Recent Results of Light Hadron Spectroscopy from BESIII

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outline

- **Introduction**
- **Recent results of light hadron spectroscopy**
  - PWA of $J/\psi \to \gamma\omega\phi$
  - PWA of $J/\psi \to \gamma\eta\eta$
  - PWA of $\psi(3686) \to p\ \bar{p}\ \pi^0$
  - PWA of $\psi(3686) \to p\ \bar{p}\ \eta$
- **Summary**

Bird View of BEPCII/BESIII

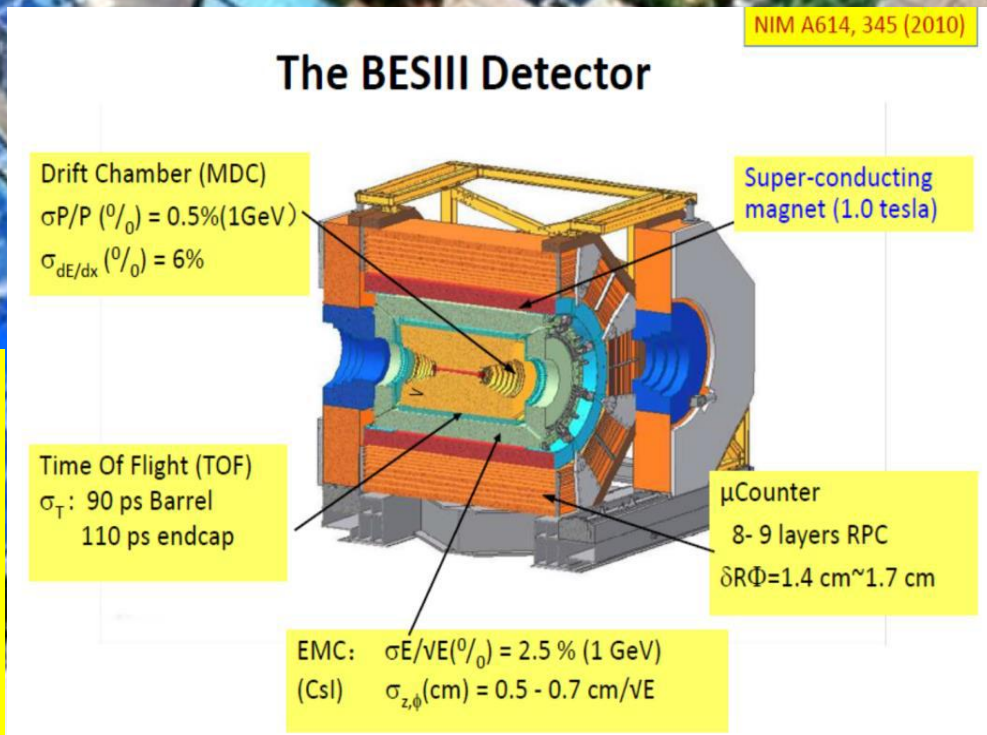
Linac

Storage ring

BESIII detector

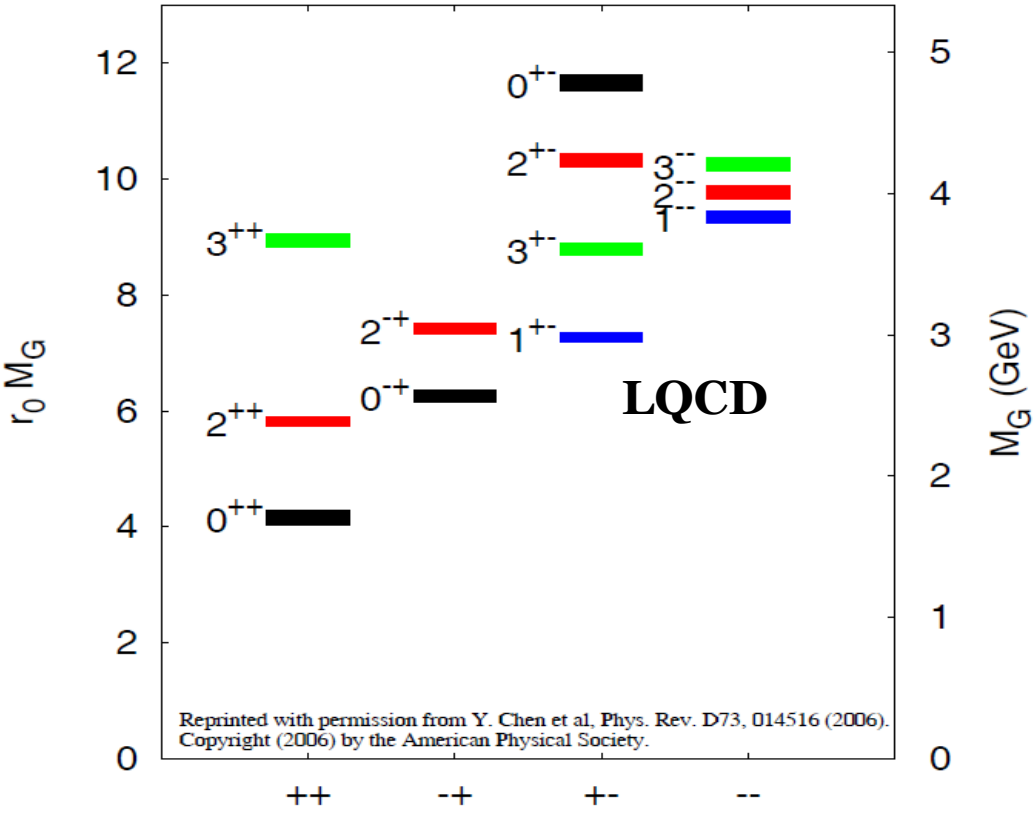
Beam energy 1.0-2.3 GeV
Energy spread: 5.16×10^{-4}

Data Set:
225M J/ψ data;
106M ψ(2S) data;
Collected in 2009,
@ BESIII.



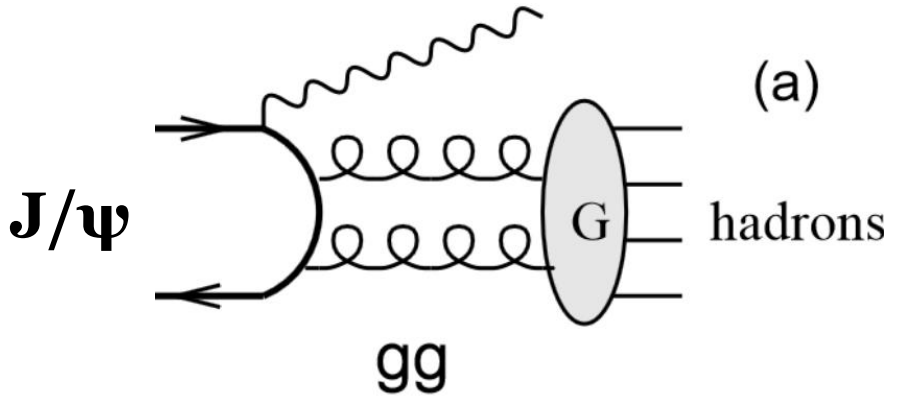
Scalar glueball candidates

- **LQCD:**
  - 0^{++} , low mass glueball, 1.5~1.7 GeV
  - $J/\psi \rightarrow \gamma PP$, even^{++}



- **$f_0(1710)$, $f_0(1500)$: glueball candidates.**

- **Experiments: $f_0(1710)$, $f_0(1790)$,X(1810); the same resonance?**



Introduction to Partial Wave Analysis(PWA)

- Construct amplitude A_i for each possible partial wave, using covariant tensor amplitude approach:

$$A_i = A_{prod} \times Propagator \times A_{decay} \quad (1)$$

eg. $J/\psi \to \gamma X$, $X \to Y + Z$,

  - A_{prod}, A_{decay}: the amplitudes on how X be produced and decays; Constructed with orbital angular momentum covariant tensors, covariant spin wave functions, operators and momenta of parent particles.
  - Propagator:
    usually $f^X_{YZ} = \frac{1}{M_X^2 - s_{YZ} - iM_X\Gamma_X}$

B.S. Zou and D.V.Bugg, Eur. Phys. J. A 16, 537–547 (2003)

- Construct differential cross section:

$$\frac{d\sigma}{d\Omega} = |\sum_i A_i|^2 \tag{2}$$

eg. $J/\psi \to \gamma X$, $X \to Pseudoscalar + Pseudoscalar$,

–

$$\frac{d\sigma}{d\Omega} = |A^{0^{++}} + A^{2^{++}} + A^{4^{++}} + ...|^2 \tag{3}$$

- Minimize the minus log likelihood function:

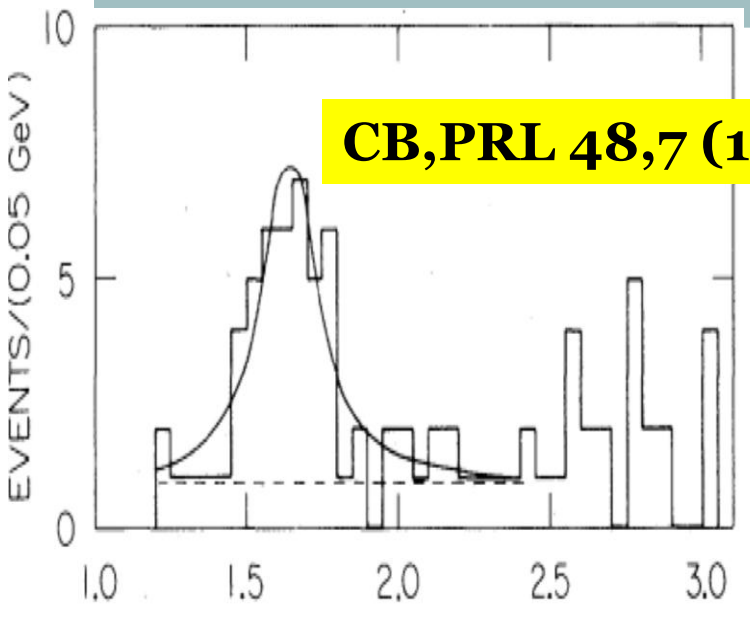
$$-ln\mathcal{L} = -\sum_{i=1}^{n} ln(\frac{d\sigma}{d\Omega}/\sigma) \tag{4}$$

- BES: Event −based PWA framework.

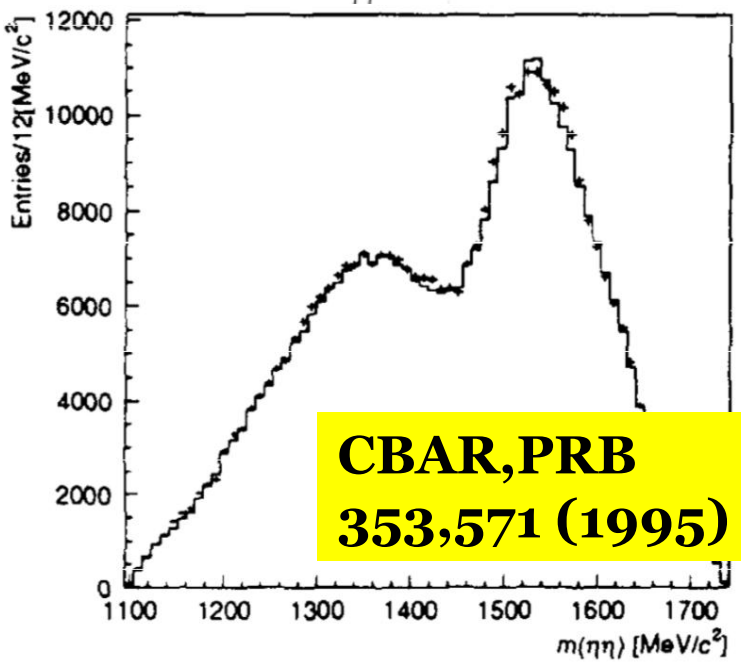
$J/\psi \rightarrow \gamma\eta\eta$

- **First studied by CB, $f_0(1710)$;**
- **Crystal barrel(2002): $p\bar{p} \rightarrow \pi^0\eta\eta$, $f_0(1500)$ found;**
- **E835(2006): $p\bar{p} \rightarrow \pi^0\eta\eta$, found $f_0(1500)$ and $f_0(1710)$;**
- **WA102, GAMS: $\eta\eta$ mode, $f_0(1710)$;**

- **BESIII:**
  - **A good lab;**
  - **Good performance of CsI crystal EMC;**
  - **Low background.**

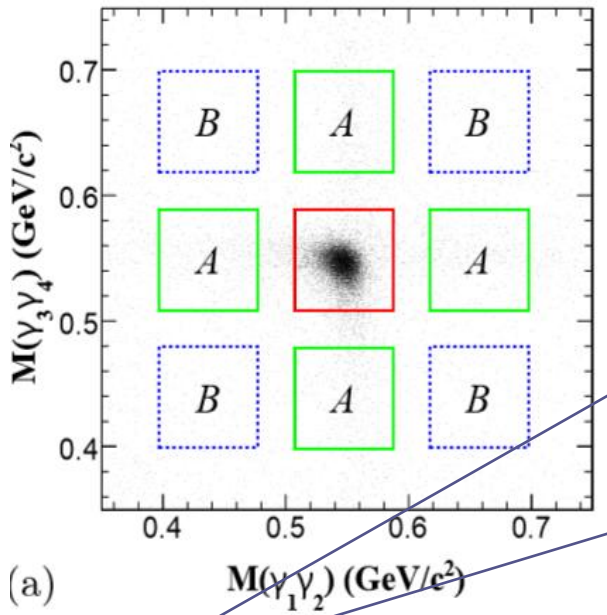


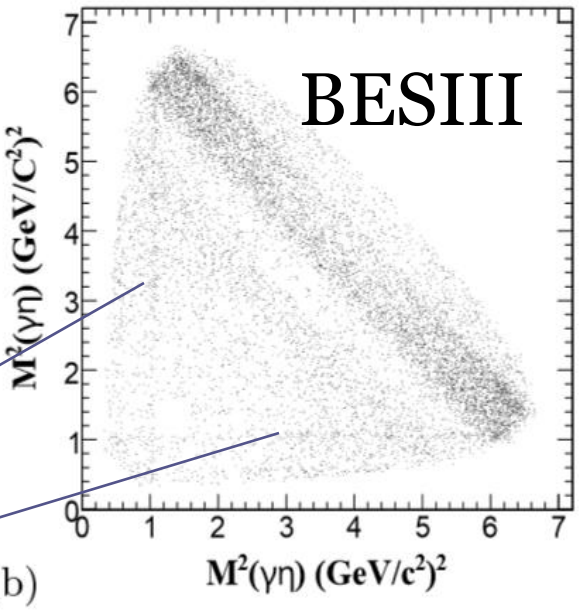
CB,PRL 48,7 (1982)

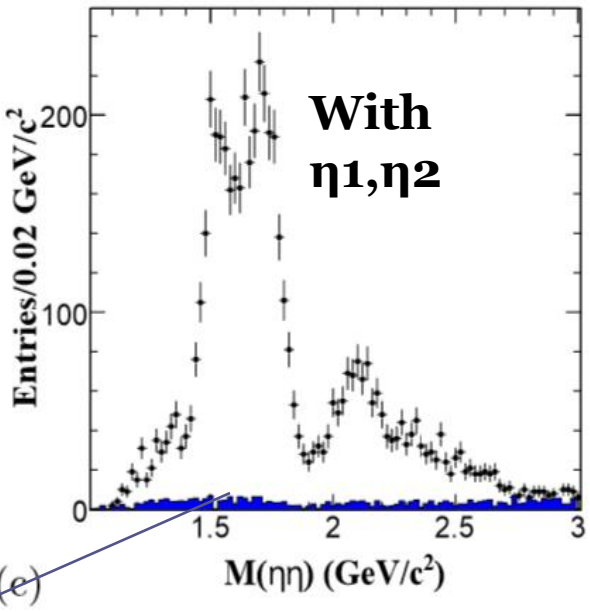


CBAR,PRB 353,571 (1995)

PWA of J/ψ→γηη, η→γγ







- **J/ψ→ ϕη, ϕ→γη, select events outside ϕ mass window.**
- **BKG: mainly non-η background, estimated by η sideband (blue shaded); low.**

- **BKG subtraction: $\ln L^{signal} = \ln L^{data} - \ln L^{sideband}$;**

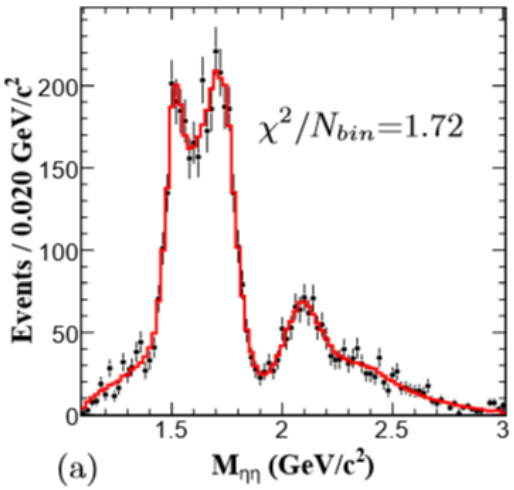
PWA of J/ψ→γηη

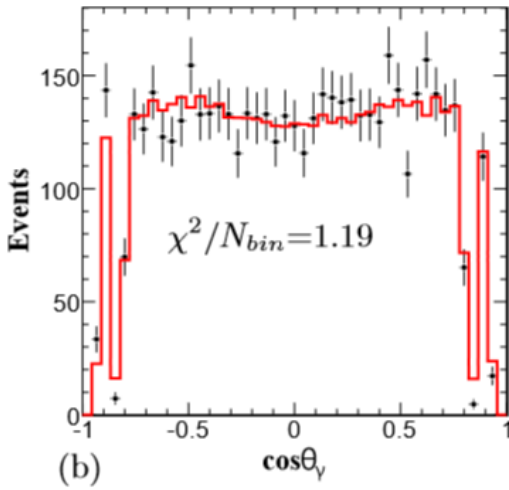
PRD. 87, 092009 (2013)

