International Workshop on using Heavy Flavors to Probe
New Hadron Spectroscopies/Dynamics

Recent Results of Light Hadron Spectra at BESIII
(X(1835), X(1870), …)

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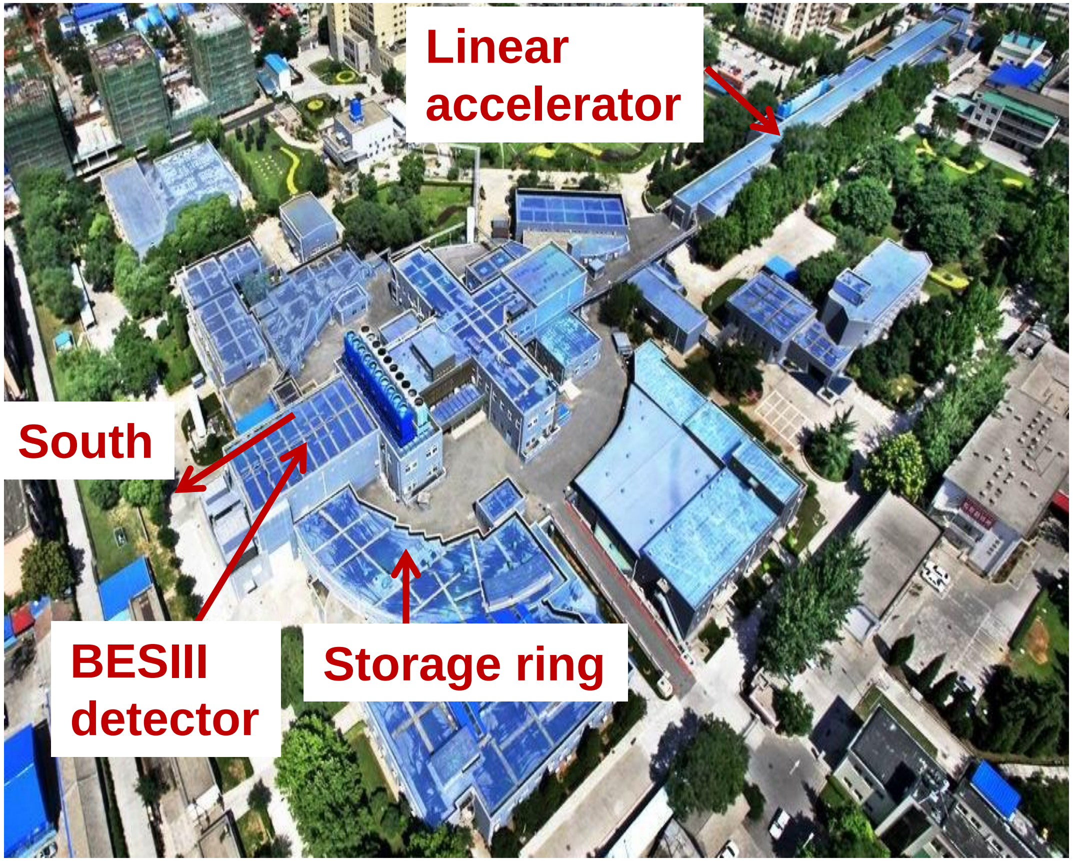
November 18-21, 2012
Haeundae Grand Hotel, Busan, South Korea

Outline

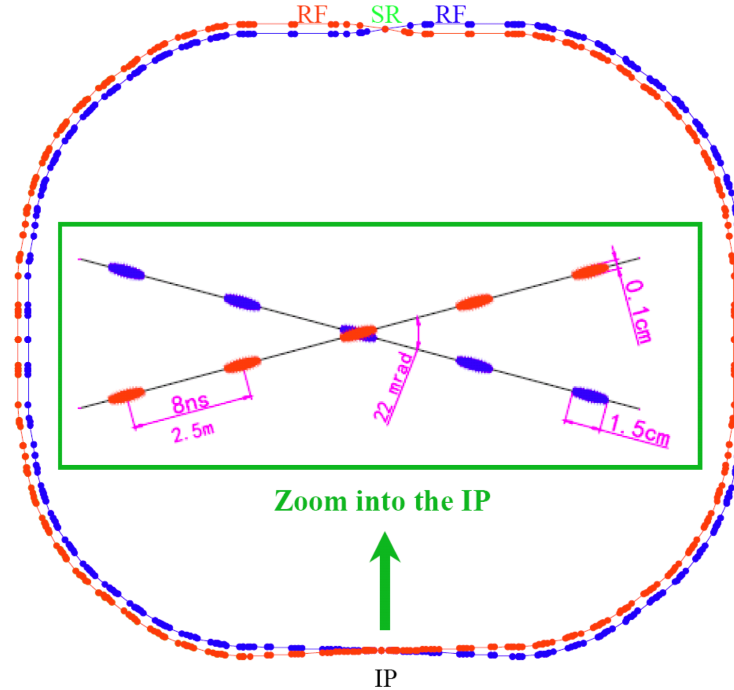
- Status of BEPCII / BESIII
- Recent Results on Light Hadron Spectroscopy
  - $p\bar{p}$ mass threshold structure in J/ψ and $\psi^{/}$ radiative decays
  - X(1835) and two new structures in $J/\psi \to \gamma\pi^+ \pi^- \eta^{/}$
  - A new structure X(1870) in $J/\psi \to \omega\eta\pi^+\pi^-$
  - $\eta(1405)$ in $J/\psi \to \gamma X$, $X \to f_0(980)\pi^0$, $f_0(980) \to \pi\pi$
  - PWA of $J/\psi \to \gamma\eta\eta$
  - PWA of $J/\psi \to \gamma\omega\phi$
  - N* states in $\psi^{/} \to p\bar{p}\pi^0$ and $\psi^{/} \to p\bar{p}\eta$
- Summary

General layout of BEPCII/BESIII



2004: start BEPCII construction
2008: test run of BEPCII
2009-now: BEPCII/BESIII data taking

Double storage rings



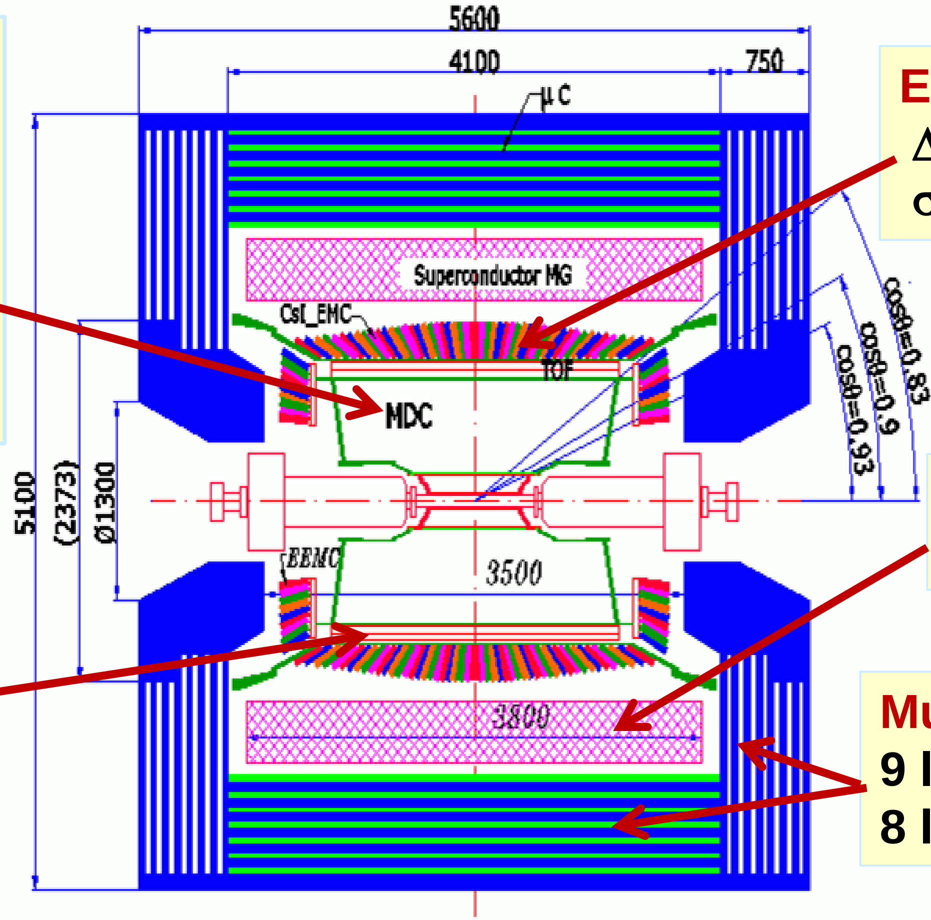
Beam energy: **1.0 - 2.3 GeV**
Designed lumi.: **1×10^{33} cm^{-2}s^{-1}**
(Peak Lumi.: 0.65×10^{33}cm^{-2}s^{-1})
Optimum energy: 1.89 GeV
Energy spread: 5.16×10^{-4}
No. of bunches: 93
Bunch length: 1.5 cm
Total current: 0.91 A
Circumference: 237 m

The BESIII Detector

NIM A614:345-399,2010

Drift Chamber (MDC):
small cell&Gas:
He/C3H8 (60/40),
43 layers
σ_{xy} = 130 μm
σ_p/p = 0.5%@1GeV
dE/dx = 6%

Time-of-Flight (TOF):
σ_T = 80ps barrel
110ps endcap



EMC: CsI crystal
$\Delta E/E$ = 2.5%@1GeV
$\sigma_Z = 0.6\text{cm}/\sqrt{E}$

Solenoid Magnet field: 1T

Muon Counter:
9 layers for barrel
8 layers for endcap

➢ The detector is hermetic for neutral and charged particles with excellent resolution, PID, and large coverage.

J/ψ and ψ' data samples

So far BESIII has collected :

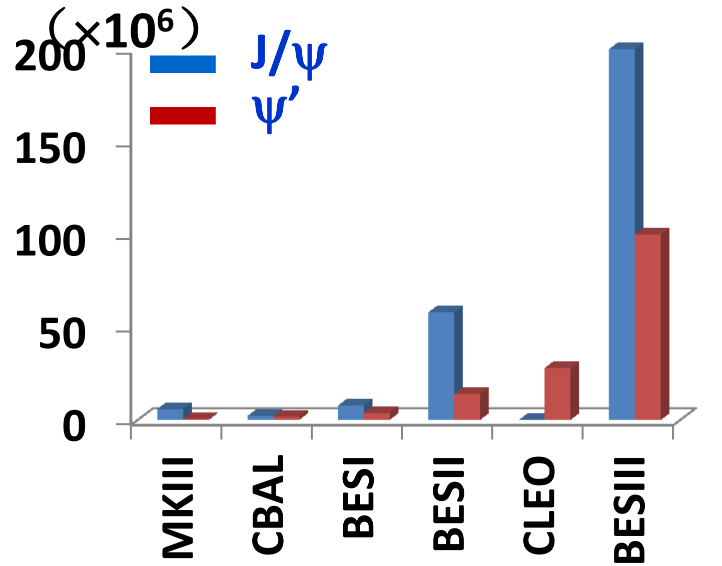
- 2009:

  225 Million J/ψ (4 times of BESII)

  106 Million ψ' (4 times of CLEOc)

- 2012: 1 Billion J/ψ

  0.4 Billion ψ'



World's largest sample of J/ψ, $\psi(2S)$

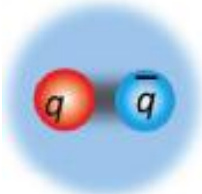
The following results are based on the data samples of 225M J/ψ and 106M ψ' events.

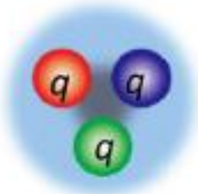
Hadron Spectroscopy

- The ultimate goal of the study of hadron spectroscopy is to understand the dynamics of the constituent interactions.
- PQCD is not applicable in the light hadron sector.
  There exist phenomenological approaches and LQCD calculations.
- Experimental data will provide necessary constrains on the parameters introduced by the theory.

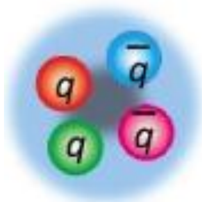
New forms of hadrons

- Conventionally we know:
  mesons ($q\bar{q}$) and baryons (qqq)





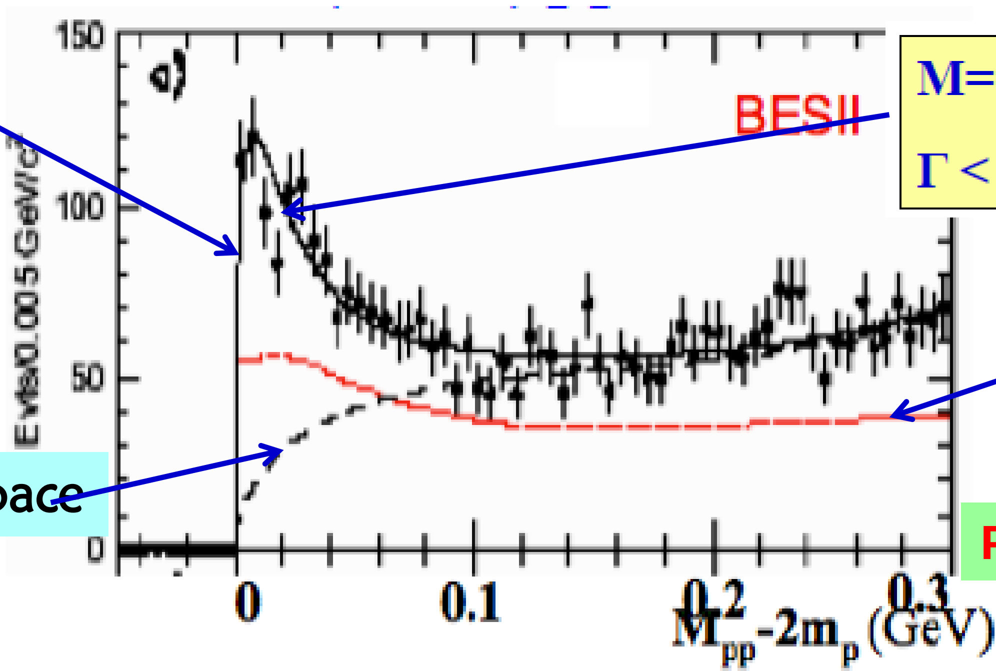
- But many more forms which are QCD allowed, namely
  - ∗ Multi-quark states: number of quarks ≥ 4
  - ∗ Hybrid states: $q\bar{q}\,g$, $qqqg$, $\cdots$
  - ∗ Glueballs: gg, ggg, $\cdots$



Observed an enhancement at $p\bar{p}$ mass threshold @ BESII

$J/\psi \to \gamma p\bar{p}$ (58M J/ψ events)

A fit using an acceptance-weighted S-wave BW Plus bkg.



