发现 $Z_c(3900)$

-- BESIII实验最新进展 --

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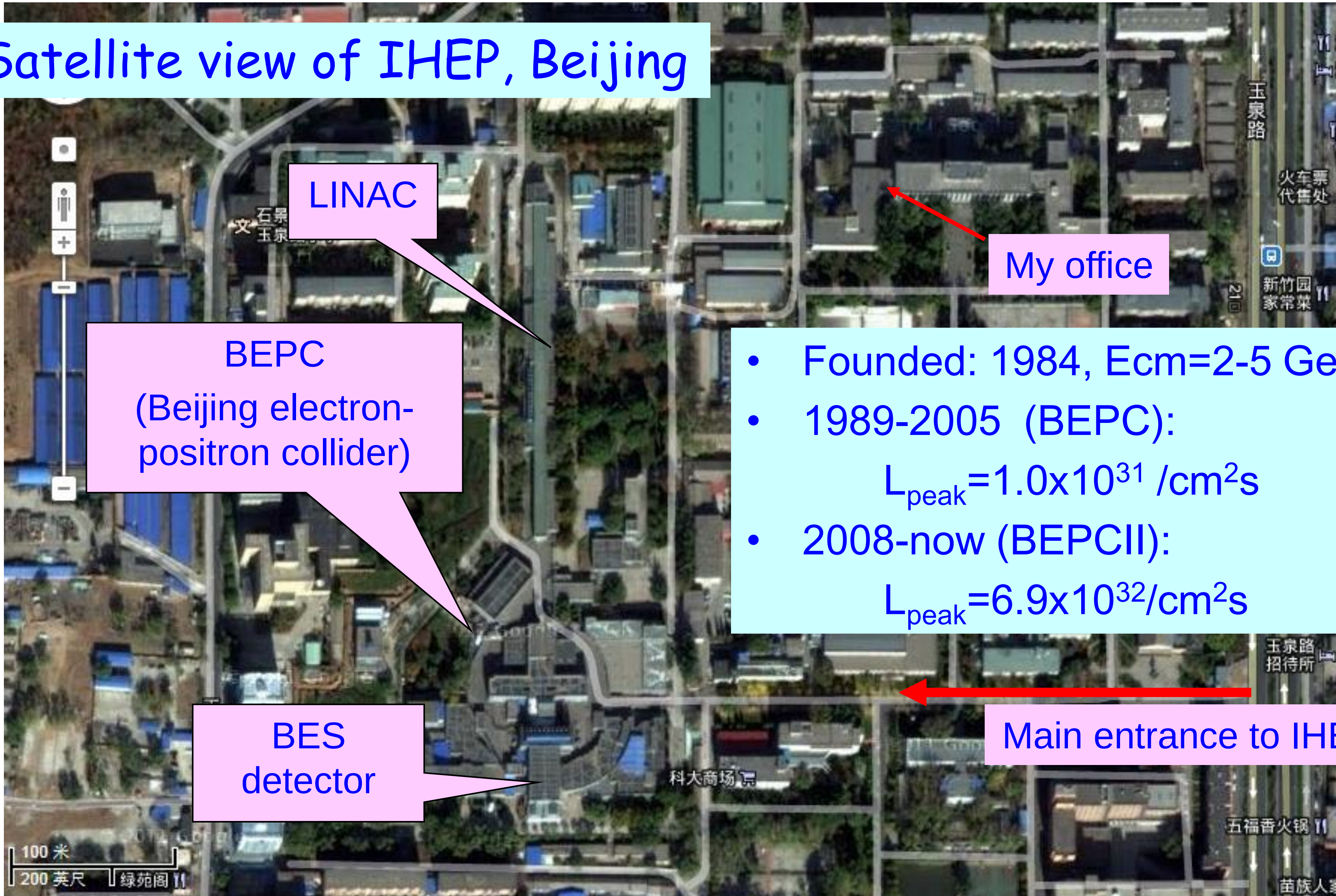
2013年5月16日

Outline

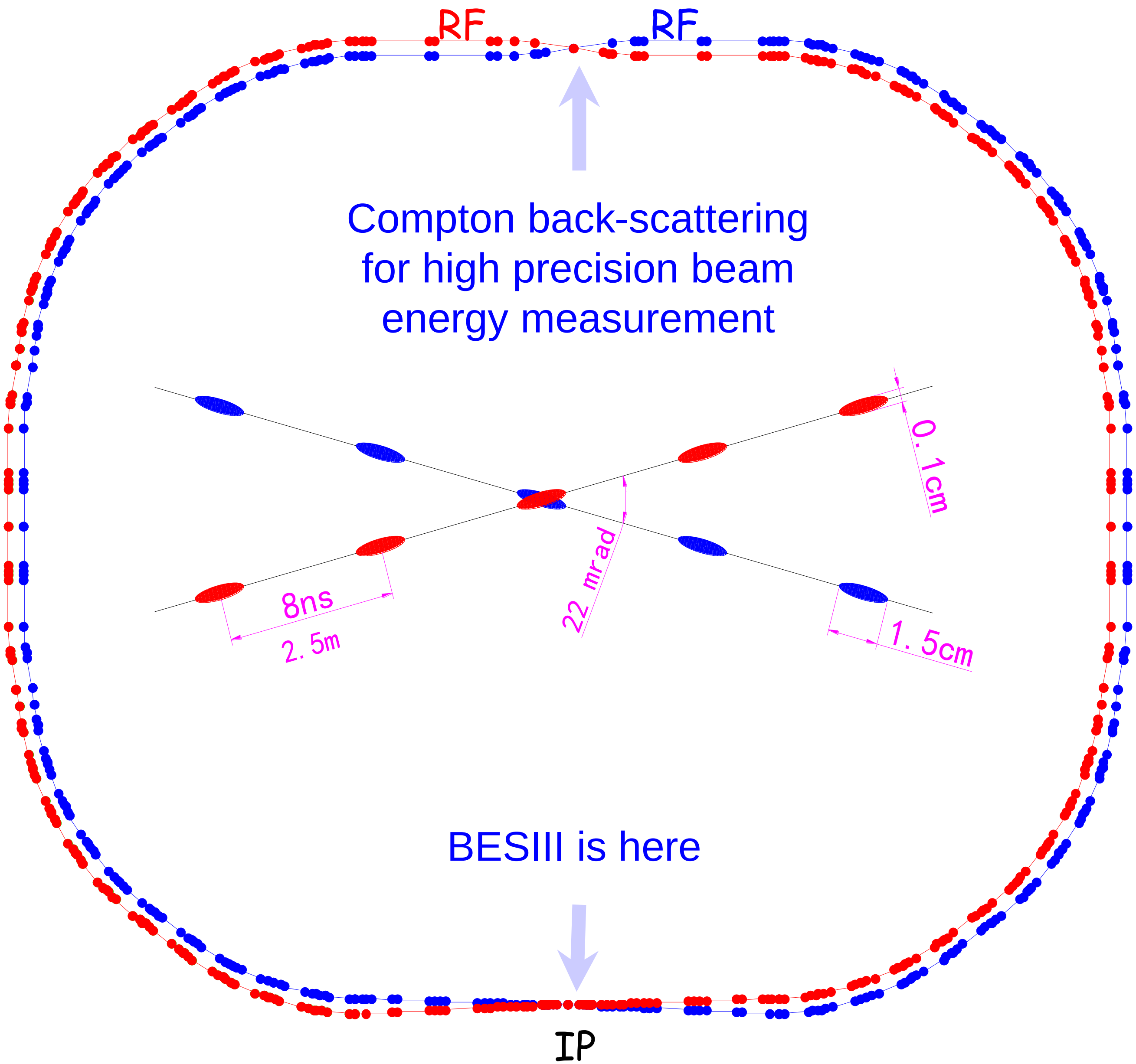
- BESIII and physics program
- Charmonium & XYZ states
- Zc(3900)
- Summary

The Beijing Electron Positron Collider



- Founded: 1984, Ecm=2-5 GeV
- 1989-2005 (BEPC):
  L_{peak}=1.0x10^{31} /cm^{2}s
- 2008-now (BEPCII):
  L_{peak}=6.9x10^{32}/cm^{2}s

BEPC II: Large crossing angle, double-ring



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}

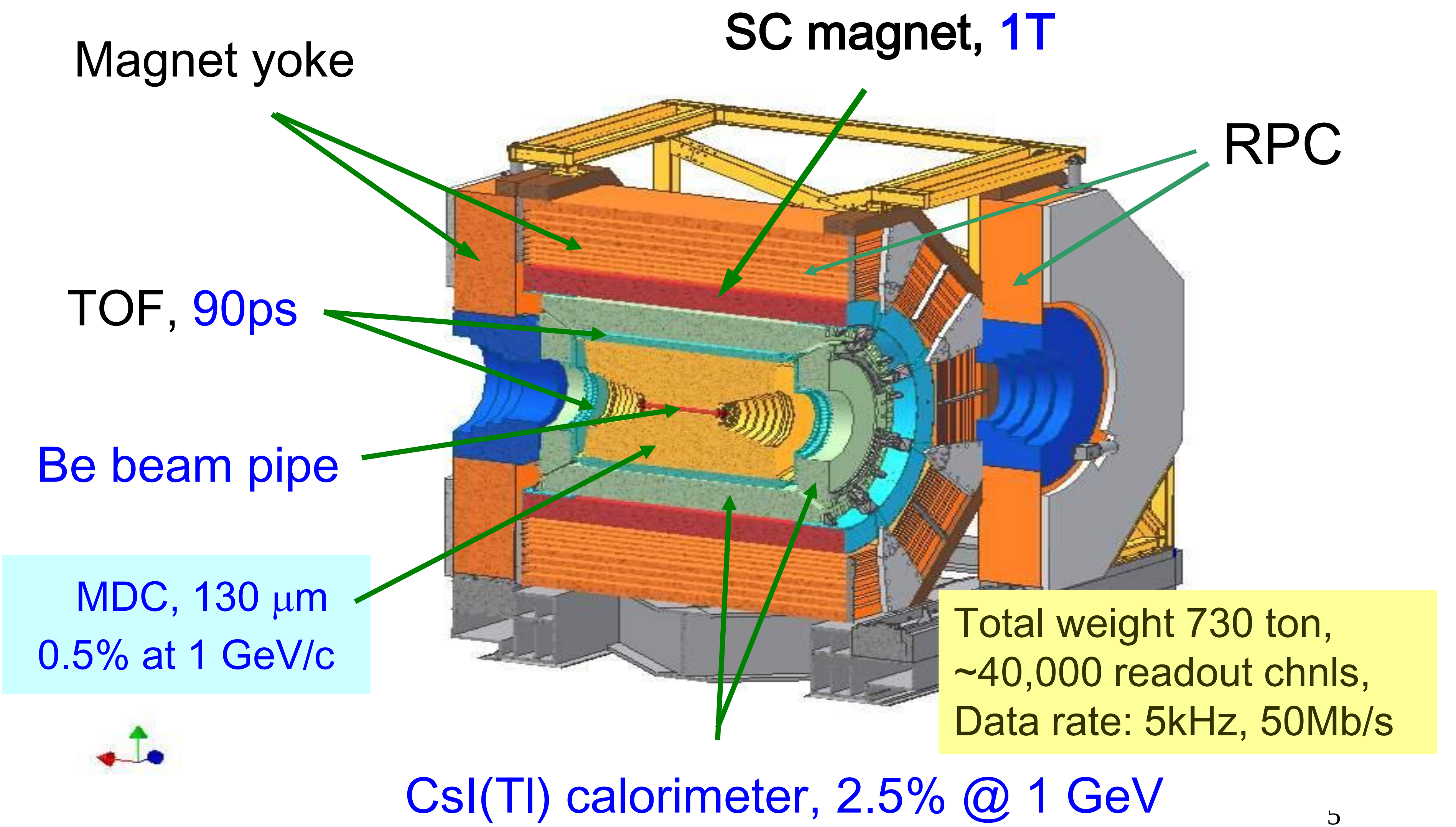
No. of bunches:
93

Bunch length:
1.5 cm

Total current:
0.91 A

SR mode:
0.25A @ 2.5 GeV

BESIII Detector



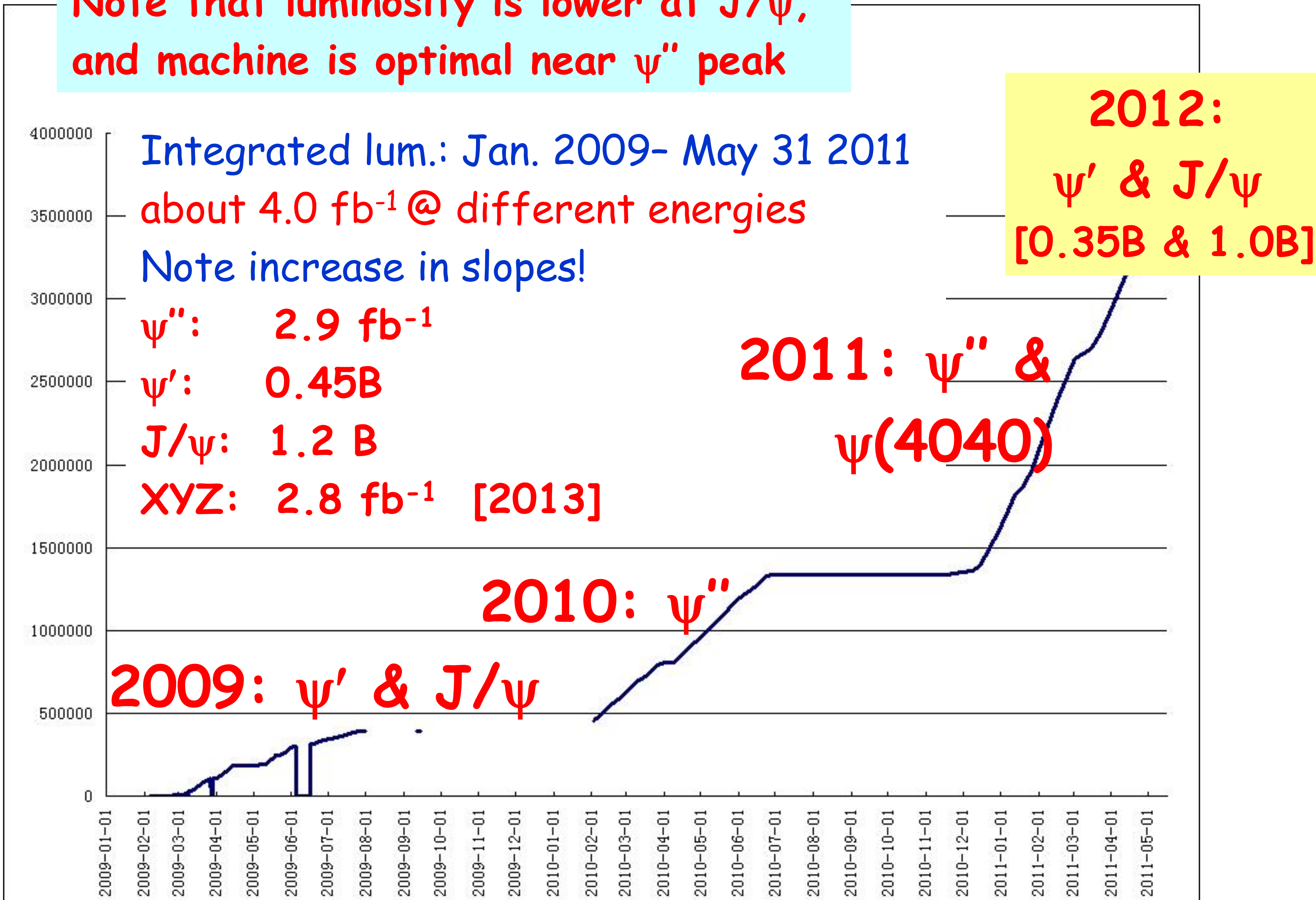
BESIII Physics Programs

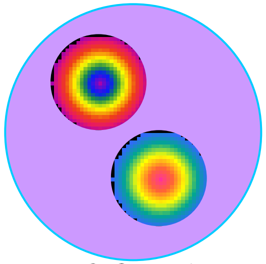
This is not a BESIII logo!

