

“The landscape of Flavour Physics towards the high intensity era”
XXII International Baldin Seminar on High Energy Physics Problems
9th - 10th December 2014
Palazzo della Carovana
Scuola Normale Superiore – Pisa (ITALY)



Status and Prospects of BES III Experiment

Marco Maggiora on behalf of the BESIII Collaboration
Department of Physics and INFN – Turin, Italy





BESIII Collaboration

<http://bes3.ihep.ac.cn>

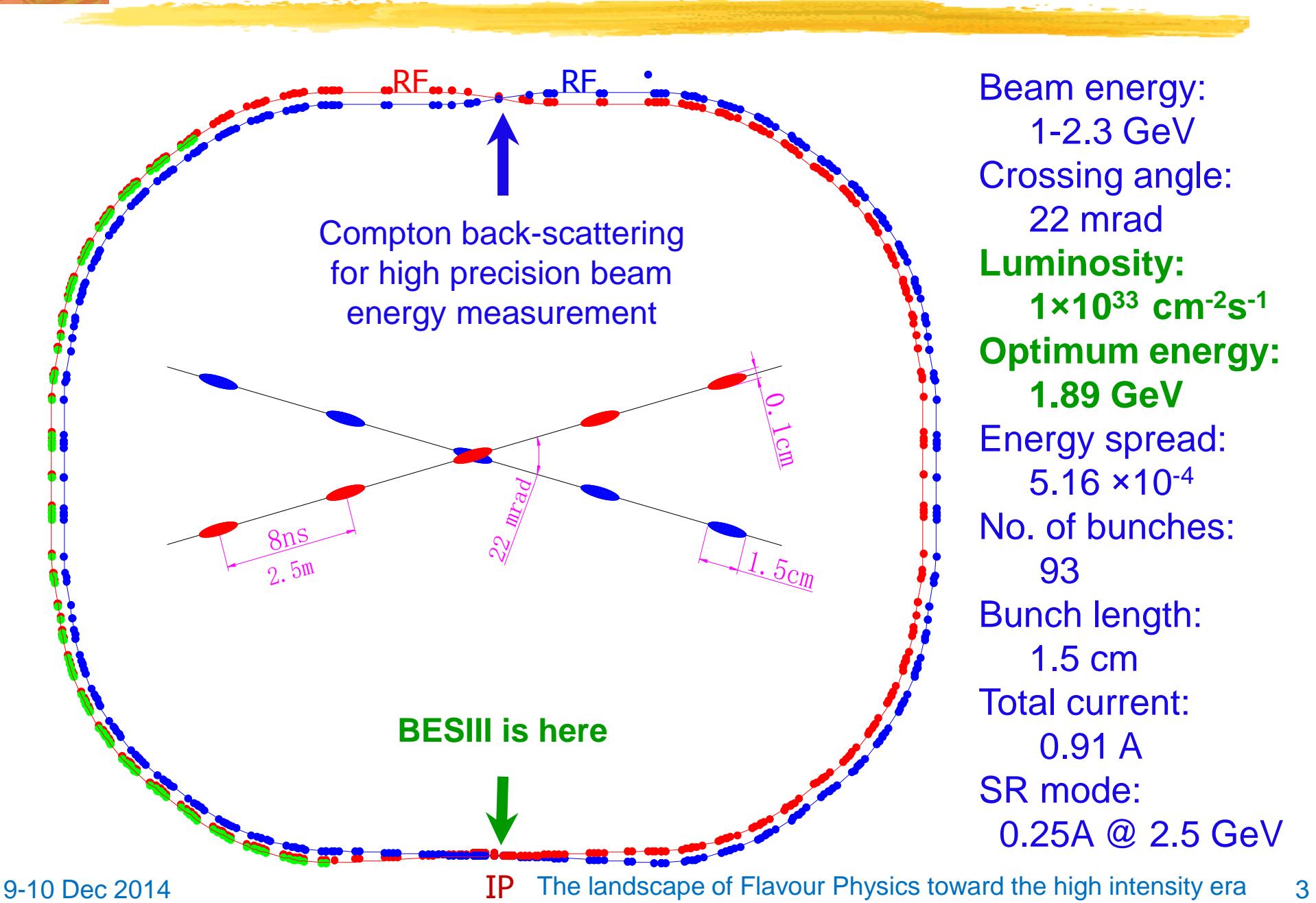
Political Map of the World, June 1999



~350 members
53 institutions
11 countries

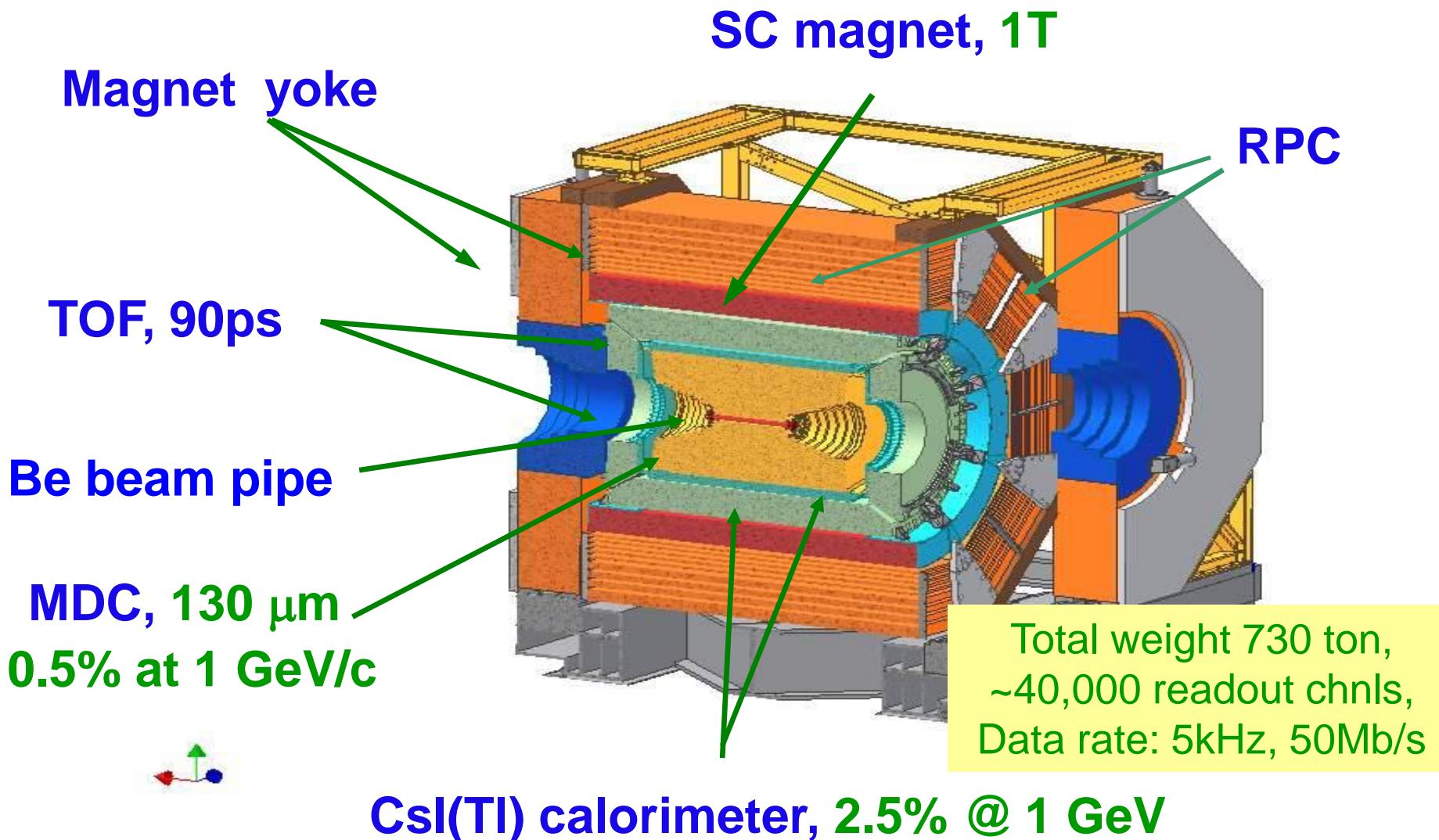


BEPCII



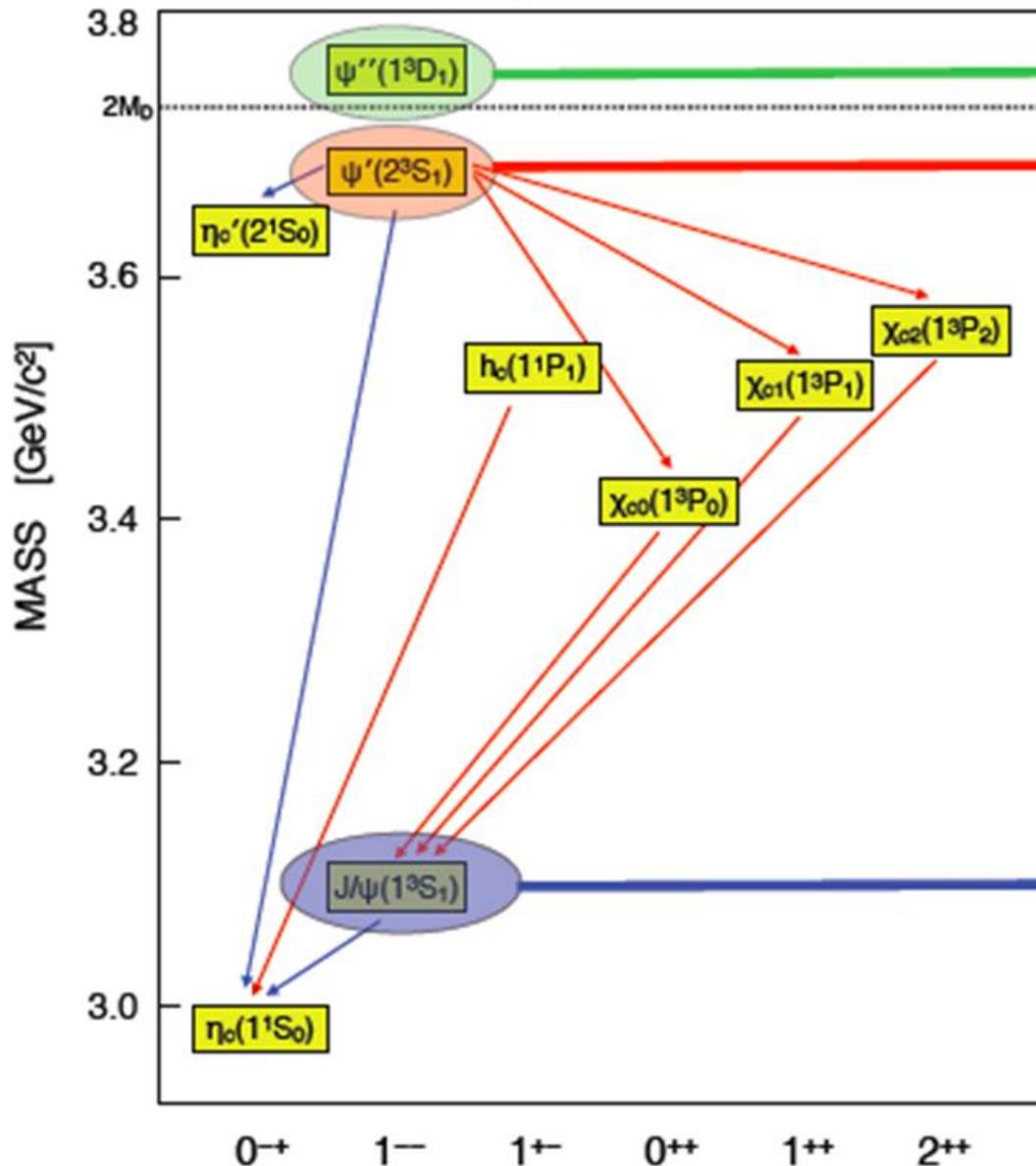


BESIII Spectrometer





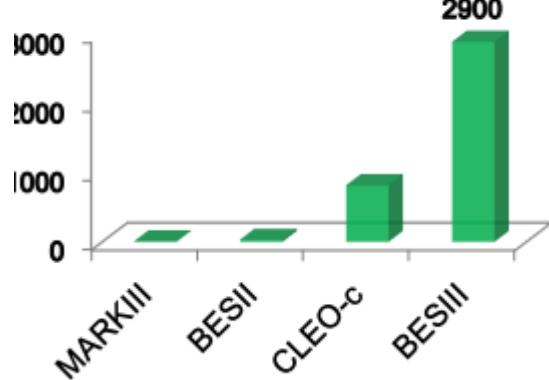
BESIII data set



2.9 fb⁻¹ / 20 fb⁻¹

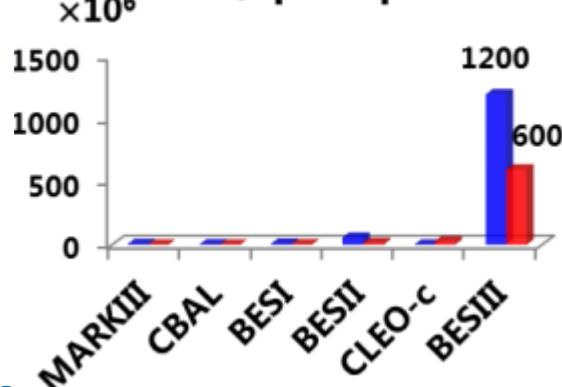
0.6 B / 3 B (106 M)

pb⁻¹ $\Psi(3770)$



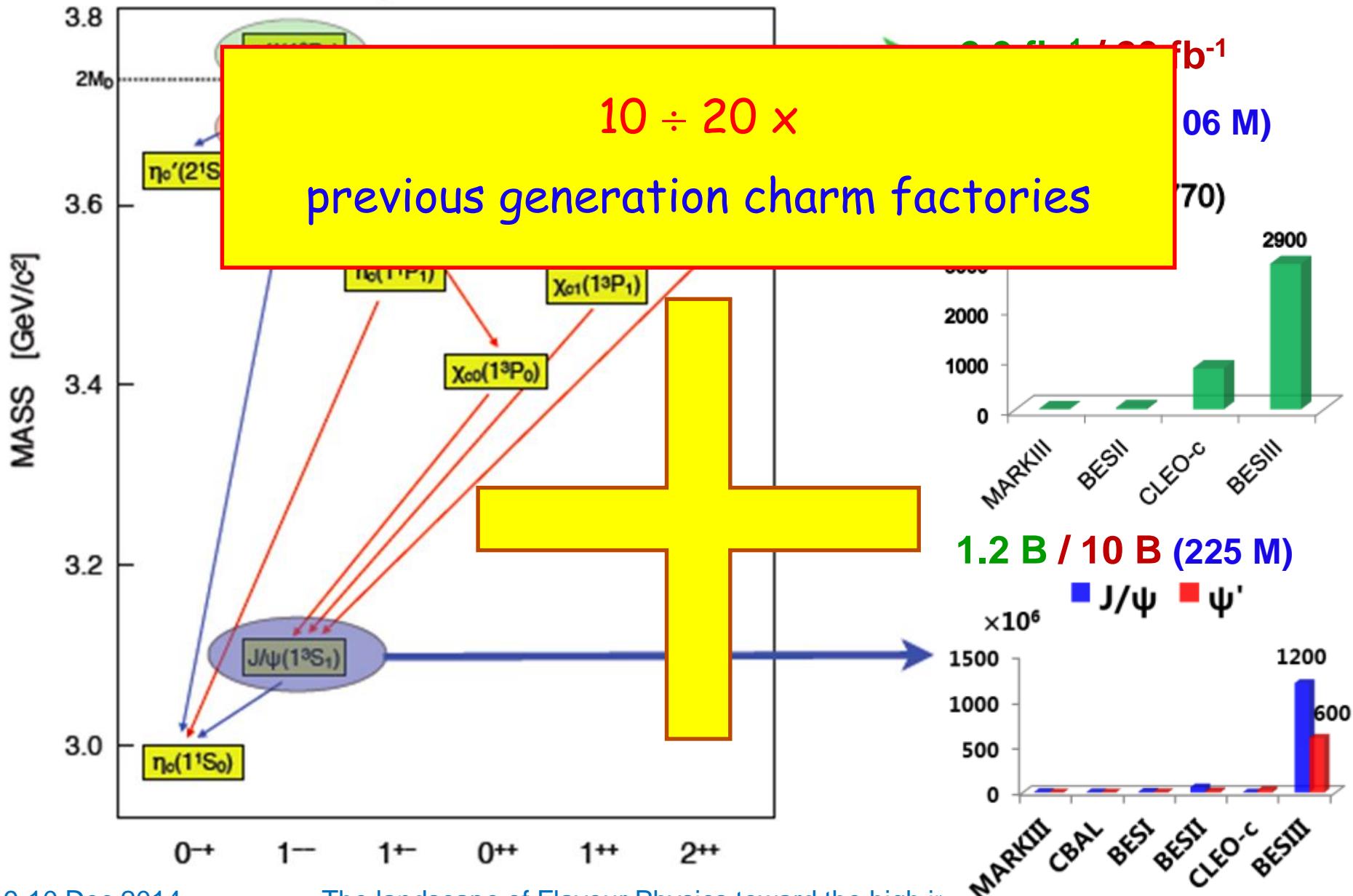
1.3 B / 10 B (225 M)

\square J/ ψ \blacksquare Ψ'





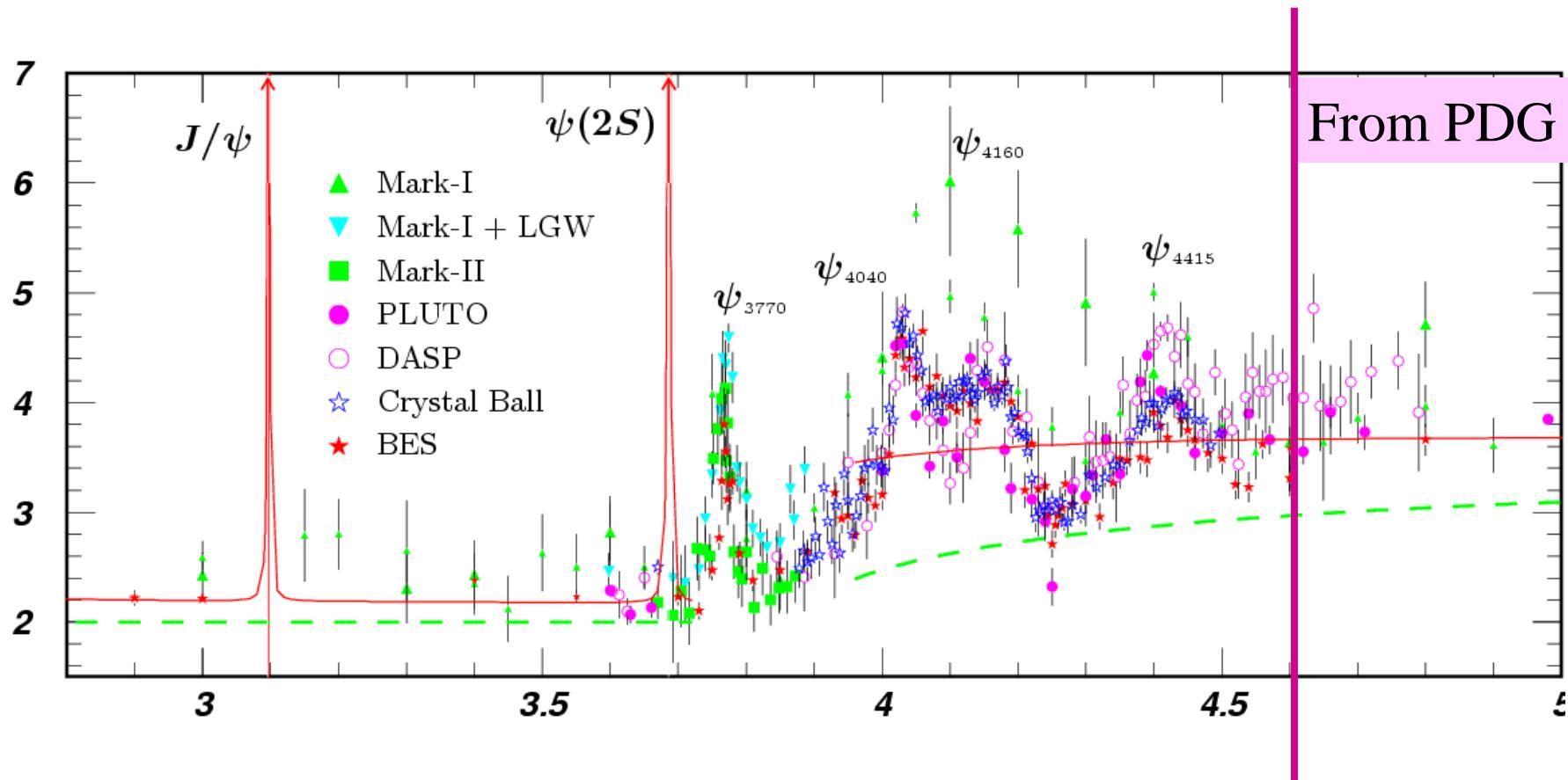
BESIII data set





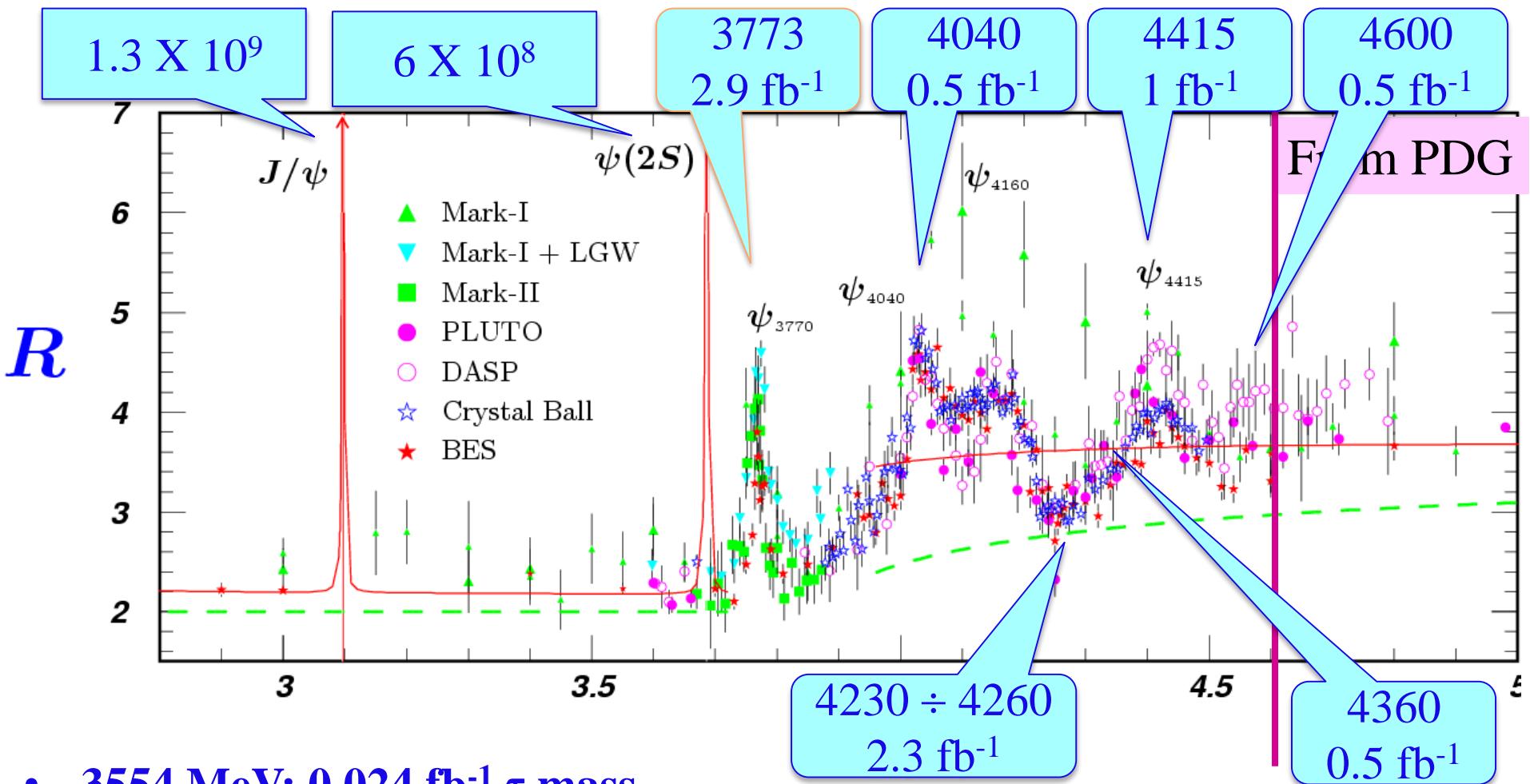
BESIII production of Charmonium(like) states

R





BESIII production of Charmonium(like) states



- **3554 MeV: 0.024 fb^{-1} τ mass**
- **$4100 \div 4400 \text{ MeV: } 0.5 \text{ fb}^{-1}$ coarse scan**
- **$3850 \div 4590 \text{ MeV: } 0.5 \text{ fb}^{-1}$ fine scan**

BEPCII can reach here!



■ best solution:

- $f_0(1500), f_0(1710), f_0(2100);$
 $f_2'(1525), f_2(1810), f_2(2340);$
0⁺⁺ phase space, $\phi\eta$

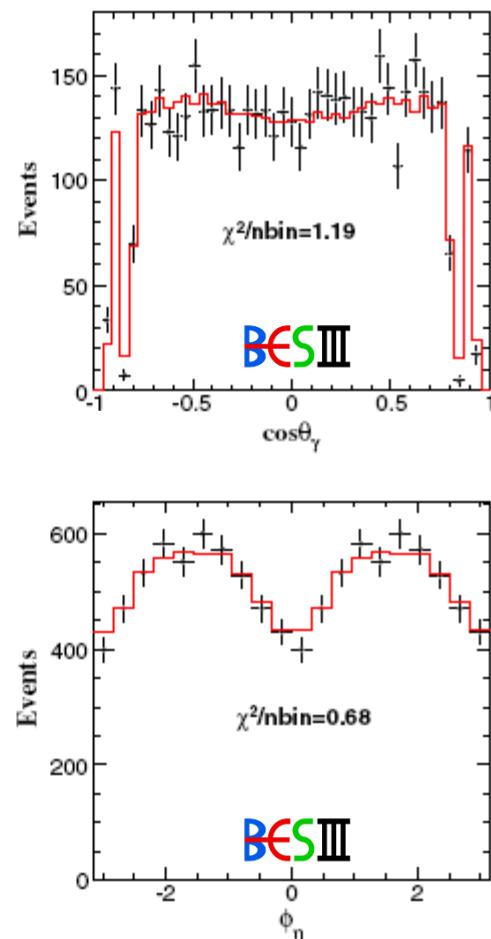
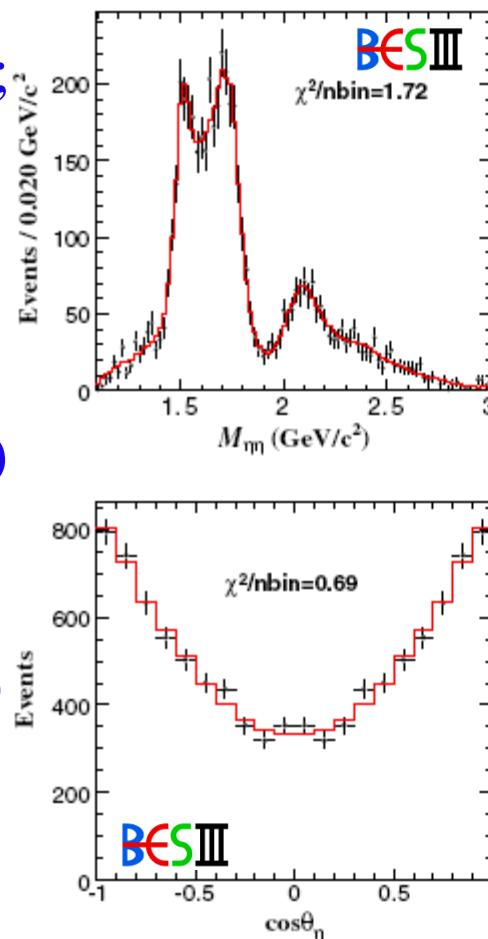
■ no significant evidence of:

- scalar:
 $f_0(1370), f_0(1790), f_0(2020)$
 $f_0(2200), f_0(2330)$
- tensor:
 $f_2(2010), f_2(2150), f_J(2220)$

source of sys. unc.

■ $\phi\eta$ background:

- interference of ϕ tail accounted for
- source of systematic uncertainties





	Resonance	Mass(MeV/ c^2)	Width(MeV/ c^2)	$\mathcal{B}(J/\psi \rightarrow \gamma X \rightarrow \gamma\eta\eta)$	Significance
	$f_0(1500)$	1468^{+14+23}_{-15-74}	$136^{+41+28}_{-26-100}$	$(1.65^{+0.26+0.51}_{-0.31-1.40}) \times 10^{-5}$	8.2σ
	$f_0(1710)$	$1759 \pm 6^{+14}_{-25}$	$172 \pm 10^{+32}_{-16}$	$(2.35^{+0.13+1.24}_{-0.11-0.74}) \times 10^{-4}$	25.0σ
	$f_0(2100)$	$2081 \pm 13^{+24}_{-36}$	273^{+27+70}_{-24-23}	$(1.13^{+0.09+0.64}_{-0.10-0.28}) \times 10^{-4}$	13.9σ
	$f_2'(1525)$	$1513 \pm 5^{+4}_{-10}$	75^{+12+16}_{-10-8}	$(3.42^{+0.43+1.37}_{-0.51-1.30}) \times 10^{-5}$	11.0σ
	$f_2(1810)$	1822^{+29+66}_{-24-57}	$229^{+52+88}_{-42-155}$	$(5.40^{+0.60+3.42}_{-0.67-2.35}) \times 10^{-5}$	6.4σ
	$f_2(2340)$	$2362^{+31+140}_{-30-63}$	$334^{+62+165}_{-54-100}$	$(5.60^{+0.62+2.37}_{-0.65-2.07}) \times 10^{-5}$	7.6σ

no significant evidence of:

- scalar: $f_0(1370)$, $f_0(1790)$, $f_0(2020)$, $f_0(2200)$, $f_0(2330)$
- tensor: $f_2(2010)$, $f_2(2150)$, $f_J(2220)$

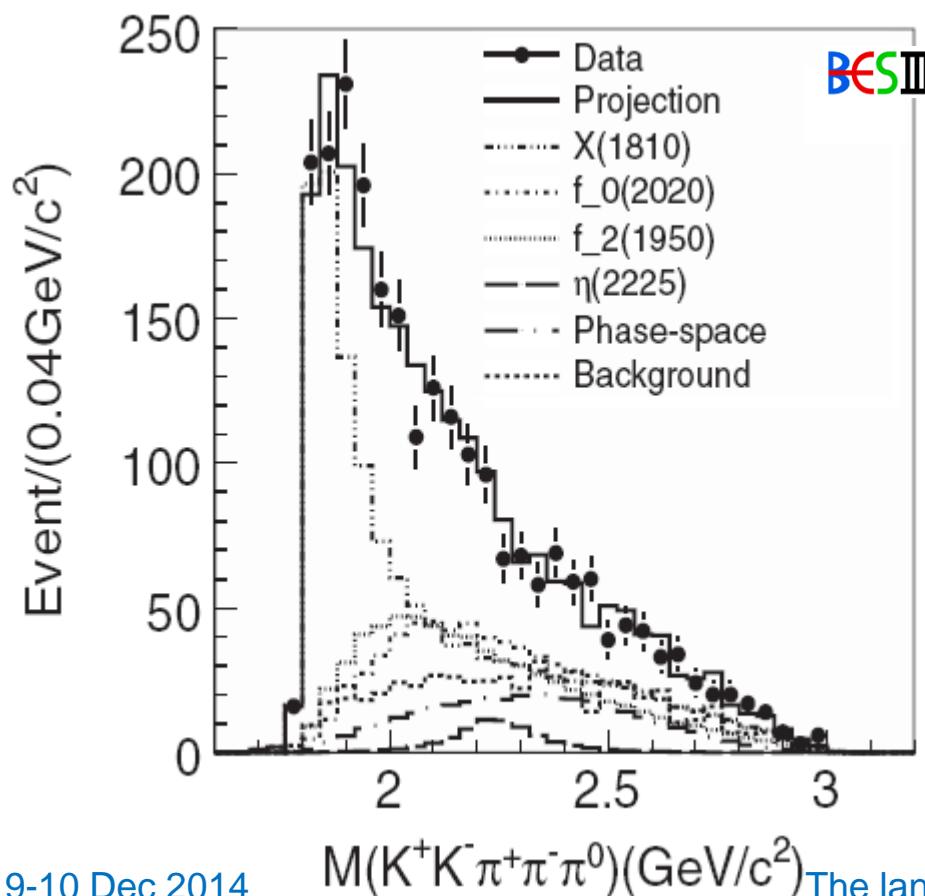


- doubly OZI suppressed:

$\psi \rightarrow \gamma\omega\phi$ (DOZI)

predicted $\propto 1/10$

$\psi \rightarrow \gamma\phi\phi$ (OZI)



- looking for best solution:

- M, Γ and J^{PC} of $X(1810)$
- other known mesons [PDG]
- different J^{PC} of phase space
- different combinations of additional mesons [PDG]

- best solution:

$X(1810), f_0(2020), f_2(1950), \eta(2225), f_0(2020)$, phase space and background

- systematic uncertainties:

- $f_2(1920), f_0(2020), \eta(2225)$: standard deviation from PDG, replacing by other of similar mass but same J^{PC}
- model dependence



- **X(1810) resonance parameters:**

$$M = 1795 \pm 7(\text{stat})^{+13}_{-5}(\text{sys}) \pm 19(\text{mod}) \text{ MeV}/c^2$$

$$\Gamma = 95 \pm 10(\text{stat})^{+21}_{-34}(\text{sys}) \pm 75(\text{mod}) \text{ MeV}/c^2$$

$$\mathcal{B}(J/\psi \rightarrow \gamma X(1810)) \times \mathcal{B}(X(1810) \rightarrow \omega\phi) =$$

$$(2.00 \pm 0.08(\text{stat})^{+0.45}_{-1.00}(\text{sys}) \pm 1.30(\text{mod})) \times 10^{-4}$$

- confirmed @ BESIII: best solution:

$$J^{PC} = 0^{++}$$

- **X(1810) vs $f_0(1710)$:**

unconclusive, further investigation is needed

- **search for X(1810):**

- in other decay modes: K^*K^* , $\omega\omega$, ...

[$J/\psi \rightarrow \gamma\eta(1760)$, $\eta(1760) \rightarrow \omega\omega$ observed by BESII: PRD 73, 112007]

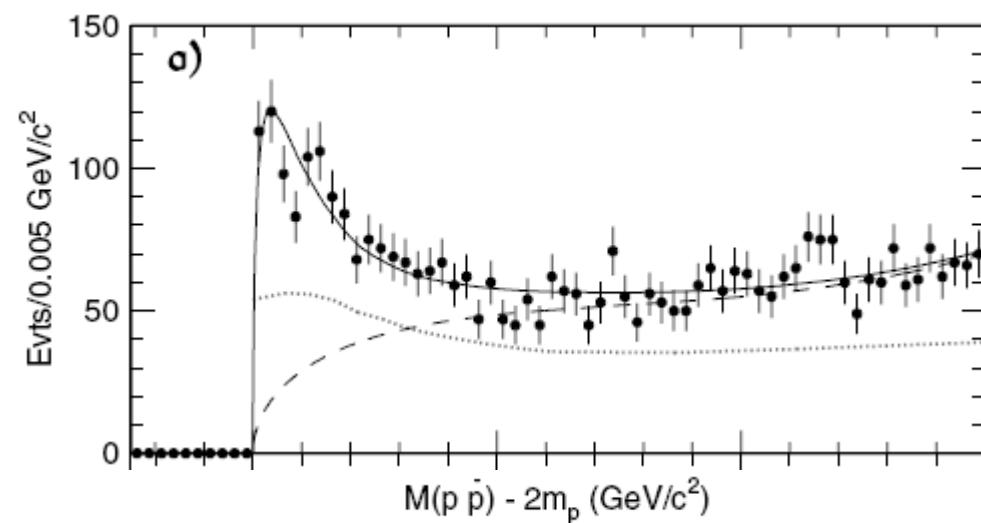
- in other production processes: $J/\psi \rightarrow \phi\omega\phi$, $J/\psi \rightarrow \omega\phi\omega$



$J/\psi \rightarrow \gamma p\bar{p}$: enhancement at threshold

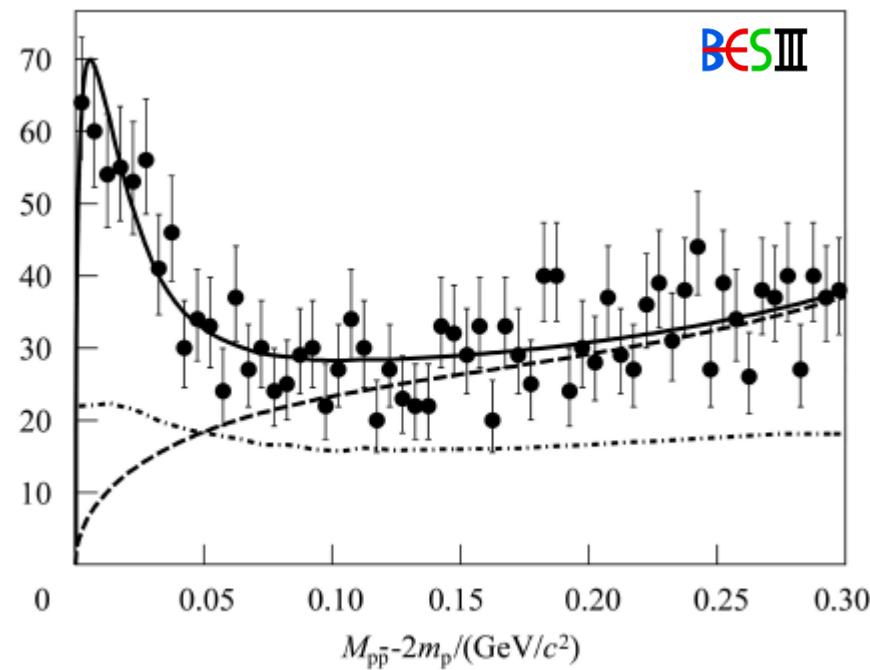
normal meson? pp bound state? multiquark? glueball? FSI effect?

