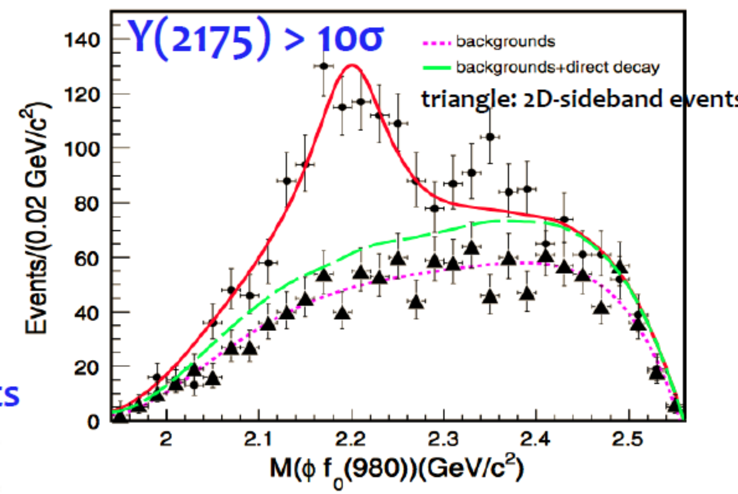
Study of $J/\psi \to \eta\phi\pi^+\pi^-$

PRD 91,052017 (2015)

based on 0.225 billion J/ψ events



- Y(2175) was observed by BABAR, then confirmed by BESII, BELLE and BABAR;
- Different interpretations have been proposed:
  - $s\bar{s}$-gluon hybrid? excited ϕ state?
  - tetraquark state? $\Lambda\bar{\Lambda}$ bound state?
  - an ordinary $\phi f_0(980)$ resonance produced by FSI?
- Confirmation and study of the Y(2175) with a large data sample is necessary for clarifying its nature.



Product branching fraction of

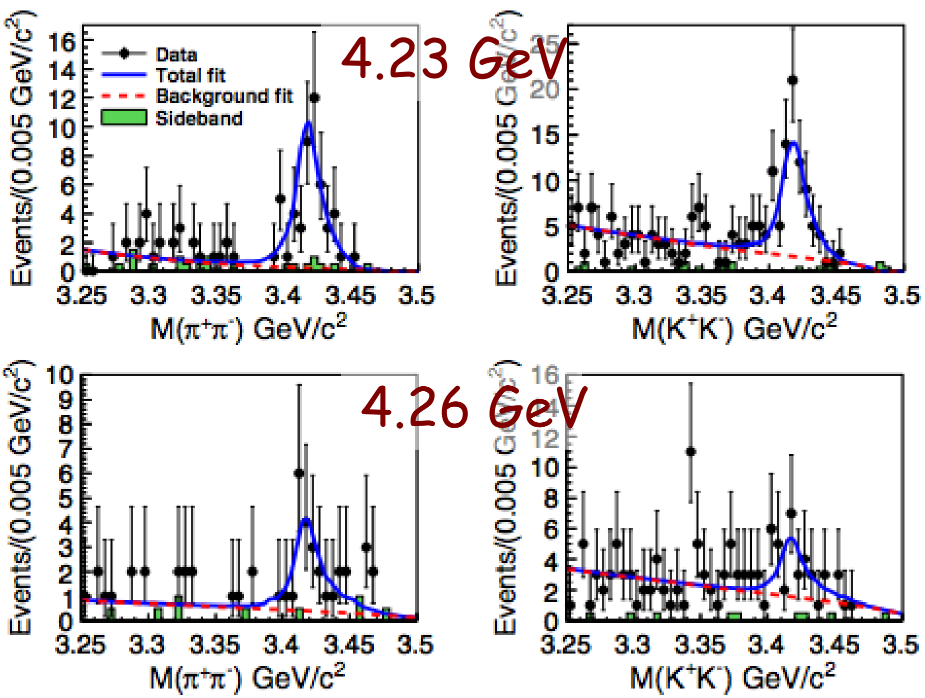
$J/\psi \to \eta Y(2175)$, $Y(2175) \to \phi f_0(980)$, $f_0(980) \to \pi\pi$ is measured to be: $(1.20 \pm 0.14 \pm 0.37) \times 10^{-4}$

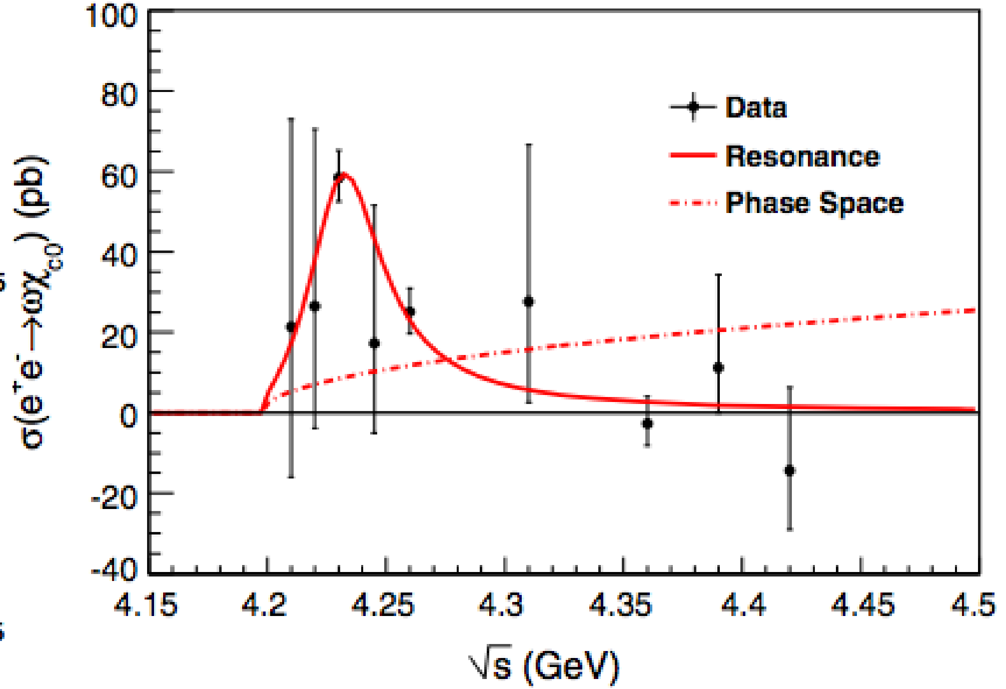
Mass and width are in agreement with previous measurements

Collaboration	Process	M (MeV/c^2)	Γ (MeV)
BABAR [2]	$e^+e^- \to \phi f_0$ (ISR)	$2175 \pm 10 \pm 15$	$58 \pm 16 \pm 20$
BESII [3]	$J/\psi \to \eta\phi f_0(980)$	$2186 \pm 10 \pm 6$	$65 \pm 23 \pm 17$
BELLE [4]	$e^+e^- \to \phi f_0$ (ISR)	$2079 \pm 13^{+79}_{-28}$	$192 \pm 23^{+25}_{-61}$
BABAR (updated) [5]	$e^+e^- \to \phi f_0$ (ISR)	$2172 \pm 10 \pm 8$	$96 \pm 19 \pm 12$
BESIII	$J/\psi \to \eta\phi f_0(980)$	$2200 \pm 6 \pm 5$	$104 \pm 15 \pm 15$

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

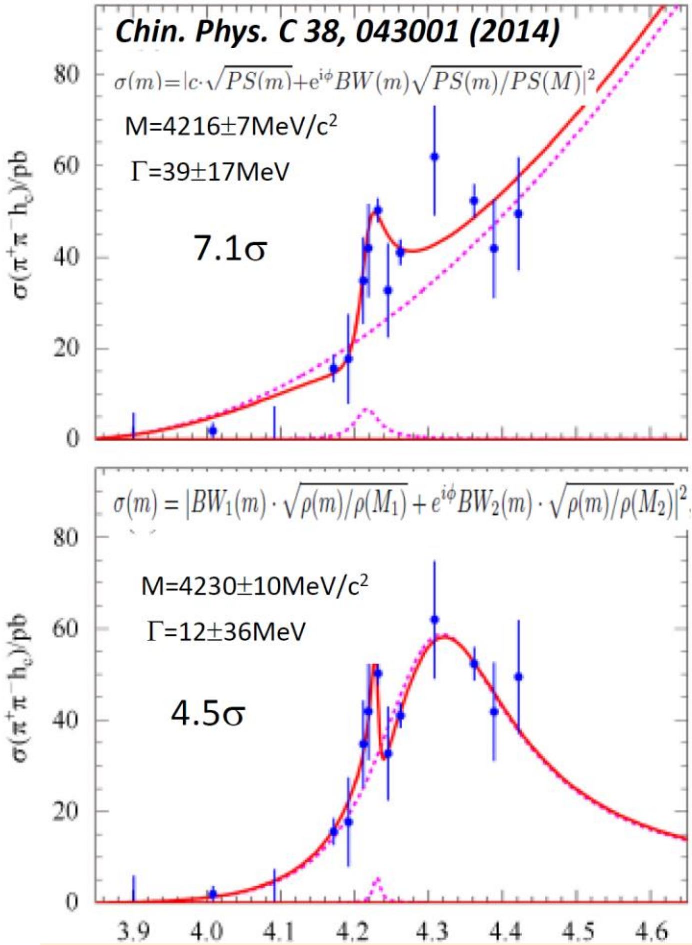
PRL114, 092003 (2015)



