Recent results on charmonium and light hadron spectroscopy at BESIII

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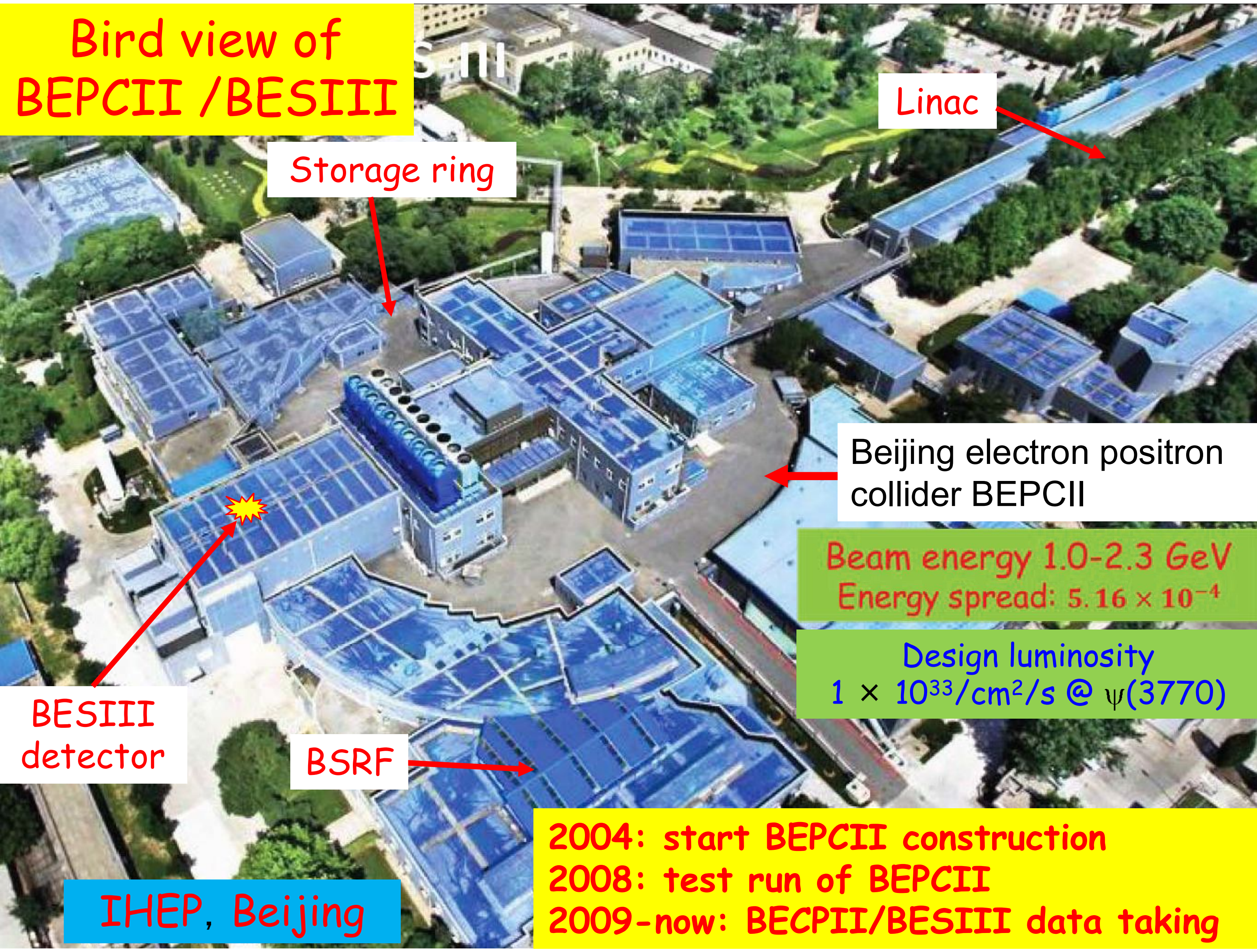
Outline

- **Introduction**
- **Study of h_c in ψ(2S) → $\pi 0$ h_c**
- **Precise measurement of η_c mass and width**
- **Observation of η_c' in ψ' → $\gamma KK\pi$**
- **Spin-parity analysis of the ppbar mass threshold enhancement X(ppbar) in J/ψ and ψ' radiative decays**
- **η(1405) in** $J/\psi \to \gamma f_0(980)\pi^0, f_0(980) \to 2\pi$
- **PWA of** $J/\psi \to \gamma\eta\eta$ **and** $J/\psi \to \gamma\omega\phi$
- **Summary**

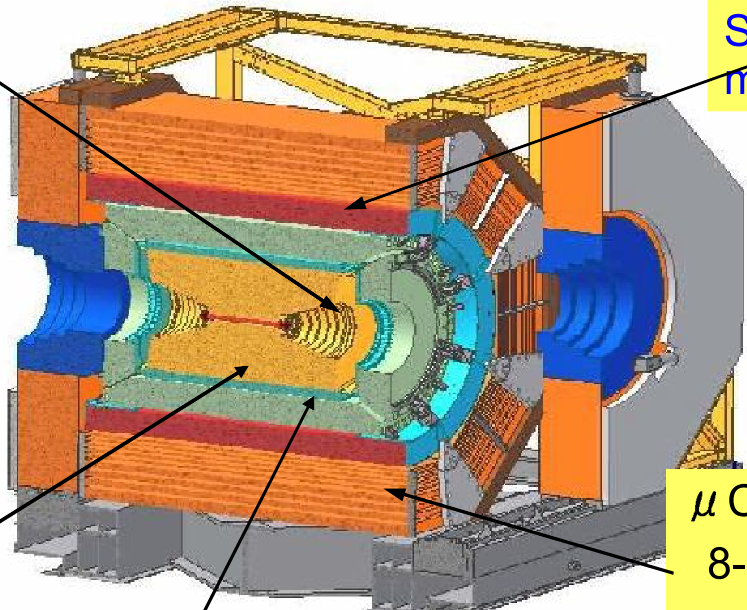

Bird view of
BEPCII /BESIII
Linac
Storage ring
Beijing electron positron
collider BEPCII
Beam energy 1.0-2.3 GeV
Energy spread: 5.16×10^{-4}
Design luminosity
$1 \times 10^{33}/cm^2/s$ @ $\psi(3770)$
BESIII
detector
BSRF
IHEP, Beijing
2004: start BEPCII construction
2008: test run of BEPCII
2009-now: BECPII/BESIII data taking

The BESIII Detector

NIM A614, 345 (2010)

Drift Chamber (MDC)
$\sigma P/P$ ($^0/_0$) = 0.5%(1GeV)
$\sigma_{dE/dx}$ ($^0/_0$) = 6%

Super-conducting magnet (1.0 tesla)



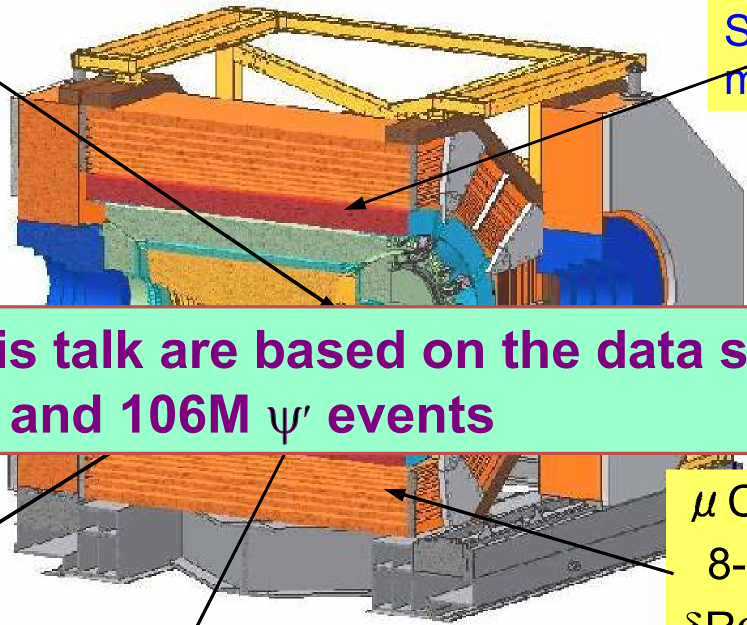
Time Of Flight (TOF)
σ_T : 90 ps Barrel
110 ps endcap

μ Counter
8- 9 layers RPC
$\delta R\Phi$=1.4 cm~1.7 cm

EMC: $\sigma E/\sqrt{E}$($^0/_0$) = 2.5 % (1 GeV)
(CsI) $\sigma_{z,\phi}$(cm) = 0.5 - 0.7 cm/$\sqrt{E}$

The BESIII Detector

NIM A614, 345 (2010)



Drift Chamber (MDC)
$\sigma P/P$ ($^0/_0$) = 0.5%(1GeV)
$\sigma_{dE/dx}$ ($^0/_0$) = 6%

Super-conducting magnet (1.0 tesla)