BESII: PRL 91, 022001 (2003)



$M = (1860^{+3}_{-10} {}^{+5}_{-25}) \text{ MeV}/c^2$
 $\Gamma < 38 \text{ MeV}/c^2$ (90% C.L.)
compatible with S-wave BW

BESIII: CPC 34 , 421 (2010)

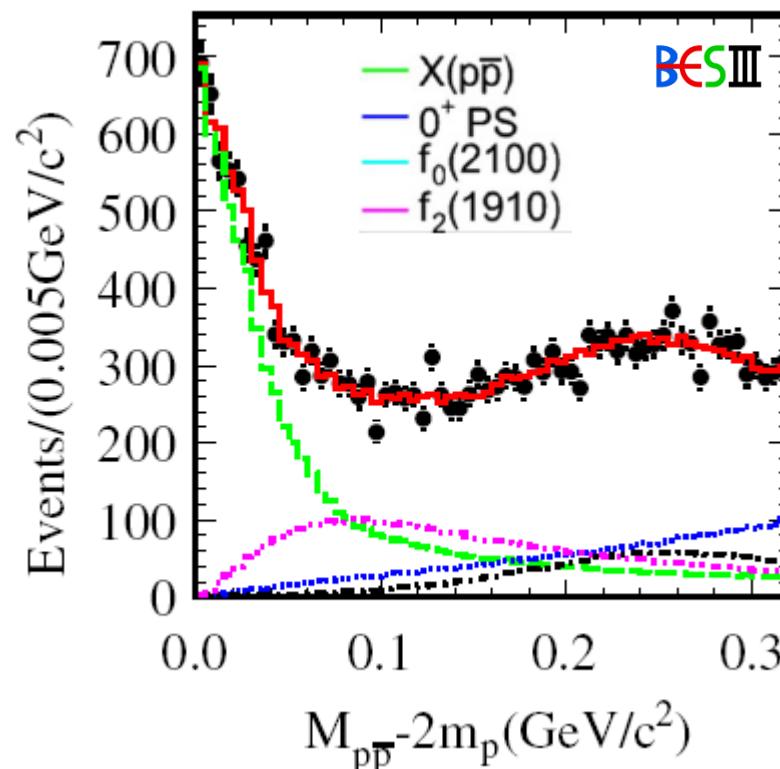


$M = (1861^{+6}_{-13} {}^{+7}_{-26}) \text{ MeV}/c^2$
 $\Gamma < 30 \text{ MeV}/c^2$ (90% C.L.)
compatible with S-wave BW

Spin-parity analysis essential to determine nature and role in spectrum



- PWA of $J/\psi \rightarrow \gamma p\bar{p}$:
 - never performed before
- best solution:
 - $X(p\bar{p})$ [$>>30\sigma$], $f_2(1910)$ and $f_0(2100)$ fixed @PDG,
 - 0^{++} phase space and S-wave ($I=0$) FSI
- systematic uncertainties:
 - $f_2(2150)$, $f_2(1950)$, and other resonances from PDF, 0^{-+} PS
 - FSI model dependence

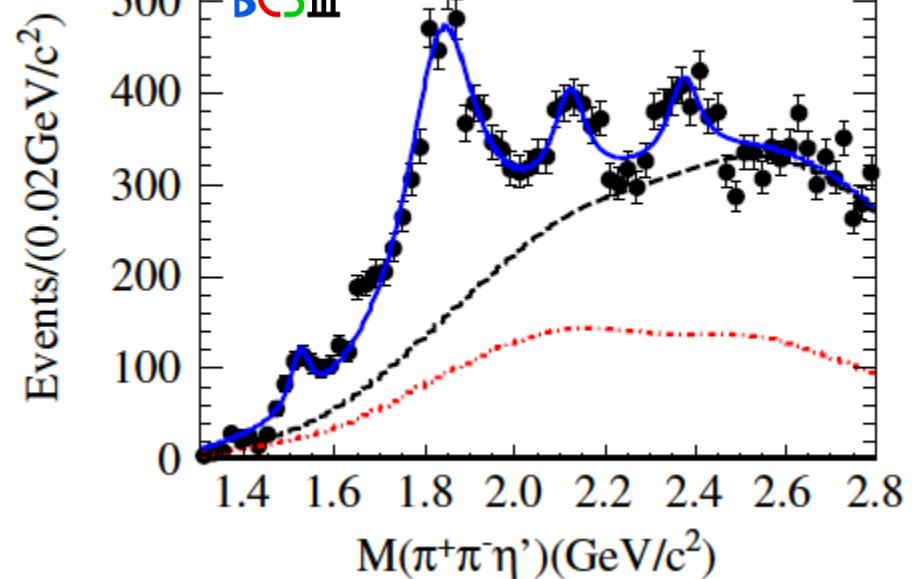
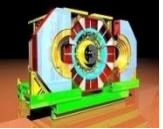


$J^{PC} = 0^{-+}, >6.8\sigma$ better than other J^{PC} assignments

$$M = 1832^{+19}_{-5}(\text{stat})^{+18}_{-17}(\text{sys}) \pm 19(\text{mod}) \text{ MeV}/c^2$$

$$\Gamma = 13 \pm 39(\text{stat})^{+10}_{-13}(\text{sys}) \pm 4(\text{mod}) \text{ MeV}/c^2 \text{ or } \Gamma < 76 \text{ MeV}/c^2 \text{ (90\% C.L.)}$$

$$\mathcal{B}(J/\psi \rightarrow \gamma X(p\bar{p})) \times \mathcal{B}(X(p\bar{p}) \rightarrow p\bar{p}) = 9.0^{+0.4}_{-1.1}(\text{stat})^{+1.5}_{-5.0}(\text{sys}) \pm 2.3(\text{mod}) \times 10^{-5}$$



X(1835):

$$M = (1836.5 \pm 3.0^{+5.6}_{-2.1}) \text{ MeV}/c^2$$

$$\Gamma = (190 \pm 9^{+38}_{-36}) \text{ MeV}/c^2$$

$>20\sigma$

X(2120):

$$M = (2122.4 \pm 6.7^{+4.7}_{-2.7}) \text{ MeV}/c^2$$

$$\Gamma = (83 \pm 16^{+31}_{-11}) \text{ MeV}/c^2$$

$>7.2\sigma$

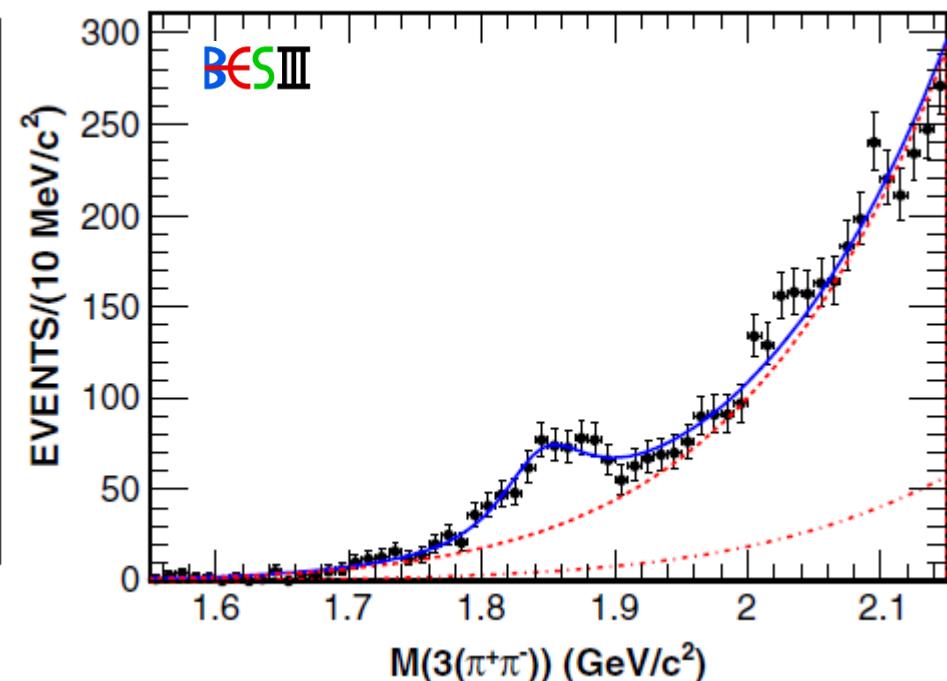
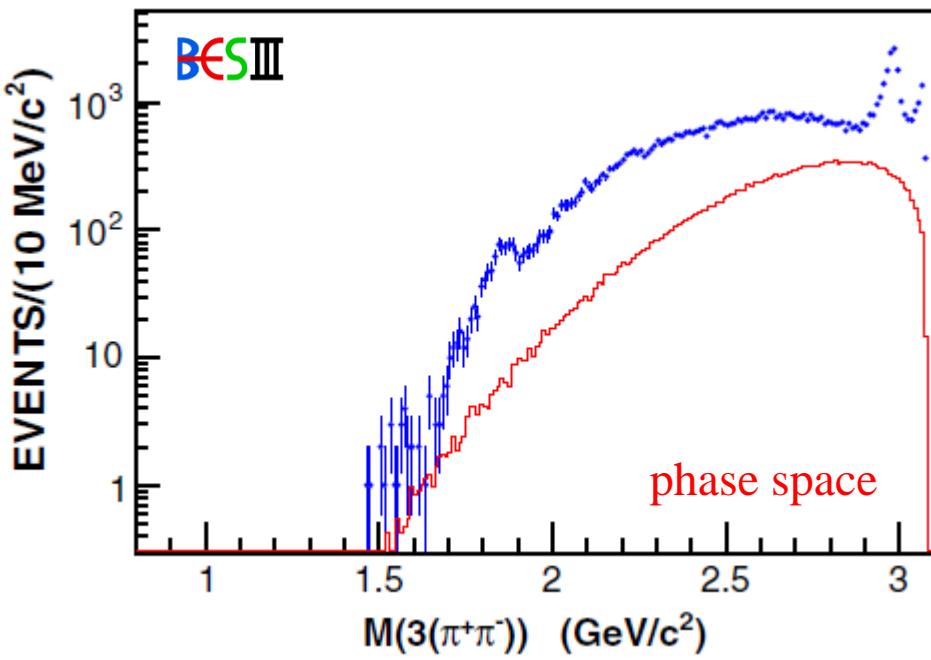
X(2370):

$$M = (2376.3 \pm 8.7^{+3.2}_{-4.3}) \text{ MeV}/c^2$$

$$\Gamma = (83 \pm 17^{+44}_{-6}) \text{ MeV}/c^2$$

$>6.4\sigma$

- PWA is needed to determine spin and parity
- consistent with $J^P = 0^-$



$$M = (1842.2 \pm 4.2^{+7.1}_{-2.6}) \text{ MeV}/c^2$$

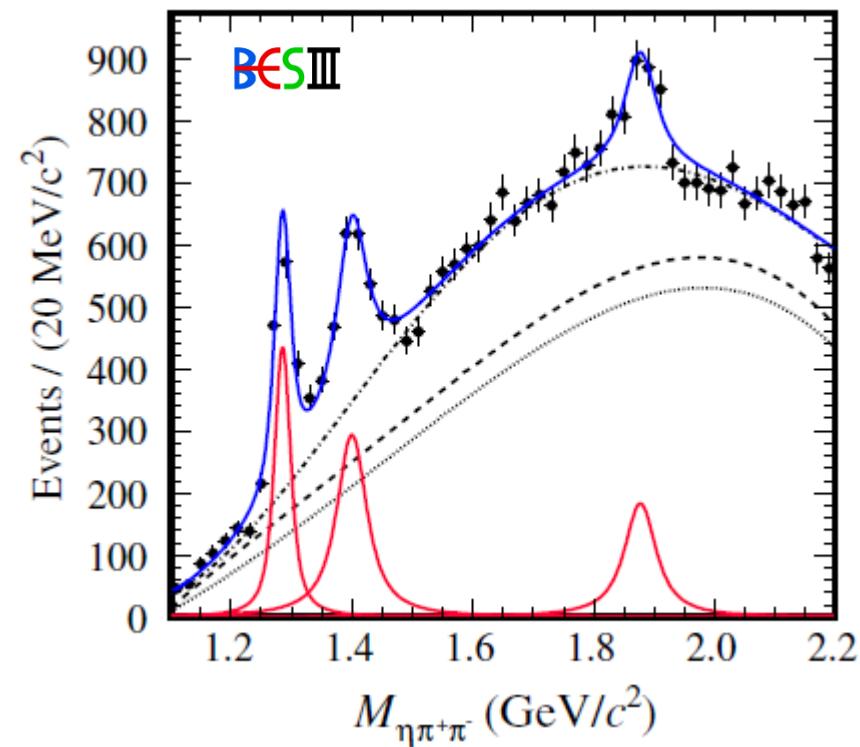
$$\Gamma = (83 \pm 14 \pm 11) \text{ MeV}/c^2$$

$>7.6\sigma$

- PWA is needed to determine spin and parity
- no η' detected



$J/\psi \rightarrow \omega\eta\pi^+\pi^-$



- PWA is needed
to determine spin and parity

$X(1870)$:

$$M = (1877.3 \pm 6.3^{+3.4}_{-7.4}) \text{ MeV/c}^2$$

$$\Gamma = (57 \pm 12^{+19}_{-4}) \text{ MeV/c}^2$$

$$B = (1.50 \pm 0.26^{+0.72}_{-0.36}) \cdot 10^{-4}$$

$\eta(1405)$:

$$M = (1399.8 \pm 2.2^{+2.8}_{-0.1}) \text{ MeV/c}^2$$

$$\Gamma = (52.8 \pm 7.6^{+0.1}_{-7.6}) \text{ MeV/c}^2$$

$$B = (1.89 \pm 0.21^{+0.21}_{-0.23}) \cdot 10^{-4}$$

$f_1(1285)$:

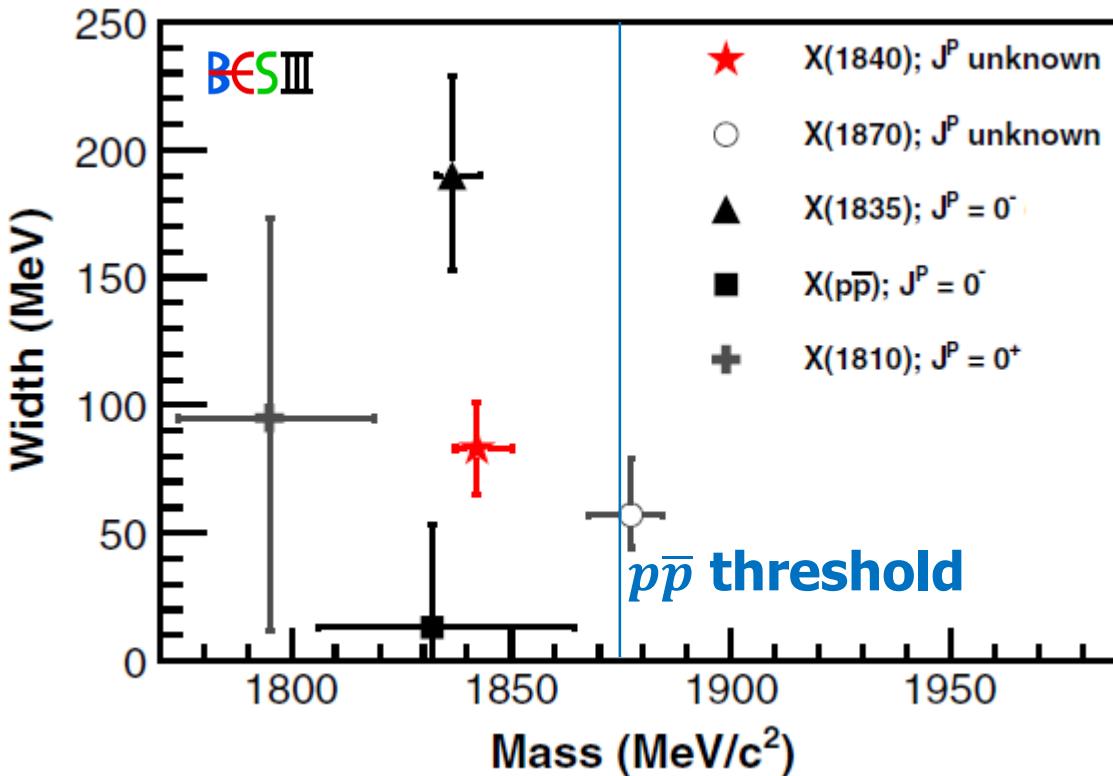
$$M = (1285.1 \pm 1.0^{+1.6}_{-0.3}) \text{ MeV/c}^2$$

$$\Gamma = (22.0 \pm 3.1^{+2.0}_{-1.5}) \text{ MeV/c}^2$$

$$B = (1.25 \pm 0.10^{+0.19}_{-0.20}) \cdot 10^{-4}$$



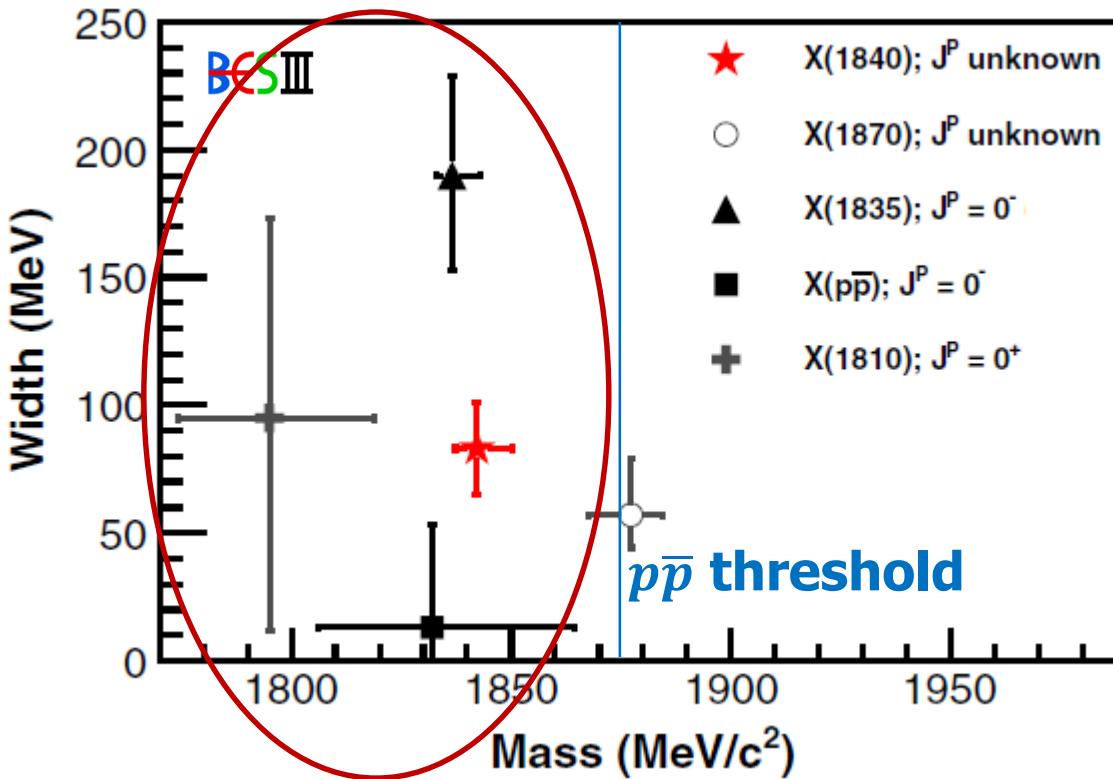
BESIII: a partial summary



- ★ X(1840): $J/\psi \rightarrow \gamma 3(\pi^+\pi^-)$ [PRD88, 091502]
- X(1870): $J/\psi \rightarrow \omega\eta\pi^+\pi^-$ [PRL107, 182001]
- ▲ X(1835): $J/\psi \rightarrow \gamma(\eta\pi^+\pi^-)$ [PRL106, 072002]
- X(1840): $J/\psi \rightarrow \gamma(p\bar{p})$ [PRL108, 112003]
- ✚ X(1840): $J/\psi \rightarrow \gamma(\omega\phi)$ [PRD87, 032008]



BESIII: a partial summary



- J/ψ radiative decays
- not found in ψ' radiative decays
- non a pure FSI
- PWA is needed

- ★ $X(1840)$: $J/\psi \rightarrow \gamma 3(\pi^+\pi^-)$ [PRD88, 091502]
- $X(1870)$: $J/\psi \rightarrow \omega\eta\pi^+\pi^-$ [PRL107, 182001]
- ▲ $X(1835)$: $J/\psi \rightarrow \gamma(\eta\pi^+\pi^-)$ [PRL106, 072002]
- $X(1840)$: $J/\psi \rightarrow \gamma(p\bar{p})$ [PRL108, 112003]
- ✚ $X(1840)$: $J/\psi \rightarrow \gamma(\omega\phi)$ [PRD87, 032008]

X(18??):

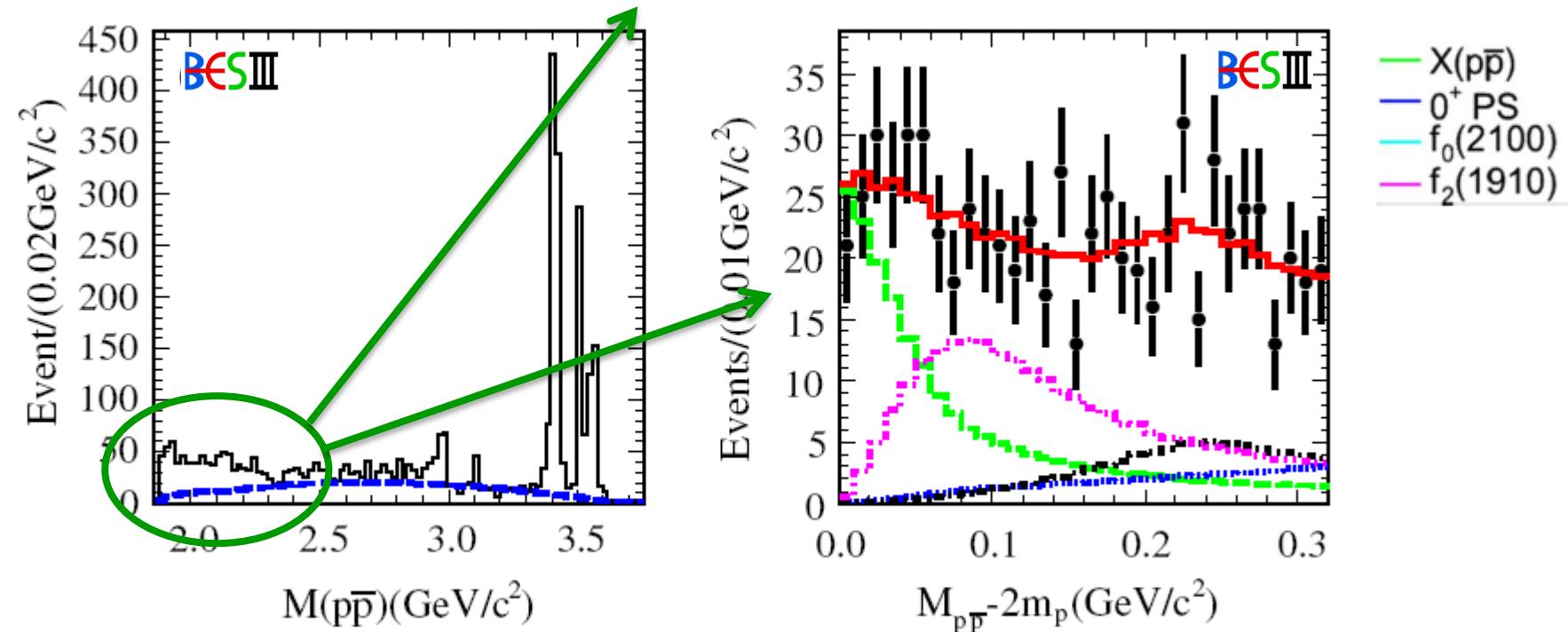
- near $(p\bar{p})$ threshold
- is a single particle??



BESIII: PWA of $\psi(2S) \rightarrow \gamma p\bar{p}$, $M_{pp} < 2.2$ GeV

PRL 108, 112003

$p\bar{p}$ mass-spectrum at threshold clearly differs from that in J/ψ decays



M , Γ , and J^{PC} fixed to those obtained for J/ψ decays

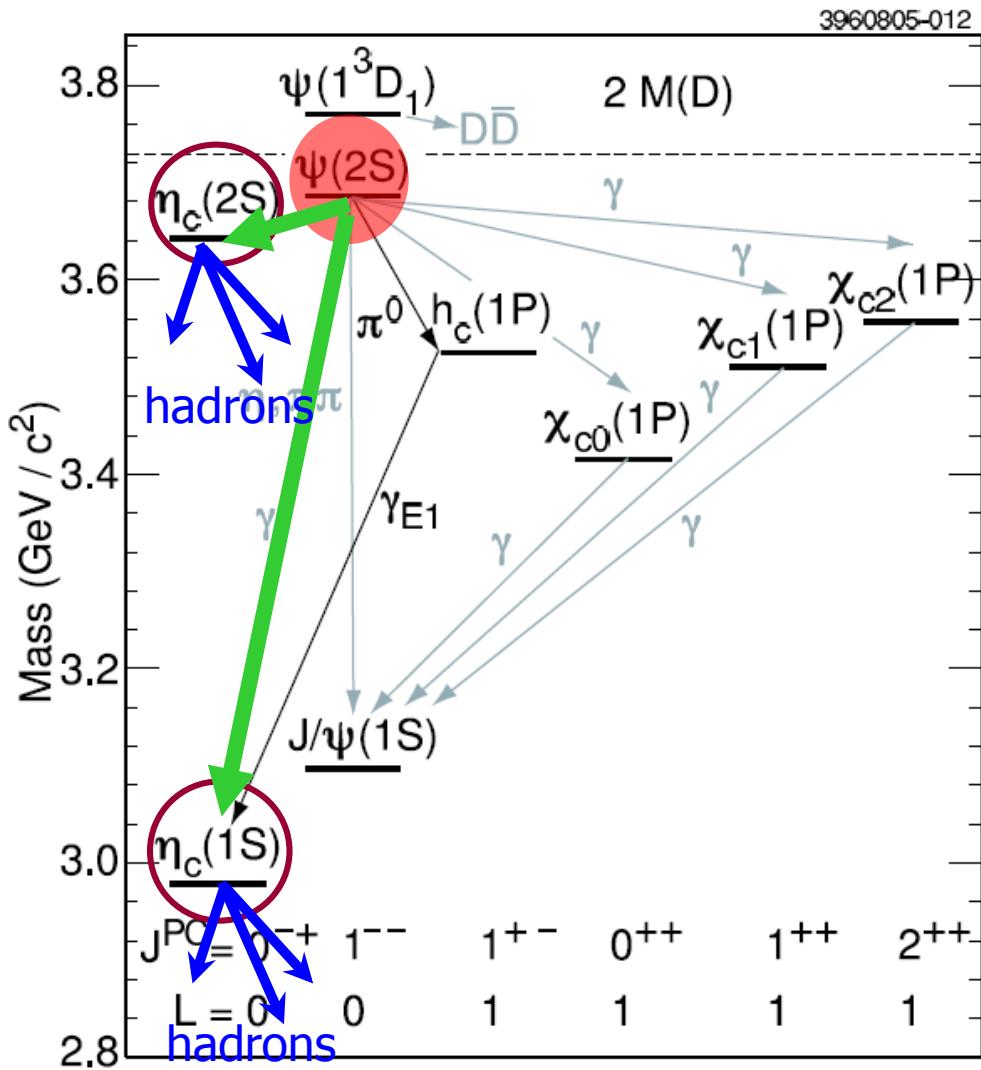
$$\mathcal{B}(\psi(2S) \rightarrow \gamma X(pp)) \times \mathcal{B}(X(pp) \rightarrow pp) =$$

$$4.57 \pm 0.36(\text{stat})^{+1.23}_{-4.07}(\text{sys}) \pm 1.28(\text{mod}) \times 10^{-6}$$

$$R = \frac{\mathcal{B}(\psi(2S) \rightarrow \gamma X(p\bar{p}))}{\mathcal{B}(J/\psi \rightarrow \gamma X(p\bar{p}))} = 5.08^{+0.71}_{-0.45}(\text{stat})^{+0.67}_{-3.58}(\text{sys}) \pm 0.12(\text{mod}) \% < 12\%!$$



$\Psi(2S) \rightarrow \gamma \eta_c(1S), \gamma \eta_c(2S)$



η_c mass:
charmonium
ground state

M1 transition:
first observation of
 $\Psi' \rightarrow \gamma \eta_c'$



$\eta_c(1S)$

The S-wave spin-singlet charmonium ground state, found in 1980

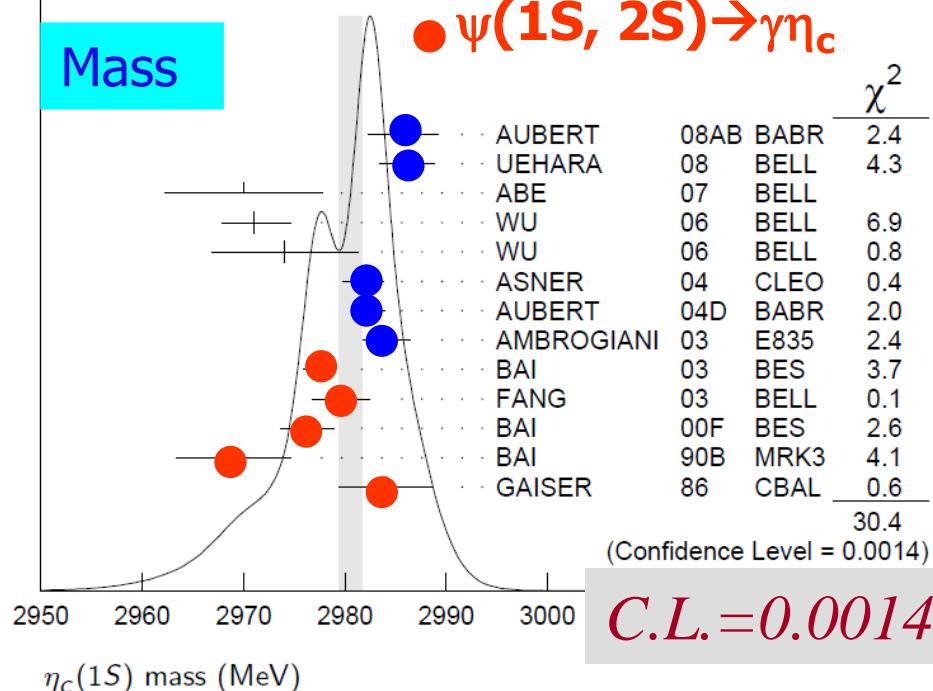
M & Γ measurements:

- J/ ψ radiative transitions: $M \sim 2978.0 \text{ MeV}/c^2$, $\Gamma \sim 10 \text{ MeV}/c^2$
- $\gamma\gamma$ processes / $B \rightarrow K\eta_c$: $M = (2983.1 \pm 1.0) \text{ MeV}/c^2$, $\Gamma = (31.3 \pm 1.9) \text{ MeV}/c^2$

● $\gamma\gamma$, $p\bar{p}$, B decay

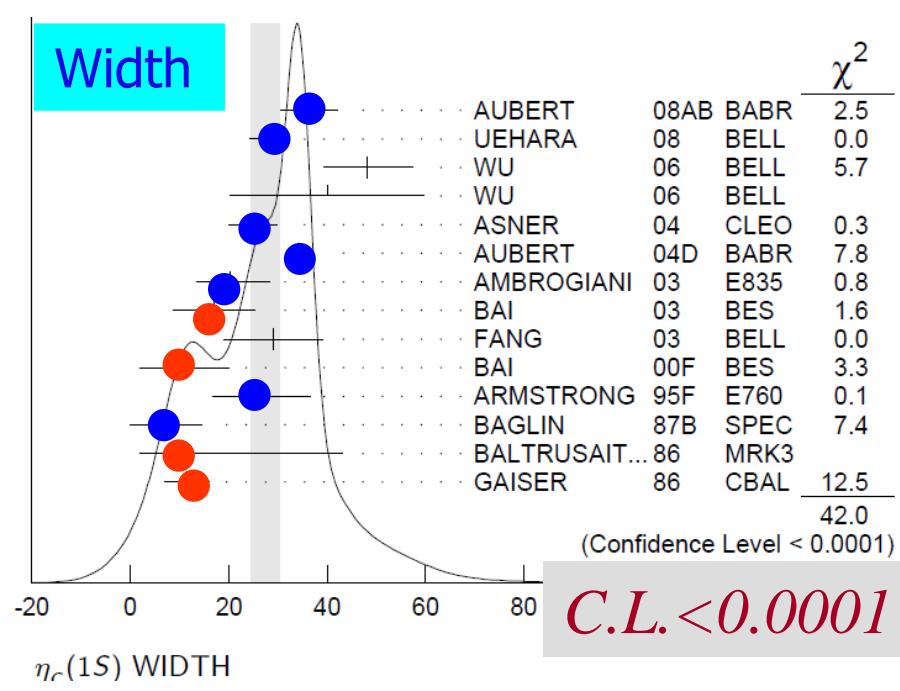
● $\psi(1S, 2S) \rightarrow \gamma\eta_c$

Mass



$C.L. = 0.0014$

Width

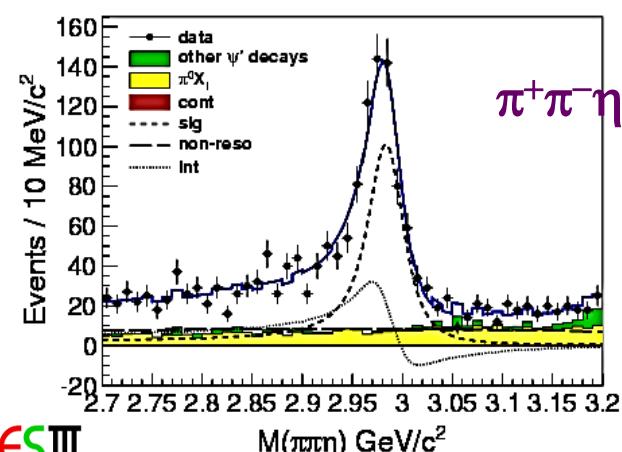
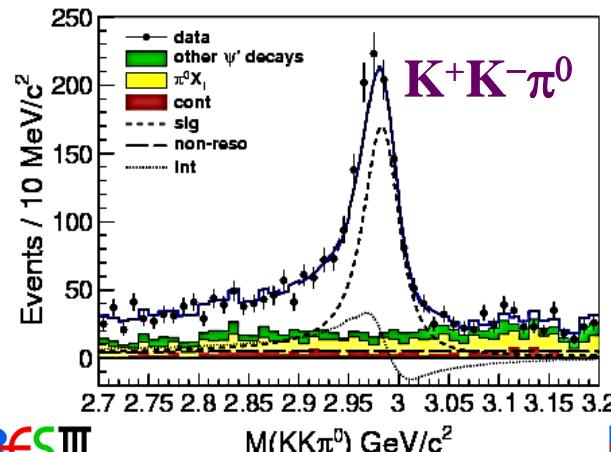
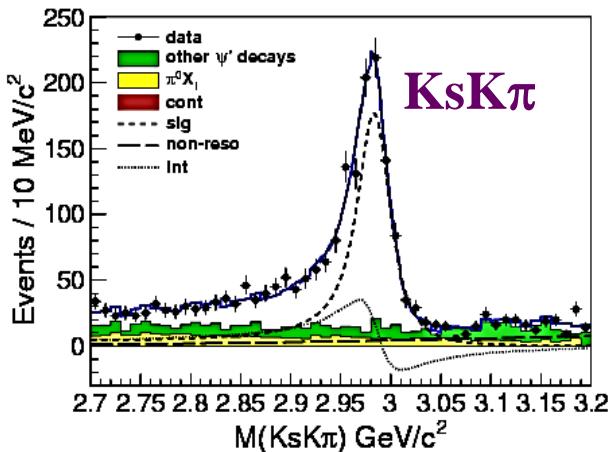


$C.L. < 0.0001$



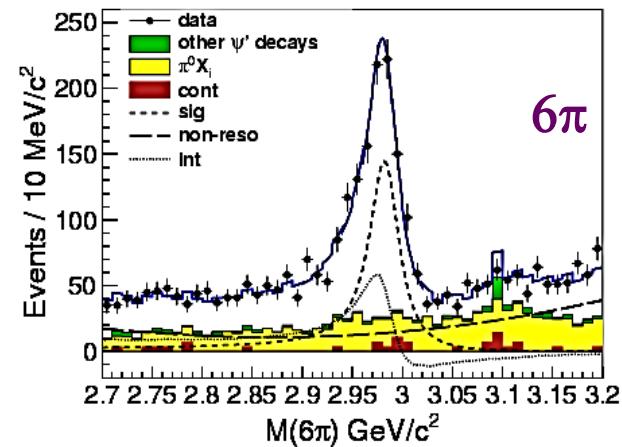
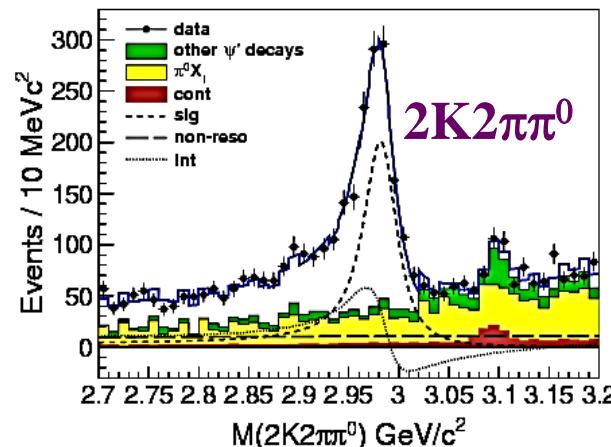
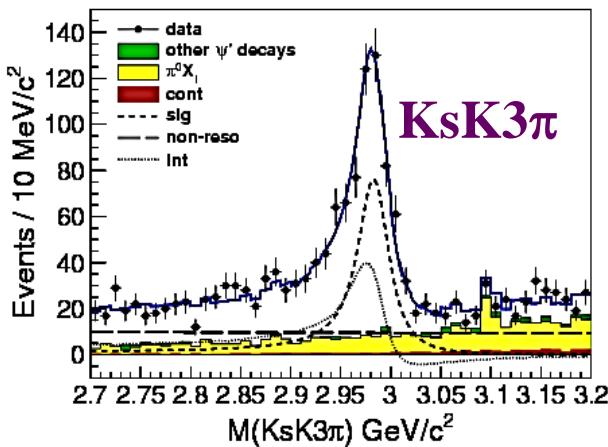
BESIII: $\psi(2S) \rightarrow \gamma\eta_c(1S)$

PRL 108, 222002 (2012)



BESIII

BESIII



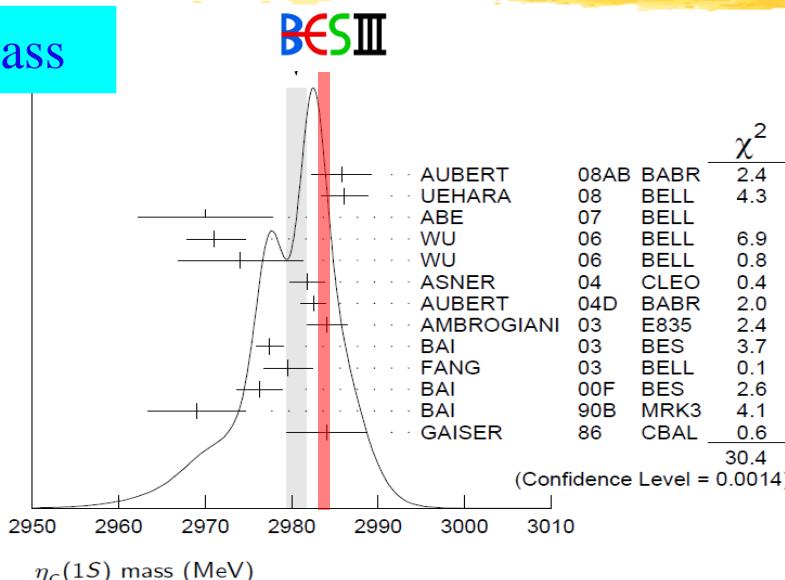
**Significant interference between η_c and non-resonant
→ simultaneous fit to 6 modes, Mass = $2984.3 \pm 0.6 \pm 0.6 \text{ MeV}/c^2$
 $\Gamma = 32.0 \pm 1.2 \pm 1.0 \text{ MeV}/c^2$**



