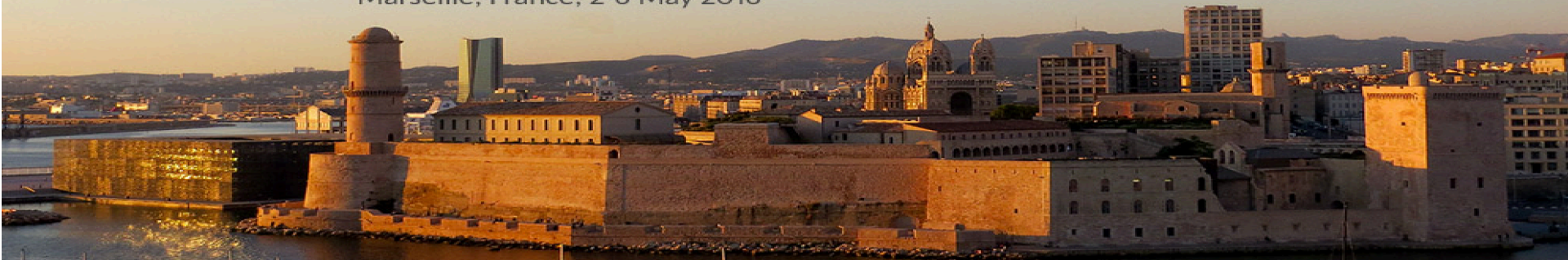


The 16th International Conference on B-physics at Frontier Machines

BEAUTY 2016

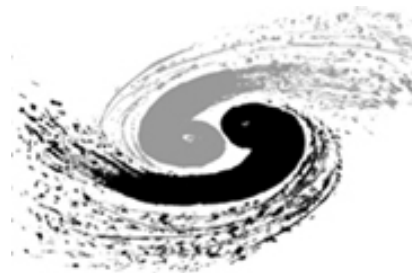
Marseille, France, 2-6 May 2016



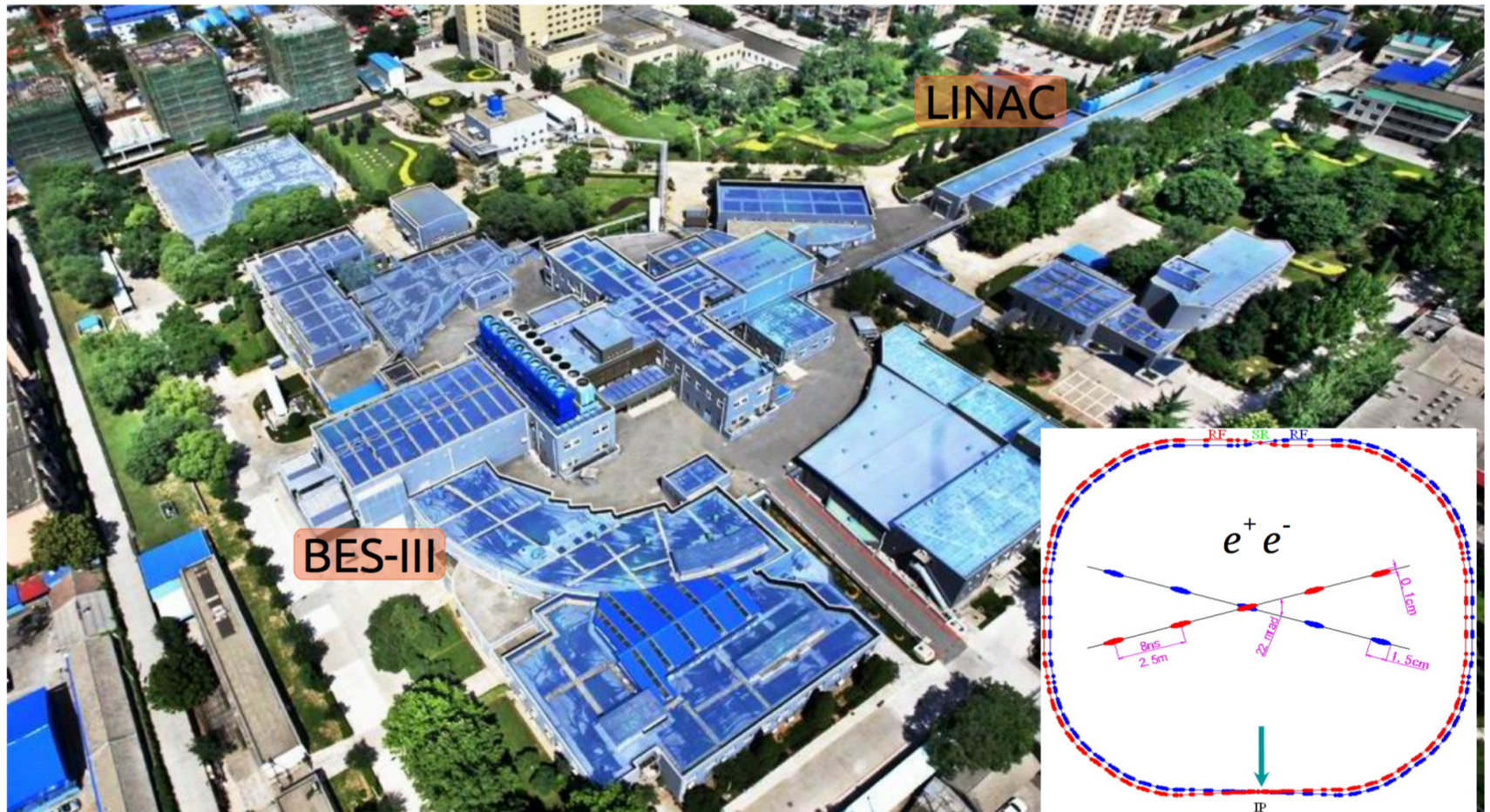
XYZ studies at BESIII

Liangliang WANG (IHEP, Beijing, China)

