

PWA7

7TH INTERNATIONAL WORKSHOP ON PION-NUCLEON PARTIAL WAVE
ANALYSIS AND THE INTERPRETATION OF BARYON RESONANCES

23-27 September 2013, Camogli (ITALY)



Recent BESIII results and spectroscopy

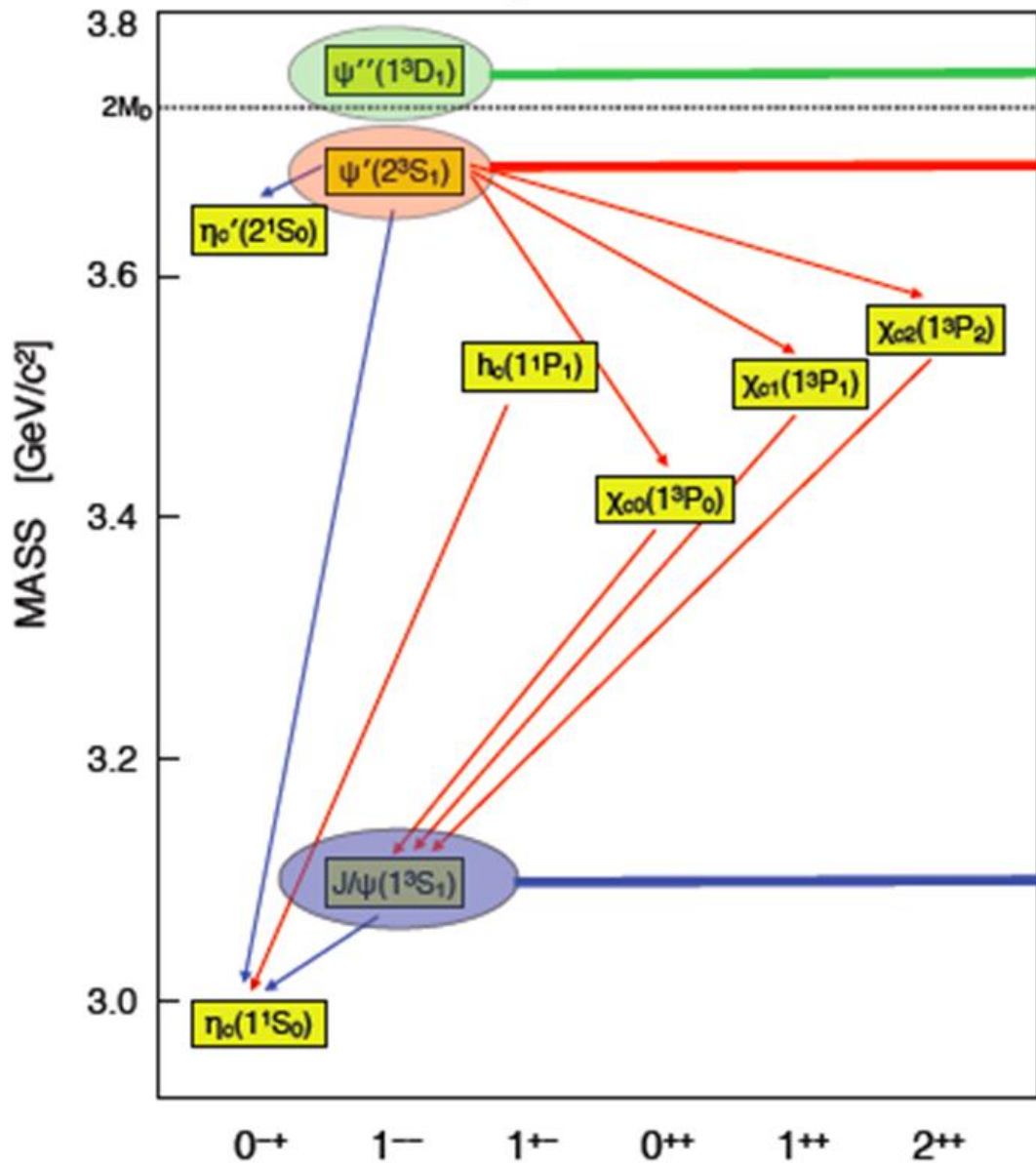
Marco Maggiora on behalf of the BESIII Collaboration

Department of Physics and INFN – Turin, Italy



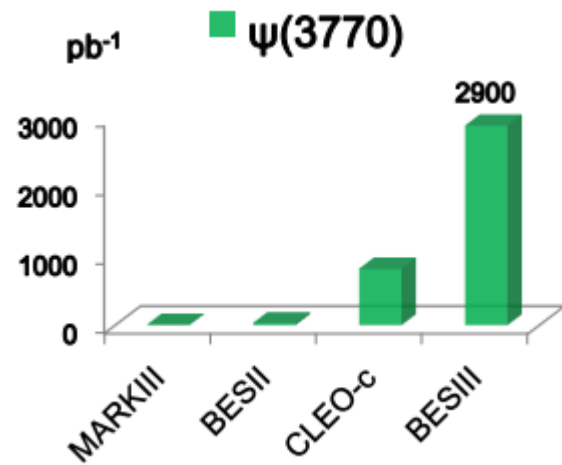


BESIII data set

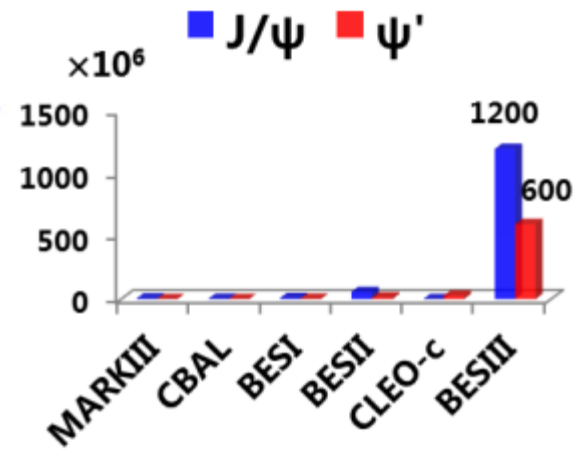


2.9 fb⁻¹ / 20 fb⁻¹

0.6 B / 3 B (106 M)

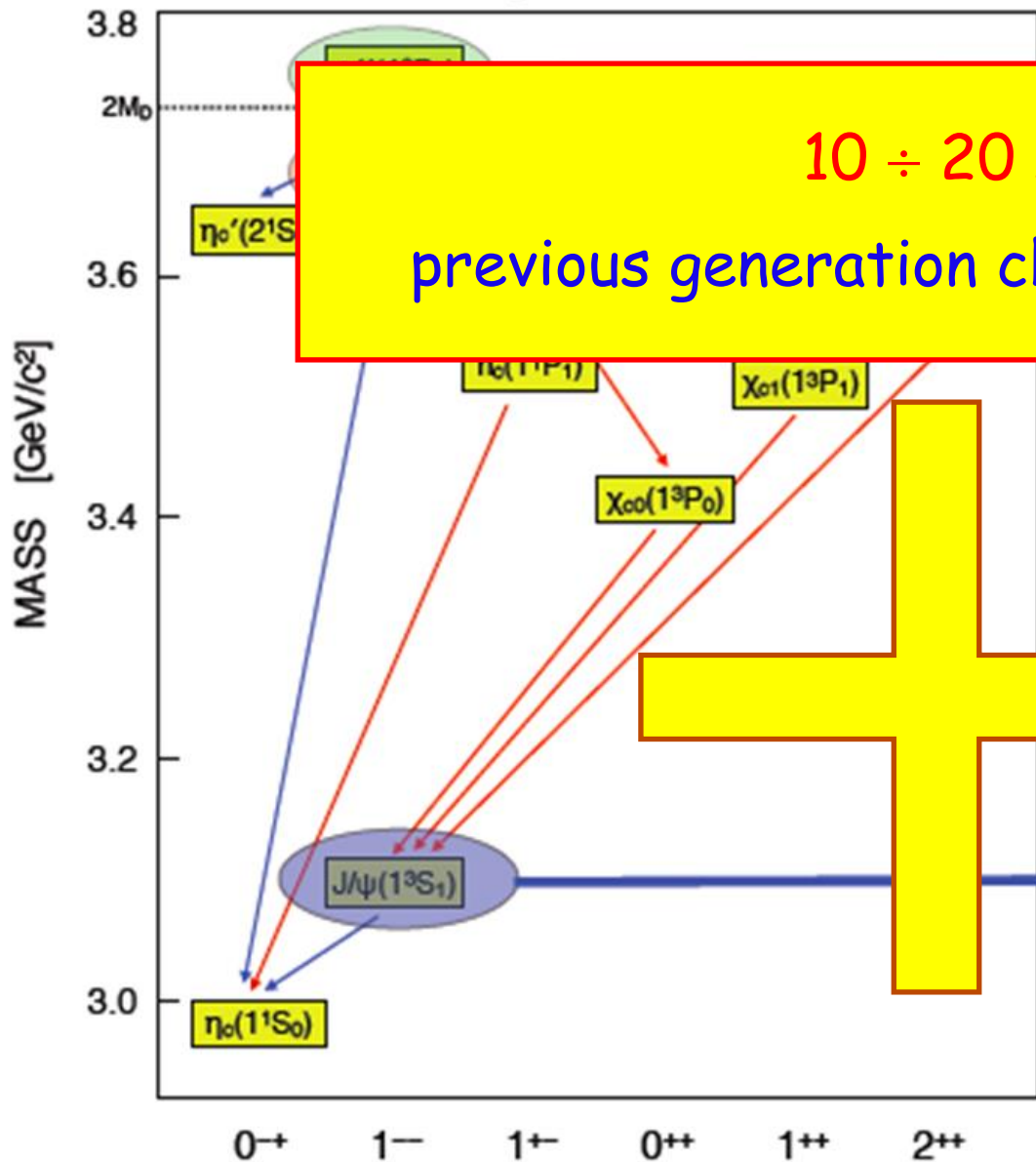


1.2 B / 10 B (225 M)

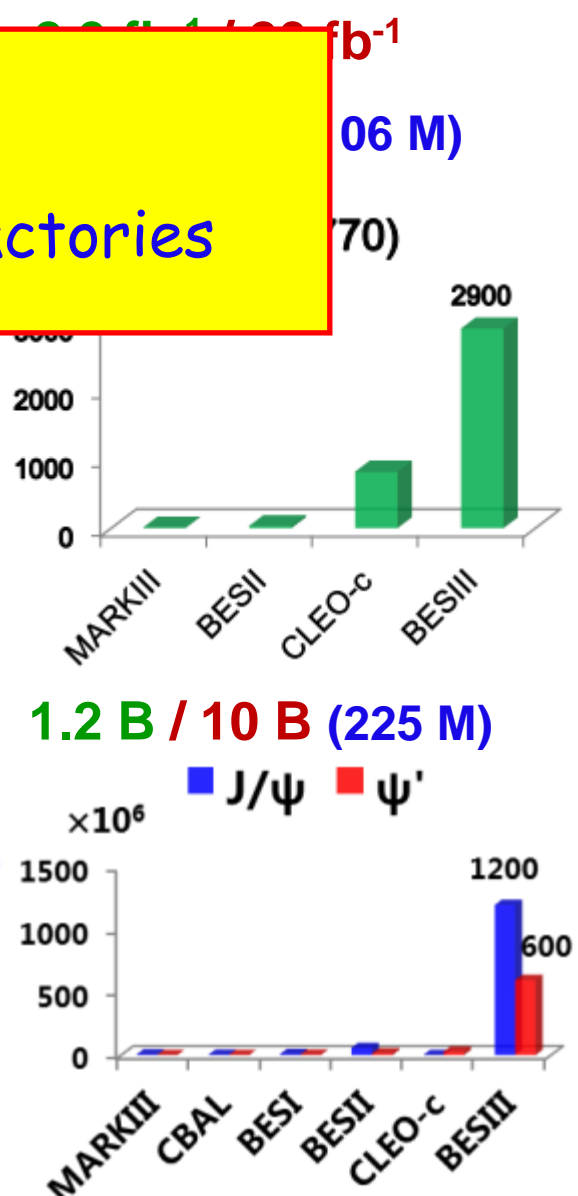




BESIII data set



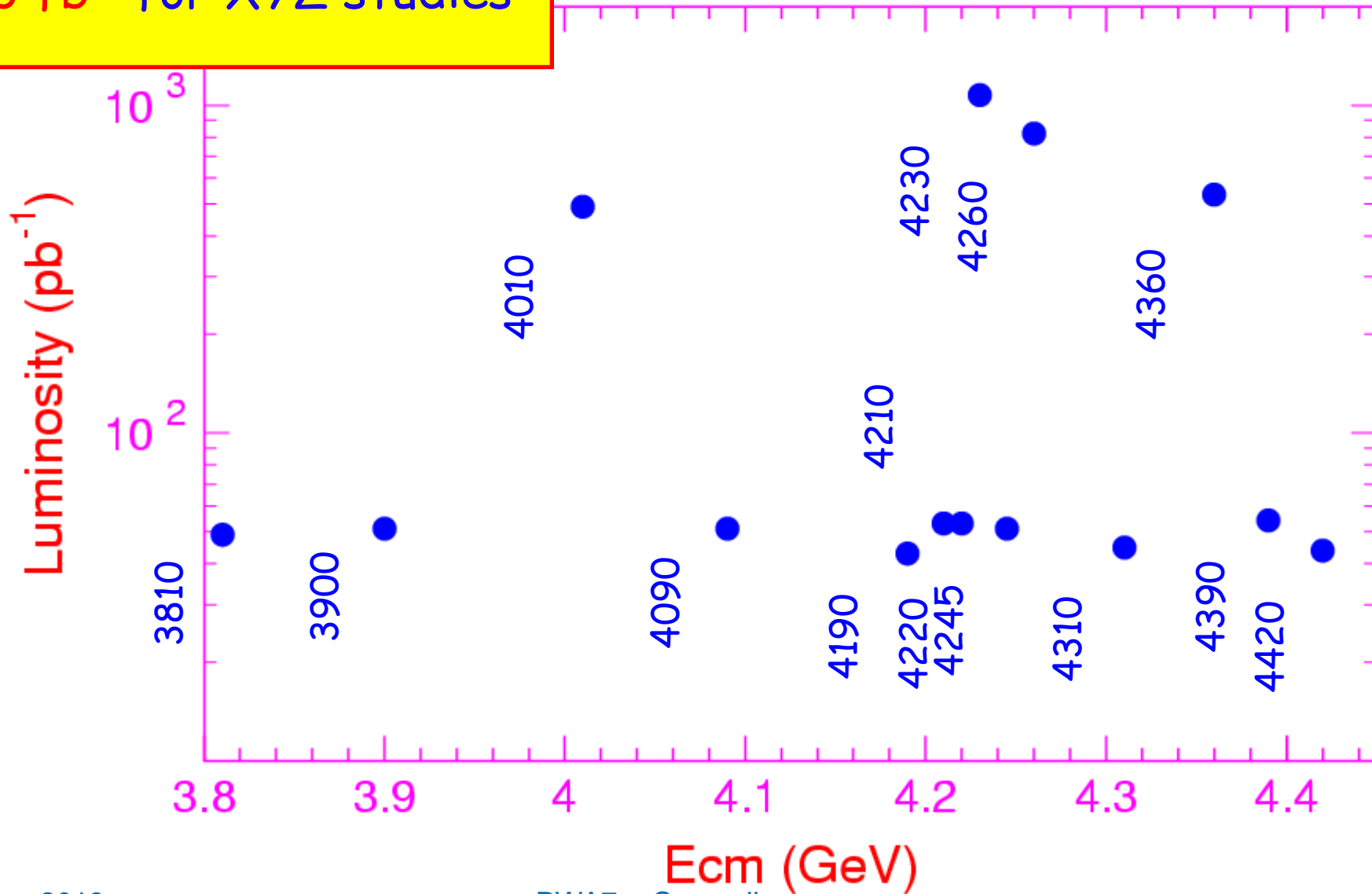
10 ÷ 20 ×
previous generation charm factories





BESIII data set

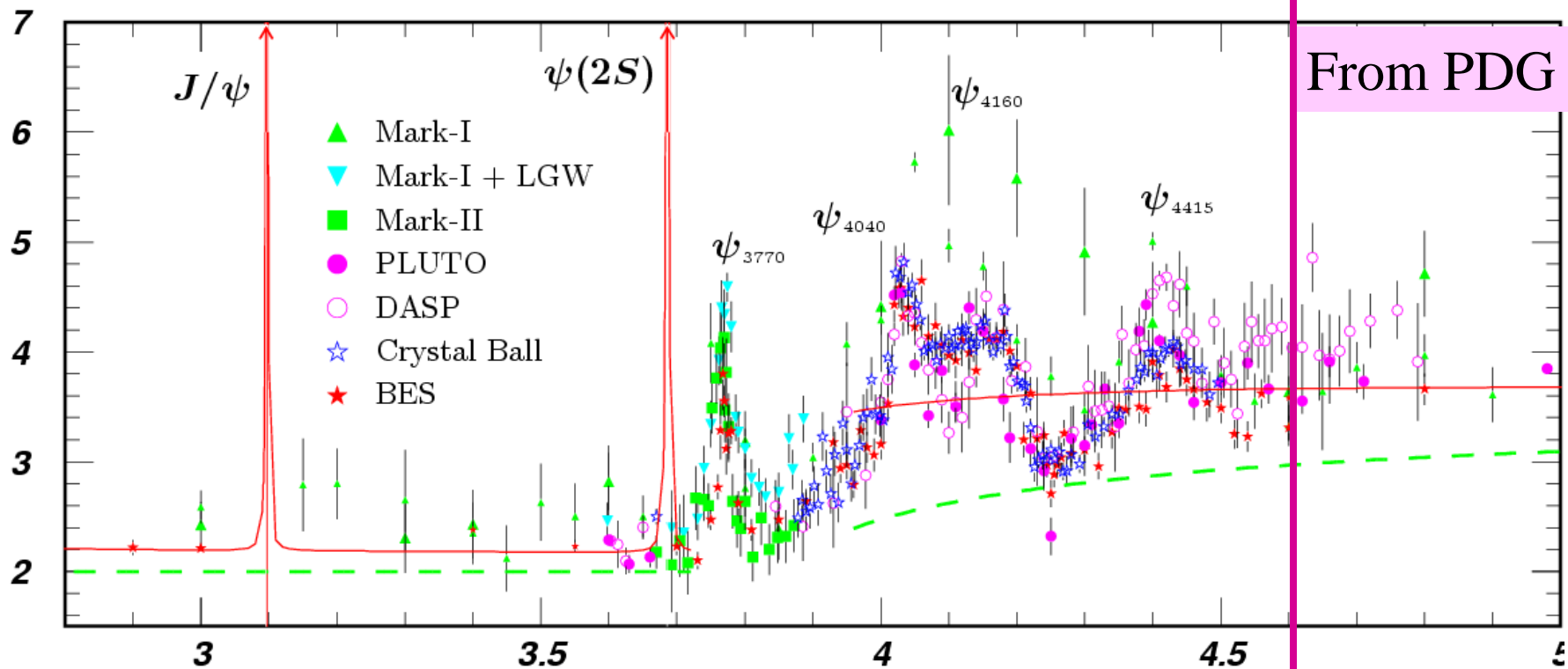
3.3 fb⁻¹ for XYZ studies





BESIII production of Charmonium(like) states

R

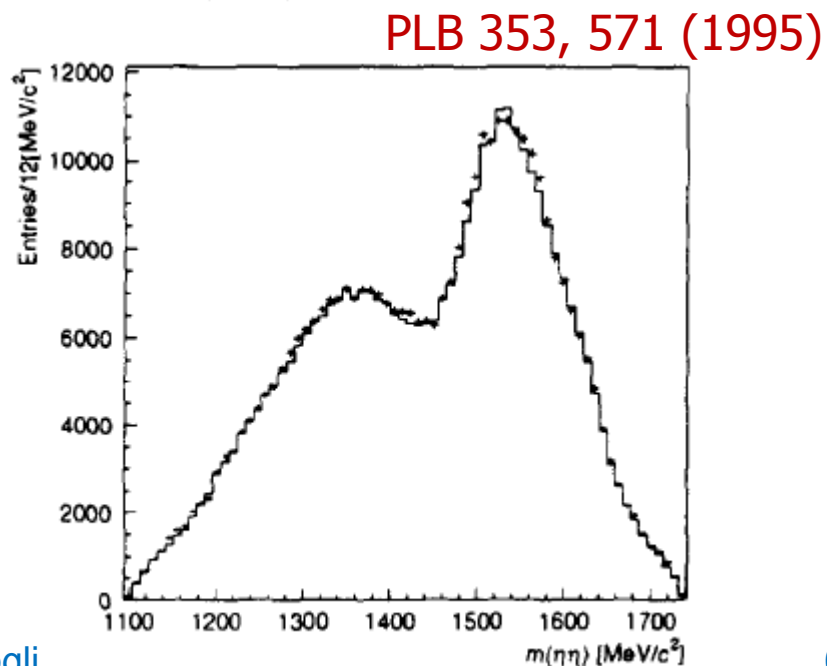
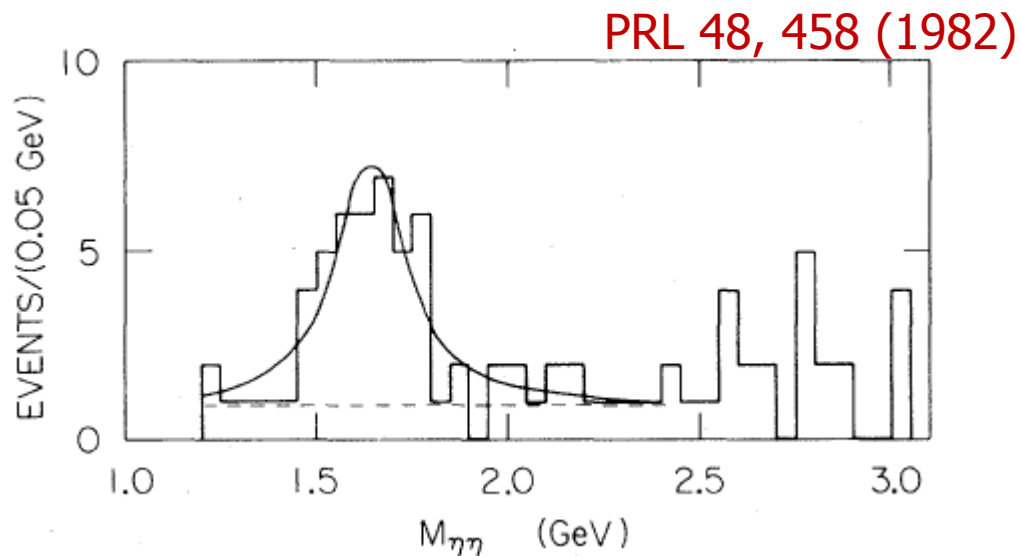


BEPCII can reach here!



$J/\psi \rightarrow \gamma\eta\eta$

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





best solution:

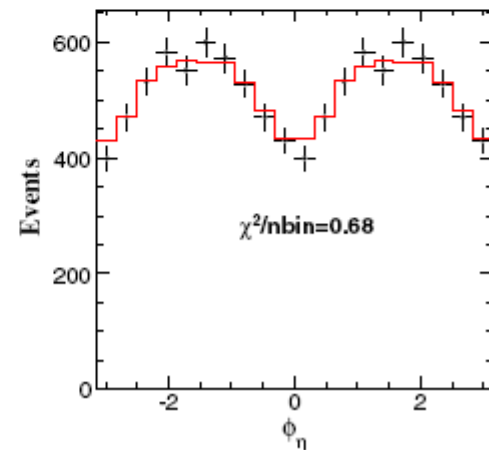
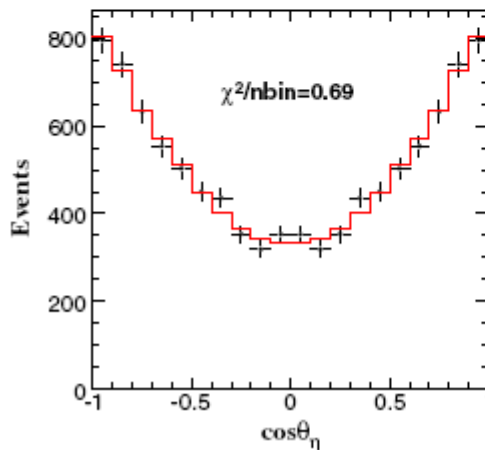
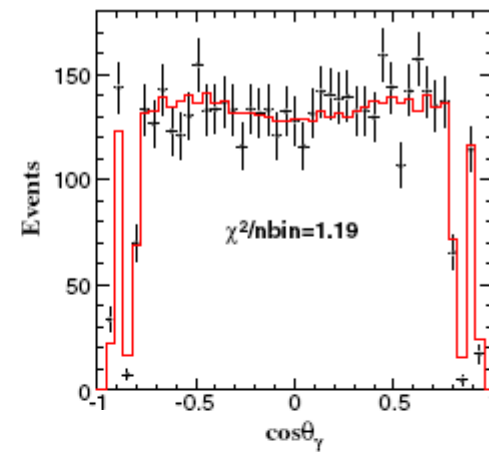
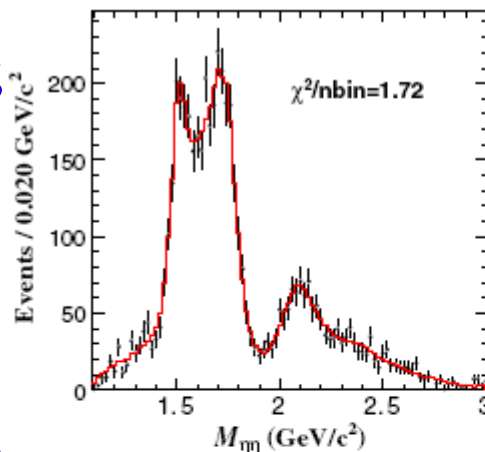
- $f_0(1500), f_0(1710), f_0(2100);$
 $f_0'(1525), f_0(1810), f_0(2340);$
 0^{++} phase space, $\phi\eta$

no significant evidence of:

- scalar:
 $f_0(1370), f_0(1790), f_0(2020)$
 $f_0(2200), f_0(2330)$
- tensor:
 $f_2(2010), f_2(2150), f_J(2220)$
 source of sys. unc.