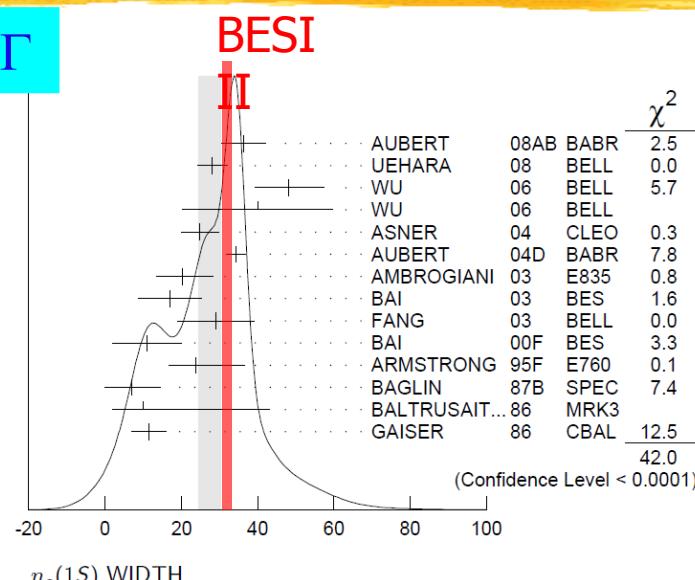
$\eta_c(1S)$: BESIII vs literature

PRL 108, 222002 (2012)

Mass



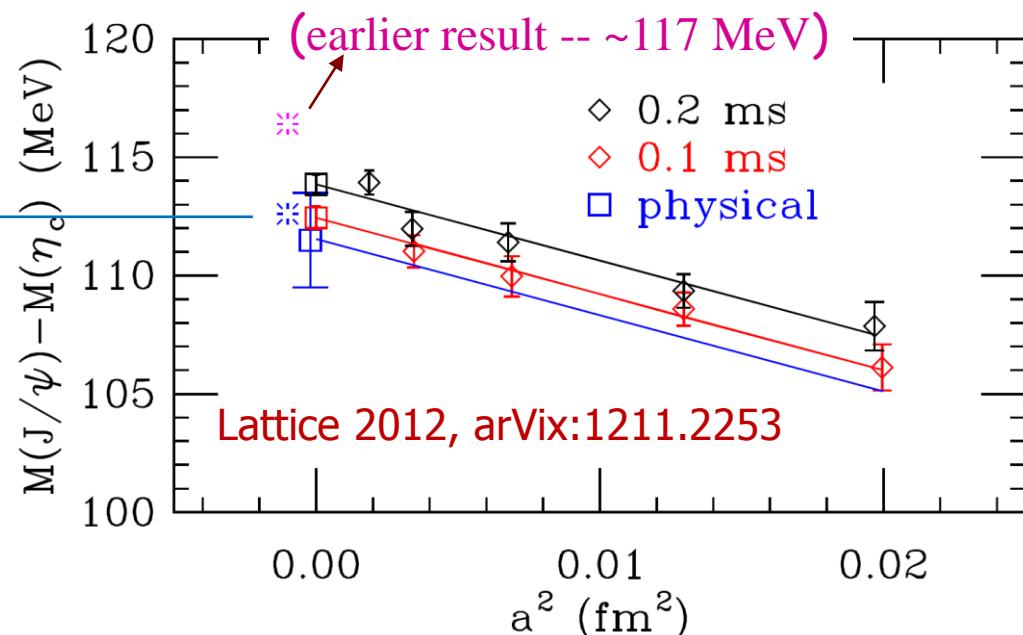
Γ



Hyperfine splitting (BESIII alone)

$$\Delta M(1S) = 112.5 \pm 0.8 \text{ MeV}/c^2$$

Closer to prediction
than earlier result





Observed in different production mechanisms

1. $B \rightarrow K\eta_c'$
2. $\gamma\gamma \rightarrow \eta_c' \rightarrow KK\pi$
3. double charmonium production

Belle: PRL 89 102001 (2002)
CLEOc: PRL 92 142001 (2004)
Belle: NPPS.184 220 (2008); PRL 98 082001(2007)
BaBar: PRL 92 142002 (2004); PR D72 031101(2005)
BaBar: PR D84 012004 (2011)

M1 transition $\psi' \rightarrow \gamma\eta_c'$

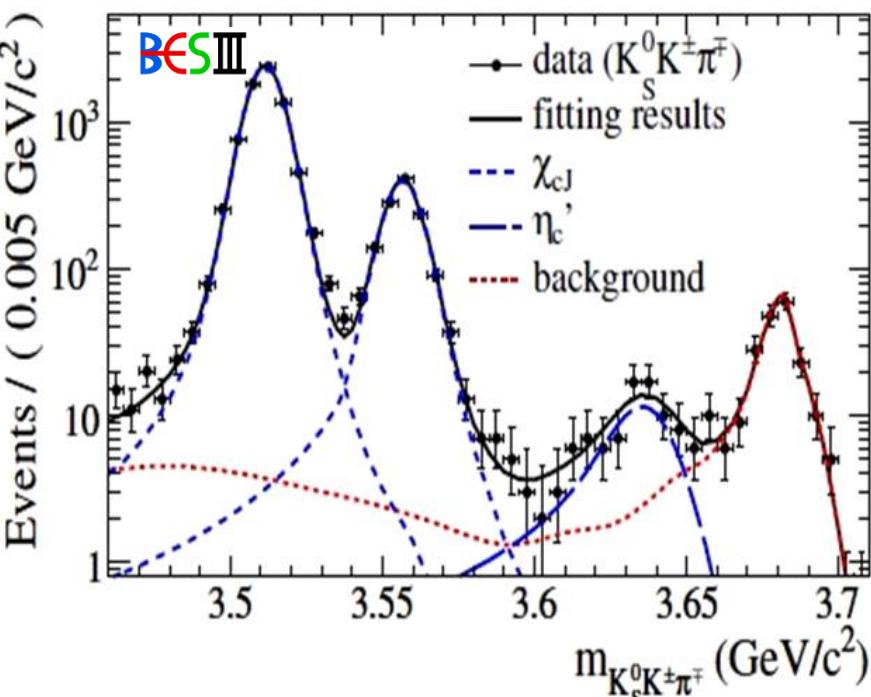
1. CLEO found no signal in 25M ψ' .

$$\mathcal{B}(\psi' \rightarrow \gamma\eta_c') < 7.6 \times 10^{-4}$$

PRD 81 052002 (2010)

2. BESIII: first observation of $\eta_c' \rightarrow KK\pi$;
find evidence in $\eta_c' \rightarrow K_s K3\pi$

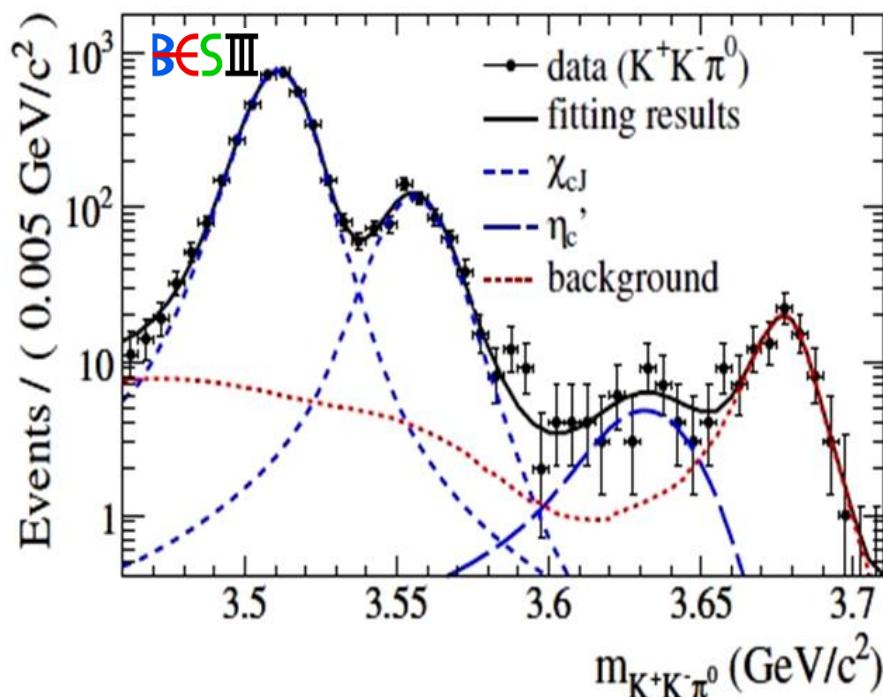
Experimental challenge : search for photons of 50 MeV



$$M = 3637.6 \pm 2.9 \pm 1.6 \text{ MeV}/c^2$$

$$\mathcal{B}(\psi' \rightarrow \gamma\eta_c' \rightarrow \gamma KK\pi) = (1.30 \pm 0.20 \pm 0.30) \times 10^{-5} \quad \text{Significance} > 10 \sigma$$

$$\mathcal{B}(\eta_c' \rightarrow \gamma KK\pi) = (1.9 \pm 0.4 \pm 1.1)\%$$



$$\Gamma = 16.9 \pm 6.4 \pm 4.8 \text{ MeV}/c^2$$

BABAR: PRD78, 012006 (2008)

$$\mathcal{B}(\psi' \rightarrow \gamma\eta_c') = (6.8 \pm 1.1 \pm 4.5) \times 10^{-4}$$

FIRST OBSERVATION!

Potential model:

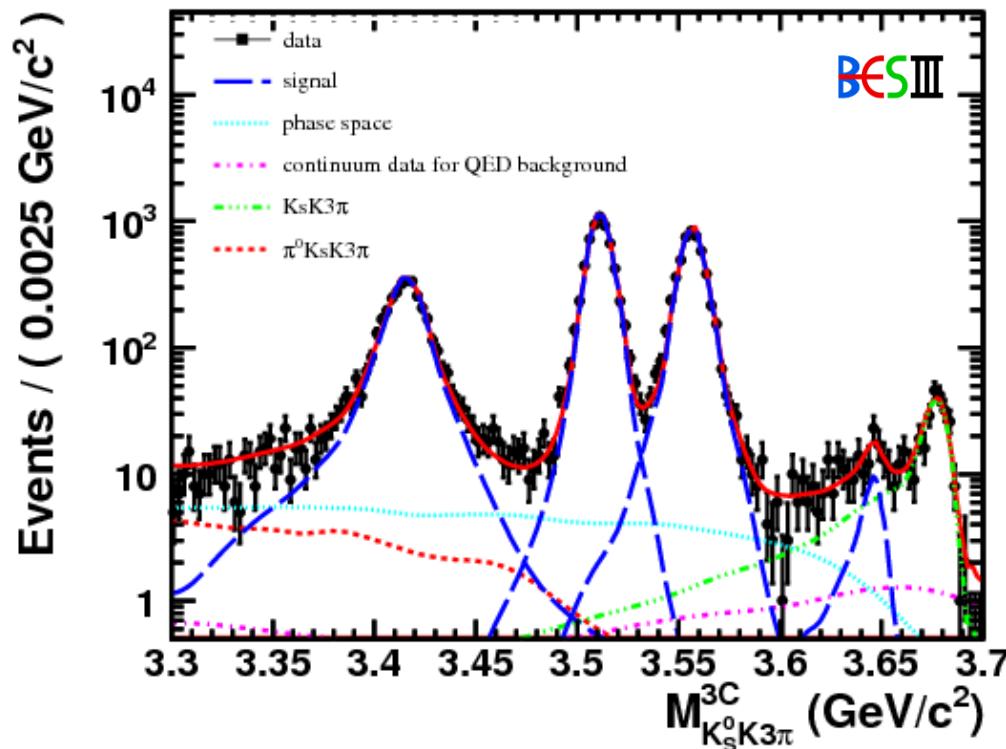
$$(0.1-6.2) \times 10^{-4}$$

PRL89, 162002(2002)

CLEOc:

$$< 7.6 \times 10^{-4}$$

PRD81, 052002 (2010)



Significance

4.2 σ

$$M = 3646.9 \pm 1.6 \pm 3.6 \text{ MeV}/c^2$$

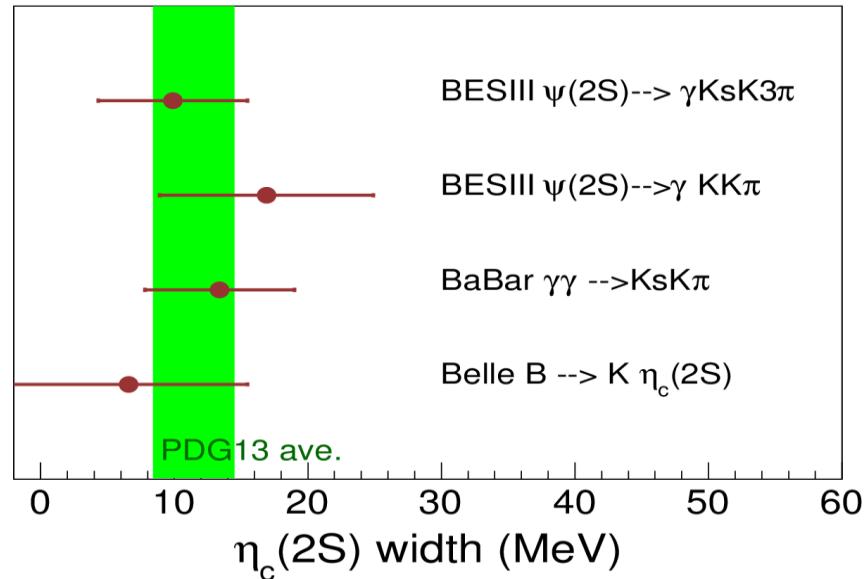
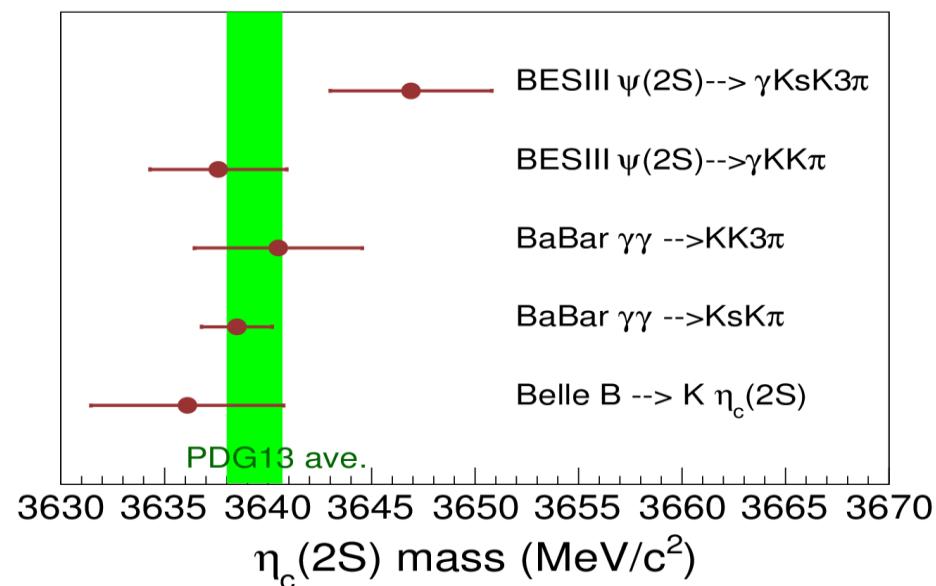
$$\Gamma = 9.2 \pm 4.8 \pm 2.9 \text{ MeV}/c^2$$

$$\mathcal{B}(\psi' \rightarrow \gamma\eta_c' \rightarrow \gamma K_s K3\pi) = (7.03 \pm 2.10 \pm 0.70) \times 10^{-6}$$



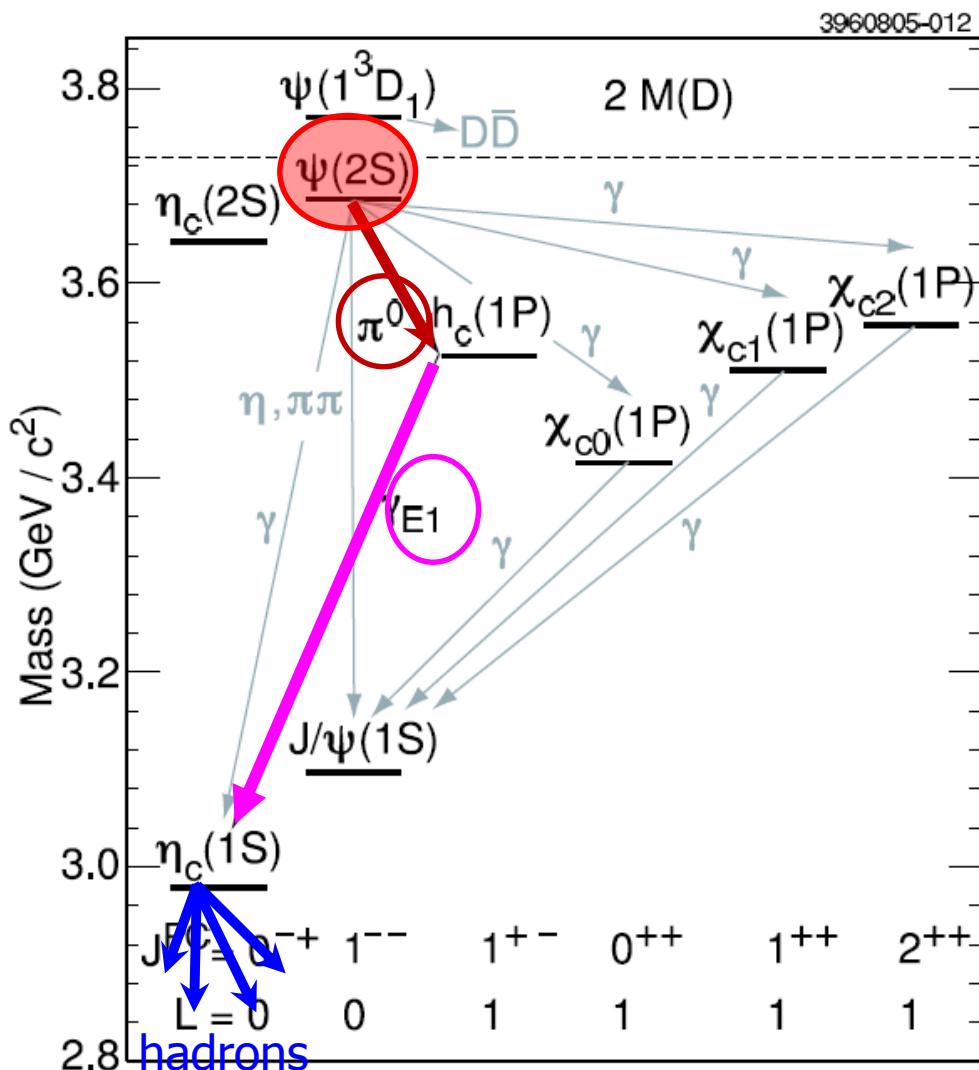
$\eta_c(2S)$: BESIII vs literature

PRL 109, 042003
PRD 87, 052005





$h_c(1P)$



“inclusive”

only detect the π^0

(compute $M(h_c)$ from kinematic)

$$\text{Rate} \propto \mathcal{B}(\psi' \rightarrow \pi^0 h_c)$$

“El tagged”

detect the π^0 & γ

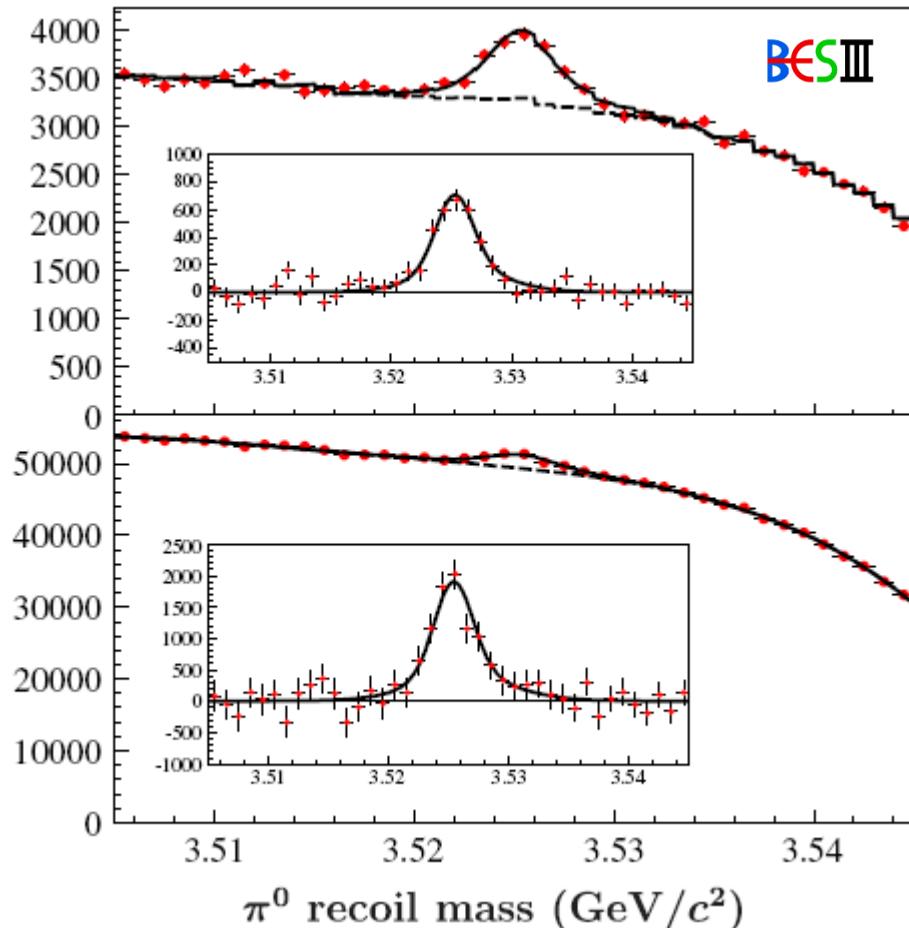
$$\text{Rate} \propto \mathcal{B}(\psi' \rightarrow \pi^0 h_c) \times \mathcal{B}(h_c \rightarrow \gamma \eta_c)$$

“exclusive”

detect the π^0 , γ & $\eta_c \rightarrow X_i$ decay prod.

Rate \propto

$$\mathcal{B}(\psi' \rightarrow \pi^0 h_c) \times \mathcal{B}(h_c \rightarrow \gamma \eta_c) \times \mathcal{B}(\eta_c \rightarrow X_i)$$

Events/1MeV/c²

$$M = 3525.40 \pm 0.13 \pm 0.18 \text{ MeV}/c^2$$

$$\Gamma = 0.73 \pm 0.45 \pm 0.28 \text{ MeV}/c^2$$

<1.44 MeV @90%

CLEOc:

PRL 101 182003 (2008)

$$M = 3525.28 \pm 0.19 \pm 0.12 \text{ MeV}/c^2$$

Γ : fixed at 0.9 MeV

Hyperfine mass splitting

$$\Delta M_{hf}(1^1P) = M(h_c) - \langle m(1^3P_J) \rangle$$

$$\text{BESIII: } 0.10 \pm 0.13 \pm 0.18 \text{ MeV}/c^2$$

$$\text{CLEOc: } 0.02 \pm 0.19 \pm 0.13 \text{ MeV}/c^2$$

By combining inclusive results with E1-photon tagged results

$$\mathcal{B}(\psi' \rightarrow \pi^0 h_c) = (8.4 \pm 1.3 \pm 1.0) \times 10^{-4}$$

$$\mathcal{B}(h_c \rightarrow \gamma \eta_c) = (54.3 \pm 6.7 \pm 5.2)\%$$

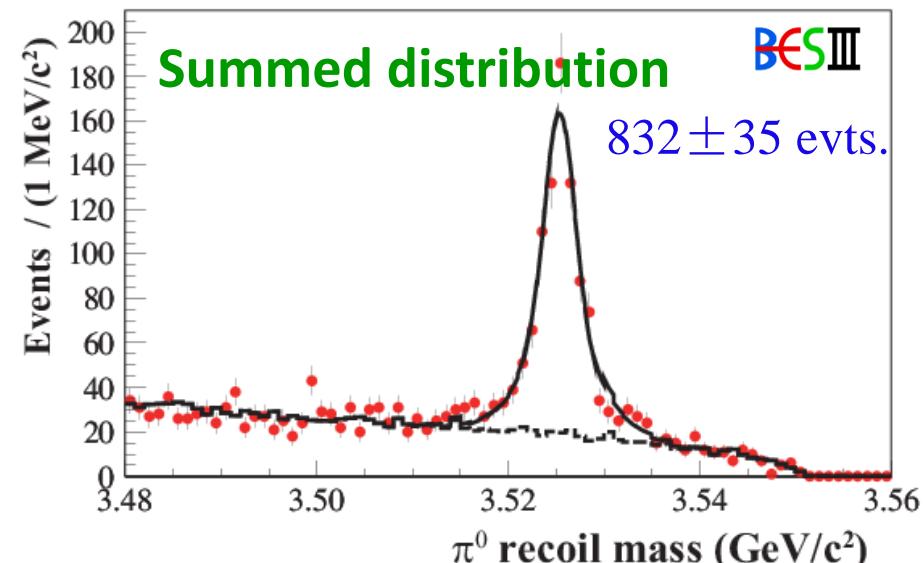
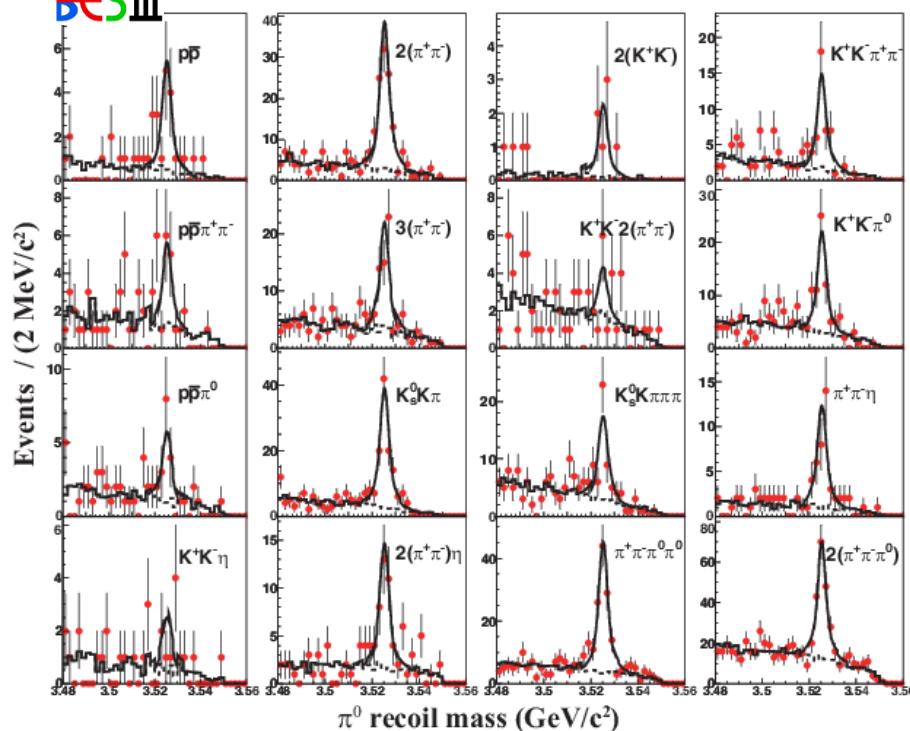
Agrees with prediction from
Kuang, Godfrey, Dude et al.



BESIII: $16 h_c(1P)$ decay modes ($\sim 40\% \eta_c(1S)$ decays)

PRD 86, 092009

BESIII



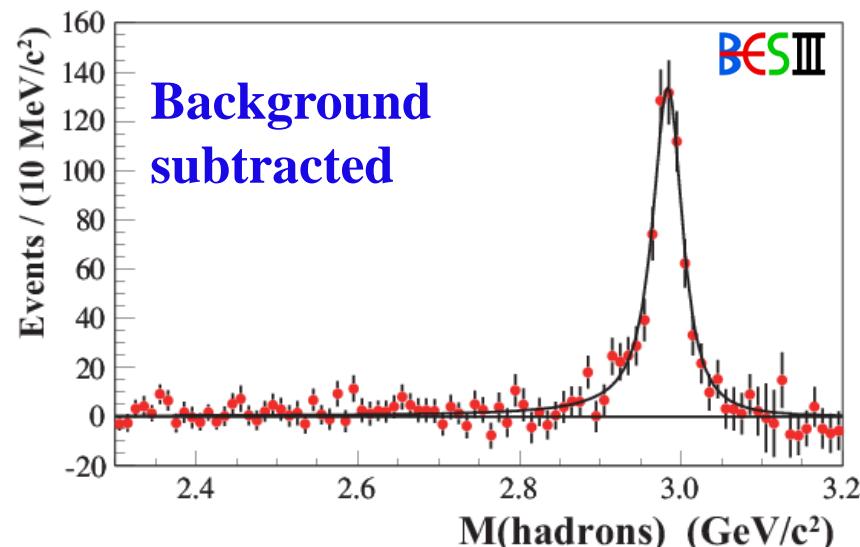
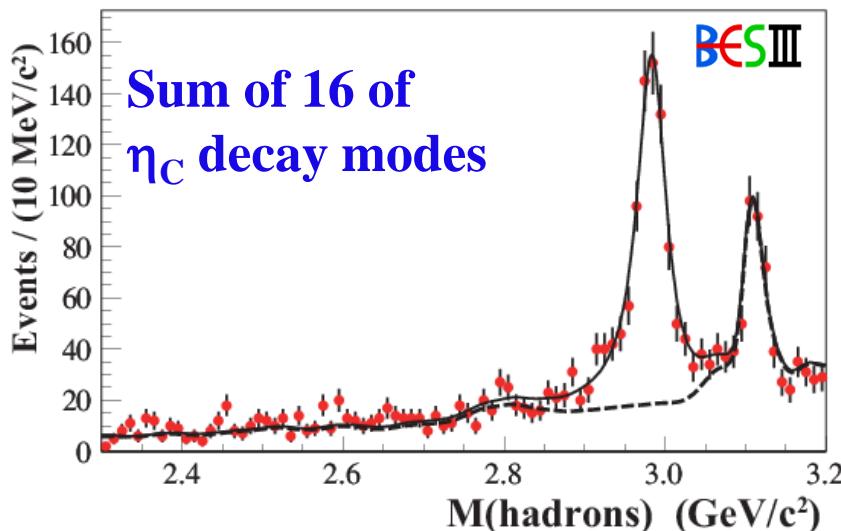
(MeV/c ²)	BESIII Exclusive	BESIII Inclusive	CLEO
M	$3525.31 \pm 0.11 \pm 0.14$	$3525.40 \pm 0.13 \pm 0.18$	$3525.21 \pm 0.27 \pm 0.14$
Γ	$0.70 \pm 0.28 \pm 0.22$	$0.73 \pm 0.45 \pm 0.28$	--
$\Delta M_{hf}(1P)$	$-0.01 \pm 0.11 \pm 0.15$	$0.10 \pm 0.13 \pm 0.18$	$0.08 \pm 0.18 \pm 0.12$

BESIII: PRL 104 132002 (2010)
CLEOc: PRL 101 182003 (2008)



BESIII: η_c parameters from $\psi(2S) \rightarrow \pi^0 h_c(1P)$, $h_c(1P) \rightarrow \gamma \eta_c(1S)$

PRD 86, 092009



η_c lineshape in $h_c \rightarrow \gamma \eta_c$ is **not as distorted** as in $\psi' \rightarrow \gamma \eta_c$ decays:
⇒ non-resonant interfering background is smaller than $\psi' \rightarrow \gamma h_c$
⇒ this channel best suited to determine η_c resonance parameters

$\psi' \rightarrow \pi^0 h_c$, $h_c \rightarrow \gamma \eta_c$

$M = 2984.49 \pm 1.16 \pm 0.52 \text{ MeV}/c^2$

$\Gamma = 36.4 \pm 3.2 \pm 1.7 \text{ MeV}$

$\psi' \rightarrow \gamma \eta_c$

PRL 108, 222002

$M = 2984.3 \pm 0.6 \pm 0.6 \text{ MeV}/c^2$

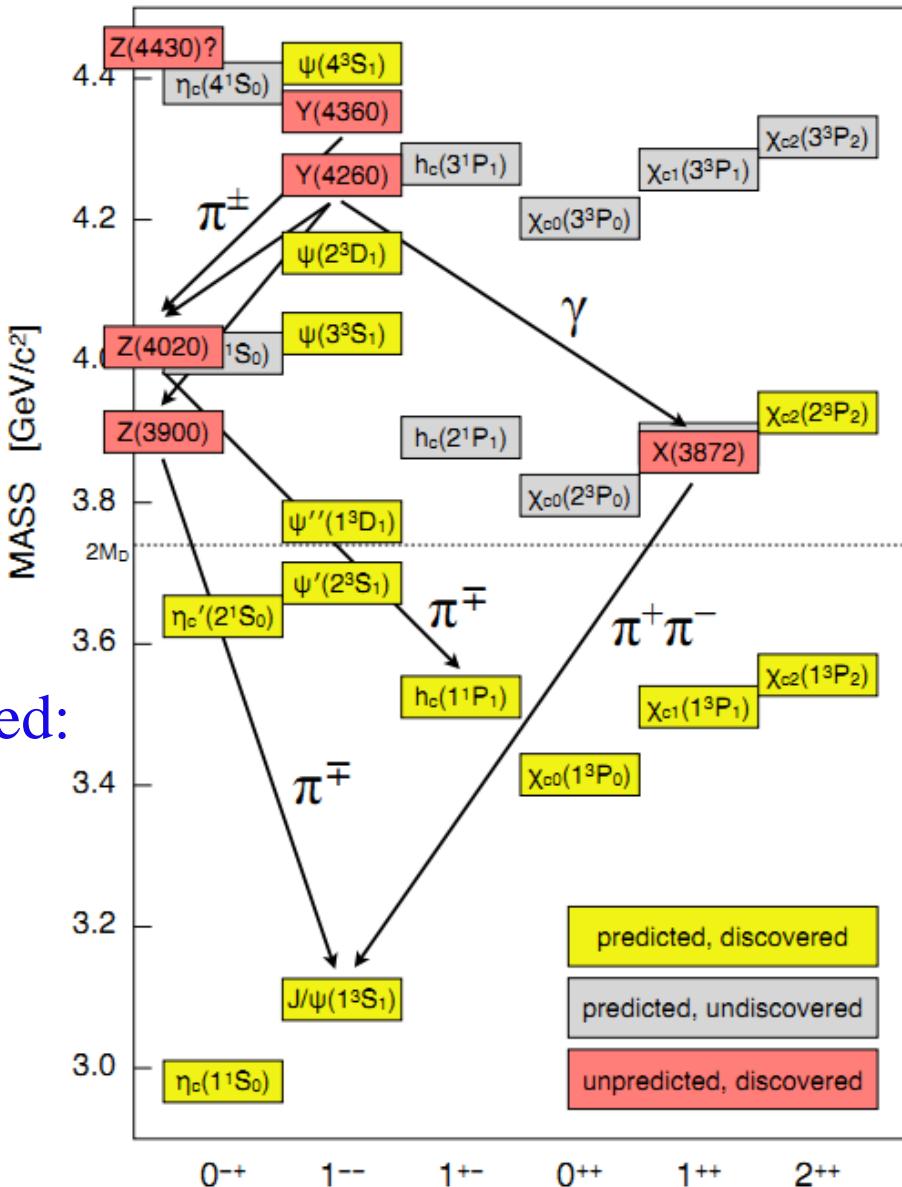
$\Gamma = 32.0 \pm 1.2 \pm 1.0 \text{ MeV}$

Consistent results, but still dominant statistical errors: more statistics is needed!



