Light Hadron Spectroscopy at BES

Shuangshi Fang（房双世）
(for BES,BESII,BESIII light hadron fans)

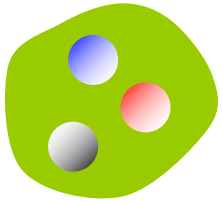
Symposium on 30 years of BES Physics
Sep. 5-6, 2019, Beijing

Outline

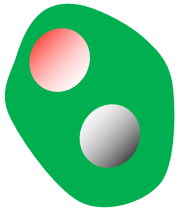
- Why light hadron spectroscopy
- Physics accomplishments
- Summary & Prospects

Light hadron spectroscopy

- Quark Model

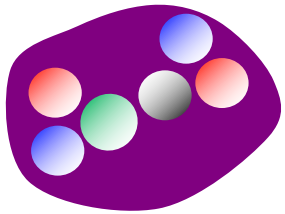


baryon

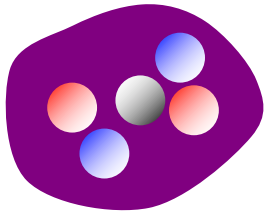


meson

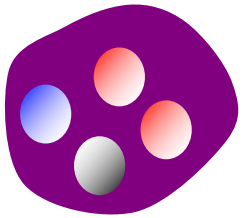
- QCD allows for hadrons beyond Quark Model



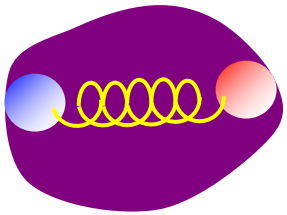
dibaryon



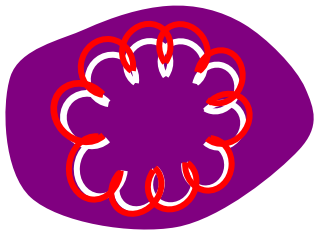
Pentaquark



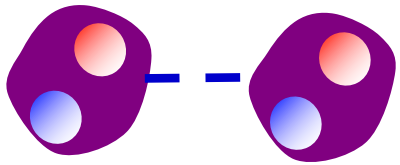
tetraquark



hybrid

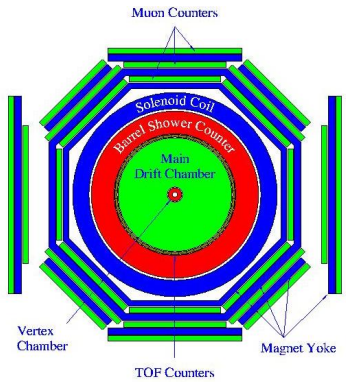


glueball



molecule

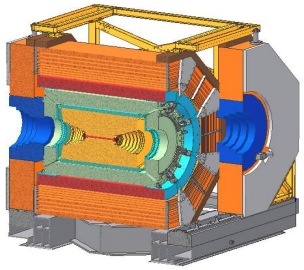
BEPC



End view of the BES detector

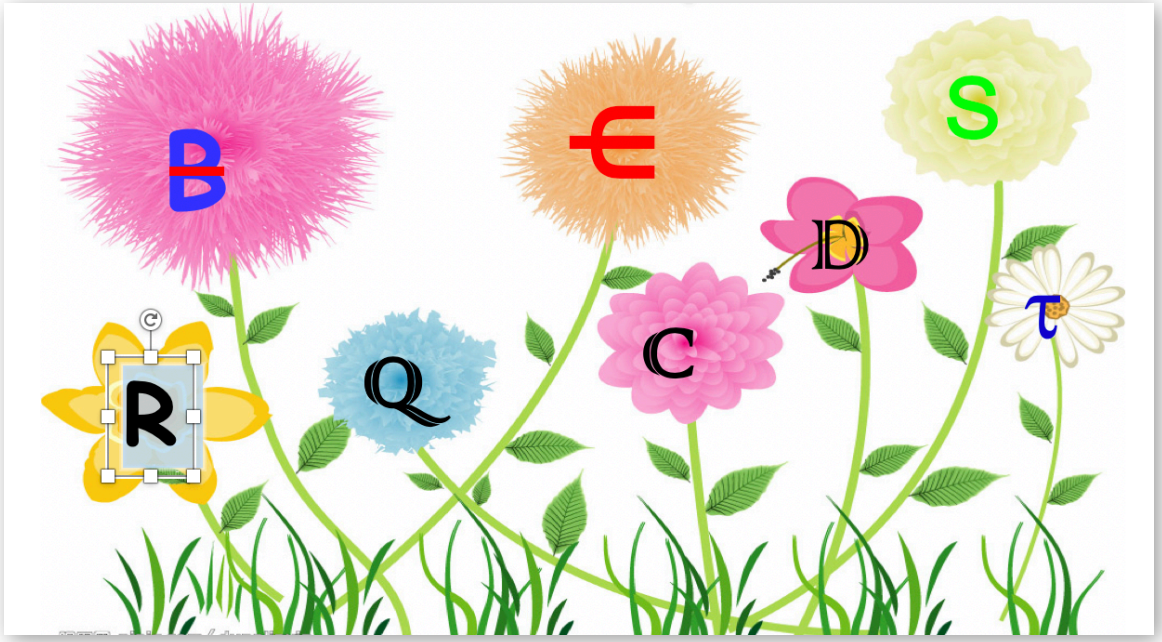
BES

BEPCII



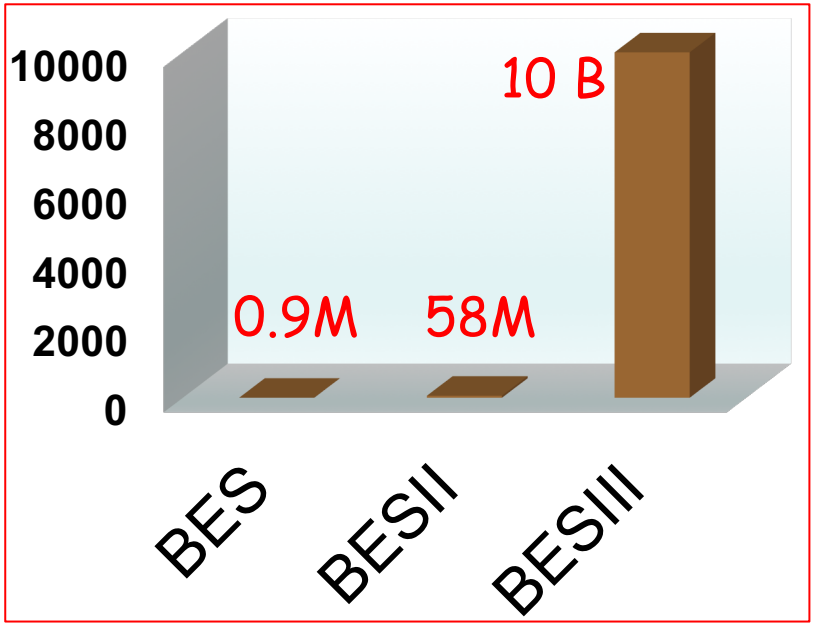
BESIII

τ –charm physics



Physics accomplishments

- Light meson spectroscopy
- Light baryon spectroscopy
- Light meson decays

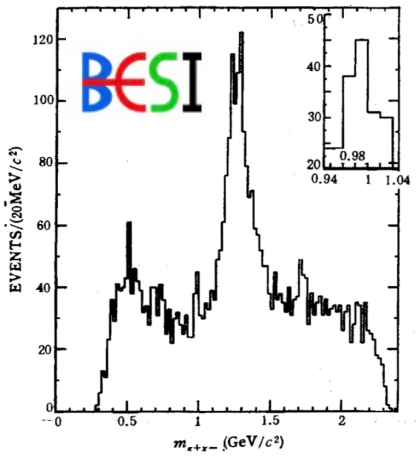


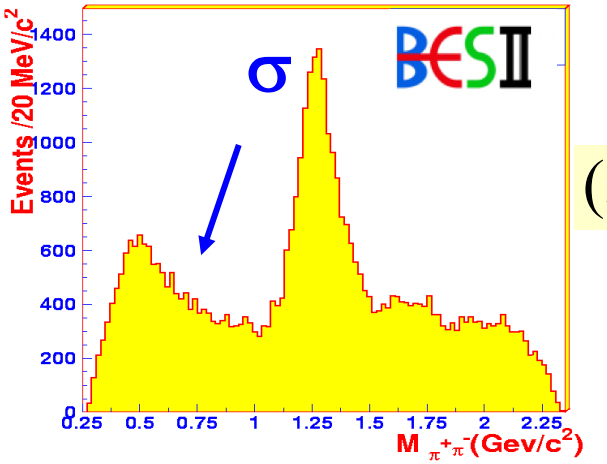
Light meson spectroscopy

- Scalar, tensor and pseudoscalar mesons
- Exotics searches

σ in J/ψ→ωππ and κ in J/ψ→K*Kπ

HEP&NP 19, 289 (1995)

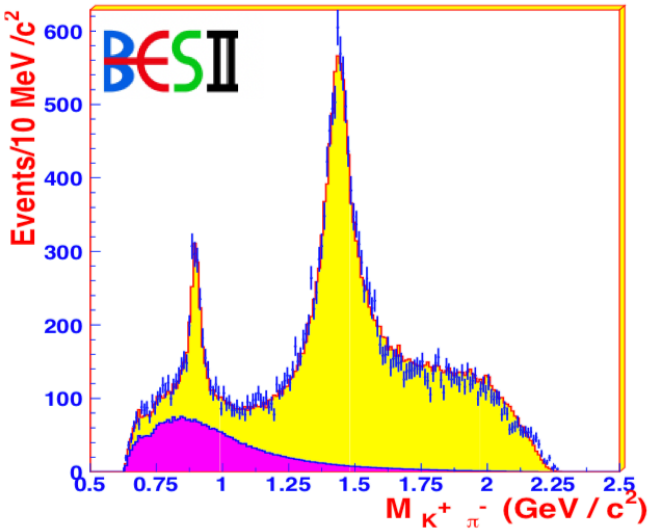




Averaged pole:

$$(541 \pm 39) - i(252 \pm 42)\ \text{MeV}$$

PLB 598 (2004) 149



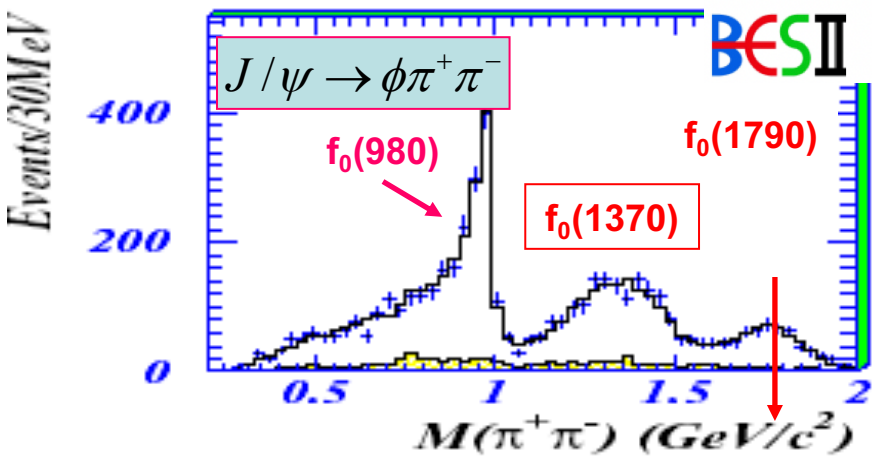
κ is needed in the fit.

