Les Rencontres de Physique de La Vallée d'Aoste

23 February – 2 March 2014, La Thuile (ITALY)

Highlights on the recent BESIII results

Marco Maggiora on behalf of the BESIII Collaboration

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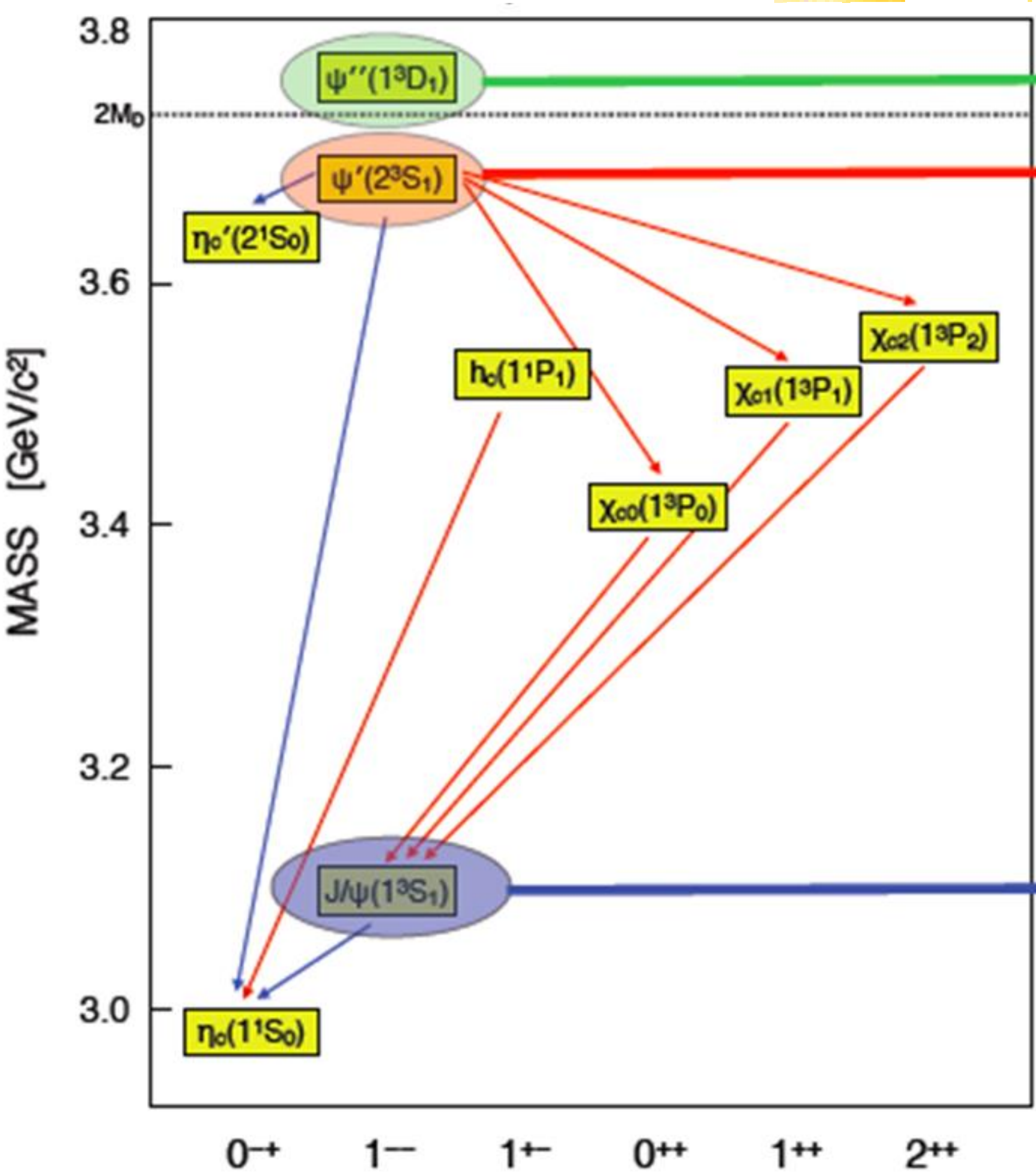
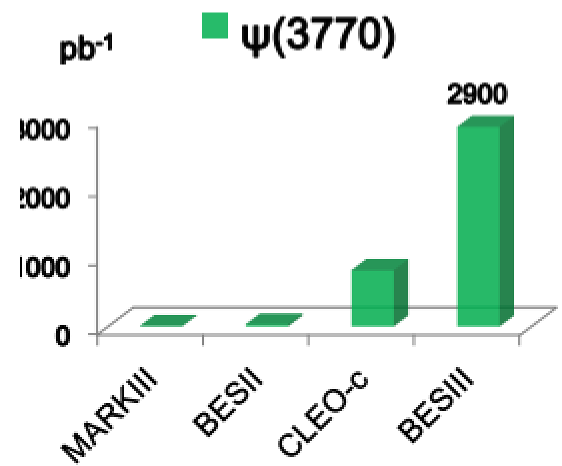
BESIII data set

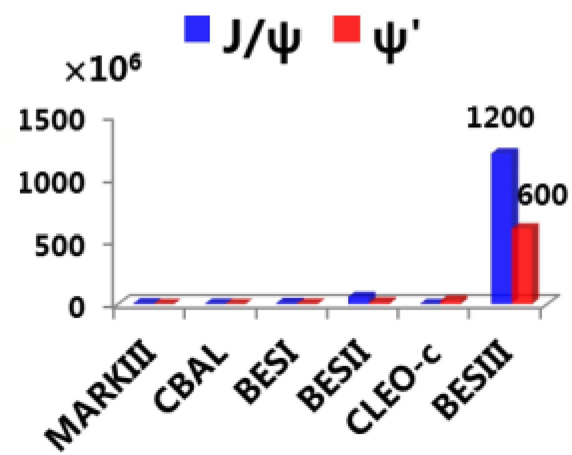


2.9 fb^{-1} / 20 fb^{-1}

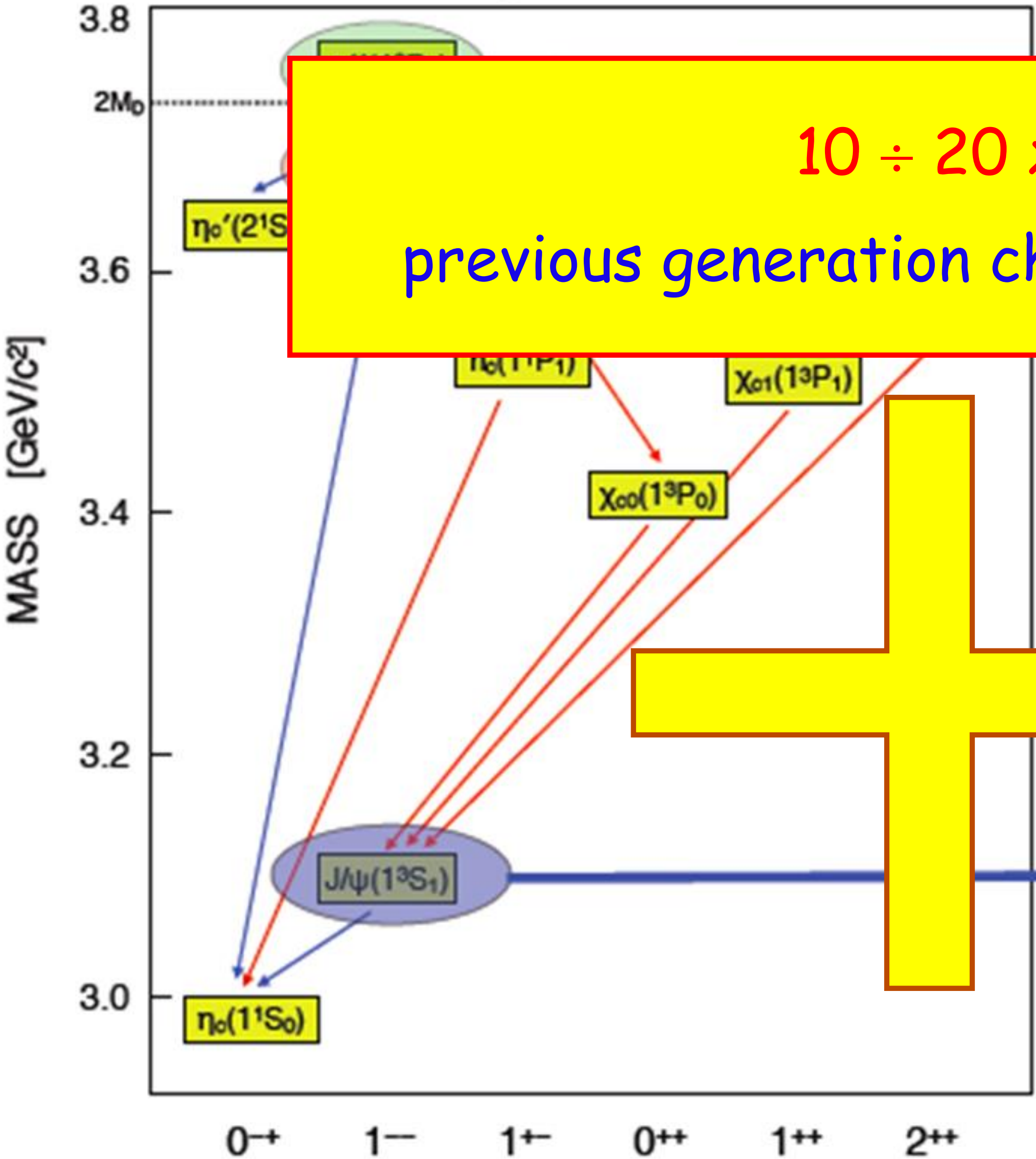
0.6 B / 3 B (106 M)



1.3 B / 10 B (225 M)



BESIII data set



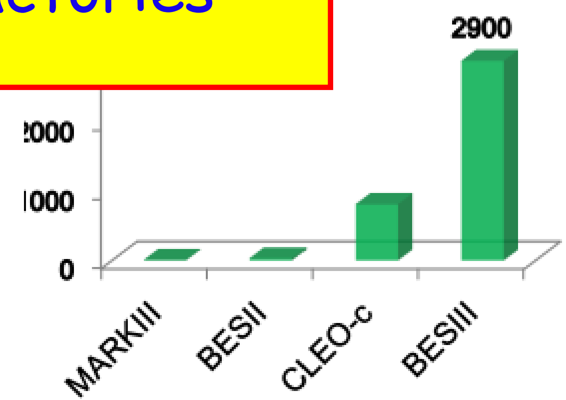
10 ÷ 20 ×

previous generation charm factories

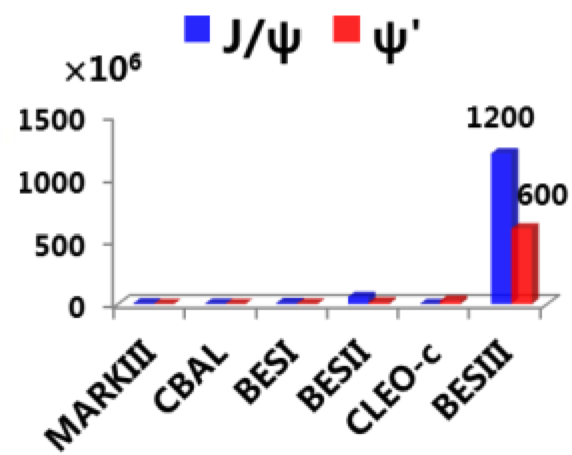
2.9 fb^{-1} / 20 fb^{-1}

.06 M)

'70)

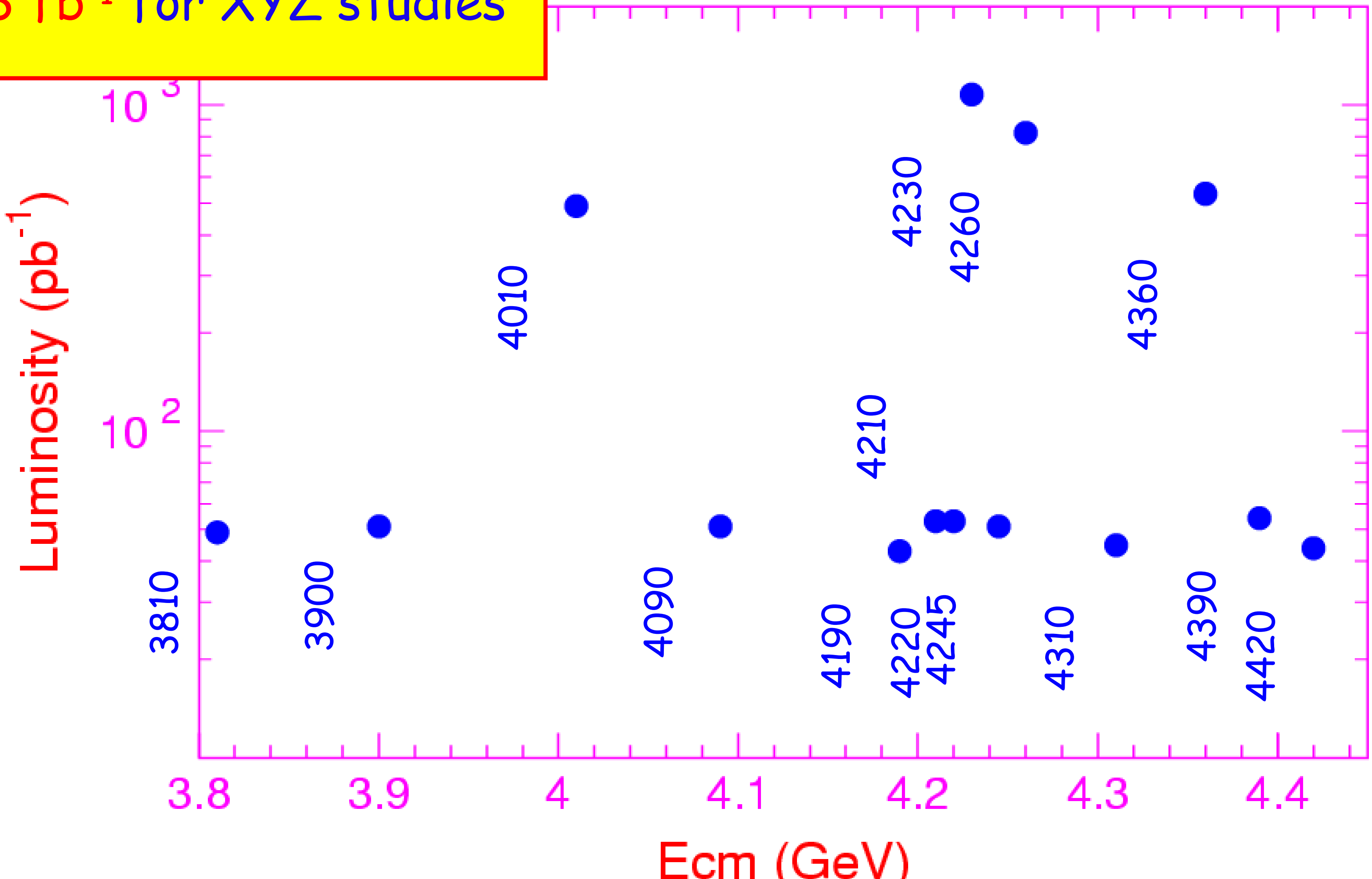


1.2 B / 10 B (225 M)

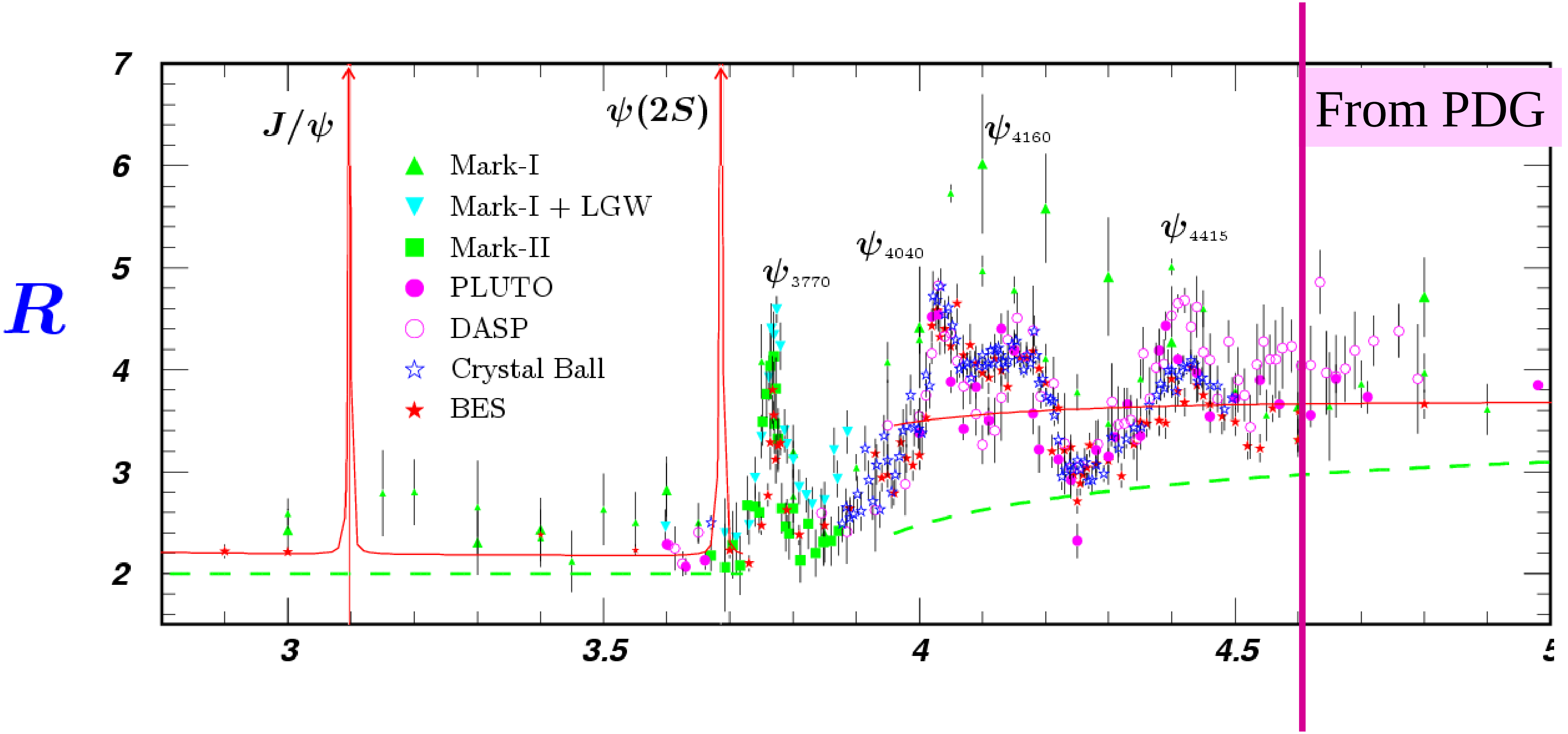


BESIII data set

3.3 fb^{-1} for XYZ studies

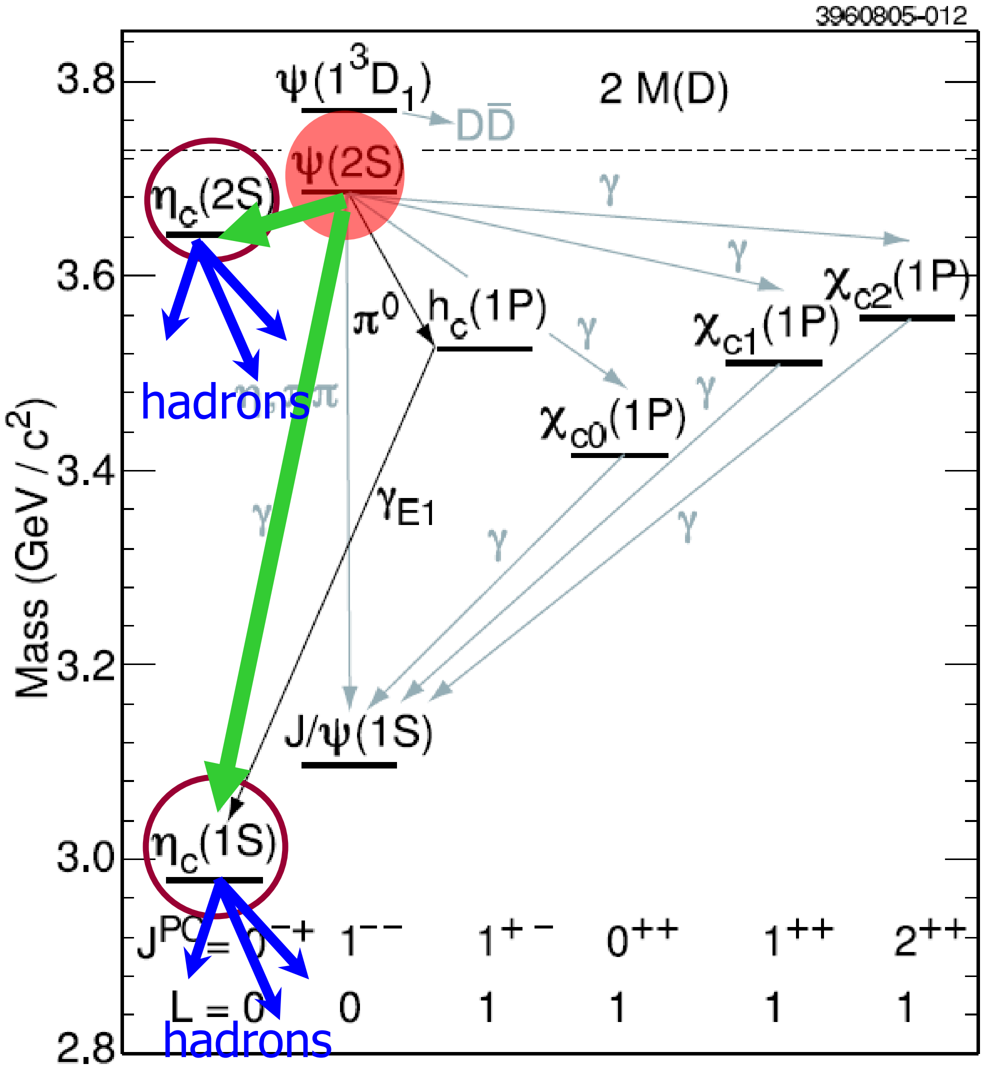


BESIII production of Charmonium(like) states



BEPCII can reach here!

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



η_c mass:
charmonium ground state

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

$\eta_c(1S)$

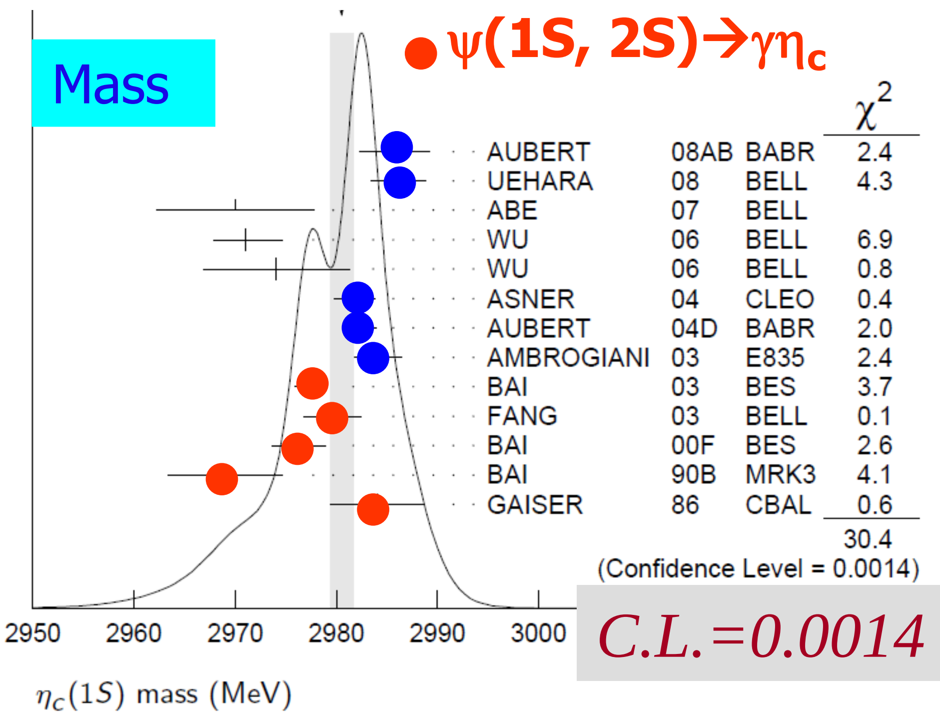
The S-wave spin-singlet charmonium ground state, found in 1980

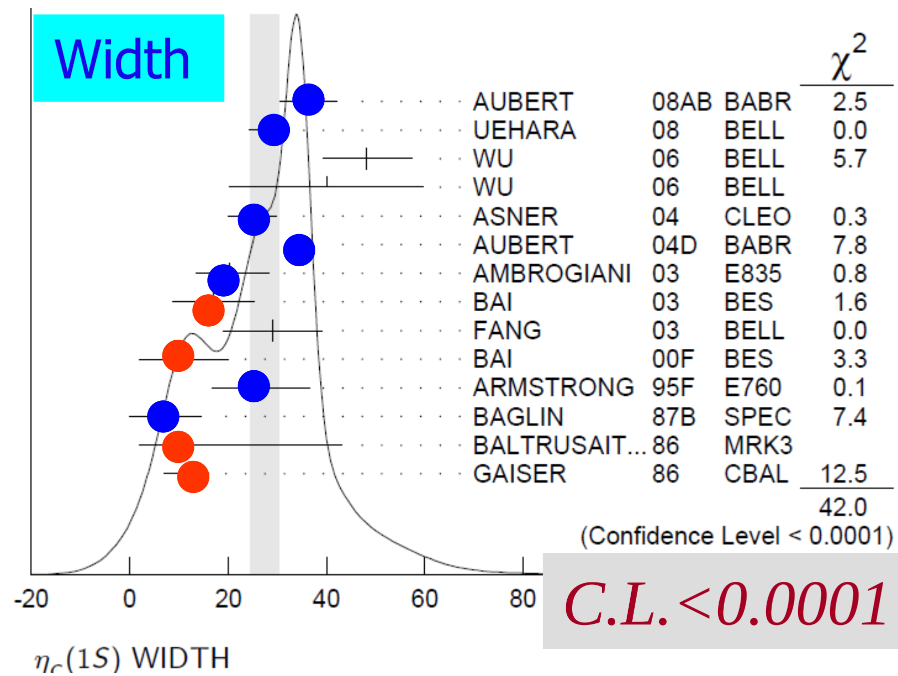
M & Γ measurements:

- 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**

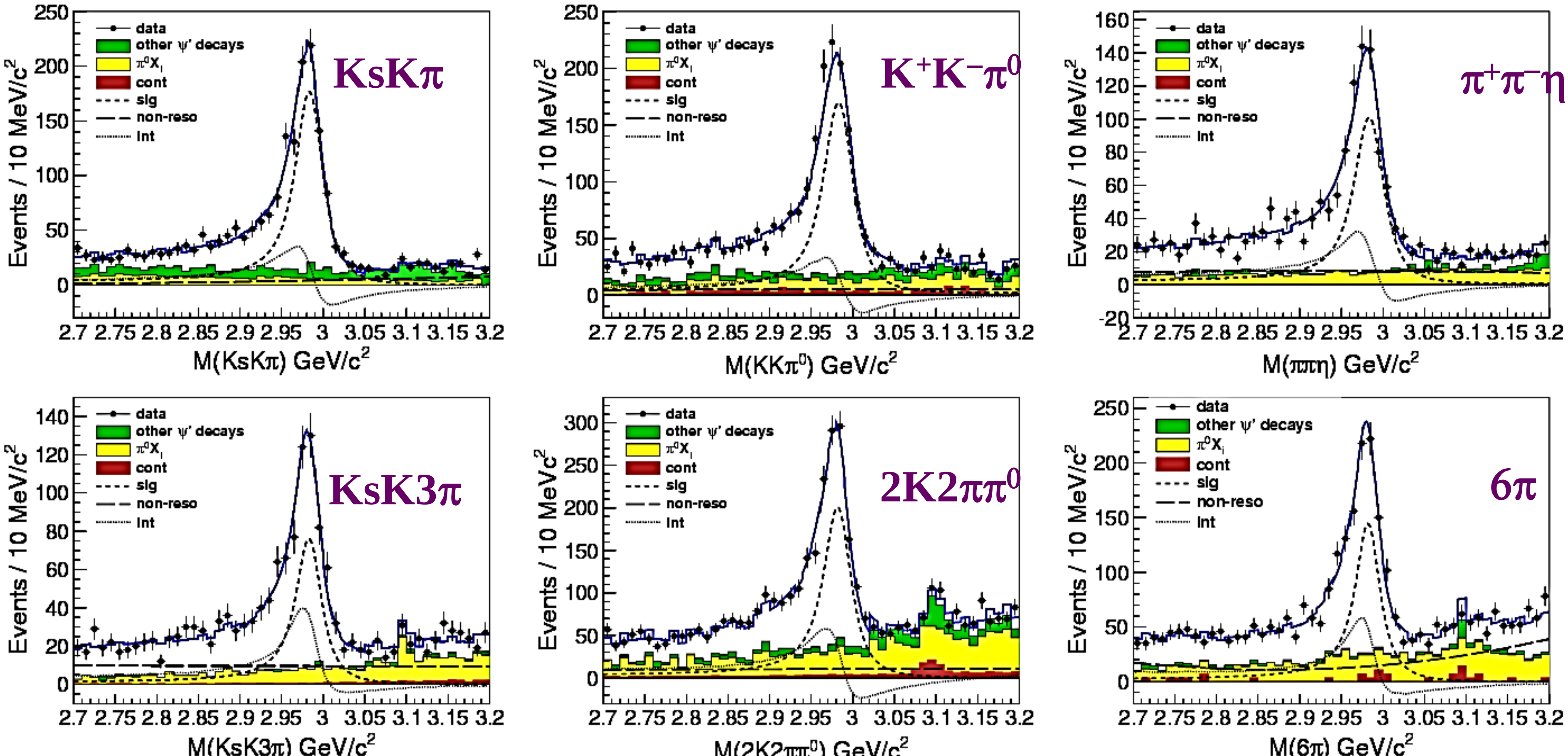
● **ψ(1S, 2S)→γη_c**





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

PRL 108, 222002 (2012)



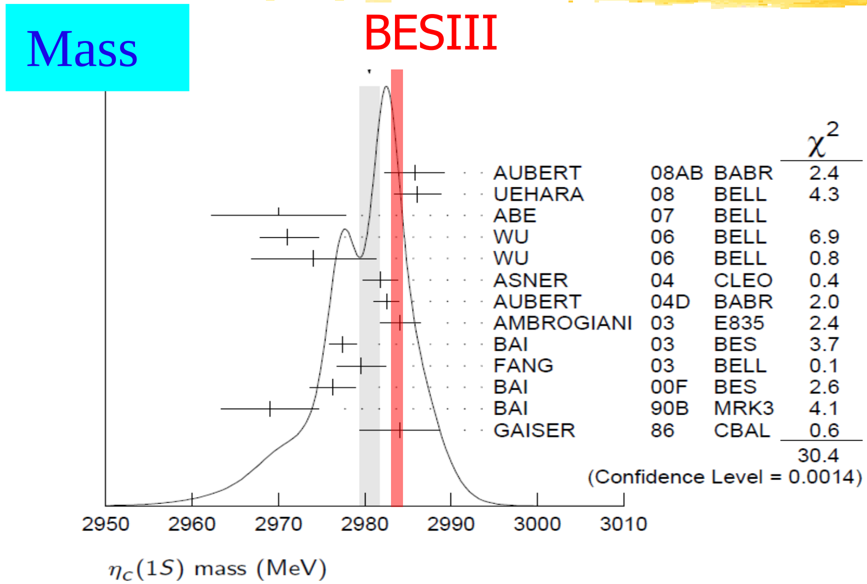
Significant interference between η_c and non-resonant

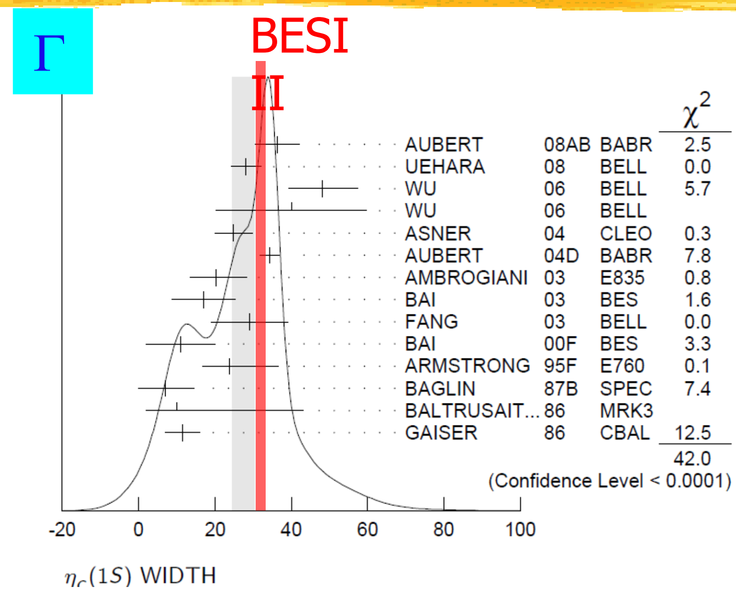
→ simultaneous fit to 6 modes, **Mass = 2984.3±0.6±0.6 MeV/c^2**

Γ = 32.0±1.2±1.0 MeV/c^2

η_c(1S): BESIII vs literature

PRL 108, 222002 (2012)

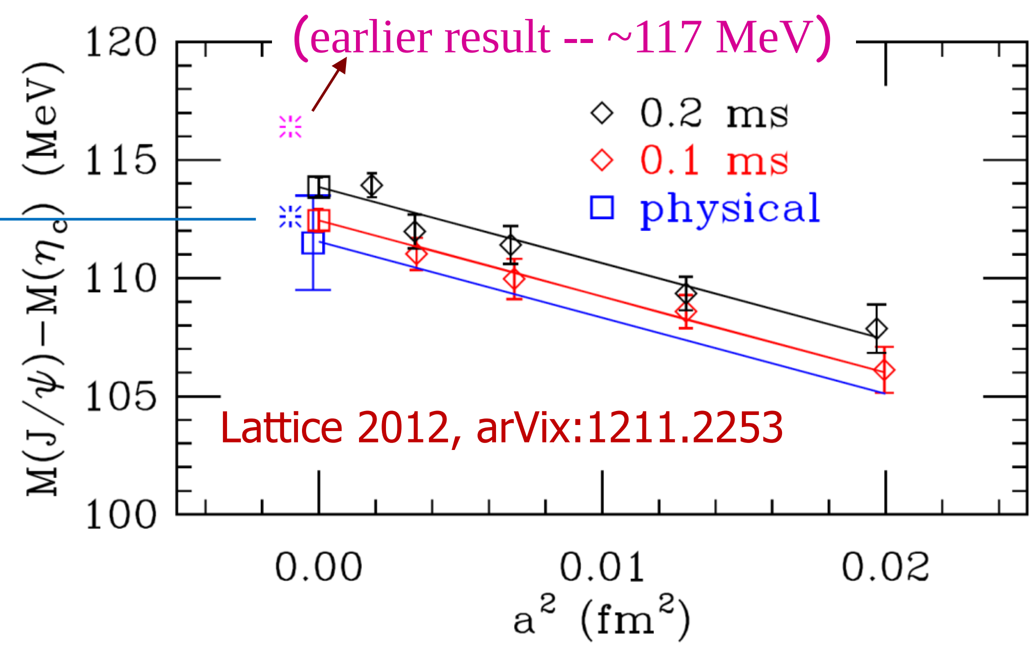




Hyperfine splitting (BESIII alone)

$\Delta M(1S)$ = 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 $\psi' \to \gamma\eta_c'$

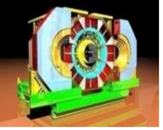
1. CLEO found no signal in 25M ψ'.

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

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

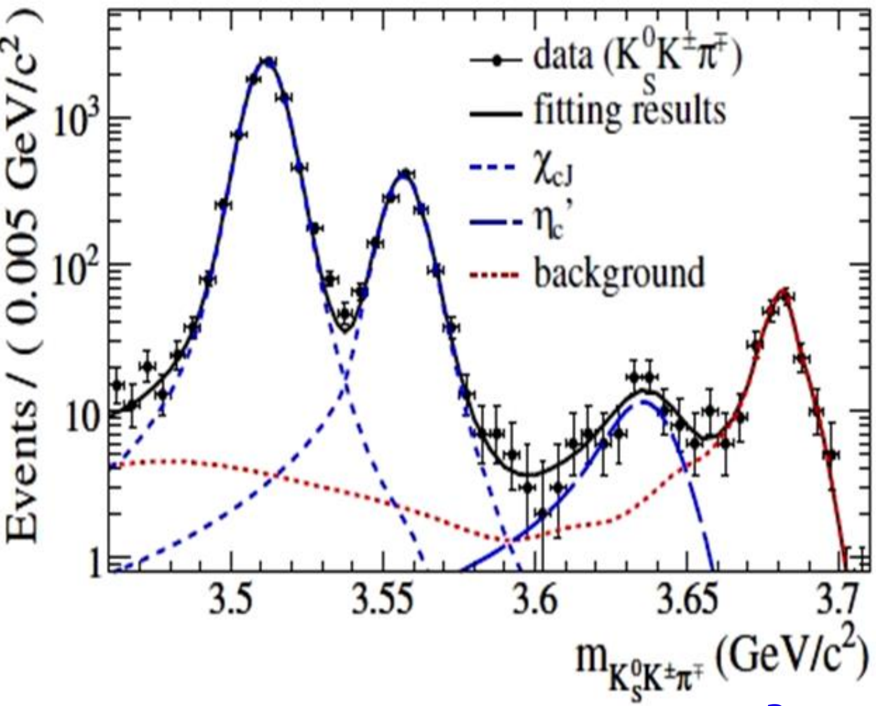
   find evidence in $\eta_c' \to K_sK3\pi$

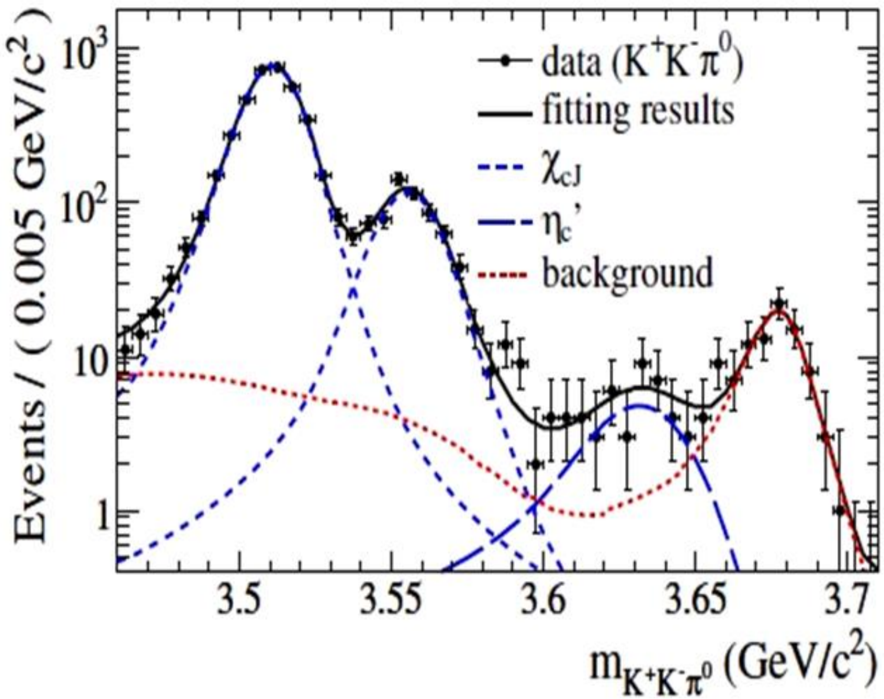
Experimental challenge : search for photons of 50 MeV



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

PRL 109, 042003





M = 3637.6±2.9±1.6 MeV/c^2 **Γ = 16.9±6.4±4.8 MeV/c^2**

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

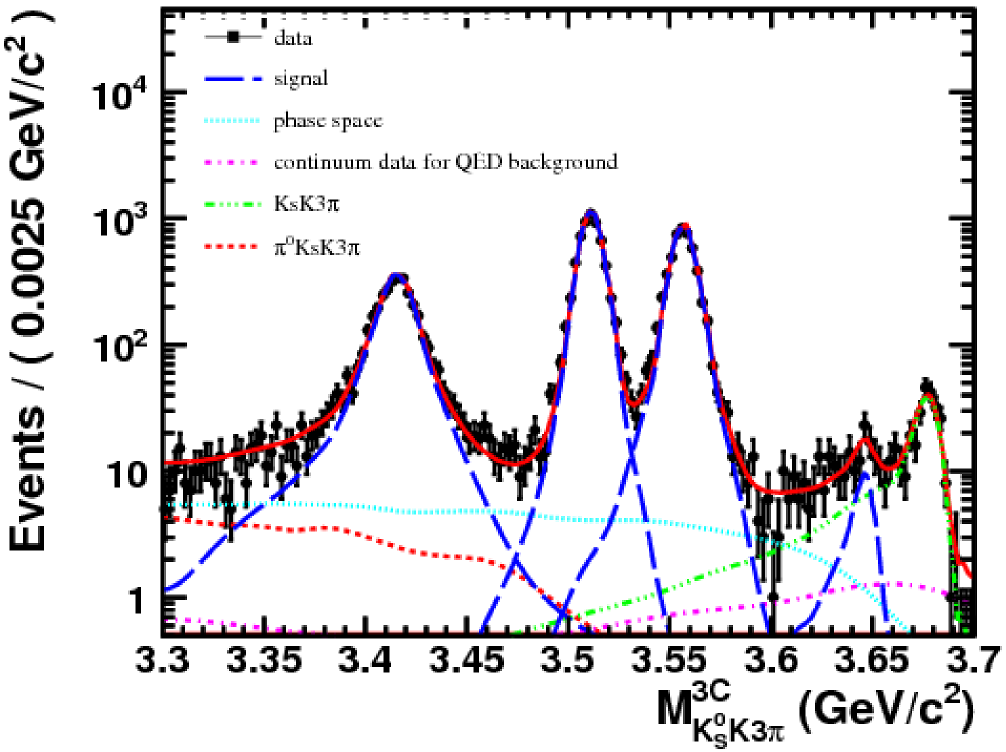
$\mathcal{B}(\eta_c' \to \gamma KK\pi)$=(1.9±0.4±1.1)% **BABAR: PRD78, 012006 (2008)**

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

Potential model:	(0.1-6.2)×10^{-4}	PRL89, 162002(2002)
CLEOc:	< 7.6×10^{-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

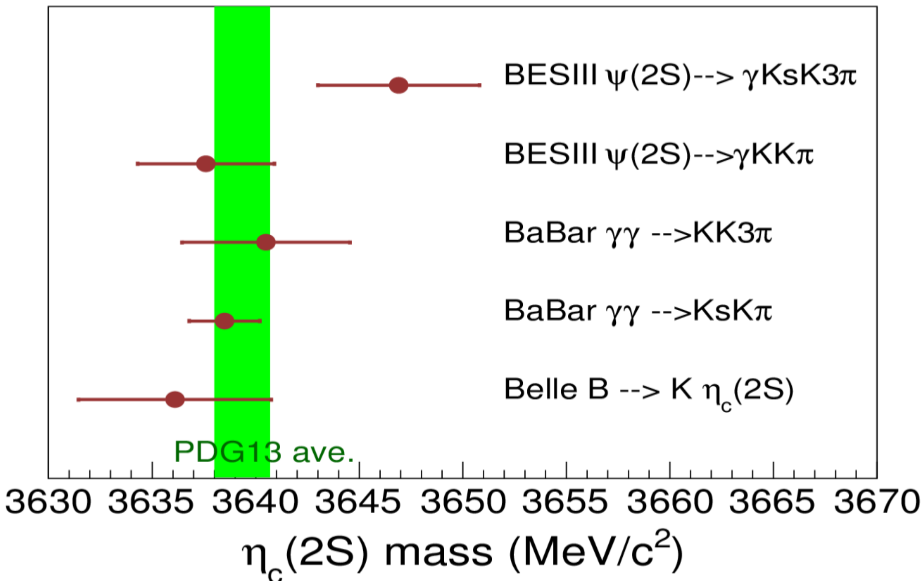
$$M = 3646.9 \pm 1.6 \pm 3.6 \ \mathrm{MeV}/c^2$$

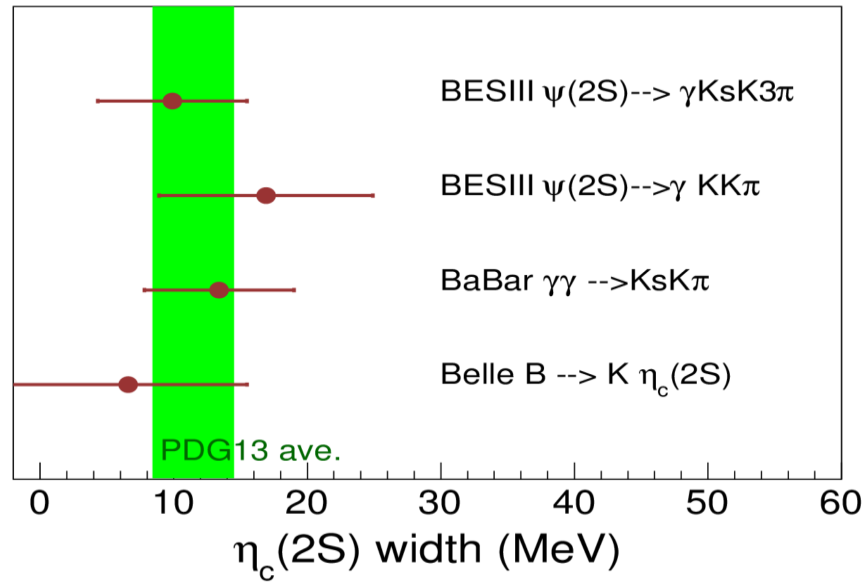
$$\Gamma = 9.2 \pm 4.8 \pm 2.9 \ \mathrm{MeV}/c^2$$

$$\mathcal{B}(\psi' \to \gamma\eta_c' \to \gamma K_sK3\pi) = (7.03 \pm 2.10 \pm 0.70) \times 10^{-6}$$

$\eta_c(2S)$: 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, $\Delta M_{hf}(1P) = M(h_c) - \langle M(1\,{}^3P_J)\rangle \neq 0$,

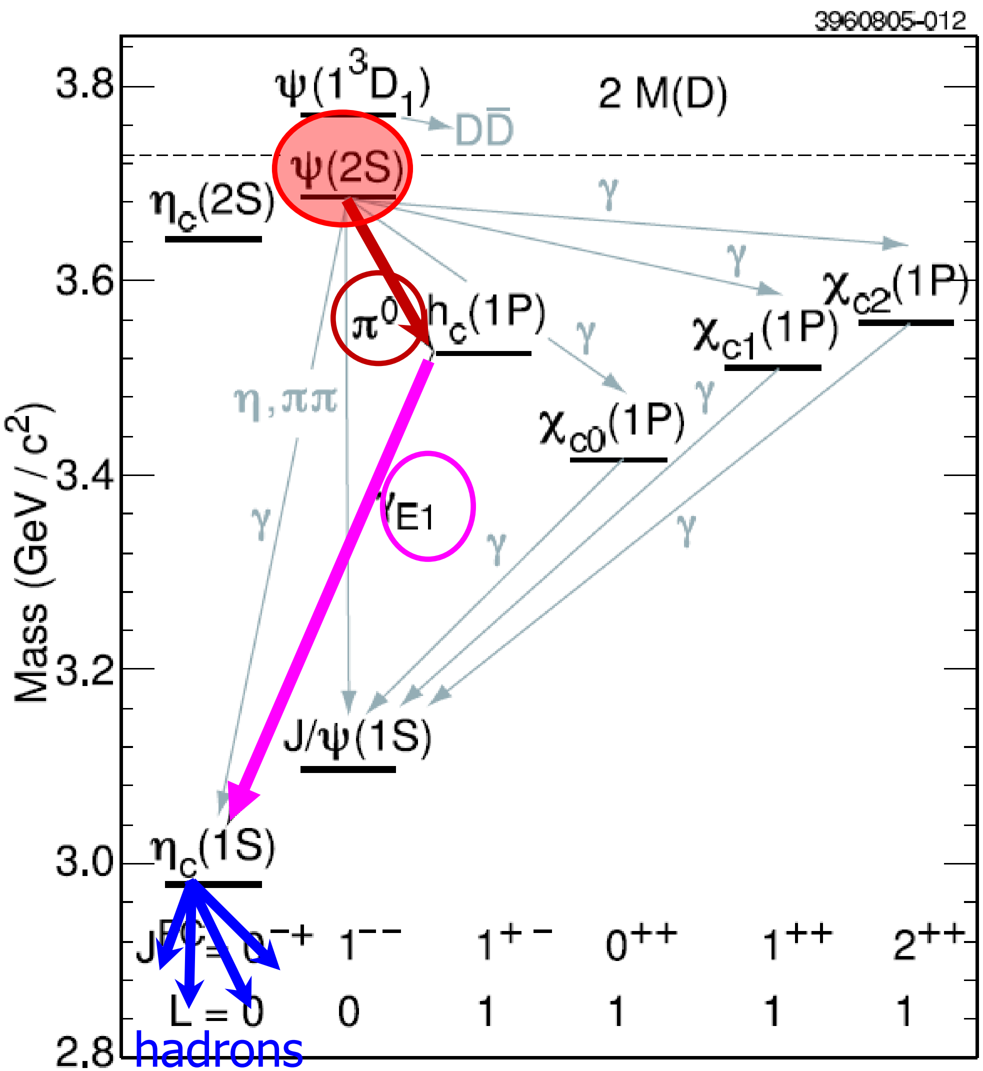
$$\langle M(1\,{}^3P_J)\rangle = [M(\chi_{c0}) + 3M(\chi_{c1}) + 5M(\chi_{c2})]/9$$

- **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"

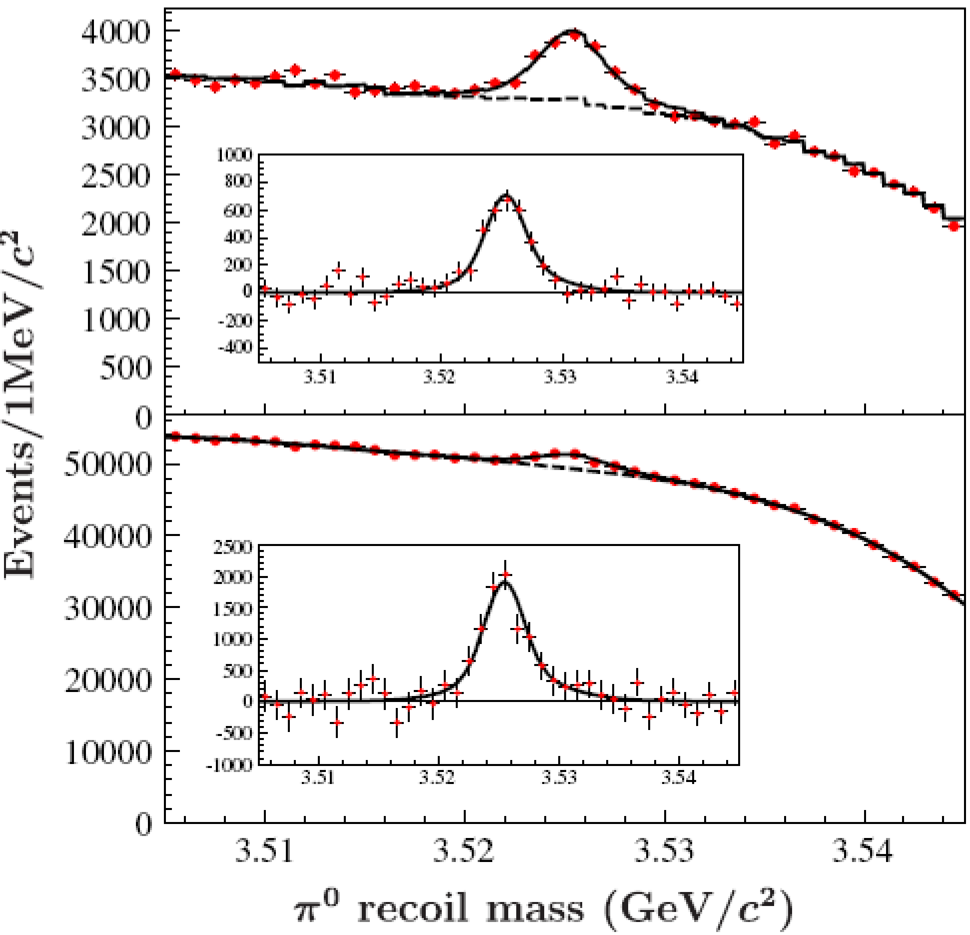
detect the π^0, γ & $\eta_c \to X_i$ decay prod.