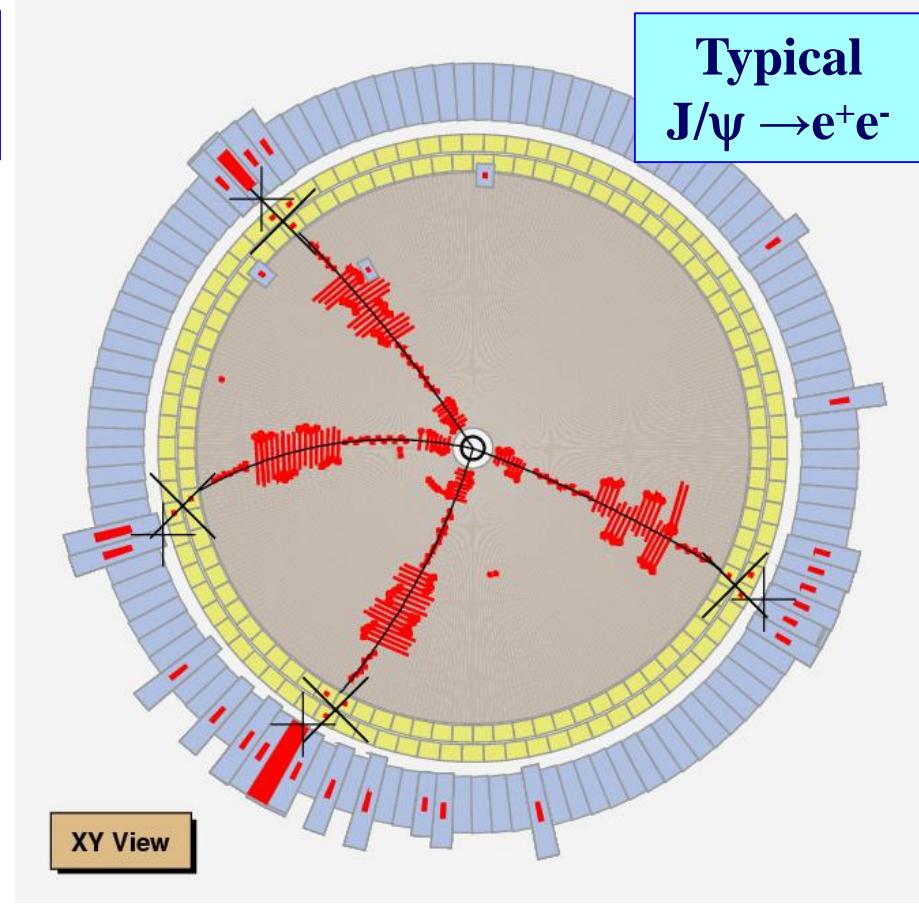
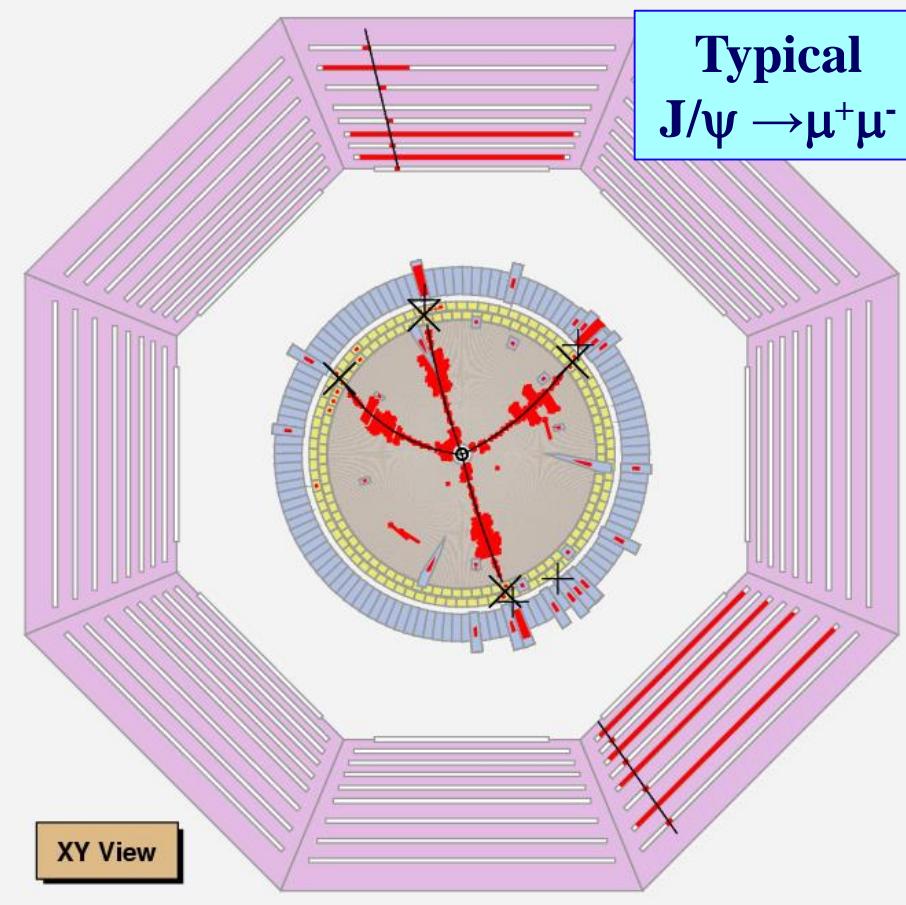
Exotic at BESIII

- all states below DD threshold have been observed and described by charm anti-charm potential model
 - only a few of the predicted states above threshold have been found
 - many new states have been observed:
 - some unexpected
 - many with properties not consistent with charmonium decays to X,Y or Z states





BESIII: $e^+e^- \rightarrow \pi^+\pi^-J/\psi$ events

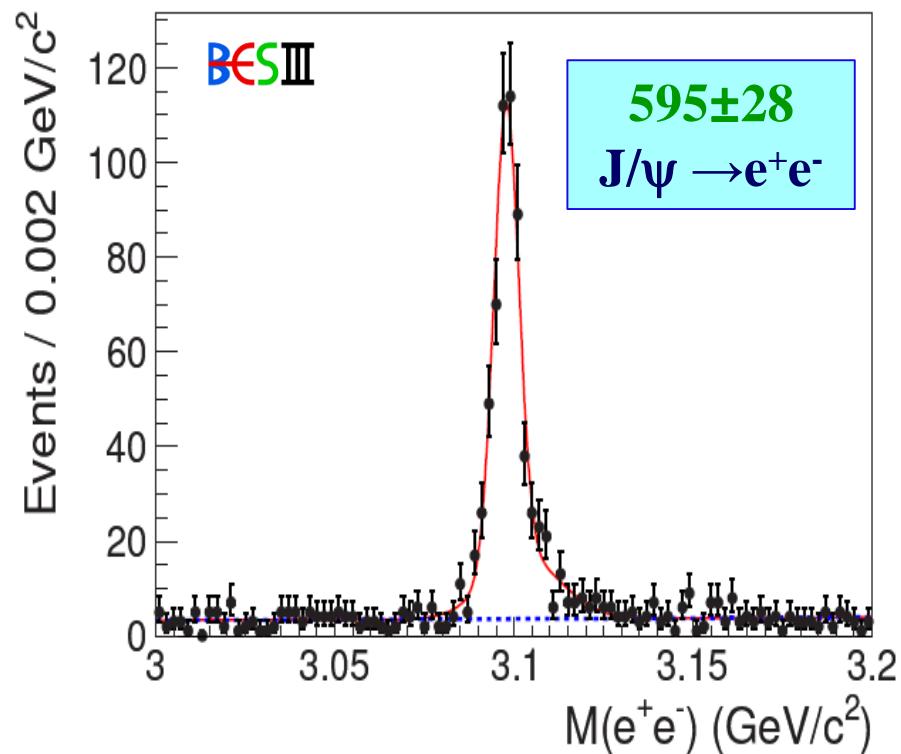
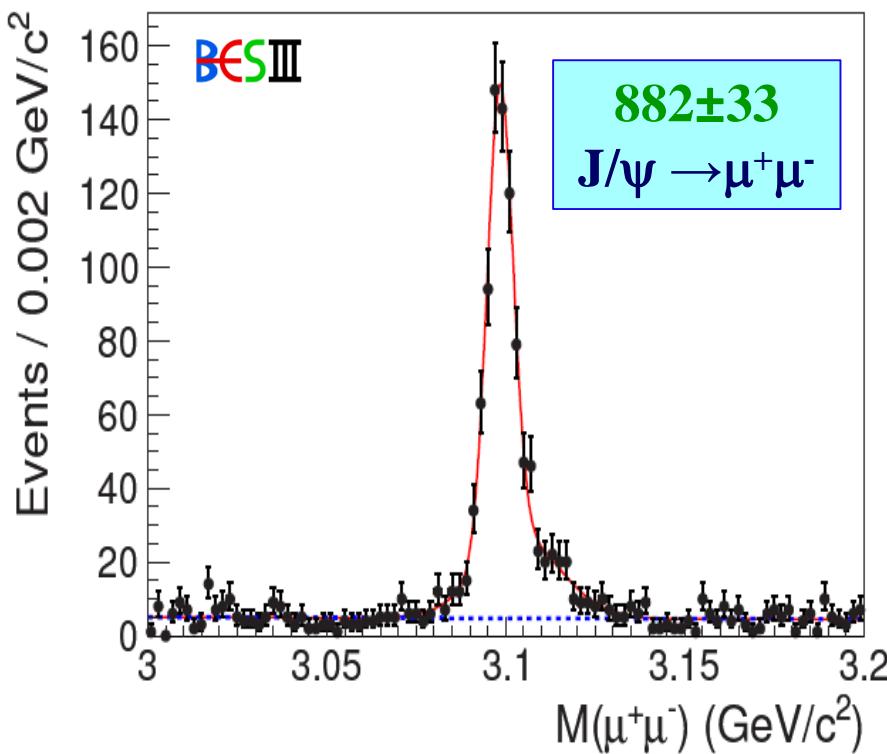


- 4 charged tracks, J/ψ reconstruct via lepton pairs
- very clean sample, very high efficiency, kinematic fit used
- only use MDC & EMC information, MC simulation reliable



BESIII: $e^+e^- \rightarrow \pi^+\pi^-J/\psi$ – J/ψ signals @ 4.260 GeV

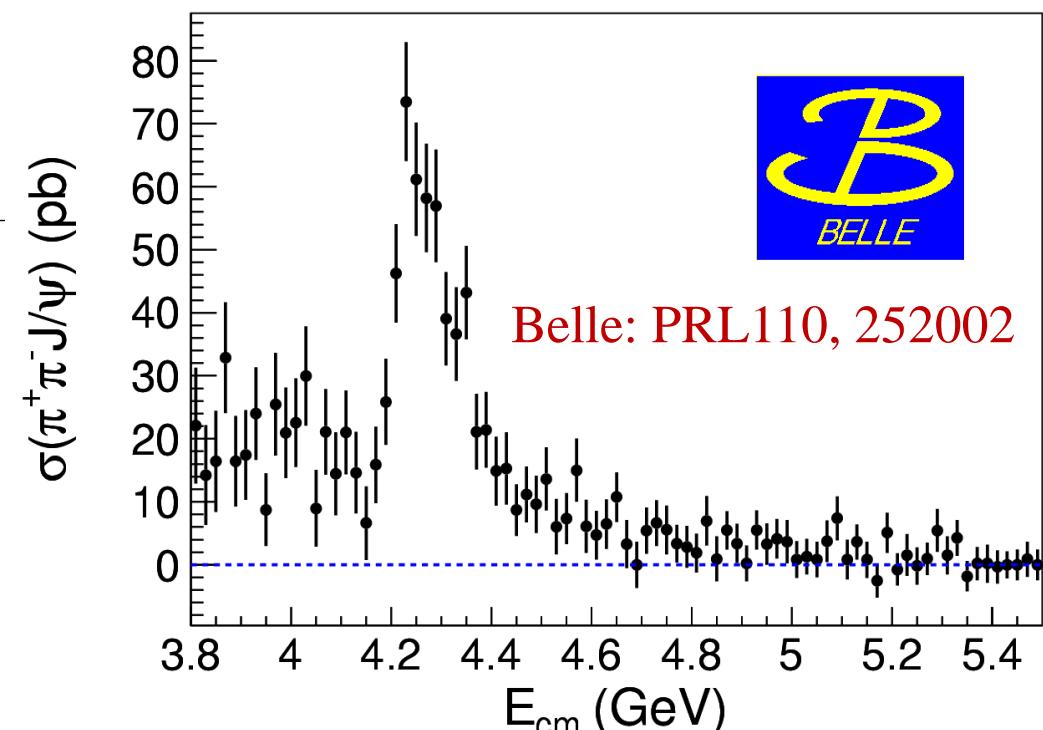
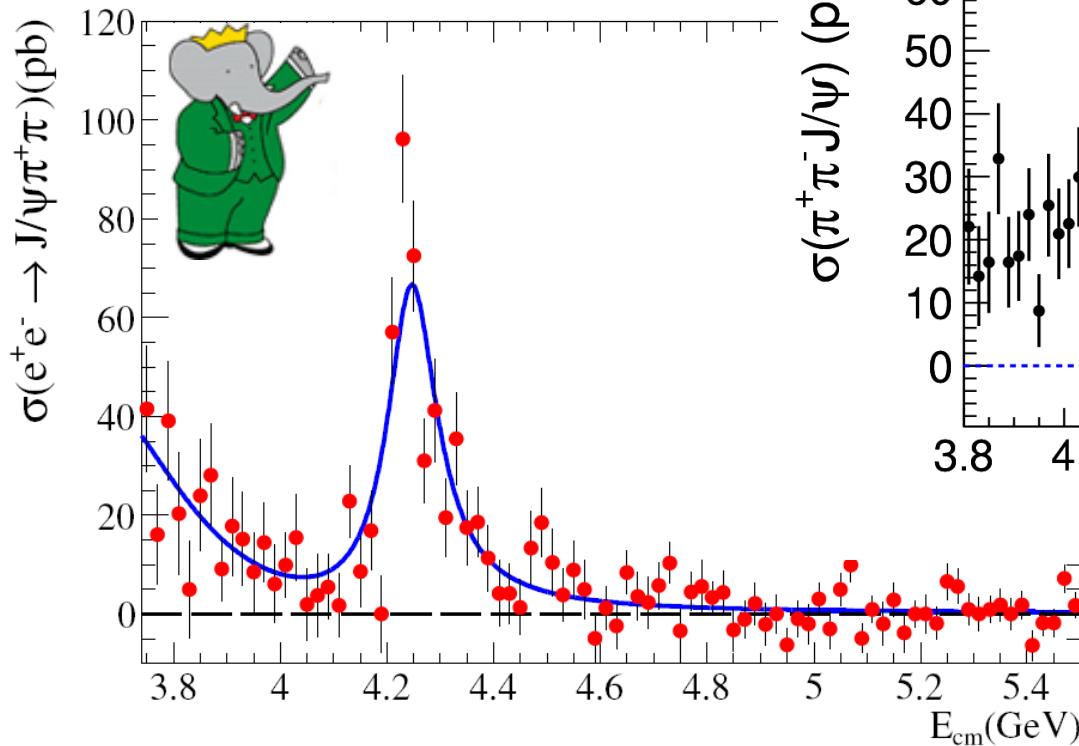
PRL 110, 252001



- Dominant background $e^+e^- \rightarrow \pi^+\pi^-\pi^+\pi^-$
- J/ψ signal: [3.08,3.12] GeV
- J/ψ sideband: [3.0,3.06] GeV or [3.14,3.20] GeV



BaBar: PRD86, 051102 (2012)



Belle: PRL110, 252002

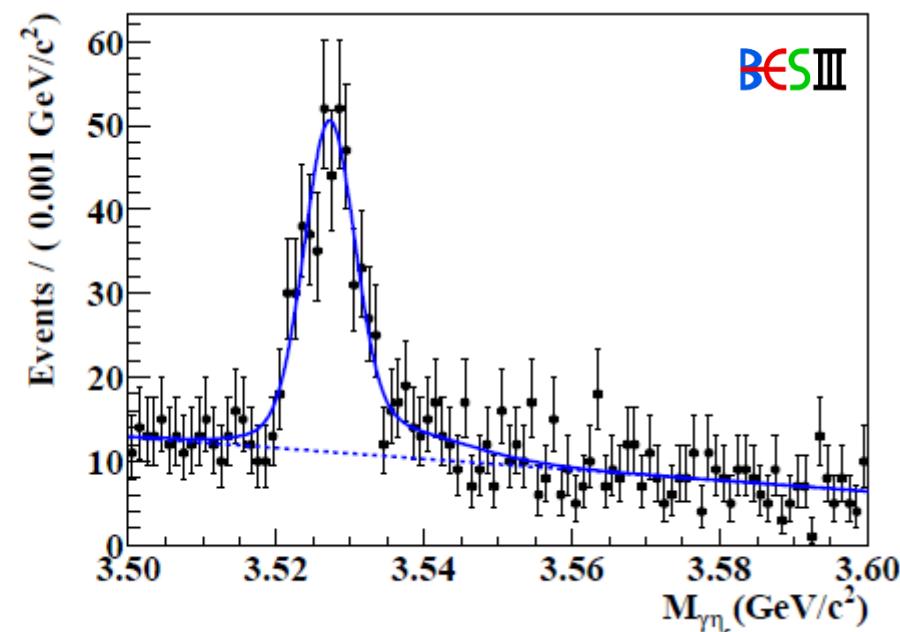
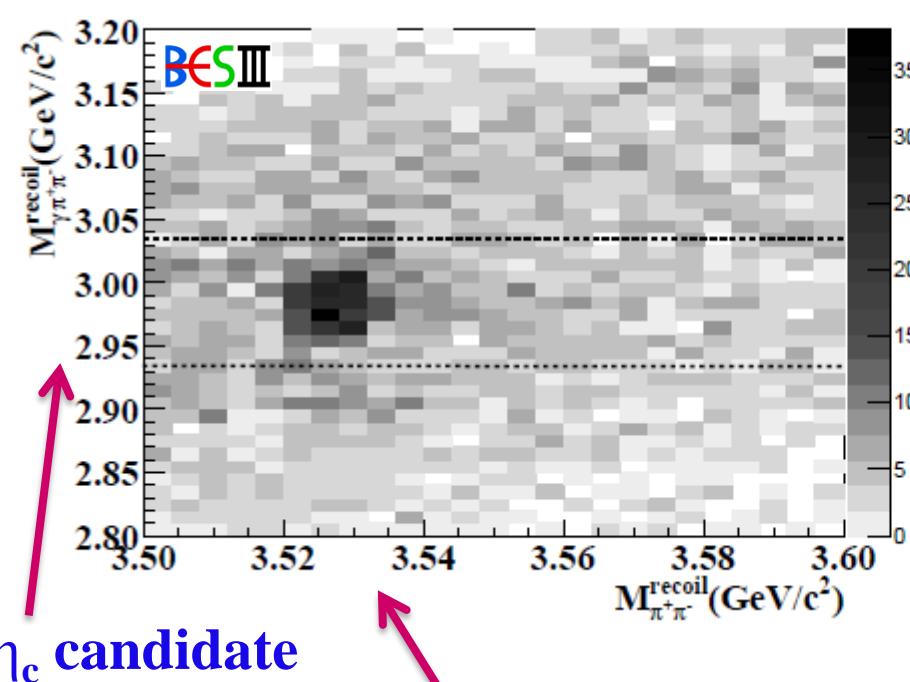
BESIII: $\sigma_B(e^+e^- \rightarrow \pi^+\pi^-J/\psi) = (62.9 \pm 1.9 \pm 3.7) \text{ pb}$

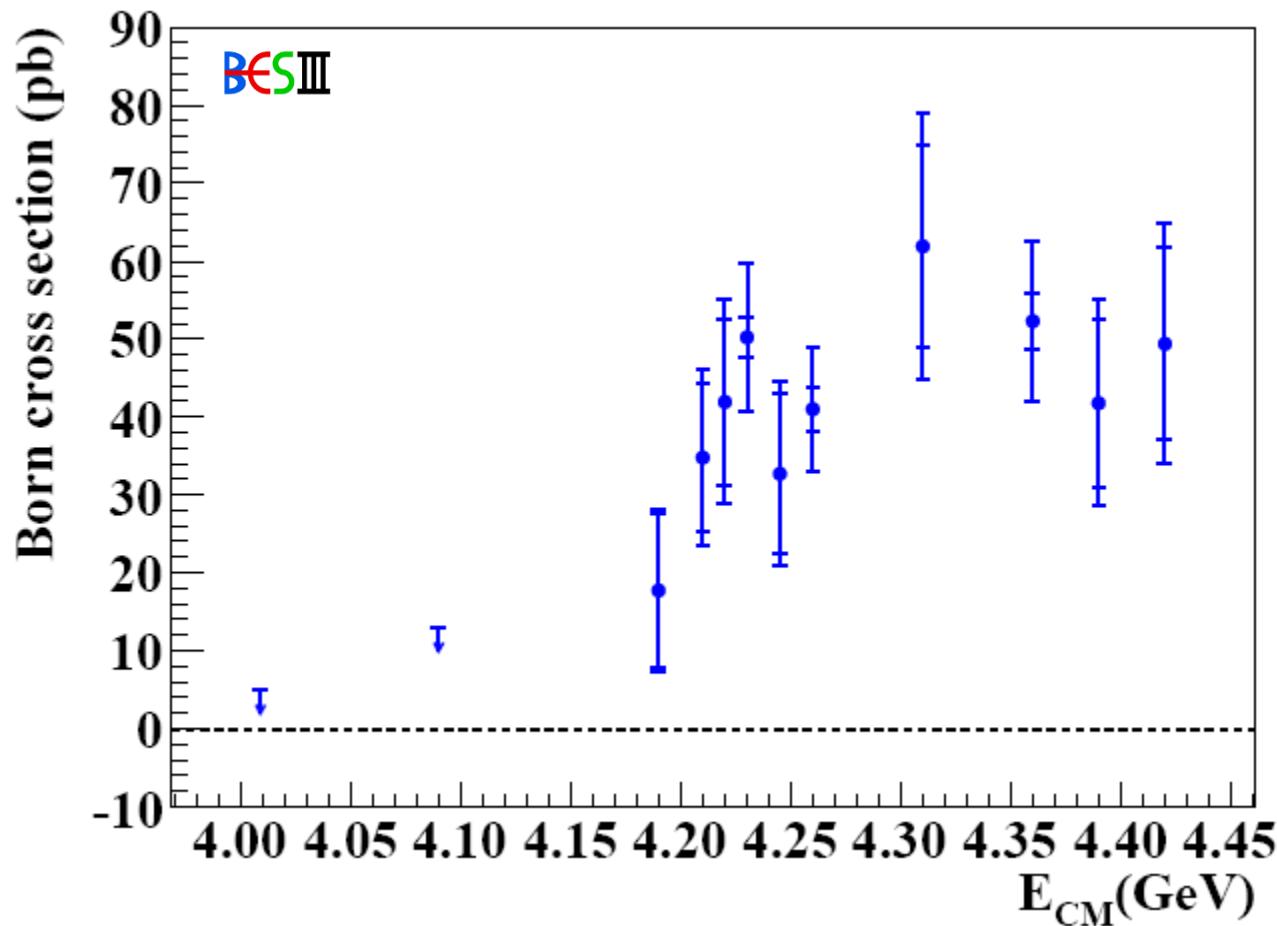
- agreement with BaBar & Belle
- best precision!

BESIII cross sections:
• more energy points
• more data!



- $h_c \rightarrow \gamma\eta_c, \eta_c \rightarrow \text{hadrons}$ [16 exclusive decay modes]
 - $p\ p, \pi^+\pi^-K^+K^-, \pi^+\pi^-p\ p, 2(K^+K^-), 2(\pi^+\pi^-), 3(\pi^+\pi^-)$
 - $2(\pi^+\pi^-)K^+K^-, K_S^0K^+\pi^- + \text{c.c.}, K_S^0K^+\pi^-\pi^+\pi^- + \text{c.c.}, K^+K^-\pi^0$
 - $p\ p\pi^0, K^+K^-\eta, \pi^+\pi^-\eta, \pi^+\pi^-\pi^0\pi^0, 2(\pi^+\pi^-)\eta, 2(\pi^+\pi^-\pi^0)$



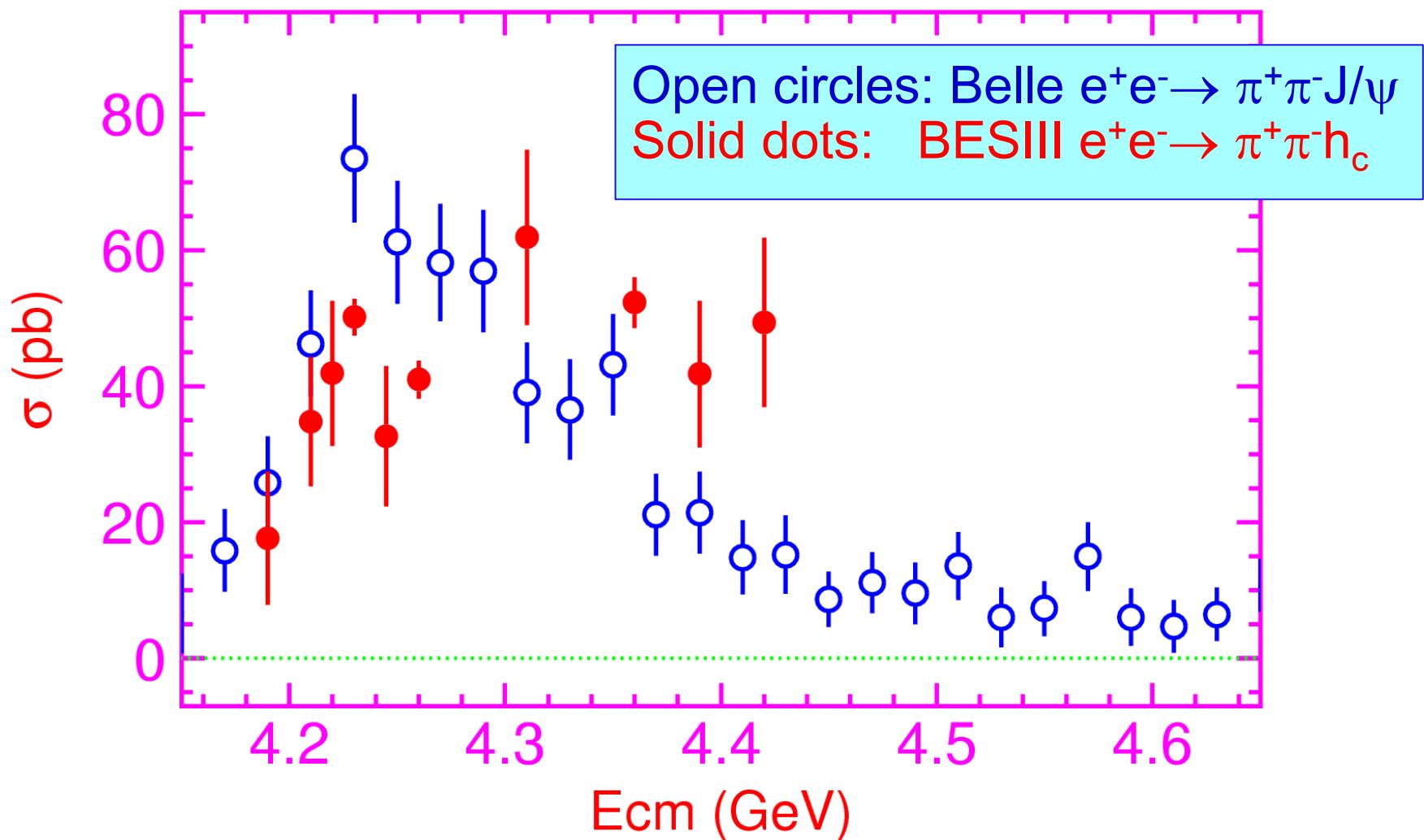


- $\sigma(e^+e^- \rightarrow \pi^+\pi^- h_c) \sim \sigma(e^+e^- \rightarrow \pi^+\pi^- J/\psi)$ but line shape different
- Local maximum ~ 4.23 GeV



$e^+e^- \rightarrow \pi^+\pi^- h_c(1P)$ vs $e^+e^- \rightarrow \pi^+\pi^- J/\psi$

PRL 111, 242001

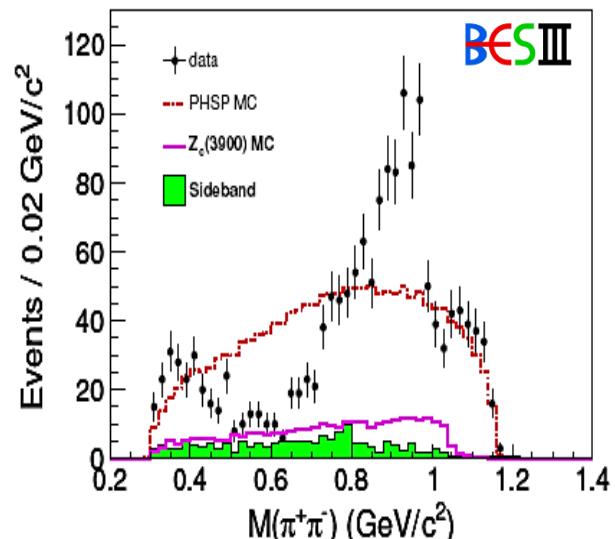
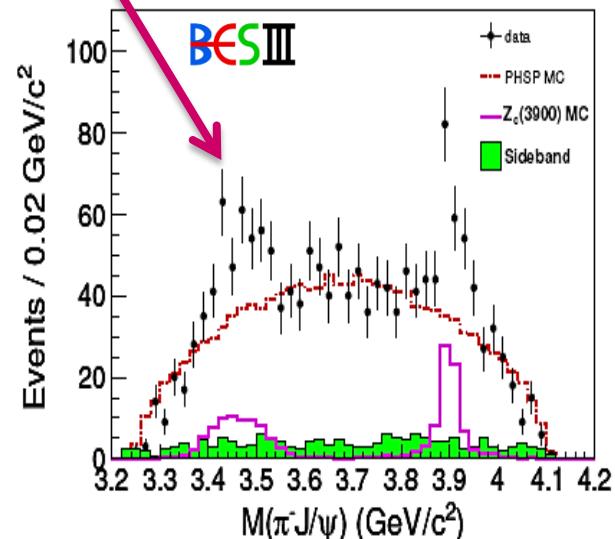
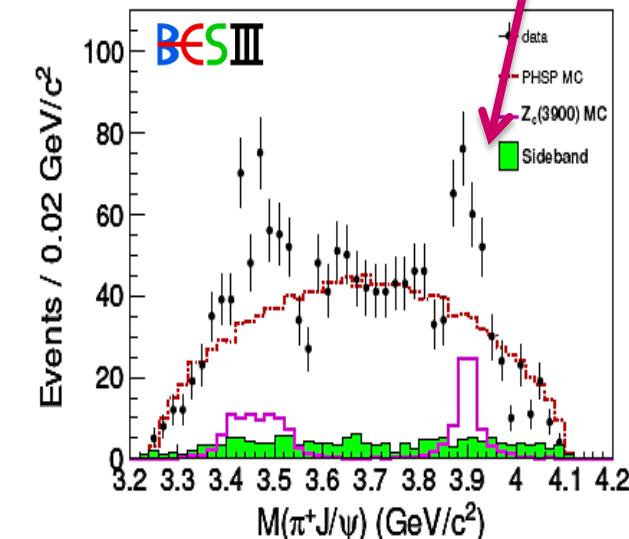
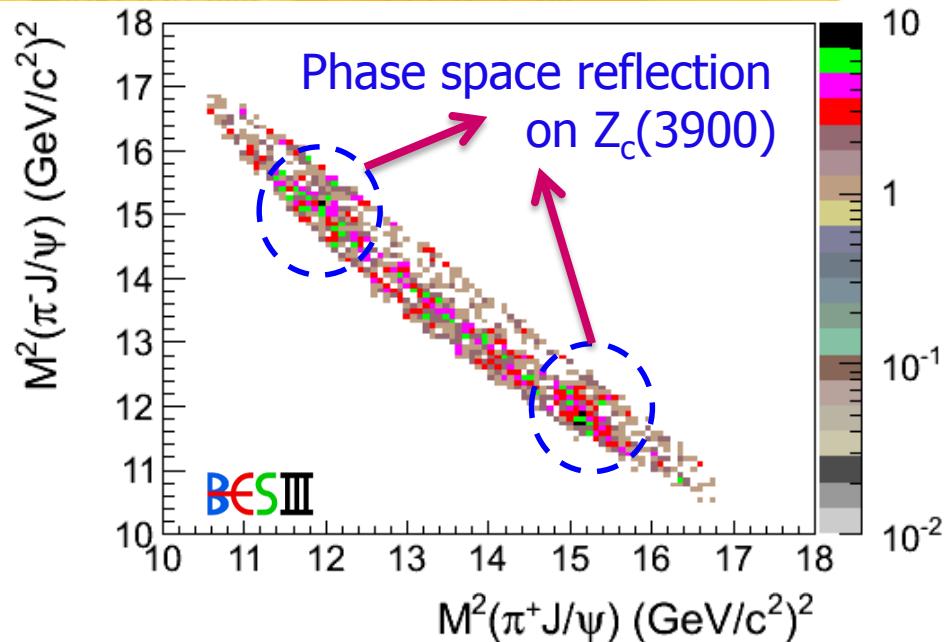
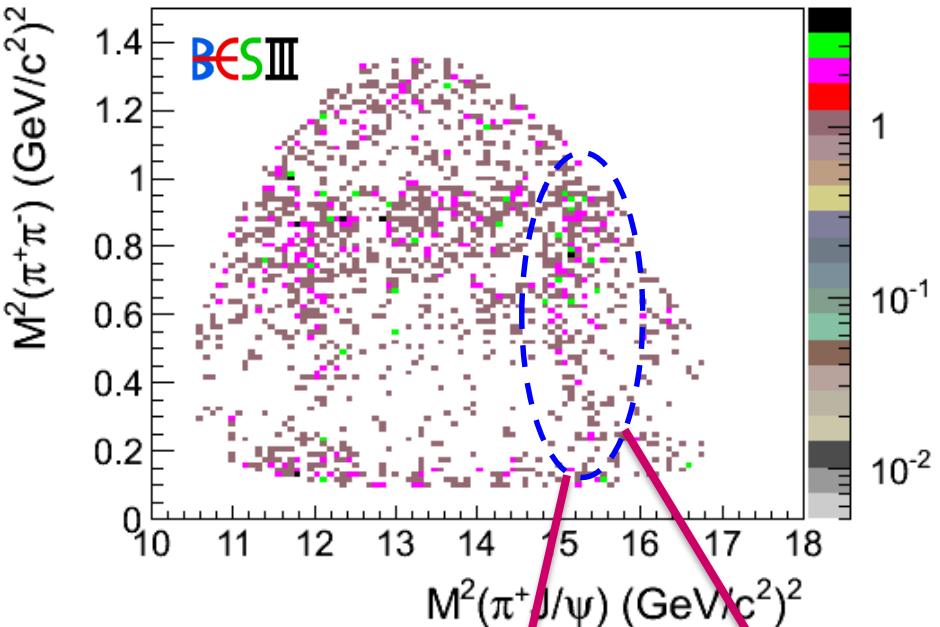


More data at higher energies needed to complete line shape measurement



BESIII: $e^+e^- \rightarrow \pi^+\pi^-J/\psi$ @ 4.260 GeV

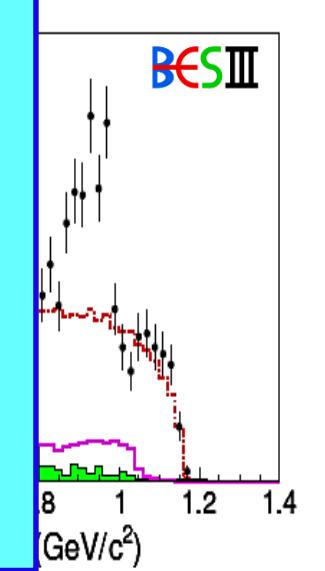
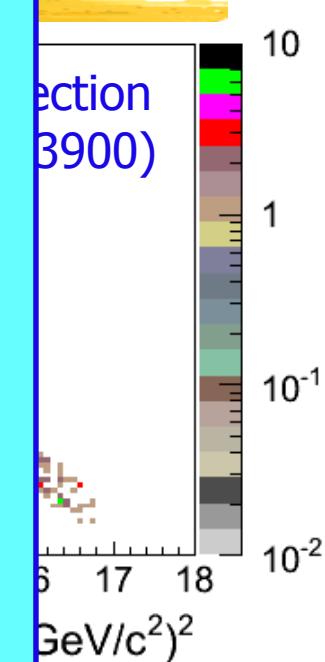
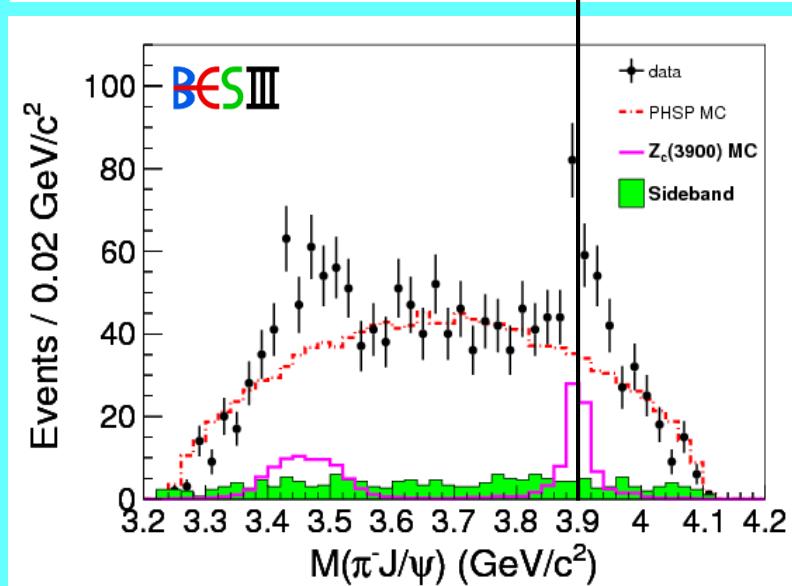
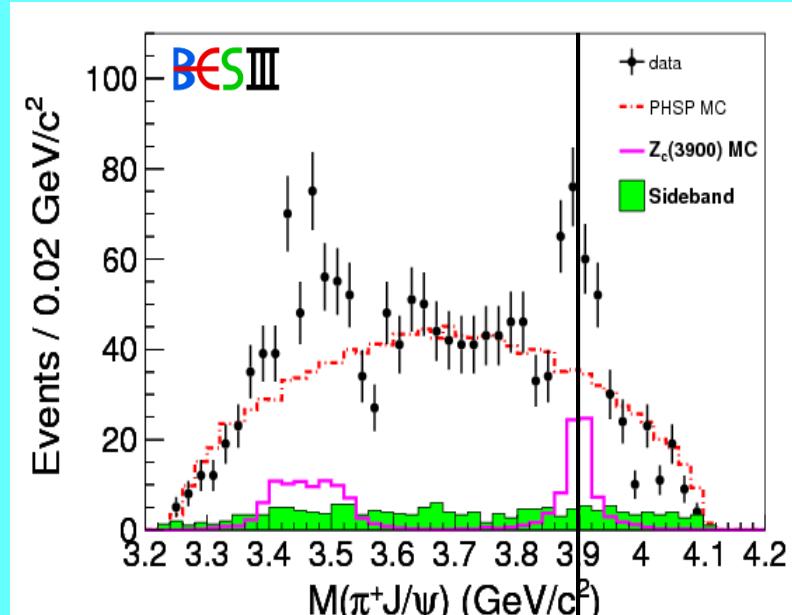
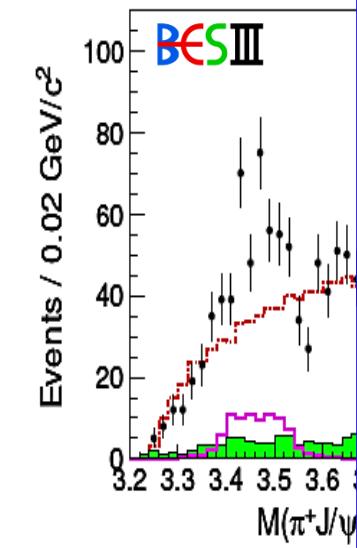
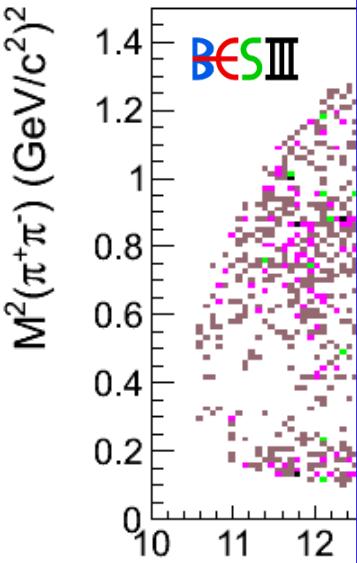
PRL 110, 252001





BESIII: $e^+e^- \rightarrow \pi^+\pi^-J/\psi$ @ 4.260 GeV

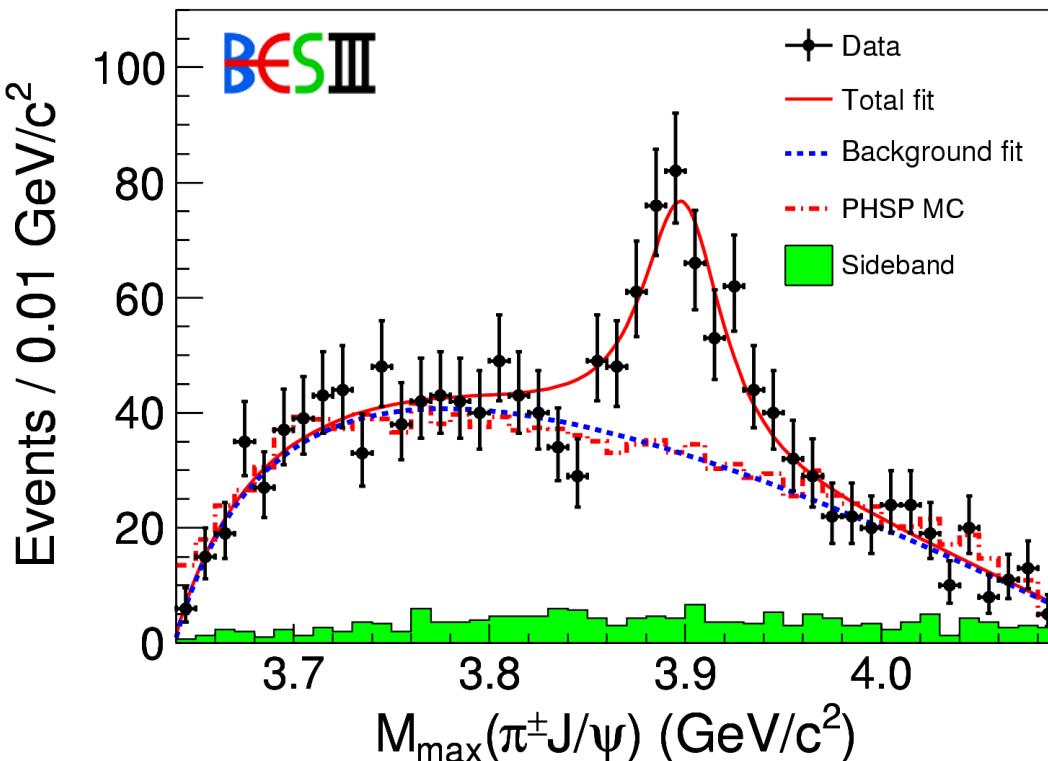
PRL 110, 252001



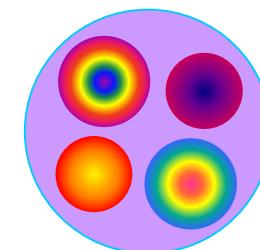


BESIII: $e^+e^- \rightarrow \pi Z_c(3900) \rightarrow \pi^\pm J/\psi$ @ 4.260 GeV

PRL 110, 252001



- couples to $\bar{c}c$
- has electric charge
- at least 4-quarks
- what is its nature?



