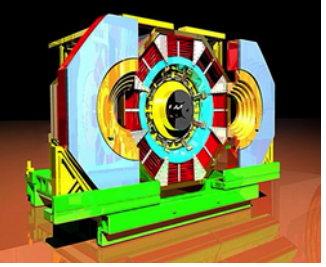


FAIRNESS

28 May - 3 June 2017

BESIII

XYZ states at BESIII

Riccardo Farinelli
University of Ferrara – INFN Ferrara
on behalf of the BESIII experiment

INFN

UNIFE

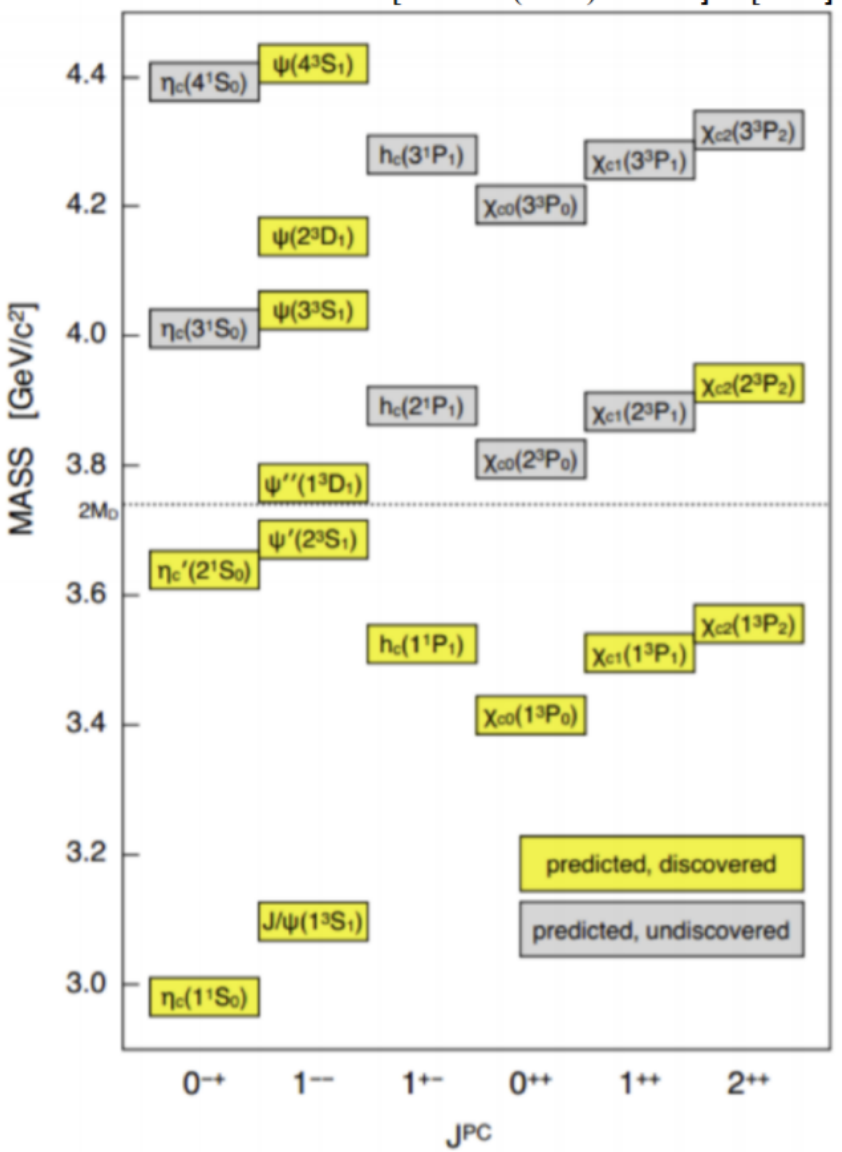
Outline

- Introduction to exotic states
- BESIII experiment and the data set
- News from X,Y,Z states

Charmonium spettroscopy

- 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

[PRD 72 (2005) 054026] & [PDG]



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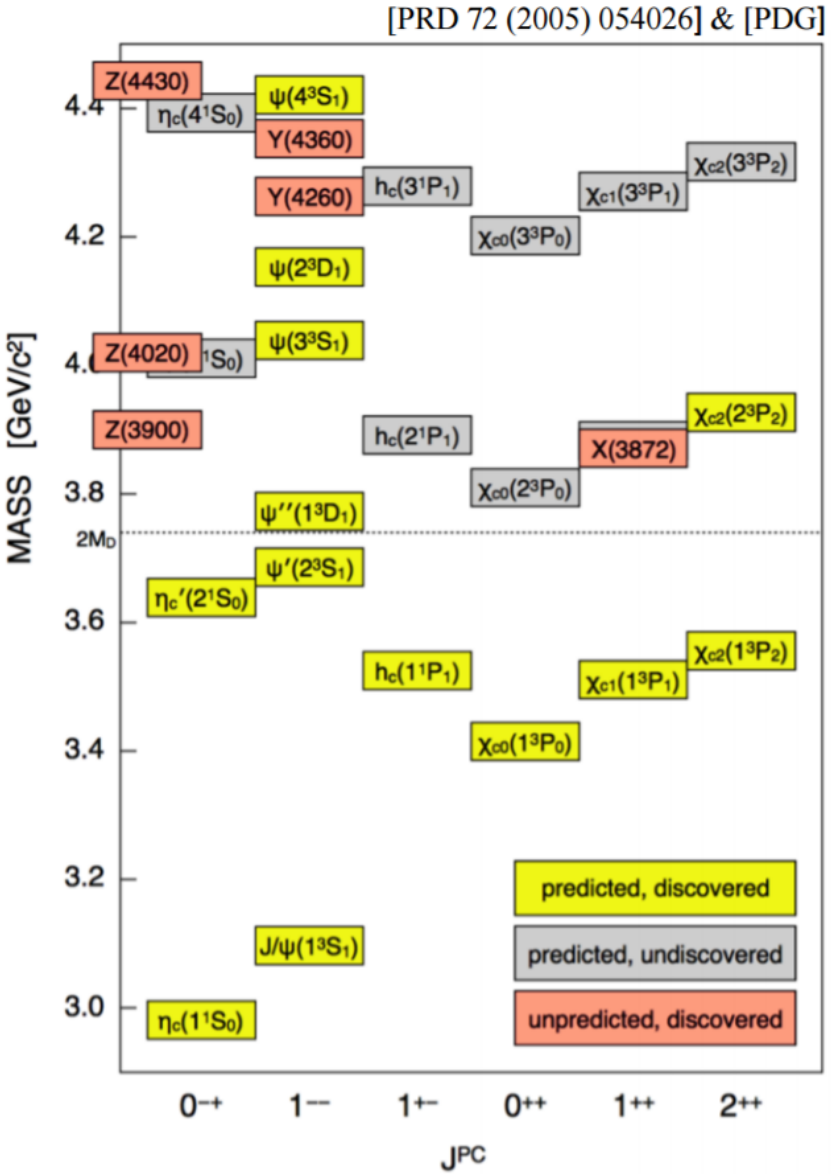