$M = 1859^{+3}_{-10}{}^{+5}_{-25}$ MeV/c^2
$\Gamma < 30$ MeV/c^2 (90% CL)

acceptance

3-body phase space

PRL 91, 022001 (2003)

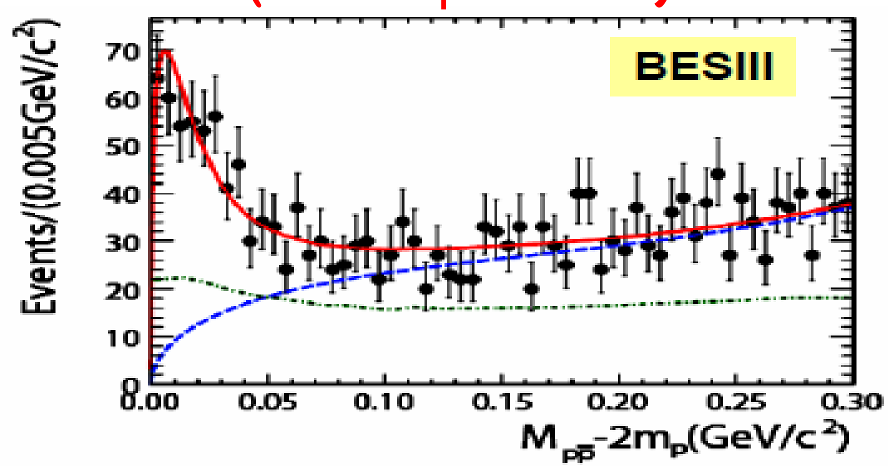
- M and Γ are not consistent with the properties of any known particle.
- Consistent with spin zero expectation.
- Theoretical interpretations:

Conventional mesons / $p\bar{p}$ bound state / multiquarks / glueball

Final state interaction (FSI) ……

Confirmed @ BESIII and CLEOc

$\psi' \to \pi^+\pi^- J/\psi$ ($J/\psi \to \gamma p\bar{p}$)
(106M ψ' events)



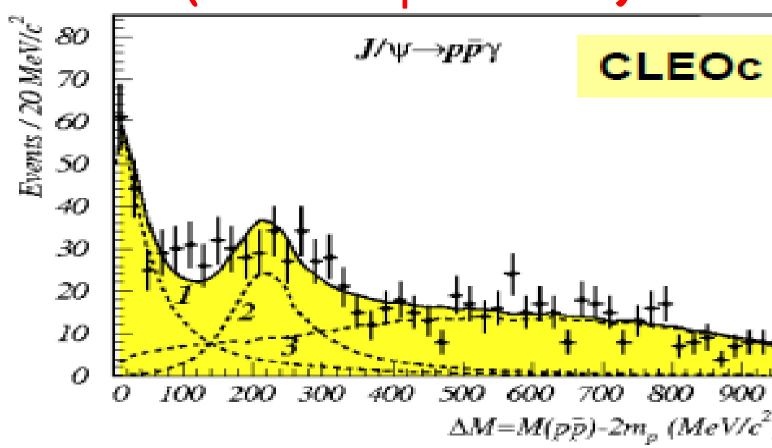
$M=1861^{+6}_{-13}{}^{+7}_{-26}$ MeV/c²

$\Gamma < 38$ MeV/c² (90% CL)

- Same fit method as that of BESII.
- Consistent with BESII results.

Chinese Physics C34(4) 421, (2010)

$\psi' \to \pi^+\pi^- J/\psi$ ($J/\psi \to \gamma p\bar{p}$)
(24.5M ψ' events)



Fit region Δm = 0-970 MeV
Consider X(2100):
M = $1837^{+10}_{-12}{}^{+9}_{-7}$ MeV/c²
Γ = 0^{+44}_{-0} MeV/c²

Fit region Δm = 0-300 MeV
Do not consider X(2100):
M = 1861^{+16}_{-6} (stat) **MeV/c²**
Γ = 0^{+32}_{-0} (stat) **MeV/c²**

PRD 82, 092002 (2010)

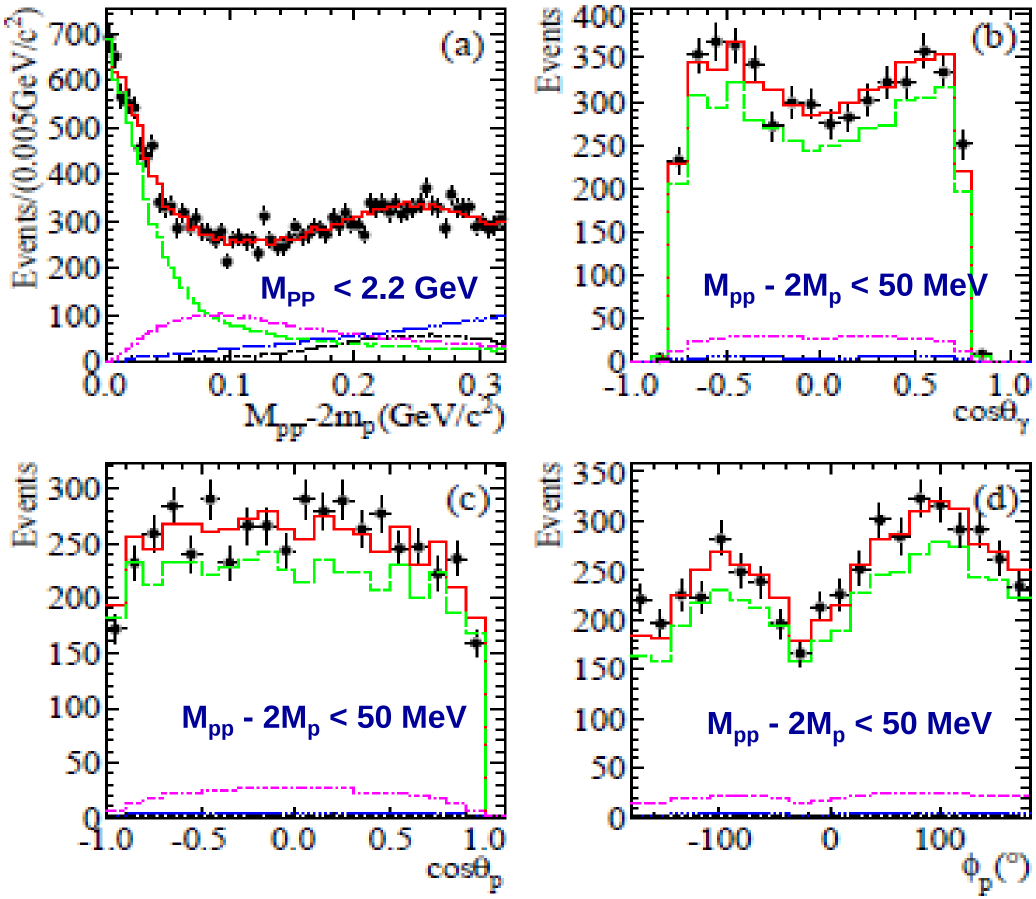
- Not observed in B-meson decay, $\psi' \to \gamma p\bar{p}$, $\Upsilon \to \gamma p\bar{p}$, $J/\psi \to \omega p\bar{p}$ at BESII, $\psi' \to X p\bar{p}$ ($X = \gamma, \pi^0, \eta$) at CLEOc.

The enhancement is not pure FSI effect.

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

First performed.

PRL 108, 112003 (2012)



- **Four components:**

  $X(p\bar{p})$, $f_2(1910)$, $f_0(2100)$ and 0^{++} PS

- **The FSI effect considered.**

- **Fit features:**
  - The fit with a BW and S-wave FSI (I=0) factor can well describe $p\bar{p}$ mass threshold structure.
  - Much better than that w/o FSI effect, $\Delta \ln L = 51$ (7.1σ).
  - Different FSI model → Model dependent uncertainty

Results:

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

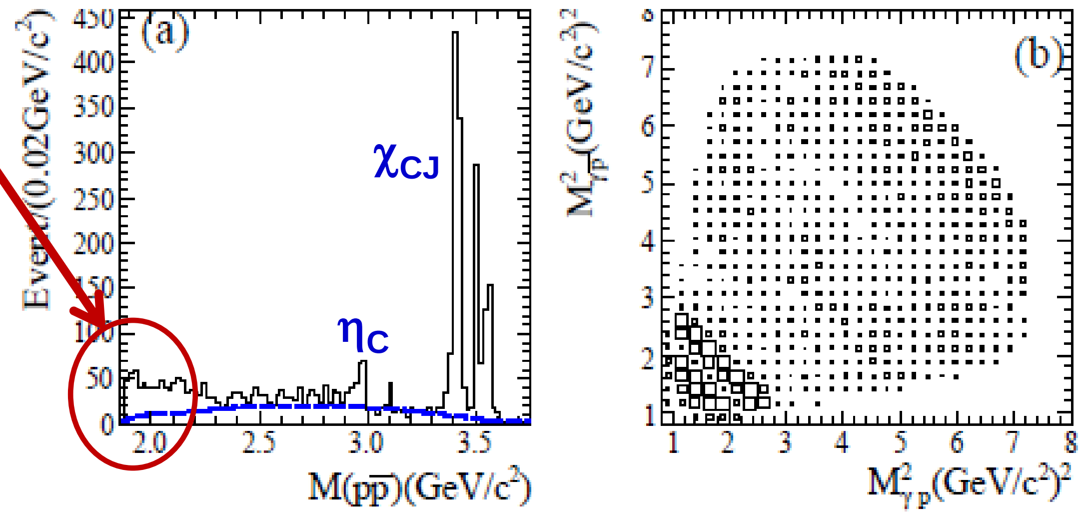
$M = 1832^{+19}_{-5}(\text{stat})^{+18}_{-17}(\text{syst}) \pm 19(\text{mod})\,\text{MeV}/c^2$

$\Gamma = 13 \pm 20(\text{stat})^{+11}_{-33}(\text{syst}) \pm 4(\text{mod})\,\text{MeV}/c^2$ or $\Gamma < 76\,\text{MeV}/c^2$ @ 90% C.L.

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

Structure at $p\bar{p}$ mass threshold of $\psi' \to \gamma p\bar{p}$ @ BESIII

- Observed a $p\bar{p}$ mass threshold excess relative to PS.
- Line shape of $p\bar{p}$ mass spectrum near threshold looks obviously differ. from that of J/ψ decays.
- No evident enhancement exist in $p\bar{p}$ threshold in Dalitz plot.



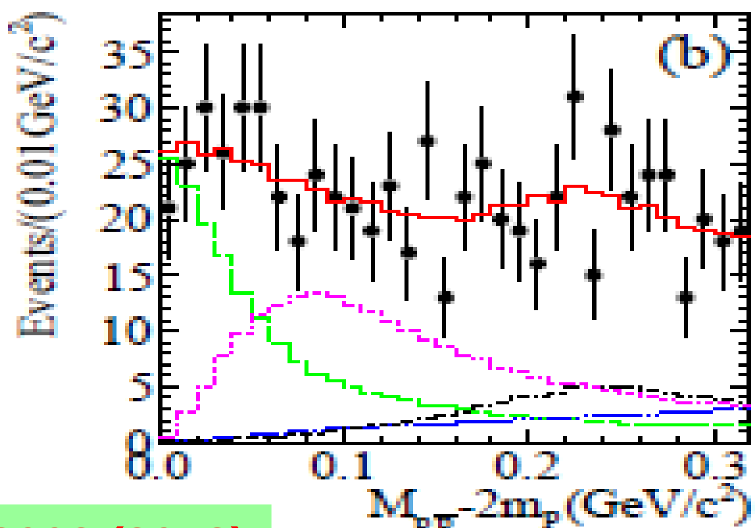
PWA Results:

- **Significance of X($p\bar{p}$) is > 6.9σ.**
- **The production ratio R:**

$$R = \frac{B(\psi' \to \gamma X(p\bar{p}))}{B(J/\psi \to \gamma X(p\bar{p}))} = (5.08^{+0.71}_{-0.45}(stat)^{+0.67}_{-3.58}(syst) \pm 0.12(mod))\%$$

It is suppressed compared with "12% rule".

