MESON SPECTROSCOPY RESULTS FROM THE BES COLLABORATION

Ji Xiaobin
For BESIII Collaboration
Institute of High Energy Physics
Beijing, China

Eleventh Conference on the Intersections of Particle and Nuclear Physics (CIPANP 2012)
May 29 – June 3, 2012
St. Petersburg, Florida

Contents

- Introduction
- $\bar{p}p$ mass threshold enhancement in $J/\psi\to\gamma\ \bar{p}p$
- X(1835) and two new structures in $J/\psi\to\gamma\eta'\pi^+\pi^-$
- X(1870) in $J/\psi\to\omega\eta\ \pi^+\pi^-$
- $a_0(980)$ - $f_0(980)$ mixing
- $\eta(1405)$ in $J/\psi\to\gamma f_0(980)\pi^0\to\gamma 3\pi$
- $\omega\phi$ threshold enhancement in $J/\psi\to\gamma\omega\phi$
- $\eta\eta$ system in $J/\psi\to\gamma\eta\eta$
- Summary

BEPC II

A high luminosity double-ring collider

Beijing Electron Positron Collider (II)

Beam energy:
1.0 – 2.3 GeV

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

Optimum energy:
1.89 GeV

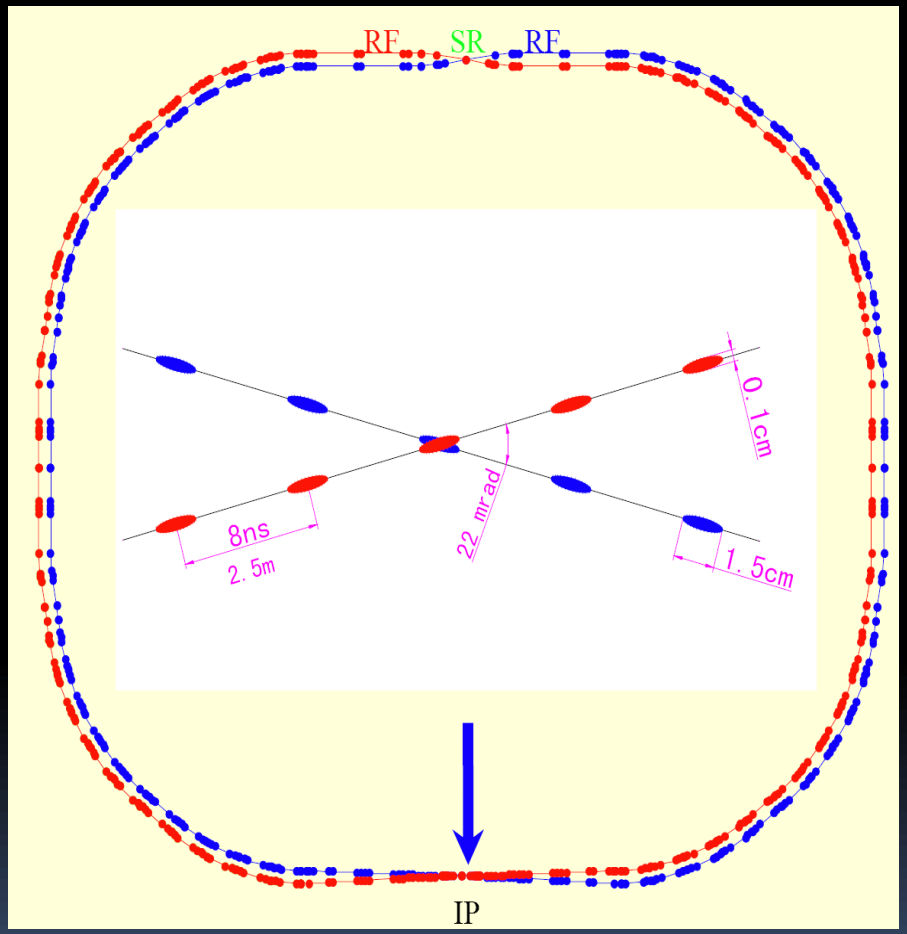
No. of bunches:
93

Bunch length:
1.5 cm

Total current:
0.91 A

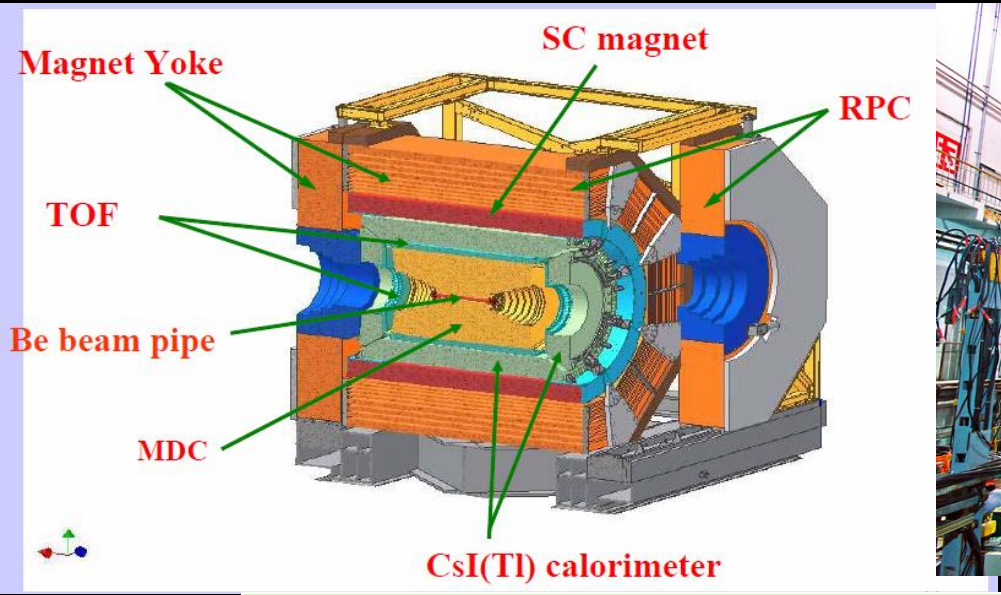
SR mode:
0.25A @ 2.5 GeV

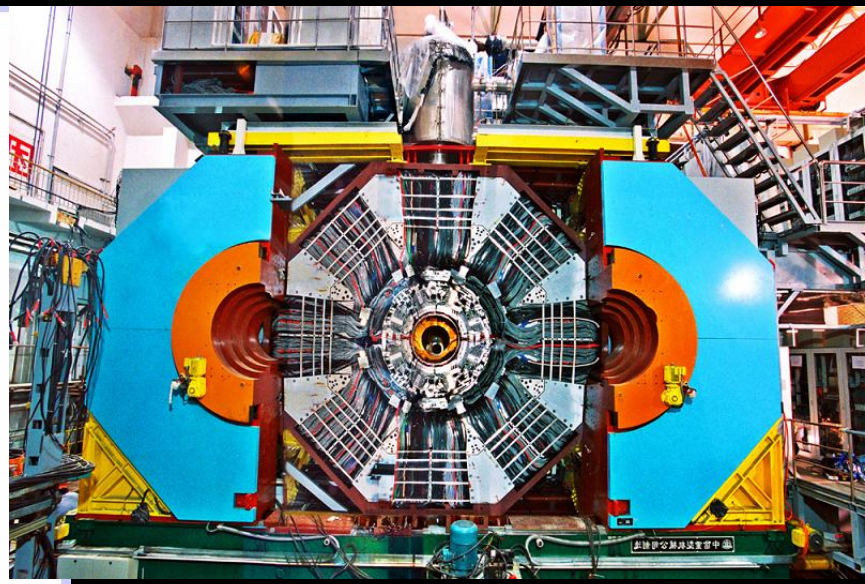
BEPC II



Beam magnets

BESIII Detector





Sub-detectors			Performance
MDC	Momentum resolution		0.5%@1GeV
	dE/dx resolution		6%
EMC	Energy resolution		2.5%@1GeV
	Spatial resolution		6 mm
TOF	Time resolution	Barrel	80 ps (Bhabha)
		Endcap	110 ps (Di-muon)
MUC	9 layers RPC, 8 layers for endcap		

BESIII Data Samples

- July 18, 2008: First e+e- collision event in BESIII
- 2009 : 106 M $\psi(2S)$ events (x4 CLEOc)
  225 M J/ψ events (x4 BESII)
- 2010 : 900 pb^{-1} $\psi(3770)$
- 2011 : 1800 pb^{-1} $\psi(3770)$
  470 pb^{-1} @ 4.01 GeV
- 2012 : ~ 0.4 billion $\psi(2S)$
  ~ 1 billion J/ψ

Light Hadron Spectroscopy

- Multi-quarks states, glueballs and hybrids have been searched for experimentally for a long time, but none have been established.
- In the past several years, a lot of unexpected experimental evidence for hadron cannot (easily) be explained by the conventional quark model

- Established the light hadron spectroscopy
- Search for non-conventional hadrons

- BESIIII advantages:
  - Gluon rich
  - Clean environment
  - Important J^{PC} filter, and isospin filter

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

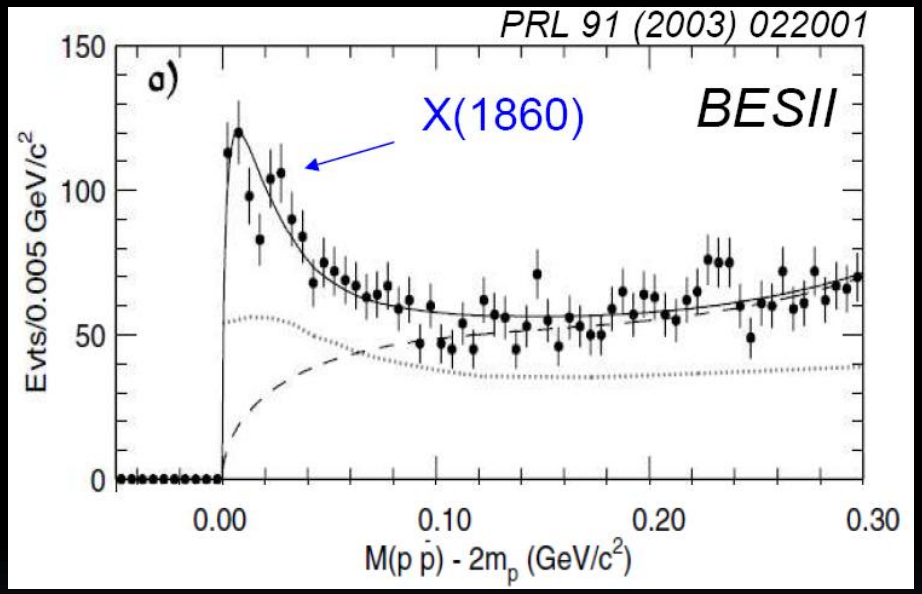
$$J/\psi \to \gamma p\bar{p}$$

- If fitted with a S-wave resonance

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

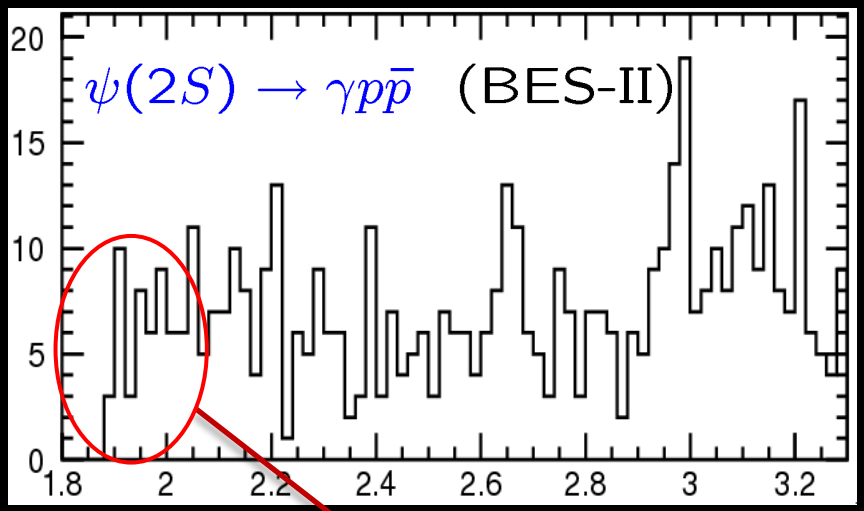
  $\Gamma < 30$ MeV/c² (90% CL)

