Light hadron Spectroscopy at BESIII

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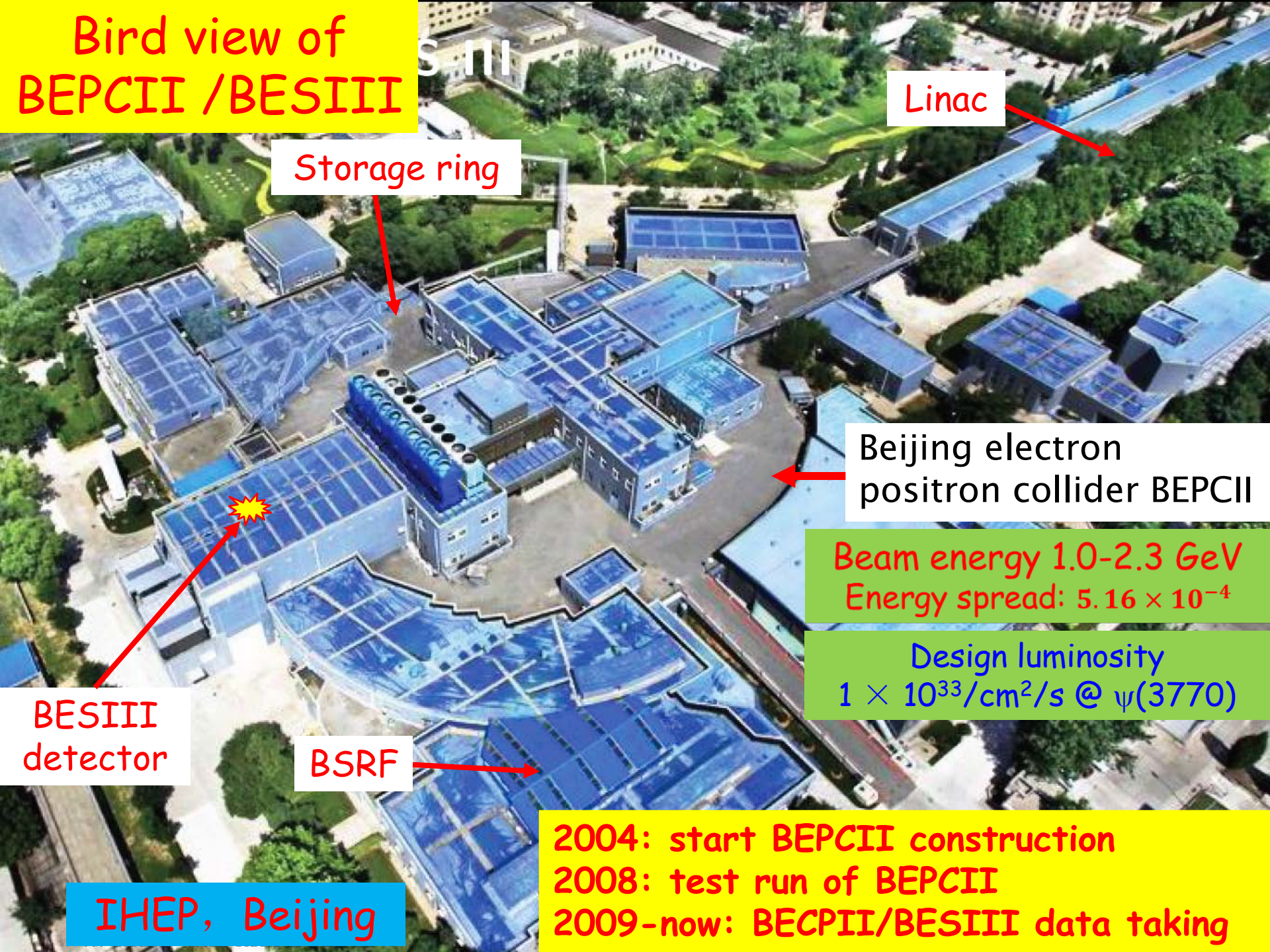
Outline

- **Introduction**
- **Recent results on hadron spectroscopy**
  - $p\bar{p}$ threshold enhancement in $J/\psi\to\gamma p\bar{p}$
  - X(1835) and two new structures in $J/\psi\to\gamma\eta'\pi^+\pi^-$
  - Isospin violate process $J/\psi\to\eta(1405)\to\gamma f_0(980)\pi\to\gamma\pi\pi\pi^0$
  - PWA results of $J/\psi\to\gamma\omega\phi$
  - PWA results of $J/\psi\to\gamma\eta\eta$
  - PWA results of $\psi'\to p\bar{p}\pi^0$
- **Summary**


Bird view of
BEPCII /BESIII
Linac
Storage ring
Beijing electron
positron collider BEPCII
Beam energy 1.0-2.3 GeV
Energy spread: 5.16×10^{-4}
Design luminosity
$1 \times 10^{33}/cm^2/s$ @ $\psi(3770)$
BESIII
detector
BSRF
2004: start BEPCII construction
2008: test run of BEPCII
2009-now: BECPII/BESIII data taking
IHEP, Beijing