On behalf of  Collaboration



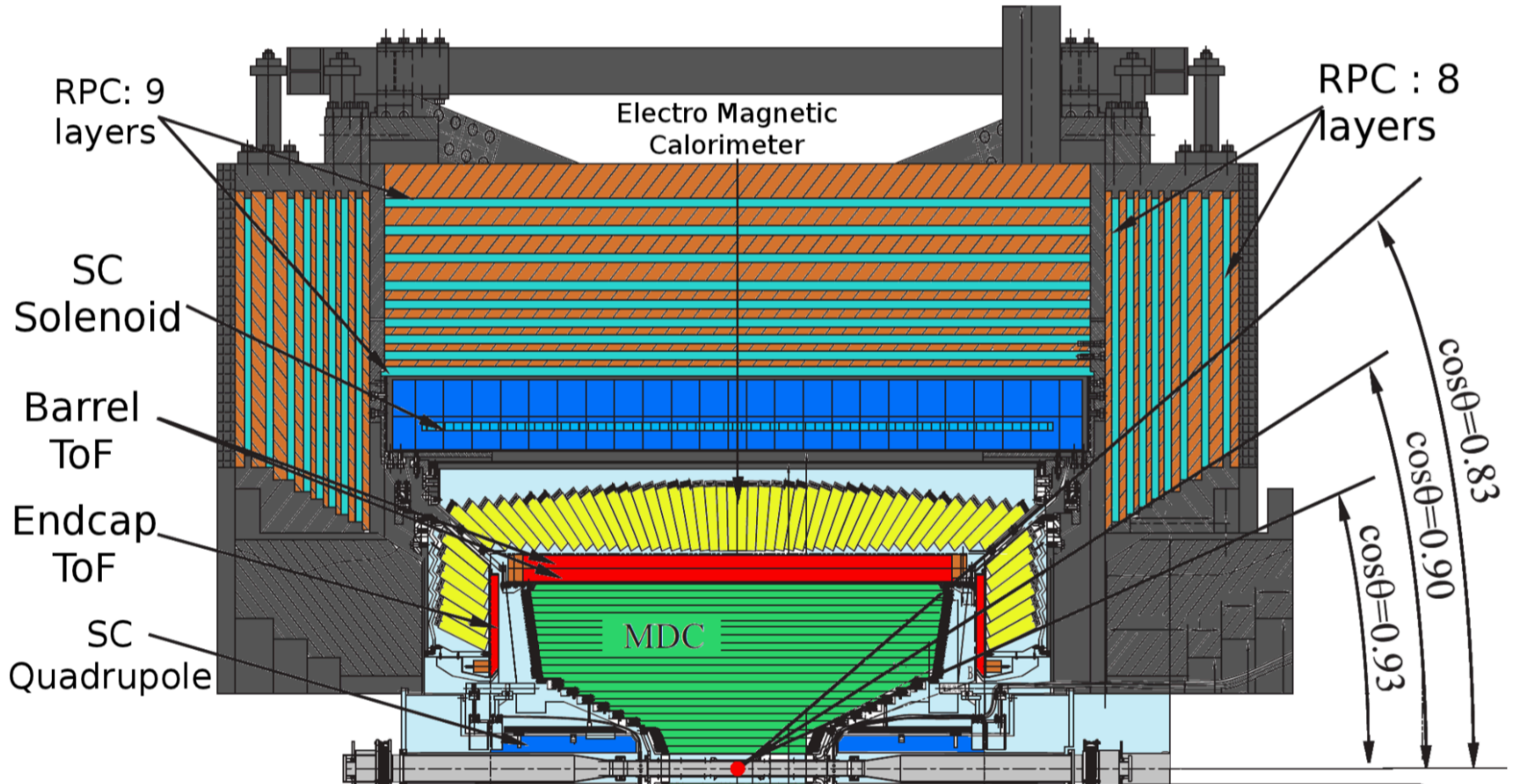
BEPCII and BESIII: a τ -charm factory



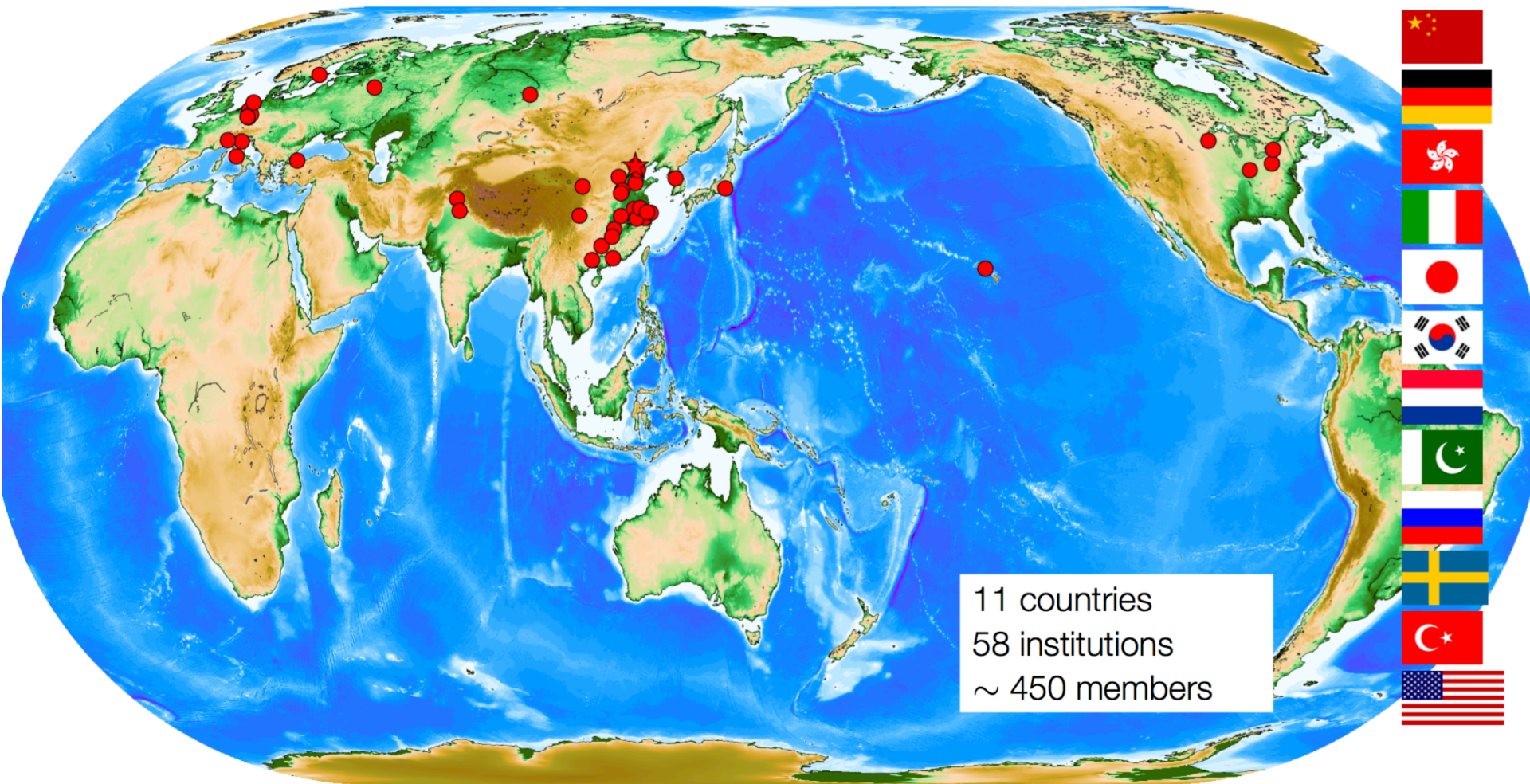
Beam Energy: 1~2.3 GeV
Beam current: 0.91 A
Crossing angle: ± 11 mrad

Design luminosity: $10^{33} \text{ cm}^{-2} \text{ s}^{-1}$ @ 1.89 GeV
Achieved on 5th April, 2016!