- B (looks like DD for D or charm physics)
- E (looks like cc for charmonium physics)
- S (for light hadron Spectroscopy)
- T (for tau physics, looks like a Roman number "III")

Luminosity since startup

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

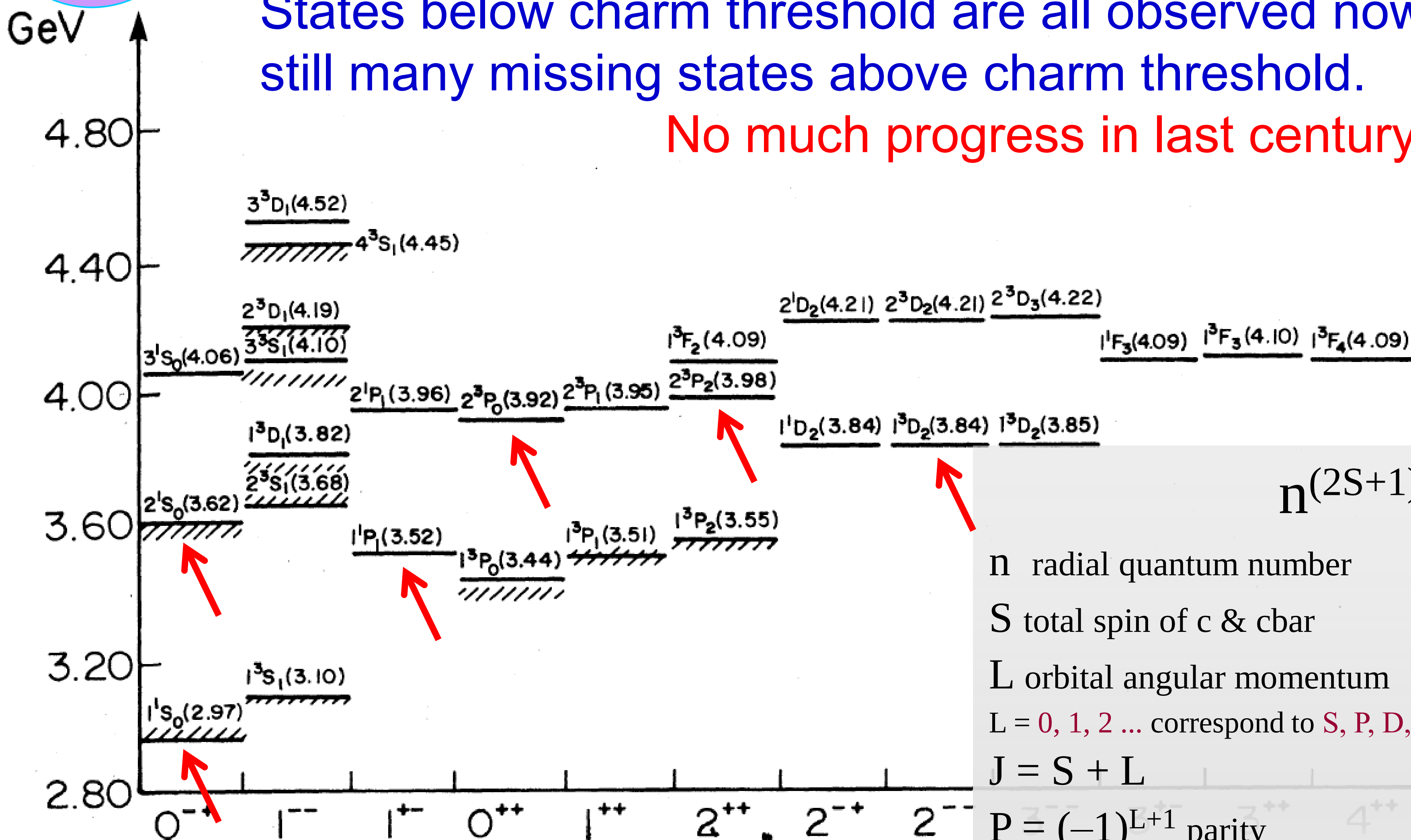




Charmonium spectroscopy

States below charm threshold are all observed now, still many missing states above charm threshold.

No much progress in last century!



$n^{(2S+1)}L_J$

n radial quantum number

S total spin of c & cbar

L orbital angular momentum

L = 0, 1, 2 ... correspond to S, P, D, …

$J = S + L$

$P = (-1)^{L+1}$ parity

$C = (-1)^{L+S}$ charge conj.

Godfrey & Isgur, PRD32, 189 (1985)

Then we found lots of XYZ states

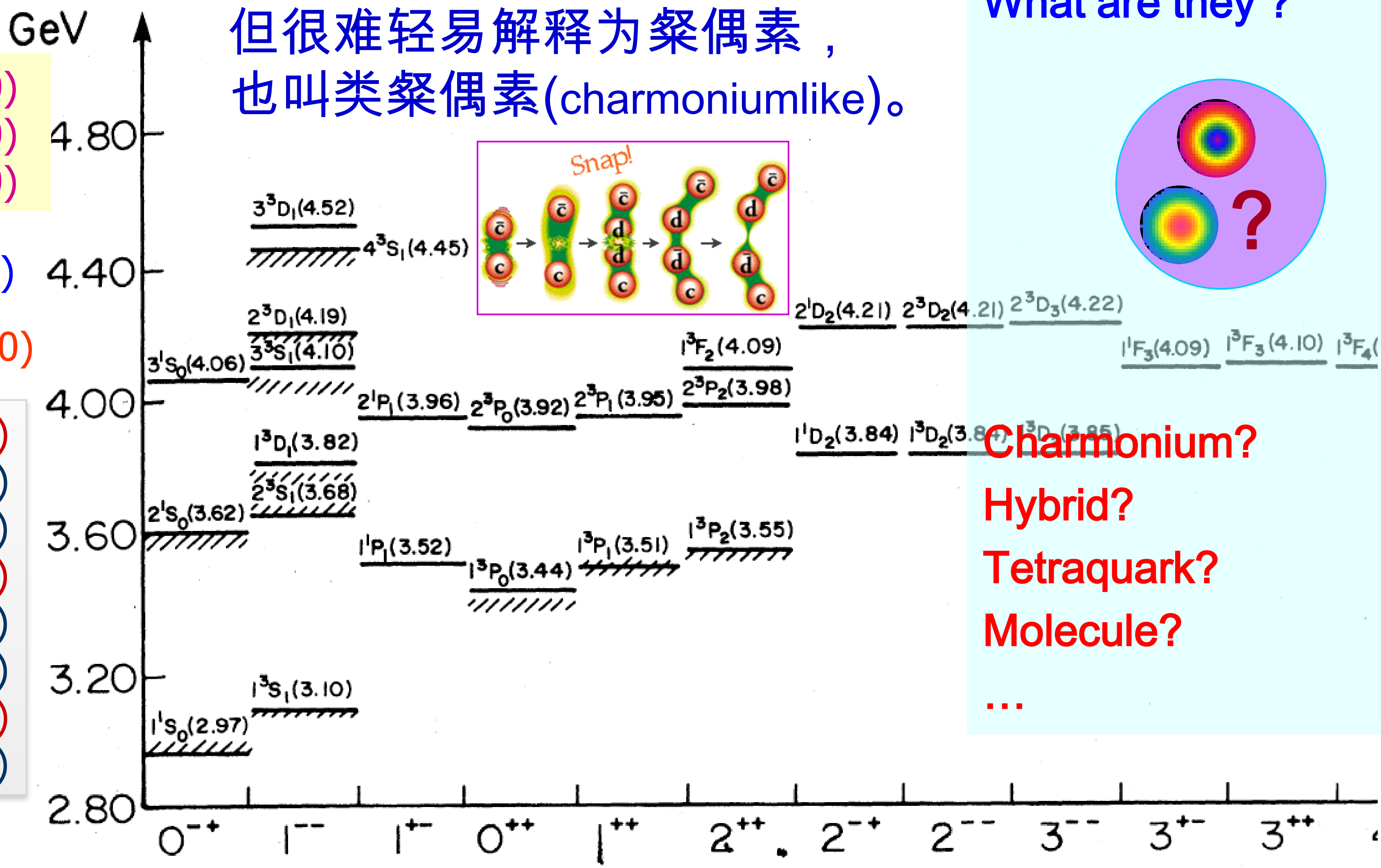
特点：衰变产物中有粲偶素，
但很难轻易解释为粲偶素，
也叫类粲偶素(charmoniumlike)。

Z(4430)
Z(4250)
Z(4050)

X(3872)

XYZ(3940)

X(3915)
X(4160)
Y(4008)
Y(4140)
Y(4260)
Y(4360)
X(4350)
Y(4660)



What are they ?

Charmonium?

Hybrid?

Tetraquark?

Molecule?

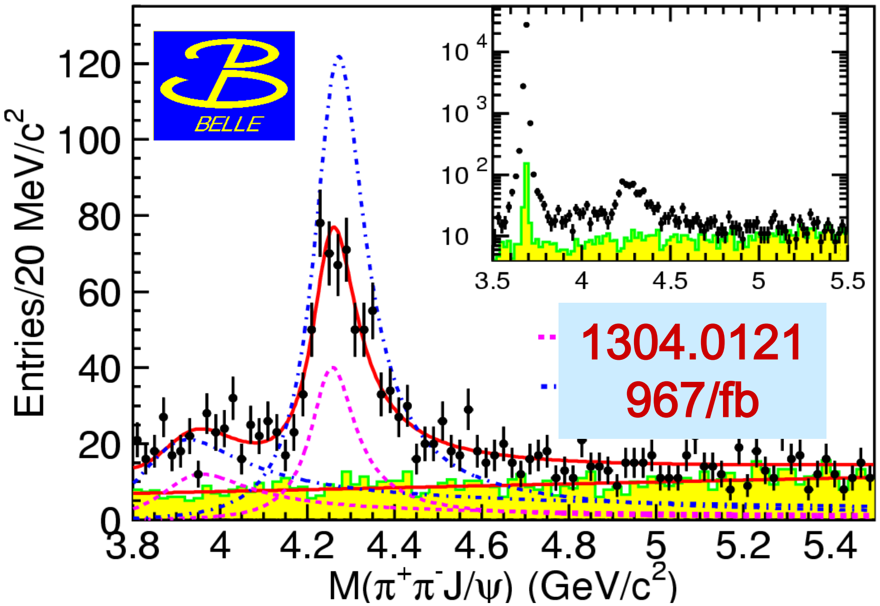
…

Not all XYZ states are charmonia!

