XYZ radiative transitions at BESIII

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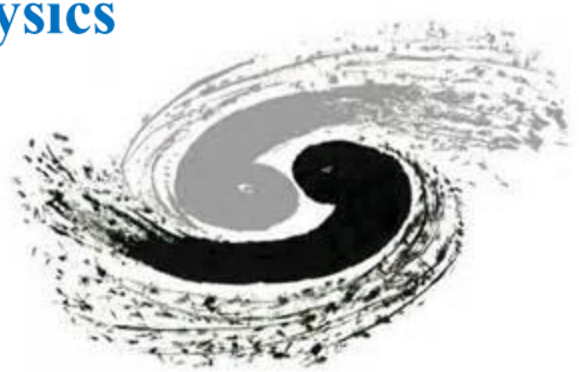
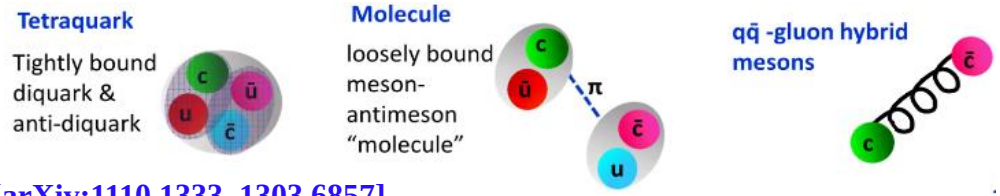


Motivation

- Many unexpected states have been observed recently above the $D\bar{D}$ threshold (XYZ).

- The features of these states point beyond the QCD models, for instance



[arXiv:1110.1333, 1303.6857]

[arXiv:1303.6608, 1304.2882, 1304.1850]

[Phys. Rev. D 78, 094504 (2008)]

X states:

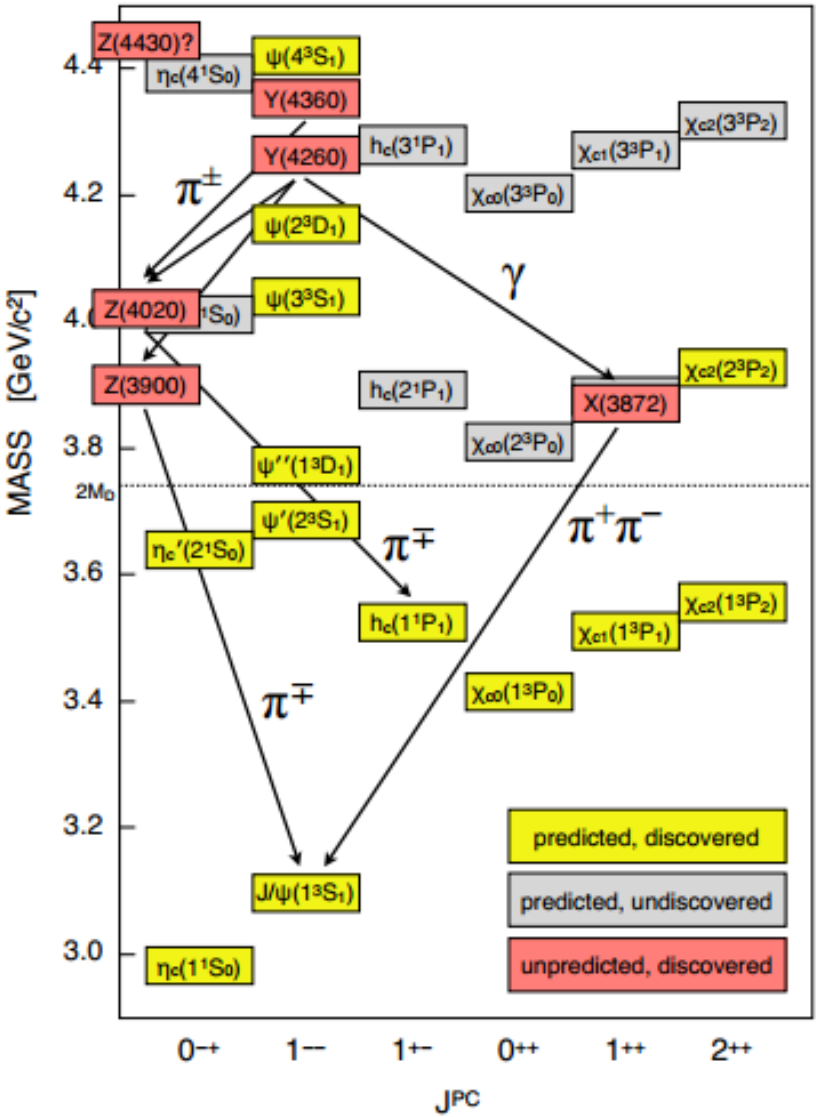
- ✓ Charmonium-like states with $J^{PC} \neq 1^{--}$.
- ✓ Observed in B decays, $p\bar{p}$ and pp collisions.

Y states:

- ✓ Charmonium-like states with $J^{PC} = 1^{--}$.
- ✓ Observed in direct e^+e^- annihilation or in ISR

Z states:

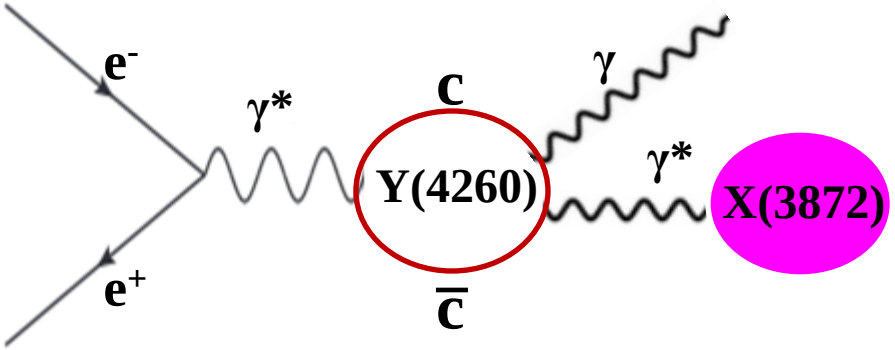
- ✓ Charmonium-like states.
- ✓ Must contain a charm-pair and a light quark-pair.

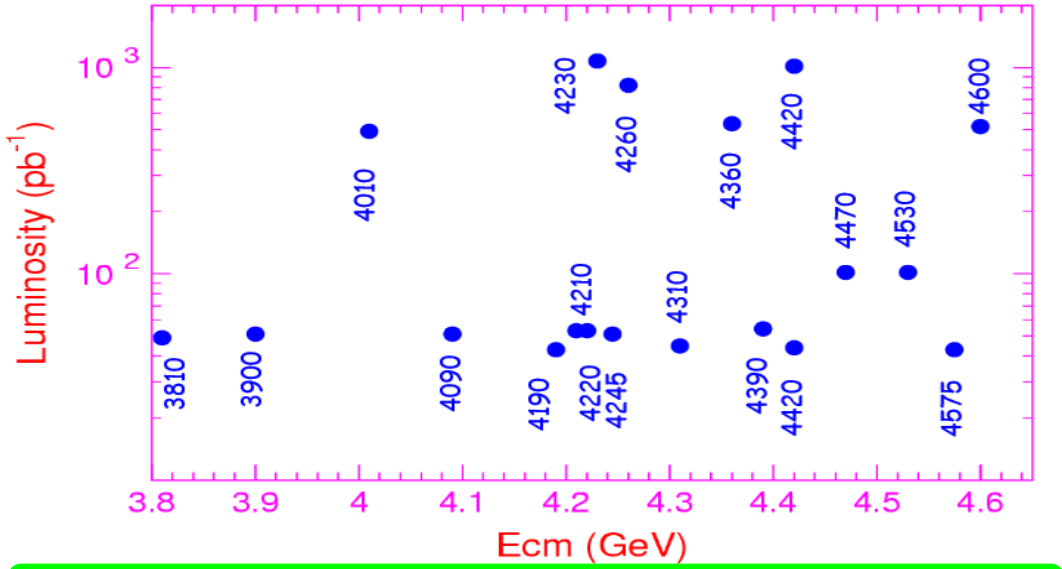


Motivation

- Radiative transition of the Y(4260) and Y(4360) to lower lying charmonium or charmonium-like state is important to study the features of XYZ states.

