Recent Results From BESIII

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for the BESIII Collaboration

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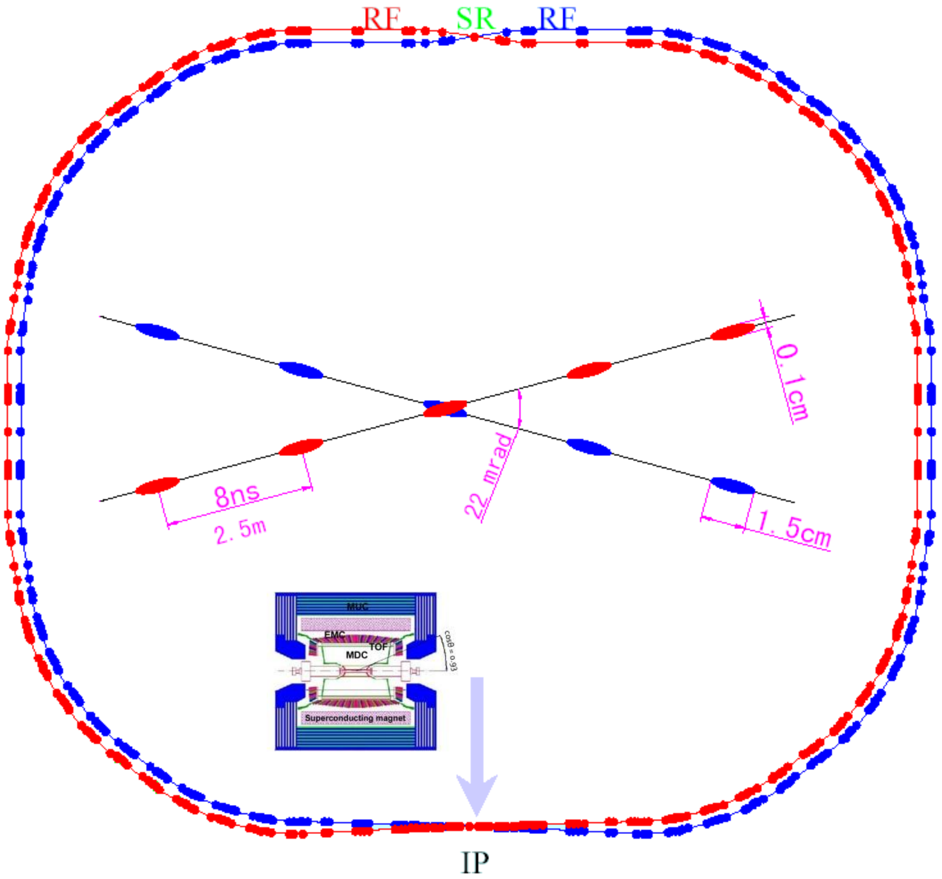
Outline

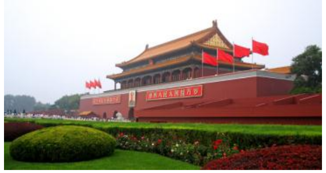
- **Introduction**
- **Recent Physics Results**
  - **Light Hadron**
  - **Charmonium**
  - **Charm (*coming soon*)**
- **Summary**

BEPCII: A High Lumi. e+e- Collider



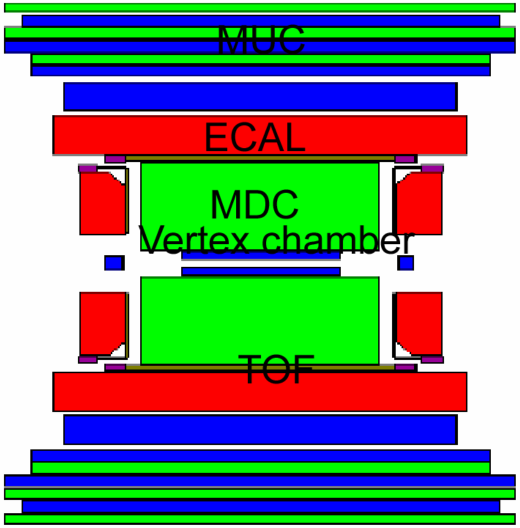
Beam energy:
1.0-2 .3GeV
Luminosity:
1×10^{33} $cm^{-2}s^{-1}$
Optimum energy:
1.89 GeV
Energy spread:
5.16×10^{-4}
No. of bunches:
93
Bunch length:
1.5 cm
Total current:
0.91 A

~ 10km to Tian-An-Men Square in east

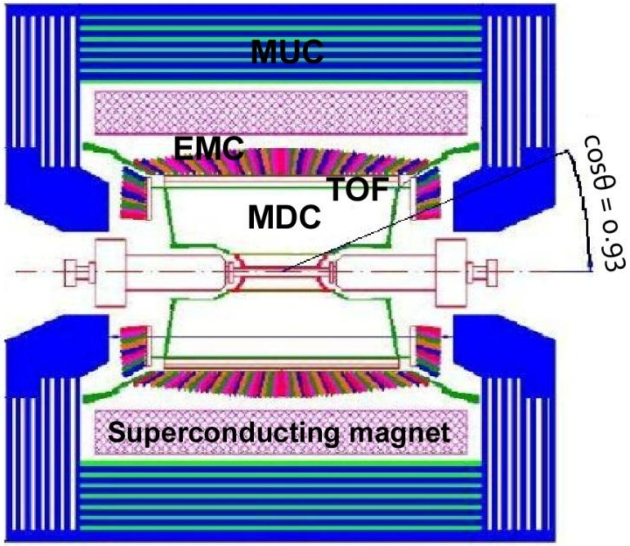


From BESII to BESIII

BES II @ BEPC



BES III @ BEPC II



	BESII	BESIII
MDC	$\sigma(p)/p = 1.78\% \cdot \sqrt{1+p^2}$ $dE/dx_{reso} = 8\%$	$\sigma(p_t)/p_t = 0.32\% \cdot p_t$ $dE/dx_{reso} < 6\%$
TOF	180 ps (for bhabha)	90 ps (for bhabha)
EMC	$\sigma(E)/E = 22\% \cdot \sqrt{E}$	$\sigma(E)/E = 2.3\% \cdot \sqrt{E}$
MUC	3 layers for barrel	9 layers for barrel, 8 for endcap

BESIII Collaboration

BESIII Data Taking Overview

- So far BESIII has collected :
  - 2009: 225 Million J/ψ
  - 2009: 106 Million ψ'(~4 ×CLEO-c)
  - 2010-11: 2.9 fb^{-1} $\psi(3770)$ (~3.5×CLEO-c)
  - May 2011: 0.5fb^{-1} @4010 MeV (one month) for Ds and XYZ spectroscopy
- BESIII will also collect:
  - more J/ψ, ψ', $\psi(3770)$
  - data at higher energies （for XYZ searches, R scan and Ds physics）

Year	Running Plan
2012	J/ψ: 1 billion / $\psi(2S)$: 0.5 billion (approved)
2013	4170 MeV: Ds decay R scan (E > 4 GeV)
2014	$\psi(2S)/\tau$ / R scan (E > 4 GeV)
2015	$\psi(3770)$: 5-10 fb^{-1} (our final goal)

Red: to be approved by BESIII Collaboration

Light Hadron @BESIII

$p\bar{p}$ mass threshold structure in $J/\psi \to \gamma (p\bar{p})$
(Chinese Physics C34,4(2010) and arXiv:1112.0942)

X(1835) in $J/\psi \to \gamma (\eta' \pi^+ \pi^-)$ *(PRL 106,072002(2011))*

X(1870) in $J/\psi \to \omega (\eta \pi^+ \pi^-)$ *(PRL 107,182001(2011))*

η(1405) in $J/\psi \to \gamma f_0(980)\pi^0 \to \gamma\, 3\pi$ *(arXiv:1201.2737→PRL)*

a0(980)-f0(980) mixing *(PRD 83,032003(2011))*

$\eta' \to \eta \pi^+ \pi^-$ matrix element *(PRD 83,012003(2011))*

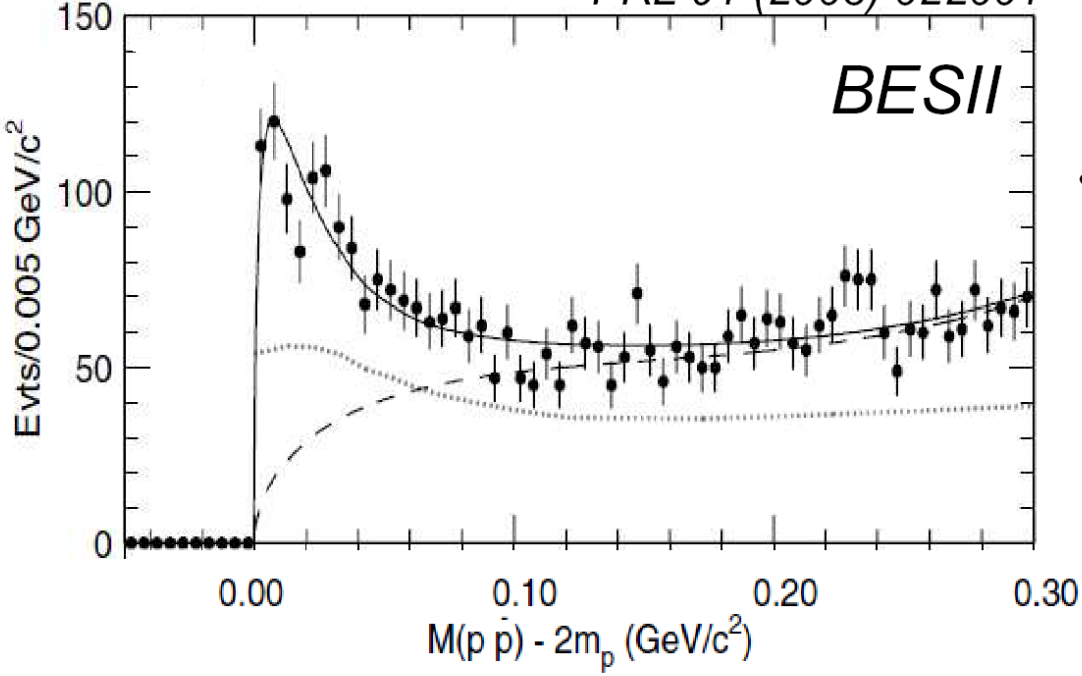
$p\bar{p}$ Mass Threshold Enhancement: a baryonium?

$p\bar{p}$ Threshold Enhancement @ BESII

- BESII observed $p\bar{p}$ enhancement close to threshold

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

PRL 91 (2003) 022001



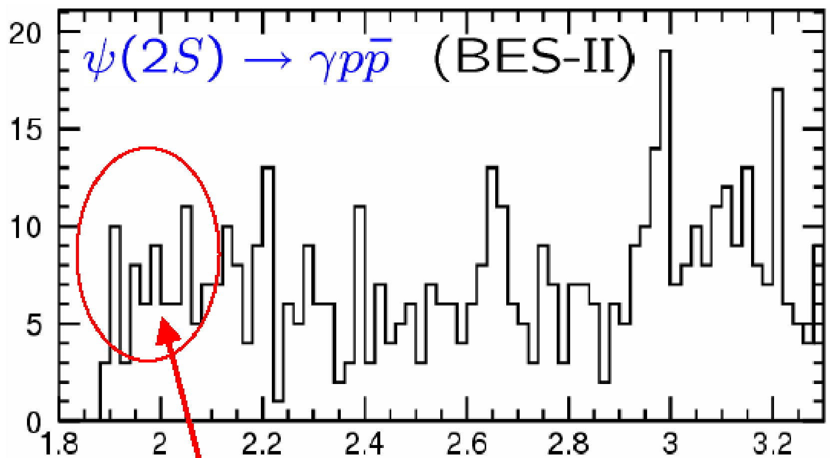
- What it could be theoretically:
  - $p\bar{p}$ bound state
  - FSI effect
  - ... ...

$M=1859^{+3}_{-10}{}^{+5}_{-25}$ MeV/c^2 $\Gamma < 30$ MeV/c^2 (90% CL)

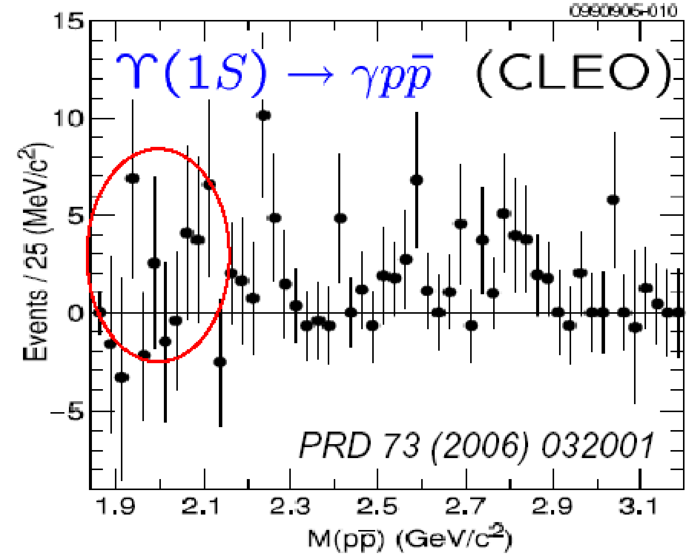
$p\bar{p}$ Threshold Enhancement: None Observations

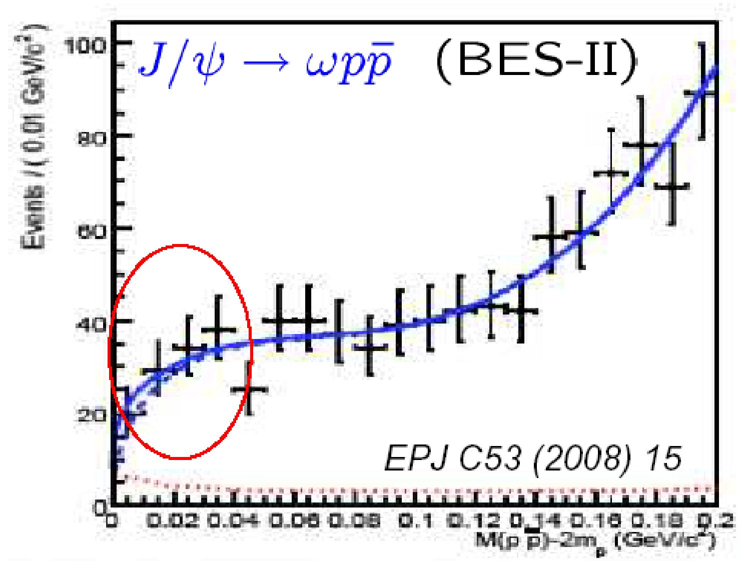
- Several ***none*** observations...

PRL 99 (2007) 011802

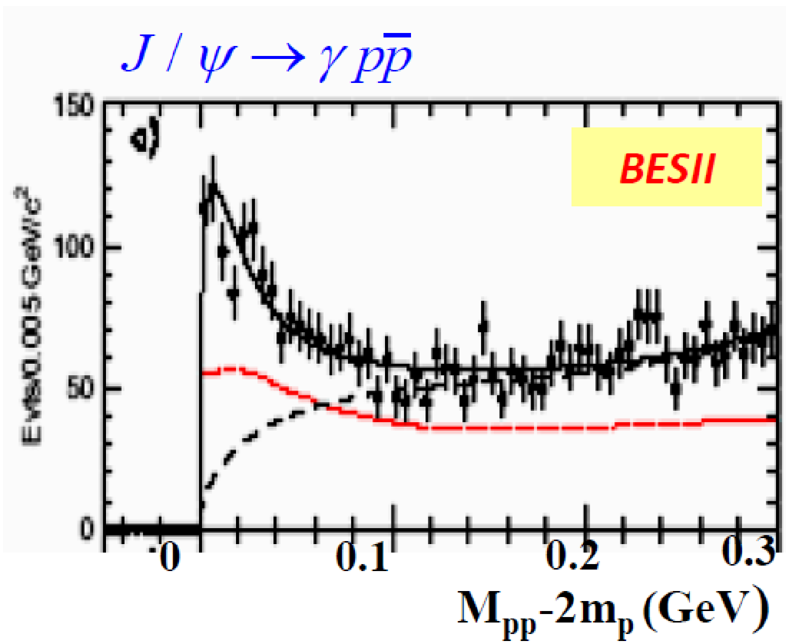


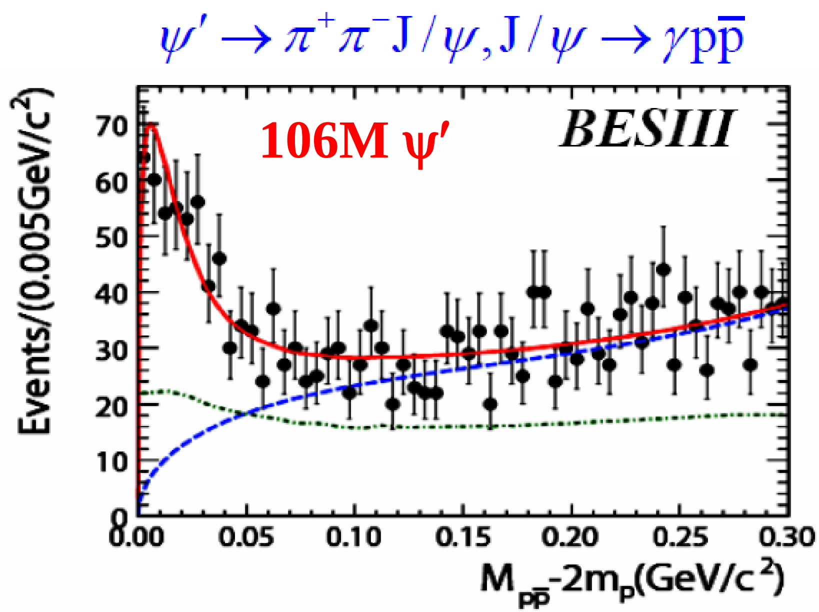
No significant signal of X(1860) found (only 2σ significance)





Mass Spectrum Fitting





$M = 1859 \,^{+3}_{-10}\,^{+5}_{-25}$ MeV/c^2

$\Gamma < 30$ MeV/c^2 (90% CL)

PRL 91 (2003) 022001

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

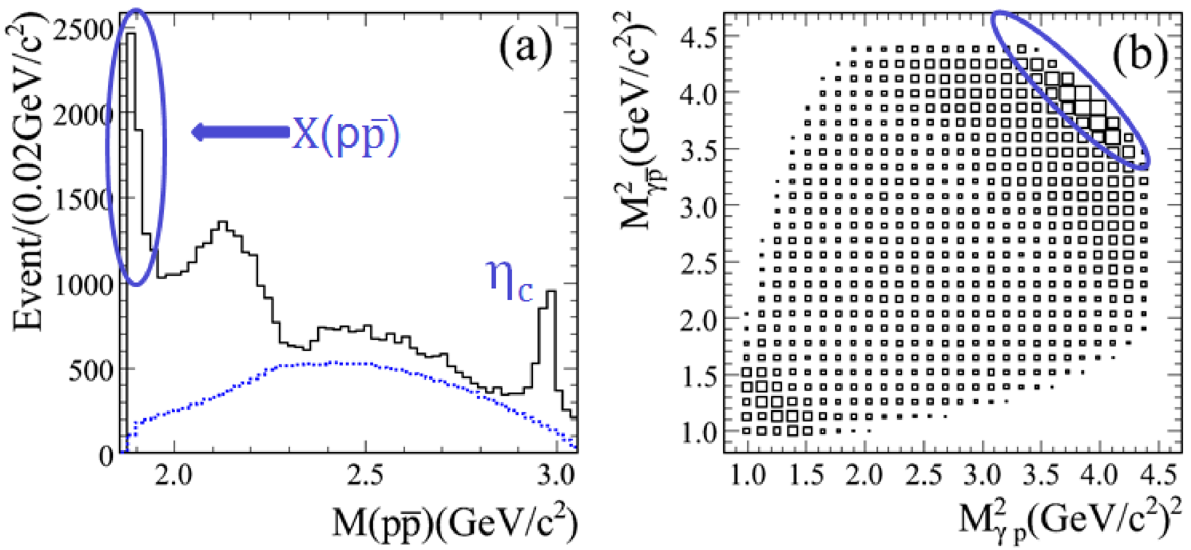
$\Gamma < 38$ MeV/c^2 (90% CL)

Chinese Physics C 34, 421 (2010)

Consistent with BESII observation, confirmed the enhancement !!

M($p\bar{p}$)threshold structure in $J/\psi \to \gamma p\bar{p}$

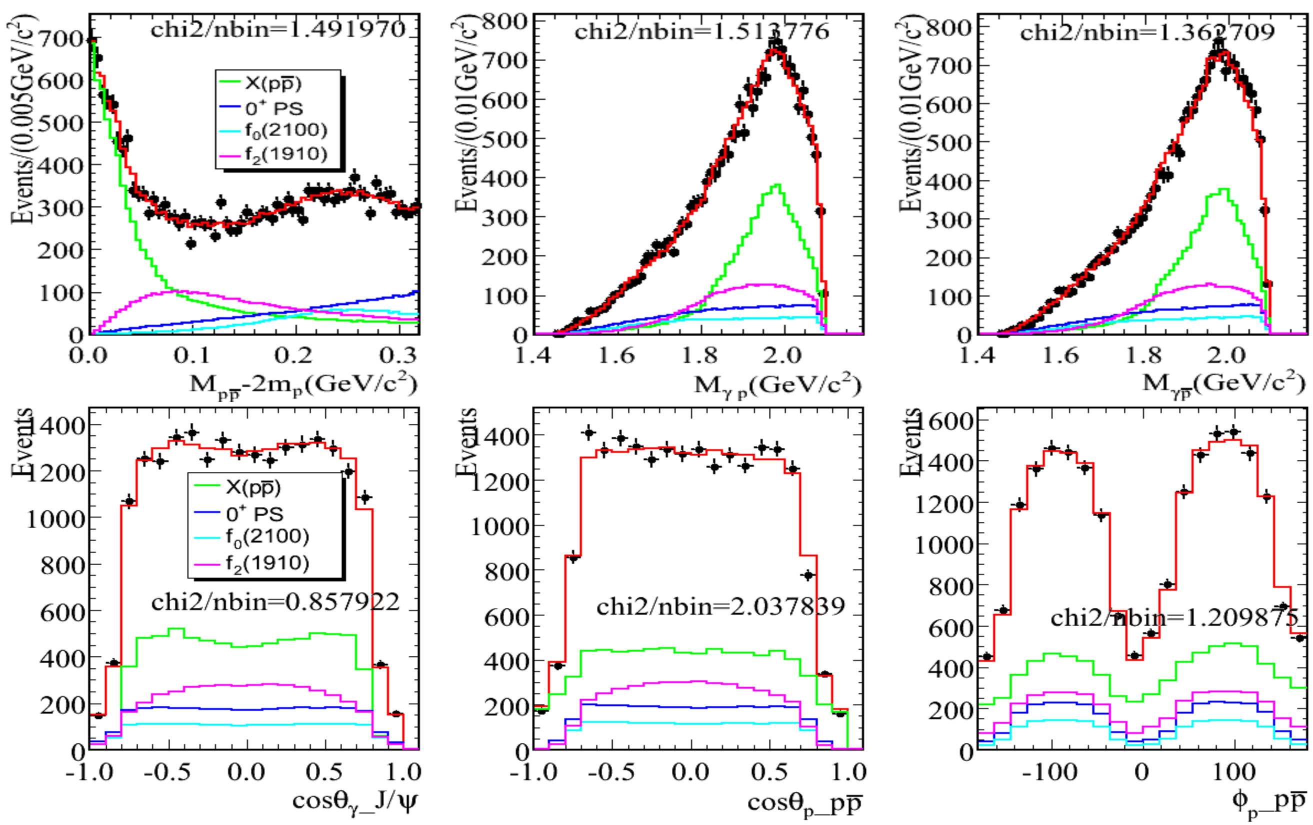
225M J/ψ



- **Evident narrow M$p\bar{p}$ threshold enhancement in J/ψ decays.**
- **Partial Wave Analysis (PWA):**
  - Concentrate on dealing with the $p\bar{p}$ mass threshold structure, especially to determine the J^{PC}.
  - Convariant tensor amplitudes (S. Dulat and B. S. Zou, Eur.Phys.J A 26:125, 2005).
  - Include the Juich-FSI effect (A. Sirbirtsen et al. Phys.Rev.D 71:054010, 2005).

Partial Wave Analysis of $J/\psi \to \gamma p\bar{p}$

Component	J^{PC}	M (GeV)	Γ (GeV)	Stat.sig.
$X(p\bar{p})$	0^{-+}	1.832 ± 0.005	0.013 ± 0.020	$\gg 30\sigma$
$f_0(2100)$	0^{++}	2.103	0.209	11.2σ
$f_2(1910)$	2^{++}	1.903	0.196	7.7σ
phase space	0^{++}	–	–	6.3σ



- The fit with a BW and S-wave FSI(I=0) factor can well describe $p\bar{p}$ mass threshold structure.
- It is much better than that without FSI effect, and $\Delta 2\ln L = 51 \Rightarrow 7.1\sigma$.

Partial Wave Analysis of $J/\psi \rightarrow \gamma p\bar{p}$

- PWA results are carefully checked from different aspects:
  - Contribution of additional resonances
  - Solution with different combinations
  - Different background levels and fitting mass ranges
  - Different BW formula
  - … …

  All uncertainties are considered as systematic errors.
- Different FSI models → Model dependent uncertainty
- Spin-parity, mass, width and B.R. of $X(p\bar{p})$:

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

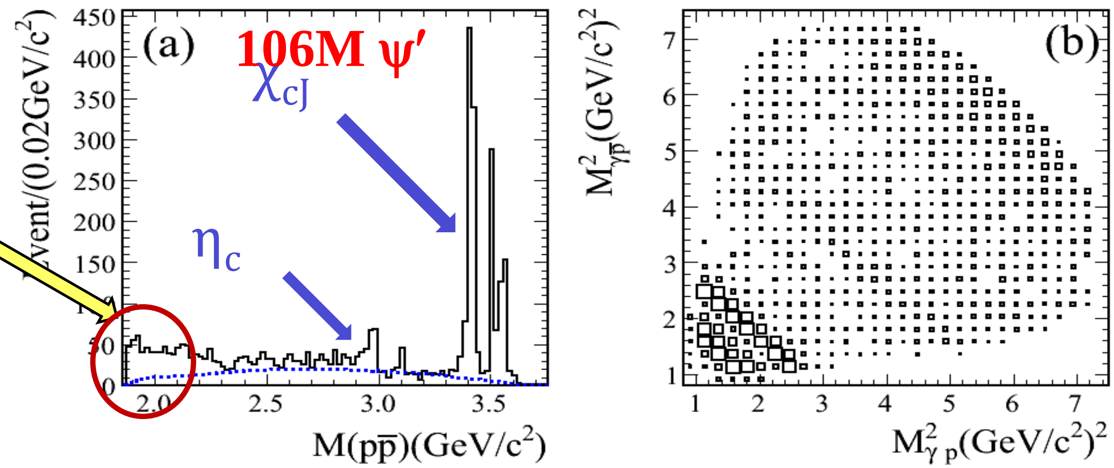
$$M = 1832 \pm 5(\text{stat})^{+15}_{-17}(\text{syst}) \pm 19(\text{mod})\ \text{MeV}/c^2$$

$$\Gamma = 13 \pm 20(\text{stat})^{+8}_{-26}(\text{syst}) \pm 4(\text{mod})\text{MeV}/c^2 \ \text{ or } \ \Gamma < 45\text{MeV}/c^2 \ @90\%\, C.L.$$

$$B(J/\psi \rightarrow \gamma X(p\bar{p}))B(X(p\bar{p}) \rightarrow p\bar{p}) = (9.0 \pm 0.7(\text{stat})^{+1.5}_{-4.8}(\text{syst}) \pm 2.3(\text{mod})) \times 10^{-5}$$

Partial Wave Analysis of $\psi' \to \gamma p\bar{p}$

Obviously different line shape of $p\bar{p}$ mass spectrum near threshold from that in J/ψ decays



PWA results:

- Significance of $X(p\bar{p})$ is larger than 6.9σ.
- The production ratio R: first measurement

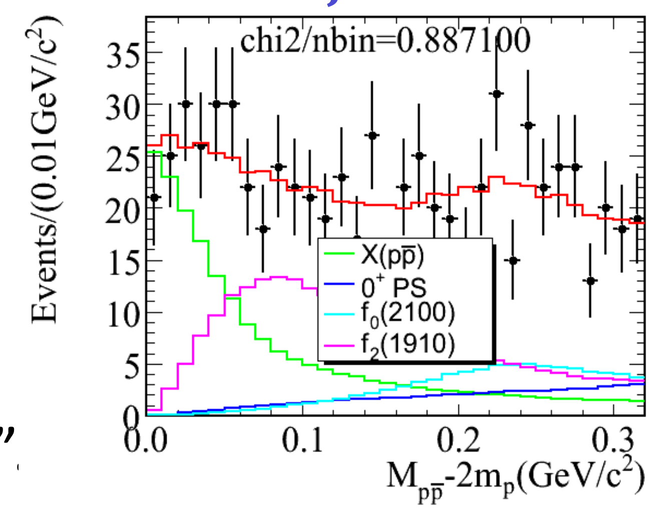
$$R = \frac{B(\psi' \to \gamma X(p\bar{p}))}{B(J/\psi \to \gamma X(p\bar{p}))}$$

$$= (5.08 \pm 0.56(stat)^{+0.64}_{-3.10}(syst) \pm 0.12(mod))\%$$

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

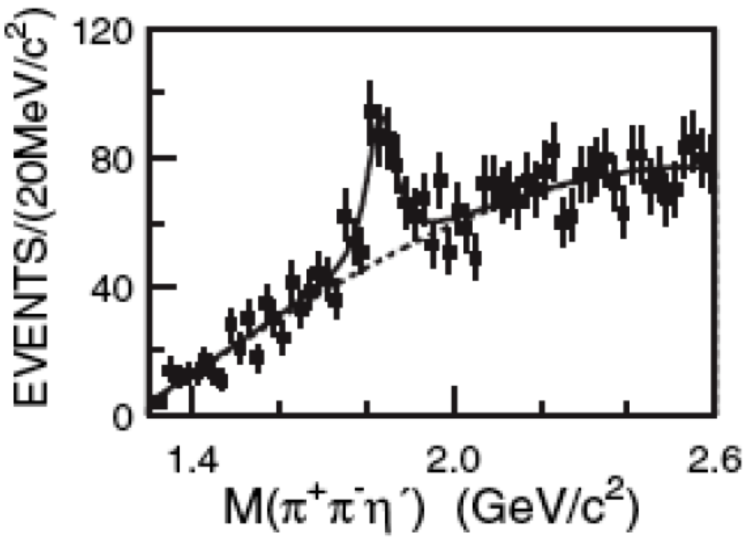
To be appear in PRL

PWA Projection:



Confirmation of X(1835) and Observation of X(2120) and X(2370) in $J/\psi \rightarrow \gamma(\eta'\pi^+\pi^-)$ decay

X(1835) @BESII



$BESII\ result$(Stat. sig. $\sim 7.7\sigma$):

$M = 1833.7 \pm 6.1(stat) \pm 2.7(syst) MeV$

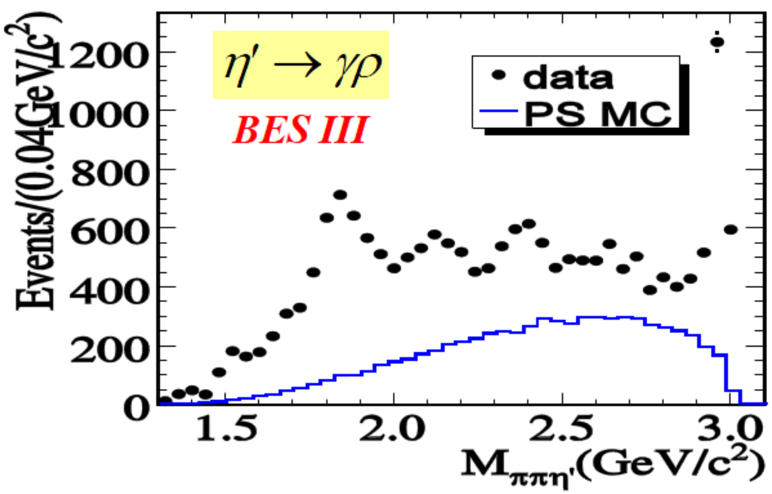
$\Gamma = 67.7 \pm 20.3(\mathrm{stat}) \pm 7.7(\mathrm{syst})\mathrm{MeV}$

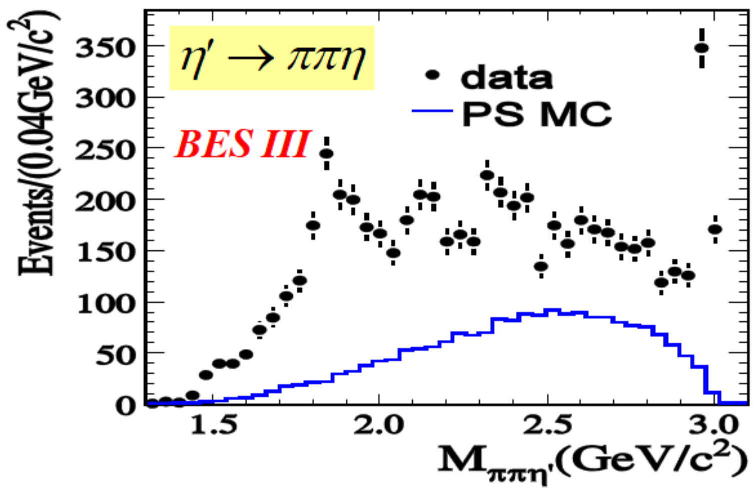
PRL 95,262001(2005)

- **LQCD predicts the glueball mass of 0^{-+} is ~2.3GeV**
- **For 0^{-+} glueball, it may have similar property as η_c (mainly decay to $\pi\pi\eta'$)**
- **$J/\psi \to \gamma\pi\pi\eta'$ is specially interested and was studied with 57M J/ψ @BESII**

Need to confirm it with BESIII ~225M J/ψ data !!!

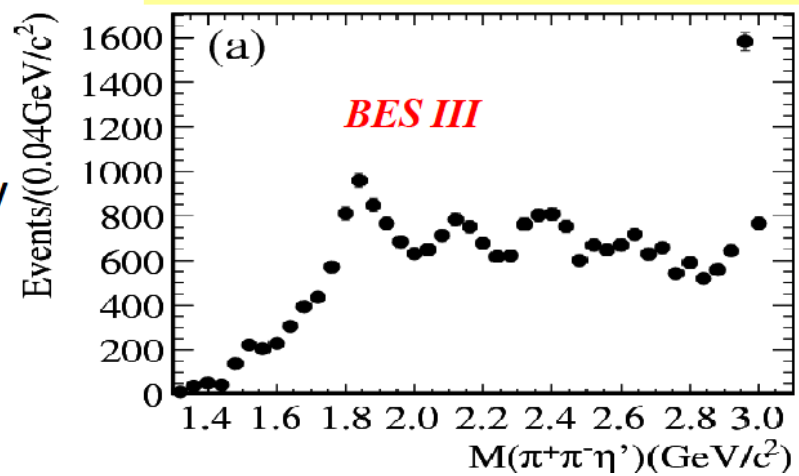
Invariant Mass of ππη'



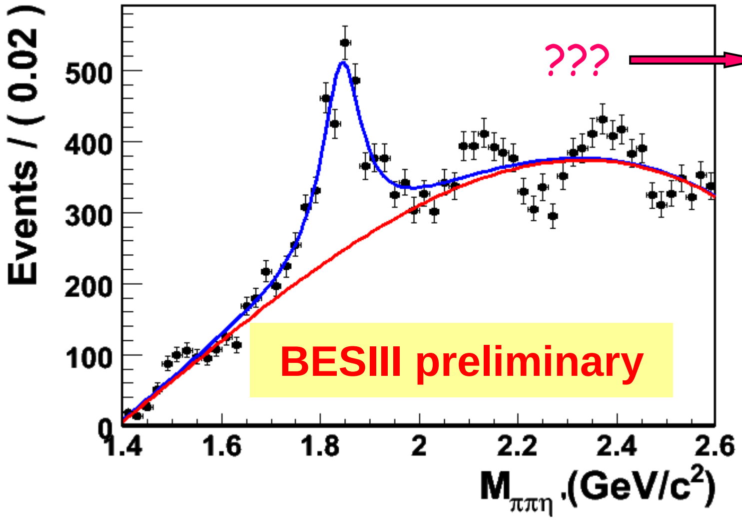


- X(1835) and η_c are evident.
- Two additional structures are observed at M~2.1GeV and 2.3GeV
- There maybe some $f_1(1510)$.

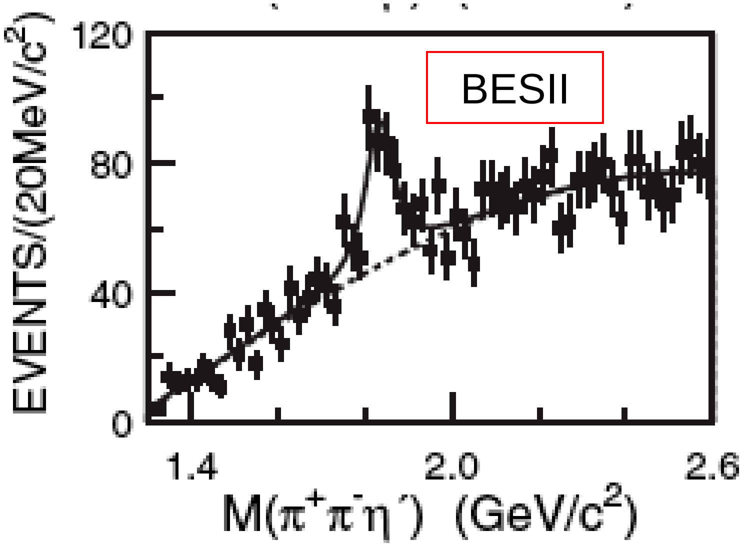
Combination for η' to $\pi^+\pi^-\eta$ and $\gamma\rho$



Fitting With One Resonance



Structures at higher mass region???



Fitting Results:

BESIII preliminary:

M = 1842.4 ± 2.8 (stat.) MeV

Γ = 99.2 ± 9.2 (stat.) MeV

Statistical significance: ~ 21σ

BESII Results:

M = 1833.7 ± 6.1 (stat.) ± 2.7(syst.) MeV

Γ = 67.7 ± 20.3 (stat.) ± 7.7(syst.) MeV

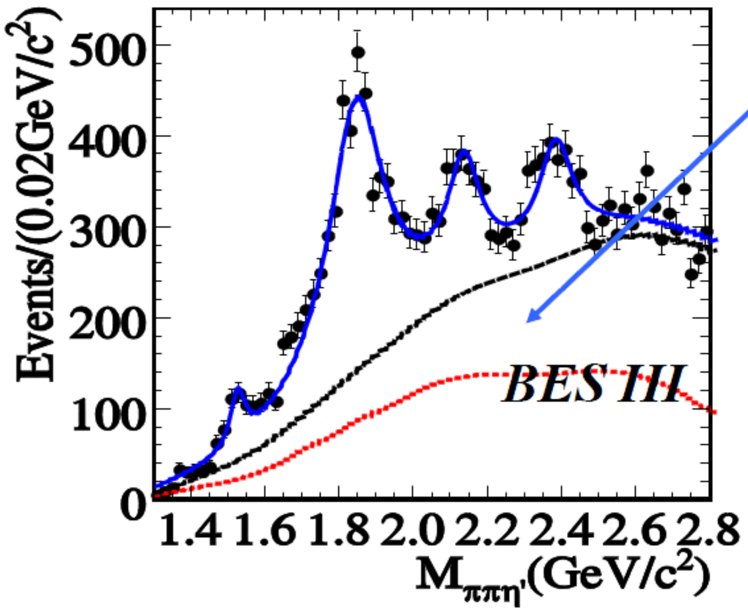
Statistical significance: ~ 7.7σ

X(1835) is confirmed in BESIII and the significance increases as statistics increases

Fitting With 4 Resonances

- Fitting with four resonances (acceptance weighted BW ⊗ gauss)
- Three background components:
  1. Contribution from non-η' events estimated by η' mass sideband
  2. Contribution from $J/\psi \to \pi^0\pi^+\pi^-\eta'$ with re-weighting method
  3. Contribution from "PS background"

$$f_{bkg}(x) = (x-m_0)^{1/2} + a_0(x-m_0)^{3/2} + a_1(x-m_0)^{5/2},\ m_0 = 2m_\pi + m_{\eta'}$$



Red line: estimated contribution of ①+ ②

Black line: total background

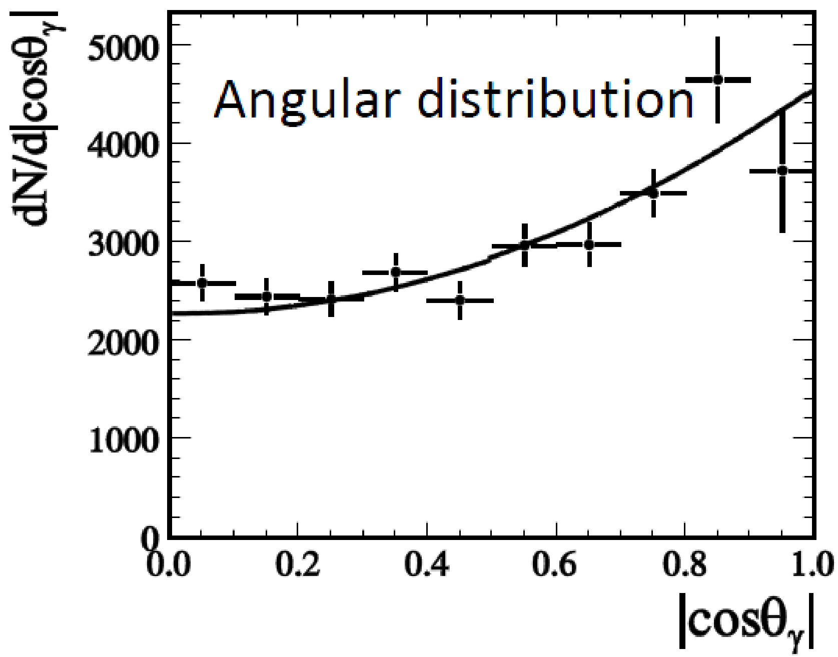
Stat. sig. is conservatively estimated:

fit range, background shape, contribution of extra resonances

PRL 106:072002,2011

Fitting Results With 4 Resonances

Resonance	M(MeV/c²)	Γ(MeV/c²)	Stat.sig.
X(1835)	$1836.5 \pm 3.0^{+5.6}_{-2.1}$	$190.1 \pm 9.0^{+38}_{-36}$	>20σ
X(2120)	$2122.4 \pm 6.7^{+4.7}_{-2.7}$	$83 \pm 16^{+31}_{-11}$	7.2σ
X(2370)	$2376.3 \pm 8.7^{+3.2}_{-4.3}$	$83 \pm 17^{+44}_{-6}$	6.4σ



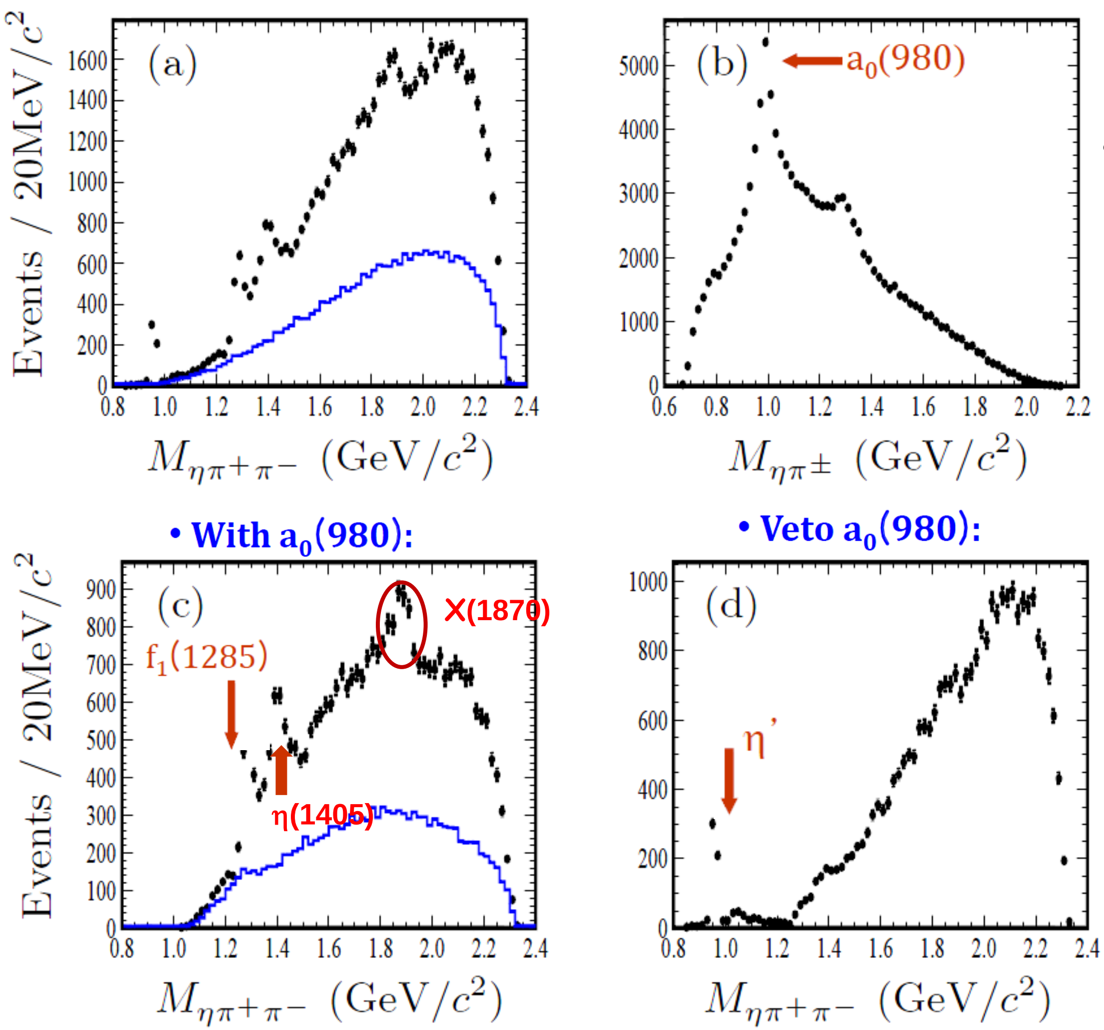
For the X(1835):

$$BR(J/\psi \to \gamma X(1835)) \cdot BR(X(1835) \to \pi^+\pi^-\eta')$$
$$= (2.87 \pm 0.09(stat)^{\pm 0.49}_{\pm 0.52}(syst)) \times 10^{-4}$$

PRL 106:072002,2011

Observation of X(1870) in $J/\psi \rightarrow \omega(\eta\pi^{+}\pi^{-})$ decay

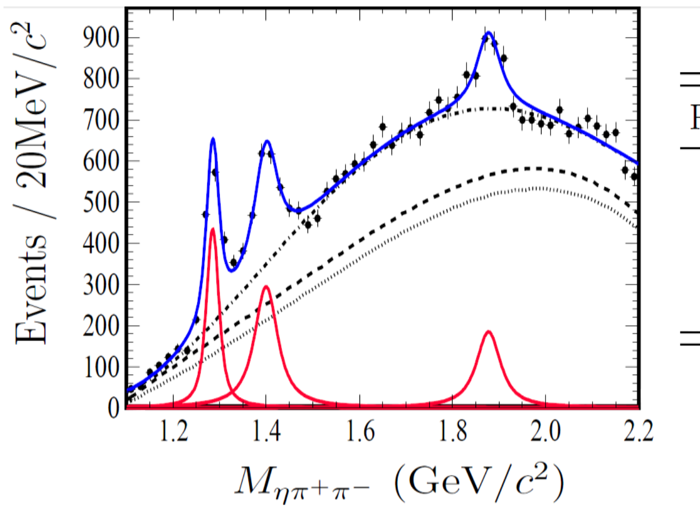
Observation of X(1870) in $J/\psi \to \omega(\pi\pi\eta)$



- In addition to the well-known η', $f_1(1285)$ and η(1405), an unknown structure (denoted as X(1870)) around 1.87GeV/c^2 is observed.
- The $f_1(1285)$, η(1405) and X(1870) decay primarily via $a_0(980)\pi$ mode.

Fitting Result of X(1870)

- Fitting with three resonances (acceptance weighted BW ⊗ Gauss)
- Background component described by Polynomial function



Fit results:

Resonance	Mass (MeV/c^2)	Width (MeV/c^2)	Branch ratio (10^{-4})
$f_1(1285)$	$1285.1 \pm 1.0^{+1.6}_{-0.3}$	$22.0 \pm 3.1^{+2.0}_{-1.5}$	$1.25 \pm 0.10^{+0.19}_{-0.20}$
$\eta(1405)$	$1399.8 \pm 2.2^{+2.8}_{-0.1}$	$52.8 \pm 7.6^{+0.1}_{-7.6}$	$1.89 \pm 0.21^{+0.21}_{-0.23}$
$X(1870)$	$1877.3 \pm 6.3^{+3.4}_{-7.4}$	$57 \pm 12^{+19}_{-4}$	$1.50 \pm 0.26^{+0.72}_{-0.36}$

significance: 7.2σ

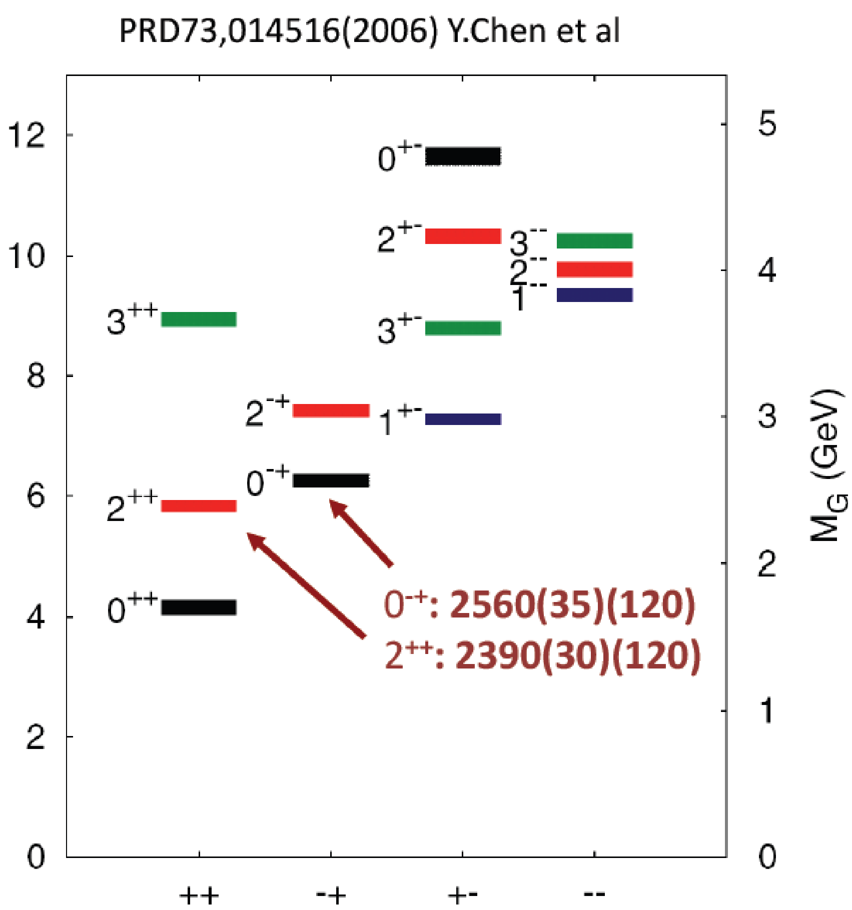
The fit is performed under the assumption that the interference between the resonances and background can be ignored.

Whether the X(1870) is the X(1835) or $\eta_2(1870)$ (Γ =225±14 MeV/c^2), or a new resonance?

Need further study.

PRL 107:182001,2011

Understand those structures?



✓ first resonant structures observed in the 2.3 GeV region:

-LQCD predicts that the lowest –lying pseudoscalar glueball: around 2.3 GeV

-$J/\psi \rightarrow \gamma\eta'\pi^+\pi^-$ is a good decay channel for finding 0^{-+} glueballs.

✓ X(2120)/X(2370) possibilities:

-pseudoscalar glueball ?

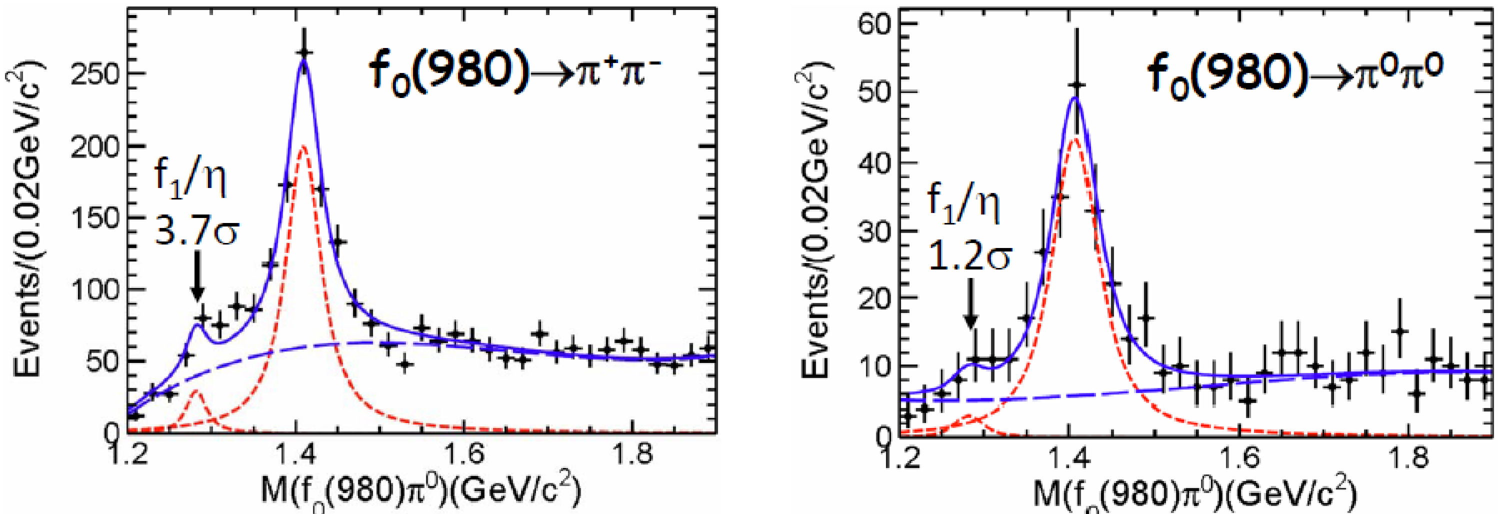
-η/η' excited states?

PRD82,074026,2010 J.F. Liu, G.J. Ding and M.L.Yan
PRD83:114007,2011 (J.S. Yu, Z.-F. Sun, X. Liu, Q. Zhao)

$\eta(1405)$ in $J/\psi \to \gamma f_0(980)\pi^0 \to \gamma\, 3\pi$

arXiv: 1201.2737v1 Accepted by PRL

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



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

- Helicity analysis indicates the peak at 1400MeV is from $\eta(1405)$, not from $f_1(1420)$

$$Br(J/\psi \to \gamma\eta(1405) \to \gamma\pi^0 f_0 \to \gamma\pi^0\pi^+\pi^-) = (1.50 \pm 0.11(stat.) \pm 0.11(syst.)) \times 10^{-5}$$

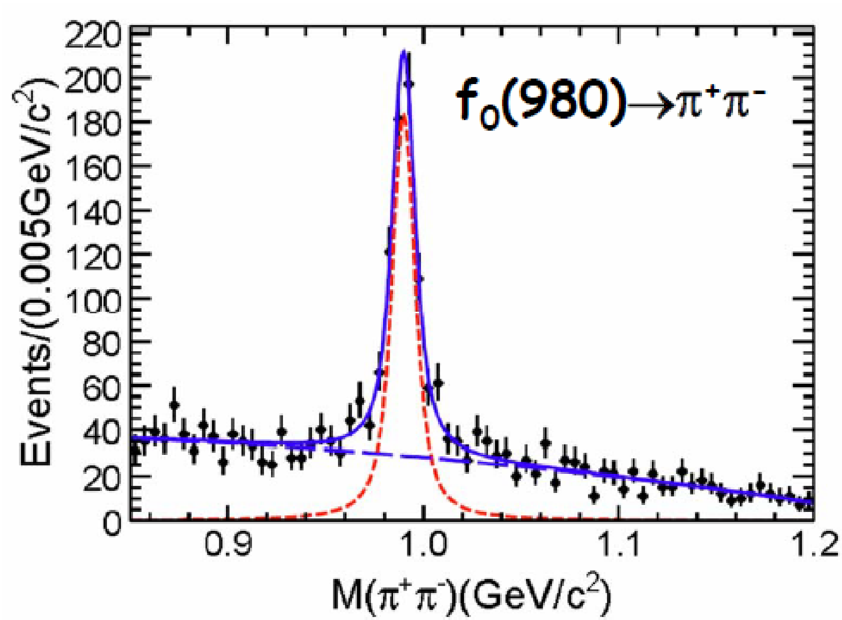
$$Br(J/\psi \to \gamma\eta(1405) \to \gamma\pi^0 f_0 \to \gamma\pi^0\pi^0\pi^0) = (7.10 \pm 0.82(stat.) \pm 0.72(syst.)) \times 10^{-6}$$

- Large Isospin-violating decay rate:

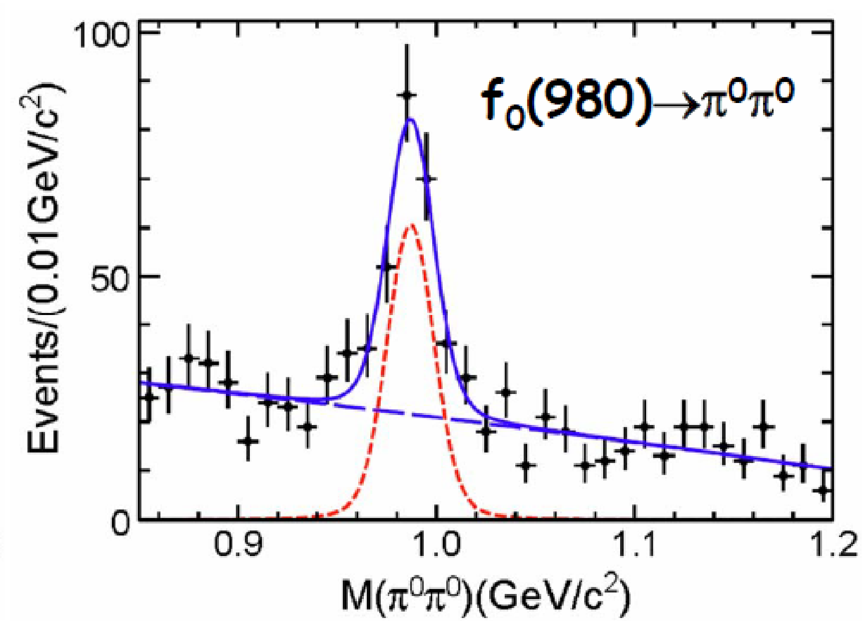
$$\frac{BR(\eta(1405) \to f_0(980)\pi^0 \to \pi^+\pi^-\pi^0)}{BR(\eta(1405) \to a_0(980)\pi^0 \to \pi^0\pi^0\eta)} \approx (17.9 \pm 4.2)\%$$

In general, magnitude of isospin violation in strong decay should be <1%.
$a_0 - f_0$ mixing alone can not explain the branching ratio of $\eta(1405) \to f_0(980)\pi^0$

Anomalous Lineshape of $f_0(980)$ in $J/\psi \to \gamma f_0(980)\pi^0$



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



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

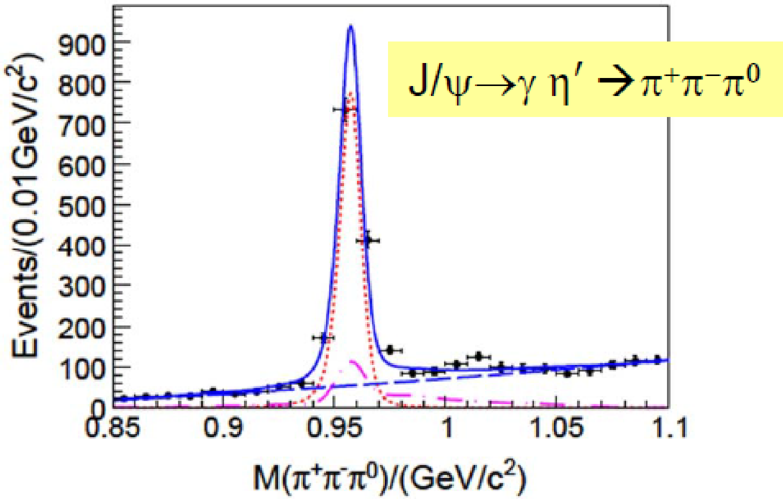
Surprising result:

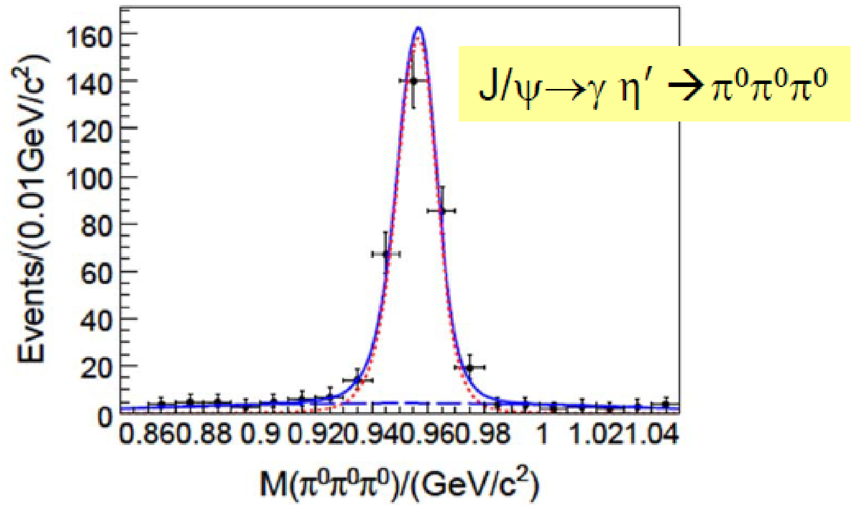
very narrow $f_0(980)$ width: <11.8 MeV/c^2 @90% C.L.

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))

New results on η’→πππ





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 :

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

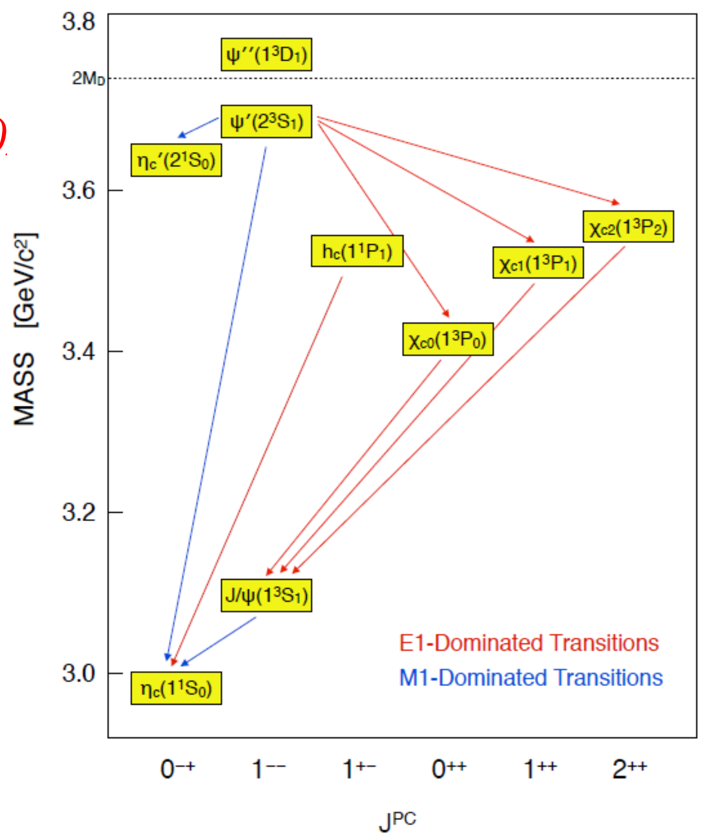
Charmonium @BESIII

Charmonium Decays

- $\psi(2S) \to \gamma\,\pi^0, \gamma\,\eta, \gamma\,\eta'$ *(PRL 105,261801(2010)*
- $\chi_{cJ} \to \phi\phi, \phi\omega, \omega\omega$ *(PRL 107,092001(2011))*
- $\chi_{cJ} \to \pi^0\pi^0,\ \eta\eta'$ *(PRD 81,052005(2010))*
- $\chi_{cJ} \to \gamma\rho, \gamma\omega, \gamma\phi$ *(PRD 83,112005(2011))*
- $\chi_{cJ} \to 4\pi^0$ *(PRD 83,012006(2011))*

Charmonium Spectroscopy

- mass and width of η_c *(arXiv:1111.0398)*
- properties of h_c *(PRL 104,132002(2010))*
- multipoles in $\psi(2S) \to \gamma\chi_{c2}$ *(arXiv:1110.1742)*



$\psi(2S) \rightarrow \gamma\,\pi^0, \gamma\,\eta, \gamma\,\eta'$

Why J/ψ(ψ′)→γP

- Important for testing various phenomenological mechanisms: Vector dominant model (VDM), η_c-$\eta^{(')}$ mixing, 2-gluon couplings to qq states, and final state radiation by light quarks.

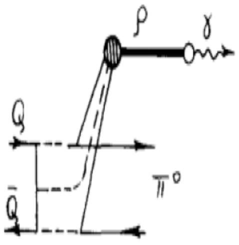


Fig. 5.16. VDM contribution into $^3S_1 \to \gamma\pi^0$

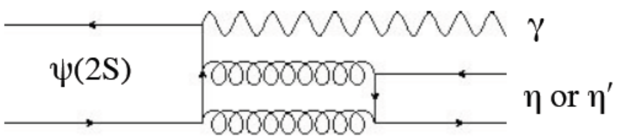
- $R_{J/\psi}$ = B(J/ψ→γη)/B(J/ψ→γη′) is predicted by 1st order perturbation theory, and is related to the mixing angle of η-η′ by following formula:

$$R_{J/\psi} = \frac{\Gamma(J/\psi \to \gamma\eta)}{\Gamma(J/\psi \to \gamma\eta')} = \left(\frac{p_\eta}{p_{\eta'}}\right)^3 \tan^2\theta$$

  And $R_{\psi'}$ = B(ψ′→γη)/B(ψ′→γη′) ≈ $R_{J/\psi}$ is expected.

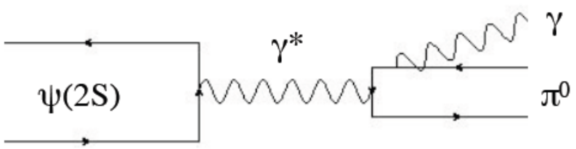
- The contribution of ψ′→γ*→γπ^0 process to B(ψ′→γπ^0) is calculated to be small (~2.2×10^{-7}), but is compatible to VDM expectations. Precise measurement will be necessary to fix the theory and to extract the form factor of γ*-γ-π^0 for time like photons.

ψ(2S) → γη$^{(')}$



⇒ ideally, study the η–η′ mixing angle, but ψ(2S) → γη is anomalously suppressed...

ψ(2S) → γπ^0



⇒ possibly study the γ* – γ – π^0 form factor for timelike γ*

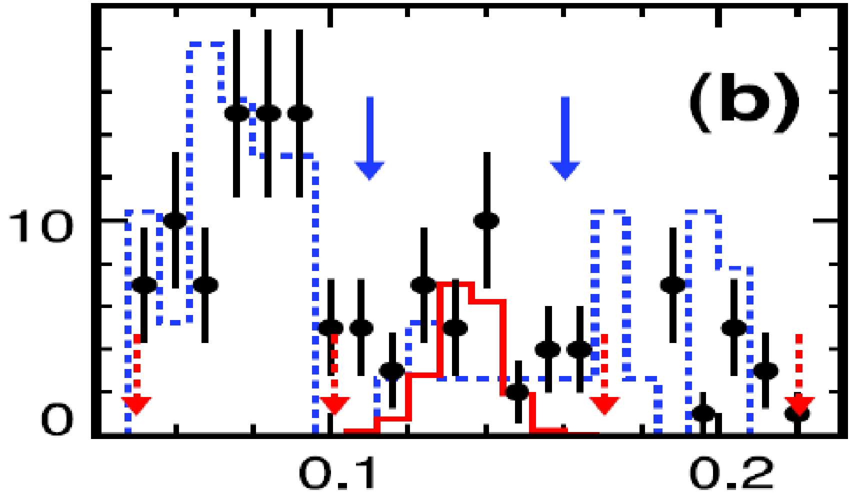
CLEO-c's Results

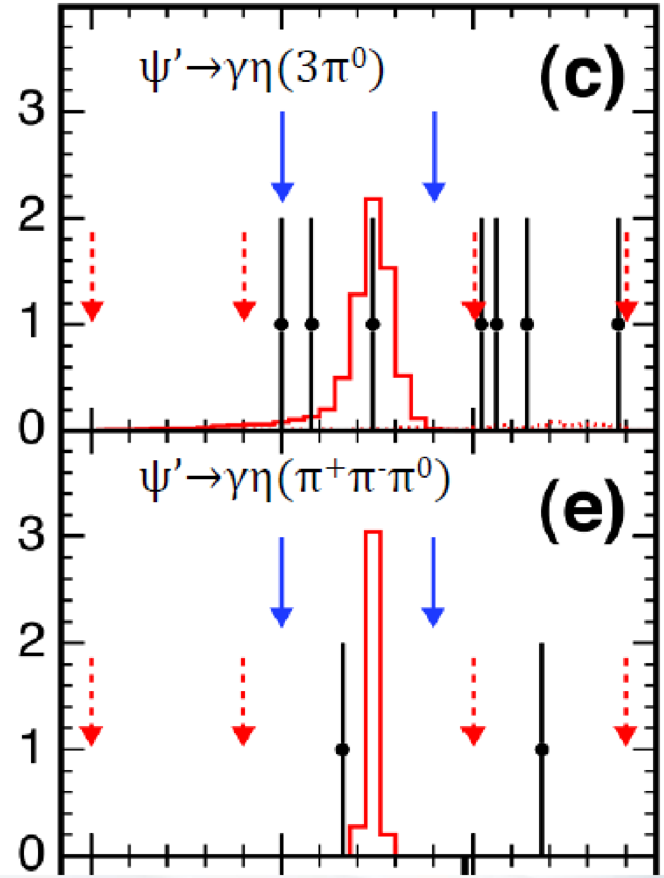
Recently, CLEOc reported their results on $J/\psi, \psi', \psi'' \to \gamma P$:

- Found no evidence for $\psi' \to \gamma \pi^0$ or $\gamma\eta$
- Upper limit for $B(\psi' \to \gamma \pi^0)$ is less than 5×10^{-6}
- Obtain $R_{\psi'} < 1.8\%$ at 90% C.L and $R_{J/\psi} = (21.1 \pm 0.9)\%$

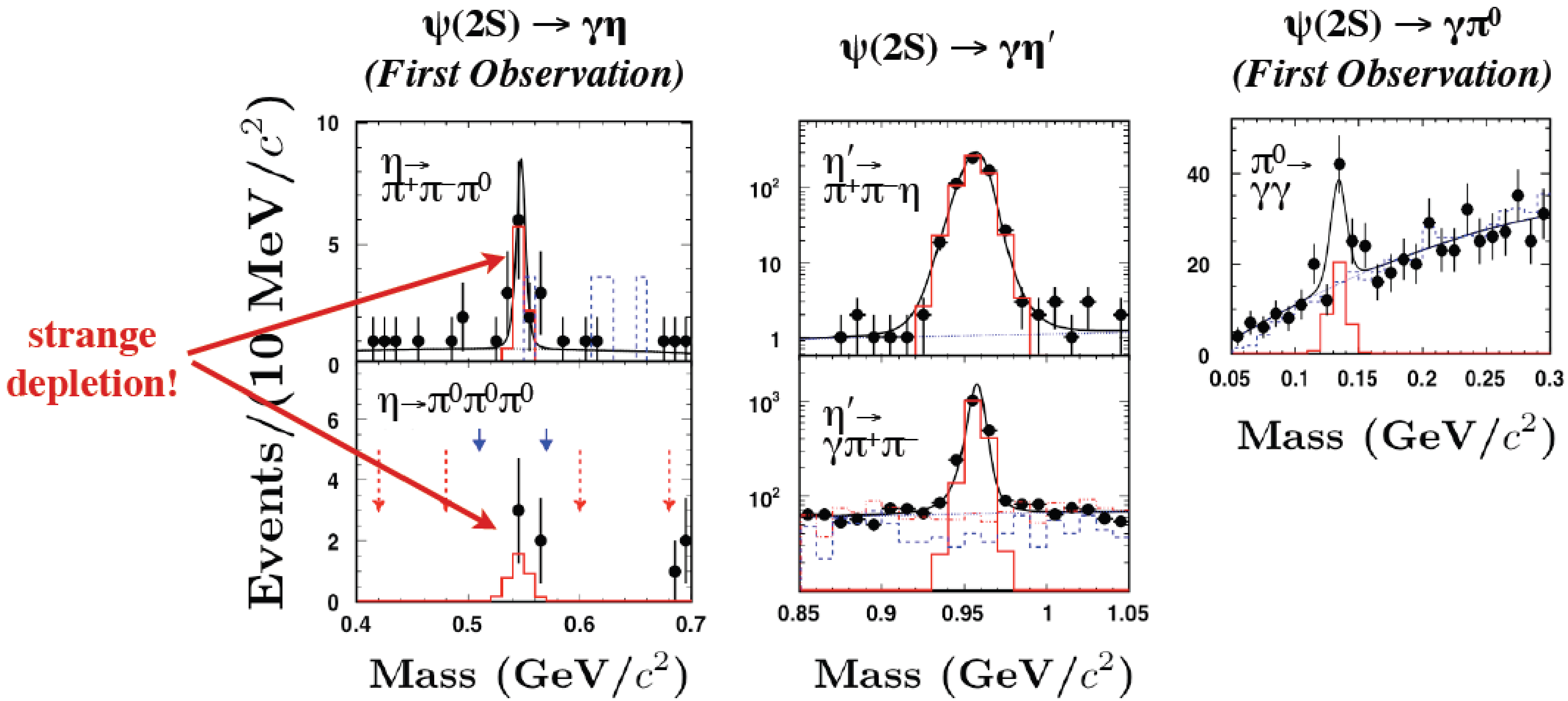
$R_{\psi'} \ll R_{J/\psi}$ poses a challenge to the theory !

CLEOc, PRD 79 111101 (2009)





Analysis with BESIII Data



Mode	BESIII	Combined BESIII	PDG
$\psi' \to \gamma\pi^0$	$1.58 \pm 0.40 \pm 0.13$	$1.58 \pm 0.40 \pm 0.13$	≤ 5
$\psi' \to \gamma\eta(\pi^+\pi^-\pi^0)$	$1.78 \pm 0.72 \pm 0.17$	$1.38 \pm 0.48 \pm 0.09$	≤ 2
$\to \gamma\eta(\pi^0\pi^0\pi^0)$	$1.07 \pm 0.65 \pm 0.08$		
$\psi' \to \gamma\eta'(\pi^+\pi^-\eta)$	$120 \pm 5 \pm 8$	$126 \pm 3 \pm 8$	121 ± 8
$\to \gamma\eta'(\pi^+\pi^-\gamma)$	$129 \pm 3 \pm 8$		

(Branching fractions in units of 10^{-6})

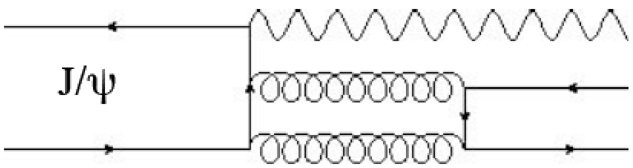
Suppressed for ψ(2S)→γη

- **For J/ψ,**

$$\frac{B(J/\psi \to \gamma\eta)}{B(J/\psi \to \gamma\eta')} = \mathbf{(21.1 \pm 0.9)\ \%}$$

consistent with other measurements of the η–η′ mixing angle.

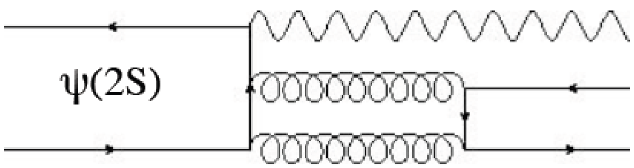
J/ψ → γη^(′)



- **But for ψ(2S),**

$$\frac{B(\psi(2S) \to \gamma\eta)}{B(\psi(2S) \to \gamma\eta')} = \mathbf{(1.10 \pm 0.38 \pm 0.07)\ \%}$$

ψ(2S) → γη^(′)



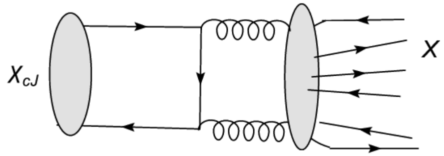
- **Why the difference?**
  - **interference with the continuum?**
  - **contributions of other processes?**
  - **something related to the "ρπ puzzle?"**

$\chi_{cJ} \rightarrow$ VV, V=ω,ϕ

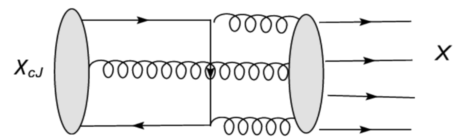
The Motivation

- Test QCD-based theory at χ_{cJ} decays

Eur.Phys.J.C2.705;
Eur.Phys.J.C14,643



χ_{cJ} hadronic decays
at QCD leading order



χ_{cJ} hadronic decays
in the color octet theory

- Puzzles for $\chi_{c0} \rightarrow$ VV: no helicity suppress

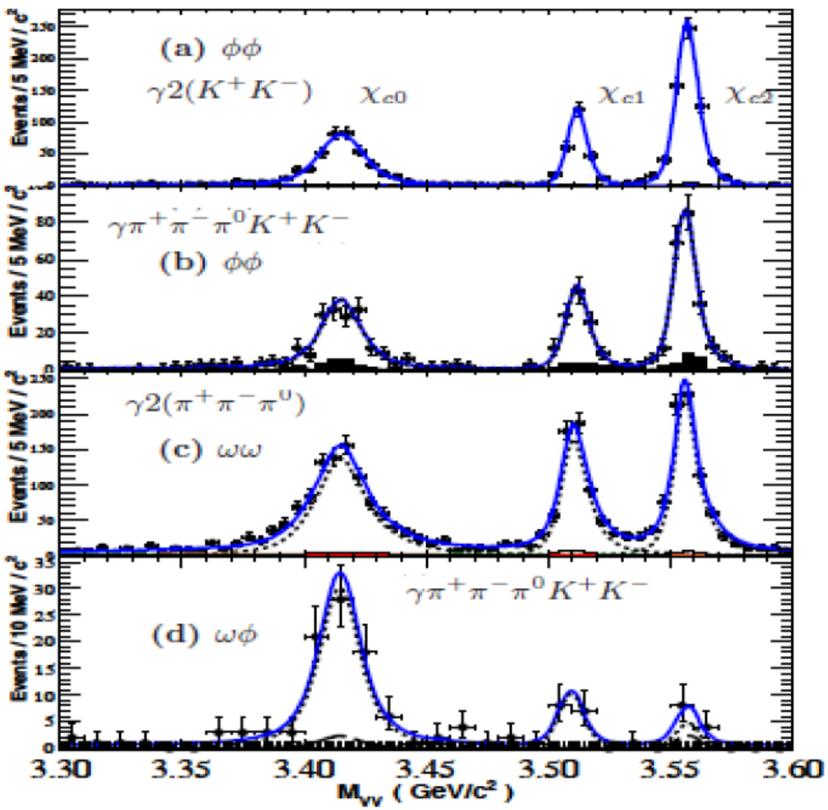
BESII results:		
BR(10^{-3})	χ_{c0}	χ_{c2}
$\phi\phi$	**0.93±0.20**	**1.5±0.3**
$\omega\omega$	**2.3±0.7**	**2.0±0.7**

PLB 642,197(2006)
PLB 630,7 (2005)

- $\chi_{c1} \rightarrow \phi\phi$, $\omega\omega$ is only allowed for L=2, suppressed ?
- $\chi_{c1} \rightarrow \phi\omega$ OZI doubly suppressed
- surprisingly these decays observed at BESIII

$\chi_{cJ} \to$ VV @ BESIII

- $\chi_{cJ} \to \phi\ \phi$ and $\chi_{cJ} \to \omega\ \omega$ are Singly OZI suppressed
- $\chi_{c1} \to \phi\phi$ and $\chi_{c1} \to \omega\omega$ is suppressed by helicity selection rule.
- $\chi_{cJ} \to \phi\omega$ is doubly OZI suppressed, not measured before yet

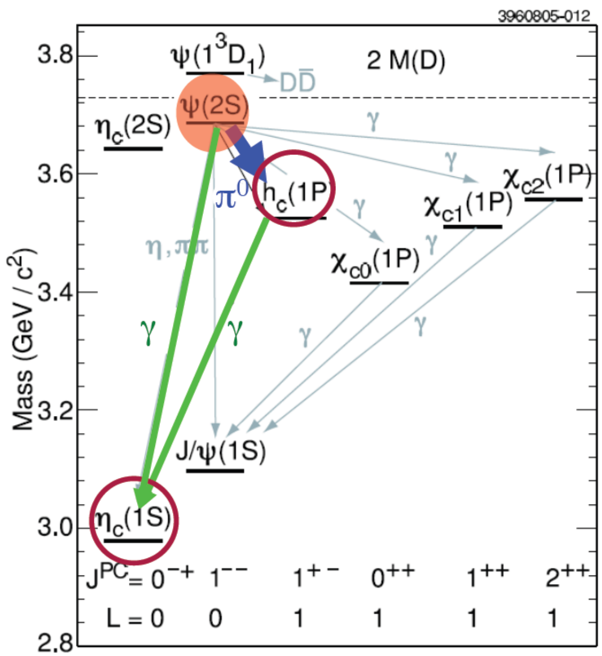


Mode	N_{net}	ϵ (%)	$\mathcal{B}(\times 10^{-4})$
$\chi_{c0} \to \phi\phi$	433 ± 23	22.4	$7.8 \pm 0.4 \pm 0.8$
$\chi_{c1} \to \phi\phi$	254 ± 17	26.4	$4.1 \pm 0.3 \pm 0.4$
$\chi_{c2} \to \phi\phi$	630 ± 26	26.1	$10.7 \pm 0.4 \pm 1.1$
$\to 2(K^+K^-)$			
$\chi_{c0} \to \phi\phi$	179 ± 16	1.9	$9.2 \pm 0.7 \pm 1.0$
$\chi_{c1} \to \phi\phi$	112 ± 12	2.3	$5.0 \pm 0.5 \pm 0.6$
$\chi_{c2} \to \phi\phi$	219 ± 16	2.2	$10.7 \pm 0.7 \pm 1.2$
$\to K^+K^-\pi^+\pi^-\pi^0$			
Combined:			
$\chi_{c0} \to \phi\phi$	—	—	$8.0 \pm 0.3 \pm 0.8$
$\chi_{c1} \to \phi\phi$	—	—	$4.4 \pm 0.3 \pm 0.5$
$\chi_{c2} \to \phi\phi$	—	—	$10.7 \pm 0.3 \pm 1.2$
$\chi_{c0} \to \omega\omega$	991 ± 38	13.1	$9.5 \pm 0.3 \pm 1.1$
$\chi_{c1} \to \omega\omega$	597 ± 29	13.2	$6.0 \pm 0.3 \pm 0.7$
$\chi_{c2} \to \omega\omega$	762 ± 31	11.9	$8.9 \pm 0.3 \pm 1.1$
$\to 2(\pi^+\pi^-\pi^0)$			
$\chi_{c0} \to \omega\phi$	76 ± 11	14.7	$1.2 \pm 0.1 \pm 0.2$
$\chi_{c1} \to \omega\phi$	15 ± 4	16.2	$0.22 \pm 0.06 \pm 0.02$
$\chi_{c2} \to \omega\phi$	< 13	15.7	< 0.2
$\to K^+K^-\pi^+\pi^-\pi^0$			

First observation

Evidence

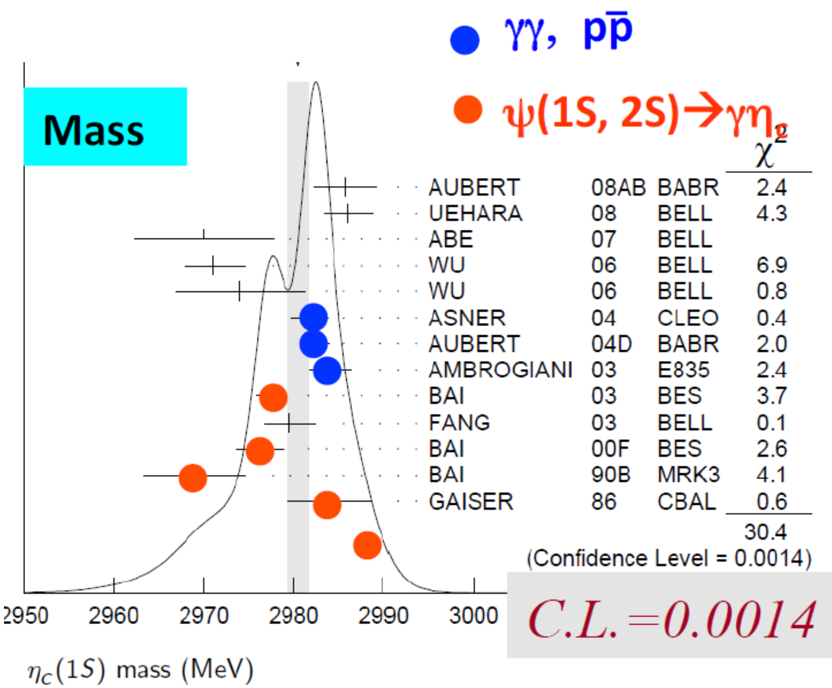
h_c & η_c

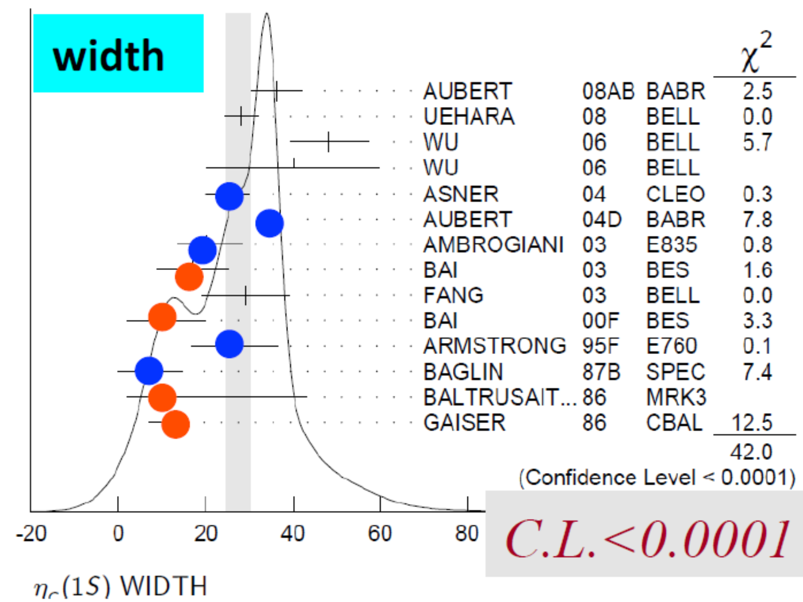


3960805-012
Mass (GeV / c²)
3.8
3.6
3.4
3.2
3.0
2.8
ψ(1³D₁)
DD̄
2 M(D)
ψ(2S)
η_c(2S)
γ
π⁰
h_c(1P)
χ_c1(1P)
χ_c2(1P)
χ_c0(1P)
η, ππ
J/ψ(1S)
η_c(1S)
J^PC = 0⁻⁺ 1⁻⁻ 1⁺⁻ 0⁺⁺ 1⁺⁺ 2⁺⁺
L = 0 0 1 1 1 1

$\eta_c(1S)$

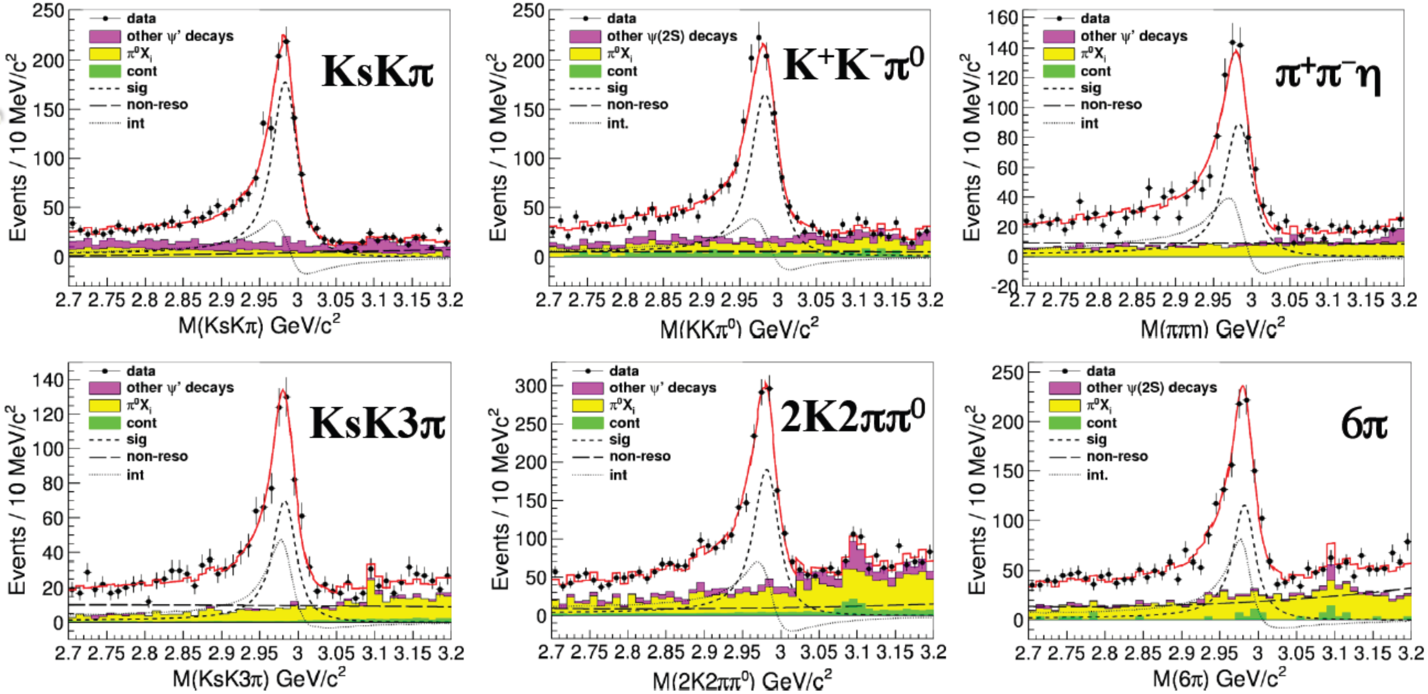
- The S-wave spin-singlet charmonium ground state, found in 1980
- M & Γ measurements:
  - -J/ψ radiative transitions: M ~ 2978.0 MeV, Γ ~ 10 MeV
  - -γγ processes: M = 2983.1±1.0 MeV/, Γ = 31.3±1.9 MeV
- CLEOc found that the η_c line shape in ψ' decays is distorted.





$\psi' \to \gamma\eta_c$, $\eta_c \to$ *exclusive* decays

interference with non-resonant background is significant!!



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

➔ *use a common phase value in the simultaneous fit.*

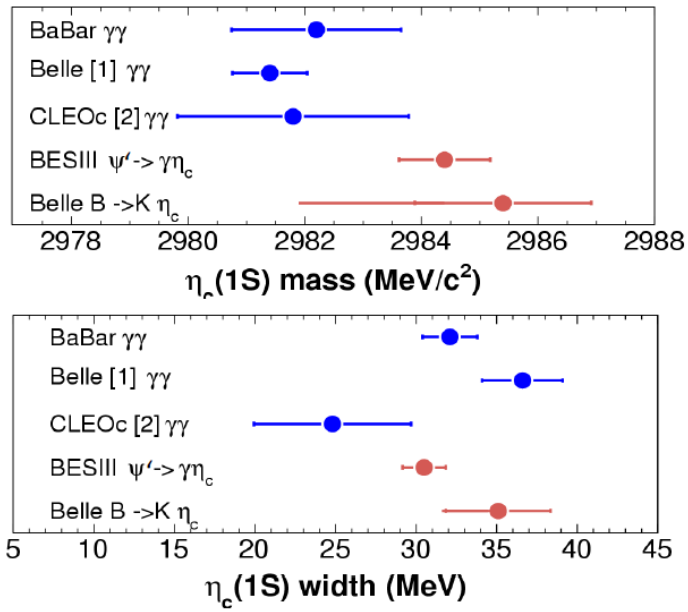
M: **2984.4 ± 0.5 ± 0.6** MeV

Γ: **30.5 ± 1.0 ± 0.9** MeV

ϕ: **2.35 ± 0.05 ± 0.04** rad

BESIII arXiv:1111:0398 →PRD

Summary of recent η_c results



Hyperfine splitting: $\Delta M(1S)$ = **112.5 ± 0.8** MeV

Theorists are happier with this value
(earlier result was too large for them)

$h_c(^1P_1)$

- Spin singlet P wave (S=0, L=1)
- Potential model: if non-zero P-wave spin-spin interaction,

  $\Delta M_{hf}(1P) = M(h_c) - \langle m(1\ ^3P_J)\rangle \neq 0$

  where $\langle m(1\ ^3P_J)\rangle = [(M(\chi_{c0})+3M(\chi_{c1})+5M(\chi_{c2})]/9$,
- CLEOc observed h_c in $ee \rightarrow \psi' \rightarrow \pi^0 h_c$, $h_c \rightarrow \gamma\eta_c$

  $\Delta M_{hf}(1P)=0.08\pm0.18\pm0.12\ MeV/c^2$

  Consistent with 1P hyperfine splitting = 0. PRL 101 182003 (2008)

Theoretical prediction:

$BF(\psi(2S) \rightarrow \pi^0 h_c) = (0.4\text{-}1.3)\times10^{-4}$

$BF(h_c \rightarrow \gamma\eta_c) = 48\%$ (NRQCD)

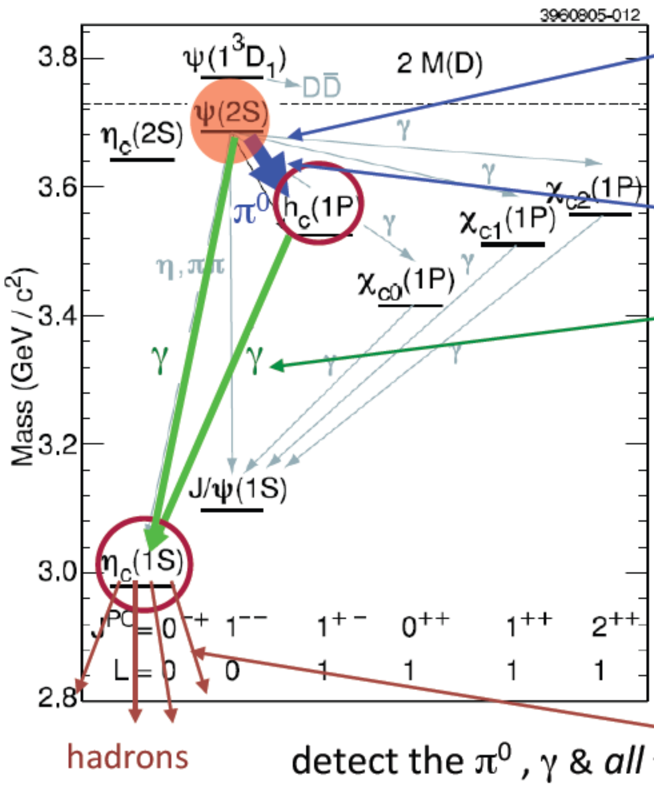
$BF(h_c \rightarrow \gamma\eta_c) = 88\%$ (PQCD)

Kuang, PR D65 094024 (2002)

$BF(h_c \rightarrow \gamma\eta_c) = 38\%$

Godfrey and Rosner, PR D66 014012(2002)

Measurements of h_c



only detect the π^0 → "inclusive"

(compute M_{h_c} from kinematics)

$$Rate \propto Bf(\psi' \to \pi^0 h_c)$$

detect the π^0 & γ → "E_1-tagged"

(compute M_{h_c} from kinematics)

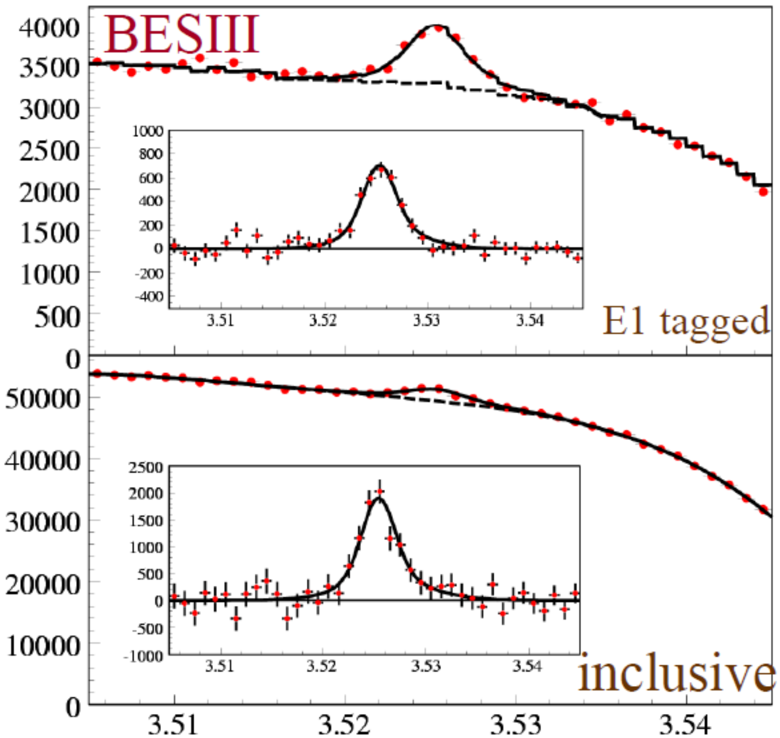
$$Rate \propto Bf(\psi' \to \pi^0 h_c) \times Bf(h_c \to \gamma\eta_c)$$

detect the π^0, γ & *all* $\eta_c \to X_i$ decay products→ "exclusive"

(compute M_{h_c} from 4-C kinematic fit)

$$Rate \propto Bf(\psi' \to \pi^0 h_c) \times Bf(h_c \to \gamma\eta_c) \times Bf(\eta_c \to X_i)$$

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



BESIII: PRL 104 132002 (2010)

Mass = **3525.40±0.13±0.18** MeV/c^2

Width = **0.73±0.45±0.28** MeV

<1.44 MeV @90%

CLEOc: PRL 101 182003 (2008)

Mass = **3525.28±0.19±0.12** MeV

Width: fixed at 0.9 MeV

Hyperfine mass splitting

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

BESIII: ***0.10±0.13±0.18*** MeV/c^2

CLEOc: ***0.02±0.19±0.13 MeV/c^2***

By combining inclusive results with E1-photon tagged results

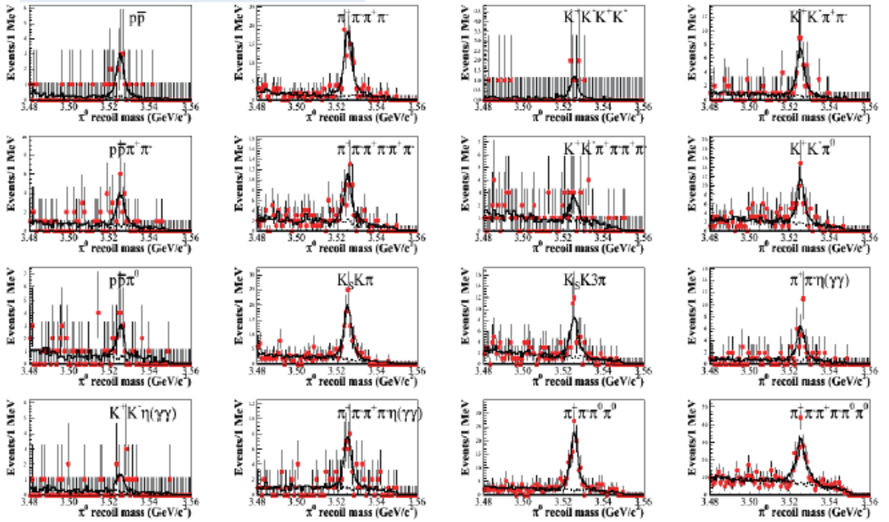
$BF(\psi' \rightarrow \pi^0 h_c)$ = **(8.4±1.3±1.0) ×10^{-4}**

$BF(h_c \rightarrow \gamma\, \eta_c)$ = **(54.3±6.7±5.2)%**

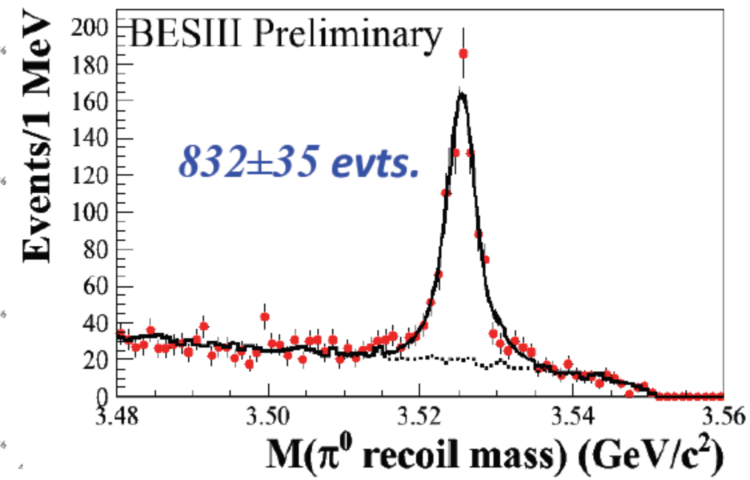
Agrees with prediction from Kuang, Godgrey, Dude et al.

$\psi' \to \pi^0 h_c$, $h_c \to \gamma\eta_c$, η_c *exclusive* decays

BESIII Preliminary



Summed distribution

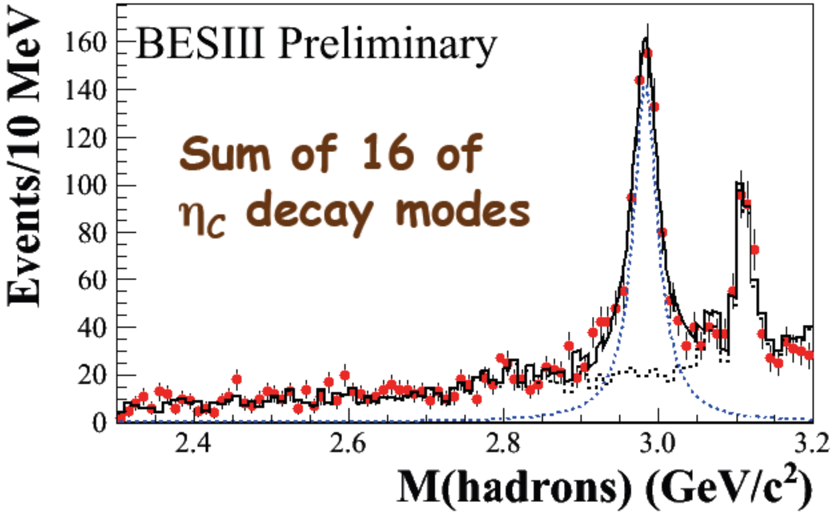


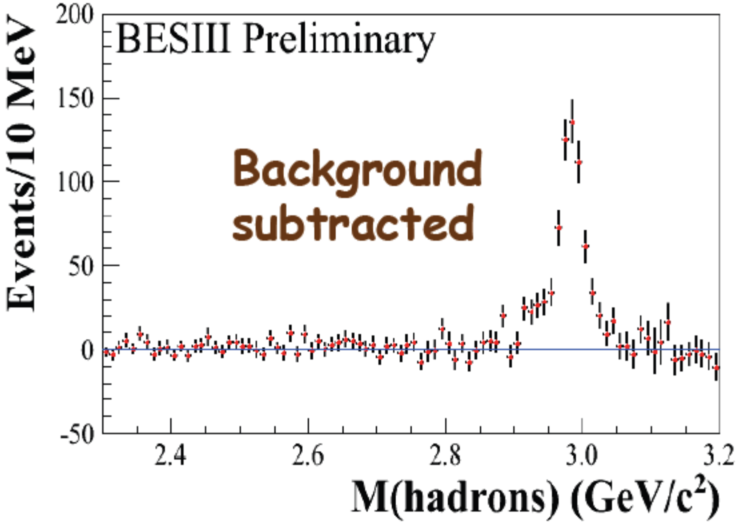
16 different η_c decay channels

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 E_1-tagged results

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





The η_c lineshape in $h_c \rightarrow \gamma\eta_c$ is not as distorted as in $\psi' \rightarrow \gamma\eta_c$ decays; the non-resonant interfering bkg is small (non-existent?). Ultimately, this channel will be best suited to determine η_c resonance parameters.

yesterday's search → today's discovery → tomorrow's calibration

Summary

BESIII has been in operation since 2008: ~106M + ~500M $\psi(2S)$, ~225M J/ψ , $2.9fb^{-1}$ $\psi(3770)$, $0.5fb^{-1}$ $\psi(4010)$ events have been collected,

Light Quark Hadrons

- **X(1860) in $J/\psi \to \gamma$ (pp)** *(Chinese Physics C34,4(2010) and arXiv:1112.0942->PRL)*
- **X(1835) in $J/\psi \to \gamma (\eta'\pi^+\pi^-)$** *(PRL 106,072002(2011))*
- **X(1870) in $J/\psi \to \omega (\eta\pi^+\pi^-)$** *(PRL 107,182001(2011))*
- **η(1405) in $J/\psi \to \gamma f_0(980)\pi^0 \to \gamma \pi^+\pi^-\pi^0$** *(arXiv:1201.2737→PRL)*
- **a0(980)-f0(980) mixing** *(PRD 83,032003(2011))*
- **$\eta' \to \eta\pi^+\pi^-$ matrix element** *(PRD 83,012003(2011*

Charmonium Decays

- $\psi(2S) \to \gamma \pi^0, \gamma \eta, \gamma \eta'$ *(PRL 105,261801(2010))*
- $\chi_{cJ} \to \phi\phi, \phi\omega, \omega\omega$ *(PRL 107,092001(2011))*
- $\chi_{cJ} \to \pi^0 \pi^0, \eta\eta'$ *(PRD 81,052005(2010))*
- $\chi_{cJ} \to \gamma\rho , \gamma\omega, \gamma\phi$ *(PRD 83,112005(2011))*
- $\chi_{cJ} \to 4\pi^0$ *(PRD 83,012006(2011))*

and more than dozens analyses in progress

Charmonium Spectroscopy

- mass and width of η_c *(arXiv:1111.0398)*
- properties of h_c *(PRL 104,132002(2010))*
- multipoles in $\psi(2S) \to \gamma\chi_{c2}$ *(arXiv:1110.1742)*

Open Charm: coming soon

Acknowledgement

Thanks to all BESIII colleagues

for their helps on preparation of this talk


THANK YOU！
PKU NEWS