

Progress in Light hadron spectroscopy at BESIII

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(On behalf of the **BESIII** Collaboration)

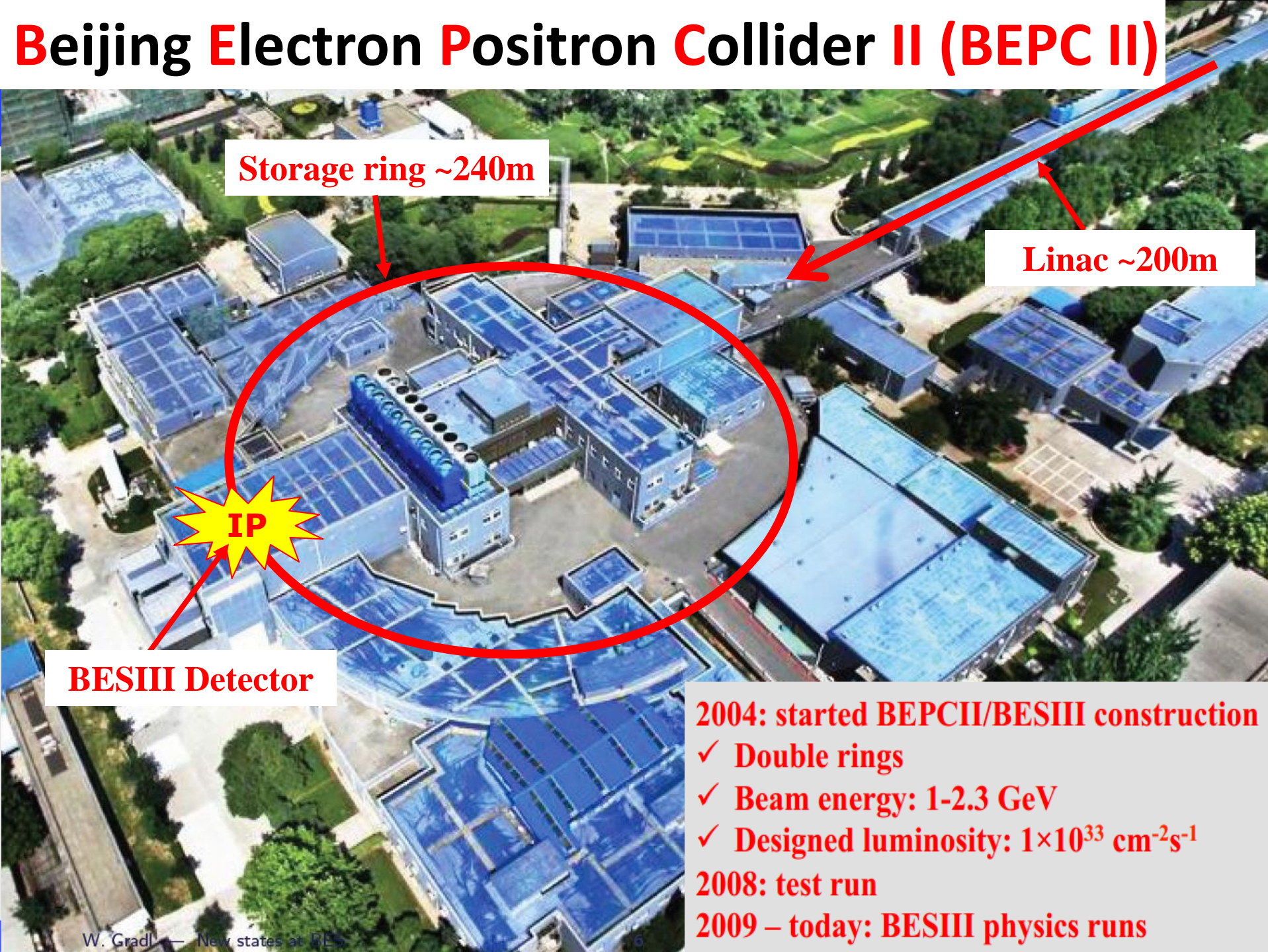


University of Science and Technology of China (USTC)

**4th International Workshop for young scientists with research
interests focused on physics at FAIR, 14-19 February, 2016
Garmisch-Partenkirchen**

OUTLINE

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 - ✓ **BESIII Collaboration**
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 - ✓ **$\eta(1405)$**
 - ✓ **Y(2175)**
 - ✓ **f_0^* & f_2^* excited states**
- **Highlights of baryon spectroscopy at BESIII**
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 - ✓ **E^* excited states**
- **Summary & Perspective**



Beijing Electron Positron Collider II (BEPC II)

Storage ring ~240m

Linac ~200m

IP

BESIII Detector

- 2004: started BEPCII/BESIII construction
- ✓ Double rings
- ✓ Beam energy: 1-2.3 GeV
- ✓ Designed luminosity: $1 \times 10^{33} \text{ cm}^{-2}\text{s}^{-1}$
- 2008: test run
- 2009 – today: BESIII physics runs

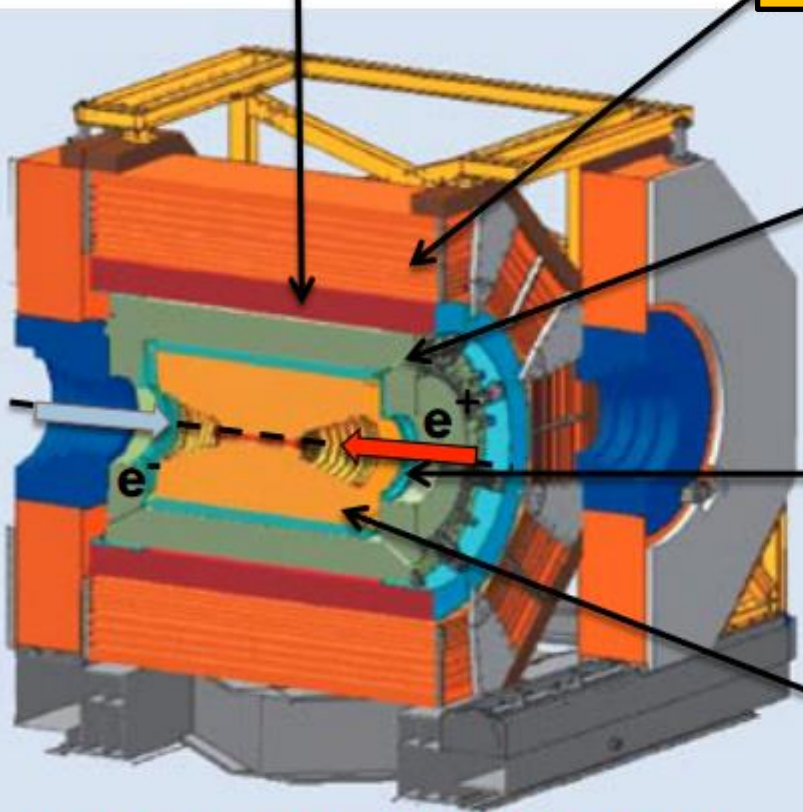
Superconducting solenoid (1T)

RPC Muon Detector
8 layers (end caps) + 9 layers (barrel)
 $\Delta\Omega/4\pi = 93\%$

Electromagnetic CsI(Tl) Calorimeter
 $\sigma_E/E < 2.5\%$ @ 1 GeV (barrel)
 $\sigma_E/E < 5\%$ @ 1 GeV (end caps)
 $\sigma_{xy} = (6 \text{ mm})/E^{1/2}$ @ 1 GeV

Time of Flight
 $\sigma_t = 90 \text{ ps}$ (barrel)
 $\sigma_t = 120 \text{ ps}$ (end caps)

Drift Chamber
 $\sigma_{r\phi} = 130 \mu\text{m}$ (single wire)
 $\sigma_{pt}/p_t = 0.5\%$ @ 1 GeV



Nucl. Instr. Meth. A614, 345 (2010)

BESIII Collaboration

Political Map of the World, June 1999

USA (5)

Univ. of Hawaii
Carnegie Mellon Univ.
Univ. of Minnesota
Univ. of Rochester
Univ. of Indiana

Europe (14)

Germany: Univ. of Bochum,
Univ. of Giessen, GSI

Univ. of Johannes Gutenberg
Helmholtz Ins. In Mainz

Russia: JINR Dubna; BINP Novosibirsk

Italy: Univ. of Torino, Univ. of Ferrara,
Frascati Lab

Netherland : KVI/Univ. of Groningen

Sweden: Uppsala Univ.

