XYZ States at BESIII

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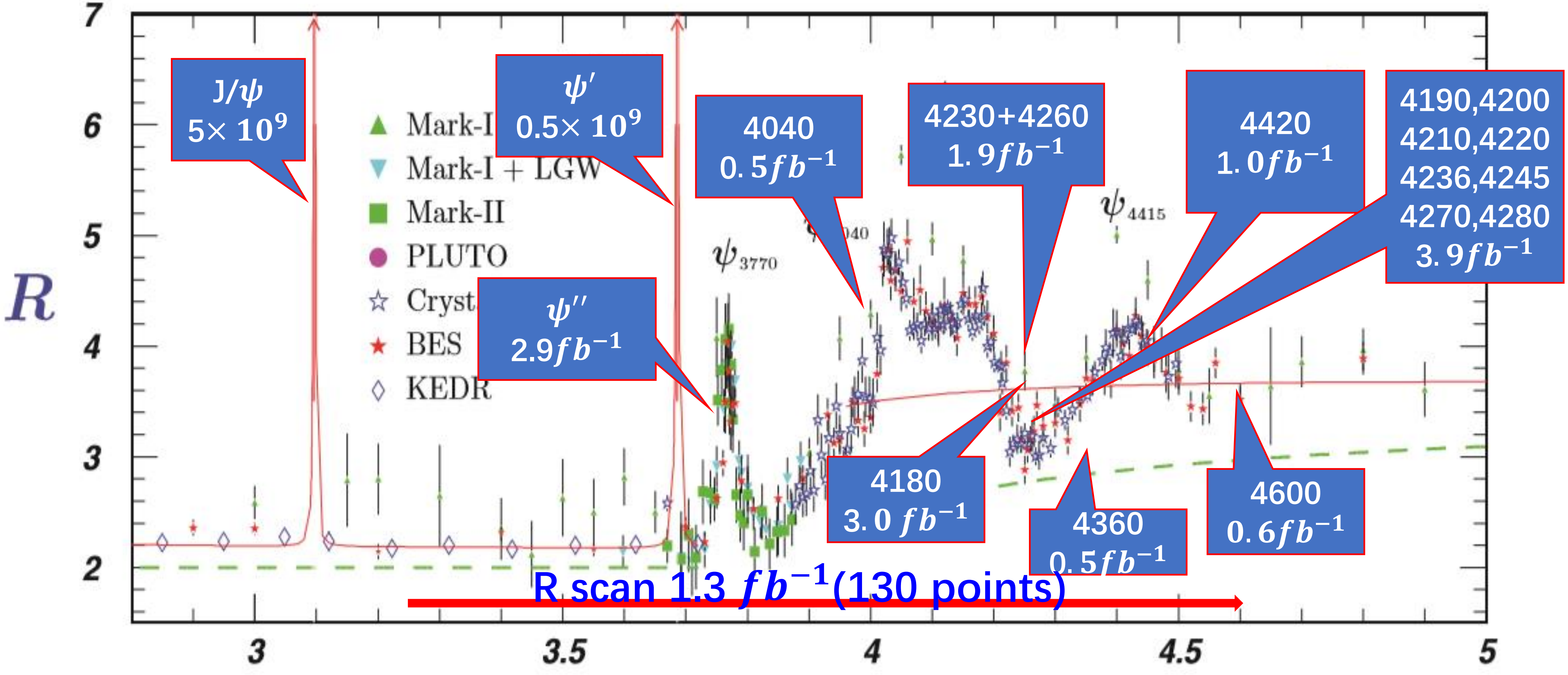
Outline

- BESIII data sets for XYZ study
- Charmoniumlike states
  - The X(3872)— $J^{pc}=1^{++}$
    $e^+e^- \to \gamma X(3872), X(3872) \to \pi^+\pi^- J/\psi$
  - The Y states — $J^{PC}=1^{--}$
    $\mathrm{Y} \to \pi^+\pi^- \mathrm{J}/\psi$, $\mathrm{Y} \to \pi^+\pi^-\psi(3686)$, $\mathrm{Y} \to \pi^+\pi^- \mathrm{h_c}$
  - The Z_c states — I=1 & decays into $c\bar{c}$
    J^P for Zc(3900), $Z_c \to \rho\eta_c$
- Summary

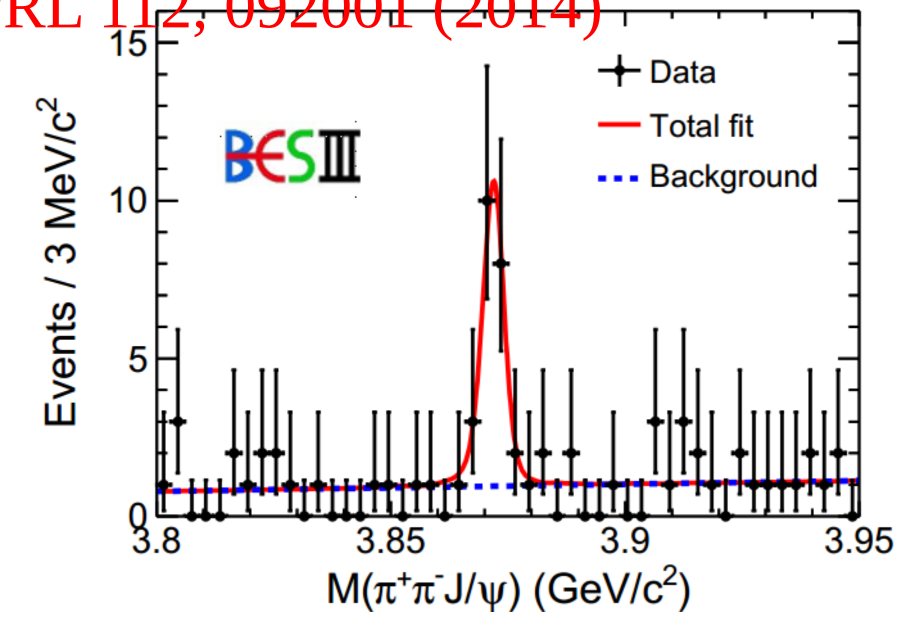
BESIII data sets for XYZ study



The X state

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

PRL 112, 092001 (2014)