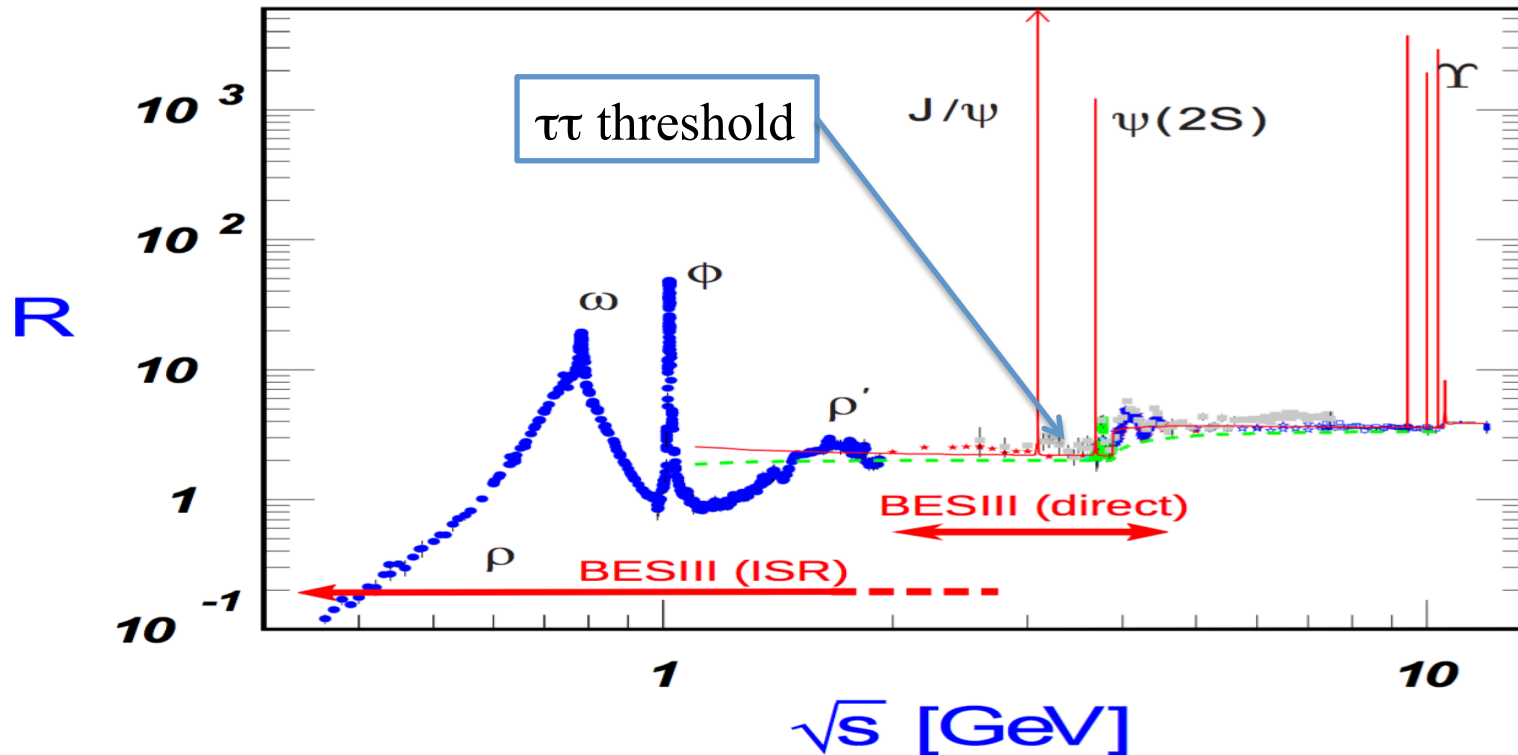
BESIII detector



BESIII Collaboration



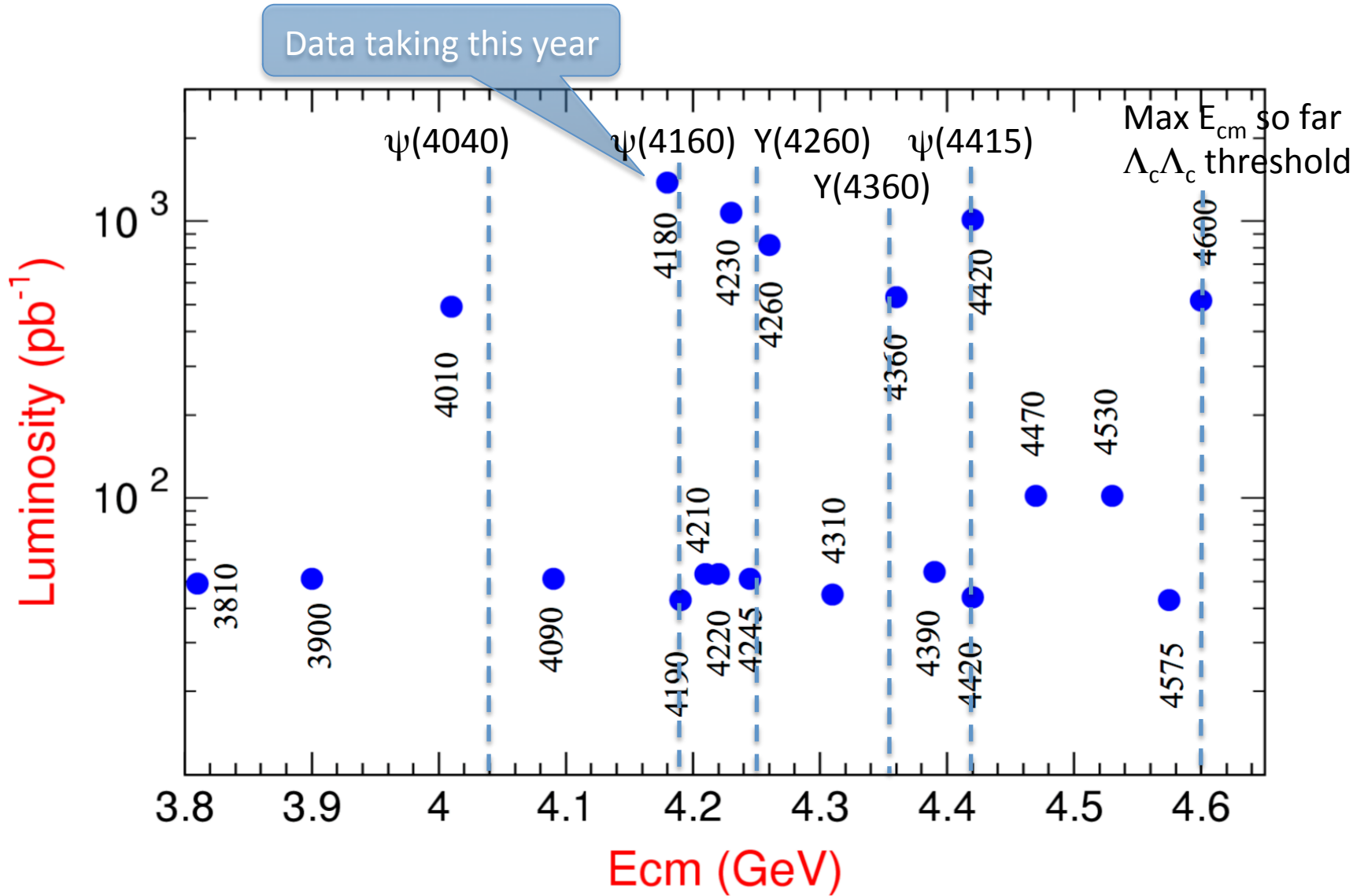
Physics program

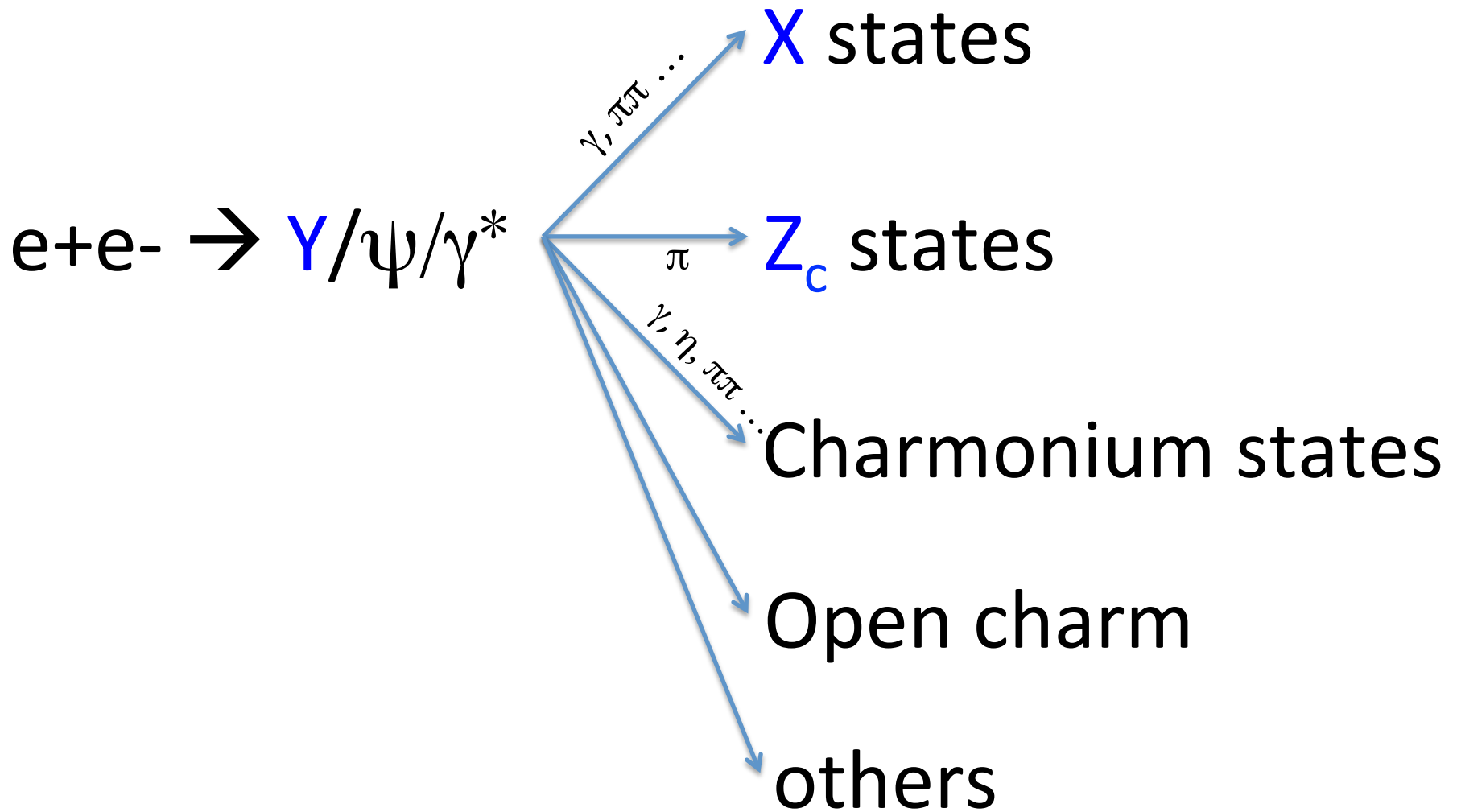


- ✓ R and QCD
- ✓ τ physics
- ✓ Light hadron physics

- ✓ Charmonium physics
- ✓ Charm Physics
- ✓ **XYZ meson physics (this talk)**

Data 4~4.6GeV for XYZ studies





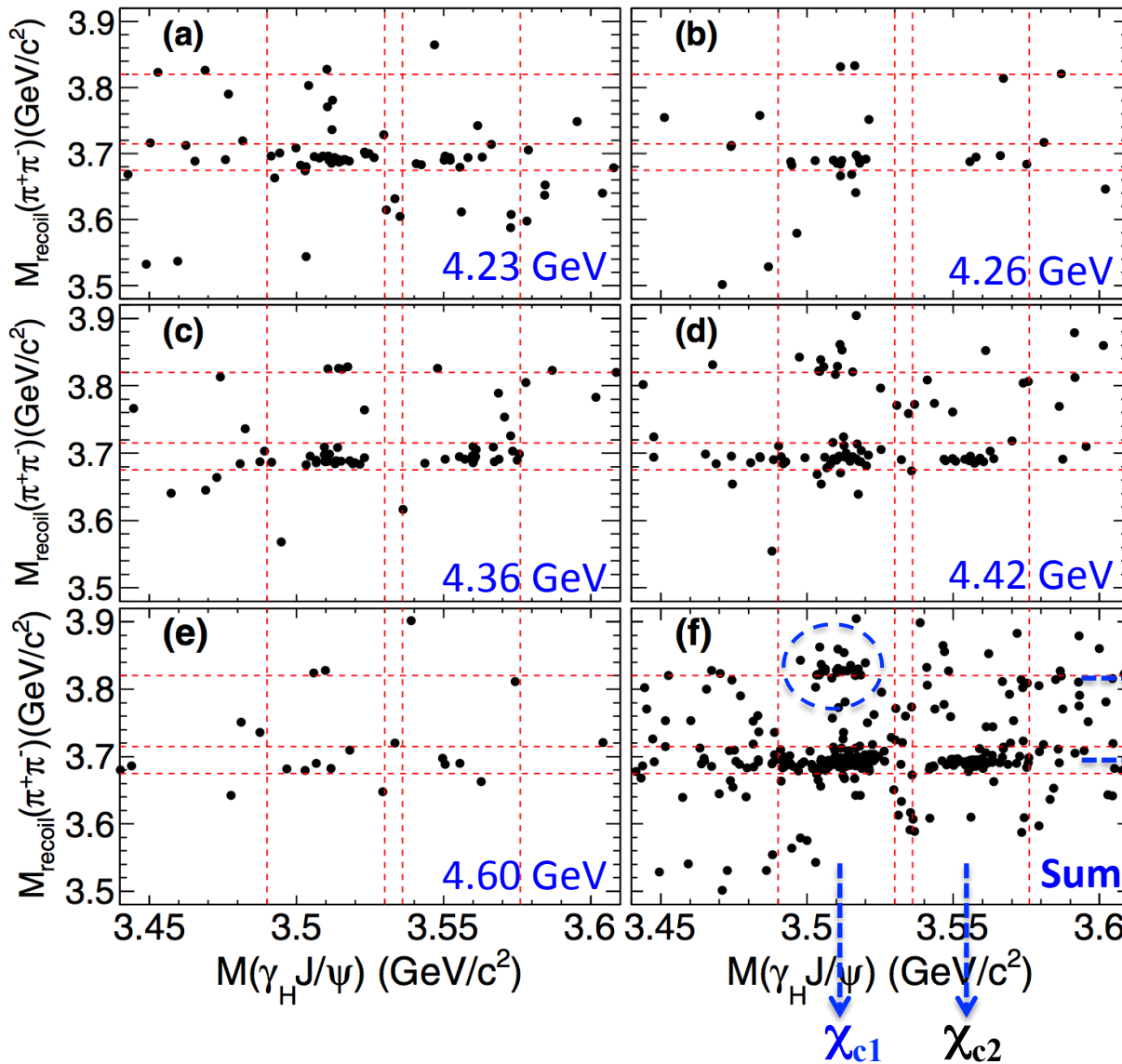
The X states

- Neutral charmoniu-like/exotic states
- J^{PC} is not 1^{--}
- Searched by photon/hadron transition at BESIII

$e^+e^- \rightarrow \pi^+\pi^- X(3823), X(3823) \rightarrow \chi_{c1}\gamma$ at BESIII

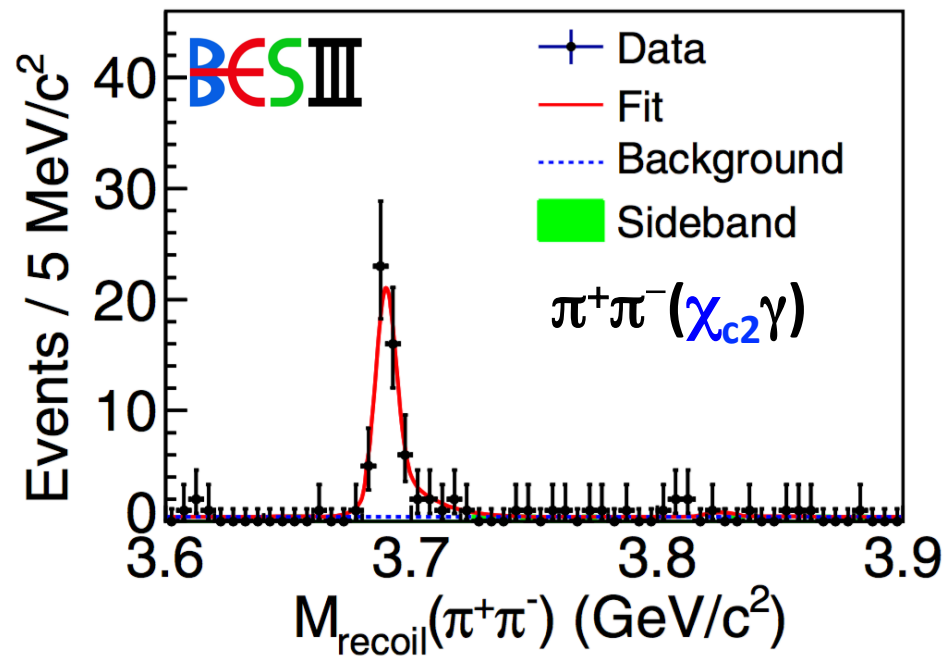
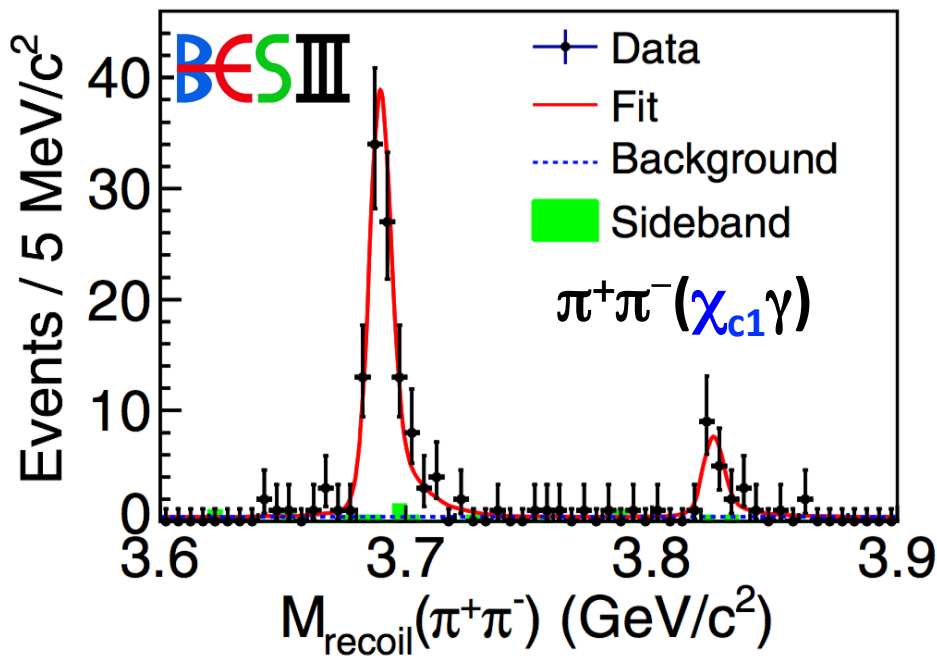
BESIII

