Study of Light Hadron Spectroscopy at BESIII

19th Particles & Nuclei International Conference

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(for BESIII collaboration)
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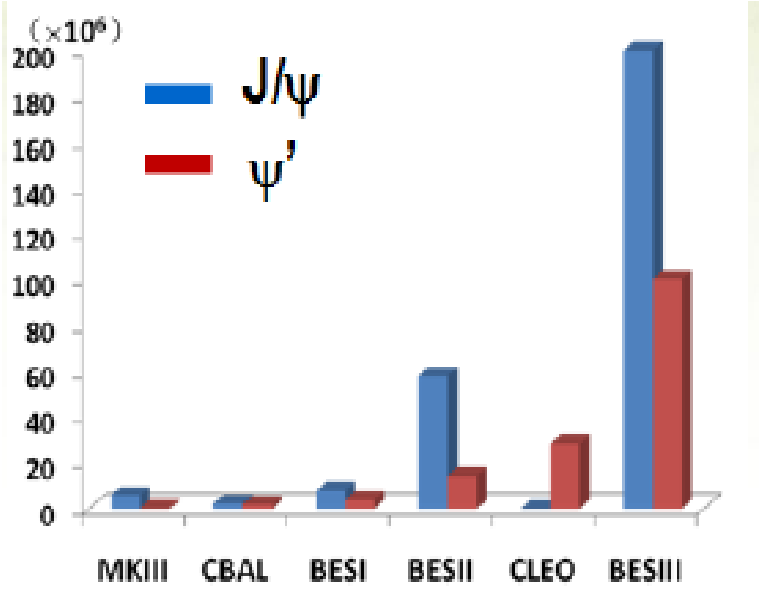
BESIII @ BEPCII



Double-ring collider

Designed Luminosity: $1\times10^{33}cm^{-2}s^{-1}$

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

Now, BESIII has the most J/ψ and ψ′ events:

April 14, 2009: ~ 106 M ψ′ events

July 28, 2009: ~ 225 M J/ψ events

We have the opportunity to investigate:

Light hadron, Charmonium physics, Charm physics, Tau and QCD.

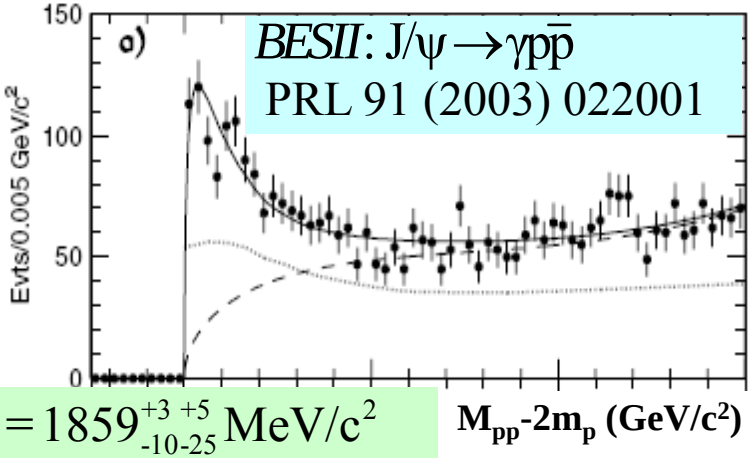
Remarks on light hadron spectroscopy

- QCD predicts the new forms of hadrons:
  - Multi-quarks: Number of quarks>=4
  - Hybrids: qqg, qqqg, …
  - Glueballs: gg, ggg, …
- None have been well established.
- Hadrons cannot (easily) be explained by conventional quark model:
  - $p\bar{p}$ threshold enhancement in $J/\psi \rightarrow \gamma\, p\bar{p}$
  - X(1835) observed in $J/\psi \rightarrow \gamma X, X \rightarrow \eta' \pi^+ \pi^-$
  - $a_0(980)$, $f_0(980)$

Outline

- Confirmation and new observations on light hadron spectroscopy
  - $p\bar{p}$ mass threshold study in the radiative decays of J/ψ
  - Confirmation of X(1835) and observation of two new resonances in $J/\psi \rightarrow \gamma\eta'\pi^+\pi^-$
  - Observation of X(1870) in $J/\psi \rightarrow \omega\eta\pi^+\pi^-$
- Study of light scalar mesons
  - Direct measurements of $a_0(980)$-$f_0(980)$ mixing via $J/\psi \rightarrow \phi f_0 \rightarrow \phi a_0$ and $\chi_{c1} \rightarrow a_0\pi^0 \rightarrow f_0\pi^0$
- Summary