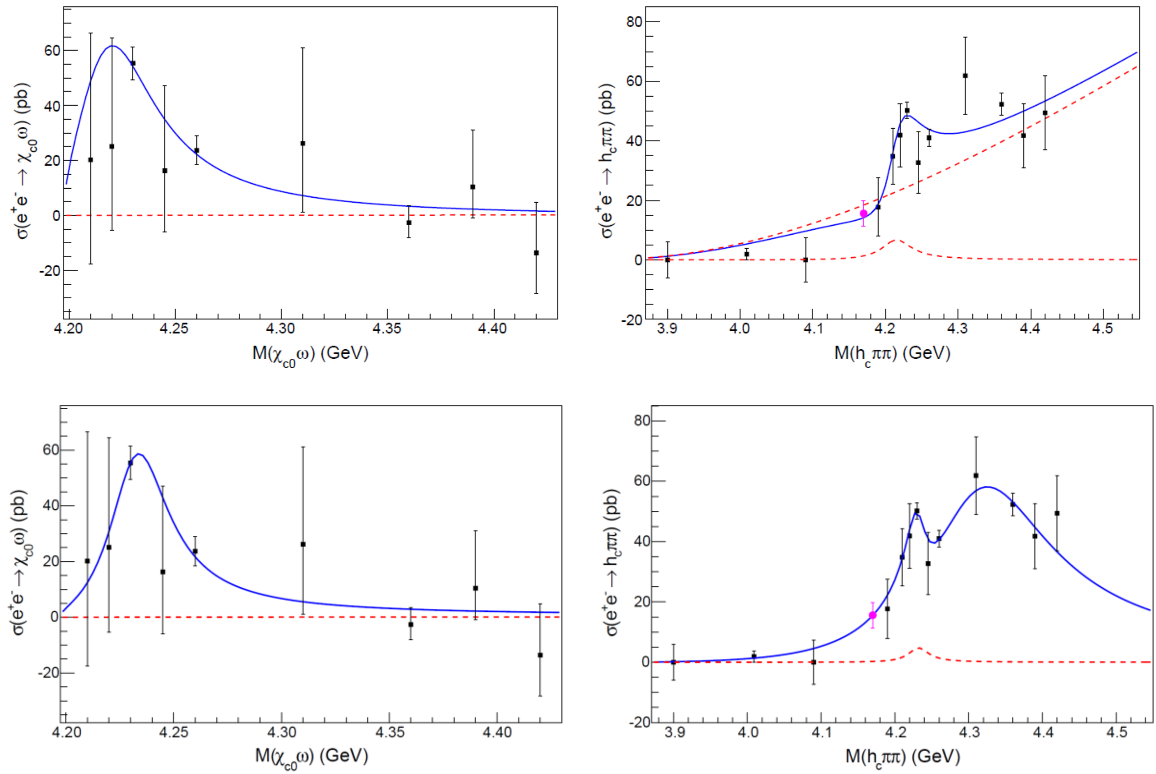


- Using scan data over 4.21 and 4.42 GeV, e+e-→$\omega\chi_{c0}$ are significant @ E_{cm}=4.23 & 4.26 GeV.
- Cross section peak near 4.23 GeV, fit with BW yields Mass=(4230±8±6) MeV, Width=(38±12±2) MeV.
- A new structure? Tetraquark [PRD 91, 117501 (2015)]? Threshold effect?

Fits to $e^+e^- \to \pi^+\pi^- h_c$ and $\omega\chi_{c0}$



PRD91, 117501(2015)



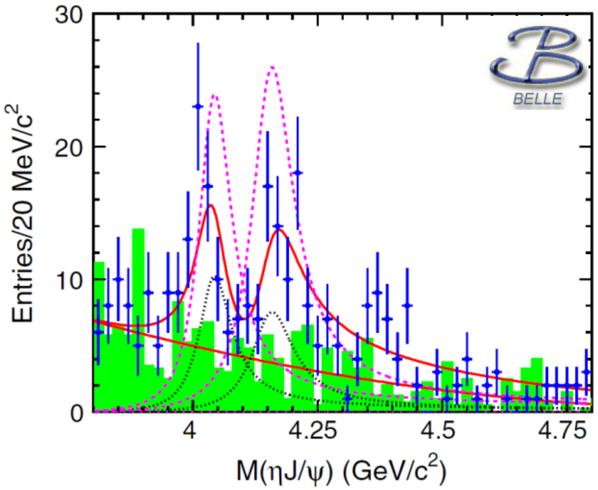
A tetraquark? (arXiv: 1412.7196)
ψ(4S)? (arXiv: 1405.3831)
Threshold effect? …

- Fit with two different scenarios：
  - Three body PHSP + a narrow resonance
  - Two resonances

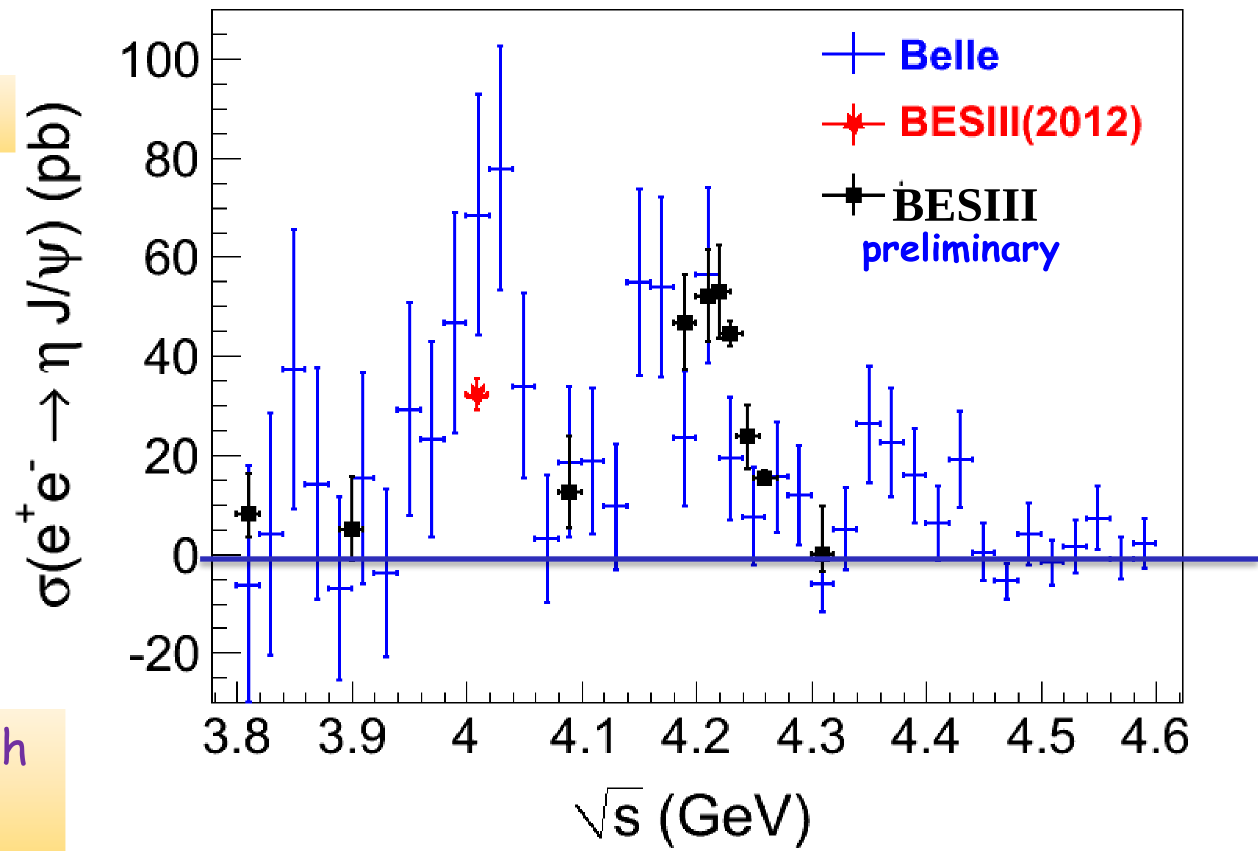
Very likely a narrow structure around 4.23GeV