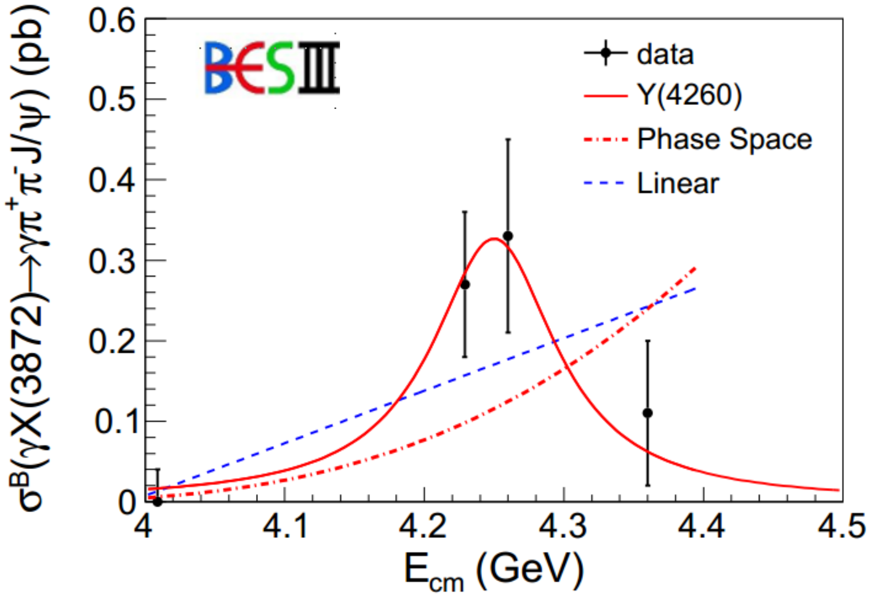
- The X(3872) signal is clearly observed: significance 6.3σ.

  M(X(3872)) = 3871.9±0.7±0.2 MeV [PDG: 3871.68 ±0.17 MeV]

- Existence of radiative transition process Y (4260) → γX(3872).

- Assuming that measured transition is from Y(4260) and $\mathcal{B}[X(3872) \to \pi^+\pi^- J/\psi]$=5%

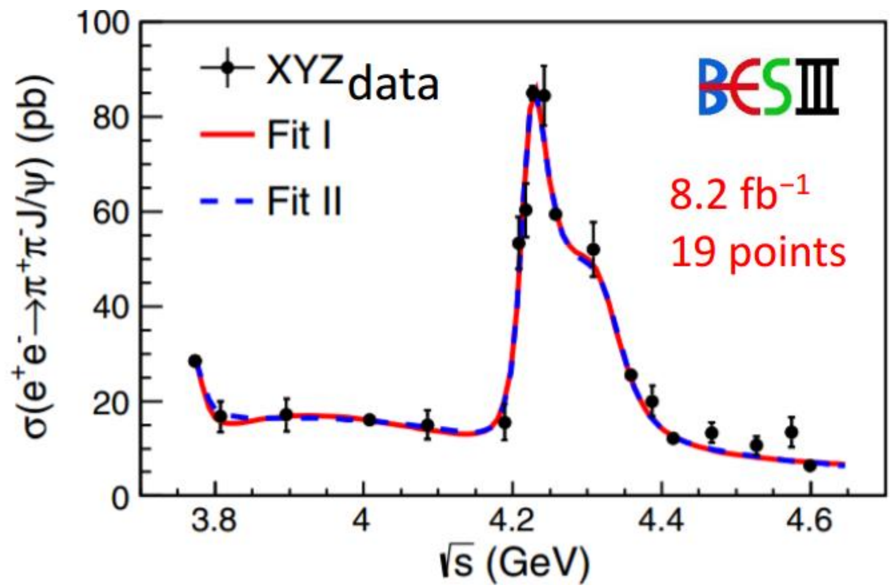
$$\frac{\mathcal{B}[Y(4260) \to \gamma X(3872)]}{\mathcal{B}(Y(4260) \to \pi^+\pi^- J/\psi)} = 0.1$$

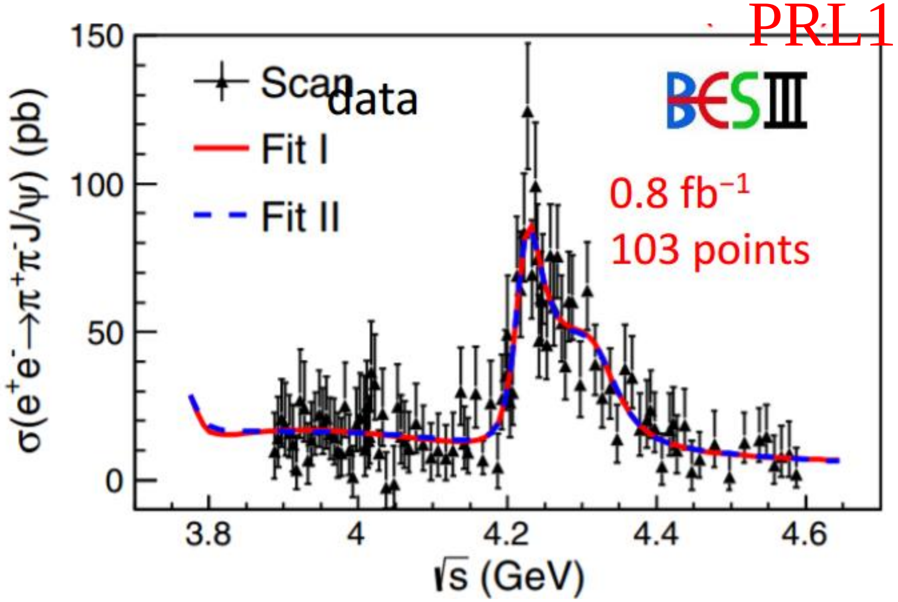


The Y states

Precise Measurement of $e^+e^- \to \pi^+\pi^- J/\psi$ Cross Section

PRL118, 092001 (2017)