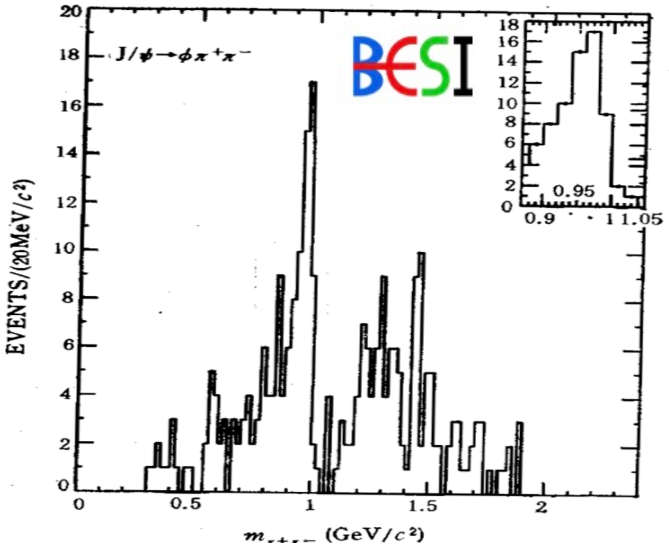
Pole position of κ:

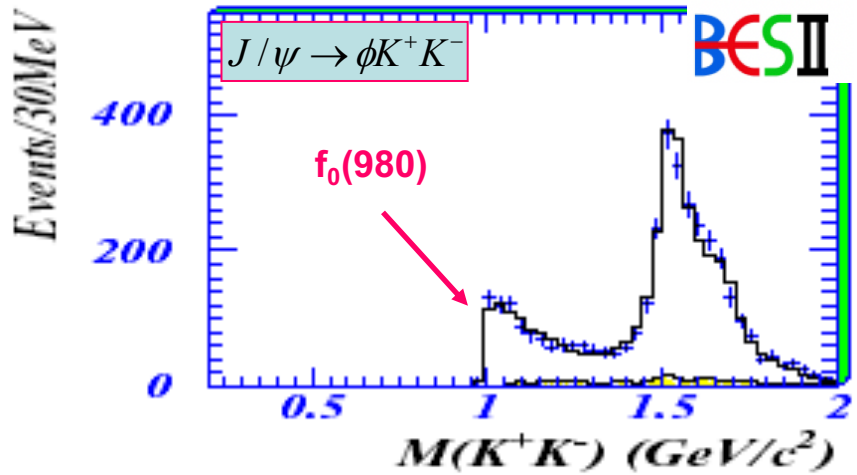
$$(841 \pm 30^{+81}_{-73}) - i(309 \pm 45^{+48}_{-72})\ \text{MeV/c}^2$$

PLB 633 (2006) 681

$f_0(980)$, $f_0(1370)$ and $f_0(1790)$



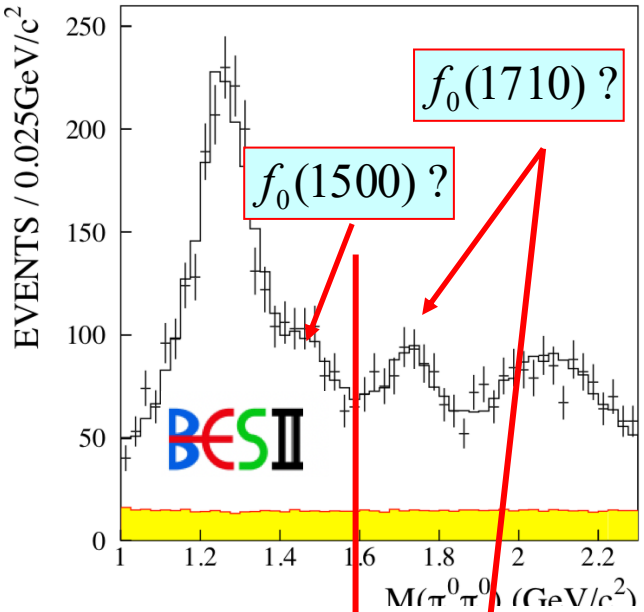


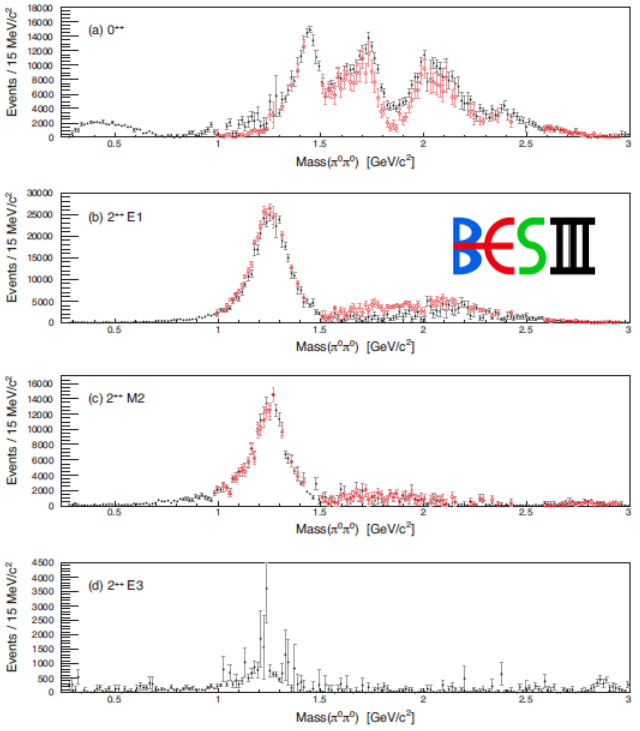


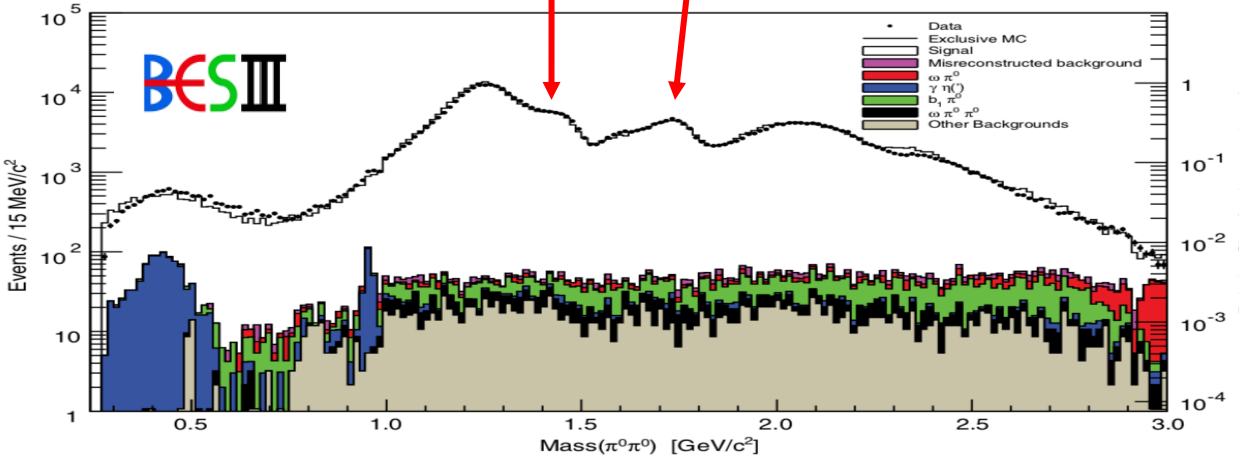
- Large coupling with KK indicates big $s\bar{s}$ component in $f_0(980)$
- Existence of $f_0(1370)$
- $f_0(1790)$ is a new scalar