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

PRD87,051101(R),2013

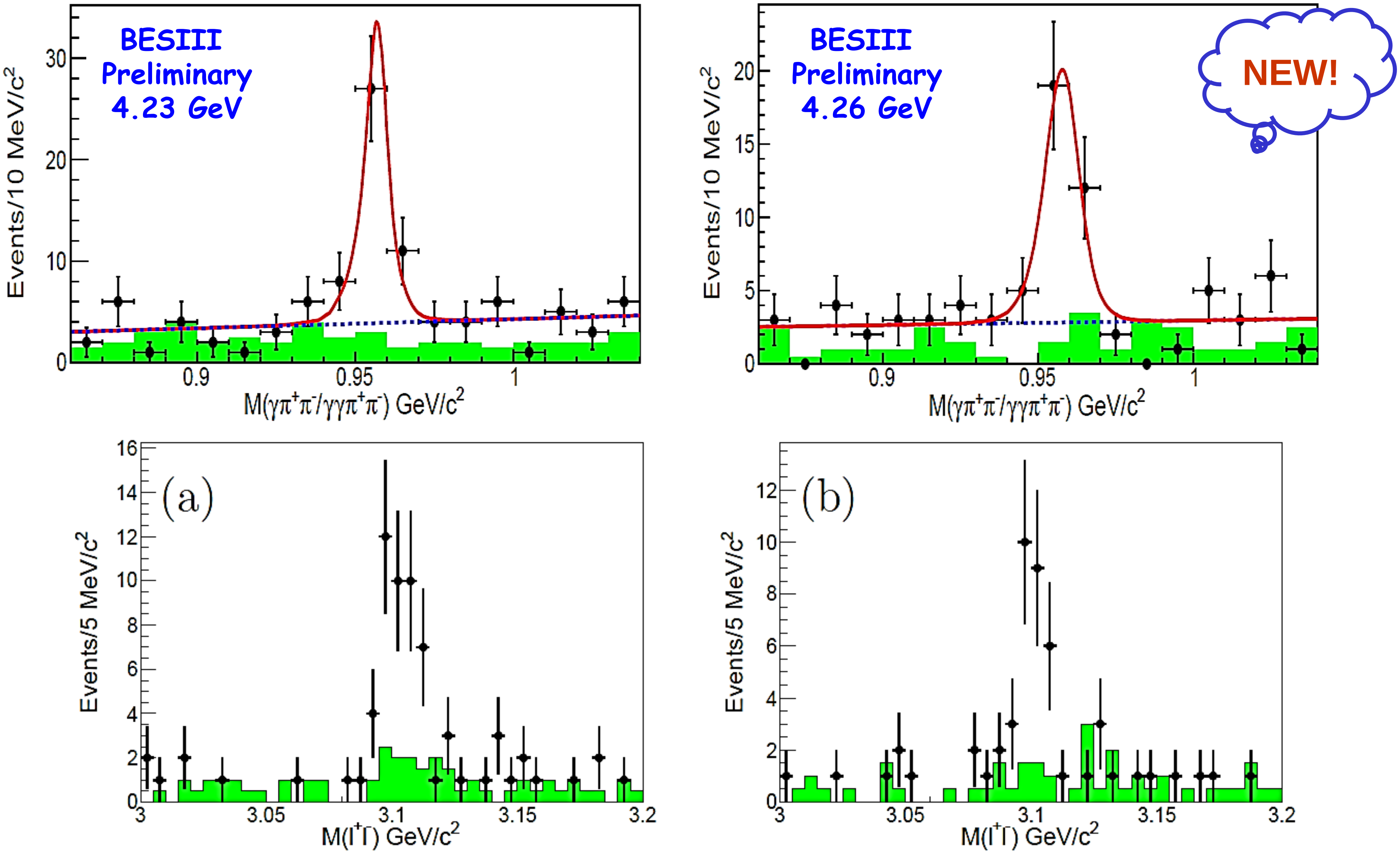


Ψ(4040) and Ψ(4160) with interference

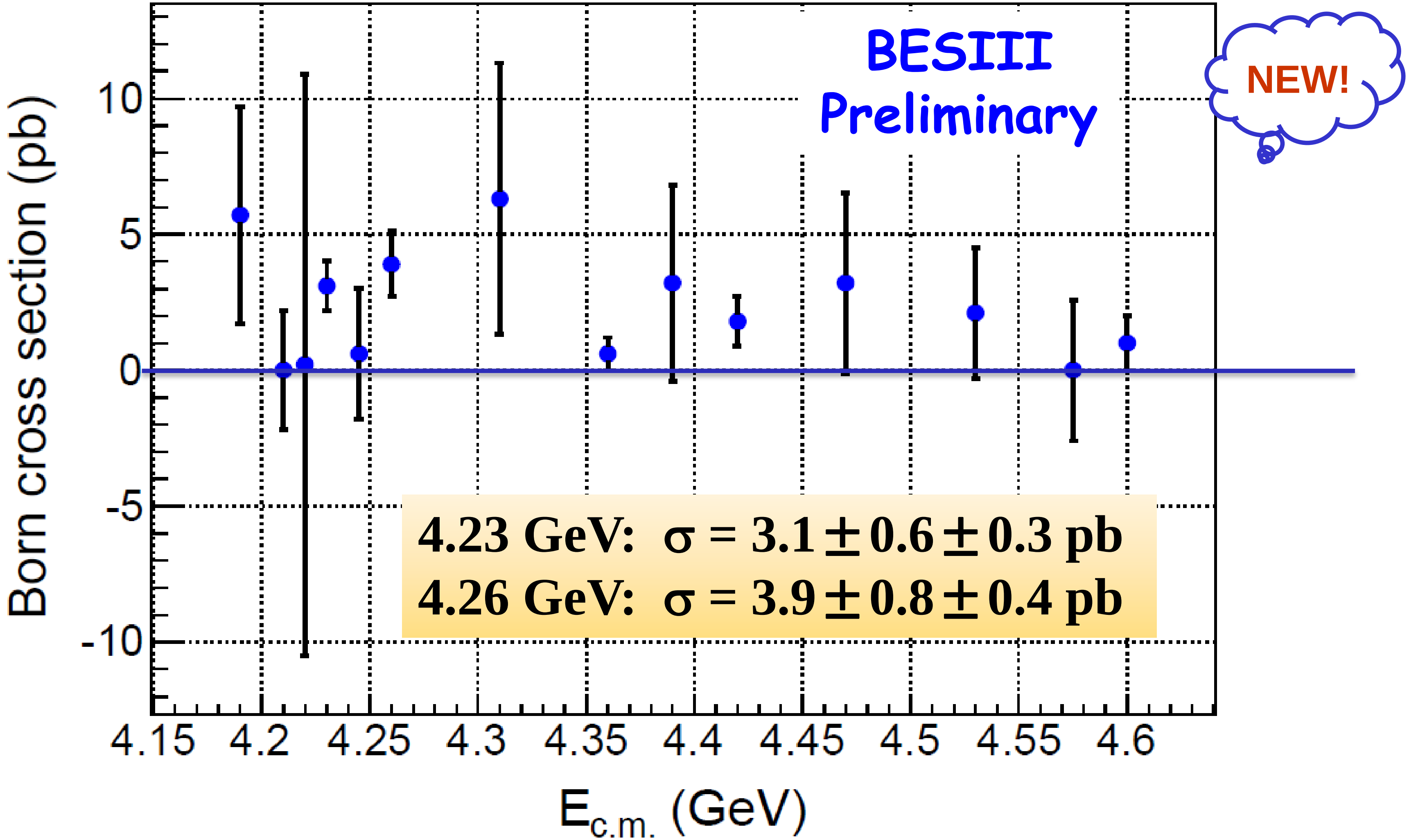


- Agree with previous results with improved precision
- The cross section peaks around 4.2 GeV
- Analysis of high energy points underway at BESIII