- **Simultaneous fit to the cross section from XYZ data(left) and R-scan data (right)**
- Fit I = $|BW1+BW2*e^{i\phi 2}+BW3*e^{i\phi 3}|^2$ or Fit II $=|exp+BW2*e^{i\phi 2}+BW3*e^{i\phi 3}|^2$

  Resonance I: M = (4222.0±3.1±1.4) MeV, Γ = (44.1±4.3±2.0) MeV ,

  Lower and narrower than previous Y(4260) PDG value

  Resonance II: M = (4320.0±10.4±7) MeV, Γ = (101.4±25±10) MeV ,

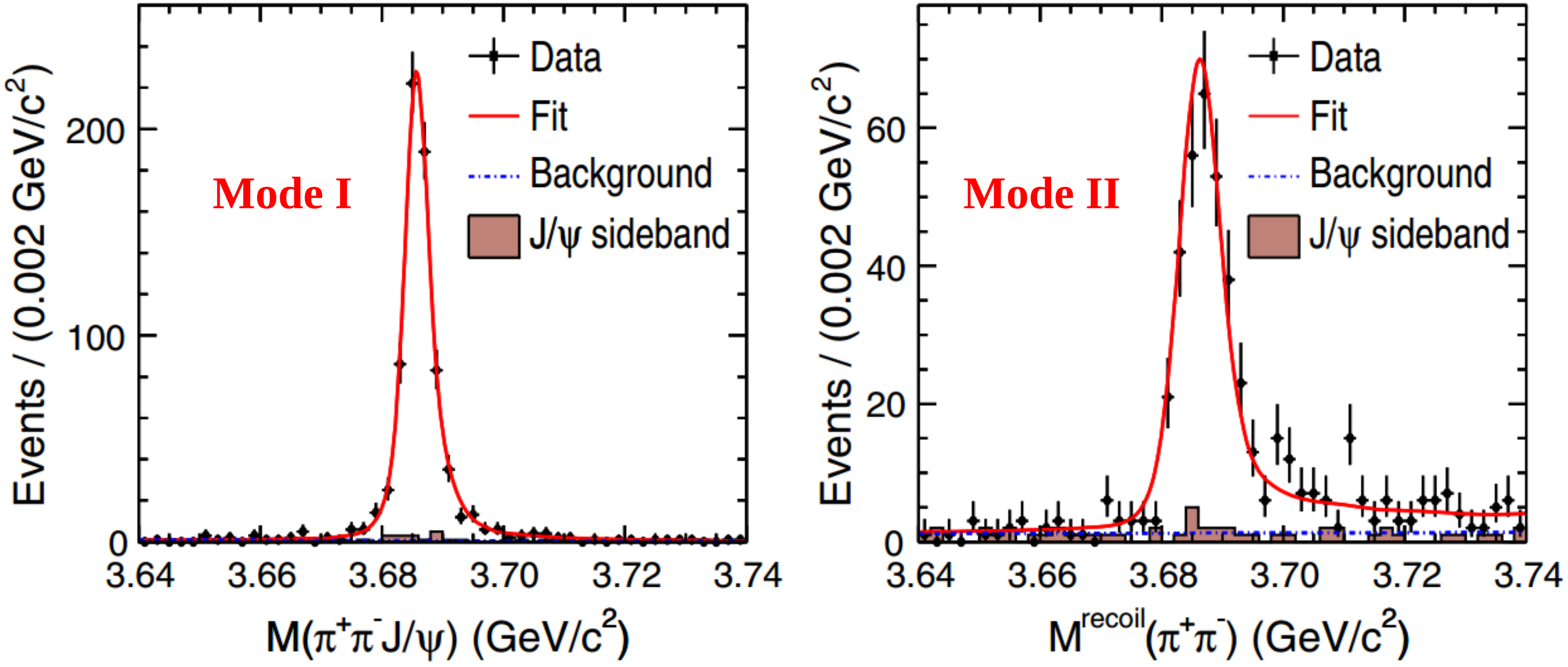
  a little bit lower than Y(4360) PDG value
- **The significance of the second resonance is 7.6σ**
- **The first observation of Y(4360) → $\pi^+\pi^- J/\psi$?**

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

PRD 96, 032004 (2017)

