XYZ PHYSICS AT BESIII

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FOR BESIII COLLABORATION

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OUTLINE

- **Introduction**

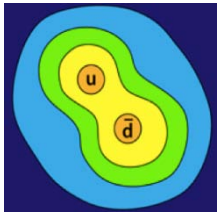
  Hadrons, XYZ states

- **XYZ Physics at BESIII**
  - **BESIII data samples for XYZ study**
  - **The XYZ states**
    I. X(3872), X(3823)
    II. Abundant structures above 4GeV
    III. $Z_c(3900)/Z_c(3885)$, $Z_c(4020)/Z_c(4025)$
- **Summary**

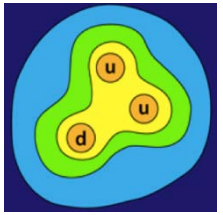
HADRONS

- **Quark Model**
  - 2 quarks for Meson
  - 3 quarks for Baryon

Meson



Baryon

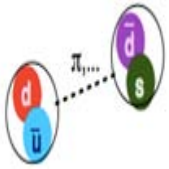


- **QCD allow hadrons with $N_{quark} \neq 2,3$**
  - Glueball: $N_{quarks} = 0$ (gg, ggg, …)
  - Hybrid: $N_{quarks} = 2$ (qqbar + gluon)
  - Molecule: bound state of more than 2 hadrons
  - Mutiquark state: $N_{quarks} > 3$
  - …

Glueball

Hybrid

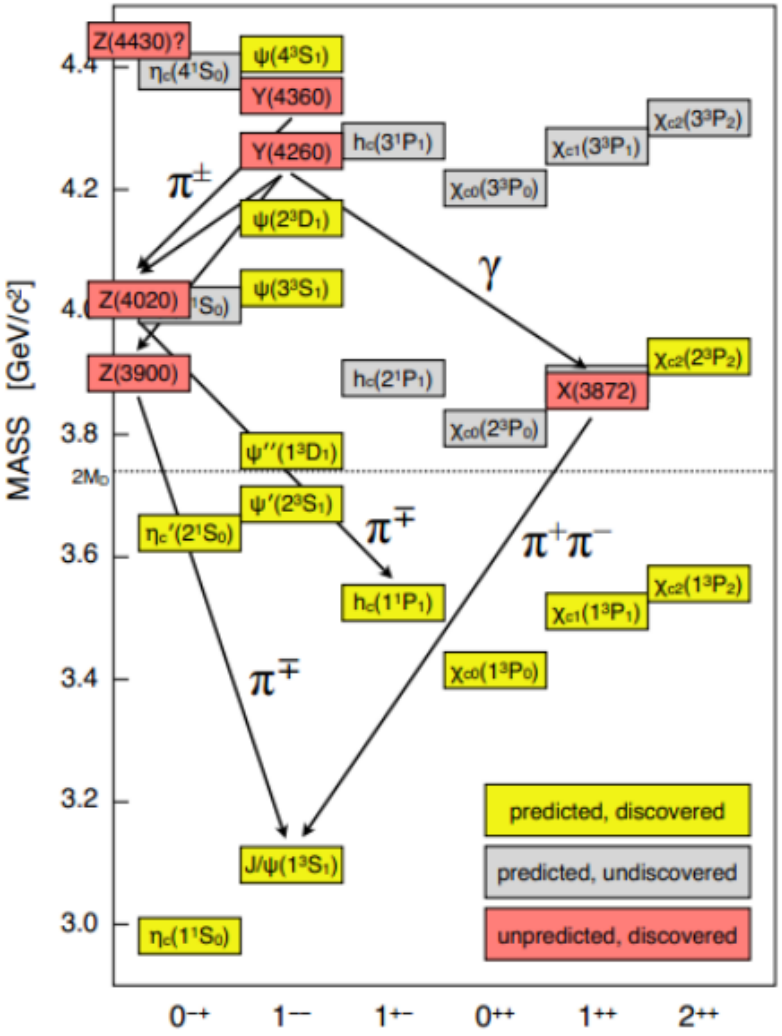
Molecule



Mutiquark

arXiv:1403.1254, S. Olsen

CHARMONIUM AND XYZ



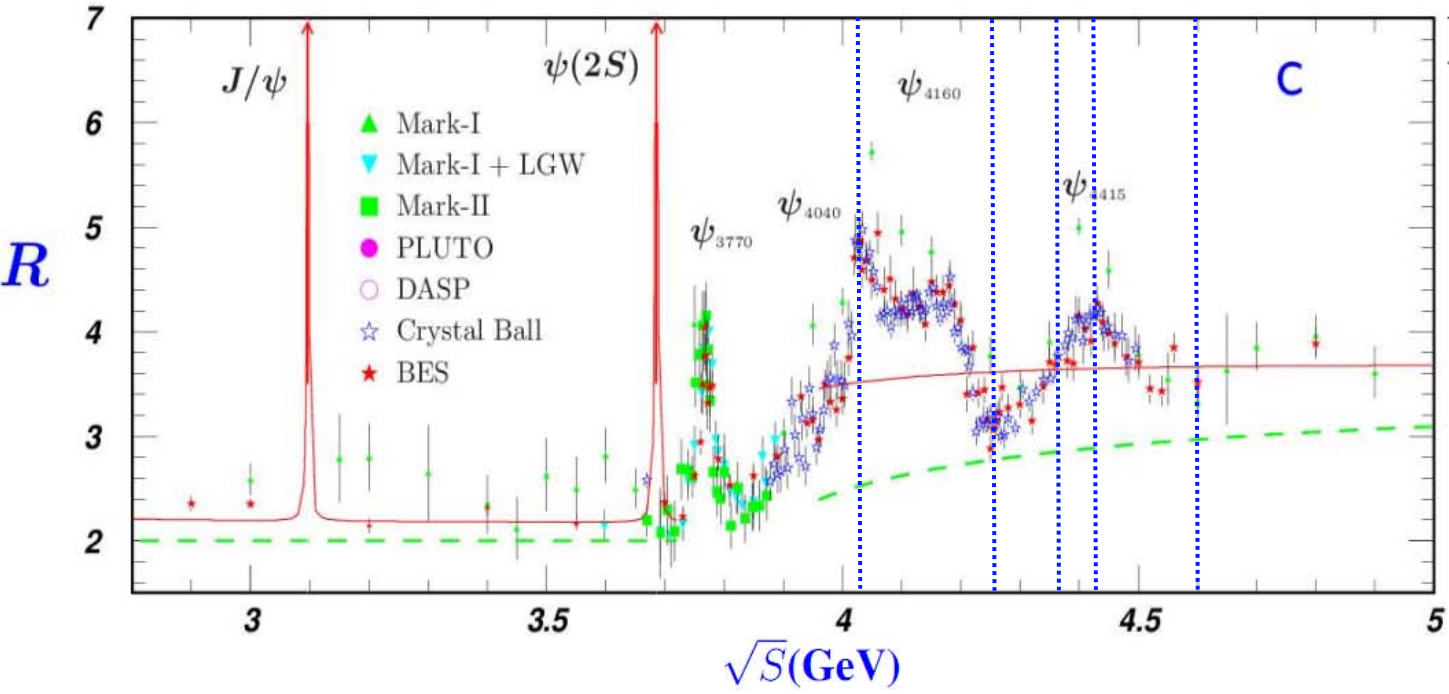
- **Below open-charm threshold:**

  Good agreement between discovery and theoretical prediction.