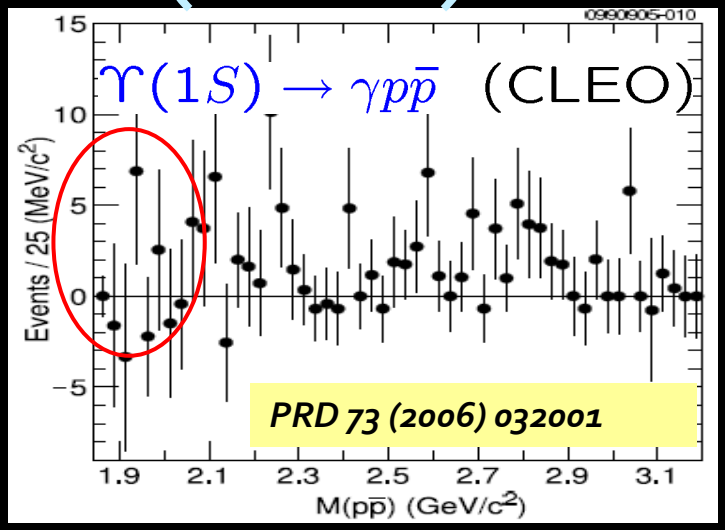
- Theoretical speculation:
  - $\bar{p}p$ bound state?
  - FSI effect?
  - … …

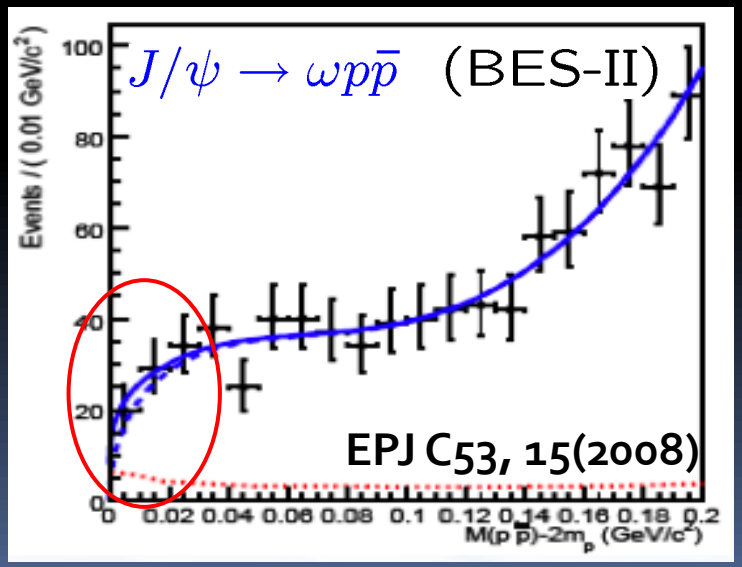


Non-observation of X(1860)

PRL 99 (2007) 011802



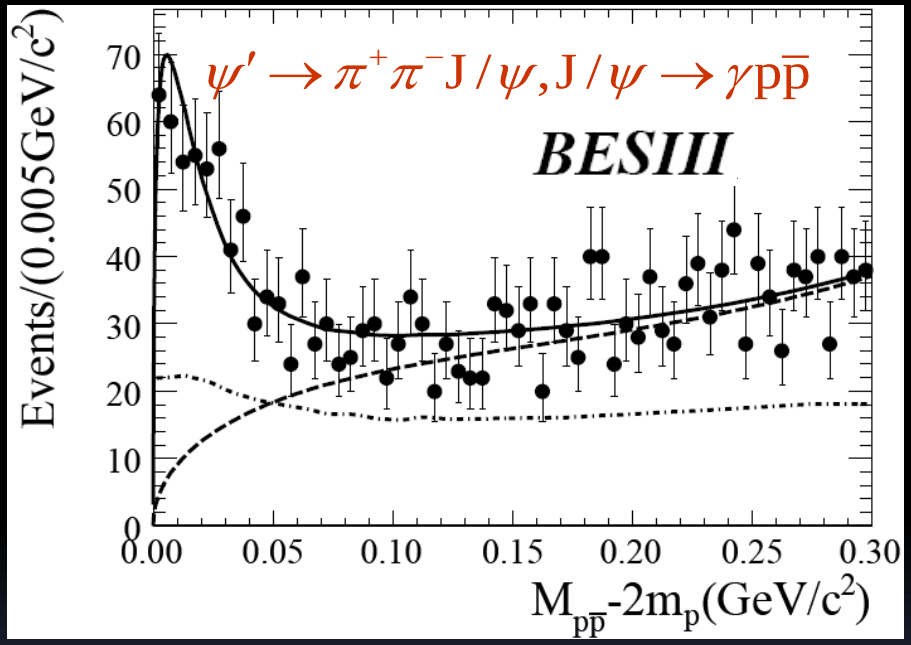




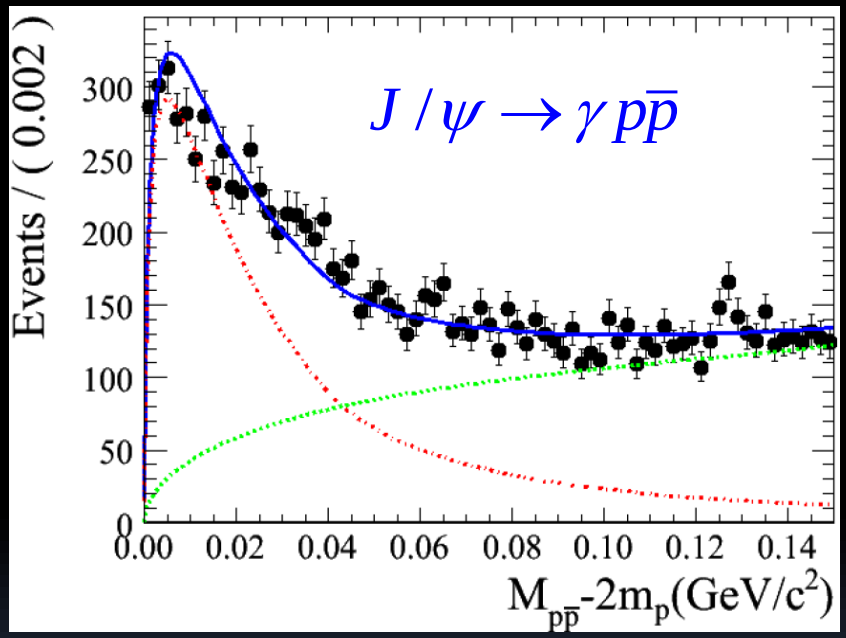
No significant signal of X(1860) found (only 2σ significance)

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

Chinese Physics C 34(2010)421



BESIII results



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

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

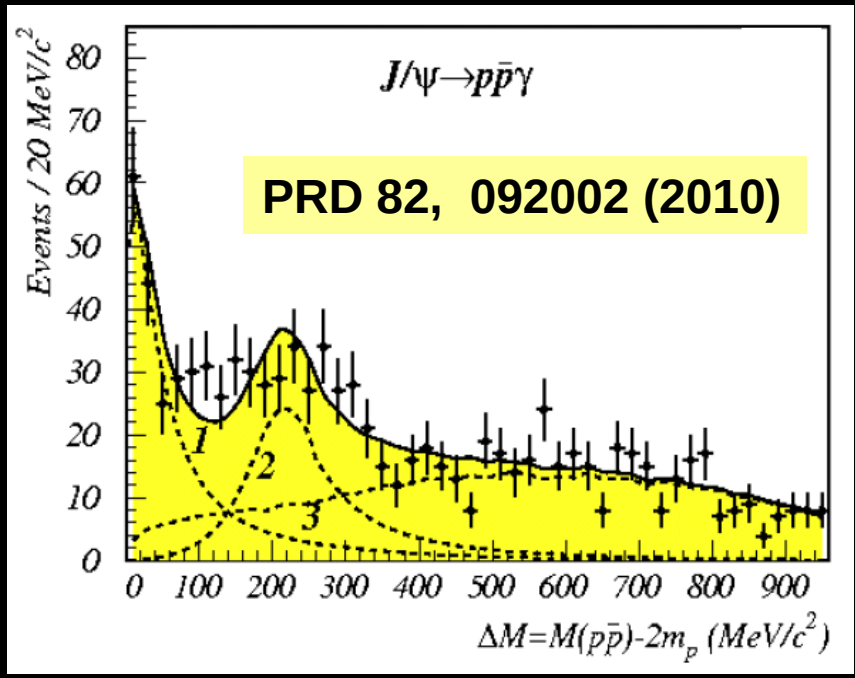
Consistent observation by BESIII !

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

- CLEO-c does the same fit as that BES, they obtain $M(R_{thr})= 1861^{+6}_{-16}$ (MeV/c²), $\Gamma(R_{thr}) = 0^{+32}_{-0}$ (MeV/c²) which agree with BESII results.
- CLEO-c fit with three contributions: $R_{thr}+f_0(2100)+PS$ $M(R_{thr})= 1837^{+10}_{-12}{}^{+9}_{-7}$(MeV/c²), $\Gamma(R_{thr}) = 0^{+44}_{-0}$ (MeV/c²)

  CL = 26.1%

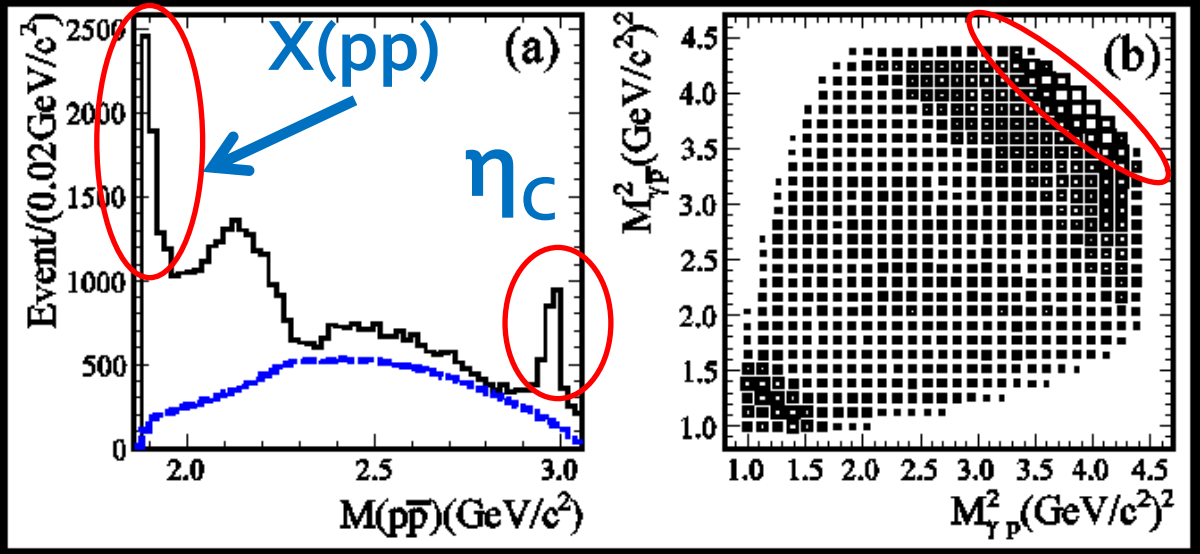
  BES considered 2nd and 3rd parts as systematic errors.



