Recent results of XYZ study at BESIII

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Outline

- Introduction

  Exotic states, XYZ, BESIII

- Selected recent results:

  X states, not covered in this talk

  $Z_c(3900)$ spin parity determination

  Y study via cross section line-shape

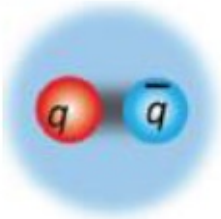
- Summary

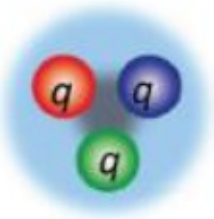
What's exotic state?

- Conventional hadrons consist of 2 or 3 quarks:

Naive Quark Model:

meson



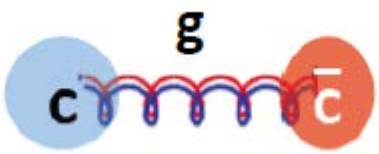


baryon

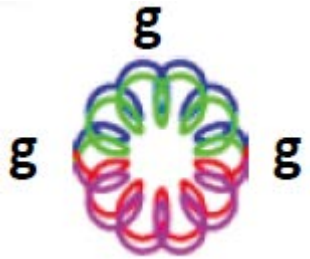
- QCD predicts the exotic state:

Multi-quark states: (N >= 4)

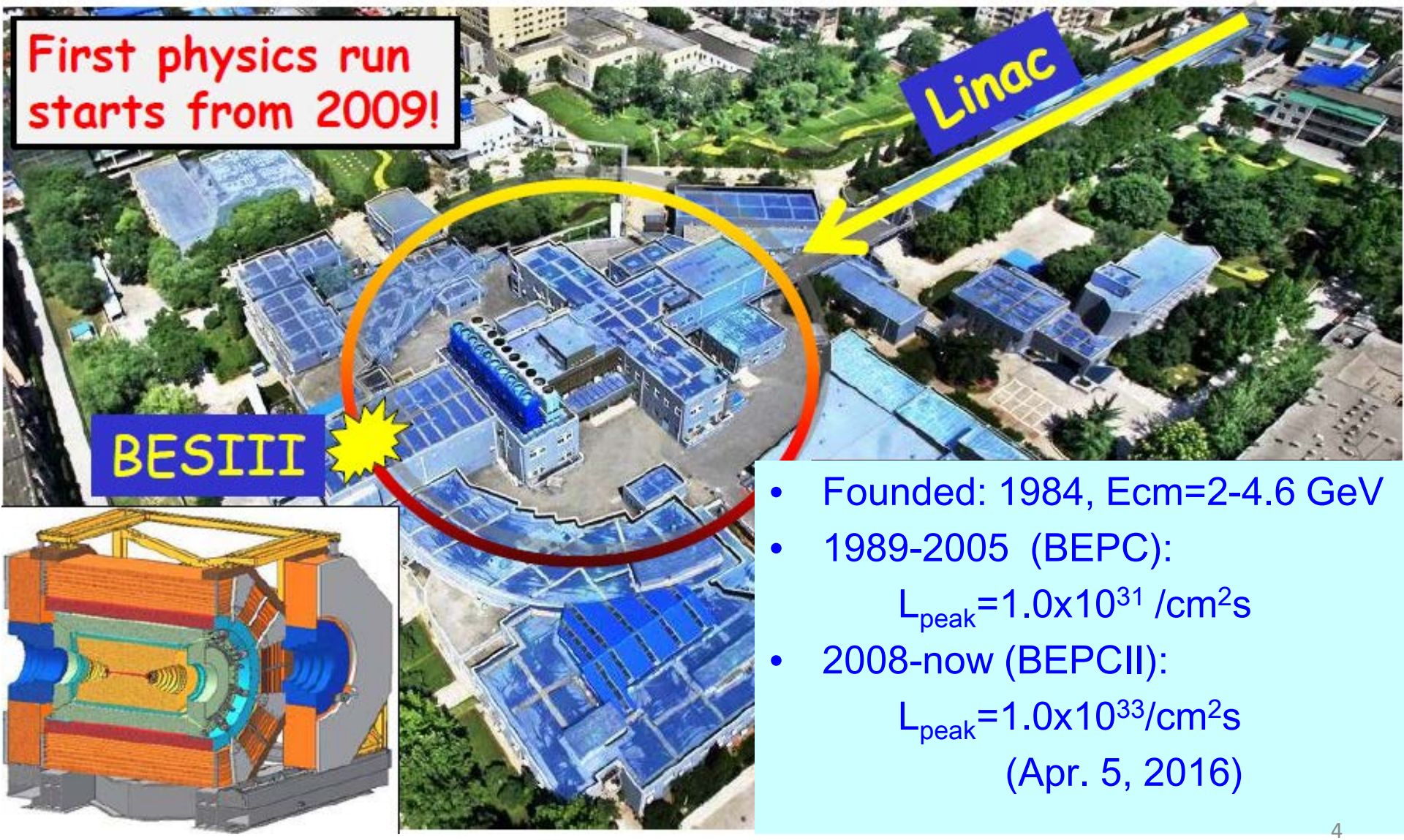
Hybrids: $q\bar{q}g$, qqqg…



Glueballs: gg, ggg



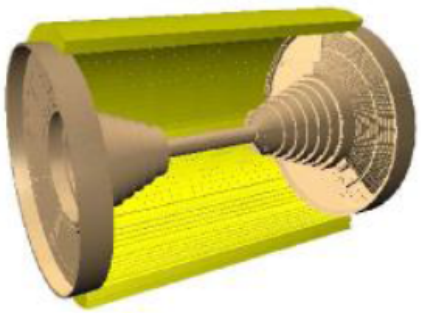
The BESIII Experiment



- Founded: 1984, Ecm=2-4.6 GeV
- 1989-2005 (BEPC):
  L_{peak}=1.0x10^{31} /cm^{2}s
- 2008-now (BEPCII):
  L_{peak}=1.0x10^{33}/cm^{2}s
  (Apr. 5, 2016)

BESIII Detector

MDC

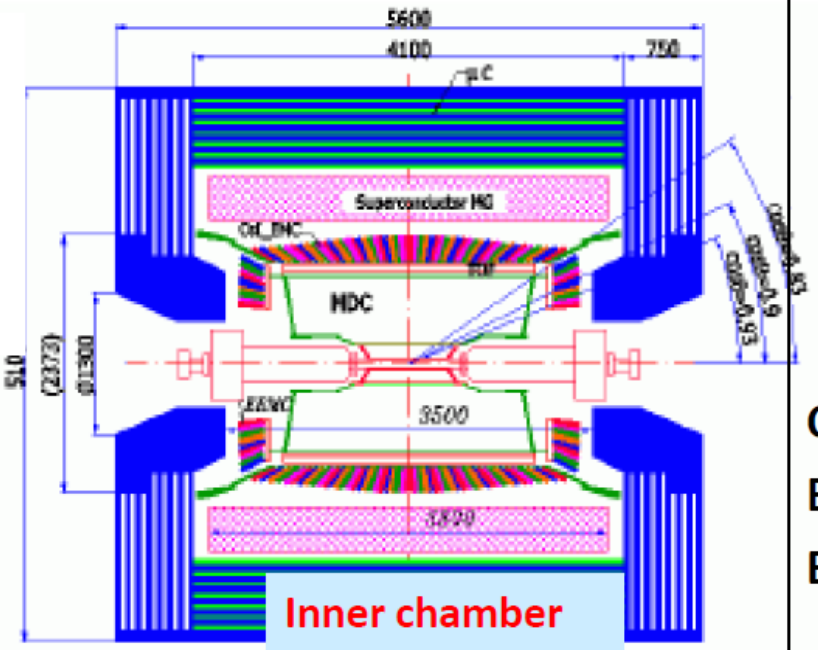


R inner: 63mm ;

R outer: 810mm

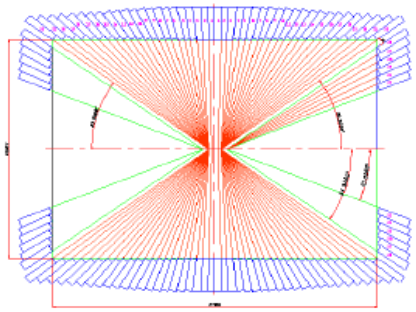
Length: 2582 mm

Layers: 43



Inner chamber replaced by CGEM is ongoing

CsI(Tl) EMC



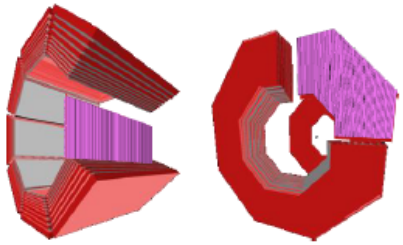
Crystals: 28 cm(15 X_0)

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

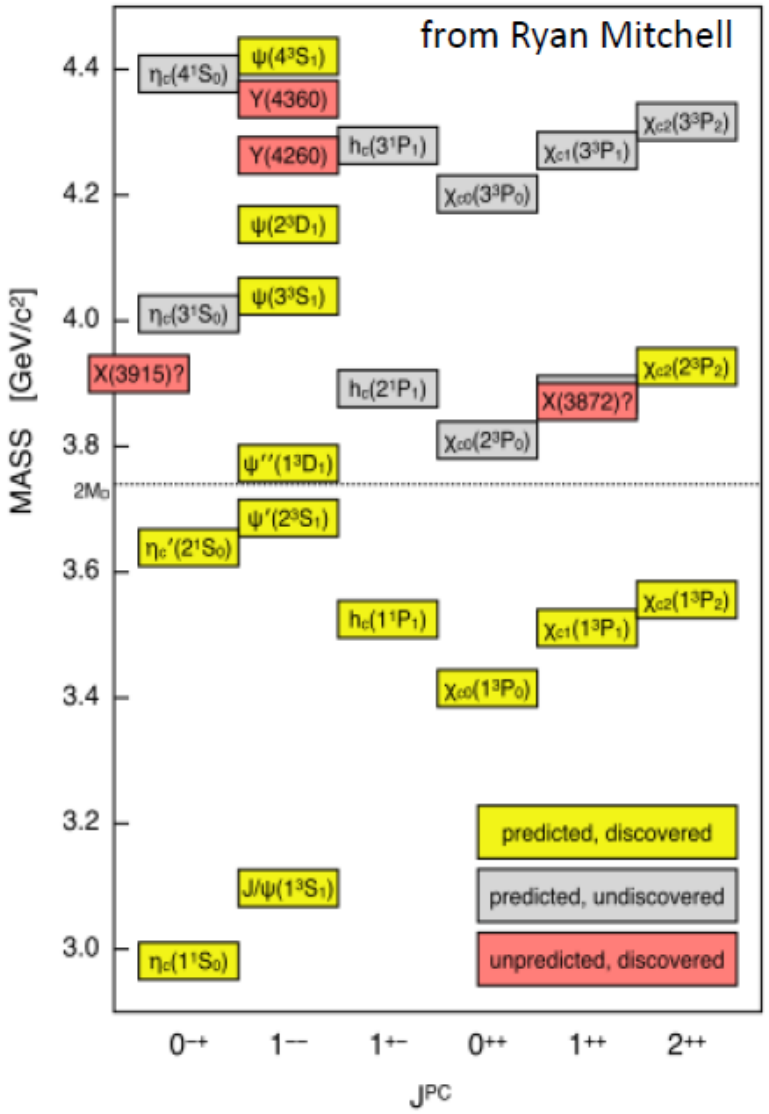
BTOF: two layers

ETOF: → MRPC

Installation completed in Oct., 2015

60ps (120ps)