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



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

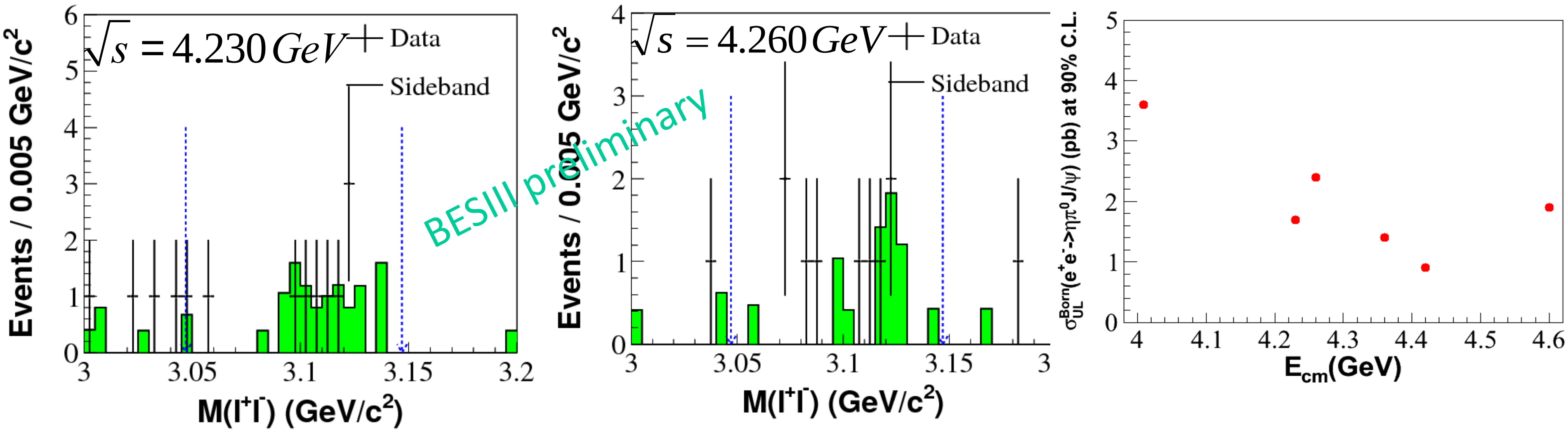


4.23 GeV: $\sigma = 3.1 \pm 0.6 \pm 0.3$ pb

4.26 GeV: $\sigma = 3.9 \pm 0.8 \pm 0.4$ pb

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

Isospin violation Y(4260)→$\pi^0\eta J/\psi$

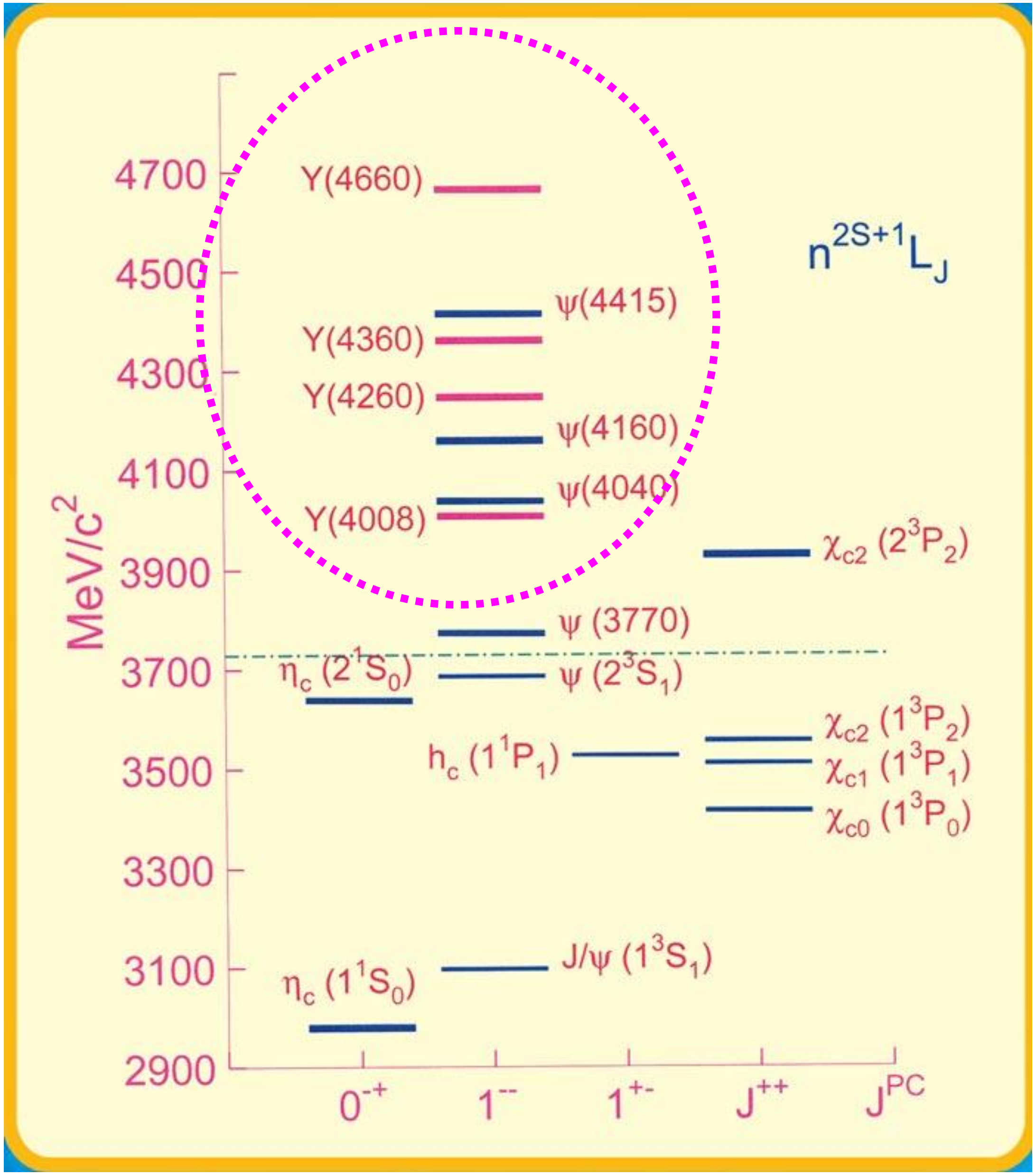


No significant signal observed with current BESIII data !
Can not provide effective constraint to models…

$\sqrt{s}$ (GeV)	$\mathcal{L}$ (pb^{-1})	$(1+\delta^r)$	$(1+\delta^v)$	$(\epsilon^{ee}Br^{ee}+\epsilon^{\mu\mu}Br^{\mu\mu})$ (%)	N^{obs}	N^{bkg}	N^{up}	σ^{Born}_{UL} (pb)
4.009	482	0.838	1.044	$2.1\pm0.1(sys.)$	5	1	598.1	3.6
4.230	1007	0.844	1.056	$2.2\pm0.1(sys.)$	12	11	592.9	1.7
4.260	804	0.847	1.054	$2.2\pm0.1(sys.)$	12	8	654.1	2.4
4.360	523	0.942	1.051	$2.2\pm0.1(sys.)$	5	4	283.2	1.4
4.420	1023	0.951	1.053	$2.3\pm0.1(sys.)$	5	6	342.7	0.9
4.600	567	0.965	1.055	$2.4\pm0.1(sys.)$	6	3	418.4	1.9

