Charged Z_c at BESIII

— a charged charmoniumlike structure —

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(for the BESIII Collaboration)

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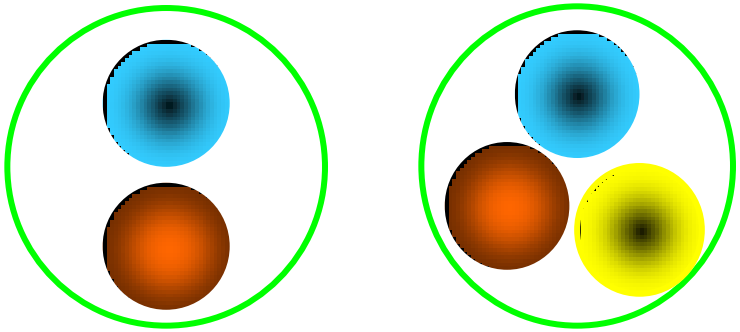
Outline

- Conventional & exotic hadrons
- How to study exotic hadrons
- BESIII analysis & results
- Summary & perspectives

Hadrons：normal & exotic

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

Quark model



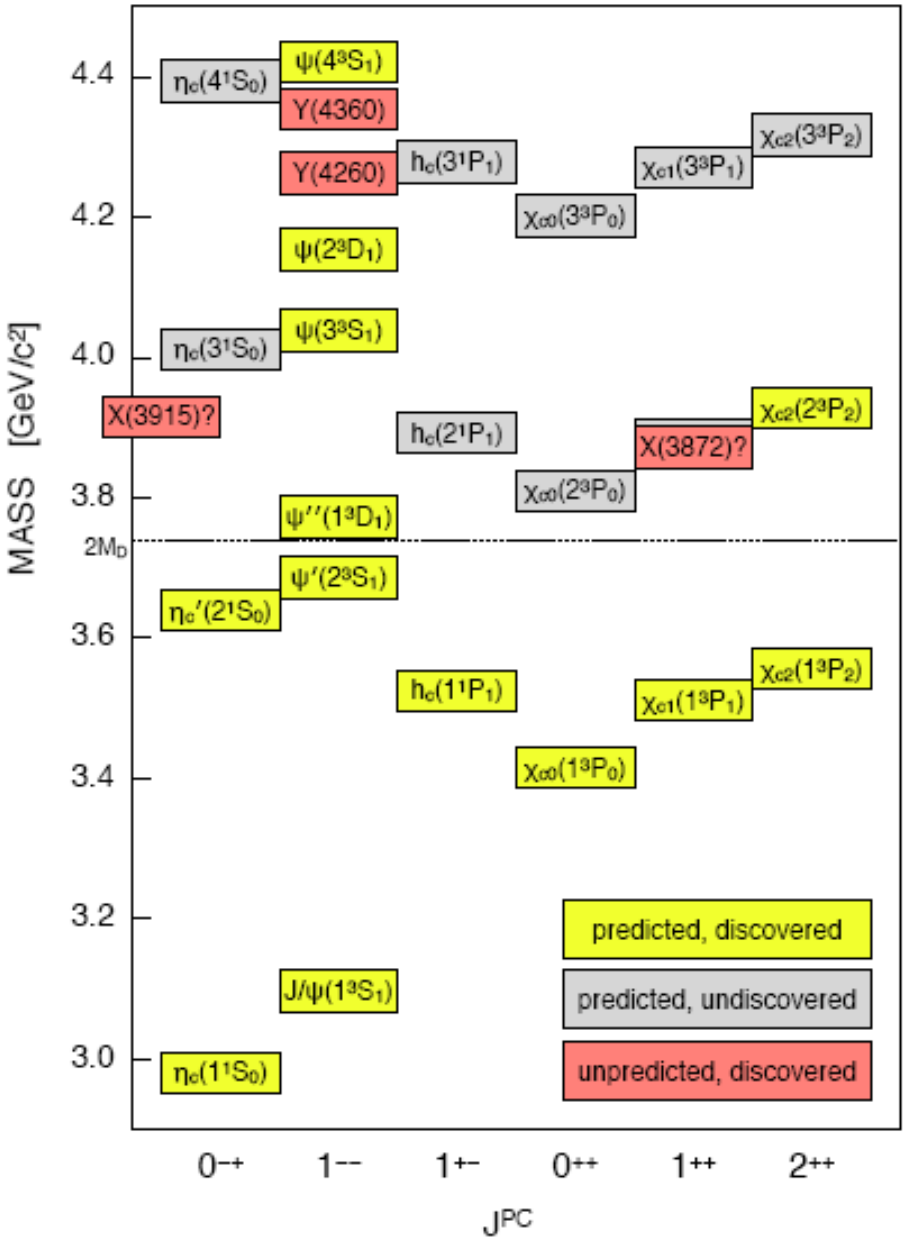
- QCD allows hadrons with $N_{quarks} \neq 2, 3$
  - glueball : $N_{quarks} = 0$ (gg, ggg, …)
  - Hybrid : $N_{quarks} = 2(3)$ + excited gluon
  - multiquark state : $N_{quarks} > 3$
  - molecule : bound state of more than 2 hadrons

A bit history on exotics hunting

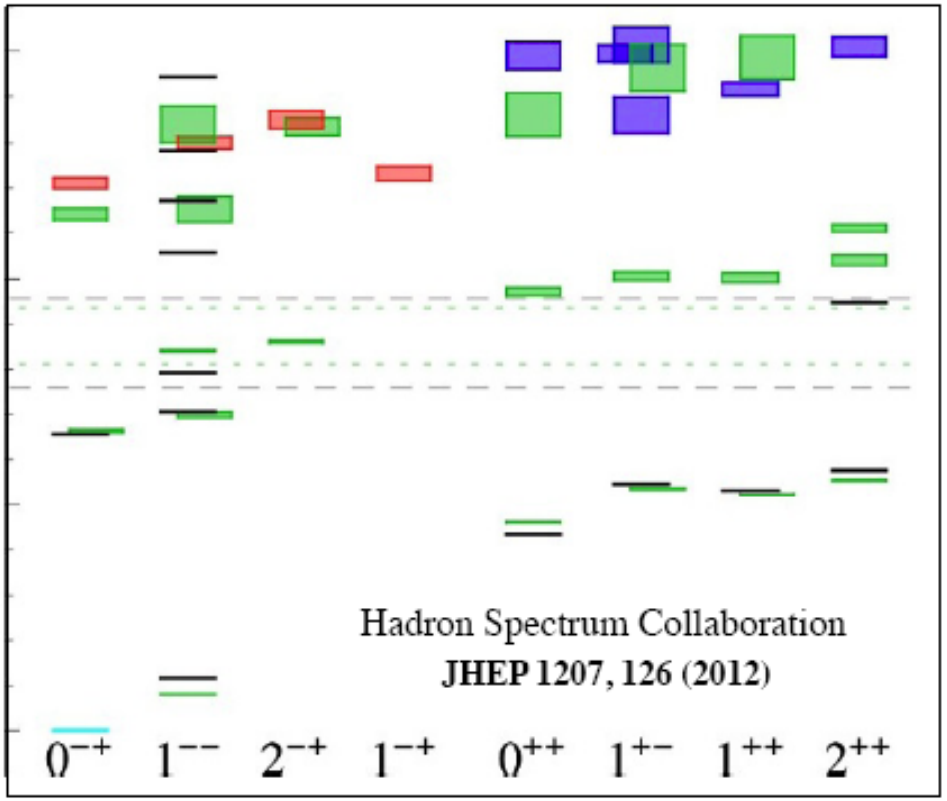
- "The absence of exotics is one of the most obvious features of QCD" – R. L. Jaffe, 2005
- Deuteron ➔ H state, $\Omega^-\Omega^-$ bound state, …
- No solid signature of glueballs
- Pentaquark state appeared and disappeared

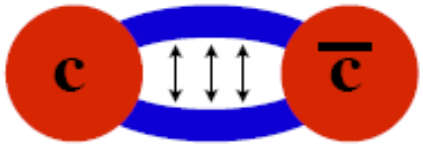
  ("The story of pentaquark shows how poorly we understand QCD" – F. Wilczek, 2005)
- There are lots of new states from low to high mass in various experiments! Are they normal or exotic?

Charmonium spectroscopy



Lattice QCD:

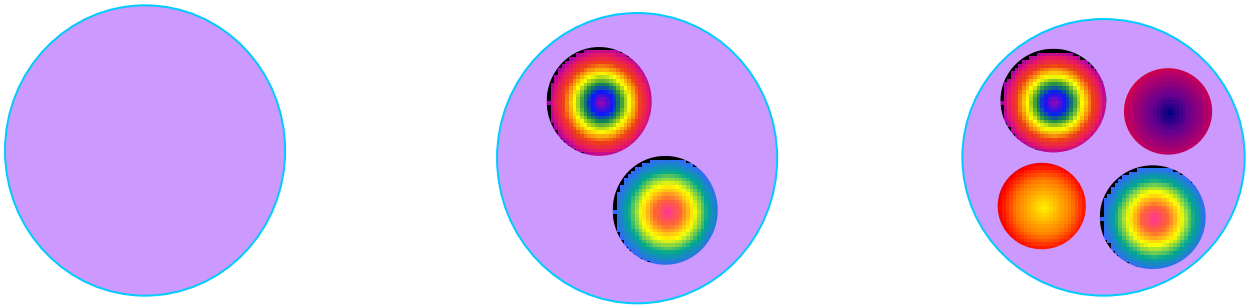




HYBRID CHARMONIUM?

