XYZ states at BESIII

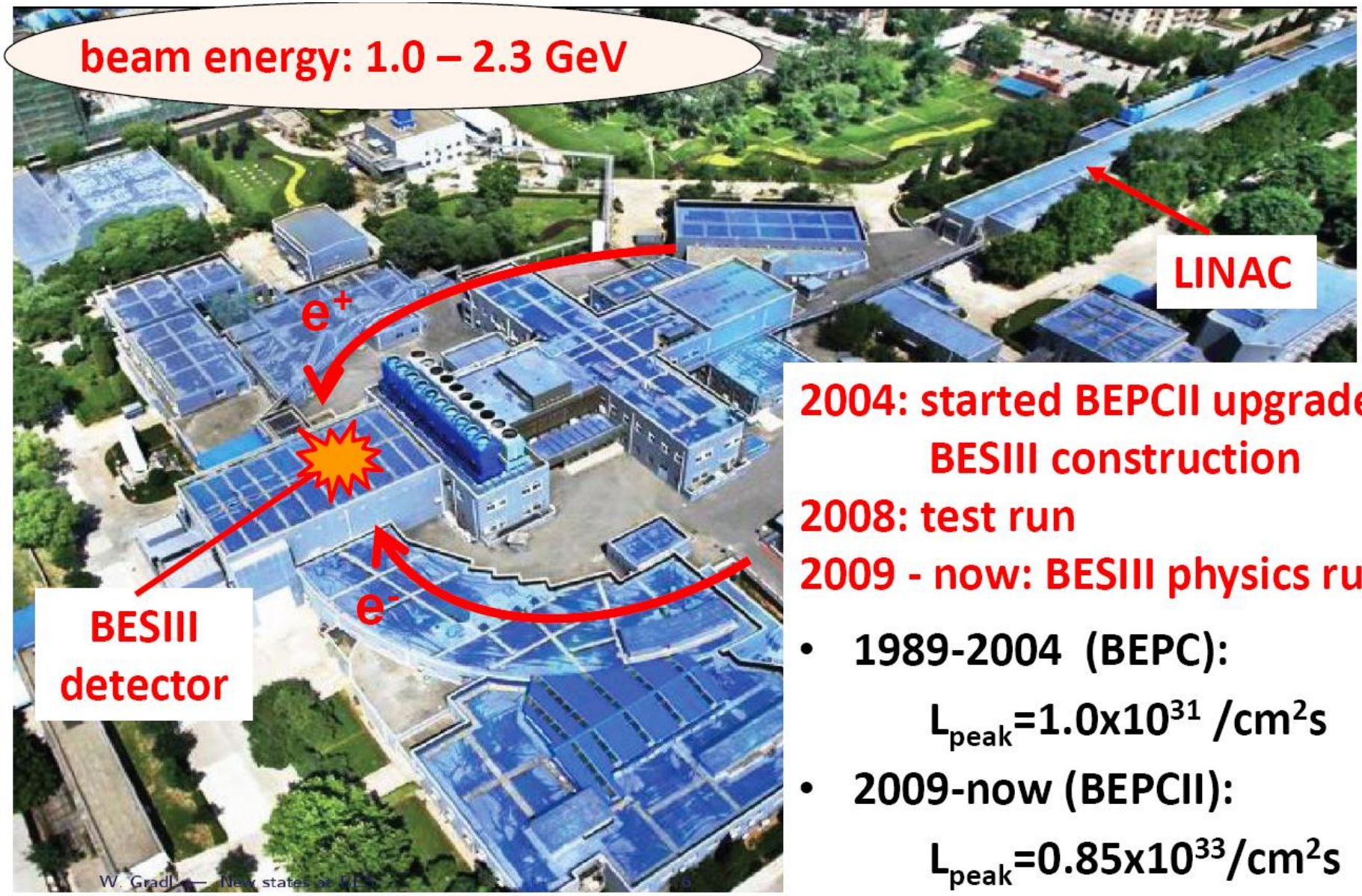
中国科学院高能物理研究所
Institute of High Energy Physics Chinese Academy of Sciences

Ping Ronggang

On behalf of BESIII Collaboration

Institute of High Energy Physics, CAS
pingrg@ihep.ac.cn

Beijing Electron Positron Collider (BEPC)



2004: started BEPCII upgrade, BESIII construction

2008: test run

2009 - now: BESIII physics run

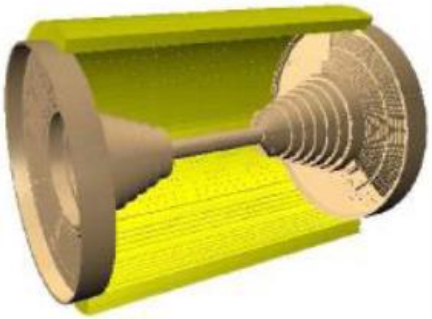
- 1989-2004 (BEPC):

  $L_{peak}=1.0\times10^{31}$ /cm^{2}s
- 2009-now (BEPCII):

  $L_{peak}=0.85\times10^{33}$/cm^{2}s

BESIII Detector

MDC

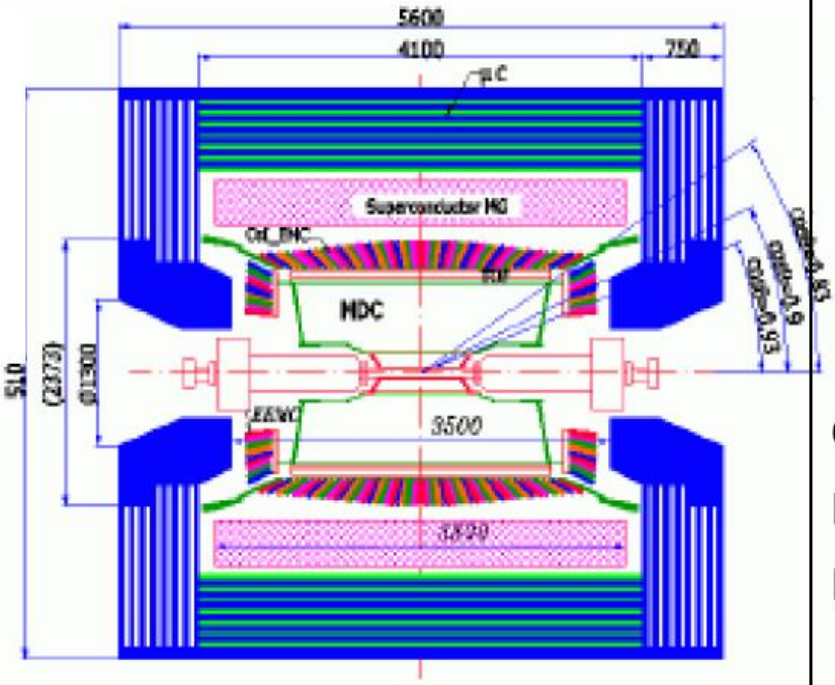


R inner: 63mm ;

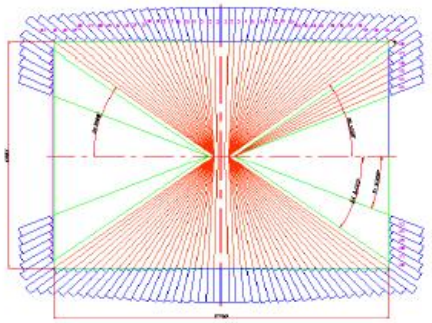
R outer: 810mm

Length: 2582 mm

Layers: 43



CsI(Tl) EMC



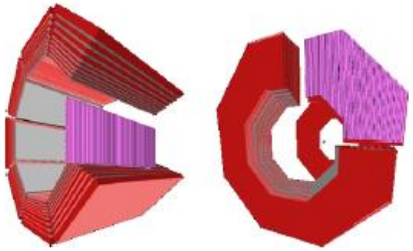
Crystals: 28 cm(15 X_0)

Barrel: $|\cos\theta|<0.83$

Endcap:

$0.85 < |\cos\theta| < 0.93$

RPC MUC



BMUC: 9 layers – 72 modules

EMUC: 8 layers – 64 modules

TOF

BTOF: two layers

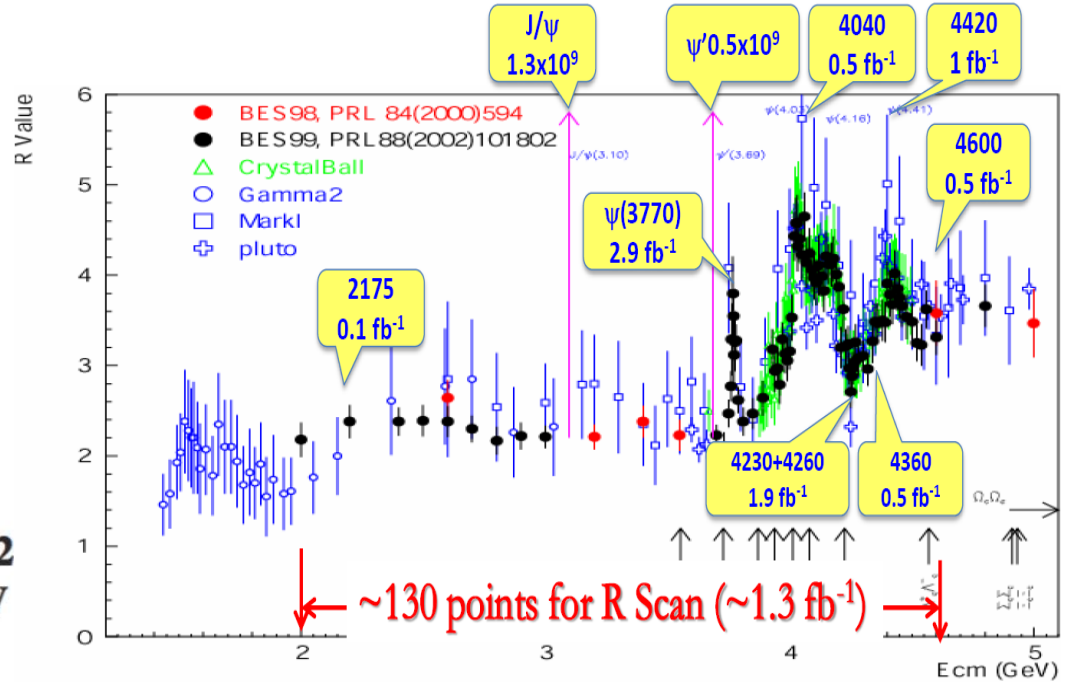
ETOF: 48 scintillators for each

MRPC --- new ETOF

BESIII data samples

2009: 106M ψ(2S)
225M J/ψ
2010: 975 pb^{-1} at ψ(3770)
2011: 2.9 fb^{-1} at **ψ(3770)** *(total)*
482 pb^{-1} at **4.01 GeV**
2012: 0.45B **ψ(2S)** *(total)*
1.3B **J/ψ** *(total)*
2013: 1092 pb^{-1} at **4.23 GeV**
826 pb^{-1} at **4.26 GeV**
540 pb^{-1} at **4.36 GeV**
~50 pb^{-1} at **3.81, 3.90, 4.09, 4.19, 4.2**
4.22, 4.245, 4.31, 4.39, 4.42 GeV
2014: 1029 pb^{-1} at **4.42 GeV**
110 pb^{-1} at **4.47 GeV**
110 pb^{-1} at **4.53 GeV**
48 pb^{-1} at **4.575 GeV**
567 pb^{-1} at **4.6 GeV**
0.8 fb^{-1} **R-scan** from 3.85 to 4.59 GeV (104 points)
2015: **R-scan** from 2-3 GeV + **2.175 GeV** data
2016: ~3fb^{-1} at 4.18 GeV (for **D$_s$**) *JUST COMPLETED*

