

The BES-III experiment

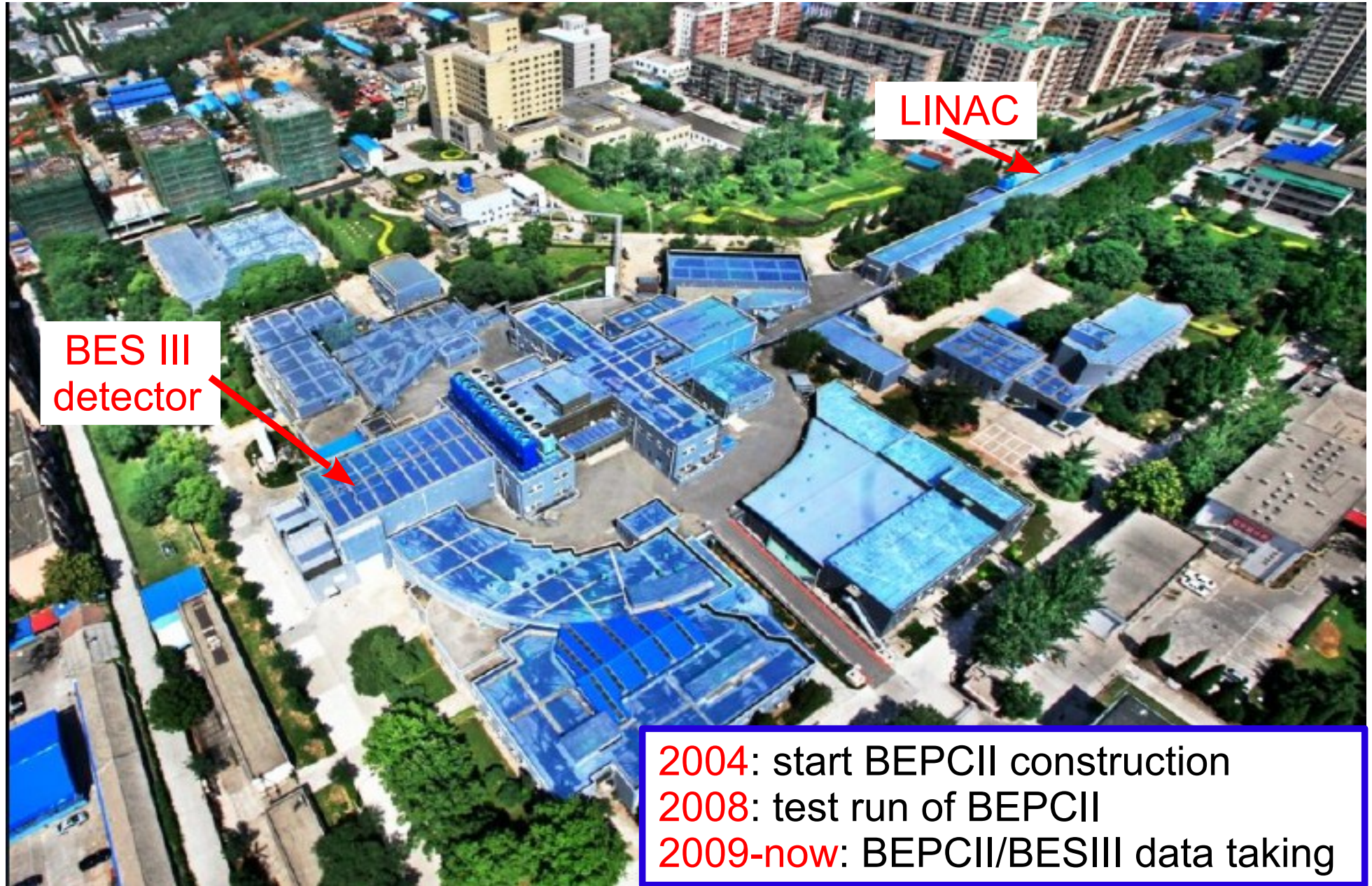
Nefedov Yuri

for the BES-III collaboration

JINR Dubna

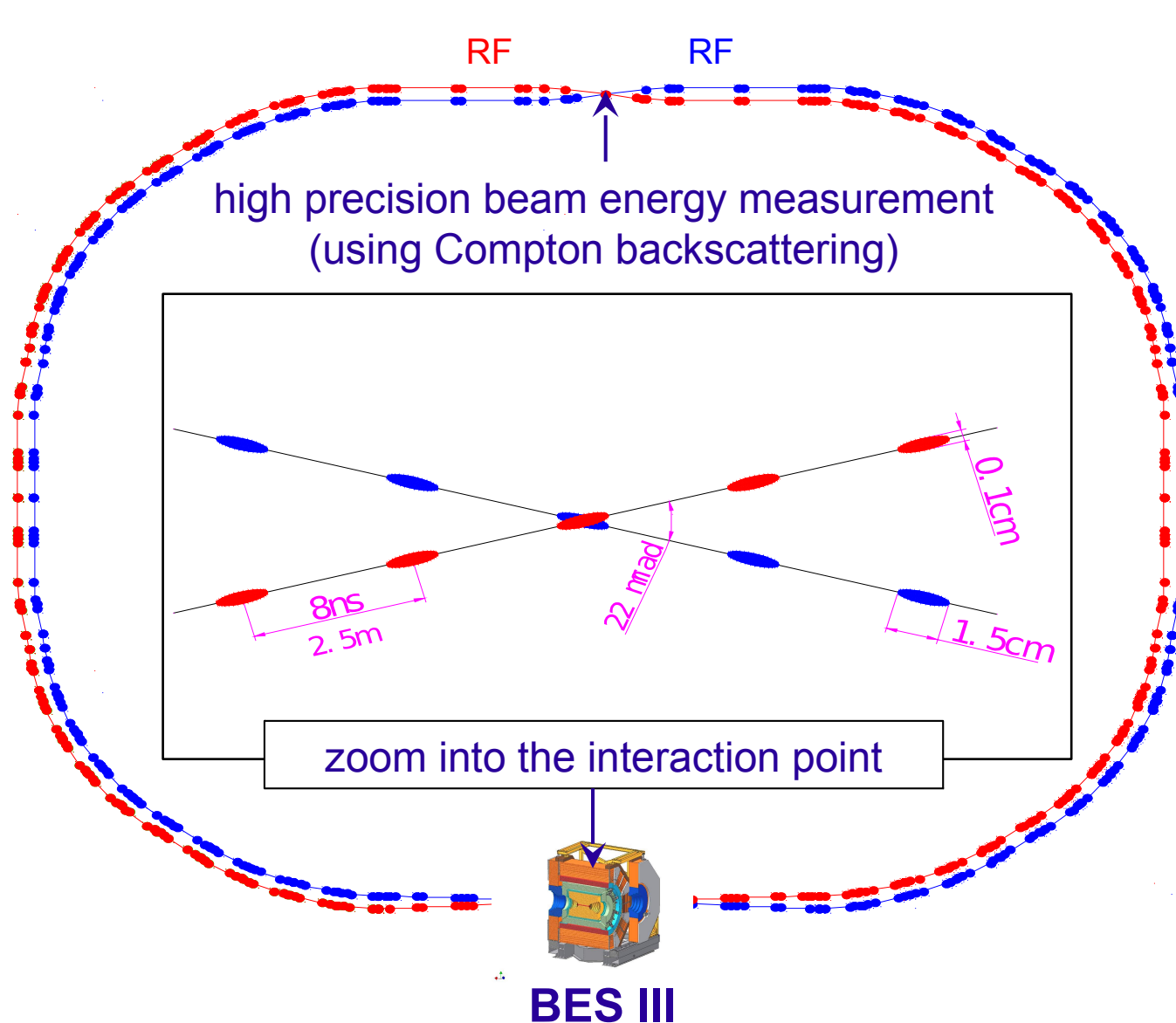
**XXX International Workshop on High Energy Physics
Protvino, Russian Federation, June 23-27 2014**

BEPCII/BESIII at IHEP (Beijing)



2004: start BEPCII construction
2008: test run of BEPCII
2009-now: BEPCII/BESIII data taking

Beijing Electron Positron Collider (BEPCII)

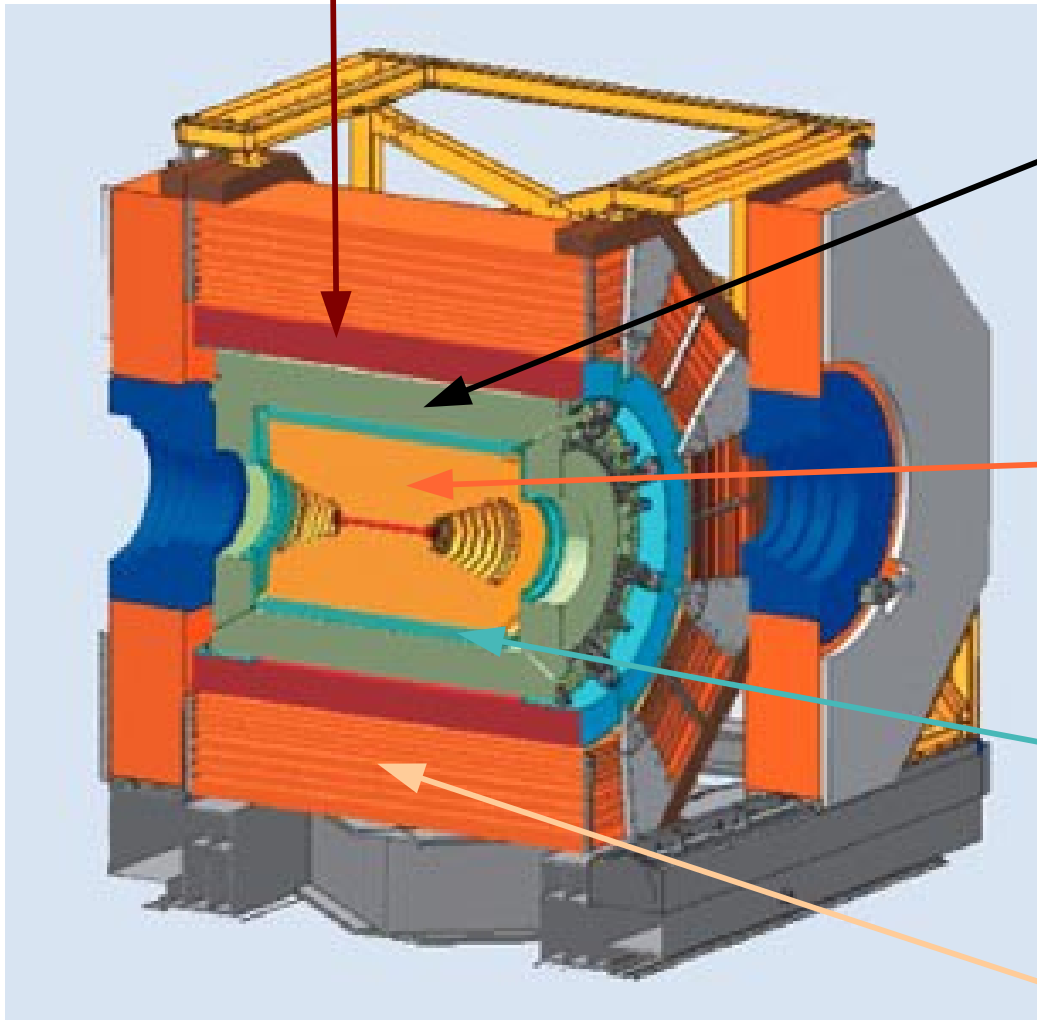


- Double-ring
- Large crossing angle
- Beam energy:
1.0 - 2.3 GeV
- Energy spread:
 5.16×10^{-4}
- Design luminosity:
 $1 \times 10^{33} / \text{cm}^2 / \text{s}$
@ $\psi(3770)$
- Achieved luminosity:
 $\sim 0.65 \times 10^{33} / \text{cm}^2 / \text{s}$
- Beam energy measurement:
 5×10^{-5}

The BES-III detector

NIM A614, 345(2010)