How to identify an exotic charmonium state?

- Find a clear signature for exotic state!



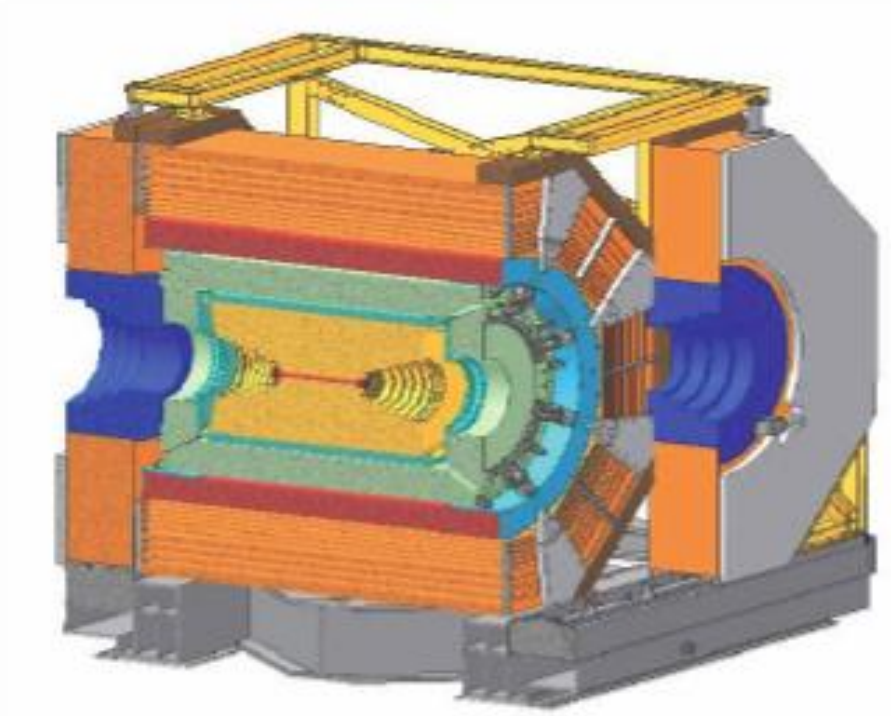
- Decays to charmonium thus has a $\bar{c}c$ pair!
- With electric charge thus has two more light quarks!

$$\rightarrow N_{quark} \geq 4 !$$

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

The BESIII Experiment

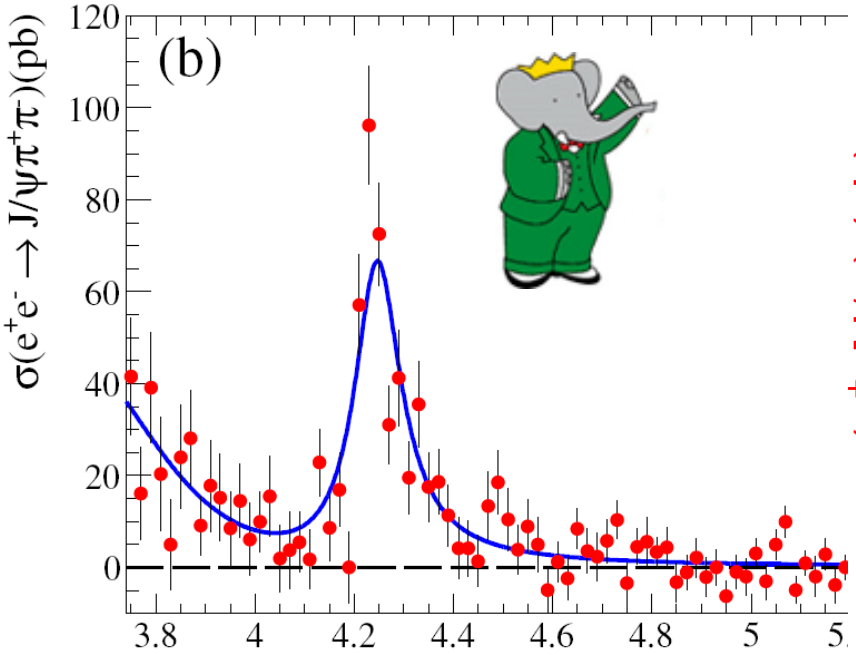
- Located at the Institute for High Energy Physics (Beijing)
  - BEPCII: symmetric e^+e^- collisions up to 4.4 GeV center of mass
- Hermetic BESIII detector:
  - tracking chamber: 0.5% transverse momentum resolution at 1 GeV/c
  - CsI(Tl) calorimeter: 2.5% energy resolution for 1 GeV photons
  - time of flight
  - muon detector
- Collaboration: about 350 members from 50 institutions in 11 countries

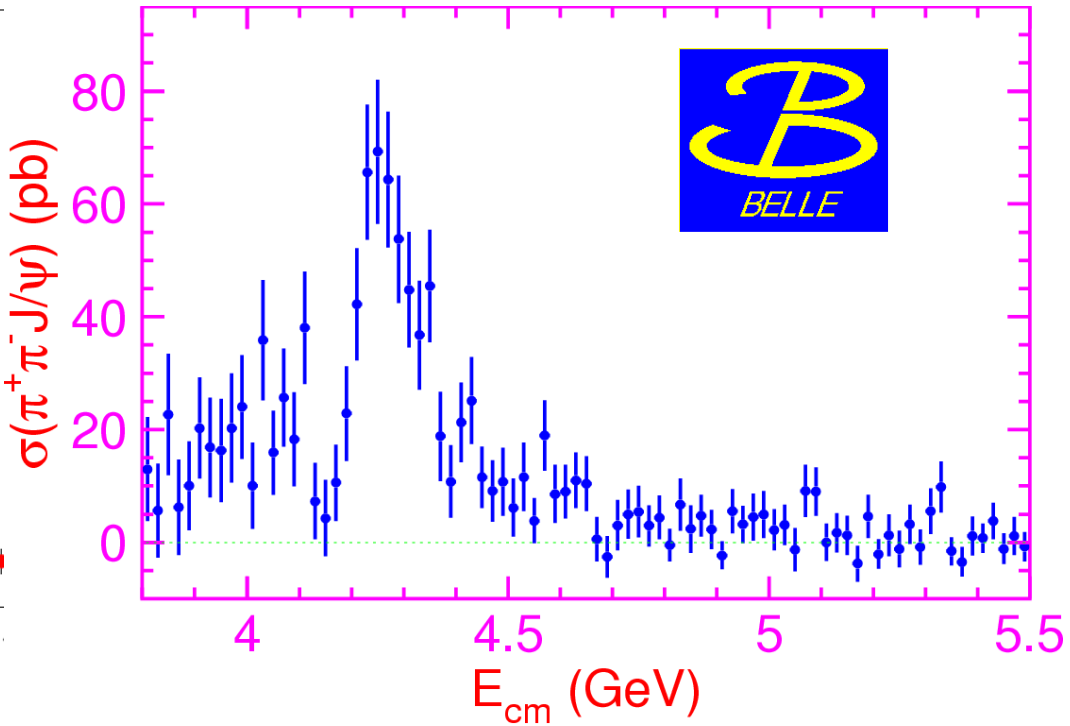


The first BESIII physics run was completed in 2009.