2017. 500/pb each for 7 energy points between 4.19~4.28 GeV
400/pb around chic_c1
200/pb around X(3872)

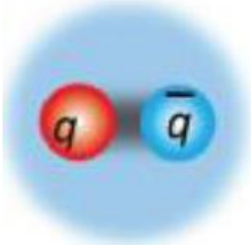


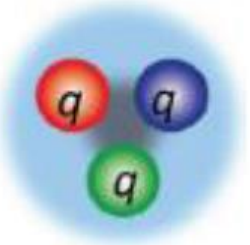
New forms of hadron

- Conventional hadrons consist of 2 or 3 quarks:

Naive Quark Model:

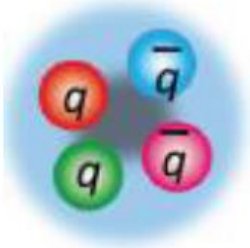
meson



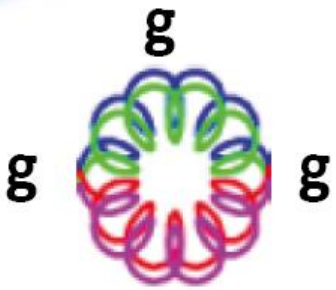


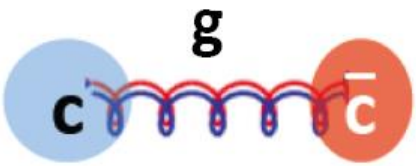
baryon

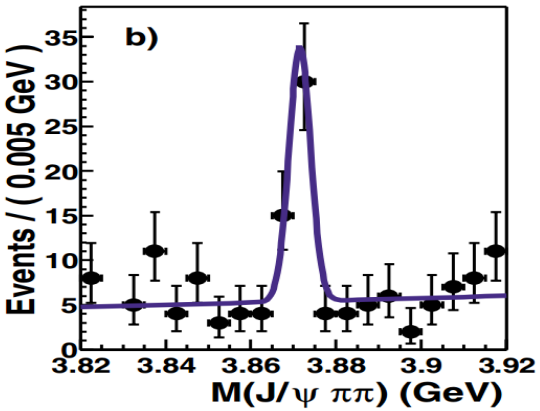
- QCD predicts the new forms of hadrons:
  - Multi-quark states： Number of quarks >= 4



  - Hybrids： $q\bar{q}g$， qqqg …
  - Glueballs： gg， ggg …







Belle: Phys.Rev.Lett. 91 (2003) 262001

$$B^{\pm} \to K^{\pm}\pi^{+}\pi^{-}J/\psi$$

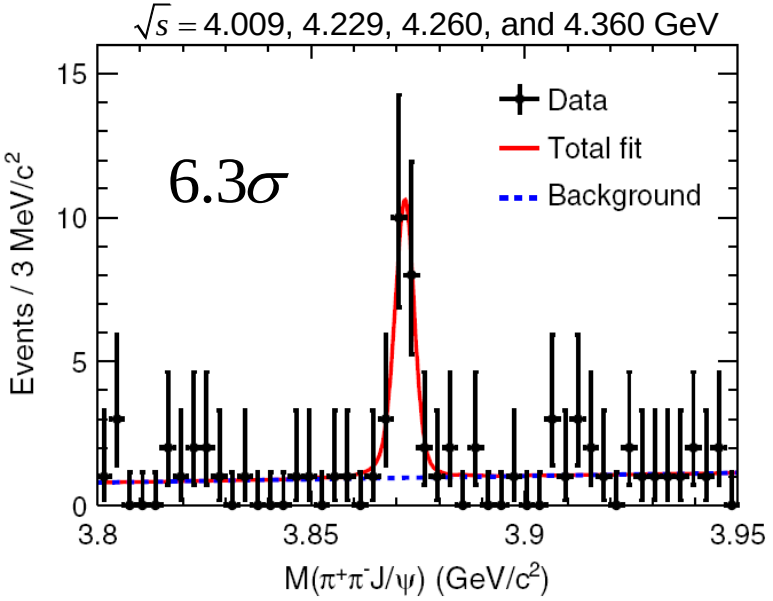
$X(3872)$

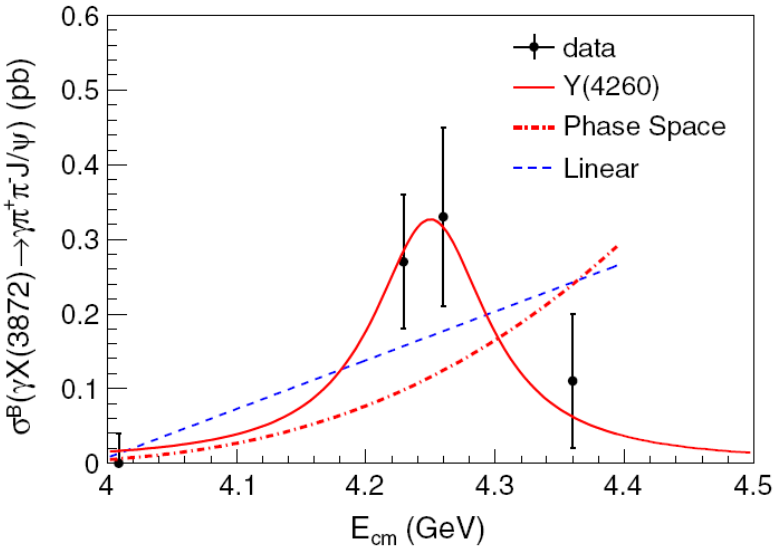
$$I^{G}(J^{PC}) = 0^{+}(1^{++})$$

Mass m=3871.69 $\pm$ 4 MeV

Full width Γ < 1.2 MeV, CL = 90%

BESIII Collaboration, PRL 112, 092001 (2014)





M=3871.9±0.7 ± 0.2

$\sqrt{s}$ (GeV)	$\sigma^B[e^+e^-\to\gamma X(3872)]\cdot\mathcal{B}(X(3872)\to\pi^+\pi^- J/\psi)$ (pb)
4.009	$0.00\pm0.04\pm0.01$ or <0.11
4.229	$0.27\pm0.09\pm0.02$
4.260	$0.33\pm0.12\pm0.02$
4.360	$0.11\pm0.09\pm0.01$ or <0.36

$Y(4260)\to\gamma X(3872)$

$X(3823)$ or $\psi(3823)$

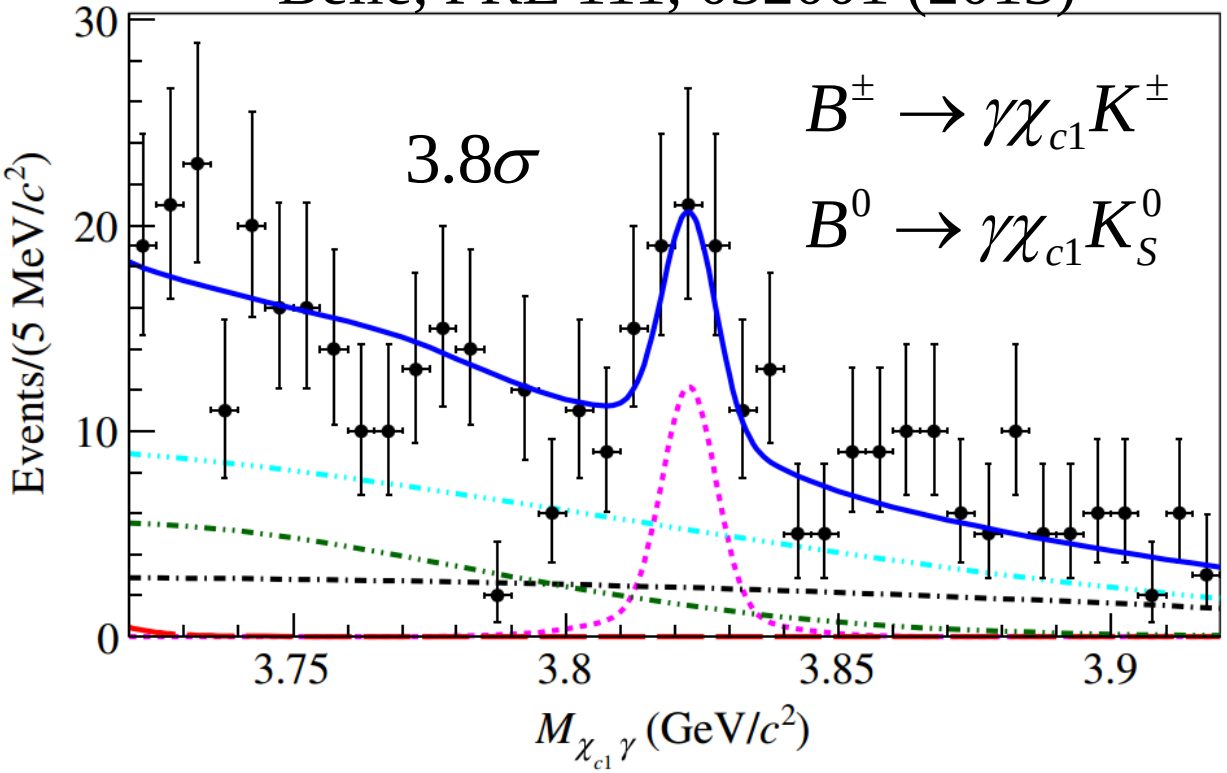
$$I^G(J^{PC}) = ?^?(2^{--})$$

Mass m=3822.2 $\pm$ 1.2 MeV

Full width Γ < 16 MeV, CL = 90%

- *X*(3823) observed by Belle Collaboration for the first time

Belle, PRL 111, 032001 (2013)