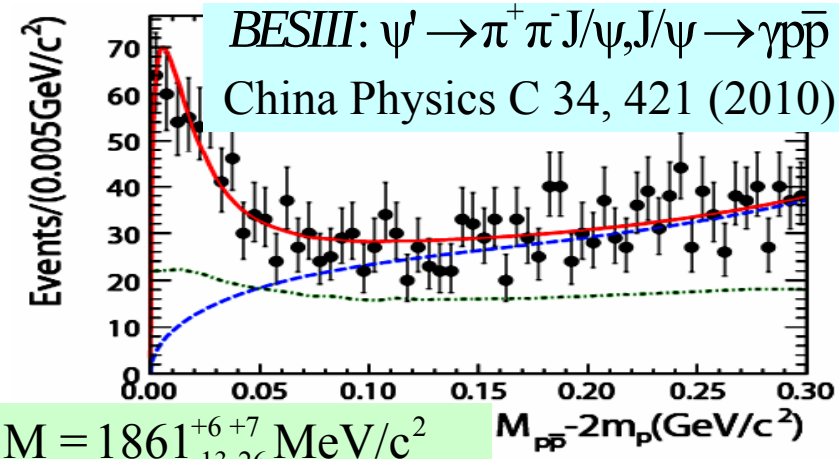
$p\bar{p}$ threshold study in J/ψ radiative decays



BESII: $J/\psi \rightarrow \gamma p\bar{p}$
PRL 91 (2003) 022001

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

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

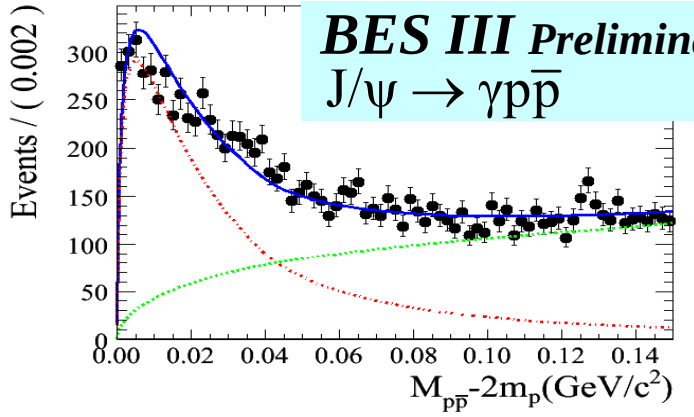


BESIII: $\psi' \rightarrow \pi^+\pi^- J/\psi, J/\psi \rightarrow \gamma p\bar{p}$
China Physics C 34, 421 (2010)

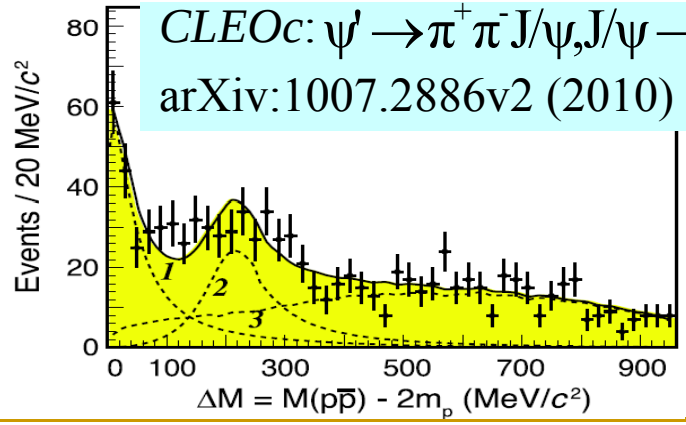
$M = 1861^{+6\ +7}_{-13-26}\ \mathrm{MeV/c^2}$

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

- **Observed at BESII in 2003**
- **Confirmed by CLEOc and BESIII**
- **Agree with BESII results**