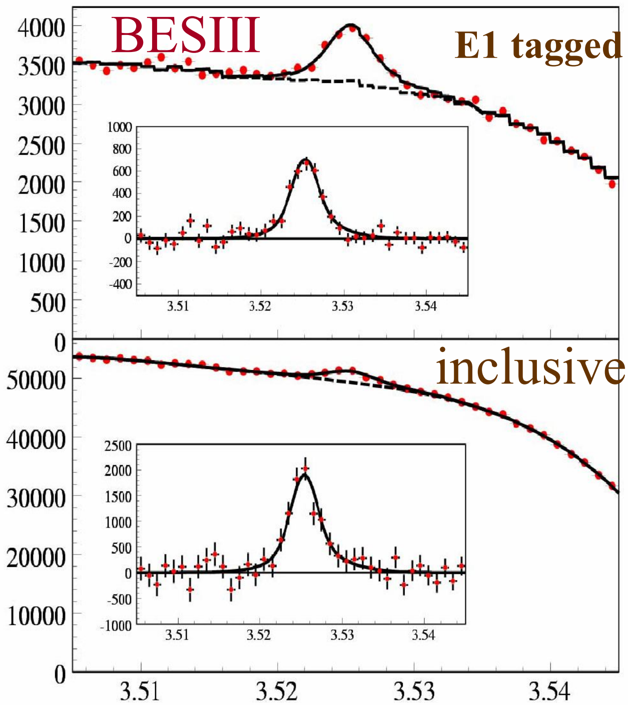
The results in this talk are based on the data samples of 225M J/ψ events and 106M ψ' events

Time Of Flight (TOF)
σ_T: 90 ps Barrel
110 ps endcap

μ Counter
8- 9 layers RPC
$\delta R\Phi$=1.4 cm~1.7 cm

EMC: $\sigma E/\sqrt{E}$($^0/_0$) = 2.5 % (1 GeV)
(CsI) $\sigma_{z,\phi}$(cm) = 0.5 - 0.7 cm/$\sqrt{E}$

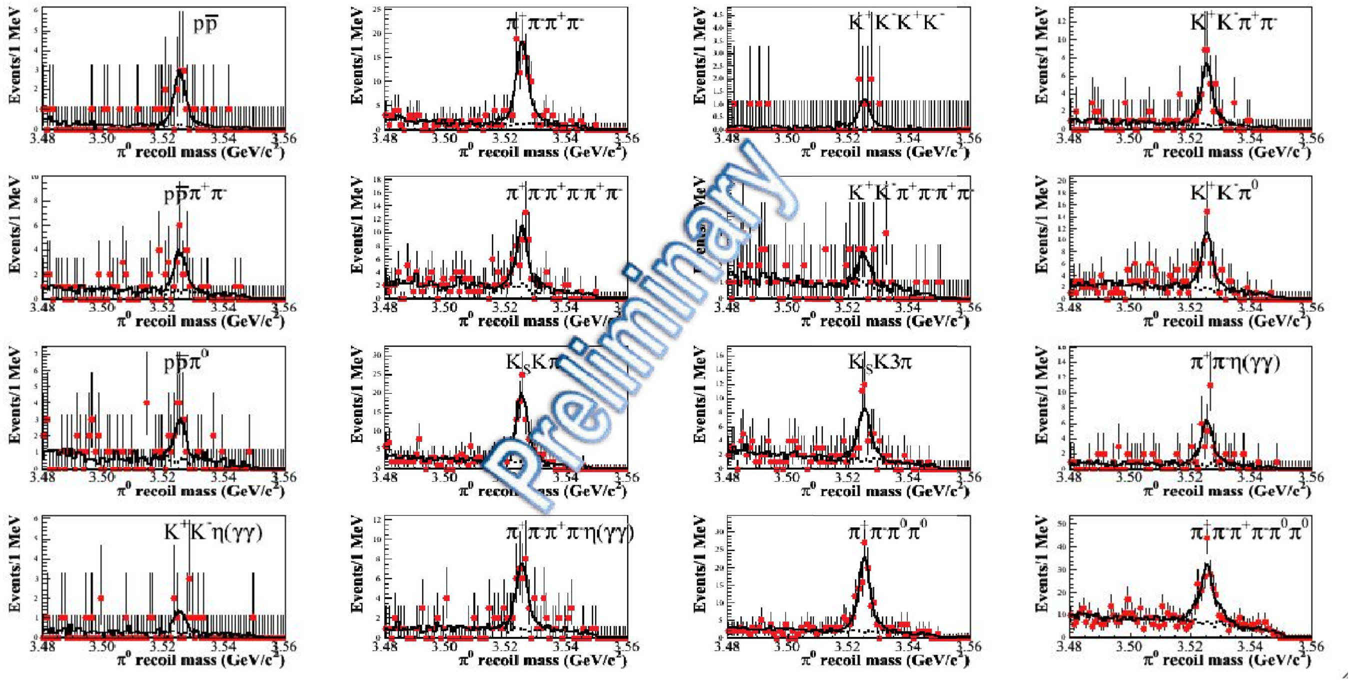
$\psi' \rightarrow \pi^0 h_c$ @ BESIII



PRL104, 132002, (2010)

- Select inclusive π^0 ($\psi' \rightarrow \pi^0 h_c$)
- Select E1-photon in $h_c \rightarrow \gamma\eta_c$ (w/o E1 tagged)
- E1-tagged selection gives
  $M(h_c)=3525.40\pm0.13\pm0.18$MeV
  ($\Delta M_{hf}(1P)=0.10\pm0.13\pm0.18$MeV/$c^2$)
  $\Gamma(h_c)=0.73\pm0.45\pm0.28$MeV
  (first measurement)
  (<1.44MeV at 90% CL)
  $Br(\psi' \rightarrow \pi^0 h_c) \times Br(h_c \rightarrow \gamma\eta_c)=$ $(4.58\pm0.40\pm0.50)\times10^{-4}$
- E1-untagged selection gives
  $Br(\psi' \rightarrow \pi^0 h_c) = (8.4\pm1.3\pm1.0)\times10^{-4}$
- Combining branching fractions leads to
  $Br(h_c \rightarrow \gamma\eta_c) = (54.3\pm6.7\pm5.2)\%$
  (first measurement)

$\psi' \rightarrow \pi^0 h_c$, $h_c \rightarrow \gamma\eta_c$, η_c exclusive decays @ BESIII



Simultaneous fit to π^0 recoiling mass

χ^2/d.o.f. = 32/46

Mass = **3525.31 ± 0.11 ± 0.15** MeV/c^2

Width = **0.70 ± 0.28 ± 0.25** MeV

Consistent with BESIII inclusive results PRL104,132002(2010)

CLEOc exlusive results

$M(h_c)$=3525.21±0.27±0.14 MeV/c^2

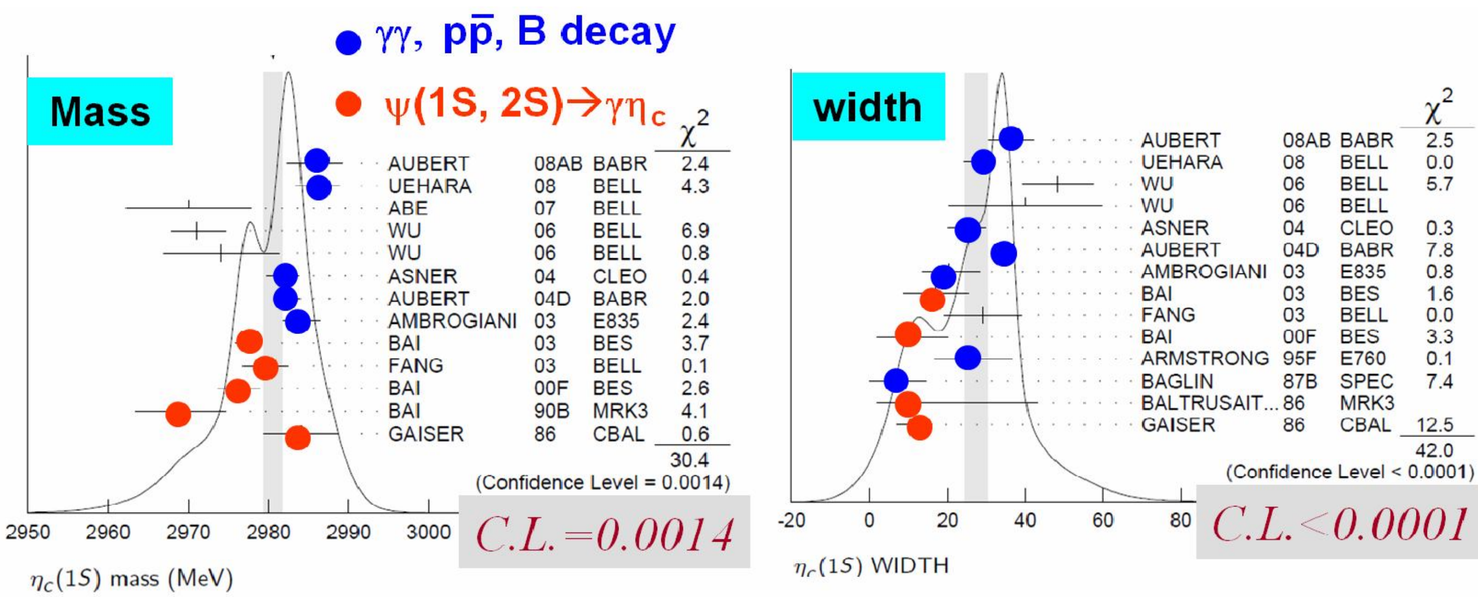
N = 136±14

PRL101, 182003(2008)