The BESIII Detector

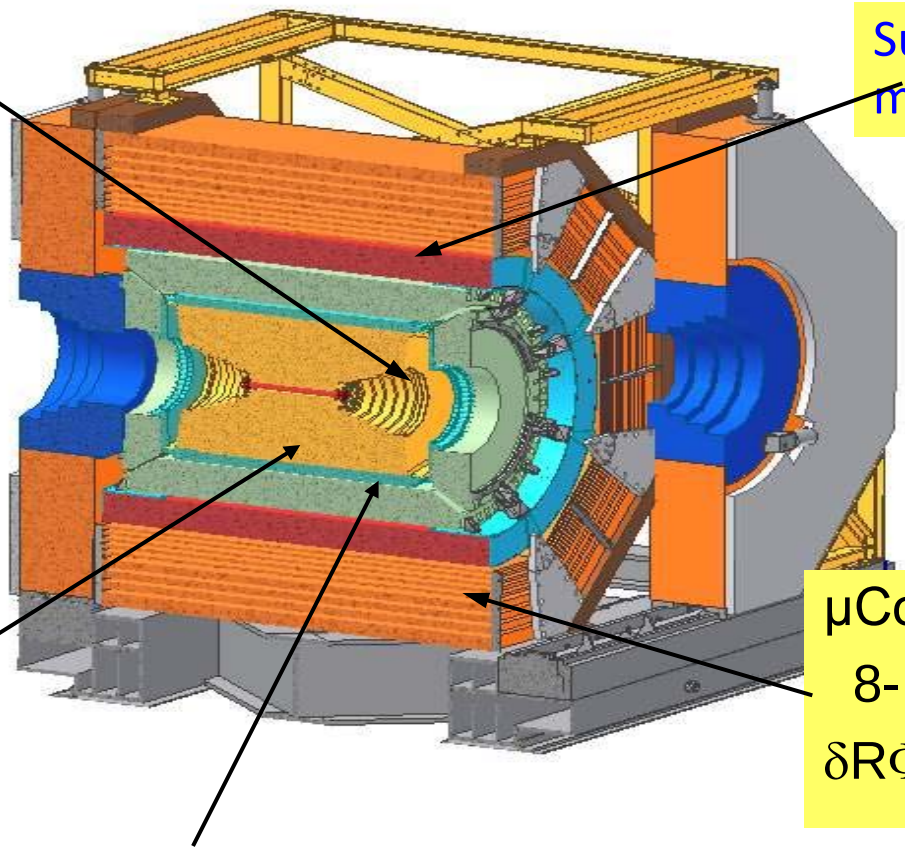
NIM A614, 345 (2010)

Drift Chamber (MDC)

$\sigma P/P$ ($^0/_0$) = 0.5%(1GeV）

$\sigma_{dE/dx}$ ($^0/_0$) = 6%

Super-conducting magnet (1.0 tesla)



Time Of Flight (TOF)

σ_T : 90 ps Barrel

110 ps endcap

μCounter

8- 9 layers RPC

$\delta R\Phi$=1.4 cm~1.7 cm

EMC: $\sigma E/\sqrt{E}$($^0/_0$) = 2.5 % (1 GeV)

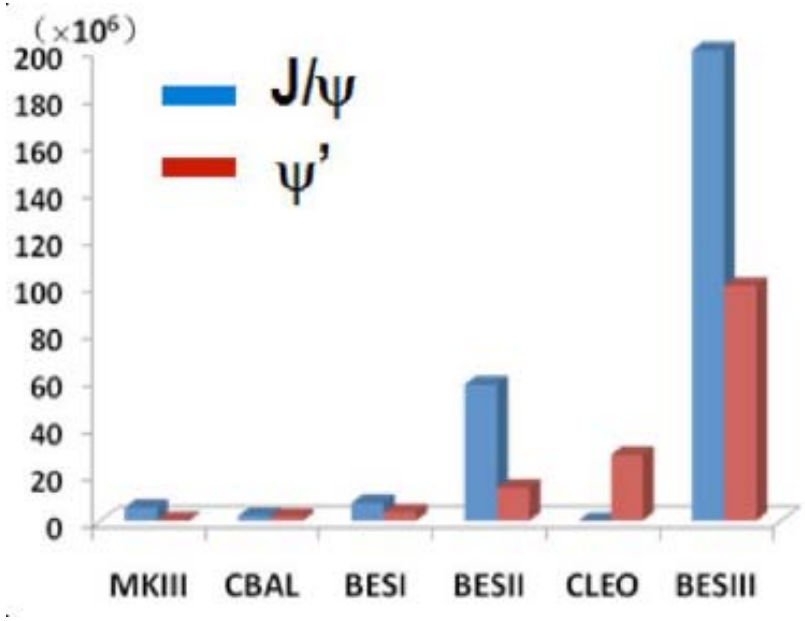
(CsI) $\sigma_{z,\phi}$(cm) = 0.5 - 0.7 cm/$\sqrt{E}$

J/ψ and ψ' data samples

So far BESIII has collected:

- **2009: 225Million J/ψ**
- **2012: 1 Billion J/ψ**

- **2009: 106 Million ψ'**
- **2012: 0.4 Billion ψ'**

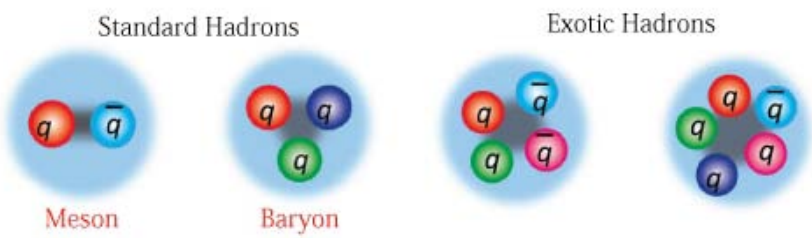


The results in this talk are based on the data samples of 225M J/psi events and 106M psi(3686) events.

Introduction

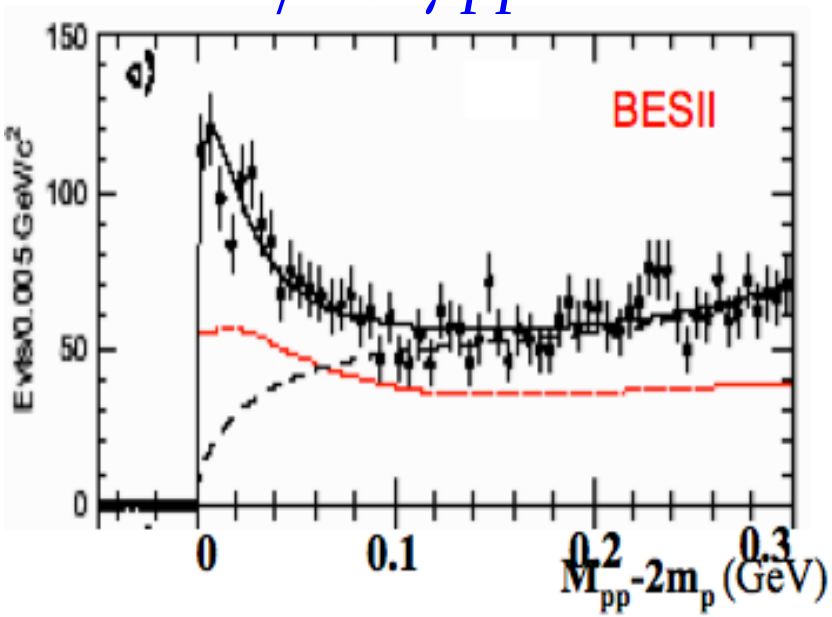
- For light hadron spectrosopy: some experimental result can't be explained by quark model.

