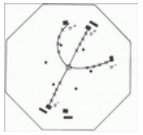
Exotics @ BESIII

Riccardo Farinelli
on behalf of
BESIII collaboration

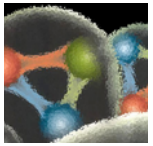
Outline

The BESIII experiment



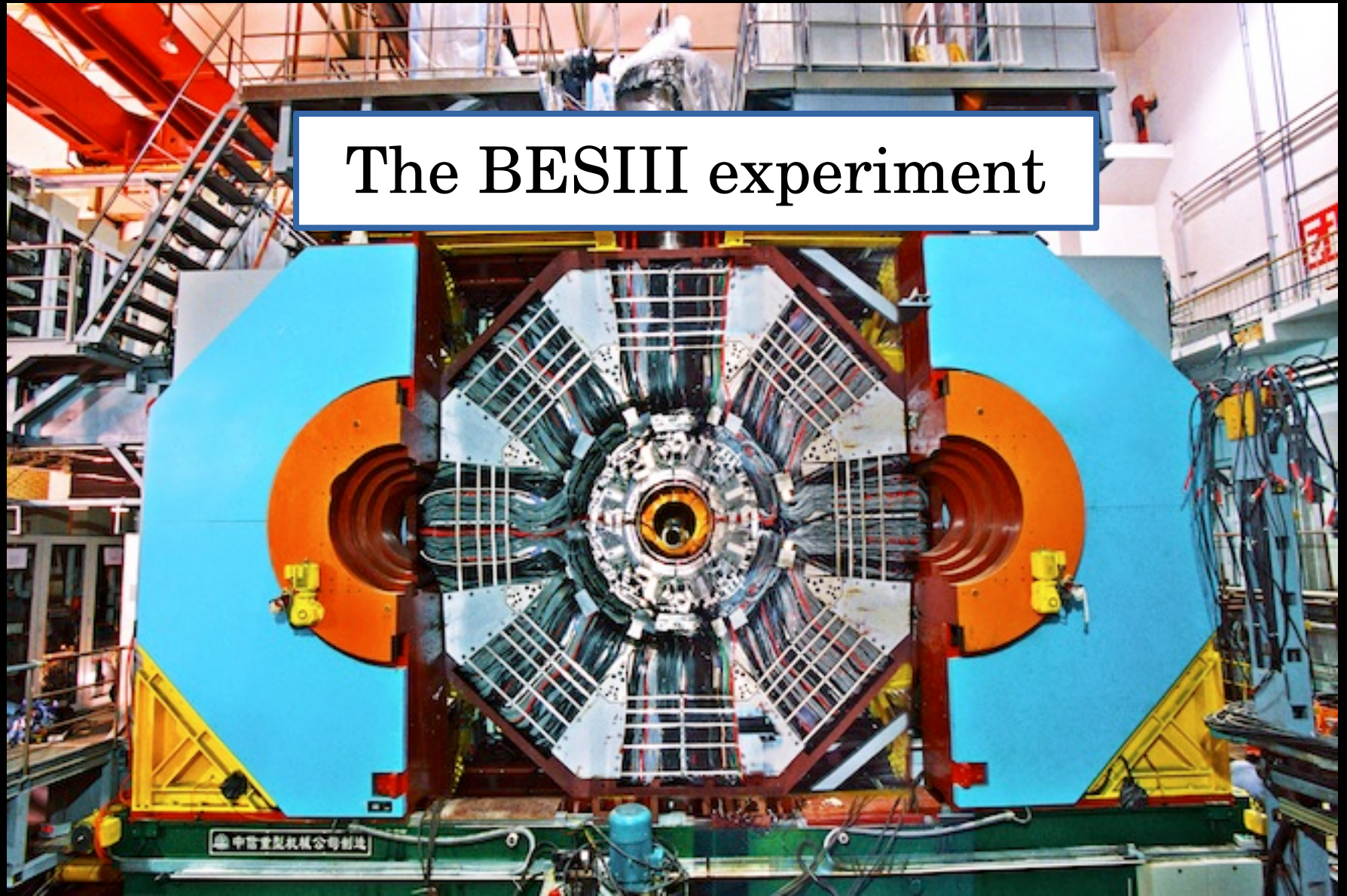
Charmonium-like spectroscopy

Exotics particles search:
XYZ states



A key particle: Y(4660)

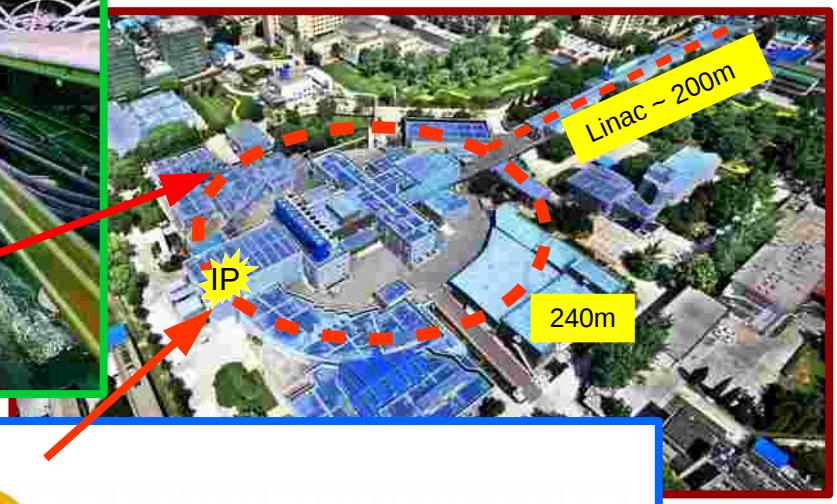
Future plans for BESIII
and BEPCII


The BESIII experiment

BEijing Spectrometer and the electron positron collider

Nucl. Instr. Meth. A614, 345 (2010)

- Beijing Electron-Positron Collider **BEPCII** and BEijing Spectrometer **BESIII** operate in the τ-charm energy region
- Luminosity = 10^{33} cm^{-2} s^{-1}
- **Energy $_{cm}$: 2 – 4.6 GeV**
- The physics program includes:
  - Test of precision EW
  - Studies on hadron spectroscopy with high statistic
  - Exotics charmed states (i.e. XYZ states)
  - Studies of physics in the τ-charm energy region
  - …



