Hadrons and Hadron Interactions in QCD 2015

--- Effective Theories and Lattice ---

Yukawa Institute for Theoretical Physics

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Highlights on BESIII recent results

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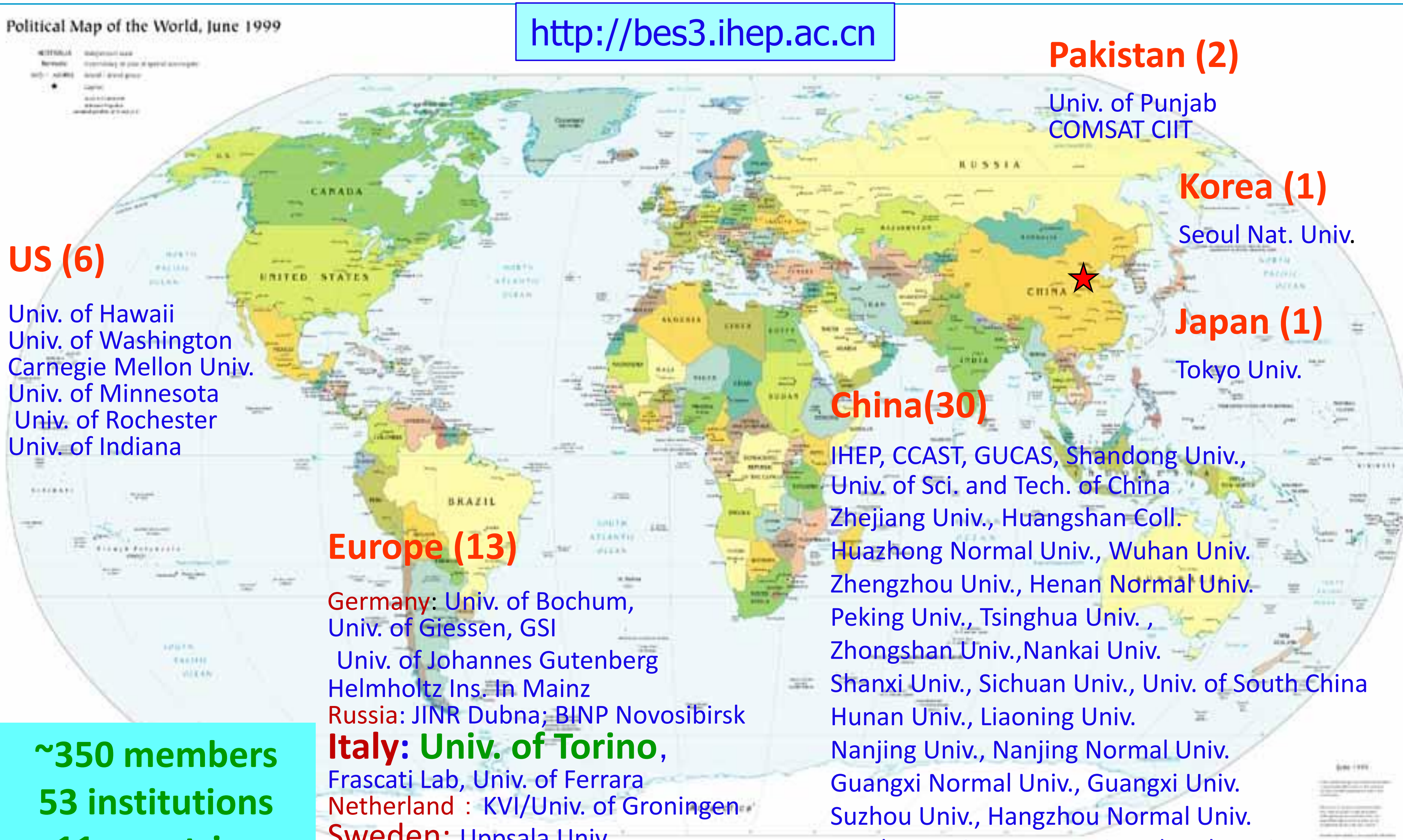
BESIII Collaboration

http://bes3.ihep.ac.cn



Pakistan (2)

Univ. of Punjab
COMSAT CIIT

Korea (1)

Seoul Nat. Univ.

Japan (1)

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US (6)

Univ. of Hawaii
Univ. of Washington
Carnegie Mellon Univ.
Univ. of Minnesota
Univ. of Rochester
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China(30)

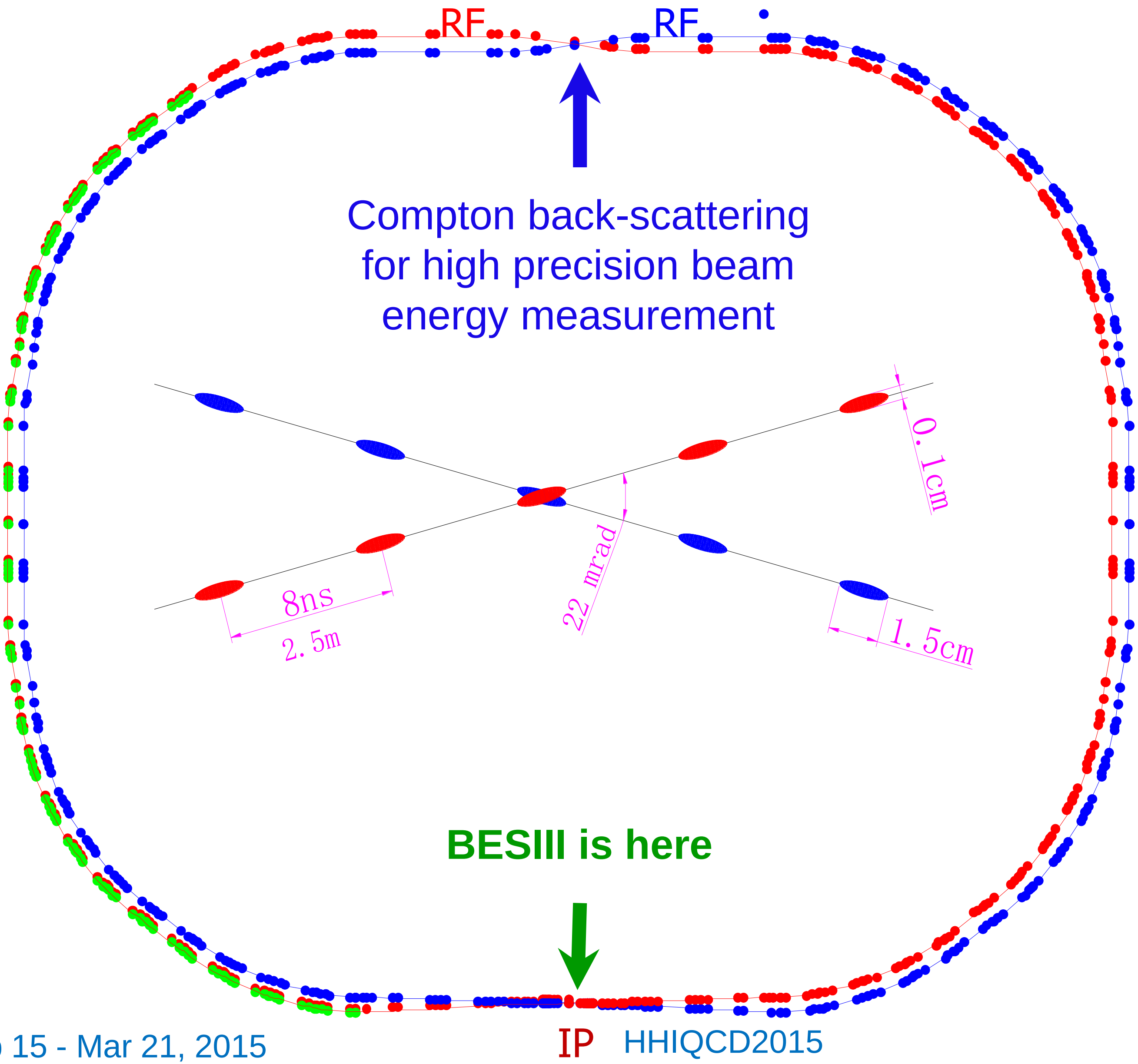
IHEP, CCAST, GUCAS, Shandong Univ.,
Univ. of Sci. and Tech. of China
Zhejiang Univ., Huangshan Coll.
Huazhong Normal Univ., Wuhan Univ.
Zhengzhou Univ., Henan Normal Univ.
Peking Univ., Tsinghua Univ. ,
Zhongshan Univ.,Nankai Univ.
Shanxi Univ., Sichuan Univ., Univ. of South China
Hunan Univ., Liaoning Univ.
Nanjing Univ., Nanjing Normal Univ.
Guangxi Normal Univ., Guangxi Univ.
Suzhou Univ., Hangzhou Normal Univ.
Lanzhou Univ., Henan Sci. and Tech. Univ.
Hong Kong Univ., Hong Kong Chinese 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,
Frascati Lab, Univ. of Ferrara
Netherland : KVI/Univ. of Groningen
Sweden: Uppsala Univ.
Turkey: Turkey Accelerator Center

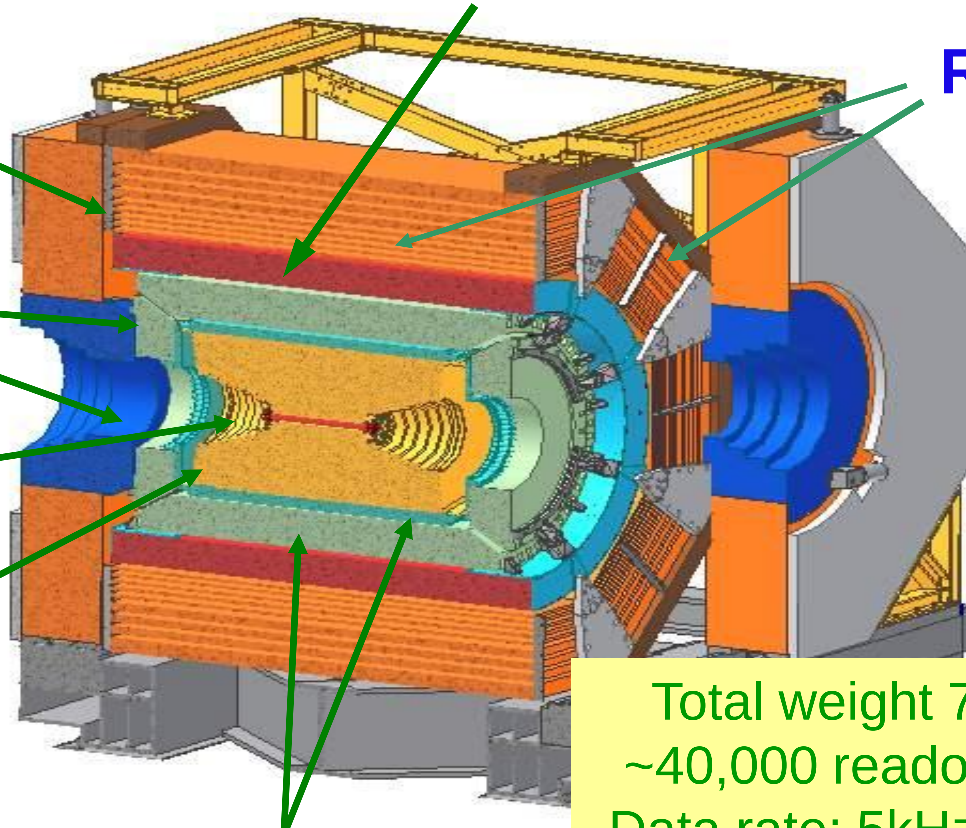
~350 members
53 institutions
11 countries

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



SC magnet, 1T

Magnet yoke

RPC

TOF, 90ps

Be beam pipe

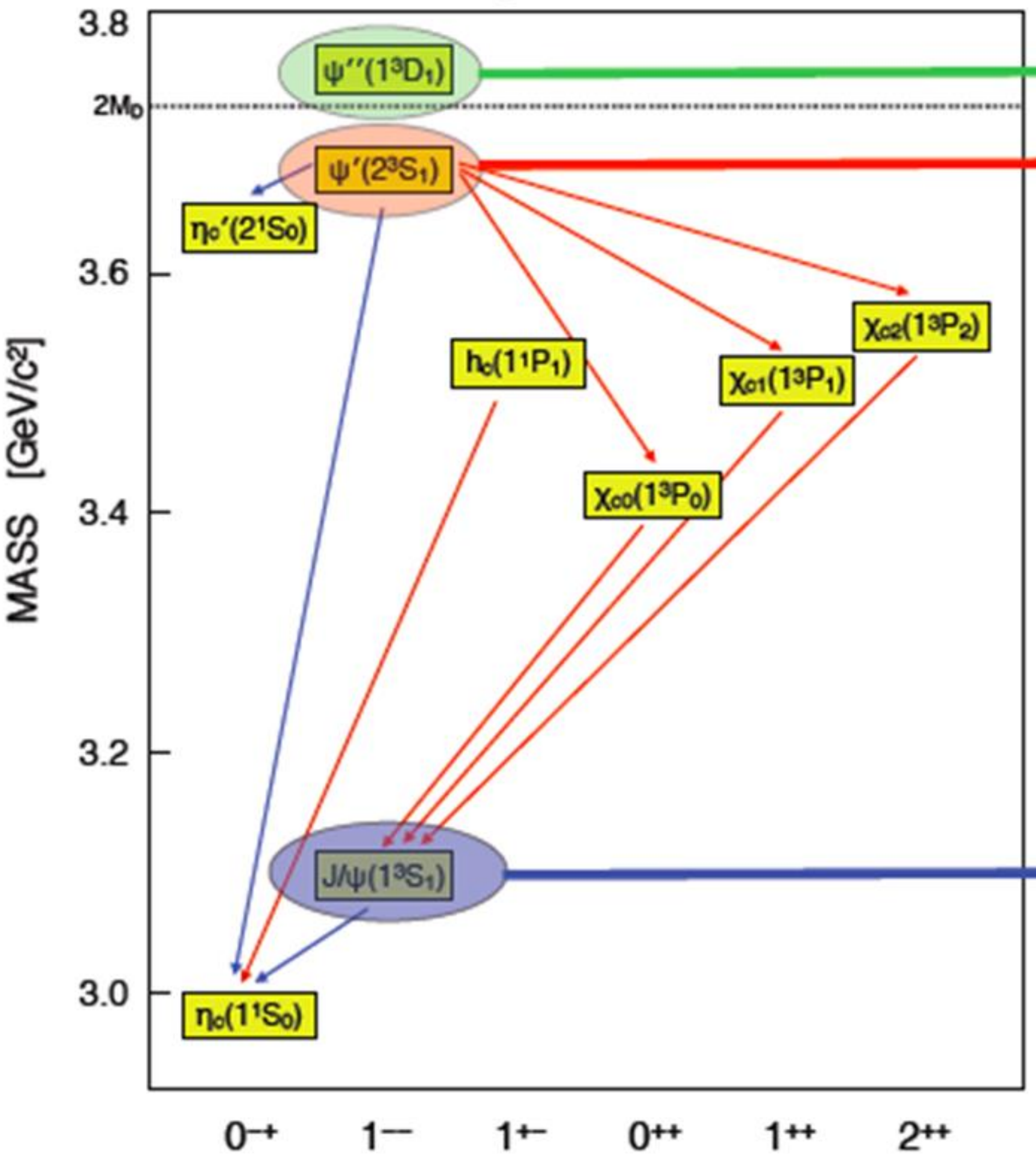
MDC, 130 μm

0.5% at 1 GeV/c

Total weight 730 ton,
~40,000 readout chnls,
Data rate: 5kHz, 50Mb/s

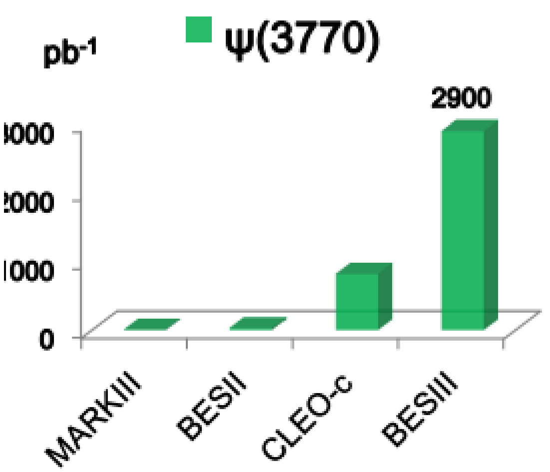
CsI(Tl) calorimeter, 2.5% @ 1 GeV

BESIII data set

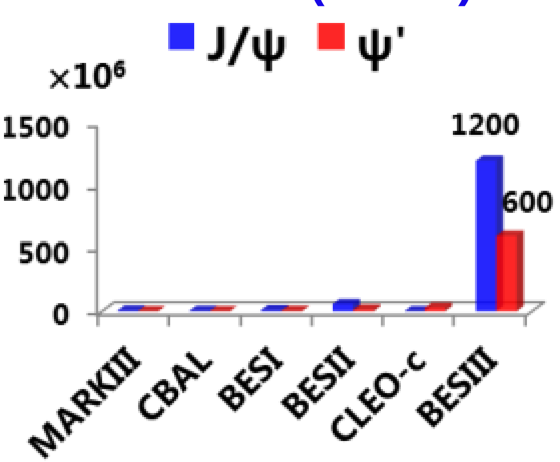


2.9 fb^{-1} / 20 fb^{-1}

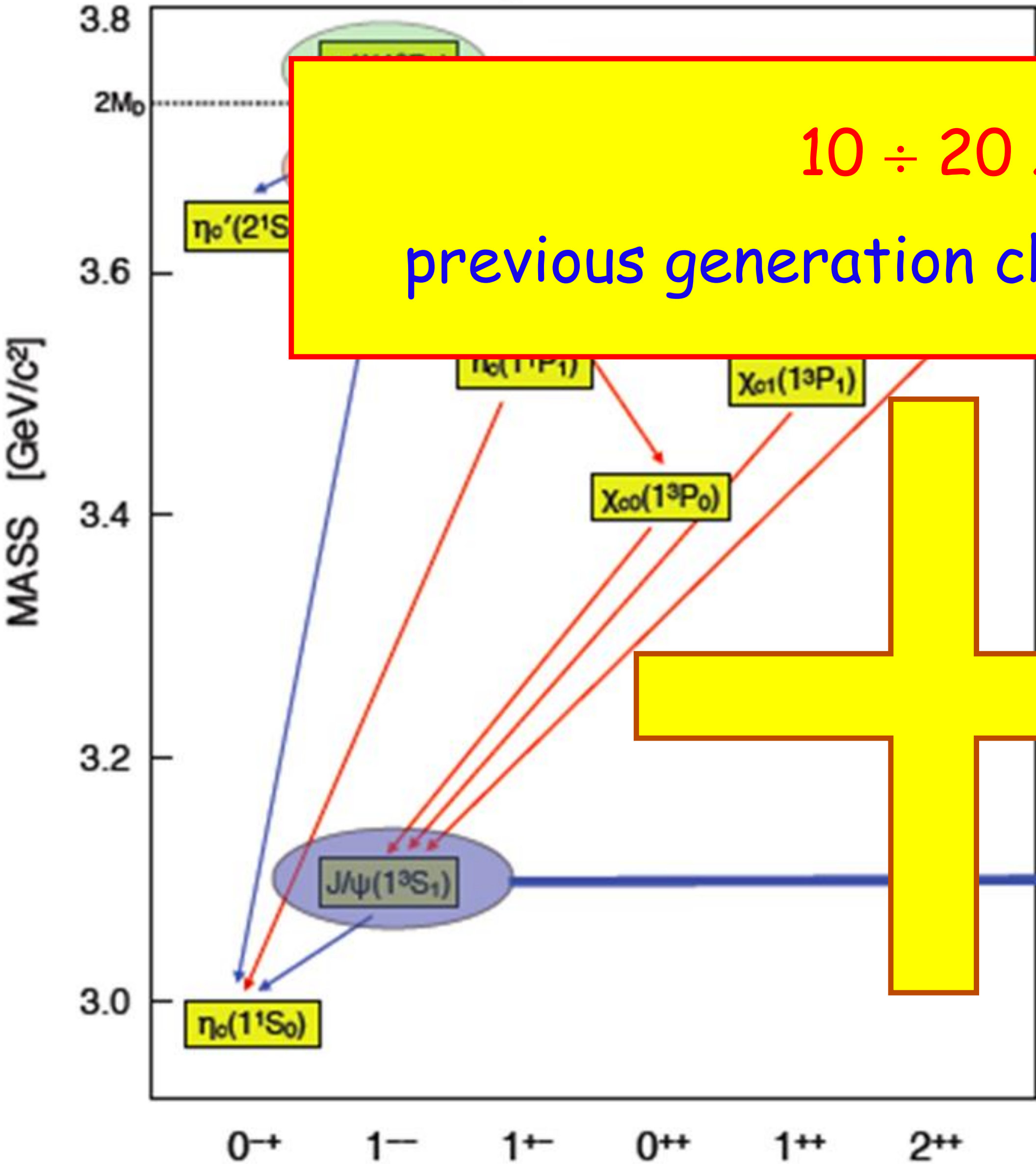
0.6 B / 3 B (106 M)



1.3 B / 10 B (225 M)



BESIII data set



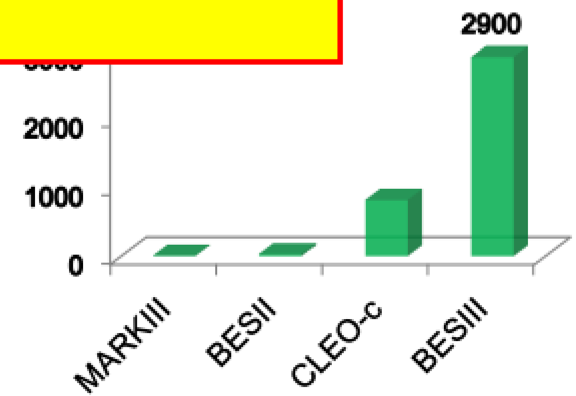
10 ÷ 20 ×

previous generation charm factories

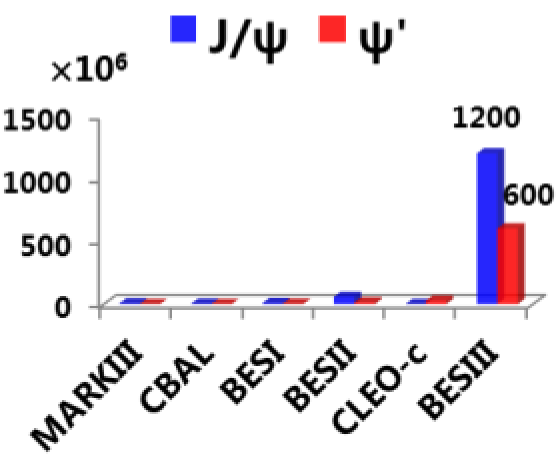
fb^{-1}

06 M)

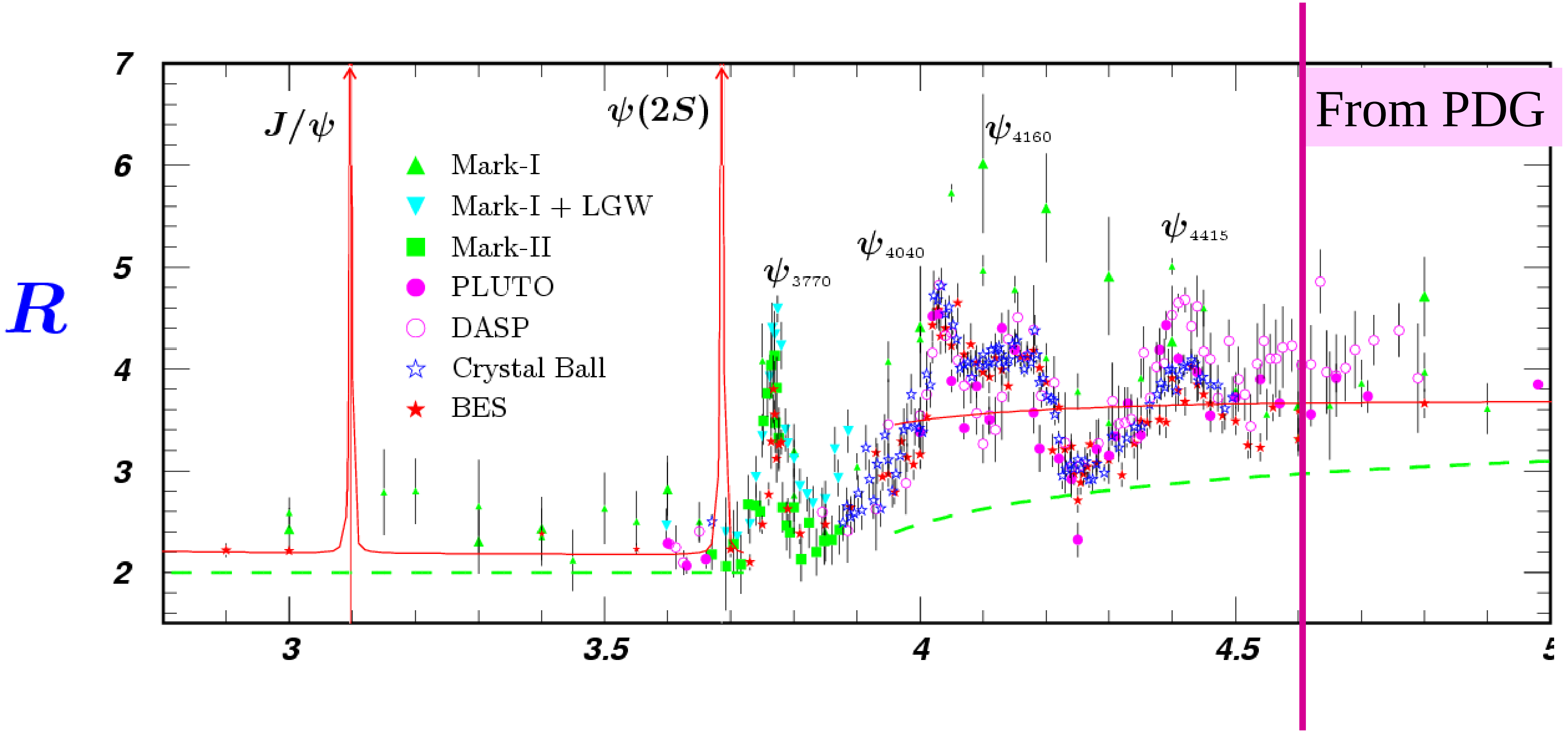
70)



1.2 B / 10 B (225 M)

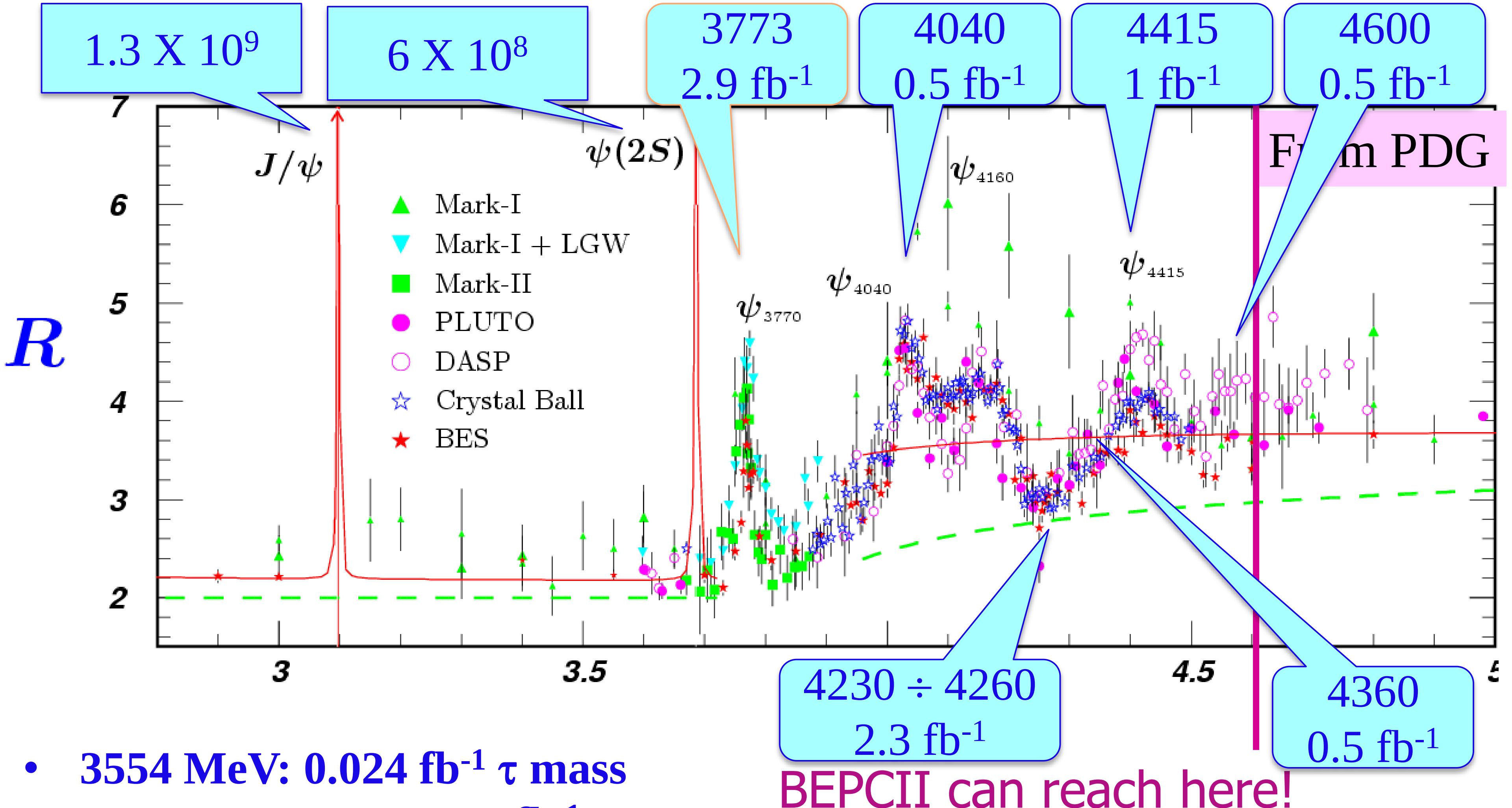


BESIII production of Charmonium(like) states



BEPCII can reach here!

BESIII production of Charmonium(like) states

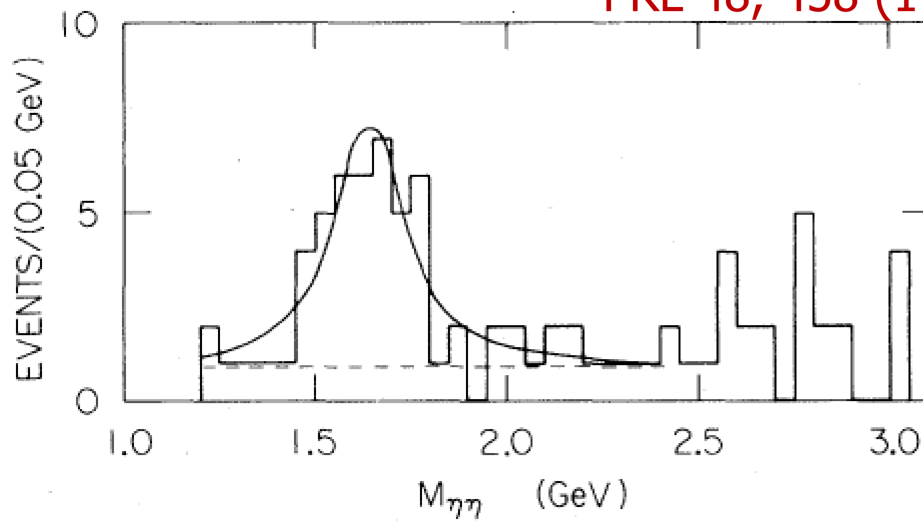


- **3554 MeV: 0.024 fb^{-1} τ mass**
- **4100 ÷ 4400 MeV: 0.5 fb^{-1} coarse scan**
- **3850 ÷ 4590 MeV: 0.5 fb^{-1} fine scan**

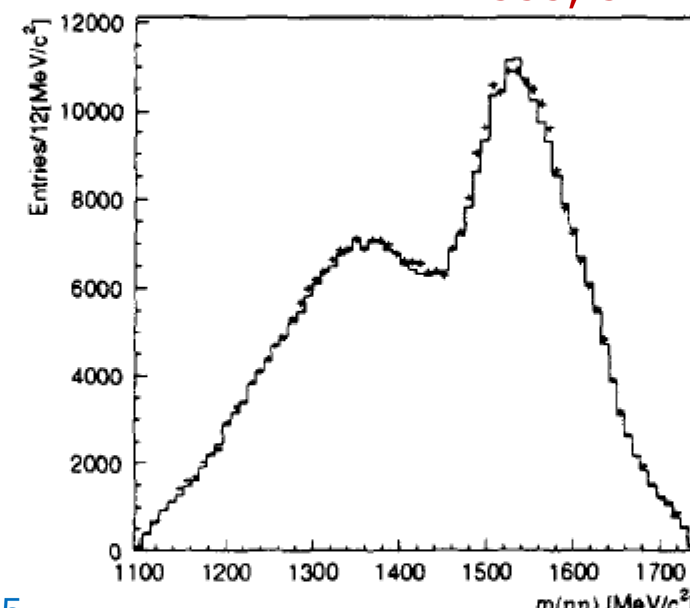
$J/\psi \to \gamma\eta\eta$

- **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:**
  $f_0(1500)$ [$\eta\eta$ mode]

PRL 48, 458 (1982)



PLB 353, 571 (1995)

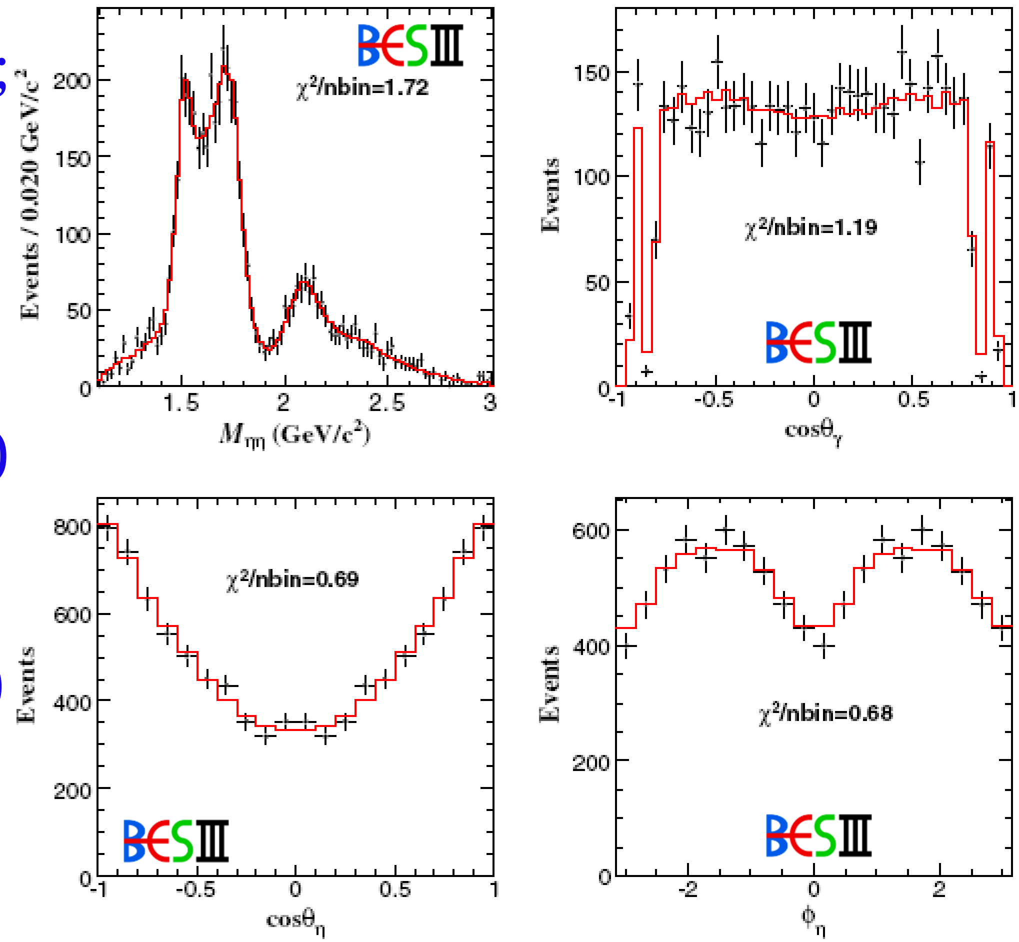


BESIII: PWA of $J/\psi \to \gamma\eta\eta$, $\eta \to \gamma\gamma$

PRD 87, 092009

- **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

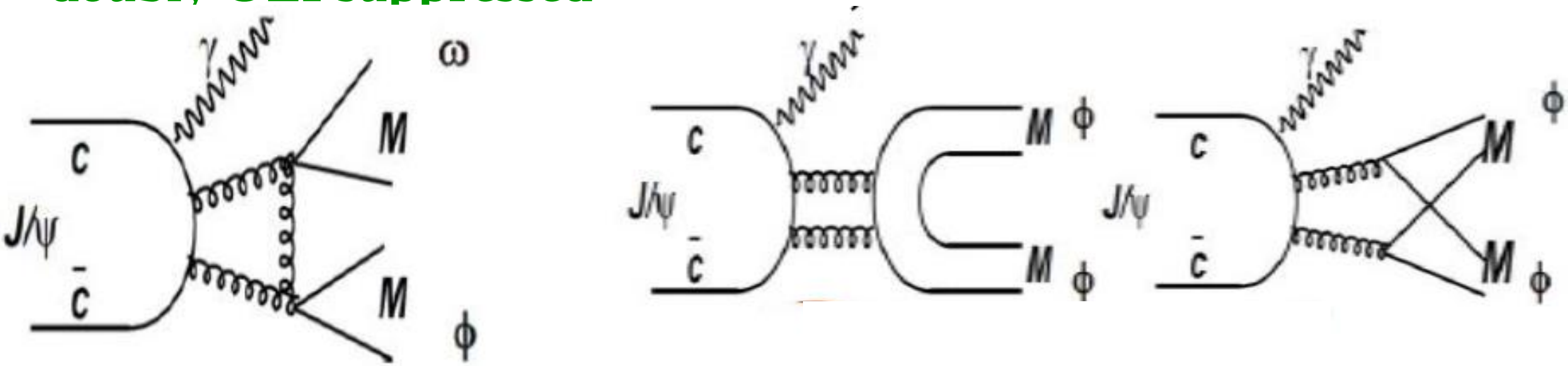
Resonance	Mass(MeV/c^2)	Width(MeV/c^2)	$\mathcal{B}(J/\psi \to \gamma X \to \gamma\eta\eta)$	Significance
$f_0(1500)$	1468^{+14+23}_{-15-74}	$136^{+41+28}_{-26-100}$	$(1.65^{+0.26+0.51}_{-0.31-1.40}) \times 10^{-5}$	8.2 σ
$f_0(1710)$	$1759\pm6^{+14}_{-25}$	$172\pm10^{+32}_{-16}$	$(2.35^{+0.13+1.24}_{-0.11-0.74}) \times 10^{-4}$	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: $f_2(2010)$, $f_2(2150)$, $f_J(2220)$

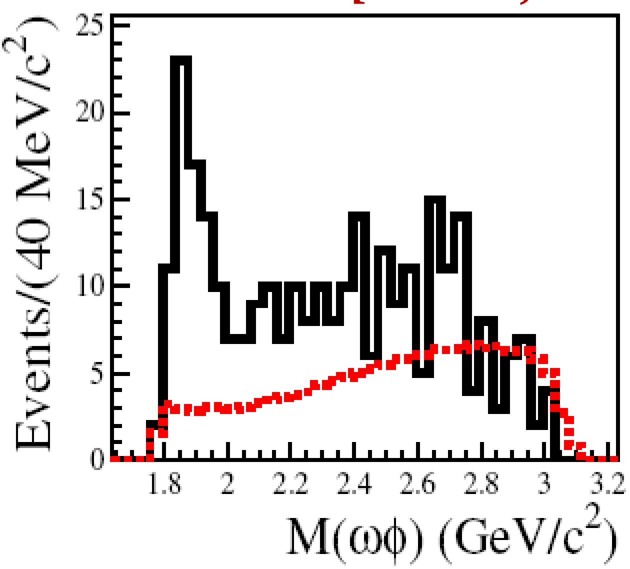
$J/\psi \to \gamma\omega\phi$

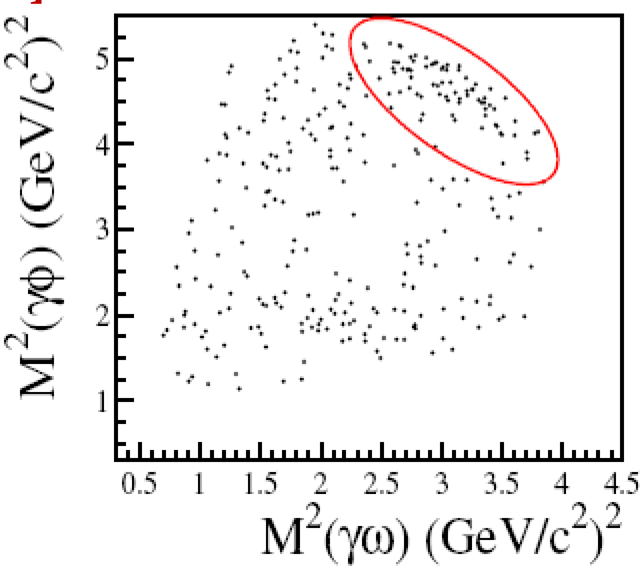
- **doubly OZI suppressed**



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

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





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

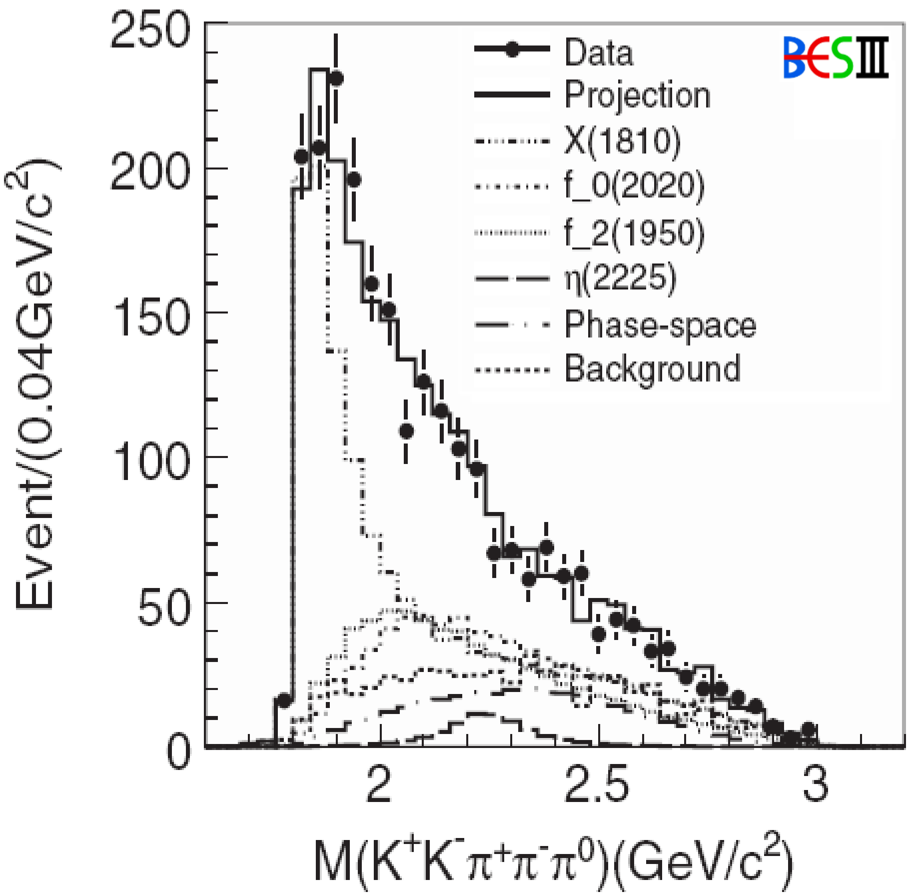
$\Gamma = (105 \pm 20 \pm 28)$ MeV/c^2

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

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

PRD 87, 032008

- **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), η(2225), f_0(2020), phase space and background
- **systematic uncertainties:**
  - f_2(1920), f_0(2020), η(2225): standard deviation from PDG, replacing by other of similar mass but same J^{PC}
  - model dependence



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

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

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

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

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

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

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

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

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

  unconclusive, further investigation is needed

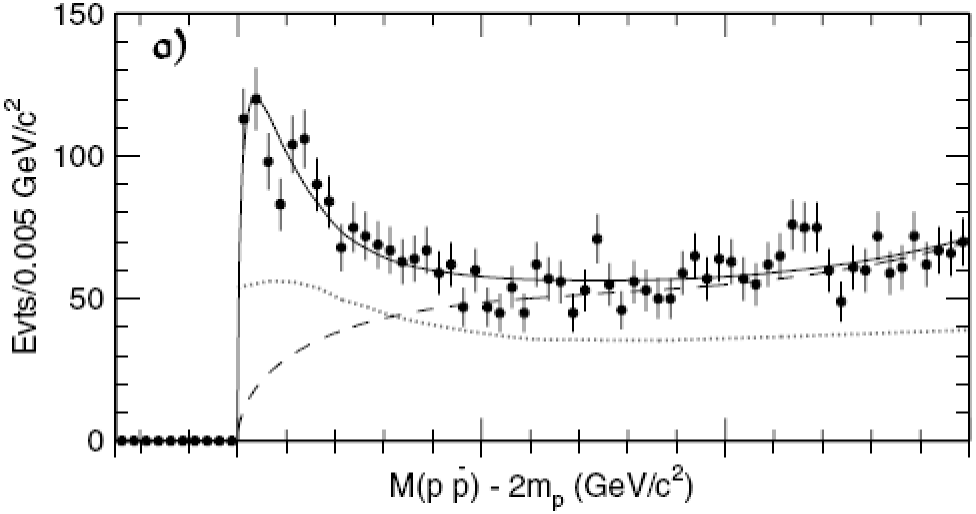
- **search for X(1810):**
  - in other decay modes: K*K*, ωω, …

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

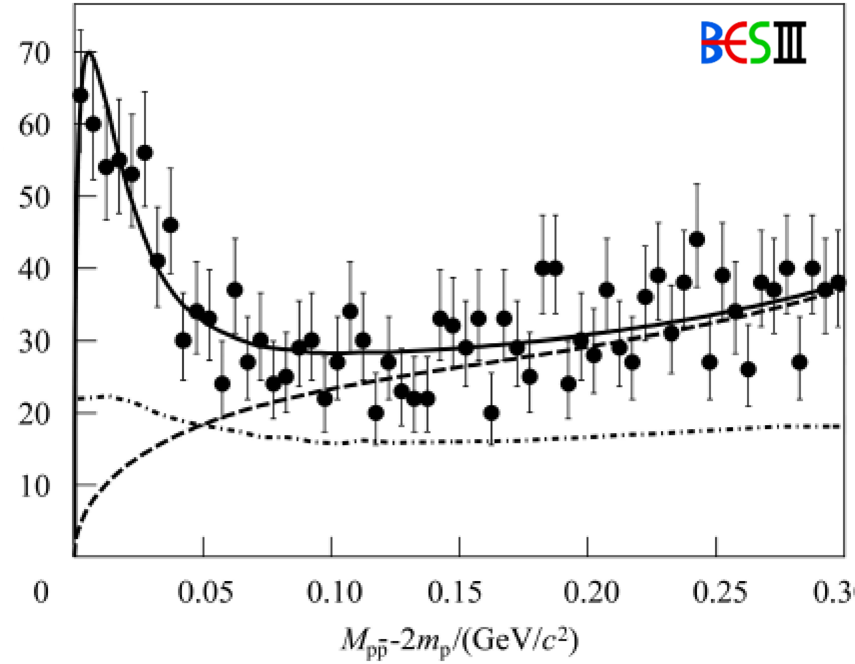
$J/\psi \to \gamma p\bar{p}$: enhancement at threshold

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

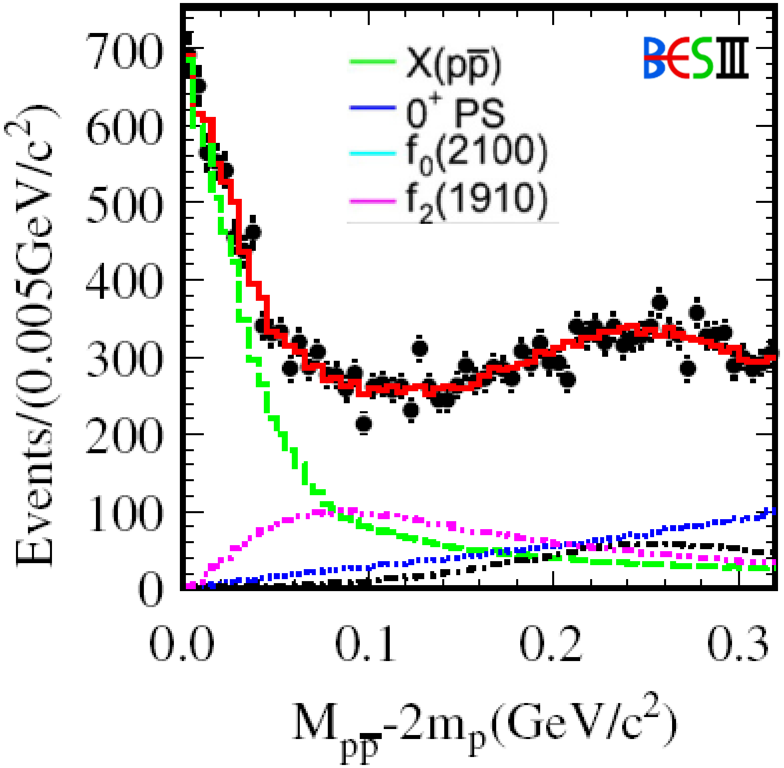
M = $(1861^{+6}_{-13}\ {}^{+7}_{-26})$ MeV/c^2
Γ < 30 MeV/c^2 (90% C.L.)
compatible with S-wave BW