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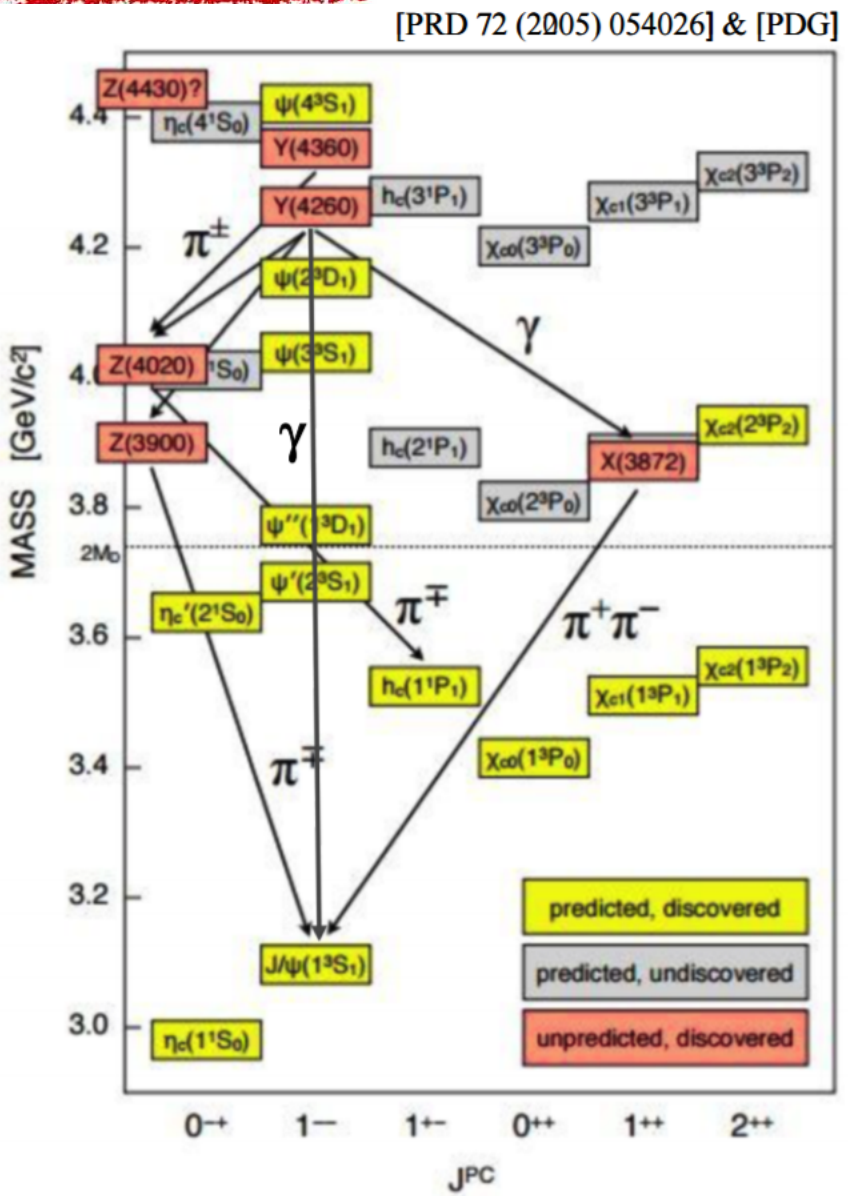

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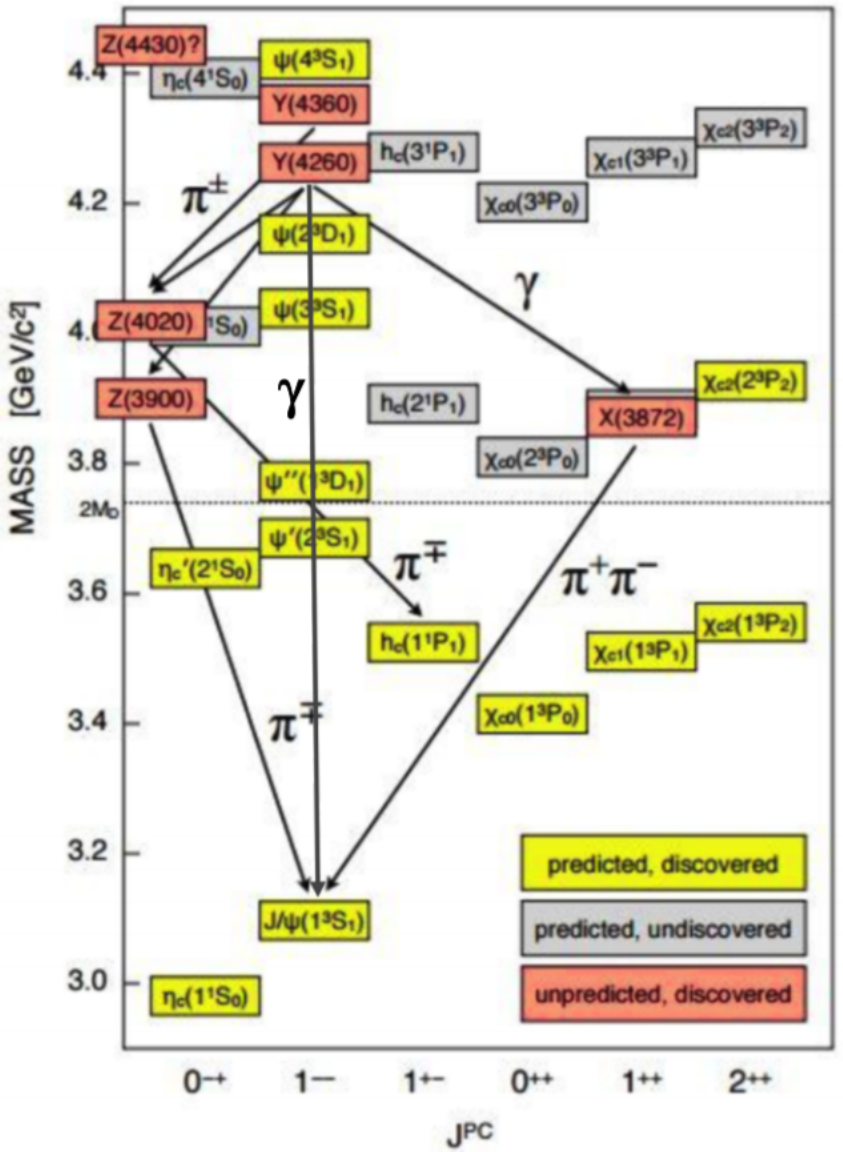
BESIII is a suitable experiment to access to these states