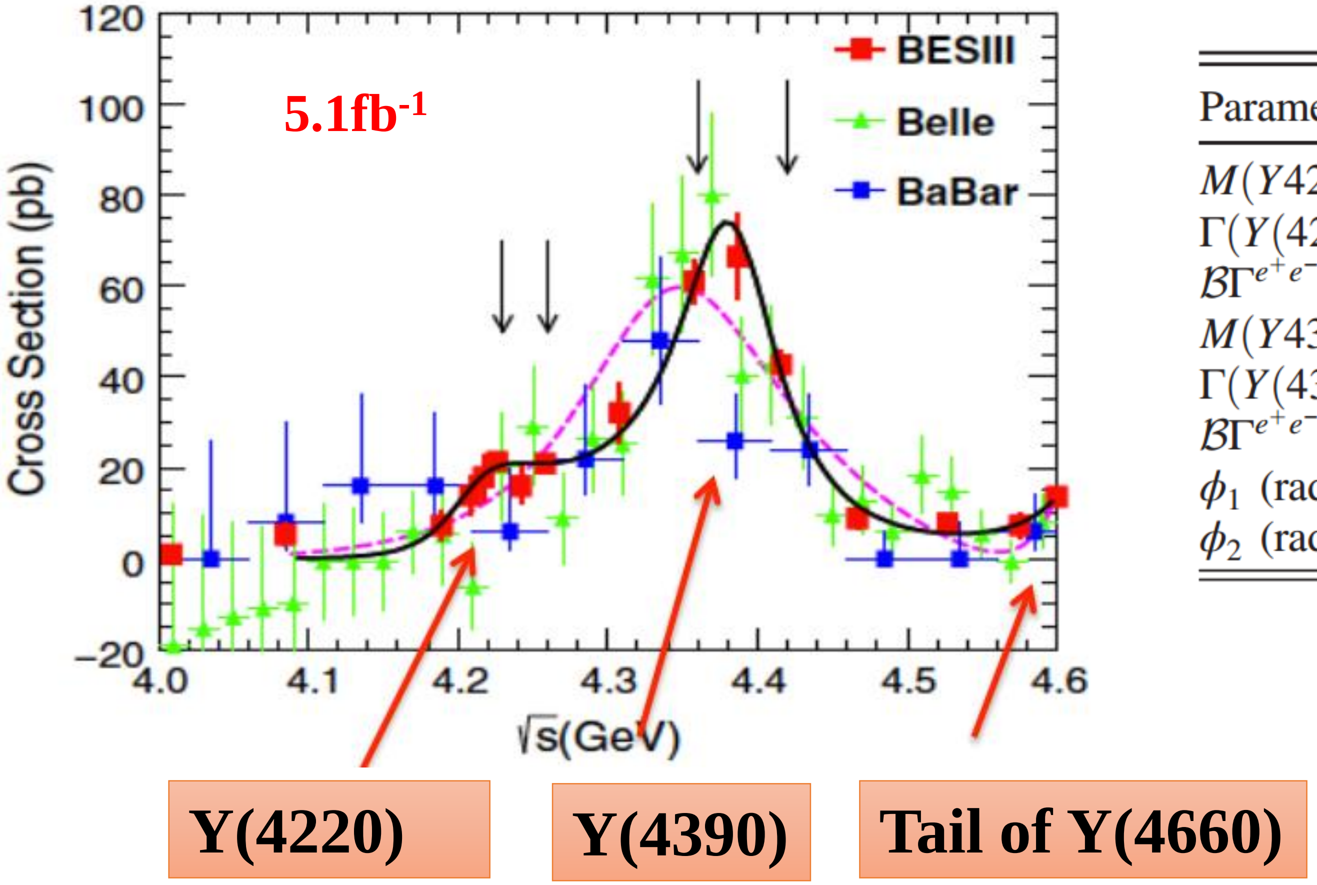
- **Reconstructed modes**
  - **Mode I:** $\psi(3686) \to \pi^+\pi^- J/\psi$, $J/\psi \to l^+l^-(l = e/\mu)$.
  - **Mode II:** $\psi(3686) \to neutrals + J/\psi$,

$neutrals$=($\pi^0\pi^0$, π^0, η and $\gamma\gamma$), $J/\psi \to l^+l^-(l = e/\mu)$.



Ecm=4.416 GeV

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



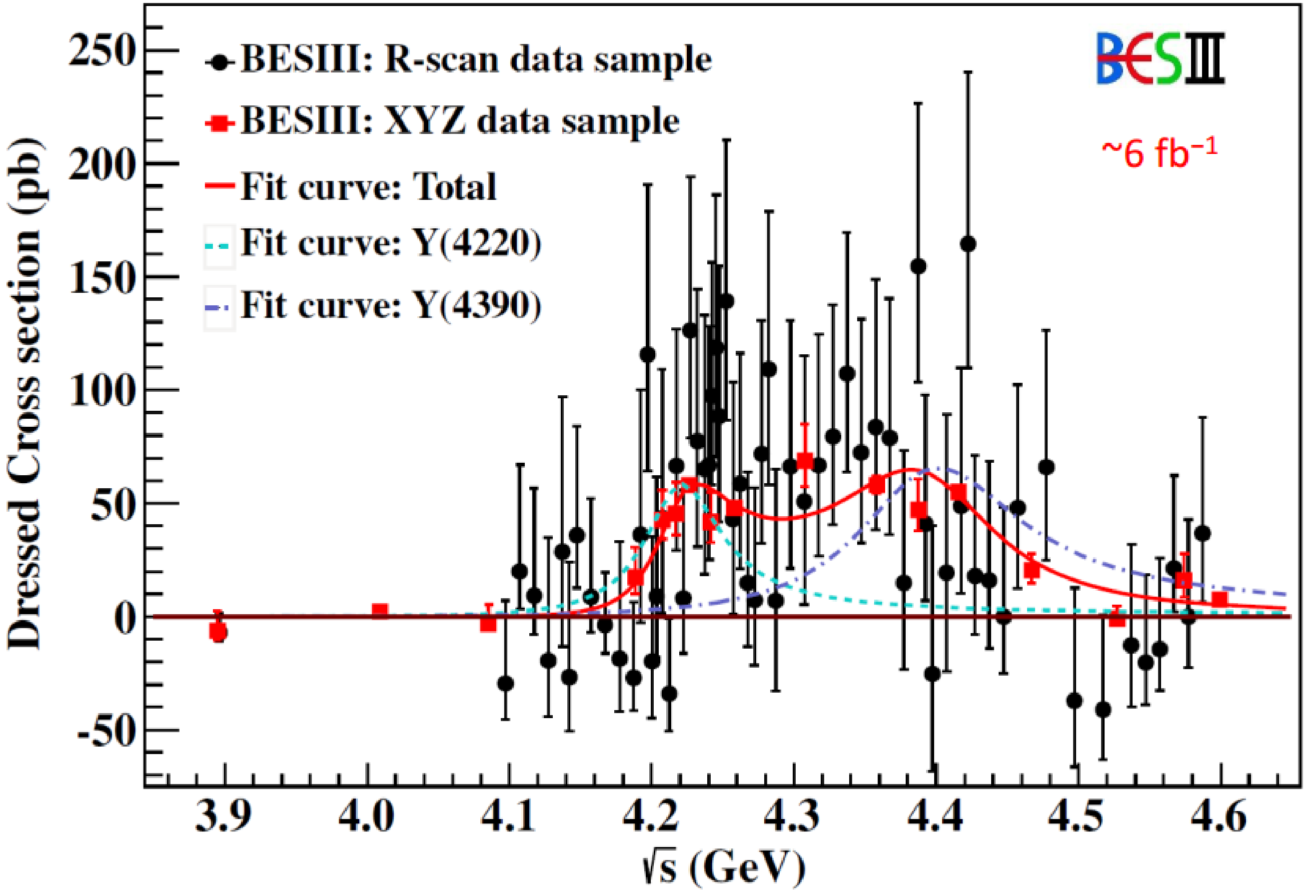
PRD 96, 032004 (2017)

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

- Fix parameters of the Y(4660) to Belle results.
- The Y(4220) is necessary(significance = 5.8σ)

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

PRL118, 092002 (2017)



The cross sections are of the same order of magnitude as those of the $e^+e^- \rightarrow \pi^+\pi^-$ J/$\psi(\psi(3686))$, but follow a different line shape.

