Hadron Spectroscopy at BESIII

Xiaobin Ji
IHEP, CAS
on behalf of the BESIII Collaboration

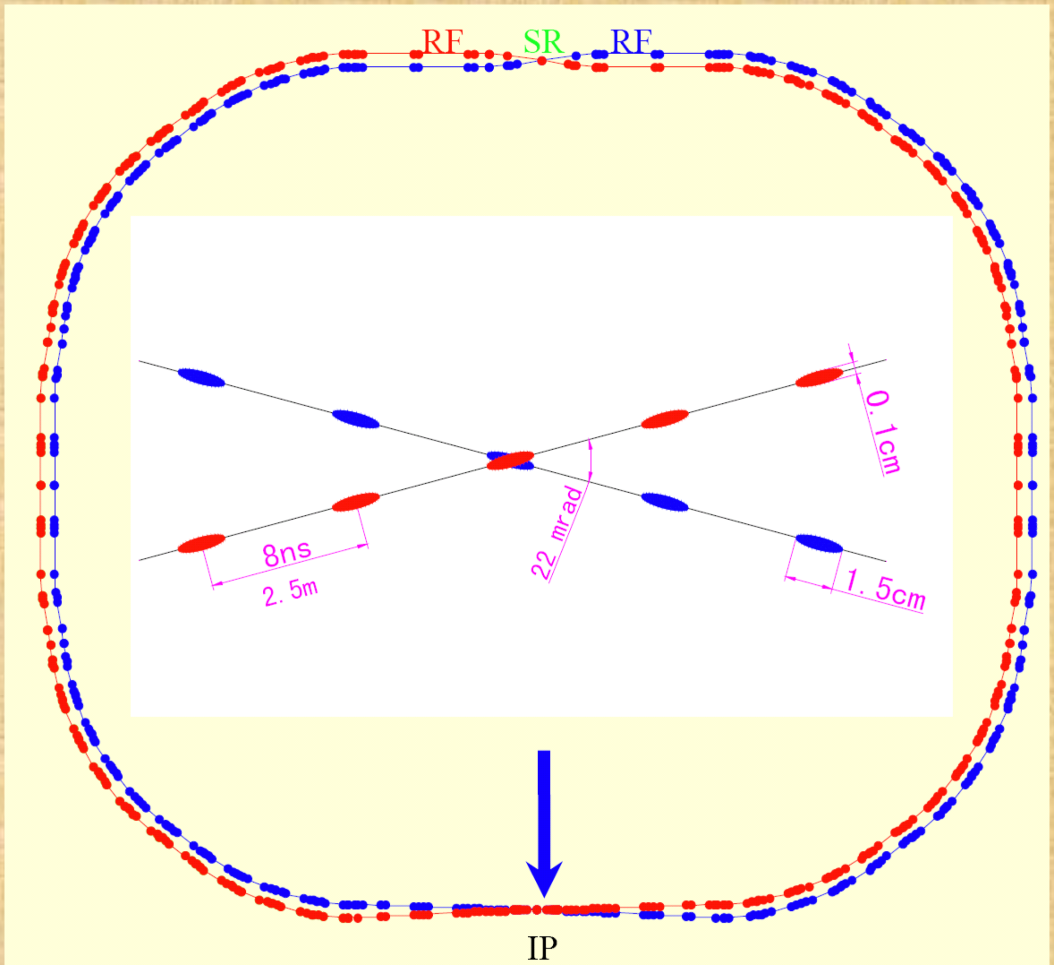
International Workshop
on Hadron Structure and Spectroscopy
Suzdal, Russia
18 -20 May 2015

Outline

- Introduction
- Light meson spectroscopy
- Baryon spectroscopy
- Summary

Beijing Electron Positron Collider (II)

BEPCII parameters



Beam energy:
1.0 – 2.3 GeV

Design Luminosity:
$1\times10^{33}\ cm^{-2}\ s^{-1}$
$(0.8\times10^{33}\ cm^{-2}\ s^{-1})$

Optimum energy:
1.89 GeV

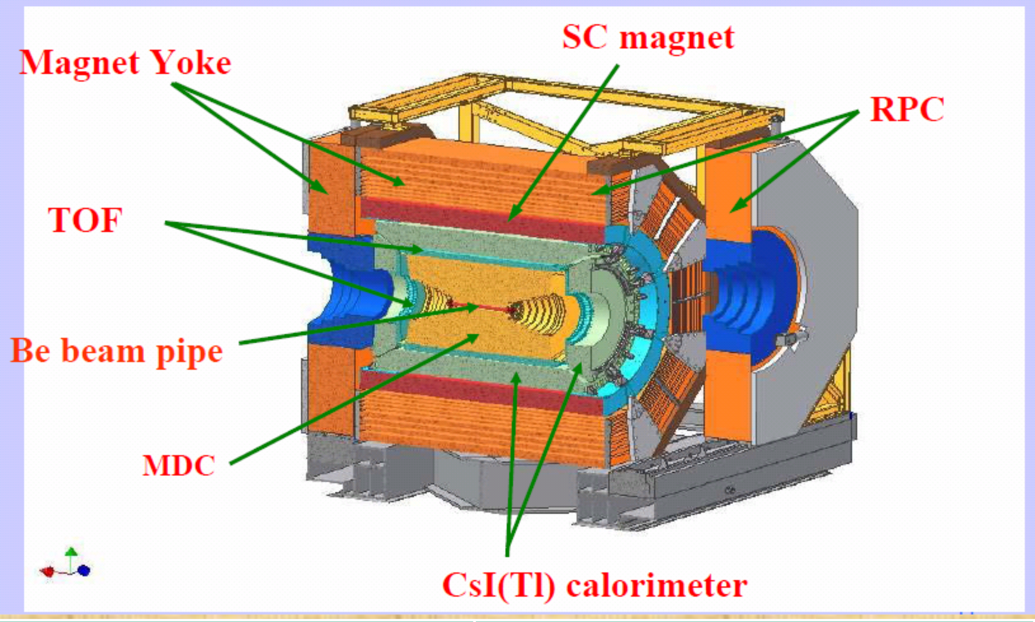
No. of bunches:
93

Bunch length:
1.5 cm

Total current:
0.91 A

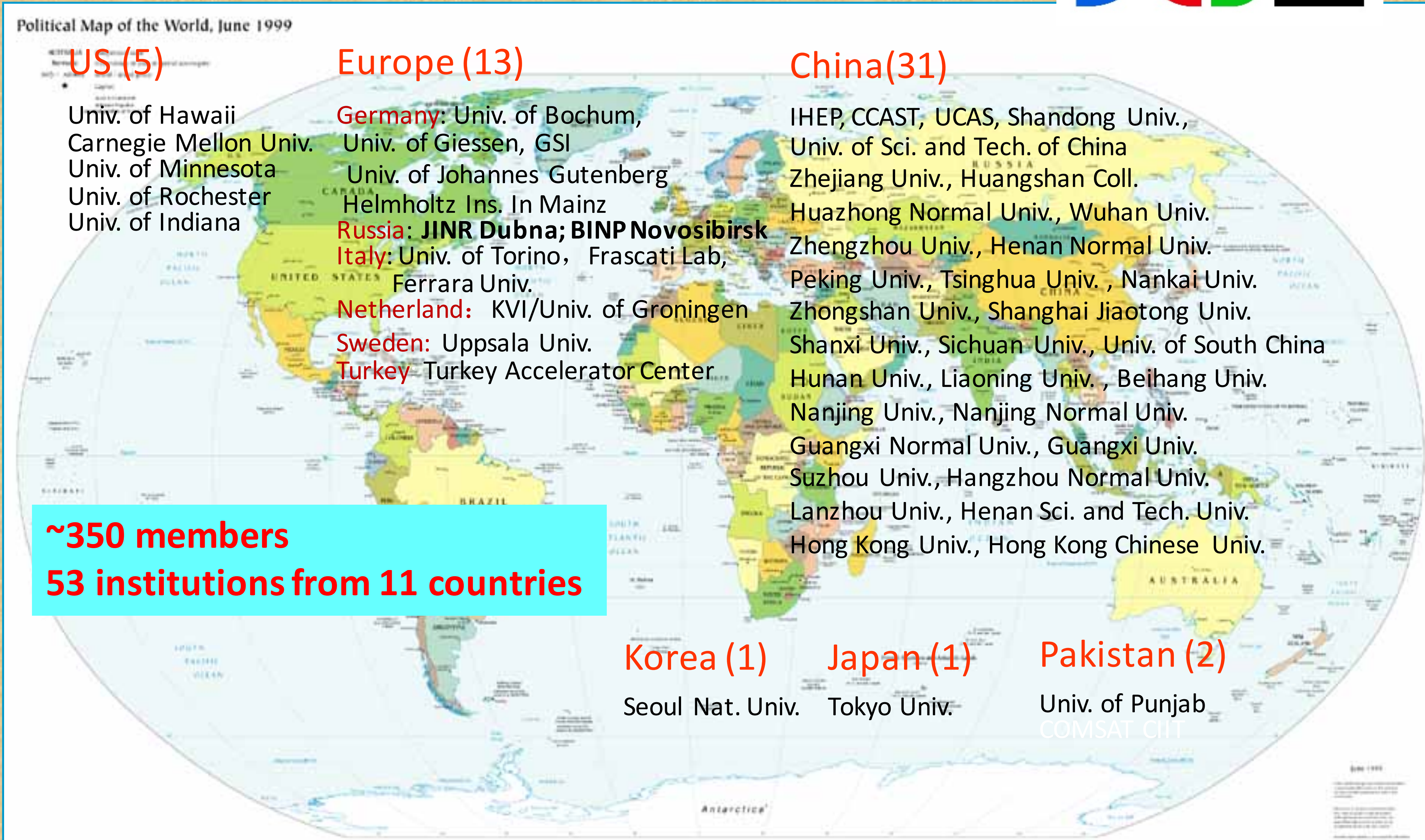
SR mode:
0.25A @ 2.5 GeV

BESIII detector and it's performance



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 Collaboration



US (5)

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

Europe (13)

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， Frascati Lab, Ferrara Univ.
Netherland： KVI/Univ. of Groningen
Sweden: Uppsala Univ.
Turkey Turkey Accelerator Center

China(31)

IHEP, CCAST, UCAS, 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. , Nankai Univ.
Zhongshan Univ., Shanghai Jiaotong Univ.
Shanxi Univ., Sichuan Univ., Univ. of South China
Hunan Univ., Liaoning Univ. , Beihang Univ.
Nanjing Univ., Nanjing Normal Univ.
Guangxi Normal Univ., Guangxi Univ.
Suzhou Univ., Hangzhou Normal Univ.
Lanzhou Univ., Henan Sci. and Tech. Univ.
Hong Kong Univ., Hong Kong Chinese Univ.

~350 members
53 institutions from 11 countries

Korea (1)

Seoul Nat. Univ.

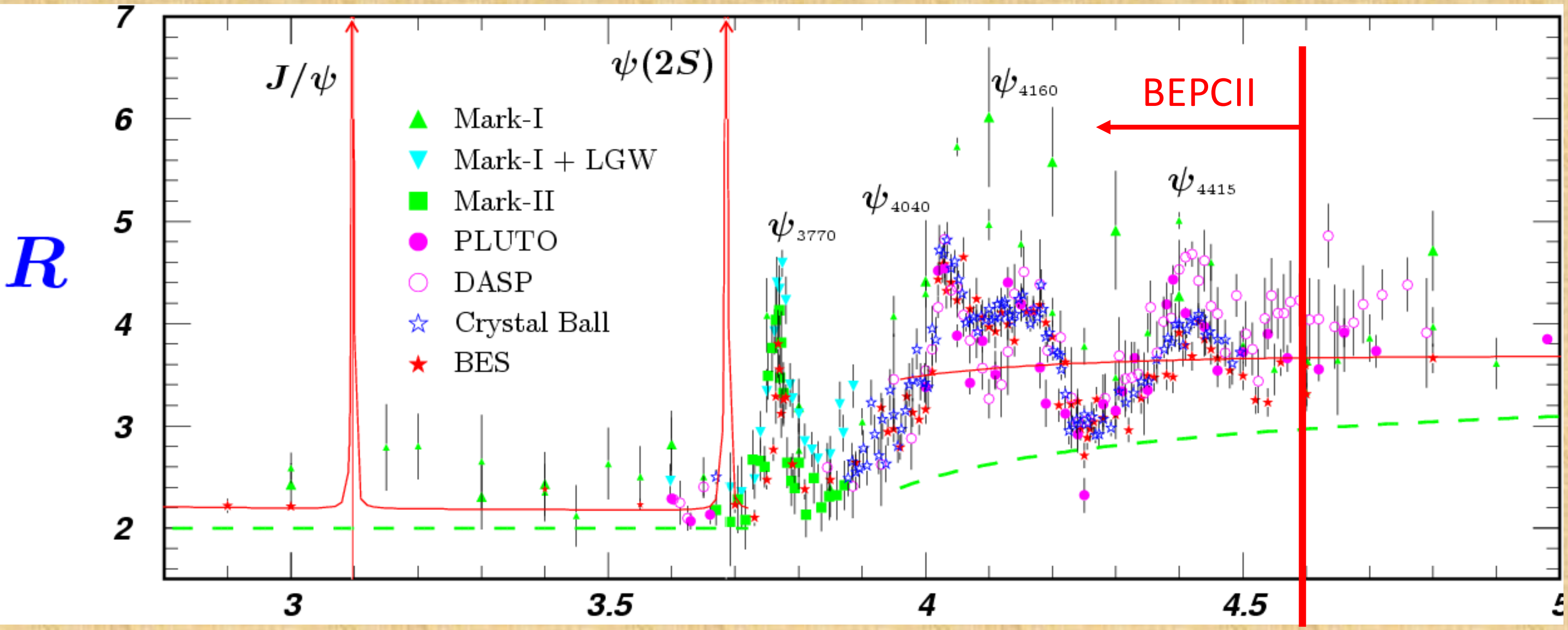
Japan (1)

Tokyo Univ.

Pakistan (2)