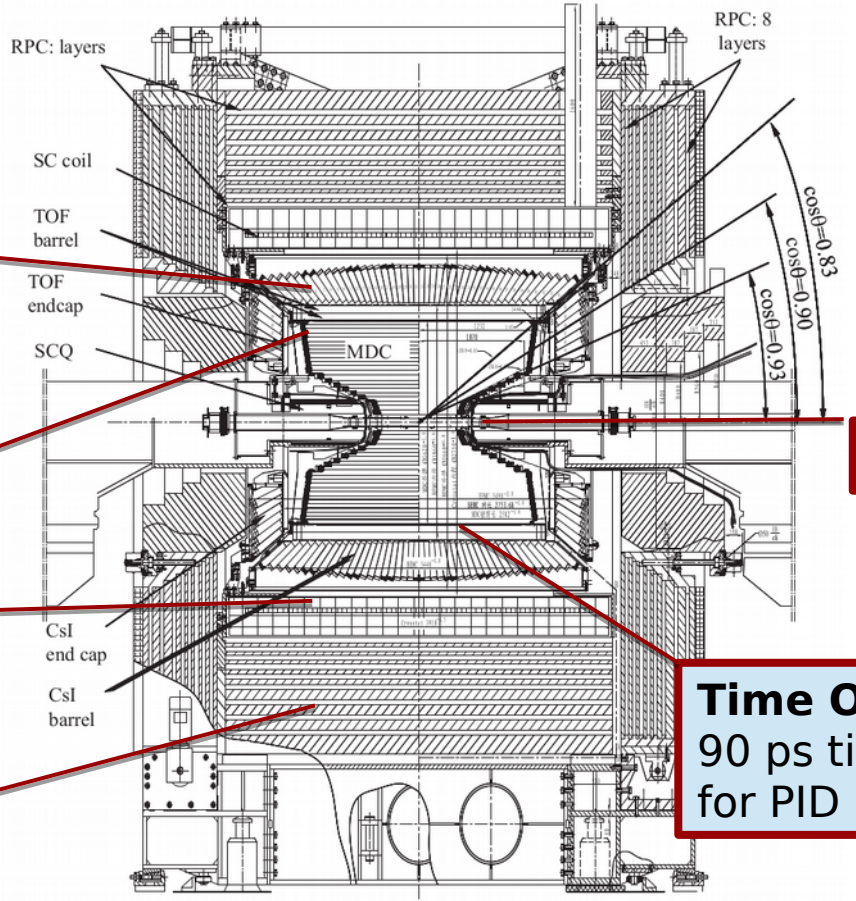
BESIII detector

Electromagnetic Calorimeter (CsI)
dE/E ~ 2.5 % @ 1 GeV/c

Multilayer Drift Chamber
120 μm spatial resolution
dp/p ~ 0.5% @ 1 GeV/c

Superconducting magnet
magnetic field = 1 Tesla

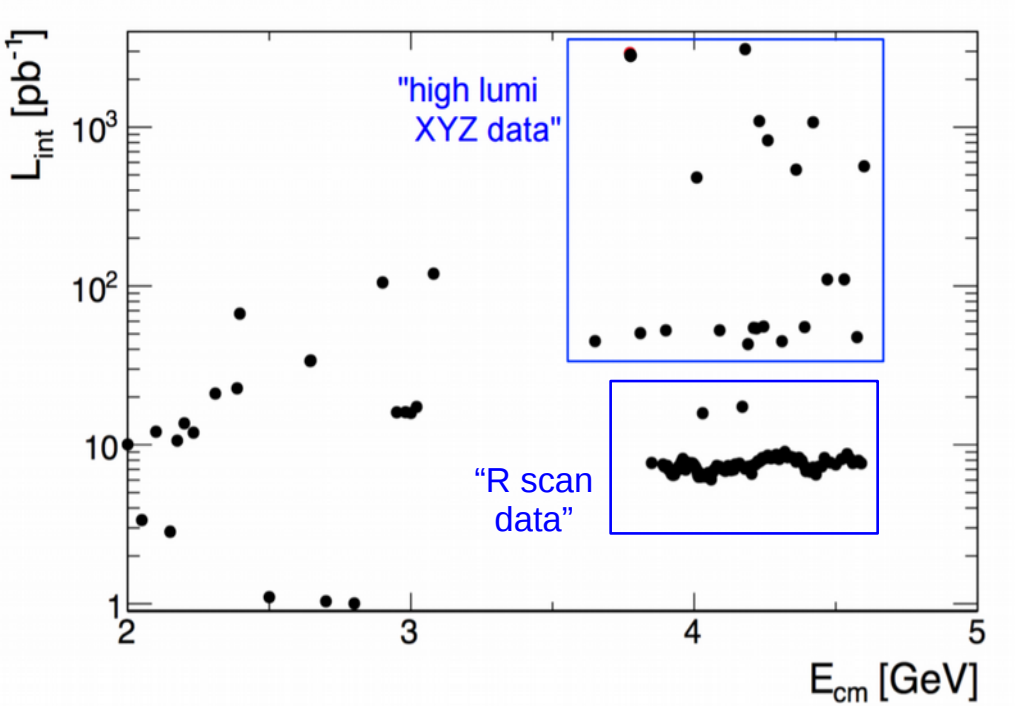
RPC for muon ID



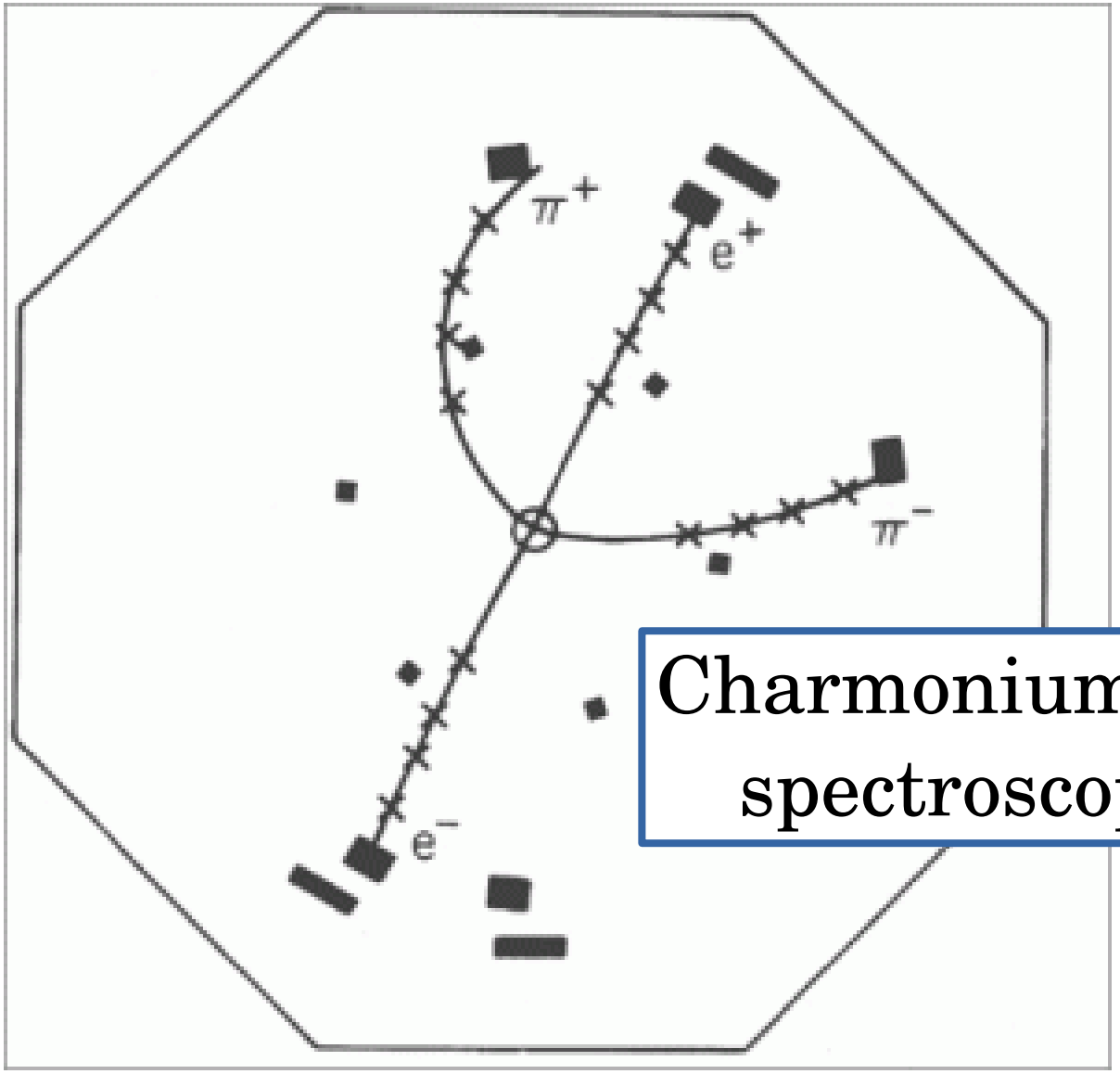
Beam pipe

Time Of Flight
90 ps time resolution for PID

BESIII dataset



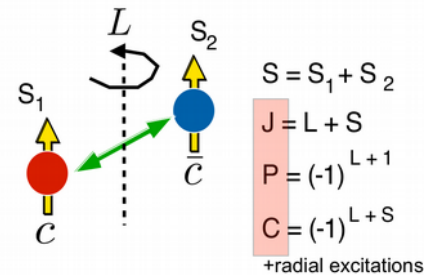
World's largest data samples of J/ψ, ψ(2S), ψ(3770) and ψ(4040) ψ(4160) Y(4260) decays.

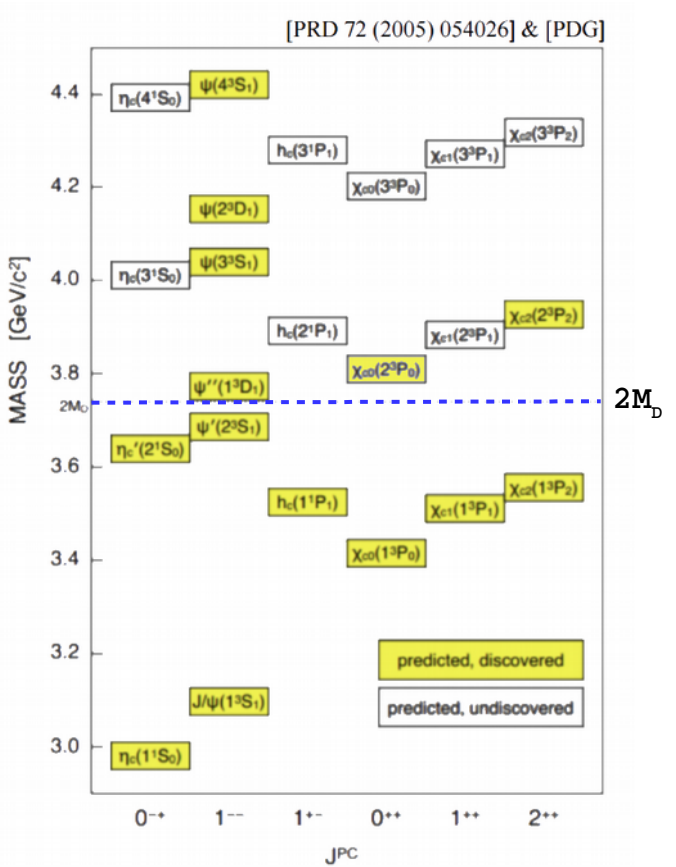


Charmonium-like spectroscopy

Charmonium-like spectroscopy

Potential model is used to describe $c\bar{c}$ states



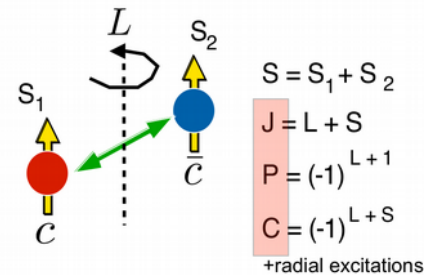


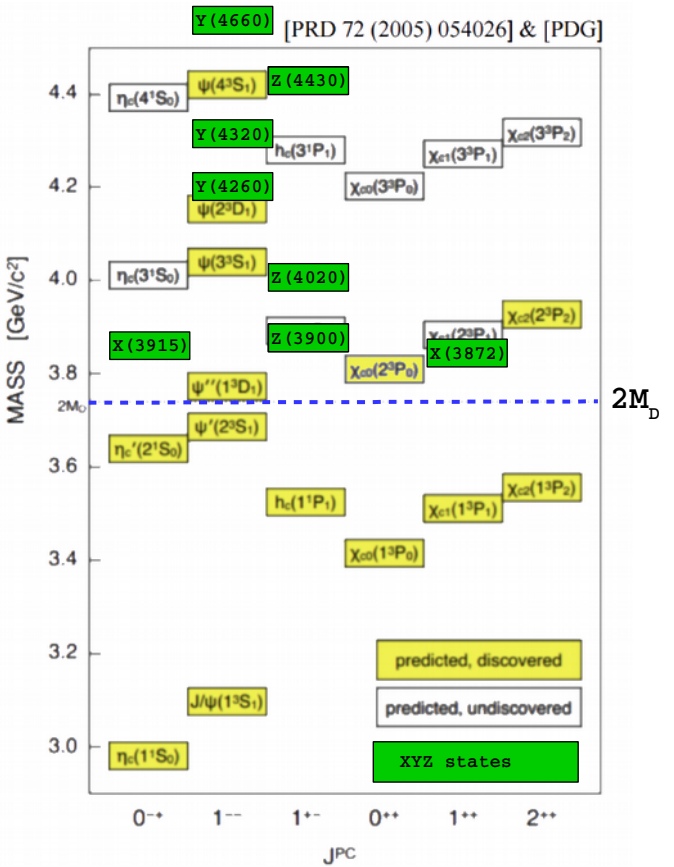
⇩ Below the 2 M_D threshold the predicted masses of the charmonium states match

⇧ Above the 2 M_D threshold there are many predicted states but only a few have been experimentally measured