The central value of the mass is close to the resonance mass reported by BES with $M(R) = 1833.7 \pm 6.1 \pm 2.7$ MeV/c², observed in $J/\psi\to\gamma R$, $R\to\pi^+\pi^-\eta'$ [PRL 95 (2005) 262001]

PWA of J/ψ → γ p $\bar{p}$ @BESIII

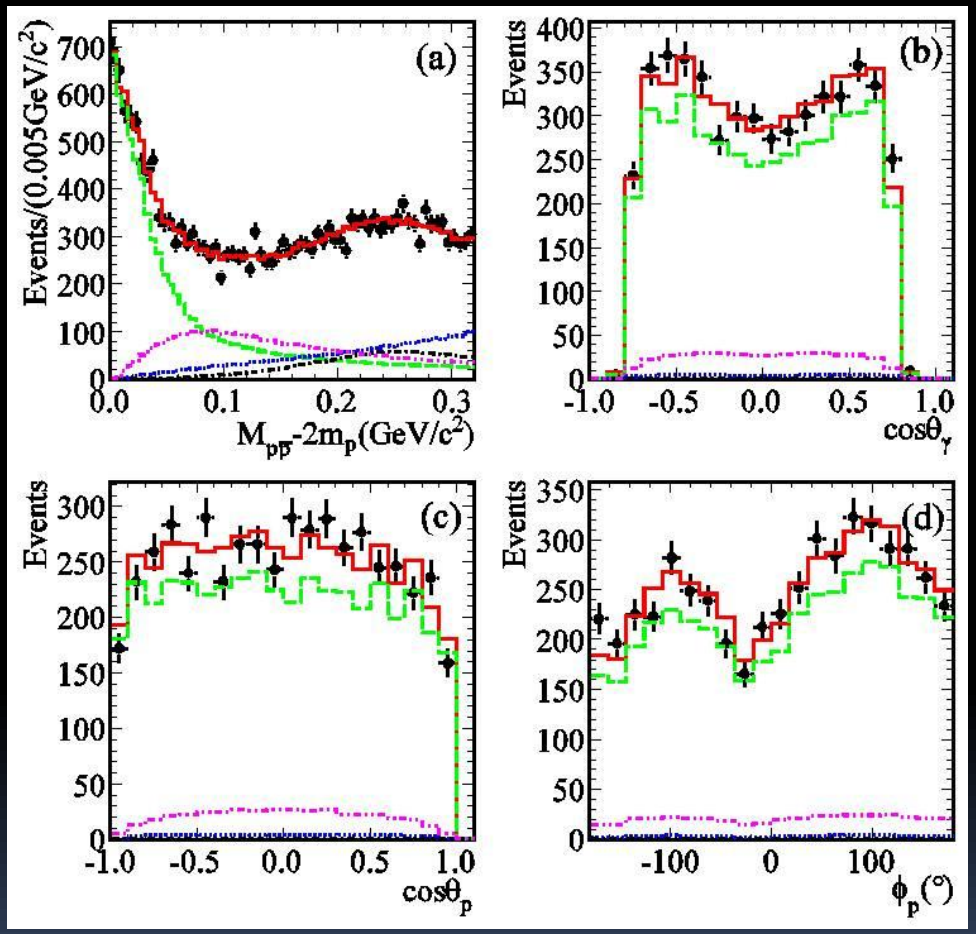
- PWA of $J/\psi \to \gamma p\bar{p}$ was first performed (225 M J/ψ)



- Concentrate on dealing with the $\bar{p}p$ mass threshold structure, especially on determine the J^{PC}
- Covariant 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)

PWA of J/ψ → γ p $\bar{p}$ @BESIII

- The fit with a BW and S-wave FSI (I=0) factor can well describe the $p\bar{p}$ mass threshold structure
- It is much better than that without FSI effect, and Δ2lnL = 51 (7.1σ)
- Components: X(pp), f0(2100), f2(1910), phase space



PRL 108, 112003 (2012)

PWA of J/ψ → γ p $\bar{p}$ @BESIII

- 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

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

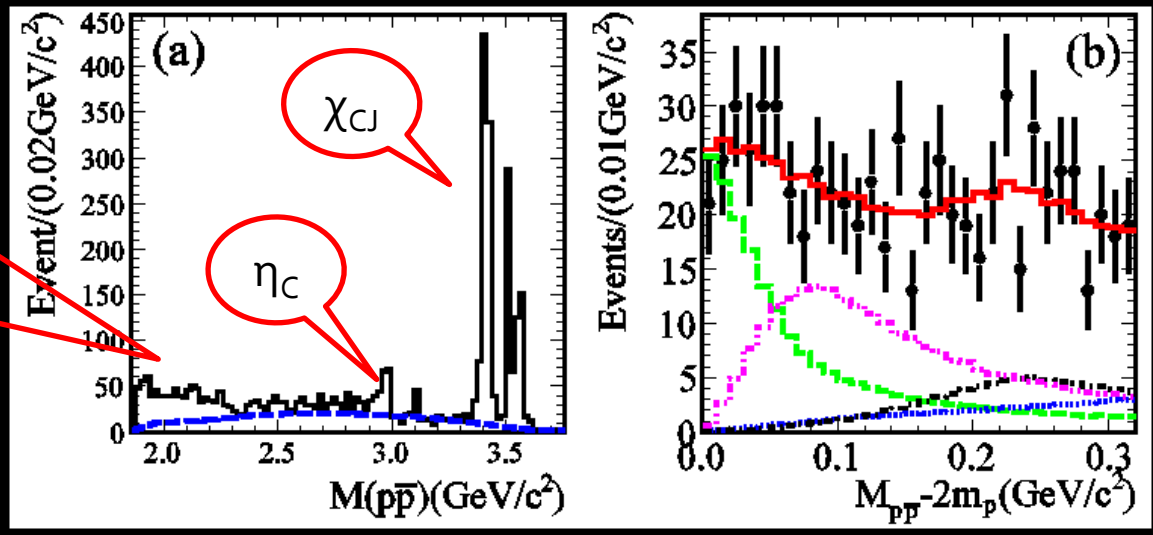
  $M = 1832^{+19}_{-5}$ (stat.) $^{+18}_{-17}$ (sys.) ±19 (model) MeV/c^2

  $\Gamma = 13 \pm 39$ (stat.) $^{+10}_{-13}$ ±4(model) MeV/c^2 or $\Gamma < 76$ MeV/c^2 at 90% C.L.

  $Br(J/\psi \to \gamma X) \bullet B(X \to \bar{p}p) = (9.0^{+0.4}_{-1.1}(\text{stat.})^{+1.5}_{-5.0}(\text{sys.}) \pm 2.3(\text{model})) \times 10^{-5}$

PWA of ψ′ → γ p $\bar{p}$ @BESIII

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



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

First measurement

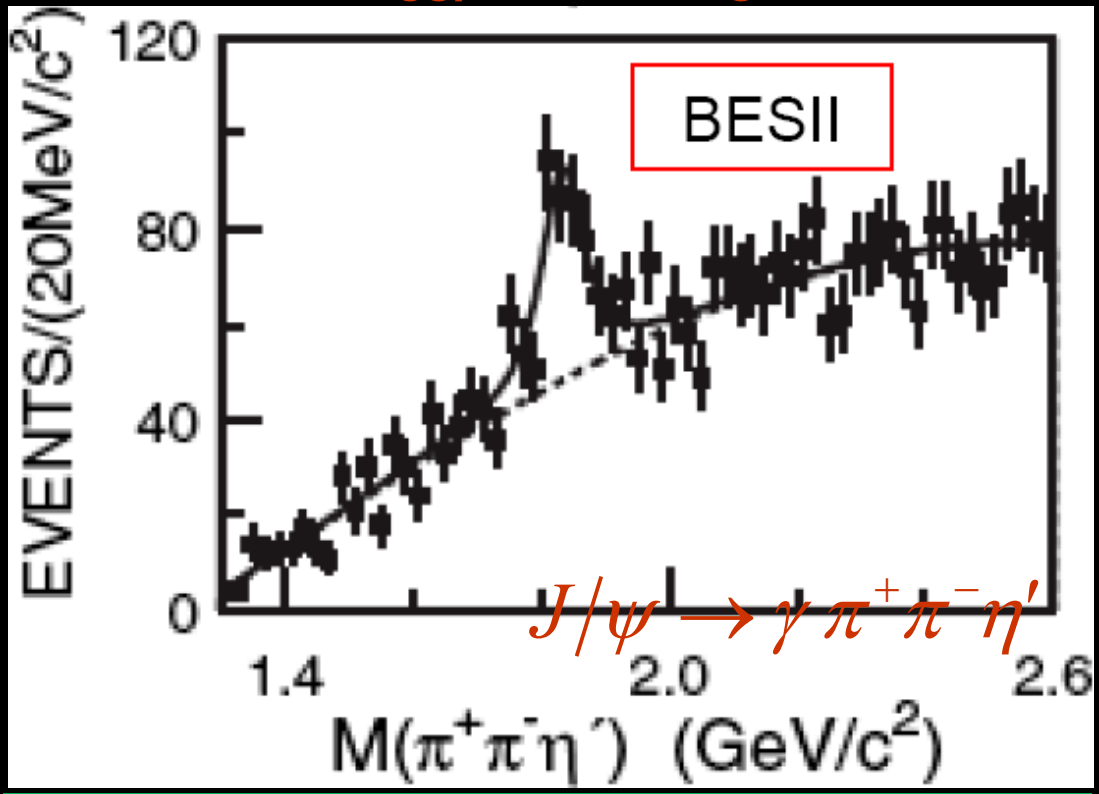
$$R = \frac{B(\psi' \to \gamma X(p\bar{p}))}{B(J/\psi \to \gamma X(p\bar{p}))} = 5.08^{+0.71}_{-0.45}(\text{stat.})^{+0.67}_{-3.58}(\text{syst.}) \pm 0.12(\text{model})\%$$

- It is suppressed compared with "12% rule"

X(1835) at BESII

- LQCD predicts the glueball of 0^{-+} is ~ 2.3 GeV
- For 0^{-+} glueball, it may have similar property as η_c (mainly decay to $\pi\pi\eta'$)
- $J/\psi\to\gamma\eta'\pi^+\pi^-$ is specially interested and was studied with 58 M J/ψ at BESII
- X(1835): *$p\bar{p}$ bound state? η excitation? same as X(pp)?*

PRL 95,262001(2005)



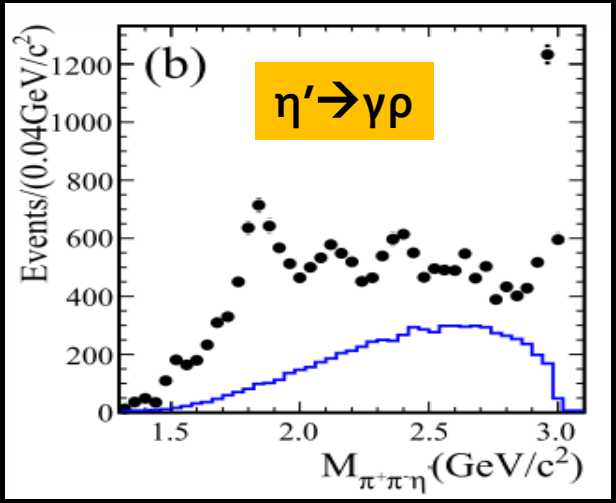
M = 1833.7±6.1±2.7 MeV/c²

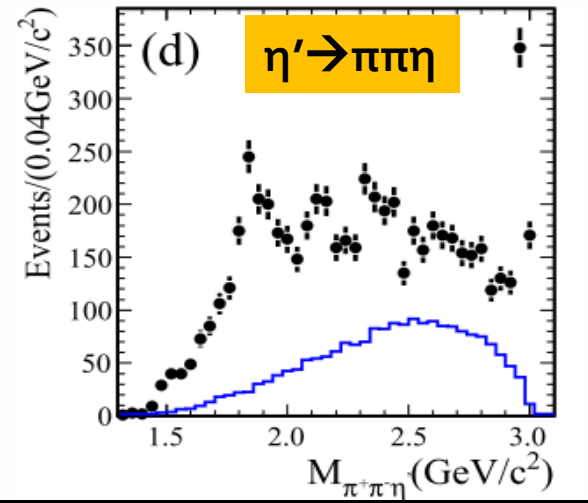
Γ = 67.7±20.3±7.7 **MeV/c²**

$B(J/\psi\to\gamma X) \times B(X\to\pi^+\pi^-\eta') = (2.2\pm0.4\pm0.4)\times 10^{-4}$