Charmonium Spectroscopy

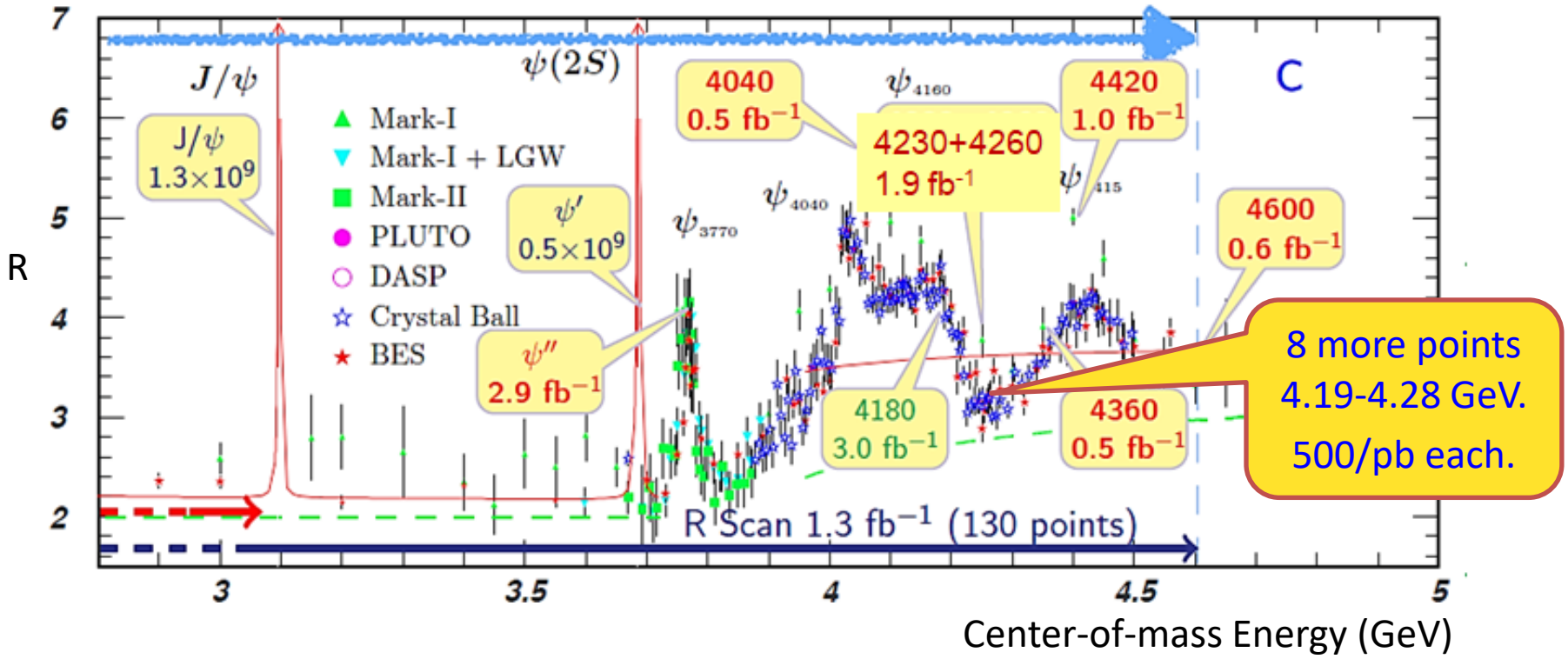


- **Above open charm threshold:**
  - many expected states not observed
  - many unexpected observed

- **Below open charm threshold:**

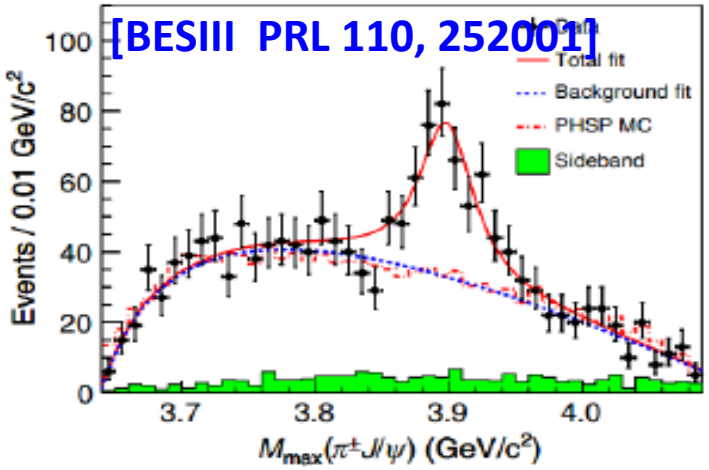
Good agreement between discovery and theoretical prediction.

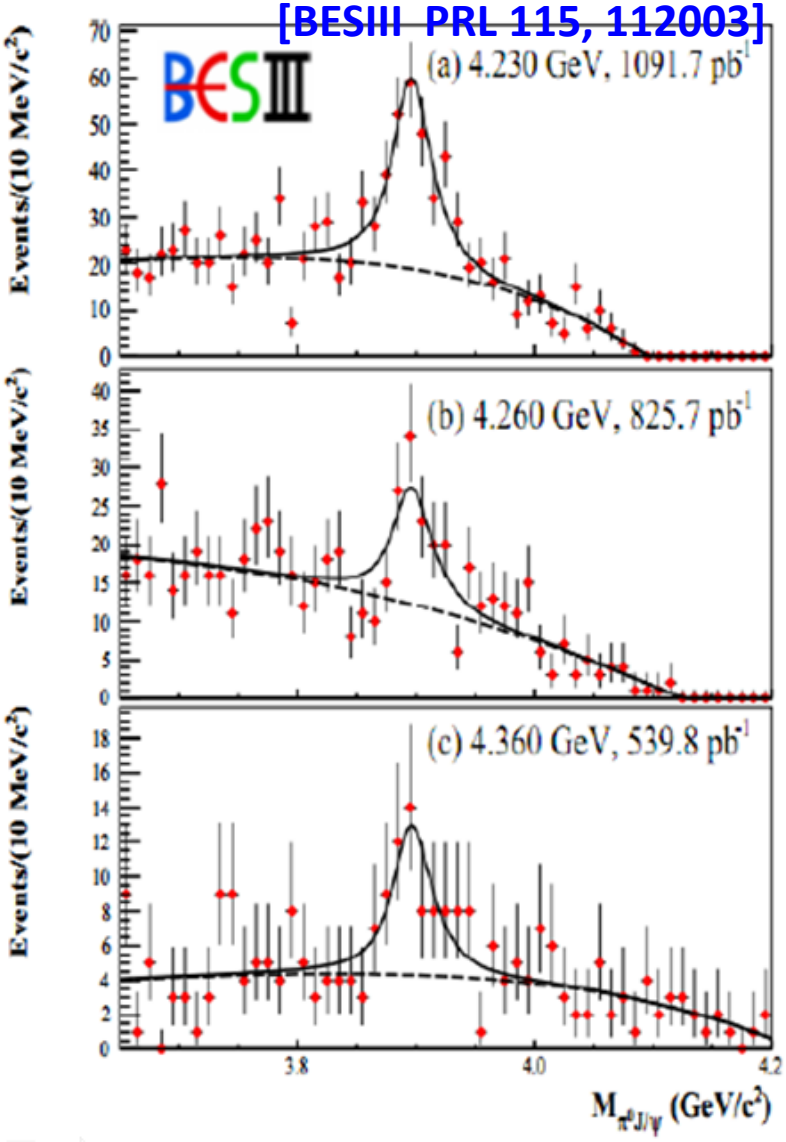
Data samples



- **Luminosity ~ 8/fb (above 4 GeV)**
- **Huge data samples around Ψ(4040), Ψ(4160), Y(4260), Y(4360), Ψ(4415) and Y(4660)**

$Z_c(3900)^{\pm/0}$ in $e^+e^- \rightarrow \pi\pi J/\psi$





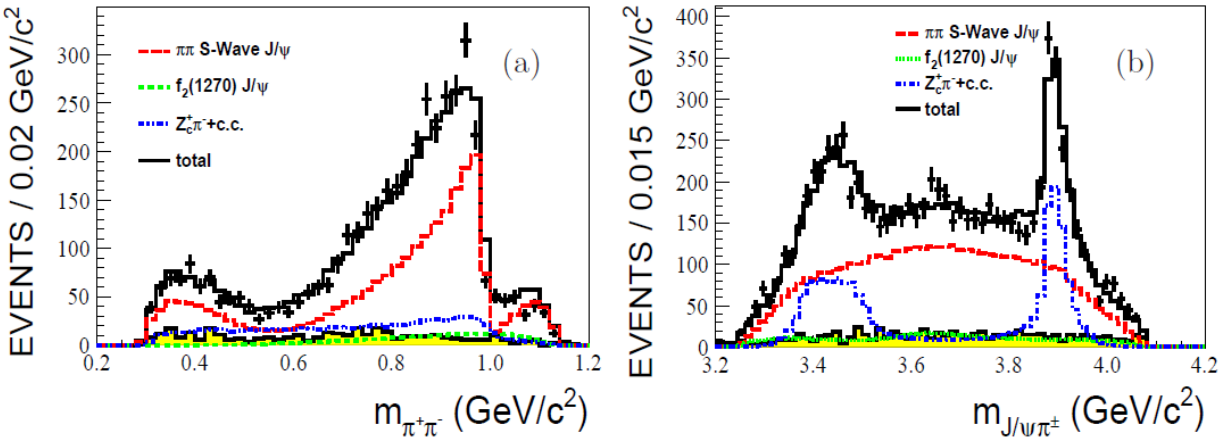
- $Z_c(3900)^{\pm}$, BESIII, Belle, CLEOc data, in 2013
- $Z_c(3900)^0$, evidence with 3.7σ by CLEOc, observed with >10σ by BESIII

Zc(3900)	Mass(MeV)	Width(MeV)
$Z_c(3900)^{\pm}$	3899.0±3.6±4.9	46±10±20
$Z_c(3900)^0$	3894.8±2.3±2.7	29.6±8.2±8.2

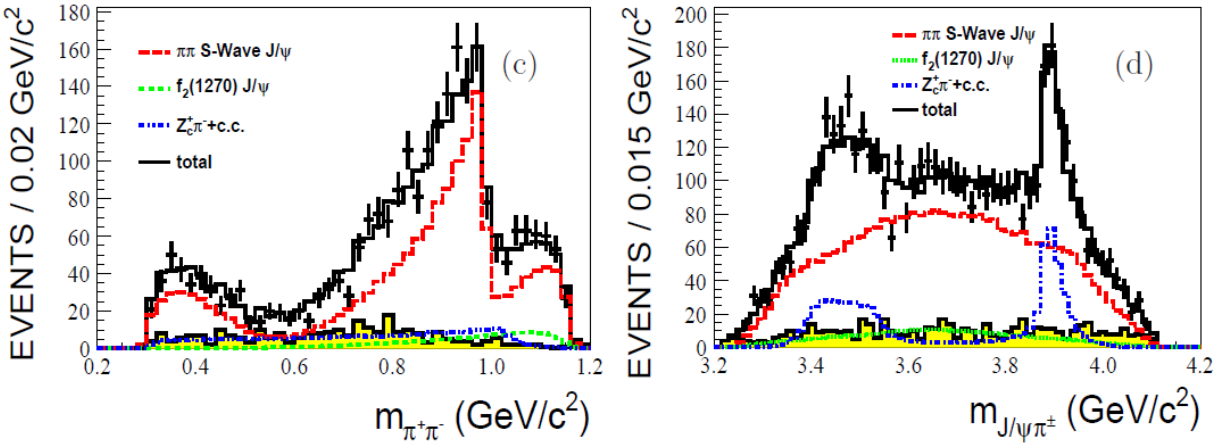
An iso-spin triplet established!