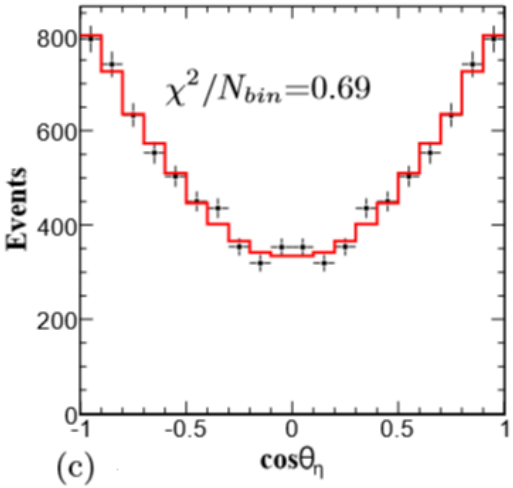
- **The best solution: $f_0(1500)$, $f_0(1710)$,$f_0(2100)$; $f'_2(1525)$,$f_2(1810)$,$f_2(2340)$ phase space+$\phi\eta$;**

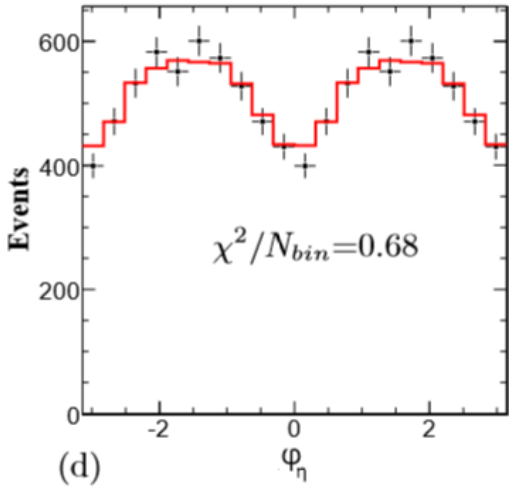
- **No significant evidence:**

For the scalar: $f_0(1790)$ $f_0(1370)$, $f_0(2020)$, $f_0(2200)$ and $f_0(2330)$;
For the tensor: the possible tesor $f_2(2010)$, $f_2(2150)$ and $f_J(2220)$;
Change between with/without adding them in global fit : one resource of sys.error.









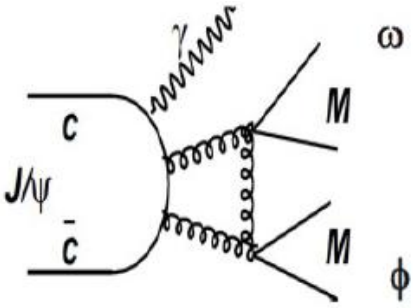
- **$\phi\eta$ background: impact from interference of ϕ tail considered. An alternative fit without $\phi\eta$ is taken as one resource of sys.error.**

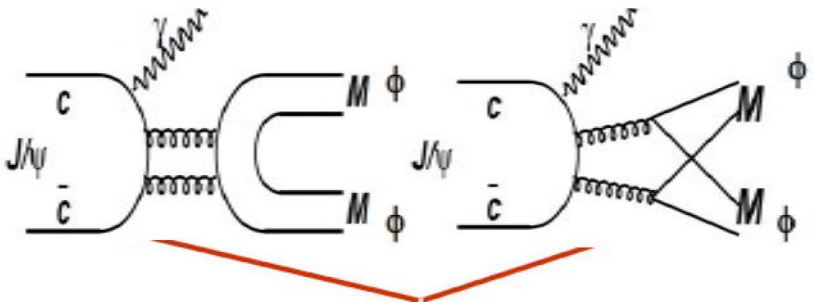
Resonance	Mass(MeV/c^2)	Width(MeV/c^2)	$\mathcal{B}(J/\psi \to \gamma X \to \gamma\eta\eta)$	Significance
$f_0(1500)$	1468^{+14+23}_{-15-74}	$136^{+41+28}_{-26-100}$	$(1.65^{+0.26+0.51}_{-0.31-1.40}) \times 10^{-5}$	8.2 σ
$f_0(1710)$	$1759\pm6^{+14}_{-25}$	$172\pm10^{+32}_{-16}$	$(2.35^{+0.13+1.24}_{-0.11-0.74})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

- **Dominant scalar: $f_0(1710)$, $f_0(2100)$;**
- **Tensor components: $f'_2(1525)$,$f_2(1810)$,$f_2(2340)$.**
- **No significant $f_0(1370)$, $f_0(1790)$, $f_J(2220)$ in $\eta\eta$ mode ;**
- **Br of $f_0(1710)$ in J/ψ radiative decays : LQCD;**

J/ψ→γωϕ

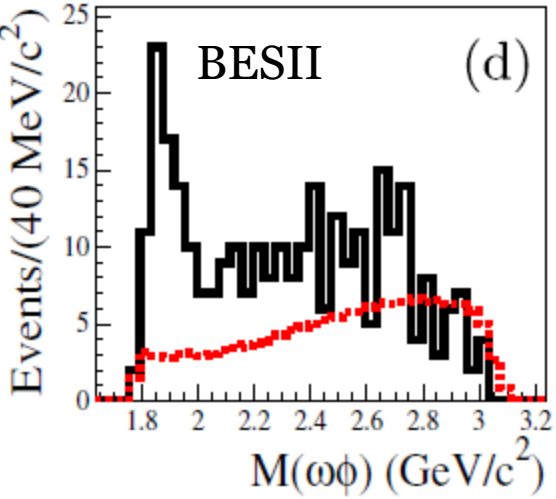
- Double OZI supressed,

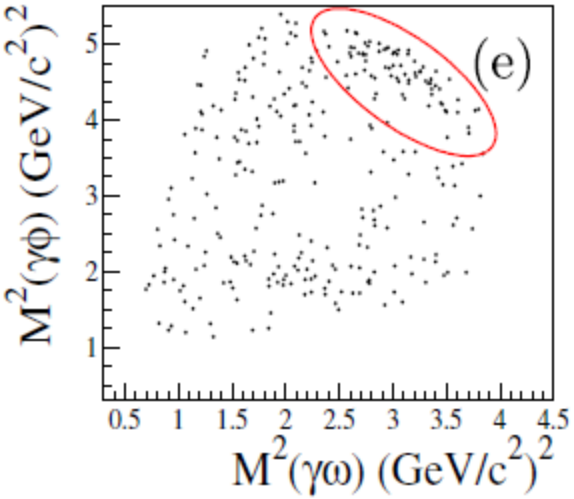




J/ψ→γωϕ (DOZI) predicted $\propto 1/10$ J/ψ→γϕϕ (OZI)