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

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

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



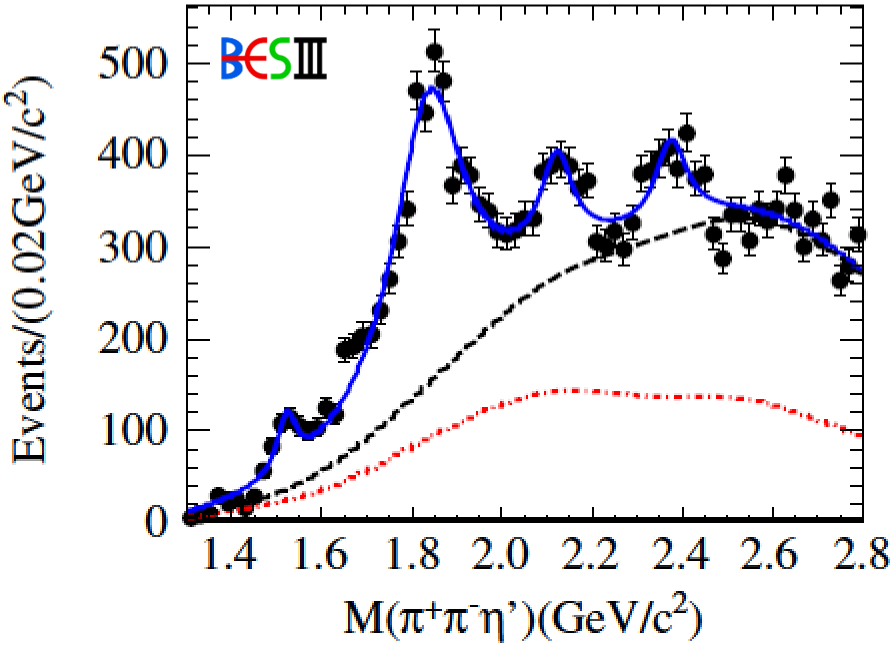
J^{PC}= 0^{-+} , >6.8σ better than other J^{PC} assignments

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

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

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

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

$>7.2\sigma$

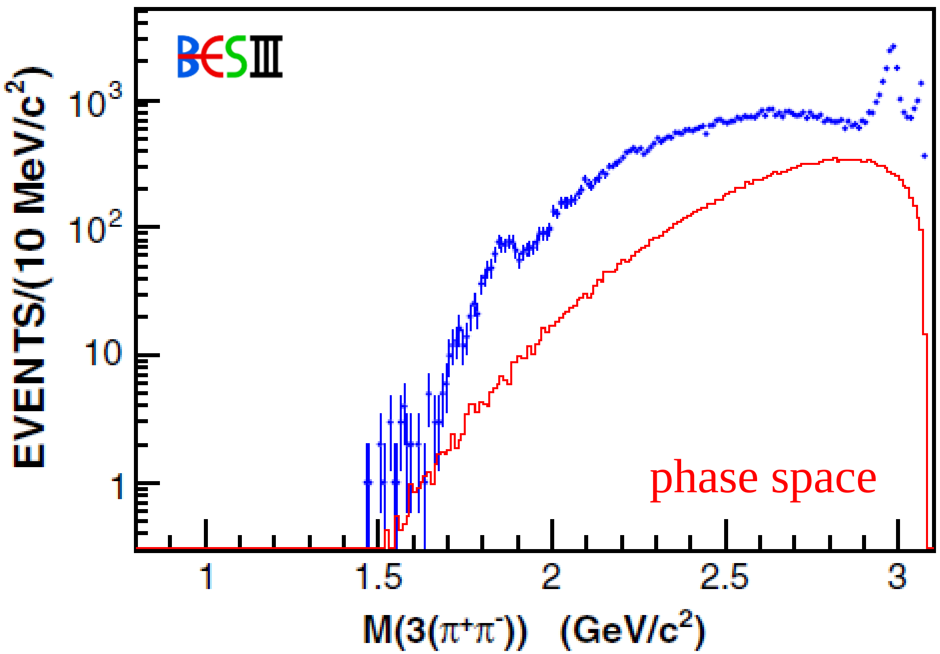
X(2370):

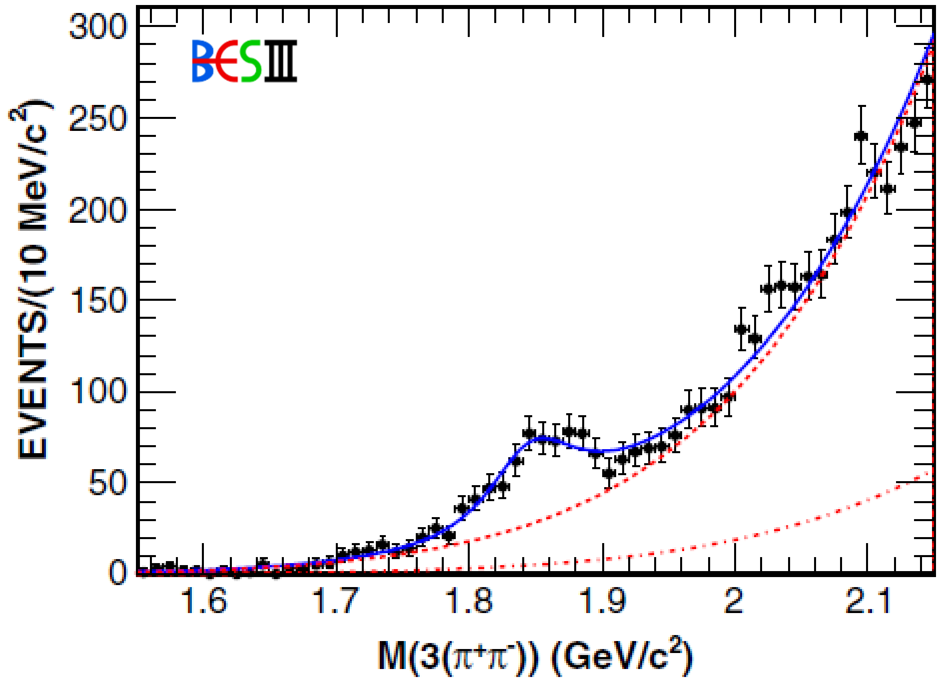
$M = (2376.3 \pm 8.7^{+3.2}_{-4.3})$ MeV/c^2

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

$>6.4\sigma$

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





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

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

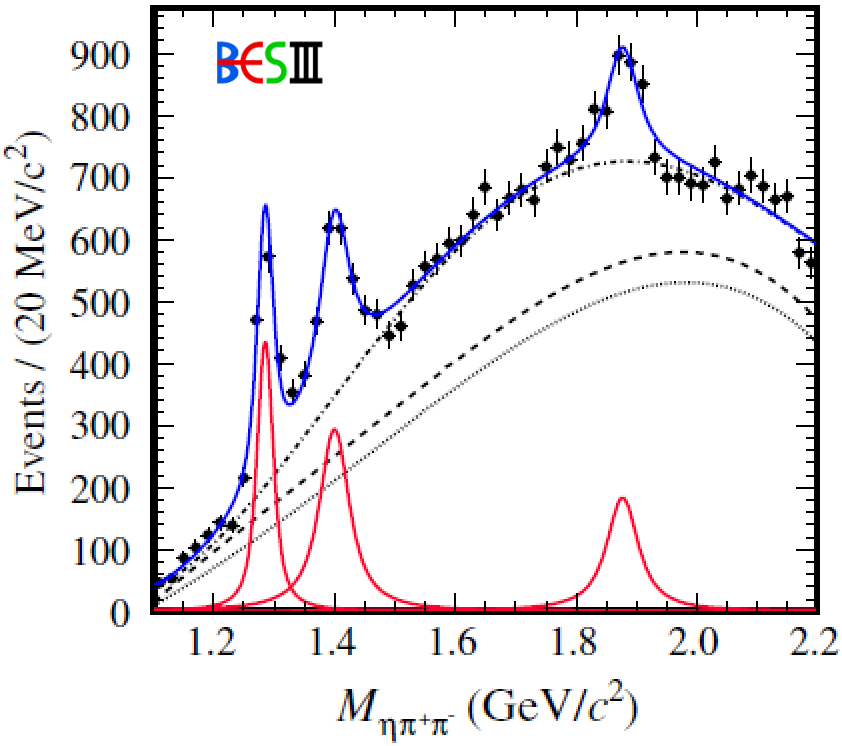
$>7.6\sigma$

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

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/c^2

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

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

η(1405):

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

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

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

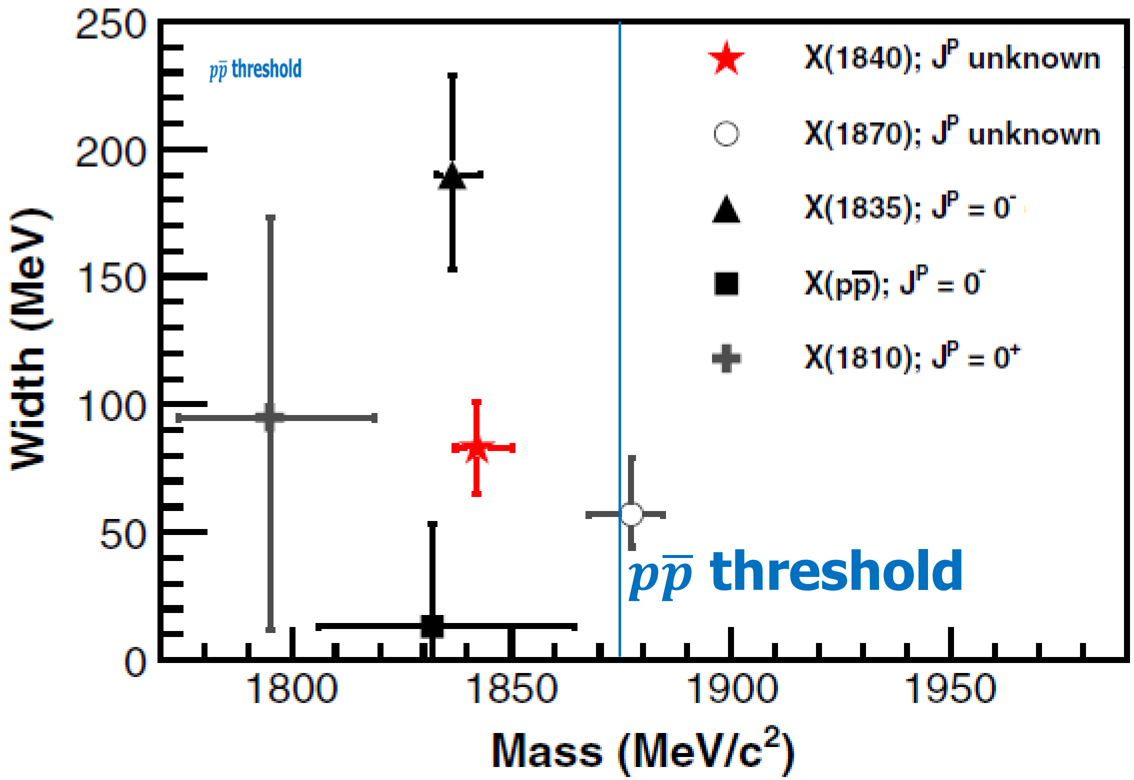
f_1(1285):

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

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

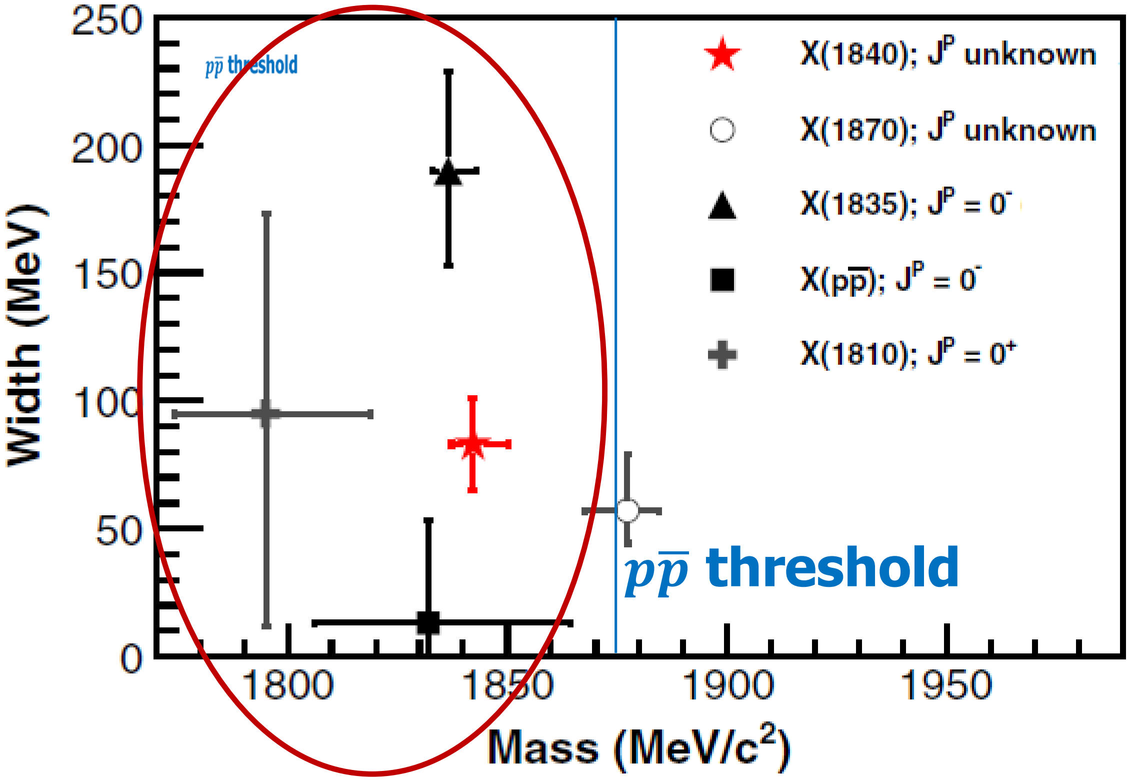
$B = (1.25 \pm 0.10^{+0.19}_{-0.20}) \cdot 10^{-4}$

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): $J/\psi \to \gamma 3(\pi^+\pi^-)$ [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]**

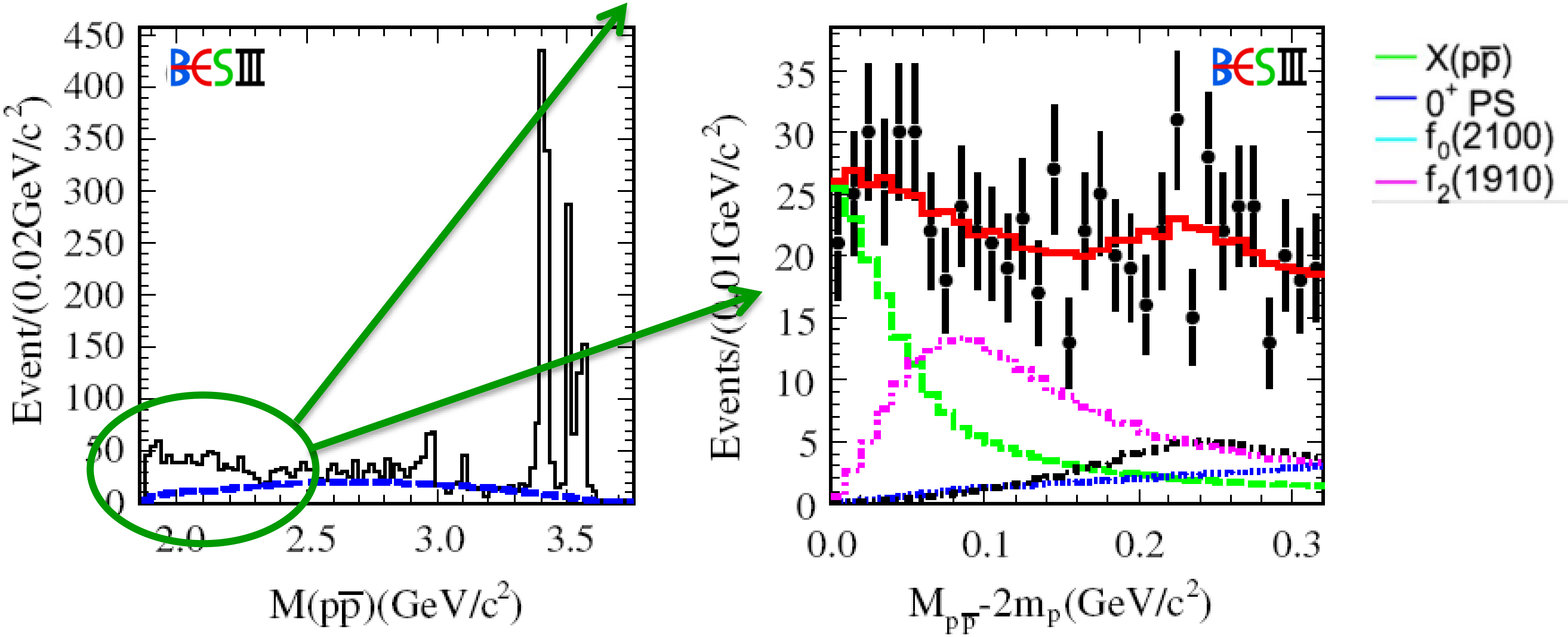
X(18??):

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

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

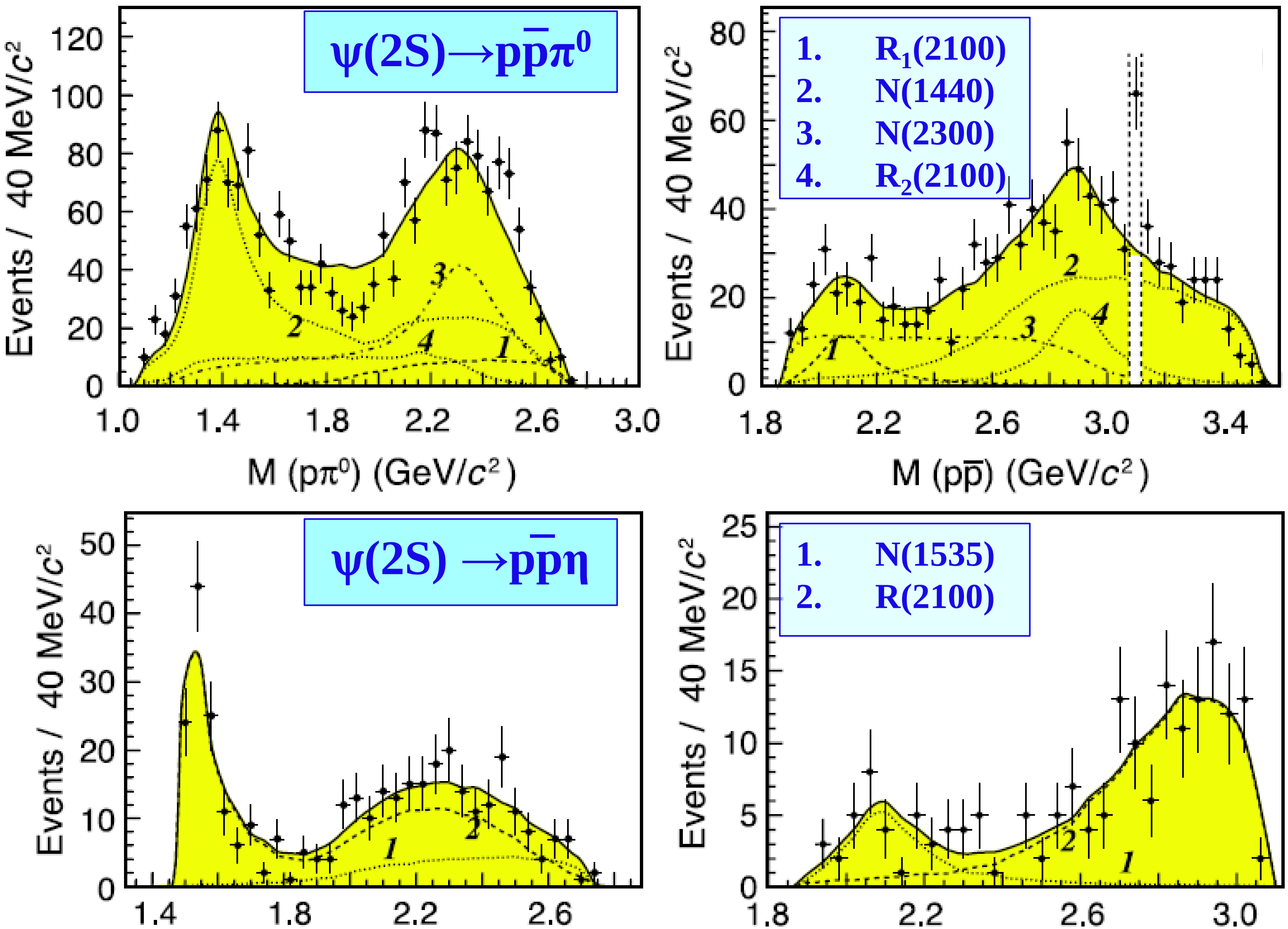
$$\mathcal{B}(\psi(2S)\to\gamma X(pp)) \times \mathcal{B}(X(pp)\to pp) =$$

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

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

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

CLEOc: 24.5 M ψ(2S) [PRD 82, 092002]

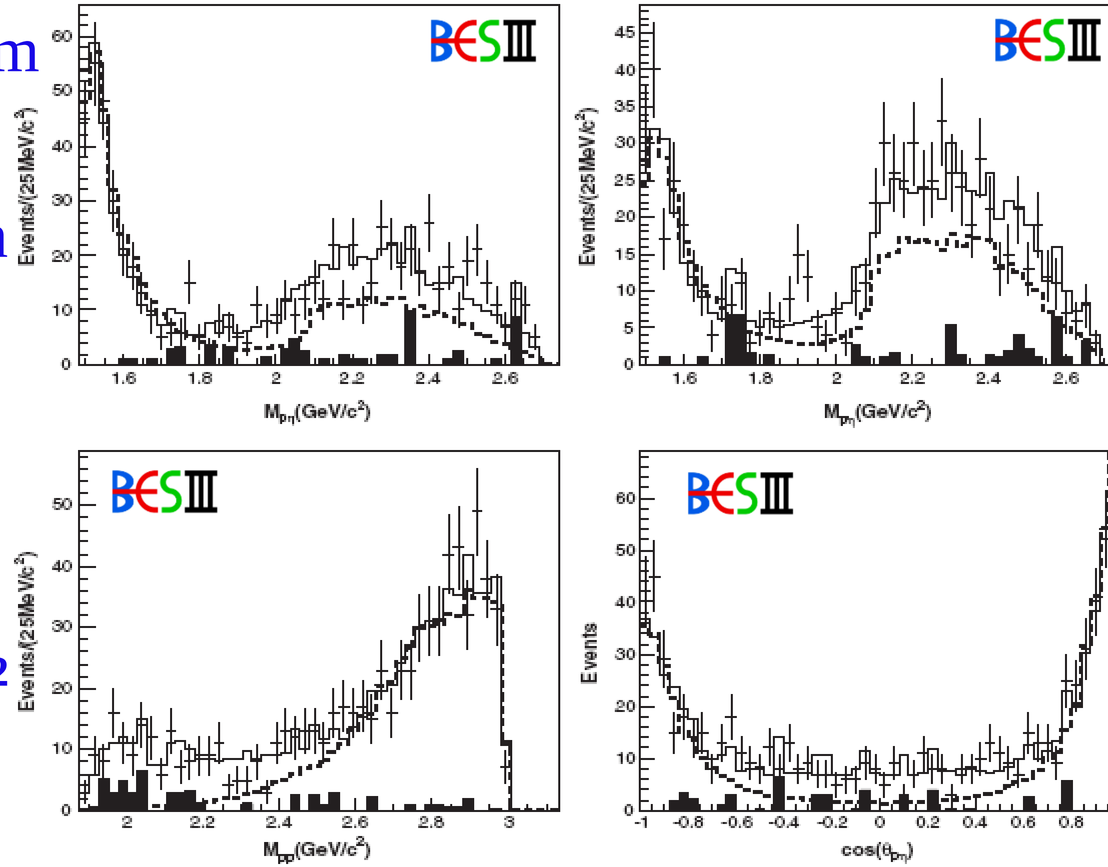


Without interference effects

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

PRD 88, 032010

- **low background:**
  - sidebands and continuum
- **best solution:**
  N(1535) combined with an interfering phase space
- **$p\bar{p}$ enhancement:**
  <3σ
- **N(1535):**
  - **$M=(1524\pm5^{+10}_{-4})$ MeV/c^2**
  - **$\Gamma= (130^{+27+10}_{-24\,-10})$ MeV/c^2**
- **suppressed (<12%):**

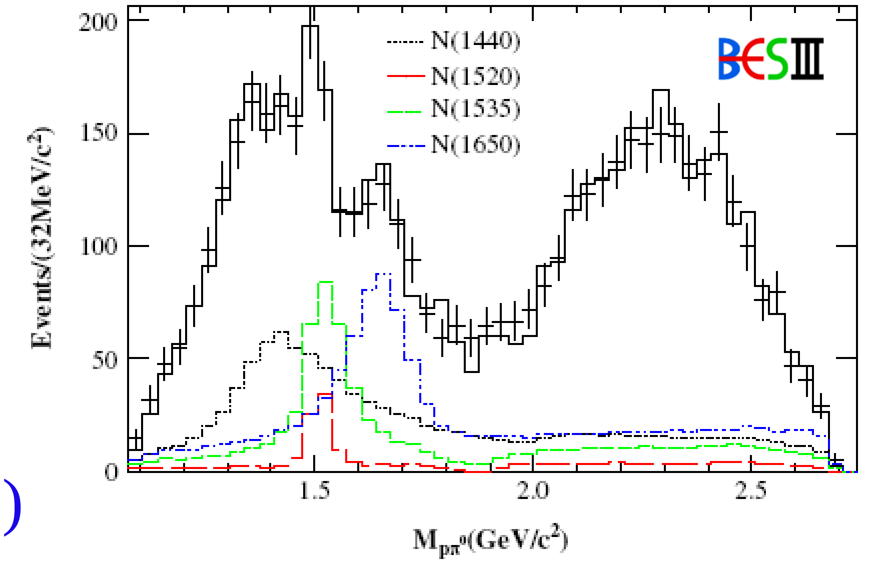


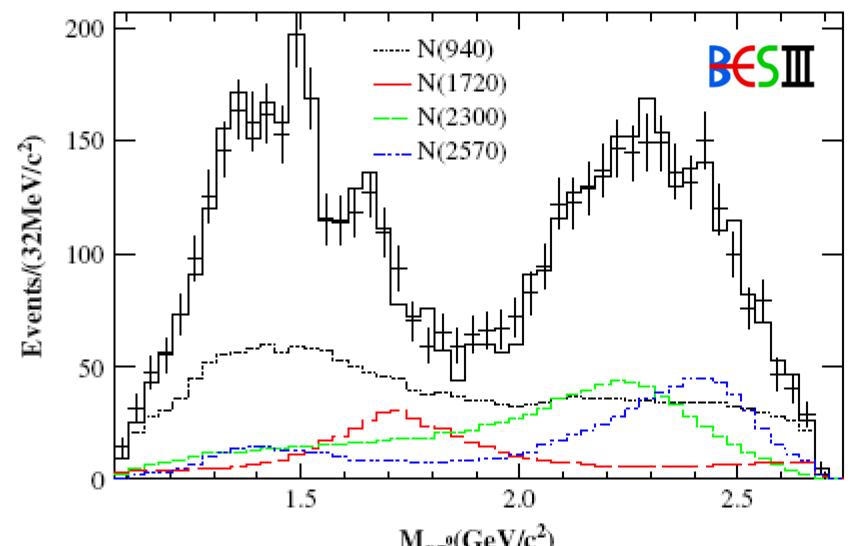
$$Q_{p\bar{p}\eta} = \frac{\mathcal{B}(\psi(2S) \to p\bar{p}\eta)}{\mathcal{B}(J/\psi \to p\bar{p}\eta)} = (3.2\pm0.46)\%$$

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

PRL 110, 022001

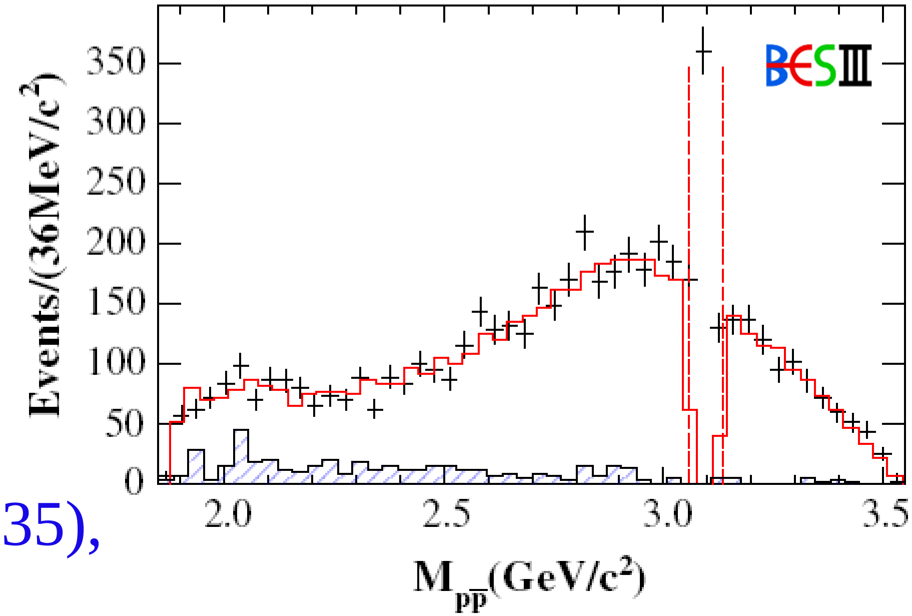
- **2-body decay:**
  - $\psi(2S)\to X\pi^0$, $X\to p\bar{p}$
  - $\psi(2S)\to p\bar{N}^*$, $\bar{N}^*\to\bar{p}\pi^0$+c.c.
- **isospin conservation:**
  Δ suppressed
- **best solution:**
  N(1440), N(1520), N(2090), N(1535)
  N(1650), N(1720),
  N(2300) [1/2$^+$], N(2570) [5/2$^-$]
- **no significant evidence:**
  - N(1885), N(2065)
  - $p\bar{p}$ enhancement
- **systematic uncertainties:**
  - additional possible resonances





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

- **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



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

PRL 110, 022001

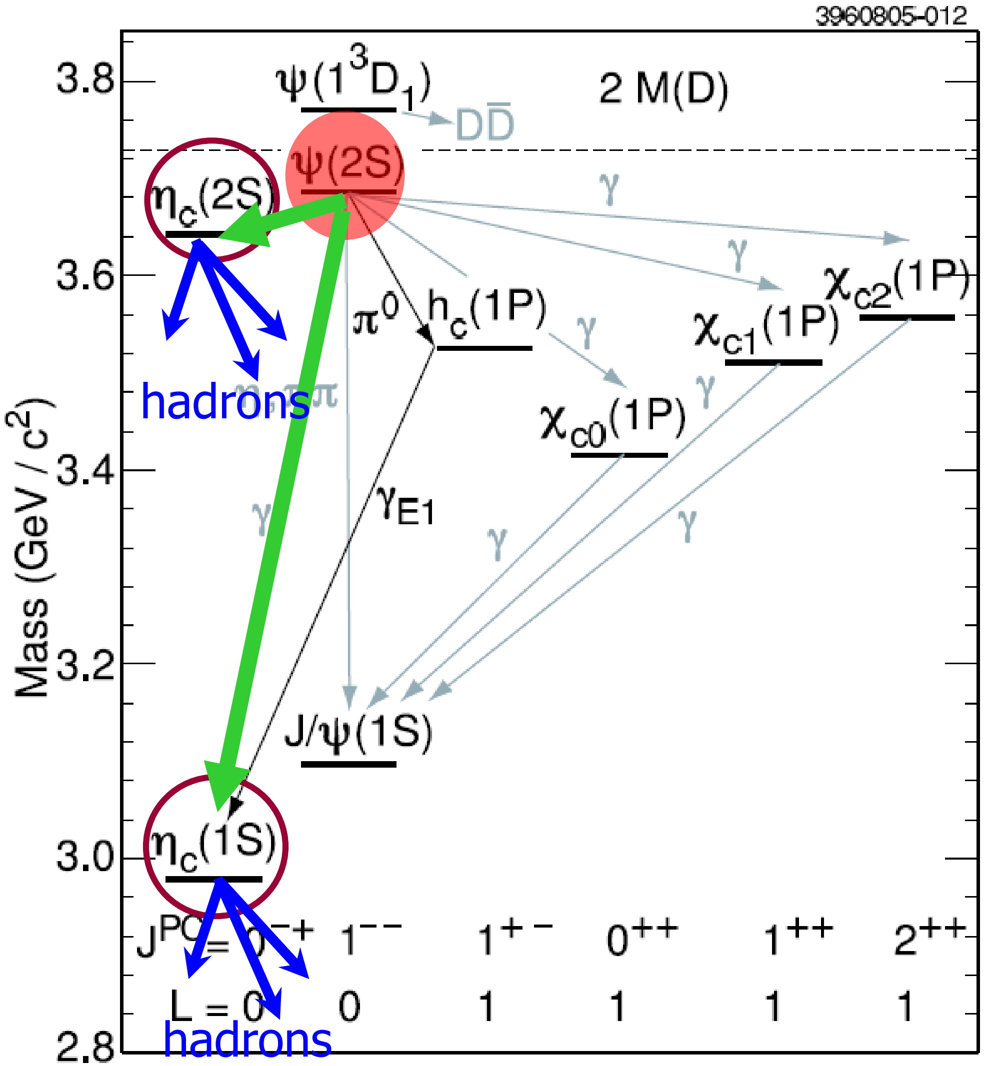
- **branching fraction:**

  $\mathcal{B}(\psi(2S) \to p\bar{p}\pi^0) = (1.65\pm0.03\pm0.15)\times10^{-4}$

- **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**	$\mathbf{11.7\sigma}$

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



η_c mass:
charmonium ground state

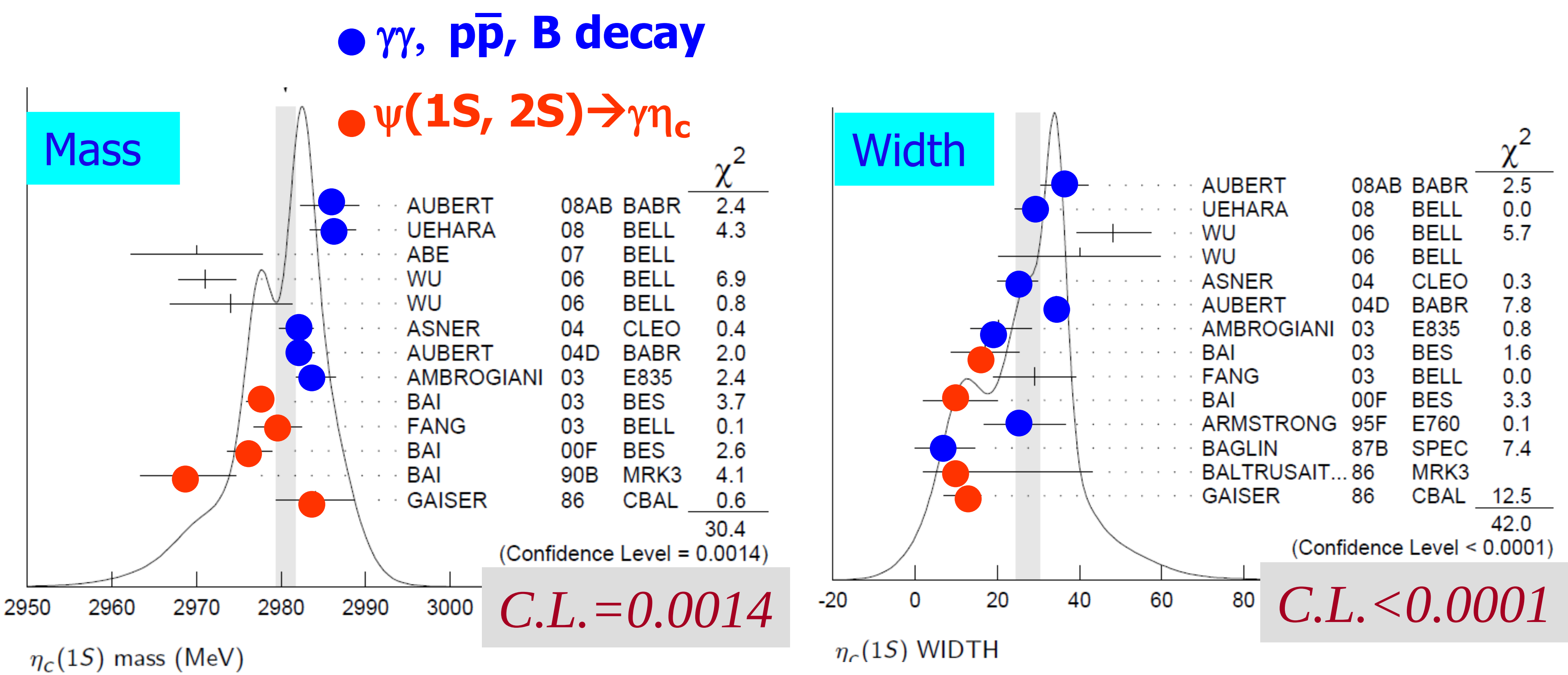
M1 transition:
first observation of $\psi' \rightarrow \gamma\eta'_c$

$\eta_c(1S)$

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

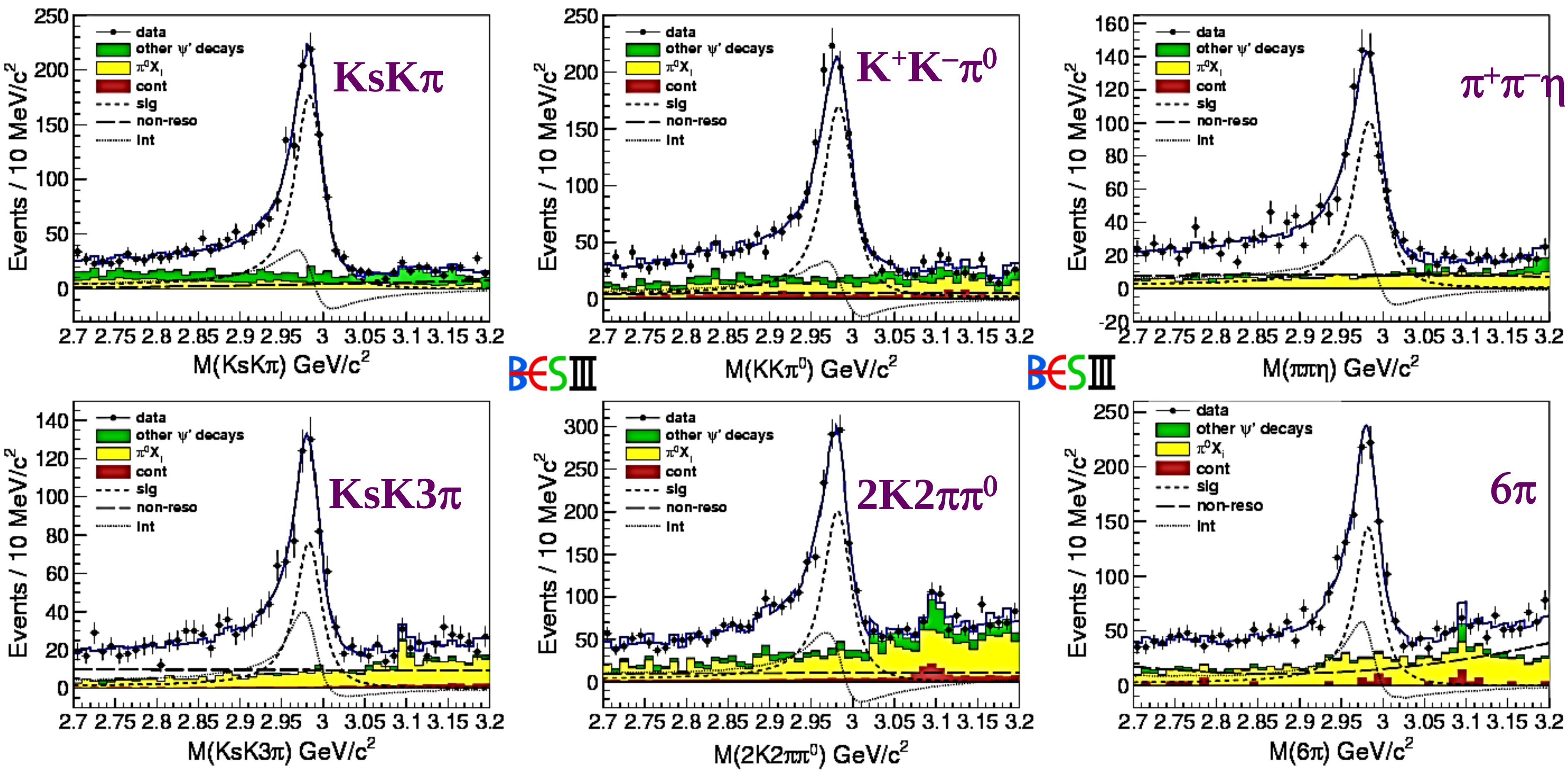
M & Γ measurements:

- 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**



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

PRL 108, 222002 (2012)



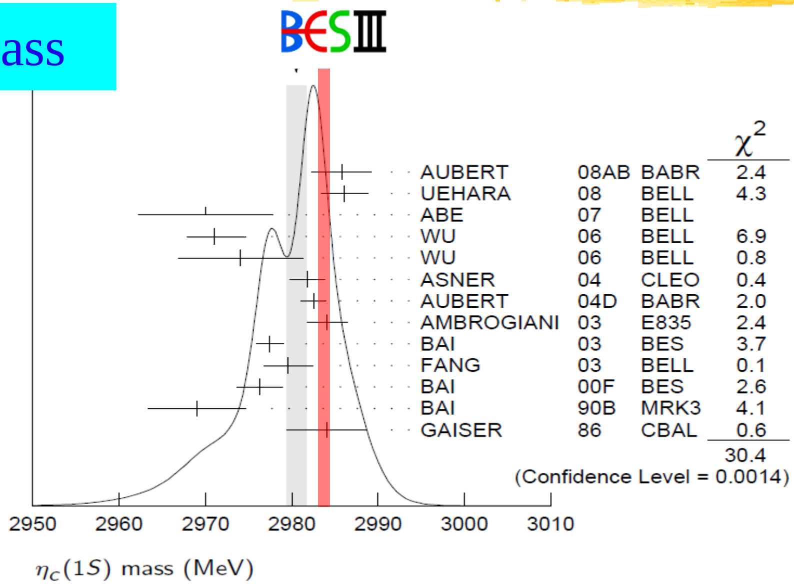
Significant interference between η_c and non-resonant

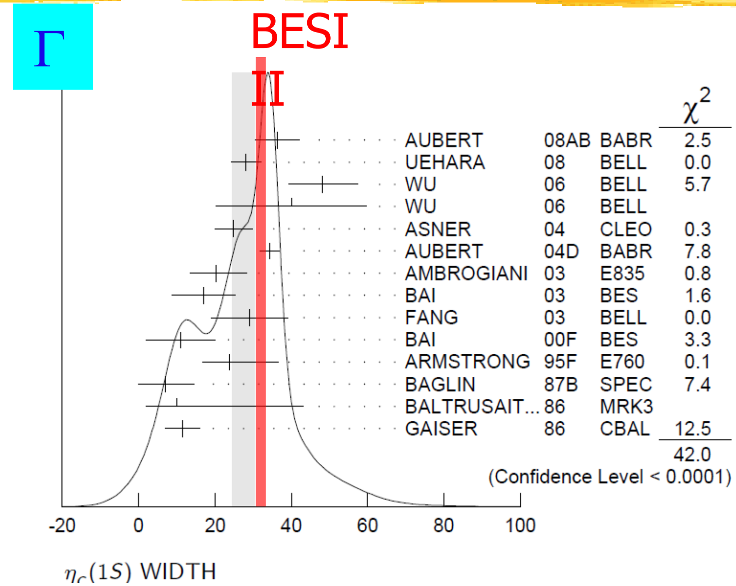
→ simultaneous fit to 6 modes, **Mass = 2984.3±0.6±0.6 MeV/c²**

Γ = 32.0±1.2±1.0 MeV/c²

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

PRL 108, 222002 (2012)

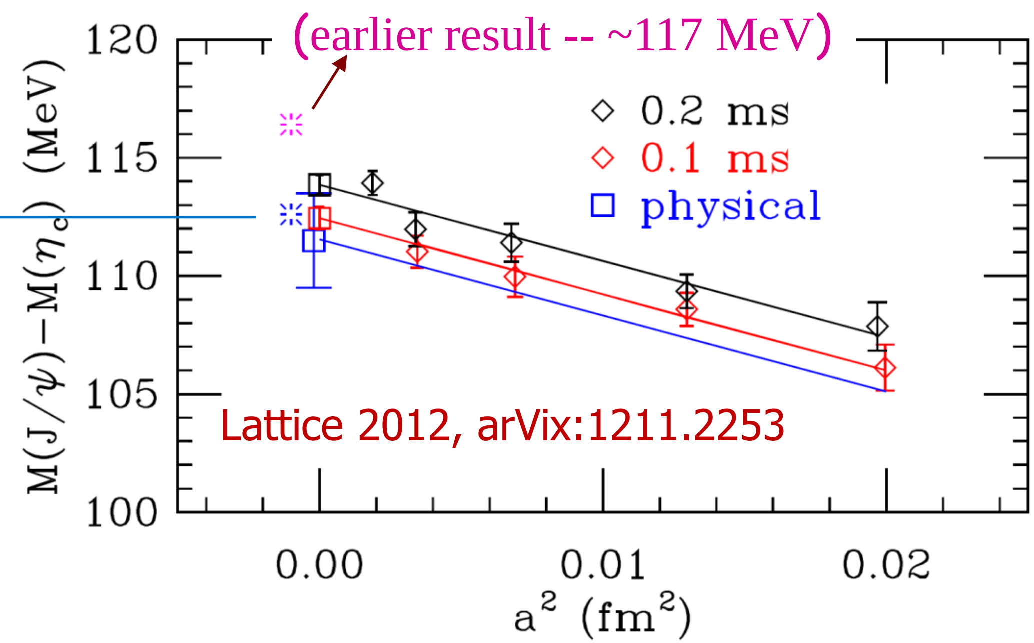




Hyperfine splitting (BESIII alone)

$\Delta M(1S) = 112.5 \pm 0.8$ MeV/c²

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 $\psi' \to \gamma\eta_c'$

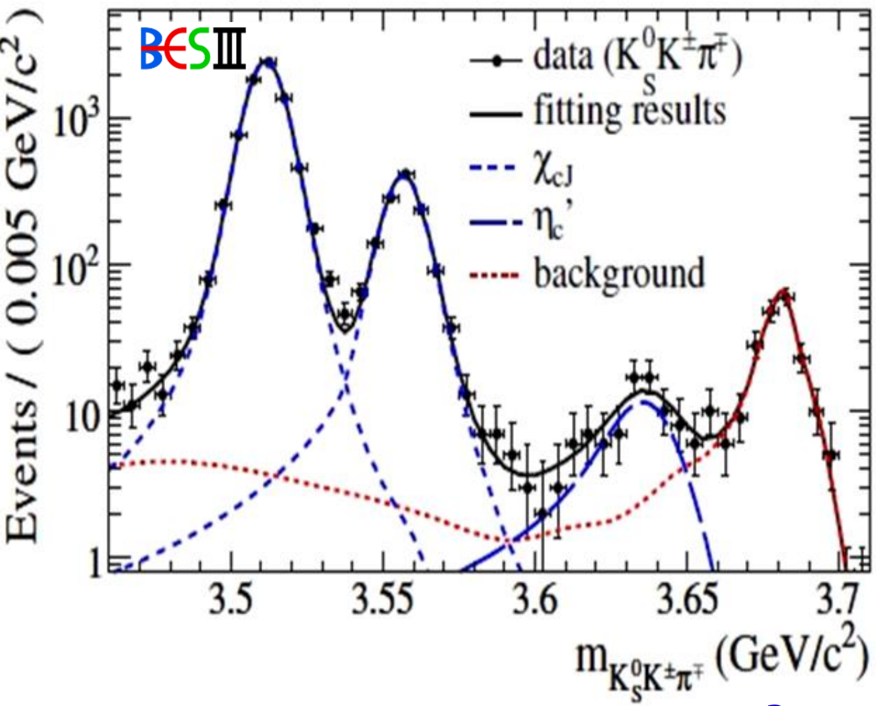
1. CLEO found no signal in 25M ψ'.
   $\mathcal{B}(\psi' \to \gamma\eta_c') < 7.6 \times 10^{-4}$ PRD 81 052002 (2010)

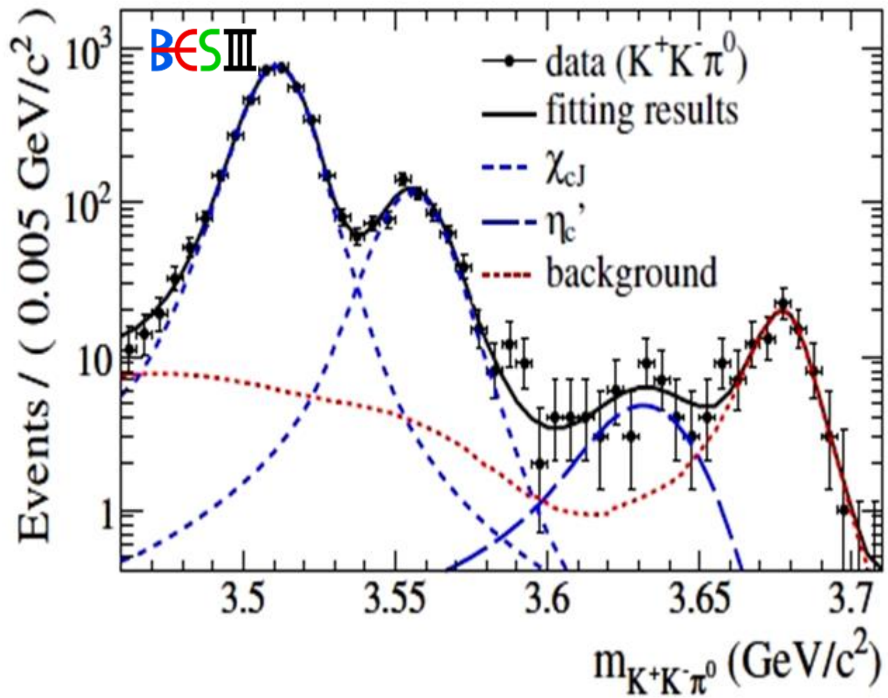
2. BESIII: first observation of $\eta_c' \to KK\pi$;
   find evidence in $\eta_c' \to K_sK3\pi$