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) - <m(1^3P_J)>

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

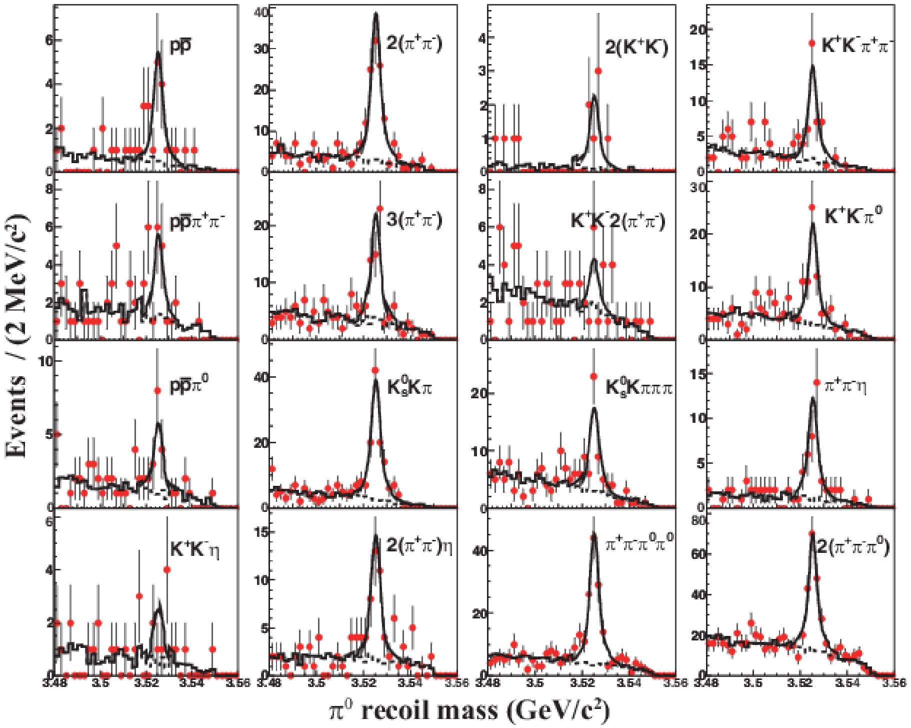
$\mathcal{B}(\psi' \to \pi^0 h_c)$ = **(8.4 ± 1.3 ± 1.0) × 10^{-4}**

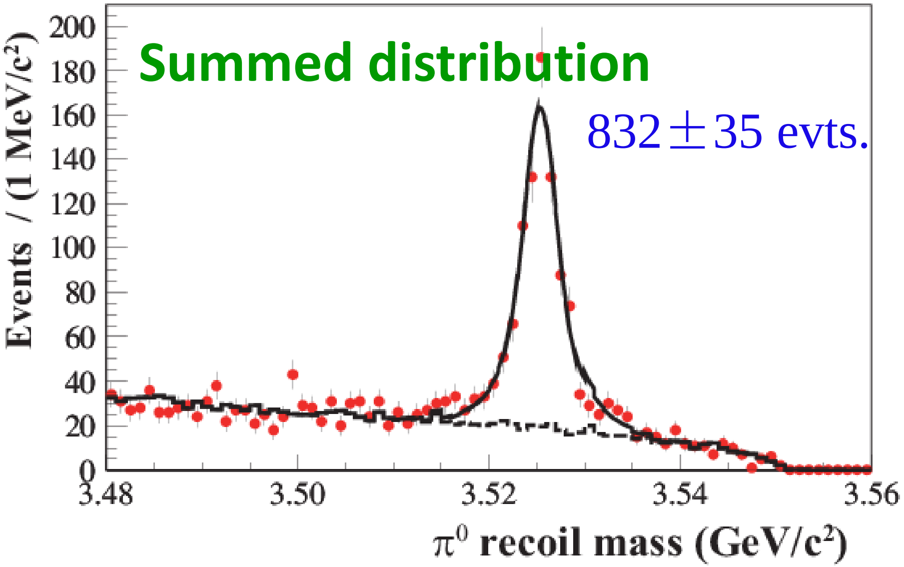
$\mathcal{B}(h_c \to \gamma \eta_c)$ = **(54.3 ± 6.7 ± 5.2)%**

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

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

PRD 86, 092009



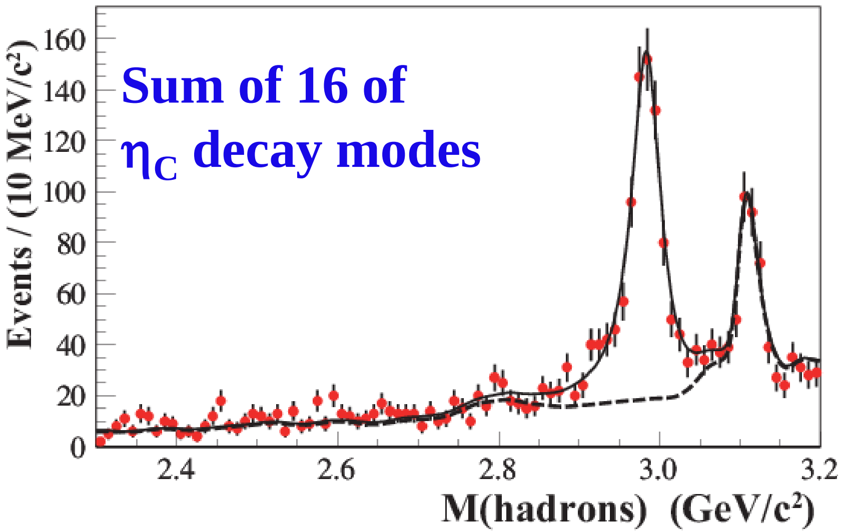


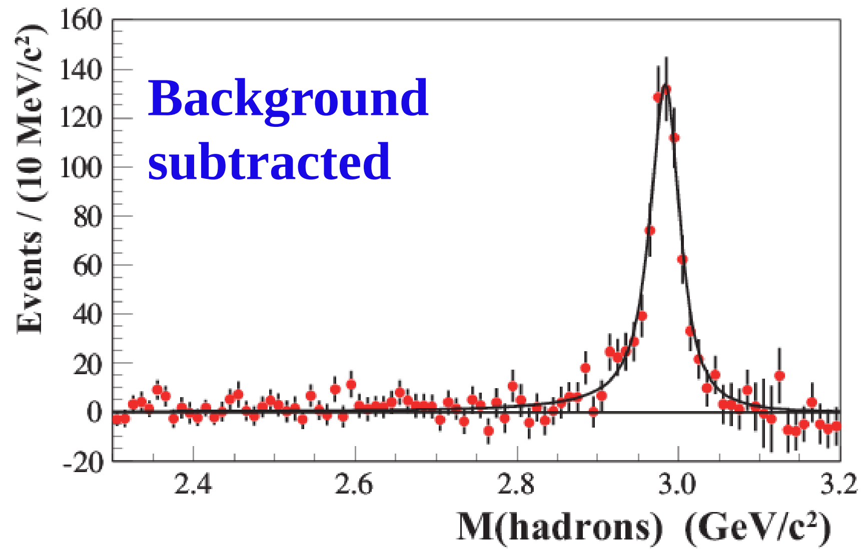
(MeV/c^2)	BESIII Exclusive	BESIII Inclusive	CLEO
M	3525.31±0.11±0.14	3525.40±0.13±0.18	3525.21±0.27±0.14
Γ	0.70±0.28±0.22	0.73±0.45±0.28	--
$\Delta M_{hf}(1P)$	-0.01±0.11± 0.15	0.10±0.13±0.18	0.08± 0.18± 0.12

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

$\psi' \to \gamma\eta_c$

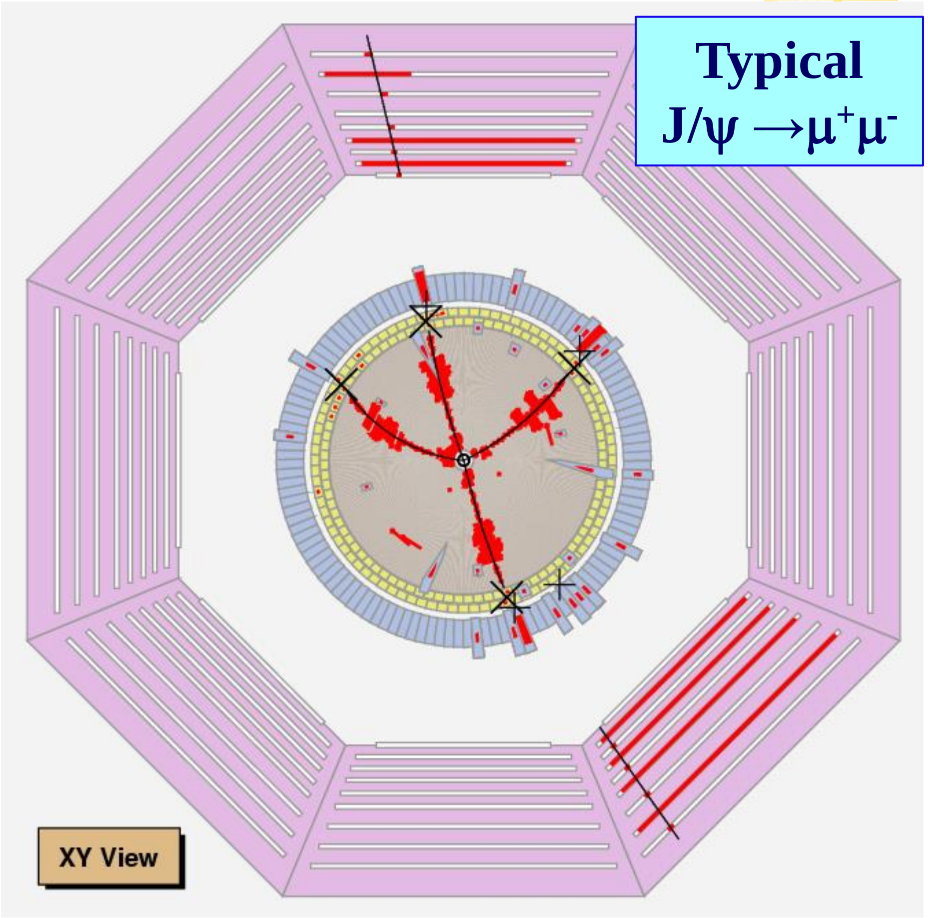
PRL 108, 222002

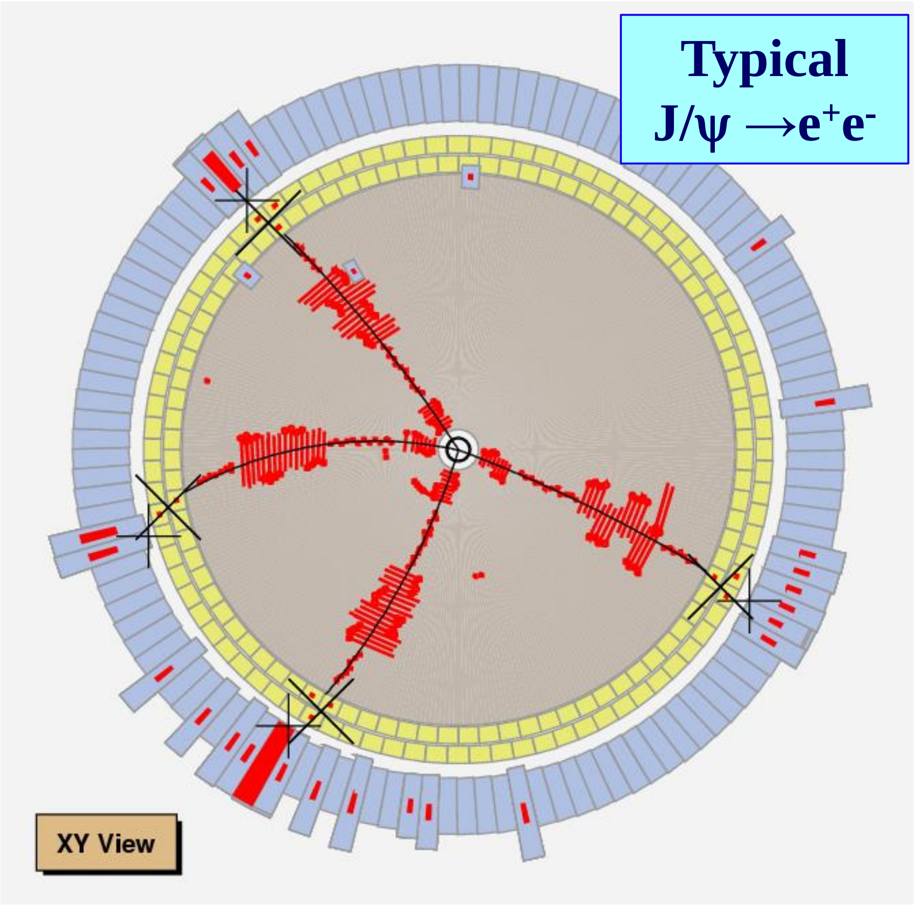
M = 2984.3±0.6±0.6 MeV/c²

Γ = 32.0±1.2±1.0 MeV

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

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

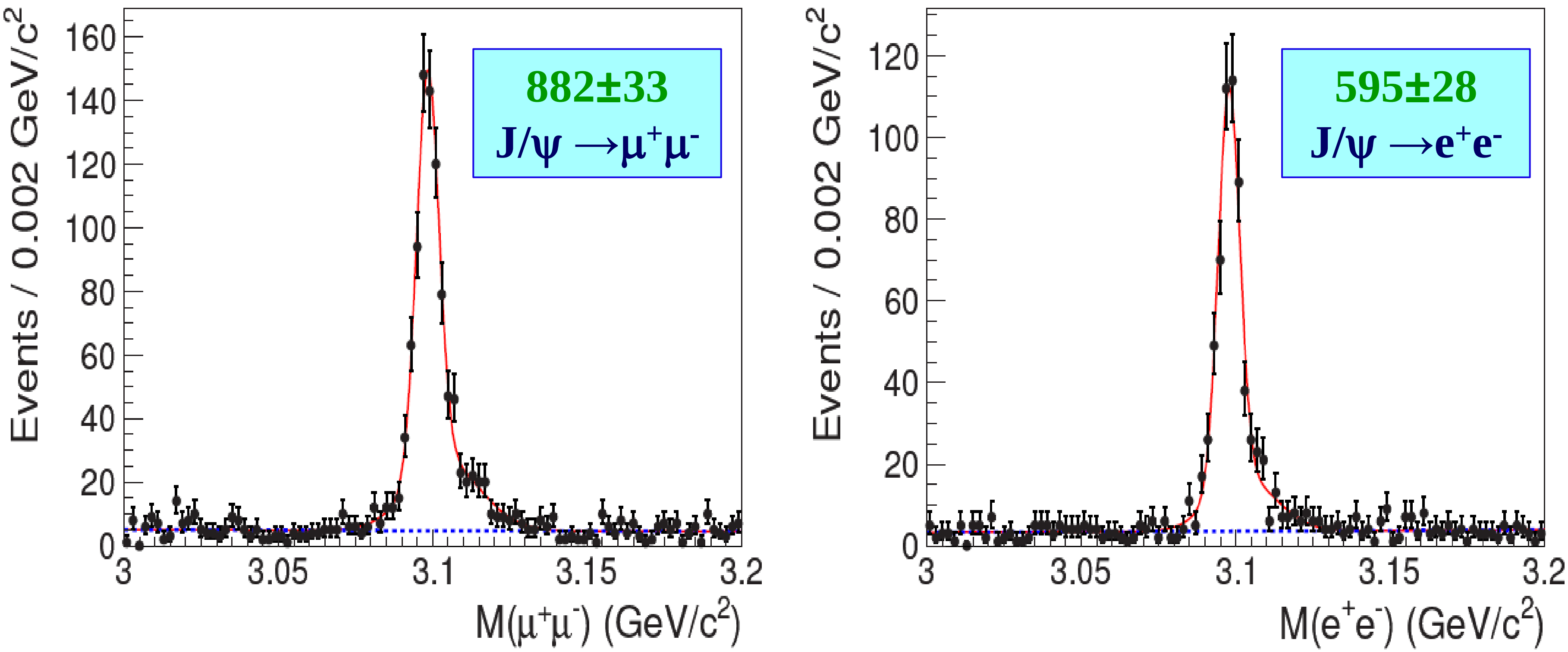




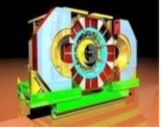
- 4 charged tracks, J/ψ reconstruct via lepton pairs
- very clean sample, very high efficiency, kinematic fit used
- only use MDC & EMC information, MC simulation reliable

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

PRL 110, 252001



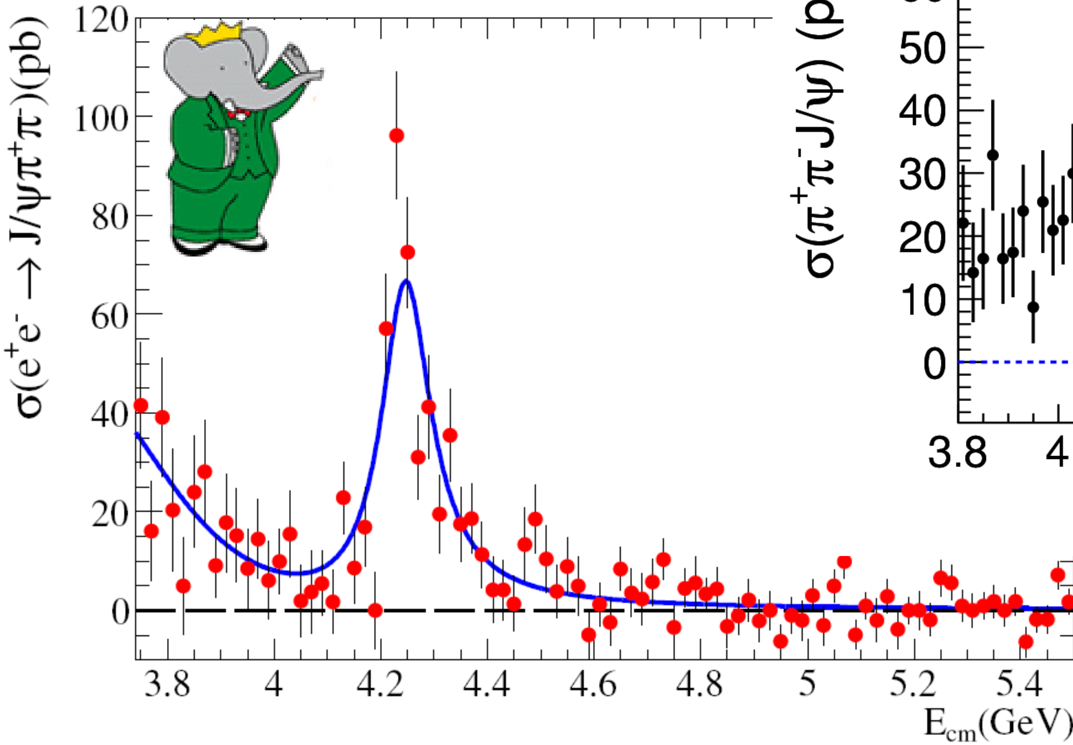
- Dominant background $e^+e^- \to \pi^+\pi^-\pi^+\pi^-$
- J/ψ signal: [3.08,3.12] GeV
- J/ψ sideband: [3.0,3.06] GeV or [3.14,3.20] GeV

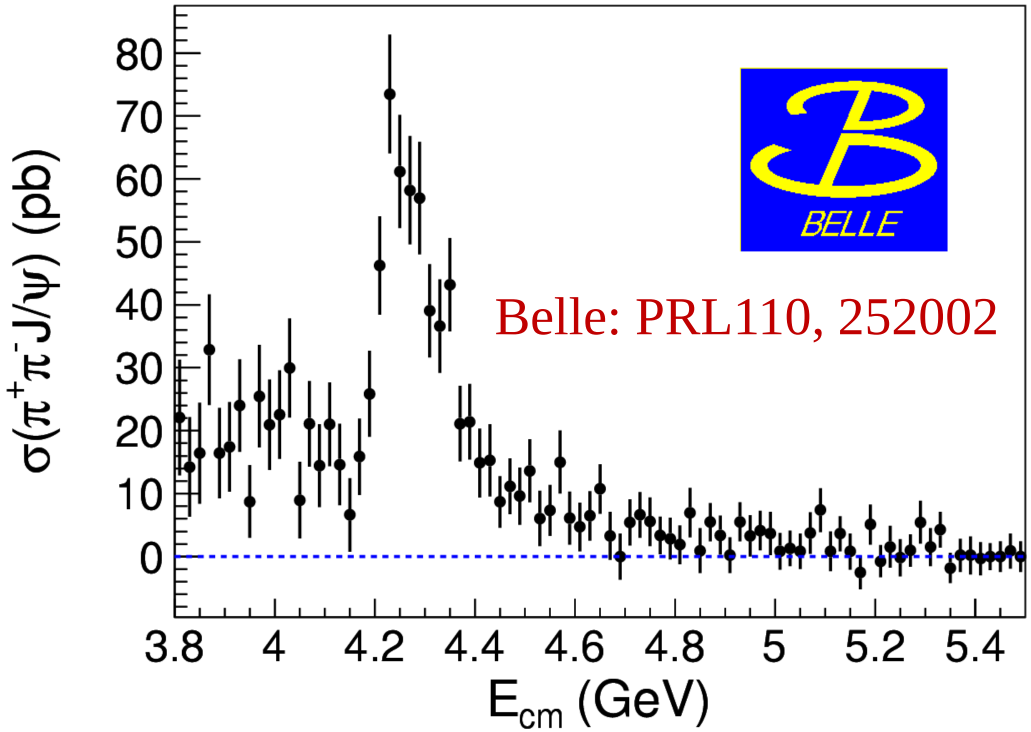


$e^+e^- \to \pi^+\pi^- J/\psi$ – cross sections @ 4.260 GeV

PRL 110, 252001

BaBar: PRD86, 051102 (2012)

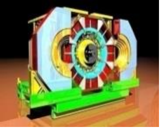




Belle: PRL110, 252002

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

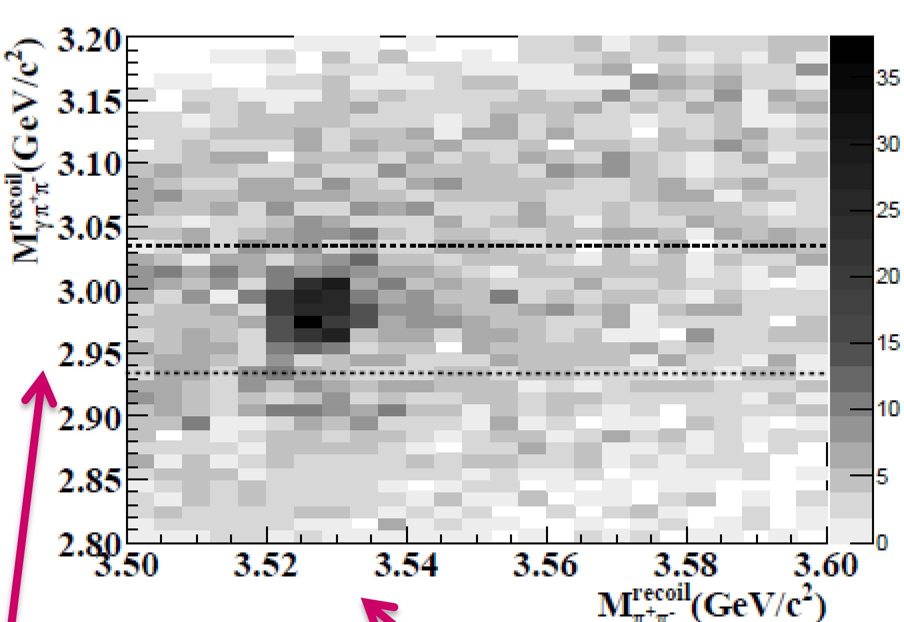
BESIII: $\sigma_B(e^+e^- \to \pi^+\pi^- J/\psi)$ = **(62.9±1.9±3.7) pb**
- agreement with BaBar & Belle
- best precision!

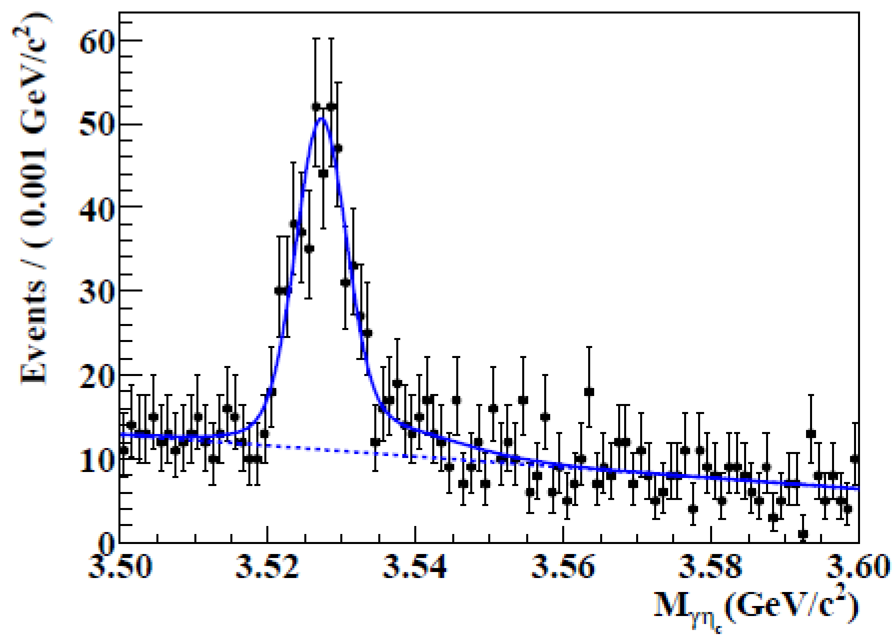


BESIII: $e^+e^- \to \pi^+\pi^- h_c(1P)$ @ 4.260 GeV

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., $K^+K^-\pi^0$
  - $p\bar{p}\pi^0$, $K^+K^-\eta$, $\pi^+\pi^-\eta$, $\pi^+\pi^-\pi^0\pi^0$, $2(\pi^+\pi^-)\eta$, $2(\pi^+\pi^-\pi^0)$