$f_0(1500)$ and $f_0(1710)$ in $J/\psi \to \gamma\pi\pi$

$J/\psi \to \gamma\pi^0\pi^0$



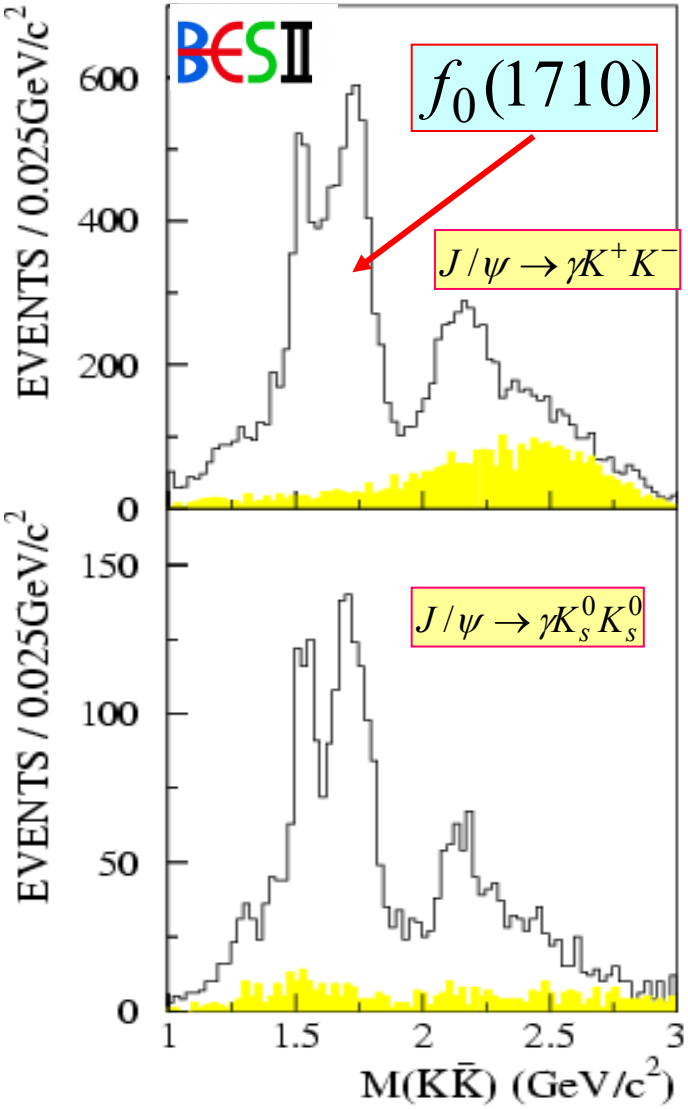




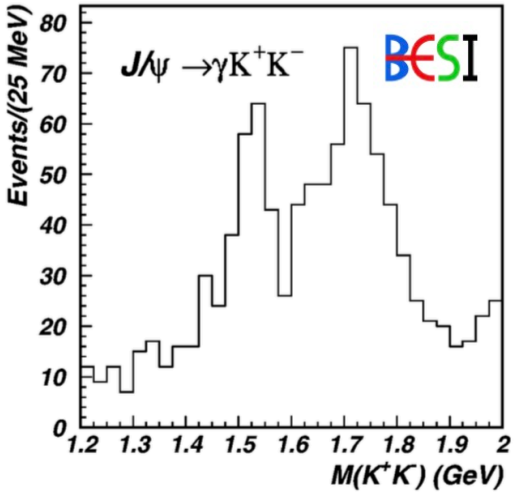
Phys. Rev. D 92, 052003（2015）

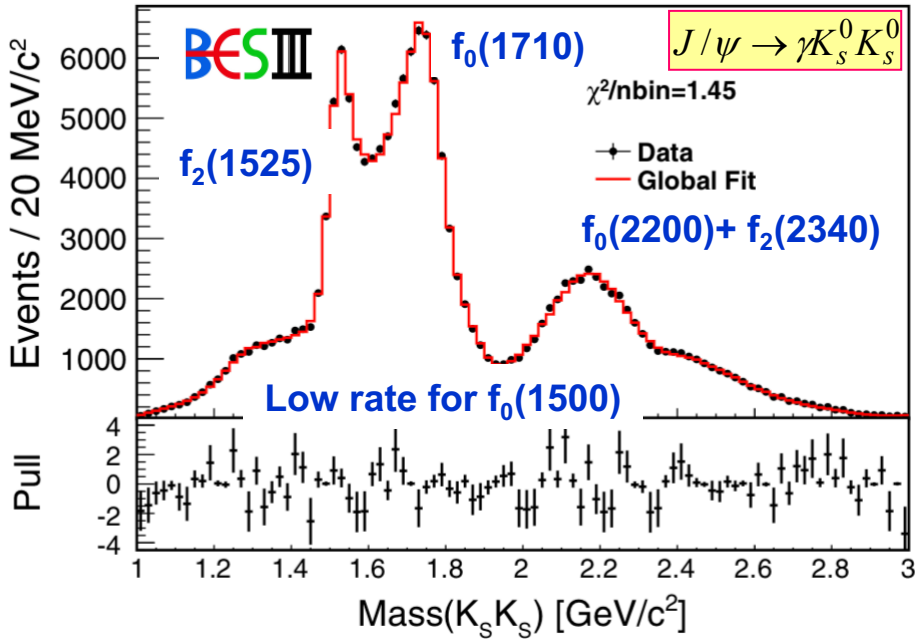
- **Model independent**
- **0^{++}: σ, $f_0(1370)$, $f_0(1500)$, $f_0(1710)$ and $f_0(2020)$**
- **2++: dominated by $f_2(1270)$**

$f_0(1500)$ and $f_0(1710)$ in $J/\psi \to \gamma KK$



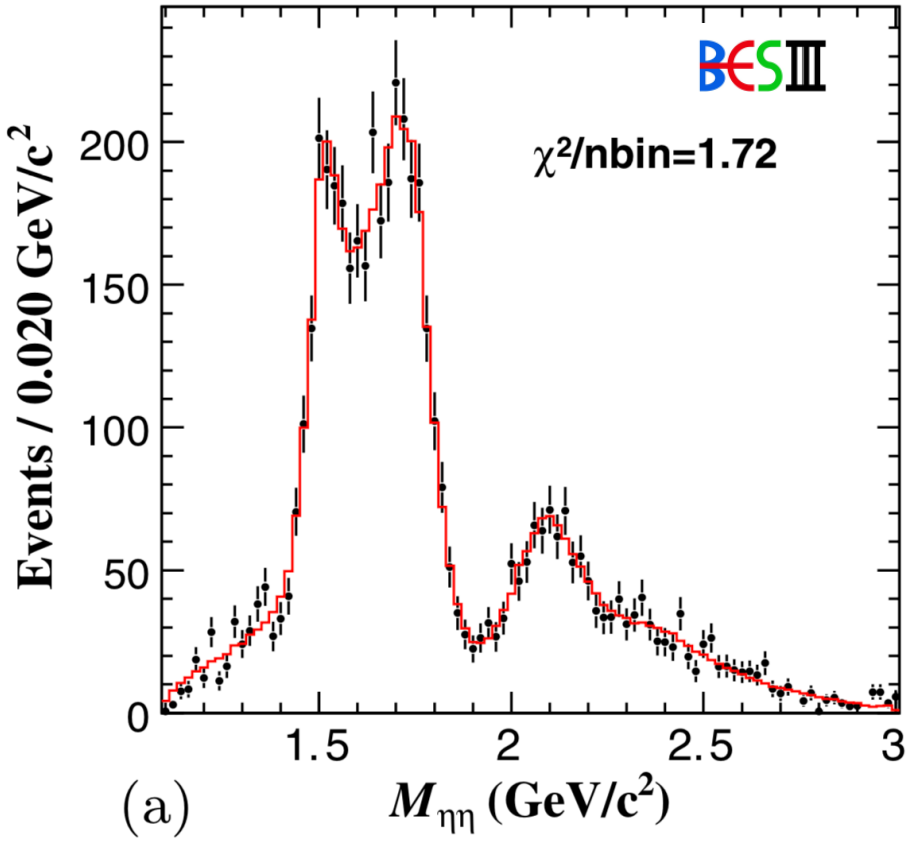
PRD 68 (2003) 052003





PRD 98, 072003 (2018)

$f_0(1500)$ and $f_0(1710)$ in $J/\psi \to \gamma\eta\eta$



- $f_0(1710)$ 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)

Phys. Rev. D. 87, 092009 (2013)

About $f_0(1500)$ and $f_0(1710)$

- Clearly observed in J/ψ radiative decays
- **Production rate of $f_0(1500)$ in J/ψ radiative decays is lower than that of $f_0(1710)$**

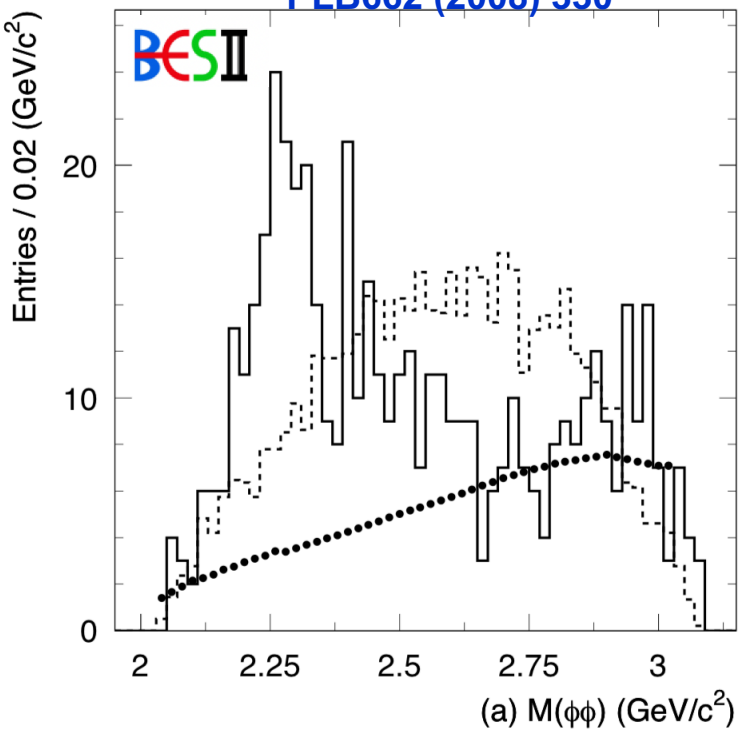
$$B(J/\psi \to \gamma f_0(1500)) \sim 3\times10^{-4}$$

$$B(J/\psi \to \gamma f_0(1710)) > 1.9\times10^{-3}$$

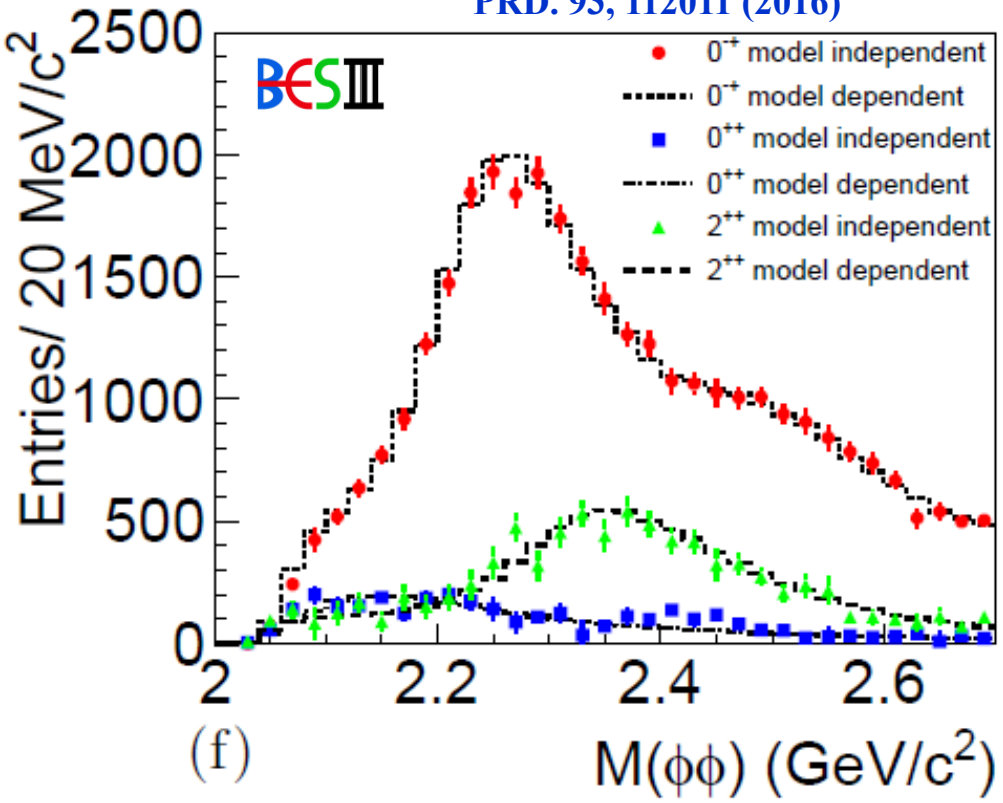
- **$f_0(1710)$ has stronger coupling to gluons than $f_0(1500)$ → which one contains more glueball content?**

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

PLB662 (2008) 330



PRD. 93, 112011 (2016)

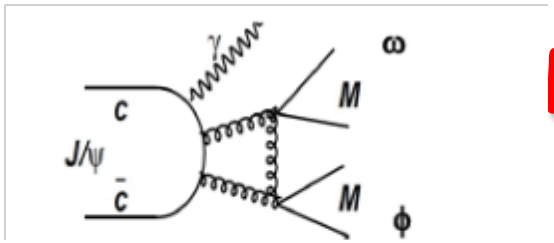


- Dominant contribution from pseudoscalars
  - η(2225) is confirmed;
  - η(2100) and X(2500) are observed

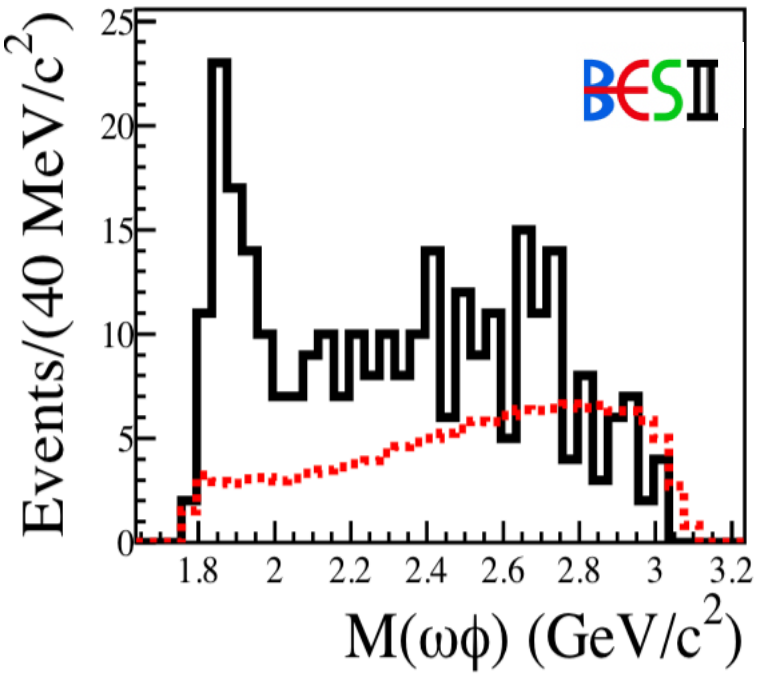
- Tensor contributions are from $f_2(2010)$, $f_2(2300)$ and $f_2(2340)$