What do we do at BESIII

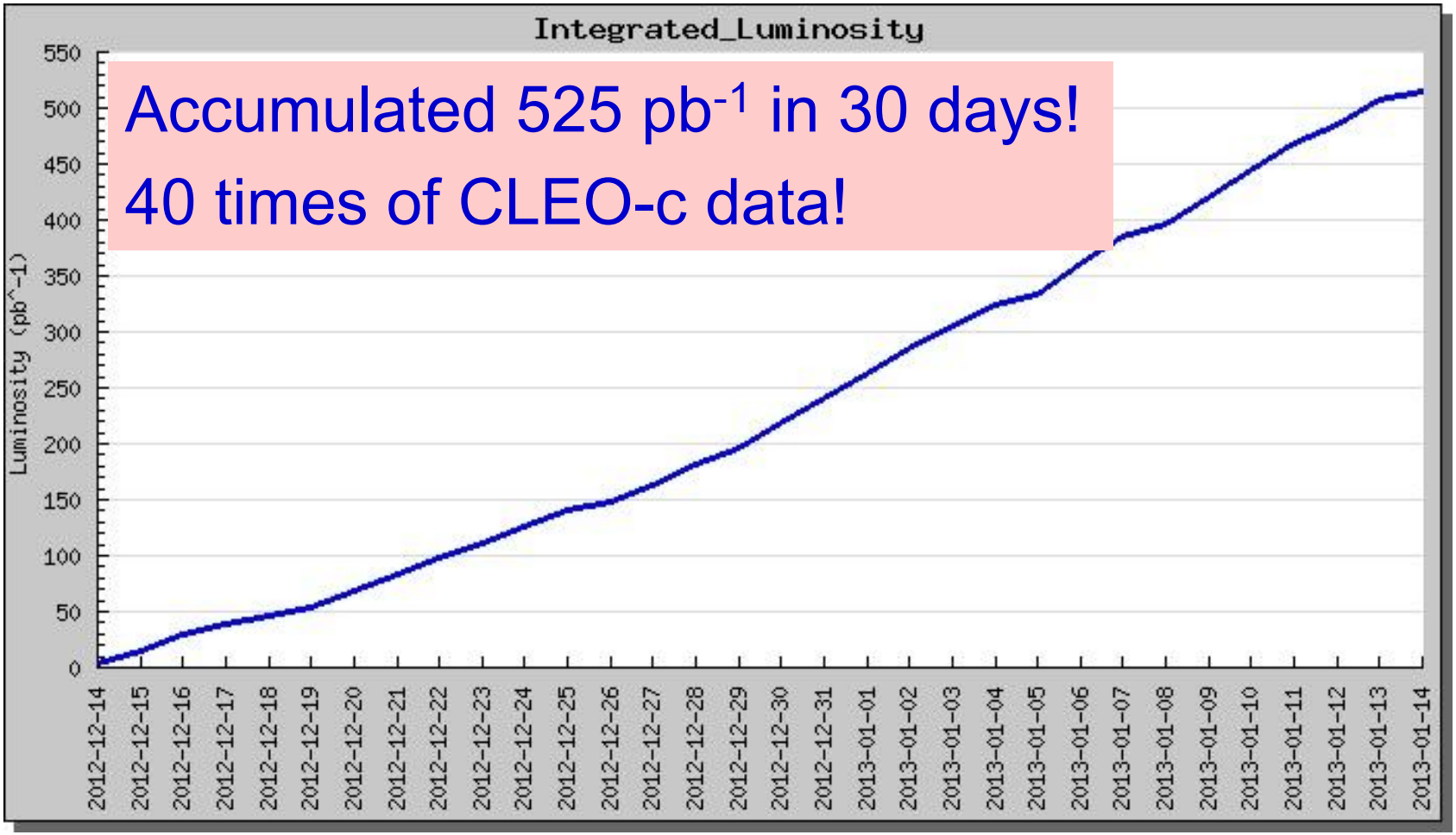
We may search for such state if it decays into $\pi^{\pm}J/\psi$!





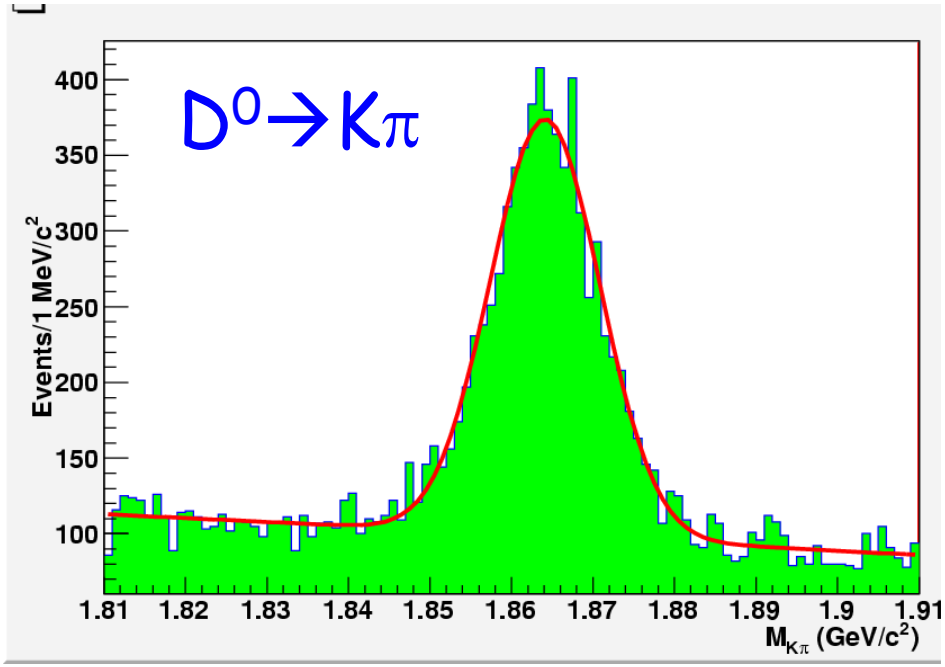
- $\sigma(e^+e^- \to \pi^+\pi^- J/\psi)$ reaches maximum at ~4.26 GeV
- We proposed a 45 days' data taking for 500 pb^{-1} data at peak
- ~1500 reconstructed events are expected [3xB-factories]

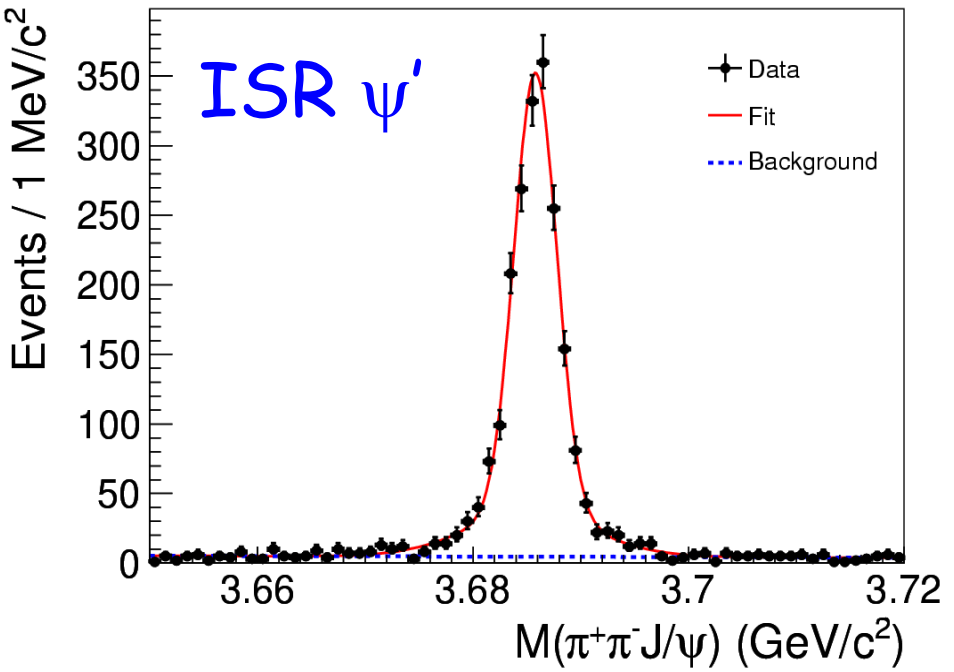
Data taking at BESIII



- Highest energy BEPCII ever reach, L_{peak} ~ 5.3x10^{32}/cm^2/s !
- BEMS measures Ecm at 1 MeV level !
- Low background, low noise, all sub-detectors excellent !