$\phi\eta$ background:

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





Resonance	Mass(MeV/c ²)	Width(MeV/c ²)	$\mathcal{B}(J/\psi \rightarrow \gamma X \rightarrow \gamma\eta\eta)$	Significance
$f_0(1500)$	1468^{+14+23}_{-15-74}	$136^{+41+28}_{-26-100}$	$(1.65^{+0.26+0.51}_{-0.31-1.40}) \times 10^{-5}$	8.2σ
$f_0(1710)$	$1759 \pm 6^{+14}_{-25}$	$172 \pm 10^{+32}_{-16}$	$(2.35^{+0.13+1.24}_{-0.11-0.74}) \times 10^{-4}$	25.0σ
$f_0(2100)$	$2081 \pm 13^{+24}_{-36}$	273^{+27+70}_{-24-23}	$(1.13^{+0.09+0.64}_{-0.10-0.28}) \times 10^{-4}$	13.9σ
$f'_2(1525)$	$1513 \pm 5^{+4}_{-10}$	75^{+12+16}_{-10-8}	$(3.42^{+0.43+1.37}_{-0.51-1.30}) \times 10^{-5}$	11.0σ
$f_2(1810)$	1822^{+29+66}_{-24-57}	$229^{+52+88}_{-42-155}$	$(5.40^{+0.60+3.42}_{-0.67-2.35}) \times 10^{-5}$	6.4σ
$f_2(2340)$	$2362^{+31+140}_{-30-63}$	$334^{+62+165}_{-54-100}$	$(5.60^{+0.62+2.37}_{-0.65-2.07}) \times 10^{-5}$	7.6σ

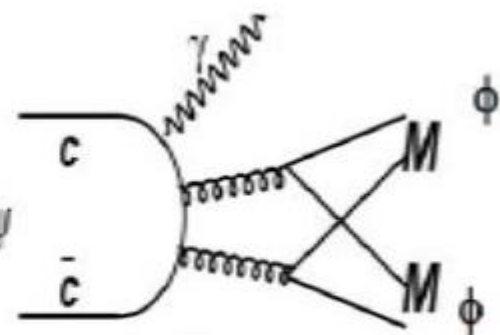
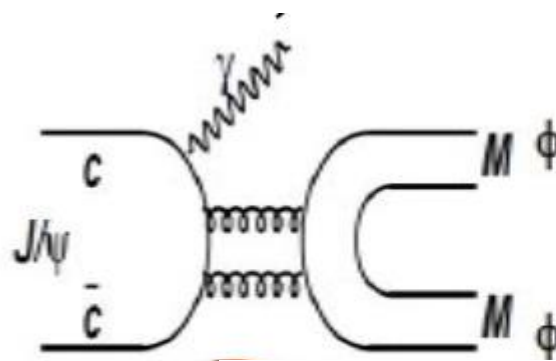
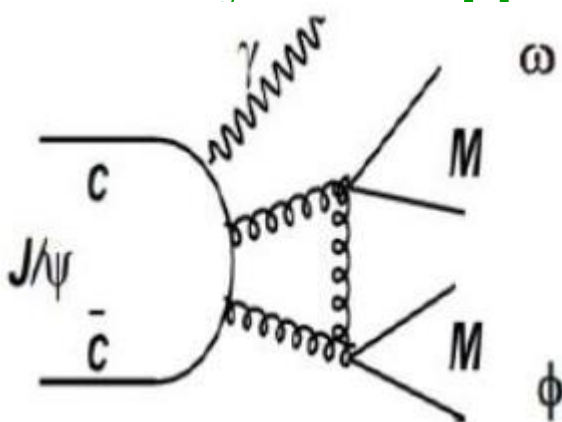
no significant evidence of:

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



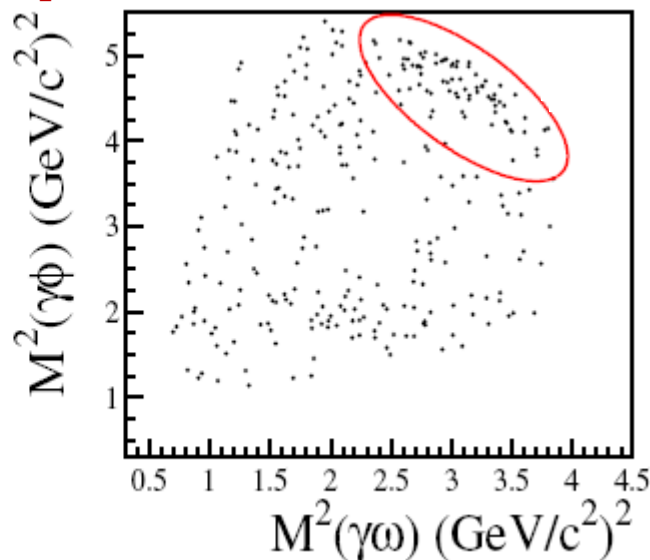
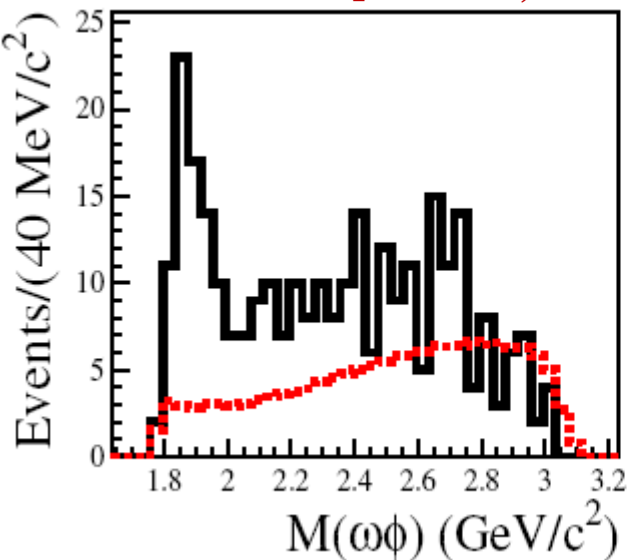
$J/\psi \rightarrow \gamma \omega \phi$

- doubly OZI suppressed



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

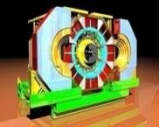
- BESII: [PRL 96, 162002]



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

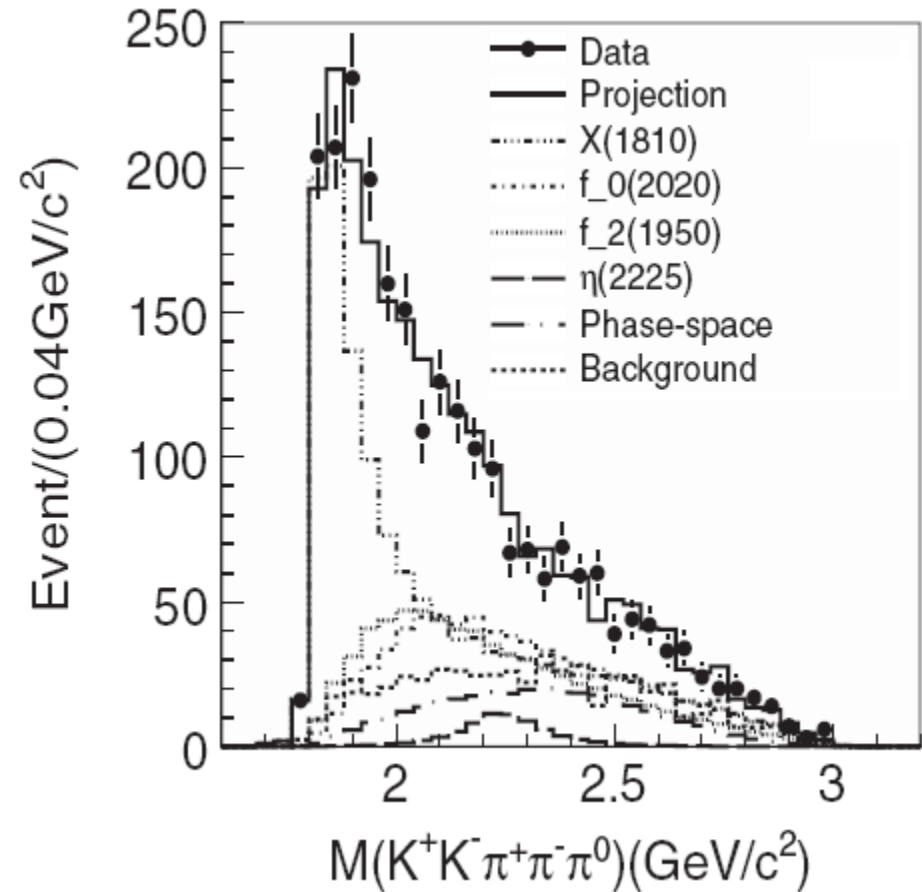
$$\Gamma = (105 \pm 20 \pm 28) \text{ MeV}/c^2$$

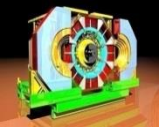
0^{++} favoured over
 0^{-+} and 2^{++}



- **looking for best solution:**
 - M , Γ and J^{PC} of $X(1810)$
 - other know mesons [PDG]
 - different J^{PC} of phase space
 - different combinations of additional mesons [PDG]
- **best solution:**

$X(1810)$, $f_0(2020)$, $f_2(1950)$, $\eta(2225)$, $f_0(2020)$, phase space and background
- **systematic uncertainties:**
 - $f_2(1920)$, $f_0(2020)$, $\eta(2225)$: standard deviation from PDG, replacing by other of similar mass but same J^{PC}
 - model dependence





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

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

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

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

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

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

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

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

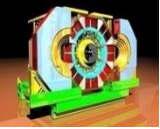
unconclusive, further investigation is needed

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

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

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

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

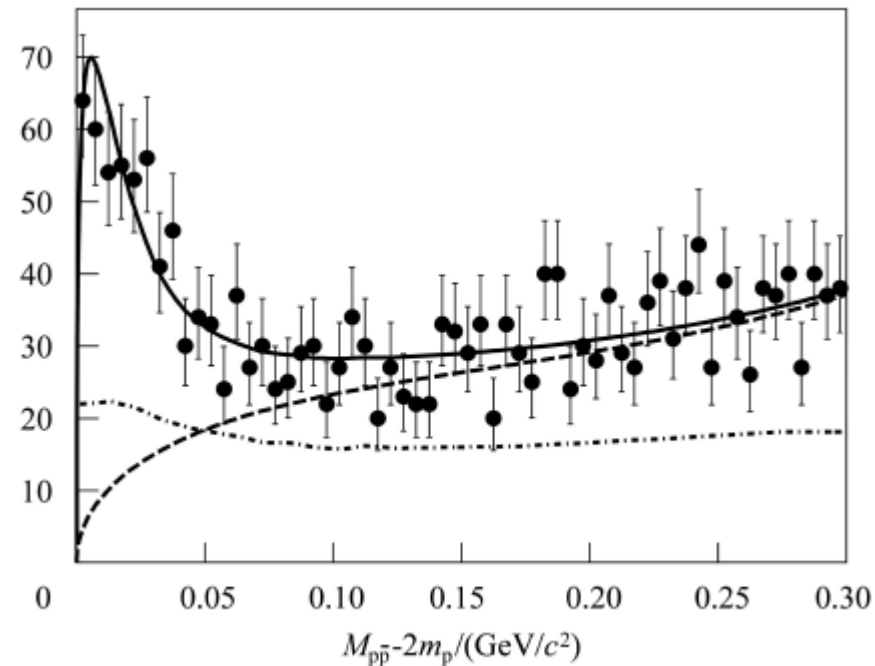
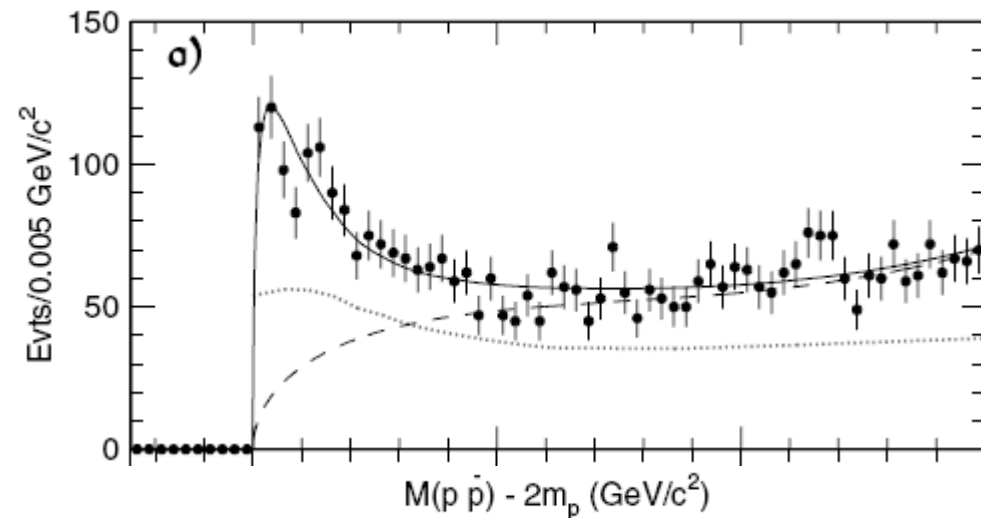


$J/\psi \rightarrow \gamma p\bar{p}$: enhancement at threshold

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

BESII: PRL 91, 022001 (2003)

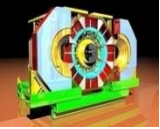
BESIII: CPC 34, 421 (2010)



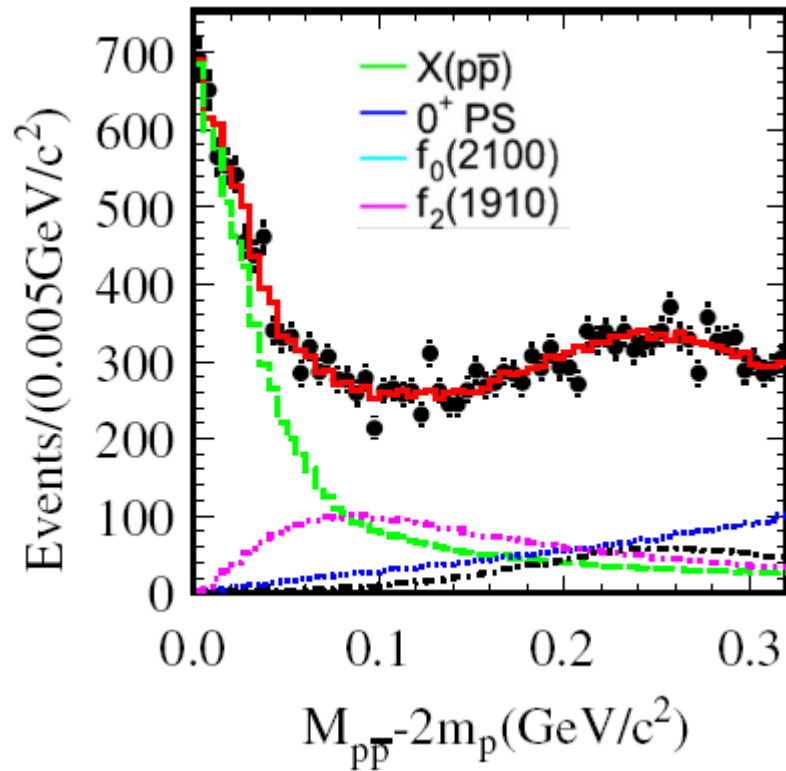
$M = (1860_{-10}^{+3} \quad -25^{+5}) \text{ MeV}/c^2$
 $\Gamma < 38 \text{ MeV}/c^2$ (90% C.L.)
 compatible with S-wave BW

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

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



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



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

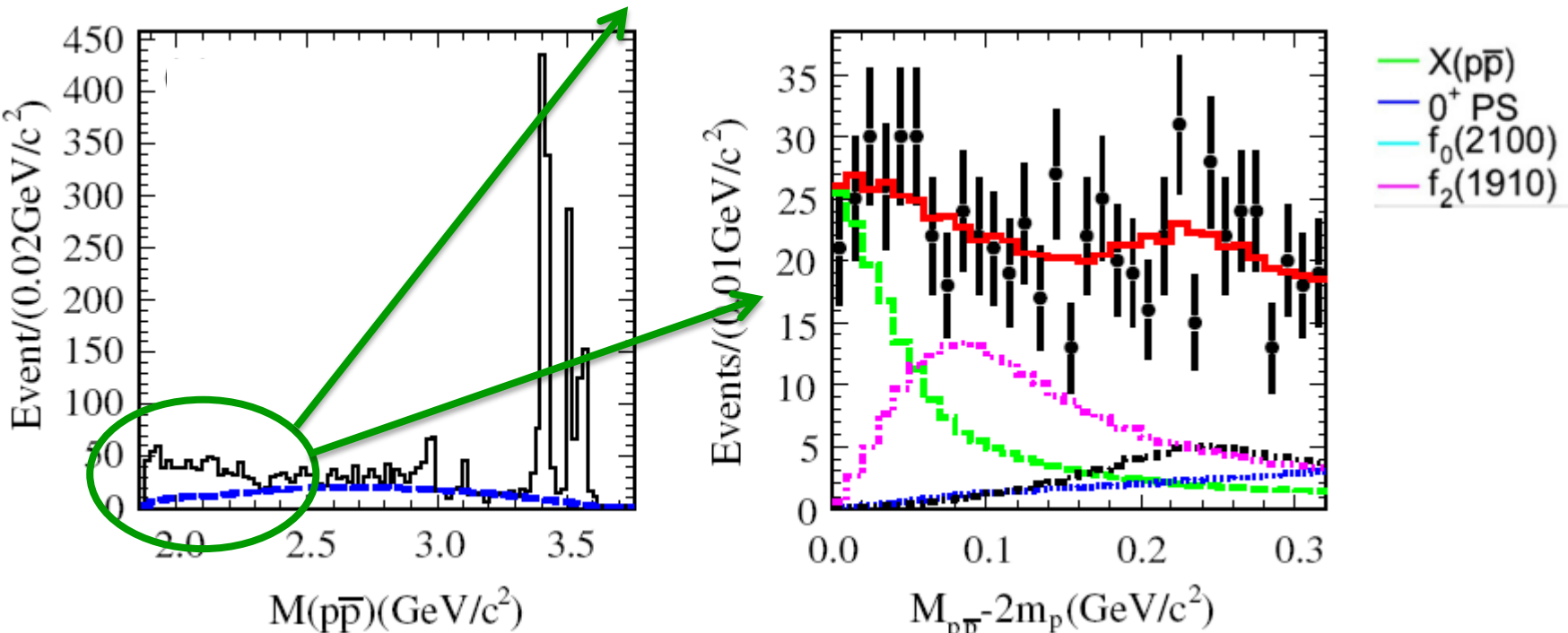
$$M = 1832_{-5}^{+19}(\text{stat})_{-17}^{+18}(\text{sys}) \pm 19(\text{mod}) \text{ MeV}/c^2$$

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

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



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



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

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

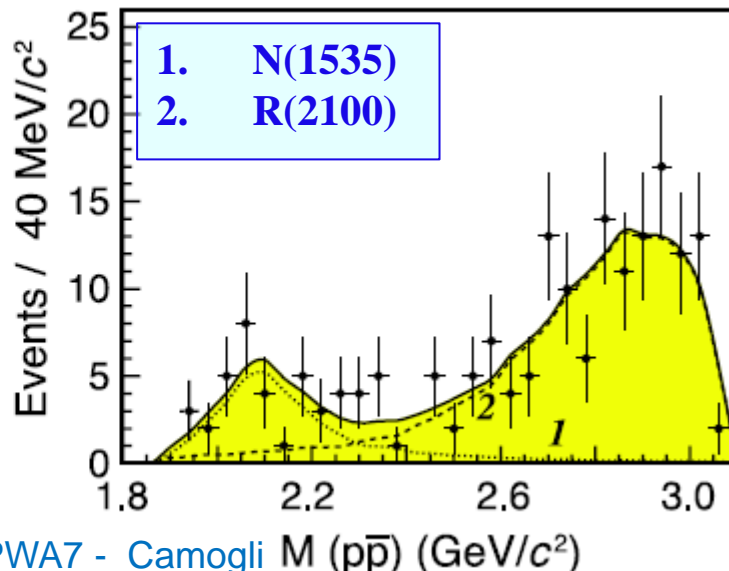
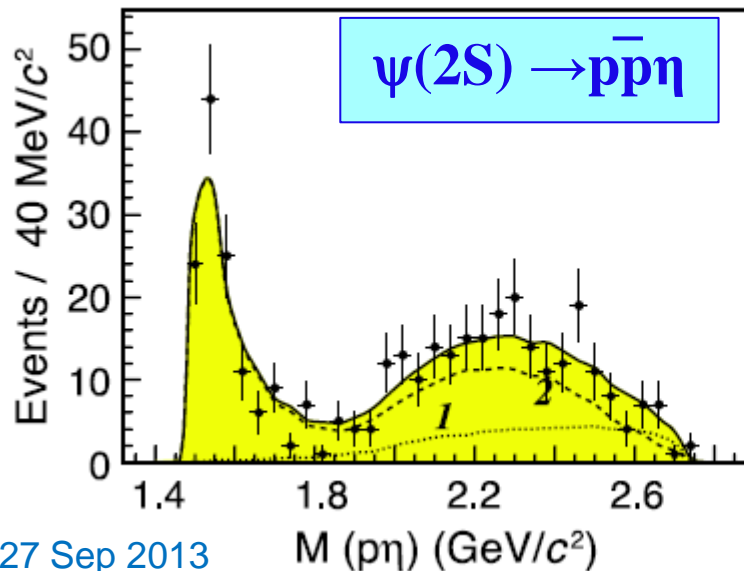
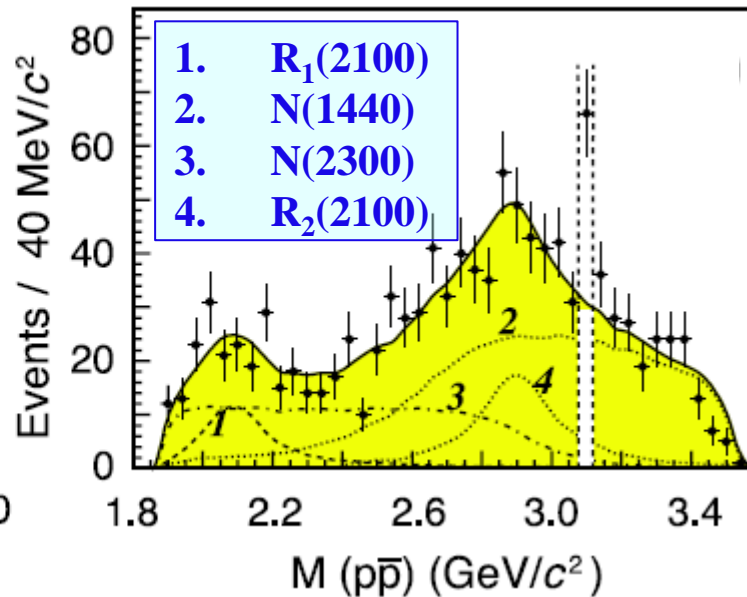
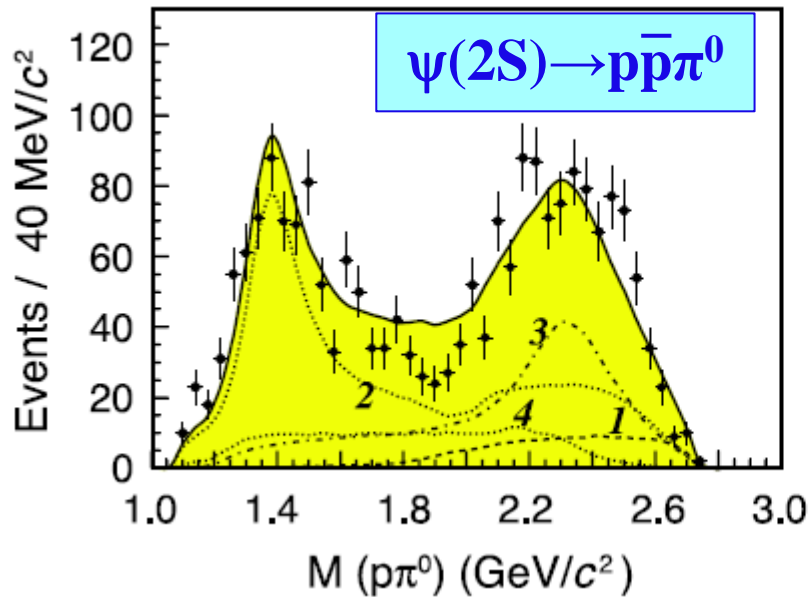
$$4.57 \pm 0.36(\text{stat})^{+1.23}_{-4.07}(\text{sys}) \pm 1.28(\text{mod}) \times 10^{-6}$$

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



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

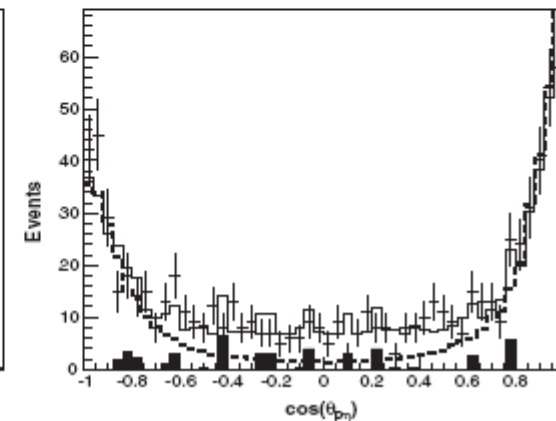
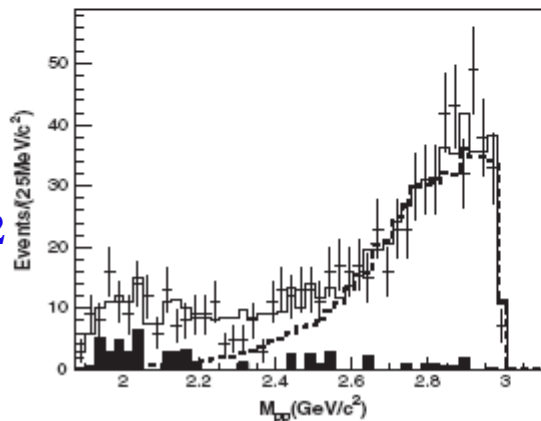
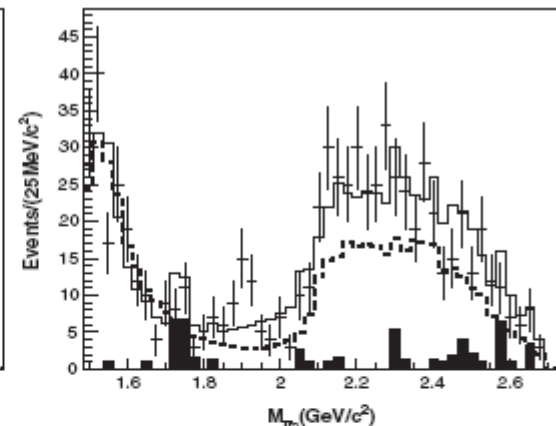
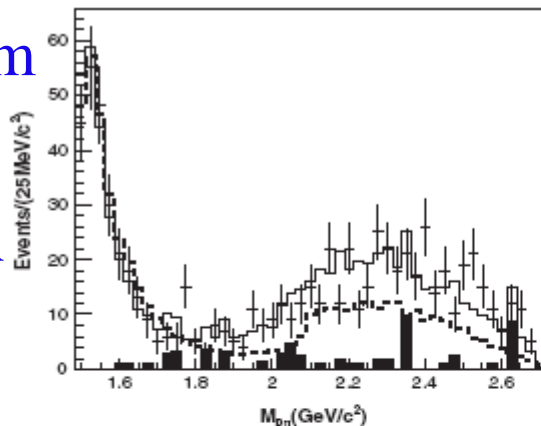
CLEOc: 24.5 M $\psi(2S)$ [PRD 82, 092002]



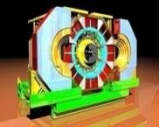
Without interference effects



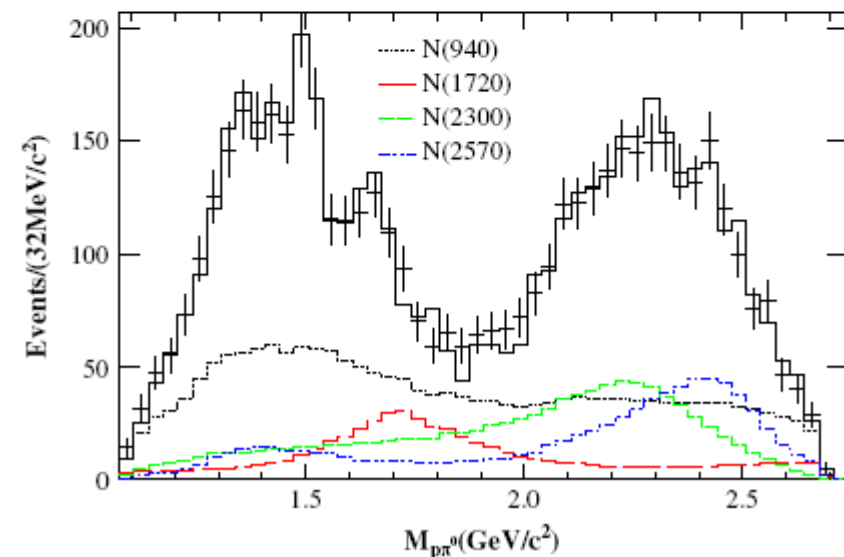
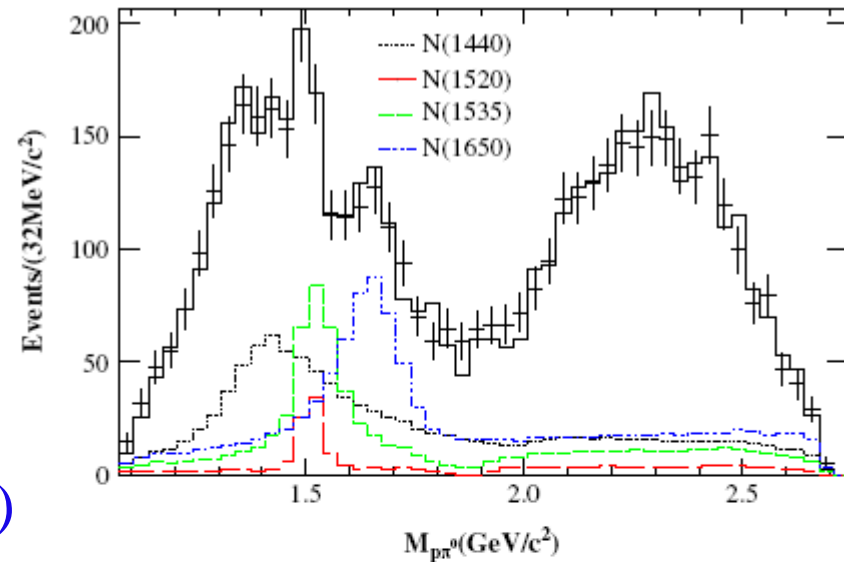
- **low background:**
 - sidebands and continuum
- **best solution:**
N(1535) combined with an interfering phase space
- **$p\bar{p}$ enhancement:**
 $<3\sigma$
- **N(1535):**
 - $M = (1524 \pm 5^{+10}_{-4}) \text{ MeV}/c^2$
 - $\Gamma = (130^{+27+10}_{-24 -10}) \text{ MeV}/c^2$
- **suppressed ($<12\%$):**