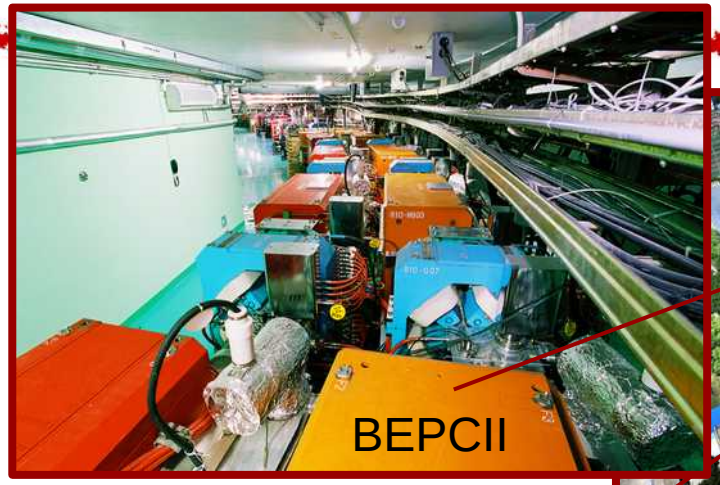
[PRD 72 (2005) 054026] & [PDG]

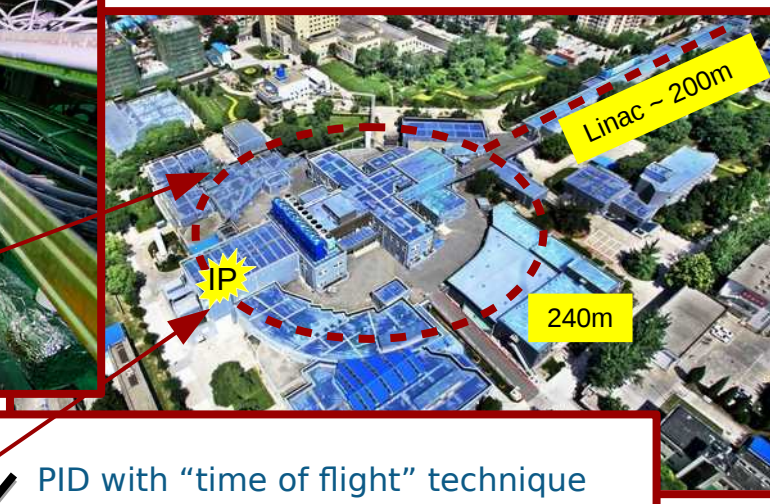


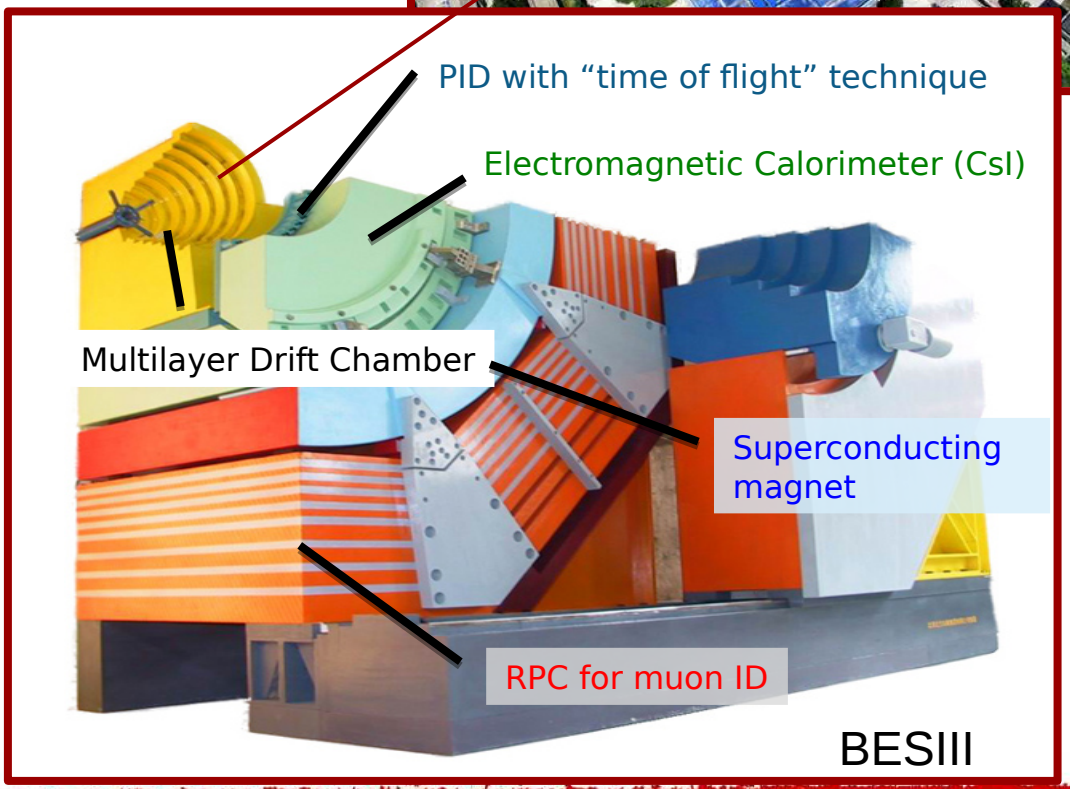
BESIII @ IHEP

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

- The Beijing Electron-Positron Collider BEPCII and the Beijing Spectrometer BESIII are τ-charm factory.
- E_{cm} = 2 – 4.6 GeV
- $\mathcal{L}_{achieved} = 10^{33}\ cm^{-2}s^{-1}$
- Data taking until 2022 with the chance to continue up to 2027
- The physics program includes:
  - High precision test of EW interaction
  - High statistic studies of light hadron spectroscopy
  - The exotic charmonium states
  - Studies of charm physics
  - Studies of τ physics