Super conducting magnet: 1 T



EMC: CsI cristal

- Energy resolution: **2.5% @1GeV**
- Spatial resolution: **6mm**

MDC:

- Spatial resolution: $\sigma_{xy} = 120\mu\text{m}$
- Momentum resolution: **0.5% @ 1GeV**
- **dE/dx** resolution: 6%

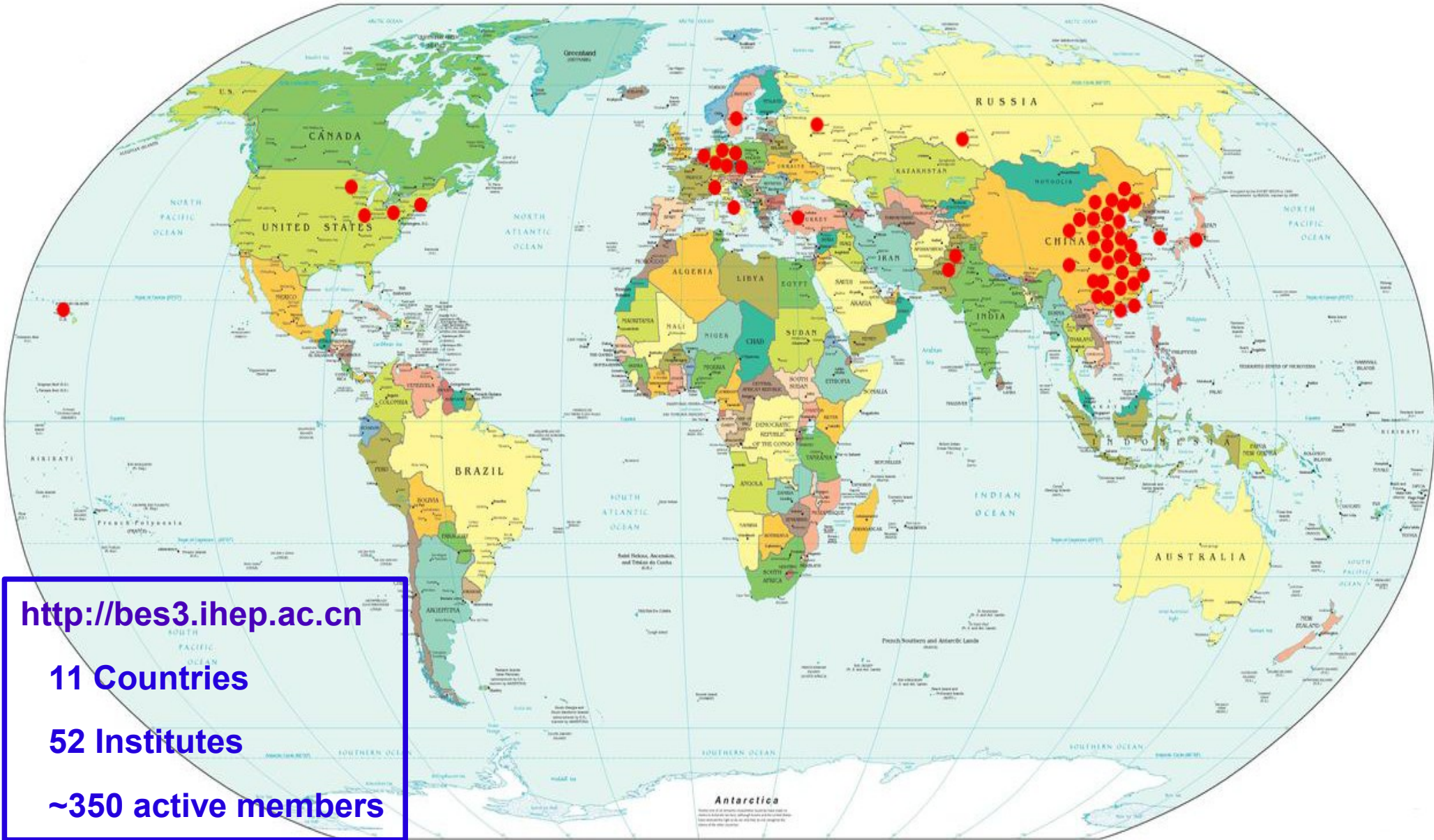
TOF:

- Time resolution: **100ps** (barrel)
110ps (endcaps)

Muon ID:

- 9 layers RPC, 8 for endcaps

The BES-III Collaboration



Data samples at BES-III

July 19, 2008: first e⁺e⁻ collision event in BES-III

Energy & physics	N or L	Comments
J/ψ at 3.097 GeV	1.3 x10 ⁹	2009+2012: 20 x BES-II
ψ(2S) at 3.686 GeV	0.4 x10 ⁹	2009+2012: 20 x CLEO-c
ψ(3770) at 3.773 GeV	2.9 fb ⁻¹	2010+2011: 3.5 x CLEO-c
ψ(4040) at 4.009 GeV	0.5 fb ⁻¹	2011: world only data
tau mass scan around 3.554 GeV	24 pb ⁻¹	2011
Υ(4260) at 4.23 and 4.26 GeV	1.9 fb ⁻¹	2013
Υ(4360) at 4.36 GeV	0.5 fb ⁻¹	2013
Υ scan: 4.10 – 4.40 GeV	0.5 fb ⁻¹	2013
R scan: 3.85 – 4.59 GeV	0.8 fb ⁻¹	2014
4.60 GeV	0.5 fb ⁻¹	2014

Data used for analyzes

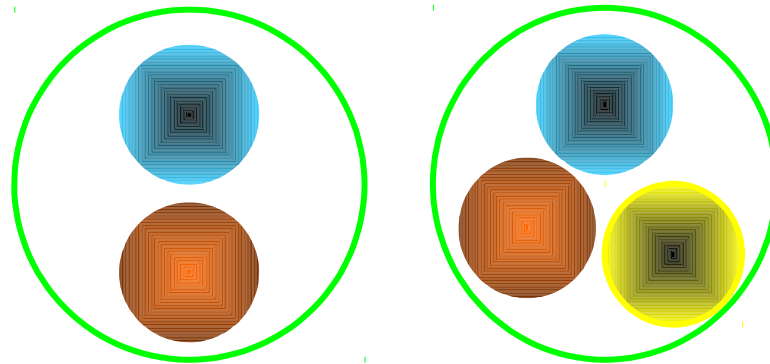
presented today

Observation of charged charmonium-like states

- Introduction
- Discovery of $Z_c(3900)$ & $Z_c(3885)$
 - $e^+e^- \rightarrow Y(4260) \rightarrow \pi^+\pi^-J/\psi$: PRL110, 252001 (2013)
 - $e^+e^- \rightarrow \pi^+(D\bar{D}^*)^- + \text{c.c.}$: PRL 112, 022001 (2014)
- Observation of $Z_c(4025)$ & $Z_c(4020)$
 - $e^+e^- \rightarrow \pi^+\pi^- h_c$: PRL111, 242001 (2013)
 - $e^+e^- \rightarrow D^{*+}\bar{D}^{*0}\pi^-$ (c.c.) : PRL112, 132001 (2014)

Exotic hadrons

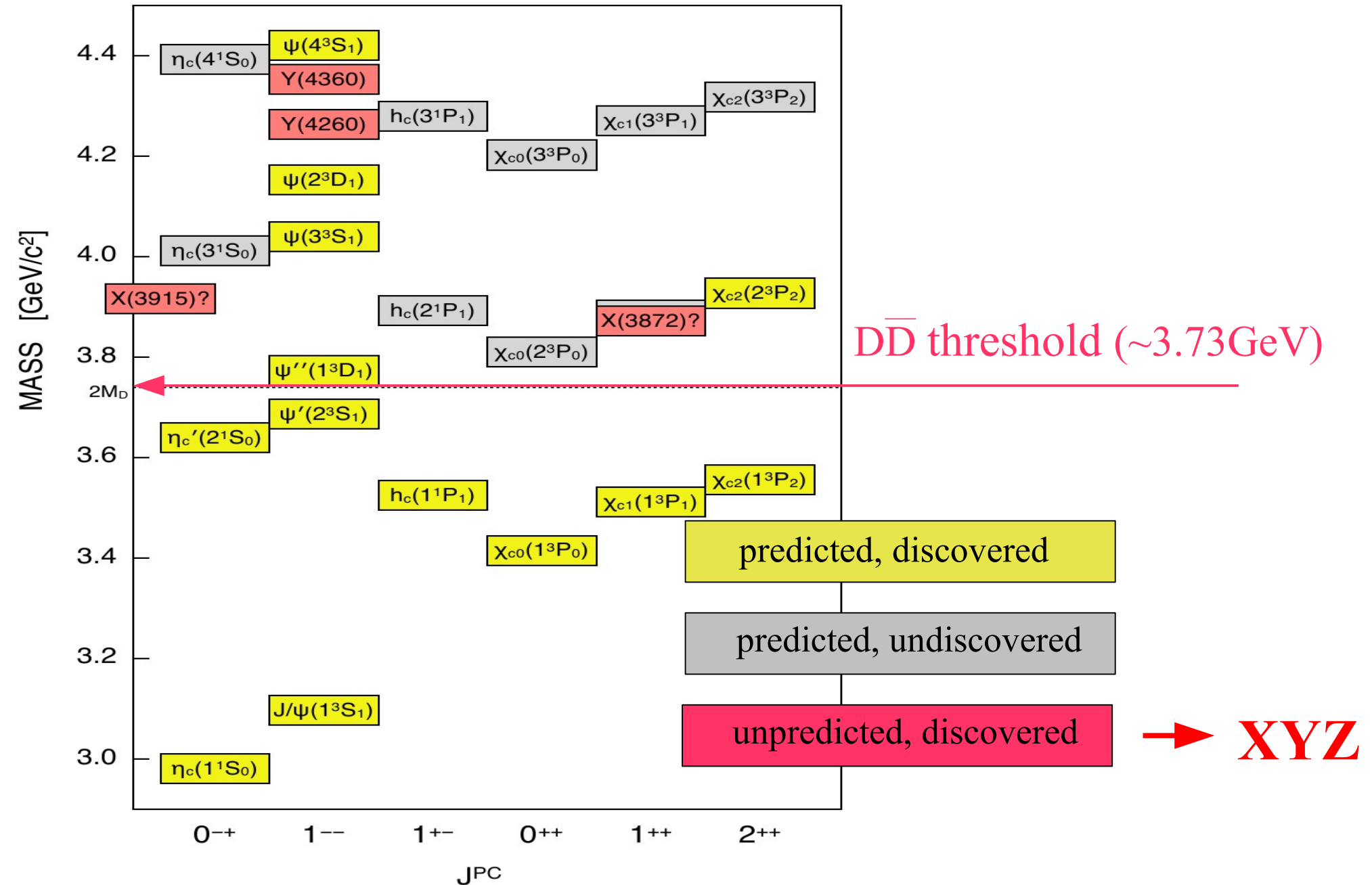
- ▶ Quark model: mesons – 2 quarks, baryons – 3 quarks



QCD imposes no restrictions on the number of quarks in hadrons:

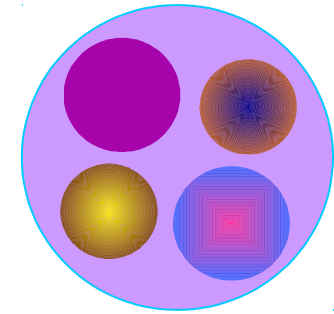
- ▶ glueball: $N_{\text{quarks}} = 0$ (gg, ggg, ...)
- ▶ hybrid: $N_{\text{quarks}} = 2$ (or more) + excited gluon
- ▶ multiquark state: $N_{\text{quarks}} > 3$
- ▶ molecule: bound state of more than 2 hadrons