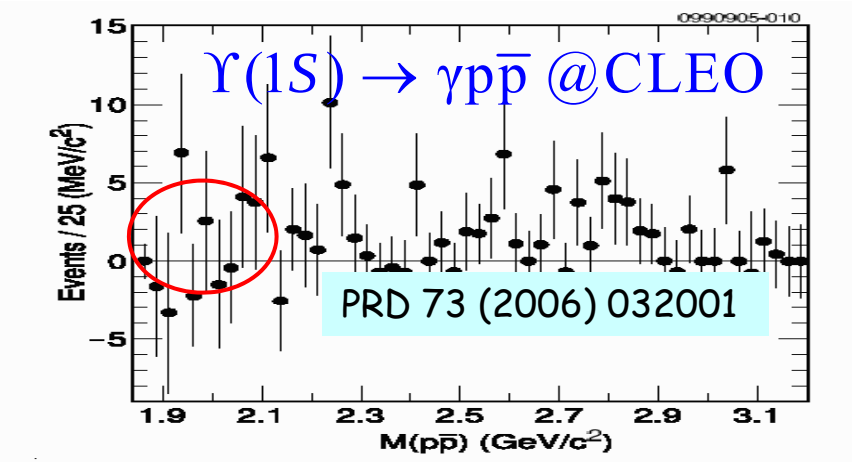


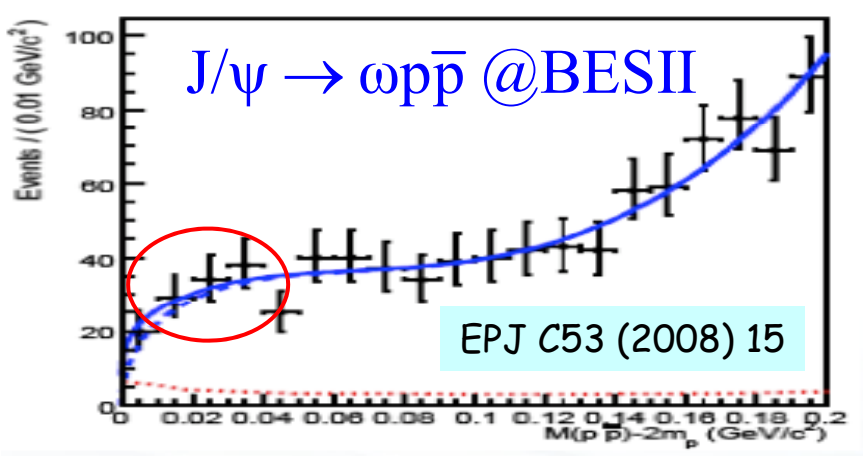
BES III Preliminary
$J/\psi \rightarrow \gamma p\bar{p}$

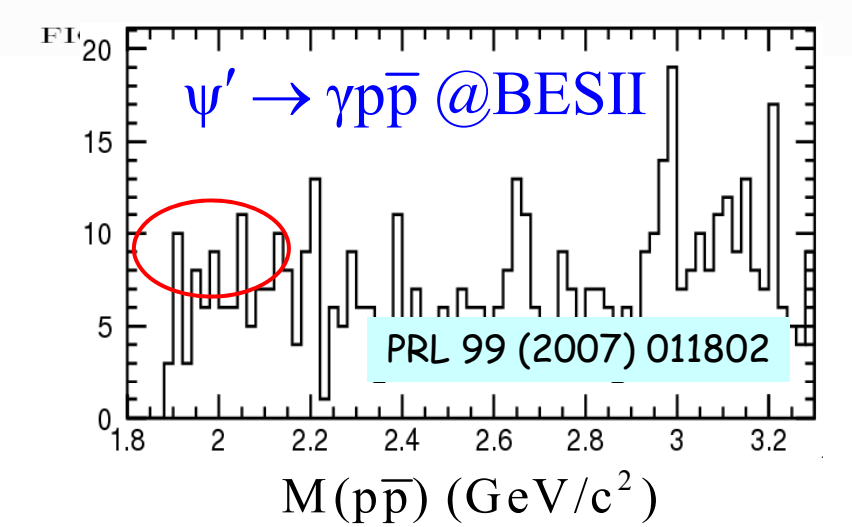


CLEOc: $\psi' \rightarrow \pi^+\pi^- J/\psi, J/\psi \rightarrow \gamma p\bar{p}$
arXiv:1007.2886v2 (2010)

Several non-observations

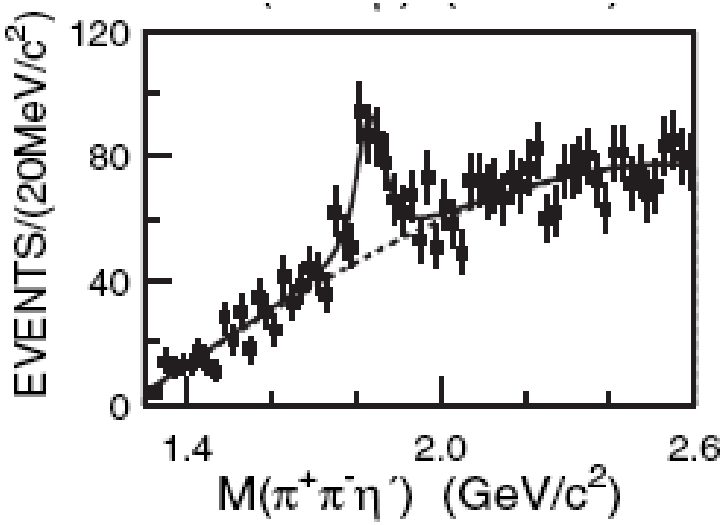






- No significant narrow strong enhancement near threshold.
- Pure FSI interpretation of the narrow and strong ppbar threshold enhancement is disfavored.
- Other possibilities: ppbar bound state or glueball ...?

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



BESII result (Stat. sig. ~ 7.7σ):

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

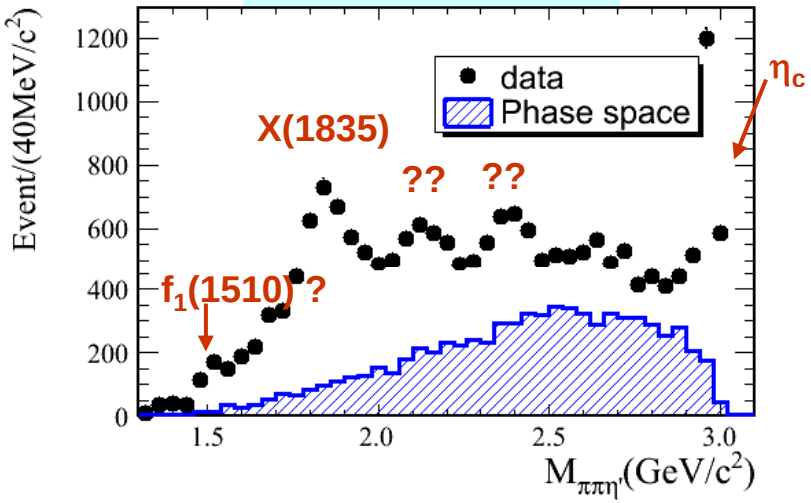
$$\Gamma = 67.7 \pm 20.3(\text{stat}) \pm 7.7(\text{syst}) \text{MeV}$$