Univ. of Punjab
COMSAT CIIT

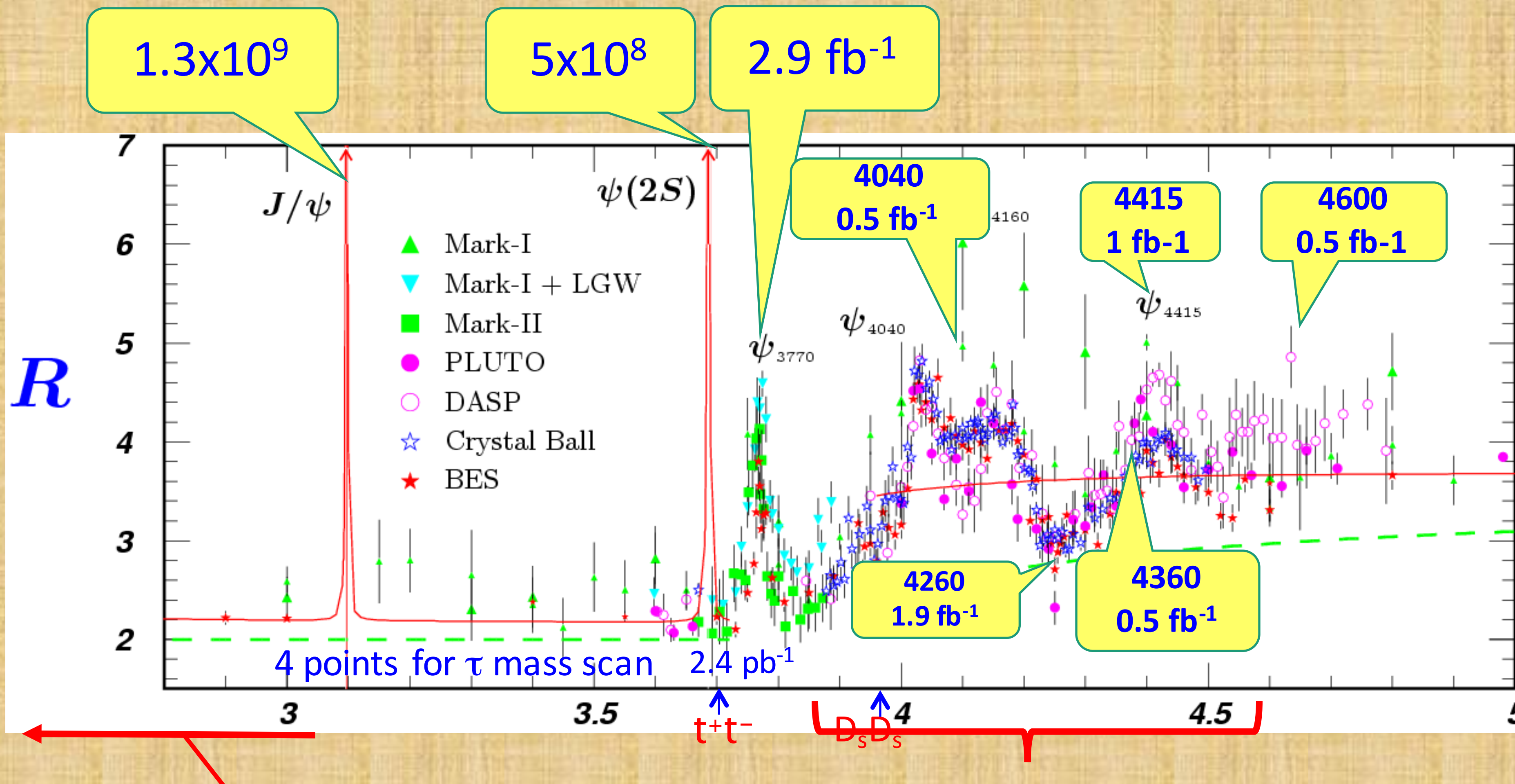
Production of charmonium(like) states



Vector ψ/Y states can be produced directly

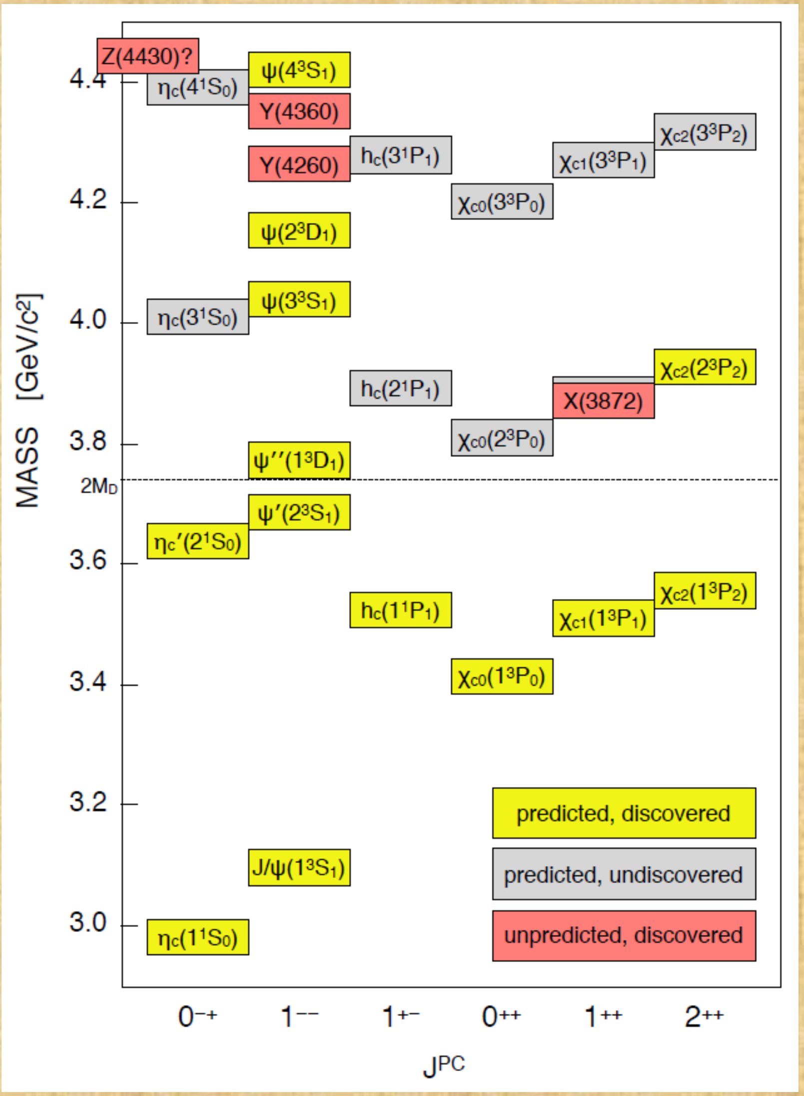
C-even states can be produced from radiative transitions

Data Samples



R scan : 19 point, 2 – 3 GeV, ~ 0.5 fb-1; 104 points, 3.85 – 4.59 GeV, 0.8 fb-1

Physics at BESIII



- Charmonium(-like) physics:
- - **XYZ**
- - Spectroscopy
- - transitions and decays
- Light hadron physics:
- **- meson & baryon spectroscopy**
- **- glueball & hybrid**
- - two-photon physics
- - e.m. form factors of nucleon
- Open Charm physics:
- - (semi)leptonic + hadronic decays
- - decay constant, form factors
- - CKM matrix: Vcd, Vcs
- - D0-D0bar mixing and CP violation
- - rare/forbidden decays
- QCD & Tau physics:
- - precision R-measurement
- - Tau decays and tau mass scan
- …and many more.

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

Meson spectroscopy at BESIII

- X(18??)
  - X(1860) in $J/\psi \to \gamma \bar{p}p$
  - X(1835) in $J/\psi \to \gamma \pi^+\pi^-\eta'$
  - X(1870) in $J/\psi \to \omega\eta\pi\pi$
  - X(1840) in $J/\psi \to \gamma 3(\pi^+\pi^-)$
  - X(1810) in $J/\psi \to \gamma\omega\phi$

PRL 108, 112003

PRL 106, 072002

PRL 107, 182001

PRD 88, 091502

PRD 87, 032008

- η(1405) in $J/\psi \to \gamma 3\pi$, $(\omega,\phi)\eta\pi\pi$
- Y(2175) in $J/\psi \to \phi\eta\pi\pi$

PRL 108, 182001; PRD 91, 052017

PRD 91, 052017

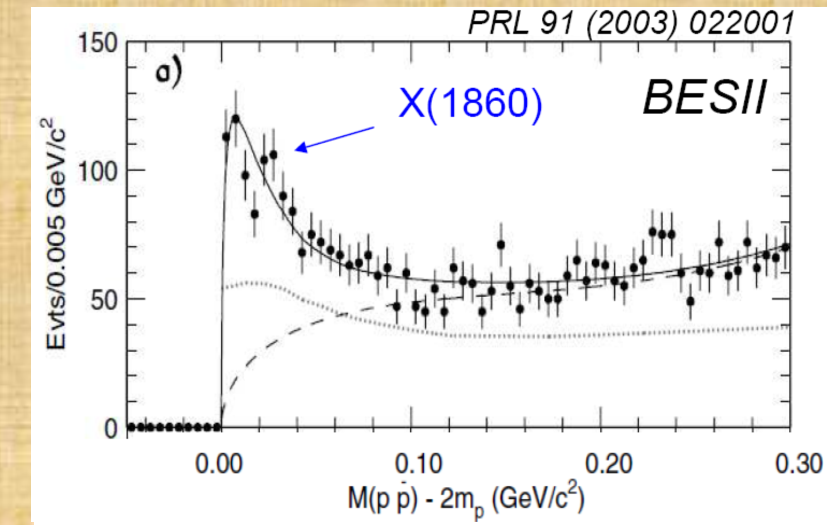
PRD 87, 092009

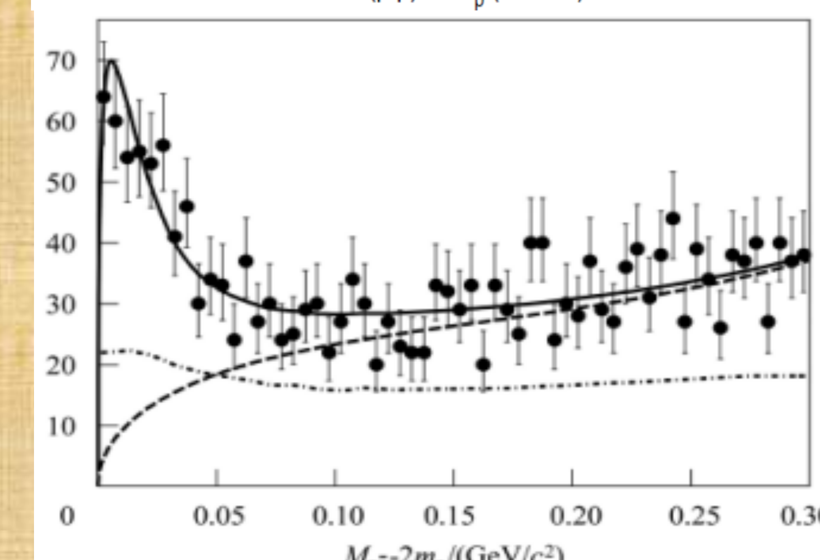
- PWA of $J/\psi \to \gamma\eta\eta$

Based on 225 M J/ψ data.

X(1860) in $J/\psi \to \gamma \bar{p}p$

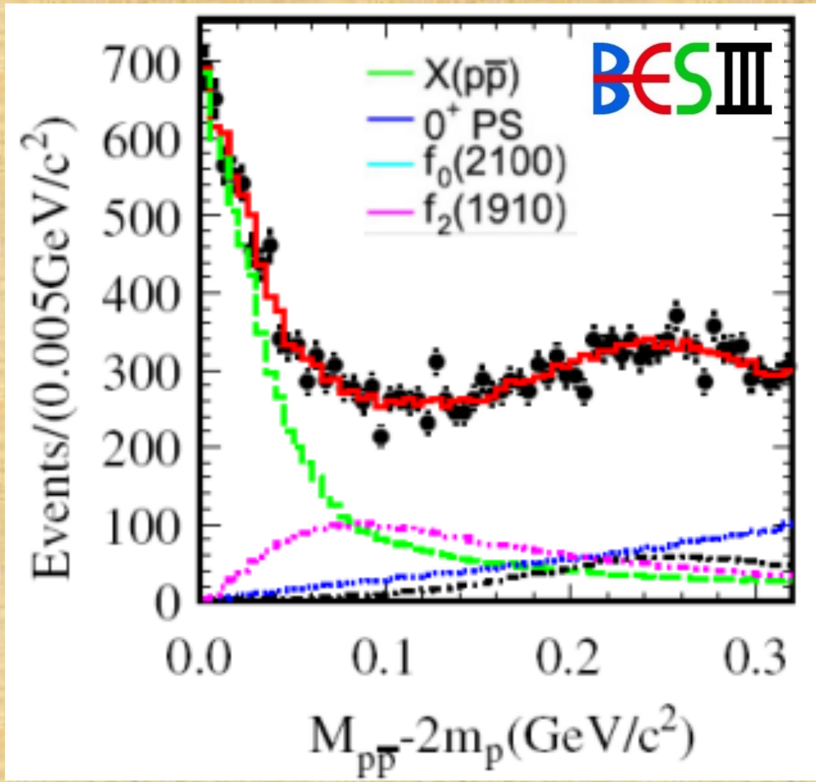
- First observed more than 10 years ago at BESII, confirmed by CLEO-c
- Mass close to the $\bar{p}p$ threshold
- Very narrow width (< 30 MeV/c^2 at 90% C.L.)
- Confirmed by BESIII and CLEOc
- Possible theoretical interpretation:
  - Normal meson, multi-quark, glueball?
  - Final state interaction (FSI)?
  - $\bar{p}p$ bound states?





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

PRL 108, 112003



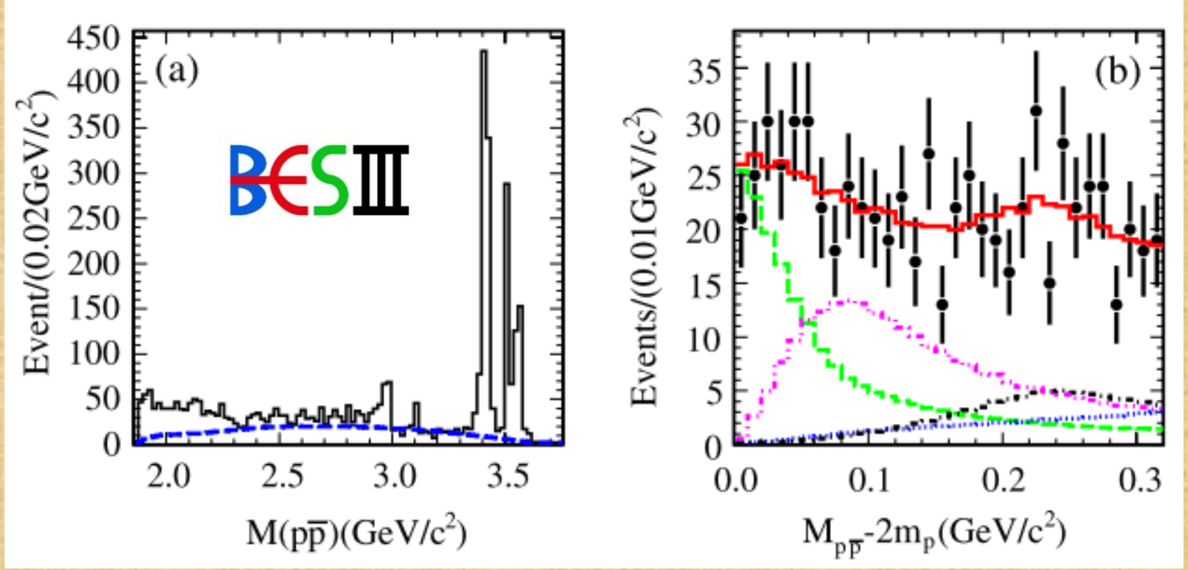
- PWA for the region below 2.2 GeV
- The fit with a BW and S-wave FSI (I=0) factor can well describe the $\bar{p}p$ mass threshold structure
- $J^{PC} = 0^{-+}$, > 6.8 σ better than other J^{PC} assignments
- $M = 1832^{+19}_{-5}(\text{stat})^{+18}_{-17}(\text{sys.}) \pm 19(\text{mod})$ MeV/c^2
- $\Gamma = 13 \pm 39^{+10}_{-13} \pm 4$ MeV/c^2 or < 76 MeV/c^2 (90% C.L.)

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

PWA of $\psi(2S) \to \gamma \bar{p}p$

PRL 108, 112003

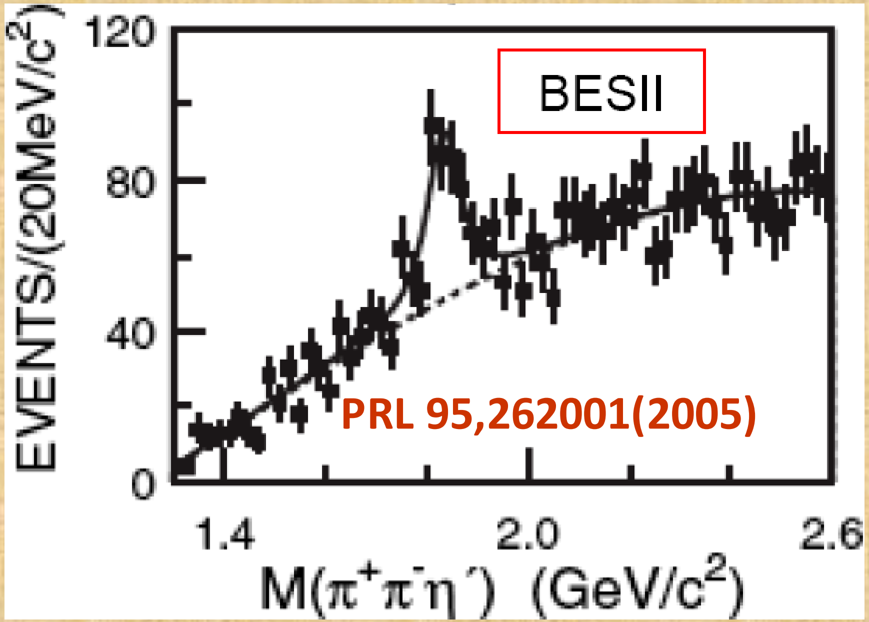
- Threshold structure differs from that in J/ψ decays
- M, Γ and JPC fixed to those obtained from J/ψ decays

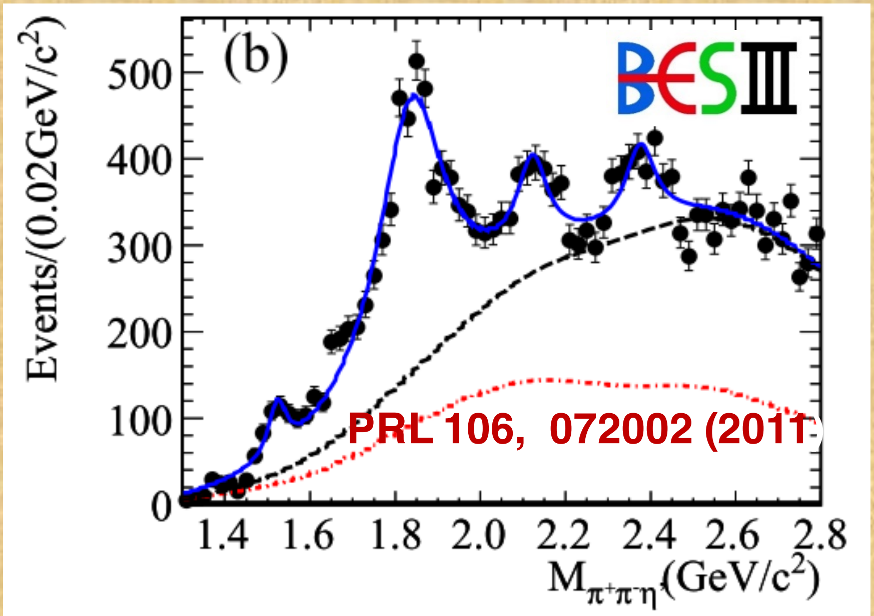


$$\mathcal{B}(\psi(2S)\to\gamma X(pp)) \times \mathcal{B}(X(pp)\to pp) = 4.57\pm0.36(stat)^{+1.23}_{-4.07}(sys)\pm1.28(mod))\times10^{-6}$$

$$R = \frac{\mathcal{B}(\psi(2S)\to\gamma X(p\bar{p}))}{\mathcal{B}(J/\psi\to\gamma X(p\bar{p}))} = 5.08^{+0.71}_{-0.45}(stat)^{+0.67}_{-3.58}(sys)\pm0.12(mod))\% < 12\%!$$

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





- X(1835) was observed at BESII,
  and confirmed with BESIII
- Two additional structures are observed at BESIII
- $p\bar{p}$ bound state? η excitation? same as X($p\bar{p}$)?