Turkey: Turkey Accelerator Center

Mongolia (1)

Ins. of Phy. & Tech.

Korea (1)

Seoul Nat. Univ.

Japan (1)

Tokyo Univ.

Pakistan (2)

Univ. of Punjab
COMSAT CIIT

China (34)

IHEP, CCAST, GUCAS, Shandong Univ.,
Univ. of Sci. and Tech. of China

Zhejiang Univ., Huangshan Coll.

Huazhong Normal Univ., Wuhan Univ.

Zhengzhou Univ., Henan Normal Univ.

Peking Univ., Tsinghua Univ. ,

Zhongshan Univ., Nankai Univ.

Shanxi Univ., Sichuan Univ., Univ. of South China

Hunan Univ., Liaoning Univ.

Nanjing Univ., Nanjing Normal Univ.

Guangxi Normal Univ., Guangxi Univ.

Suzhou Univ., Hangzhou Normal Univ.

Lanzhou Univ., Henan Sci. and Tech. Univ.

Beihang Univ., Beijing Petrol Chemical Univ.

~400 members
58 institutions
12 countries

<http://bes3.ihep.ac.cn>

BESIII Physics

➤ Charmonium(like) physics

- XYZ
- Spectroscopy
- Transitions and decays

➤ Light hadron physics

• Mesons and baryons spectroscopy

- Glueballs and hybrids
- Electromagnetic form factors
- Two-photon physics

➤ Open charm physics

- (semi) leptonic and hadronic decays
- Form factors
- CKM matrix: V_{cd} V_{cs}
- D^0 - D^0 bar mixing and CP violation
- Rare/forbidden decays

➤ QCD and τ physics

- Precise R value measurement
-


$$1.3 \times 10^9 \text{ J}/\psi$$

$$4.5 \times 10^8 \psi'$$

Highlights of meson spectroscopy at BESIII

✓ **X(18??) states**

✓ **$\eta(1405)$**

✓ **Y(2175)**

✓ **f_0^* & f_2^* excited states**

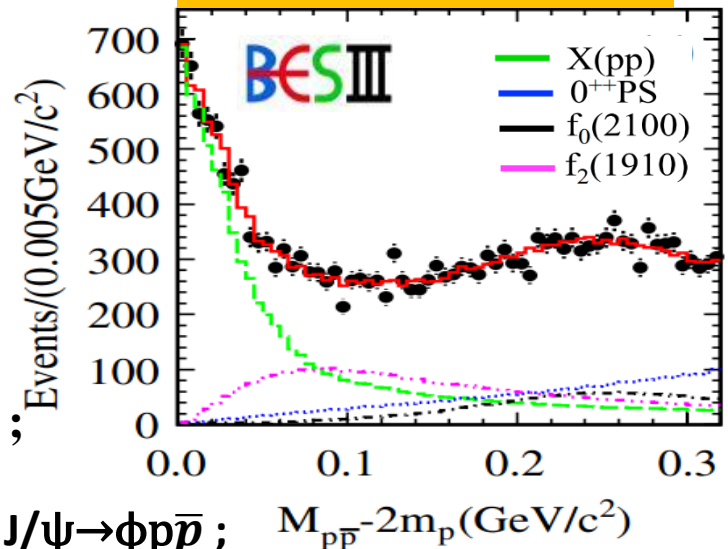
X(1860) in PWA of $J/\psi \rightarrow \gamma p \bar{p}$

now called X($p\bar{p}$)

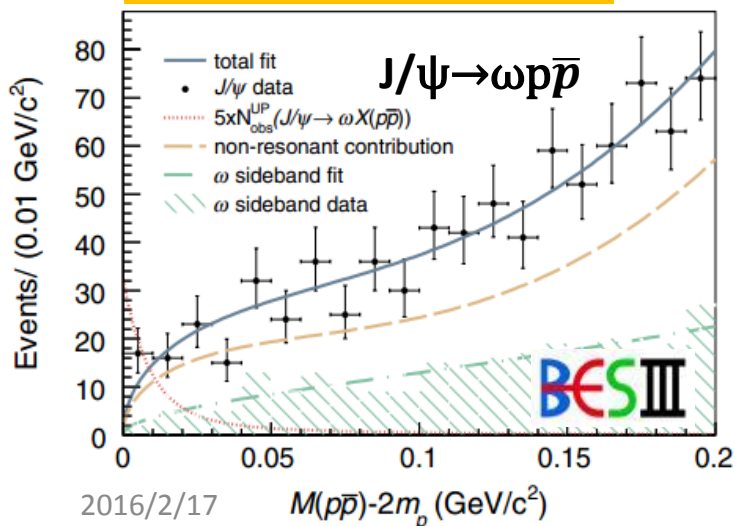
- Strong enhancement first observed at BESII [PRL 91,022001(2003)] and confirmed by CLEO-c [PRD82,092002(2012)];
- PWA was firstly performed at BESIII;
- Significance of the X($p\bar{p}$) component $> 30\sigma$, $> 5\sigma$ for the other components;
- The 0^{-+} assignment is better than other J^{PC} ;
- $M = 1832^{+19}_{-5}(\text{stat})^{+18}_{-17}(\text{syst}) \pm 19(\text{mode}) \text{ MeV}/c^2$;
- $\Gamma < 76 \text{ MeV}/c^2$ (90% C.L.);

No similar structure was observed in $J/\psi \rightarrow \omega p \bar{p}$ or $J/\psi \rightarrow \phi p \bar{p}$;

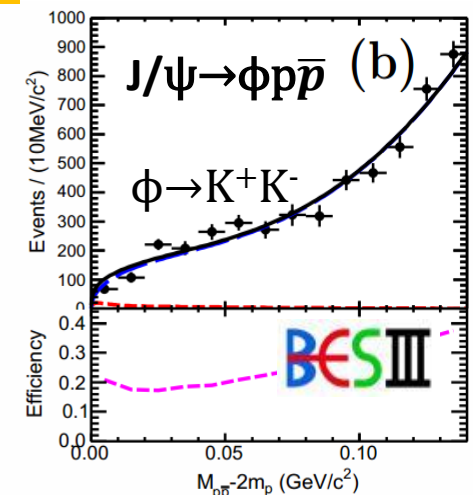
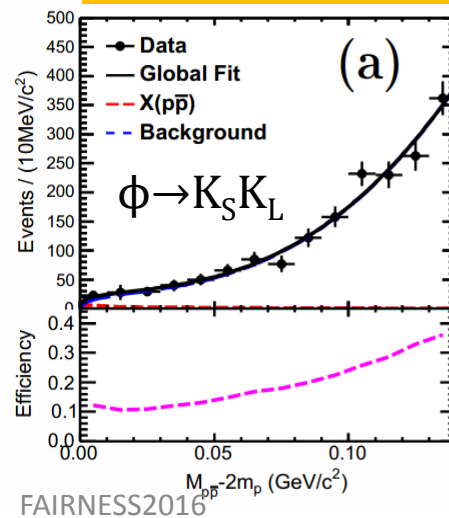
PRL 108,112003(2012)