Charmonium-like spectroscopy

Potential model is used to describe $c\bar{c}$ states



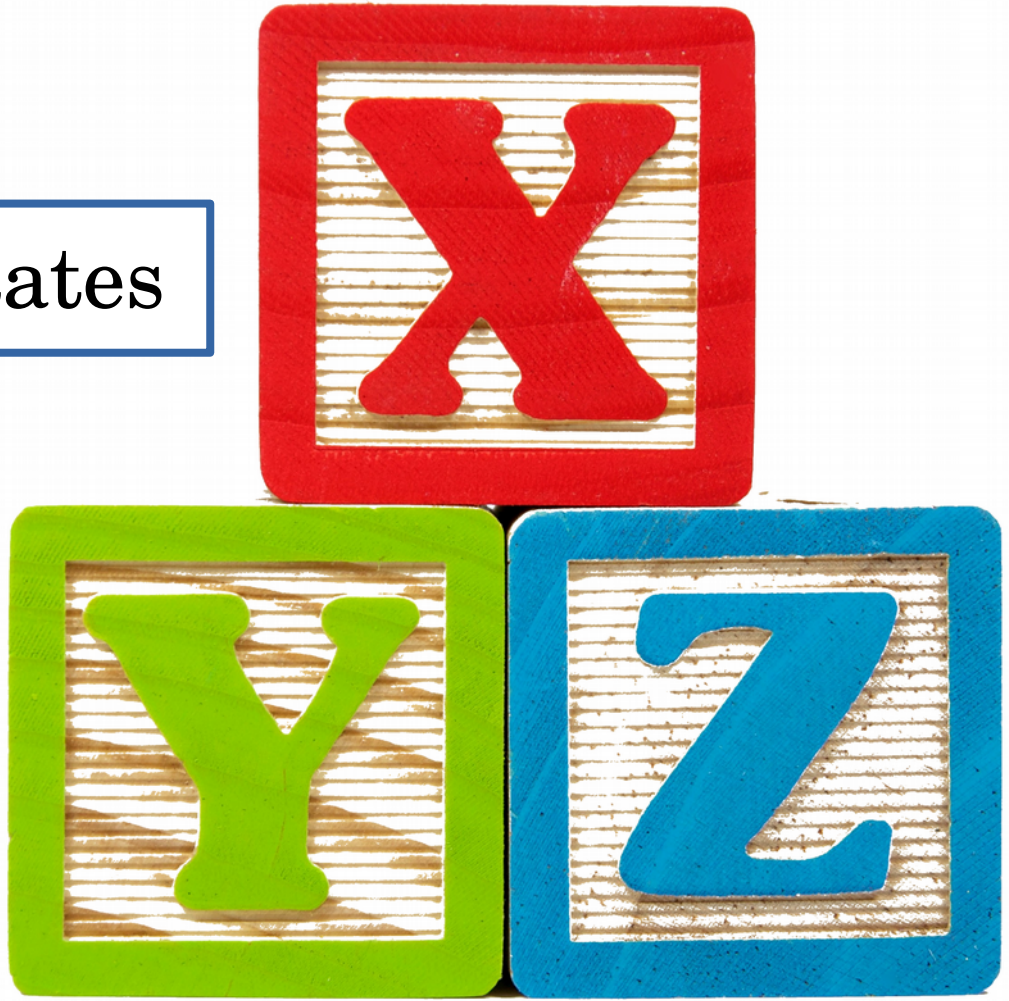


⇩ Below the 2 M_D threshold the predicted masses of the charmonium states match

⇧ Above the 2 M_D threshold there are many predicted states but only a few have been experimentally measured

An abundance of states that do not fit the prediction has been discovered

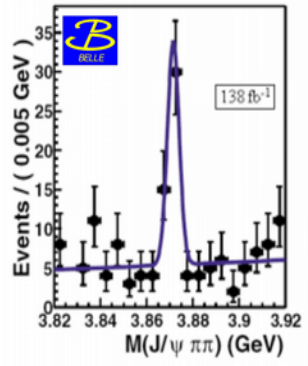
Exotics particles: XYZ states



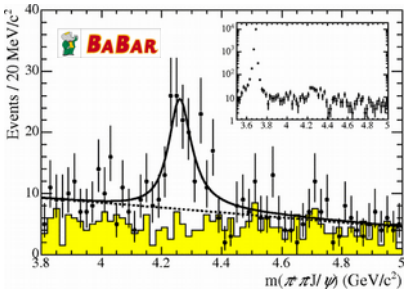
Introduction to exotics

Belle: PRL **91**, 262001 (2003)

$B \to K\,\mathbf{X} \to K\,(\pi^+\pi^-\,J/\psi)$



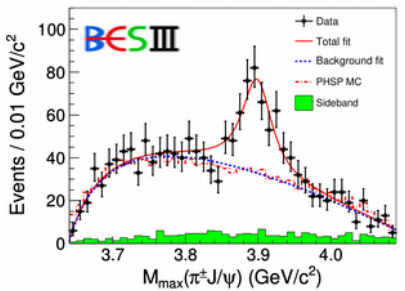
BaBar: PRD **89**, 111103 (2005)

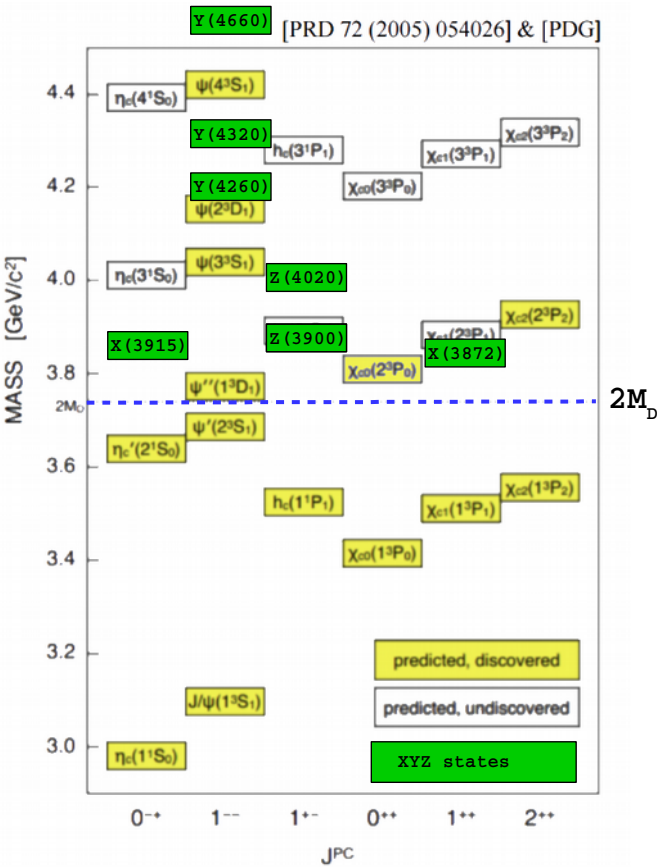


$e^+e^- \to \gamma_{ISR}\ \mathbf{Y} \to \gamma_{ISR}\ (\pi^+\pi^-\,J/\psi)$

BESIII: PRL **110**, 252001 (2013)

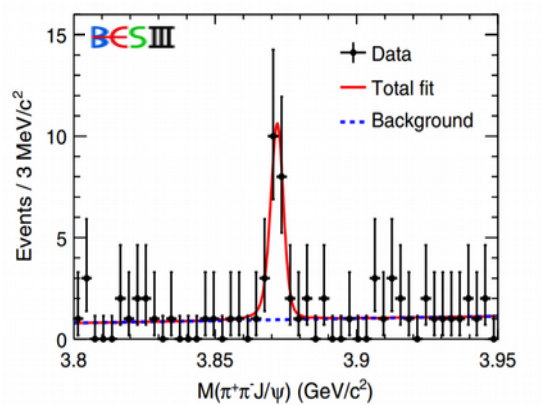
$e^+e^- \to \pi^-\mathbf{Z}^+ \to \pi^-(\pi^+\,J/\psi)$



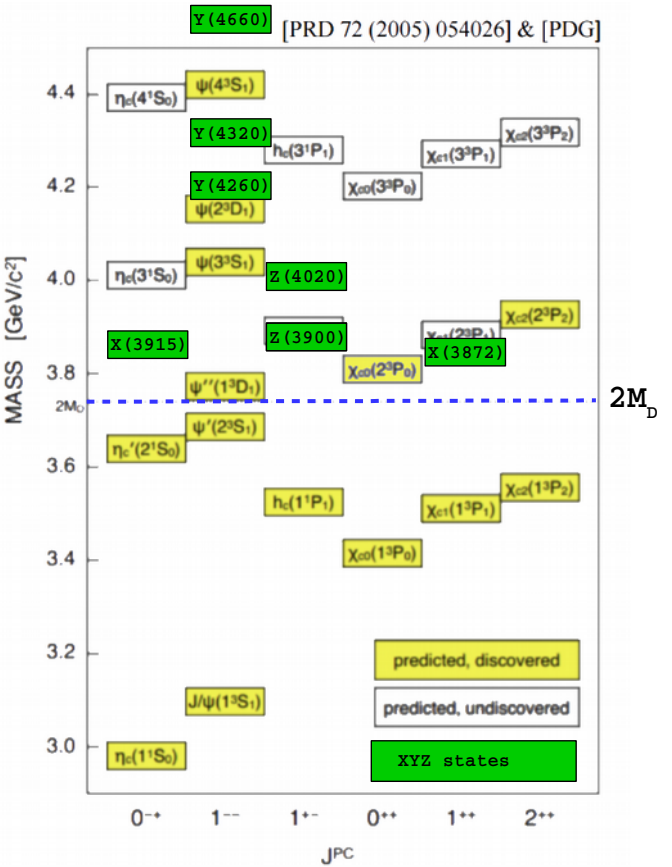


Introduction to exotics

PRL **112**, 092001 (2014)

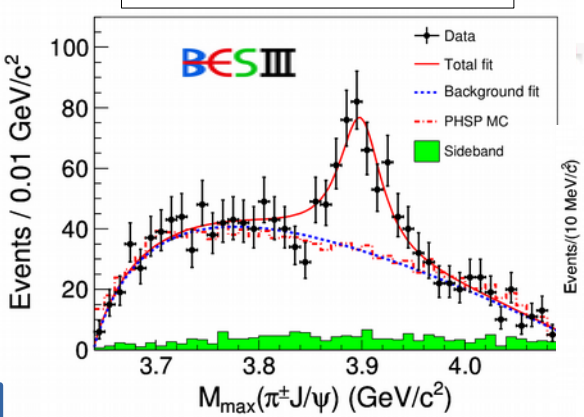


Observation support the existence of the radiative transition process $Y(4260) \rightarrow \gamma X(3872)$

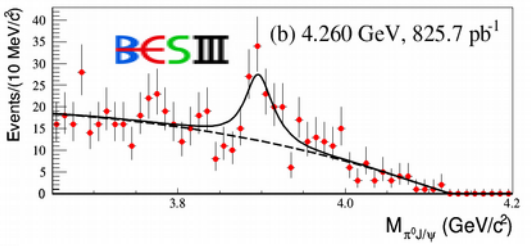


Z: $e^+e^- \to \pi^+(\pi^- J/\psi)$, $\pi^0(\pi^0 J/\psi)$

PRL **110**, 252001 (2013)