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

Resonance	M (MeV/c²)	Γ (MeV/c²)	significance
X(1835)	$1836.5 \pm 3.0^{+5.6}_{-2.1}$	$190 \pm 9^{+38}_{-36}$	$\gg 20\sigma$
X(2120)	$2122.4 \pm 6.7^{+4.7}_{-2.7}$	$83 \pm 16^{+31}_{-11}$	$> 7.2\sigma$
X(2370)	$2376.3 \pm 8.7^{+3.2}_{-4.3}$	$83 \pm 17^{+44}_{-6}$	$> 6.4\sigma$

- Br(J/ψ→γX(1835))•Br(X(1835)→π+π-η’)
  = (2.87 ±0.09+0.49-0.52)x10-4
- 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

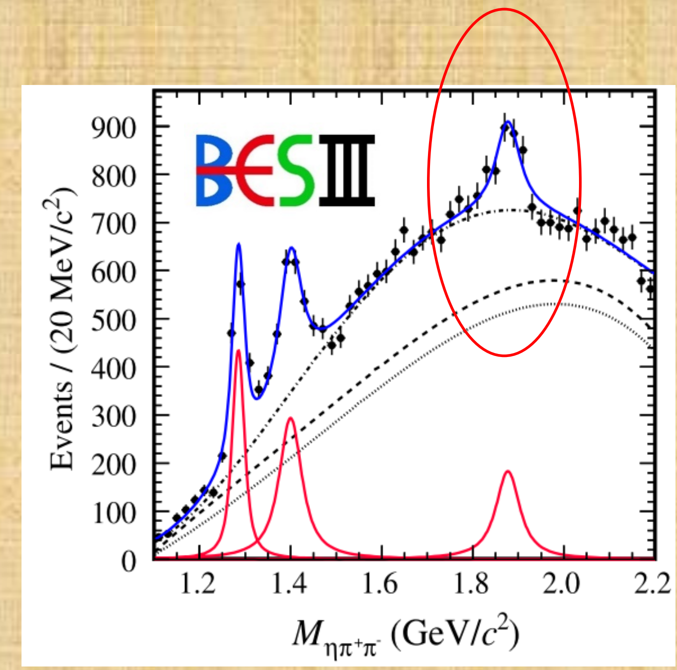
X(1870) in $J/\psi \to \omega\eta\pi\pi$

- $J/\psi \to \omega X(1870)$, $X(1870) \to a^{\pm}(980)\pi^{\mp}$
- f1(1285), $\eta(1405)$, X(1870)

$$M = (1877.3 \pm 6.3^{+3.4}_{-7.4})\ \mathrm{MeV}/c^2$$

$$\Gamma = (57 \pm 12^{+19}_{-4})\ \mathrm{MeV}/c^2$$

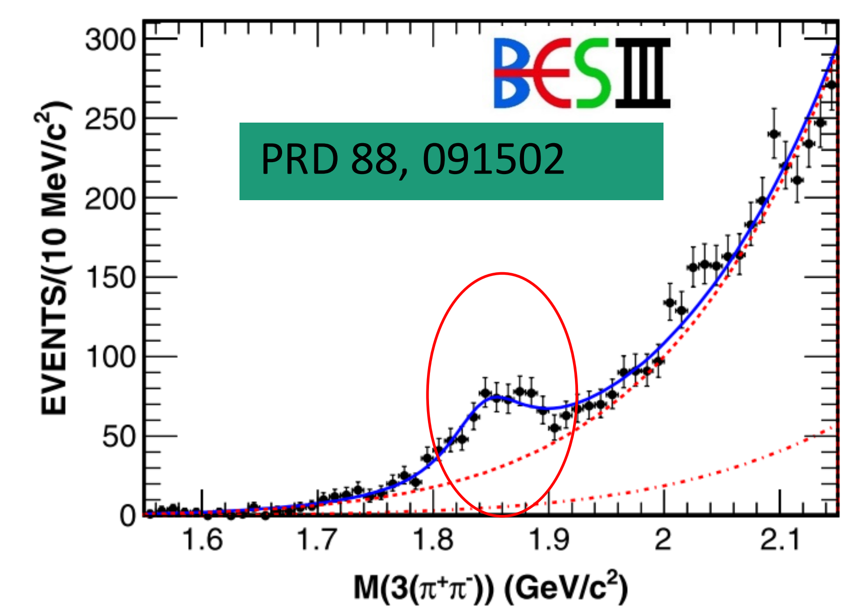
$$B = (1.50 \pm 0.26^{+0.72}_{-0.36}) \cdot 10^{-4}$$



PRL 107, 182001

- PWA is needed to determine spin-parity

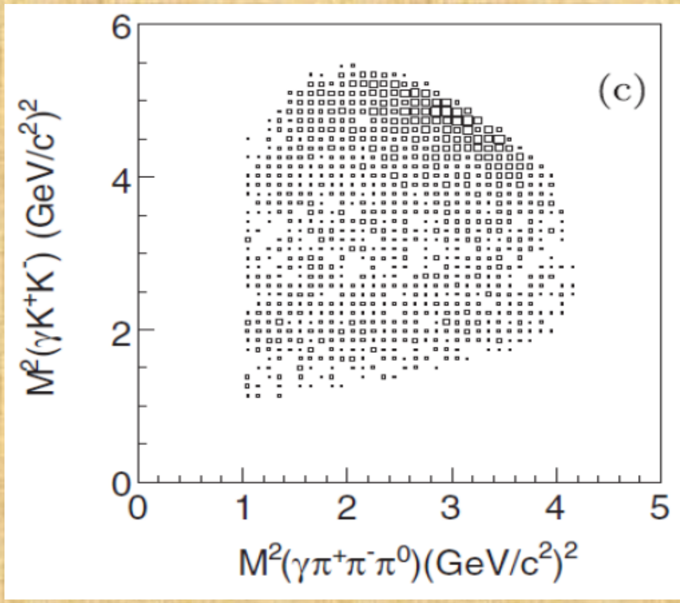
X(1840) in $J/\psi \rightarrow \gamma 3(\pi^+\pi^-)$

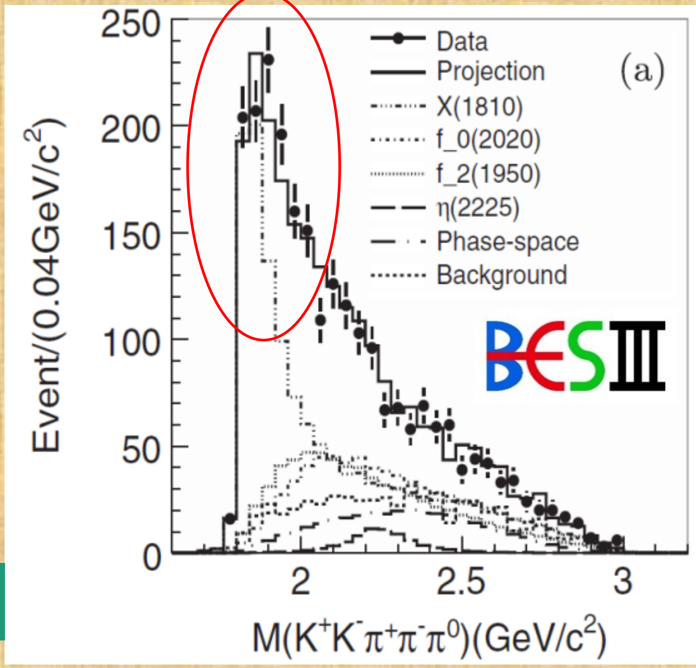


- Mass is consistent with that of X(1835), but the width is much smaller
- $M = 1842.2 \pm 4.2^{+7.1}_{-2.6}$ MeV/c^2, $\Gamma = 83 \pm 14 \pm 11$ MeV
- A new decay modes of X(1835)?

PWA of $J/\psi \to \gamma\omega\phi$

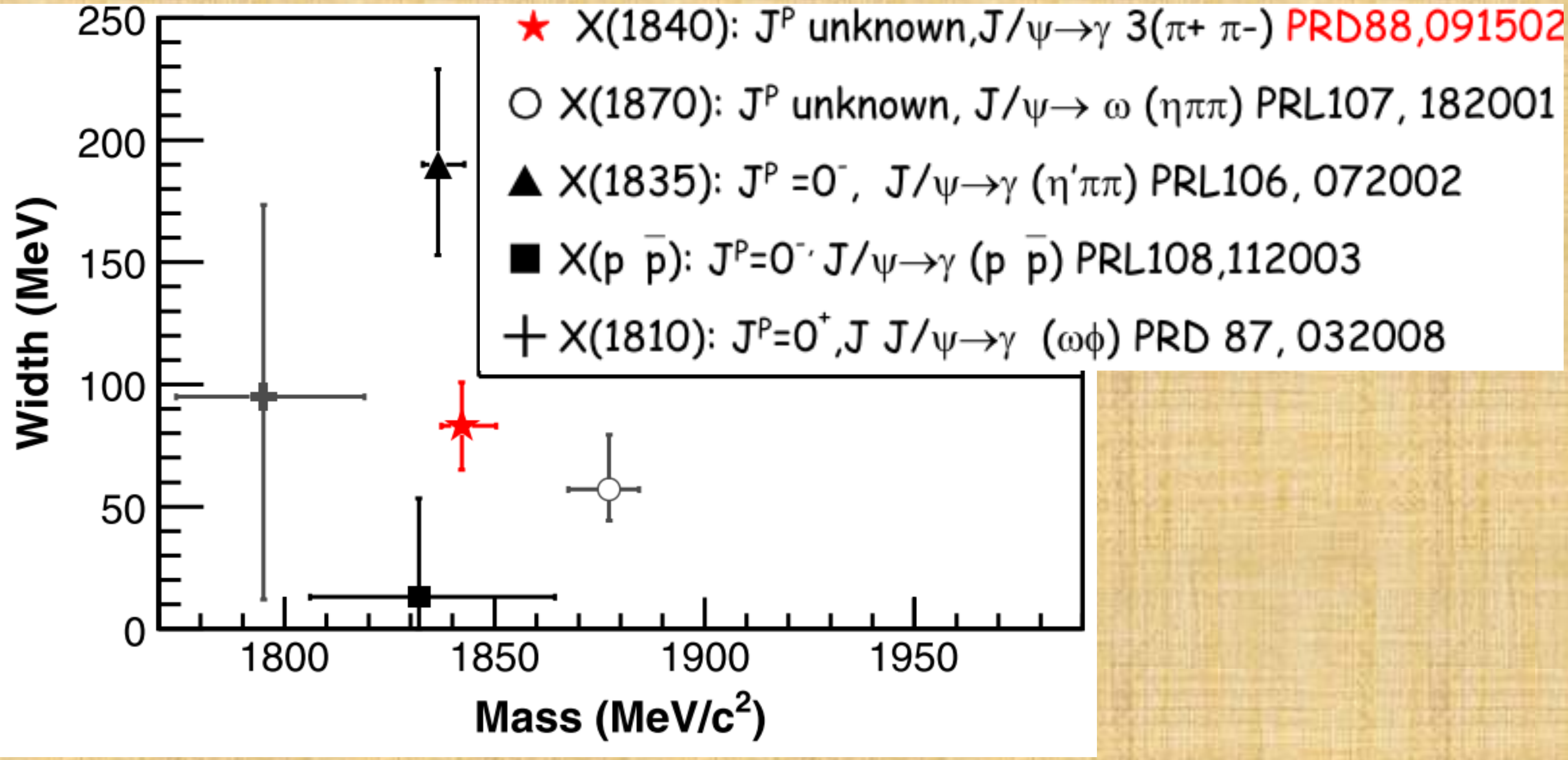
- DOZI process
- Confirmed the enhancement observed at BESII
- $M = 1795 \pm 7^{+13}_{-5} \pm 19(\text{model})$ MeV/c^2
  $\Gamma = 95 \pm 10^{+21}_{-34} \pm 75(\text{model})$ MeV
- Spin-parity is determined to be 0^+
- The same as $f_0(1710)/f_0(1790)$, or a new state?





PRD 87, 032008

Comparison of BES observation



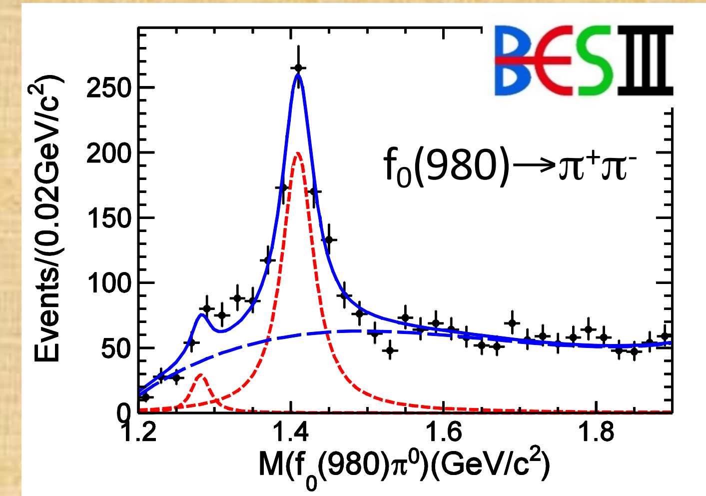
- X(18??) near the threshold position of proton-antiproton
- Are they the same particles?
  It is crucial to identify these observations.

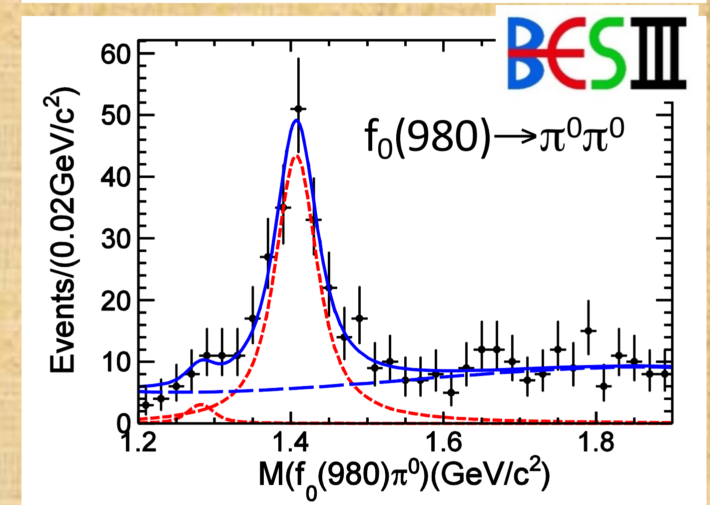
$\eta(1405)$ in $J/\psi \rightarrow \gamma f_0(980)\pi^0$

- $\eta(1405)$:
  pseudoscalar glueball candidate, but not supported by LQCD
- First observed: (isospin breaking) $\eta(1405) \rightarrow f_0(980)\pi^0$
- Helicity analysis indicates the peak at 1400 MeV is from $\eta(1405)$, not from $f_1(1420)$
- Large isospin-violating decay rate:

$$\frac{BR(\eta(1405) \rightarrow f_0(980)\pi^0)}{BR(\eta(1405) \rightarrow a_0(980)\pi)} \approx (17.9 \pm 4.2)\%$$

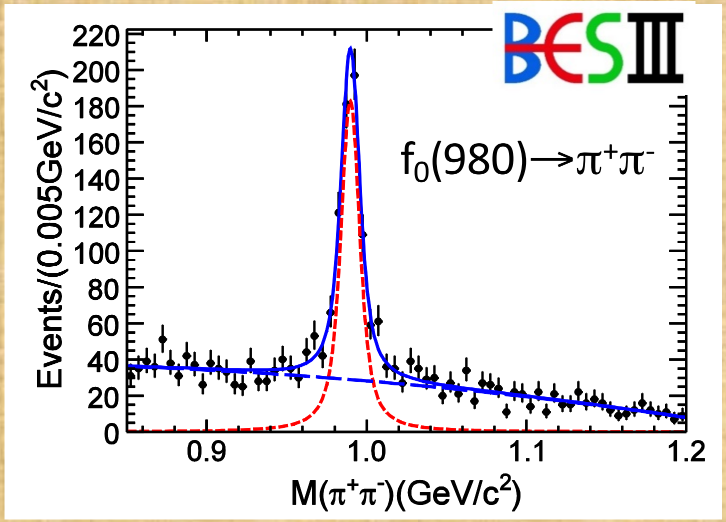
a_0-f_0 mixing alone can not explain the Br. of $\eta(1405) \rightarrow f_0(980)\pi^0$

