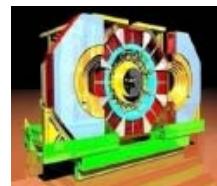


# Recent results of light hadron spectroscopy at BESIII

Sun Zhentian

University of Science and Technology of China  
(For BESIII Collaboration)

**YongPyong Winter Conference  
on Particle Physics, Feb. 2013, YongPyong, Korea**

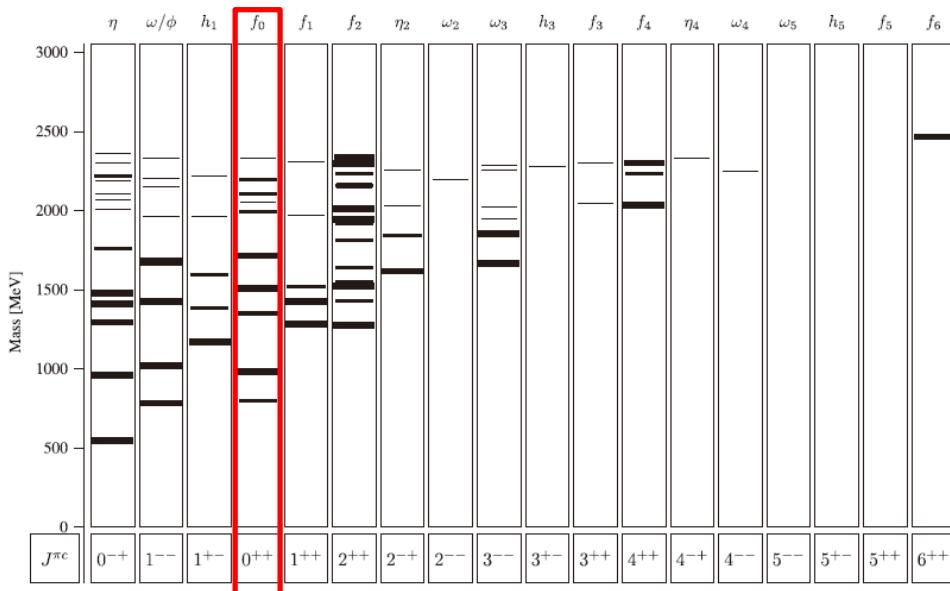


# Outline

- Introduction
- X(1835) and two new structure in  $J/\psi \rightarrow \gamma\eta'\pi^+\pi^-$
- $p\bar{p}$  threshold enhancement in  $J/\psi \rightarrow \gamma p\bar{p}$
- X(1870) in  $J/\psi \rightarrow \omega X$ ,  $X \rightarrow a_0(980)\pi \rightarrow \eta\pi\pi$
- $\omega\phi$  threshold enhancement in  $J/\psi \rightarrow \gamma\omega\phi$
- Preliminary PWA results of  $J/\psi \rightarrow \gamma\eta\eta$
- Isospin violate process  $J/\psi \rightarrow \gamma\eta(1405) \rightarrow \gamma f_0(980)\pi^0 \rightarrow \gamma\pi\pi\pi^0$
- Observation of two new  $N^*$  resonances in  $\psi' \rightarrow p\bar{p}\pi^0$
- Summary

# Introduction

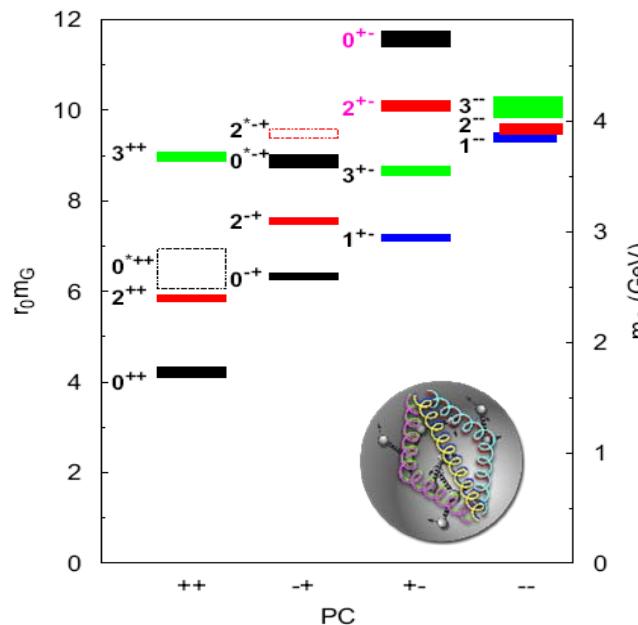
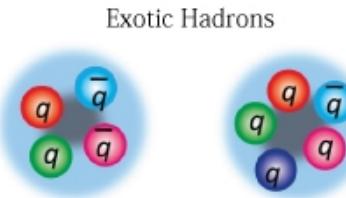
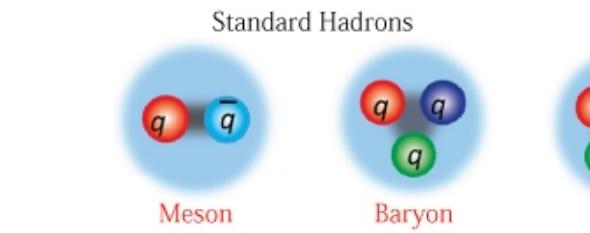
- About light hadron spectroscopy:
- ✓ Perturbative QCD is not suitable for such low-energy region.  
(LQCD, phenomenological theory...)...
- ✓ Some experimental result can't be explained by quark model.  
The abundance of scalar mesons, missing baryon problem...



Experimental light flavoured meson spectrum. Phys. Rept.454, 2007

# Introduction

- ✓ QCD allow the existence exotic states: glueball( $gg$ ), multiquarks( $q\bar{q}q\bar{q}$ ), hybrid( $q\bar{q}g$ ), molecular states...