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±2.9±1.6 MeV/c² **Γ = 16.9±6.4±4.8 MeV/c²**

$\mathcal{B}(\psi' \to \gamma\eta_c' \to \gamma KK\pi) = (1.30\pm0.20\pm0.30)\times10^{-5}$ **Significance >10 σ**

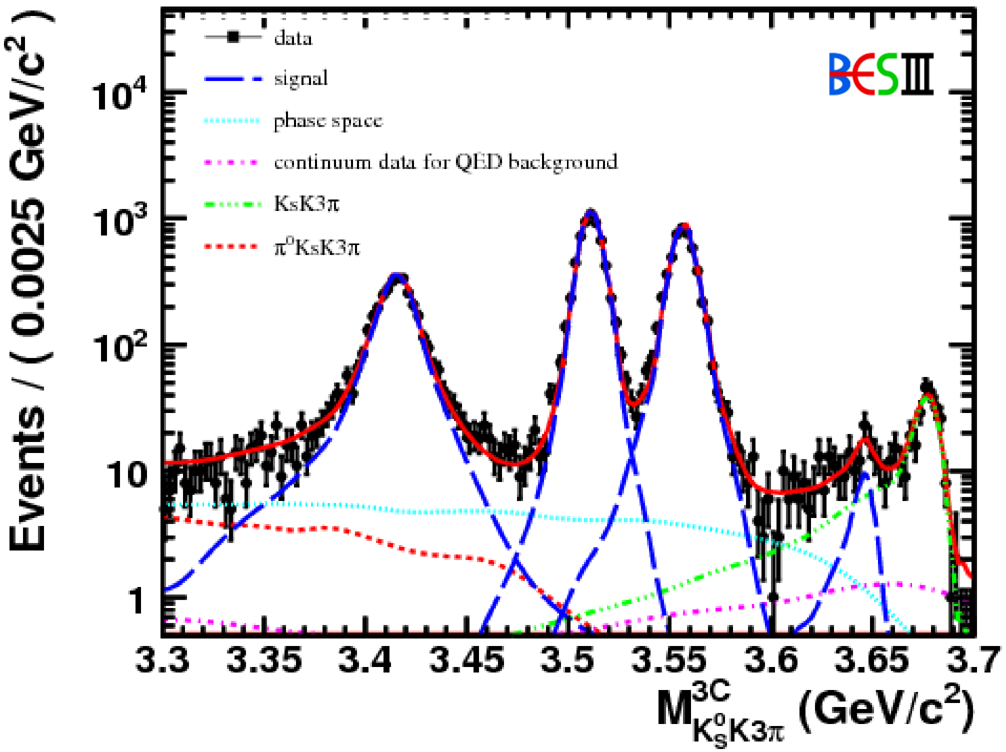
$\mathcal{B}(\eta_c' \to \gamma KK\pi) = (1.9\pm0.4\pm1.1)\%$ **BABAR: PRD78, 012006 (2008)**

$\mathcal{B}(\psi' \to \gamma\eta_c') = (6.8\pm1.1\pm4.5)\times10^{-4}$ **FIRST OBSERVATION!**

Potential model:	$(0.1\text{-}6.2)\times10^{-4}$	PRL89, 162002(2002)
CLEOc:	$< 7.6\times10^{-4}$	PRD81, 052002 (2010)

BESIII: $\psi(2S) \to \gamma\eta_c(2S)$, $\eta_c(2S) \to K_s K 3\pi$

PRD 87, 052005



Significance

4.2 σ

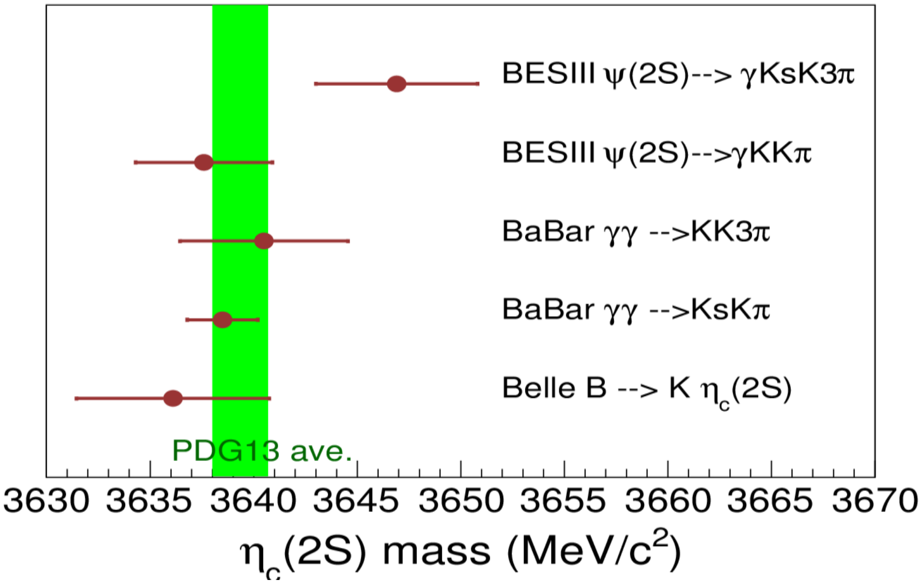
$$M = 3646.9 \pm 1.6 \pm 3.6 \ \mathrm{MeV}/c^2$$

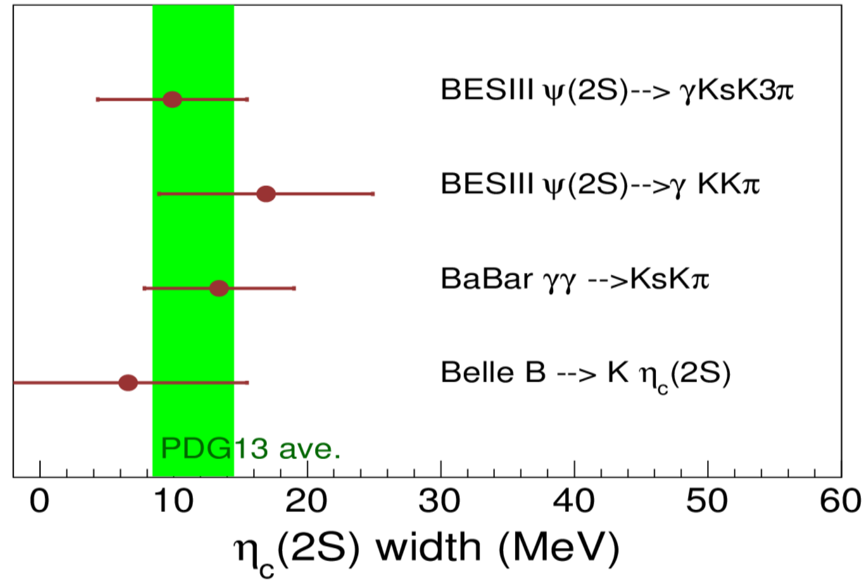
$$\Gamma = 9.2 \pm 4.8 \pm 2.9 \ \mathrm{MeV}/c^2$$

$$\mathcal{B}(\psi' \to \gamma\eta_c' \to \gamma K_s K 3\pi) = (7.03 \pm 2.10 \pm 0.70) \times 10^{-6}$$

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

PRL 109, 042003
PRD 87, 052005





$h_c(1P)$

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

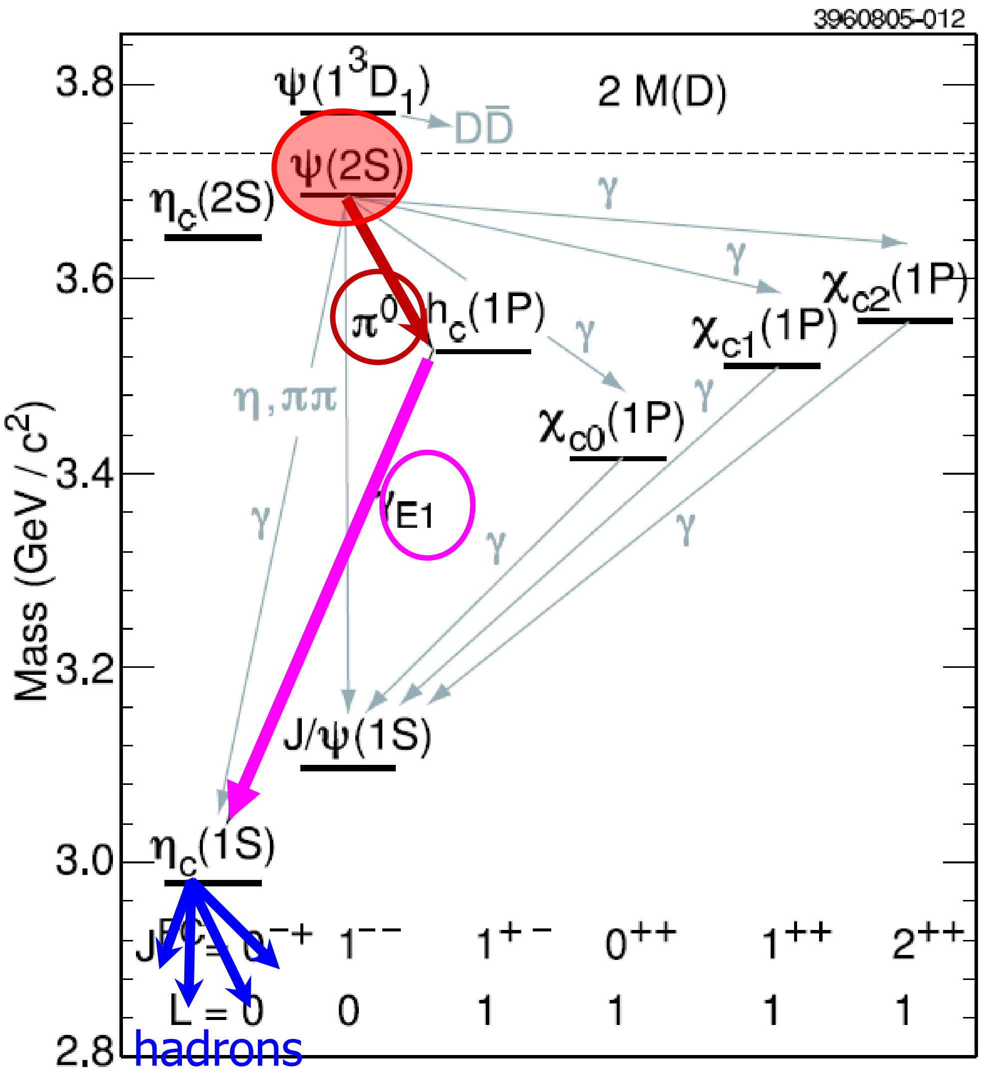
  $$\langle M(1\ ^3P_J)\rangle = [M(\chi_{c0})+3M(\chi_{c1})+5M(\chi_{c2})]/9$$

- **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

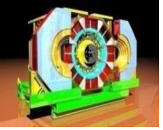
Rate $\propto \mathcal{B}(\psi' \to \pi^0 h_c) \times \mathcal{B}(h_c \to \gamma\eta_c)$

"exclusive"

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

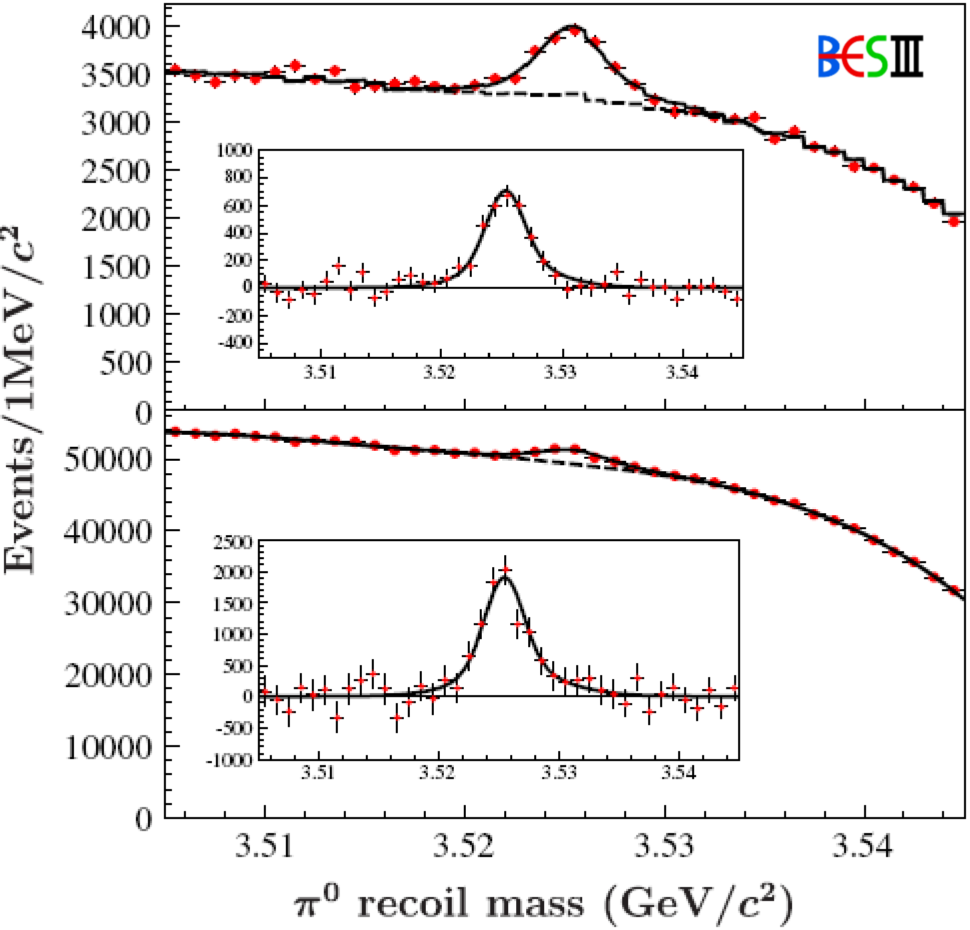
Rate $\propto$

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



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

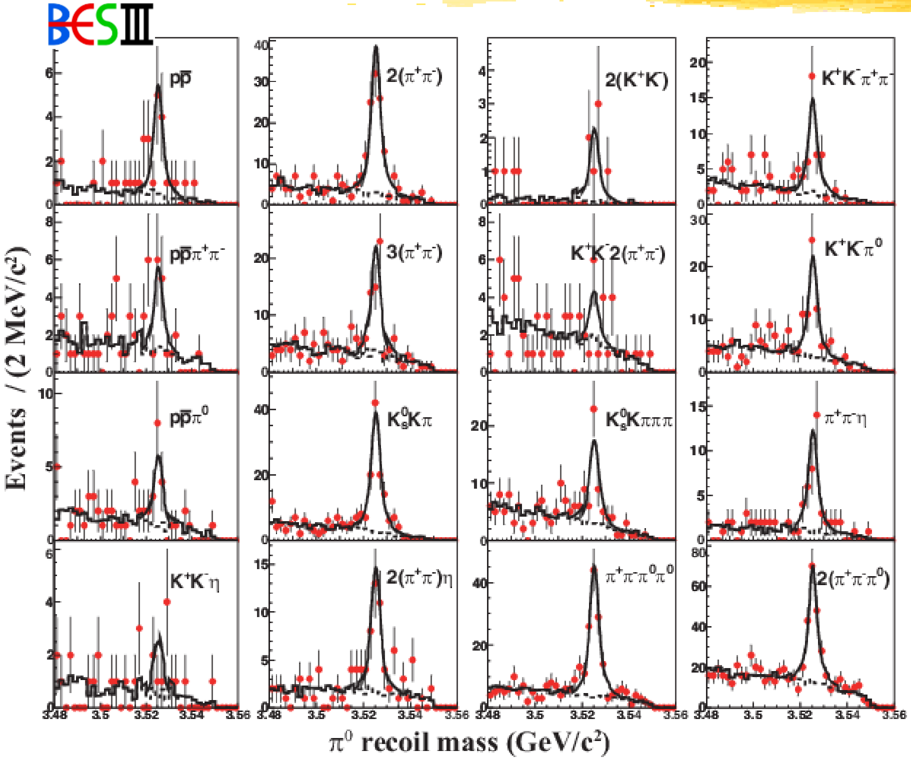
$\mathcal{B}(\psi' \to \pi^0 h_c) =$ **(8.4 ± 1.3 ± 1.0) × 10^{-4}**

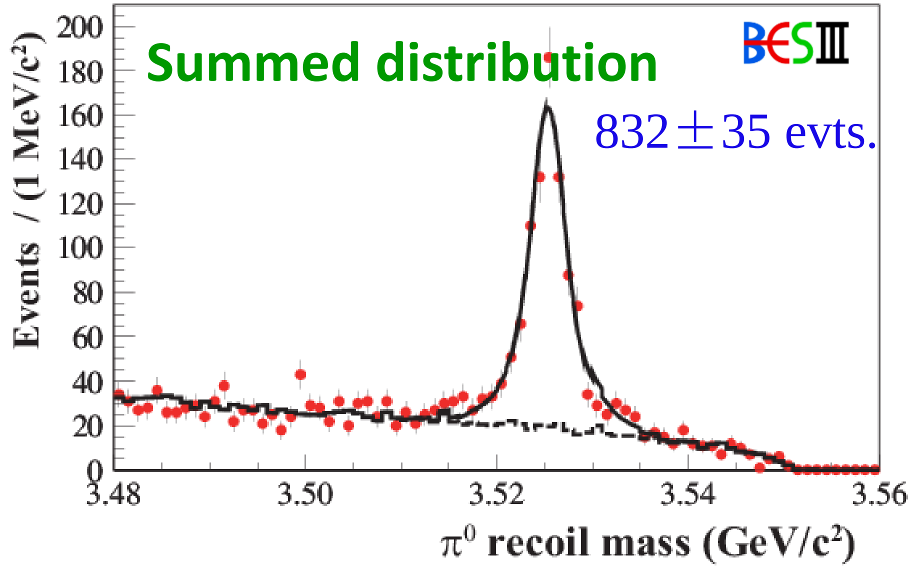
$\mathcal{B}(h_c \to \gamma\eta_c) =$ **(54.3 ± 6.7 ± 5.2)%**

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

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

PRD 86, 092009



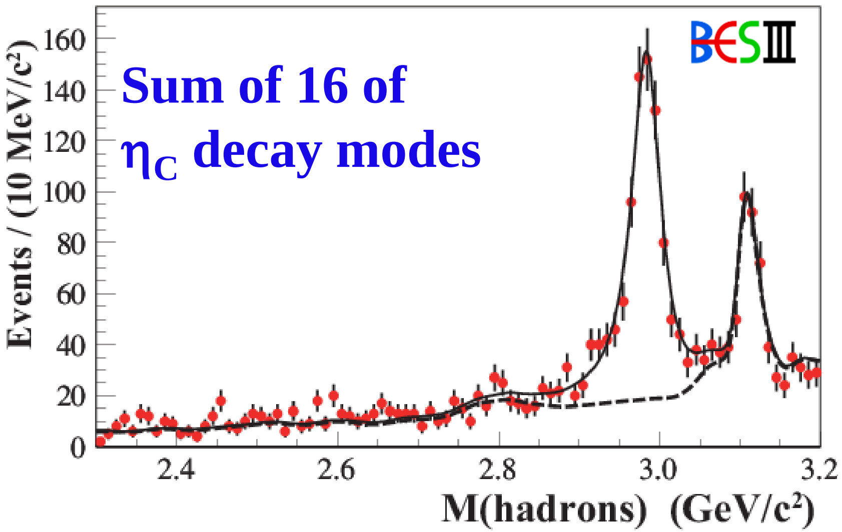


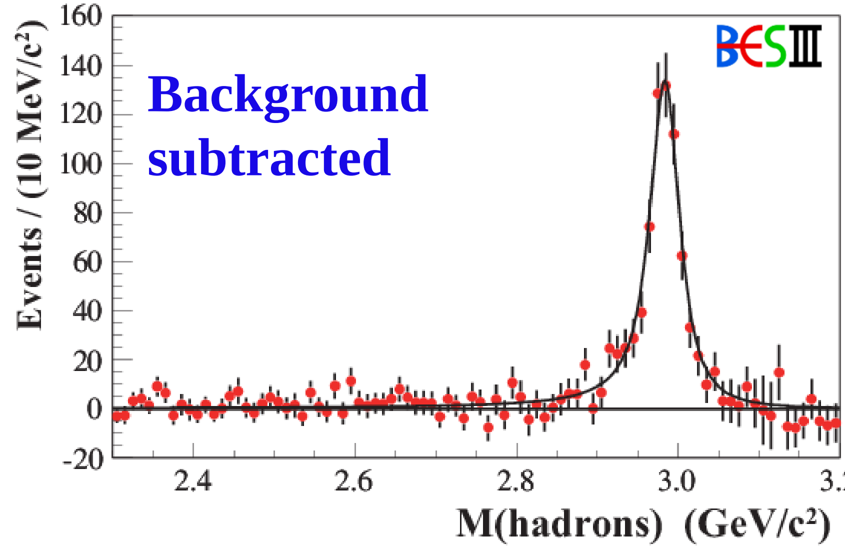
(MeV/c^2)	BESIII Exclusive	BESIII Inclusive	CLEO
M	3525.31±0.11±0.14	3525.40±0.13±0.18	3525.21±0.27±0.14
Γ	0.70±0.28±0.22	0.73±0.45±0.28	--
ΔM_{hf}(1P)	-0.01±0.11± 0.15	0.10±0.13±0.18	0.08± 0.18± 0.12

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:

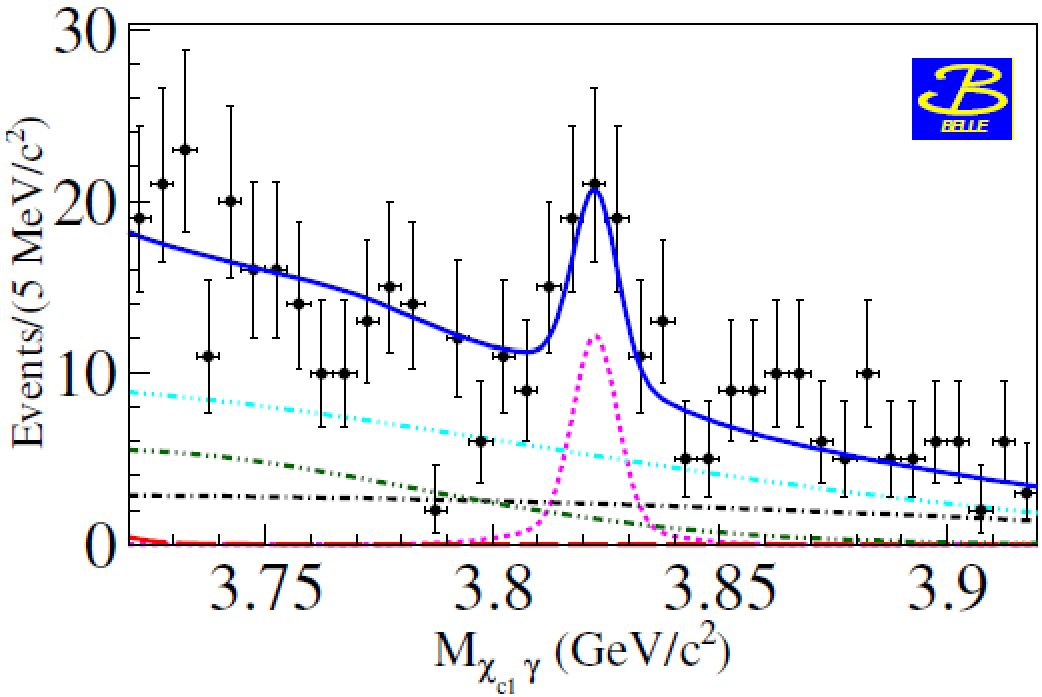
$\Rightarrow$ non-resonant interfering background is smaller than $\psi' \to \gamma h_c$

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

$\psi' \to \pi^0 h_c,\ h_c \to \gamma\eta_c$	$\psi' \to \gamma\eta_c$ (PRL 108, 222002)
M = 2984.49±1.16±0.52 MeV/c²	**M = 2984.3±0.6±0.6 MeV/c²**
Γ = 36.4±3.2±1.7 MeV	**Γ = 32.0±1.2±1.0 MeV**

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

BELLE: X(3823)



- using $772 \cdot 10^6$ $B\overline{B}$
- $B \to K\, \gamma\chi_{c1}$

M = (3823.1±1.8±0.7) MeV/c^2
3.8σ

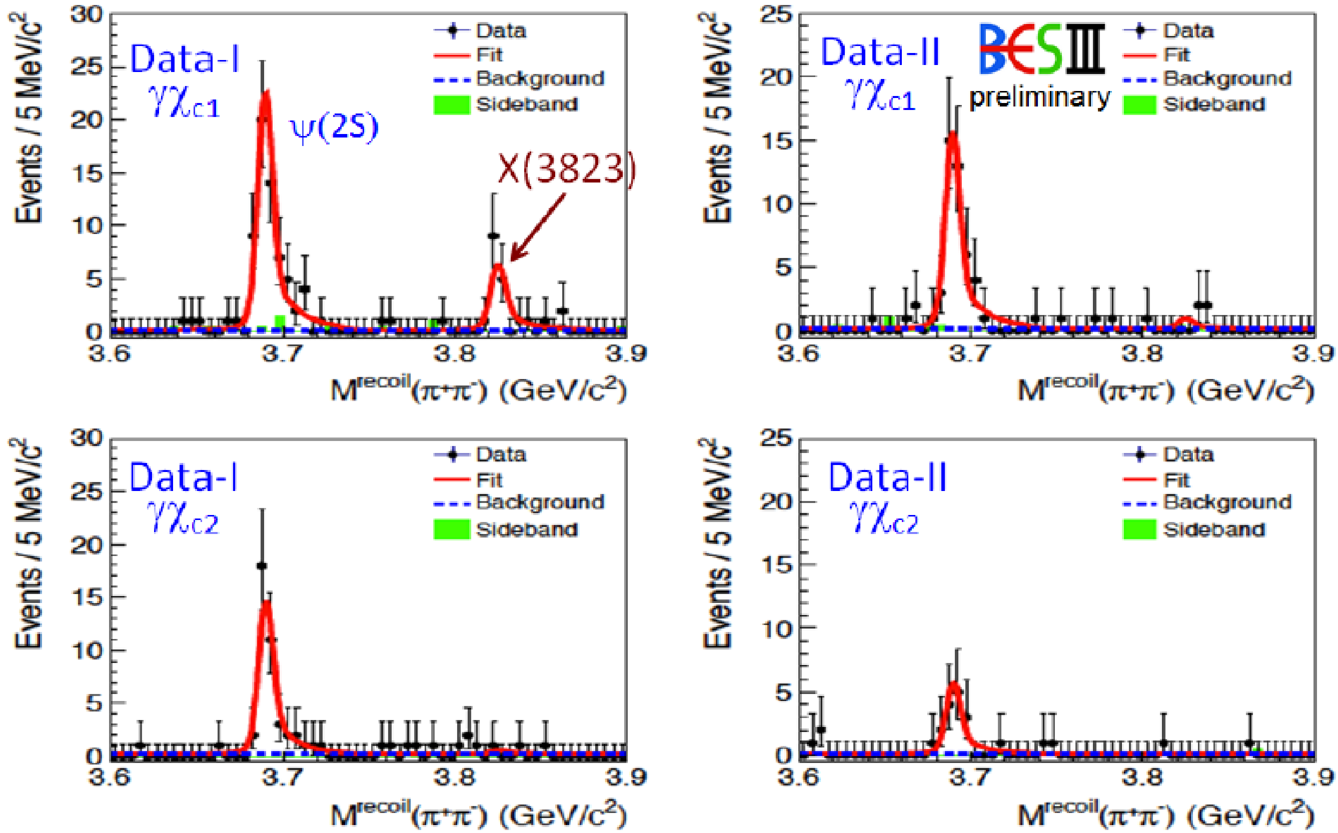
Mass and width compatible with a $\psi_2(1^3D_2)$ state

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

BESIII preliminary

Simultaneous fit to two data set:

- Data-1
  ≥ 4.36 GeV/c^2
- Data-2:
  [4.23,4.26] GeV/c^2



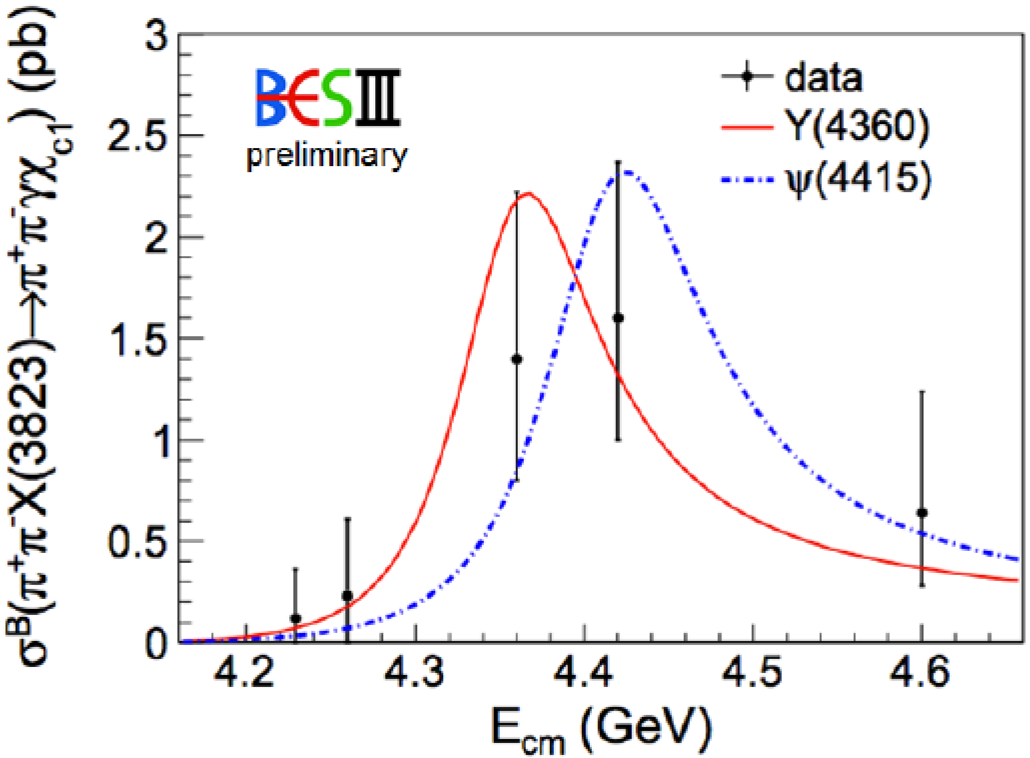
M = (3821.7±1.3±0.7) MeV/c^2

6.7σ

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

Energy-dependent cross section for

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



Compatible with both $Y(4360)$ and $\psi(4415)$ line shapes

Mass and width ∼ in agreement with potential model

Production ratio

$$R_{21} \equiv \frac{\mathcal{B}(X(3823) \to \gamma\chi_{c2})}{\mathcal{B}(X(3823) \to \gamma\chi_{c1})}$$

~ 0.2 prediction

< 0.43 at 90% C.L.

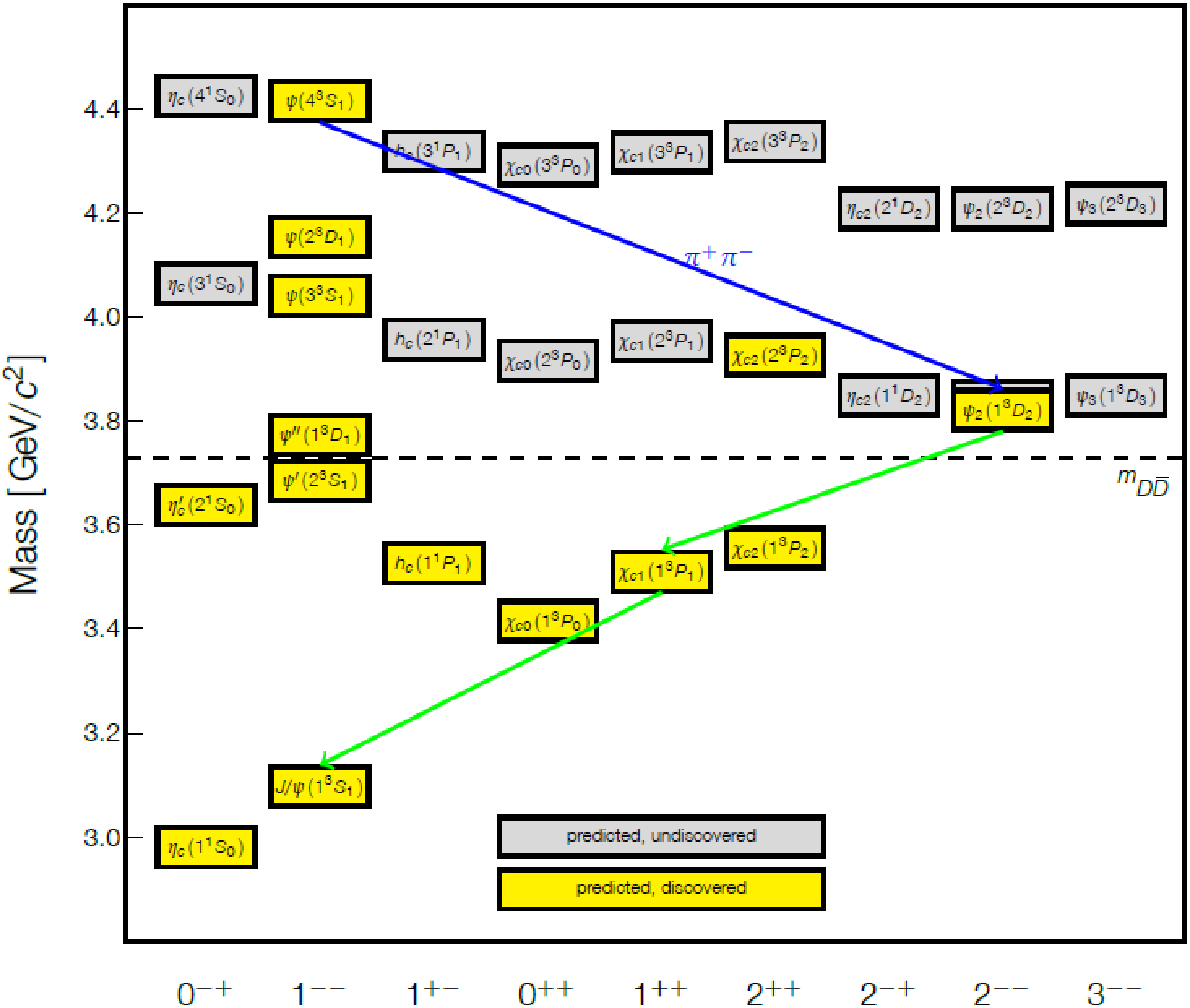
Exclusion:

$1^1D_2 \to \gamma\chi_{c1}$ forbidden

$1^3D_3 \to \gamma\chi_{c1}$ has zero amplitude

Not enough statistics to distinguish S and D wave from data

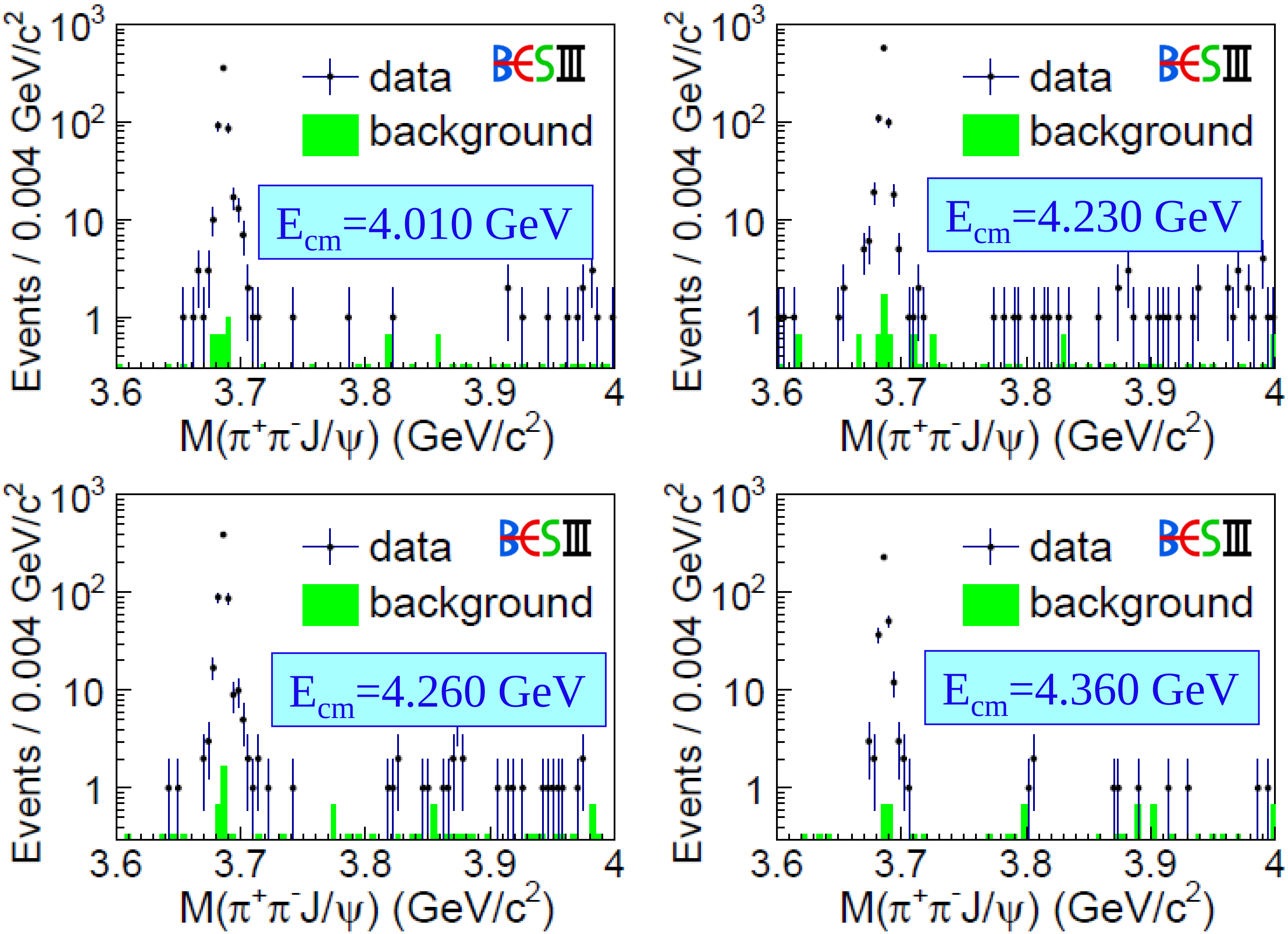
Higher Charmonium states: a new family member?



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

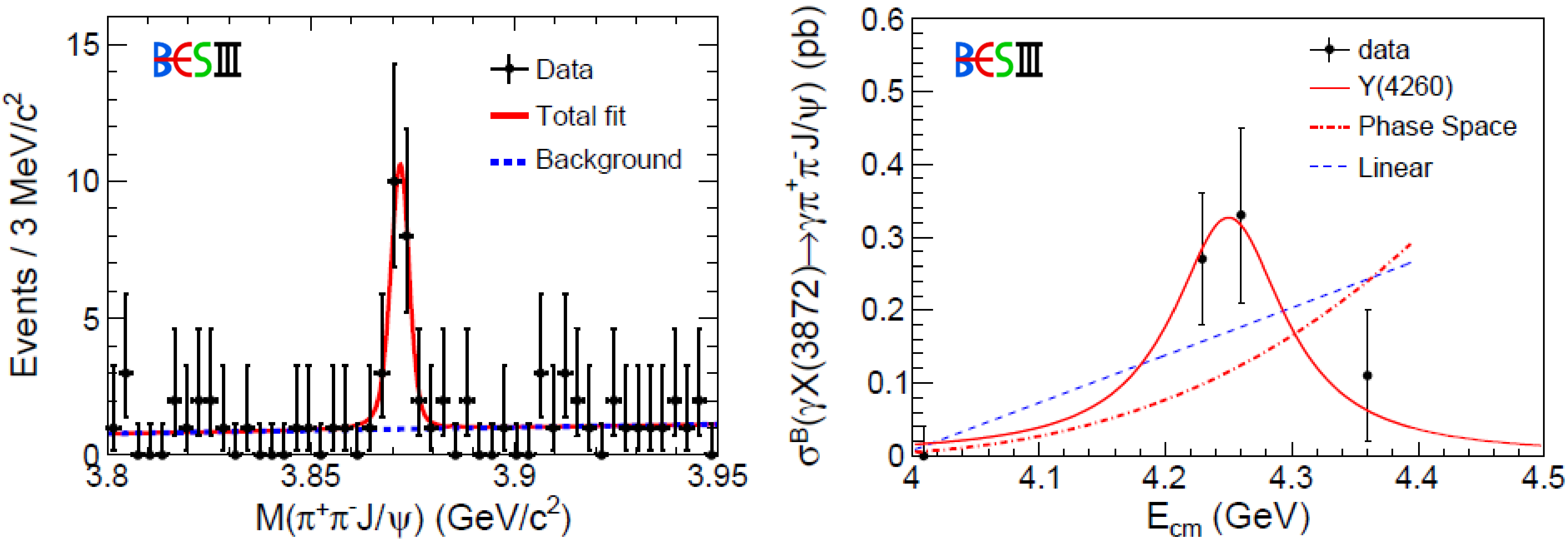
PRL 112, 092001

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



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

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

[PDG: 3871.68±0.17 MeV]

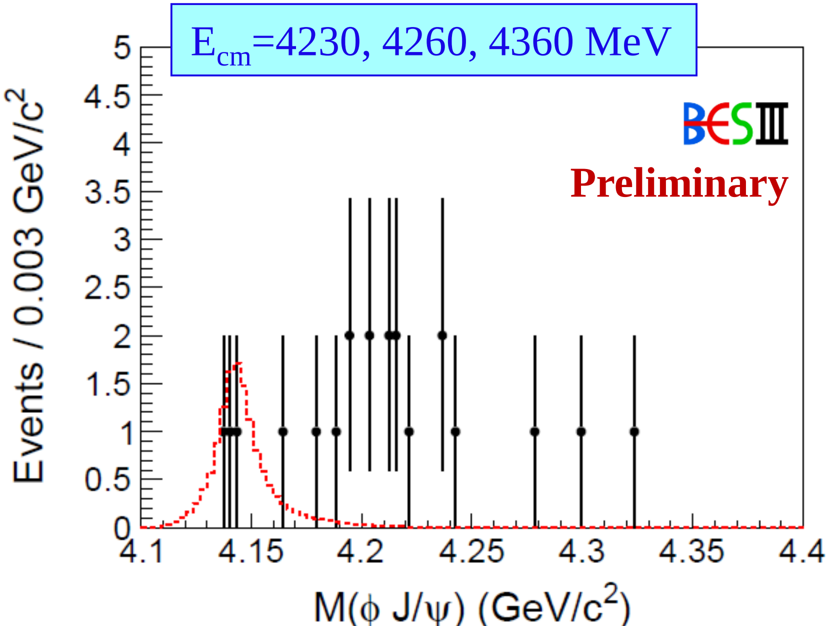
Could be a Y(4260) → γX(3872)!