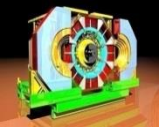


$$Q_{p\bar{p}\eta} = \frac{\mathcal{B}(\psi(2S) \rightarrow p\bar{p}\eta)}{\mathcal{B}(J/\psi \rightarrow p\bar{p}\eta)} = (3.2 \pm 0.46)\%$$

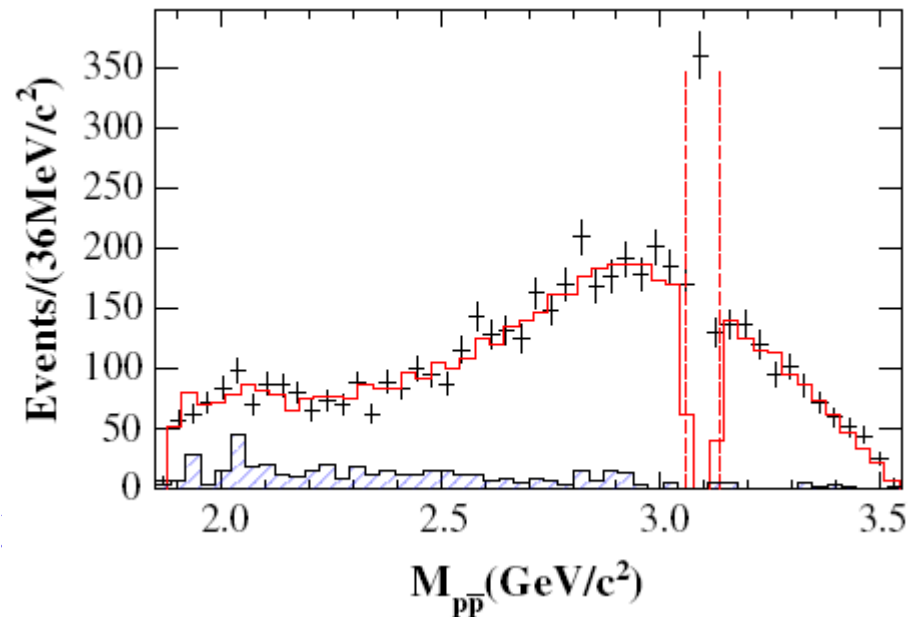


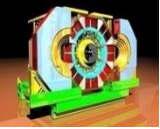
- **2-body decay:**
 - $\psi(2S) \rightarrow X\pi^0, X \rightarrow p\bar{p}$
 - $\psi(2S) \rightarrow p\bar{N}^*, \bar{N}^* \rightarrow \bar{p}\pi^0 + c.c.$
- **isospin conservation:**
 - Δ suppressed
- **best solution:**
 - N(1440), N(1520), N(2090), N(1535)
 - N(1650), N(1720),
 - N(2300) [1/2⁺], N(2570)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





- **2-body decay:**
 - $\psi(2S) \rightarrow X\pi^0, X \rightarrow p\bar{p}$
 - $\psi(2S) \rightarrow p\bar{N}^*, \bar{N}^* \rightarrow \bar{p}\pi^0 + c.c.$
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 - N(2300) [1/2⁺], N(2570) [5/2⁻]**
- **no significant evidence:**
 - N(1885), N(2065)
 - $p\bar{p}$ enhancement
- **systematic uncertainties:**
 - additional possible resonances





▪ **branching fraction:**

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

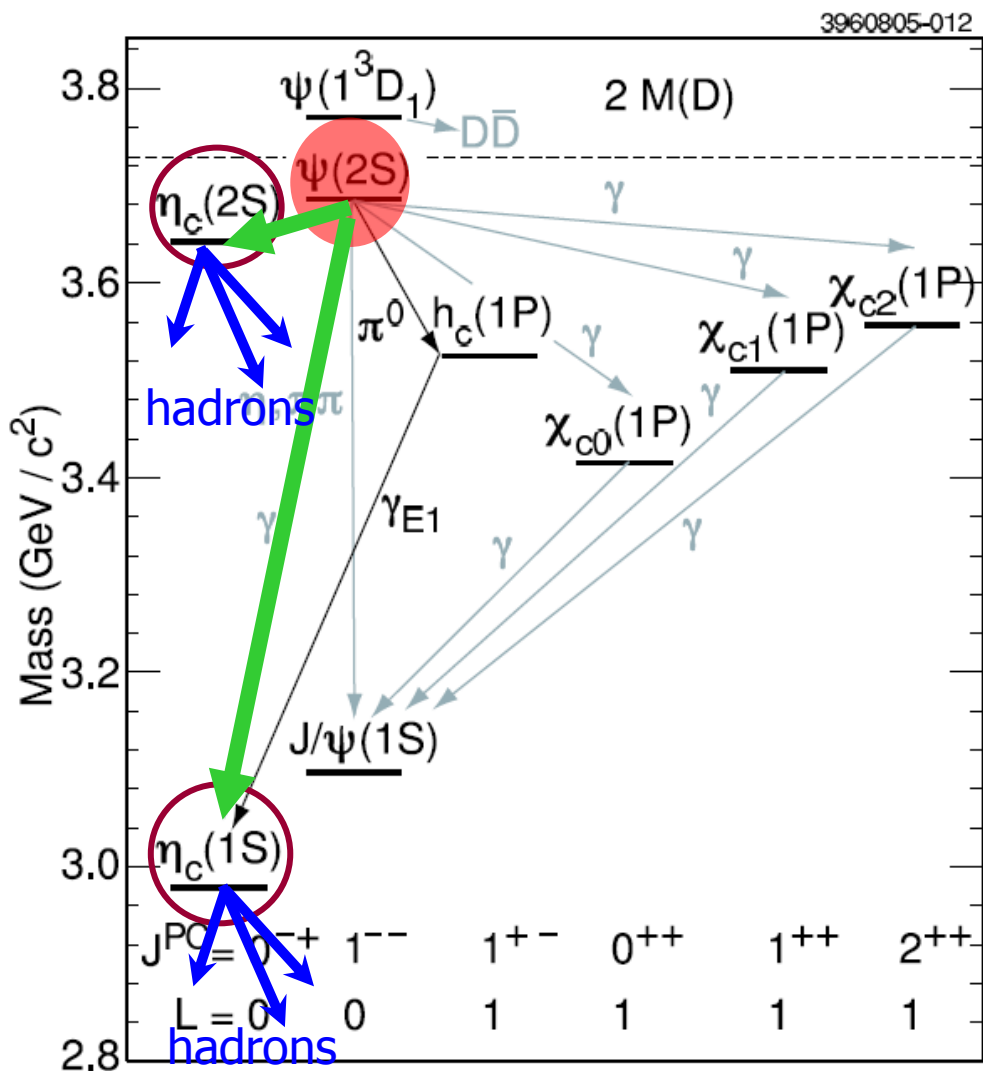
▪ **PWA:**

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

Resonance	$M(\text{MeV}/c^2)$	$\Gamma(\text{MeV}/c^2)$	ΔS	ΔN_{dof}	Sig.
N(1440)	1390^{+11+21}_{-21-30}	$340^{+46+70}_{-40-156}$	72.5	4	11.5σ
N(1520)	1510^{+3+11}_{-7-9}	115^{+20+0}_{-15-40}	19.8	6	5.0σ
N(1535)	1535^{+9+15}_{-8-22}	120^{+20+0}_{-20-42}	49.4	4	9.3σ
N(1650)	1650^{+5+11}_{-5-30}	150^{+21+14}_{-22-50}	82.1	4	12.2σ
N(1720)	1700^{+30+32}_{-28-35}	$450^{+109+149}_{-94-44}$	55.6	6	9.6σ
N(2300)$_{1/2^+}$	$2300^{+40+109}_{-30-0}$	$340^{+30+110}_{-30-58}$	120.7	4	15.0σ
N(2570)$_{5/2^-}$	2570^{+19+34}_{-10-10}	250^{+14+69}_{-24-21}	78.9	6	11.7σ



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



η_c mass:
charmonium
ground state

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



$\eta_c(1S)$

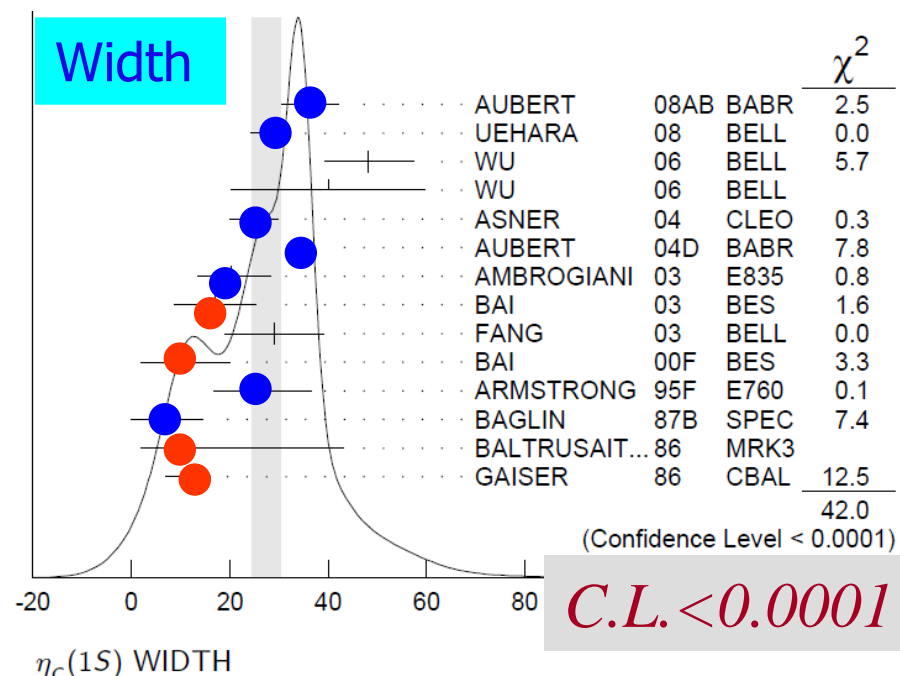
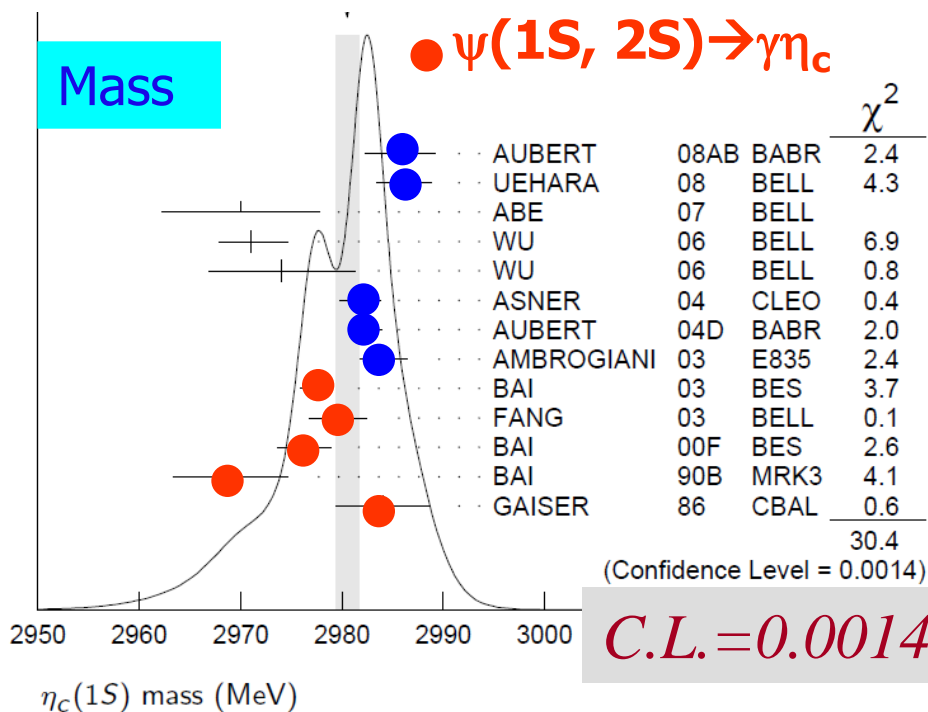
The S-wave spin-singlet charmonium ground state, found in 1980

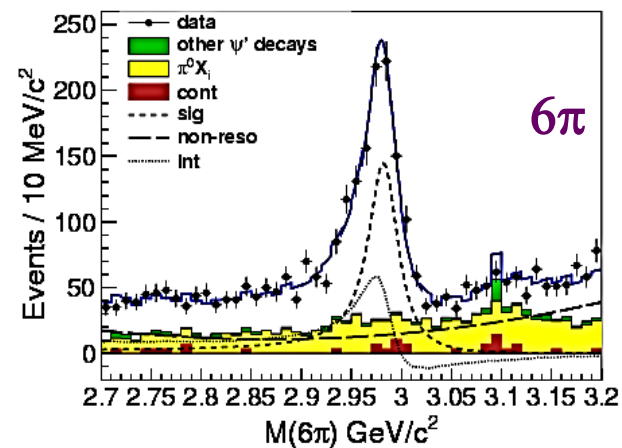
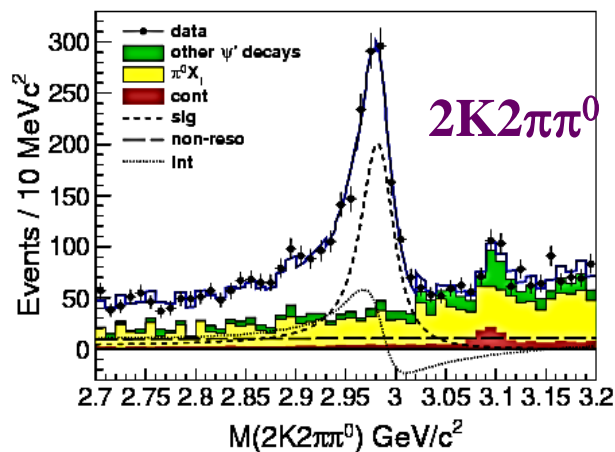
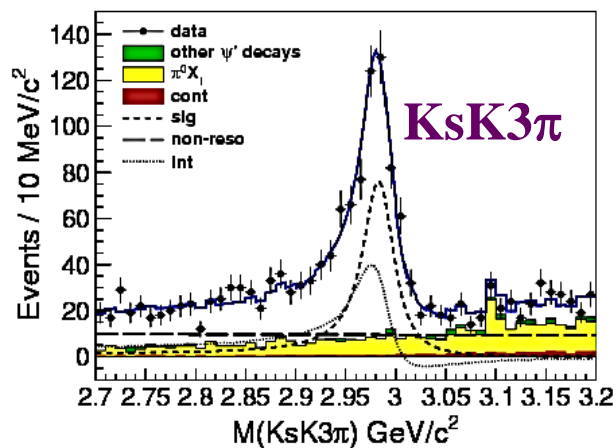
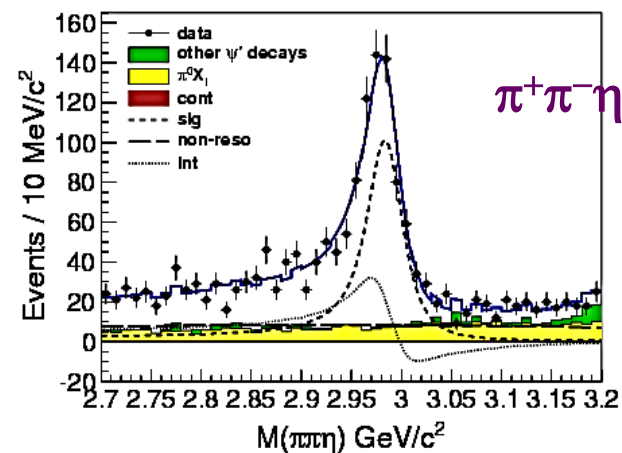
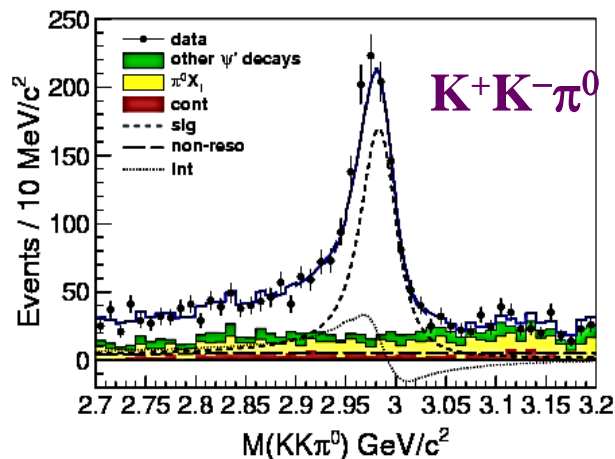
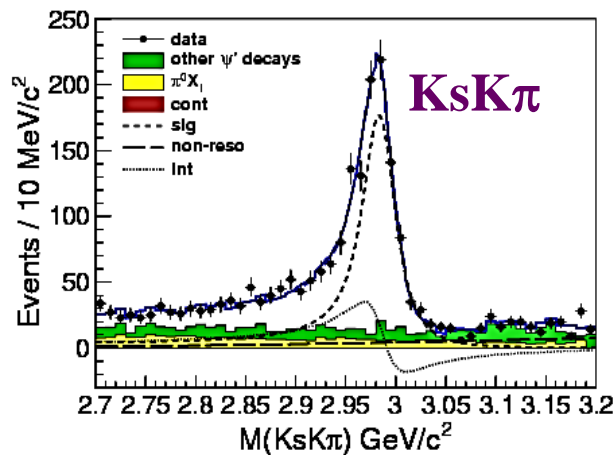
M & Γ measurements:

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

● $\gamma\gamma$, $p\bar{p}$, B decay

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

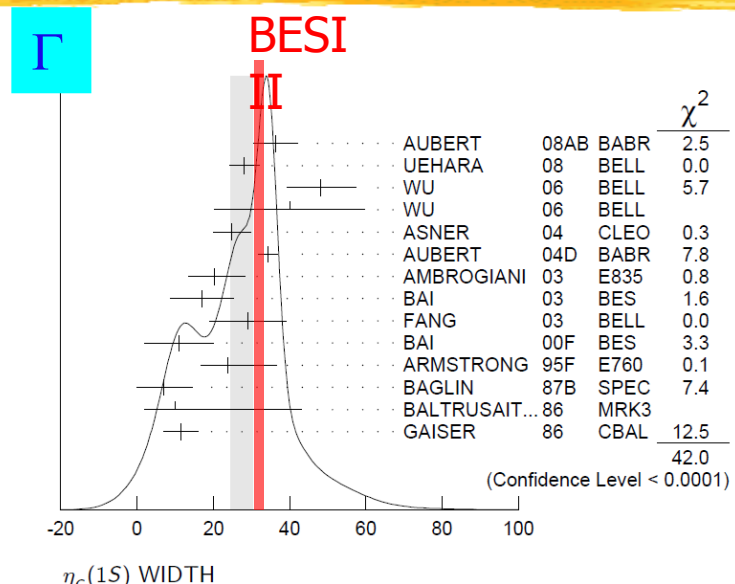
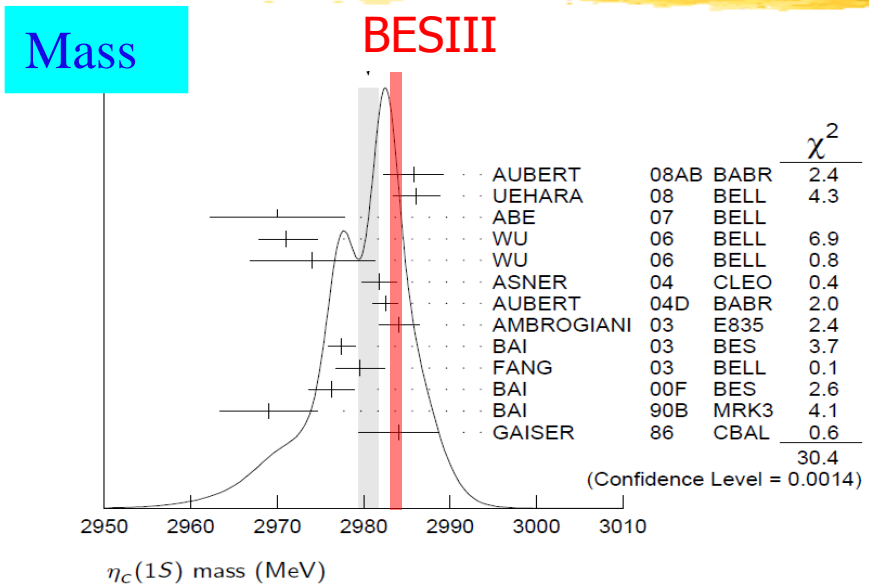




Significant interference between η_c and non-resonant

→ simultaneous fit to 6 modes, Mass = $2984.3 \pm 0.6 \pm 0.6$ MeV/c²

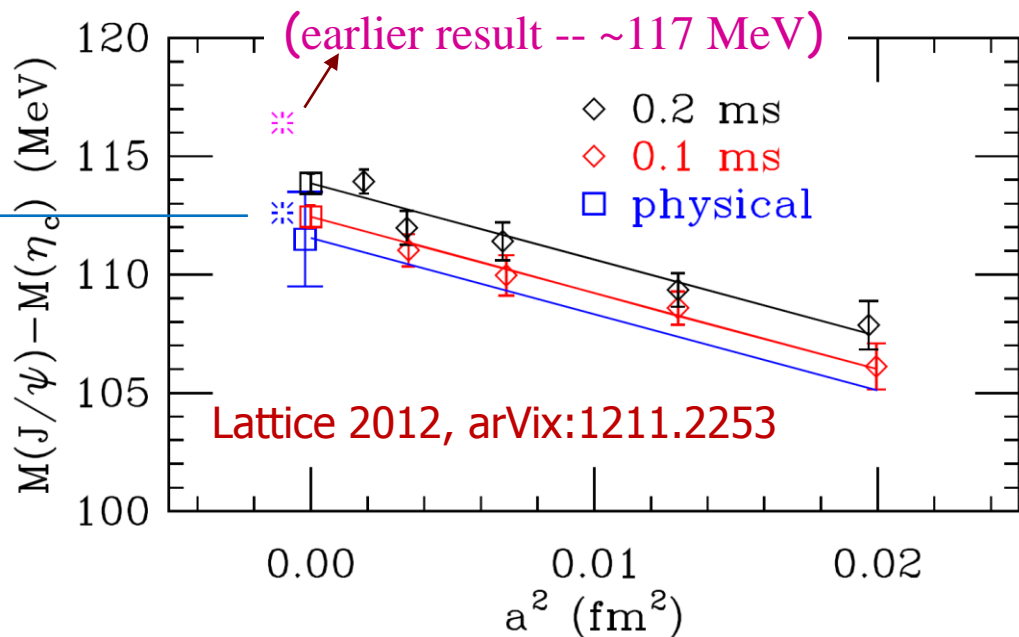
$\Gamma = 32.0 \pm 1.2 \pm 1.0$ MeV/c²

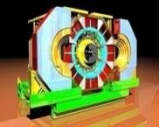


Hyperfine splitting (BESIII alone)

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

Closer to prediction
then earlier result





Observed in different production mechanisms

1. $B \rightarrow K\eta_c'$ Belle: PRL 89 102001 (2002)
CLEOc: PRL 92 142001 (2004)
2. $\gamma\gamma \rightarrow \eta_c' \rightarrow KK\pi$ Belle: NPPS.184 220 (2008); PRL 98 082001(2007)
BaBar: PRL 92 142002 (2004); PR D72 031101(2005)
3. double charmonium production BaBar: PR D84 012004 (2011)

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

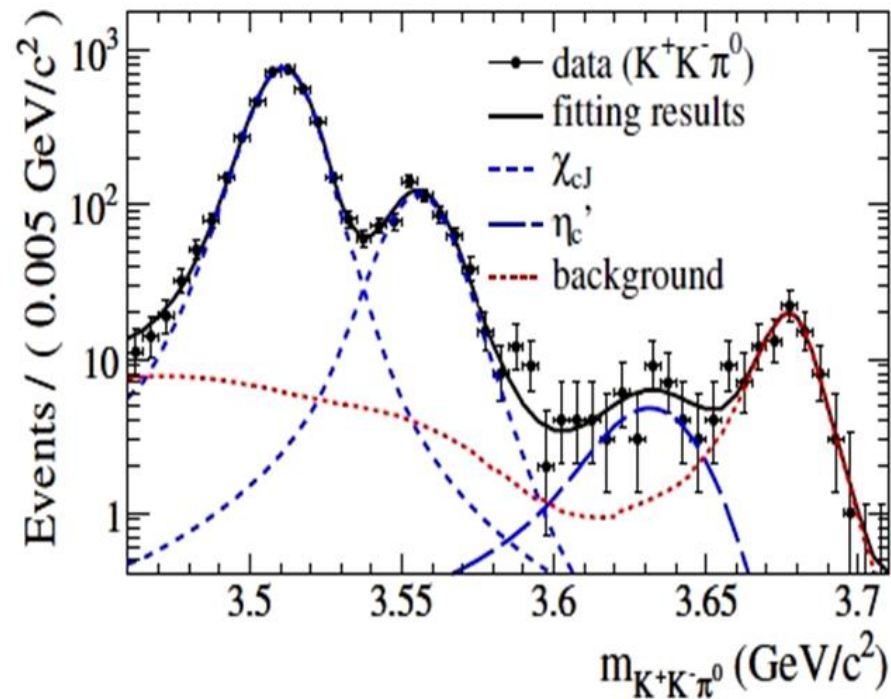
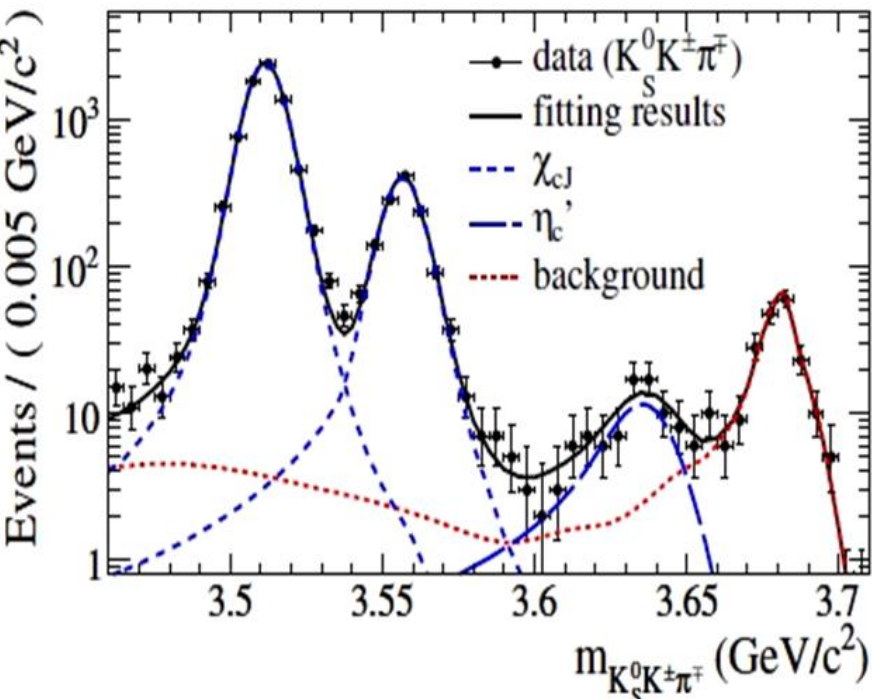
1. CLEO found no signal in 25M ψ' .