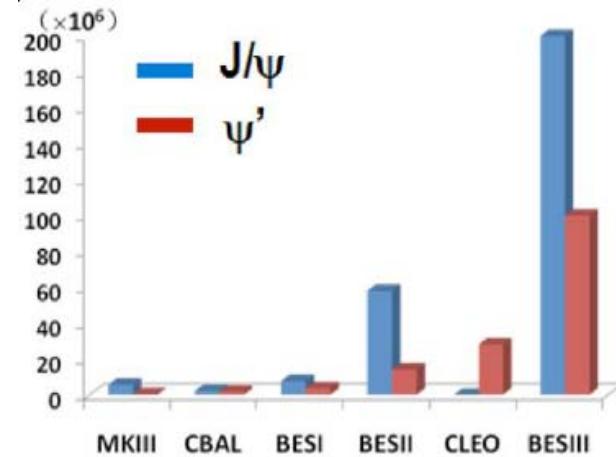


The glueball mass spectrum predicted by LQCD.  
PRD 60, 034509 (1999)

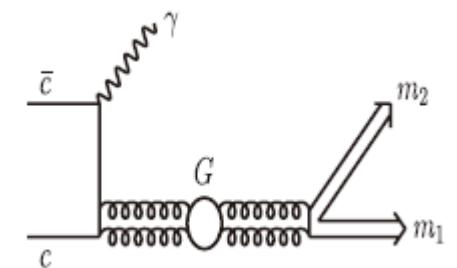
**There is still no exotic state well established.**

# Introduction

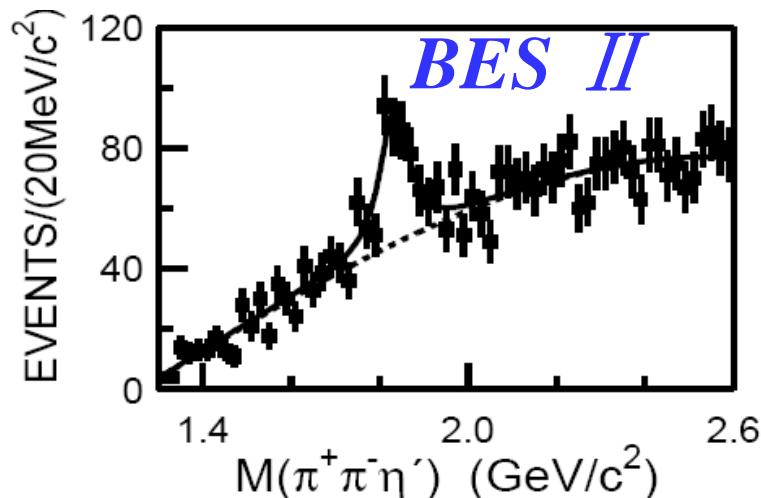
- Data Samples:
  - ✓ BesII: 58M  $J/\psi$ , 14M  $\psi(2S)$
  - ✓ BesIII round one: 225M  $J/\psi$ , 106M  $\psi(2S)$   
The result in this talk are mainly based on the two data samples.
  - ✓ BesIII round two: 1billion  $J/\psi$ , 0.4billion  $\psi(2S)$



- The advantage of BESIII's data sampels:
  - ✓ Radiative  $J/\psi$  decay is glueball rich process.
  - ✓ Clean environment for  $e^+e^-$  annihilation



# X(1835) and two new structure in $J/\psi \rightarrow \gamma \eta' \pi^+ \pi^-$

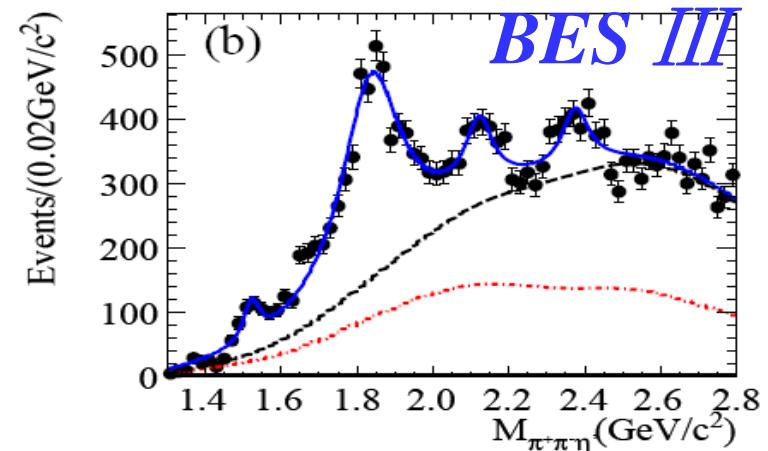


- **BESII, PRL 95,262001(2005)**

$$M = (1833.7 \pm 6.1 \pm 2.7) \text{MeV}/c^2$$

$$\Gamma = (67.7 \pm 20.3 \pm 7.7) \text{MeV}/c^2$$

$$\begin{aligned} \text{Br}(J/\psi \rightarrow \gamma X) \cdot \text{Br}(X \rightarrow \eta' \pi^+ \pi^-) \\ = (2.2 \pm 0.4 \pm 0.4) \times 10^{-4} \end{aligned}$$



- **BESIII, PRL 106, 072002(2011)**
- **Conform the existence of X(1835),**
- **Two new states are observed.**

# X(1835) and two new structure in $J/\psi \rightarrow \gamma \eta' \pi^+ \pi^-$

- the parameters of the 3 states.