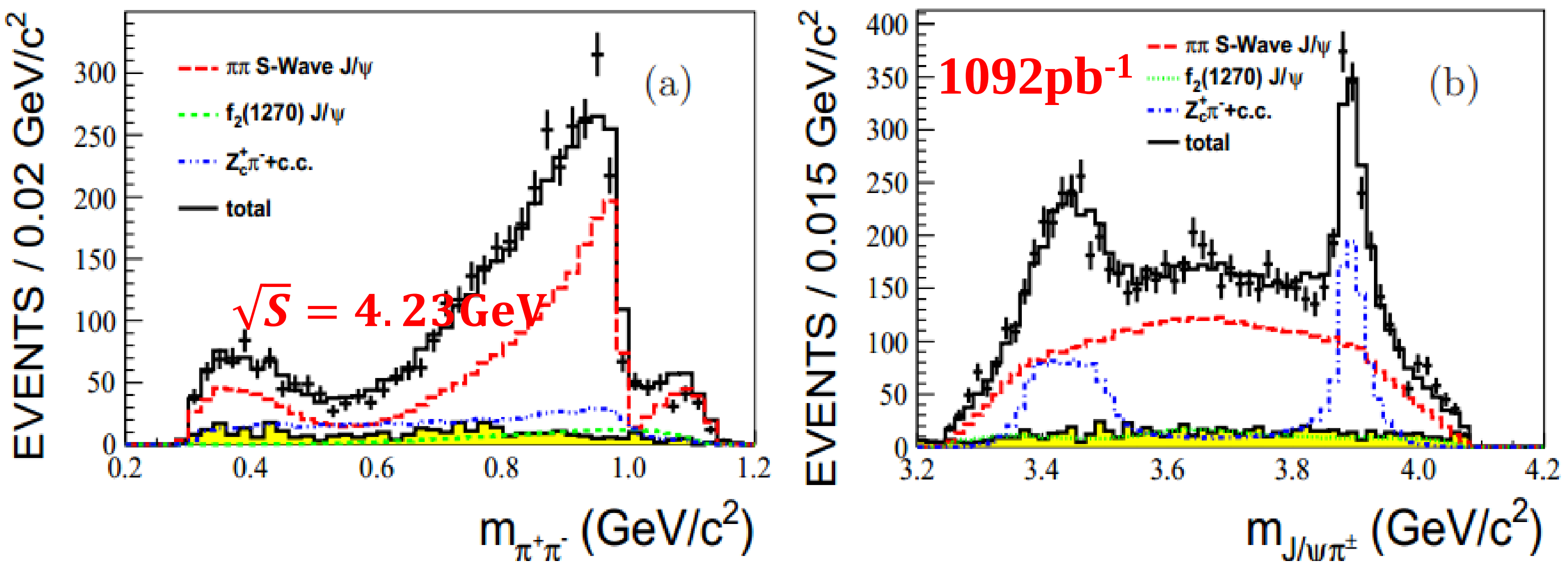
- Fitted with coherent sum of two Breit-Wigner like structure

$M_1=4218.4^{+5.5}_{-4.5}\pm0.9$ MeV/c^2, $\Gamma_1= 66.0^{+12.3}_{-8.3}\pm0.4$ MeV $\rightarrow$ Y(4220)

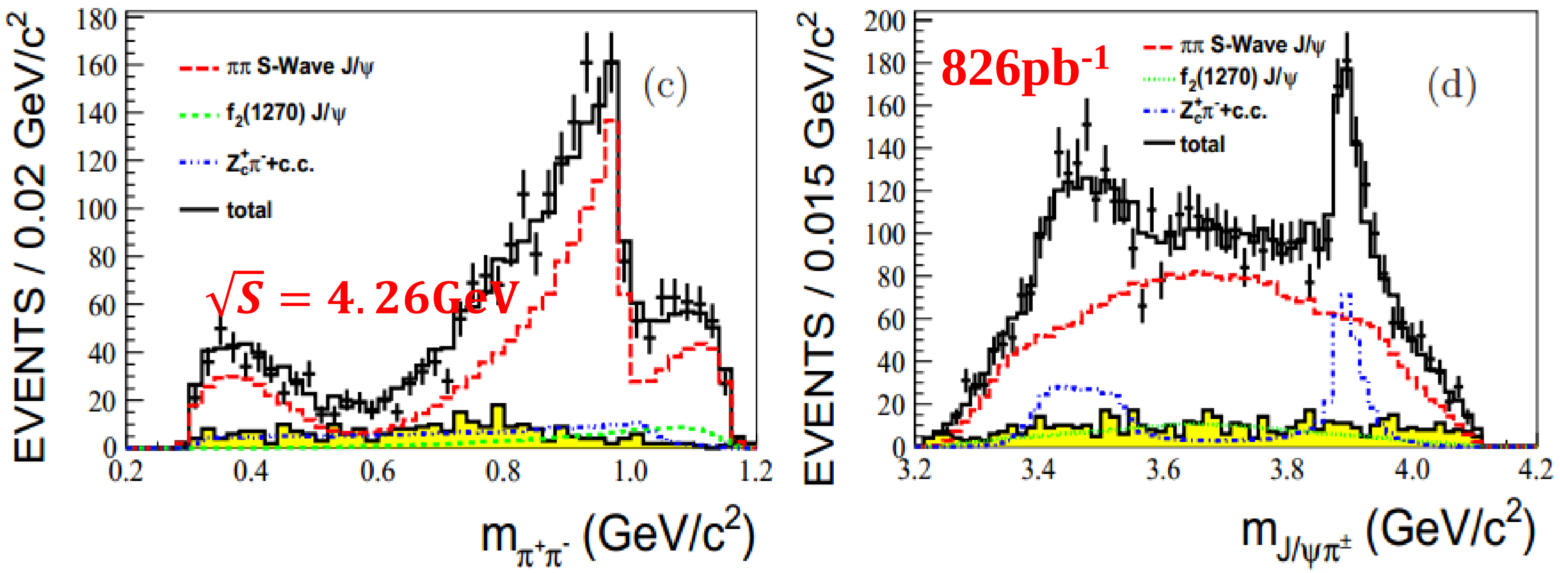
$M_2=4391.5^{+6.3}_{-6.8}\pm1.0$ MeV/c^2, $\Gamma_2=139.5^{+16.2}_{-20.6}\pm0.6$ MeV $\rightarrow$ Y(4390)