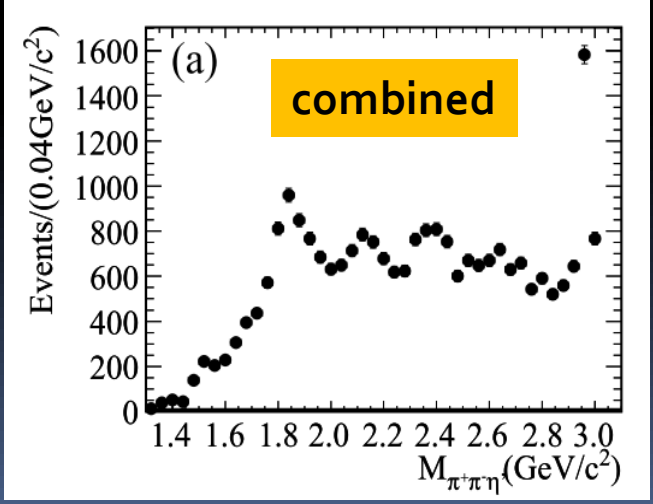
sig. = 7.7σ

X(1835) in J/ψ→γππη' @BESIII





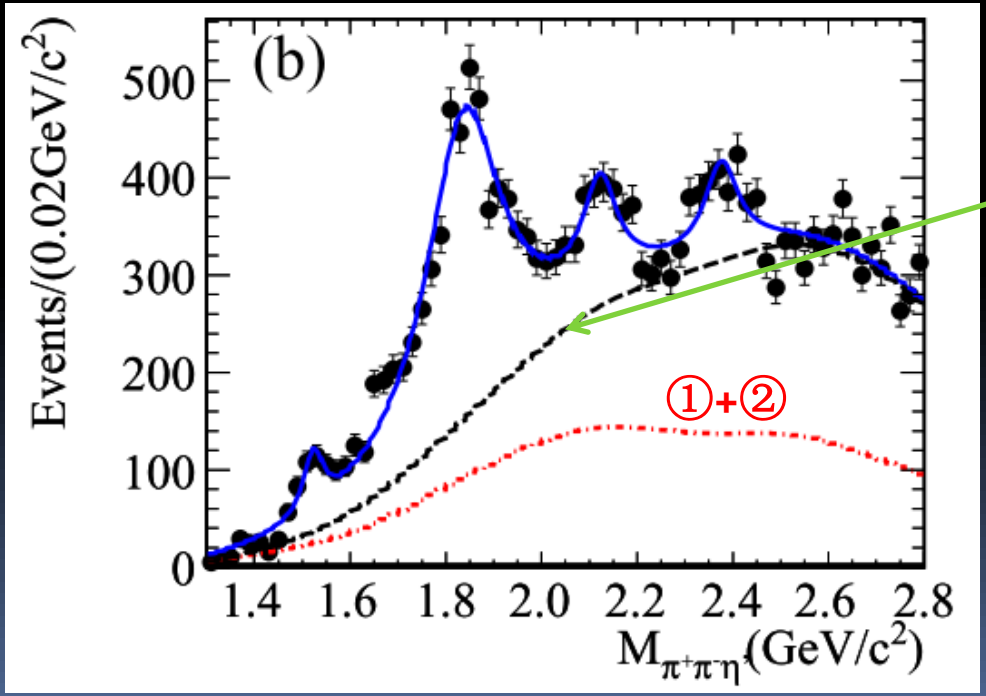
BESIII
225 M J/ψ



- X(1835) and η_C are evident
- Two additional structures are observed at M ~ 2.1 GeV and 2.3 GeV
- There maybe some $f_1(1510)$
- If ππη' invariant mass spectrum is fitted with only one resonance, results are consistent with BESII

Fitting results

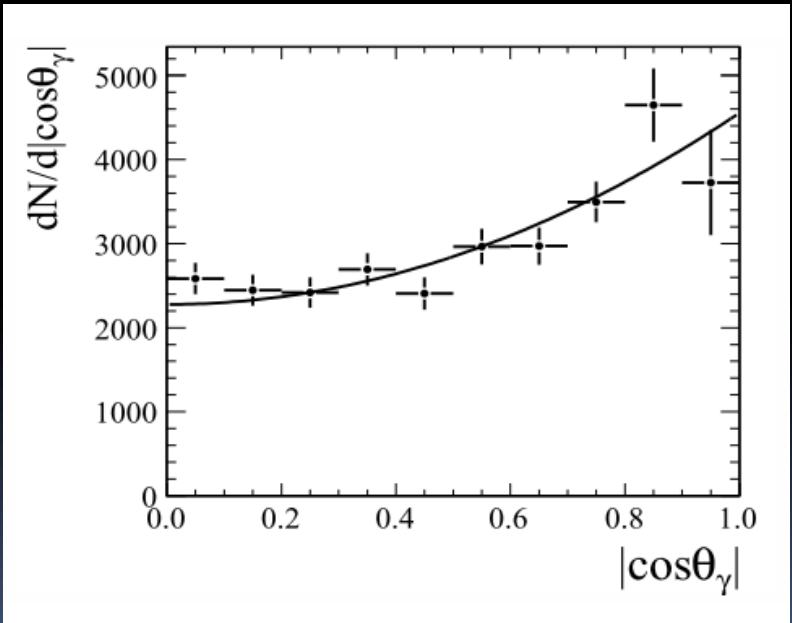
- Fitting with 4 resonances (acceptance weighted BW ⊗gauss)
  - ① Contribution from non-η′ events estimated by η′ sideband
  - ② Contribution from J/ψ→πππη with re-weighting method
  - ③ Contribution from "phase space background"
    $f_{bkg}(x)=(x-m_o)^{1/2}+a0(x-m_o)^{3/2}+a1(x-m_o)^{5/2}$, $m_o=2m_\pi+m_{\eta'}$



Fitting results

PRL 106, 072002 (2011)

Resonance	M (MeV/c²)	Γ (MeV/c²)	significance
X(1835)	$1836.5\pm3.0^{+5.6}_{-2.1}$	$190\pm9^{+38}_{-36}$	>> 20σ
X(2120)	$2122.4\pm6.7^{+4.7}_{-2.7}$	$83\pm16^{+31}_{-11}$	> 7.2σ
X(2370)	$2376.3\pm8.7^{+3.2}_{-4.3}$	$83\pm17^{+44}_{-6}$	> 6.4σ



For X(1835)

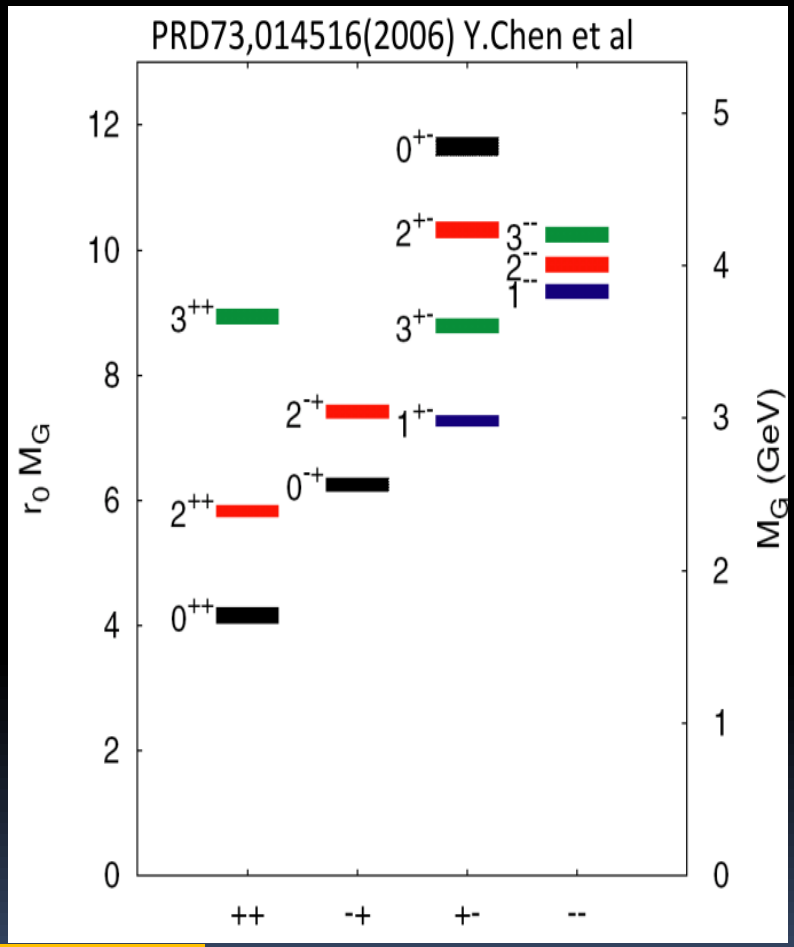
$Br(J/\psi\rightarrow\gamma X(1835))\bullet Br(X(1835)\rightarrow\pi^+\pi^-\eta') = (2.87\pm0.09^{+0.49}_{-0.52})\times10^{-4}$

The polar angle of the photon in J/ψ CMS is consistent with expectation for pseudoscalar

PWA is needed, inference among the resonances needs to be considered.

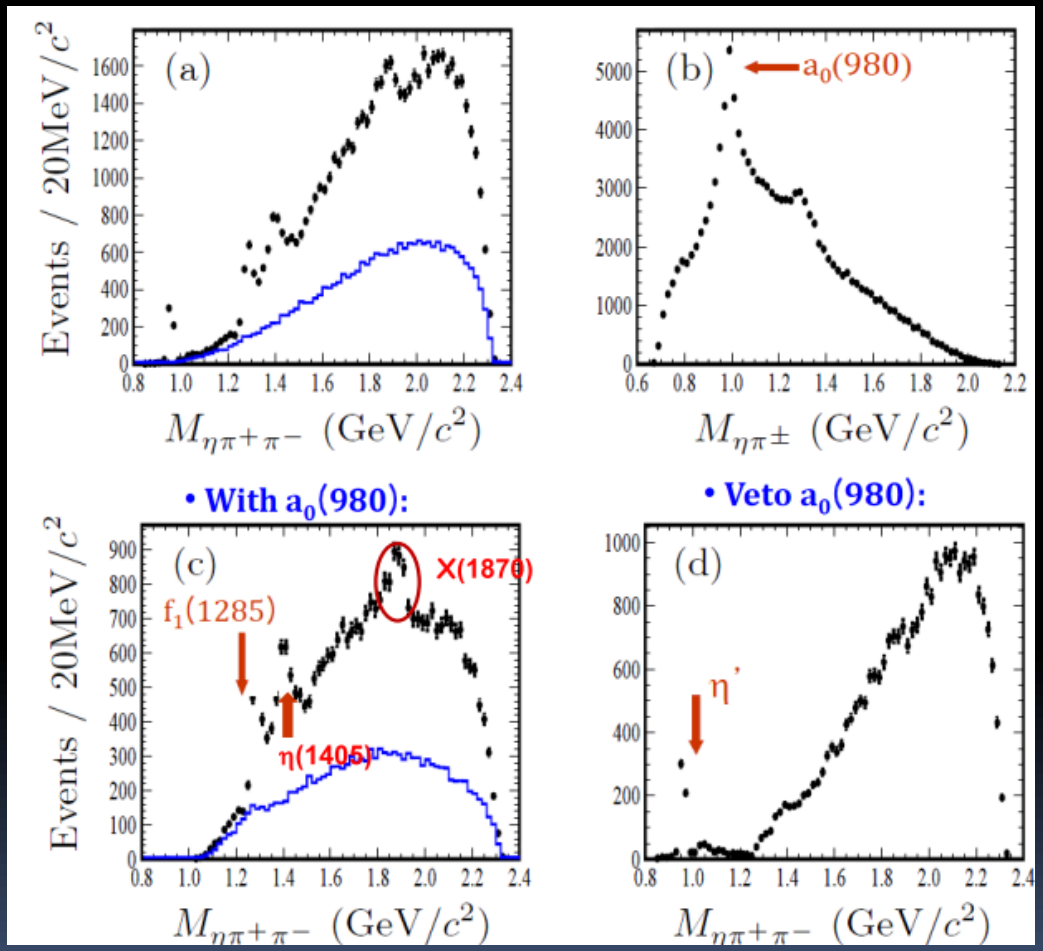
Why are X(2120)/X(2370) interstering?