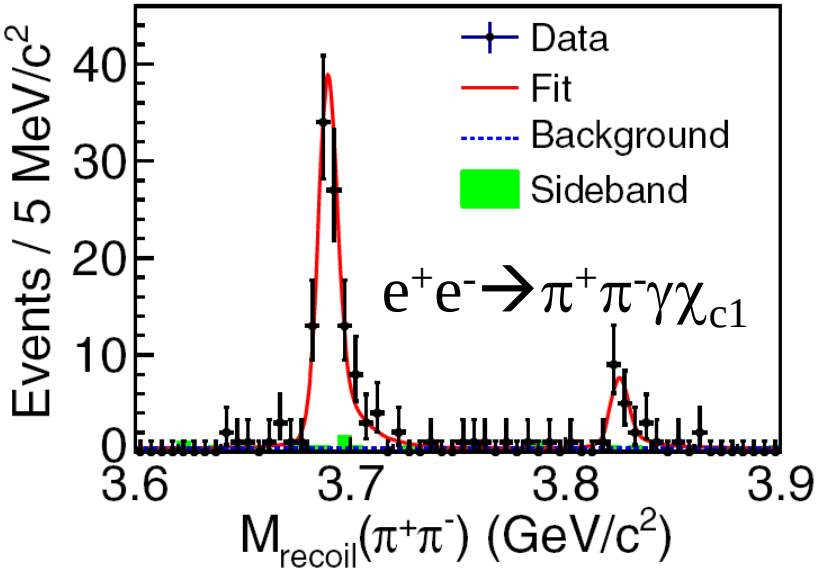
C=+

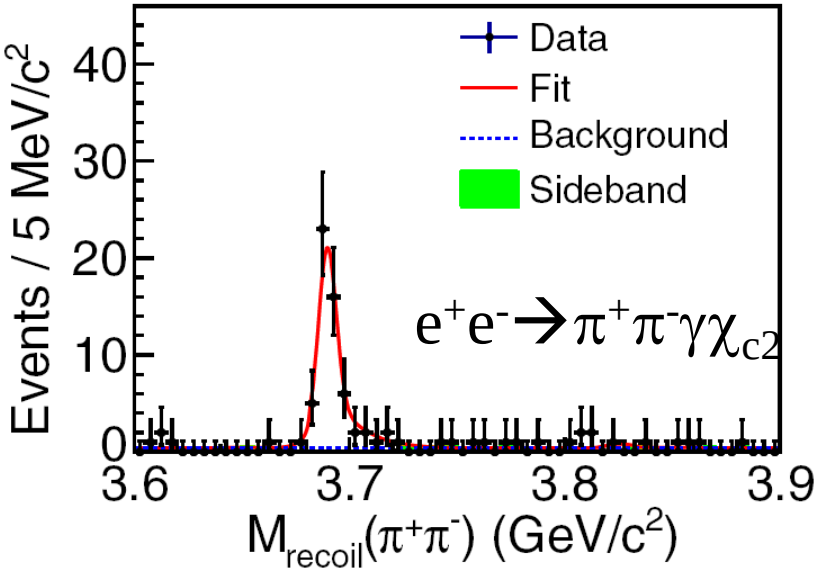
Mass m=3823.1 ± 1.9 MeV,

Full width Γ < 24 MeV, CL = 90%

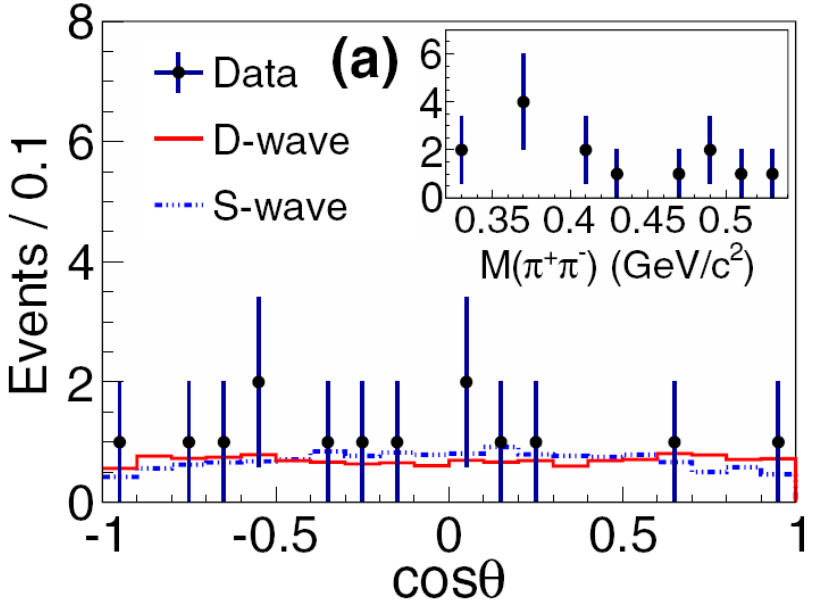
- *X*(3823) not seen in $\gamma\chi_{c2}$

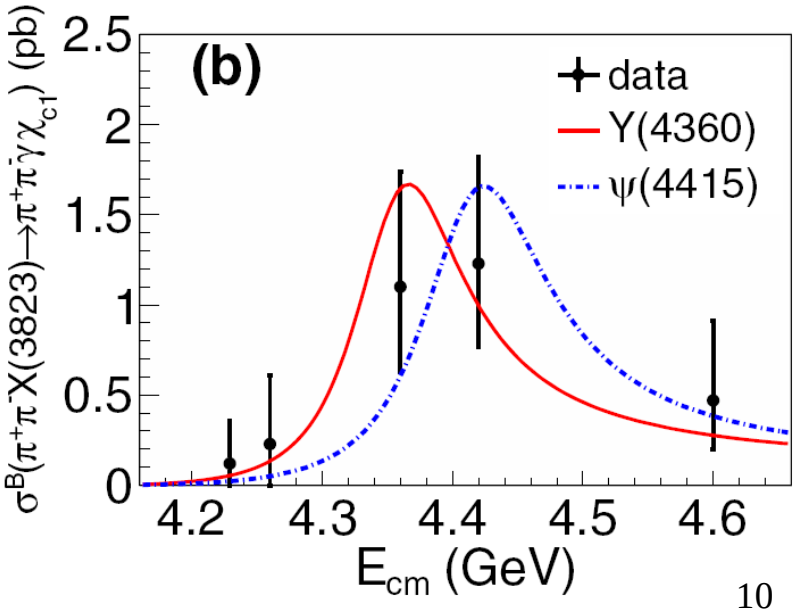
BESIII:PRL 115, 011803 (2015)





M=3821.7±1.3 ±0.7 MeV





$X(4140)$ (BESIII: $Y(4140)$)

$$0^+(J^{PC}) = 0^+(1^{++})$$

Mass m=4146.8 $\pm$ 2.5 MeV

Full width Γ = 19^{+8}_{-7} MeV

- 2009, CDF Colla. PRL 102, 242002

  Evidence for *X*(4140) with sig. 3.8 σ in $B^+ \rightarrow J/\psi\phi K^+$

  mass : $4143.0 \pm 2.9(\text{stat}) \pm 1.2(\text{syst})$ MeV

  width : $11.7^{+8.3}_{-5.0}(\text{stat}) \pm 3.7(\text{syst})$ MeV

- 2017, LHCb Colla., PRL 118, 022003

  3 fb^{-1} pp-bar collision data, *X*(4140) with sig. >5 σ in $B^+ \rightarrow J/\psi\phi K^+$, $J^{PC}=1^{++}$, with sig. >4 σ

  mass : $4146.5 \pm 4.5^{+4.6}_{-2.8}$ MeV

  width : $83 \pm 21^{+21}_{-14}$ MeV

- 2010, Belle Colla., PRL 104, 112004

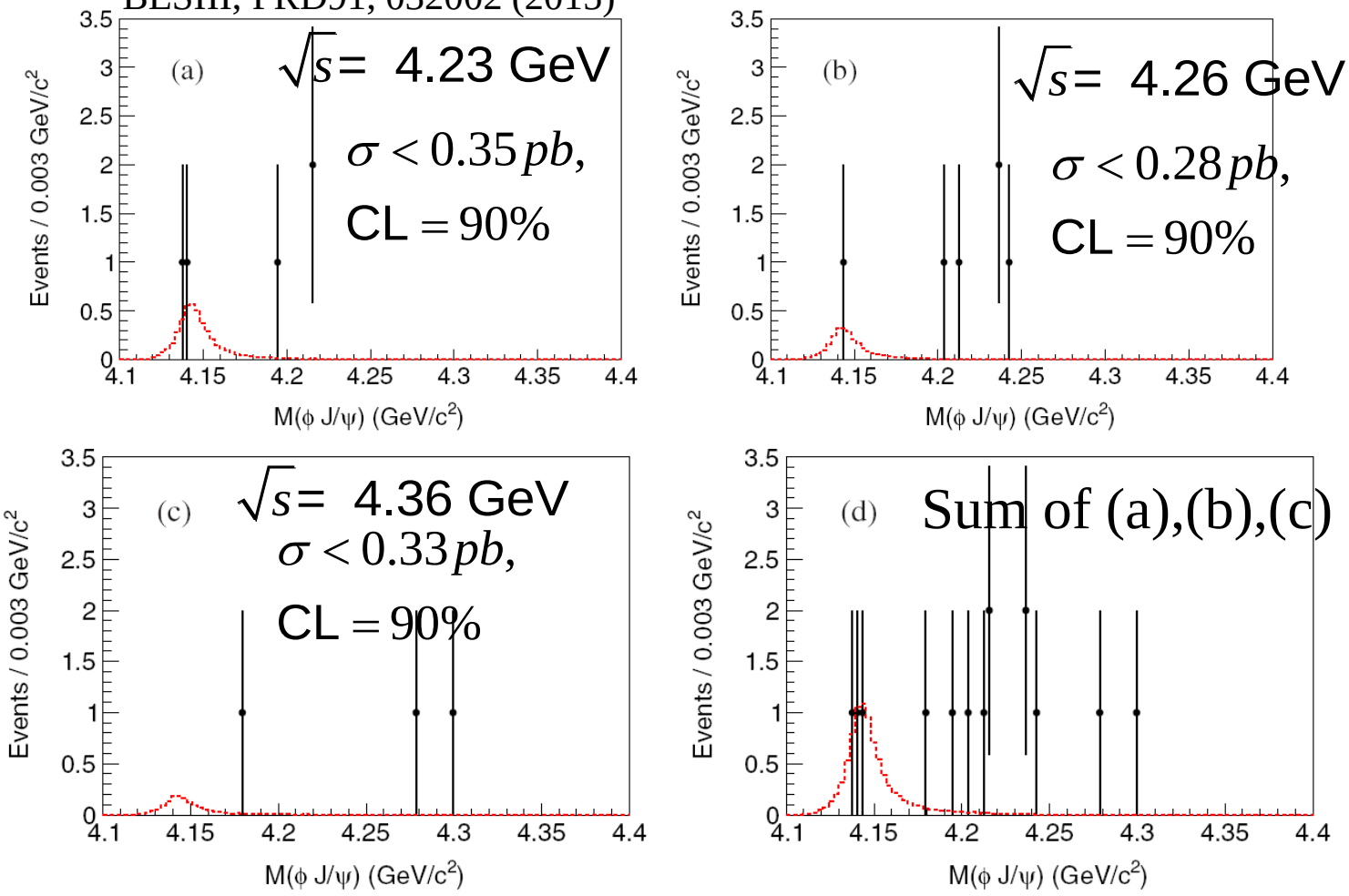
  825 fb^{-1} Y(nS) data, no evidence for *X*(4140),
  But evidence X(4350): with sig. 3.2 σ in $\gamma\gamma \rightarrow J/\psi\phi$

  mass: $4350.6^{+4.6}_{-5.1}(\text{stat}) \pm 0.7(\text{syst})$

  width: $13^{+18}_{-9}(\text{stat}) \pm 4(\text{syst})$

Search for the Y(4140) via $e^+e^- \to \gamma\phi J/\psi$ at $\sqrt{s}$= 4.23, 4.26 and 4.36 GeV

BESIII, PRD91, 032002 (2015)



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

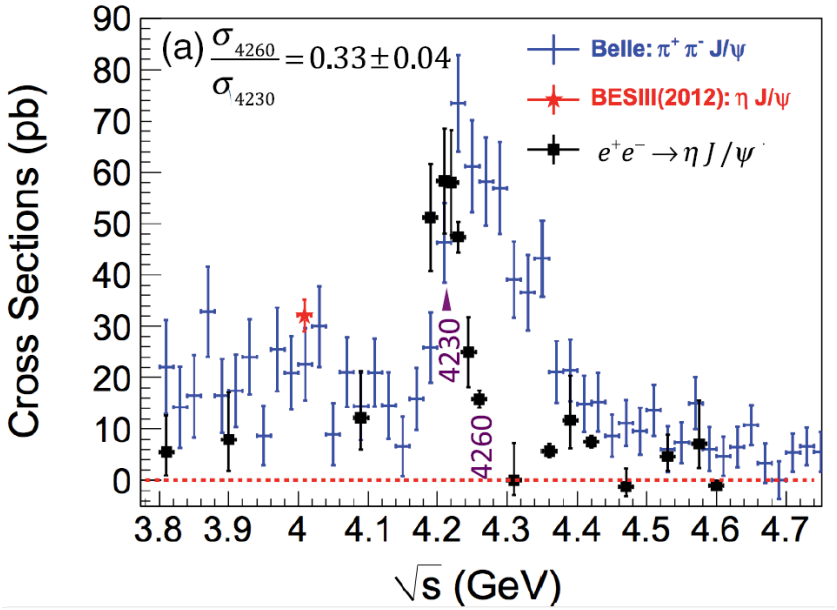
$Y(4230), Y(4260)$

- Babar reported the observation of $Y(4260)$ in $e^+e^- \rightarrow \gamma_{isr}\pi^+\pi^- J/\psi$ (PRL94, 142001), and confirmed in CLEO data and Belle data. Their weighted average give