The Z_c states

Determination of J^P of Zc(3900)



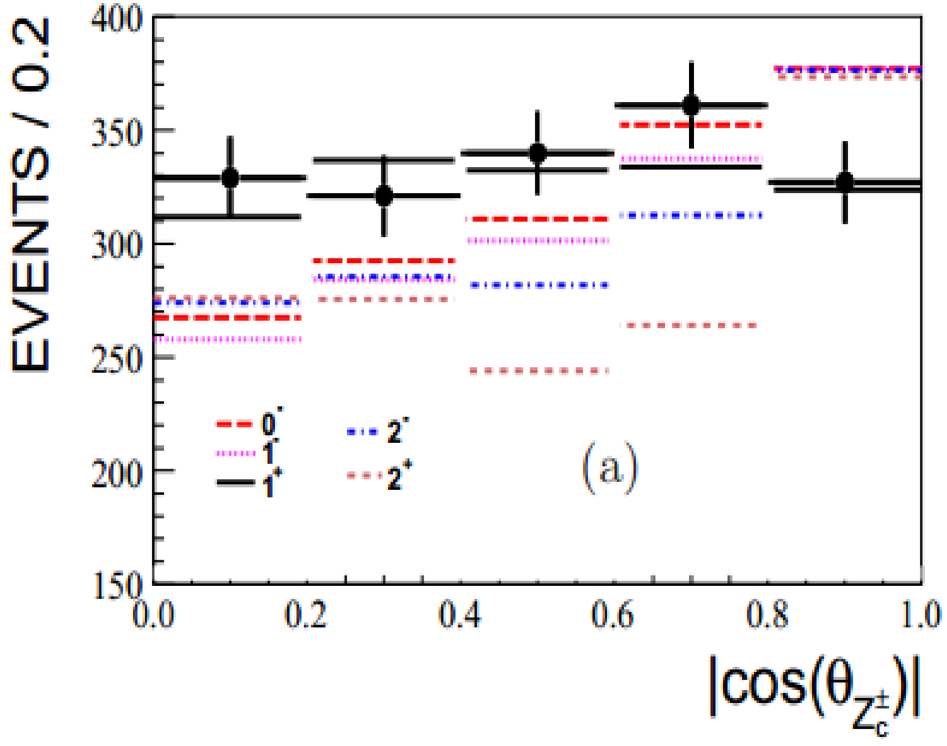
$\pi\pi$ S-Wave include σ, f_0(980),and f_0(1370).



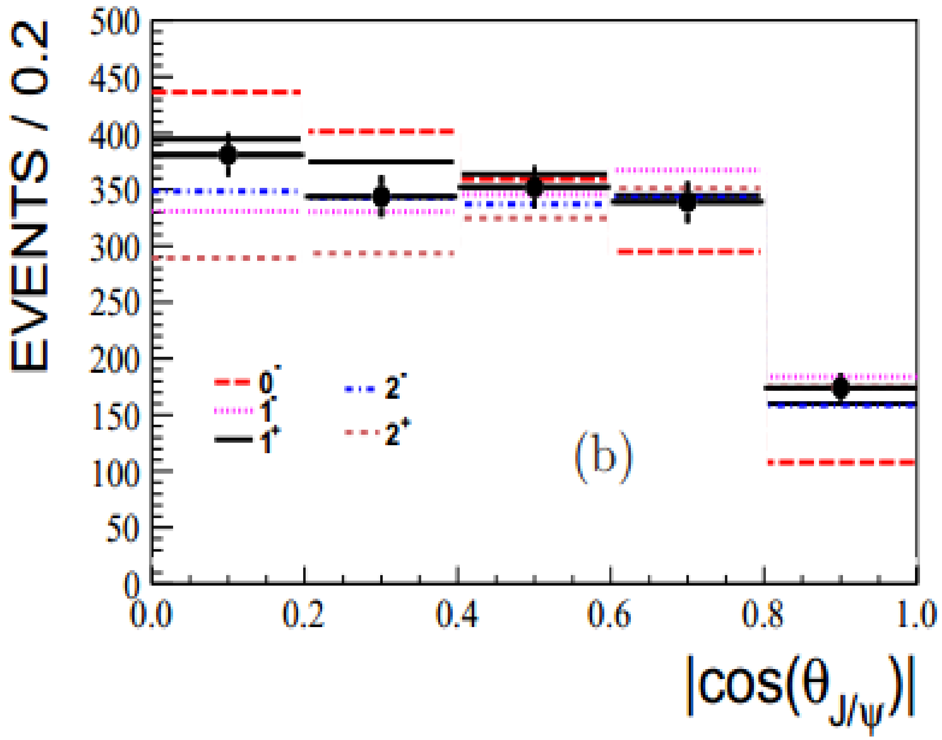
PRL 119, 072001 (2017)