S-wave Breit-Wigner with efficiency correction

$$M = (3899.0 \pm 3.6 \pm 4.9) \text{ MeV}/c^2$$

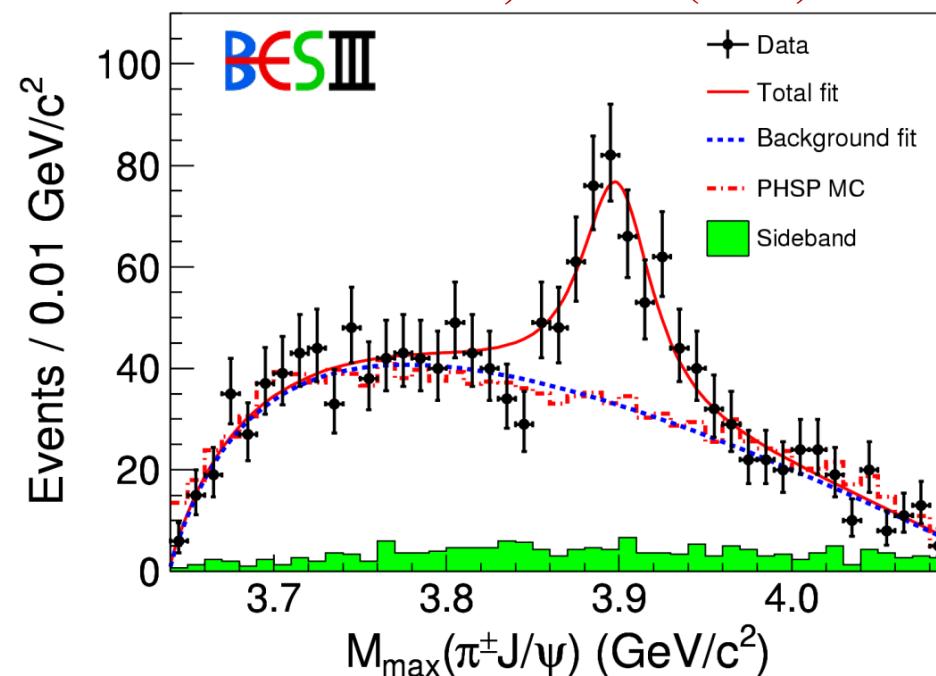
$$\Gamma = (46 \pm 10 \pm 20) \text{ MeV}/c^2$$

$$R = (21.5 \pm 3.3 \pm 7.5)\%$$

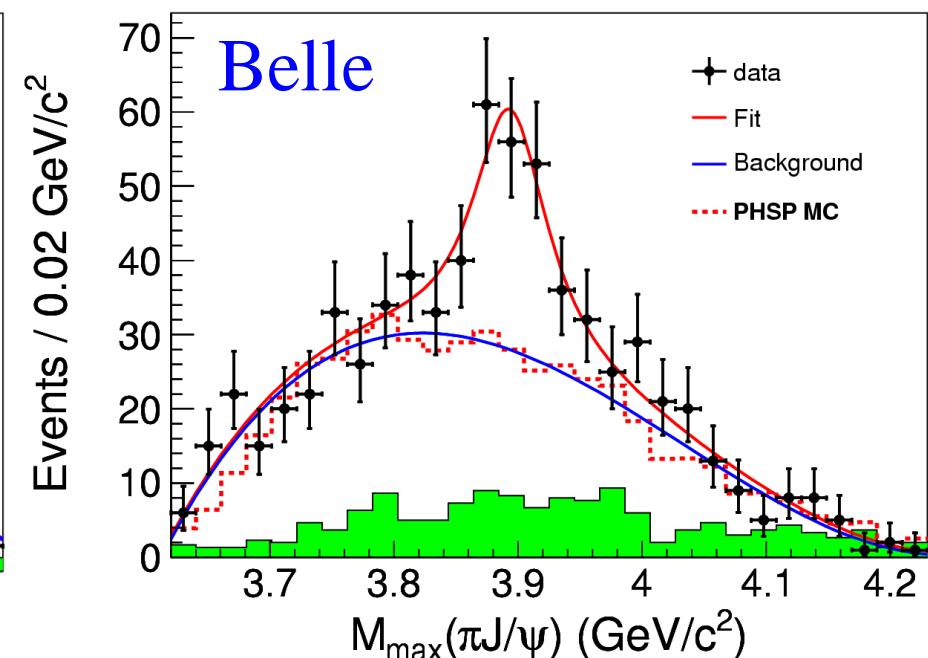
Significance
 $>8\sigma$



PRL 110, 252001 (2013)



PRL 110, 252002 (2013)



$$M = (3899.0 \pm 3.6 \pm 4.9) \text{ MeV}/c^2$$

$$\Gamma = (46 \pm 10 \pm 20) \text{ MeV}/c^2$$

 307 ± 48 events $>8\sigma$

$$M = (3894.5 \pm 6.6 \pm 4.5) \text{ MeV}/c^2$$

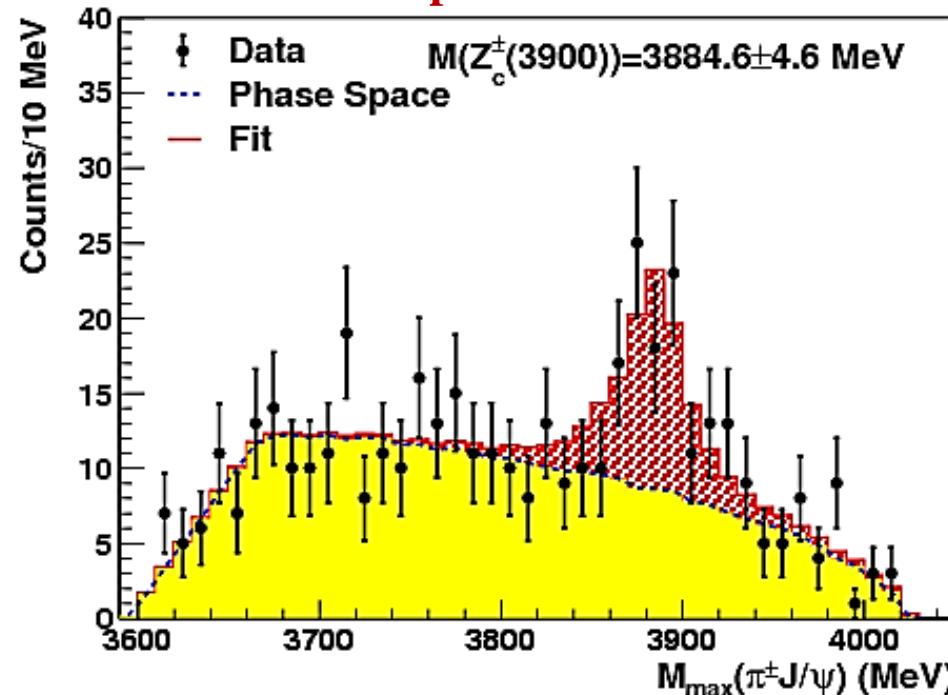
$$\Gamma = (63 \pm 24 \pm 26) \text{ MeV}/c^2$$

 159 ± 49 events $>5.2\sigma$



K. Seth & co. @ 4.170 GeV

hep-ex:1304.3036

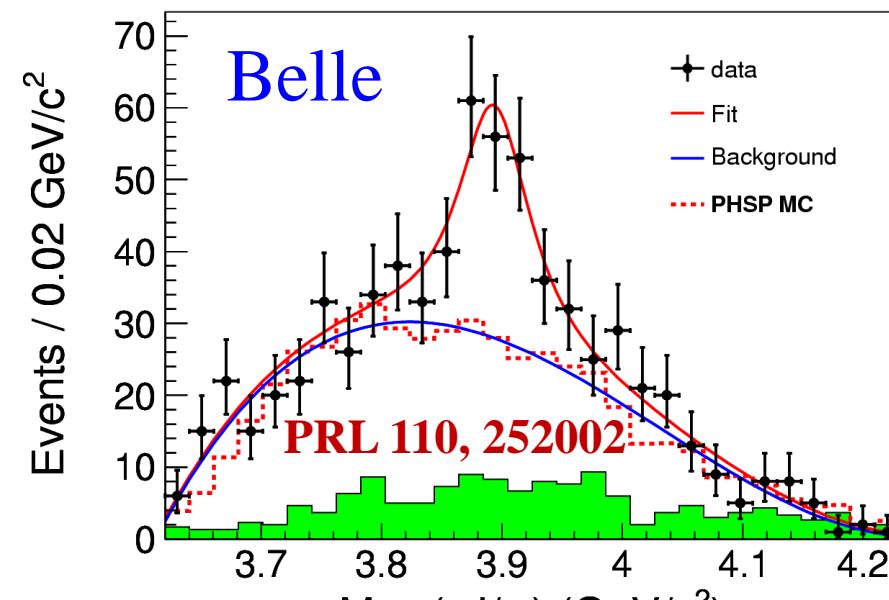
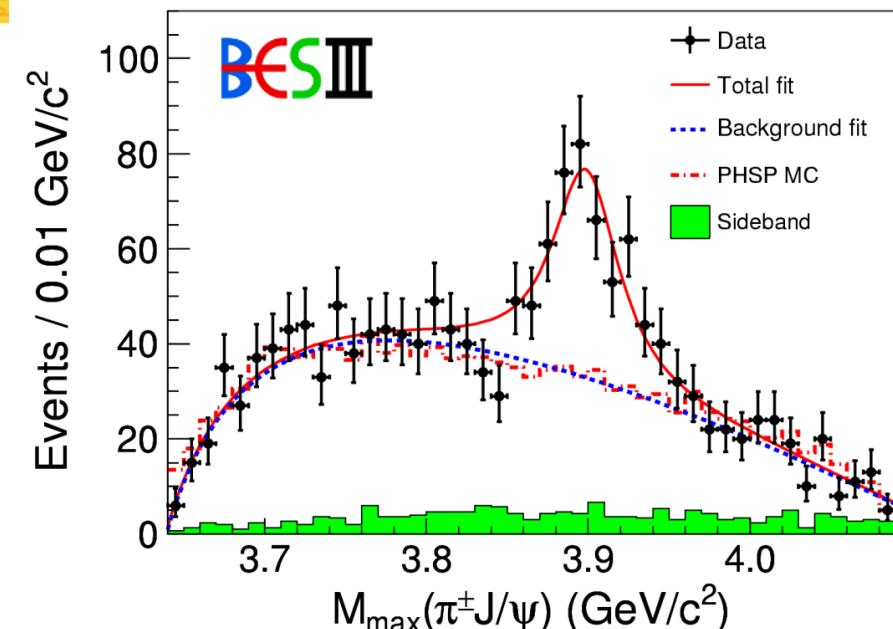


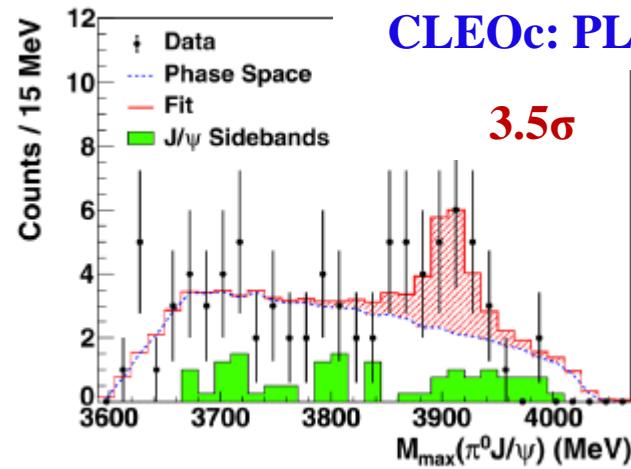
$$M = (3885 \pm 5 \pm 1) \text{ MeV}/c^2$$

$$\Gamma = (34 \pm 12 \pm 4) \text{ MeV}/c^2$$

81 ± 20 events

6.1σ



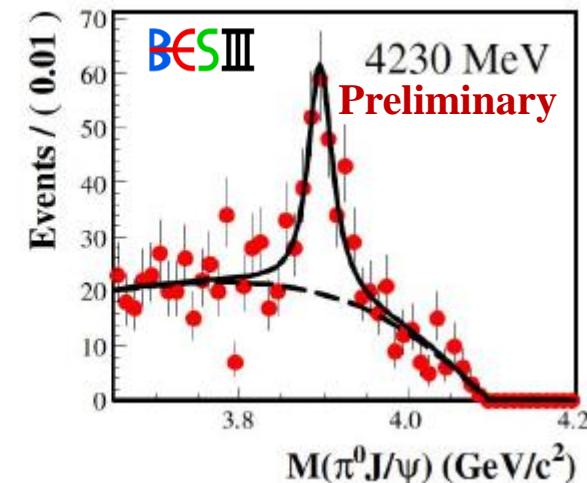
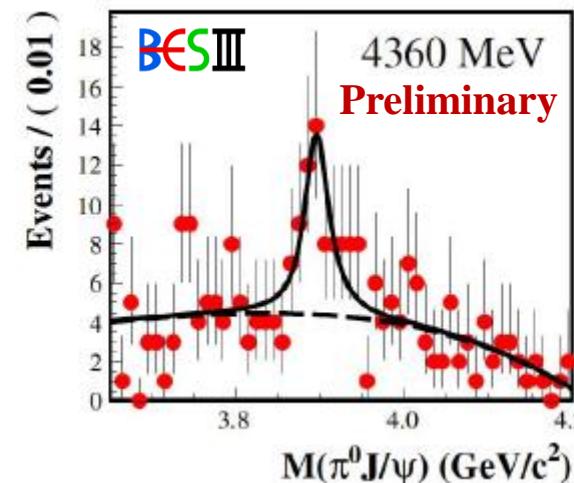
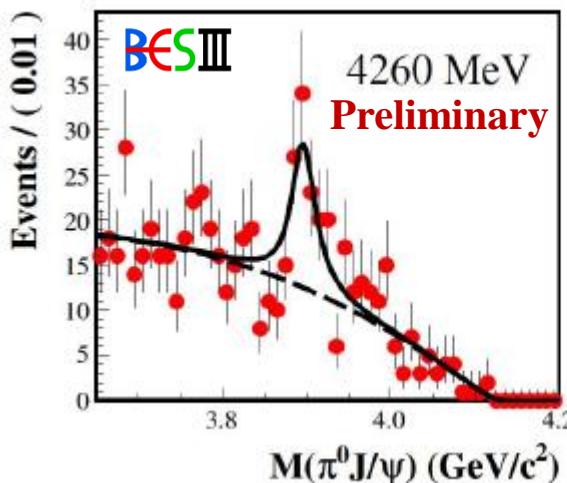


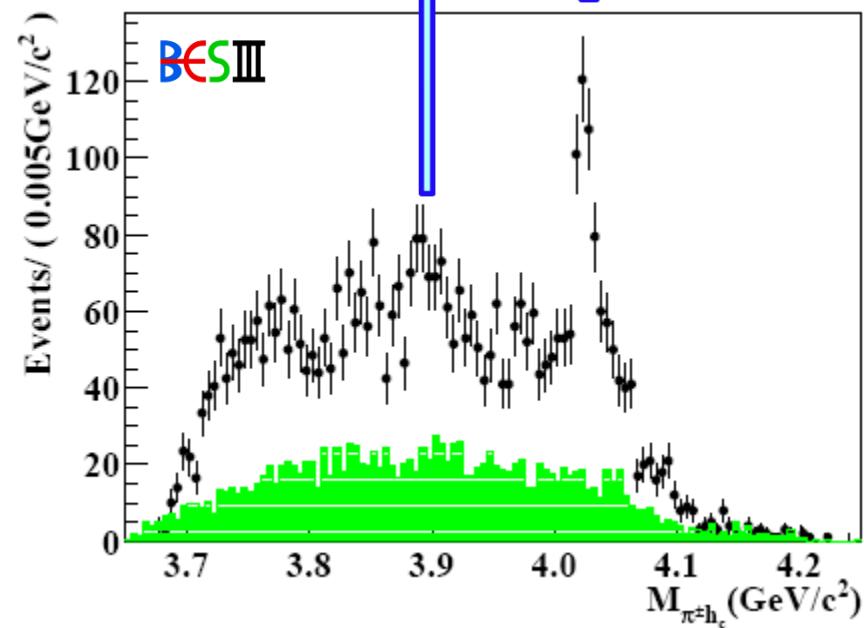
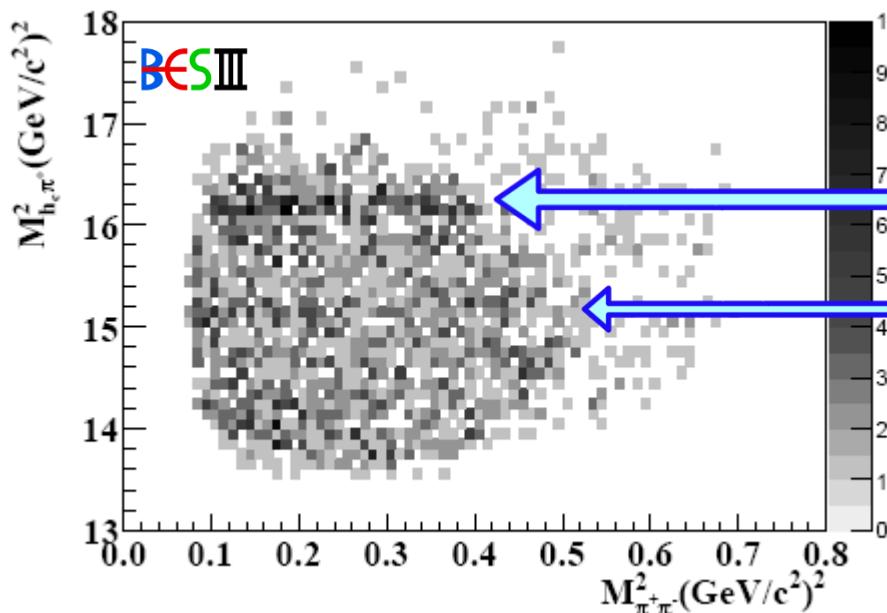
BESIII PRELIMINARY!

- 2.8fb^{-1} data at 10 energy points from 4230~4420 MeV
- $Z_c(3900)^0$ is observed clearly at:
 $E_{cm}=4230, 4260, 4360\text{MeV}$

$M = (3894.8 \pm 2.3) \text{ MeV}/c^2$
 $\Gamma = (29.6 \pm 8.2) \text{ MeV}/c^2$
 10.4 σ

An isospin triplet for $Z_c(3900)$ has been established



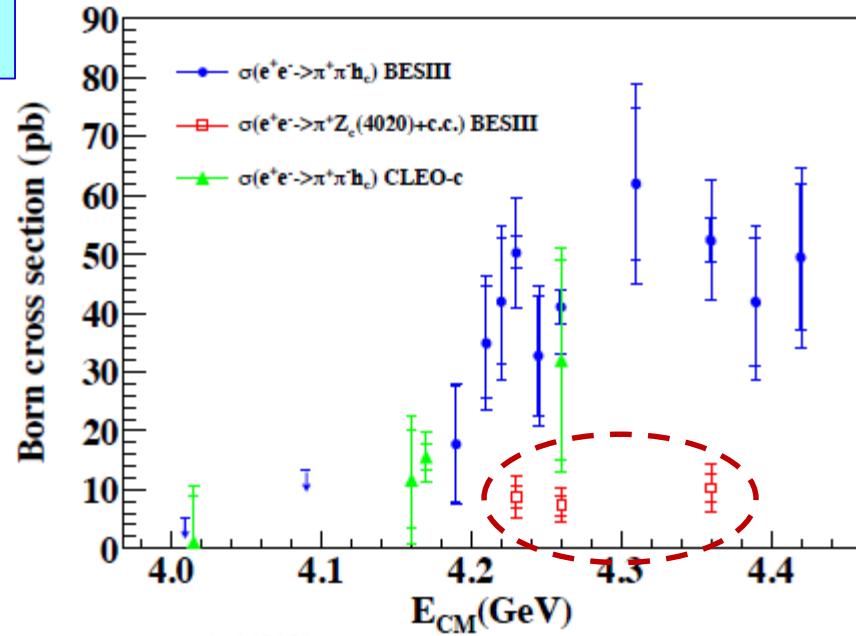
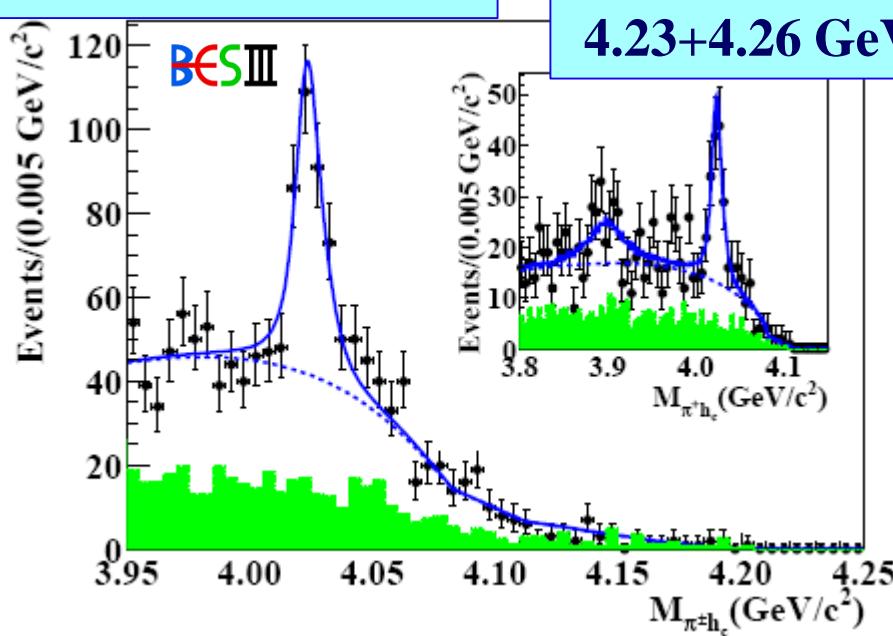


- **all collected energies**
[3.900 \div 4.420 GeV]
- $h_c \rightarrow \gamma \eta_c, \eta_c \rightarrow \text{hadrons}$
[16 exclusive decay modes]



Simultaneous fit to 4.26/4.36 GeV data and 16 η_c decay modes.

4.23+4.26+4.36 GeV



$M = (4022.9 \pm 0.8 \pm 2.7) \text{ MeV}/c^2$

$\Gamma = (7.9 \pm 2.7 \pm 2.6) \text{ MeV}/c^2$

$> 8.9\sigma$

4.26 GeV:

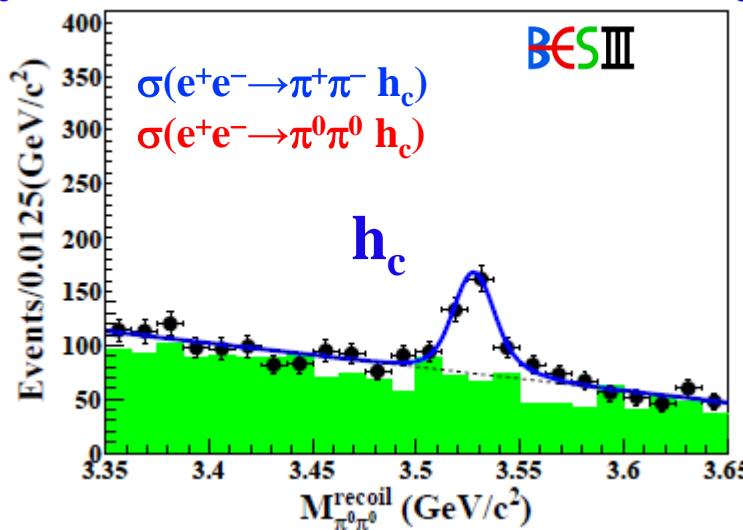
$\sigma(e^+e^- \rightarrow \pi Z_c(3900)^+ \pi^- \rightarrow \pi^+\pi^- h_c) = < 11 \text{ pb (90\% C.L.)}$

$\mathcal{B}(h_c \rightarrow \gamma \eta_c)$



BESIII PRELIMINARY!

- 2.8 fb^{-1} data at 10 energy points from $4230 \sim 4420 \text{ MeV}$
- $Z_c(4020)^0$ is observed clearly at: $E_{cm}=4230, 4260, 4360 \text{ MeV}$

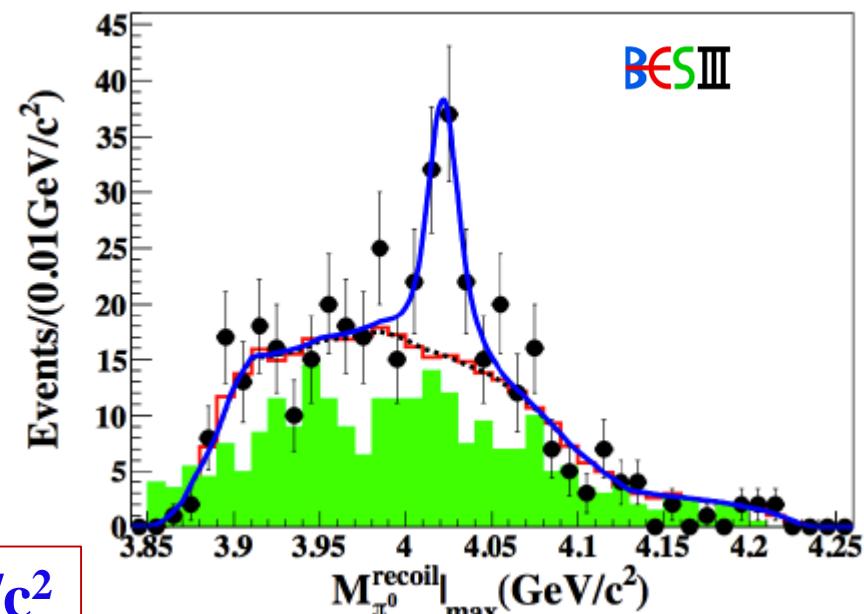


$$M_{Z_c(4020)^0} = (4023.9 \pm 2.2 \pm 3.8) \text{ MeV}/c^2$$

$$M_{Z_c(4020)^{\pm}} = (4022.9 \pm 0.8 \pm 2.7) \text{ MeV}/c^2$$

$\Gamma_{Z_c(4020)^0}$ fixed @ $\Gamma_{Z_c(4020)^{\pm}}$

>5 σ

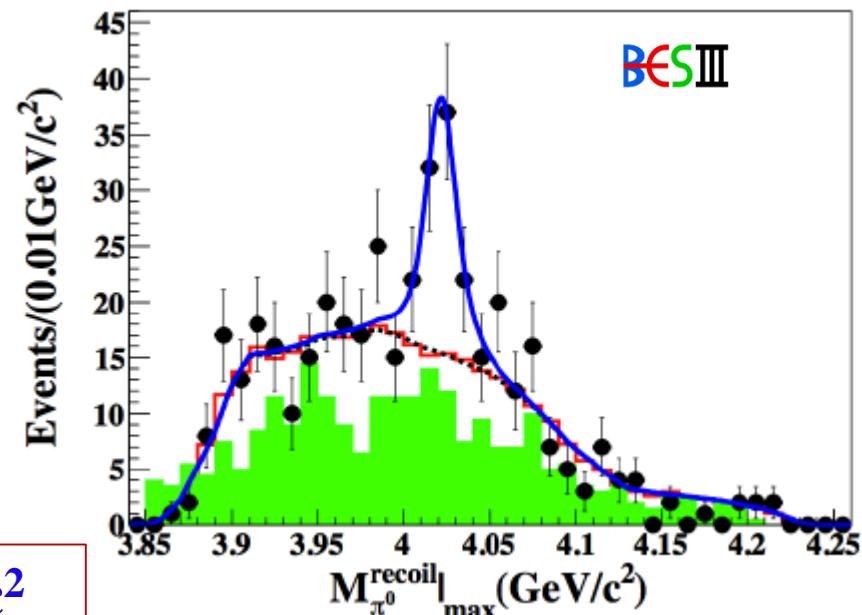
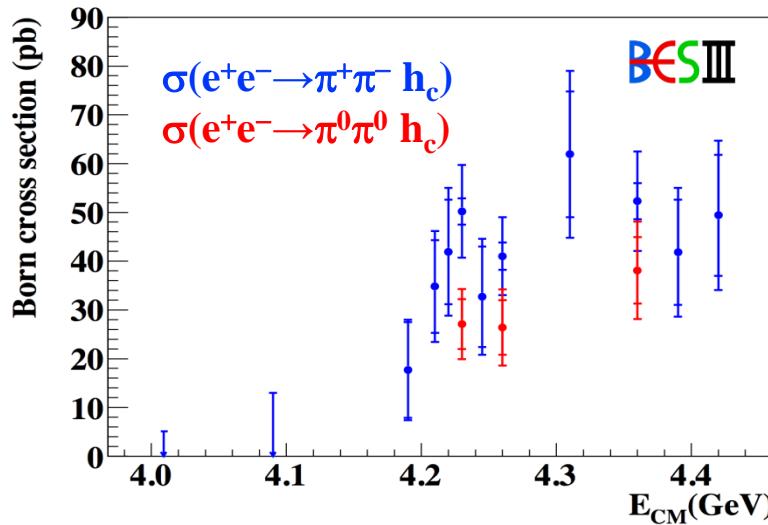


An isospin triplet for
 $Z_c(4020)$
has also been observed



BESIII PRELIMINARY!

- 2.8 fb^{-1} data at 10 energy points from $4230 \sim 4420 \text{ MeV}$
- $Z_c(4020)^0$ is observed clearly at: $E_{cm}=4230, 4260, 4360 \text{ MeV}$



$$M_{Z_c(4020)^0} = (4023.6 \pm 2.2 \pm 3.8) \text{ MeV}/c^2$$

$$M_{Z_c(4020)^{\pm}} = (4022.9 \pm 0.8 \pm 2.7) \text{ MeV}/c^2$$

$\Gamma_{Z_c(4020)^0}$ fixed @ $\Gamma_{Z_c(4020)^{\pm}}$

$>5\sigma$

An isospin triplet for $Z_c(4020)$ has also been observed

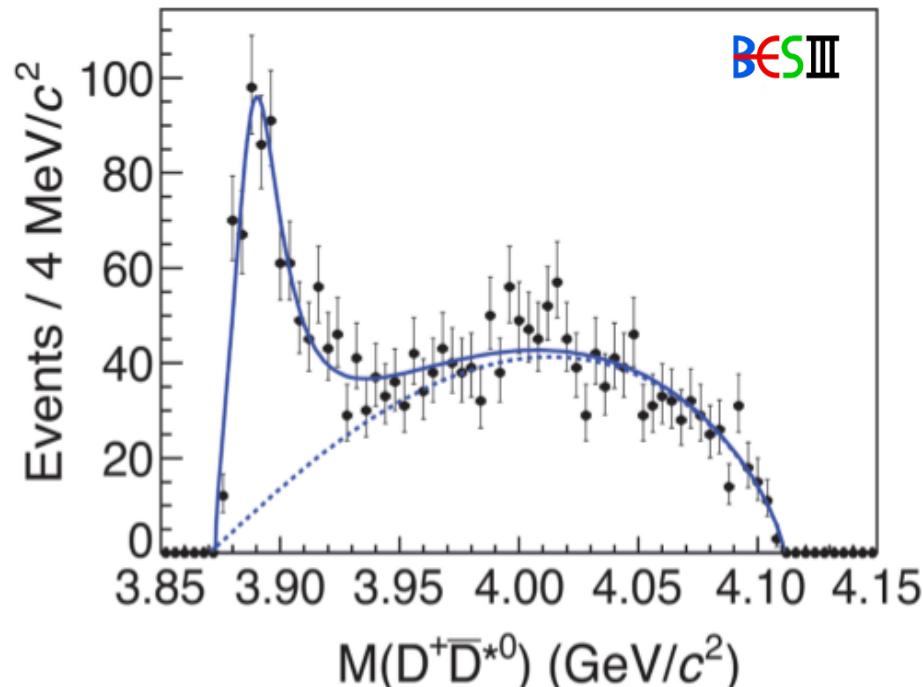
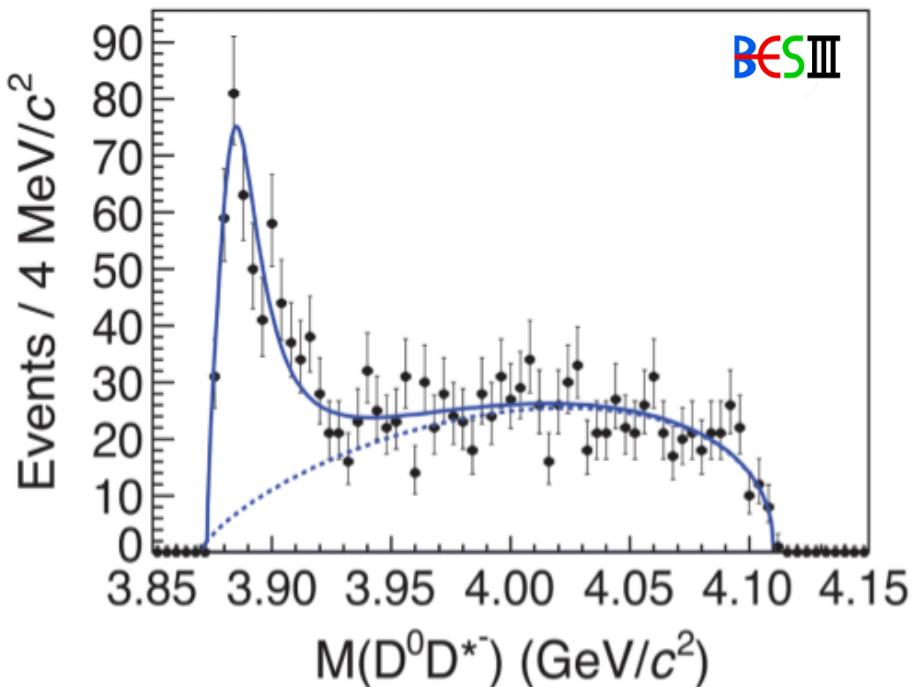
$\sigma(e^+e^- \rightarrow \pi^+\pi^- h_c) \sim 2 \sigma(e^+e^- \rightarrow \pi^0\pi^0 h_c)$
isospin conservation



BESIII: $e^+e^- \rightarrow \pi^- Z_c(3885) \rightarrow \pi^- (D\bar{D}^*)^+ + c.c.$ @ 4.260 GeV

PRL 112, 022001

525 pb⁻¹ data @ 4260 MeV



$$\begin{aligned} M &= (3883.9 \pm 1.5 \pm 4.2) \text{ MeV}/c^2 \\ \Gamma &= (24.8 \pm 3.3 \pm 11.0) \text{ MeV}/c^2 \\ &> 18\sigma \end{aligned}$$

$\pi Z_c(3885)$ ang. dist. favours $J^P = 1^+$
disfavours $1^- e 0^-$

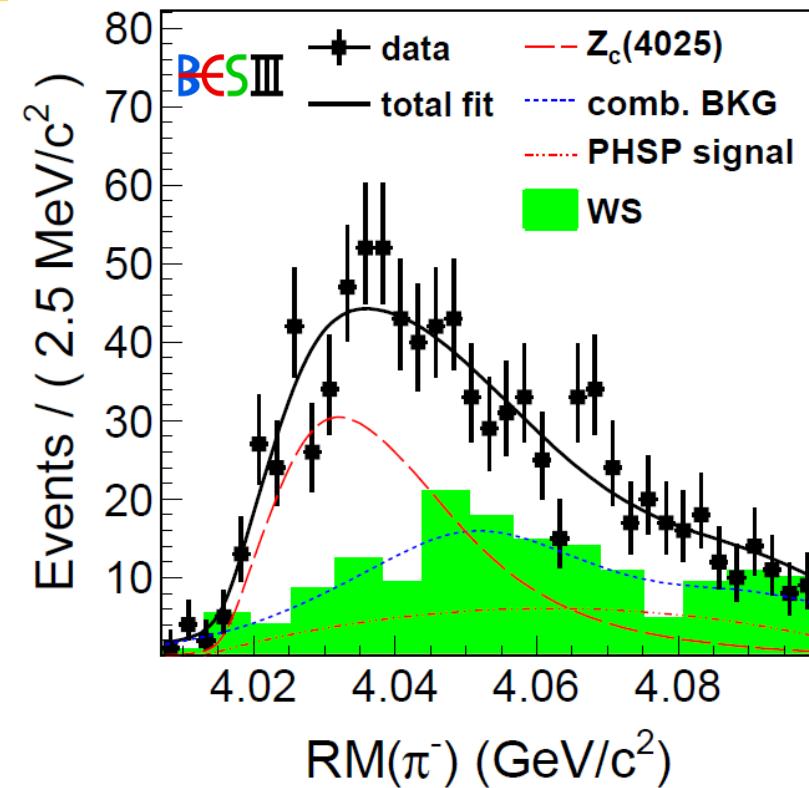
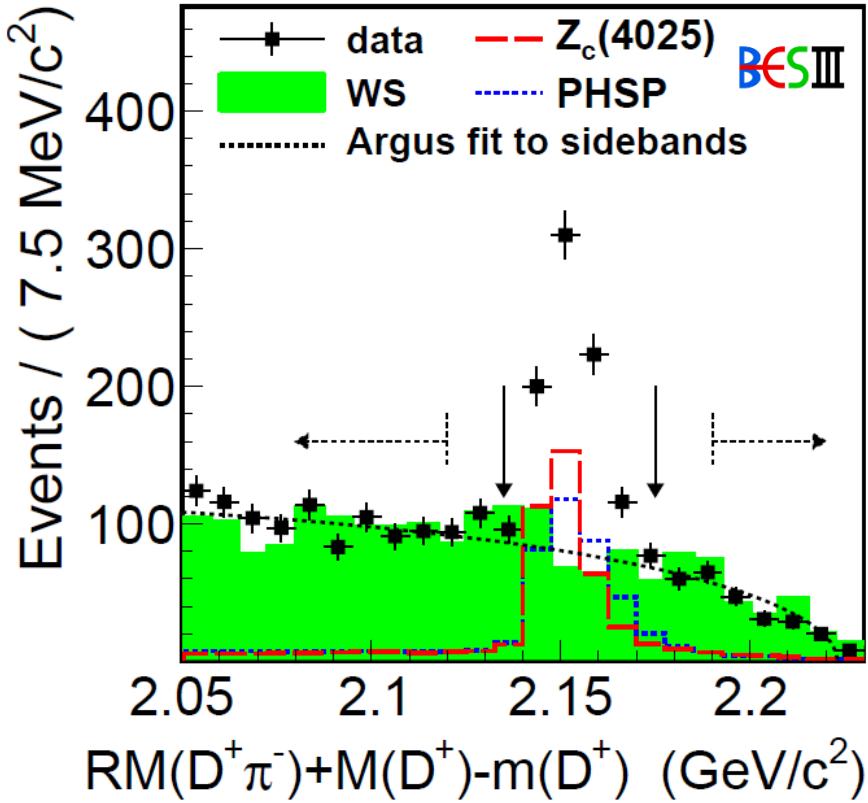
$$\sigma(e^+e^- \rightarrow \pi^- Z_c(3885)^+ \times Z_c(3885)^+ \rightarrow (D\bar{D}^*)^+ + c.c.) = (83.5 \pm 6.6 \pm 22.0) \text{ pb}$$