Data quality is excellent





$\Delta M_D = 0.5 \pm 0.2$ MeV

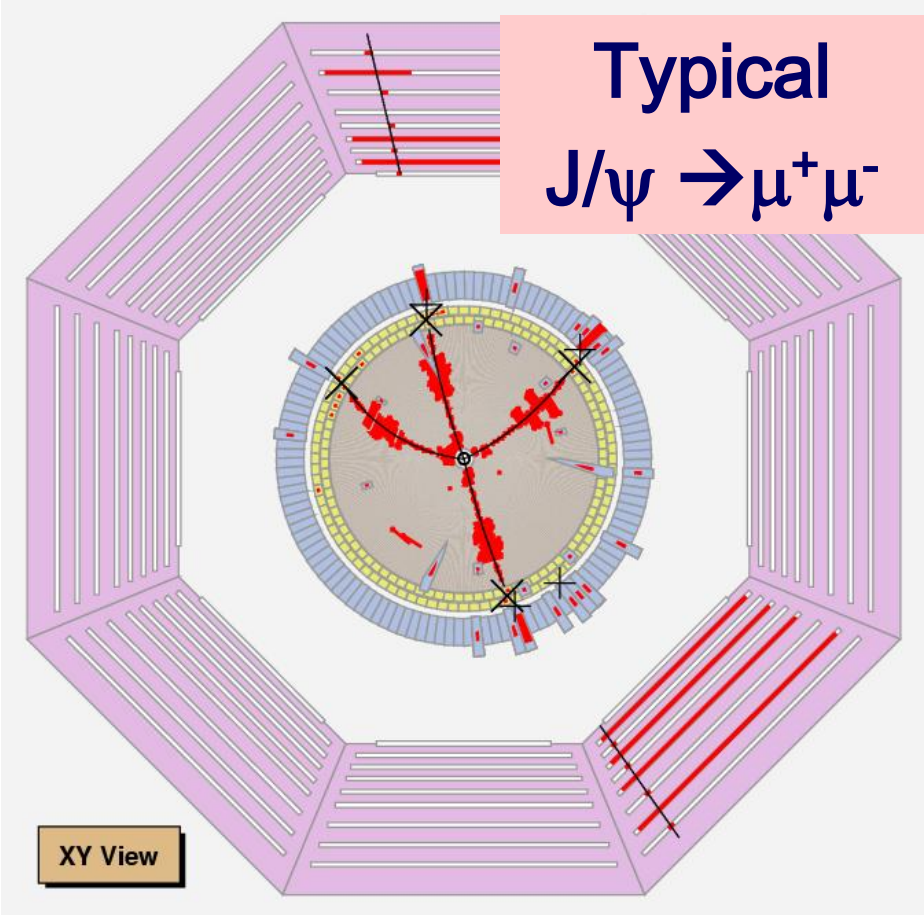
$\sigma M_D = 6.0 \pm 0.1$ MeV

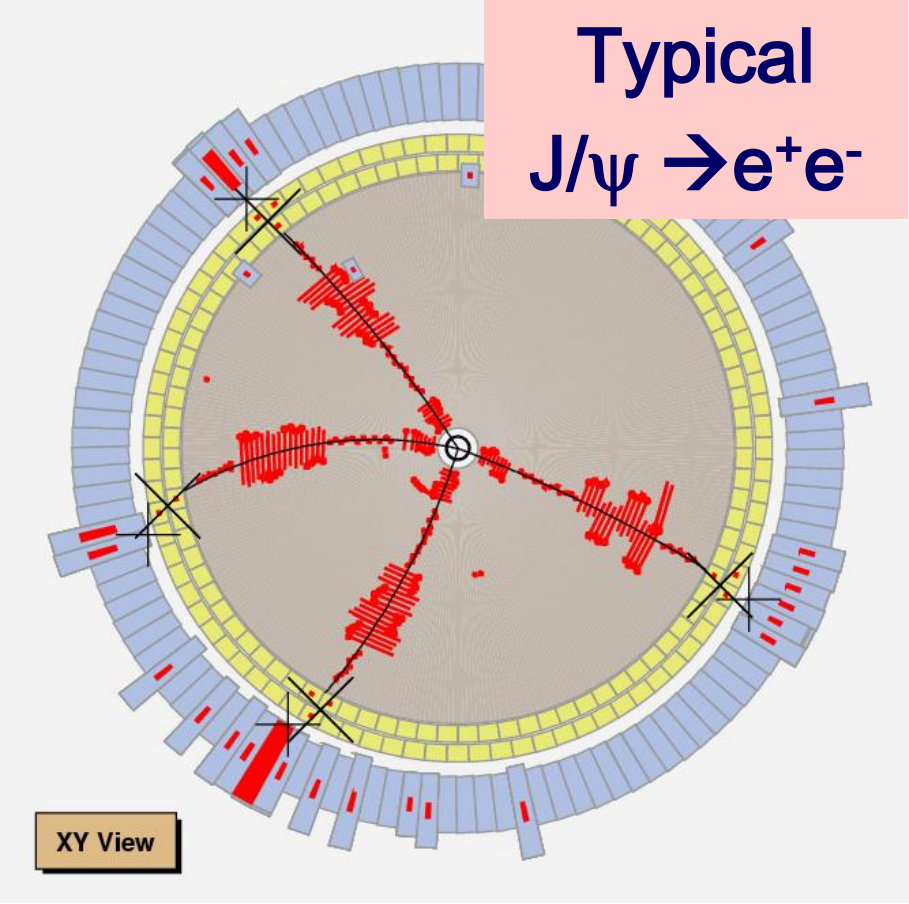
$\Delta M_{\psi'} = 0.2 \pm 0.1$ MeV

$\sigma M_{\psi'} = 2.0 \pm 0.1$ MeV

- Data calibration, reconstruction, MC simulation were finished shortly after the data taking …
- Production version was ready earlier March …

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

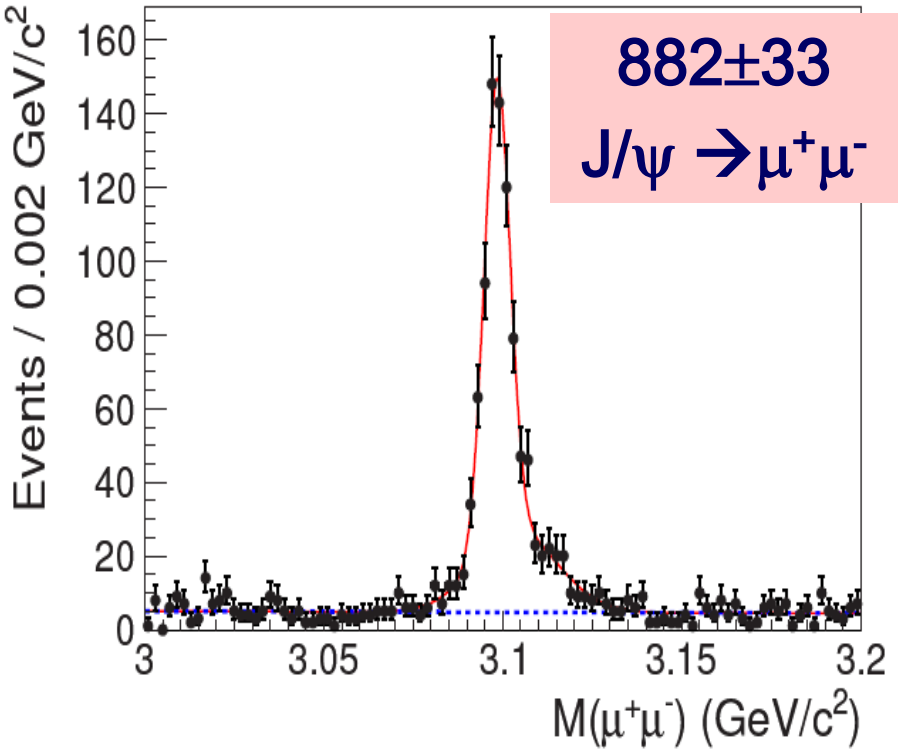


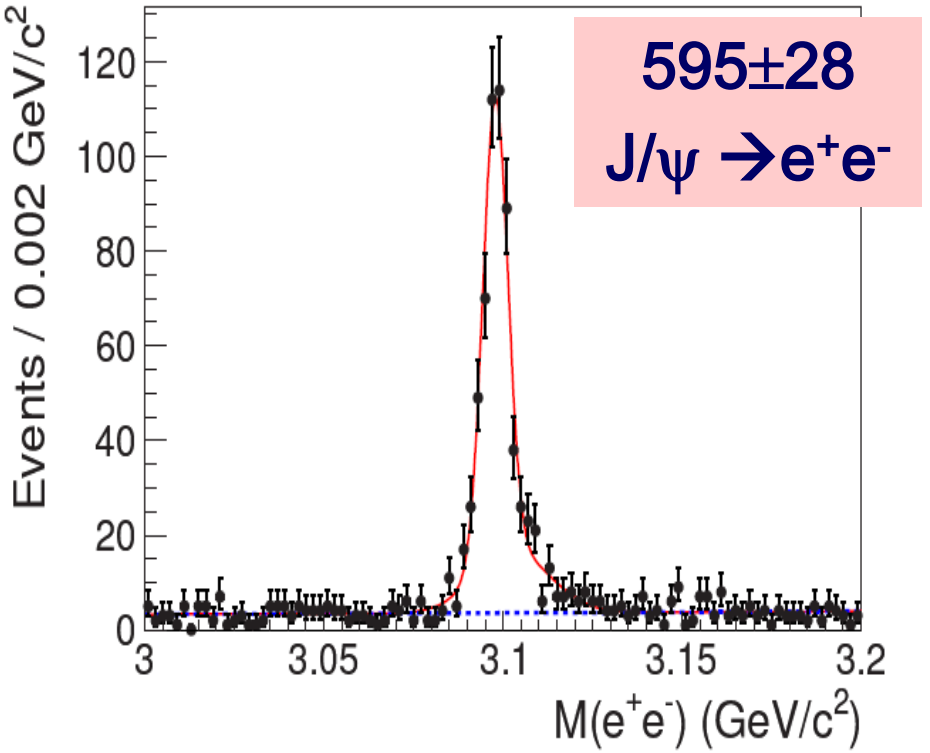


- Select 4 charged tracks and reconstruct J/ψ with lepton pair.
- Very clean sample, very high efficiency. Use kinematic fit.
- Only use MDC & EMC information, MC simulation reliable.