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

PRD 81 052002 (2010)

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

Experimental challenge : search for photons of 50 MeV



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

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

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

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

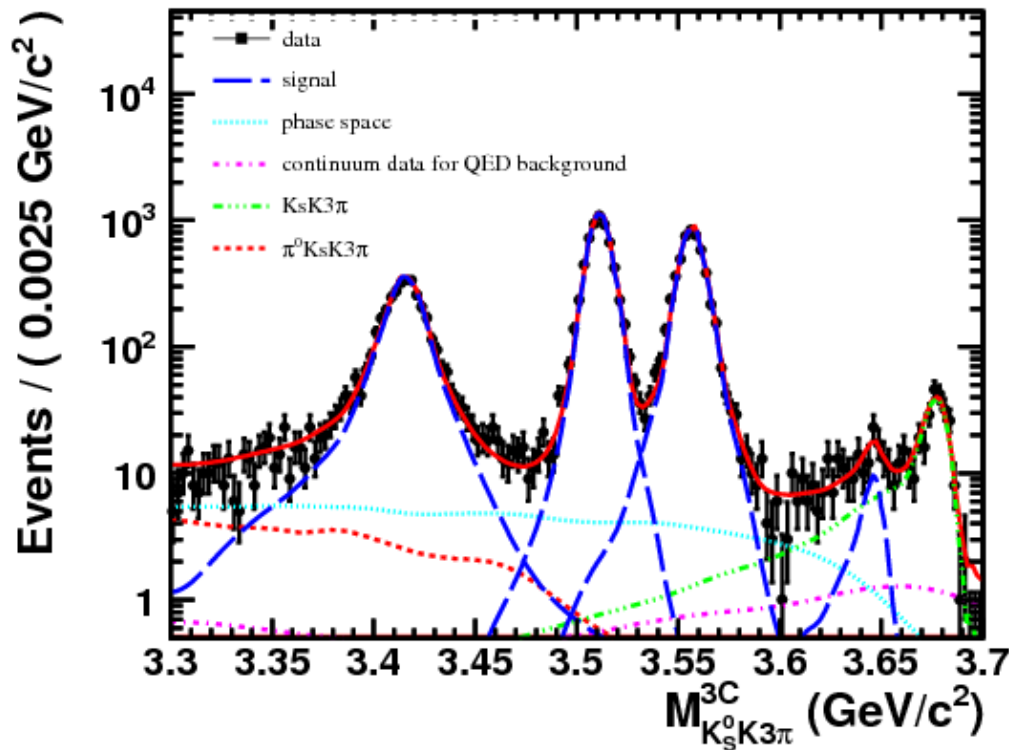
BABAR: PRD78, 012006 (2008)

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

FIRST OBSERVATION!

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

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



Significance

4.2 σ

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

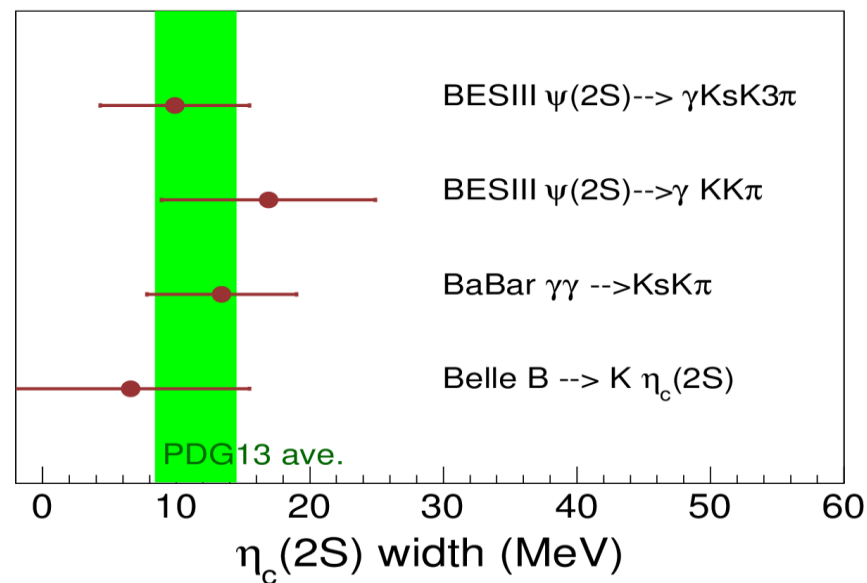
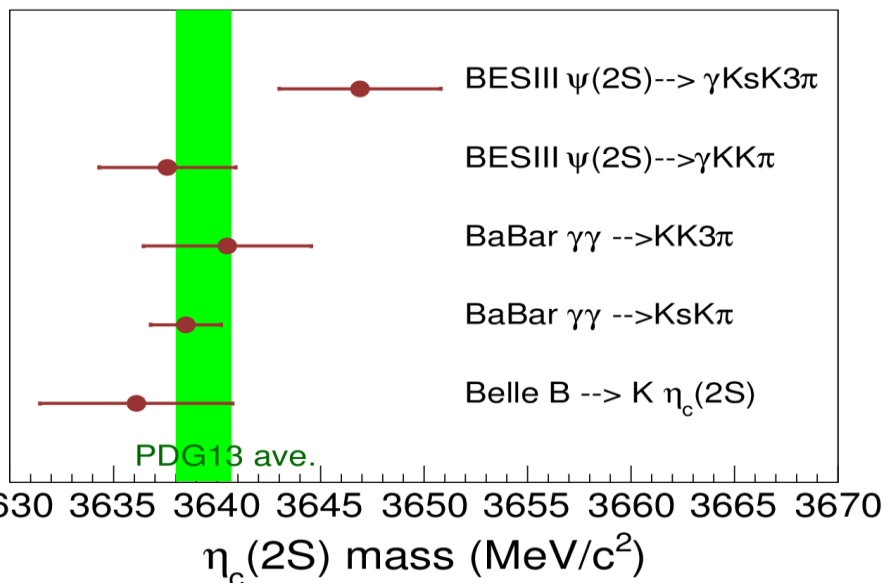
$$\Gamma = 9.2 \pm 4.8 \pm 2.9 \text{ MeV}/c^2$$

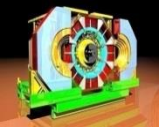
$$\mathcal{B}(\psi' \rightarrow \gamma\eta_c' \rightarrow \gamma K_s K3\pi) = (7.03 \pm 2.10 \pm 0.70) \times 10^{-6}$$



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

PRL 109, 042003
PRD 87, 052005

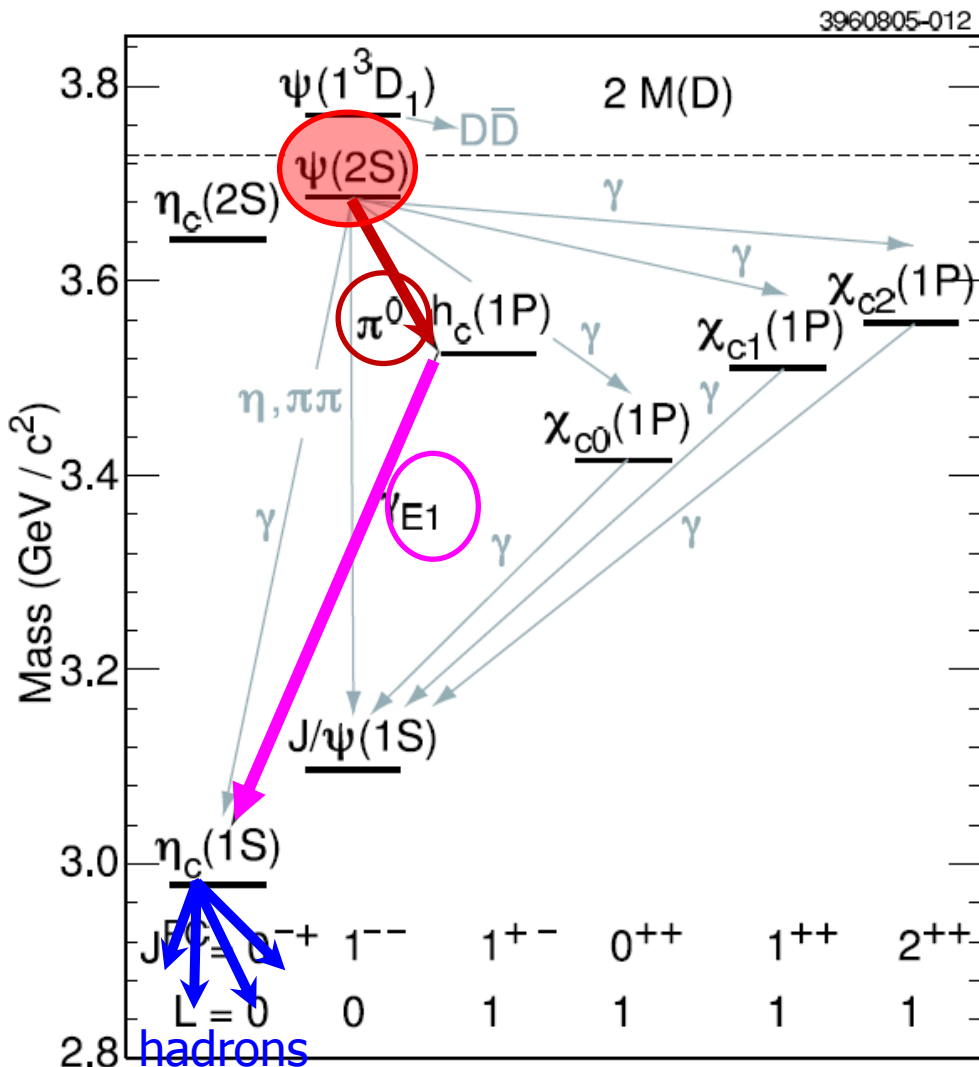




$h_c(1P)$

- **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:**
 - $\mathcal{B}(\psi' \rightarrow \pi^0 h_c) = (0.4-1.3) \times 10^{-3}$, $\mathcal{B}(h_c \rightarrow \gamma \eta_c) = 41\%$ (NRQCD)
 $\mathcal{B}(h_c \rightarrow \gamma \eta_c) = 88\%$ (PQCD)

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



“inclusive”

only detect the π^0

(compute $M(h_c)$ from kinematic)

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

“E1 tagged”

detect the π^0 & γ

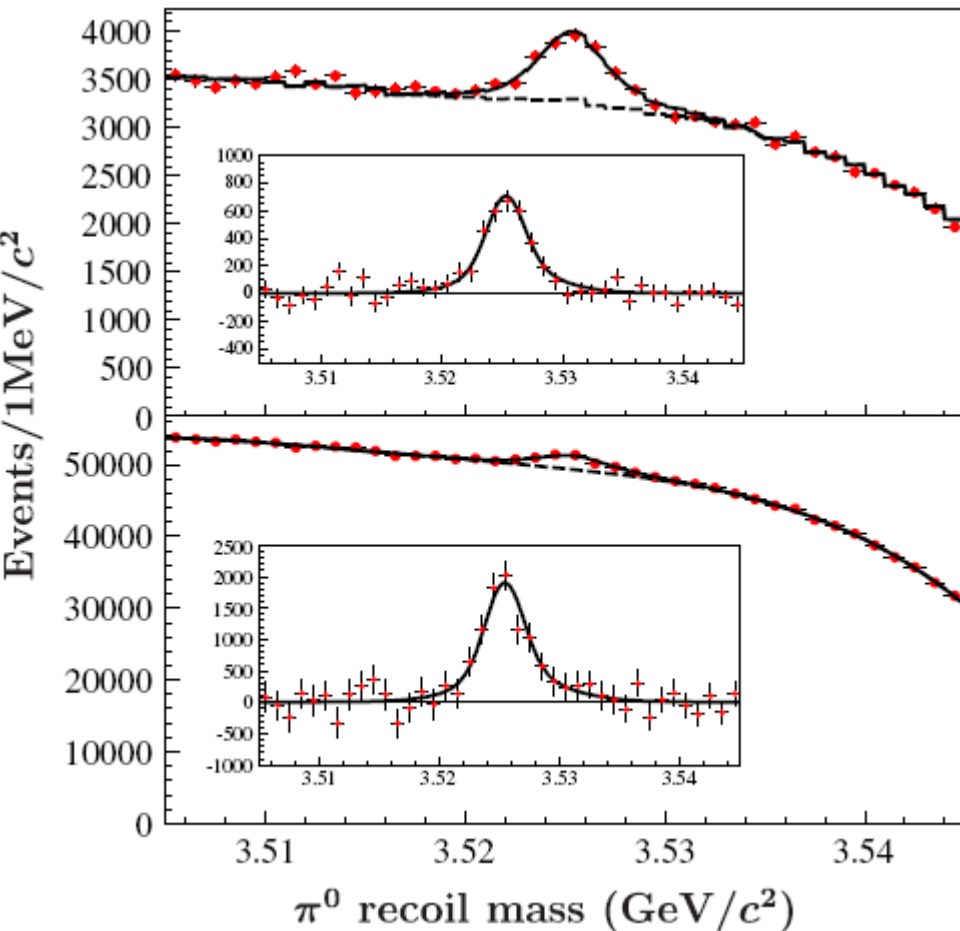
Rate $\propto \mathcal{B}(\psi' \rightarrow \pi^0 h_c) \times \mathcal{B}(h_c \rightarrow \gamma \eta_c)$

“exclusive”

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

Rate \propto

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



$M = 3525.40 \pm 0.13 \pm 0.18 \text{ MeV}/c^2$
 $\Gamma = 0.73 \pm 0.45 \pm 0.28 \text{ MeV}/c^2$
 $< 1.44 \text{ MeV} @ 90\%$

CLEOc: PRL 101 182003 (2008)

$M = 3525.28 \pm 0.19 \pm 0.12 \text{ MeV}/c^2$
 Γ : fixed at 0.9 MeV

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

BESIII: $0.10 \pm 0.13 \pm 0.18 \text{ MeV}/c^2$
 CLEOc: $0.02 \pm 0.19 \pm 0.13 \text{ MeV}/c^2$

By combining inclusive results with E1-photon tagged results

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

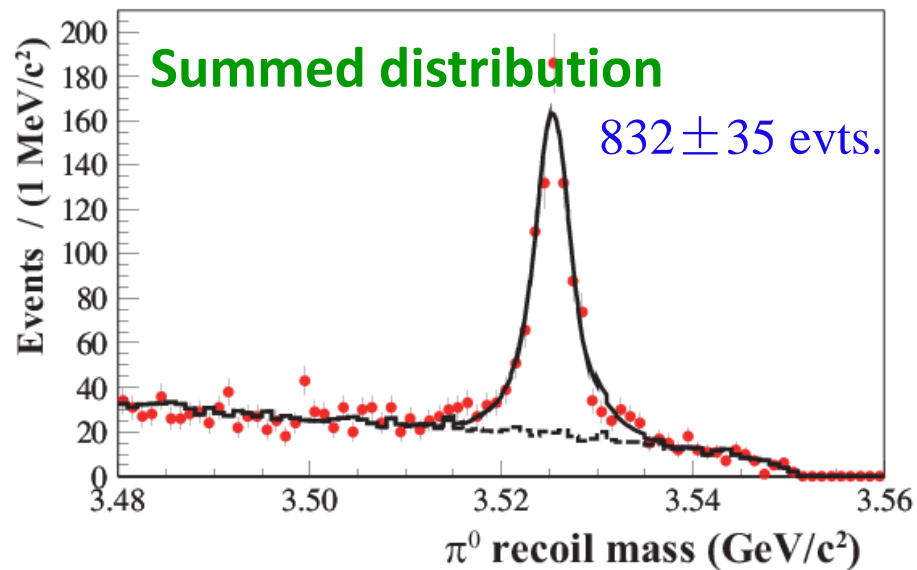
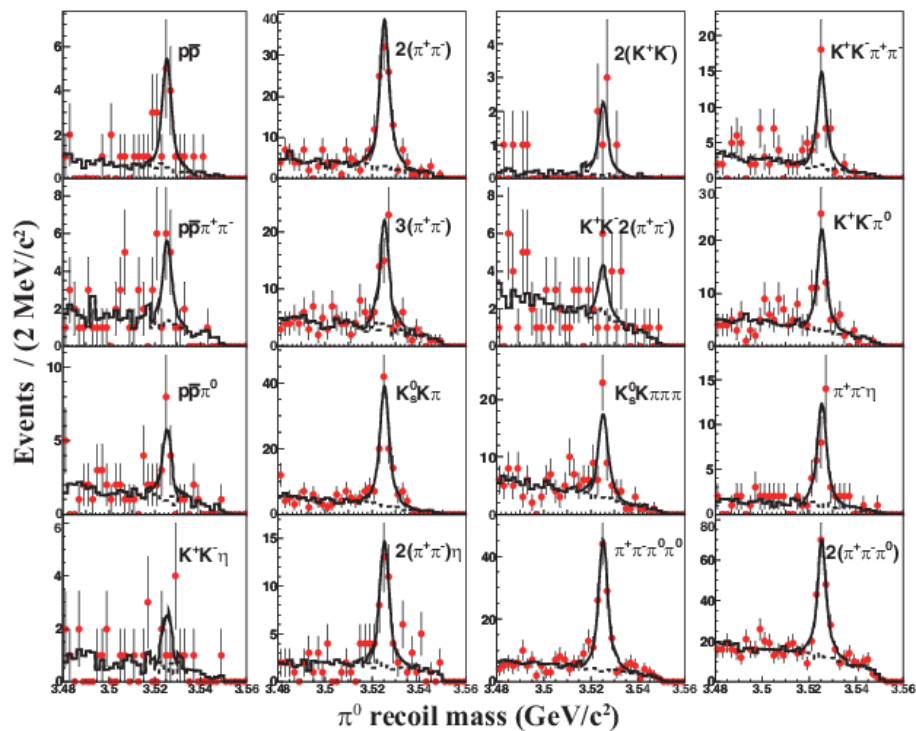
$\mathcal{B}(h_c \rightarrow \gamma \eta_c) = (54.3 \pm 6.7 \pm 5.2)\%$

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



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

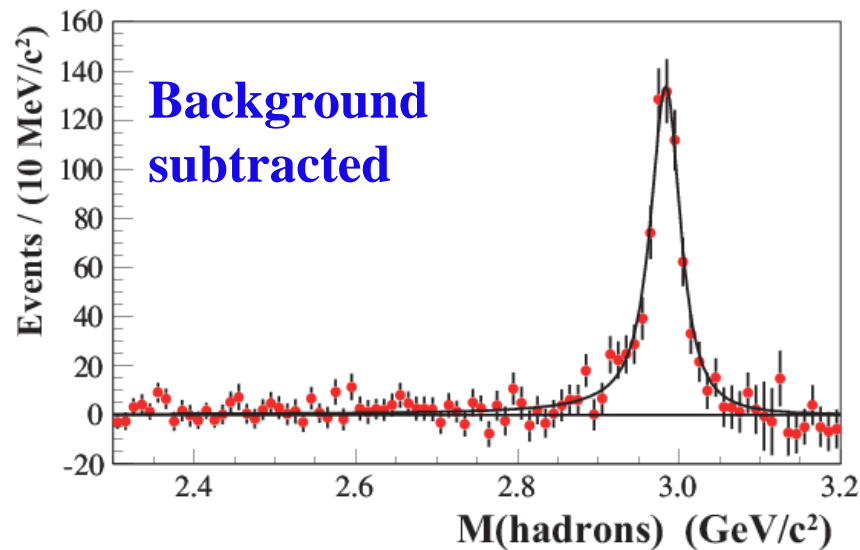
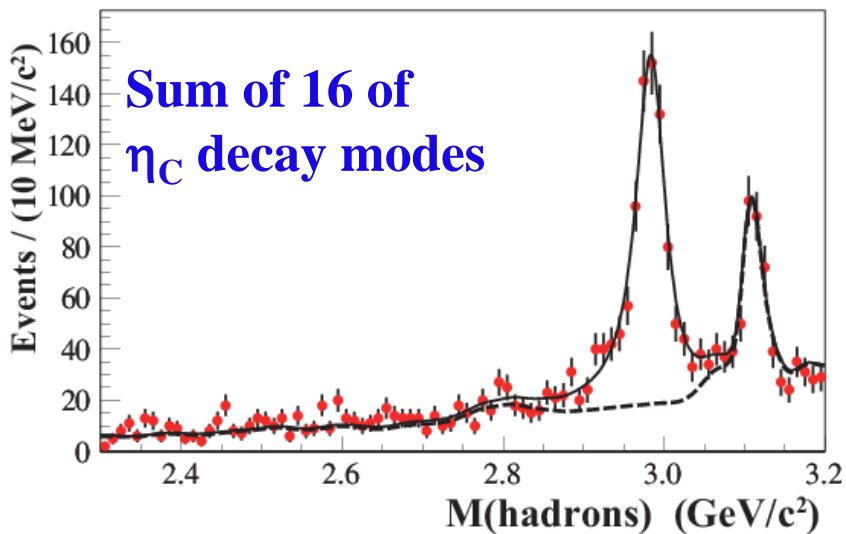
PRD 86, 092009



(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)



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

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

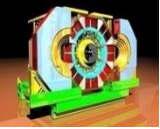
$M = 2984.49 \pm 1.16 \pm 0.52 \text{ MeV}/c^2$
 $\Gamma = 36.4 \pm 3.2 \pm 1.7 \text{ MeV}$

$\psi' \rightarrow \gamma \eta_c$

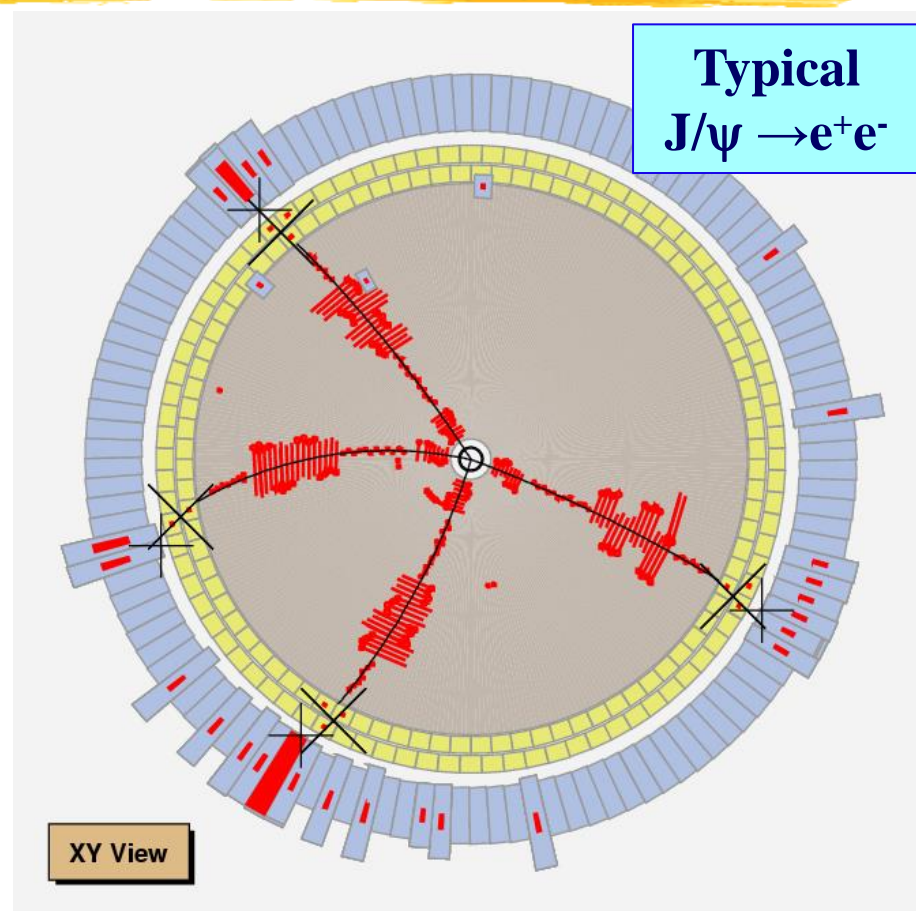
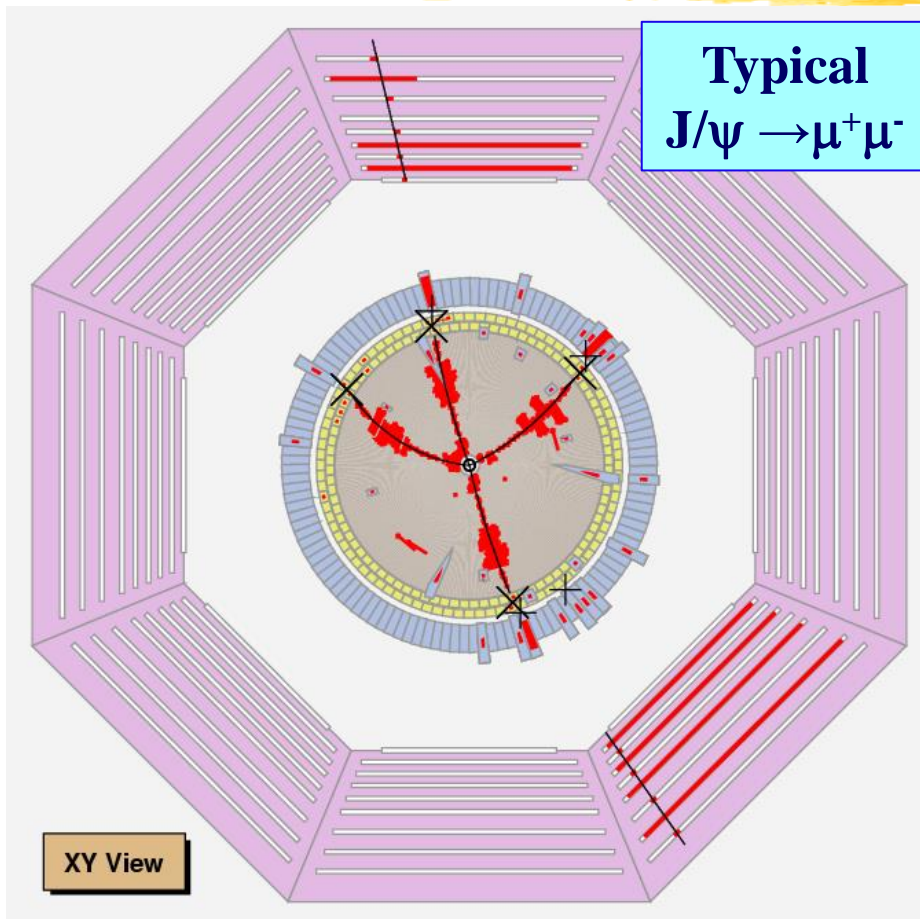
PRL 108, 222002

$M = 2984.3 \pm 0.6 \pm 0.6 \text{ MeV}/c^2$
 $\Gamma = 32.0 \pm 1.2 \pm 1.0 \text{ MeV}$

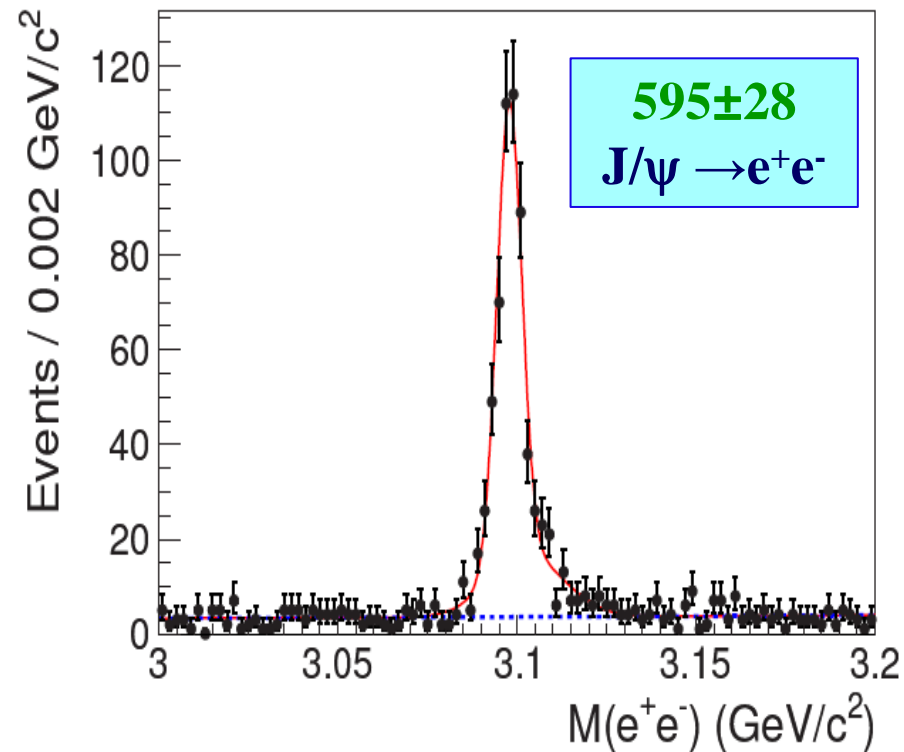
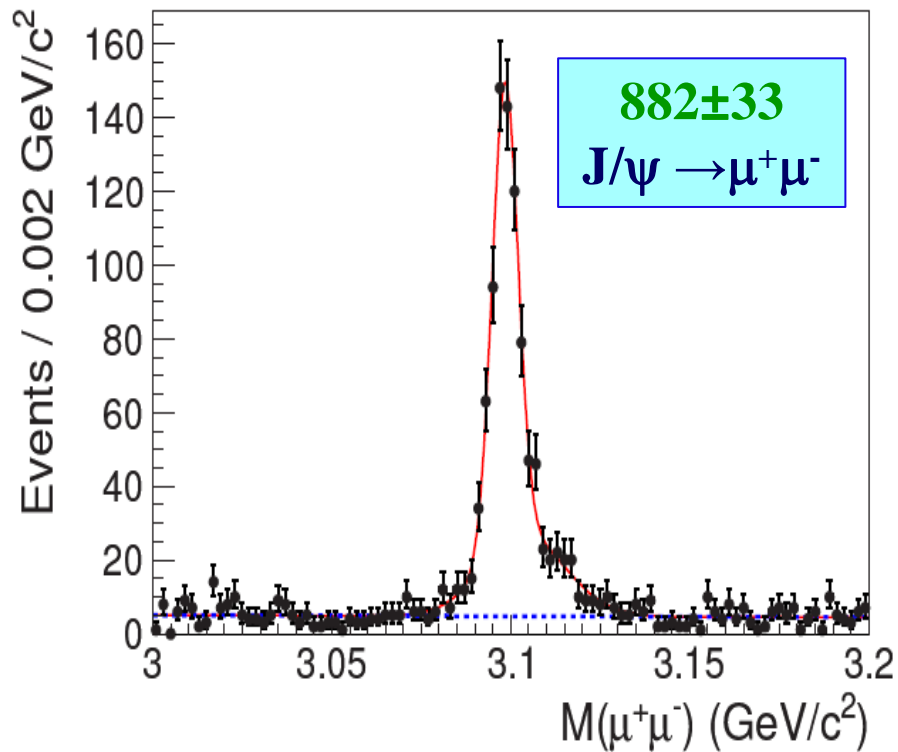
Consistent results, but still dominant statistical errors: more statistics is needed!