- BESII





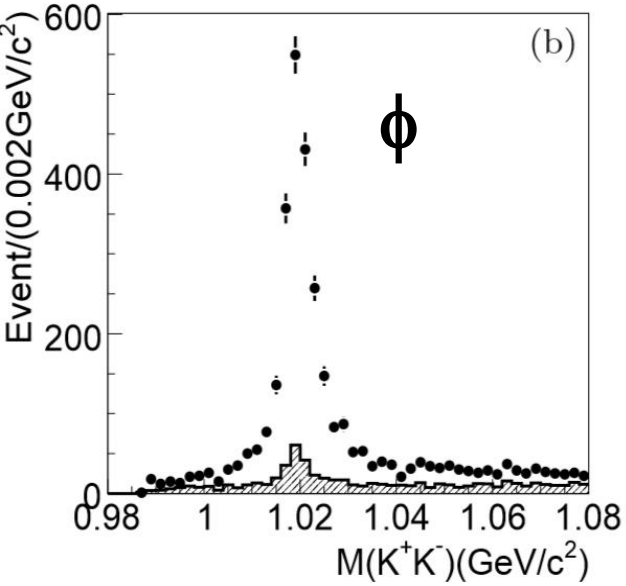
$$M = 1812^{+19}_{-26} \pm 18 MeV/c^2$$

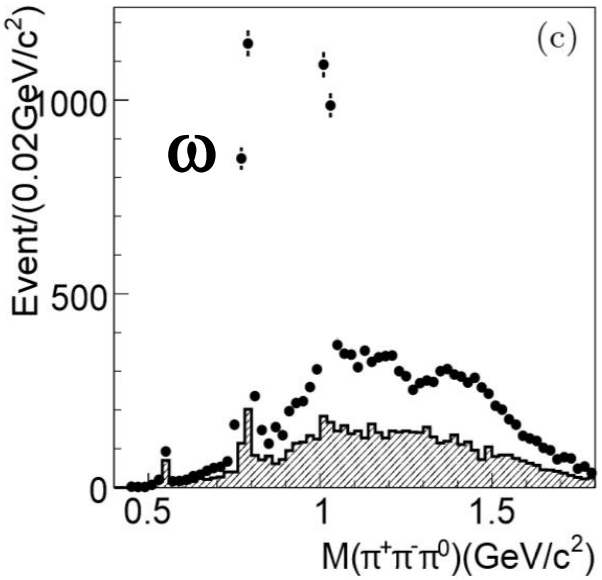
$$\Gamma = 105 \pm 20 \pm 28 MeV/c^2$$

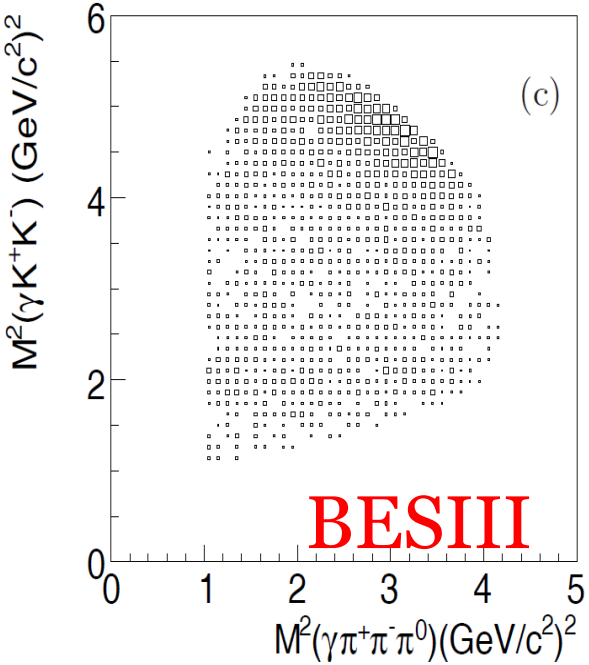
J^{PC} favors 0^{++} over 0^{-+} and 2^{++}

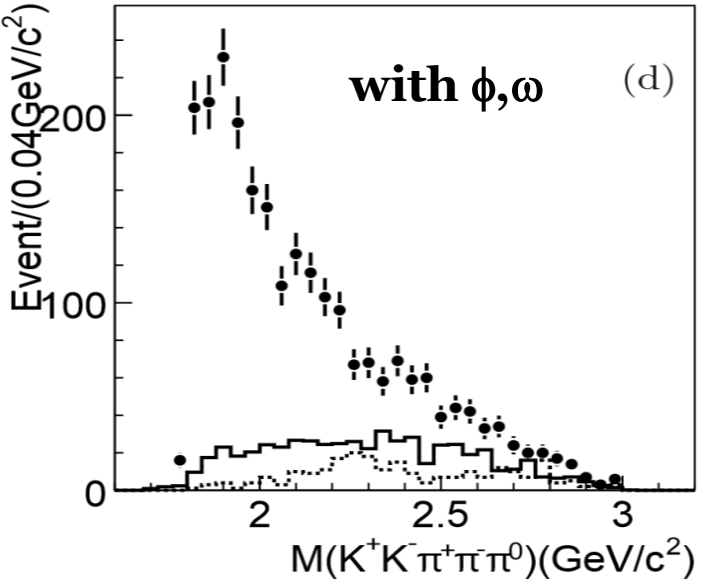
PRL 96, 162002(2006)

PWA of J/ψ→γωϕ









solid : BKG estimated from the sideband ;
dashed : inclusive J/ψ MC samples;

- **BKG subtraction:**
  ln L ^{signal}= ln L ^{data}–ln L ^{sideband} ;

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

PRD 87 ,032008(2013)

To get the best solution:

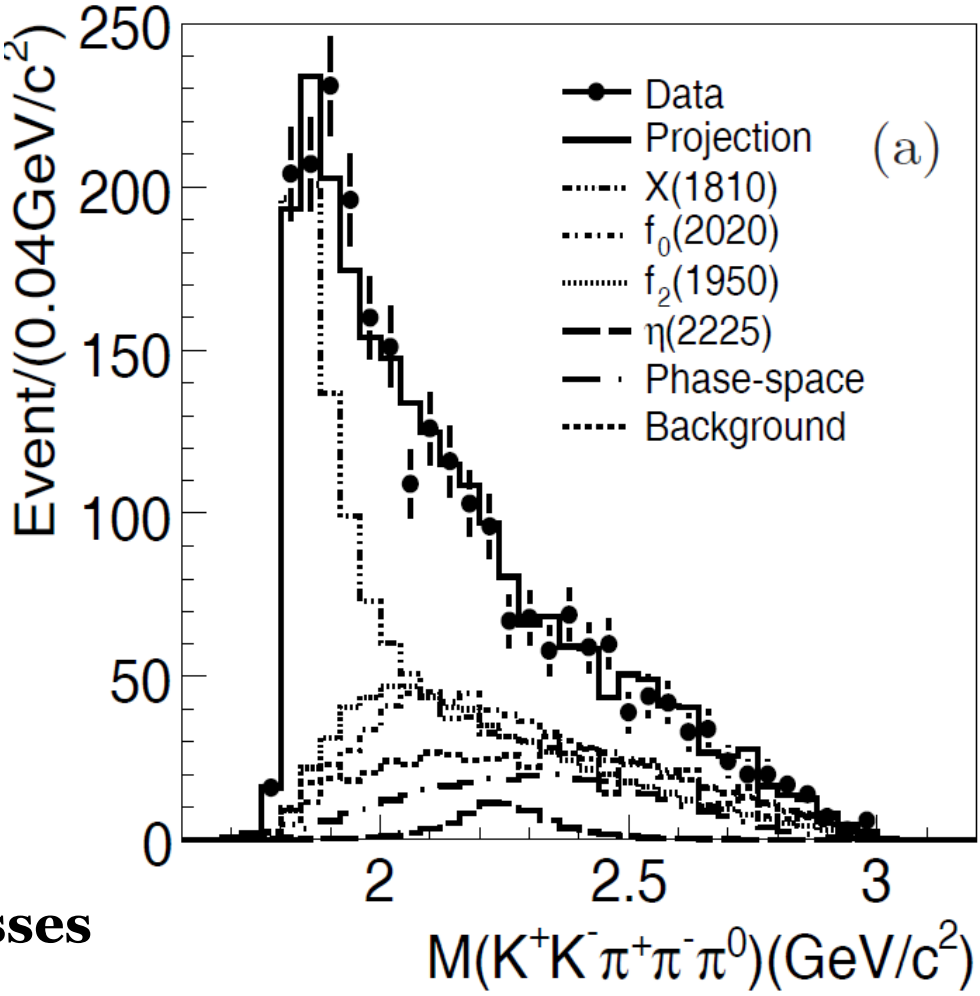
- **M , Γ and J^{PC} of X(1810);**
- **Other known mesons @ PDG;**
- **Different J^{PC} of phase space;**
- **Different combinations of additional mesons in PDG;**

The best solution:

X(1810), $f_0(2020)$, $f_2(1950)$, η(2225),phase space and BKG.

For systematic error:

- **$f_2(1920)$, $f_0(2020)$, η(2225) : standard deviation from PDG; Replaced by others of similar masses and same J^{PC} ;**
- **Uncertainty of model dependence of X(1810).**



- **X(1810):**

➢ **$M=1795\pm7(stat)^{+13}_{-5}(sys)\pm19(mod)$;**
$\Gamma=95\pm10(stat)^{+21}_{-34}(sys)\pm75(mod)$;
$B(J/\psi\rightarrow\gamma X(1810))\times B(X(1810)\rightarrow\omega\phi)$
$=(2.00\pm0.08(stat)^{+0.45}_{-1.00}(sys)\pm1.30(mod))\times10^{-4}$

➢ Confirmed @ BESIII, $J^{PC}=0^{++}$;

➢ Compare with $f_0(1710)$: no conclusion.