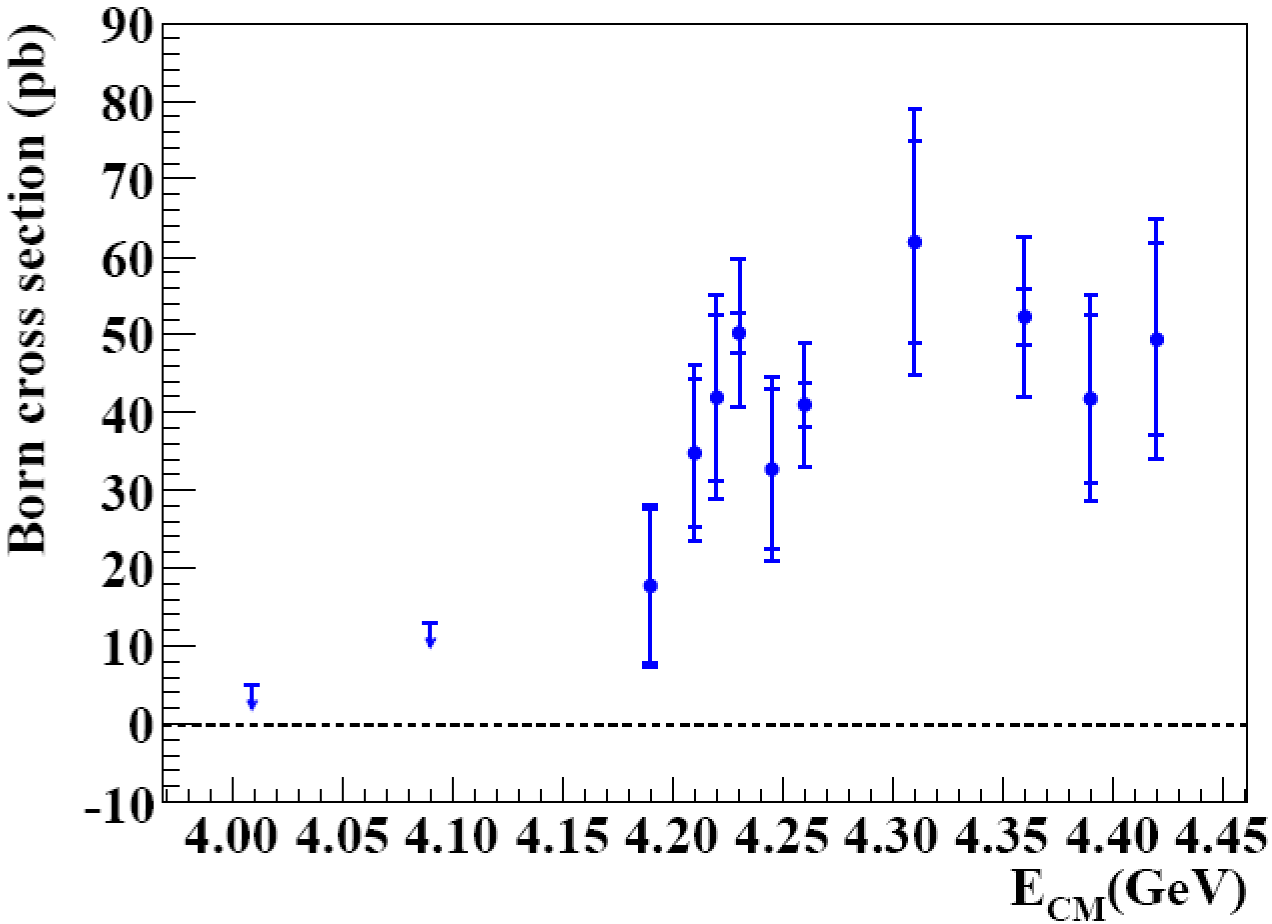


η_c candidate

h_c candidate

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

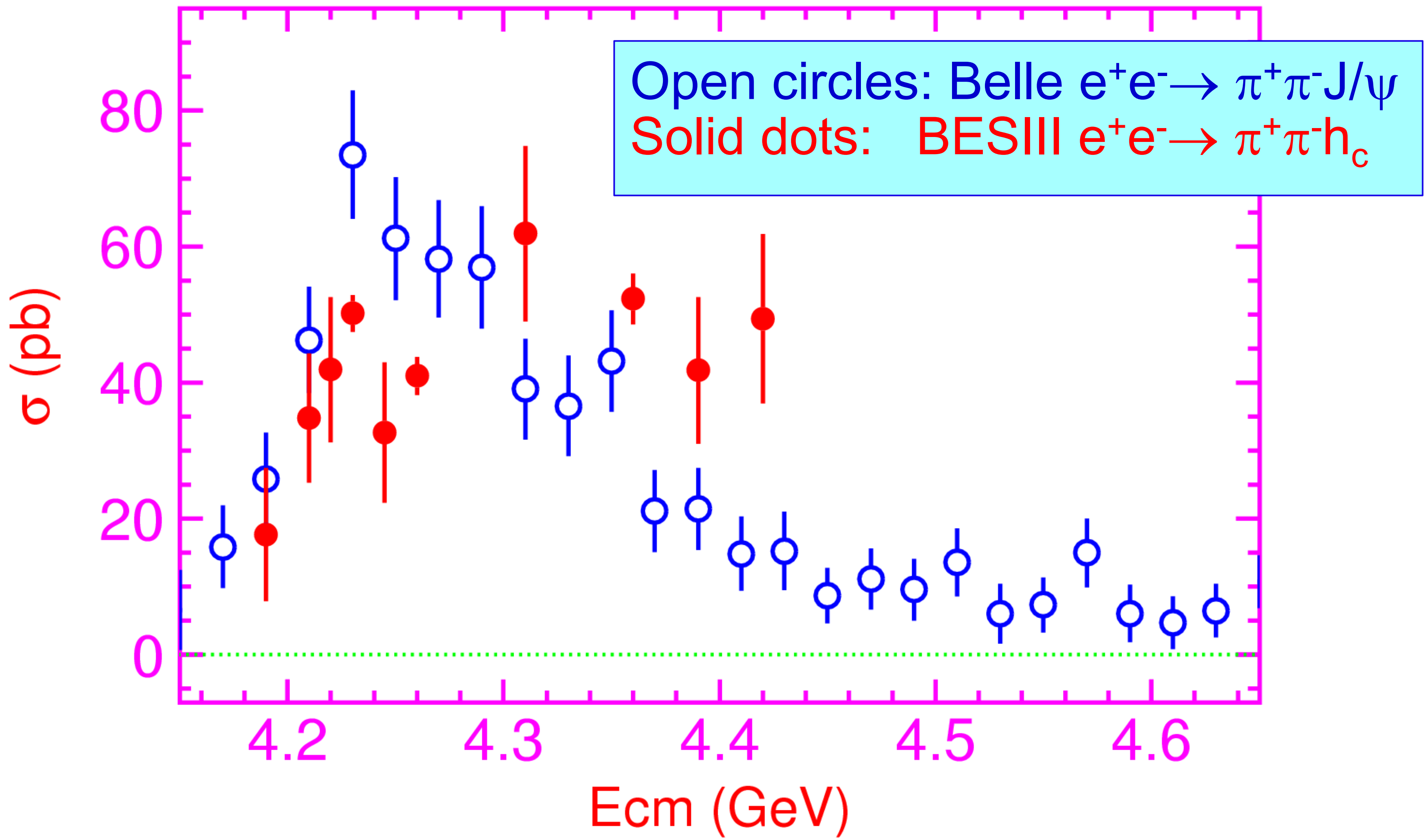
PRL 111, 242001



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

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

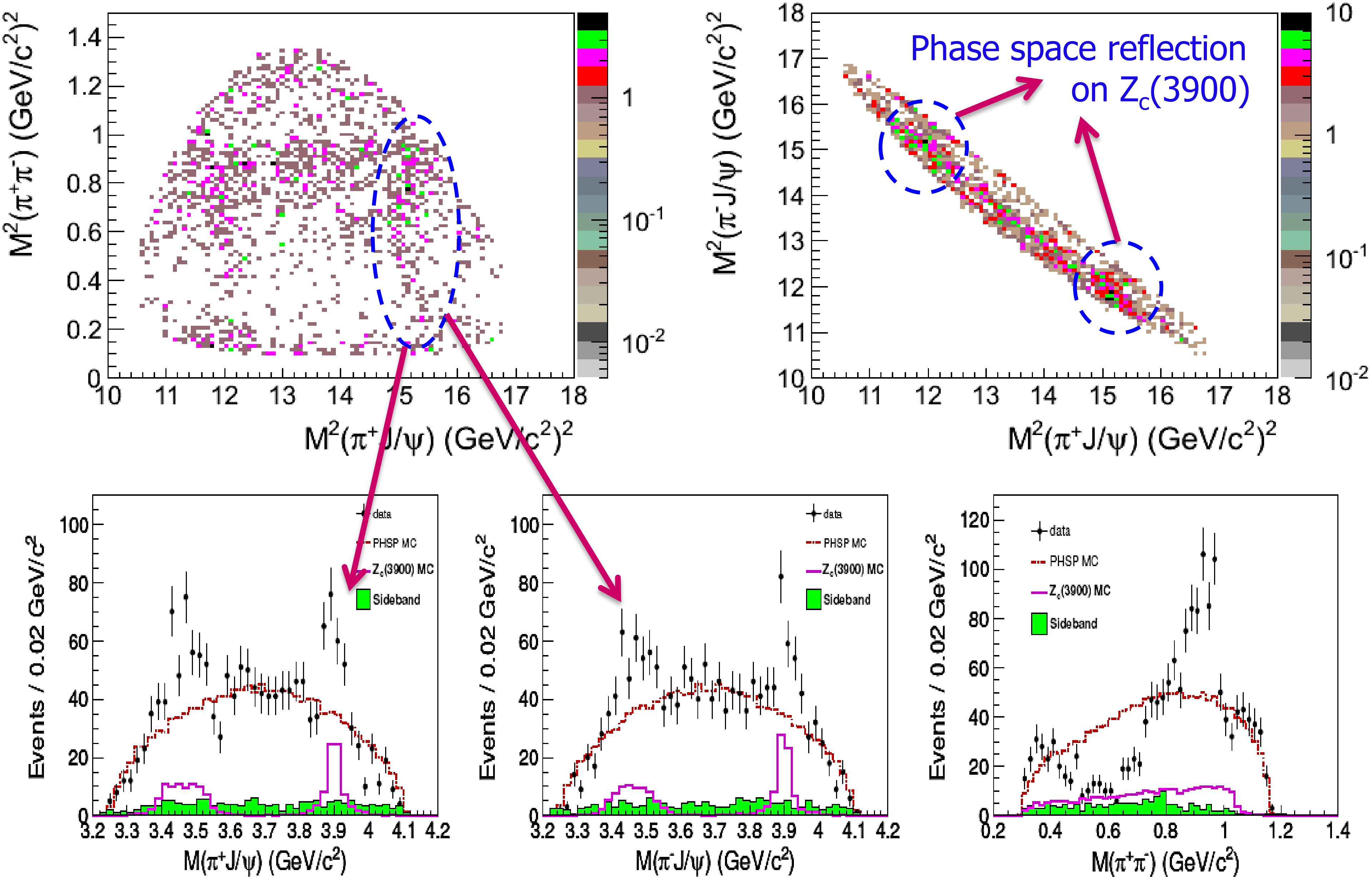
PRL 111, 242001



More data at higher energies needed to complete line shape measurement

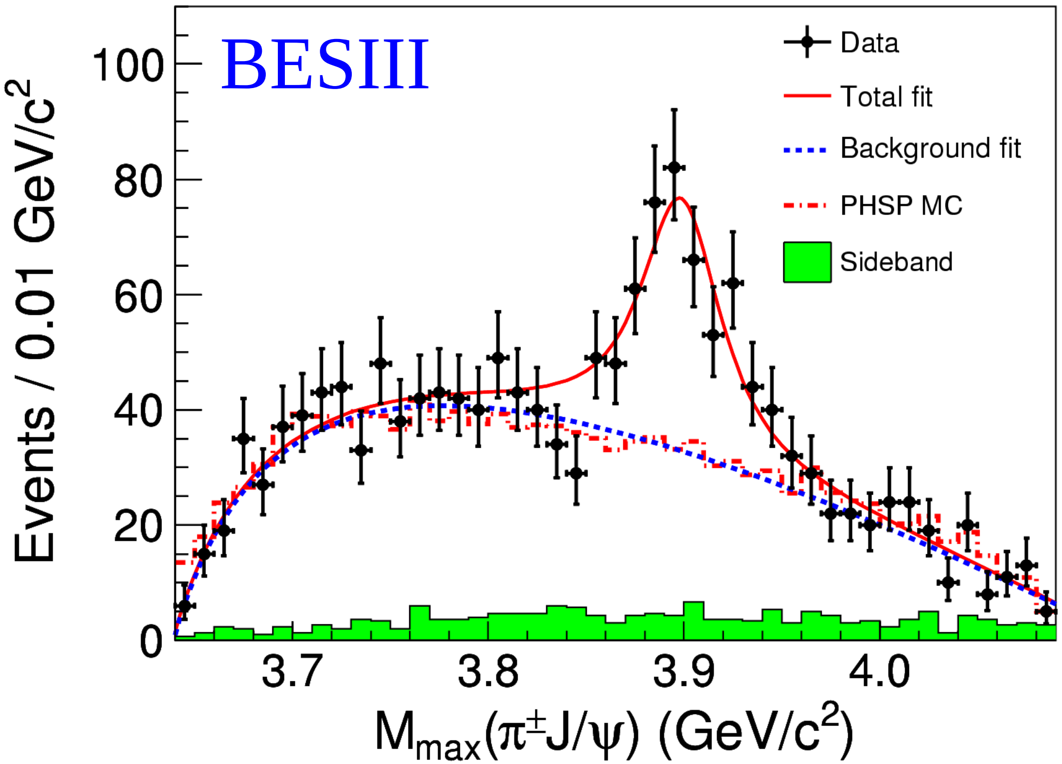
BESIII: $e^+e^- \to \pi^+\pi^- J/\psi$ @ 4.260 GeV

PRL 110, 252001

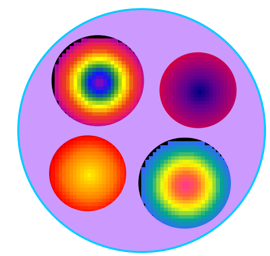


BESIII: $e^+e^- \to \pi\, Z_c(3900) \to \pi^+\pi^- J/\psi$ @ 4.260 GeV

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

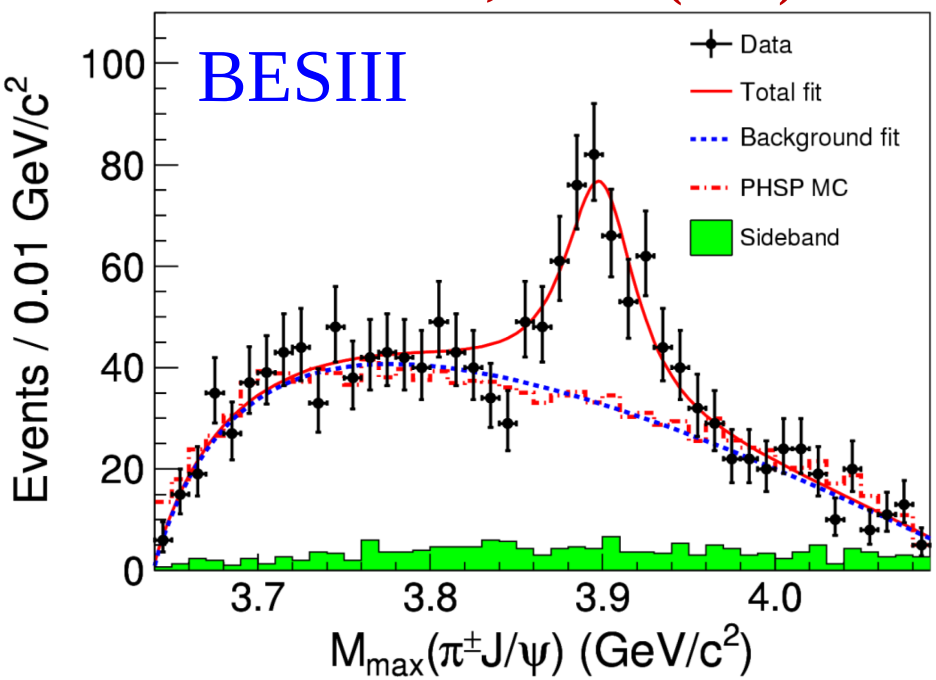
Γ = (46±10±20) MeV/c^2

R = (21.5±3.3±7.5)%

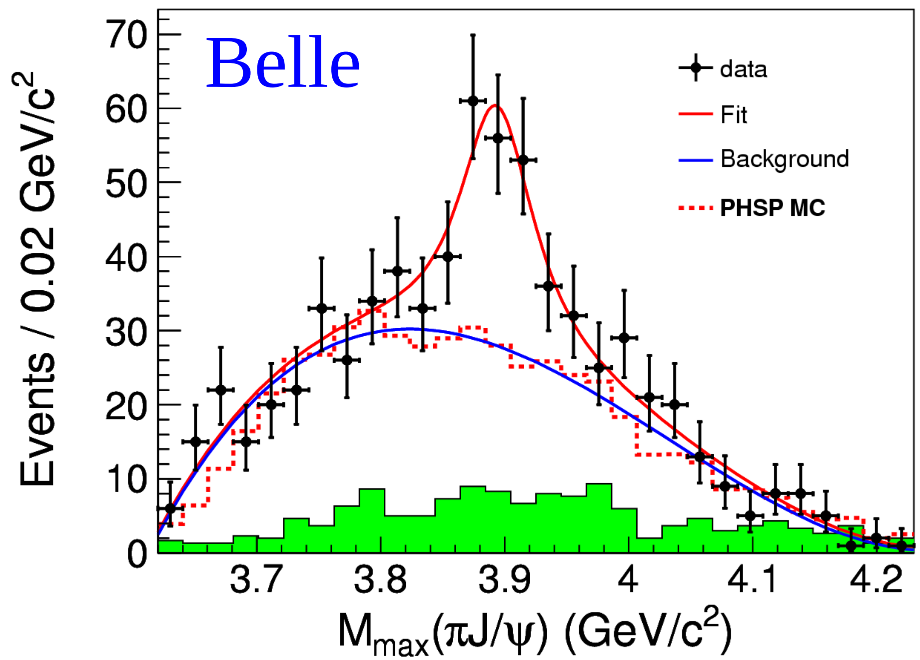
Significance >8σ

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

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

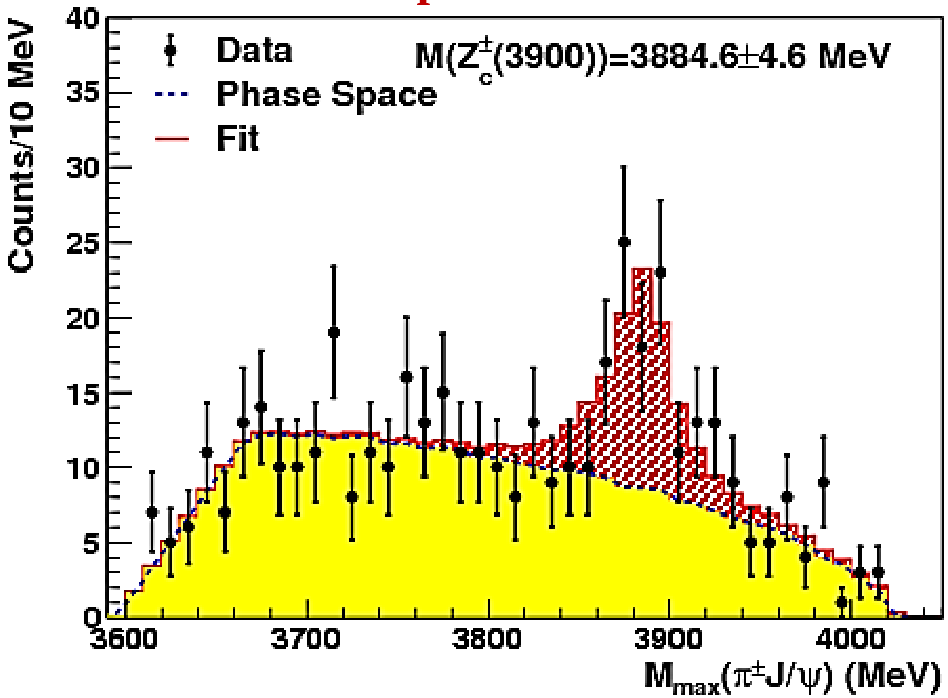
M = (3894.5±6.6±4.5) MeV/c²
Γ = (63±24±26) MeV/c²
159±49 events
>5.2σ

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

PRL 110, 252001

K. Seth & co. @ 4.170 GeV

hep-ex:1304.3036

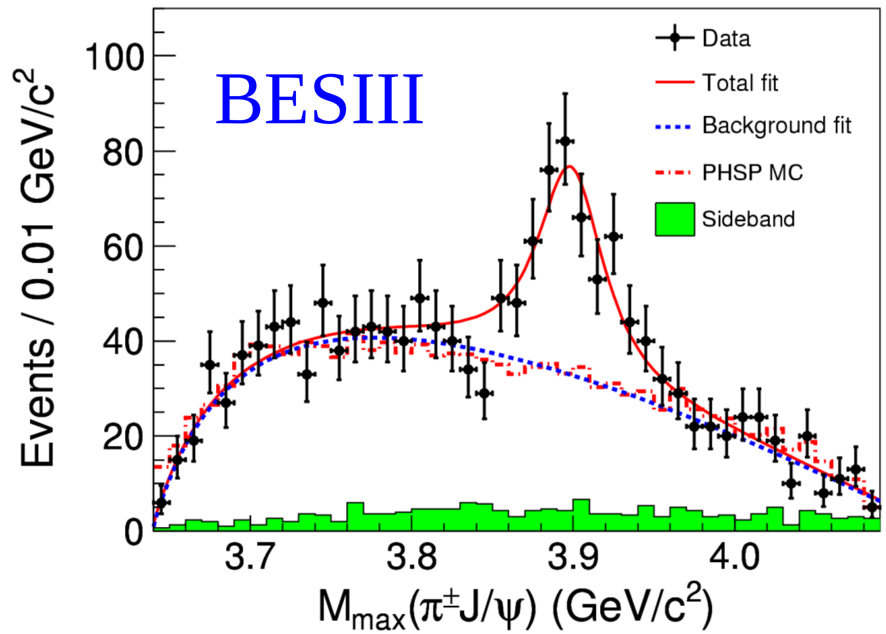


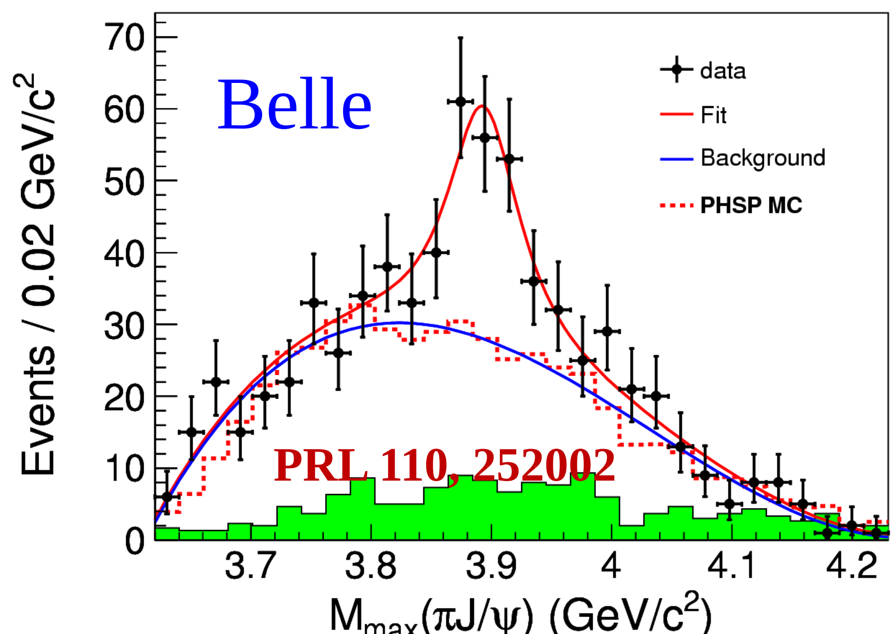
M = (3885±5±1) MeV/c²

Γ = (34±12±4) MeV/c²

81±20 events

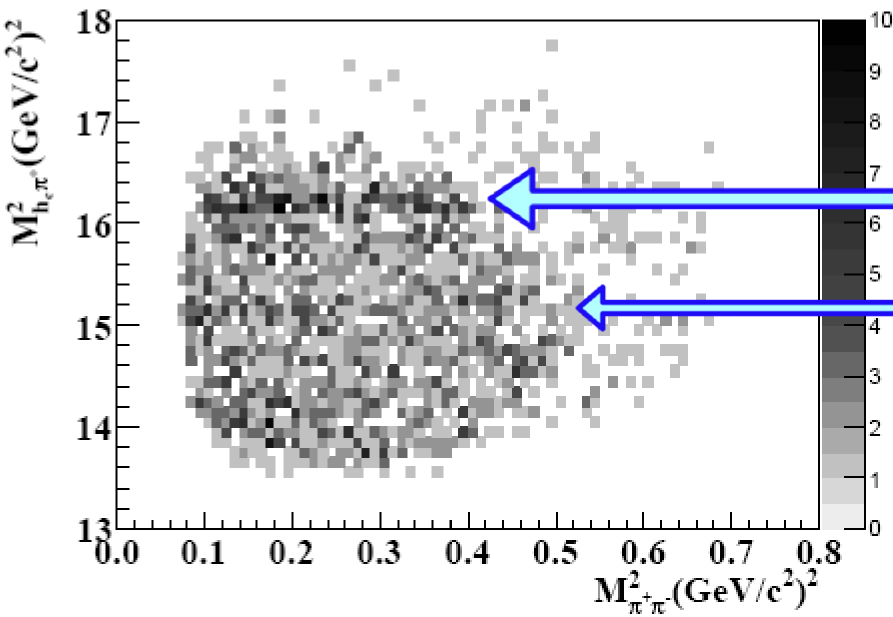
6.1σ

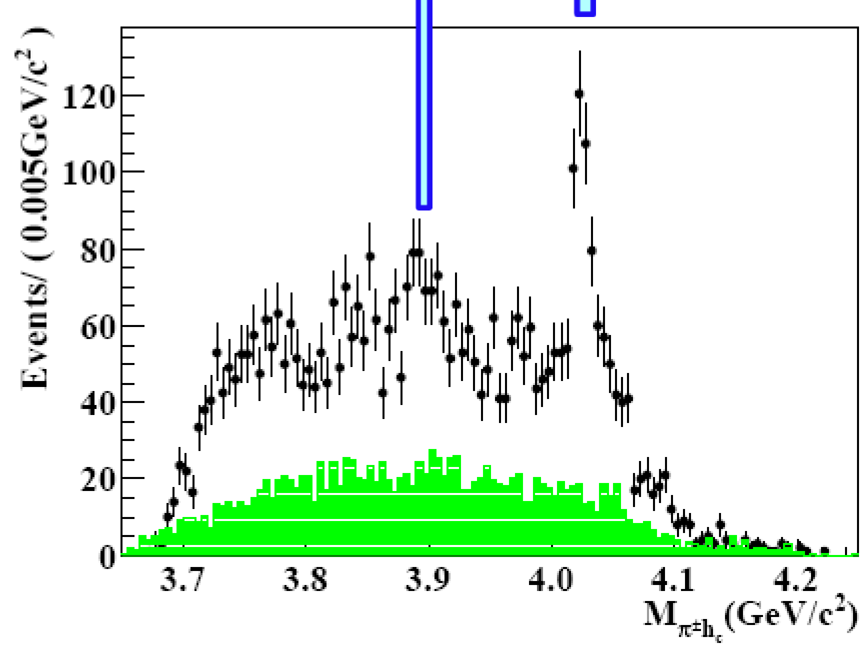




$e^+e^- \to \pi Z_c(4020) \to \pi^+\pi^- h_c(1P)$ – all energies

PRL 111, 242001





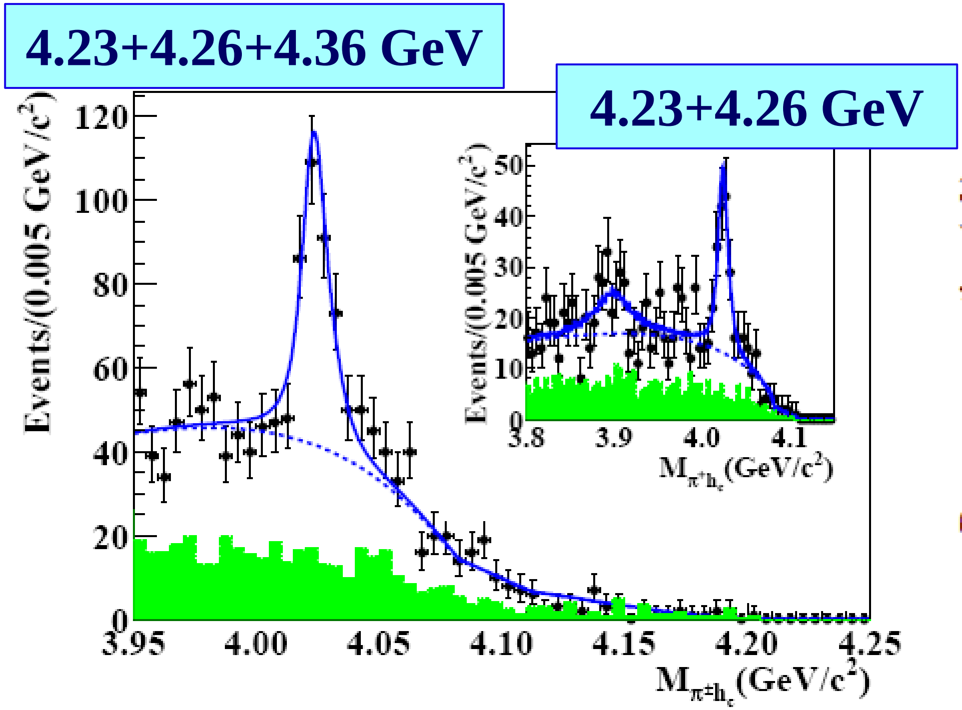
- **all collected energies**
  [3.900 ÷ 4.420 GeV]