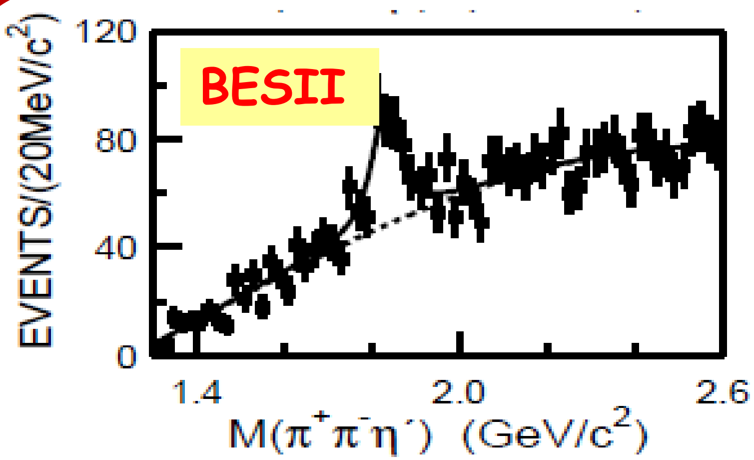
PWA fit projection



PRL 108, 112003 (2012)

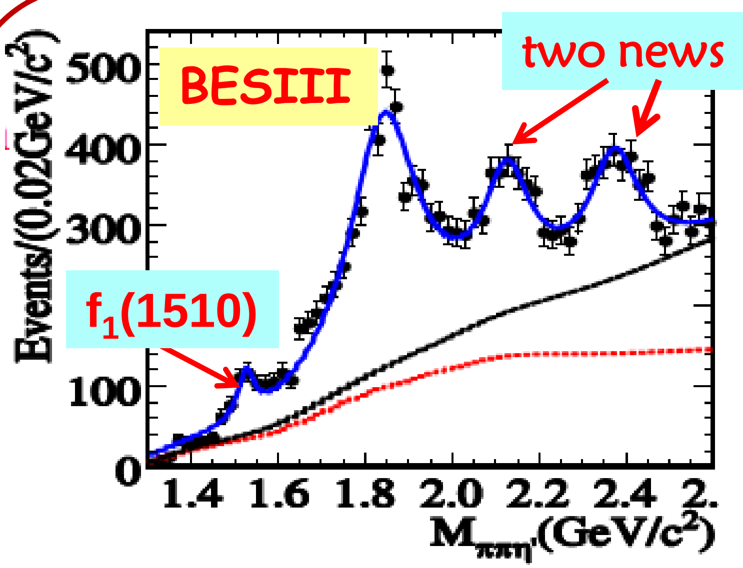
X(1835) and two new structures in $J/\psi \to \gamma\pi^+\pi^-\eta'$

$J/\psi \to \gamma\pi^+\pi^-\eta'$ ($\eta' \to \pi^+\pi^-\eta, \eta \to \gamma\gamma$ and $\eta' \to \gamma\rho, \rho \to \pi^+\pi^-$)



◆ **BESII Results:** **PRL 95, 262001 (2005)**

- $M = 1833.7 \pm 6.1(stat) \pm 2.7(syst)$ MeV/c^2
- $\Gamma = 67.7 \pm 20.3(stat) \pm 7.7(syst)$ MeV/c^2
- $B(J/\psi \to \gamma X(1835)) \cdot B(X(1835) \to \pi^+\pi^-\eta') = (2.2 \pm 0.4(stat) \pm 0.4(syst)) \times 10^{-4}$
- **Statistical Significance 7.7σ**



◆ **BESIII Results:** **PRL 106, 072002 (2011)**

Resonance	M(MeV/c²)	Γ(MeV/c²)	Stat.Sig.
X(1835)	$1836.5 \pm 3.0^{+5.6}_{-2.1}$	$190.1 \pm 9.0^{+38}_{-36}$	>20σ
X(2120)	$2122.4 \pm 6.7^{+4.7}_{-2.7}$	$83 \pm 16^{+31}_{-11}$	7.2σ
X(2370)	$2376.3 \pm 8.7^{+3.2}_{-4.3}$	$83 \pm 17^{+44}_{-6}$	6.4σ

- $B(J/\psi \to \gamma X(1835)) \cdot B(X(1835) \to \pi^+\pi^-\eta') =$
$$(2.87 \pm 0.09(stat)^{+0.49}_{-0.52}(syst)) \times 10^{-4}$$
- For **X(1835)**, the angular distribution of the radiative photon is consistent with **0^{-+}** assignment. **(> 20σ)**

PWA is needed to understand their properties!

What's the nature of X(1835), X(2120) and X(2370) ?

- X(1835) observed in $J/\psi \to \gamma \pi^+ \pi^- \eta'$
  - The measured width at BESIII is larger than that from BESII.

    * Observed $p\bar{p}$ sub-threshold enhancement X(1860) in $J/\psi \to \gamma p\bar{p}$ at BESII and confirmed at BESIII and CLEOc.
    * Are the X(1835) and X($p\bar{p}$) the same resonant state?
    * $p\bar{p}$ bound state ? glueball? η' excited state ? ……

    Still remain unclear at present!

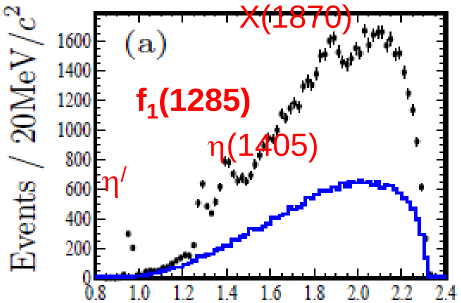
- X(2120) / X(2370) observed in $J/\psi \to \gamma \pi^+ \pi^- \eta'$
  - The first time resonant structures are observed at ~2.1 and 2.4GeV . Interesting since:

    * LQCD predicts the lowest 0^{-+} glueballs at~2.4GeV.
    * A good channel for finding 0^{-+} glueballs.

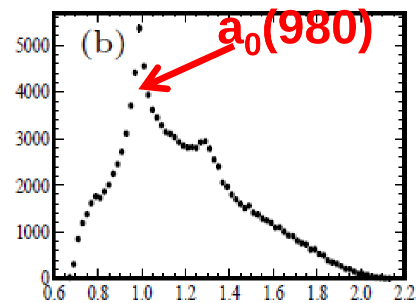
  - **Their nature:** pseudoscalar glueball? η/η' excited states? ……

- **A PWA is needed to measure their J^{PC}, M and Γ more precisely, and planned with much higher statistics J/ψ data sample.**

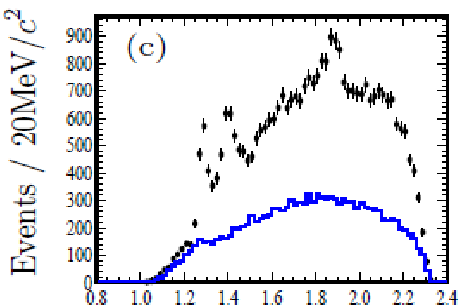
X(1870) in $J/\psi \to \omega X$, $X \to a_0^{\pm}(980)\pi^{\mp}$, $a_0^{\pm}(980) \to \eta\pi^{\pm}$



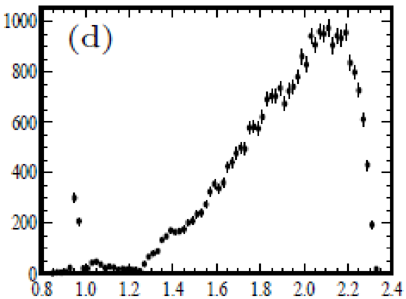
M($\eta\pi^+\pi^-$) GeV



M($\eta\pi^{\pm}$) GeV



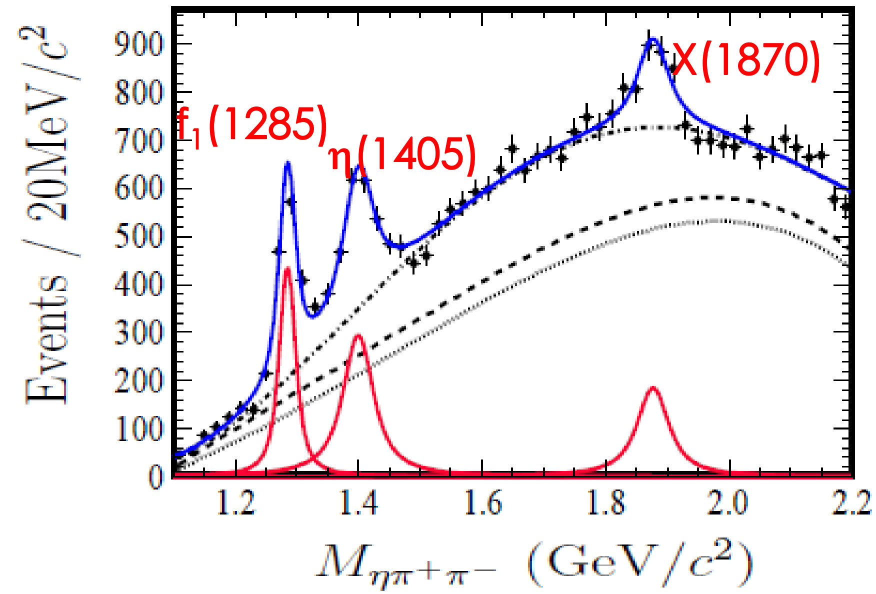
M($\eta\pi^+\pi^-$) in a 100 MeV mass window of $a_0(980)$



M($\eta\pi^+\pi^-$) in non-$a_0(980)$ region

A study of $J/\psi \to \omega\eta\pi^+\pi^-$ at BESIII

PRL 107, 182001 (2011)



M, Γ, and $B(J/\psi \to \omega X) \cdot B(X \to a_0\pi) \cdot B(a_0 \to \eta\pi)$

Resonance	Mass (MeV/c^2)	Width (MeV/c^2)	$\mathcal{B}$ (10^{-4})	Stat.Sig.
$f_1(1285)$	$1285.1 \pm 1.0^{+1.6}_{-0.3}$	$22.0 \pm 3.1^{+2.0}_{-1.5}$	$1.25 \pm 0.10^{+0.19}_{-0.20}$	> 10σ
$\eta(1405)$	$1399.8 \pm 2.2^{+2.8}_{-0.1}$	$52.8 \pm 7.6^{+0.1}_{-7.6}$	$1.89 \pm 0.21^{+0.21}_{-0.23}$	> 10σ
$X(1870)$	$1877.3 \pm 6.3^{+3.4}_{-7.4}$	$57 \pm 12^{+19}_{-4}$	$1.50 \pm 0.26^{+0.72}_{-0.36}$	7.2σ

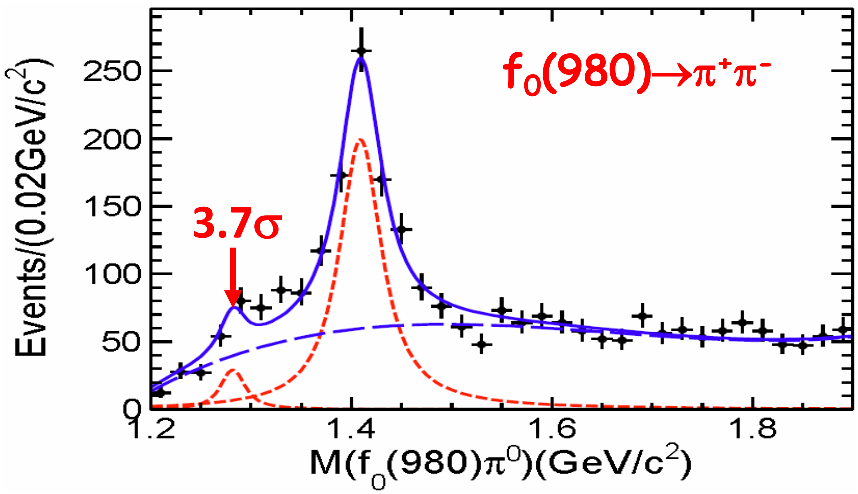
Is X(1870) due to X(1835), $\eta_2(1870)$, an interference of both, or a new resonance ? J^{PC} ?

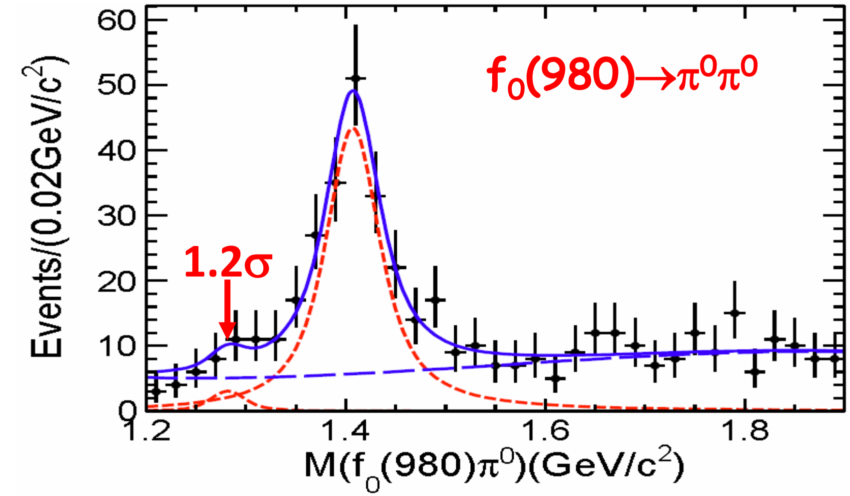
Need PWA !