- $X(1835)$

$$M = 1836.5 \pm 3.0(\text{stat})^{+5.6}_{-2.1}(\text{syst}) \text{ MeV}/c^2$$

$$\Gamma = 190 \pm 9(\text{stat})^{+38}_{-36}(\text{syst}) \text{ MeV}/c^2$$

- $X(2120)$

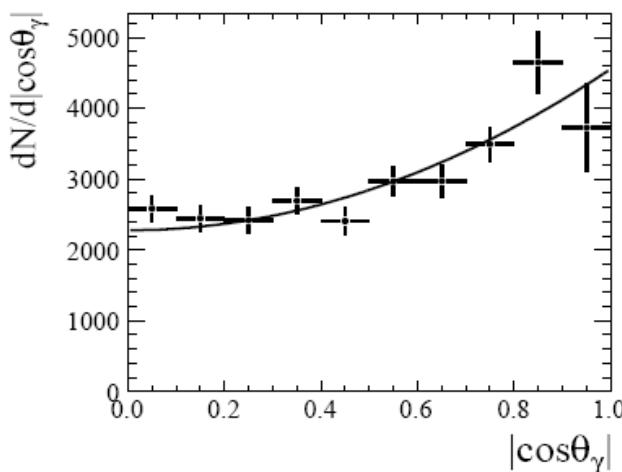
$$M = 2122.4 \pm 6.7(\text{stat})^{+4.7}_{-2.7}(\text{syst}) \text{ MeV}/c^2$$

$$\Gamma = 83 \pm 16(\text{stat})^{+31}_{-11}(\text{syst}) \text{ MeV}/c^2$$

- $X(2370)$

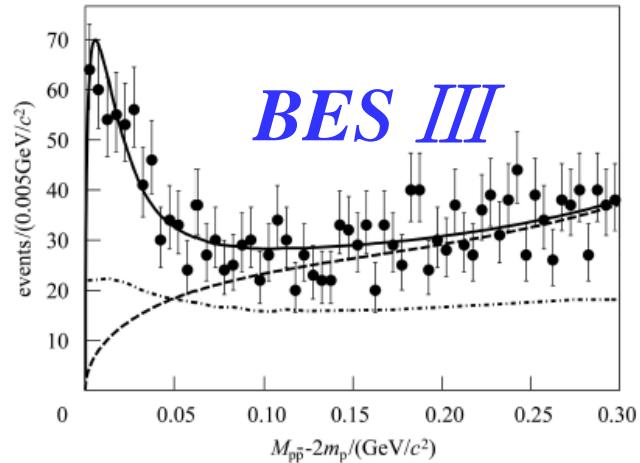
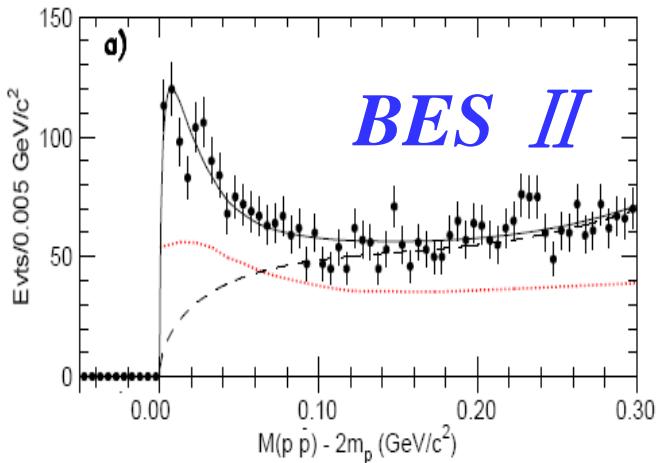
$$M = 2376.3 \pm 8.7(\text{stat})^{+3.2}_{-4.3}(\text{syst}) \text{ MeV}/c^2$$

$$\Gamma = 83 \pm 17(\text{stat})^{+44}_{-6}(\text{syst}) \text{ MeV}/c^2$$



- The angular distribution  $X(1835)$  consistent with  $0^-$
- Lattice QCD predicted the lowest  $0^-$  glueball to be around 2.3GeV.
- PWA needed to determine the  $J^{PC}$  of the 3 structures.

# $p\bar{p}$ threshold enhancement in $J/\psi \rightarrow \gamma p\bar{p}$



- Observed by **BESII.**  
**PRL91(2003)022001**
- Confirmed at **BESIII** with  
 $\psi' \rightarrow \pi\pi J/\psi$ ,  $J/\psi \rightarrow \gamma p\bar{p}$
- **CPC34(2010)421**

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

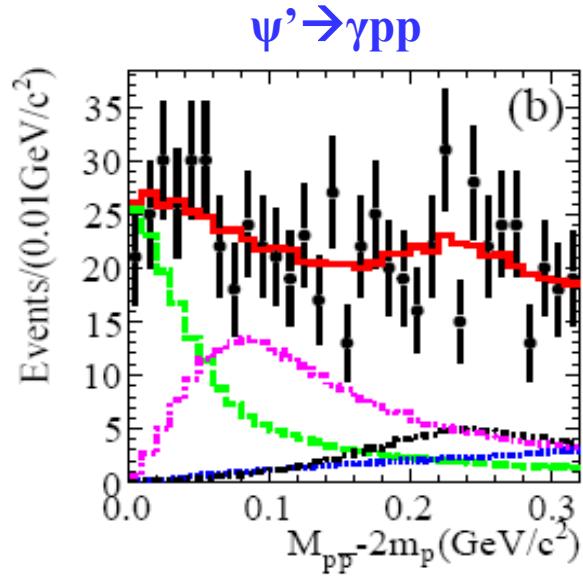
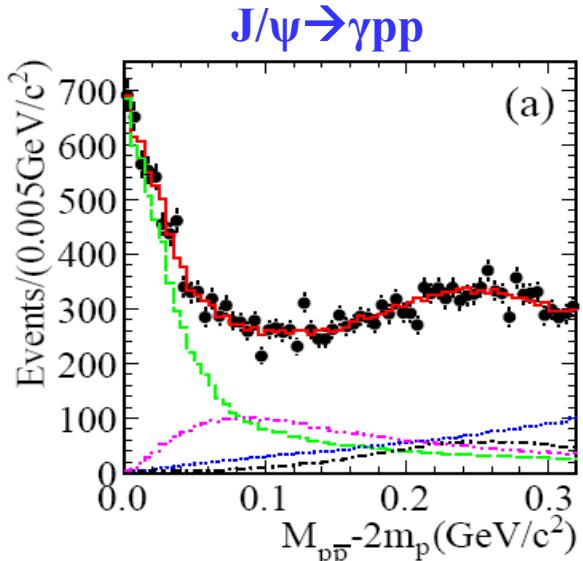
$$\Gamma < 30 \text{ MeV}/c^2 @ 90\% CL.$$

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

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

- Not observed in B-meson decay nor  $J/\psi \rightarrow \omega/\pi^0 p\bar{p}$   
→ the enhancement isn't pure FSI effect
- normal meson/pbar bound state/multiquark state/glueball?