- **Above open-charm threshold:**

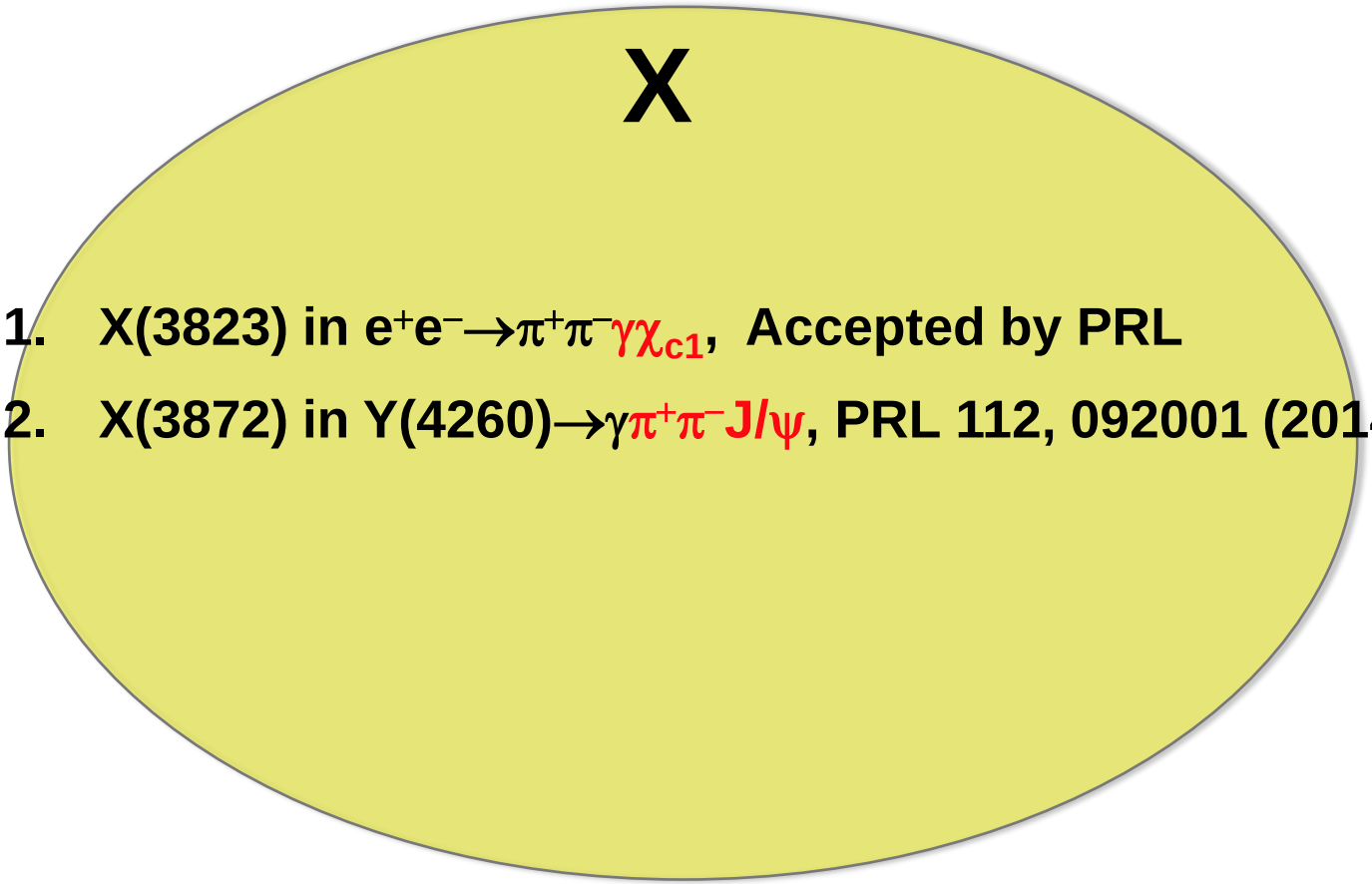
  A series of new states with charmonium in final states, but not conventional charmonium states (called charmonium-like or XYZ).

DATA SAMPLES FOR XYZ STUDY



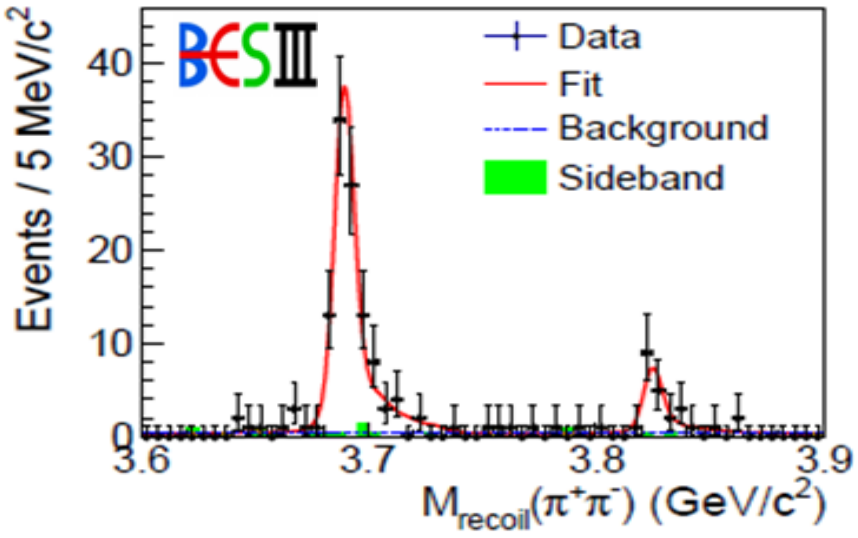
CM energy (GeV)	L (pb^{-1})
3.81	50.54±0.03
3.90	52.61±0.03
4.009	481.96±0.01
4.09	52.63±0.03
4.19	43.09±0.03
4.21	54.55±0.03
4.22	54.13±0.03
4.23^1	44.40±0.03
4.23^2	1047.34±0.14
4.245	55.59±0.04
4.26^1	523.74±0.10
4.26^2	301.93±0.08
4.31	44.90±0.03
4.36	539.84±0.10
4.39	55.18±0.04
4.42^1	44.67±0.03
4.42^2	1028.89±0.13
4.47	109.94±0.04
4.53	109.98±0.04
4.575	47.67±0.03
4.60	566.93±0.11