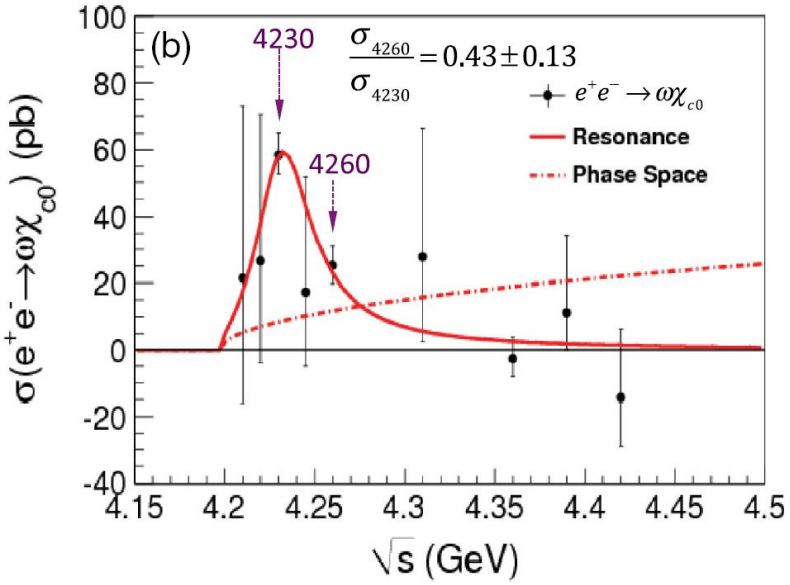
$$M = 4259 \pm 9 \text{ MeV}, \quad \Gamma = 120 \pm 12 \text{ MeV}$$

- BESIII, scan data sets

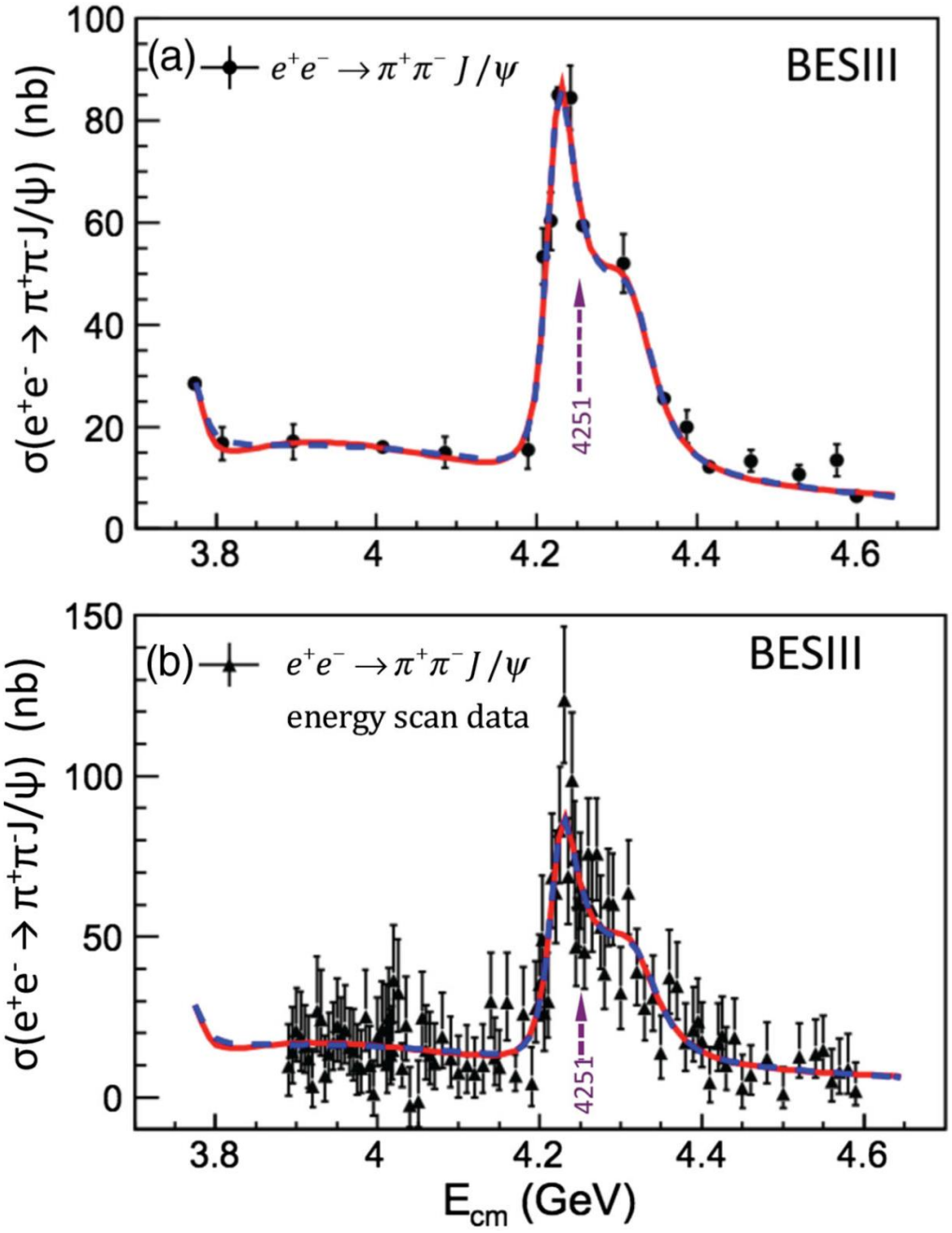
BESIII, PRD91,112005(2015)



BESIII, PRL114,092003(2015)



BESIII, PRL118,092001 (2017)



Two data sets

I: $\int L dt > 19 pb^{-1}$,

Ecm=3773~4599 MeV

19 energy points

II: 7-9pb^{-1}/point,

Ecm=3882~4567 MeV

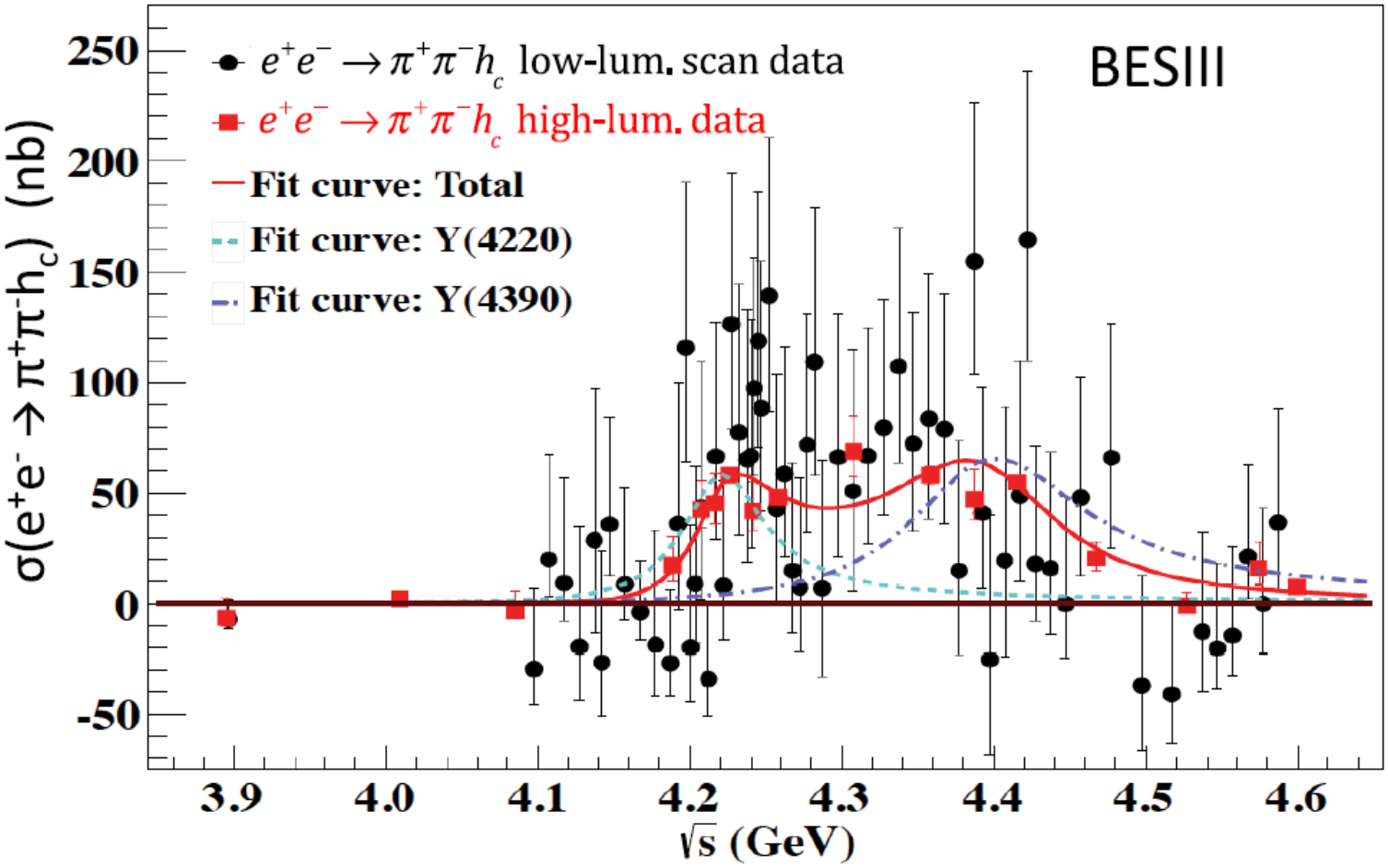
$$M_1 = 4222 \pm 4 \text{ MeV},$$
$$\Gamma_1 = 44 \pm 5 \text{ MeV},$$
$$M_2 = 4320 \pm 13 \text{ MeV},$$
$$\Gamma_2 = 101^{+27}_{-22} \text{ MeV},$$

To ask for more data taking

Ecms=4290,4300,4310,4320,
4330,4340,4350,4370,4380,
4390 MeV.