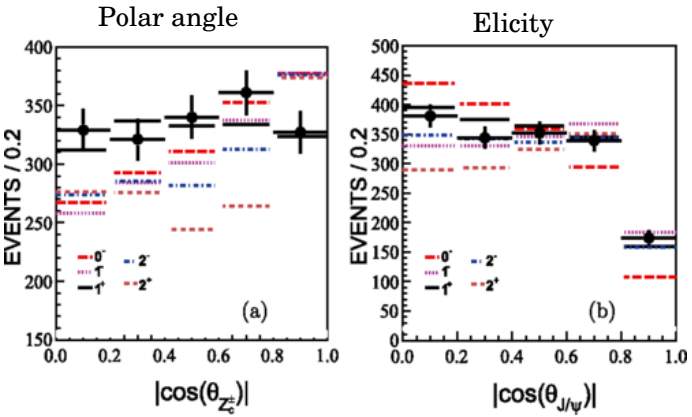
PRL **115**, 112003 (2015)



- Structure electrically charge and close to charmonium:
  - Decay J/ψ → contains $c\bar{c}$
  - Electrically charged → contains $u\bar{d}$

M = **3899.0** (± 3.6 ± 4.9) MeV , Γ = **46** (± 10 ± 20) MeV

- Confirmed by CLEO-c and Belle
- Discovered in neutral decays at different energies with a significance > **10 σ**
- The likelihood method support quantum number $J^P = 1^+$ with a significance > **7 σ**

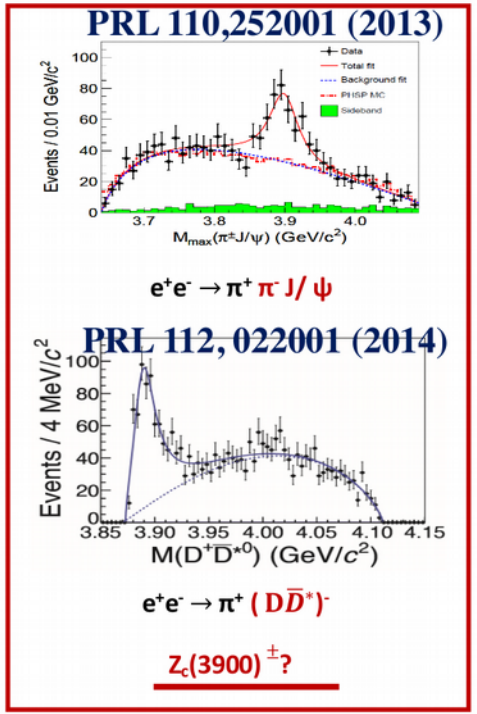


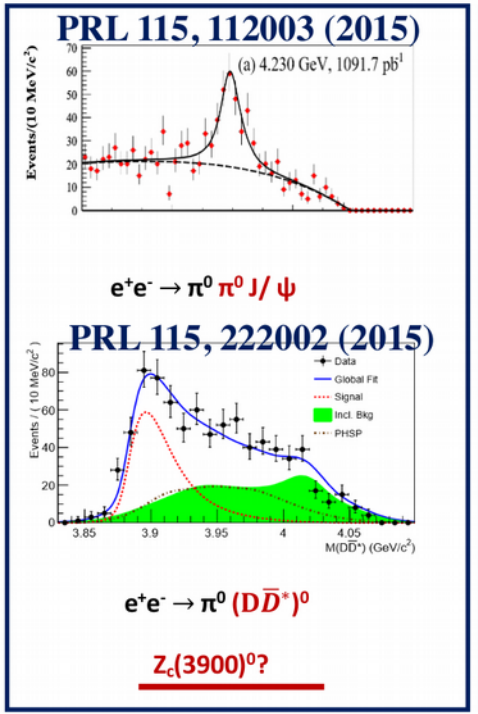
PRL **119**, 072001 (2017)

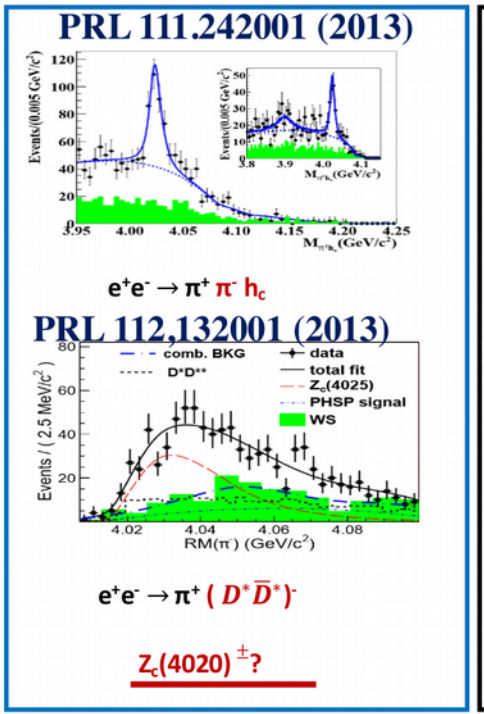
Isospin triplet stablished

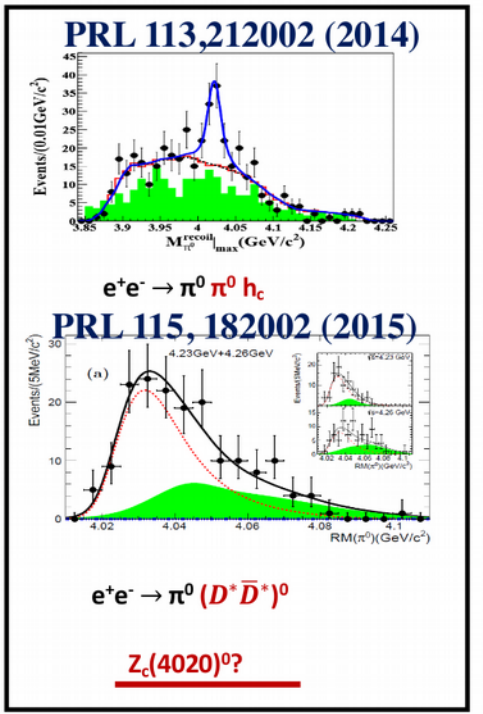
Quantum number determined

More Z states



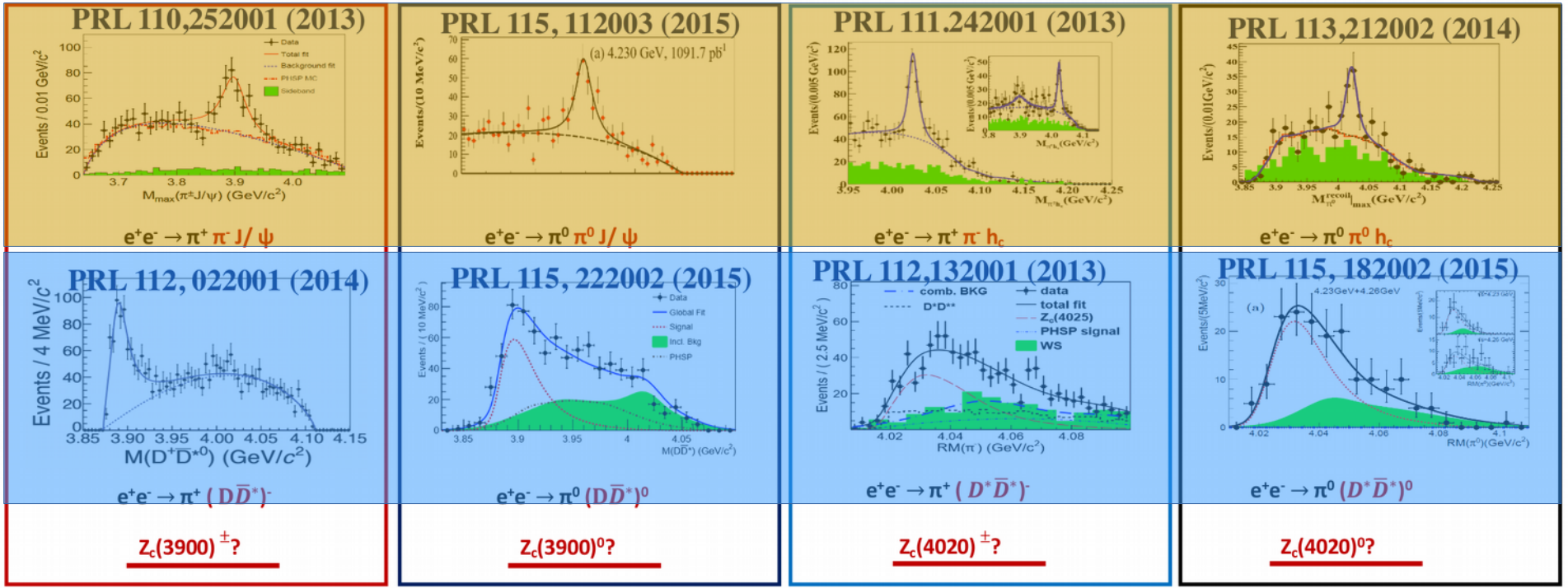






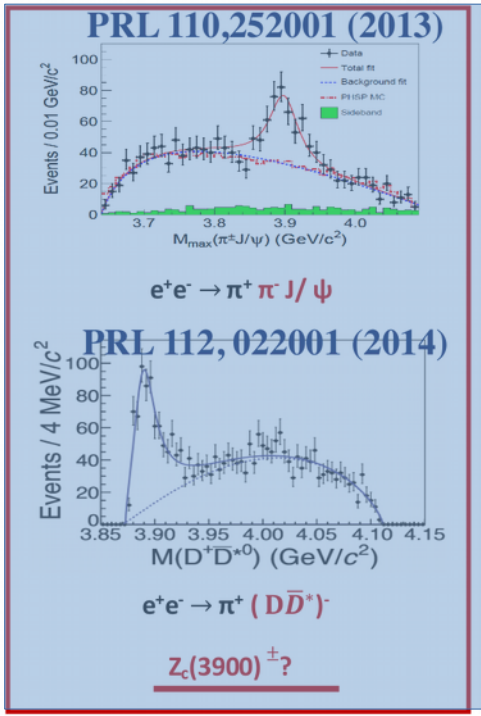
- Several Z decays have been measured in $c\bar{c}$ and open charm states
- Isospin triplet is established for all of them
- Masses and widths are comparable