PRD 87, 112004(2013)

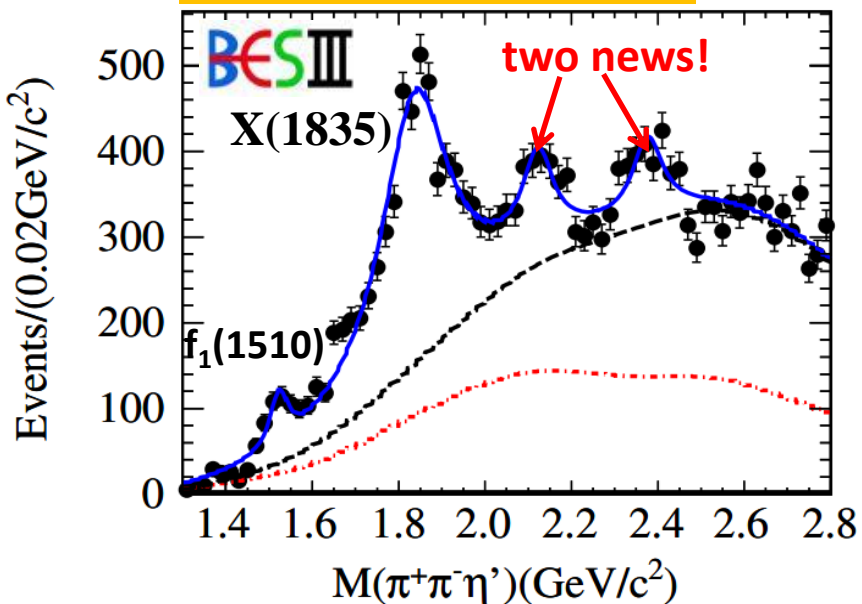


arXiv:1512.08197



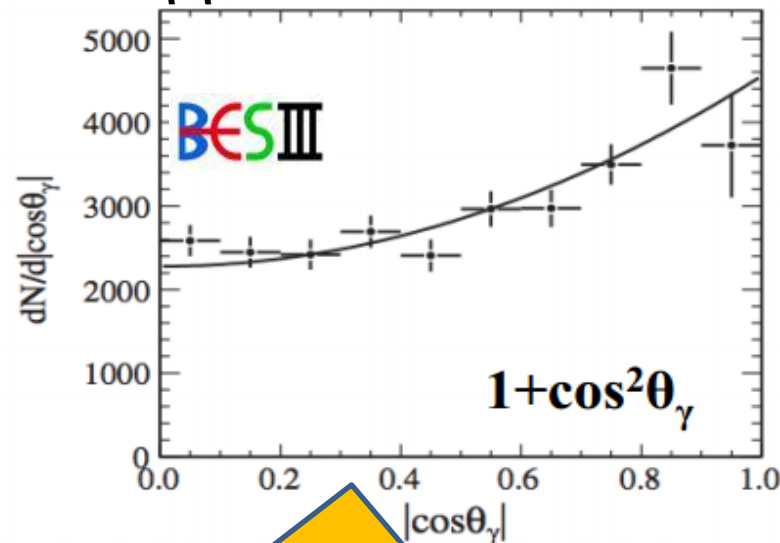
X(1835) in $J/\psi \rightarrow \gamma \pi^+ \pi^- \eta'$

PRL 106, 072002 (2011)



Resonance	$M(\text{MeV}/c^2)$	$\Gamma(\text{MeV}/c^2)$	N_{event}	
$f_1(1510)$	1522.7 ± 5.0	48 ± 11	230 ± 37	$>5.7\sigma$
X(1835)	1836.5 ± 3.0	190.1 ± 9.0	4265 ± 131	$>20\sigma$
X(2120)	2122.4 ± 6.7	83 ± 16	647 ± 103	$>7.2\sigma$
X(2370)	2376.3 ± 8.7	83 ± 17	565 ± 105	$>6.4\sigma$

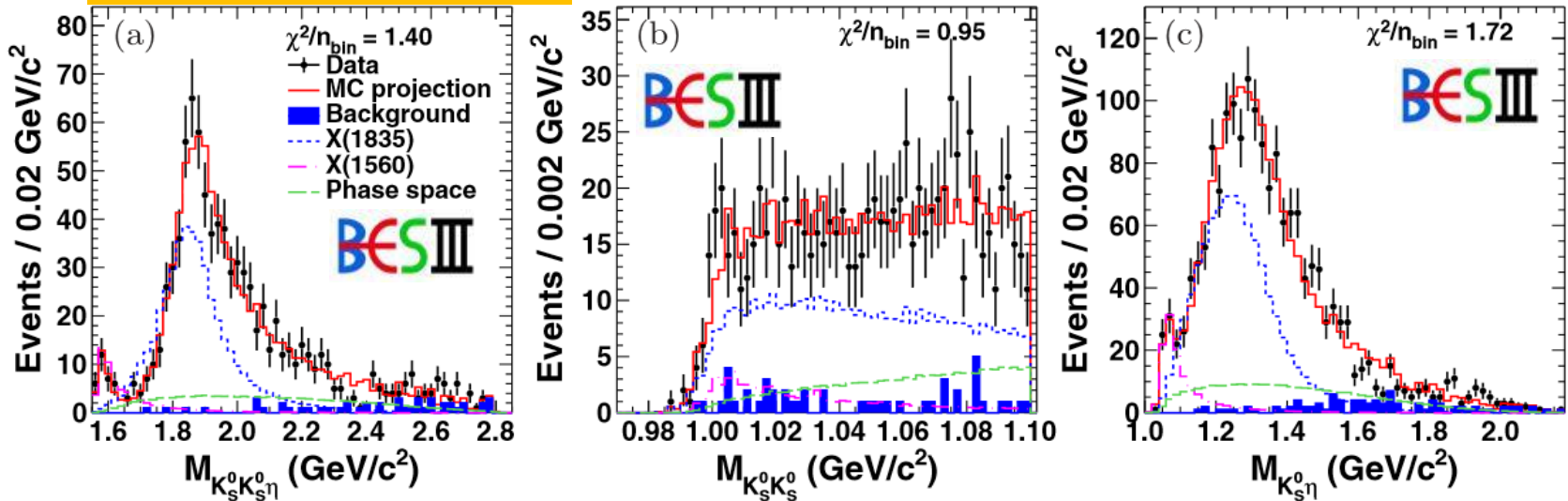
- X(1835) was first observed at BES, and then confirmed at BESII [PRL95,262001(2005)];
- **Significance of the X(1835) is $>20\sigma$;**
- **J^{PC} is assigned to be 0^- ;**
- Two additional structures observed at BESIII;
- Nature of X(2120)/X(2370): pseudoscalar glueball? η/η' excited states?



the angular distribution of the radiative photon is consistent with expectations for pseudoscalar 0^- ;

