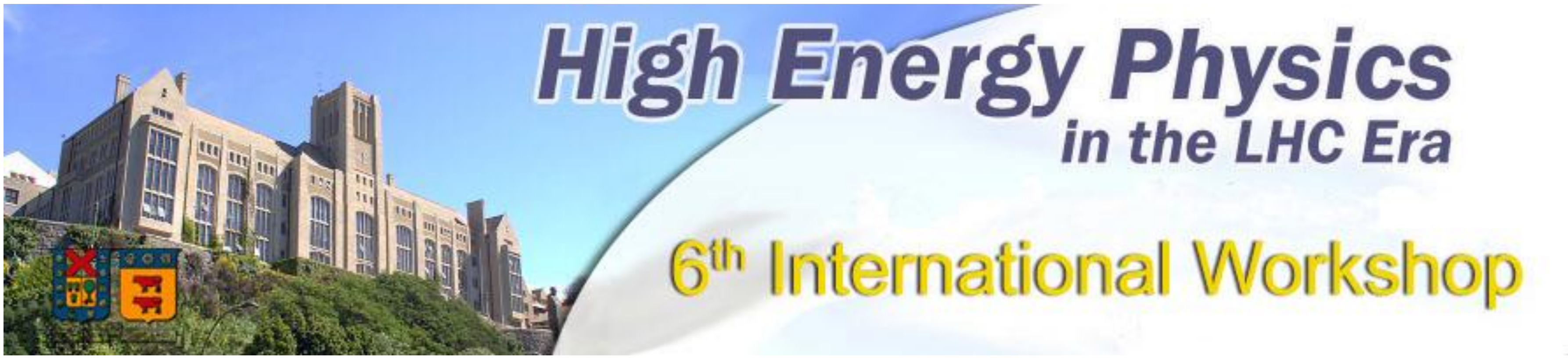
Universidad Técnica Federico Santa María

Valparaiso, Chile

January 6th - 12th 2016



Hadron Spectroscopy at BESIII

Marco Maggiora

BESIII Collaboration

Department of Physics and INFN – Turin, Italy

Universidad Técnica Federico Santa María

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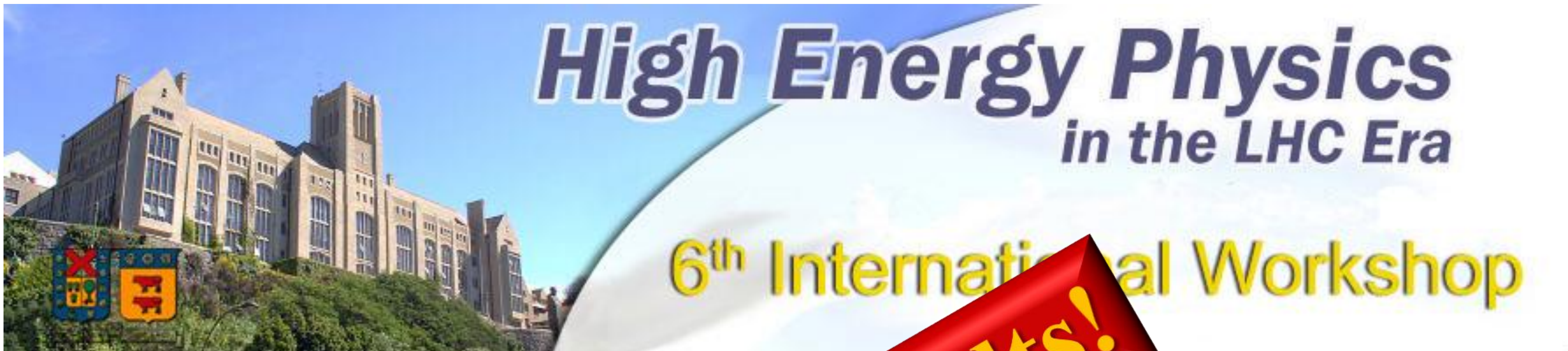


Selected results!

Hadron Spe opy at BESIII

Maggiora

SIII Collaboration

Department of Physics and INFN – Turin, Italy

INFN Istituto Nazionale di Fisica Nucleare

BESIII Collaboration

http://bes3.ihep.ac.cn

Pakistan (2)

Univ. of Punjab
COMSAT CIIT

Korea (1)

Seoul Nat. Univ.

Japan (1)

Tokyo Univ.

US (5)

Univ. of Hawaii
Carnegie Mellon Univ.
Univ. of Minnesota
Univ. of Rochester
Univ. of Indiana

China(31)

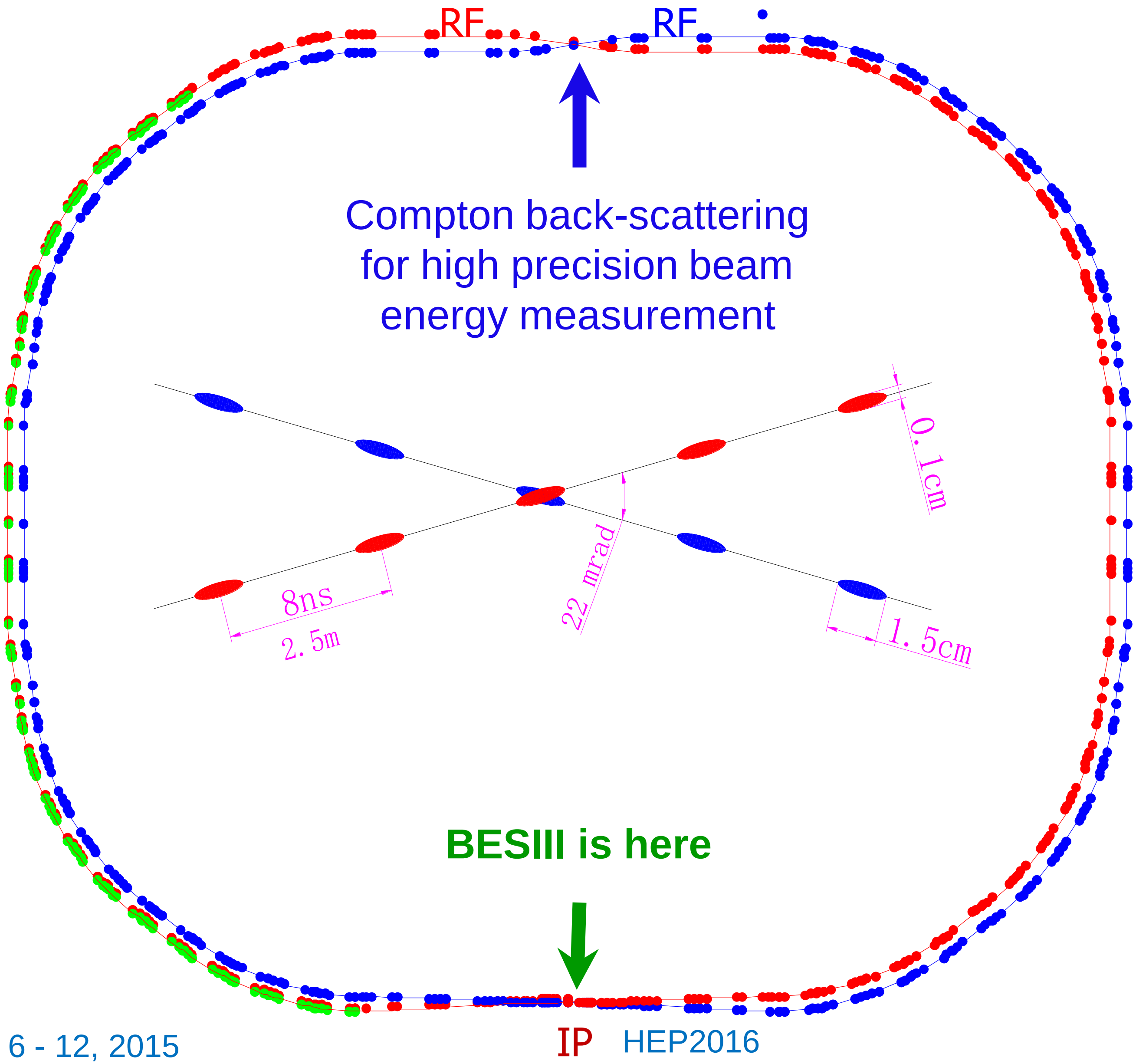
IHEP, CCAST, GUCAS, Shandong Univ.,
Univ. of Sci. and Tech. of China
Zhejiang Univ., Huangshan Coll.
Huazhong Normal Univ., Wuhan Univ.
Zhengzhou Univ., Henan Normal Univ.
Peking Univ., Tsinghua Univ. ,
Zhongshan Univ.,Nankai Univ.
Shanxi Univ., Sichuan Univ., Univ. of South China
Hunan Univ., Liaoning Univ.
Nanjing Univ., Nanjing Normal Univ.
Guangxi Normal Univ., Guangxi Univ.
Suzhou Univ., Hangzhou Normal Univ.
Lanzhou Univ., Henan Sci. and Tech. Univ.
Beihang Univ., Beijing Petrol Chemical Univ.

Europe (13)

Germany: Univ. of Bochum,
Univ. of Giessen, GSI
Univ. of Johannes Gutenberg
Helmholtz Ins. In Mainz
Russia: JINR Dubna; BINP Novosibirsk
Italy: Univ. of Torino and INFN,
INFN Frascati Lab, Univ. of Ferrara and INFN
Netherland : KVI/Univ. of Groningen
Sweden: Uppsala Univ.
Turkey: Turkey Accelerator Center

~400 members
53 institutions
11 countries

BEPCII



Beam energy:
1-2.3 GeV
Crossing angle:
22 mrad
Design Luminosity:
1×10^{33} $cm^{-2}s^{-1}$
Optimum energy:
1.89 GeV
Energy spread:
5.16×10^{-4}
No. of bunches:
93
Bunch length:
1.5 cm
Total current:
0.91 A
SR mode:
0.25A @ 2.5 GeV

BESIII Spectrometer

Magnet yoke

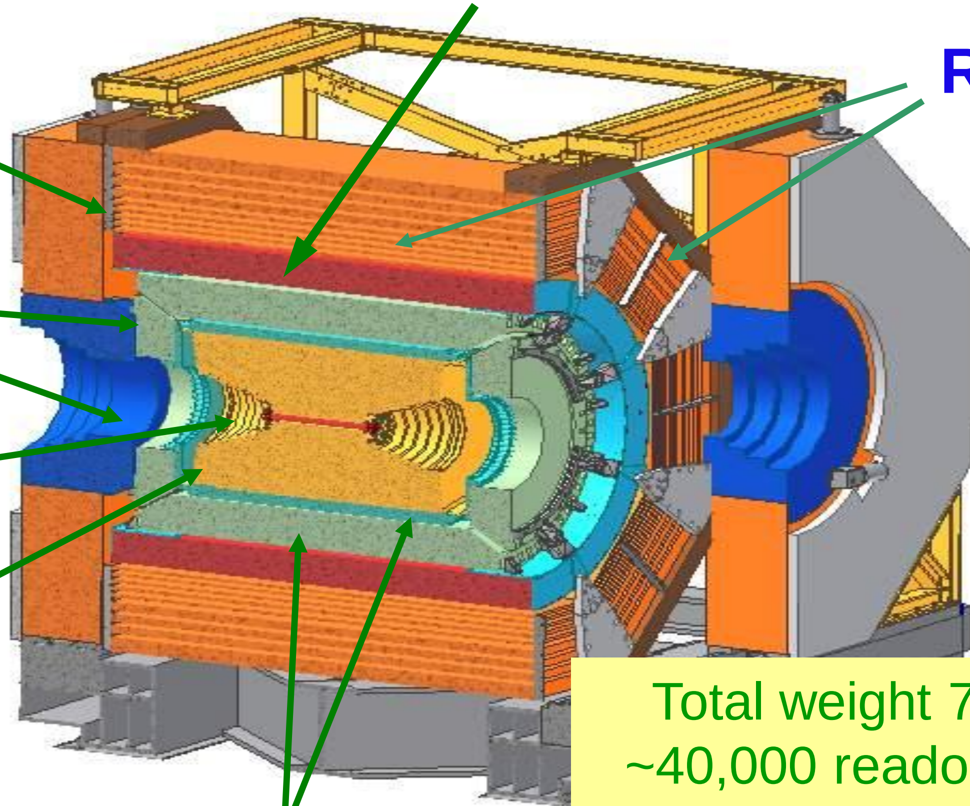
SC magnet, 1T

RPC

TOF, 90ps

Be beam pipe

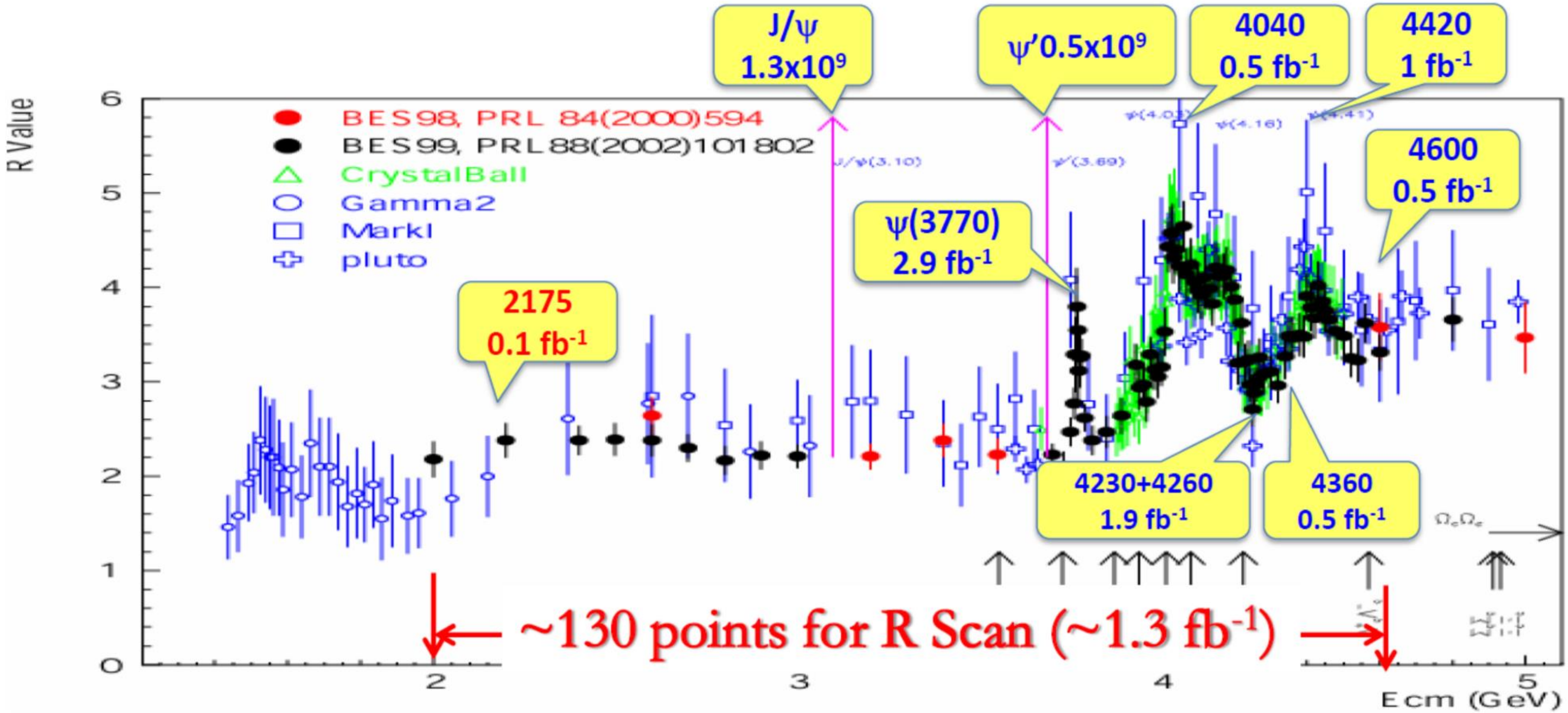
MDC, 130 μm
0.5% at 1 GeV/c



Total weight 730 ton,
~40,000 readout chnls,
Data rate: 6kHz, 50Mb/s

CsI(Tl) calorimeter, 2.5% @ 1 GeV

BESIII data set



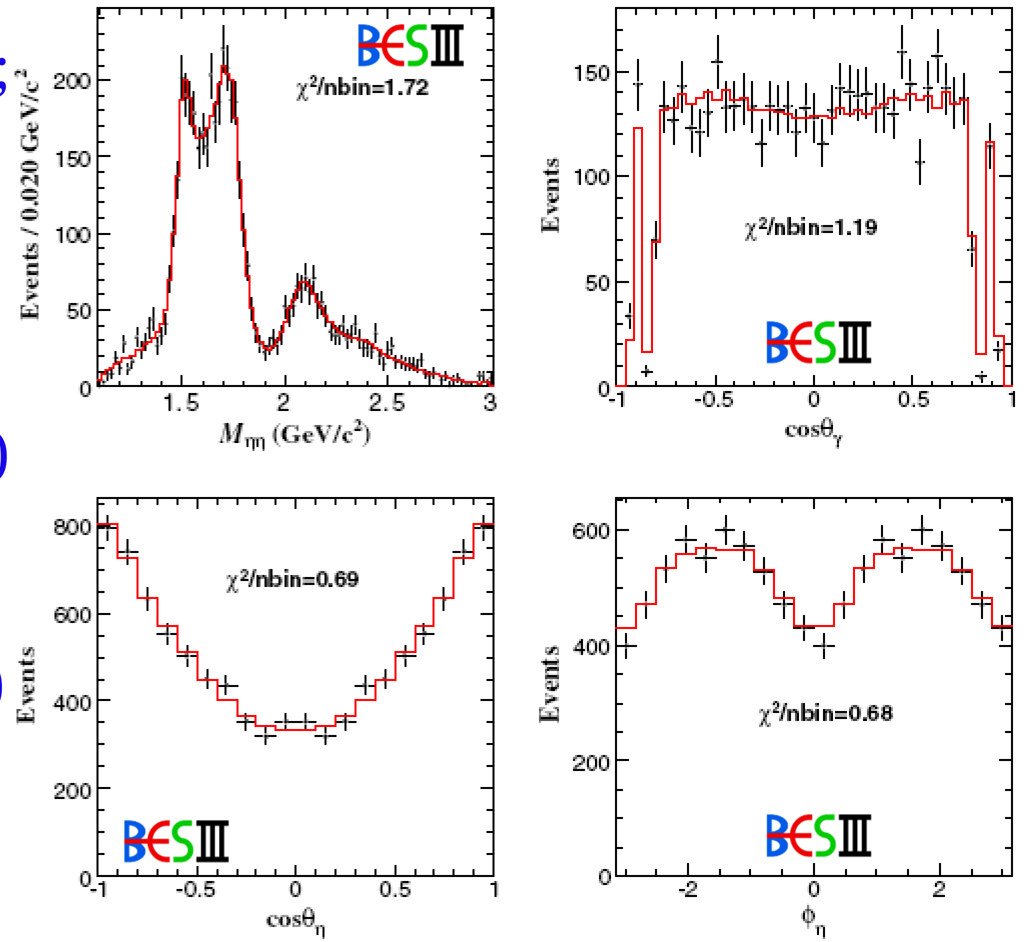
- World largest data sample on J/ψ, ψ(2S), ψ(3770),Y(4260)… in e^+e^- collisions
- From light mesons spectroscopy to $\Lambda_c\Lambda_c$
- Also ISR, photon-photon physics, τ physics…

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

PRD 87, 092009

- **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 od systematic uncertainties

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

PRD 87, 092009

Resonance	Mass(MeV/c^2)	Width(MeV/c^2)	$\mathcal{B}(J/\psi \to \gamma X \to \gamma\eta\eta)$	Significance
$f_0(1500)$	1468^{+14+23}_{-15-74}	$136^{+41+28}_{-26-100}$	$(1.65^{+0.26+0.51}_{-0.31-1.40}) \times 10^{-5}$	8.2 σ
$f_0(1710)$	$1759\pm6^{+14}_{-25}$	$172\pm10^{+32}_{-16}$	$(2.35^{+0.13+1.24}_{-0.11-0.74}) \times 10^{-4}$	25.0 σ
$f_0(2100)$	$2081\pm13^{+24}_{-36}$	273^{+27+70}_{-24-23}	$(1.13^{+0.09+0.64}_{-0.10-0.28}) \times 10^{-4}$	13.9 σ
$f_2^{'}(1525)$	$1513\pm5^{+4}_{-10}$	75^{+12+16}_{-10-8}	$(3.42^{+0.43+1.37}_{-0.51-1.30}) \times 10^{-5}$	11.0 σ
$f_2(1810)$	1822^{+29+66}_{-24-57}	$229^{+52+88}_{-42-155}$	$(5.40^{+0.60+3.42}_{-0.67-2.35}) \times 10^{-5}$	6.4 σ
$f_2(2340)$	$2362^{+31+140}_{-30-63}$	$334^{+62+165}_{-54-100}$	$(5.60^{+0.62+2.37}_{-0.65-2.07}) \times 10^{-5}$	7.6 σ

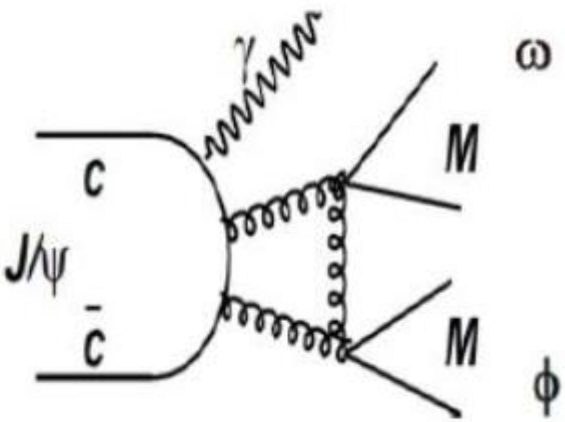
no significant evidence of:

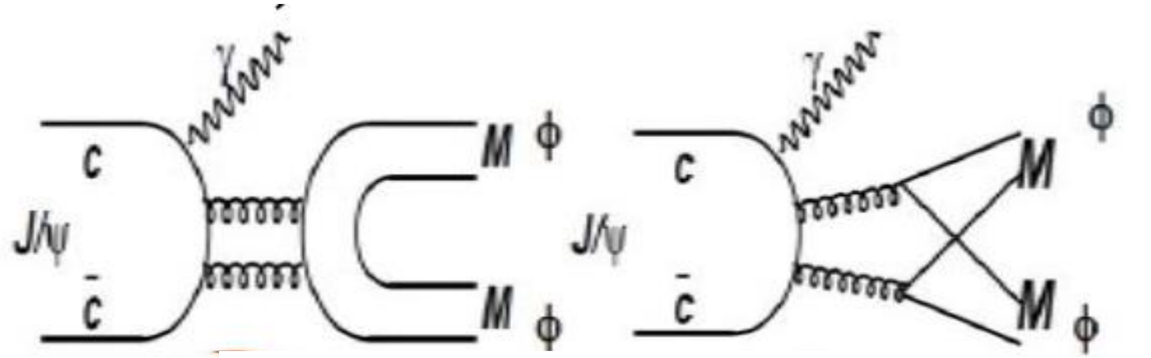
- scalar: $f_0(1370)$, $f_0(1790)$, $f_0(2020)$, $f_0(2200)$, $f_0(2330)$
- tensor: $f_2(2010)$, $f_2(2150)$, $f_J(2220)$

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

PRD 87, 032008

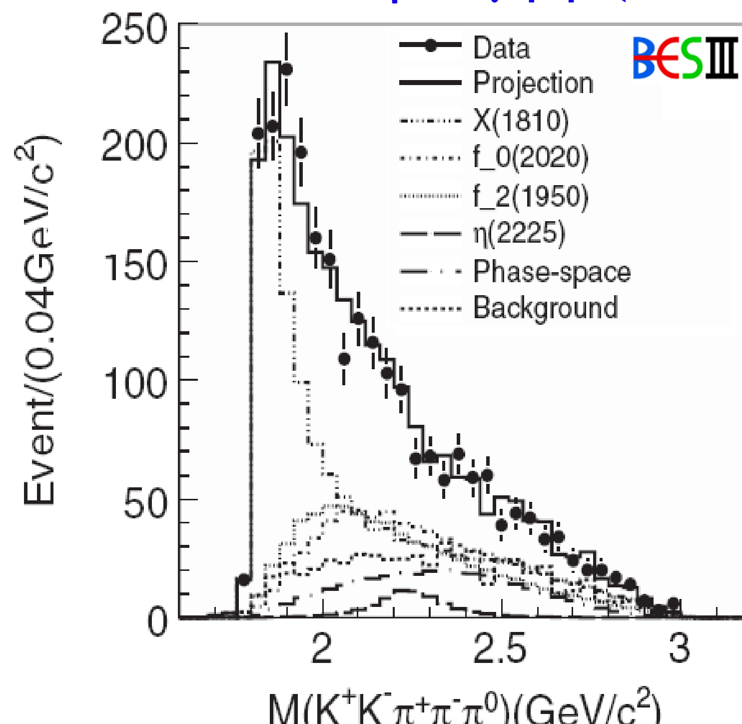
- **doubly OZI suppressed**





$\psi\rightarrow\gamma\omega\phi$ (DOZI) predicted $\propto$ 1/10 $\psi\rightarrow\gamma\phi\phi$ (OZI)

- **BESII:** X(1810) **[PRL 96, 162002]**
- **BESIII best solution:**
  X(1810), f_0(2020),f_2(1950), η(2225), f_0(2020), phase space and background



BESIII: $J/\psi \to \gamma X(1810)$, $X(1810) \to \omega\phi$ PRD 87, 032008

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

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

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

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

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

- **confirmed @ BESIII: best solution:**

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

- **X(1810) vs $f_0(1710)$:**
  unconclusive, further investigation is needed

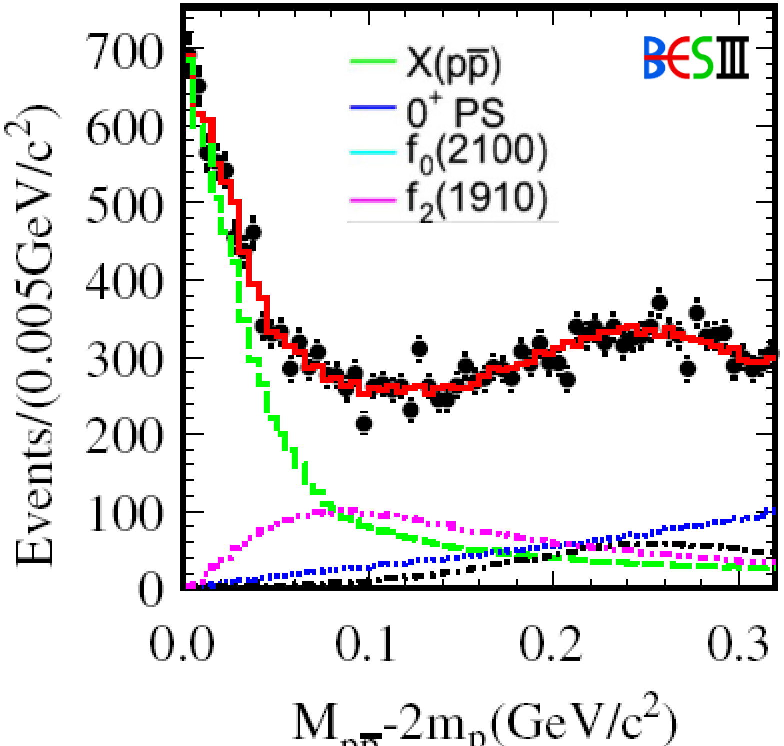
- **search for X(1810):**
  - in other decay modes: K^*K^*, $\omega\omega$, …

    [$J/\psi \to \gamma\eta(1760)$, $\eta(1760) \to \omega\ \omega$ observed by BESII: PRD 73, 112007]
  - in other production processes: $J/\psi \to \phi\omega\phi$, $J/\psi \to \omega\phi\omega$

BESIII: PWA of $J/\psi \to \gamma p\bar{p}$, $M_{p\bar{p}}$<2.2 GeV/c^2

PRL 108, 112003

- **PWA of $J/\psi \to \gamma p\bar{p}$:**
  - never performed before
- **best solution:**
  $X(p\bar{p})$ [>>**30σ**], $f_2(1910)$ 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



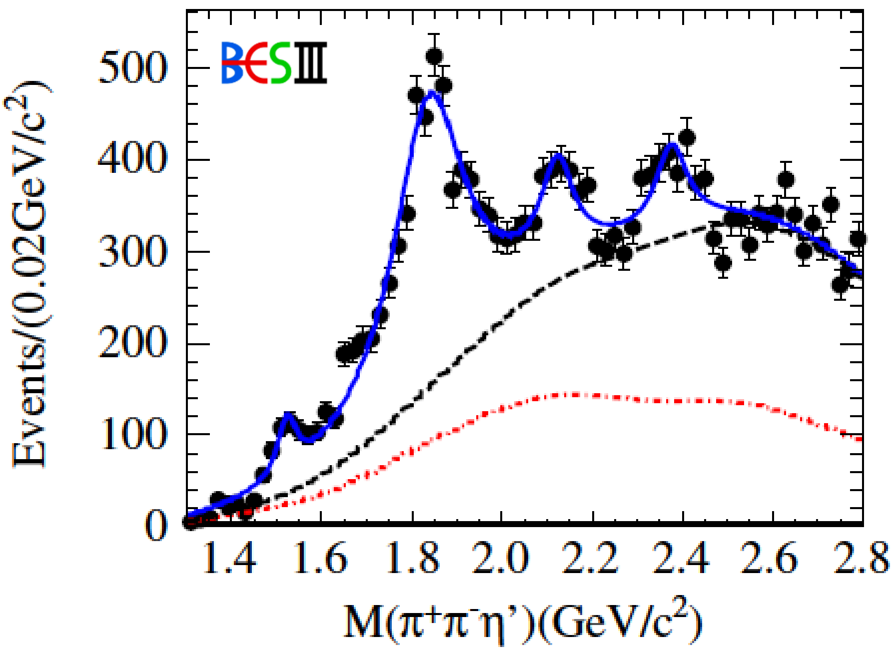
$J^{PC} = 0^{-+}$, >6.8σ better than other J^{PC} assignments

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

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

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

BESIII: $J/\psi \to \gamma X(1835)$, $X(1835) \to \pi^+\pi^-\eta'$ PRL 106, 072002



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

X(1835):

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

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

$>20\sigma$

X(2120):

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

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

$>7.2\sigma$

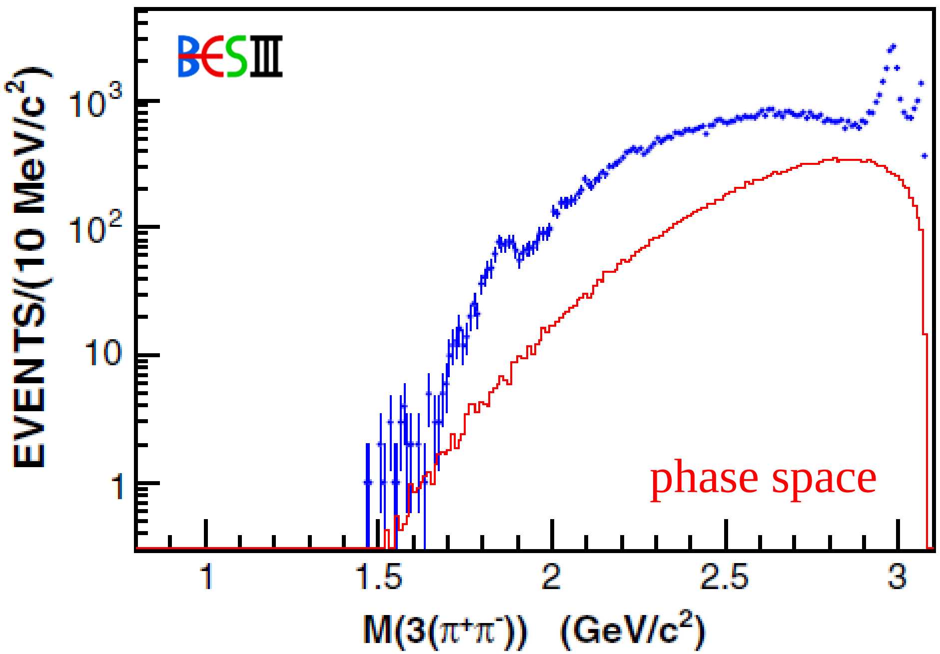
X(2370):

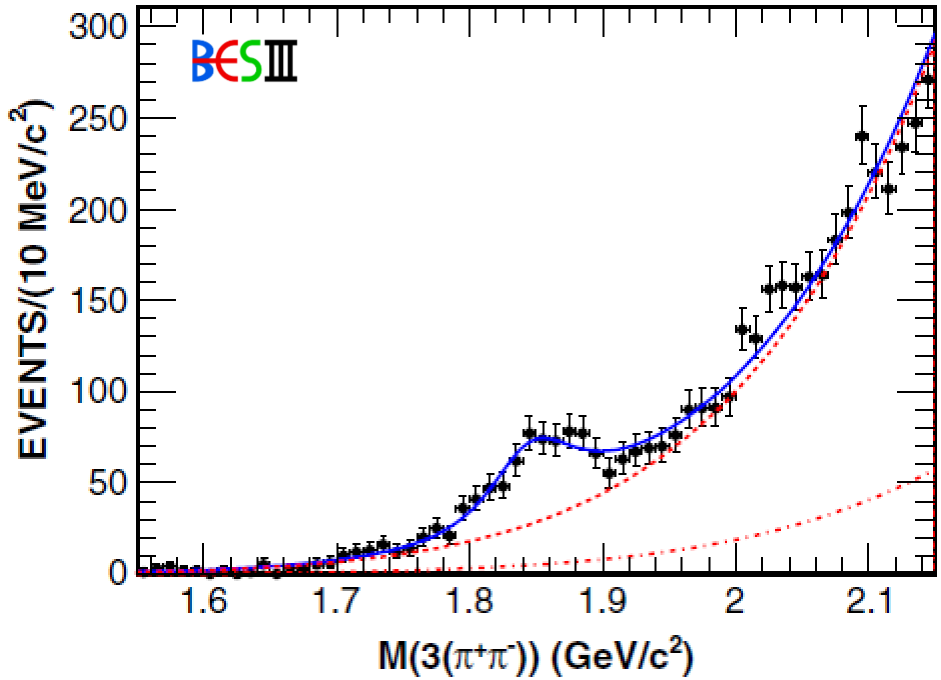
$M = (2376.3 \pm 8.7^{+3.2}_{-4.3})$ MeV/c^2

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

$>6.4\sigma$

BESIII: $J/\psi \to \gamma X(1840)$, $X(1840) \to 3(\pi^+\pi^-)$ PRD 88, 091502





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

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

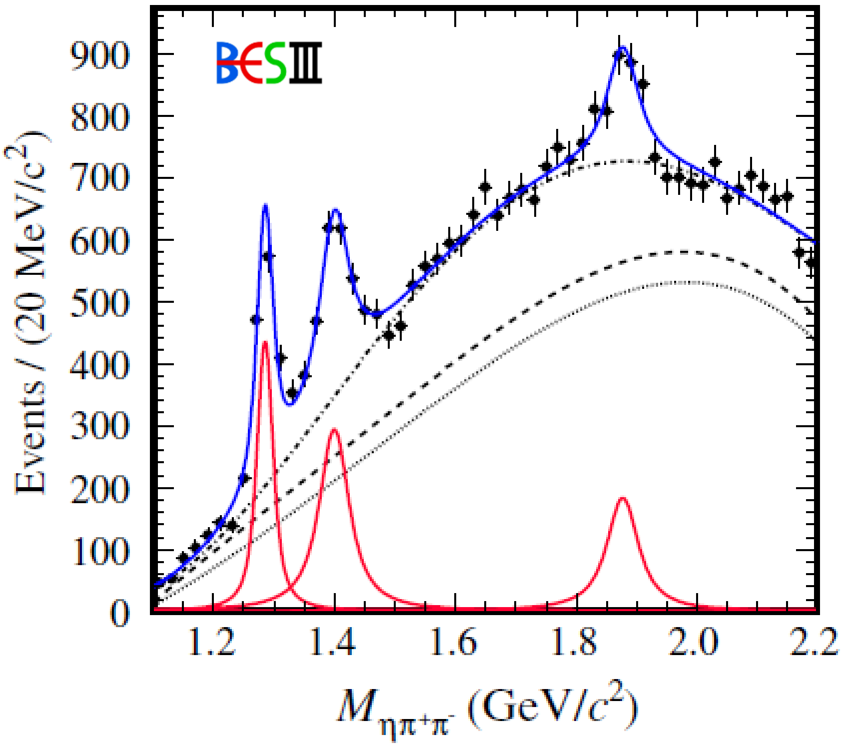
$>7.6\sigma$

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

BESIII: $J/\psi \to \omega X(1870)$, $X(1870) \to a^{\pm}(980)\pi^{\mp}$

PRL 107, 182001

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



- PWA is needed to determine spin and parity

X(1870):

$M = (1877.3 \pm 6.3^{+3.4}_{-7.4})$ MeV/c²

$\Gamma = (57 \pm 12^{+19}_{-4})$ MeV/c²

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

η(1405):

$M = (1399.8 \pm 2.2^{+2.8}_{-0.1})$ MeV/c²

$\Gamma = (52.8 \pm 7.6^{+0.1}_{-7.6})$ MeV/c²

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

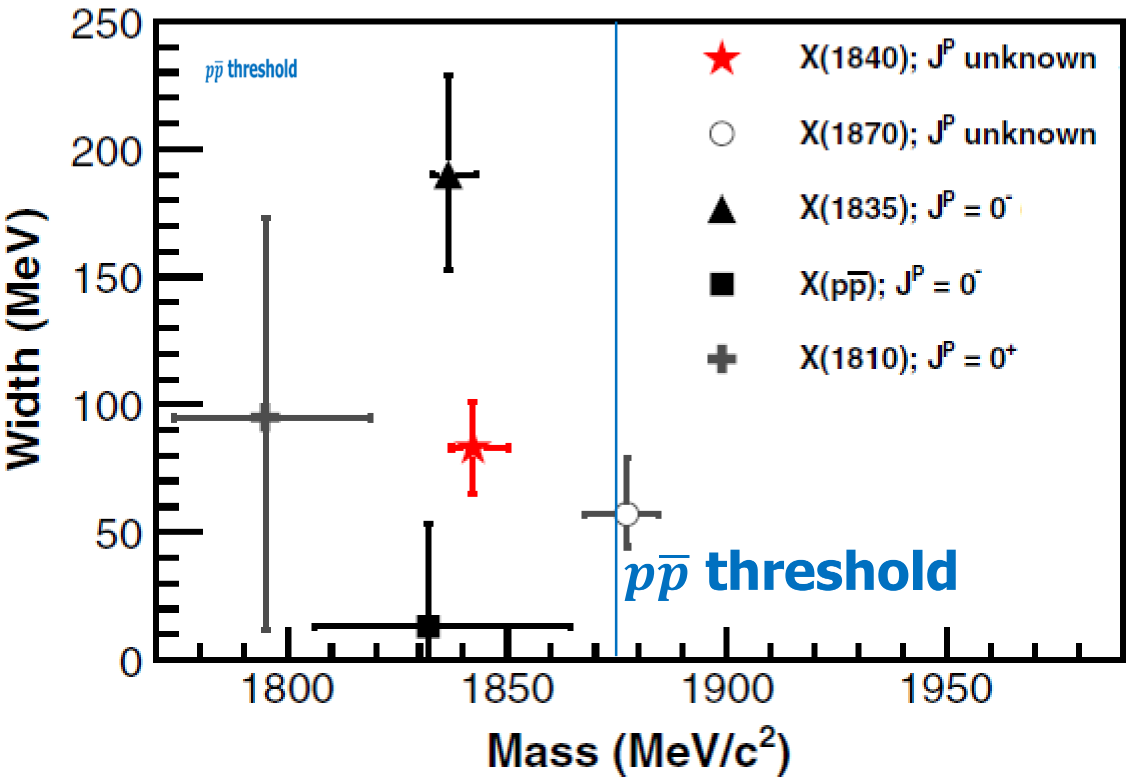
f_1(1285):

$M = (1285.1 \pm 1.0^{+1.6}_{-0.3})$ MeV/c²

$\Gamma = (22.0 \pm 3.1^{+2.0}_{-1.5})$ MeV/c²

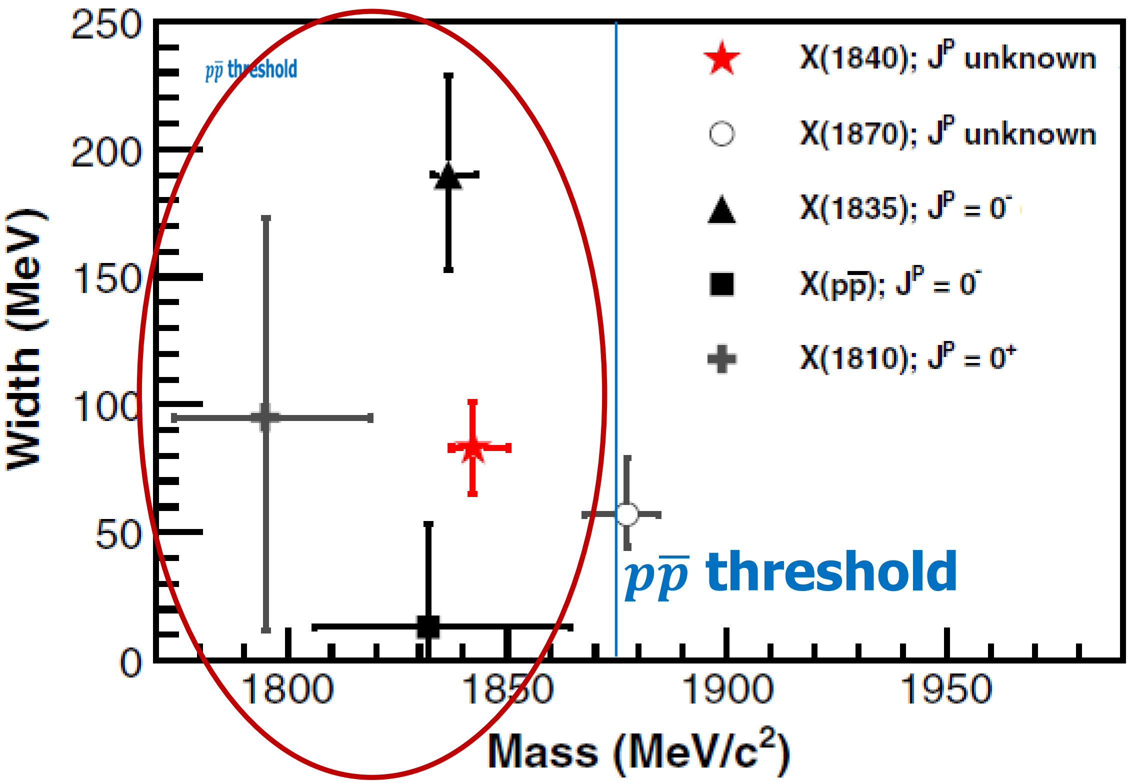
$B = (1.25 \pm 0.10^{+0.19}_{-0.20}) \cdot 10^{-4}$

BESIII: a partial summary



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

BESIII: a partial summary



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

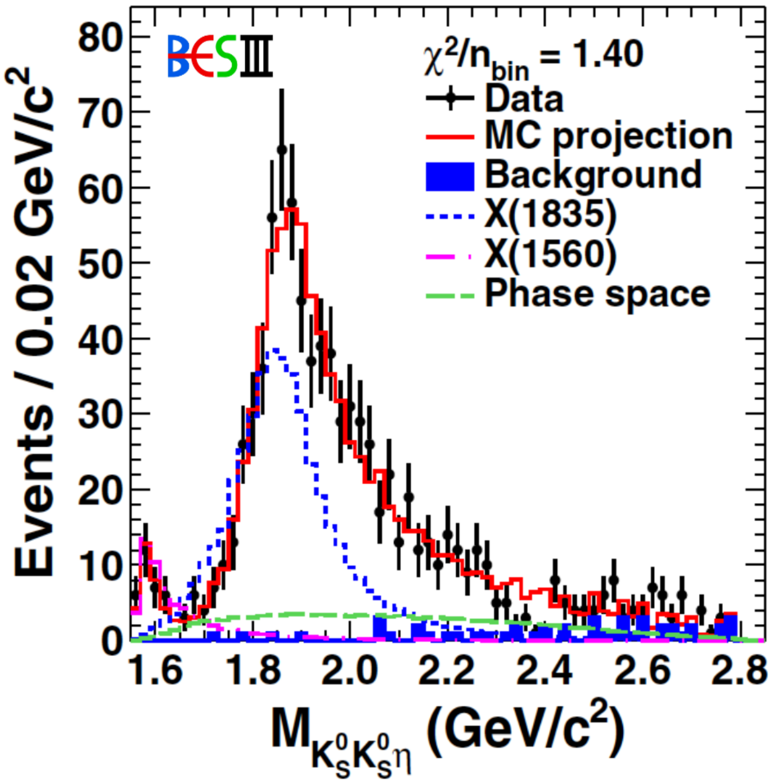
- ★ **X(1840): J/ψ → γ3($\pi^+\pi^-$) [PRD88, 091502]**
- ○ **X(1870): J/ψ → ωη$\pi^+\pi^-$ [PRL107, 182001]**
- ▲ **X(1835): J/ψ → γ(η$\pi^+\pi^-$) [PRL106, 072002]**
- ■ **X(1840): J/ψ → γ($p\bar{p}$) [PRL108, 112003]**
- ✚ **X(1840): J/ψ → γ(ωϕ) [PRD87, 032008]**

X(18??):
- **near ($p\bar{p}$) threshold**
- **is a single particle?!?**

BESIII: PWA of $J/\psi \to \gamma K^0_s K^0_s \eta$, M_{KK}<1.1 GeV/c^2

PRL 115, 091803

- **PWA of $J/\psi \to \gamma K^0_s K^0_s \eta$:**
  - a structure around 1.85 GeV strongly correlated with $f_0(960)$



- **$X(1560) \to f_0(980)\eta$:**

  $J^{PC} = 0^{-+}$, >8.9σ

  within 2σ from η(1405)/η(1475)

  $$M = 1565 \pm 8^{+0}_{-63}\ \mathrm{MeV}/c^2$$

  $$\Gamma = 45^{+14}_{-13}{}^{+21}_{-28}\ \mathrm{MeV}/c^2$$

- **$X(1835) \to \gamma K^0_s K^0_s \eta$:**

  $J^{PC} = 0^{-+}$, >12.9σ, consistent with X(1835) observed in $J/\psi \to \gamma \pi^+ \pi^- \eta'$

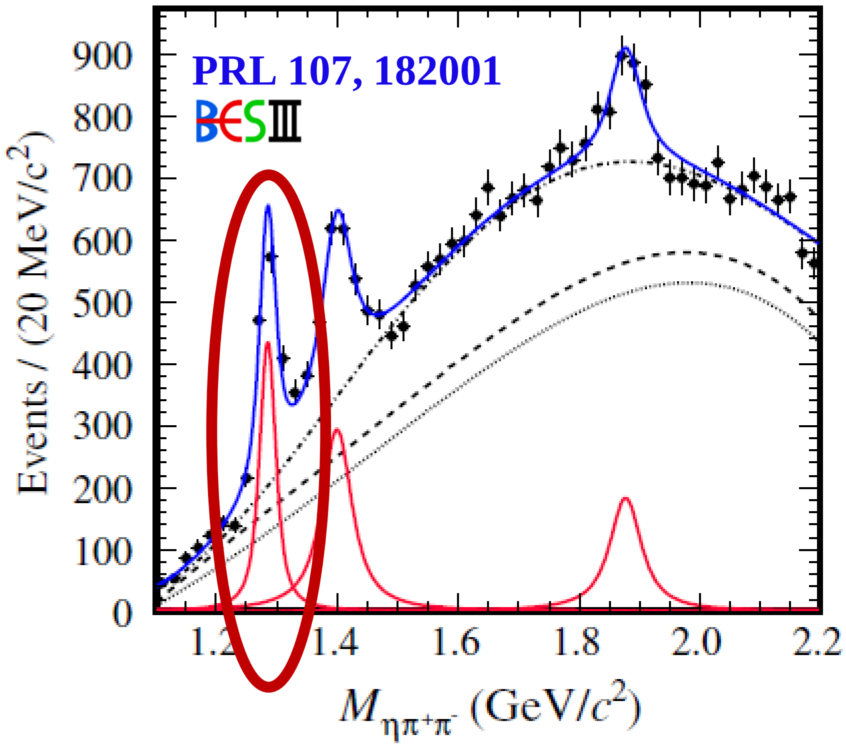
$$M = 1844 \pm 9(\mathrm{stat})^{+16}_{-25}(\mathrm{sys})\ \mathrm{MeV}/c^2 \qquad \Gamma = 192^{+20}_{-17}{}^{+62}_{-43}\ \mathrm{MeV}/c^2$$

$$\mathcal{B}(J/\psi \to \gamma X(1835)) \times \mathcal{B}(X(1835) \to K_s K_s \eta) = (3.31^{+0.33}_{-0.30}{}^{+1.96}_{-1.29}) \times 10^{-5}$$

BESIII: $J/\psi \to \phi f_1(1285)$, $f_1(1285) \to \eta\pi^+\pi^-$

PRD 91, 052017

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



$f_1(1285)$:

$M = (1285.1 \pm 1.0^{+1.6}_{-0.3})$ MeV/c²

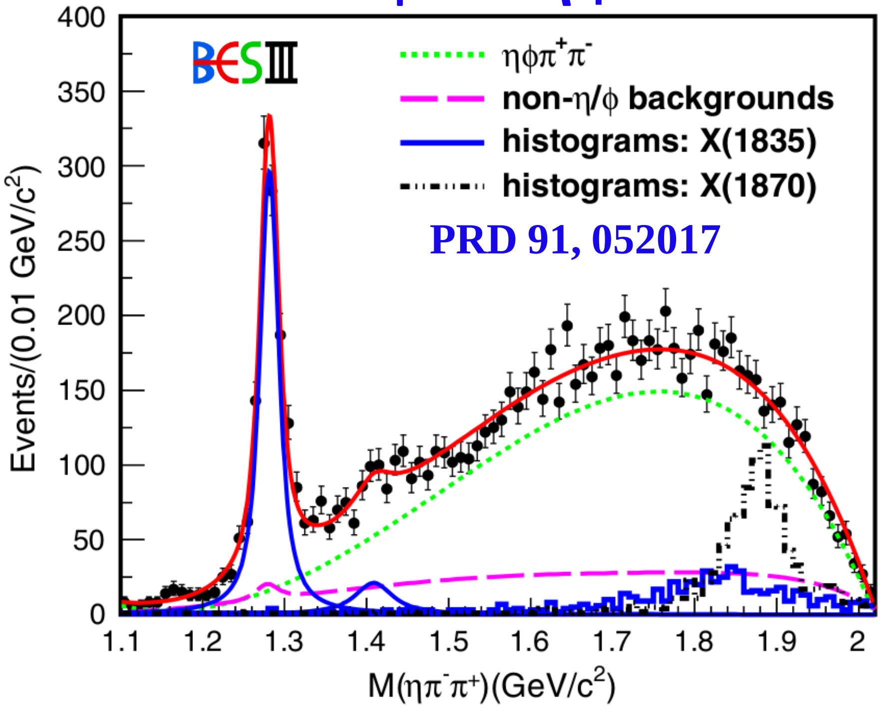
$\Gamma = (22.0 \pm 3.1^{+2.0}_{-1.5})$ MeV/c²