500pb^{-1} per point

BESIII, PRL, 118, 092002(2017)

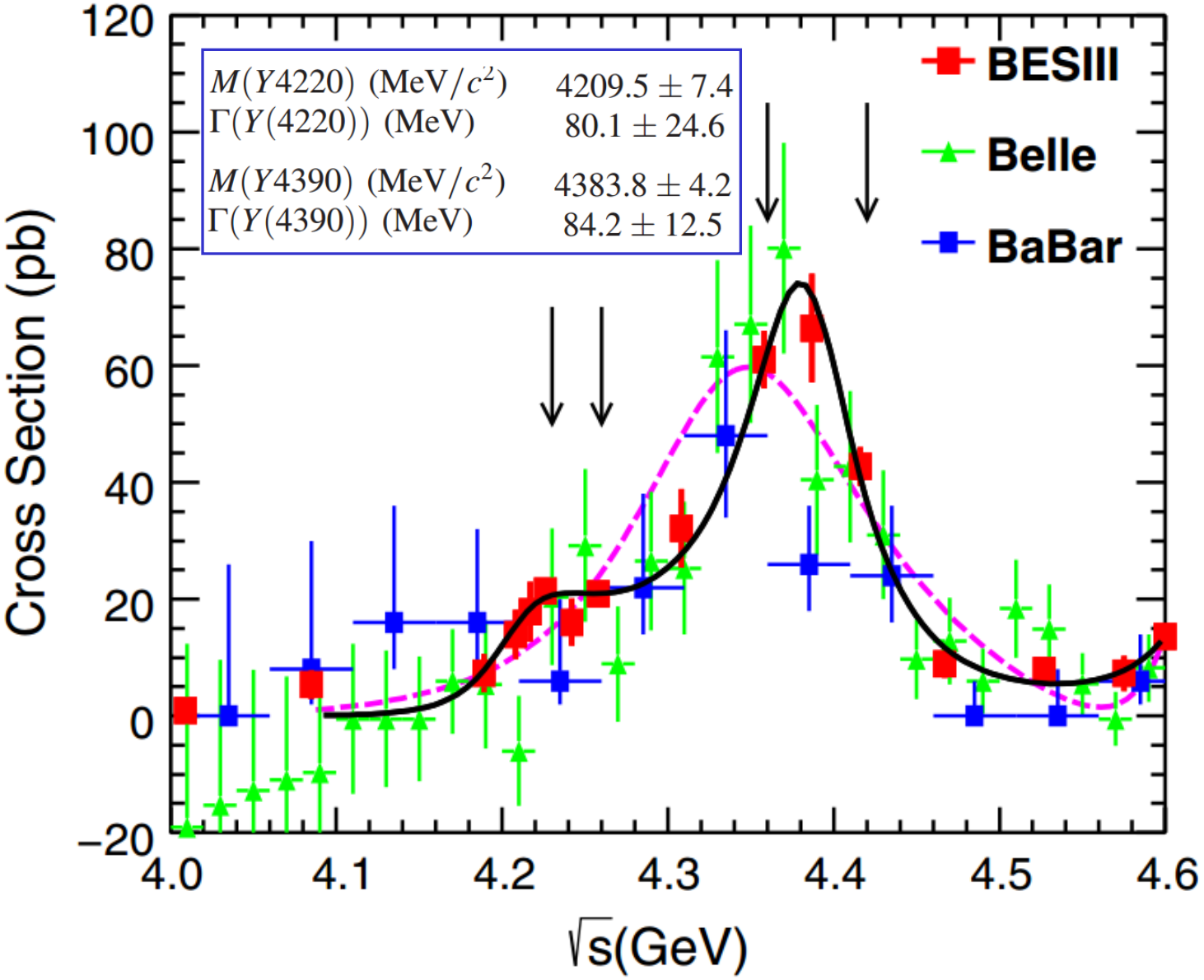


$$M_1 = 4218 \pm 4 \text{ MeV}, \qquad \Gamma_1 = 66 \pm 9 \text{ MeV},$$

$$M_2 = 4392 \pm 6 \text{ MeV}, \qquad \Gamma_2 = 140 \pm 16 \text{ MeV},$$

Cross section for $e^+e^- \to \pi^+\pi^-\psi(3686)$

BESIII, PRD96, 032004 (2017)



$Y(4660)$

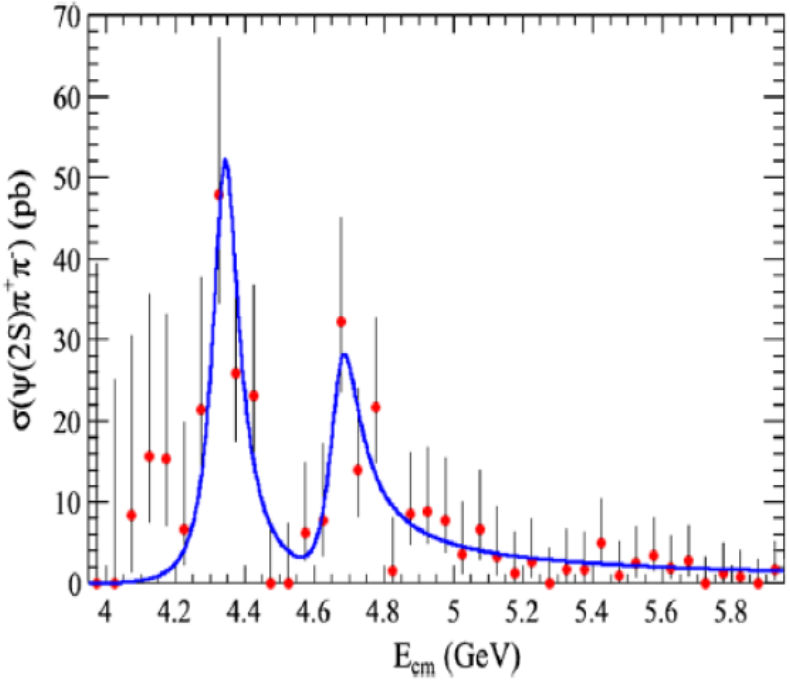
Y(4660) from Babar and Bell in the ISR process

$e^+ e^- \to \psi(3686)\, \pi^+ \pi^-$ by means of ISR

BaBar

M=4669 ± 22 , Γ=104 ± 49

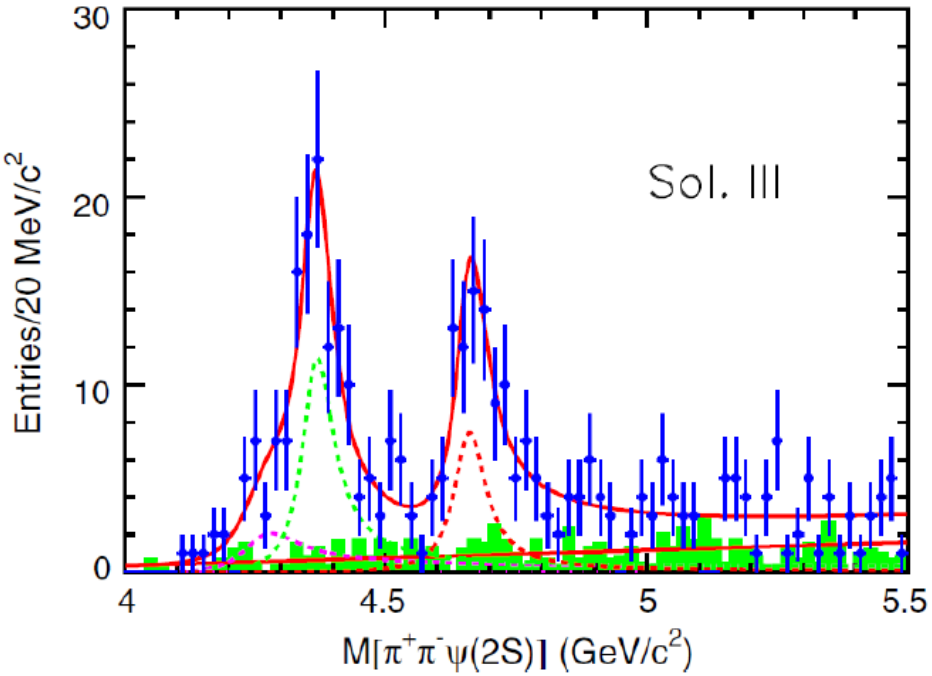
PHYSICAL REVIEW D **89,** 111103(R) (2014)



Belle

M=4652 ± 13 , Γ=68 ± 11

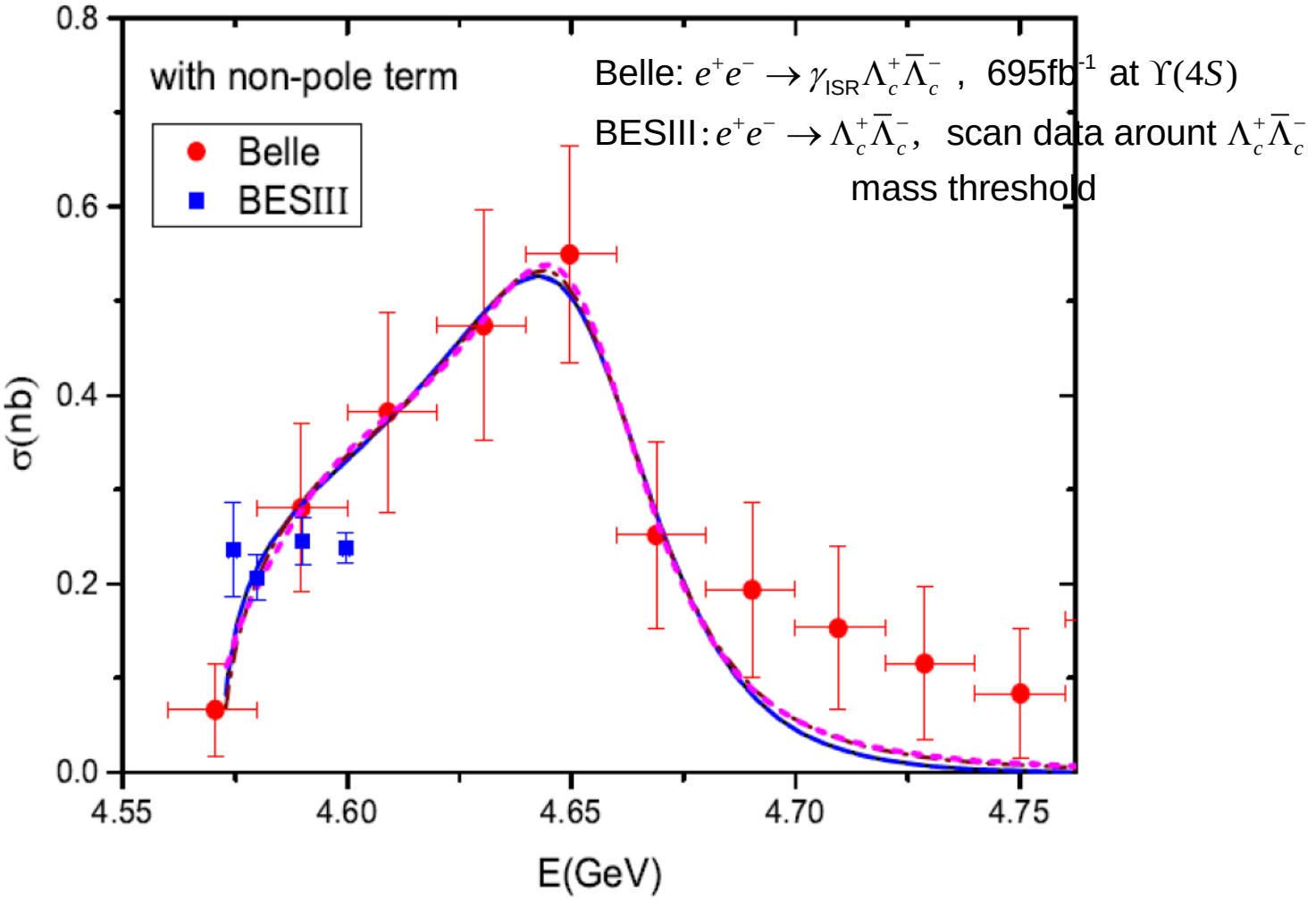
PHYSICAL REVIEW D **91,** 112007 (2015)



Observation of Y(4660) → $\Lambda_c\Lambda_c$-bar

Belle G. Pakhlova *et al.* [Belle Collaboration], Phys. Rev. Lett. 101, 172001 (2008).