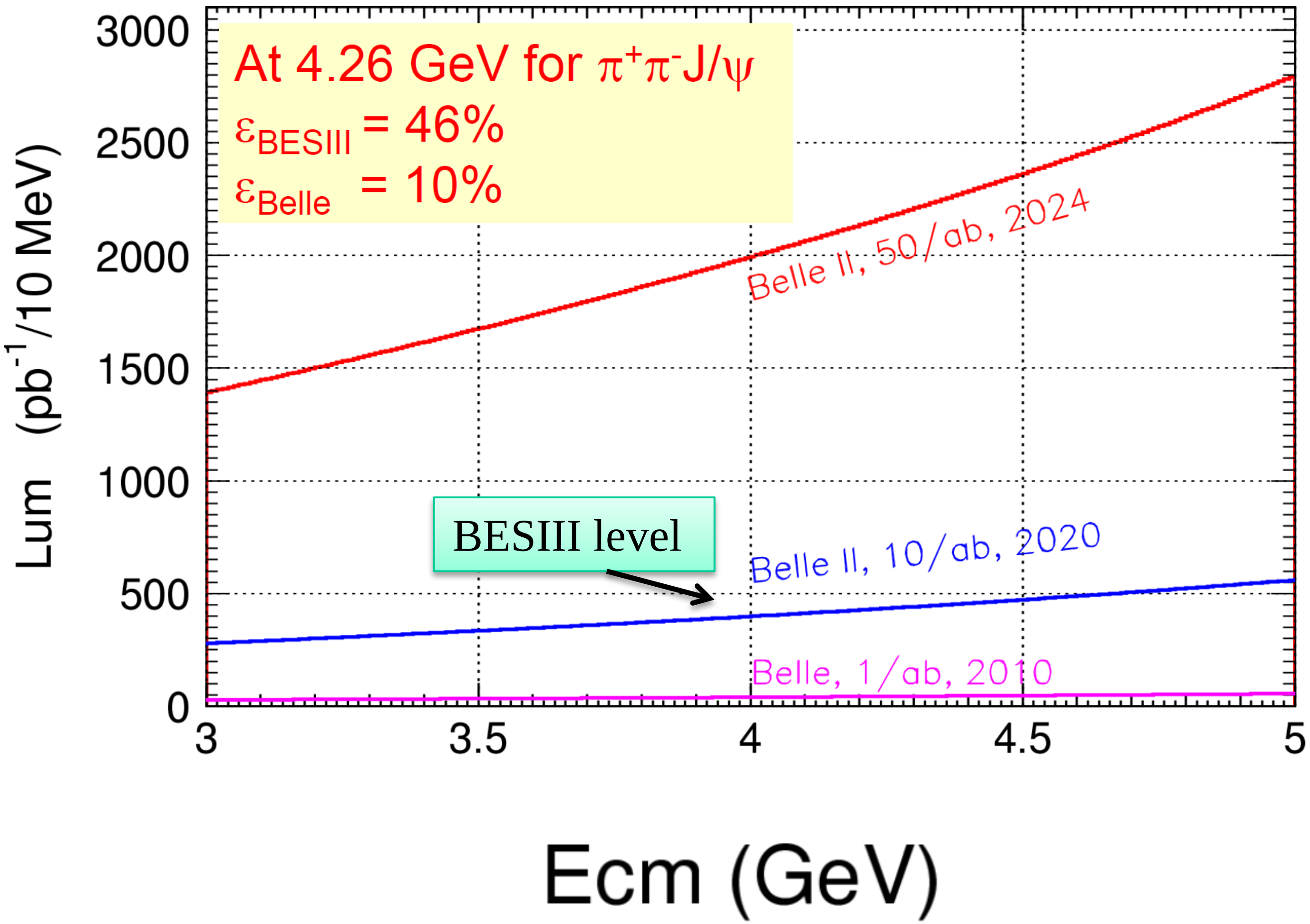
BESIII preliminary

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

BelleII is very promising with ISR method



The Z_c states

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

BESIII: PRL 110, 252001 (2013)

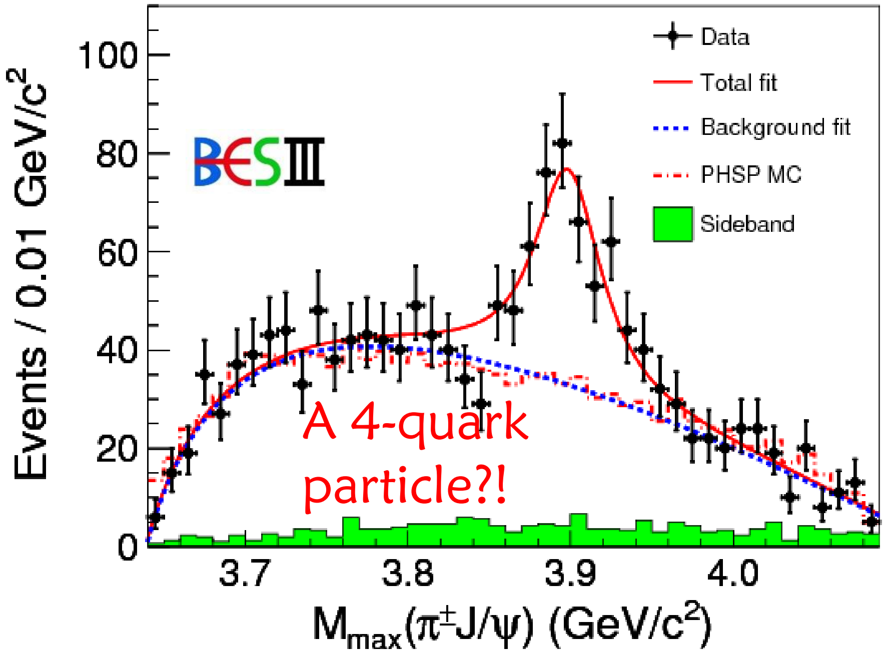
$Z_c(3900)^+$:

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

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

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

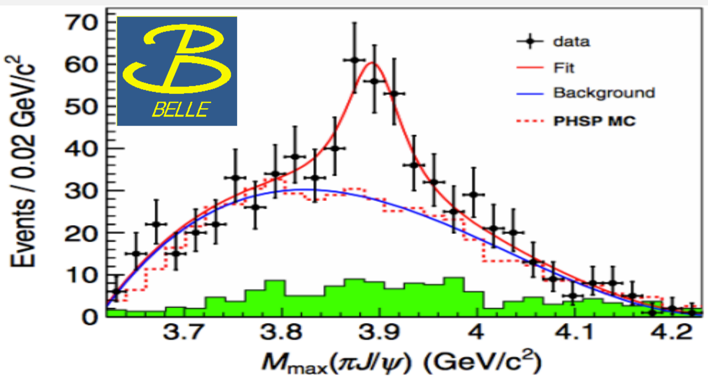
Decays to J/ψ → contains $c\bar{c}$
Electric charge → contains $u\bar{d}$



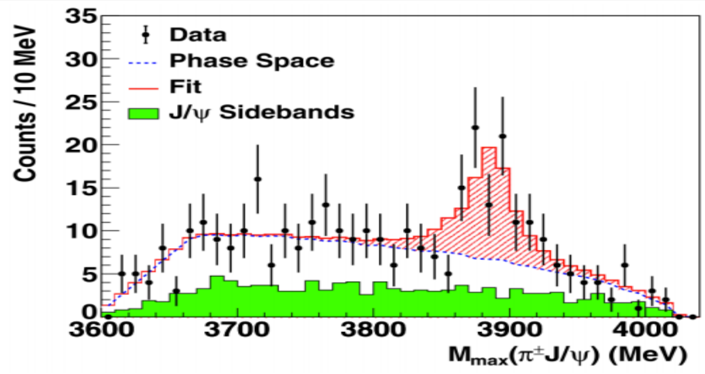
$$\sigma[e^+e^- \to \pi^+\pi^- J/\psi] = 62.9 \pm 1.9 \pm 3.7\ \text{pb at 4.26 GeV}$$

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

Belle with ISR data (PRL 110, 252002)

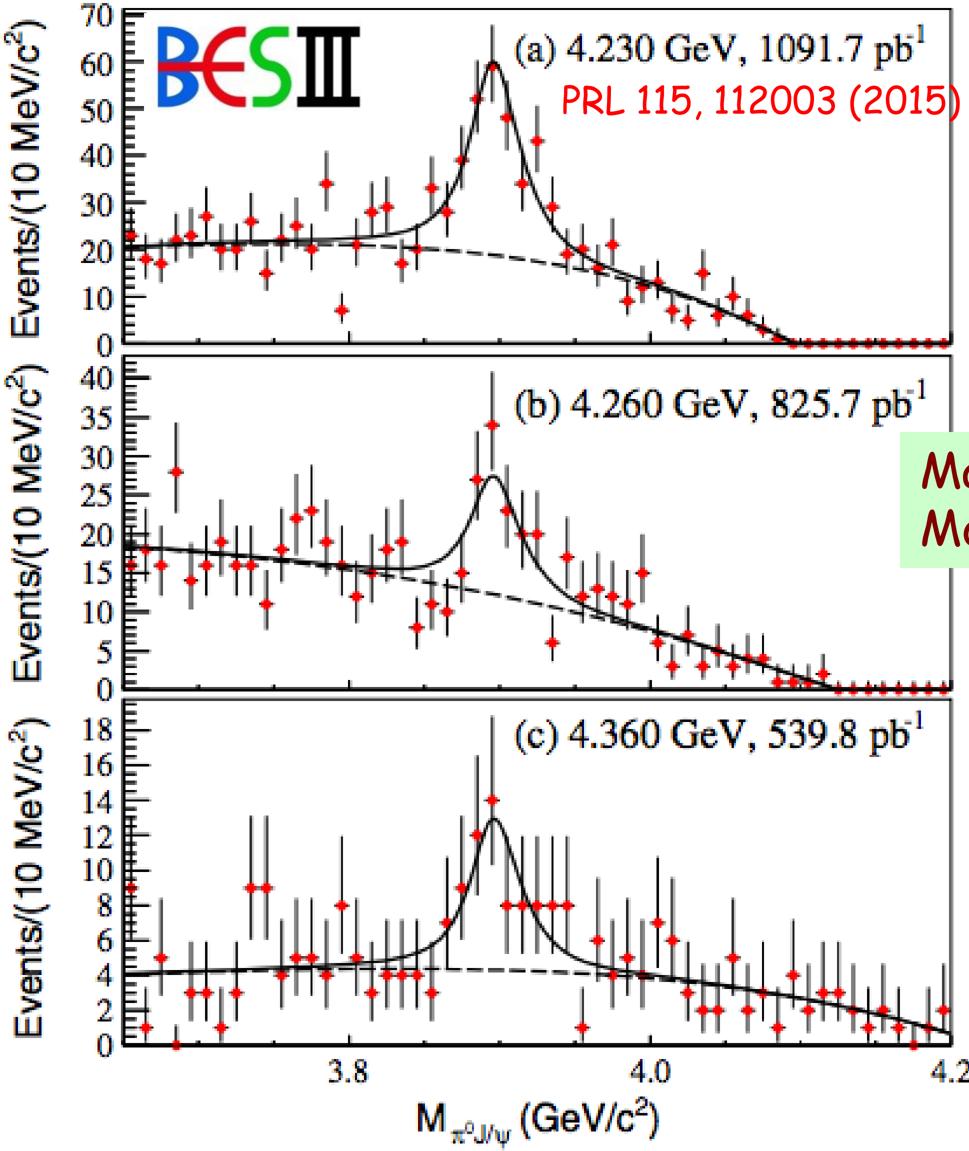


CLE0c data at 4.17 GeV (PLB 727, 366)



Neutral isospin partner: $Z_c(3900)^0$

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



A neutral structure on $\pi^0 J/\psi$ invariant mass is observed !