- It is the first time in J/ψ radiative decays resonant structures are observed in the 2.4 GeV region, it is interesting since:
  - LQCD predicts that the lowest lying pseudoscalar glueball : around 2.4 GeV
  - J/ψ→γππη′ decay is a good channel to find 0-+ glueballs
- Nature of X(2120)/X(2370)
  - 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)

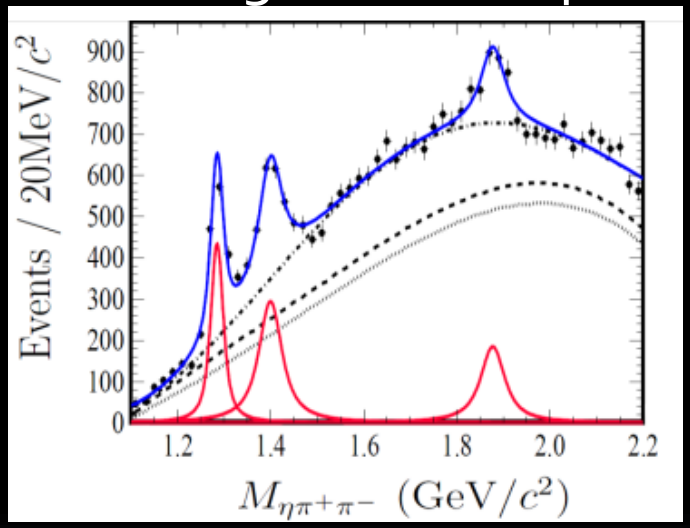
Observation of X(1870) in J/ψ→ω(ππη)



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

Fitting results of X(1870)

- Fitting with 3 resonances
- Background component described by Polynomial function



PRL 107, 182001,2011

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

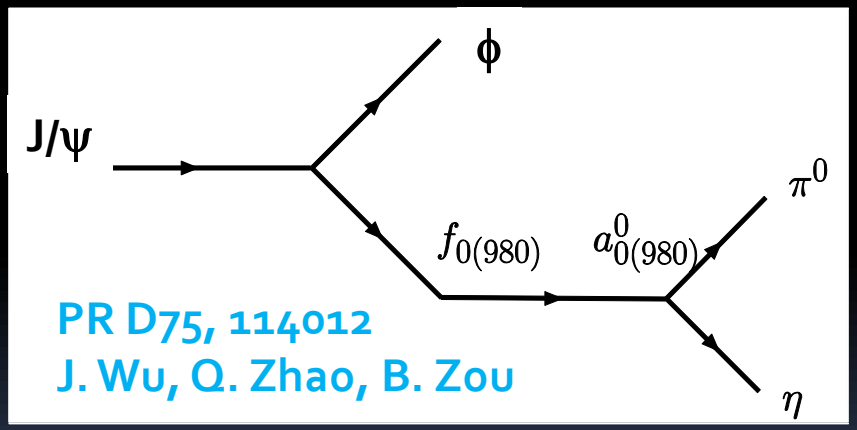
7.2σ

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

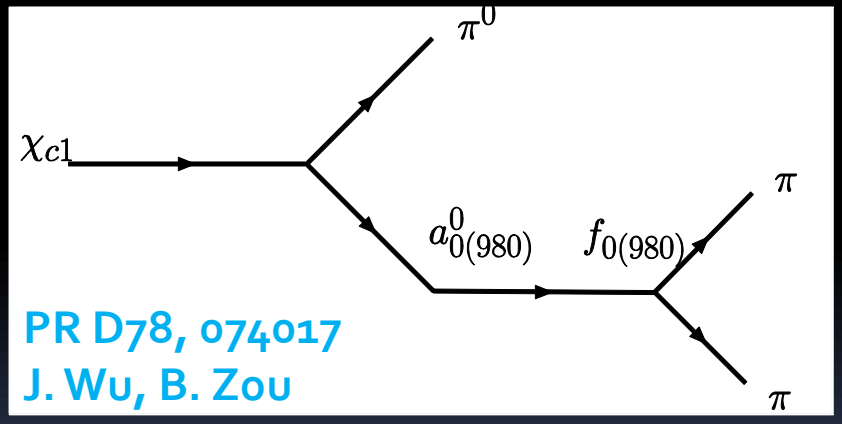
Whether the X(1870) is the X(1835) or $\eta_2(1870)$ (Γ=225±14 MeV/c²), or a new resonance, need further study.

$a_0(980)$ – $f_0(980)$ mixing

- Light scalar mesons f_0 and a_0 are still controversial.
- Described as quark-antiquarks, four quarks, KK-bar molecule, qq-bar g hybrids, etc.
- Study of mixing important to clarify their nature.
- $J/\psi \to \phi f_0 \to \phi a_0 \to \phi\eta\pi$ and $\chi_{c1} \to a_0\pi^0 \to f_0\pi^0 \to \pi^+\pi^-\pi^0$ provide complementary information:



PR D75, 114012
J. Wu, Q. Zhao, B. Zou



PR D78, 074017
J. Wu, B. Zou

$$\xi_{fa}(s) = \frac{d\Gamma_{X\to Yf_0(980)\to Ya_0(980)\to Y\pi^0\eta(s)}}{d\Gamma_{X\to Yf_0(980)\to Y\pi\pi(s)}}$$

$$\xi_{af}(s) = \frac{d\Gamma_{X\to Ya_0(980)\to Yf_0(980)\to Y\pi\pi(s)}}{d\Gamma_{X\to Ya_0(980)\to Y\pi^0\eta(s)}}$$

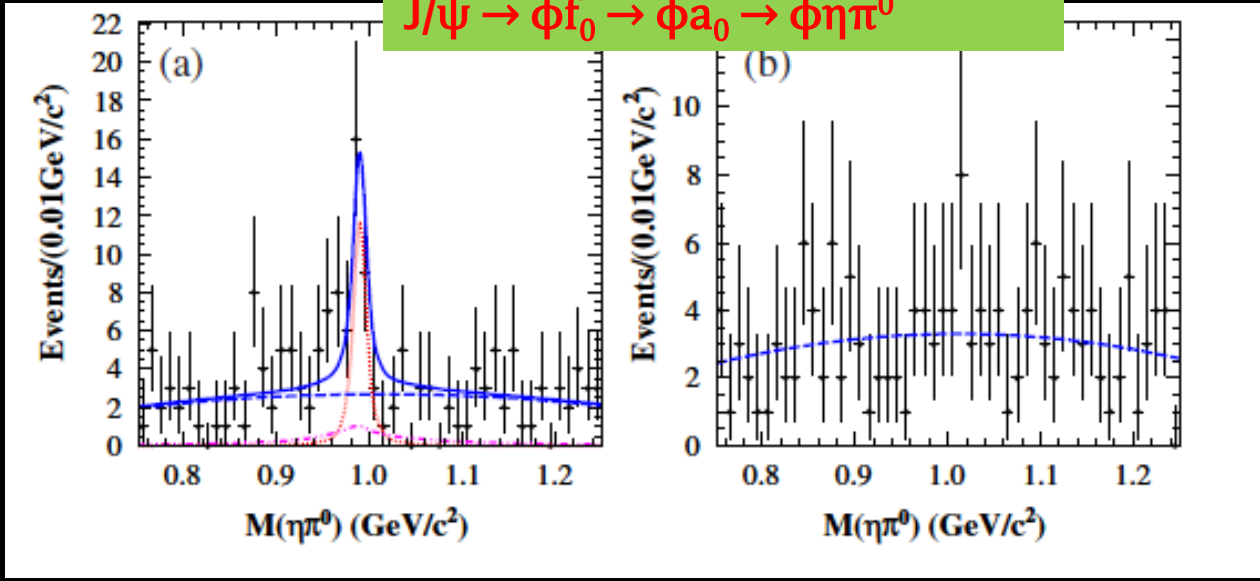
Mixing intensity

$a_0(980)$ – $f_0(980)$ mixing

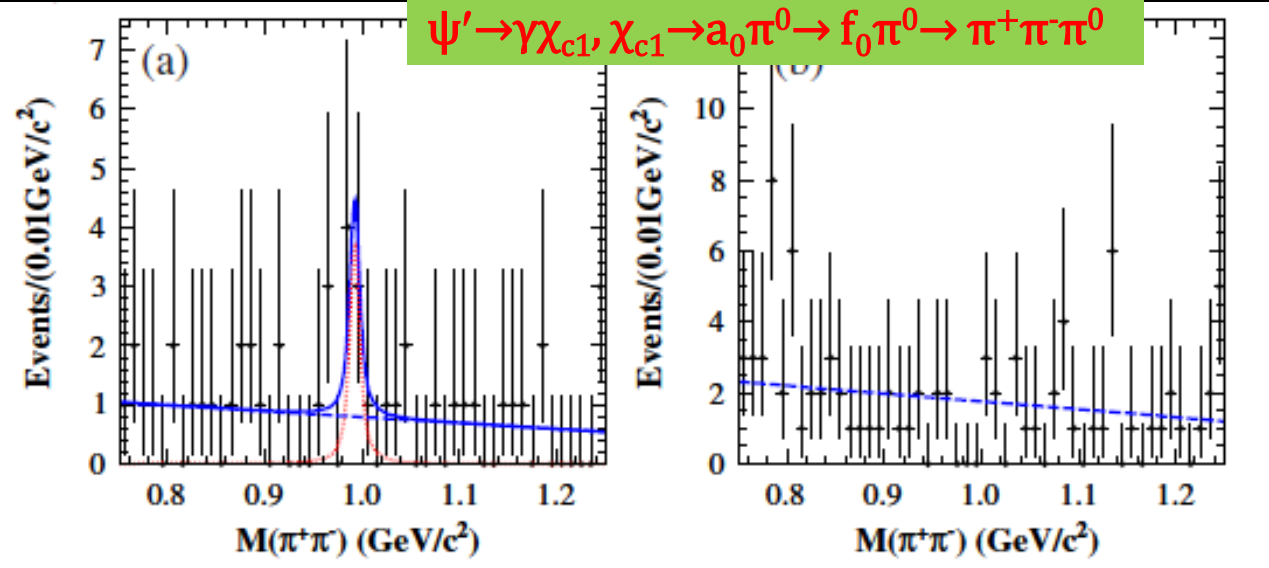
PRD83 032003(2011)

Mixing peaks expected at ~991 MeV/c^2 with 8 MeV/c^2 width.

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



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

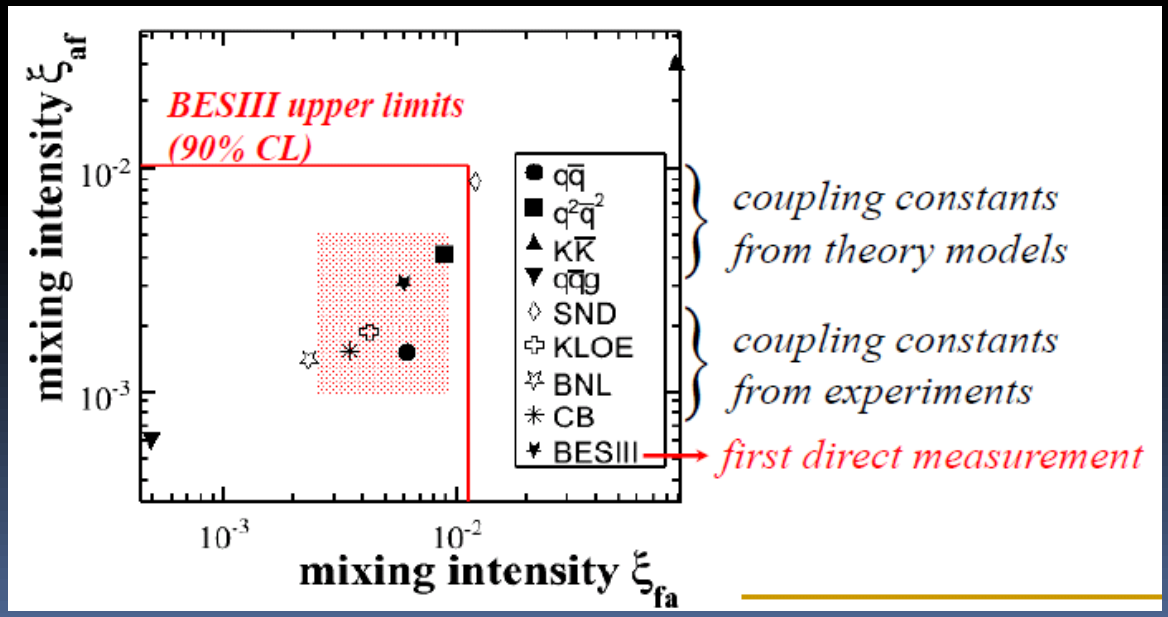


$a_0(980)$ – $f_0(980)$ mixing

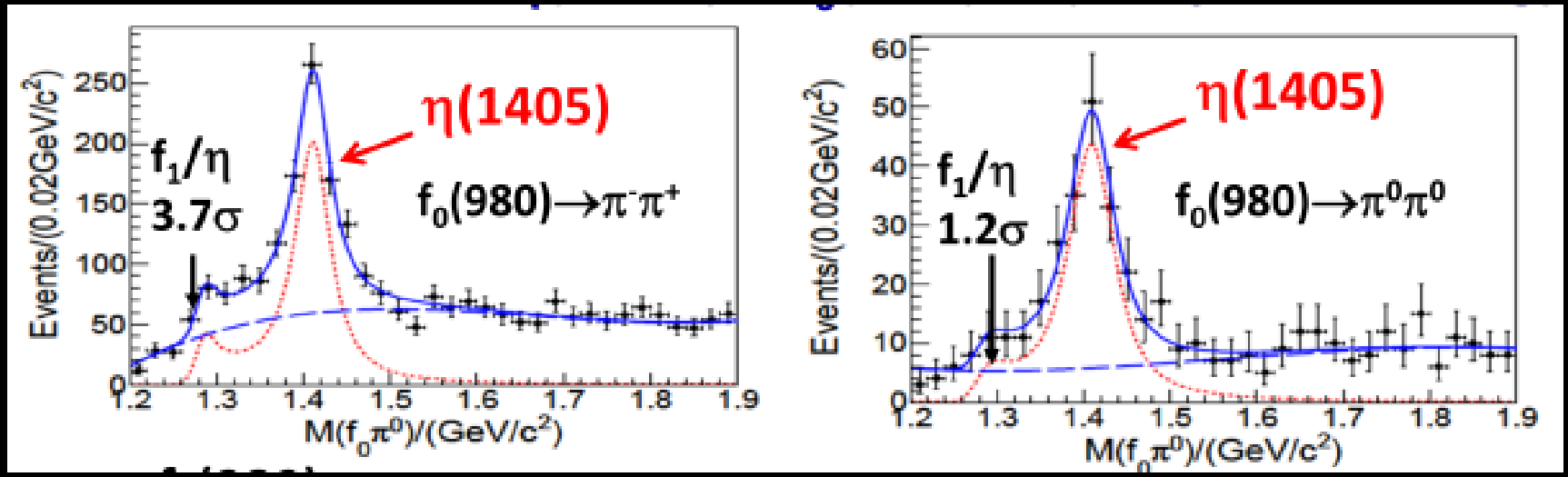
- **Mixing intensity**

✸ ξ_{fa} = (0.60±0.20(stat.) ±0.12(sys.) ±0.26(para)%
(<1.1% @90% C.L.)