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

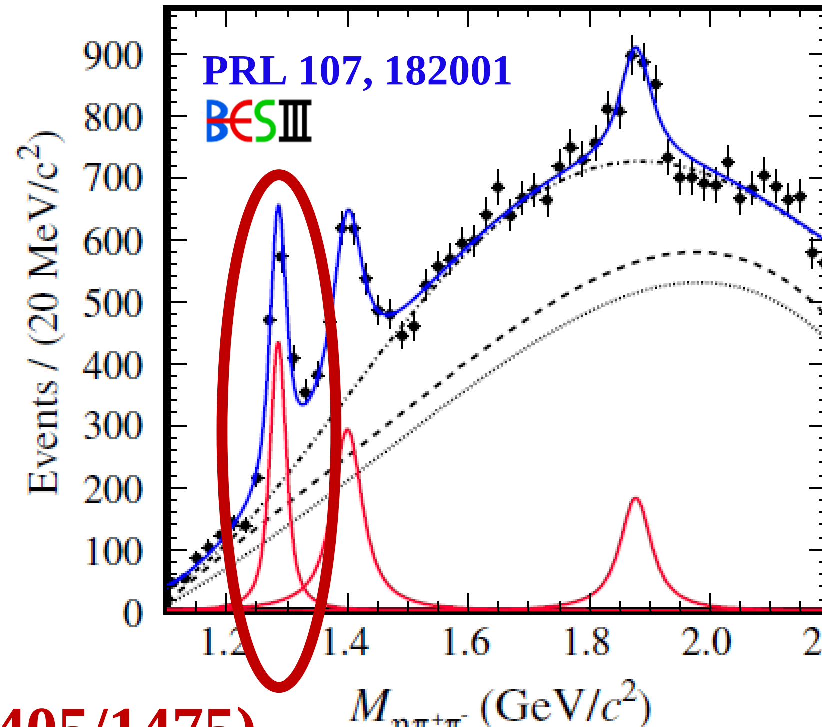
BESIII: $J/\psi \to \phi f_1(1285)$, $f_1(1285) \to \eta\pi^+\pi^-$

PRD 91, 052017

$J/\psi \to \eta\phi\pi^+\pi^-$



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



$J/\psi \to \eta\phi\pi^+\pi^-$: $f_1(1285)$, and $\eta(1295/1405/1475)$

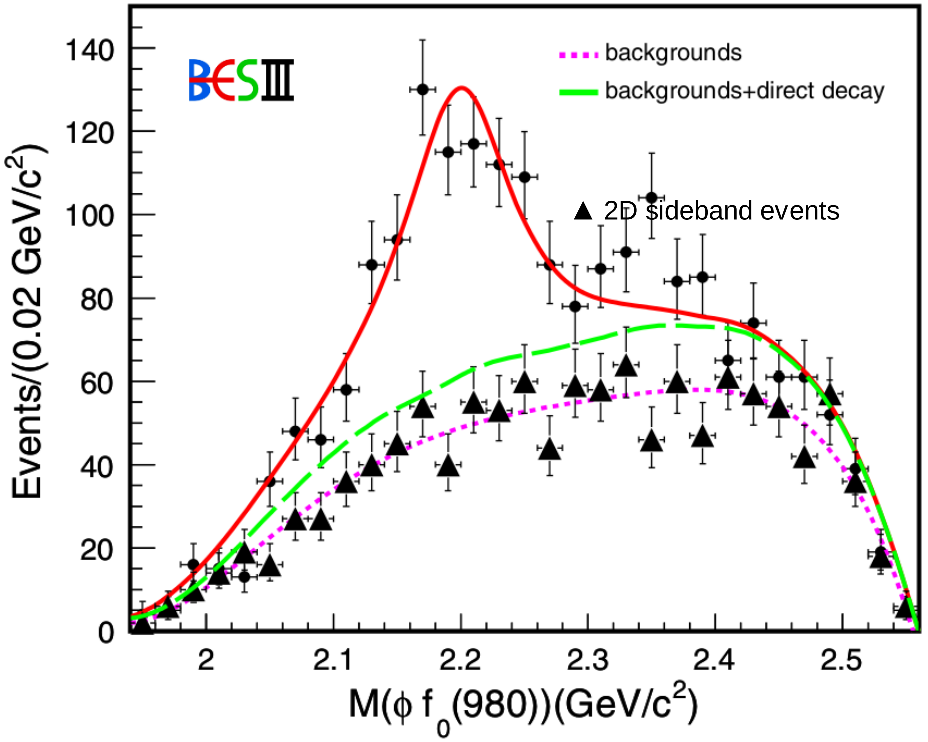
$J/\psi \to \eta\phi\pi^+\pi^-$	$J/\psi \to \eta\omega\pi^+\pi^-$
$f_1(1285)$:	**$f_1(1285)$:**
$M = (1281.7 \pm 0.6)\ \mathrm{MeV}/c^2$	$M = (1285.1 \pm 1.0^{+1.6}_{-0.3})\ \mathrm{MeV}/c^2$
$\Gamma = (21.0 \pm 1.7)\ \mathrm{MeV}/c^2$	$\Gamma = (22.0 \pm 3.1^{+2.0}_{-1.5})\ \mathrm{MeV}/c^2$
$B = (1.20 \pm 0.06) \cdot 10^{-4}$	$B = (1.25 \pm 0.10^{+0.19}_{-0.20}) \cdot 10^{-4}$

BESIII: $J/\psi \to \eta Y(2175)$, $Y(2175) \to \phi f_0(980)$, $f_0(980) \to \pi^+\pi^-$

PRD 91, 052017

Y(2175):

- **first observed at BABAR, then confirmed by BESII, BELLE and BABAR**
- **its nature is yet undefined**
- **higher statistics is neeeded to clarify its nature**
- **in agreement with previous measurements**



$\mathcal{B}(J/\psi \to \eta Y(2175)) \times \mathcal{B}(Y(2175) \to \phi f_0(980)) \times \mathcal{B}(f_0(980) \to \pi^+\pi^-) =$

$= (1.20 \pm 0.14 \pm 0.37) \times 10^{-4}$

Y(2175):

$M = (2200 \pm 6 \pm 5)$ MeV/c^2

$\Gamma = (104 \pm 15 \pm 15)$ MeV/c^2

> 10

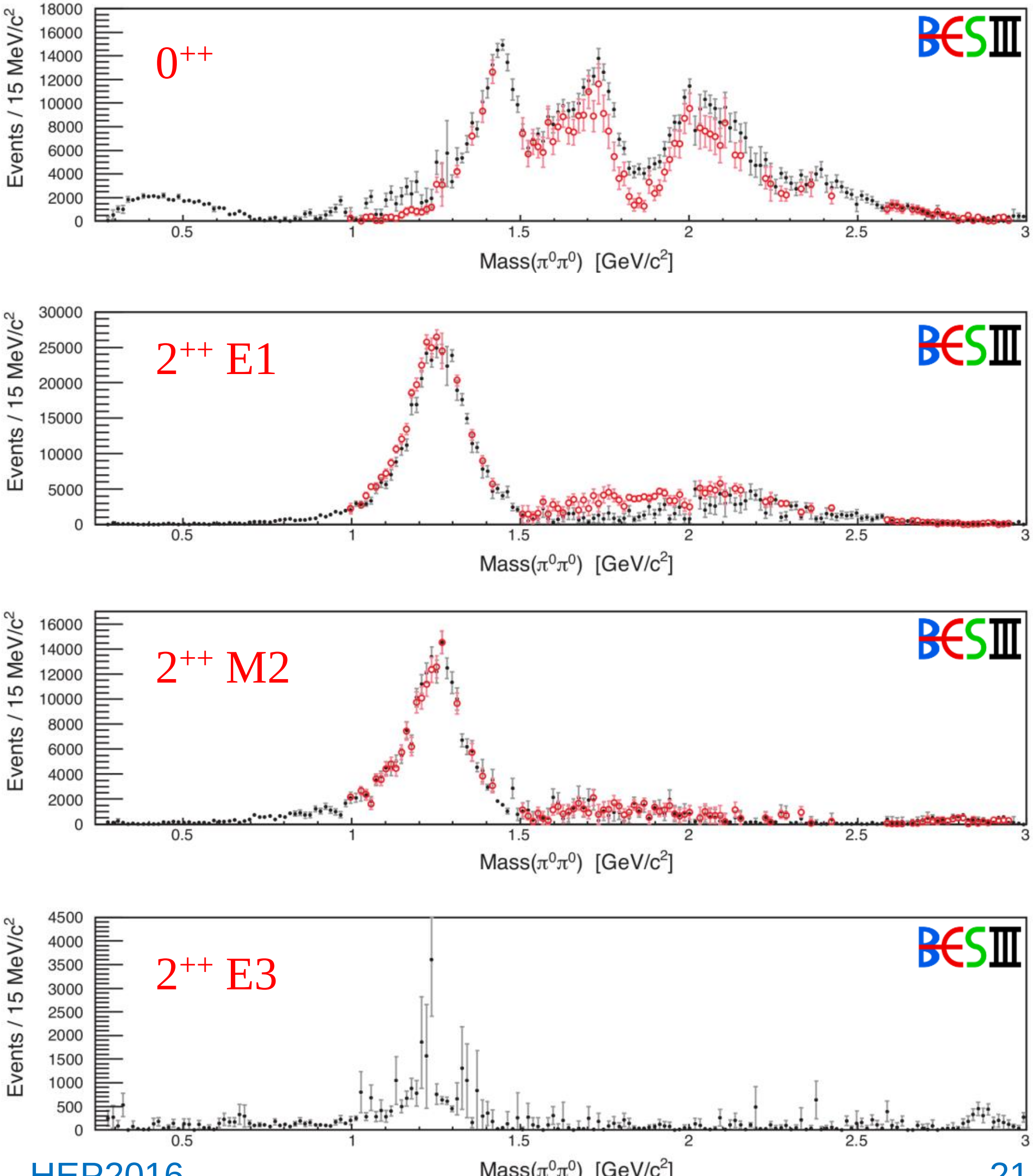
BESIII: PWA of $J/\psi \to \gamma\pi^0\pi^0$

PRD 92, 052003

Model independent

- **0^{++}** :
  $f_0(500)$, $f_0(1370)$, $f_0(1500)$, $f_0(1710)$ and $f_0(2020)$

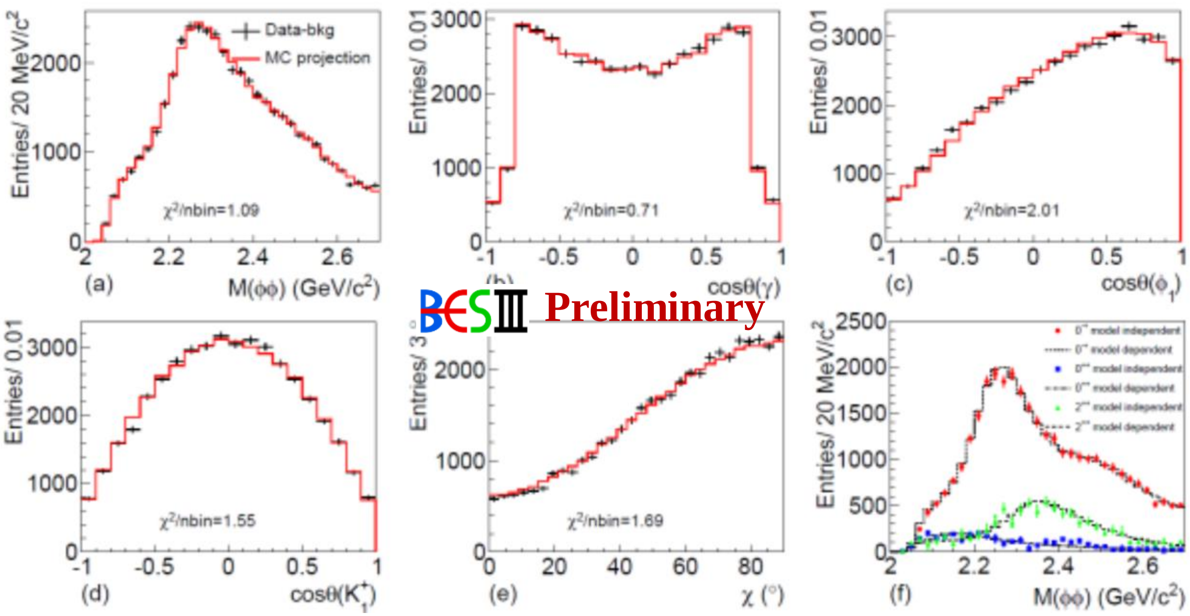
- **2^{++}** :
  dominated by $f_2(1270)$



BESIII: PWA of $J/\psi \to \gamma\phi\phi$

Preliminary

Exploring the pseudoscalar sector above 2 GeV: not only η(2225)!
A new hunt for pseudoscalar excitations and 0^{-+} glueballs



Resonance	$M(\mathrm{MeV}/c^2)$	$\Gamma(\mathrm{MeV}/c^2)$	B.F.$(\times 10^{-4})$	Sig.
$\eta(2225)$	2216^{+4+18}_{-5-11}	185^{+12+44}_{-14-17}	$(2.40 \pm 0.10^{+2.47}_{-0.18})$	28.1σ
$\eta(2100)$	2050^{+30+77}_{-24-26}	$250^{+36+187}_{-30-164}$	$(3.30 \pm 0.09^{+0.18}_{-3.04})$	21.5σ
X(2500)	2470^{+15+63}_{-19-23}	230^{+64+53}_{-35-33}	$(0.17 \pm 0.02^{+0.02}_{-0.08})$	8.8σ
$f_0(2100)$	2102	211	$(0.43 \pm 0.04^{+0.24}_{-0.03})$	24.2σ
$f_2(2010)$	2011	202	$(0.35 \pm 0.05^{+0.28}_{-0.15})$	9.5σ
$f_2(2300)$	2297	149	$(0.44 \pm 0.07^{+0.09}_{-0.15})$	6.4σ
$f_2(2340)$	2339	319	$(1.91 \pm 0.07^{+0.72}_{-0.69})$	10.7σ
0^{-+} PHSP			$(2.74 \pm 0.15^{+0.16}_{-1.48})$	6.8σ

Pseudoscalars:

- **η(2225)**: confirmed
- **η(2100)** and **X(2500)**:
  large statistical significance

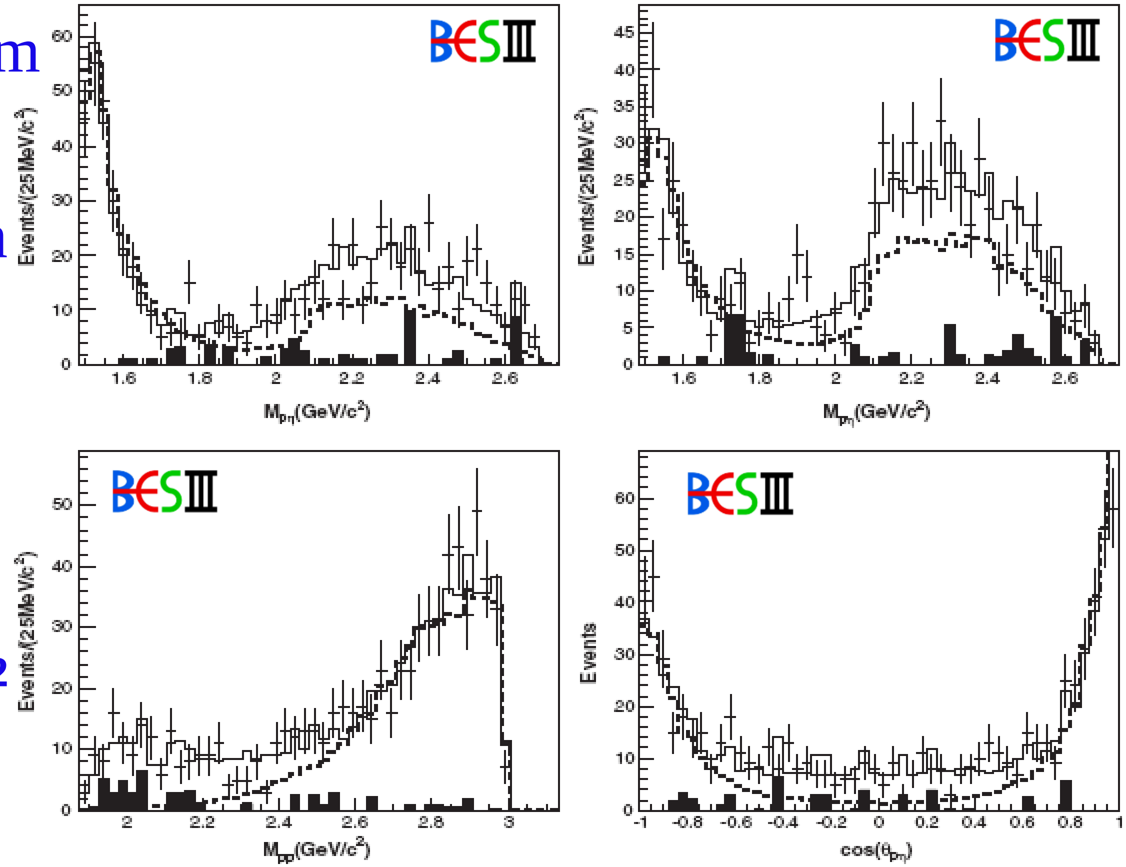
Tensors:

- **$f_2(2010)$, $f_2(2300)$** and **$f_2(2040)$** alredy observed in $\bar{p}p$ ractions
- strong contribution from **$f_2(2040)$**

Results from Model-dependent PWA and MI-PWA are consistent

BESIII: PWA of $\psi(2S) \to p\bar{p}\eta$

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



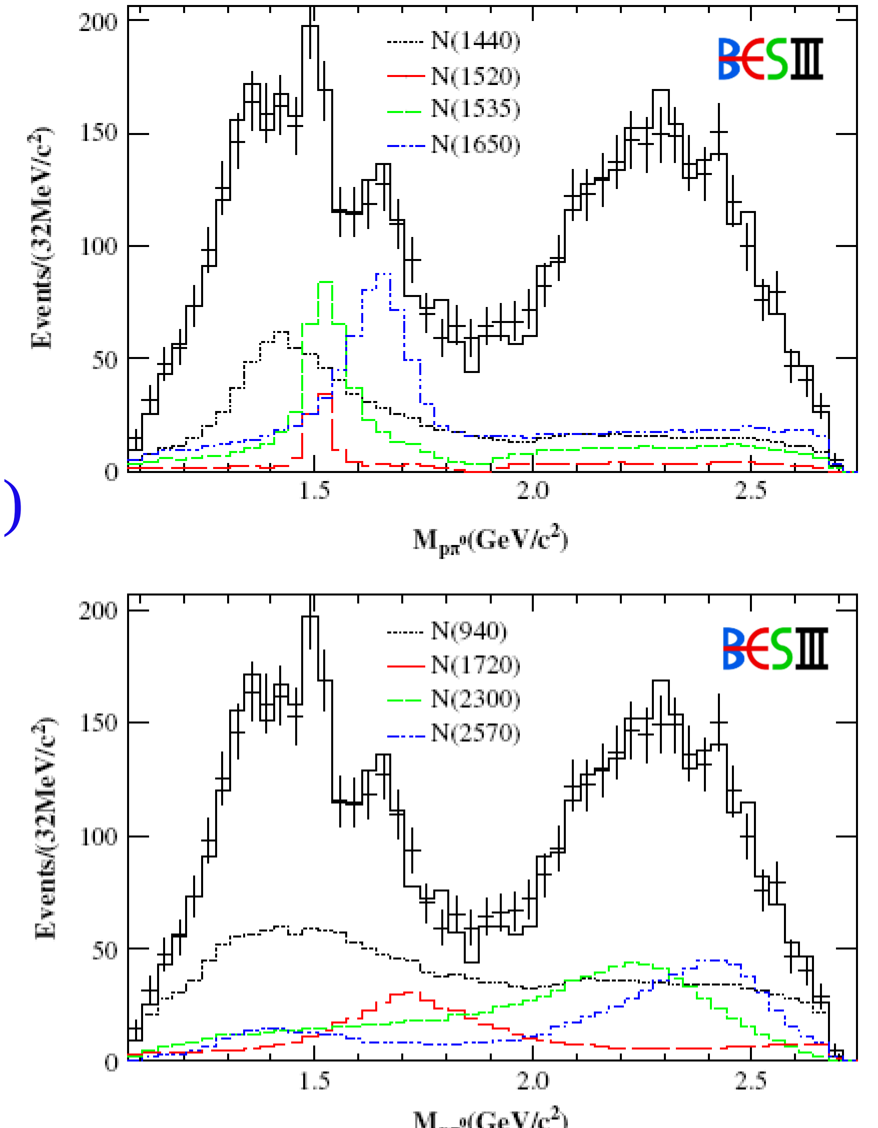
- **suppressed (<12%):**

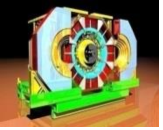
$$Q_{p\bar{p}\eta} = \frac{\mathcal{B}(\psi(2S) \to p\bar{p}\eta)}{\mathcal{B}(J/\psi \to p\bar{p}\eta)} = (3.2 \pm 0.46)\%$$

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

PRL 110, 022001

- **2-body decay:**
  - $\psi(2S)\to X\pi^0$, $X\to p\bar{p}$
  - $\psi(2S)\to p\bar{N}^*$, $\bar{N}^*\to \bar{p}\pi^0$+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





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  - N(1885), N(2065)
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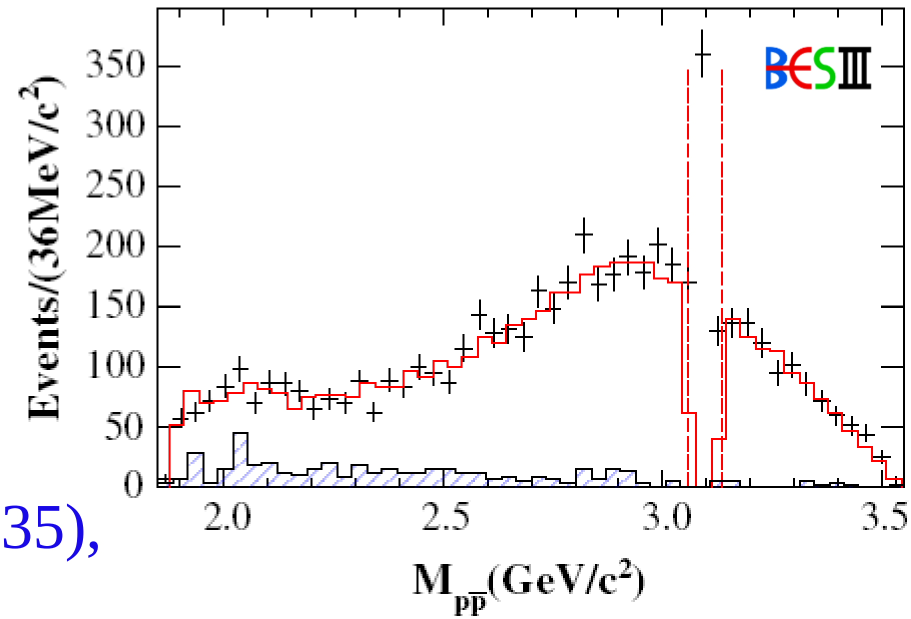
  - additional possible resonances

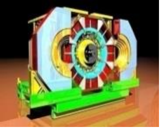


BESIII: PWA of $\psi(2S)\to p\bar{p}\pi^0$

PRL 110, 022001

- **branching fraction:**
  $\mathcal{B}(\psi(2S) \to p\bar{p}\pi^0) = (1.65\pm0.03\pm0.15)\times10^{-4}$
- **PWA:**
  - **two new resonances**
  - N(1885) and N(2065), <5σ
  - $p\bar{p}$ resonance <4σ

Resonance	$M(\mathrm{MeV}/c^2)$	$\Gamma(\mathrm{MeV}/c^2)$	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) $1/2^+$	$\mathbf{2300^{+40+109}_{-30-0}}$	$\mathbf{340^{+30+110}_{-30-58}}$	**120.7**	**4**	$\mathbf{15.0\sigma}$
N(2570) $5/2^-$	$\mathbf{2570^{+19+34}_{-10-10}}$	$\mathbf{250^{+14+69}_{-24-21}}$	**78.9**	**6**	$\mathbf{11.7\sigma}$



BESIII: $\psi(2S) \rightarrow \Xi(1690/1820)^- \Lambda \bar{\Xi}^+$, $\Xi(1690/1820)^- \rightarrow K^- \Lambda$

PRD 91, 092006

confirming earlier observations

- **$\Xi(1690)^-$: 4.9σ**

M = (1687.7±3.8±1.0) MeV/c^2

Γ = (27.1±10.0±2.7) MeV/c^2

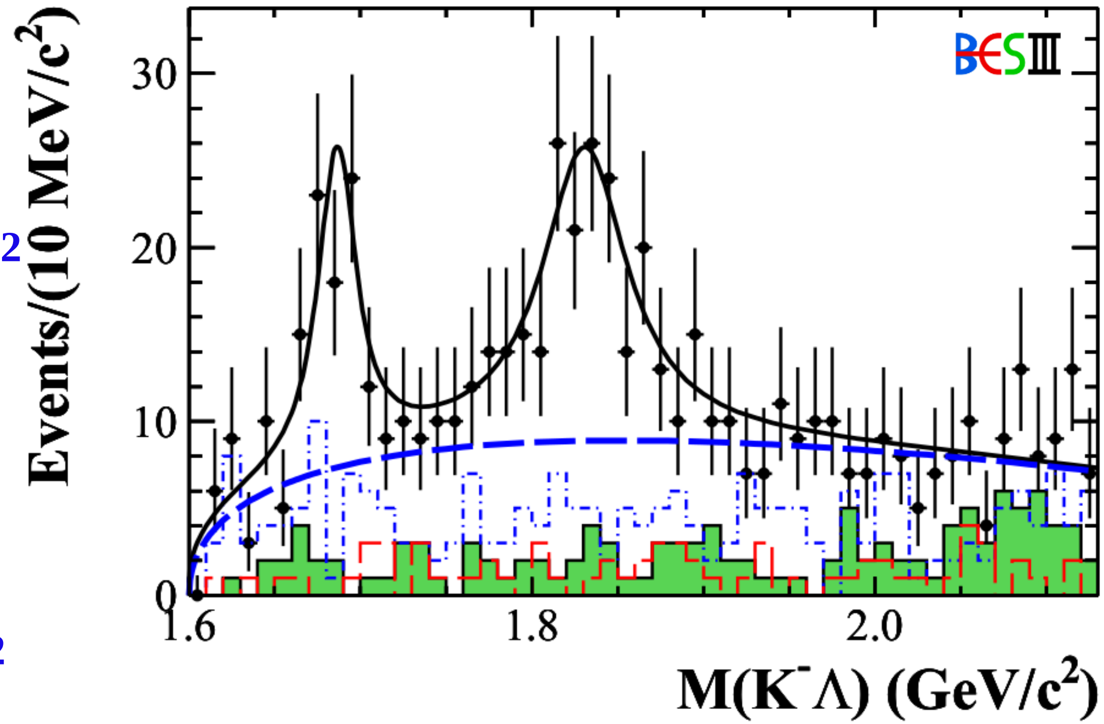
[PDG: **M = (1690±10) MeV/c^2**,
Γ = <30 MeV/c^2]

- **$\Xi(1820)^-$: 6.2σ**

M = (1826.7±5.5±1.6) MeV/c^2

Γ = (54.4±15.7±4.2) MeV/c^2

[PDG: **M = (1823±5) MeV/c^2**, **Γ = 24^{+15} MeV/c^2**]



first measurements

$\mathcal{B}(\psi(2S) \rightarrow \Xi(1690)^- \Lambda \Xi^+)$ x $\mathcal{B}(\Xi(1690)^- \rightarrow K^- \Lambda)$ = $(5.21 \pm 1.48 \pm 0.57) \times 10^{-6}$

$\mathcal{B}(\psi(2S) \rightarrow \Xi(1820)^- \Lambda \Xi^+)$ x $\mathcal{B}(\Xi(1820)^- \rightarrow K^- \Lambda)$ = $(12.03 \pm 2.94 \pm 1.22) \times 10^{-6}$

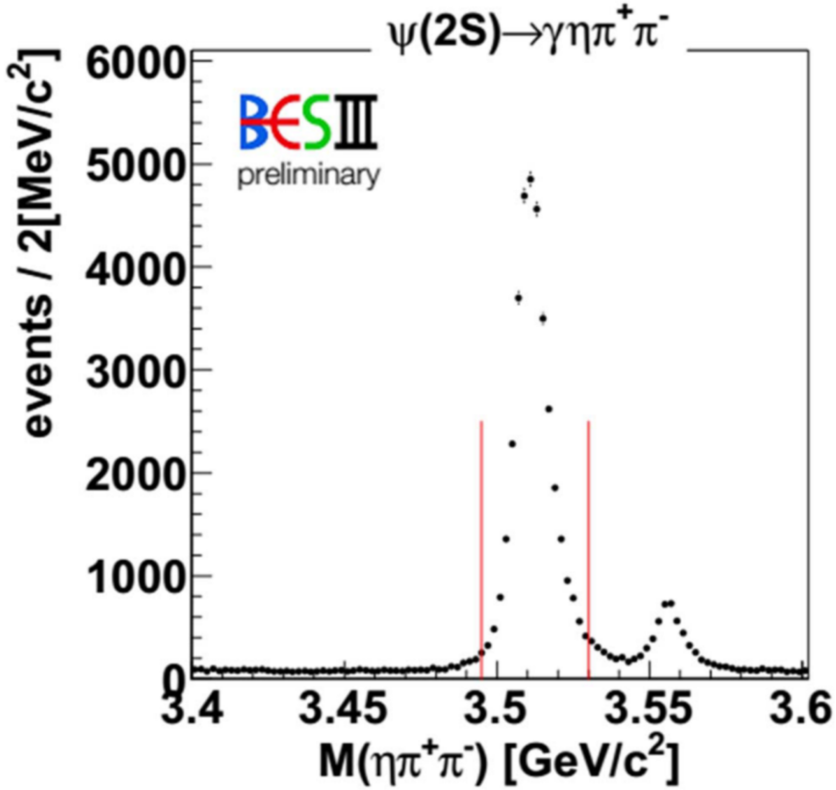
BESIII: amplitude analysis of $\chi_{c1} \to \eta\pi^+\pi^-$

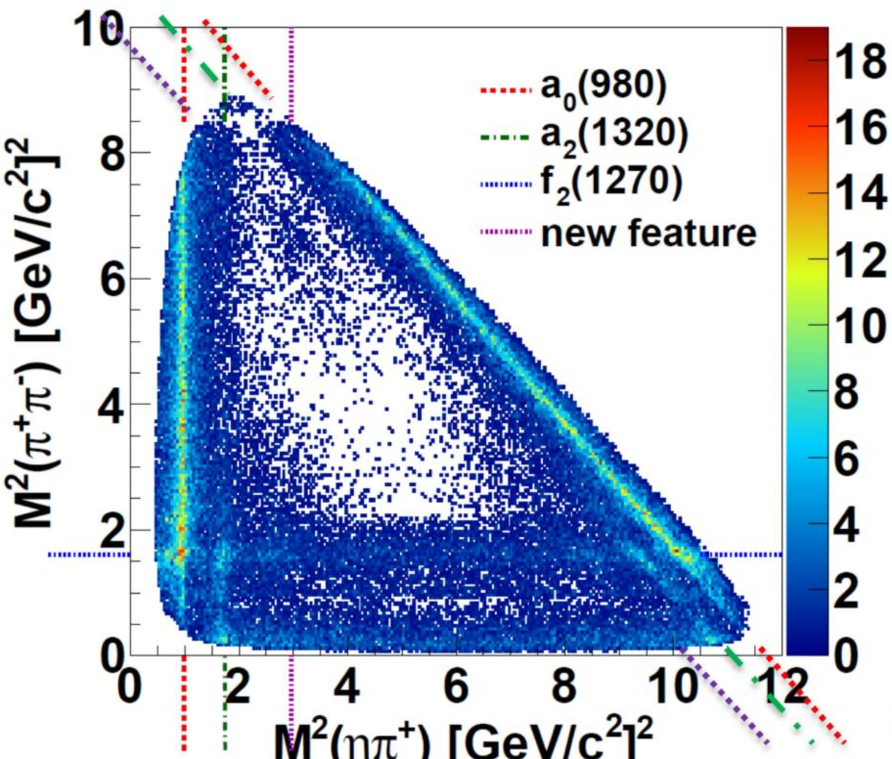
Preliminary

- χ_{c1} **provides a rich environment to investigate 1^{-+} states:**
  - $\pi_1(1600)$ investigated by CLEO-c in χ_{c1} decays
  - decays to $\eta\pi$ reported for $\pi_1(1400)$ only
- a_0 **and** a_2 **still need further investigation**

world largest data sample: ~ 35k χ_{c1}

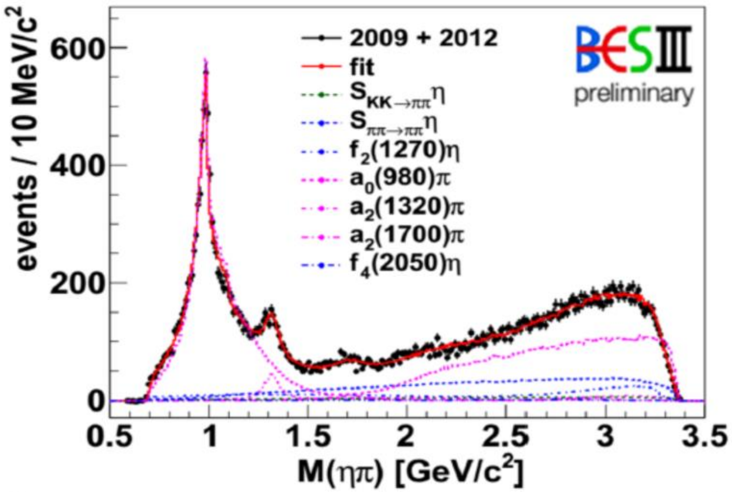
compatible with an $a_2(1700)$ contribution

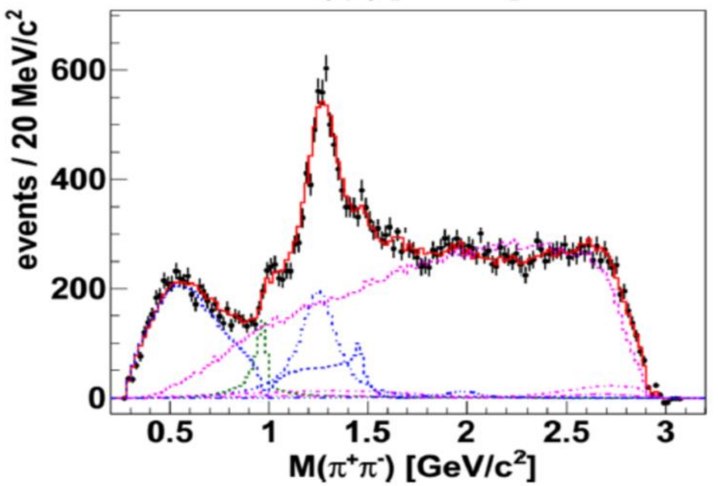




BESIII: amplitude analysis of $\chi_{c1} \to \eta\pi^+\pi^-$

Preliminary

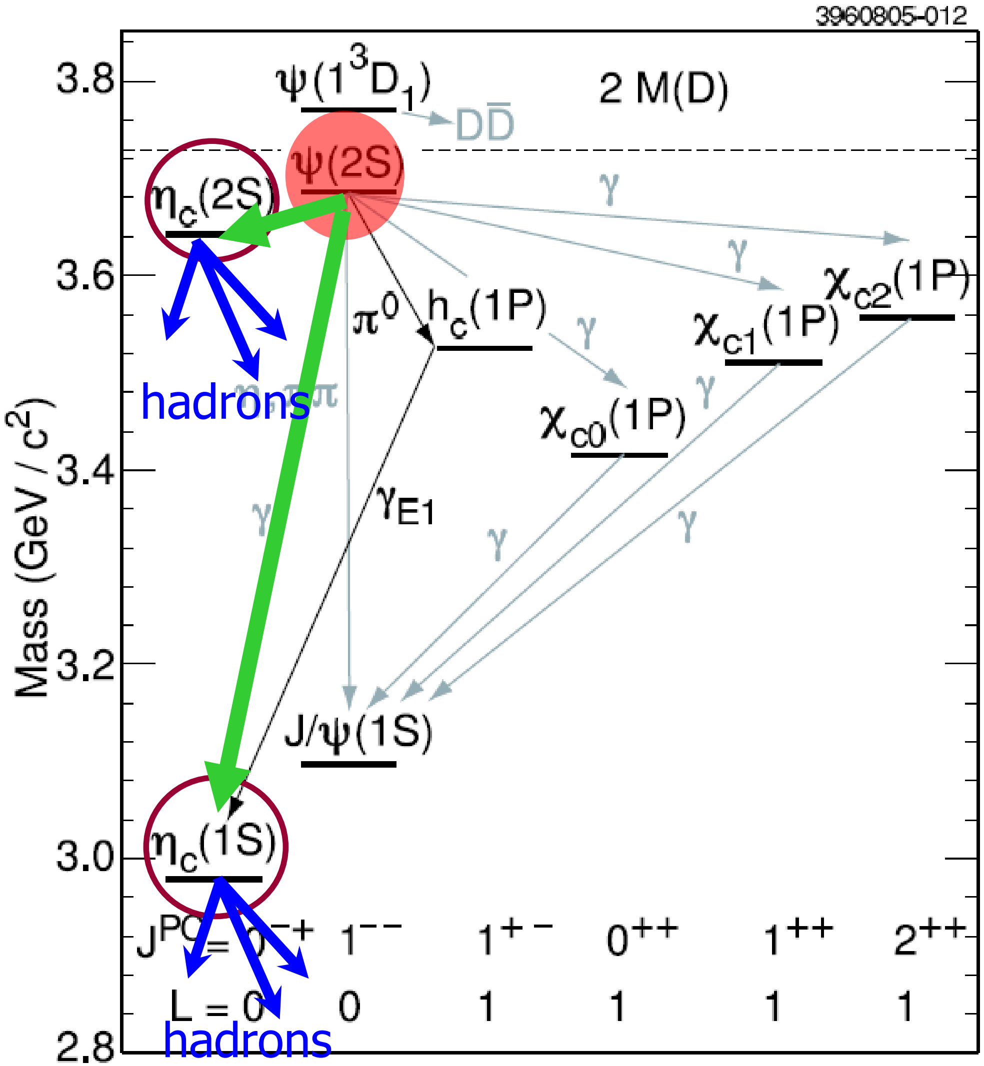




Decay	$\mathcal{B}(\chi_{c1} \to \eta\pi^+\pi^-)$ $[10^{-3}]$	
$\eta\pi^+\pi^-$	$4.819 \pm 0.031 \pm 0.088 \pm 0.210$	
$a_0(980)^+\pi^-$	$3.506 \pm 0.034 \pm 0.182 \pm 0.153$	
$a_2(1320)^+\pi^-$	$0.185 \pm 0.009 \pm 0.038 \pm 0.008$	
$a_2(1700)^+\pi^-$	$0.048 \pm 0.005 \pm 0.014 \pm 0.002$	
$S_{KK}\eta$	$0.123 \pm 0.007 \pm 0.018 \pm 0.005$	
$S_{pp}\eta$	$0.791 \pm 0.019 \pm 0.037 \pm 0.035$	
$(\pi^+\pi^-)_S\eta$	$0.859 \pm 0.021 \pm 0.031 \pm 0.037$	
$f_2(1270)\eta$	$0.371 \pm 0.012 \pm 0.054 \pm 0.016$	
$f_4(2050)\eta$	$0.027 \pm 0.004 \pm 0.009 \pm 0.001$	
$J^{PC} = 1^{-+}$	U.L. [90% C.L.]	
$\pi_1(1400)$	0.028 ± 0.010	< 0.048
$\pi_1(1600)$	0.005 ± 0.005	< 0.016
$\pi_1(2015)$	0.003 ± 0.002	< 0.008

- **first observation of $a_2(1700)$ in χ_{c1} decays**
- **first indication of $g'_{\eta'\pi} \neq 0$ from $a_0(980) \to \eta\pi$ lineshape**
- **evalutation of upper limits for $\mathcal{B}(\chi_{c1} \to \pi_1(1400/1600/2015)^+\pi^-)$**

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



η_c mass:
charmonium ground state

M1 transition:
first observation of $\psi' \rightarrow \gamma\eta'_c$

$\eta_c(1S)$

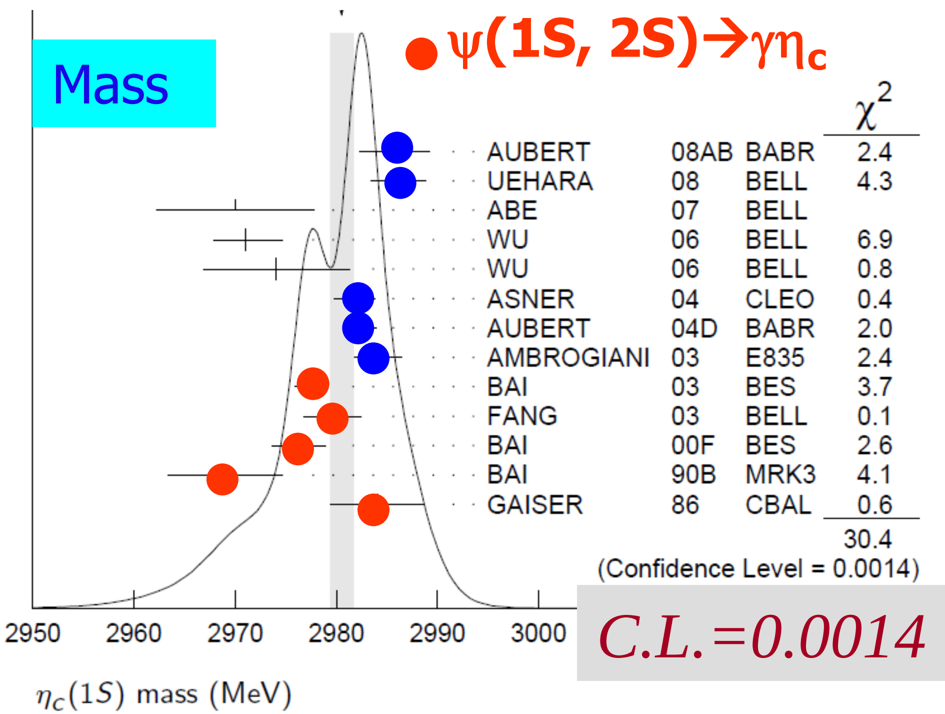
The S-wave spin-singlet charmonium ground state, found in 1980

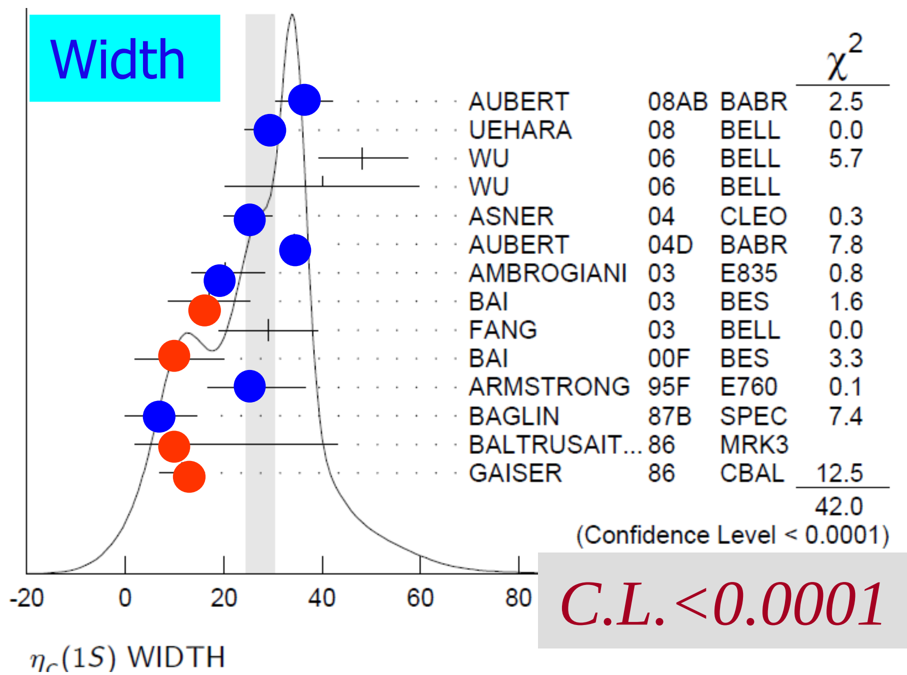
M & Γ measurements:

- J/ψ radiative transitions: **M ~ 2978.0 MeV/c², Γ ~ 10 MeV/c²**
- γγ processes / B→Kη_c: **M = (2983.1±1.0) MeV/c², Γ = (31.3±1.9) MeV/c²**

● γγ, **$p\bar{p}$, B decay**

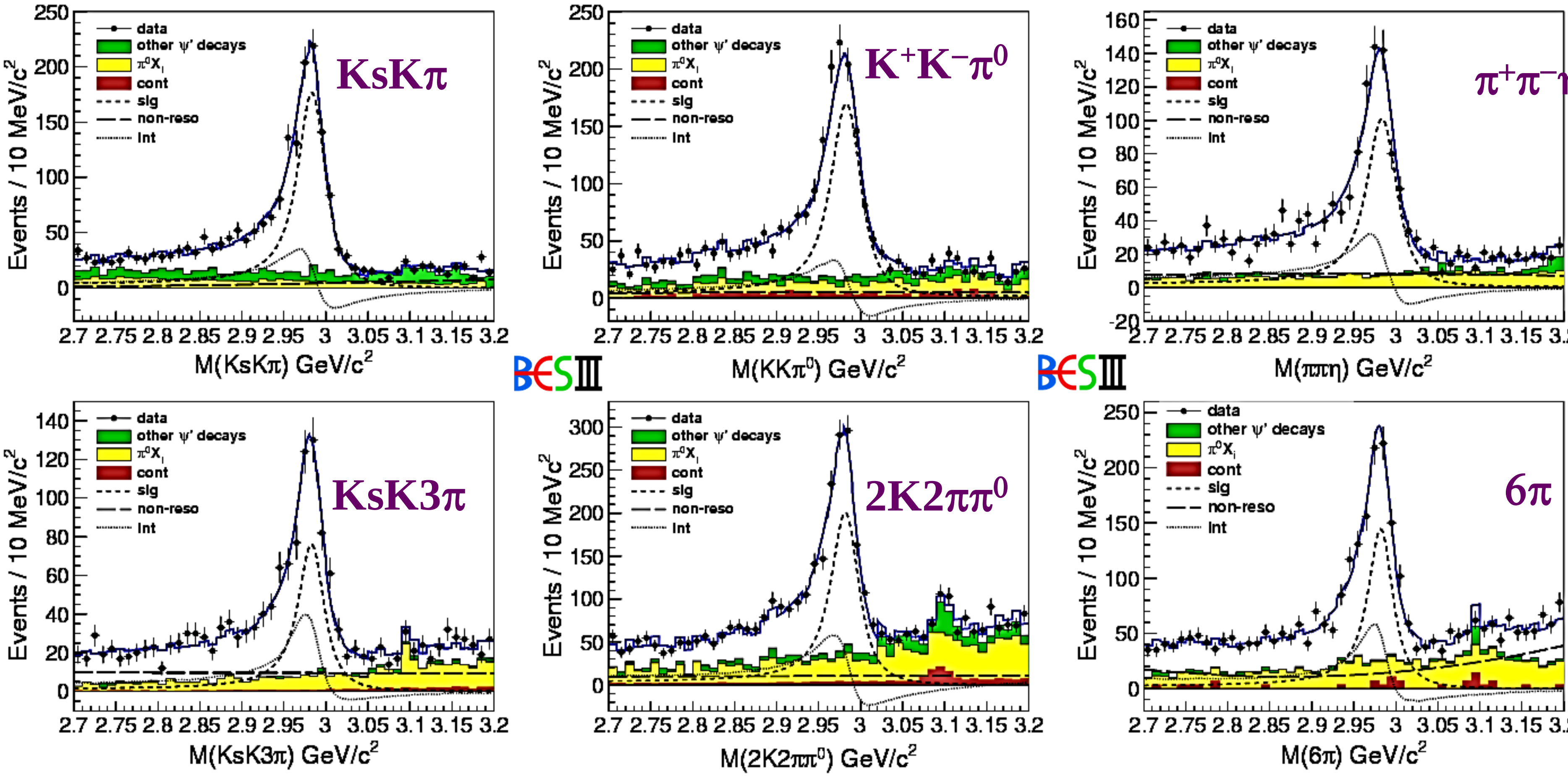
● **ψ(1S, 2S)→γη_c**





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

PRL 108, 222002 (2012)



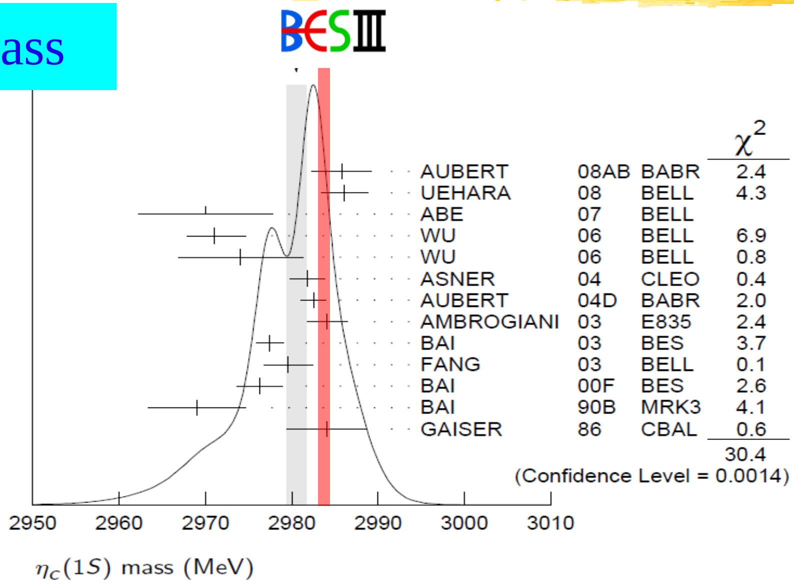
Significant interference between η_c and non-resonant