PRL **115**, 011803



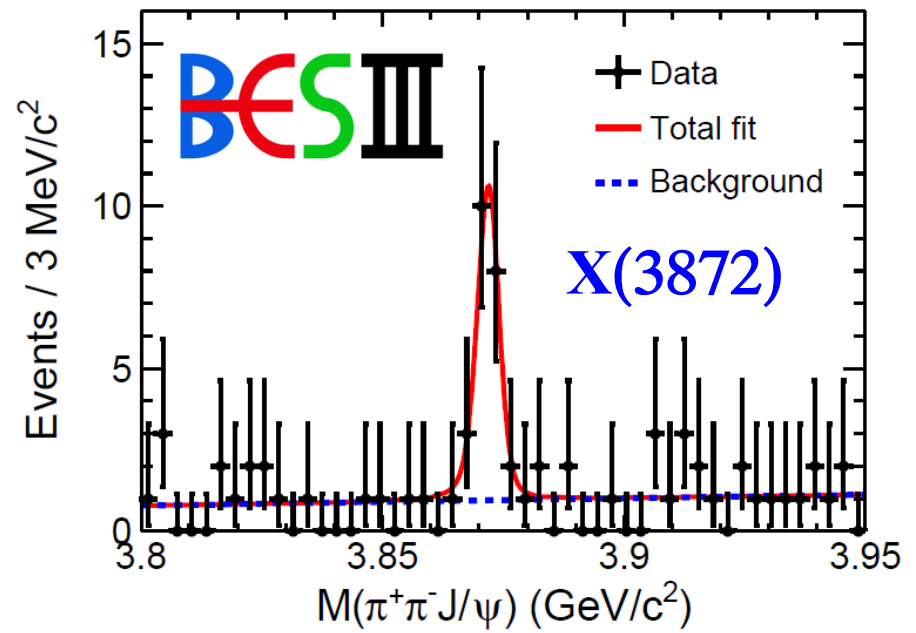
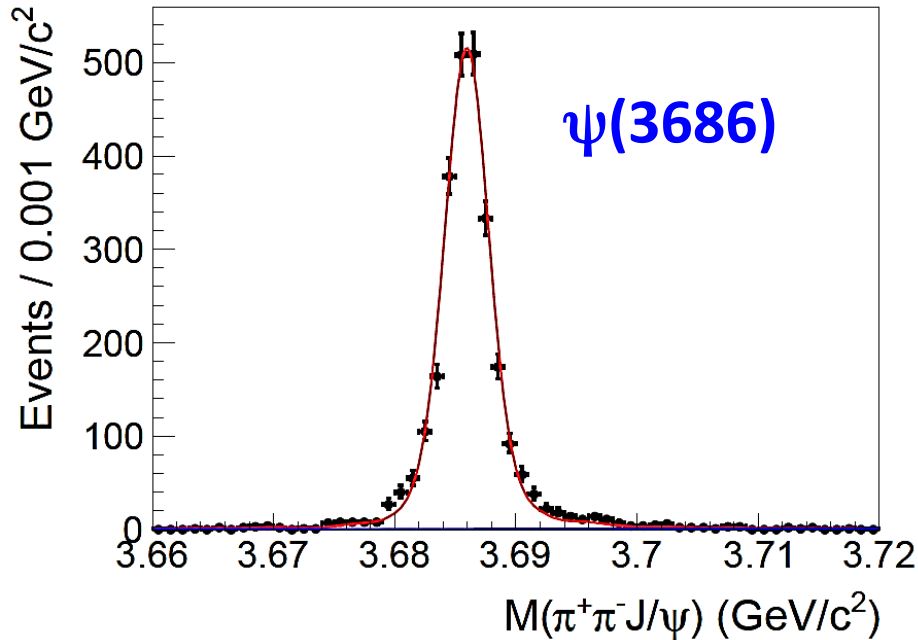
- Reconstruct $\chi_{c1/2} \rightarrow \gamma J/\psi$, $J/\psi \rightarrow ll$ ($l=e/m$)
- Five large data sets used ($\sim 4.1 \text{ fb}^{-1}$)

$e^+e^- \rightarrow \pi^+\pi^- X(3823), X(3823) \rightarrow \chi_{c1}\gamma$ at BESIII



- A simultaneous fit of different data sets
- Signal: MC simulated shape
Background: linear function
- $M=3821.7\pm 1.3\pm 0.7$ MeV; Significance: 6.2σ , observation !
- Mass and narrow width agree with potential model prediction for $\psi(1^3D_2)$

Observation of X(3872) at BESIII via $e^+e^- \rightarrow \gamma\pi^+\pi^-J/\psi$ @ 4.26 GeV for the first time



ISR ψ' signal is used for mass, and resolution calibration.

$N=1818$; $\Delta M=0.34 \pm 0.04$ MeV; $\Delta\sigma_M=1.14 \pm 0.07$ MeV

$N(X(3872)) = 20.1 \pm 4.5$

6.3 σ

PRL 112, 092001 (2014)

$M(X(3872)) = 3871.9 \pm 0.7 \pm 0.2$ MeV

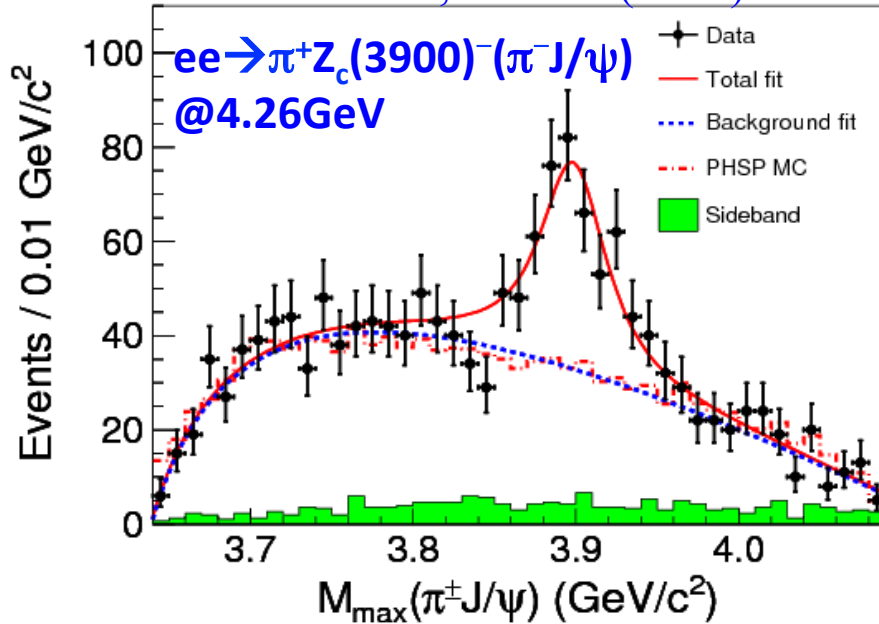
[PDG: 3871.68 ± 0.17 MeV]

The Z_c family

- Charged exotic states
- Observed via π transition at BESIII

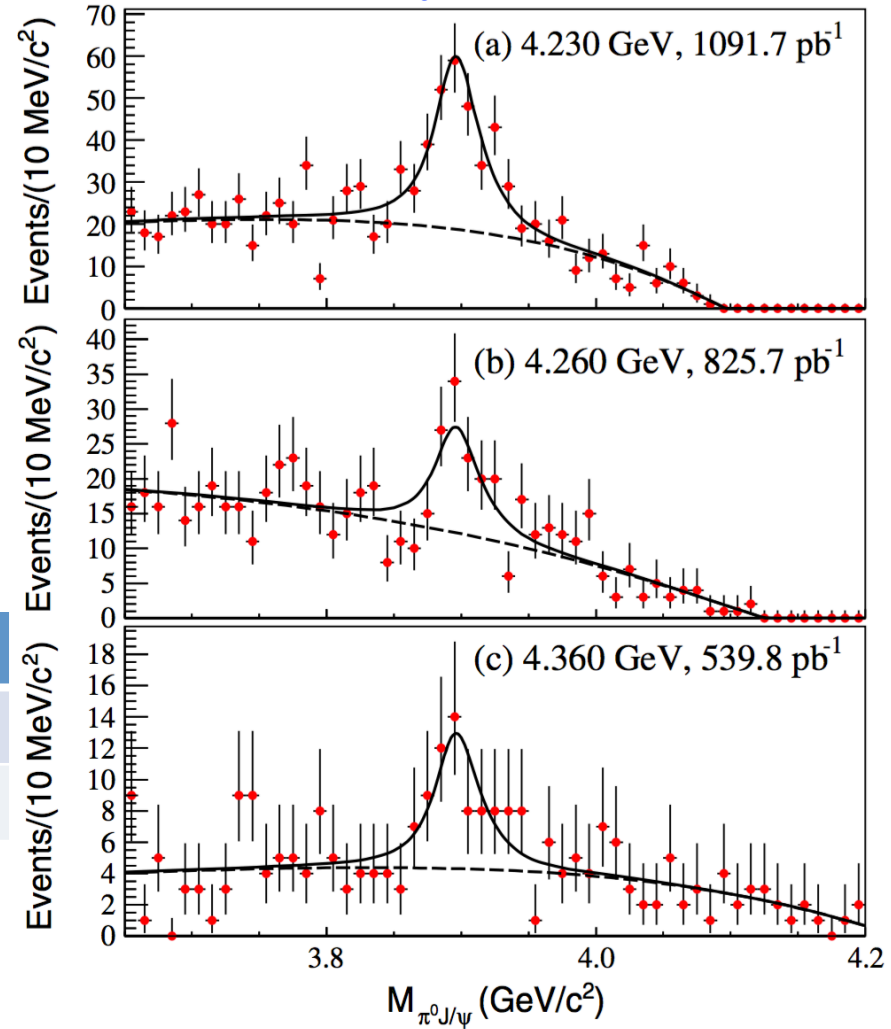
$$ee \rightarrow \pi Z_c(3900)^{\pm/0} \rightarrow \pi(\pi J/\psi)$$