# PWA of $J/\psi \rightarrow \gamma pp\bar{p}$ and $\psi' \rightarrow \gamma pp\bar{p}$



- PRL108(2012)112003
- PWA with Julich-FSI effects considered.
- $J^{PC}=0^{-+}$

$$M = 1832^{+19}_{-5} {}^{+18}_{-17} \pm 19 \text{ MeV}/c^2$$

$$M = 13 \pm 39^{+10}_{-13} \pm 4 \text{ MeV}/c^2$$

$$\text{Br}(J/\psi \rightarrow \gamma X) \cdot \text{Br}(X \rightarrow pp\bar{p})$$

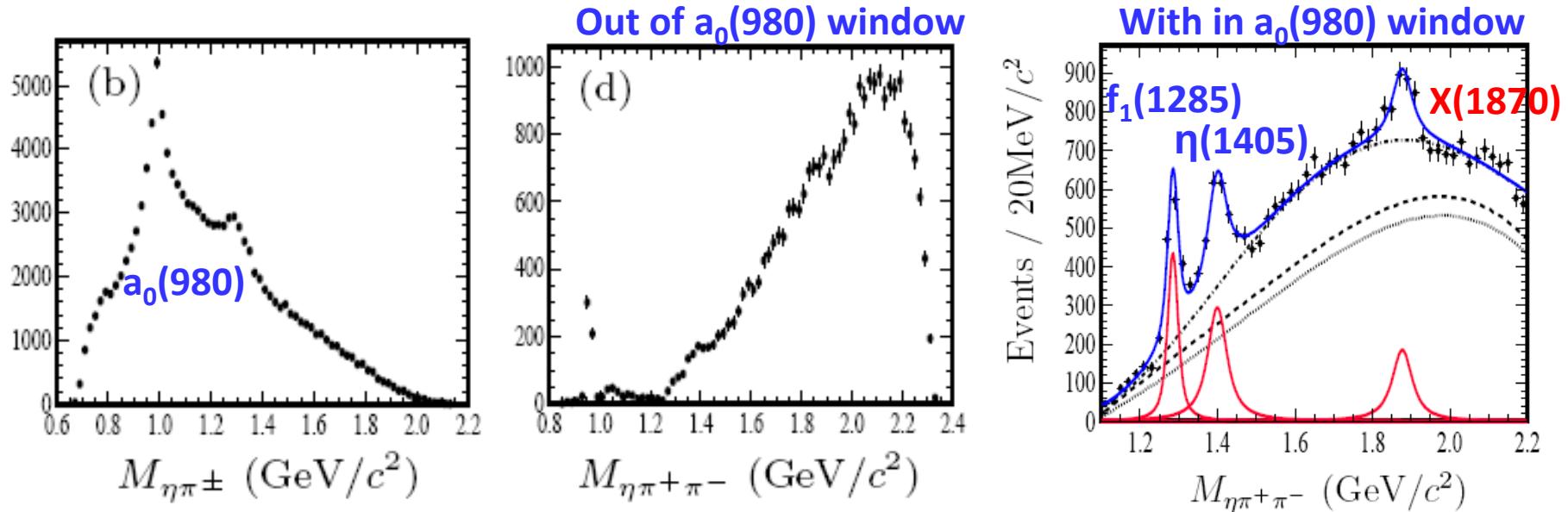
$$= (9.0^{+0.4}_{-1.1} {}^{+1.5}_{-5.0} \pm 2.3) \times 10^{-5}$$

$$R = \frac{\text{Br}(\psi' \rightarrow \gamma X)}{\text{Br}(J/\psi \rightarrow \gamma X)}$$

$$= (5.08^{+0.71}_{-0.45} {}^{+0.67}_{-3.58} \pm 0.12)\%$$

❑ **X(pp) and X(1835)  
observed in  $J/\psi \rightarrow \gamma \eta'\pi\pi$   
are the same state?**

# $X(1870)$ in $J/\psi \rightarrow \omega X$ , $X \rightarrow a_0(980)\pi \rightarrow \eta\pi^+\pi^-$

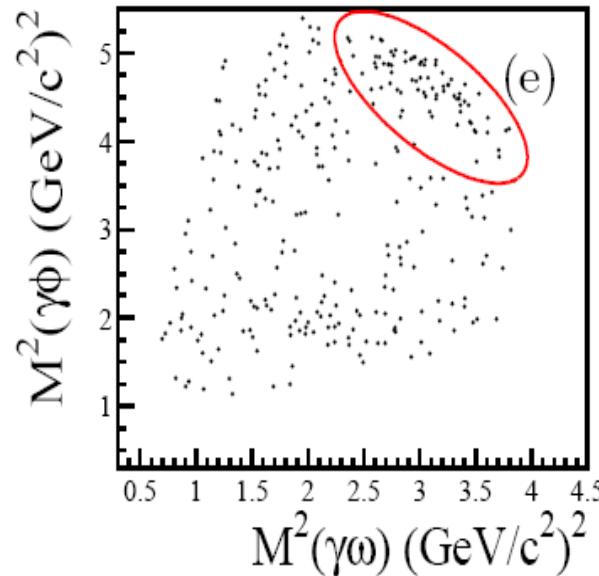
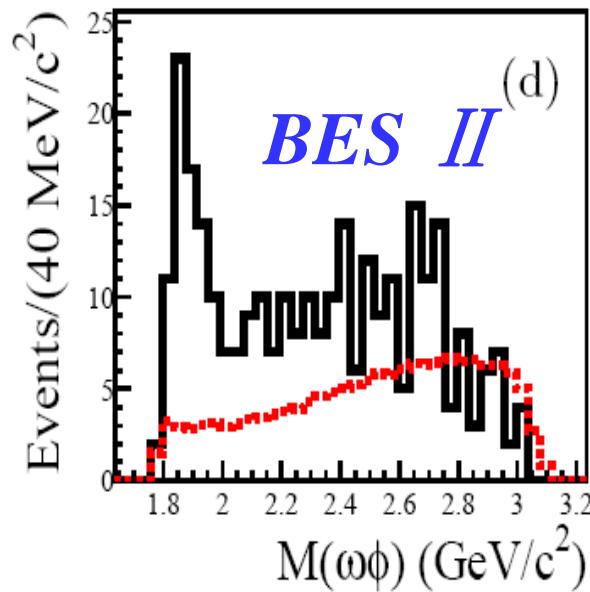


- **PRL 107, 182001(2011)**

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

- $X(1870)$   $J^{PC}$ ?  $X(1835)$ ? Need PWA.