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

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]

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

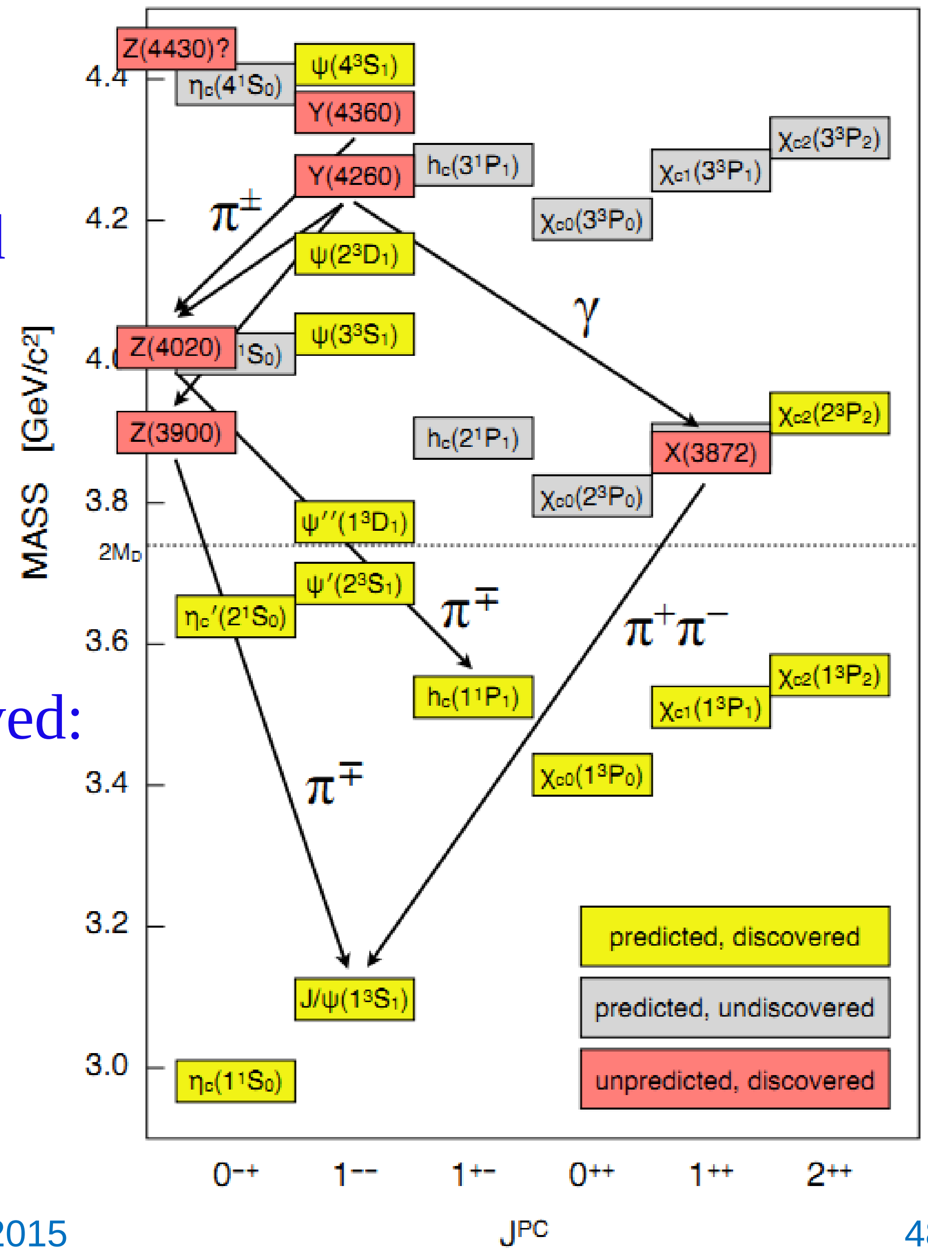
[1] PRL 112, 092001

[2] arXiv:0910.3138

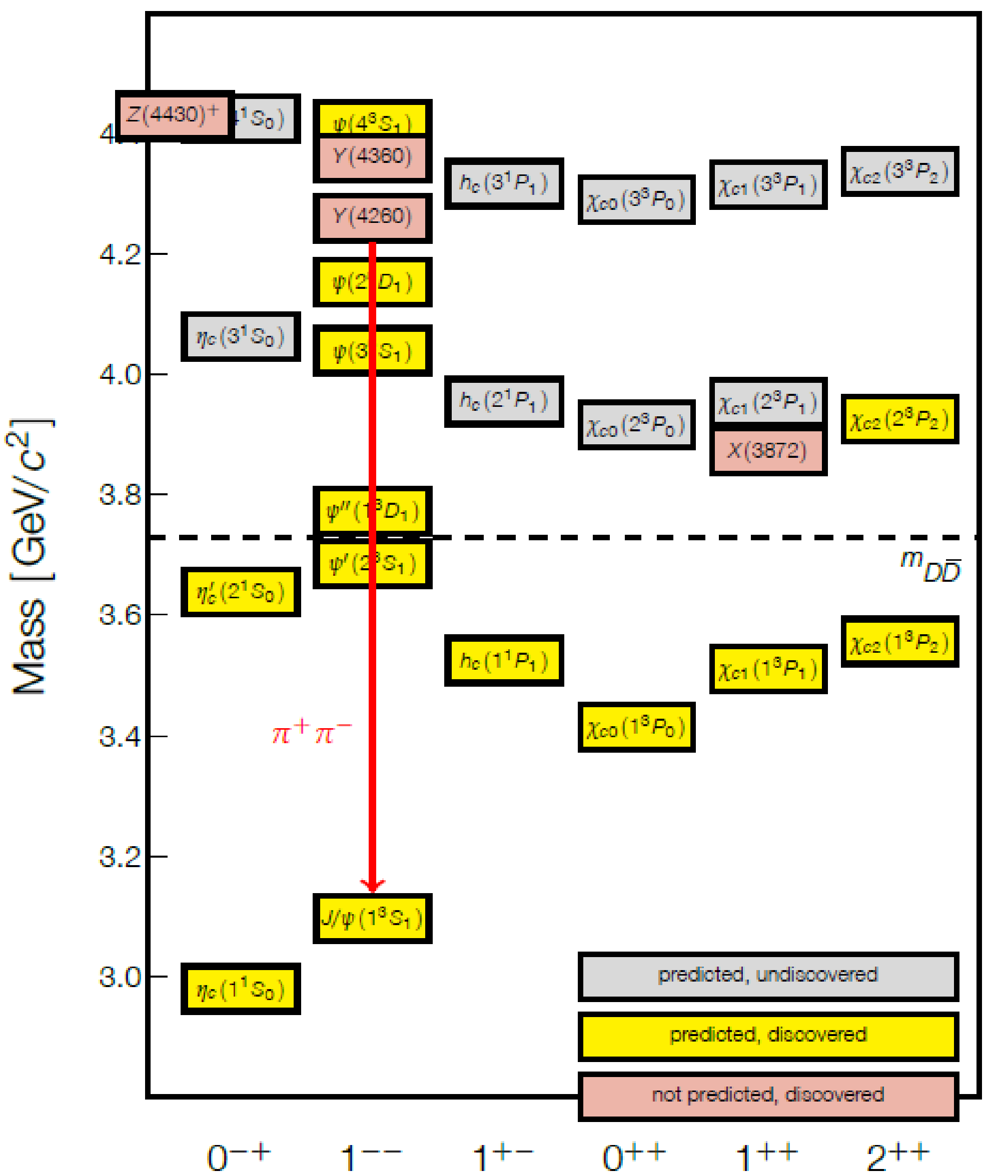
[3] PR D80, 054019

Exotic at BESIII

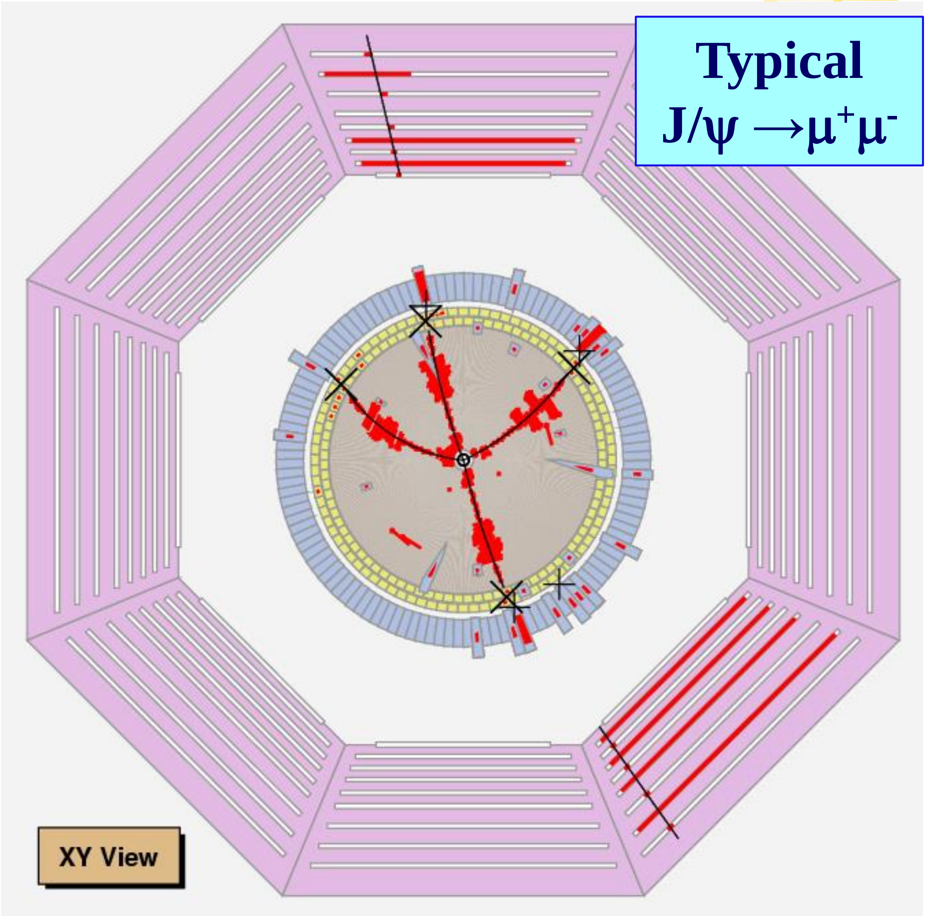
- all states below DD threshold have been observed and described by charm anti-charm potential model
- only a few of the predicted states above threshold have been found
- many new states have been observed:
  - some unexpected
  - many with properties not consistent with charmonium decays to X,Y or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

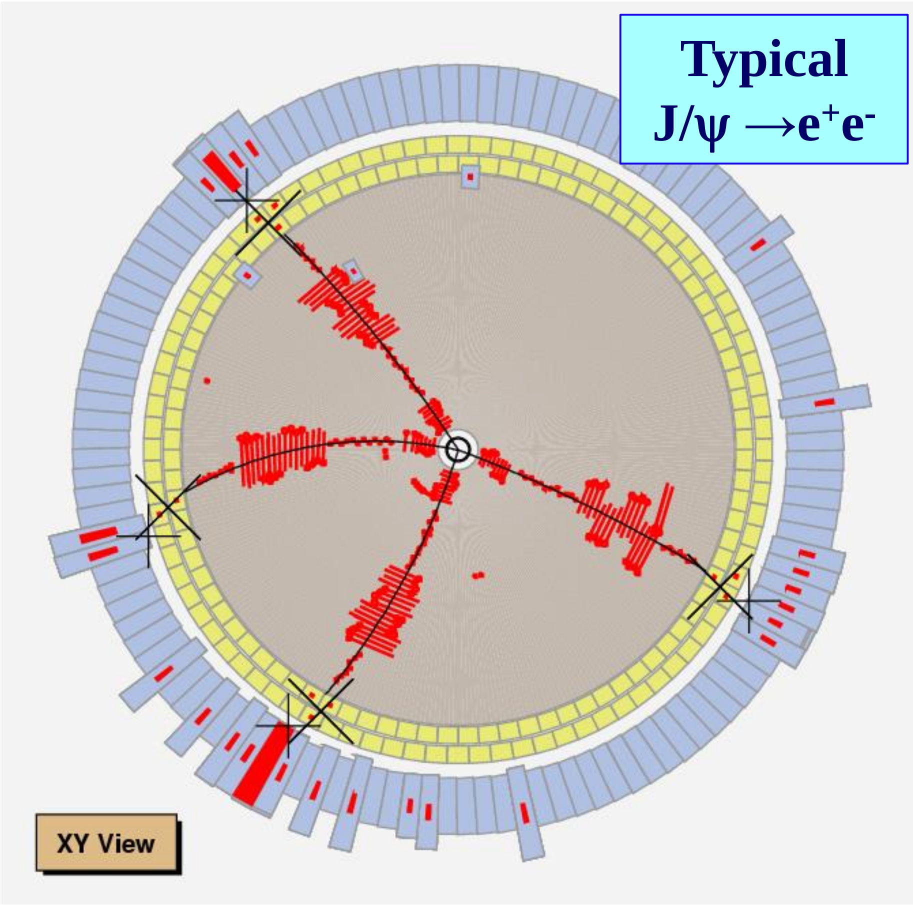


BESIII: $e^+e^- \to \pi^+\pi^- J/\psi$ events



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

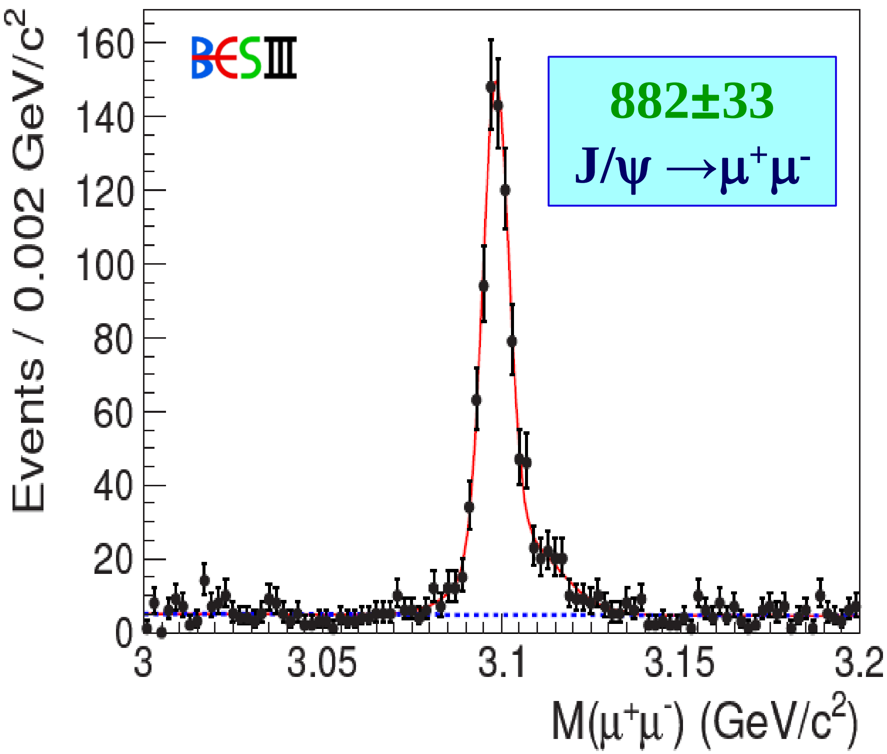


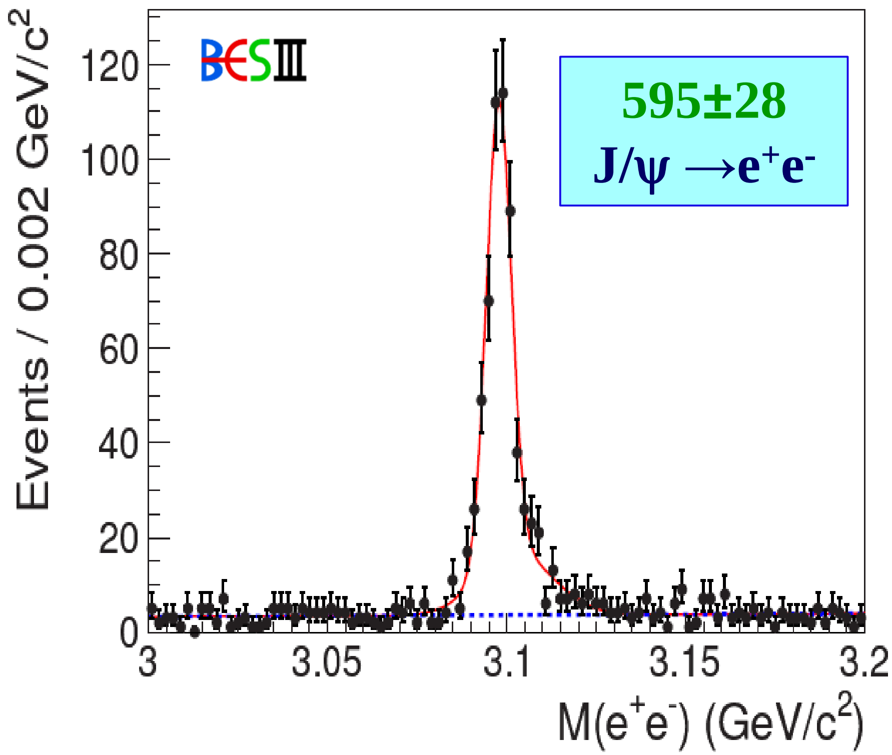


- 4 charged tracks, J/ψ reconstruct via lepton pairs
- very clean sample, very high efficiency, kinematic fit used
- only use MDC & EMC information, MC simulation reliable

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

PRL 110, 252001



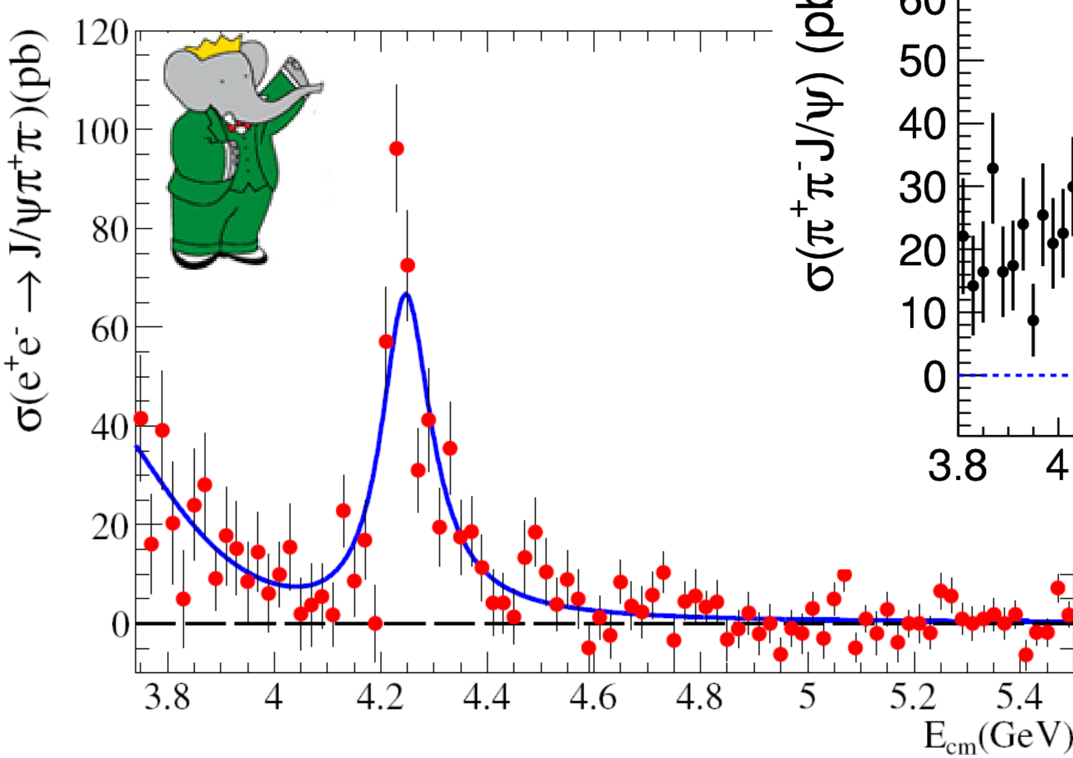


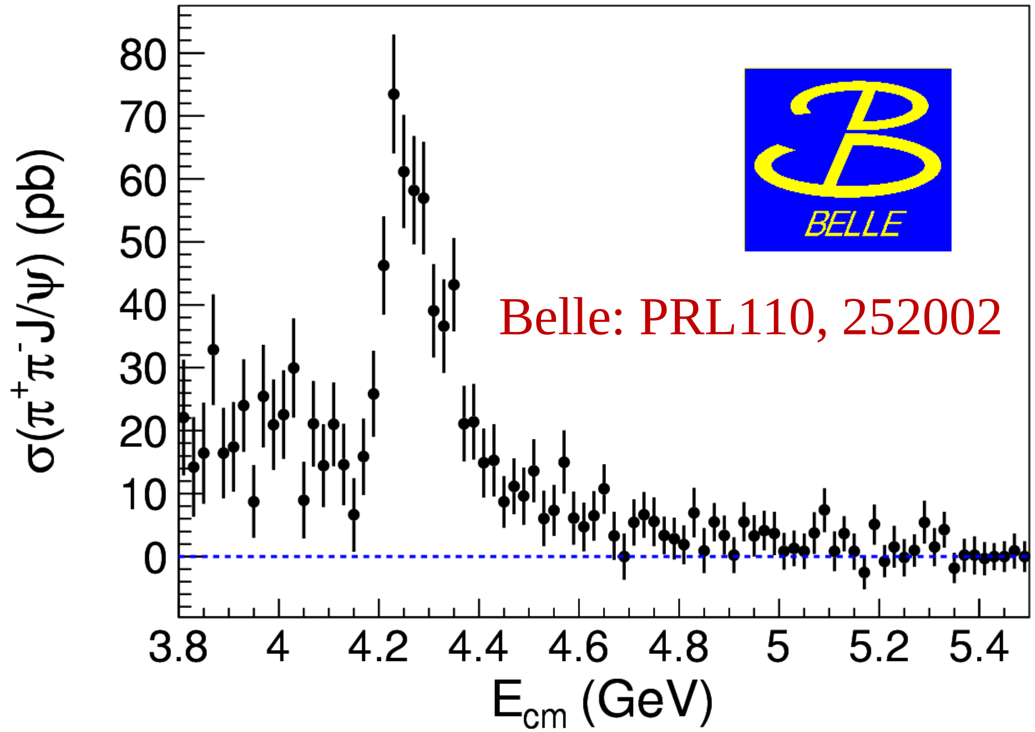
- Dominant background $e^+e^- \to \pi^+\pi^-\pi^+\pi^-$
- J/ψ signal: [3.08,3.12] GeV
- J/ψ sideband: [3.0,3.06] GeV or [3.14,3.20] GeV

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

PRL 110, 252001

BaBar: PRD86, 051102 (2012)





Belle: PRL110, 252002

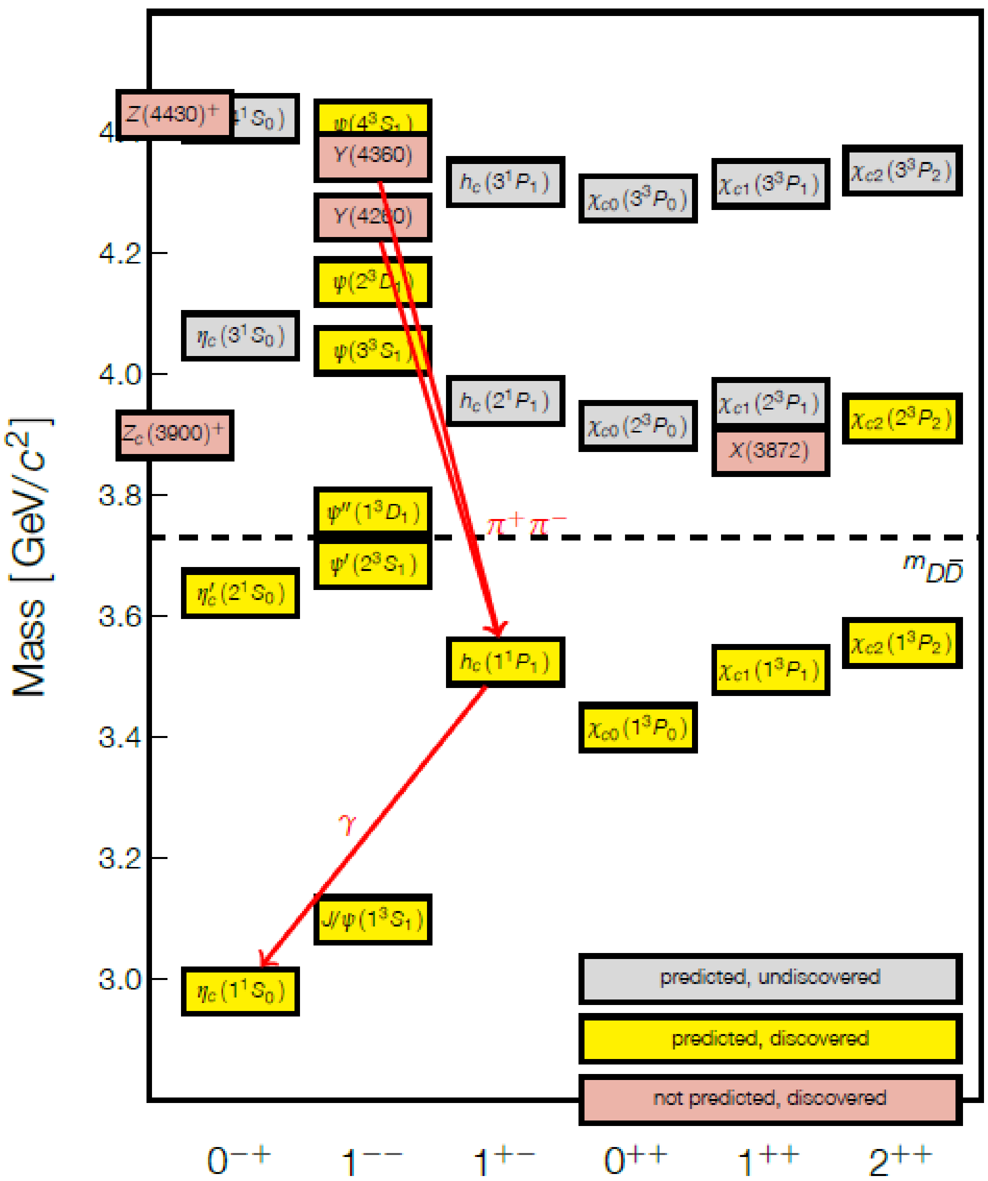
BESIII cross sections:

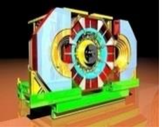
- more energy points
- more data!

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

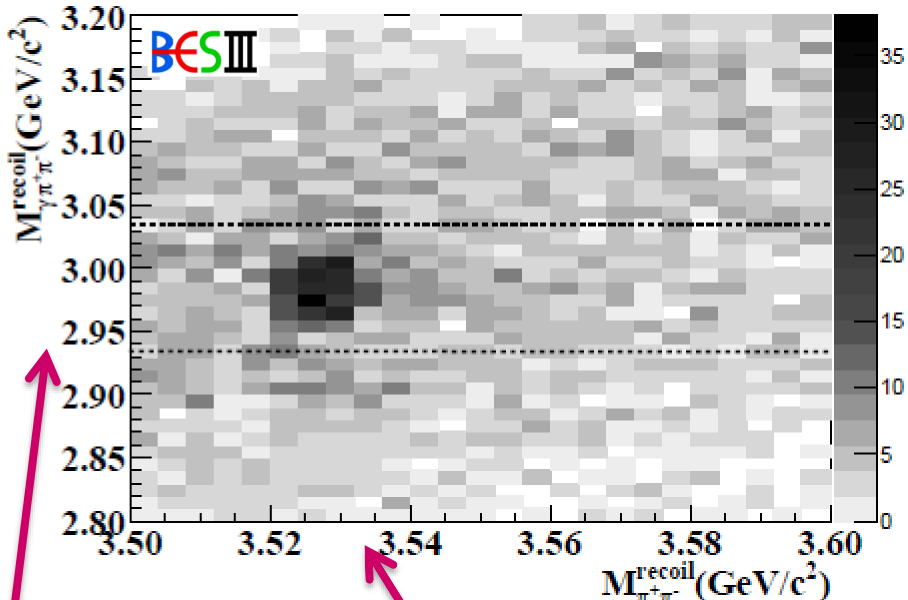


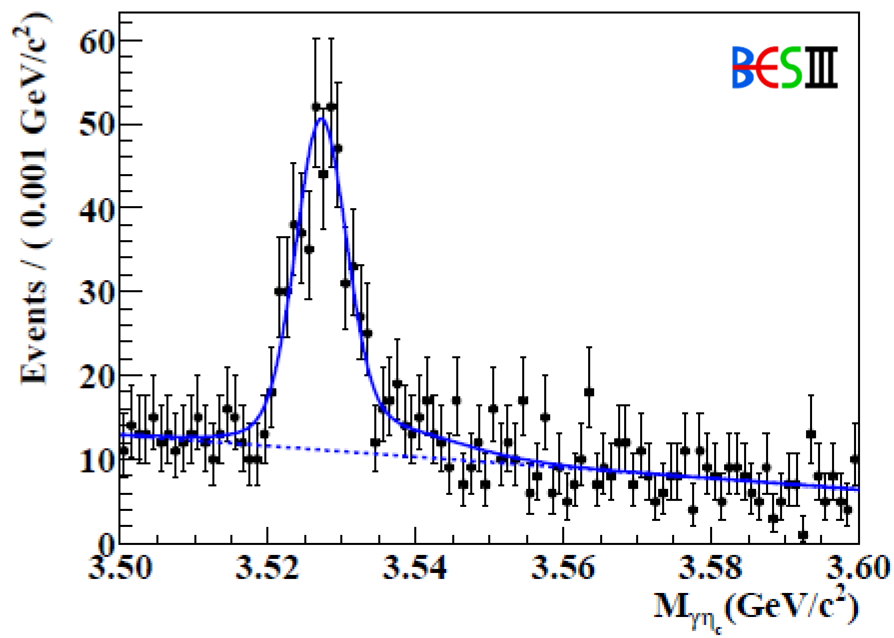


BESIII: $e^+e^- \to \pi^+\pi^- h_c(1P)$ @ 4.260 GeV

PRL 111, 242001

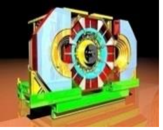
- **$h_c \to \gamma\eta_c$, $\eta_c \to$ hadrons [16 exclusive decay modes]**
  - $p\bar{p}$, $\pi^+\pi^-K^+K^-$, $\pi^+\pi^-p\bar{p}$, $2(K^+K^-)$, $2(\pi^+\pi^-)$, $3(\pi^+\pi^-)$
  - $2(\pi^+\pi^-)K^+K^-$, $K_S^0K^+\pi^-$+c.c., $K_S^0K^+\pi^-\pi^+\pi^-$+c.c., $K^+K^-\pi^0$
  - $p\bar{p}\pi^0$, $K^+K^-\eta$,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





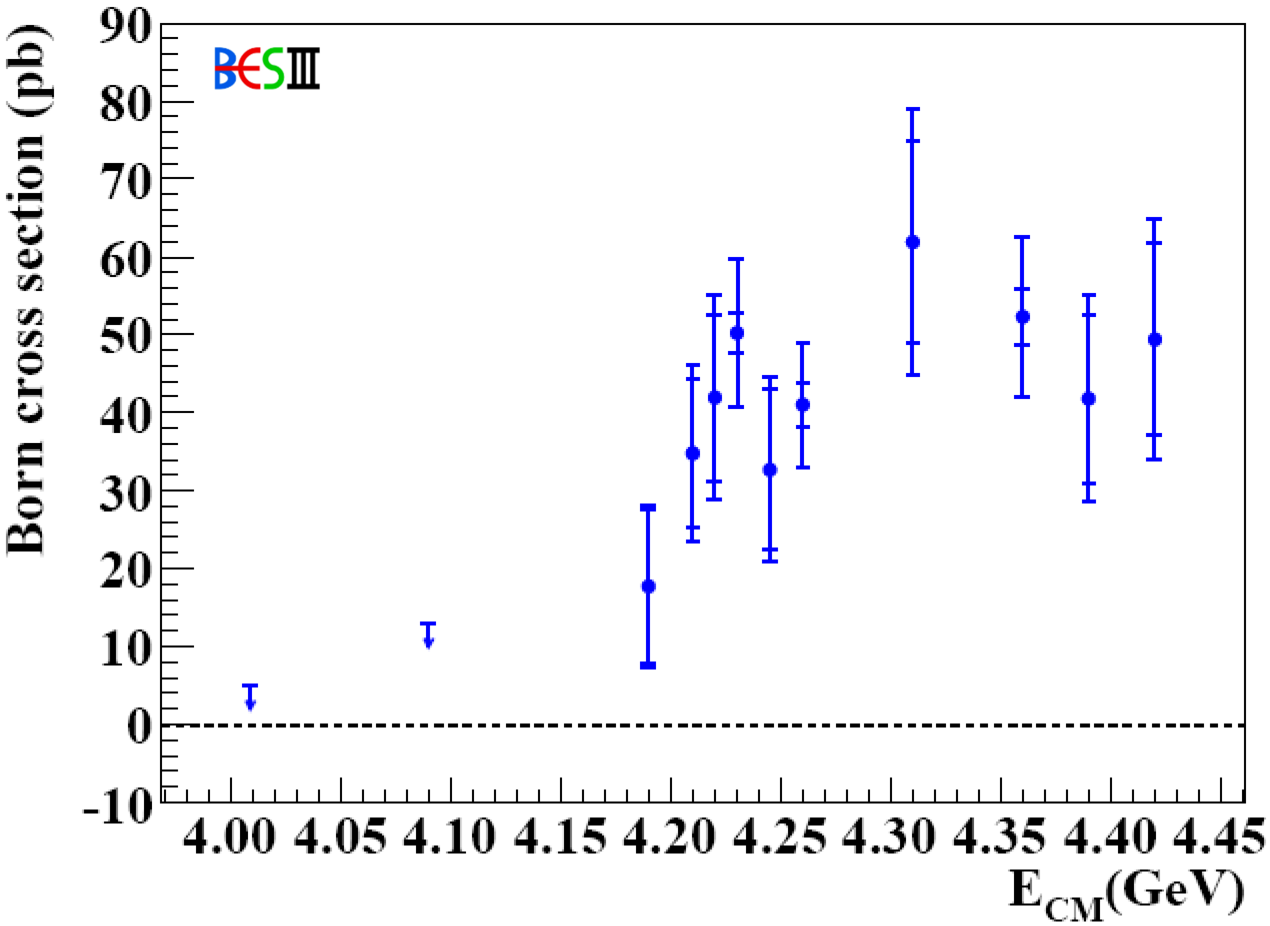
η_c candidate

h_c candidate



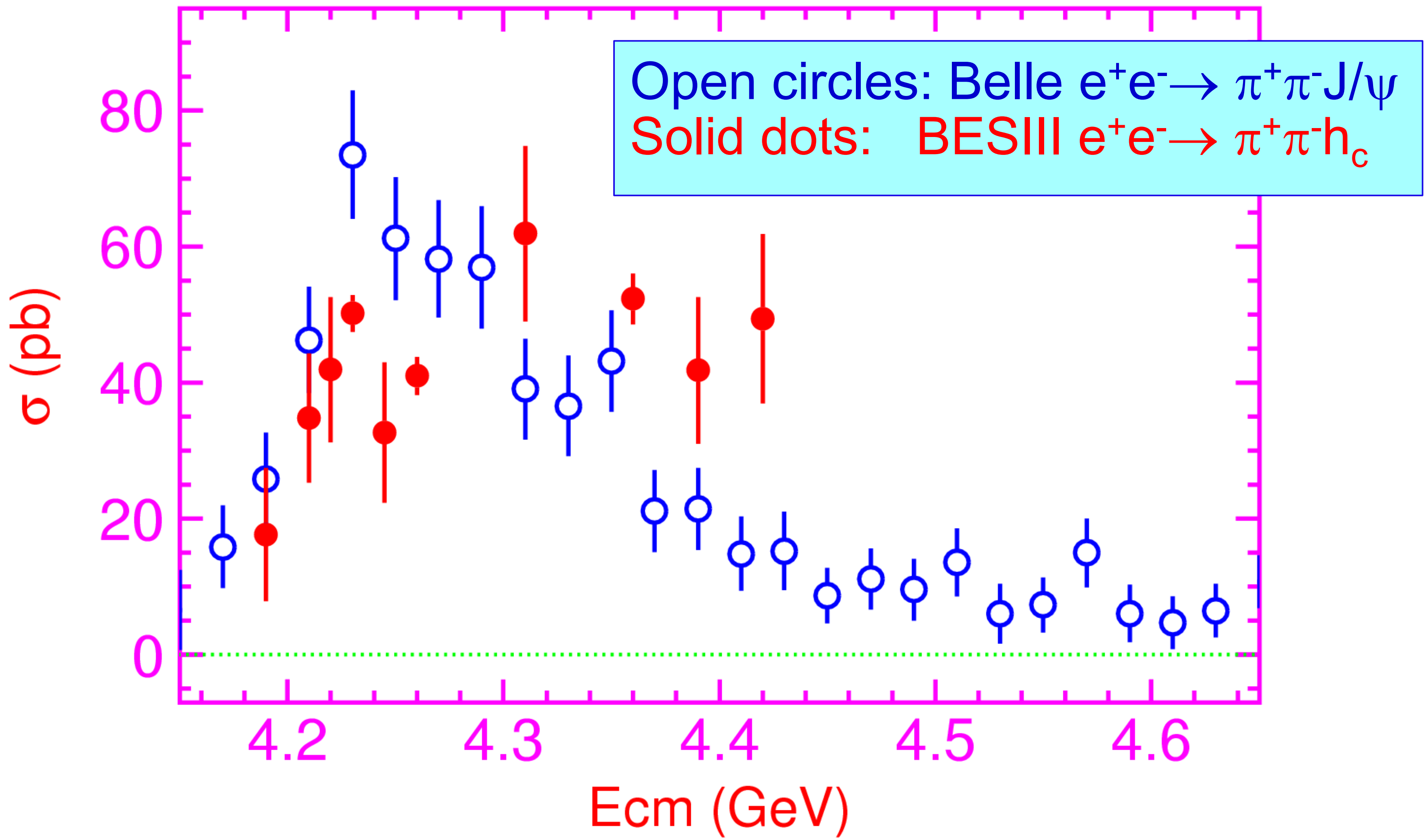
BESIII: $e^+e^- \to \pi^+\pi^- h_c(1P)$

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**

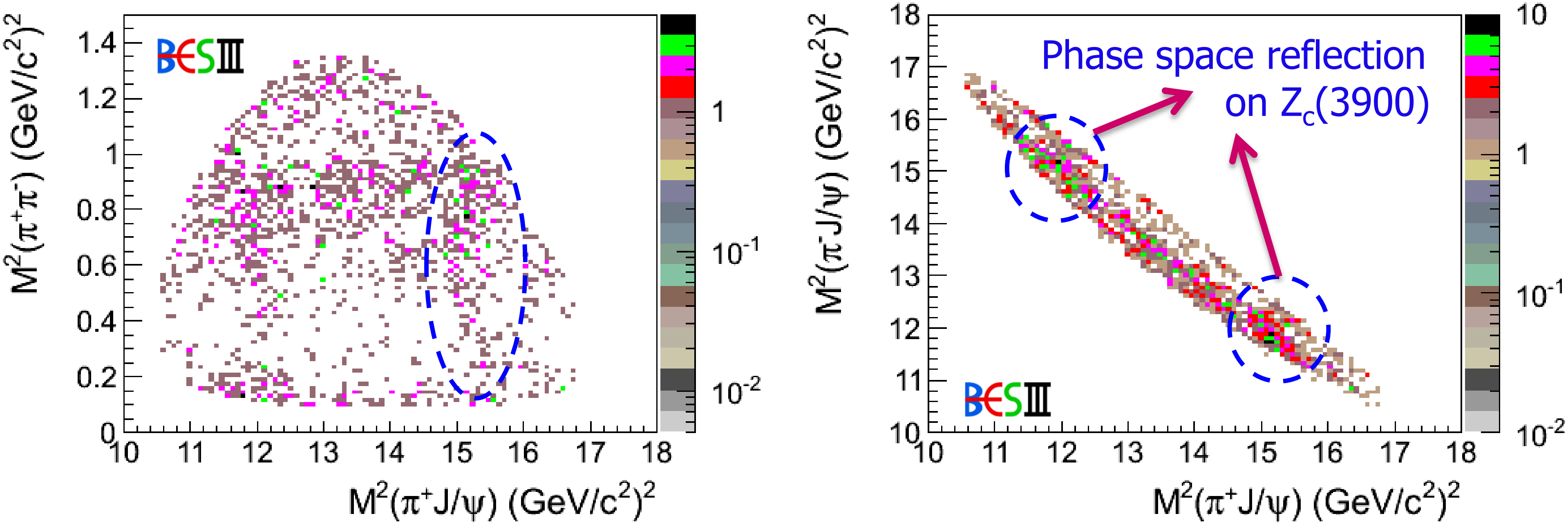
$e^+e^- \to \pi^+\pi^- h_c(1P)$ vs $e^+e^- \to \pi^+\pi^- J/\psi$



More data at higher energies needed to complete line shape measurement

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

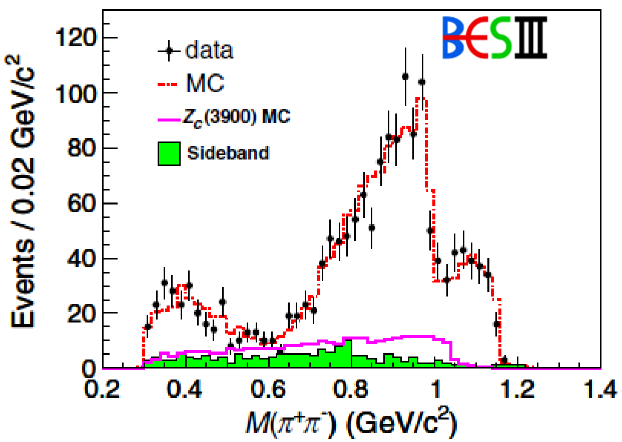
PRL 110, 252001

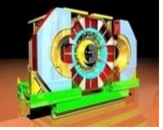


Modelling $\pi^+\pi^-$ with know structure:

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

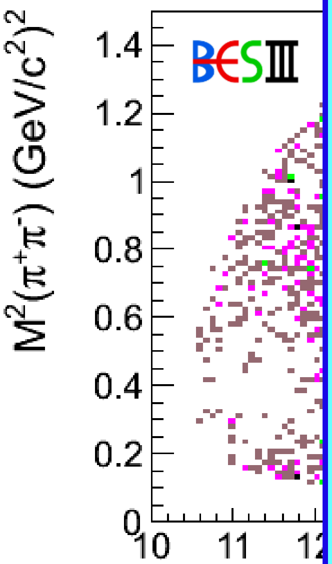
Fits quite well $\pi^+\pi^-$ projection

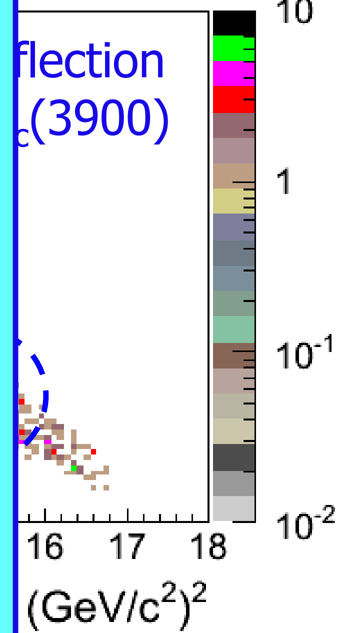


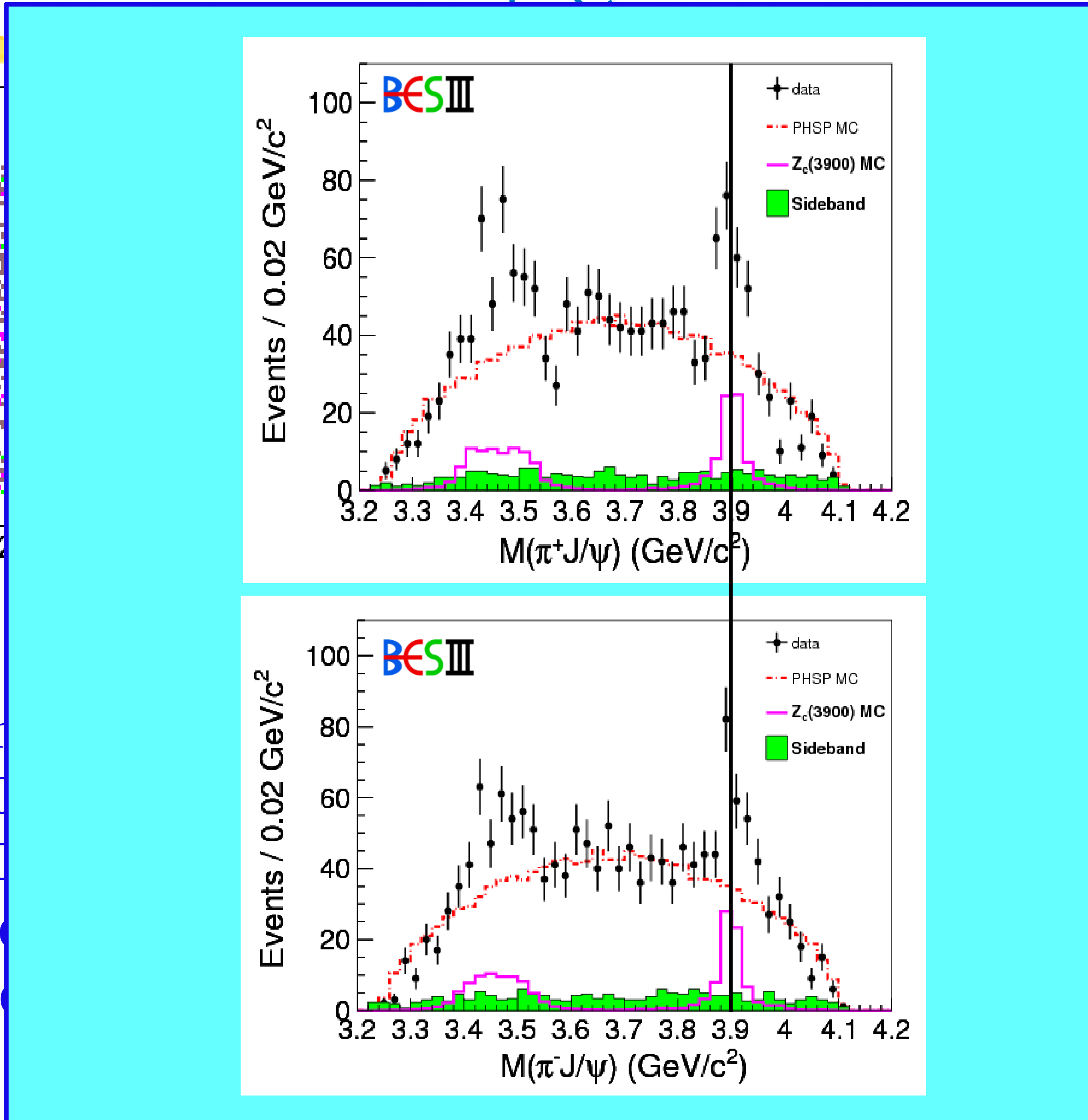


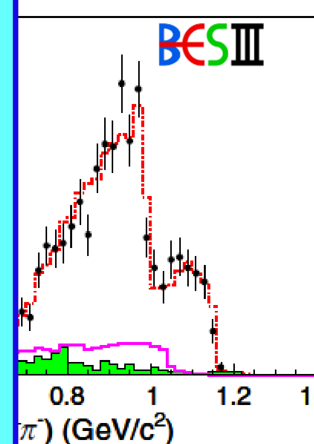
BESIII: $e^+e^- \to \pi^+\pi^- J/\psi$ @ 4.260 GeV

PRL 110, 252001









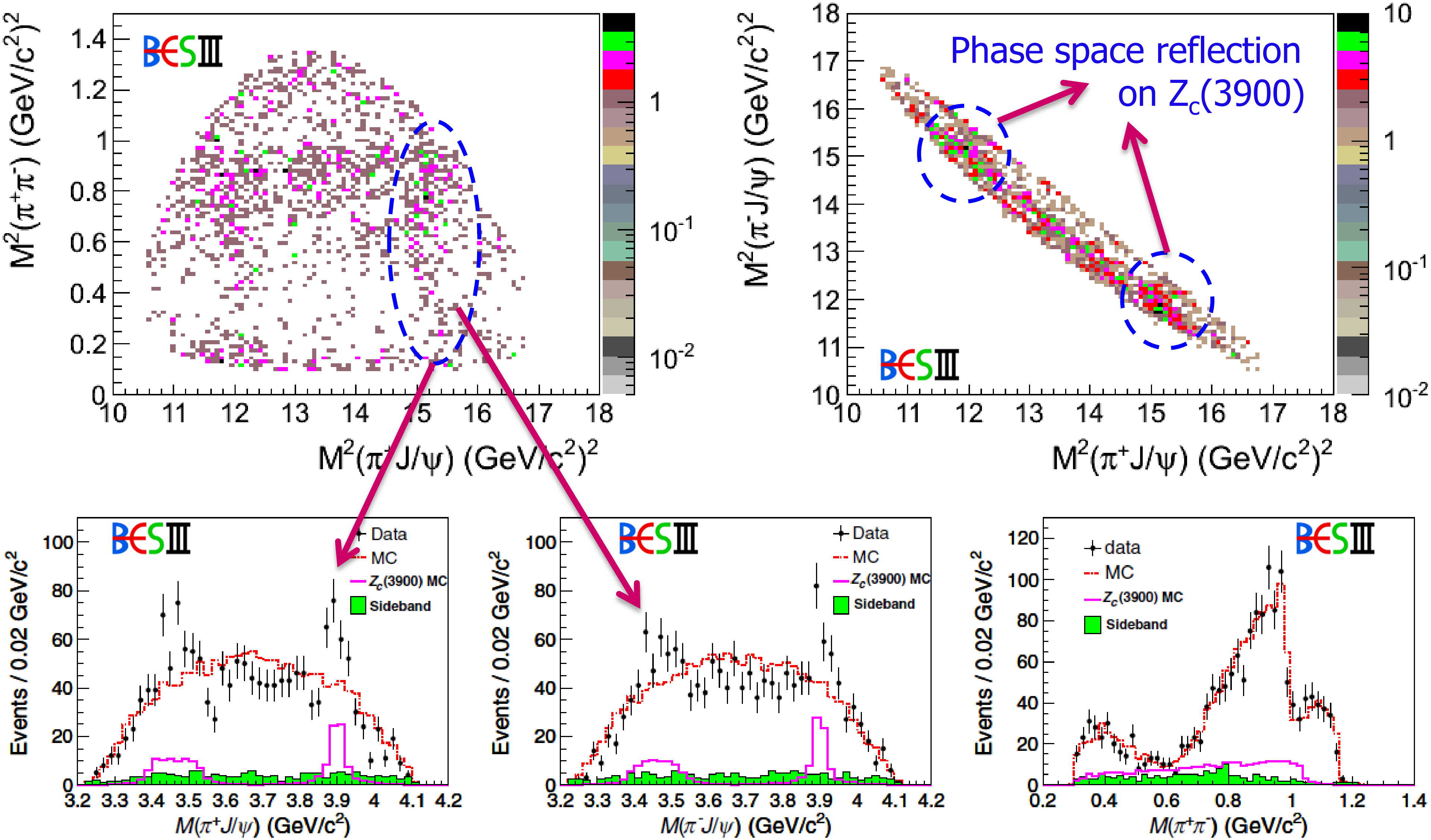
Modellin

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

Fits quit

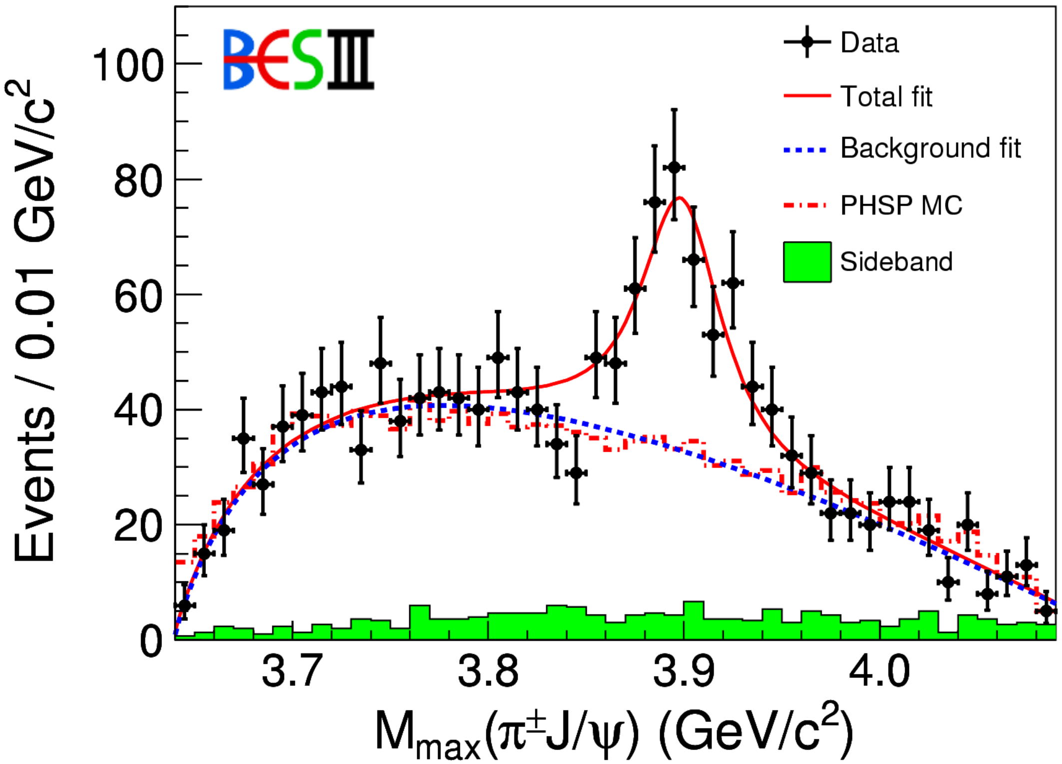
BESIII: $e^+e^- \to \pi^+\pi^- J/\psi$ @ 4.260 GeV

PRL 110, 252001

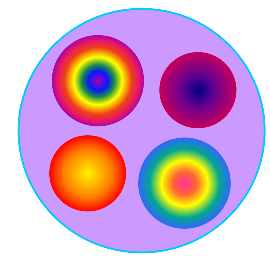


BESIII: $e^+e^- \to \pi\, Z_c(3900) \to \pi^+\pi^- J/\psi$ @ 4.260 GeV

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±3.6±4.9) MeV/c^2

Γ = (46±10±20) MeV/c^2

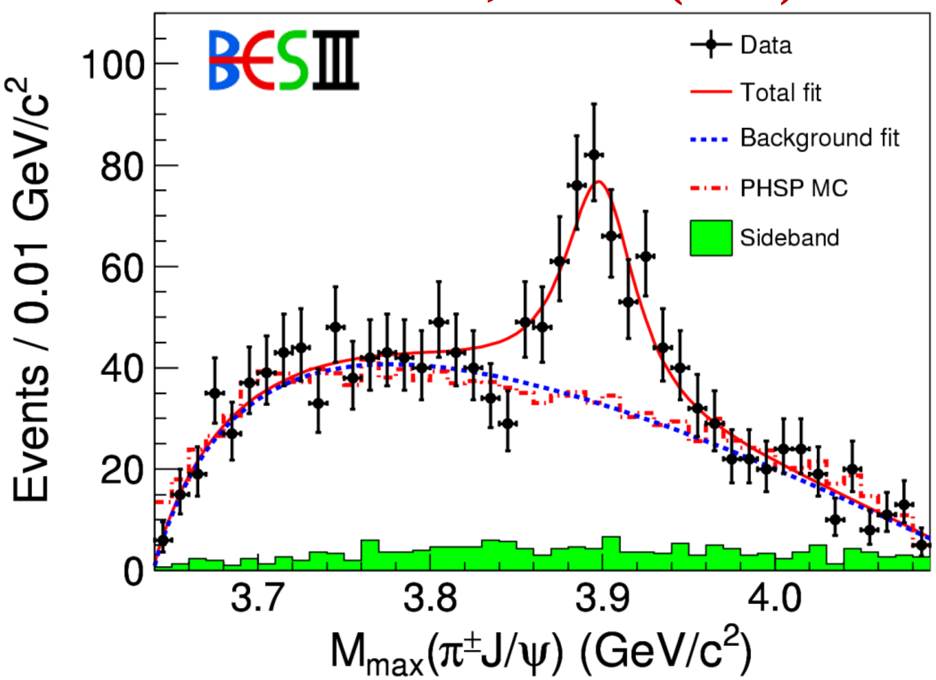
R = (21.5±3.3±7.5)%

Significance >8σ

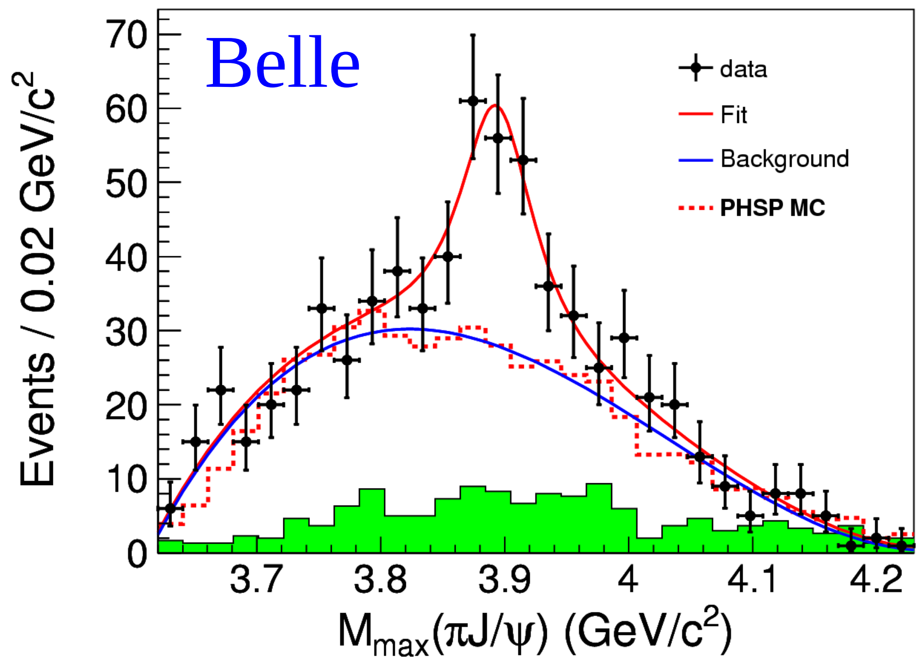
$e^+e^- \to \pi\, Z_c(3900) \to \pi^+\pi^- J/\psi$ @ 4.260 GeV