✸ ξ_{af} = (0.31±0.16(stat.) ±0.14(sys.) ±0.03(para)%
(<1.0% @90% C.L.)



η(1405) in J/ψ→γf$_0$(980)π^0, f$_0$(980)→2π



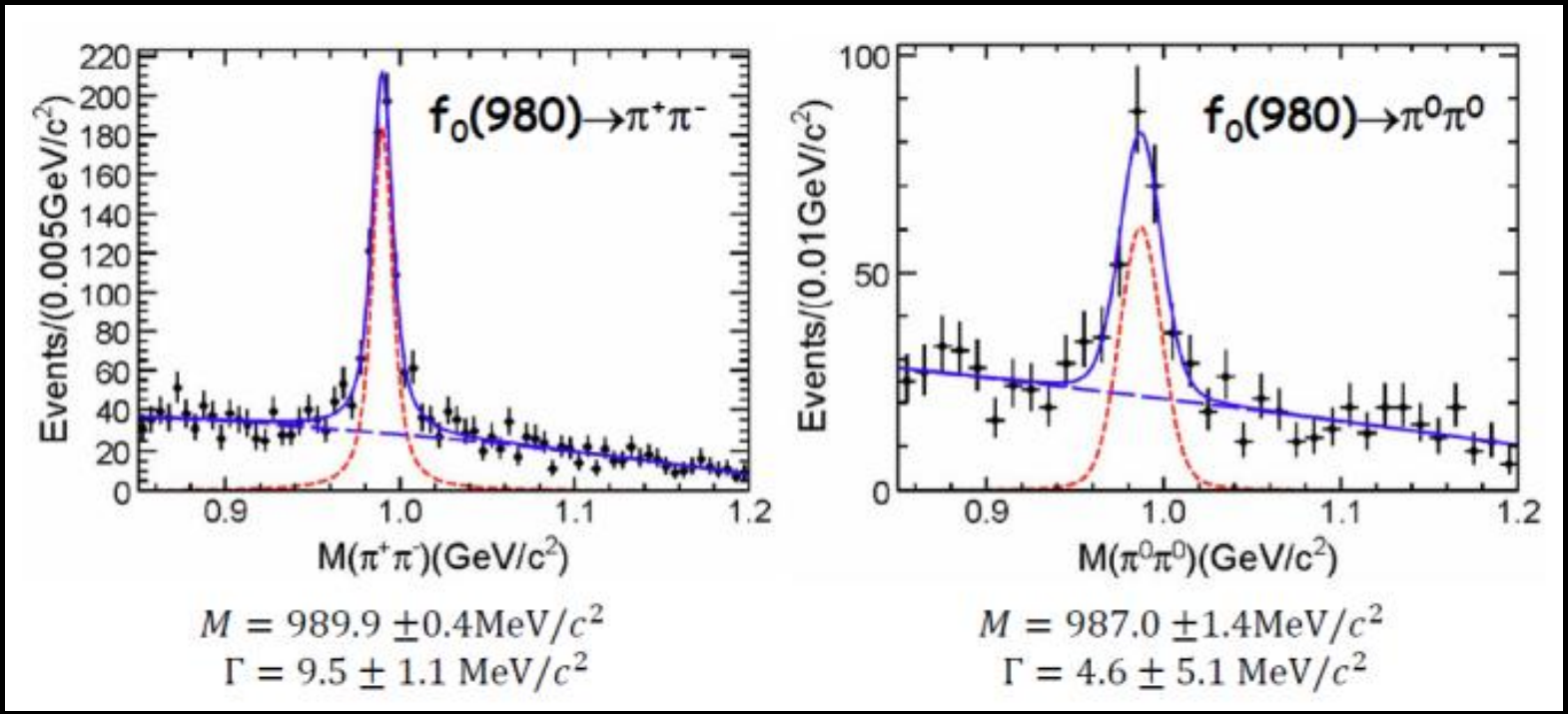
- First observed: η(1405)→f$_0$(980)π^0 (isospin breaking)
- Helicity analysis indicates the peak at 1400 MeV is from η(1405), not from f1(1420)
- Large isospin-violating decay rate: (η(1405)→f$_0$(980)π^0)

$$\frac{BR(\eta(1405)\to f_0(980)\pi^0)}{BR(\eta(1405)\to a_0(980)\pi)}\approx(17.9\pm4.2)\%$$

arXiv: 1201.2737v1, Accepted by PRL

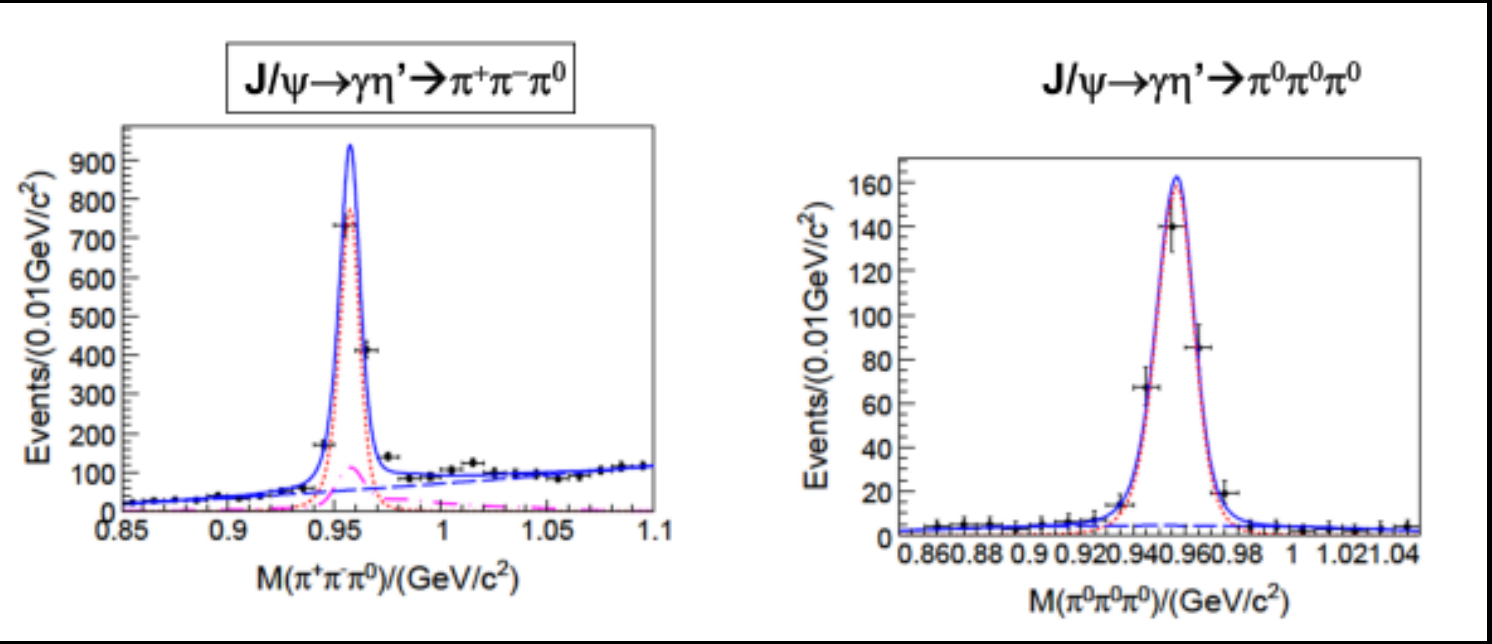
In general, magnitude of isospin violation in strong decay shold be < 1%. Ao-fo mixing alone can not explain the Br of η(1405)→fo(980)π^0

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



- Surprising result:
  vary narrow $f_0(980)$ width: < 11.8 MeV/c^2 @ 90% C.L.
  Much narrow than the world average (PDG2010: 40-100 MeV/c^2)
- Theoretical explanation: effect of Triangle Singularity?
  J.J. Wu et al. PRL 108, 081803 (2012)

New results on η'→πππ



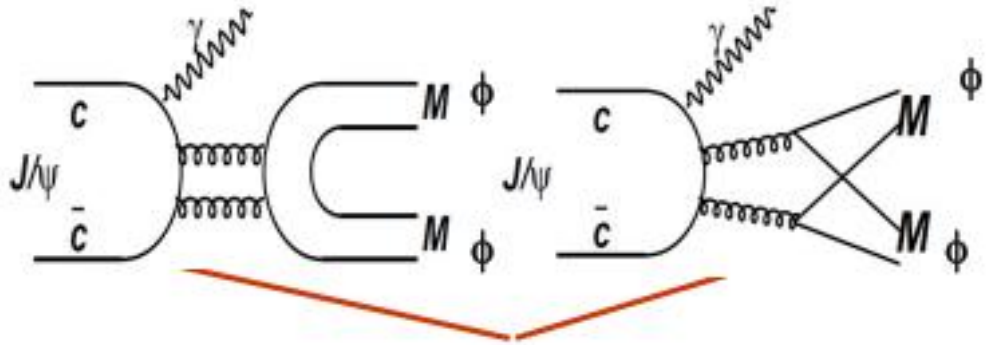
$$Br(\eta' \to \pi^+\pi^-\pi^0) = (3.83 \pm 0.15 \pm 0.39) \times 10^{-3} \quad \text{(PDG2010: } (3.6^{+1.1}_{-0.93}) \times 10^{-3}\text{)}$$
$$Br(\eta' \to \pi^0\pi^0\pi^0) = (3.56 \pm 0.22 \pm 0.34) \times 10^{-3} \quad \text{(PDG2010: } (1.68 \pm 0.22) \times 10^{-3}\text{)}$$

For 3pi⁰ decay, two time larger than the world average value.