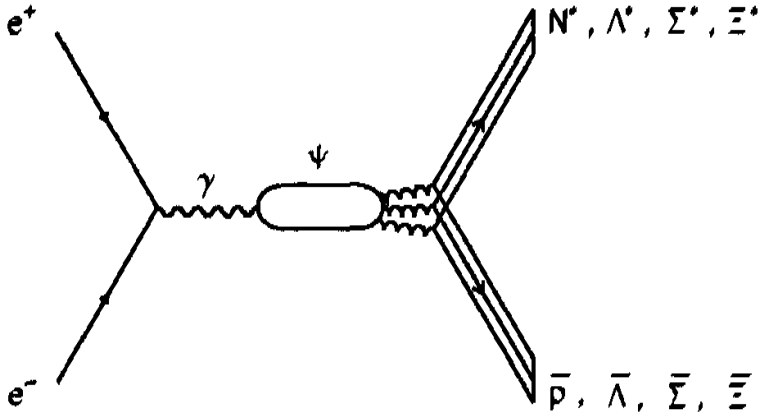
➢ Need further study;

➢ **Search for X(1810) in other mode: $J/\psi\rightarrow\phi\omega\phi$, $\omega\omega\phi$, do the couple channels analysis…**

Baryon spectroscopy

- NRCQM model

- "missing resonance problem";
- Mass revesal problem: N*(1535), N*(1440);
- Need experimental measurements…



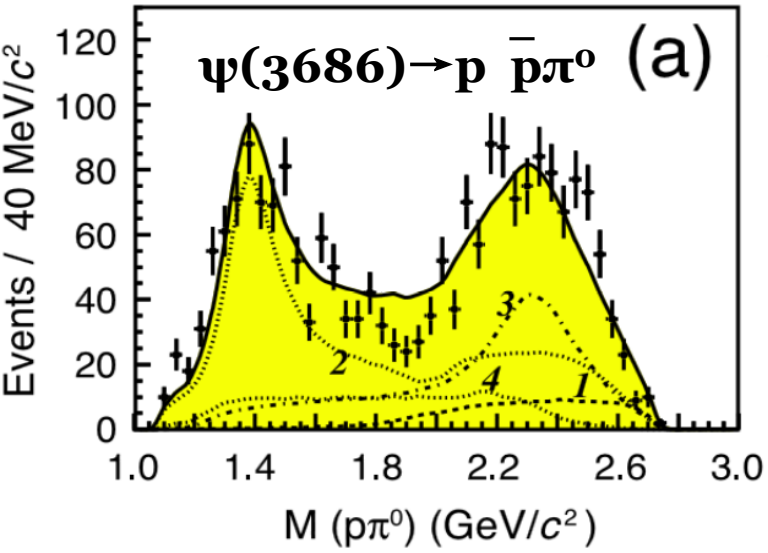
- J/ψ, ψ' : N*, Λ*,Ξ*,Σ*

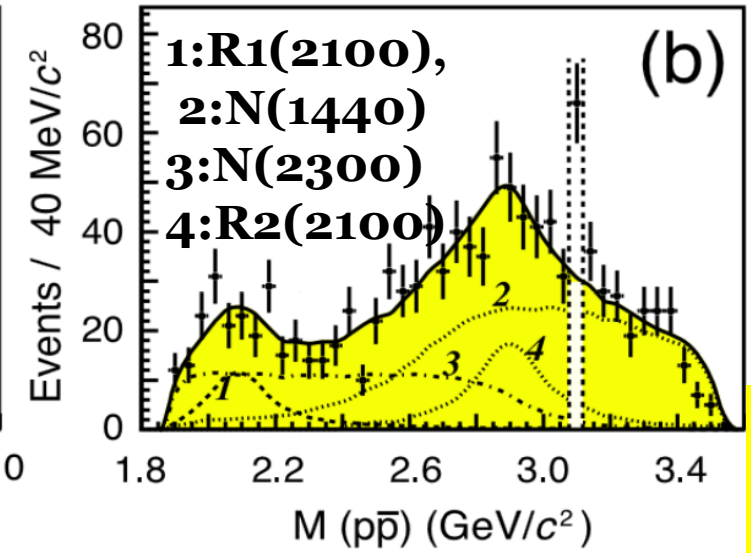
- Advantages: Isospin conservation, rich production of hybrid baryons (qqqg) …

CLEO-c

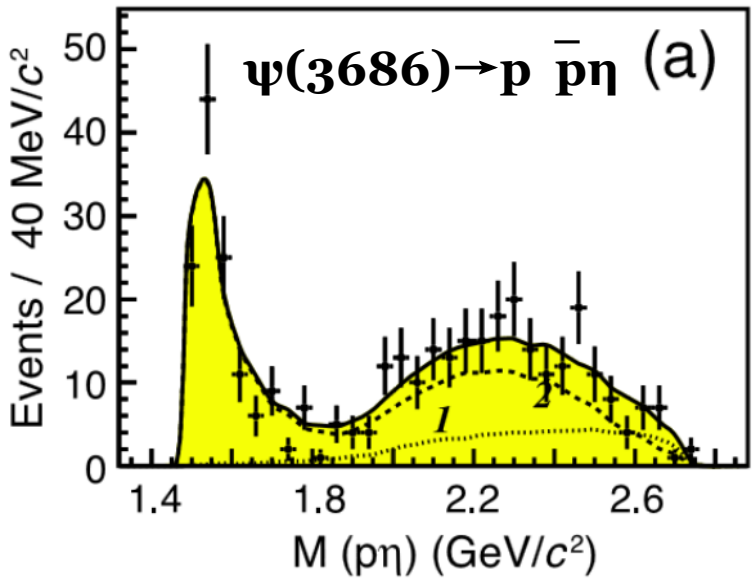
PRD 82, 092002(2010)

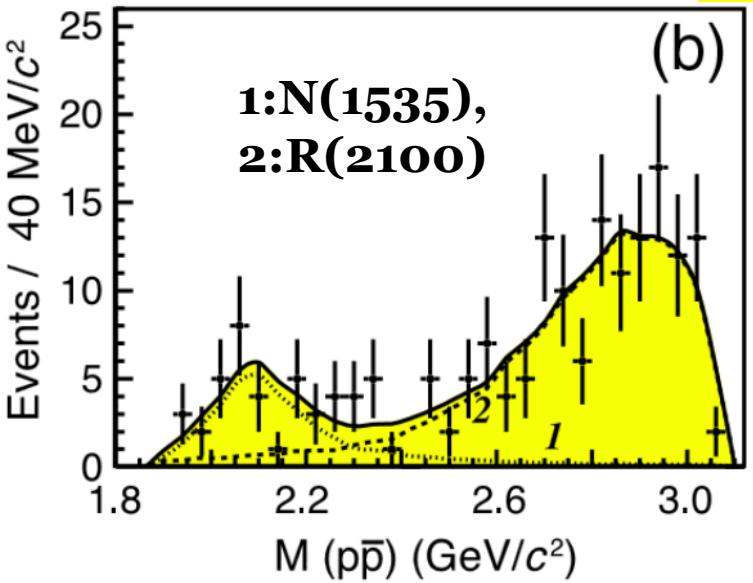
24.5 M ψ(2S)