Determination of J^P of $Z_c(3900)$

4.23GeV



4.26GeV



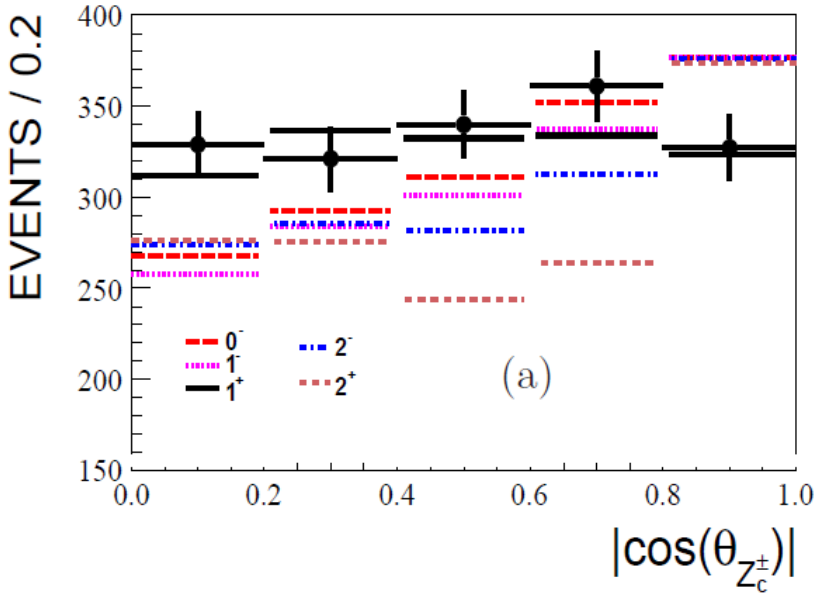
Amplitude analysis with helicity formalism

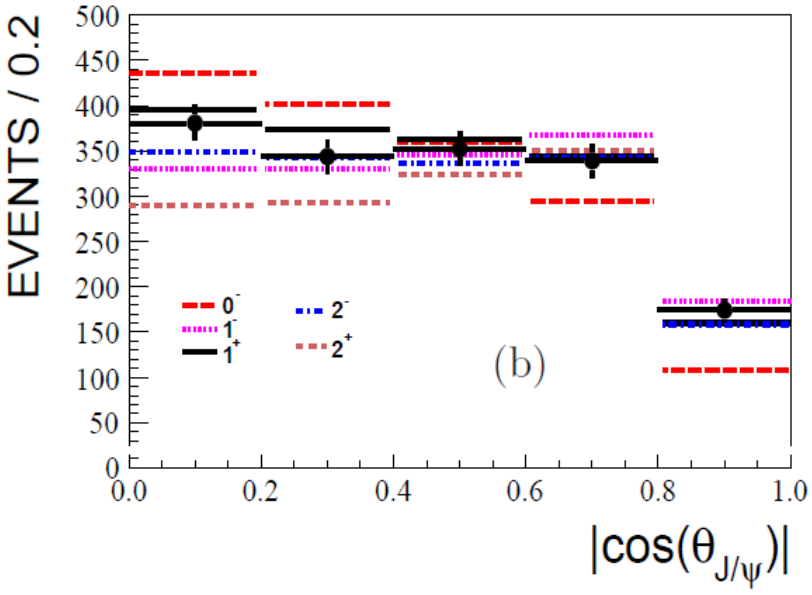
Simultaneous fit to data samples at 4.23 GeV and 4.26 GeV

$\pi\pi$ spectrum parameterized by σ, $f_0(980)$, $f_2(1270)$, $f_3(1370)$,

PRL 119, 072001 (2017)

Determination of J^P of $Z_c(3900)$





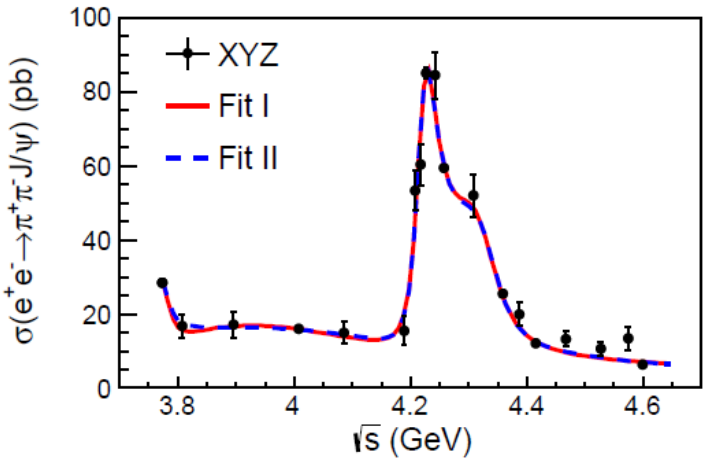
Hypothesis	$\Delta(-2\ln L)$	Δ(ndf)	Significance
1^+ over 0^-	94.0	13	7.6σ
1^+ over 1^-	158.3	13	10.8σ
1^+ over 2^-	151.9	13	10.5σ
1^+ over 2^+	96.0	13	7.7σ

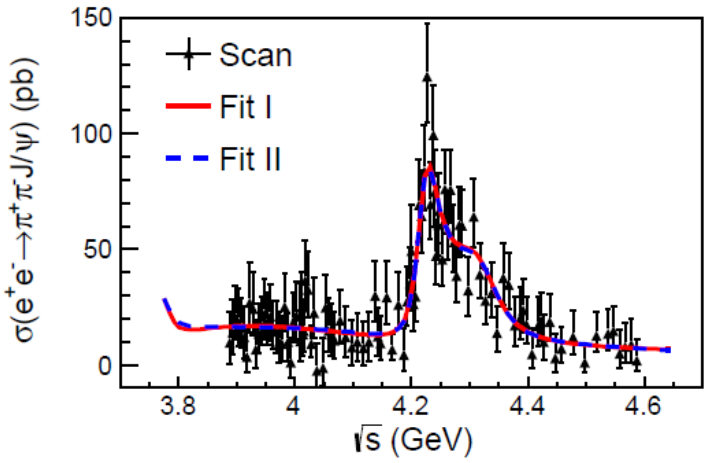
J^P of Z_c favor 1^+ with statistical significance larger than 7 σ over other quantum numbers.

$$M_{\rm pole} = (3881.2 \pm 4.2_{\rm stat} \pm 52.7_{\rm syst})\ {\rm MeV}/c^2$$
$$\Gamma_{\rm pole} = (51.8 \pm 4.6_{\rm stat} \pm 36.0_{\rm syst})\ {\rm MeV}$$

PRL 119, 072001 (2017)

Cross section measurement of $e^+e^- \rightarrow \pi^+\pi^- J/\Psi$

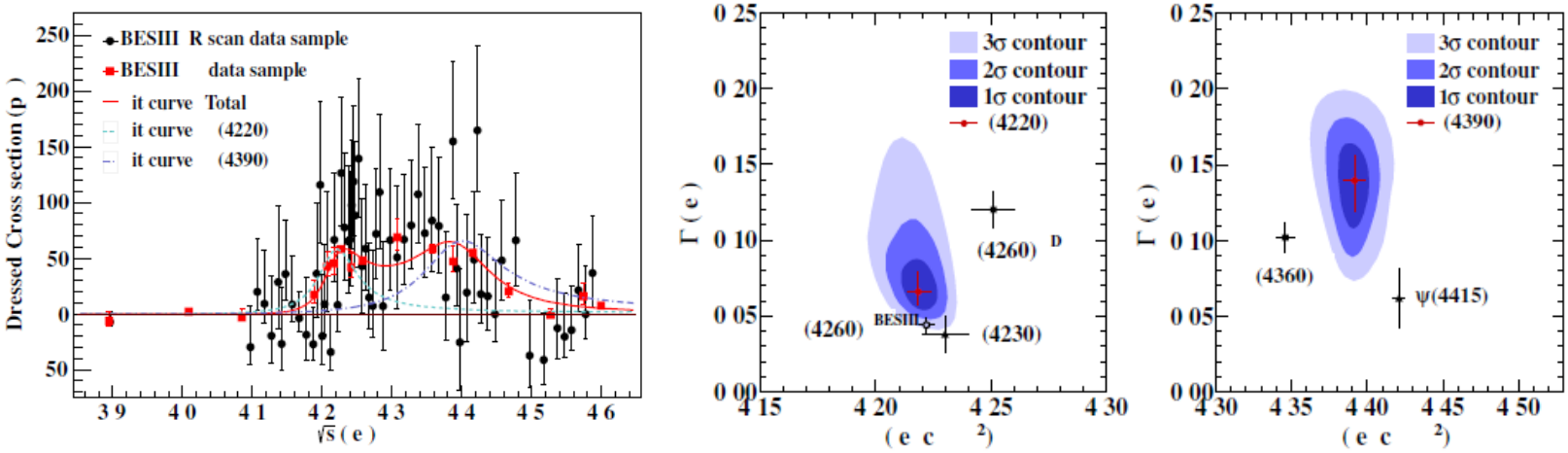




- Coherent sum of two BW-like structures + one incoherent $\Psi(3770)$
  - $M = (4222.0 \pm 3.1 \pm 1.4)$ MeV, $\Gamma = (44.1 \pm 4.3 \pm 2.0)$ MeV
    Lower and narrower than previous Y(4260) PDG values
  - $M = (4320.0 \pm 10.4 \pm 7)$ MeV, $\Gamma = (101.4 \pm 25 \pm 10)$ MeV
    A little bit lower than Y(4360) PDG value
- Compared with one BW fit, the sig. of the second BW is 7.6 σ
- Y(4260) + Y(4360)? The first observation of Y(4360) $\rightarrow \pi^+\pi^- J/\Psi$?

PRL 118, 092001 (2017)

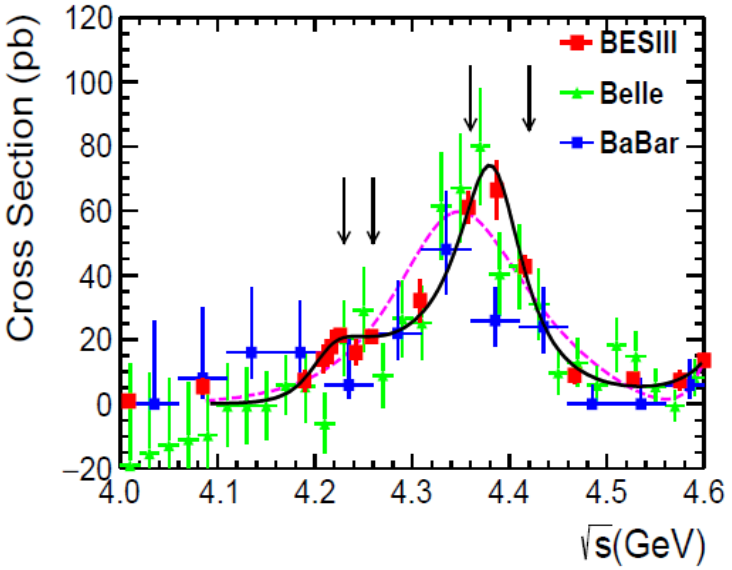
Cross section measurement of $e^+e^- \rightarrow \pi^+\pi^- h_c$



- Fitted with coherent sum of two BW-like structures
  - $M = (4218.4^{+5.5}_{-4.5} \pm 0.9)$ MeV, $\Gamma = (66.0^{+12.3}_{-8.3} \pm 0.4)$ MeV
  - $M = (4391.5^{+6.3}_{-6.8} \pm 1)$ MeV, $\Gamma = (139.5^{+16.2}_{-20.6} \pm 0.6)$ MeV
- The lower one is consistent with the state observed in $\pi^+\pi^- J/\Psi$ around 4222 MeV

PRL 118, 092002 (2017)

Cross section measurement of $e^+e^- \rightarrow \pi^+\pi^-\Psi'$

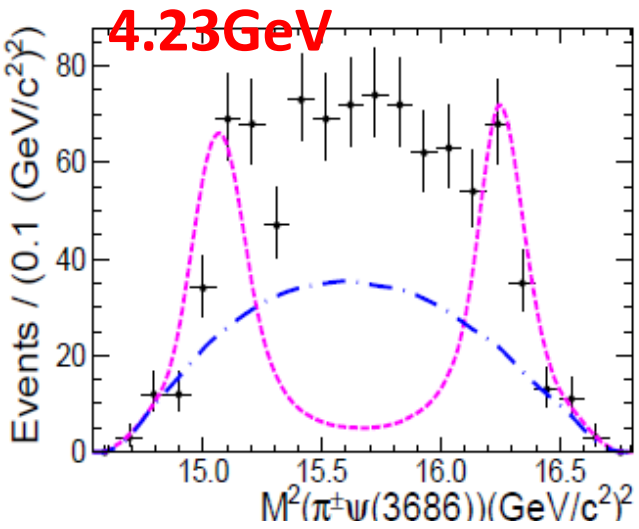


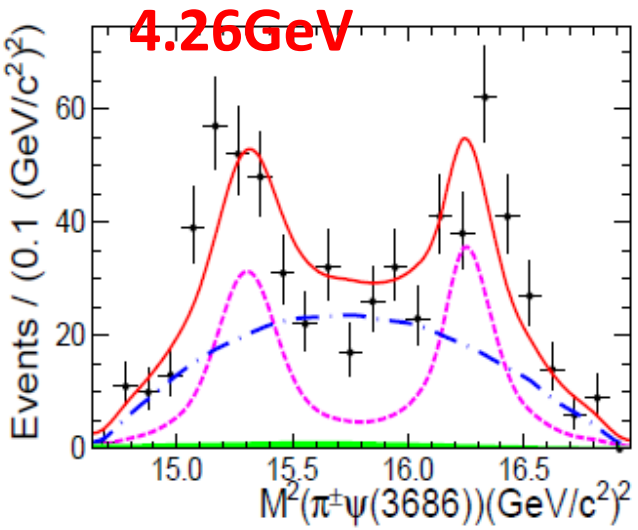
Parameters	Solution I	Solution II
$M(Y4220)$ (MeV/c^2)	4209.5 ± 7.4	
$\Gamma(Y(4220))$ (MeV)	80.1 ± 24.6	
$\mathcal{B}\Gamma^{e^+e^-}(Y(4220))$ (eV)	0.8 ± 0.7	0.4 ± 0.3
$M(Y4390)$ (MeV/c^2)	4383.8 ± 4.2	
$\Gamma(Y(4390))$ (MeV)	84.2 ± 12.5	
$\mathcal{B}\Gamma^{e^+e^-}(Y(4390))$ (eV)	3.6 ± 1.5	2.7 ± 1.0
ϕ_1 (rad)	3.3 ± 1.0	2.8 ± 0.4
ϕ_2 (rad)	0.8 ± 0.9	4.7 ± 0.1

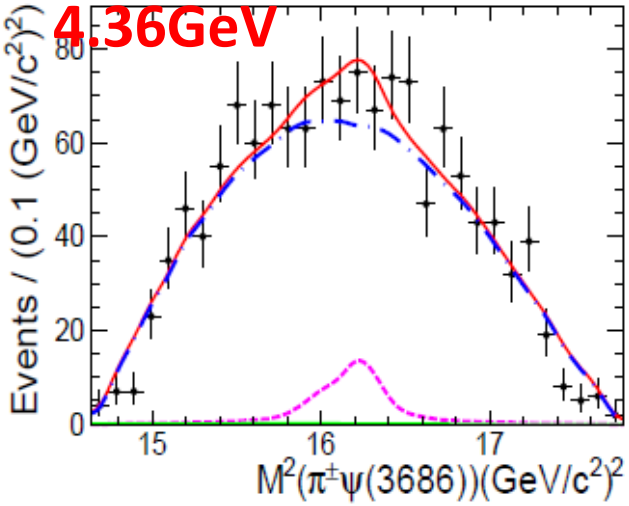
- A clear peak around Y(4360), consistent with the results from Belle and Babar, but with much improved precision.
- A binned χ^2 fit with 3 resonances: Y(4220), Y(4390), Ψ(4660)
- The significance of Y(4220) is 5.8 σ.