PRL 110, 252001 (2013)



PRL 115, 112003(2015)

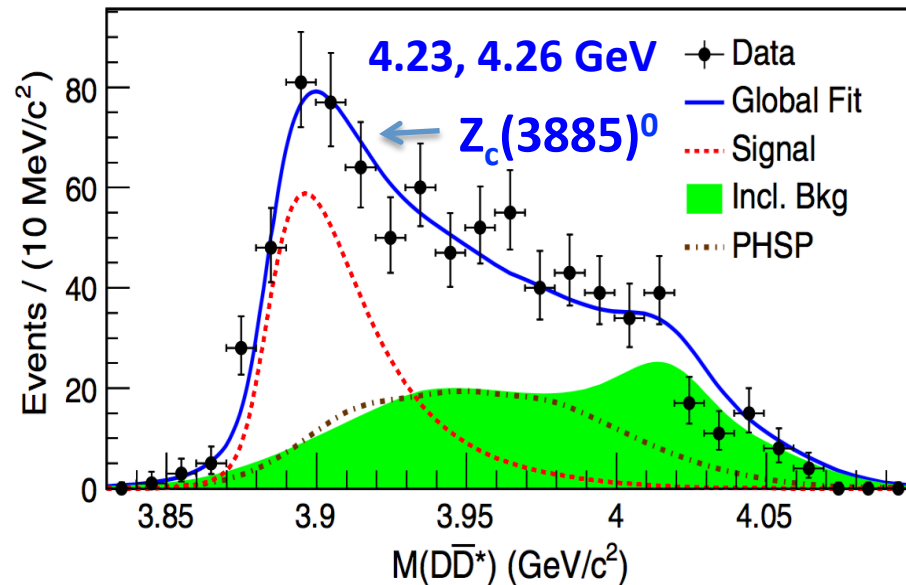
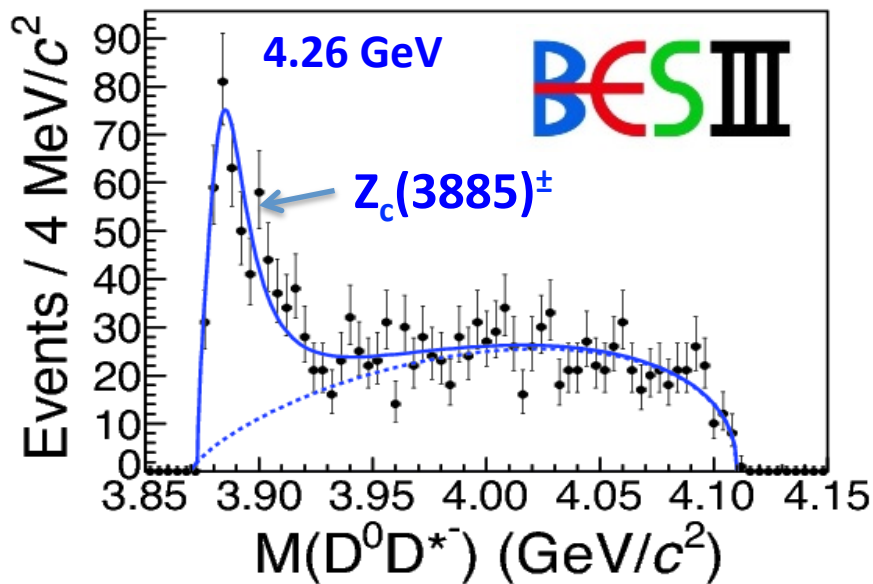
$$ee \rightarrow \pi^0 Z_c(3900)^0 (\pi^0 J/\psi)$$



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

Mass $\sim m(DD^*)$

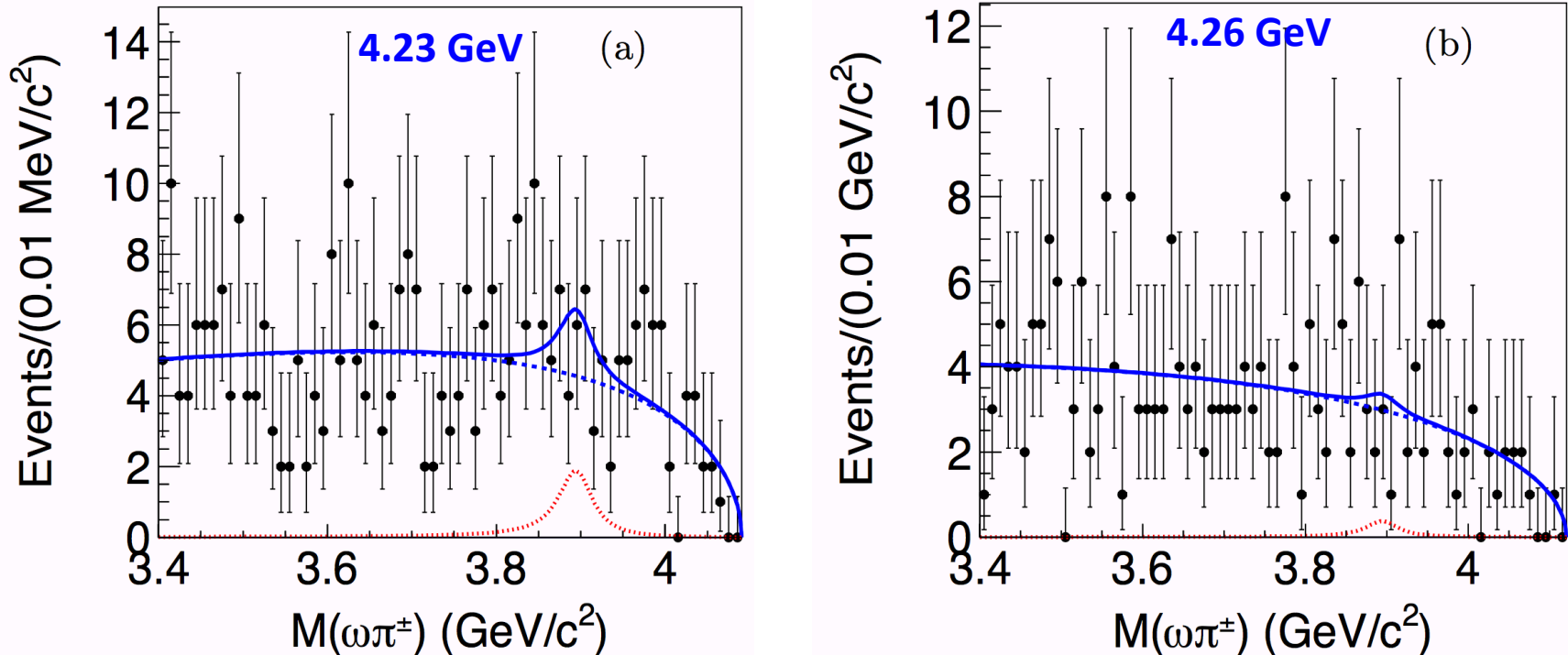
$$ee \rightarrow \pi Z_c(3885)^{\pm/0} \rightarrow \pi(DD^*)^{\pm/0}$$



$Z_c(3885)$	Mass(MeV)	Width(MeV)	reference
$Z_c(3885)^{\pm}$ (single D-tag)	$3883.9 \pm 1.5 \pm 4.2$	$24.8 \pm 3.3 \pm 11.0$	PRL 112, 022001(2014)
$Z_c(3885)^{\pm}$ (double D-tag)	$3881.7 \pm 1.6 \pm 2.6$	$26.6 \pm 2.0 \pm 2.3$	PRD 92, 092006 (2015)
$Z_c(3885)^0$ (single D-tag)	$3885.7^{+4.3}_{-5.7} \pm 8.4$	$35^{+11}_{-12} \pm 15$	PRL 115, 222002 (2015)

Search for $ee \rightarrow \pi Z_c(3900) \rightarrow \pi(\omega\pi)$

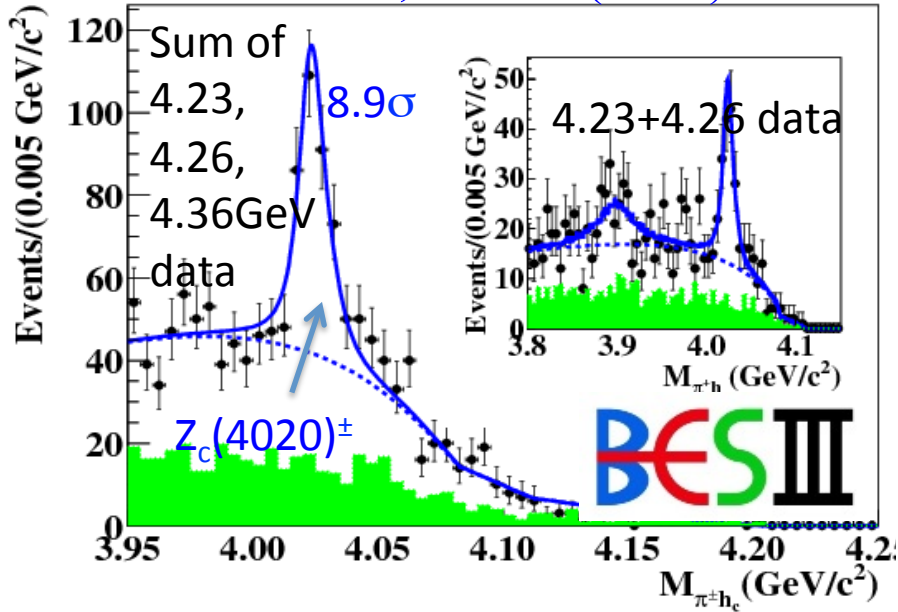
PRD 92, 032009(2015)