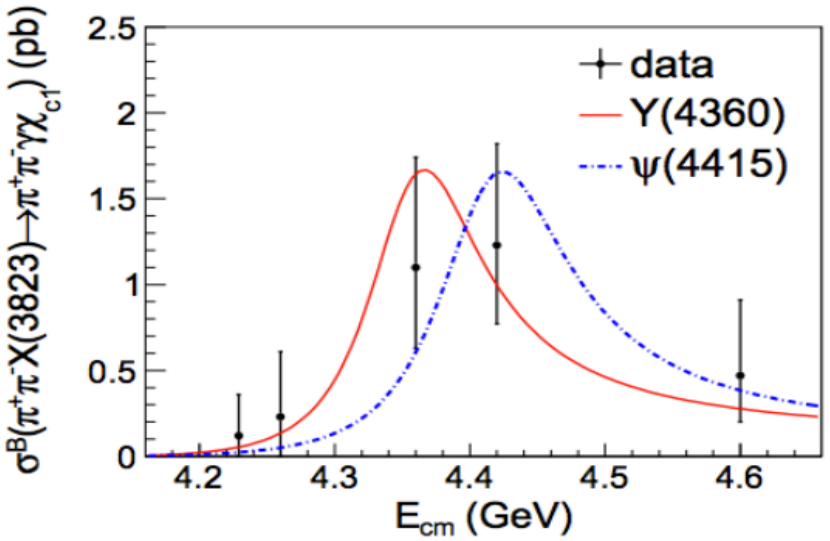
- **Luminosity ~ 5/fb.**
- **Huge data samples around ψ(4040), Y(4260), Y(4360), ψ(4415) and Y(4660).**


X
1. X(3823) in $e^+e^-\to\pi^+\pi^-\gamma\chi_{c1}$, Accepted by PRL
2. X(3872) in Y(4260)$\to\gamma\pi^+\pi^-J/\psi$, PRL 112, 092001 (2014)

X(3823)

arXiv:1503.08203, Accept ed by PRL

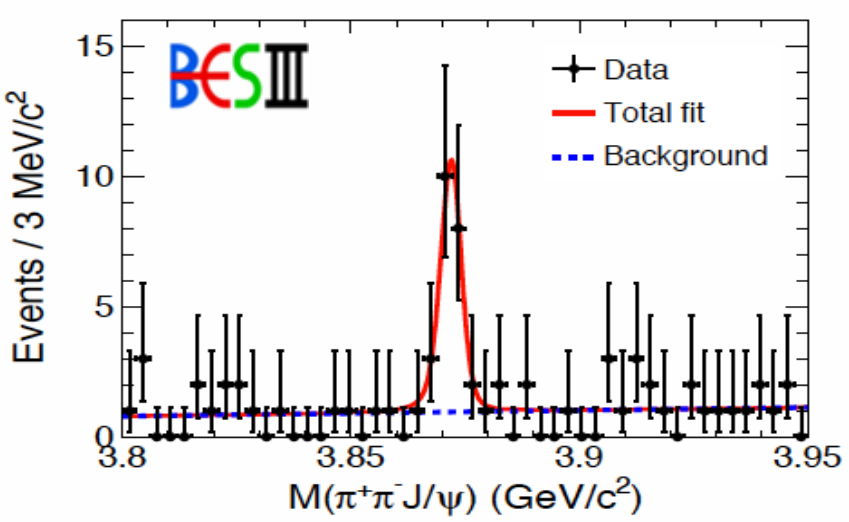


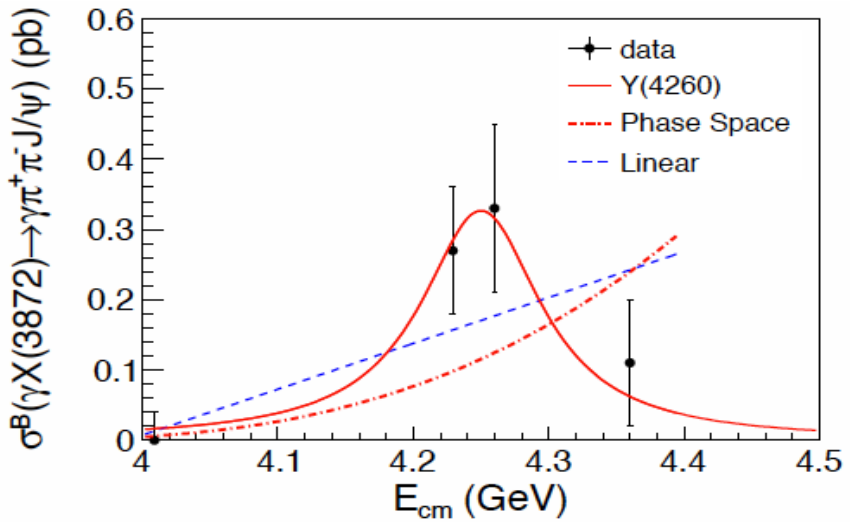


- **Potential model: $1^3D_2 \rightarrow \gamma\chi_{c1},\gamma\chi_{c2}$ with large width.**
- **M = 3821.7 ± 1.3 ± 0.7 MeV, Γ < 16 MeV, Significance: 6.2σ!**
- **Good candidate of $\psi(1^3D_2)$**
- **Both Y(4360) and ψ(4415) line shape give reasonable description.**

X(3872)

PRL 112, 092001 (2014)





- **M = 3871.9±0.7±0.2 MeV, Γ < 2.4 MeV, Significance: 6.3σ**
- **Radiative transition process Y(4260)→γX(3872), a new Y(4260) decay mode, new X(3872) production mode.**

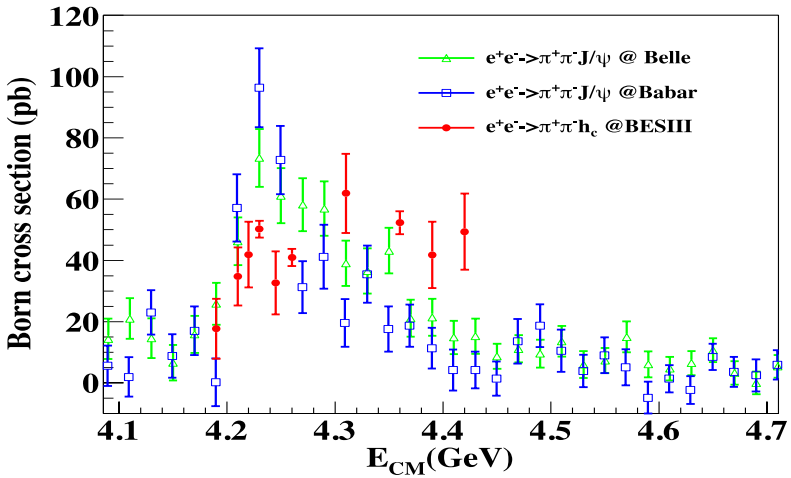
If we take $\mathcal{B}(X(3872) \to \pi^+\pi^- J/\psi) \sim 5\%$, (>2.6% in PDG)