- This study is possible at BESIII experiment, which has collected a large amount of data at different center-of-mass (CM) energies above 3.8 GeV.





BESIII has collected around 4.6fb^{-1} data above 3.8 GeV during 2013-2014.

❖ **This talk includes the results of following analyses:**

✓ **Observation of $e^+e^-\to\gamma X(3872)$**

PRL 112, 092001 (2014)

✓ **Electronic width of X(3872)**

arXiv:1505.02559 (2015)

✓ **Search for Y(4140) via $e^+e^-\to\gamma\phi J/\psi$**

PRD 91, 032002 (2015)

✓ **Evidence for $e^+e^-\to\gamma\chi_{c1,2}$**

[arXiv:1411.6336 (2015)]

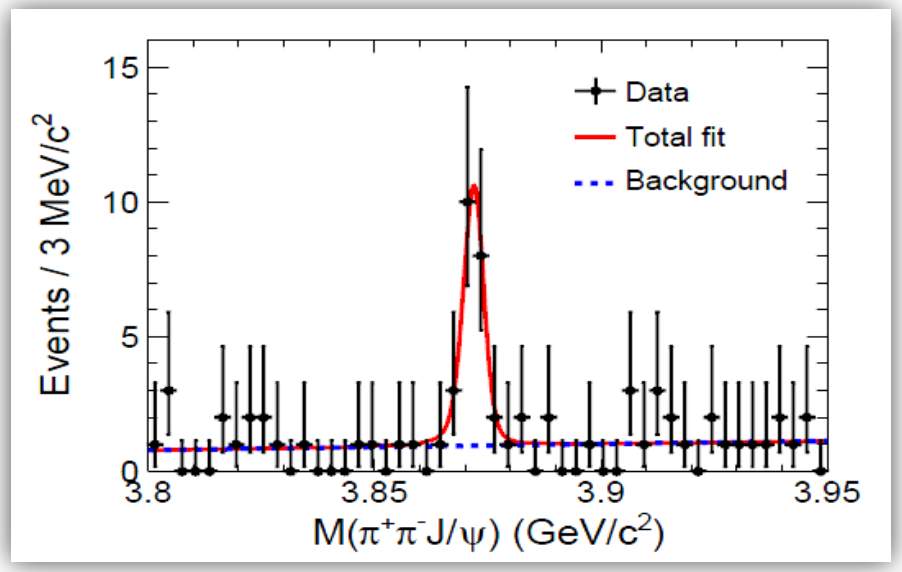
Observation of $e^+e^- \rightarrow \gamma X(3872)$

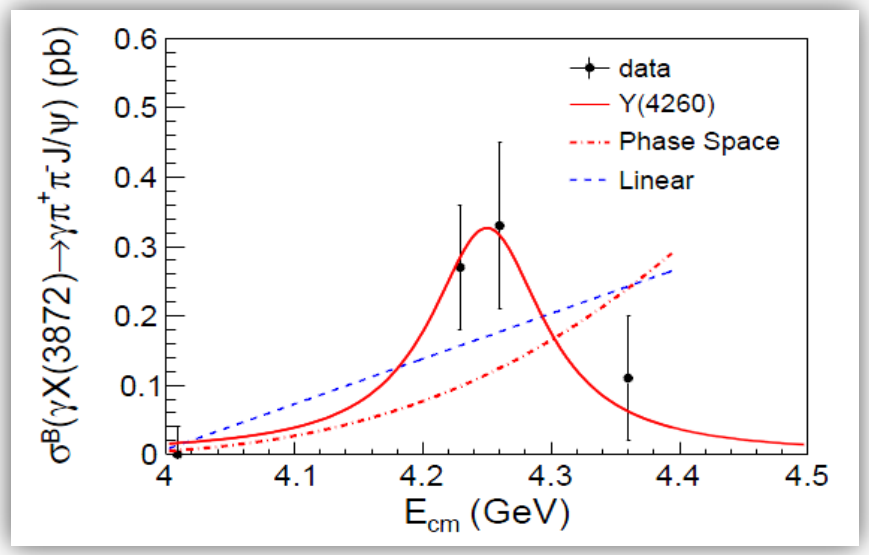
PRL 112, 092001 (2014)

- Perform a search for X(3872) with $X(3872) \rightarrow \pi^+\pi^- J/\psi$ using the data at the CM energies of 4.23 GeV, 4.26 GeV and 4.36 GeV.
- Summed over all the CM energies to perform the maximum likelihood (ML) fit.
- Maximum significance is observed to 6.3σ.

  $\mathbf{m_{X(3872)} = 3871.9 \pm 0.7 \pm 0.2\ MeV/c^2}$
- Observation supports the existence of the radiative transition of Y(4260) → γX(3872), but not very conclusive.
- If X(3832) decays from Y(4260):

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

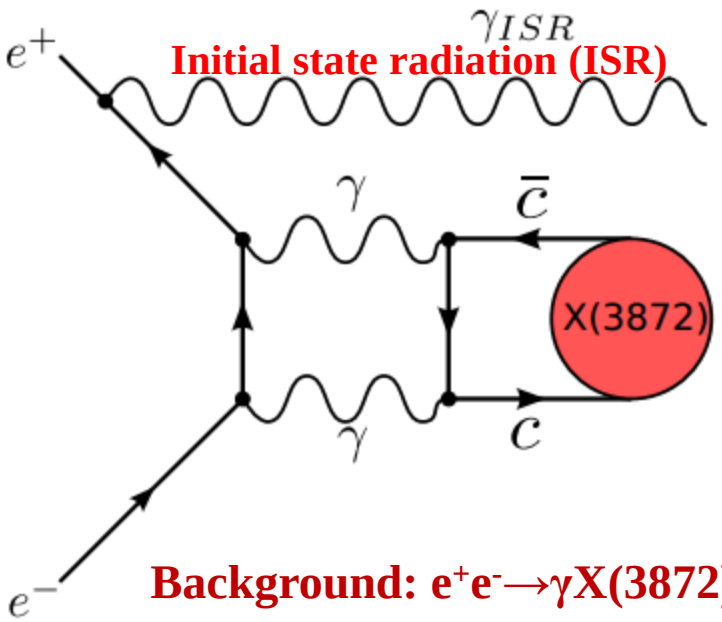




Electronic width of X(3872)

arXiv:1505.02559 (2015)

- Electronic width of X(3872) strongly depends on its substructure.
- Theoretical predictions are under construction.
- More precise value of electronic width may rule out some models for structure.
- Production via a two-photon box diagram.