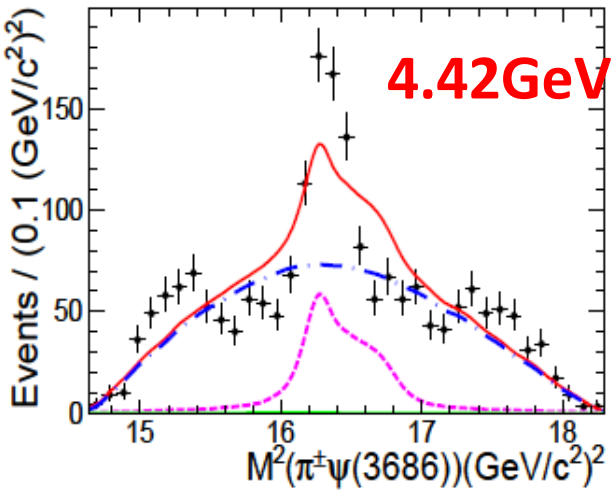
PRD 96, 032004 (2017)

Charged structures in $e^+e^- \rightarrow \pi^+\pi^-\Psi'$









Different structures at different energy points.

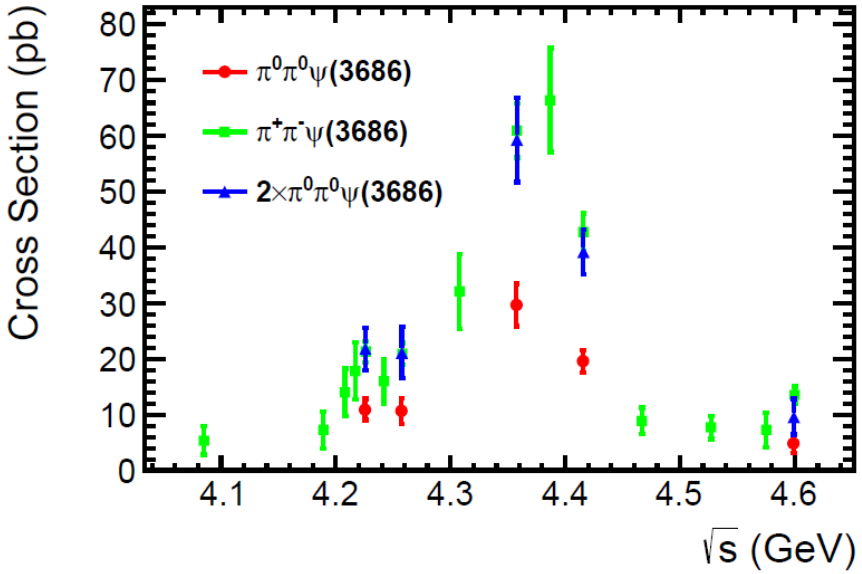
Structure @4.42 GeV
Significance of 9.2σ
M=4032.1±2.4MeV
Γ =26.1±5.3MeV

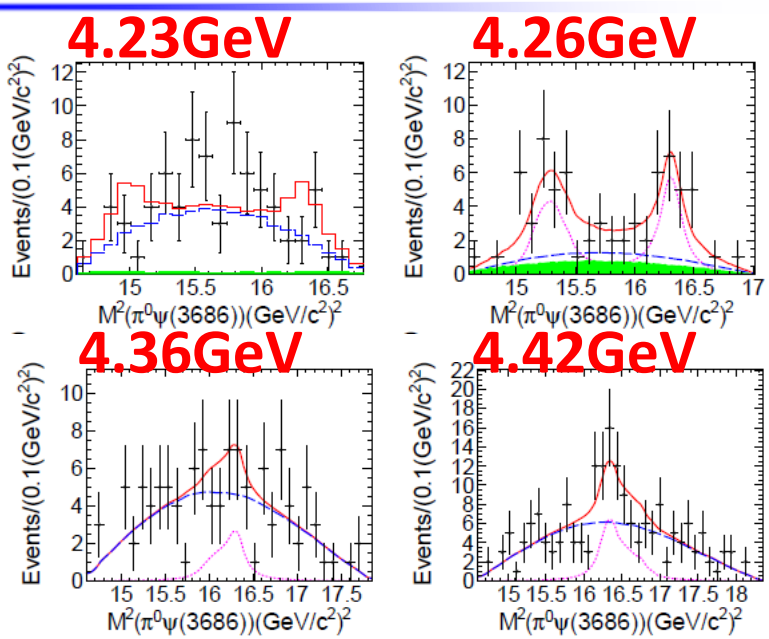
New Zc? Need more Investigation!!!

Discrepancies between the fit model and data!

PRD 96, 032004 (2017)

Cross section measurement of $e^+e^- \rightarrow \pi^0\pi^0\Psi'$



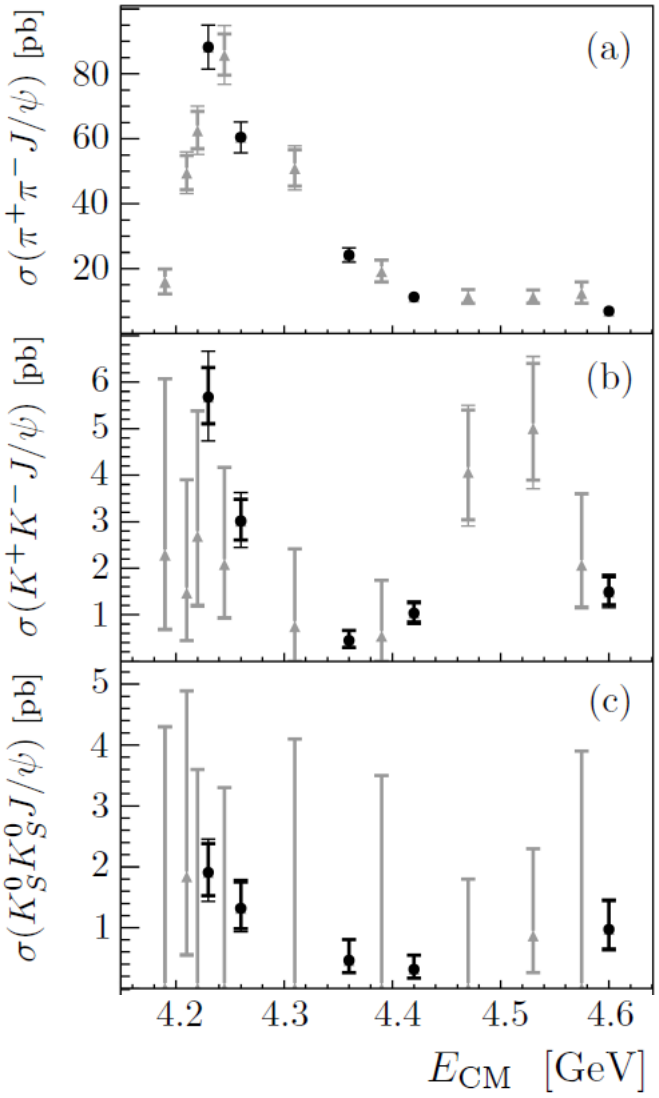


- Cross section measured at 16 energy points from 4.008 to 4.6 GeV, consistent with ½ $\pi^+\pi^-\Psi'$

- Dalitz plots consistent with the $\pi^+\pi^-\Psi'$

arXiv: 1710.10740

Cross section measurement of e^+e^- →KKJ/Ψ



Cross section measured at 14 energy points from 4.189 to 4.6 GeV

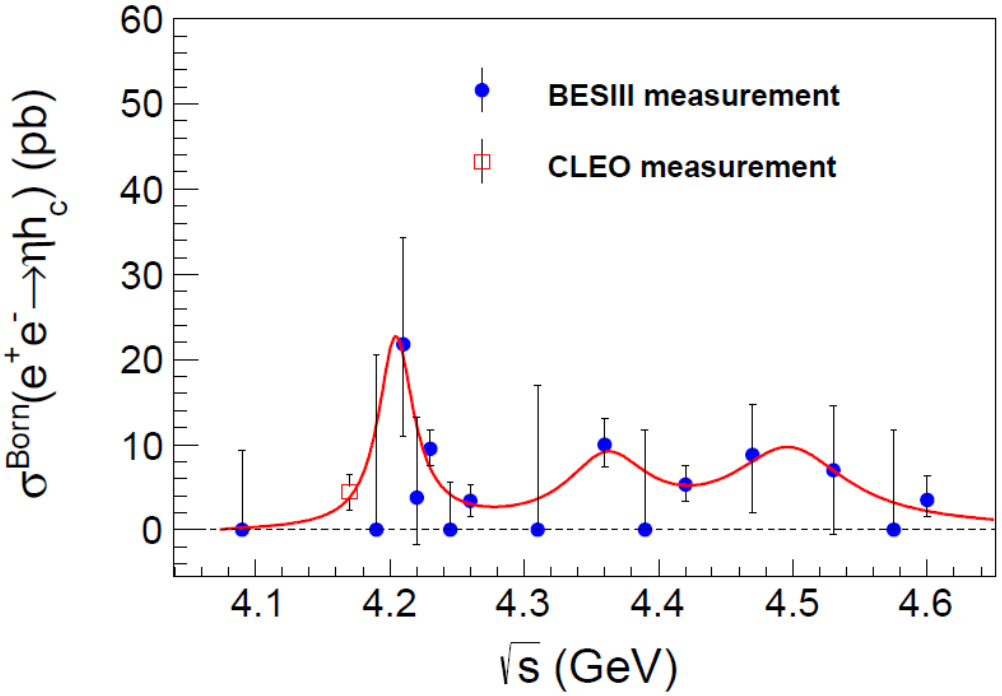
Energy dependence differ from $\pi^+\pi^-$J/Ψ

Evidence for a structure around 4.5 GeV

Neutral and charged kaons consistent with expectations from isospin conservation.