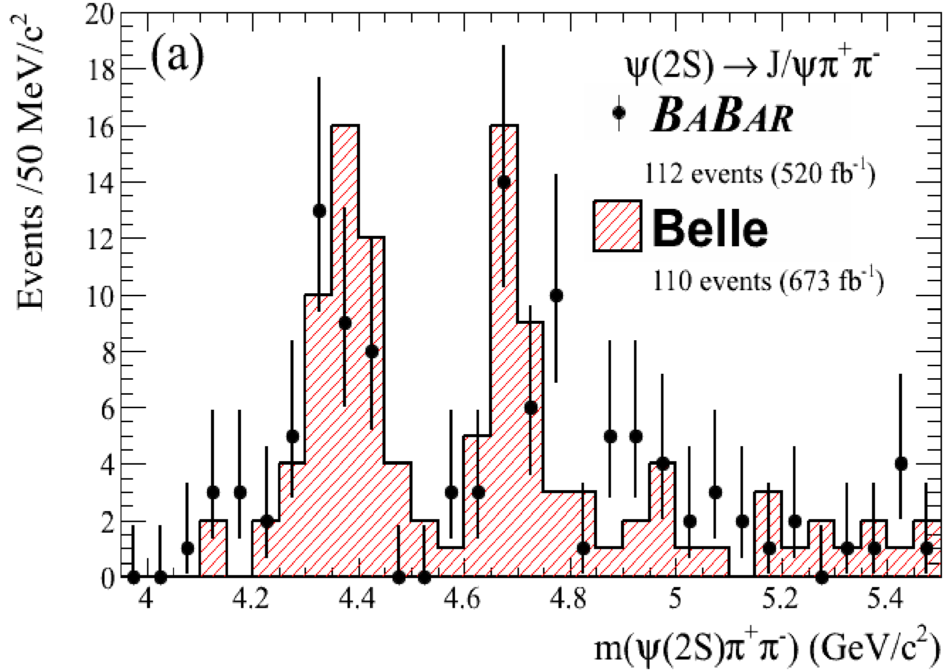
The Y states

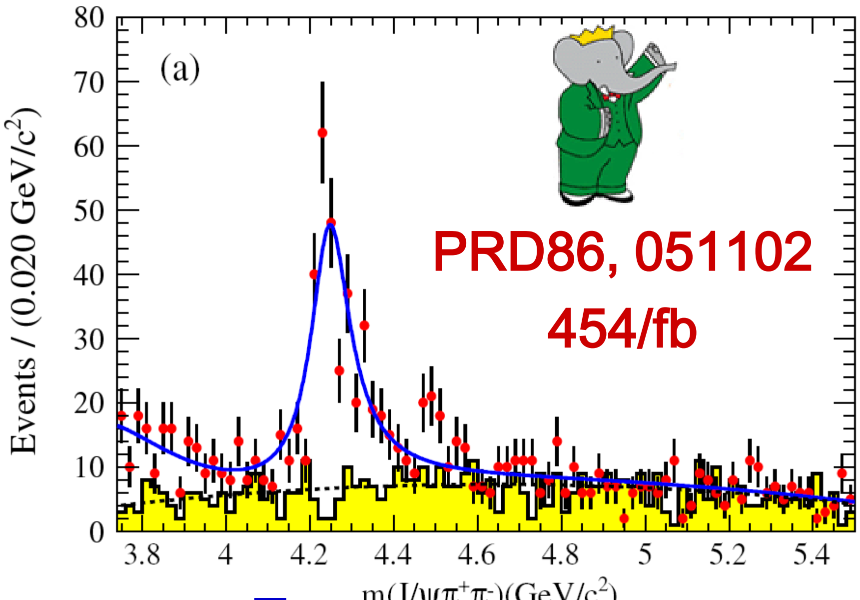
Belle: PRL99, 142002, 670/fb

BaBar: 1211.6271



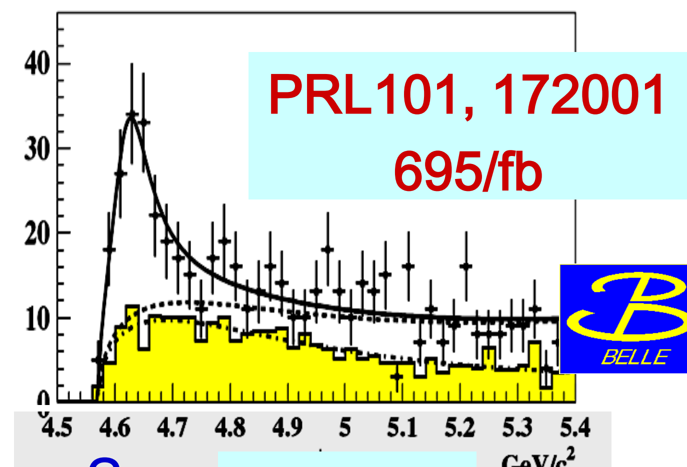
1304.0121
967/fb





PRD86, 051102
454/fb

Y(4008)
Y(4260)
Y(4360)
Y(4660)
Y(4630)



PRL101, 172001
695/fb

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

Above $\bar{D}D$ threshold, decay to open charm?

Observation of the $Z_c(3900)$
— a charged charmoniumlike structure —

BESIII: 3月24日

Belle: 3月30日

CLEOc：4月10日

Z_c established！

symmetry dimensions of particle physics

A joint Fermilab/SLAC publication

home departments science topics image bank pdf issues archives

Photo: IHEP Beijing

breaking

March 26, 2013

BESIII collaboration catches new particle

A new particle spotted at China's Beijing Electron Positron Collider raises more questions than it answers.

By Kelen Tuttle

PDF Download

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Feature: Chasing charm in China

Elsewhere on the web

BESIII experiment

IHEP press release: Observation of a

The plot has thickened for scientists studying a recently discovered particle at the Beijing Electron Spectrometer. For the past three months, the BESIII collaboration has studied the "Y(4260)" particle, discovered in 2005, to try to understand why this anomalous creature refuses to conform to scientists' understanding of similar particles. Surprisingly, the first result from these studies is the observation another new, unexpected and mysterious particle named the "Z_c(3900)."

The Y(4260), originally discovered by the BaBar collaboration, is a bit of an odd duck. Other particles with similar characteristics—called "charmonium"—are composed of a charm quark and an anti-charm quark held together by the strong force. Yet the Y(4260) doesn't seem to fit this

most popular

March 7, 2013
Spin
Objects as large as a planet or as small as a photon can have the property of spin. Spin is also the reason we can watch movies in 3D.

March 26, 2013
How particle physics improves your life
From MRIs to shrink wrap, particle physics technology improves the world we live in.

March 22, 2013
Great minds lauded at physics prize ceremony
A crowd full of stars from the field of particle physics—along with one from Hollywood—celebrated recent achievements.

symmetry tweeting

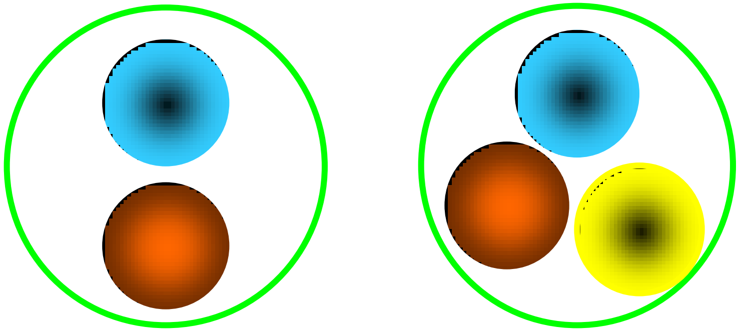
March 28, 2013
NOvA #neutrino detector, still under construction, already taking 3D images of particles: http://t.co/fsOPwqDWsc (cc @NOvANuz)

March 27, 2013
Before the Dark Energy Survey even begins, the Dark Energy Camera is exceeding expectations in the astro community: http://t.co/n7e8Hkkbpn

Hadrons： normal & exotic

- Hadrons are composed from 2 (meson) quarks or
  3 (baryon) quarks

Quark model



- QCD doesnot forbid hadrons with $N_{quarks} \neq 2, 3$
  - glueball : $N_{quarks} = 0$ (gg, ggg, …)
  - hybrid : $N_{quarks} = 2$ (or more) + excited gluon
  - multiquark state : $N_{quarks} > 3$
  - molecule : bound state of more than 2 hadrons

A bit history on exotics hunting

- "The absence of exotics is one of the most obvious features of QCD" – R. L. Jaffe, 2005
- Deuteron ➔ H state, $\Omega^{-}\Omega^{-}$ bound state, …
- No solid signature of glueballs
- Pentaquark state appeared and disappeared

  ("The story of pentaquark shows how poorly we understand QCD" – F. Wilczek, 2005)
- There are lots of new states from low to high mass in various experiments! Are they normal or exotic?

Why hard to identify exotic state?

- Which dwarf was named “Happy”?

- I donot know …

No solid signature!

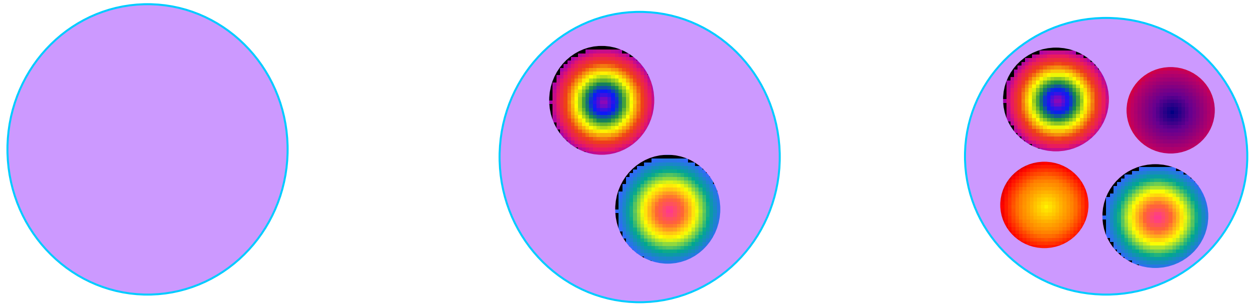
Why hard to identify exotic state?

- Which beauty is “Snow White”?

- Yes, I know!   “Hair black as ebony [乌木，黑檀]”.
- Very clear signature!

How to identify an exotic meson?

- Find a clear signature for exotic state!



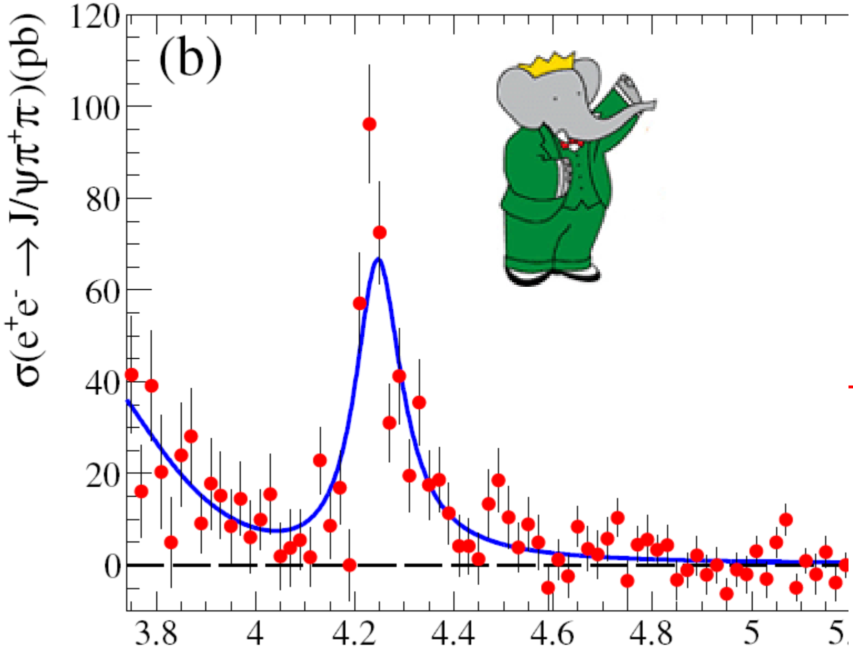
- Decays to charmonium thus has a $\bar{c}c$ pair!
- With electric charge thus has two more light quarks!

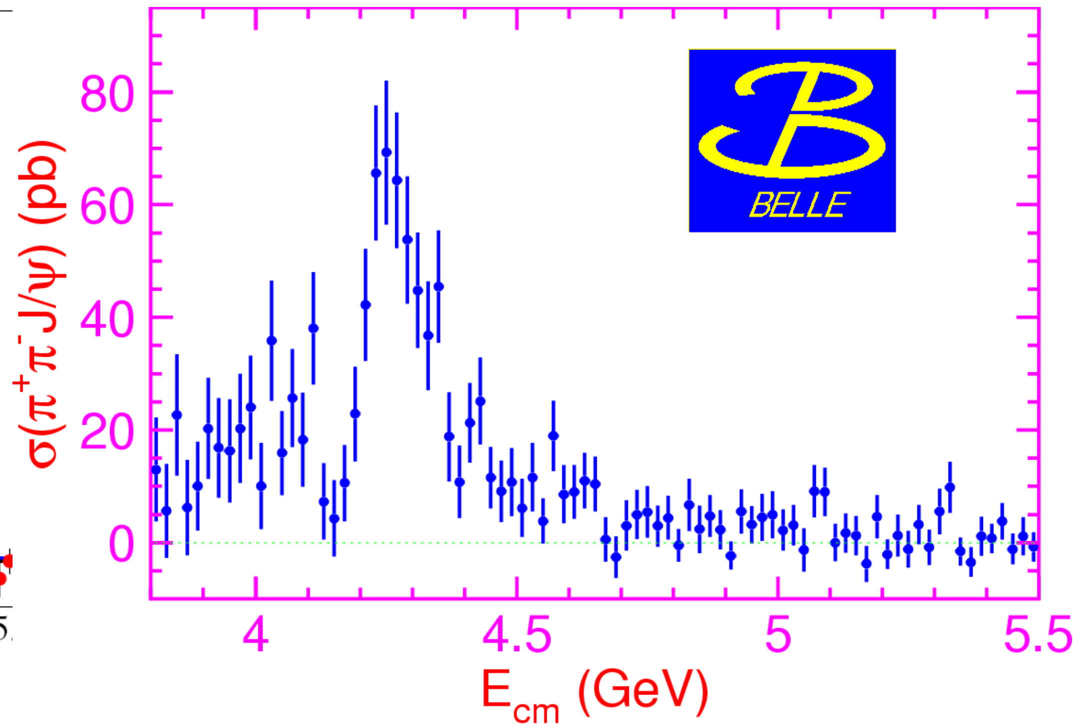
➔ $N_{quark} \geq 4$!