Background: $e^+e^- \to \gamma X(3872)$

PRL 112, 092001 (2014)

- Decay mode:

$$e^+e^- \longrightarrow X(3872)\gamma_{ISR} \longrightarrow \pi^+\pi^- J/\psi\gamma_{ISR}$$
$$\longrightarrow \pi^+\pi^-\ell^+\ell^-\gamma_{ISR} \quad , \qquad \ell = \mu, e$$

- Absolute value of the cosine of ISR photon is required to be greater than 0.95 to avoid any background from radiative $e^+e^- \to \gamma X(3872)$.
- 2 constraint (2C) kinematic fit: $m_\gamma^{mis} = 0, \quad m_{l^+l^-} = m_{J/\psi}$
- Use the data at the CM energies of 4.009 GeV, 4.23 GeV, 4.26 GeV and 4.36 GeV.

Electronic width of X(3872)

arXiv:1505.02559 (2015)

- No significant peak of X(3872) is found at any of the four CM energies.
- Set an upper limit for the electronic width of X(3872).

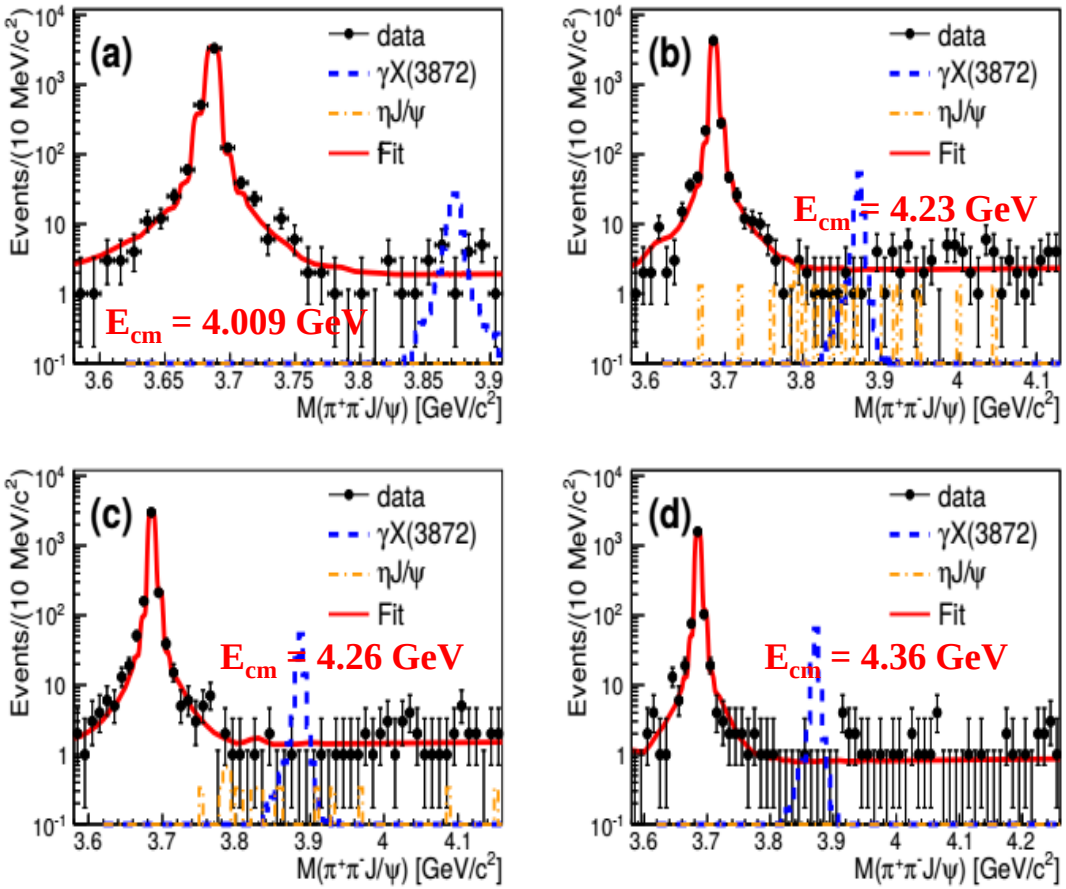
Calculation of Γ_{ee}

- The number of observed X(3872) is given by

$$\frac{dN_A^{obs}}{dx} = \mathcal{L}\varepsilon_A W(s,x)\sigma^A(m(s,x))\mathcal{B}(A \to f)$$

$$\Rightarrow N_A^{obs} = \varepsilon_A \mathcal{L}\Gamma_{ee}^A \mathcal{B}(A \to f) I_A$$

- for $A = X(3872), \psi(2S)$.
- ε_A is the reconstruction efficiency
- $I_A = \int b_A(m(s,x))W(s,x)dx \quad , \quad x = 1 - m^2/s$
- $W(s,x)$ is the radiator function
- $b_A(m)$ is the relativistic Breit-Wigner function over Γ_{ee}^A



[Rev. Mod. Phys. 83, 1545 (2011)]

Electronic width of X(3872)

arXiv:1505.02559 (2015)

Electronic width:

$$\Gamma_{ee}^{A}\mathcal{B}(A \to \pi^+\pi^- J/\psi) = \frac{N_A}{\varepsilon_A \mathcal{L}\, I_A \mathcal{B}(J/\psi \to \ell^+\ell^-)}$$

c.m. energy [GeV]	4.009	4.230	4.260	4.360
$\mathcal{L}$ [pb^{-1}]	482	1092	826	540
$I_{\psi(3686)}$ [pb/keV]	310	172	161	133
$I_{X(3872)}$ [pb/keV]	671	247	225	174
$\varepsilon_{\psi(3686)}$	0.303	0.286	0.286	0.282
$\varepsilon_{X(3872)}$	0.314	0.324	0.325	0.327
$N^{\psi(2S)}$	4168 ± 65	5026 ± 71	3547 ± 60	1846 ± 43
$\Gamma_{ee}^{\psi(3686)}$ [eV]	2198 ± 34	2232 ± 32	2223 ± 38	2176 ± 51
$\Gamma_{ee}^{X(3872)}\mathcal{B}(X(3872) \to \pi^+\pi^- J/\psi)$ at 90% C.L. [eV]	0.630	0.314	0.319	0.646

- Use a weighted average method to compute the final value of the electronic width of ψ(3686).

$$\Gamma_{ee}^{\psi(3686)} = 2213 \pm 18_{stat} \pm 99_{syst} \text{ eV}$$

- Combined all the likelihoods to X(3872) to compute the final value of $\Gamma_{ee}^{X(3872)}$

$$\Gamma_{ee}^{X(3872)} B(X(3872) \to \pi^+\pi^- J/\psi) < 0.13 \text{ eV at the 90\% C.L.}$$

This measurement improves upon the current existing limit 6.2 eV [Phys. Rev. D 71, 052001 (2005)] by a factor of 46.

Search for Y(4140) via $e^+e^- \to \gamma\phi J/\psi$

PRD 91, 032002 (2015)

Mystery of Y(4140):

- The CDF experiment first reported the evidence for a new state called Y(4140) in the decay process of $B^+ \to \phi J/\psi K^+$ [Phys. Rev Lett. **102**, 242002 (2009); arXiv:1101.6058].
- Belle experiment has reported null results in the same decay process and two photon production [Phys. Rev Lett. **104**, 112004 (2010)].
- LHCb has also reported negative results for the decay process of $B^+ \to \phi J/\psi K^+$ [Phys. Rev D **85**, 091103 (2012)].
- CMS and D0 collaborations have recently confirmed the observation CDF experiment in the same decay process [Phys. Lett. B 734, 261 (2014), Phys. Rev D **89**, 0912004 (2014)].
- BaBar has also investigated the same decay mode and found no evidence of Y(4140) production [Phys. Rev D 91, 012003 (2012)].