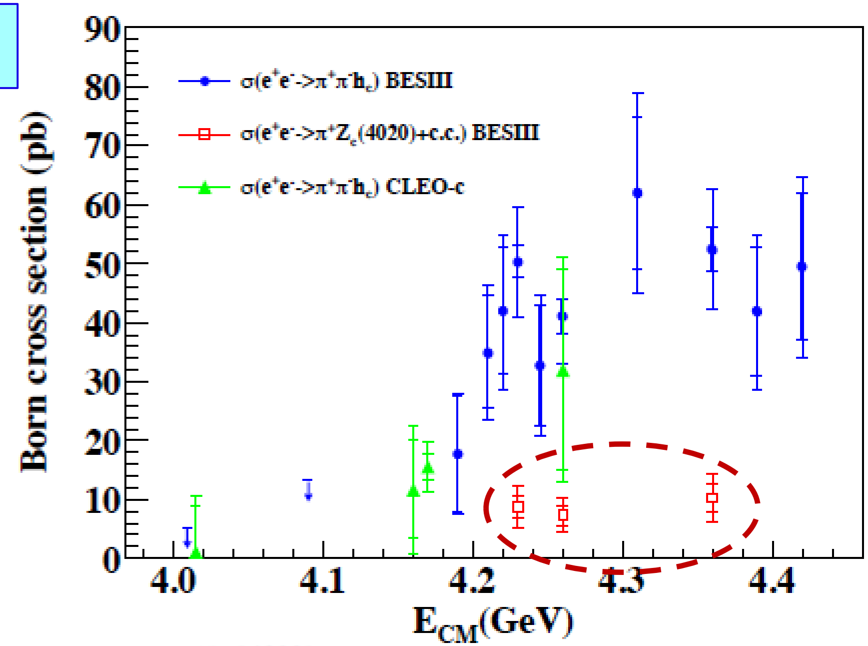
- **$h_c \to \gamma\eta_c$, $\eta_c \to$ hadrons**
  [16 exclusive decay modes]

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





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

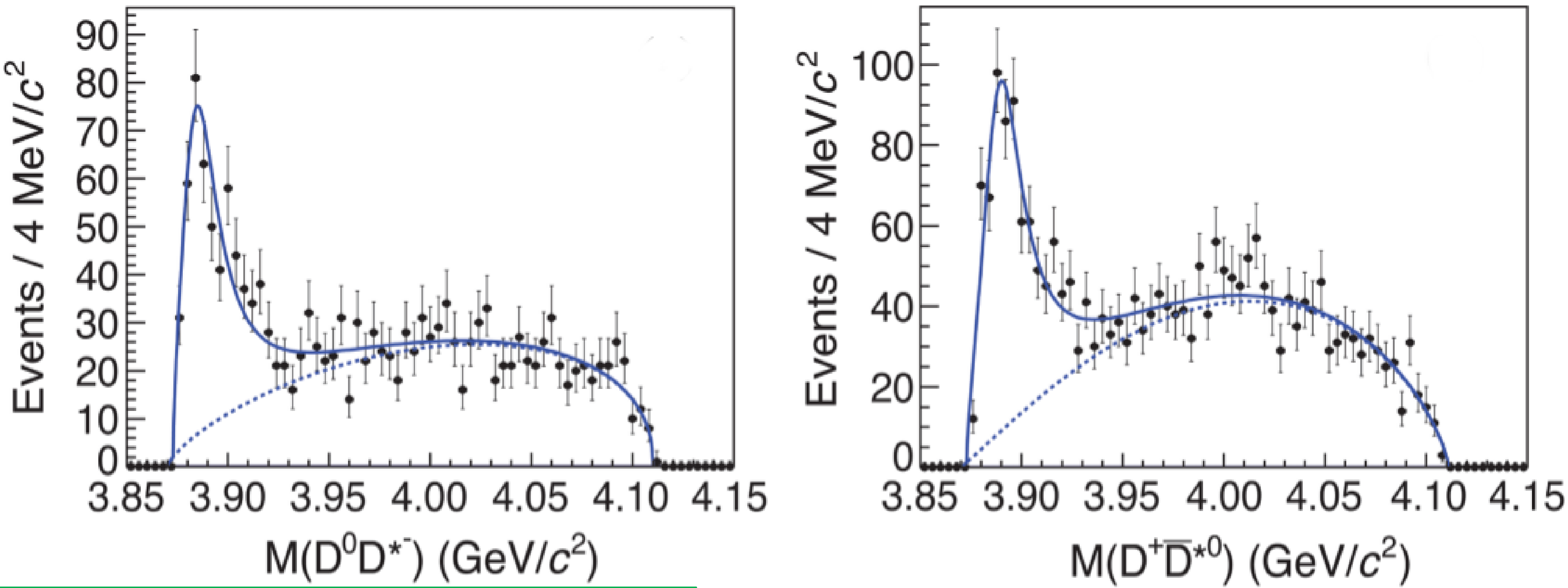
$M = (4022.9 \pm 0.8 \pm 2.7)$ MeV/c^2
$\Gamma = (7.9 \pm 2.7 \pm 2.6)$ MeV/c^2
$>8.9\sigma$

$\sigma(4.23\text{ GeV}) = (8.7 \pm 1.9 \pm 2.8 \pm 1.4)$ pb
$\sigma(4.26\text{ GeV}) = (7.4 \pm 1.7 \pm 2.1 \pm 1.2)$ pb
$\sigma(4.36\text{ GeV}) = (10.3 \pm 2.3 \pm 3.1 \pm 1.6)$ pb

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

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

PRL 112, 022001



M = (3883.9±1.5±4.2) MeV/c^2

Γ = (24.8±3.3±11.0) MeV/c^2

>18σ

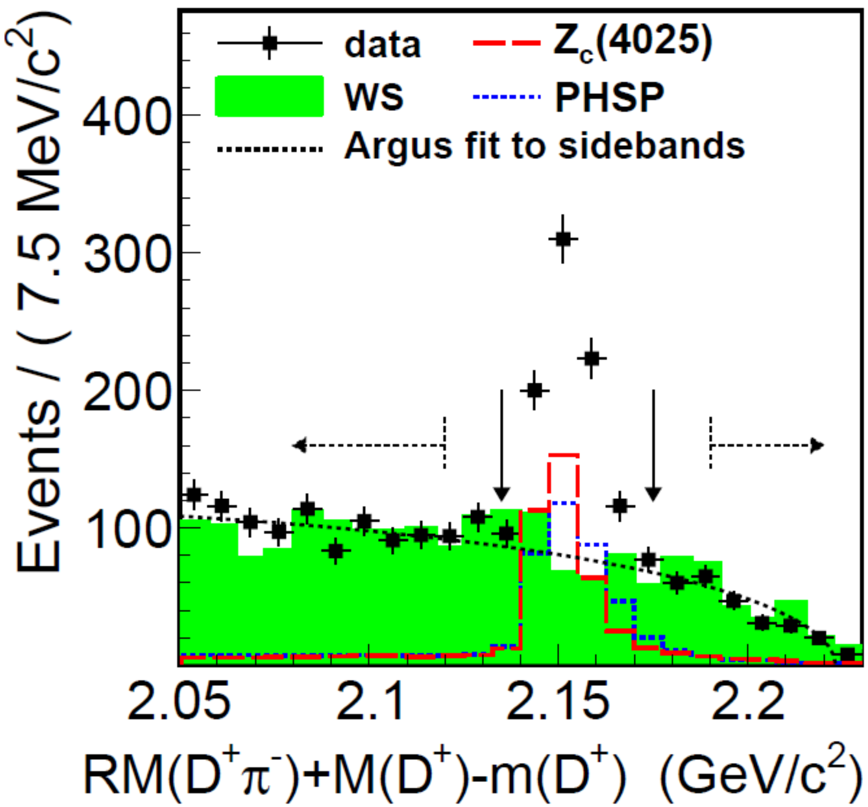
$\pi Z_c(3885)$ ang. dist. favours $J^P = 1^+$
disfavours 1^- e 0^-

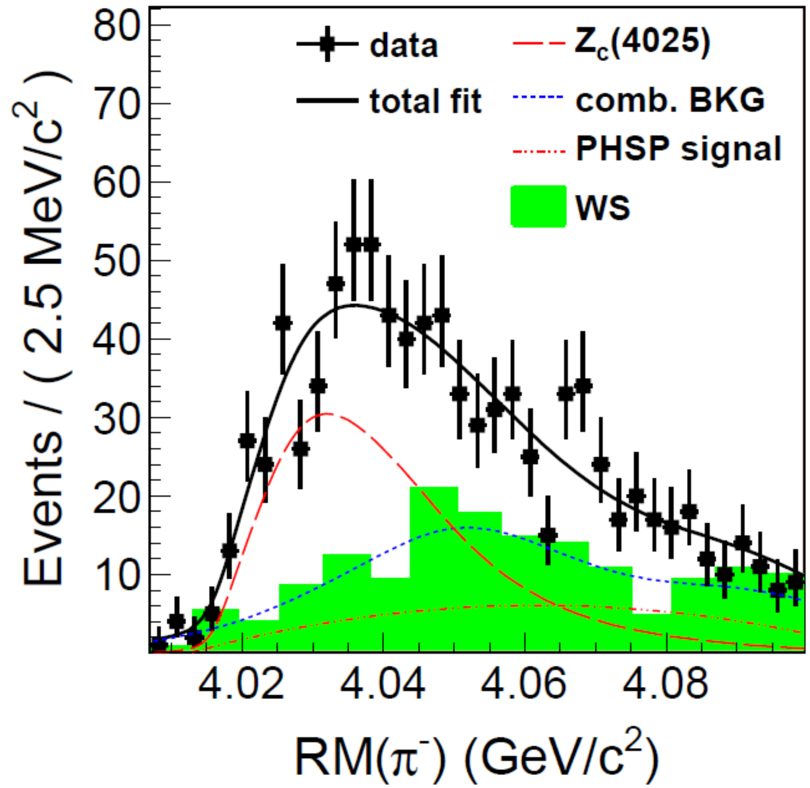
$$\sigma(e^+e^- \to \pi^- Z_c(3885)^+ \times Z_c(3885)^+ \to (D\bar{D}^*)^+ + c.c.) = (83.5 \pm 6.6 \pm 22.0)\ \text{pb}$$

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

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

hep-ex:1308.2760





M = (4026.3±2.6±3.7) MeV/c^2

Γ = (24.8±5.7±7.7) MeV/c^2

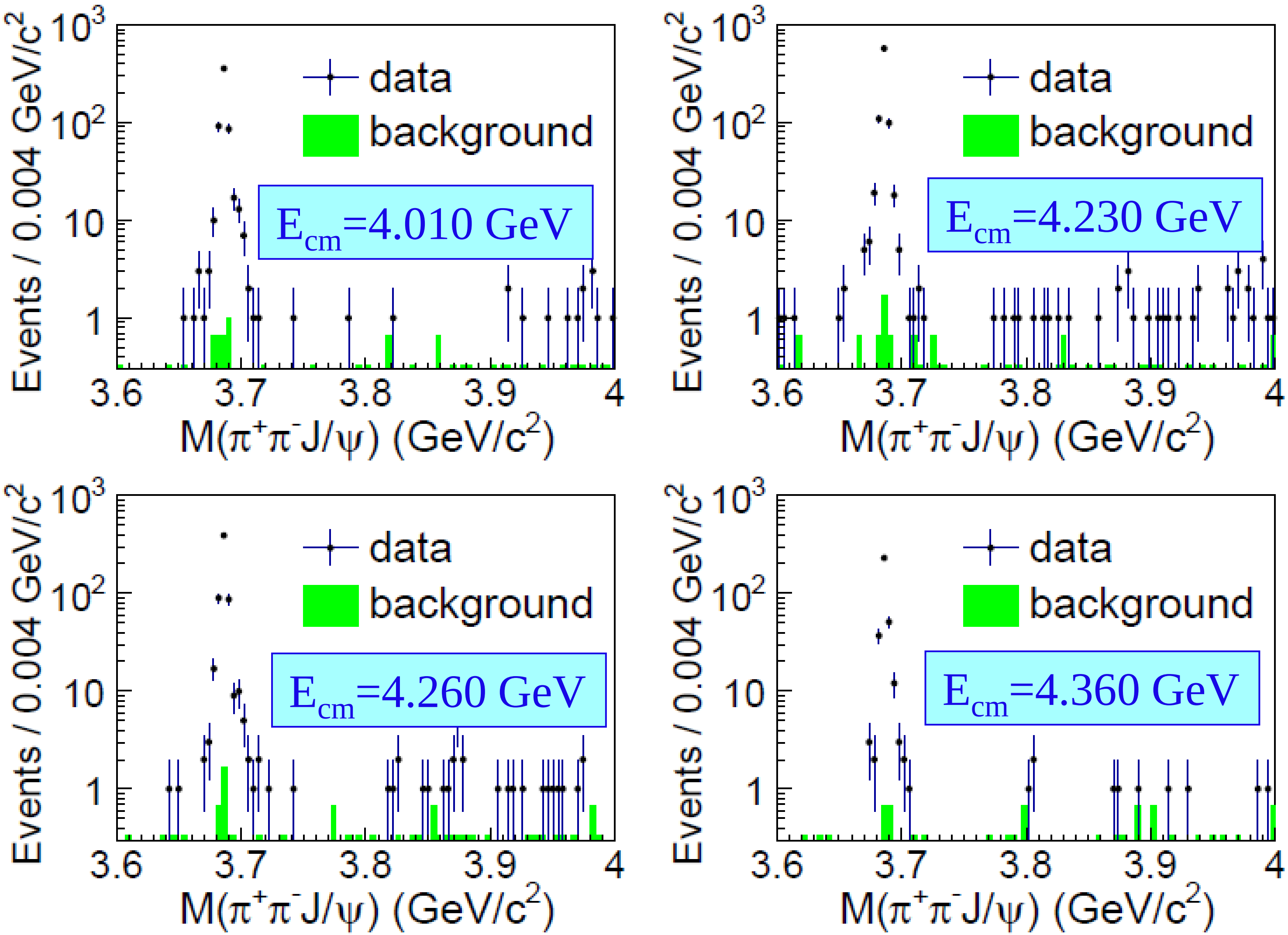
>10σ

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

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

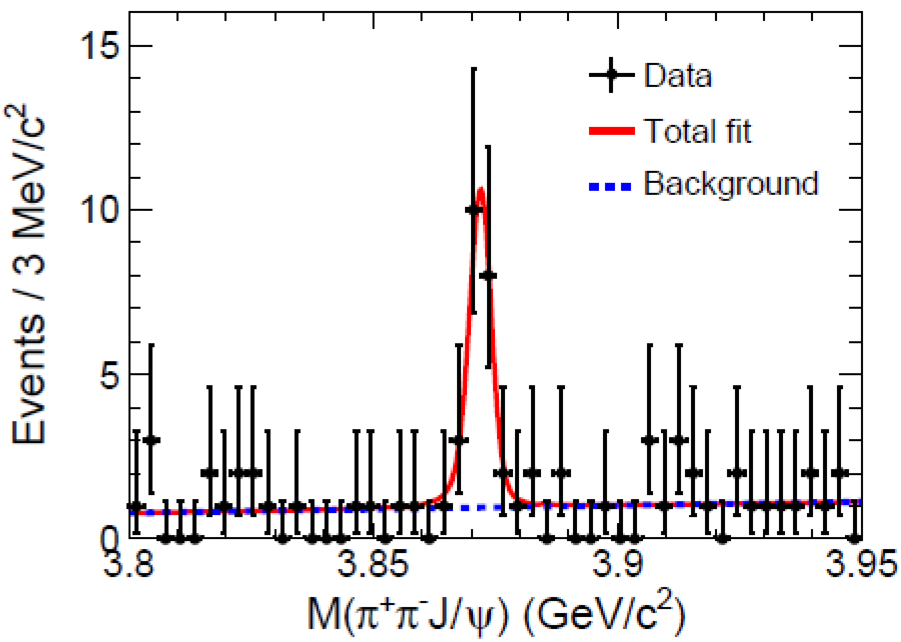
BESIII: $e^+e^- \to \gamma X(3872) \to \gamma\pi^+\pi^- J/\psi$

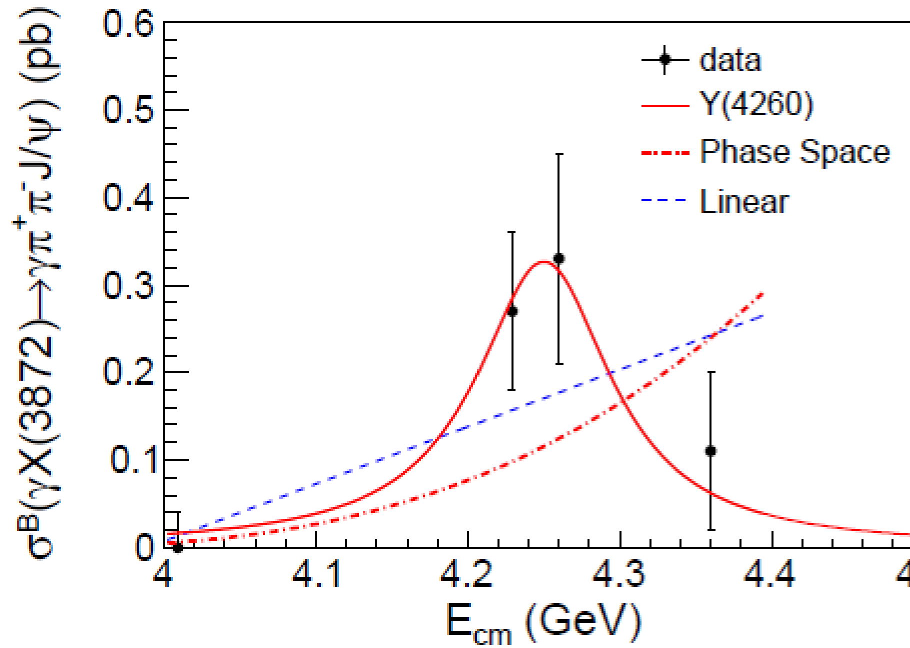
Clear ISR ψ′ signal for data validation
X(3872) signal at around 4.230-4.260 GeV



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

hep-ex:1310.4101





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 = consistent with σ_M
>6.3σ

[PDG: 3871.68±0.17 MeV]

Could be a Y(4260) → γX(3872)!

Summary

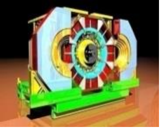
- **huge statistics:**
  - J/ψ, ψ(2S), ψ(1D)
  - XYZ studies

- **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

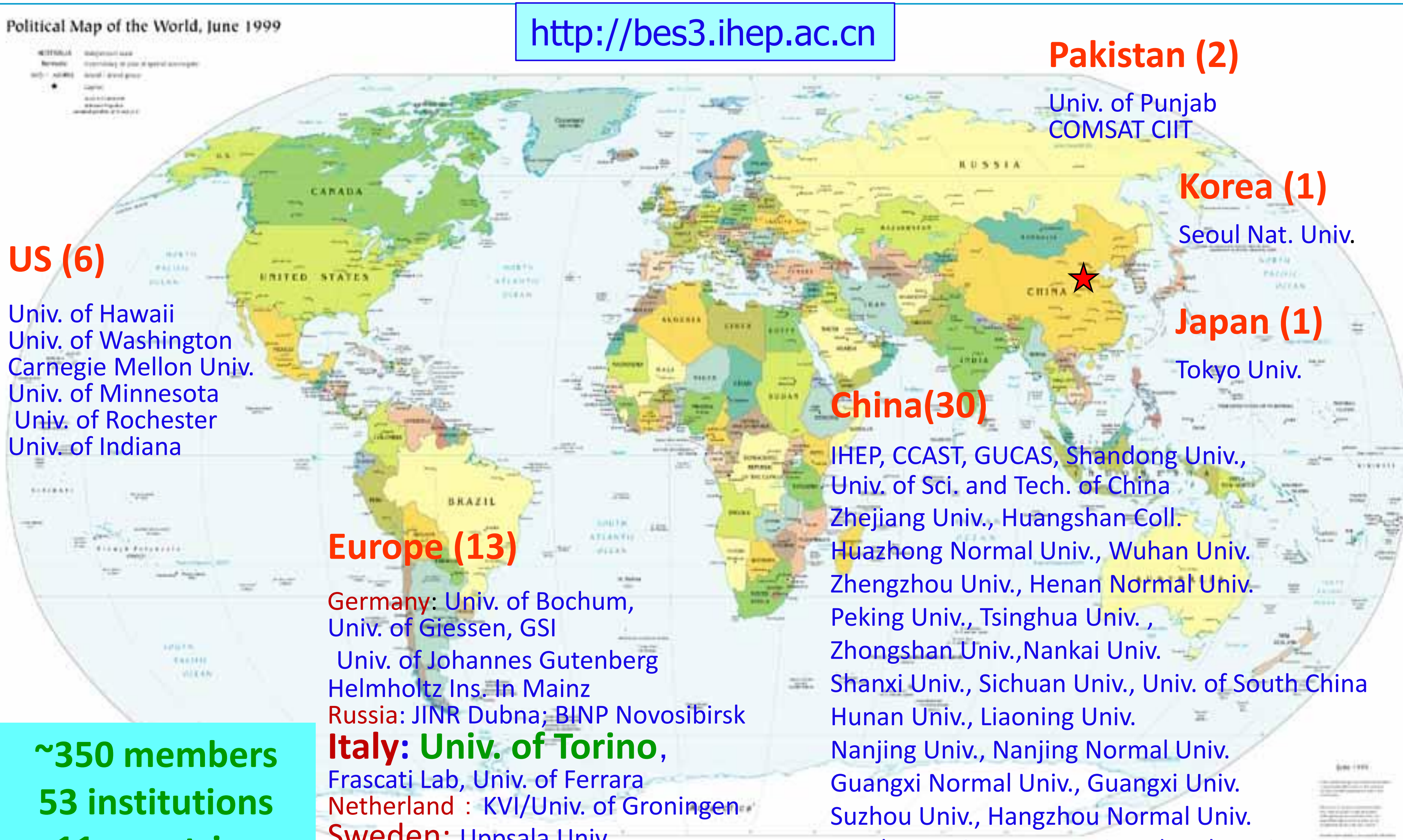
- **stay tuned:**
  - many new exciting results on their way

Question time

Thanks!



BESIII Collaboration



http://bes3.ihep.ac.cn

Pakistan (2)

Univ. of Punjab
COMSAT CIIT

Korea (1)

Seoul Nat. Univ.

Japan (1)

Tokyo Univ.

US (6)

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

China(30)

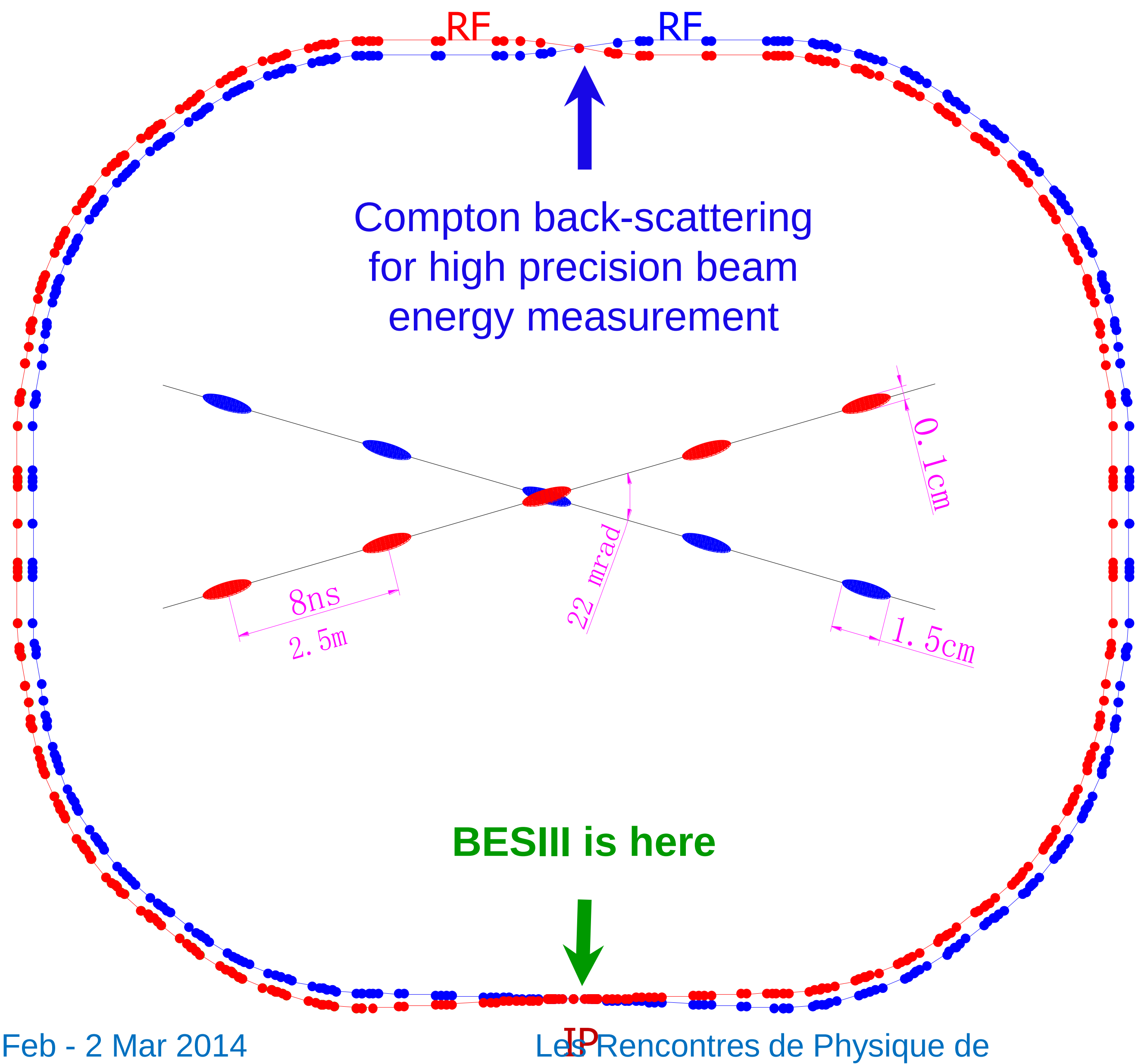
IHEP, CCAST, GUCAS, Shandong Univ.,
Univ. of Sci. and Tech. of China
Zhejiang Univ., Huangshan Coll.
Huazhong Normal Univ., Wuhan Univ.
Zhengzhou Univ., Henan Normal Univ.
Peking Univ., Tsinghua Univ. ,
Zhongshan Univ.,Nankai Univ.
Shanxi Univ., Sichuan Univ., Univ. of South China
Hunan Univ., Liaoning 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