An iso-spin triplet is established !

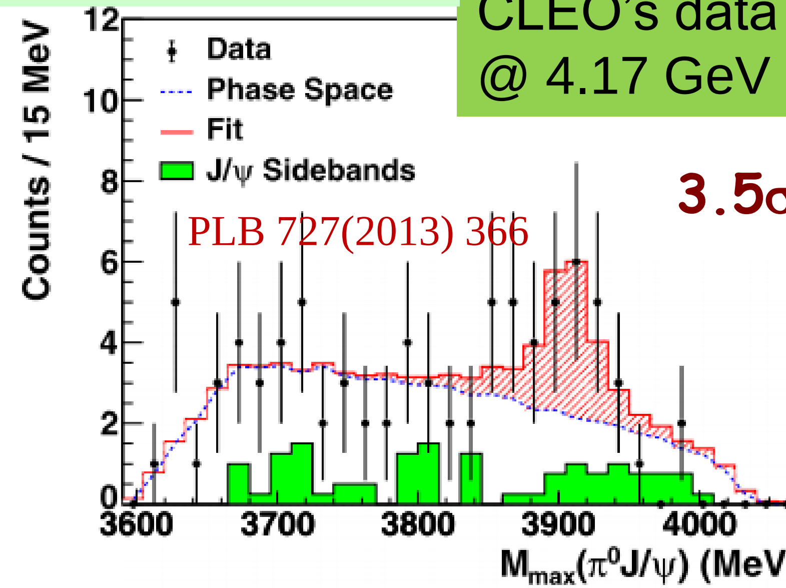
$M = 3894.8 \pm 2.3 \pm 3.2$ MeV

$\Gamma = 29.6 \pm 8.2 \pm 8.2$ MeV

Significance = 10.4σ

Mass near DD* threshold
Molecules? Tetraquark?

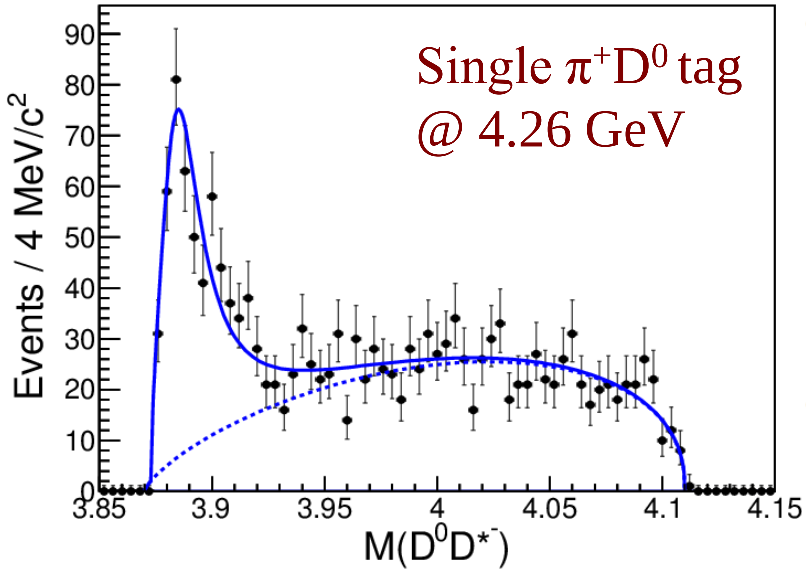
CLEO's data
@ 4.17 GeV

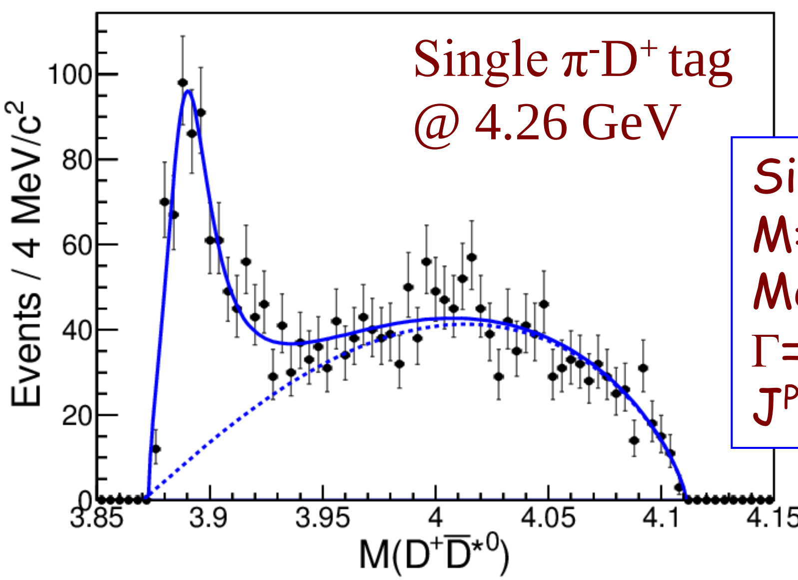


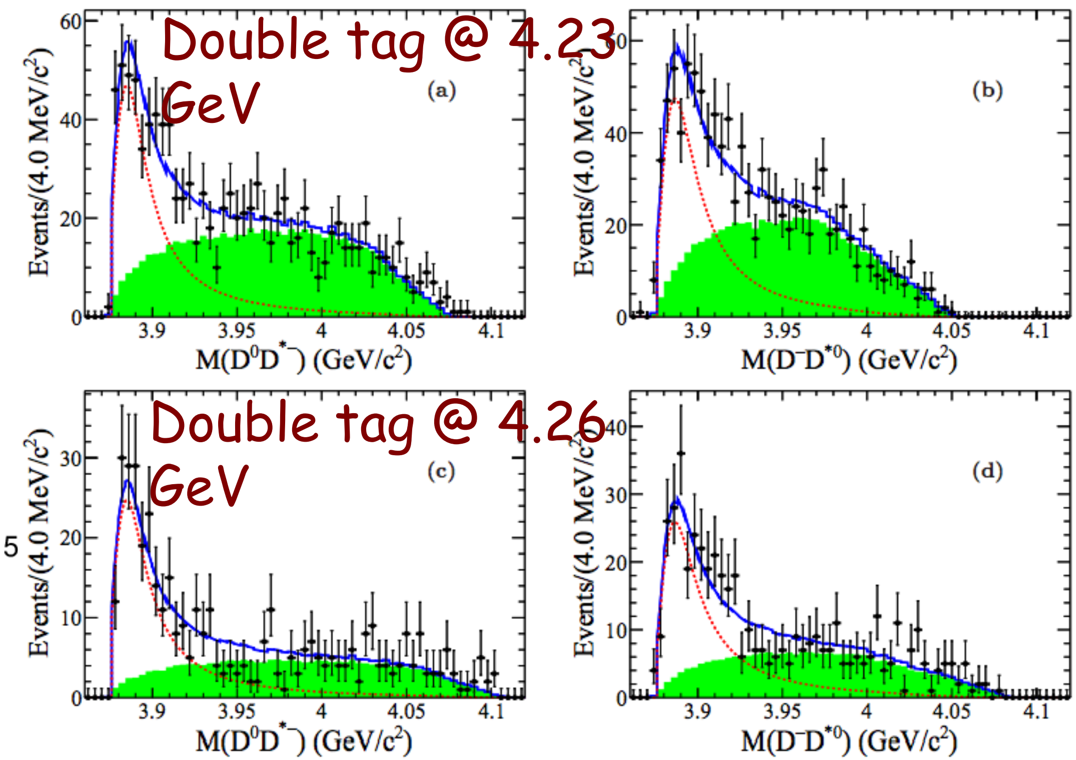
$e^+e^- \rightarrow (DD^*)^+\pi^- + c.c.$?