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



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



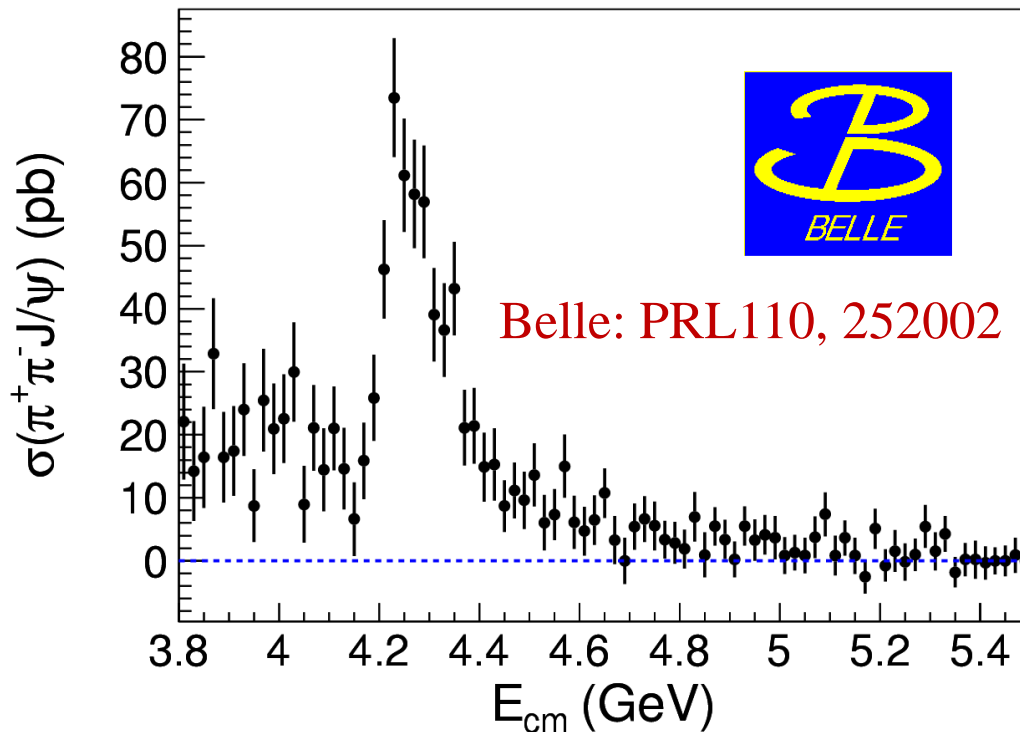
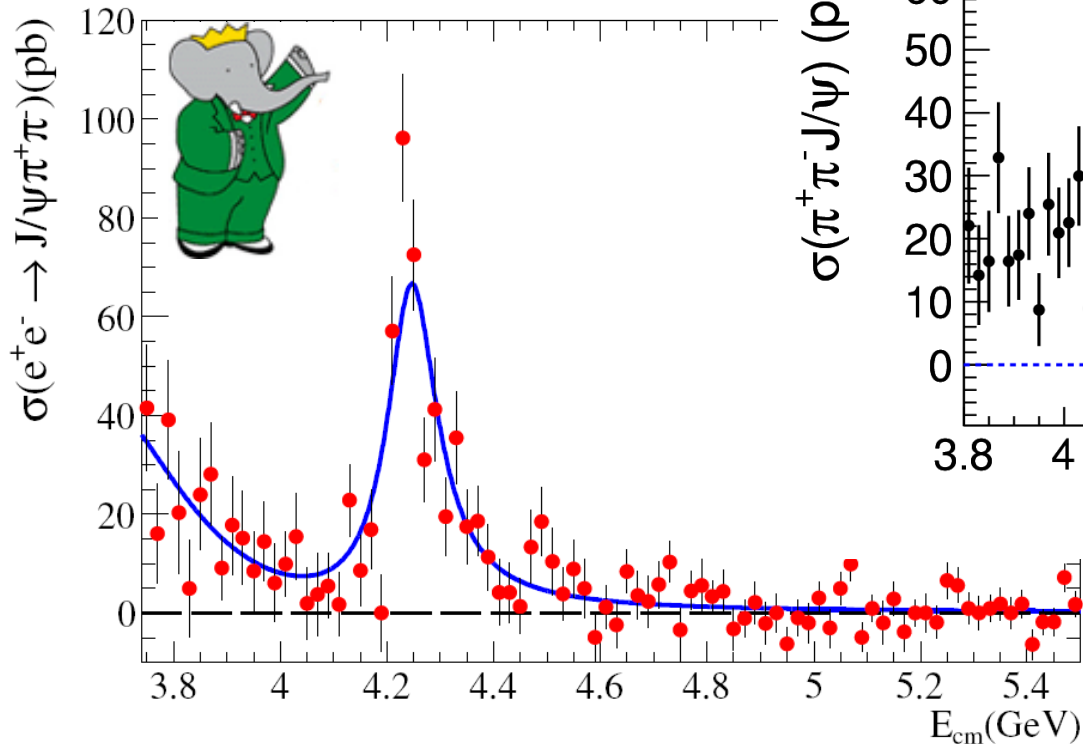
- Dominant background $e^+e^- \rightarrow \pi^+\pi^-\pi^+\pi^-$
- J/ψ signal: [3.08,3.12] GeV
- J/ψ sideband: [3.0,3.06] GeV or [3.14,3.20] GeV



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

PRL 110, 252001

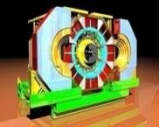
BaBar: PRD86, 051102 (2012)



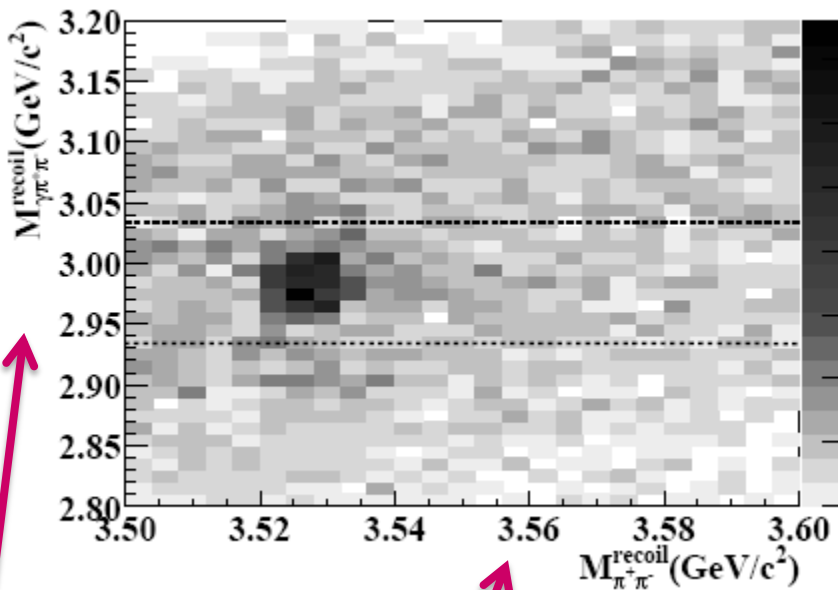
- BESIII cross sections:
- more energy points
 - more data!

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

- agreement with BaBar & Belle
- best precision!

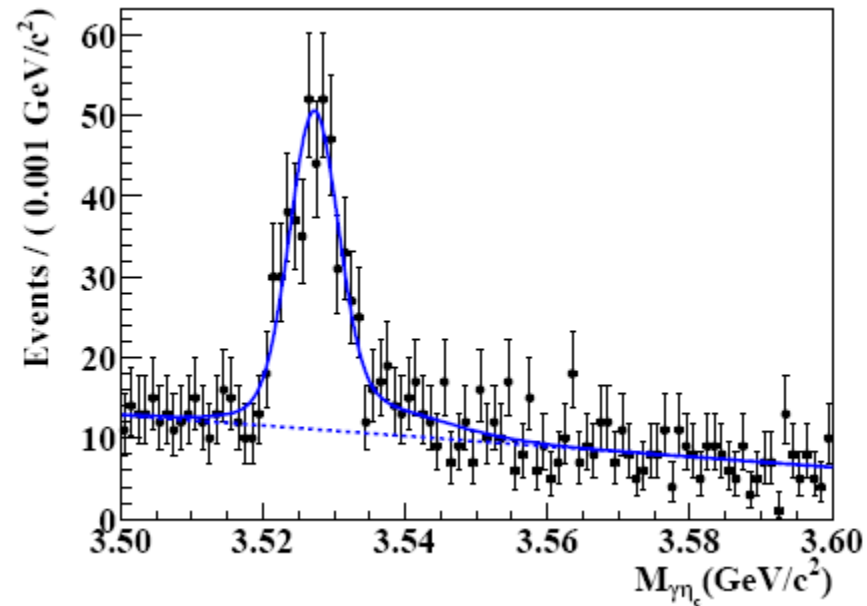


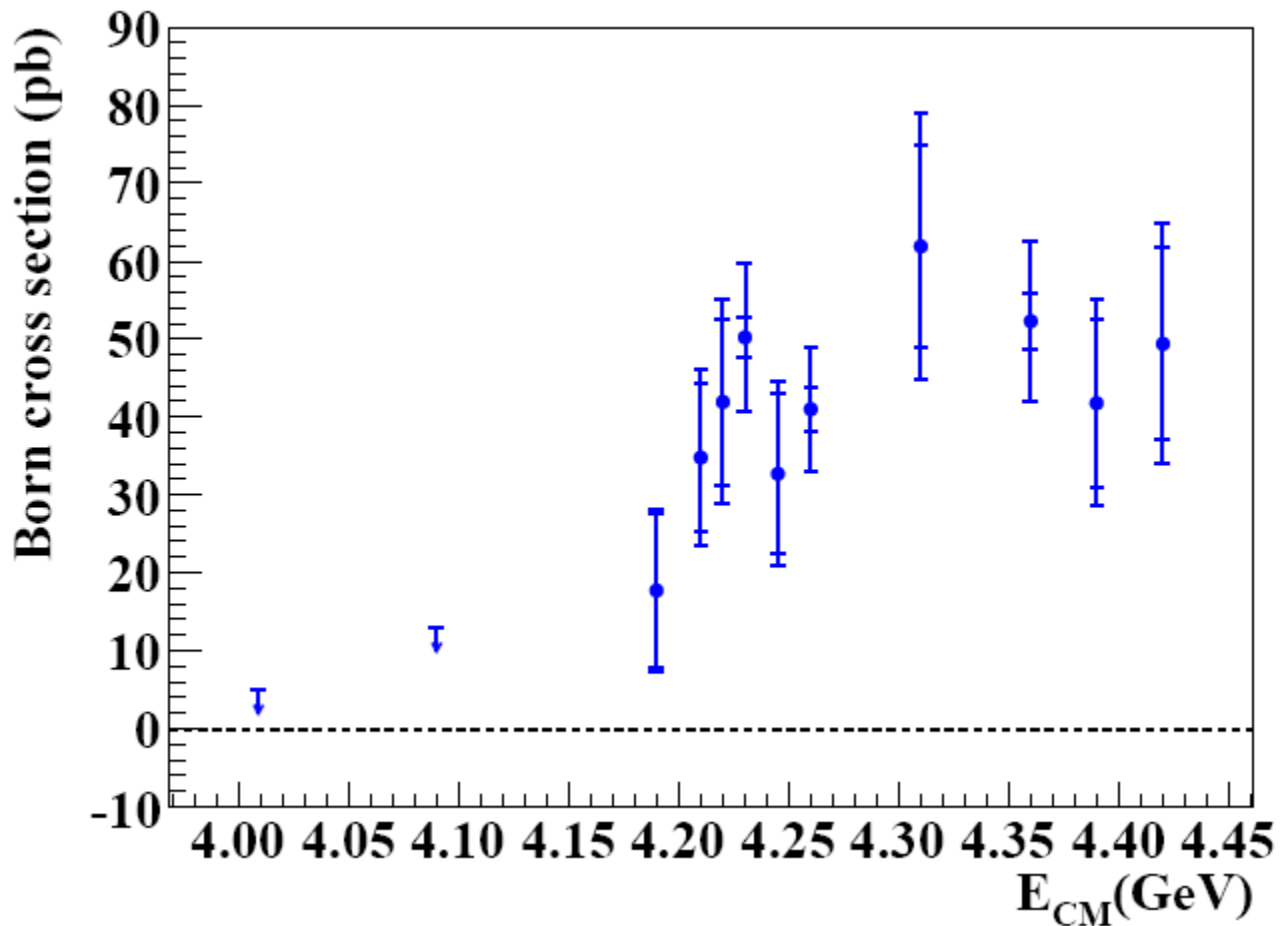
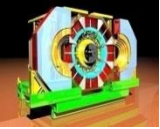
- $h_c \rightarrow \underline{\gamma}\eta_c, \eta_c \rightarrow$ hadrons [16 exclusive decay modes]
 - $p \bar{p}, \pi^+\pi^-K^+K^-, \pi^+\pi^-p \bar{p}, 2(K^+K^-), 2(\pi^+\pi^-), 3(\pi^+\pi^-)$
 - $2(\pi^+\pi^-)K^+K^-, K_S^0K^+\pi^-+c.c., K_S^0K^+\pi^-\pi^+\pi^-+c.c., K^+K^-\pi^0$
 - $p \bar{p}\pi^0,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



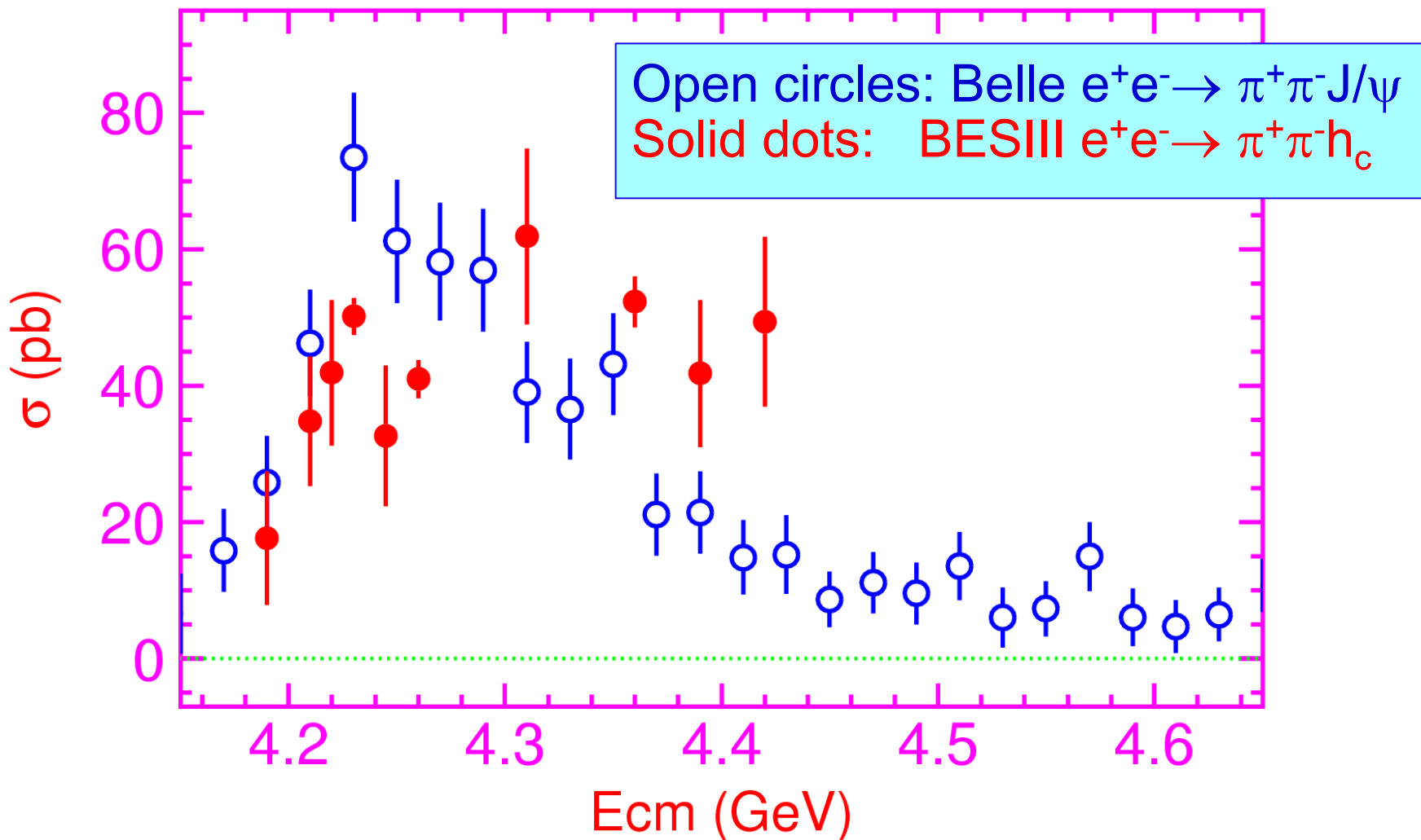
η_c candidate

h_c candidate

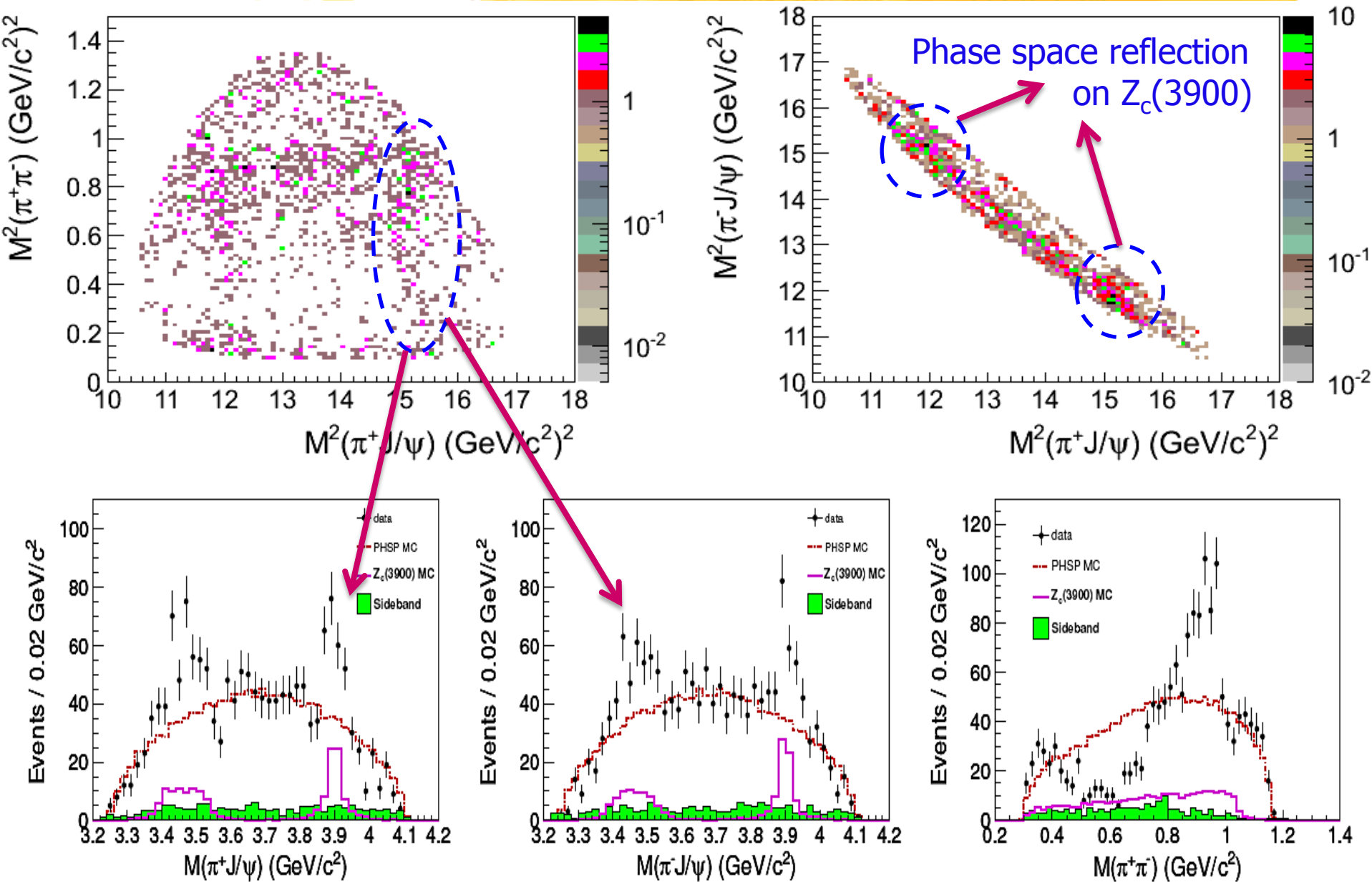




- $\sigma(e^+e^- \rightarrow \pi^+\pi^-h_c) \sim \sigma(e^+e^- \rightarrow \pi^+\pi^-J/\psi)$ but line shape different
- Local maximum ~ 4.23 GeV



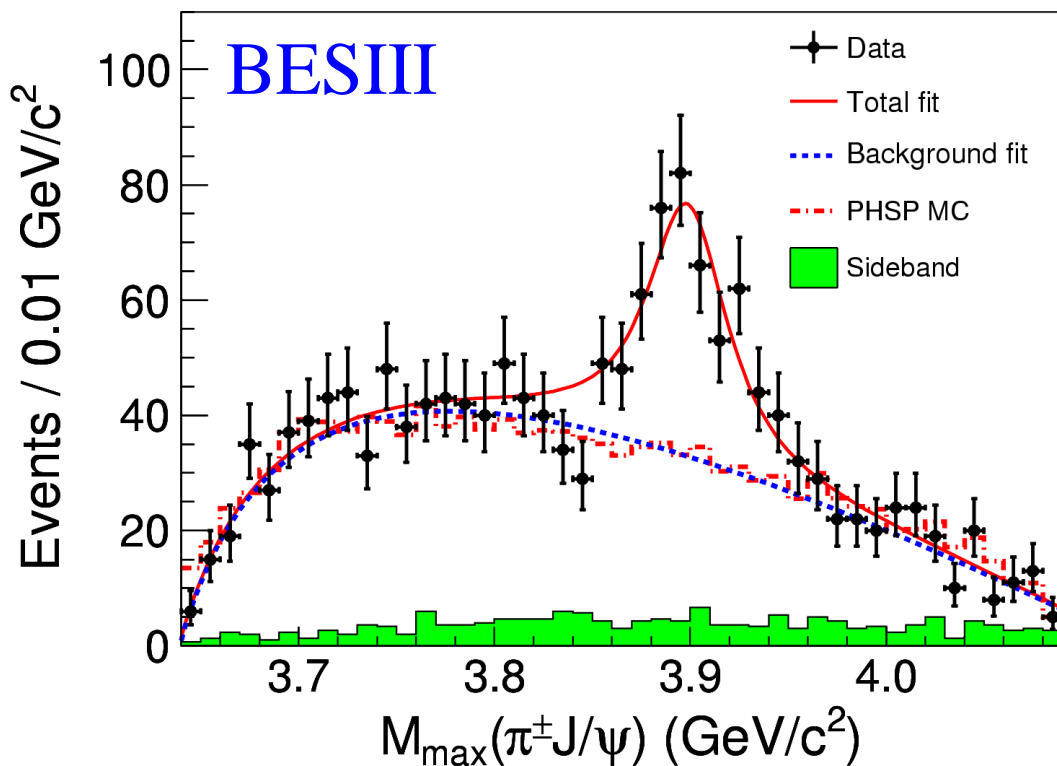
More data at higher energies needed to complete line shape measurement



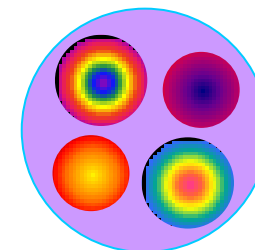


BESIII: $e^+e^- \rightarrow \pi Z_c(3900) \rightarrow \pi^+\pi^-J/\psi$ @ 4.260 GeV

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

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

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

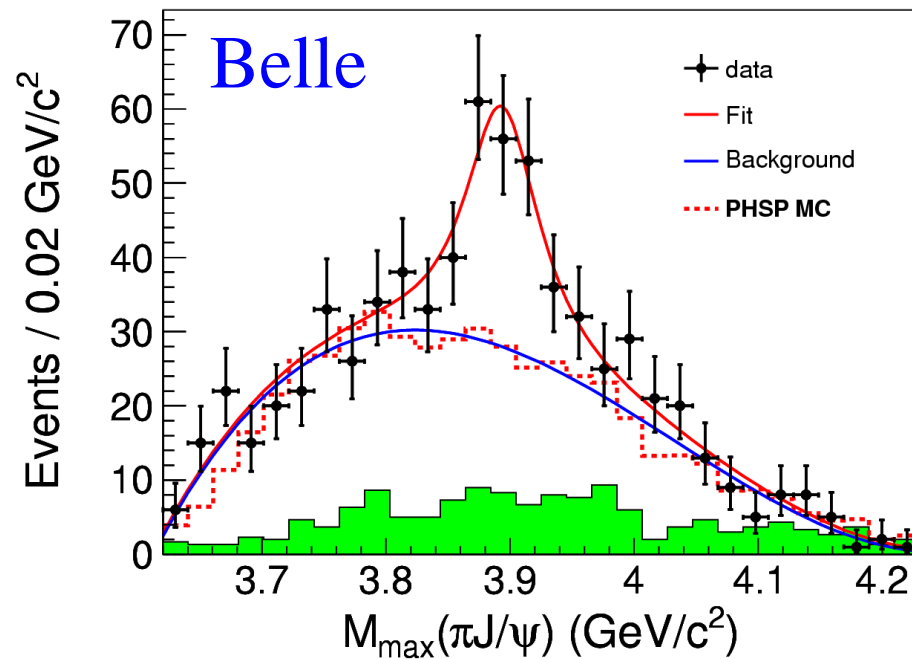
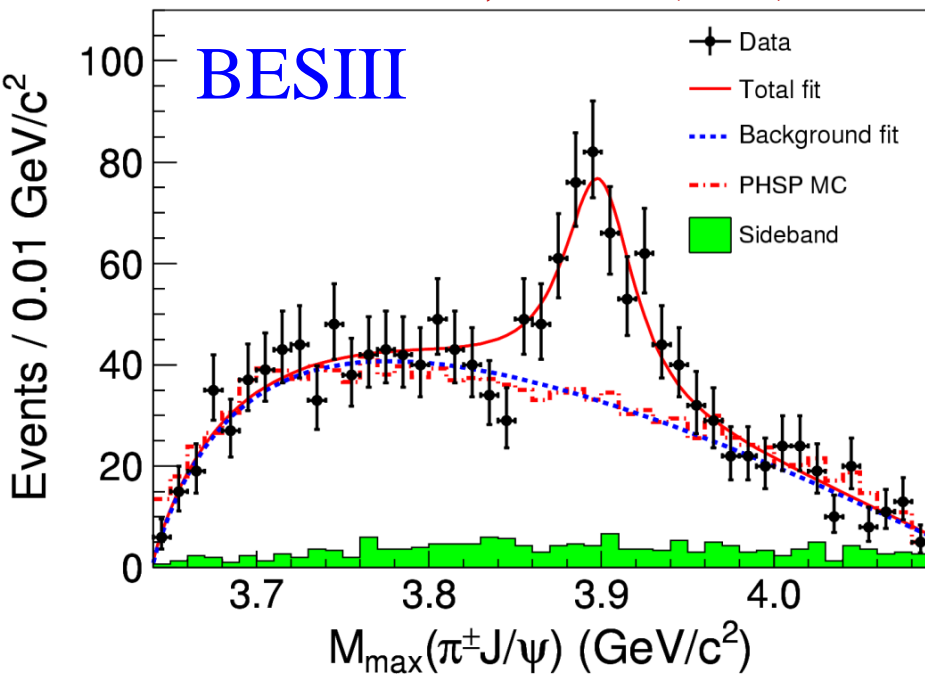
$$R = (21.5 \pm 3.3 \pm 7.5)\%$$