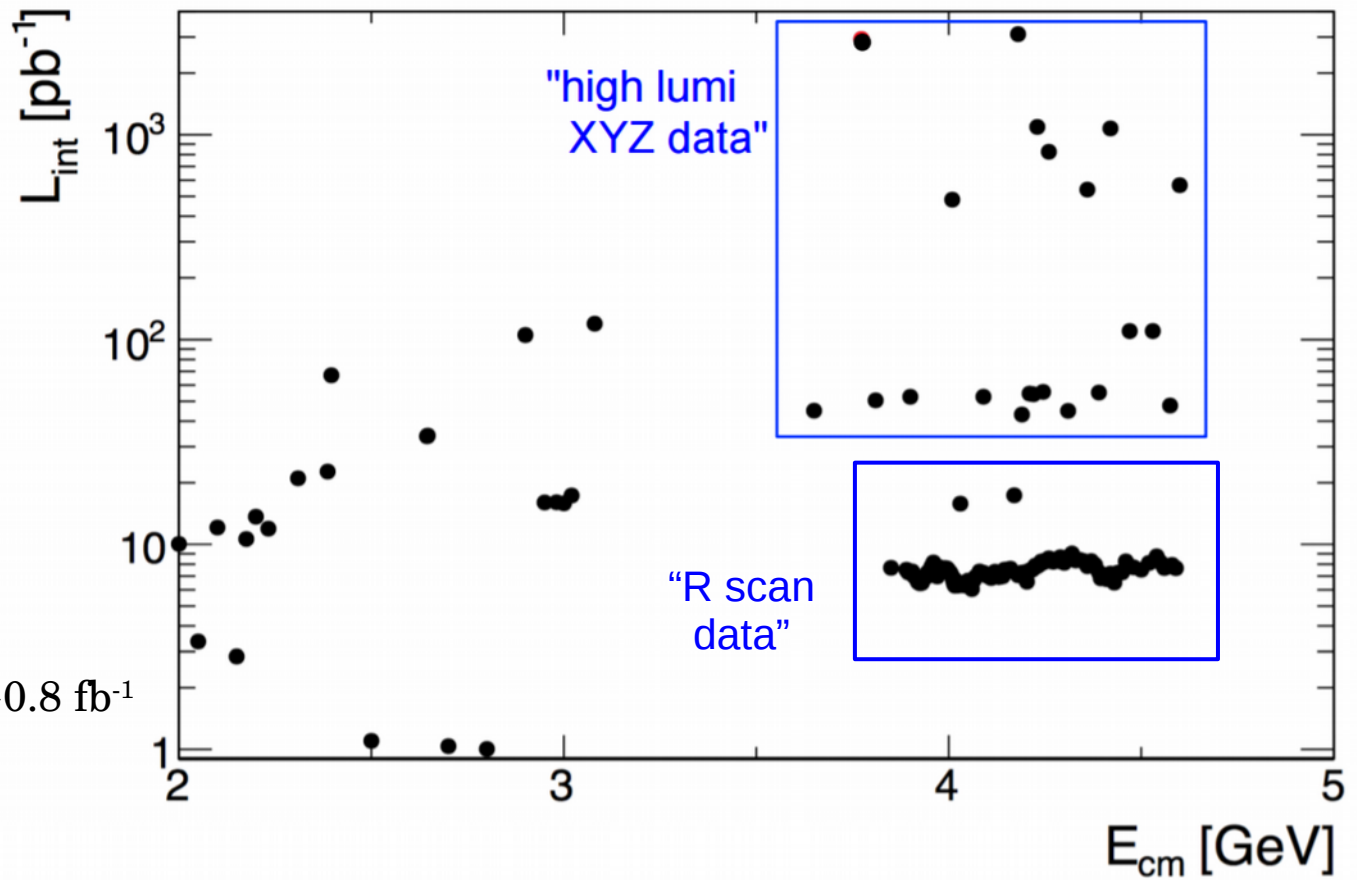




BESIII data set

From 2009 to 2015:

- 1.3×10^9 J/ψ
- 5×10^8 ψ(2S)
- 2.9 fb^{-1} @ ψ(3770)
- 0.5 fb^{-1} @ ψ(4040)
- 2.3 fb^{-1} @ 4230/4260 MeV
- 0.5 fb^{-1} @ 4360 MeV
- 0.5 fb^{-1} @ 4600 MeV
- 1 fb^{-1} @ ψ(4415)
- 0.1 fb^{-1} @ 4470/4530 MeV
- 0.04 fb^{-1} around Λ_c threshold
- 1 fb^{-1} @ 4420 MeV
- R scan:
  - 2-3 GeV, 19 points, ~0.5 fb^{-1}
  - 3.85-4.59 GeV, 104 points, ~0.8 fb^{-1}



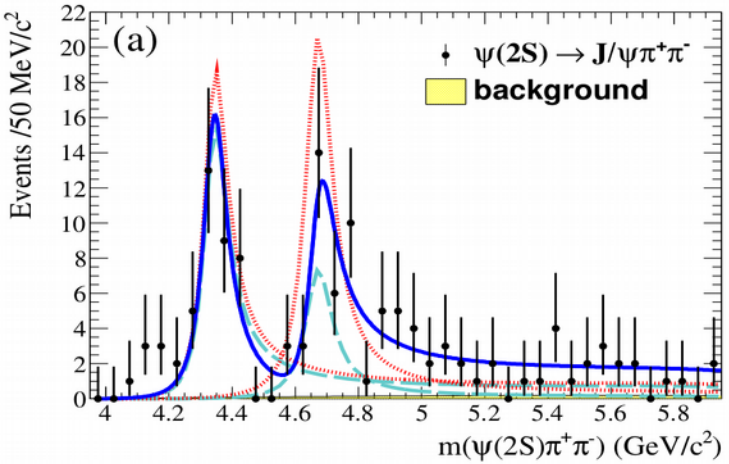
- On-going data taking

Y states

Preliminary	$e^+e^- \to \pi^+\pi^- \psi(2S)$
PRL **118**, 092001 (2017)	$e^+e^- \to \pi^+\pi^- J/\psi$
PRL **118**, 092002 (2017)	$e^+e^- \to \pi^+\pi^- h_c$
PRL **114**, 092003 (2015)	$e^+e^- \to \omega \chi_{cJ}$

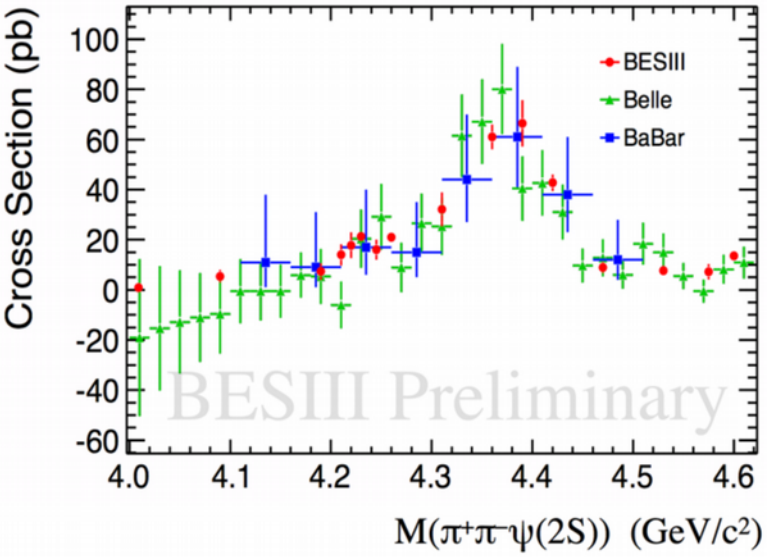
Y state: $e^+e^- \rightarrow \pi^+\pi^- \psi(2S)$