Charmonium and XYZ – states



Z_c – charged charmonium-like meson

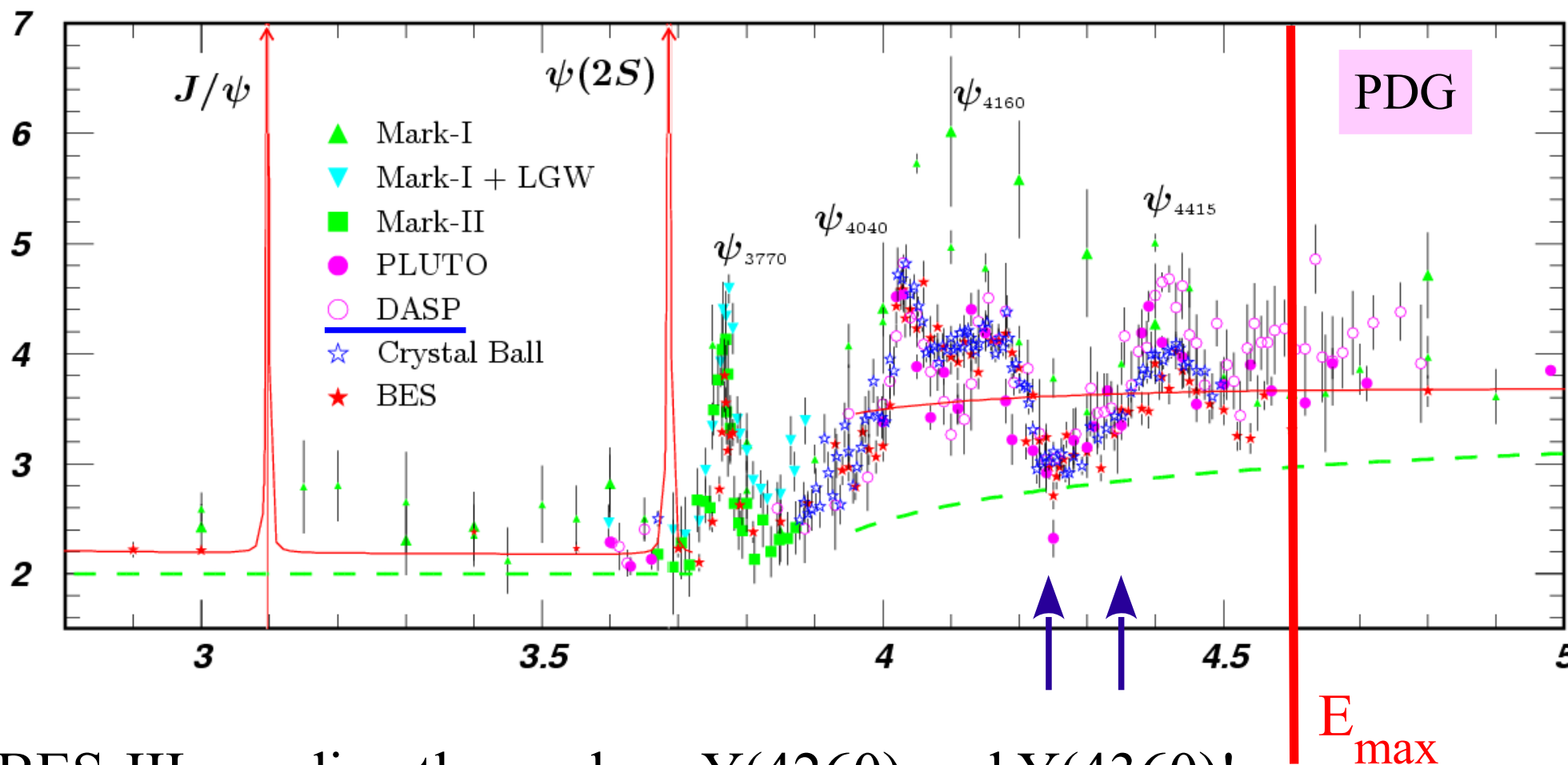
- Well defined signature of event:
 - decay into known charmonium state
 - electric charge $\Rightarrow N_{\text{quark}} \geq 4$



- Possible directions of searches:
 $\pi^\pm J/\psi$, $\pi^\pm h_c(1P)$, $\pi^\pm \psi(2S)$, $\pi^\pm \chi_{cJ} \dots$
- BES-III: $e^+e^- \rightarrow \pi^\pm + Z_c$; $e^+e^- \rightarrow \rho^\pm + Z_c \dots$

What can we do at BES-III?

R

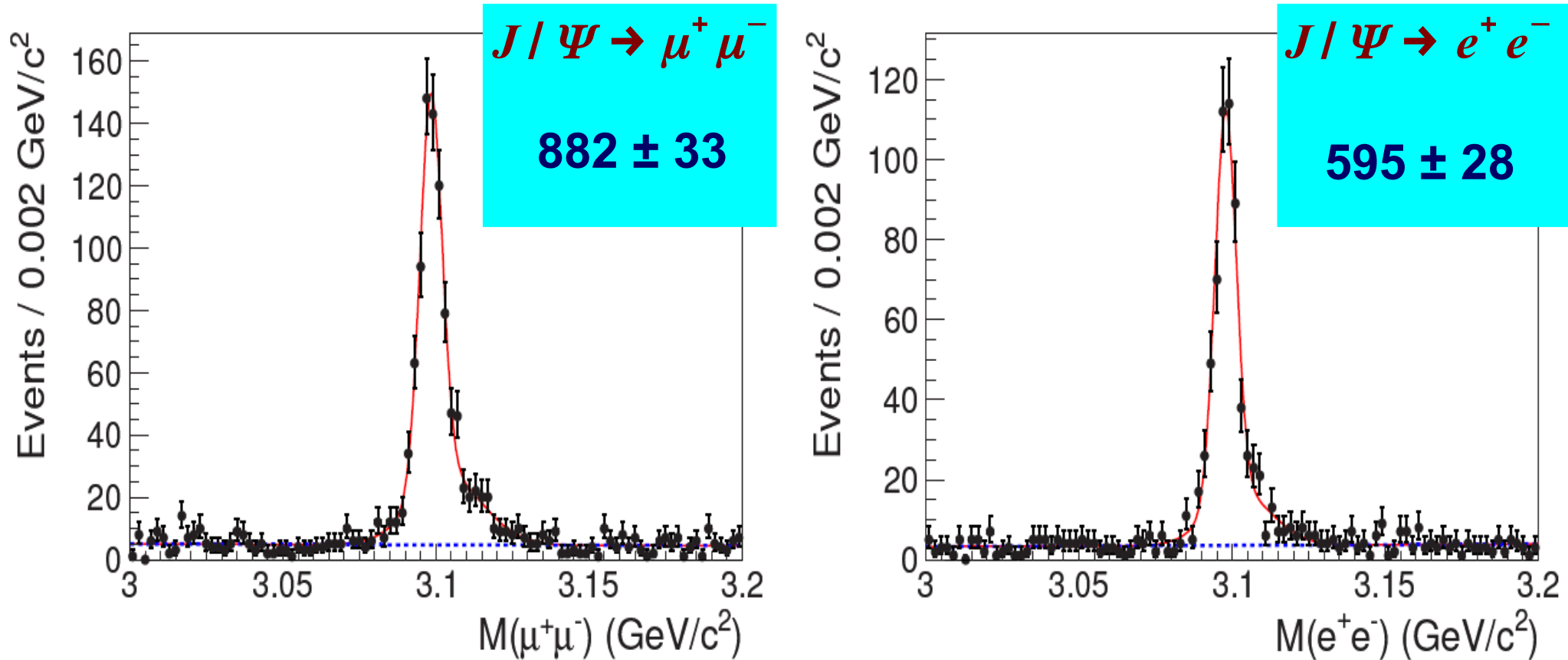


BES-III can directly produce $Y(4260)$ and $Y(4360)$!

$\sigma(e^+ e^- \rightarrow \pi^+ \pi^- J/\Psi)$ maximal for these energies

$$e^+e^- \rightarrow Y(4260) \rightarrow \pi^+\pi^-J/\psi$$

BES-III: PRL110, 252001

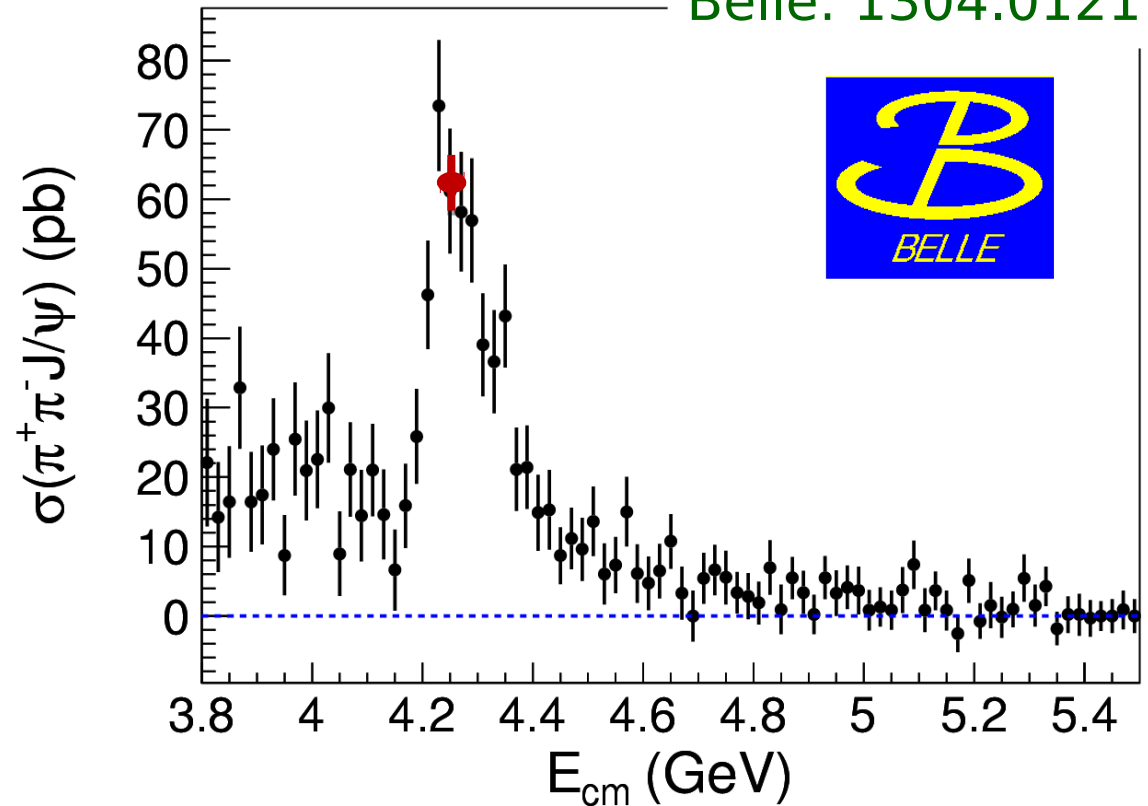
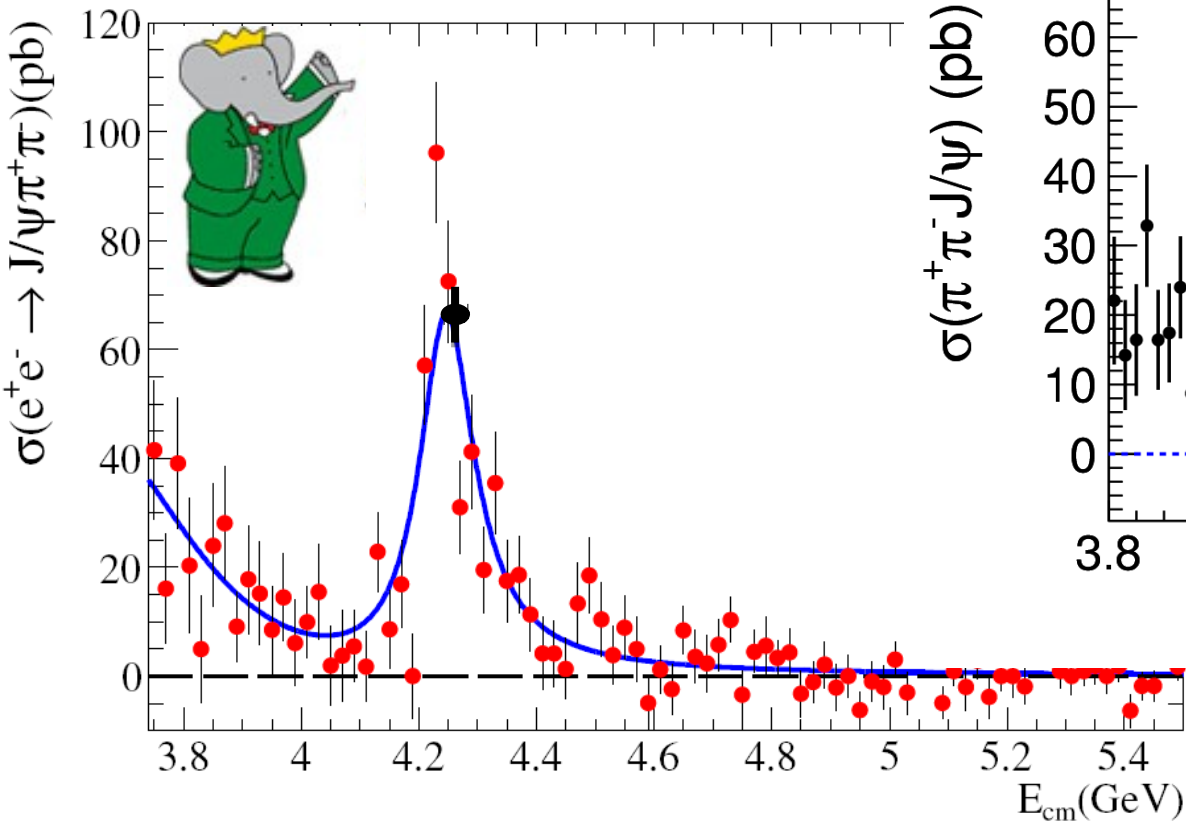