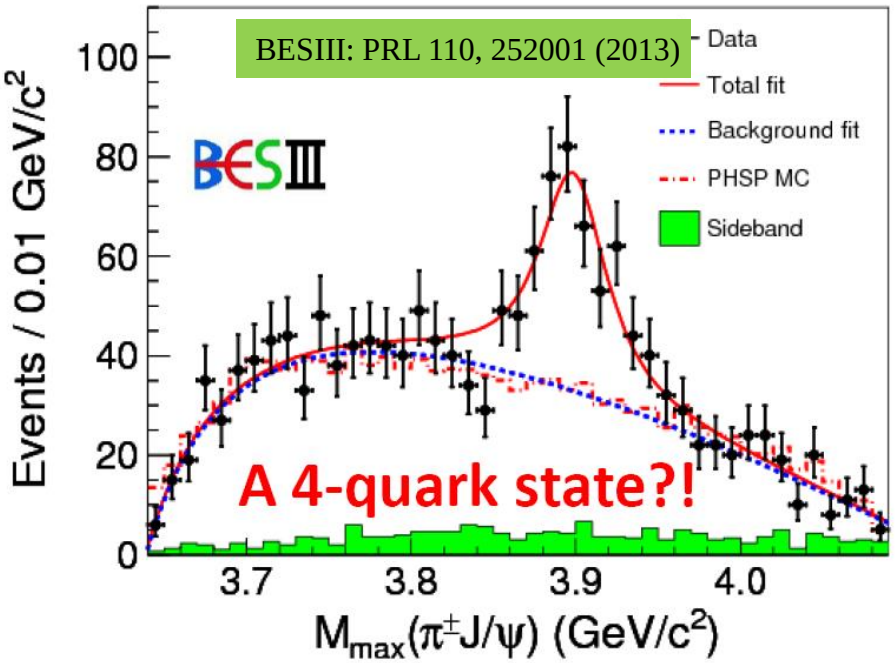
BESIII Ablikim *et al.*, arXiv:1710.00150 [hep-ex].



Ecms will be upgraded to 4.6~4.9 GeV in 2018-2019

Zc states

Observation of Zc(3900)



$Z_c(3900)^+$: J^P=?

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

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

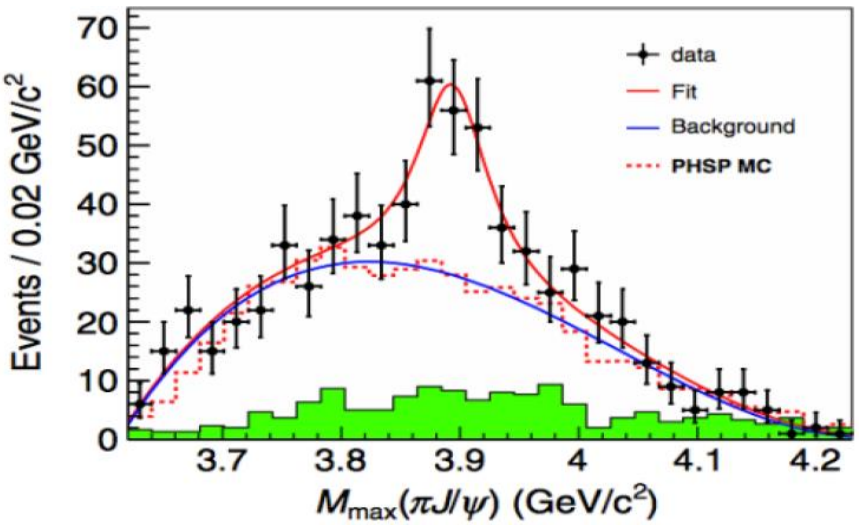
Mass close to $D\bar{D}^*$ threshold

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

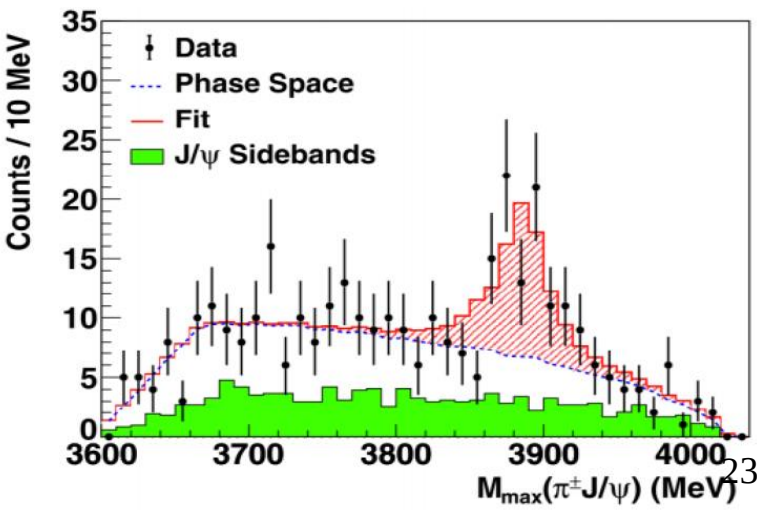
$\sigma[e^+e^- \to \pi^+\pi^- J/\psi] = 62.9 \pm 1.9 \pm 3.7$ pb at 4.26 GeV

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

Belle with ISR data (PRL110,252002)

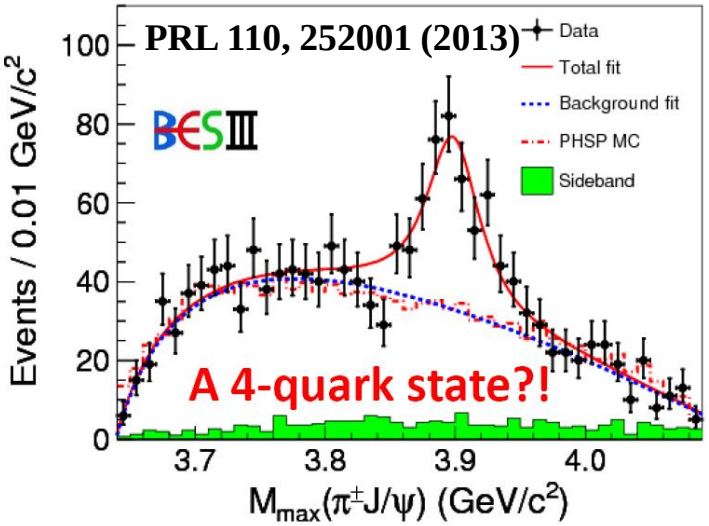


CLEOc data at 4.17 GeV (PLB 727,366)

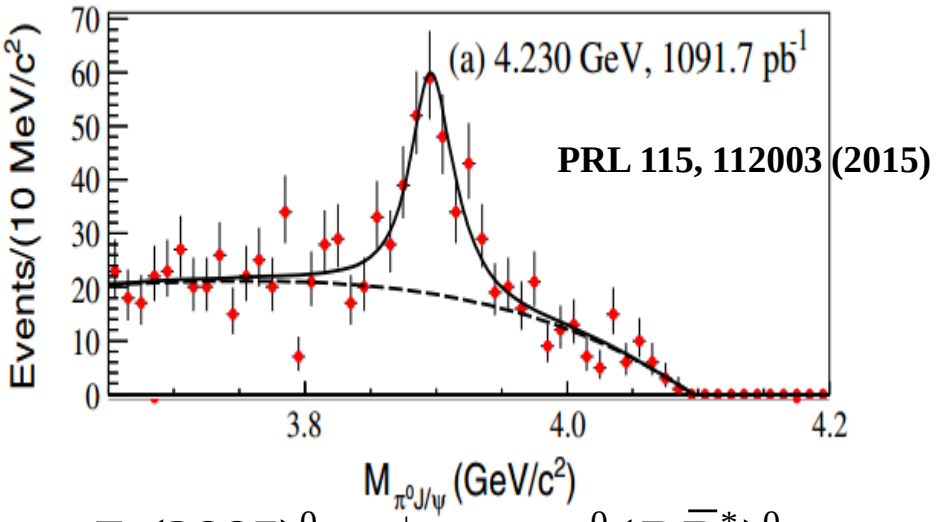


Overview Zc states from BESIII

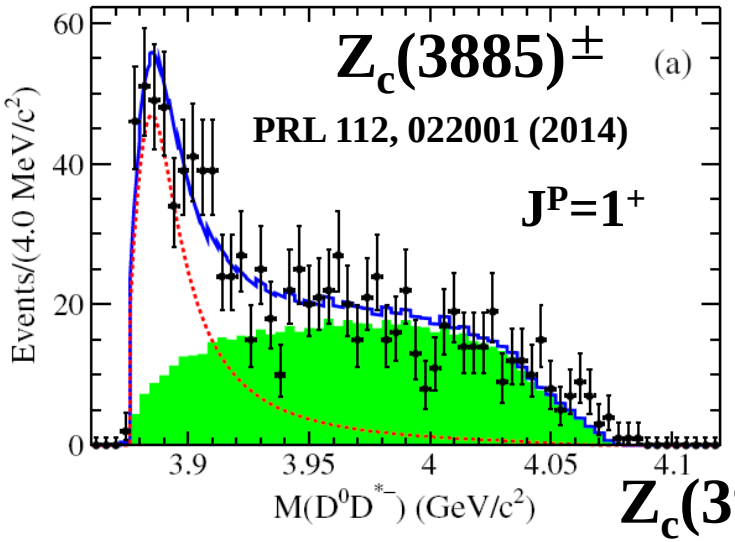
$Z_c(3900)^{\pm} : e^+e^- \to \pi^+\pi^- J/\psi$



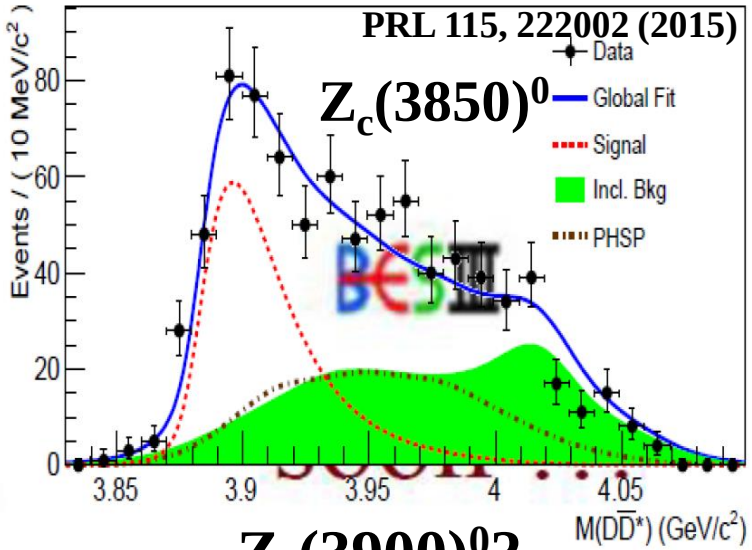
$Z_c(3900)^0 : e^+e^- \to \pi^0\pi^0 J/\psi$



$Z_c(3885)^{\pm} : e^+e^- \to \pi^{\pm}(D\bar{D}^*)^{\mp}$



$Z_c(3885)^0 : e^+e^- \to \pi^0(D\bar{D}^*)^0$



$Z_c(3900)^{\pm}$?

$Z_c(3900)^0$?