# $\omega\phi$ threshold enhancement in $J/\psi \rightarrow \gamma\omega\phi$

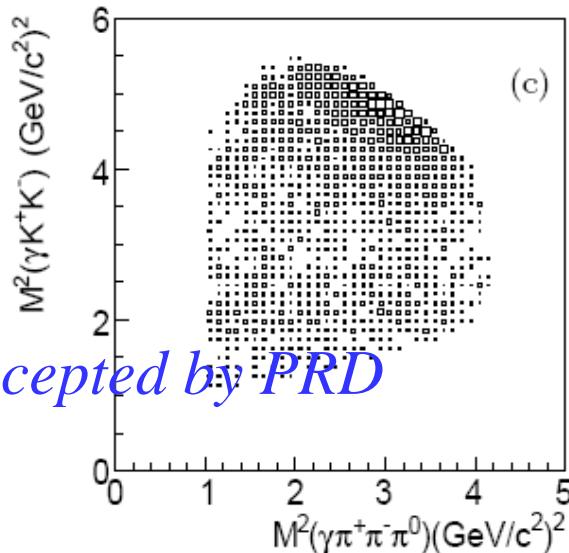
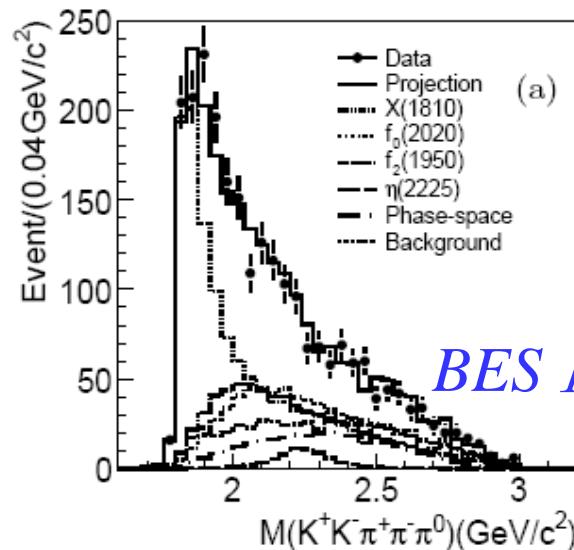


- First observed in BESII. [Phys. Rev. Lett. 96\(2006\)162002](#)
- Partial wave analysis with helicity covariant amplitude.
- Threshold enhancement: X(1810)

$J^{PC} = 0^{++}$ ,  $M = 1812_{-26}^{+19} \pm 18 \text{ MeV}/c^2$     $\Gamma = 105 \pm 20 \pm 28 \text{ MeV}/c^2$

$$B(J/\psi \rightarrow \gamma X(1810)) \cdot B(X(1810) \rightarrow \omega\phi) = (2.61 \pm 0.27 \pm 0.65) \times 10^{-4}$$

# $\omega\phi$ threshold enhancement in $J/\psi \rightarrow \gamma\omega\phi$

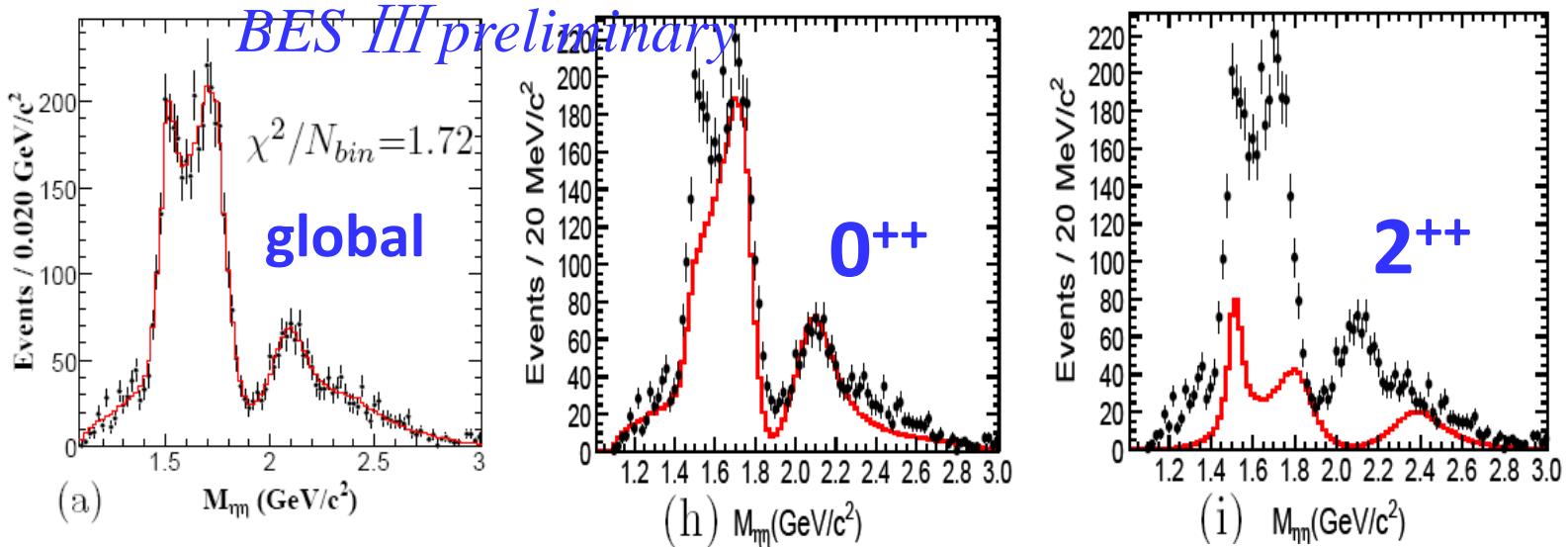


- PWA with covariant tensor amplitude. Arxiv: 1211.5668
- Threshold enhancement: X(1810)  
 $J^{PC} = 0^{++}$ ,  $M = 1795 \pm 7^{+23}_{-5} \text{ MeV}/c^2$        $\Gamma = 95 \pm 10^{+78}_{-34} \text{ MeV}/c^2$   
 $B(J/\psi \rightarrow \gamma X(1810)) \cdot B(X(1810) \rightarrow \omega\phi) = (2.00 \pm 0.08^{+1.38}_{-1.00}) \times 10^{-4}$
- DOZI suppressed, the branch fraction is too large.  
 Why? X(1810) is exotic states? f0(1710)?