- **Based on a PWA of the $e^+e^- \to \pi^+\pi^- J/\psi$ at $\sqrt{S} = 4.23, 4.26$GeV.**
- **Assume Zc to have $J^P=1^+$, parameterized with Flatte formula.**
- **Pole Mass=(3881.2±4.2±52.7)MeV, Pole width=(51.8±4.6±36.0)MeV**

Determination of J^P of Zc(3900)



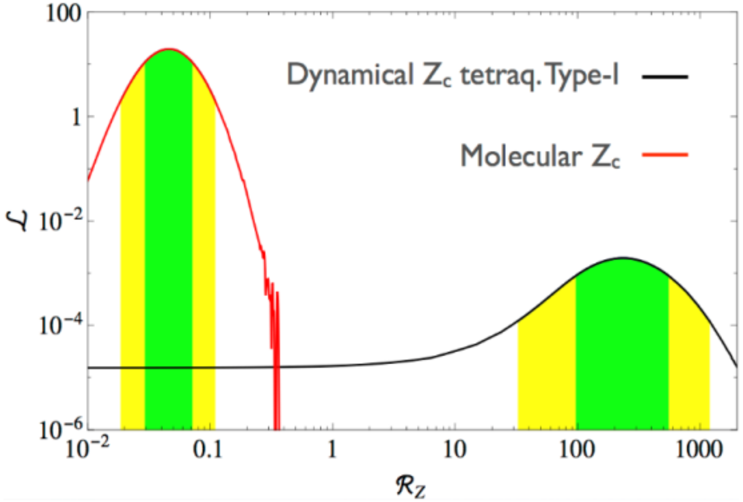
Polar angle distribution of Zc $^{\pm}$ in the process $e^+e^- \rightarrow Zc^+\pi^-$+ c.c.

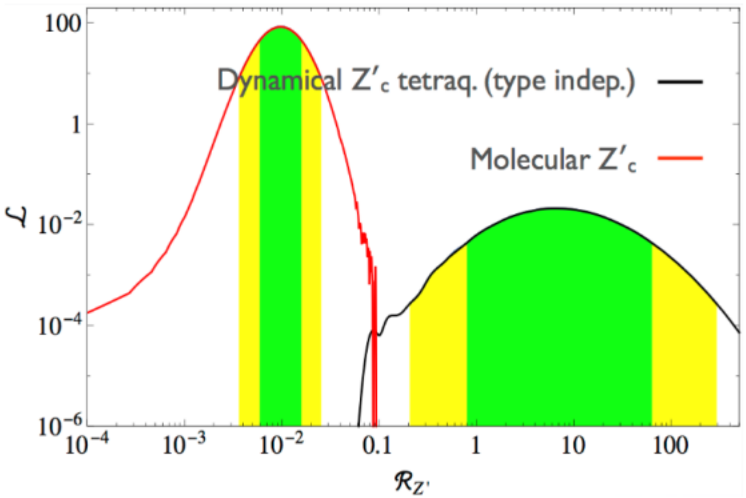


Helicity angle distribution of J/ψ in the $Zc^{\pm} \rightarrow \pi^{\pm}$ J/ψ.

The significance of the J^P=1+ hypothesis over the alternative J^P possibilities to be larger than 7σ .

Search for $Z_c \to \rho\eta_c$





$$R_z = \frac{B(Z_c \to \rho\eta_c)}{B(Z_c \to \pi J/\psi)} \qquad R_{Z'} = \frac{B(Z_c' \to \rho\eta_c)}{B(Z_c' \to \pi h_c)}$$

A.Esposito, A.L.Guerrieri, A.Pilloni, Phys. Lett. B 746, 194 (2015)

- The ratios of $Z_c^{(\prime)} \to \rho\eta_c$ to $Z_c^{(\prime)} \to \pi J/\psi(\pi h_c)$ may distinguish the tetra-quark and molecule models.
- The green band and yellow band show the 1σ and 2σ confidence range of the corresponding theoretical model.