Comparison:
isospin violation in η'→πππ

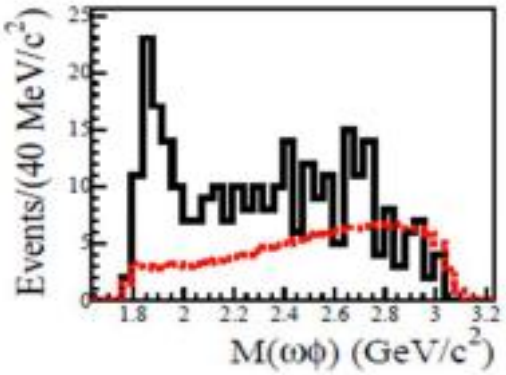
$$\frac{BR(\eta' \to \pi^+\pi^-\pi^0)}{BR(\eta' \to \pi^+\pi^-\eta)} \approx 0.9\%, \qquad \frac{BR(\eta' \to \pi^0\pi^0\pi^0)}{BR(\eta' \to \pi^0\pi^0\eta)} \approx 1.6\%$$

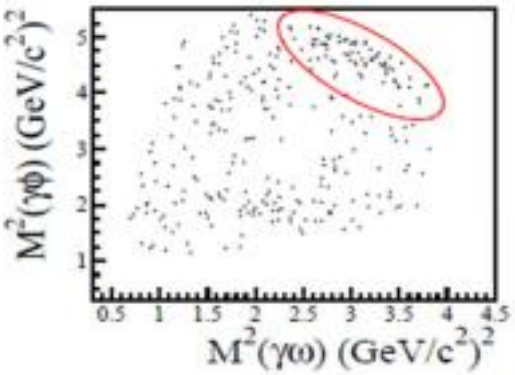
ωϕ threshold enhancement in J/ψ→γωϕ



$J/\psi \to \gamma\phi\phi, \phi \to K^+K^-$ **(OZI)** $J/\psi \to \gamma\omega\phi$ **(DOZI)**

BESII





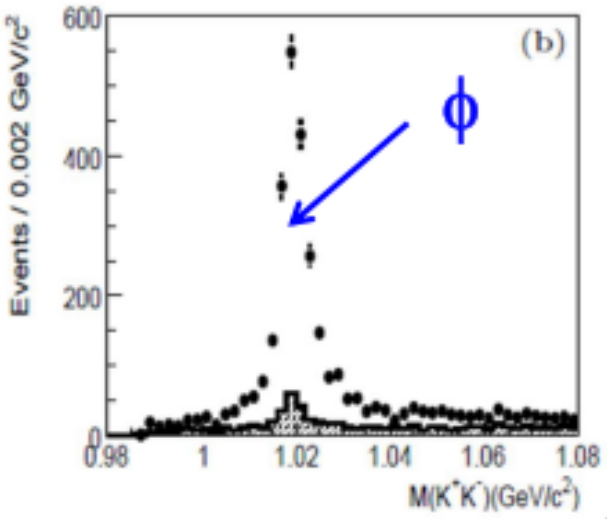
$M = 1812^{+19}_{-26} \pm 18\ \mathrm{MeV/c^2}$

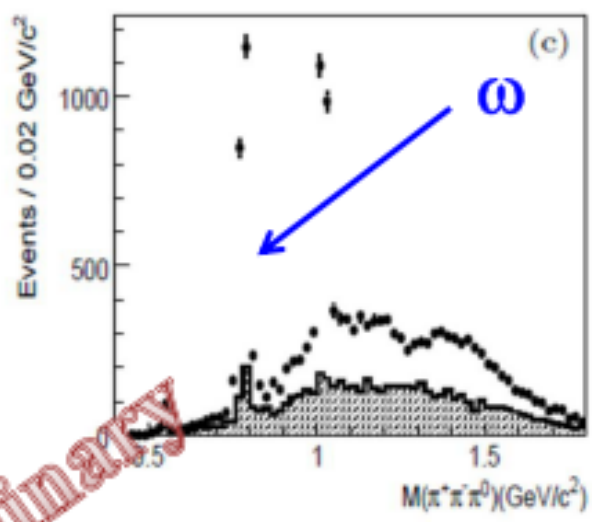
$\Gamma = 105 \pm 20 \pm 28\ \mathrm{MeV/c^2}$

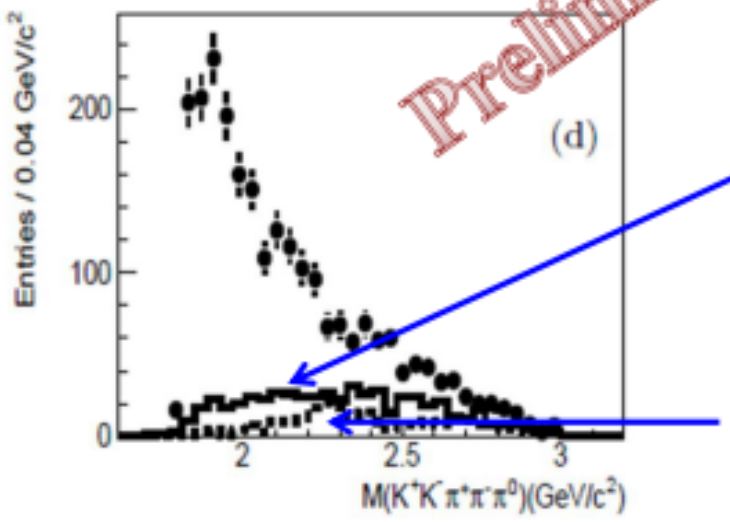
J^{PC} favors 0^{++} over 0^{-+} and 2^{++}

Phys. Rev. Lett. 96(2006)162002

J/ψ→γωϕ @ BESIII





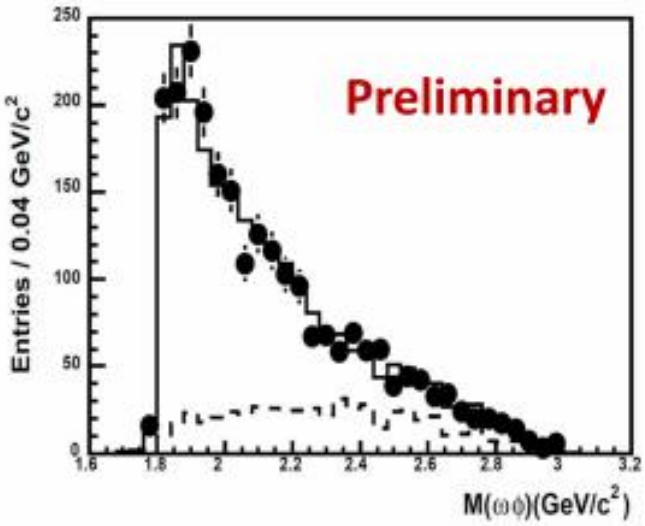


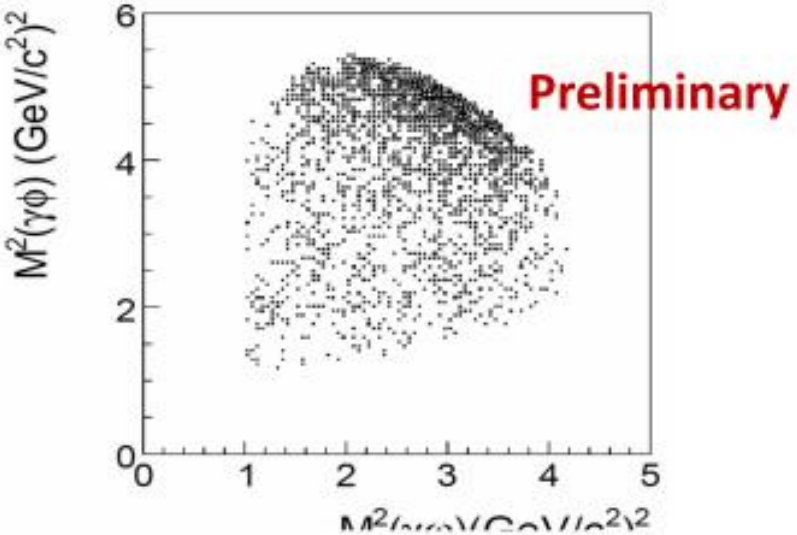
Preliminary

Backgrounds estimated from ω and ϕ sidebands

Backgrounds estimated from inclusive MC -- mainly from ωK*K

Preliminary PWA results @BESIII





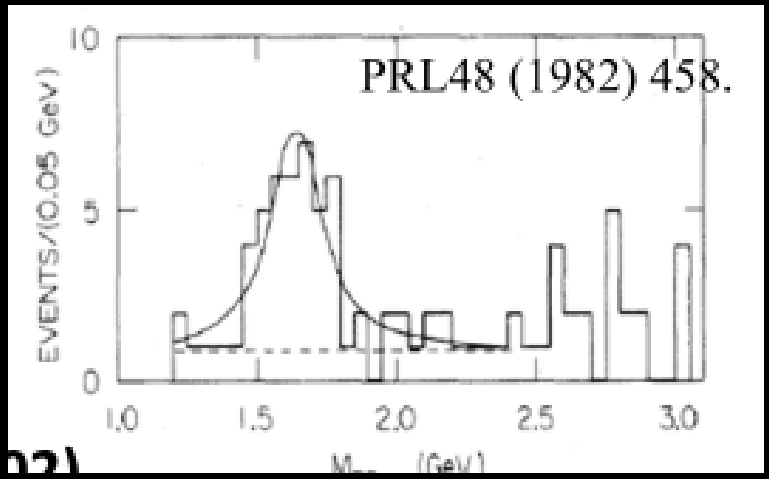
Resonance	J^{PC}	$M(\mathrm{MeV}/c^2)$	$\Gamma(\mathrm{MeV}/c^2)$	Significance
$X(1810)$	0^{++}	1795 ± 7	95 ± 10	$> 30\sigma$
$f_2(1950)$	2^{++}	1944	472	$> 10\sigma$
$f_0(2020)$	0^{++}	[illegible]2	442	$> 10\sigma$
$\eta(2225)$	0^{-+}	2240	1903	6.4σ

Preliminary

Is X(1810) the $f_0(1710)/f_0(1790)$ or new states?

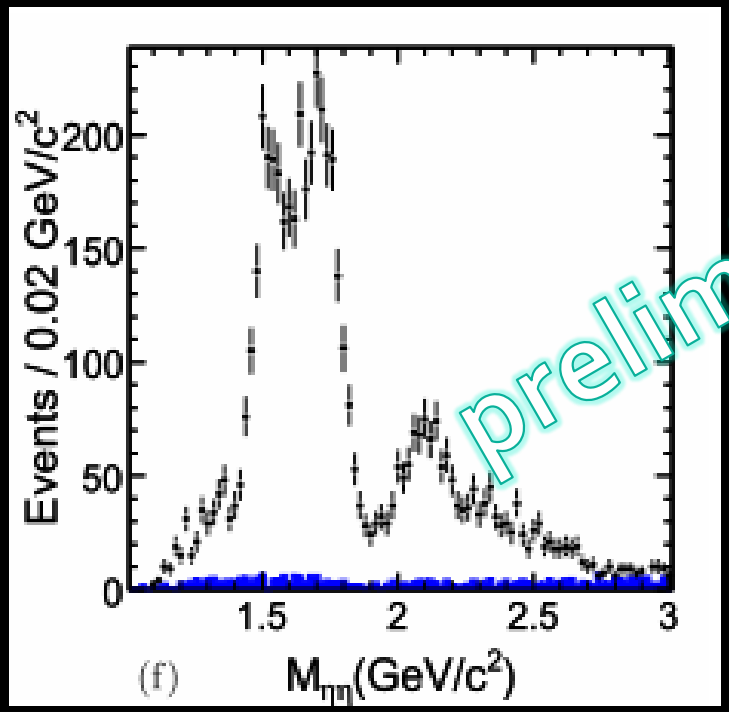
Study of ηη system

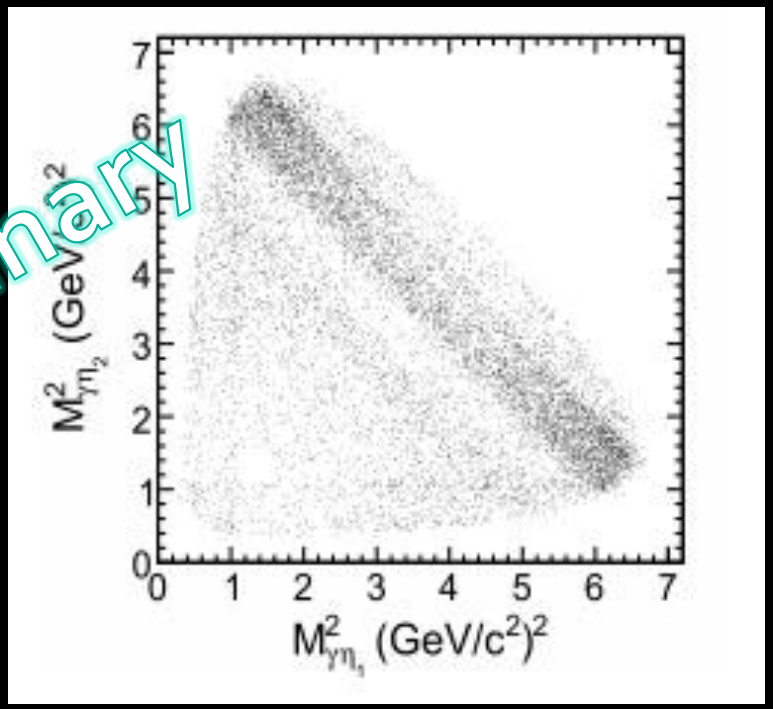
- First observed fo(1710) from J/ψ radiative decays to ηη by Crystal Ball in 1982