$\eta(1405)$ in $J/\psi \to \gamma X$, $X \to f_0(980)\pi^0$, $f_0(980) \to 2\pi$

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

PRL 108, 182001 (2012)





- Evidence for an enhancement at ~ 1.3GeV (potentially from $f_1(1285)/\eta(1295)$)
- Analysis of angular distribution indicates the peak at 1.4GeV is from $\eta(1405)$ ($J^P=0^-$), not from $f_1(1420)$ ($J^P=1^+$). Stat. sig. > 10σ.
- Large Isospin-violating decay rate:

$$\frac{Br(\eta(1405) \to f_0(980)\pi^0 \to \pi^+\pi^-\pi^0)}{Br(\eta(1405) \to a_0(980)\pi^0 \to \pi^0\pi^0\eta)} \approx (17.9 \pm 4.2)\%$$

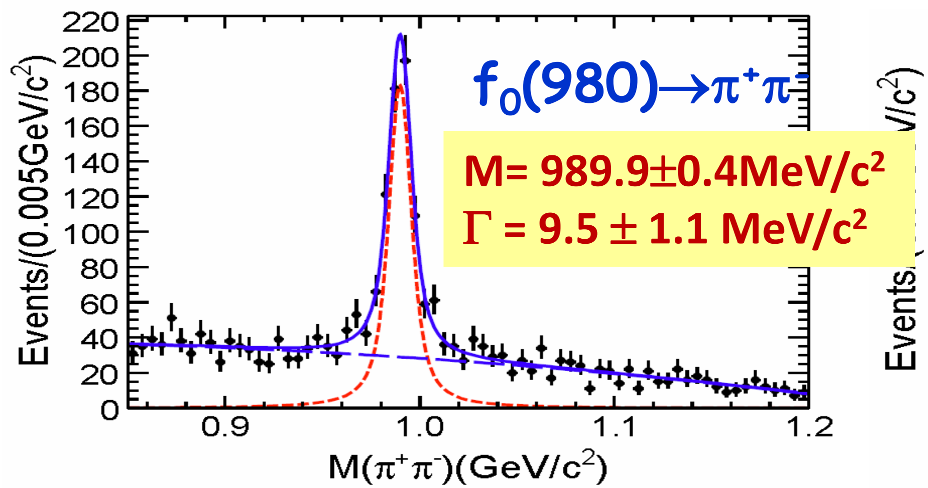
- In general, magnitude of isospin violation in strong decay should be <1%.

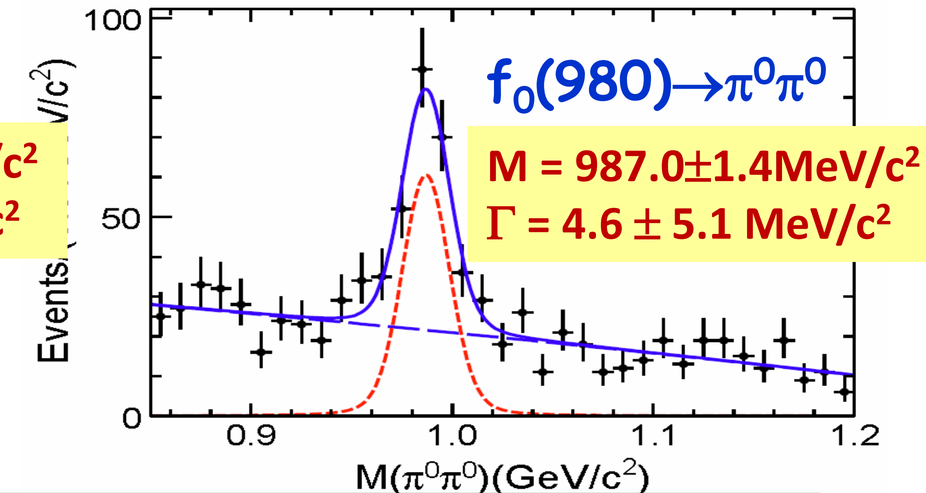
PRD 83,032003 (2011)

$$\xi_{af} = \frac{Br(\chi_{c1} \to f_0(980)\pi^0 \to \pi^+\pi^-\pi^0)}{Br(\chi_{c1} \to a_0(980)\pi^0 \to \eta\pi^0\pi^0)} < 1\%(90\%\ C.L.)$$

a_0-f_0 mixing alone can not explain the branching ratio of $\eta(1405) \to f_0(980)\pi^0$

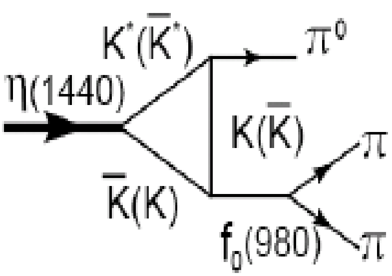
♦ Anomalous line shape of $f_0(980)$ in $J/\psi \to \gamma 3\pi$



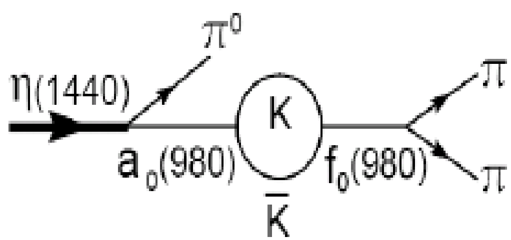


Surprising Result: The measured width of $f_0(980)$ is much narrower than the world average (PDG 2012: 40-100 MeV/c^2)

♦ Triangle Singularity (TS) mechanism



Triangle Singularity (TS)



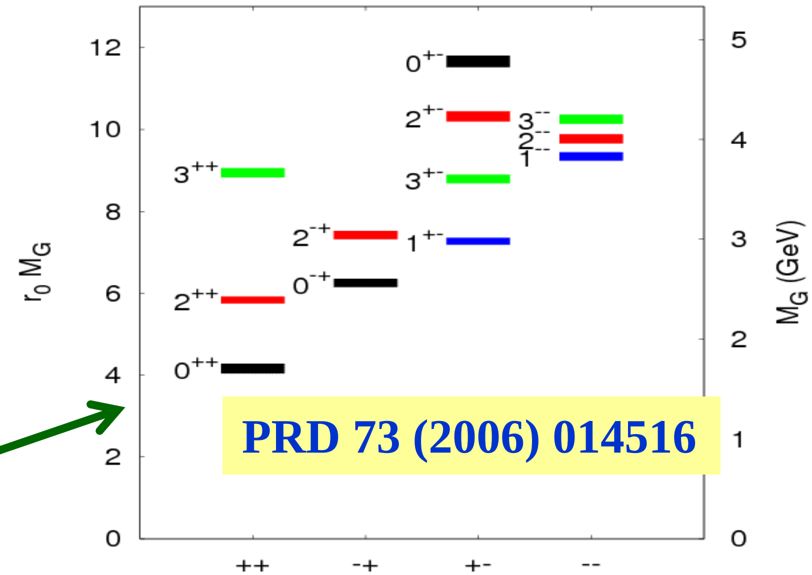
$a_0 - f_0$ mixing

- K^*K in TS mechanism is on-shell.
- TS is much more dominant than $a_0 - f_0$ mixing term.
  - Explains the large isospin violations in $\eta(1405) \to \pi^+\pi^-\pi^0$.
  - Predicts a narrow peak at $M(\pi^+\pi^-) \sim 980$ MeV.

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

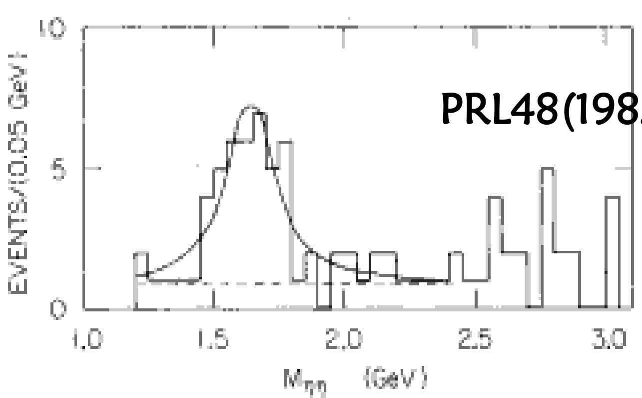
Study of ηη system

- LQCD predicts the lowest glueball state is 0^{++} with M~1.5 -1.7GeV, the next lightest glueball is 2^{++} with M~2.3 GeV.
- The mixing of glueball with nearby qq meson makes the situation more difficult.



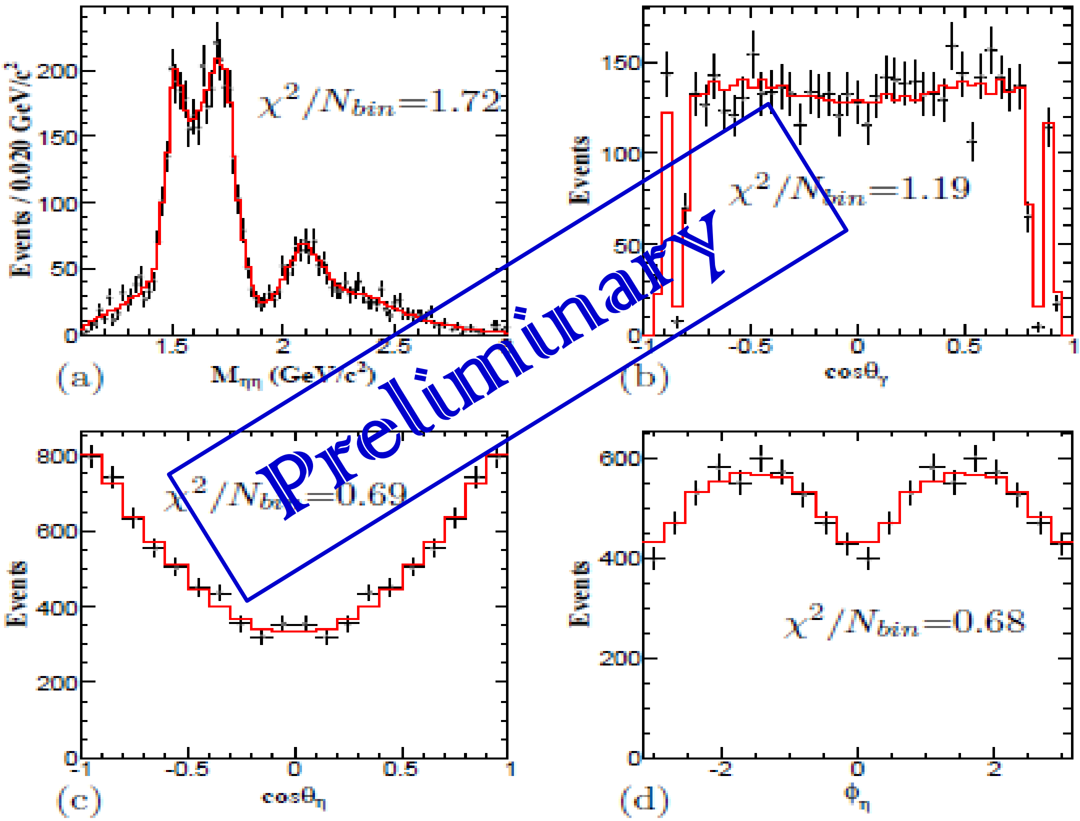
Glueball spectrum from unquenched LQCD calculations. r_0^{-1} = 410 MeV

- Early study of $J/\psi \to \gamma\eta\eta$ was made by Crystal Ball in 1982. Found J^{PC} of the resonance ~ 1.7GeV is 2^{++} .



- Other experiments:
  - Crystal ball Collaboration (2002) analyzed the final states of $\pi^0\pi^0\pi^0$, $\eta\pi^0\pi^0$ and $\pi^0\eta\eta$, found a 2^{++} (~1870MeV), but no $f_0(1710)$.
  - E835(2006): ppbar$\to\pi^0\eta\eta$, found $f_0(1500)$ and $f_0(1710)$.
  - WA102 and GAMS all identified $f_0(1710)$ in ηη.

Preliminary PWA results of $J/\psi \to \gamma\eta\eta$ @ BESIII

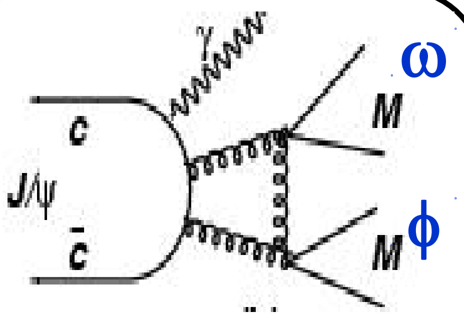


For $J/\psi \to \gamma PP$ (Pseudoscalars), only intermediate states with J^{PC}=even^{++} are possible.