arXiv: 1802.01216

Cross section measurement of $e^+e^- \rightarrow \eta h_c$



- 16 channels searched.
- Clear signals at 4.226 and 4.358 GeV

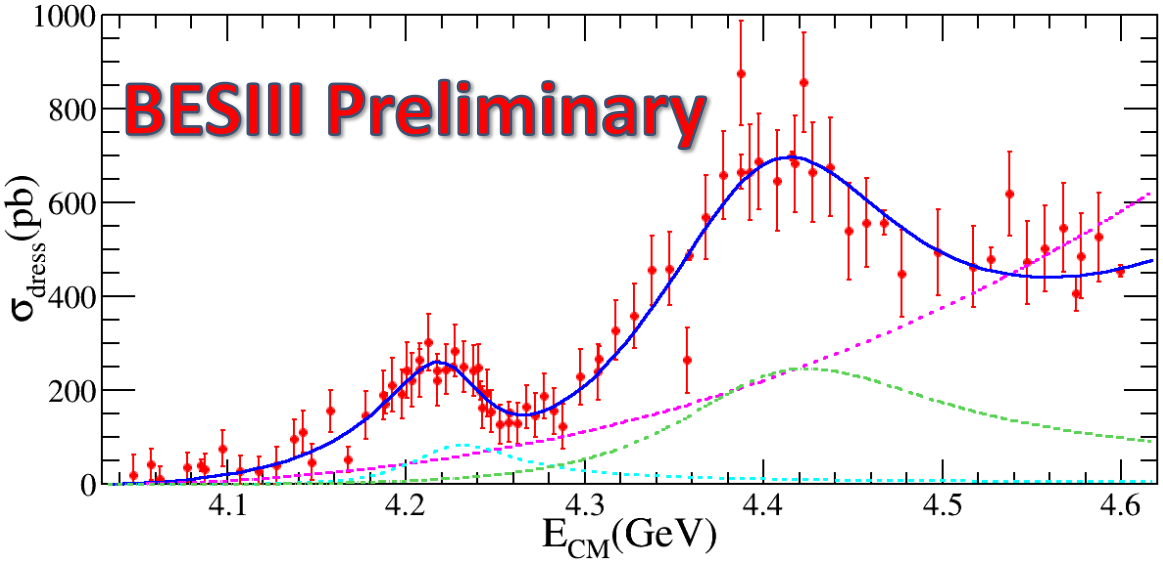
$M = (4204 \pm 6)$ MeV
$\Gamma = (32 \pm 22)$ MeV

- A fit with a coherent sum of 3 BW functions.

arXiv: 1704.08033

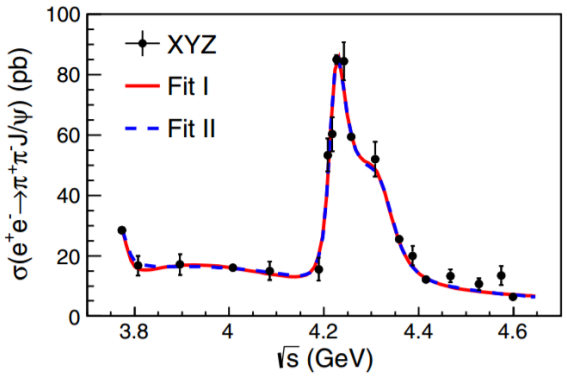
Measurement of $e^+e^- \rightarrow \pi^+D^0D^{*-}$+c.c.

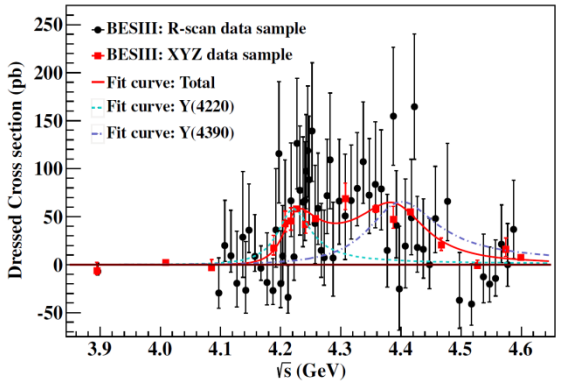
1st measurement by Belle in 2009. (PRD 80, 091101), ISR technique, limited statistics.

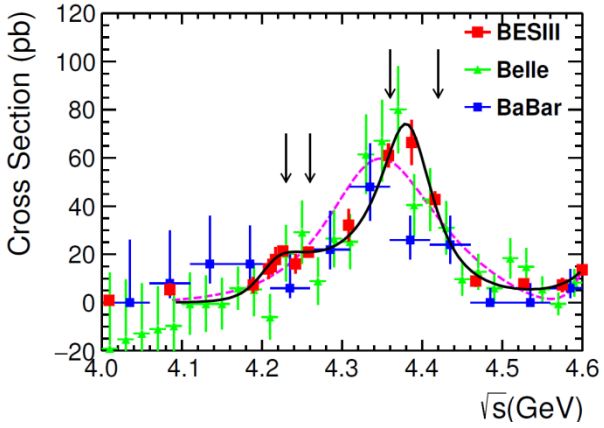


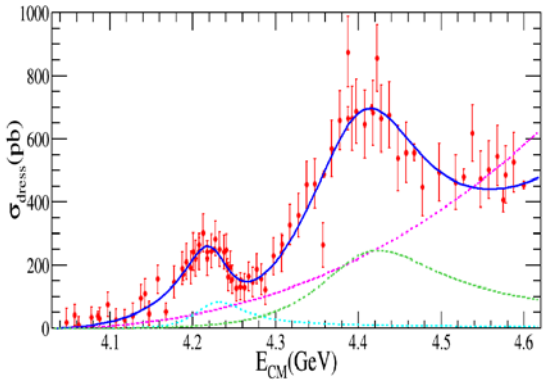
- Coherent sum of 3-body phase space and 2 Breit-Wigner functions
  - M = (4228.6±4.1±5.0) MeV, Γ = (77.1±6.8±2.7) MeV
  - M = (4404.6±7.4±4.8) MeV, Γ = (191.7±13.0±15.1) MeV
- Two structures are consistent with those in $\pi\pi h_c$, $\pi\pi\Psi'$
- Evidence of open charm production from Y states.

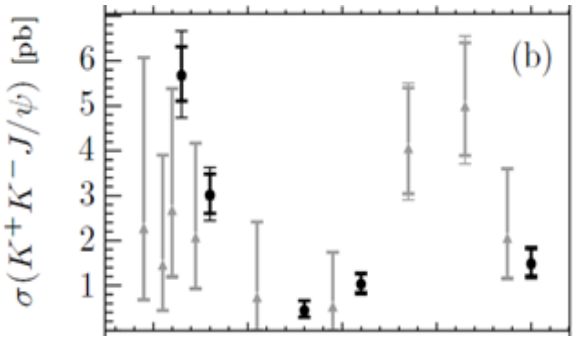
Y(4260) → Y(4220): What is it?

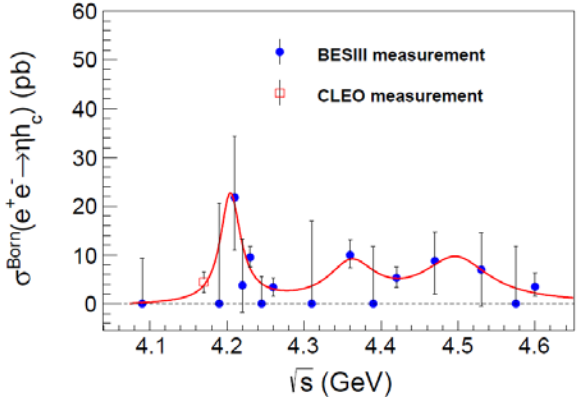












Y(4220): Mass ~ 4220 MeV, Width ~ 60 MeV

Summary

- Lots of progress in charmonium-like studies recently.
- J^P of $Z_c(3900)$ is determined to be 1^+ .
- Observation of Z_c states, a new structure in $\pi\Psi'$.
- Measurements of many final states,

  $Y(4260) \rightarrow Y(4220)$ with more decay modes now.
- The nature of many XYZ states are still not clear, more efforts are expected.

Thank You

Backup

Determination of J^P of $Z_c(3900)$

TABLE I: Significance of the spin parity 1^+ over other quantum numbers for $Z_c^\pm$. The significance is obtained for given change in ndf, $\Delta(\text{ndf})$. In each case, $\Delta(\text{ndf}) = 2\times4+5$, where 2×4 ndf account for the coupling strength for $e^+e^- \to Z_c^\pm\pi^\mp$ at the two data sets, and the additional five ndf are the contribution of the common degrees of freedom for the Z_c resonant parameters and the coupling strength for $Z_c^\pm \to J/\psi\pi^\pm$.

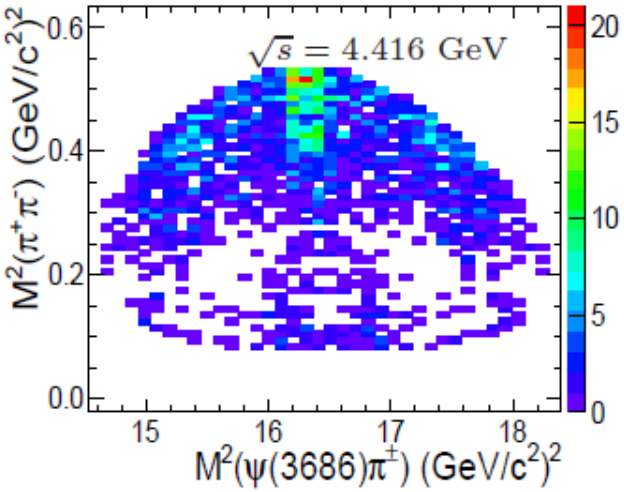
Hypothesis	$\Delta(-2\ln L)$	$\Delta(\text{ndf})$	Significance
1^+ over 0^-	94.0	13	7.6σ
1^+ over 1^-	158.3	13	10.8σ
1^+ over 2^-	151.9	13	10.5σ
1^+ over 2^+	96.0	13	7.7σ

$$e^+e^- \to Z_c(3900)^+\pi^- + c.c. \to J/\psi\pi^+\pi^-$$

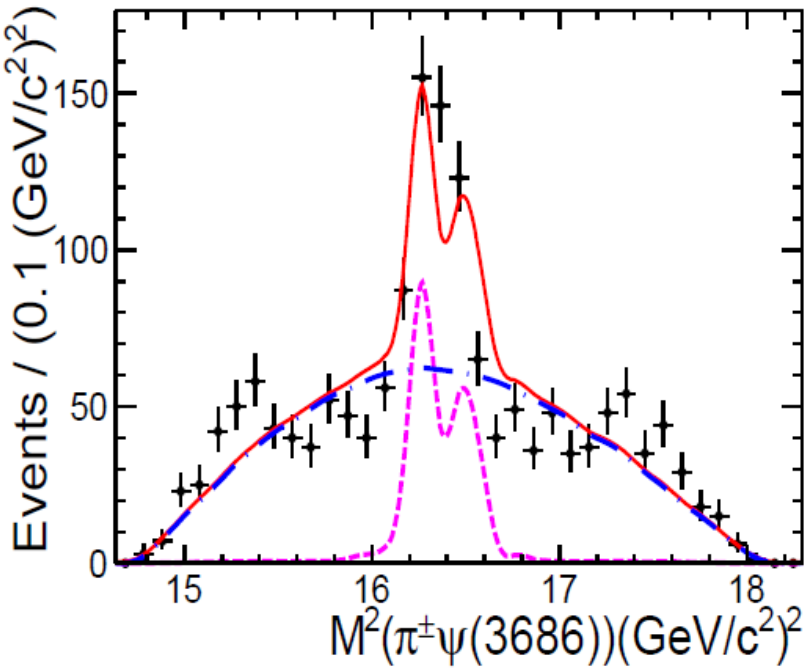
$$(21.8 \pm 1.0_{\text{stat}} \pm 4.4_{\text{syst}}) \text{ pb at } \sqrt{s} = 4.23 \text{ GeV}$$

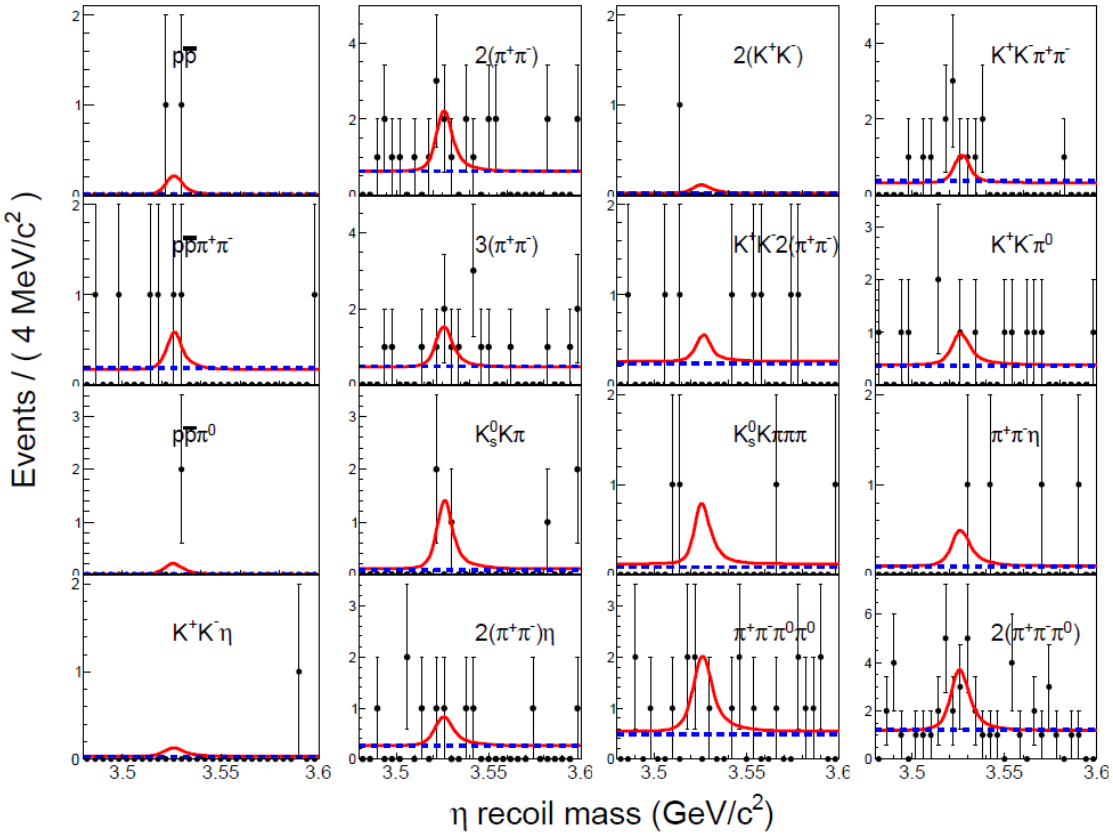
$$(11.0 \pm 1.2_{\text{stat}} \pm 5.4_{\text{syst}}) \text{ pb at } \sqrt{s} = 4.26 \text{ GeV}.$$