- Do searches in $\pi^{\pm}J/\psi$, $\pi^{\pm}\psi(2S)$, $\pi^{\pm}\chi_{cJ}$, …

What do we do at BESIII

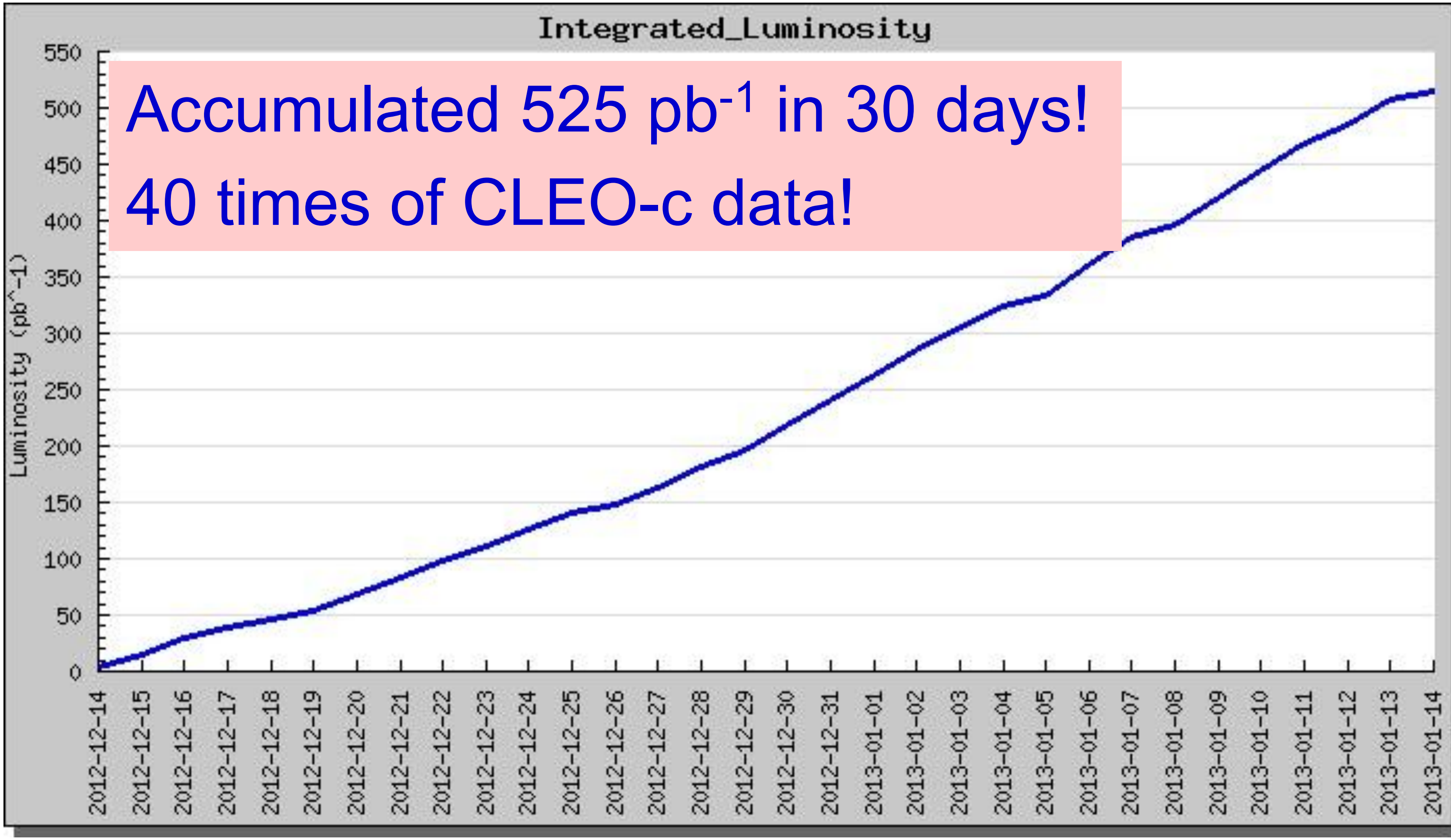
We may search for such state if it decays into $\pi^{\pm} J/\psi$!





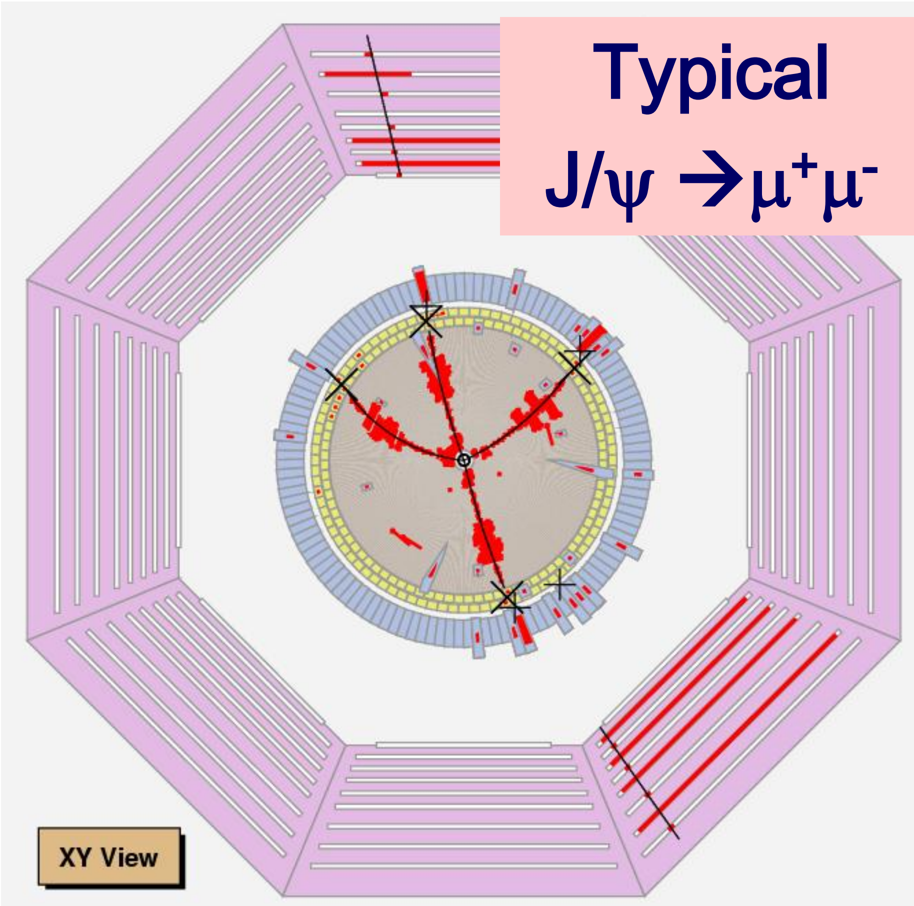
- $\sigma(e^+e^- \to \pi^+\pi^- J/\psi)$ reaches maximum at ~4.26 GeV
- We proposed a 45 days' data taking for 500 pb^{-1} data at peak
- ~1500 reconstructed events are expected [3xB-factories]

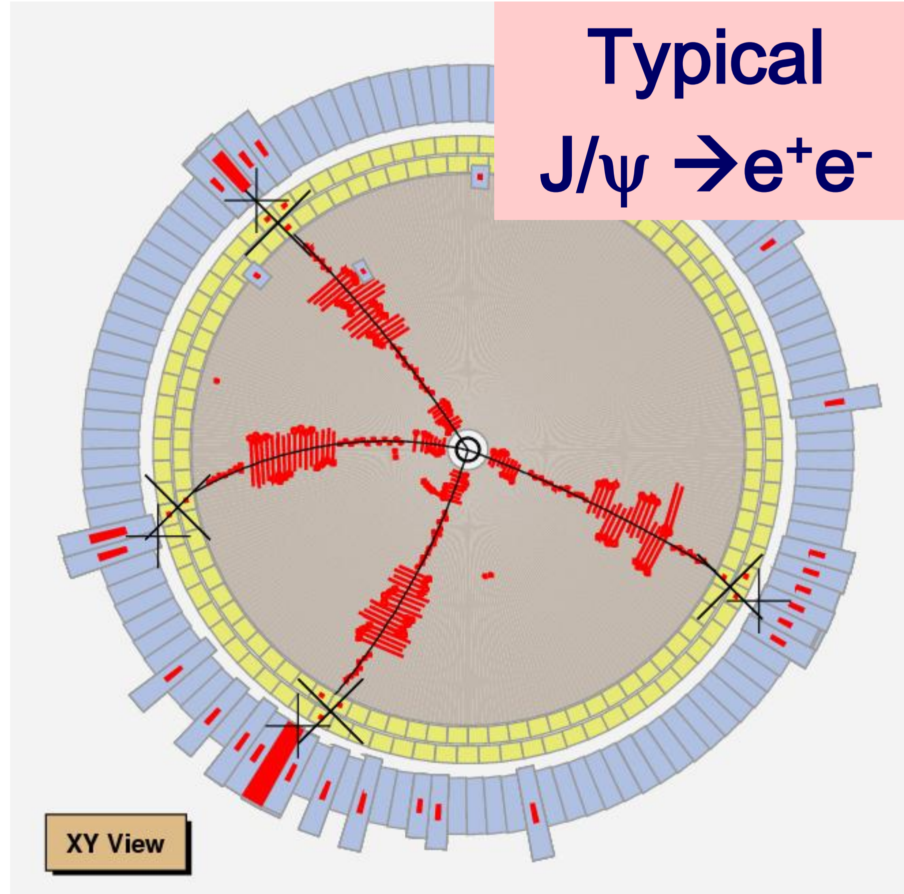
Data taking at BESIII



- Highest energy BEPCII ever reach, $L_{peak} \sim 5.3 \times 10^{32}/cm^2/s$!
- BEMS measures Ecm at 1 MeV level !
- Low background, low noise, all sub-detectors excellent !

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

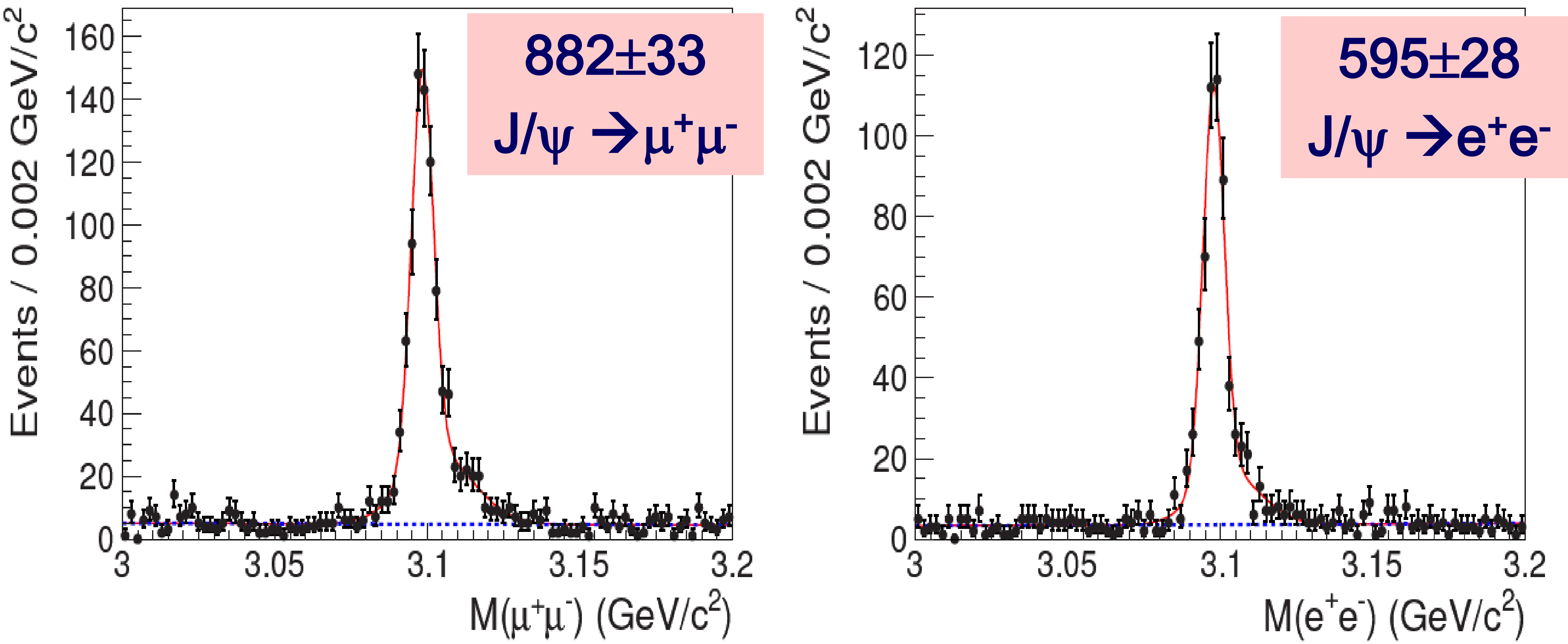




- Select 4 charged tracks and reconstruct J/ψ with lepton pair.
- Very clean sample, very high efficiency. Use kinematic fit.
- Only use MDC & EMC information, MC simulation reliable.