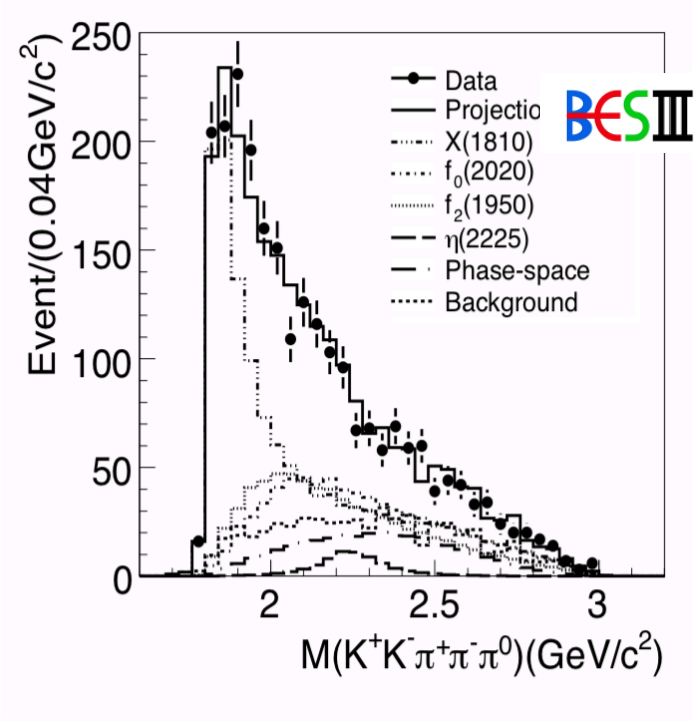
PWA of J/ψ→γωϕ

225M J/ψ



PRD 87, 032008(2013)

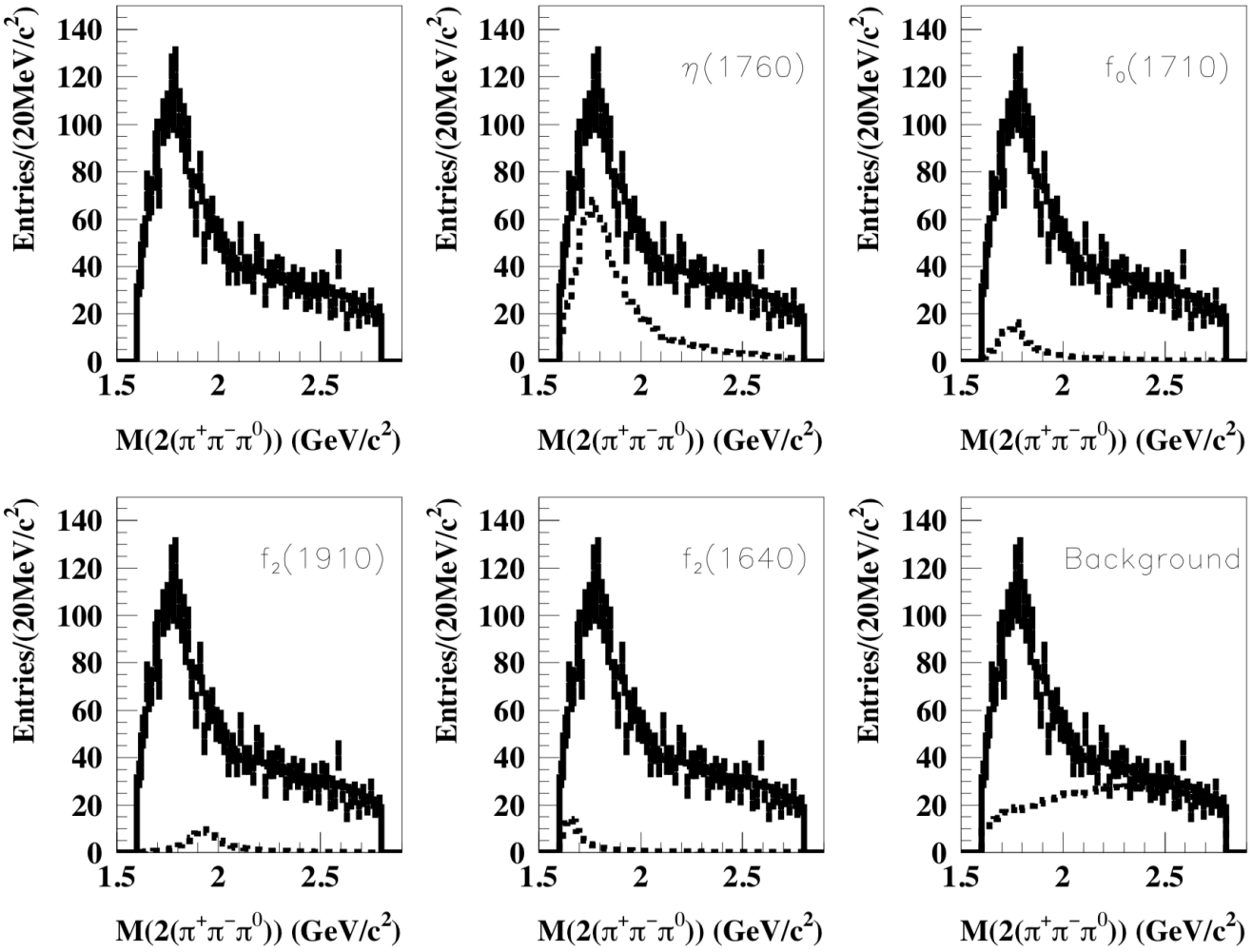




- Confirmed the enhancement observed at BESII
- M= $1795\pm7^{+13}_{-5}\pm19$(model) MeV/c2,
  $\Gamma=95\pm10^{+21}_{-34}\pm75$(model) MeV
- Spin-parity is determined to be 0^+
- the same as $f_0(1710)/f_0(1790)$, or a new state ?

PWA of J/ψ→γωω

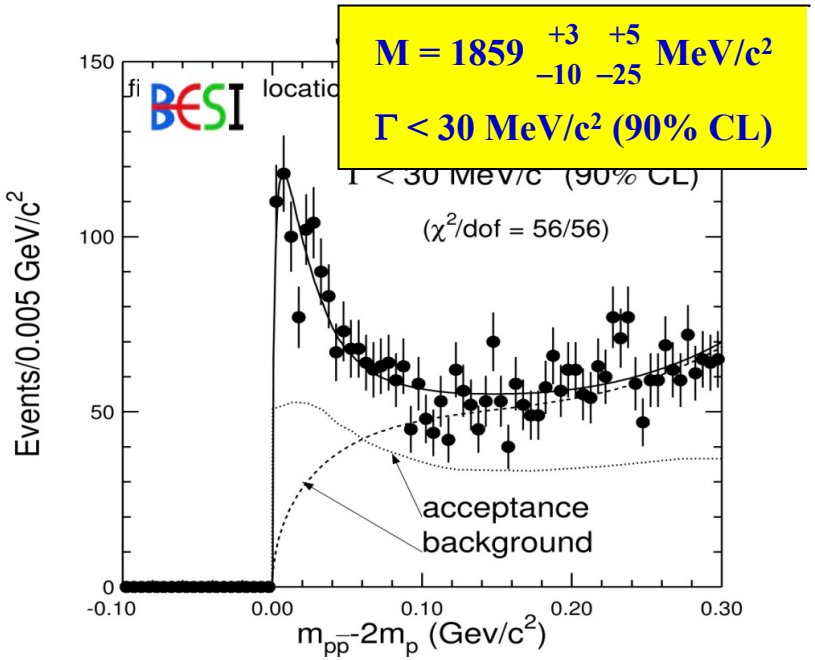
PRD 73, 112007(2006)



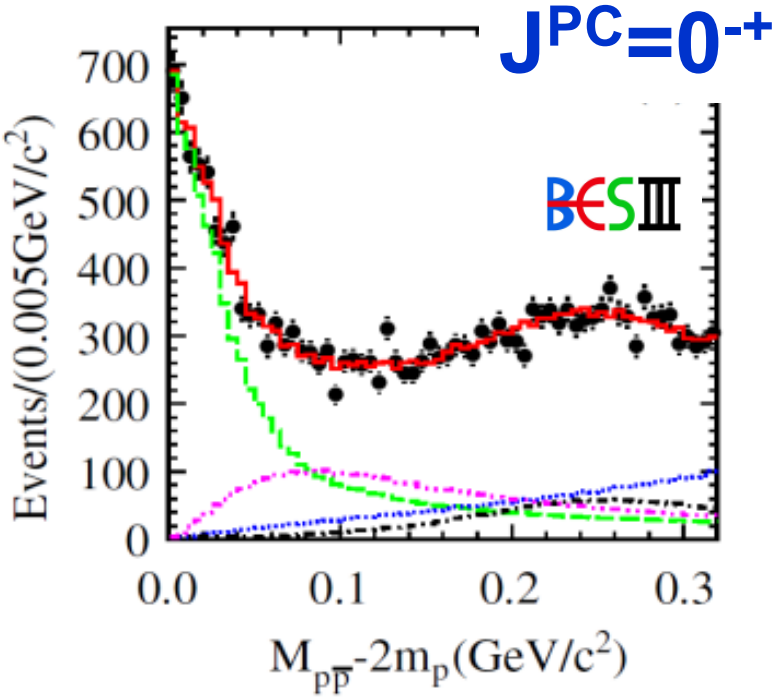
Exotic hadrons

Threshold enhancement in $J/\psi \to \gamma p\ \bar{p}$

PRL91, 022001 (2003)



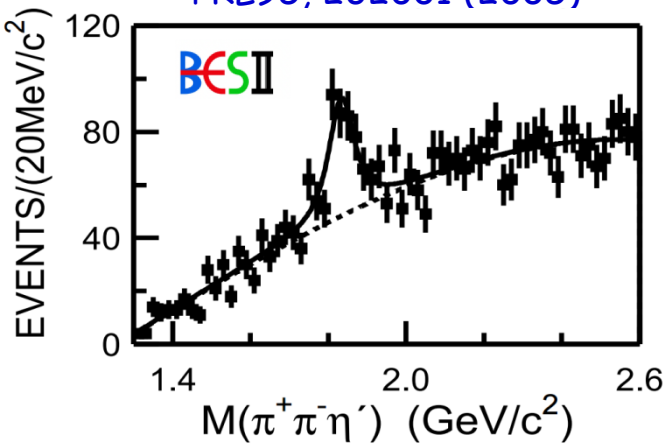
PRL 108, 112003 (2012)



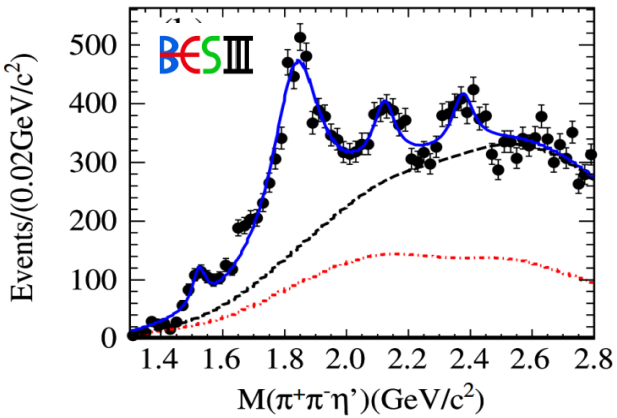
Baryonium ?? New decay modes ?