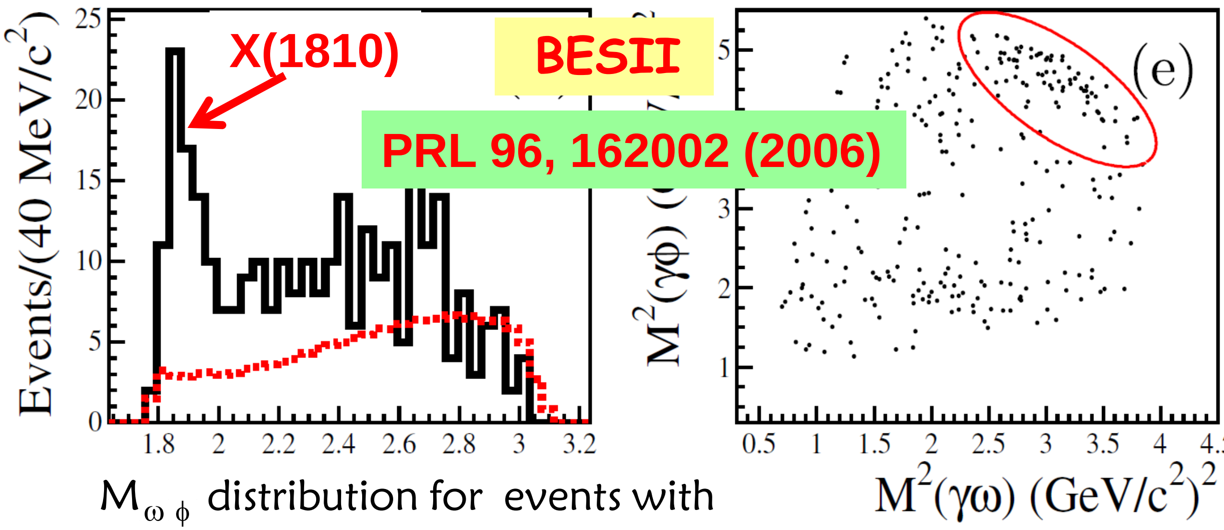
- 0^{++}: $f_0(1500)$ (8.2 σ), $f_0(1710)$ (25 σ), $f_0(2100)$ (13.9 σ), 0^{++} PS
- 2^{++}: $f_2'(1525)$ (11 σ), $f_2(1810)/f_2(1950)$ (6.4 σ)
- 4^{++}: $f_4(2340)$ (7.6 σ)

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}	$136^{+41+28}_{-26-100}$	$(1.61^{+0.29+0.49}_{-0.32-1.37}) \times 10^{-5}$	8.2 σ
$f_0(1710)$	1759^{+6+15}_{-6-25}	172^{+10+32}_{-10-16}	$(2.35^{+0.07+1.24}_{-0.07-0.74}) \times 10^{-4}$	25.0 σ
$f_0(2100)$	2081^{+13+24}_{-13-36}	273^{+27+70}_{-24-23}	$(9.99^{+0.57+5.64}_{-0.52-2.46}) \times 10^{-5}$	13.9 σ
$f_2'(1525)$	1513^{+5+4}_{-5-10}	75^{+12+14}_{-10-8}	$(3.41^{+0.43+1.37}_{-0.50-1.29}) \times 10^{-5}$	11.0 σ
$f_2(1810)/f_2(1950)$	1822^{+29+66}_{-24-57}	$229^{+52+88}_{-42-155}$	$(5.38^{+0.60+3.41}_{-0.67-2.34}) \times 10^{-5}$	6.4 σ
$f_2(2340)$	$2362^{+31+140}_{-30-63}$	$334^{+62+165}_{-54-100}$	$(5.58^{+0.61+2.36}_{-0.65-2.06}) \times 10^{-5}$	7.6 σ

$M_{\omega\phi}$ threshold enhancement in $J/\psi \to \gamma\omega\phi$ @ BESII



$J/\psi \to \gamma\omega\phi$ is DOZI suppressed process

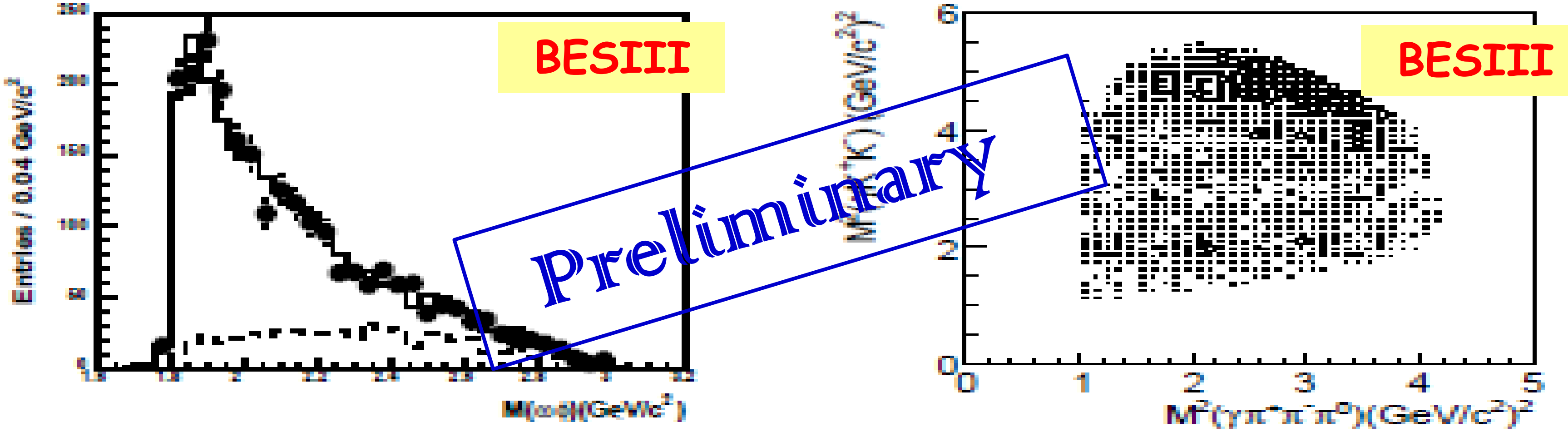


$M_{\omega\phi}$ distribution for events with
$|m_{K+K-} - m_{\phi}| < 15$MeV
$|m_{\pi+\pi-\pi0} - m_{\omega}| < 30$MeV

PWA Results @ BESII:

- $M = 1812^{+19}_{-26} \pm 18$ MeV/c^2 ; $\Gamma = 105 \pm 20 \pm 28$ MeV/c^2
  $B(J/\psi \to \gamma X) \cdot B(X \to \omega\phi) = (2.61 \pm 0.27 \pm 0.65) \times 10^{-4}$
- The enhancement favors $J^{PC} = 0^{++}$ over 0^{-+} and 2^{++}, stat. sig.>10σ.
- Not compatible with any known conventional state.
  Is it the same 0^{++} observed in $\gamma K\bar{K}$ or $\phi\pi\pi$ ($f_0(1710)$ or $f_0(1790)$), or is it a glueball, or a hybrid ……

Preliminary PWA results of J/ψ→γ ω φ @ BESIII



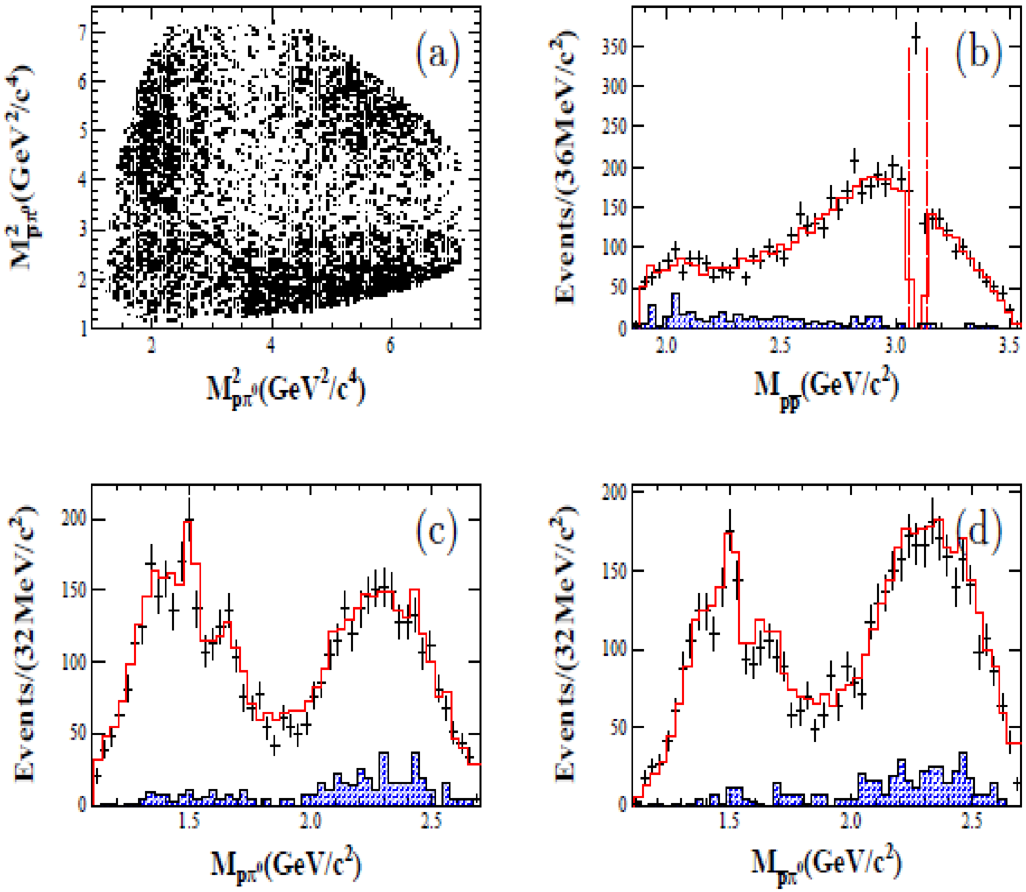
Resonance	J^{PC}	$M(\mathrm{MeV}/c^2)$	$\Gamma(\mathrm{MeV}/c^2)$	Events	ΔS	Δndf	Significance
$X(1810)$	0^{++}	1795 ± 7	95 ± 10	1319 ± 52	783	4	$> 30\sigma$
$f_2(1950)$	2^{++}	1944	472	665 ± 40	211	2	20.4σ
$f_0(2020)$	0^{++}	1992	442	715 ± 45	100	2	13.9σ
$\eta(2225)$	0^{-+}	2226	185	70 ± 30	23	2	6.4σ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

- For X(1810): M , Γ and Br are consistent with that of BESII results.
  Confirms that the J^{PC} is 0^{++} with stat. sig. of > 30σ .
  Not compatible to X(1835) and X($p\bar{p}$) due to diff. M and J^{PC}.
- Is X(1810) the $f_0(1710)/f_0(1790)$ or a new state ?

Further looking in diff. decay modes (ωω, K*K*…) and diff. production processes (J/ψ→ φ ω φ , ω ω φ …) is desirable !

Observation of two new N^* in $\psi' \to p\bar{p}\,\pi^0$ @ BESIII

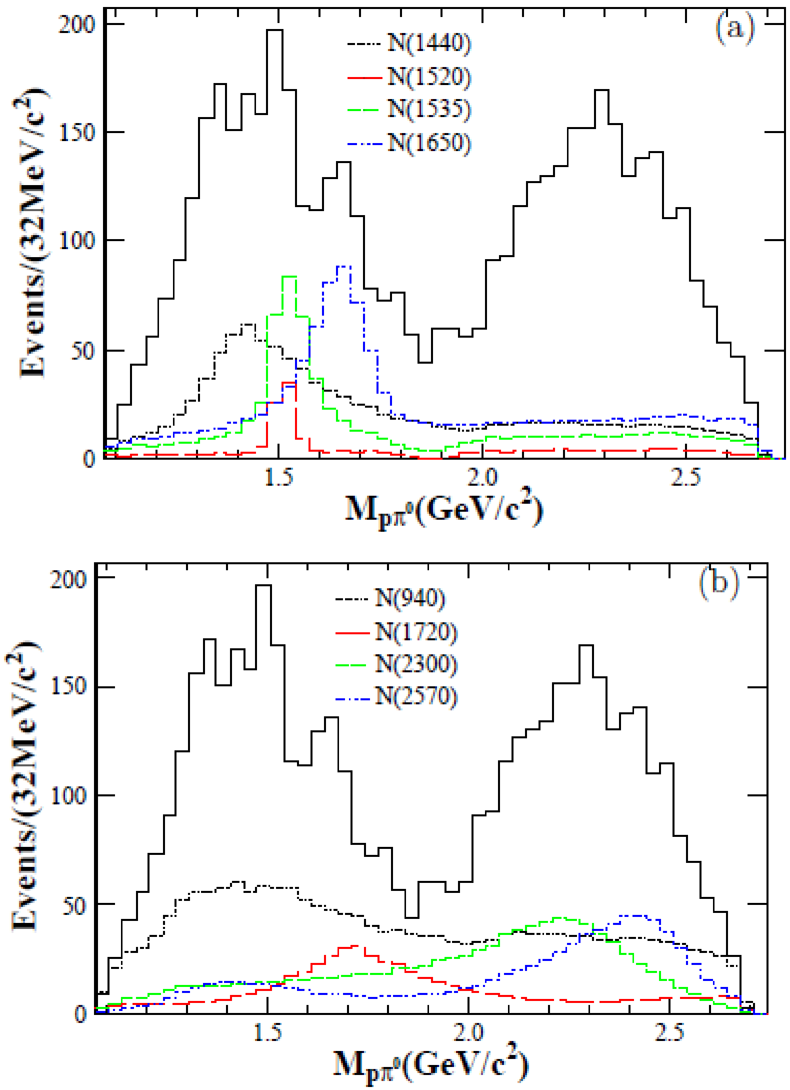
- Non-relativistic quark model is successful in interpreting the excited baryons.
- Predicted more excited states (“missing resonance problem”).
- J/ψ and ψ' decays offer an opportunity to search for the missing resonances.