The J/ψ signals

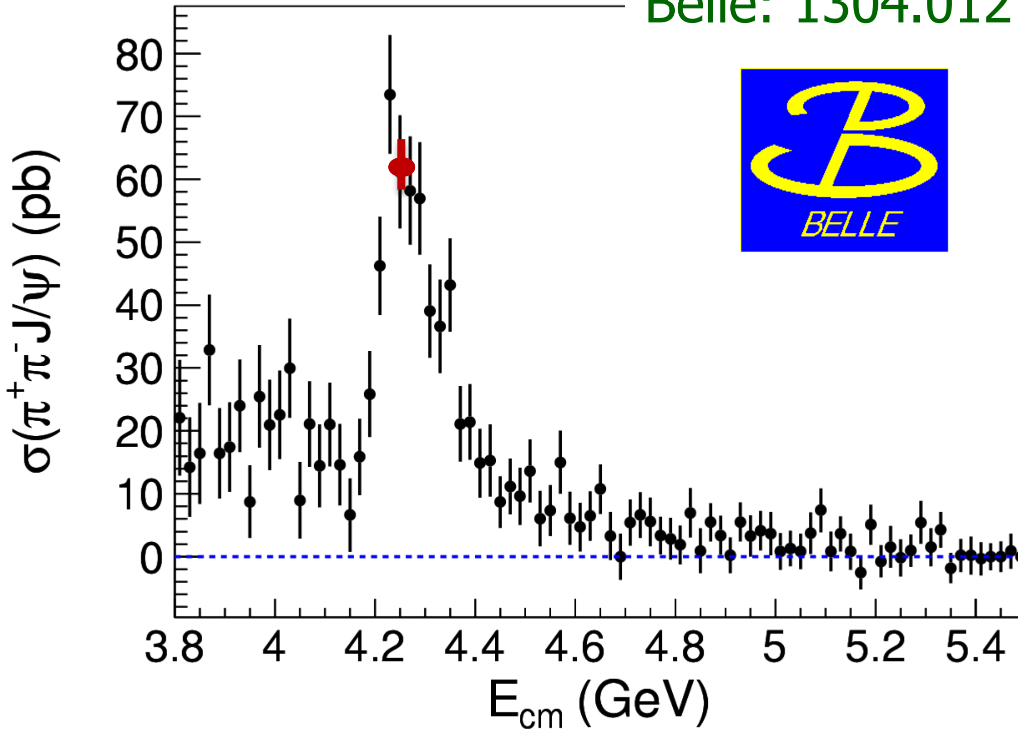
BESIII: arXiv:1303.5949



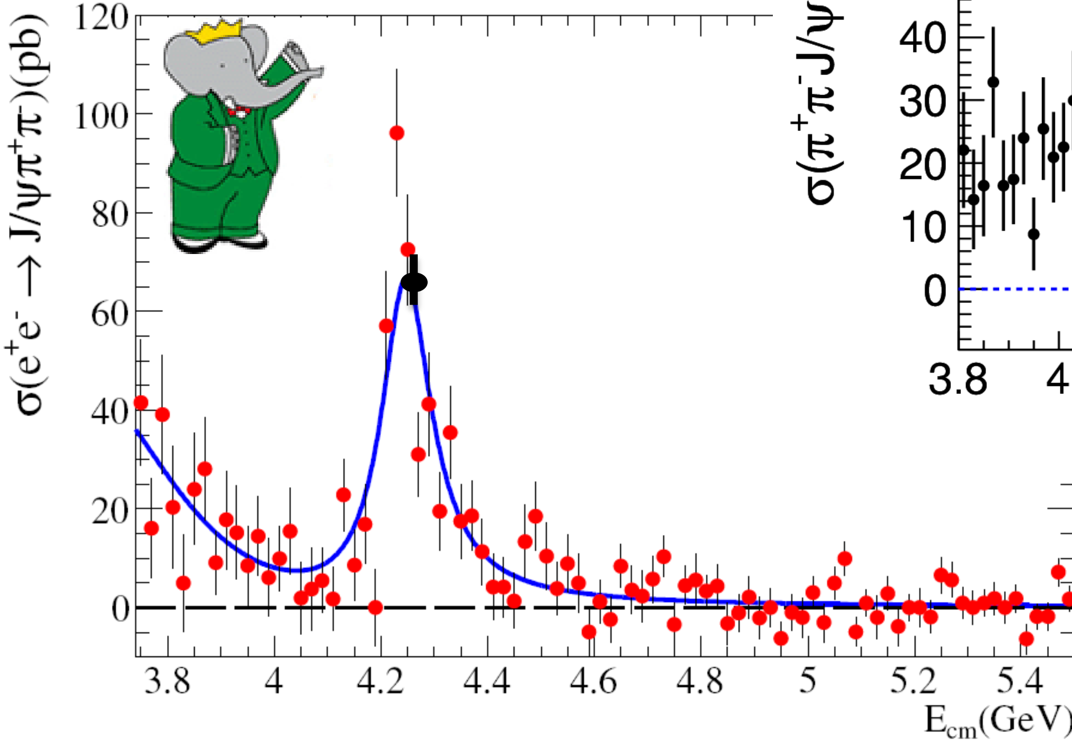
- Dominant background $e^+e^- \to \pi^+\pi^-\pi^+\pi^-$
- J/ψ signal: [3.08,3.12] GeV
- J/ψ sideband: [3.0,3.06] GeV or [3.14,3.20] GeV, 3xsignal
- At least 4 independent analyses, all get similar results !

Cross section of $e^+e^- \to \pi^+\pi^- J/\psi$

Belle: 1304.0121



BaBar: PRD86, 051102 (2012)



BESIII: arXiv:1303.5949

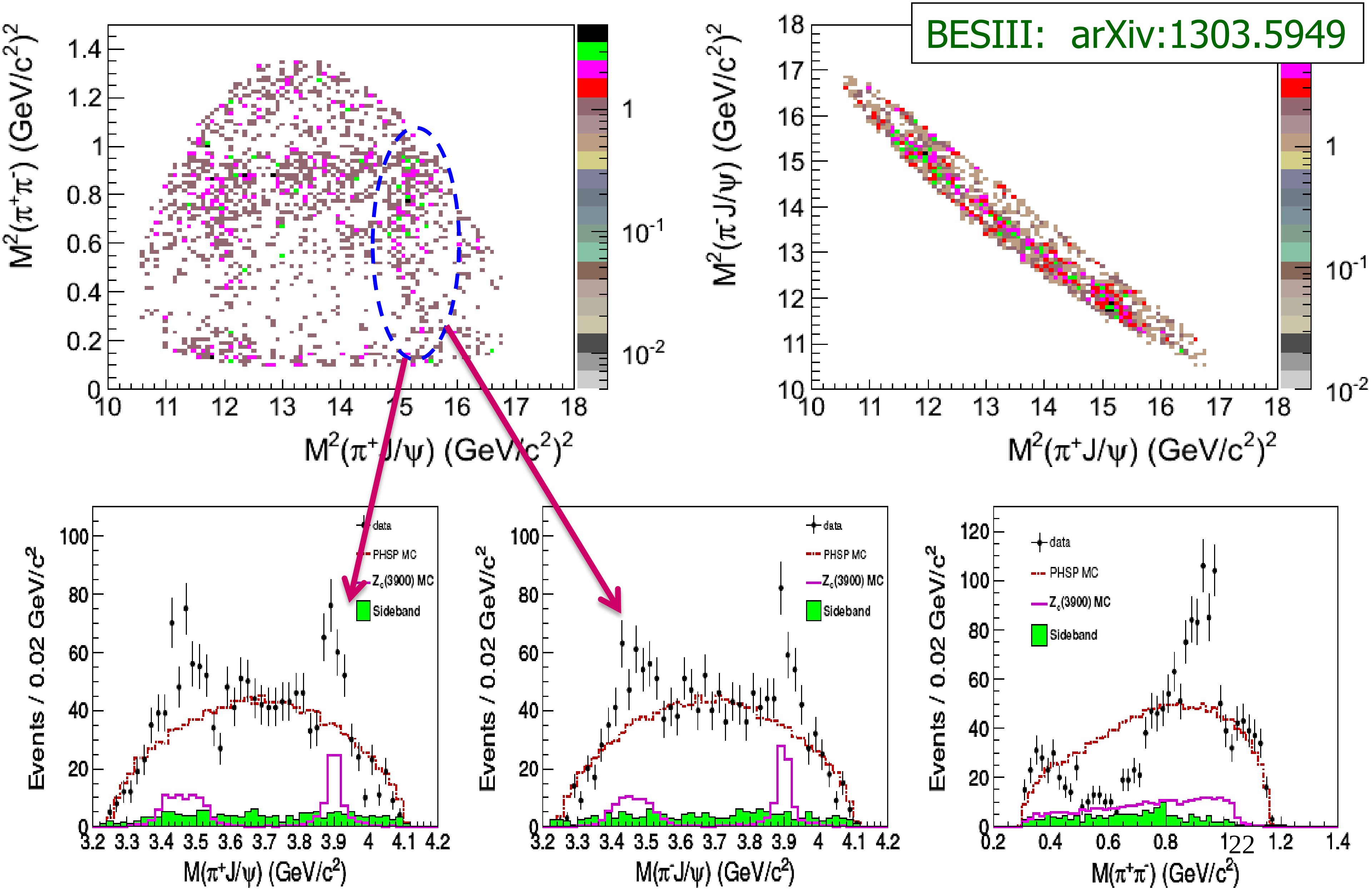
BESIII: $\sigma(e^+e^- \to \pi^+\pi^- J/\psi)$

$= (62.9 \pm 1.9 \pm 3.7)$ pb

Agree with BaBar & Belle!

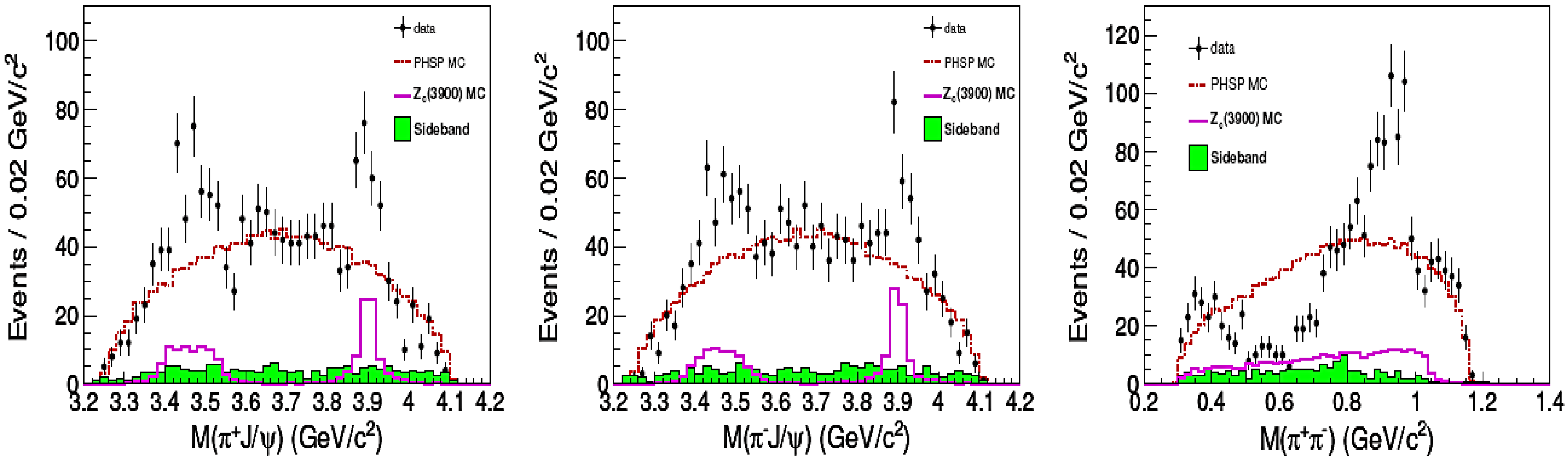
Best precision!

Dalitz plots & 1D projections

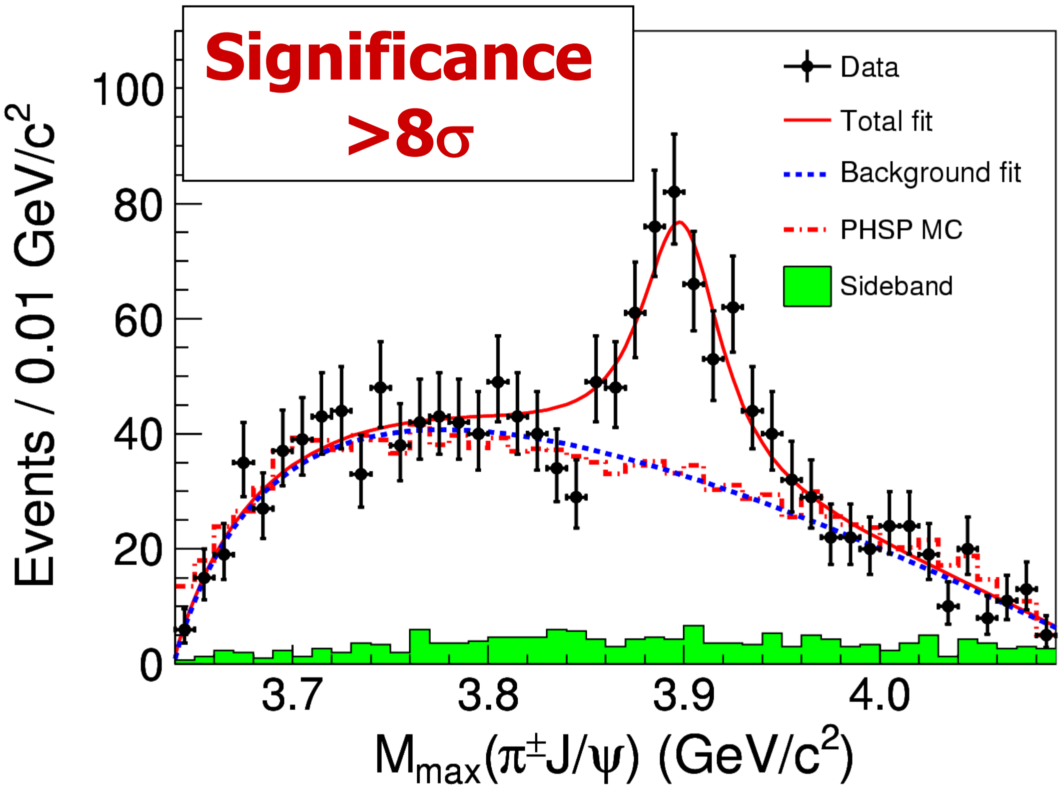


Is it a real signal?