- Isospin (I=1) for $Z_c(3900)$ established

$$\frac{\sigma(e^+e^- \to Z_c{}^0(3900)\pi^0 \to \pi^0\pi^0 J/\psi)}{\sigma(e^+e^- \to Z_c{}^\pm(3900)\pi^\mp \to \pi^+\pi^- J/\psi)} = 0.45 \pm 0.08 \text{ at } \sqrt{s} = 4.26\text{GeV}$$

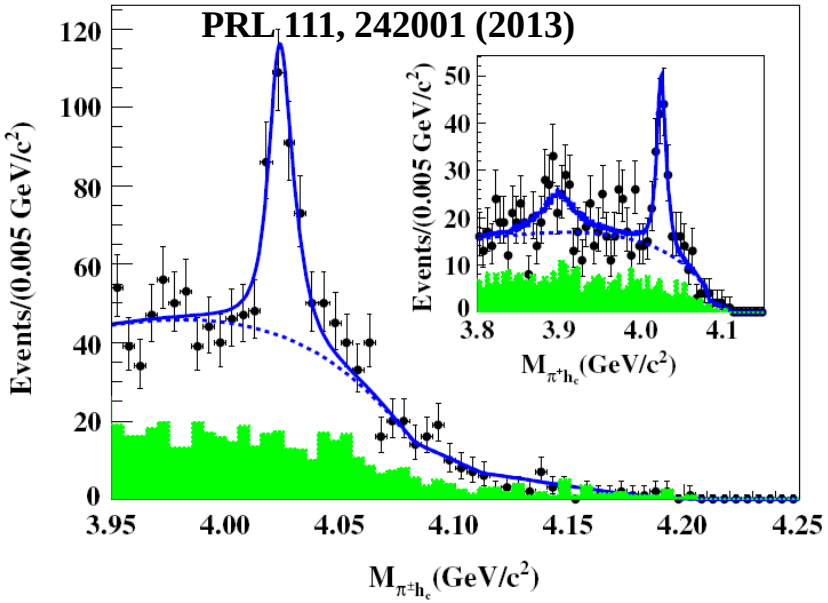
- Isospin (I=1) for $Z_c(3885)$ established

$$\frac{\sigma(e^+e^- \to Z_c{}^0(3885)\pi^0 \to \pi^0(DD^*)^0)}{\sigma(e^+e^- \to Z_c{}^\pm(3885)\pi^\mp \to \pi^\pm(DD^*)^\mp)} = 0.56 \pm 0.21 \text{ at } \sqrt{s} = 4.26\text{GeV}$$

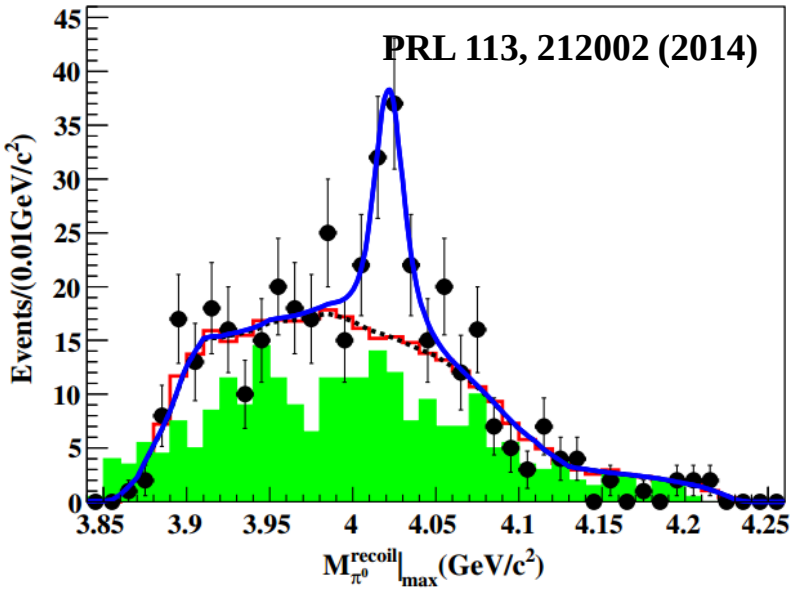
- Mass and width in Breit-Wigner parametrization

Zc 态	M(MeV)	Γ(MeV)	过程	实验
$Z_c^\pm(3900)$	3899.0 ± 6.1	46 ± 22	$Y(4260) \to \pi^\pm(\pi^\mp J/\psi)$	BESIII
	3894.5 ± 8.0	63.0 ± 35.4	$e^+e^- \to \gamma_{ISR}\pi^\pm(\pi^\mp J/\psi)$	Belle
	3897.6 ± 1.2	43.5 ± 1.5	$Y(4230), Y(4260) \to \pi^\pm(\pi^\mp J/\psi)$	BESIII
$Z_c^\pm(3885)$	3890.5 ± 1.8	28.0 ± 4.0	$Y(4260) \to \pi^\pm(D^0\bar{D}^*)^\mp$	BESIII

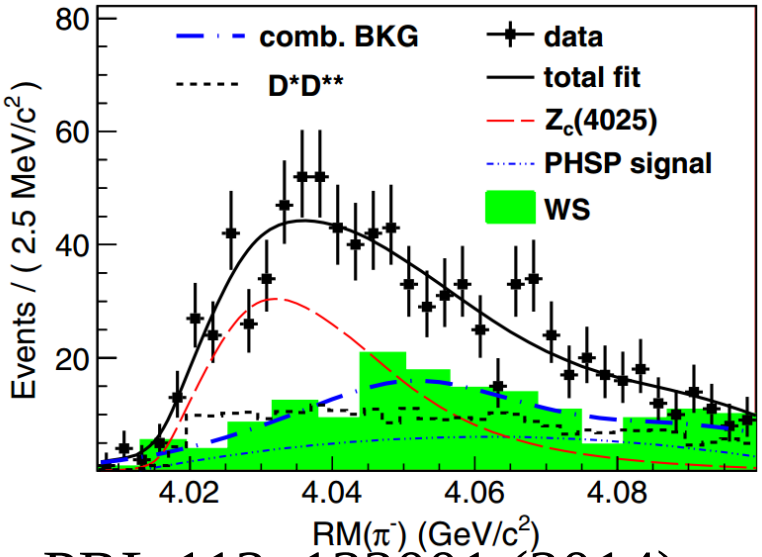
$Z_c(4020)^{\pm} : e^+e^- \to \pi^+\pi^- h_c$



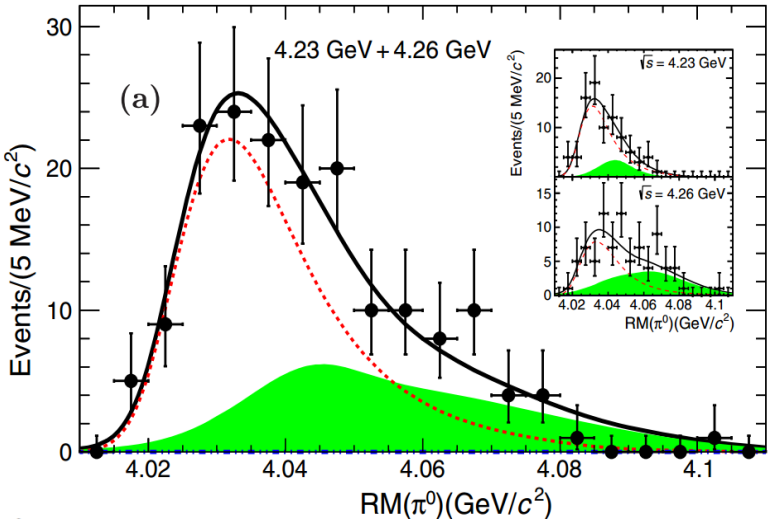
$Z_c(4020)^0 : e^+e^- \to \pi^0\pi^0 h_c$



$Z_c(4025)^{\pm} : e^+e^- \to \pi^{\pm}(D^*\bar{D}^*)^{\mp}$



$Z_c(4025)^0 : e^+e^- \to \pi^0(D^*\bar{D}^*)^0$



PRL 112, 132001 (2014)

PRL 115, 182002 (2015)

- Isospin (I=1) for $Z_c(4020)$ established

$$\frac{\sigma(e^+e^- \to Z_c^{\ 0}(4020)\pi^0 \to \pi^0\pi^0 J/\psi)}{\sigma(e^+e^- \to Z_c^{\ \pm}(4020)\pi^{\mp} \to \pi^+\pi^- J/\psi)} = 0.77 \pm 0.40 \text{ at } \sqrt{s} = 4.23\text{GeV}$$

- Isospin (I=1) for $Z_c(4025)$ established

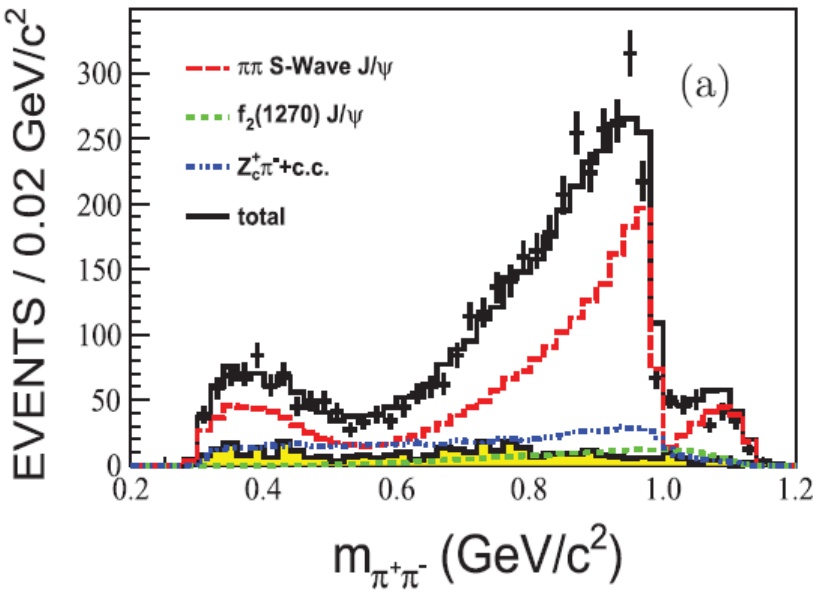
$$\frac{\sigma(e^+e^- \to Z_c^{\ 0}(3885)\pi^0 \to \pi^0(DD^*)^0)}{\sigma(e^+e^- \to Z_c^{\ \pm}(3885)\pi^{\mp} \to \pi^{\pm}(DD^*)^{\mp})} = 0.49 \pm 0.13 \text{ at } \sqrt{s} = 4.26\text{GeV}$$

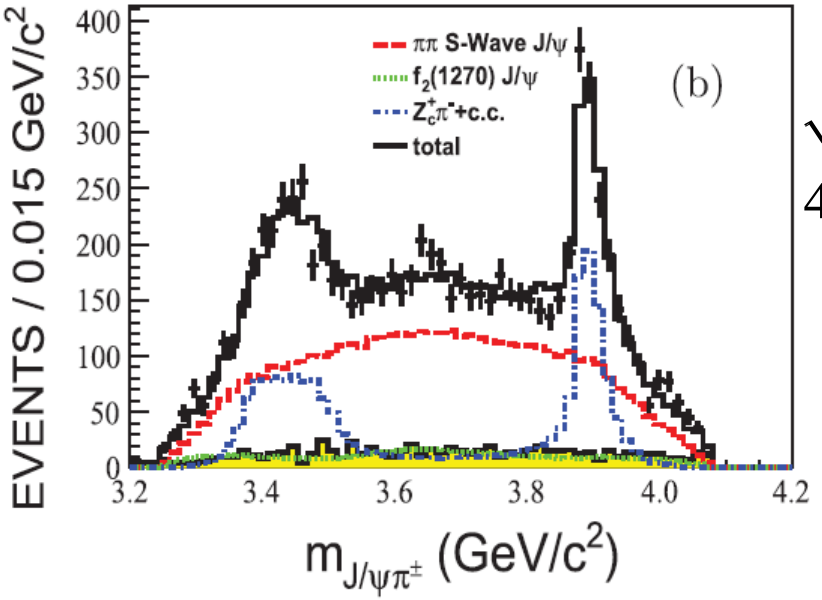
- Mass and width in Breit-Wigner parametrization