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



BESIII: $e^+e^- \rightarrow \pi Z_c(4025) \rightarrow \pi^- (D^* \bar{D}^*)^+ + c.c.$ @ 4.260 GeV

PRL 112, 132001



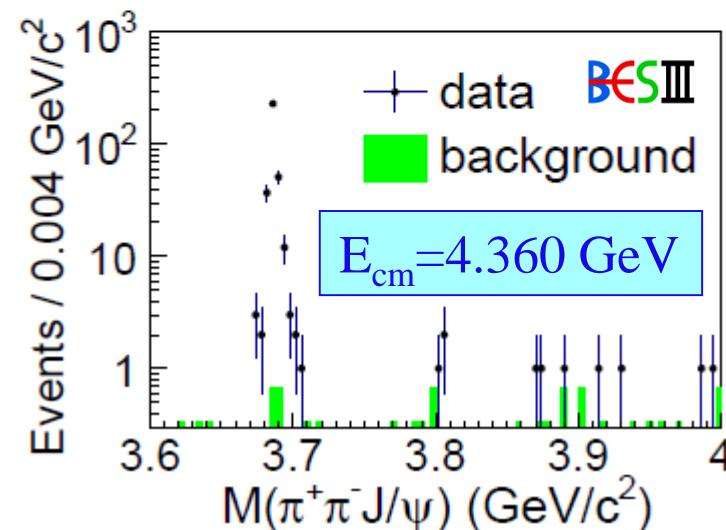
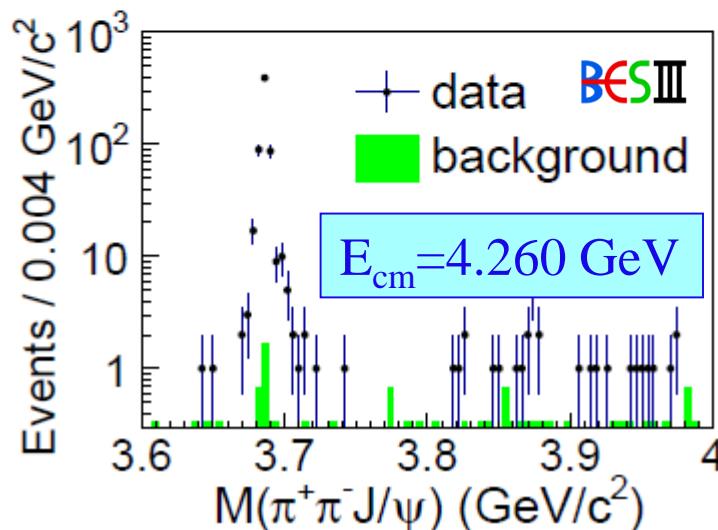
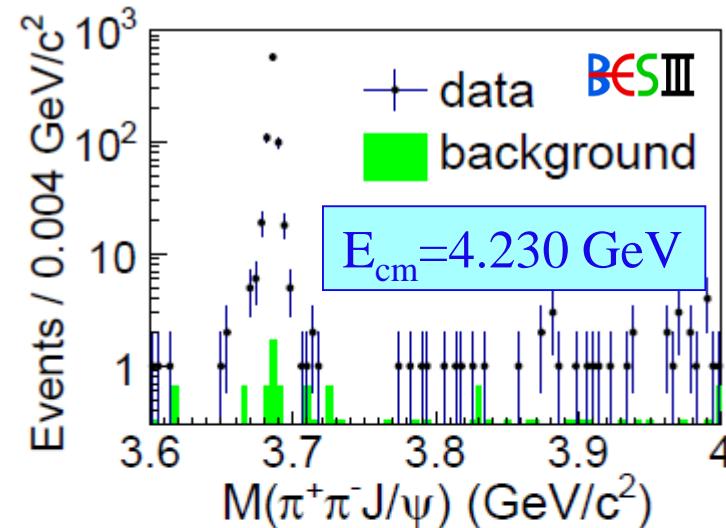
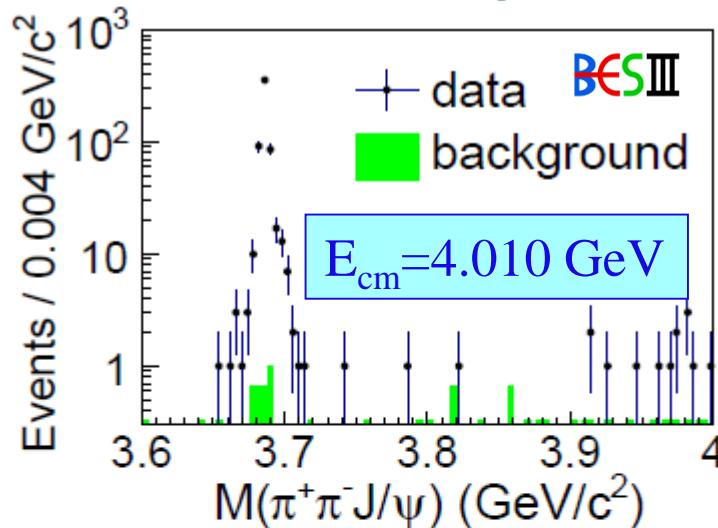
M = $(4026.3 \pm 2.6 \pm 3.7)$ MeV/c²
 $\Gamma = (24.8 \pm 5.7 \pm 7.7)$ MeV/c²
>10 σ

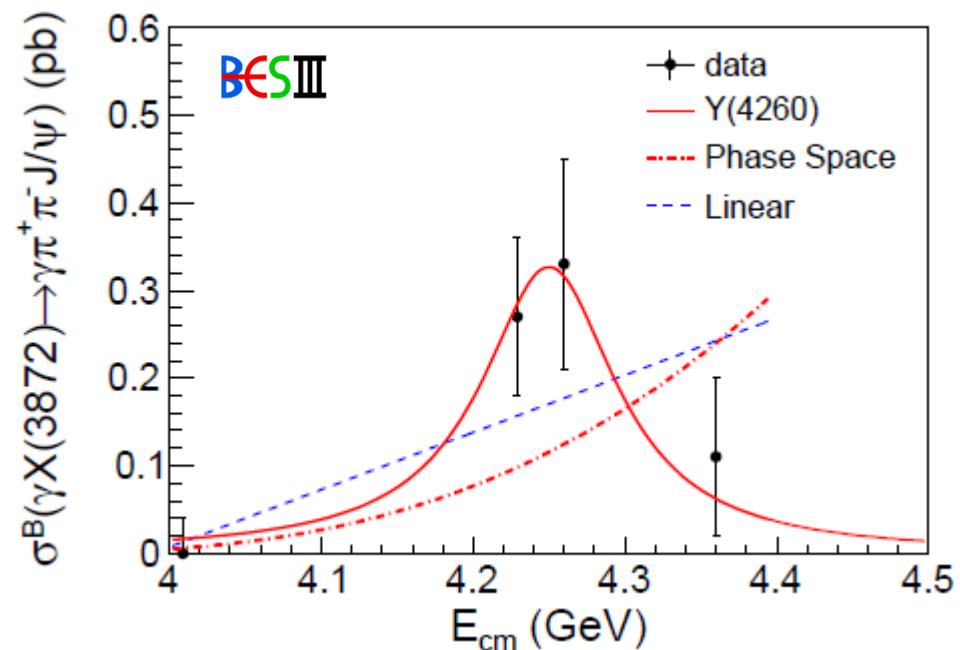
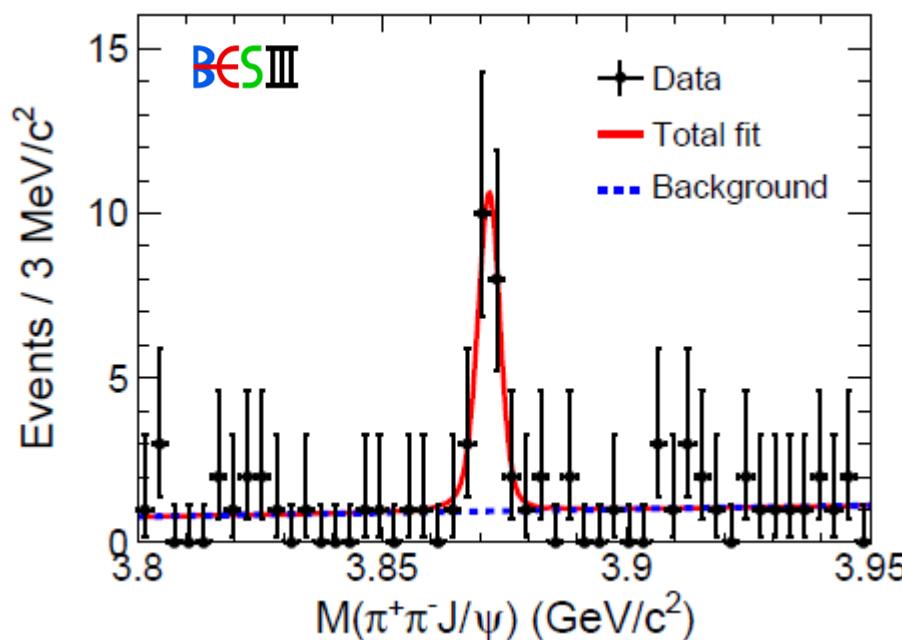
$\sigma(e^+e^- \rightarrow \pi^- (D^* \bar{D}^*)^+ + c.c.) = (137 \pm 9 \pm 15)$ pb

$$R = \frac{\sigma(e^+e^- \rightarrow \pi^- Z_c \rightarrow \pi^- (D^* \bar{D}^*)^+ + c.c.)}{\sigma(e^+e^- \rightarrow \pi^- (D^* \bar{D}^*)^+ + c.c.)} = (65 \pm 9 \pm 6)\%$$



Clear ISR ψ' signal for data validation
X(3872) signal at around 4.230-4.260 GeV





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

$$\mu_{\psi(3686)} = -(0.34 \pm 0.04) \text{ MeV}/c^2; \quad \sigma_M = (1.14 \pm 0.07) \text{ MeV}$$

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

$$M = (3871.9 \pm 0.7 \pm 0.2) \text{ MeV}/c^2$$

$$\Gamma = <2.4 \text{ MeV}/c^2 \text{ with } 90\% \text{ CL}$$

[PDG: $3871.68 \pm 0.17 \text{ MeV}$]

Could be a $Y(4260) \rightarrow \gamma X(3872)$!

$$R = \frac{\sigma(Y(4260) \rightarrow \gamma X(3872))}{\sigma(Y(4260) \rightarrow \pi^+\pi^-J/\psi)} \sim 11\%$$



BESIII: Z_c states

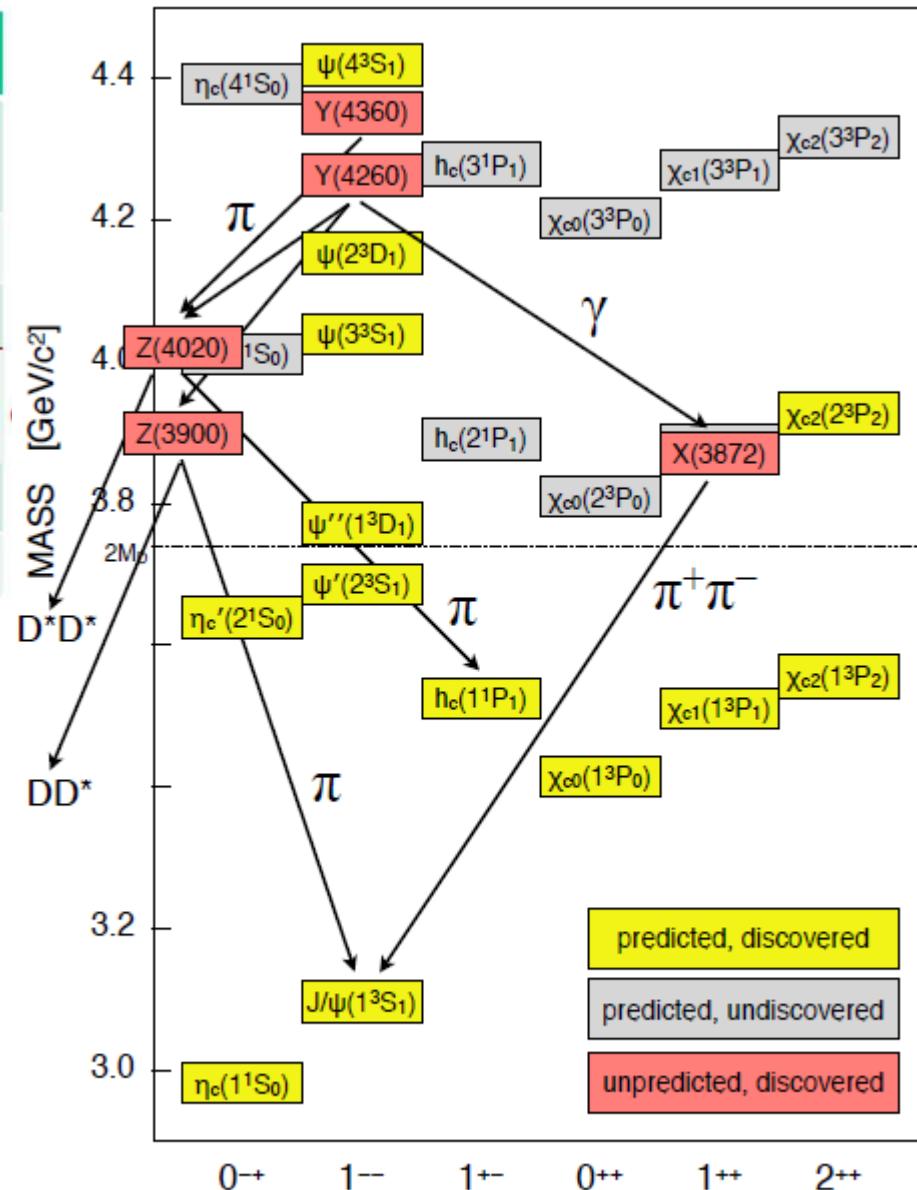
Channel	Mass (MeV/c ²)	Width (MeV)
$\pi J/\psi$	$3899.0 \pm 3.6 \pm 4.9$	$46 \pm 10 \pm 20$
	3894.8 ± 2.3 (Prel.)	29.6 ± 8.2 (Prel.)
$(D \bar{D}^*)^\pm$	$3883.9 \pm 1.5 \pm 4.2$	$24.8 \pm 3.3 \pm 11.0$
	2 σ difference	1 σ difference
πh_c	$4022.9 \pm 0.8 \pm 2.7$	$7.9 \pm 2.7 \pm 2.6$
	$4023.9 \pm 2.2 \pm 3.9$ (Prel.)	
$(D^* \bar{D}^*)^\pm$	$4026.3 \pm 2.6 \pm 3.7$	$24.8 \pm 5.6 \pm 7.7$
	1 σ difference	2 σ difference

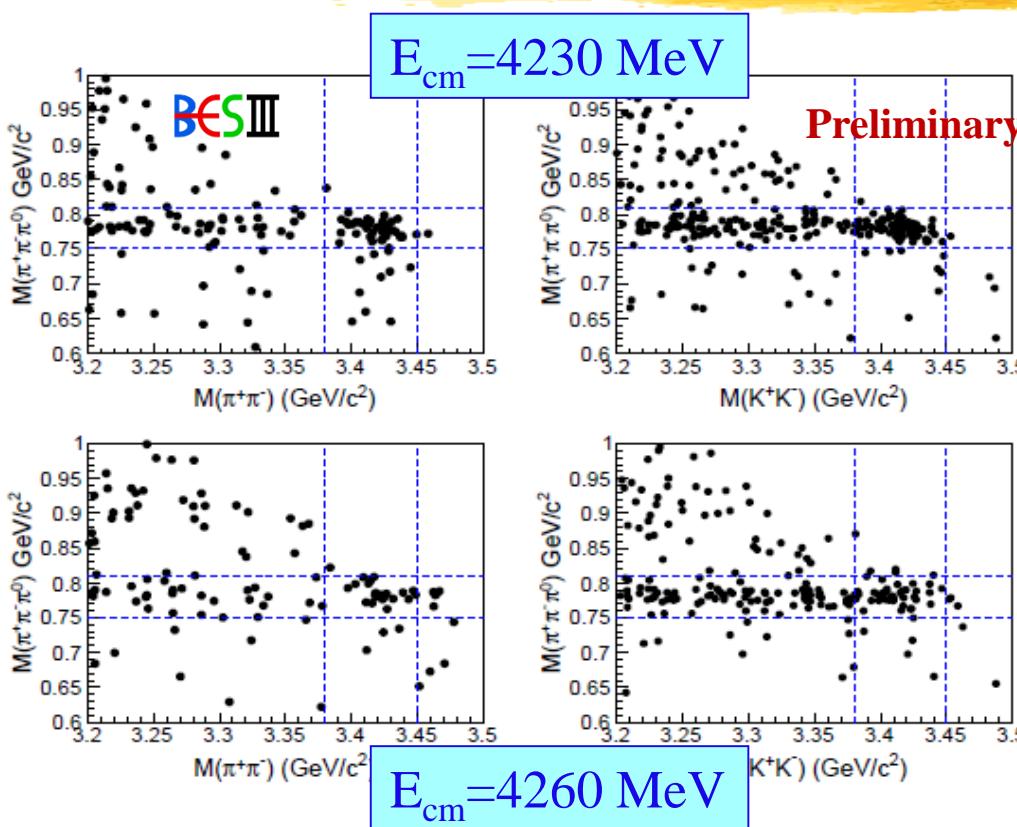
Thresholds:

- DD^* : 3875 MeV
- D^*D^* : 4014 MeV

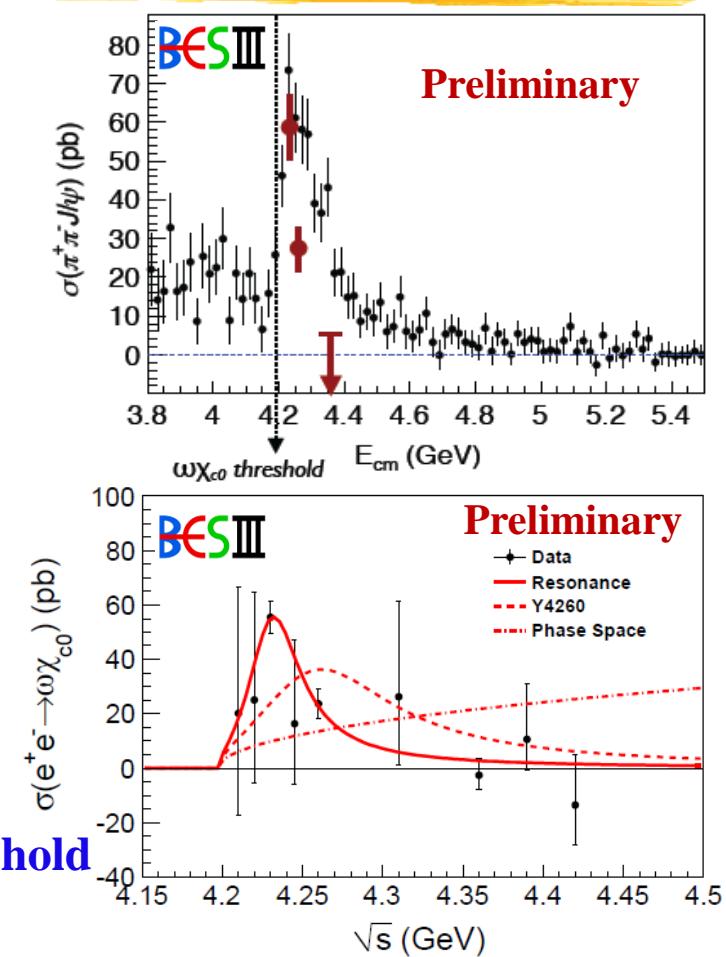
Z_c states @ BESIII:

- at least 4 quarks: charged
- near threshold
- isospin $I=1$
- are they one or two states





- The mass of $Y(4260)$ is very close to $\omega\chi_{cJ}$ mass threshold
- Observation of $\omega\chi_{c0}$ at 4230, 4260 MeV data
- No evidence of $\omega\chi_{c0}$ at 4360 MeV
- No evidence of $\omega\chi_{c1}/\omega\chi_{c1}'$ at 4230/4260/4360 MeV
- Line shape seems inconsistent with $Y(4260)$
- BW fitting: a narrow structure around 4230MeV.



A fine structure at 4230MeV?
Preliminary

$$M = (4230 \pm 8 \pm 6) \text{ MeV}/c^2$$

$$\Gamma = (38 \pm 12 \pm 2) \text{ MeV}/c^2$$

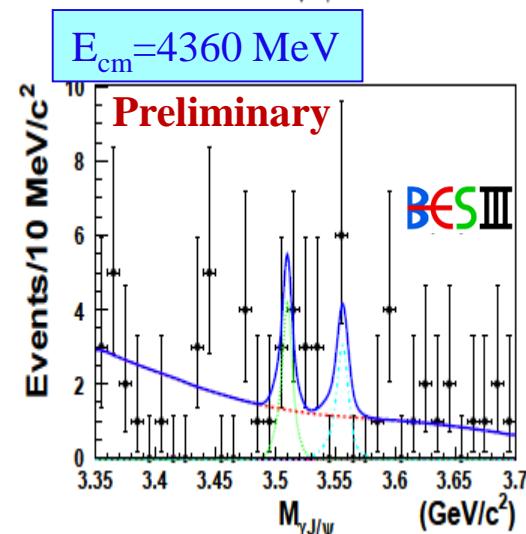
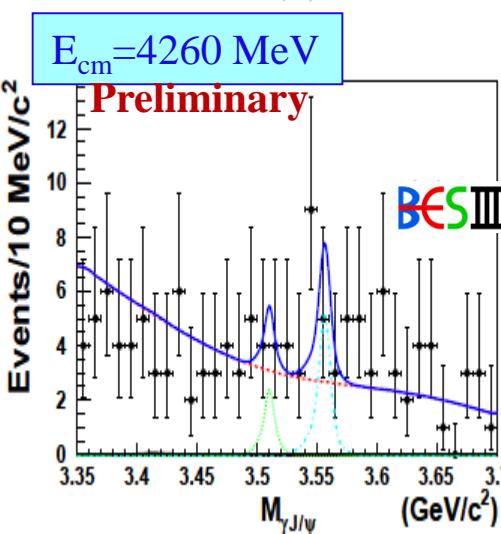
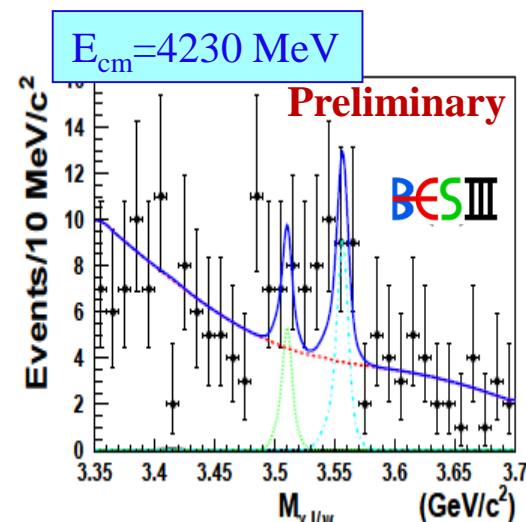
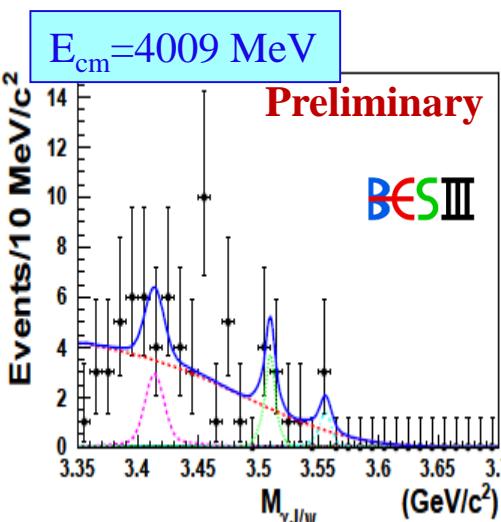


BESIII: $e^+e^- \rightarrow \gamma\chi_{cJ}$ ($\chi_{cJ} \rightarrow \gamma J/\psi$, $J/\psi \rightarrow \mu^+\mu^-$)

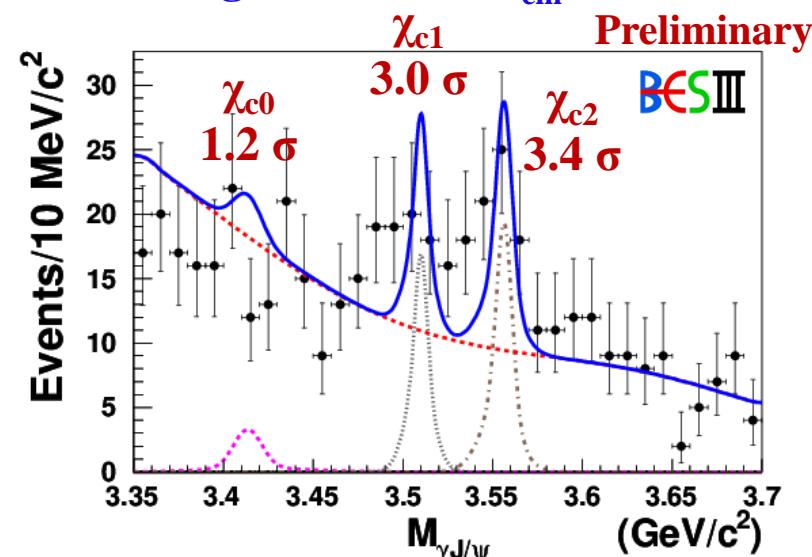
arXiv:1411.6336

- Statistically incompatible with background (radiative $\mu\mu$)

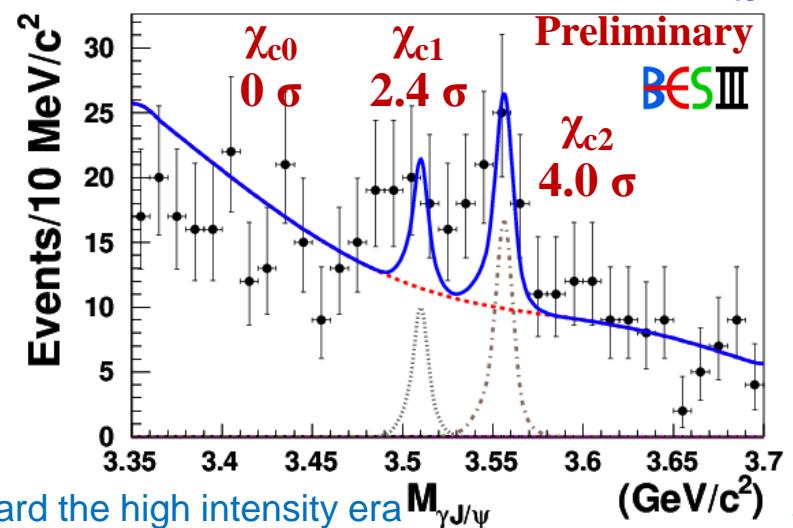
- Limited statistics



- Summing events @ 4 E_{cm}

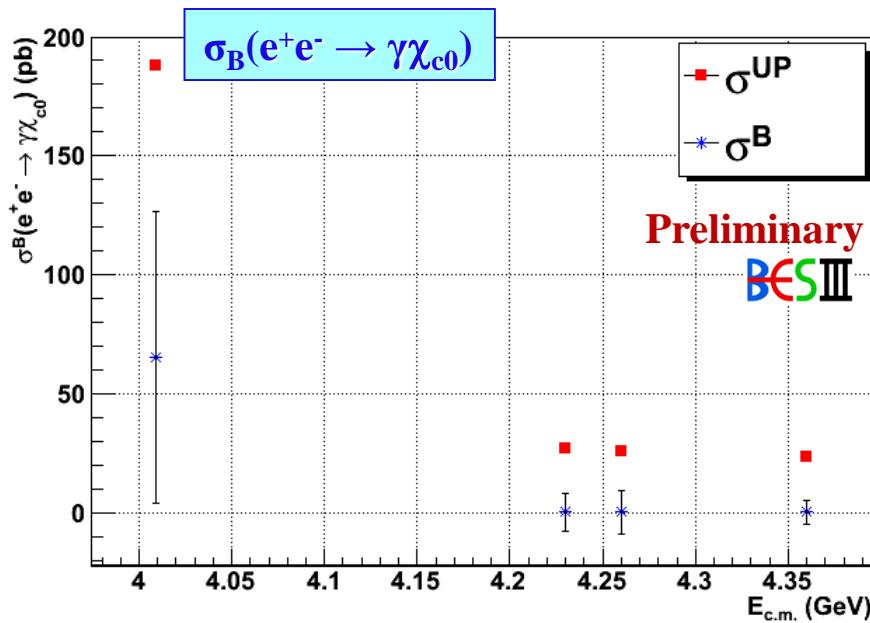


- Simultaneous fit @ 4 E_{cm} assuming $Y(4260)$ lineshape for $\sigma(e^+e^- \rightarrow \gamma\chi_{cJ})$



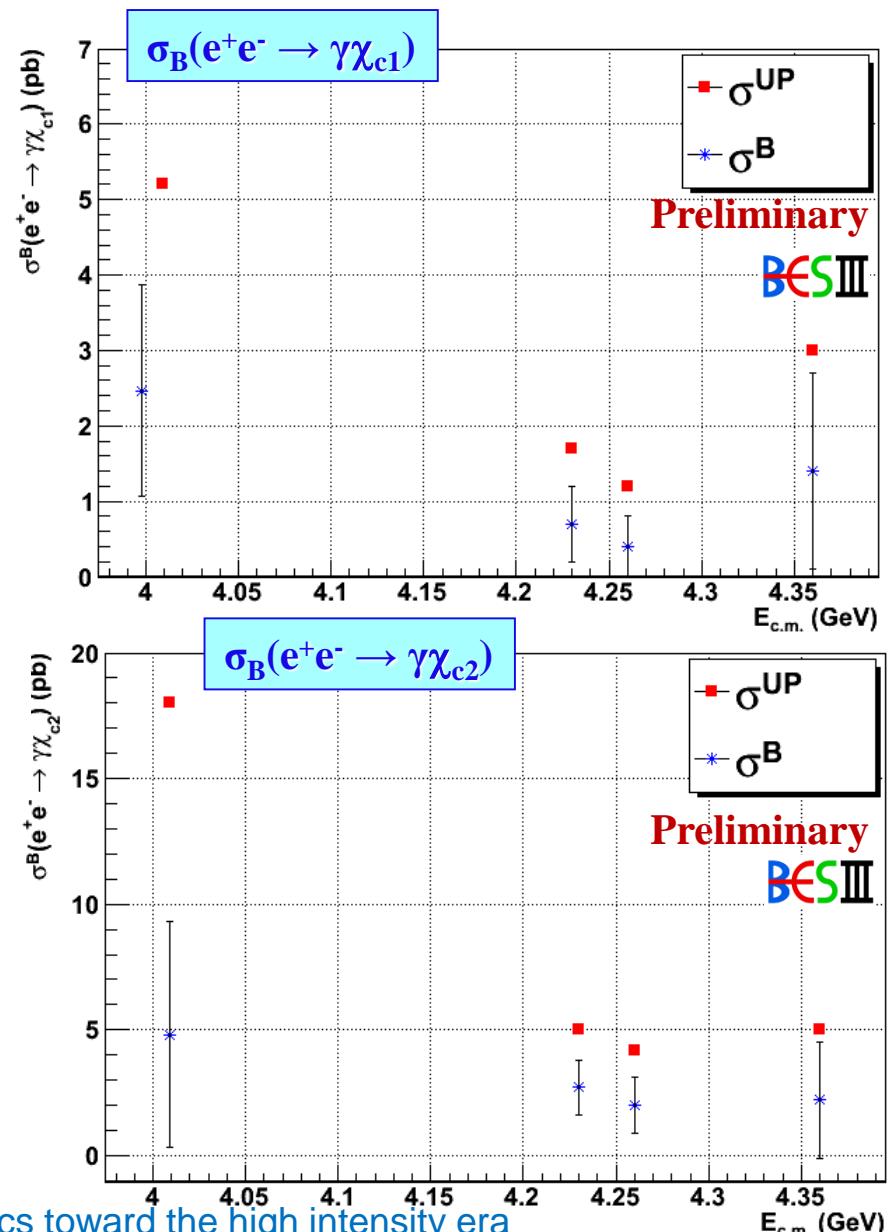


- $\sigma_B(e^+e^- \rightarrow \gamma\chi_{cJ})$ Born measured cross section



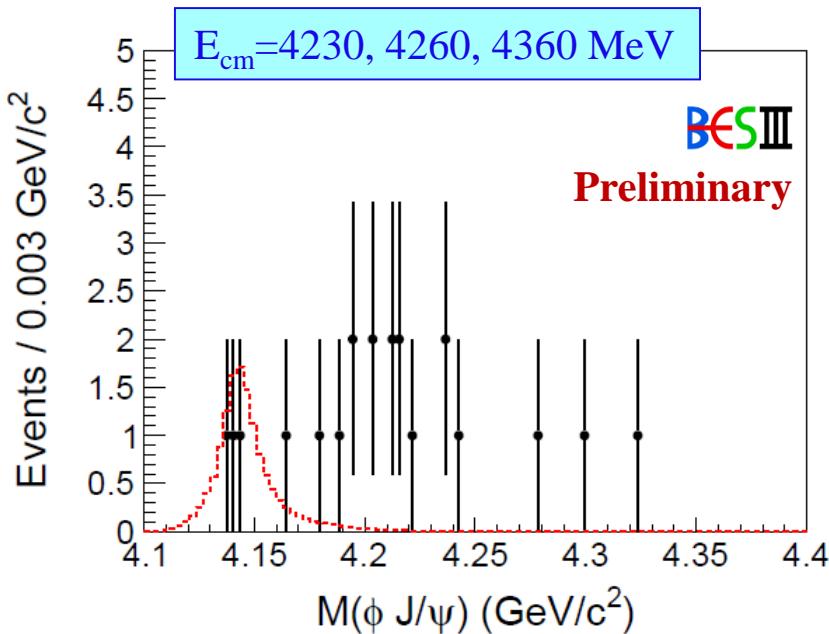
σ^{UP} compatible
with NRQCD theoretical
predictions [1]

[1] arXiv:1310.8597





- 3 ϕ decay modes considered: $\phi \rightarrow K^+K^-$, $\phi \rightarrow K_S K_L$, $\phi \rightarrow \pi^+\pi^-\pi^0$
- 2 J/ψ decay modes considered: $J/\psi \rightarrow \mu^+\mu^-$, $J/\psi \rightarrow e^+e^-$



No evidence of $Y(4140)$

UP @ 90% C.L. for

$$\sigma^B(e^+e^- \rightarrow \gamma Y(4140)) \cdot B(Y(4140) \rightarrow \gamma\phi J/\psi)$$

E_{cm} (MeV)	L (pb^{-1})	$\sigma^B \cdot B$
4.23	1094	< 0.35
4.26	827	< 0.28
4.36	545	< 0.33

Including systematic uncertainty

Assuming:

- $\sigma^B(e^+e^- \rightarrow \gamma X(3872)) \cdot B(X(3872) \rightarrow \pi^+\pi^- J/\psi)$ [1]:
- $E_{cm} = 4230 \text{ MeV}$: $0.27 \pm 0.09 \text{ (stat.)} \pm 0.02 \text{ (syst.) pb}$
- $E_{cm} = 4260 \text{ MeV}$: $0.33 \pm 0.12 \text{ (stat.)} \pm 0.02 \text{ (syst.) pb}$
- $B(X(3872) \rightarrow \pi^+\pi^- J/\psi) = 5\%$ [2]
- $B(Y(4140) \rightarrow \phi J/\psi) = 30\%$ [3]

[1] PRL 112, 092001

[2] arXiv:0910.3138

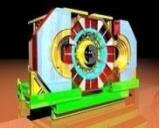
[3] PR D80, 054019

$$R = \frac{\sigma(e^+e^- \rightarrow \gamma Y(4140))}{\sigma(e^+e^- \rightarrow \gamma X(3872))} \leq 0.1 \text{ @ } 4230/4260 \text{ MeV}$$



Summary

- **huge statistics:**
 - J/ψ , $\psi(2S)$, $\psi(1D)$
 - XYZ studies
 - R scans
- **near future:**
 - collect data at higher energies to complete scans
 - higher luminosity expected from BEPCII
 - analyse the full data samples
 - many PWA to be completed
- **stay tuned:**
 - many new exciting results on their way



Question time

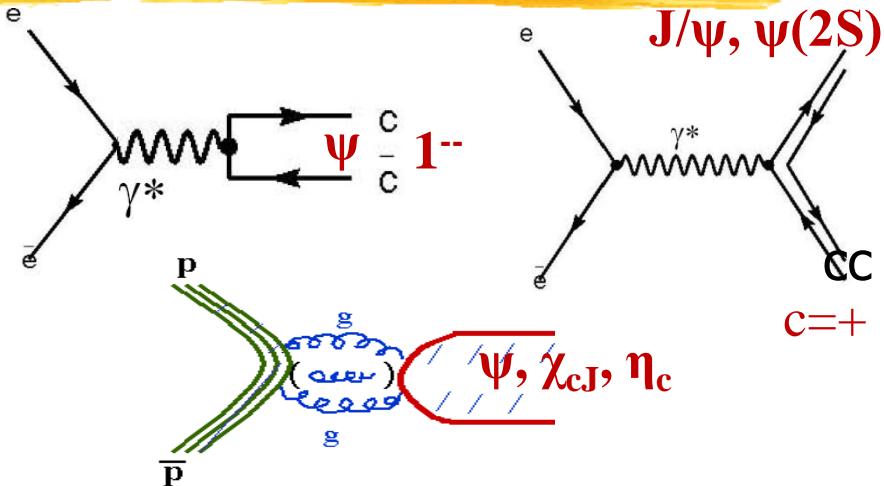


Thanks!