- Is it due to $\pi^+\pi^-$ S-wave states, like σ, $f_0(980)$, …? **N**
- Is it due to $\pi^+\pi^-$ D-wave states, like $f_2(1270)$, …? **N**
- Are there two states, one at 3.4, the other 3.9 GeV? **N**
- Exist in both e^+e^- & $\mu^+\mu^-$ samples? **Y**
- Exist in both $\pi^+\pi^-$ low mass and high mass samples? **Y**
- Background fluctuation? **N**

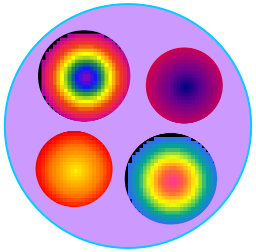


The $Z_c(3900)$ signal



BESIII: arXiv:1303.5949
PRL (in press)

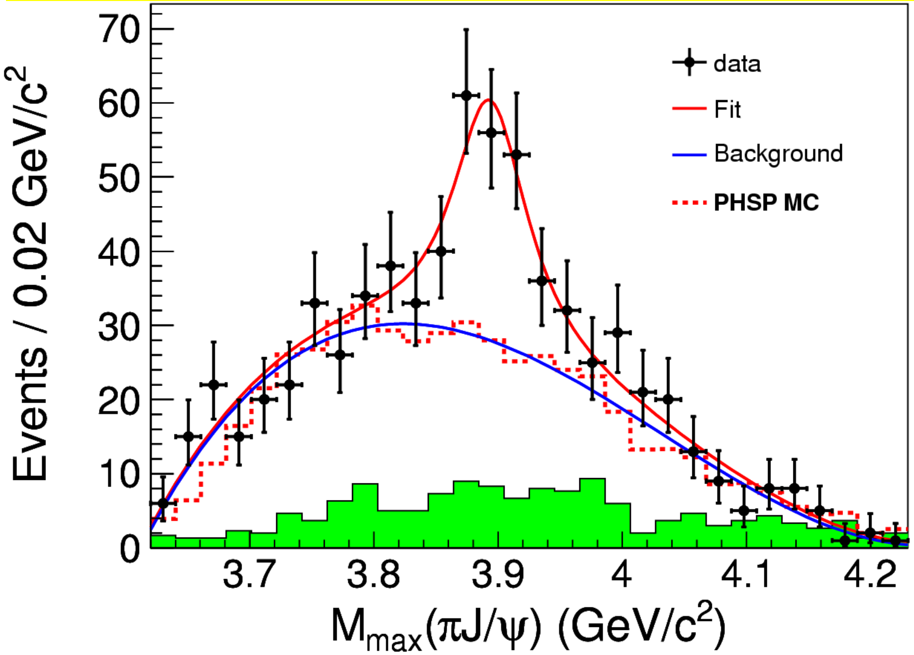
- Couples to $c\bar{c}$
- Has electric charge
- At least 4-quarks
- What is its nature?



- S-wave Breit-Wigner with efficiency correction
- Mass = (3899.0±3.6±4.9) MeV
- Width = (46±10±20) MeV
- Fraction = (21.5±3.3±7.5)%

Observed in two experiments!

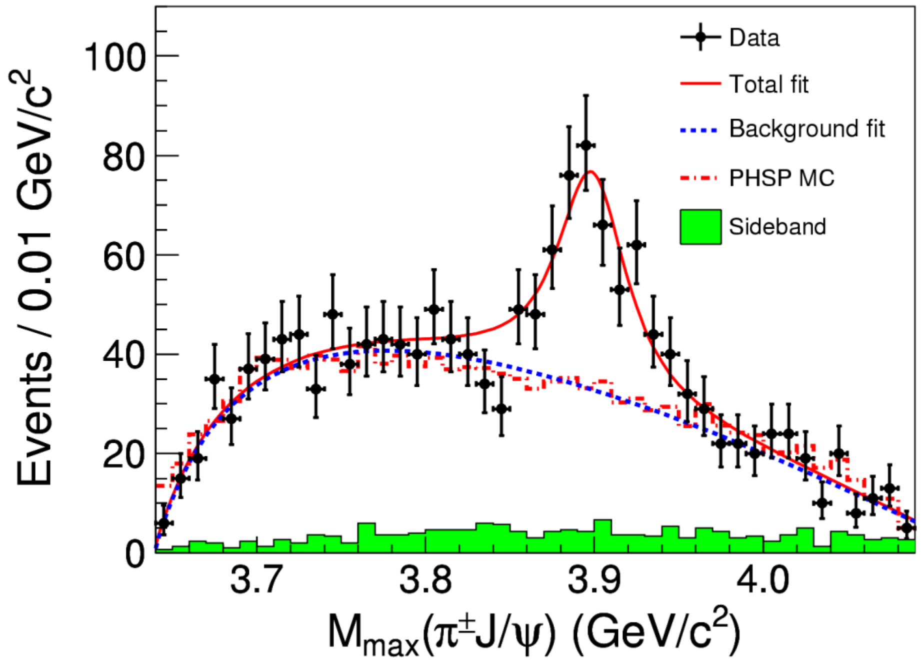
Belle with ISR: 1304.0121



- $M = 3894.5 \pm 6.6 \pm 4.5$ MeV
- $\Gamma = 63 \pm 24 \pm 26$ MeV
- 159 ± 49 events
- $>5.2\sigma$

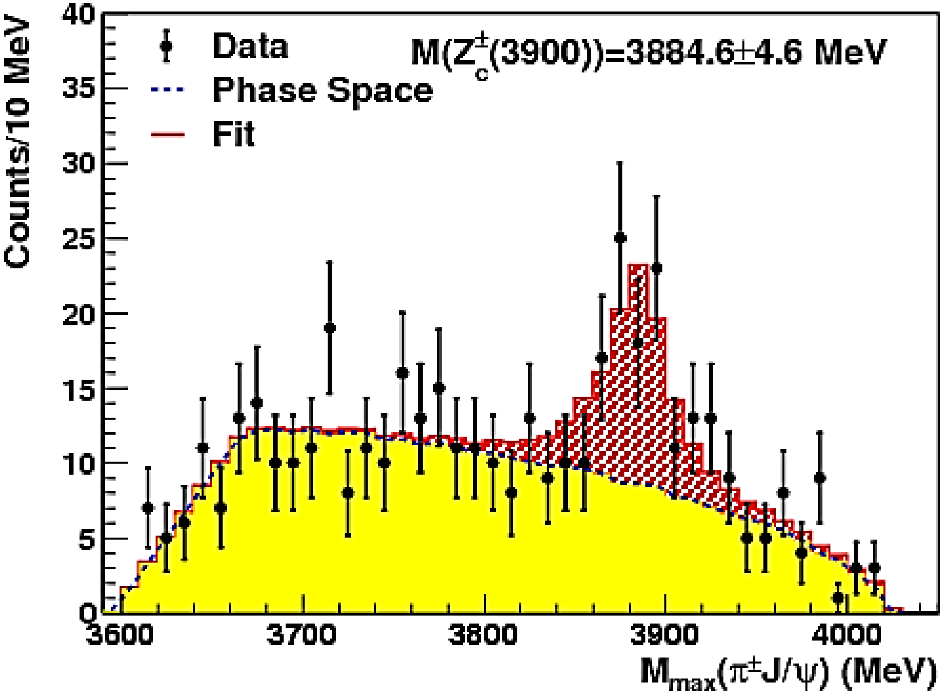
BESIII: 1303.5949

- $M = 3899.0 \pm 3.6 \pm 4.9$ MeV
- $\Gamma = 46 \pm 10 \pm 20$ MeV
- 307 ± 48 events
- $>8\sigma$



Confirmed!

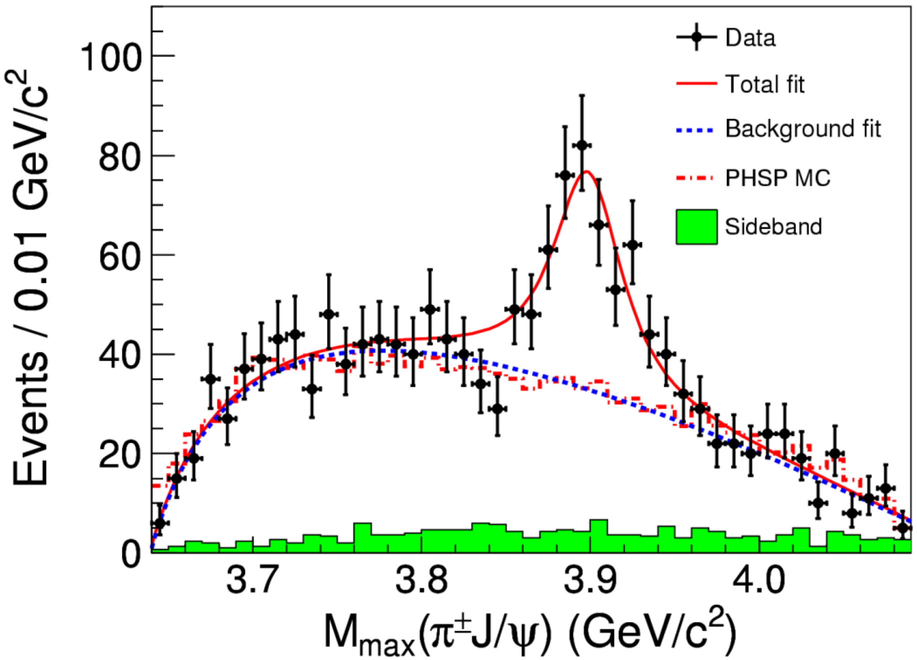
CLEO at 4.17 GeV: 1304.3036



- M = 3885±5±1 MeV
- Γ = 34±12±4 MeV
- 81 ± 20 events
- 6.1σ

BESIII: 1303.5949

- M = 3899.0±3.6±4.9 MeV
- Γ = 46±10±20 MeV
- 307 ± 48 events
- >8σ



21 citations since results released

1. arXiv:1304.3036 Title: Observation of the Charged Hadron Zc(3900) at sqrt(s)=4170 MeV
Authors: T. Xiao, S. Dobbs, A. Tomaradze, Kamal K. Seth

2. arXiv:1304.2882 Title: Electromagnetic Structure of the Z_c(3900)
Authors: E. Wilbring, H.-W. Hammer, U.-G. Mei ßner

3. arXiv:1304.1850 Title: Could Z_{c}(3900) be a I^{G}J^{P}=1^{+}1^{+} D^{*}\bar{D} molecular state?
Authors: Chun-Yu Cui, Yong-Lu Liu, Wen-Bo Chen, Ming-Qiu Huang

4. arXiv:1304.1301 Title: Interpreting Z(3900)
Authors: Namit Mahajan

5. arXiv:1304.0345 Title: The doubly heavies: (Qbar Q qbar q), (Q Q qbar qbar) tetraquarks and (Q Q q) baryons
Authors: Marek Karliner, Shmuel Nussinov

6. arXiv:1304.0380 Title: Z_c(3900) - what is inside?
Authors: M.B. Voloshin

7. arXiv:1304.0121 Title: Study of e+ e- to π+ π- J/ψ and Observation of a Charged Charmonium-like State at Belle
Authors: Belle Collaboration

8. arXiv:1303.6857 Title:A J^PG=1++ Charged Resonance in the Y(4260) to pi+pi- J/psi Decay?
Authors: R. Faccini, L. Maiani, F. Piccinini, A. Pilloni, A.D. Polosa, V. Riquer

9. arXiv:1303.6842 Title: Predictions of charged charmonium-like structures with hidden-charm and open-strange channel
Authors: Dian-Yong Chen, Xiang Liu, Takayuki Matsuki

10. arXiv:1303.6608 Title: Consequences of Heavy Quark Symmetries for Hadronic Molecules
Authors: Feng-Kun Guo, Carlos Hidalgo-Duque, Juan Nieves, Manuel Pavon Valderrama

11. arXiv:1303.6355 Title: Decoding the riddle of Y(4260) and Z_c(3900)
Authors: Qian Wang, Christoph Hanhart, Qiang Zhao

What next?

- We are accumulating 3x more data
- Precise resonant parameters
- Spin-parity [PWA on going]
- More decay modes [DD*, πh_c, $\pi\psi'$, $\rho\eta_c$, …]
- Production mechanisms, production rate
- Test various theoretical models
- Neutral partner of Z_c
- Other Z_c states? Z_c' states?
- …

Summary

- BESIII has collected large data samples for hadron spectroscopy, charmonium, charm, and tau physics
- Lots results published recently
- BESIII started study of the XYZ particles
- More results will come soon, stay tuned!

Thanks a lot!

Thanks a lot!

Thanks a lot!

Table 1: Results on the cross section of $e^+e^- \to \pi^+\pi^- J/\psi$.

CM energy	(4.260 ± 0.001) GeV
Integrated luminosity	$525(1 \pm 1\%)$ pb^{-1}
Radiative correction factor	0.818
Number of $J/\psi \to e^+e^-$	595 ± 28
Efficiency of $J/\psi \to e^+e^-$	38.4%
Cross section from $J/\psi \to e^+e^-$	(60.7 ± 2.9) pb
Number of $J/\psi \to \mu^+\mu^-$	882 ± 33
Efficiency of $J/\psi \to \mu^+\mu^-$	53.8%
Cross section from $J/\psi \to \mu^+\mu^-$	(64.4 ± 2.4) pb
Cross section from combined e^+e^- and $\mu^+\mu^-$	$(62.9 \pm 1.9 \pm 3.7)$ pb

Source	$\mu^+\mu^-$	e^+e^-
Luminosity	1.0	1.0
MC Statistics	0.5	0.7
Tracking	4.0	4.0
Background shape	0.5	3.4
$Y(4260)$ line-shape	0.6	0.6
Kinematic fit	2.2	2.3
Branching ratios	1.0	1.0
Decay model	3.1	3.1
Others	1.0	1.0
Total	5.9	6.8
e^+e^- & $\mu^+\mu^-$ combined	5.9	

Table 3: Results on the $Z_c(3900)$.

Number of signal events	307 ± 48
Significance	$> 8\sigma$
Mass	$(3899.0 \pm 3.6 \pm 4.9)$ MeV$/c^2$
Width	$(46 \pm 10 \pm 20)$ MeV
$R = \frac{\sigma(e^+e^- \to \pi^\pm Z_c(3900)^\mp \to \pi^+\pi^- J/\psi)}{\sigma(e^+e^- \to \pi^+\pi^- J/\psi)}$	$(21.5 \pm 3.3 \pm 7.5)\%$

Table 4: Summary of the systematic errors for $Z_c(3900)$ resonant parameters.