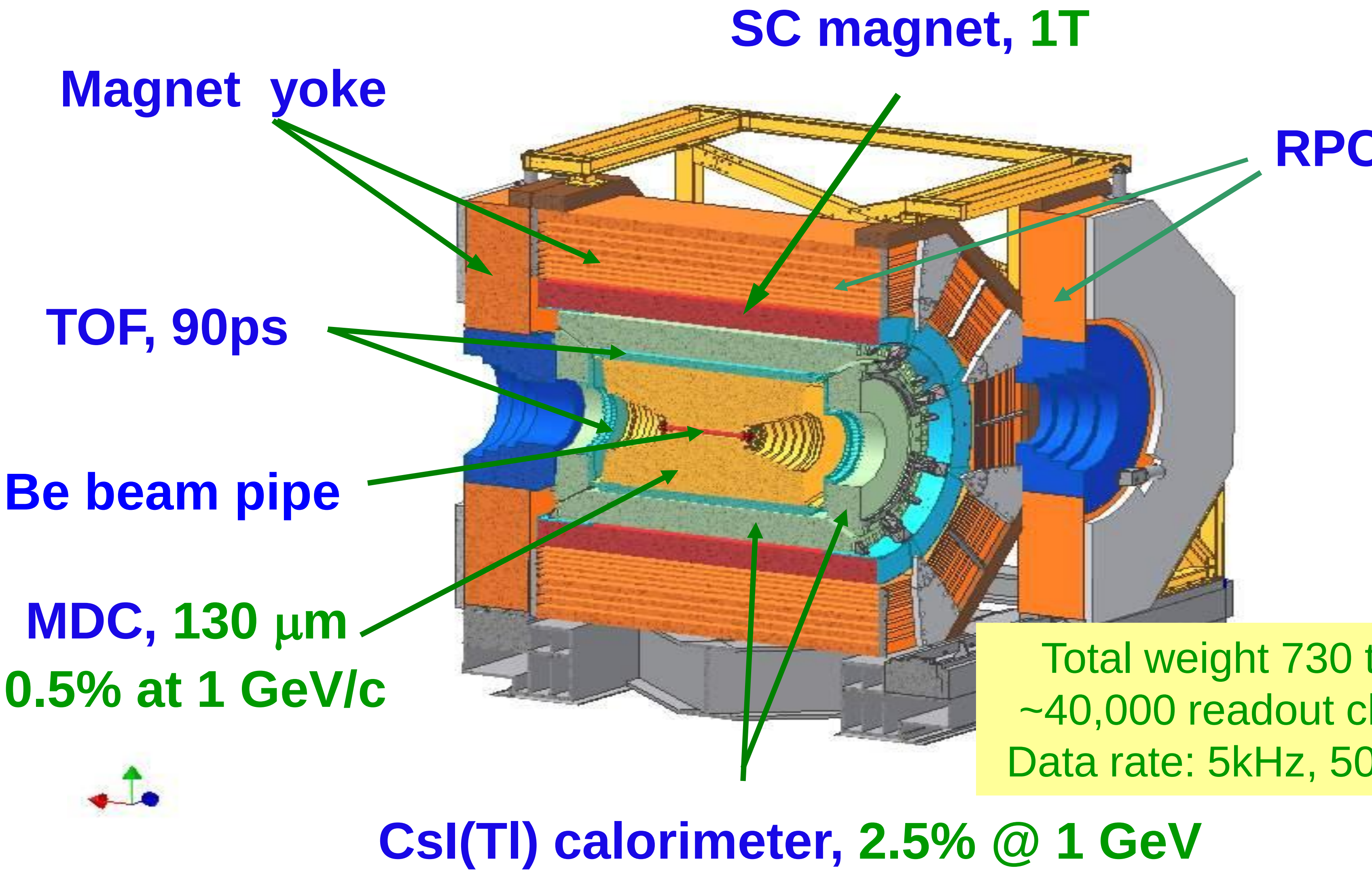
~350 members
53 institutions
11 countries

BEPCII



Beam energy:
1-2.3 GeV
Crossing angle:
22 mrad
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

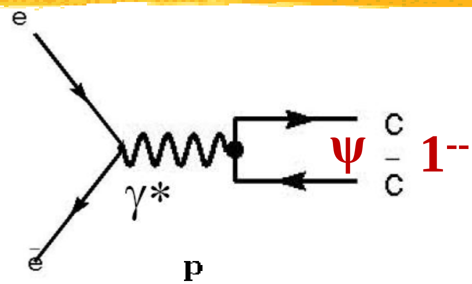
BESIII Spectrometer

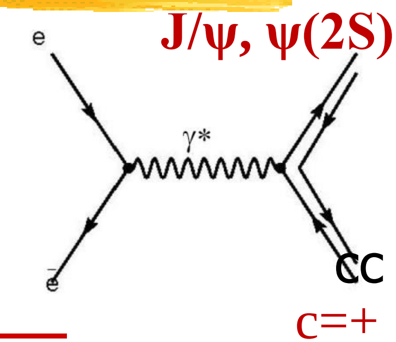


Total weight 730 ton,
~40,000 readout chnls,
Data rate: 5kHz, 50Mb/s

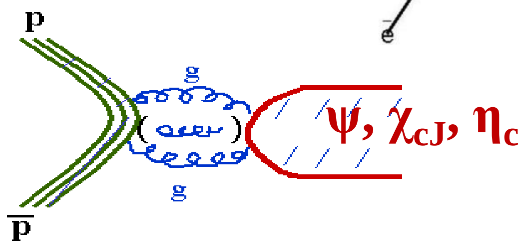
How to produce Charmonium states

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

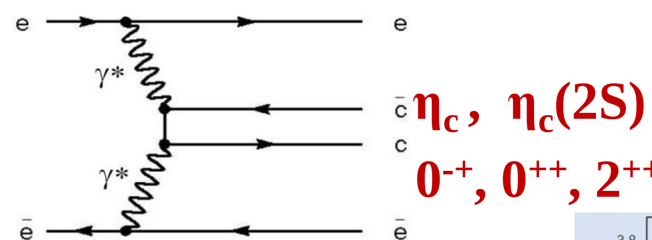




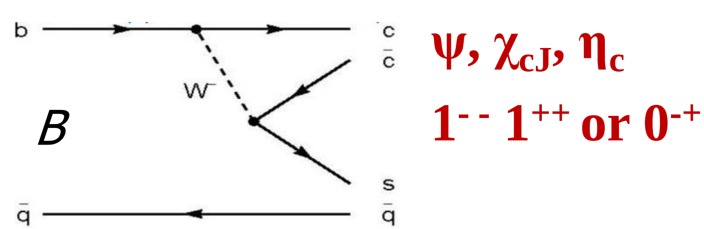
2. $p\bar{p}$ annihilation



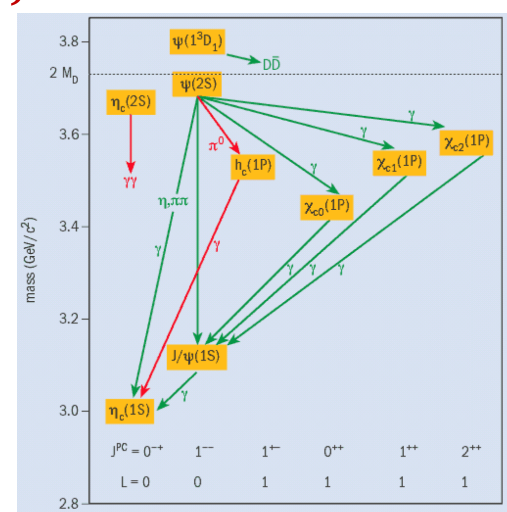
3. Two-photon process



4. B decays



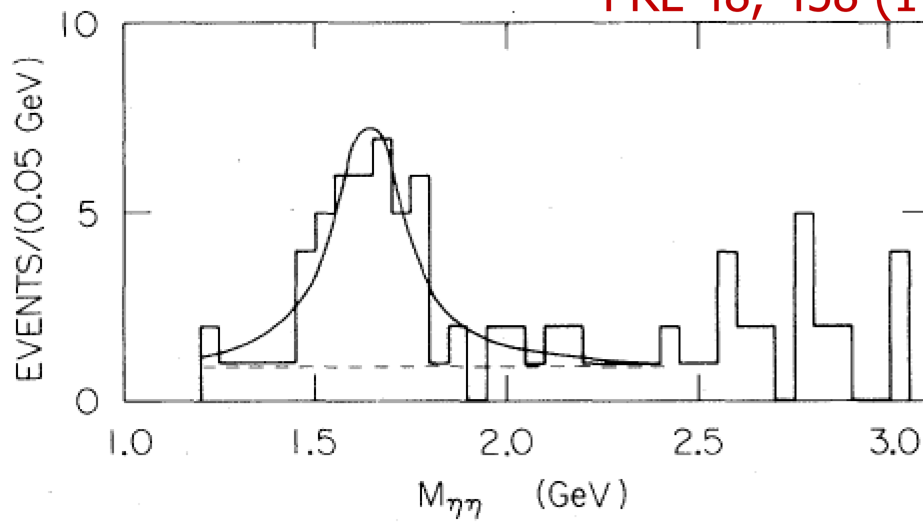
5. Charmonium transition



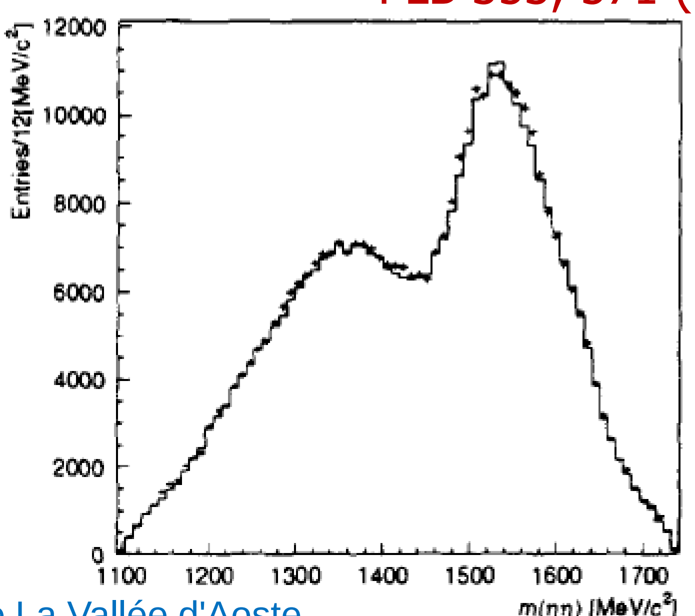
$J/\psi \to \gamma\eta\eta$

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

PRL 48, 458 (1982)



PLB 353, 571 (1995)

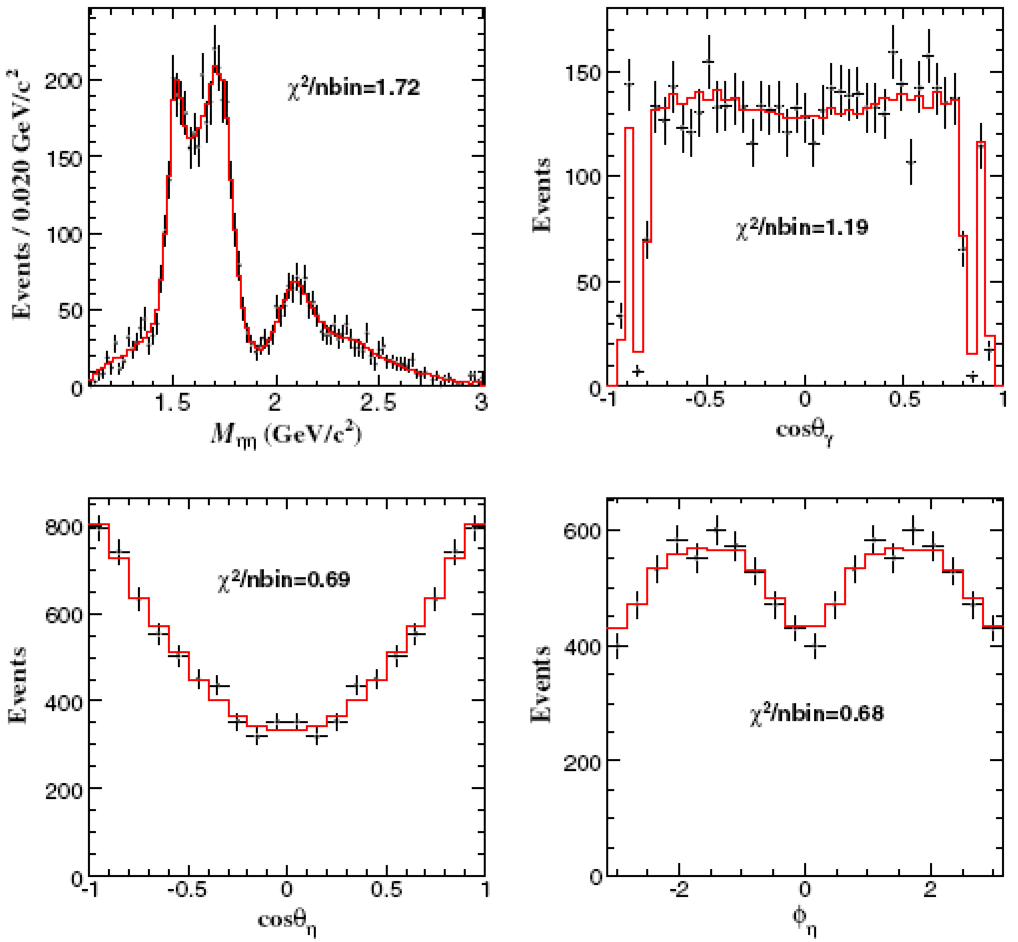


BESIII: PWA of $J/\psi \to \gamma\eta\eta$, $\eta \to \gamma\gamma$

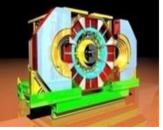
PRD 87, 092009

- **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

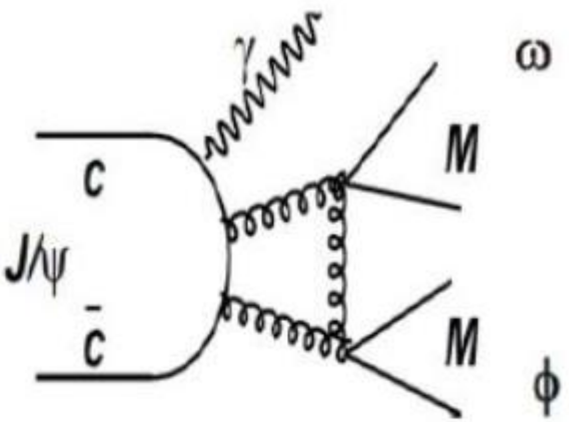
Resonance	Mass(MeV/c^2)	Width(MeV/c^2)	$\mathcal{B}(J/\psi \to \gamma X \to \gamma\eta\eta)$	Significance
$f_0(1500)$	1468^{+14+23}_{-15-74}	$136^{+41+28}_{-26-100}$	$(1.65^{+0.26+0.51}_{-0.31-1.40}) \times 10^{-5}$	$8.2\ \sigma$
$f_0(1710)$	$1759\pm6^{+14}_{-25}$	$172\pm10^{+32}_{-16}$	$(2.35^{+0.13+1.24}_{-0.11-0.74})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

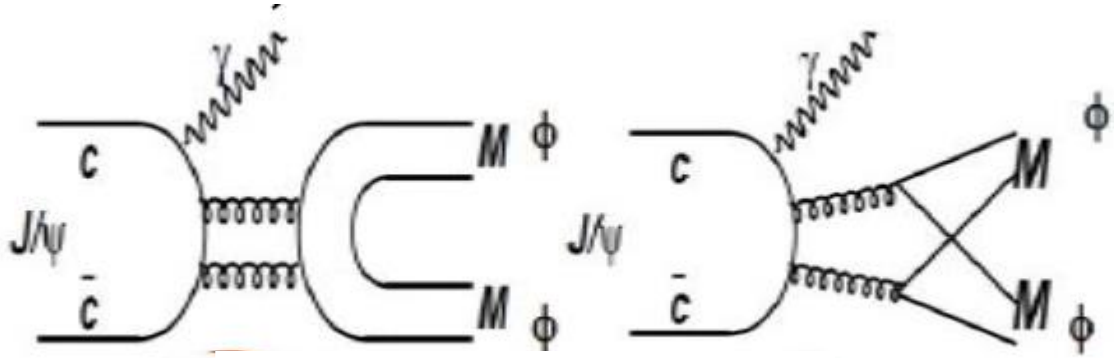
no significant evidence of:

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

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

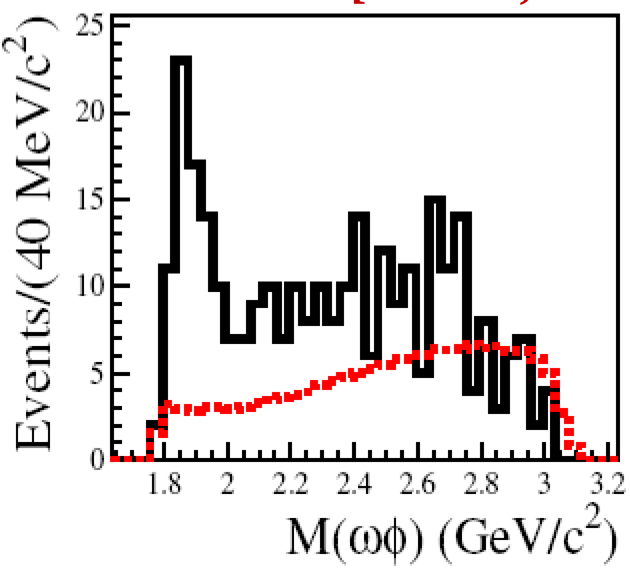
- **doubly OZI suppressed**

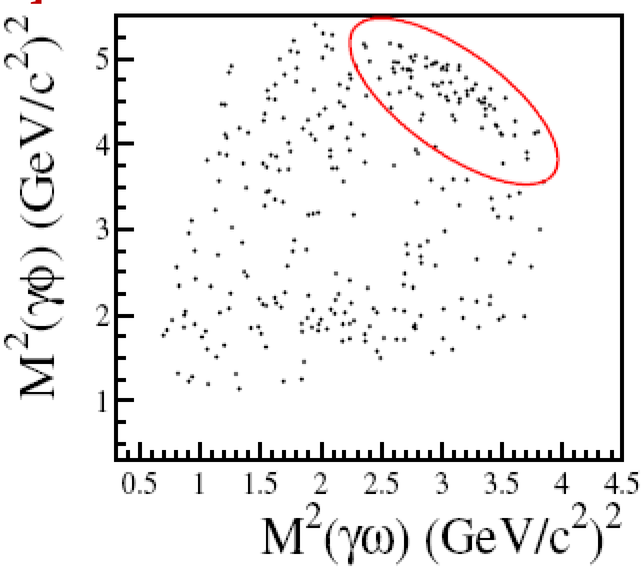




$\psi\to\gamma\omega\phi$ (DOZI) **predicted $\propto$ 1/10** **$\psi\to\gamma\phi\phi$ (OZI)**

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





$M = (1812^{+19}_{-26} \pm 18)$ MeV/c²

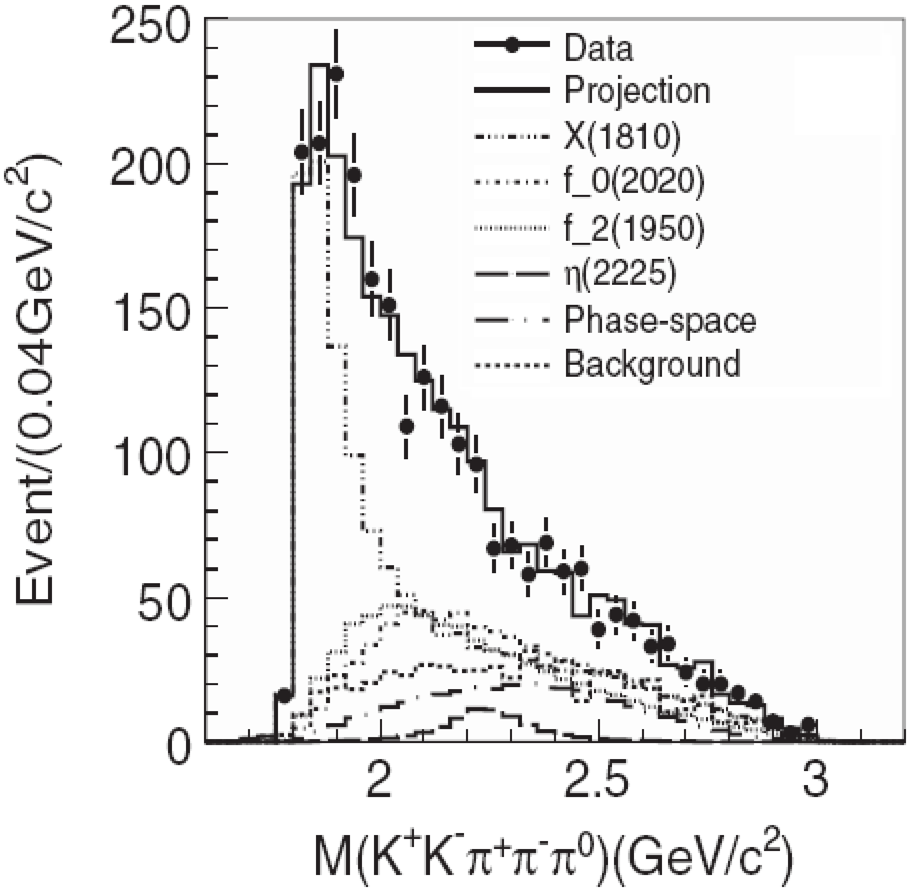
$\Gamma = (105 \pm 20 \pm 28)$ MeV/c²

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

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

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:**

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

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

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

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

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

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

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

  unconclusive, further investigation is needed

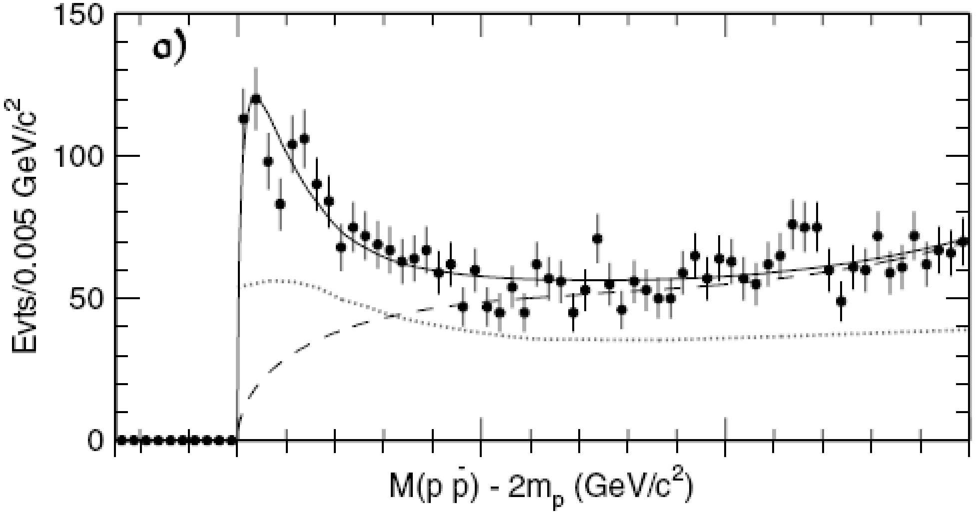
- **search for X(1810):**
  - in other decay modes: K*K*, ωω, …

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

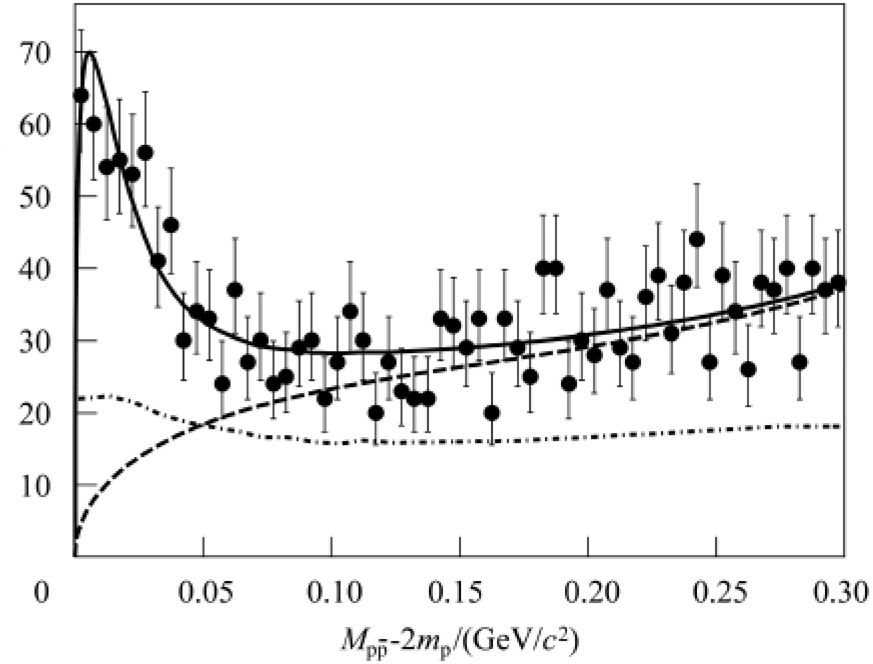
$J/\psi \to \gamma p\bar{p}$: enhancement at threshold

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
$\Gamma < 38$ MeV/c^2 (90% C.L.)
compatible with S-wave BW

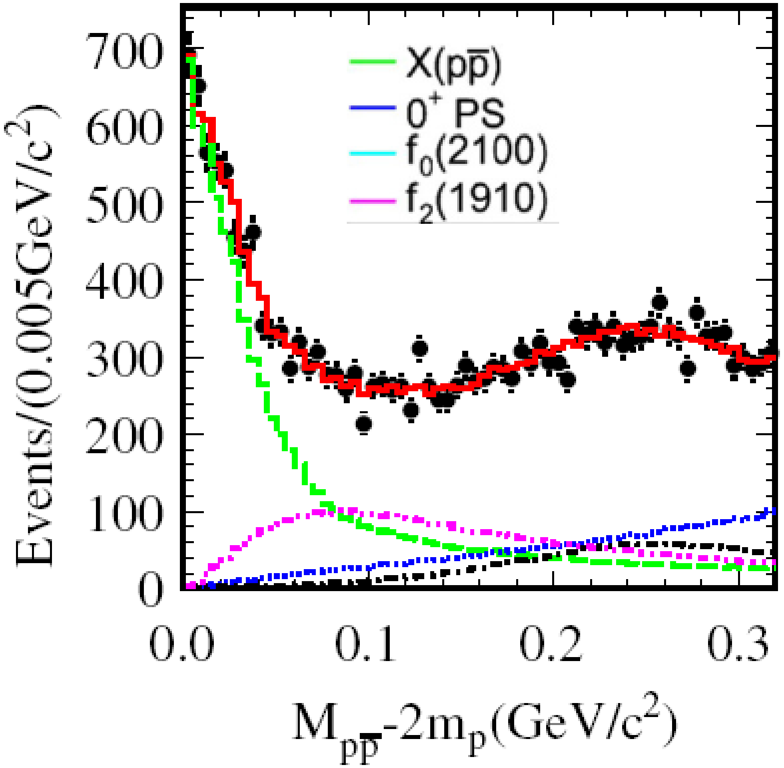
$M = (1861^{+6}_{-13}\,{}^{+7}_{-26})$ MeV/c^2
$\Gamma < 30$ MeV/c^2 (90% C.L.)
compatible with S-wave BW