X(1835) in PWA of $J/\psi \rightarrow \gamma K_S^0 K_S^0 \eta$

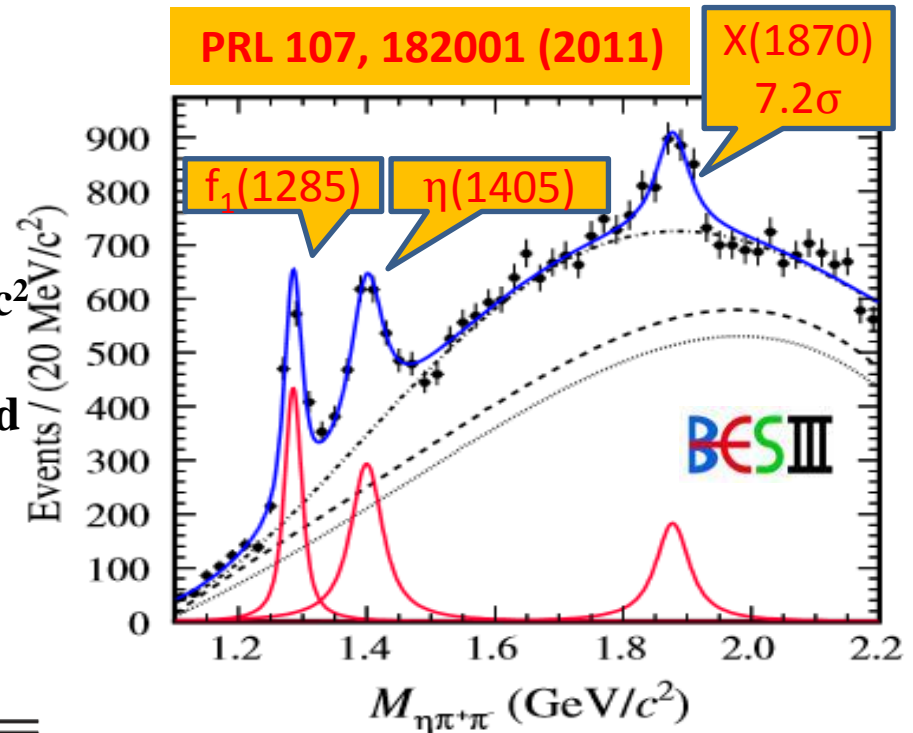
PRL 115, 091803 (2015)



- PWA of events with $M(K_S^0 K_S^0) < 1.1 \text{ GeV}/c^2$ and $M(K_S^0 K_S^0 \eta) < 2.8 \text{ GeV}/c^2$;
 - Final fit results:
 - the data can be best described with three components: $X(1835) \rightarrow f_0(980)\eta$, $X(1560) \rightarrow f_0(980)\eta$, and a non-resonant $f_0(980)\eta$ component ;
 - J^{PC} of $X(1835)$, $X(1560)$, and non-resonant component are all found to be 0^{++} ;
- $M = 1844 \pm 19 \text{ (stat)}^{+16}_{-25} \text{ (syst)} \text{ MeV}/c^2 \quad \Gamma = 192^{+20}_{-17} \text{ (stat)}^{+62}_{-43} \text{ (syst)} \text{ MeV} \quad (>12.9\sigma)$
 $BR = (3.31^{+0.33}_{-0.30} \text{ (stat)}^{+1.96}_{-1.29} \text{ (syst)}) \times 10^{-5}$
- $M = 1565 \pm 8 \text{ (stat)}^{+0}_{-63} \text{ (syst)} \text{ MeV}/c^2 \quad \Gamma = 45^{+14}_{-13} \text{ (stat)}^{+21}_{-28} \text{ (syst)} \text{ MeV} \quad (>8.9\sigma)$
- Consistent with the $X(1835)$ observed in $J/\psi \rightarrow \gamma \pi^+ \pi^- \eta$;

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

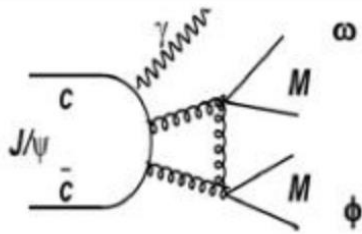
- First observation of $J/\psi \rightarrow \omega X(1870)$ and $X(1870) \rightarrow a_0^\pm(980) \pi^\mp$ with the significance 7.2σ ;
- J^{PC} is unknown;
- $M = 1877.3 \pm 6.3(\text{stat})^{+3.4}_{-7.4}(\text{syst}) \text{ MeV}/c^2$
- $\Gamma = 57 \pm 12(\text{stat})^{+19}_{-4.0}(\text{syst}) \text{ MeV}/c^2$;
- $f_1(1285)$ and $\eta(1405)$ are also observed with significances $>10\sigma$;
- the product branching fractions for $X(1870)$, $f_1(1285)$ and $\eta(1405)$ are measured for the first time.



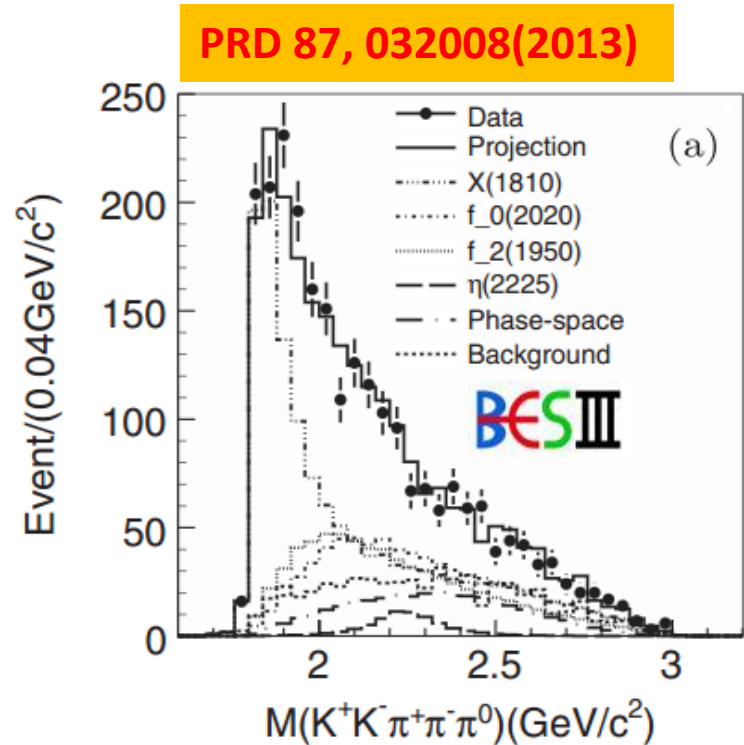
Resonance	Mass (MeV/c^2)	Width (MeV/c^2)	$\mathcal{B}(10^{-4})$
$f_1(1285)$	$1285.1 \pm 1.0^{+1.6}_{-0.3}$	$22.0 \pm 3.1^{+2.0}_{-1.5}$	$1.25 \pm 0.10^{+0.19}_{-0.20}$
$\eta(1405)$	$1399.8 \pm 2.2^{+2.8}_{-0.1}$	$52.8 \pm 7.6^{+0.1}_{-7.6}$	$1.89 \pm 0.21^{+0.21}_{-0.23}$
$X(1870)$	$1877.3 \pm 6.3^{+3.4}_{-7.4}$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

Whether the resonant structure of X(1870) is due to the X(1835), the $\eta_2(1870)$, an interference of both, or a new resonance still needs further study!