This particle is considered to be a good candidate for $D_s^* \overline{D_s^*}$ molecular.

[Phys. Rev D **80**, 05409 (2009)]

Search for Y(4140) via $e^+e^-\to\gamma\phi J/\psi$

PRD 91, 032002 (2015)

Event selection for $e^+e^-\to\gamma\phi J/\psi$; $J/\psi\to e^+e^-/\mu^+\mu^-$

- **For $\phi\to K^+K^-$**

  Partial reconstruction, only one K is required to be reconstructed.

- **For $\phi \to K_L^0 K_S^0$**

  Partial reconstruction, only K_S is required to be reconstructed, but K_L is considered as a missing track

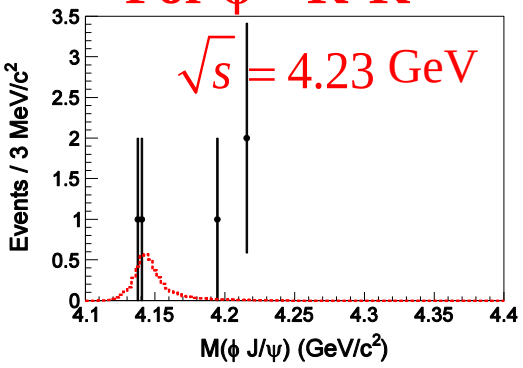
- **For $\phi\to\pi^+\pi^-\pi^0$**

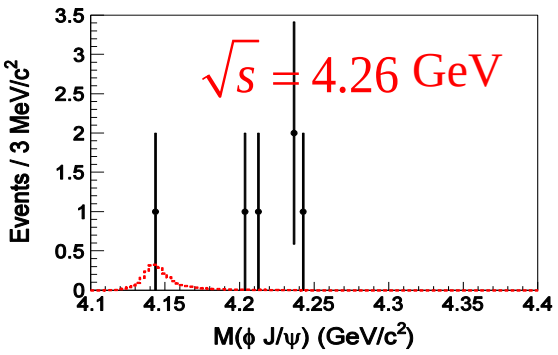
  Fully reconstructed the decay process.

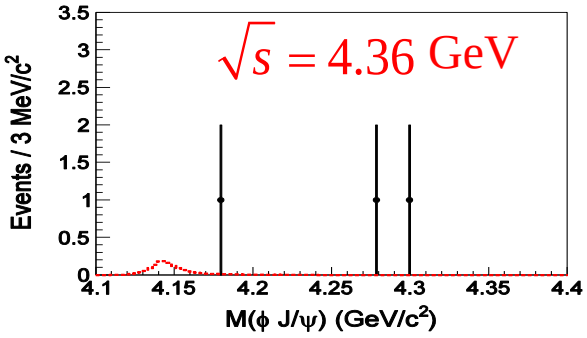
Search for Y(4140) via $e^+e^- \to \gamma\phi J/\psi$

PRD 91, 032002 (2015)