# Study of $J/\psi \rightarrow \gamma\eta\eta \rightarrow \gamma\gamma\gamma\gamma\gamma$

- $\frac{1}{P.S.} \Gamma(G \rightarrow \pi\pi : K\bar{K} : \eta\eta : \eta\eta' : \eta'\eta')$  predicted to be 3:4:1:0:1. Glueball is flavor blindness. The analysis for other processes are in process.
- Neutral channels can take advantage of excellent performance of electromagnetic calorimeter of BESIII.
- GPUPWA package is developed to perform PWA of large data samples.

# Preliminary PWA results of $J/\psi \rightarrow \gamma\eta\eta$

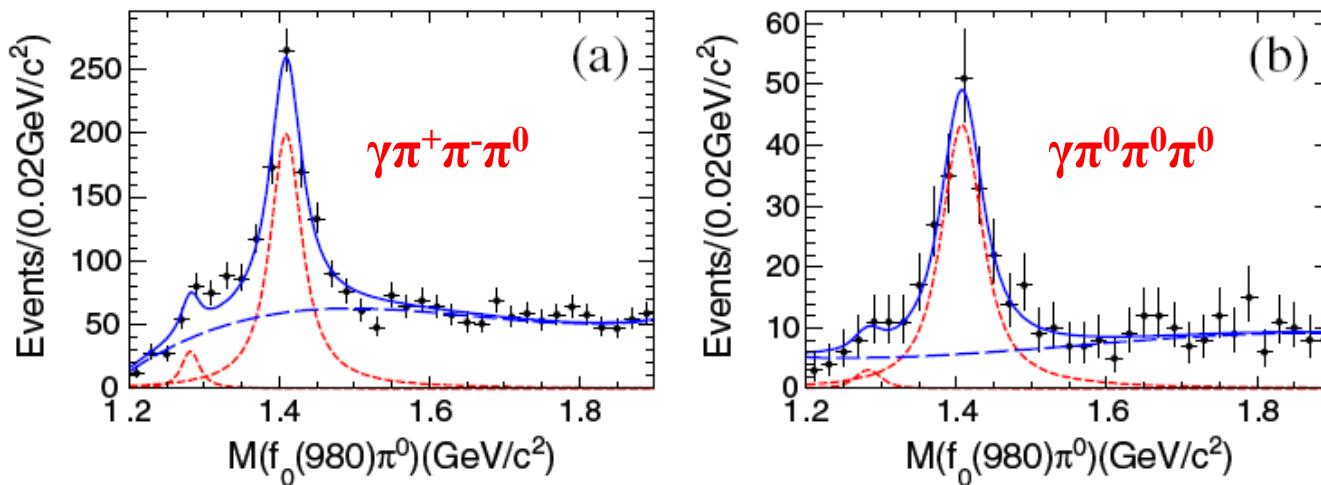


Resonance	Mass(MeV/ $c^2$ )	Width(MeV/ $c^2$ )	$\mathcal{B}(J/\psi \rightarrow \gamma X \rightarrow \gamma\eta\eta)$	Significance
$f_0(1500)$	$1468^{+14+23}_{-15-74}$	$136^{+41+28}_{-26-100}$	$(1.61^{+0.29+0.49}_{-0.32-1.37}) \times 10^{-5}$	$8.2\sigma$
$f_0(1710)$	$1759^{+6+15}_{-6-25}$	$172^{+10+32}_{-10-16}$	$(2.35^{+0.07+1.24}_{-0.07-0.74}) \times 10^{-4}$	$25.0\sigma$
$f_0(2100)$	$2081^{+13+24}_{-13-36}$	$273^{+27+70}_{-24-23}$	$(9.99^{+0.57+5.64}_{-0.52-2.46}) \times 10^{-5}$	$13.9\sigma$
$f'_2(1525)$	$1513^{+5+4}_{-5-10}$	$75^{+12+14}_{-10-8}$	$(3.41^{+0.43+1.37}_{-0.50-1.29}) \times 10^{-5}$	$11.0\sigma$
$f_2(1810)/f_2(1950)$	$1822^{+29+66}_{-24-57}$	$229^{+52+88}_{-42-155}$	$(5.38^{+0.60+3.41}_{-0.67-2.34}) \times 10^{-5}$	$6.4\sigma$
$f_2(2340)$	$2362^{+31+140}_{-30-63}$	$334^{+62+165}_{-54-100}$	$(5.58^{+0.61+2.36}_{-0.65-2.06}) \times 10^{-5}$	$7.6\sigma$

- **$f_0(1710)$  and  $f_0(2100)$  are the dominant scalars.**
- **$f_0(1500)$  exists ( $8.2\sigma$ ).**
- **$f'_2(1525)$  is the dominant tensor**