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



BaBar 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)



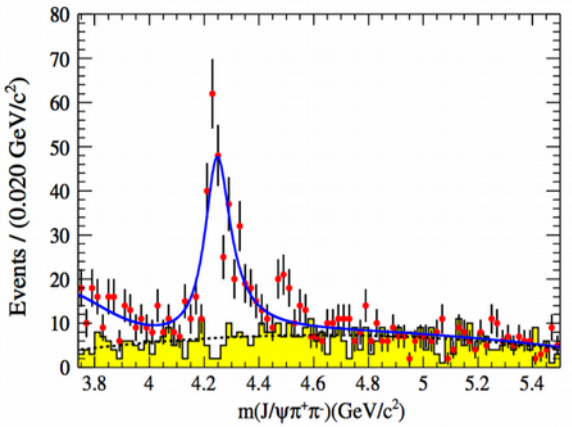
Y state: $e^+e^- \rightarrow \pi^+\pi^- J/\psi$

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

Belle experiment also claimed the discovery of another resonance labeled Y(4008)

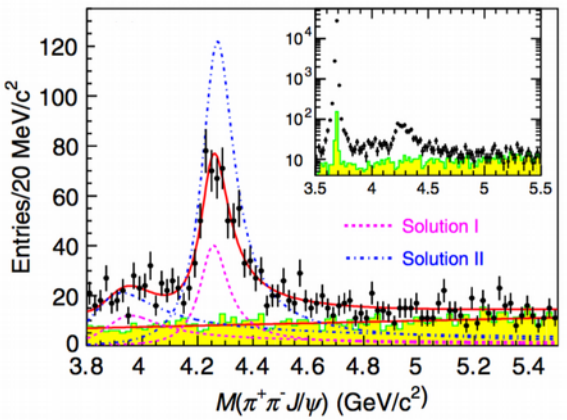
$e^+e^- \rightarrow \pi^+\pi^- J/\psi$ using ISR at BaBar

PRD 86, 051102(R) (2012)



$e^+e^- \rightarrow \pi^+\pi^- J/\psi$ using ISR at Belle

PRL 110, 252002 (2013)



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

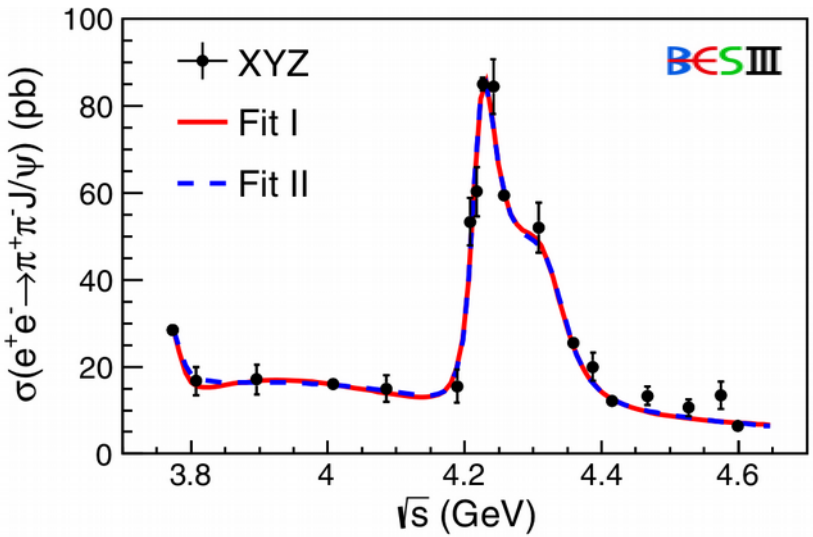
PRL **118**, 092001 (2017)

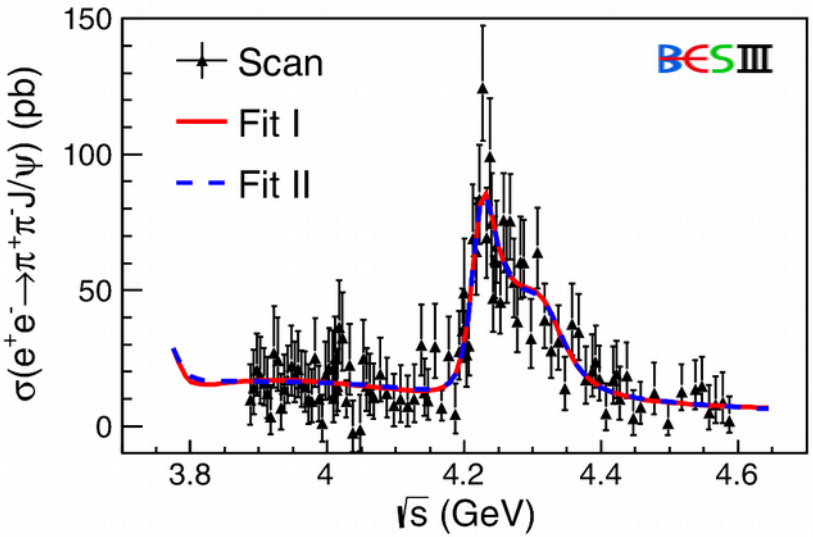
L = 9.05 fb^{-1} from 3.77 to 4.60 GeV

- Selection criteria :
  - 4 charged particles
  - Net charge = 0
  - $|\cos\theta| < 0.93$
  - 4C kinematic fit
- Measurement performed with two data sets
- The fit with a single peak has a smaller significance
  Two resonances describe the data with a significance > **7.6 σ**

M_1 = **4222** ± 3.1 ± 1.4 MeV , Γ_1 = **44.1** ± 4.3 ± 2.0 MeV
M_2 = **4320** ± 10.4 ± 7.0 MeV, Γ_2 = **101.4** $^{+25.3}_{-19.7}$ ± 10.2 MeV

- Y(4320) has been seen for the first time and it is compatible with Y(4360) measured by Belle and BaBar