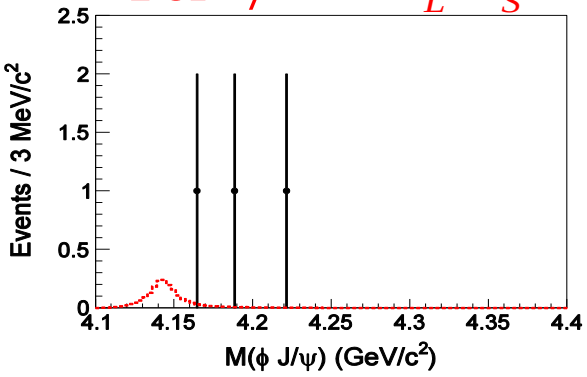
For $\phi \to K^+K^-$

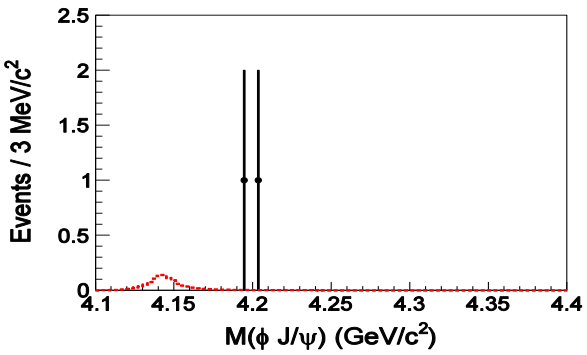


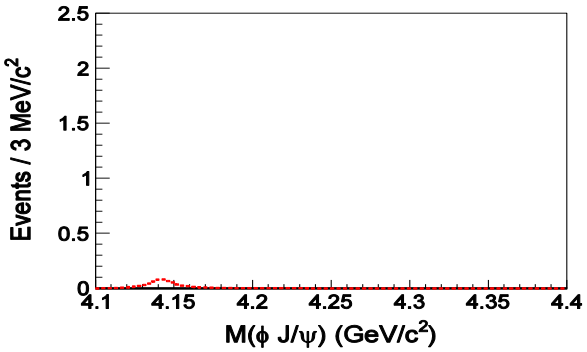




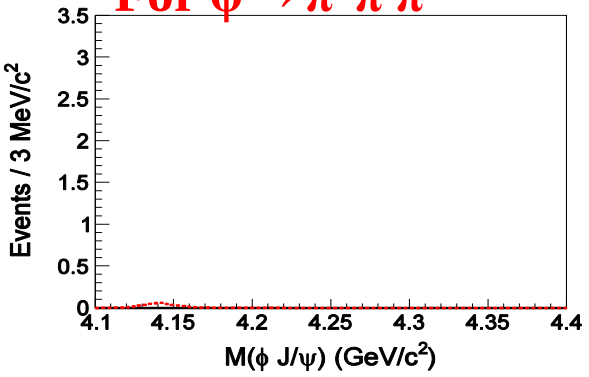
For $\phi \to K_L^0 K_S^0$

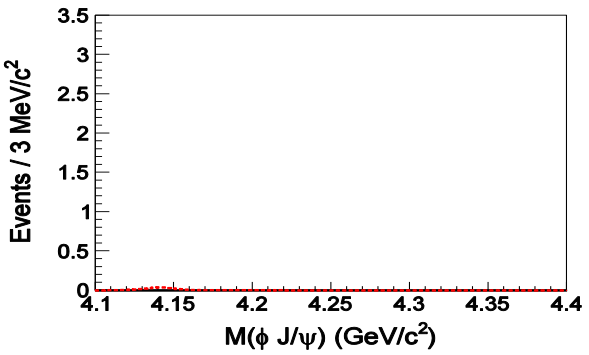


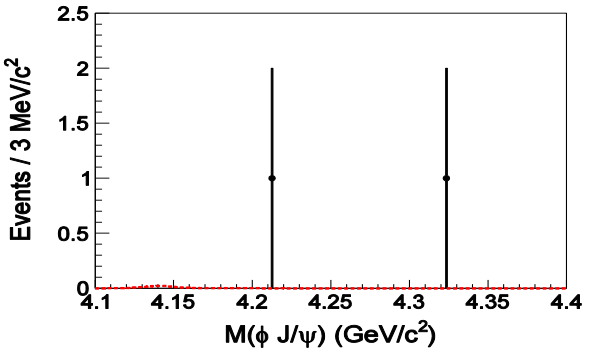




For $\phi \to \pi^+\pi^-\pi^0$



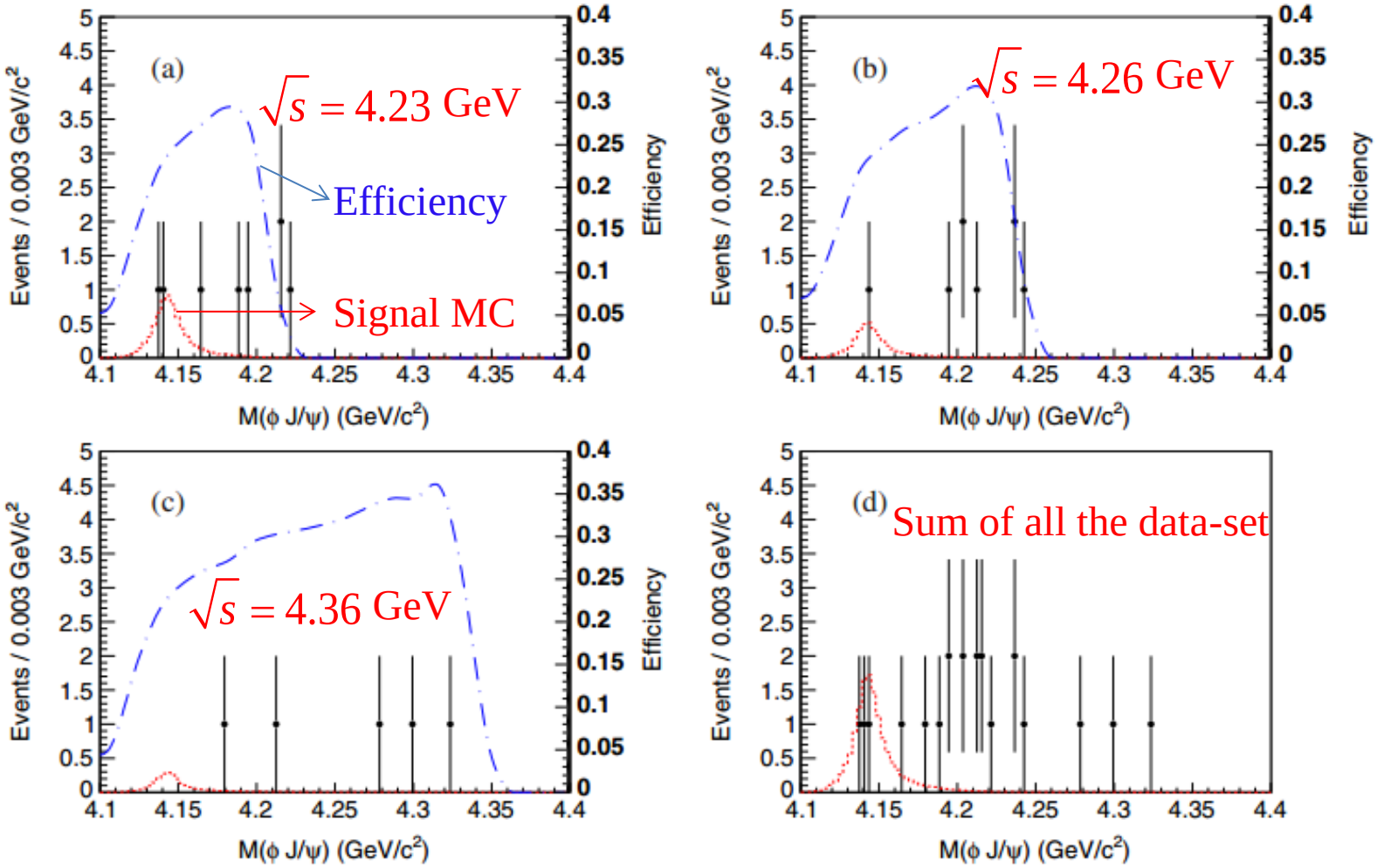




Search for Y(4140) via $e^+e^- \to \gamma\phi J/\psi$

PRD 91, 032002 (2015)

Combine 6 modes (3 ϕ modes $\otimes$ 2 J/ψ modes)



Search for Y(4140) via $e^+e^- \to \gamma\phi J/\psi$

PRD 91, 032002 (2015)

- No evidence of Y(4140) signal is found in any of the three CM energies.
- Set the 90% C.L. upper limit for $\sigma^B \cdot \mathcal{B} = \sigma(e^+e^- \to \gamma Y(4140)) \cdot \mathcal{B}(Y(4140) \to \phi J/\psi)$.

$\sqrt{s}$ (GeV)	Luminosity (pb^{-1})	$(1+\delta)$	n^{prod}	$\sigma^B \cdot \mathcal{B}$ (pb)
4.23	1094	0.840	< 339	< 0.35
4.26	827	0.847	< 207	< 0.28
4.36	545	0.944	< 179	< 0.33

Where, $(1+\delta)$ is the radiative correction obtained from the QED calculation.

[Yad. Fiz. **41**, 733 (1985)]

The upper limits can be compared with the X(3872) production rate

$\sigma^B(e^+e^- \to \gamma X(3872)) \times \mathcal{B}(X(3872) \to \pi^+\pi^- J/\psi)$ PRL 112, 092001 (2014)

Take $\mathcal{B}(X(3872) \to \pi^+\pi^- J/\psi)$ = 5%. arXiv: 0910.3138

And $\mathcal{B}(Y(4140) \to \phi J/\psi)$ = 30%, molecular calculation, PRD 80, 054019.