- Lum = 525 pb^{-1}
- J/ψ clearly identified in dilepton decay modes

Cross-section of $e^+e^- \rightarrow \pi^+\pi^- J/\psi$

Belle: 1304.0121

BaBar: PRD86, 051102 (2012)

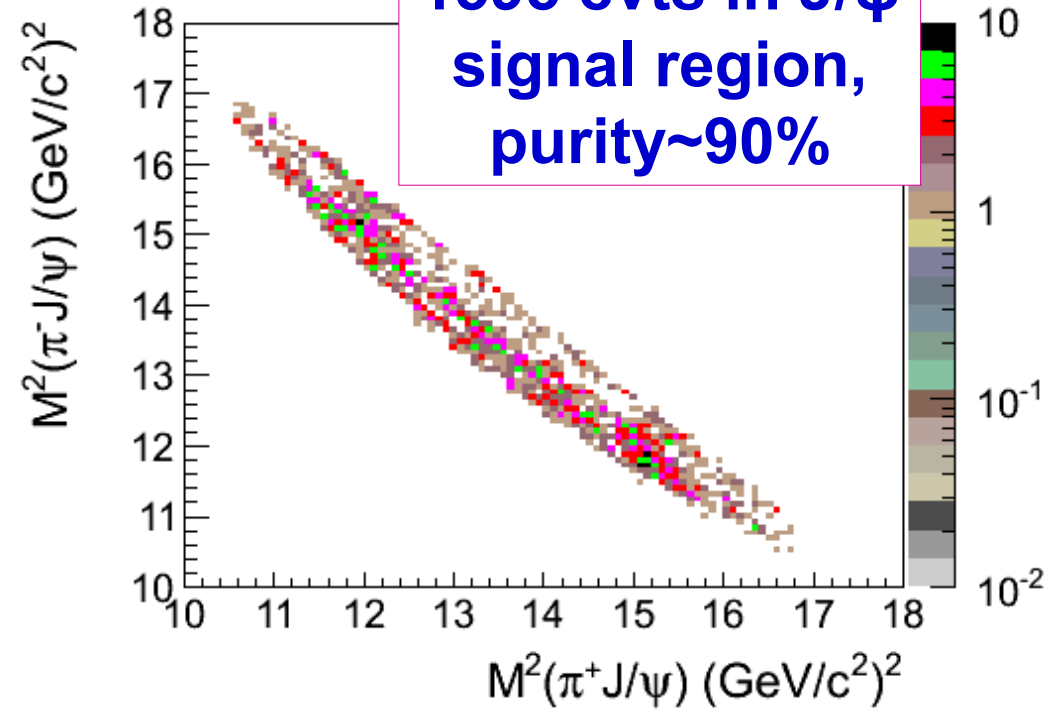
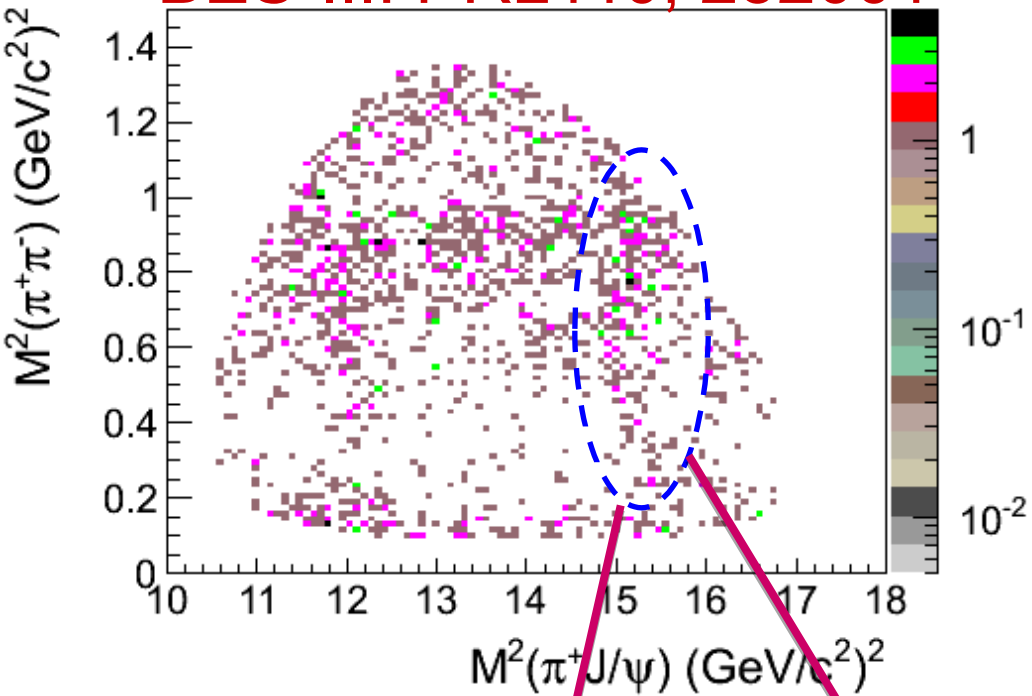


BES-III: PRL110, 252001: $\sigma(e^+e^- \rightarrow \pi^+\pi^- J/\psi) = 62.9 \pm 1.9 \pm 3.7$ pb

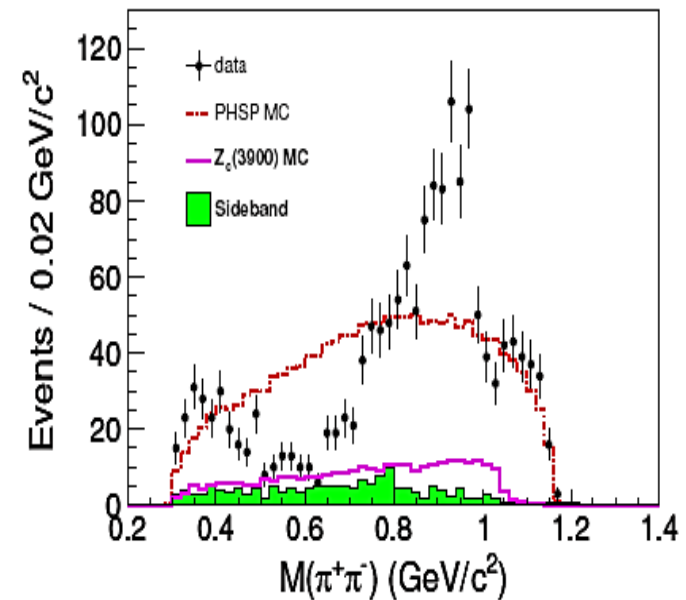
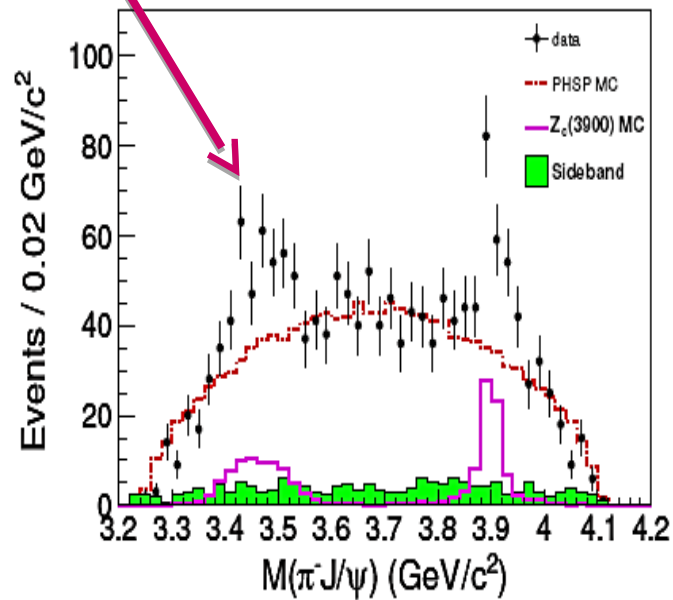
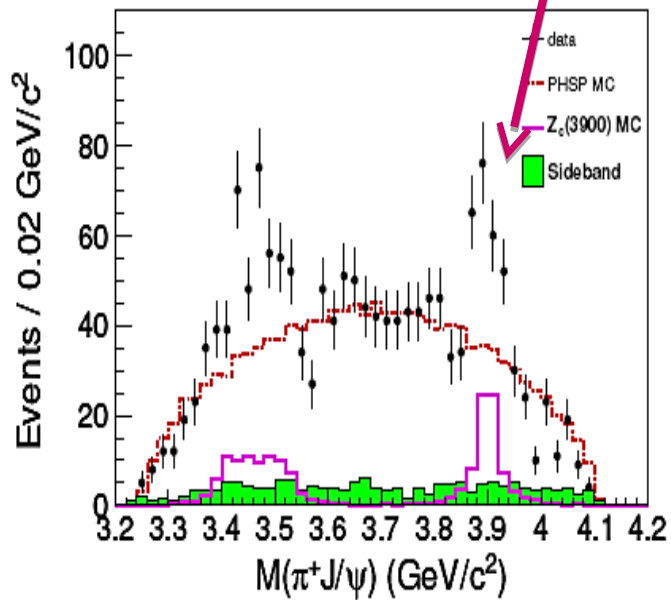
- good agreement with BaBar and Belle