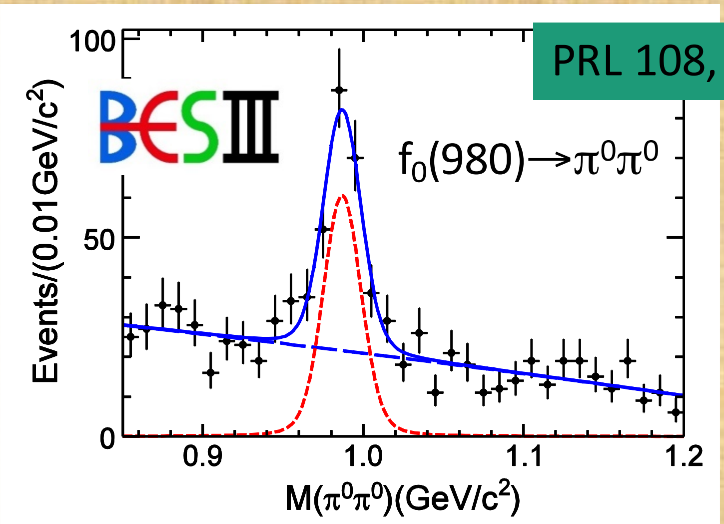




PRL 108, 182001

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





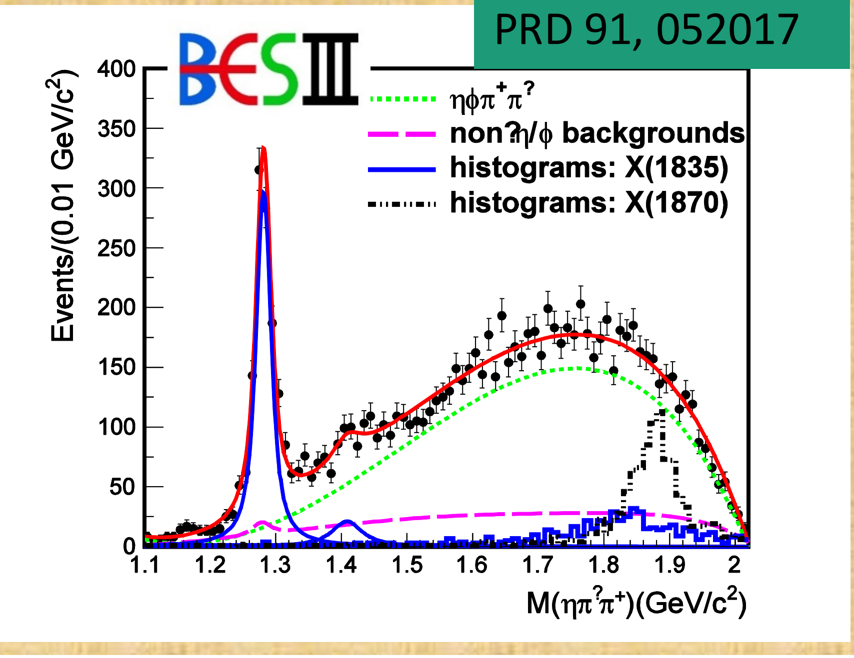
PRL 108, 182001

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

J/ψ→φηππ

- The dominate contributions are: $\phi f_1(1285)$ and $\eta Y(2175)$
- Other contributions < 5 σ, η(1405), ~ 3.6 σ

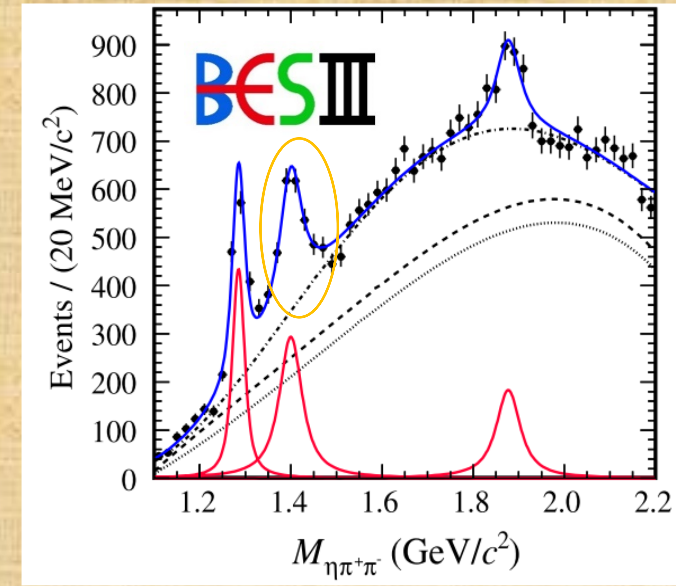
PRD 91, 052017



Decay mode	Branching fraction $\mathcal{B}$
$J/\psi \to \eta Y(2175)$, $Y(2175) \to \phi f_0(980)$, $f_0(980) \to \pi^+\pi^-$	$(1.20 \pm 0.14 \pm 0.37) \times 10^{-4}$
$J/\psi \to \phi f_1(1285)$, $f_1(1285) \to \eta\pi^+\pi^-$	$(1.20 \pm 0.06 \pm 0.14) \times 10^{-4}$
$J/\psi \to \phi\eta(1405)$, $\eta(1405) \to \eta\pi^+\pi^-$	$(2.01 \pm 0.58 \pm 0.82)$ $(< 4.45) \times 10^{-5}$
$J/\psi \to \phi X(1835)$, $X(1835) \to \eta\pi^+\pi^-$	$< 2.80 \times 10^{-4}$
$J/\psi \to \phi X(1870)$, $X(1870) \to \eta\pi^+\pi^-$	$< 6.13 \times 10^{-5}$

$\eta(1405)$ in $J/\psi \to \omega\eta\pi\pi$

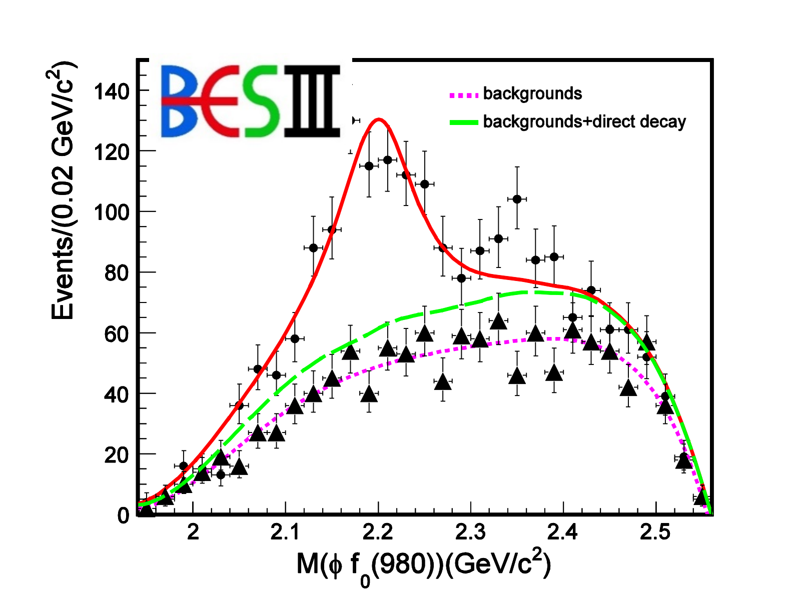
- $J/\psi \to \omega\, \eta(1405)$, $\eta(1405) \to a^{\pm}(980)\pi^{\mp}$
- $M = 1399.8 \pm 2.2\ ^{+2.8}_{-0.1}$ MeV/c2
  $\Gamma = 52.8 \pm 7.6\ ^{+0.1}_{-7.6}$ MeV
  Br = $(1.89 \pm 0.21^{+0.21}_{-0.23}) \times 10^{-4}$
- Compare with $J/\psi \to \phi\eta(1405)$, $\eta(1405)$: more u and d quark than s quark?



PRL 107, 182001

Y(2175) in $J/\psi \to \phi\eta\pi\pi$

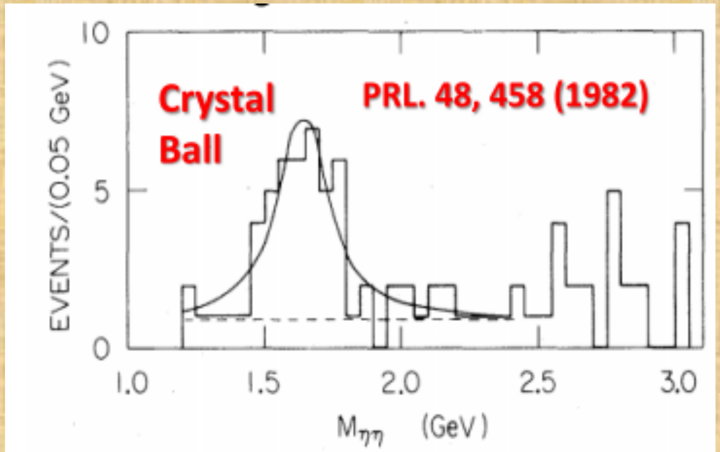
- Y(2175) /ϕ(2170), first observed by Babar, confirmed by Belle and BESII
- $J/\psi \to \eta Y(2175)$
  $\quad\quad |\to \phi f_0(980)$
  $\quad\quad\quad |\to \pi\pi$
- Hybird?
- Strangeonium?

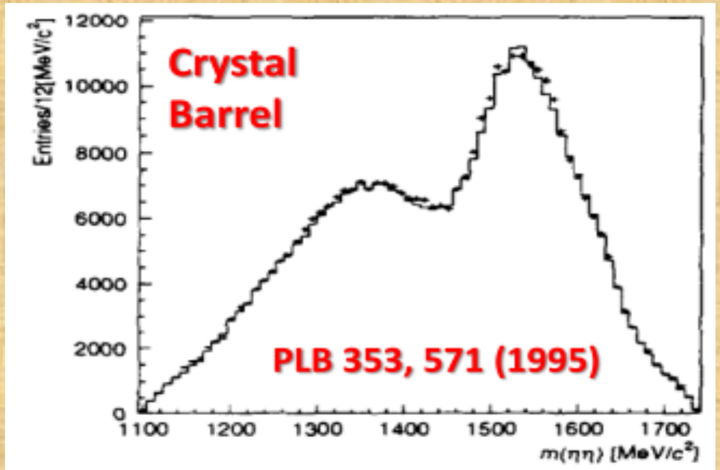


Resonance	N_{obs}	Significance	Efficiency(%)
$Y(2175)$	471 ± 54	$> 10\sigma$	9.10 ± 0.01
$f_1(1285)$	1154 ± 56	$\cdots$	22.14 ± 0.09
$\eta(1405)$	172 ± 50 (< 345)	3.6σ	19.75 ± 0.12
$X(1835)$	394 ± 360 (< 1522)	1.1σ	13.85 ± 0.14
$X(1870)$	25 ± 73 (< 330)	0.8σ	13.73 ± 0.14

$J/\psi \rightarrow \gamma\eta\eta$

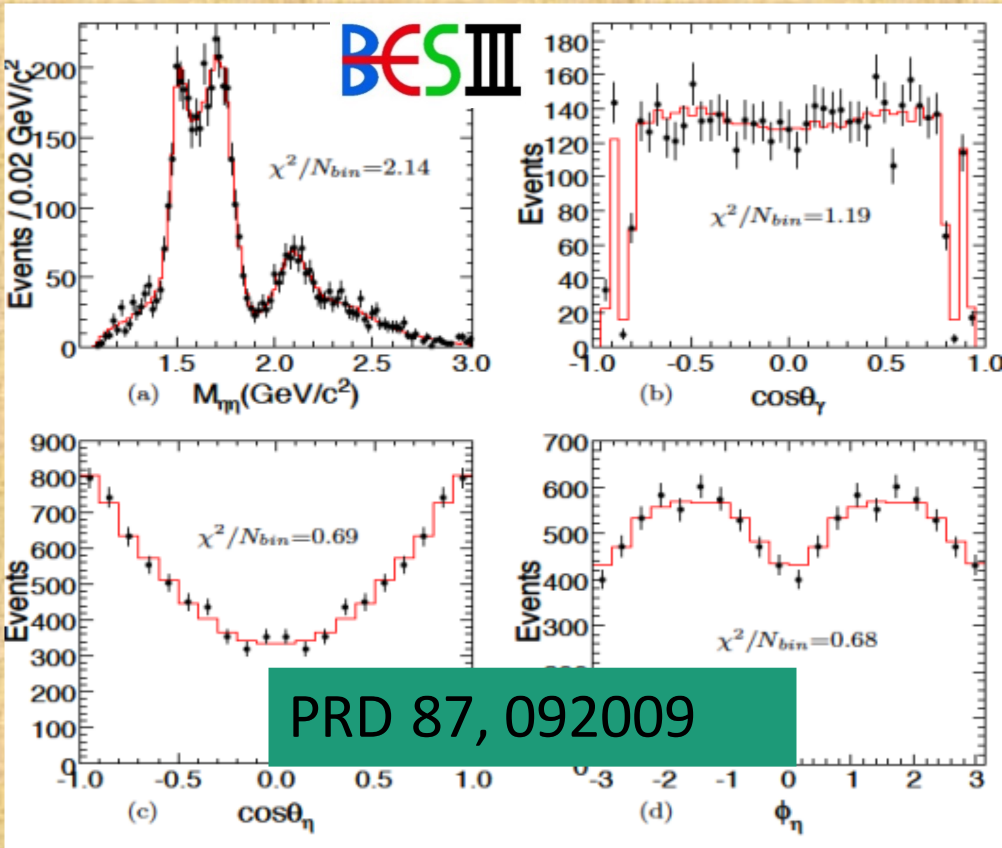
- Lattice QCD predicts that the lowest lying 0^{++} glueball occurs in 1.5 to 1.7 GeV/c^2, and the lightest 2^{++} glueball has mass around 2.2 GeV/c^2
- $\eta\eta$ system: event^{++} states (mainly 0^{++} and 2^{++}), ideal place for search of scalar and tensor glueballs
- First studied by Crystal Ball (1982): $f_0(1710)$
- Crystal Barrel (1995): $f_0(1500)$
- E835 (2006): $f_0(1500)$, $f_0(1710)$
- WA102, GAMS: $f_0(1500)$





PWA of J/ψ→γηη

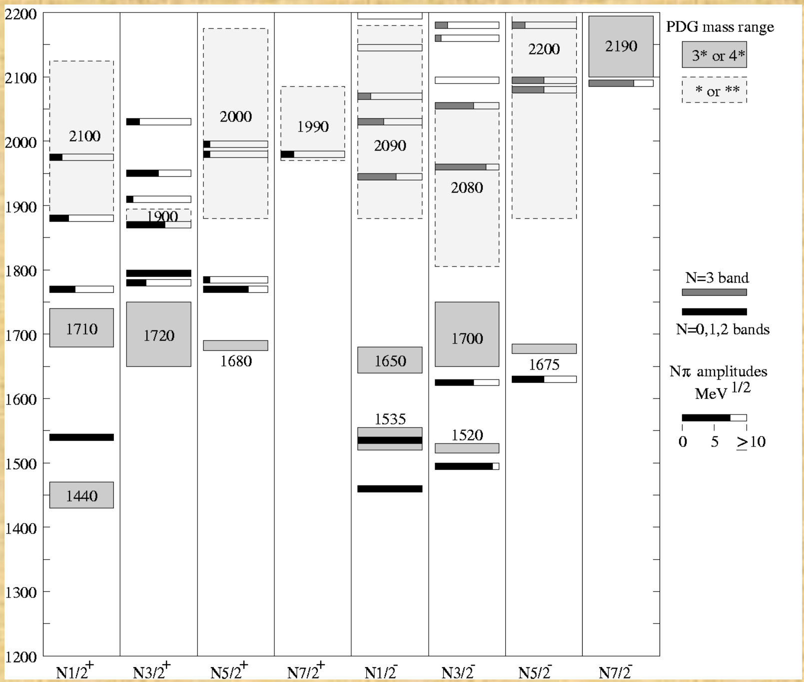
- $f_0(1710)$ and $f_0(2100)$ are dominant scalars
- $f_0(1500)$ exists (8.2σ)
- The significant tensor contribution comes from $f_2'(1525)$
- $f_2(1810)$ and $f_2(2340)$ exist
- No evidence for $f_J(2200)$



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+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

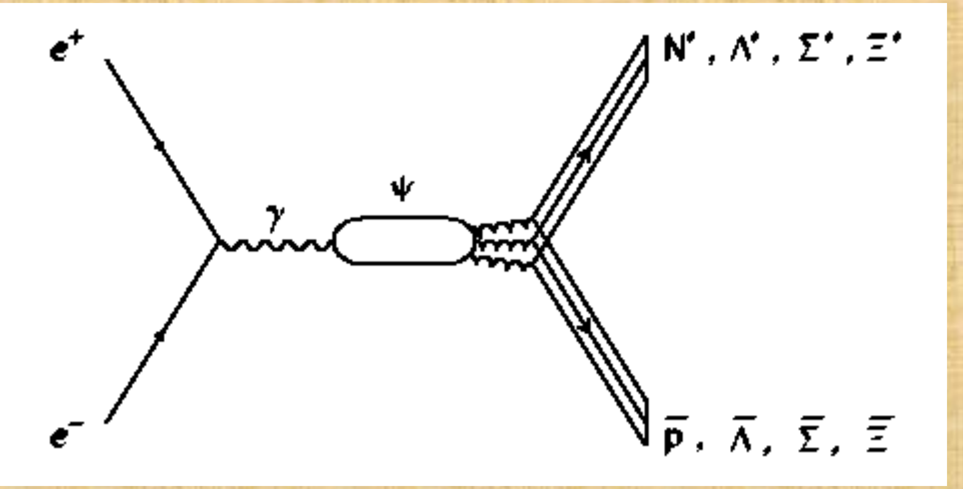
Study of Excited Baryon States

- Probe the internal structure of light quark baryons
- Search for missing baryons predicted by quark model
- Obtain a better understanding of the strong interaction force in the non-perturbative regime