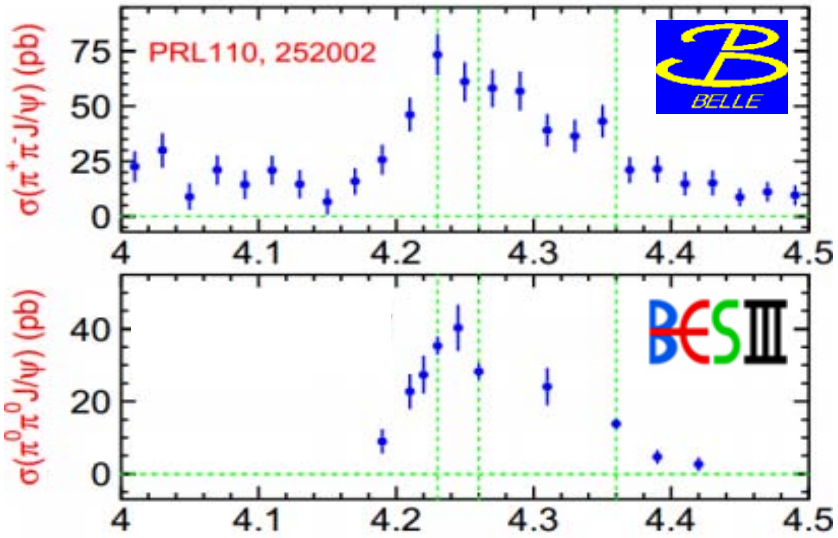
$\frac{\sigma(e^+e^- \to \gamma X(3872))}{\sigma(e^+e^- \to \pi^+\pi^- J/\psi)} \sim 11.2\%$ Large transition ratio !

Y

1. Cross section of $e^+e^- \to \pi\pi J/\psi(h_c)$, PRL 110, 252001
2. Cross section of $e^+e^- \to \omega\chi_{c0}$, PRL 114, 092003 (2015)
3. Cross section $e^+e^- \to \eta J/\psi$, PRD 91, 112005 (2015)
4. Cross section $e^+e^- \to \eta' J/\psi$, Preliminary

$e^+e^- \to \pi\pi J/\psi(h_c)$

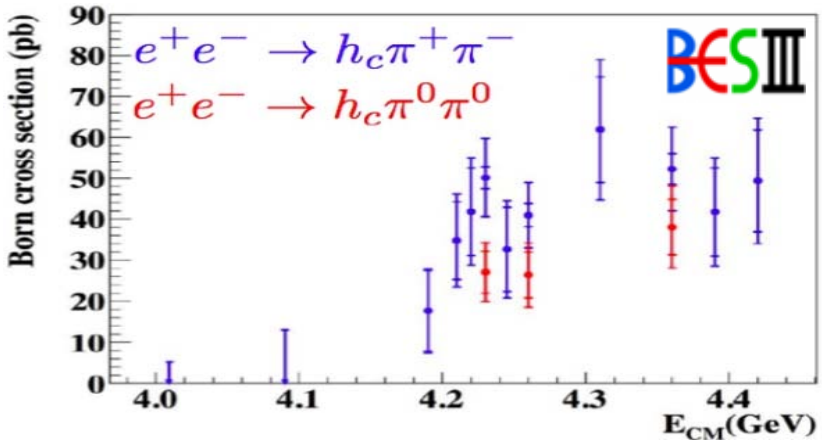




[$\sigma(\pi^0\pi^0 J/\psi)$: arXiv: 1506.06018]

[$\sigma(\pi^+\pi^- h_c)$: PRL 111, 242001 (2013)]

[$\sigma(\pi^0\pi^0 h_c)$: PRL 113, 212002 (2014)]



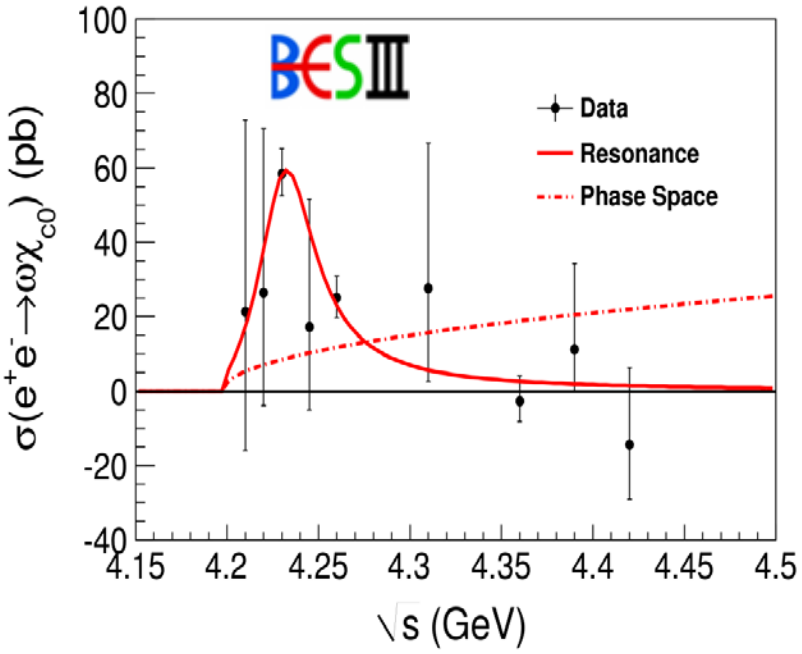
◆ $\sigma(\pi^+\pi^- h_c) \sim \sigma(\pi^+\pi^- J/\psi)$, but different line-shape !

A possible structure near 4.23 GeV for $\sigma(\pi^+\pi^- h_c)$.

◆ The ratio of cross section for $e^+e^- \to \pi\pi h_c$ between neutral and charged mode, $R_{\pi\pi hc} = 0.63 \pm 0.09$; And comparing the cross section for $e^+e^- \to \pi^0\pi^0/\psi$ and $e^+e^- \to \pi^+\pi^-/\psi$, no large iso-spin violation in $\sigma(\pi\pi h_c)$ and $\sigma(\pi\pi J/\psi)$!

Observation of $e^+e^- \to \omega\chi_{c0}$

PRL 114, 092003 (2015)



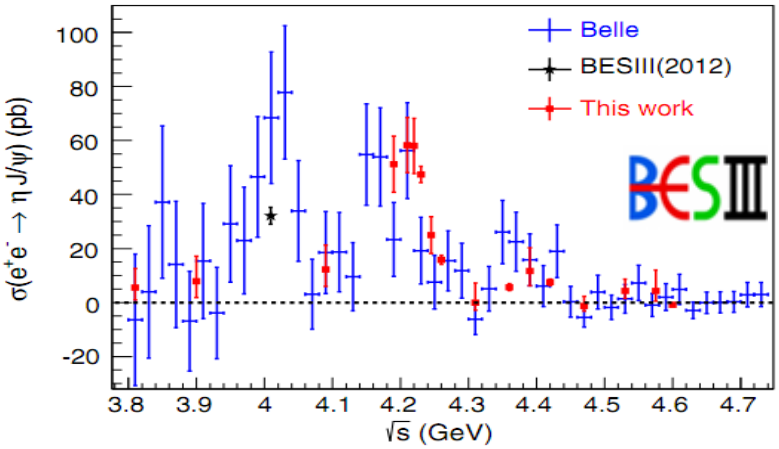
- **Cross section peak near 4.23 GeV**
- **Assuming the $\omega\chi_{c0}$ signals come from a resonance, fitting with BW yields:**
  - M = 4230±8±6 MeV, Γ = 38±12±2 MeV
  - Γ_{ee} . B($\omega\chi_{c0}$) = 2.9±0.7±0.4 eV