Dalitz plots

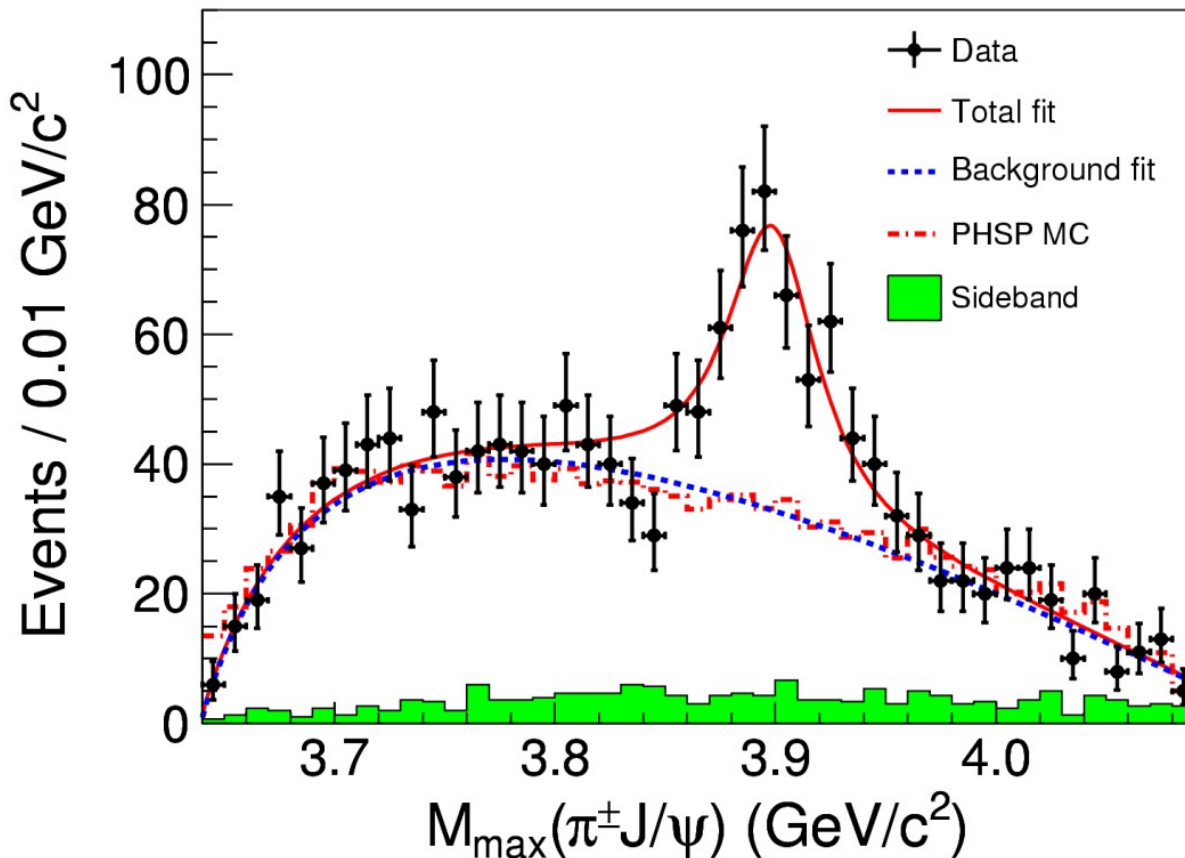
BES-III: PRL 110, 252001



1595 evts in J/ψ signal region, purity~90%



$Z_c(3900)$ in BES-III at 4.26 GeV



$M = 3899.0 \pm 3.6 \pm 4.9$ MeV

$\Gamma = 46 \pm 10 \pm 20$ MeV

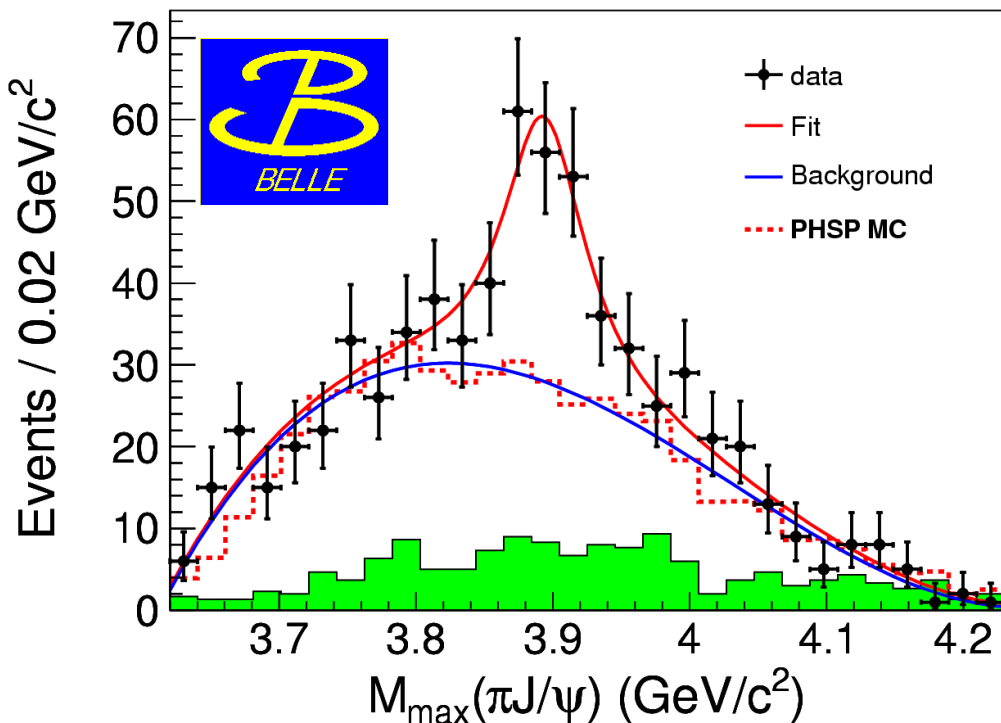
307 ± 48 events

Significance $> 8\sigma$

PRL 110, 252001 (2013): >150 citations

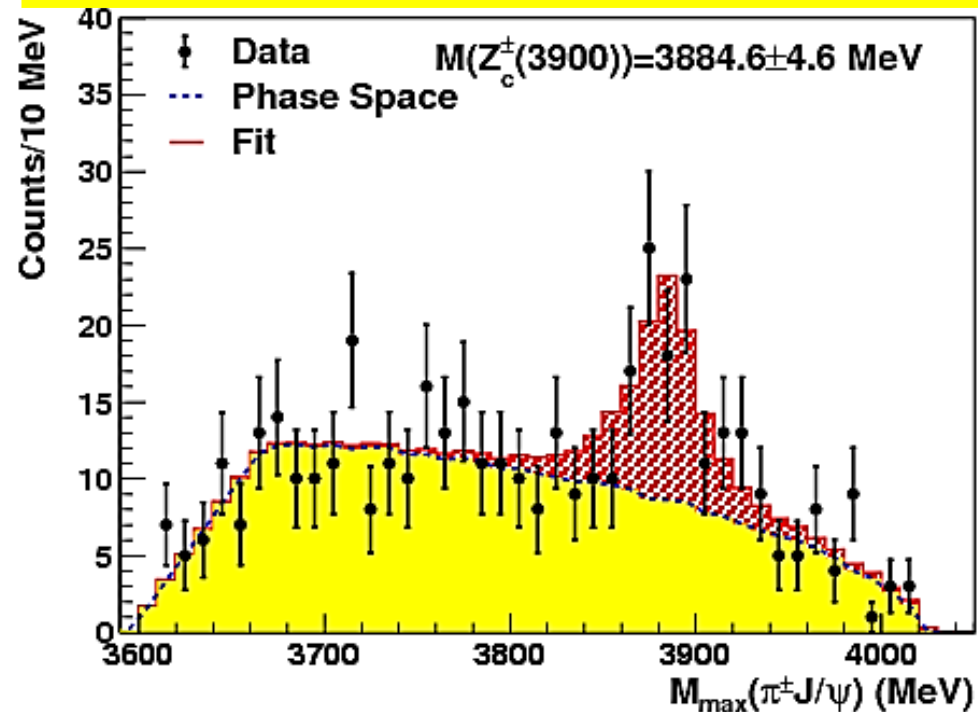
$Z_c^\pm(3900)$ – the first charged charmonium-like state
confirmed by other experiments!

Belle: $e^+e^- \rightarrow \gamma(\text{ISR}) + \pi^+\pi^- J/\psi$
 Belle: PRL110, 252002



$M = 3894.5 \pm 6.6 \pm 4.5 \text{ MeV}$
 $\Gamma = 63 \pm 24 \pm 26 \text{ MeV}$
 $159 \pm 49 \text{ events}$
 $> 5.2\sigma$

CLEOc: $e^+e^- \rightarrow \psi(4160) \rightarrow$
 $\rightarrow \pi^+\pi^- J/\psi$ (PLB727,366)

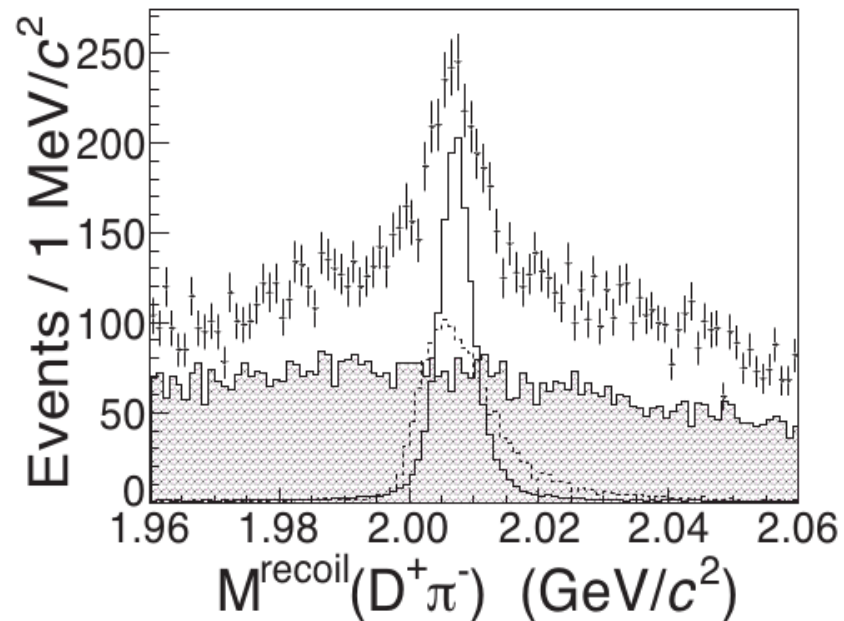
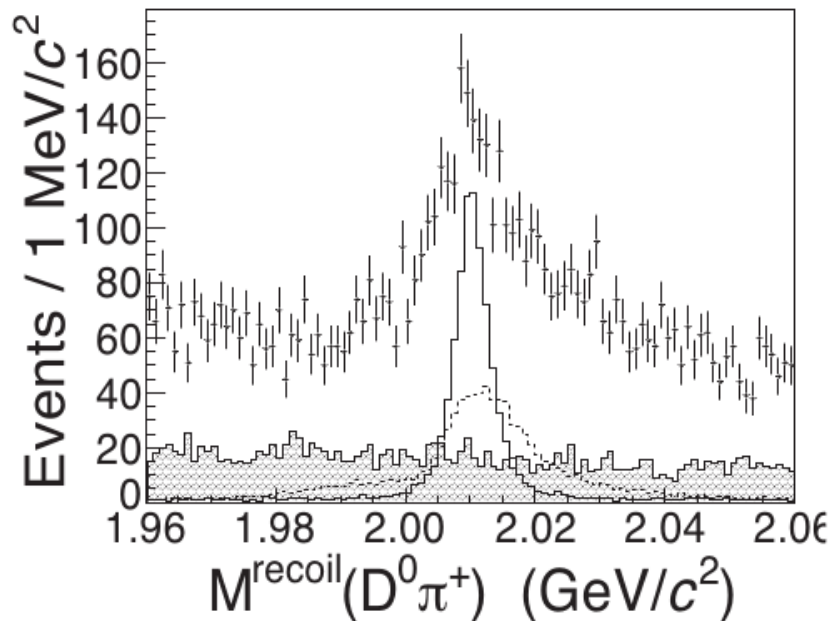
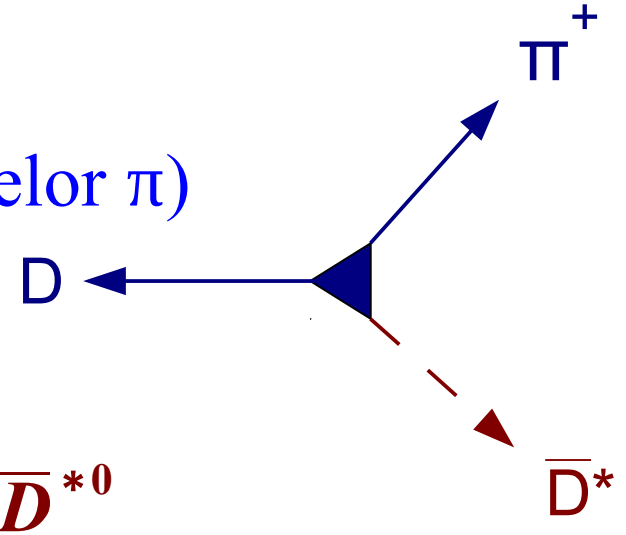