Baryon spectroscopy at BESIII

- Experimental Advantages:
- Pure isospin ½



For $J/\psi \rightarrow N\bar{N}\pi$ and $J/\psi \rightarrow N\bar{N}\pi\pi$, $N\pi$ and $N\pi\pi$ systems are limited to be pure isospin

- Not only N*, Λ*, Σ*, but also Ξ*

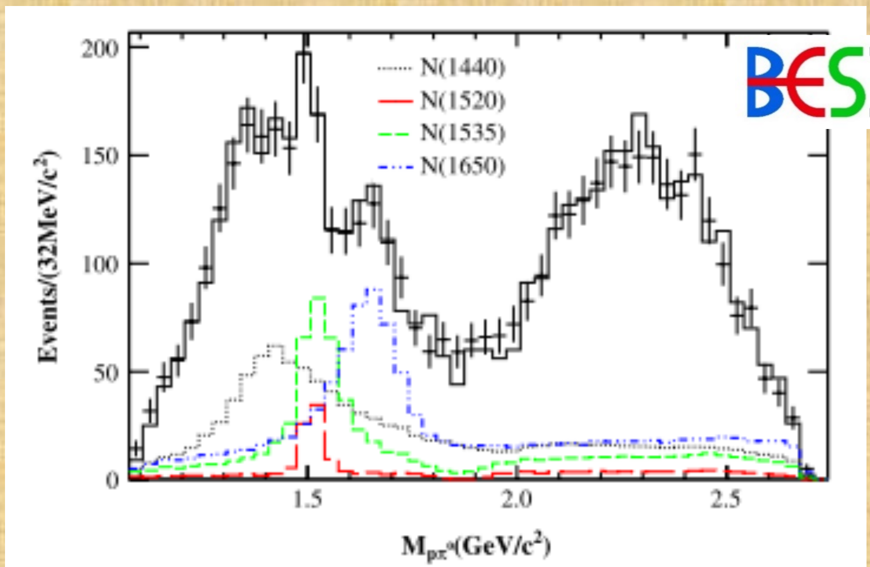
Baryon spectroscopy at BESIII

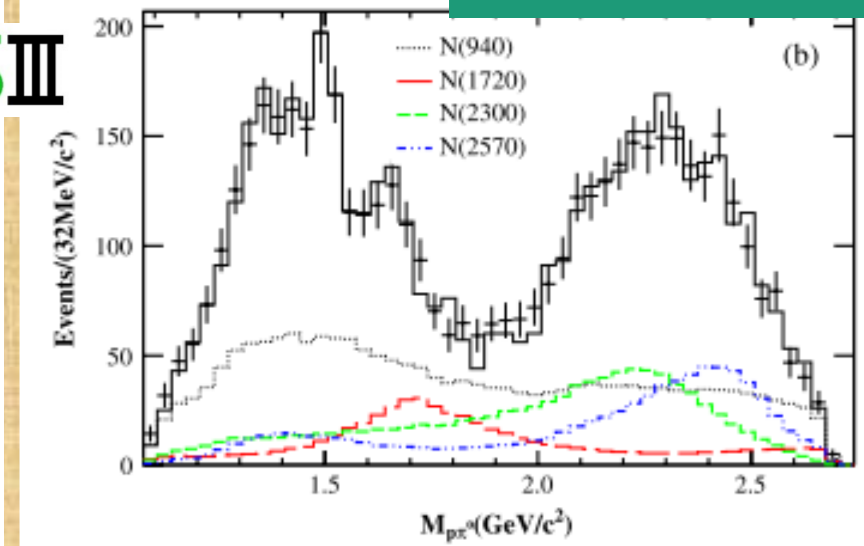
- PWA of $\psi(3686) \to \bar{p}p\pi^0$
- PWA of $\psi(3686) \to \bar{p}p\eta$
- Measurements of $\psi(3686) \to (\gamma)K^-\Lambda\,\bar{\Xi}^+ + c.c.$
- Observation of $\psi(3686) \to \Lambda\,\bar{\Sigma}^\pm\pi^\mp + c.c.$

Based on 106 M $\psi(3686)$ data.

PWA of $\psi(3686)\rightarrow p\ \bar{p}\ \pi^0$

PRL 110, 022001





- Two new N* are observed, N(2300) (1/2+) and N(2570) (5/2-)
- Mass and width of 5 well-known N* are measured
- No clear evidence for N(1885) and N(2065)

Resonance	M(MeV$/c^2$)	Γ(MeV$/c^2$)	ΔS	$\Delta N_{\rm dof}$	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)	$\mathbf{2300^{+40+109}_{-30-0}}$	$\mathbf{340^{+30+110}_{-30-58}}$	**120.7**	**4**	$\mathbf{15.0\sigma}$
N(2570)	$\mathbf{2570^{+19+34}_{-10-10}}$	$\mathbf{250^{+14+69}_{-24-21}}$	**78.9**	**6**	$\mathbf{11.7\sigma}$

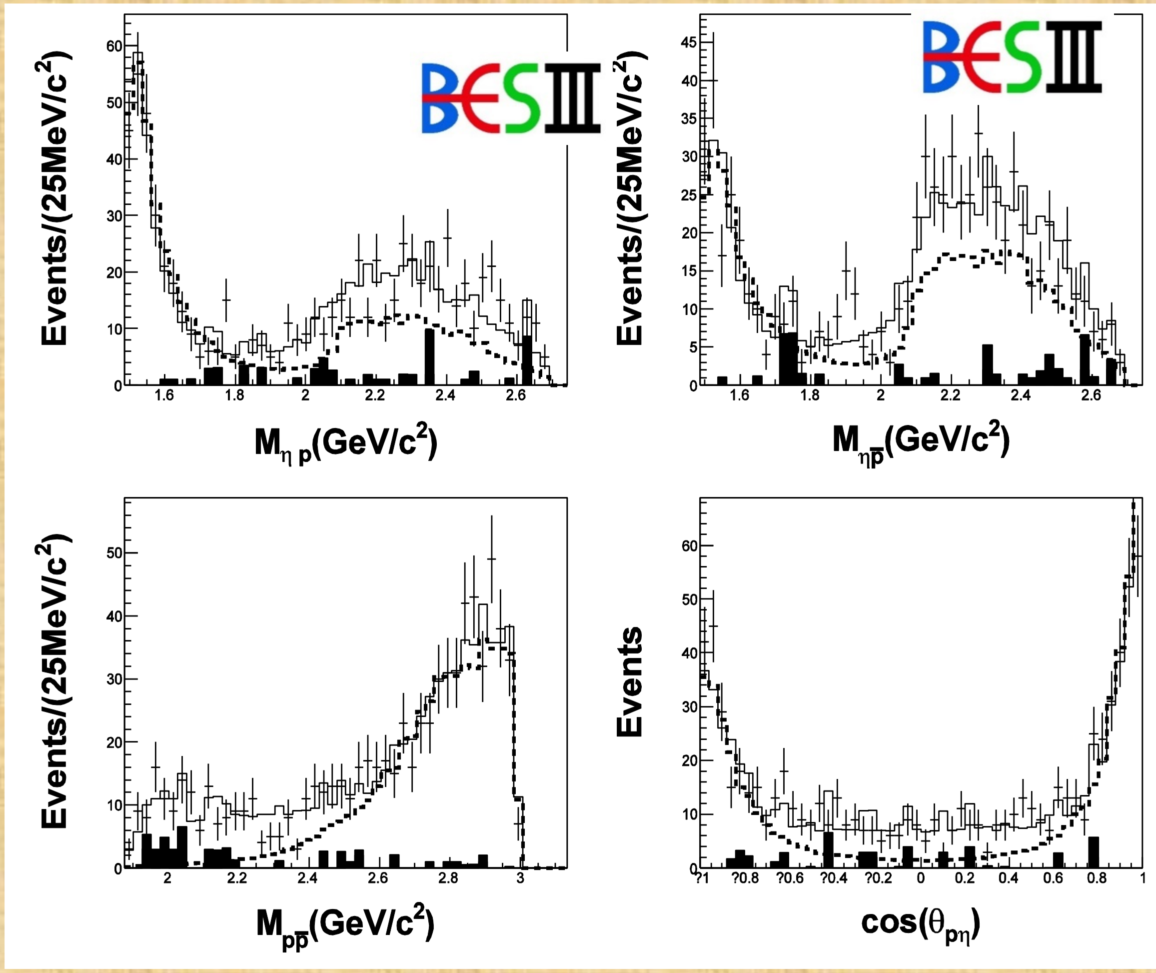
PWA of ψ(3686)→p $\bar{p}$ η

PRD 88, 032010

- N(1535) and PHSP are dominant contribution
- M = $1524 \pm 5^{+10}_{-4}$ MeV/c²

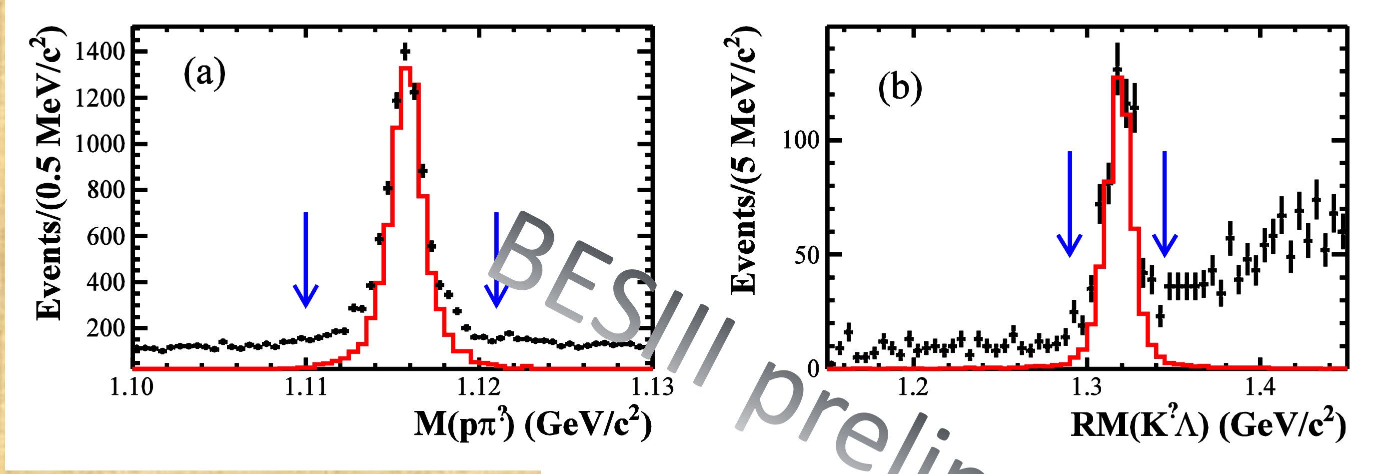
$\Gamma = 130^{+27+57}_{-24-10}$ MeV

$Br\left(\psi(3686) \to pN(1535)\right)$
$\times Br(N(1535) \to \bar{p}\eta)$
$= (5.2 \pm 0.3^{+3.2}_{-1.2})\times 10^{-5}$

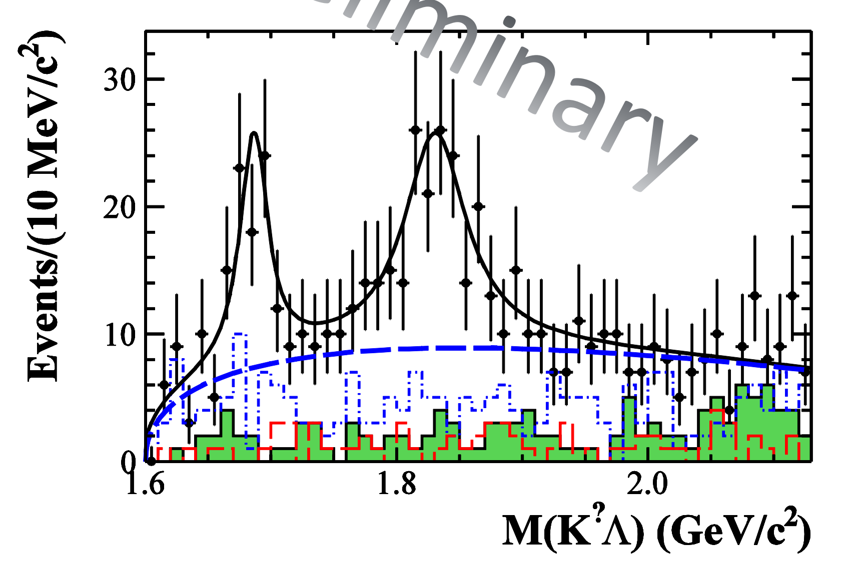


Measurements of $\psi(3686) \to (\gamma) K^{-} \Lambda \bar{\Xi}^{+} + c.c.$

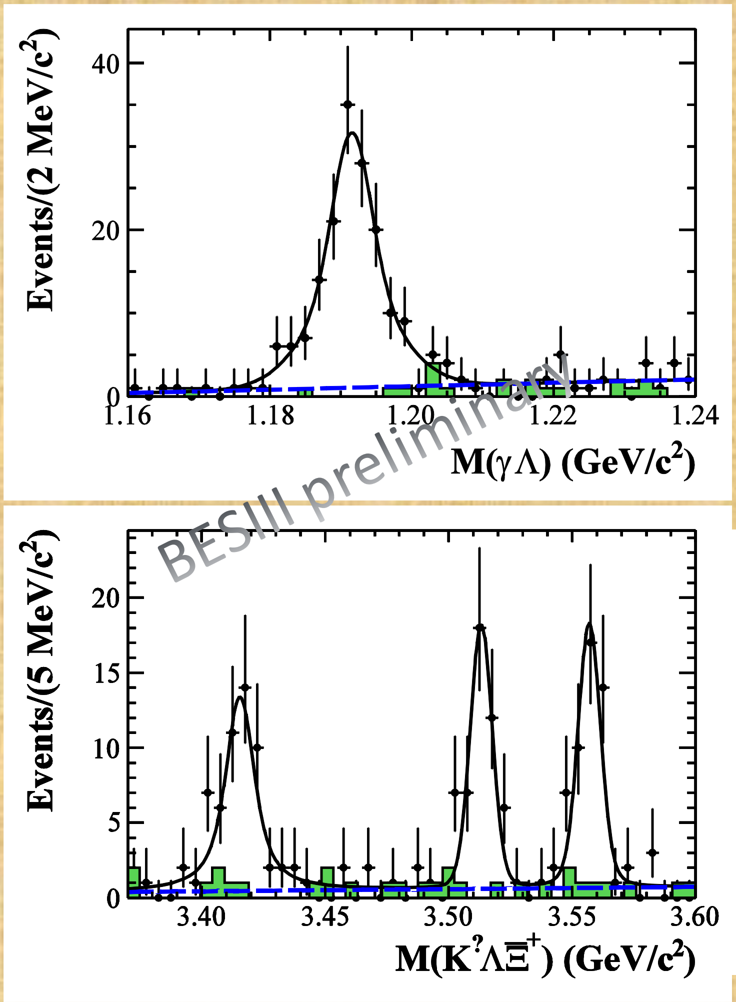
arXiv:1504.02025



- Only reconstruct KΛ to improve statistics
- Ξ(1690) and Ξ(1820) are observed in $\psi(3686) \to K^{-} \Lambda \bar{\Xi}^{+} + c.c.$
- Resonances parameters are consist with PDG



Measurements of $\psi(3686) \to (\gamma)K^{-}\Lambda\,\bar{\Xi}^{+} + c.c.$

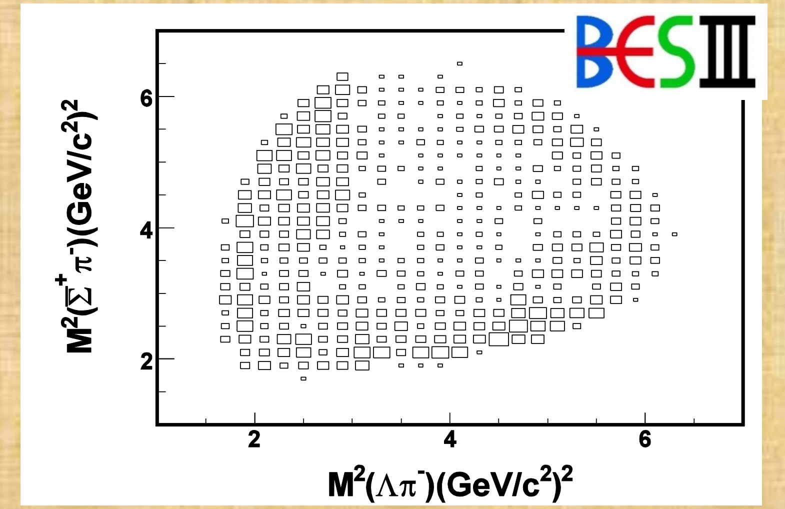


- Clear Σ^0 and χ_{CJ} status with low background
- The Br of $\psi(3686) \to K^{-}\Sigma^{0}\,\bar{\Xi}^{+}$ and $\chi_{CJ} \to K^{-}\Lambda\,\bar{\Xi}^{+}$ are measured