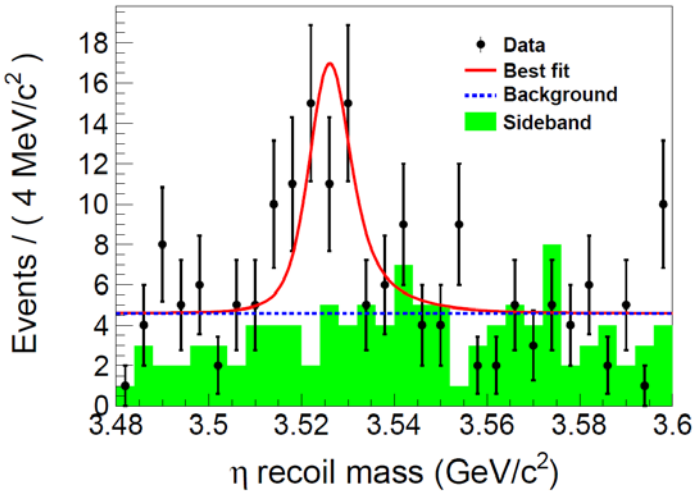
PRL 119, 072001 (2017)



A similar fit to data with the additional requirement $M^2(\pi^+\pi^-) > 0.3$ (GeV/c^2)^2 is performed, which yields a mass of $M = 4030.3 \pm 0.1$ MeV/c^2 and a width of $\Gamma = 5.1 \pm 0.2$ MeV. The corresponding projection of the fit and data on the $M^2(\pi^\pm\psi(3686))$ distribution is shown in Fig. 4, and the fit C.L. is 50%.



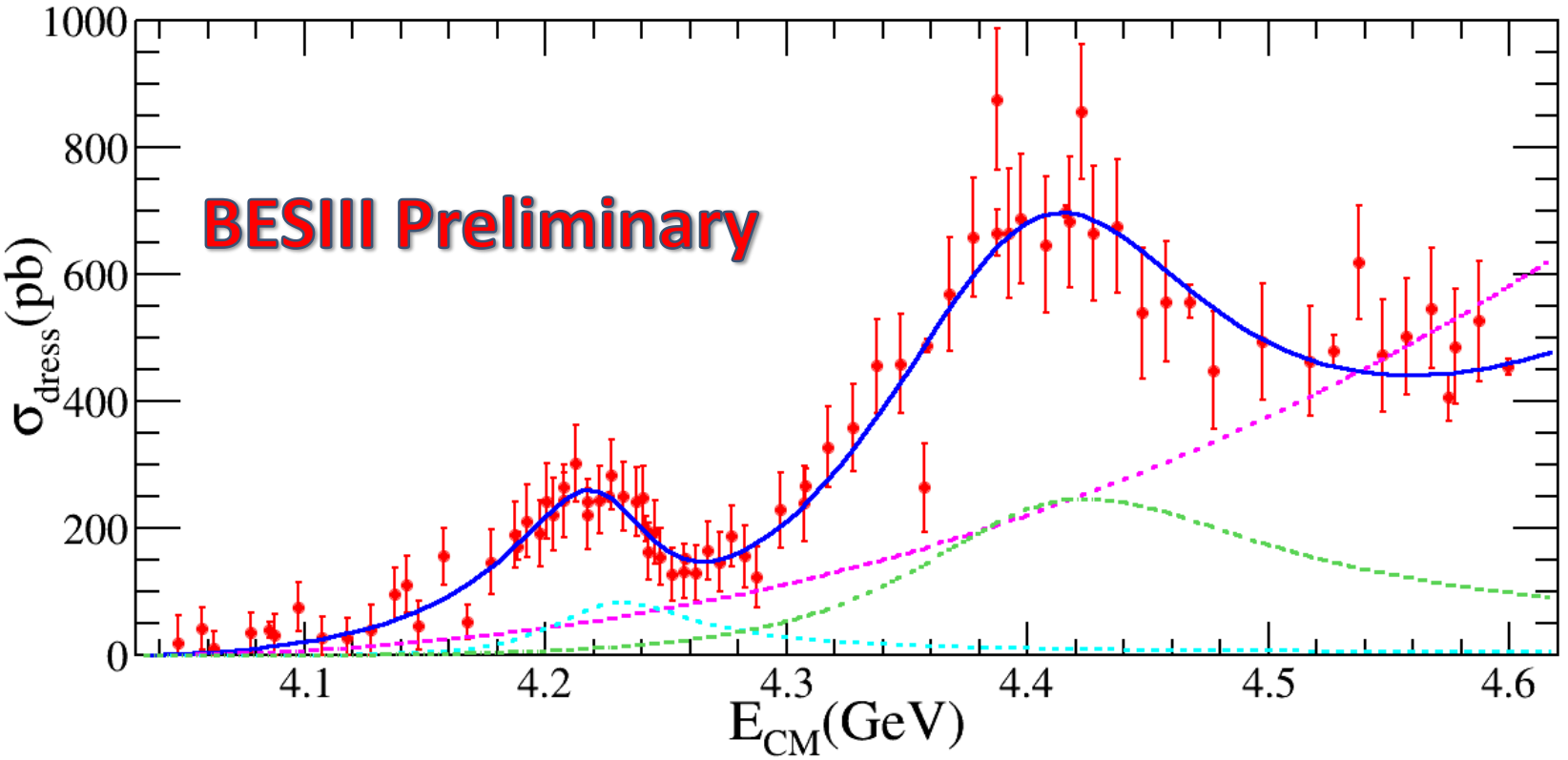

Events / (4 MeV/c^2)
$p\bar{p}$
$2(\pi^+\pi^-)$
$2(K^+K^-)$
$K^+K^-\pi^+\pi^-$
$p\bar{p}\pi^+\pi^-$
$3(\pi^+\pi^-)$
$K^+K^-2(\pi^+\pi^-)$
$K^+K^-\pi^0$
$p\bar{p}\pi^0$
$K^0_sK\pi$
$K^0_sK\pi\pi\pi$
$\pi^+\pi^-\eta$
$K^+K^-\eta$
$2(\pi^+\pi^-)\eta$
$\pi^+\pi^-\pi^0\pi^0$
$2(\pi^+\pi^-\pi^0)$
3.5
3.55
3.6
η recoil mass (GeV/c^2)


Events / (4 MeV/c^2)
Data
Best fit
Background
Sideband
3.48
3.5
3.52
3.54
3.56
3.58
3.6
η recoil mass (GeV/c^2)

Measurement of $e^+e^- \rightarrow \pi^+ D^0 D^{*-} + c.c.$

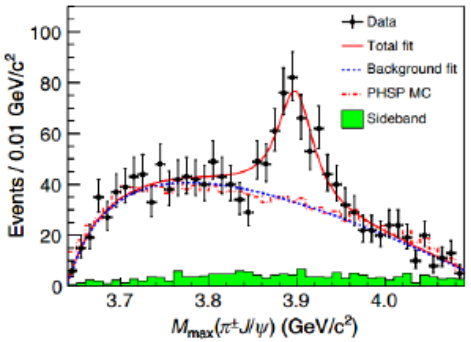
$$\sigma_{dress} = \frac{N^{obs}}{\mathcal{L}(1+\delta^r)B(D^0 \to K^-\pi^+)\varepsilon}$$

$$\sigma_{\mathrm{dress}}(m) = |c \cdot \sqrt{P(m)} + e^{i\phi_1} B_1(m) \sqrt{\frac{P(m)}{P(M_1)}} + e^{i\phi_2} B_2(m) \sqrt{\frac{P(m)}{P(M_2)}}|^2$$

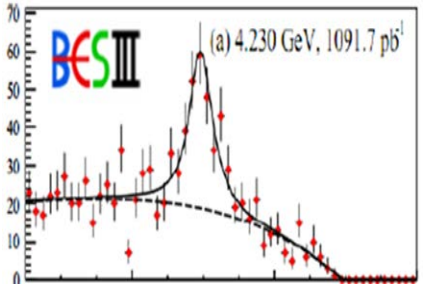


Fit with a constant (pink dashed triple-dot line) and two constant width relativistic BW functions (green dashed double-dot line and aqua dashed line).

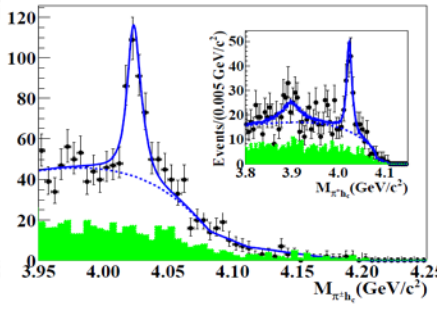
Overview of Z_c states



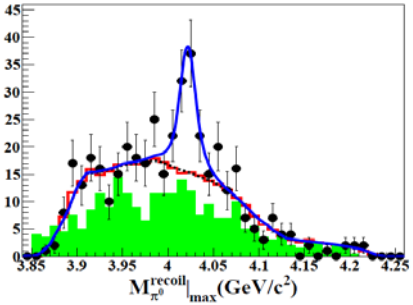
$e^+e^- \to \pi^-\pi^+ J/\psi$



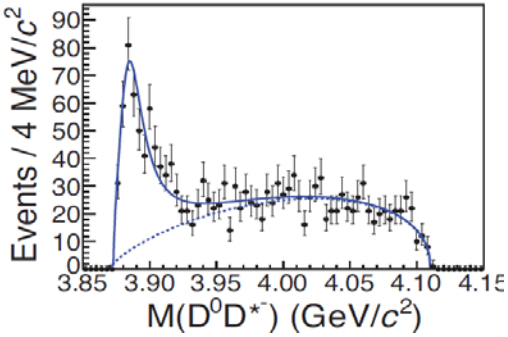
$e^+e^- \to \pi^0\pi^0 J/\psi$



$e^+e^- \to \pi^-\pi^+ h_c$



$e^+e^- \to \pi^0\pi^0 h_c$

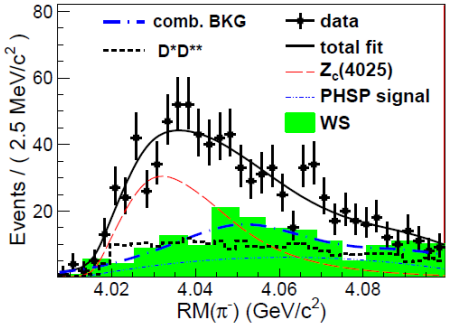


$e^+e^- \to \pi^{\pm}(D\bar{D}^*)^{-/+}$

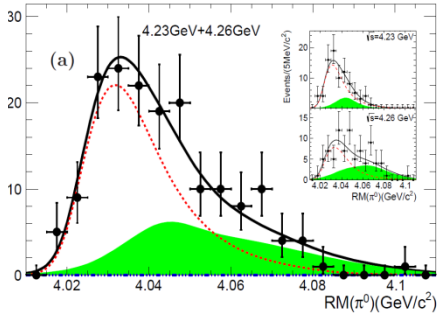
Preliminary

BESIII

soon…



$e^+e^- \to \pi^{\pm}(D^*\bar{D}^*)^{-/+}$



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

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

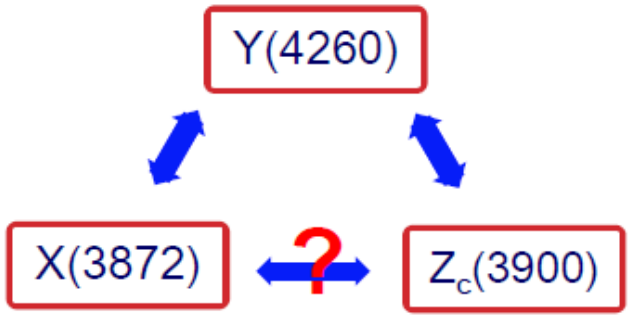
$Z_c(3900)^0$?