X(???) states $J/\psi\to\gamma\pi^+\pi^-\eta'$

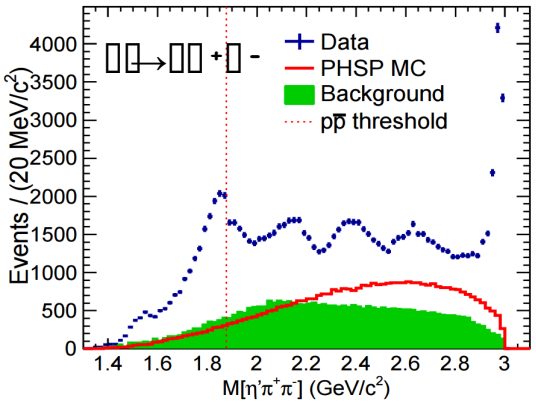
PRL95, 262001 (2005)



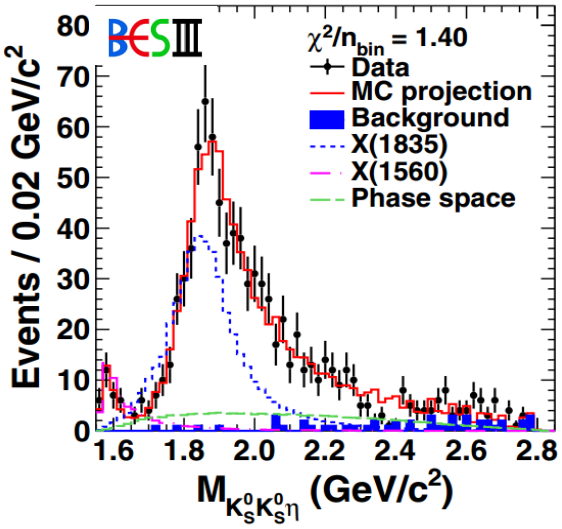
PRL106, 072006 (2011)



PRL 117, 042002 (2016)



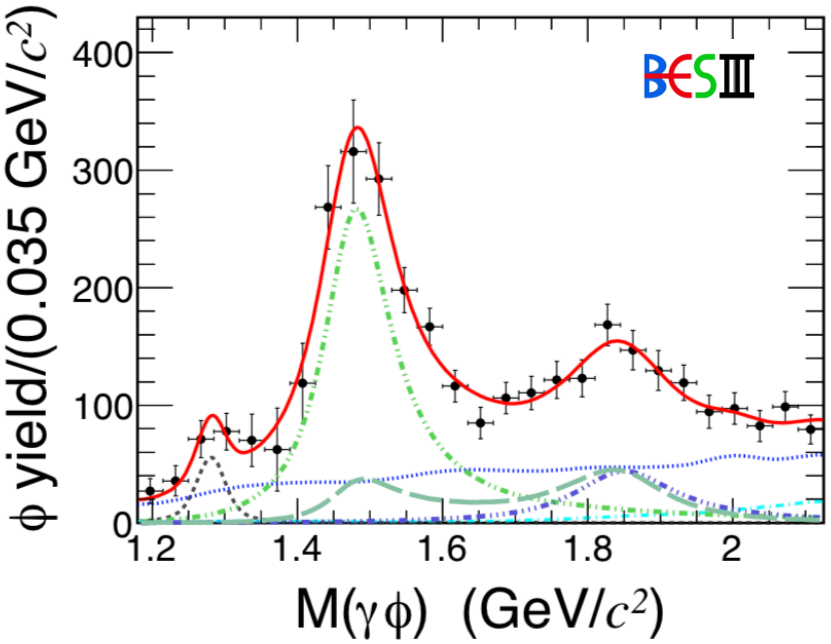
PRL 115, 091803 (2015)



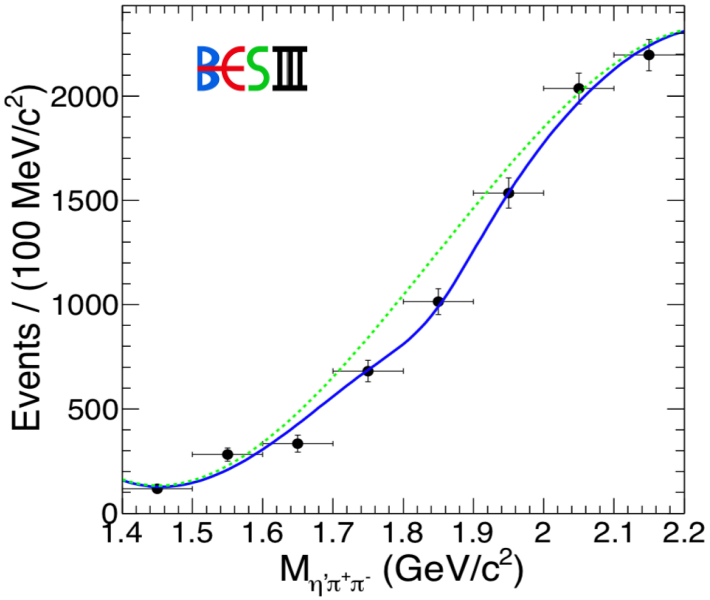
Resonance	M(MeV/c^2)	Γ(MeV/c^2)	Stat.Sig.
X(1835)	$1836.5\pm3.0^{+5.6}_{-2.1}$	$190.1\pm9.0^{+38}_{-36}$	>20σ
X(2120)	$2122.4\pm6.7^{+4.7}_{-2.7}$	$83\pm16^{+31}_{-11}$	7.2σ
X(2370)	$2376.3\pm8.7^{+3.2}_{-4.3}$	$83\pm17^{+44}_{-6}$	6.4σ

Existence of a structure strongly coupling to p $\bar{p}$!

X(1835) in $J/\psi\to\gamma\gamma\phi$ and $J/\psi\to\omega\pi^+\pi^-\eta'$



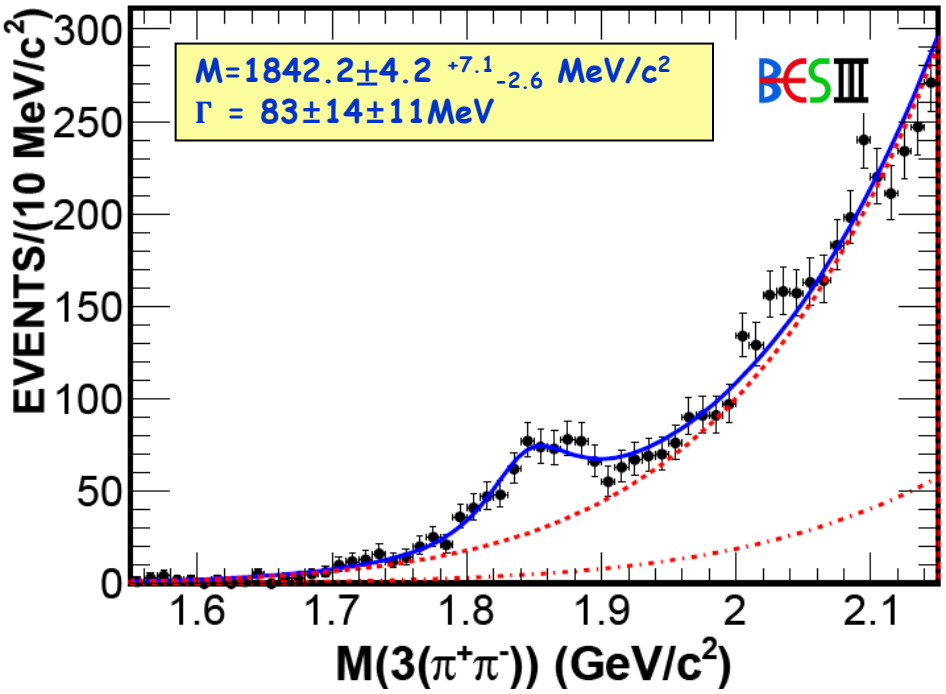
PRD 97, 051101(R) (2018)



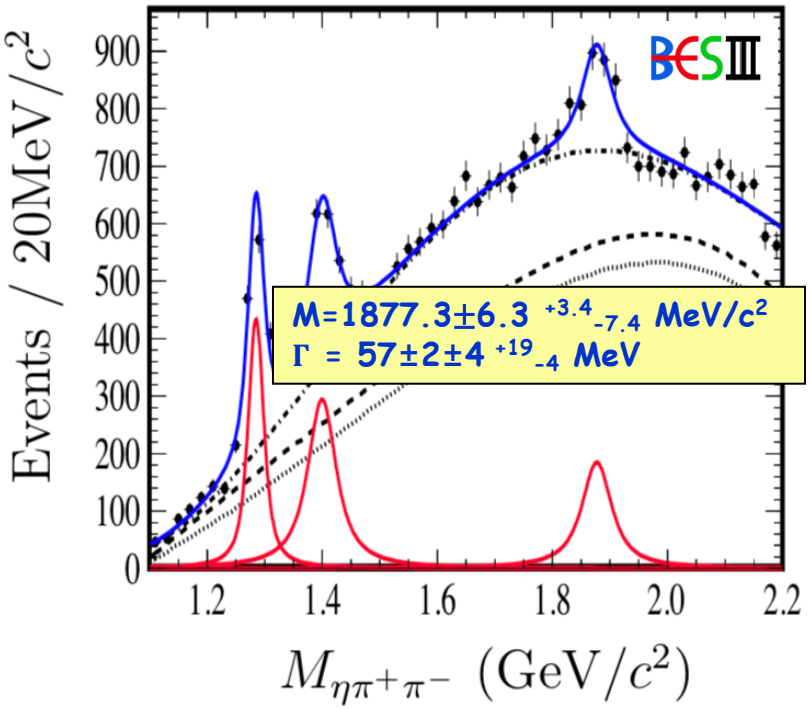
PRD 99, 071101)(2019)

X(1840) in $J/\psi\to\gamma 3(\pi^+\pi^-)$ and X(1870) in $J/\psi\to\omega\pi^+\pi^-\eta$

PRD 88, 091502 (2013)

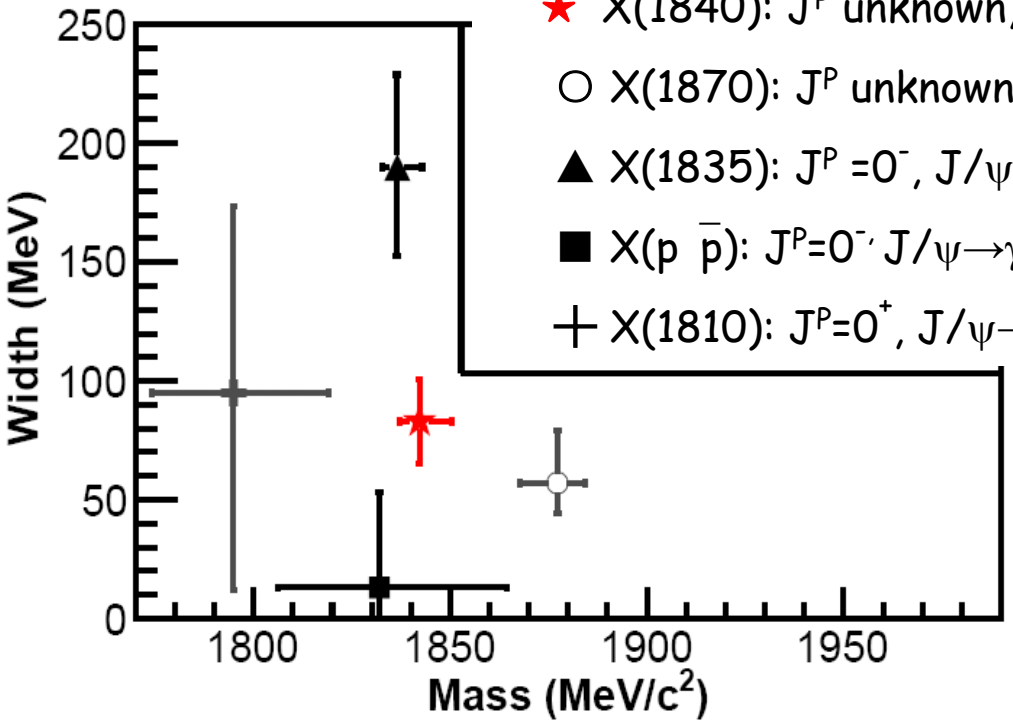


PRL107, 182001 (2011)



New decay modes of X(1835)?