PRL 95,262001(2005)

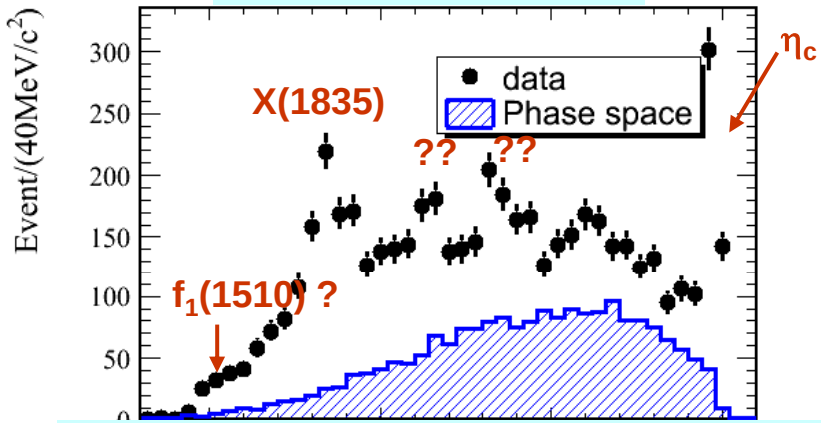
- Theoretical interpretations: $p\bar{p}$ bound state / radial excitation of η'?
- Confirmation of X(1835) is necessary with higher statistics data sample and better detector at BESIII.
- A 0^{-+} glueball may have similar property as η_c (the main η_c decay mode is $\pi\pi\eta'$).
- LQCD predicts the 0^{-+} glueball mass is ~2.3GeV.
- Search for possible structures in $J/\psi \rightarrow \gamma\eta'\pi^+\pi^-$ with higher statistics data sample and better detector at BESIII.

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

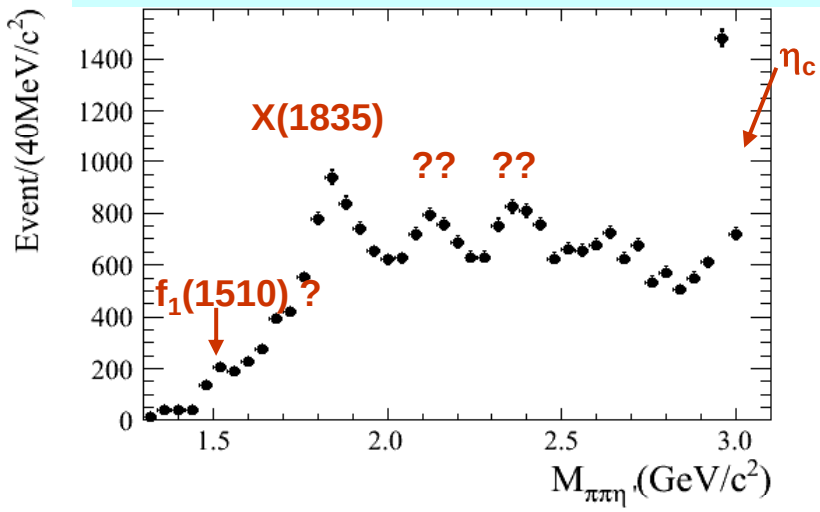
$\eta' \to \gamma\rho$ @BESIII



$\eta' \to \pi^+\pi^-\eta$ @BESIII



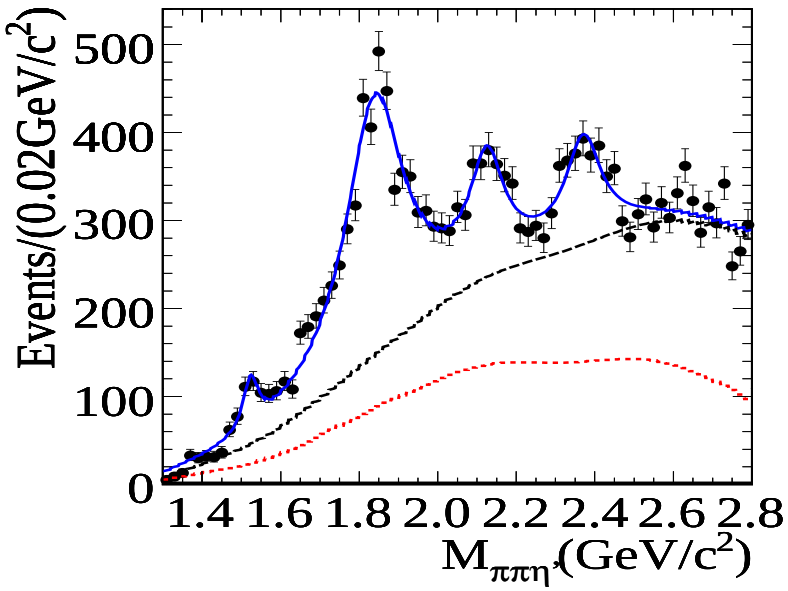
Combination for η' to $\pi^+\pi^-\eta$ and $\gamma\rho$



- X(1835) and η_c is significant.
- Two additional structures at 2.1GeV (denoted as X(2120)) and 2.3GeV (denoted as X(2370)) are observed.
- There maybe some $f_1(1510)$.