Note for this structure:

- ✓ **A tetraquark? (PRD 91,117501(2015))**
- ✓ **ψ(4S)? (EPJC 74:3208 (2014))**
- ✓ **Threshold effect?**
- ✓ **…**

Observation of $e^+e^- \to \eta J/\psi$

PRD 91, 112005 (2015)

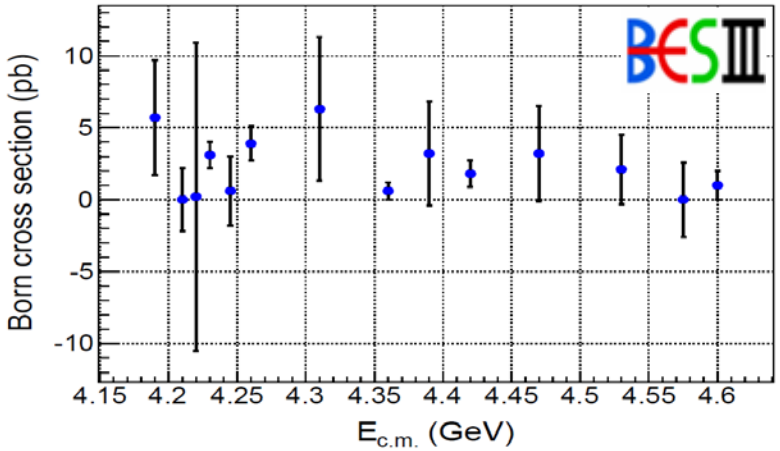


- **Agree with previous results, more precision**
- **Structure near 4.23 GeV**

  More data 4.10~4.20 GeV is needed!

Observation of $e^+e^- \to \eta' J/\psi$

BESIII Preliminary

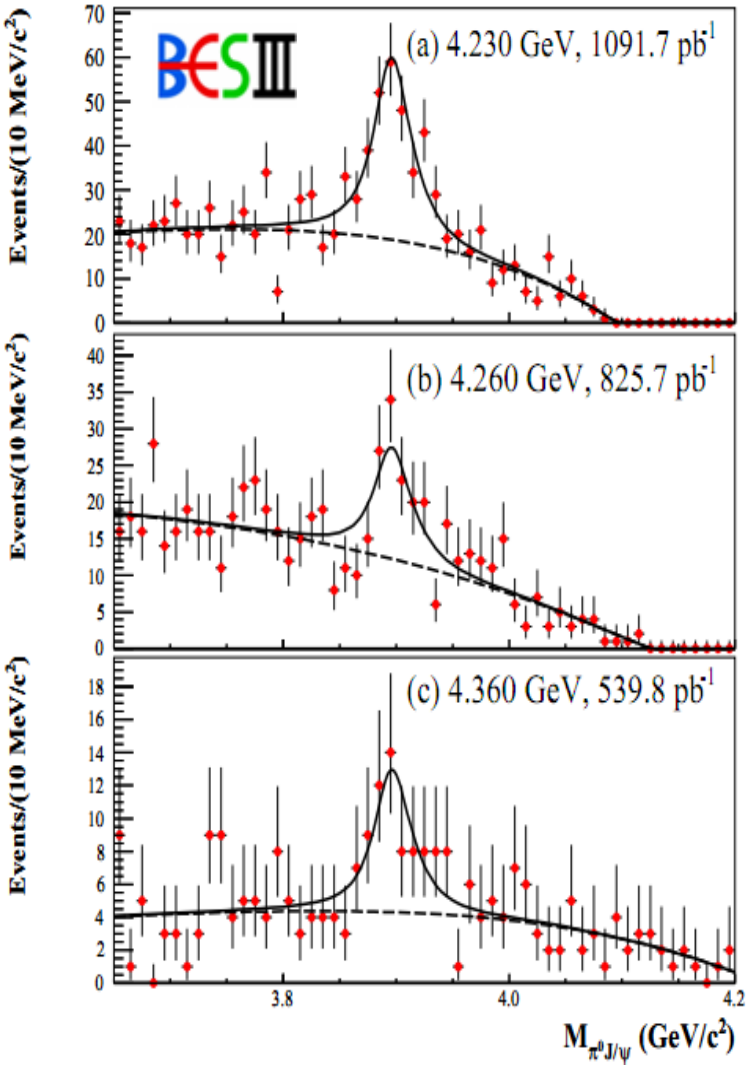


- **First observation at $\sqrt{s}$ = 4.23 & 4.26 GeV, cannot tell the line-shape due to statistics.**
- **$\sigma(\eta' J/\psi)$ is much lower than $\sigma(\eta J/\psi)$, in contradiction to the calculation in the framework of NRQCD (PRD 89, 074006 (2014)).**

Z_c

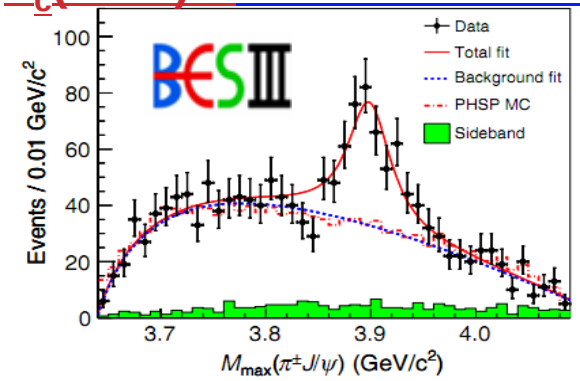
1. $Z_c(3900)^0$ in $e^+e^- \to \pi^0\pi^0 J/\psi$, arXiv: 1506.06018
2. Search for $Z_c(3900)^{\pm} \to$ light hadrons, Preliminary
3. $Z_c(3885)^{\pm}$ in $e^+e^- \to \pi^{+/-}(D\bar{D}^*)^{-/+}$, Preliminary, Double Tag
4. $Z_c(4020)^0$ in $e^+e^- \to \pi^0\pi^0 h_c$, PRL 113, 212002
5. $Z_c(4025)^0$ in $e^+e^- \to \pi^0(D^*\bar{D}^*)^0$, Preliminary

$Z_c(3900)^{\pm}$ AND $Z_c(3900)^0$



$Z_c(3900)^{\pm}$: PRL 110, 252001 (2013)