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

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

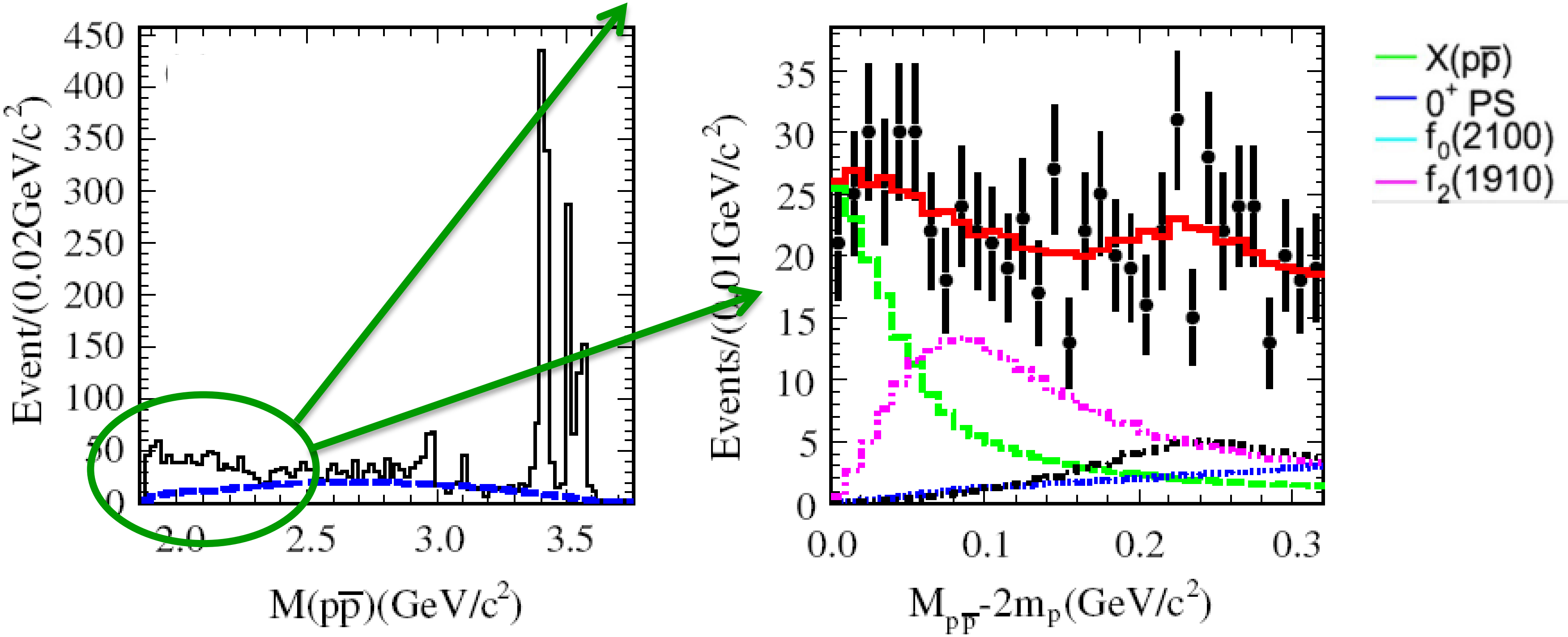
$$\mathbf{\Gamma = 13 \pm 39(stat)^{+10}_{-13}(sys) \pm 4(mod)\ MeV/c^2 \text{ or } \Gamma < 76\ MeV/c^2\ (90\%\ C.L.)}$$

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

BESIII: 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

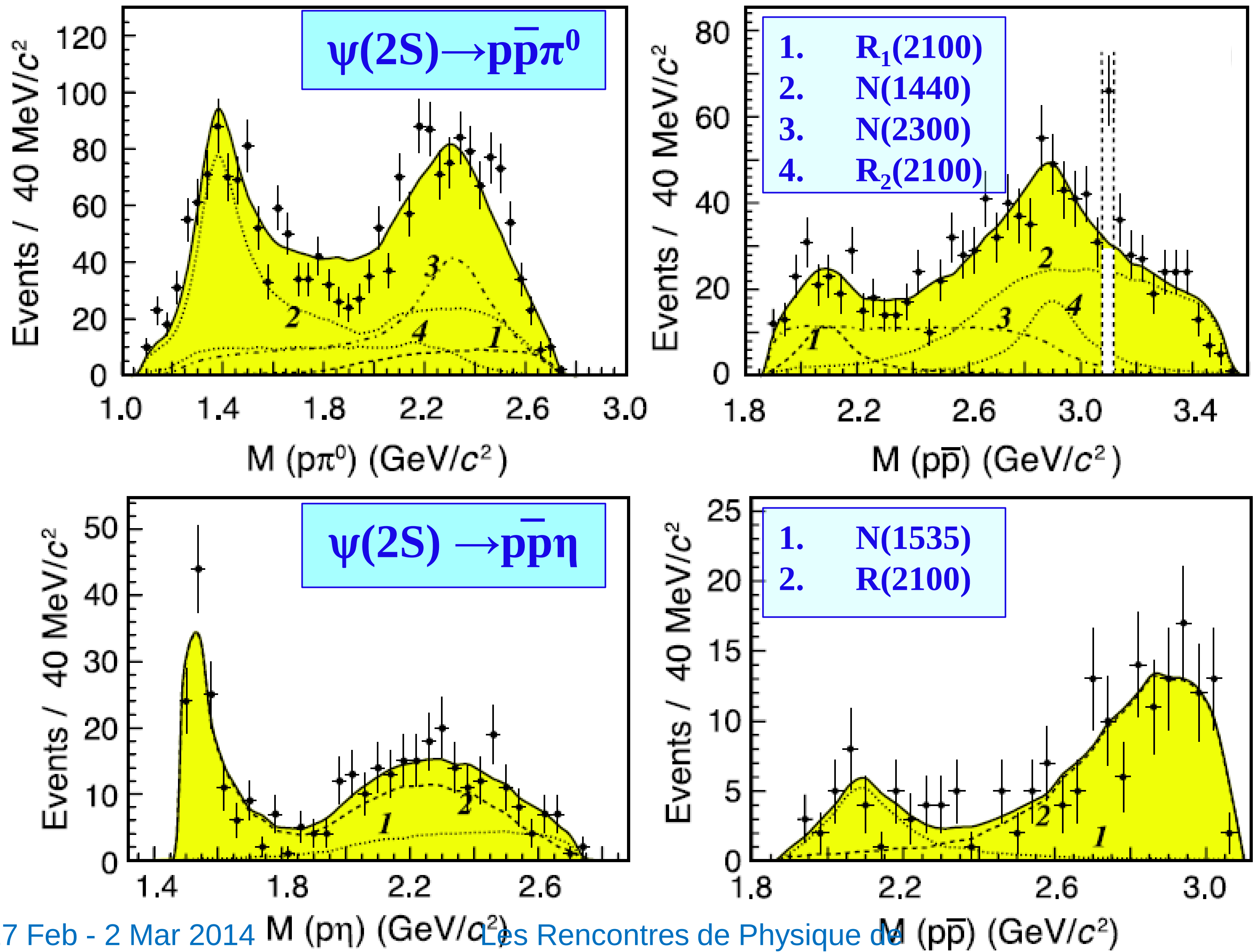
$\mathcal{B}(\psi(2S)\to\gamma X(pp)) \times \mathcal{B}(X(pp)\to pp) =$

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

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

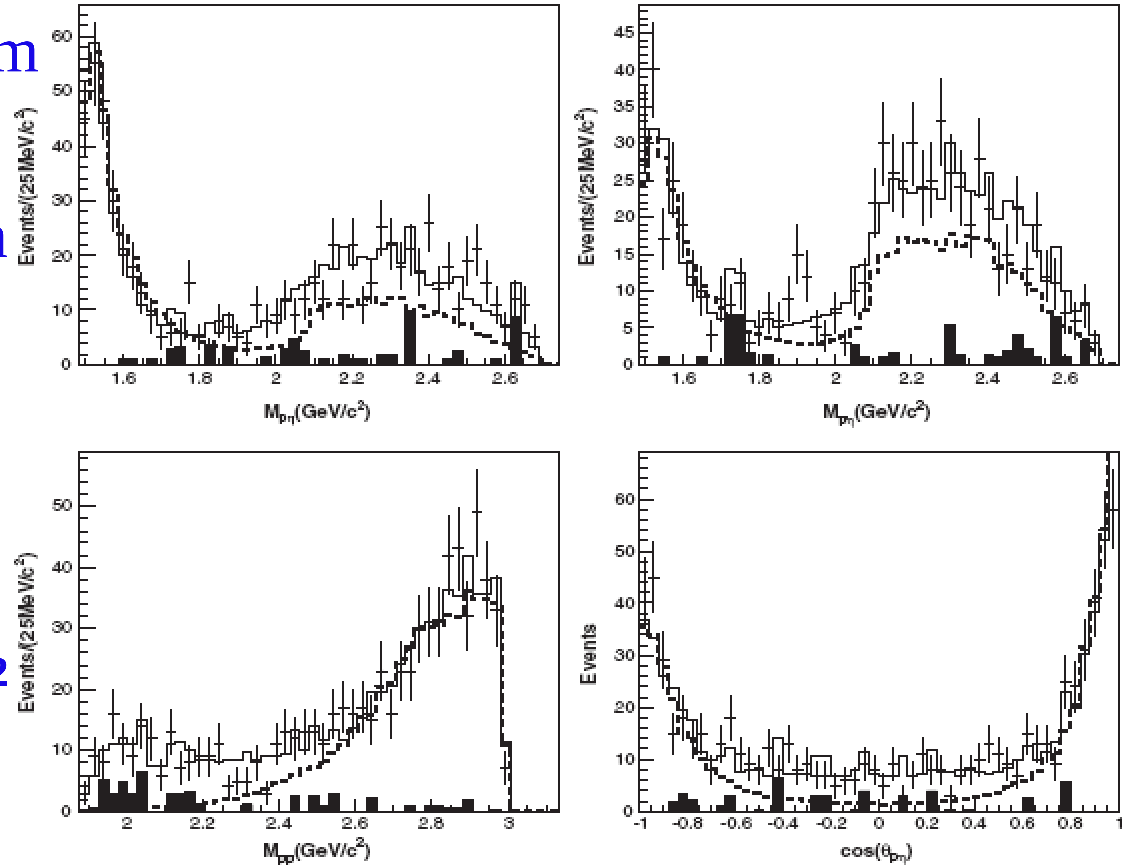


Without interference effects

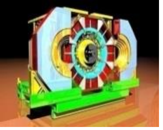
BESIII: PWA of $\psi(2S) \to p\bar{p}\eta$

PRD 88, 032010

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



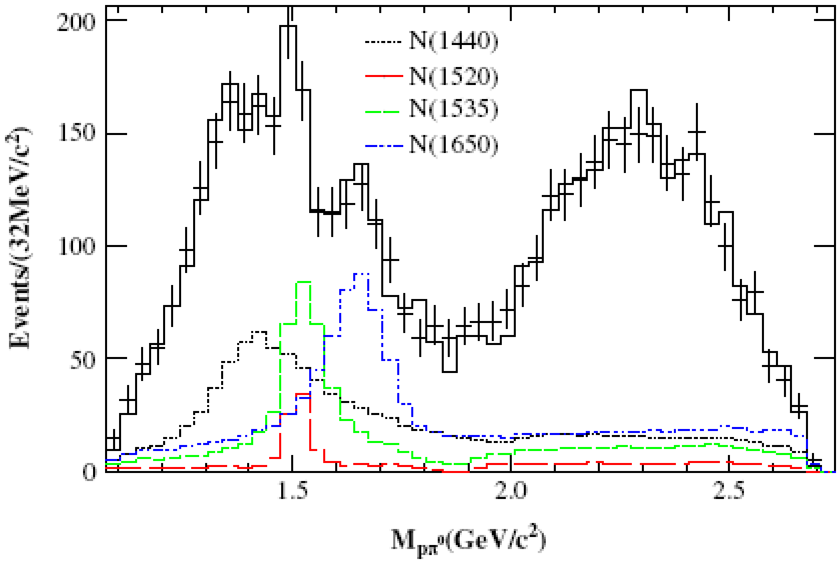
$$Q_{p\bar{p}\eta} = \frac{\mathcal{B}(\psi(2S) \to p\bar{p}\eta)}{\mathcal{B}(J/\psi \to p\bar{p}\eta)} = (3.2\pm0.46)\%$$

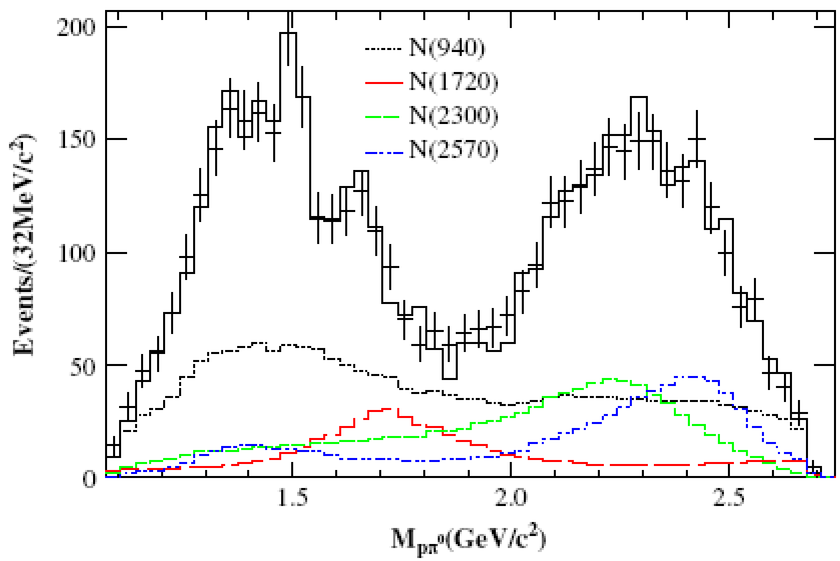


BESIII: PWA of $\psi(2S)\rightarrow p\bar{p}\pi^0$

PRL 110, 022001

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

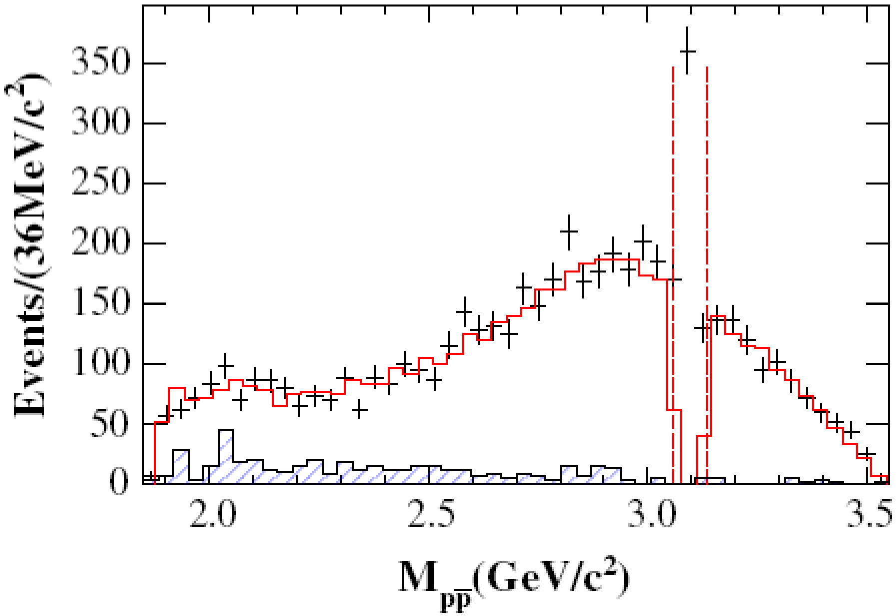




BESIII: PWA of $\psi(2S)\to p\bar{p}\pi^0$

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(15
  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:**

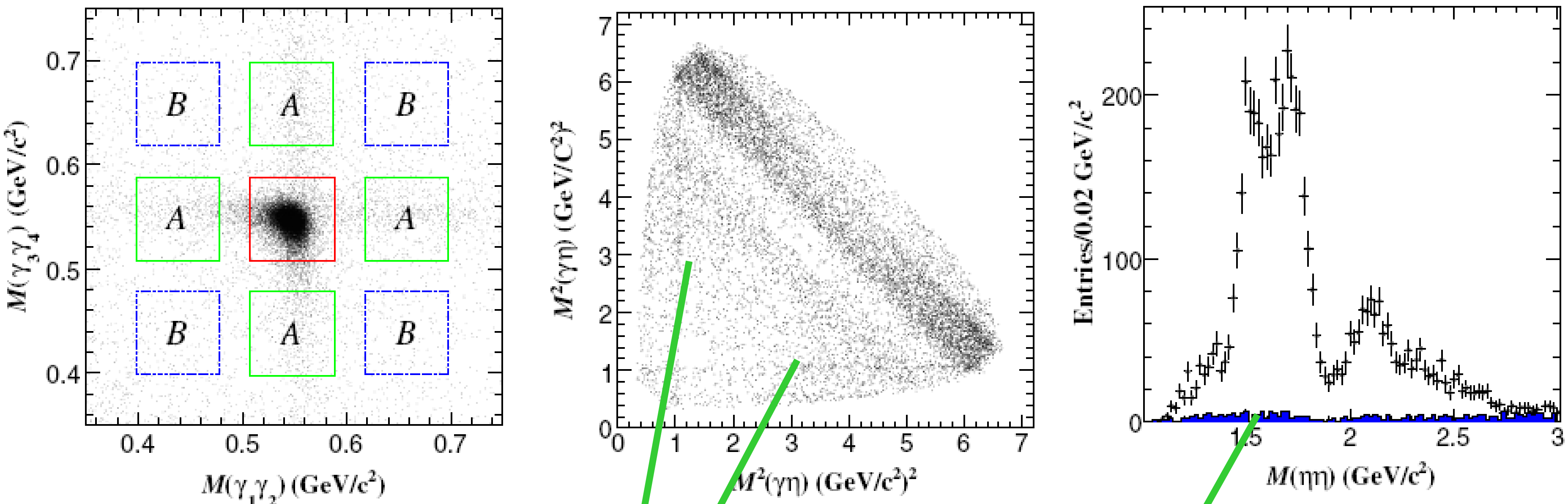
  $\mathcal{B}(\psi(2S) \to p\bar{p}\pi^0) = (1.65\pm0.03\pm0.15)\times10^{-4}$

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

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

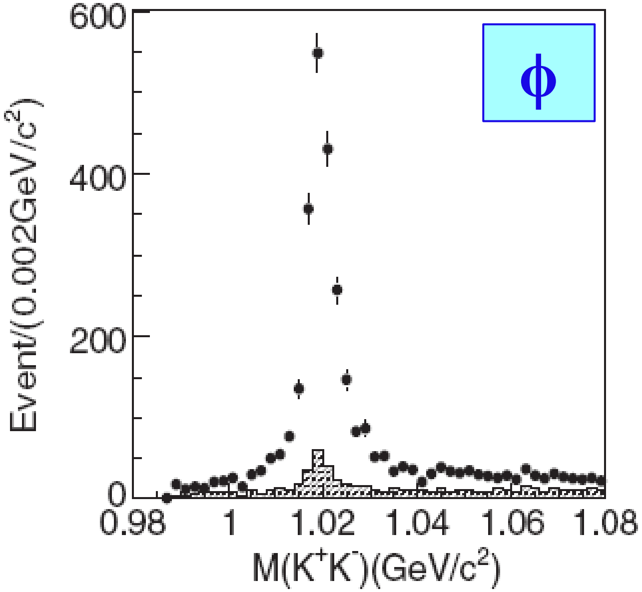
PRD 87, 092009

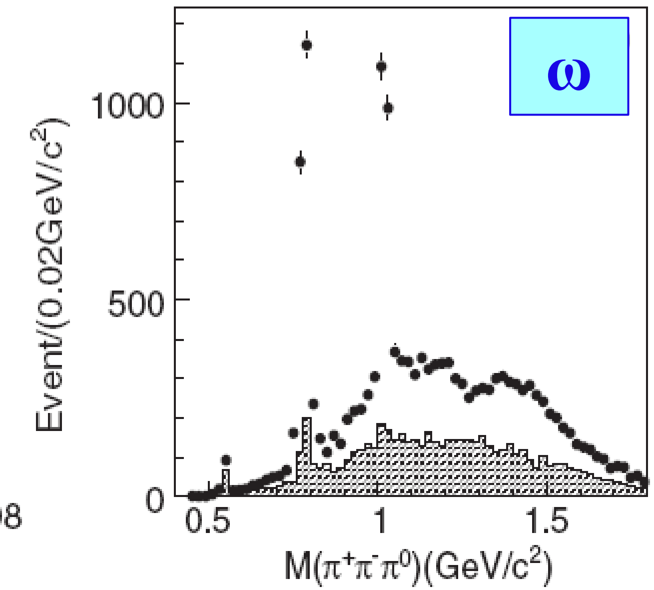


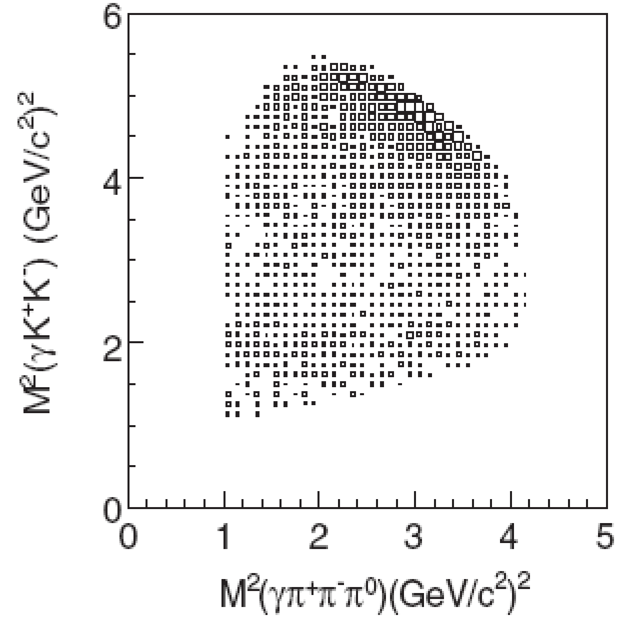
- **$J/\psi \to \phi\eta$, $\phi \to \gamma\eta$:**
  - select events outside ϕ window
- **background:**
  - low and mostly non-η background,
  - estimanted by η sidebands (blue shadow)
- **background subtraction:**
  - $\ln \mathcal{L}^{signal} = \ln \mathcal{L}^{data} - \ln \mathcal{L}^{sideband}$