$\eta_c(1S)$

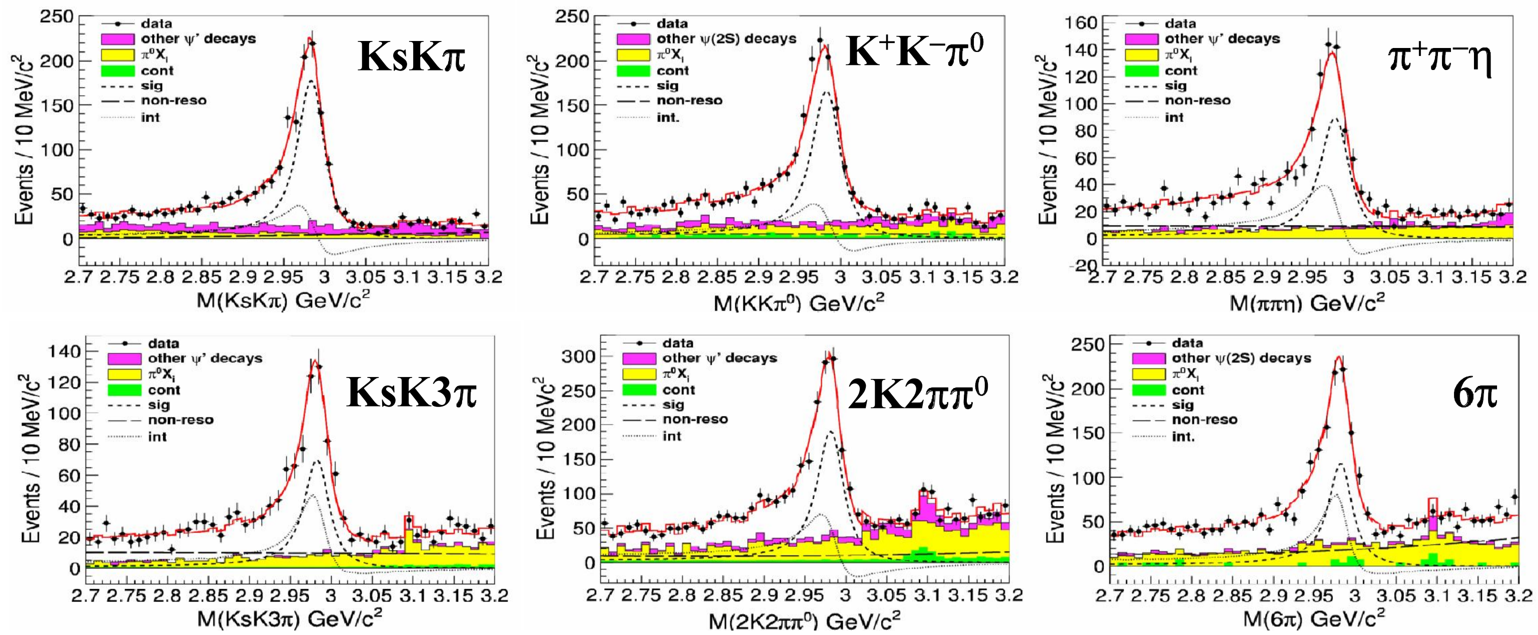
- Ground state of $c\bar{c}$ system, but its properties are not well known:

  J/ψ radiative transition: $M \sim 2978.0 MeV/c^2$, $\Gamma \sim 10 MeV$
  $\gamma\gamma$ process: $M = 2983.1 \pm 1.0 MeV/c^2$, $\Gamma = 31.3 \pm 1.9 MeV$



- CLEOc found the distortion of the η_c lineshape in ψ' decays
- $c\bar{c}$ hyperfine splitting: $M(J/\psi)$- $M(\eta_c)$ is important experimental input to test the lattice QCD, but is dominated by error on $M(\eta_c)$

$\psi' \rightarrow \gamma\eta_c$, $\eta_c \rightarrow$ exclusive decays @ BESIII



Interference with non-resonant is significant !

Relative phase ϕ values from each mode are consistent within 3σ,

➔ use a common phase value in the simultaneous fit.

M: **2984.3 ± 0.6 ± 0.6** MeV

Γ: **32.0 ± 1.2 ± 1.0** MeV

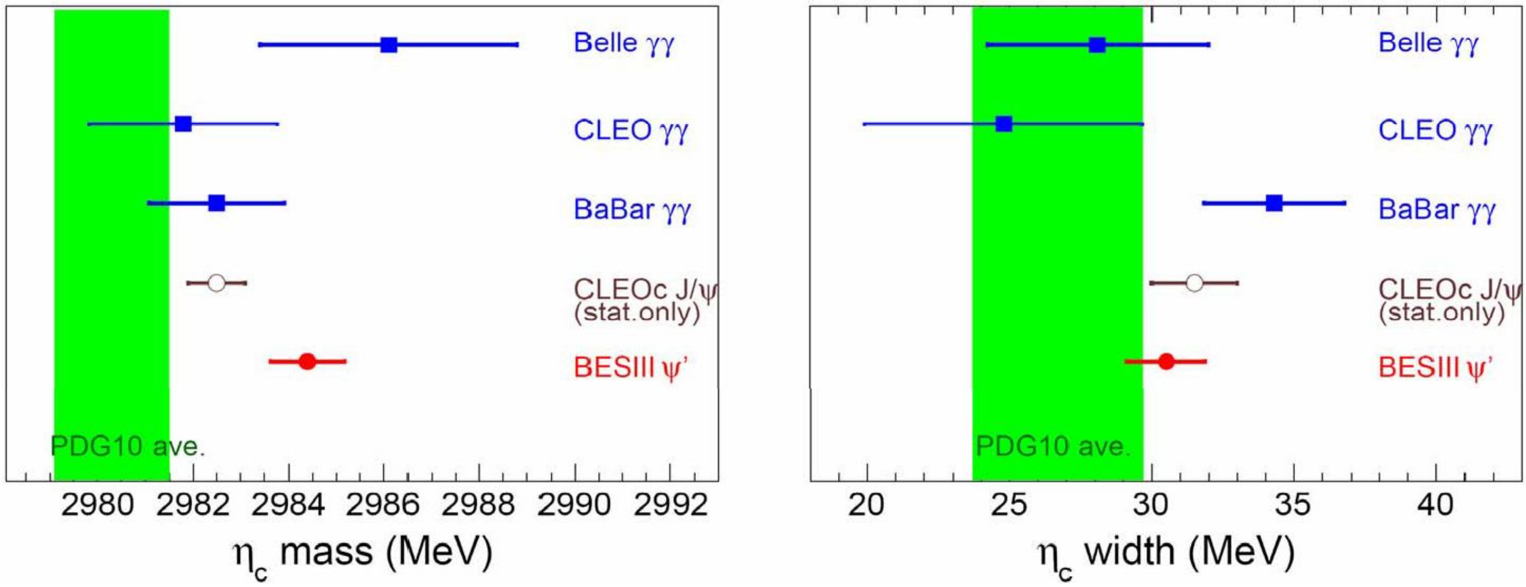
ϕ: **2.40 ± 0.07 ± 0.08** rad

or **4.19 ± 0.03 ± 0.09** rad

arXiv:1111:0398 PRL 108(2012)222002

Comparison of the mass and width for η_c

The world average in PDG2010 was using earlier measurements



Hyperfine splitting: $\Delta M(1S)$ = **112.6 ± 0.8 MeV**

Consistent with B factory results in other production mechanisms.
Agree with lattice QCD calculations of the charmonium hyperfine splitting

Observation of $\psi' \to \gamma\eta_c(2S)$

- First "observation" by Crystal Ball in 1982 (M=3.592, B=0.2%-1.3% from $\psi' \to \gamma X$, never confirmed by other experiments.)