$Z_c(3900)^0$: arXiv: 1506.06018



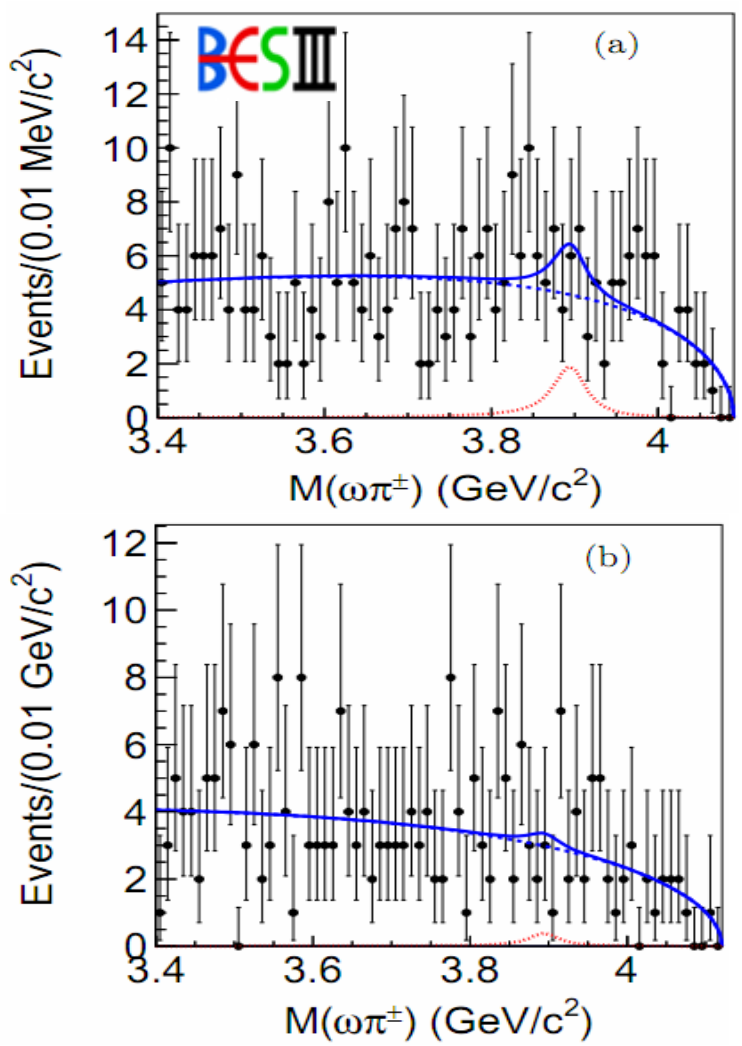
$Z_c(3900)$	Mass / MeV/c^2	Width / MeV
$Z_c(3900)^{\pm}$	3899.0±3.6±4.9	46±10±20
$Z_c(3900)^0$	3894.8±2.3±2.7	29.6±8.2±8.2

- $Z_c(3900)^{\pm}$, observed by BESIII in 2013, well confirmed by Belle and CLEO-c.
- $Z_c(3900)^0$, evidence with 3.7σ by CLEO-c, observe with >10σ by BESIII.

An iso-spin triplet $Z_c(3900)$ established!

$Z_C(3900)^{\pm}$: SEARCH IN $\omega\pi^{\pm}$

BESIII Preliminary



- **$Z_c(3900)^+$: mass close to DD*-bar threshold**
  - **Decays to J/ψ → contains cc-bar**
  - **Electric charge → contains ud-bar**
  - **A 4-quark particle?!**
- **Searching for new decay of $Z_c(3900)$ can provide useful information on its internal structure.**
- **No significant $Z_c \to \omega\pi$ is observed**

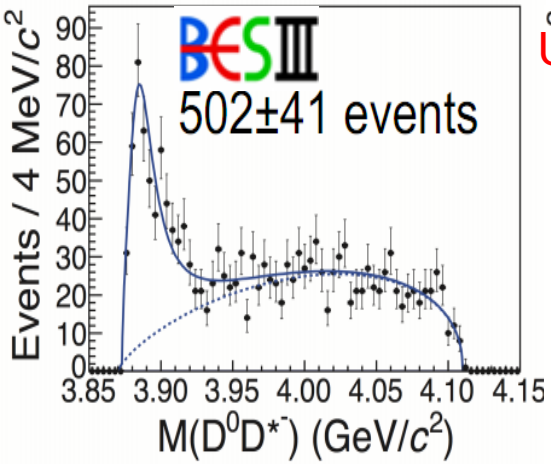
$\sigma(e^+e^- \to Z_c\pi, Z_c \to \omega\pi) < 0.27$ pb @ 4.23 GeV

$\sigma(e^+e^- \to Z_c\pi, Z_c \to \omega\pi) < 0.18$ pb @ 4.26 GeV

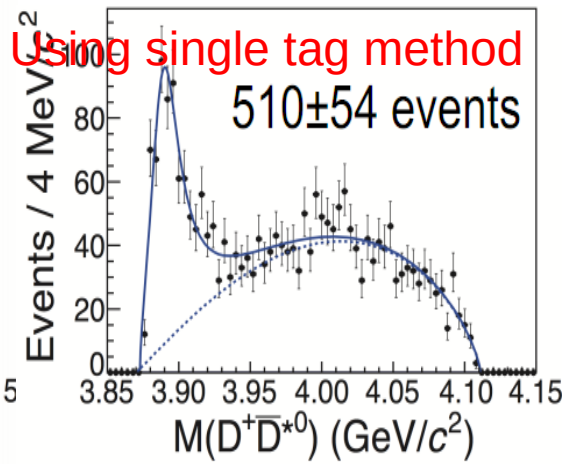
- **Provide a significant input to clarify its dynamical origin.**

$Z_C(3885)^{\pm}$

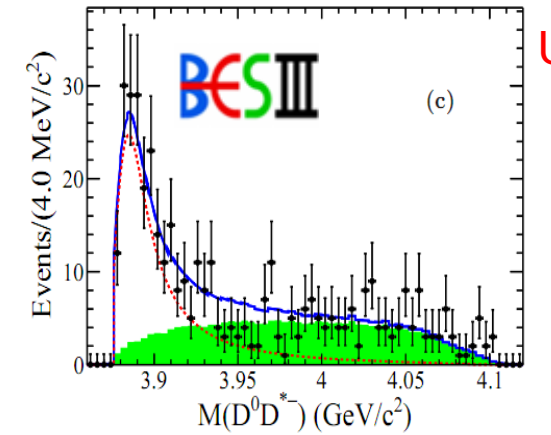
PRL 112, 022001 (2014)



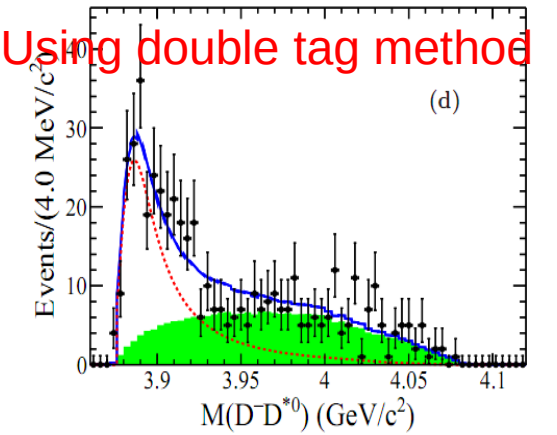
Using single tag method



BESIII Preliminary



Using double tag method



- Enhancement at $D\bar{D}^*$ threshold.
- **$Z_c(3885)^{\pm}$ observed !**

Mass and width consistent with each other between two method, but more precise with double tag method.