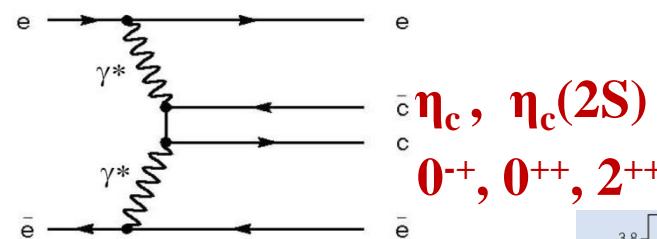


How to produce Charmonium states

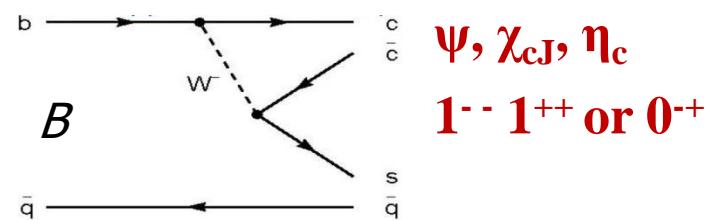
1. e^+e^- annihilation (including ISR/double charmonium)



2. $p\bar{p}$ annihilation

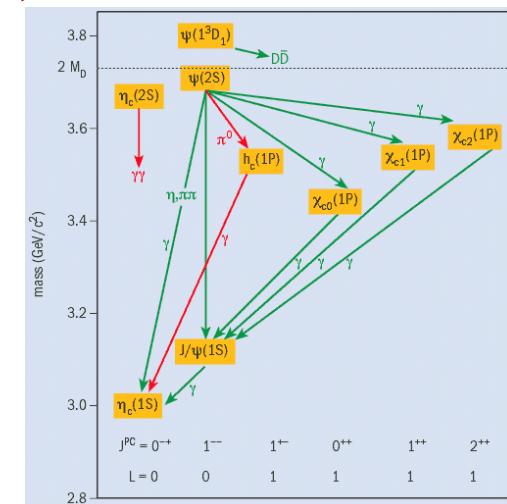


3. Two-photon process



4. B decays

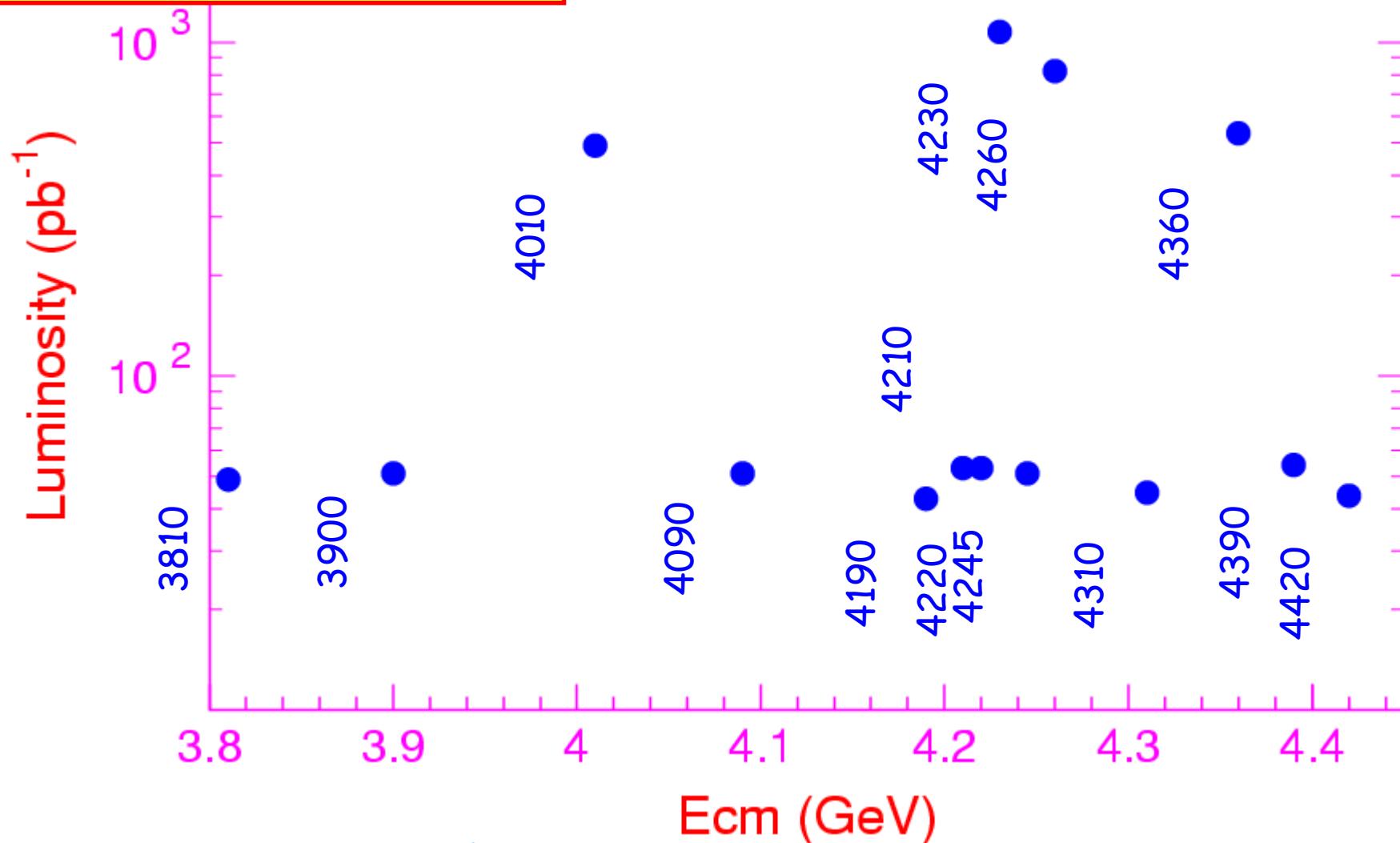
5. Charmonium transition





BESIII data set

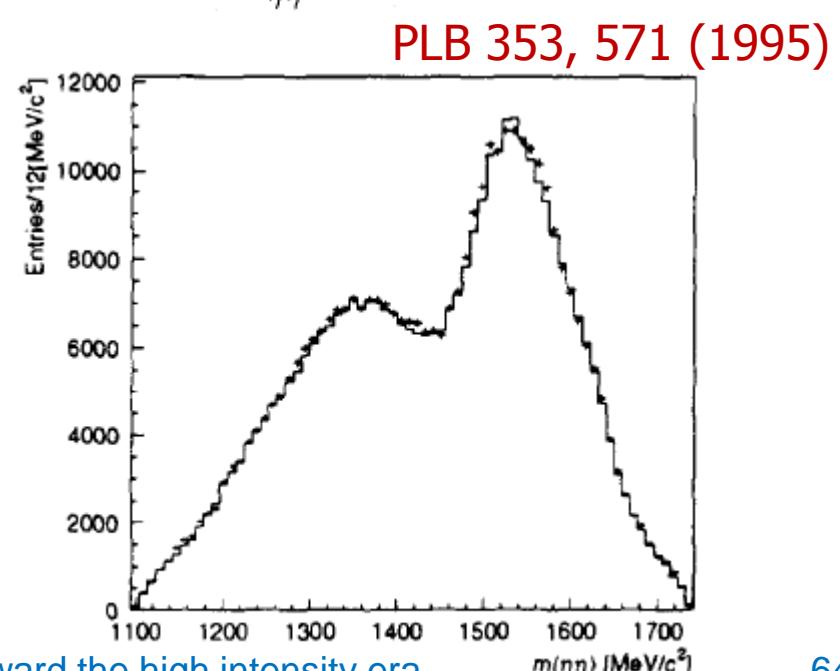
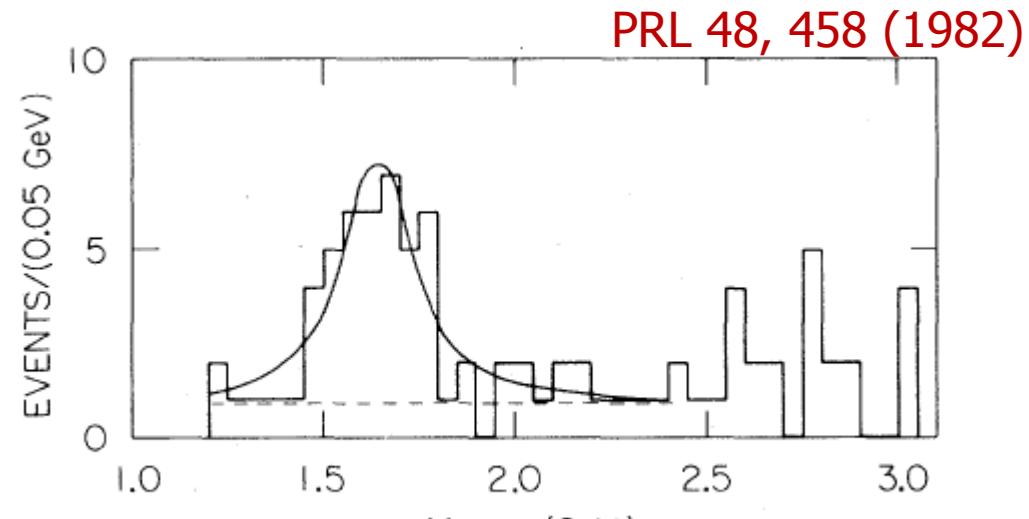
3.3 fb^{-1} for XYZ studies





J/ ψ $\rightarrow \gamma\eta\eta$

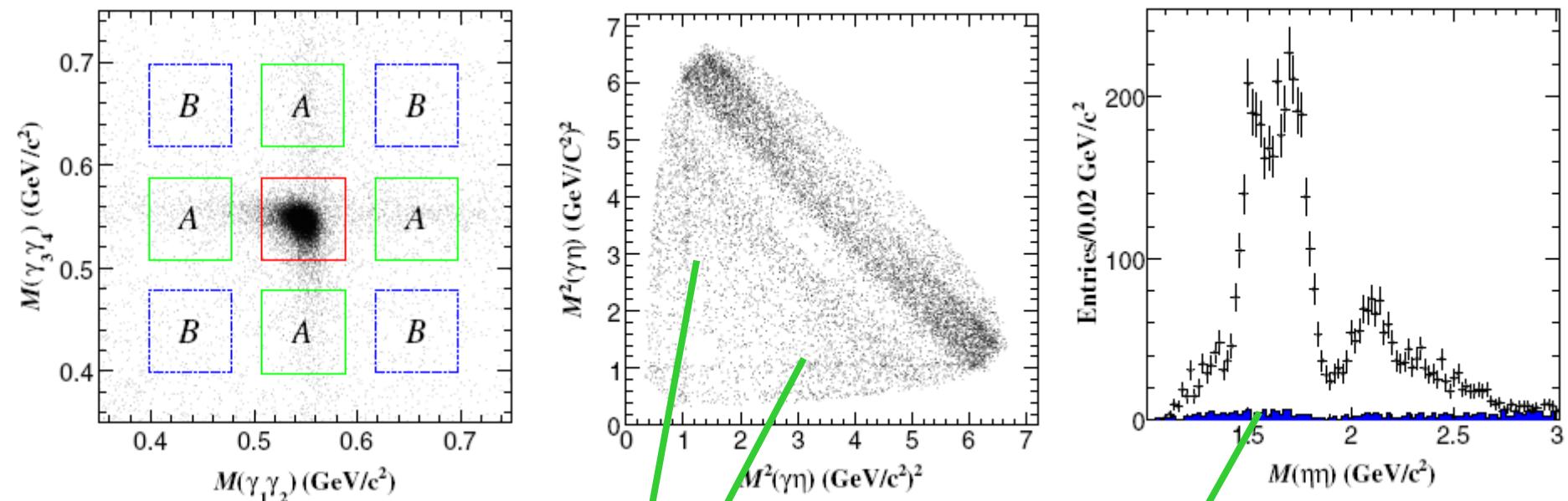
- first studied by Crystal Ball (1982): $f_0(1710)$
- Crystal Barrel (1995): $f_0(1500)$ [$p\bar{p} \rightarrow \pi^0\eta\eta$]
- E835 (2006):
 $f_0(1500)$ [$p\bar{p} \rightarrow \pi^0\eta\eta$]
 $f_0(1710)$ [$p\bar{p} \rightarrow \pi^0\eta\eta$]
- WA102, GAMS:
 $f_0(1500)$ [$\eta\eta$ mode]





BESIII: PWA of $J/\psi \rightarrow \gamma\eta\eta$, $\eta \rightarrow \gamma\gamma$

PRD 87, 092009

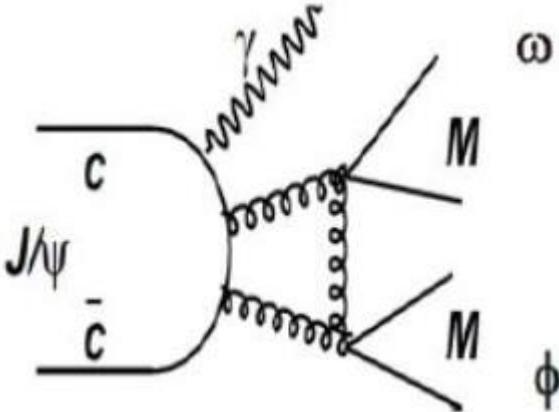


- **$J/\psi \rightarrow \Phi\eta$, $\Phi \rightarrow \gamma\eta$:**
 - select events outside Φ window
- **background:**
 - low and mostly non- η background,
 - estimated by η sidebands (blue shadow)
- **background subtraction:**
 - $\ln \mathcal{L}_{\text{signal}} = \ln \mathcal{L}_{\text{data}} - \ln \mathcal{L}_{\text{sideband}}$



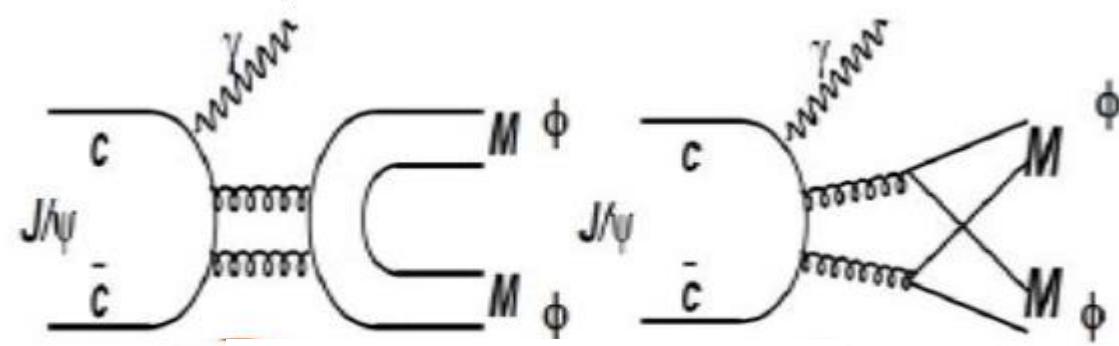
$J/\psi \rightarrow \gamma\omega\phi$

- doubly OZI suppressed



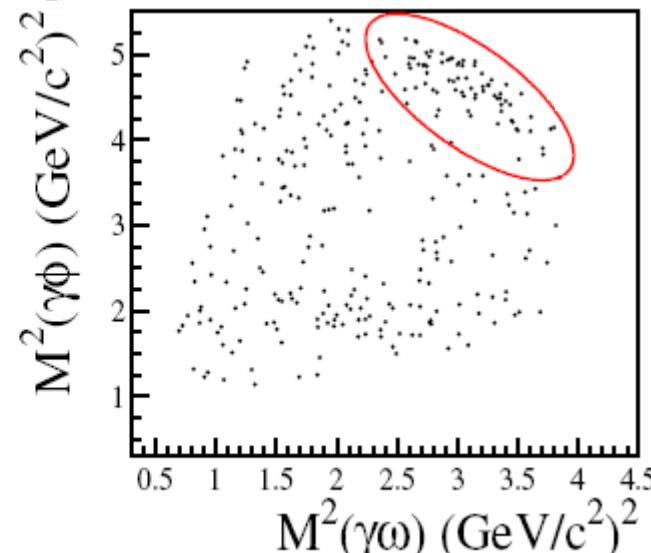
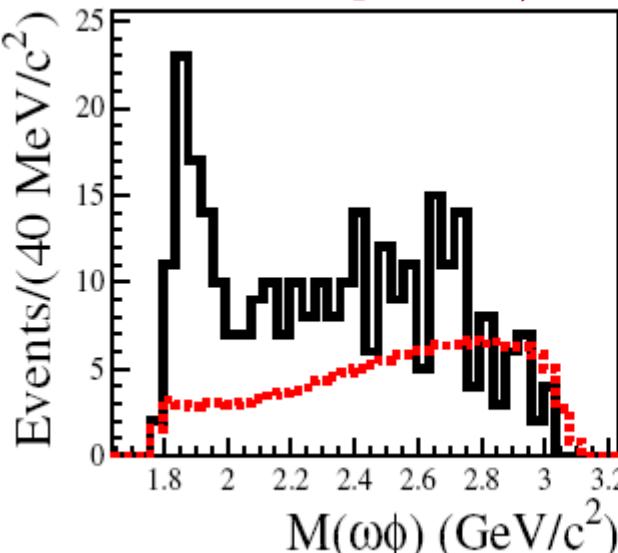
$\psi \rightarrow \gamma\omega\phi$ (DOZI)

predicted $\propto 1/10$



$\psi \rightarrow \gamma\phi\phi$ (OZI)

- BESII: [PRL 96, 162002]



$$M = (1812^{+19}_{-26} \pm 18) \text{ MeV}/c^2$$

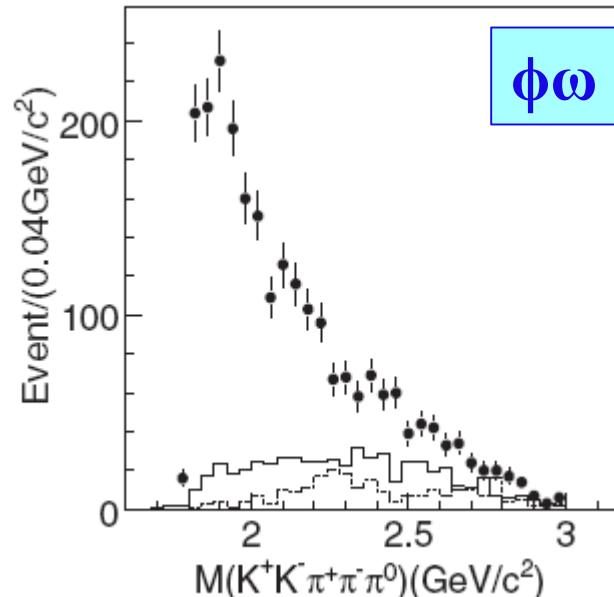
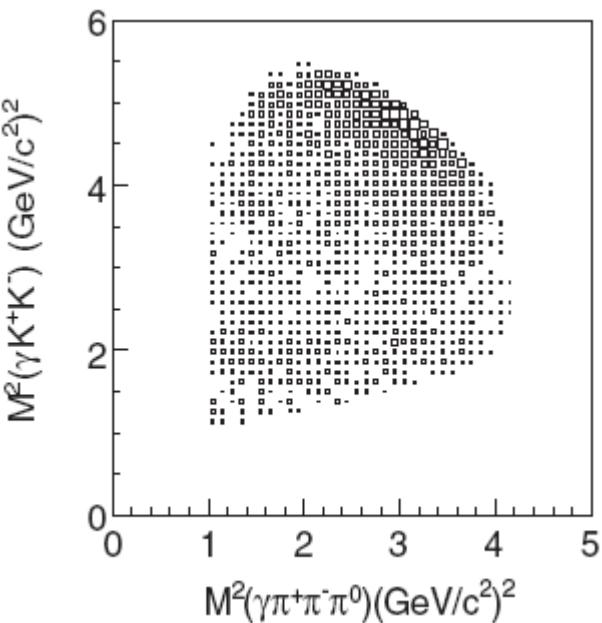
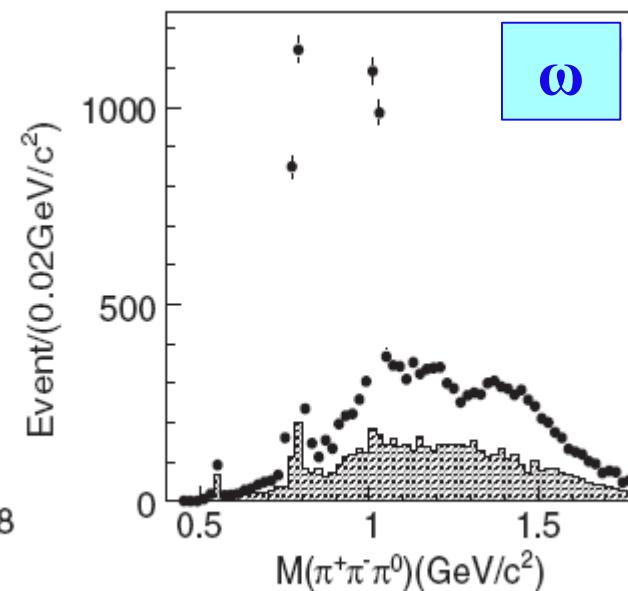
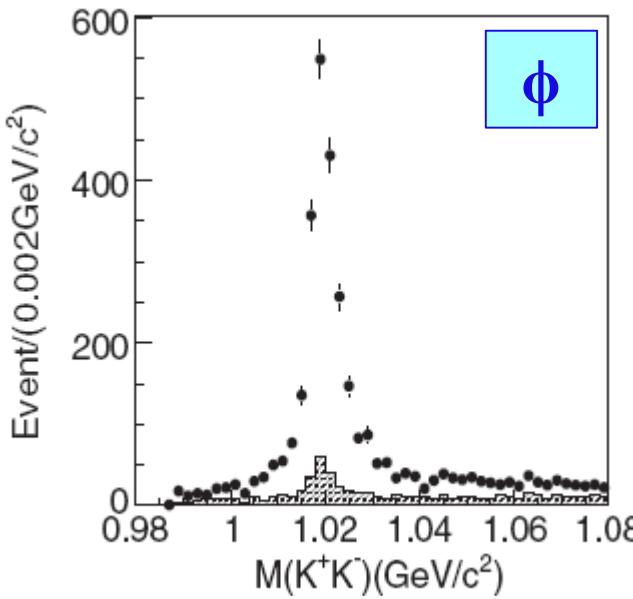
$$\Gamma = (105 \pm 20 \pm 28) \text{ MeV}/c^2$$

0^{++} favoured over
 0^{-+} and 2^{++}



BESIII: PWA of $J/\psi \rightarrow \gamma\omega\phi$

PRD 87, 032008

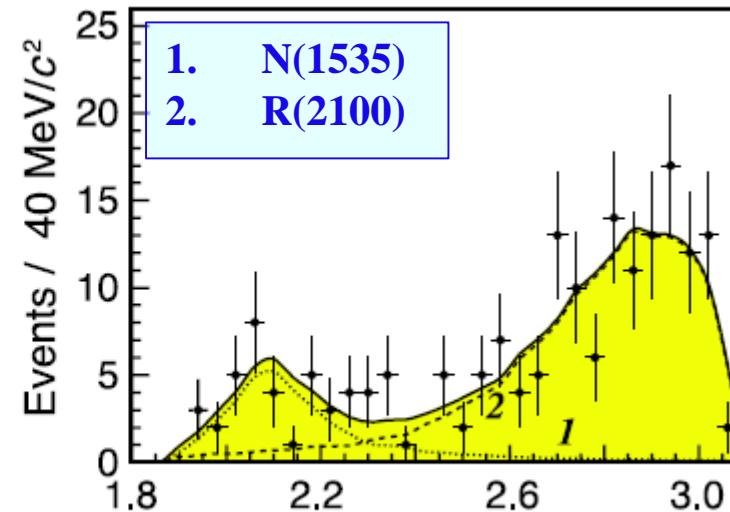
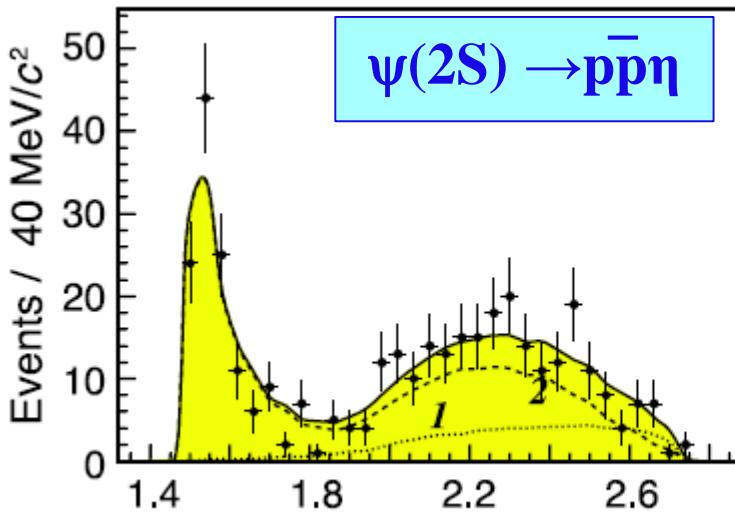
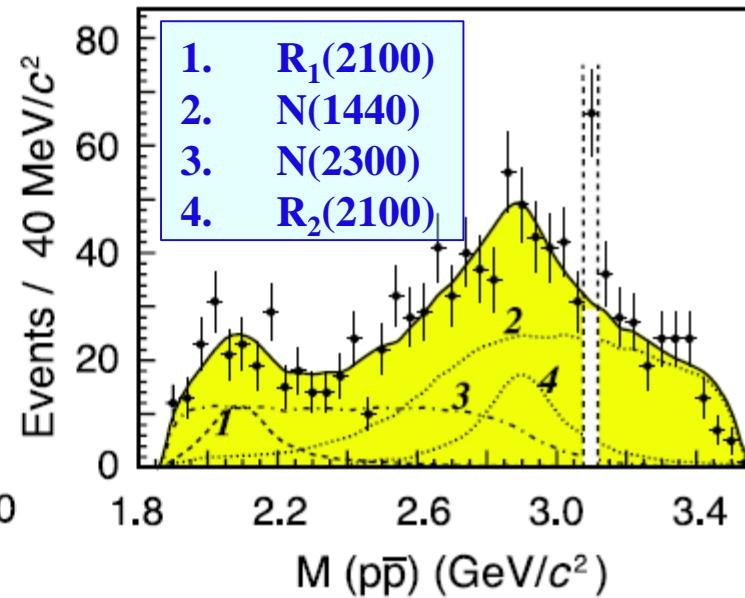
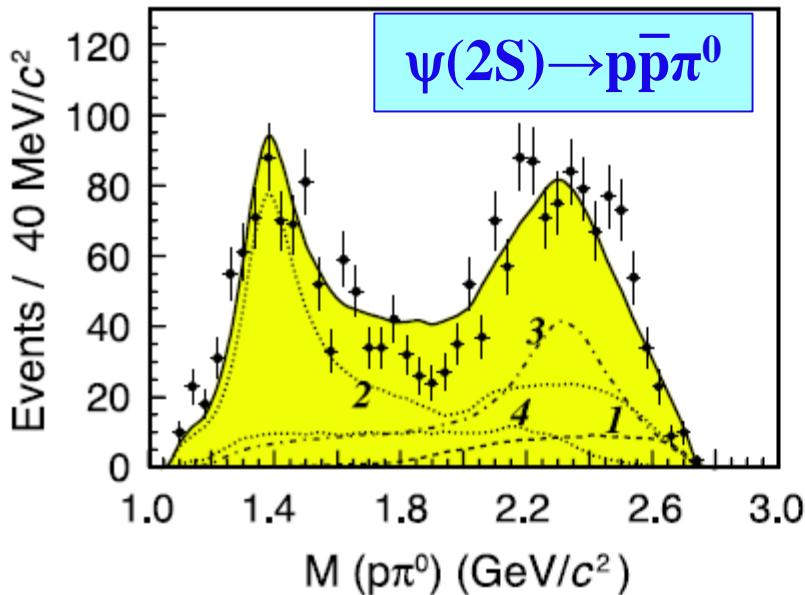


- **solid:**
 - background estimated from sidebands
- **dashed:**
 - inclusive J/ψ MC samples
- **background subtraction:**
 - $\ln \mathcal{L}_{\text{signal}} = \ln \mathcal{L}_{\text{data}} - \ln \mathcal{L}_{\text{sideband}}$



PWA of $\psi(2S) \rightarrow p\bar{p}\pi^0$ and $\psi(2S) \rightarrow p\bar{p}\eta$

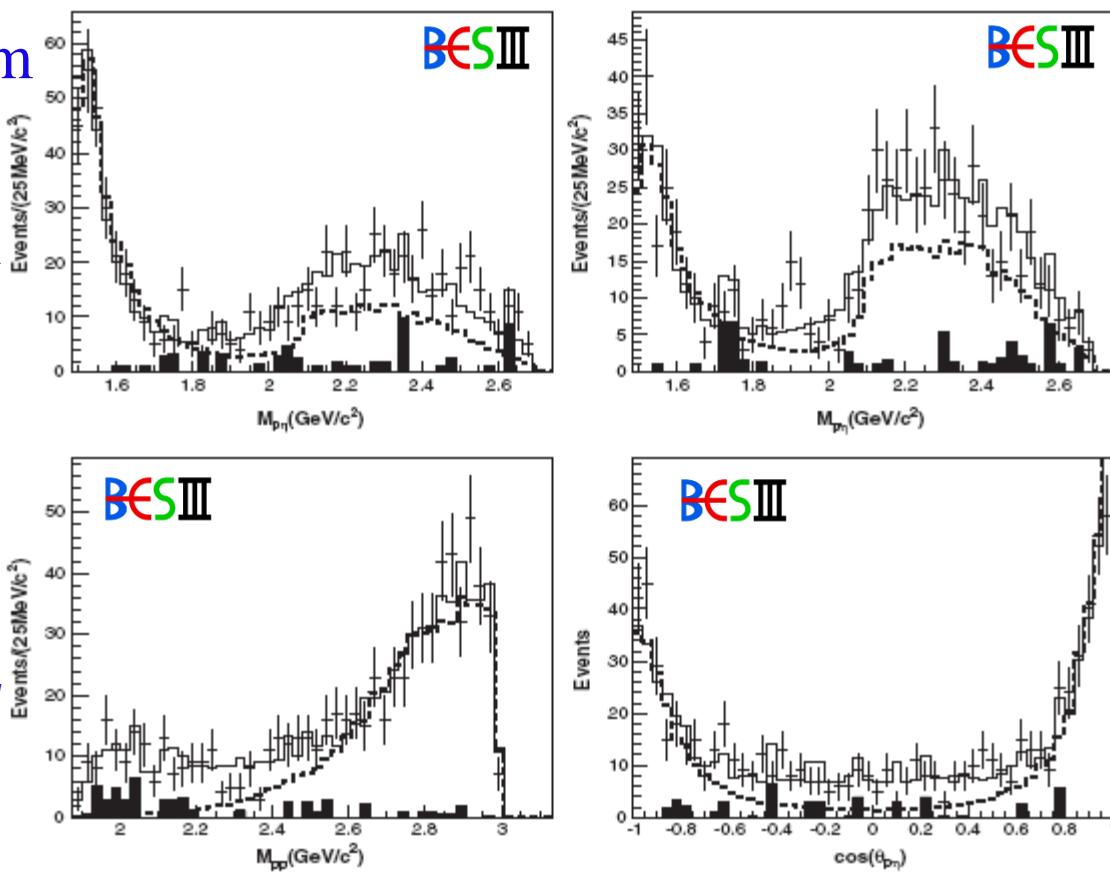
CLEOc: 24.5 M $\psi(2S)$ [PRD 82, 092002]



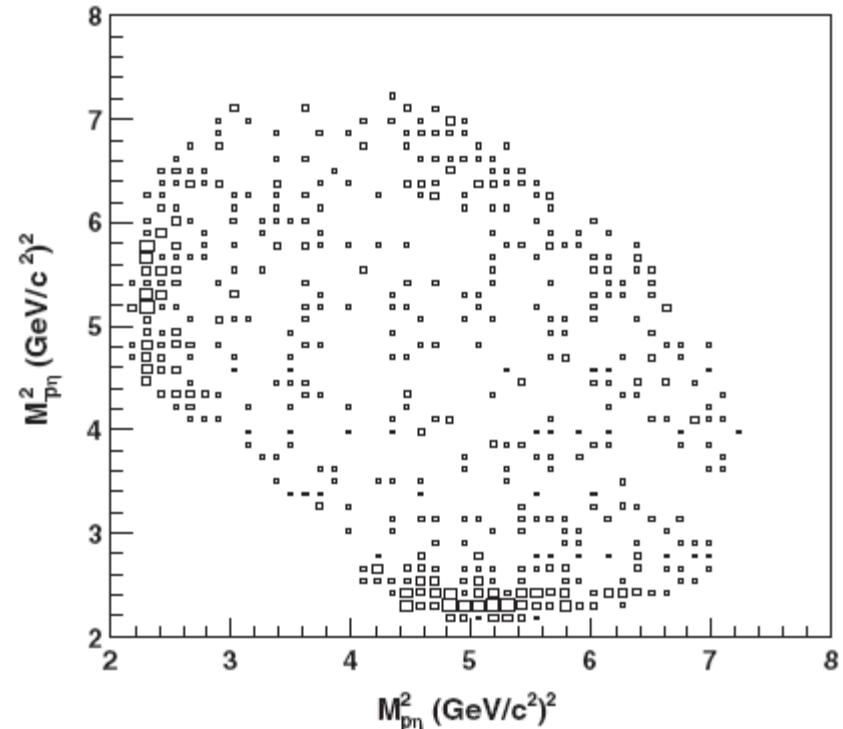
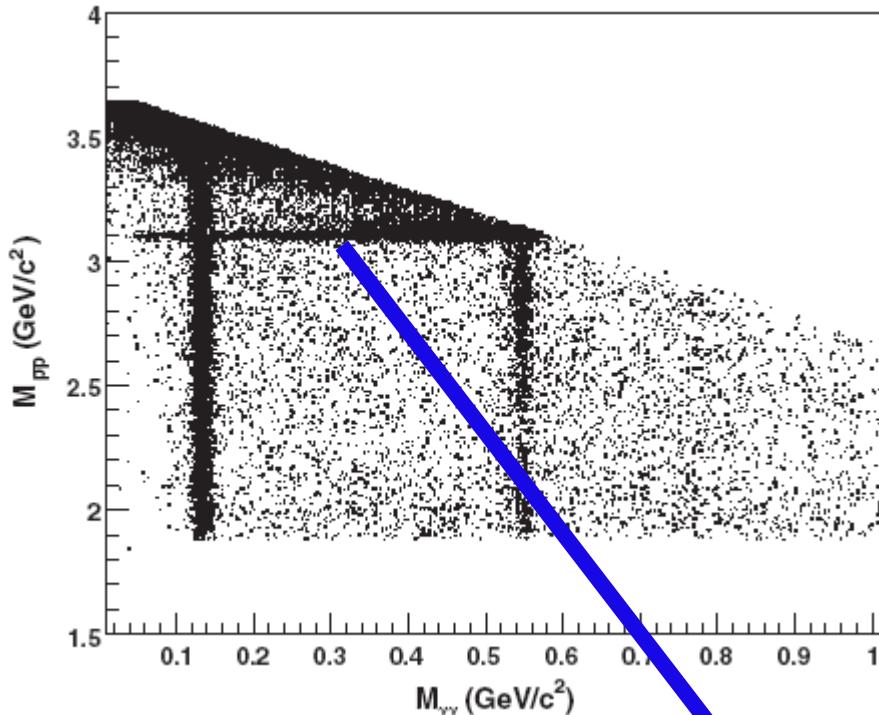
Without interference effects



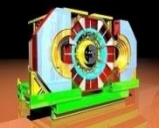
- low background:
 - sidebands and continuum
- best solution:
 - N(1535) combined with an interfering phase space
- $p\bar{p}$ enhancement:
 - <3 σ
- N(1535):
 - $M = (1524 \pm 5^{+10}_{-4}) \text{ MeV}/c^2$
 - $\Gamma = (130^{+27+10}_{-24-10}) \text{ MeV}/c^2$
- suppressed (<12%):



$$Q_{p\bar{p}\eta} = \frac{\mathcal{B}(\psi(2S) \rightarrow p\bar{p}\eta)}{\mathcal{B}(J/\psi \rightarrow p\bar{p}\eta)} = (3.2 \pm 0.46)\%$$



$\psi(2S) \rightarrow J/\psi X$, $J/\psi \rightarrow p\bar{p}$ subtracted



■ 2-body decay:

- $\psi(2S) \rightarrow X\pi^0, X \rightarrow p\bar{p}$
- $\psi(2S) \rightarrow p\bar{N}^*, \bar{N}^* \rightarrow \bar{p}\pi^0 + c.c.$

■ isospin conservation:

Δ suppressed

■ best solution:

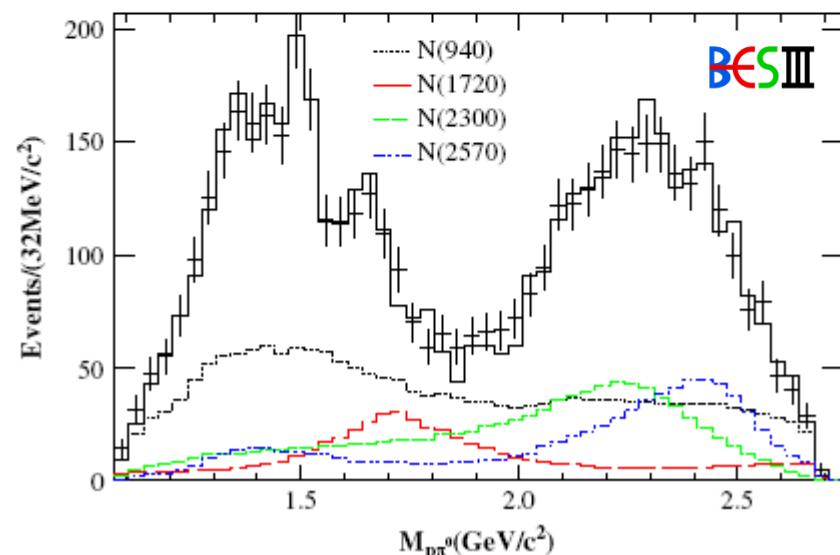
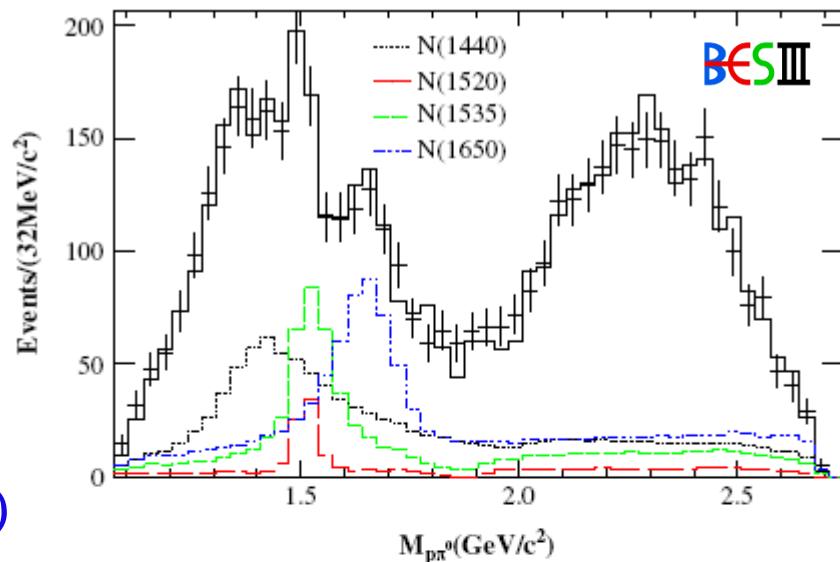
$N(1440), N(1520), N(2090), N(1535)$
 $N(1650), N(1720),$
 $N(2300) [1/2^+], N(2570) [5/2^-]$