Source	Mass (MeV)	Width (MeV)	Ratio (%)
Absolute mass scale	1.8	-	-
S/P-wave	2.1	3.7	2.6
Flatté	2.1	15.4	0.0
Background shape	3.5	12.1	7.1
Resolution	-	1.0	0.2
Total	4.9	20.0	7.5

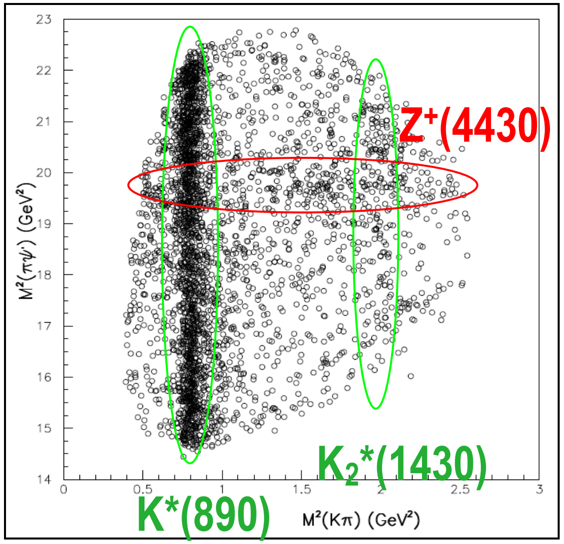
Belle observed $Z(4430)^{\pm} \to \psi(2S)\pi^{\pm}$

PRL100, 142001 (2008)

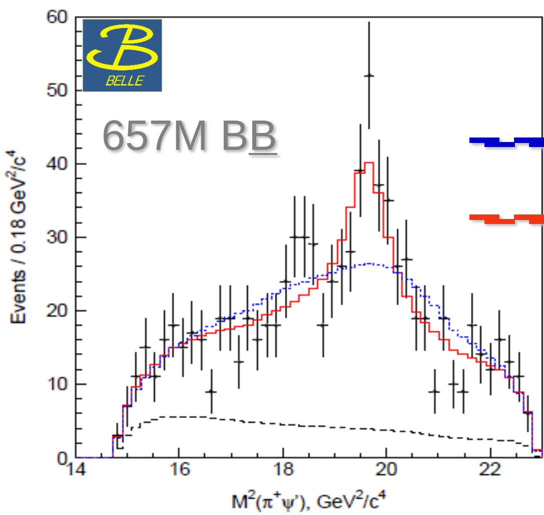
- Found in $\psi(2S)\pi^+$ from $B\to\psi(2S)\pi^+K$. Z parameters from fit to $M(\psi(2S)\pi^+)$
- Confirmed through Dalitz-plot analysis of $B\to\psi(2S)\pi^+K$
- $B\to\psi(2S)\pi^+K$ amplitude: coherent sum of Breit-Wigner contributions
- **Models: all known $K^*\to K\pi^+$ resonances only**

  all known $K^*\to K\pi^+$ and $Z^+\to\psi(2S)\pi^+$ ⇨ favored by data

$M^2(\psi(2S)\pi^+)$



$M^2(K\pi^+)$



$M^2(\psi(2S)\pi^+)$ after K* veto

Significance: 6.4σ

fit for model with K*'s only

fit for model with K*'s and Z

$$M = 4433\,^{+15}_{-12}\,^{+19}_{-13}\ \mathrm{MeV}$$

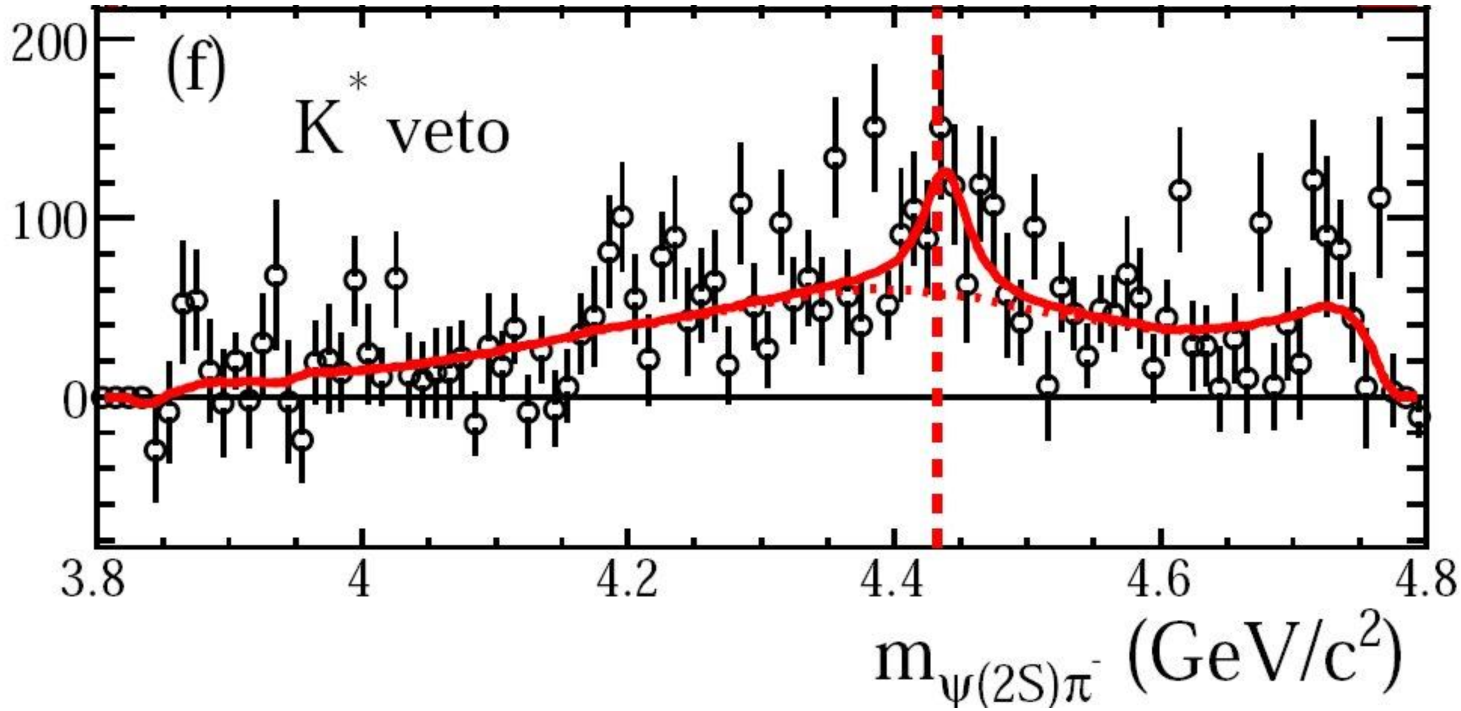
$$\Gamma = 107\,^{+86}_{-43}\,^{+74}_{-53}\ \mathrm{MeV}$$

PRD80, 031104 (2009)

- **[cu][cd] tetraquark? neutral partner in $\psi'\pi^0$ expected**
- **$D^*\underline{D}_1(2420)$ molecule? should decay to $D^*\underline{D}^*\pi$**

BaBar doesn't see a significant Z(4430)$^+$

PRD79, 112001 (2009)



"For the fit … equivalent to the Belle analysis…we obtain mass & width values that are consistent with theirs,… but only ~1.9σ from zero; fixing mass and width increases this to only ~3.1σ."

$BF(B^0 \to Z^+K) \times BF(Z^+ \to \psi(2S)\pi^+) < 3.1 \times 10^{-5}$

Belle PRL: $(4.1 \pm 1.0 \pm 1.4) \times 10^{-5}$

Belle observed Two $Z^{\pm}\to\chi_{c1}\pi^{\pm}$

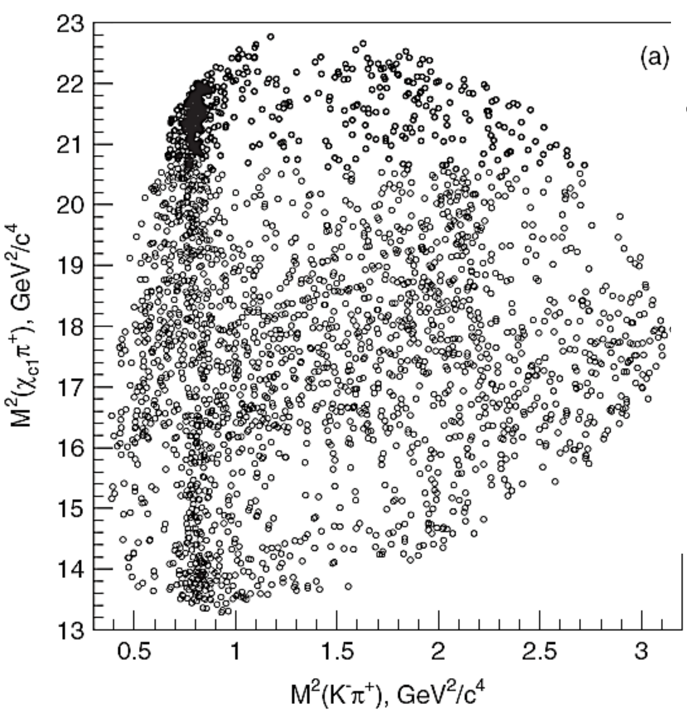
- Dalitz-plot analysis of $\underline{B}^0\to\chi_{c1}\pi^+K^-$ $\chi_{c1}\to J/\psi\gamma$ with 657M B$\underline{B}$
- Dalitz plot models: known $K^*\to K\pi$ only

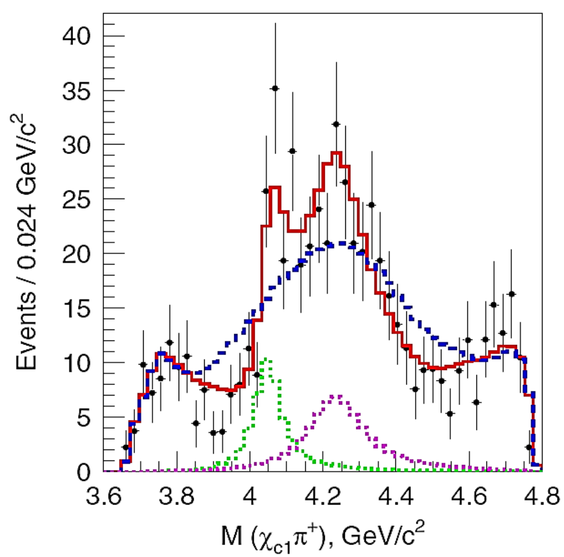
  K^*'s + one $Z\to\chi_{c1}\pi^{\pm}$

  K^*'s + two $Z^{\pm}$ states ⇨ favored by data

PRD 78, 072004 (2008)

Significance: 5.7σ





$M(\chi_{c1}\pi^+)$
for $1<M^2(K^-\pi^+)<1.75\,\mathrm{GeV}^2$

fit for model with K*'s

fit for double Z model

Z_1 contribution

Z_2 contribution

$$M_{Z_1} = 4051 \pm 14\,^{+20}_{-41}\ \mathrm{MeV}$$

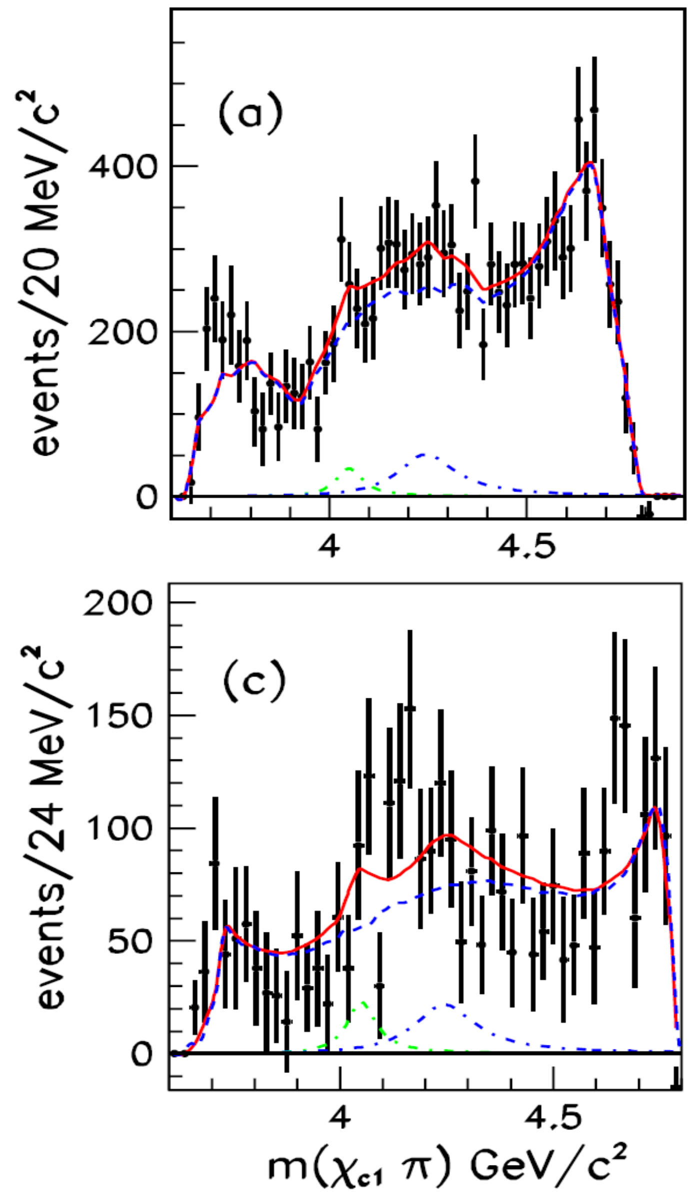
$$\Gamma_{Z_1} = 82\,^{+21}_{-17}\,^{+47}_{-22}\ \mathrm{MeV}$$

$$M_{Z_2} = 4248\,^{+44}_{-29}\,^{+180}_{-35}\ \mathrm{MeV}$$

$$\Gamma_{Z_2} = 177\,^{+54}_{-39}\,^{+316}_{-61}\ \mathrm{MeV}$$

BaBar doesn't see significant $Z^{\pm} \to \chi_{c1}\pi^{\pm}$

PRD85, 052003 (2012)



$$\mathcal{B}(\bar{B}^0 \to Z_1(4050)^+ K^-) \times \mathcal{B}(Z_1(4050)^+ \to \chi_{c1}\pi^+) < 1.8 \times 10^{-5},$$