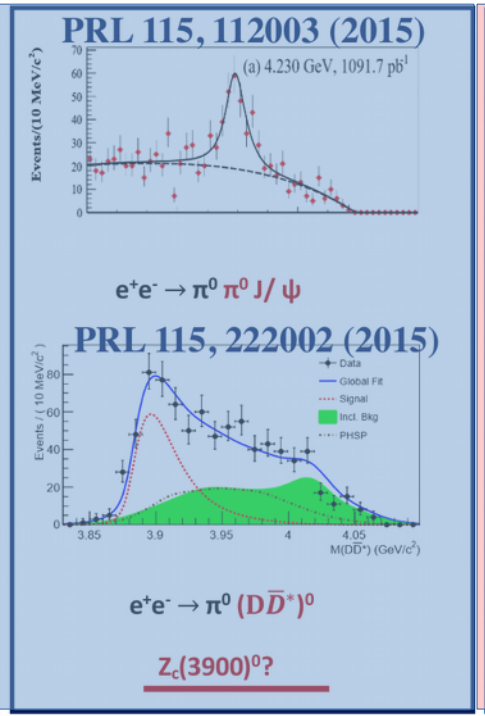
More Z states

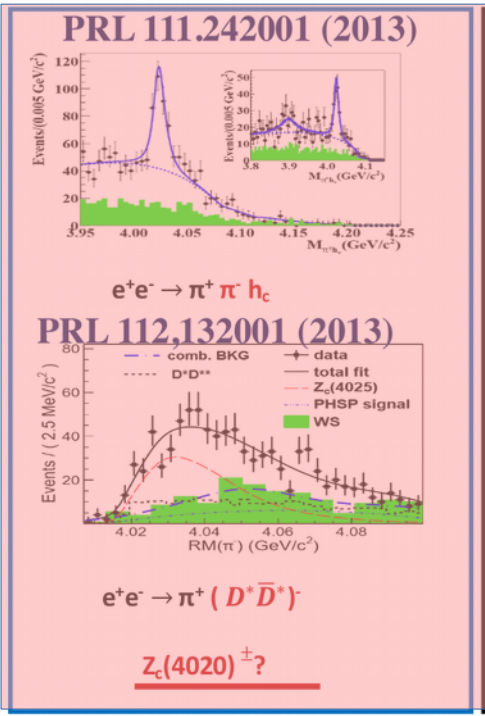


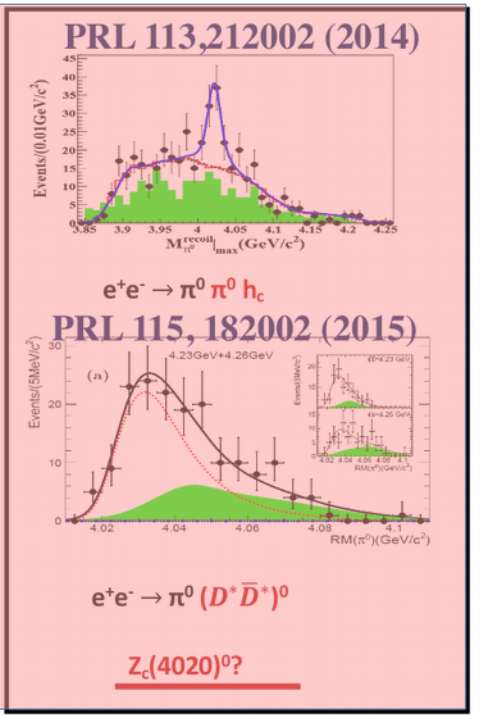
- Several Z decays have been measured in $c\bar{c}$ and open charm states
- Isospin triplet is established for all of them
- Masses and widths are comparable

More Z states





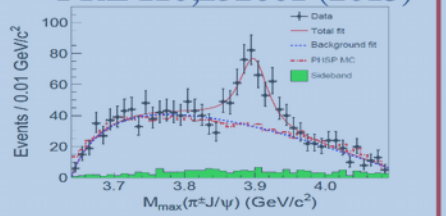




- Several Z decays have been measured in $c\bar{c}$ and open charm states
- Isospin triplet is established for all of them
- Masses and widths are comparable

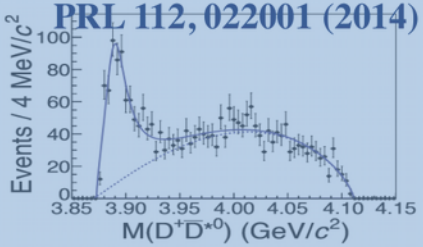
More Z states

PRL 110,252001 (2013)



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

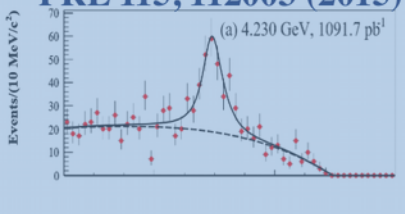
PRL 112, 022001 (2014)



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

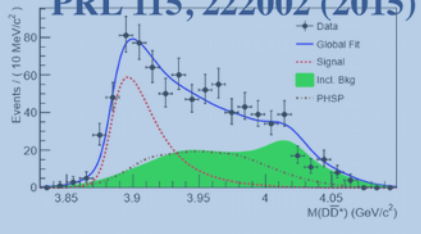
$Z_c(3900)^{\pm}$?

PRL 115, 112003 (2015)



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

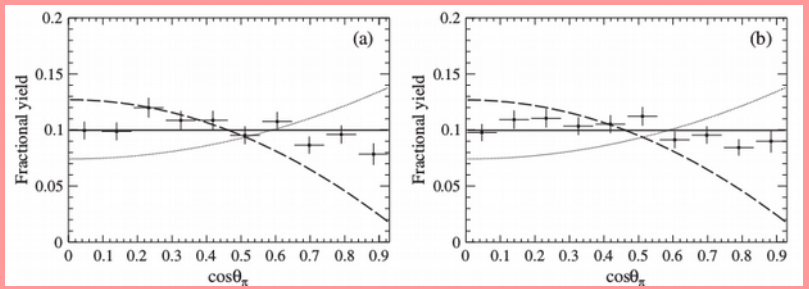
PRL 115, 222002 (2015)



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

$Z_c(3900)^0$?

PRD **92**, 092006 (2015)



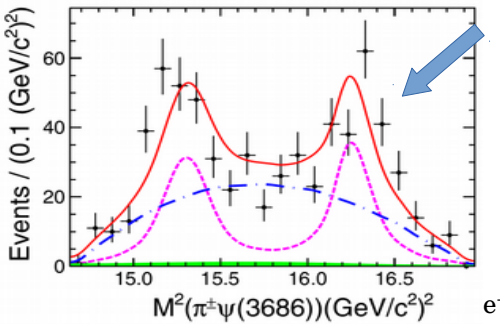
Quantum number $J^P = 1^+$ determined also in $Z_c^-(3885) \to (D\bar{D}^*)^-$

- Several Z decays have been measured in $c\bar{c}$ and open charm states
- Isospin triplet is established for all of them
- Masses and widths are comparable

More Z: $e^+e^- \to \pi^+(\pi^- \psi(2S))$

- Recently Z(4020) has been recently observed in the invariant mass spectrum of $\pi^{\pm,0}\ \psi(2S)$

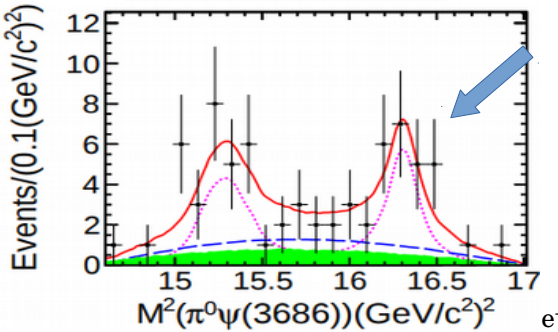
PRL **96**, 032004 (2017)



$e^+e^- \to \pi^+\pi^-\ \psi(2S)$

- Another isospin triplet has been established

PRD **97**, 052001 (2018)

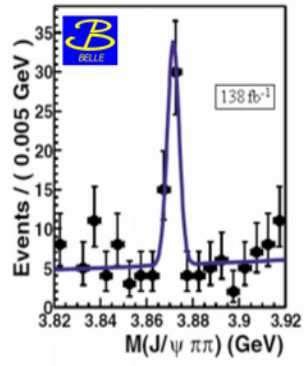


$e^+e^- \to \pi^0\pi^0\ \psi(2S)$

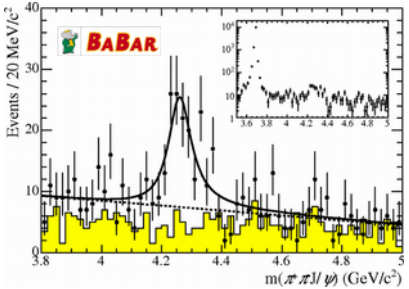
Introduction to exotics

Belle: PRL **91**, 262001 (2003)

$B \to K\,\mathbf{X} \to K\,(\pi^+\pi^-\,J/\psi)$



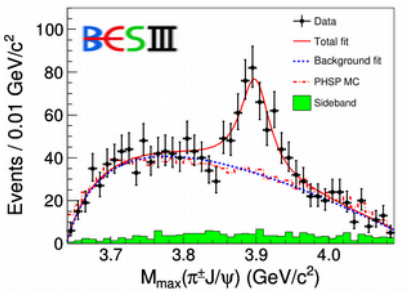
BaBar: PRD **89**, 111103 (2005)

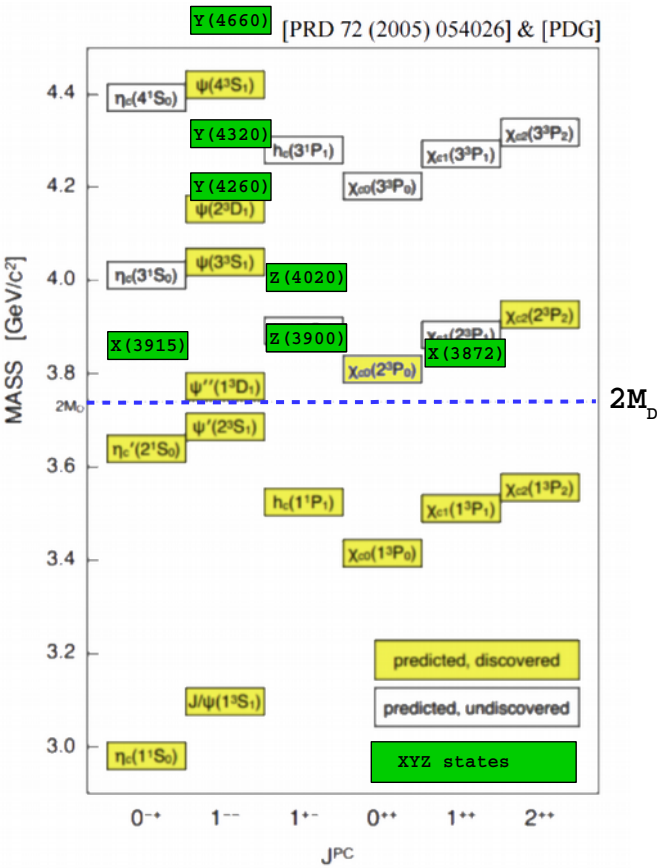


$e^+e^- \to \gamma_{ISR}\,\mathbf{Y} \to \gamma_{ISR}\,(\pi^+\pi^-\,J/\psi)$

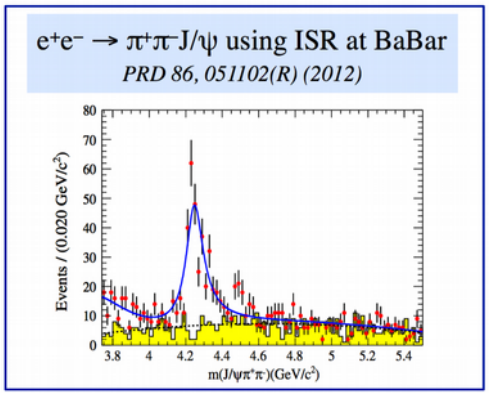
BESIII: PRL **110**, 252001 (2013)