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

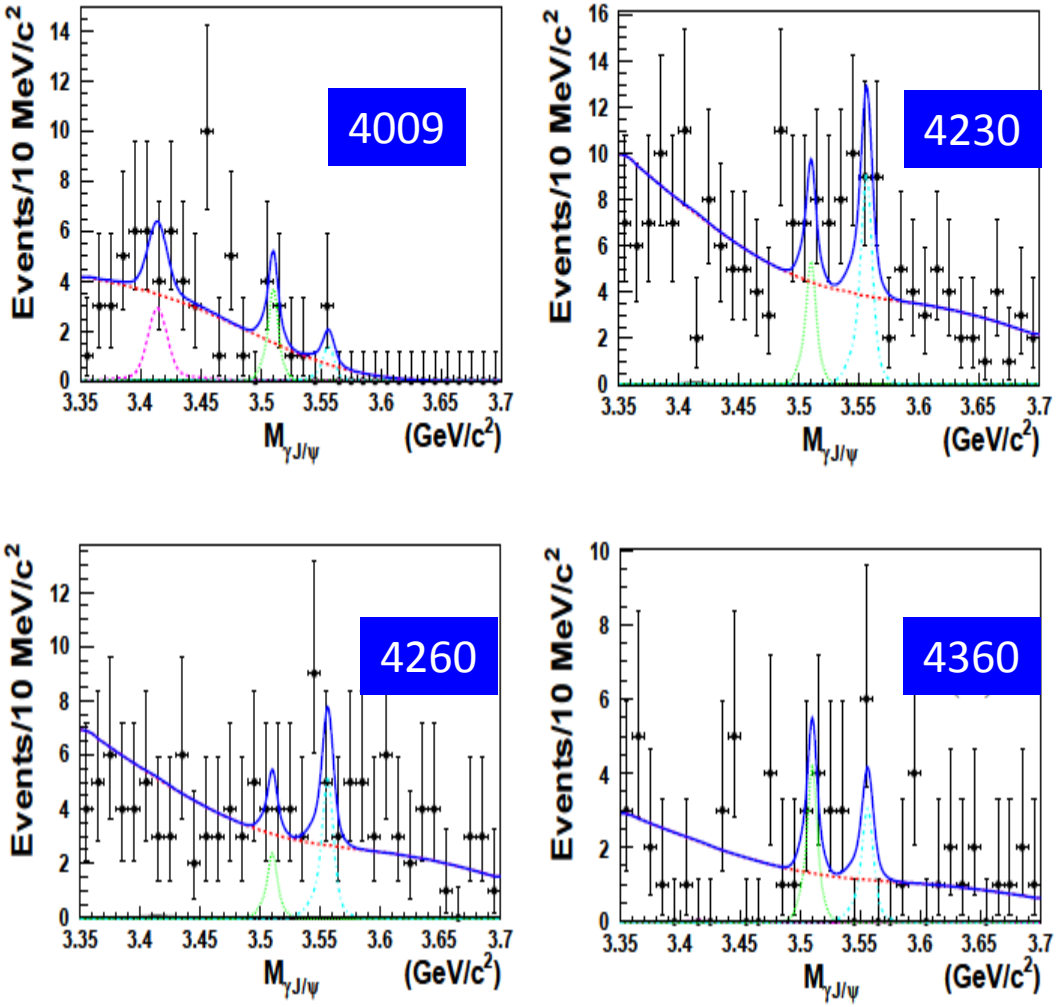
Evidence for $e^+e^- \to \gamma\chi_{c1,2}$

[arXiv:1411.6336 (2015)]

- Reconstruct the χ_{cJ} by its $\gamma J/\psi$ decay mode, where J/ψ decays to $\mu^+\mu^-$ in the final state.
- Perform a 5C kinematic fit with two charged track and two photon candidates with a constraint that the di-muon invariant mass distribution must peak at J/ψ mass position.
- Perform the ML fit to the $M_{\gamma J/\psi}$ distribution to extract the signal events.

Signal: a double-Gaussian with shape parameters determined from MC at 4260 MeV

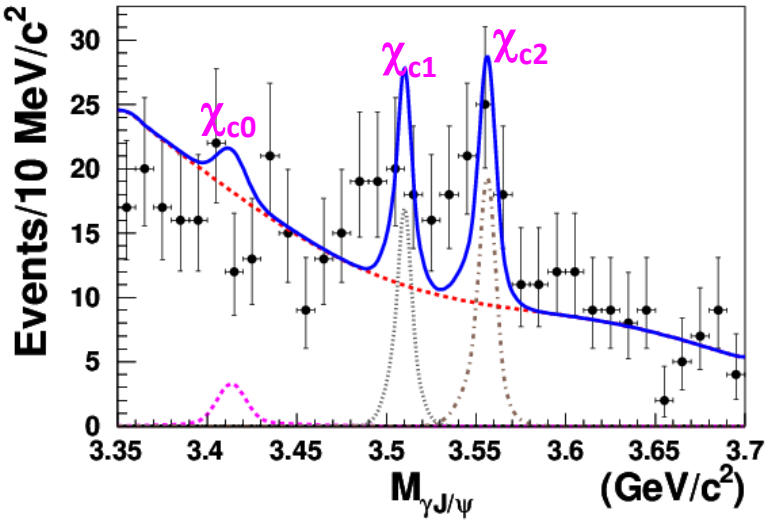
Background: radiative dimu MC shape



Evidence for $e^+e^- \to \gamma\chi_{c1,2}$

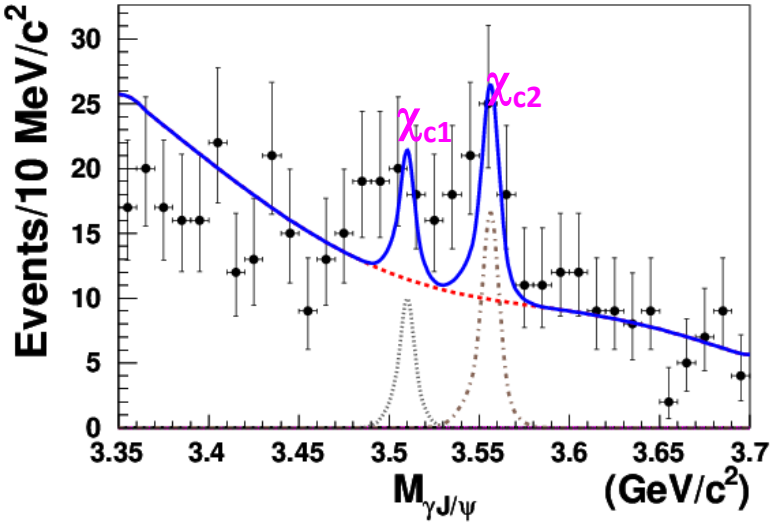
[arXiv:1411.6336 (2015)]

- Perform the ML fit after combining all the four CM energies of data



The statistical significance values are observed to **1.2σ, 3.0σ, 3.4σ** *for* χ_{c0}, χ_{c1} and χ_{c2} resonances, respectively.

A simultaneous fit to M(γJ/ψ) at 4 CM energy points *with* *assuming the production $\sigma(e^+e^- \to \gamma\chi_{cJ})$ at different $\sqrt{s}$ follows the lineshape of Y(4260)*



The statistical significance values are observed to 0σ, **2.4σ, 4.0σ** *for* χ_{c0}, χ_{c1} and χ_{c2} resonances, respectively.

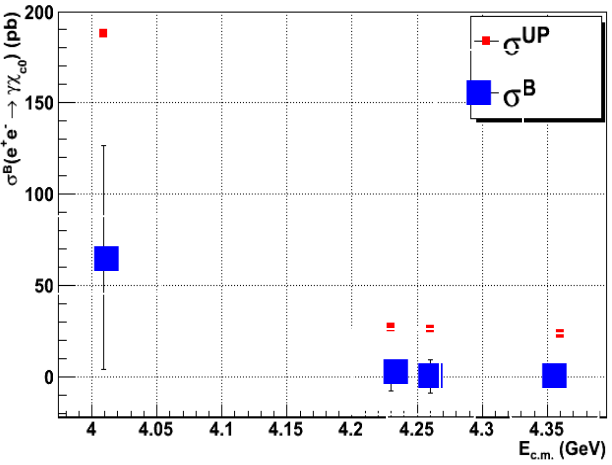
Evidence for $e^+e^- \to \gamma\chi_{c1,2}$

[arXiv:1411.6336 (2015)]