  The abundance of scalar mesons, missing baryon problem…
- PQCD is not applicable in the light hadron sector. There exist phenomenological approaches and LQCD calculations.
- QCD allow the existence exotic states: glueball(gg), multiquarks($q\bar{q}q\bar{q}$), hybrid($q\bar{q}g$), molecular states…



Observation of X(ppbar) on BESII

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



Theoretical interpretation:

- conventional meson?
- ppbar bound state/multiquark
- glueball
- Final state interaction (FSI)
- …

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

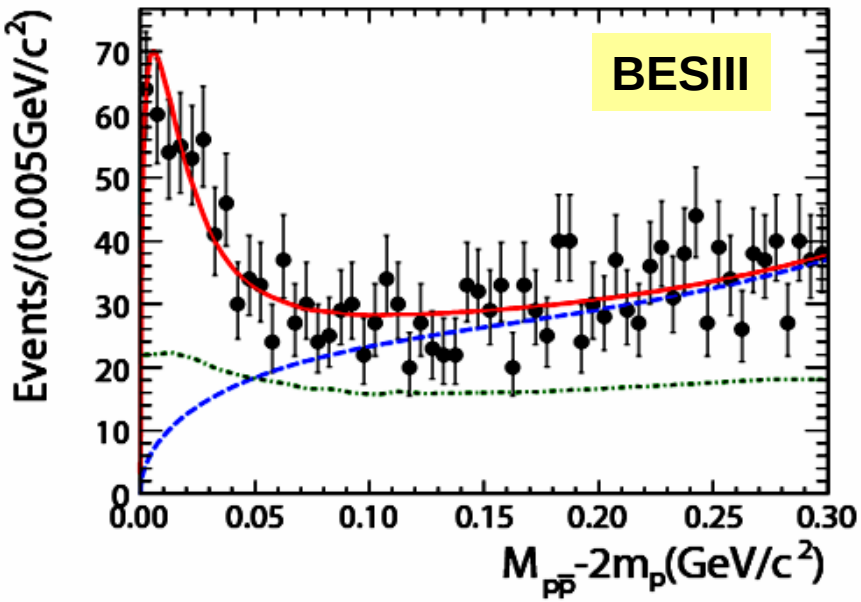
$\Gamma < 30$ MeV/c² (90% CL)

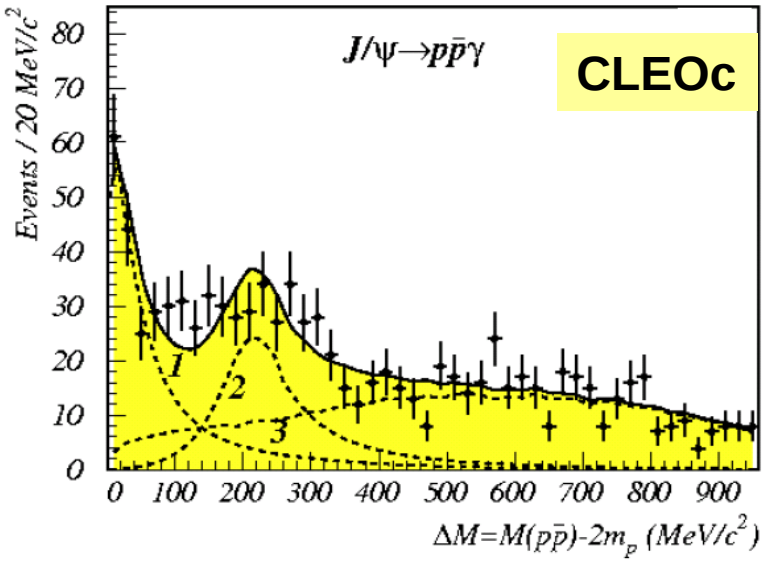
PRL 91 (2003) 022001

Confirmation of on BESIII and CLEOc

Fit with one resonance at BESII did:

$\psi' \to \pi^+\pi^- J/\psi, J/\psi \to \gamma p\bar{p}$





$M=1861^{+6}_{-13}{}^{+7}_{-26}$ MeV/c²

$\Gamma < 38$ MeV/c² (90% CL)

$M(R_{thr}) = 1861^{+6}_{-16}$ (MeV), $\Gamma(R_{thr}) = 0^{+32}_{-0}$ (MeV),

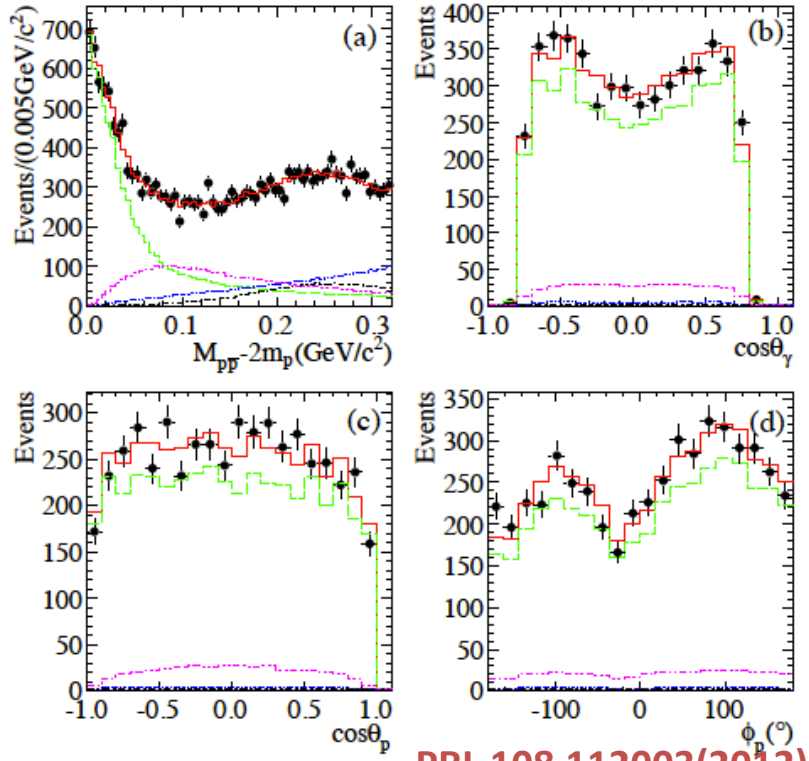
$B_1(J/\psi \to \gamma R_{thr}) \times B_2(R_{thr} \to p\bar{p}) = (5.9^{+2.8}_{-3.2}) \times 10^{-5}$