PRL 110, 252001

PRL 110, 252001 (2013)



PRL 110, 252002 (2013)



BESIII:

M = (3899.0±3.6±4.9) MeV/c^2

Γ = (46±10±20) MeV/c^2

307±48 events

>8σ

Belle:

M = (3894.5±6.6±4.5) MeV/c^2

Γ = (63±24±26) MeV/c^2

159±49 events

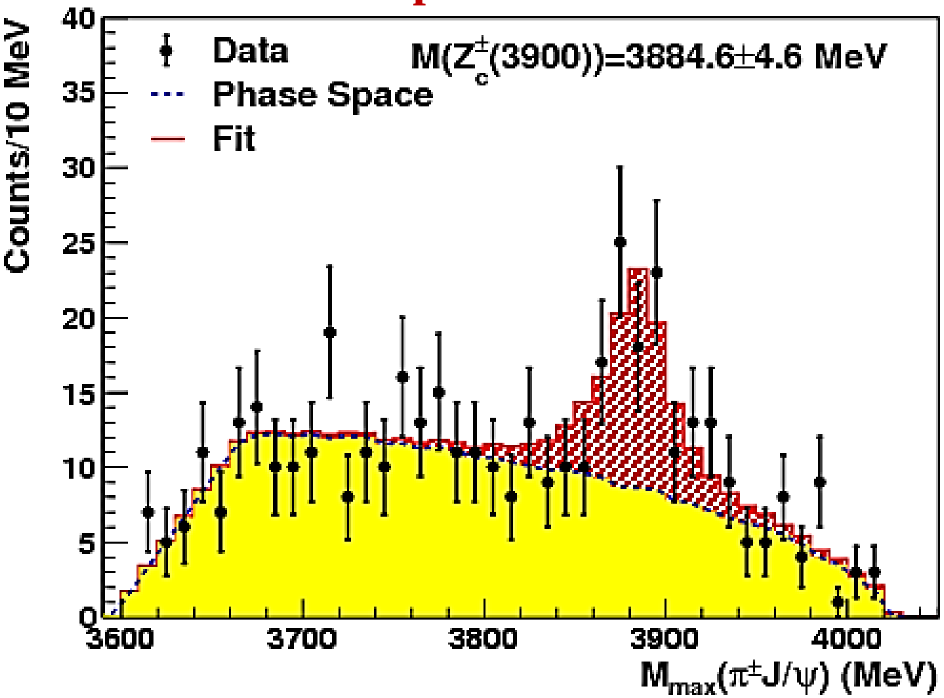
>5.2σ

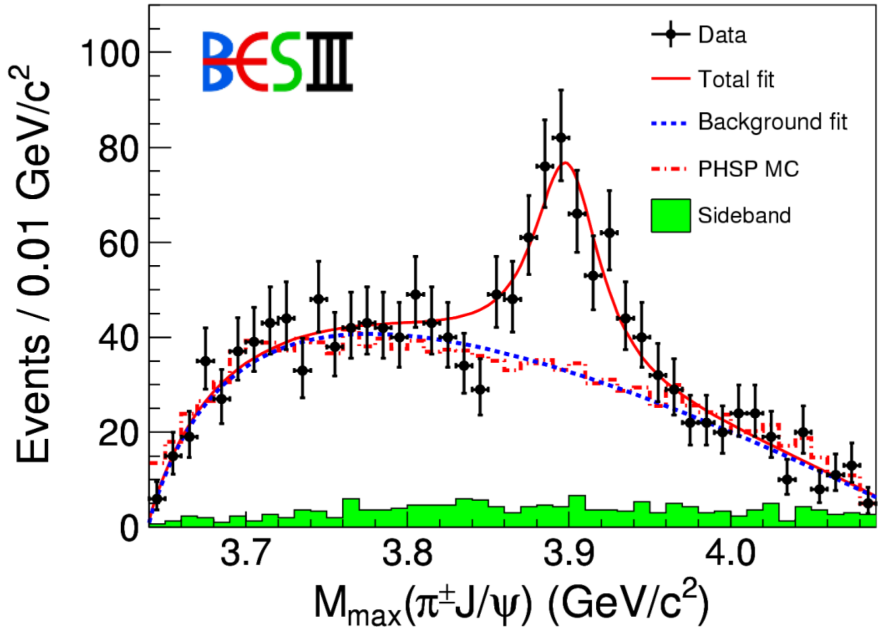
$e^+e^- \to \pi\, Z_c(3900) \to \pi^+\pi^- J/\psi$ @ 4.260 GeV

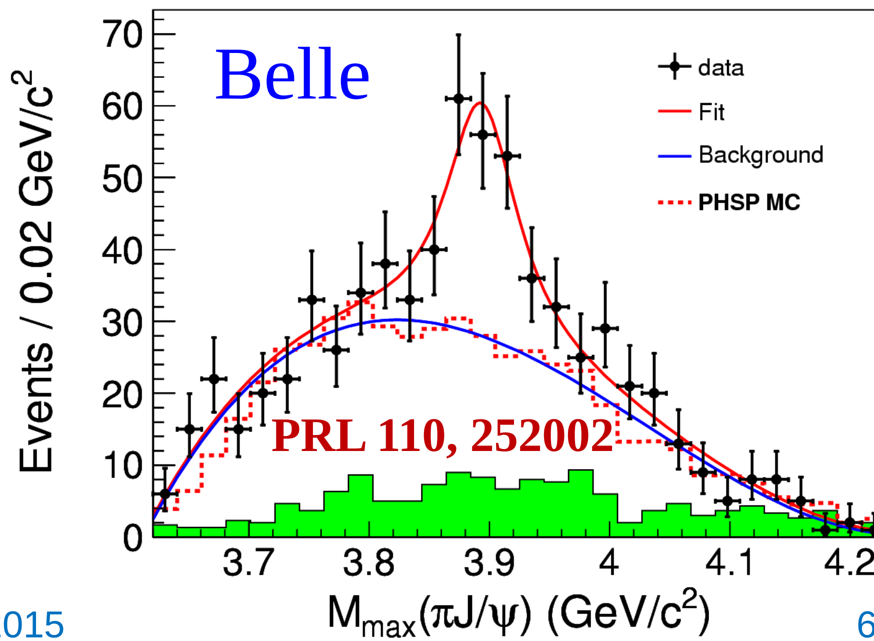
PRL 110, 252001

K. Seth & co. @ 4.170 GeV

hep-ex:1304.3036







M = (3885±5±1) MeV/c^2

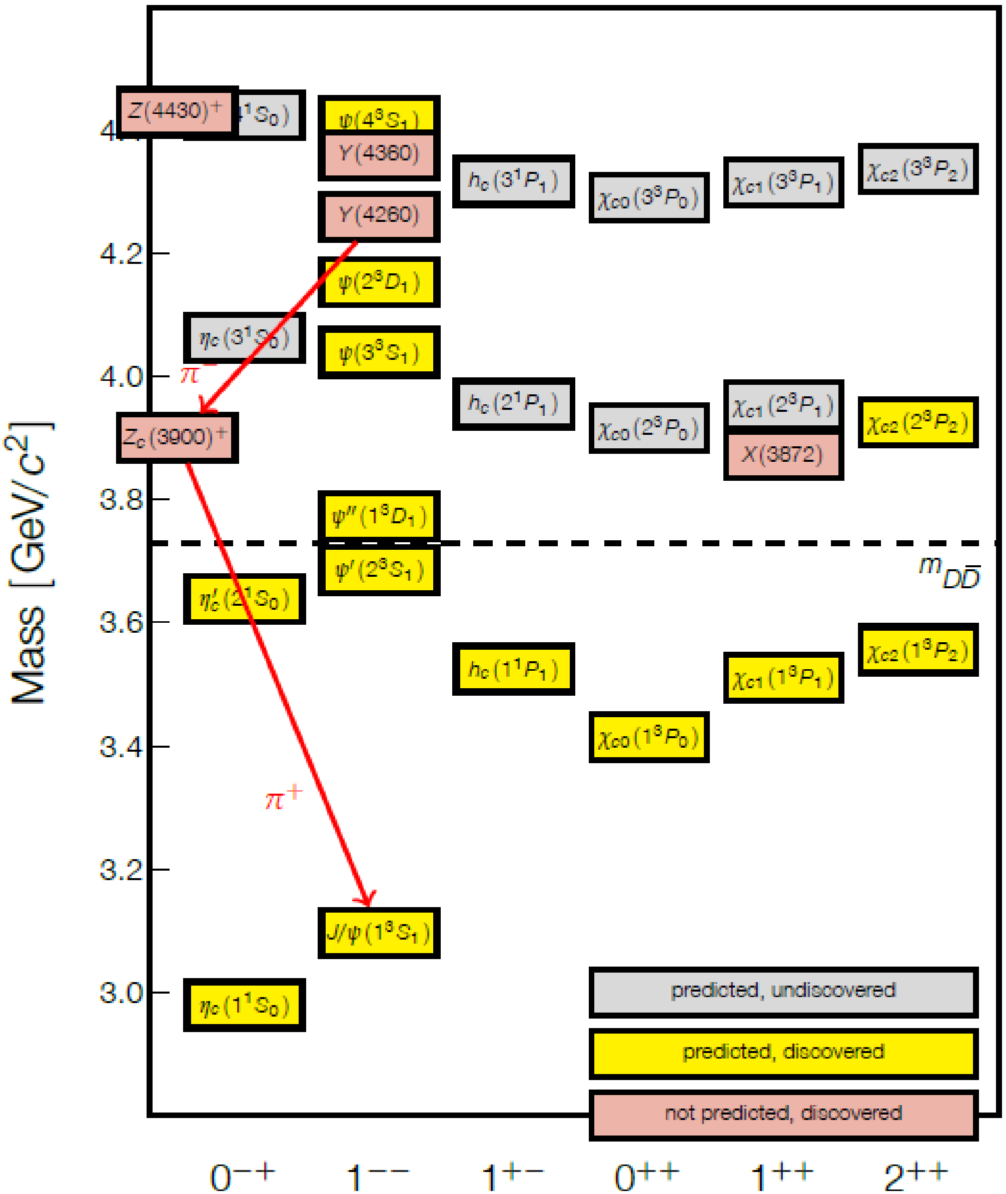
Γ = (34±12±4) MeV/c^2

81±20 events

6.1σ

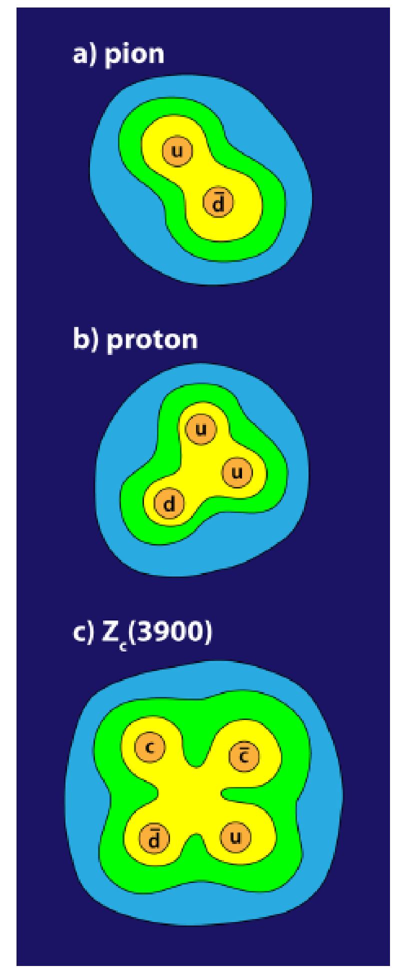
$e^+e^- \to \pi\, Z_c(3900) \to \pi^+\pi^- J/\psi$ @ 4.260 GeV

PRL 110, 252001



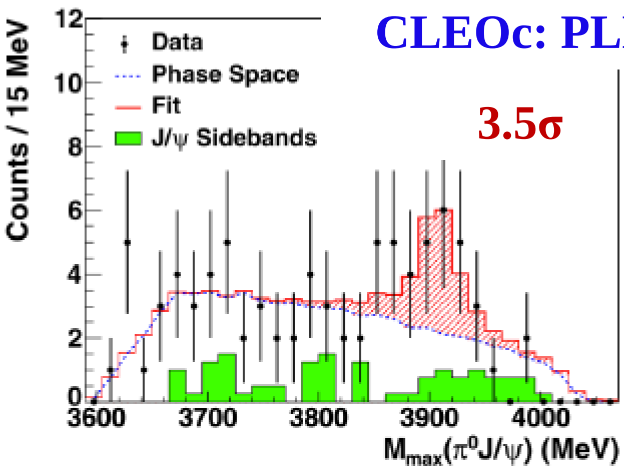
One of APS

2013 highlights



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

Preliminary



CLEOc: PLB 727, 366

BESIII PRELIMINARY!

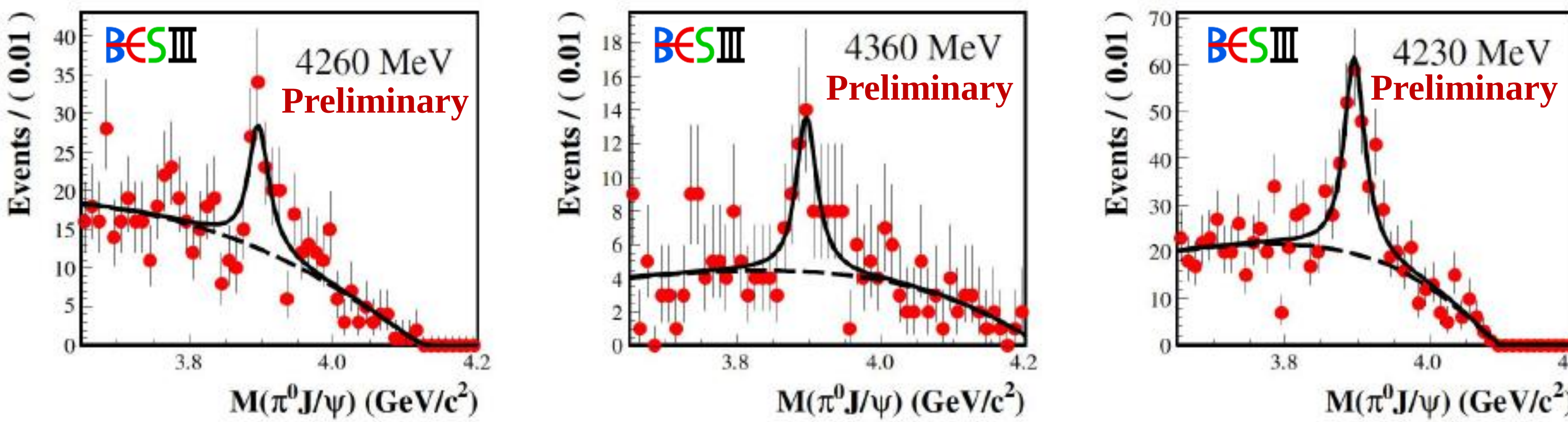
- $2.8\,fb^{-1}$ data at 10 energy points from 4230~4420 MeV
- $Z_c(3900)^0$ is observed clearly at:
  E_{cm}=4230, 4260, 4360MeV

$M = (3894.8 \pm 2.3 \pm 2.7)\ MeV/c^2$

$\Gamma = (29.6 \pm 8.2 \pm 8.2)\ MeV/c^2$

$>10\sigma$

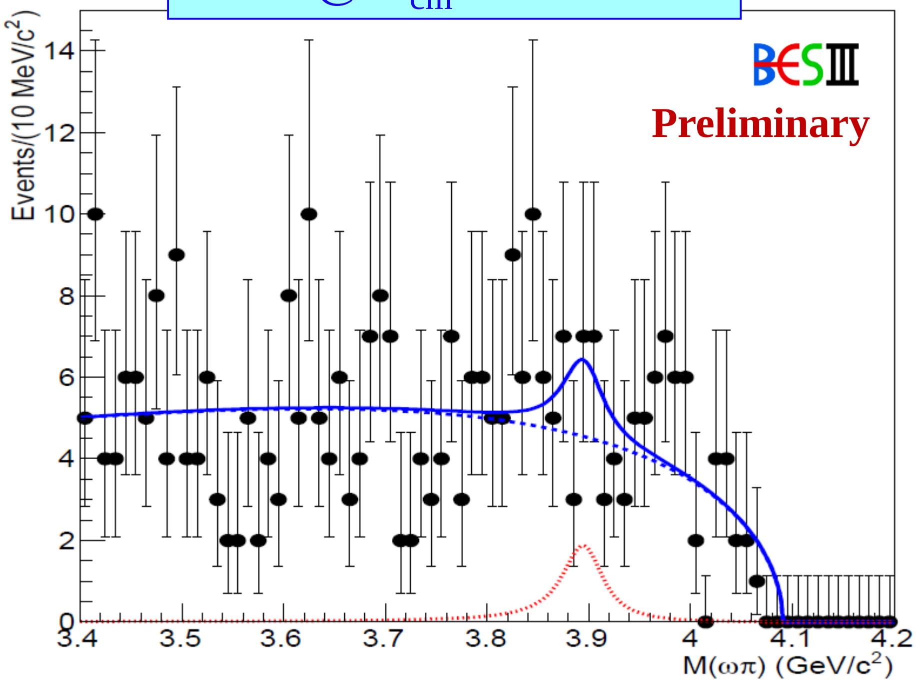
An isospin triplet for $Z_c(3900)$ has been established



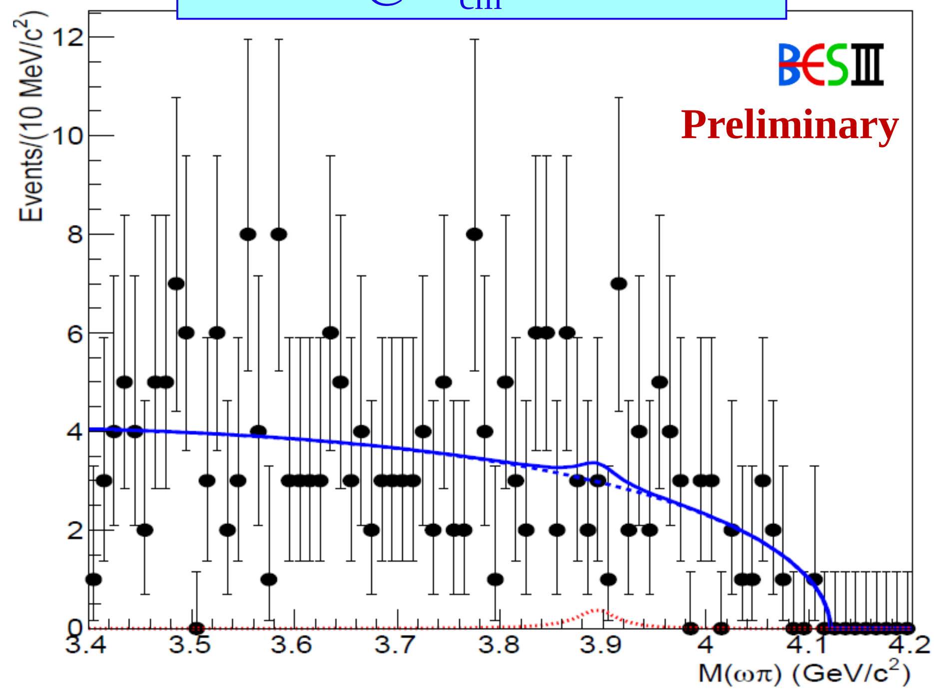
$e^+e^- \rightarrow \pi^{\mp} Z_c(3900)^{\pm} \rightarrow \pi^+\pi^-\omega$ @ 4.230-4.260 GeV

Preliminary

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



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

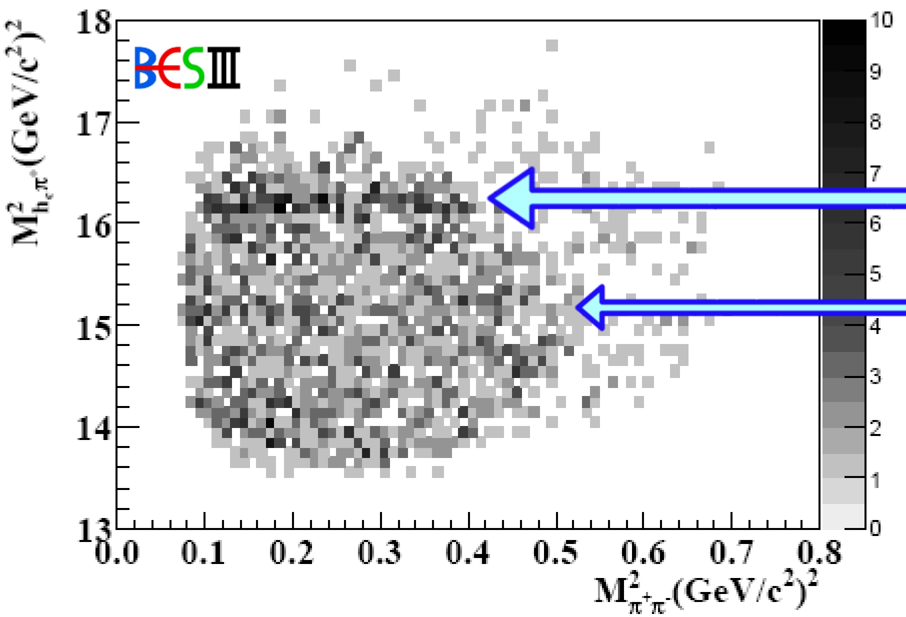


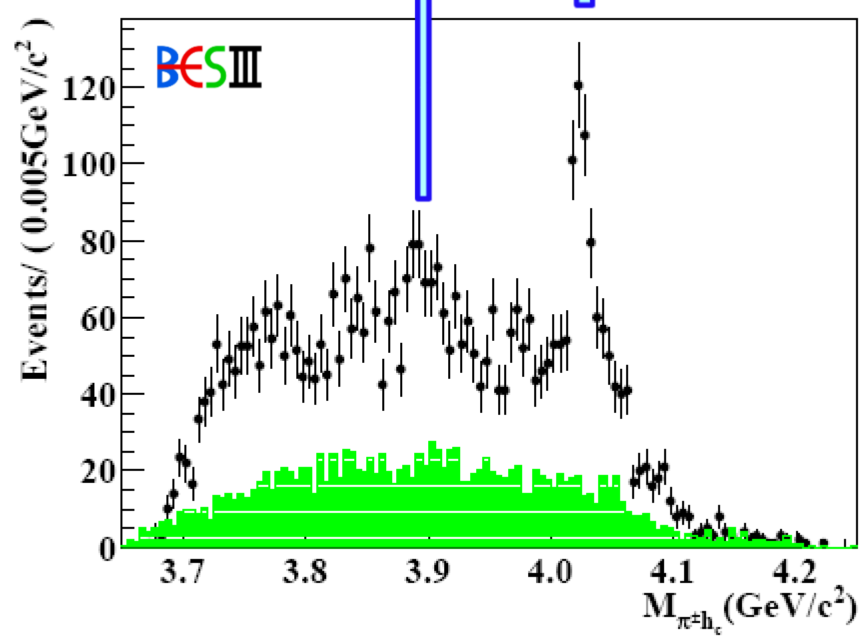
No evidence of a $Z_c(3900)$ signal

- **$\sigma(e^+e^- \rightarrow \pi^{\mp} Z_c(3900)^{\pm}, Z_c(3900) \rightarrow \pi\omega) < 0.27$ pb @ 4.23 GeV 90%**
- **$\sigma(e^+e^- \rightarrow \pi^{\mp} Z_c(3900)^{\pm}, Z_c(3900) \rightarrow \pi\omega) < 0.18$ pb @ 4.26 GeV 90%**

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

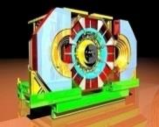
PRL 111, 242001





- **all collected energies**
  [3.900 ÷ 4.420 GeV]

- **$h_c \to \gamma\eta_c$, $\eta_c \to$ hadrons**
  [16 exclusive decay modes]



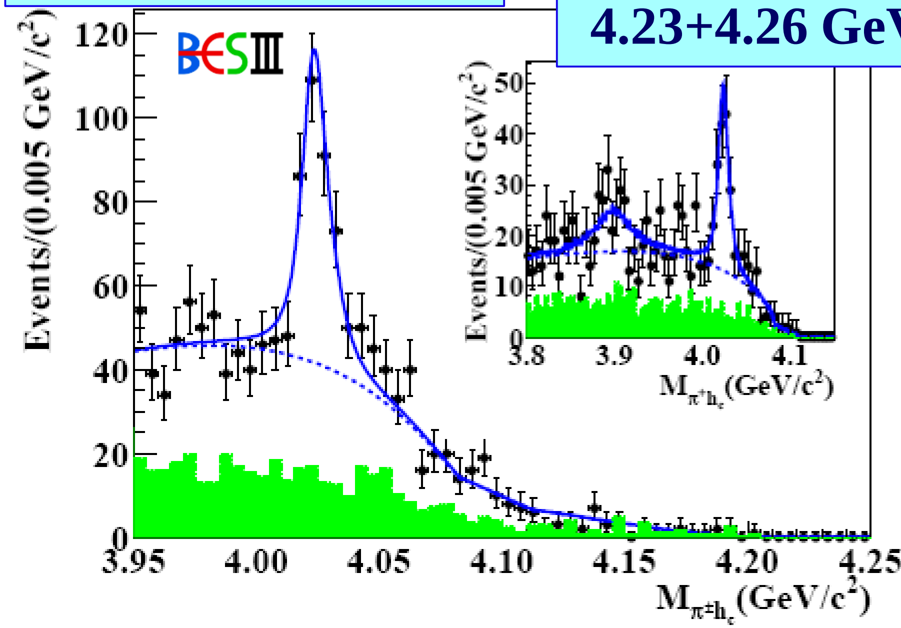
$e^+e^- \to \pi\, Z_c(4020) \to \pi^+\pi^- h_c(1P)$ – 4.23/4.26/4.36 GeV

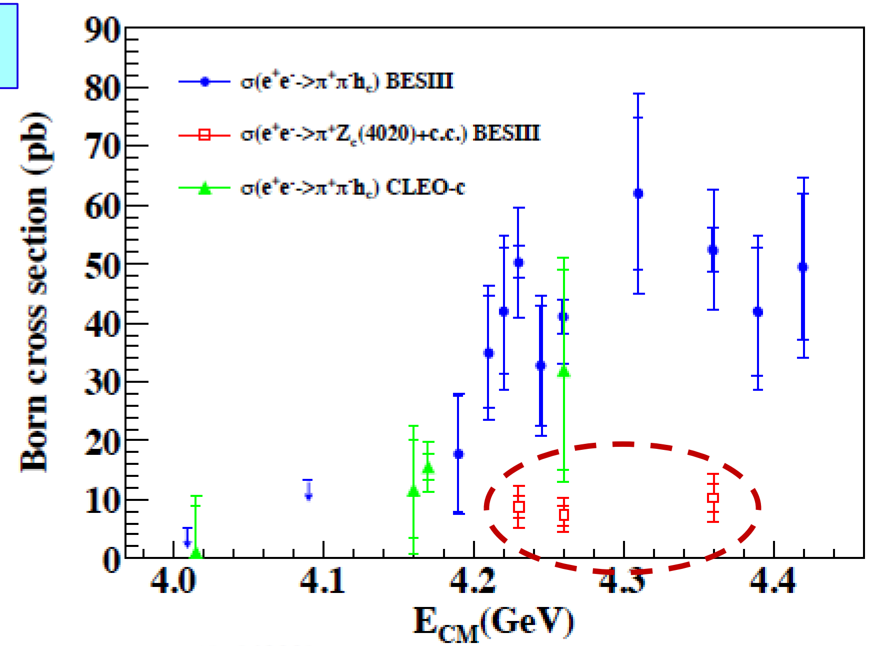
PRL 111, 242001

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

4.23+4.26+4.36 GeV

4.23+4.26 GeV





M = (4022.9±0.8±2.7) MeV/c^2

Γ = (7.9±2.7±2.6) MeV/c^2

>8.9σ

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

σ(4.23 GeV) = (8.7±1.9±2.8±1.4) pb

σ(4.26 GeV) = (7.4±1.7±2.1±1.2) pb

σ(4.36 GeV) = (10.3±2.3±3.1±1.6) pb

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

4.26 GeV:

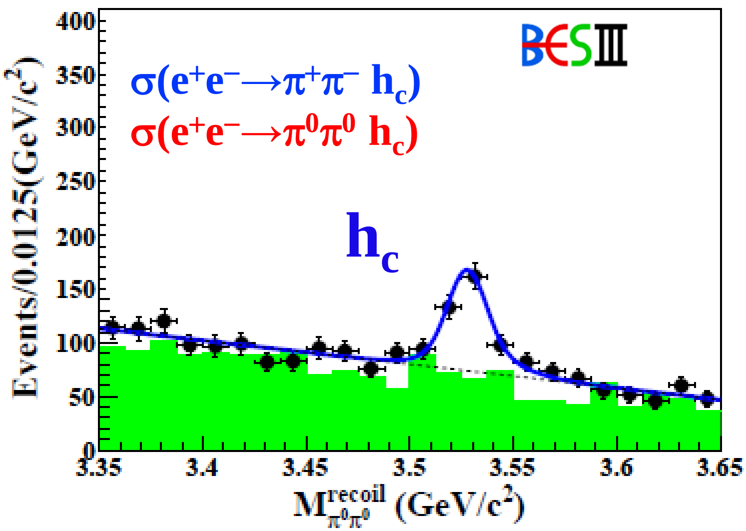
$\sigma(e^+e^- \to \pi Z_c(3900)^+\pi^- \to \pi^+\pi^- h_c) = < 11$ pb (90% C.L.)

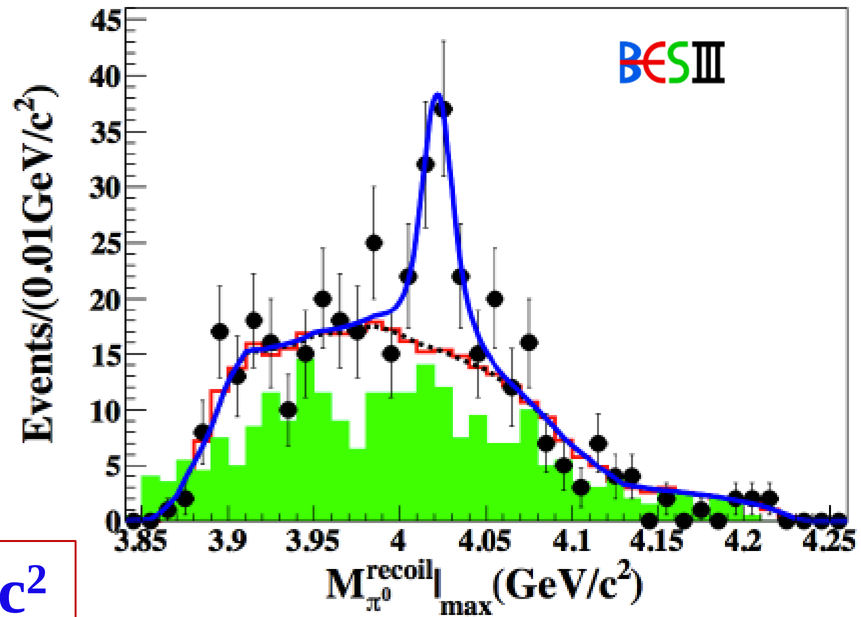
$e^+e^- \to \pi Z_c(4020)^0 \to \pi^0\pi^0 h_c(1P)$ – 4.23/4.26/4.36 GeV

PRL 113, 212002

BESIII PRELIMINARY!

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





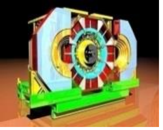
$M_{Z_c(4020)^0}$ = (4023.9±2.2±3.8) MeV/c^2

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

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

>5σ

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

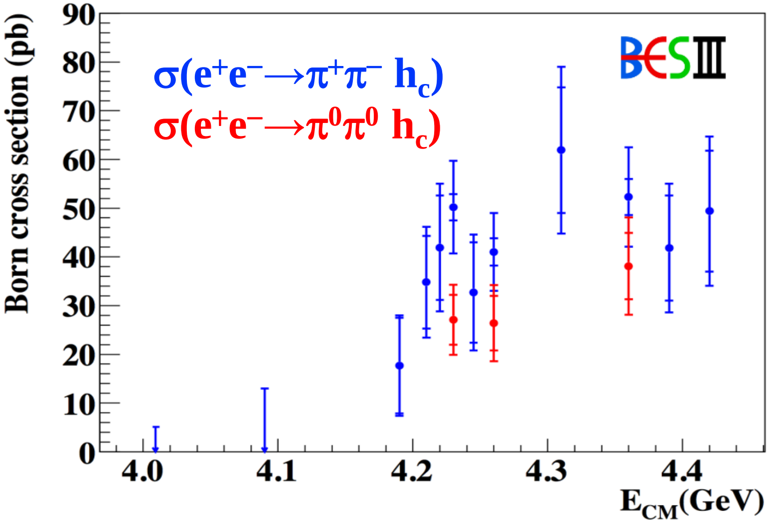


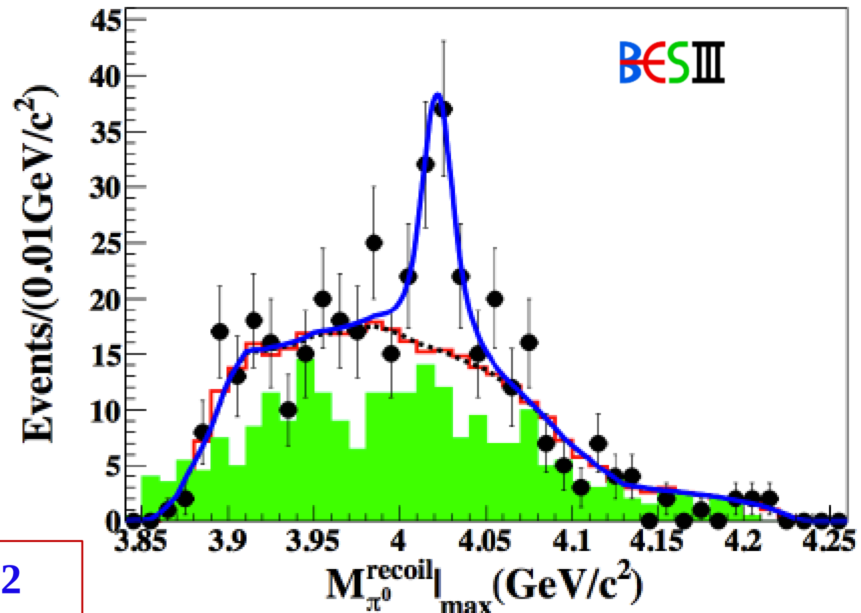
$e^+e^- \rightarrow \pi Z_c(4020)^0 \rightarrow \pi^0\pi^0 h_c(1P)$ – 4.23/4.26/4.36 GeV

PRL 113, 212002

BESIII PRELIMINARY!

- $2.8fb^{-1}$ 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

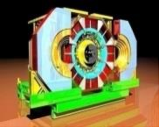
$\Gamma_{Z_c(4020)^0}$ fixed @ $\Gamma_{Z_c(4020)^\pm}$

$>5\sigma$

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

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

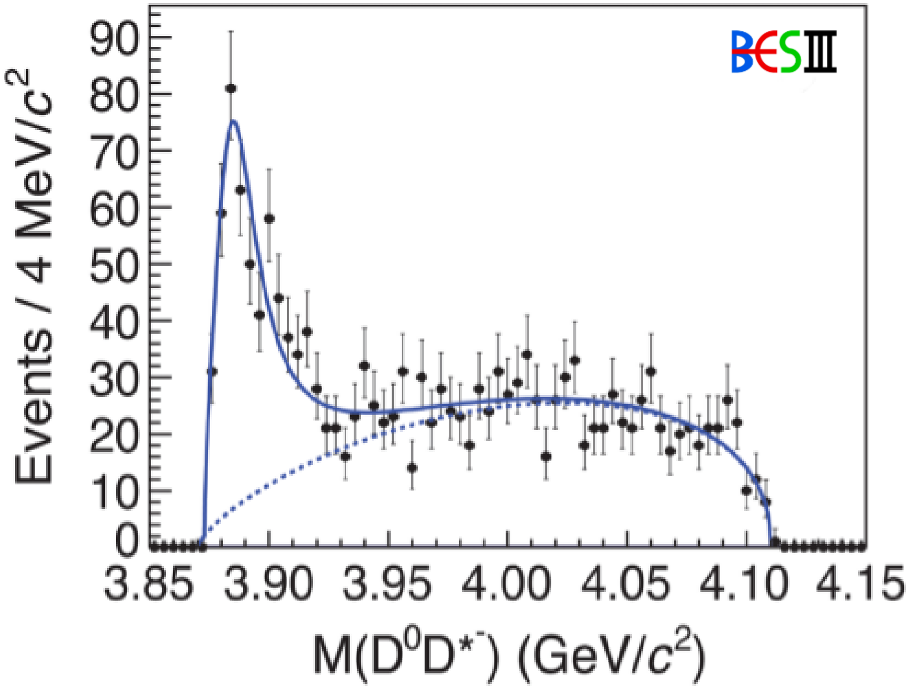
isospin conservation

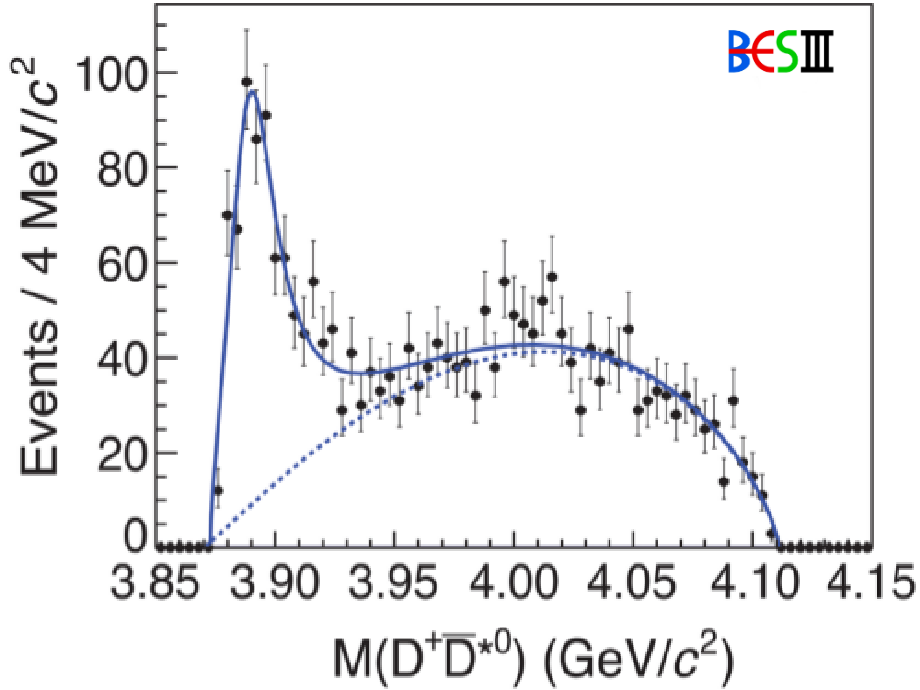


BESIII: $e^+e^- \to \pi Z_c(3885) \to \pi^- (D\bar{D}^*)^+$+c.c. @ 4.260 GeV

PRL 112, 022001

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





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^-

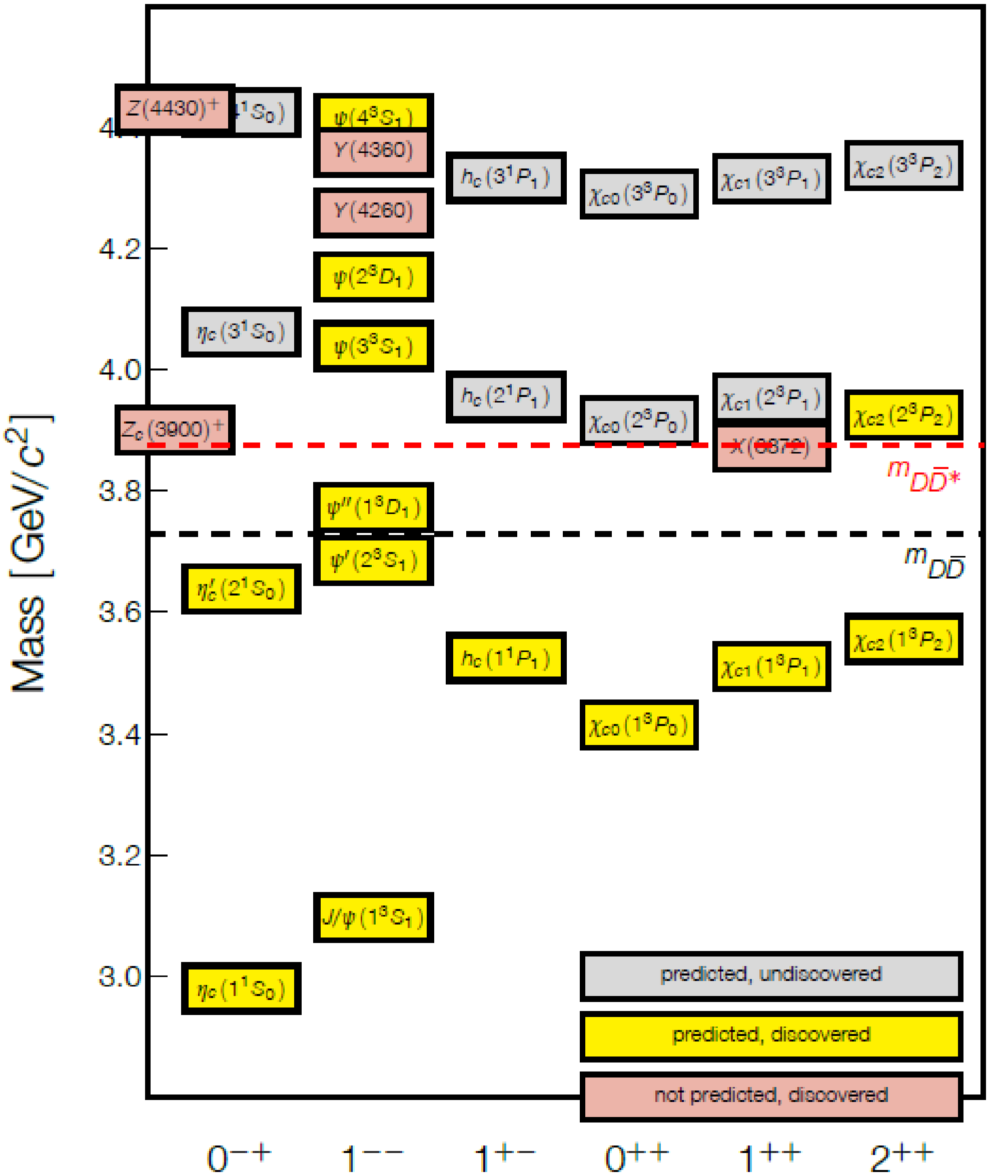
$$\sigma(e^+e^- \to \pi^- Z_c(3885)^+ \times Z_c(3885)^+ \to (D\bar{D}^*)^+ \text{ +c.c.}) = (83.5 \pm 6.6 \pm 22.0) \text{ pb}$$

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

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

PRL 112, 022001

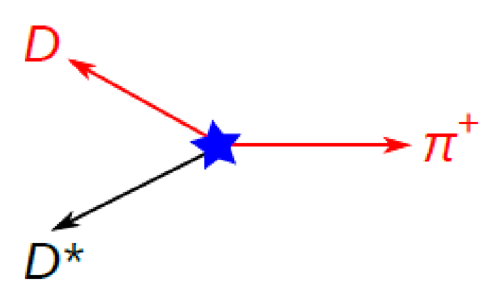
525 pb^{-1} data @ 4260 MeV: single tag analysis



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

Single tag analysis:

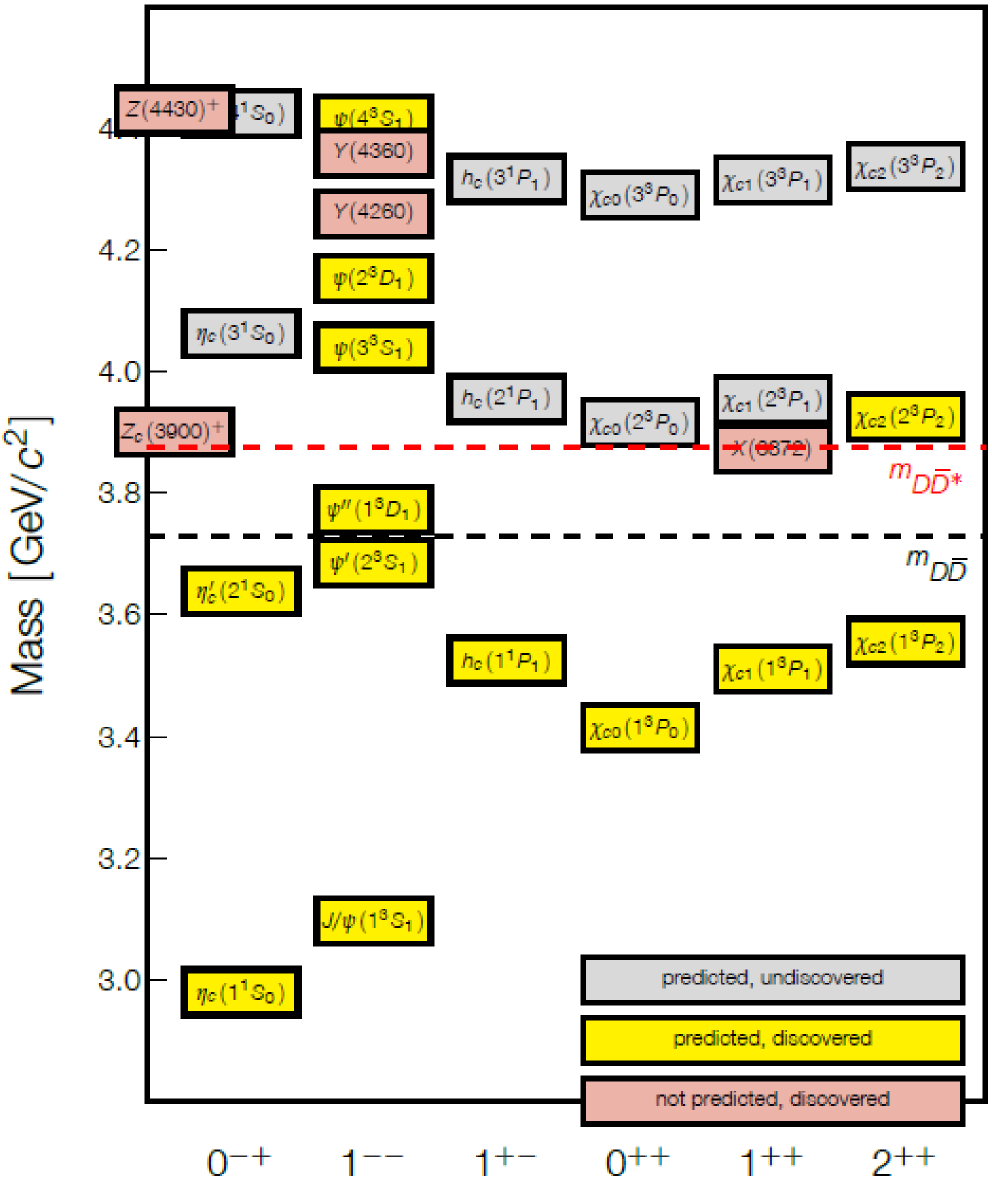
- reconstruct 'bachelor' π^+ and $D^0 \to K^-\pi^+$ or $D^- \to K^+\pi^-\pi^-$
- require D^* in missing mass
- veto $e^+e^- \to (D^*\bar{D}^*)^0$
- apply kinematic fit; look in mass recoiling against π^+



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

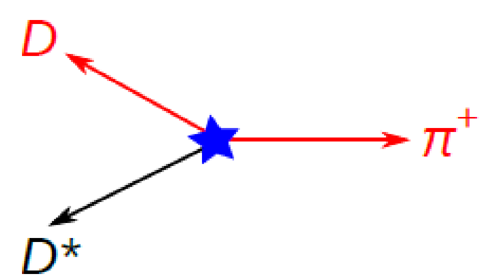
BESIII preliminary

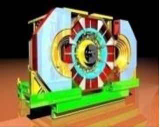
525 pb^{-1} data @ 4260 MeV: double tag analysis