BESIII PRL 112, 022001 (2014)

arXiv: 1509.01398





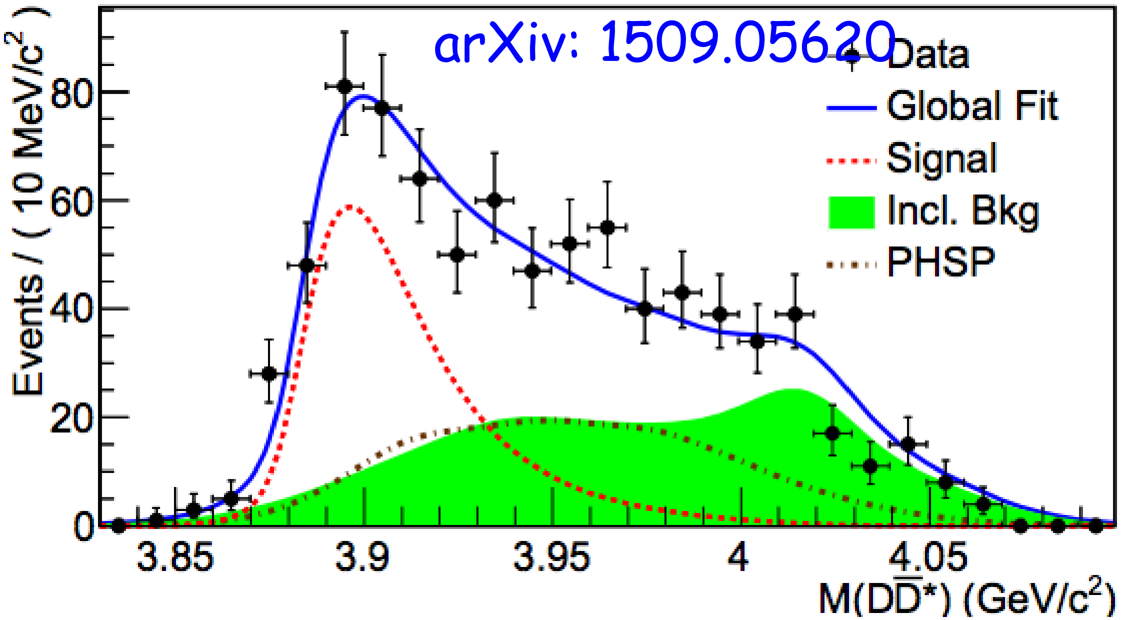


Single tag
$M=3883.9\pm1.5\pm4.2$ MeV
$\Gamma=24.8\pm3.3\pm11.0$ MeV
$J^P=1^+$

Double tag
$M=3881.7\pm1.6\pm2.1$ MeV
$\Gamma=26.6\pm2.0\pm2.3$ MeV
$J^P=1^+$

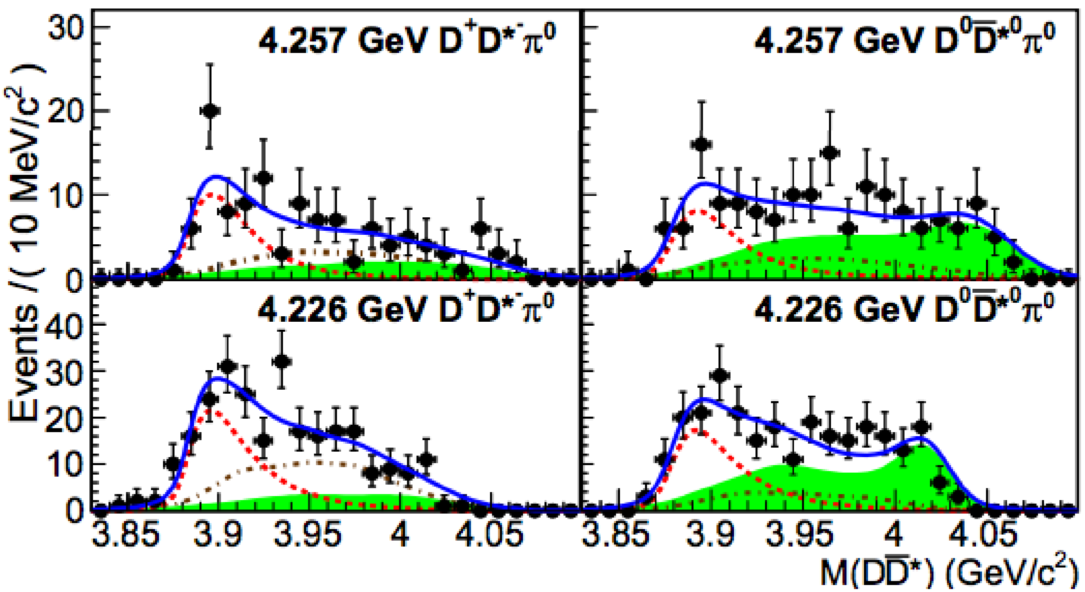
Good agreement between ST & DT method
$Z_c(3900)$ vs. $Z_c(3885)$ → Same resonance ?!

Neutral iso-spin $e^+e^- \rightarrow (DD^*)^0\pi^0$+c.c.



Partial reconstruction method - Single tag

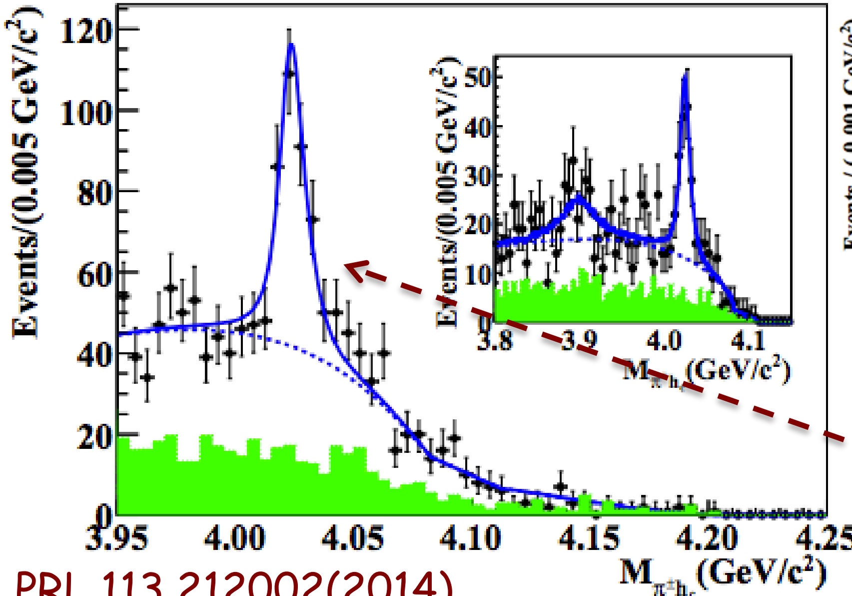
$M=3885.7^{+4.3}_{-5.7}\pm 8.4$ MeV
$\Gamma=35^{+11}_{-12}\pm 15$ MeV
Significance: >10σ

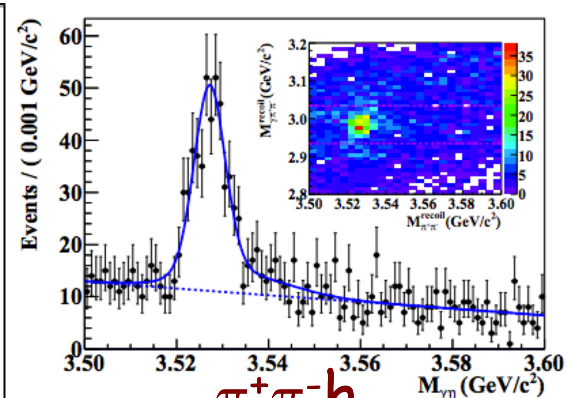


- Good agreement between neutral state and charged state
- An iso-spin triplet established in DD* channel
- Might be same as $Z_c(3900)$
- Molecule state? Tetraquark?

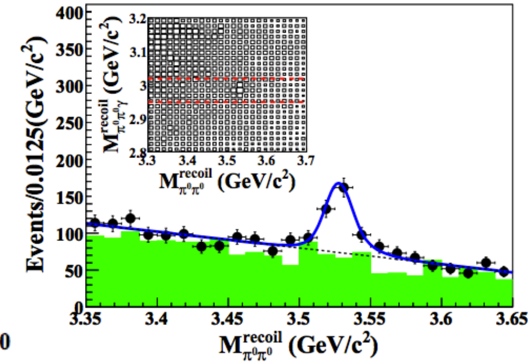
$e^+e^- \rightarrow \pi^+\pi^- h_c$ & $\pi^0\pi^0 h_c$

PRL111,242001(2013)



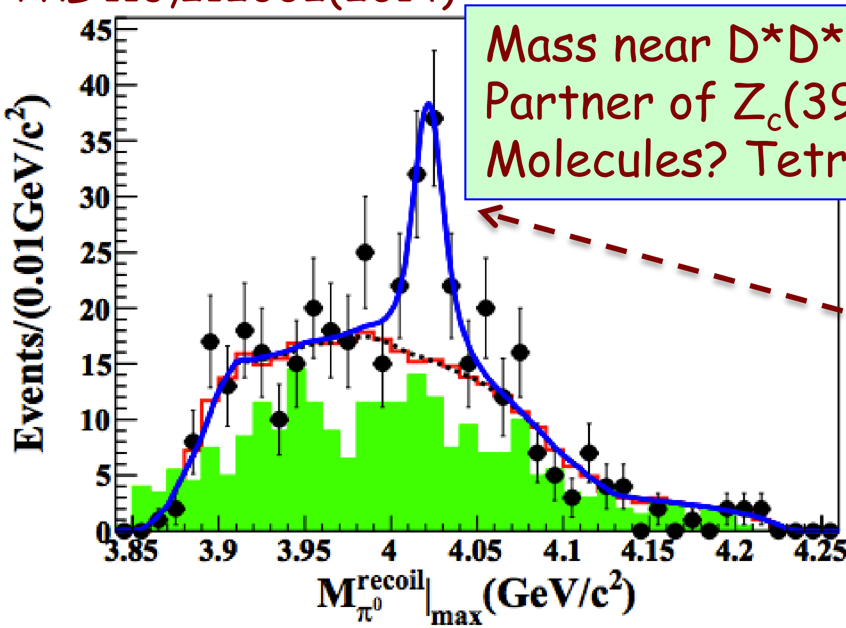


$\pi^+\pi^- h_c$



$\pi^0\pi^0 h_c$

PRL 113,212002(2014)



Mass near D*D* threshold
Partner of $Z_c(3900)$?
Molecules? Tetraquark?