Comparisons of the observations at BES



★ X(1840): J^P unknown, $J/\psi\to\gamma 3(\pi^+\pi^-)$ PRD88,091502

○ X(1870): J^P unknown, $J/\psi\to\omega\pi^+\pi^-\eta$ PRL107, 182001

▲ X(1835): $J^P=0^-$, $J/\psi\to\gamma\pi^+\pi^-\eta'$ PRL106, 072002

■ X(p $\bar{p}$): $J^P=0^-$, $J/\psi\to\gamma p\ \bar{p}$ PRL108,112003

┼ X(1810): $J^P=0^+$, $J/\psi\to\gamma\omega\phi$ PRD 87, 032008

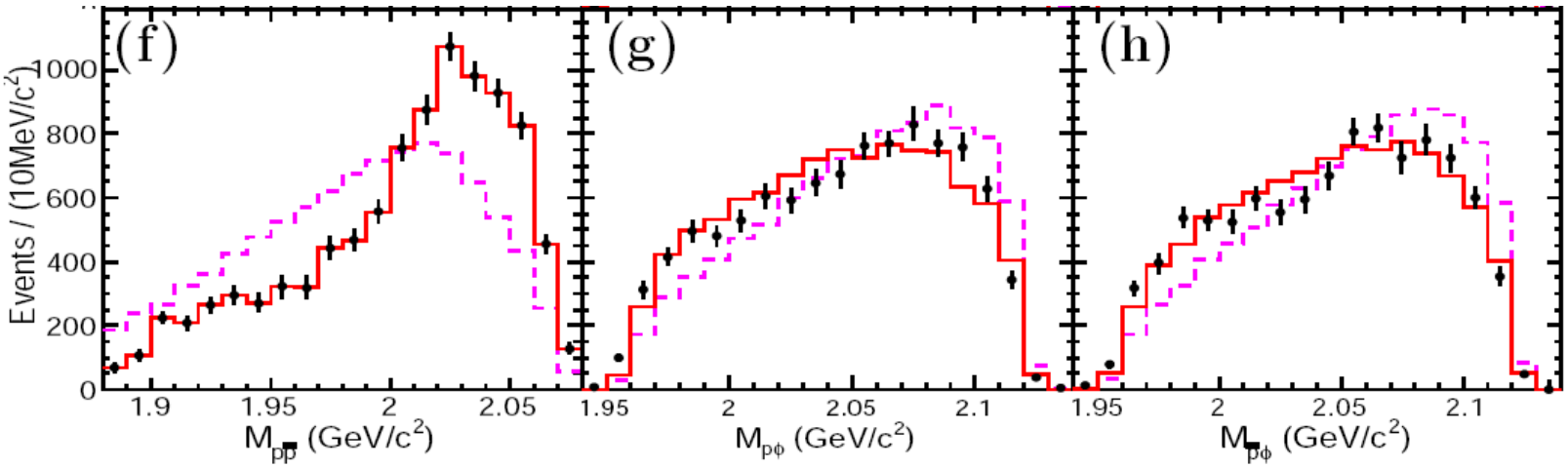
X(18??) near the threshold position of proton-antiproton

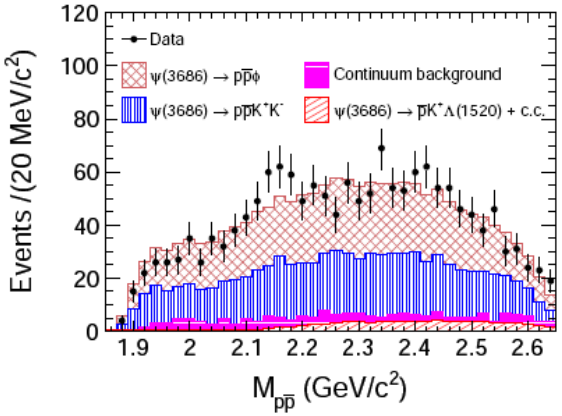
Are they the same particle? It is crucial to identify these observations.

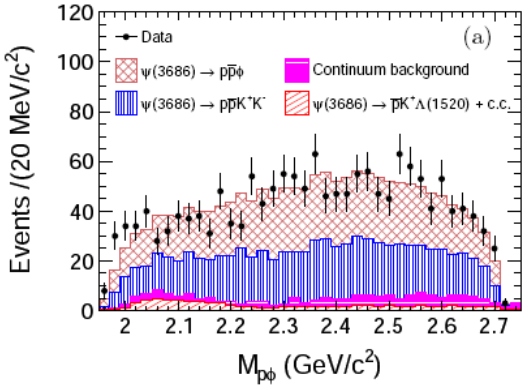
Search for exotics in $J/\psi(\psi')\to\phi p\bar{p}$

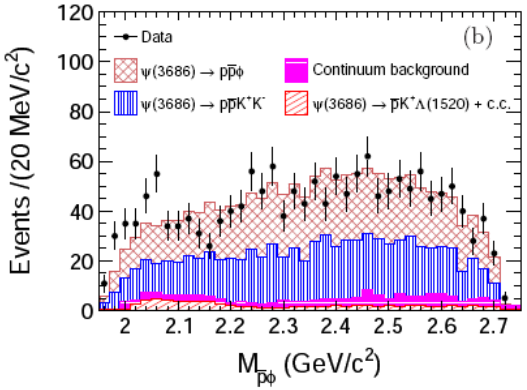
PRD93, 052010 (2016)

PRD99, 112010 (2019)









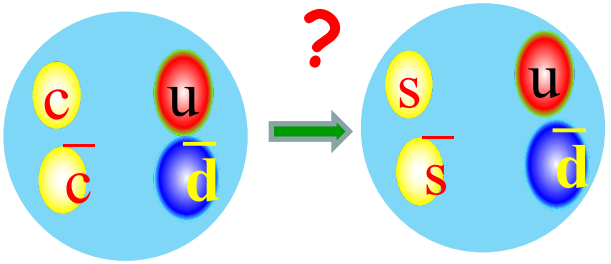
No evident structure is observed

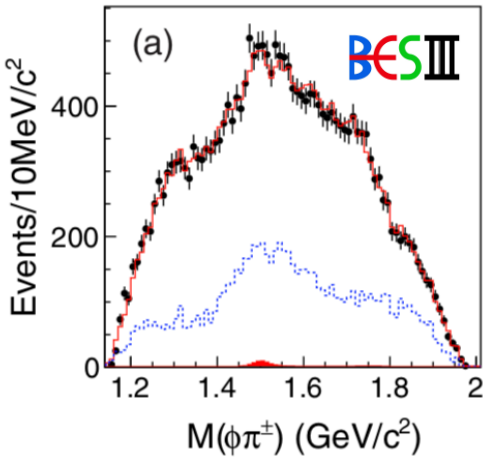
Search for Zs in e+e-→ φπ π

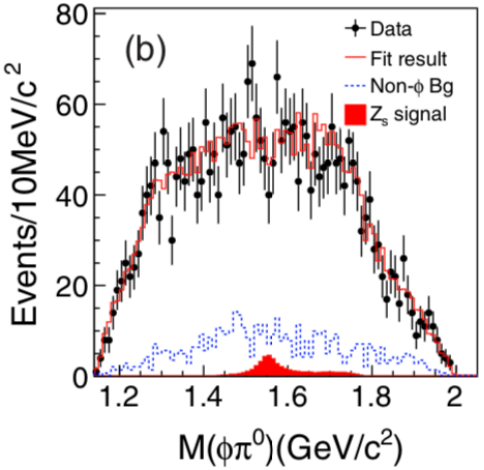
PRD99，011101(2018)

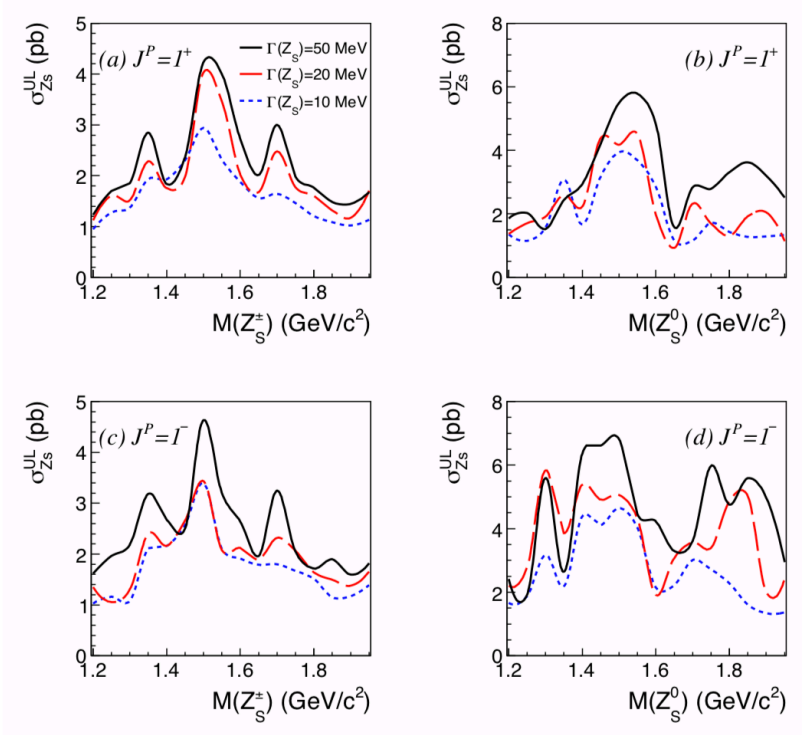
$Y(4260) \rightarrow J/\psi\pi^+\pi^-$ charm, ⇒ Z_c

$Y(2175) \rightarrow \phi(1020)\pi^+\pi^-$ strange ⇒ Z_s ?



