Results Of Hadron Spectroscopy From BESIII

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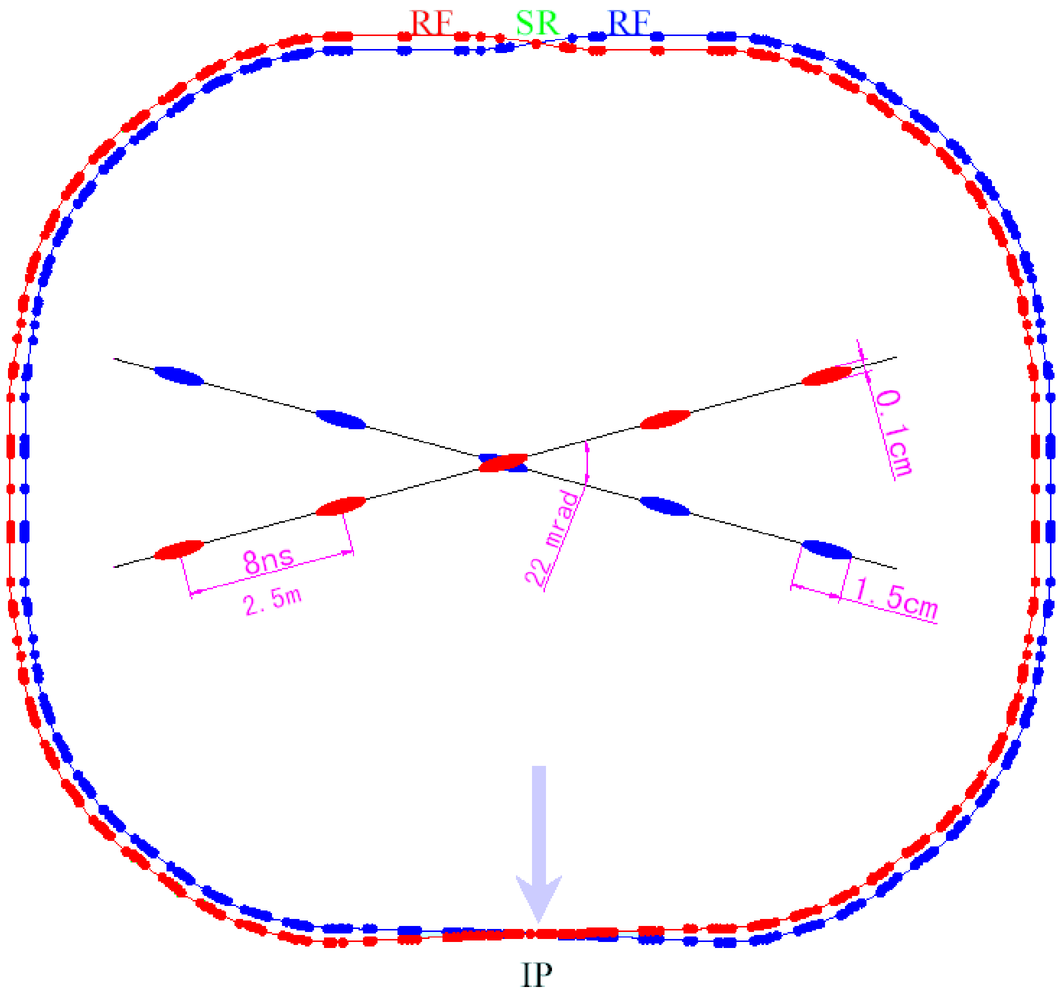
for the BESIII Collaboration

The 3rd Workshop on Hadron Physics in China and Opportunities in US
August 8-11, 2011, Weihai, Shangdong, China

Outline

- **Introduction**
- **Latest Results On Hadron Spectroscopy**
  - $p\bar{p}$ **threshold enhancement in J/ψ and ψ′ decays**
  - **Confirmation of X(1835) and observation of X(2120) and X(2370) in** $J/\psi \to \gamma(\eta'\pi^+\pi^-)$ **decay**
  - **Observation of X(1870) in** $J/\psi \to \omega(\eta\pi^+\pi^-)$ **decay**
  - **a0(980) − f0(980) mixing**
- **Prospects & Summary**

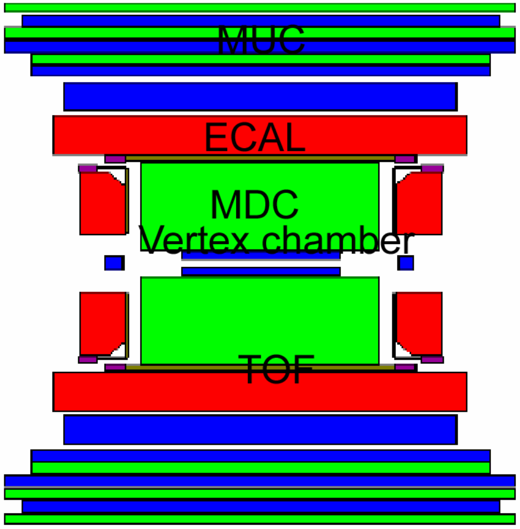
BEPCII Storage Ring



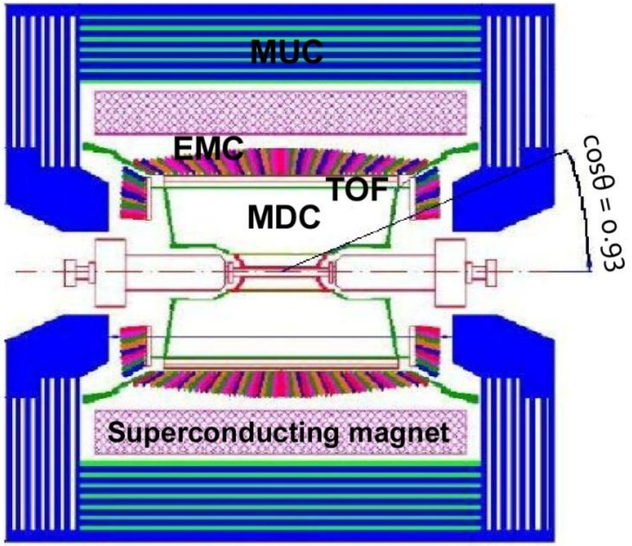
Beam energy:
1.0-2 .3GeV
Luminosity:
$1\times10^{33}\ cm^{-2}s^{-1}$
Optimum energy:
1.89 GeV
Energy spread:
5.16×10^{-4}
No. of bunches:
93
Bunch length:
1.5 cm
Total current:
0.91 A

From BESII to BESIII

BES II @ BEPC



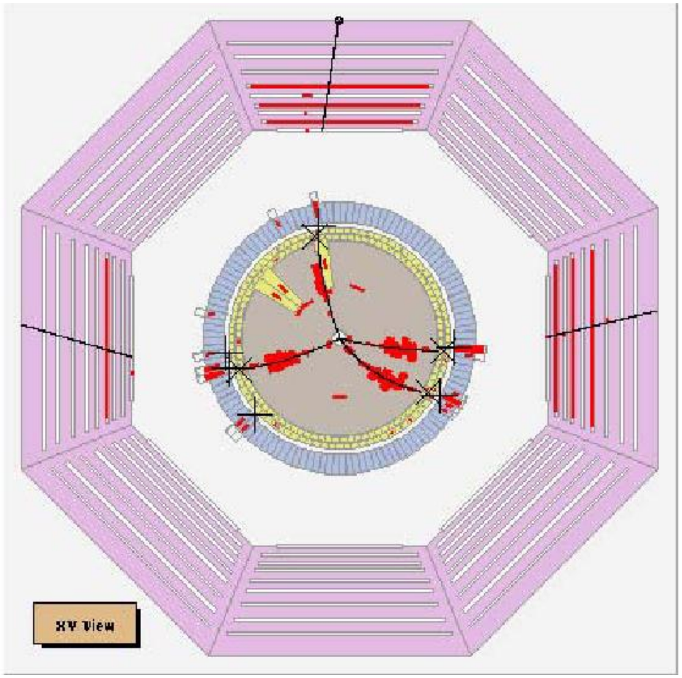
BES III @ BEPC II



	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

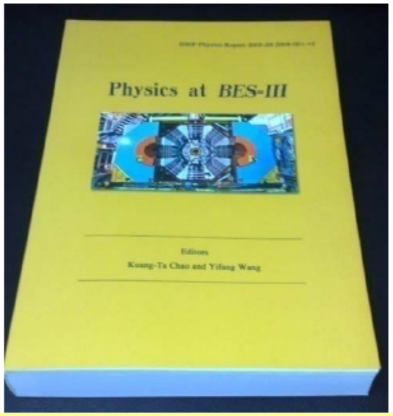
BESIII Milestones

Mar. 2008: first full cosmic-ray event
Apr. 30, 2008: Move the BESIII to IP
Jul. 19, 2008: First e^+e^- collision event in BESIII
Nov. 2008: ~14M $\psi(2S)$ events collected
Apr. 14, 2009: ~ 106M $\psi(2S)$ events collected (×4 CLEOc)
May 30, 2009: 42 pb^{-1} at continuum collected
Jul. 28, 2009: ~225M J/ψ events collected (×4 BESIII)
2010 - 2011: 2.9fb^{-1} $\psi(3770)$ events (× 3.5 CLEOc)
May 2011: 0.5fb^{-1} $\psi(4010)$ events collected



Main Physics Topics @BESIII

- Light hadron spectroscopy
  - Full spectra: normal & exotic hadrons QCD
  - How quarks form a hadron ? non-pQCD
- Charm physics
  - CKM matrix elements ➔ SM and beyond
  - $D\overline{D}$ mixing and CPV ➔ SM and beyond
- Charmonium physics
  - Spectroscopy and transition ➔ pQCD & non-pQCD
  - New states above open charm thresholds ➔ exotic hadrons ?
  - pQCD: ρπ puzzle ➔ a probe to non-pQCD or ?
- Tau physics and QCD
  - Precision measurement of the tau mass and R value
- Search for rare and forbidden decays



hep-ex/0809.1869
IJMP A V24,No 1(2009) supp

Precision test of SM and search for new physics

Why Hadron Spectroscopy?

Study of spectroscopy is one of the major approaches to understand deeper structure and interaction of the matter

Atomic spectroscopy ⟺ Atomic Structure

Nuclear spectroscopy ⟺ Nuclear Structure

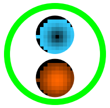
Hadron spectroscopy ⟺ Hadron Structure

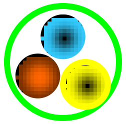
Light Hadrons

- Ordinary hadrons are consists of 2 or 3 quarks

quark model：

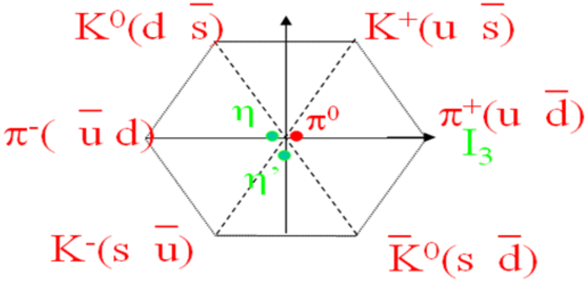
Meson:	$q\ \bar{q}$
Baryon:	$q\ q\ q$



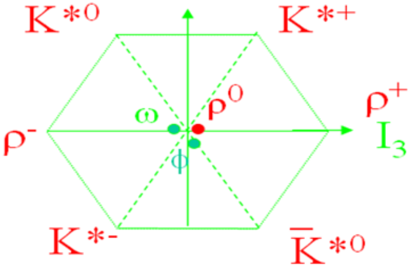


$(q\ \bar{q})$: $\quad {}^{2S+1}L_J \quad J^{PC} \quad P=(-1)^{L+1}$

${}^1S_0 \quad 0^-$



${}^3S_1 \quad 1^-$



$$\pi^0 = \frac{u\bar{u} - d\bar{d}}{\sqrt{2}}$$

Exotic Hadrons

QCD allows different type of hadrons：

- **Multiquark：quark >＝4**
- **hybrids： $\bar{q}qg$，qqqg …**
- **glueball： gg，ggg …**

Searching for above hadron states is one of the important topics for many experiments。In past decades, although none of above states has been established, there do exist some open questions:

1) much more states than predicted exist in some mass region

2) some of states are hard to be understood as ordinary hadrons

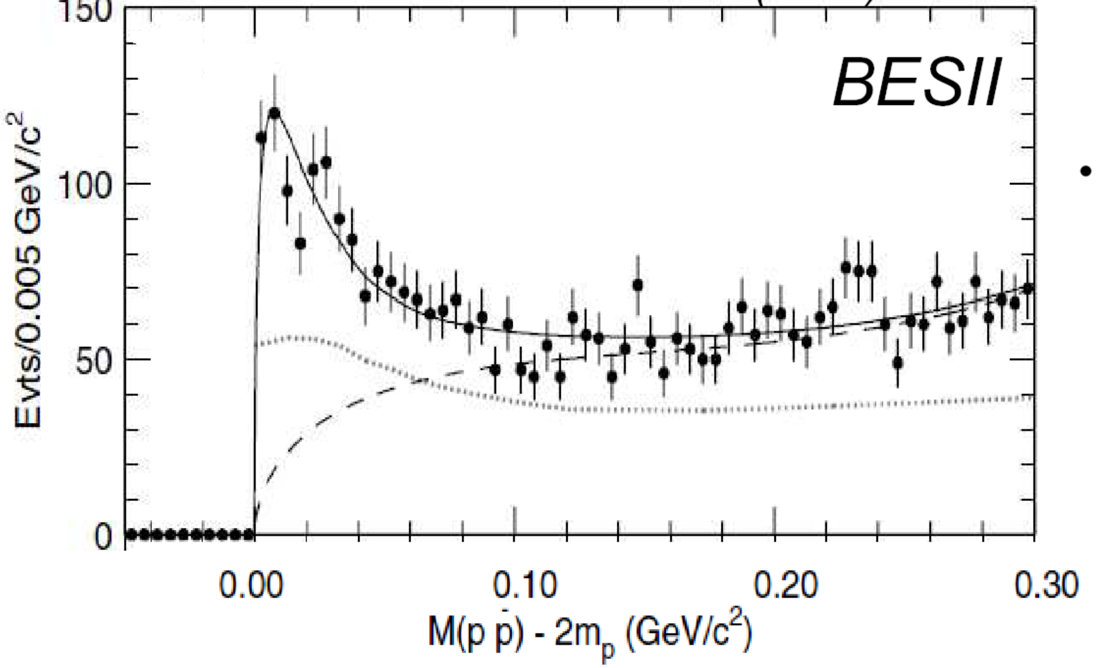
$p\bar{p}$ Threshold Enhancement

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

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

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

PRL 91 (2003) 022001



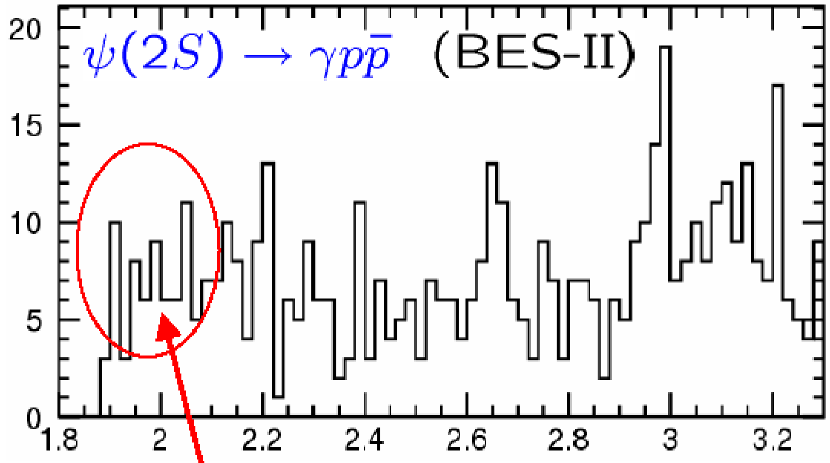
- What it could be theoretically:
  - $p\bar{p}$ bound state
  - FSI effect
  - ••• •••

$M=1859^{+3}_{-10}{}^{+5}_{-25}$ MeV/c² $\Gamma < 30$ MeV/c² (90% CL)

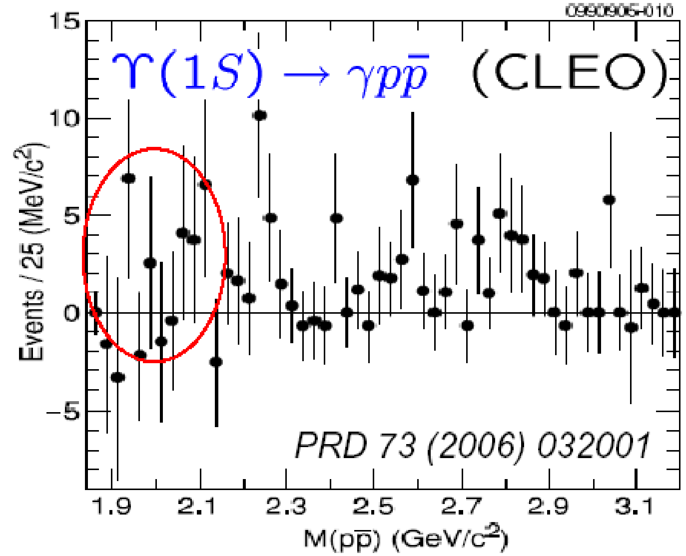
$p\bar{p}$ Threshold Enhancement: None Observations

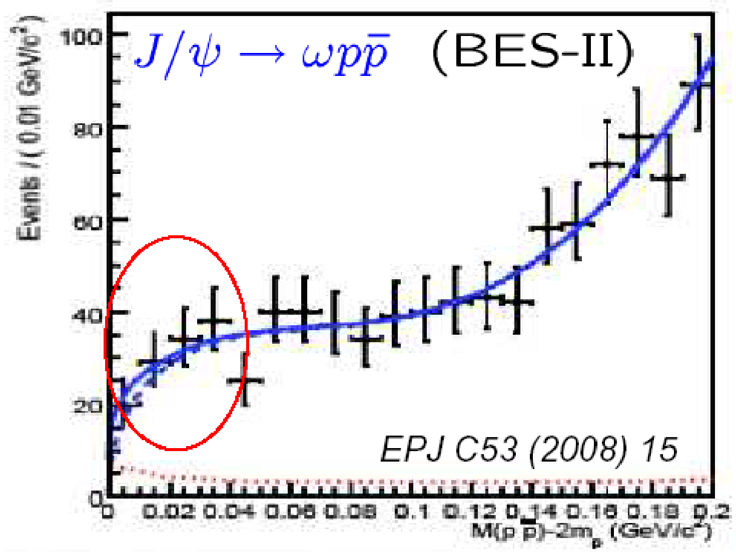
- Several ***none*** observations...

PRL 99 (2007) 011802

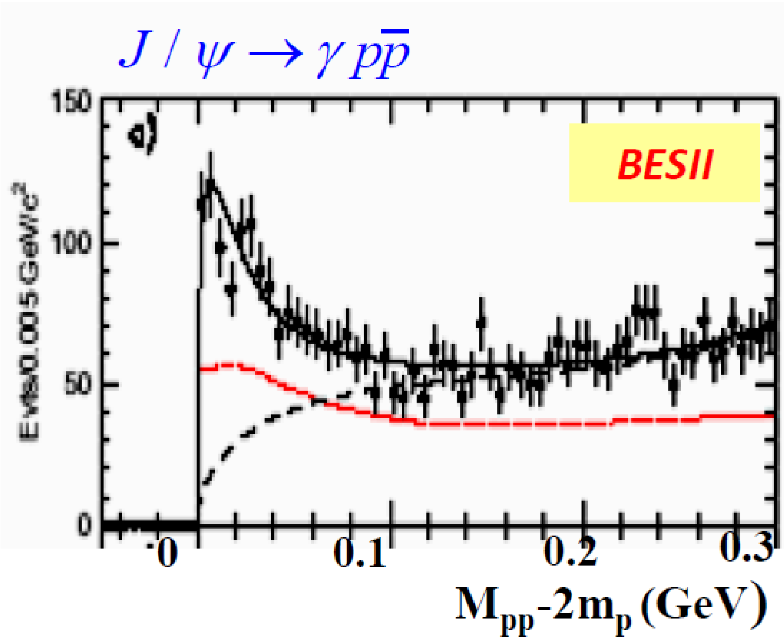


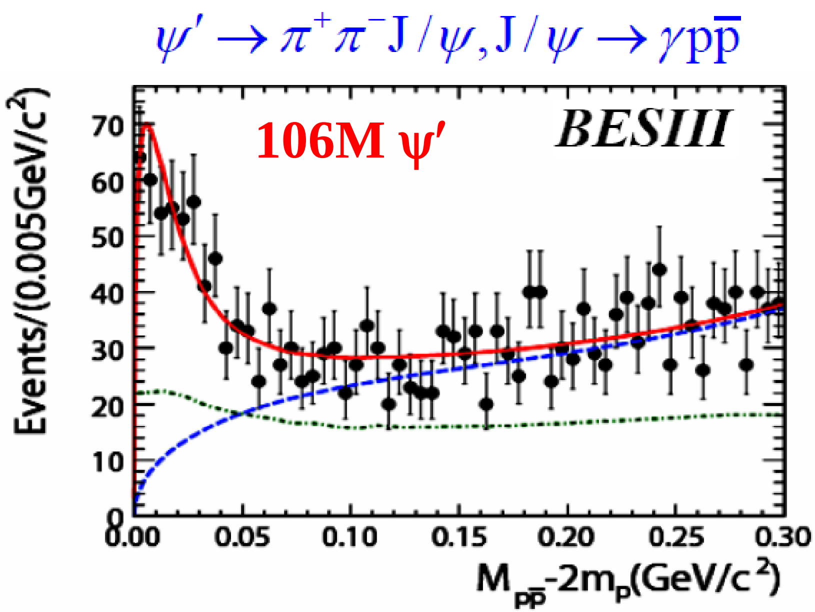
No significant signal of X(1860) found (only 2σ significance)





Mass Spectrum Fitting





$M = 1859 \,^{+3}_{-10}\,^{+5}_{-25}$ MeV/c²

$\Gamma < 30$ MeV/c² (90% CL)

PRL 91 (2003) 022001

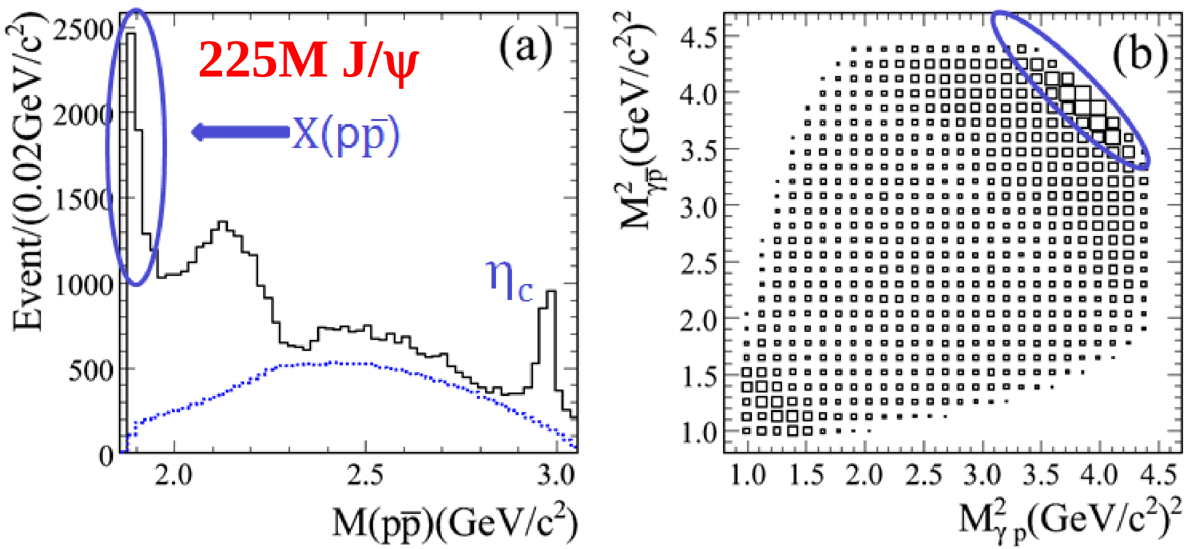
$M = 1861 \,^{+6}_{-13}\,^{+7}_{-26}$ MeV/c²

$\Gamma < 38$ MeV/c² (90% CL)

Chinese Physics C 34, 421 (2010)

Consistent with BESII observation, confirmed the enhancement !!

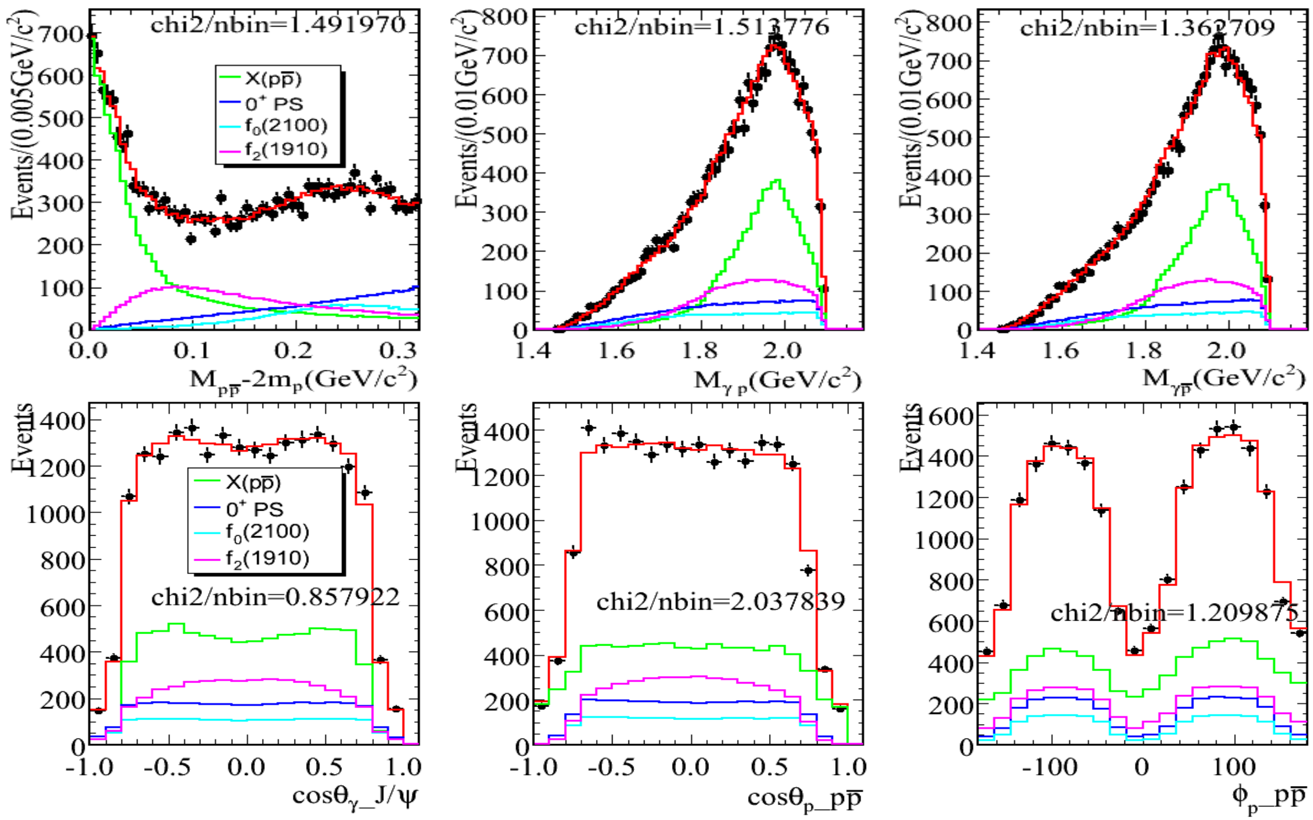
M($p\bar{p}$) threshold structure in $J/\psi \to \gamma p\bar{p}$



- **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).

Preliminary PWA Results for J/ψ→γpp̄

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 pp̄ mass threshold structure.
- It is much better than that without FSI effect, and Δ2lnL=51 ⇒ 7.1σ.

Preliminary PWA Results for $J/\psi \to \gamma p\bar{p}$

- 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.

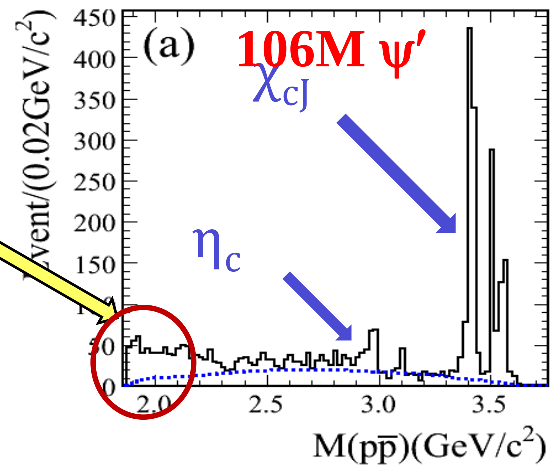
$M = 1832 \pm 5(\text{stat})^{+15}_{-17}(\text{syst}) \pm 19(\text{mod})\ \text{MeV}/c^2$

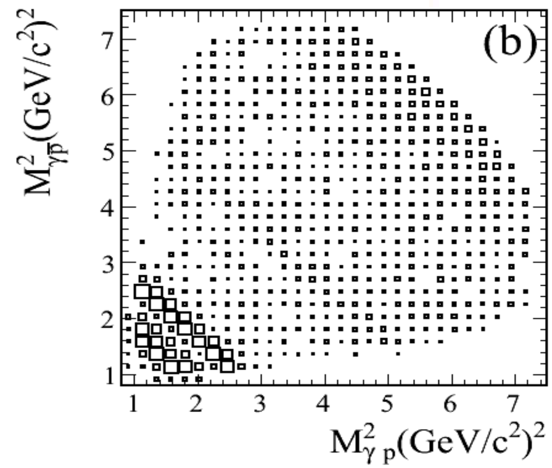
$\Gamma = 13 \pm 20(\text{stat})^{+8}_{-26}(\text{syst}) \pm 4(\text{mod})\text{MeV}/c^2$ or $\Gamma < 45\text{MeV}/c^2$ @ $90\%\ C.L.$

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

Preliminary PWA Results for ψ′→γpp̄

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





PWA results:

- Significance of X(pp̄) is larger than 6.9σ.
- The production ratio R:

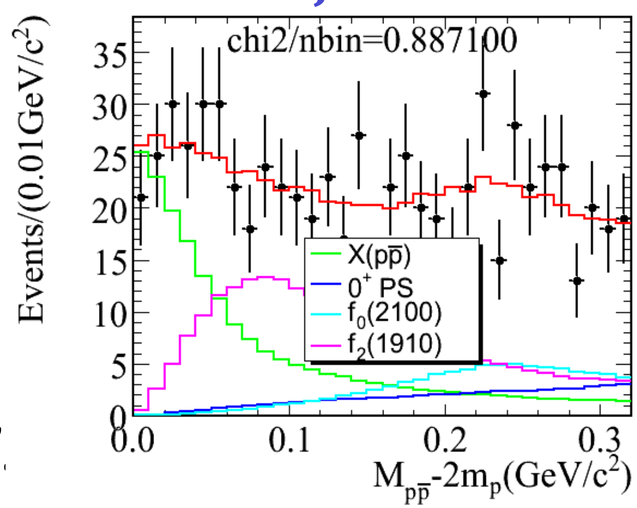
first measurement

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

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

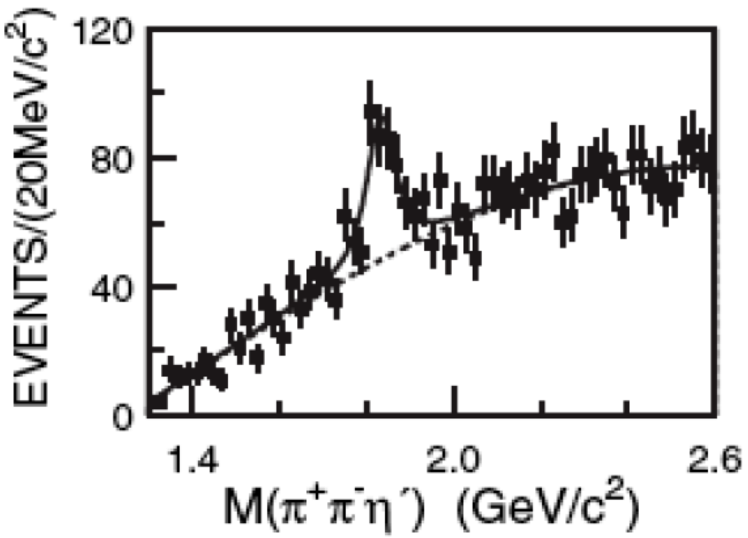
- It is suppressed compared with “12% rule”.

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



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

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

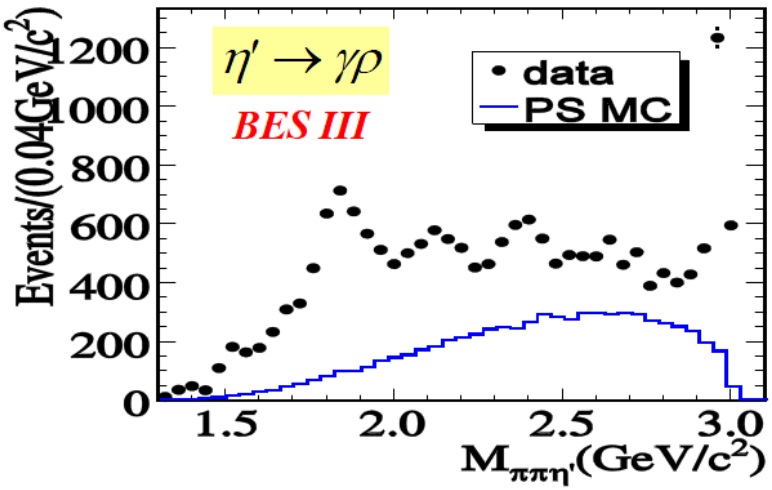
$$\Gamma = 67.7 \pm 20.3(\text{stat}) \pm 7.7(\text{syst})\text{MeV}$$

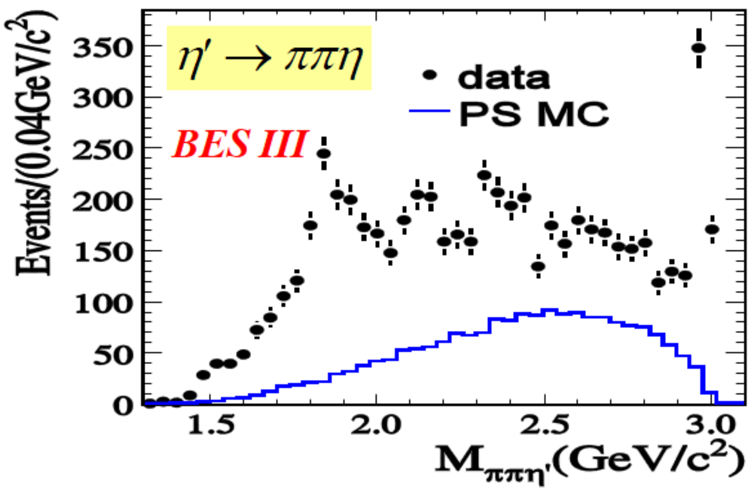
PRL 95,262001(2005)

- **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**

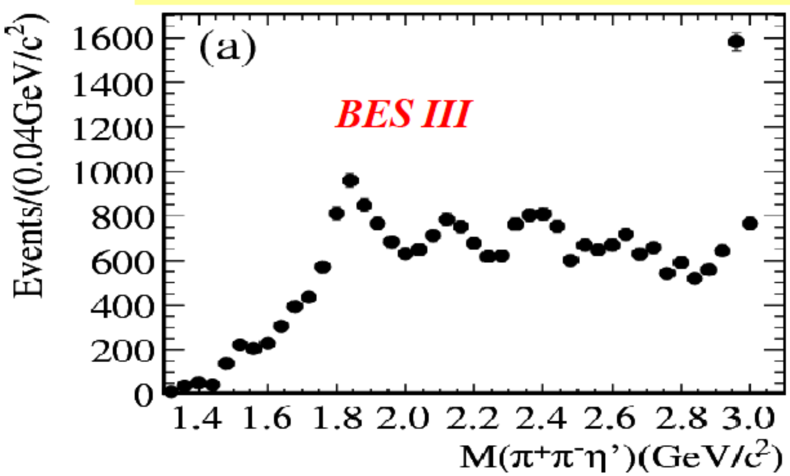
Need to confirm it with BESIII ~225M J/ψ data !!!

Invariant Mass of $\pi\pi\eta'$



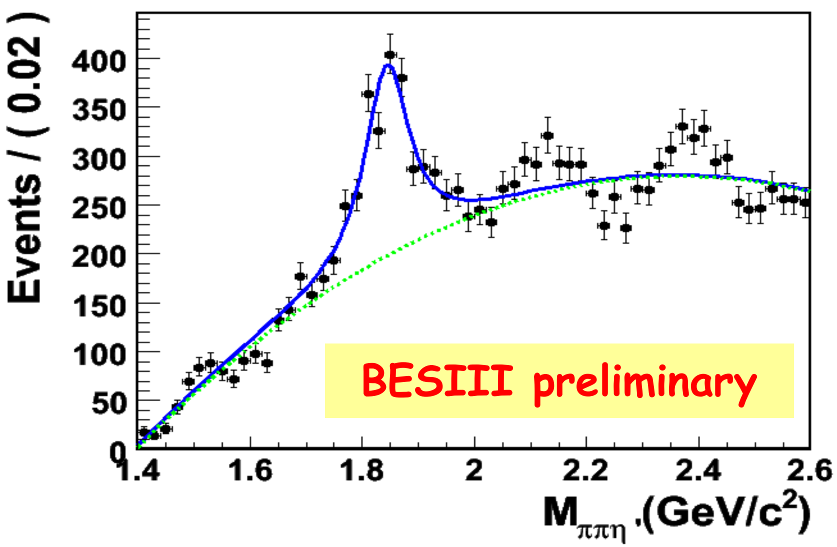


Combination for η' to $\pi^+\pi^-\eta$ and $\gamma\rho$

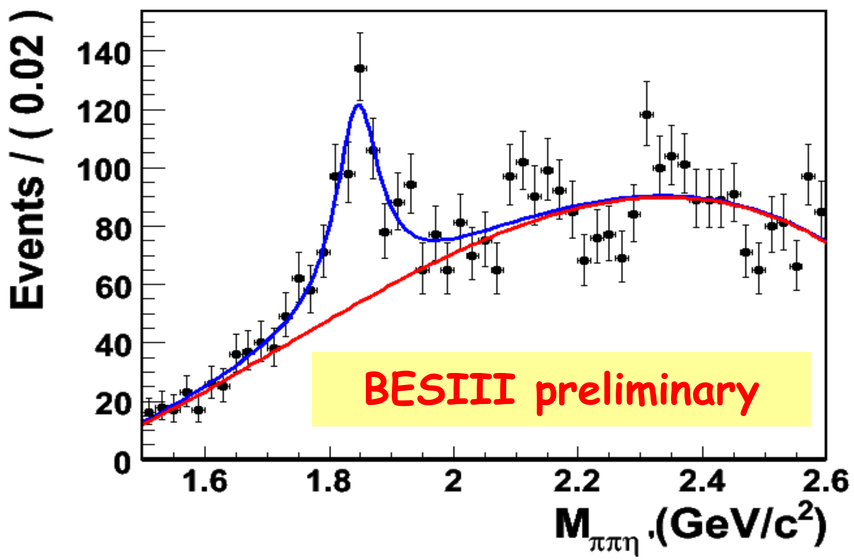


- X(1835) and η_c are evident.
- Two additional structures are observed at M~2.1GeV and 2.3GeV
- There maybe some $f_1(1510)$.

X(1835) @BESIII



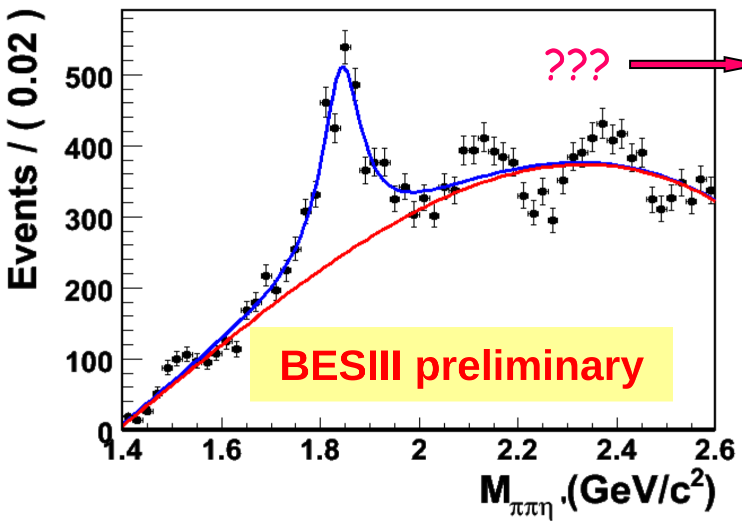
Statistical Significance ~18 σ



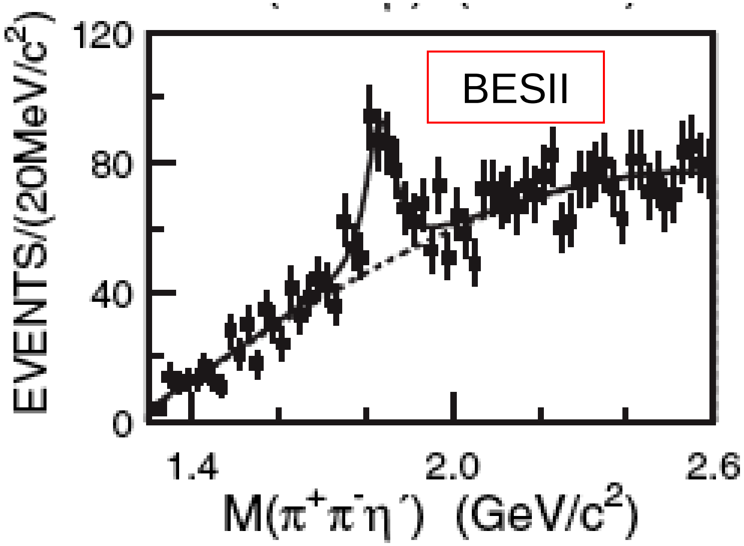
Statistical Significance ~9 σ

Bump around 1835MeV becomes much more clear from BESIII ~225M J/ψ

Fitting With One Resonance



Structures at higher mass region???



Fitting Results:

BESIII preliminary:

$M = 1842.4 \pm 2.8$ (stat.) MeV

$\Gamma = 99.2 \pm 9.2$ (stat.) MeV

Statistical significance: ~ 21σ

BESII Results:

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

$\Gamma = 67.7 \pm 20.3$ (stat.) $\pm$ 7.7(syst.) MeV

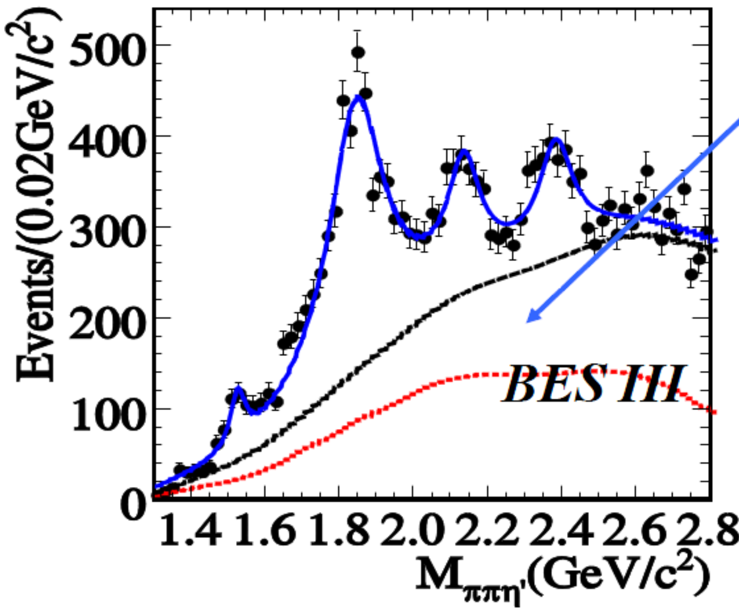
Statistical significance: ~ 7.7σ

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

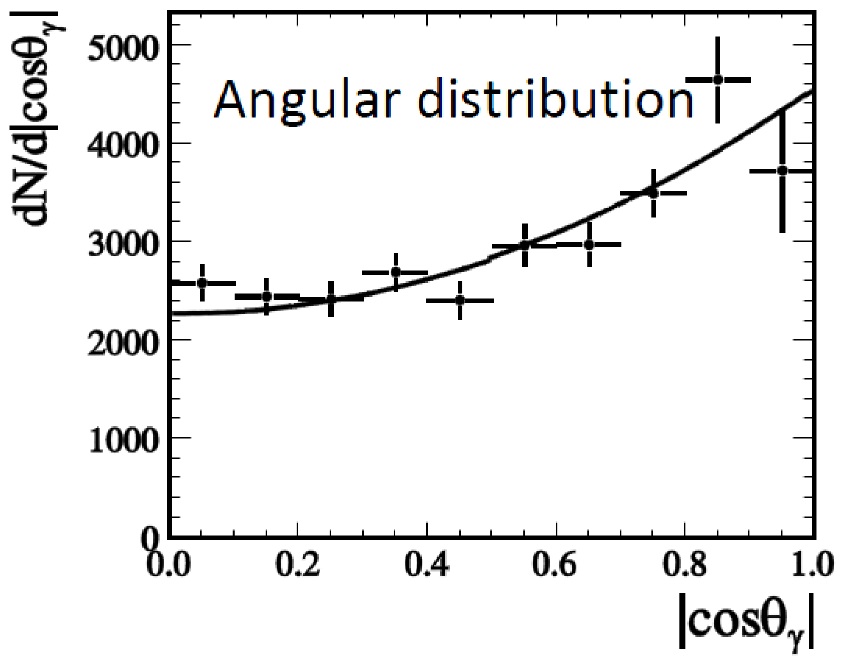
Black line: total background

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/c^2)	Γ(MeV/c^2)	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



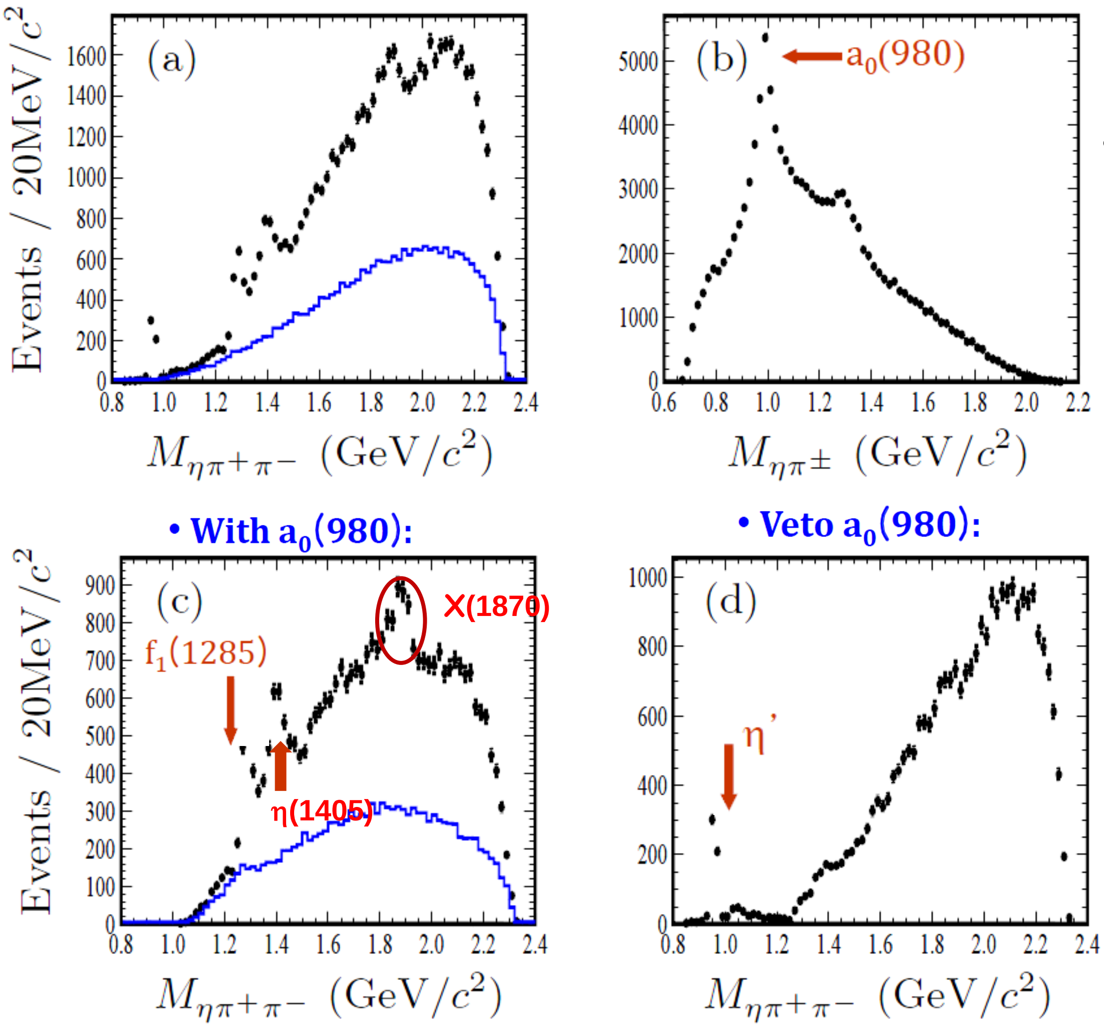
For the X(1835):

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

PRL 106:072002,2011

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

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

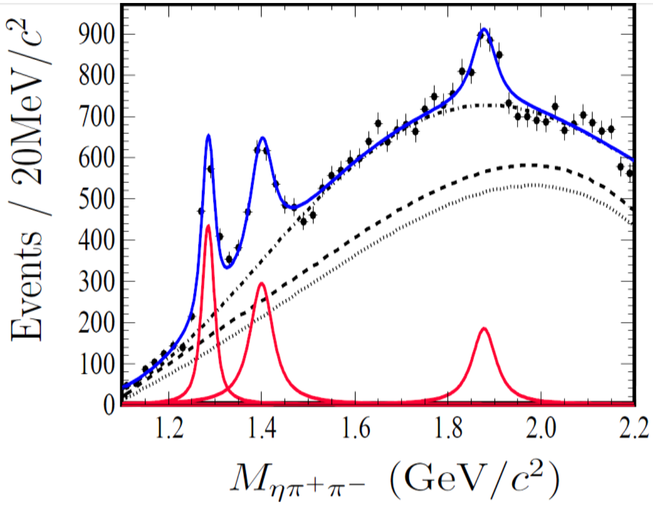


- In addition to the well-known η', $f_1(1285)$ and η(1405), an unknown structure (denoted as X(1870)) around 1.87GeV/c^2 is observed.
- The $f_1(1285)$, η(1405) and X(1870) decay primarily via $a_0(980)\pi$ mode.

Submitted to PRL

Fitting Result of X(1870)

- Fitting with three resonances (acceptance weighted BW $\otimes$ 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.

Submitted to PRL

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

- The resonant parameters of $f_1(1285)$ and $\eta(1405)$ agree quite well with PDG values.
- A structure with mass of ~1.87 GeV/c^2 and width of ~57 MeV/c^2 is observed with a significance of ~7.2σ .
- Whether X(1860) ($J/\psi \to \gamma p\bar{p}$), X(1835) ($J/\psi \to \gamma\eta'\pi\pi$) and X(1870) ($J/\psi \to \omega\eta\pi\pi$) are the same resonance still need both experimental and theoretical study.

Submitted to PRL

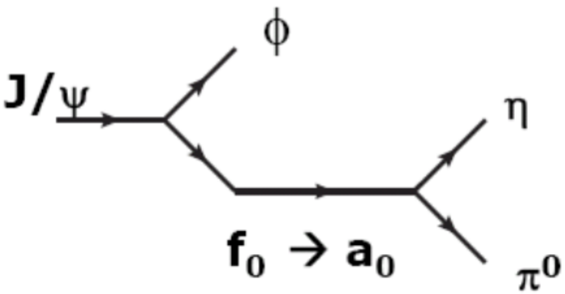
a0(980) – f0(980) mixing

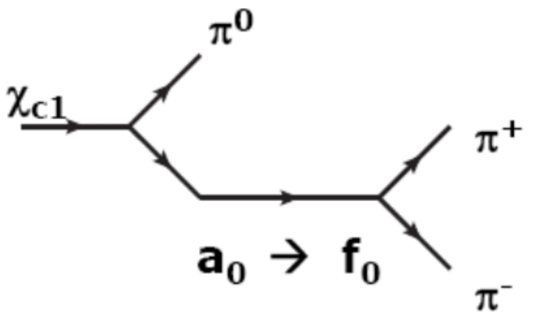
a0(980)-f0(980) Mixing

- Mixing intensity provides important information to understand the nature of $a_0(980)$ and $f_0(980)$.
- Narrow peak (8 MeV) at around 980 MeV can be expected in $\eta\pi$ ($J/\psi \to \phi f_0 \to \phi a_0 \to \phi\eta\pi$ case) or $\pi^+\pi^-$ ($\chi_{c1} \to a_0\pi^0 \to f_0\pi^0 \to \pi^+\pi^-\pi^0$ case) invariant mass spectra.

J.Wu, Q.Zhao, B.Zou PRD75 114012,
C. Hanhart etc. PRD76 074028,
etc.

J.Wu, B.Zou PRD78 074017



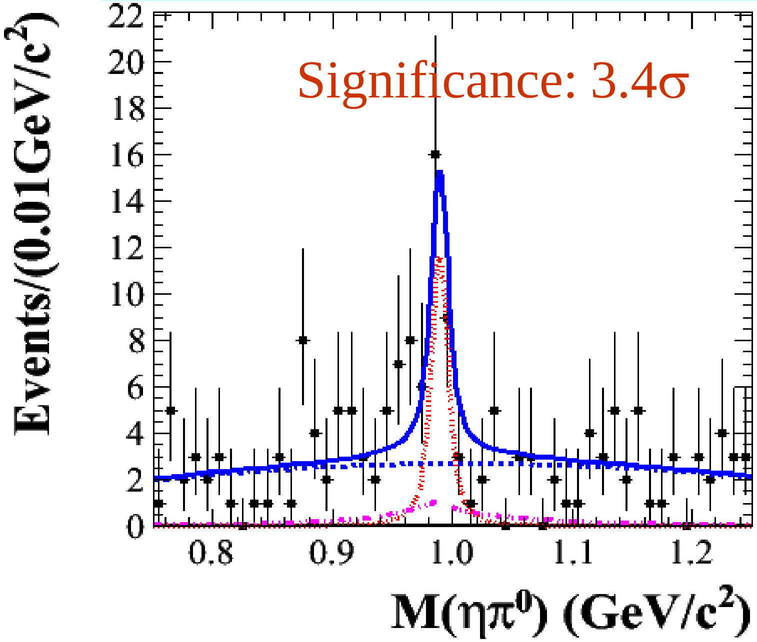


$J/\psi \to \phi f_0 \to \phi a_0 \to \phi\eta\pi$

$\chi_{c1} \to a_0\pi^0 \to f_0\pi^0 \to \pi^+\pi^-\pi^0$

a_0-f_0 Mixing: $f_0 \to a_0$ transition

Phys.Rev.D83,032003 (2011)



.... Mixing signal

--- a_0(980) contribution from $J/\psi \to \gamma^*/K^*K \to \phi a_0(980)$

--- Background polynomial

$N(\text{mixing}) = 25.8 \pm 8.6(\text{stat.})$

< 39.7 (90% C.L)

$Br(J/\psi \to \phi f_0 \to \phi a_0 \to \phi \eta \pi^0)$

$= (3.3 \pm 1.1(\text{stat.}) \pm 0.4(\text{sys.}) \pm 1.4(\text{para.})) \times 10^{-6}$

$< 5.4 \times 10^{-6}$ (90% C.L.)

Mixing intensity:

$$\xi_{fa} = \frac{Br(J/\psi \to \phi f_0 \to \phi a_0 \to \phi \eta \pi^0)}{Br(J/\psi \to \phi f_0 \to \phi \pi\pi)^{[BESII]}}$$

$= (0.60 \pm 0.20(\text{stat.}) \pm 0.12(\text{sys.}) \pm 0.26(\text{para.}))\%$

$< 1.1\%$ (90% C.L.)

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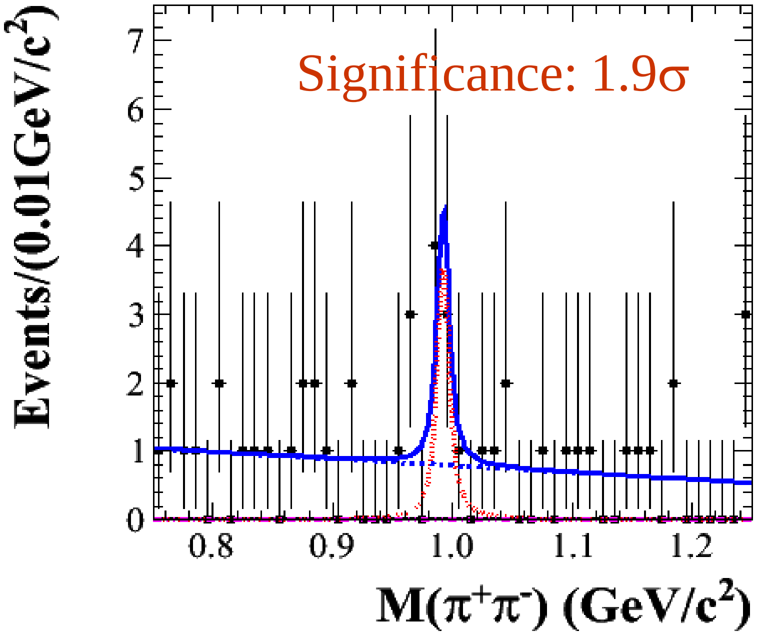


…. Mixing signal

--- $f_0(980)$ contribution from other processes

--- Background polynomial

N(mixing)=6.4±3.2(stat.)

<13.0 (90% C.L)

$Br(\psi' \to \gamma\chi_{c1}, \chi_{c1} \to a_0\pi^0 \to f_0\pi^0 \to \pi^+\pi^-\pi^0)$

$=(2.7 \pm 1.4(stat.) \pm 0.7(sys.) \pm 0.3(para.)) \times 10^{-7}$

$<6.0 \times 10^{-7}$ (90% C.L.)

Mixing intensity:

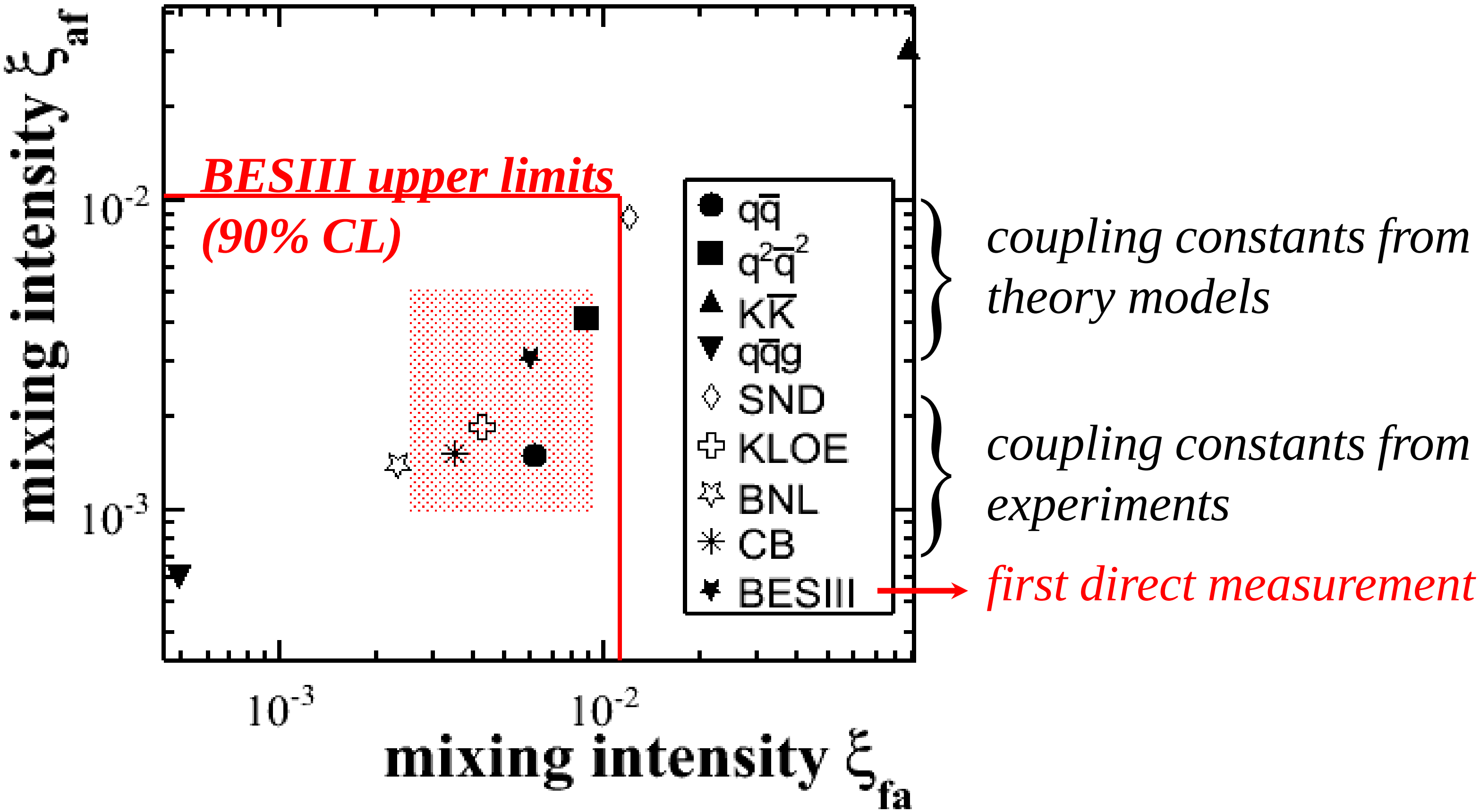
$$\xi_{af} = \frac{Br(\chi_{c1} \to a_0\pi^0 \to f_0\pi^0 \to \pi^+\pi^-\pi^0)}{Br(\chi_{c1} \to \pi^0 a_0 \to \eta\pi^0\pi^0)^{[PDG]}}$$

$= (0.31 \pm 0.16(stat.) \pm 0.14(sys.) \pm 0.03(para.))\%$

<1.0% (90% C.L.)

Comparison with different predictions

➢Mixing intensities can be derived from measured / predicted $f_0 \rightarrow K^+K^-$, $\pi\pi$, $a_0 \rightarrow K^+K^-$, $\eta\pi$ coupling constants *(Wu et al. PRD75, 114012(2007) and references within)*



Summary

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

- **Following results obtained for hadron spectroscopy:**
  - **Confirmation of $p\bar{p}$ threshold enhancement and X(1835)**
  - **Observation of X(2120) and X(2370)**
  - **Observation of X(1870)**
  - **a0(980) − f0(980) mixing**

  and more than a dozen analyses in progress

- **More data and more exciting results are expected, stay tuned**

Acknowledgement

Thanks to all BESIII colleagues

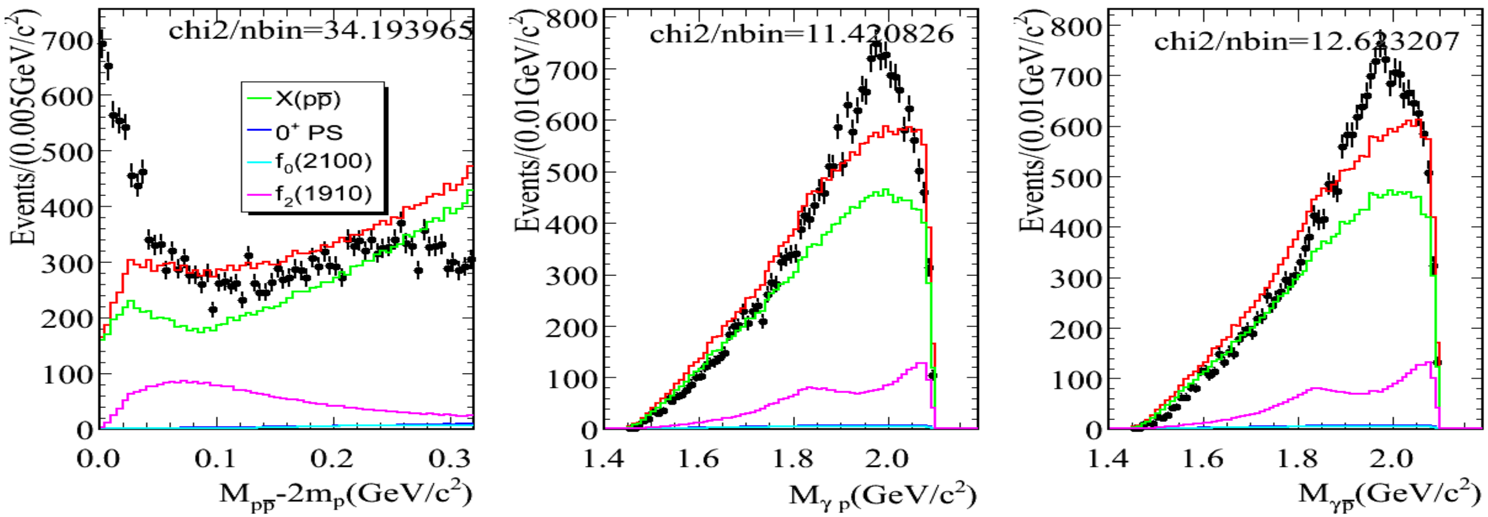
for their helps on preparation of this talk


THANK YOU！
PKU NEWS

Backup

PWA projections in $J/\psi \to \gamma p\bar{p}$

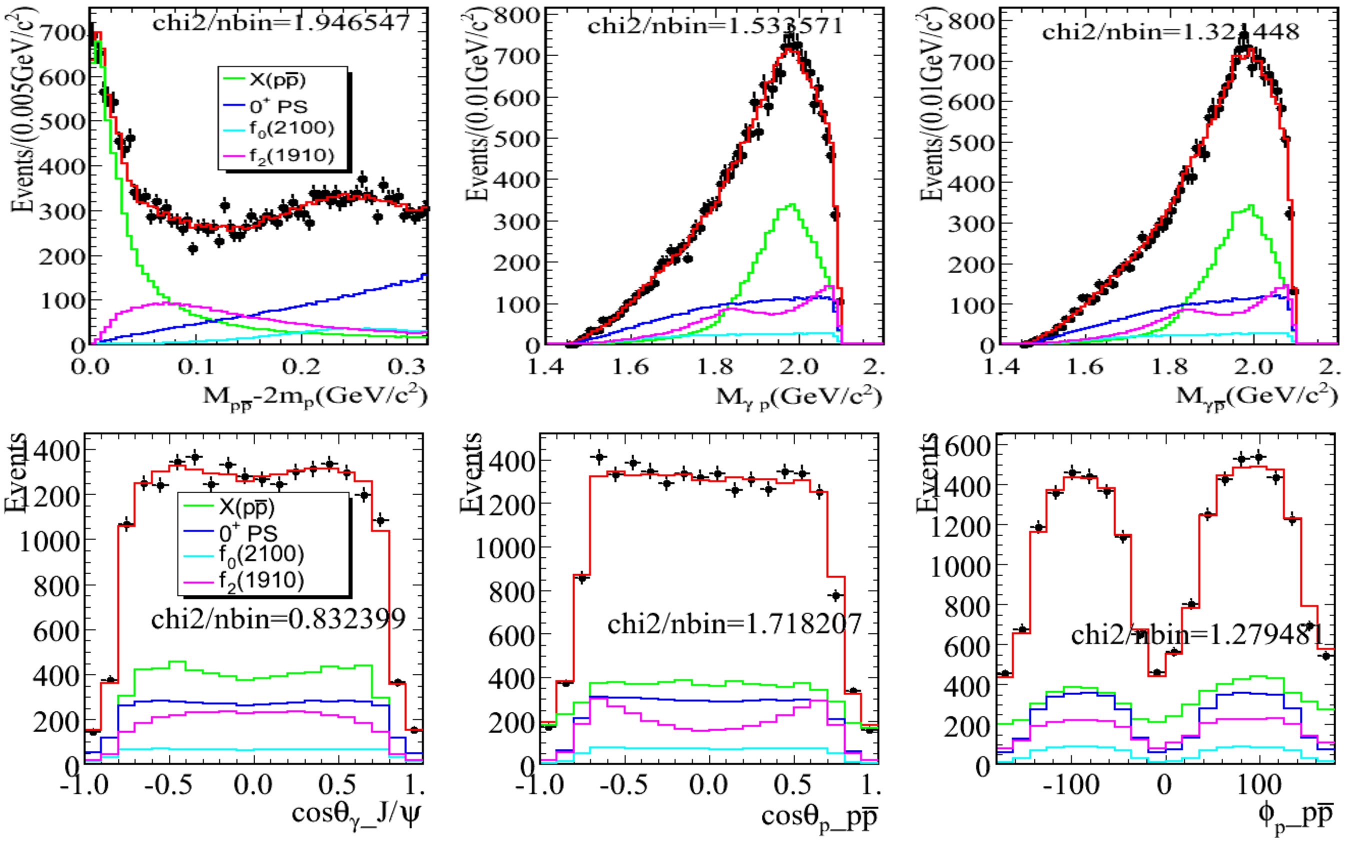
Fit $p\bar{p}$ mass threshold structure with pure FSI effect



- **It is hard to fit the $p\bar{p}$ threshold structure with pure FSI effect.**

PWA results (without FSI) of $J/\psi \to \gamma p\bar{p}$

Component	J^{PC}	M (GeV)	Γ (GeV)	Stat.sig.
$X(p\bar{p})$	0^{-+}	1.861 ± 0.001	0.001 ± 0.006	$\gg 30\sigma$
$f_0(2100)$	0^{++}	2.103	0.209	11.2σ
$f_2(1910)$	2^{++}	1.903	0.196	9.8σ
phase space	0^{++}	–	–	6.4σ



Measurement of X(pp̄) without FSI

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

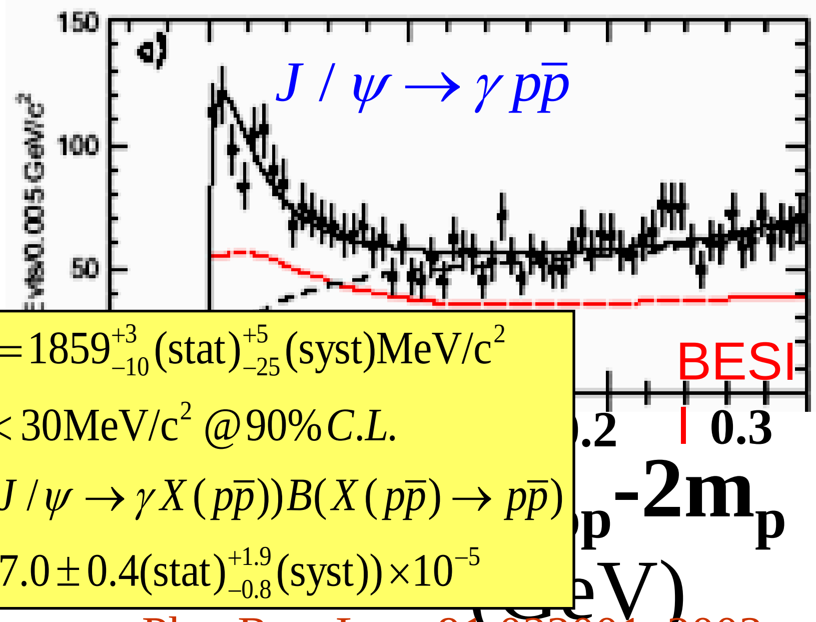
$J^{pc} = 0^{-+}$

$M = 1861 \pm 1(\text{stat})^{+12}_{-4}(\text{syst})\text{MeV}/c^2$

$\Gamma = 1 \pm 6(\text{stat})^{+16}_{-0}(\text{syst})\text{MeV}/c^2$ or $\Gamma < 29\text{MeV}/c^2$ @ 90% *C.L.*

$B(J/\psi \to \gamma X(p\bar{p}))B(X(p\bar{p}) \to p\bar{p}) = (8.6 \pm 0.3(\text{stat})^{+2.2}_{-3.1}(\text{syst})) \times 10^{-5}$

- Consistent with BESII and BESIII published results without FSI

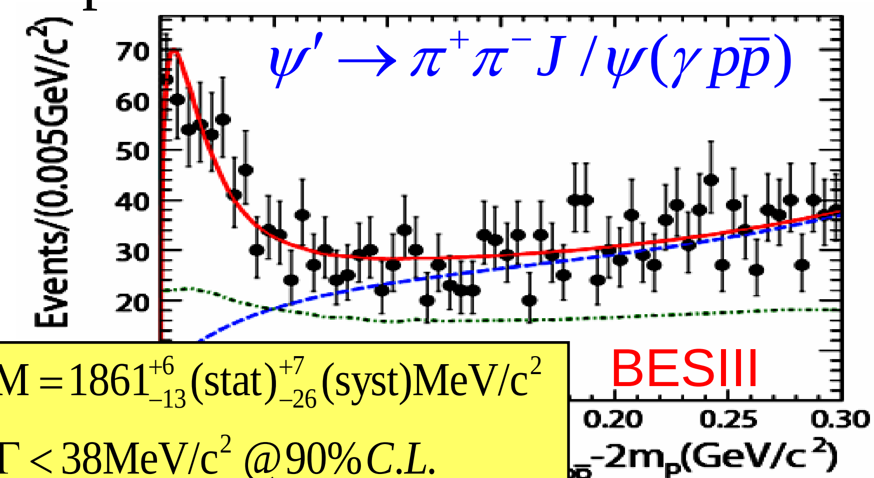


$M = 1859^{+3}_{-10}(\text{stat})^{+5}_{-25}(\text{syst})\text{MeV}/c^2$

$\Gamma < 30\text{MeV}/c^2$ @ 90% *C.L.*

$B(J/\psi \to \gamma X(p\bar{p}))B(X(p\bar{p}) \to p\bar{p})$
$= (7.0 \pm 0.4(\text{stat})^{+1.9}_{-0.8}(\text{syst})) \times 10^{-5}$

Phy. Rev. Lett. 91:022001, 2003



$M = 1861^{+6}_{-13}(\text{stat})^{+7}_{-26}(\text{syst})\text{MeV}/c^2$

$\Gamma < 38\text{MeV}/c^2$ @ 90% *C.L.*

Chinese Physics C 34:421, 2010

PWA results (without FSI) of $\psi' \to \gamma p\bar{p}$

- Significance of X(pp̄) is > 10σ.
- The production ratio R:

$$R = \frac{B(\psi' \to \gamma X(p\bar{p}))}{B(J/\psi \to \gamma X(p\bar{p}))} = (4.80 \pm 0.47(\text{stat})^{+2.20}_{-1.05}(\text{syst}))\%$$

- It is suppressed compared with “12% rule”.