- **If this is $Zc(3900)^+$, open charm decays are suppressed, since**

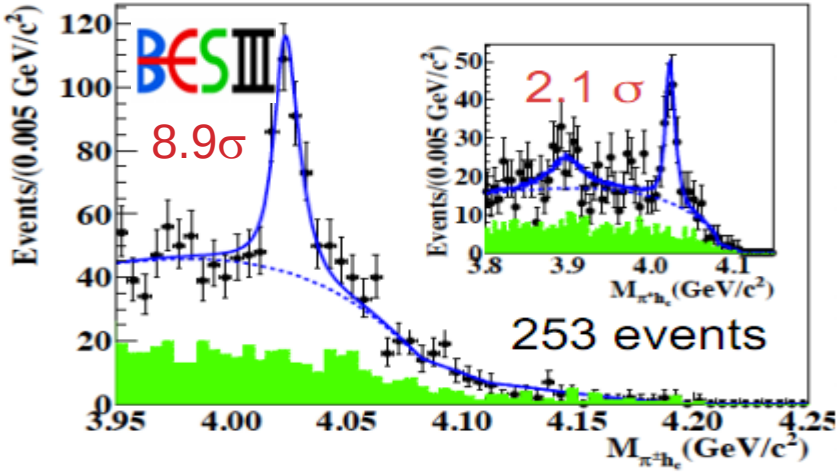
$$\frac{\Gamma(Z_c(3885)\to D\bar{D}^*)}{\Gamma(Z_c(3900)\to\pi J/\psi)} = 6.2 \pm 1.1 \pm 2.7$$

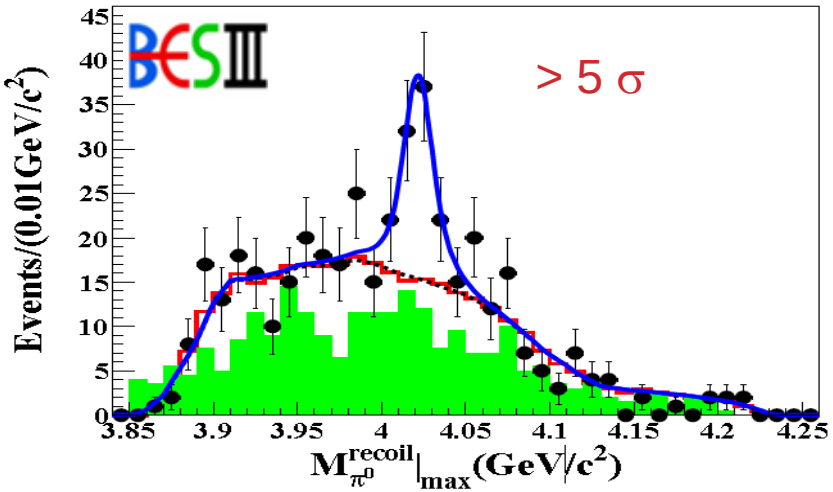
Compared to e.g.

$$\frac{\mathcal{B}(\psi(4040) \to D^{(*)}\bar{D}^{(*)})}{\mathcal{B}(\psi(4040) \to J/\psi\eta)} = 192 \pm 27$$

Different dynamics in $Y(4260)$-$Z_c(3900)$ system!

$Z_c(4020)^{\pm}$ AND $Z_c(4020)^0$





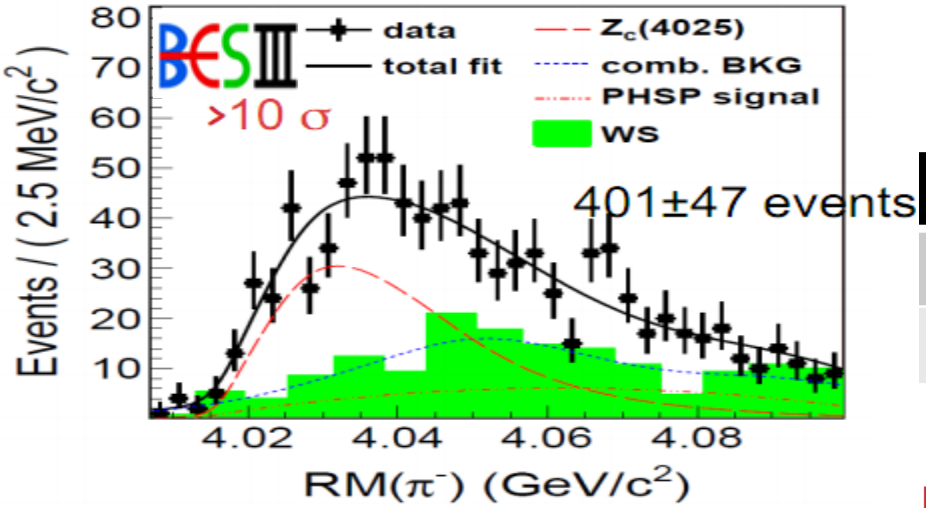
$Z_c(4020)^{\pm}$: PRL 111, 242001 (2013)
$Z_c(4020)^0$: PRL 113, 212002 (2014)

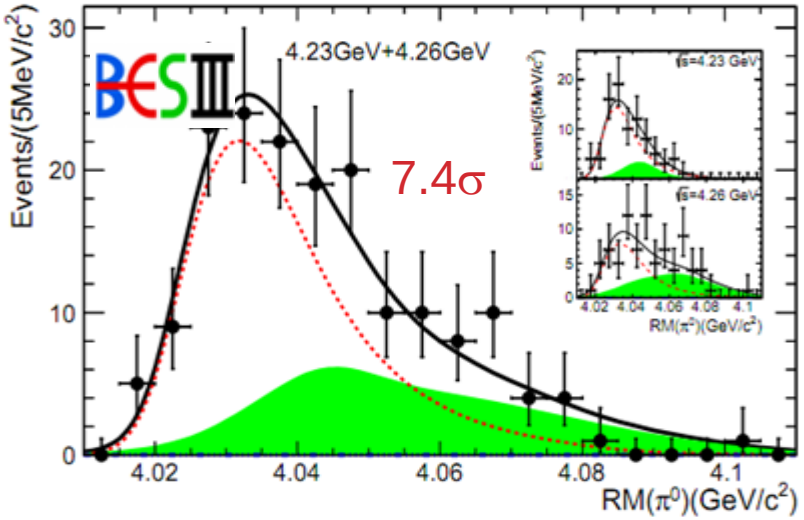
$Z_c(4020)$	Mass / MeV/c^2	Width / MeV
$Z_c(4020)^{\pm}$	4022.9±0.8±2.7	7.9±2.7±2.6
$Z_c(4020)^0$	4023.8±2.2±3.8	Fixed(=7.9)

- $Z_c(4020)^{\pm/0}$ observed !
- A weak evidence for $Z_c(3900)\to\pi^{\pm}h_c$
- $Z_c(4020)^+$, near the threshold of D*D*-bar, similar to the $Z_c(3900)^+$, at least 4 quarks composed, not a conventional charmonium state.