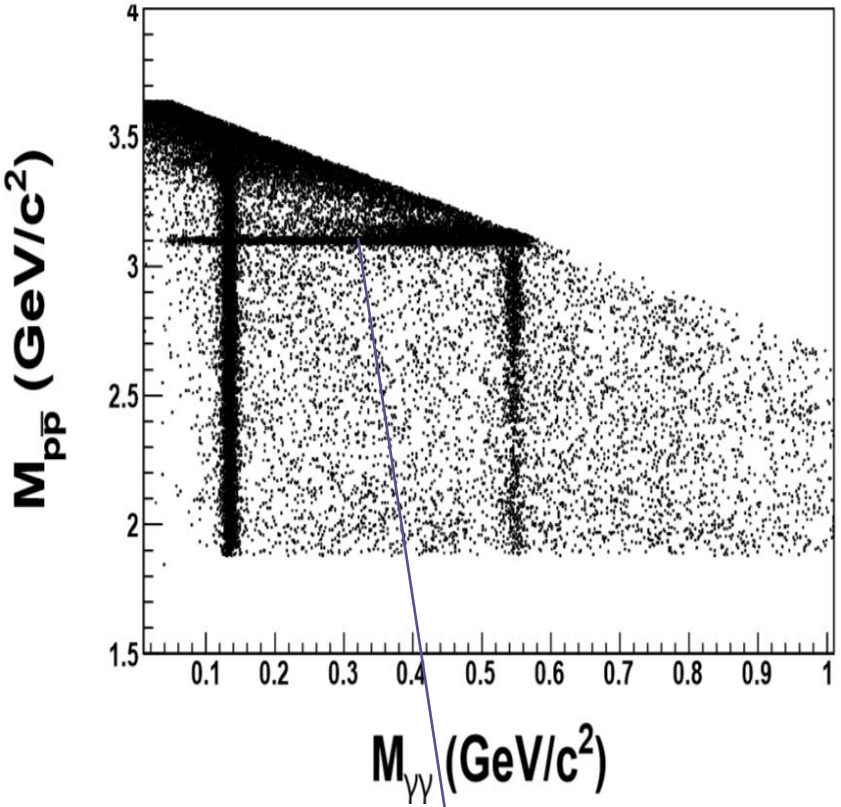


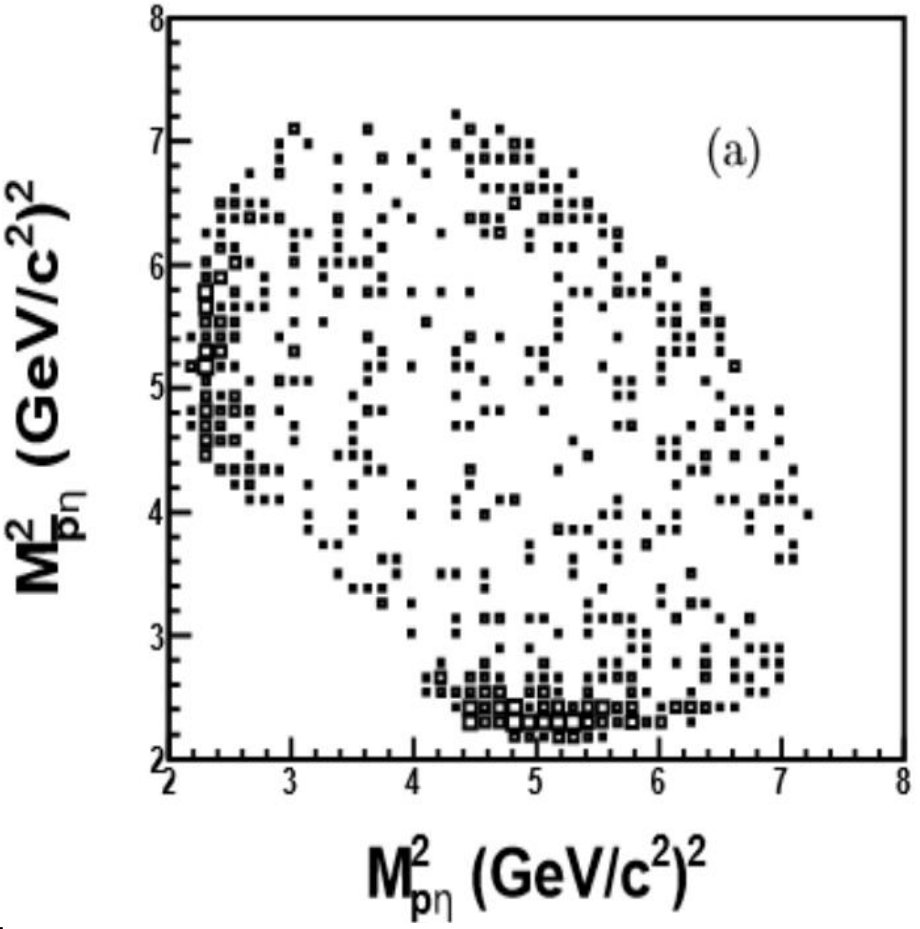
Without interference effects.





PWA of ψ(3686)→p $\bar{p}$η

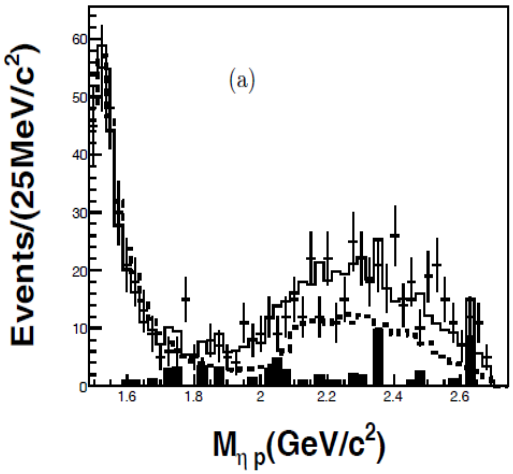


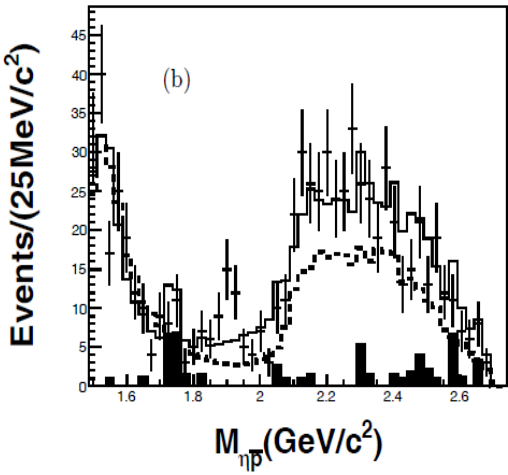


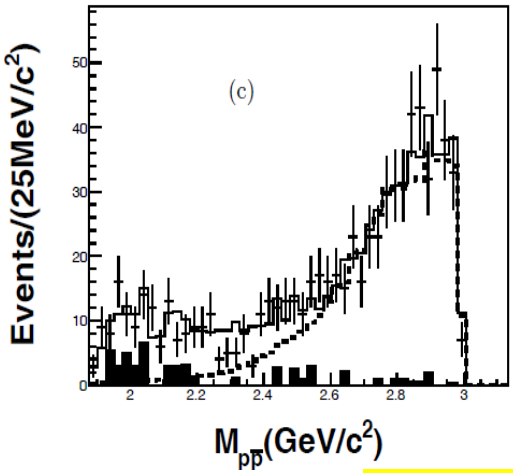
ψ(3686)→XJ/ψ, J/ψ→p $\bar{p}$, subtracted.

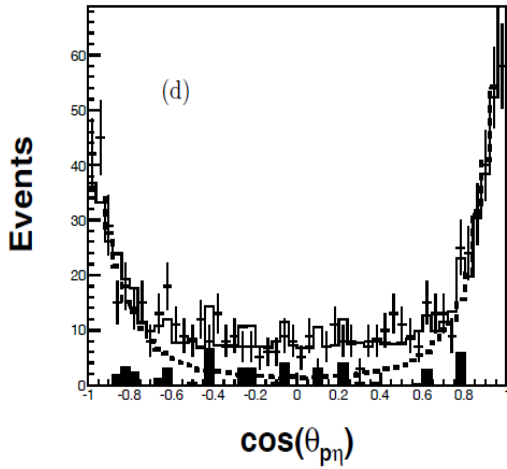
PWA of ψ(3686)→p $\bar{p}$η

- BKG: sidebands and continuum data; low;
- **Best solution**: N(1535) combined with an interfering phase space;
- N(1535):
  - M=1524±5^{+10}_{-4} MeV/c²
  - Γ=$130^{+27}_{-24}{}^{+56}_{-10}$ MeV/c²







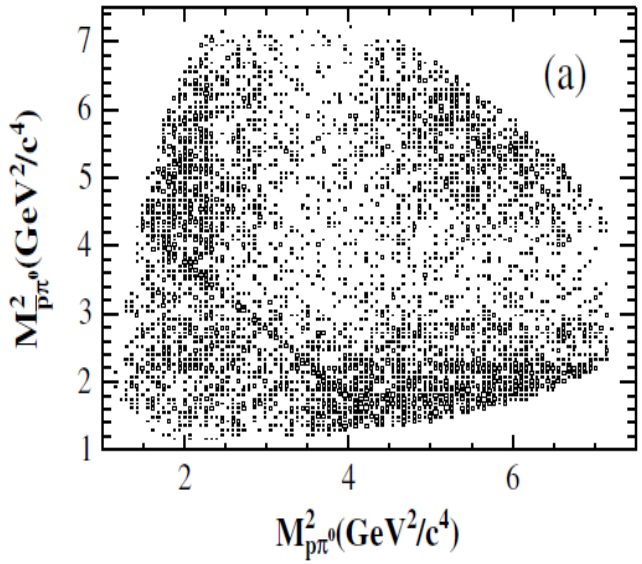


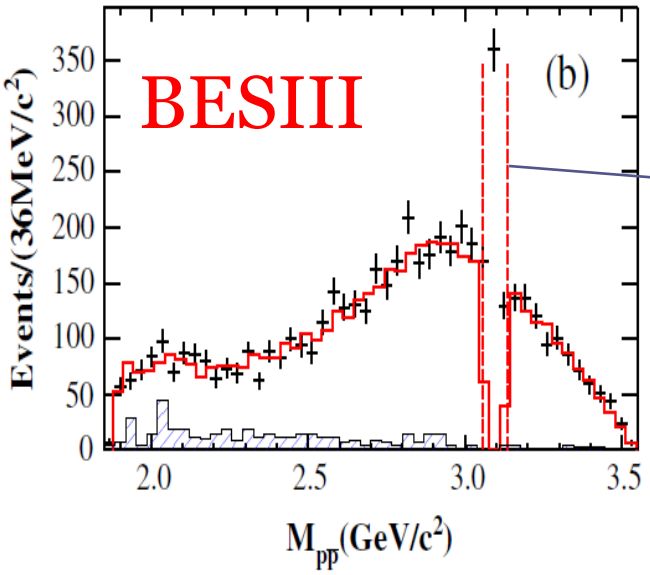
PRD 88,032010(2013)