Significance
>8 σ



PRL 110, 252001 (2013)

PRL 110, 252002 (2013)



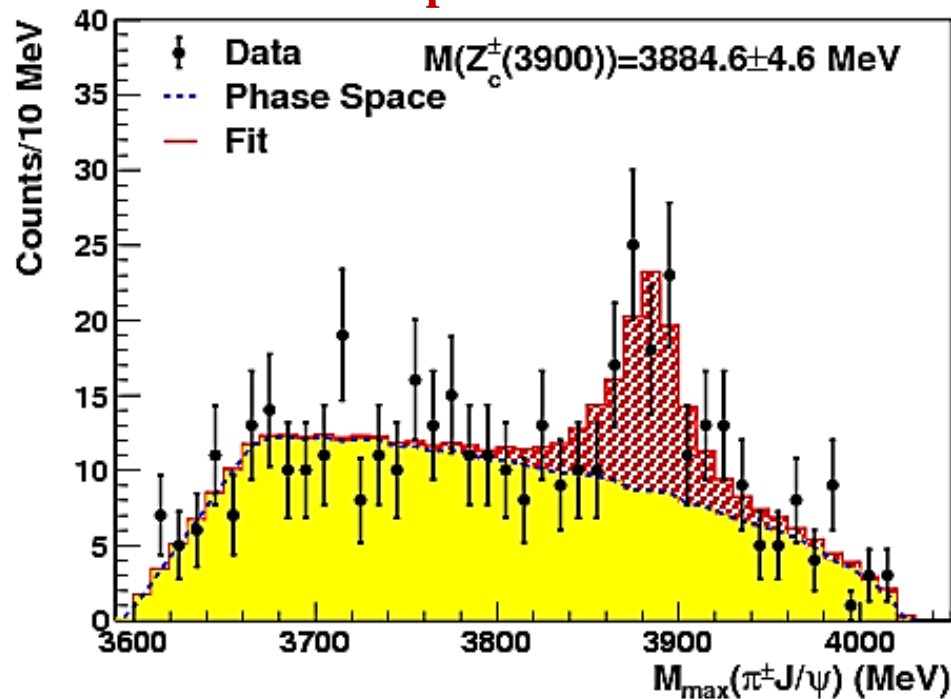
$M = (3899.0 \pm 3.6 \pm 4.9) \text{ MeV/c}^2$
 $\Gamma = (46 \pm 10 \pm 20) \text{ MeV/c}^2$
307 ± 48 events
>8σ

$M = (3894.5 \pm 6.6 \pm 4.5) \text{ MeV/c}^2$
 $\Gamma = (63 \pm 24 \pm 26) \text{ MeV/c}^2$
159 ± 49 events
>5.2σ



CLEOc @ 4.170 GeV

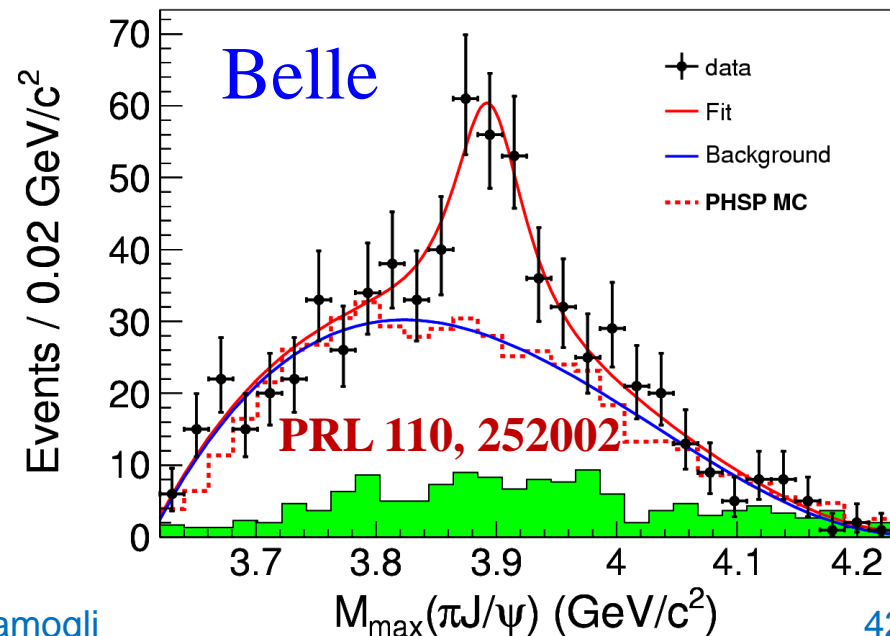
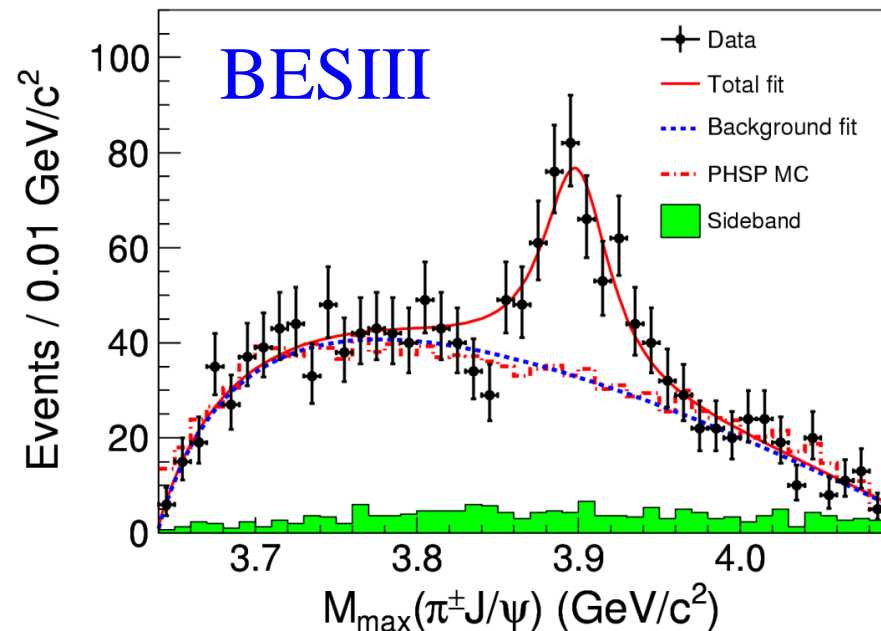
hep-ex:1304.3036

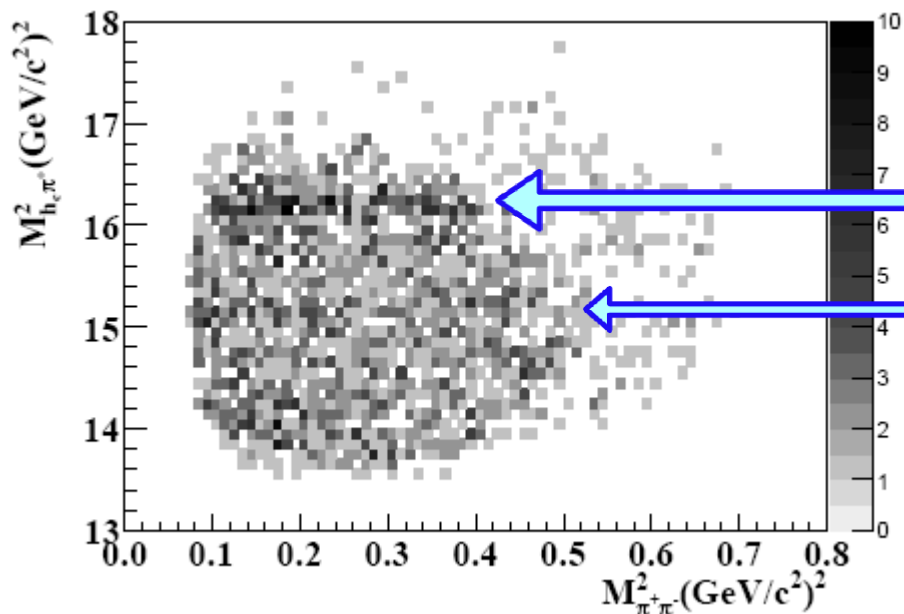


$$M = (3885 \pm 5 \pm 1) \text{ MeV}/c^2$$

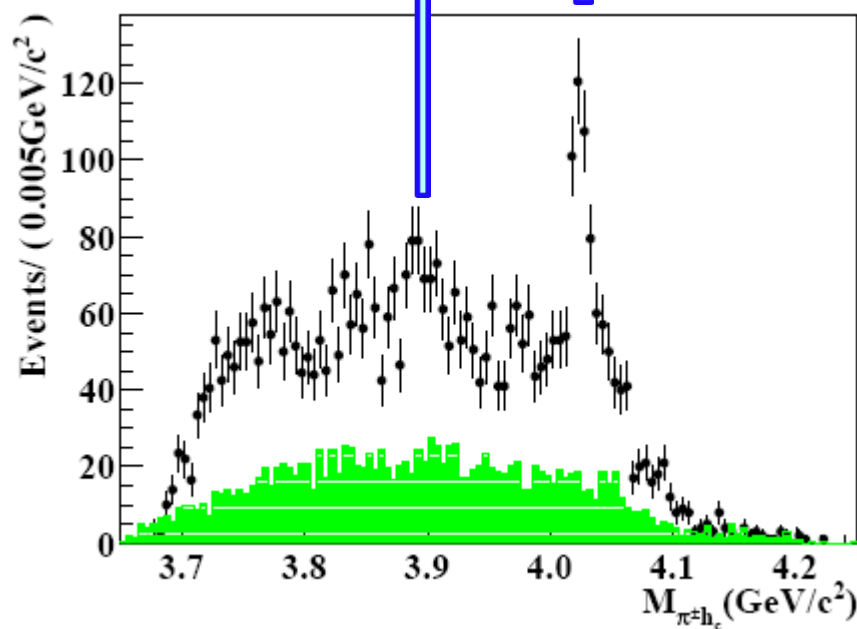
$$\Gamma = (34 \pm 12 \pm 4) \text{ MeV}/c^2$$

$$81 \pm 20 \text{ events}$$

$$6.1\sigma$$


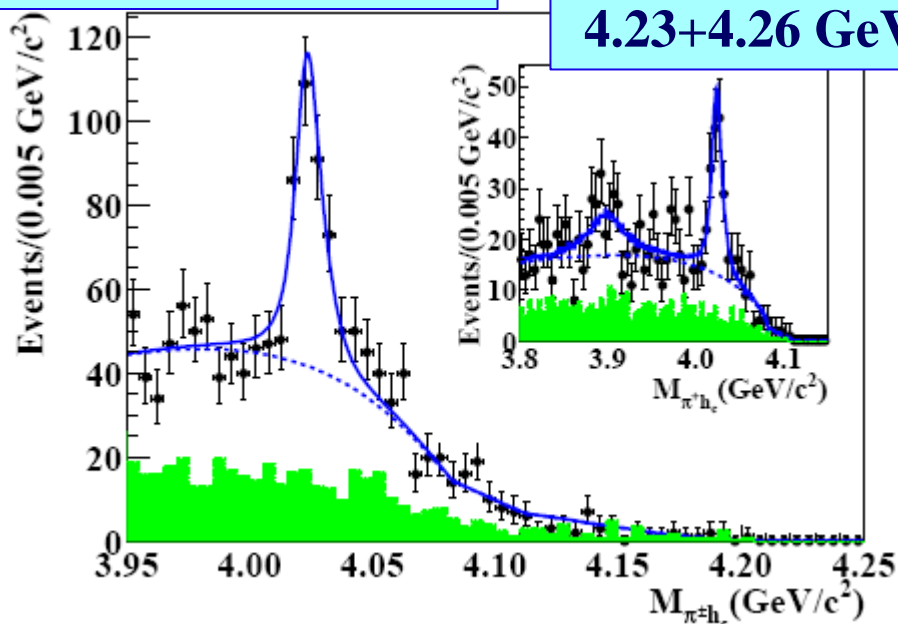


- all collected energies
[3.900 ÷ 4.420 GeV]
- $h_c \rightarrow \gamma\eta_c, \eta_c \rightarrow$ hadrons
[16 exclusive decay modes]

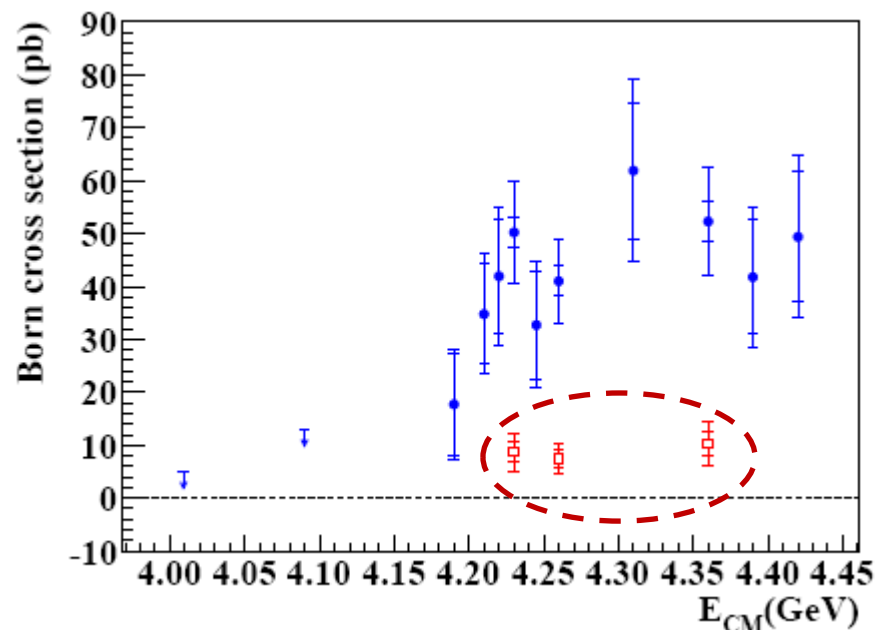


Simultaneous fit to 4.26/4.36 GeV data and 16 η_c decay modes.

4.23+4.26+4.36 GeV



4.23+4.26 GeV



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

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

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

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

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

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

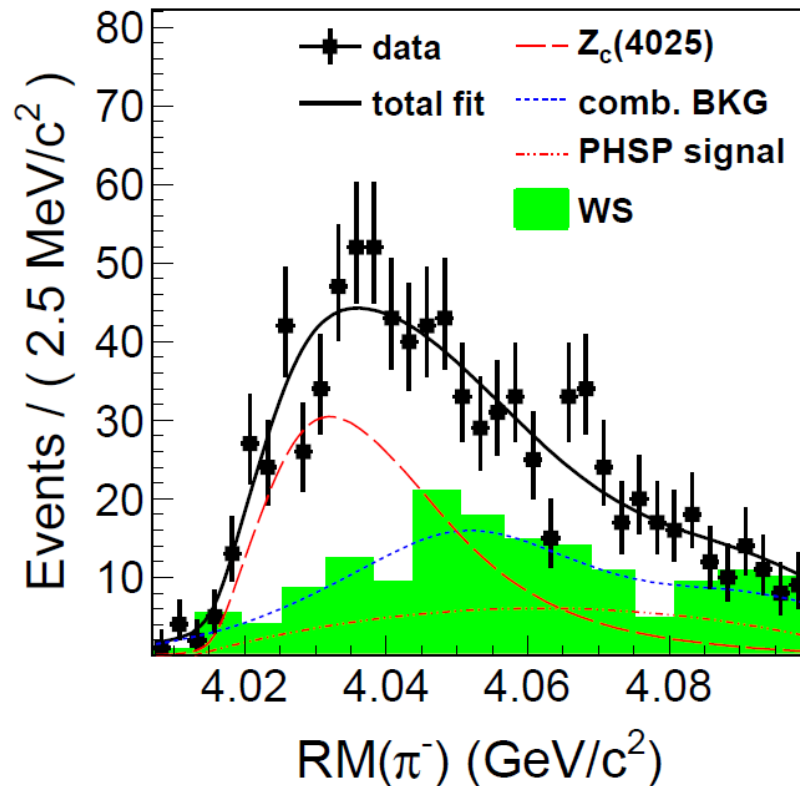
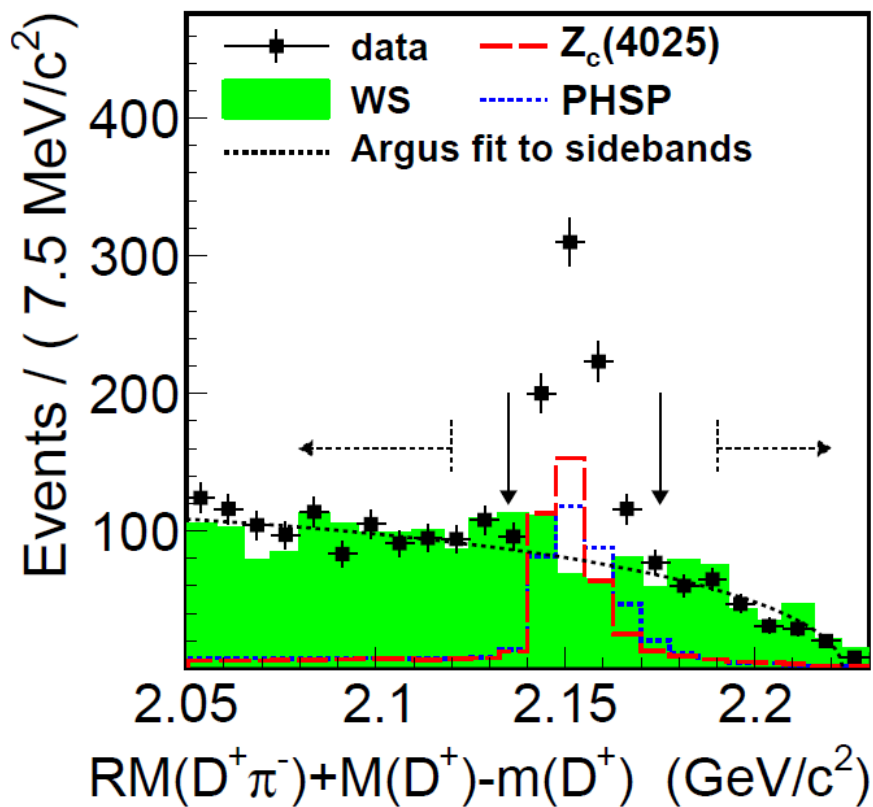
$$\Gamma = (7.9 \pm 2.7 \pm 2.6) \text{ MeV}/c^2$$

$$> 8.9\sigma$$



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

hep-ex:1308.2760



$M = (4026.3 \pm 2.6 \pm 3.7) \text{ MeV}/c^2$
 $\Gamma = (24.8 \pm 5.7 \pm 7.7) \text{ MeV}/c^2$
 $> 10\sigma$

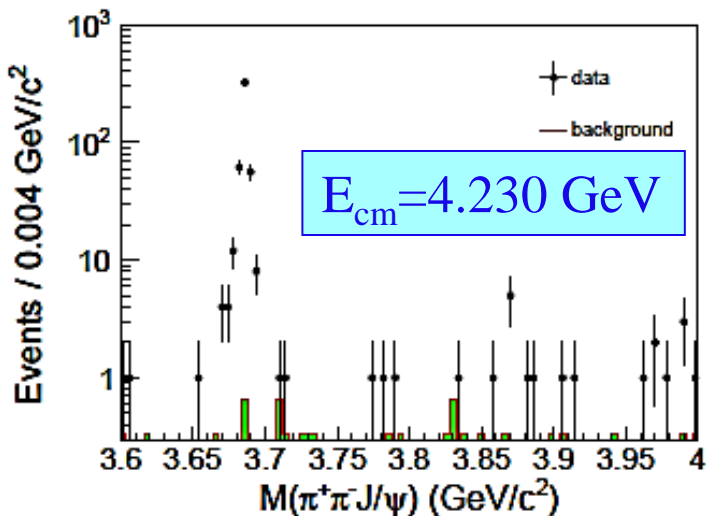
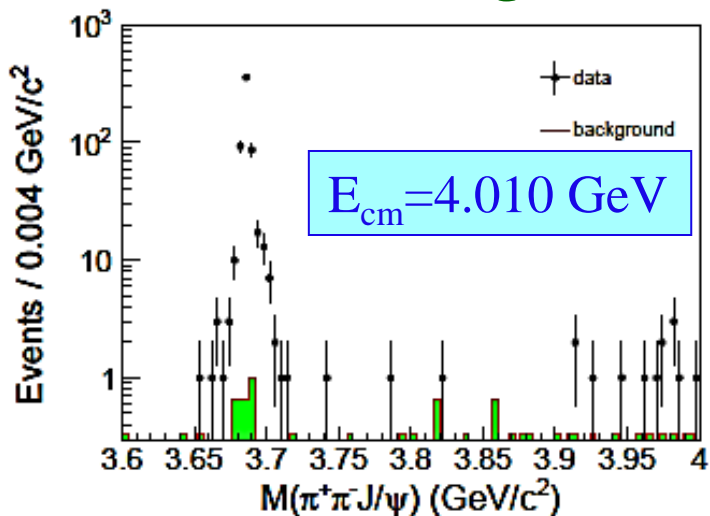
$\sigma(e^+e^- \rightarrow \pi^- (D^* \bar{D}^*)^+ + \text{c.c.}) = (137 \pm 9 \pm 15) \text{ pb}$

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

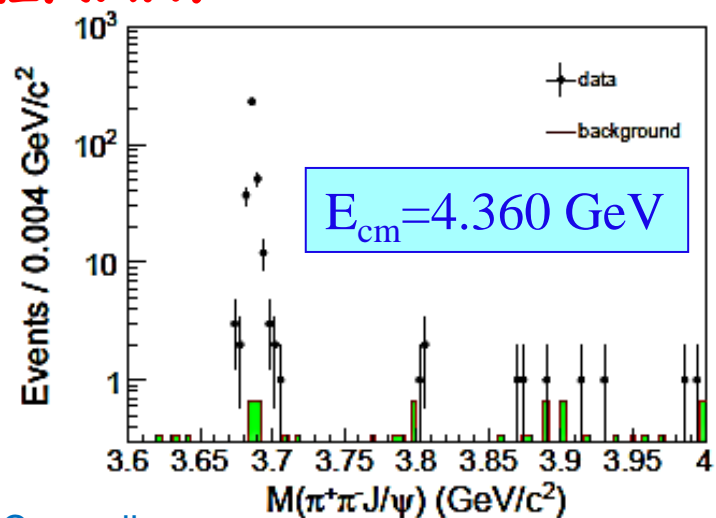
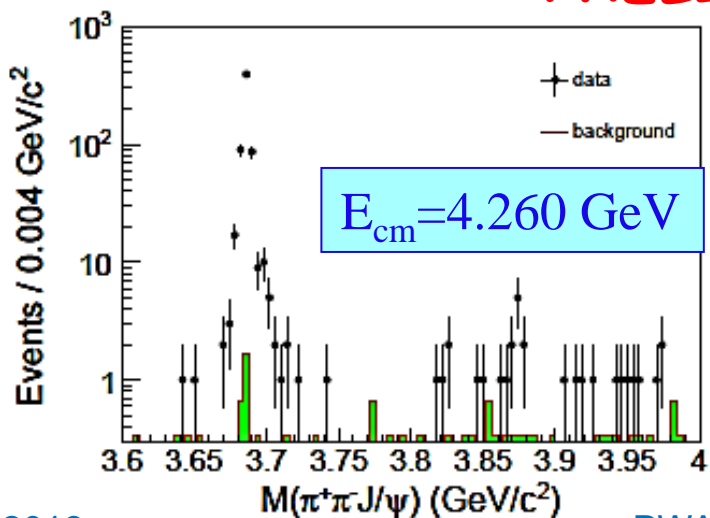


BESIII: $e^+e^- \rightarrow \gamma X(3872) \rightarrow \gamma\pi^+\pi^-J/\psi$

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

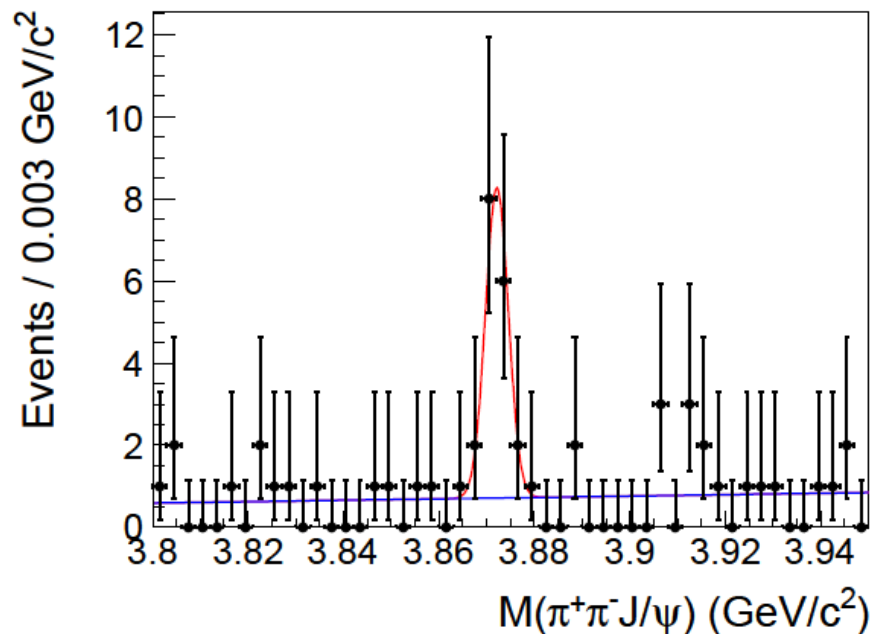
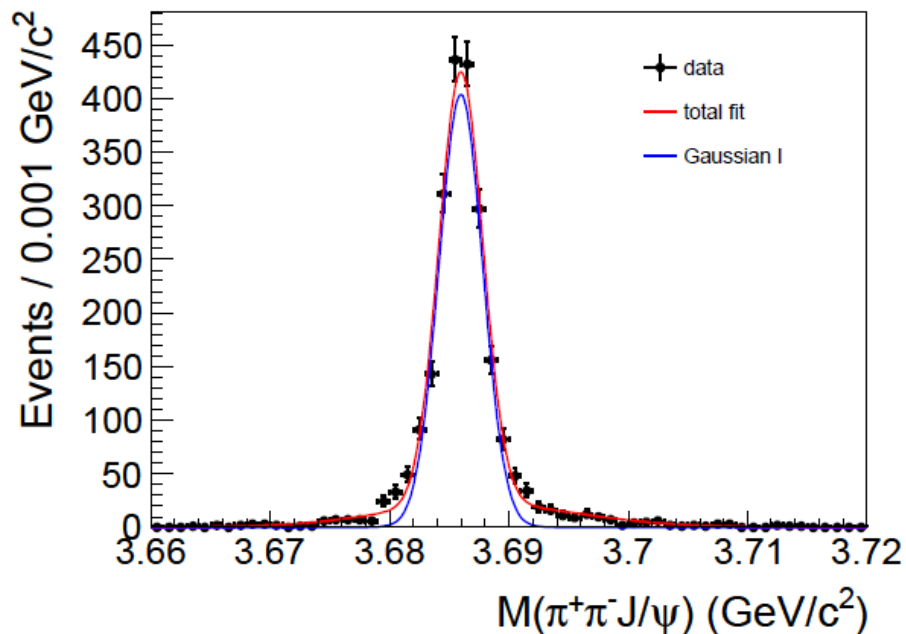


PRELIMINARY





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



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

$N(\psi')=1242$; $M = (3685.96 \pm 0.05) \text{ MeV}/c^2$; $\sigma_M = (1.84 \pm 0.06) \text{ MeV}$

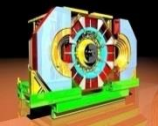
$N(X(3872)) = 15.0 \pm 3.9$

$M = (3872.1 \pm 0.8 \pm 0.3) \text{ MeV}/c^2$

$>5.3\sigma$

PRELIMINARY

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



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

\sqrt{s} (GeV)	$\sigma^B[e^+e^- \rightarrow \gamma X(3872)] \cdot \mathcal{B}(X(3872) \rightarrow \pi^+ \pi^- J/\psi)$ (pb)
4.009	< 0.13 at 90% C.L.
4.230	$0.32 \pm 0.15 \pm 0.02$
4.260	$0.35 \pm 0.12 \pm 0.02$
4.360	< 0.39 at 90% C.L.