$\to$ simultaneous fit to 6 modes, **Mass = 2984.3±0.6±0.6 MeV/c^2**

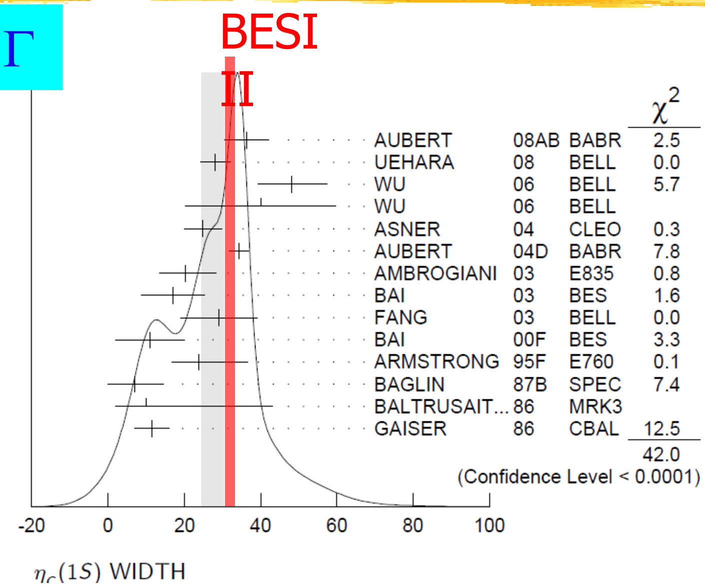
Γ = 32.0±1.2±1.0 MeV/c^2

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

Mass



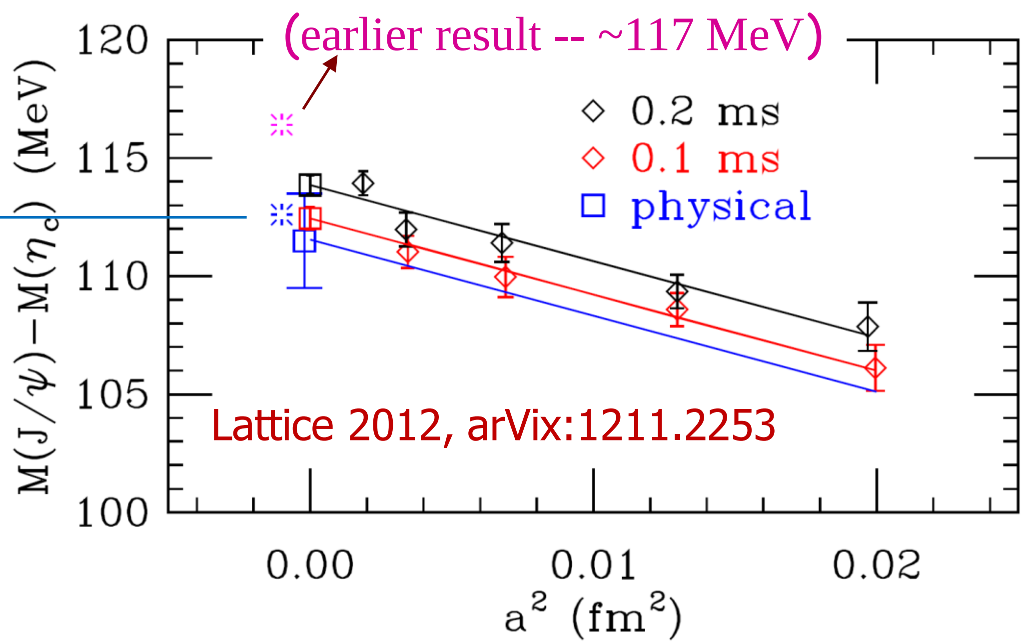
Γ



Hyperfine splitting (BESIII alone)

$\Delta M(1S)$ = 112.5±0.8 MeV/c^2

Closer to prediction then earlier result



$\eta_c(2S)$

Observed in different production mechanisms

1. $B \to K\eta_c'$
2. $\gamma\gamma \to \eta_c' \to KK\pi$
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 $\psi' \to \gamma\eta_c'$

1. CLEO found no signal in 25M ψ'.

   $\mathcal{B}(\psi' \to \gamma\eta_c') < 7.6 \times 10^{-4}$ PRD 81 052002 (2010)

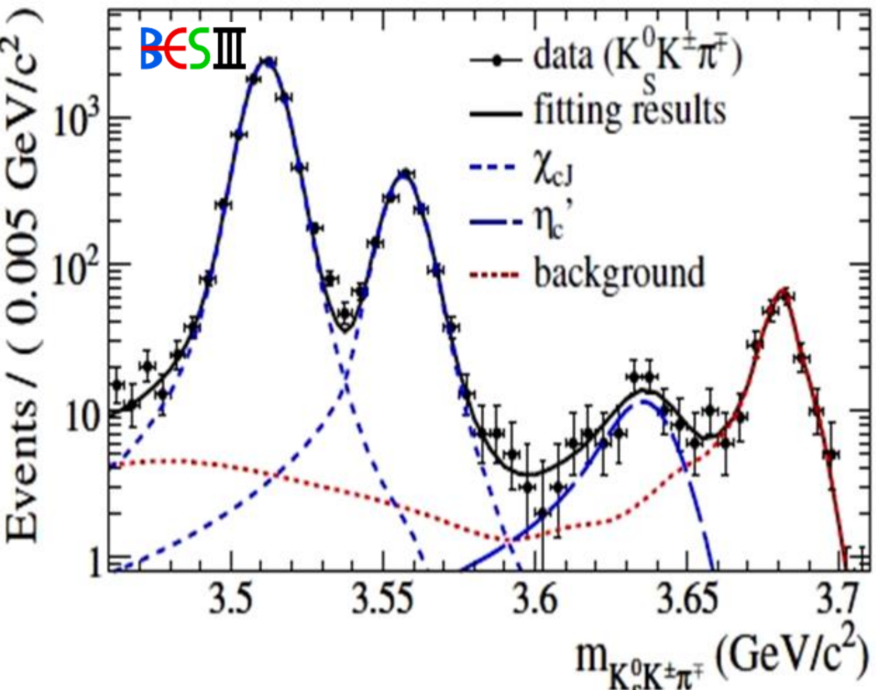
2. BESIII: first observation of $\eta_c' \to KK\pi$;

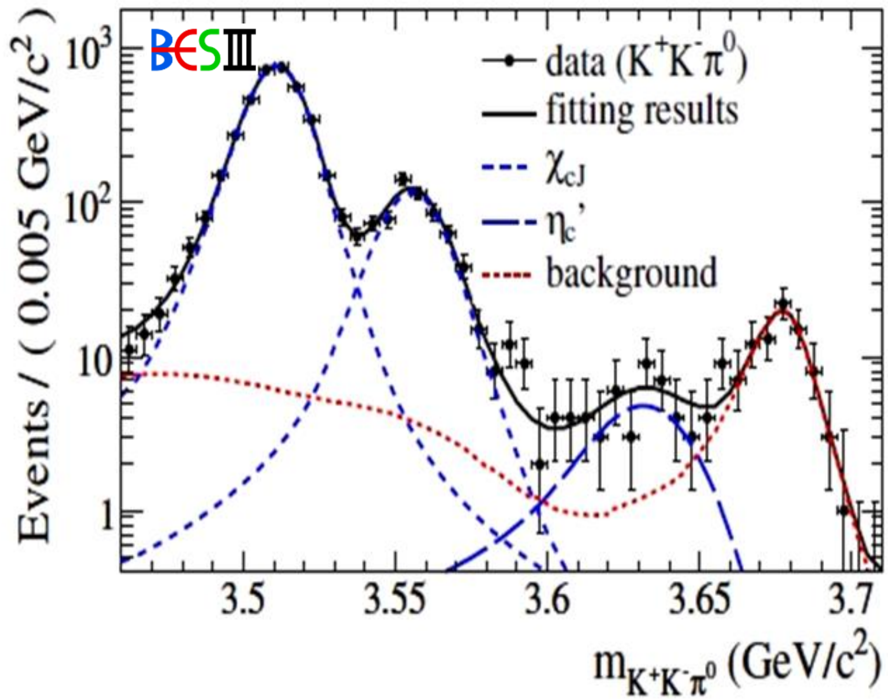
   find evidence in $\eta_c' \to K_sK3\pi$

Experimental challenge : search for photons of 50 MeV

BESIII: $\psi(2S) \to \gamma\eta_c(2S)$, $\eta_c(2S) \to KK\pi$

PRL 109, 042003





$M = 3637.6 \pm 2.9 \pm 1.6$ MeV/c^2 **$\Gamma = 16.9 \pm 6.4 \pm 4.8$ MeV/c^2**

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

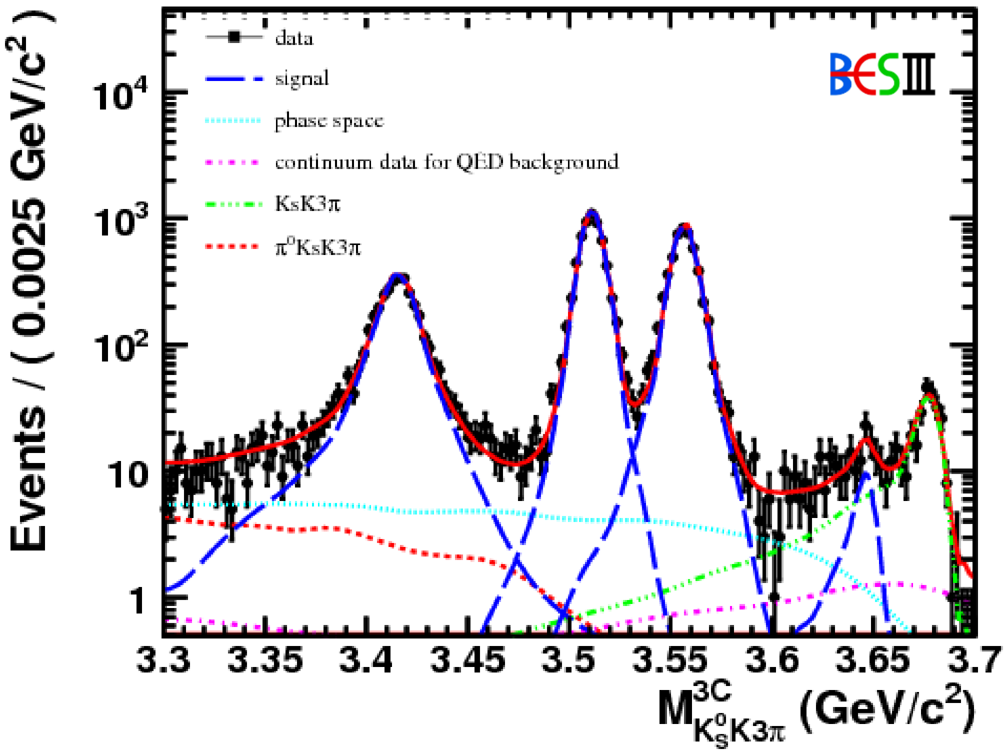
$\mathcal{B}(\eta_c' \to \gamma KK\pi) = (1.9 \pm 0.4 \pm 1.1)\%$ **BABAR: PRD78, 012006 (2008)**

$\mathcal{B}(\psi' \to \gamma\eta_c') = (6.8 \pm 1.1 \pm 4.5) \times 10^{-4}$ **FIRST OBSERVATION!**

Potential model: $(0.1\text{-}6.2) \times 10^{-4}$ PRL89, 162002(2002)

CLEOc: $< 7.6 \times 10^{-4}$ PRD81, 052002 (2010)

BESIII: $\psi(2S) \to \gamma\eta_c(2S)$, $\eta_c(2S) \to K_sK3\pi$ PRD 87, 052005



Significance

4.2 σ

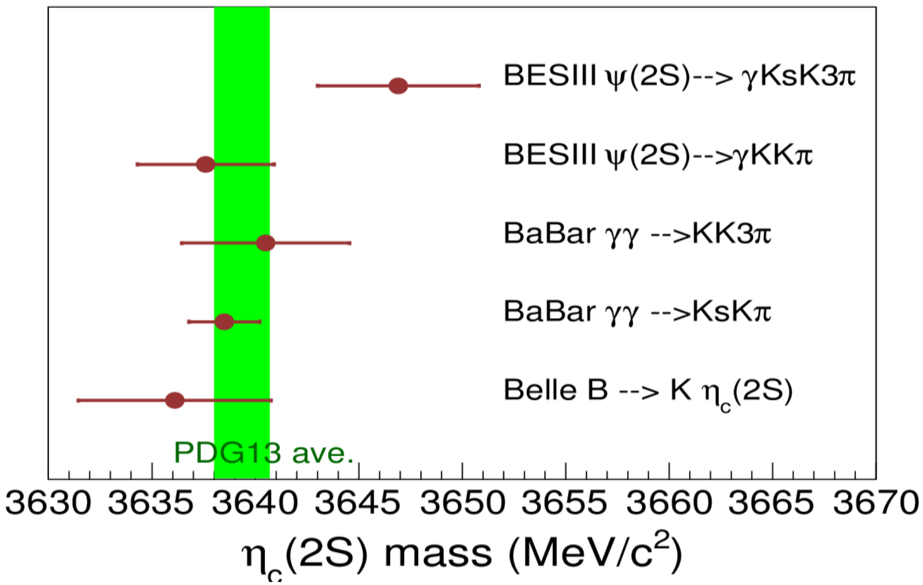
$$M = 3646.9 \pm 1.6 \pm 3.6 \ \mathrm{MeV}/c^2$$

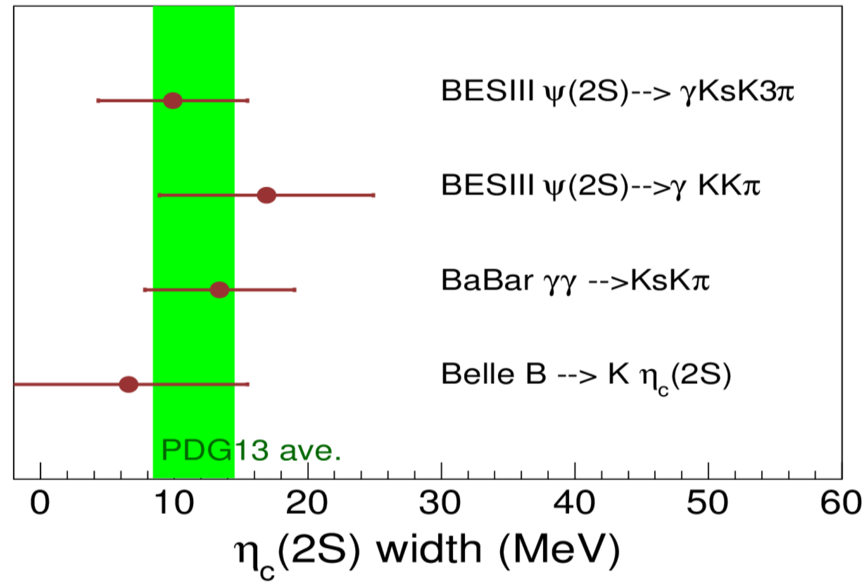
$$\Gamma = 9.2 \pm 4.8 \pm 2.9 \ \mathrm{MeV}/c^2$$

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

η_c(2S): BESIII vs literature

PRL 109, 042003
PRD 87, 052005





$h_c(1P)$

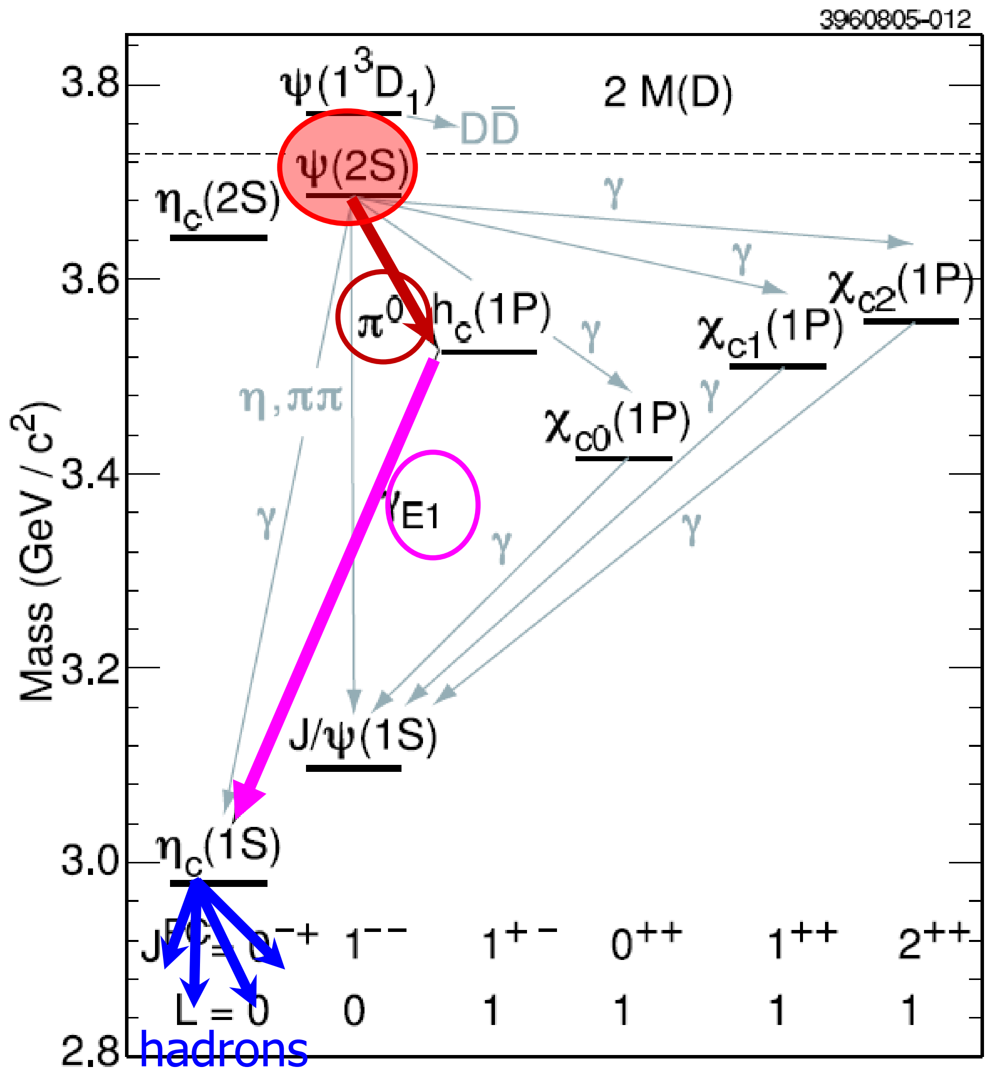
- **Spin singlet P wave (S=0, L=1)**
- Potential model: if non-vanishing P-wave spin-spin interaction, $\Delta M_{hf}(1P) = M(h_c) - \langle M(1\,^3P_J)\rangle \neq 0$,

$$\langle M(1\,^3P_J)\rangle = [M(\chi_{c0}) + 3M(\chi_{c1}) + 5M(\chi_{c2})]/9$$

- **Theoretical predictions:**
  - $\mathcal{B}(\psi' \to \pi^0 h_c) = (0.4\text{-}1.3)\times 10^{-3}$, $\mathcal{B}(h_c \to \gamma\eta_c) = 41\%$ (NRQCD)
    $\mathcal{B}(h_c \to \gamma\eta_c) = 88\%$ (PQCD)
    Y. P. Kuang, PR D65, 094024 (2002)
  - $\mathcal{B}(h_c \to \gamma\eta_c) = 38\%$ Godfrey and Rosner, PR D66, 014012 (2002)
- First reported by E760 in decay $pp \to h_c \to J/\psi\pi^0$, not confirmed
  Evidence found by E835 in $pp \to h_c \to \gamma\eta_c$ PR D72 032001 (2005)
- Observed by CLEO in $\psi' \to \pi^0 h_c$, $h_c \to \gamma\eta_c$ PRL 95 102003 (2005)
- **Recent results from BESIII**

BESIII: $\psi(2S) \to \pi^0 h_c(1P)$, $h_c(1P) \to \gamma\eta_c(1S)$

PRL 104, 132002



"inclusive"

only detect the π^0

(compute $M(h_c)$ from kinematic)

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

"*E1* tagged"

detect the π^0 & γ

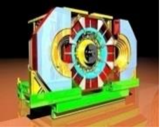
Rate $\propto \mathcal{B}(\psi' \to \pi^0 h_c) \times \mathcal{B}(h_c \to \gamma\eta_c)$

"exclusive"

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

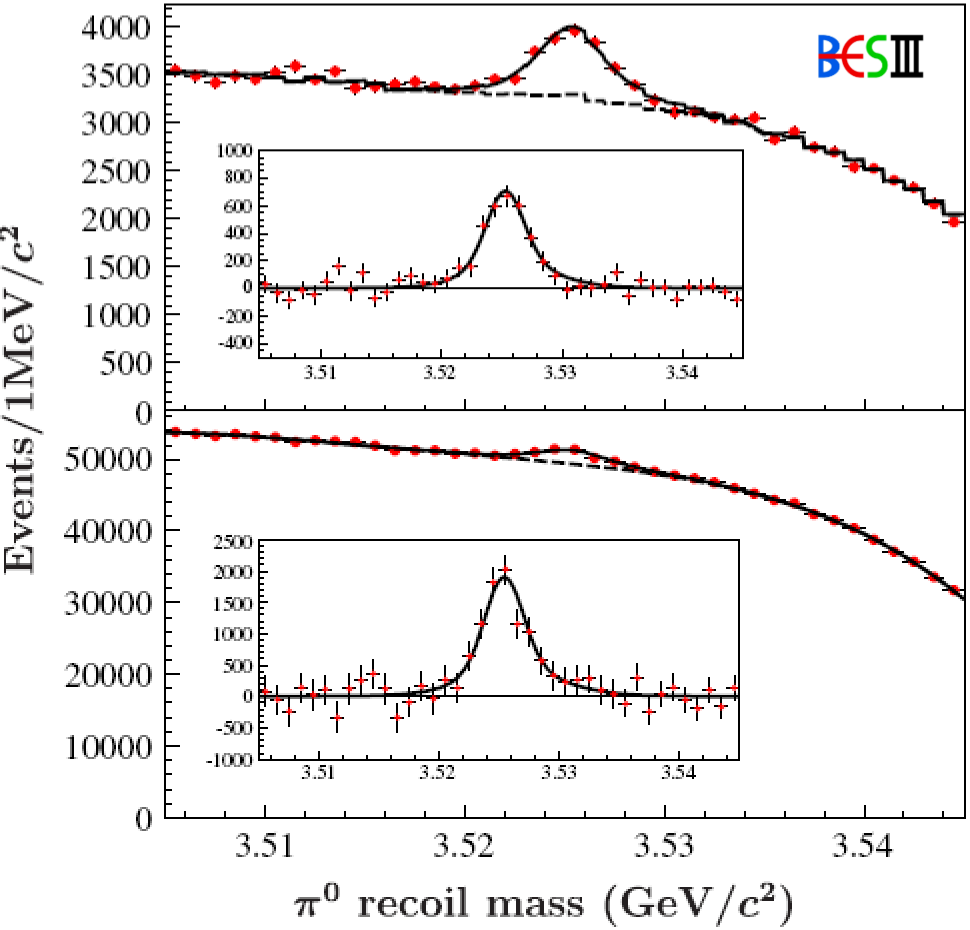
Rate $\propto$

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



BESIII: $\psi(2S) \to \pi^0 h_c(1P)$, $h_c(1P) \to \gamma\eta_c(1S)$

PRL 104, 132002



M = **3525.40±0.13±0.18 MeV/c^2**

Γ = **0.73±0.45±0.28 MeV/c^2**

<1.44 MeV @90%

CLEOc: PRL 101 182003 (2008)

M = **3525.28±0.19±0.12** MeV/c^2

Γ : fixed at 0.9 MeV

Hyperfine mass splitting

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

BESIII: **0.10±0.13±0.18** MeV/c^2

CLEOc: **0.02±0.19±0.13 MeV/c^2**

By combining inclusive results with E1-photon tagged results

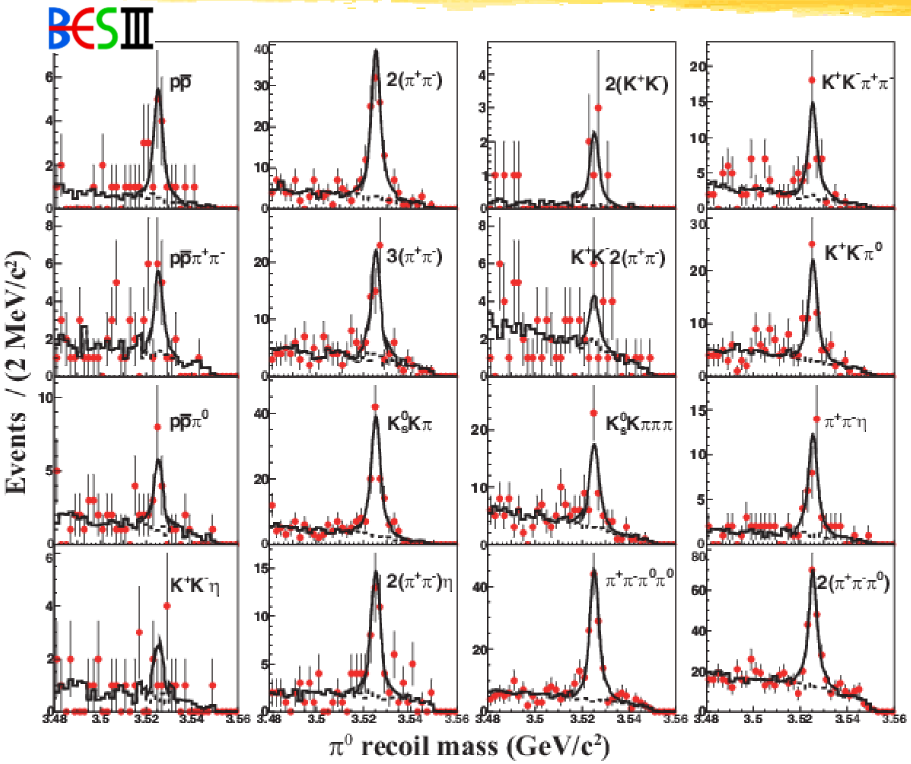
$\mathcal{B}(\psi' \to \pi^0 h_c) =$ **(8.4±1.3±1.0)×10^{-4}**

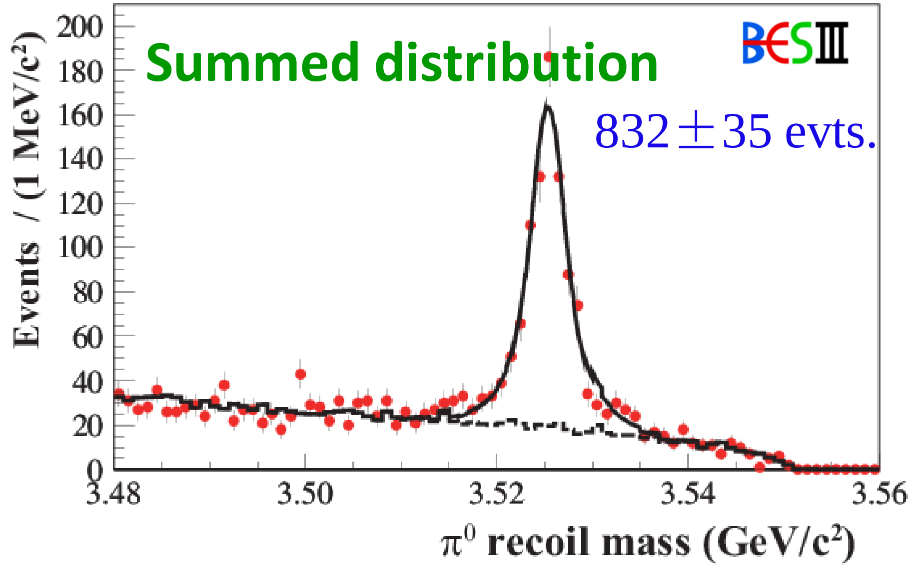
$\mathcal{B}(h_c \to \gamma\, \eta_c) =$ **(54.3±6.7±5.2)%**

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

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

PRD 86, 092009



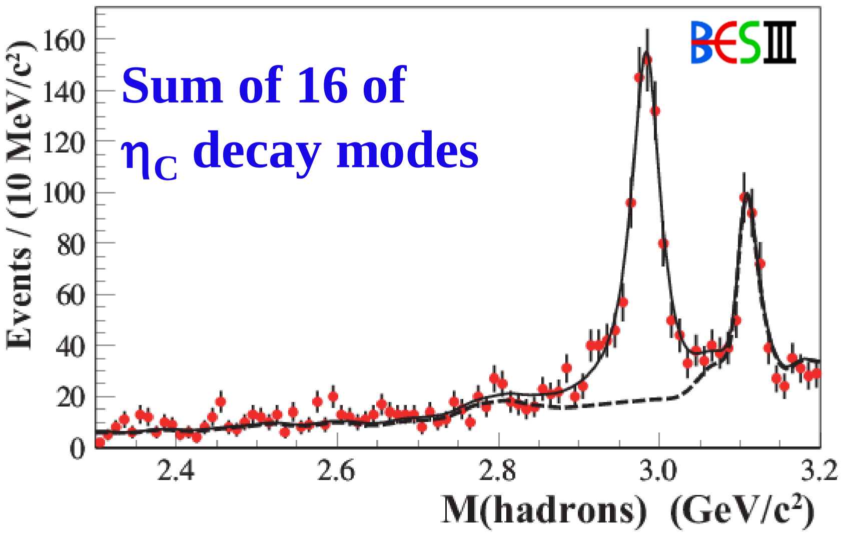


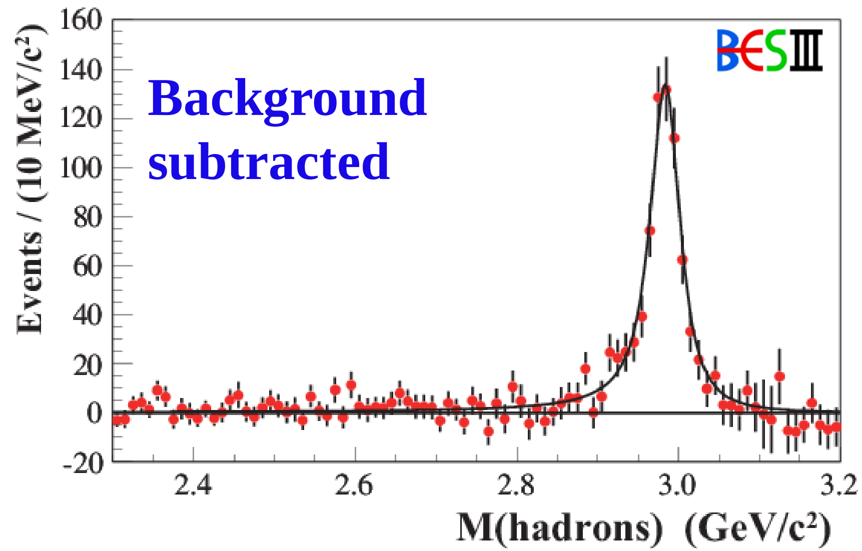
(MeV/c^2)	BESIII Exclusive	BESIII Inclusive	CLEO
M	3525.31±0.11±0.14	3525.40±0.13±0.18	3525.21±0.27±0.14
Γ	0.70±0.28±0.22	0.73±0.45±0.28	--
$\Delta M_{hf}(1P)$	-0.01±0.11± 0.15	0.10±0.13±0.18	0.08± 0.18± 0.12

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

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

PRD 86, 092009





η_c lineshape in $h_c \to \gamma\eta_c$ is **not as distorted** as in $\psi' \to \gamma\eta_c$ decays:

$\Rightarrow$ non-resonant interfering background is smaller than $\psi' \to \gamma h_c$

$\Rightarrow$ this channel best suited to determine η_c resonance parameters

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

M = 2984.49±1.16±0.52 MeV/c²

Γ = 36.4±3.2±1.7 MeV

$\psi' \to \gamma\eta_c$

PRL 108, 222002

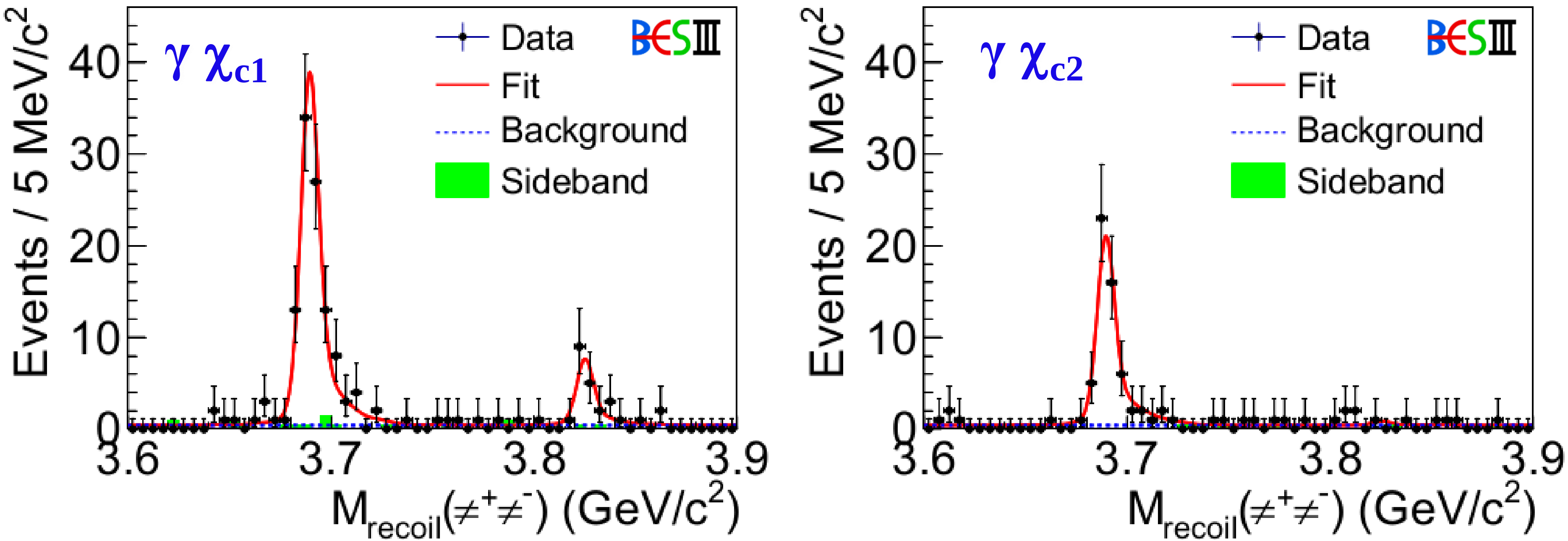
M = 2984.3±0.6±0.6 MeV/c²

Γ = 32.0±1.2±1.0 MeV

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

BESIII: $e^+e^- \to \pi^+\pi^- X(3823) \to \pi^+\pi^-\gamma\ \chi_{c1}$

PRL 115, 011803



- simultaneous fit to two data set at differente center of mass energies
- consistent with Belle data
- good candidate for $\psi(1^3D_2)$

M = (3821.7±1.3±0.7) MeV/c^2
Γ = < 16 MeV/c^2 at 90% C.L.
6.2σ

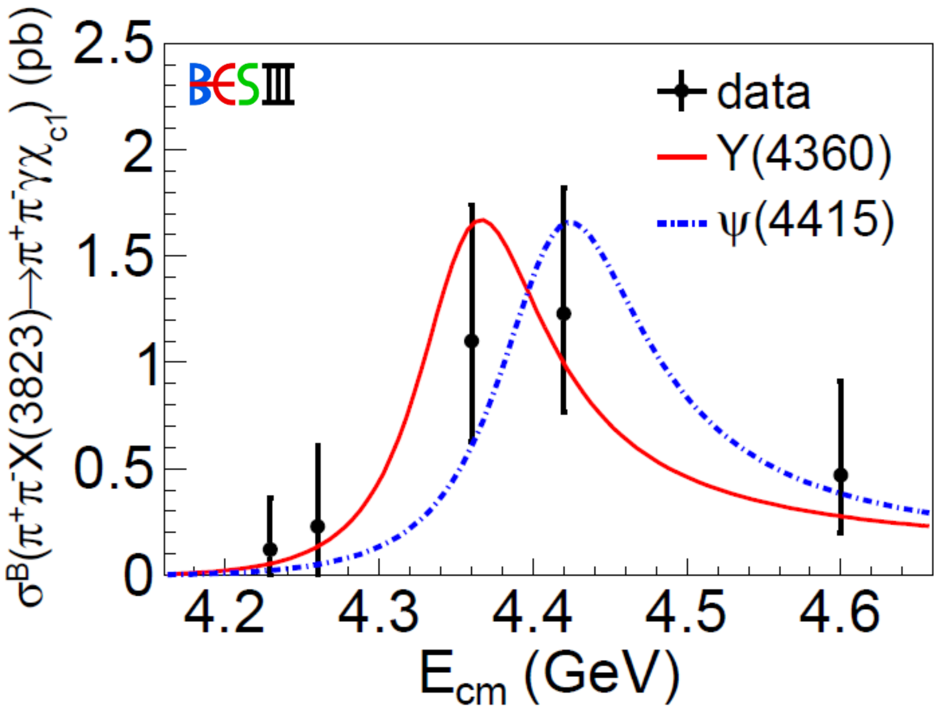
BESIII: $e^+e^- \to \pi^+\pi^- X(3823) \to \pi^+\pi^-\gamma\,\chi_{c1}$

PRL 115, 011803

$$R = \frac{\sigma[e^+e^-\to\pi^+\pi^- X(3823)]\cdot\mathcal{B}(X(3823)\to\gamma\chi_{c1})}{\sigma[e^+e^-\to\pi^+\pi^-\psi']\cdot\mathcal{B}(\psi'\to\gamma\chi_{c1})}$$

$= 0.20^{+0.13}_{-0.10}$ (4.36 GeV)

$= 0.39^{+0.21}_{-0.17}$ (4.42 GeV)



Mass and width in agreement with potential model

Production ratio:

$$R_{12} = \frac{\mathcal{B}(X(3823)\to\gamma\chi_{c2})}{\mathcal{B}(X(3823)\to\gamma\chi_{c1})}$$

< 0.42 at 90% C.L.

~ 0.24 [PRD 55, 4001]

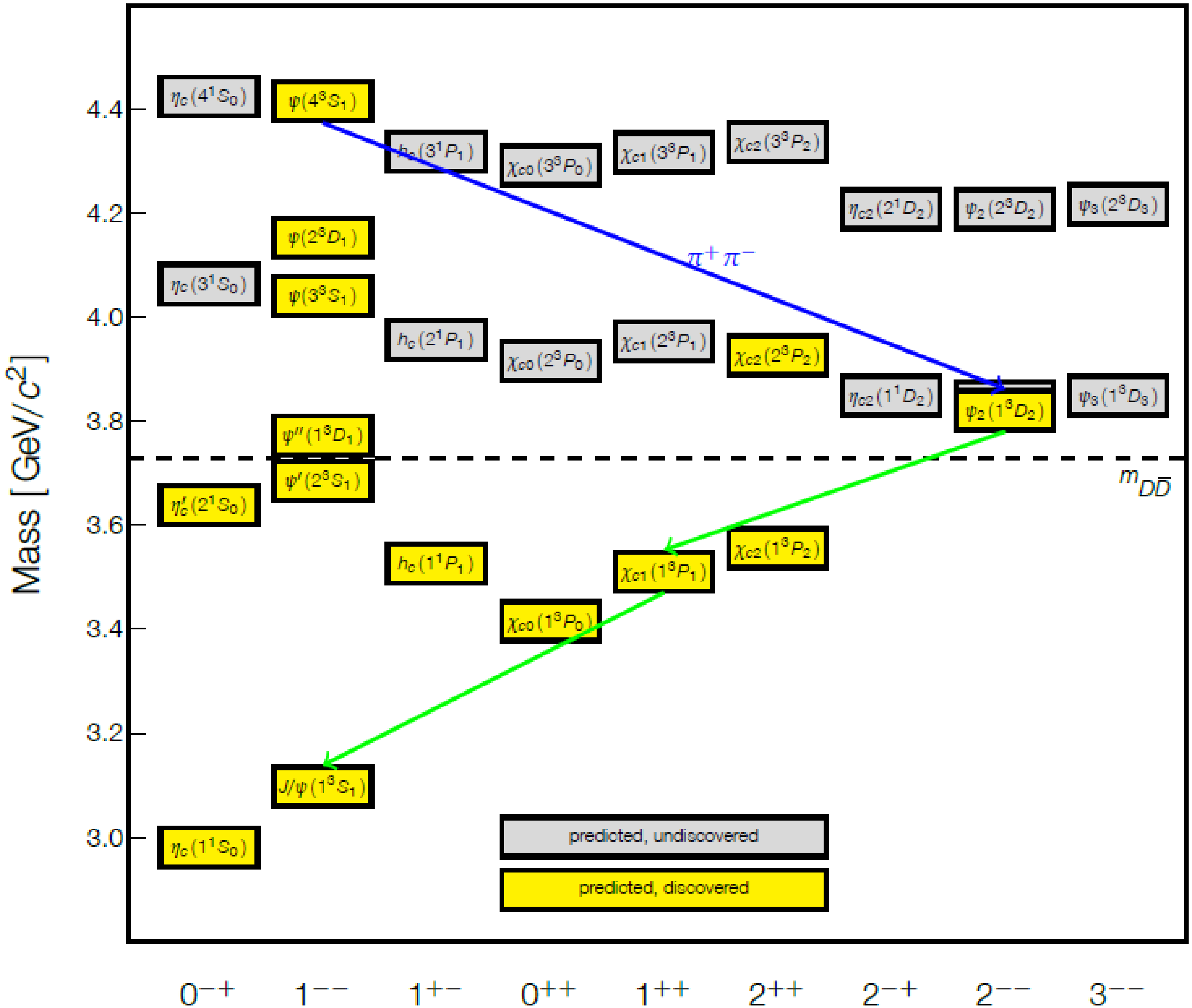
- compatible with both lineshapes!
- statistics does not allow to resolve S from expected D wave

Exclusions:

- $1^1D_2 \to \gamma\,\chi_{c1}$ forbidden
- $1^3D_3 \to \gamma\,\chi_{c1}$ has 0 amplitude

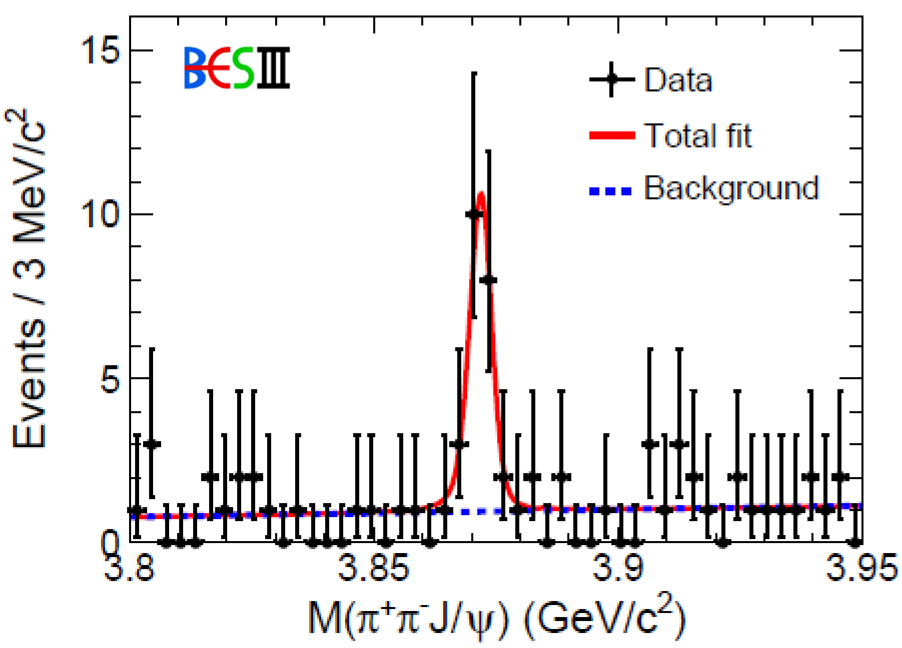
compatible with $\psi(1^3D_2)$

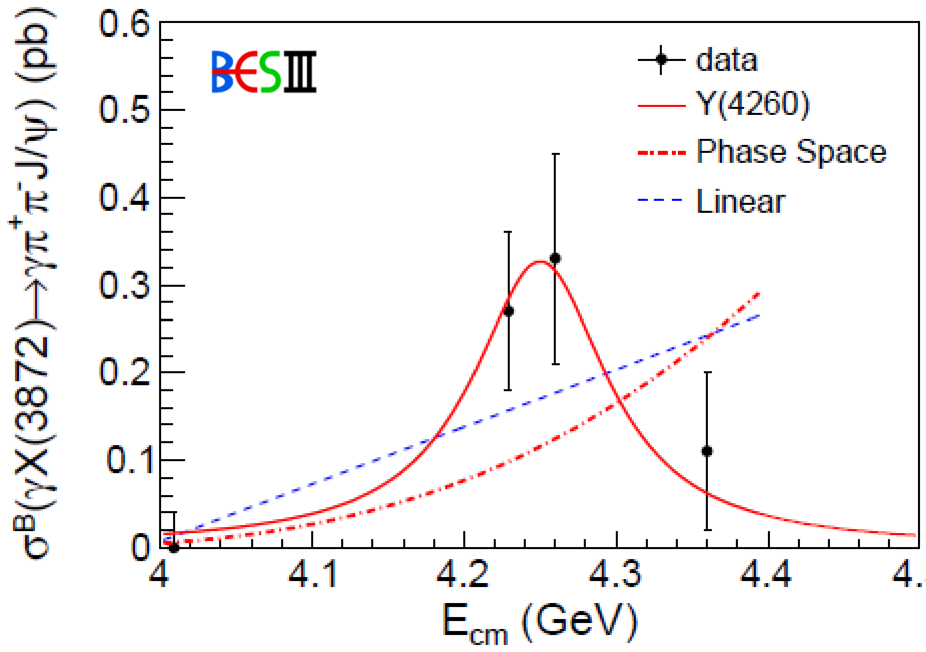
Higher Charmonium states: a new family member?



BESIII: $e^+e^- \rightarrow \gamma X(3872) \rightarrow \gamma\pi^+\pi^- J/\psi$

PRL 112, 092001





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

$\mu_{\psi(3686)}$ = - (0.34±0.04) MeV/c^2; σ_M= (1.14±0.07) MeV

N(X(3872)) = 20.1±4.5

M = (3871.9±0.7±0.2) MeV/c^2

Γ = <2.4 MeV/c^2 with 90% CL

6.3σ

[PDG: 3871.68±0.17 MeV]

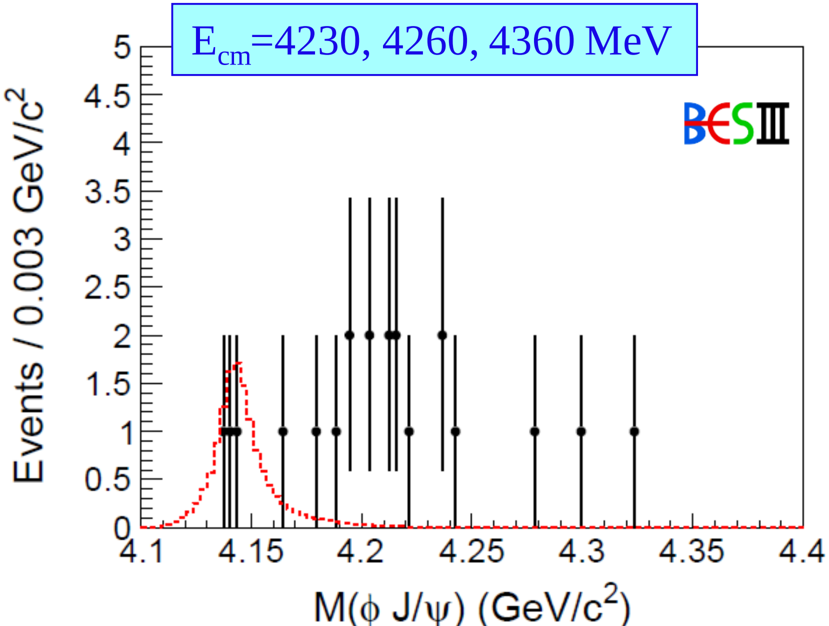
Could be a Y(4260) → γX(3872)!