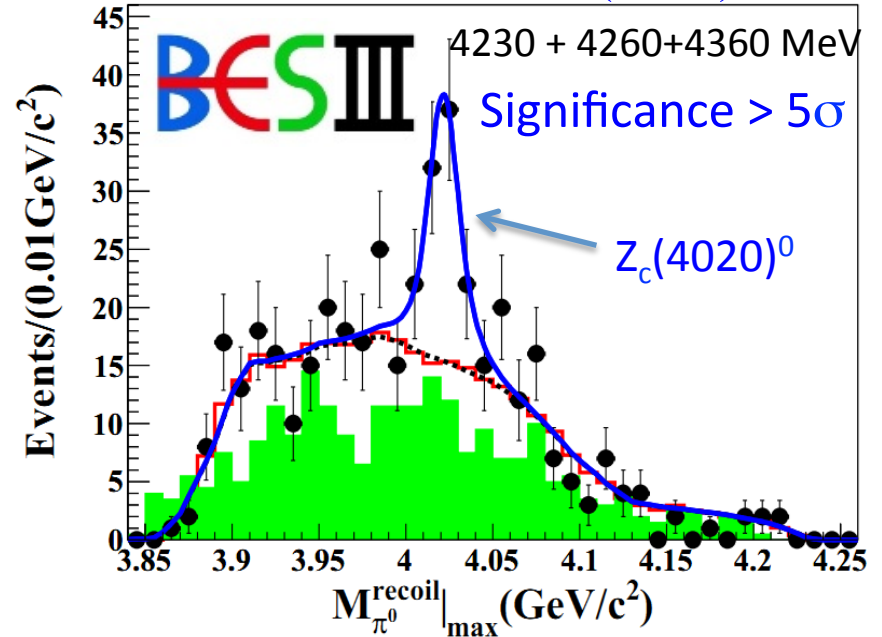
- Searching for new decays of $Z_c(3900)$ to light hadrons: distinguish a resonance from threshold effects
- No significant $Z_c \rightarrow \omega\pi$ is observed:
 $\sigma(e+e^- \rightarrow Z_c\pi, Z_c \rightarrow \omega\pi) < 0.26$ pb @ 4.23 GeV
 $\sigma(e+e^- \rightarrow Z_c\pi, Z_c \rightarrow \omega\pi) < 0.18$ pb @ 4.26 GeV

$$ee \rightarrow \pi Z_c(4020)^{\pm/0} \rightarrow \pi(\pi h_c)$$

PRL 111, 242001(2013)



PRL 113, 212002 (2014)



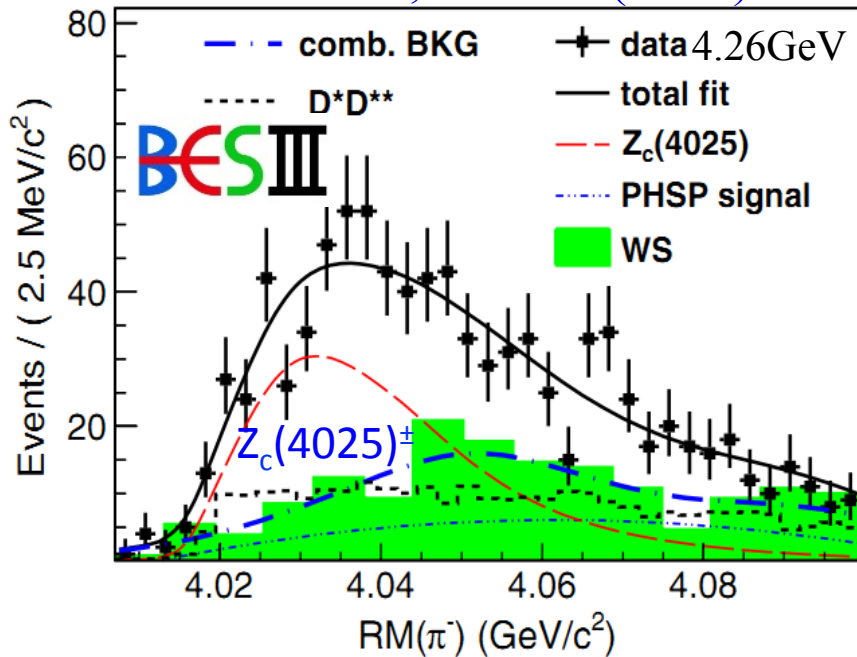
No significant signal for $Z_c(3900)^{\pm} \rightarrow \pi^{\pm} h_c$

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

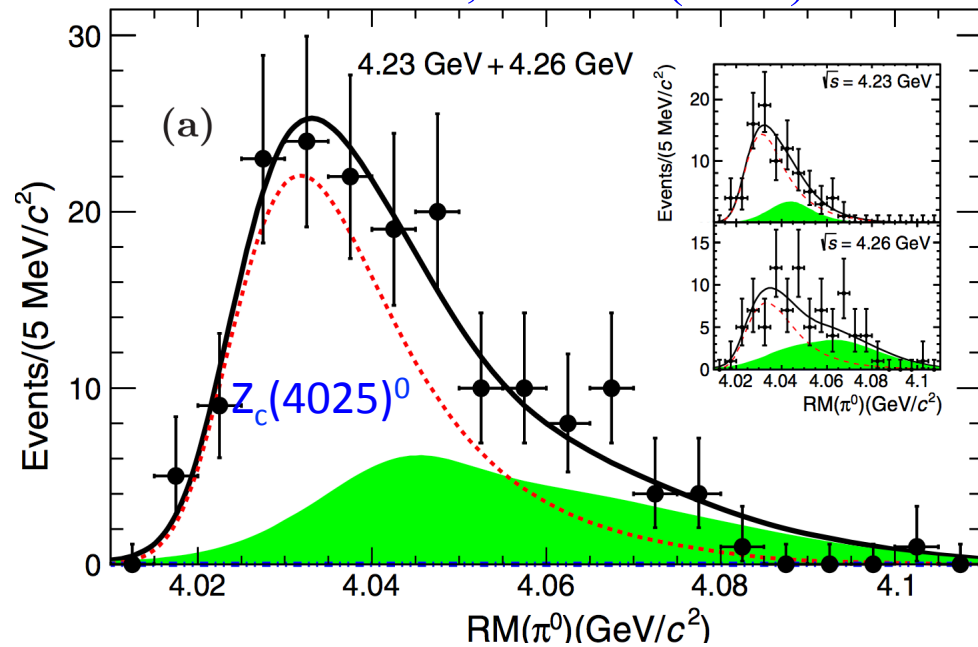
$\sim m(D^* D^*)$

$$e^+e^- \rightarrow \pi Z_c(4025)^{\pm/0} \rightarrow \pi(D^*D^*)^{\pm/0}$$

PRL 112, 132001 (2014)



PRL 115, 182002 (2015)



Z _c (4025)	Mass(MeV)	Width(MeV)
Z _c (4025) [±]	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}

Discussion of the Z_c family

Z_c	Mass (MeV/c ²)	Width (MeV)	Decay mode (X_i)	J^P
$Z_c(3900)^+$	$3899.0 \pm 3.6 \pm 4.9$	$46 \pm 10 \pm 20$	$\pi^+ J/\psi$	1^+
$Z_c(3900)^0$	$3894.8 \pm 2.3 \pm 2.7$	$29.6 \pm 8.2 \pm 8.2$	$\pi^0 J/\psi$	
$Z_c(3885)^+$	$3882.3 \pm 1.1 \pm 1.9^\#$	$26.5 \pm 1.7 \pm 2.3^\#$	$(DD^*)^+$	1^+
$Z_c(3885)^0$	$3885.7^{+4.3}_{-5.7} \pm 8.4$	$35^{+11}_{-12} \pm 15$	$(DD^*)^0$	
$Z_c(4020)^+$	$4022.9 \pm 0.8 \pm 2.7$	$7.9 \pm 2.7 \pm 2.6$	$\pi^+ h_c$	
$Z_c(4020)^0$	$4023.8 \pm 2.2 \pm 3.8$	Fixed to 7.9	$\pi^0 h_c$	
$Z_c(4025)^+$	$4026.3 \pm 2.6 \pm 3.7$	$24.8 \pm 5.6 \pm 7.7$	$(D^* D^*)^+$	
$Z_c(4025)^0$	$4025.5^{+2.0}_{-4.7} \pm 3.1$	$23.0 \pm 6.0 \pm 1.0$	$(D^* D^*)^0$	

Preliminary result from PWA

From angular distribution

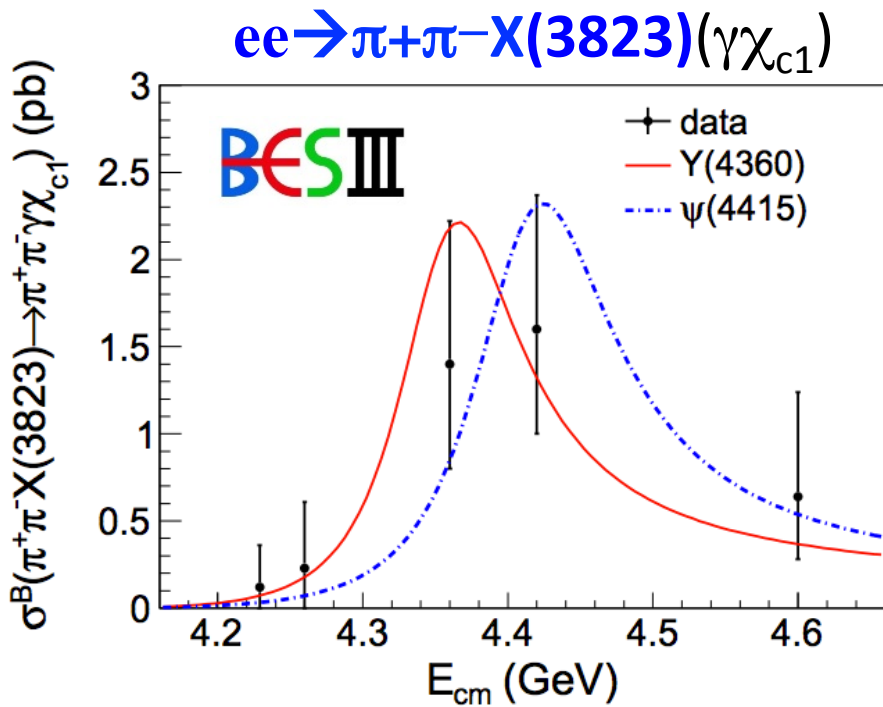
combined results of single and double D-tag