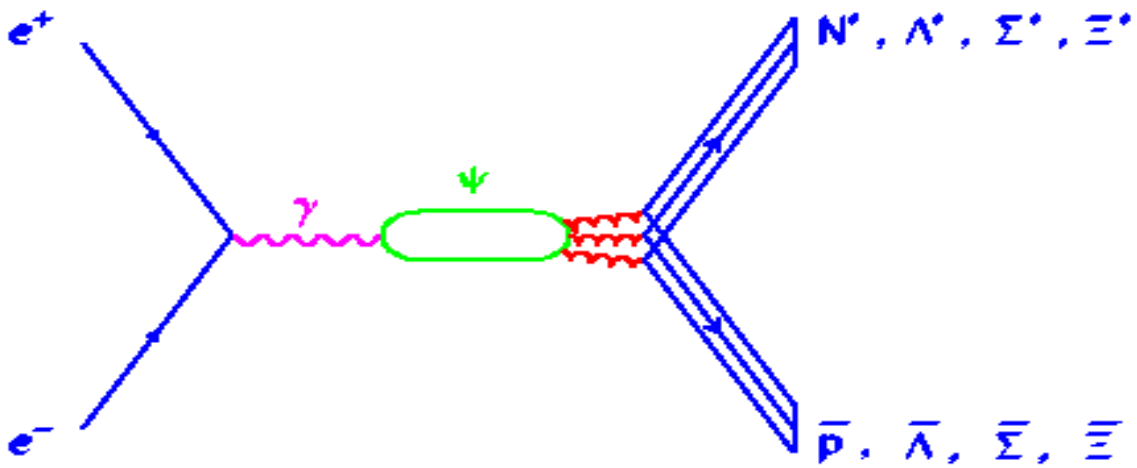




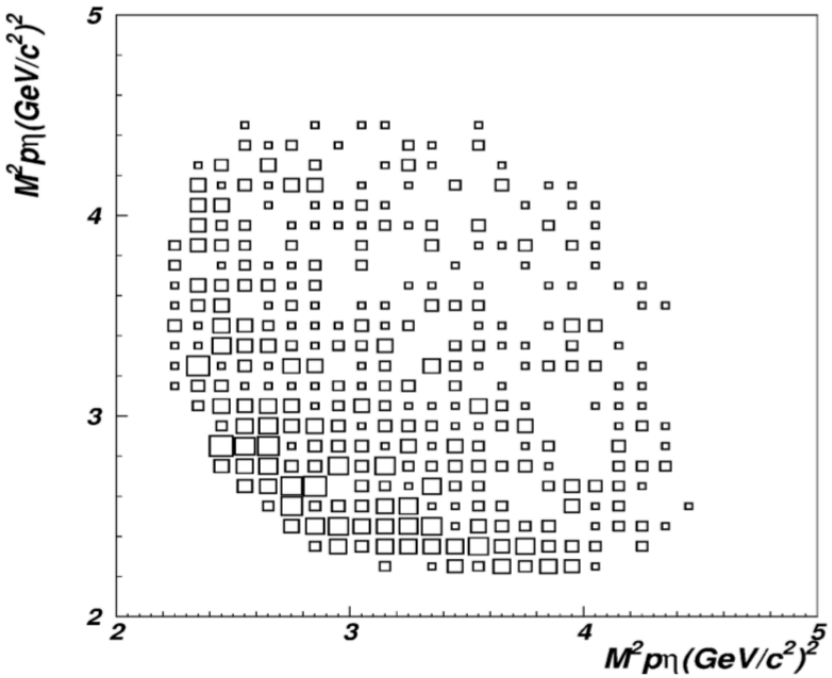


No evident structure observed in φπ mass spectra

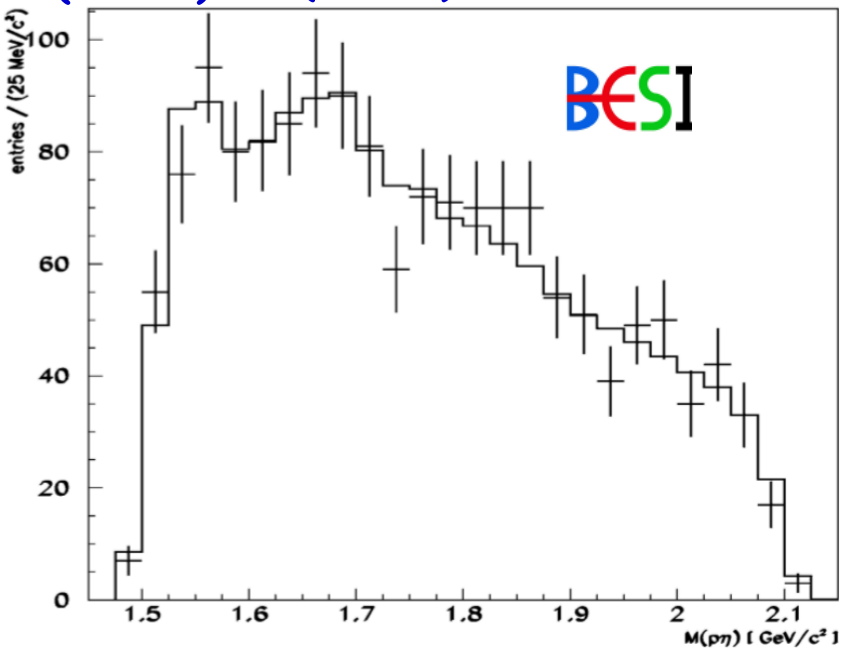
Baryon spectroscopy



N*s in $J/\psi \to \eta p \bar{p}$



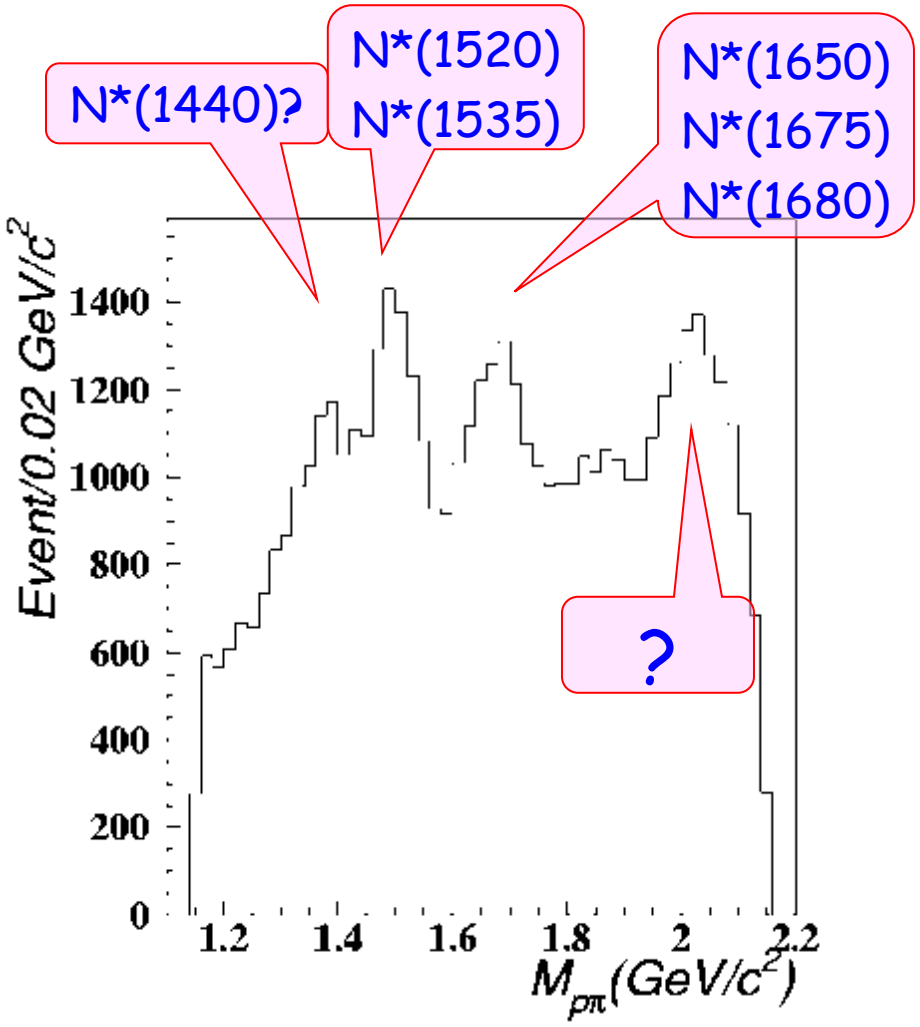
N(1535) N(1650)

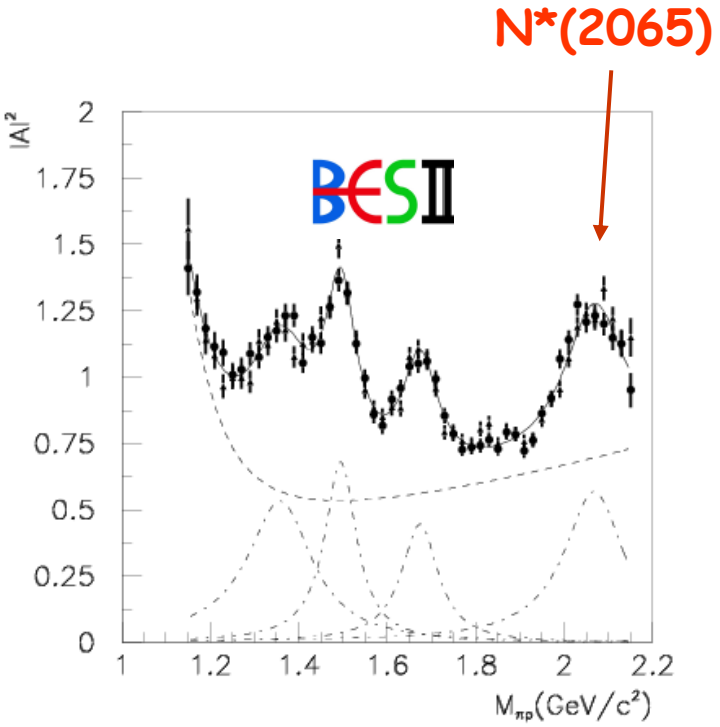


First PWA on excited baryons at BES !