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

BESIII: $e^+e^- \to \gamma\phi J/\psi$ ($J/\psi \to \mu^+\mu^-, e^+e^-$)

PRD 91, 032002

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



No evidence of Y(4140)

UP @ 90% C.L. for

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

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 uncertainties

Assuming:

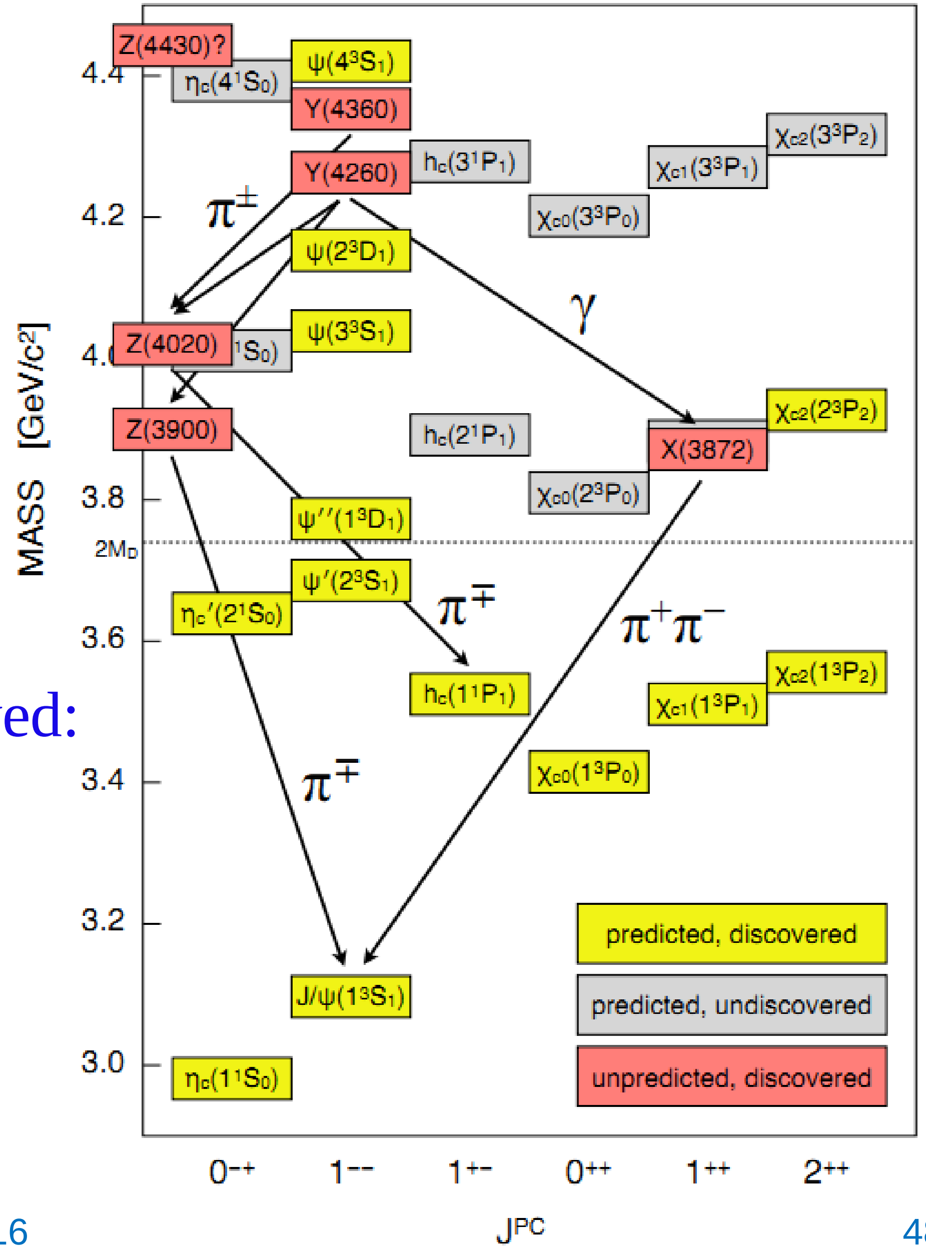
- $\sigma^B(e^+e^- \to \gamma X(3872)) \cdot B(X(3872) \to \pi^+\pi^- J/\psi)$ [1]:
  - E_{cm}=4230 MeV: **0.27 ± 0.09 (stat.) ± 0.02 (syst.) pb**
  - E_{cm}=4260 MeV: **0.33 ± 0.12 (stat.) ± 0.02 (syst.) pb**
- $B(X(3872) \to \pi^+\pi^- J/\psi) = 5\%$ [2]
- $B(Y(4140) \to \phi J/\psi) = 30\%$ [3]

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

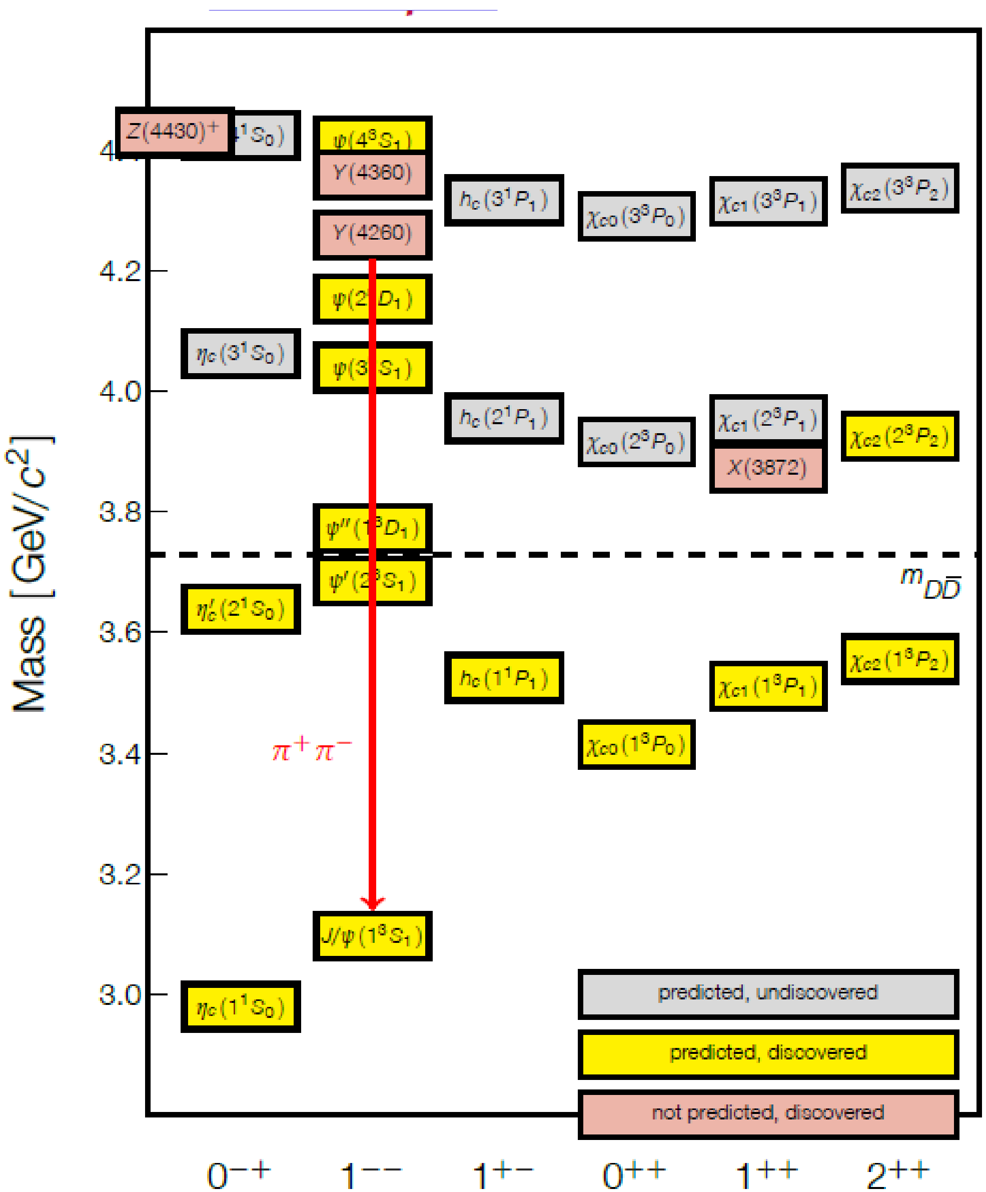
[1] PRL 112, 092001
[2] arXiv:0910.3138
[3] PR D80, 054019

Exotic at BESIII

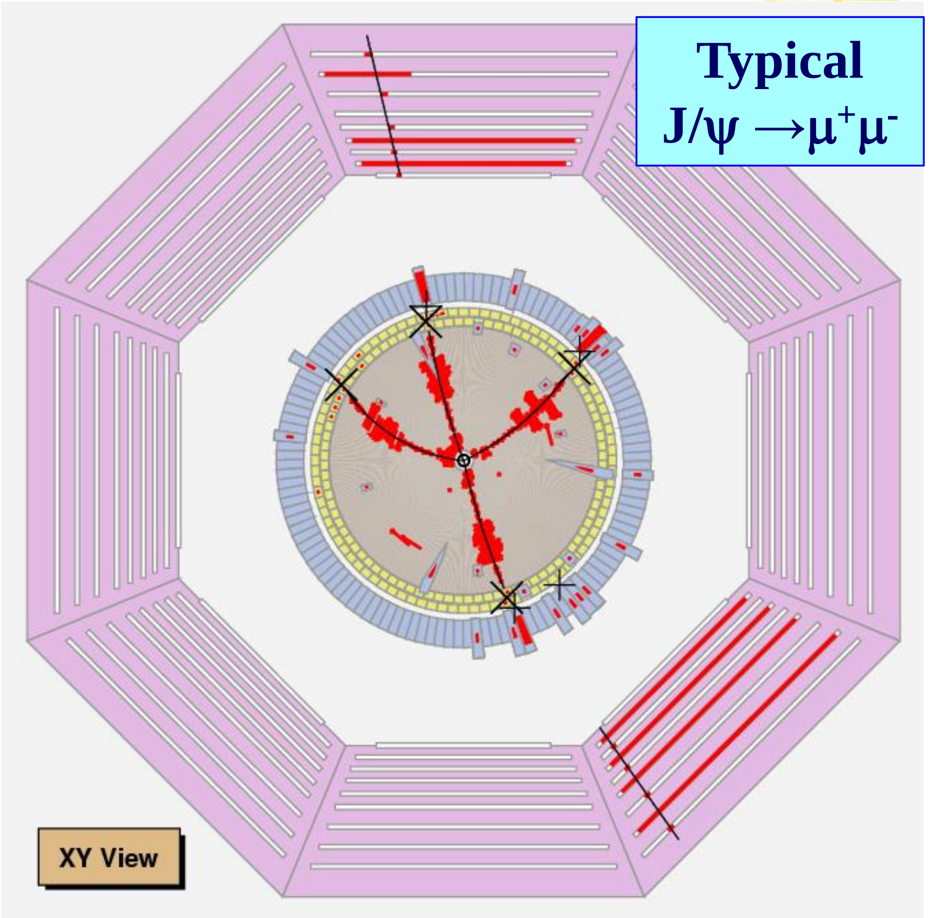
- all states below DD threshold have been observed and described by charm anti-charm potential model
- only a few of the predicted states above threshold have been found
- many new states have been observed:
  - some unexpected
  - many with properties not consistent with charmonium decays to X,Y or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

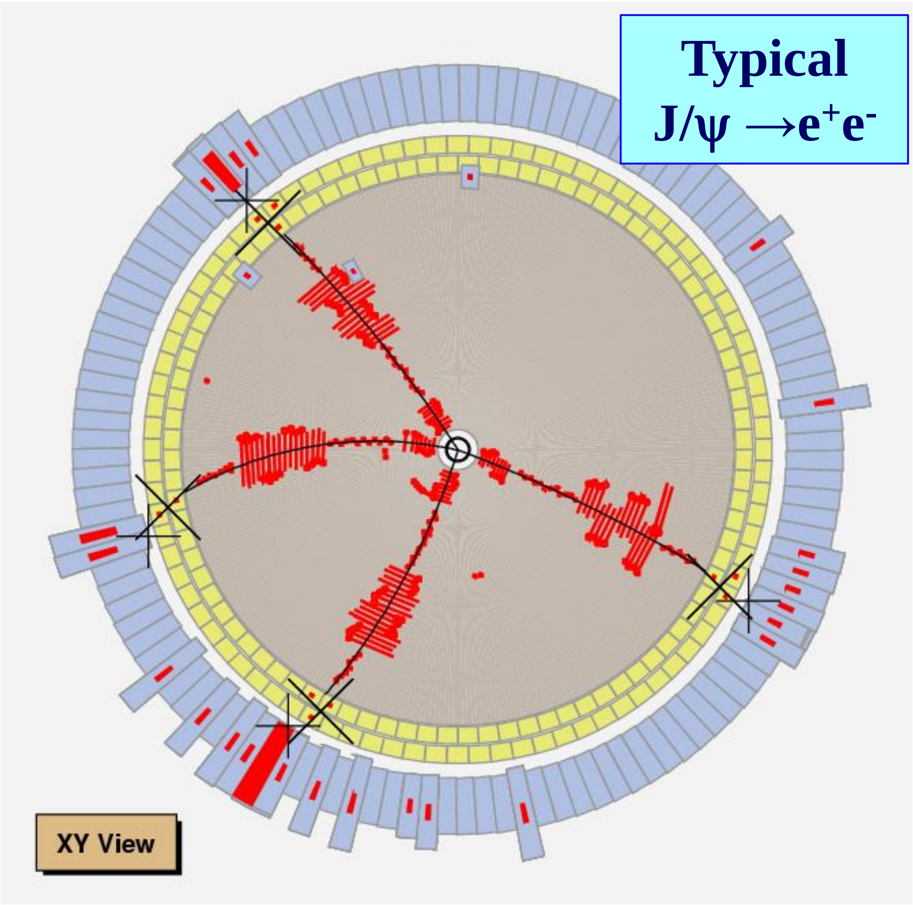


BESIII: $e^+e^- \rightarrow \pi^+\pi^- J/\psi$ events



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

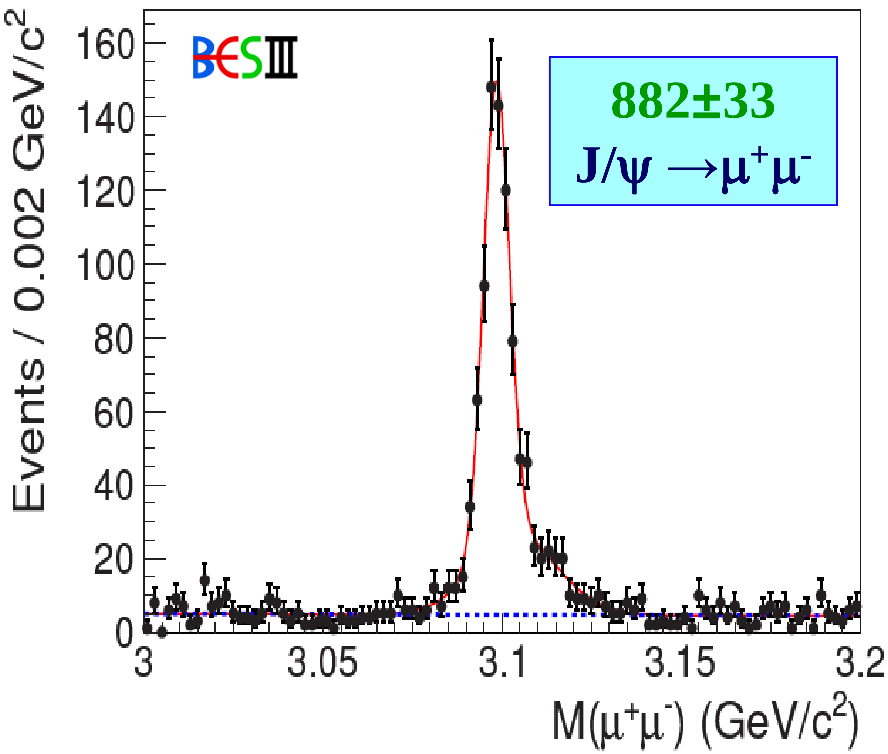


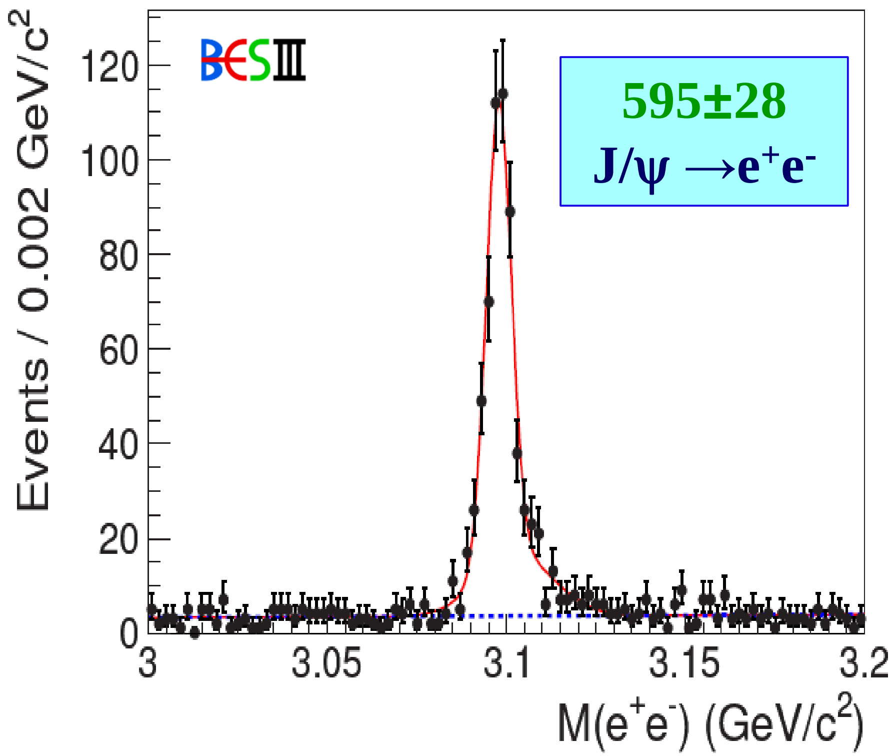


- 4 charged tracks, J/ψ reconstruct via lepton pairs
- very clean sample, very high efficiency, kinematic fit used
- only use MDC & EMC information, MC simulation reliable

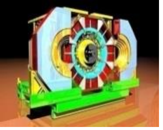
BESIII: $e^+e^- \to \pi^+\pi^- J/\psi$ – J/ψ signals @ 4.260 GeV

PRL 110, 252001





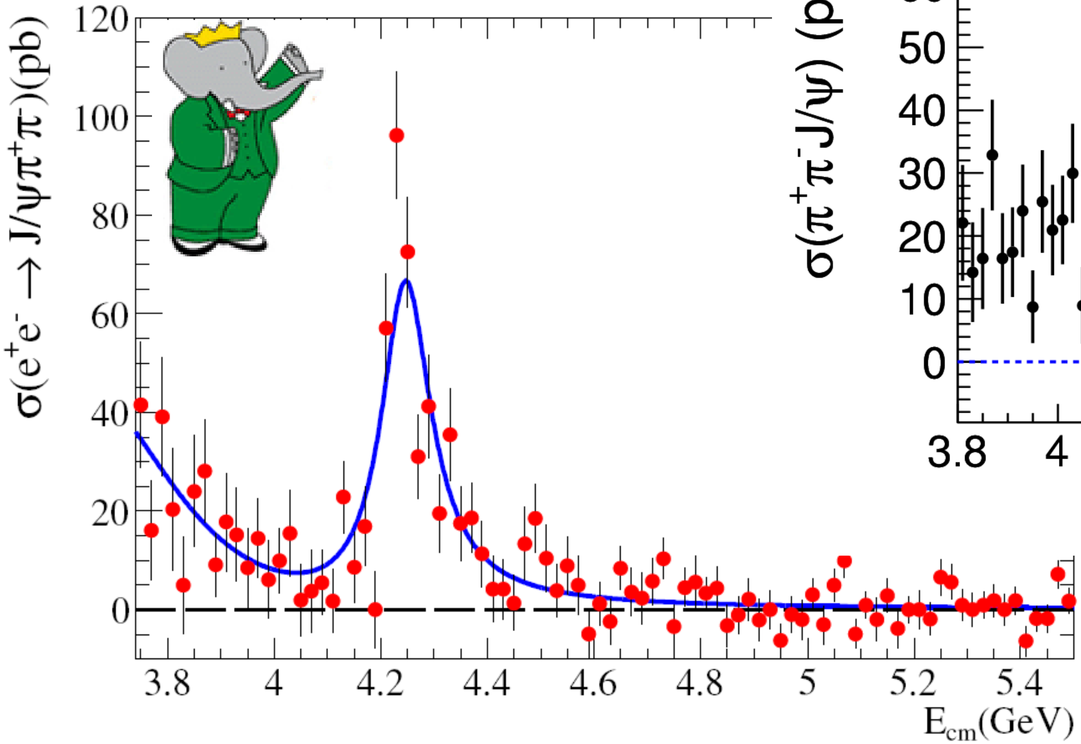
- Dominant background $e^+e^- \to \pi^+\pi^-\pi^+\pi^-$
- J/ψ signal: [3.08,3.12] GeV
- J/ψ sideband: [3.0,3.06] GeV or [3.14,3.20] GeV

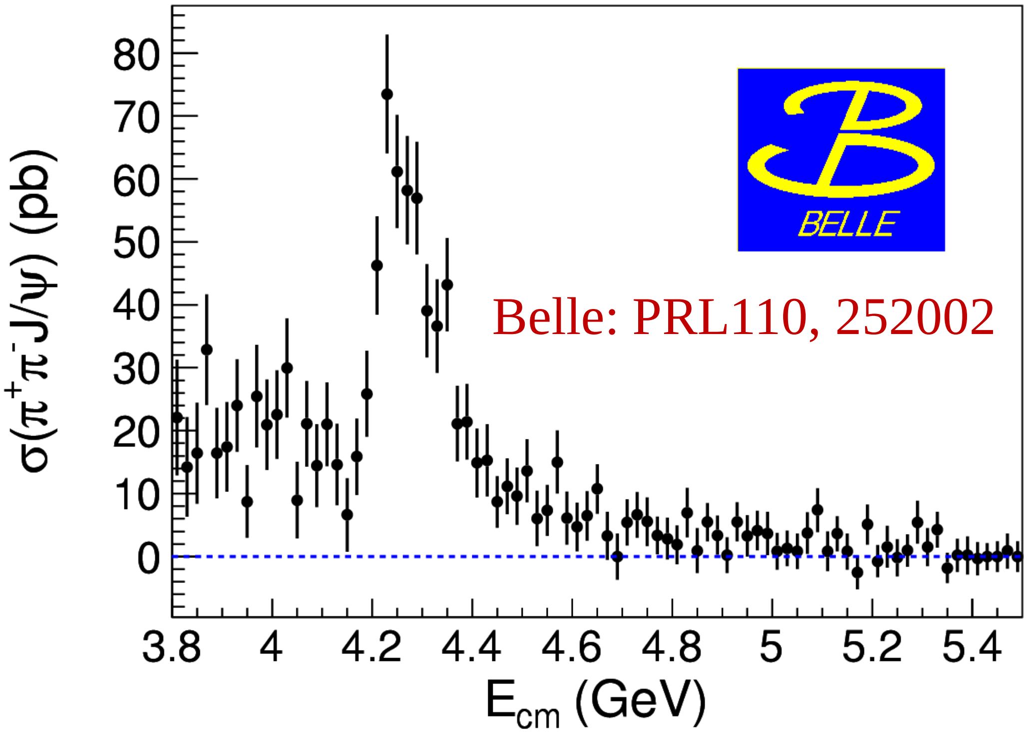


$e^+e^- \to \pi^+\pi^- J/\psi$ – cross sections @ 4.260 GeV

PRL 110, 252001

BaBar: PRD86, 051102 (2012)





Belle: PRL110, 252002

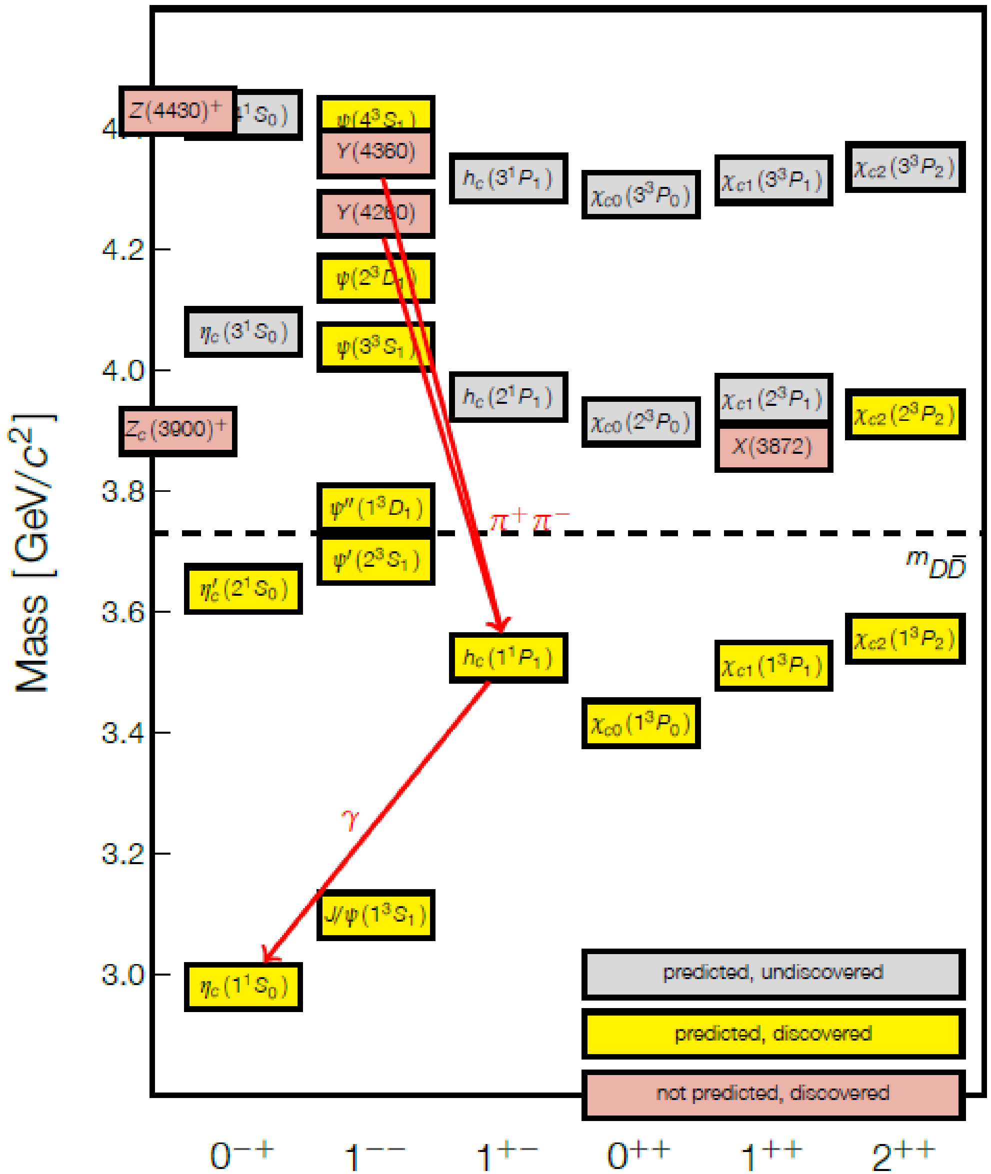
BESIII cross sections:

- more energy points
- more data!

BESIII: $\sigma_B(e^+e^- \to \pi^+\pi^- J/\psi)$ = **(62.9±1.9±3.7) pb**

- agreement with BaBar & Belle
- best precision!

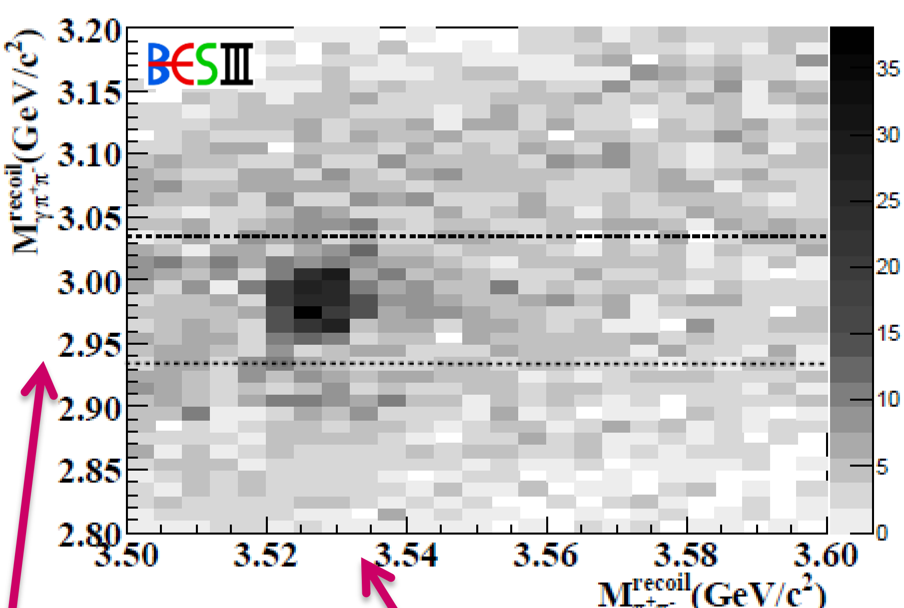
BESIII: $e^+e^- \to \pi^+\pi^- h_c(1P)$ events

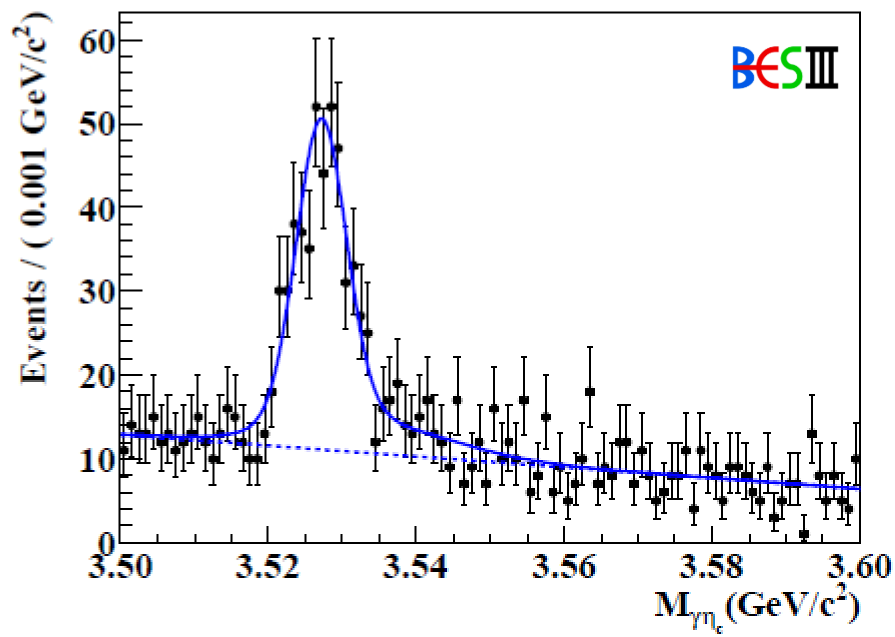


BESIII: $e^+e^- \to \pi^+\pi^- h_c(1P)$ @ 4.260 GeV

PRL 111, 242001

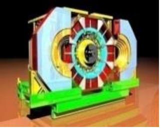
- **$h_c \to \gamma\eta_c$, $\eta_c \to$ hadrons [16 exclusive decay modes]**
  - $p\bar{p}$, $\pi^+\pi^-K^+K^-$, $\pi^+\pi^-p\bar{p}$, $2(K^+K^-)$, $2(\pi^+\pi^-)$, $3(\pi^+\pi^-)$
  - $2(\pi^+\pi^-)K^+K^-$, $K_S^0K^+\pi^-$+c.c., $K_S^0K^+\pi^-\pi^+\pi^-$+c.c., $K^+K^-\pi^0$
  - $p\bar{p}\pi^0$, $K^+K^-\eta$,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





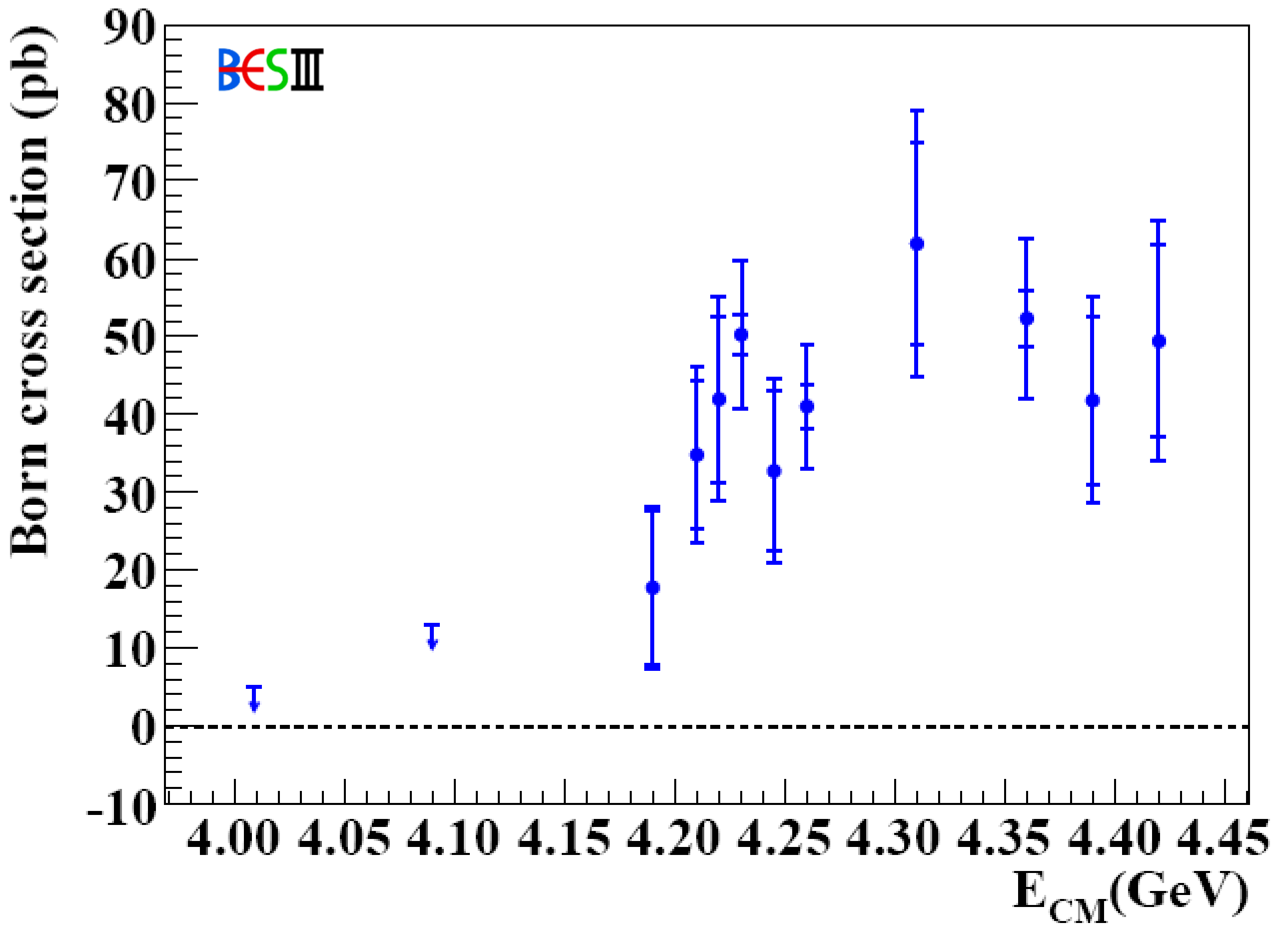
η_c candidate

h_c candidate

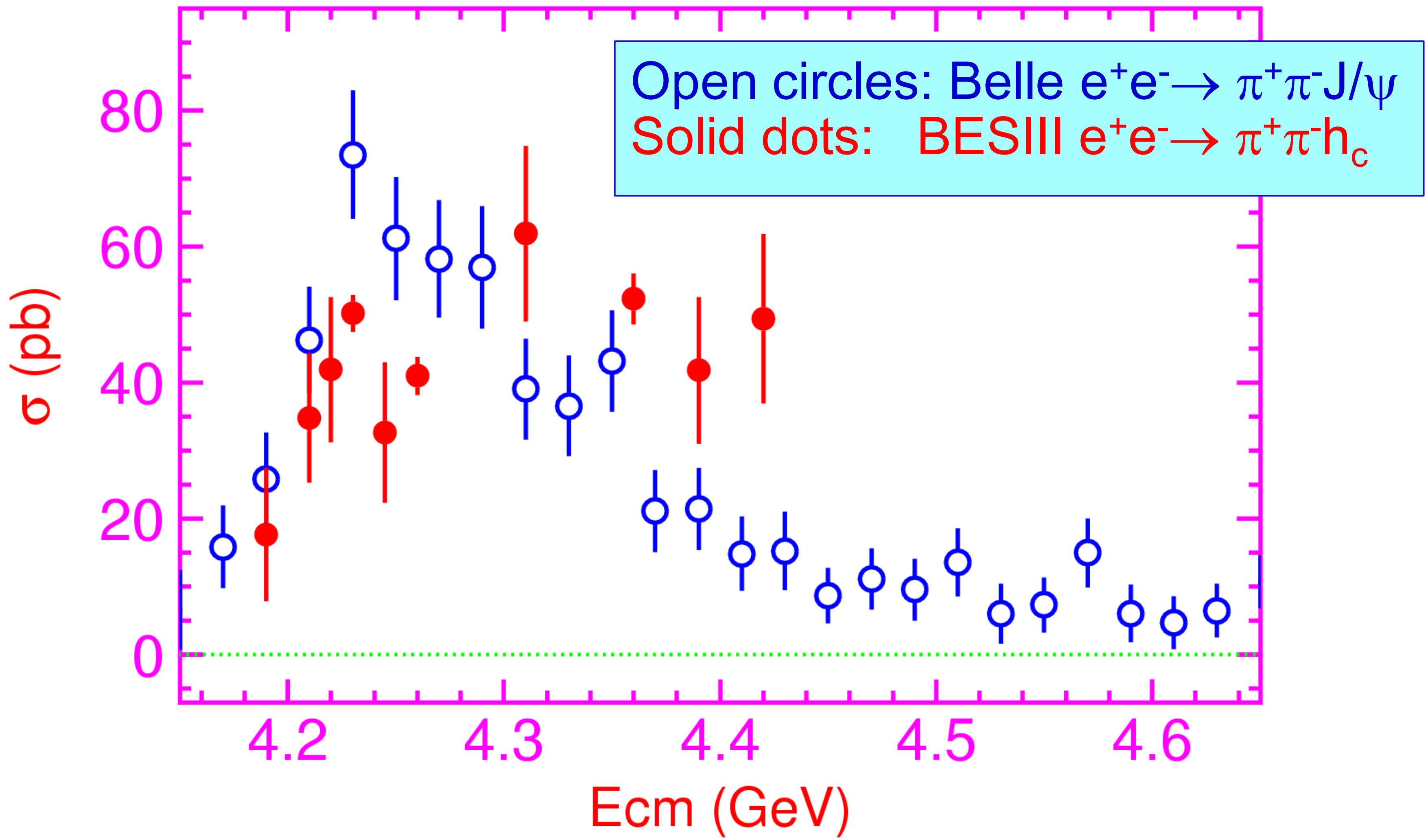


BESIII: $e^+e^- \to \pi^+\pi^- h_c(1P)$

PRL 111, 242001



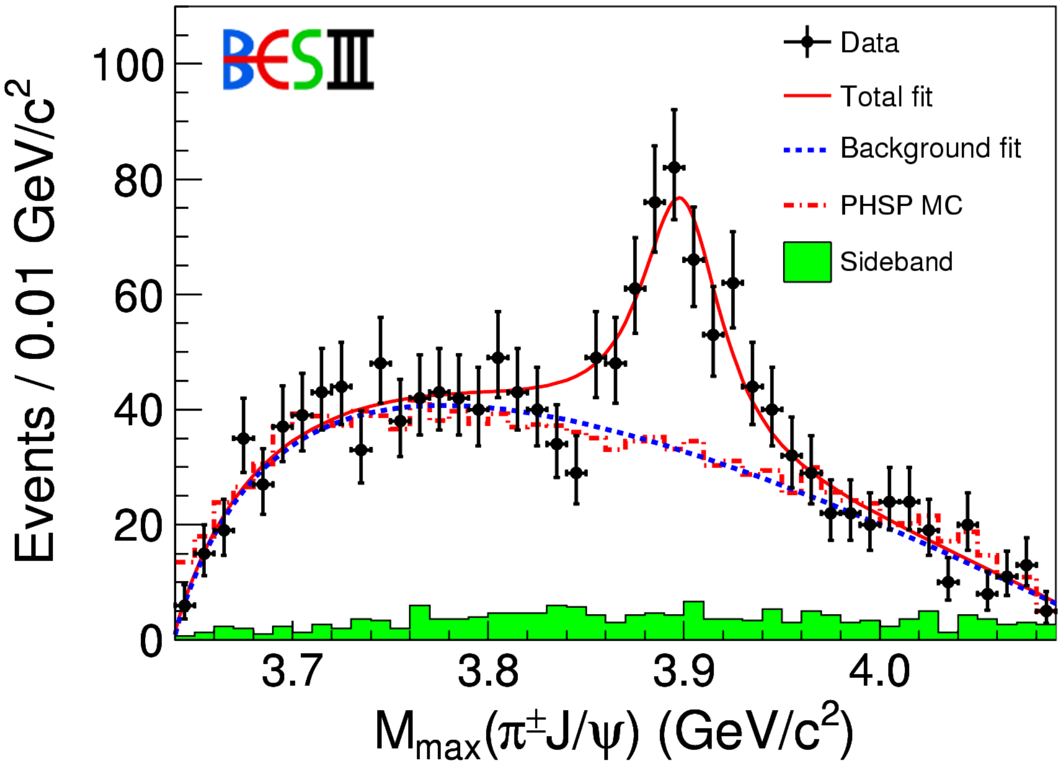
- $\sigma(e^+e^- \to \pi^+\pi^- h_c) \sim \sigma(e^+e^- \to \pi^+\pi^- J/\psi)$ **but line shape different**
- **Local maximum ~ 4.23 GeV**



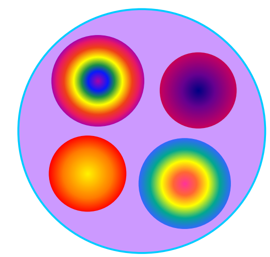
More data at higher energies needed to complete line shape measurement

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

PRL 110, 252001



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



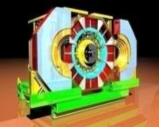
S-wave Breit-Wigner with efficiency correction

M = (3899.0±3.6±4.9) MeV/c^2

Γ = (46±10±20) MeV/c^2

R = (21.5±3.3±7.5)%

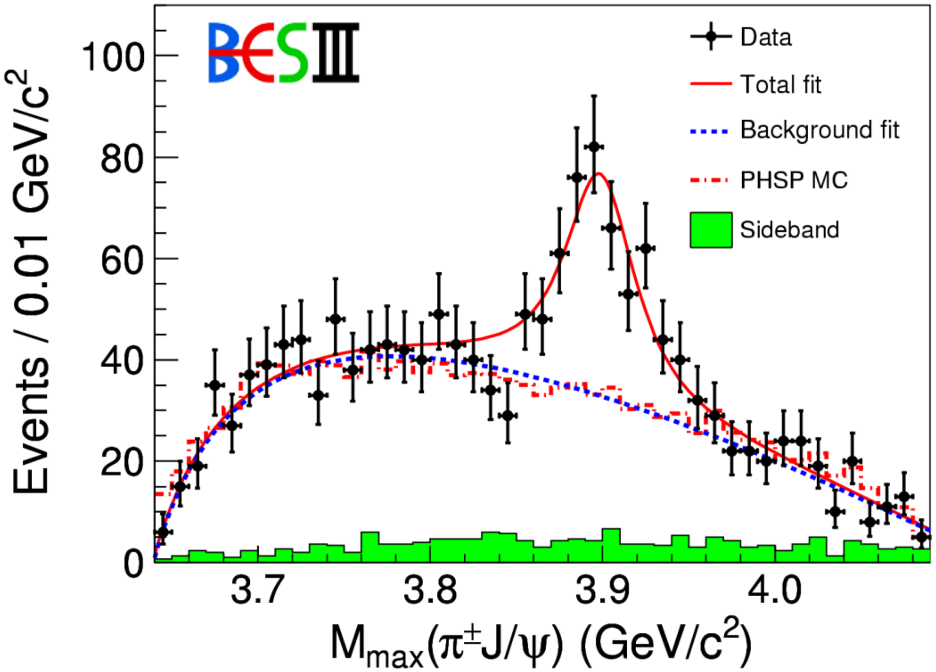
Significance >8σ



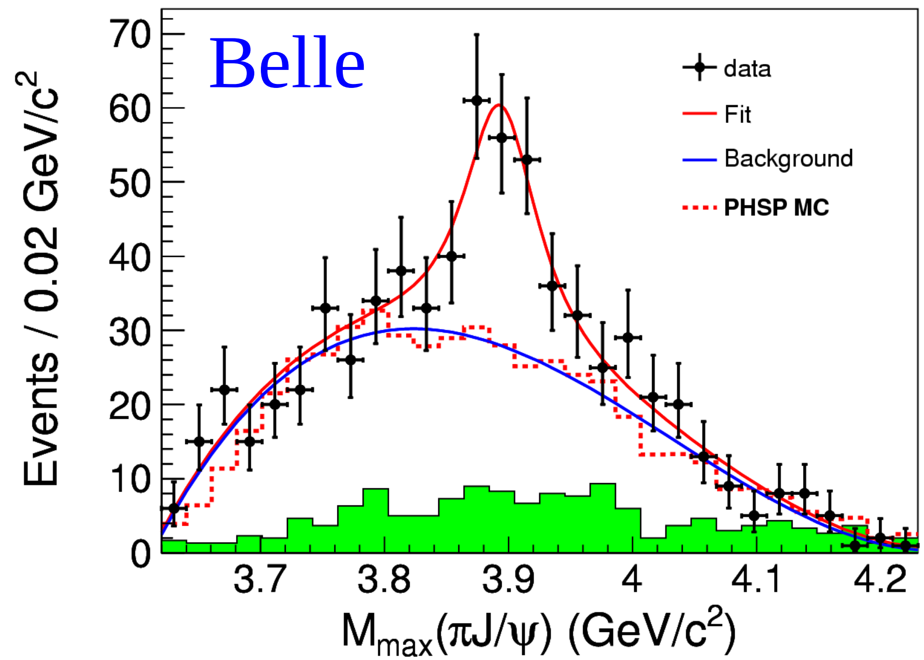
$e^+e^- \rightarrow \pi\, Z_c(3900) \rightarrow \pi^+\pi^- J/\psi$ @ 4.260 GeV

PRL 110, 252001

PRL 110, 252001 (2013)

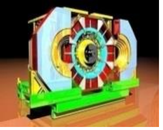


PRL 110, 252002 (2013)