Chinese Physics C 34, 421 (2010)

PRD 82, 092002(2010)

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

- PWA of $J/\psi \to \gamma p\bar{p}$ was first performed
- The fit with a BW and S-wave FSI(I=0) factor can well describe ppb mass threshold structure.
- It is much better than that without FSI effect, and $\Delta 2\ln L=51$ (7.1σ)
- Different FSI models→Model dependent uncertainty



PRL 108,112003(2012)

- Spin-parity, mass, width and B.R. of X(ppbar):

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

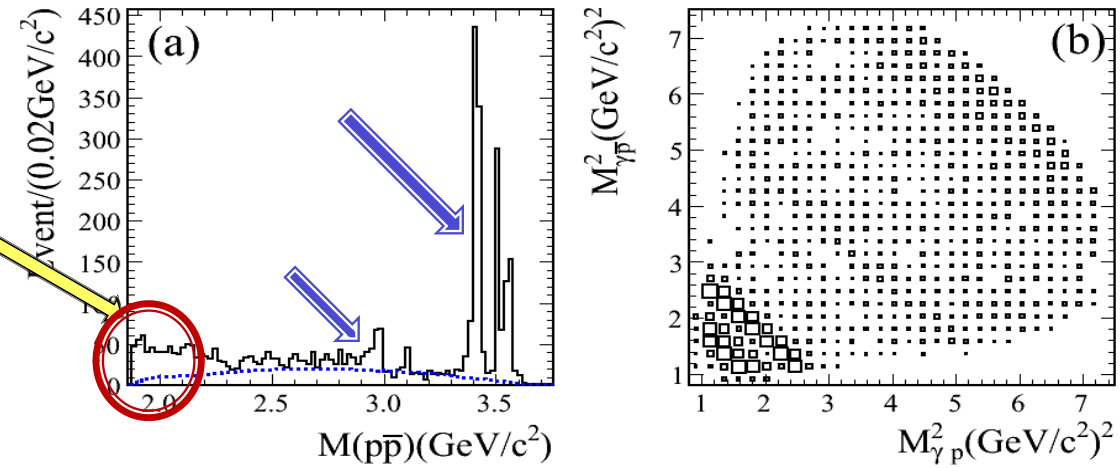
$$M=1832^{+19}_{-5}(\text{stat})^{+18}_{-17}(\text{syst})\pm 19(\text{mod})\text{MeV}/c^2$$

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

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

$M_{p\bar{p}}$ threshold structure of $\psi' \to \gamma p\bar{p}$ on BESIII

Obviously different line shape of ppbar mass spectrum near threshold from that in J/ψ decays



PWA results:

- Significance of X(ppbar) is > 6.9σ.
- The production ratio R:

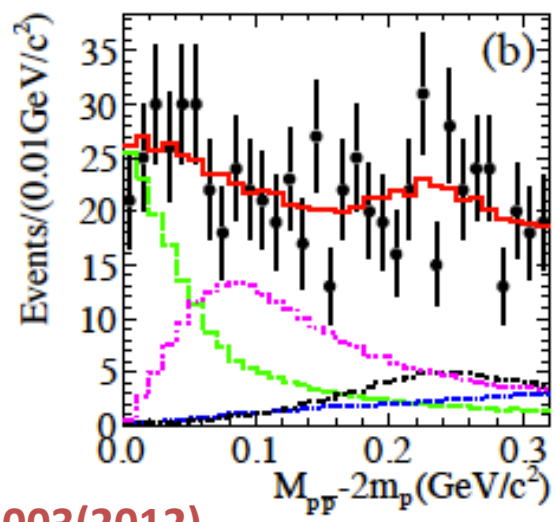
first measurement

$$R = \frac{B(\psi' \to \gamma X(p\bar{p}))}{B(J/\psi \to \gamma X(p\bar{p}))}$$

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

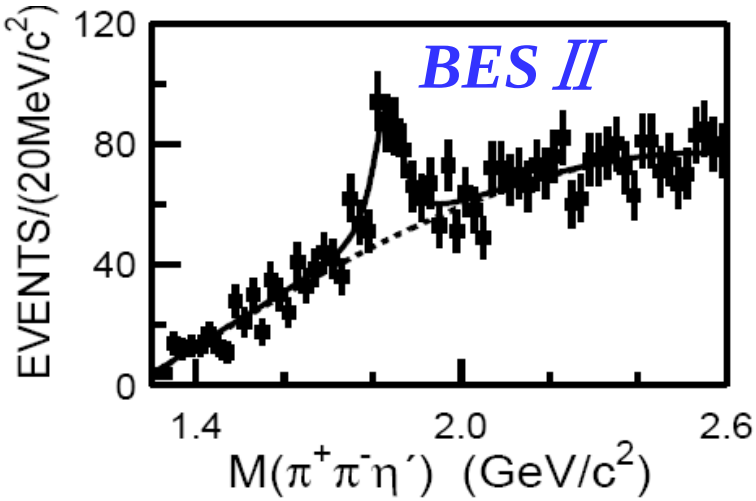
- It is suppressed compared with "12% rule".