X(1810) in PWA of $J/\psi \rightarrow \gamma \omega \phi$



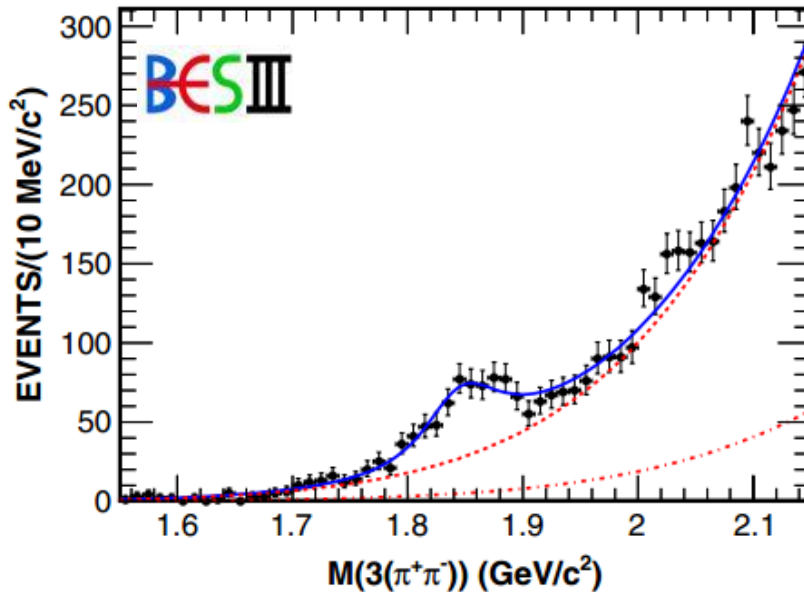
- $J/\psi \rightarrow \gamma \omega \phi$ is double OZI suppressed;
- The X(1810) is first observed by PWA at BESII [PRL 96, 162002 (2006)] ;
- X(1810) observed and confirmed at BESIII with the significance $>30\sigma$;
- the J^{PC} of the X(1810) is 0^{++} ;
- The enhancement is not compatible with either the X(1835) or the X($p\bar{p}$) due to the different masses and spin-parity.



Resonance	J^{PC}	$M(\text{MeV}/c^2)$	$\Gamma(\text{MeV}/c^2)$	Events	ΔS	Δndf	Significance
X(1810)	0^{++}	1795 ± 7	95 ± 10	1319 ± 52	783	4	$>30\sigma$
$f_2(1950)$	2^{++}	1944	472	665 ± 40	211	2	20.4σ
$f_0(2020)$	0^{++}	1992	442	715 ± 45	100	2	13.9σ
$\eta(2225)$	0^{-+}	2226	185	70 ± 30	23	2	6.4σ
Coherent nonresonant component	0^{-+}	319 ± 24	45	2	9.1σ

X(1840) in $J/\psi \rightarrow \gamma 3(\pi^+\pi^-)$

PRD 88, 091502 (2013)

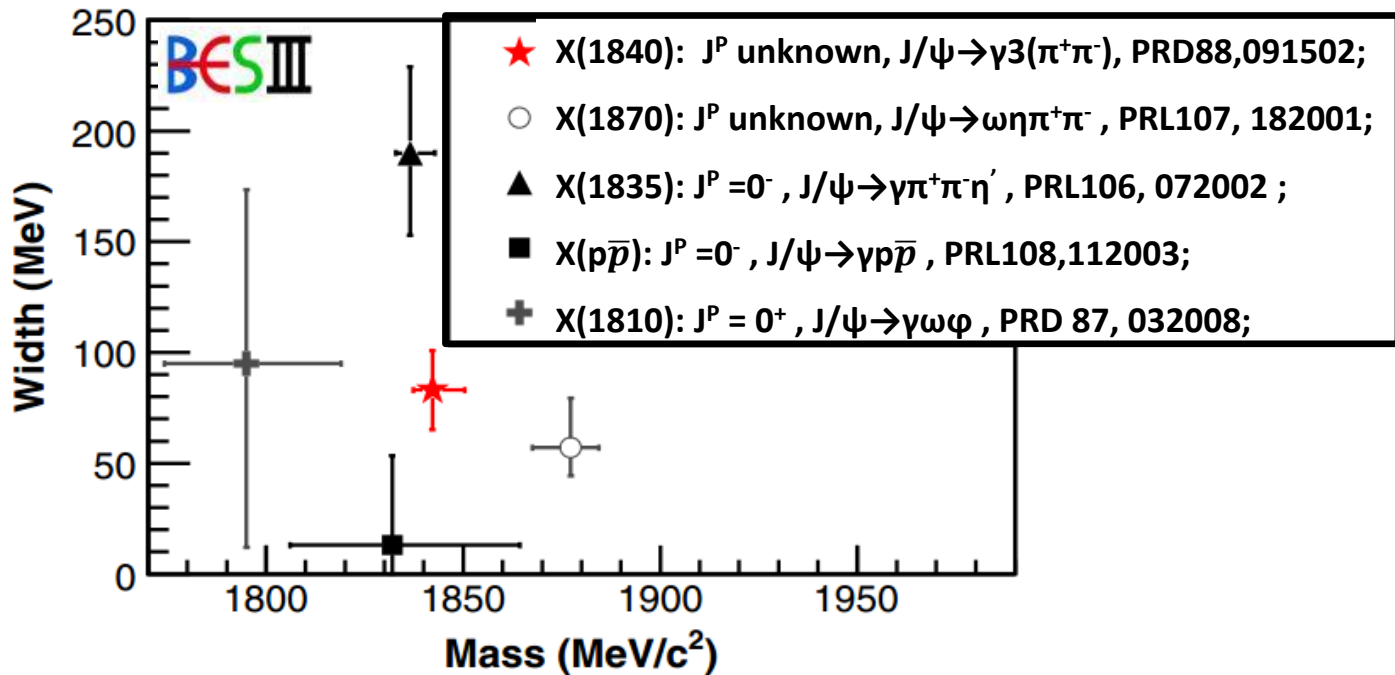


- A structure at $1.84\text{GeV}/c^2$ is observed in the mass spectrum $3(\pi^+\pi^-)$ with a significance of 7.6σ ;
- J^{PC} is unknown;
- $M=1842.2 \pm 4.2^{+7.1}_{-2.6} \text{ MeV}/c^2$;
 $\Gamma=83 \pm 14 \pm 11 \text{ MeV}/c^2$;

$$B(J/\psi \rightarrow \gamma X(1840)) \times B(X(1840) \rightarrow 3(\pi^+\pi^-)) = (2.44 \pm 0.36^{+0.60}_{-0.74}) \times 10^{-5}$$

- ✓ The mass is consistent with that of X(1835), but the width is significantly different from either of them, and much smaller than $\Gamma_{X(1835)} = 190.1 \pm 9.0^{+38}_{-36} \text{ MeV}/c^2$;
- ✓ We cannot determine whether X(1840) is a new state or a new decay modes of existing X(1835);

Comparison of X(18??) at BESIII



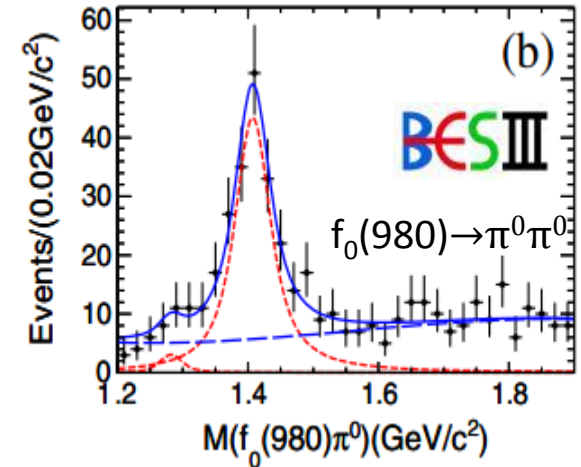
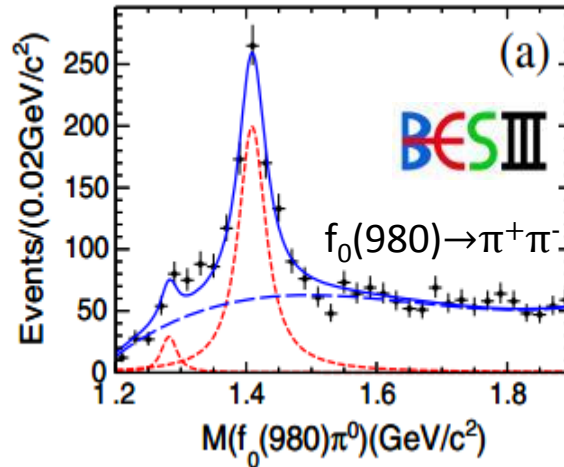
X(18??) are near proton-antiproton threshold:

- **The X(1810) is not compatible with either the X(1835) or the X($p\bar{p}$) due to the different masses and J^{PC} ;**
- **X($p\bar{p}$) may be the tail of X(1835);**
- **X(1840) is in agreement with X(1835) and X($p\bar{p}$), while its width is significantly different;**
- **More studies are needed to confirm;**

$\eta(1405)$ in $J/\psi \rightarrow \gamma 3\pi$

PRL 108, 182001 (2012)

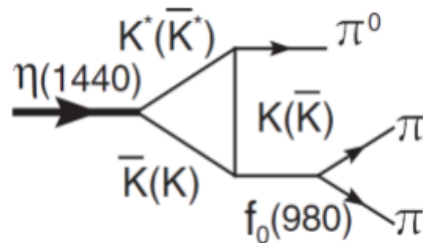
- $\eta(1440) \left\{ \begin{array}{l} \eta(1405) \rightarrow a_0 \pi \\ \eta(1475) \rightarrow K^* \bar{K} \end{array} \right.$
- One or two resonances?



The isospin violated decay $\eta(1405) \rightarrow f_0(980)\pi^0$ is observed for the first time with a significance $>10\sigma$.

$$\frac{BR(\eta(1405) \rightarrow f_0(980)\pi^0)}{BR(\eta(1405) \rightarrow a_0(980)\pi)} \approx 25\%$$

Large isospin breaking!



Triangle Singularity (TS)

one $\eta(1440)$ is enough to describe the experimental data !

J.J.Wu et al, PRL 108, 081803(2012)

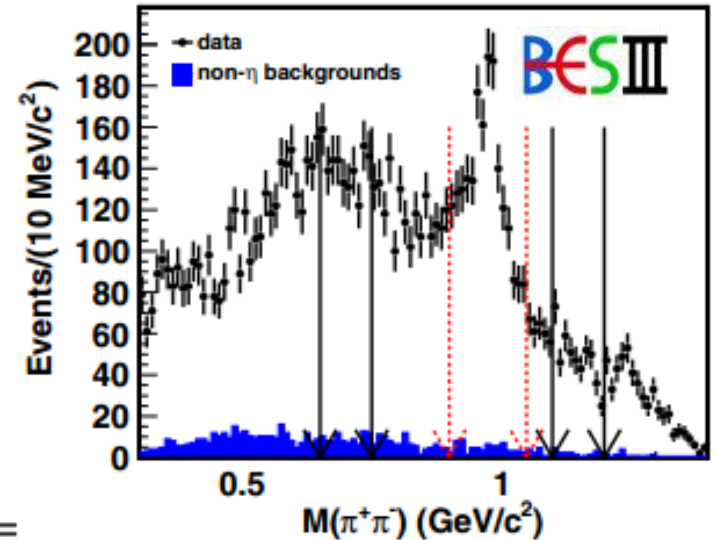
Resonance	$M(\text{MeV}/c^2)$	$\Gamma(\text{MeV}/c^2)$	Branching ratios
$\eta(1405)(\pi^+ \pi^- \pi^0)$	1409.0 ± 1.7	48.3 ± 5.2	$(1.50 \pm 0.11 \pm 0.11) \times 10^{-5}$
$\eta(1405)(\pi^0 \pi^0 \pi^0)$	1407.0 ± 3.5	55.0 ± 11.0	$(7.10 \pm 0.82 \pm 0.72) \times 10^{-6}$

Y(2175) in $J/\psi \rightarrow \phi \eta \pi^+ \pi^-$

also called $\phi(2170)$

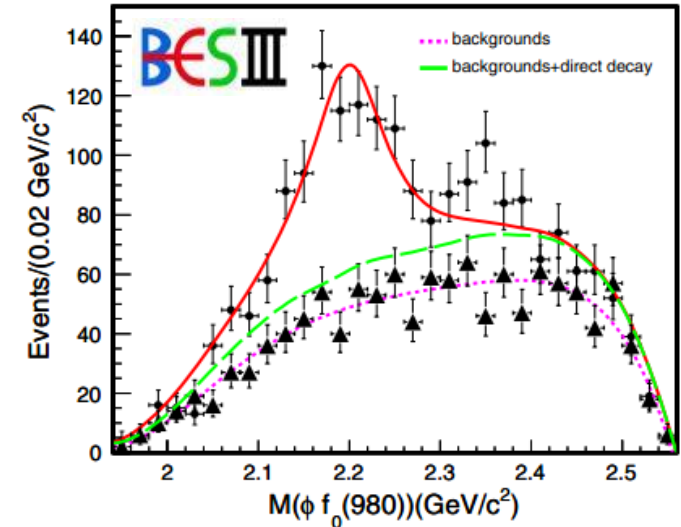
PRD 91,052017 (2015)

- First observed by Babar [PRD 74, 091103(2006)] and confirmed by Belle [PRD 80,031101(2009)] and BESII [PRL 100102003 (2008)] ;
- Clear $f_0(980)$ signal at BESIII;
- Observation of the Y(2175) resonance with significance $>10\sigma$;
- The interference between Y(2175) and direct three-body decay is 2.5σ ;



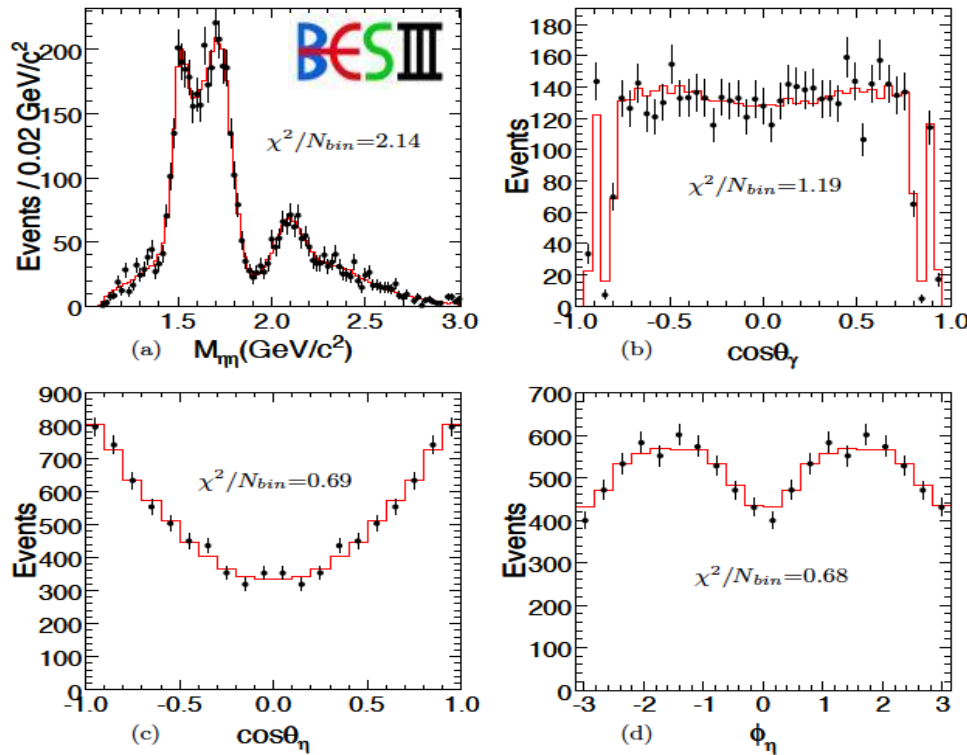
Collaboration	Process	M (MeV/ c^2)	Γ (MeV)
BABAR [2]	$e^+e^- \rightarrow \phi f_0$ (ISR)	$2175 \pm 10 \pm 15$	$58 \pm 16 \pm 20$
BESII [3]	$J/\psi \rightarrow \eta \phi f_0(980)$	$2186 \pm 10 \pm 6$	$65 \pm 23 \pm 17$
BELLE [4]	$e^+e^- \rightarrow \phi f_0$ (ISR)	$2079 \pm 13^{+79}_{-28}$	$192 \pm 23^{+25}_{-61}$
BABAR (updated) [5]	$e^+e^- \rightarrow \phi f_0$ (ISR)	$2172 \pm 10 \pm 8$	$96 \pm 19 \pm 12$
BESIII	$J/\psi \rightarrow \eta \phi f_0(980)$	$2200 \pm 6 \pm 5$	$104 \pm 15 \pm 15$

s-quark counterpart of the Y(4260)?
 ss -gluon hybrid? Or excited ϕ state? Tetraquark state? $\Lambda\Lambda$ bound state? Ordinary $\phi f_0(980)$ resonance produced by interactions between the final state particles?



f_0^* & f_2^* states in PWA of $J/\psi \rightarrow \gamma\eta\eta$

PRD 87, 092009 (2013)

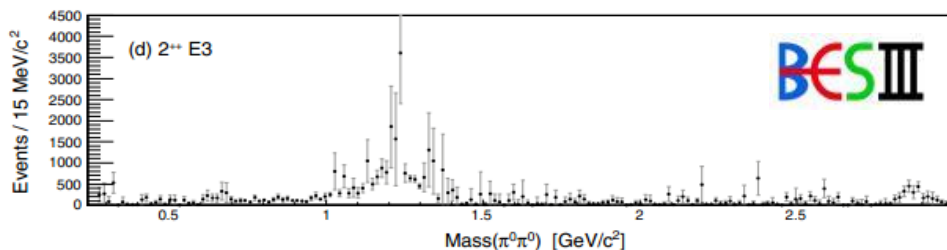
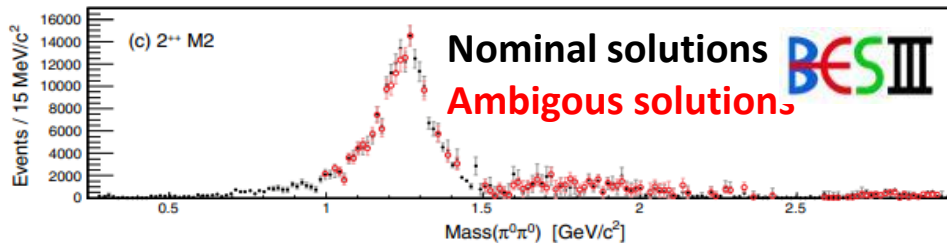
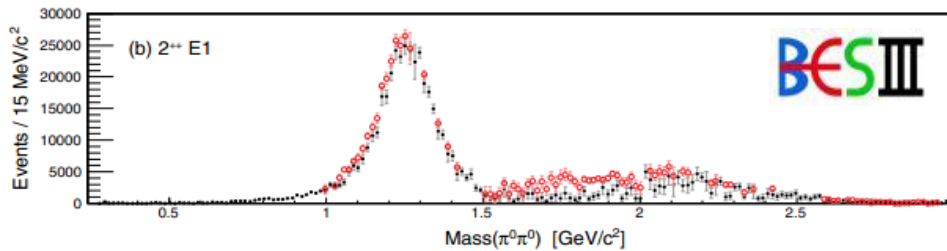
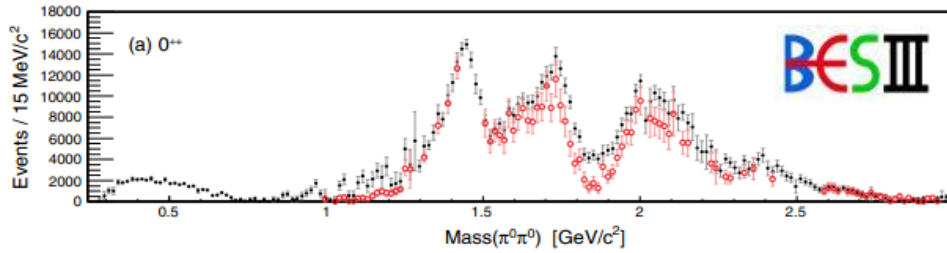


- $f_0(1710)$ and $f_0(2100)$ are dominant scalars
- $f_0(1500)$ exists (8.2σ)
- $f_2'(1525)$ is the dominant tensor
- $f_2(1810)$ and $f_2(2340)$ exist (6.4 and 7.6σ)
- No evidence for $f_J(2220)$

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}	$136^{+41+28}_{-26-100}$	$(1.65^{+0.26+0.51}_{-0.31-1.40}) \times 10^{-5}$	8.2σ
$f_0(1710)$	$1759 \pm 6^{+14}_{-25}$	$172 \pm 10^{+32}_{-16}$	$(2.35^{+0.13+1.24}_{-0.11-0.74}) \times 10^{-4}$	25.0σ
$f_0(2100)$	$2081 \pm 13^{+24}_{-36}$	273^{+27+70}_{-24-23}	$(1.13^{+0.09+0.64}_{-0.10-0.28}) \times 10^{-4}$	13.9σ
$f_2'(1525)$	$1513 \pm 5^{+4}_{-10}$	75^{+12+16}_{-10-8}	$(3.42^{+0.43+1.37}_{-0.51-1.30}) \times 10^{-5}$	11.0σ
$f_2(1810)$	1822^{+29+66}_{-24-57}	$229^{+52+88}_{-42-155}$	$(5.40^{+0.60+3.42}_{-0.67-2.35}) \times 10^{-5}$	6.4σ
$f_2(2340)$	$2362^{+31+140}_{-30-63}$	$334^{+62+165}_{-54-100}$	$(5.60^{+0.62+2.37}_{-0.65-2.07}) \times 10^{-5}$	7.6σ

f_0^* & f_2^* states in PWA of $J/\psi \rightarrow \gamma \pi^0 \pi^0$

PRD 92, 052003(2015)



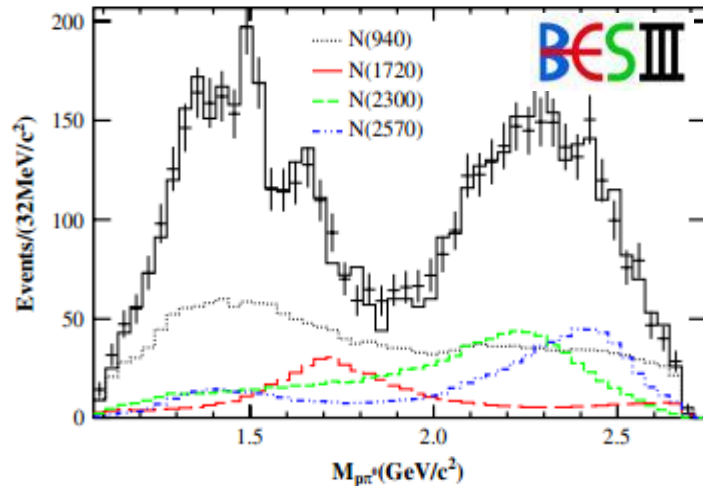
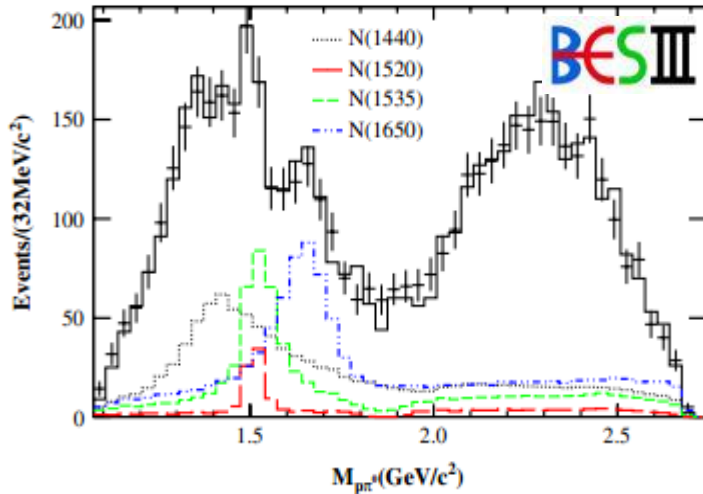
- Model-independent PWA;
- Provide a description of the scalar and tensor components of the $\pi^0 \pi^0$ system;
- 0^{++} : $\sigma(f_0(500))$, $f_0(1370)$, $f_0(1500)$, $f_0(1710)$, and $f_0(2020)$;
- 2^{++} : dominant by $f_2(1270)$;

Highlights of baryon spectroscopy at BESIII

- ✓ **N*** excited states
- ✓ **E*** excited states

N^* baryon in PWA of $\psi' \rightarrow p\bar{p}\pi^0$

PRL 110, 022001 (2013)

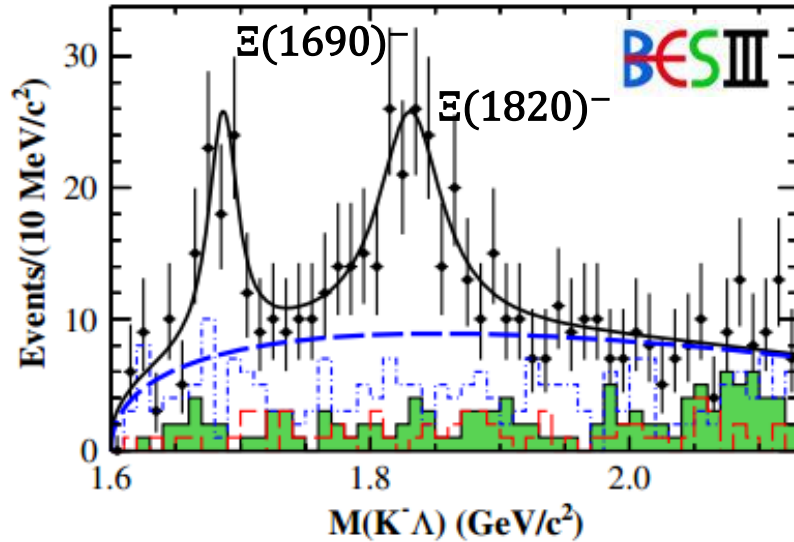


- In this PWA, 7 N^* intermediate resonances are observed;
- **Two new baryonic excited states $N(2300)$ ($\frac{1}{2}^+$) and $N(2570)$ ($\frac{5}{2}^-$) are observed;**
- No clear evidence for $N(1885)$ or $N(2065)$ has been found;

Resonance	$M(\text{MeV}/c^2)$	$\Gamma(\text{MeV}/c^2)$	ΔS	ΔN_{dof}	Sig.
$N(1440)$	1390^{+11+21}_{-21-30}	$340^{+46+70}_{-40-156}$	72.5	4	11.5σ
$N(1520)$	1510^{+3+11}_{-7-9}	115^{+20+0}_{-15-40}	19.8	6	5.0σ
$N(1535)$	1535^{+9+15}_{-8-22}	120^{+20+0}_{-20-42}	49.4	4	9.3σ
$N(1650)$	1650^{+5+11}_{-5-30}	150^{+21+14}_{-22-50}	82.1	4	12.2σ
$N(1720)$	1700^{+30+32}_{-28-35}	$450^{+109+149}_{-94-44}$	55.6	6	9.6σ
$N(2300)$	$2300^{+40+109}_{-30-0}$	$340^{+30+110}_{-30-58}$	120.7	4	15.0σ
$N(2570)$	2570^{+19+34}_{-10-10}	250^{+14+69}_{-24-21}	78.9	6	11.7σ

Ξ^* in $\psi' \rightarrow K^- \Lambda \bar{\Xi}^+ + c.c$ & $\gamma K^- \Lambda \bar{\Xi}^+ + c.c$

PRD 91, 092006 (2015)



- Evidence for $\Xi(1690)$ were found firstly in Kp reactions [PLB 80, 145 (1978)], and BARBAR recently assigned $J^P = (\frac{1}{2})^-$ [PRD 78, 034008 (2008)];
- Clear evidence for $\Xi(1820)$ observed in $K\Lambda$ mass spectrum [PLB 62, 477 (1976)];
- $\Xi(1690)$ and $\Xi(1820)$ well established, but need further investigation;

- $\Xi(1690)$ and $\Xi(1820)$ are confirmed;
- Mass and width consistent with PDG;
- First observation in charmonium decay;

	$\Xi(1690)^-$	$\Xi(1820)^-$
$M(\text{MeV}/c^2)$	$1687.7 \pm 3.8 \pm 1.0$	$1826.7 \pm 5.5 \pm 1.6$
$\Gamma(\text{MeV})$	$27.1 \pm 10.0 \pm 2.7$	$54.4 \pm 15.7 \pm 4.2$
Event yields	74.4 ± 21.2	136.2 ± 33.4
Significance(σ)	4.9	6.2
Efficiency(%)	32.8	26.1
$B(10^{-6})$	$5.21 \pm 1.48 \pm 0.57$	$12.03 \pm 2.94 \pm 1.22$
$M_{\text{PDG}}(\text{MeV}/c^2)$	1690 ± 10	1823 ± 5
$\Gamma_{\text{PDG}}(\text{MeV})$	< 30	24^{+15}_{-10}

Summary & Perspective

- Based on the largest data sets of J/ψ , $\psi(3686)$ collected at BESIII, the recent progresses in the light hadron spectroscopy are presented;
 - ✓ $X(18??)$ states: $X(p\bar{p})$, $X(1835)$, $X(1870)$, $X(1810)$, $X(1840)$;
 - ✓ $\eta(1405)$: $\eta(1405) \rightarrow f_0(980)\pi^0$, isospin violated;
 - ✓ $Y(2175)$: confirm $Y(2175)$, significance $>10\sigma$;
 - ✓ f_0^* & f_2^* states: $f_0(1500)$, $f_0(1710)$, $f_0(2100)$, $f_0(2020)$; $f_2(1270)$, $f_2'(1525)$, $f_2(1810)$, $f_2(2340)$;
 - ✓ N^* : $N(1440)$, $N(1520)$, $N(1535)$, $N(1650)$, $N(1720)$;
two new: $N(2300)$, $N(2570)$;
 - ✓ Ξ^* : $\Xi(1690)$ and $\Xi(1820)$ are confirmed in charmonium decay ;
- BESIII provides the opportunity to make very precise studies of J/ψ , $\psi(3686)$ decay, J/ψ , $\psi(3686)$ is excellent laboratory to study light hadron spectroscopy;
- With the high statistics data accumulated at the BESIII, more interesting results are expected to be coming soon!

Thank you!