- Events with $p\bar{p}$ arising from J/ψ are excluded.
- The threshold enhancement in $p\bar{p}$ mass spectrum is visible.
- N^* with spin 7/2 or larger is not considered.

arXiv:1207.0233

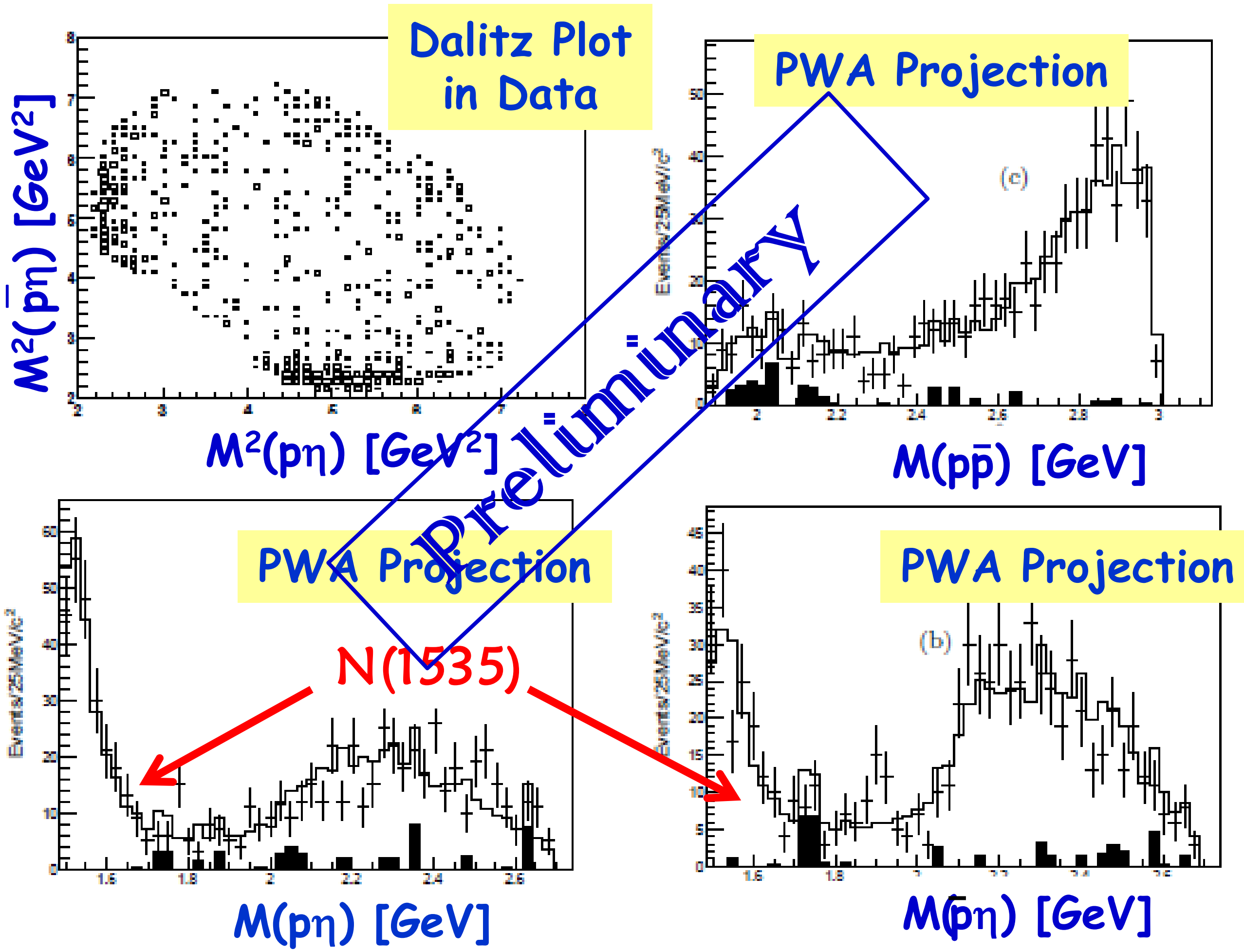
PWA Results:



- Soft-pion theory indicates that the off-shell decay is needed. N(940) with M=940MeV and Γ=0 MeV is included in PWA.
- A 1^{--} $p\bar{p}$ resonance candidate described by BW function is tested. The largest sig. is 4σ at M=2000MeV and Γ=50MeV.
  The threshold enhancement most likely due to interference of N* resonances.
- No clear evidence for N(1885)/N(2065).
- Two new N* resonances N(2300) and N(2570) are observed with $1/2^{+}$ and $5/2^{-}$.

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

Preliminary results on N* baryons in $\psi' \to p\bar{p}\eta$ @ BESIII



- No significant contribution from other resonance ~ $p\bar{p}$ mass enhancement. **significance< 3.5σ**
- N(1535) was firstly studied by PWA in $J/\psi \to p\bar{p}\eta$ at BESII, and confirmed here.

$M = 1524^{+5+10}_{-5-4}$ MeV,

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

Consistent with PDG.
sig.>5σ ; J^P 1/2⁻

* $B(\Psi' \to N(1535)\bar{p}) \times B(N(1535) \to p\eta) + c.c. = (5.2^{+0.3+3.2}_{-0.3-1.2}) \times 10^{-5}$
* $B(\Psi' \to p\bar{p}\eta) = (6.4 \pm 0.2 \pm 0.6) \times 10^{-5}$ PDG2010: $(6.0 \pm 1.2) \times 10^{-5}$
* $B(\Psi' \to p\bar{p}\eta) / B(J/\Psi \to p\bar{p}\eta) = (3.2 \pm 0.4)\%$ Suppressed compared with "12% rule"

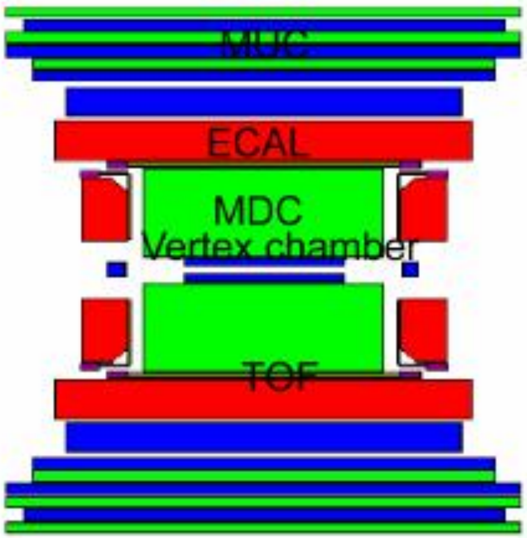
Summary

- BESIII is successfully operating since 2008:
  - World largest data samples at J/ψ, ψ', $\psi(3770)$, $\psi(4040)$ already collected, more data in future!
- Recent results on light hadron spectroscopy
  - Confirmation of $p\bar{p}$ threshold enhancement
  - Confirms X(1835) and obser. two new structures in $J/\psi \to \gamma\pi\pi\eta'$
  - Observation of a new structure X(1870) in $J/\psi \to \omega\eta\pi^+\pi^-$
  - First observation of $\eta(1405) \to f_0(980)\pi^0$ (isospin breaking)
  - $\eta\eta$ system in $J/\psi \to \gamma\eta\eta$
  - Confirms X(1810) in $J/\psi \to \gamma\omega\phi$
  - Observation of two new excited baryonic states N(2300) and N(2570)in $\psi' \to p\bar{p}\pi^0$. N(1535) is confirmed in $\psi' \to p\bar{p}\eta$.
- Expect many more results from BESIII in future!

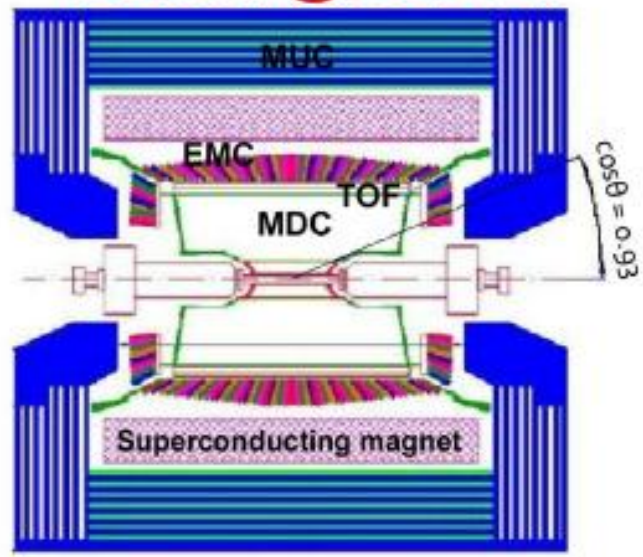
Backup Slides

From BESII to BESIII

BES II @ BEPC



BES III @ BEPC II



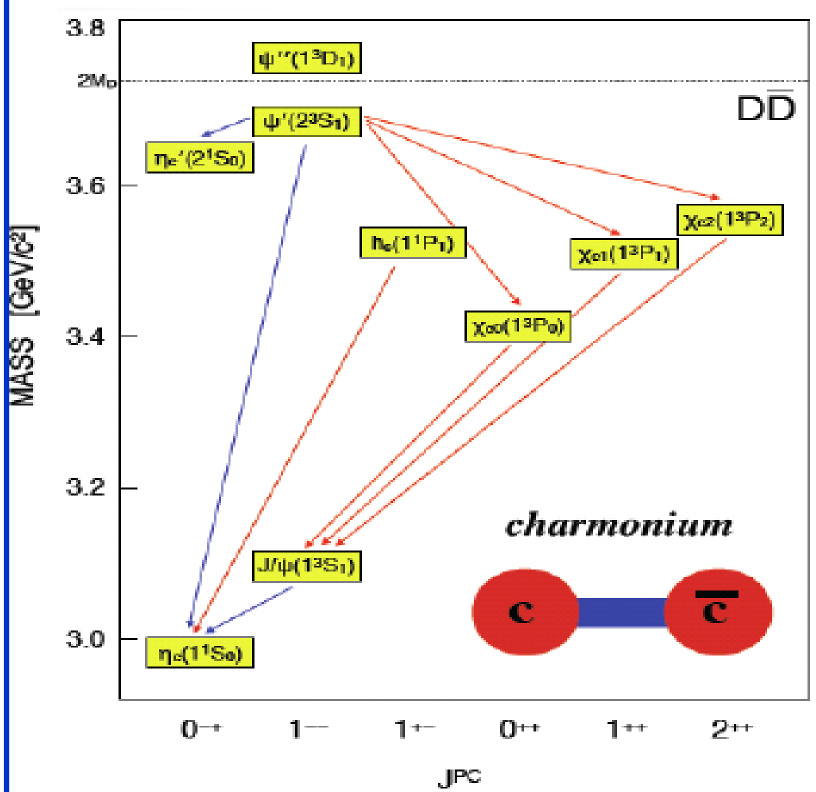
	BESII	BESIII
MDC	$\sigma(p)/p = 1.78\,\% \cdot \sqrt{1+p^2}$ $dE/dx_{reso} = 8\,\%$	$\sigma(p_t)/p_t = 0.32\,\% \cdot p_t$ $dE/dx_{reso} < 6\,\%$
TOF	180 ps (for bhabha)	90 ps (for bhabha)
EMC	$\sigma(E)/E = 22\% \cdot \sqrt{E}$	$\sigma(E)/E = 2.3\,\% \cdot \sqrt{E}$
MUC	3 layers for barrel	9 layers for barrel, 8 for endcap

BESI started data-taking in 1989 and was upgraded in 1998 to BESII.

BESI collected **7.8 M J/ψ** events and **3.7 M ψ′** events.

BESII collected **58 M J/ψ** events and **14 M ψ′** events.

BESIII - physics using "charm"



Charmonium physics:
- Spectroscopy
- transitions and decays

Light hadron physics:
- meson & baryon spectroscopy
- glueball & hybrid
- two-photon physics
- e.m. form factors of nucleon

Charm physics:
- (semi)leptonic + hadronic decays
- decay constant, form factors
- CKM matrix: Vcd, Vcs
- D^0-D^0bar mixing and CP violation
- rare/forbidden decays

Tau physics:
- Tau decays near threshold
- tau mass scan

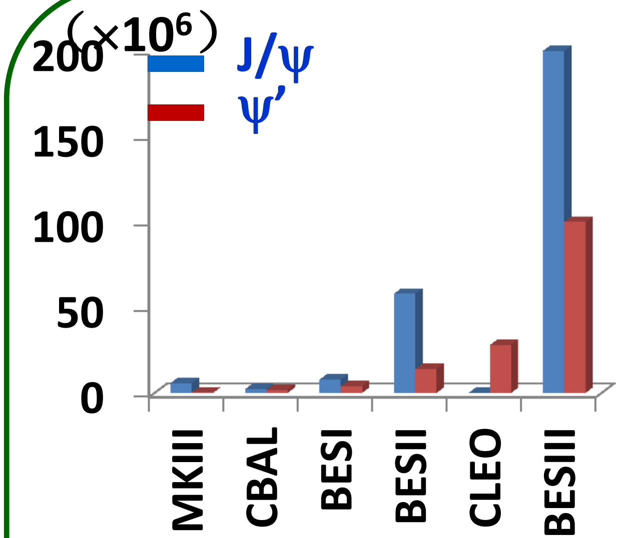
...and many more.