The J/ψ signals

BESIII: arXiv:1303.5949

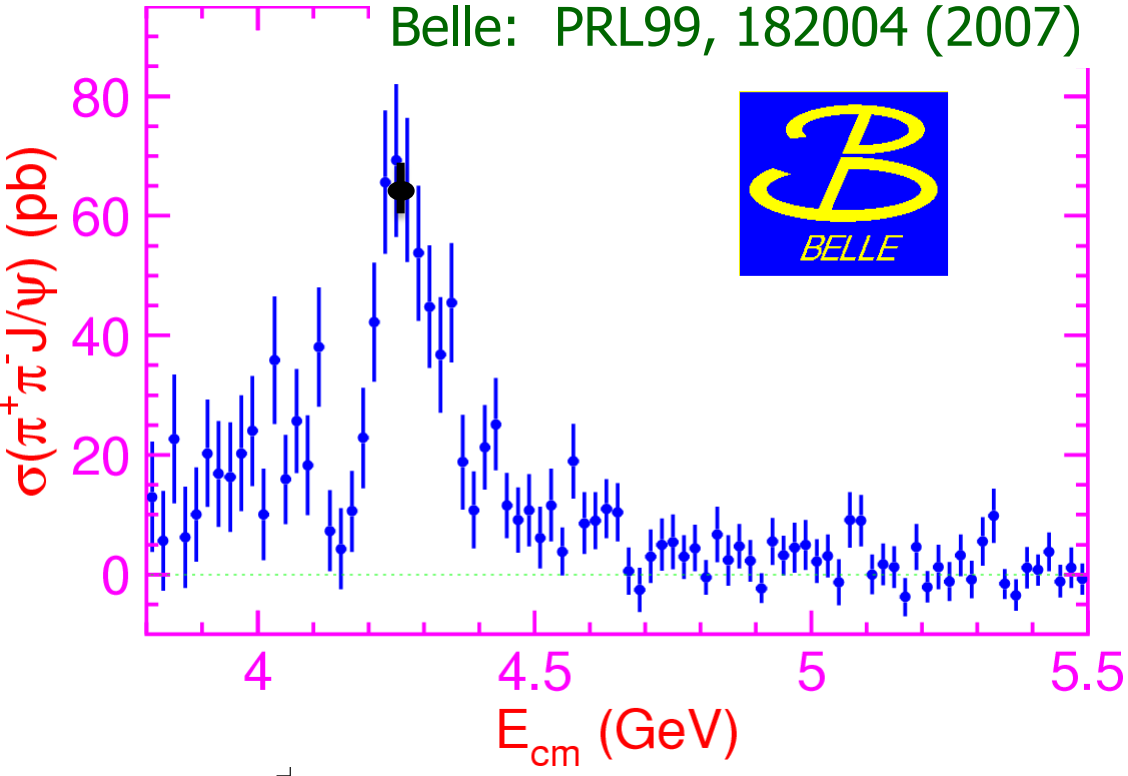




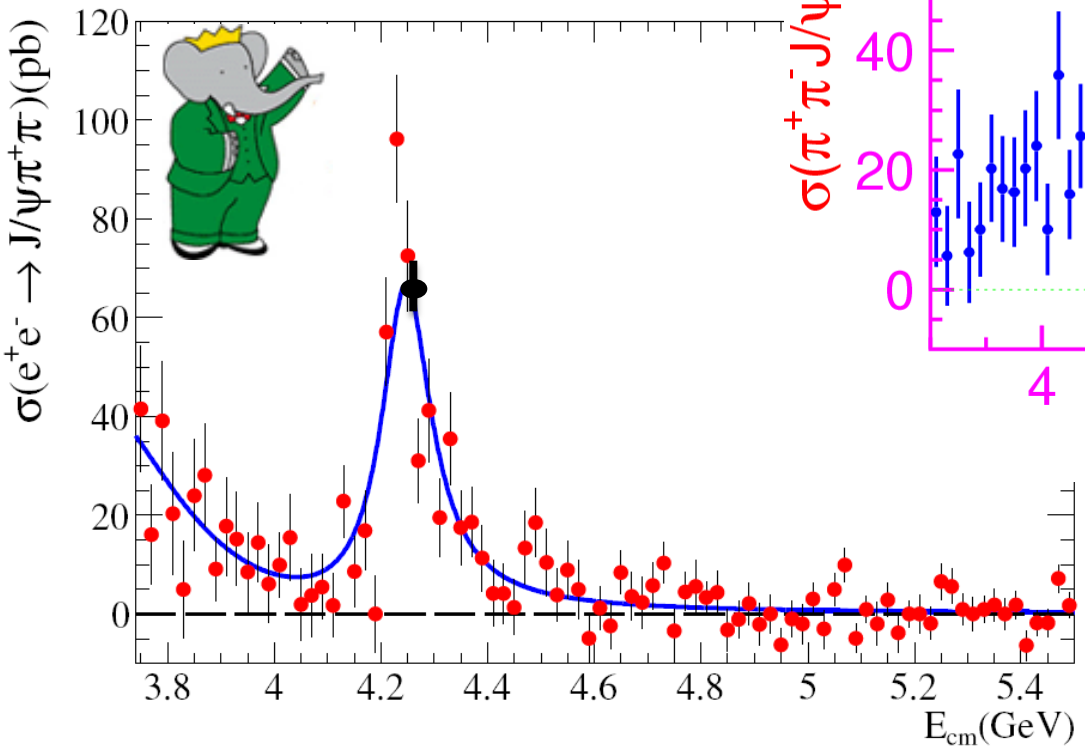
- Dominant background $e^+e^- \to \pi^+\pi^-\pi^+\pi^-$
- J/ψ signal: [3.08,3.12] GeV
- J/ψ sideband: [3.0,3.06] GeV or [3.14,3.20] GeV, 3xsignal
- At least 4 independent analyses, all get similar results !

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

Belle: PRL99, 182004 (2007)



BaBar: PRD86, 051102 (2012)



BESIII: arXiv:1303.5949

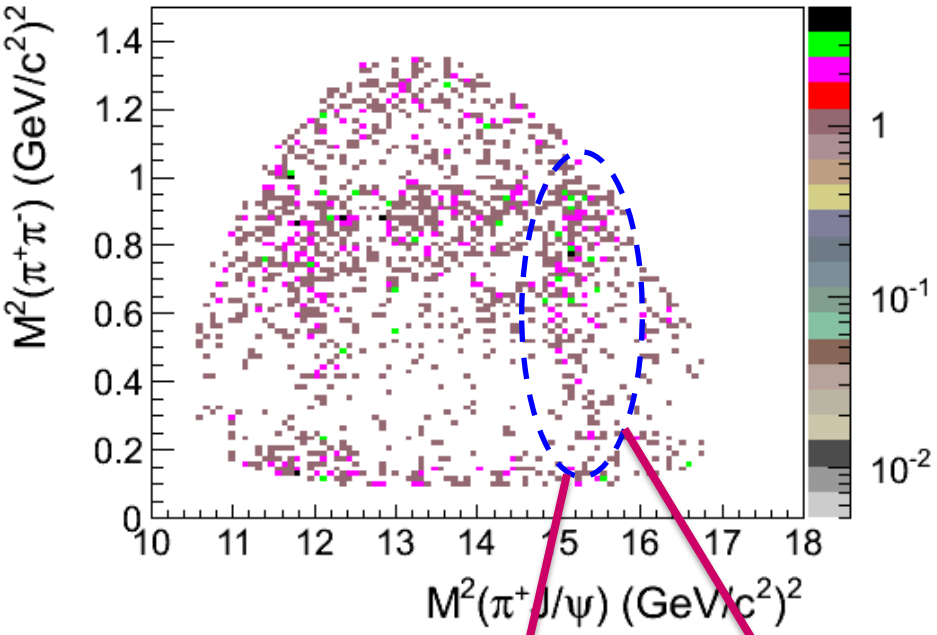
BESIII: $\sigma(e^+e^- \to \pi^+\pi^- J/\psi)$ = (62.9±1.9±3.7) pb

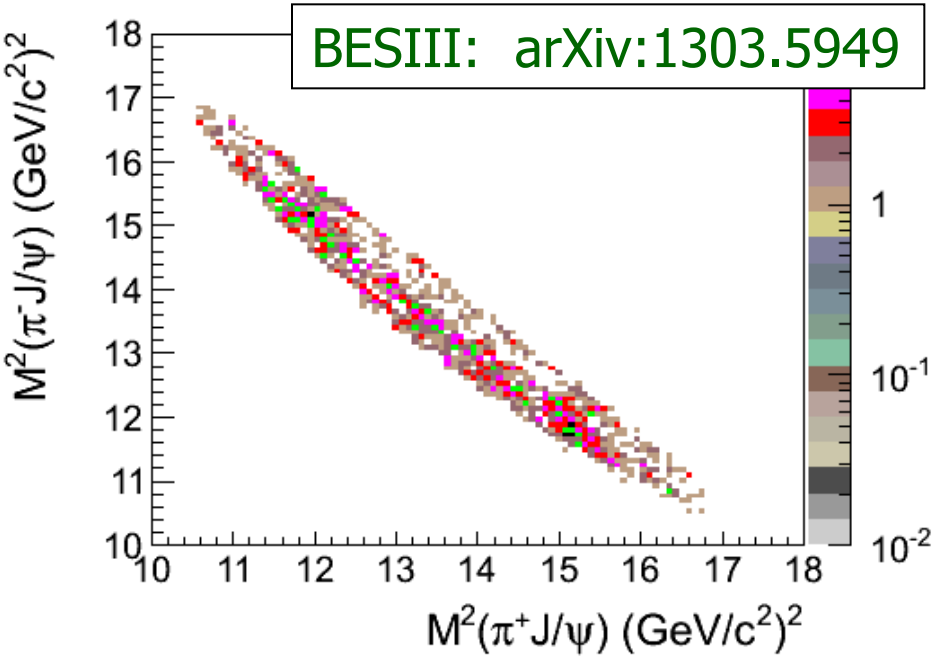
Agree with BaBar & Belle!