Observation of N（2065）in $J/\psi \to p \bar{n} \pi$

PRL97 (2006) 062001





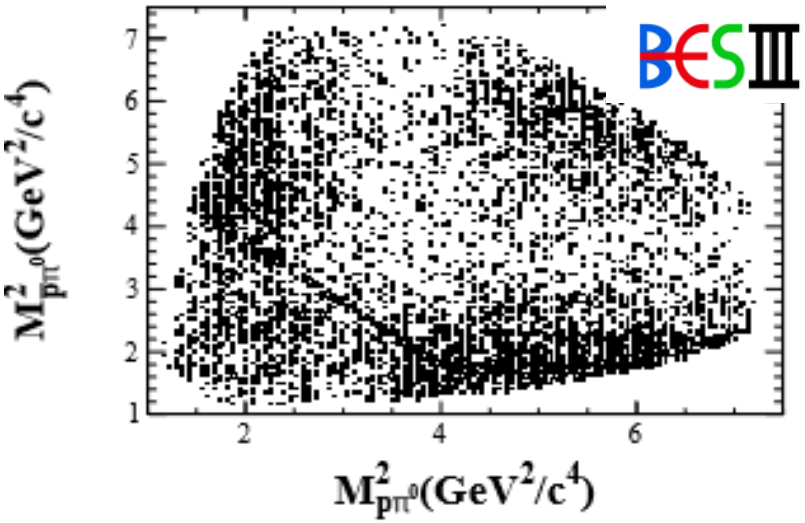
$$M = 2065 \pm 3^{+15}_{-30}\ \mathrm{MeV/c^2}$$

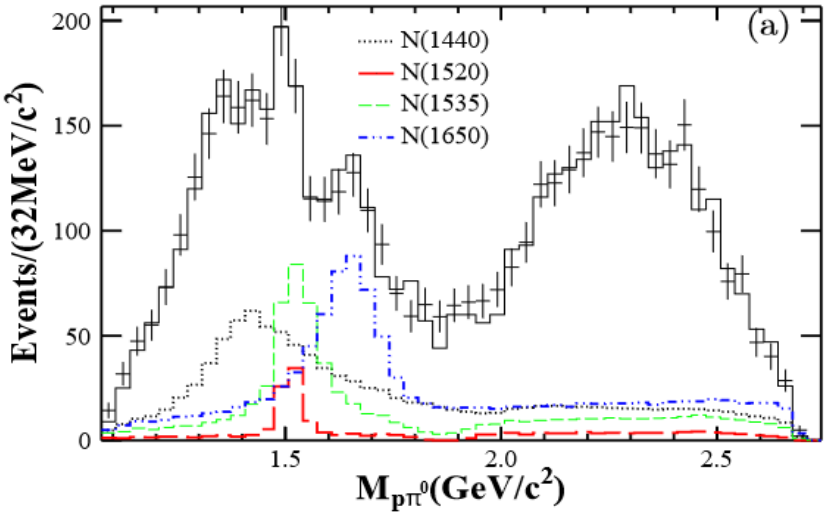
$$\Gamma = 175 \pm 12 \pm 40\ \mathrm{MeV/c^2}$$

Two new N*s in $J/\psi \to p\bar{p}\pi^0$

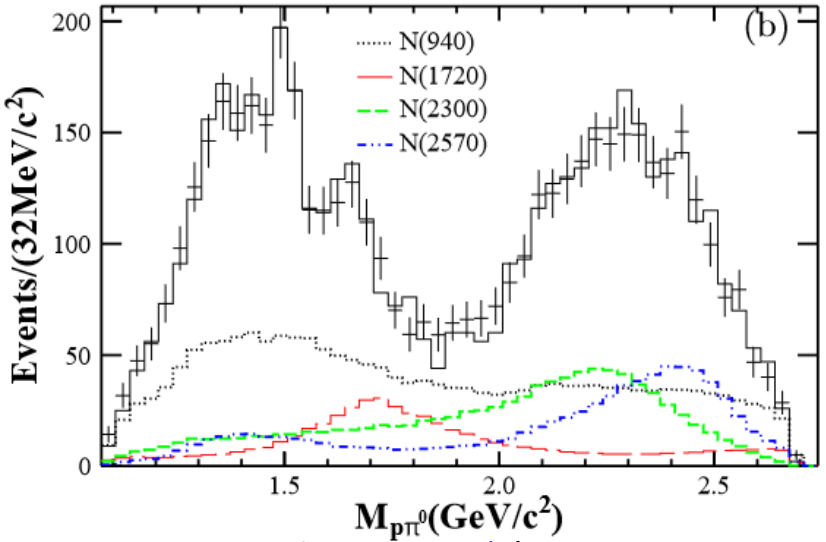
PRL 110 (2013) 022001

106 M ψ' events





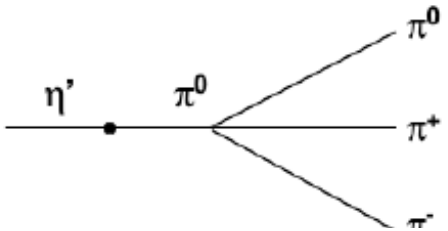
Resonance	M(MeV/c^2)	Γ(MeV/c^2)
$N(1440)$	1390^{+11+21}_{-21-30}	$340^{+46+70}_{-40-156}$
$N(1520)$	1510^{+3+11}_{-7-9}	115^{+20+0}_{-15-40}
$N(1535)$	1535^{+9+15}_{-8-22}	120^{+20+0}_{-20-42}
$N(1650)$	1650^{+5+11}_{-5-30}	150^{+21+14}_{-22-50}
$N(1720)$	1700^{+30+32}_{-28-35}	$450^{+109+149}_{-94\ \ -44}$
$N(2300)$	$2300^{+40+109}_{-30-0}$	$340^{+30+110}_{-30-58}$
$N(2570)$	2570^{+19+34}_{-10-10}	250^{+14+69}_{-24-21}



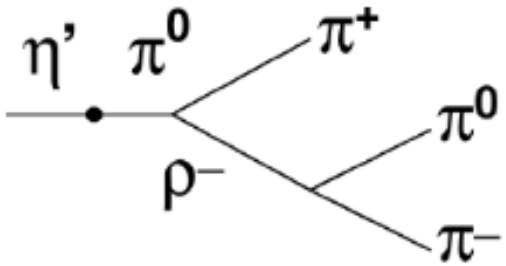
Two new baryonic excited states are observed !

Light meson decays

Observation of $\eta' \to \rho^+\pi^- + c.c.$

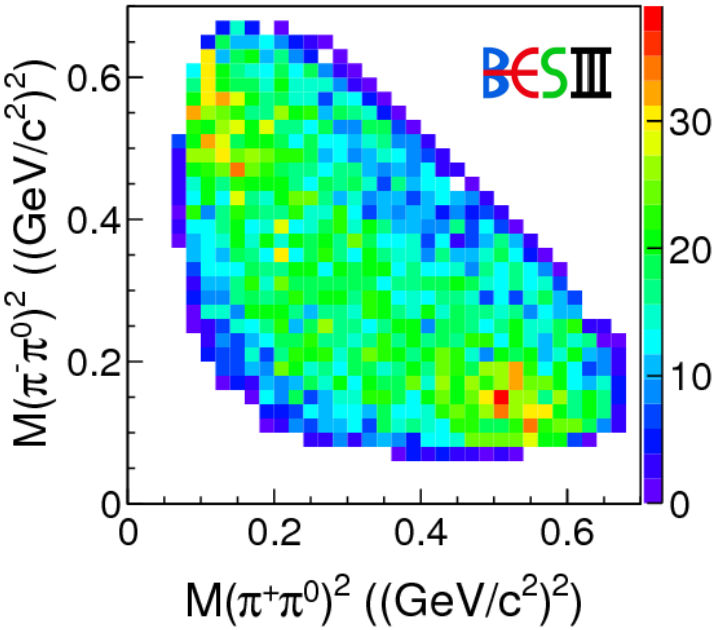


PRD19,2188(1979)

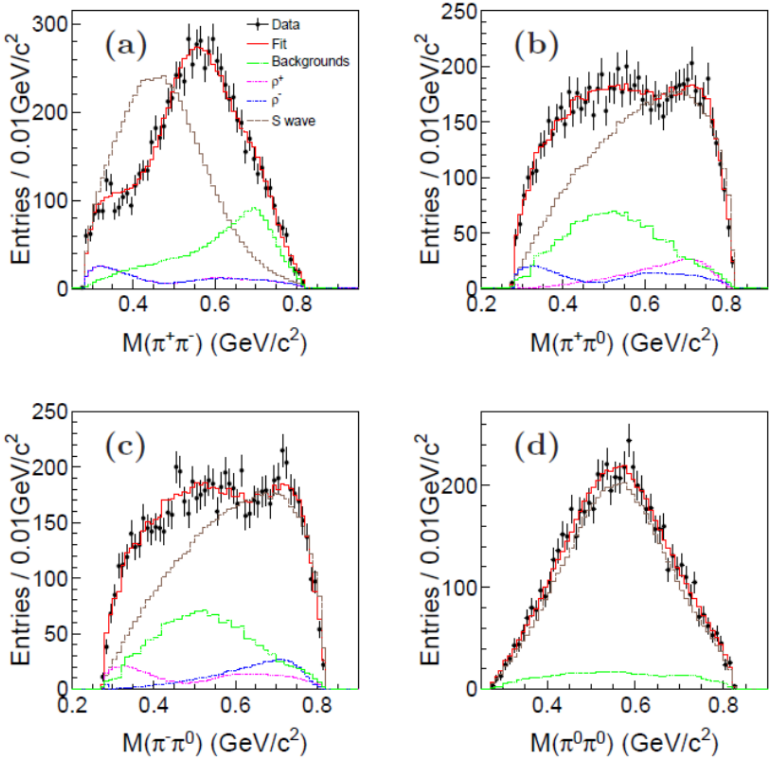


$$r = \frac{\Gamma_{\eta' \to \pi^+\pi^-\pi^0}}{\Gamma_{\eta' \to \eta\pi^+\pi^-}} \approx (16.8)\frac{3}{16}\left(\frac{m_d - m_u}{m_s}\right)^2$$

Nucl. Phys. A716,186(2003)

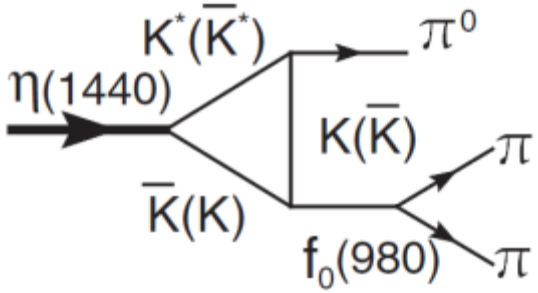


PRL, 118, 012001(2017)



Observation of $\eta(1405)\to f_0(980)\pi^0$

- $\eta(1440)$
  - $\eta(1405)\to a_0\pi$
  - $\eta(1475)\to K^*\ \bar{K}$
- its existence is controversial

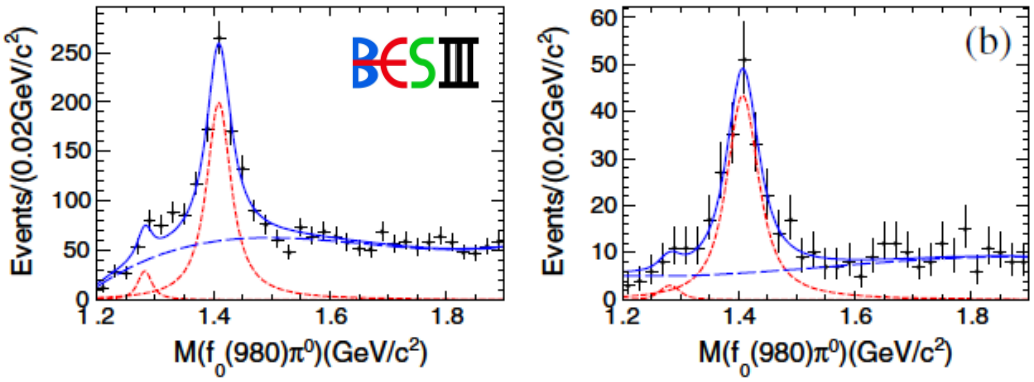


Triangle Singularity (TS)

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

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

PRL 108, 182001 (2012)



Resonance	$M(\mathrm{MeV}/c^2)$	$\Gamma(\mathrm{MeV}/c^2)$
$\eta(1405)(\pi^+\pi^-\pi^0)$	1409.0 ± 1.7	48.3 ± 5.2
$\eta(1405)(\pi^0\pi^0\pi^0)$	1407.0 ± 3.5	55.0 ± 11.0

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

Large isospin breaking!

Summary& Prospects

- 30 years of BES experiment
- Rich physics in light hadrons
  - Light hadron spectroscopy → Quark model
  - Light hadron decays → QCD
  - ……
- 10 billion J/ψ events available at BESIII !
  - A unique opportunity to map the light hadron spectroscopy
- **More surprises at BESIII !**

Thank you !