It seems $X(3872)$ is from $Y(4260)$ decays. At 4.26 GeV,

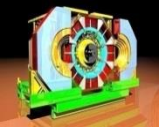
$$\sigma^B(e^+e^- \rightarrow \pi^+ \pi^- J/\psi) = (62.9 \pm 1.9 \pm 3.7) \text{ pb},$$

$$\frac{\sigma[e^+e^- \rightarrow \gamma X(3872)] \cdot \mathcal{B}(X(3872) \rightarrow \pi^+ \pi^- J/\psi)}{\sigma(e^+e^- \rightarrow \pi^+ \pi^- J/\psi)} = (5.6 \pm 2.0) \times 10^{-3}$$

If we take $\mathcal{B}(X(3872) \rightarrow \pi^+ \pi^- J/\psi) \sim 5\%$, ($> 2.6\%$ in PDG)

$$\frac{\sigma(e^+e^- \rightarrow \gamma X(3872))}{\sigma(e^+e^- \rightarrow \pi^+ \pi^- J/\psi)} \sim 11.2\% \quad \text{Large transition ratio !}$$

PRELIMINARY



Summary

- **huge statistics:**
 - J/ψ , $\psi(2S)$, $\psi(1D)$
 - 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>

Political Map of the World, June 1999

■ SOVEREIGN STATE
 ■ DEPENDENT TERRITORY
 ■ TERRITORY OF DISPUTE
 ■ UNRECOGNIZED STATE
 ■ CAPITAL
 ■ INTERNATIONAL TERRITORY
 ■ MARITIME TERRITORY

US (6)

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

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

Pakistan (2)

- Univ. of Punjab
- COMSAT CIIT

Korea (1)

- Seoul Nat. Univ.

Japan (1)

- Tokyo Univ.

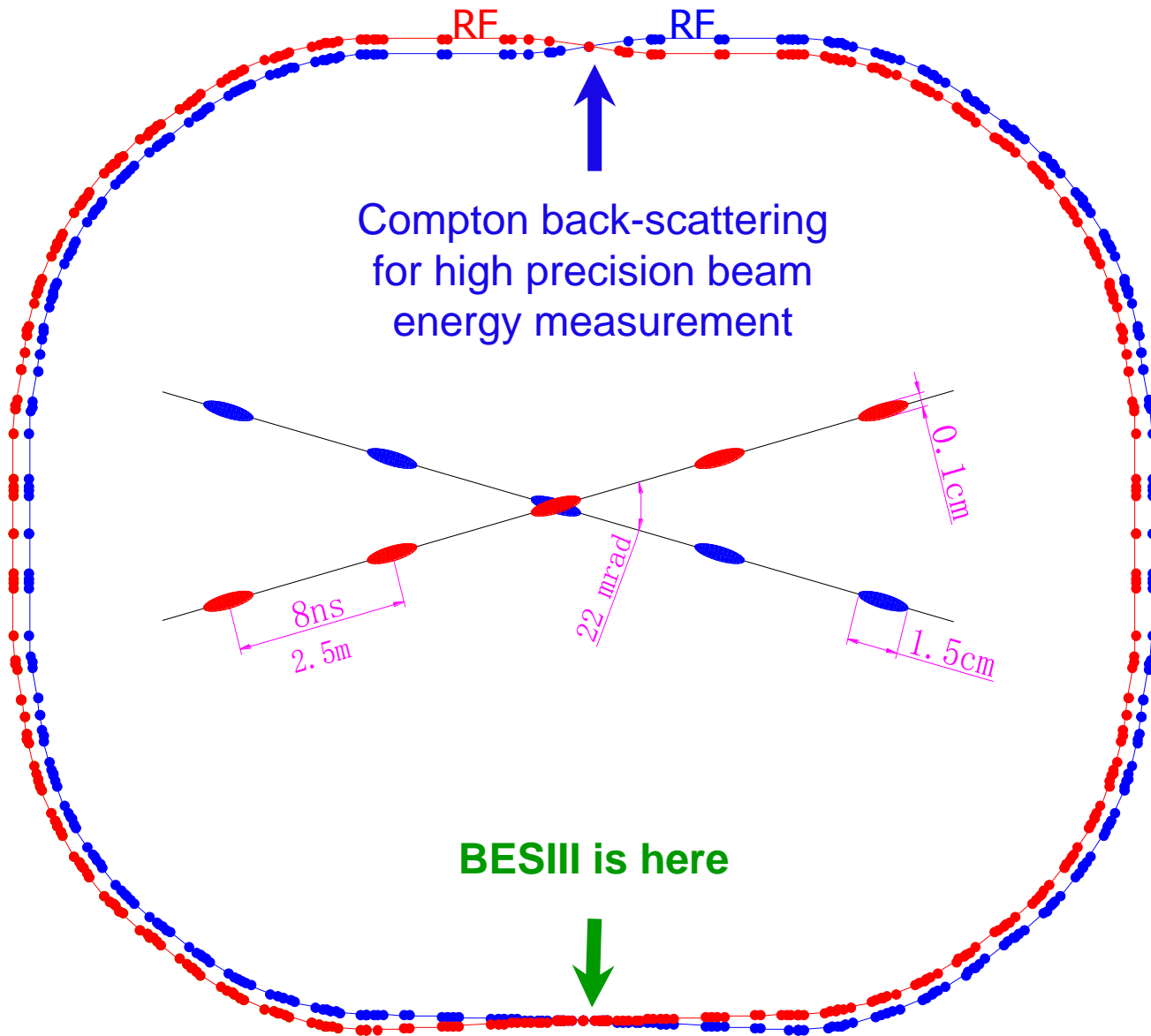
China(30)

- 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.

~350 members
53 institutions
11 countries



BEPCII



Beam energy:

1-2.3 GeV

Crossing angle:

22 mrad

Luminosity:

$1 \times 10^{33} \text{ cm}^{-2}\text{s}^{-1}$

Optimum energy:

1.89 GeV

Energy spread:

5.16×10^{-4}

No. of bunches:

93

Bunch length:

1.5 cm

Total current:

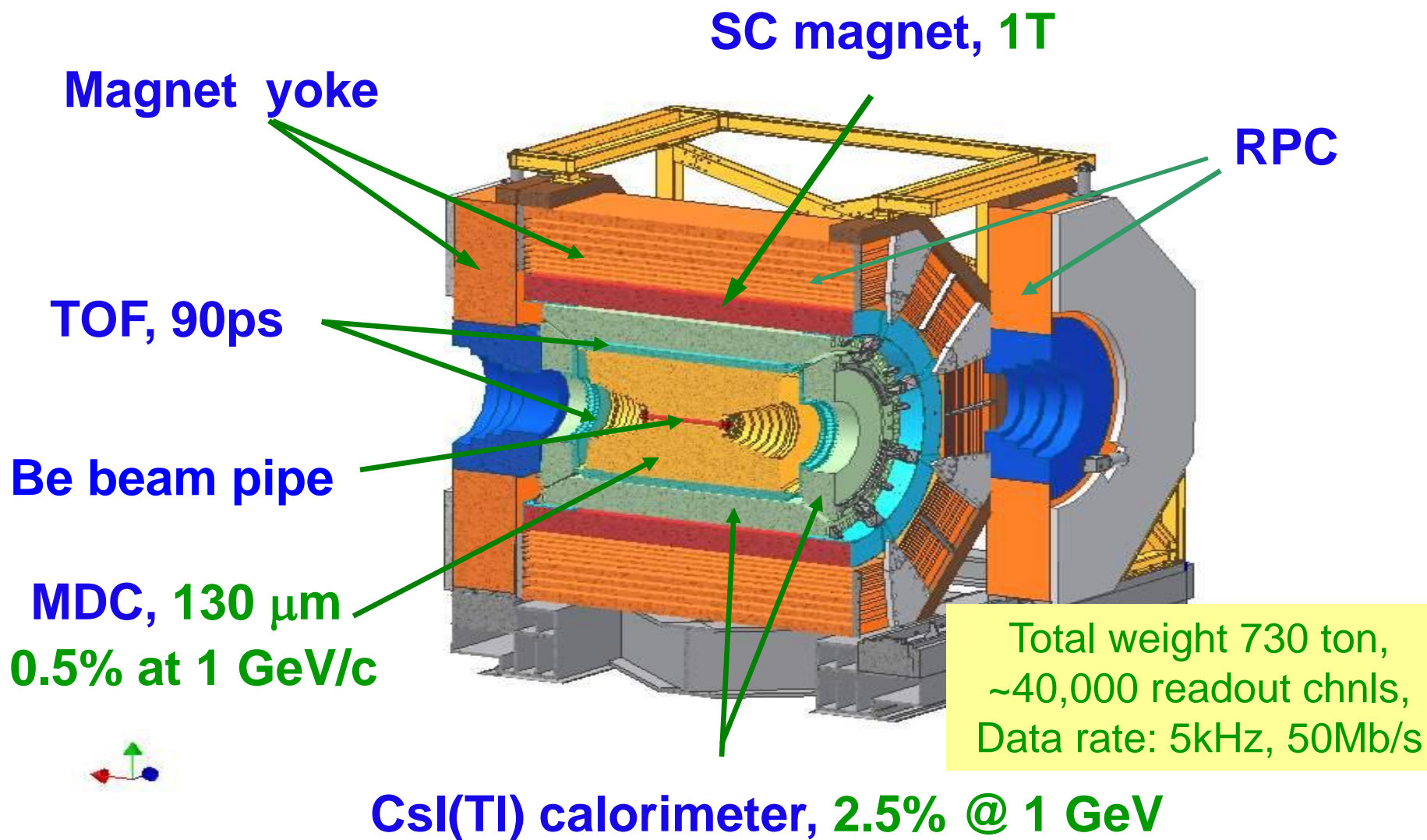
0.91 A

SR mode:

0.25A @ 2.5 GeV



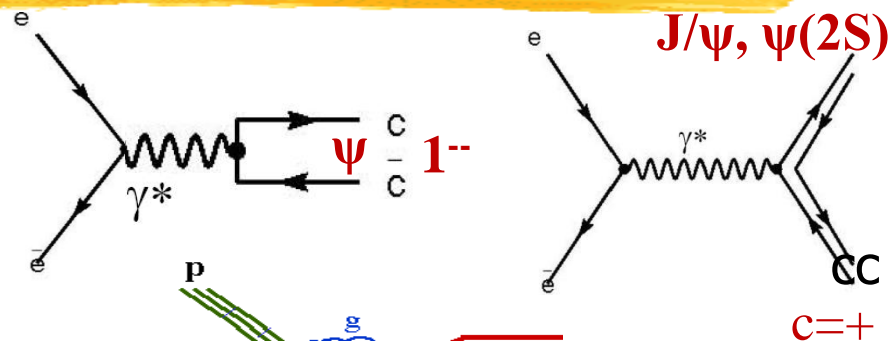
BESIII Spectrometer



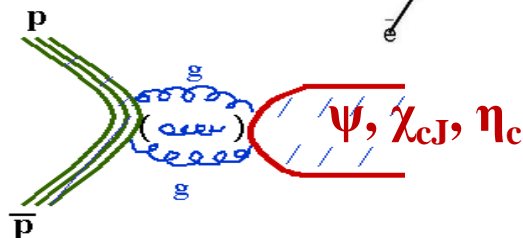


How to produce Charmonium states

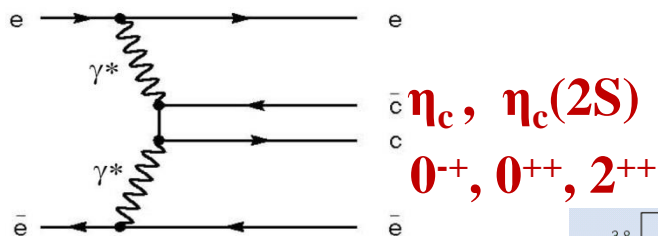
1. e^+e^- annihilation (including ISR/double charmonium)



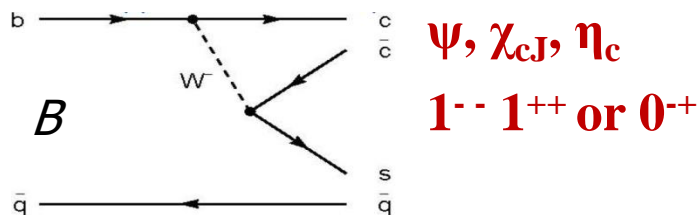
2. $p\bar{p}$ annihilation



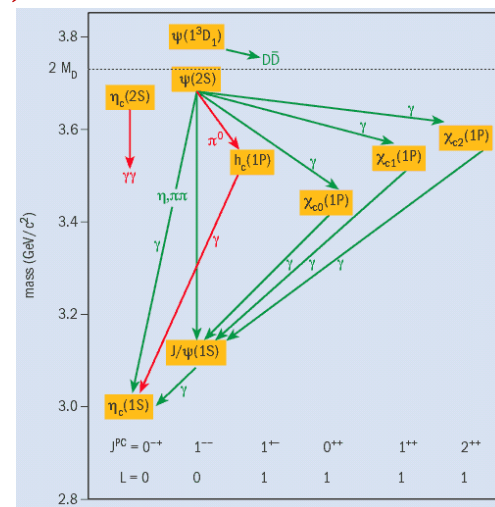
3. Two-photon process

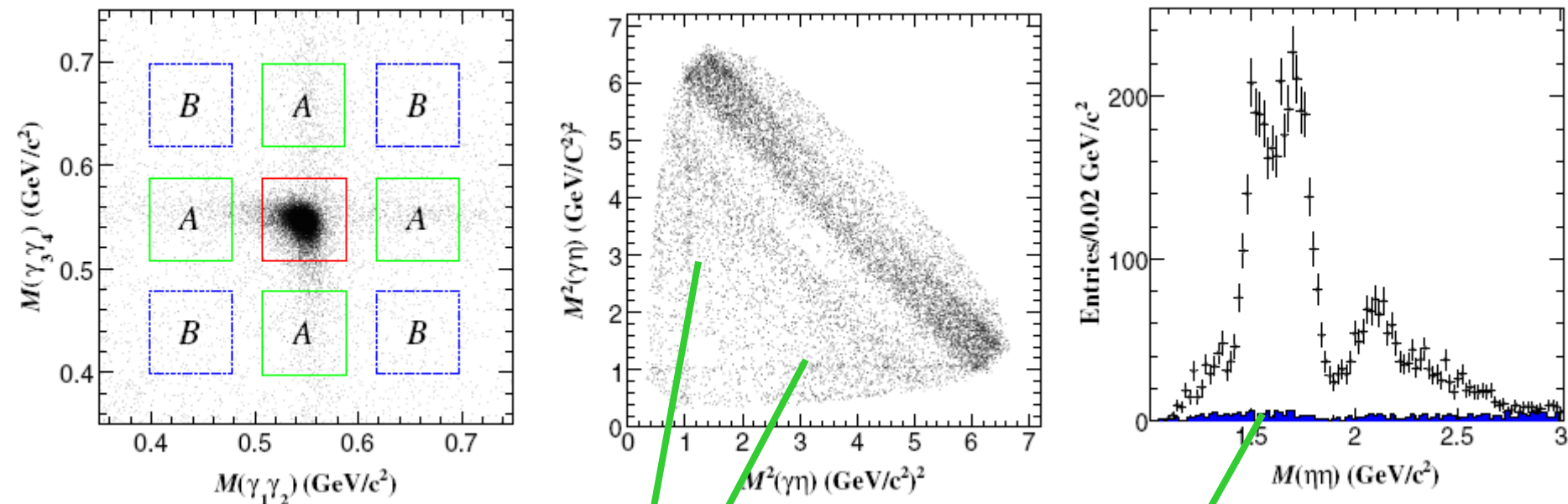


4. B decays

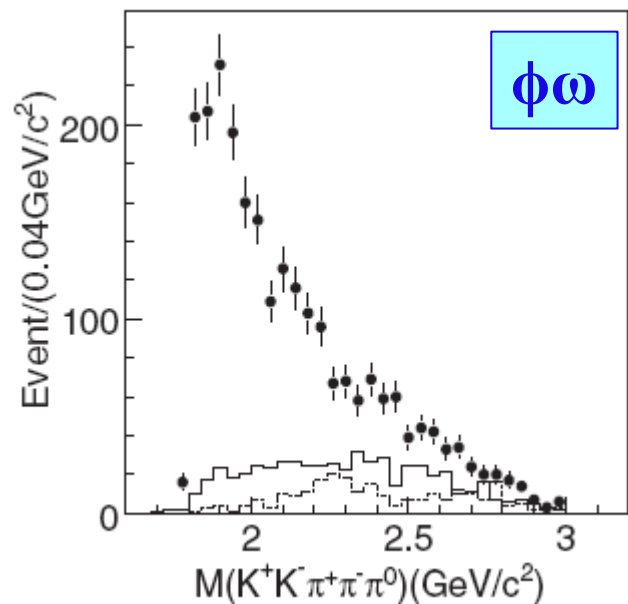
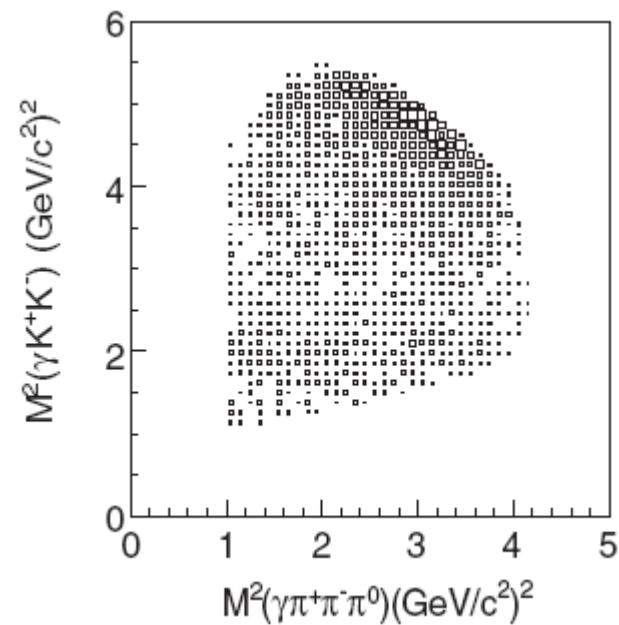
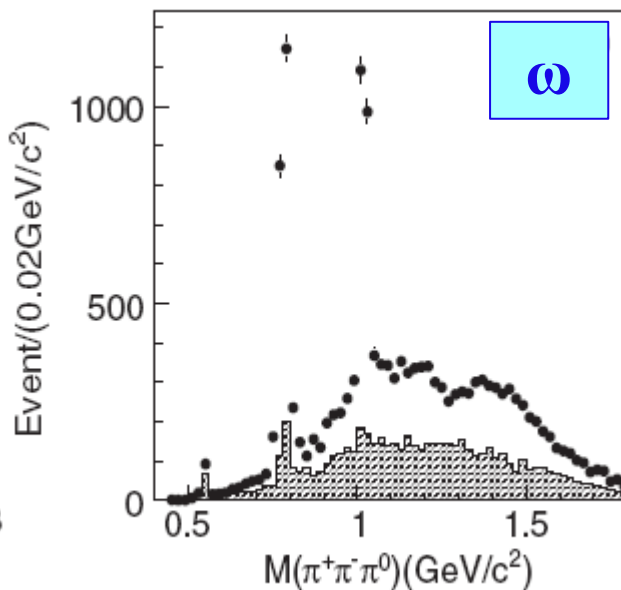
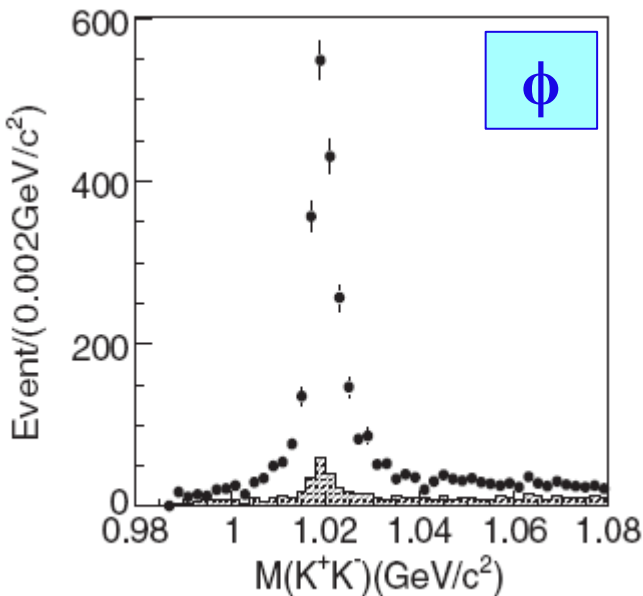


5. Charmonium transition





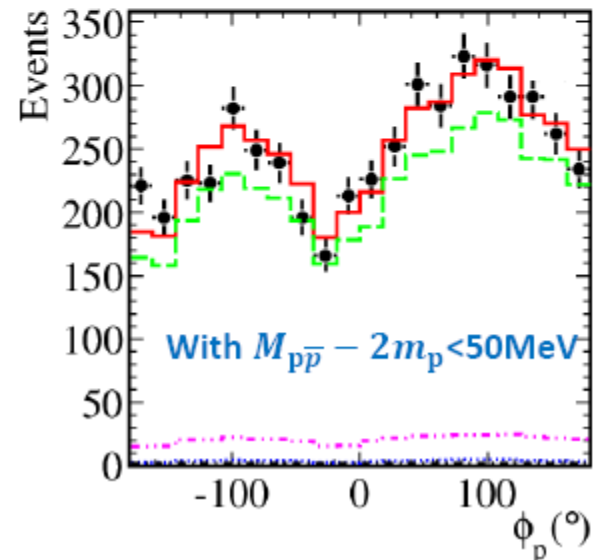
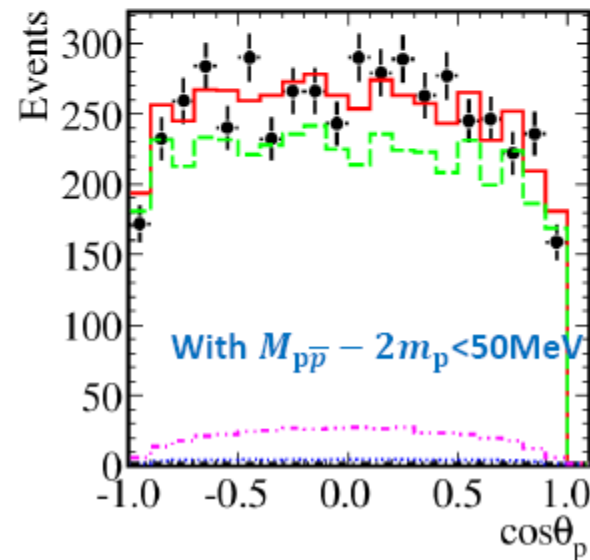
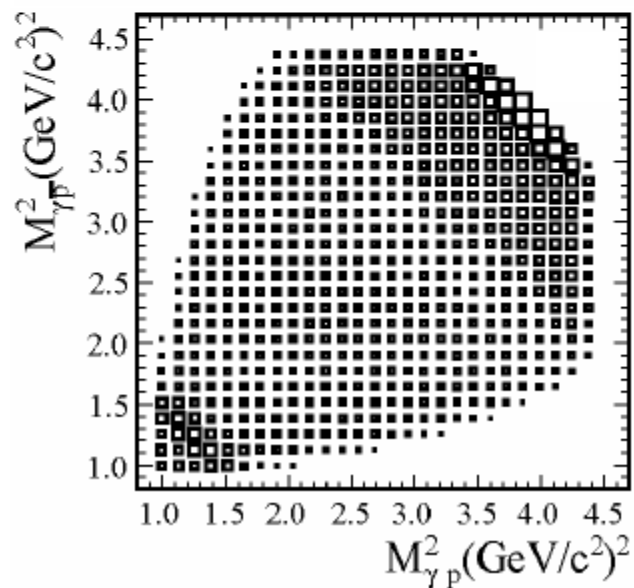
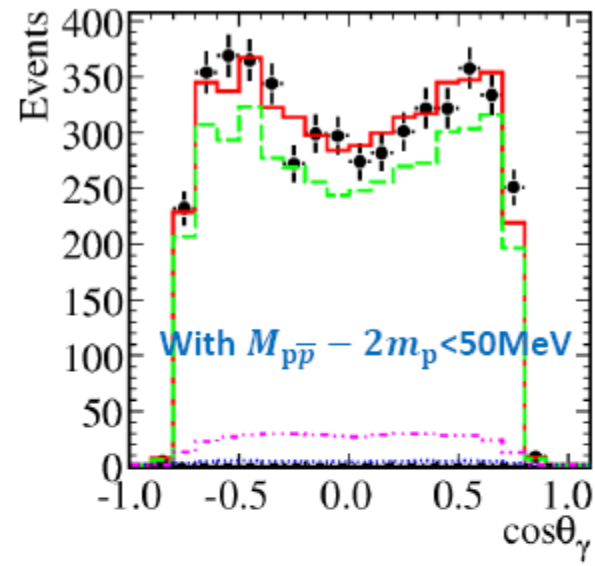
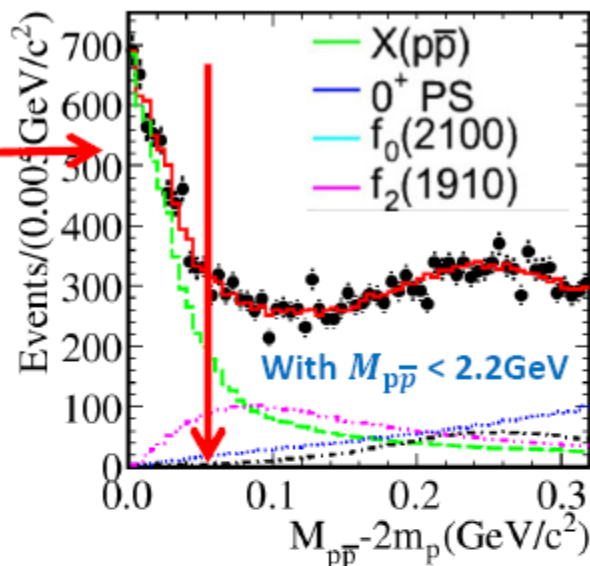
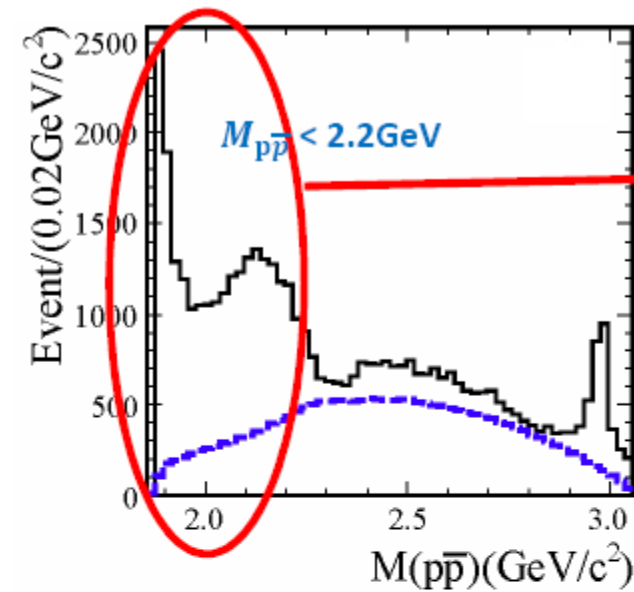
- **$J/\psi \rightarrow \phi\eta$, $\phi \rightarrow \gamma\eta$:**
 - select events outside ϕ window
- **background:**
 - low and mostly non- η background,
 - estimated by η sidebands (blue shadow)
- **background subtraction:**
 - $\ln \mathcal{L}^{\text{signal}} = \ln \mathcal{L}^{\text{data}} - \ln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