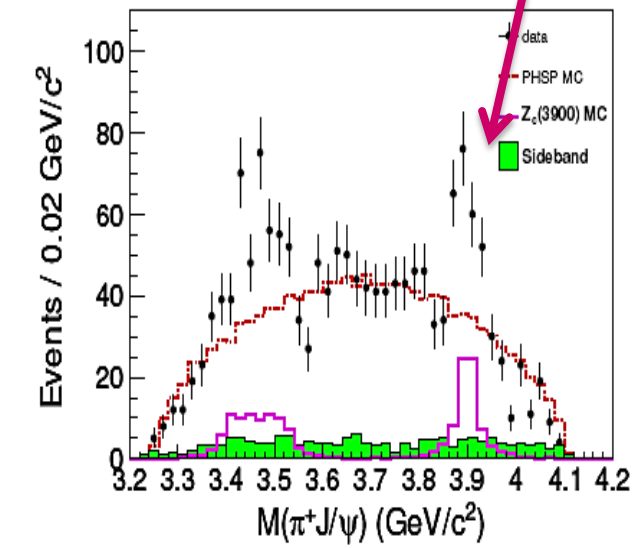
Best precision!

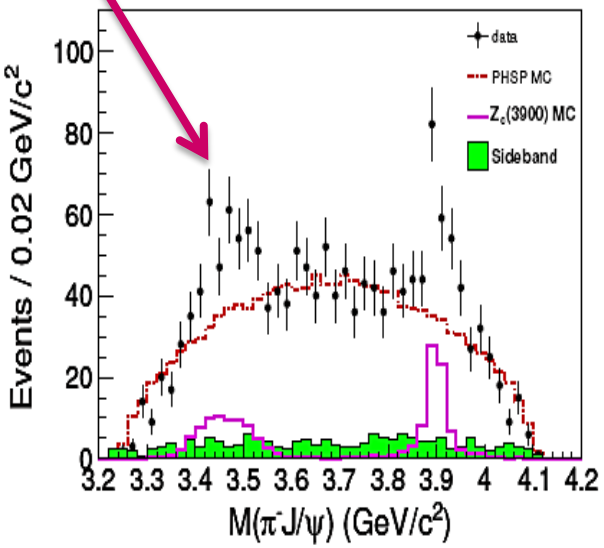
Dalitz plots & 1D projections

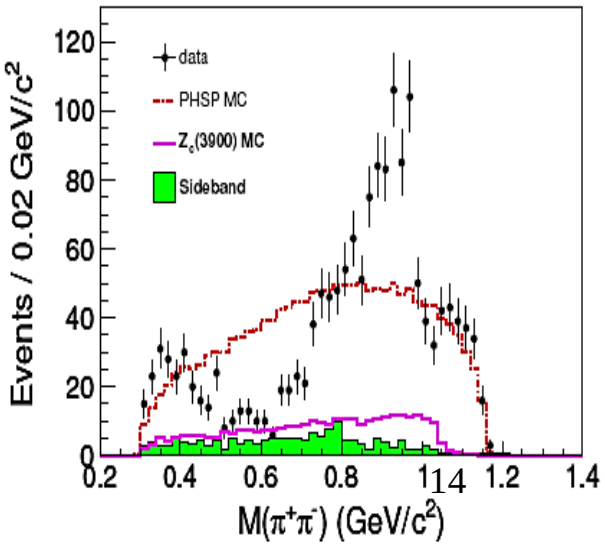
BESIII: arXiv:1303.5949





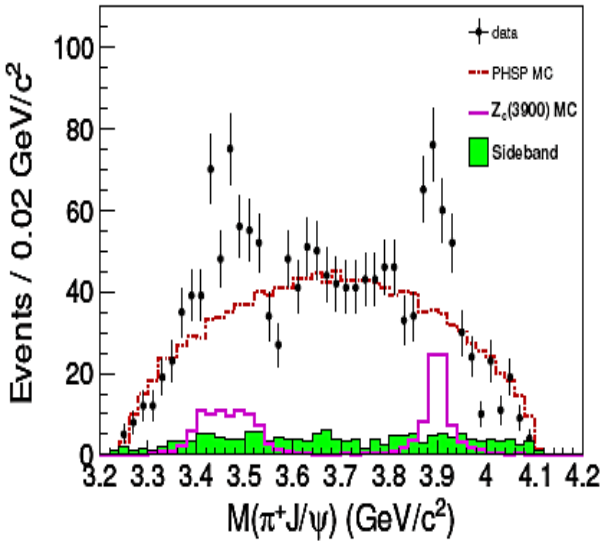


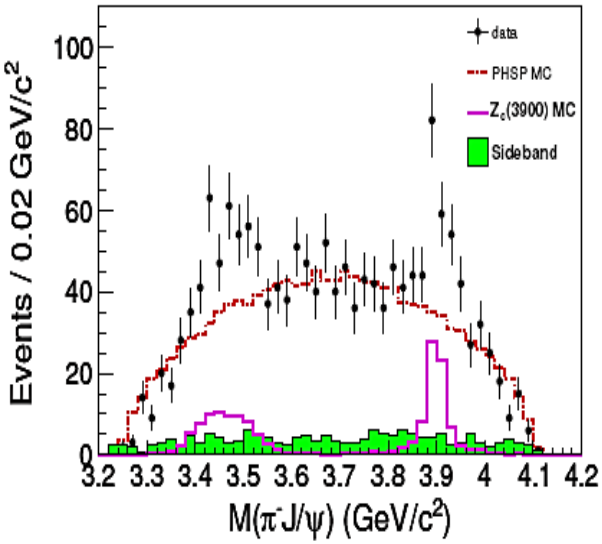


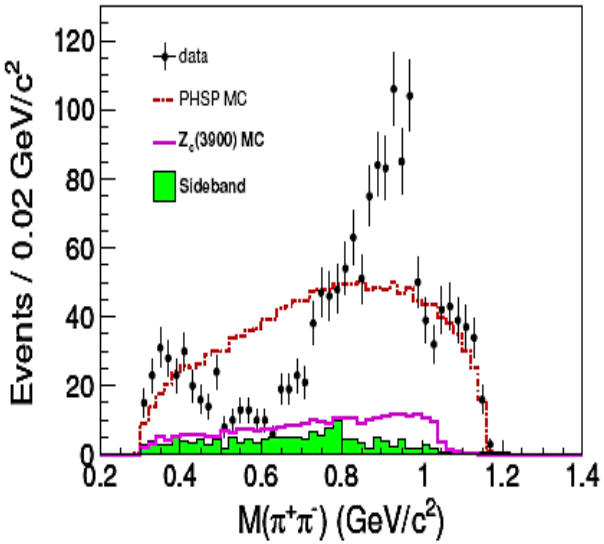


Is it a real signal?