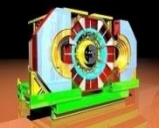
■ no significant evidence:

- $N(1885), N(2065)$
- $p\bar{p}$ enhancement

■ systematic uncertainties:

- additional possible resonances





- **2-body decay:**

- $\psi(2S) \rightarrow X\pi^0, X \rightarrow p\bar{p}$
- $\psi(2S) \rightarrow p\bar{N}^*, \bar{N}^* \rightarrow \bar{p}\pi^0 + c.c.$

- **isospin conservation:**

- Δ suppressed

- **best solution:**

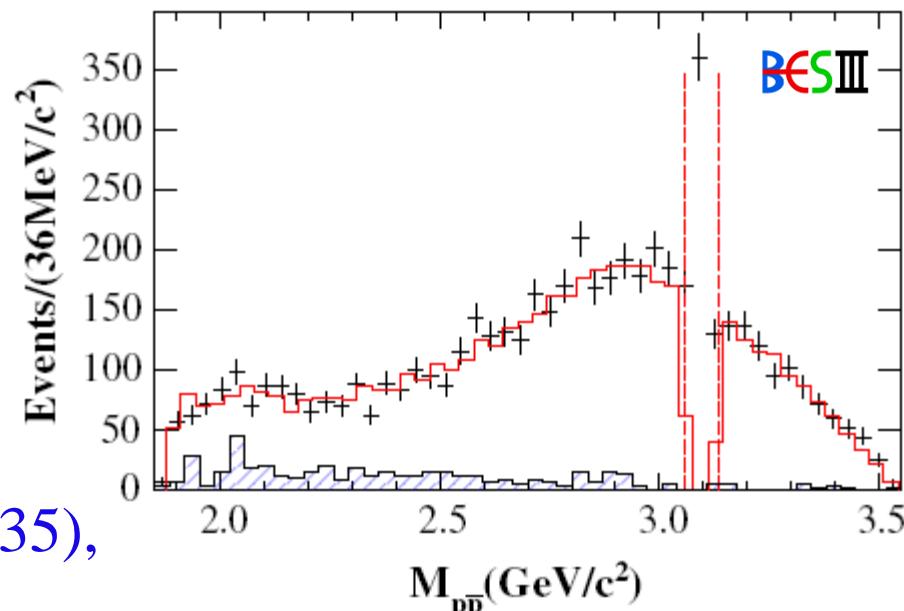
- N(1440), N(1520), N(2090), N(1535),
N(1650), N(1720),
N(2300) [1/2⁺], N(2570) [5/2⁻]

- **no significant evidence:**

- N(1885), N(2065)
- p \bar{p} enhancement

- **systematic uncertainties:**

- additional possible resonances





■ branching fraction:

$$\mathcal{B}(\psi(2S) \rightarrow p\bar{p}\pi^0) = (1.65 \pm 0.03 \pm 0.15) \times 10^{-4}$$

■ PWA:

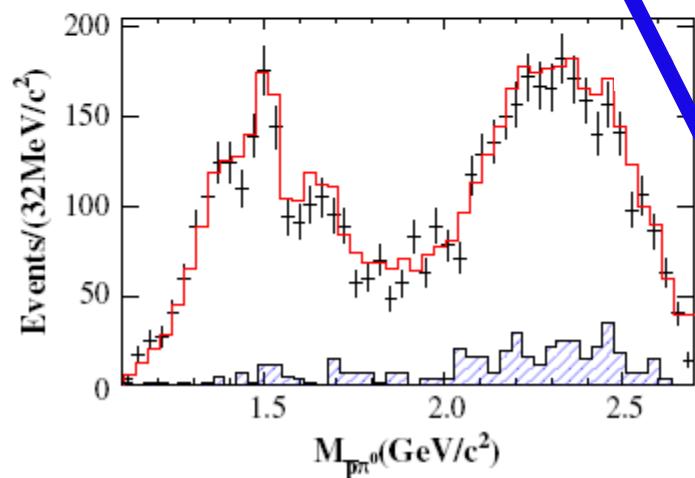
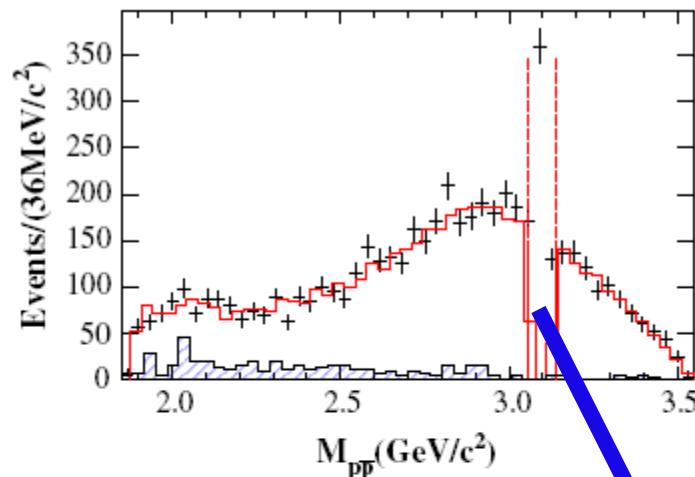
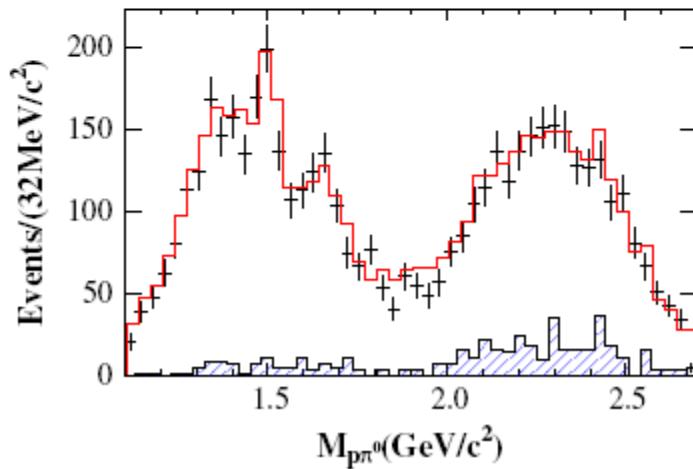
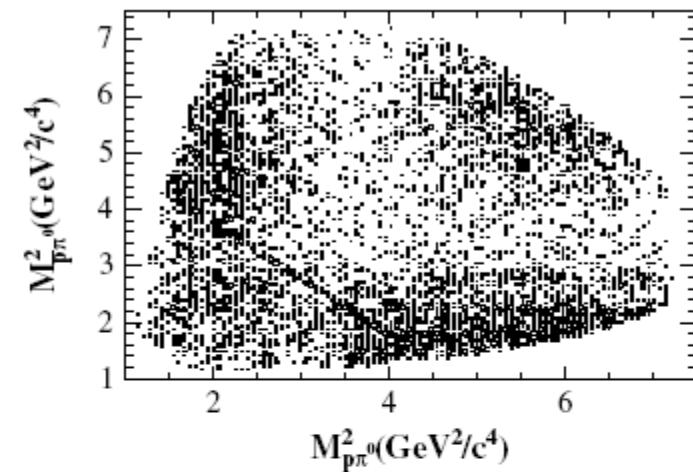
- two new resonances
- $N(1885)$ and $N(2065)$, $< 5\sigma$
- $p\bar{p}$ resonance $< 4\sigma$
-

Resonance	$M(\text{MeV}/c^2)$	$\Gamma(\text{MeV}/c^2)$	ΔS	ΔN_{dof}	Sig.
$N(1440)$	1390^{+11+21}_{-21-30}	$340^{+46+70}_{-40-156}$	72.5	4	11.5σ
$N(1520)$	1510^{+3+11}_{-7-9}	115^{+20+0}_{-15-40}	19.8	6	5.0σ
$N(1535)$	1535^{+9+15}_{-8-22}	120^{+20+0}_{-20-42}	49.4	4	9.3σ
$N(1650)$	1650^{+5+11}_{-5-30}	150^{+21+14}_{-22-50}	82.1	4	12.2σ
$N(1720)$	1700^{+30+32}_{-28-35}	$450^{+109+149}_{-94-44}$	55.6	6	9.6σ
$N(2300)$	$2300^{+40+109}_{-30-0}$	$340^{+30+110}_{-30-58}$	120.7	4	15.0σ
$N(2570)$	2570^{+19+34}_{-10-10}	250^{+14+69}_{-24-21}	78.9	6	11.7σ



BESIII: PWA of $\psi(2S) \rightarrow p\bar{p}\pi^0$

PRL 110, 022001

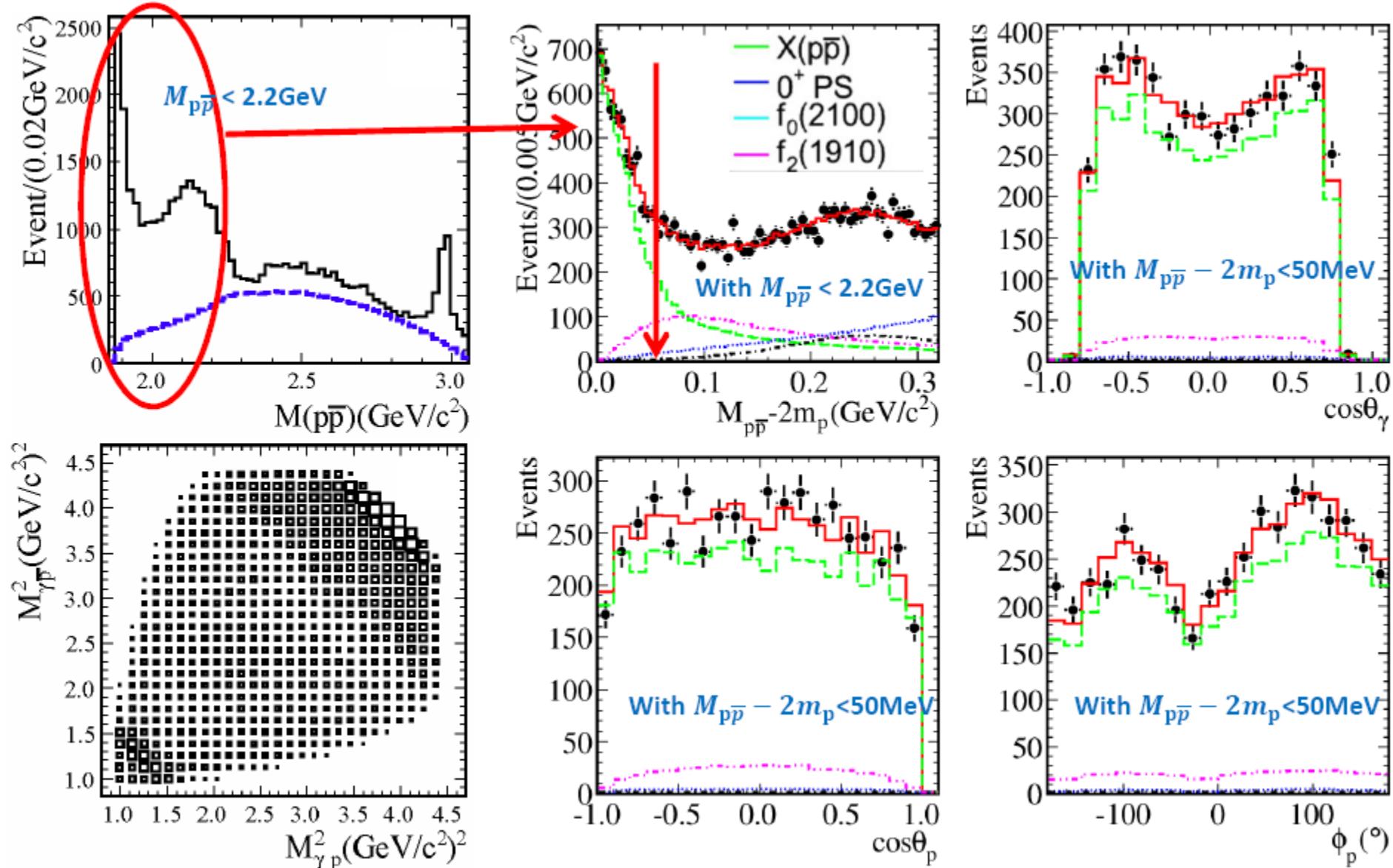


shaded:
background:
• continuum
• non- π^0
background

$\psi(2S) \rightarrow J/\psi X$, $J/\psi \rightarrow p\bar{p}$ subtracted



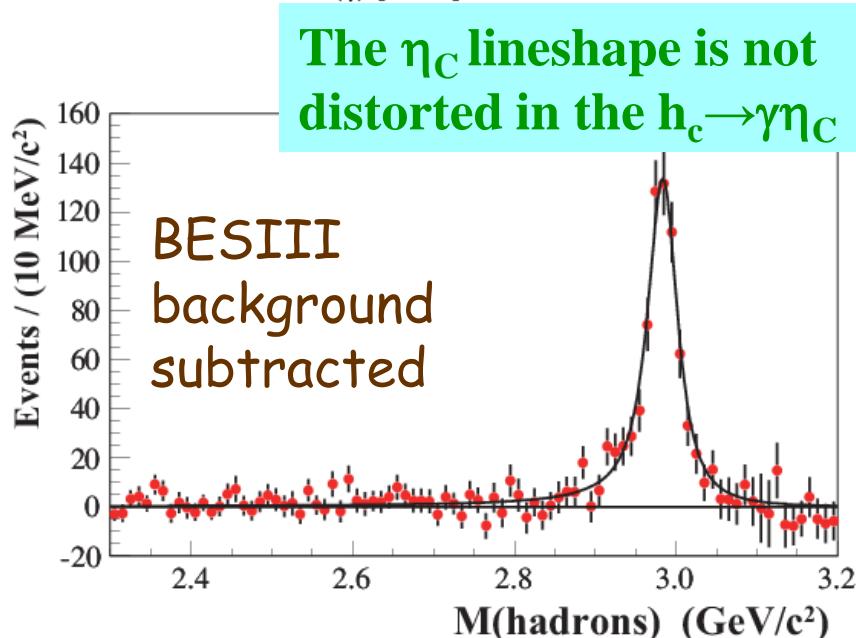
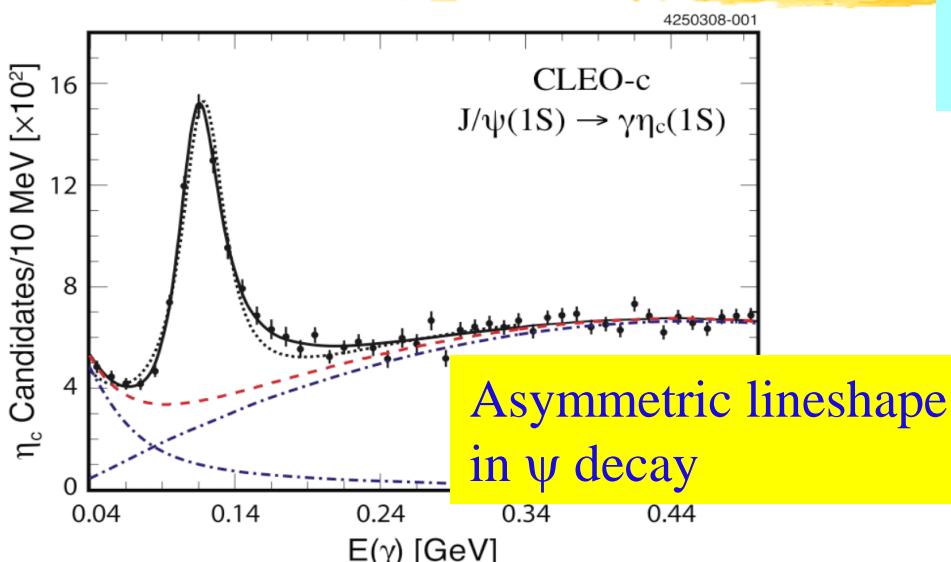
BESIII: PWA of $J/\psi \rightarrow \gamma p\bar{p}$, $M_{p\bar{p}} < 2.2$ GeV PRL 108, 112003



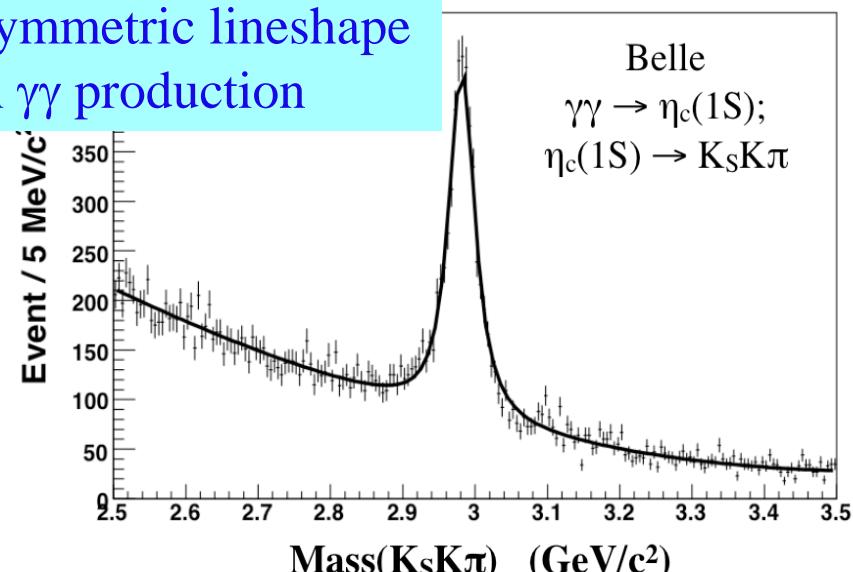


BESIII: η_c parameters from $\psi(2S) \rightarrow \pi^0 h_c(1P)$, $h_c(1P) \rightarrow \gamma \eta_c(1S)$

PRD 86, 092009



Symmetric lineshape in $\gamma\gamma$ production



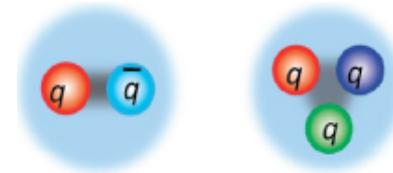
- CLEO-c observe a distortion of η_c lineshape in charmonium radiative decay
PRL102, 011801 (2009)
- The lineshape of η_c from BELLE is symmetric
- The abnormal line shape is also observed in BESIII exclusive channels in $\psi' \rightarrow \gamma \eta_c$ but not in $\psi' \rightarrow \pi^0 h_c$, $h_c \rightarrow \gamma \eta_c$



Hadronic exotic states

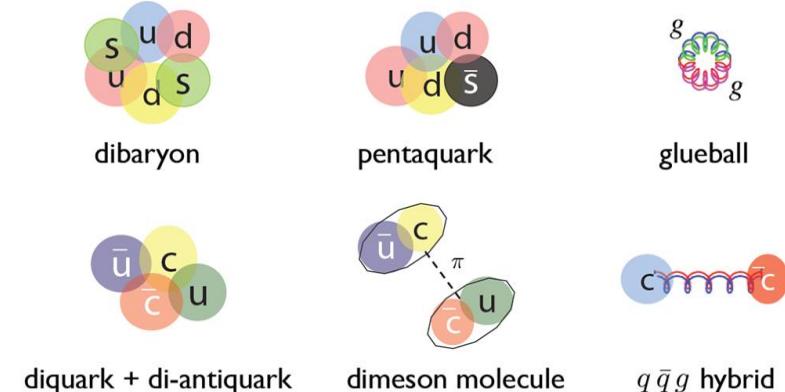
- Experiments :

- Hadrons are composed of 2 (meson) or 3 (baryon) quarks
- Described very well in quark model (QM)



- QCD suggests:

- Confinement : stable hadrons need to be colorless
- Gluon-gluon interactions : hadron with gluons (hybrids and glueballs) could exist
- Allow hadrons with $N_{\text{quarks}} \neq 2, 3$ (multi-quarks)

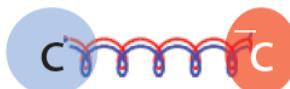
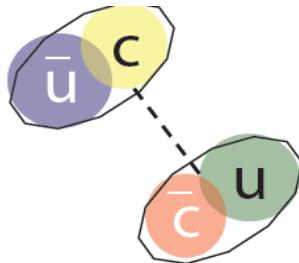


Can we find evidence for these interesting exotic hadrons?

A long history of searching for the exotic hadron,
no solid conclusion was reached in past a few decades,
some hints on charmonium-like and bottomonium-like particles, recently.



Exotic Meson (Charmonium-Like)



Molecular states:

- Loosely bound states of a pair of mesons,
- bound by the long-range color-singlet pion exchange,
- weakly bound, mesons tend to decay as if they were free.

Tetraquarks:

- bound states of four quarks,
- bound by colored-force between quarks,
- decay through rearrangement,
- many states with the same multiplet, some are with non-zero charge, or strangeness

Hybrids:

- bound states with a pair of quarks and one excited gluon
- Lattice and model predictions for lowest lying charmonium hybrid $m \sim 4200$ MeV



Z_c states

The most promising way to searching for the exotic hadrons

- Decay into a charmonium or $D^{(*)} \bar{D}^{(*)}$ pair

– thus contains hidden-cc pair

- Have electric charge,

– thus has two more light quarks

At least 4 quarks, not a conventional meson

- Observed in final states :

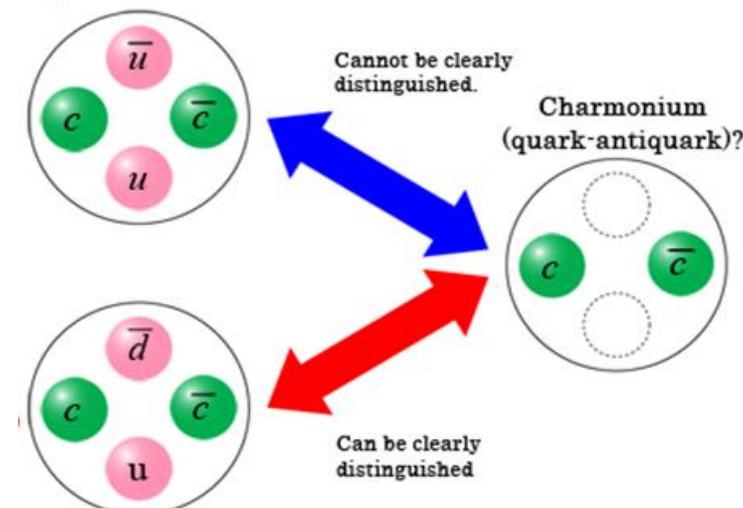
– $\pi^\pm J/\psi$, $\pi^\pm \psi(2S)$, $\pi^\pm h_c$, $\pi^\pm \chi_{cJ}$, $(D^{(*)} \bar{D}^{(*)})^{\pm}$, ...

- Experimental search:

– BESIII/CLEO-c : $e^+ e^- \rightarrow \pi^\pm + \text{Exotics}$,

– Belle/BaBar : $e^+ e^- \rightarrow (\gamma_{\text{ISR}}) \pi^\pm + \text{Exotics}$,

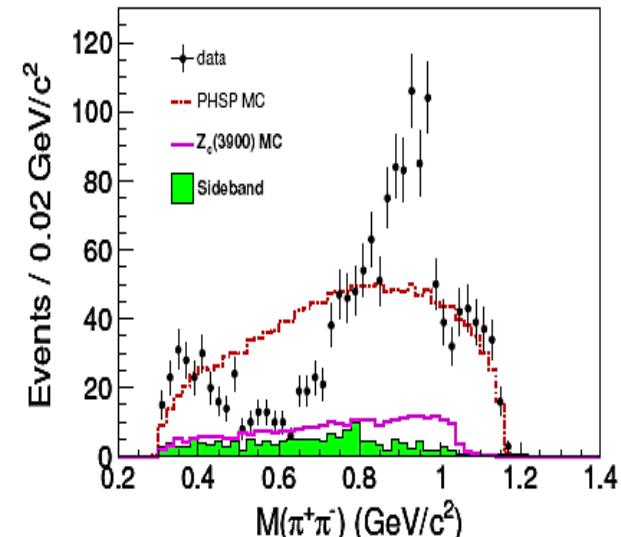
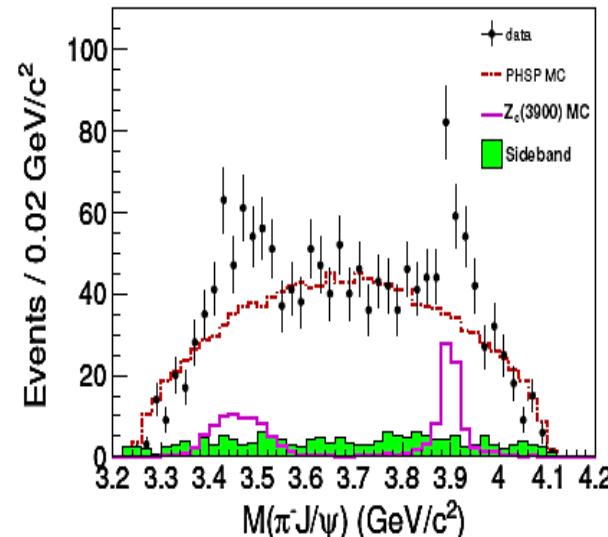
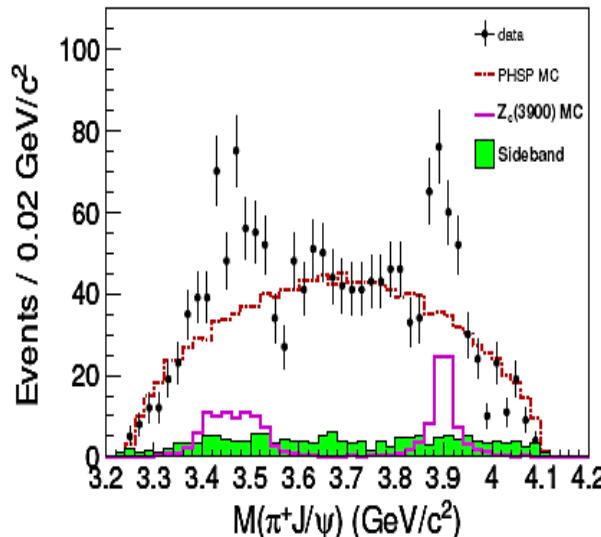
– Belle/BaBar/LHCb: $B \rightarrow K^\pm + \text{Exotics}$, ...





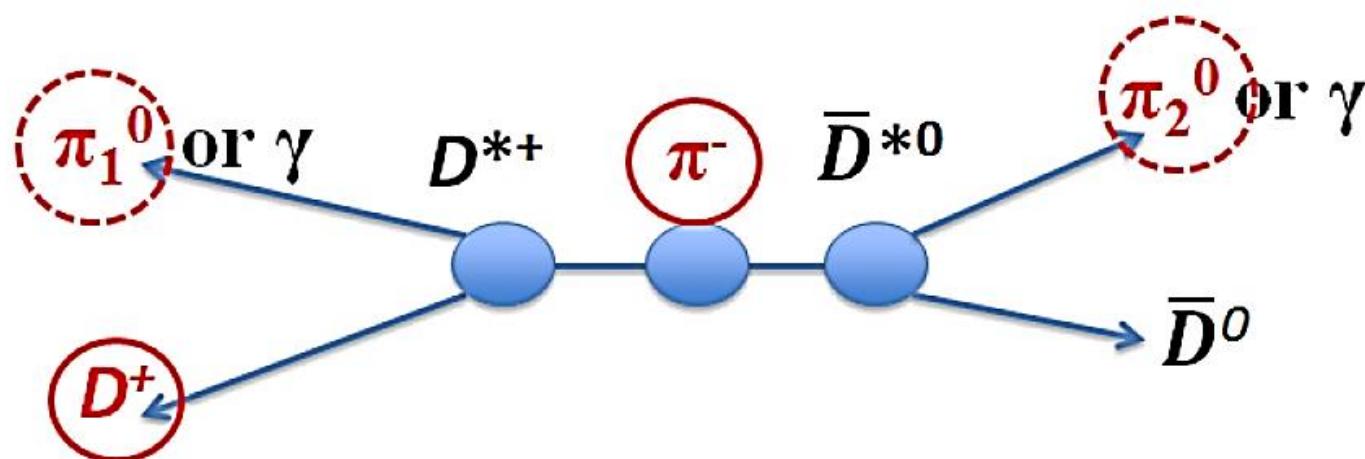
Is it a real signal?

- Is it due to $\pi^+\pi^-$ S-wave states, like σ , $f_0(980)$, ...? N
- Is it due to $\pi^+\pi^-$ D-wave states, like $f_2(1270)$, ...? N
- Are there two states, one at 3.4, the other 3.9 GeV? N
- Exist in both e^+e^- & $\mu^+\mu^-$ samples? Y
- Exist in both $\pi^+\pi^-$ low mass and high mass samples? Y
- Background fluctuation? N





- 827 pb⁻¹ data at E_{CM}=4.260 GeV
- Tag a D⁺ and a bachelor π⁻, reconstruct one π⁰ to suppress the background.



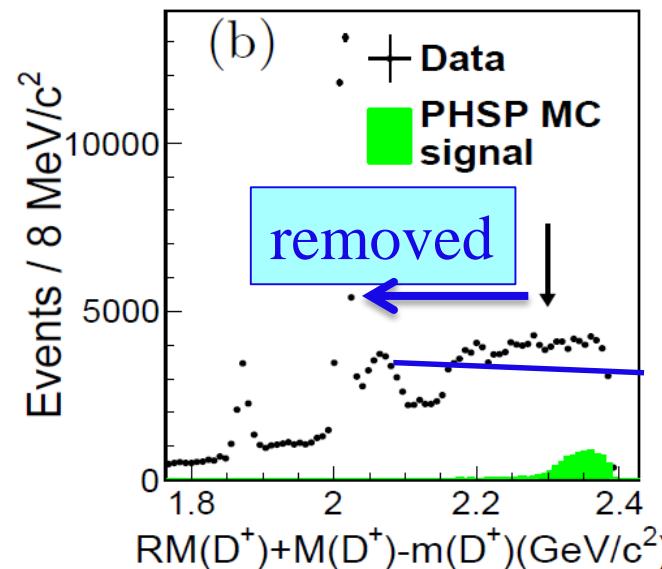
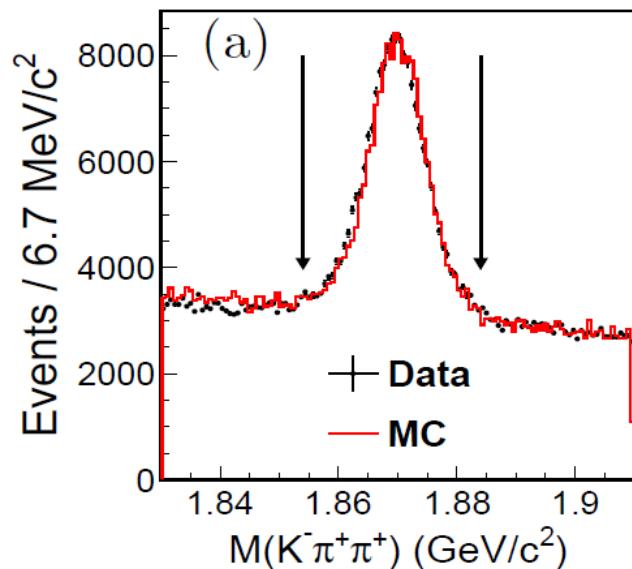
Topology of the decays of the signal process:

- thick line circled: D⁺ and π⁻ detected in the final states
- dashed line circled: at least one of π₁⁰ or π₂⁰ tagged

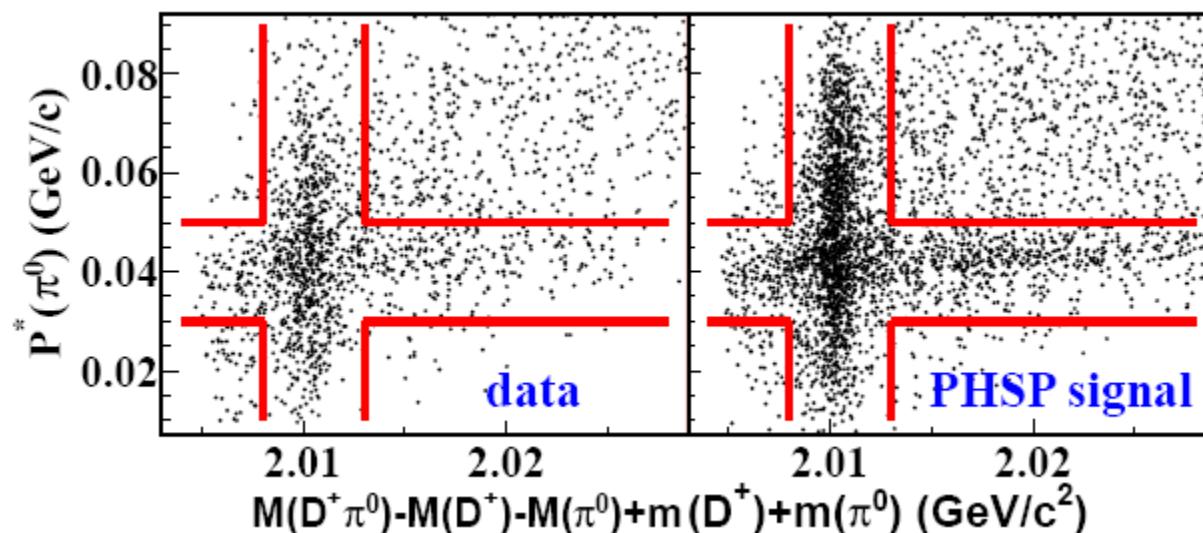


BESIII: $e^+e^- \rightarrow \pi Z_c(4025) \rightarrow \pi^- (D^* D^*)^+ + c.c.$ @ 4.260 GeV

hep-ex:1308.2760



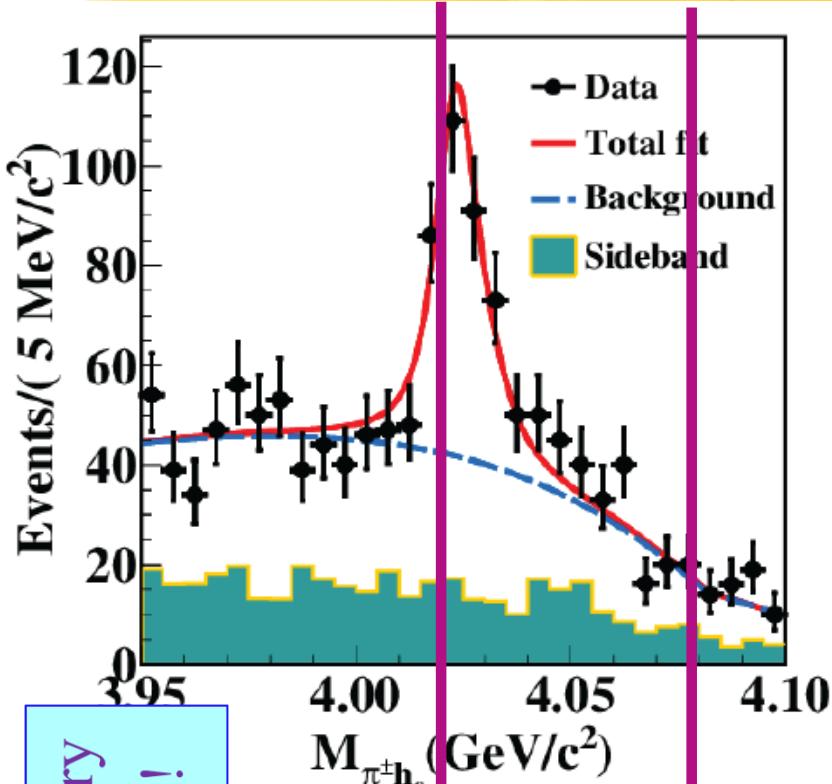
Remove
 DD , DD^* ,
 D^*D^* ,
 $DsDs$, ...





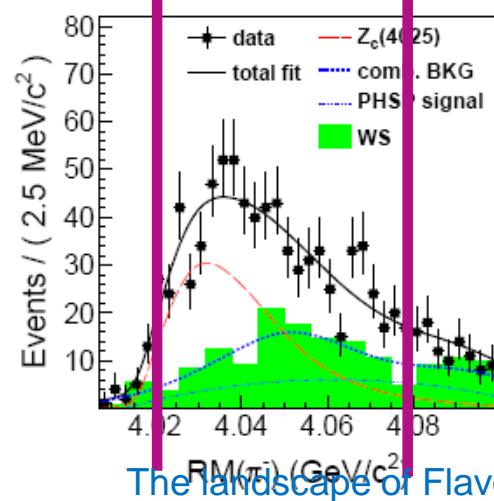
BESIII: $Z_c(4020)=Z_c(4025)?$

PRL 111, 242001
hep-ex:1308.2760



BESIII preliminary

The Z_c' is found!



$$M(4020) = (4021.8 \pm 1.0 \pm 2.5) \text{ MeV}$$

$$M(4025) = (4026.3 \pm 2.6 \pm 3.7) \text{ MeV}$$

$$\Gamma(4020) = (5.7 \pm 3.4 \pm 1.1) \text{ MeV}$$

$$\Gamma(4025) = (24.8 \pm 5.7 \pm 7.7) \text{ MeV}$$

Close to $D^*\bar{D}^*$ threshold (4017 MeV)

**Mass consistent with each other
but.. width $\sim 2\sigma$ difference**

**Interference with other amplitudes
may change the results**

Coupling to \bar{D}^*D^* is much larger
than to πh_c if they are the same state

Will fit with Flatte formula



What is the X(3872)?

- Mass: Very close to $\bar{D}^0 D^{*0}$ threshold
- Width: Very narrow, < 1.2 MeV
- $J^{PC}=1^{++}$ [LHCb]
- Production
 - in $\bar{p}p/p\bar{p}$ collision – rate similar to charmonia
 - In B decays – KX similar to $\bar{c}c$, K^*X smaller than $\bar{c}c$
 - $Y(4260) \rightarrow \gamma + X(3872)$ [BESIII, preliminary]
- Decay BR: open charm $\sim 50\%$, charmonium~O(%)
- Nature (very likely exotic)
 - Loosely $\bar{D}^0 D^{*0}$ bound state (like deuteron?)?
 - Mixture of excited χ_{c1} and $\bar{D}^0 D^{*0}$ bound state?
 - Many other possibilities (if it is not χ'_{c1} , where is χ'_{c1} ?)