Belle: $(3.0^{+1.5}_{-0.8}{}^{+3.7}_{-1.6})\mathrm{x}10^{-5}$

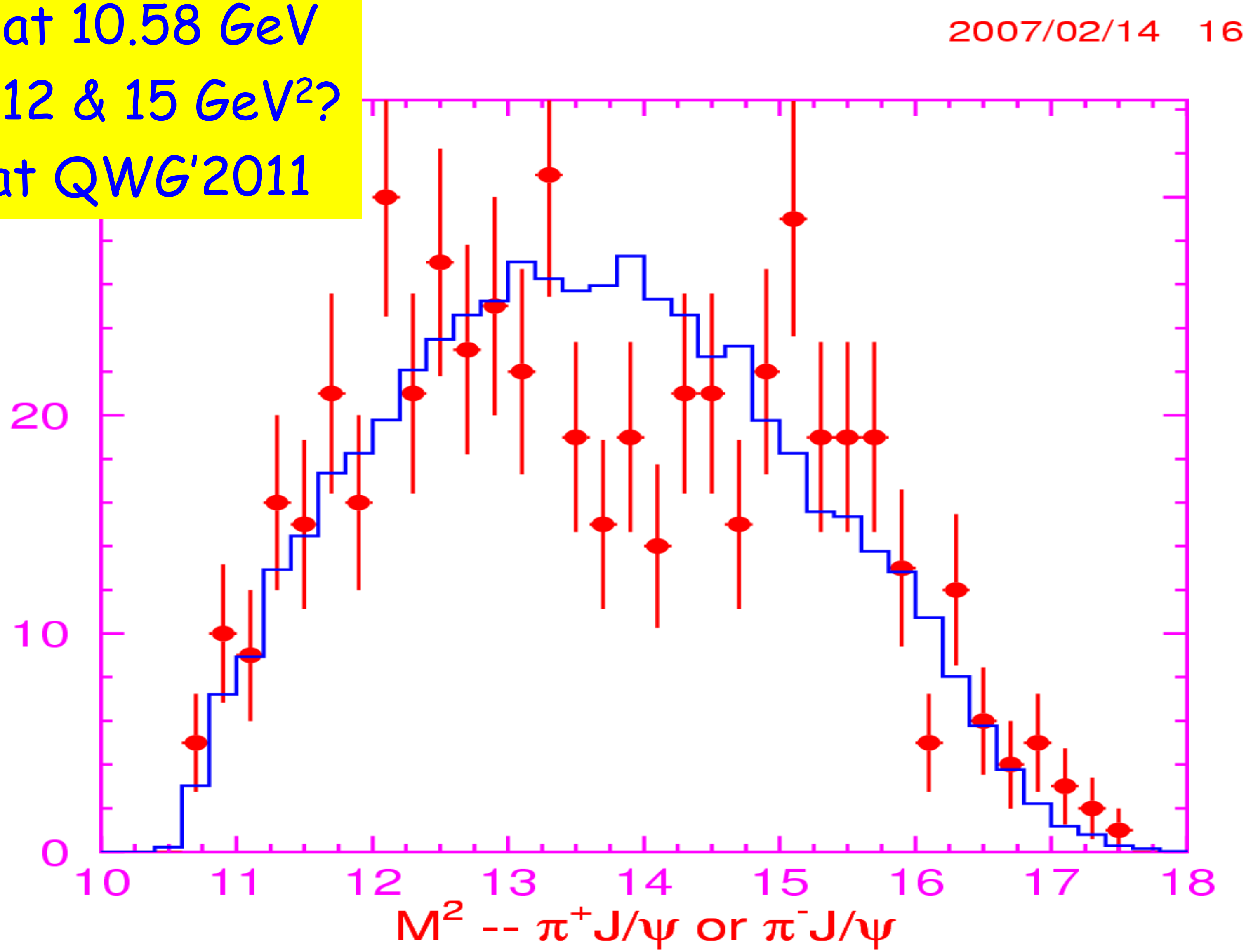
$$\mathcal{B}(\bar{B}^0 \to Z_2(4250)^+ K^-) \times \mathcal{B}(Z_2(4250)^+ \to \chi_{c1}\pi^+) < 4.0 \times 10^{-5},$$

Belle: $(4.0^{+2.3}_{-0.9}{}^{+19.7}_{-0.5})\mathrm{x}10^{-5}$

"We find that it is possible to obtain a good description of our data without the need for additional resonances in the $\chi_{c1}\pi$ system."

M(ππJ/ψ)∈[4.2, 4.4] GeV via ISR

550/fb at 10.58 GeV
Peaks at 12 & 15 GeV^2?
Shown at QWG'2011



XYZ states

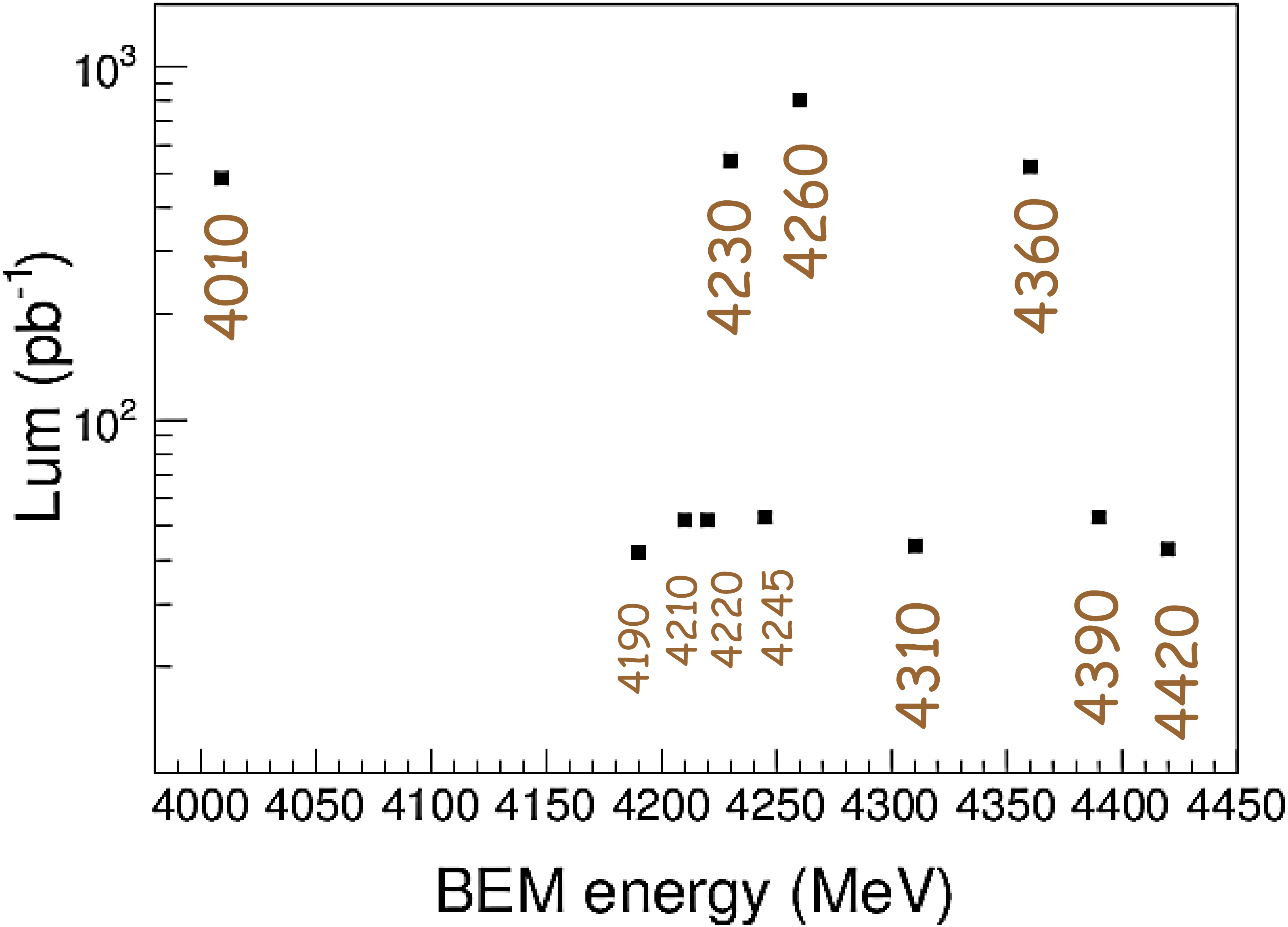
neutral X and Y

Name	J^{PC}	Γ(MeV)	Decay modes	Experiments	interpretation
X(3872)	$1^{++}/2^{-+}$	<1.2	$\pi\pi J/\psi$, $\gamma J/\psi$, DD^*, …	Belle/CDF/D0/BaBar/ LHCb	$\bar{D}D^*$ molecule?
X(3940)	$0^{?+}$	~37	DD^* (not DD, $\omega J/\psi$)	Belle	η_c''(?)
Y(3940)	$?^{?+}$	~30	$\omega J/\psi$ (not DD^*)	Belle/BaBar	
Y(4140)	$?^{?+}$	~11	$\phi J/\psi$	CDF(not Belle/LHCb)	$c\underline{c}s\underline{s}$?
X(4160)	$0^{?+}$	~140	D^*D^* (not DD, DD^*)	Belle	η_c''(?)
Y(4008)	1^{--}	~220	$\pi\pi J/\psi$	Belle (not Babar)	$\psi(4040)$?
Y(4260)	1^{--}	~80	$\pi\pi J/\psi$	BaBar/CLEO/Belle	$c\underline{c}g$ hybrid?
X(4350)	$?^{?+}$	~13	$\gamma\gamma$, $\phi J/\psi$	Belle	$c\underline{c}s\underline{s}$?
Y(4360)	1^{--}	~75	$\pi\pi\psi(2S)$	BaBar/Belle	
Y(4660)	1^{--}	~50	$\pi\pi\psi(2S)$, $\Lambda_c\Lambda_c$ (?)	Belle/BaBar	

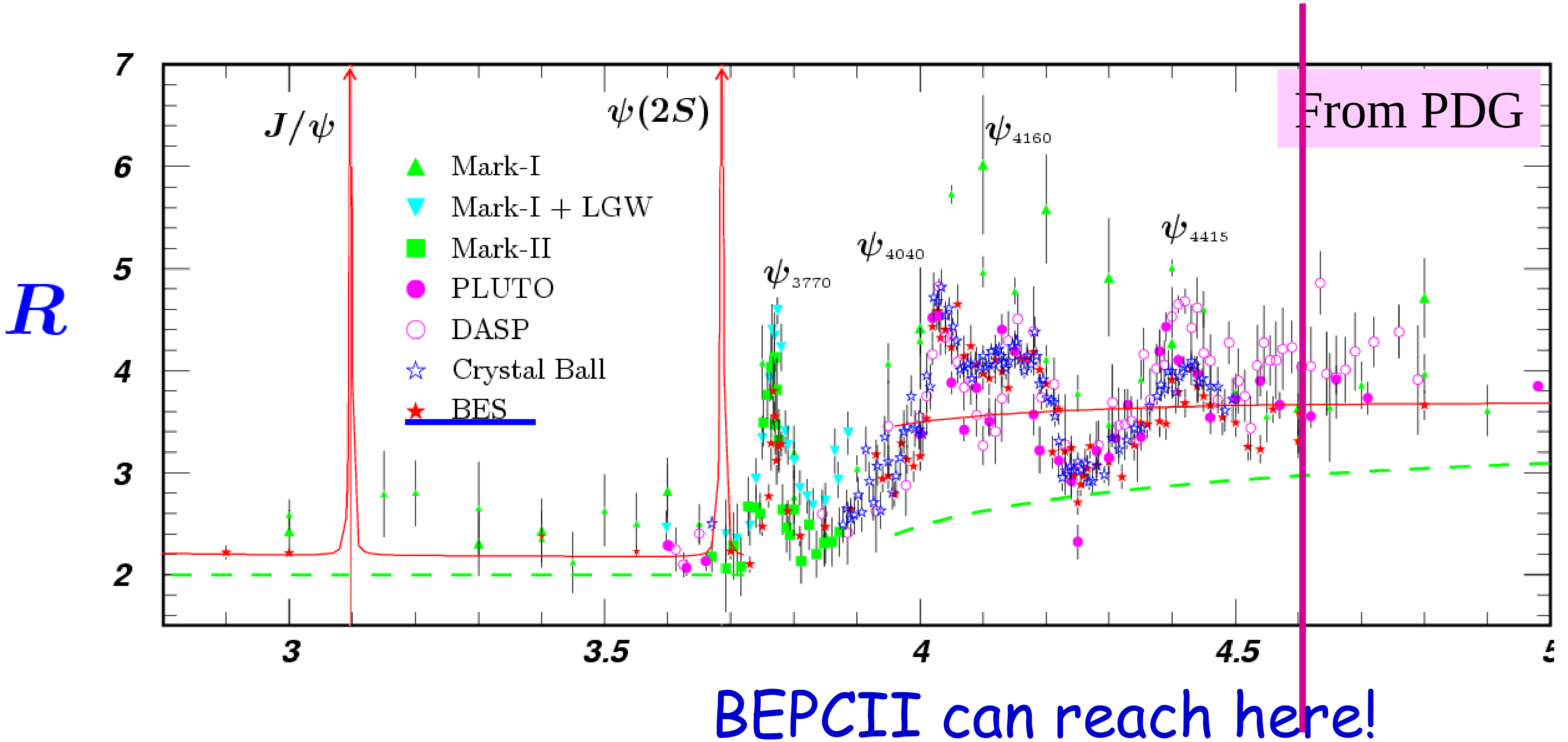
charged Z

$Z^{\pm}(4430)$	$?^{??}$	~100	$\psi(2S)\pi^{\pm}$	Belle (not Babar)	4-quark?
$Z^{\pm}(4050)$	$?^{??}$	~80	$\chi_{c1}\pi^{\pm}$	Belle (not Babar)	4-quark?
$Z^{\pm}(4250)$	$?^{??}$	~180	$\chi_{c1}\pi^{\pm}$	Belle (not Babar)	4-quark?

BESIII data samples for XYZ study



BESIII: 粲偶素、类粲偶素的产生



ψ/Υ 粒子可以直接产生（出现在上图中）

电荷共轭宇称为正的粒子可以通过辐射跃迁产生