Another iso-spin triplet $Z_c(4020)$ is established !

$Z_c(4025)^{\pm}$ AND $Z_c(4025)^0$





$Z_c(4025)^{\pm}$: PRL 112, 132001 (2013)
$Z_c(4025)^0$: BESIII Preliminary

$Z_c(4025)$	Mass / MeV/c^2	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

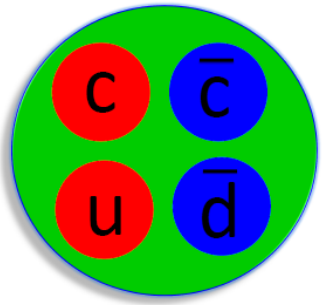
- $Z_c(4025)^{\pm/0}$ observed.
- The resonance parameters of $Z_c(4020)$ and $Z_c(4025)$ are consistent within 1.5σ.
- Coupling to $\bar{D}^*D^*$ is much larger than to πh_c if $Z_c(4025)$ and $Z_c(4020)$ are the same state.

$$\frac{\Gamma(Z_c(4020) \to D^*\bar{D}^*)}{\Gamma(Z_c(4020) \to \pi h_c)} = 12 \pm 5$$

NATURE of Z_c STATES

- **At least 4 quarks, not a conventional meson**

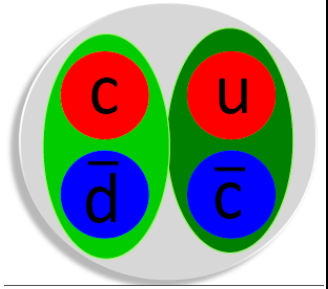
- **Tetraquark state?**



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?**



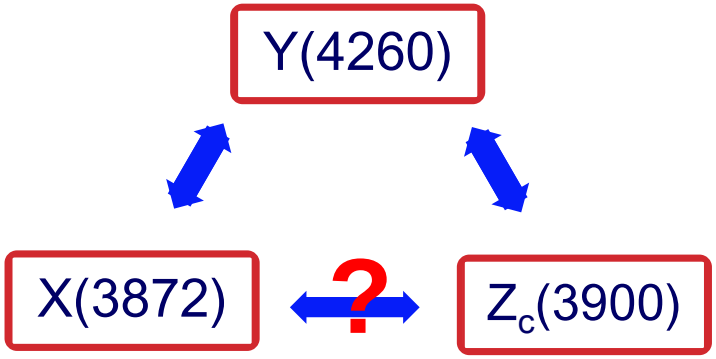
Phys. Rev. Lett. 111, 132003 (2013); Phys. Rev. D 89, 094026 (2014)

Phys. Rev. D 89, 074029 (2014); Phys. Rev. D 88, 074506 (2013); etc

- **Final States Interactions?**
- **…**

SUMMARY

- **Lots of progress in charmonium-like studies at BESIII recently**
- **Observation of Z_c states**
- **X、Y、Z particles are correlated!**



- **Measurements of many hidden charm final states**
- **BESIII may continue data taking for XYZ study until 2020-2022.**

THANK YOU

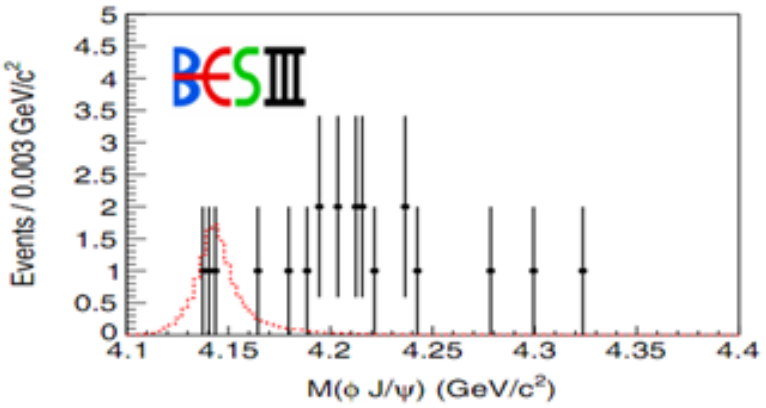
（谢谢）

BACKUP

SUMMARY OF Z_C STATES AT BESIII

State	Mass(MeV)	Width(MeV)	Decay mode	Process
$Z_c(3900)^{\pm}$	$3899.0 \pm 3.6 \pm 4.9$	$46 \pm 10 \pm 20$	$\pi^{\pm} J/\psi$	$e^+e^- \to \pi^+\pi^- J/\psi$
$Z_c(3900)^0$	$3894.8 \pm 2.3 \pm 2.7$	$29.6 \pm 8.2 \pm 8.2$	$\pi^0 J/\psi$	$e^+e^- \to \pi^0\pi^0 J/\psi$
$Z_c(3885)^{\pm}$	$3883.9 \pm 1.5 \pm 4.2$ [single D tag] $3884.3 \pm 1.2 \pm 1.5$ [double D tag]	$24.8 \pm 3.3 \pm 11.0$ [single D tag] $23.8 \pm 2.1 \pm 2.6$ [double D tag]	D^0D^{*-} D^-D^{*0}	$e^+e^- \to \pi^+D^0D^{*-}$ $e^+e^- \to \pi^+D^-D^{*0}$
$Z_c(4020)^{\pm}$	$4022.9 \pm 0.8 \pm 2.7$	$7.9 \pm 2.7 \pm 2.6$	$\pi^{\pm} h_c$	$e^+e^- \to \pi^+\pi^- h_c$
$Z_c(4020)^0$	$4023.9 \pm 2.2 \pm 3.8$	fixed	$\pi^0 h_c$	$e^+e^- \to \pi^0\pi^0 h_c$
$Z_c(4025)^{\pm}$	$4026.3 \pm 2.6 \pm 3.7$	$24.8 \pm 5.6 \pm 7.7$	$D^{*0}D^{*-}$	$e^+e^- \to \pi^+(D^* \bar{D}^*)^-$

No significant $e^+e^- \to \gamma Y(4140) \to \gamma\phi J/\psi$



PRD 91. 032002 (2015)

Upper limit at the 90% C.L. for $\sigma^B \cdot \mathcal{B} = \sigma^B\left(e^+e^- \to \gamma Y(4140)\right) \cdot \mathcal{B}(Y(4140) \to \phi J/\psi)$

$\sqrt{s}$ (GeV/c²)	σ^B·BR(pb)
4.23	<0.35
4.26	<0.28
4.36	<0.33

Compared with $X(3872)$ production. PRL 112, 092001

$$\sigma^B\left(e^+e^- \to \gamma X(3872)\right) \cdot \mathcal{B}(X(3872) \to \pi^+\pi^- J/\psi)$$

$= 0.27 \pm 0.09(\text{stat}) \pm 0.02(\text{syst})$ pb at $\sqrt{s}$= 4.23 GeV,

$= 0.33 \pm 0.12(\text{stat}) \pm 0.02(\text{syst})$ pb at $\sqrt{s}$ = 4.26 GeV.

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.

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