Zc 态	M(MeV)	Γ(MeV)	过程	实验
$Z_c^{\pm}(4020)$	4022.9 ± 2.8	7.9 ± 3.7	$e^+e^- \to \pi^{\pm}(\pi^{\mp}h_c)$	BESIII
$Z_c^{\pm}(4025)$	4026.3 ± 4.5	24.5 ± 9.5	$Y(4260) \to \pi^{\pm}(D^*\bar{D}^*)^{\mp}$	BESIII

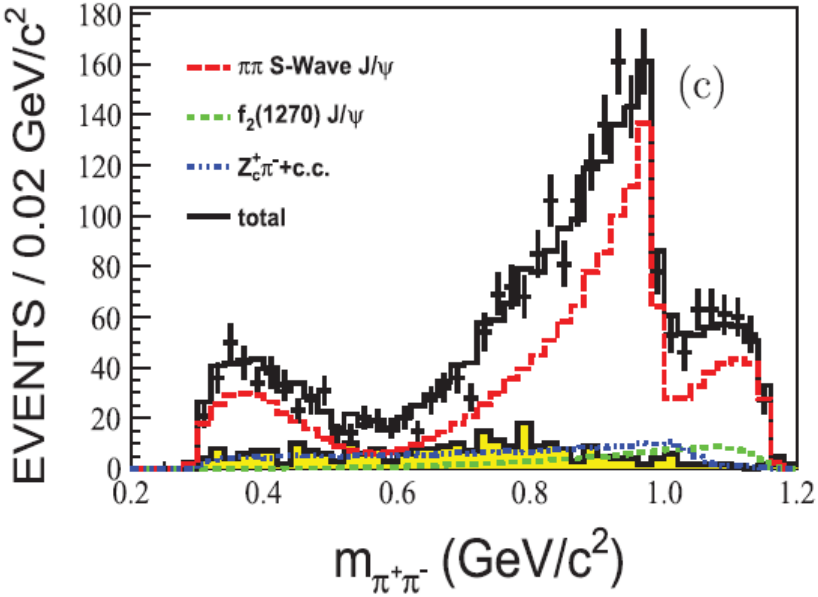
Fit results assuming Z_c to be 1^+

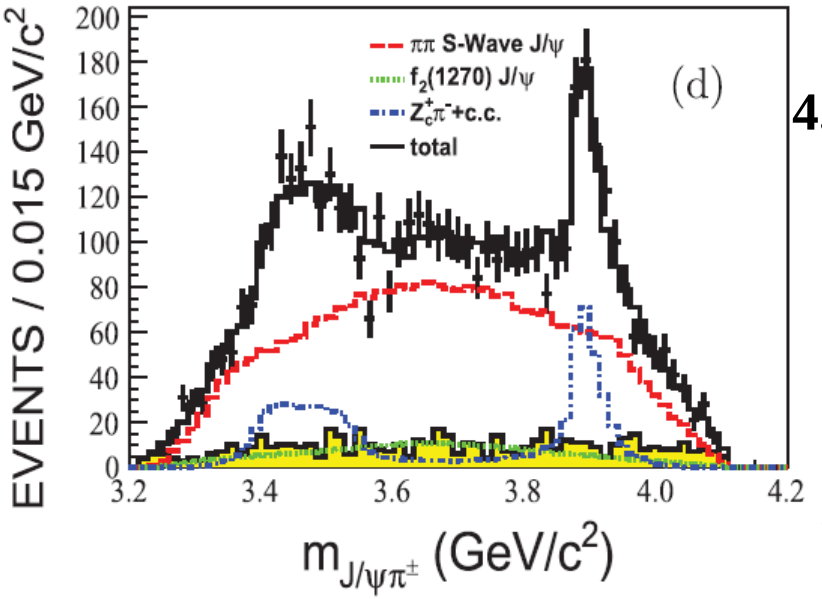
PRL 119, 072001 (2017), BESIII





$\sqrt{s}$ = 4.23 GeV

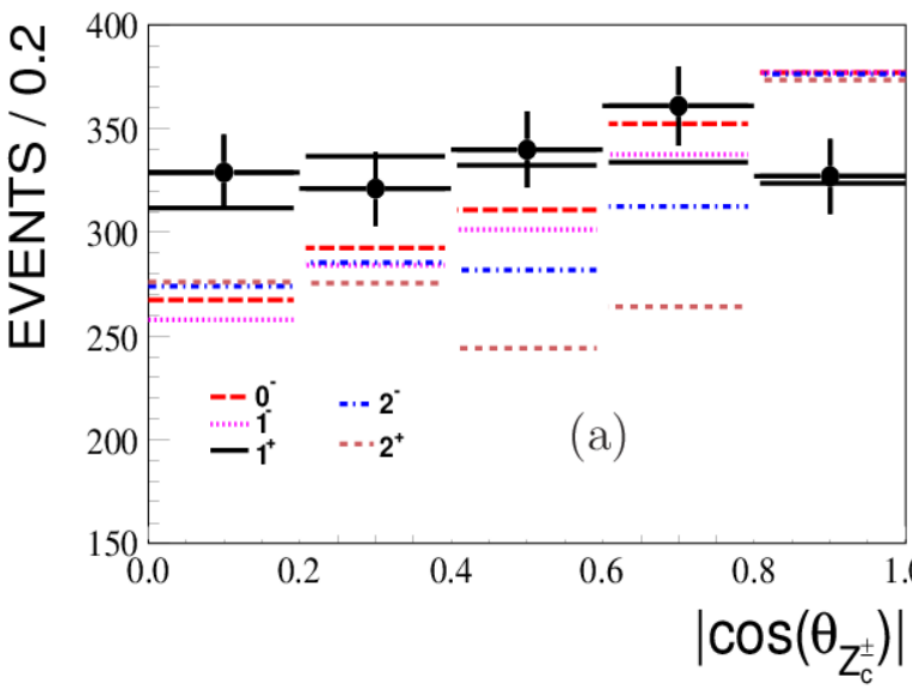


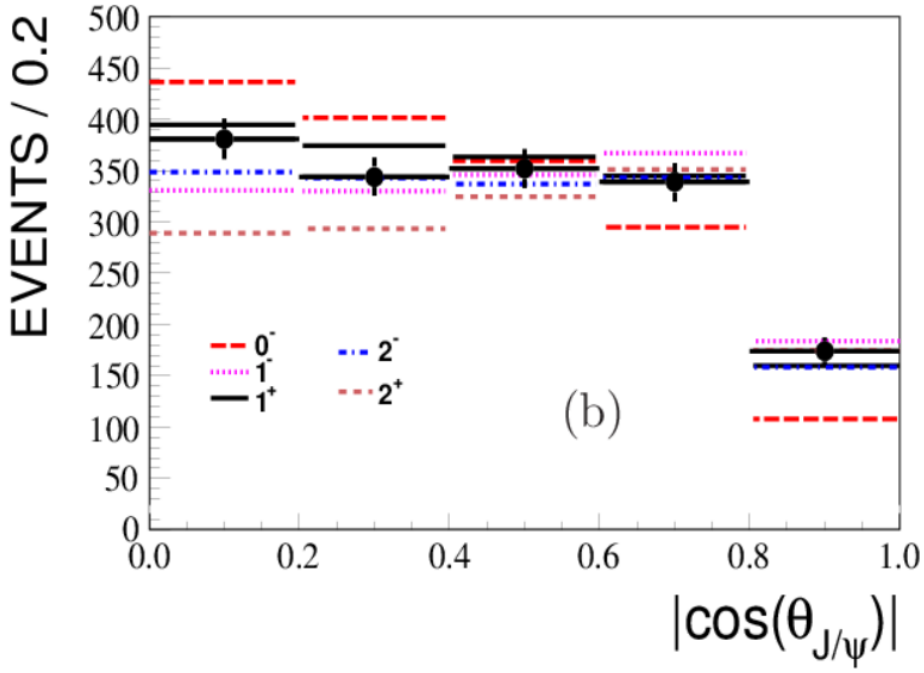


4.26 GeV

Angular distributions for different J^P within Z_c mass region

PRL 119, 072001 (2017), BESIII





- Events in the Z_c mass region $M_{\pi J/\psi} \in (3.86, 3.92)$ GeV
- Background events subtracted
- θ_{Zc} : the polar angle of Z_c, $\theta_{J/\psi}$: helicity angle of J/ψ
- Data favors the spin-parity 1^+ for Z_c

Statistical significance for the Z_c as 1^+ state

- Test two hypotheses

Null hypothesis H_0 :

data described with $[\sigma_0, f_0(980), f_2(1270), f_0(1370), Z_c(J^P \neq 1^+)]$

Alternative hypothesis H_1:

data described with $[\sigma_0, f_0(980), f_2(1270), f_0(1370), Z_c(1^+),$ **other** $Z_c(J^P \neq 1^+)]$

Significance to distinguish the quantum number 1^+ over other quantum numbers.

Hypothesis	$2\Delta(-\ln L)$	$\Delta(ndf)$	significance
1^+ over 0^-	94.0	4×2+5	7.6σ
1^+ over 1^-	158.3	4×2+5	10.8σ
1^+ over 2^-	151.9	4×2+5	10.5σ
1^+ over 2^+	96.0	4×2+5	7.7σ

Comments from PRL referees and editor

■ Comments from PRL referees arXiv:1706.04100

The BESIII collaboration has an excellent track record in the field of spectroscopy in the sector of charmonia and charmonium-like mesons…..

Using partial-wave analyses, spin and parity of one of the charged states containing a pair of ch
an

BESIII 合作组在粲偶素和类粲偶素谱学领有着出色的记录,。。。。。。。,

This is a very important contribution in view of the ongoing discussion of the nature of these puzzling states.

Besides mass, width, and production cross sections, open questions remained, and in particular spin and parity are crucial properties to know in order to understand the structure of this and make connections to other observations. The present paper unambiguously answers this question, by ruling out other than the 1+ spin-parity assignment with significances exceeding seven standard deviations.

The measurement will undoubtedly trigger a significant number of phenomenological publications.

- **Selected as Physics synopsis by the PRL Journal**

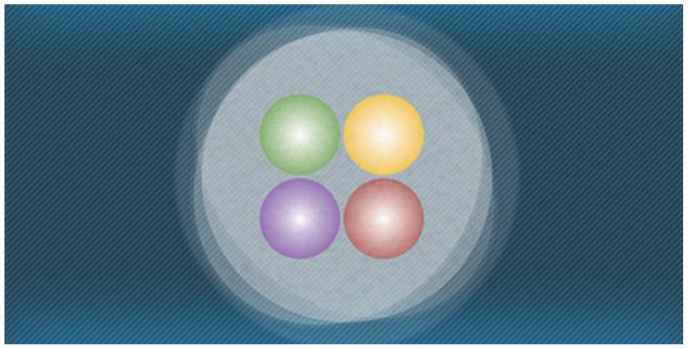
Determination of the Spin and Parity of the Zc(3900), M. Ablikim *et al.* (BESIII Collaboration), Phys. Rev. Lett. **119**, 072001 – Published 16 August 2017

Physics synopsis: https://physics.aps.org/synopsis-for/10.1103/PhysRevLett.119.072001

Synopsis: Filling in a Tetraquark's Profile

August 16, 2017

An analysis of electron-positron collision data has determined the spin and parity of a particle thought to consist of four quarks.



Fermilab

- 高能物理研究所/ 2017高能新闻

Zc(3900)的自旋和宇称量子数确立

Summary

- Observation of charmonium like states open a new window for the study of multiquark dynamics
- BEPC/BESIII could be a *Y*-factory, and more data taking is under consideration for XYZ study
- Coupled channel analyses in progress, more results come soon.

Stay tuned

Thank for your attention