BESIII data sets and future plans

- **2008 :** July 19 first e^+e^- collider event at BESIII
  Nov.: ~ 14M $\psi(2S)$ events for detector calibration
- **2009 :** 106M $\psi(2S)$ events (4 times of CLEOc)
  225M J/ψ events (4 times of BESII)
  ~ 42 pb^{-1} at continuum (3.65 GeV)
- **2010 :** 900 pb^{-1} @ 3770 MeV
- **2011 :** 2000 pb^{-1} @ 3770 MeV
  470 pb^{-1} @ 4010 MeV

} 3.5 XCLEOc

- **2012:** τ mass scan, R scan [2.0, 3.65] GeV
  0.4 billion $\psi(2S)$ and 1 billion J/ψ events



World's largest sample of J/ψ, $\psi(2S)$ and $\psi(3770)$

Tentative future running plans:

* 2013: E_{CM} = 4260 and 4360 MeV for 'XYZ' studies (0.5 fb^{-1} each); τ mass scan/R scan
* 2014 and 2015: E_{CM} = 4170 MeV for D_s (~2.4 fb^{-1}); additional $\psi(3770)$ data

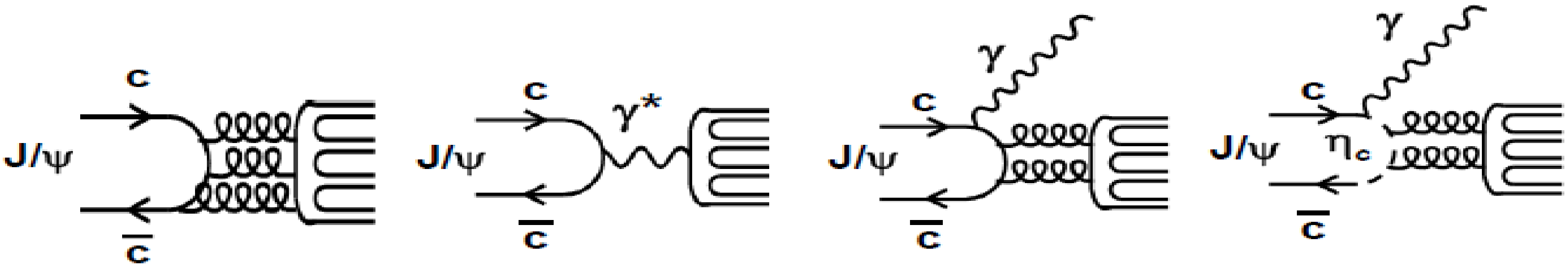
The following results are based on 225M J/ψ and 106M $\psi(2S)$ events.

Main contents in the study of the hadron spectroscopy

- Meson spectrum ($q\bar{q}$)
- New forms of hadrons (glueballs, hybrid states, multi-quark states)
- Baryon spectrum (qqq)

J/ψ decays provide ideal lab for hadron spectroscopy

The lowest order diagrams for J/ψ → hadrons:



3-gluon | Electromagnetic | Radiative | Via η_c

- A good lab to hunt for new forms of hadrons
- A good lab to study meson spectroscopy
- A good lab for excited baryon states

Observation of $X(p\bar{p})$ in $J/\psi \to \gamma p\bar{p}$ @ BESII

X(1860) has large BR to $p\bar{p}$

- **BES measured:**

$$BR(J/\psi \to \gamma X(1860)) \bullet BR(X(1860) \to p\bar{p}) \sim 7\times 10^{-5}$$

- **For a 0^{-+} meson:**

$$BR(J/\psi \to \gamma X(1860)) \sim 0.5-2\times 10^{-3}$$

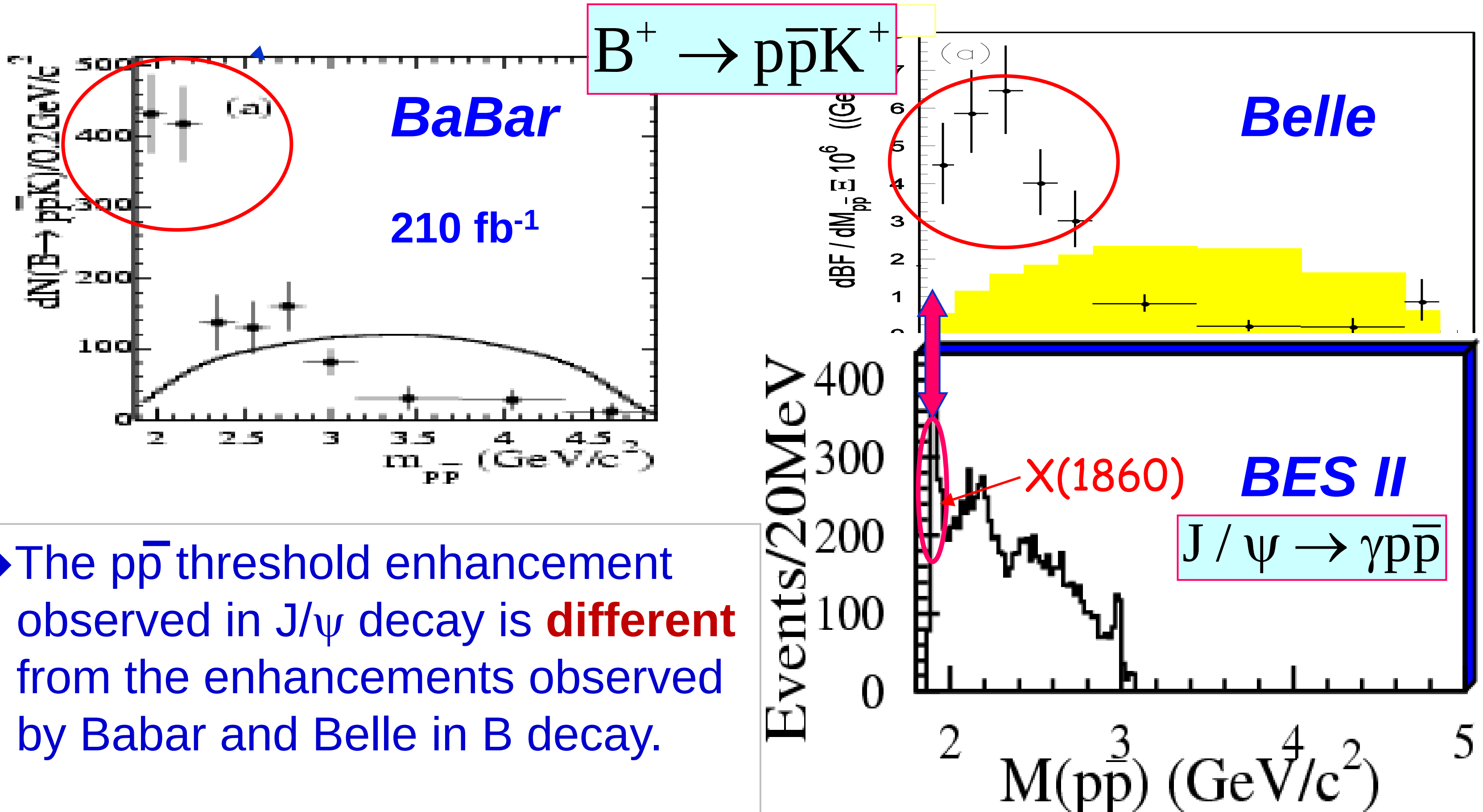
- **So we would have:**

$$BR(X(1860) \to p\bar{p}) \sim 4-14\%$$

(This BR to $p\bar{p}$ might be the largest among all PDG particles)

Considering that decaying into $p\bar{p}$ is only from the tail of X(1860) and the phase space is very small, *such a BR indicates X(1860) has large coupling to $p\bar{p}$!*

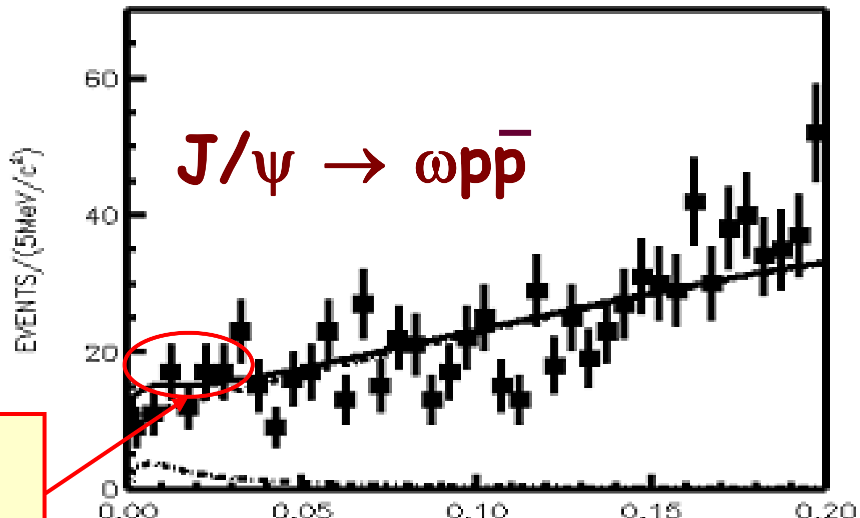
Not in $B^+ \to p\bar{p}K^+$ at *BaBar* and *Belle*



- The $p\bar{p}$ threshold enhancement observed in J/ψ decay is **different** from the enhancements observed by Babar and Belle in B decay.

- The one in B decay can be explained by **fragmentation**.

This narrow threshold enhancement is NOT observed in $J/\psi \to \omega p\bar{p}$ at BESII



$M_{p\bar{p}} - 2M_p$ GeV/c^2

No narrow strong enhancement near threshold

$$Br(J/\psi \to \omega X)/Br(J/\psi \to \gamma X) < 0.5\% \; @95\% \;\; \text{C.L.}$$

This narrow threshold enhancement is NOT observed in Υ(1S)→γpp̄ at CLEO

$$Br(\Upsilon(1S)\to\gamma\ X)/Br(J/\psi\to\gamma\ X) < 0.7\%\quad @\ 90\%\quad CL$$

PRD73, 032001(2006)

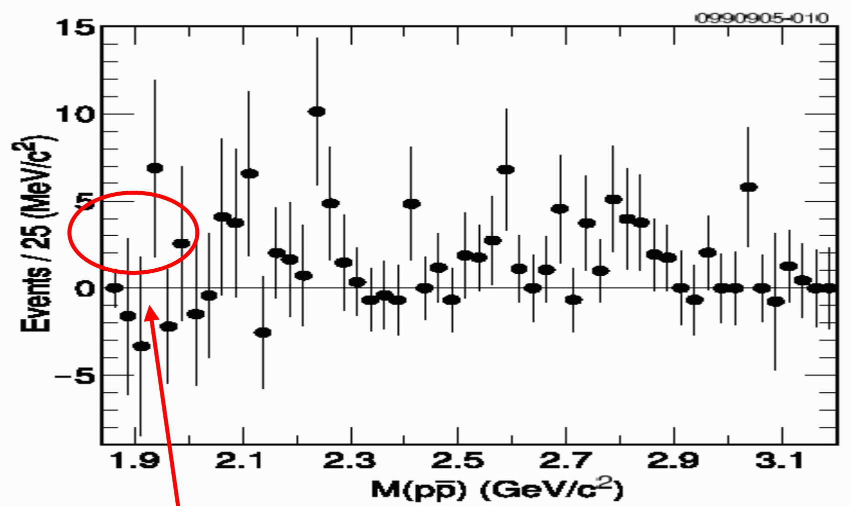


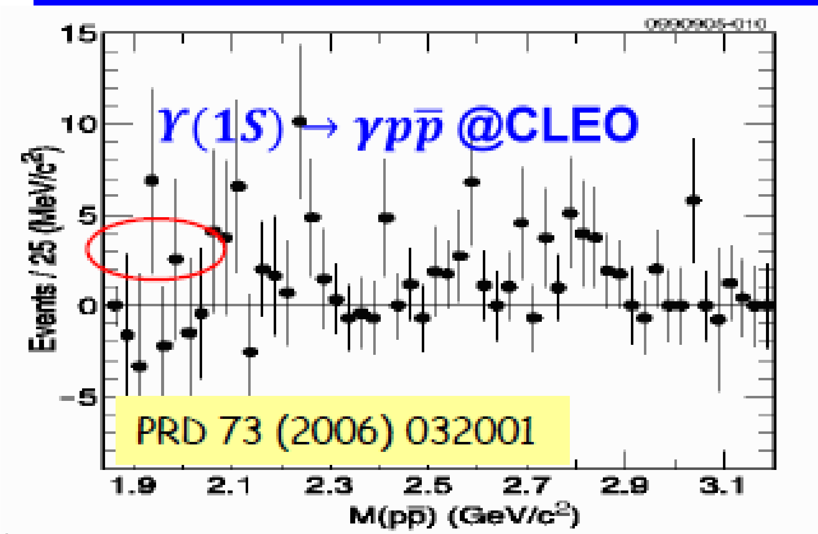
FIG. 7: Invariant mass of $p\bar{p}$ from $\Upsilon(1S)\to\gamma p\bar{p}$.

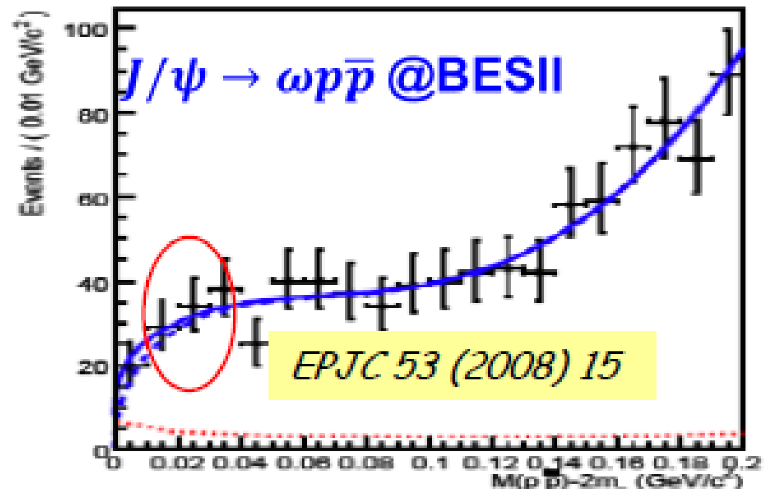
No enhancement near threshold

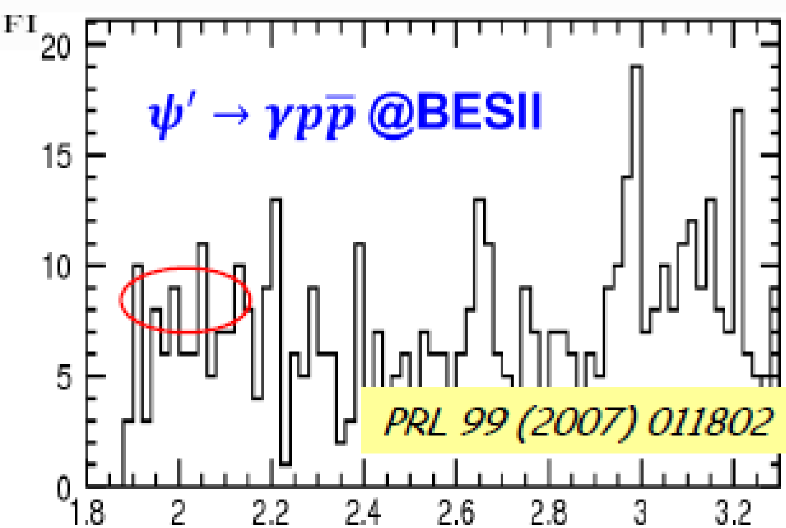
- This result cannot be explained by pure FSI effect, since FSI is a universal effect.