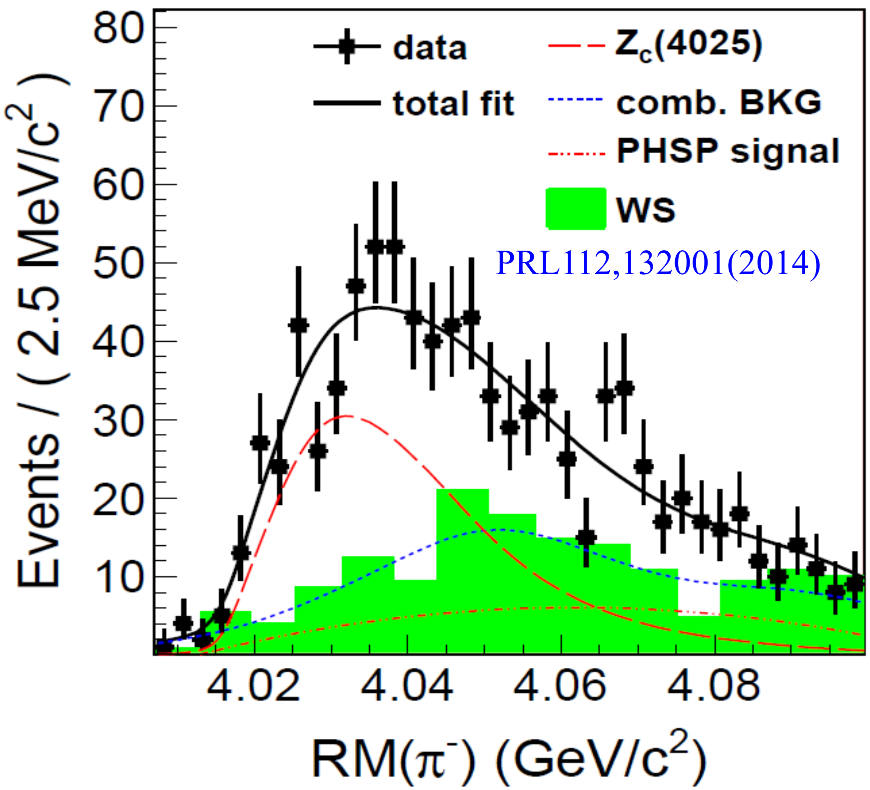
Charged $Z_c(4020)^\pm$
Mass=(4022.9±0.8±2.7) MeV
Width=(7.9±2.7±2.6) MeV
Significance: >8.9σ

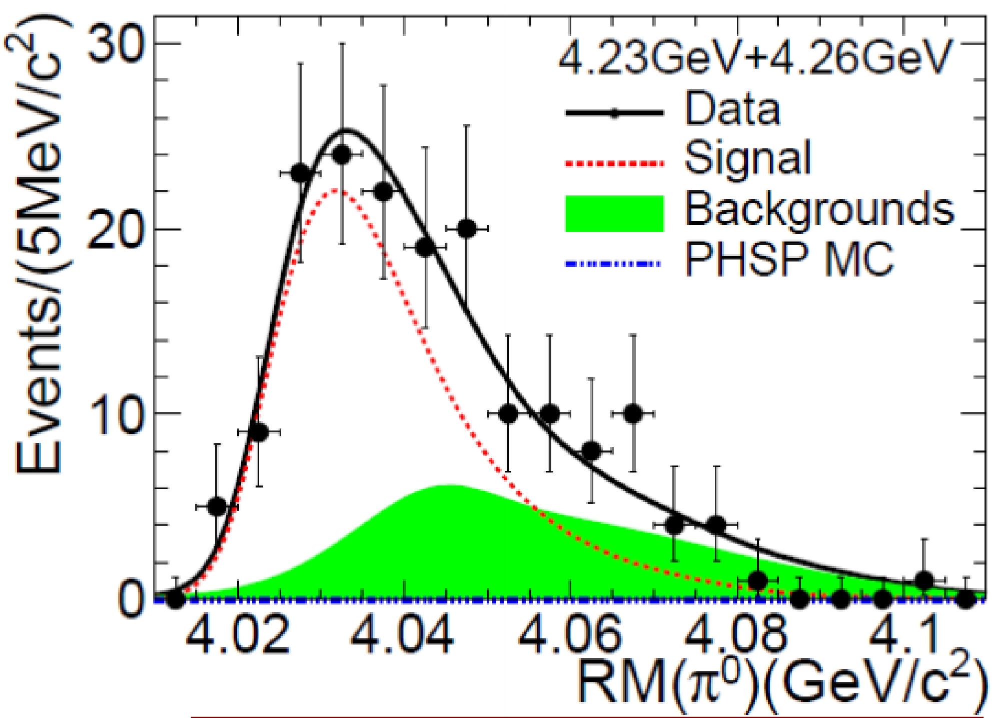
Neutral $Z_c(4020)^0$
Mass=(4023.9±2.2±3.8) MeV
Width: fixed to charged partner
Significance: 5σ

An spin triplet is established !

$e^+e^- \to \pi^-(D^*D^*)^+/\pi^0(D^*D^*)^0$+c.c.

arXiv: 1507.02404





Charged $Z_c(4025)$:
M=(4026.3±2.6±3.7) MeV
Γ=(24.8±5.6±7.7) MeV
Significance: >10σ

Agrees !

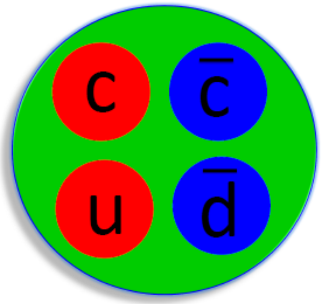
Neutral $Z_c(4025)^0$:
M=($4025.5^{+2.0}_{-4.7}$±3.1) MeV
Γ=(23.0±6.0±1.0) MeV
Significance: >5.9σ

New isospin triplet?

$Z_c(4025)$ and $Z_c(4020)$ have similar mass, but different width.

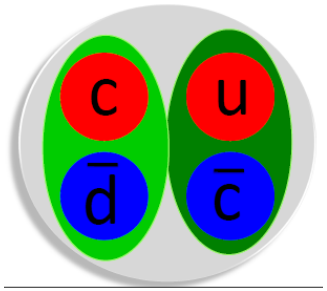
What's the nature of these Z states?

- At least 4 quarks, not a conventional meson
- 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?
- …

We found more questions to answer

- In the X sector
  - Where the X(3872) & X(3823) come from? Resonance decays or continuum production?
  - May other X states be produced and where?
- In the Y/ψ sector
  - Is the Y(4260) a single resonance? Is Y(4008) a real structure?
  - Does the Y(4360) decay only to $\pi\pi\psi'$? Not to $\eta J/\psi$?
  - What is hidden behind $\pi\pi h_c$? Large coupling to spin-singlet, is a hybrid state observed?
  - Correlation between charm production & charmonium transitions?
  - May we observe the charmonium 3^3D_1 state at ~4.5 GeV?
- In the Z sector
  - Are the Z_c and Z_c' from resonance decays or continuum prod.?
  - Are there excited Z_c states and Z_{cs} states [D^*D_s or DD_s^*]?
- In the C sector
  - Charm spectroscopy: D^*, D_0, D_1, D_2, D_{s0}, D_{s1}, D_{s2}, ...
  - Charm decays: D_s and Λ_c samples are too small …

Summary

- BESIII produces significant XYZ results…
- X & Y states are difficult to distinguish from normal meson, charged Z_c states provide solid evidence.
- Quark composition is still puzzling.
- More results are coming, we would finally understand them.

Thank you (谢谢)!