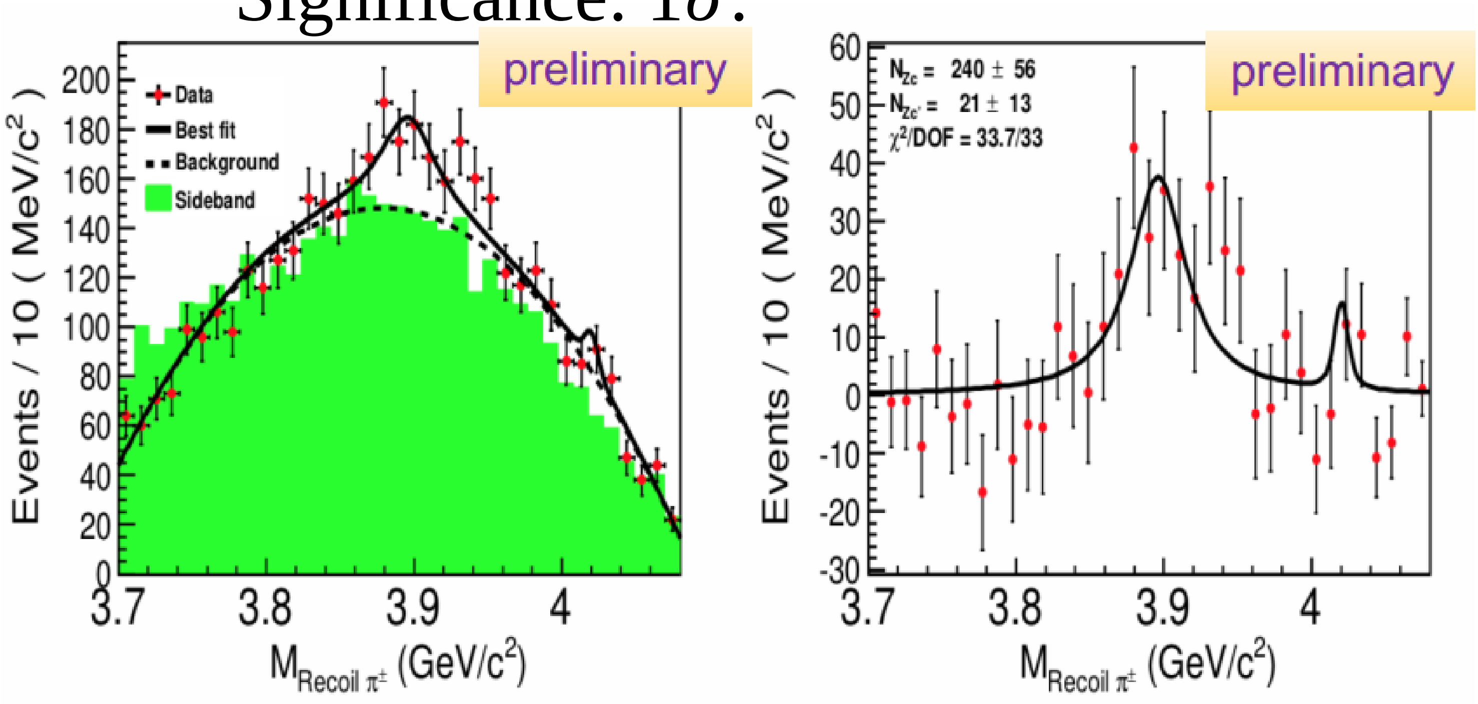
Evidence for $Z_c \to \rho\eta_c$

preliminary

- $e^+e^- \to \pi^+\pi^-\pi^0\eta_c$
- $\eta_c \to$ 9 hadronic decays

Decay mode	BR
$\eta_c \to p\bar{p}$	~0.13%
$\eta_c \to 2(K^+K^-)$	~0.15%
$\eta_c \to \pi^+\pi^-K^+K^-$	~1.50%
$\eta_c \to K^+K^-\pi^0$	~1.20%
$\eta_c \to p\bar{p}\pi^0$	~0.18%
$\eta_c \to K_SK\pi$	~1.80%
$\eta_c \to \pi^+\pi^-\eta$	~1.60%
$\eta_c \to K^+K^-\eta$	~0.57%
$\eta_c \to \pi^+\pi^-\pi^0\pi^0$	~2.40%

- Strong evidence for $e^+e^- \to \pi Z_c, Z_c \to \rho\eta_c$ at $\sqrt{s} = 4.23\text{GeV}$
  Significance: 4.3σ.
- $e^+e^- \to \pi Z_c', Z_c' \to \rho\eta_c$ not seen.
  Significance: 1σ.

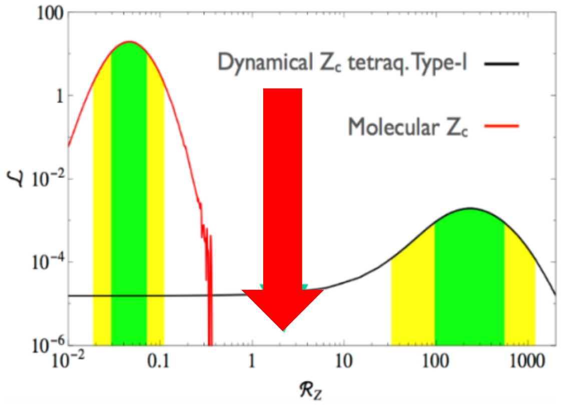


$e^+e^- \to \pi Z_c, Z_c \to \rho\eta_c$ at $\sqrt{s} = 4.23\text{GeV}$

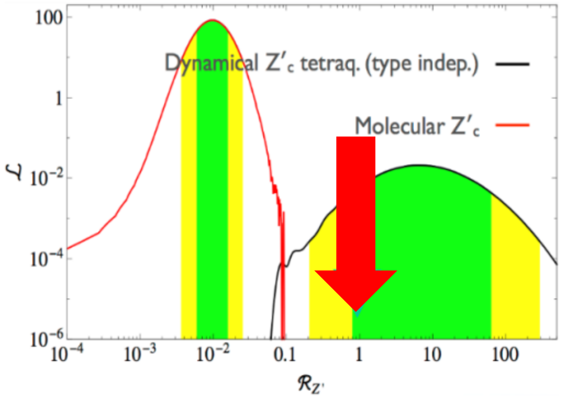
Evidence for $Z_c \to \rho\eta_c$

preliminary

	$\sqrt{s} = 4.23$ GeV	$\sqrt{s} = 4.26$ GeV	$\sqrt{s} = 4.36$ GeV	Tetra-quarks-I	Tetra-quarks-II	Molecule
$R_{Z_c(3900)}$	2.1 ± 0.8	< 6.4	...	230^{+330}_{-140}	$0.27^{+0.40}_{-0.17}$	$0.046^{+0.025}_{-0.017}$
$R_{Z_c(4020)}$	< 1.9	< 1.2	< 1.0	$6.6^{+56.8}_{-5.8}$		$0.010^{+0.006}_{-0.004}$



$$R_z = \frac{B(Z_c \to \rho\eta_c)}{B(Z_c \to \pi J/\psi)}$$



$$R_{Z'} = \frac{B(Z'_c \to \rho\eta_c)}{B(Z'_c \to \pi h_c)}$$

A.Esposito et al, Phys. Lett. B 746, 194 (2015)

Also calculations predict very different values:

$R_Z = 10^{-3} \sim 10^{2}$!

arXiv:1806.05651
arXiv:1512.01938
PRD 91, 034032 (2015)
PRD 90, 054006 (2014)
EPJC 73, 2561 (2013)

Summary

- BESIII collaboration has performed a detailed study of the XYZ at 3.8-4.6 GeV
  - **Observation of Y(4260) → $\gamma X(3872)$.**
  - **Measurement of Born cross-section for different channels reveal complex structures and new Y states**
  - **$J^P=1^+$ for Zc(3900), evidence for $Z_c \rightarrow \rho\eta_c$**
  - BESIII will take more data and continue the study.

Thanks!!!