Decay	Branching fraction
$\psi(3686) \to K^-\Lambda\bar{\Xi}^+$	$(3.86 \pm 0.27 \pm 0.32) \times 10^{-5}$
$\psi(3686) \to \Xi(1690)^-\bar{\Xi}^+,\ \Xi(1690)^- \to K^-\Lambda$	$(5.21 \pm 1.48 \pm 0.57) \times 10^{-6}$
$\psi(3686) \to \Xi(1820)^-\bar{\Xi}^+,\ \Xi(1820)^- \to K^-\Lambda$	$(12.03 \pm 2.94 \pm 1.22) \times 10^{-6}$
$\psi(3686) \to K^-\Sigma^0\bar{\Xi}^+$	$(3.67 \pm 0.33 \pm 0.28) \times 10^{-5}$
$\psi(3686) \to \gamma\chi_{c0},\ \chi_{c0} \to K^-\Lambda\bar{\Xi}^+$	$(1.90 \pm 0.30 \pm 0.16) \times 10^{-5}$
$\psi(3686) \to \gamma\chi_{c1},\ \chi_{c1} \to K^-\Lambda\bar{\Xi}^+$	$(1.32 \pm 0.20 \pm 0.12) \times 10^{-5}$
$\psi(3686) \to \gamma\chi_{c2},\ \chi_{c2} \to K^-\Lambda\bar{\Xi}^+$	$(1.68 \pm 0.26 \pm 0.15) \times 10^{-5}$
$\chi_{c0} \to K^-\Lambda\bar{\Xi}^+$	$(1.96 \pm 0.31 \pm 0.16) \times 10^{-4}$
$\chi_{c1} \to K^-\Lambda\bar{\Xi}^+$	$(1.43 \pm 0.22 \pm 0.12) \times 10^{-4}$
$\chi_{c2} \to K^-\Lambda\bar{\Xi}^+$	$(1.93 \pm 0.30 \pm 0.15) \times 10^{-4}$

Observation of $\psi(3686) \to \Lambda \bar{\Sigma}^{\pm}\pi^{\mp} + c.c.$

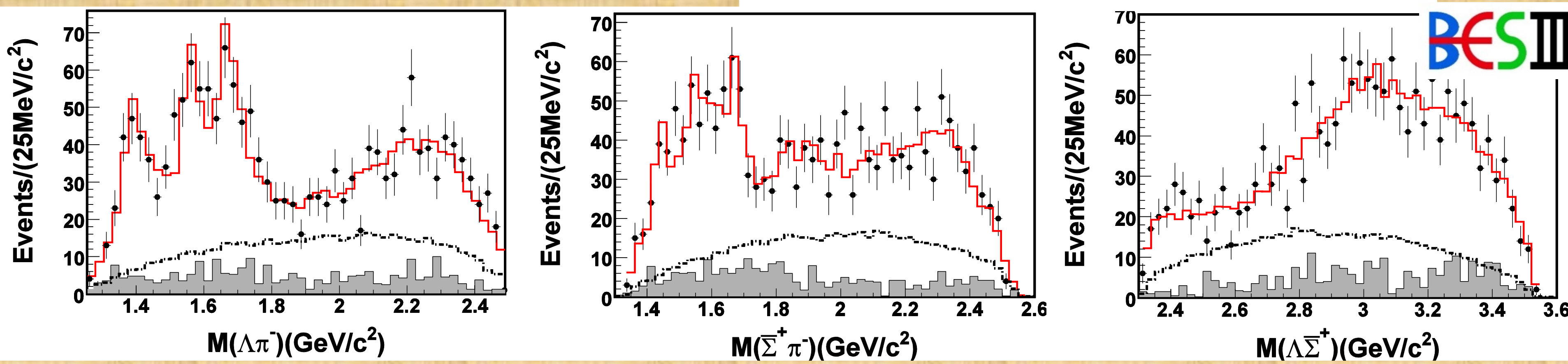
PRD 88, 112007



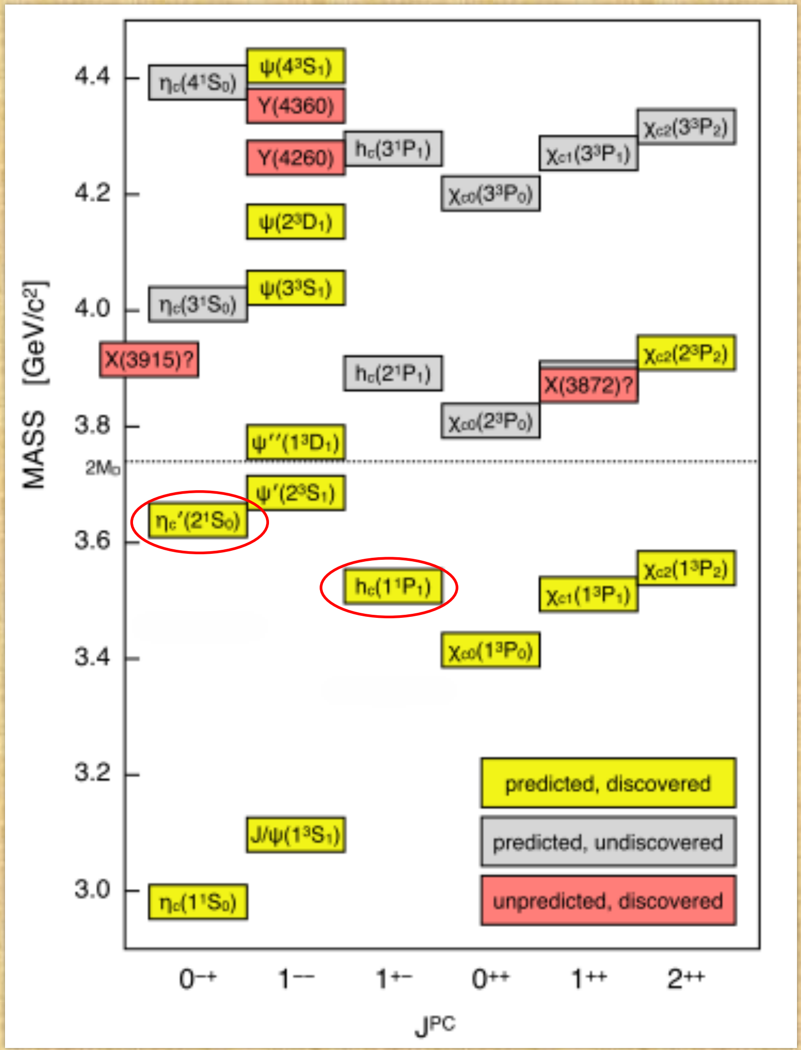
- Λ^* and Σ^* can be found in the mass spectrum of $\Lambda\pi$ and $\Sigma\pi$ respsctively
- Br are measured

$$\mathcal{B}(\psi(3686) \to \Lambda\bar{\Sigma}^+\pi^- + \text{c.c.}) = (1.40 \pm 0.03 \pm 0.13) \times 10^{-4},$$

$$\mathcal{B}(\psi(3686) \to \Lambda\bar{\Sigma}^-\pi^+ + \text{c.c.}) = (1.54 \pm 0.04 \pm 0.13) \times 10^{-4},$$



Charmonium states

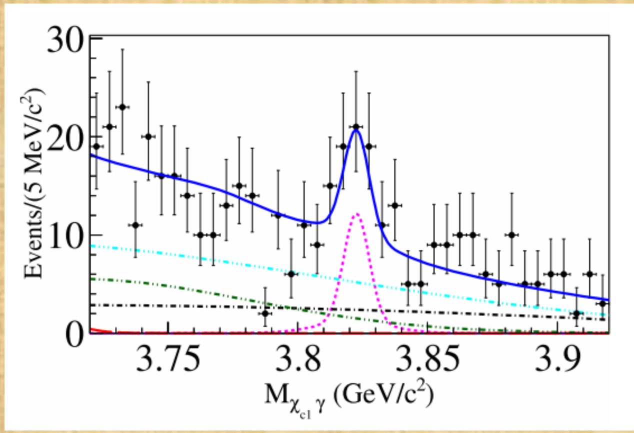


- η_C, BESIII results:
  PRL 108, 222002 (2012)
  M = 2984.3±0.6 ±0.6 MeV/c^2,
  Γ=32.0 ±1.2 ±1.0 MeV
- η_C(2S),
  $KK\pi$, PRL 109, 042003,
  $K_SK3\pi$, PRD 87, 052005
- h_c,
  $\psi(2S)\to\pi^0 h_c$,
  PRL 104, 132002,
  PRD 86, 092009,
  $e^+e^-\to\pi^+\pi^- h_c$,
  PRL 111, 242001

XYZ

$e^+e^- \rightarrow \pi^+\pi^- X(3823) \rightarrow \pi^+\pi^-\gamma\chi_{c1}$

- X(3823) found at Belle from $B \rightarrow K\gamma\chi_{c1}$ (3.8σ)



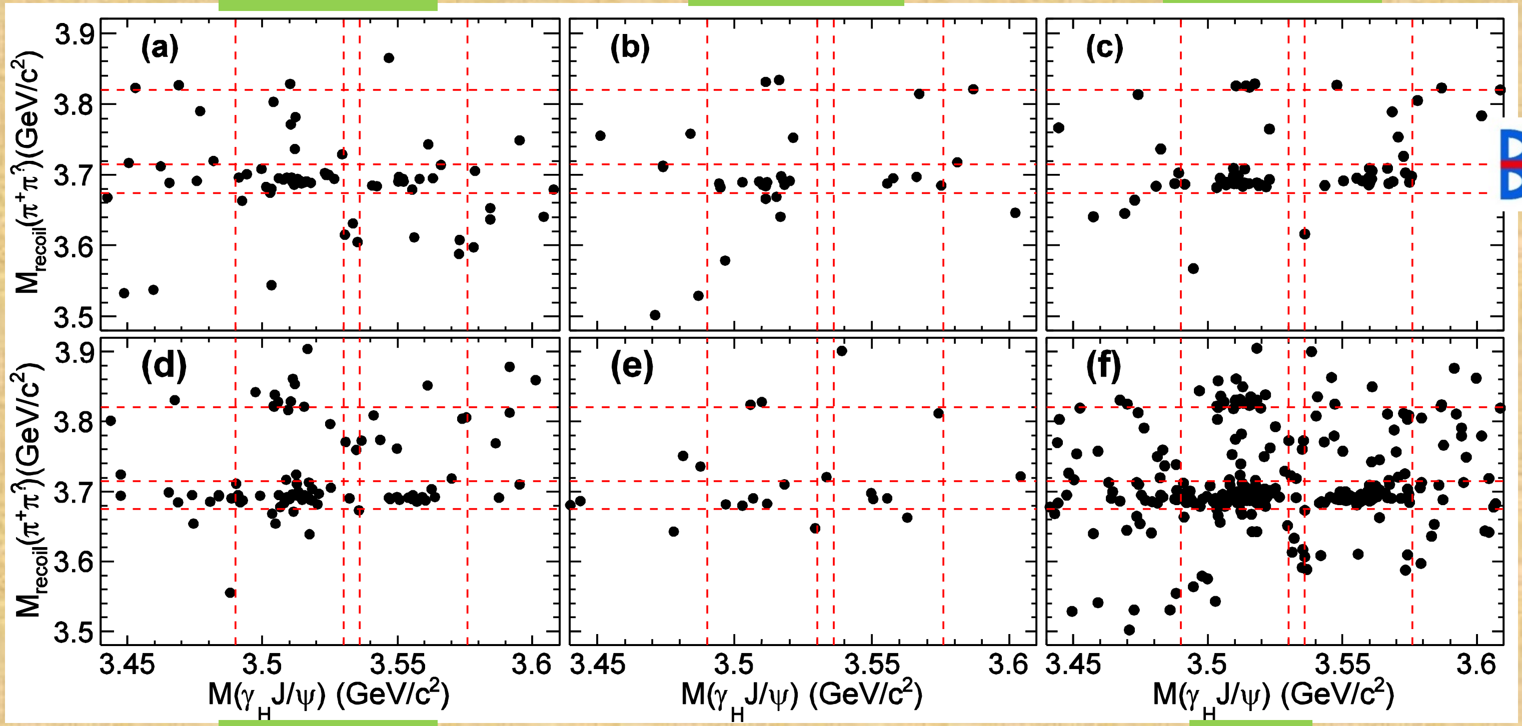
(PRL 111, 032001 (2013))

- Mass and width compatible with $\psi_2(1^3D_2)$ state
- BESIII use 5 large data sets (4.23, 4.26, 4,36, 4.42, 4.60 GeV) with total luminosity ~ 4.1 fb^{-1}
- Search from the process $e^+e^- \rightarrow \pi^+\pi^-\gamma\chi_{c1}$

$e^+e^- \rightarrow \pi^+\pi^- X(3823) \rightarrow \pi^+\pi^-\gamma\chi_{c1}$

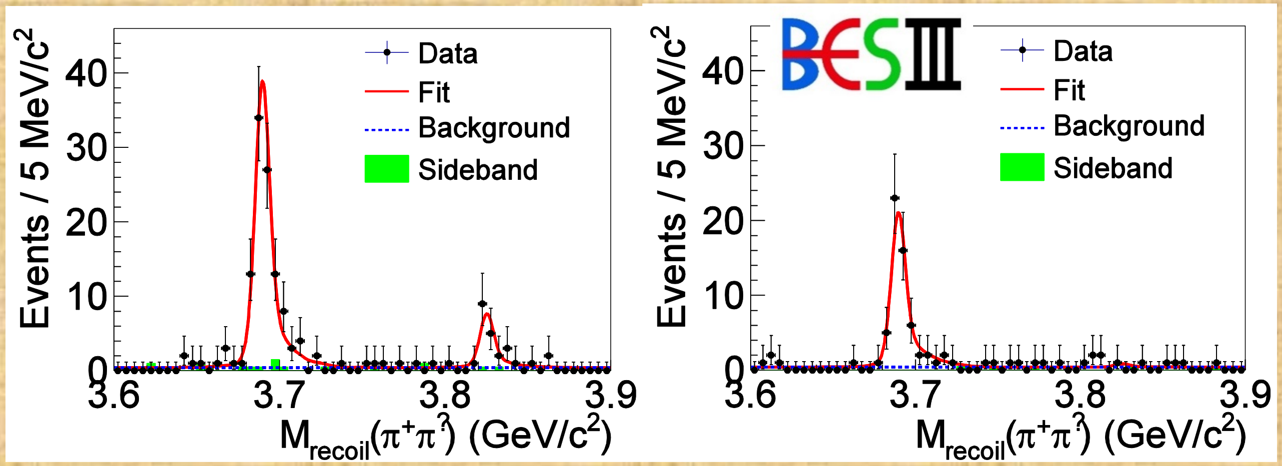
χ_{c1} is reconstructed from $\gamma J/\psi$, look in recoiling mass agaist $\pi^+\pi^-$

4.23 GeV | 4.26 GeV | 4.36 GeV

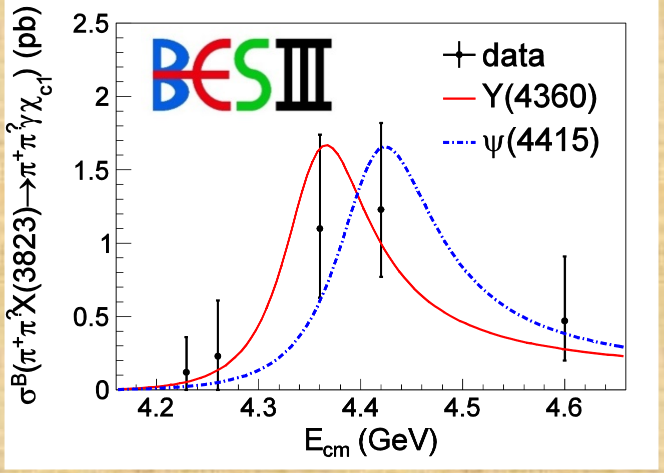


4.42 GeV | 4.60 GeV | sum

$e^+e^- \to \pi^+\pi^- X(3823) \to \pi^+\pi^-\gamma\chi_{c1}$



- M = 3821.7±1.3 ±0.7 MeV/c^2
- Γ< 16 MeV at 90% C.L.
- Cross section for the process compatible with both Y(4360) and ψ(4415) line shapes



Observation of $e^+e^- \to \gamma X(3872)$

- X(3872): mass very close to $\bar{D}^0 D^{*0}$ threshold
  vary narrow width, < 1.2 MeV
  $J^{PC}=1^{++}$

  exotic?