M = (3899.0±3.6±4.9) MeV/c²
Γ = (46±10±20) MeV/c²
307±48 events
>8σ

M = (3894.5±6.6±4.5) MeV/c²
Γ = (63±24±26) MeV/c²
159±49 events
>5.2σ

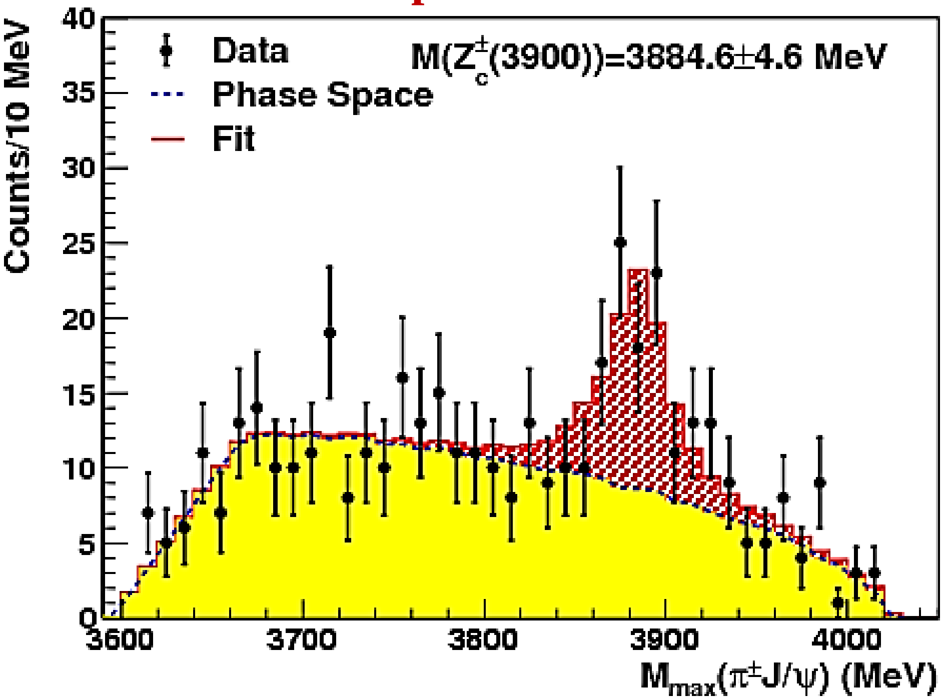


$e^+e^- \to \pi Z_c(3900) \to \pi^+\pi^- J/\psi$ @ 4.260 GeV

PRL 110, 252001

K. Seth & co. @ 4.170 GeV

hep-ex:1304.3036

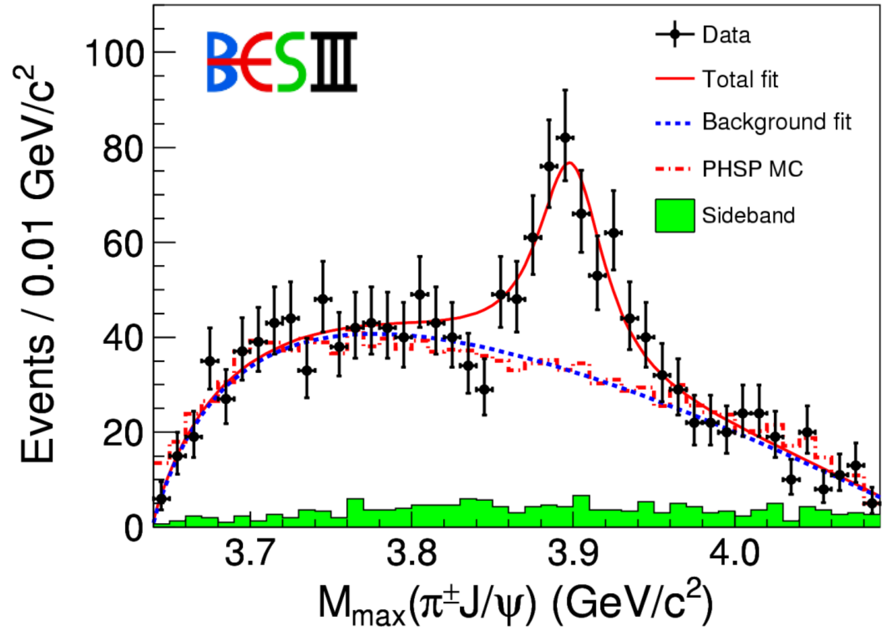


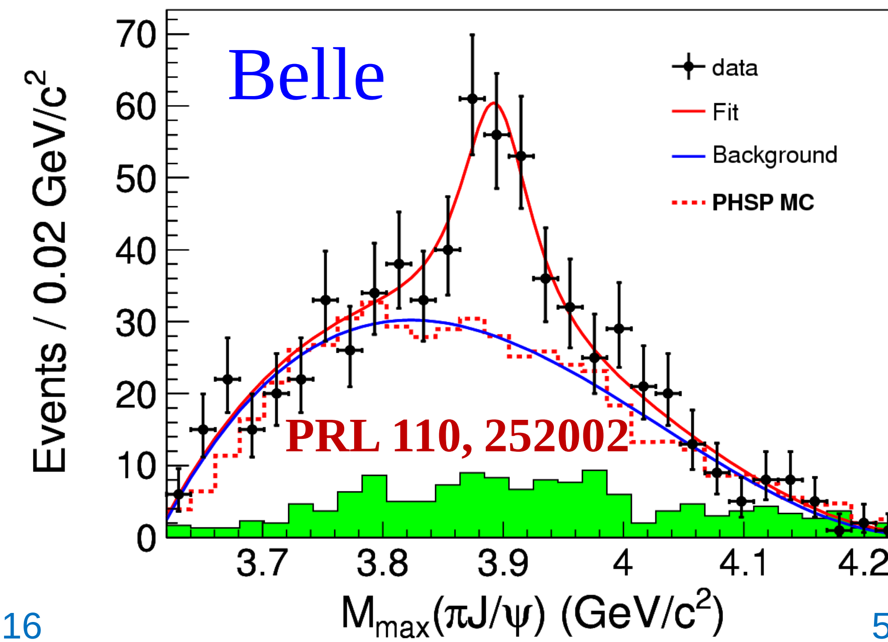
M = (3885±5±1) MeV/c²

Γ = (34±12±4) MeV/c²

81±20 events

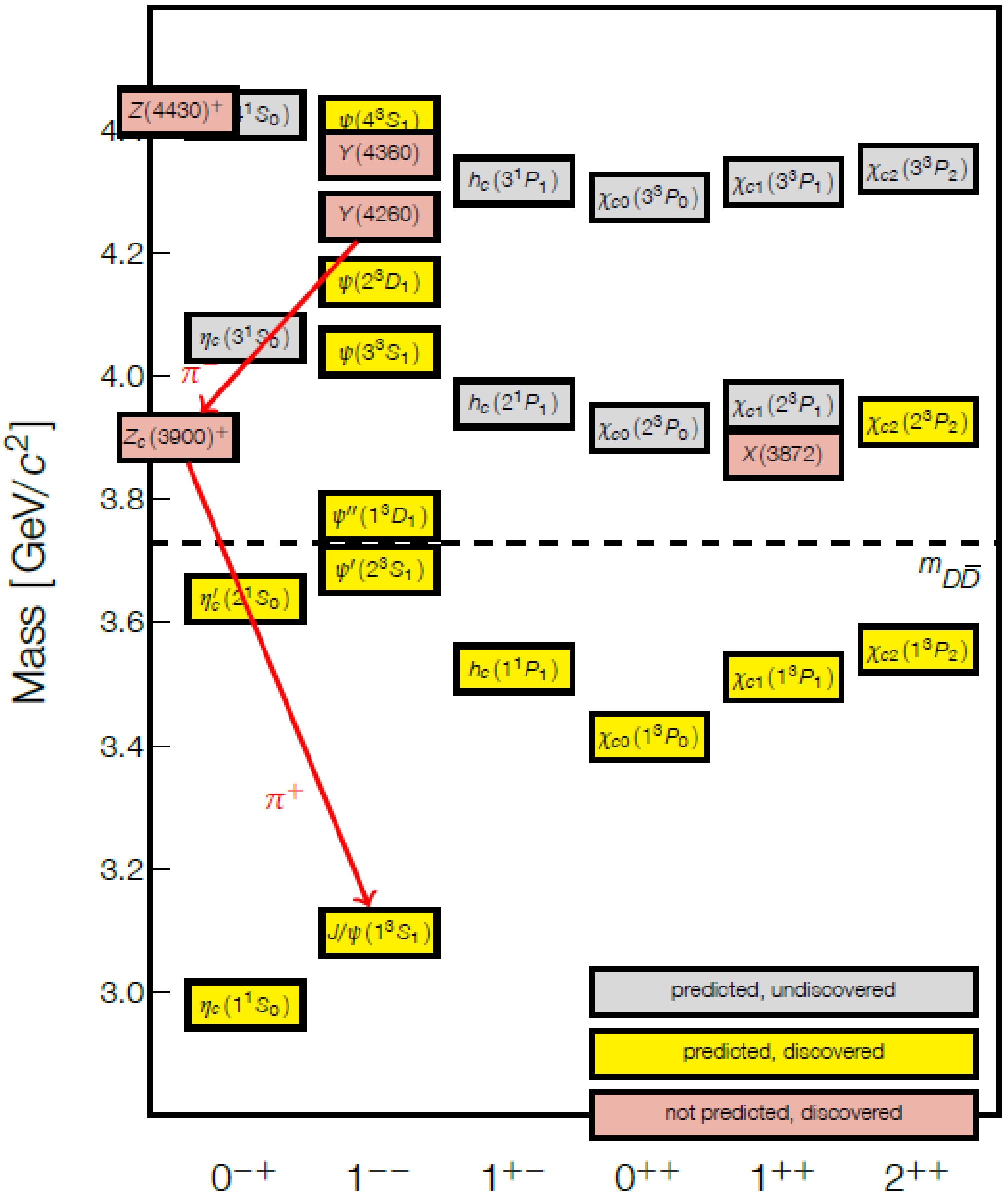
6.1σ





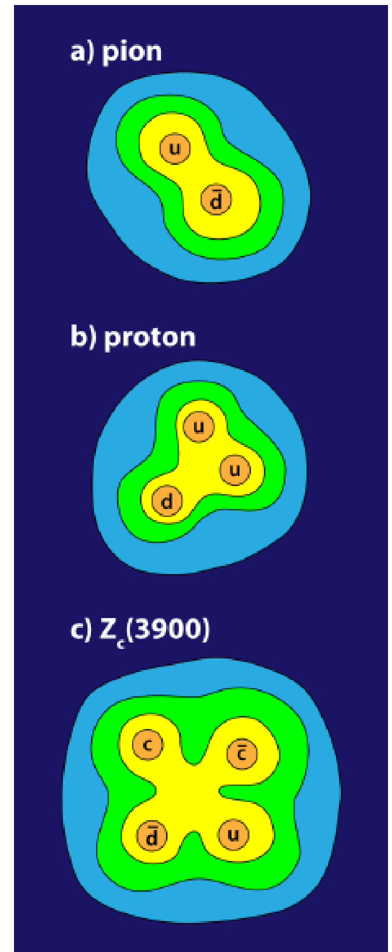
$e^+e^- \to \pi\, Z_c(3900) \to \pi^+\pi^- J/\psi$ @ 4.260 GeV

PRL 110, 252001



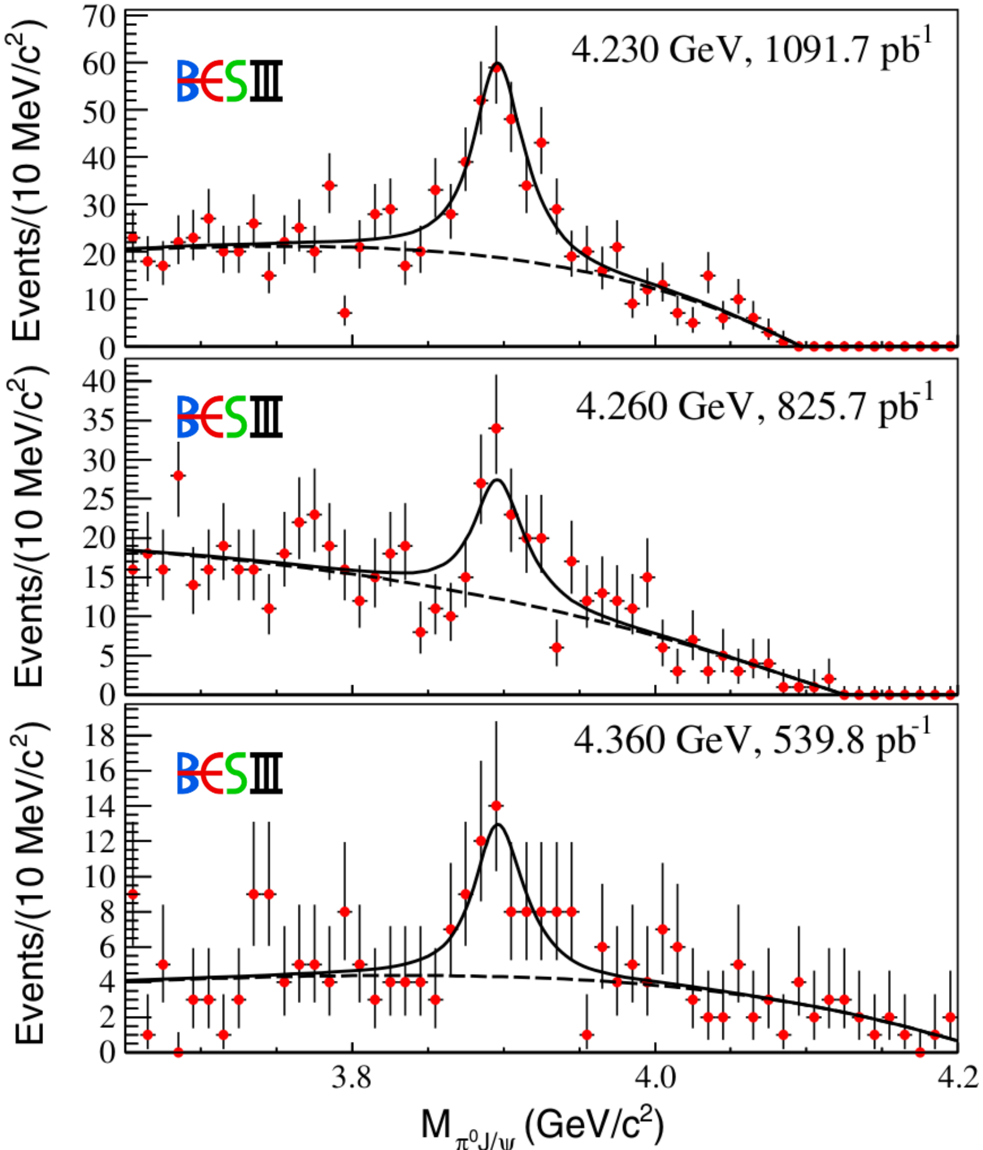
One of APS

2013 highlights



$e^+e^- \rightarrow \pi^0 Z_c(3900)^0 \rightarrow \pi^0\pi^0 J/\psi$ @ 4.230-4.260 GeV

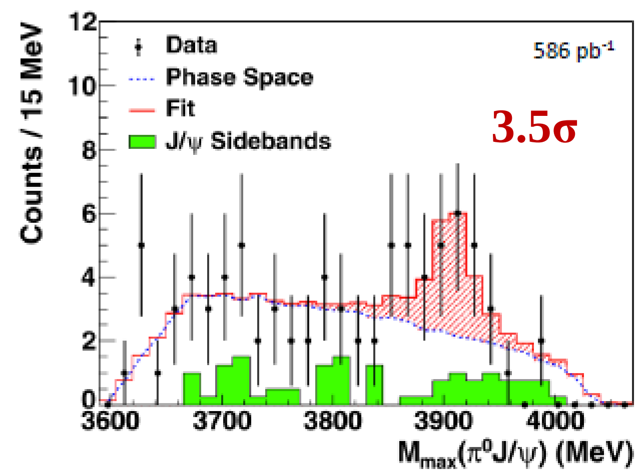
PRL 115, 112003



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

M = $(3894.8\pm2.3\pm3.2)$ MeV/c^2
Γ = $(29.6\pm8.2\pm8.2)$ MeV/c^2
10.4σ

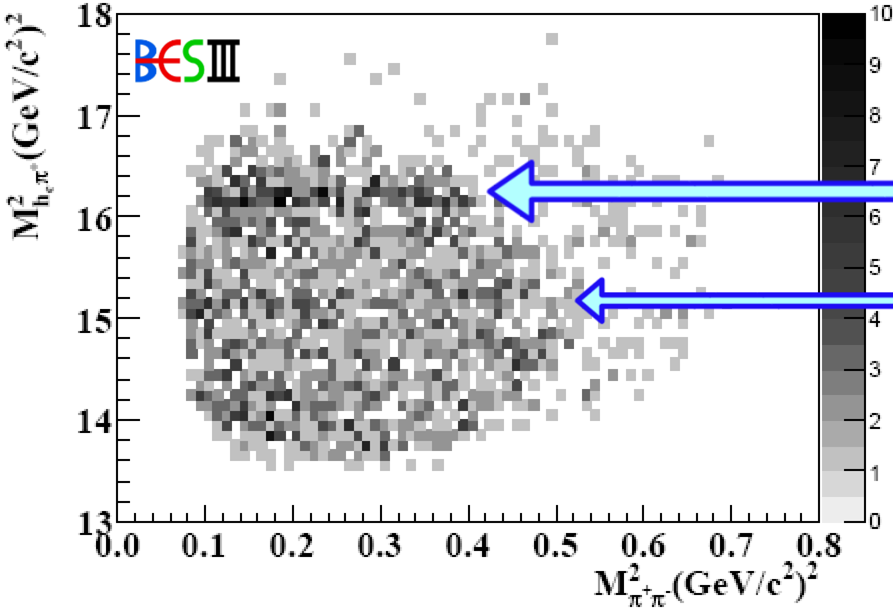
CLEOc: PLB 727, 366

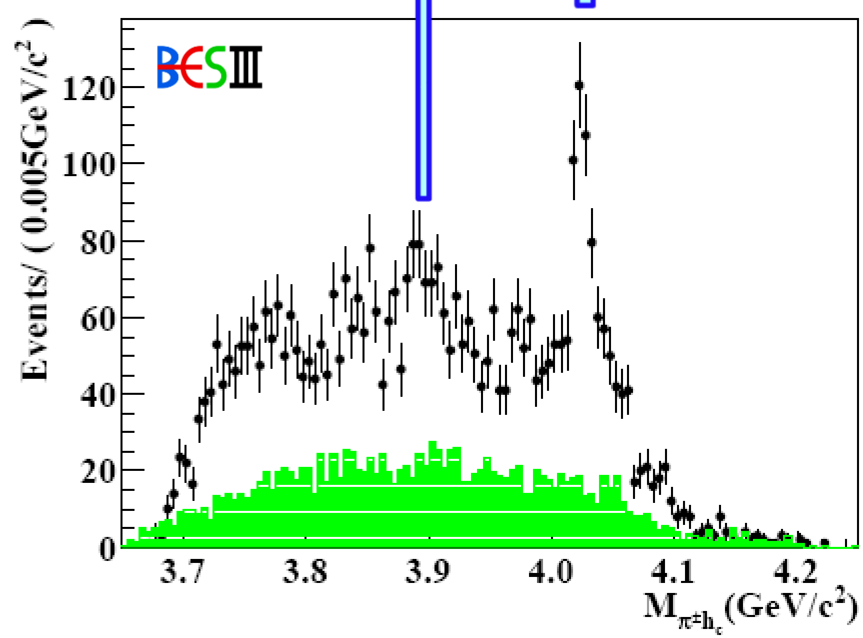


An isospin triplet for $Z_c(3900)$ has been established

$e^+e^- \to \pi\, Z_c(4020) \to \pi^+\pi^- h_c(1P)$ – all energies

PRL 111, 242001



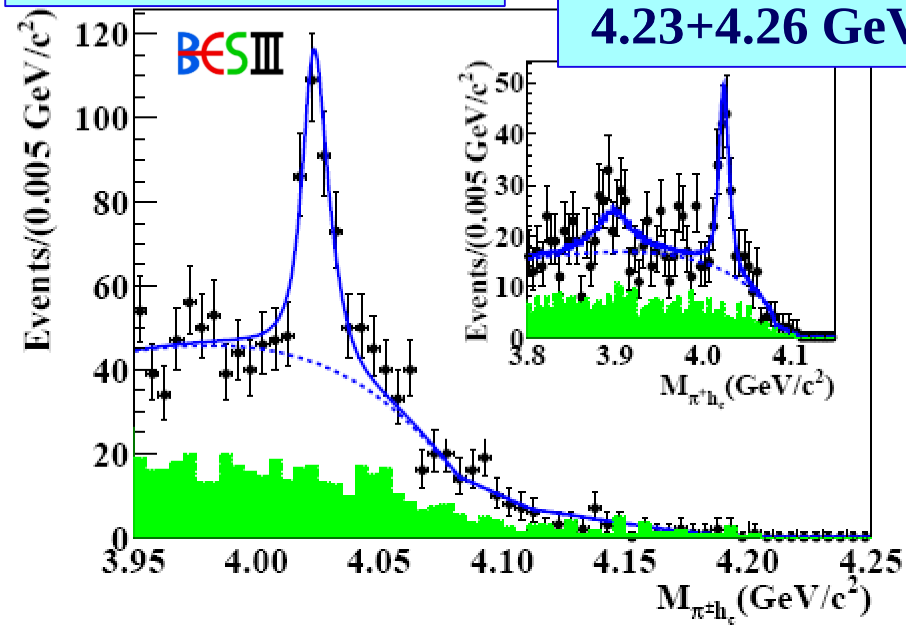


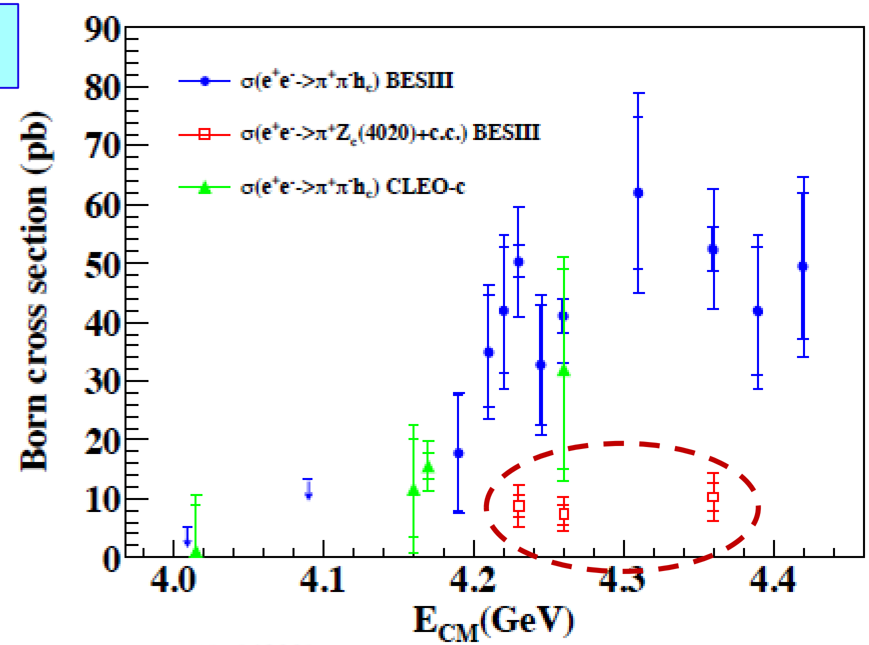
- **all collected energies**
  [3.900 ÷ 4.420 GeV]
- **$h_c \to \gamma\eta_c$, $\eta_c \to$ hadrons**
  [16 exclusive decay modes]

$e^+e^- \to \pi Z_c(4020) \to \pi^+\pi^- h_c(1P)$ – 4.23/4.26/4.36 GeV

PRL 111, 242001

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





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

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

$>8.9\sigma$

$\sigma(e^+e^- \to \pi Z_c(4020) \to \pi^+\pi^- h_c)$

$\sigma(4.23$ GeV$) = (8.7 \pm 1.9 \pm 2.8 \pm 1.4)$ pb

$\sigma(4.26$ GeV$) = (7.4 \pm 1.7 \pm 2.1 \pm 1.2)$ pb

$\sigma(4.36$ GeV$) = (10.3 \pm 2.3 \pm 3.1 \pm 1.6)$ pb

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

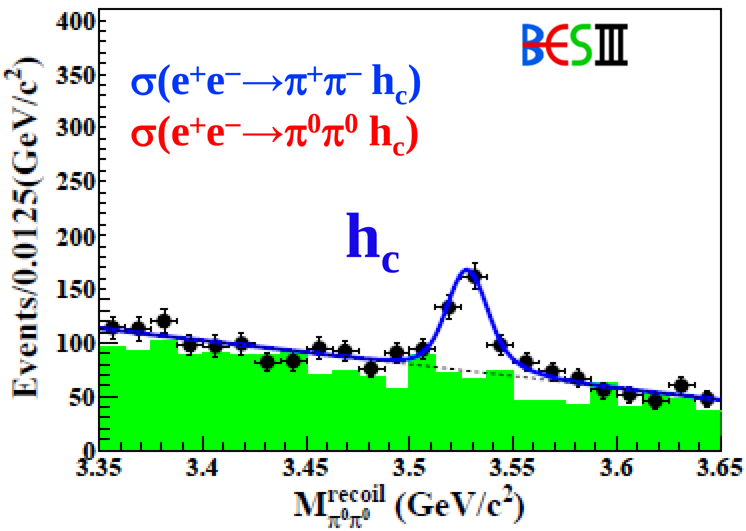
4.26 GeV:

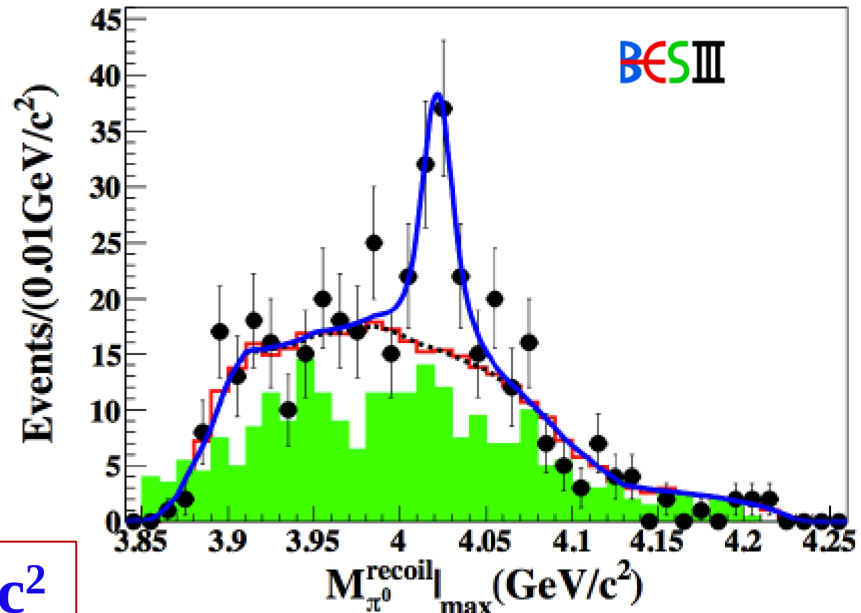
$\sigma(e^+e^- \to \pi Z_c(3900)^+ \pi^- \to \pi^+\pi^- h_c) = < 11$ pb (90% C.L.)

$e^+e^- \to \pi\, Z_c(4020)^0 \to \pi^0\pi^0 h_c(1P)$ – 4.23/4.26/4.36 GeV

PRL 113, 212002

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





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

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

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

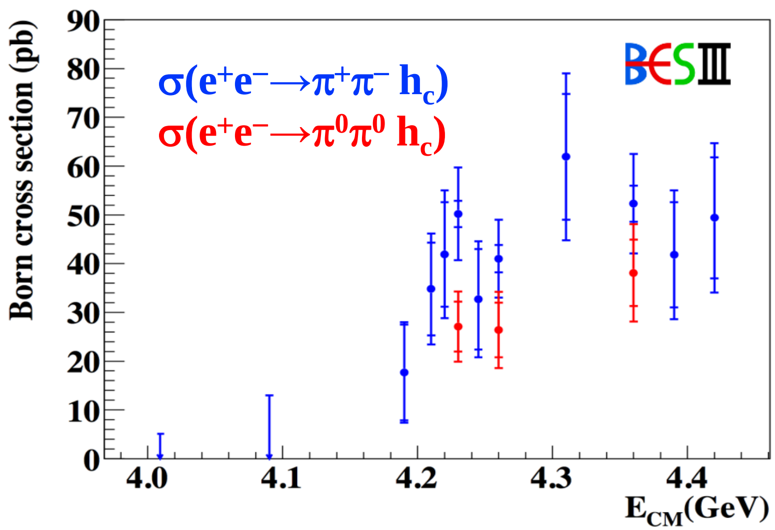
$>5\sigma$

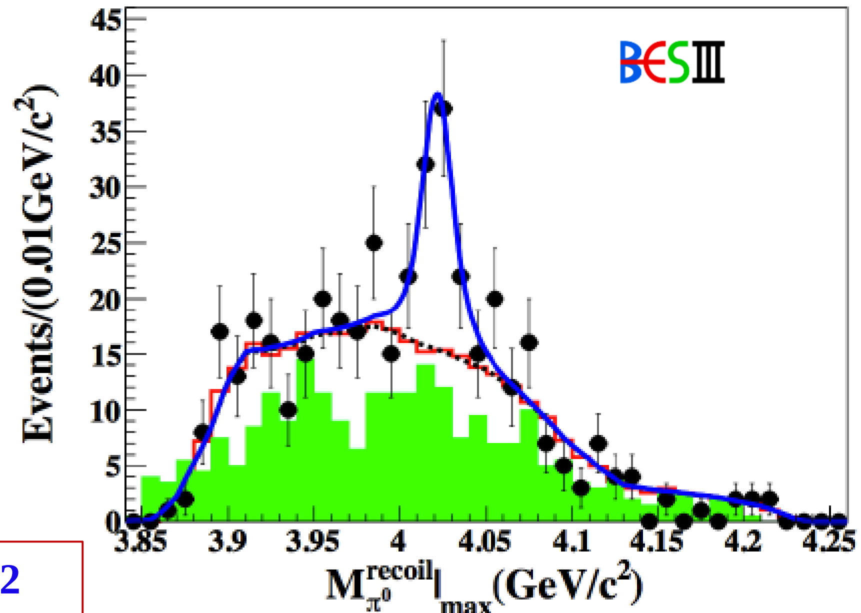
An isospin triplet for $Z_c(4020)$ has also been observed

$e^+e^- \to \pi Z_c(4020)^0 \to \pi^0\pi^0 h_c(1P)$ – 4.23/4.26/4.36 GeV

PRL 113, 212002

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





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

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

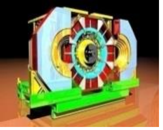
$\Gamma_{Z_c(4020)^0}$ fixed @ $\Gamma_{Z_c(4020)^\pm}$

>5σ

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

$\sigma(e^+e^-\to\pi^+\pi^- h_c) \sim 2\, \sigma(e^+e^-\to\pi^0\pi^0 h_c)$

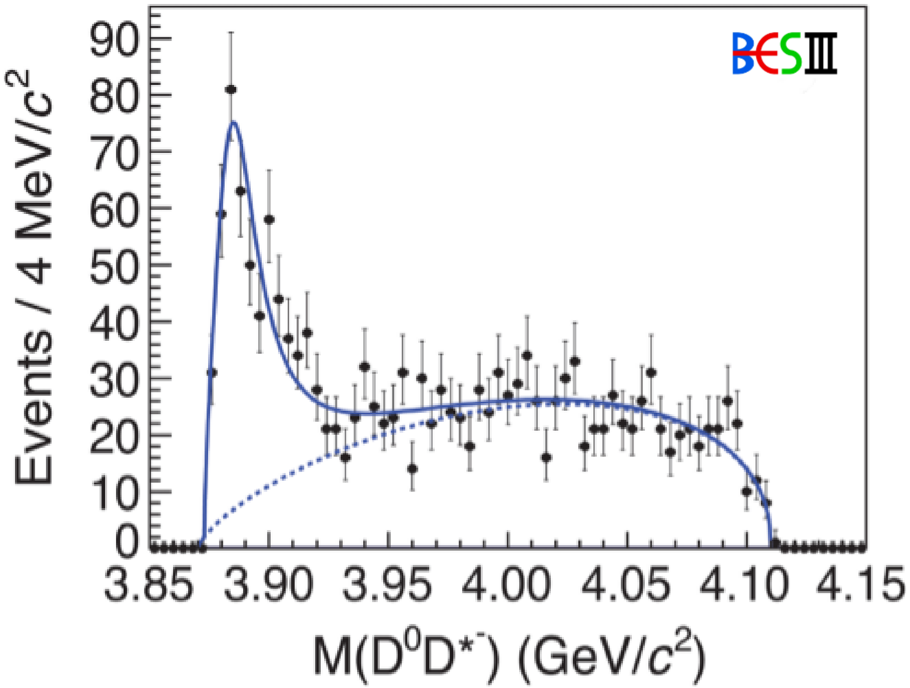
isospin conservation

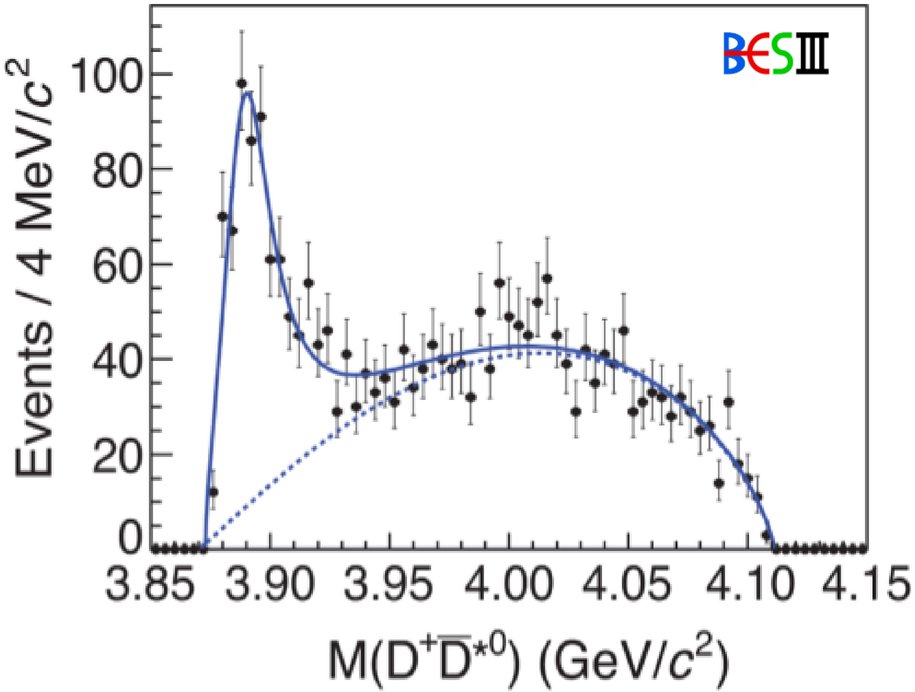


BESIII: $e^+e^- \to \pi Z_c(3885) \to \pi^- (D\bar{D}^*)^+$+c.c. @ 4.260 GeV

PRL 112, 022001

525 pb^{-1} data @ 4260 MeV: <u>single tag analysis</u>



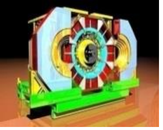


M = (3883.9±1.5±4.2) MeV/c^2
Γ = (24.8±3.3±11.0) MeV/c^2
>18σ

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

$$\sigma(e^+e^- \to \pi^- Z_c(3885)^+ \times Z_c(3885)^+ \to (D\bar{D}^*)^+ \text{ +c.c.}) = (83.5\pm6.6\pm22.0) \text{ pb}$$

$$R = \frac{\Gamma(Z_c(3885) \to D^*\bar{D}^*)}{\Gamma(Z_c(3900) \to \pi J/\psi)} = (6.2\pm1.1\pm2.7)$$



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

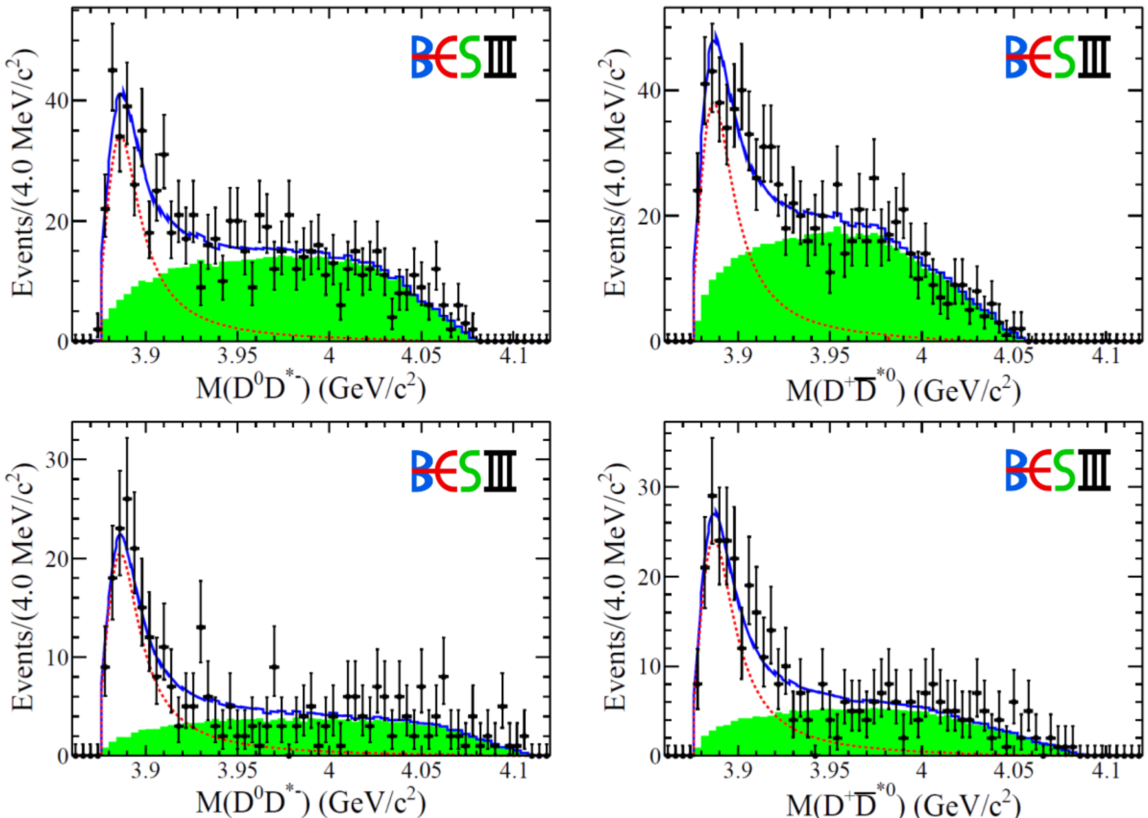
PRD 92, 092006

525 pb^{-1} data @ 4260 MeV: <u>double tag analysis</u>

$e^+e^- \to \pi^+ D^0 D^{*-}$ | $e^+e^- \to \pi^+ D^- D^{*0}$

1090 pb^{-1} @ 4.23 GeV

827 pb^{-1} @ 4.26 GeV



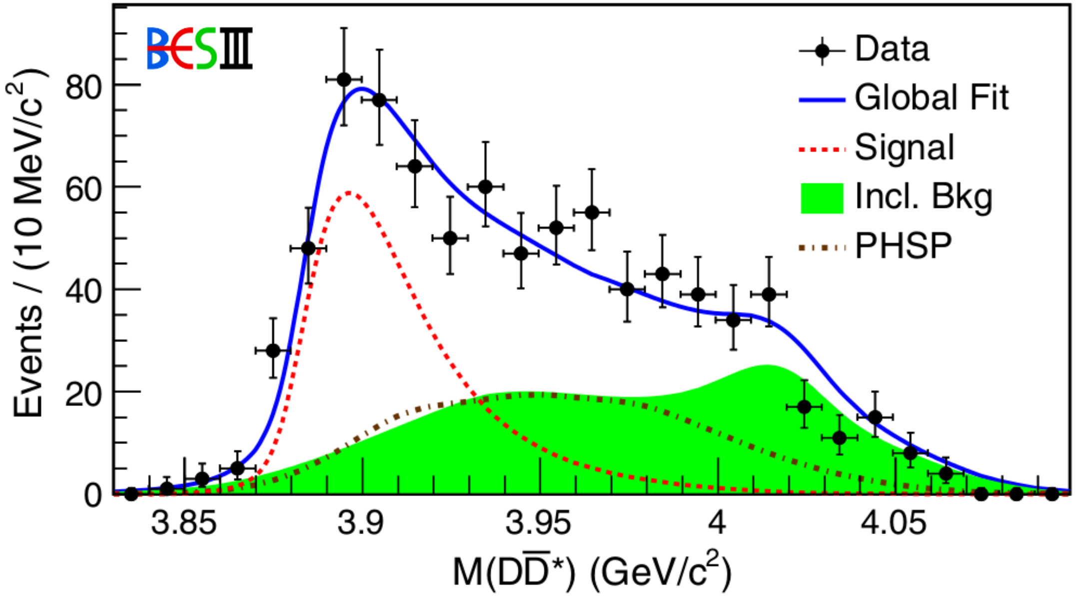
M = (3881.7±1.6±2.1) MeV/c^2
Γ = (26.6±2.0±2.3) MeV/c^2
>10σ , $J^P = 1^+$

Compatible with but significantly more precise than single-tag analysis

BESIII: $e^+e^- \to \pi Z_c(3885) \to \pi^0 (D\bar{D}^*)^0$+c.c. @ 4.260 GeV

PRL 115, 222002

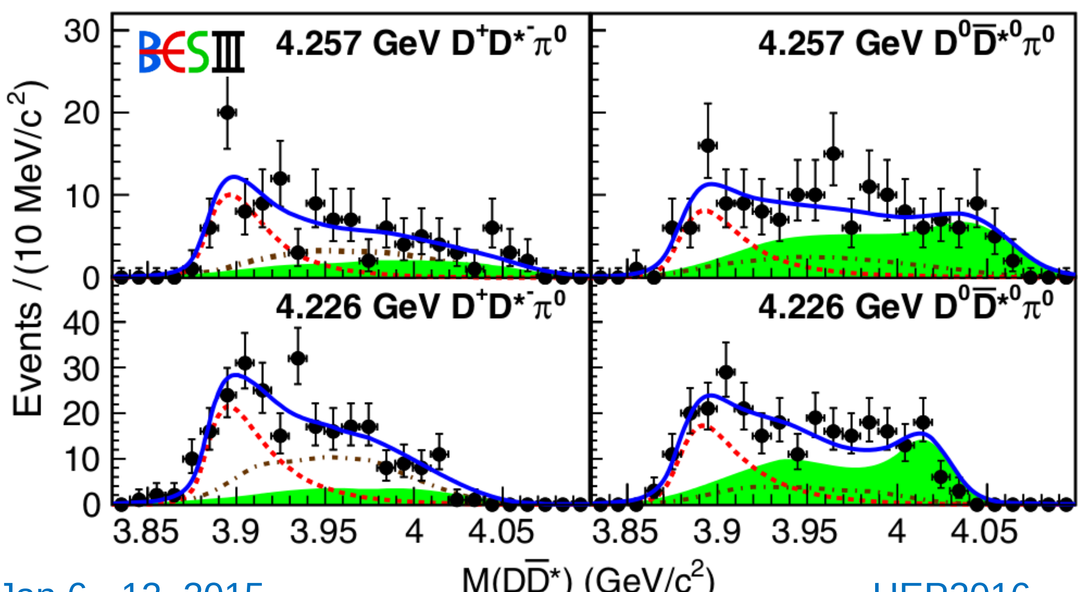
1092 pb^{-1} data @ 4226 MeV, 826 pb^{-1} data @ 4257 MeV: <u>single tag analysis</u>



$M = (3885.7^{+4.3}_{-5.7} \pm 8.4)$ MeV/c^2

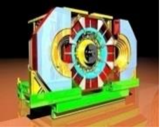
$\Gamma = (35^{+11}_{-12} \pm 15)$ MeV/c^2

$>10\sigma$



- **good agreement among neutral and charged states**
- **an isospin triplet established in DD* channel as well**

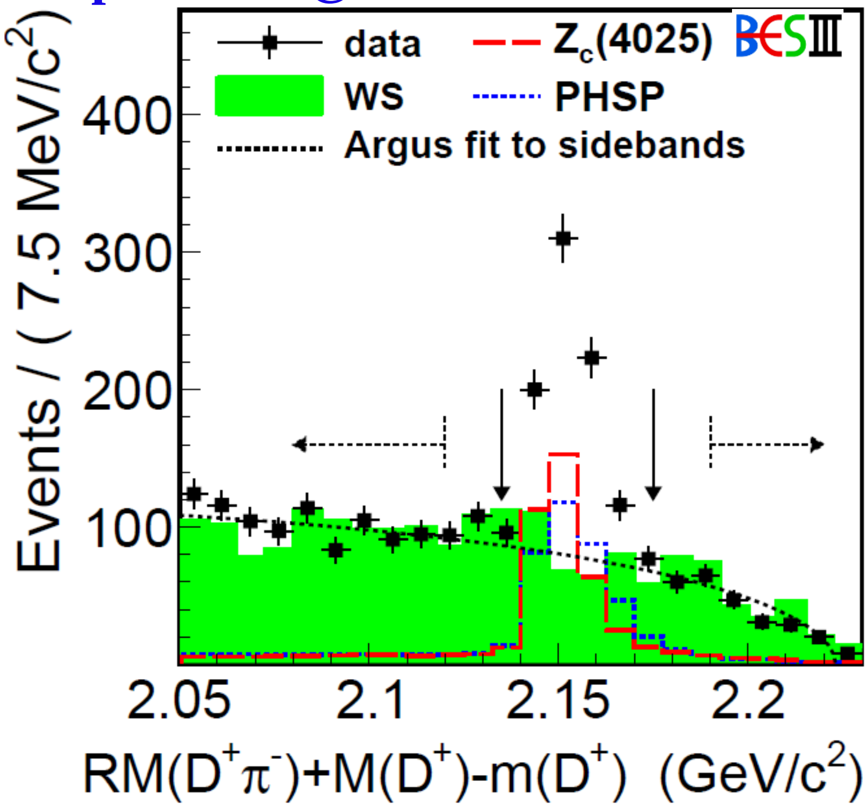
  the same of $Z_c(3900)$?
- **Molecule state? Tetraquark?**

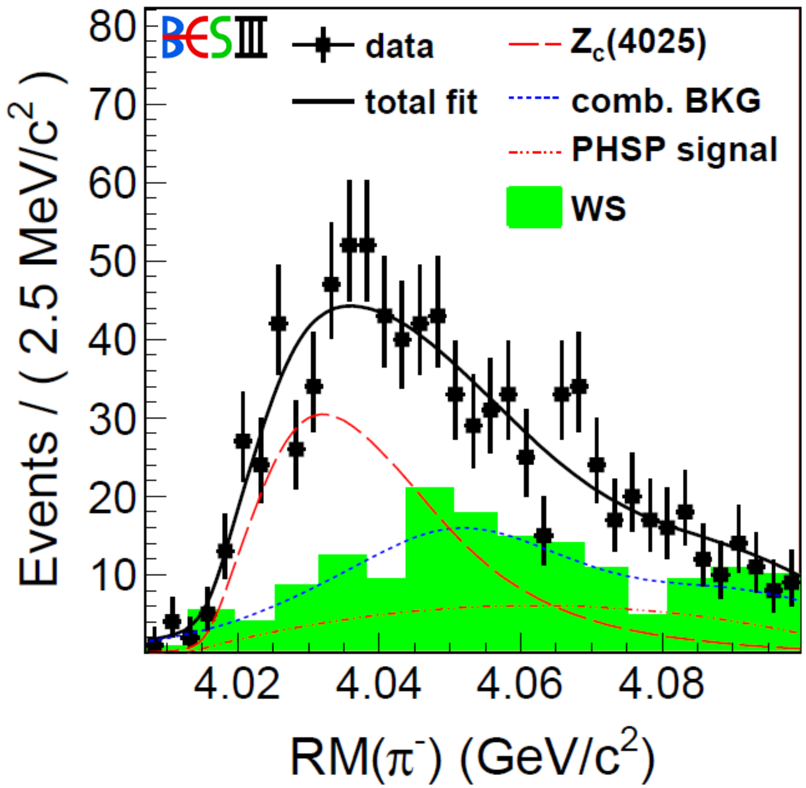


BESIII: $e^+e^- \to \pi Z_c(4025) \to \pi^- (D^*\bar{D}^*)^+ + c.c.$ @ 4.260 GeV

PRL 112, 132001

827 pb^{-1} data @ 4260 MeV:





M = (4026.3±2.6±3.7) MeV/c^2

Γ = (24.8±5.7±7.7) MeV/c^2

>10σ

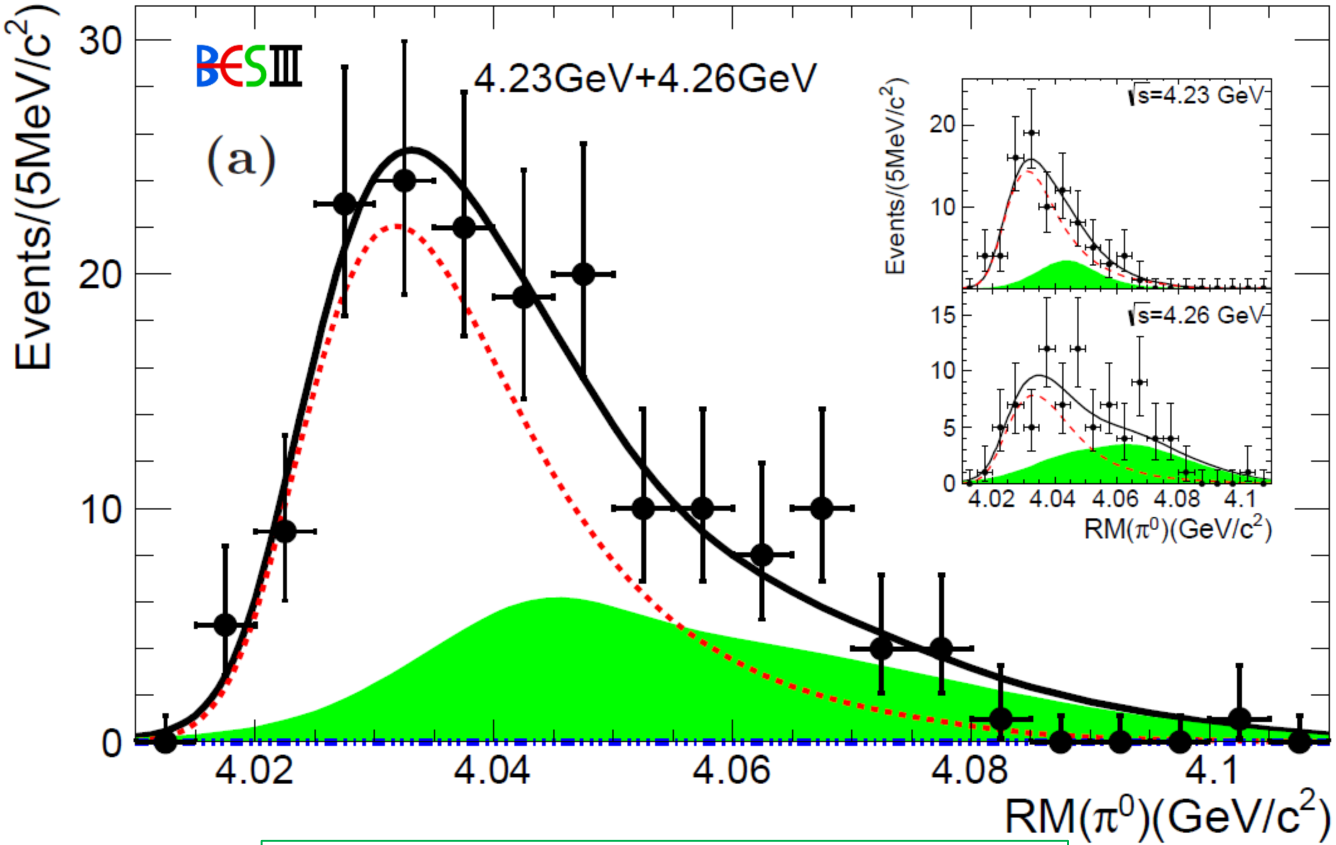
$$\sigma(e^+e^- \to \pi^- (D^*\bar{D}^*)^+ + c.c.) = (137\pm9\pm15)\ \text{pb}$$

$$R = \frac{\sigma(e^+e^- \to \pi^- Z_c^+ \to \pi^- (D^*\bar{D}^*)^+ + c.c.)}{\sigma(e^+e^- \to \pi^- (D^*\bar{D}^*)^+ + c.c.)} = (65\pm9\pm6)\%$$

BESIII: $e^+e^- \to \pi Z_c(4025) \to \pi^0 (D^*\bar{D}^*)^0$+c.c. @ 4.260 GeV

arXiv: 1507.02404

1092 pb^{-1} data @ 4226 MeV, 826 pb^{-1} data @ 4257 MeV:



$M = (4025.5^{+2.0}_{-4.7} \pm 3.1)$ MeV/c^2

$\Gamma = (23.0 \pm 6.0 \pm 1.0)$ MeV/c^2

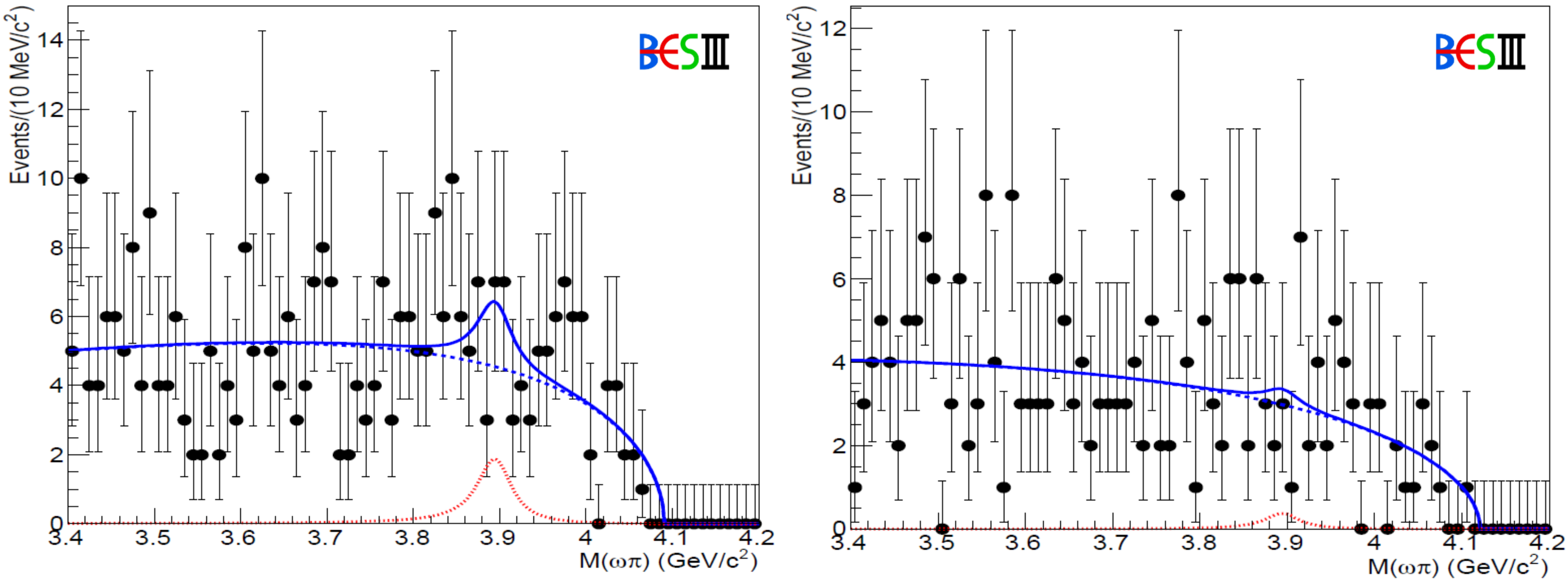
$>5.9\sigma$

$Z_c(4025)$ and $Z_c(4020)$ have similar mass but different width

$e^+e^- \to \pi^\mp Z_c(3900)^\pm \to \pi^+\pi^-\omega$ @ 4.230-4.260 GeV

PRD 92, 032009

1092 pb^{-1} data @ 4.23 GeV, 826 pb^{-1} data @ 4.26 GeV:



No evidence of a $Z_c(3900)$ signal

- $\sigma(e^+e^- \to \pi^\mp Z_c(3900)^\pm, Z_c(3900) \to \pi\omega) < 0.26$ pb @ 4.23 GeV 90%

- $\sigma(e^+e^- \to \pi^\mp Z_c(3900)^\pm, Z_c(3900) \to \pi\omega) < 0.18$ pb @ 4.26 GeV 90%

A missing $Z_c \to \omega\pi$ (a typical decay mode of a 1^+ resonance) may indicate that the cc annihilation in Z_c is suppressed

BESIII: a summary of Z_c observations

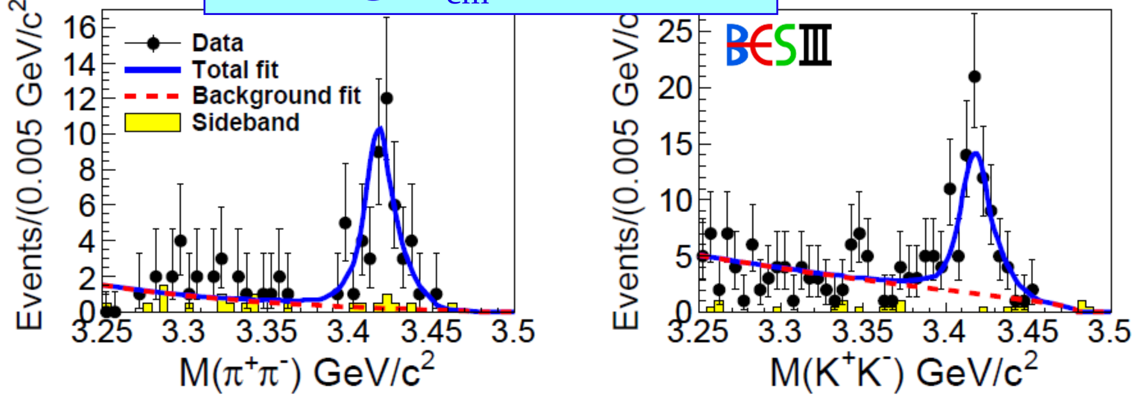
State]	Mass (MeV/c²)	Width (MeV)	Decay	Process	[Ref]
$Z_c(3900)^{\pm}$	3899.0±3.6±4.9	46±10±20	$\pi^{\pm}J/\psi$	$e^+e^- \to \pi^+\pi^-J/\psi$	[1]
$Z_c(3900)^0$	3894.8±2.3±2.7	29.6±8.2±8.2	$\pi^0 J/\psi$	$e^+e^- \to \pi^0\pi^0 J/\psi$	[2]
$Z_c(3885)^{\pm}$	3883.9±1.5±4.2 Single D tag	24.8±3.3±11.0 Single D tag	$(D\bar{D}^*)^{\pm}$	$e^+e^- \to (D\bar{D}^*)^{\pm}\pi^{\mp}$	[3]
	3881.7±1.6±2.1 Double D tag	26.6±2.0±2.3 Double D tag	$(D\bar{D}^*)^{\pm}$	$e^+e^- \to (D\bar{D}^*)^{\pm}\pi^{\mp}$	[4]
$Z_c(3885)^0$	$3885.7^{+4.3}_{-5.7}$±8.4	35^{+11}_{-12}±15	$(D\bar{D}^*)^0$	$e^+e^- \to (D\bar{D}^*)^0\pi^0$	[5]
$Z_c(4020)^{\pm}$	4022.9±0.8±2.7	7.9±2.7±2.6	$\pi^{\pm}h_c$	$e^+e^- \to \pi^+\pi^-h_c$	[6]
$Z_c(4020)^0$	4023.9±2.2±3.8	fixed	$\pi^0 h_c$	$e^+e^- \to \pi^0\pi^0 h_c$	[7]
$Z_c(4025)^{\pm}$	4026.3±2.6±3.7	24.8±5.6±7.7	$D^*\bar{D}^*$	$e^+e^- \to (D^*\bar{D}^*)^{\pm}\pi^{\mp}$	[8]
$Z_c(4025)^0$	$4025.5^{+2,0}_{-4.7}$±3.1	23.0±6.0±1.0	$D^*\bar{D}^*$	$e^+e^- \to (D^*\bar{D}^*)^0\pi^0$	[9]

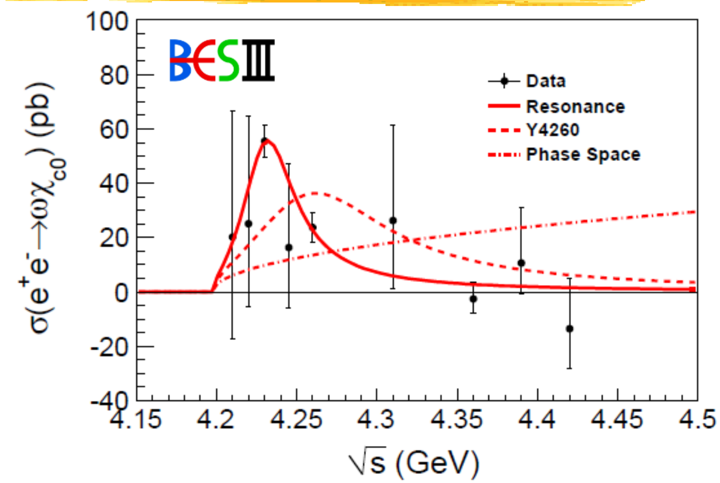
[1] PRL,110,252001; [2] PRL 115, 112003; [3] PRL,112, 022001; [4] PRD 92, 092006
[5] PRL 115, 222002; [6] PRL,110, 252001; [7] PRL,113,212002; [9] PRL,112, 132001
[9] arXiv:1507.02404

BESIII: $e^+e^- \to \omega\chi_{c0}$ ($\chi_{c0} \to \pi^+\pi^-, K^+K^-$)

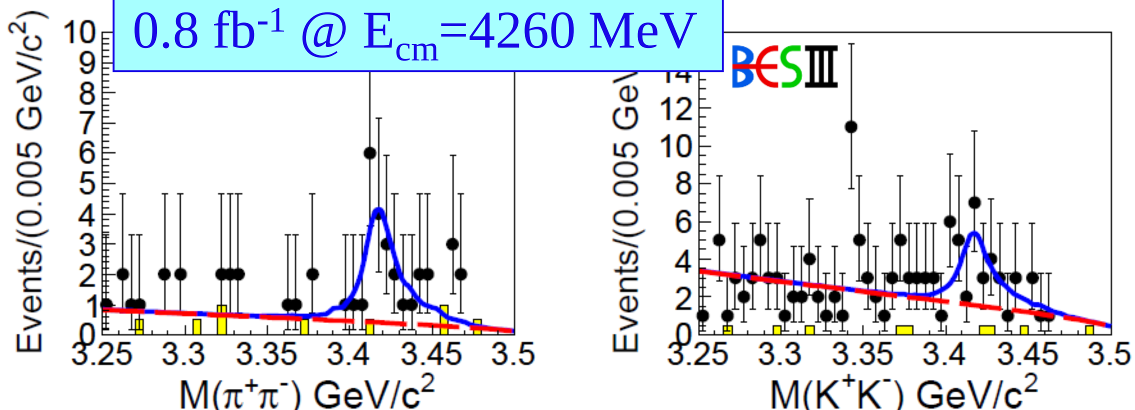
PRL 114, 092003

$1\ fb^{-1}$ @ E_{cm}=4230 MeV





$0.8\ fb^{-1}$ @ E_{cm}=4260 MeV



σ ($e^+e^- \to \omega\chi_{c0}$) =

- (55.4±6.0±5.9) pb @ 4.23 GeV
- (23.7±5.3±3.5) pb @ 4.26 GeV

A fine structure at 4230MeV?

- 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 $\omega\chi_{c1}/\omega\chi_{c2}$ at 4230/4260/4360 MeV
- Line shape seems inconsistent with Y(4260)
- BW fitting: a narrow structure around 4230MeV.

Assuming $\omega\chi_{c0}$ from a resonance:

M = (4230±8±6) MeV/c^2

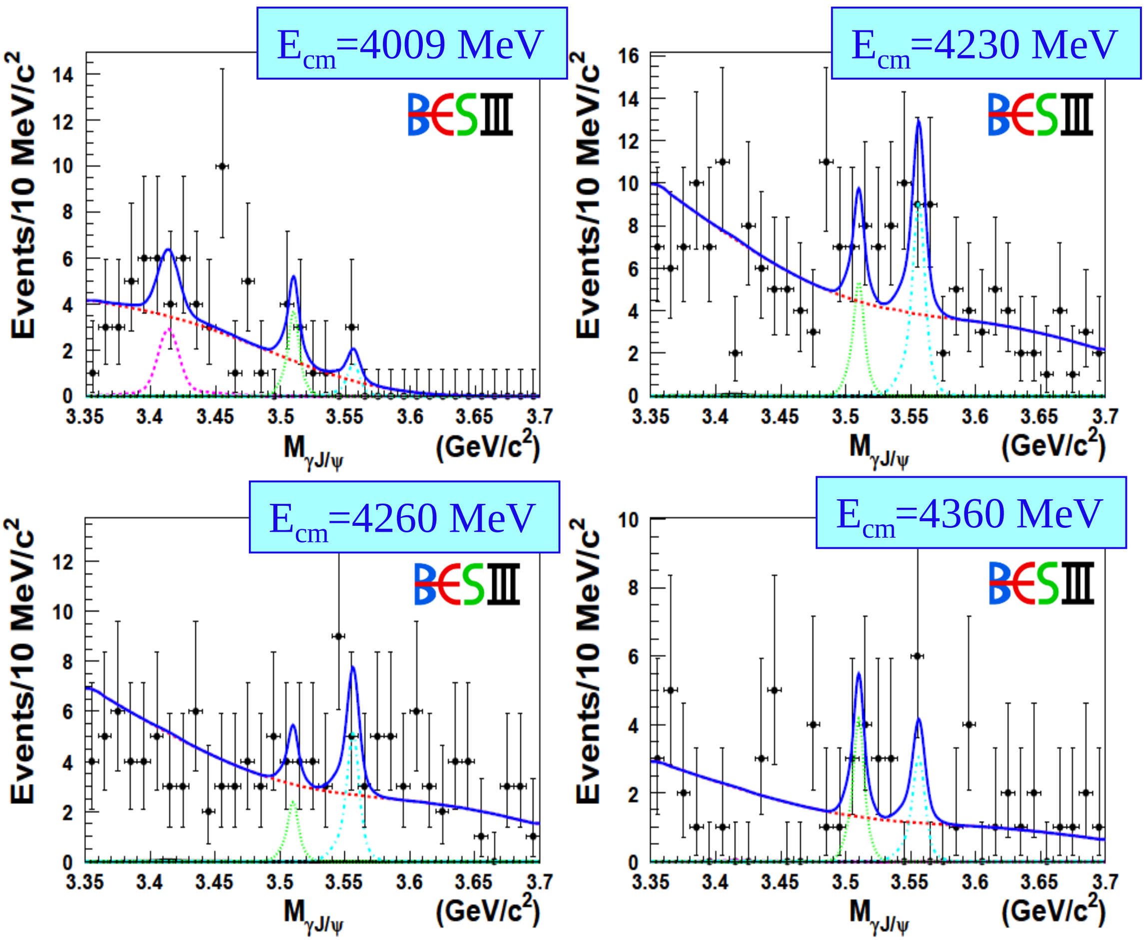
Γ = (38±12±2) MeV/c^2

> 9σ

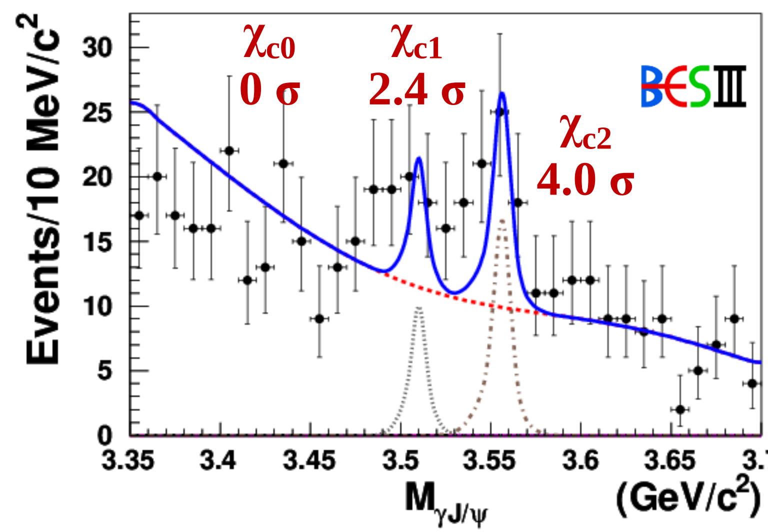
BESIII: $e^+e^- \to \gamma\chi_{cJ}$ ($\chi_{cJ} \to \gamma J/\psi$, $J/\psi \to \mu^+\mu^-$)

CPC 39(4), 041001

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



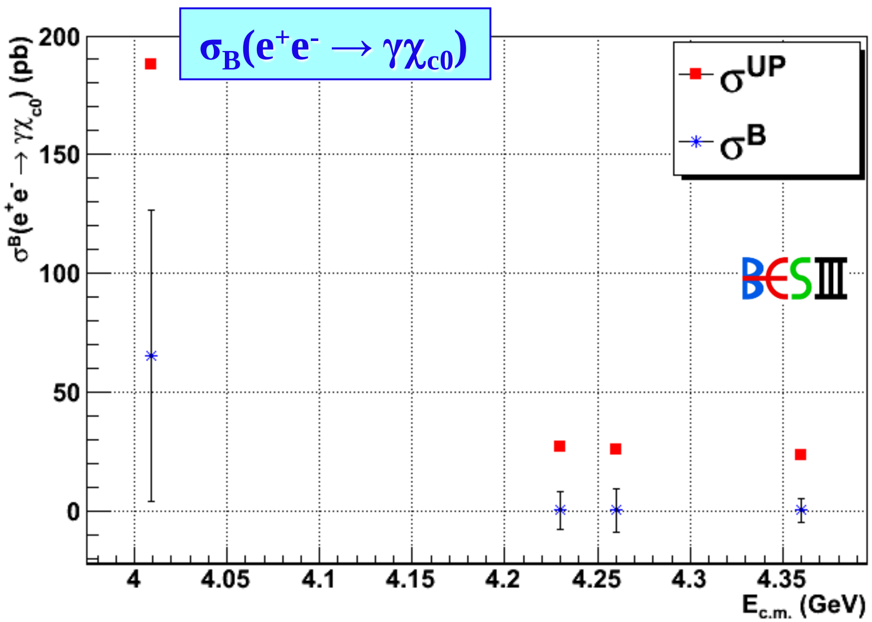
- Simultaneous fit @ 4 E_{cm} assuming Y(4260) lineshape for $\sigma(e^+e^- \to \gamma\chi_{cJ})$

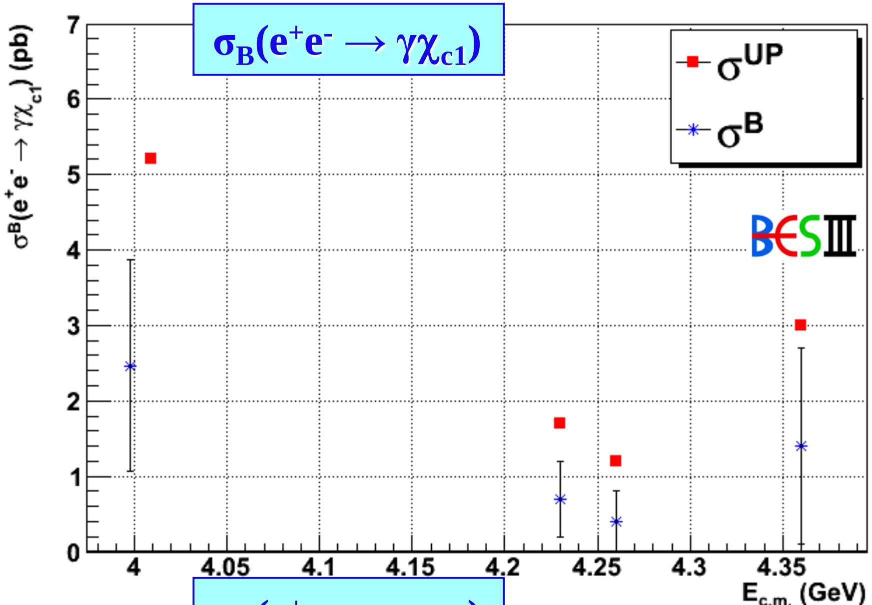


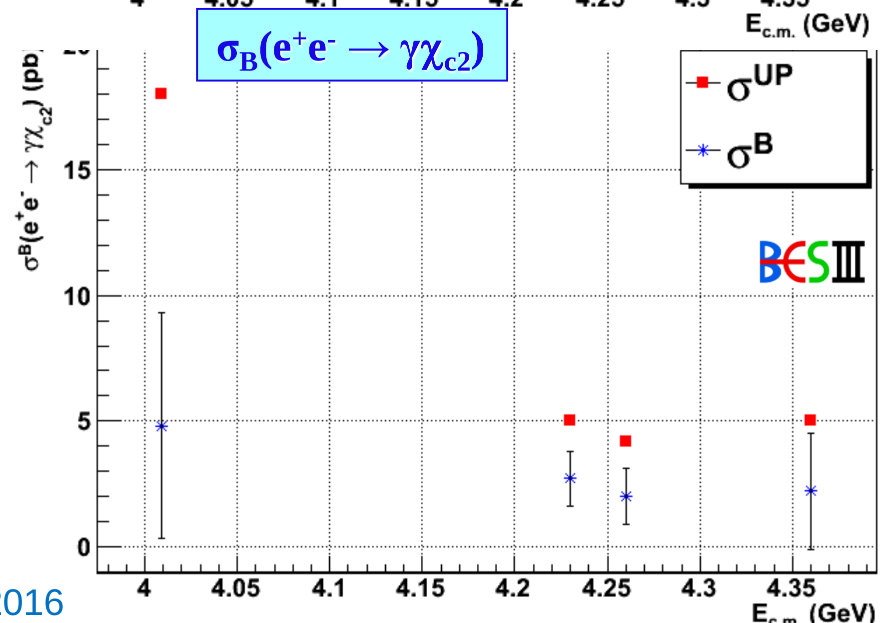
BESIII: $e^+e^- \to \gamma\chi_{cJ}$ ($\chi_{cJ} \to \gamma J/\psi$, $J/\psi \to \mu^+\mu^-$)

CPC 39(4), 041001

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







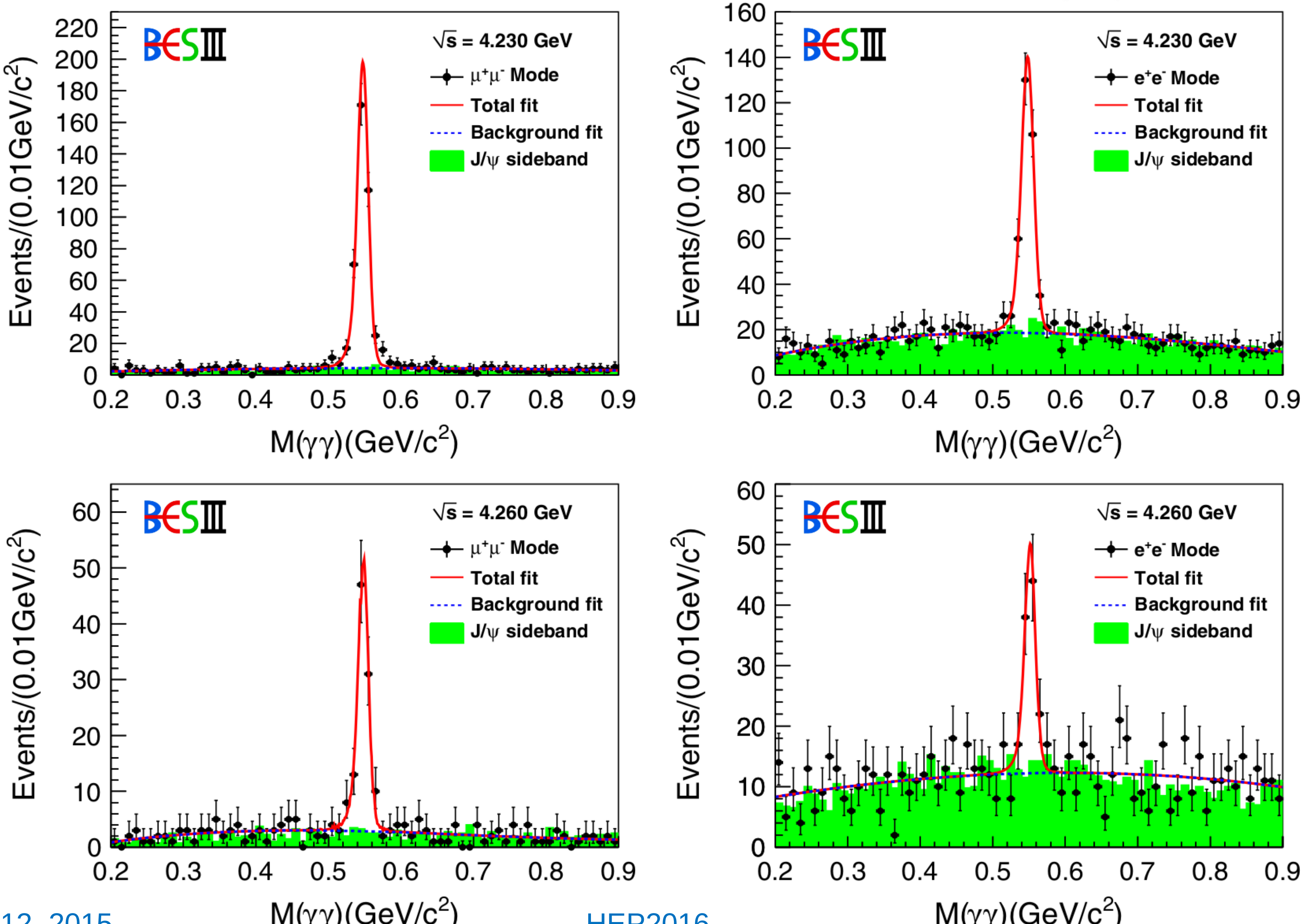
σ^{UP} compatible with NRQCD thoretical predictions [1]

[1] arXiv:1310.8597

BESIII: $e^+e^- \to \eta J/\psi$ and $e^+e^- \to \pi^0 J/\psi$

PRD 91, 112005

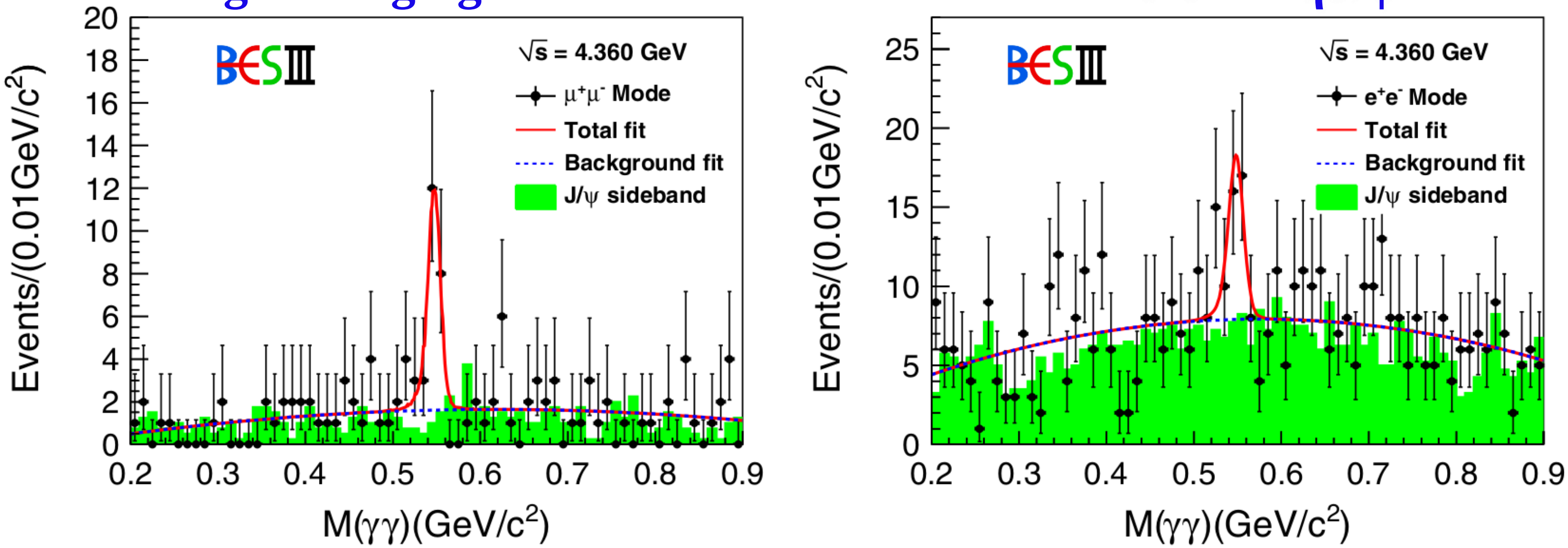
17 CM energies ranging from 3810 MeV to 4600 MeV: $e^+e^- \to \eta J/\psi$



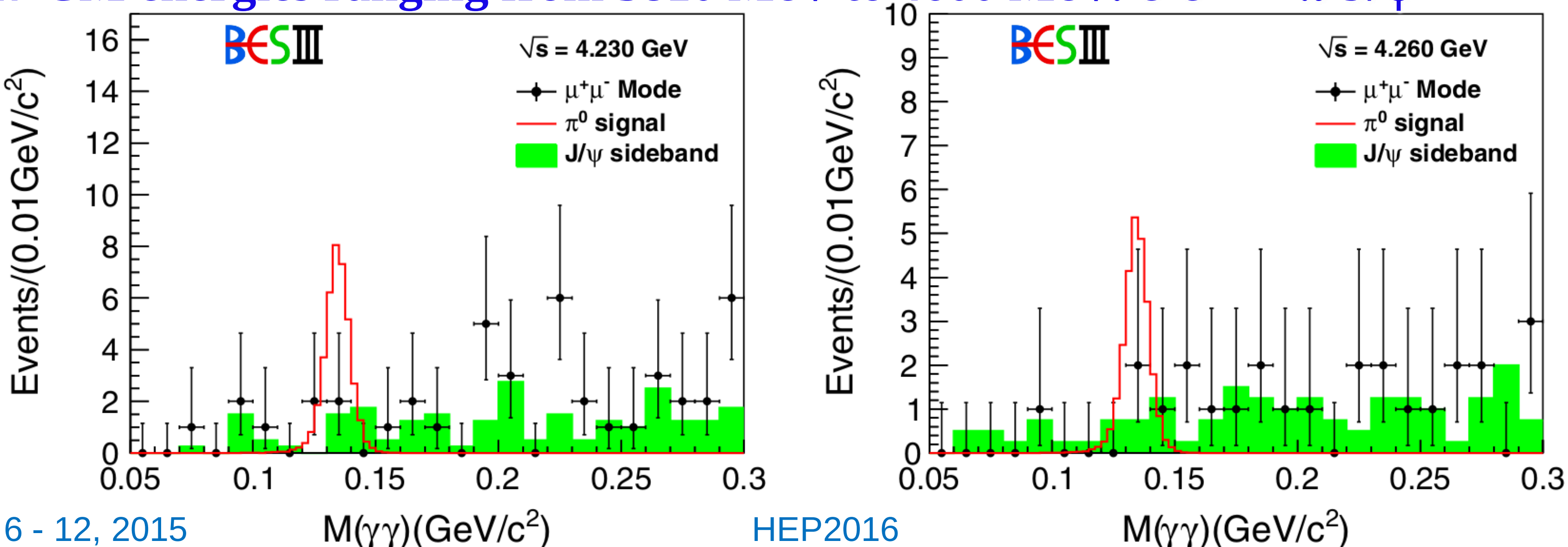
BESIII: $e^+e^- \to \eta J/\psi$ and $e^+e^- \to \pi^0 J/\psi$

PRD 91, 112005

17 CM energies ranging from 3810 MeV to 4600 MeV: $e^+e^- \to \eta J/\psi$



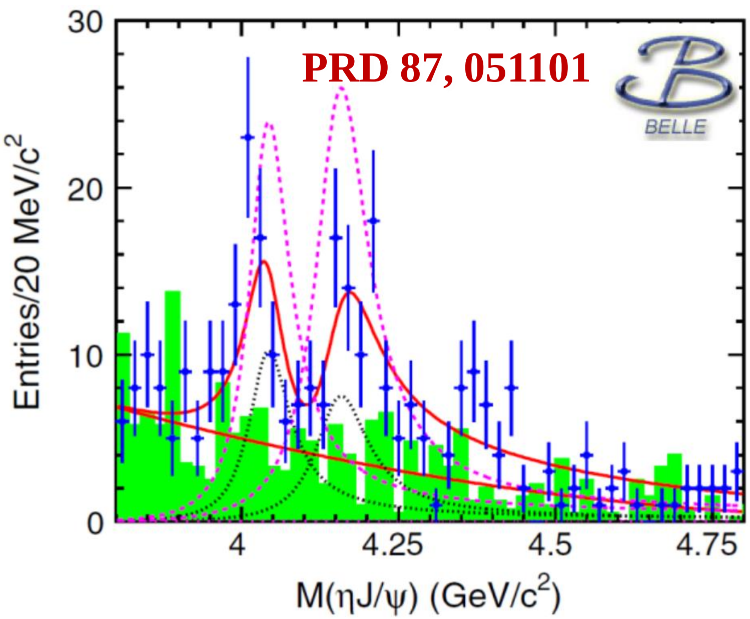
17 CM energies ranging from 3810 MeV to 4600 MeV: $e^+e^- \to \pi^0 J/\psi$

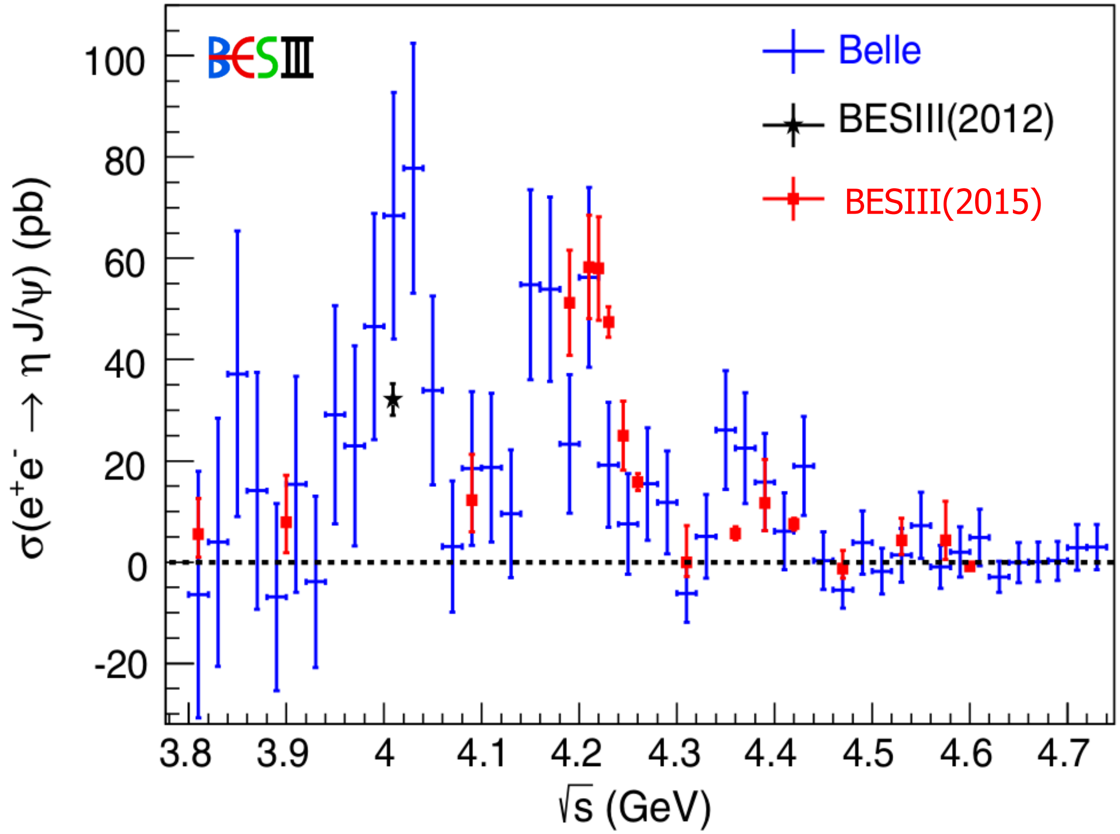


BESIII: $e^+e^- \to \eta J/\psi$

PRD 91, 112005

- $\sigma_B(e^+e^- \to \eta J/\psi)$ **Born measured cross section**





ψ(4040) and ψ(4160) with interference

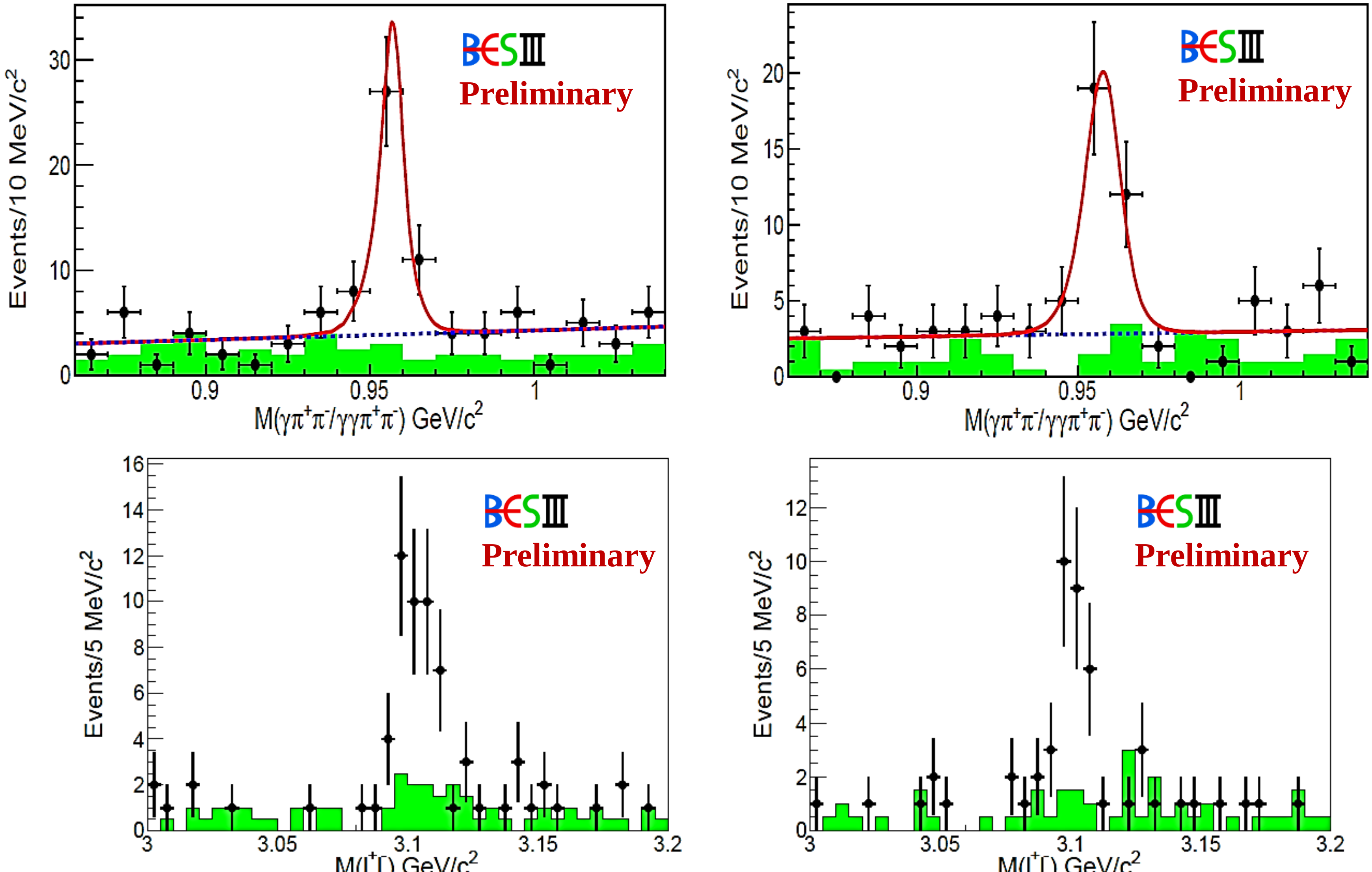
- **good agreement with previous results and more precise**
- **cross sections peaks at ~ 4.2 GeV**
- **higher energy points' analysis on going**

BESIII: $e^+e^- \to \eta' J/\psi$

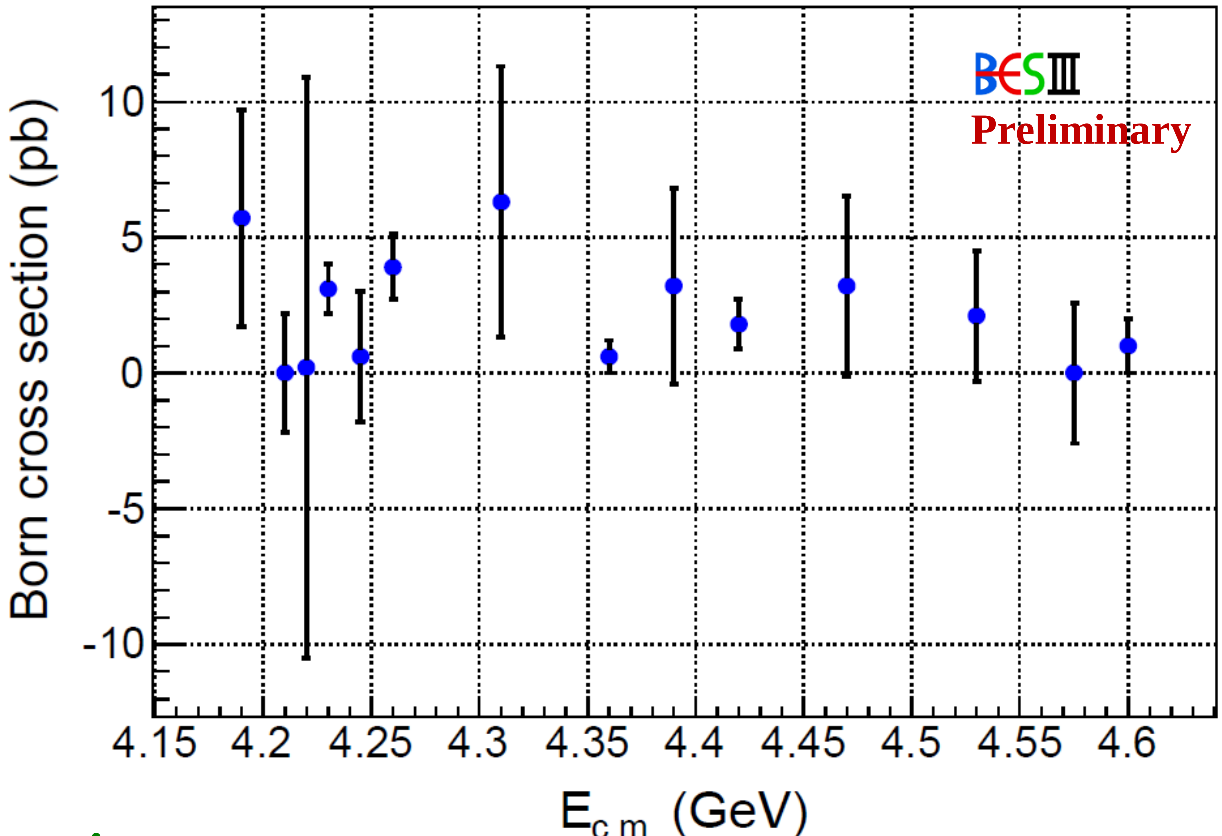
preliminary

1 fb^{-1} @ E_{cm}=4230 MeV

0.8 fb^{-1} @ E_{cm}=4260 MeV



BESIII: $e^+e^- \to \eta' J/\psi$



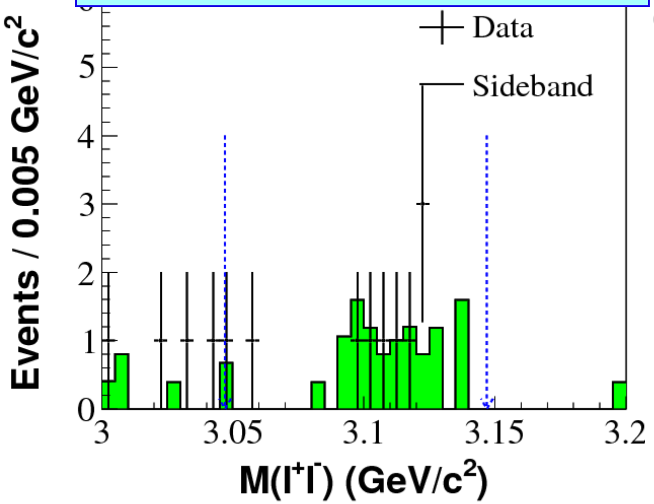
- first observation
- too low statistics to infer line shape but σ $(e^+e^- \to \eta' J/\psi)$ =
  - (3.1±0.6±0.3) pb @ 4.23 GeV
  - (3.9±0.8±0.4) pb @ 4.26 GeV

BESIII: Y(4260) → $\pi^0 \eta J/\psi$

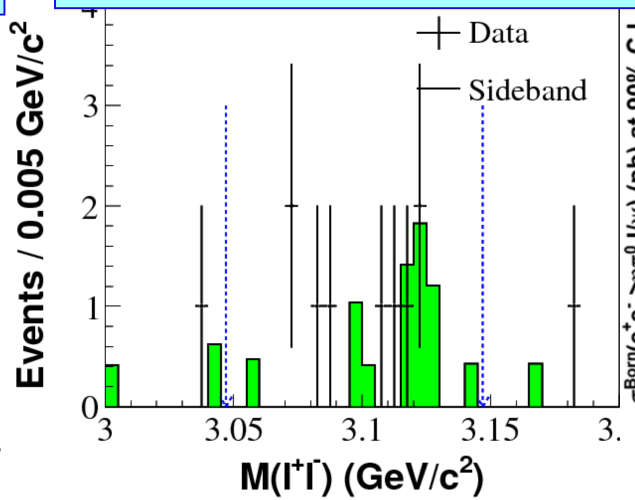
PRD 92, 012008

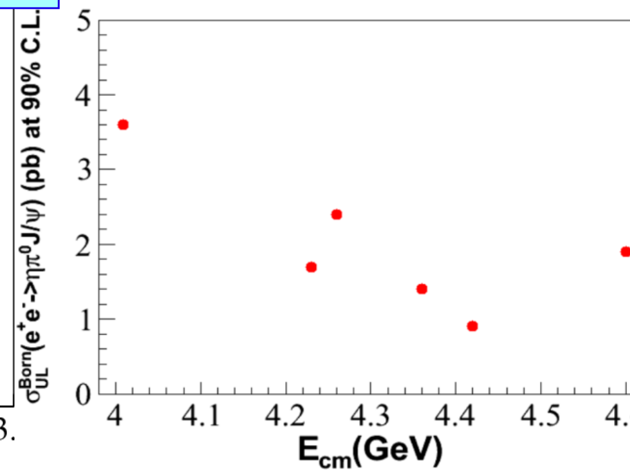
Search for isospin violating Y(4260) → $\pi^0 \eta J/\psi$ decay mode

1 fb^{-1} @ E_{cm}=4230 MeV



0.8 fb^{-1} @ E_{cm}=4260 MeV





- no significant signal observed with current BESIII data
- can not provide effective constraints to theoretical models

$\sqrt{s}$ (GeV)	$\mathcal{L}(pb^{-1})$	$(1+\delta^r)$	$(1+\delta^v)$	$(\epsilon^{ee}\mathcal{B}^{ee}+\epsilon^{\mu\mu}\mathcal{B}^{\mu\mu})$ (%)	N^{obs}	N^{bkg}	N^{up}	σ^{Born}_{UL} (pb)
4.009	482.0	0.838	1.044	2.1 ± 0.1(sys)	5	1	598.1	3.6
4.226	1047.3	0.844	1.056	2.2 ± 0.1(sys)	12	11	592.9	1.7
4.257	825.6	0.847	1.054	2.2 ± 0.1(sys)	12	8	654.1	2.4
4.358	539.8	0.942	1.051	2.2 ± 0.1(sys)	5	4	283.2	1.4
4.416	1028.9	0.951	1.053	2.3 ± 0.1(sys)	5	6	342.7	0.9
4.599	566.9	0.965	1.055	2.4 ± 0.1(sys)	6	3	418.4	1.9

Summary

- **huge statistics:**
  - J/ψ, ψ(2S), ψ(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

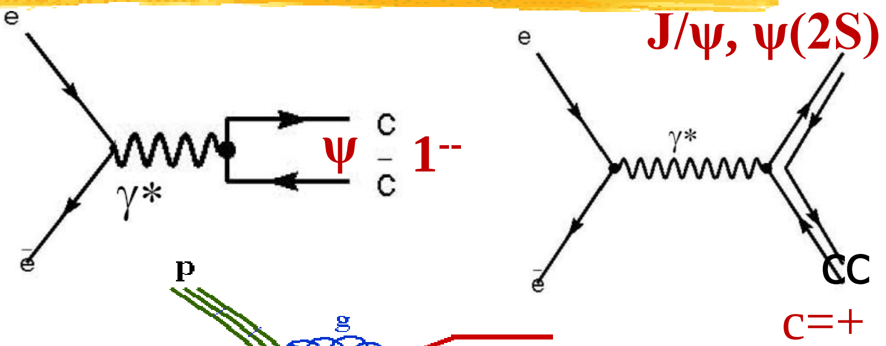
Question time

Thanks for your attention!