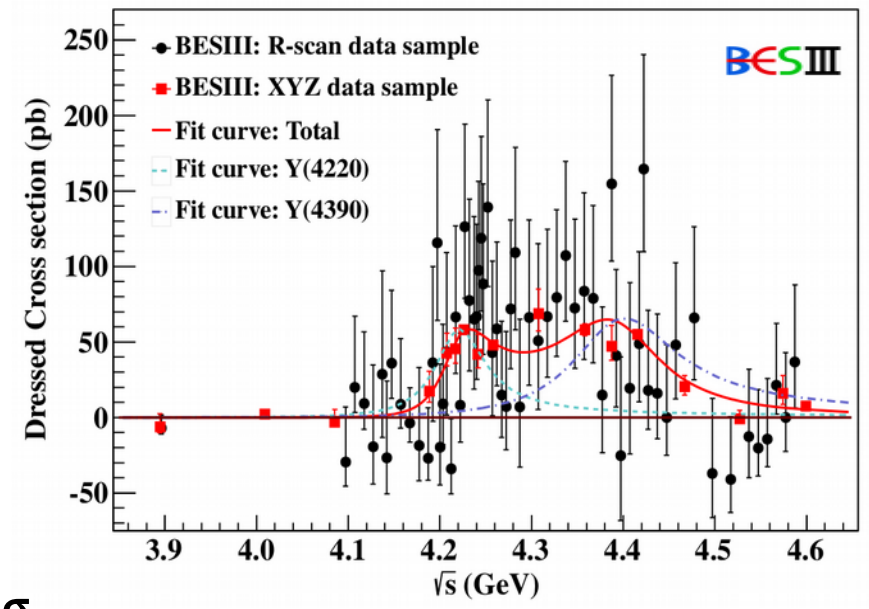


Y state: $e^+e^- \to \pi^+\pi^- h_c$

PRL **118**, 092002 (2017)

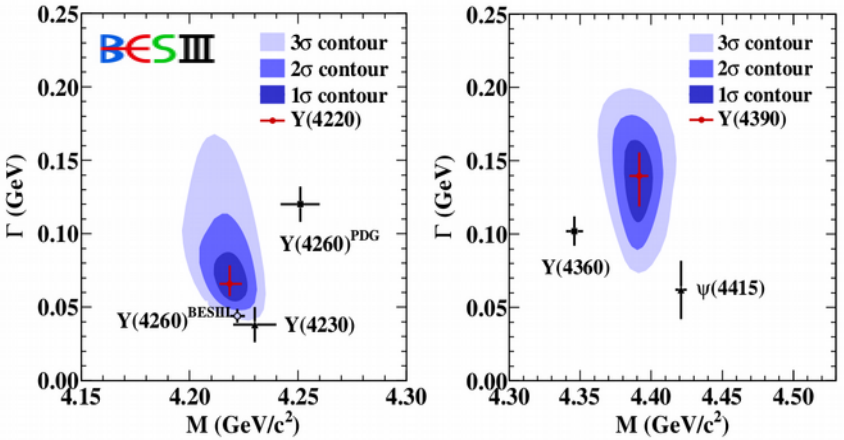
L ~ 9 fb^{-1} from 3.868 to 4.60 GeV

- Selection criteria:
  - $h_c \to \gamma \eta_c$, $\eta_c \to$ 16 exclusive channels
  - Net charge = 0
  - $|\cos\theta| < 0.93$
- 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

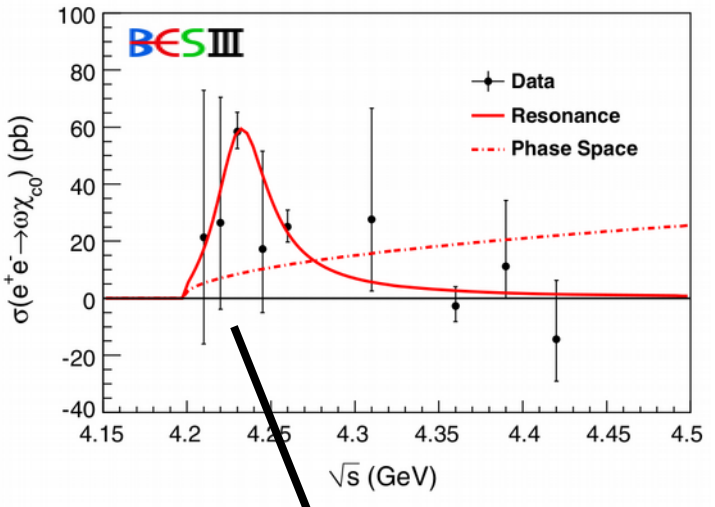


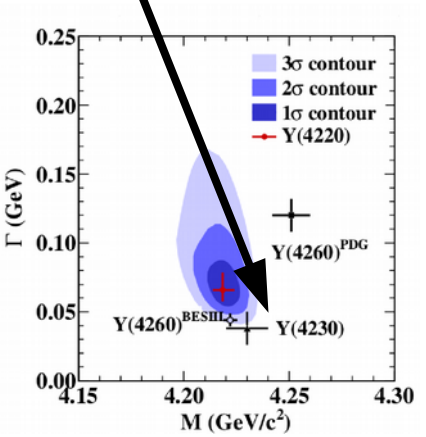
Y state: $e^+e^- \rightarrow \omega \chi_{cJ}$

Nine energy points from 4.21 to 4.42 GeV

PRL **114**, 092003 (2015)

- Selection criteria:
  - 4 charged particles and 2(3) γ for χ_{c0} ($\chi_{c1,2}$)
  - Net charge = 0
  - $|\cos\theta| < 0.93$
- The data suffer the low statistic
  A resonances describes the data with a significance > **9 σ**





$M = \mathbf{4230} \pm 8 \pm 6$ MeV , $\Gamma = 38 \pm 12 \pm 2$ MeV

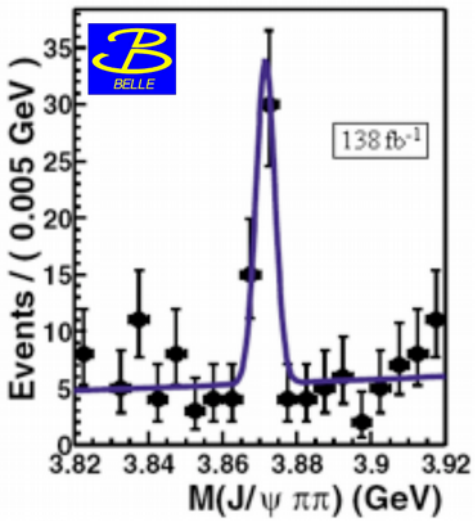
- Only $\omega \chi_{c0}$ channel shows a significant cross section, $\omega \chi_{c1,2}$ have a cross section compatible with 0.
- The mass and width are compatible with the Y in $\pi^+\pi^-$ h_c decay

X (3872)

PRL **112**, 092001 (2014) $e^+e^- \rightarrow \gamma \pi^+\pi^- J/\psi$

X state: some history

PRL **91**, 262001 (2003)