- Published results about $\eta_c(2S)$ observation:

Experiment	M [MeV]	Γ [MeV]	Process
Belle [1]	$3654 \pm 6 \pm 8$	—	$B^{\pm} \to K^{\pm}\ \eta_c(2S), \eta_c(2S) \to K_S K^{\pm}\pi^{\mp}$
CLEO [2]	$3642.9 \pm 3.1 \pm 1.5$	$6.3 \pm 12.4 \pm 4.0$	$\gamma\gamma \to \eta_c(2S) \to K_S K^{\pm}\pi^{\mp}$
BaBar [3]	$3630.8 \pm 3.4 \pm 1.0$	$17.0 \pm 8.3 \pm 2.5$	$\gamma\gamma \to \eta_c(2S) \to K_S K^{\pm}\pi^{\mp}$
BaBar [4]	$3645.0 + 5.5^{+4.9}_{-7.8}$	—	$e^+e^- \to J/\psi c\bar{c}$
PDG [5]	3638 ± 4	14 ± 7	—

Combined with the results based on two-photon processes from BaBar and Belle reported at ICHEP 2010, the world average $\Gamma(\eta_c(2S))=12\pm3$ MeV

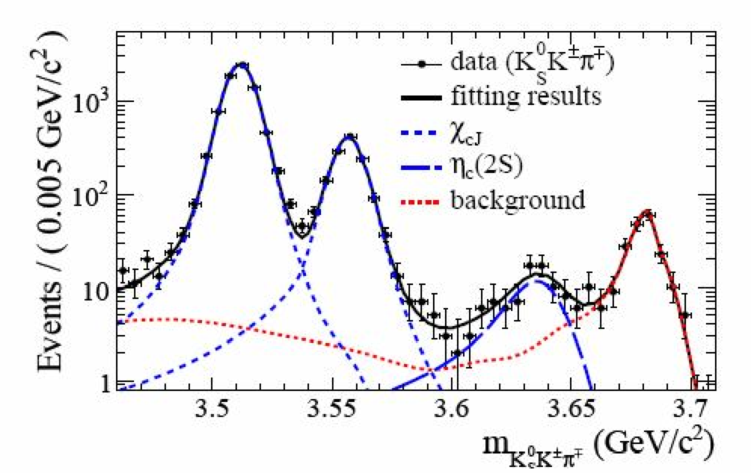
- The M1 transition $\psi' \to \gamma\eta_c(2S)$ has not been observed.

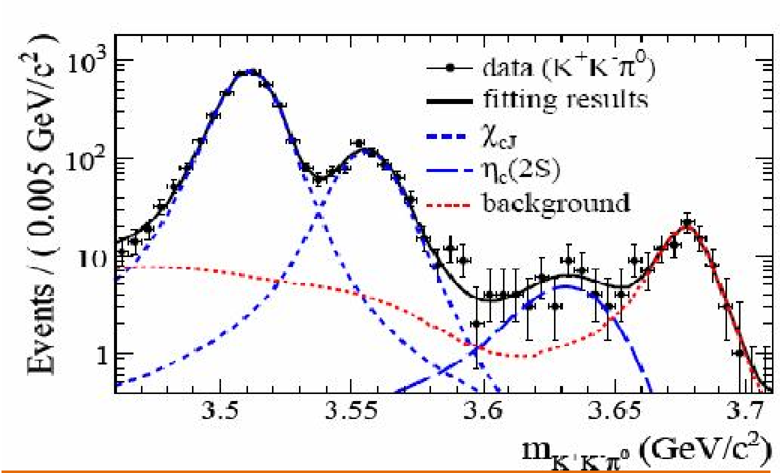
(experimental challenge : search for real photons ~50MeV,)

- Better chance to observe $\eta_c(2S)$ in ψ' radiative transition with ~106M ψ' data at BESIII.

- Decay mode studied: $\psi' \to \gamma\eta_c(2S) \to \gamma K_S K\pi$ & $K^+K^-\pi^0$

Observation of $\eta_c(2S)$ in $\psi' \Rightarrow \gamma\eta_c(2S)$, $\eta_c(2S) \Rightarrow K_s K\pi$, $K^+K^-\pi^0$





1205.5103v2[hep-exp], accepted by PRL

simultaneous fit results:

$M(\eta_c(2S))$ = (3637.6 ± 2.9 ± 1.6) MeV
$\Gamma(\eta_c(2S))$ = (16.9 ± 6.4 ± 4.8) MeV
Statistical significance larger than 10.2σ!

$Br(\psi' \to \gamma\eta_c(2S) \to \gamma KK\pi)$ $= (1.30 \pm 0.20_{stat} \pm 0.30_{sys}) \times 10^{-5}$

+

$Br(\eta_c(2S) \to KK\pi) = (1.9 \pm 0.4 \pm 1.1)\%$
From BABAR(PRD78,012006)

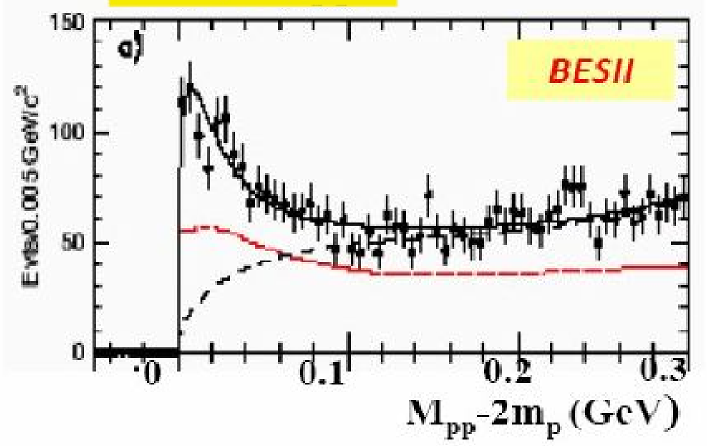
$Br(\psi' \to \gamma\eta_c(2S))$ $= (6.8 \pm 1.1_{stat} \pm 4.5_{sys}) \times 10^{-4}$

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

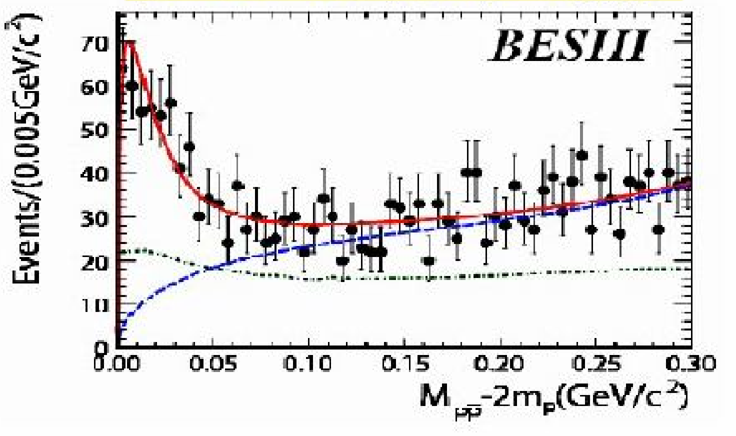
Potential model: $(0.1 – 6.2) \times 10^{-4}$
PRL89,162002(2002)

Enhancement at $p\bar{p}$ threshold in $J/\psi \to \gamma p\bar{p}$

$J/\psi \to \gamma p\bar{p}$



$\psi' \to \pi^+\pi^- J/\psi,\ J/\psi \to \gamma p\bar{p}$



Observed at BESII in 2003 (PRL,022001)
agree with spin zero expectation
M =$1860^{+3}_{-10}{}^{+5}_{-25}$ MeV, Γ< 38 MeV (90% CL)

Confirmed at BESIII in 2010
(CPC 34,421 (2010))
M =$1859^{+6}_{-13}{}^{+6}_{-26}$ MeV, Γ< 30 MeV (90% CL)

Many possibilities:

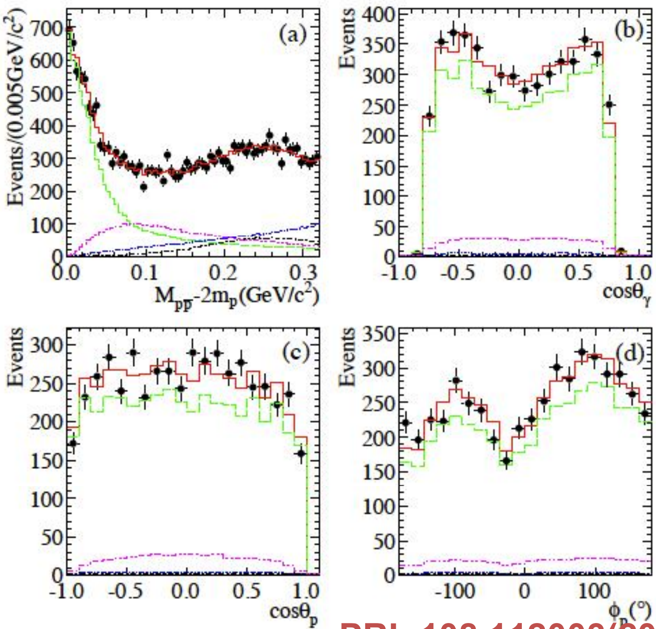
normal meson/ $p\bar{p}$ bound state/multiquark/glueball/Final state interaction effect(FSI)……

Spin-parity analysis

is essential for determining place in the spectrum and possible nature.