$Z_c(4020)^{\pm}$?

$Z_c(4020)^0$?

Summary

- Lots of progress in charmonium-like studies recently.
- Charged charmonium-like states (Z_c) has been observed.
- Neutral partners observed, make them isospin triplet states.
- No evidence of $Z_c(3900)$ in a light hadronic decay to $\omega\pi^{\pm}$.
- Observation of $e^+e^- \rightarrow \gamma X(3872)$ & $\pi^+\pi^- X(3823)$.
- X, Y, Z particles are correlated!



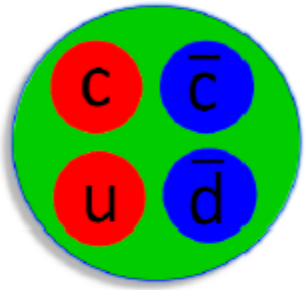
- More experimental effort is needed.

Thank You

NATURE of Z_c STATES

- At least 4 quarks, not a conventional meson

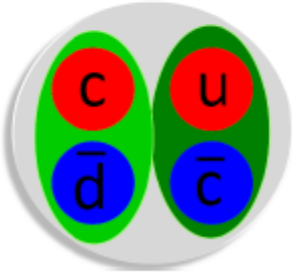
- Tetraquark state?



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

- Final States Interactions?
- …

The nature of $Z_c(3900)$?

From SPIRE HEP Database (17th, May)

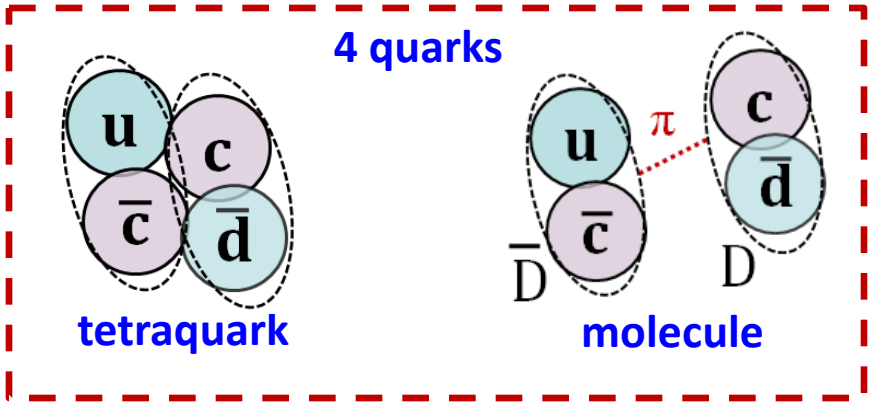
1. Tetraquarks
   arXiv: 1110.1333, 1303.6857
   arXiv: 1304. (0345, 1301, 6433, 7080, 7816)

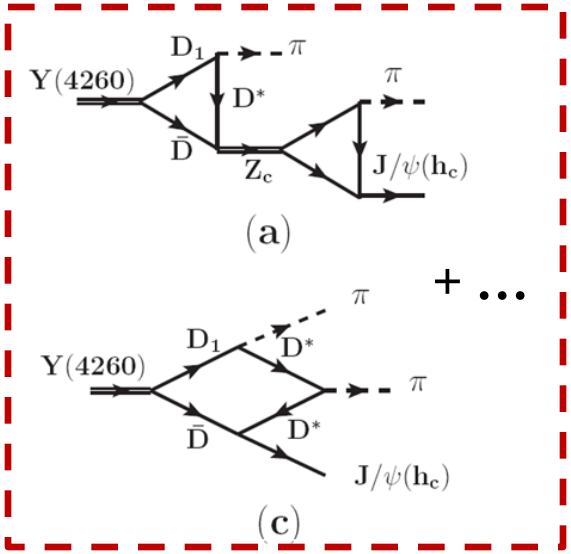
2. Hadronic molecules
   arXiv: 1303.6608,
   arXiv: 1304.(2882, 1850, 5748, 7467)

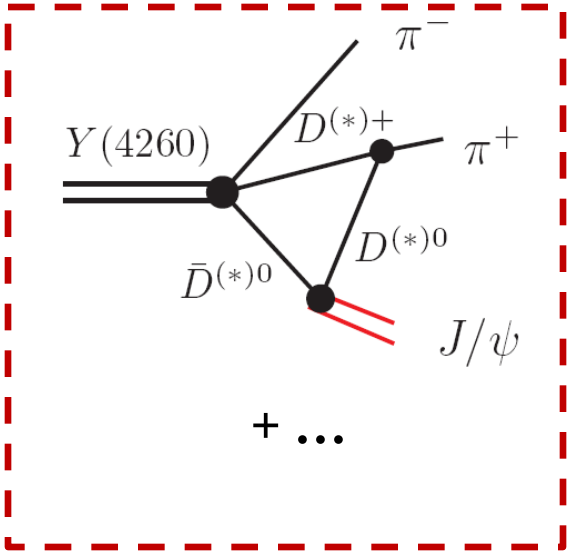
3. Four quark state (1 or 2)
   arXiv: 1304.0380

4. Meson loop
   arXiv: 1303.6355, 1304.4458

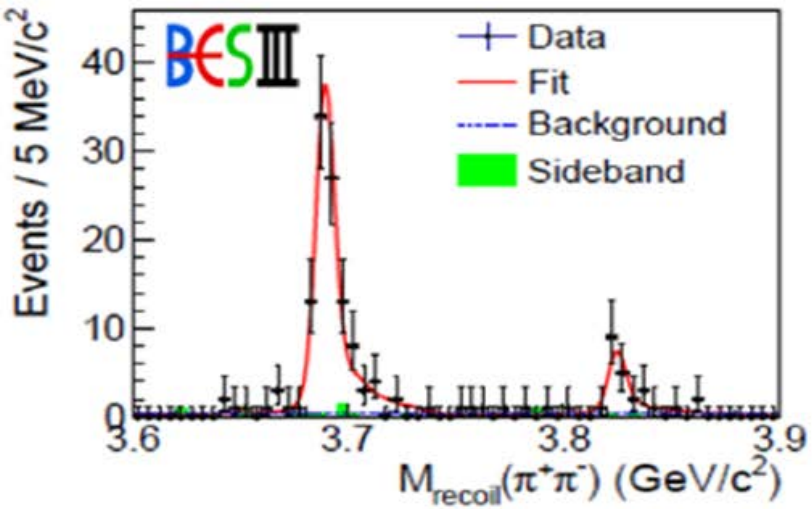
5. Initial State Pion Emission (ISPE) model
   arXiv: 1303.6842, 1304.5845

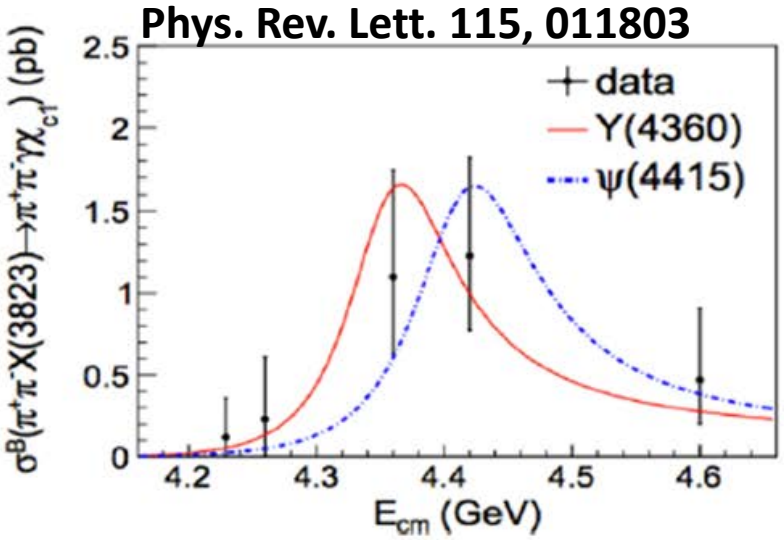






$e^+e^- \rightarrow \pi^+\pi^- X(3823) \rightarrow \pi^+\pi^-\gamma\chi_{c1}$





- M = 3821±1.3±0.7 MeV, Γ < 16 MeV, Significance: 6.2σ!
- R = B[X(3823)→$\gamma\chi_{c2}$]/B[X(3823)→$\gamma\chi_{c1}$]<0.43 @ 90% C.L.
- Both Y(4360) and Ψ(4415) line shape give reasonable description.

Agree with BELLE's 3.7σ evidence (PRL111, 032001)

- Potential Model: D wave. M~(3.810-3.840) GeV, narrow.
- R ~ 0.2

X(3823) : good candidate for $\Psi(1^3D_2)$

$e^+e^- \rightarrow \gamma X(3872) \rightarrow \gamma\pi^+\pi^- J/\psi$

[BESIII PRL112, 092001]

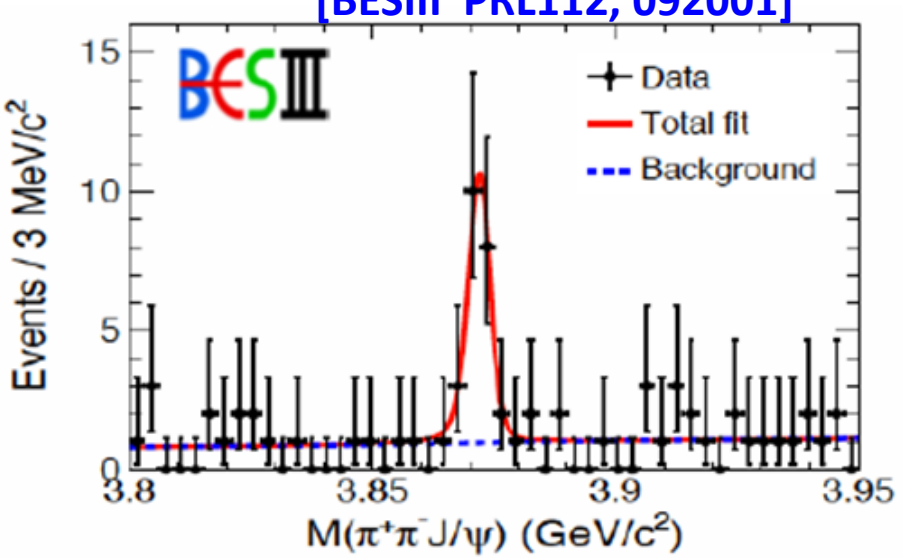
- Search for $\gamma X(3872)$ with $X(3872) \rightarrow \pi^+\pi^- J/\psi$ at Ecm = 4.23, 4.26, 4.36 GeV.

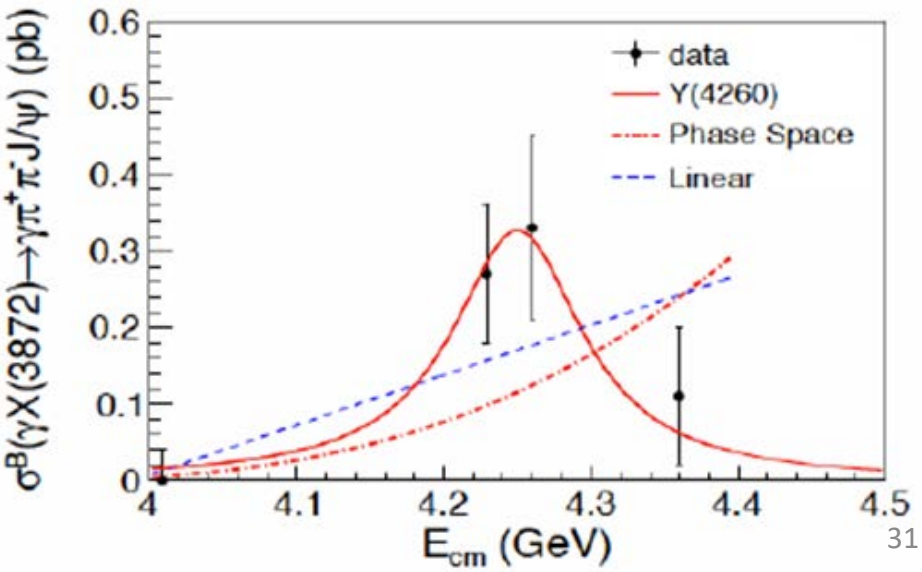
- X(3872) significance = 6.3σ, summed over all data.