- Charged Z_c decays into $\pi J/\psi$ (πh_c ...) => at least has four quark components
- Production of charged and neutral Z_c is consistent with isospin relationship => Isospin triplet?
- Are the $Z_c(3900)$ and $Z_c(3885)$ ($Z_c(4020)$ and $Z_c(4025)$) are the same state/structure? Masses and widths are consistent each other within 2σ
Favor the same J^P

The Y states (vectors)

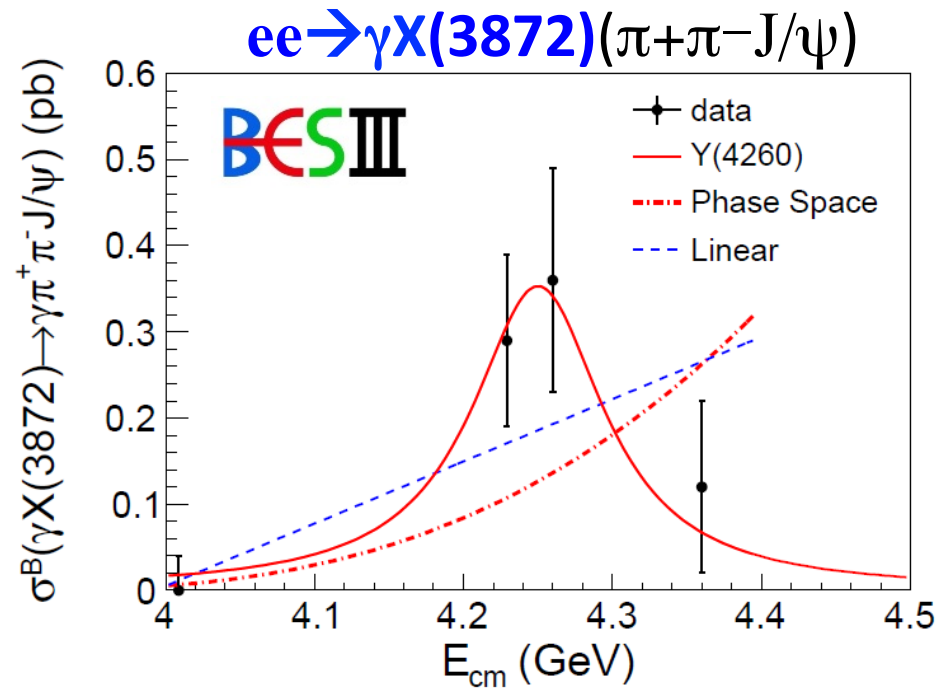
- Can be directly produced in e^+e^- annihilation
- Can not be seen from the inclusive hadronic cross section (R-scan):
measure **exclusive** hadronic cross sections at BESIII

$\sigma(ee \rightarrow X + (\pi\pi, \gamma))$



Data can not distinguish
Y(4360) and $\psi(4415)$

PRL 115, 011803 (2015)

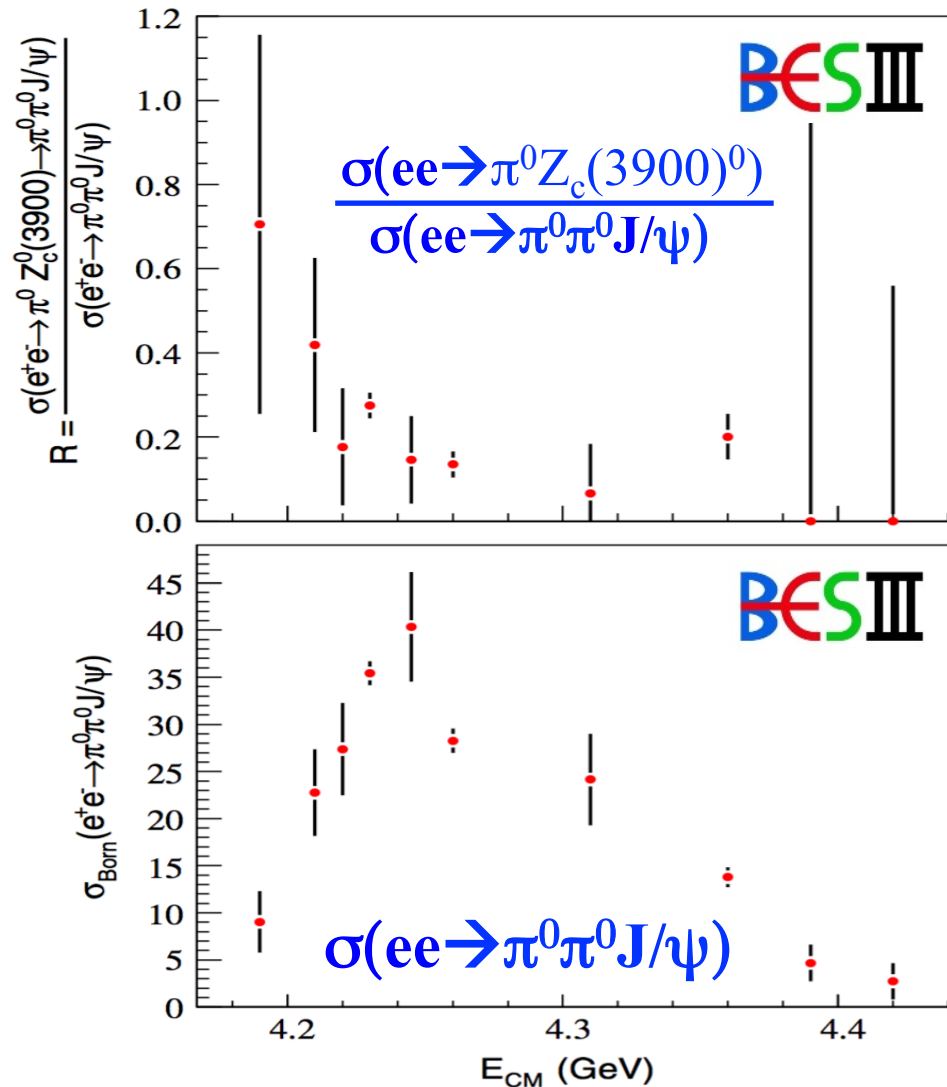


Data suggests $Y(4260) \rightarrow \gamma\chi(3872)$

PRL 112, 092001 (2014)

$\sigma(ee \rightarrow \pi^0 Z_c(3900)^0)$ and $\sigma(\pi^0 \pi^0 J/\psi)$

PRL 115, 112003(2015)

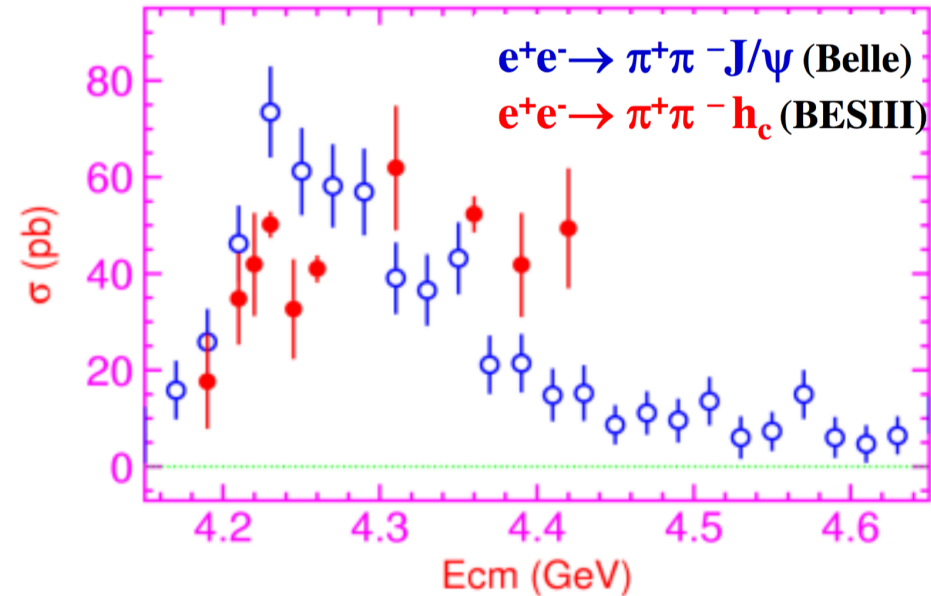
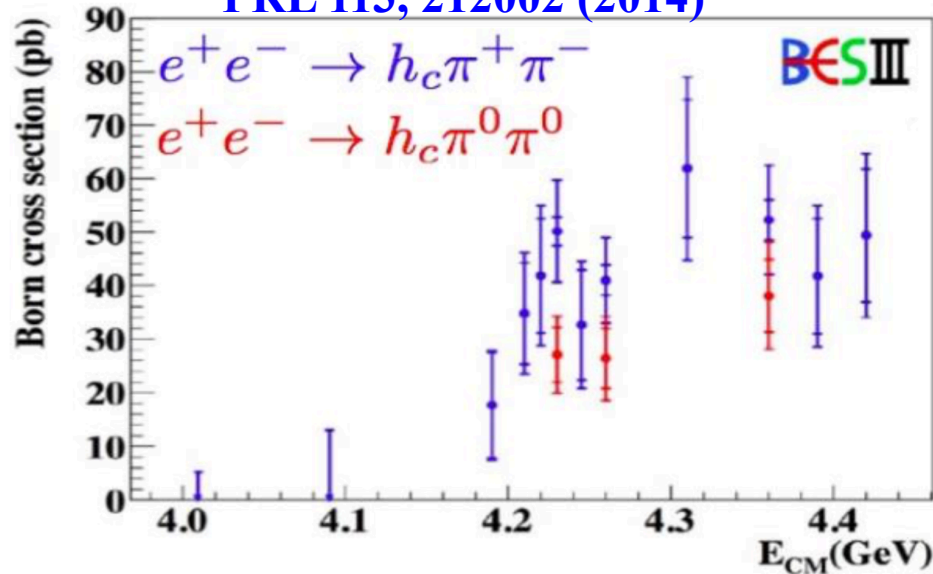


- Measured $\sigma(ee \rightarrow \pi^0 \pi^0 J/\psi) \sim$ half of $\sigma(ee \rightarrow \pi^+ \pi^- J/\psi)$ by Belle
- $\Upsilon(4260) \rightarrow \pi^0 \pi^0 J/\psi$?
- Maximum cross section is around 4.23 GeV
- $R@4.23\text{GeV} > R@4.26\text{GeV}$
R: Relative $Z_c(3900)^0$ production ratio in $\sigma(ee \rightarrow \pi^0 \pi^0 J/\psi)$
 \Rightarrow
 $\sigma(ee \rightarrow \pi^0 Z_c(3900)^0)$ has sharper peak at 4.23 GeV than $\sigma(ee \rightarrow \pi^0 \pi^0 J/\psi)$
- Rich Y states/structures between 4.2~4.3 GeV?