PWA Projection:



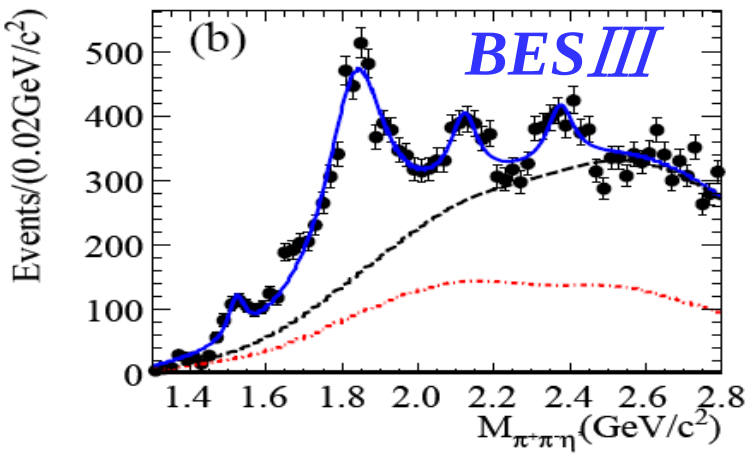
PRL 108,112003(2012)

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



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

$$M = (1833.7 \pm 6.1 \pm 2.7)\mathrm{MeV/c^2}$$
$$\Gamma = (67.7 \pm 20.3 \pm 7.7)\mathrm{MeV/c^2}$$
$$\mathrm{Br}(J/\psi \rightarrow \gamma X) \cdot \mathrm{Br}(X \rightarrow \eta' \pi^+ \pi^-)$$
$$= (2.2 \pm 0.4 \pm 0.4) \times 10^{-4}$$



- **PRL 106, 072002(2011)**
- **Confirm the existence of X(1835),**
- **Two new structures are observed.**

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

- the parameters of the 3 states.

- $X(1835)$

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

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

  Significance: >20σ

- $X(2120)$

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

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

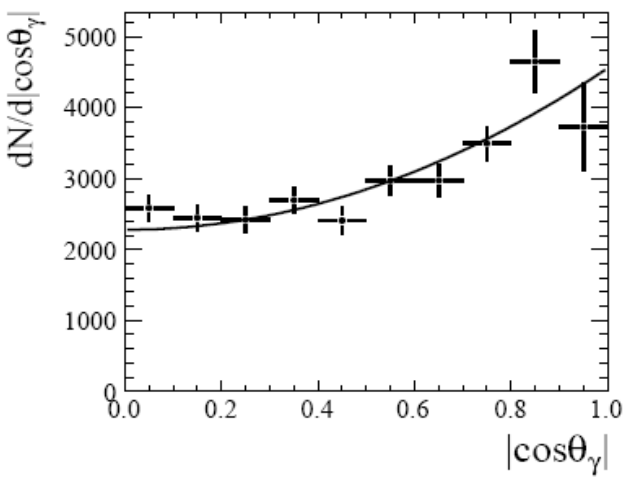
  7.2σ

- $X(2370)$

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

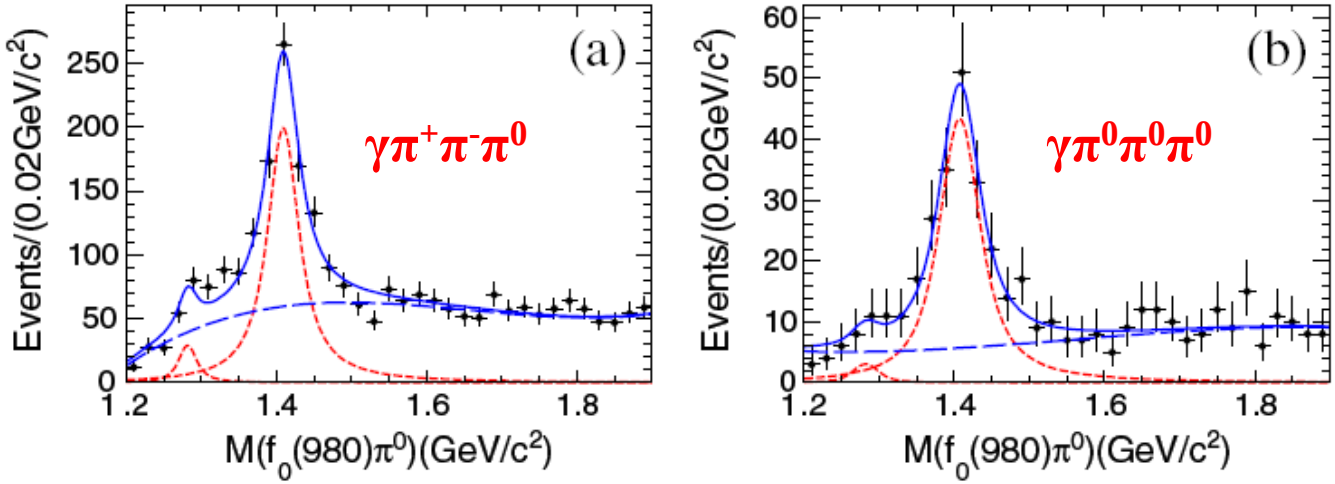
  $\Gamma = 83 \pm 17(\text{stat})^{+44}_{-6}(\text{syst})\ \text{MeV}/c^2$

  6.4σ



- **The angular distribution of radiative photon for 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.**

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.**

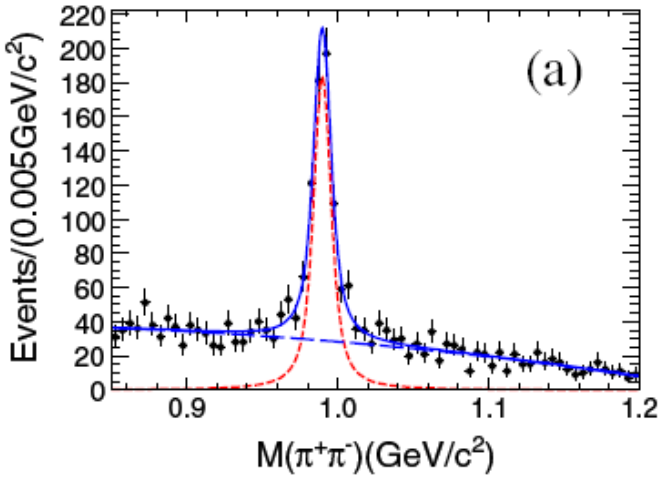
$$\mathrm{Br}(J/\psi \rightarrow \gamma\eta(1405) \rightarrow \gamma\pi^0 f_0(980) \rightarrow \gamma\pi^0\pi^+\pi^-) = (1.50 \pm 0.11 \pm 0.11) \times 10^{-5}$$