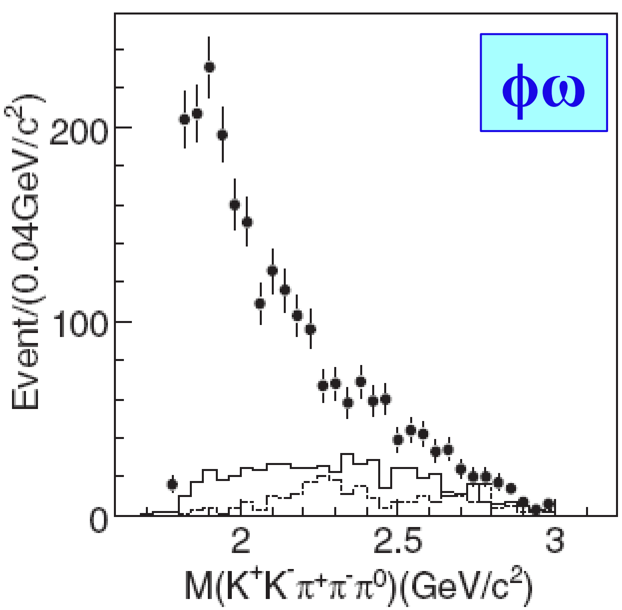
BESIII: PWA of J/ψ → γωφ

PRD 87, 032008





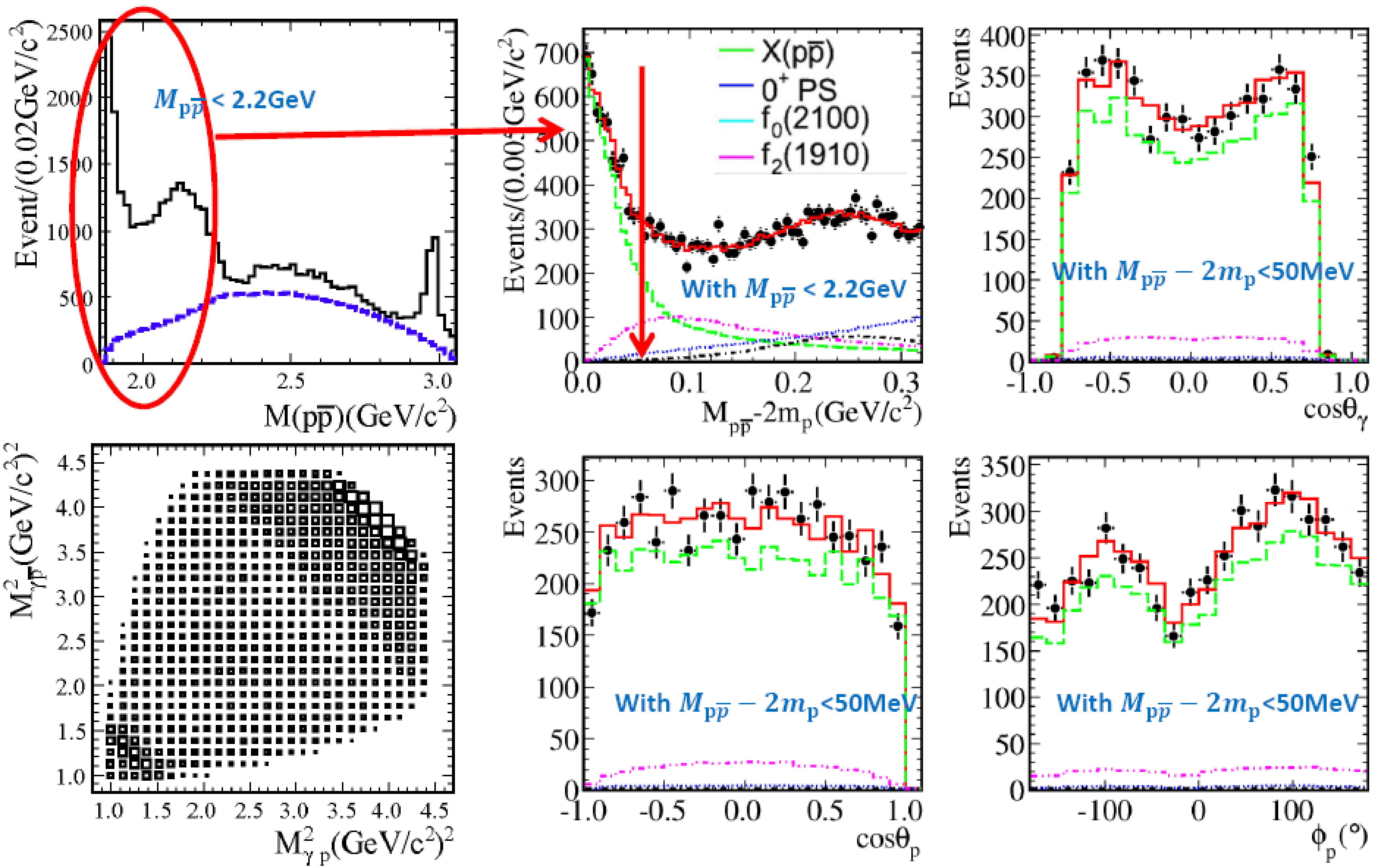


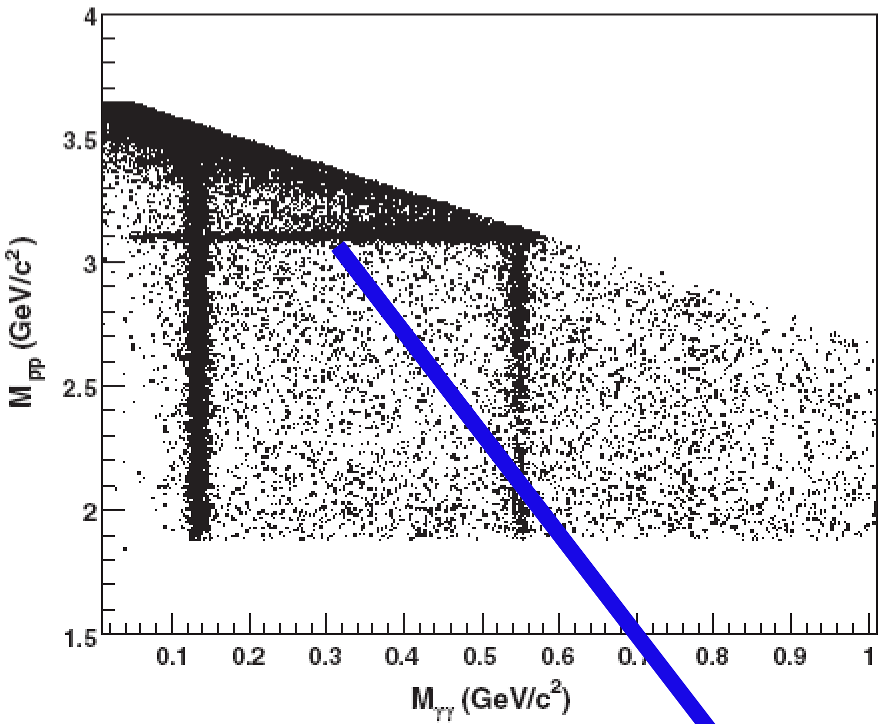


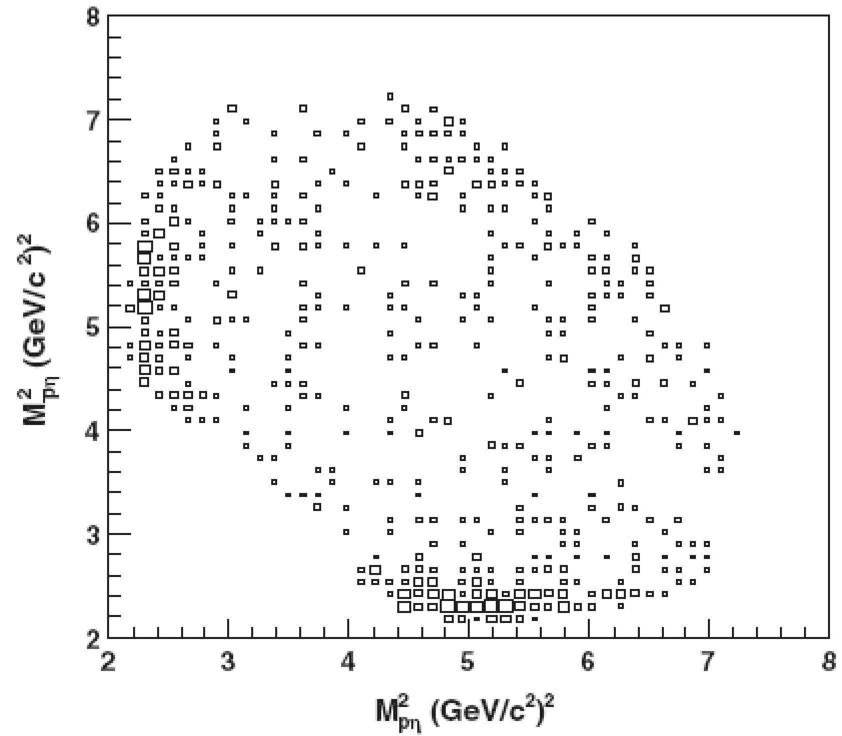
- **solid:**
  - background estimated from sidebands
- **dashed:**
  - inclusive J/ψ MC samples
- **background subtraction:**
  - $\ln \mathcal{L}^{signal} = \ln \mathcal{L}^{data} - \ln \mathcal{L}^{sideband}$

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

PRL 108, 112003



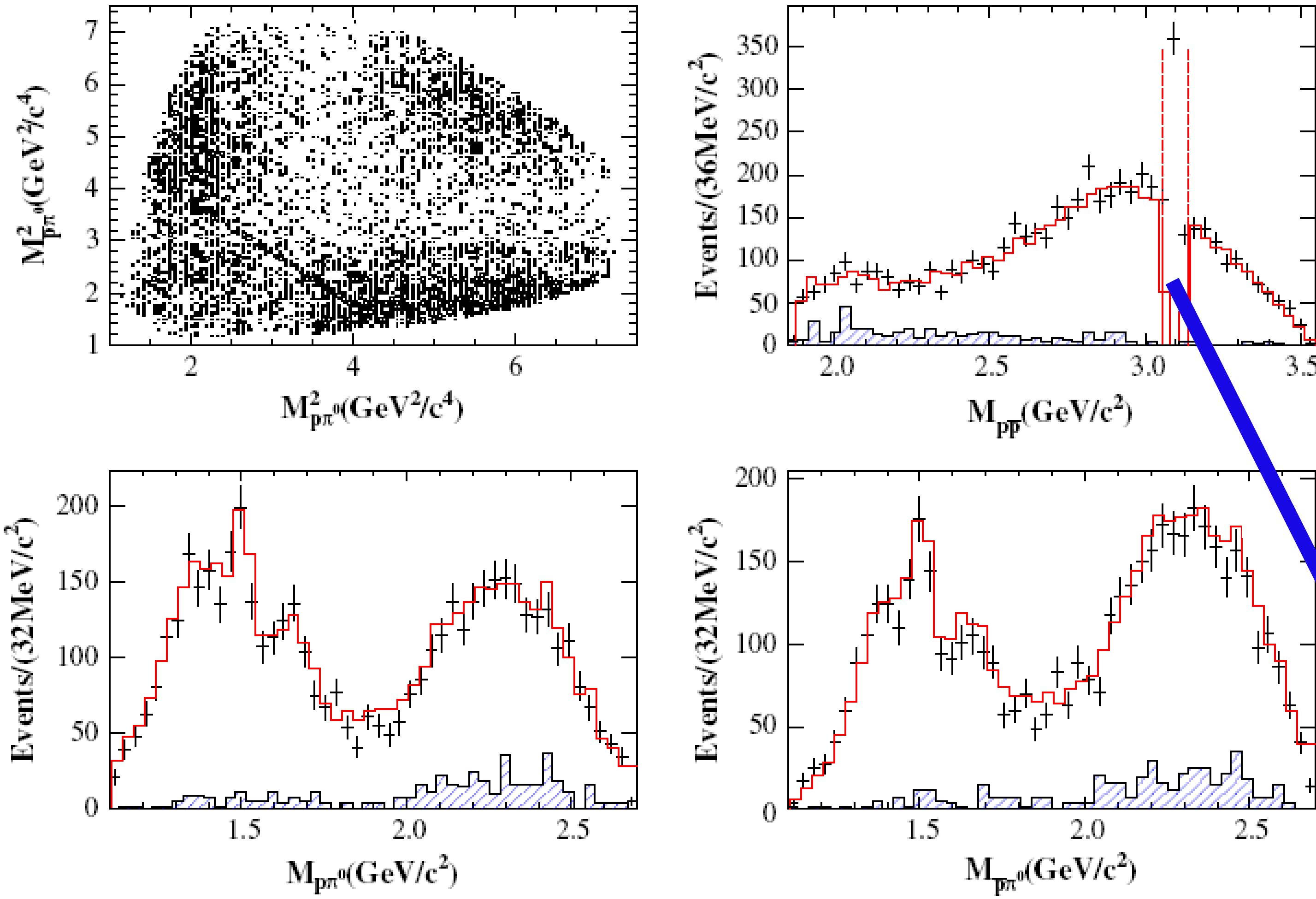




$\psi(2S) \to J/\psi\ X$, $J/\psi \to p\bar{p}$ subtracted

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

PRL 110, 022001

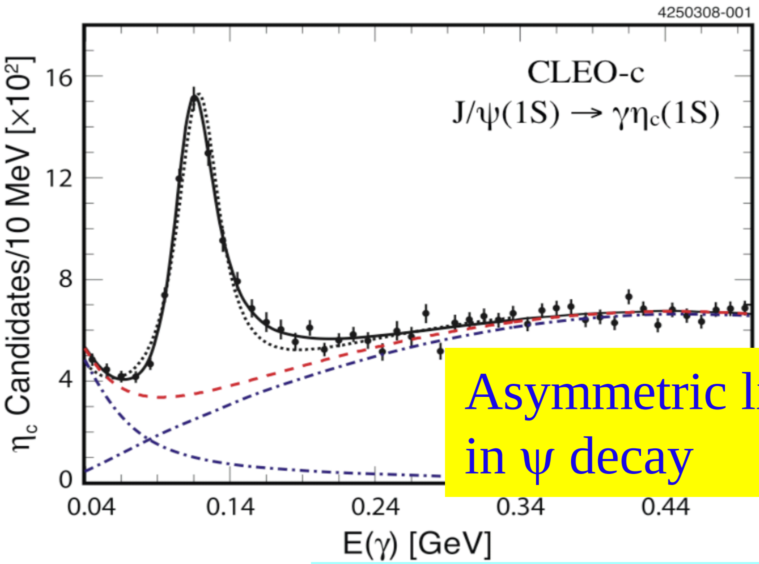


shaded:
background:
- continuum
- non-π^0 background

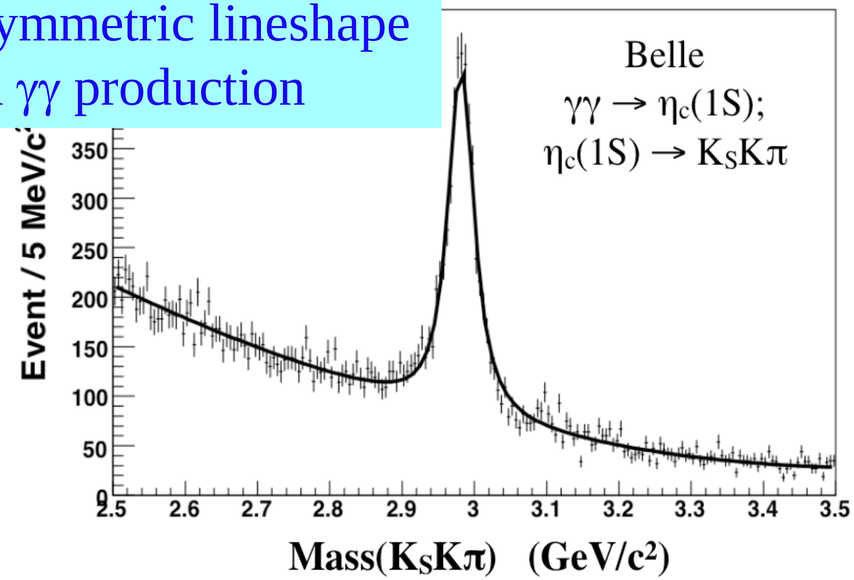
$\psi(2S) \to J/\psi\ X$, $J/\psi \to p\bar{p}$ subtracted

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

PRD 86, 092009

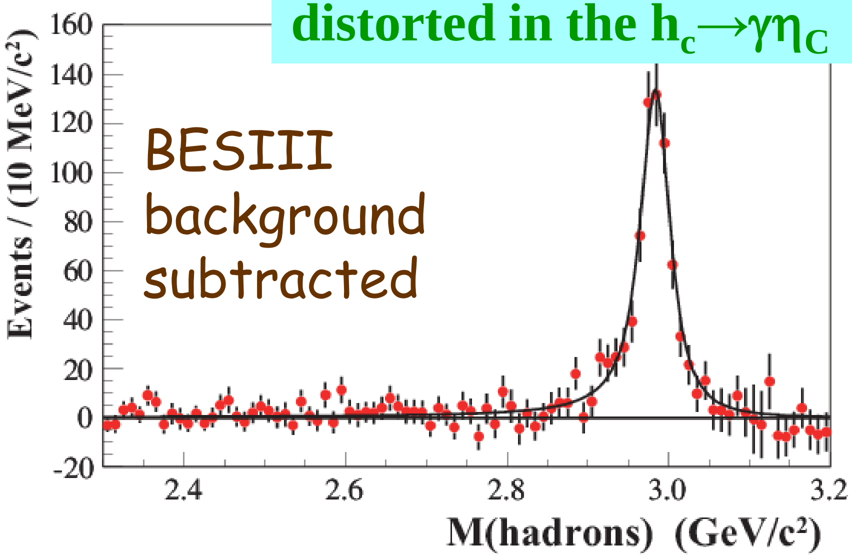


Asymmetric lineshape in ψ decay



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 $\boldsymbol{\eta_c}$ lineshape in charmonium radiative decay

  PRL102, 011801 (2009)

- The lineshape of $\boldsymbol{\eta_c}$ from BELLE is symmetric

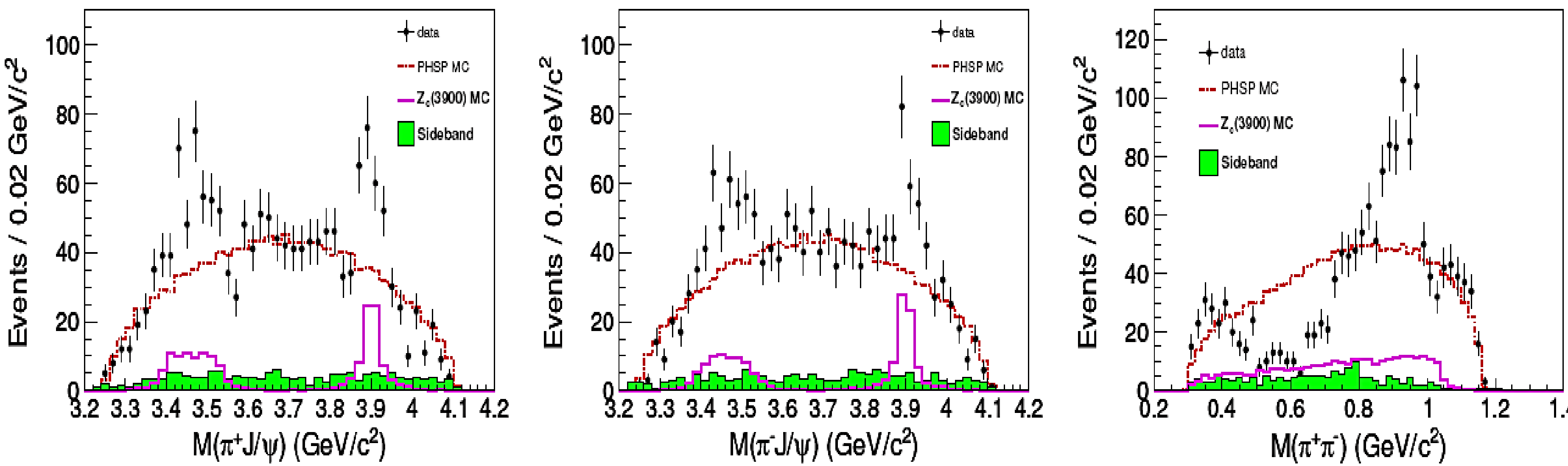
- The abnormal line shape is also observed in BESIII exclusive channels in $\boldsymbol{\psi' \to \gamma\eta_c}$ but not in $\boldsymbol{\psi' \to \to \pi^0 h_c}$, $\boldsymbol{h_c \to \gamma\eta_c}$

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

PRL 110, 252001

Is it a real signal?

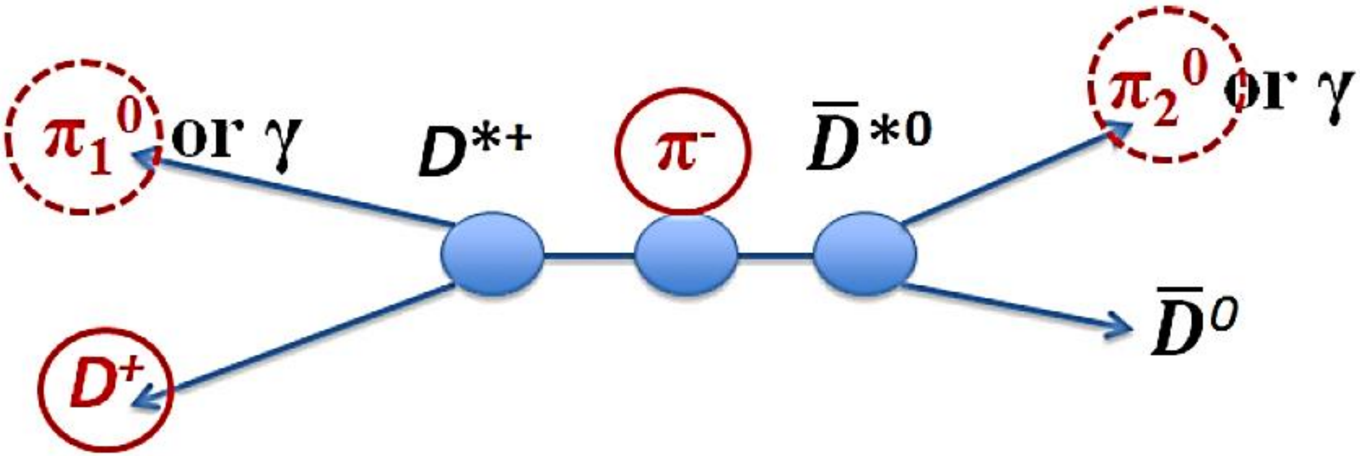
- Is it due to $\pi^+\pi^-$ S-wave states, like σ, $f_0(980)$, …? **N**
- Is it due to $\pi^+\pi^-$ D-wave states, like $f_2(1270)$, …? **N**
- Are there two states, one at 3.4, the other 3.9 GeV? **N**
- Exist in both e^+e^- & $\mu^+\mu^-$ samples? **Y**
- Exist in both $\pi^+\pi^-$ low mass and high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

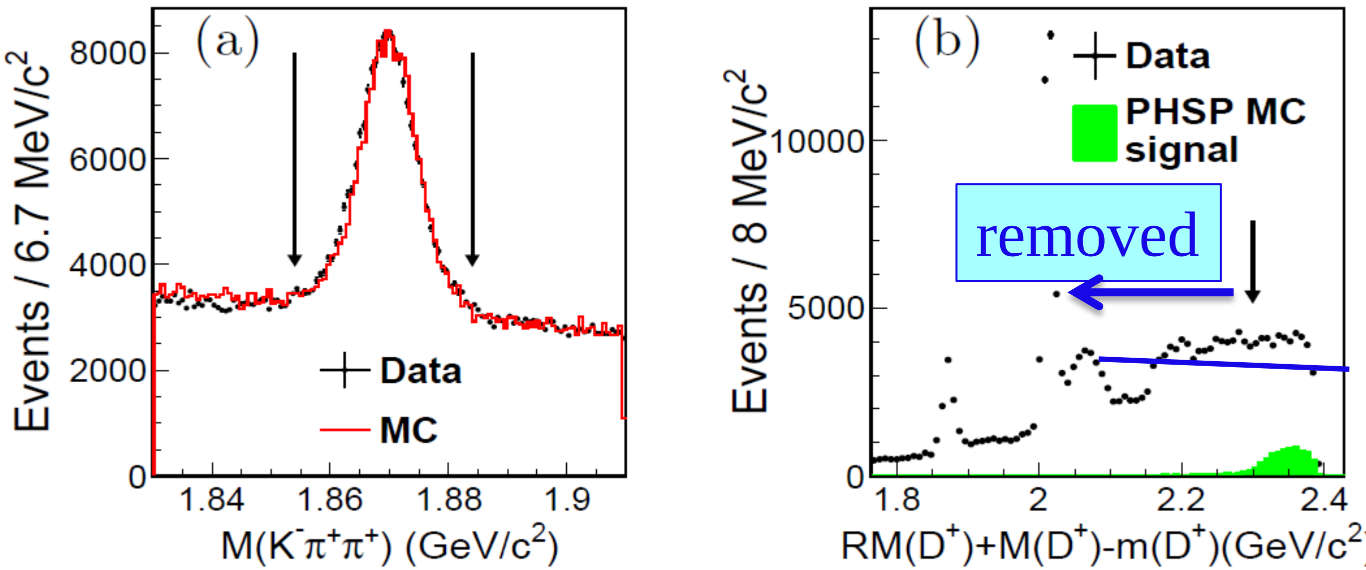


Topology of the decays of the signal process:

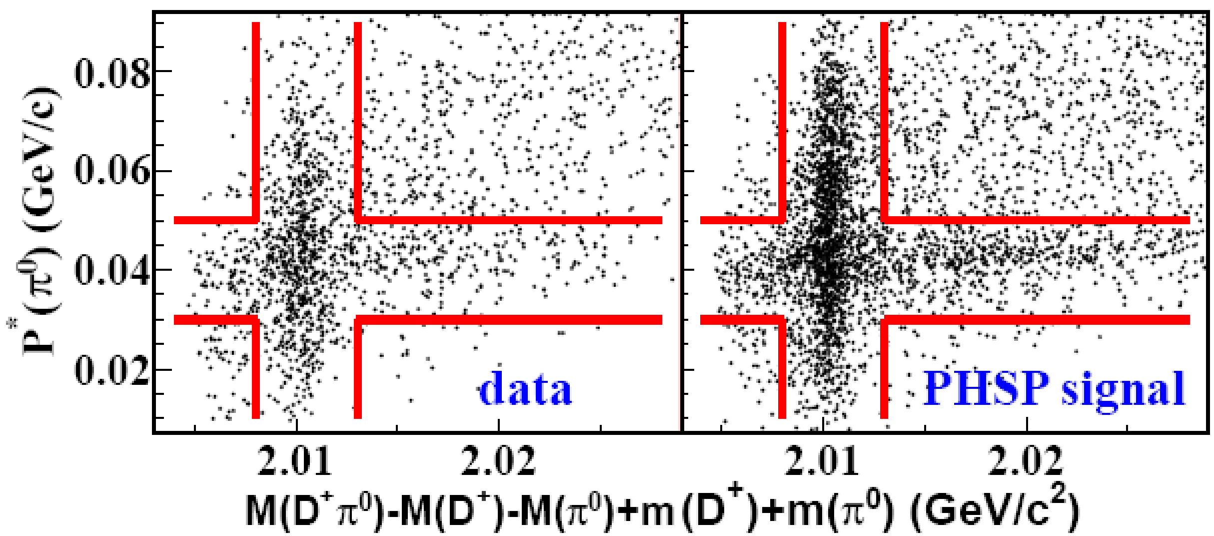
- thick line circled: D^+ and π^- detected in the final states
- dashed line circled: at least of π_1^0 or π_2^0 tagged

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

hep-ex:1308.2760

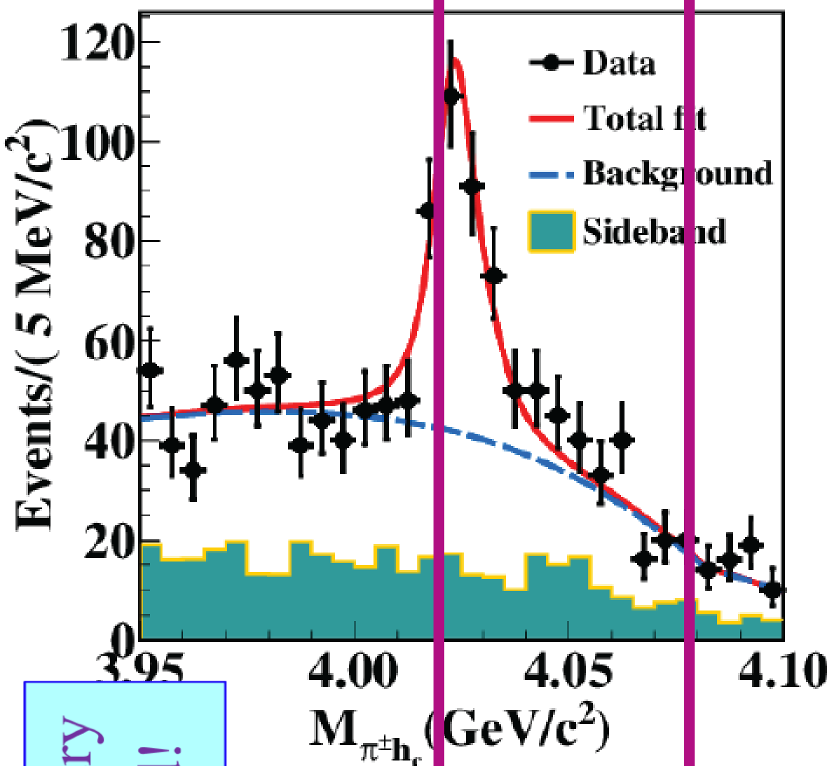


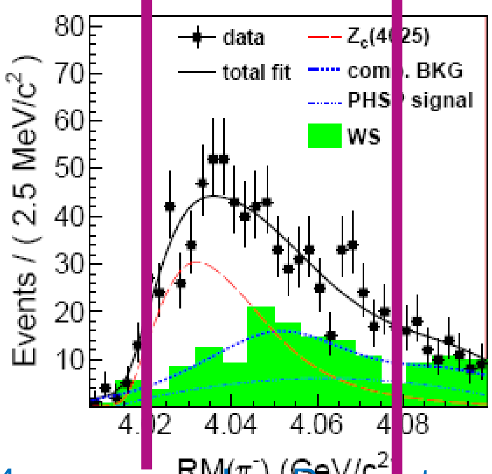
Remove DD, DD*, D*D*, DsDs, …



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

PRL 111, 242001
hep-ex:1308.2760





BESIII preliminary
The Zc' is found!

$M(4020) = (4021.8\pm1.0\pm2.5)$ MeV

$M(4025) = (4026.3\pm2.6\pm3.7)$ MeV

$\Gamma(4020) = (5.7\pm3.4\pm1.1)$ MeV

$\Gamma(4025) = (24.8\pm5.7\pm7.7)$ MeV

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

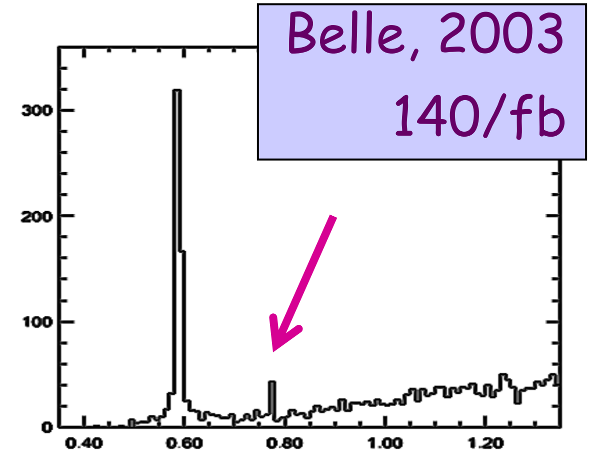
Mass consistent with each other but.. width ~2σ difference

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 $\bar{D}^0D^{*0}$ 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 $\bar{D}^0D^{*0}$ bound state (like deuteron?)?
  - Mixture of excited χ_{c1} and $\bar{D}^0D^{*0}$ bound state?
  - Many other possibilities (if it is not χ'_{c1}, where is χ'_{c1}?)