- 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

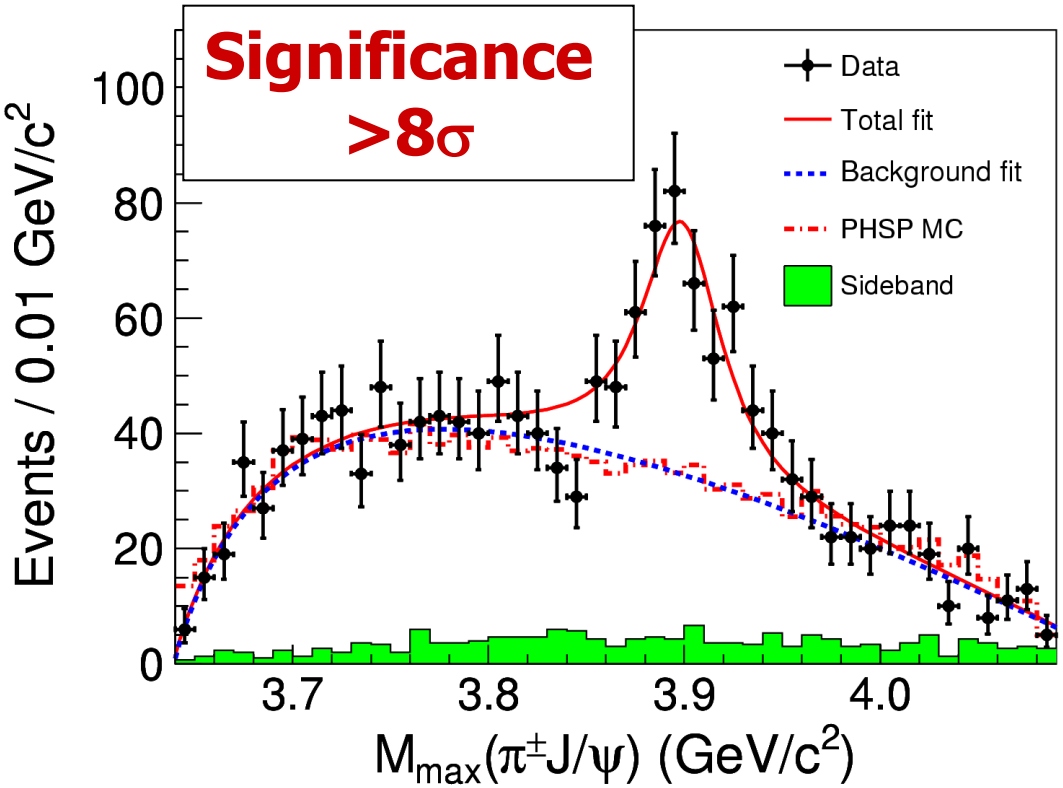




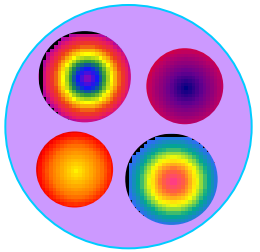


The $Z_c(3900)$ signal

BESIII: arXiv:1303.5949



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

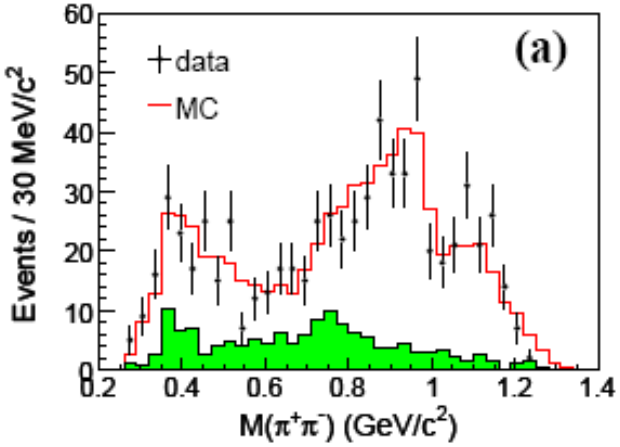


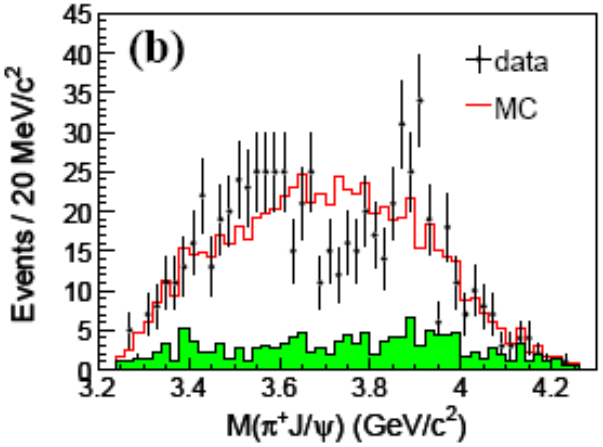
- S-wave Breit-Wigner with efficiency correction
- Mass = (3899.0±3.6±4.9) MeV
- Width = (46±10±20) MeV
- Fraction = (21.5±3.3±7.5)%

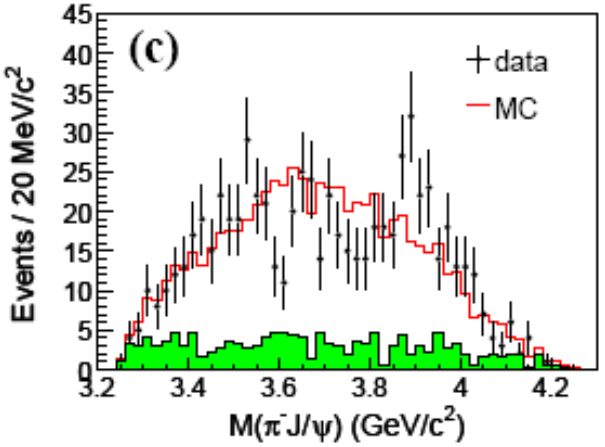
Comparison with BELL ISR observation

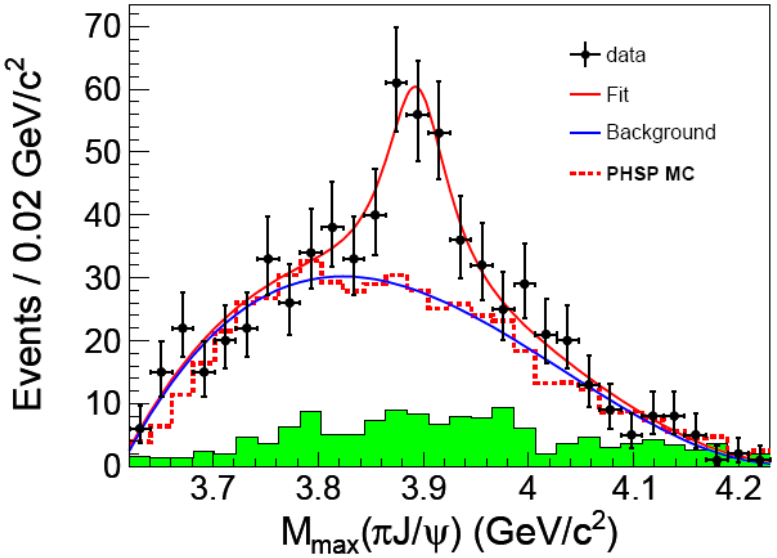
Using 967fb^{-1} data taken at Y(nS) peak

arXiv:1304.0121









$M = 3894.5 \pm 6.6 \pm 4.5$ MeV

$\Gamma = 63 \pm 24 \pm 26$ MeV

What next?

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

This triggered some theoretical works about the Zc structure:

• tetraquark state, molecular state, DD-loop rescattering structure.

Summary

- We observed a charged charmoniumlike structure, $Z_c(3900)$, in its $\pi^{\pm}J/\psi$ decays
- It is not a charmonium
- The nature is yet unknown
- We are working very hard to understand it better …

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.

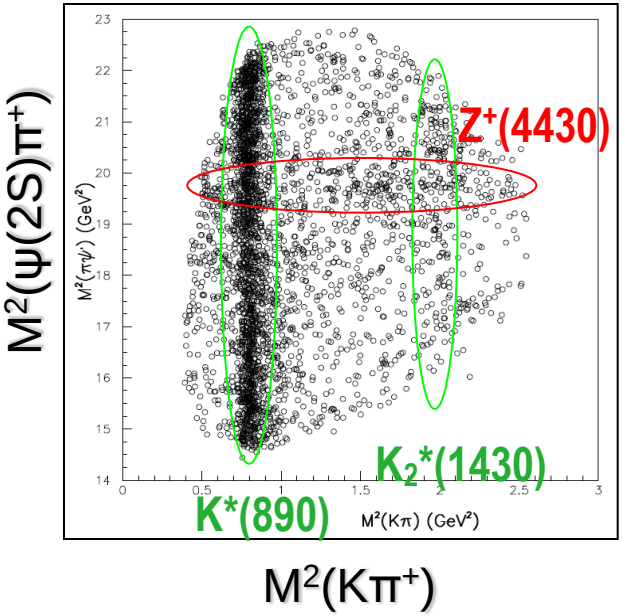
Source	Mass (MeV)	Width (MeV)	Ratio (%)
Absolute mass scale	1.8	-	-
S/P-wave	2.1	3.7	2.6
Flatté	2.1	15.4	0.0
Background shape	3.5	12.1	7.1
Resolution	-	1.0	0.2
Total	4.9	20.0	7.5

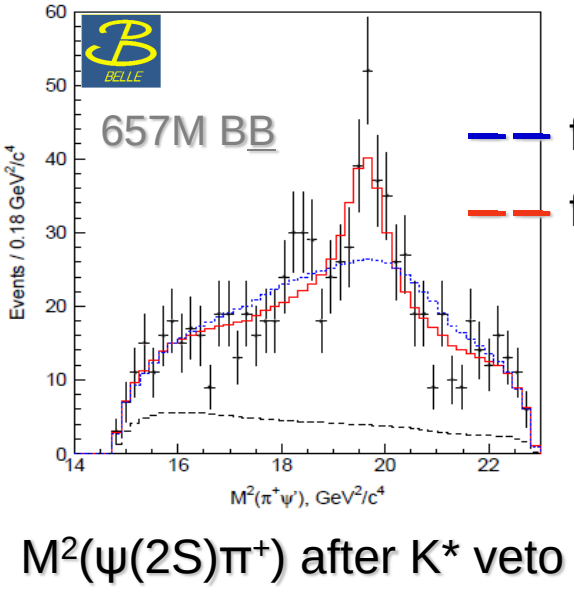
Belle observed $Z(4430)^{\pm}\to\psi(2S)\pi^{\pm}$