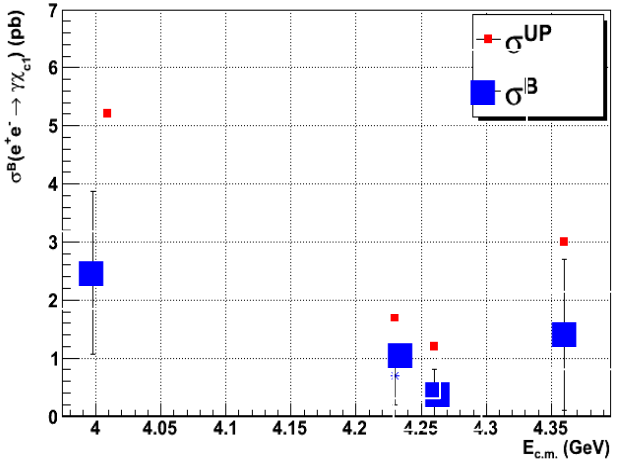
The measured Born corss-section

$\sigma(e^+e^- \to \gamma\chi_{cJ})$

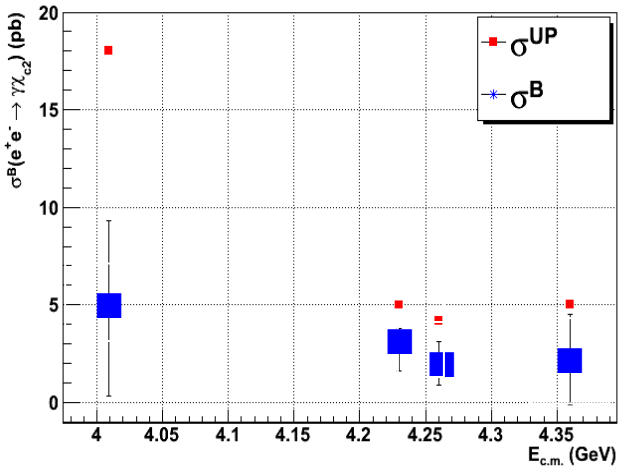
$e^+e^- \to \gamma\chi_{c0}$



$e^+e^- \to \gamma\chi_{c1}$



$e^+e^- \to \gamma\chi_{c2}$



The upper limits on the cross section of $e^+e^- \to \gamma\chi_{cJ}$ are compatible with the theoretical predication. [arXiv:1310.8597]

Summary

- BESIII has observed the process of $e^+e^-\to\gamma X(3872)$ first time with a statistical significance of 6.3σ for $\sqrt{s} > 4$ GeV. The measurements are consistent with the expectation for the raditive transition process of $Y(4260)\to\gamma X(3872)$.

- An improved 90% C.L. upper limit for the electronic width times the branching fraction of $\Gamma_{ee}^{X(3872)} B(X(3872) \to \pi^+\pi^- J/\psi)$ is observed to be 0.13 eV, which is 46 times better than previous measurements.

- No evidence of Y(4140) is found in the decay process of $e^+e^-\to\gamma\phi J/\psi$.

- We find the evidence for $e^+e^-\to\gamma\chi_{c1}$ and $e^+e^-\to\gamma\chi_{c2}$ with statistical significance of 3.0 and 3.4σ, respectively for $\sqrt{s} > 4$ GeV.

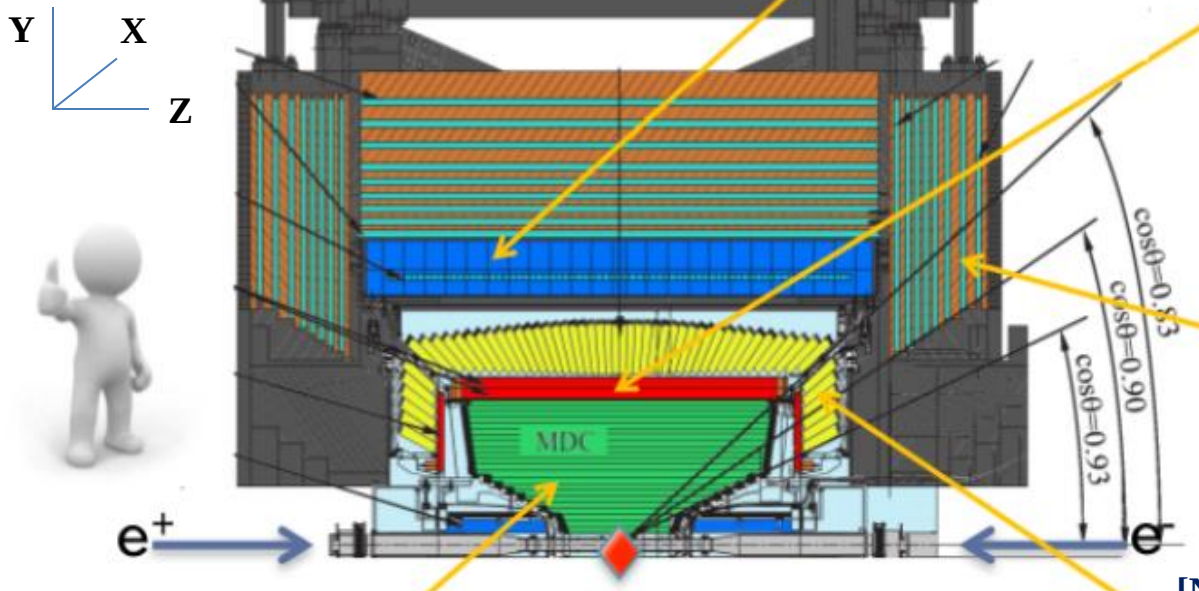
- We are still analyzing the data and looking forward to produce more exciting results in near future.

Thank you!

Back up Slide

BESIII Experiment

BESIII experiment is a symmetric electron positron collider experiment running as tau-charm region located at Institute of High Energy Physics, Beijing, China



Super conducting magnet

✓ **1 Tesla**

Time of Flight (TOF)

- **2 layer plastic scintillators**
- **Time resolution σ_T = 100 ps**
- **Particle id**

Muon system

- **9 layer RPC**

[Nucl. Instrum. Meth. A614, 345-399 (2010)]

Multilayer drift chamber (MDC)

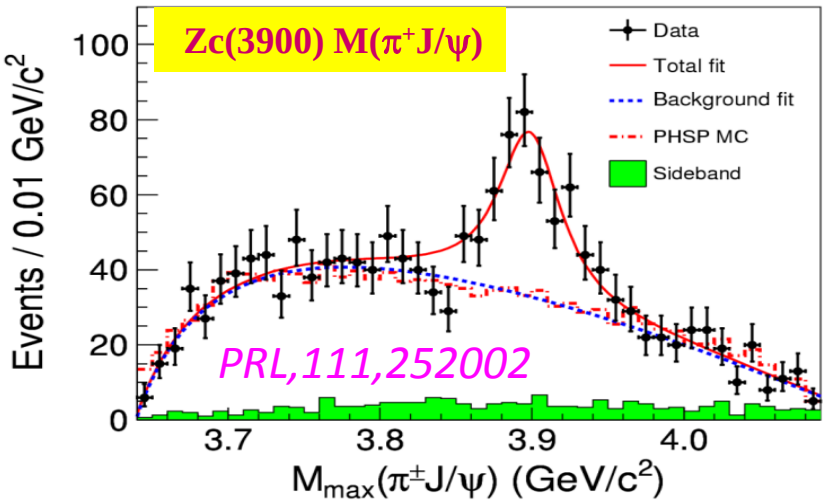
- **He/C_3H_8 (60/40)**
- **43 layers**
- **Momentum resolution σp/p = 0.5% @ 1 GeV**
- **Spatial resolution σ_{xy} = 130 μm.**