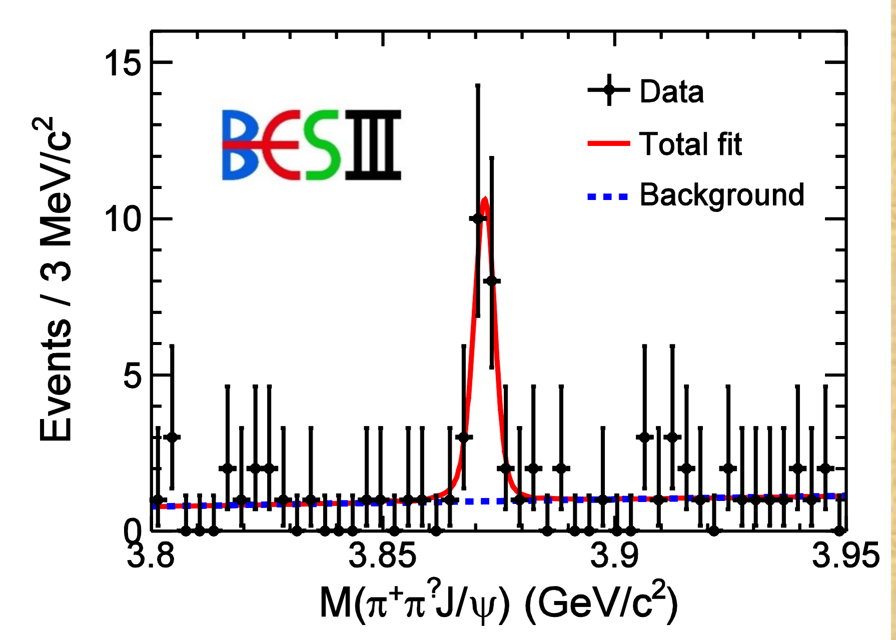
- BESIII measurement:

  6.3 σ

M = 3871.9±0.7 ±0.2 MeV

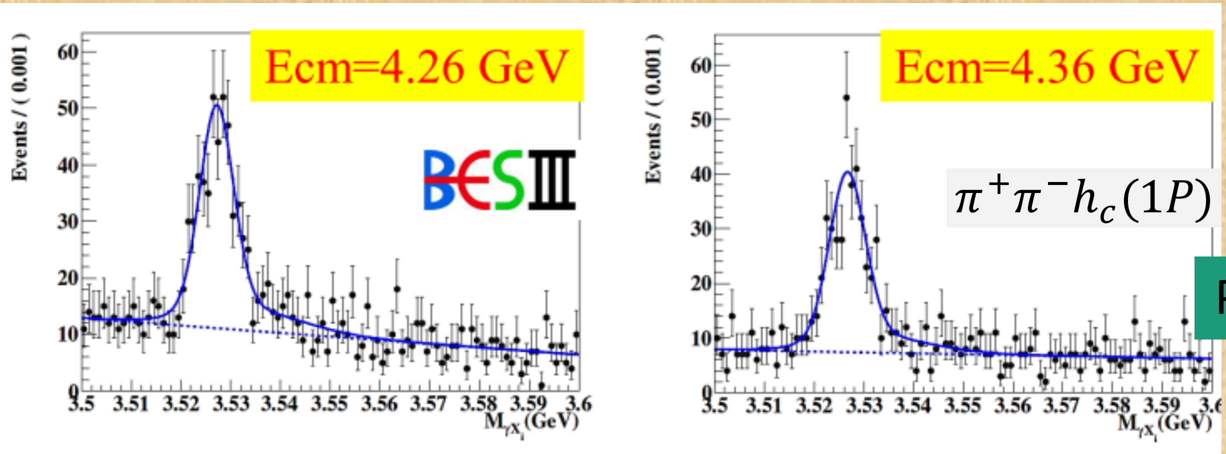
(PDG: 3871.68±0.17 MeV)

PRL 112, 092001



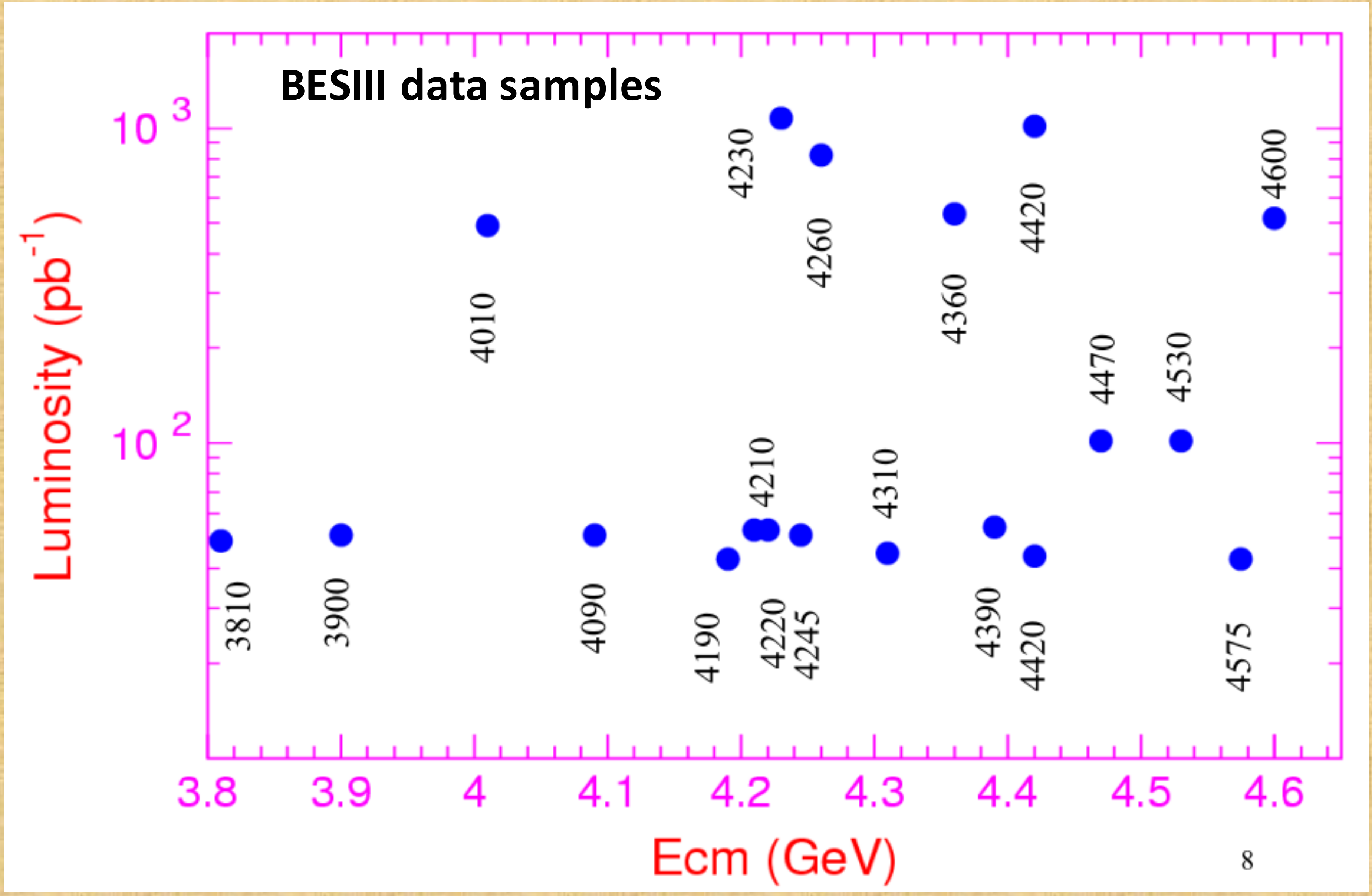
Y states

- Y states can be produced directly at BESIII
- BESIII had collected about 5/fb data from 3.8 to 4.6 GeV



PRL 111, 242001

- More decay modes can be measured, such as $\omega\chi_{c0}$, $\eta J/\psi$, $\eta' J/\psi$, $\eta\pi^0 J/\psi$, $\gamma\chi_{cJ}$, $\gamma Y(4140)$, …


BESIII data samples
Luminosity (pb^-1)
10^3
10^2
Ecm (GeV)
3.8
3.9
4
4.1
4.2
4.3
4.4
4.5
4.6
3810
3900
4010
4090
4190
4210
4220
4230
4245
4260
4310
4360
4390
4420
4420
4470
4530
4575
4600
8

Z_c states at BESIII

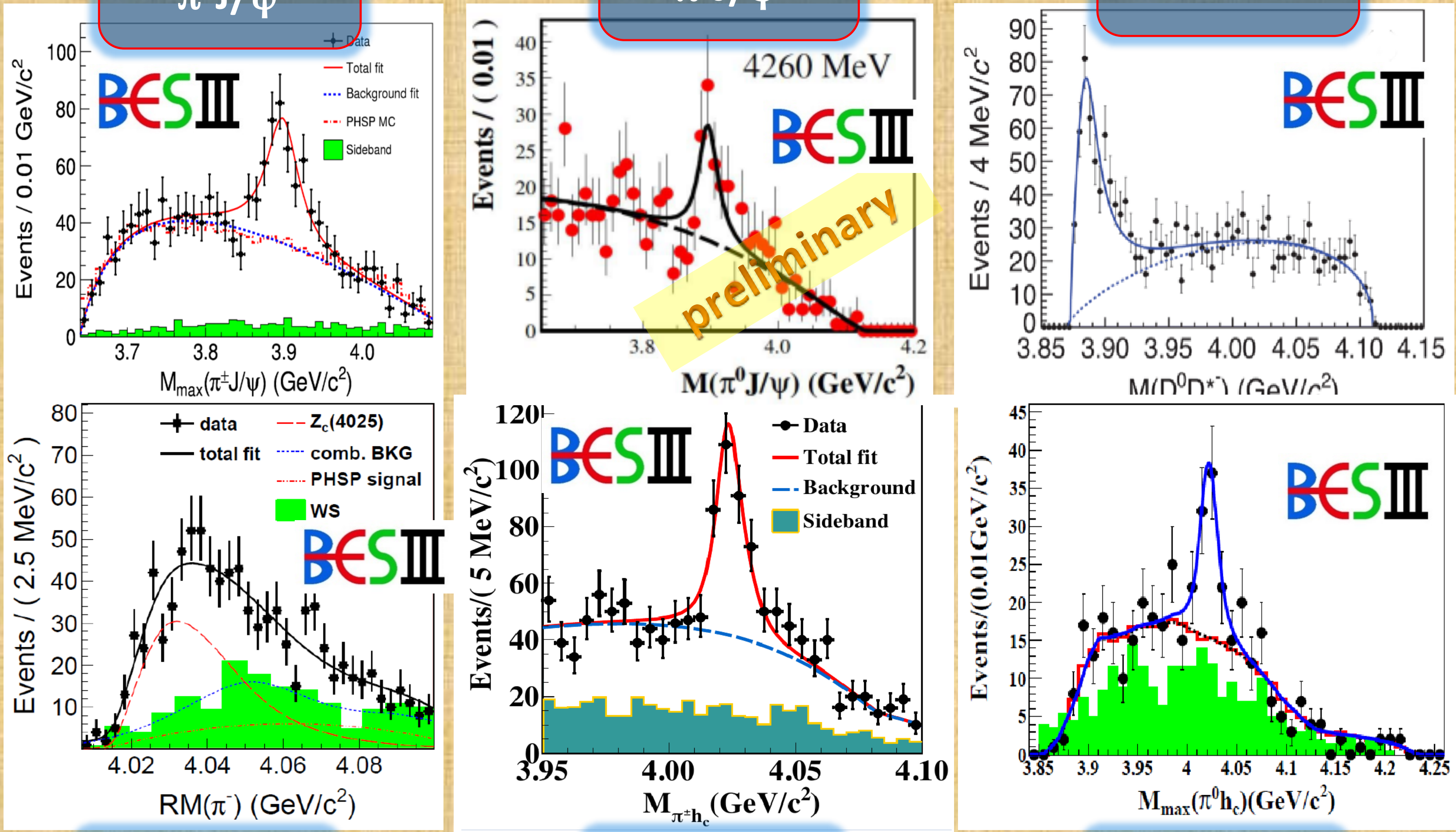
- $e^+e^- \rightarrow \pi Z_c$
- BESIII searches Z_c in variant processes
  - $Z_c^+ \rightarrow \pi^+ J/\psi$
  - $Z_c^0 \rightarrow \pi^0 J/\psi$
  - $Z_c^+ \rightarrow (D\bar{D}^*)^+$

  - $Z_c^+ \rightarrow \pi^+ h_c$
  - $Z_c^0 \rightarrow \pi^0 h_c$
  - $Z_c^+ \rightarrow (D^*\bar{D}^*)^+$

Zc(3900) $\pi^{\pm}J/\psi$

Zc(3900) $\pi^{0}J/\psi$

Zc(3885) $D\ \bar{D}^*$



Zc(4025) $D^*\ \bar{D}^*$

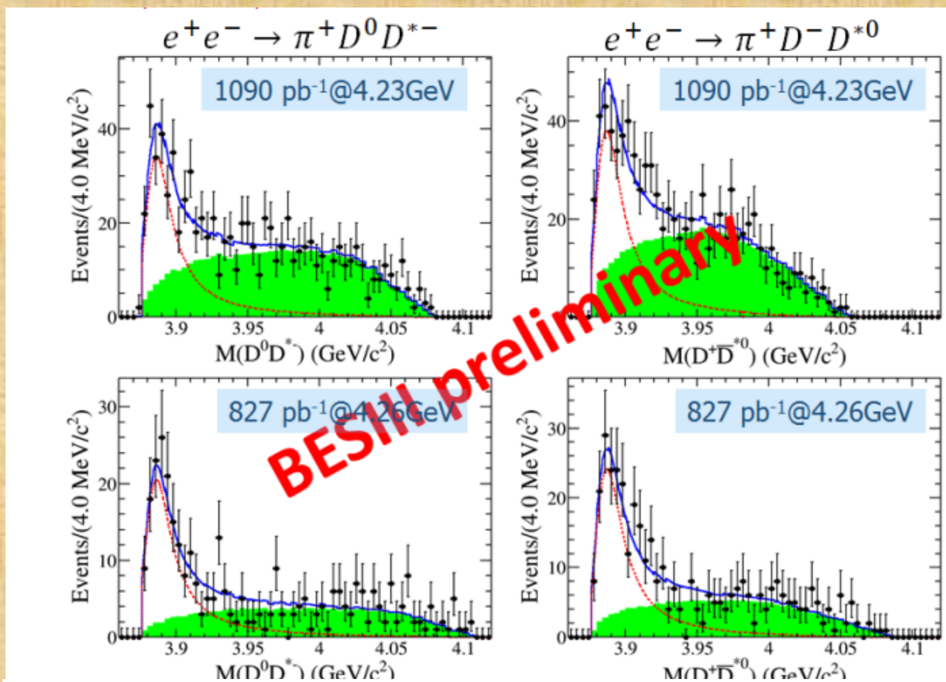
Zc(4020) $\pi^{\pm}h_c$

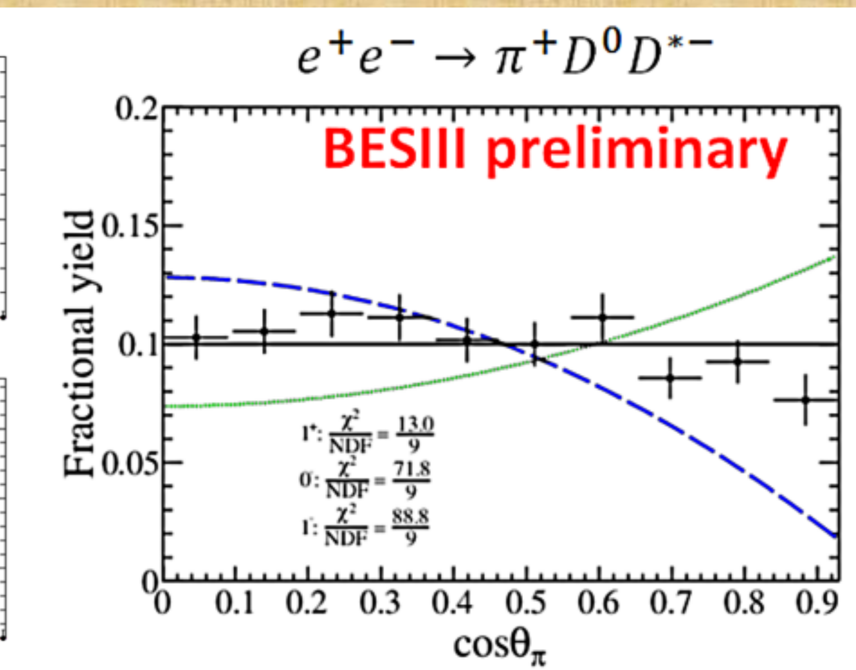
Zc(4020) $\pi^{0}h_c$

Z_c states (BESIII results)

Channel	Mass (MeV/c^2)	Width (MeV)	
$\pi^{\pm}J/\psi$	3899.0±3.6±4.9	46±10±20	PRL 110, 252001
$\pi^0 J/\psi$	3895.2±2.5±2.6	33.0±9.3±7.3	preliminary
$(D\bar{D}^*)^+$	3883.9±1.5±4.2	24.8±3.3±11.0	PRL 112, 022001
$h_c\pi^{\pm}$	4022.9±0.8±2.7	7.9±2.7±2.6	PRL 111, 242001
$h_c\pi^0$	4023.9±2.2±3.8	Fixed	PRL 113, 212002
$(D^*\bar{D}^*)^+$	4026.3±2.6±3.7	24.0±5.6±7.7	PRL 112, 132001