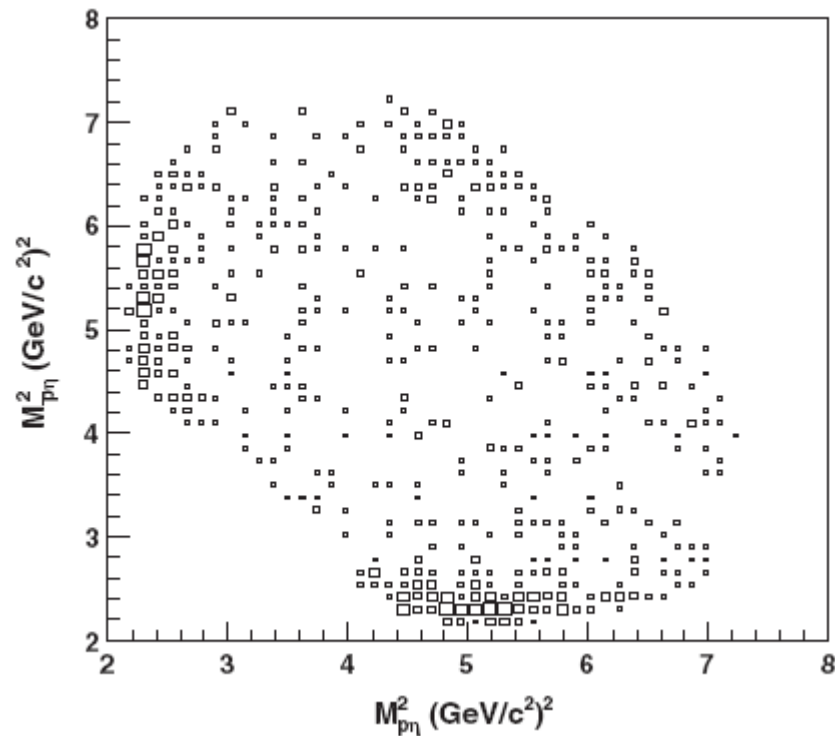
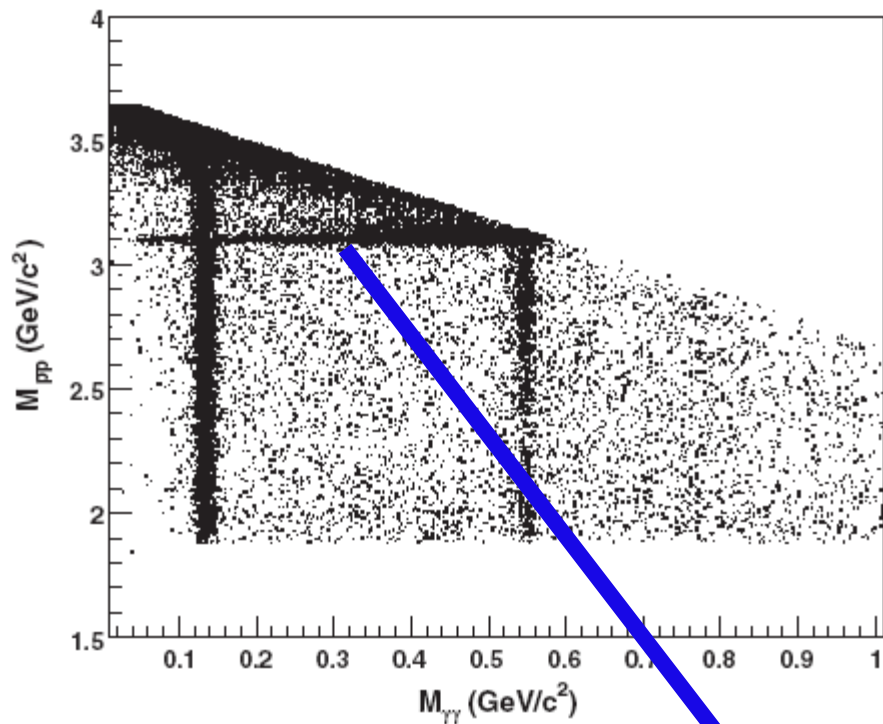


- **solid:**
 - background estimated from sidebands
- **dashed:**
 - inclusive J/ψ MC samples
- **background subtraction:**
 - $\ln \mathcal{L}^{\text{signal}} = \ln \mathcal{L}^{\text{data}} - \ln \mathcal{L}^{\text{sideband}}$

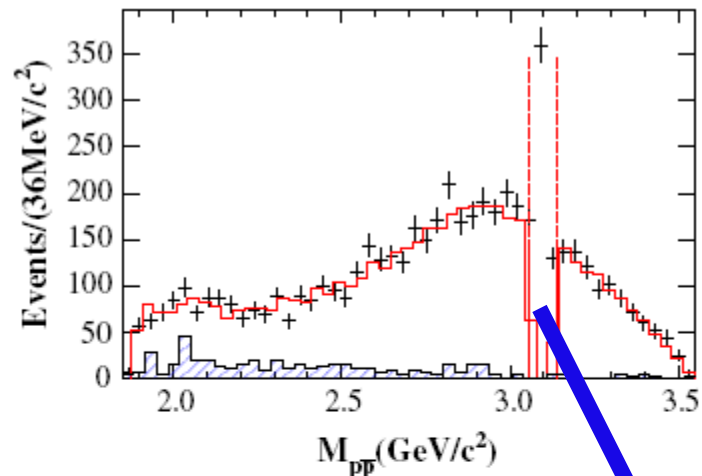
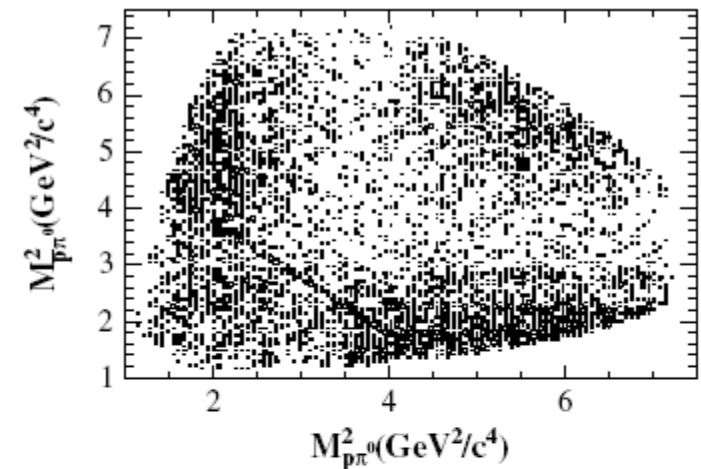


BESIII: PWA of $J/\psi \rightarrow \gamma p\bar{p}$, $M_{p\bar{p}} < 2.2 \text{ GeV}$ PRL 108, 112003

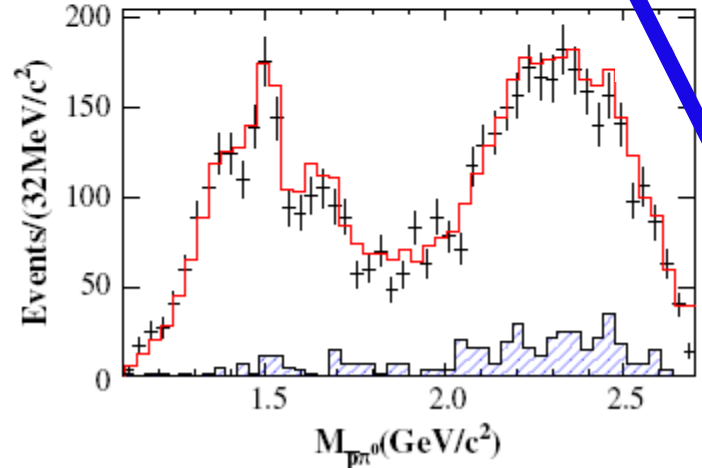
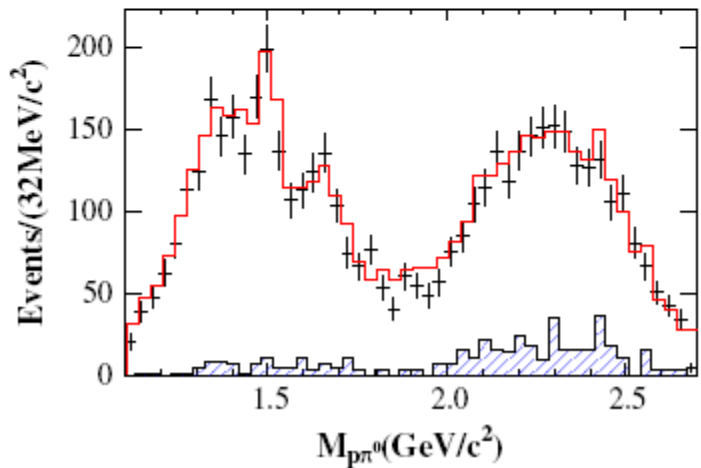




$\psi(2S) \rightarrow J/\psi X$, $J/\psi \rightarrow p\bar{p}$ subtracted



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

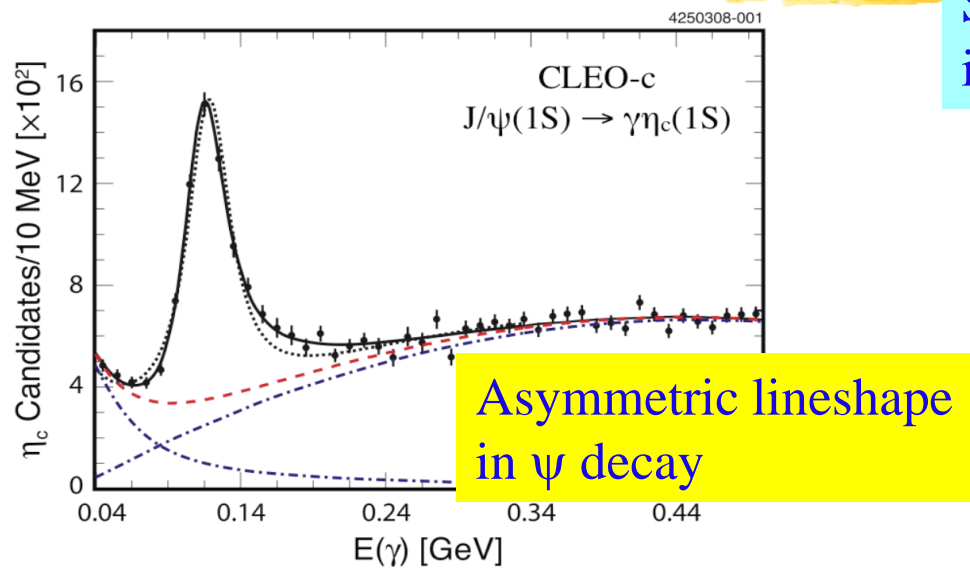


$\psi(2S) \rightarrow J/\psi X$, $J/\psi \rightarrow p\bar{p}$ subtracted

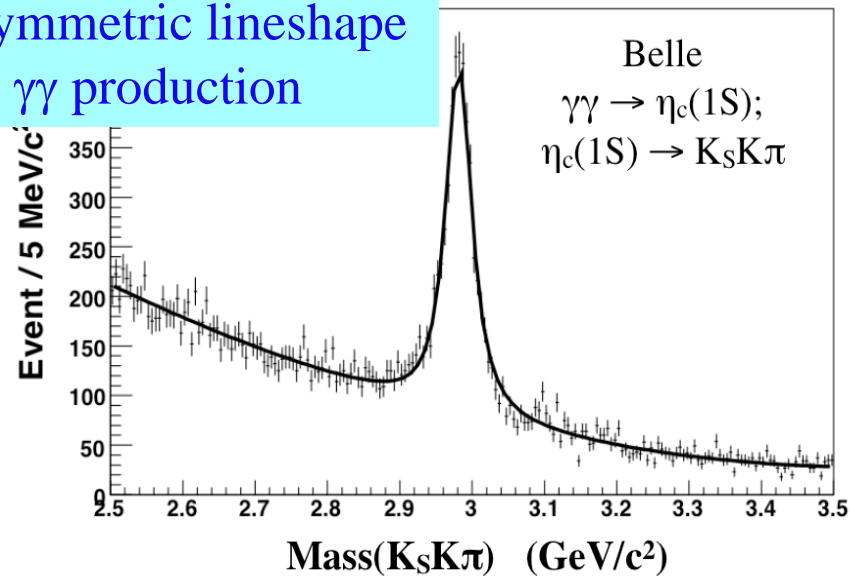


BESIII: η_c parameters from $\psi(2S) \rightarrow \pi^0 h_c(1P)$, $h_c(1P) \rightarrow \gamma \eta_c(1S)$

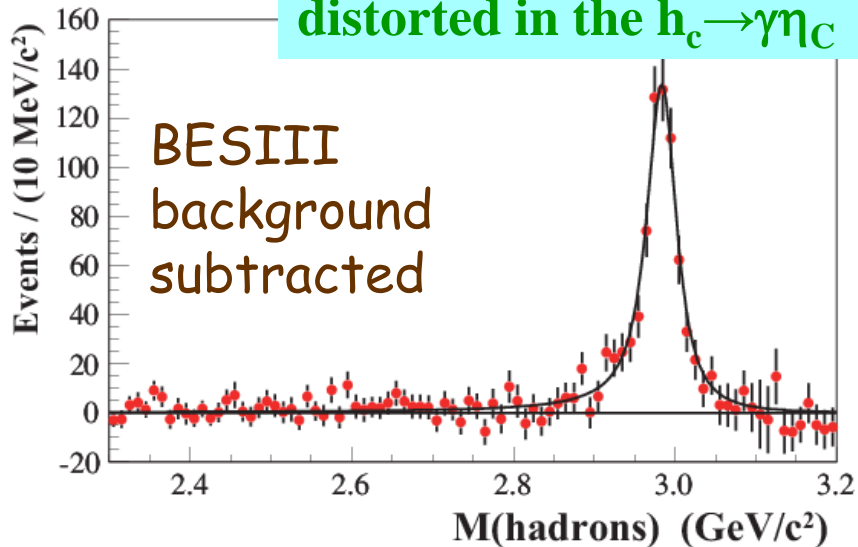
PRD 86, 092009



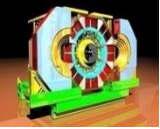
Symmetric lineshape in $\gamma\gamma$ production



The η_c lineshape is not distorted in the $h_c \rightarrow \gamma \eta_c$

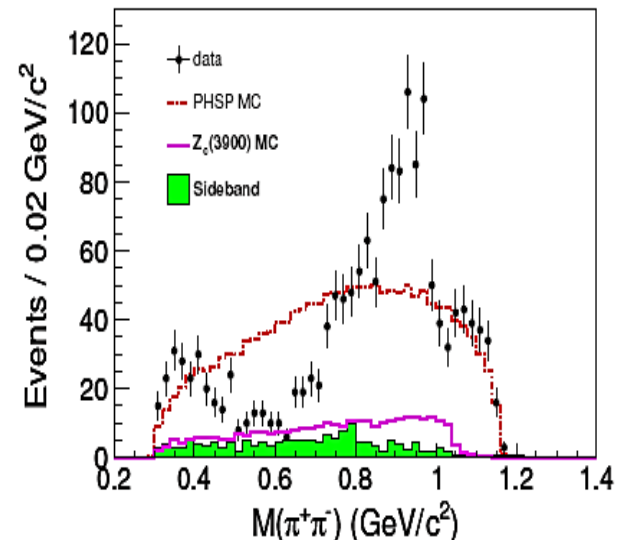
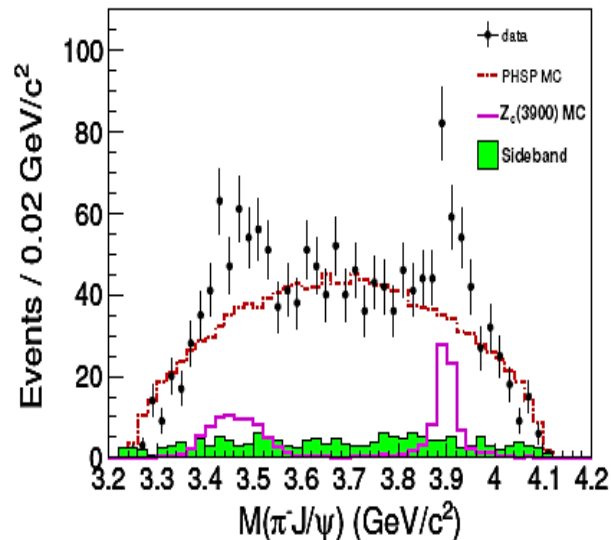
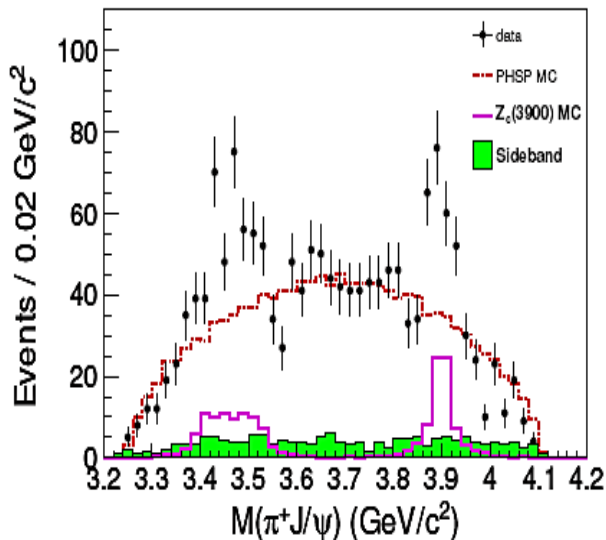


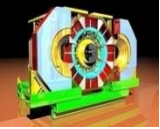
- CLEO-c observe a distortion of η_c lineshape in charmonium radiative decay
PRL102, 011801 (2009)
- The lineshape of η_c from BELLE is symmetric
- The abnormal line shape is also observed in BESIII exclusive channels in $\psi' \rightarrow \gamma \eta_c$ but not in $\psi' \rightarrow \pi^0 h_c$, $h_c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



Is it a real signal?

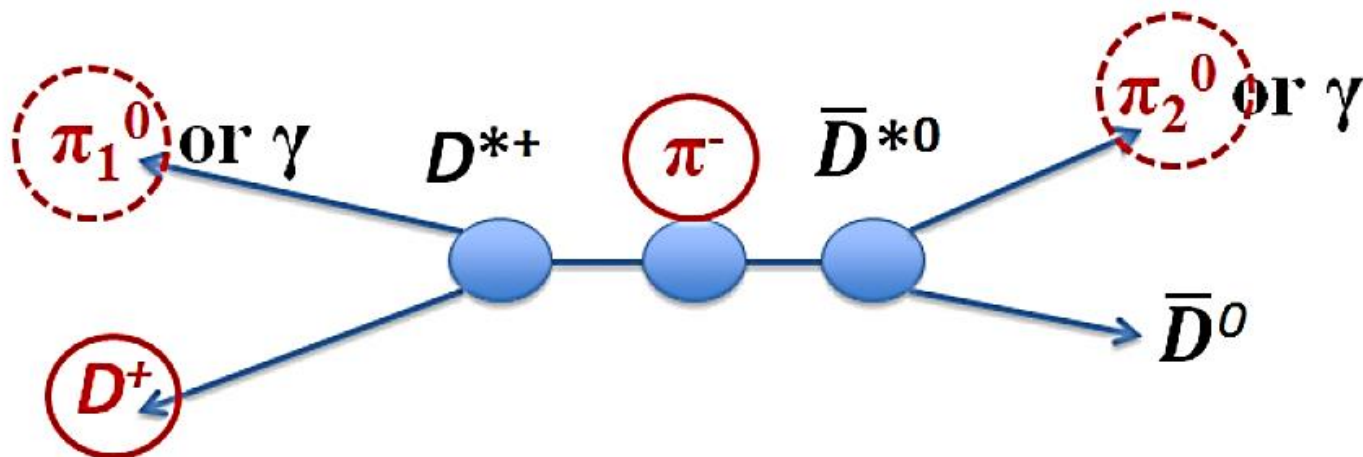
- Is it due to $\pi^+\pi^-$ S-wave states, like σ , $f_0(980)$, ...? N
- Is it due to $\pi^+\pi^-$ D-wave states, like $f_2(1270)$, ...? N
- Are there two states, one at 3.4, the other 3.9 GeV? N
- Exist in both e^+e^- & $\mu^+\mu^-$ samples? Y
- Exist in both $\pi^+\pi^-$ low mass and high mass samples?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





BESIII: $e^+e^- \rightarrow \pi Z_c(4025) \rightarrow \pi^- (D^* D^*)^+ + \text{c.c.}$ @ 4.260 GeV hep-ex:1308.2760

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



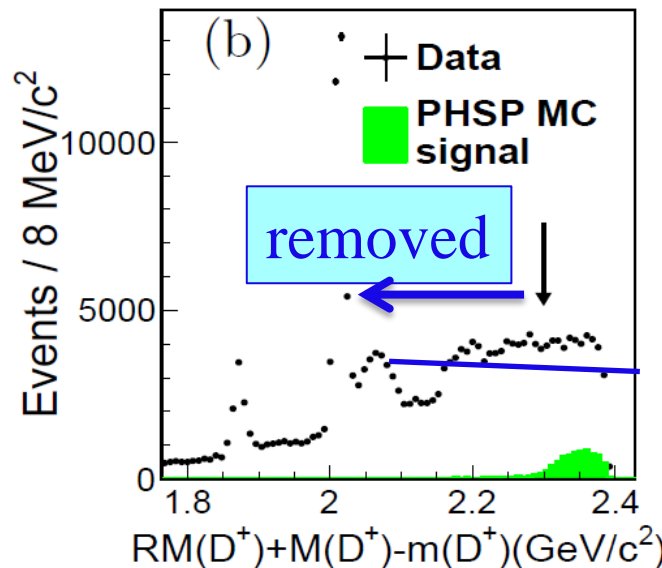
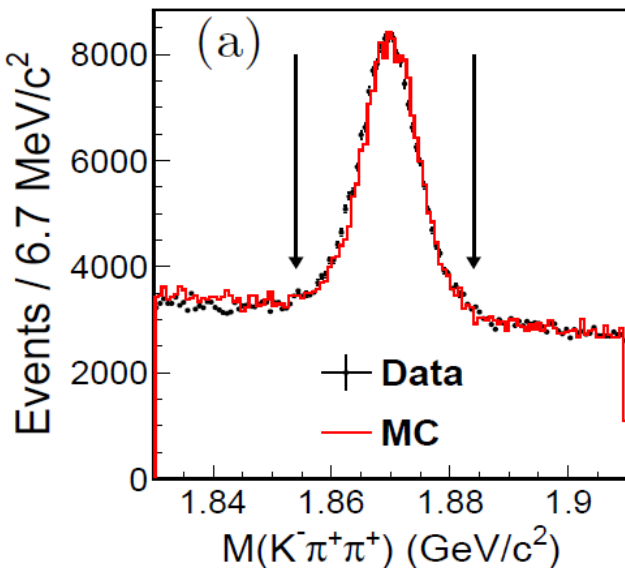
Topology of the decays of the signal process:

- 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

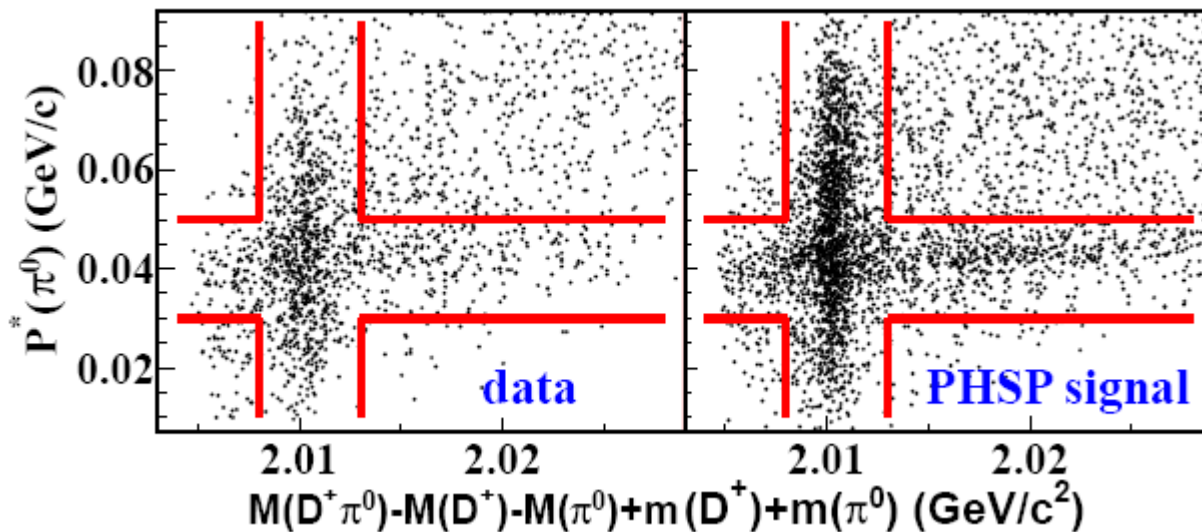


BESIII: $e^+e^- \rightarrow \pi Z_c(4025) \rightarrow \pi^- (D^* D^*)^+ + \text{c.c.}$ @ 4.260 GeV

hep-ex:1308.2760



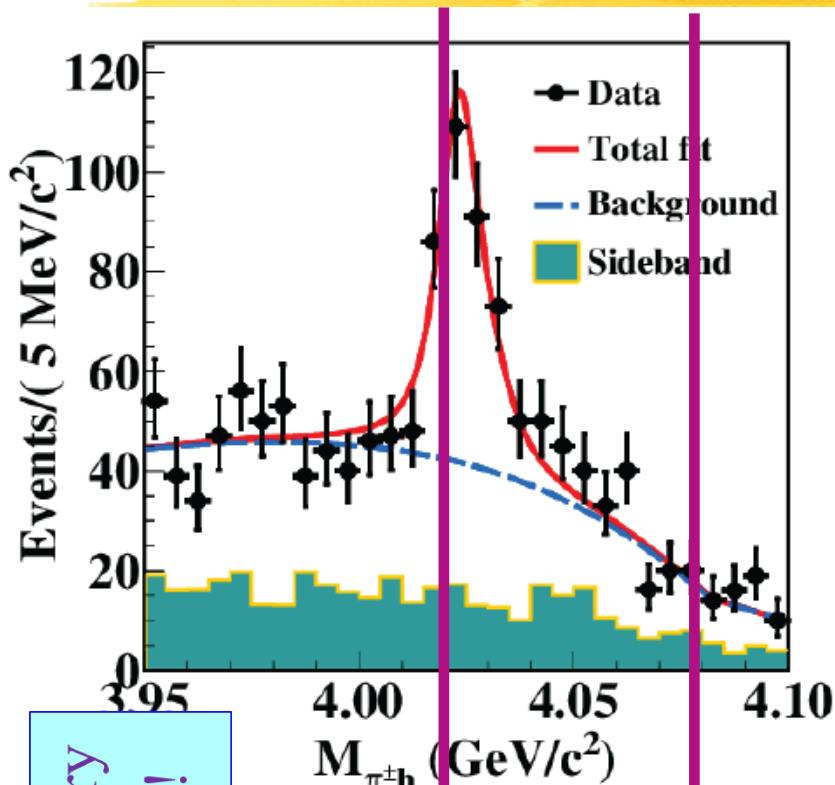
Remove DD, DD*, D*D*, DsDs, ...



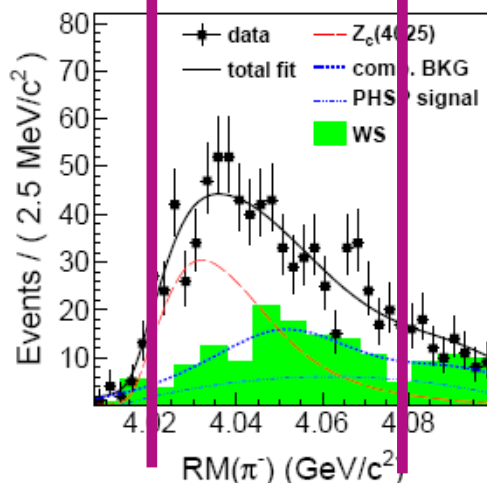


BESIII: $Z_c(4020)=Z_c(4025)$?

hep-ex:1309.1896
hep-ex:1308.2760



BESIII preliminary
The Z_c ' is found!



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

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

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

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

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

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

Interference with other amplitudes
may change the results

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

Will fit with Flatte formula



What is the X(3872)?

- Mass: Very close to $\bar{D}^0 D^{*0}$ threshold
- Width: Very narrow, < 1.2 MeV
- $J^{PC}=1^{++}$ [LHCb]
- Production
 - in $\bar{p}p/pp$ collision – rate similar to charmonia
 - In B decays – KX similar to $\bar{c}c$, K^*X smaller than $\bar{c}c$
 - $Y(4260) \rightarrow \gamma + X(3872)$ [BESIII, preliminary]
- Decay BR: open charm $\sim 50\%$, charmonium $\sim O(\%)$
- 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} ?)