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

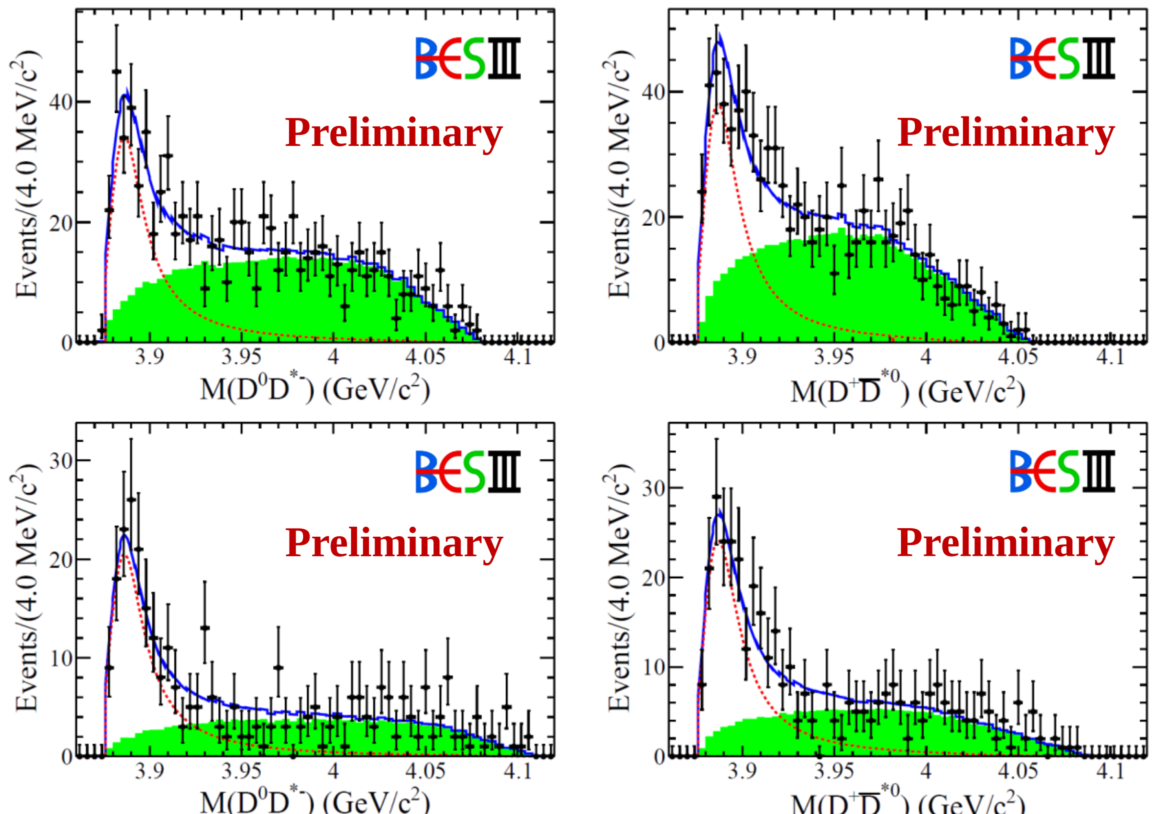
BESIII preliminary

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

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

1090 pb^{-1} @ 4.23 GeV

827 pb^{-1} @ 4.26 GeV



$M = (3884.3 \pm 1.2 \pm 1.5)$ MeV/c^2

$\Gamma = (23.8 \pm 2.1 \pm 2.5)$ MeV/c^2

$>10\sigma$

Compatible with but significantly more precise than single-tag analysis

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

BESIII preliminary

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

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

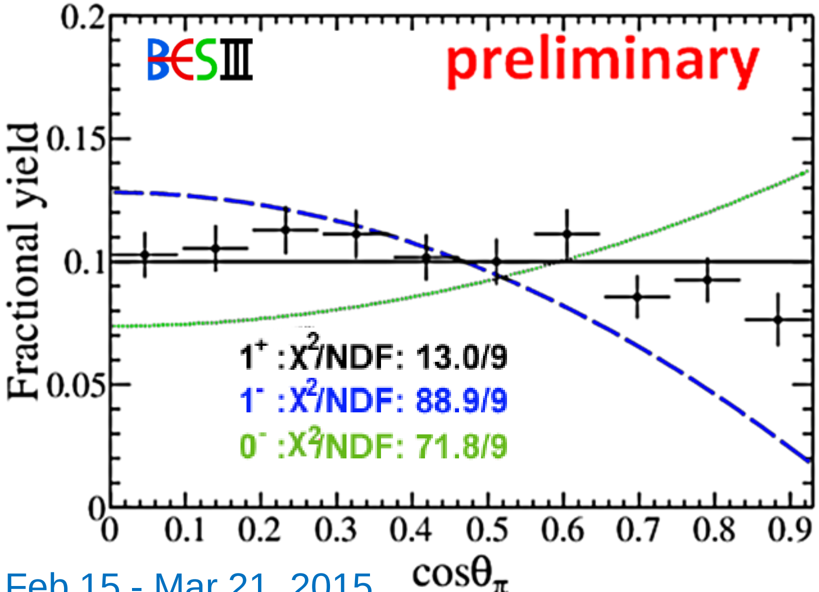
0^+ excluded by parity conservation

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

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

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

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

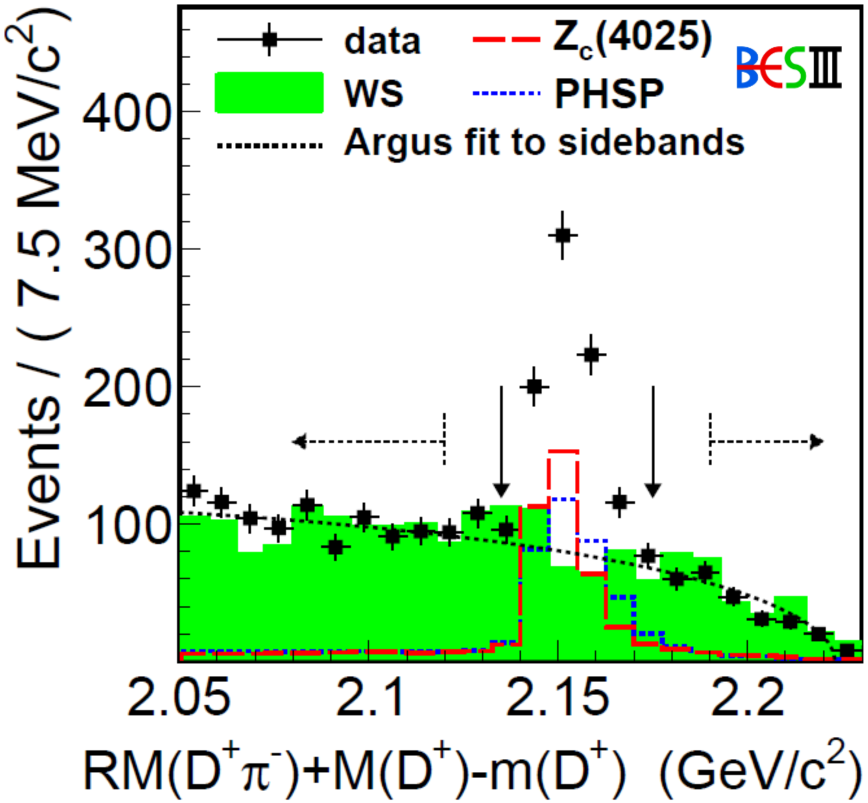


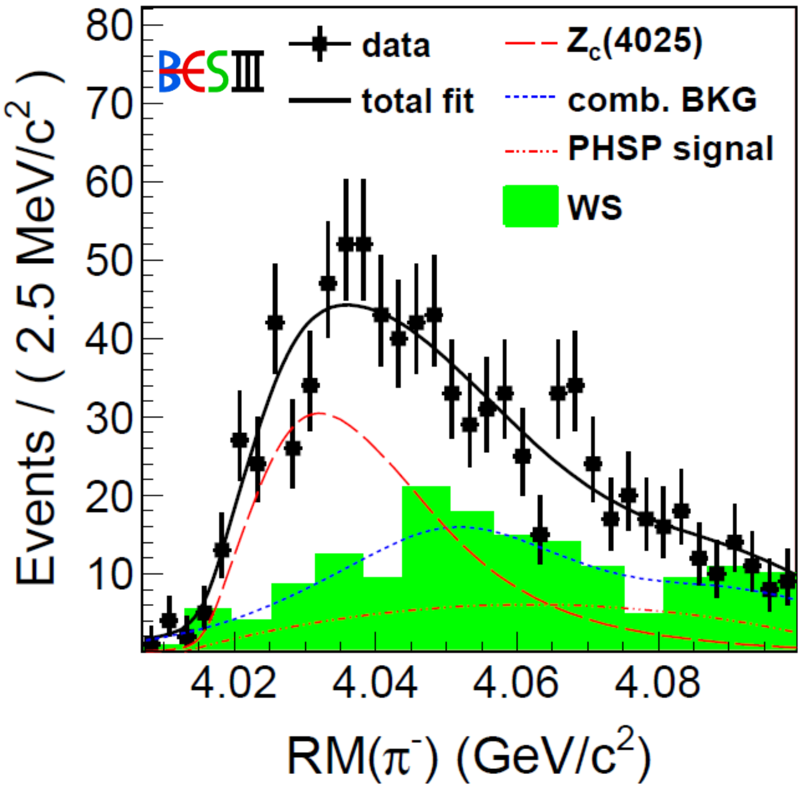
$D\bar{D}^*$ structure:
data clearly favour $J^P = 1^+$

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

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

PRL 112, 132001





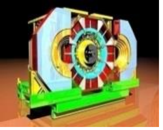
M = (4026.3±2.6±3.7) MeV/c^2

Γ = (24.8±5.7±7.7) MeV/c^2

>10σ

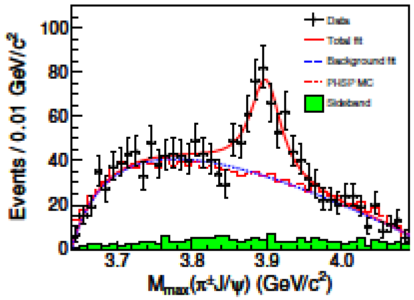
$\sigma(e^+e^- \to \pi^- (D^*\bar{D}^*)^+ + c.c.) = (137 \pm 9 \pm 15)$ pb

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

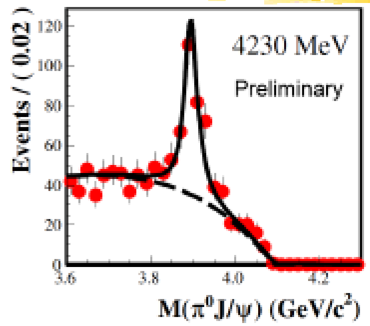


BESIII: $e^+e^- \to \pi Z_c(4025) \to \pi^- (D^*\bar{D}^*)^+ + c.c.$ @ 4.260 GeV

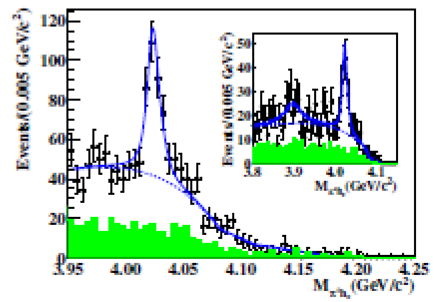
PRL 112, 132001



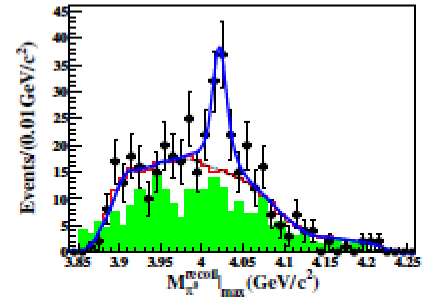
$e^+e^- \to \pi^-\pi^+ J/\psi$



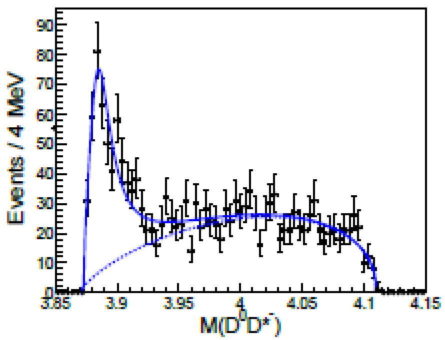
$e^+e^- \to \pi^0\pi^0 J/\psi$



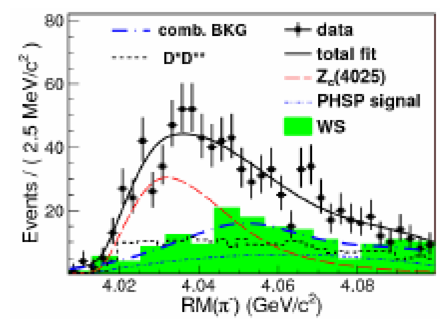
$e^+e^- \to \pi^-\pi^+ h_c$



$e^+e^- \to \pi^0\pi^0 h_c$



$e^+e^- \to \pi^-(D\bar{D}^*)^+$



$e^+e^- \to \pi^-(D^*\bar{D}^*)^+$

$Z_c(3900)^+$? **$Z_c(3900)^0$?** **$Z_c(4020)^+$?** **$Z_c(4020)^0$?**

Which is the nature of these states? Isospin triplets?

Different decay channels of the same observed states? Other decay modes?

BESIII: Z_c states

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

BESIII: Z_c states

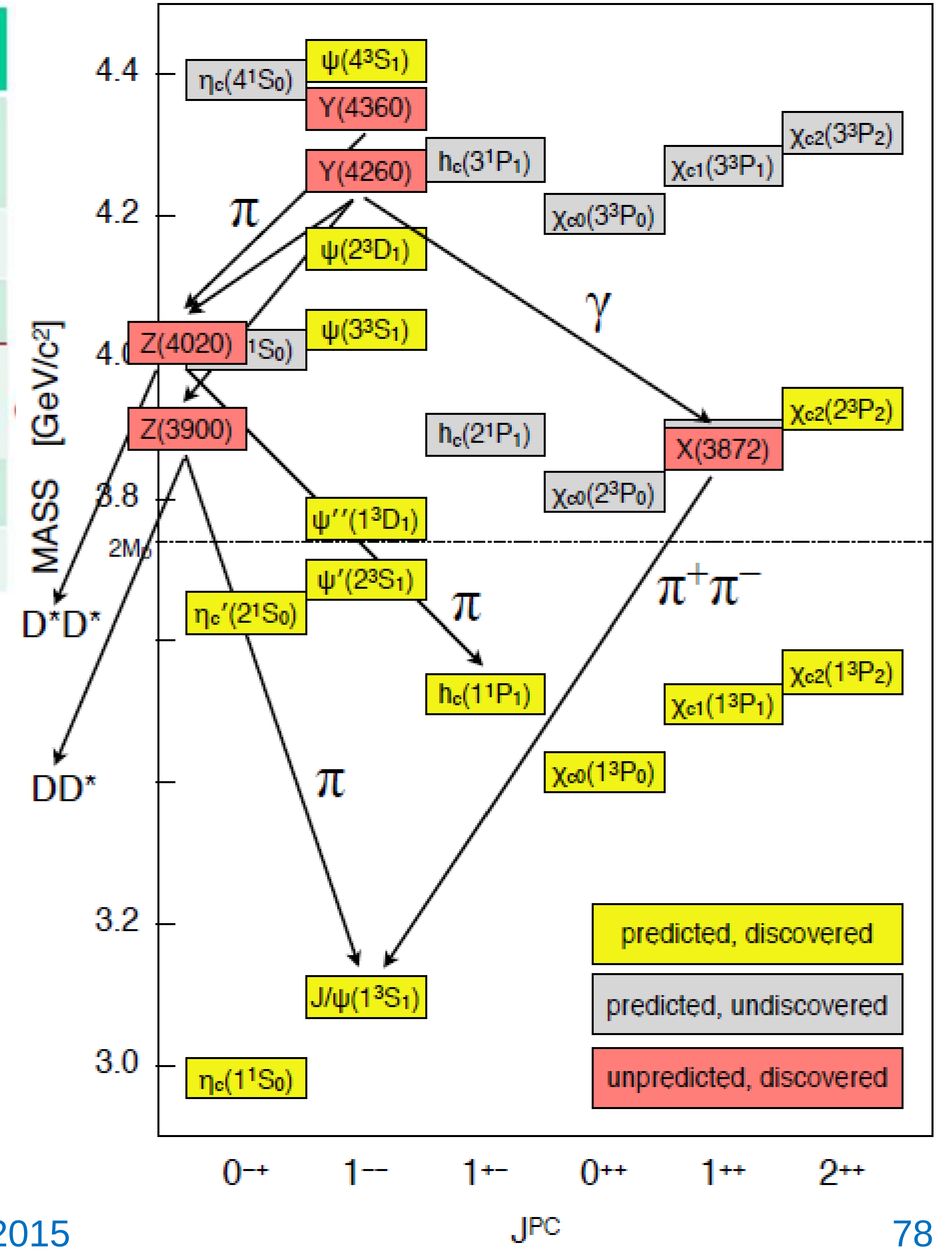
Channel	Mass (MeV/c²)	Width (MeV)
$\pi J/\psi$	$3899.0 \pm 3.6 \pm 4.9$ 3894.8 ± 2.3(Prel.)	$46 \pm 10 \pm 20$ 29.6 ± 8.2 (Prel.)
$(D\bar{D}^*)^\pm$	$3883.9 \pm 1.5 \pm 4.2$	$24.8 \pm 3.3 \pm 11.0$
	2σ difference	1σ difference
πh_c	$4022.9 \pm 0.8 \pm 2.7$ $4023.9 \pm 2.2 \pm 3.9$ (Prel.)	$7.9 \pm 2.7 \pm 2.6$
$(D^*\bar{D}^*)^\pm$	$4026.3 \pm 2.6 \pm 3.7$	$24.8 \pm 5.6 \pm 7.7$
	1σ difference	2σ difference

Thresholds:

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

Z_c states @ BESIII:

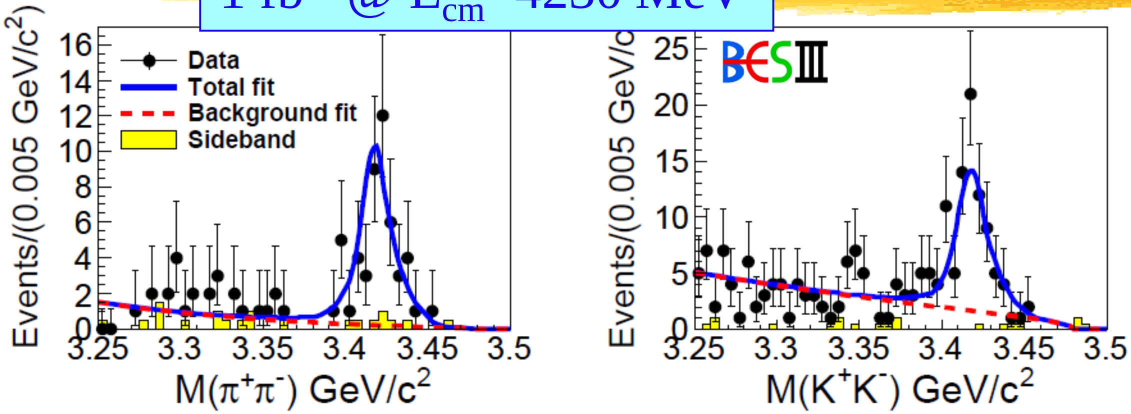
- **at least 4 quarks: charged**
- **near threshold**
- **isospin I=1**
- **are they one or two states**

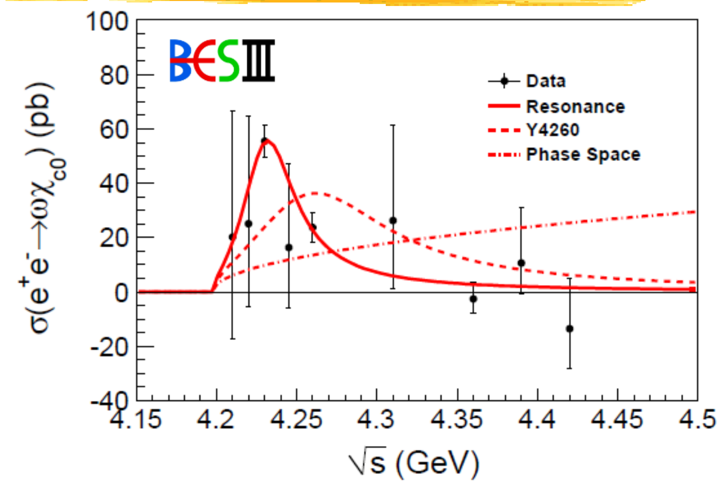


BESIII: $e^+e^- \to \omega\chi_{c0}$ ($\chi_{c0} \to \pi^+\pi^-, K^+K^-$)

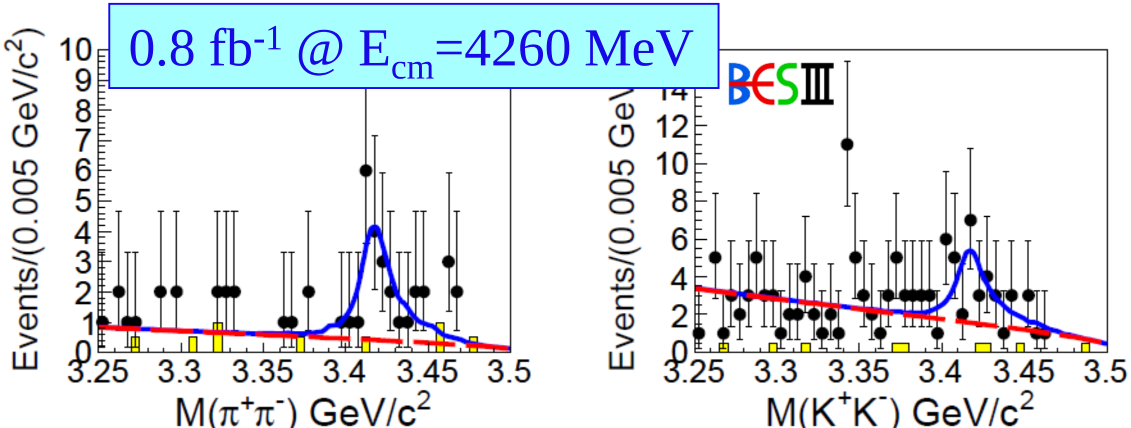
arXiv:1410.6538

$1\ fb^{-1}$ @ 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/c²

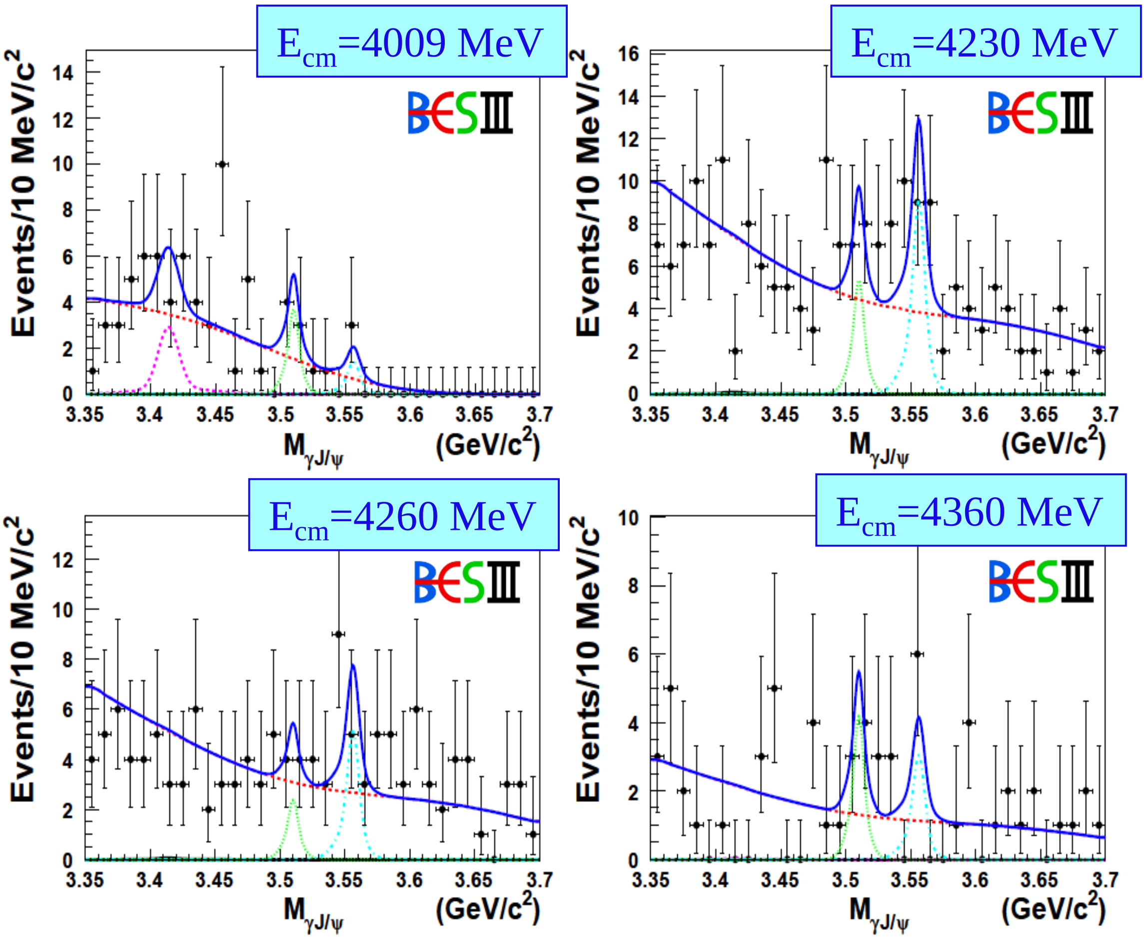
Γ = (38±12±2) MeV/c²

> 9σ

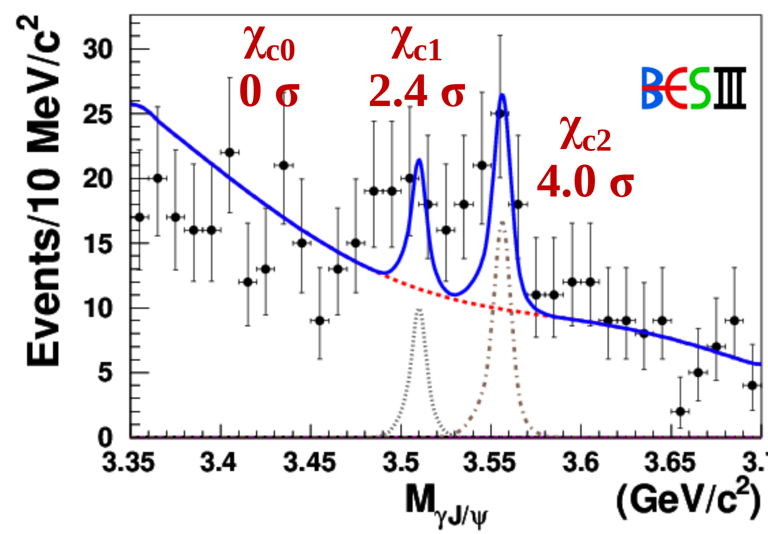
BESIII: $e^+e^- \to \gamma\chi_{cJ}$ ($\chi_{cJ} \to \gamma J/\psi$, $J/\psi \to \mu^+\mu^-$)

arXiv:1411.6336

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



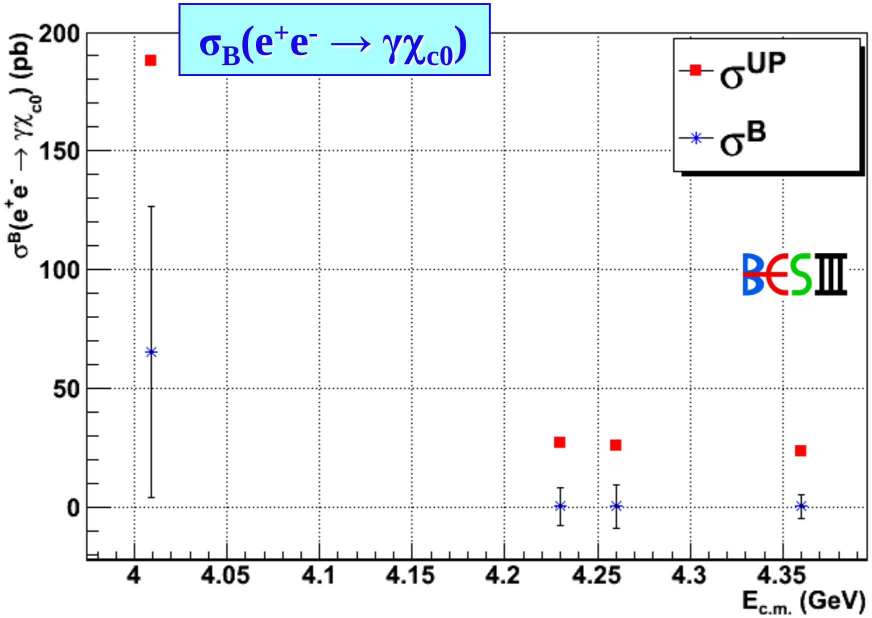
- Simultaneous fit @ 4 E_{cm} assuming Y(4260) lineshape for $\sigma(e^+e^- \to \gamma\chi_{cJ})$

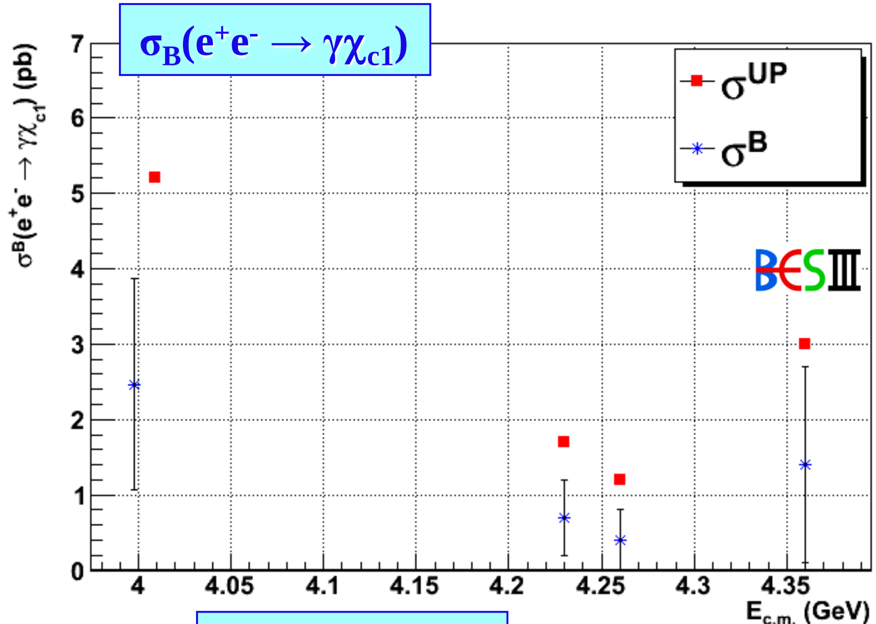


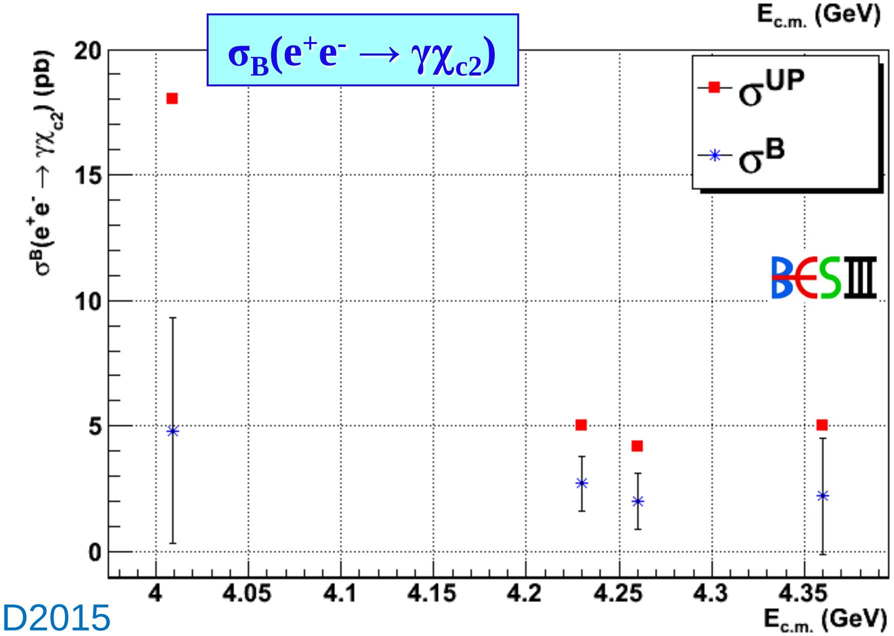
BESIII: $e^+e^- \to \gamma\chi_{cJ}$ ($\chi_{cJ} \to \gamma J/\psi$, $J/\psi \to \mu^+\mu^-$)

arXiv:1411.6336

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







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

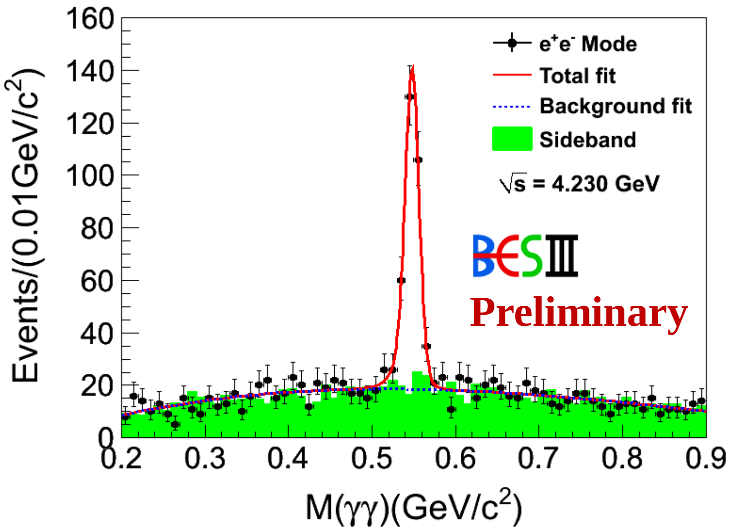
[1] arXiv:1310.8597

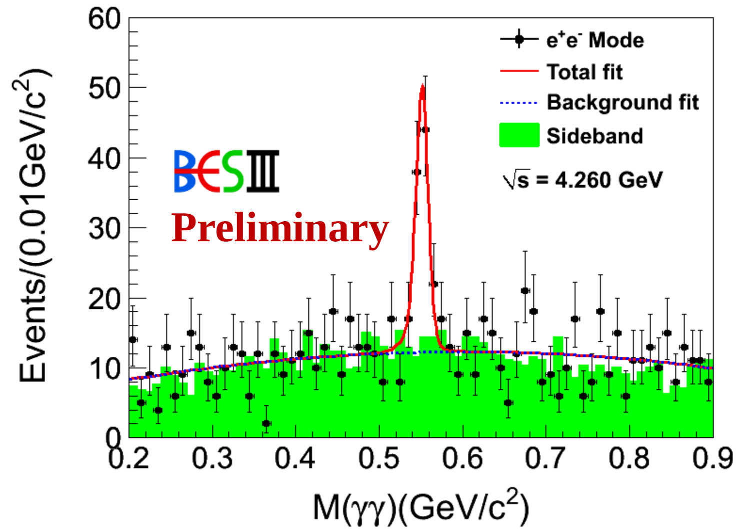
BESIII: $e^+e^- \to \eta J/\psi$

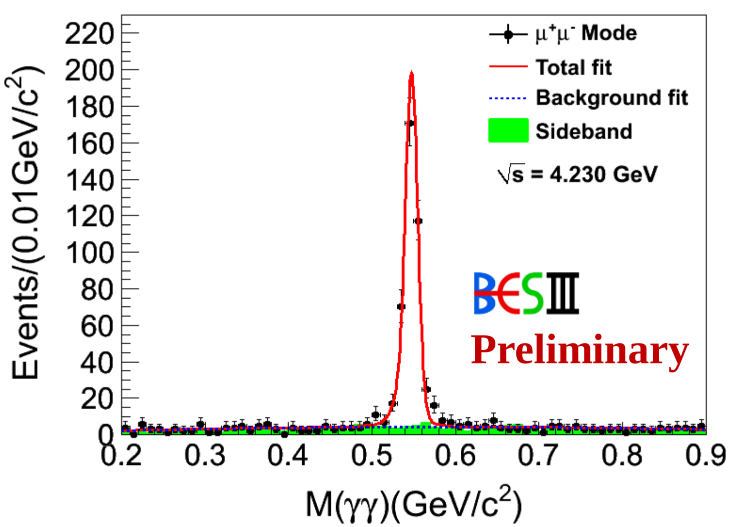
preliminary

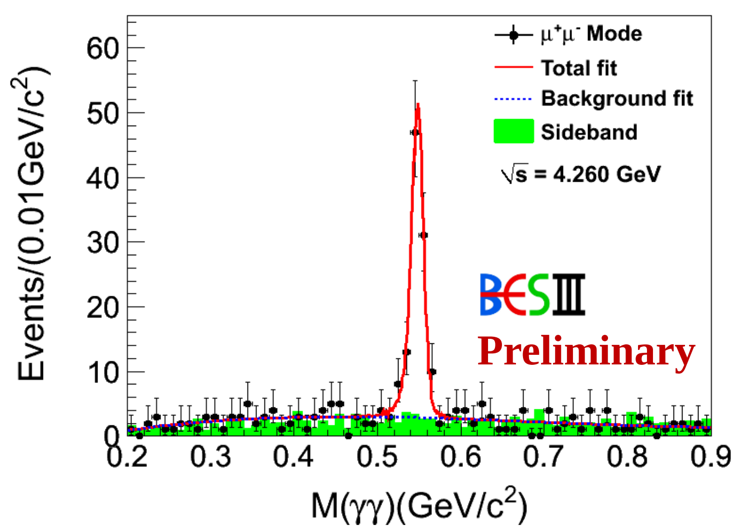
1 fb^{-1} @ E_{cm}=4230 MeV

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

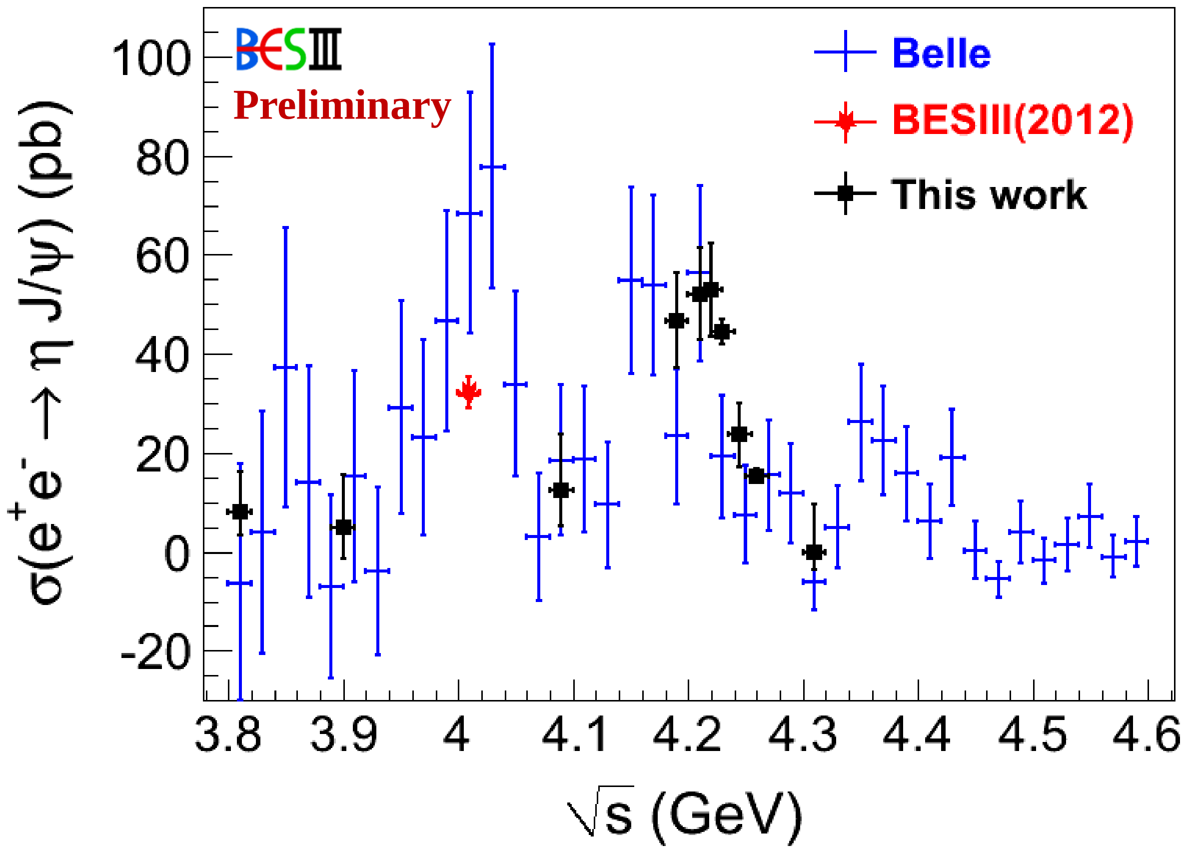








BESIII: $e^+e^- \to \eta J/\psi$



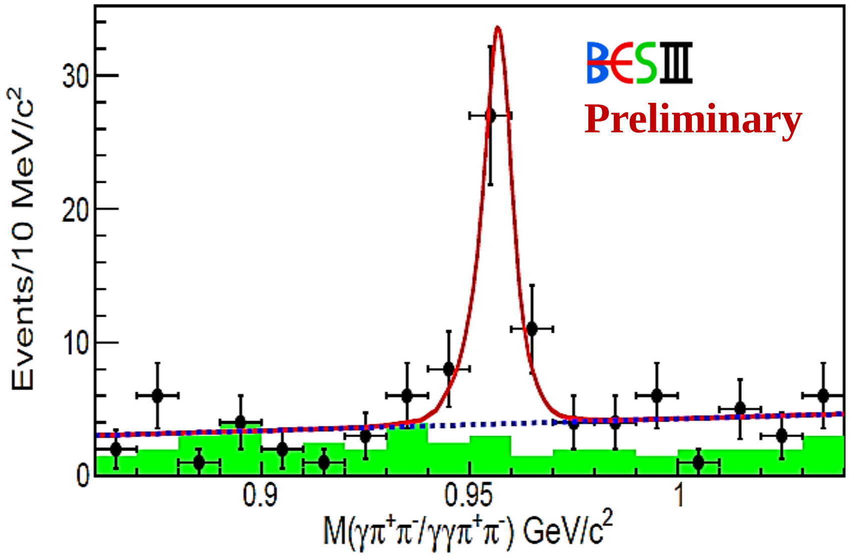
- good agreement with previous results and more precise
- cross sections peaks at ~ 4.2 GeV
- higher energy points' analysis on going

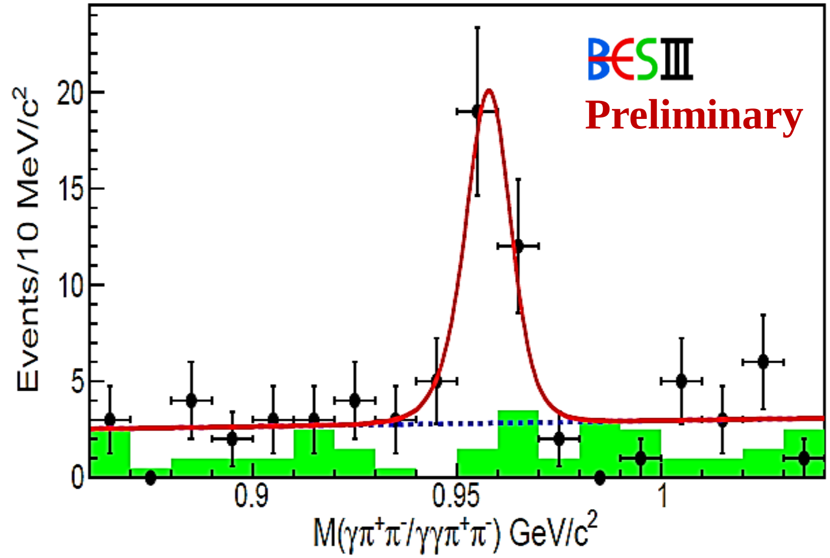
BESIII: $e^+e^- \to \eta' J/\psi$

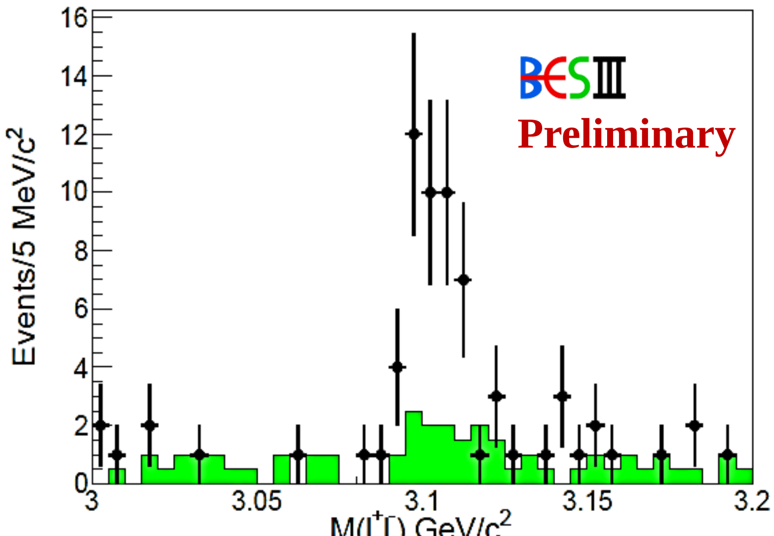
preliminary

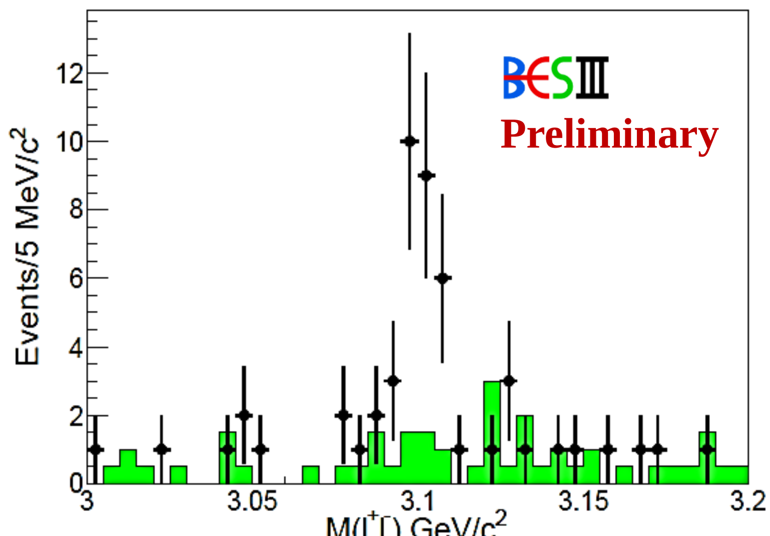
1 fb^{-1} @ E_{cm}=4230 MeV

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



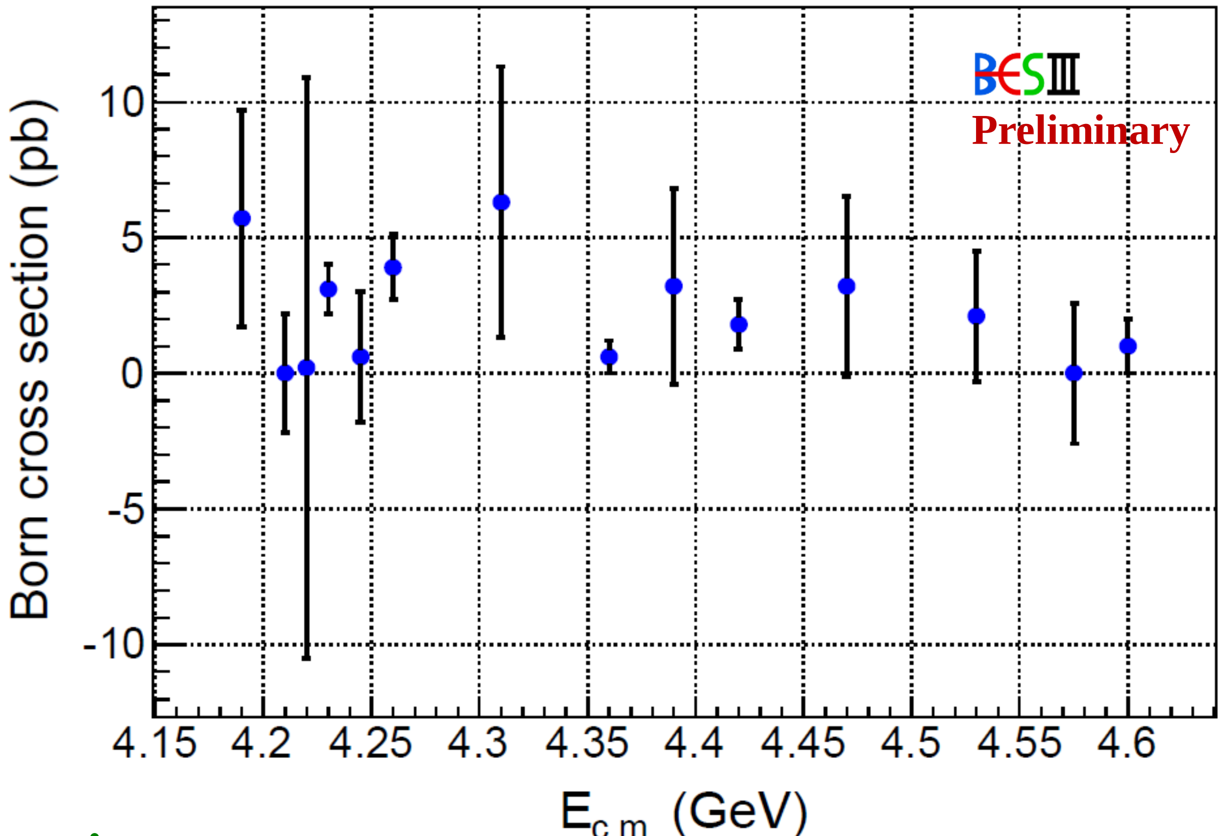






BESIII: $e^+e^- \to \eta' J/\psi$

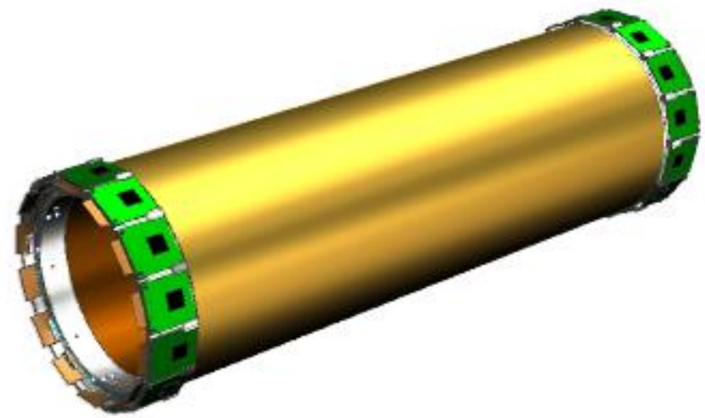
preliminary



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

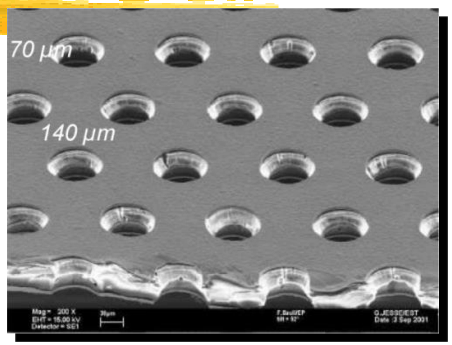
BESIII Inner Tracker upgrade

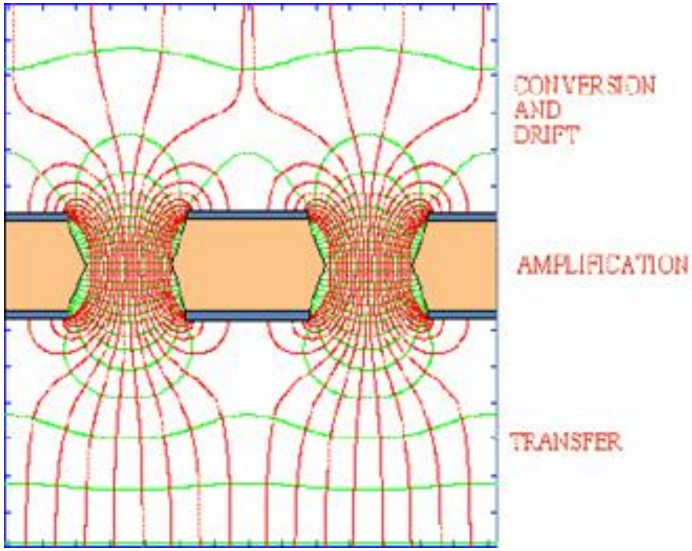
The BESIII CGEM-IT



GEM: principle of operation

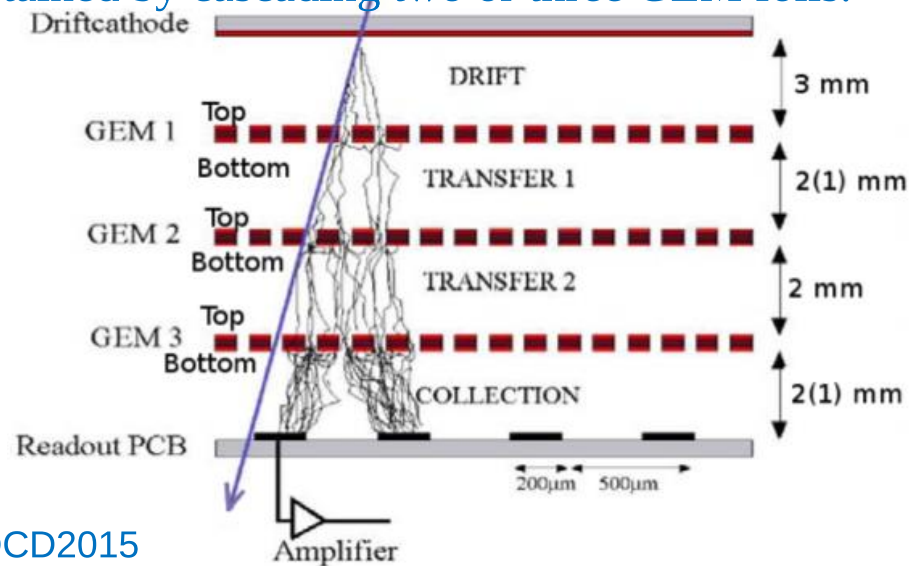
The GEM (Gas Electron Multiplier) [F.Sauli, NIM A386 (1997) 531] is a thin (50 μm) metal coated by a kapton foil perforated by a high density of holes (70 μm diameter, pitch of 140 μm)
→ standard photo-lithographic technology.