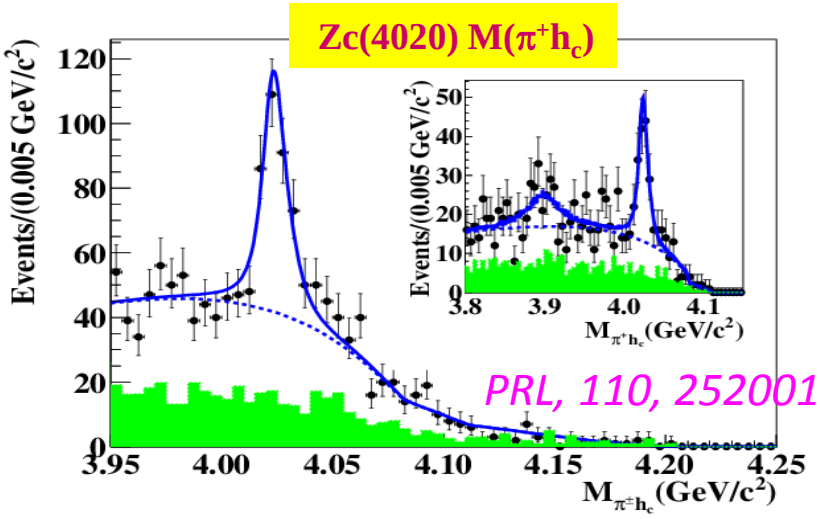
Electromagnetic calorimeter (EMC) (CsI(Tl))

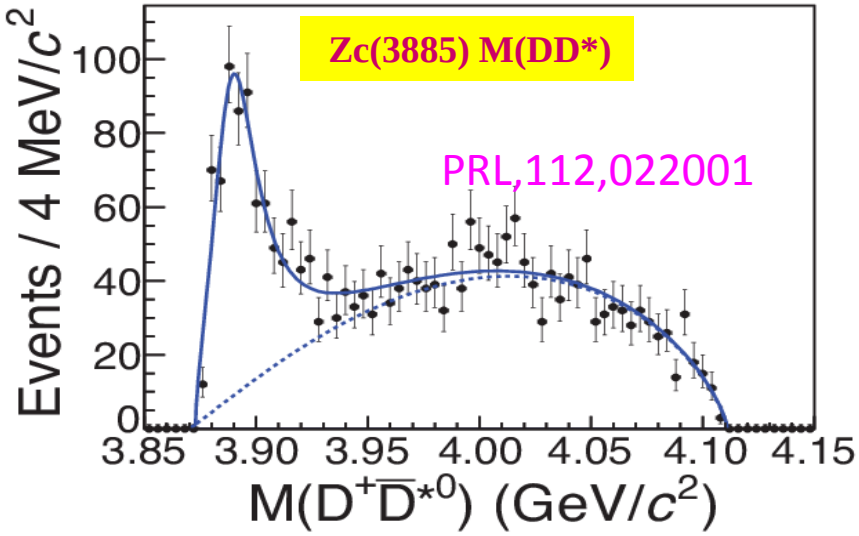
- **Barrel: 44 rings (θ_{index}) with 120 crystals**
- **Endcaps consists of 6 rings**

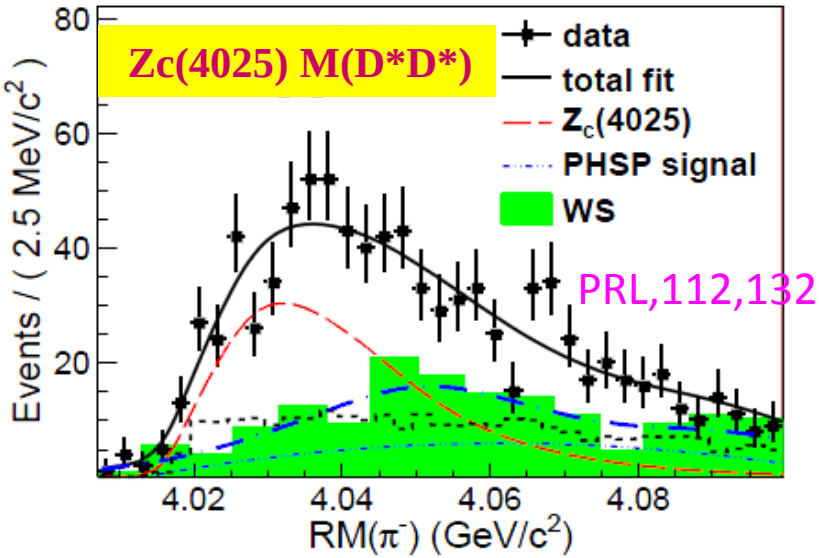
→ 6240 crystals overall

Some of the important BESIII results

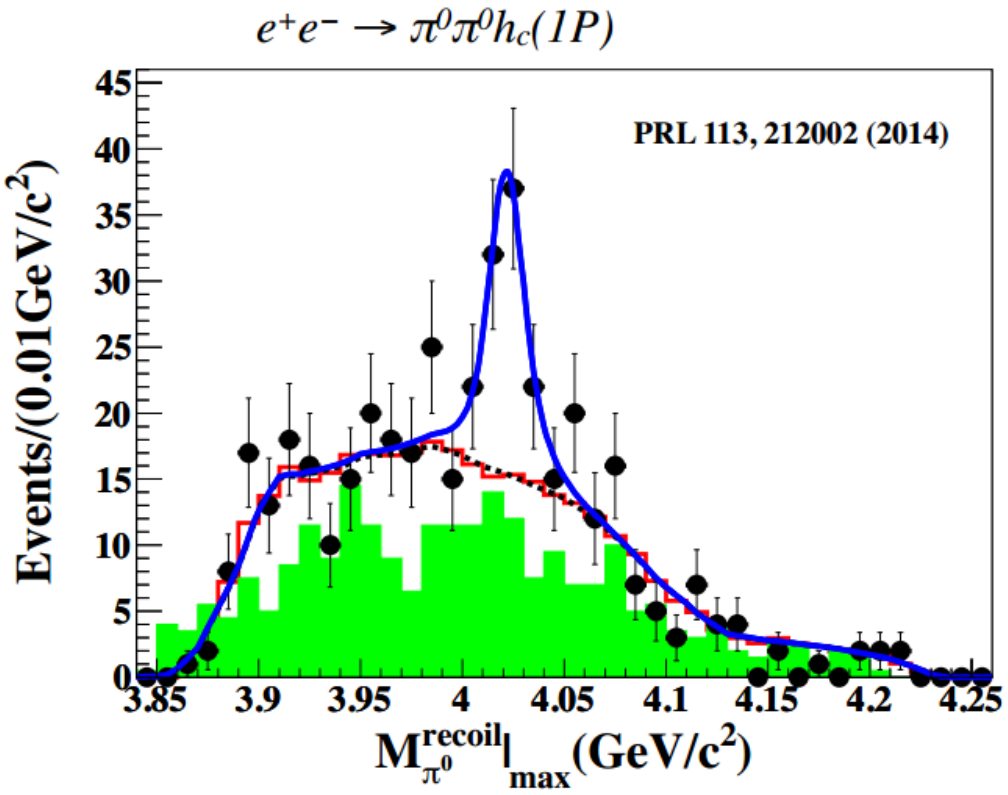








Some of the important BESIII results



$M = 4023.9 \pm 2.2 \pm 3.8$ MeV/c²

width fixed to the charged $Z_c'(4020)$

significance > 5σ