$\sigma(ee \rightarrow \pi\pi h_c)$

PRL 111, 242001(2013)

PRL 113, 212002 (2014)



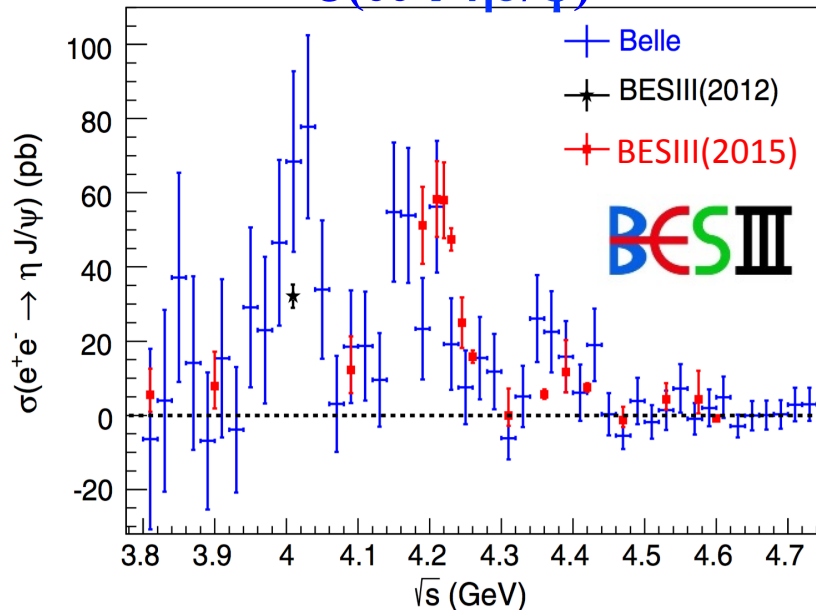
- Improved measurement of $\sigma(\pi^+\pi^-h_c)$ (CLEO studied in 2011)
- First observation of $\pi^0\pi^0h_c$
- $\sigma(\pi^0\pi^0h_c)/\sigma(\pi^+\pi^-h_c)=0.63\pm 0.09$

- $\sigma(\pi^+\pi^-h_c) \sim \sigma(\pi^+\pi^-J/\psi)$, but different line shape
- Unlikely originate from $Y(4260)$
- Hint of a more complicated underlying dynamics

$\sigma(ee \rightarrow \pi^0/\eta/\eta' + J/\psi)$

- No significant $ee \rightarrow \pi^0 J/\psi$ observed

$\sigma(ee \rightarrow \eta J/\psi)$

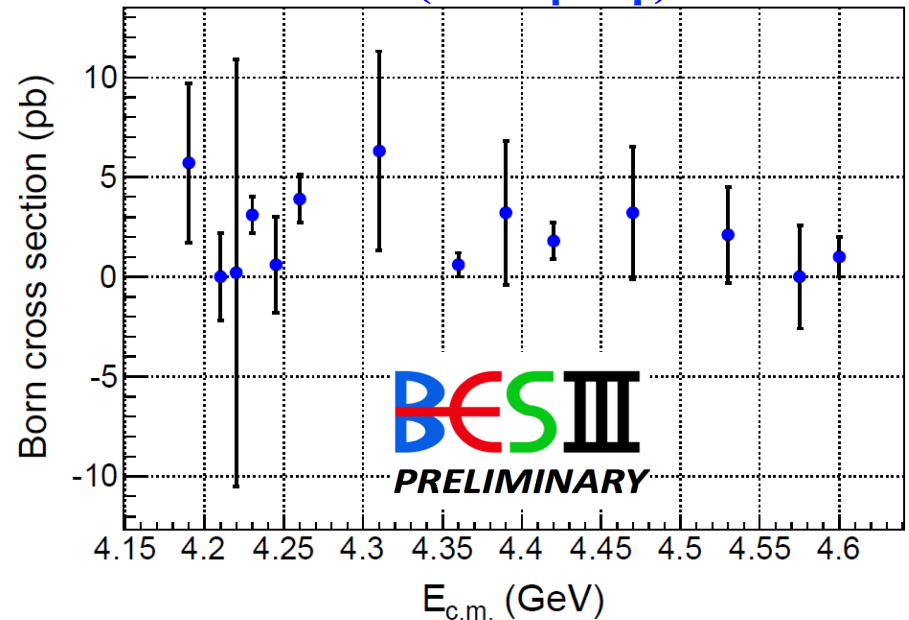


PRD 86, 071101(R) (2012)

PRD 91, 112005 (2015)

- Consistent with Belle
(PRD 87, 051101(R) (2013))
- More precise
- Line shape is different from $\sigma(ee \rightarrow \pi\pi J/\psi)$

$\sigma(ee \rightarrow \eta' J/\psi)$

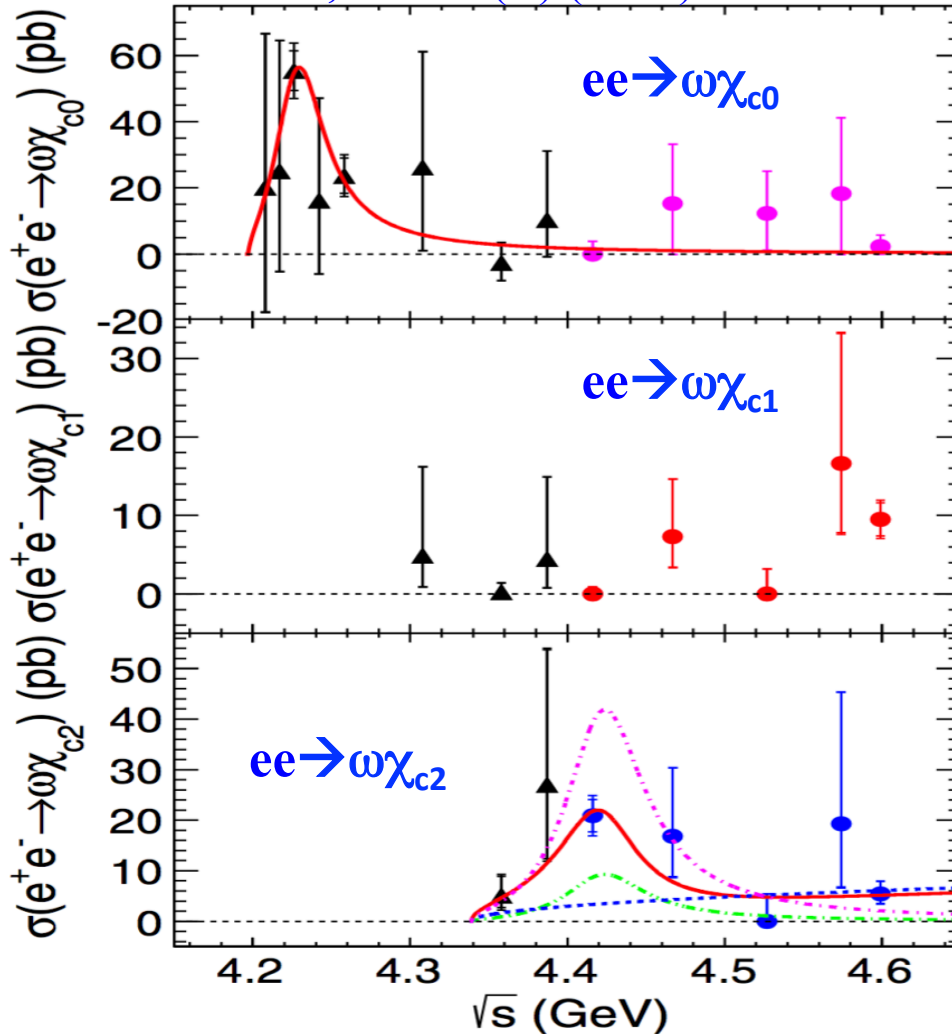


- $\psi(4160) \rightarrow \eta' J/\psi$
- No evidence for $\psi(4415)$
- Much lower than $\sigma(ee \rightarrow \eta J/\psi)$,
in contradiction to the calculation
in the framework of NRQCD
(PRD 89, 074006 (2014))

$\sigma(ee \rightarrow \omega \chi_{cJ})$

PRL 114, 092003 (2015)

PRD 93, 011102(R) (2016)



Peak at ~ 4.23 GeV

- Fit to a phase-space modified BW:
 $M = 4226 \pm 8 \pm 6$ MeV/c²
 $\Gamma = 39 \pm 12 \pm 2$ MeV
- Inconsistent with Y(4260)

- No significant $ee \rightarrow \omega \chi_{c1}$ events

Can be described by $\psi(4415)$

- Fit to $|\text{BW} + \text{Phase-Space}|^2$
- Mass and width fixed to $\psi(4415)$
- Two solutions with the same fitting quality

Summary and outlook

- BESIII has accumulated ee data between $4\sim 4.6\text{GeV}$: large luminosity around $\psi(4040)$, $\psi(4160)$, $\psi(4415)$ and $Y(4260)$, $Y(4360)$, 4.6GeV
- X: first observation of $ee\rightarrow\pi^+\pi^-X(3823)\rightarrow\pi^+\pi^-(\chi_{c1}\gamma)$
first observation of $ee\rightarrow\gamma X(3872)\rightarrow\gamma(\pi^+\pi^-J/\psi)$
- Z_c family discovered: $Z_c(3900)$, $Z_c(3885)$, $Z_c(4020)$, $Z_c(4025)$
- Y studied in exclusive hadronic cross section: data indicates connections between Y and X/ Z_c , fine structures $4.2\sim 4.3\text{GeV}$
- More data and new results expected at BESIII: e.g. exclusive open charm cross sections, amplitude analysis of the process involving exotic states and so on.

Merci! Thanks! 谢谢!