$e^+e^- \to \pi^-\mathbf{Z}^+ \to \pi^-(\pi^+\,J/\psi)$

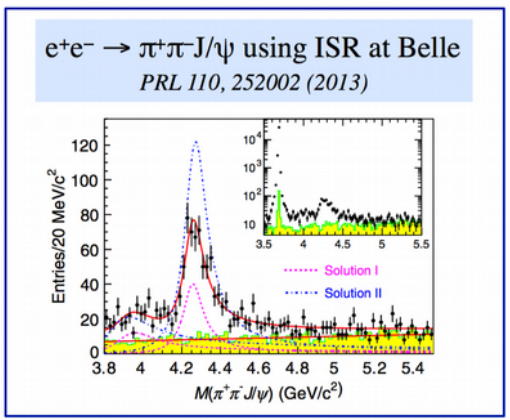




Y states: $e^+e^- \to \pi^+\pi^- J/\psi$

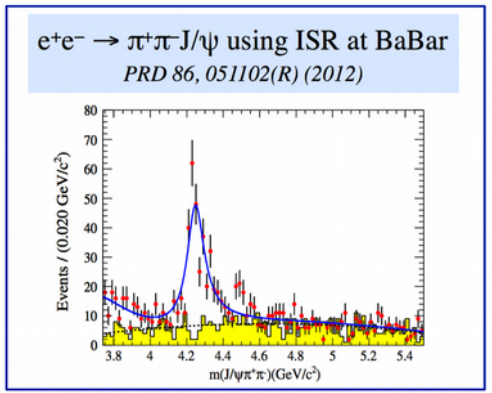


The Y(4260) has been discovered by BaBar experiment in the mass spectrum **m($\pi^+\pi^-$ J/ψ)** and then confirmed by Belle



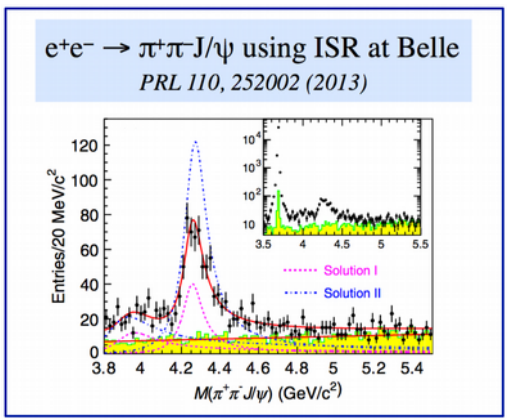
Y states: $e^+e^- \to \pi^+\pi^- J/\psi$

BESIII: PRL **118**, 092001 (2017)



The Y(4260) has been discovered by BaBar experiment in the mass spectrum **m**($\pi^+\pi^-$ J/ψ) and then confirmed by Belle

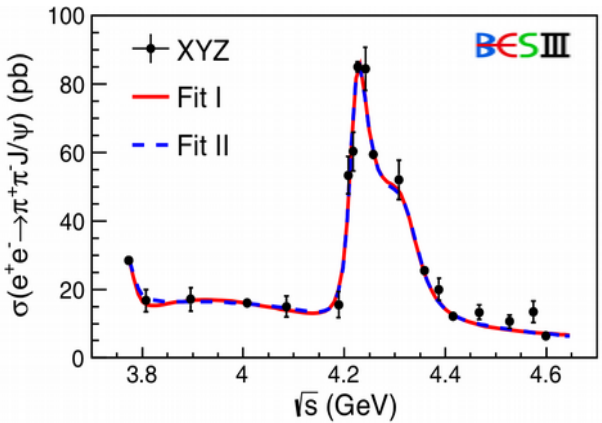
BESIII measured the cross section of this decay channel using two dataset. Two resonances describe the data with significance > **7.6 σ** while the fit with a single peak has a smaller significance

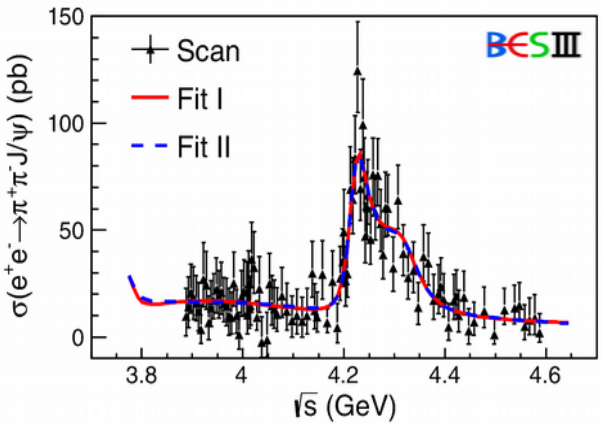


$M_1 = \mathbf{4222} \pm 3.1 \pm 1.4$ MeV , $\Gamma_1 = \mathbf{44.1} \pm 4.3 \pm 2.0$ MeV

$M_2 = \mathbf{4320} \pm 10.4 \pm 7.0$ MeV, $\Gamma_2 = \mathbf{101.4}\ ^{+25.3}_{-19.7} \pm 10.2$ MeV

Y(4320) has been seen for the first time in this channel and it is compatible with Y(4360) measured by Belle and BaBar in $\pi^+\pi^-\psi(2S)$





Y states: $e^+e^- \to \pi^+\pi^- h_c$

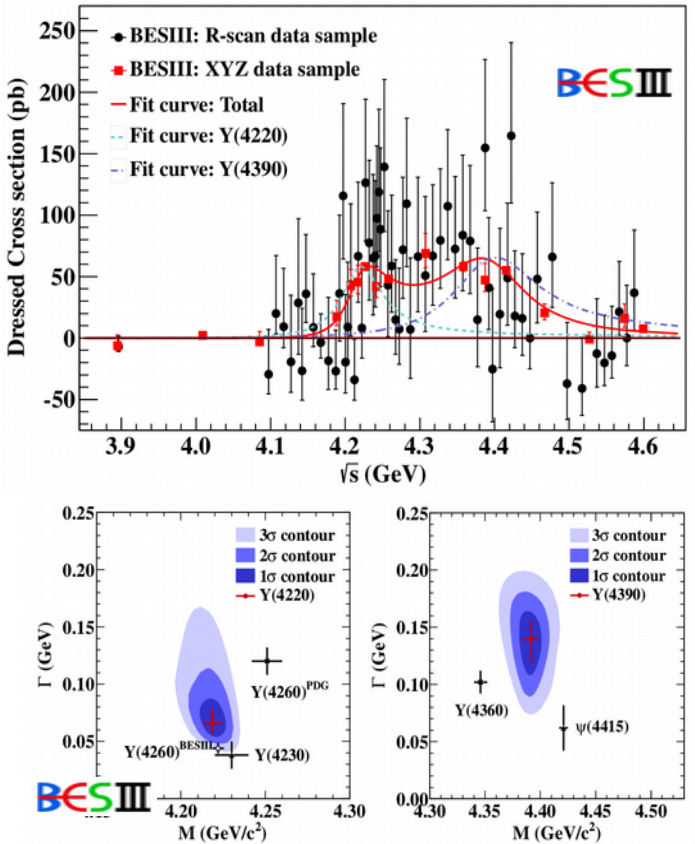
PRL **118**, 092002 (2017)

A big sample of $\mathbf{h_c}$ has been reconstructed in $h_c \to \gamma \eta_c$ and it has been used to discover new states. η_c has been reconstructed in 16 different modes

The data cannot be fitted with a single peak
Two resonances describes the data with a significance > **10 σ**

$$M_1 = \mathbf{4218.4}\ ^{+5.5}_{-4.5} \pm 0.9\ \text{MeV}\ ,\ \Gamma_1 = \mathbf{66.0}\ ^{+16.2}_{-20.6} \pm 0.4\ \text{MeV}$$
$$M_2 = \mathbf{4391.5}\ ^{+6.3}_{-4.5} \pm 0.9\ \text{MeV}\ ,\ \Gamma_2 = \mathbf{139.5}\ ^{+16.2}_{-20.6} \pm 0.4\ \text{MeV}$$

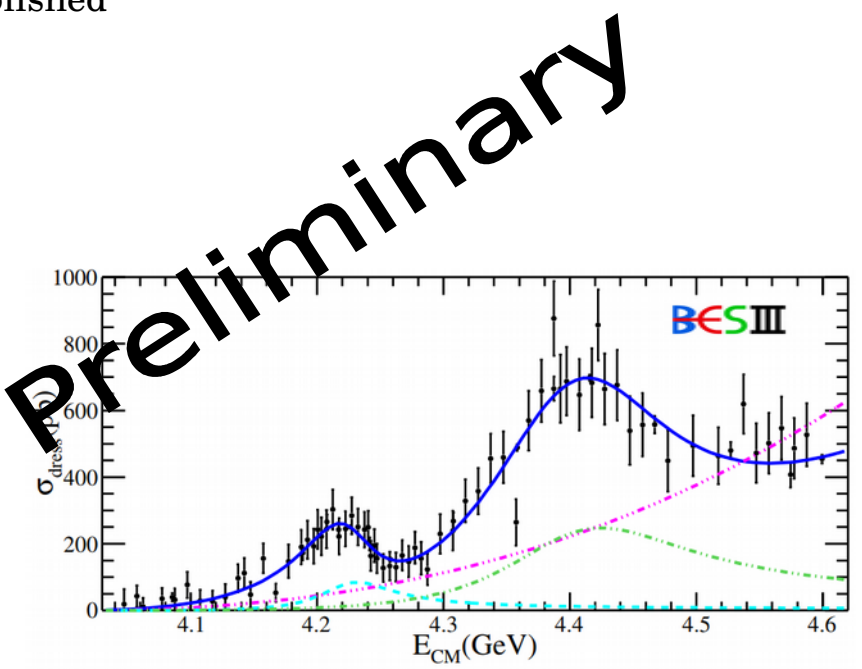
Y(4220) is compatible with the state found in $\pi^+\pi^-$ J/ψ at 4222 MeV