PWA of $J/\psi \to \gamma p\bar{p}$ @BESIII

- **PWA of J/ψ→γ ppbar was first performed**
- **The fit with a BW and S-wave FSI(I=0) factor can well describe ppb mass threshold structure.**
- **It is much better than that without FSI effect, and Δ2lnL=51 (7.1σ)**
- **Different FSI models→Model dependent uncertainty**



PRL 108,112003(2012)

- **Spin-parity, mass, width and B.R. of X(ppbar):**

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

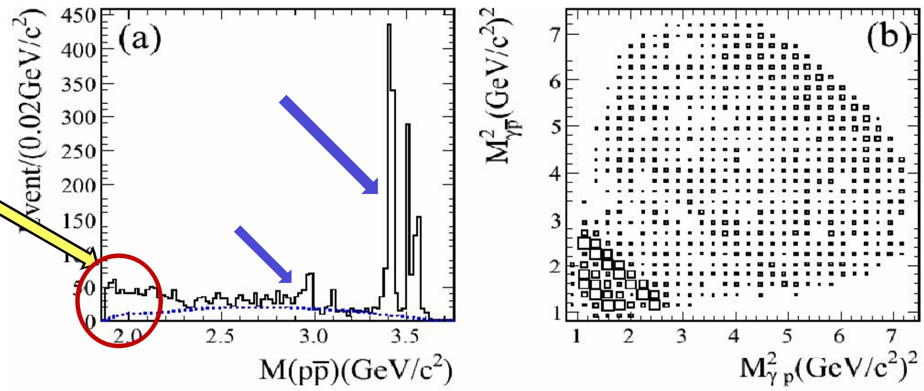
$$M=1832^{+19}_{-5}(stat)^{+18}_{-17}(syst)\pm19(mod)MeV/c^2$$

$$\Gamma=13\pm20(stat)^{+11}_{-33}(syst)\pm4(mod)MeV/c^2 \text{ or } \Gamma<76MeV/c^2\ @90\%C.L.$$

$$B(J/\psi\to\gamma X(p\bar{p}))B(X(p\bar{p})\to p\bar{p})=(9.0^{+0.4}_{-1.1}(stat)^{+1.5}_{-5.0}(syst)\pm2.3(mod))\times10^{-5}$$

M_{ppbar} threshold structure of $\psi' \to \gamma p\bar{p}$ @BESIII

Obviously different line shape of ppbar mass spectrum near threshold from that in J/ψ decays



PWA results:

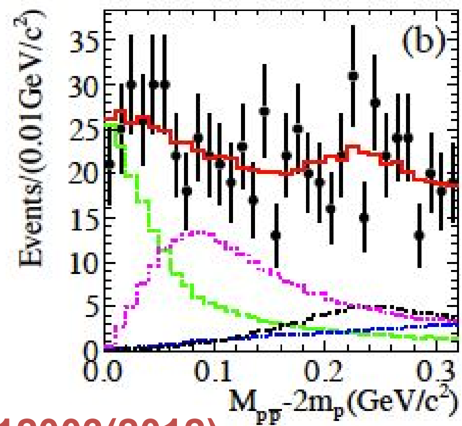
- Significance of X(ppbar) is > 6.9σ.
- The production ratio R: **first measurement**

$$R = \frac{B(\psi' \to \gamma X(p\bar{p}))}{B(J/\psi \to \gamma X(p\bar{p}))}$$

$$= (5.08^{+0.71}_{-0.45}(\text{stat})^{+0.67}_{-3.58}(\text{syst}) \pm 0.12(\text{mod}))\%$$

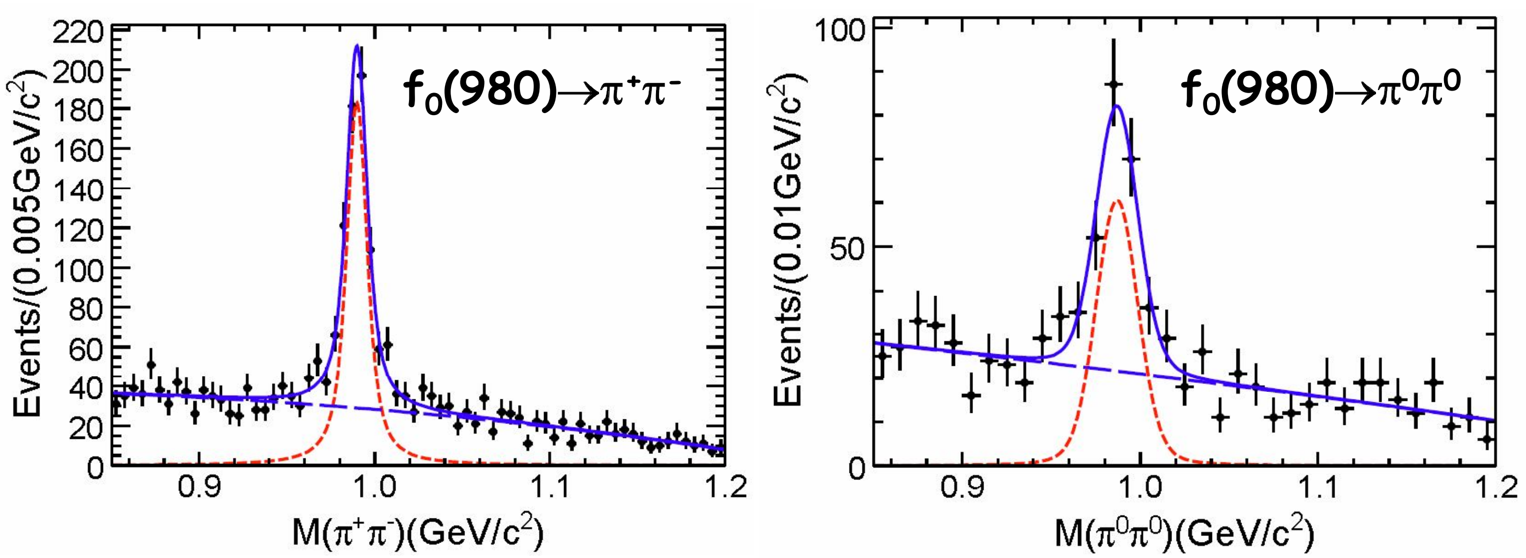
- It is suppressed compared with "12% rule".

PWA Projection:



PRL 108,112003(2012)

Anomalous line shape of $f_0(980)$ in $J/\psi \to \gamma 3\pi$



$M = 989.9 \pm 0.4 \mathrm{MeV}/c^2$
$\Gamma = 9.5 \pm 1.1\ \mathrm{MeV}/c^2$

$M = 987.0 \pm 1.4 \mathrm{MeV}/c^2$
$\Gamma = 4.6 \pm 5.1\ \mathrm{MeV}/c^2$

PRL 108, 182001 (2012)

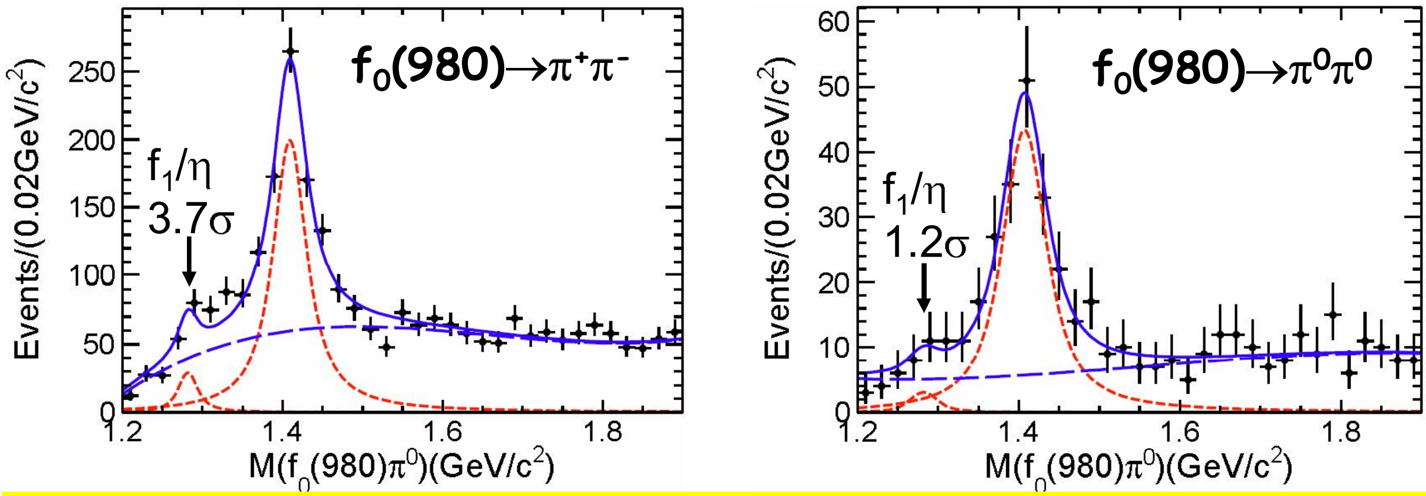
Surprising result:

very narrow $f_0(980)$ width: <11.8 MeV/c^2 @90% C.L.

much narrower than the world average (PDG 2010: 40-100 MeV/c^2)

A possible explanation is KK^* loop, Triangle Singularity (TS) (J.J. Wu et al, PRL 108, 081803(2012))

$\eta(1405)$ in $J/\psi \to \gamma f_0(980)\pi^0$, $f_0(980) \to 2\pi$



First observed: $\eta(1405) \to f_0(980)\pi^0$ (Large isospin breaking):

$$\frac{BR(\eta(1405) \to f_0(980)\pi^0 \to \pi^+\pi^-\pi^0)}{BR(\eta(1405) \to a_0(980)\pi^0 \to \pi^0\pi^0\eta)} \approx (17.9 \pm 4.2)\%$$