$M = 3886 \pm 4 \pm 2 \text{ MeV}$
 $\Gamma = 37 \pm 4 \pm 8 \text{ MeV}$
 $81 \pm 16 \text{ events}$
 $> 5\sigma$

$e^+e^- \rightarrow \pi^+(D\bar{D}^*)^- + \text{c.c.}$ at $\sqrt{s} = 4.26$ GeV

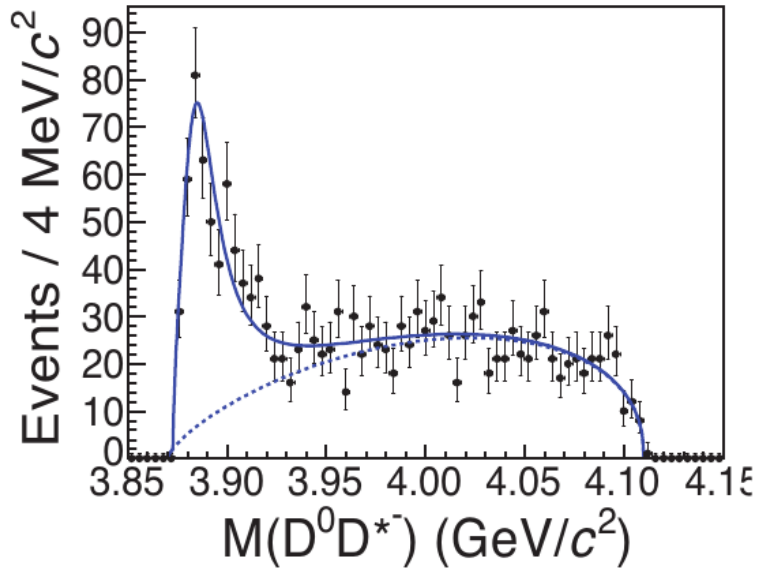
Strategy:

- 1) π^+ or π^- from primary vertex (a bachelor π)
- 2) $D^0 \rightarrow K^- \pi^+$ or $D^+ \rightarrow K^- \pi^+ \pi^+$
- 3) missing mass of D^* :

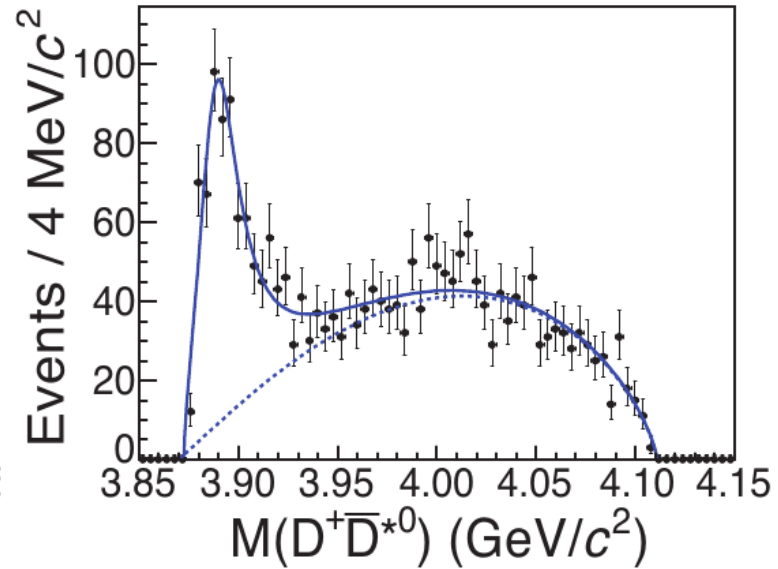


$$e^+e^- \rightarrow \pi^\pm Zc(3885) \rightarrow \pi^\pm (D\bar{D}^*)^\mp$$

PRL 112, 022001 (2014)



$M = 3882.2 \pm 1.5$ MeV
 $\Gamma = 24.6 \pm 3.3$ MeV
 $N(Zc) = 502 \pm 41$

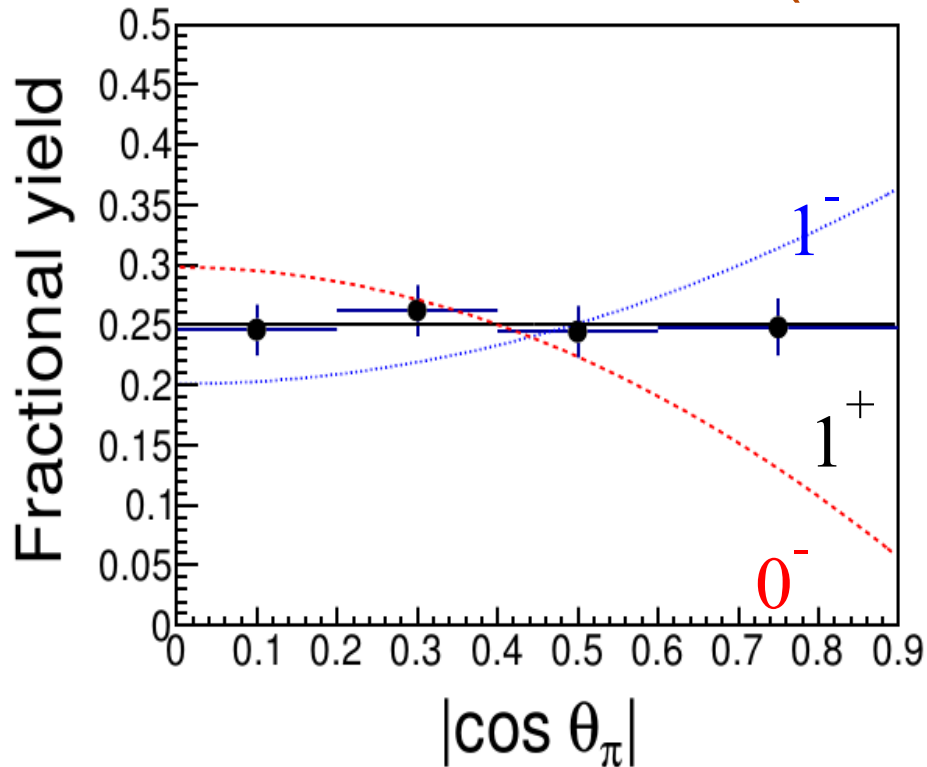


$M = 3885.5 \pm 1.5$ MeV
 $\Gamma = 24.9 \pm 3.2$ MeV
 $N(Zc) = 710 \pm 54$

$M = 3883.9 \pm 1.5 \pm 4.2$ MeV
 $\Gamma = 24.8 \pm 3.3 \pm 11.0$ MeV

Quantum numbers of $Z_c(3885)$

PRL 112, 022001 (2014)



$\cos(\theta_\pi)$ – angle of bachelor π^+
in the CMS

$J^P=0^-$, $dN/d \cos(\theta_\pi) \sim 1 - \cos^2(\theta_\pi)$

$J^P=1^-$, $dN/d \cos(\theta_\pi) \sim 1 + \cos^2(\theta_\pi)$

$J^P=1^+$, $dN/d \cos(\theta_\pi) \sim \text{flat}$

$J^P=0^+$, parity conservation

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

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

PRL 111, 242001 (2013)

- Data: 13 energy points in [3.90; 4.42] GeV; Lum = 827 pb⁻¹
- $h_c \rightarrow \gamma \eta_c$ (~50% all decays of h_c);
 $\eta_c \rightarrow p \bar{p}, 2(\pi^+ \pi^-), 2(K^+ K^-), K^+ K^- \pi^+ \pi^- \dots$
16 exclusive decay modes

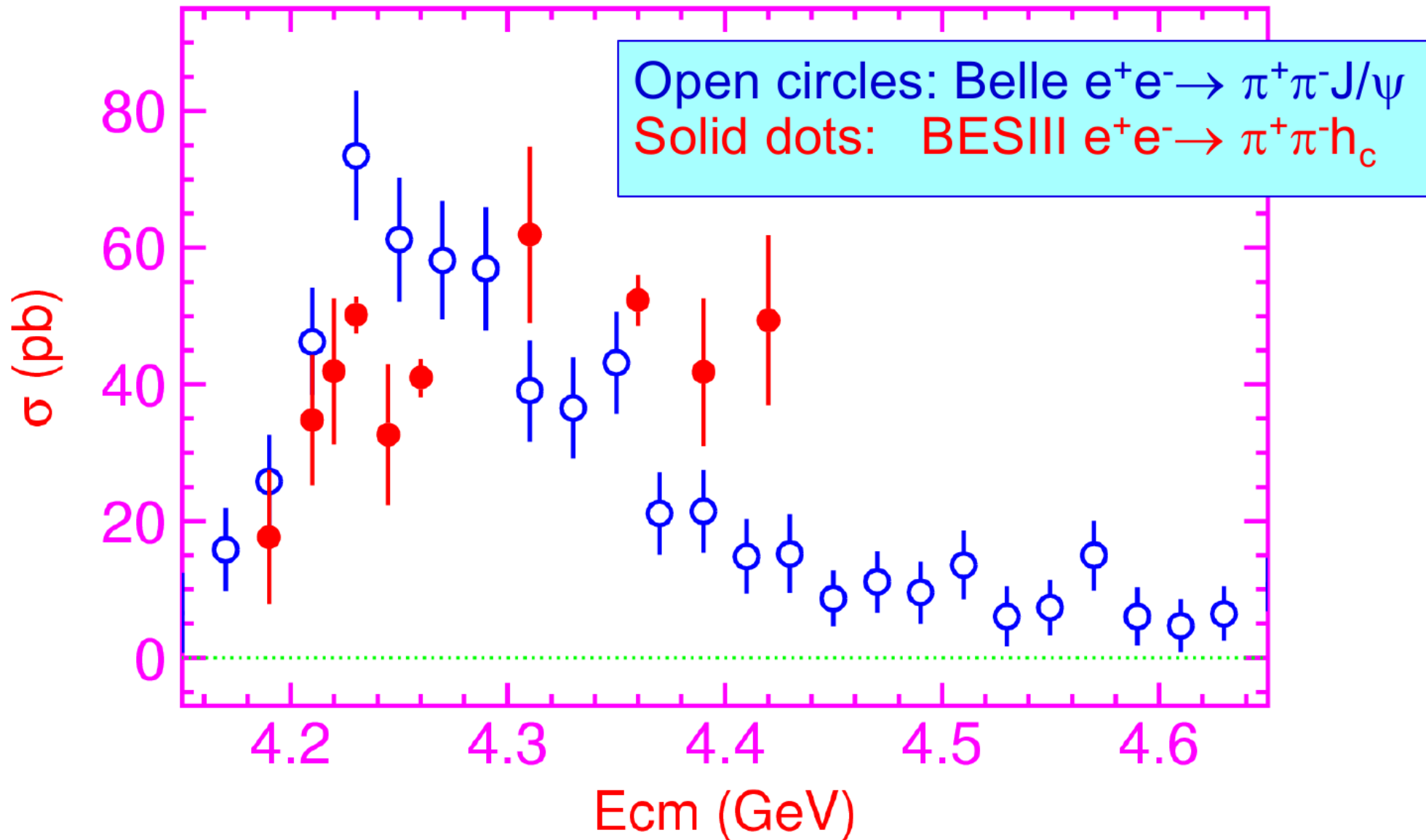
**Currently the most precise measurements
parameters of η_c BES-III: PRL 108, 222002 (2012)**