# Isospin violate process

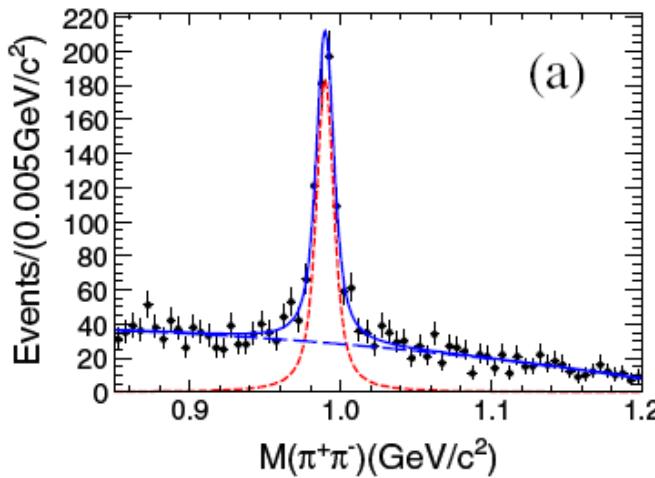
$J/\psi \rightarrow \gamma\eta(1405) \rightarrow \gamma f_0(980)\pi^0 \rightarrow \gamma\pi\pi\pi^0$



- PRL 108, 182001 (2012)
- $\eta(1405)(0^+(0^-)) \rightarrow f_0(980)(0^+(0^{++}))\pi^0(1^-(0^+))$  isospin violate process.
- $\text{Br}(J/\psi \rightarrow \gamma\eta(1405) \rightarrow \gamma\pi^0 f_0(980) \rightarrow \gamma\pi^0\pi^+\pi^-) = (1.50 \pm 0.11 \pm 0.11) \times 10^{-5}$
- $\text{Br}(J/\psi \rightarrow \gamma\eta(1405) \rightarrow \gamma\pi^0 f_0(980) \rightarrow \gamma\pi^0\pi^0\pi^0) = (7.10 \pm 0.82 \pm 0.72) \times 10^{-5}$
- The isospin-violating decay rate:  $\frac{\text{Br}(\eta(1405) \rightarrow \pi^0 f_0(980) \rightarrow \pi^0\pi^+\pi^-)}{\text{Br}(\eta(1405) \rightarrow \pi^0 a_0(980) \rightarrow \pi^0\pi^0\eta)} = (17.9 \pm 4.2)\%$
- While the  $a_0-f_0$  mixing rate is less than 1%

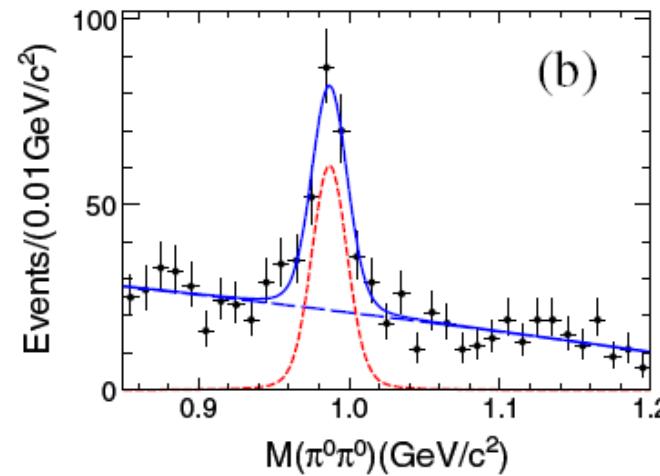
# Isospin violate process

$J/\psi \rightarrow \gamma \eta(1405) \rightarrow \gamma f_0(980)\pi^0 \rightarrow \gamma \pi\pi\pi^0$



$$M = 989.9 \pm 0.4 \text{ MeV}/c^2$$

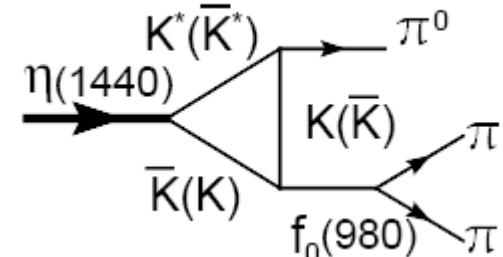
$$\Gamma = 9.5 \pm 1.1 \text{ MeV}/c^2$$



$$M = 987.0 \pm 1.4 \text{ MeV}/c^2$$

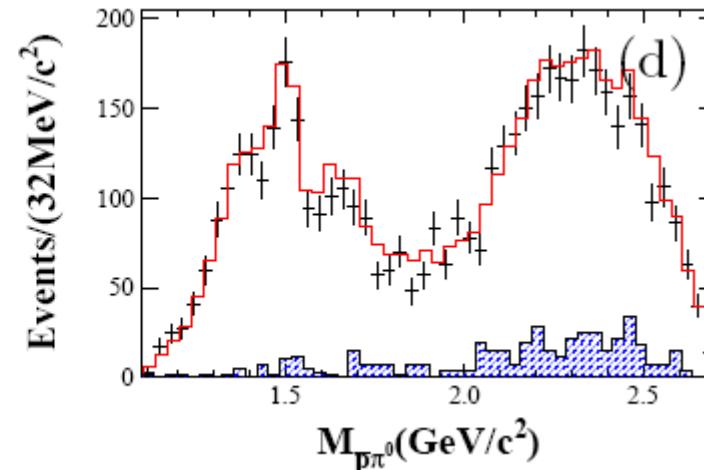
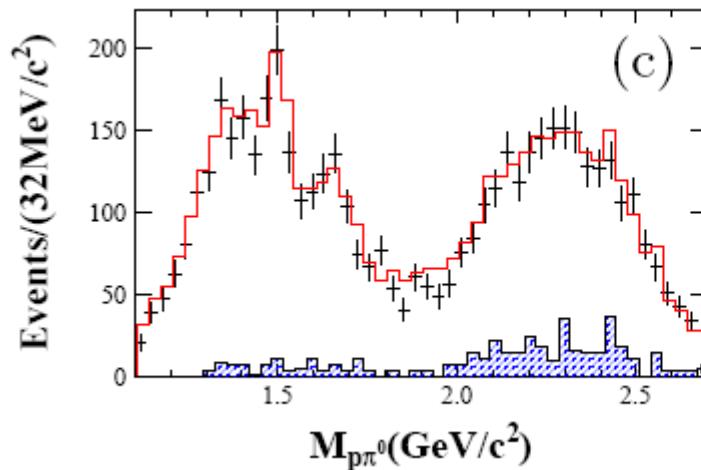
$$\Gamma = 4.6 \pm 5.1 \text{ MeV}/c^2$$

- $f_0(980)$ : PDG value  $\Gamma=40\sim100\text{MeV}$
- How to explain the narrow width of  $f_0(980)$  and large branch fraction of isospin violated process?
- Triangle singularity(TS) mechanism.  
Phys. Rev.Lett. 108, 081803 (2012).