- Production in Y(4260) decay suggestive, but not conclusive.

If from Y(4260):

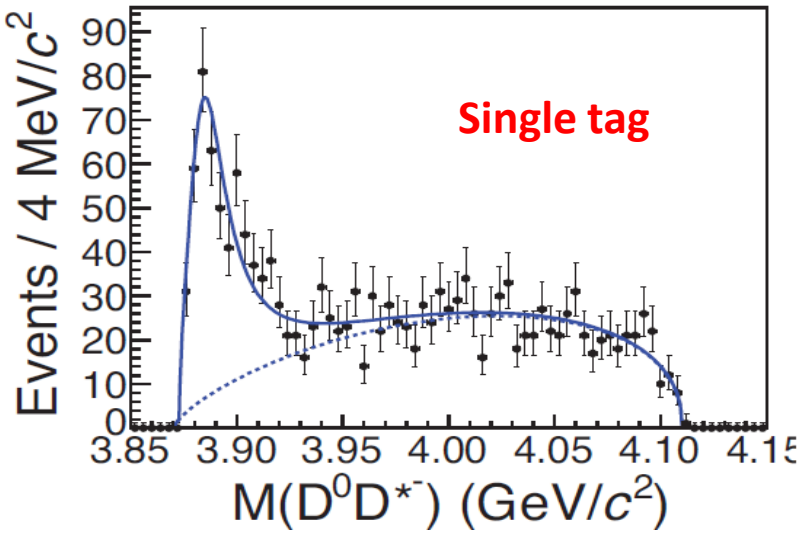
$$\frac{B(Y(4260) \rightarrow \gamma X(3872))}{B(Y(4260) \rightarrow \pi^+\pi^- J/\psi)} \sim 0.1$$

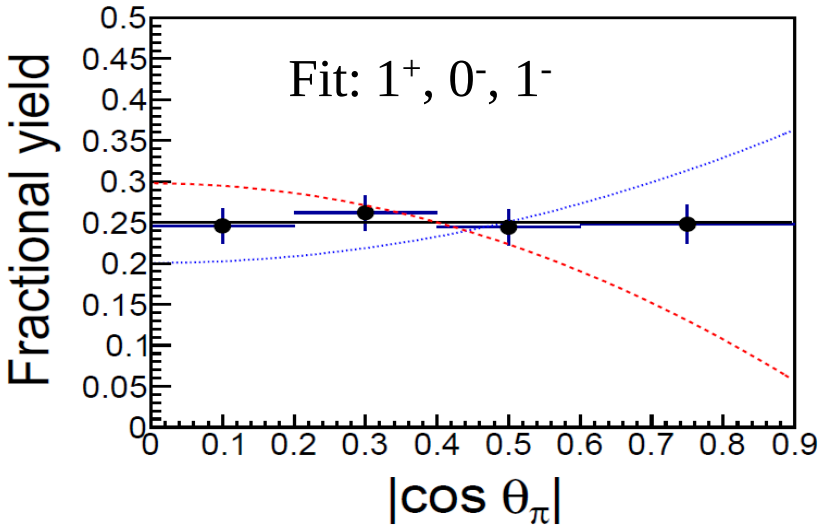


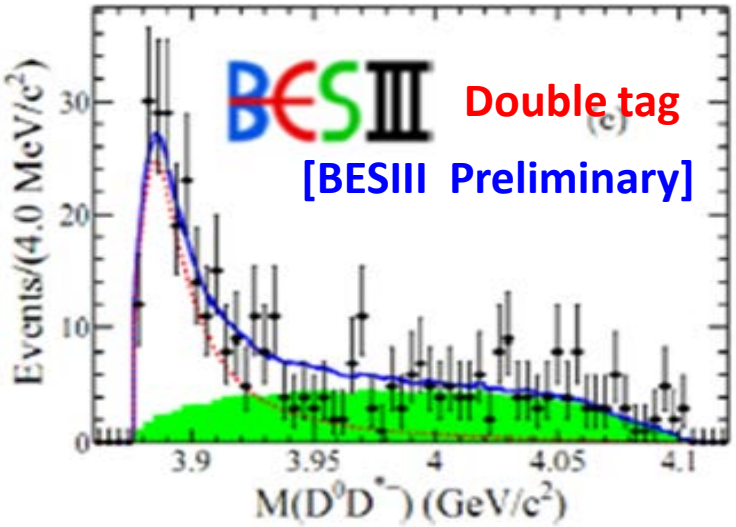


$Z_c(3885)^{\pm}$ in $e^+e^- \rightarrow \pi^{\pm}(D\bar{D}^*)^{-/+}$

[BESIII PRL 112, 022001(2014)]



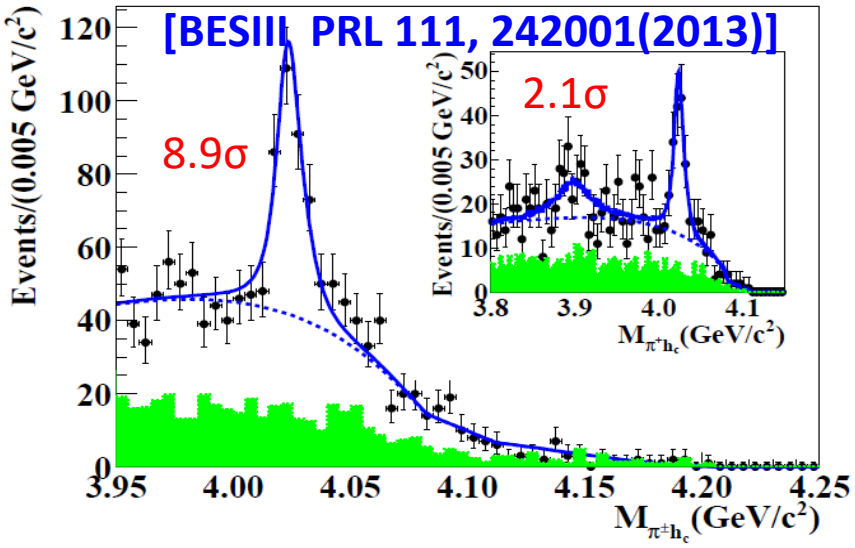


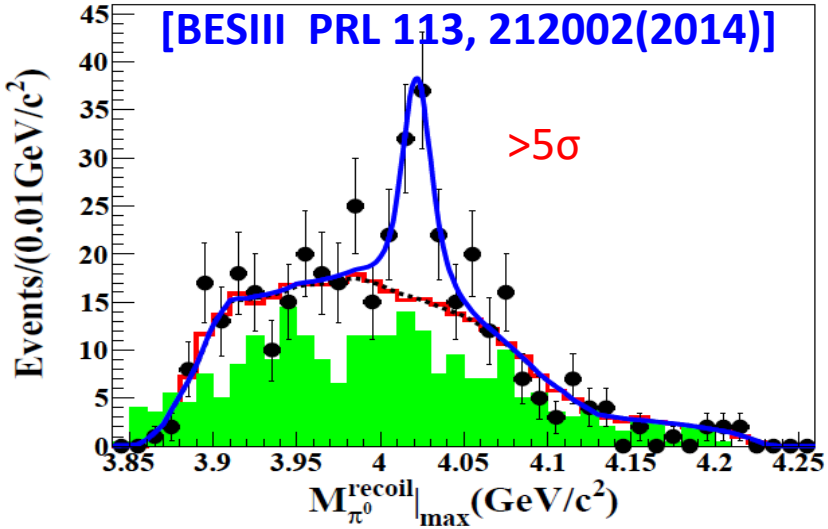


Mass = 3883.9±1.5±4.2 MeV
Width = 24.8±3.3±11.0 MeV
Fit to angular distribution favors 1^+

Mass and width close to $Z_c(3900)$

$Z_c(4020)^{\pm/0}$ in $e^+e^- \rightarrow \pi\pi h_c$





Zc(4020)	Mass(MeV)	Width(MeV)
$Z_c(4020)^{\pm}$	4022.9±0.8±2.7	7.9±2.7±2.6
$Z_c(4020)^0$	4023.8±2.2±3.8	Fixed(=7.9)

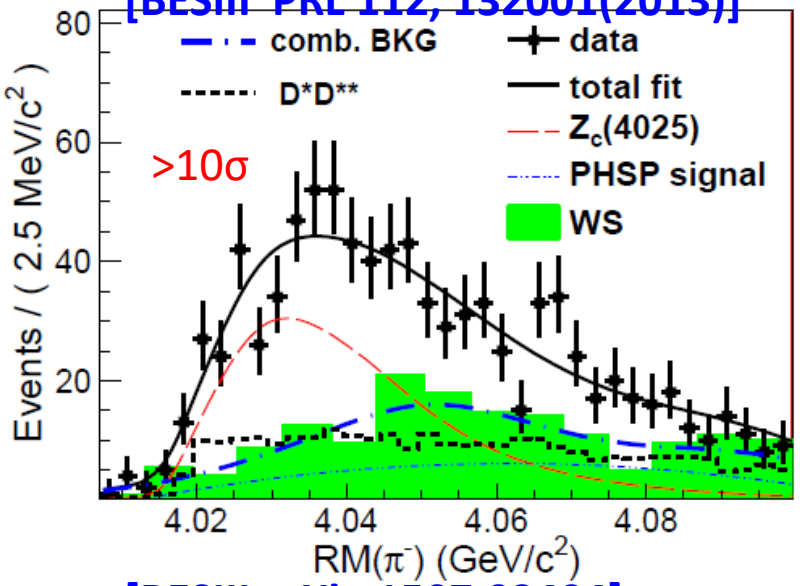
- $h_c \rightarrow \gamma\eta_c$, $\eta_c \rightarrow$ 16 hadronic channels
- $Z_c(4020)^{\pm}$, observed
- A weak evidence for $Z_c(3900) \rightarrow \pi^{\pm} h_c$

- $Z_c(4020)^0$, observed
- Another iso-spin triplet established!

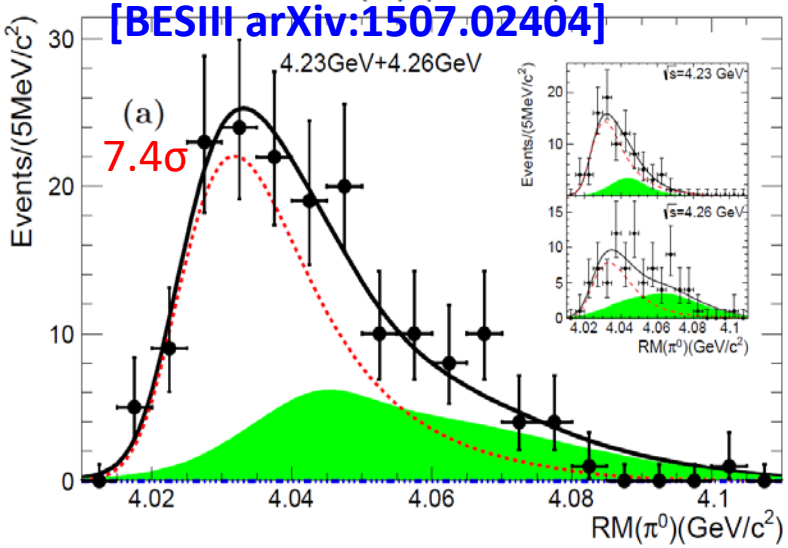
- $Z_c(4020)$, near the threshold of D*D*-bar.

$Z_c(4025)^{\pm/0}$ in $e^+e^- \rightarrow \pi^{\pm/0}(D^*\bar{D}^*)^{-/+/0}$

[BESIII PRL 112, 132001(2013)]



[BESIII arXiv:1507.02404]



Zc(4025)	Mass(MeV)	Width(MeV)
$Z_c(4025)^{\pm}$	4026.3±2.6±3.7	24.8±5.6±7.7
$Z_c(4025)^0$	$4025.5^{+2.0}_{-4.7}$±3.1	23.0±6.0±1.0

- Tag a D^+ and a bachelor π^-, reconstruct one π^0 to suppress the background
- $Z_c(4025)^{\pm}$, observed
- Coupling to D*D*-bar is much larger than to πh_c if $Z_c(4025)$ and $Z_c(4020)$ are the same state.

- $Z_c(4025)^0$, observed