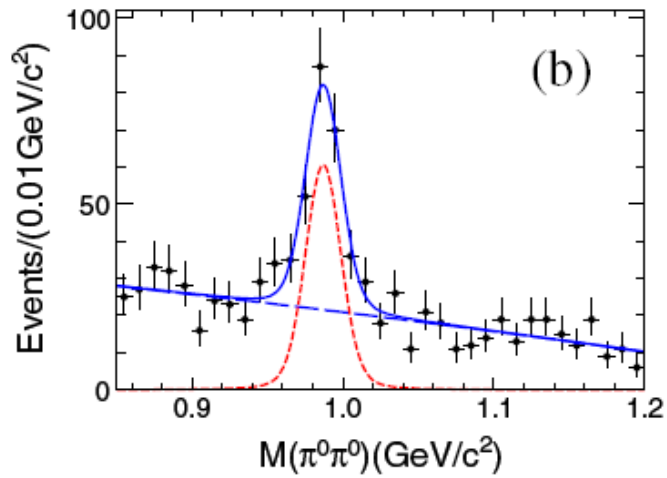
$$\mathrm{Br}(J/\psi \rightarrow \gamma\eta(1405) \rightarrow \gamma\pi^0 f_0(980) \rightarrow \gamma\pi^0\pi^0\pi^0) = (7.10 \pm 0.82 \pm 0.72) \times 10^{-5}$$

- **The isospin-violating decay rate:** $\dfrac{\mathrm{Br}(\eta(1405) \rightarrow \pi^0 f_0(980) \rightarrow \pi^0\pi^+\pi^-)}{\mathrm{Br}(\eta(1405) \rightarrow \pi^0 a_0(980) \rightarrow \pi^0\pi^0\eta)} = (17.9 \pm 4.2)\%$

Can't be explained by a_0-f_0 mixing: mix rate is less than 1%

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





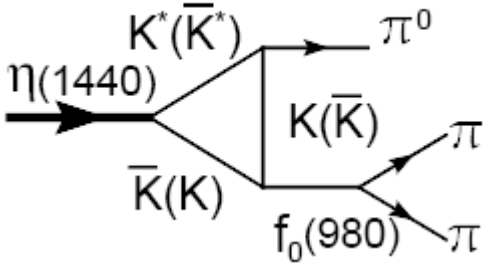
$M = 989.9 \pm 0.4 MeV/c^2$

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

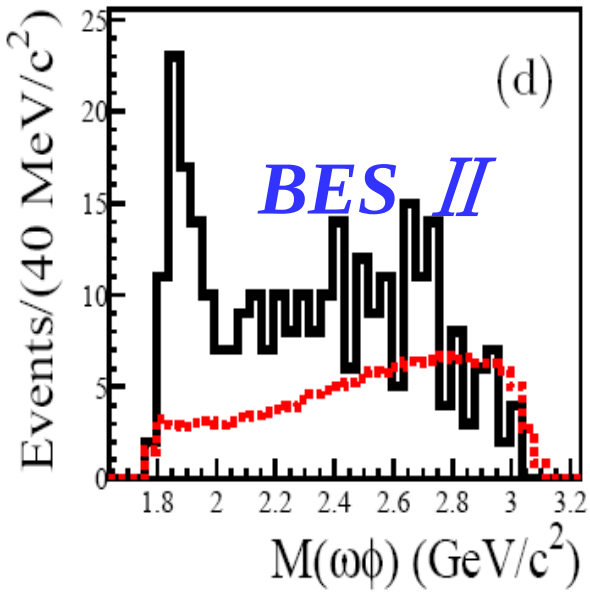
$M = 987.0 \pm 1.4 MeV/c^2$

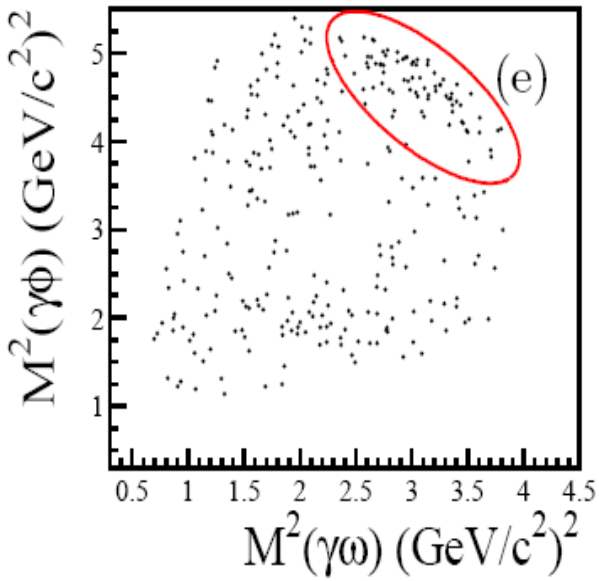
$\Gamma = 4.6 \pm 5.1 MeV/c^2$

- **$f_0(980)$: PDG value Γ=40~100MeV**
- **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).**