# Observation of two new $N^*$ resonances in $\psi' \rightarrow p\bar{p}\pi^0$

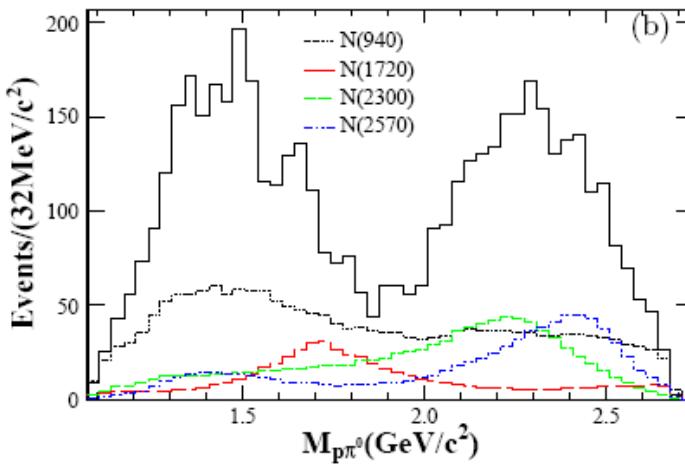
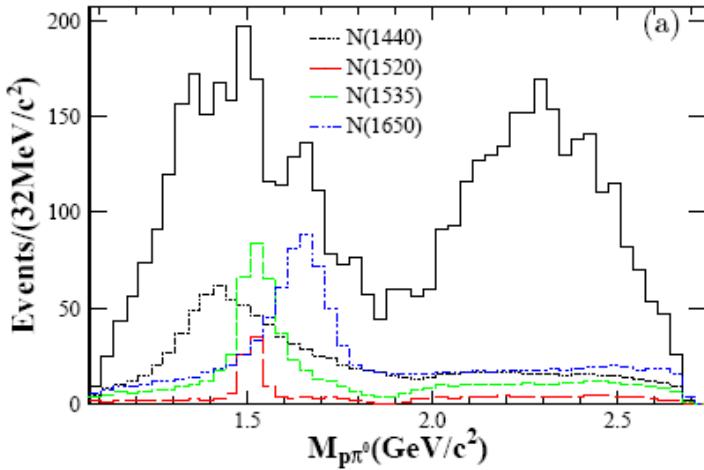
- Non-relativistic three-quark models of baryons predicted more excited states than are found experimentally (“missing resonance problem”).
- Most of the data about baryons on PDG are from  $\pi N$  scattering.
- The formula for baryons decay is much more complicated than mesons decay. FDCPWA ([Nucl.Instrum.Meth. A534 \(2004\) 241-245](#)) package is used to generated the formula.



The global fit result

Phys. Rev. Lett. 110, 022001 (2013)

# Observation of two new N\* resonances in $\psi' \rightarrow p\bar{p}\pi^0$



Resonance	N	$\epsilon$ (%)	B.F. ( $\times 10^{-5}$ )
$N(940)$	$1870^{+90+487}_{-90-327}$	$27.5 \pm 0.4$	$6.42^{+0.20+1.78}_{-0.20-1.28}$
$N(1440)$	$1060^{+90+459}_{-90-227}$	$27.9 \pm 0.4$	$3.58^{+0.25+1.59}_{-0.25-0.84}$
$N(1520)$	$190^{+14+64}_{-14-48}$	$28.0 \pm 0.4$	$0.64^{+0.05+0.22}_{-0.05-0.17}$
$N(1535)$	$673^{+45+263}_{-45-256}$	$25.8 \pm 0.4$	$2.47^{+0.28+0.99}_{-0.28-0.97}$
$N(1650)$	$1080^{+77+382}_{-77-467}$	$27.2 \pm 0.4$	$3.76^{+0.28+1.37}_{-0.28-1.66}$
$N(1720)$	$510^{+27+50}_{-27-197}$	$26.9 \pm 0.4$	$1.79^{+0.10+0.24}_{-0.10-0.71}$
$N(2300)$	$948^{+68+394}_{-68-213}$	$34.2 \pm 0.4$	$2.62^{+0.28+1.12}_{-0.28-0.64}$
$N(2570)$	$795^{+45+127}_{-45-83}$	$35.3 \pm 0.4$	$2.13^{+0.08+0.40}_{-0.08-0.30}$
Total	$4515 \pm 93$	$25.8 \pm 0.4$	$16.5 \pm 0.3 \pm 1.5$

□ Two new N\* states are observed, N(2300)(1/2<sup>+</sup>) and N(2570)(5/2<sup>-</sup>).

$$M(2300) = 2300^{+40 \quad +109}_{-30 \quad -0} \text{ MeV}/c^2 ,$$

$$\Gamma(2300) = 340^{+30 \quad +110}_{-30 \quad -58} \text{ MeV}/c^2$$

$$M(2570) = 2570^{+19 \quad +34}_{-10 \quad -10} \text{ MeV}/c^2 ,$$

$$\Gamma(2570) = 250^{+14 \quad +69}_{-24 \quad -21} \text{ MeV}/c^2$$

# Summary

- Many interesting states are observed:  $X(1835)(0^-)$ ,  $X(pp)(0^-)$ ,  $X(1870)(?)$ ,  $X(\omega\varphi)(0^{++})$
- Some of them are exotic states candidates.  
lowest scalar glueball( $f_0(1500)$ ,  $f_0(1710)$ ,  $x(\omega\varphi)...$ )  
lowest pseudo-scalar glueball( $X(2370)(?)?$ ,  $\eta(1405)$ )
- Troubled by the possible mixing between glueball and  $q\bar{q}$ , it's hard to distinguish an exotic state from normal states.
- Amplitude analysis is needed to determine the property of these states.