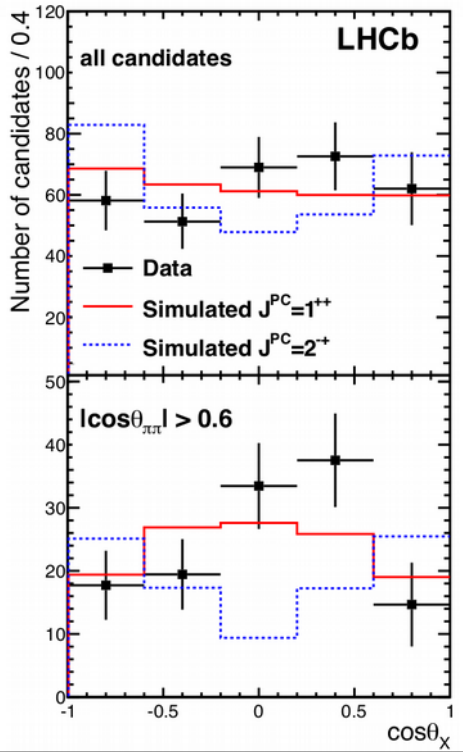
X(3872) discovered by Belle in $B \to K \pi^+\pi^- J/\psi$
confirmed by many other experiments

$M = 3872.69 \pm 0.17$ MeV , $\Gamma < 1.2$ MeV

Decays:

- $\pi^+\pi^- J/\psi$
- $\pi^0 D^0 \overline{D}^0$
- $\gamma J/\psi$ and $\gamma \psi(2S)$

CDF: PRL **93**, 072001 (2004)
D0: PRL **93**, 162002 (2004)
BaBar: PRD **71**, 071103 (2005)
LHCb: EPJ **C72**, 1972 (2012)



$J^{PC} = 1^{++}$

LHCb: PRL **101**, 222001

X state: $e^+e^- \to \gamma \pi^+\pi^- J/\psi$

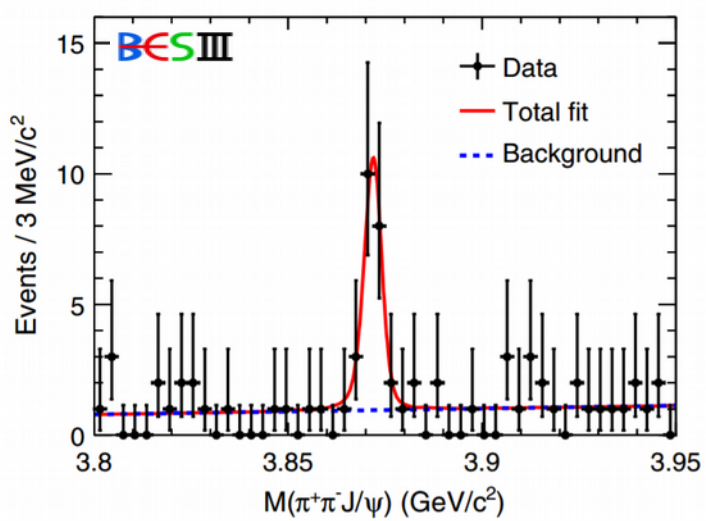
PRL **112**, 092001 (2014)

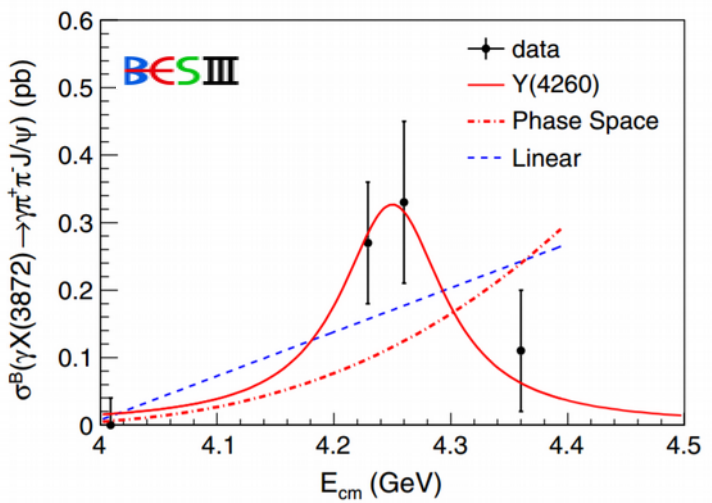
Four energy points from 4.009 to 4.360 GeV

- Selection criteria:
  - 4 charged particles and γ
  - Net charge = 0
  - $|\cos\theta| < 0.93$
- A resonances describes the data with a significance > 6.3 σ

M = **3871.9** ± 0.7 ± 0.2 MeV , $\Gamma <$ **2.4** MeV (90% C.L.)

- Cross section is consistent with the expectation for the radiative transition process Y(4260) → γ X(3872)





Z states

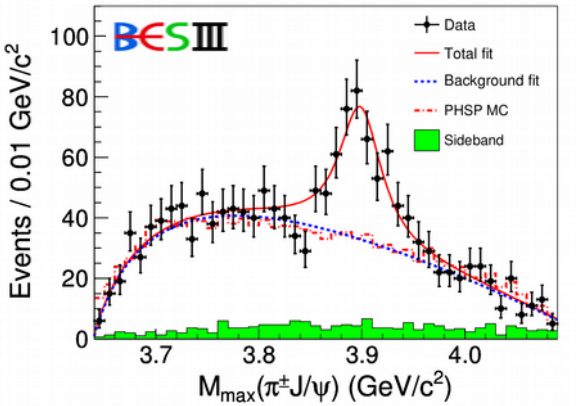
PRL **110**, 252001 (2013)	PRL **115**, 112003 (2015)	$e^+e^- \rightarrow \pi(\pi\, J/\psi)$
PRL **112**, 022001 (2014)	PRL **115**, 222002 (2015)	$e^+e^- \rightarrow \pi(D\overline{D}^*)$
PRL **111**, 242001 (2013)	PRL **113**, 212002 (2014)	$e^+e^- \rightarrow \pi(\pi h_c)$
PRL **112**, 132001 (2013)	PRL **115**, 182002 (2015)	$e^+e^- \rightarrow \pi(D^*\overline{D}^*)$

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

PRL **110**, 252001 (2013)

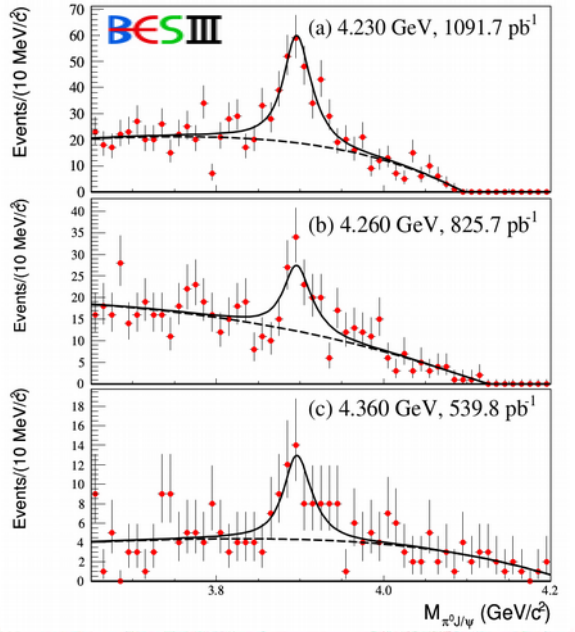
- Charged charmonium-like structure:
  - Decay to J/ψ → contains $c\bar{c}$
  - Electric charge → contains $u\bar{d}$