ωϕ threshold enhancement in J/ψ→γωϕ



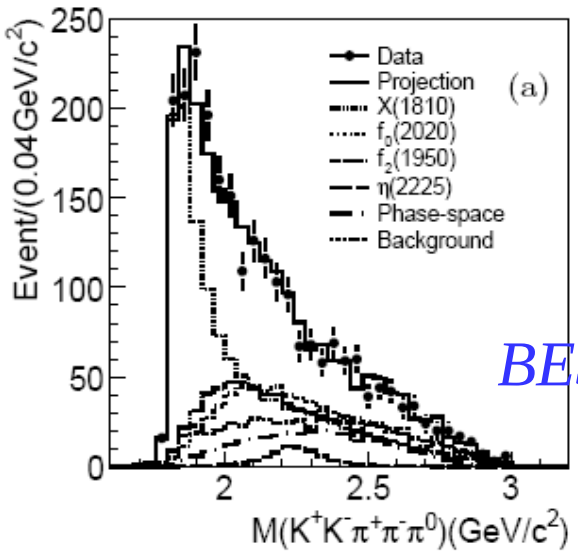


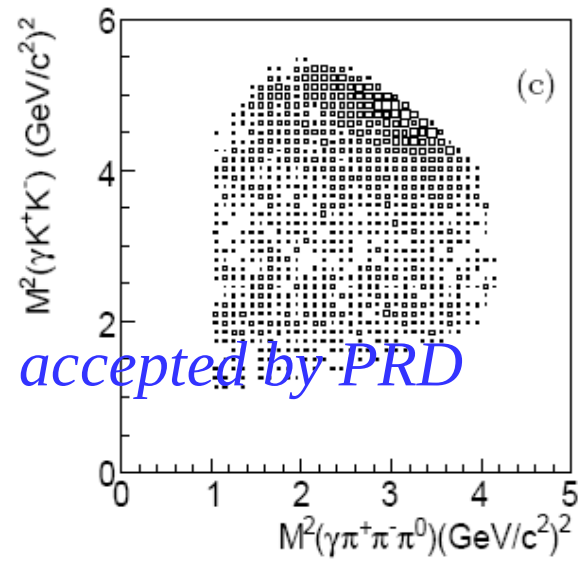
- **First observed in BESII. Phys. Rev. Lett. 96(2006)162002**
- **Partial wave analysis with helicity covariant amplitude.**
- **Threshold enhancement: X(1810)**

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

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

ωϕ threshold enhancement in J/ψ→γωϕ





BES III : accepted by PRD

- **PWA with covariant tensor amplitude. Arxiv:** 1211.5668
- **Threshold enhancement: X(1810)**

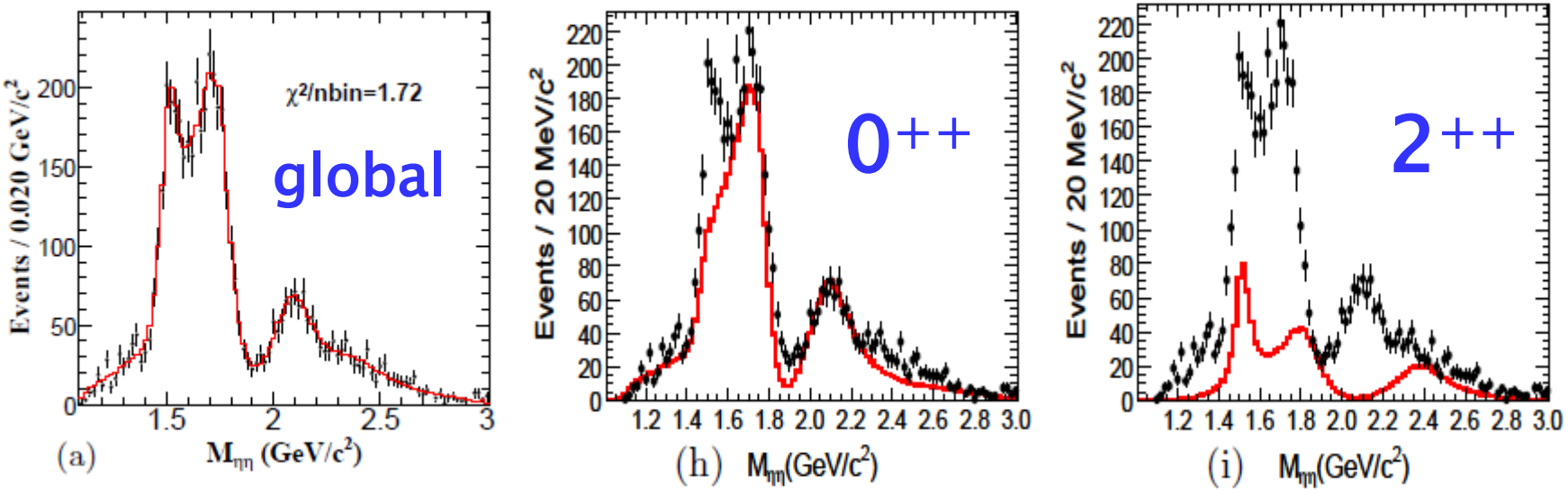
$$J^{PC} = 0^{++}, \quad M = 1795 \pm 7^{+23}_{-5}\,\mathrm{MeV/c^2} \qquad \Gamma = 95 \pm 10^{+78}_{-34}\,\mathrm{MeV/c^2}$$

$$B(J/\psi \to \gamma X(1810)) \cdot B(X(1810) \to \omega\phi) = (2.00 \pm 0.08^{+1.38}_{-1.00}) \times 10^{-4}$$

- **DOZI suppressed, the branch fraction is too large. ~1/2 Br(J/ψ→γΦΦ)**

Why? Is X(1810) exotic states? f_0(1710)?

PWA results of J/ψ→γηη



Resonance	Mass(MeV/c^2)	Width(MeV/c^2)	$\mathcal{B}(J/\psi \to \gamma X \to \gamma\eta\eta)$	Significance
$f_0(1500)$	1468^{+14+23}_{-15-74}	$136^{+41+28}_{-26-100}$	$(1.65^{+0.26+0.51}_{-0.31-1.40}) \times 10^{-5}$	$8.2\ \sigma$
$f_0(1710)$	$1759\pm6^{+14}_{-25}$	$172\pm10^{+32}_{-16}$	$(2.35^{+0.13+1.24}_{-0.11-0.74}) \times 10^{-4}$	$25.0\ \sigma$
$f_0(2100)$	$2081\pm13^{+24}_{-36}$	273^{+27+70}_{-24-23}	$(1.13^{+0.09+0.64}_{-0.10-0.28}) \times 10^{-4}$	$13.9\ \sigma$
$f_2'(1525)$	$1513\pm5^{+4}_{-10}$	75^{+12+16}_{-10-8}	$(3.42^{+0.43+1.37}_{-0.51-1.30}) \times 10^{-5}$	$11.0\ \sigma$
$f_2(1810)$	1822^{+29+66}_{-24-57}	$229^{+52+88}_{-42-155}$	$(5.40^{+0.60+3.42}_{-0.67-2.35}) \times 10^{-5}$	$6.4\ \sigma$
$f_2(2340)$	$2362^{+31+140}_{-30-63}$	$334^{+62+165}_{-54-100}$	$(5.60^{+0.62+2.37}_{-0.65-2.07}) \times 10^{-5}$	$7.6\ \sigma$