PRL 108, 182001 (2012)

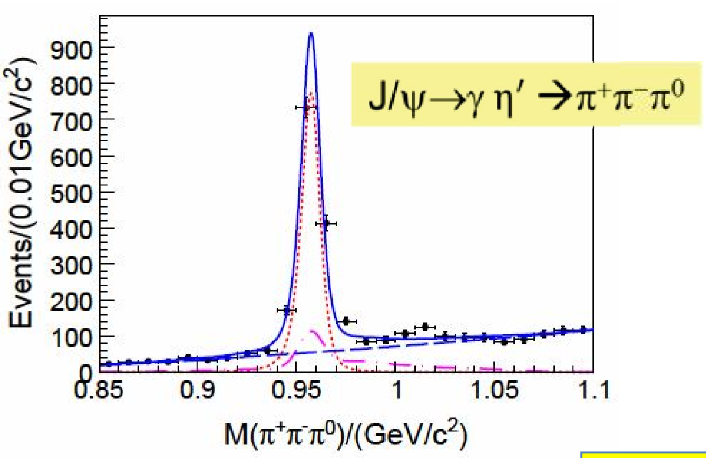
$\vee$

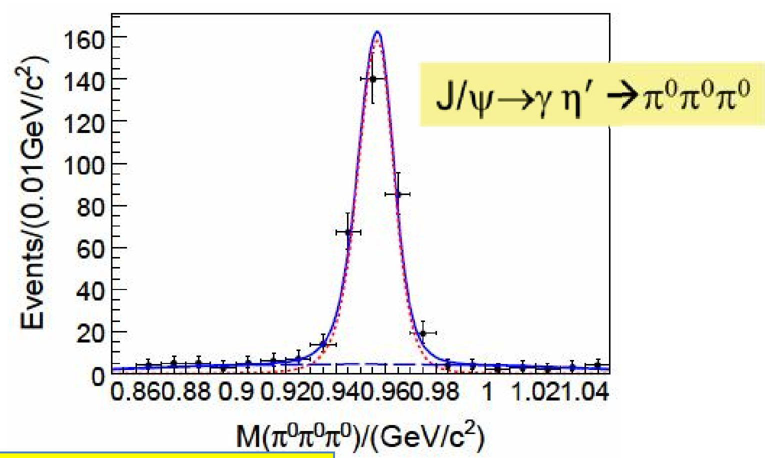
$$\xi_{af} = \frac{Br(\chi_{c1} \to f_0(980)\pi^0 \to \pi^+\pi^-\pi^0)}{Br(\chi_{c1} \to a_0(980)\pi^0 \to \eta\pi^0\pi^0)} < 1\% (90\% \ C.L.)$$

PRD, 83(2100)032003

a_0-f_0 mixing alone can not explain the branching ratio of $\eta(1405)$

New results on η'→3π





PRL 108, 182001 (2012)

New results:

$Br(\eta' \to \pi^+\pi^-\pi^0) = (3.83 \pm 0.15 \pm 0.39) \times 10^{-3}$ (PDG2010: $(3.6^{+1.1}_{-0.93}) \times 10^{-3}$)

$Br(\eta' \to \pi^0\pi^0\pi^0) = (3.56 \pm 0.22 \pm 0.34) \times 10^{-3}$ (PDG2010: $(1.68 \pm 0.22) \times 10^{-3}$)

For the decay $\eta' \to \pi^0\pi^0\pi^0$, it is two times larger than the world average value.

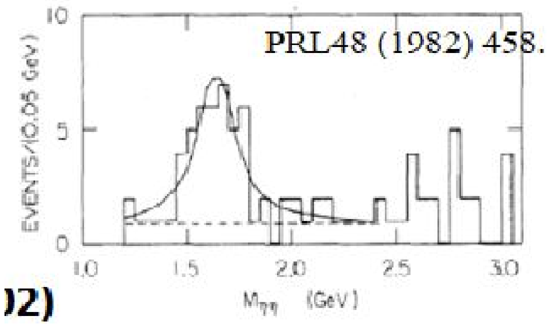
Comparison: Isospin violations in η'→πππ :

$$\frac{BR(\eta' \to \pi^+\pi^-\pi^0)}{BR(\eta' \to \pi^+\pi^-\eta)} \approx 0.9\%, \quad \frac{BR(\eta' \to \pi^0\pi^0\pi^0)}{BR(\eta' \to \pi^0\pi^0\eta)} \approx 1.6\%$$

Study of ηη system

- **First observed $f_0(1710)$ from J/ψ radiative decays to ηη by Crystal Ball in 1982.**
- **LQCD predicts:**

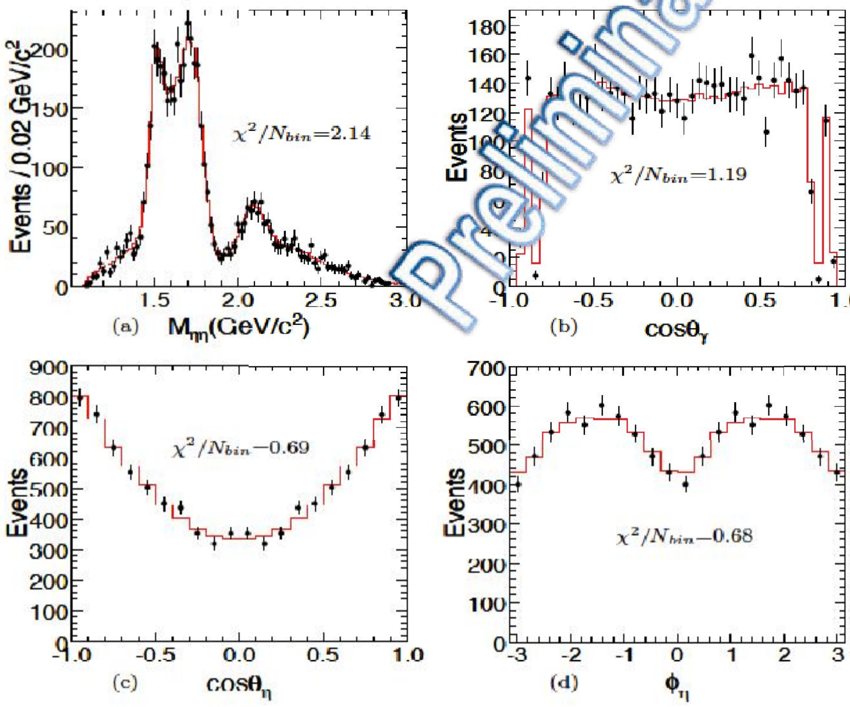
  0^{++} : 1710 ± 50 ± 80



- **Crystal Barrel Collaboration (2002) analyzed the three final states $\pi^0\pi^0\pi^0$, $\eta\pi^0\pi^0$ and $\pi^0\eta\eta$ with K matrix formalism. Found a 2^{++} (~1870MeV), but no $f_0(1710)$.**
- **E835 (2006): ppbar → $\pi^0\eta\eta$, found $f_0(1500)$ and $f_0(1710)$.**
- **WA102 and GAMS all identified $f_0(1710)$ in ηη .**

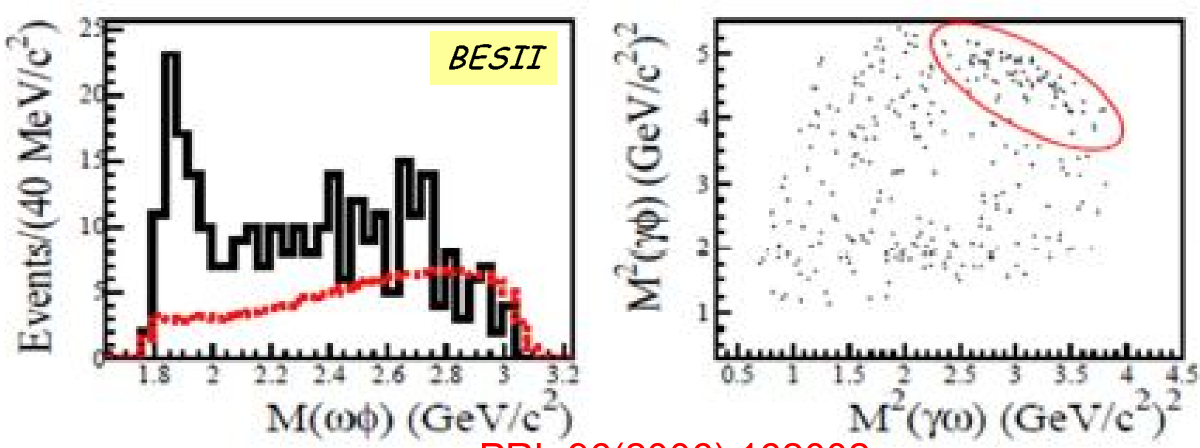
Preliminary PWA results of $J/\psi \rightarrow \gamma\eta\eta$ @BESIII

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+20}_{-15-74}	$136^{+41+8}_{-26-100}$	$(1.61^{+0.29+0.41}_{-0.32-1.28}) \times 10^{-5}$	$8.2\ \sigma$
$f_0(1710)$	1759^{+6+14}_{-6-25}	172^{+10+31}_{-10-15}	$(2.35^{+0.07+1.23}_{-0.07-0.72}) \times 10^{-4}$	$25.0\ \sigma$
$f_0(2100)$	2081^{+13+23}_{-13-34}	$273^{+27+65}_{-2[illegible]-18}$	$(9.99^{+0.57+5.52}_{-0.52-2.21}) \times 10^{-5}$	$13.9\ \sigma$
$f_2'(1525)$	1513^{+5+3}_{-5-10}	$75^{+12+15}_{[illegible]}$	$(3.41^{+0.43+1.22}_{-0.50-1.23}) \times 10^{-5}$	$11.0\ \sigma$
$f_2(1810)$	1822^{+29+61}_{-24-54}	229[illegible]	$(5.38^{+0.60+3.31}_{-0.67-2.24}) \times 10^{-5}$	$6.4\ \sigma$
$f_2(2340)$	$2362^{+31+139}_{-30-59}$	33[illegible]+16 [illegible]99	$(5.58^{+0.61+1.93}_{-0.65-1.81}) \times 10^{-5}$	$7.6\ \sigma$

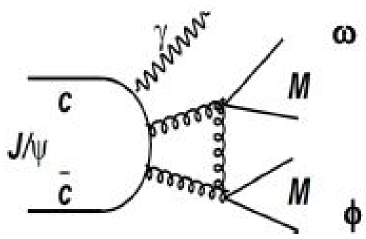


- $f_0(1710)$ and $f_0(2100)$ are dominant scalars.
- $f_0(1500)$ exists (8.2σ).
- $f_2'(1525)$ is the dominant tensor.

$M_{\omega\Phi}$ threshold enhancement in $J/\psi \rightarrow \gamma\omega\Phi$



PRL 96(2006) 162002



$J/\psi \rightarrow \gamma\omega\phi$ **(DOZI)**

For X(1810):

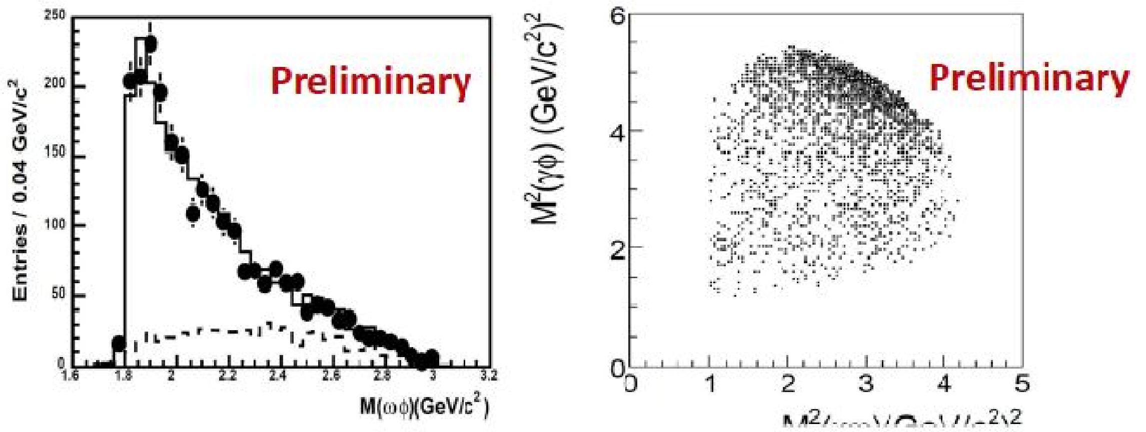
$$M = 1812^{+19}_{-26} \pm 18\ \mathrm{MeV/c^2}$$

$$\Gamma = 105 \pm 20 \pm 28\ \mathrm{MeV/c^2}$$

J^{pc} favors 0^{++} over 0^{-+} and 2^{++}

Preliminary PWA results of J/$\psi \rightarrow \gamma\, \omega\, \Phi$ @BESIII

Resonance	J^{PC}	M(MeV/c^2)	Γ(MeV/c^2)	Events	ΔS	Δndf	Significance
X(1810)	0^{++}	1795 ± 7	95 ± 10	1319 ± 52	783	4	> 30σ
f_2(1950)	2^{++}	1944	472	665 ± 40	211	2	> 10σ
f_0(2020)	0^{++}	1992	442	715 ± 45	100	2	> 10σ
η(2225)	0^{-+}	2240	190	70 ± 30	23	2	6.4σ
phase space	0^{-+}	2400	5000	319 ± 24	45	2	> 8σ



Is X(1810) the f0(1710)/f0(1790) or new state?

Summary

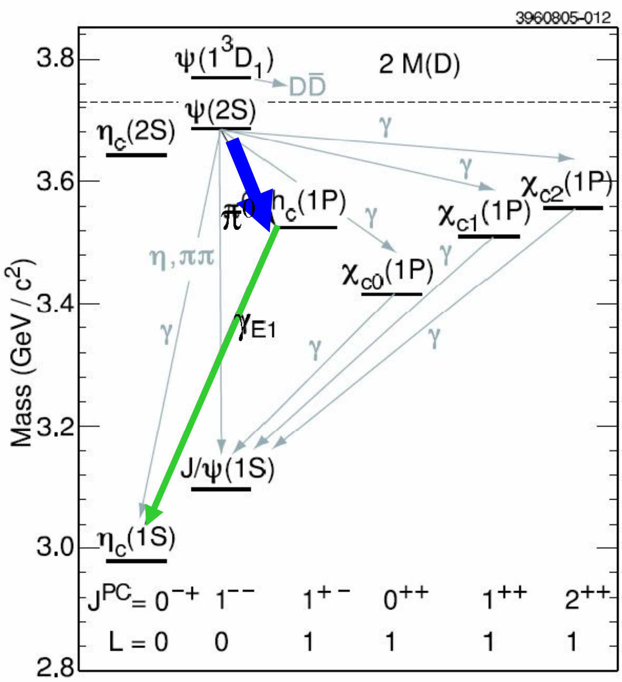
- **A lot of interesting results on charmonium and light hadron spectroscopy have been obtained at BESIII, with new observations and measurements.**

- **BESIII just took 1 billion J/ψ events and 0.4 billion ψ' events this year →**

  More and more exciting results from BESIII in the future

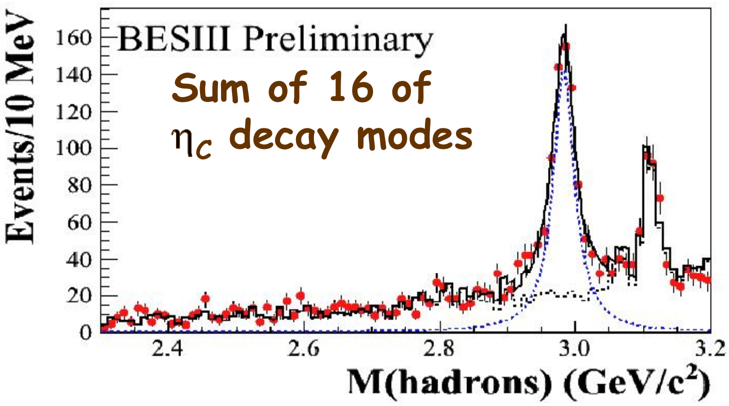
Thank you

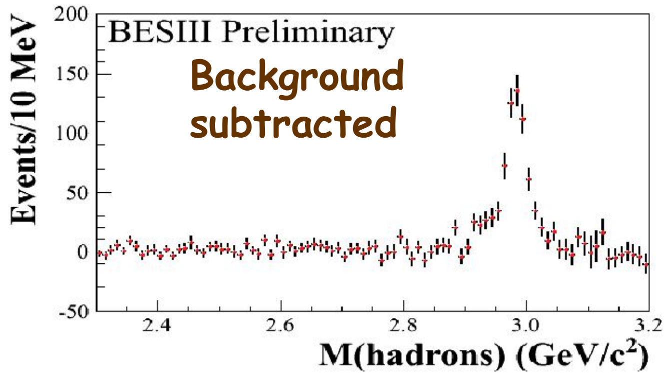
Property of h_c



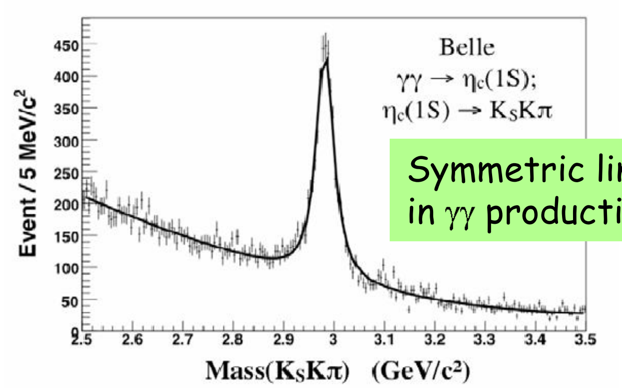
- First evidence:
  E835 in $pp \rightarrow h_c \rightarrow \gamma\eta_c$ (PRD72,092004(2005))
- CLEO-c observed h_c in $ee \rightarrow \psi' \rightarrow \pi^0 h_c$, $h_c \rightarrow \gamma\eta_c$
  $\Delta M_{hf}(1P)=0.08\pm0.18\pm0.12$ MeV/c^2
  (PRL104,132002(2010))
- Study isospin forbidden transition:
  $B(\psi' \rightarrow \pi^0 h_c)$
- Measure as well the E1 transition:
  $B(h_c \rightarrow \gamma\eta_c)$
- $M(h_c)$ gives access to hyperfine splitting of 1P states:
  $\Delta M_{hf}(1P)=M(h_c)-$
  $1/9(M(\chi_{c0})+3M(\chi_{c1})+5M(\chi_{c2}))$

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

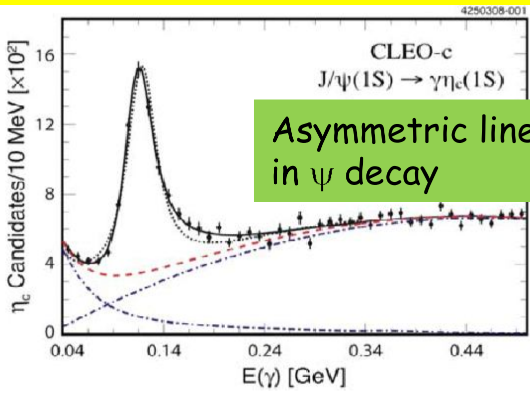




The η_c lineshape is not distorted in the $h_c \to \gamma\eta_c$, non-resonant bkg is small. This channel will be best suited to determine the η_c resonance parameters.



Symmetric lineshape in $\gamma\gamma$ production



Asymmetric lineshape in ψ decay

Is the X(1835) from the same source of X(ppbar)?

- The mass of X(ppbar) is consistent with X(1835)

- The width of X(ppbar) is much narrower.

  Possible reasons:

  – X(ppbar) and X(1835) come from different sources

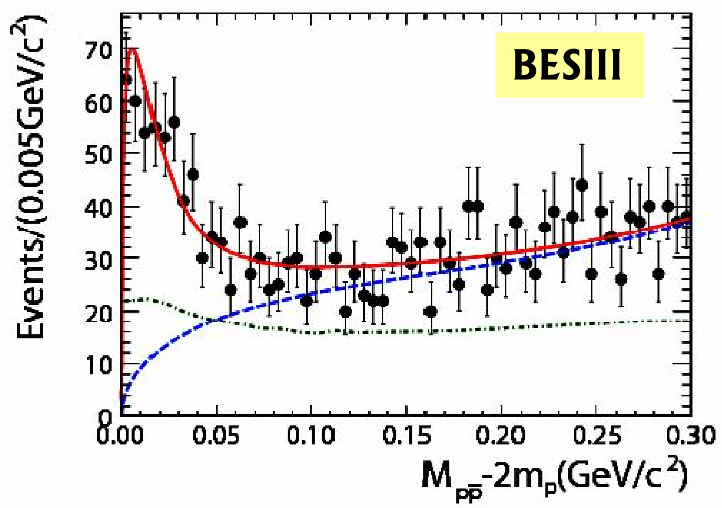
  – Interference effect in J/ψ -> γ π π η' process should not be ignored in the determination of the X(1835) mass and width

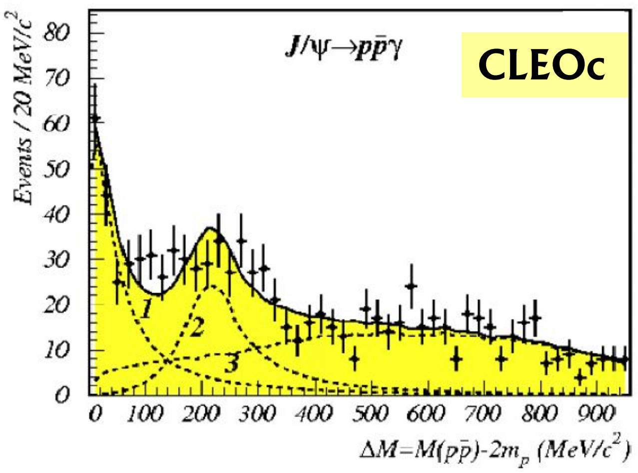
  – There may be more than one resonance in the mass peak around 1.83GeV in J/ψ -> γ π π η' decays.

Confirmation @ BESIII and CLEOc

Fit with one resonance at BESII did:

$\psi' \to \pi^+\pi^- J/\psi, J/\psi \to \gamma p\bar{p}$





$M=1861\ ^{+6}_{-13}\ ^{+7}_{-26}$ MeV/c^2

Γ < 38 MeV/c^2 (90% CL)

$M(R_{thr}) = 1861^{+3}_{-16}$ (MeV), $\Gamma(R_{thr}) = 0^{+32}_{-0}$ (MeV),

$B_1(J/\psi \to \gamma R_{thr}) \times B_2(R_{thr} \to p\bar{p}) = (5.9^{+2.8}_{-3.2}) \times 10^{-5}$

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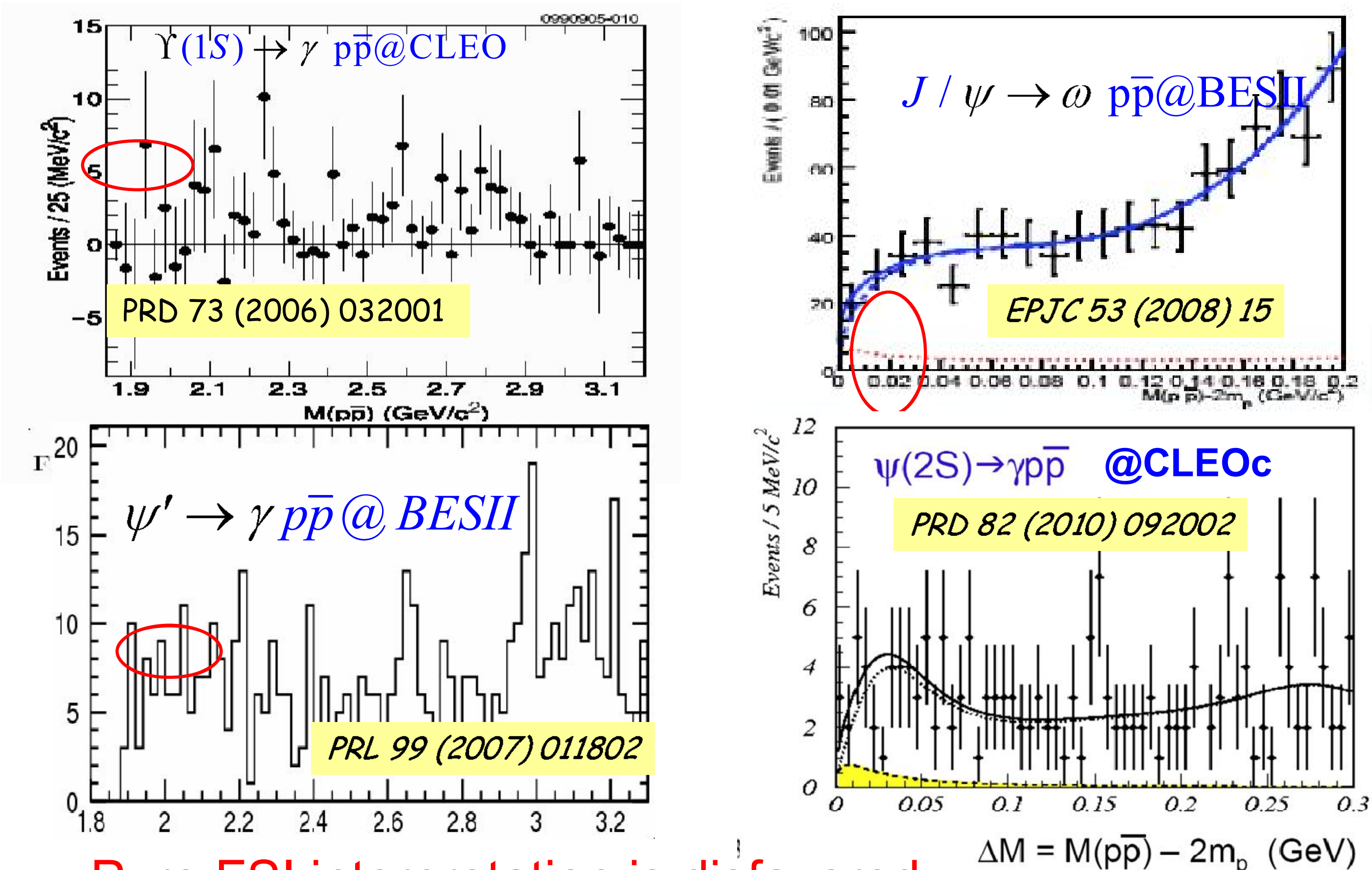
Several non-observations



Pure FSI interpretation is disfavored