$M = \mathbf{3899.0} \pm 3.6 \pm 4.9$ MeV , $\Gamma = \mathbf{46} \pm 10 \pm 20$ MeV



- Confirmed by CLEO-c and Belle

PRL **115**, 112003 (2015)



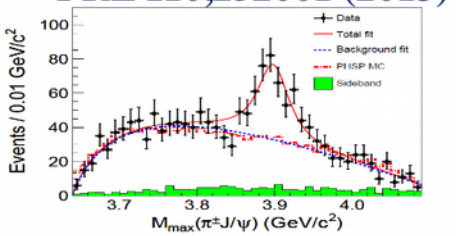
- Measured in the neutral channel at different energies with a significance > **10 σ**

- Quantum number measured with a maximum likehood fit to be $J^P = 1^+$

Isospin triplet is established

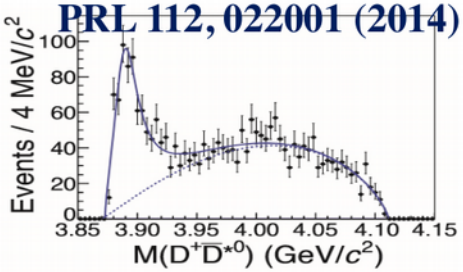
Z state summary

PRL 110,252001 (2013)



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

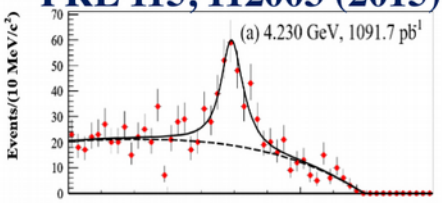
PRL 112, 022001 (2014)



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

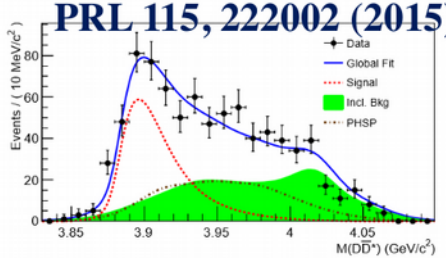
$Z_c(3900)^{\pm}$?

PRL 115, 112003 (2015)



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

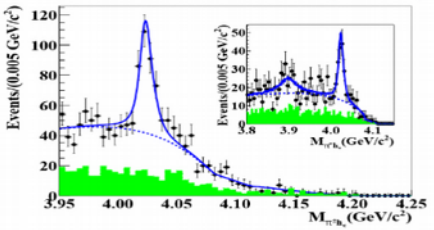
PRL 115, 222002 (2015)



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

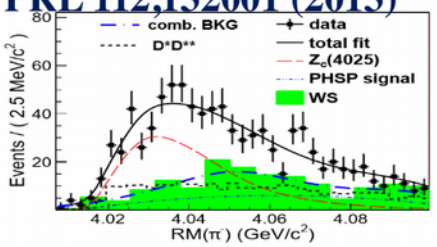
$Z_c(3900)^0$?

PRL 111.242001 (2013)



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

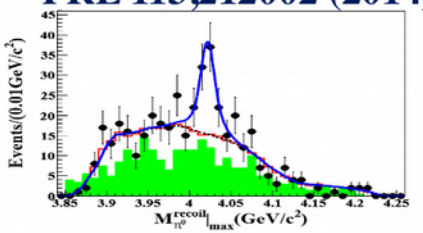
PRL 112,132001 (2013)



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

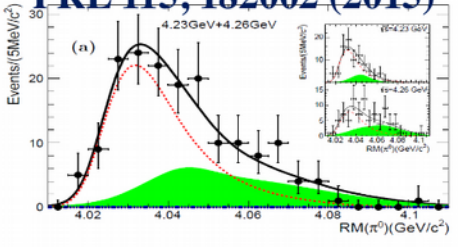
$Z_c(4020)^{\pm}$?

PRL 113,212002 (2014)



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

PRL 115, 182002 (2015)



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

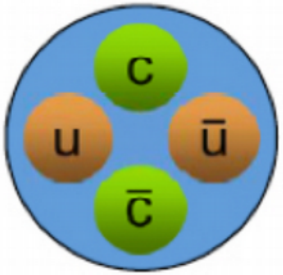
$Z_c(4020)^0$?

- 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

Nature of these states

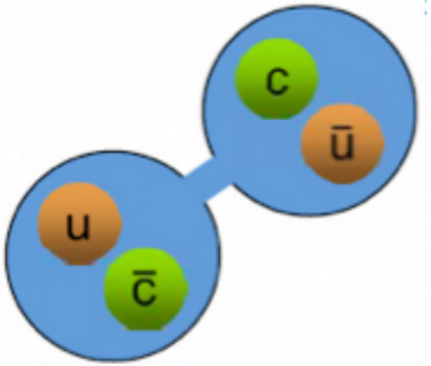
- Tetraquark state?

Phys. Rev. D87,125018(2013); Phys. Rev. D88, 074506(2013);
Phys. Rev. D89,054019(2014); Phys. Rev. D90,054009(2014);



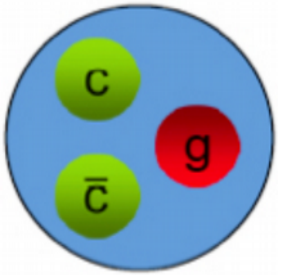
- Molecule state?

Phys. Rev. Lett. 111, 132003 (2013); Phys. Rev. D 89, 094026 (2014)
Phys. Rev. D 89, 074029 (2014); Phys. Rev. D 88, 074506 (2013)



- Charmonium hybrid?

Phys.Rev. D88 (2013) 045027;



- Other?

Conclusion

- BESIII is successfully operating since 2009 and has the World largest data sets in tau-charm mass region. It has unique data for XYZ studies
- BESIII is ideally suited to explore transitions and decays of Y states that are produced directly to investigate the XYZ-spectrum
- BESIII is creating a connection between these states that can lead to an explanation about their nature
- First two isospin triplet states Zc (3900), Zc (4020) established
- Precise measurement of the cross-section in the Y energy range
- Even the Y(4260) in $\pi^+\pi^-$ J/ψ no longer looks like a simple peak.
- After more than 10 years the XYZ puzzle is still unclear and its interpretation in not trivial


Thanks