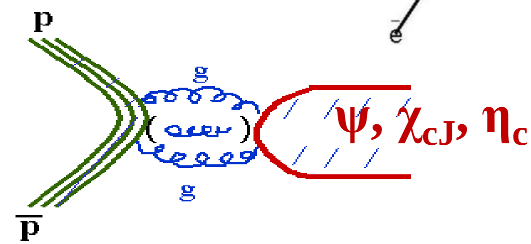
Spare slides

How to produce Charmonium states

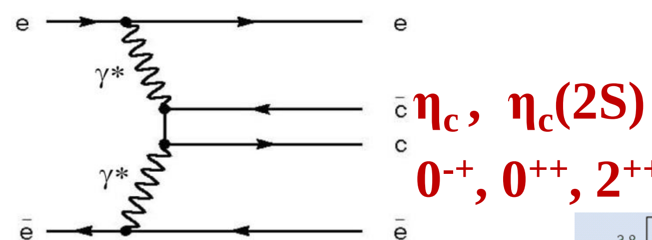
1. e^+e^- annihilation (including ISR/double charmonium)



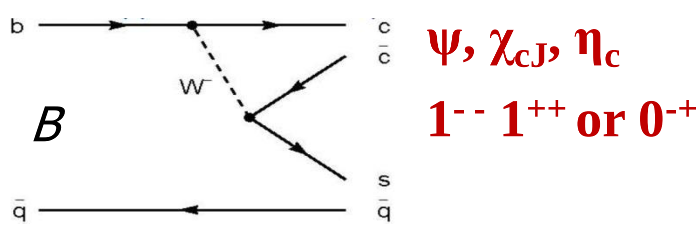
2. $p\bar{p}$ annihilation



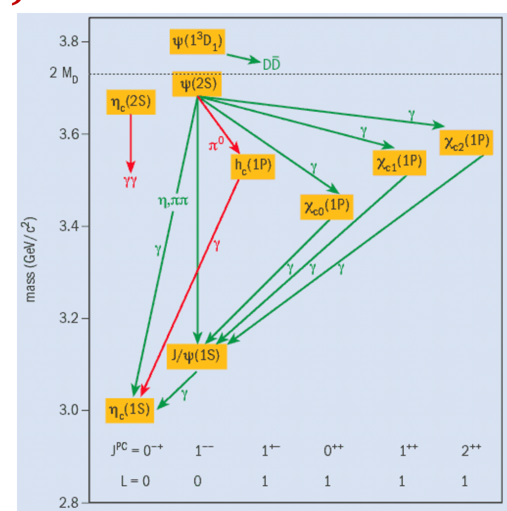
3. Two-photon process



4. B decays



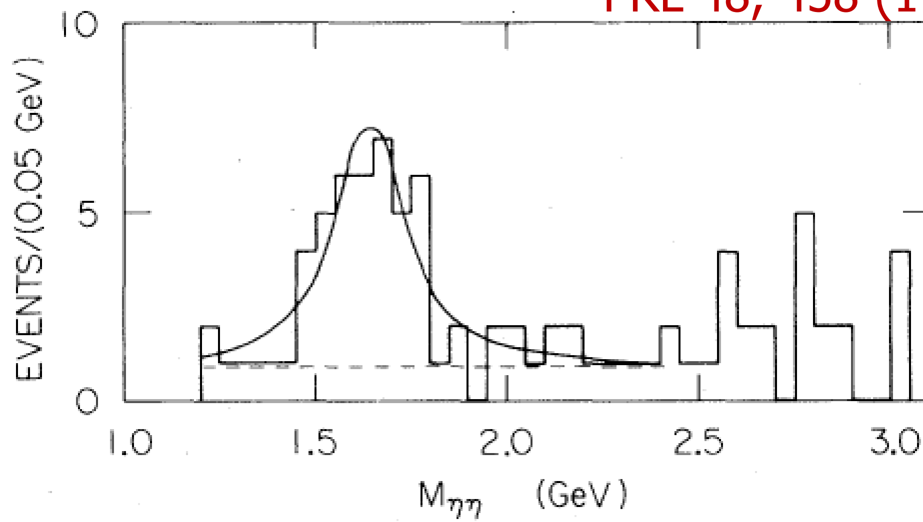
5. Charmonium transition



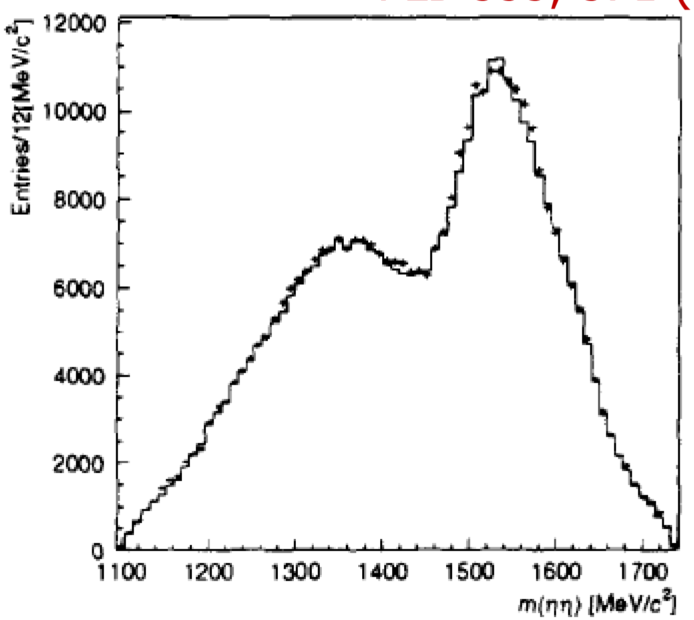
$J/\psi \to \gamma\eta\eta$

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

PRL 48, 458 (1982)

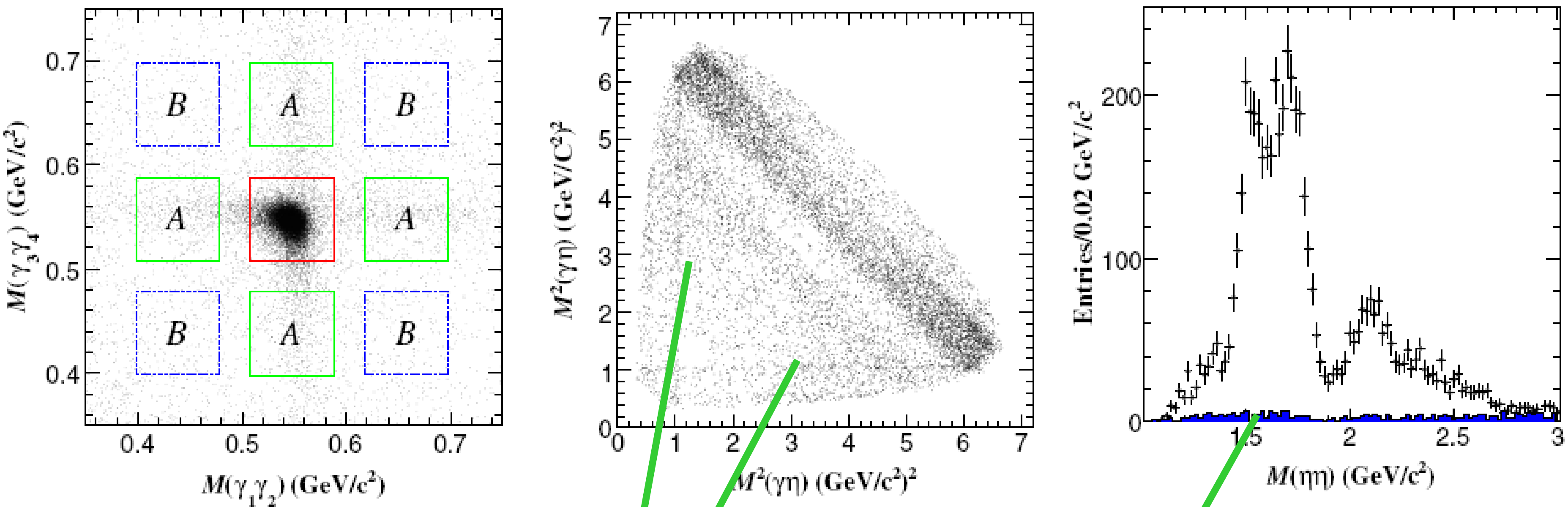


PLB 353, 571 (1995)



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

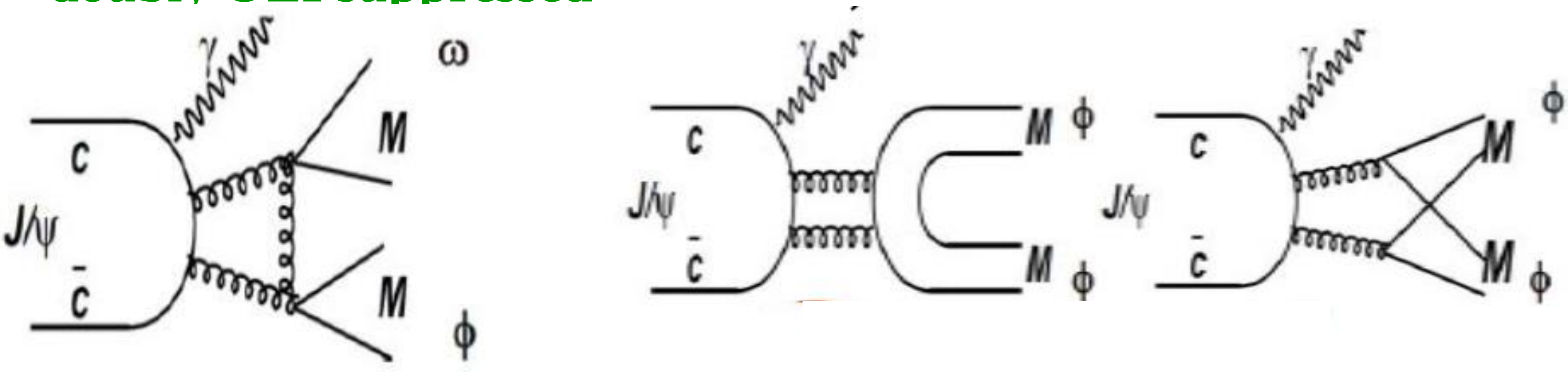
PRD 87, 092009



- **$J/\psi \to \phi\eta$, $\phi \to \gamma\eta$:**
  - select events outside ϕ window
- **background:**
  - low and mostly non-η background,
  - estimanted by η sidebands (blue shadow)
- **background subtraction:**
  - $\ln \mathcal{L}^{\text{signal}} = \ln \mathcal{L}^{\text{data}} - \ln \mathcal{L}^{\text{sideband}}$

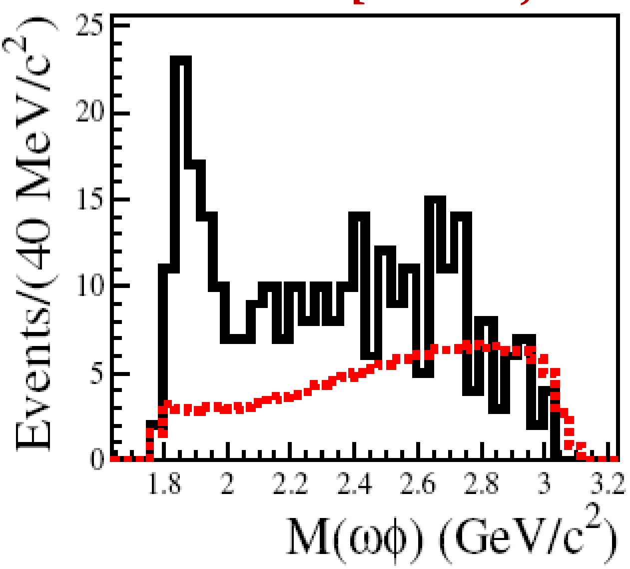
$J/\psi \to \gamma\omega\phi$

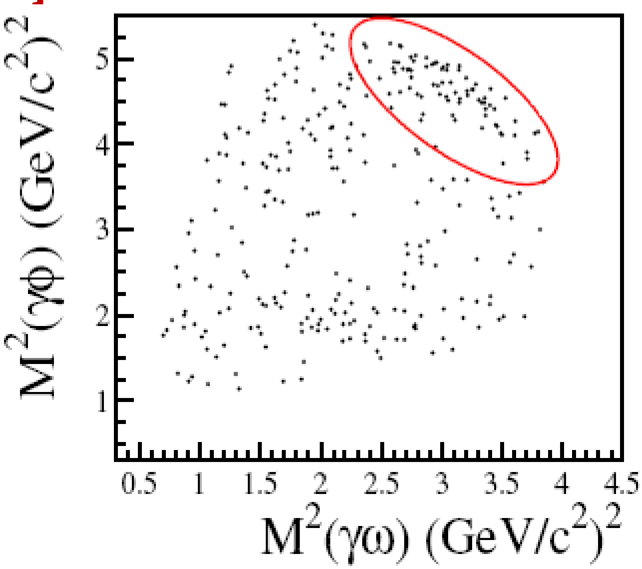
- **doubly OZI suppressed**



$\psi \to \gamma\omega\phi$ (DOZI) **predicted ∝ 1/10** **$\psi \to \gamma\phi\phi$ (OZI)**

- **BESII:** **[PRL 96, 162002]**





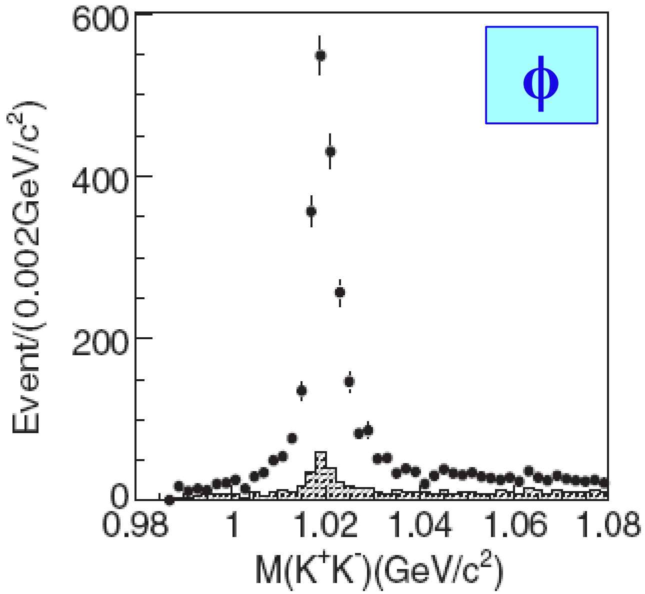
$M = (1812^{+19}_{-26} \pm 18)$ MeV/c^2

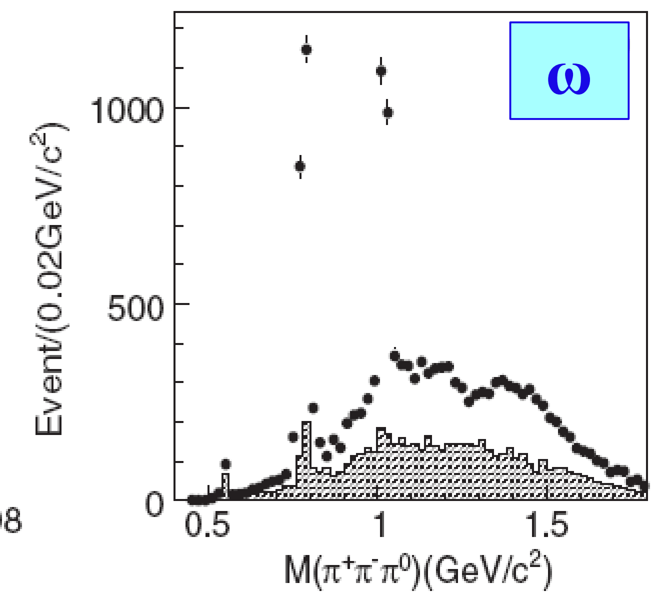
$\Gamma = (105 \pm 20 \pm 28)$ MeV/c^2

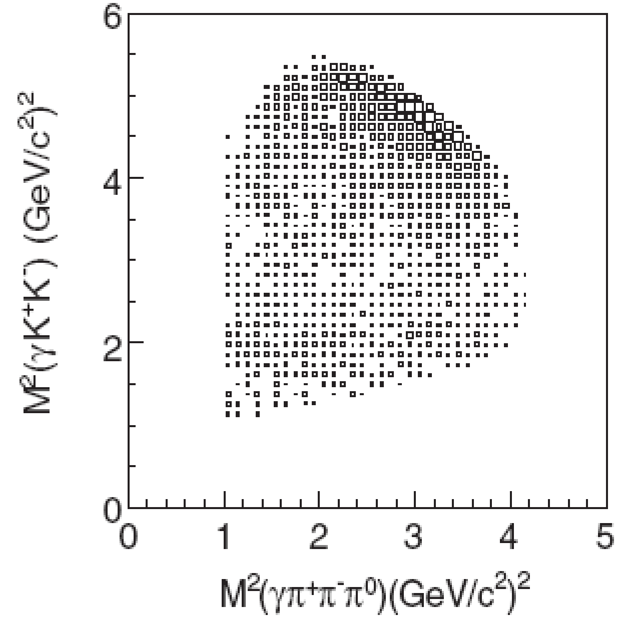
0^{++} favoured over 0^{-+} and 2^{++}

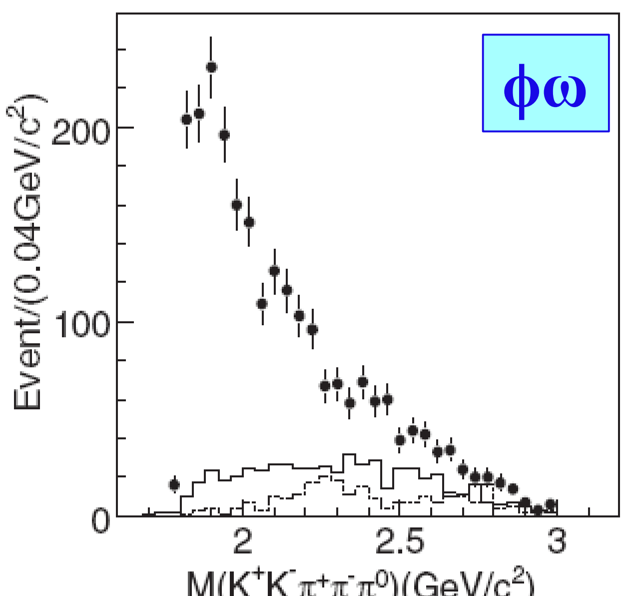
BESIII: PWA of $J/\psi \to \gamma\omega\phi$

PRD 87, 032008







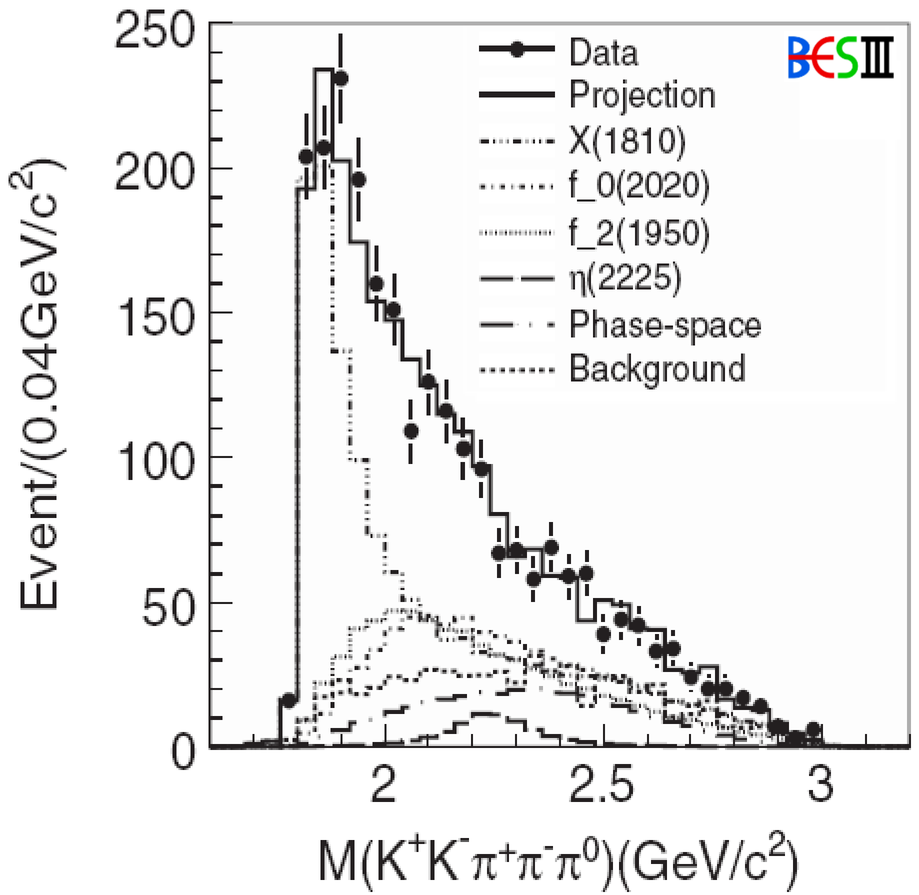


- **solid:**
  - background estimated from sidebands
- **dashed:**
  - inclusive J/ψ MC samples
- **background subtraction:**
  - $\ln \mathcal{L}^{signal} = \ln \mathcal{L}^{data} - \ln \mathcal{L}^{sideband}$

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

PRD 87, 032008

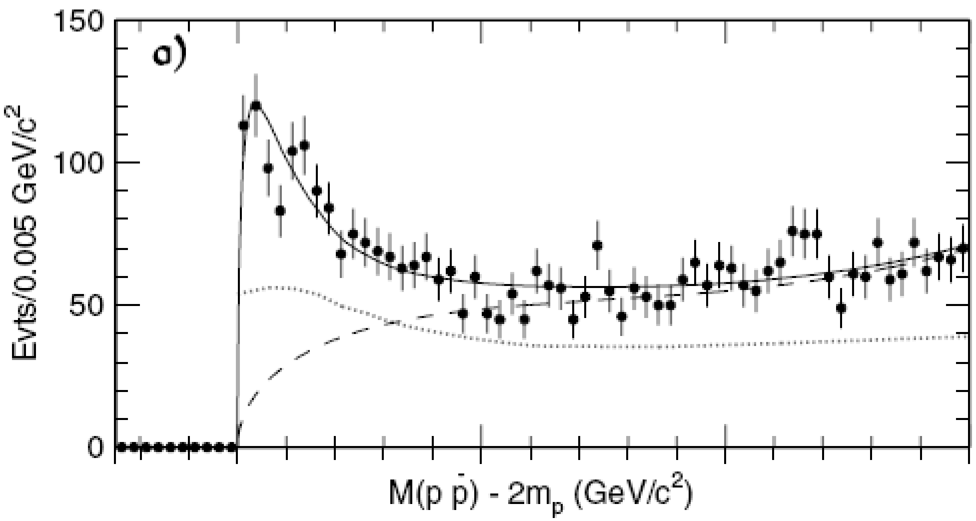
- **looking for best solution:**
  - M, Γ and J^{PC} of X(1810)
  - other know mesons [PDG]
  - different J^{PC} of phase space
  - different combinations of additional mesons [PDG]
- **best solution:**
  X(1810), $f_0(2020)$,$f_2(1950)$, $\eta(2225)$, $f_0(2020)$, phase space and background
- **systematic 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



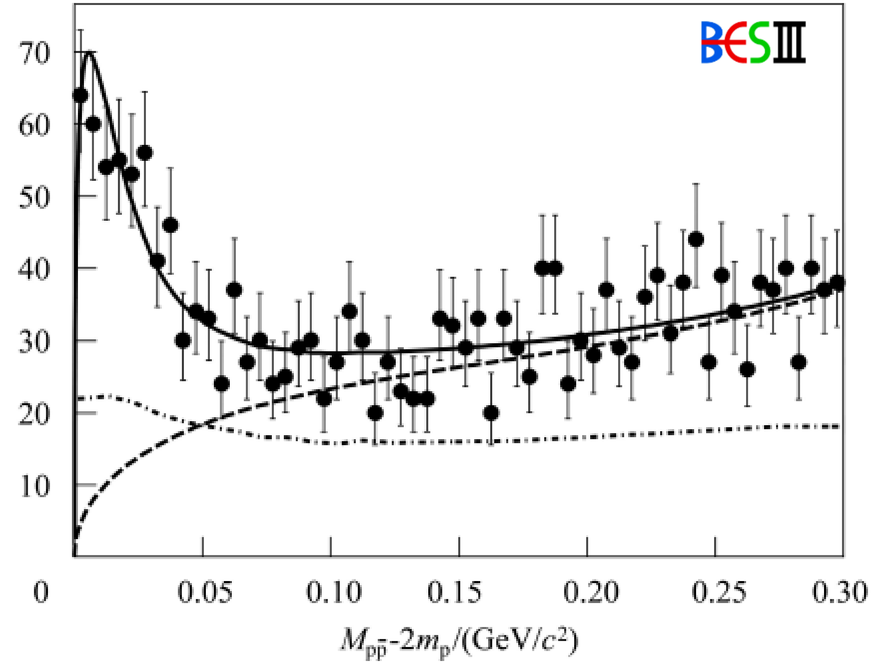
$J/\psi \to \gamma p\bar{p}$: enhancement at threshold

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

BESII: PRL 91, 022001 (2003)



BESIII: CPC 34 , 421 (2010)



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

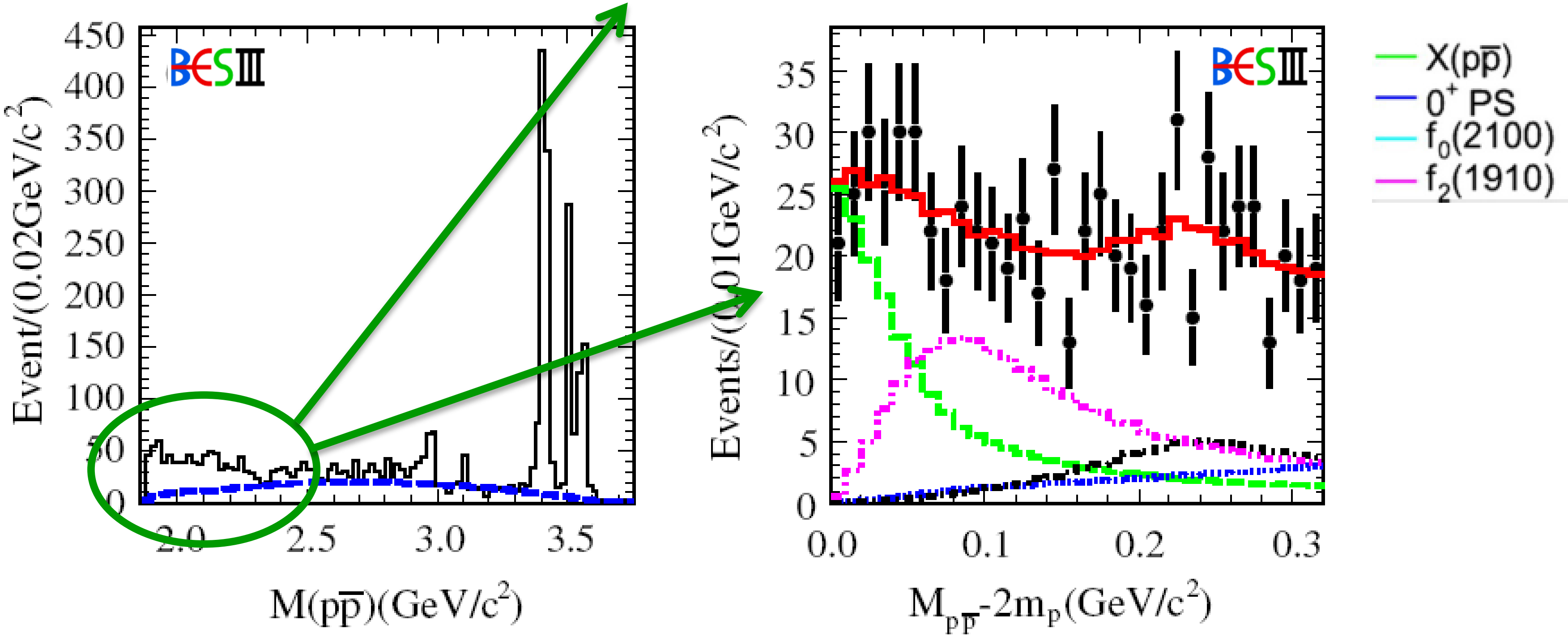
M = $(1861^{+6}_{-13}\ {}^{+7}_{-26})$ MeV/c^2
Γ < 30 MeV/c^2 (90% C.L.)
compatible with S-wave BW

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

BESIII: PWA of $\psi(2S) \to \gamma p\bar{p}$, 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

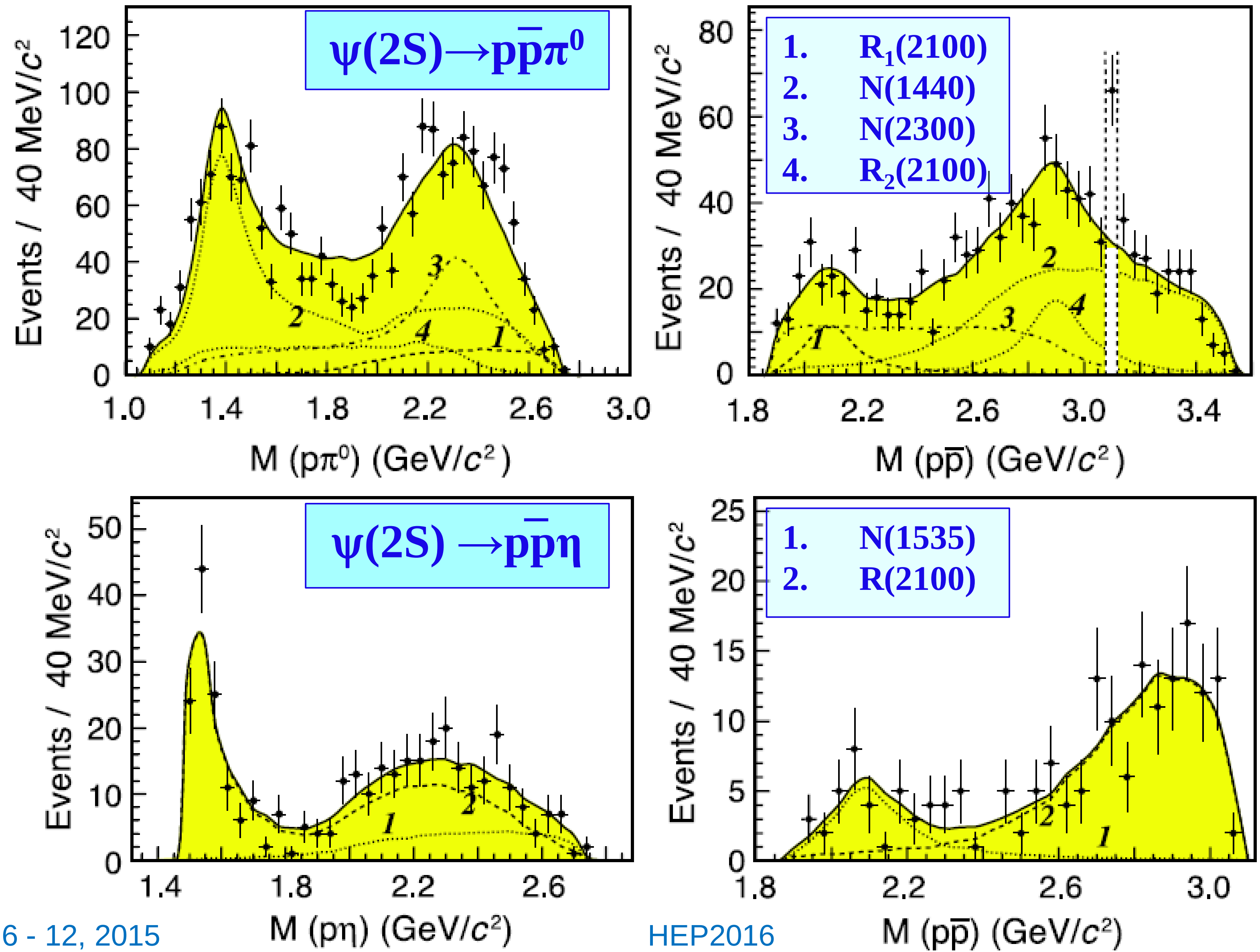
$$\mathcal{B}(\psi(2S)\to\gamma X(pp)) \times \mathcal{B}(X(pp)\to pp) =$$

$$4.57\pm0.36(\text{stat})^{+1.23}_{-4.07}(\text{sys})\pm1.28(\text{mod}))\times10^{-6}$$

$$R = \frac{\mathcal{B}(\psi(2S)\to\gamma X(p\bar{p}))}{\mathcal{B}(J/\psi\to\gamma X(p\bar{p}))} = 5.08^{+0.71}_{-0.45}(\text{stat})^{+0.67}_{-3.58}(\text{sys})\pm0.12(\text{mod}))\% < 12\%!$$

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

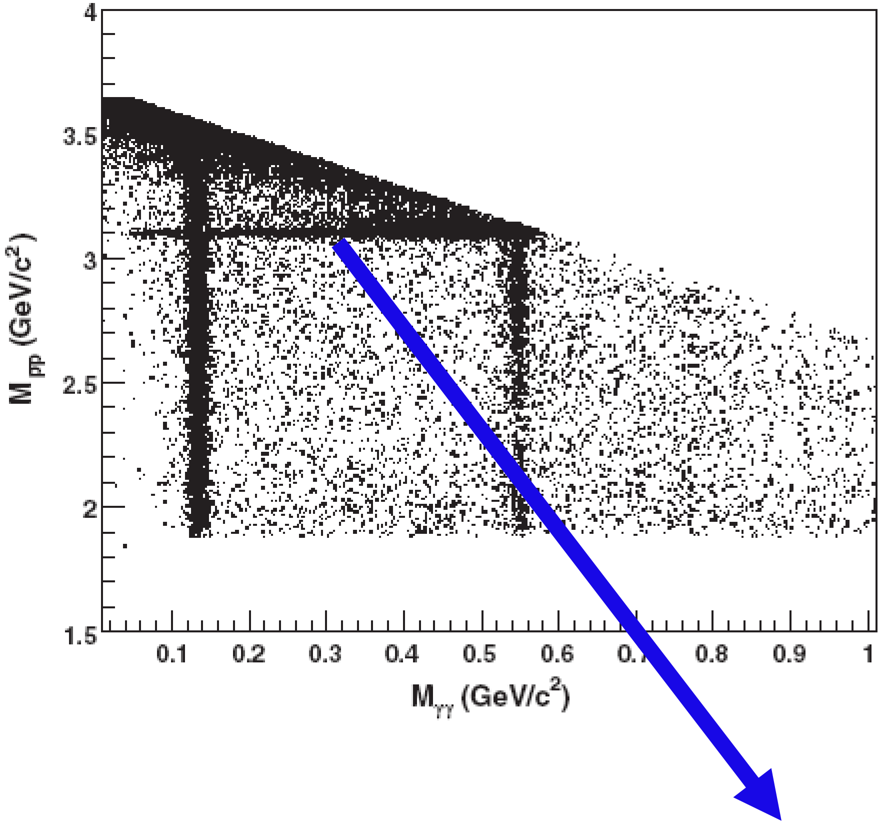
CLEOc: 24.5 M $\psi(2S)$ [PRD 82, 092002]

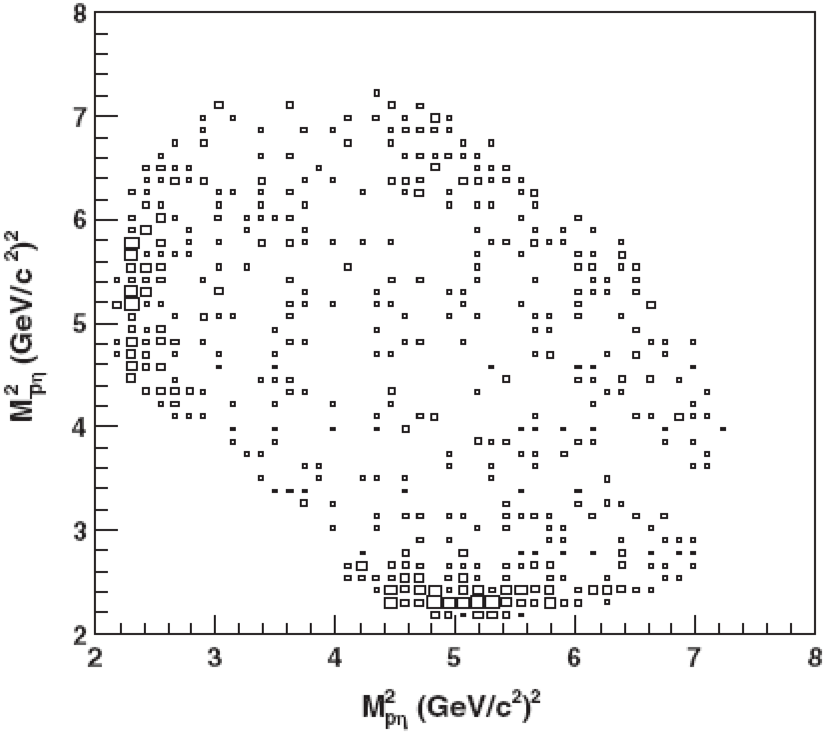


Without interference effects

BESIII: PWA of $\psi(2S) \to p\bar{p}\eta$

PRD 88, 032010

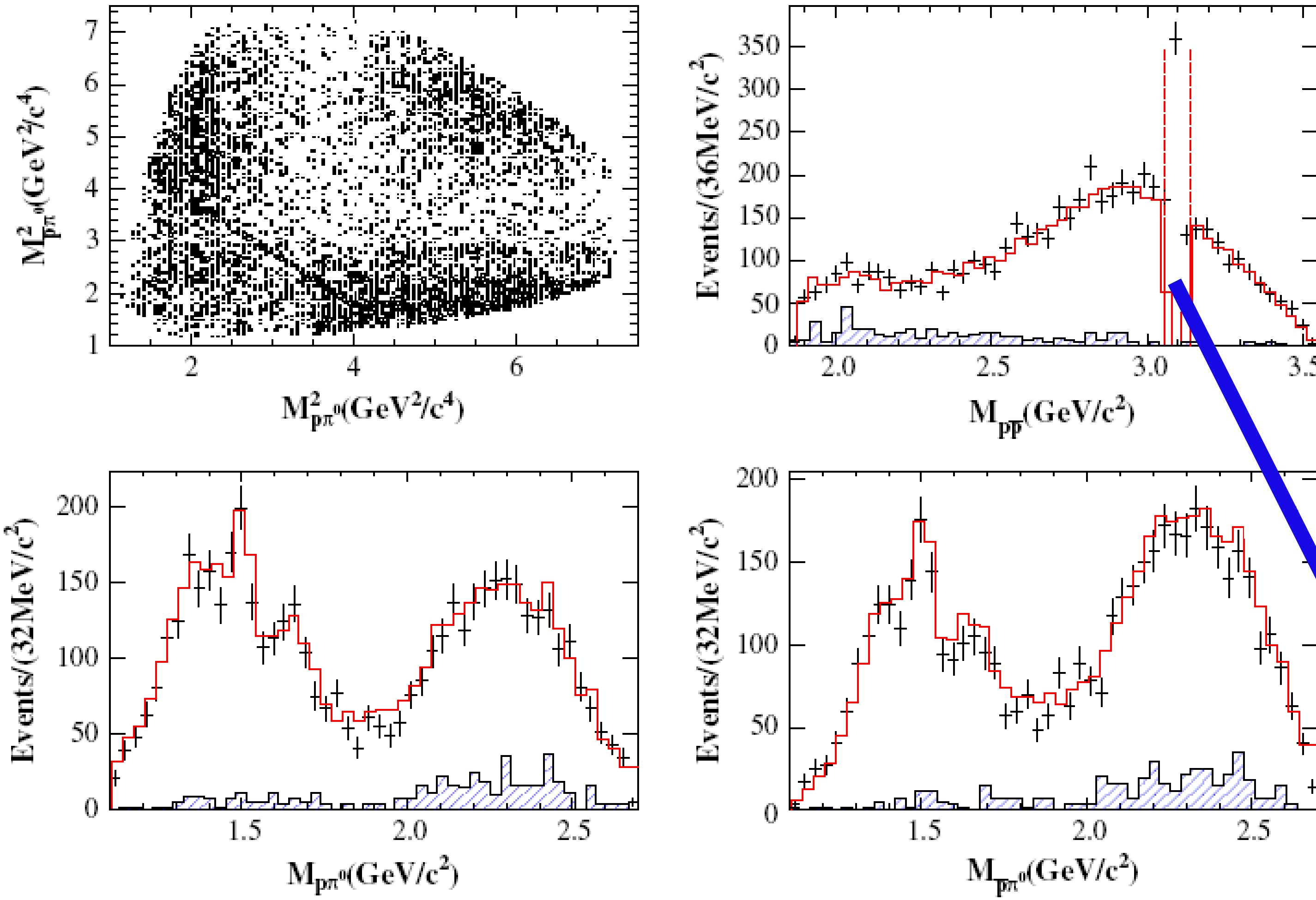




$\psi(2S) \to J/\psi\ X$, $J/\psi \to p\bar{p}$ subtracted

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

PRL 110, 022001



shaded:

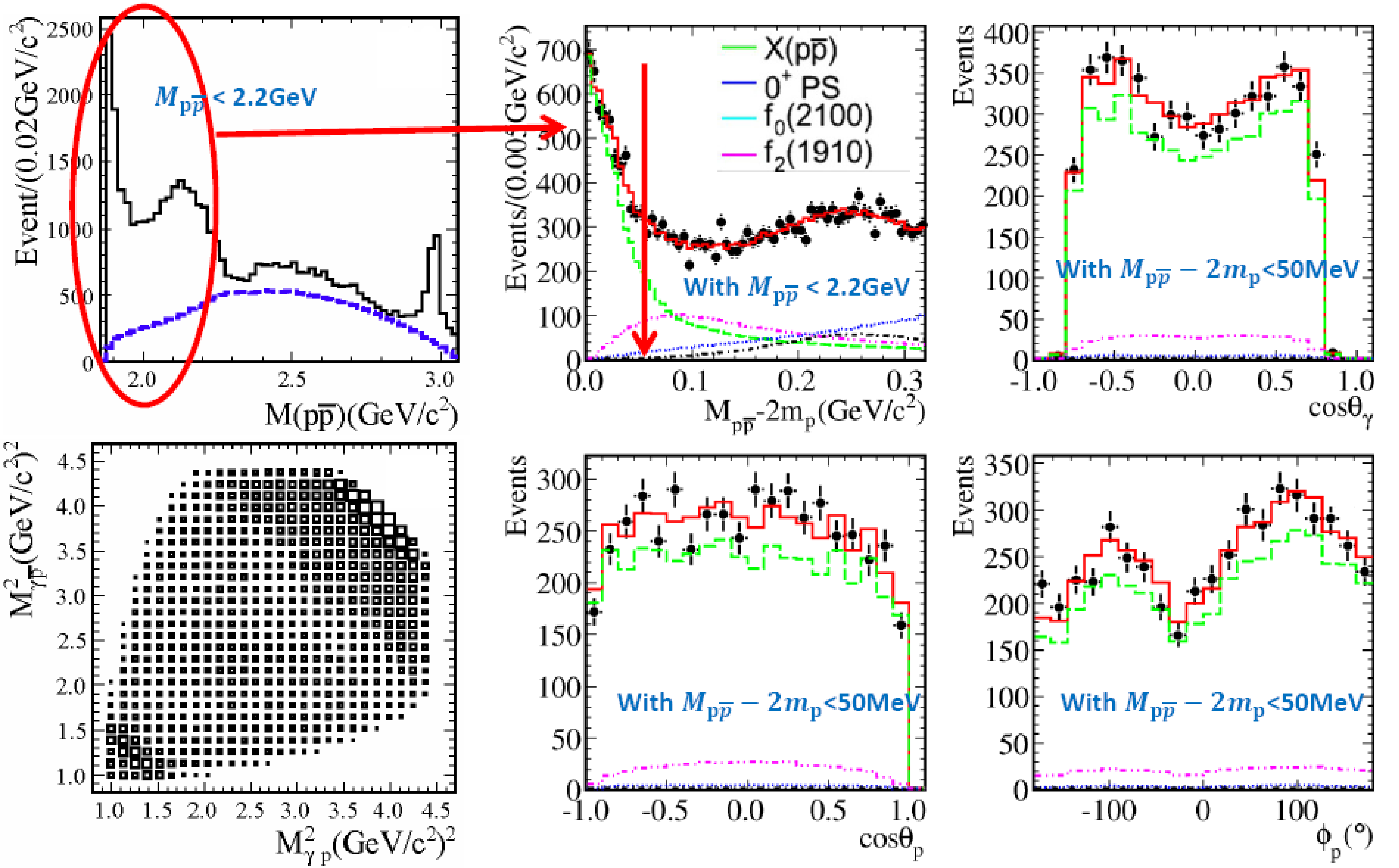
background:

- continuum
- non-π^0 background

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

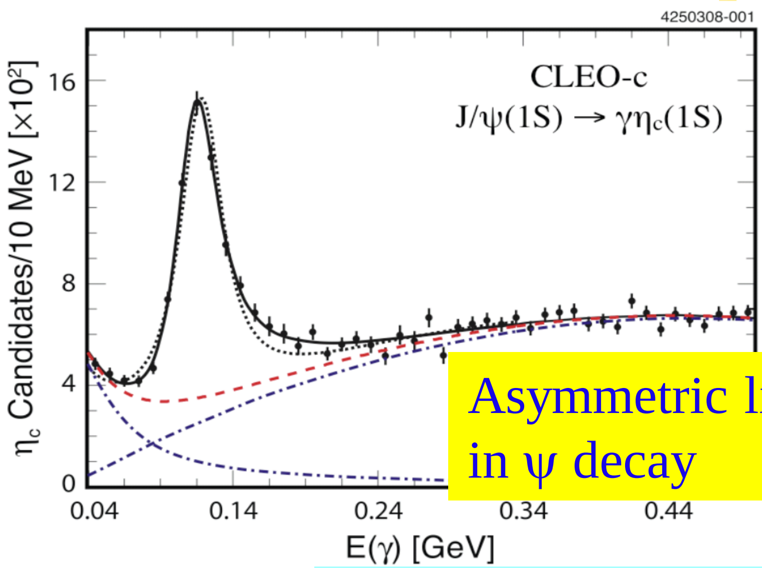
BESIII: PWA of $J/\psi \rightarrow \gamma p\bar{p}$, $M_{p\bar{p}}$<2.2 GeV

PRL 108, 112003

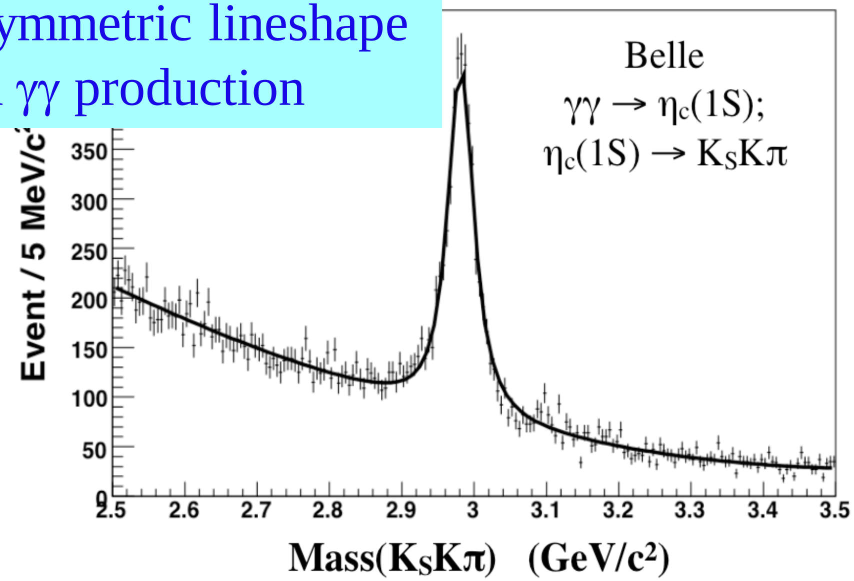


BESIII: η_c parameters from $\psi(2S) \to \pi^0 h_c(1P)$, $h_c(1P) \to \gamma\eta_c(1S)$

PRD 86, 092009

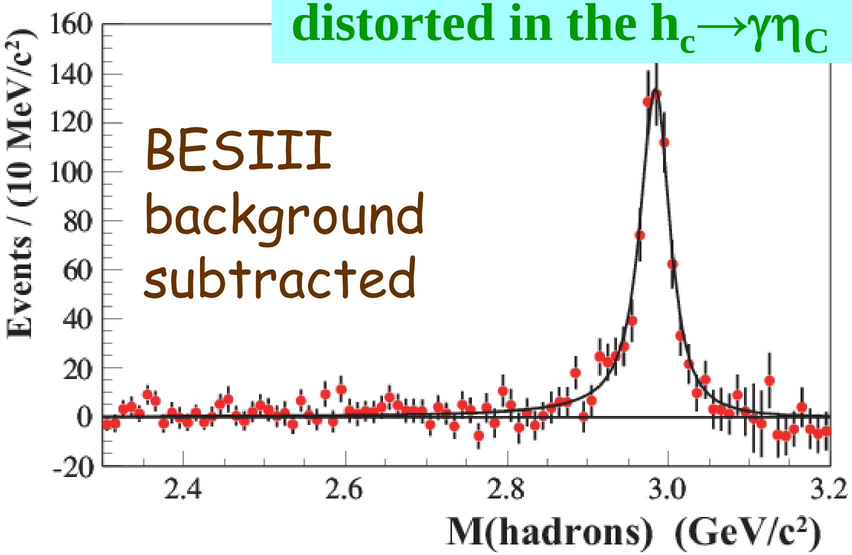


Asymmetric lineshape in ψ decay



Symmetric lineshape in $\gamma\gamma$ production

The η_C lineshape is not distorted in the $h_c \to \gamma\eta_C$



- CLEO-c observe a distortion of η_c lineshape in charmonium radiative decay

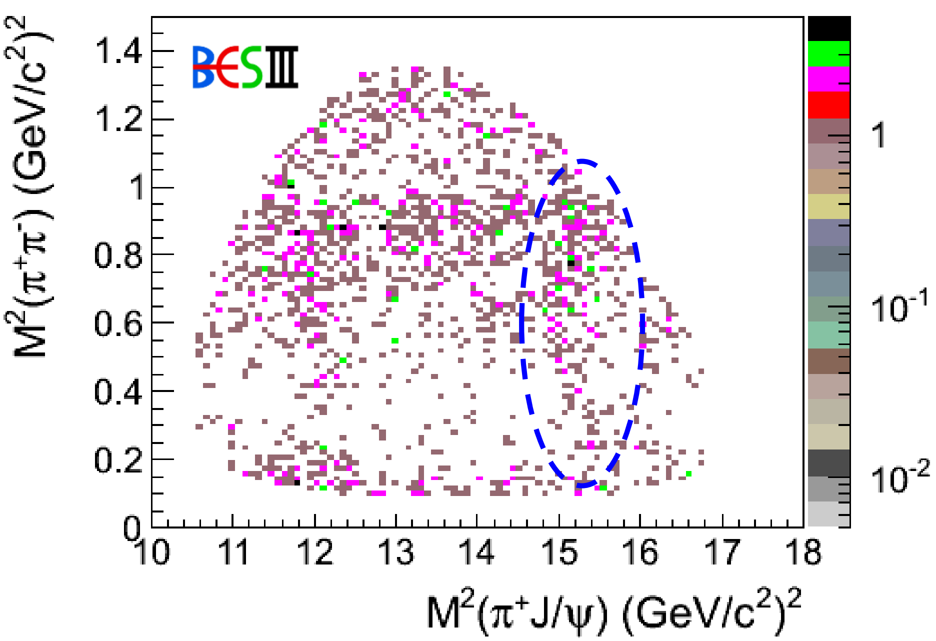
  PRL102, 011801 (2009)

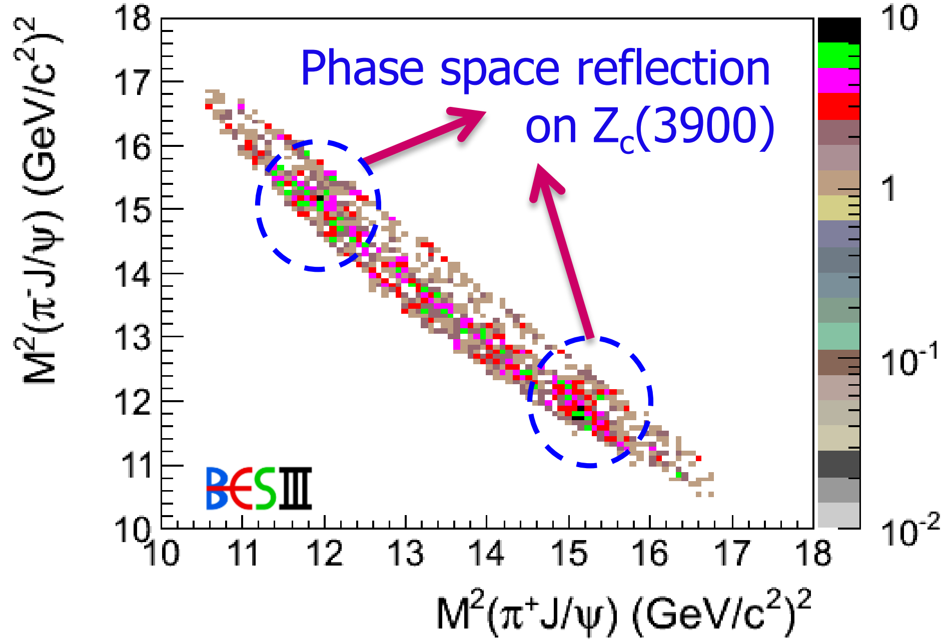
- The lineshape of η_c from BELLE is symmetric

- The abnormal line shape is also observed in BESIII exclusive channels in $\psi' \to \gamma\eta_c$ but not in $\psi' \to \to \pi^0 h_c$, $h_c \to \gamma\eta_c$