- p $\bar{p}$ enhancement <3σ;
- Supressed compare with "12% rule":

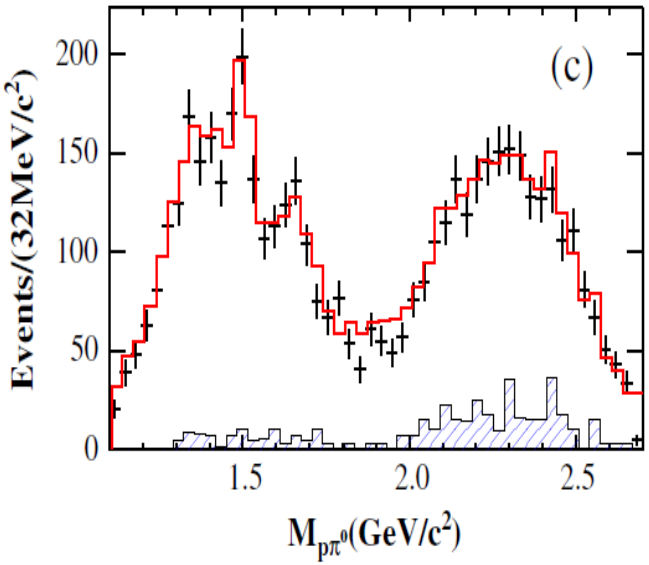
$$Q_{p\bar{p}\eta} = \frac{B(\psi(2S) \to \eta p\bar{p})}{B(J/\psi \to \eta p\bar{p})} = (3.2 \pm 0.4)\%$$

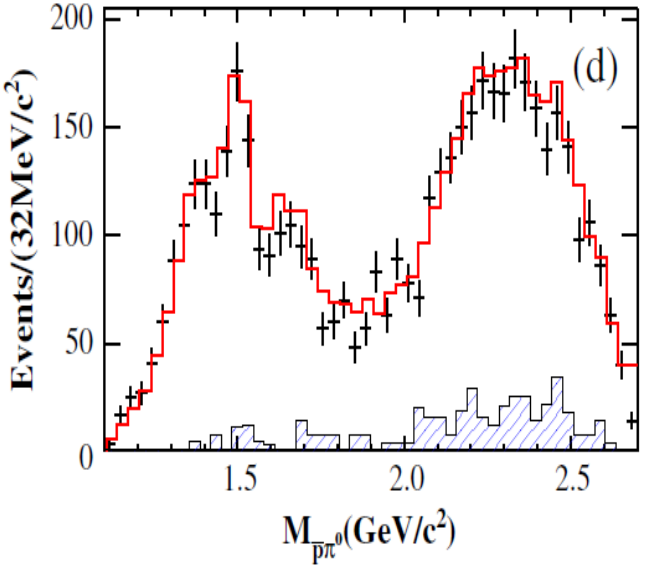
PWA of ψ(3686)→p $\bar{p}\pi^0$





ψ(3686)→XJ/ψ subtracted.

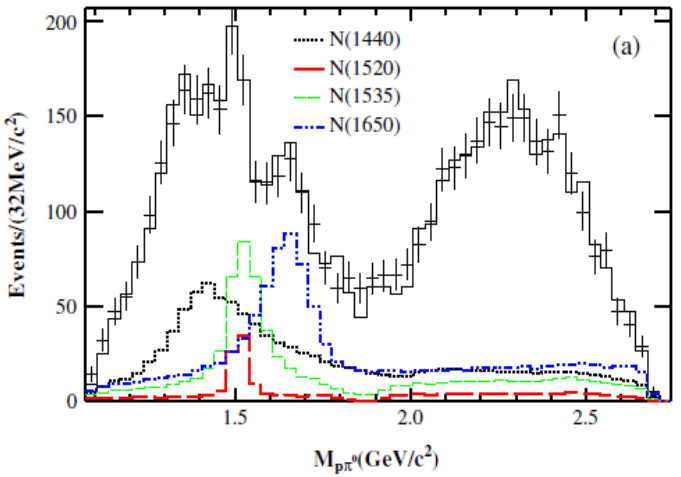


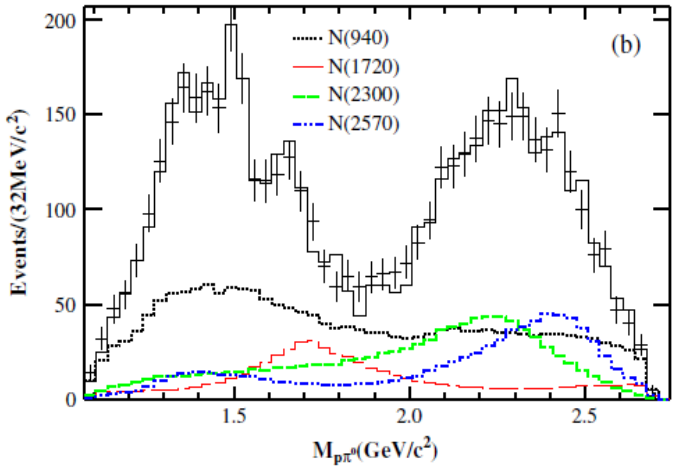


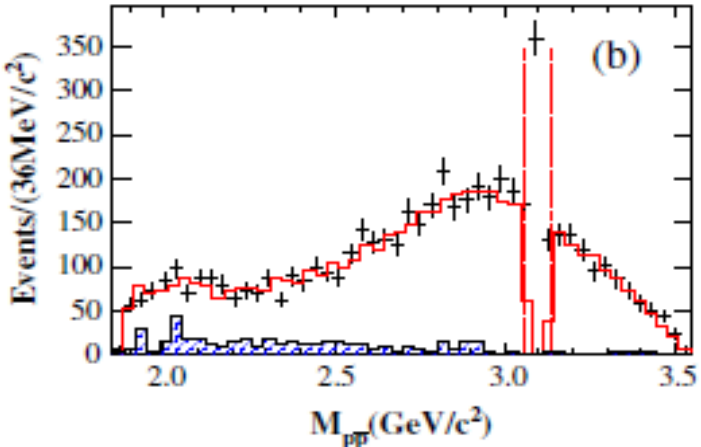
Shaded : BKG 2 sources, Continuum process, non-π^0 BKG ;

PWA of ψ(3686)→p $\bar{p}\pi^0$

- **Two body decay:**
  - ψ(3686)→ p $\bar{N}$*, $\bar{N}$*→ $\bar{p}\,\pi^0$ +c.c
    → Xπ^0 , X→p $\bar{p}$
  - Isospin conservation: Δ suppressed;
- **The best solution:**
  N(1440),N(1520),N(2090),N(1535), N(1650),N(1720),N(2300),N(2570) (J^{PC});
- **No significant evidence.**
  - N(1885) and N(2065), p $\bar{p}$ enhancement;
  - The uncertainties from additional possible resonances are considered.







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

PRL 110, 022001(2013)

$\boldsymbol{B}(\psi(3686)\to p\ \bar{p}\pi^0)=(1.65\pm0.03\pm0.15)\times10^{-4}$

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
$N(2300)(1/2)^+$	**$2300^{+40+109}_{-30-0}$**	**$340^{+30+110}_{-30-58}$**	**120.7**	**4**	**15.0σ**
$N(2570)(5/2)^-$	**2570^{+19+34}_{-10-10}**	**250^{+14+69}_{-24-21}**	**78.9**	**6**	**11.7σ**

- 2 new resonances
- No significant N(1885) or N(2065)(<5σ)
- $p\ \bar{p}$ resonance < 4σ