By applying 400-500 V between the two copper sides, an electric field as high as ~100 kV/cm is produced into the holes which act as multiplication channels for electrons produced in the gas by a ionizing particle.

Gains up to 1000 can be easily reached with a single GEM foil. Higher gains (and/or safer working conditions) are usually obtained by cascading two or three GEM foils.



A Triple-GEM detector is built by inserting three GEM foils between two planar electrodes, which act as the cathode and the anode.

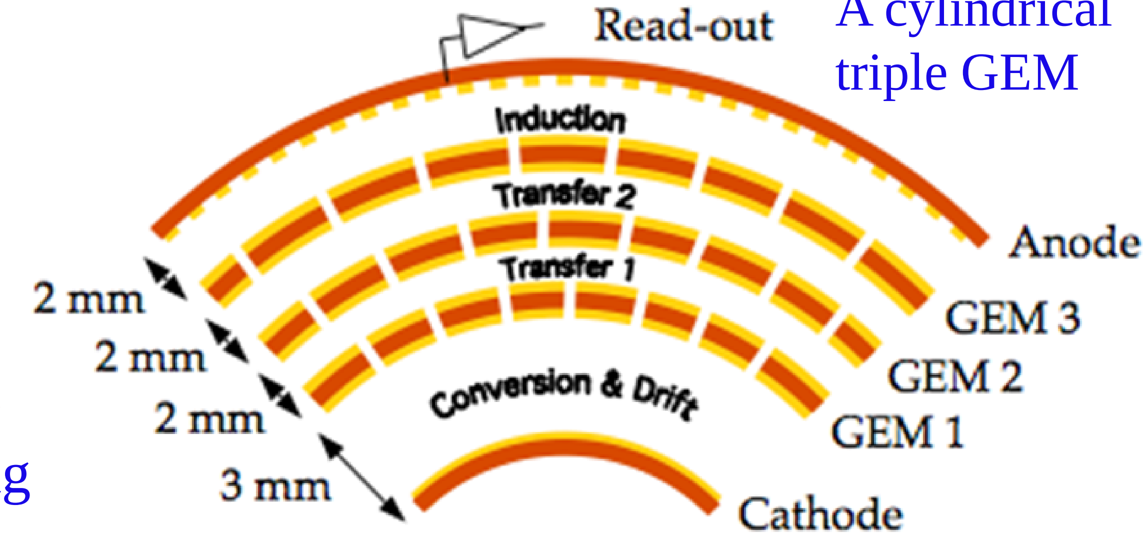
GEM detector features

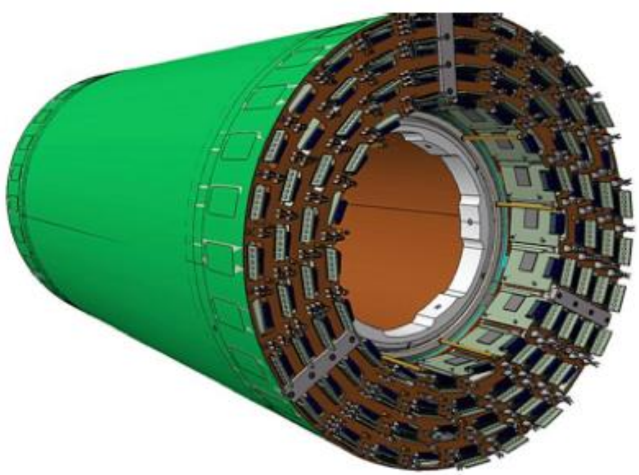
- flexible geometry → arbitrary shape: rectangular, cylindrical …
- ultra-light structure → very low material budget: <0.5% X_0/chamber
- gas multiplication separated from readout stage → arbitrary readout pattern: pad, strips (XY, UV), mixed …
- high rate capability: >50 MHz/cm^2
- high safe gains: > 10^4
- high reliability: low discharge, $P_d < 10^{-12}$ per incoming particle
- rad hard: up to 2.2 C/cm^2 integrated over the whole active area without permanent damages (corresponding to 10 years of operation at LHCb1)
- high spatial resolution: down to 60µm
- good time resolution: down to 3 ns (with CF_4)

KLOE2 CGEM-IT

- 4 CGEM layers at 13/15.5/18/20.5 cm from IP
  inside outer Drift Chamber
- 700 mm active length
- XV strips-pads readout
  (25° ÷ 30° stero angle)
- 2% X_0 total radiation length
  in the active region including
  Carbon Filter shield

A cylindrical triple GEM





The KLOE-2 Collaboration built the only existing CGEM based detector currently currently under commissioning.

Due to the operational delays of DAϕNE, the collider histing the KLOE-2 spectrometer, the investigation of its performance is still under progress.

BESIII innovations w.r.t. KLOE-2

The innovative aspects are mainly related, but not limited, to the following three items:

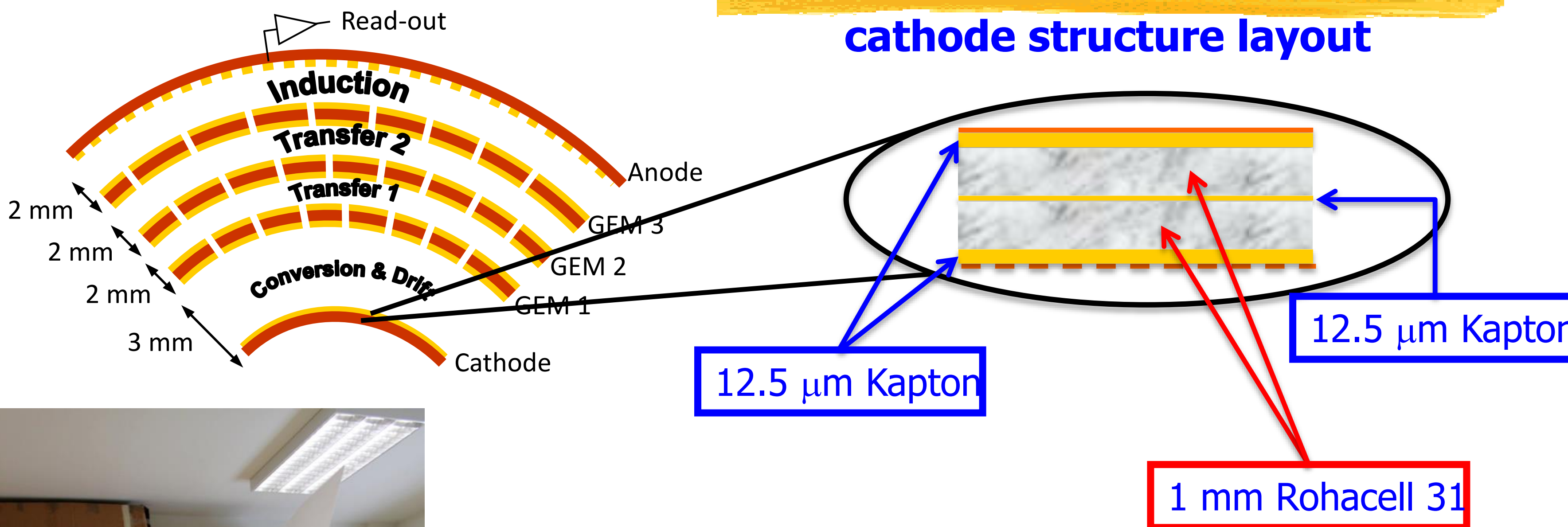
- the material used to give the mechanical rigidity to the detector structure

  (Rohacell instead of Honeycomb)

- the anode design

- the different readout mode, analogue instead of digital

BESIII: a Rohacell based cathode (and anode)



Rohacell is a very light material (density of 32 kg/m^3) that will be replace the honeycomb in the cathode and anode construction with substantial reduction of the thickness of the detector.

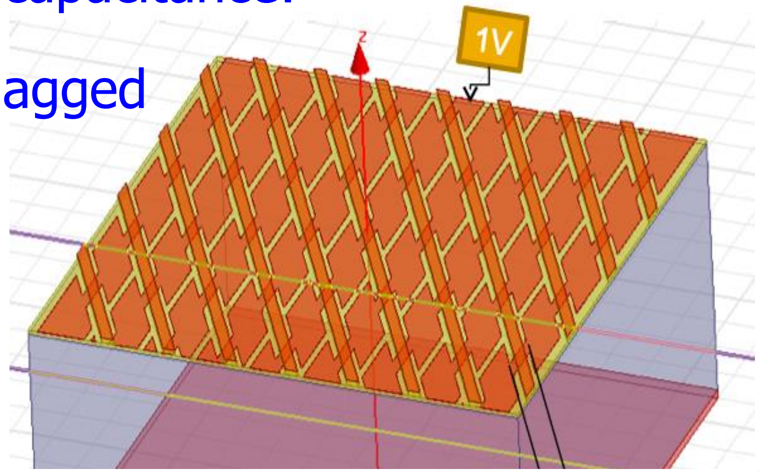
	BESIII	KLOE-2
# of X_0 for 1 layer	0.33	0.49
# of X_0 for 3 layers	0.99	1.47

This technique has been successfully tested by INFN

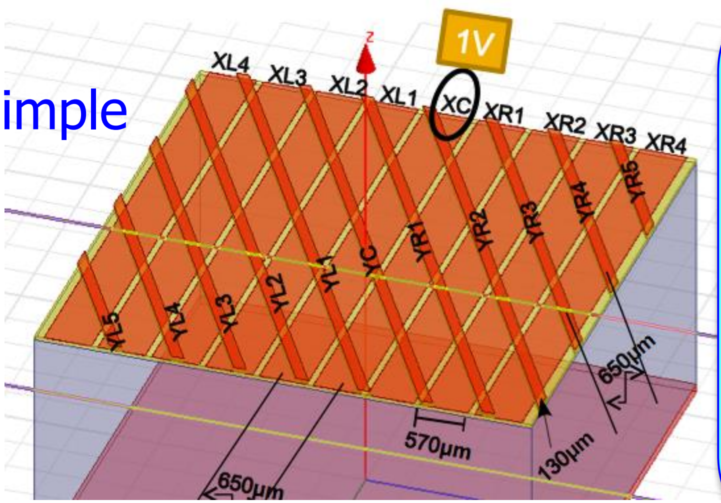
BESIII: anode design

A jagged-strip layout has been designed to minimize the strip capacitance:

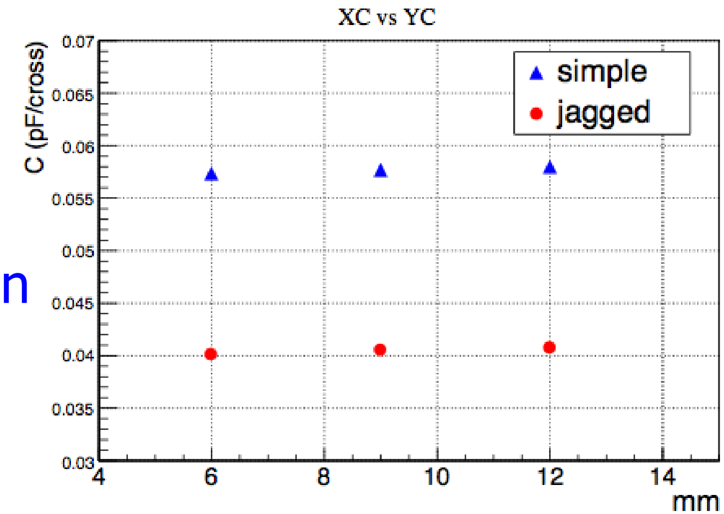
jagged



simple

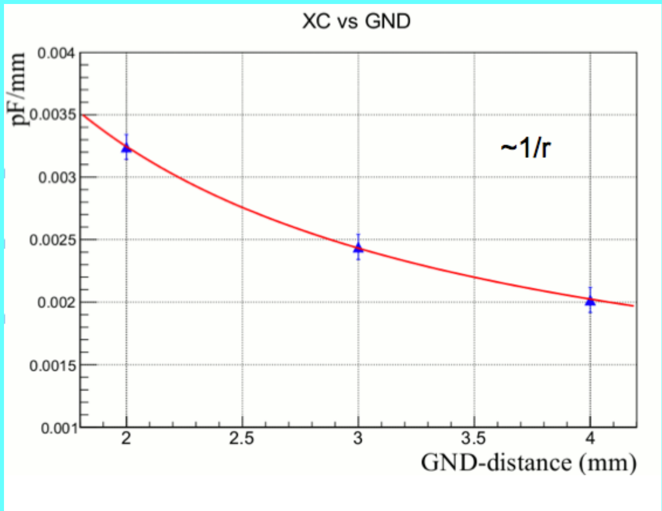


~30% inter-strip capacitance reduction compared to the standard strip configuration



In addition:

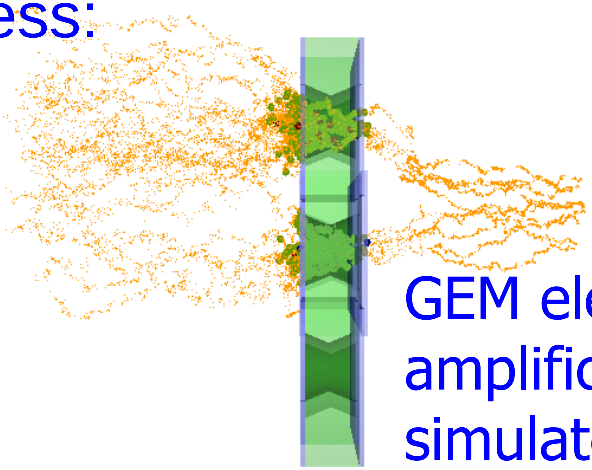
the ground will be kept at 2 – 4 mm from the strip plane support structure made of Rohacell



BESIII: anode validation and test

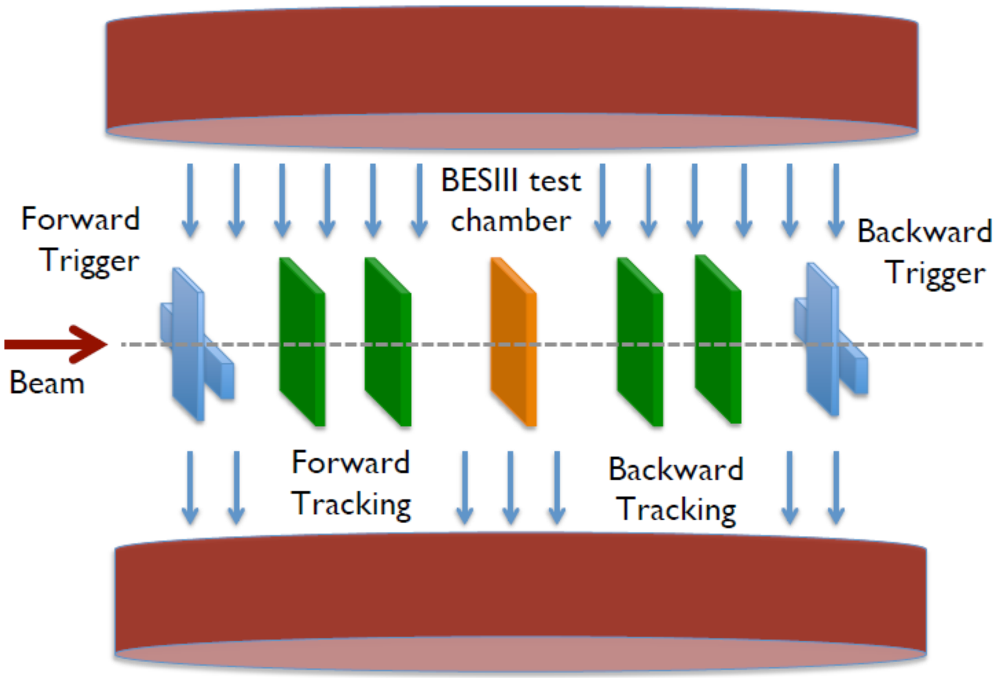
BESIII anode design validation in progress:

- Validations with Garfield simulations (in progress)



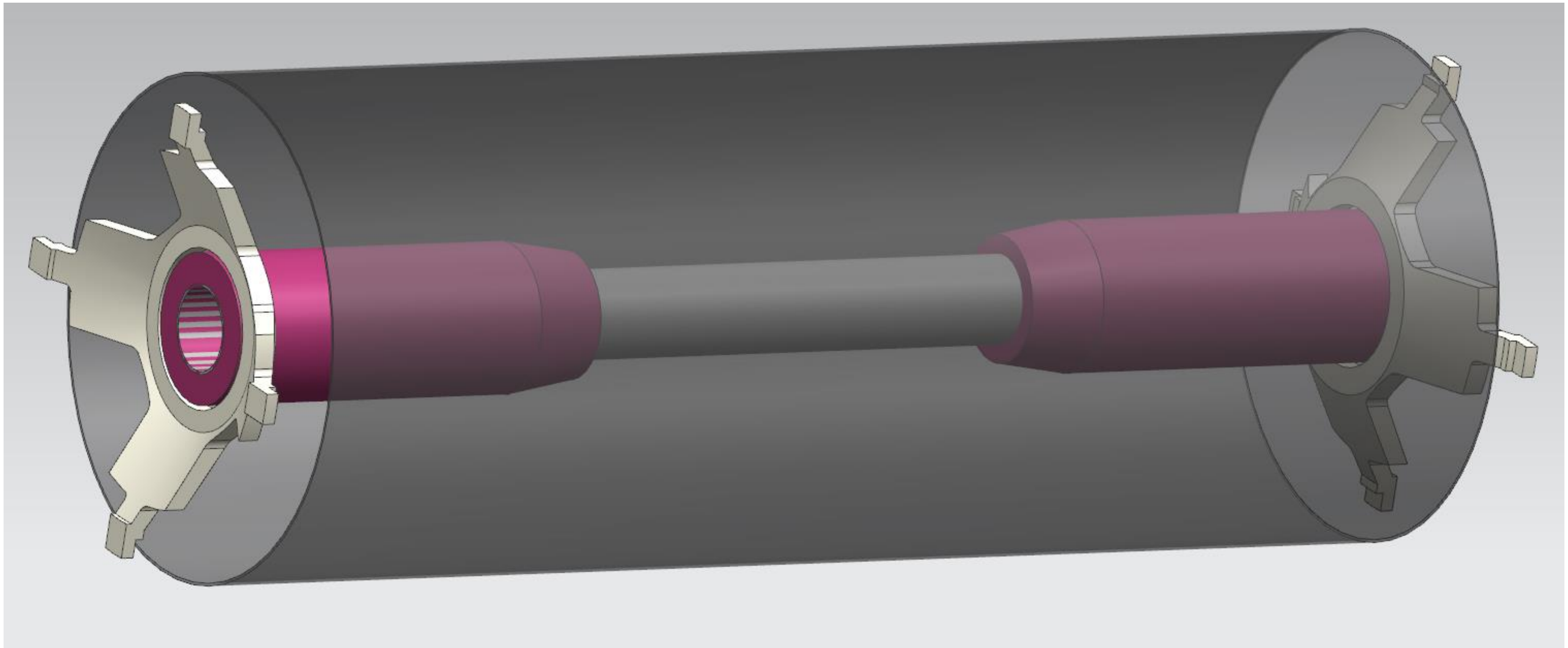
GEM electron amplification simulated by Garfield

- Prototype beam test



The BESIII CGEM-IT

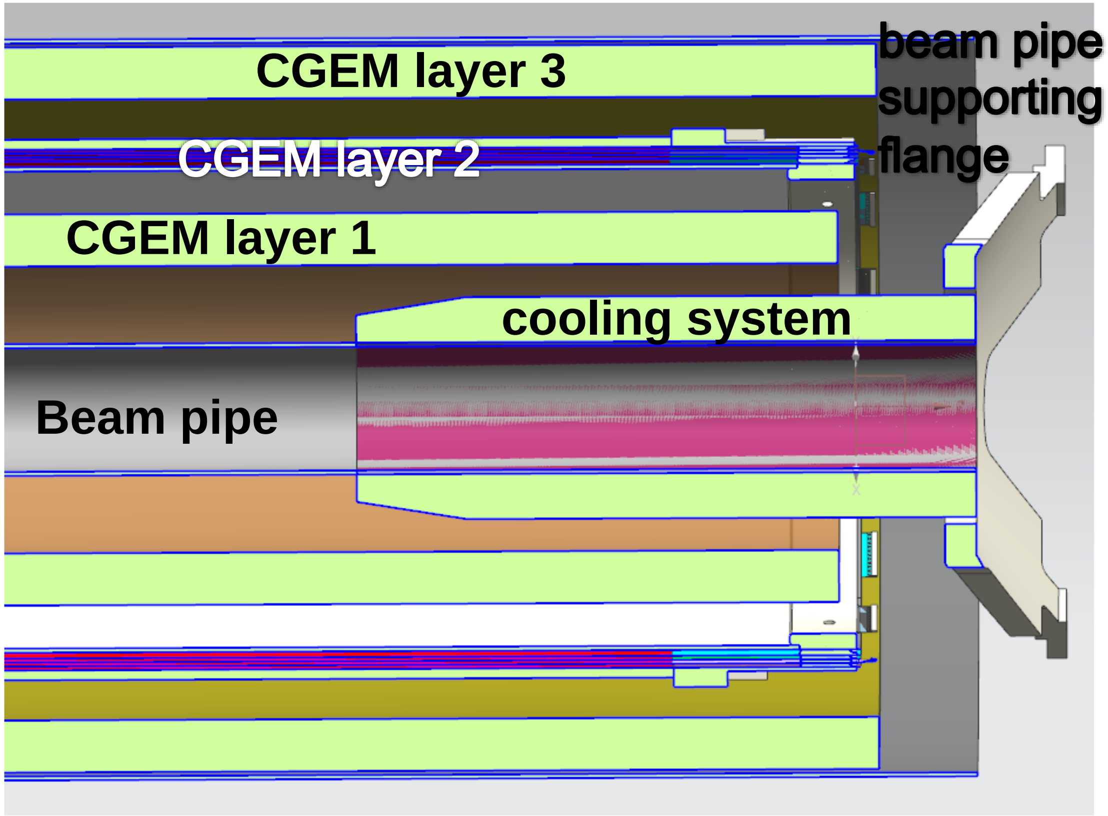
- The mechanical design account for: the mechanics of the interaction region; the location of the frontend boards; the placement of the high voltage distribution cards at the edges of detector.
- The radial dimension are limited internally by the beam pipe and externally by the Drift Chamber and on the sides by the beam pipe supporting flanges.



The BESIII CGEM-IT

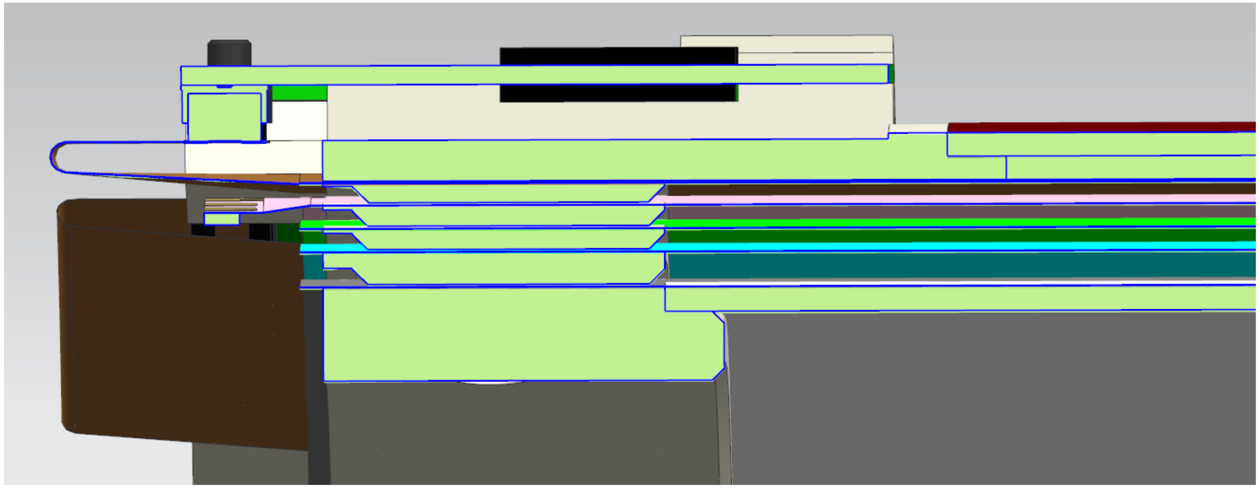
- Along the z direction the available space for the fronted electronics and the utilities is limited by a set of flanges that holds the beam pipe.

- In order to free as much space as possible the mechanical length of the three layers will be slightly incremental with the radius.



- A compact mechanical interface, called "service flange" has been designed in order to host all the utilities and to smooth the cable routing.

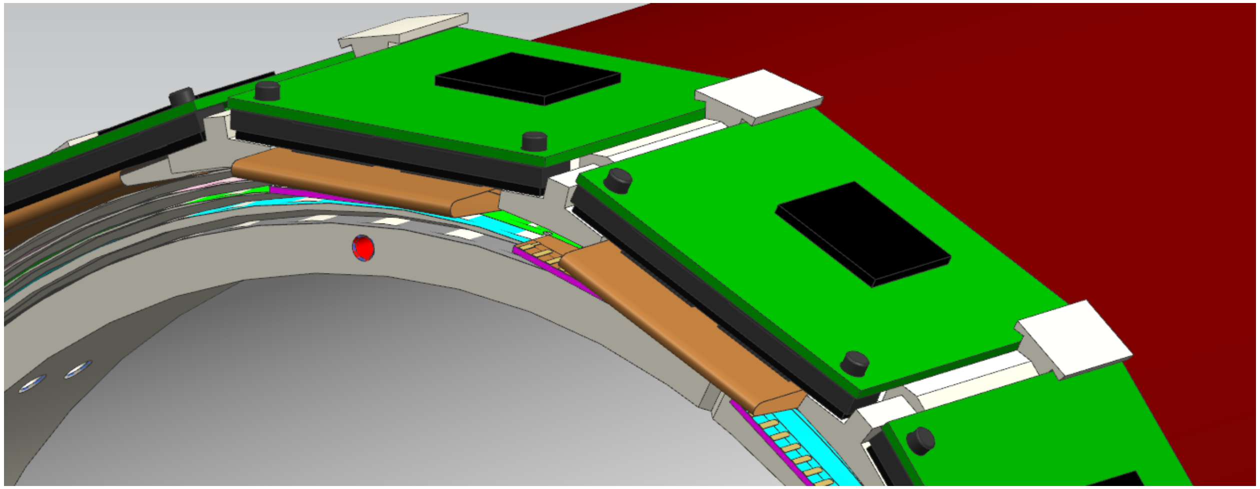
The BESIII CGEM-IT: some detector details



Section of CGEM layer 2

readout plane
GEM3
GEM2
GEM1
cathode

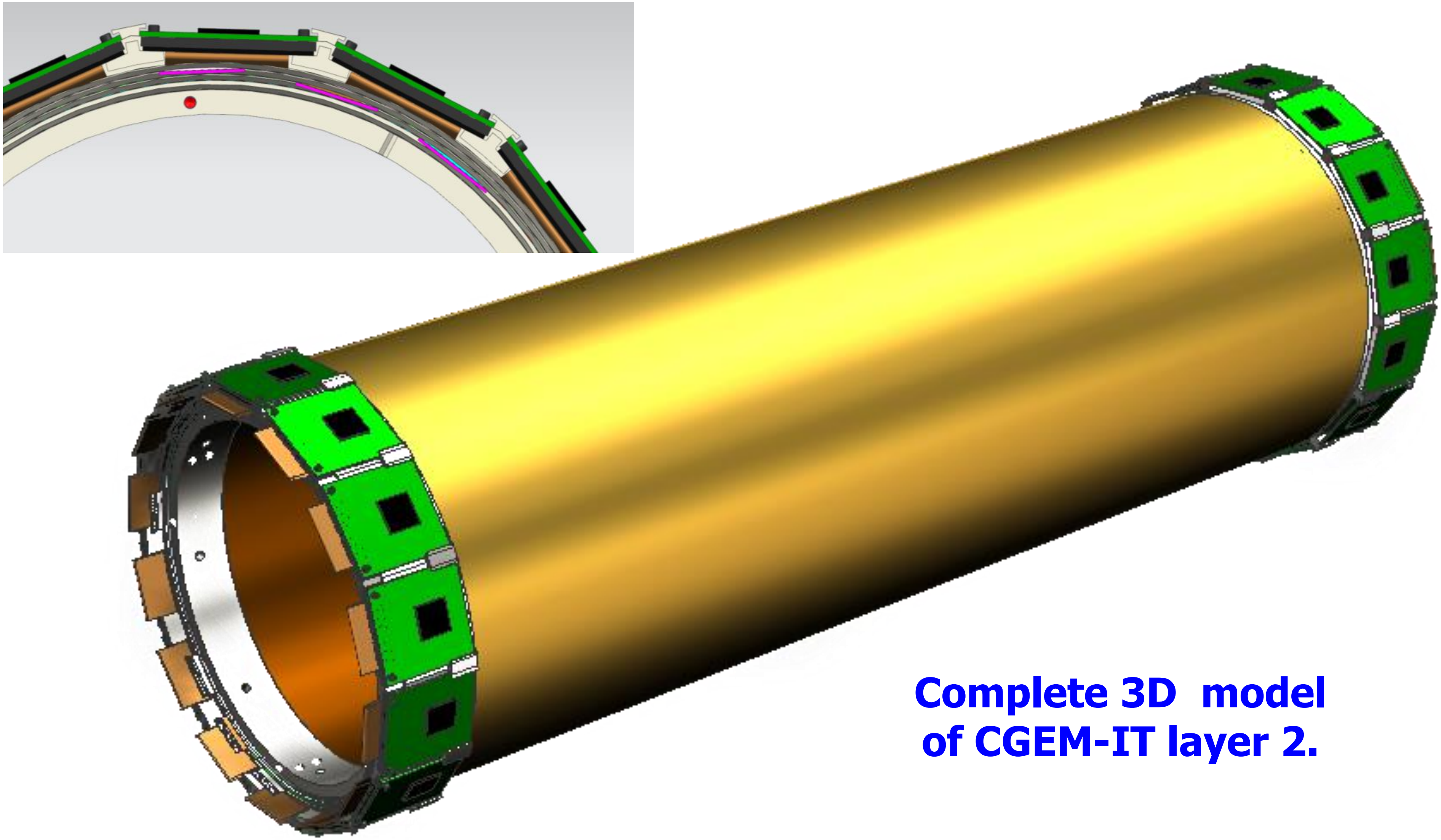
Layer 2 is the first being built; construction is in progress.



The frontend electronics cards will be located in the dead space available between the layers outside the active area.

The outermost layer frontend cards will be located on a service flange.

The BESIII CGEM-IT: a view of the detector



Complete 3D model of CGEM-IT layer 2.

BESIII CGEM-IT Front End Electronics

- **Goals**:
  - spatial resolution ~ 100 μm
  - time resolution ~ 1 ns
  - short dead time < 1 μs

A new ASIC to perform Analogue Readout is needed!

- **Design of CGEM-IT ASIC** (UMC 0.11 μm):
  - inheriting from existing design (IBM 0.13 μm)
  - BackEnd design shared by several projects
  - BackEnd porting to UMC 0.11 μm in progress
  - different input stage (suited for CGEM) to increase signal sensitivity and SNR

- **FrontEnd Simulations** in progress:
  - input stage optimized to handle capacitance in the range 20 ÷ 150 pF
  - circuit tested with a delta-pulse and GEM-like signal

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

- **Room for upgrades and R&D:**
  - BESIII CGEM-IT
  - ASIC R&D to perform CGEM-IT Analogue Readout

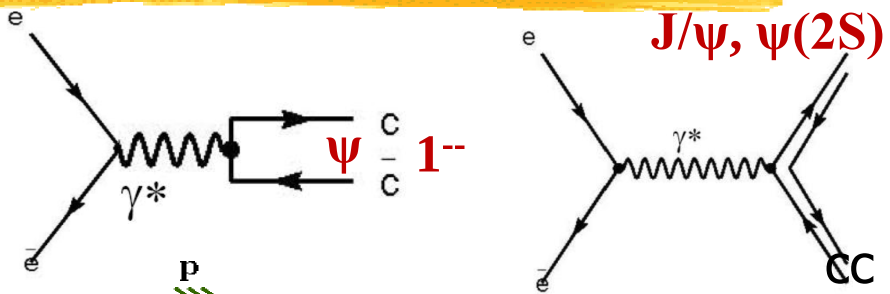
Question time

ありがとうございます!

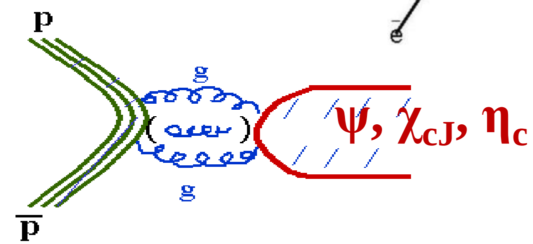
Spare slides

How to produce Charmonium states

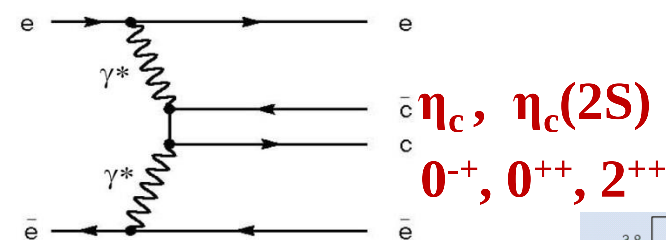
1. e^+e^- annihilation (including ISR/double charmonium)



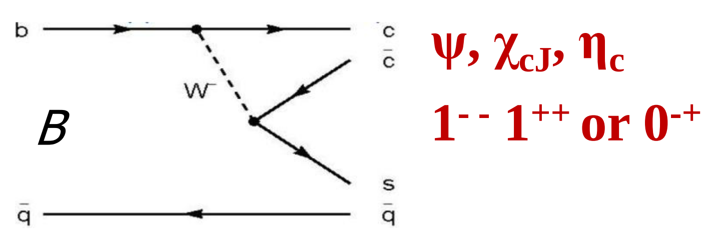
2. $p\bar{p}$ annihilation



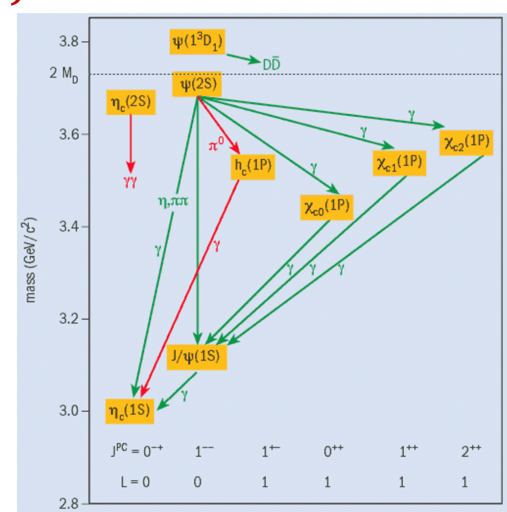
3. Two-photon process



4. B decays

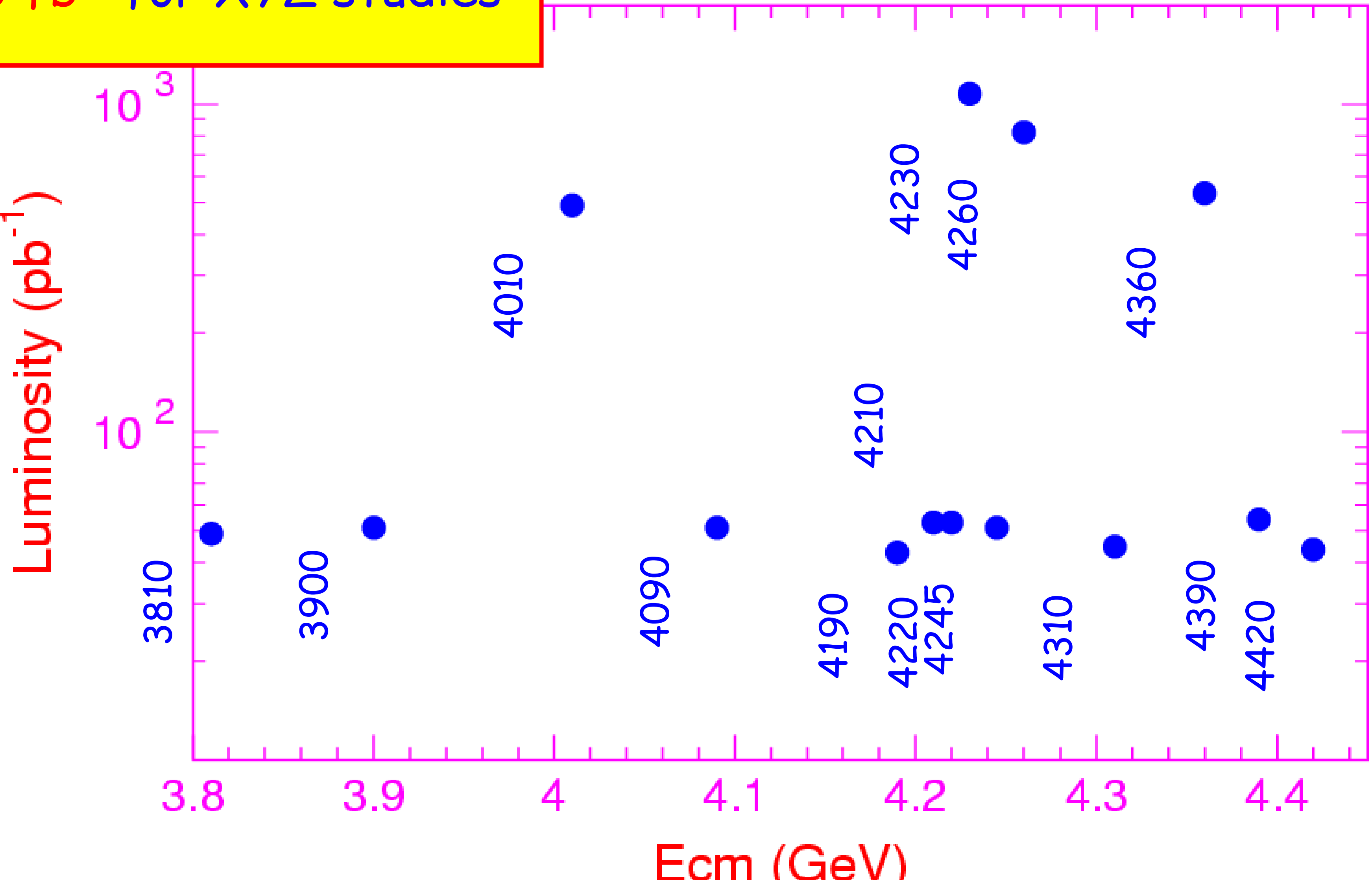


5. Charmonium transition



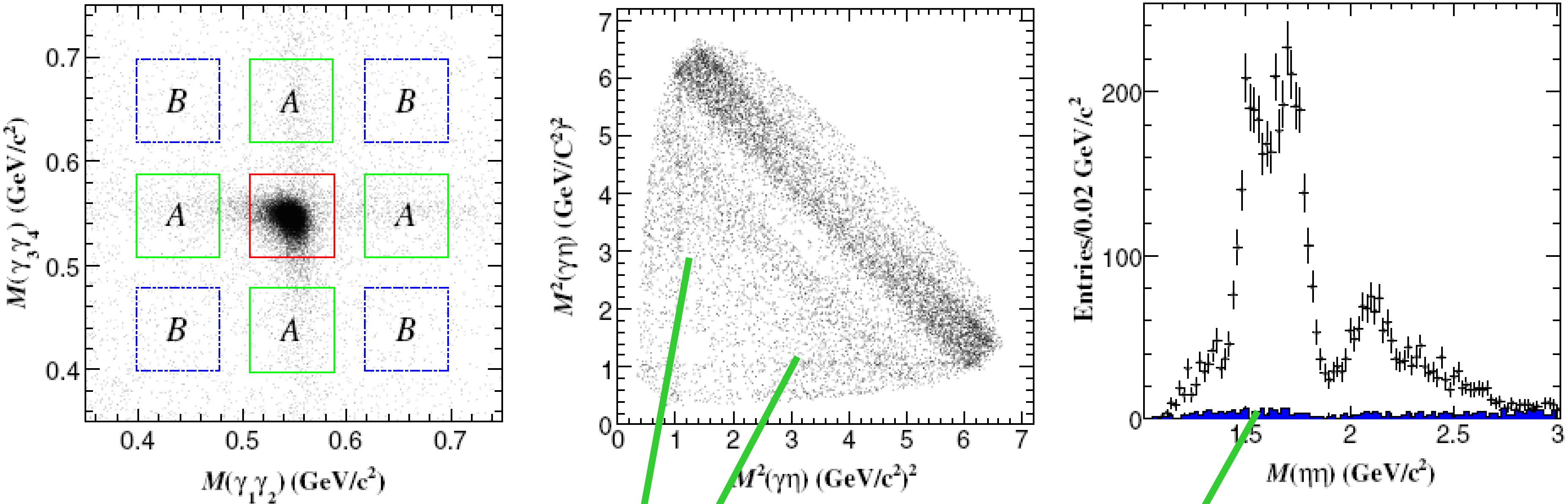
BESIII data set

3.3 fb^{-1} for XYZ studies



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

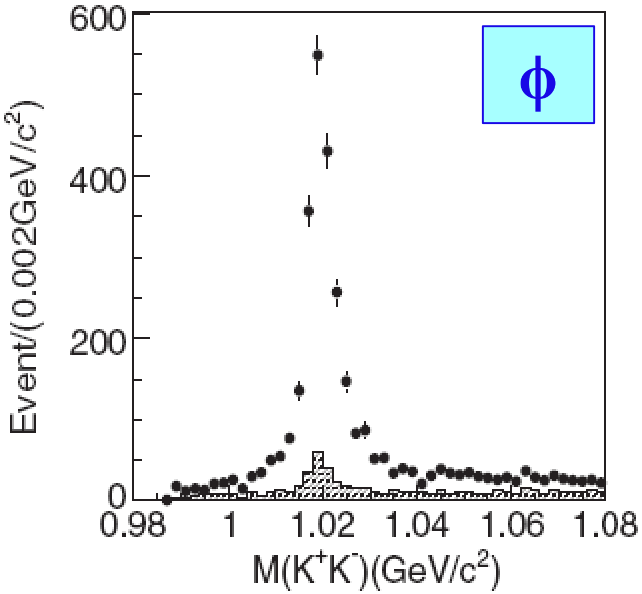
PRD 87, 092009

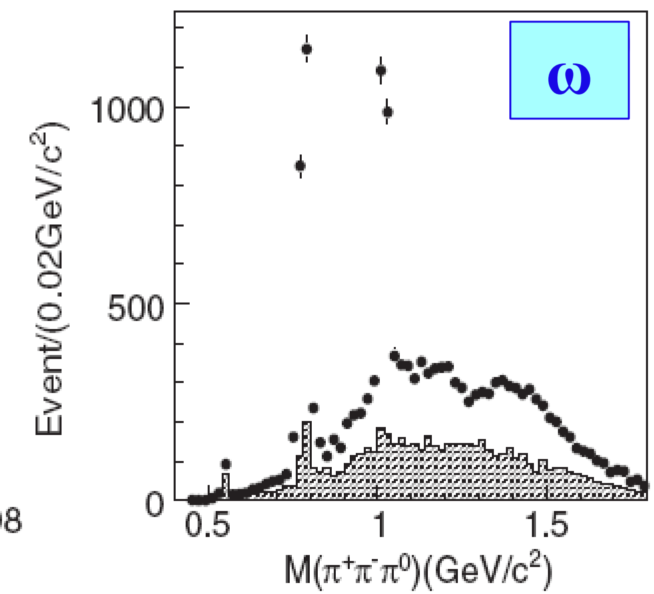


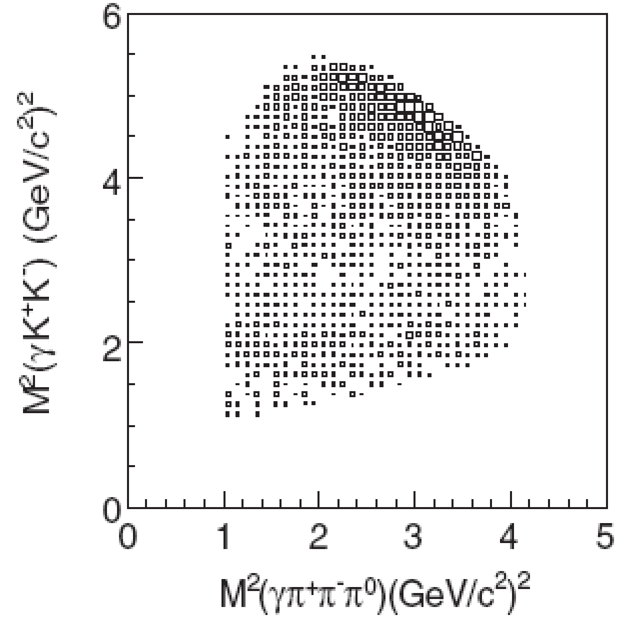
- **$J/\psi \to \phi\eta$, $\phi \to \gamma\eta$:**
  - select events outside ϕ window
- **background:**
  - low and mostly non-η background,
  - estimanted by η sidebands (blue shadow)
- **background subtraction:**
  - $\ln \mathcal{L}^{signal} = \ln \mathcal{L}^{data} - \ln \mathcal{L}^{sideband}$

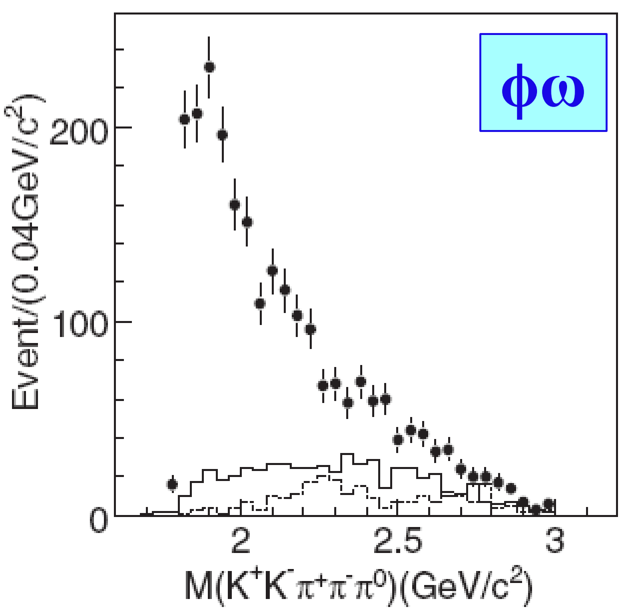
BESIII: PWA of $J/\psi \to \gamma\omega\phi$