$$M(\eta_c) = 2984.3 \pm 0.6 \pm 0.6 \text{ MeV}$$

$$\Gamma(\eta_c) = 32.0 \pm 1.2 \pm 1.0 \text{ MeV}$$

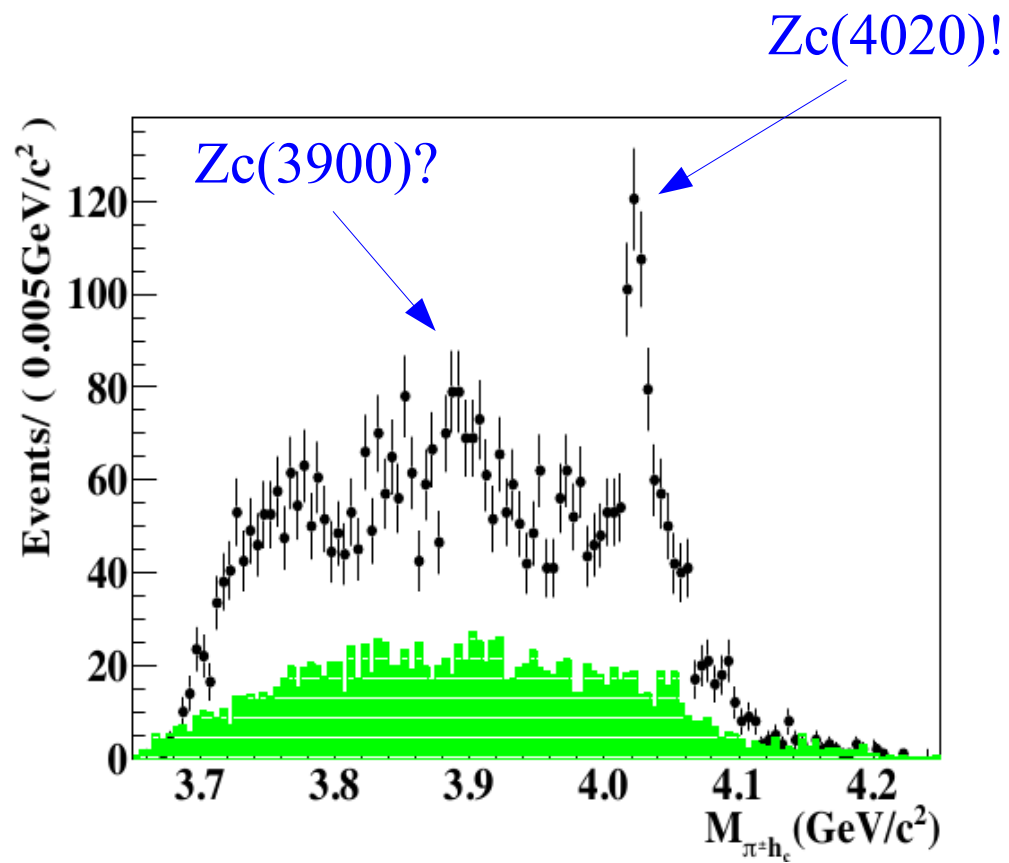
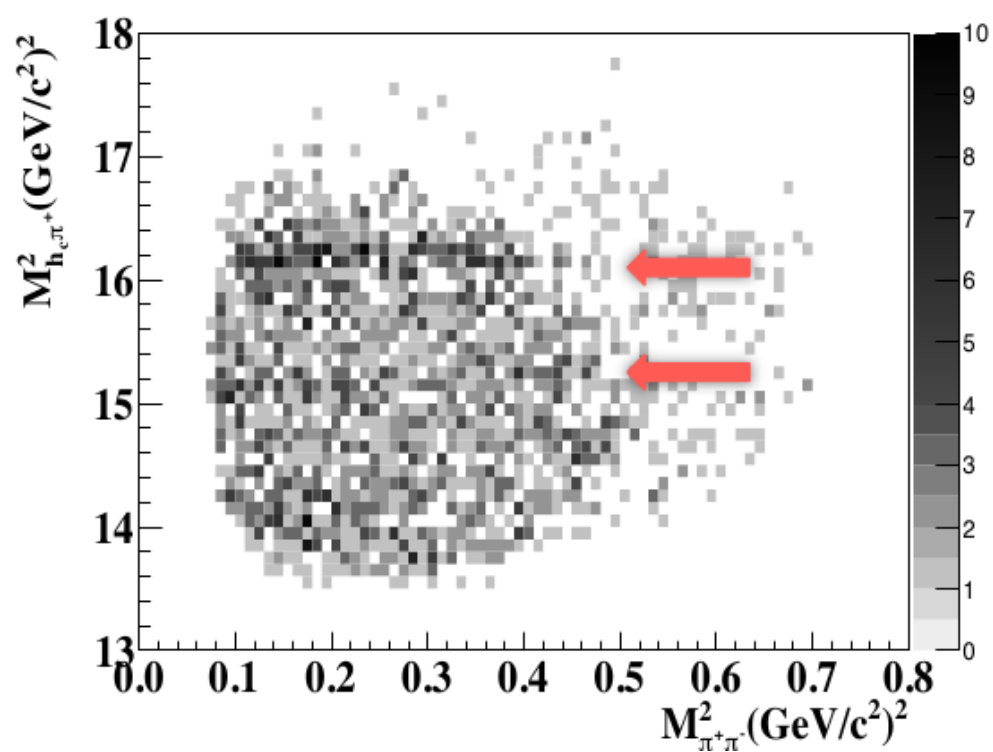
Cross-section:

$$e^+e^- \rightarrow \pi^+\pi^-h_c \quad \text{vs} \quad e^+e^- \rightarrow \pi^+\pi^-J/\psi$$

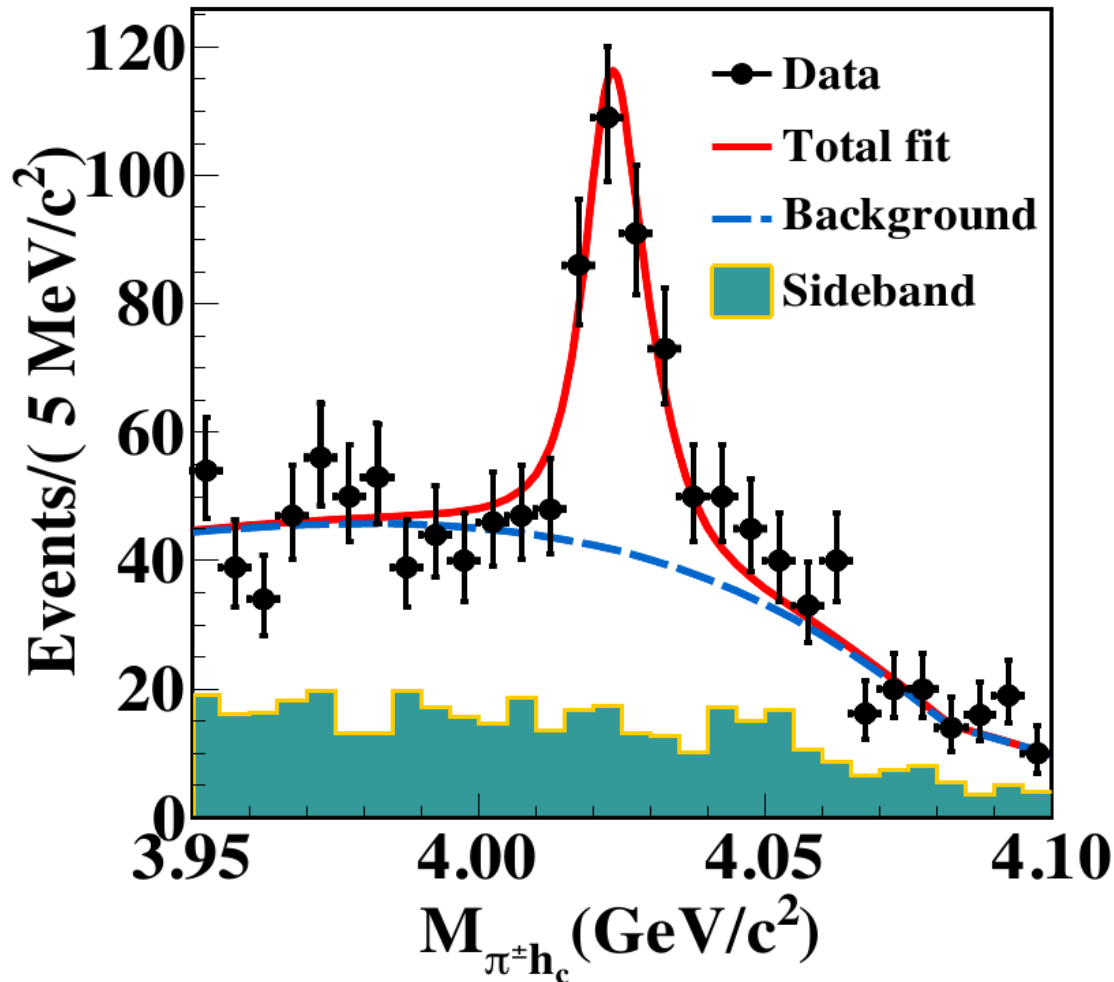


Dalitz plot

All data combined!



$$e^+e^- \rightarrow \pi^\pm Z_c(4020)^\mp \rightarrow \pi^+\pi^- h_c$$



PRL 111, 242001 (2013)

$M = 4022.9 \pm 0.8 \pm 2.7 \text{ MeV}$

$\Gamma = 7.9 \pm 2.7 \pm 2.6 \text{ MeV}$

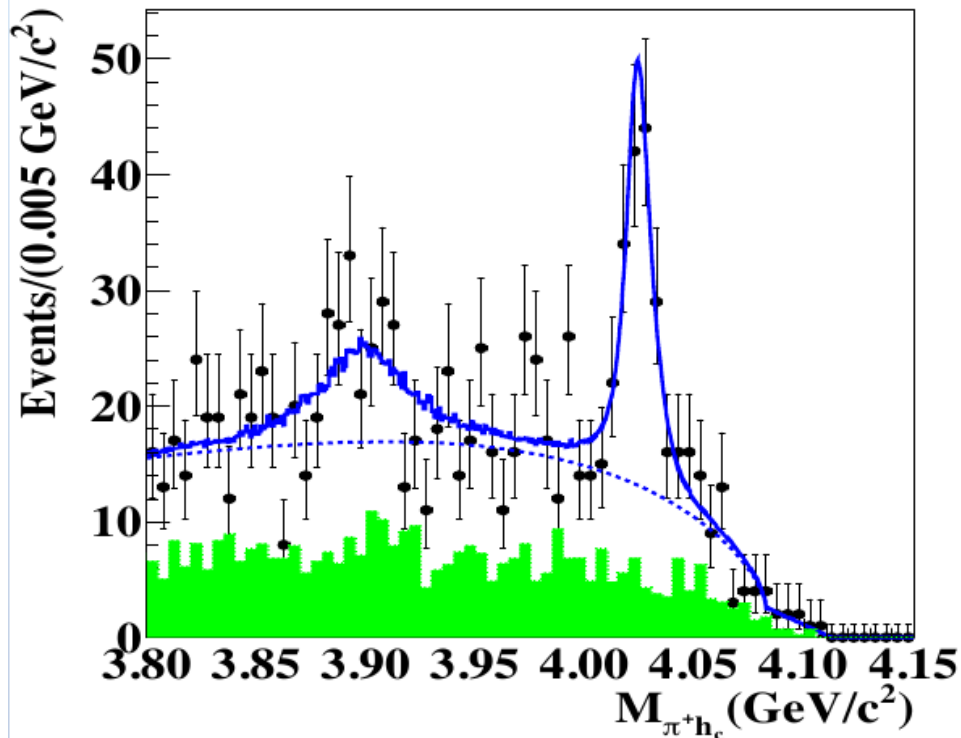
Significance $> 8.9 \sigma$

E [GeV]	N($Z_c(4020)^\pm$)
4.23	114 ± 25
4.26	72 ± 17
4.36	67 ± 15

- ♦ independent fit of each period of the data set
- ♦ independent fit of $\pi^+ h_c$ and $\pi^- h_c$

What about $Z_c(3900) \rightarrow \pi^\pm h_c$?