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





Significance: 6.4σ

fit for model with K*'s only

fit for model with K*'s and Z

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

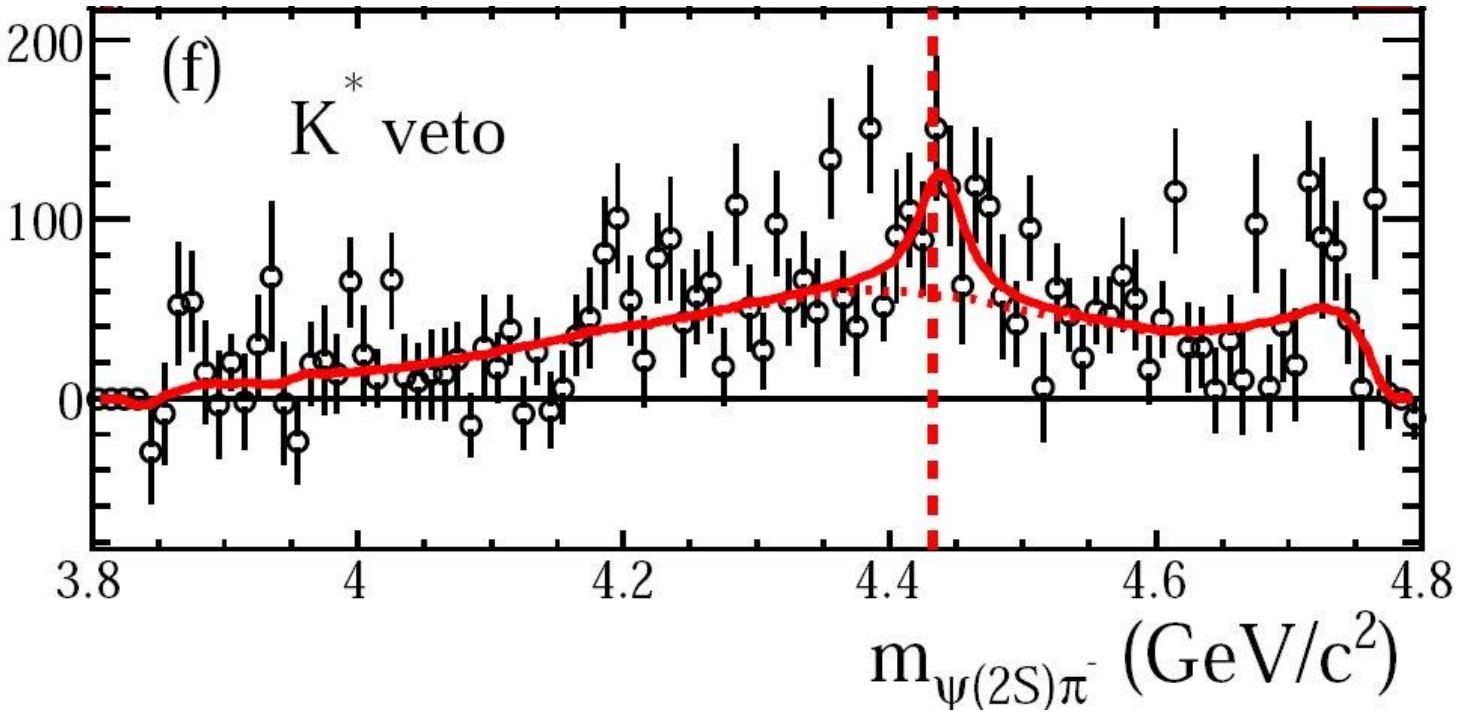
$$\Gamma = 107^{+86\,+74}_{-43\,-53}\ \text{MeV}$$

PRD80, 031104 (2009)

- **[cu][$\underline{\text{cd}}$] 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 $Z^{\pm}\to\chi_{c1}\pi^{\pm}$

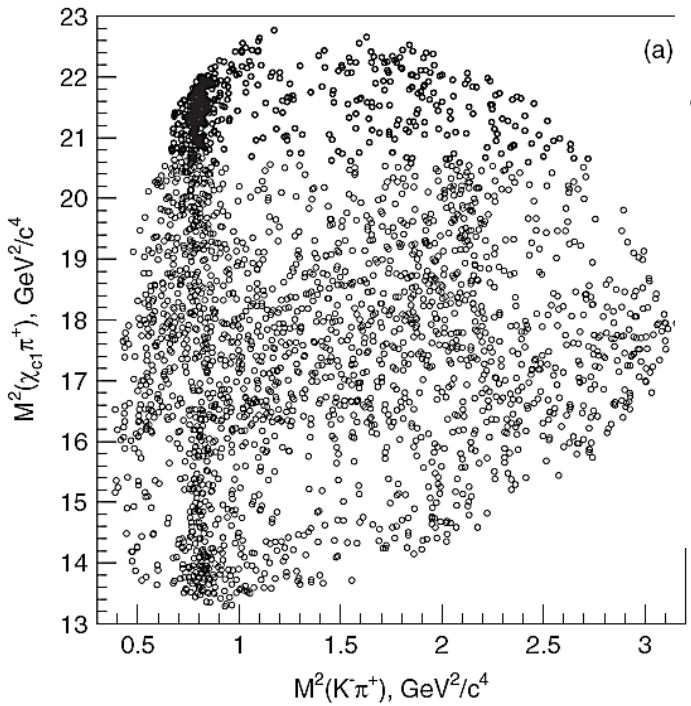
- Dalitz-plot analysis of $\underline{B^0}\to\chi_{c1}\pi^+K^-$ $\chi_{c1}\to J/\psi\gamma$ with 657M $B\underline{B}$
- Dalitz plot models: known $K^*\to K\pi$ only

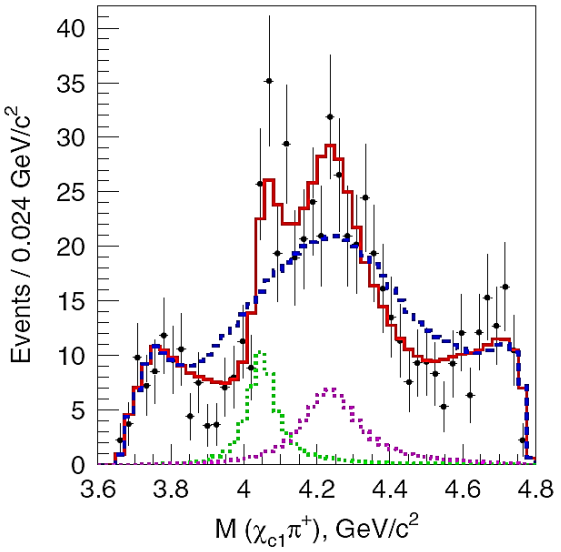
  K^*'s + one $Z\to\chi_{c1}\pi^{\pm}$

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

PRD 78, 072004 (2008)

Significance: 5.7σ





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

fit for model with K*'s

fit for double Z model

Z_1 contribution

Z_2 contribution

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

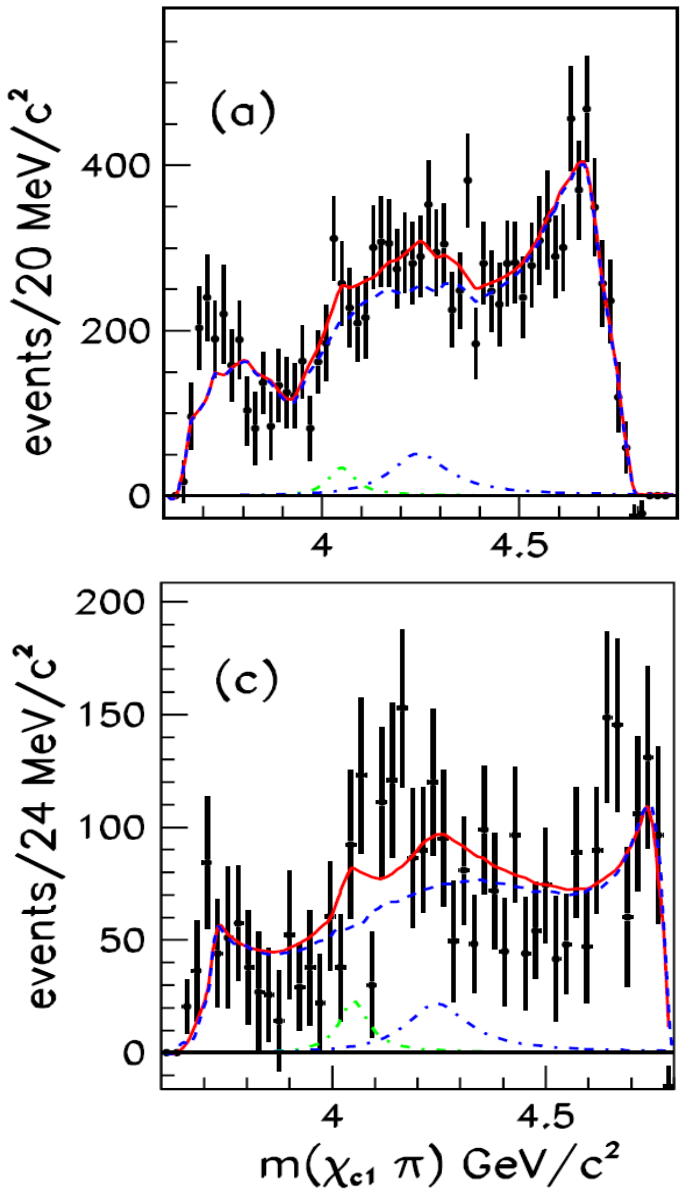
$$\Gamma_{Z_1} = 82\,^{+21\,+47}_{-17\,-22}\ \text{MeV}$$

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

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

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: $(3.0^{+1.5}_{-0.8}{}^{+3.7}_{-1.6})\times10^{-5}$

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

Belle: $(4.0^{+2.3}_{-0.9}{}^{+19.7}_{-0.5})\times10^{-5}$

"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