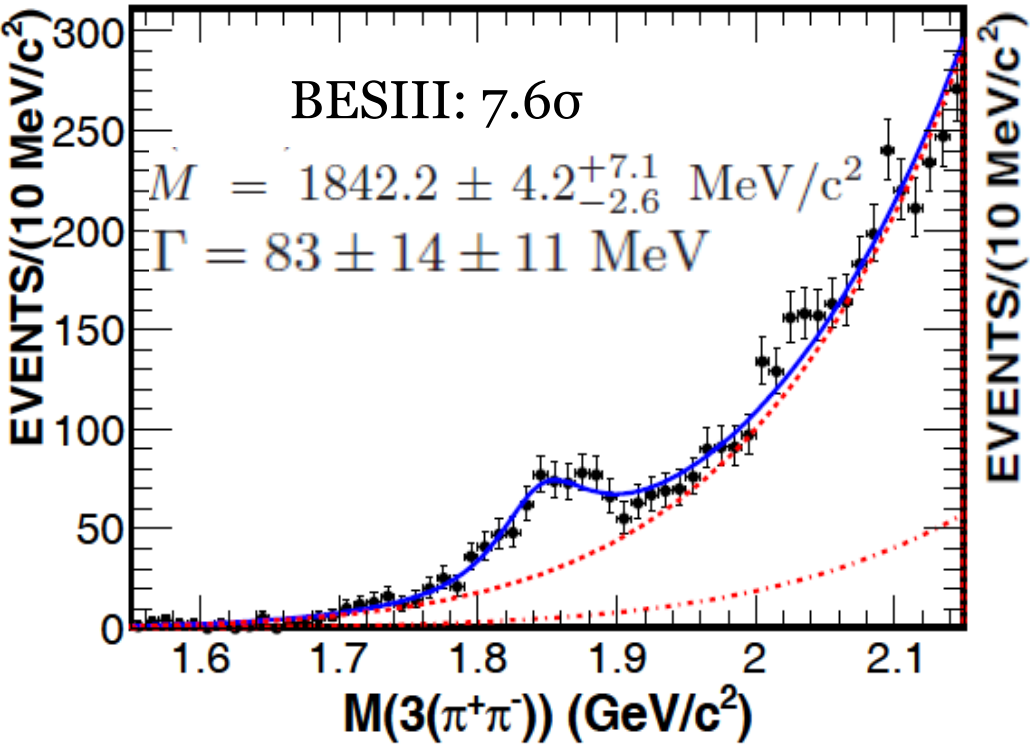
Summary

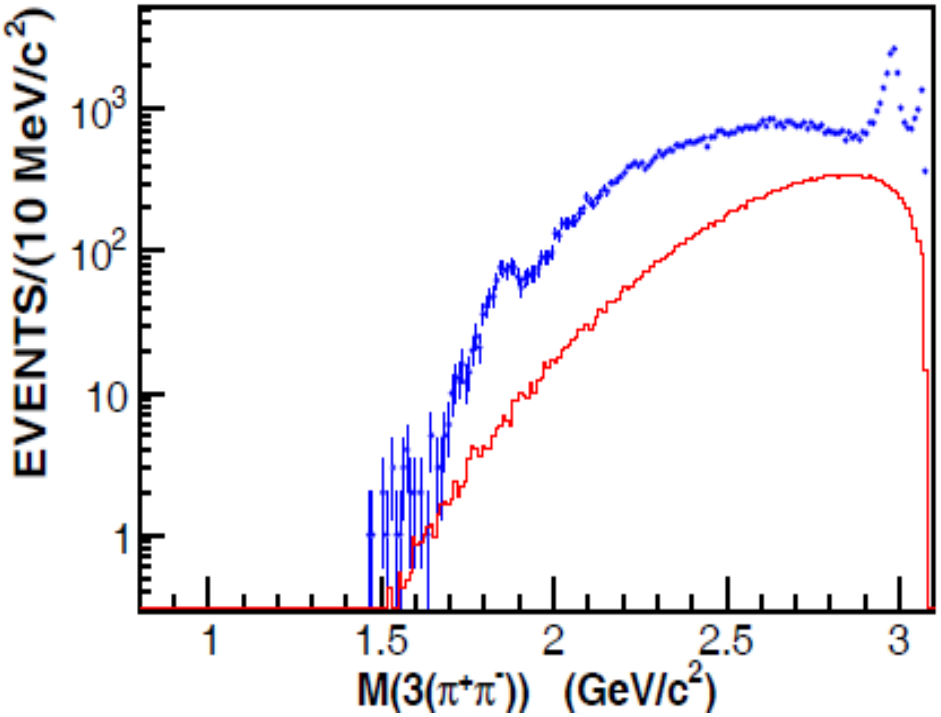
- **Light hadron spectroscopy: the recent results are presented,**
  - PWA of $J/\psi \to \gamma\omega\phi$
  - PWA of $J/\psi \to \gamma\eta\eta$
  - PWA of $\psi(3686) \to p\ \bar{p}\ \pi^0$
  - PWA of $\psi(3686) \to p\ \bar{p}\ \eta$
- **~1 billion J/ψ & 0.4 billion ψ′ events were taken last year;**
- **More results are expected to come soon !**

Thank you!

BACK UP

$J/\psi \to \gamma 3(\pi^+ \pi^-)$

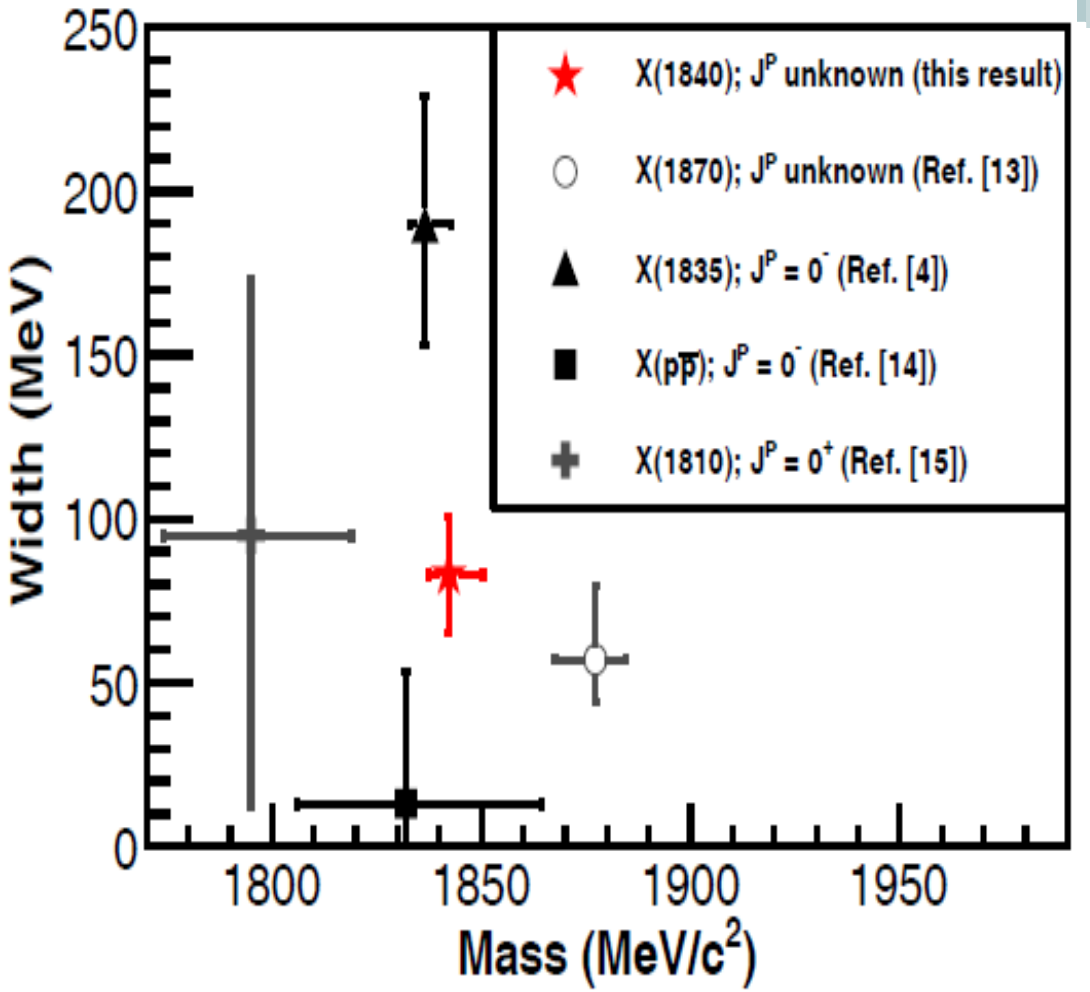




arXiv:1305.5333 submitted to PRL

- **BG: $\pi^0 3(\pi^+\pi^-)$ +PHSP（3rd-order poly）;**
- **$B(J/\psi \to \gamma X(1840)) \times B(X(1840) \to 3(\pi^+\pi^-))$ $= (2.44 \pm 0.36^{+0.60}_{-0.74}) \times 10^{-5}$;**
- **No η' observed, $B(\eta' \to 3(\pi^+\pi^-)) < 3.1 \times 10^{-5}$.**

- **New decay mode observed;**
- **M:X(1835) and X(p $\bar{p}$), Γ :not;**
- **Can't determine : a new or existing state?**
- **Further study about spin parity…**



Ref[4]:PR L 106, 072002 (2011).
Ref[13]: PRL 107, 182001 (2011).
Ref[14]: PRL 108, 112003 (2012)
Ref[15]:PRD 87, 032008 (2013).