Fitting of 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 $J/\psi \rightarrow \pi^0\pi^+\pi^-\eta'$ with re-weighting method
  3. Contribution from "PS background"



PRL 106, 072002 (2011)

Red line: estimated contribution of 1.+ 2.

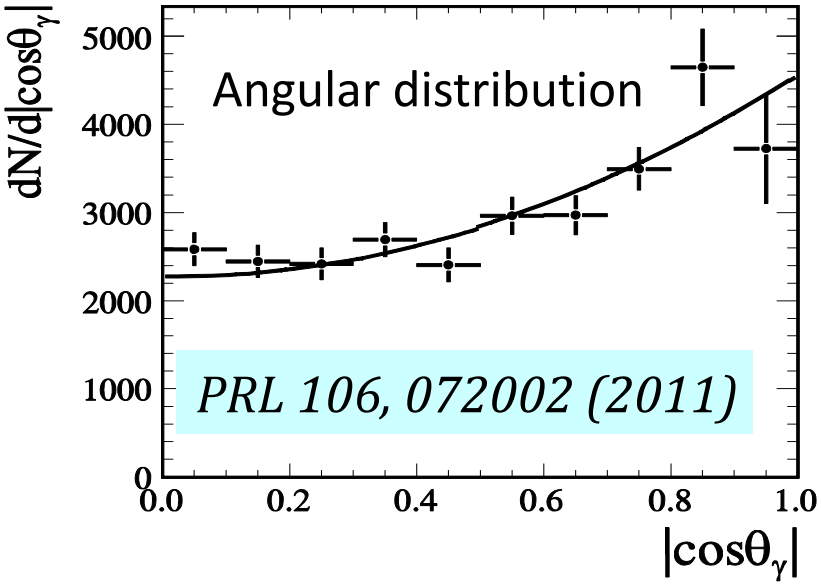
Black line: total background

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)	$1836.5 \pm 3.0^{+5.6}_{-2.1}$	$190 \pm 9^{+38}_{-36}$	>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

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



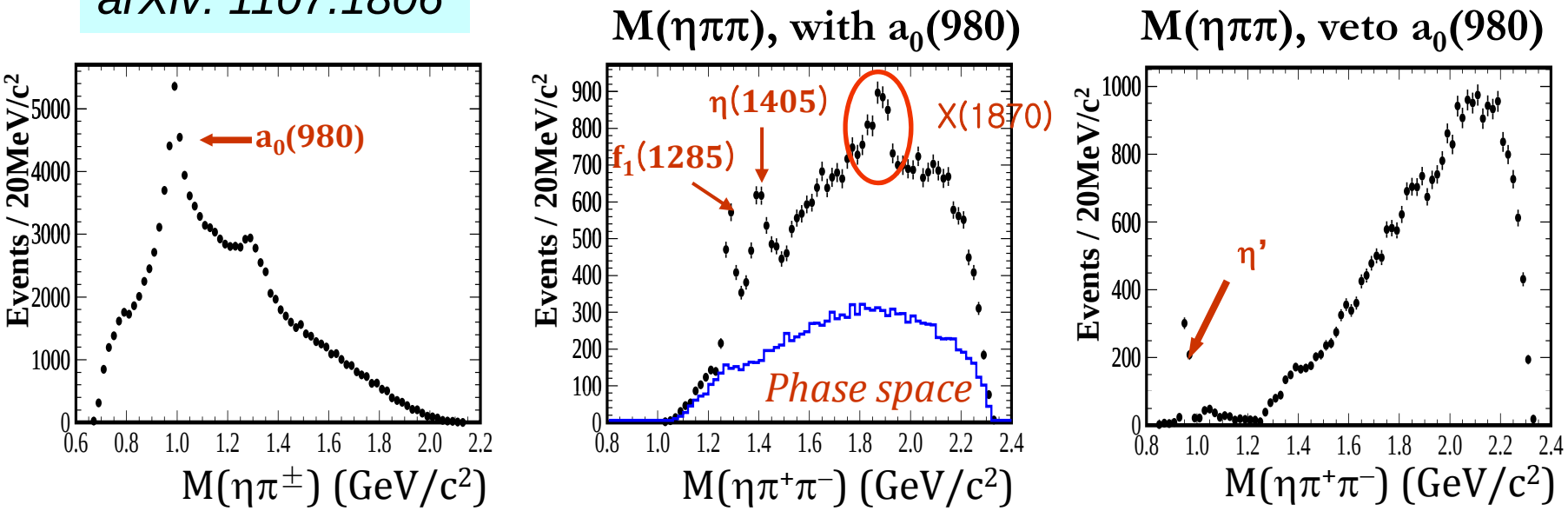
X(1835) consistent with 0^{-+}, but the others are not excluded.

Recap of $J/\psi \rightarrow \gamma\eta'\pi^+\pi^-$

- 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 5σ.
- 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.
- The study of the decay pattern is of crucial importance, i.e. in relative channels ($\eta\pi\pi$) and with other side particles ($\omega,\phi,\ldots$).

Analysis of J/ψ→ωηππ on BESIII

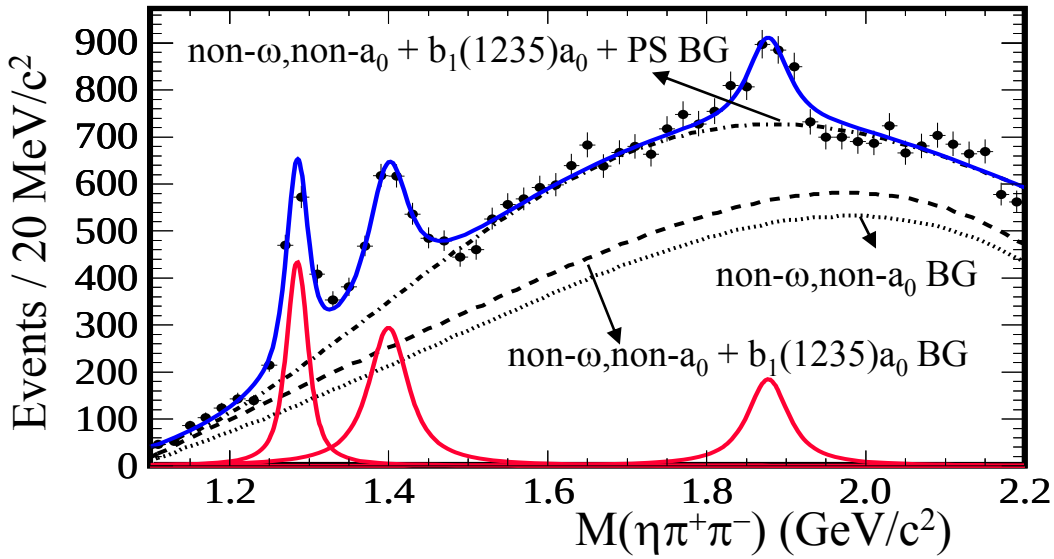
arXiv: 1107.1806



- 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.

Mass spectrum fitting results

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



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

arXiv: 1107.1806

Res.	M(MeV/c²)	Γ(MeV/c²)	Br(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)	$1877.3 \pm 6.3^{+3.4}_{-7.4}$	$57 \pm 12^{+19}_{-4}$	$1.50 \pm 0.26^{+0.72}_{-0.36}$

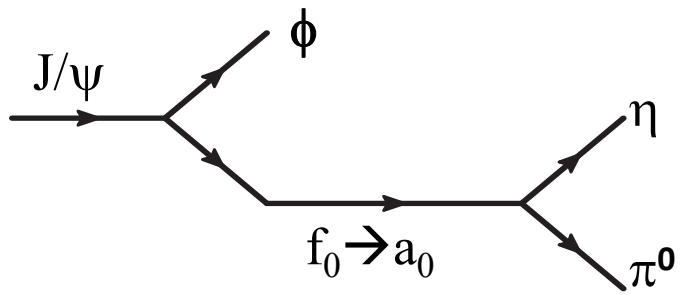
significance: 7.2σ

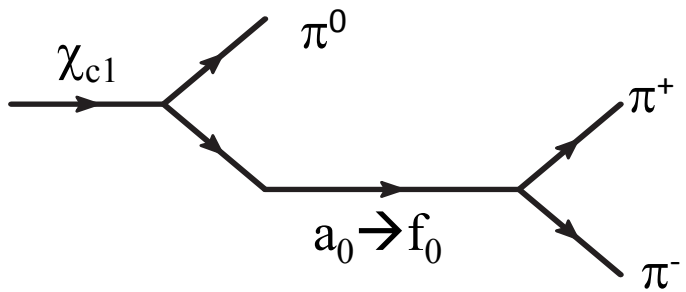
Recap of $J/\psi \rightarrow \omega\eta\pi^+\pi^-$

- A structure denoted as X(1870) is seen via the process: $J/\psi \rightarrow \omega X$, $X \rightarrow a_0(980)\pi$.
- Whether X(1860) ($J/\psi \rightarrow \gamma p\bar{p}$), X(1835) ($J/\psi \rightarrow \gamma\eta'\pi\pi$) and X(1870) ($J/\psi \rightarrow \omega\eta\pi\pi$) are the same resonance still need both experimental and theoretical study.
- BR($J/\psi \rightarrow \omega\eta(1405)$) is firstly measured. The product BR is smaller than its production in the radiative J/ψ decays, which indicates $\eta(1405)$ may couple strongly to gluons.

$a_0(980)$-$f_0(980)$ mixing

- a0(980)/f0(980): $q\bar{q}$, four quarks, $K\bar{K}$ molecule, hybrids,…
- Study of the mixing of $a_0(980)$ and $f_0(980)$ will shed new light on the enigmatic light scalars. No firm experimental determination.
- A narrow peak (8MeV) between the charged and neutral kaon thresholds (987~995 MeV).





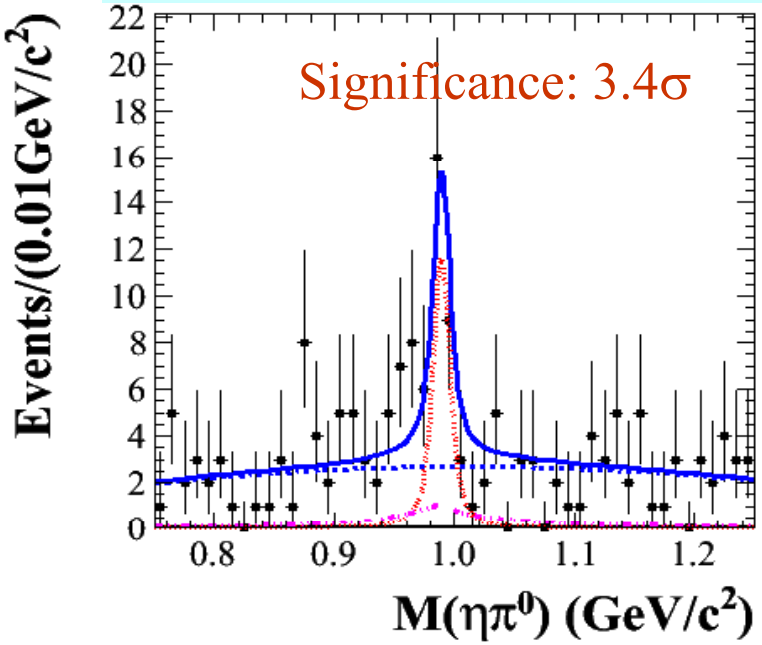
J.J.Wu, Q.Zhao, B.Zou PRD75 114012,

C. Hanhart etc. PRD76 074028, etc.

J.J.Wu, B.Zou PRD78 074017

$f_0(980) \rightarrow a_0(980)$ transition: $J/\psi \rightarrow \phi f_0 \rightarrow \phi a_0 \rightarrow \phi\eta\pi^0$

Phys.Rev.D83,032003 (2011)



.... Mixing signal

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

--- Background polynomial

N(mixing)=25.8±8.6(stat.)

<39.7 (90% C.L)

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

$$=(3.3\pm1.1(\text{stat.})\pm0.4(\text{sys.})\pm1.4(\text{para.}))\times10^{-6}$$

$$<5.4\times10^{-6}\ (90\%\ \text{C.L.})$$

Mixing intensity:

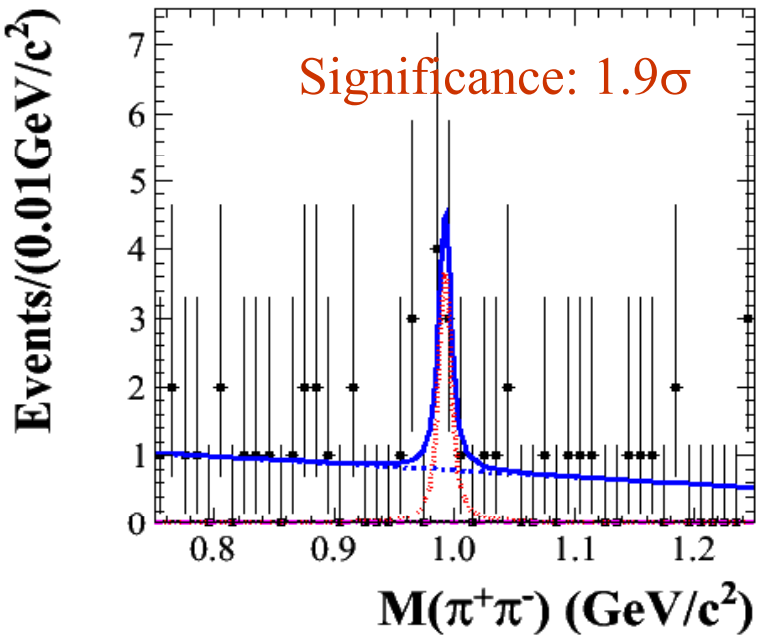
$$\xi_{fa}=\frac{Br(J/\psi \rightarrow \phi f_0 \rightarrow \phi a_0 \rightarrow \phi\eta\pi^0)}{Br(J/\psi \rightarrow \phi f_0 \rightarrow \phi\pi\pi)^{[BESII]}}$$

$$=(0.60\pm0.20(\text{stat.})\pm0.12(\text{sys.})\pm0.26(\text{para.}))\%$$

$$<1.1\%\ (90\%\ \text{C.L.})$$

$a_0(980) \rightarrow f_0(980)$ transition: $\psi' \rightarrow \gamma\chi_{c1}, \chi_{c1} \rightarrow a_0\pi^0 \rightarrow f_0\pi^0 \rightarrow \pi^+\pi^-\pi^0$

Phys.Rev.D83,032003 (2011)



…. Mixing signal

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

--- Background polynomial

$N(\text{mixing}) = 6.4 \pm 3.2(\text{stat.})$

$< 13.0\ (90\%\ \text{C.L})$

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

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

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

Mixing intensity:

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

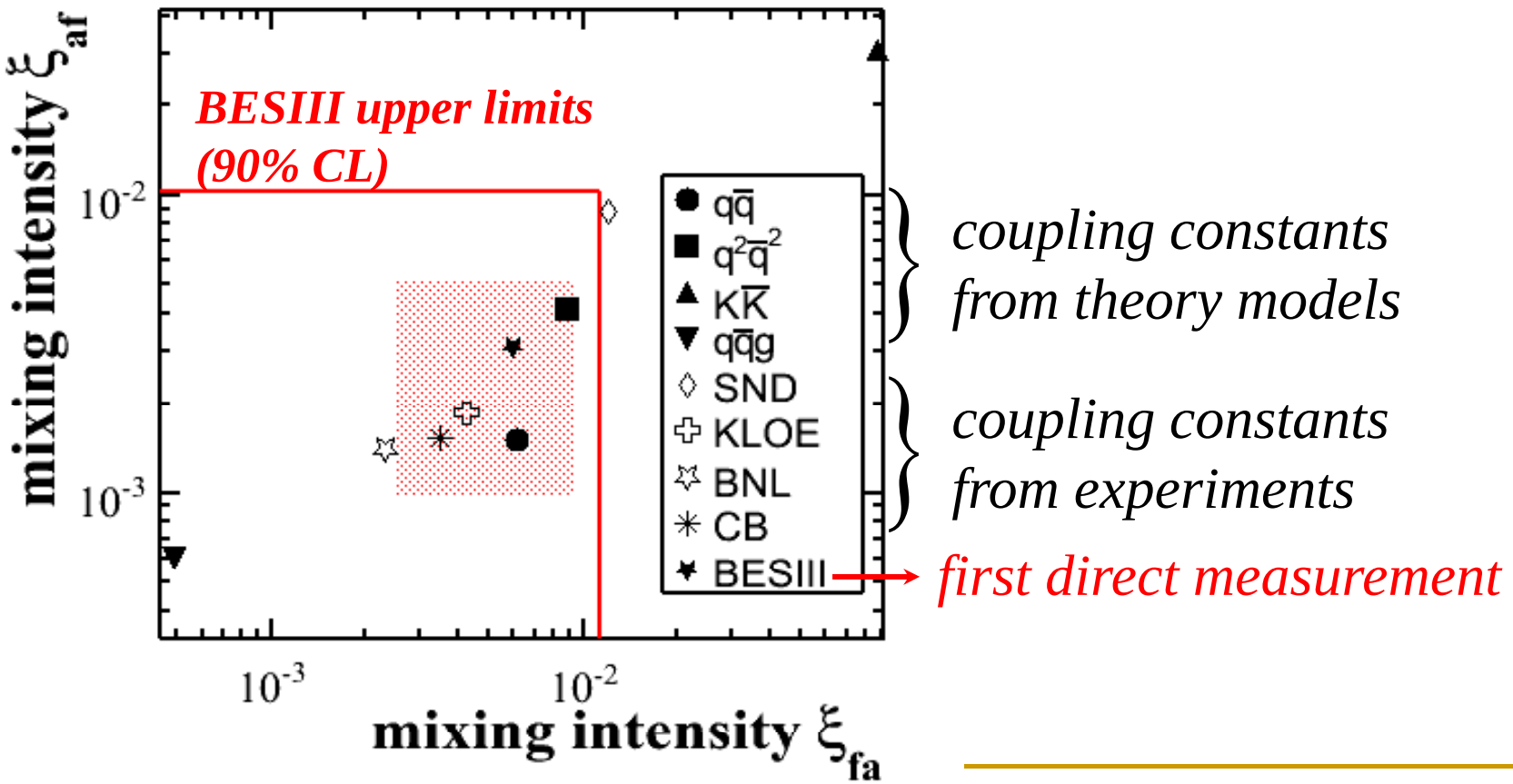
$= (0.31 \pm 0.16(\text{stat.}) \pm 0.14(\text{sys.}) \pm 0.03(\text{para.}))\%$

$< 1.0\%\ (90\%\ \text{C.L.})$

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

- The discoveries of $p\bar{p}$ mass threshold enhancement and X(1835) at BESII are confirmed with much higher statistics and significance at BESIII.
- In addition to X(1835), two new resonances, X(2120) and X(2360) are observed in the channels of $J/\psi \rightarrow \gamma\eta'\pi^+\pi^-$.
- A new process $J/\psi \rightarrow \omega X(1870) \rightarrow \omega a_0(980)\pi$ is observed.
- Whether or not the X(1860), X(1835) and X(1870) are from the same source, still needs further study.
- Study the $f_0(980) \rightarrow a_0(980)$ transition in $J/\psi \rightarrow \phi f_0 \rightarrow \phi a_0$ and the $a_0(980) \rightarrow f_0(980)$ transition in $\chi_{c1} \rightarrow a_0\pi^0 \rightarrow f_0\pi^0$. The mixing intensities are extracted from experiment, which will help to understand the structure of $a_0(980)$ and $f_0(980)$.

Thanks for your attention!