- 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^{++} (~1870), but no $f_0(1710)$
- E835 (2006): $\bar{p}p \rightarrow \pi^0\eta\eta$, found $f_0(1500)$ and $f_0(1710)$
- WA102 and GAMS all identified fo(1710) in ηη

J/ψ→γηη @ BESIII

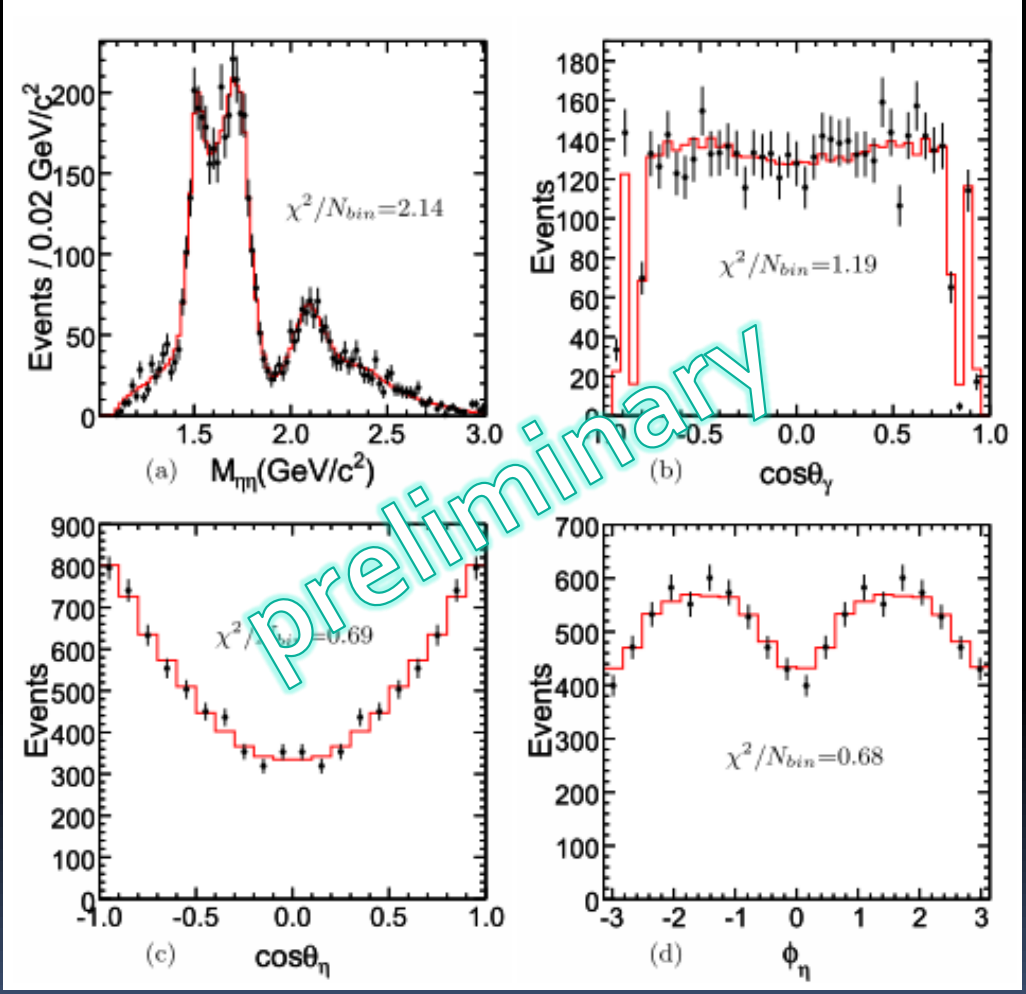




preliminary

- Clear resonance
- Low background

Preliminary PWA results of J/ψ→γηη



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

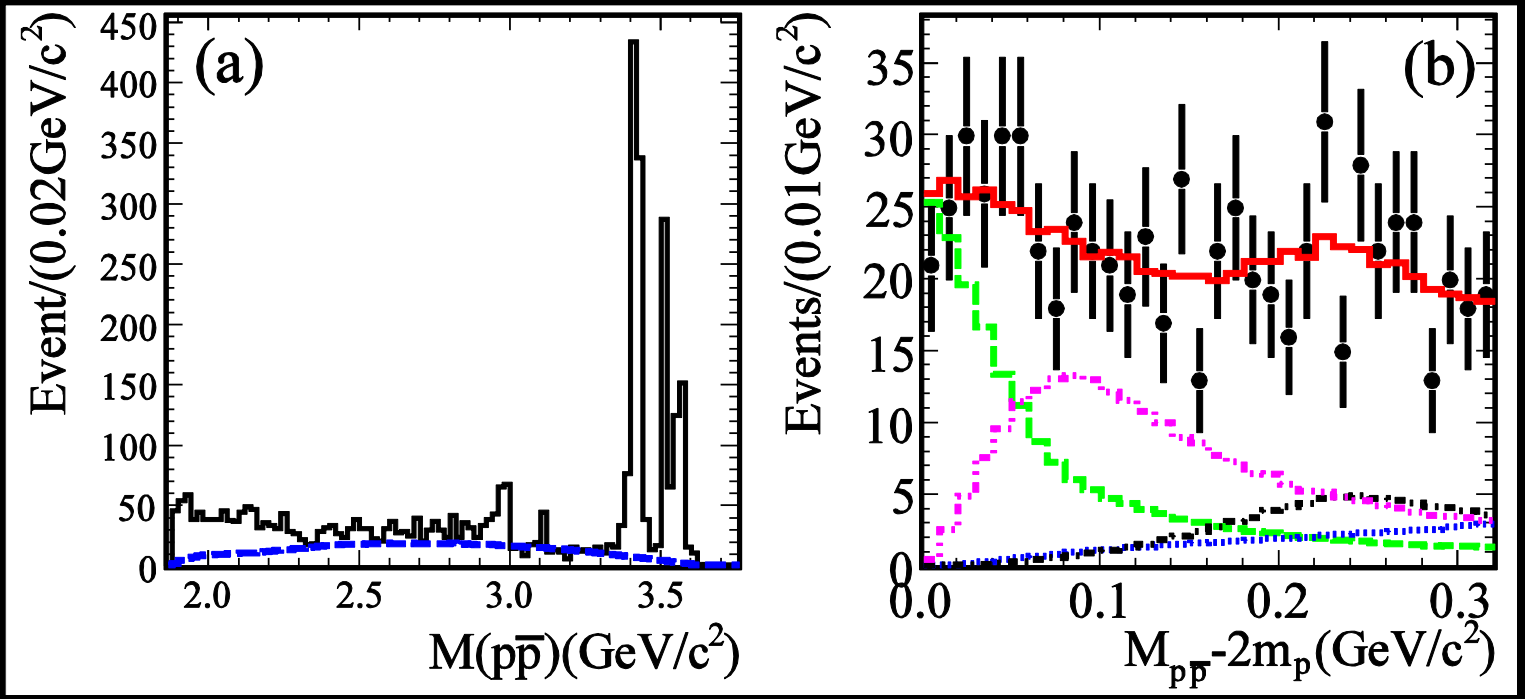
Preliminary PWA results of J/ψ→γηη

Resonance	Mass(MeV/c^2)	Width(MeV/c^2)	$\mathcal{B}(J/\psi \to \gamma X \to \gamma\eta\eta)$	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 σ
$f_0(1710)$	1759^{+6+14}_{-6-25}	172^{+10+3}_{-10-1}	$(2.35^{+0.07+1.23}_{-0.07-0.72}) \times 10^{-4}$	25.0 σ
$f_0(2100)$	2081^{+13+23}_{-13-34}	27^{+3}_{-2} $^{6}_{-18}$	$(9.99^{+0.57+5.52}_{-0.52-2.21}) \times 10^{-5}$	13.9 σ
$f_2'(1525)$	1513^{+5+3}_{-5-10}	$^{+12+15}_{-10-9}$	$(3.41^{+0.43+1.22}_{-0.50-1.23}) \times 10^{-5}$	11.0 σ
$f_2(1810)$	1822^{+29+61}_{-24-54}	$229^{+52+64}_{-42-152}$	$(5.38^{+0.60+3.31}_{-0.67-2.24}) \times 10^{-5}$	6.4 σ
$f_2(2340)$	$2362^{+31+139}_{-30-59}$	$334^{+62+164}_{-54-99}$	$(5.58^{+0.61+1.93}_{-0.65-1.81}) \times 10^{-5}$	7.6 σ

Summary

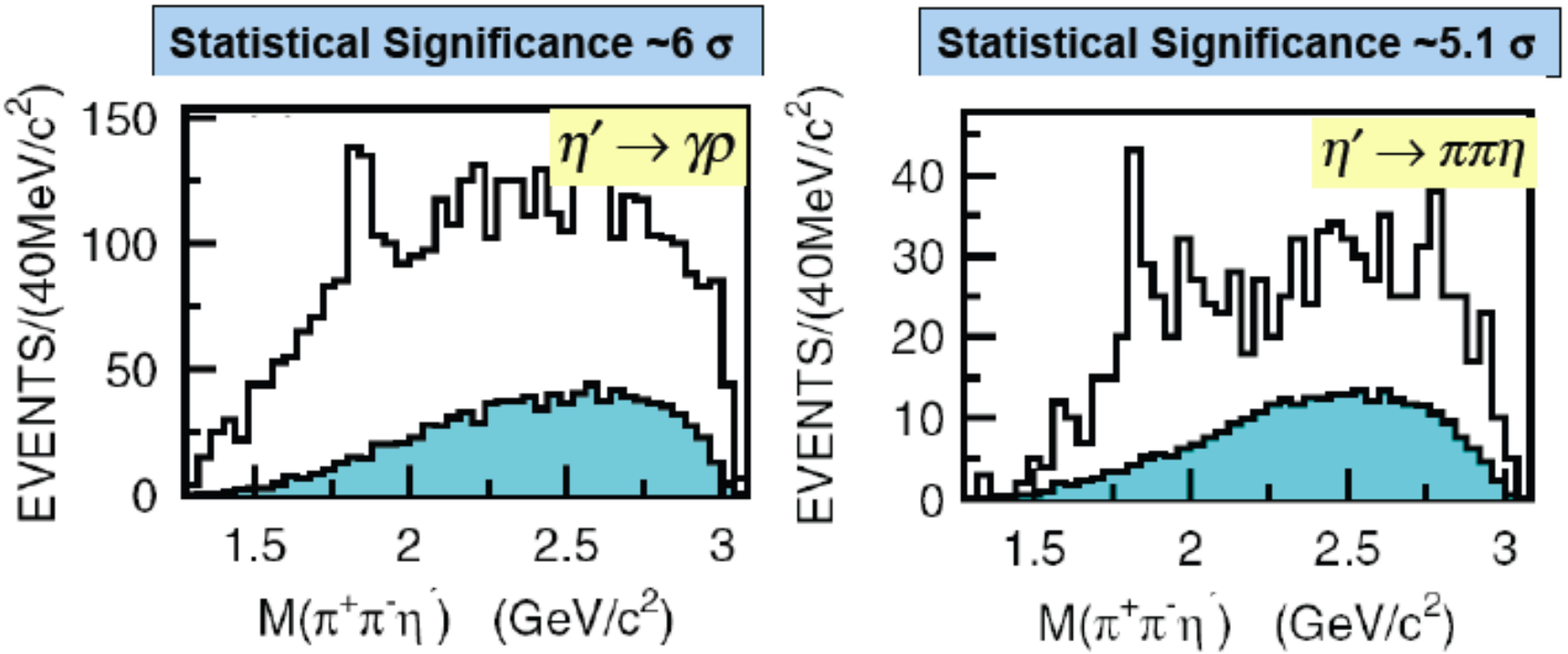
- $\bar{p}p$ threshold enhancement is confirmed at BESIII, and PWA is performed
- X(1835) is confirmed at BESIII, and two new structures are found : X(2120) and X(2370)
- X(1870) is found in $J/\psi \to \omega\eta\ \pi^+\pi^-$
- $a_0(980) - f_0(980)$ mixing is meausred
- $\eta(1405)$ is observed in $J/\psi \to \gamma f0(980)\pi 0$ (large Isospin violating)
- Preliminary results on $\omega\phi$ threshold enhancement and $\eta\eta$ system
- With more than 1 B J/ ψ and 0.5 B $\psi(2S)$, more exciting results are expected

Thank you!



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

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



PRL 95,262001(2005)