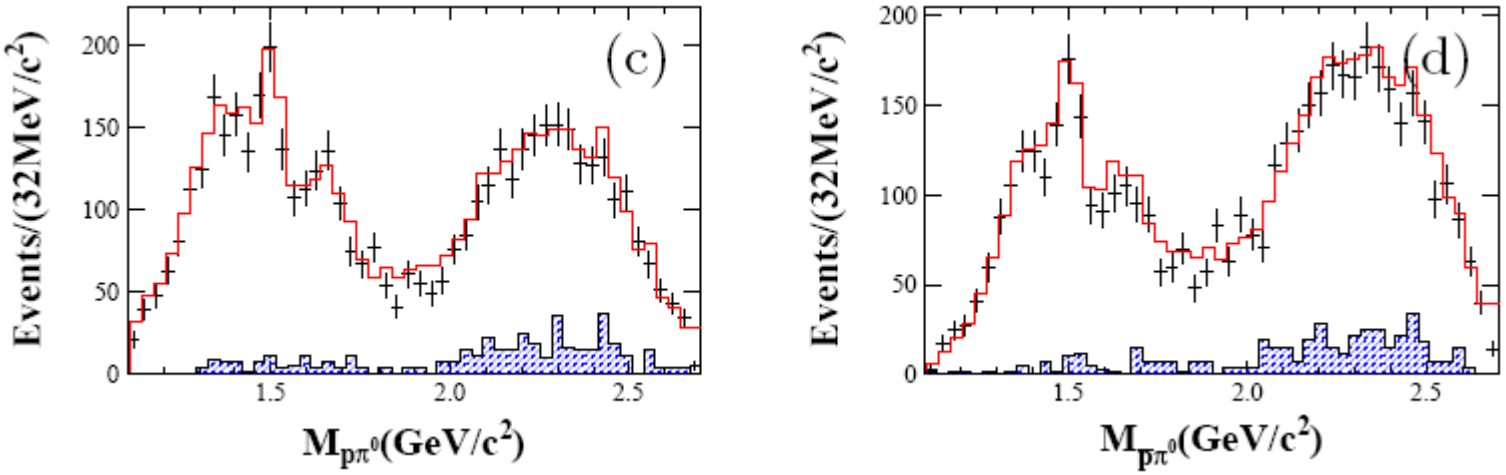
arXiv:1301.0053

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

BES III : accepted by PRD

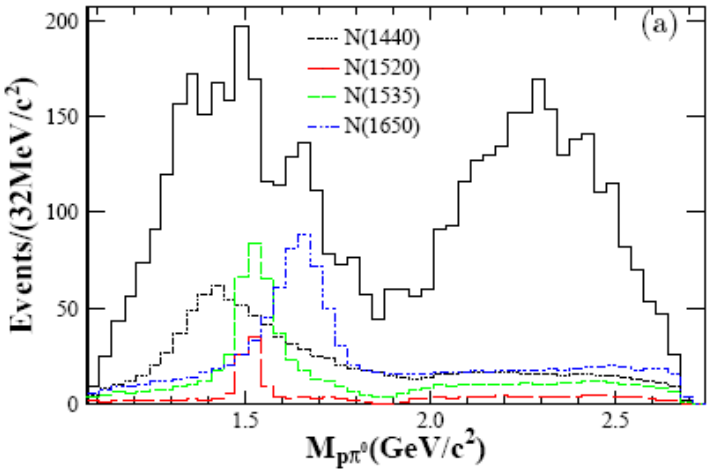
Observation of two new N* resonances in $\psi' \rightarrow p\bar{p}\pi^0$

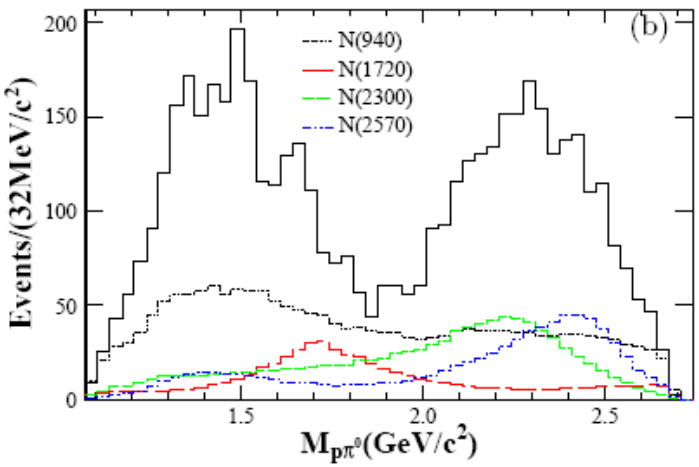
- Non-relativistic three-quark models of baryons predicted more excited states than are found experimentally ("missing resonance problem").
- Most of the data about baryons on PDG are from πN scattering.
- The formula for baryons decay is much more complicated than mesons decay. FDCPWA (Nucl.Instrum.Meth. 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 $\psi' \to p\bar{p}\pi^0$





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

- **19 states on PDG with Spin<5/2 are considered.**
- **7 states and N(940) (represent virtual proton) with significance > 5σ are kept .**
- **Two new N* states are observed, N(2300)($1/2^+$) and N(2570)($5/2^-$).**

Summary

- **A lot of interesting results on light hadron spectroscopy have been obtained on BESIII:**
  - confirmation of the enhancement at $p\bar{p}$ mass threshold in $J/\psi \to \gamma p\bar{p}$, and $J^{pc} = 0^{-+}$.
  - Confirmation of X(1835) and two new structures in $J/\psi \to \gamma\eta'\pi^+\pi^-$
  - First observation: $\eta(1405) \to f_0(980)\pi^0$ (isospin breaking).
  - $\omega\phi$ threshold enhancement in $J/\psi \to \gamma\omega\phi$
  - $\eta\eta$ system in $J/\psi \to \gamma\eta\eta$
  - Two new N* states are found in $\psi' \to p\bar{p}\pi^0$
- **BESIII just took 1 billion J/ψ events and 0.4 billion $\psi(3686)$ events last year.**

  More and more exciting results from BESIII in the future.

Thank you