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

PRL 110, 252001

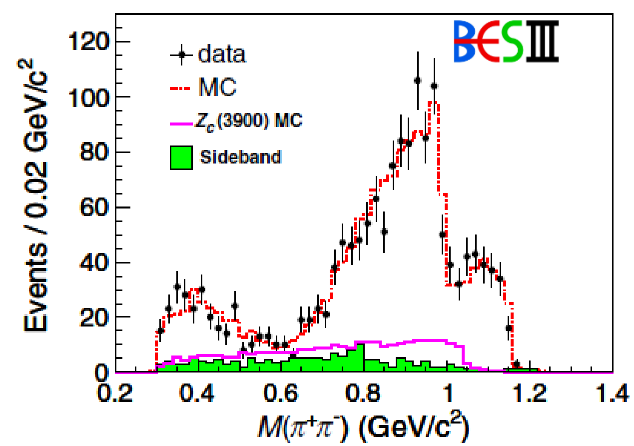




Modelling $\pi^+\pi^-$ with know structure:

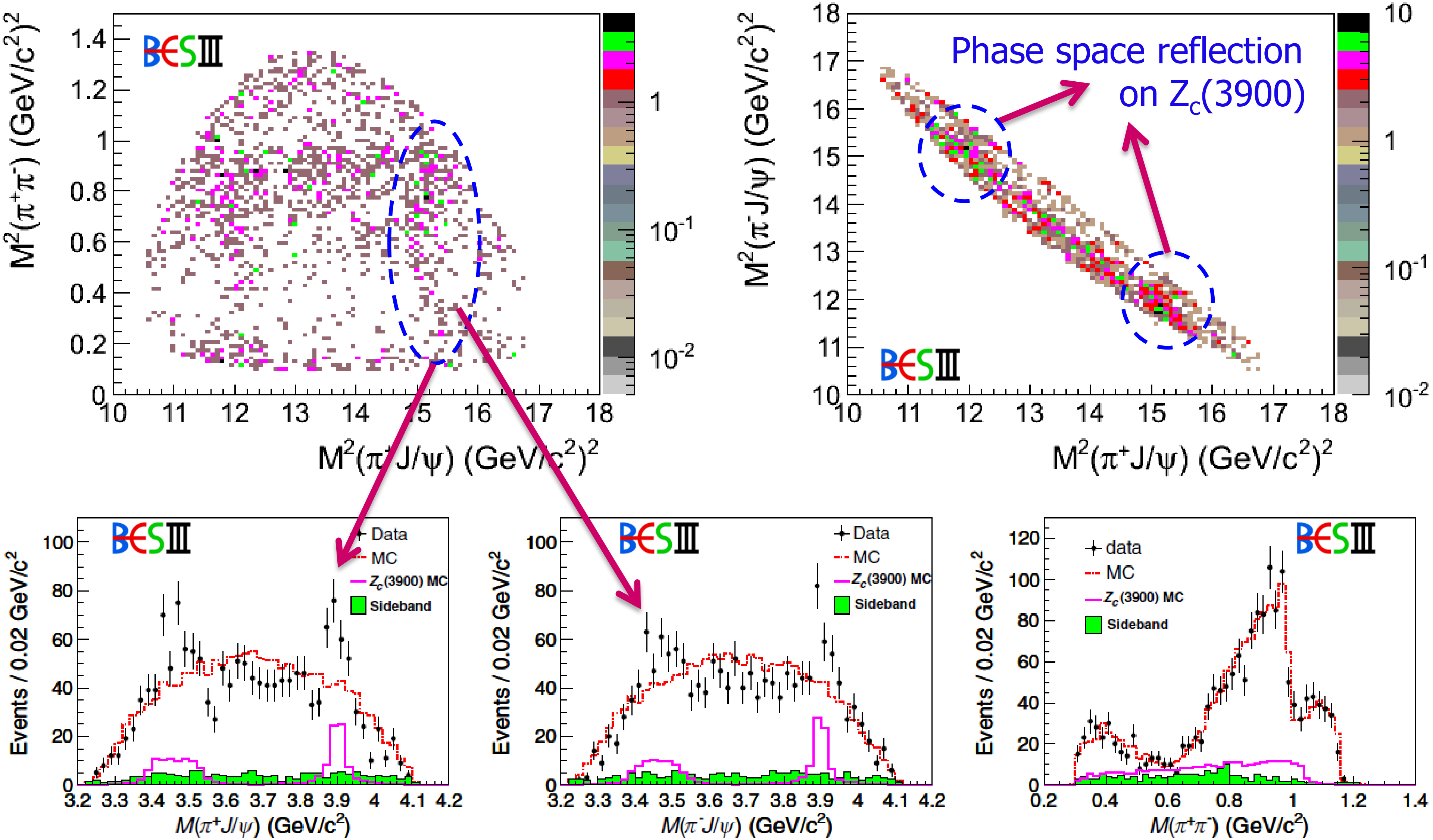
- $f_0(500)$
- $f_0(980)$
- non-resonant

Fits quite well $\pi^+\pi^-$ projection



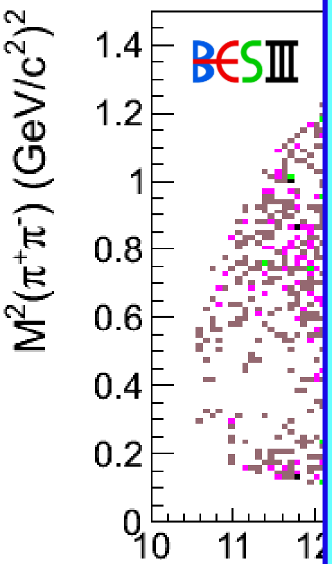
BESIII: $e^+e^- \to \pi^+\pi^- J/\psi$ @ 4.260 GeV

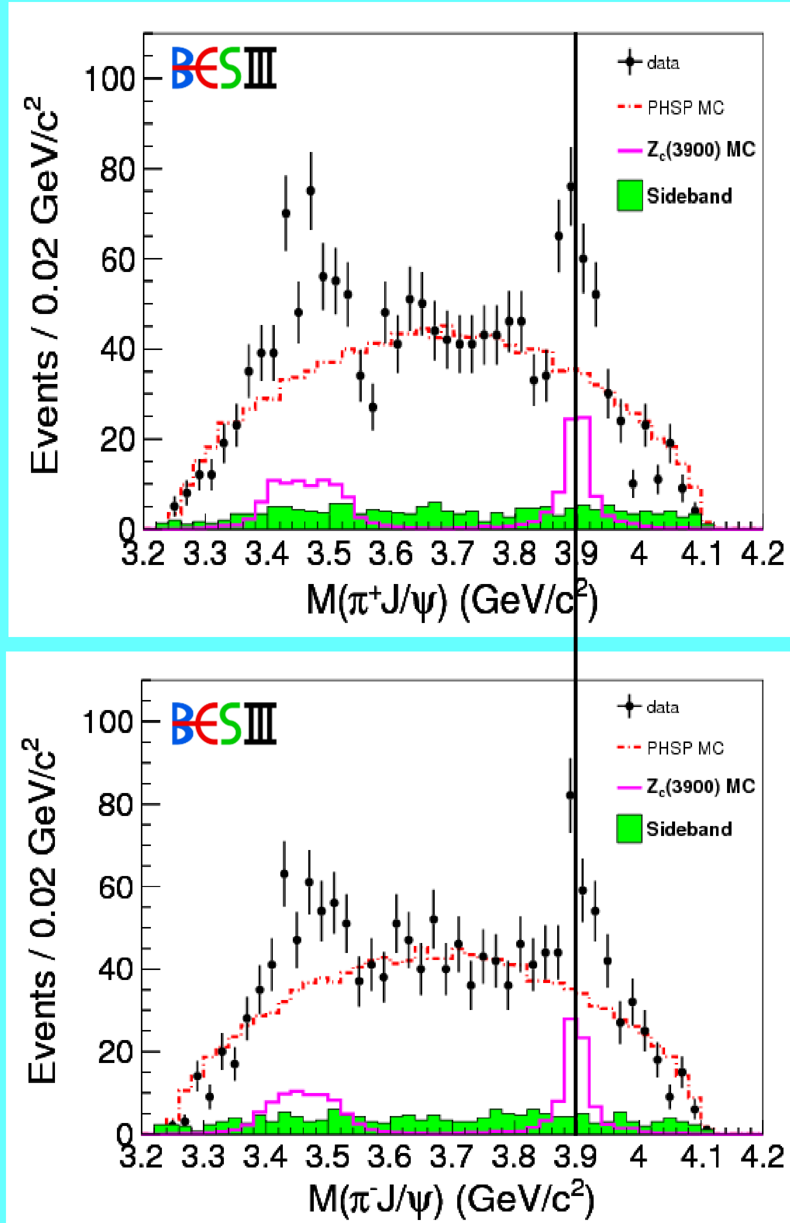
PRL 110, 252001

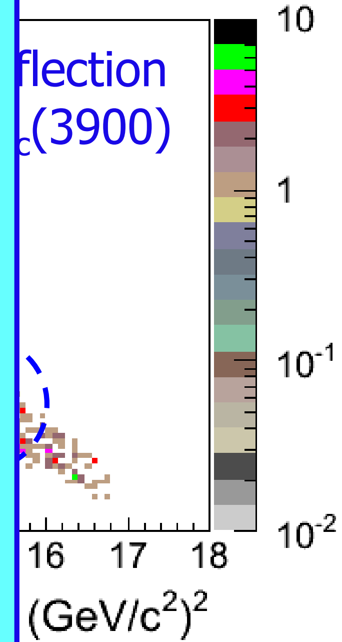


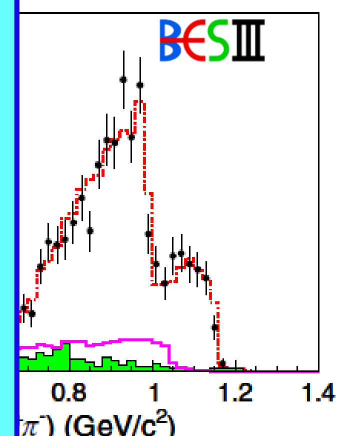
BESIII: $e^+e^- \to \pi^+\pi^- J/\psi$ @ 4.260 GeV

PRL 110, 252001





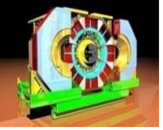




Modellin

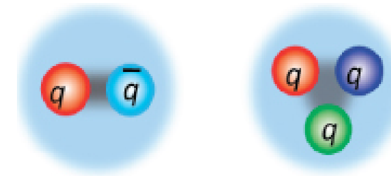
- f_0(500
- f_0(980
- non-r

Fits quit

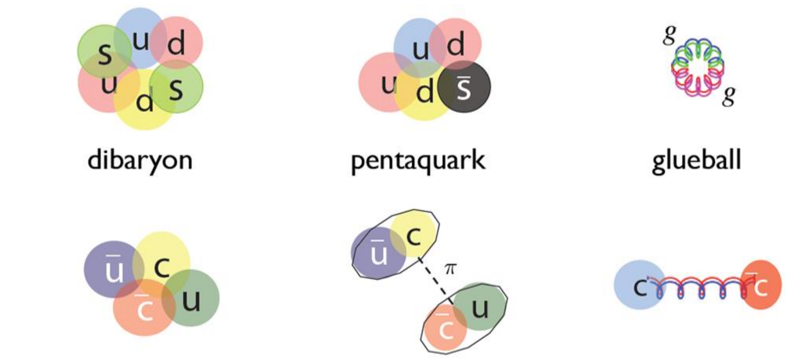


Hadronic exotic states

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



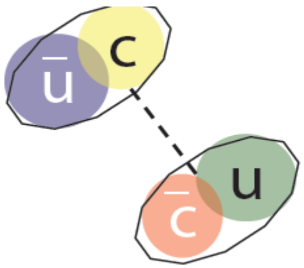
- **QCD suggests:**
  - **Confinement : stable hadrons need to be colorless**
  - **Gluon-gluon interactions : hadron with gluons (hybrids and glueballs) could exist**
  - **Allow hadrons with $N_{quarks} \neq 2, 3$ (multi-quarks)**



Can we find evidence for these interesting exotic hadrons?

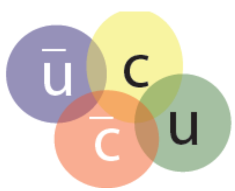
A long history of searching for the exotic hadron,
no solid conclusion was reached in past a few decades,
some hints on charmomium-like and bottomnium-like particles, recently.

Exotic Meson (Charmonium-Like)



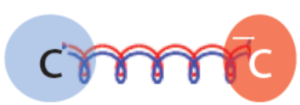
Molecular states:

- 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

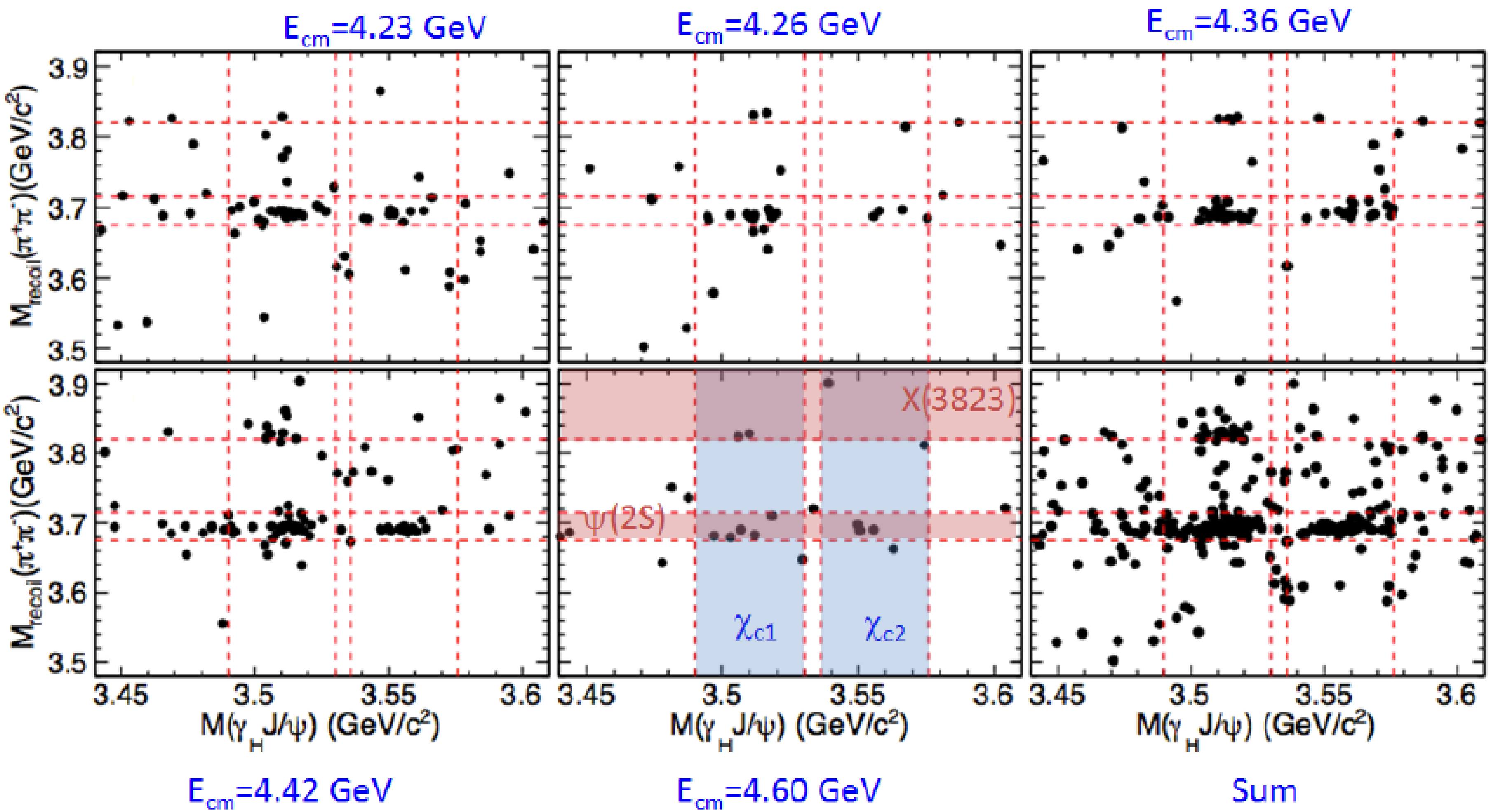


Hybrids:

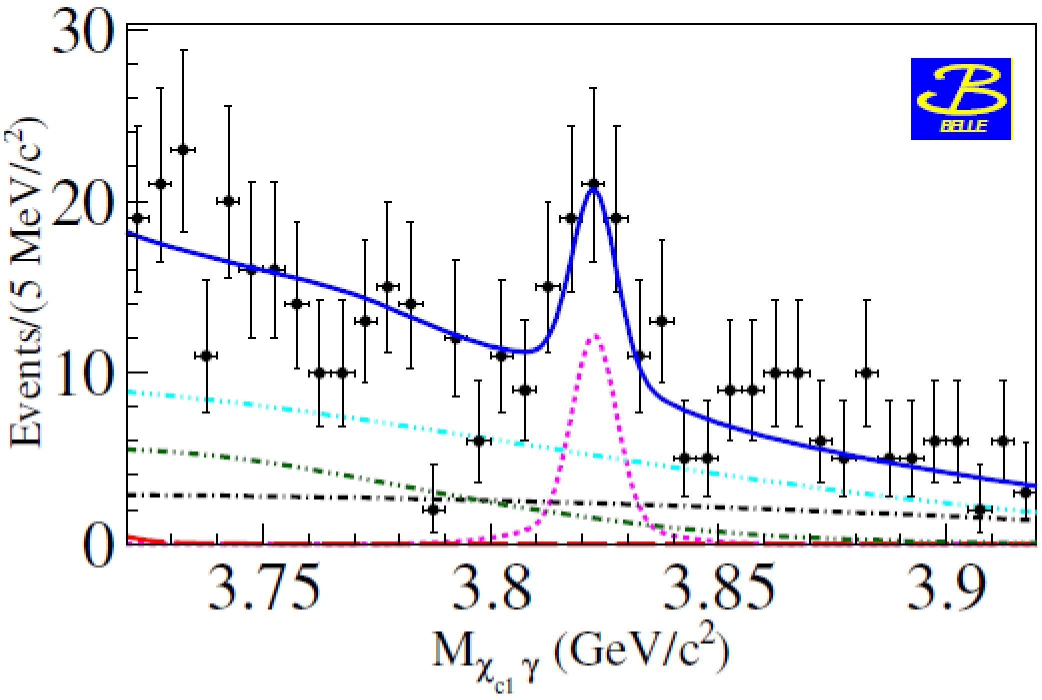
- bound states with a pair of quarks and one excited gluon
- Lattice and model predictions for lowest lying charmonium hybrid m~4200 MeV

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

- Reconstructing $\chi_{c1,2} \to \gamma J/\psi \to \gamma l^+l^-$
- Consider recoiling mass against the $\pi^+\pi^-$ system: $M(\pi^+\pi^-)$ in 5 large data set: total luminosity ~ 4.1 fb^{-1}



BELLE: X(3823)



- using $772 \cdot 10^6$ $B\bar{B}$
- $B \rightarrow K\ \gamma\chi_{c1}$

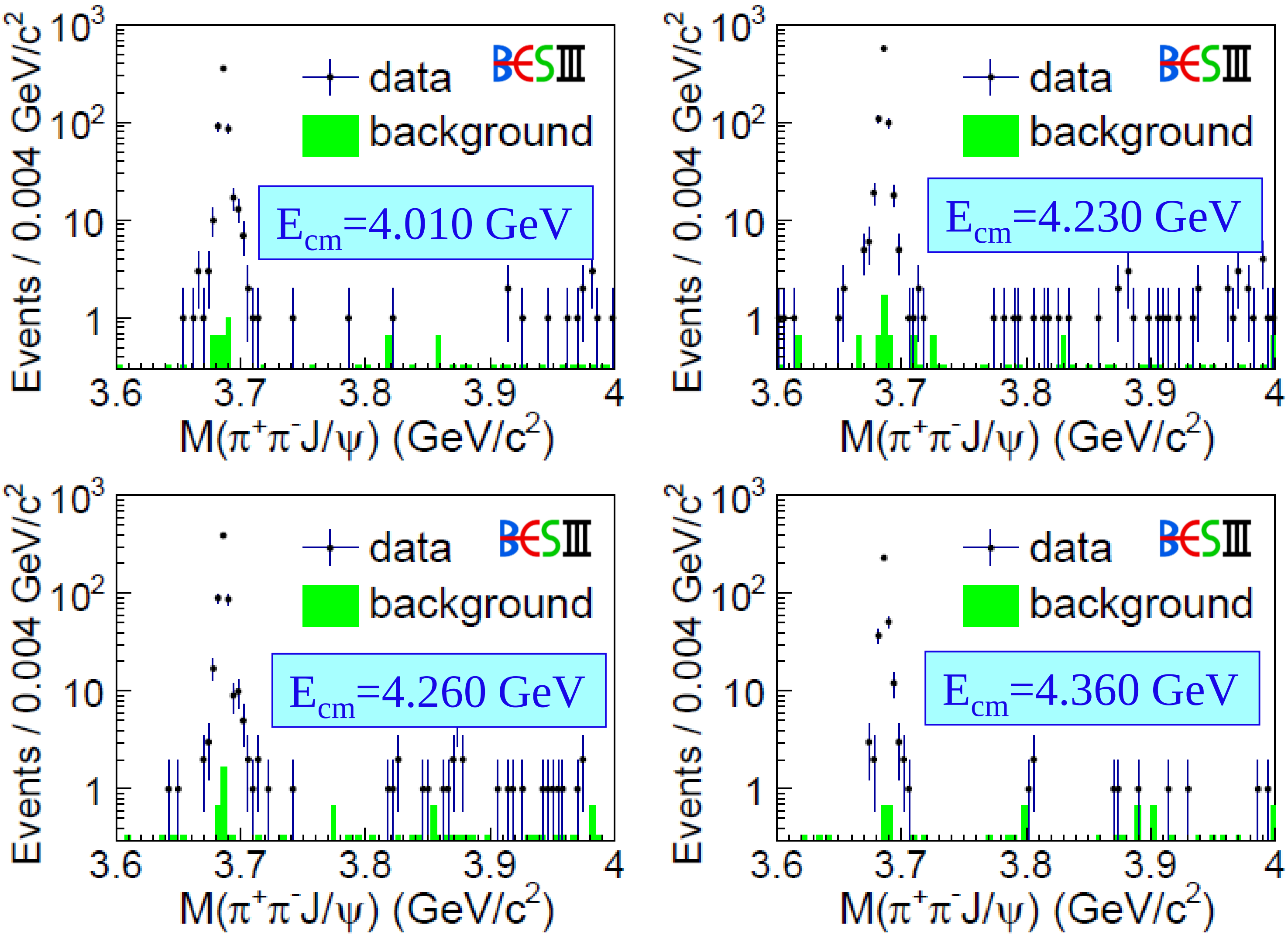
M = (3823.1±1.8±0.7) MeV/c²
3.8σ

Mass and width compatible with a $\psi_2(1^3D_2)$ state

BESIII: $e^+e^- \to \gamma X(3872) \to \gamma\pi^+\pi^- J/\psi$

PRL 112, 092001

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



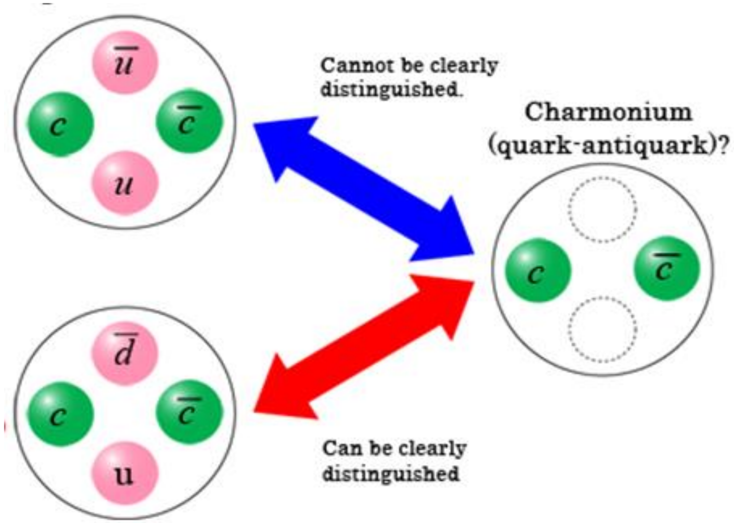
Z_c states

The most promising way to searching for the exotic hadrons

- Decay into a charmonium or $D^{(*)}\bar{D}^{(*)}$ pair
  - thus contains hidden-$c\bar{c}$ 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 : $e^+e^- \to \pi^{\pm}$ +Exotics, ….
  - Belle/BaBar : $e^+e^- \to (\gamma_{ISR})\pi^{\pm}$+Exotics, ….
  - Belle/BaBar/LHCb: $B \to K^{\pm}$+Exotics, …

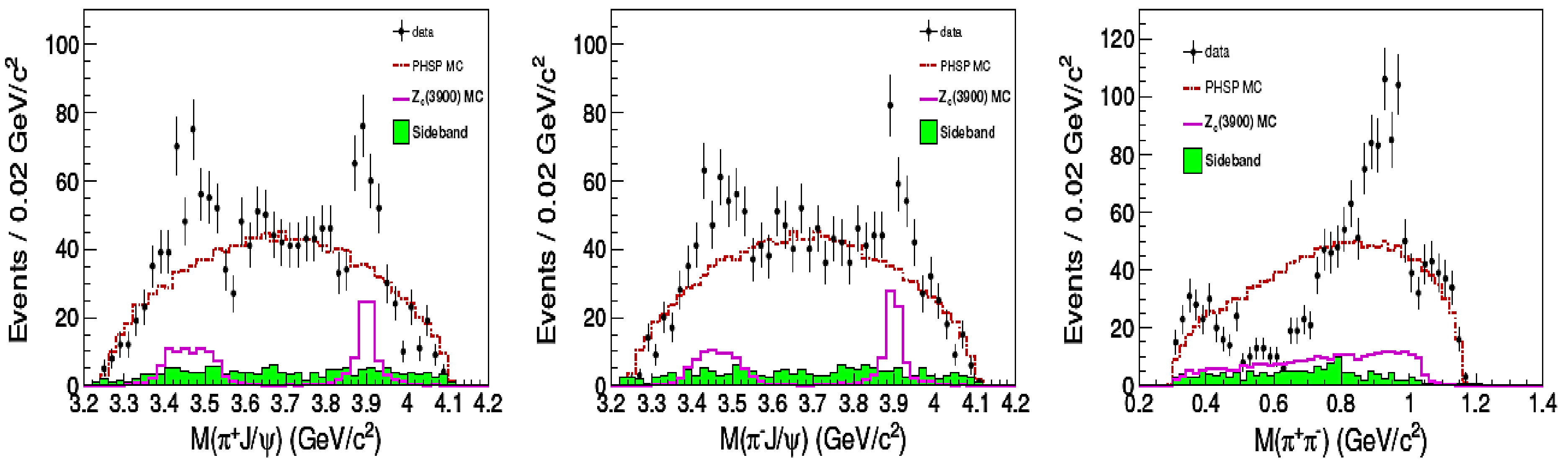


BESIII: $e^+e^- \to \pi^+\pi^- J/\psi$

PRL 110, 252001

Is it a real signal?

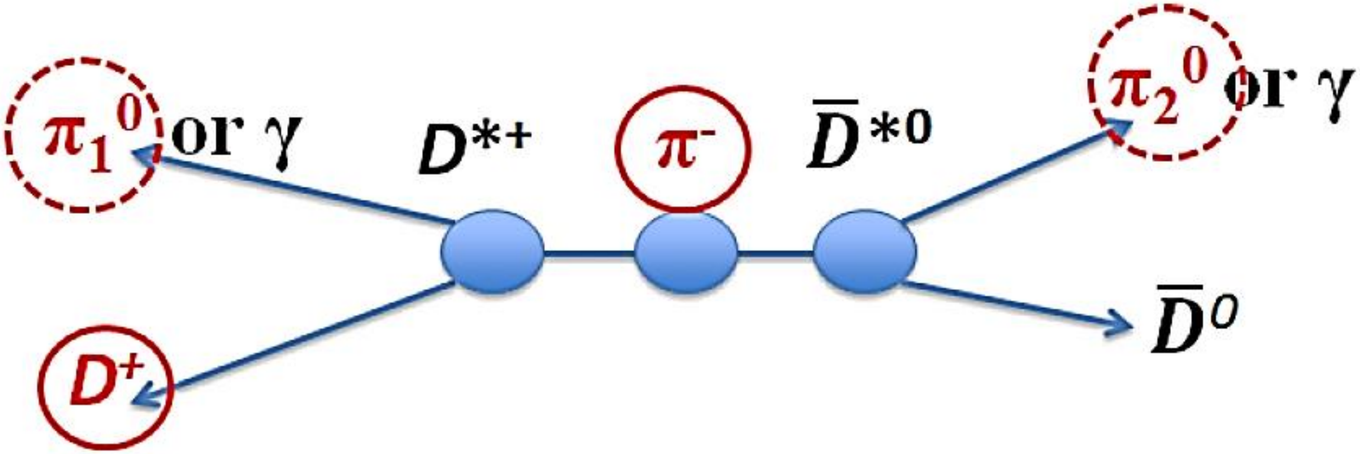
• Is it due to $\pi^+\pi^-$ S-wave states, like σ, $f_0(980)$, …?	N
• Is it due to $\pi^+\pi^-$ D-wave states, like $f_2(1270)$, …?	N
• Are there two states, one at 3.4, the other 3.9 GeV?	N
• Exist in both e^+e^- & $\mu^+\mu^-$ samples?	Y
• Exist in both $\pi^+\pi^-$ low mass and high mass samples?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



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

hep-ex:1308.2760

- **827 pb^{-1}** data at E_{CM}=4.260 GeV
- Tag a D^+ and a bachelor π^-, reconstruct one π^0 to suppress the background.



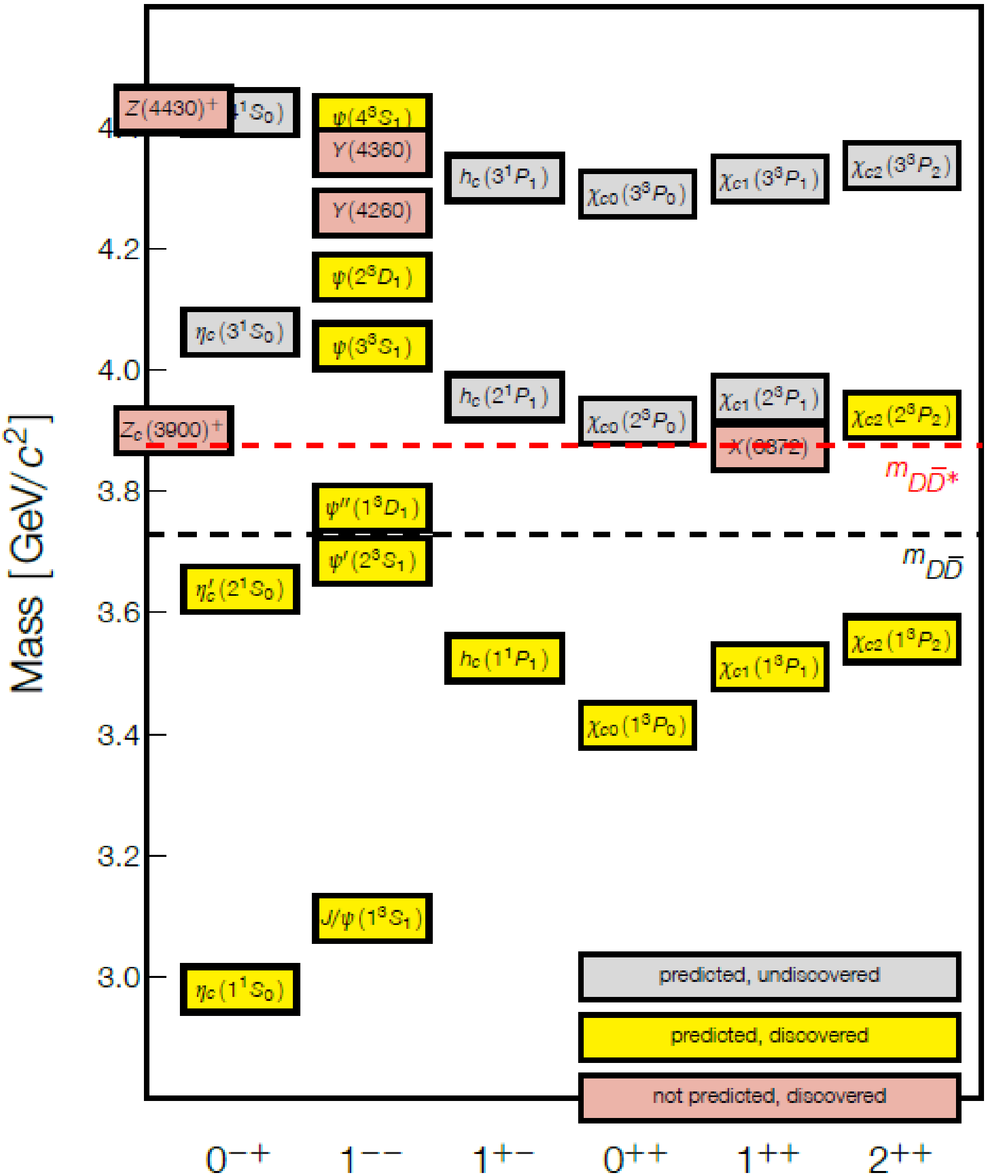
Topology of the decays of the signal process:

- thick line circled: D^+ and π^- detected in the final states
- dashed line circled: at least of π_1^0 or π_2^0 tagged

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

PRL 112, 022001

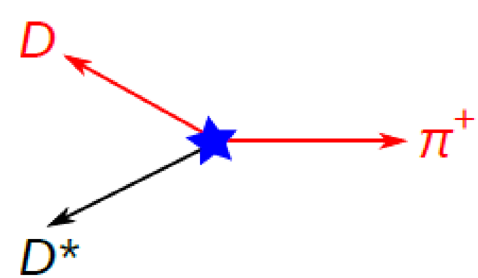
525 pb^{-1} data @ 4260 MeV: single tag analysis



Decay mode $Z_c(3900)^+ \to (D\bar{D}^*)^+$?

Single tag analysis:

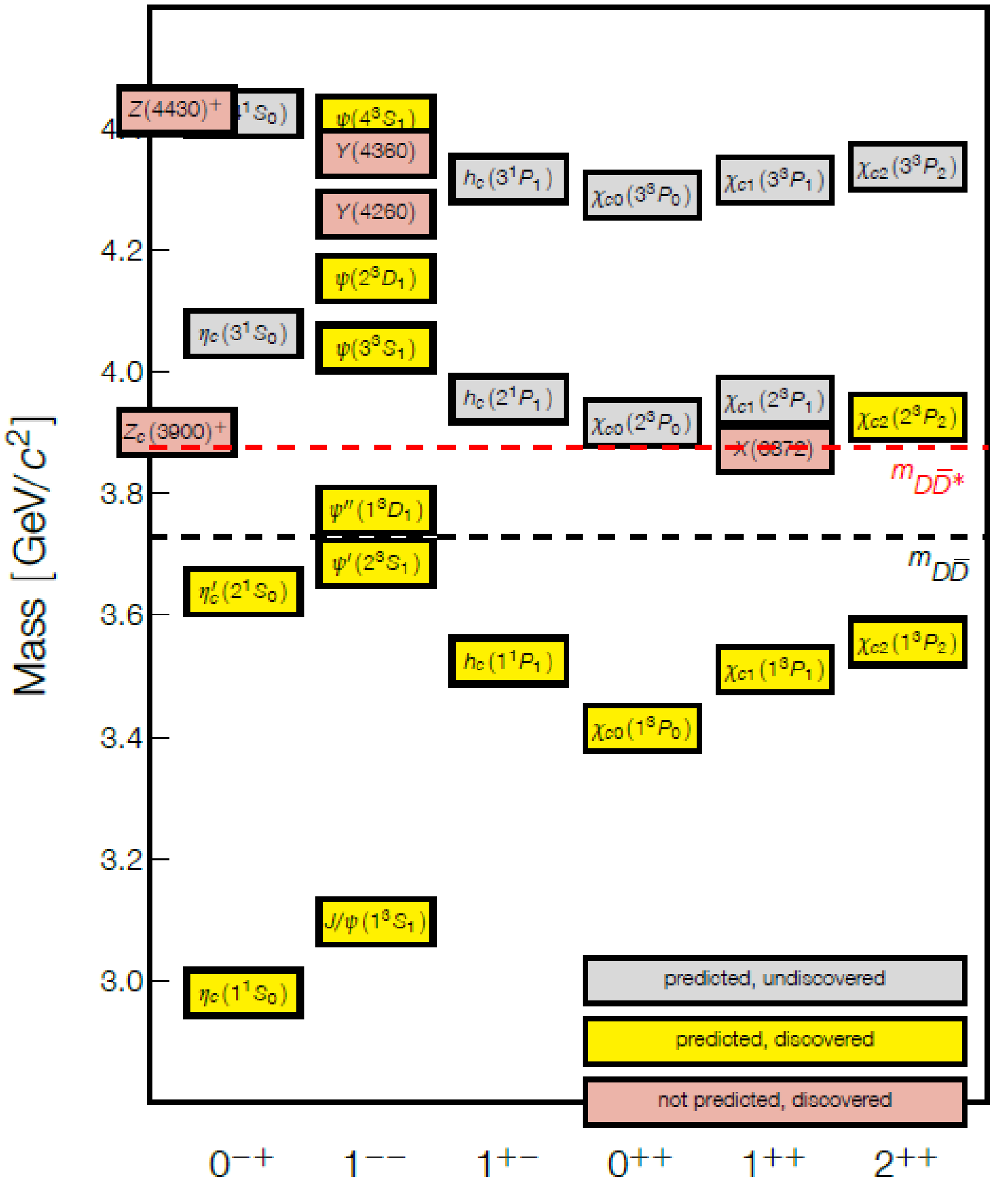
- reconstruct 'bachelor' π^+ and $D^0 \to K^-\pi^+$ or $D^- \to K^+\pi^-\pi^-$
- require D^* in missing mass
- veto $e^+e^- \to (D^*\bar{D}^*)^0$
- apply kinematic fit; look in mass recoiling against π^+



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

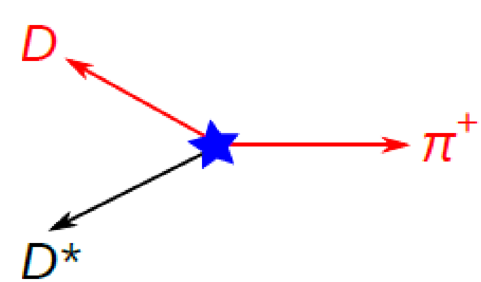
BESIII preliminary

525 pb^{-1} data @ 4260 MeV: double tag analysis



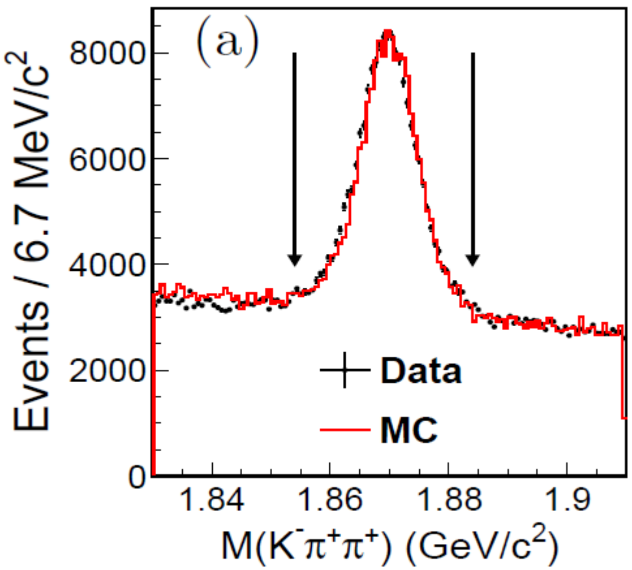
New: Double tag analysis

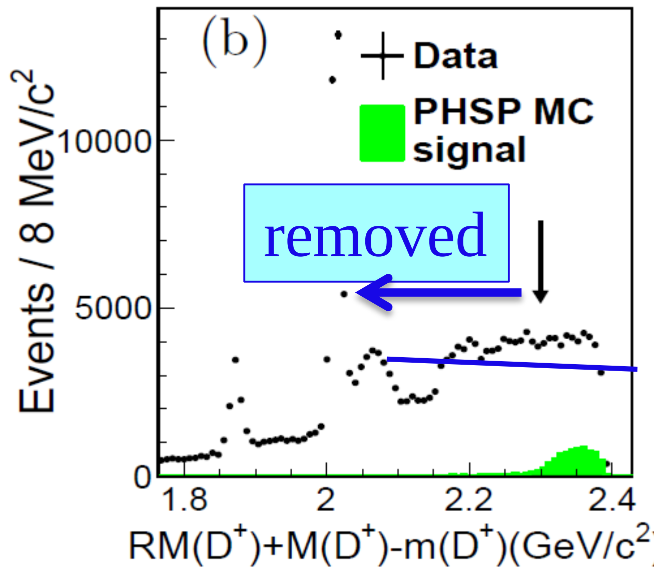
- reconstruct 'bachelor' π^+ and D^0, D^- in 4 or 6 decay modes
- require π from D^* in missing mass
- improved statistics, much better control over background shape improved systematics
- apply kinematic fit; look in mass recoiling against π^+



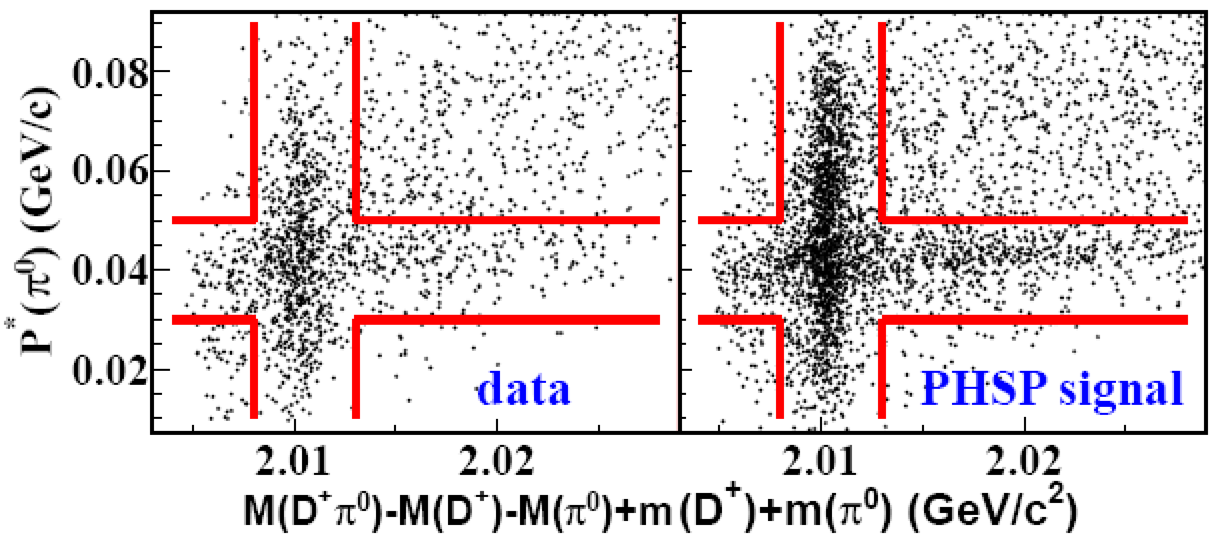
BESIII: $e^+e^- \to \pi Z_c(4025) \to \pi^- (D^*D^*)^+$+c.c. @ 4.260 GeV

hep-ex:1308.2760





Remove DD, DD*, D*D*, DsDs, …



BESIII: $Z_c(3885)^+$ quantum numbers?

PRD 92, 092006

525 pb^{-1} data @ 4260 MeV: **double tag analysis**

$\cos\theta_\pi$: angle between bachelor pion and beam axis in CMS

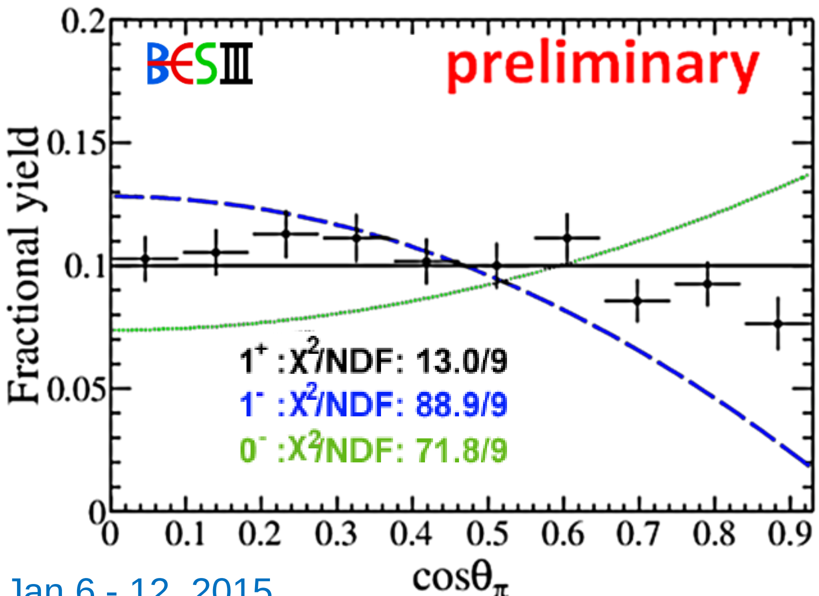
0^+ excluded by parity conservation

0^- π and $Z_c(3885)$ in P-wave, with $J_z = \pm 1$ $\rightarrow$ $dN/d\cos\theta_\pi \propto 1 - \cos^2\theta_\pi$

1^- π and $Z_c(3885)$ in P-wave $\rightarrow$ $dN/d\cos\theta_\pi \propto 1 + \cos^2\theta_\pi$

1^+ π and $Z_c(3885)$ in S or D wave;
assuming D wave small near threshold $\rightarrow$ flat distribution in $\cos\theta_\pi$

$e^+e^- \rightarrow \pi^+ D^0 D^{*-}$

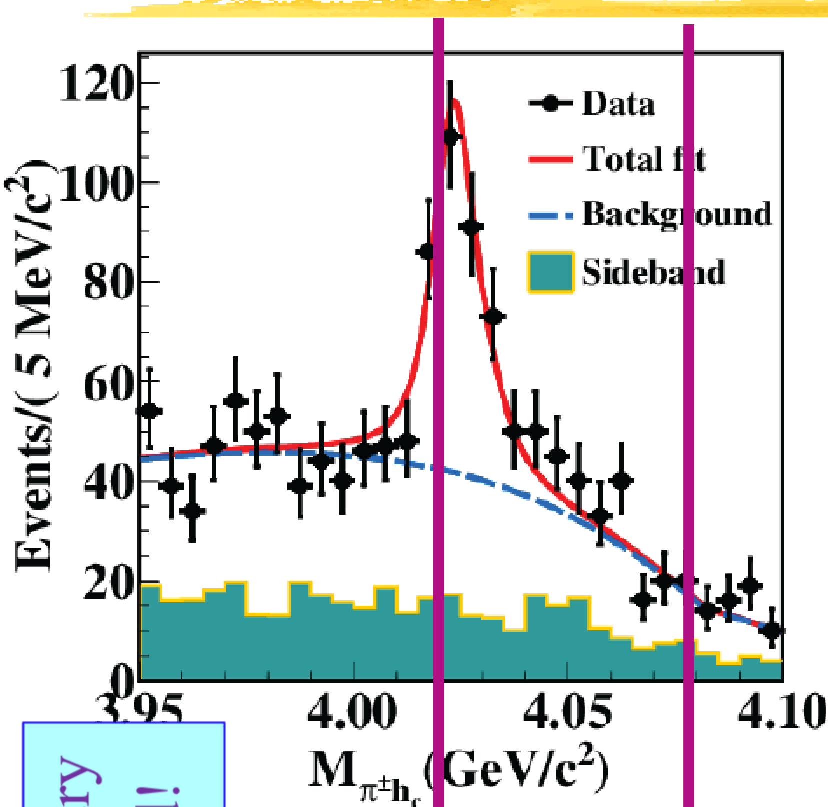


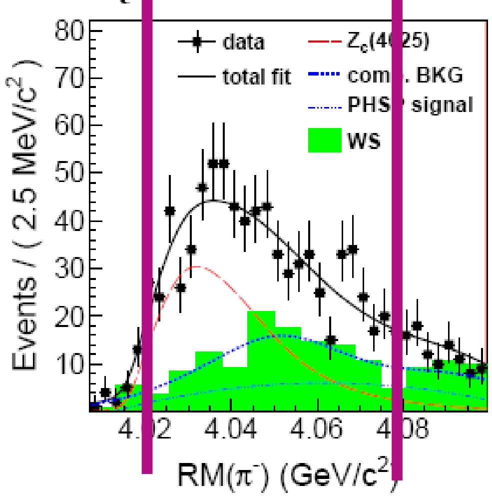
$D\bar{D}^*$ structure:
data clearly favour $J^P = 1^+$

Confirms J^P for $Z_c(3885)$
from single tag analysis

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

PRL 111, 242001
PRL 112, 132001





BESIII preliminary
The Zc' is found!

M(4020) = (4021.8±1.0±2.5) MeV

M(4025) = (4026.3±2.6±3.7) MeV

Γ(4020) = (5.7±3.4±1.1) MeV

Γ(4025) = (24.8±5.7±7.7) MeV

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

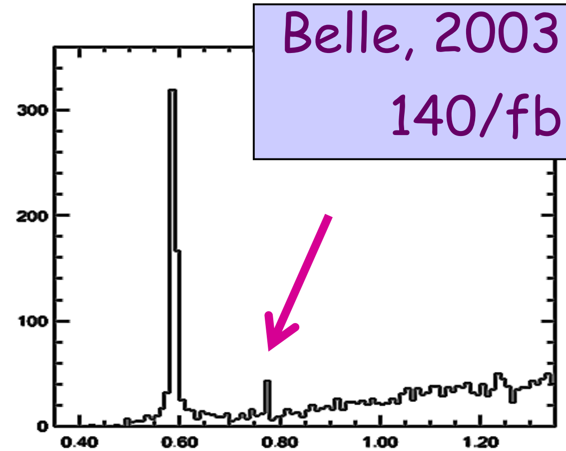
Mass consistent with each other but.. width ~2σ difference

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 $\bar{p}p$/pp collision – rate similar to charmonia
  - In B decays – KX similar to $c\bar{c}$, K*X smaller than $c\bar{c}$
  - **Y(4260)→γ+X(3872) [BESIII, preliminary]**
- Decay BR: open charm ~ 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}?)

The ISR Technique

BESIII: