New Observations on Light Hadron Spectroscopy at BESIII

Hongwei LIU

For BESIII Collaboration

Institute of High Energy Physics (IHEP)

XIV International Conference on Hadron Spectroscopy
Munich, 13- 17 June ,2011

Outline

- **Introduction**
- **$p\bar{p}$ mass threshold study in J/ψ and ψ' radiative decays**
- **Confirmation of X(1835) and observation of two new resonances in $J/\psi \to \gamma\pi^+\pi^-\eta'$**
- **Observation of the new process of**
  $$J/\psi \to \omega X(1870) \to \omega a_0(980)\pi \to \omega\eta\pi^+\pi^-$$
- **Summary**

Introduction

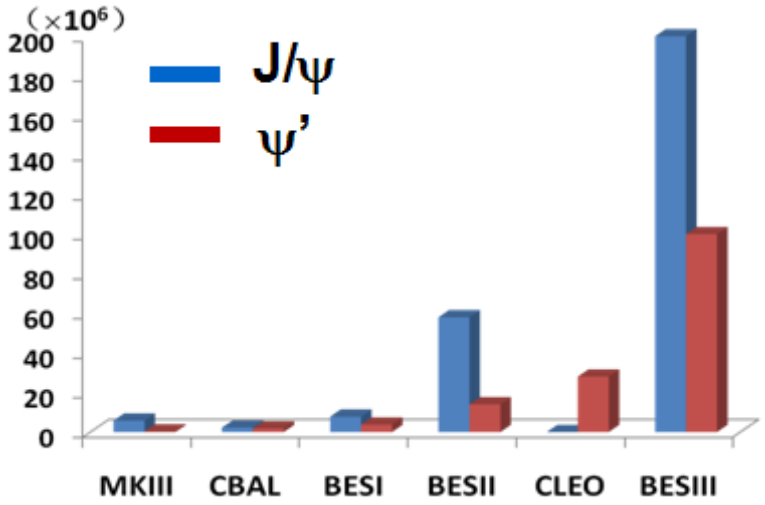
- **Multi-quark states, glueballs and hybrids have been searched for experimentally for a very long time, but none have been established.**

- **However, during the past three years, a lot of unexpected experimental evidence for hadrons cannot (easily) be explained by the conventional quark model.**

  For example, at BESII:

  - $p\bar{p}$ **threshold enhancement was observed in** $J/\psi \to \gamma p\bar{p}$
  - **X(1835) was observed in** $J/\psi \to \gamma\pi^+\pi^-\eta'$

The BEPCII/BESIII Project



Double-ring collider

Designed Luminosity: 1×10^{33} $cm^{-2}s^{-1}$

Record Luminosity : $6.5\times10^{32}cm^{-2}s^{-1}$ @3770MeV

Beginning of 2004, construction starts

Apr. 14, 2009: ~106 M ψ' events (42.3pb^{-1} at 3.65GeV)

July 28, 2009: ~225 M J/ψ events (2.9 fb^{-1} ψ(3770))

We have opportunities to confirm the existence of $p\bar{p}$ threshold enhancement and X(1835) at BESIII… and for new observations!

$p\bar{p}$ mass threshold study in J/ψ and ψ' radiative decays

$p\bar{p}$ mass threshold enhancement in

$$J/\psi \to \gamma p\bar{p}$$ @BESII,BESIII

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

no similar structures in

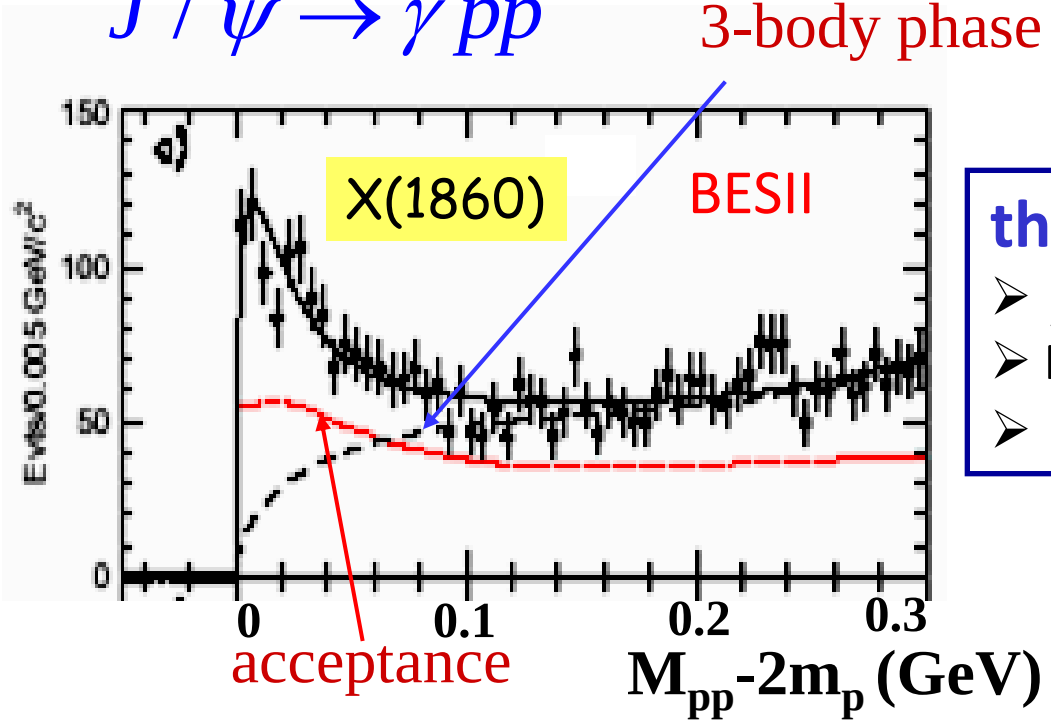
$$\psi' \to \gamma p\bar{p}$$ @BESII,BESIII

$$J/\psi \to \omega\, p\bar{p}$$ @BESII

$$\Upsilon(1S) \to \gamma\, p\bar{p}$$ @CLEO

Observation of $p\bar{p}$ mass threshold enhancement @ BESII

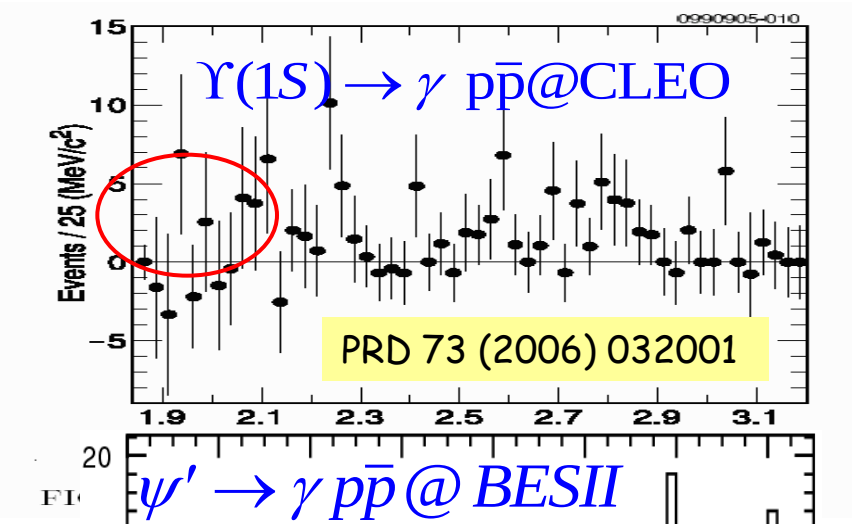
$J/\psi \to \gamma p\bar{p}$

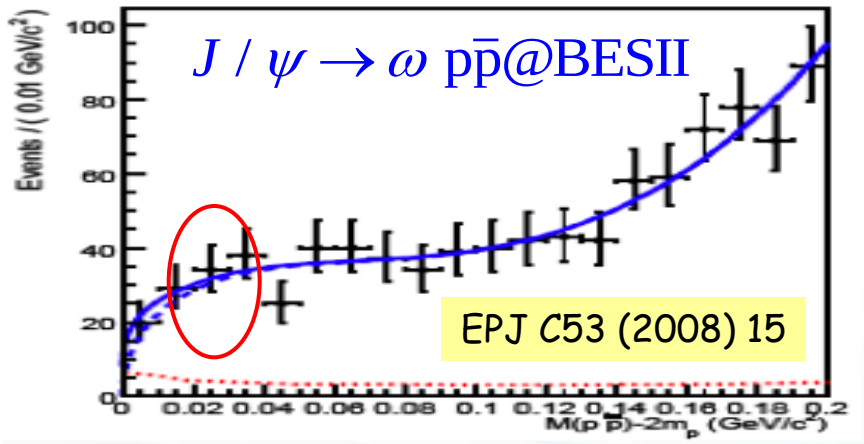


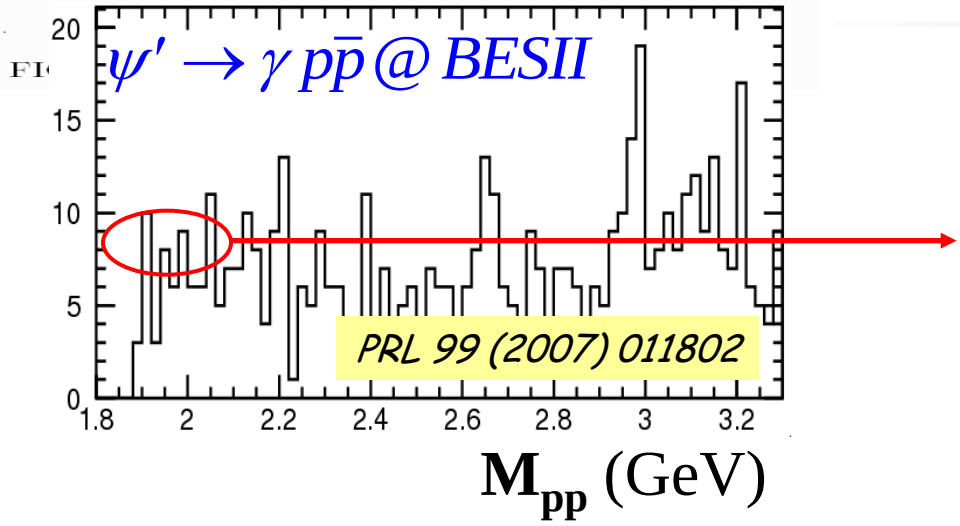
theoretical speculation:

- $p\bar{p}$ bound state (baryonium)
- FSI effect
- ……

Several non-observations



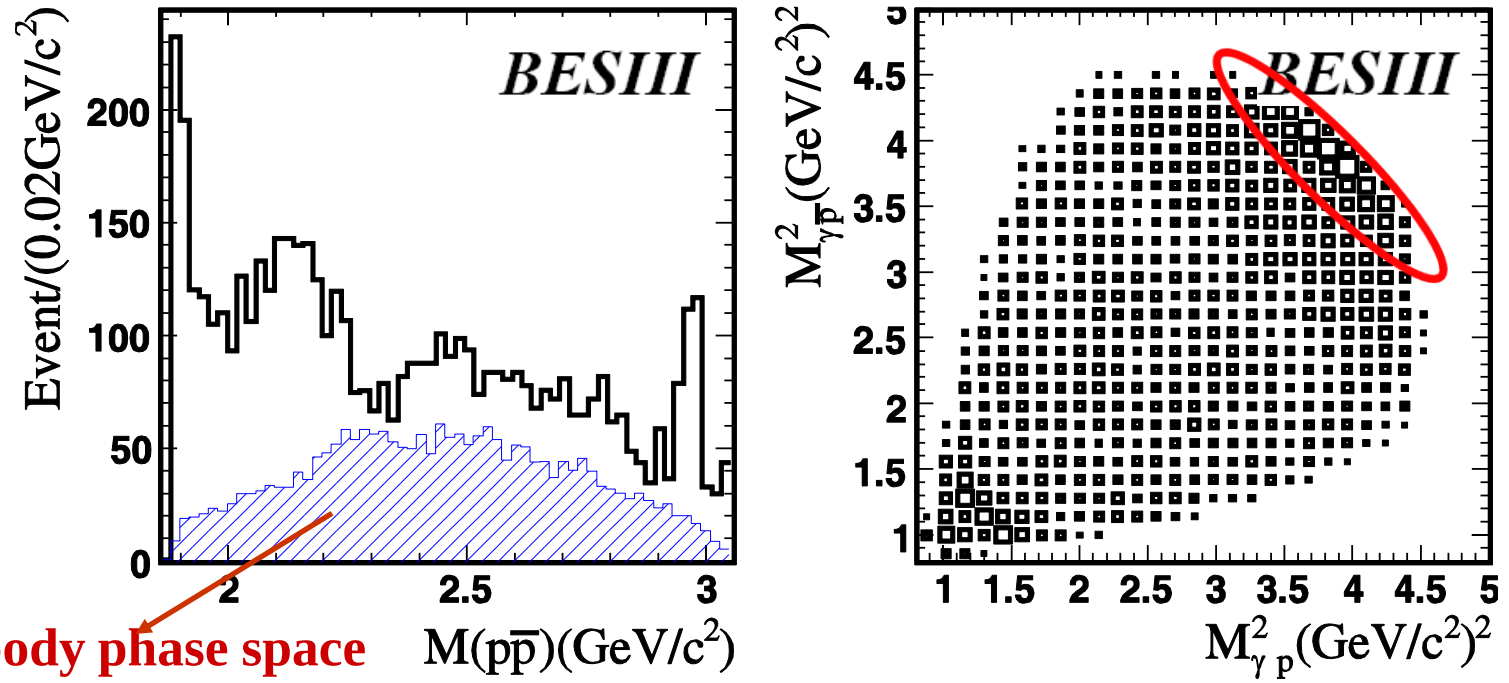




No significant narrow strong enhancement near threshold (~2σ if fitted with X(1860))

$p\bar{p}$ Mass Spectrum and Dalitz Plot

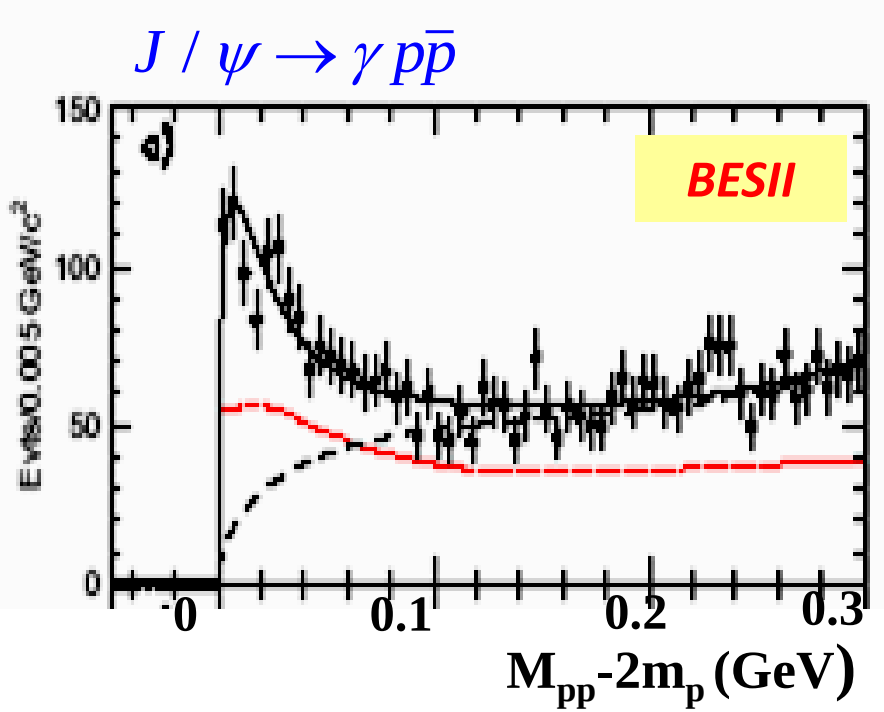
$$\psi' \to \pi^+\pi^- J/\psi, J/\psi \to \gamma p\bar{p}$$



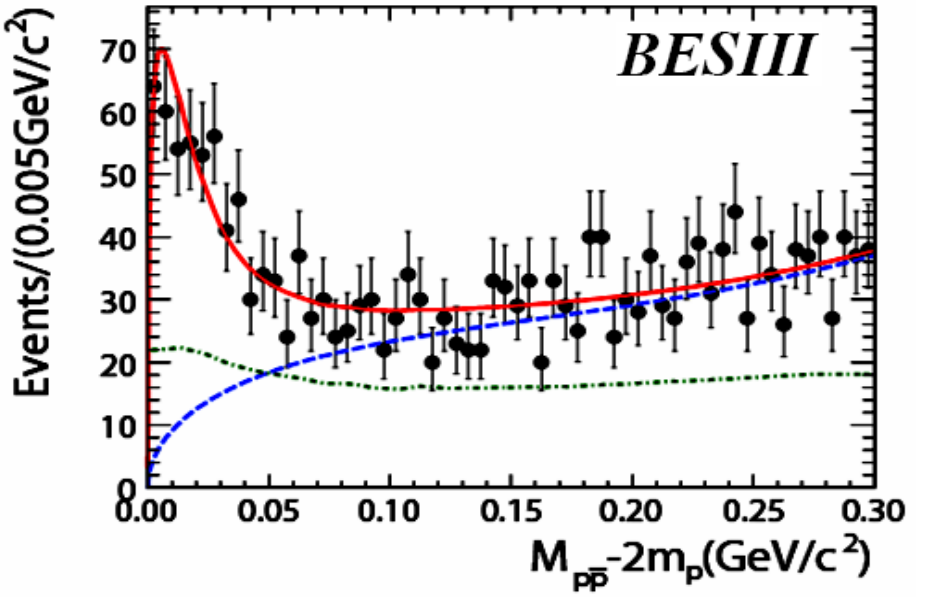
- Narrow threshold enhancement is evident in $p\bar{p}$ mass spectrum.

Mass spectrum fitting

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



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



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

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

PRL 91 (2003) 022001

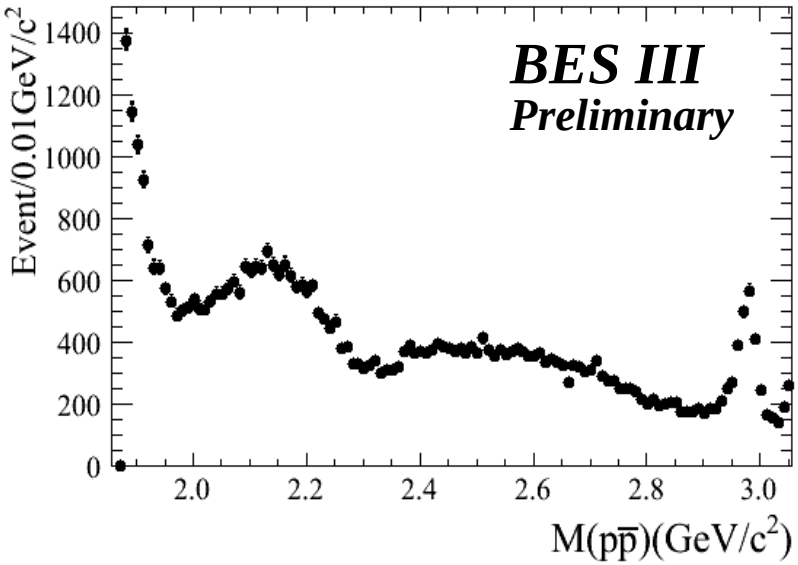
$M = 1861\ ^{+6}_{-13}\ ^{+7}_{-26}$ MeV/c^2

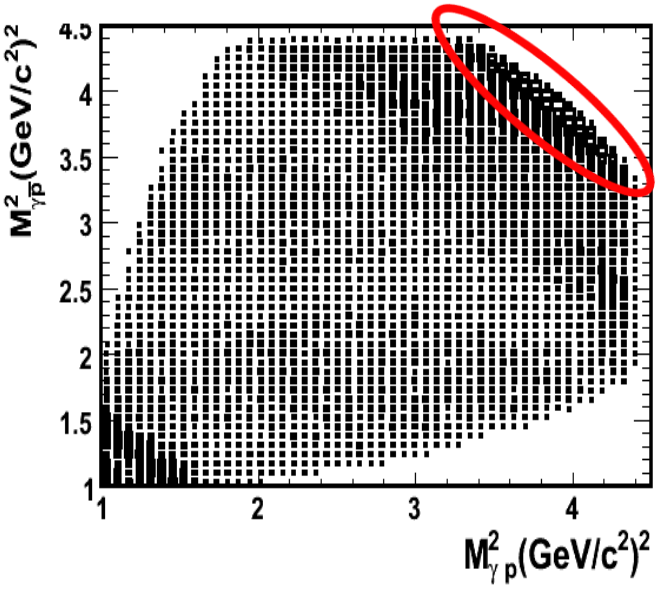
$\Gamma < 38$ MeV/c^2 (90% CL)

Chinese Physics C 34, 421 (2010)

$p\bar{p}$ invariant mass spectrum and Dalitz plot

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

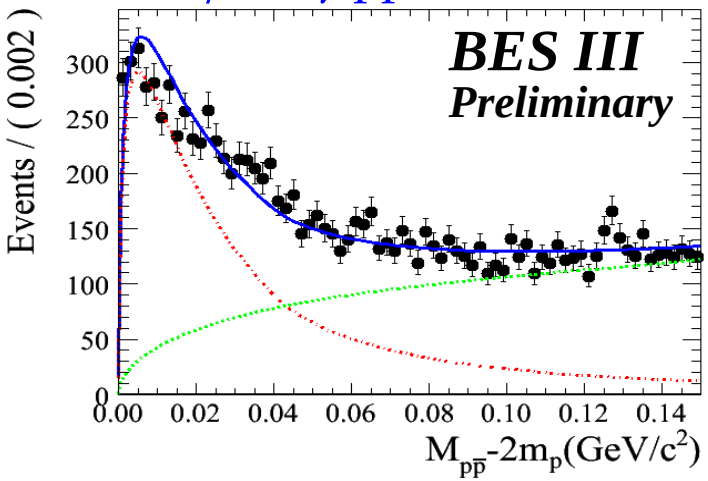




Significant narrow threshold enhancement exists

Mass spectrum fitting

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

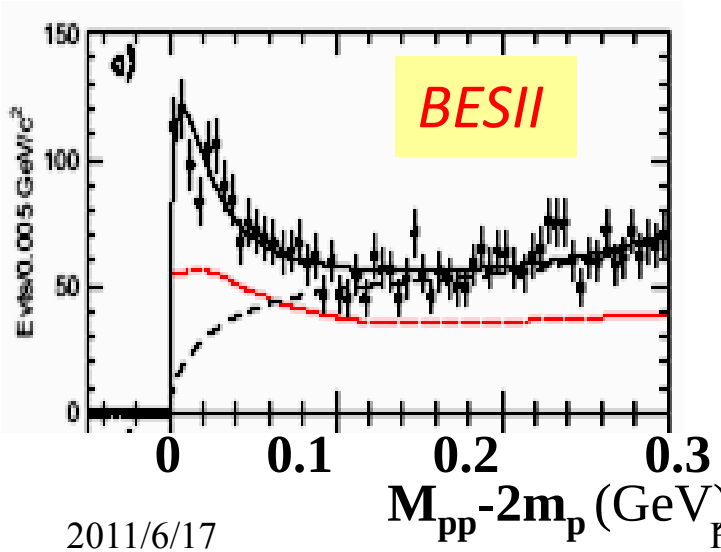


Fit result:

$\text{Mass}=1861.6 \pm 0.8 MeV/c^2$

$\Gamma < 8$ MeV(90% CL)

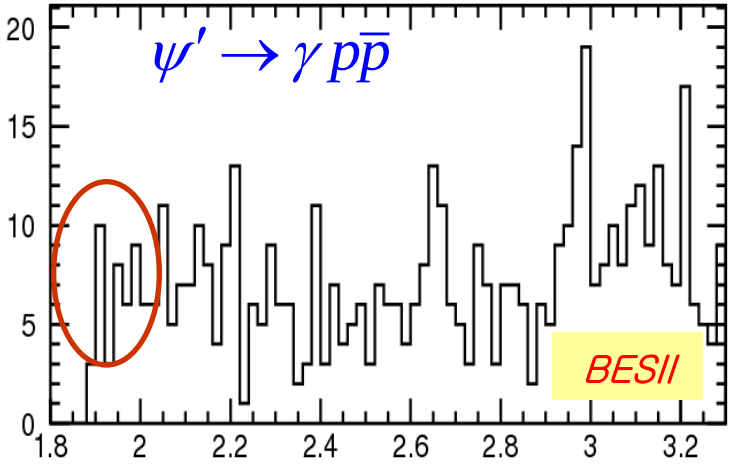
Study on more sophisticated fits, such as including FSI, is ongoing



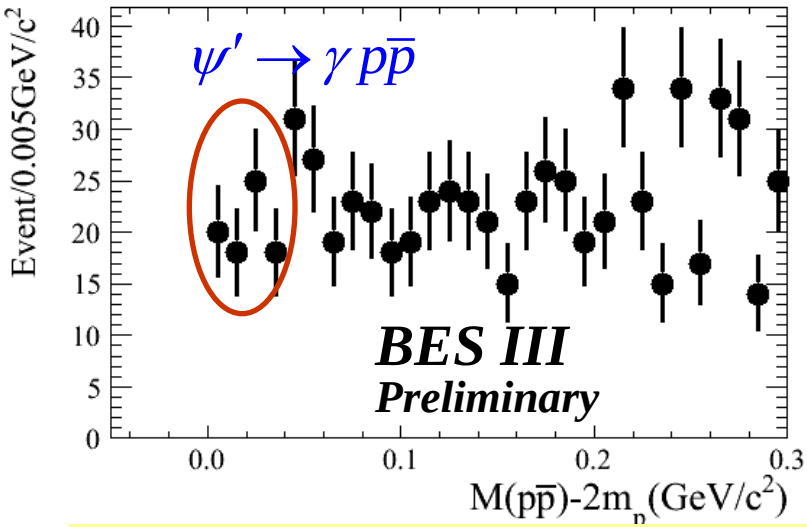
$M=1859^{+3}_{-10}{}^{+5}_{-25}$ MeV/c^2

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

$p\bar{p}$ threshold mass spectrum in ψ′ radiative decay



PRL 99 (2007) 011802



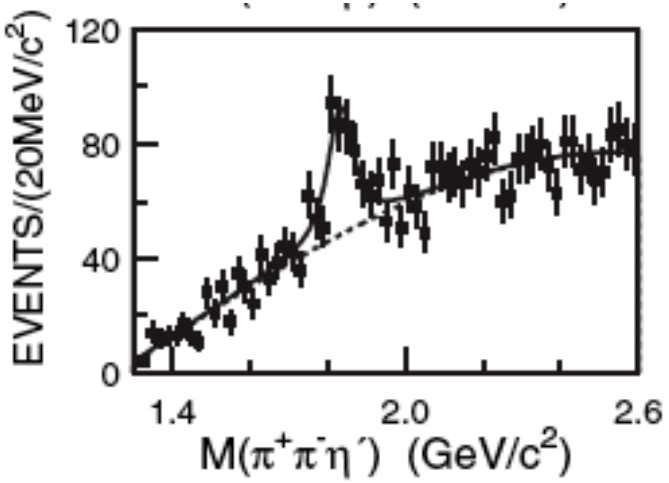
No significant narrow strong enhancement near threshold (~2σ if fitted with X(1860))

No obvious narrow threshold enhancement

Pure FSI interpretation of the narrow and strong $p\bar{p}$ threshold enhancement is disfavored.

Confirmation of X(1835) and observation of two new structures in $J/\psi \to \gamma \pi^+ \pi^- \eta'$

Observation of X(1835) in $J/\psi \to \gamma \pi^+ \pi^- \eta'$ at BESII



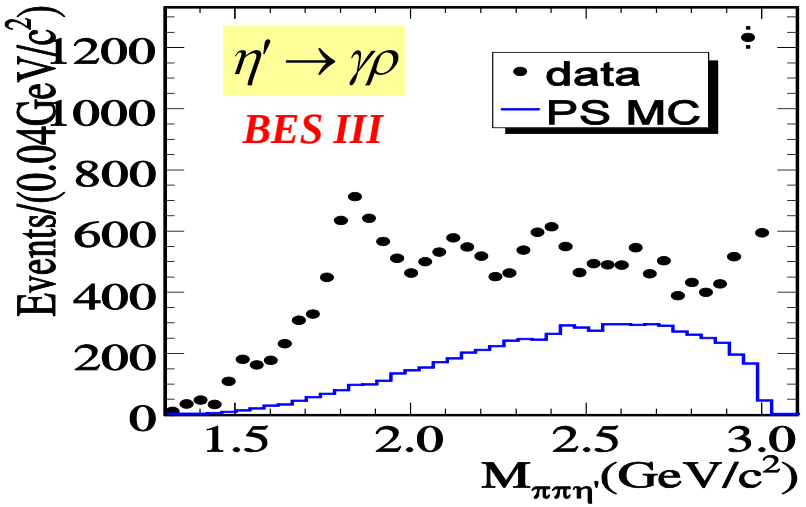
$$BESII\ result(\text{Stat. sig.} \sim 7.7\sigma):$$
$$M = 1833.7 \pm 6.1(stat) \pm 2.7(syst) MeV$$
$$\Gamma = 67.7 \pm 20.3(\text{stat}) \pm 7.7(\text{syst})\text{MeV}$$

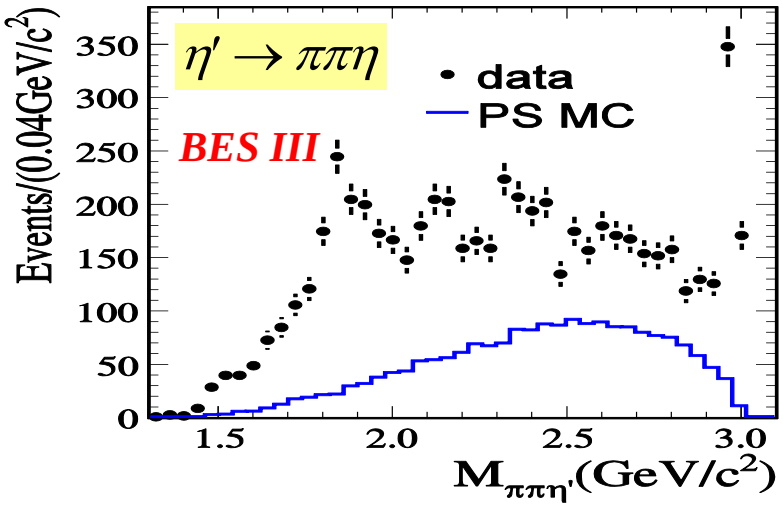
PRL 95,262001(2005)

- Confirmation of X(1835) is necessary with high statistic data sample.
- LQCD predicts the 0^{-+} glueball mass is ~2.3GeV.
- A 0^{-+} glueball may have similar property as η_c (the main η_c decay mode is $\pi\pi\eta'$).

→It is important and interesting to study $J/\psi \to \gamma\pi^+\pi^-\eta'$

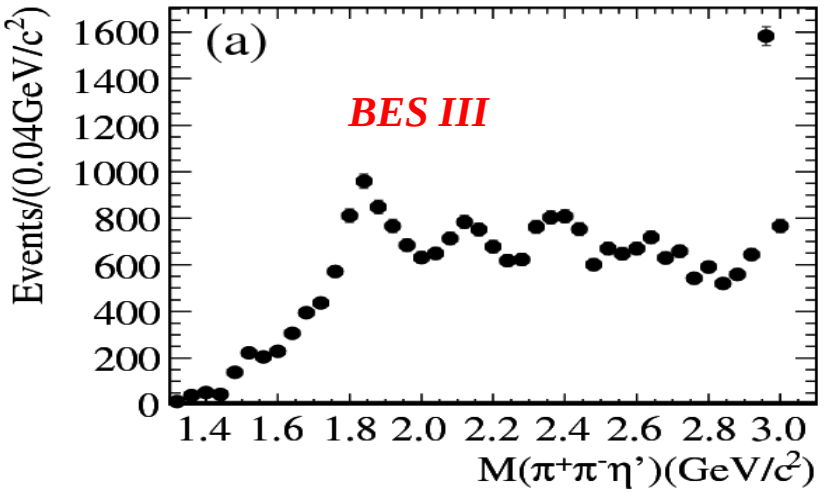
Mass spectrum of $\pi^+\pi^-\eta'$





- 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 for the combined mass spectrum

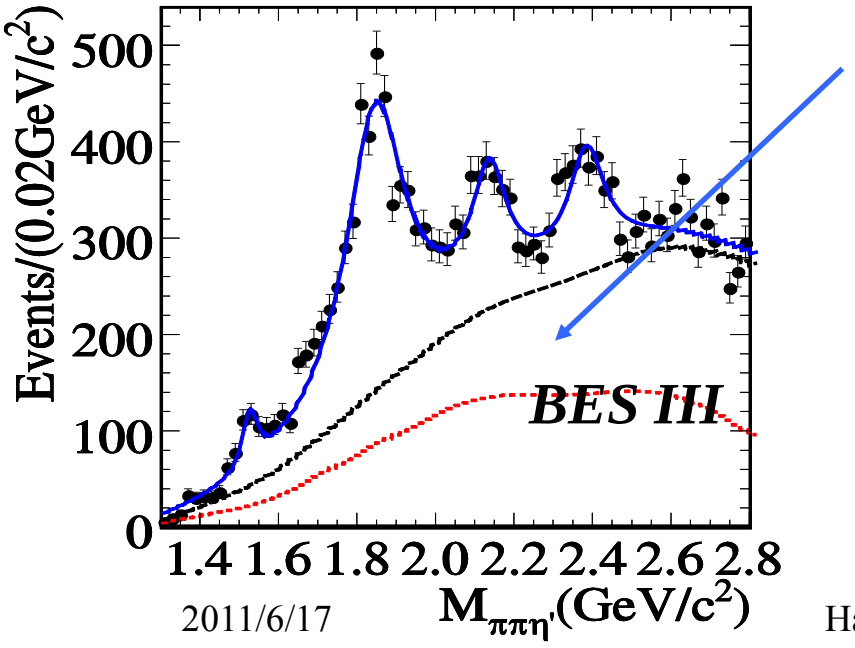
- Fitting with four resonances (acceptance weighted BW ⊗ gauss)
- Three background components:

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"

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



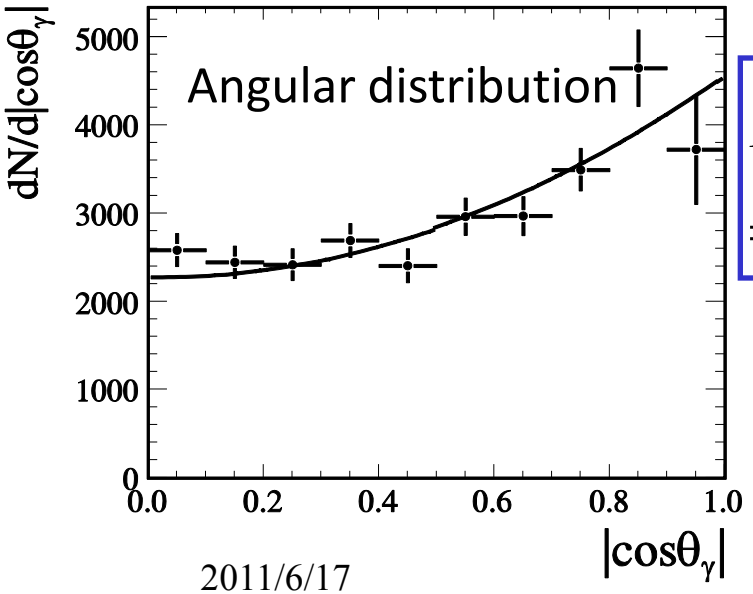
Red line: estimated contribution of ①+ ②

Black line: total background

Stat. sig. is conservatively estimated:
fit range, background shape, contribution of extra resonances

Fit results for the combined two η' decays:

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):

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

- **X(1835) resonance is confirmed at BESIII, but the width is significantly larger than that measured at BESII with one resonance in the fit.**
- **Two new resonances, X(2120) and X(2370), are observed with significances larger than 7.2σ and 6.4σ respectively.**
- **PWA is needed not only to determine the spin-parities of above three resonances, but also to make more precise measurements on masses, widths and BRs by considering possible interferences among them.**

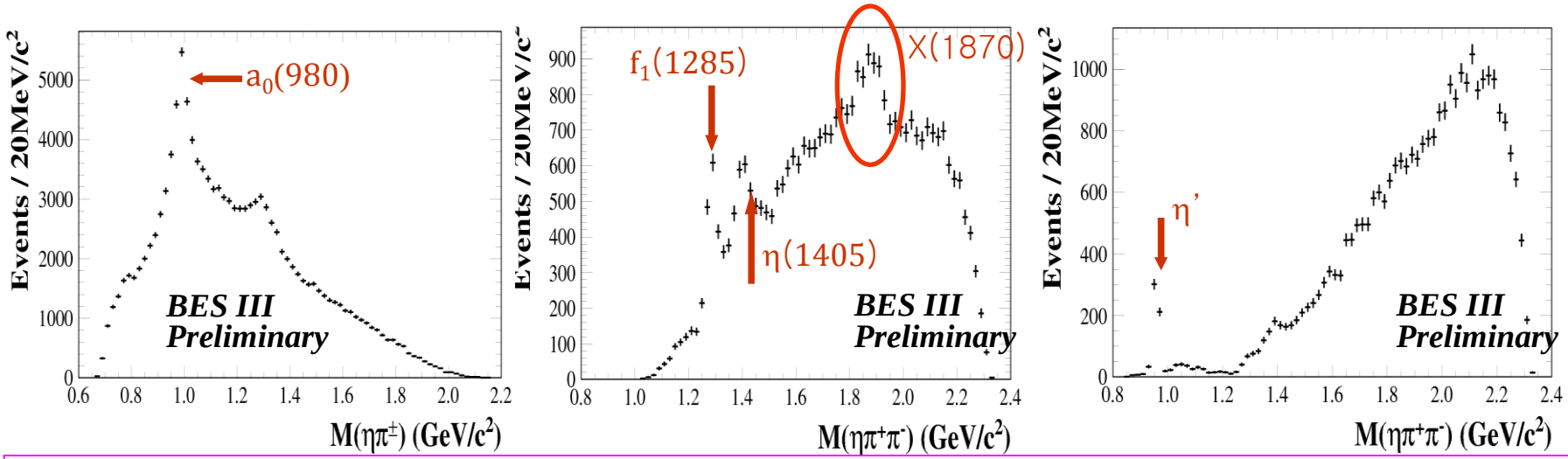
Observation of $J/\psi \to \omega X(1870) \to \omega a_0(980)\pi$

in

$J/\psi \to \omega \pi^+ \pi^- \eta$

Analysis of $J/\psi \to \omega\pi^+\pi^-\eta$ @BESIII

- **With $a_0(980)$:**
- **Veto $a_0(980)$:**

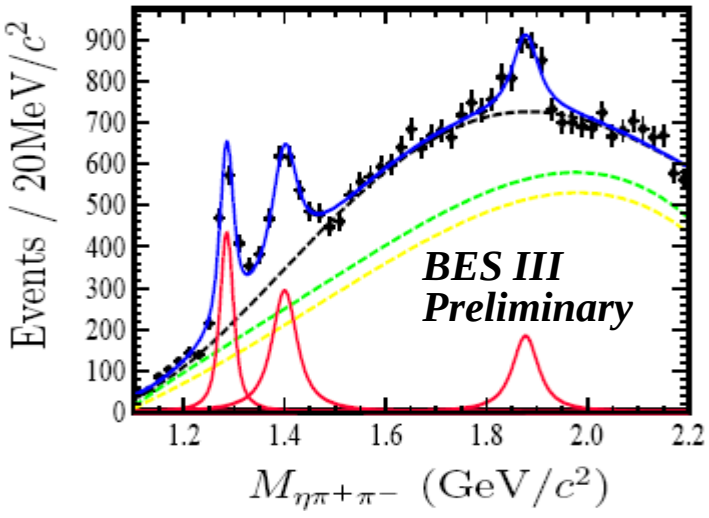


In addition to the well-known η', $f_1(1285)$ and η(1405), an unknown structure (denoted as X(1870)) around 1.87GeV/c^2 is observed.

The $f_1(1285)$, η(1405) and X(1870) primarily decay via $a_0(980)\pi^{\pm}$ mode.

Mass spectrum fitting

- 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 $\eta_2(1870)$ ($\Gamma = 225 \pm 14$ MeV/c^2), or a new resonance?

Need further study.

Summary

- $X(1860) \to p\bar{p}$ **is confirmed in J/ψ radiative decay, and no obvious similar structure was observed in ψ' radiative decay.**
- $X(1835) \to \pi^+\pi^-\eta'$ **is confirmed in** $J/\psi \to \gamma\pi^+\pi^-\eta'$**,**

  and two new resonances, X(2120) and X(2370) are observed

  with significance larger than 7.2σ and 6.4σ respectively.
- **A new process** $J/\psi \to \omega X(1870) \to \omega a_0(980)\pi$ **is observed.**
- **Whether or not the X(1860), X(1835) and X(1870) are from the same source, still needs further study.**

Thank you!

Summary on the previous experimental results

- **The strong and narrow $p\bar{p}$ mass threshold enhancement has only been observed in J/ψ radiative decay, not in any other place so far.**

- **Any model trying to interpret the mass threshold enhancement should also answer why it is not observed in other places, especially in ψ(2S) and ϒ(1S) radiative decays as well as in $J/\psi \to \omega\, p\bar{p}$ process.**

Mass spectrum fitting method

- Fit function:
  - signal: acceptance weighted S-wave BW function:

$$BW(M) \propto \frac{q^{(2l-1)}k^3}{(M^2 - M_0^2)^2 + M^2\Gamma^2}$$

    - q : the proton momentum in CMS of ppb
    - k : the photon momentum
    - k: the ppb orbital angular momentum

  - background shape: $f_{bkg}(\delta) = \delta^{1/2} + a_1\delta^{3/2} + a_2\delta^{5/2}$

a_1 and a_2 are obtain from a fit to an uniform phase space MC sample

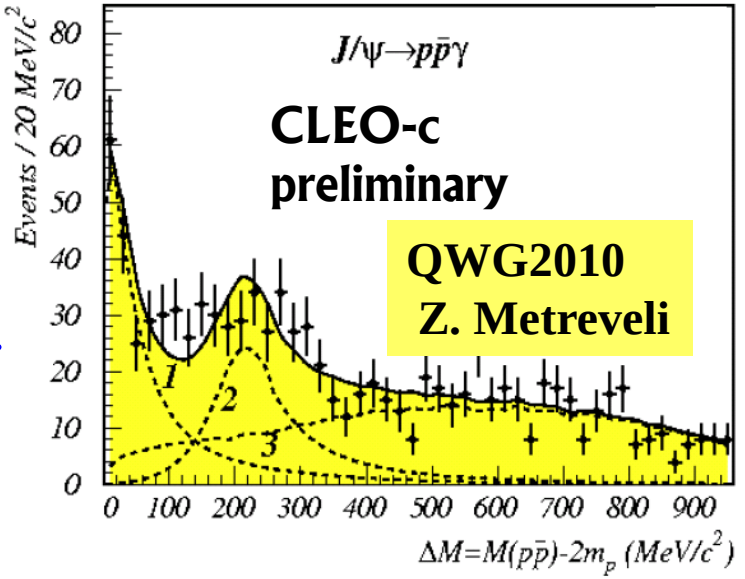
$p\bar{p}$ threshold enhancement @ CLEOc

- **CLEO-c does fit the same as BES and obtains:**

$M(R_{thr}) = 1861^{+6}_{-16}$ (MeV), $\Gamma(R_{thr}) = 0^{+32}_{-0}$ (MeV),

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

agrees with BESII results [PRL91(2003)022011].



- **CLEO-c fits with three contributions:**

$R_{thr} + f_0(2100) + PS$
(1) (2) (3)

$M(R_{thr}) = 1837^{+10}_{-12}{}^{+9}_{-7}$ (MeV),

$\Gamma(R_{thr}) = 0^{+44}_{-0}$ (MeV), CL = 26.1%

$B_1(J/\psi\to\gamma R_{thr}) \times B_2(R_{thr}\to p\bar{p}) = (11.4^{+4.3}_{-3.0}{}^{+4.2}_{2.6}) \times 10^{-5}$

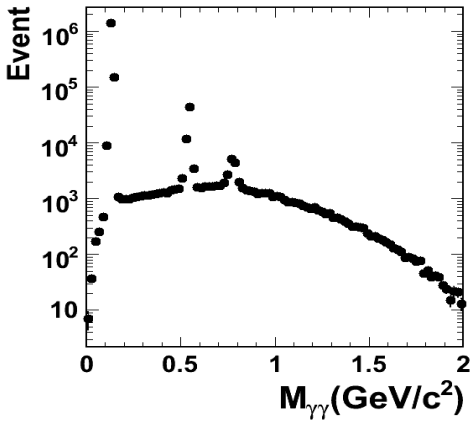
The central value of the mass is close to the sub-threshold resonance mass reported by BES with M(R) = 1833.7±6.1±2.7 (MeV), observed in $J/\psi\to\gamma R$, $R\to\pi^+\pi^-\eta'$ [PRL 95 (2005) 262001].

BES considered these (2) and (3) as systematic errors.

Event selection for $J/\psi \to \gamma\pi^+\pi^-\eta'(\eta' \to \gamma\rho, \rho \to \pi^+\pi^-)$

- Initial selection criteria：
  - $N_{charged}$=4， N_γ>=2
  - N_π>2
  - Kinematic fit(4C):
    $\chi^2_{4C}(\gamma\gamma\pi^+\pi^-\pi^+\pi^-)$<40

    $\chi^2_{4C}(\gamma\gamma\pi^+\pi^-\pi^+\pi^-) < \chi^2_{4C}(\gamma\gamma K^+K^-\pi^+\pi^-)$



$J/\psi \to \pi^0\pi^+\pi^-\pi^+\pi^-$

$J/\psi \to \eta\pi^+\pi^-\pi^+\pi^-$

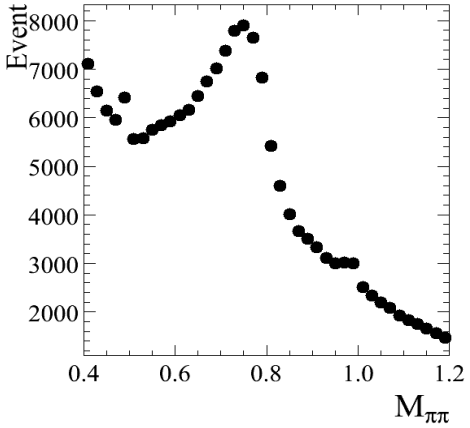
$J/\psi \to \omega\pi^+\pi^-\pi^+\pi^-(\omega \to \gamma\pi^0)$

- Final selection criteria：
  - Reduce background from $\pi^0\pi^+\pi^-\pi^+\pi^-$:

    $\left|m_{\gamma\gamma} - m_\pi\right| < 0.04GeV$

    $\left|m_{\gamma\gamma} - m_\eta\right| < 0.03GeV$

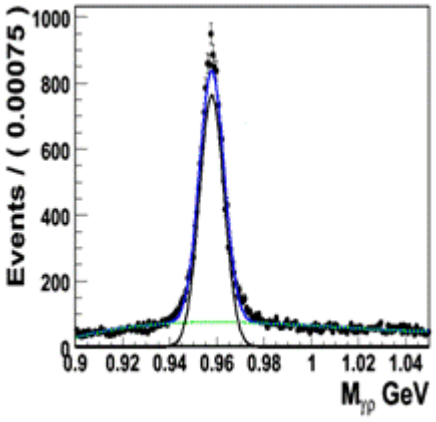
    $0.72GeV < m_{\gamma\gamma} < 0.82GeV$



  - Selection for $\rho$and η' signal:

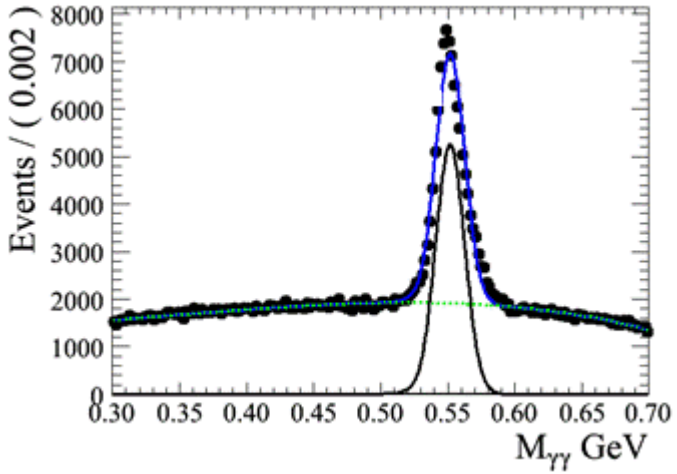
    $|M_{\pi\pi} - m_\rho| < 0.2GeV$

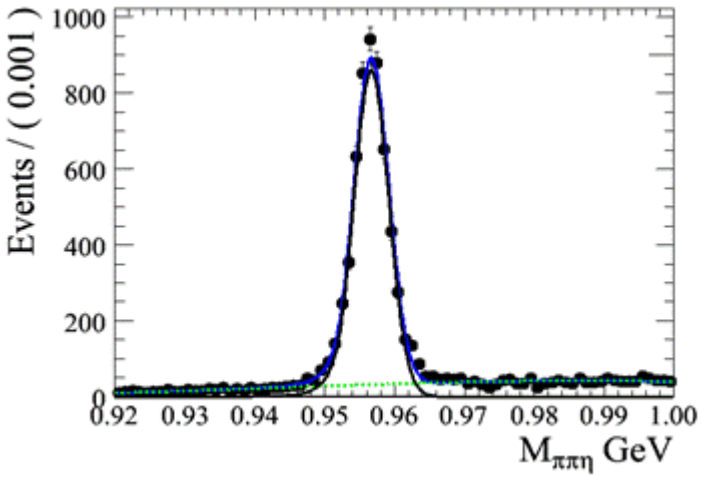
    $|M_{\gamma\rho} - m_{\eta'}| < 0.018GeV$



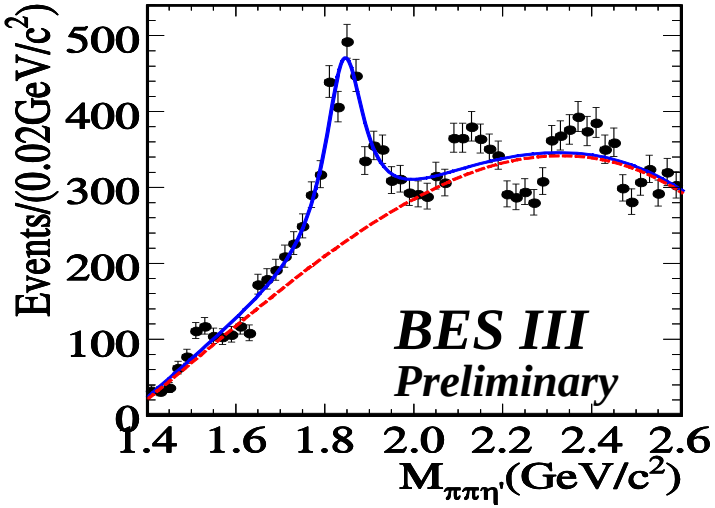
Event selection for $J/\psi \to \gamma\pi^+\pi^-\eta'(\eta' \to \pi^+\pi^-\eta)$

- Initial selection criteria：
  - $N_{charged}$=4， N_γ>=2
  - N_π>2
  - Kinematic fit(4C,5C):
    $\chi^2_{4C}(\gamma\gamma\gamma\pi^+\pi^-\pi^+\pi^-)$<40
    $\chi^2_{5C}(\gamma\eta\pi^+\pi^-\pi^+\pi^-)$<40
- Final selection criteria：
  - selection for η and η' signal:
    $|M_{\gamma\gamma} - m_\eta| < 0.03\text{GeV}$
    $|M_{\pi\pi\eta} - m_{\eta'}| < 0.01\text{GeV}$



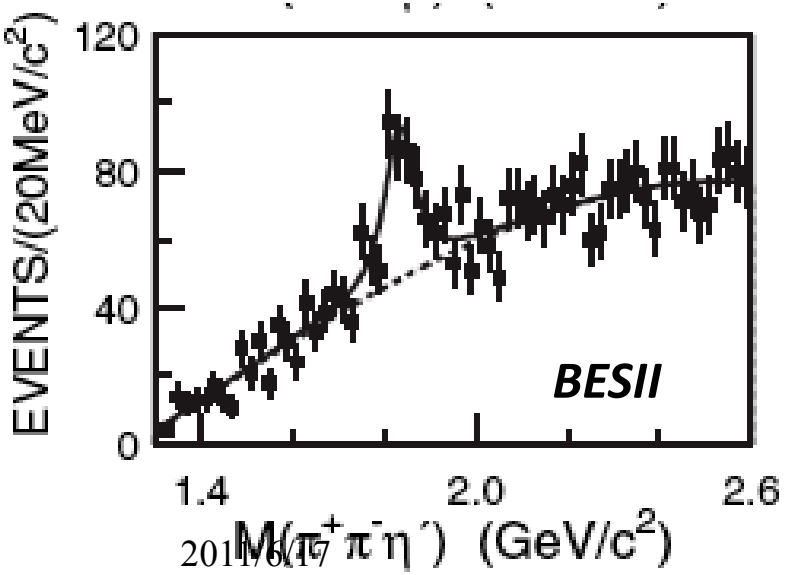


Fitting for the combined mass spectrum



Fitting with one resonance as BESII

$$Fit\ result(\text{Stat. sig.}\sim 20\sigma):$$
$$M = 1839.9 \pm 3.0(stat)MeV$$
$$\Gamma = 104.5 \pm 10.5(stat)MeV$$

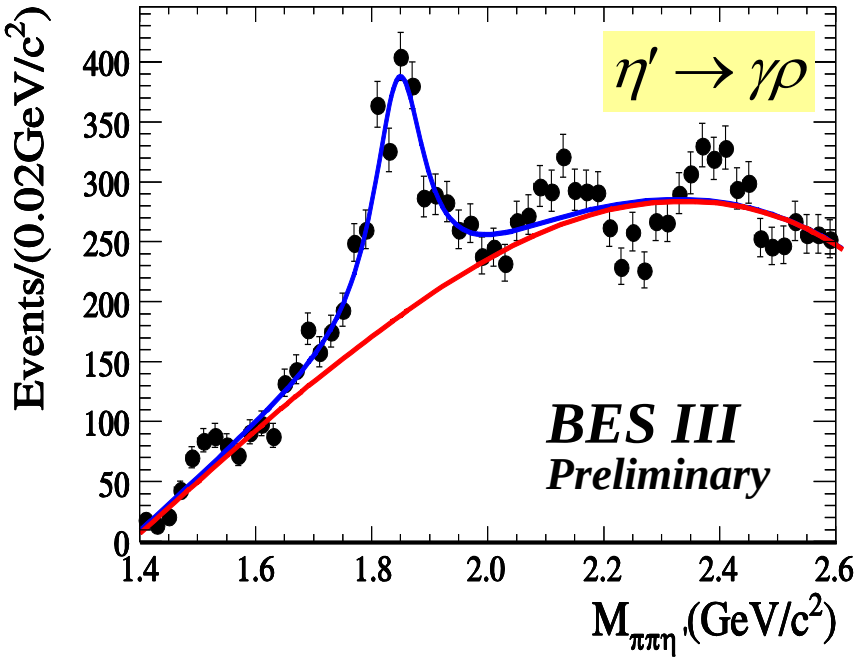


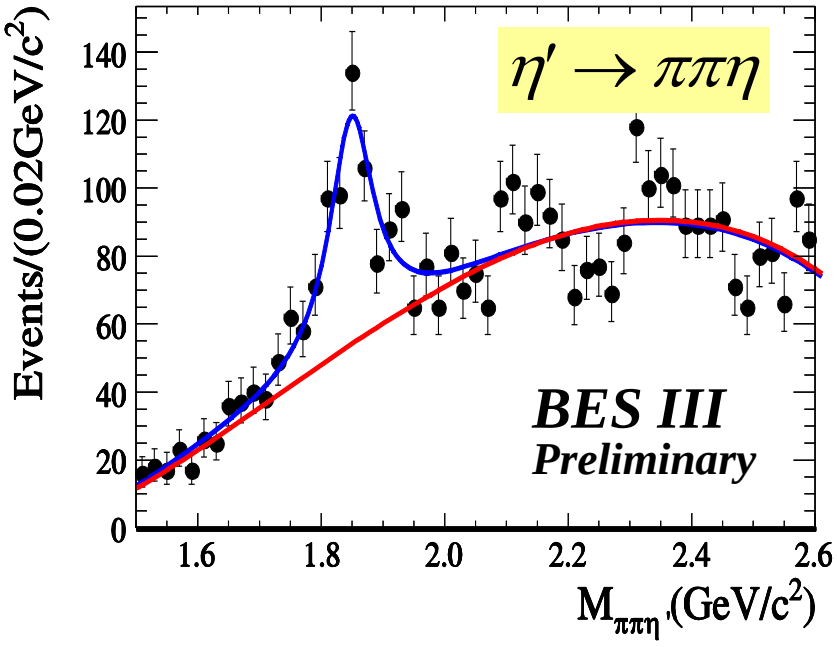
$$BESII\ result(\text{Stat. sig.} \sim 7.2\sigma):$$
$$M = 1836.5 \pm 3.0(stat)^{+5.6}_{-3.1}(syst)MeV$$
$$\Gamma = 190 \pm 9(\text{stat})^{+38}_{-36}(\text{syst})\text{MeV}$$

X(1835) confirmed by BESIII

Mass spectrum of $\pi^+\pi^-\eta'$

Fit with one resonances + polynomial background:



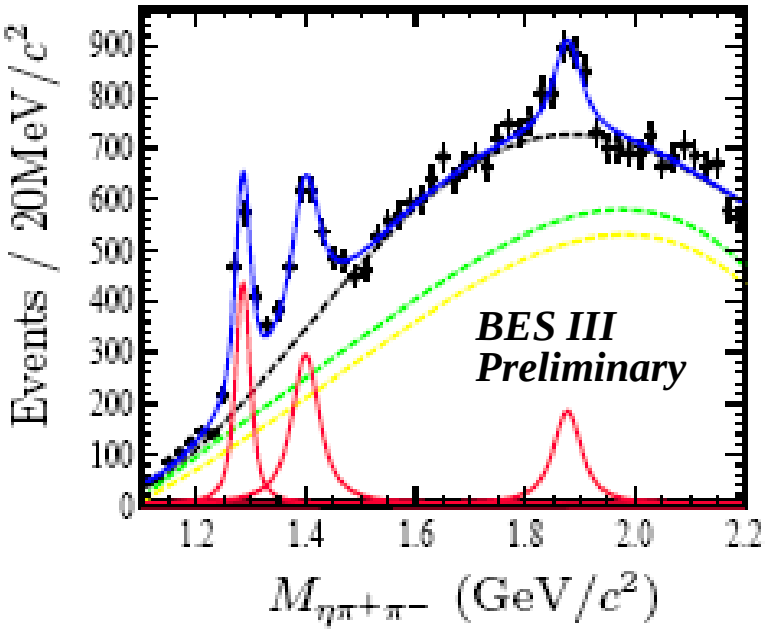


Stat. sig. ~18σ

Stat. sig. ~9σ

Mass spectrum fitting

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

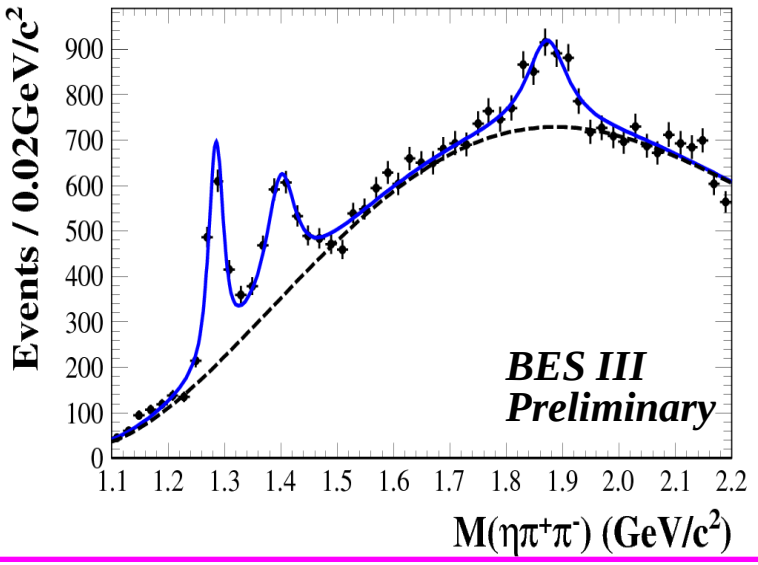


Resonance	Mass (MeV/c^2)	Width (MeV/c^2)	Branch ratio (10^{-4})
$f_1(1285)$	$1285.1 \pm 1.0^{+1.6}_{-0.3}$	$22.0 \pm 3.1^{+2.0}_{-1.5}$	$1.25 \pm 0.10^{+0.19}_{-0.20}$
$\eta(1405)$	$1399.8 \pm 2.2^{+2.8}_{-0.1}$	$52.8 \pm 7.6^{+0.1}_{-7.8}$	$1.89 \pm 0.21^{+0.21}_{-0.23}$
$X(1870)$	$1877.3 \pm 6.3^{+3.4}_{-7.4}$	$57 \pm 12^{+19}_{-4}$	$1.50 \pm 0.26^{+0.72}_{-0.36}$

Study of Background component is ongoing

Mass spectrum fitting

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



$$Fit\ result\ (stat.\ sig.\sim 7.2\sigma)$$
$$M = 1877.3 \pm 6.3 MeV$$
$$\Gamma = 57 \pm 12 MeV$$
$$BR = (1.50 \pm 0.26) \times 10^{-4}$$

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 $\eta_2(1870)$ ($\Gamma = 225 \pm 14$ MeV/c^2), or a new resonance, needs further study.