Y states: $e^+e^- \to \pi^+ D^0 D^{*-}$

An open charm decays has been discovered and soon will be published

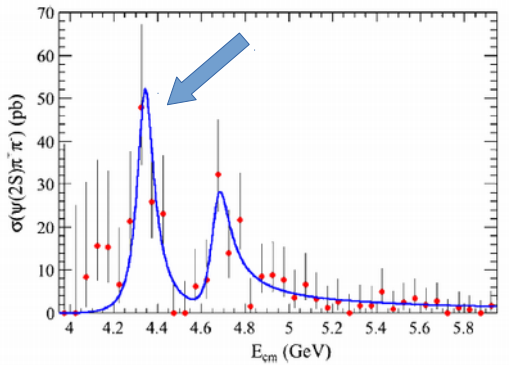
$M_1 = \mathbf{4228.6} \pm 4.1 \pm 5.9$ MeV , $\Gamma_1 = \mathbf{77.1} \pm 6.8 \pm 6.9$ MeV
$M_2 = \mathbf{4404.6} \pm 7.4 \pm 5.5$ MeV , $\Gamma_2 = \mathbf{191.7} \pm 13.0 \pm 17.1$ MeV



Y states: $e^+e^- \to \pi^+\pi^- \psi(2S)$

BaBar: PRD **89**, 111103(R)

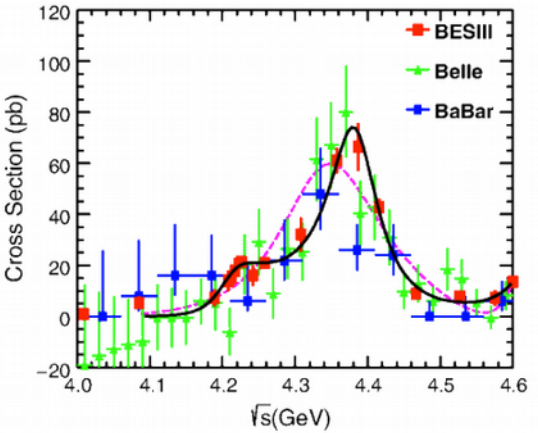
BaBar and Belle saw two resonances in the mass spectrum **m**($\pi^+\pi\psi(2S)$) later confirmed by Belle: Y(4360) and Y(4660)



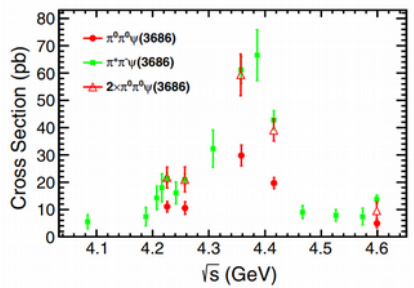
BESIII confirms the line shape for Y(4360) and measure:

M_1 = **4209.5** ± 7.4 ± 1.4 MeV , Γ_1 = **80.1** ± 12.5 ± 2.1 MeV
M_2 = **4383.8** ± 4.2 ± 0.8 MeV , Γ_2 = **84.2** ± 12.5 ± 2.1 MeV

BESIII: PRD **96**, 032004(2017)



Cross section measurements in charge and neutral channels shows results in agreement with the isospin simmetry



$$R_{\pi^+\pi^-\psi(3686)} = \frac{\sigma(e^+e^- \to \pi^0\pi^0\psi(3686))}{\sigma(e^+e^- \to \pi^+\pi^-\psi(3686))} = 0.48 \pm 0.04 \pm 0.02$$

BESIII: PRD **97**,052001(2018)

Y states summary

BESIII observed two resonances with similar mass and width

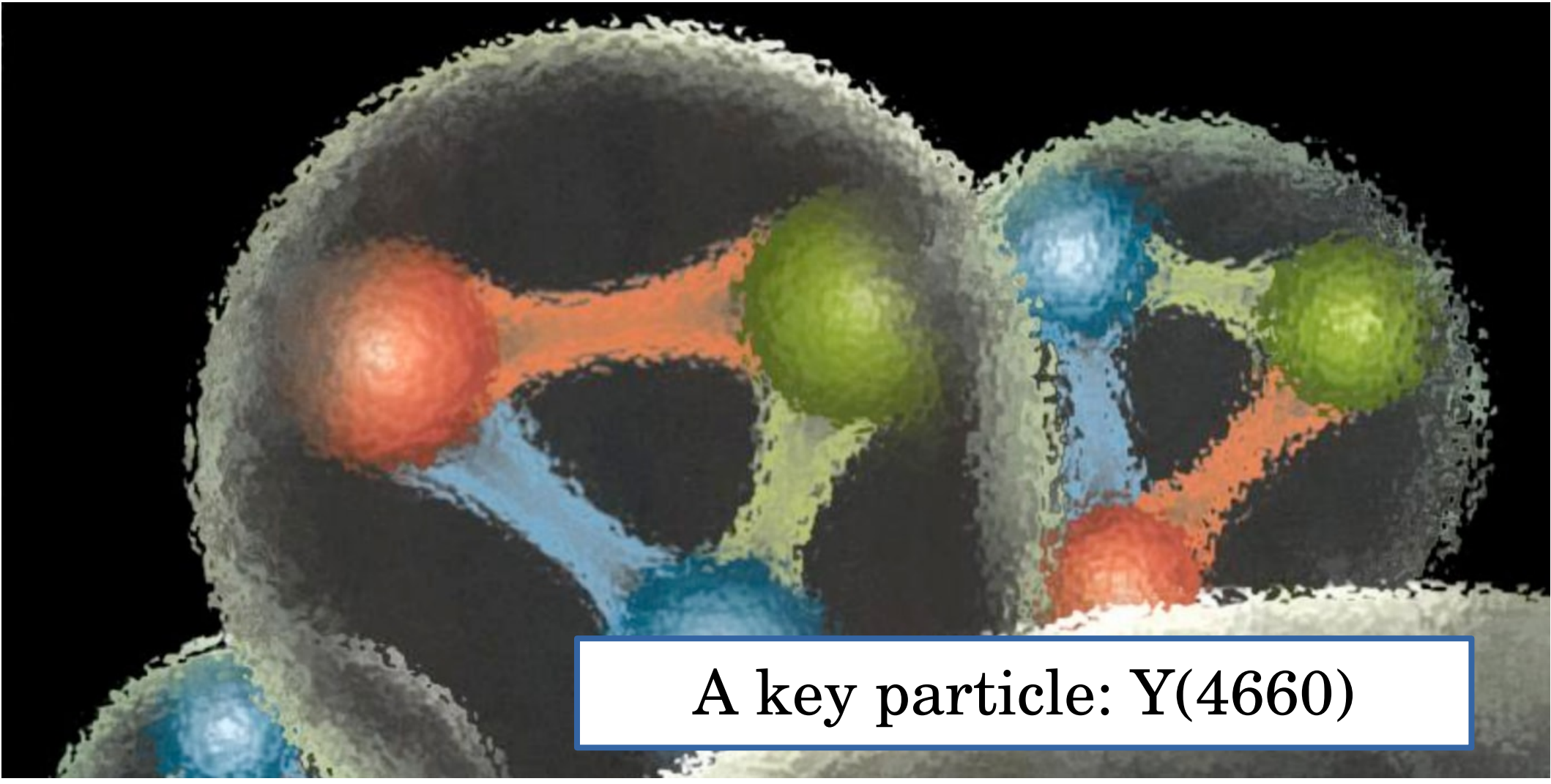
in the energy range between 4.1 and 4.5 GeV in the channels:

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

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

$$e^+e^- \rightarrow \pi^+ D^0 D^{*-} \text{ (preliminary)}$$

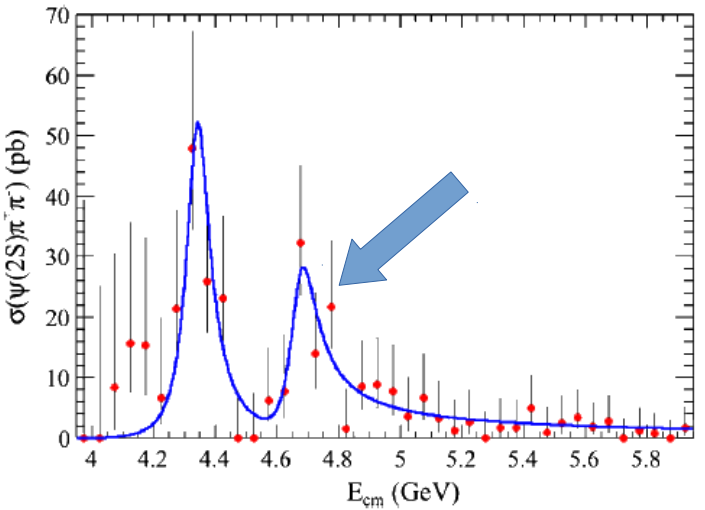
$$e^+e^- \rightarrow \pi^+\pi^- \psi(2S)$$


A key particle: Y(4660)

Y (4660) → $\pi^+\pi^-$ ψ(2S)

BaBar and Belle observed a resonance in e^+e^- → $\pi^+\pi^-$ ψ(2S) by means of ISR

BaBar: PRD **89**, 111103(R)



M = **4669** ± 22 , Γ = **104** ± 49 MeV

Belle: PRD **91**, 112007(2015)

M = **4652** ± 13 , Γ = **68** ± 11 MeV

Y (4660) → $\pi^+\pi^-$ J/ψ

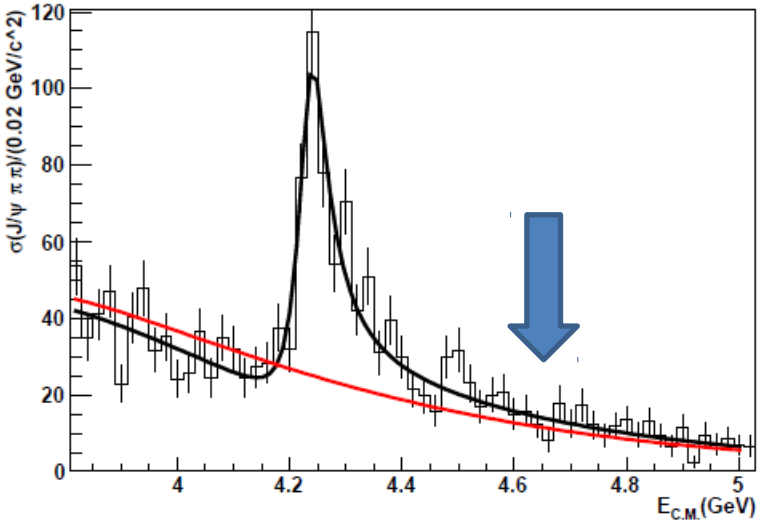
BaBar and Belle observed a resonance in $e^+e^- \to \pi^+\pi^- \psi(2S)$ by means of ISR

BaBar: PRD **86**, 051102 (R) (2012)

No evidence of Y(4660) in the channel $e^+e^- \to \pi^+\pi^-$ J/ψ despite this would be expected to be large if Y(4660) is a $c\bar{c}$ state while at 90% C.L.

$$\frac{\text{Br}\,[Y(4660) \to \pi^+\pi^- J/\psi]}{\text{Br}\,[Y(4660) \to \pi^+\pi^- \psi(2S)]} < 0.46$$

according to BaBar data in arXiv:0808.1543 [hep-ex], as elaborated in arXiv:0911.2178v5 [hep-ph] (2017).