PRD 87, 032008



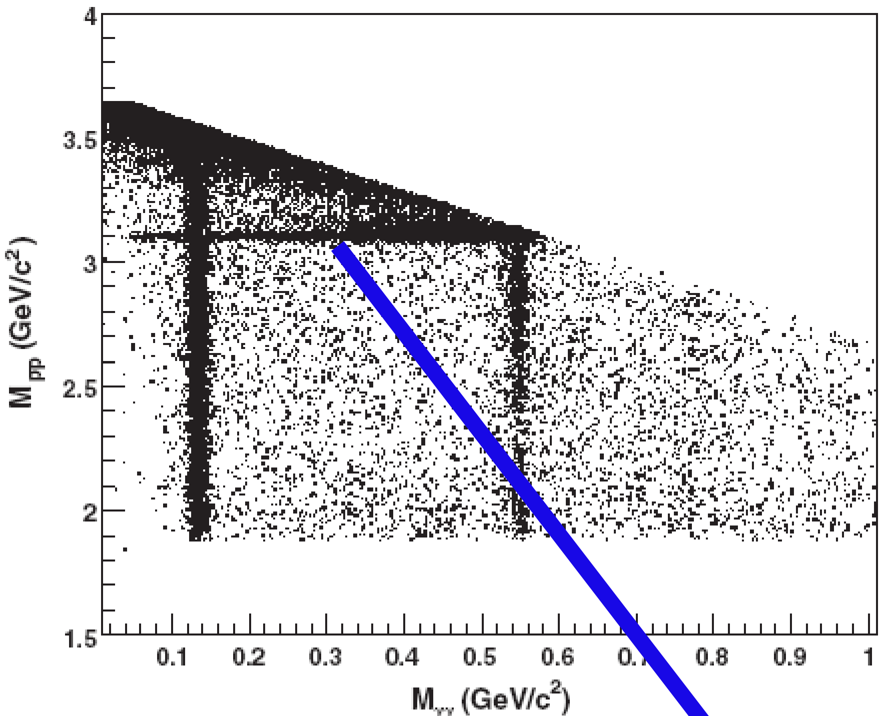


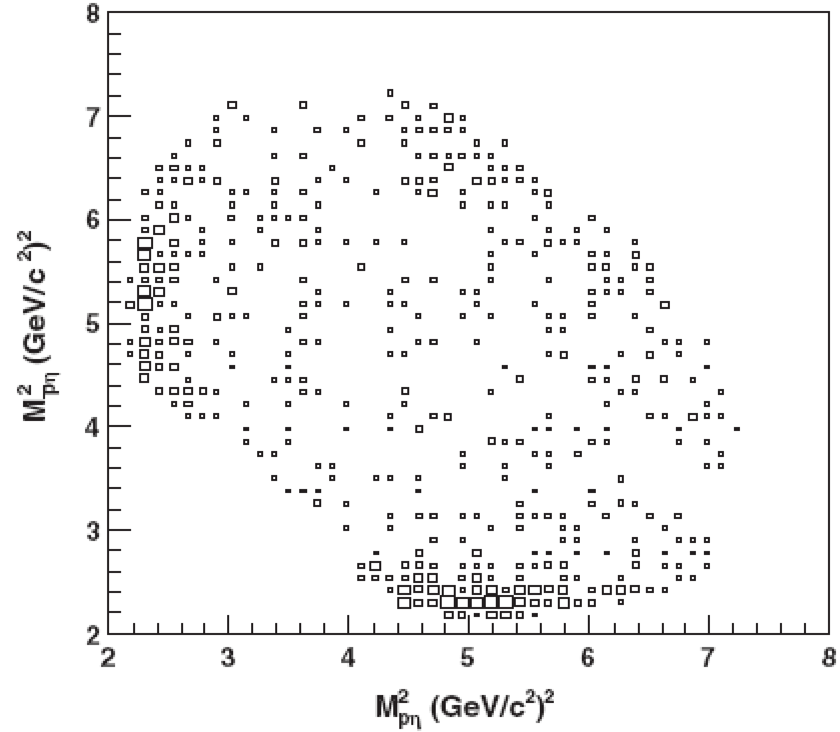




- **solid:**
  - background estimated from sidebands
- **dashed:**
  - inclusive J/ψ MC samples
- **background subtraction:**
  - $\ln \mathcal{L}^{signal} = \ln \mathcal{L}^{data} - \ln \mathcal{L}^{sideband}$

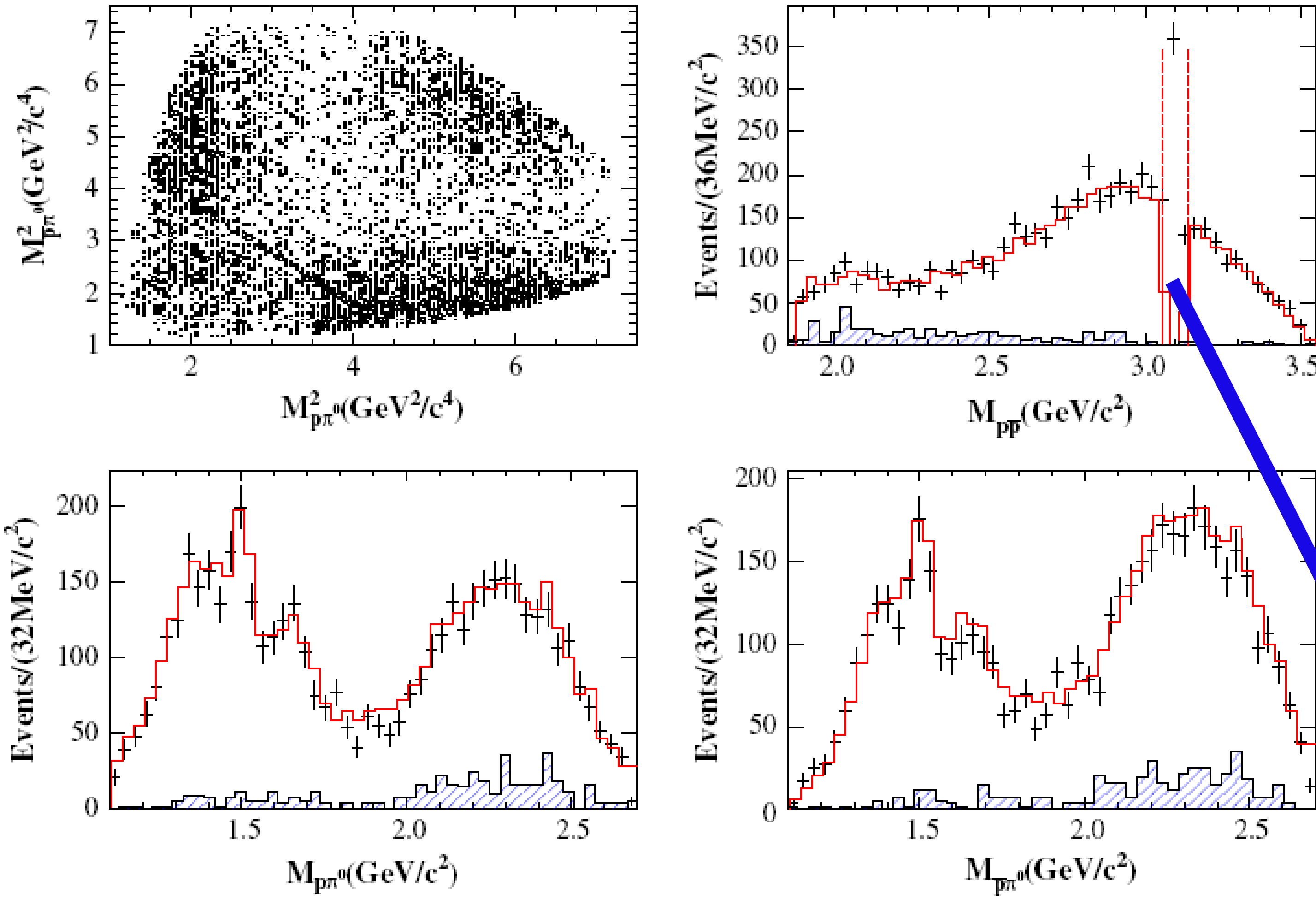
BESIII: PWA of $\psi(2S) \to p\bar{p}\eta$





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

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



shaded:

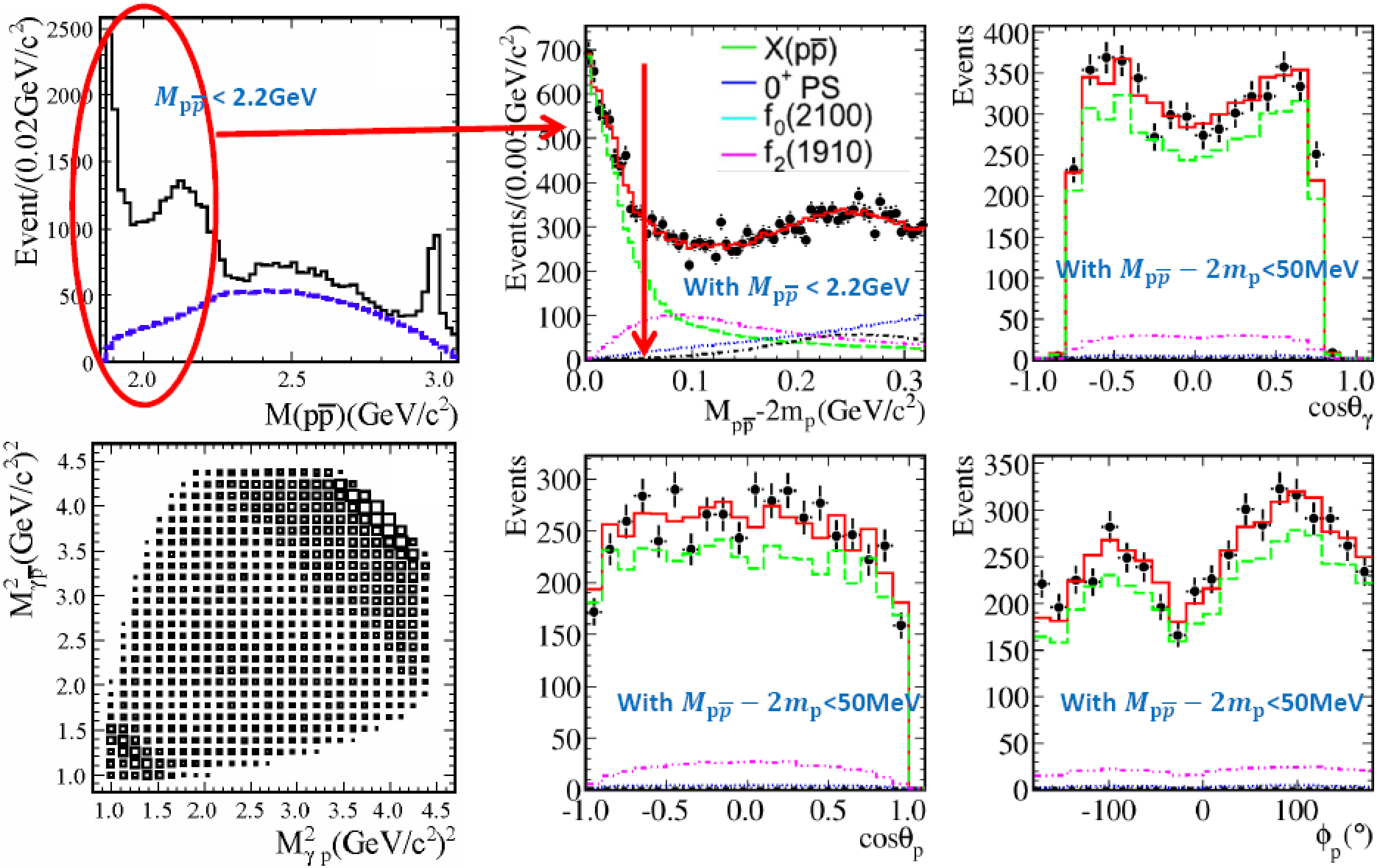
background:

- continuum
- non-π^0 background

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

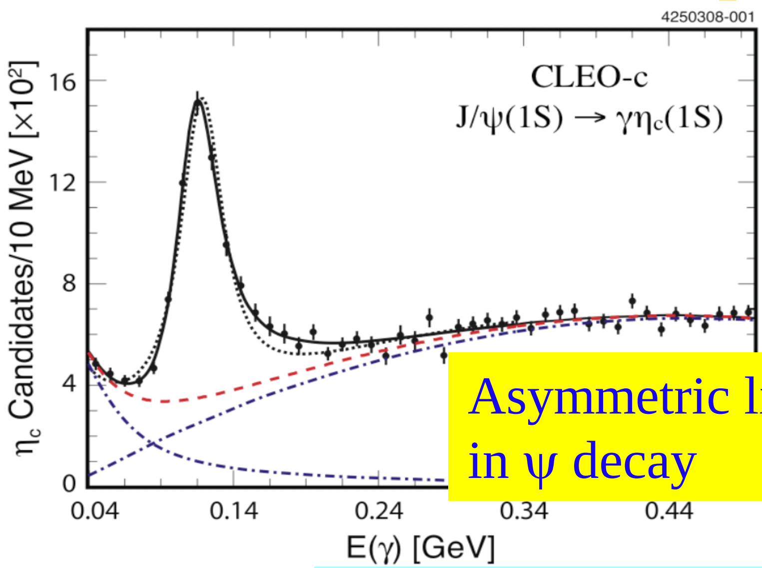
BESIII: PWA of $J/\psi \to \gamma p\bar{p}$, $M_{p\bar{p}}$<2.2 GeV

PRL 108, 112003



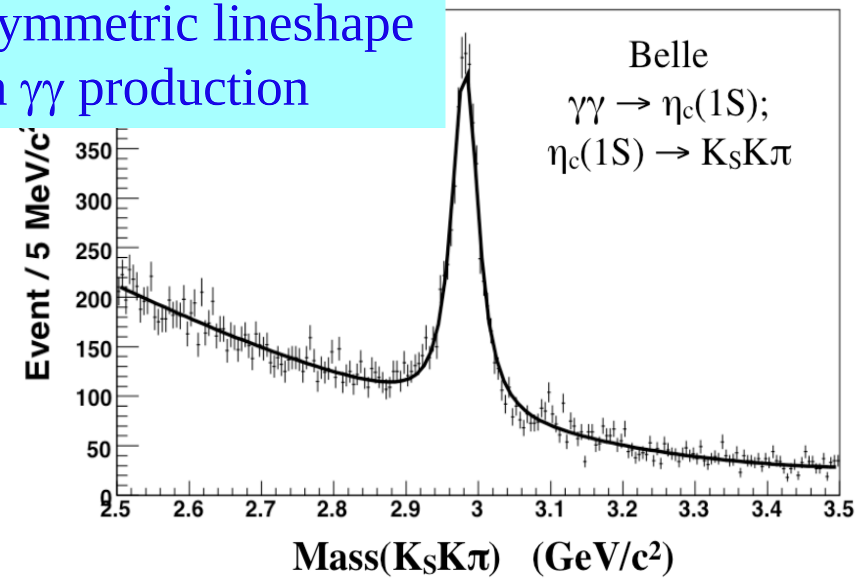
BESIII: η_c parameters from $\psi(2S) \rightarrow \pi^0 h_c(1P)$, $h_c(1P) \rightarrow \gamma\eta_c(1S)$

PRD 86, 092009

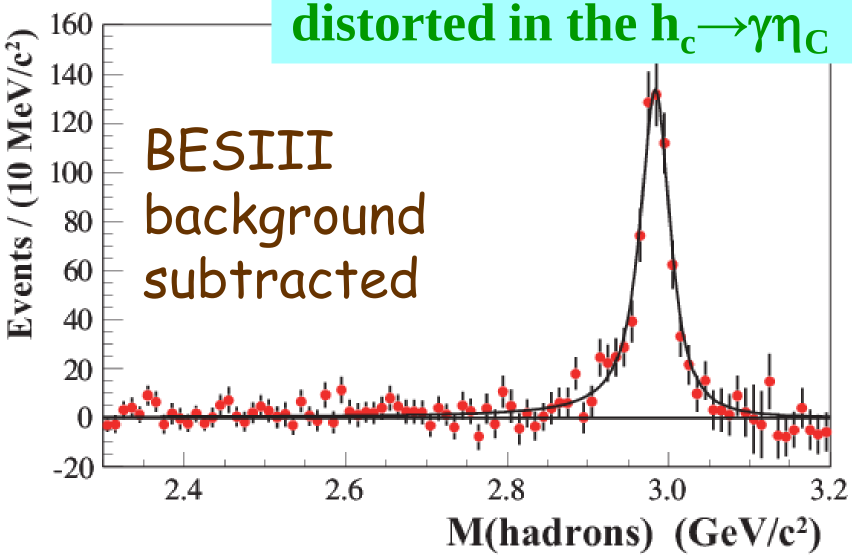


Asymmetric lineshape in ψ decay

Symmetric lineshape in $\gamma\gamma$ production



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



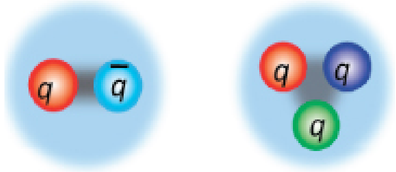
- CLEO-c observe a distortion of η_c lineshape in charmonium radiative decay

PRL102, 011801 (2009)

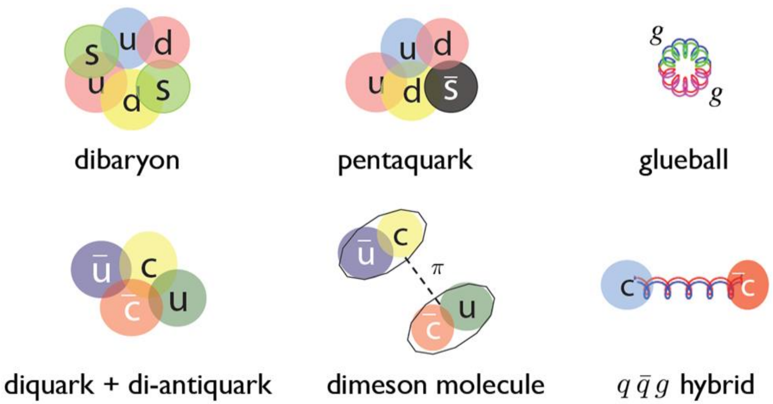
- The lineshape of η_c from BELLE is symmetric
- The abnormal line shape is also observed in BESIII exclusive channels in $\psi' \rightarrow \gamma\eta_c$ but not in $\psi' \rightarrow \rightarrow \pi^0 h_c$, $h_c \rightarrow \gamma\eta_c$

Hadronic exotic states

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



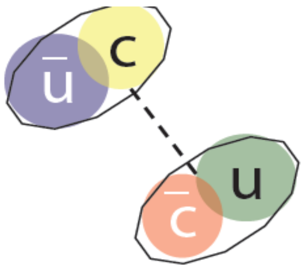
- **QCD suggests:**
  - **Confinement : stable hadrons need to be colorless**
  - **Gluon-gluon interactions : hadron with gluons (hybrids and glueballs) could exist**
  - **Allow hadrons with $N_{quarks} \neq 2, 3$ (multi-quarks)**



Can we find evidence for these interesting exotic hadrons?

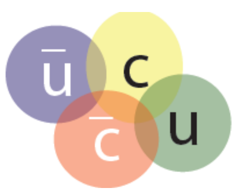
A long history of searching for the exotic hadron, no solid conclusion was reached in past a few decades, some hints on charmomium-like and bottomnium-like particles, recently.

Exotic Meson (Charmonium-Like)



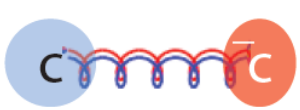
Molecular states:

- 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

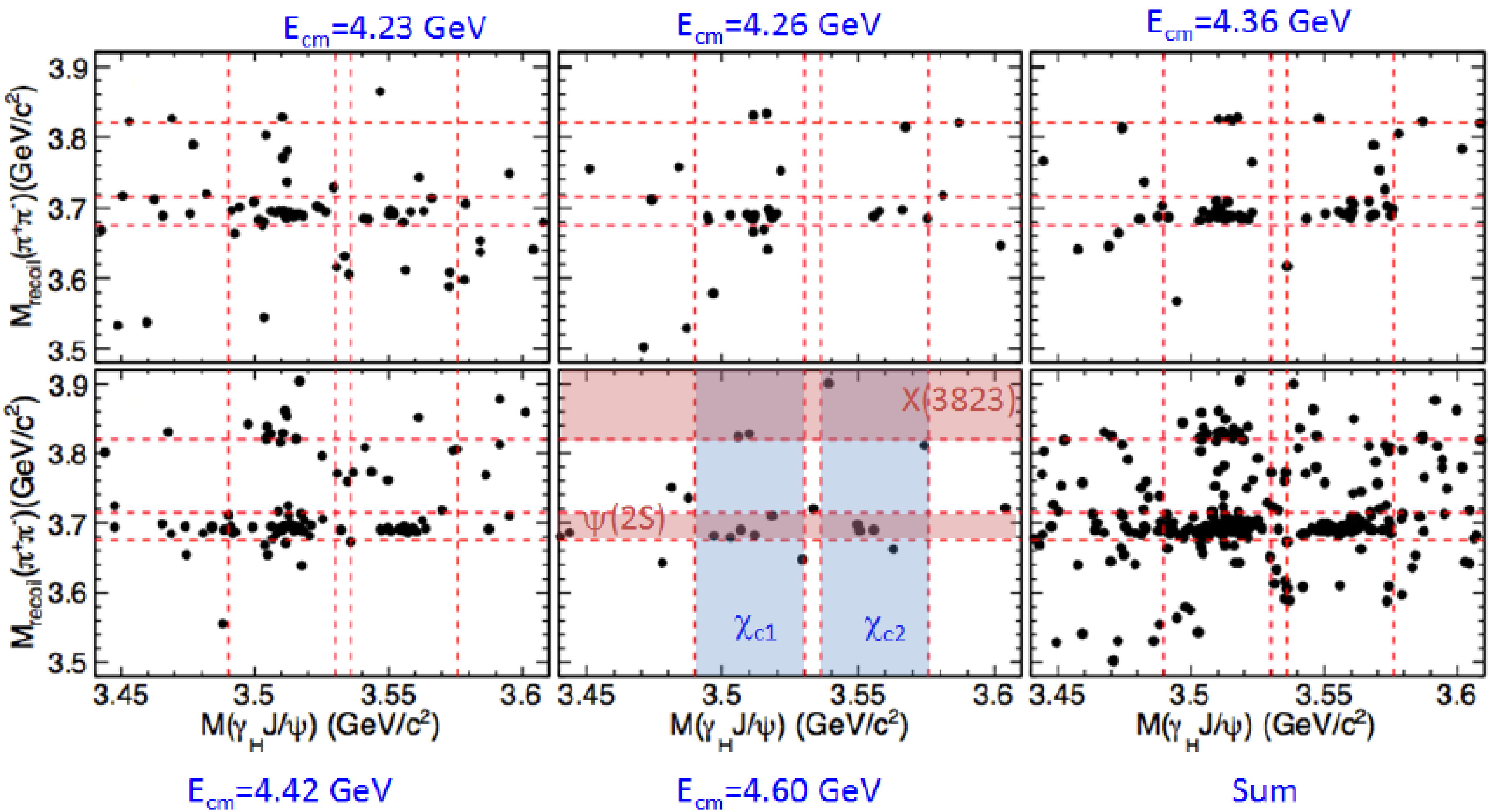


Hybrids:

- 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}



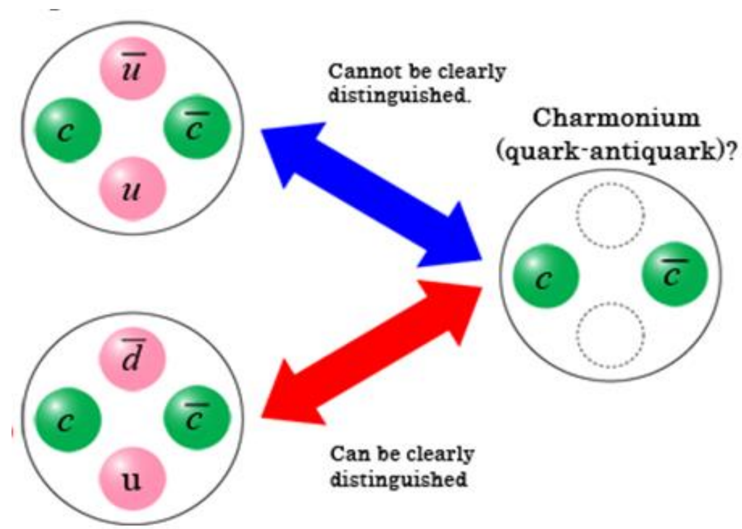
Z_c states

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, …

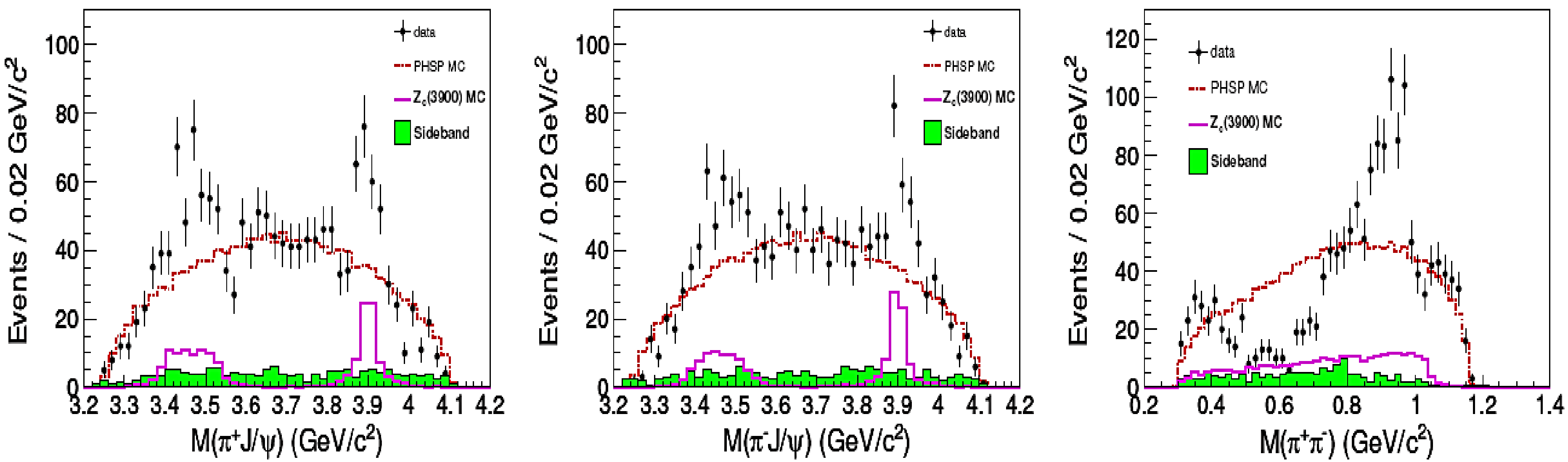


BESIII: $e^+e^- \to \pi^+\pi^- J/\psi$

PRL 110, 252001

Is it a real signal?

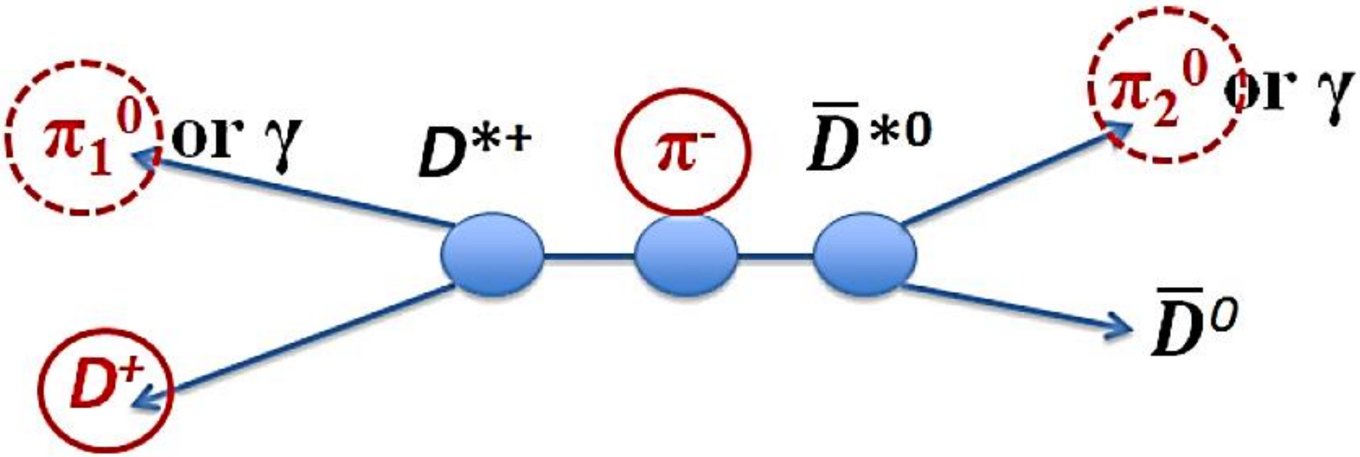
- Is it due to $\pi^+\pi^-$ S-wave states, like σ, $f_0(980)$, …? **N**
- Is it due to $\pi^+\pi^-$ D-wave states, like $f_2(1270)$, …? **N**
- Are there two states, one at 3.4, the other 3.9 GeV? **N**
- Exist in both e^+e^- & $\mu^+\mu^-$ samples? **Y**
- Exist in both $\pi^+\pi^-$ low mass and high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

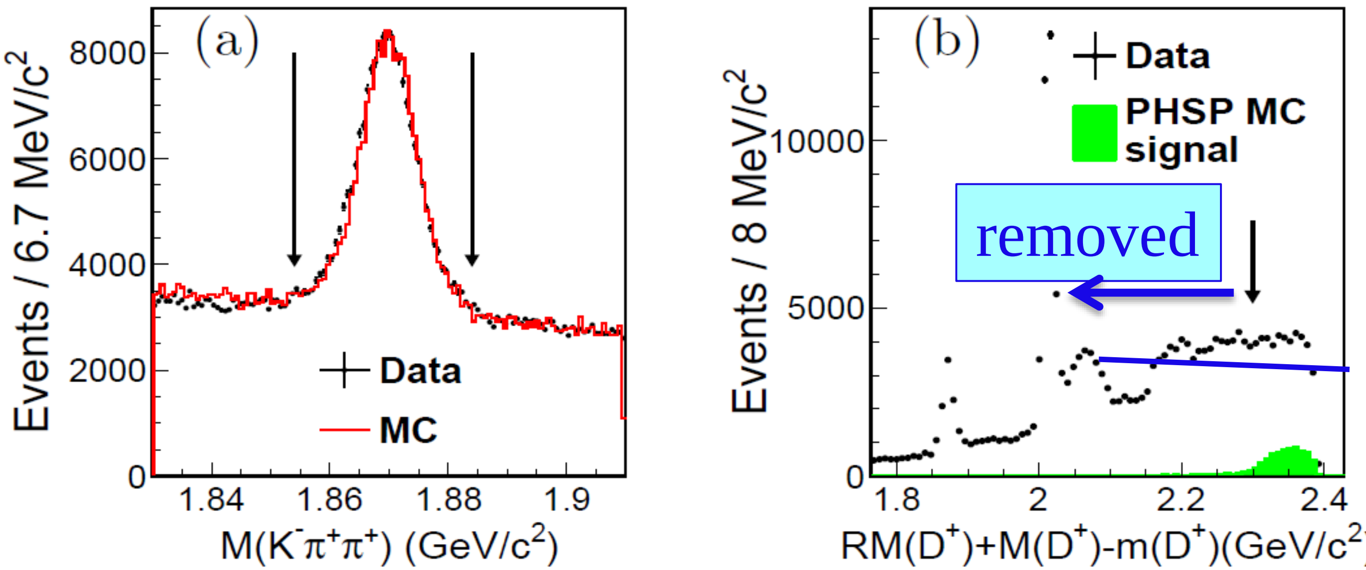


Topology of the decays of the signal process:

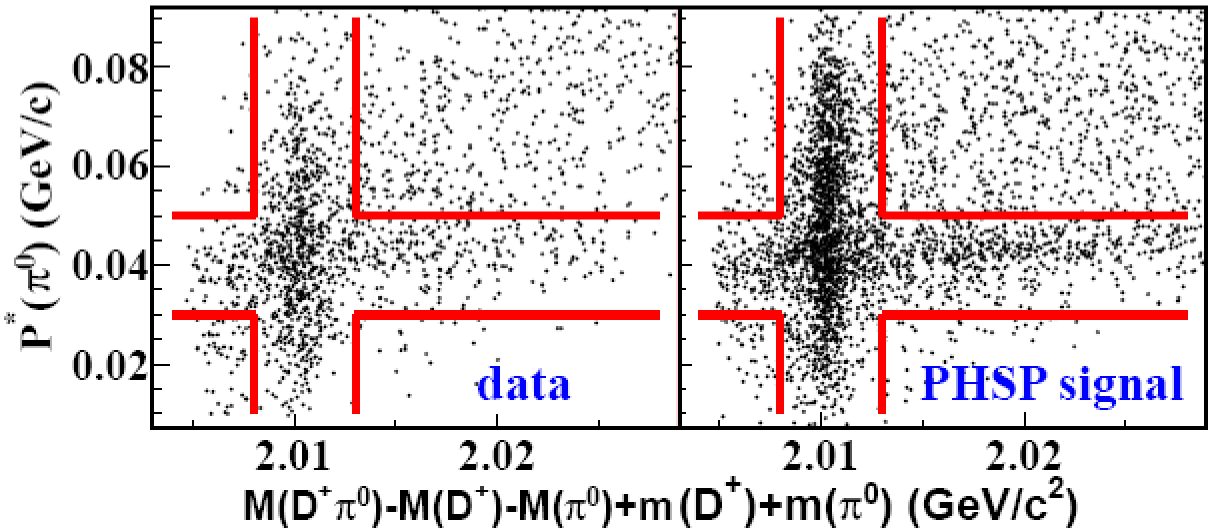
- thick line circled: D^+ and π^- detected in the final states
- dashed line circled: at least of π_1^0 or π_2^0 tagged

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

hep-ex:1308.2760

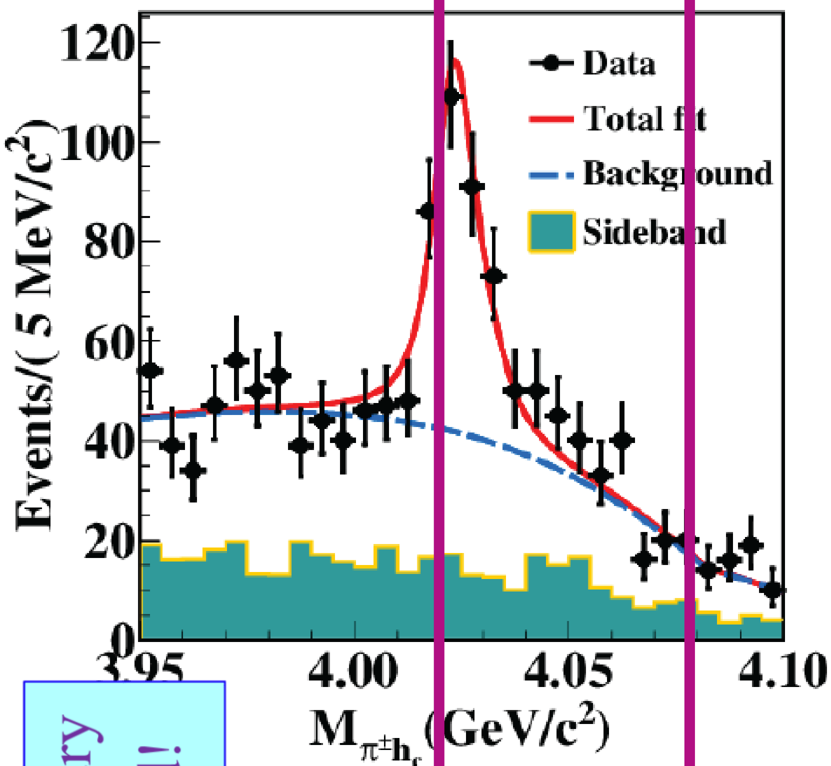


Remove DD, DD*, D*D*, DsDs, …

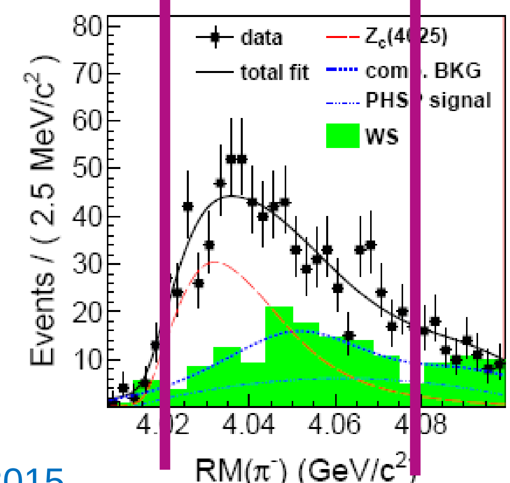


BESIII: $Z_c(4020)=Z_c(4025)$?

PRL 111, 242001
hep-ex:1308.2760



BESIII preliminary
The 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)

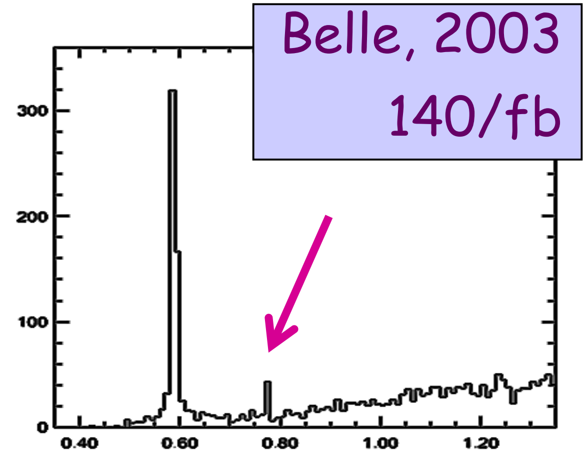
Mass consistent with each other but.. width ~2σ difference

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

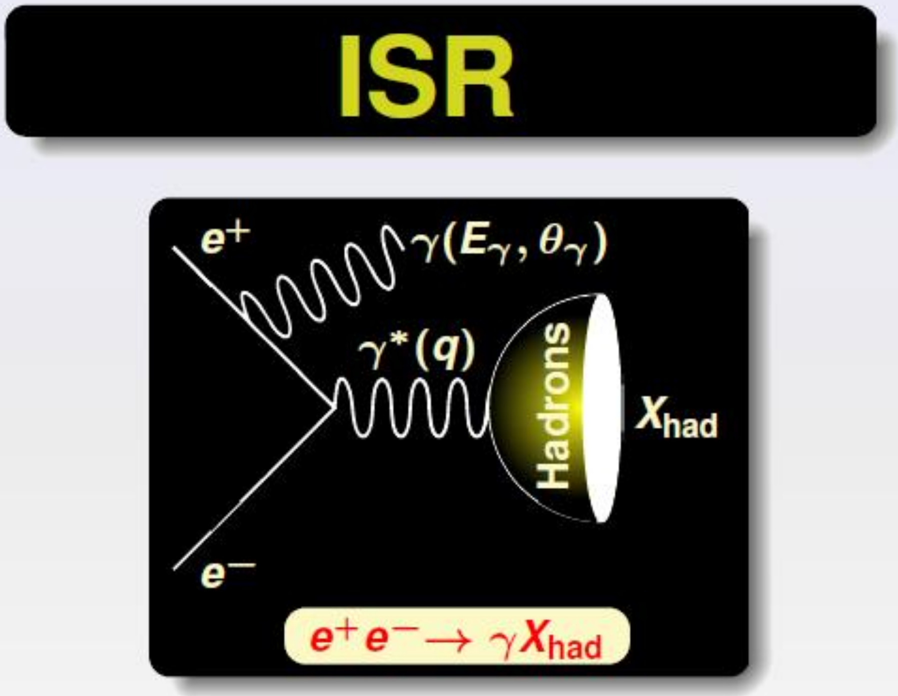
What is the X(3872)?



- 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 $\bar{c}c$, K*X smaller than $\bar{c}c$
  - **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

ISR at BESIII



ISR: Physics motivations

- Existing results, obtained by ***BaBar*** (ISR), show interesting and unexpected behaviors, mainly at thresholds, for

$$e^+e^- \to p\bar{p} \quad \text{and} \quad e^+e^- \to \Lambda\bar{\Lambda}$$

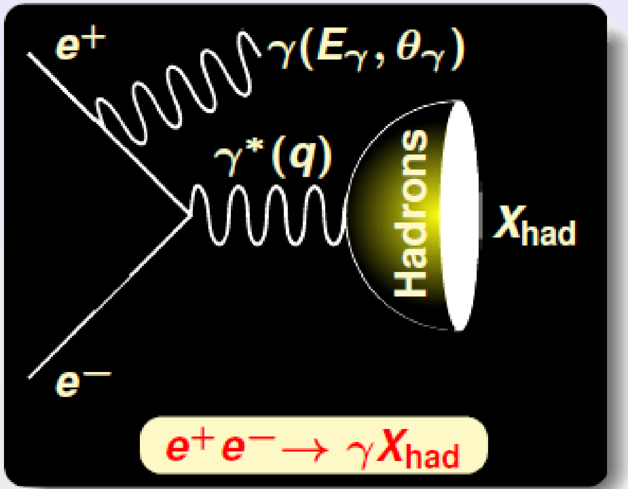
- Only one measurement (**FENICE** with energy scan) for

$$e^+e^- \to n\bar{n}$$

There are physical limits in reaching the threshold of many of these channels via energy scan (stable hadrons produced at rest can not be detected)

The Initial State Radiation technique provides a unique tool to access threshold regions working at higher resonances

Initial State Radiation



- $$\frac{d^2\sigma}{dE_\gamma d\theta_\gamma} = W(E_\gamma, \theta_\gamma) \cdot \sigma_{e^+e^- \rightarrow X_{had}}(s)$$
- $$W(E_\gamma, \theta_\gamma) = \frac{\alpha}{\pi x}\left(\frac{2 - 2x + x^2}{\sin^2\theta_\gamma}\right)$$

- $s = q^2$, q .... X_{had} momentum
- E_γ, θ_γ ... CM γ energy, scatt. ang.
- E_{CM} .... CM e^+e^- energy
- $x = E_\gamma / 2E_{CM}$

Advantages

- All energies (q^2) at the same time
  $\Downarrow$
  Better control on systematics
  (e.g. greatly reduced point to point)
- Detected ISR $\Rightarrow$ full X_{had} angular coverage
- CM boost $\Rightarrow$ $\begin{cases} \text{at threshold } \epsilon \neq 0 \\ \text{energy resolution} \sim 1 \text{ MeV} \end{cases}$

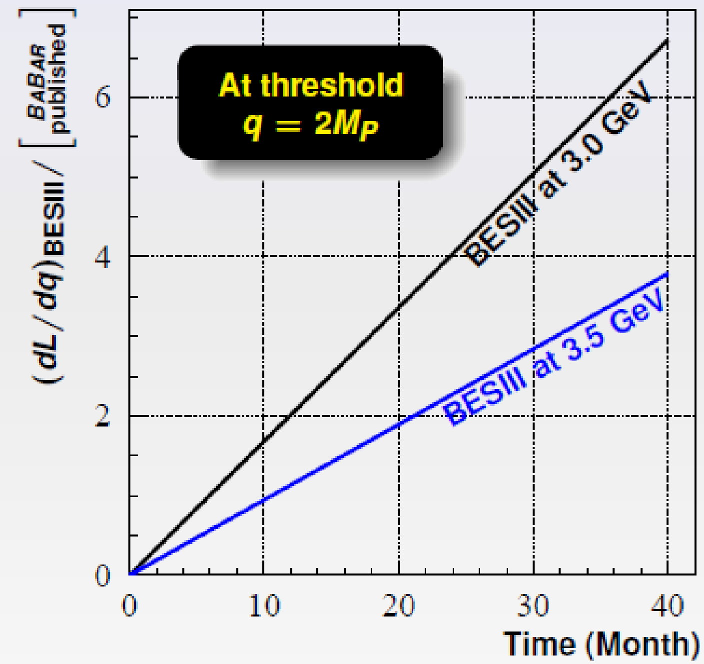
ISR: BESIII vs BABAR

ISR Luminosity

$$\frac{dL}{dq} = \frac{2q}{E_{cm}^2} L_{ee} \int_{\cos\theta_\gamma^{min}}^{\cos\theta_\gamma^{max}} W(E_\gamma, \theta_\gamma)\, d\cos\theta_\gamma$$

L_{ee} .... total luminosity

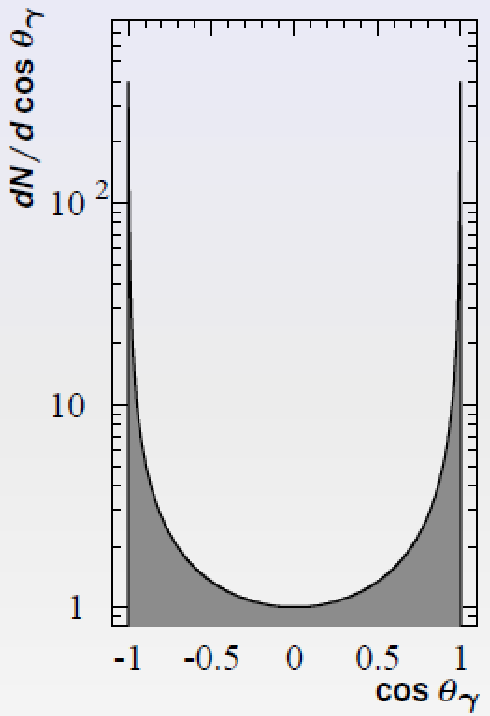
$\theta_\gamma^{min,\,max}$ ..... geom. accept.



BESIII: lower CM energy ⇒ lower background ⇒ ISR γ detection + 0^o and No ISR γ detection ⇒ $\times$2.5 and $\times$5 in statistics

ISR angular distribution and zero-degree tagging

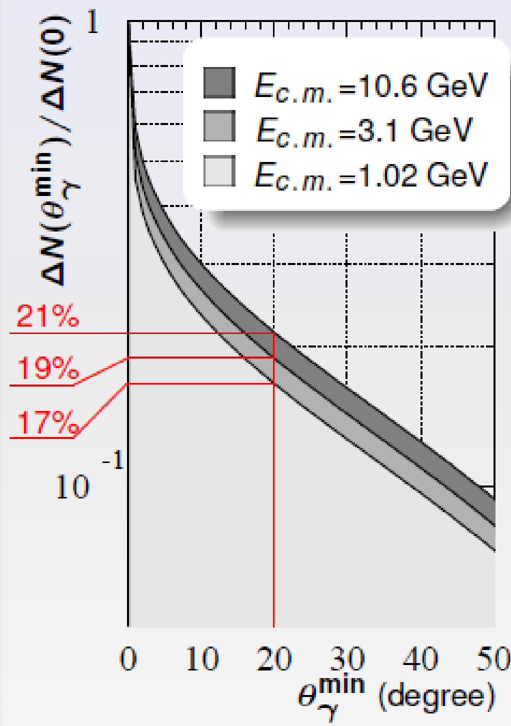
ISR angular distribution peaked at low angles



$$\frac{dN}{d\cos\theta_\gamma} = \frac{1-\cos\theta_\gamma^2}{\left(1-\beta_e^2\cos^2\theta_\gamma\right)^2}$$

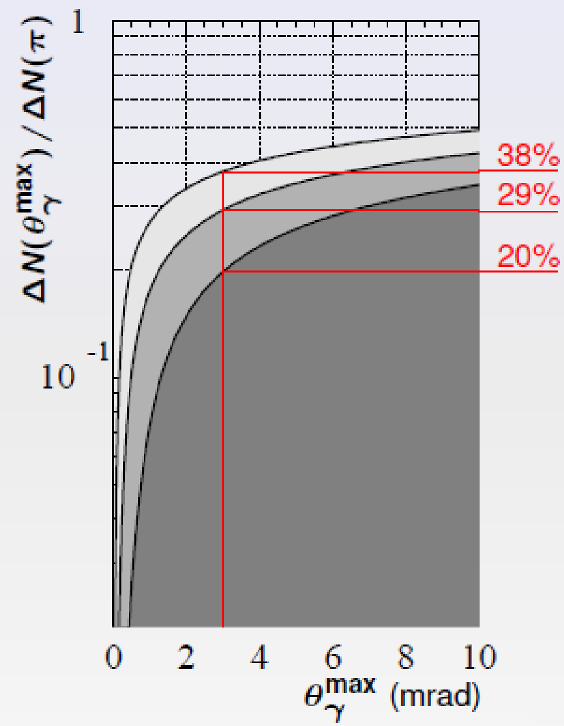
$$\beta_e = \sqrt{1-4m_e^2/E_{c.m.}^2}$$

$$\Delta N(\theta^{min}) \propto \int_{\theta_\gamma^{min}}^{90^o} d\theta_\gamma \frac{dN}{d\theta_\gamma}$$



With a typical $\theta_\gamma^{min} = 20^o$ $\sim$ 80% of events is lost!

$$\Delta N(\theta^{max}) \propto \int_0^{\theta_\gamma^{max}} d\theta_\gamma \frac{dN}{d\theta_\gamma}$$



With $\theta^{max} = 3$ mrad more statistics than at wide angle!

BESIII Zero Degree Detector

- J/Ψ, $\Psi(2S)$, $\psi(3770)$ resonances decay with high BR's to final states with π^0 and γ_{FS} (final state)
- At BESIII these decay channels represent severe backgrounds for typical ISR final states with γ_{IS} detected at wide angle

- π^0 and final γ angular distributions are isotropic
- ISR angular distribution is peaked at small angles

$\Rightarrow$

A zero-degree radiative photon tagger will suppress most of these backgrounds

A new zero-degree detector (**ZDD**),
has been installed on summer 2011 at BESIII
to tag ISR photons
as well as to measure the luminosity