- only 4.23 and 4.26 GeV
- parameters of $Z_c(3900)$ were fixed at the previous BES-III measurements



significance $\sim 2.1\sigma$

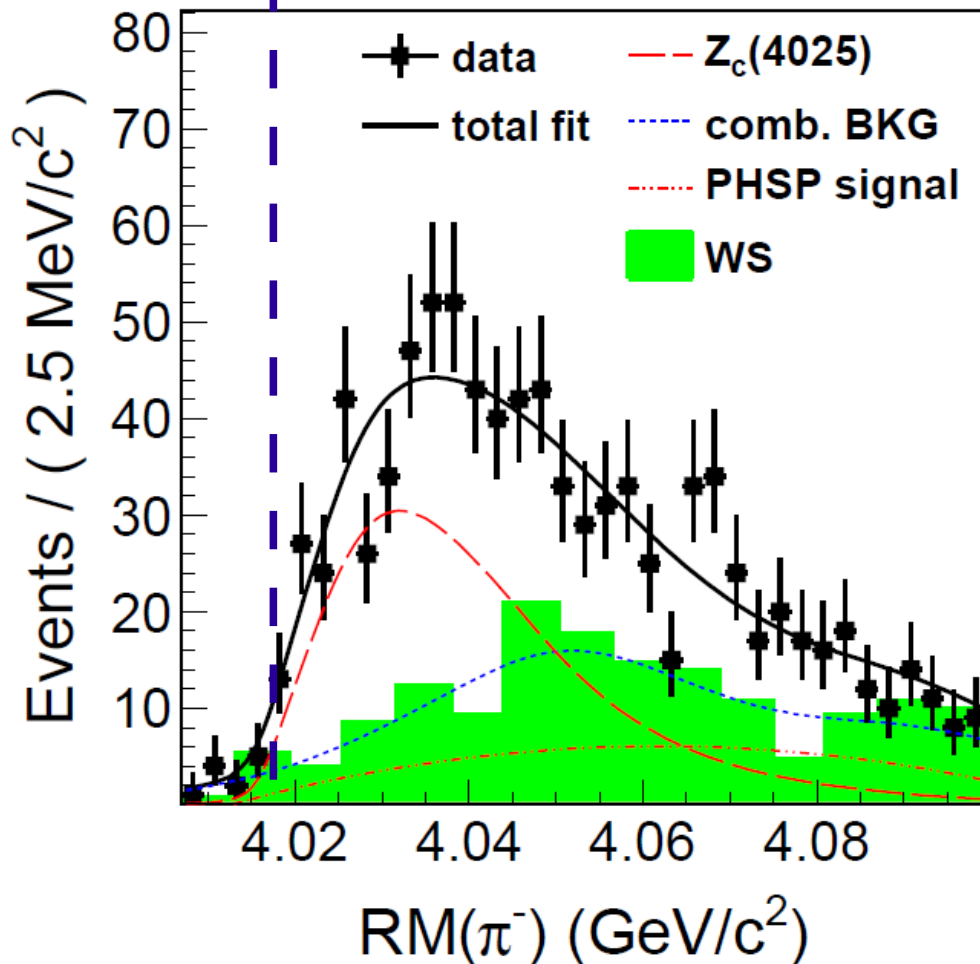
$$\sigma(e^+e^- \rightarrow \pi^\pm Z_c^\mp(3900) \rightarrow \pi^+\pi^-h_c)$$

E [GeV]	σ [pb]	90% CL
4.23		< 13
4.26		< 11

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

- data: 827 pb⁻¹ at 4.26 GeV

$$m(D^{*+}) + m(\bar{D}^{*0})$$



PRL 112, 132001 (2014)

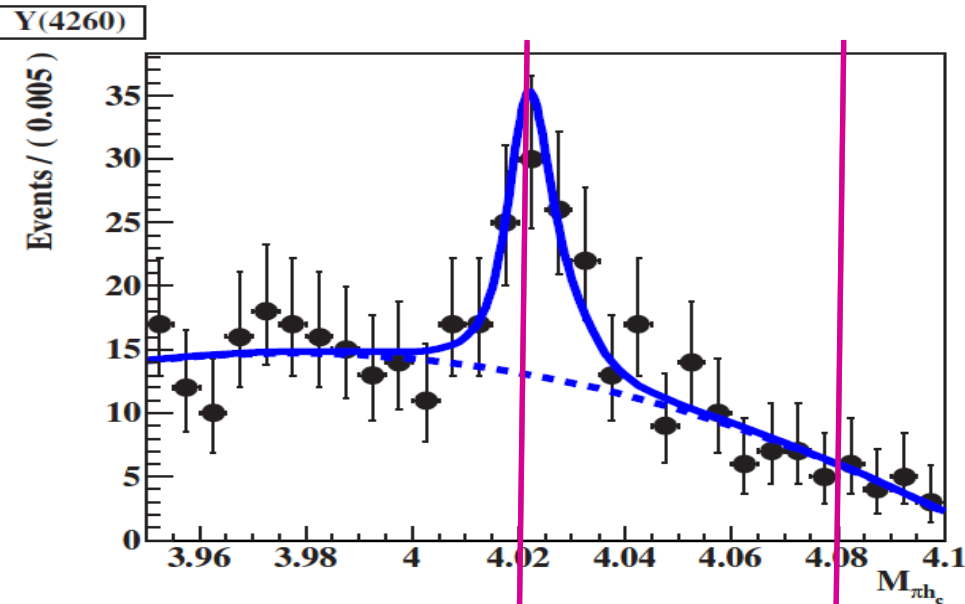
$$M = 4026.3 \pm 2.6 \pm 3.7 \text{ MeV}$$

$$\Gamma = 24.8 \pm 5.6 \pm 7.7 \text{ MeV}$$

$$N = 401 \pm 47$$

$$\text{Significance} > 10 \sigma$$

$Z_c(4025) = Z_c(4020)$?

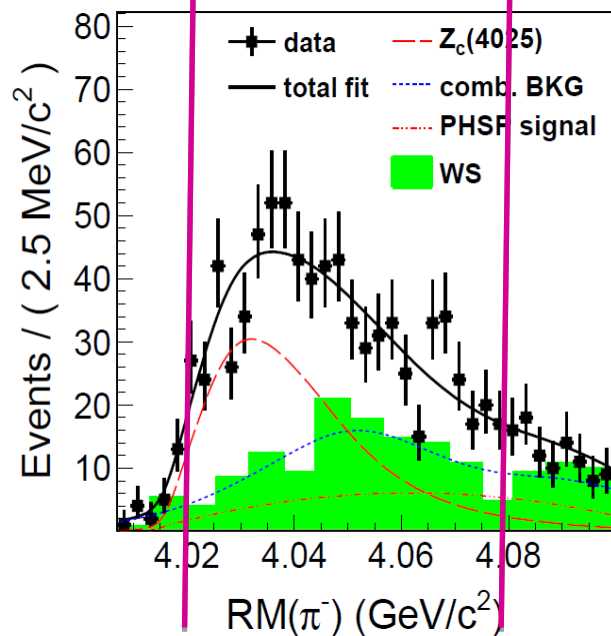


- $M(4020) = 4022.9 \pm 0.8 \pm 2.7$ MeV
- $M(4025) = 4026.3 \pm 2.6 \pm 3.7$ MeV
- $\Gamma(4020) = 7.9 \pm 2.7 \pm 2.6$ MeV
- $\Gamma(4025) = 24.8 \pm 5.6 \pm 7.7$ MeV

Mass consistent with each other but width $\sim 1.5\sigma$ difference

Close to D^*D^* threshold (4017 MeV)

Interference with other amplitudes may change the results



Summary of Zc mesons

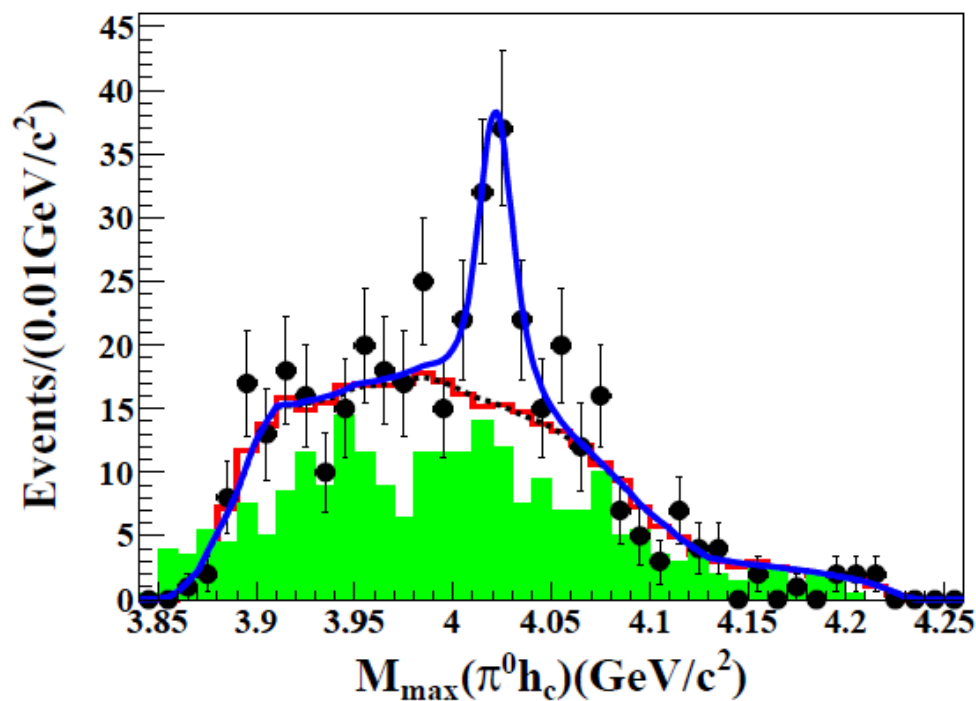
Channel	Mass [MeV/c ²]	Width [MeV]
$J/\psi \pi^+$	$3899.0 \pm 3.6 \pm 4.9$	$46 \pm 10 \pm 20$
$(D\bar{D}^*)^+$	$3883.9 \pm 1.5 \pm 4.2$	$24.8 \pm 3.3 \pm 11.0$
$h_c \pi^+$	$4022.9 \pm 0.8 \pm 2.7$	$7.9 \pm 2.7 \pm 2.6$
$(D^*\bar{D}^*)^+$	$4026.3 \pm 2.6 \pm 3.7$	$24. \pm 5.6 \pm 7.7$

- Zc(3900) & Zc(3885) close to $D\bar{D}^*$ threshold (3875MeV)
- Zc(4020) & Zc(4025) close to $D^*\bar{D}^*$ threshold (4017MeV)

Neutral isospin partner of $Z_c(4020)$:

$$e^+e^- \rightarrow \pi^0 Z_c(4020)^0 \rightarrow \pi^0 \pi^0 h_c$$

- Simultaneous fit of 4.23; 4.26 and 4.36 GeV data



PRELIMINARY BES-III

$$M = 4023.6 \pm 2.2 \pm 3.9 \text{ MeV}$$

Γ – fixed to charged $Z_c(4020)^\pm$

Significance $> 5 \sigma$

Summary

- **BES-III successfully takes data since 2009. World largest data samples of J/ψ , $\psi(2S)$, $\psi(3770)$, $\psi(4040)$ and $Y(4260)$ are collected and are growing.**
- **Number of physical results are published, among recent:**
 - **Observation of a charged charmoniumlike structure in $e^+e^- \rightarrow \pi^+\pi^-J/\psi$ at $\sqrt{s} = 4.26$ GeV (*PRL 110, 252001(2013)*)**
 - **Observation of a charged $(D\bar{D}^*)$ - mass peak in $e^+e^- \rightarrow \pi^+(D\bar{D}^*)$ at $E_{cm} = 4.26$ GeV (*PRL 112, 022001(2014)*)**
 - **Observation of a charged charmoniumlike structure $Z_c(4020)$ and search for the $Z_c(3900)$ in $e^+e^- \rightarrow \pi^+\pi^-h_c$ (*PRL 111, 242001(2013)*)**
 - **Observation of a charged charmoniumlike structure in $e^+e^- \rightarrow \pi^-(D^*\bar{D}^*)^+$ at $\sqrt{s} = 4.26$ GeV (*PRL 112, 132001(2014)*)**
- **Preliminary observation of neutral partner of $Z_c(4020)$ is presented.**
- **Expect much more results from BES-III in coming years.**