Y (4660) → DD

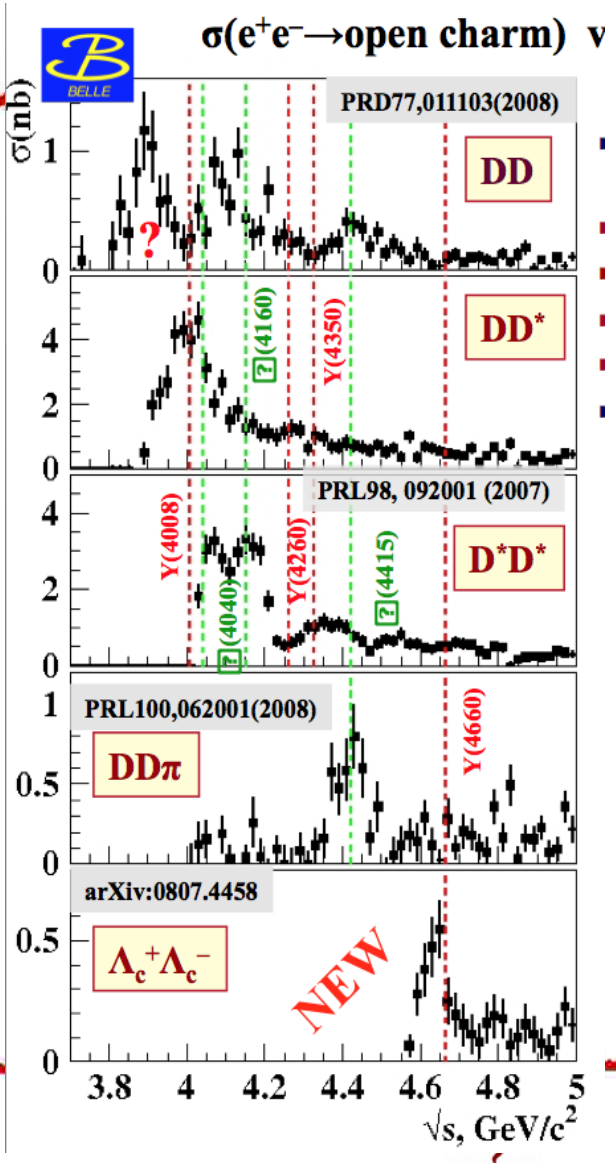
BaBar and Belle observed a resonance in $e^+e^- \to \pi^+\pi^- \psi(2S)$ by means of ISR

No evidence of Y(4660) in the channel $e^+e^- \to \pi^+\pi^- J/\psi$ despite this would be expected to be large if Y(4660) is a $c\bar{c}$ state while at 90% C.L.

$$\frac{\text{Br}\,[Y(4660) \to \pi^+\pi^- J/\psi]}{\text{Br}\,[Y(4660) \to \pi^+\pi^- \psi(2S)]} < 0.46$$

according to BaBar data in arXiv:0808.1543 [hep-ex], as elaborated in arXiv:0911.2178v5 [hep-ph] (2017).

Neither in open charm channels.



$Y(4660) \rightarrow \Lambda_c \bar{\Lambda}_c$

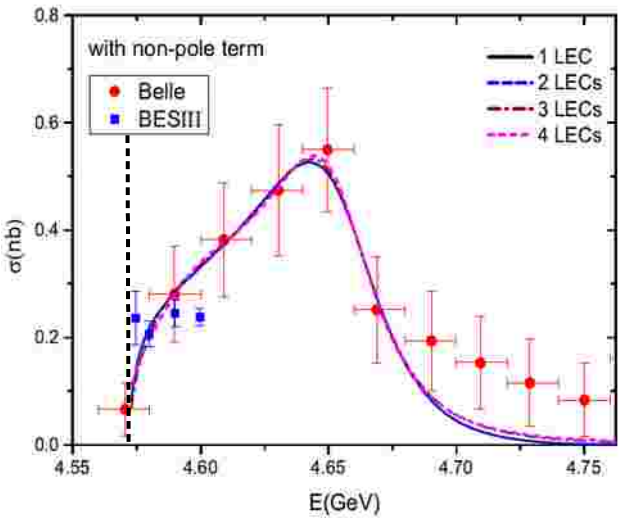
Belle collaboration observed the baryonic decay of Y(4660)

M = **4652.5** ± 3.4 , Γ = **62.6** ± 5.6 MeV

BESIII has no sufficient energy to confirm the entire line-shape. The trend of the first results seems different

Belle PRL **101**, 172001 (2008)

BESIII arXiv:1710.00150 [hep-ex]



$Y(4660) \rightarrow \Lambda_c \bar{\Lambda}_c$

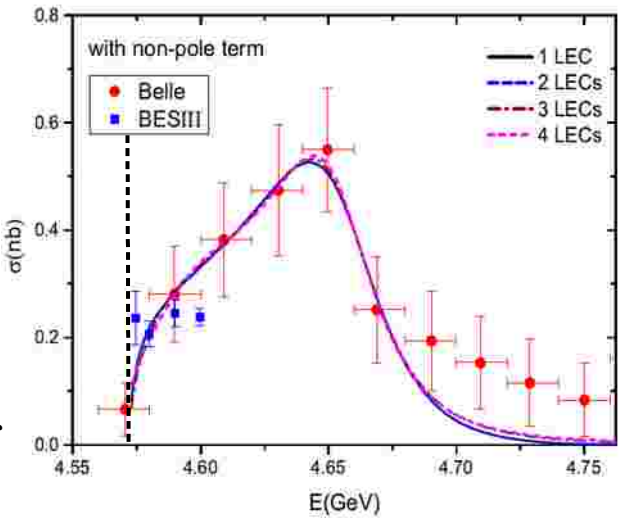
Belle collaboration observed the baryonic decay of Y(4660)

M = **4652.5** ± 3.4 , Γ = **62.6** ± 5.6 MeV

Belle PRL **101**, 172001 (2008)

BESIII arXiv:1710.00150 [hep-ex]

$\sigma_{\Lambda c \bar{\Lambda} c}$ ~ 0.55 nb @ peak is comparable to $\sigma(e^+ e^- \rightarrow p\bar{p})$ ~ 0.8 nb @ threshold while $\sigma_{\pi\pi\psi(2S)}$ ~ 0.04 nb.



Y(4660) baryonic coupling > 10 * Y(4660) mesonic coupling

→ There is another mesonic decay with much larger BR than $\pi\pi\psi(2S)$?
→ or Y(4660) is a hidden-charmed baryonium ??

BESIII has no sufficient energy to confirm the entire line-shape. The trend of the first results seems different

BESIII and BEPCII upgrades

BEPCII and BESIII upgrades

The beam energy of BEPCII will be increased up to 2.45 GeV in order to study the $\Lambda_c\overline{\Lambda}_c$ lineshape

The top-up injection will be implemented to keep the beam current nearly constant so that the integral luminosity can be improved by 20-30%

A new inner tracker with Cylindrical triple-GEM technology will increase the spatial resolution of secondary vertex, improving the $\Lambda_c\overline{\Lambda}_c$ precision measurement

The end-cap time of flight detector has been improved with a MRPC to achieve a time resolution of 65 ps

Conclusion

- A large number of Z states has been discovered in charmonium and open-charm decays. Masses and widths are compatible. Isospin triplet has been established for all the decays. Quantum number $J^P = 1^+$ has been measured in a couple of channels

- Y(4220) and Y(4390) have been observed in several decays while the Y(4660) shows a more puzzling behavior.

- An increase of the beam energy will enable a comparison between BESIII and Belle results about the $\Lambda_c\overline{\Lambda}_c$ cross section line-shape

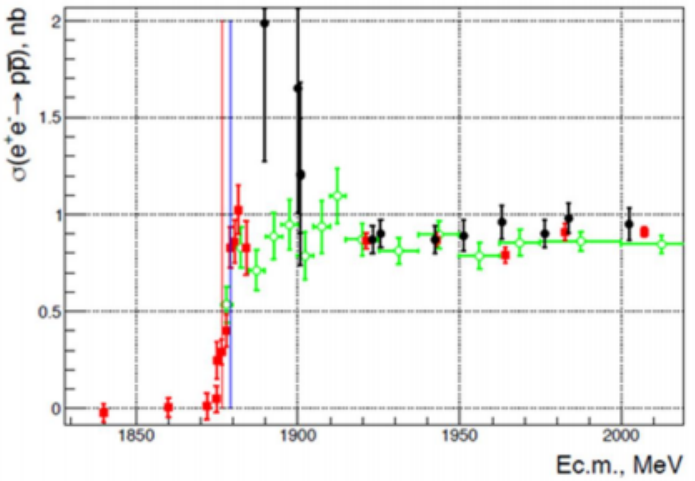

Thanks

Backup

e+e- → p pbar

CMD3 New Results

e+e- -> ppbar Born cross section



Our new 2017 data in comparison with BaBar and CMD-3 2011-2012 scans
(R.R. Akhmetshin et al., (CMD-3 Collaboration), Phys. Lett. B759, 634 (2016).)

Y(4660) hidden charm baryonium ?

- According to R. Faccini et al. arXiv:0911.2178(2017),
  [see also L. Maiani, F. Piccinini, A. D. Polosa and V. Riquer, Phys. Rev. D 72, 031502]
  Y(4660) fulfills the old Rossi Veneziano, G.F. Chew paradigm
  [Nucl.Phys. B123,507(1977) , G.F.Chew Nucl.Phys. B79 (1974) 365]
  of a charm tetraquark (hidden charm baryonium) decay:
  mostly poping up from the vacuum a light quark pair and
  falling apart as a charmed baryon pair