$e^+e^- \to \pi^+(\bar{D}^*D)^-$ with double tag



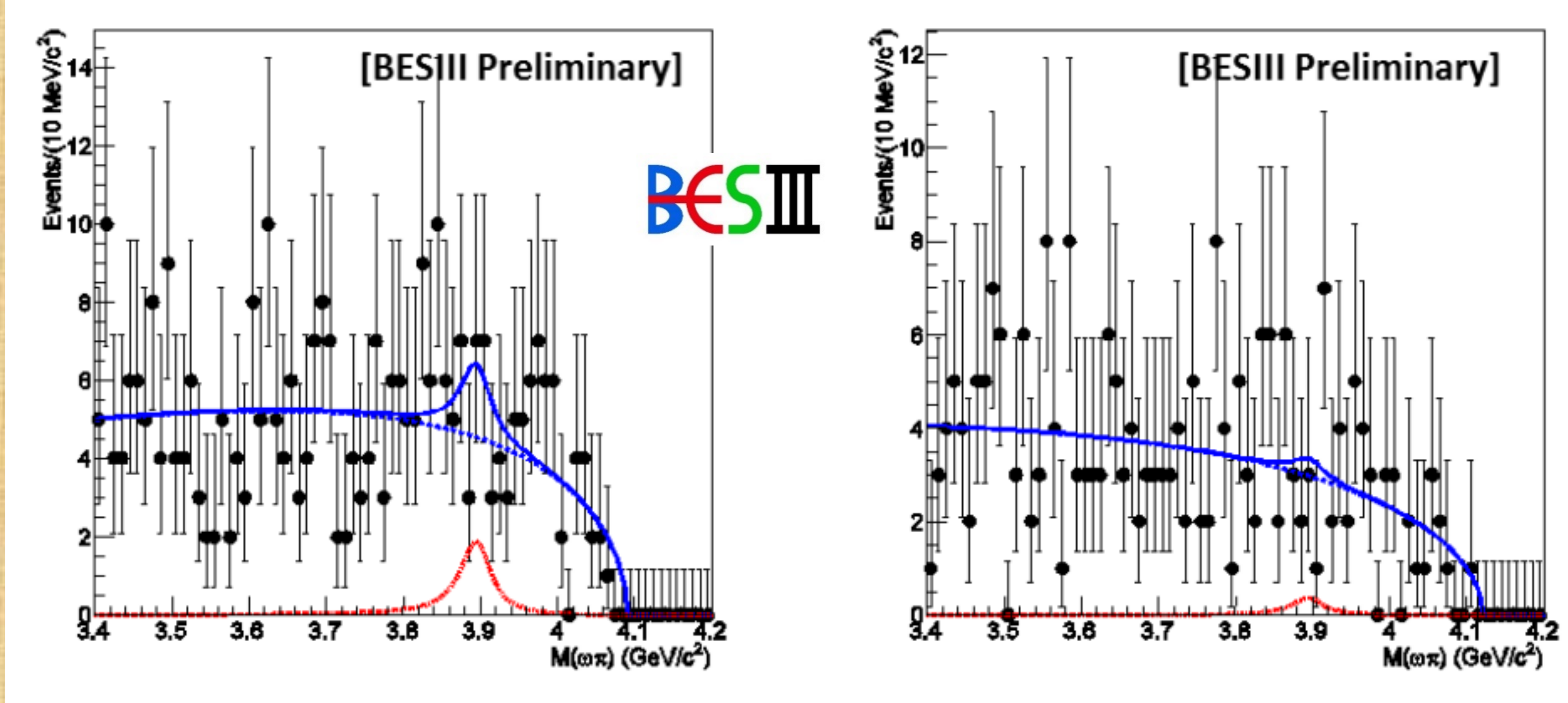


		BESIII single D tags PRL 112, 022001	BESIII double D tags preliminary
M_{pole} [MeV/c^2]		$3883.9 \pm 1.5(stat) \pm 4.2(syst)$	$3884.3 \pm 1.2(stat) \pm 1.5(syst)$
Γ_{pole} [MeV]		$24.8 \pm 3.3(stat) \pm 11.0(syst)$	$23.8 \pm 2.1(stat) \pm 2.6(syst)$
$\sigma \times \mathcal{B}$[pb]	4.23 GeV		$106.8 \pm 7.1(stat) \pm 9.5(syst)$
	4.26 GeV	$83.5 \pm 6.6(stat) \pm 22.0(syst)$	$88.0 \pm 6.1(stat) \pm 7.9(syst)$

$$\sigma \times \mathcal{B} \equiv \sigma(e^+e^- \to \pi^\pm Z_c(3885)^\mp) \times \mathcal{B}(Z_c(3885)^\mp \to (D\bar{D}^*)^\mp)$$

- Zc(3885) data clearly favour $J^P = 1^+$

Search Z_c in other decay models $Z_c(3900) \to \omega\pi$



$\sigma(e^+e^- \to Z_c^+\pi^-, Z_c^+ \to \omega\pi^+) < 0.27\,\text{pb}$ $\sigma(e^+e^- \to Z_c^+\pi^-, Z_c^+ \to \omega\pi^+) < 0.18\,\text{pb}$

- Compared to sum of Zc→πJ/ψ and $(\bar{D}^*D)^+$

$$\Gamma(Z_c^+ \to \omega\pi^+) < 0.2\%\ \Gamma_{tot}$$

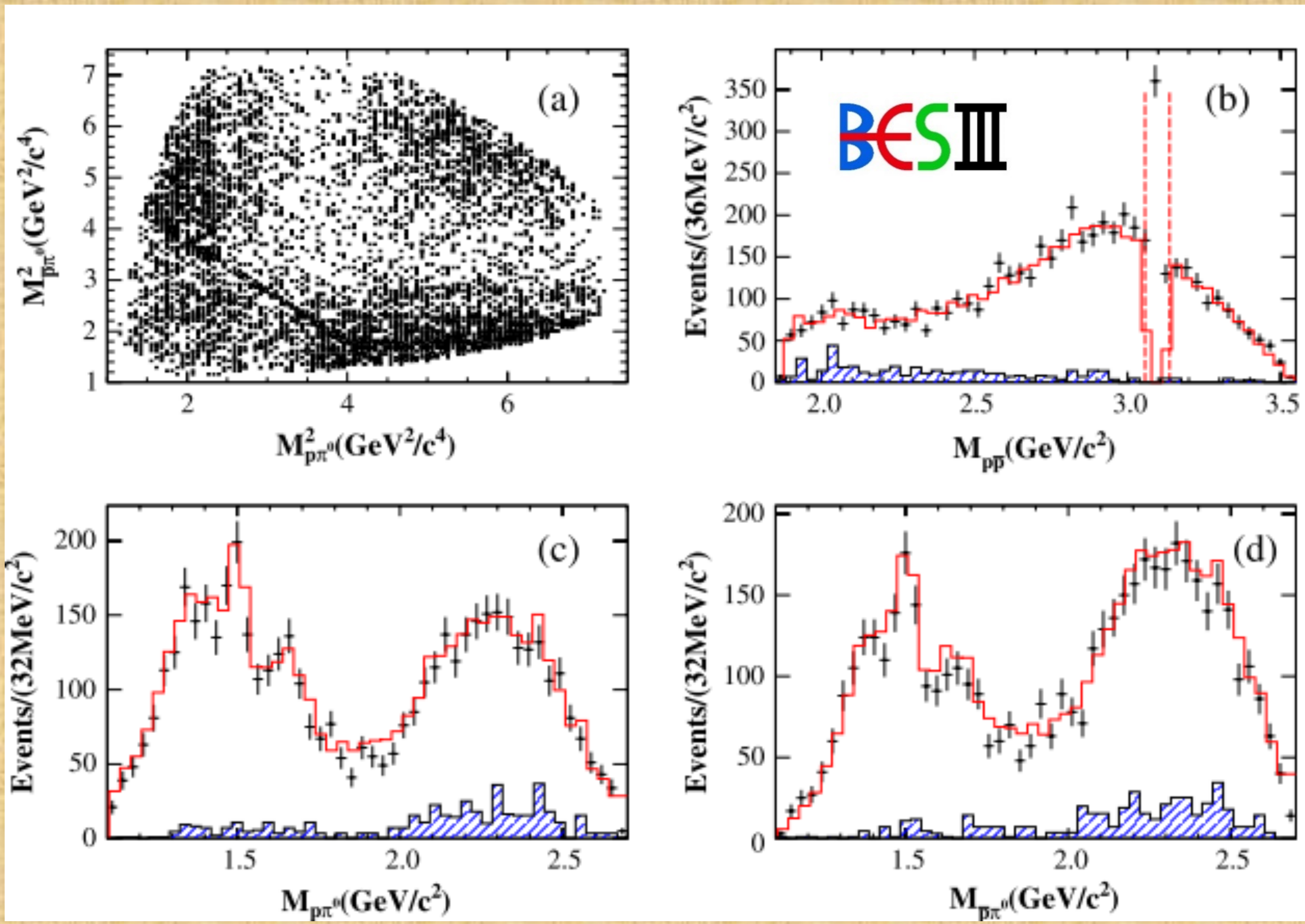
What's the nature of these Z_c states?

- At least 4 quarks, not a conventional meson
- Tetraquark states?
  PRD 87, 125018 (2013); PRD 88, 074506 (2013);
  PRD 89, 054019 (2014); PRD 90, 054009 (2014); etc
- $D^{(*)}\overline{D}^{(*)}$ molecule states?
  PRL 111, 132003 (2013); PRD 89, 094026 (2014);
  PRD 89, 074029 (2014); PRD 88, 074506 (2014); etc
- FSI?
- Cusp;
- … …

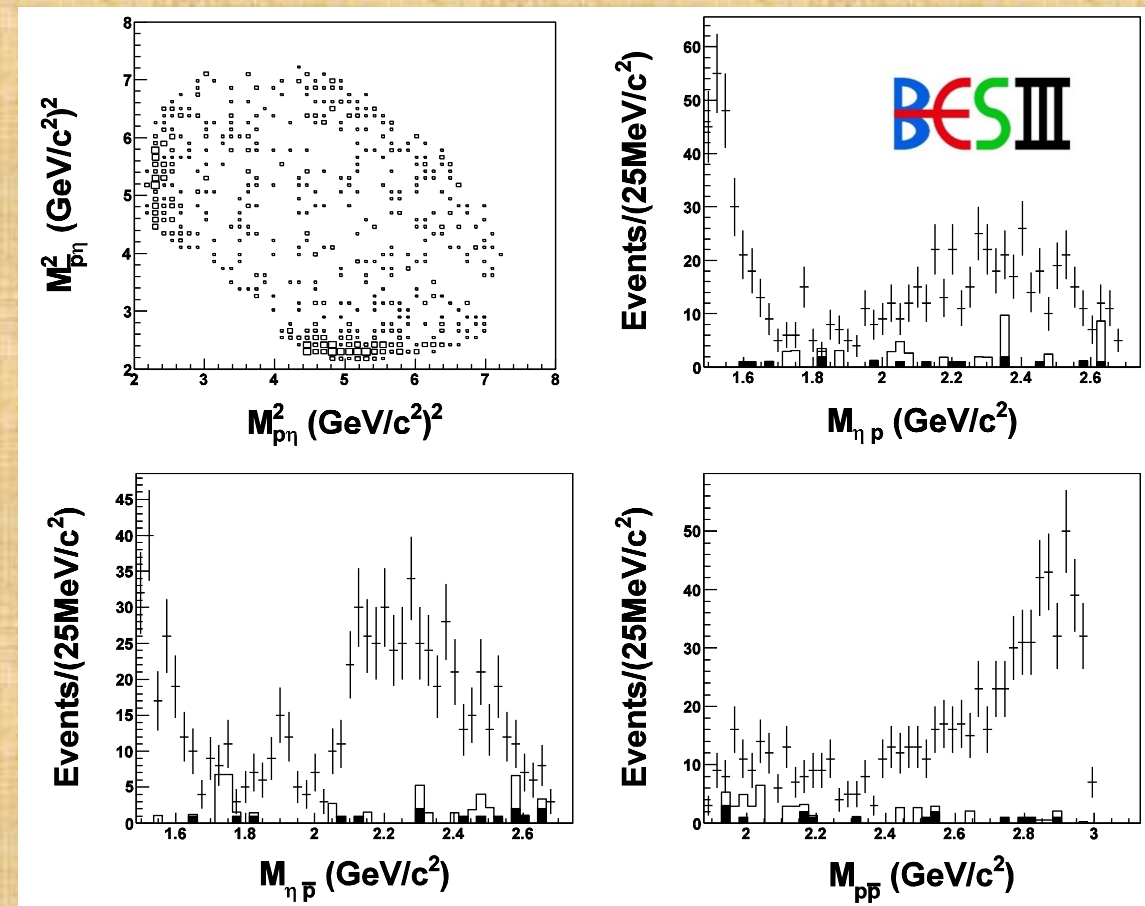
Summary

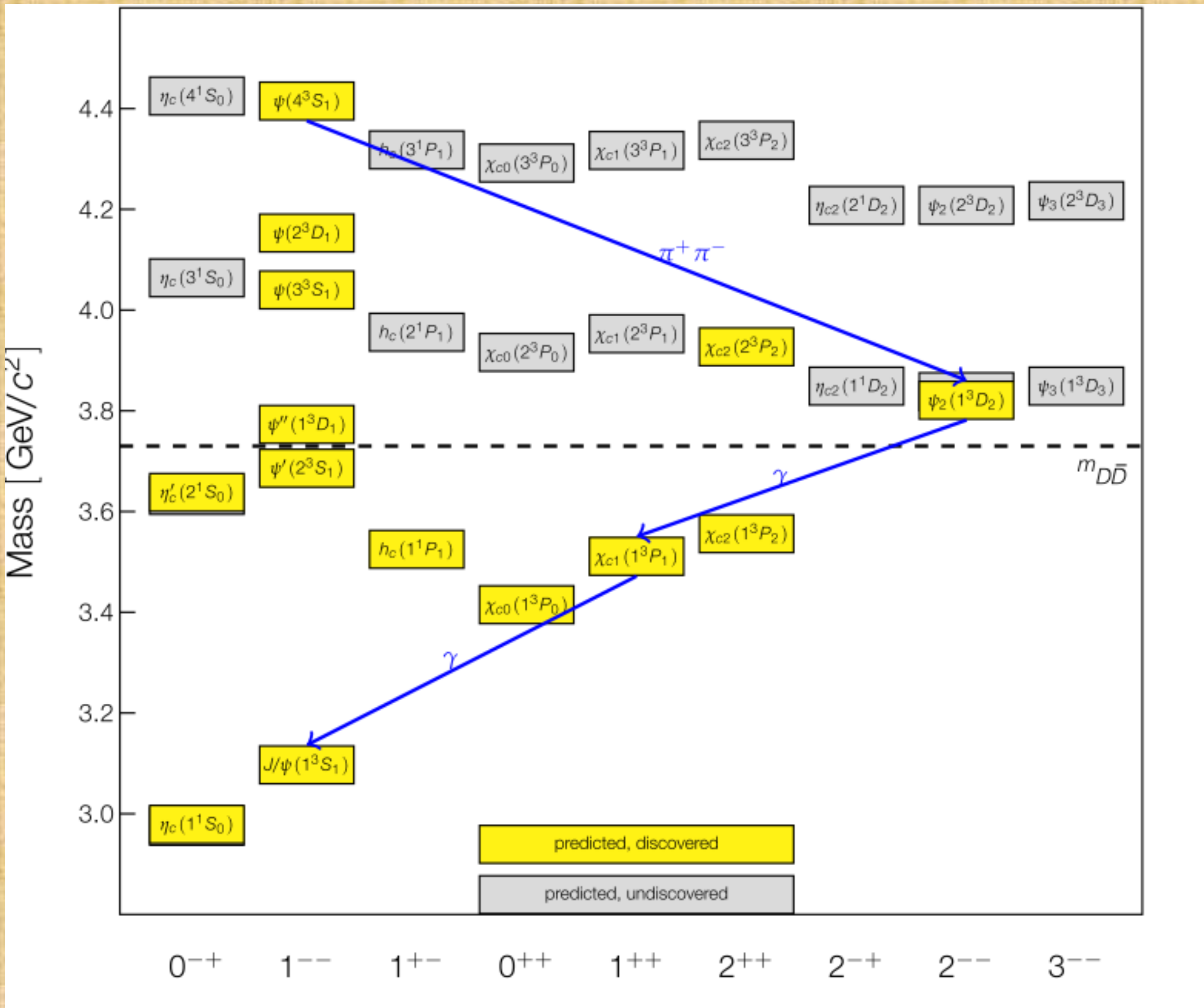
- BESIII is successfully operating since 2008, and continues to take data.
- An excellent place to study hadron spectroscopy (higher statistics and lower background), complementary to hadron scattering and photoproduction experiments
- Many interesting results have been obtained based on 225 M J/ψ and 106 M $\psi(3686)$ data
- Expect more results with 1.3 B J/ψ and 0.5 B $\psi(3686)$ data

$\psi(3686)\to p\bar{p}\pi^0$ @ BESIII



$\psi(3686)\to p\ \bar{p}\ \eta$ @ BESIII





Mass [GeV/c²]
4.4
4.2
4.0
3.8
3.6
3.4
3.2
3.0
ηc(4¹S0)
ψ(4³S1)
hc(3¹P1)
χc0(3³P0)
χc1(3³P1)
χc2(3³P2)
ηc2(2¹D2)
ψ2(2³D2)
ψ3(2³D3)
ψ(2³D1)
ηc(3¹S0)
ψ(3³S1)
π+π−
hc(2¹P1)
χc0(2³P0)
χc1(2³P1)
χc2(2³P2)
ηc2(1¹D2)
ψ2(1³D2)
ψ3(1³D3)
ψ″(1³D1)
ψ′(2³S1)
ηc′(2¹S0)
mDD̄
γ
χc2(1³P2)
hc(1¹P1)
χc1(1³P1)
χc0(1³P0)
γ
J/ψ(1³S1)
ηc(1¹S0)
predicted, discovered
predicted, undiscovered
0−+
1−−
1+−
0++
1++
2++
2−+
2−−
3−−

Observation of Y(4260)→γX(3872)

- A new Y(4260) decay mode
- A new X(3872) production mode