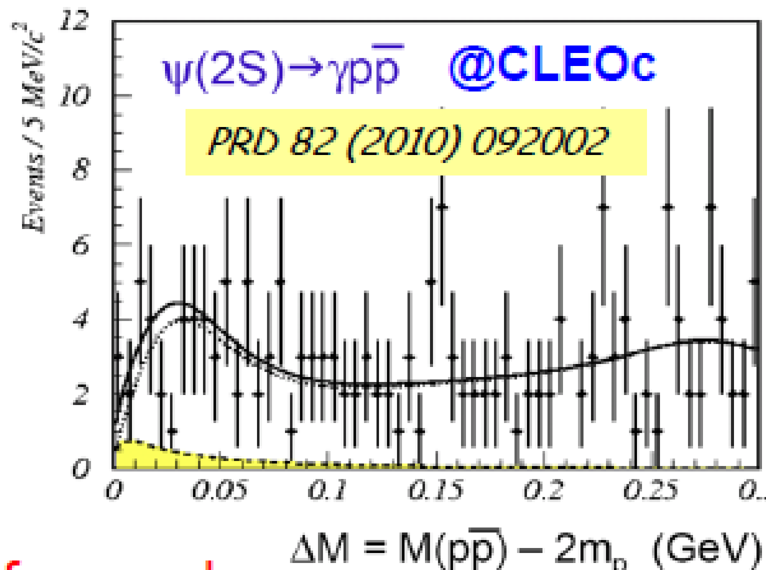
⇒ Pure FSI interpretation of the narrow and strong pp̄ threshold enhancement is disfavored.

Several non-observations









Pure FSI interpretation is disfavored

Is the X(1835) from the same source of $X(p\bar{p})$?

- The mass of $X(p\bar{p})$ is consistent with X(1835)

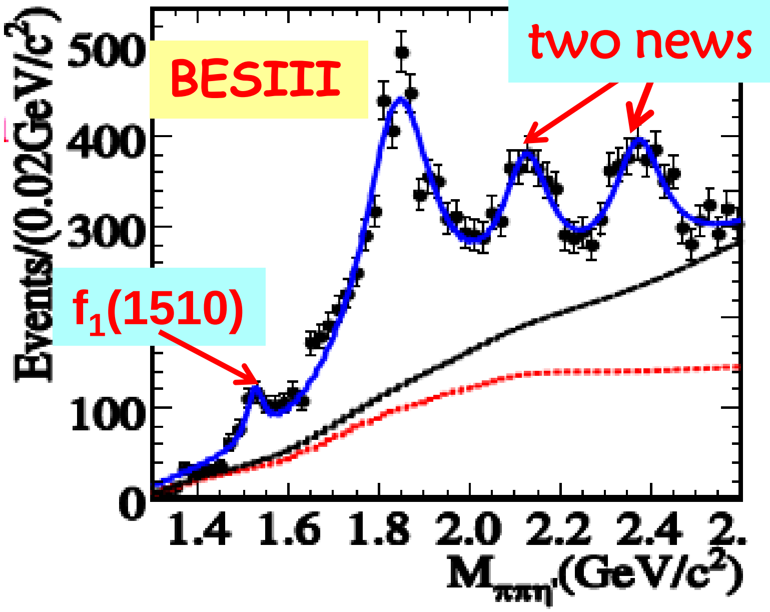
- The width of $X(p\bar{p})$ is much narrower.

  Possible reasons:

  - $X(p\bar{p})$ and X(1835) come from different sources
  - Interference effect in $J/\psi \to \gamma\pi\pi\eta'$ process should not be ignored in the determination of the X(1835) mass and width
  - There may be more than one resonance in the mass peak around 1.83GeV in $J/\psi \to \gamma\pi\pi\eta'$ decays.

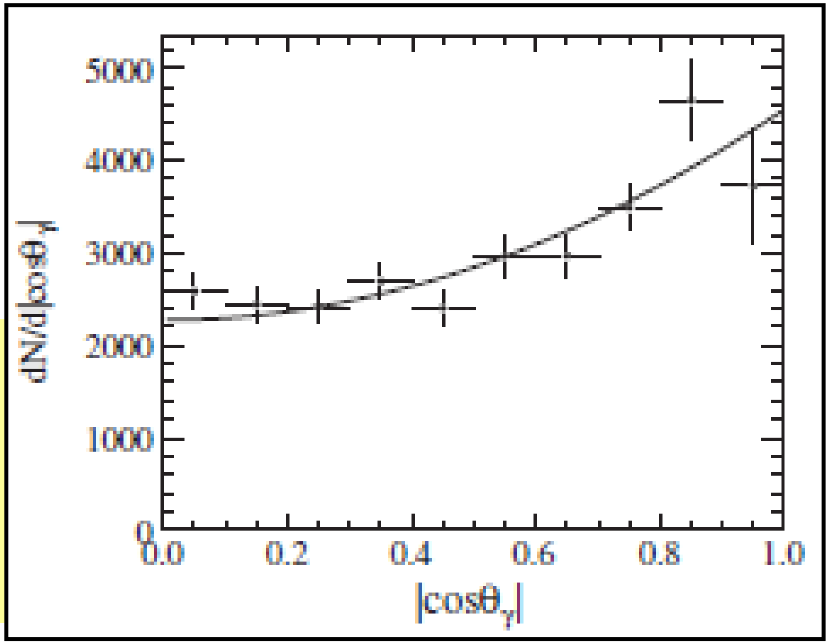
X(1835) and two new structures in $J/\psi \to \gamma\pi^+\pi^-\eta'$

$J/\psi \to \gamma\pi^+\pi^-\eta'$ ($\eta' \to \pi^+\pi^-\eta$, $\eta \to \gamma\gamma$ and $\eta' \to \gamma\rho$, $\rho \to \pi^+\pi^-$)



PRL 106, 072002 (2011)

The background subtracted, acceptance-corrected $|\cos\theta_\gamma|$ districution for X(1835).



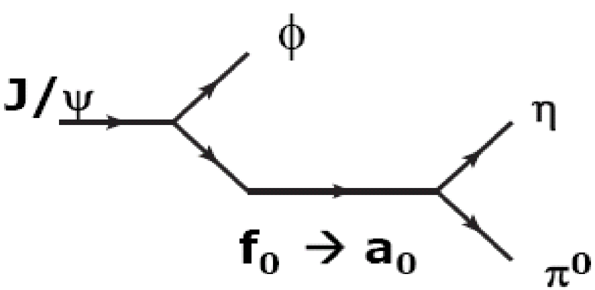
- Errors are statistical only.
- The solid line is a fit to $1+\cos^2\theta_\gamma$, which is expected for a pseudoscalar.

Study of $a_0(980)$ – $f_0(980)$ mixing from $J/\psi \to \phi f_0(980) \to \phi a_0^0(980) \to \phi\eta\pi^0$ $\psi' \to \gamma\chi_{c1} \to \gamma\pi^0 a_0^0(980) \to \gamma\pi^0 f_0(980) \to \gamma\pi^0\pi^+\pi^-$

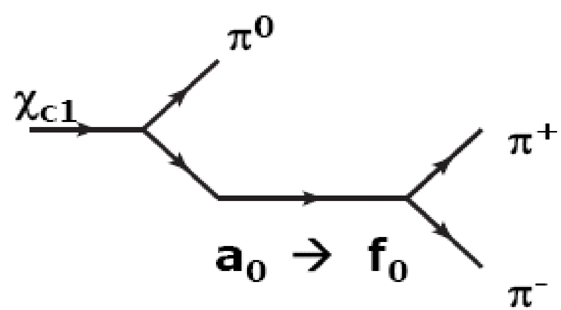
PRD 83, 032003 (2011)

- **Mixing intensity provides important information in understanding the nature of $a_0(980)$ and $f_0(980)$.**
- **Narrow peak (8 MeV) at around 980 MeV can be expected in $\eta\pi$ ($J/\psi \to \phi f_0 \to \phi a_0 \to \phi\eta\pi$ case) or $\pi^+\pi^-$ ($\chi_{c1} \to a_0\pi^0 \to f_0\pi^0 \to \pi^+\pi^-\pi^0$ case) invariant mass spectra.**

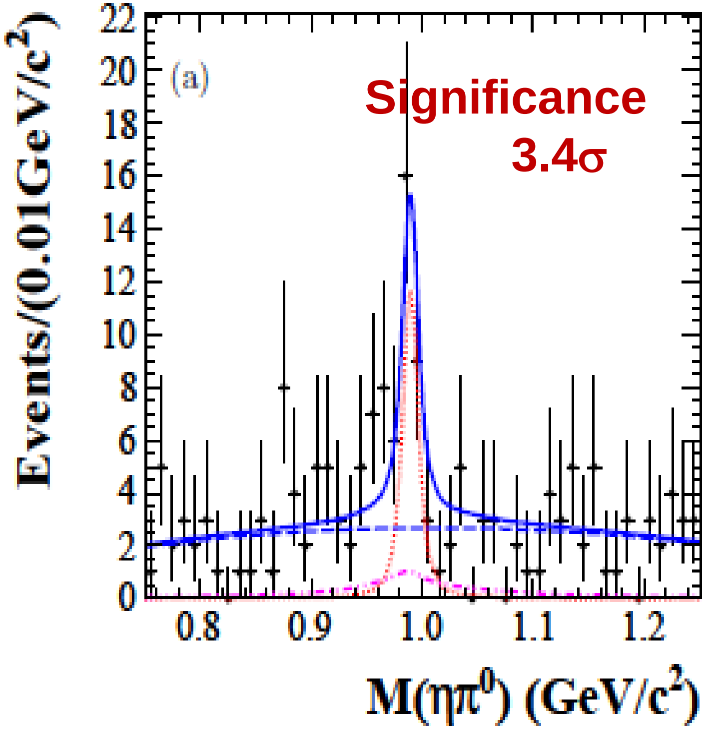
J.Wu, Q.Zhao, B.Zou PRD75 114012,
C. Hanhart etc. PRD76 074028,
etc.



J.Wu, B.Zou PRD78 074017



$a_0(980)\to f_0(980)$ mixing: $f_0 \to a_0$ transition from $J/\psi\to \phi\, f_0\to \phi\, a_0\to \phi\, \eta\pi^0$



.... Mixing signal

--- $a_0(980)$ contribution from $J/\psi\to\gamma^*/K^*K\to\phi a_0(980)$

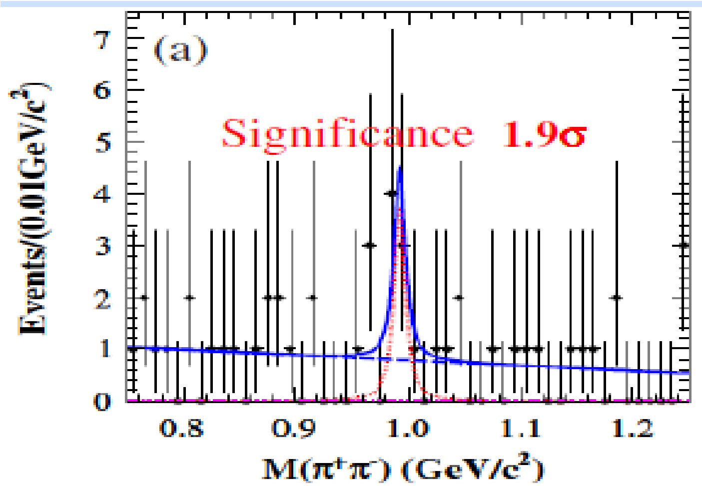
--- Background polynomial

$$Br(J/\psi\to\phi f_0(980)\to\phi a_0^0(980)\to\phi\eta\pi^0)$$
$$=(3.3\pm1.1(stat)\pm0.4(syst)\pm1.4(para))\times10^{-6}$$
$$(<5.4\times10^{-6}\ @\ 90\%\ C.L.)$$

Mixing Intensity:

$$\xi_{fa}=\frac{Br(J/\psi\to\phi f_0(980)\to\phi a_0^0(980)\to\phi\eta\pi^0)}{Br(J/\psi\to\phi f_0(980)\to\phi\pi\pi)}$$
$$=(0.60\pm0.20(stat)\pm0.13(syst)\pm0.26(para))\%$$
$$(<1.1\%\ @\ 90\%\ C.L.)$$

$a_0(980)\to f_0(980)$ mixing:
$a_0 \to f_0$ transition from $\psi' \to \gamma\chi_{c1}, \chi_{c1} \to a_0\pi^0 \to f_0\pi^0 \to \pi^+\pi^-\pi^0$



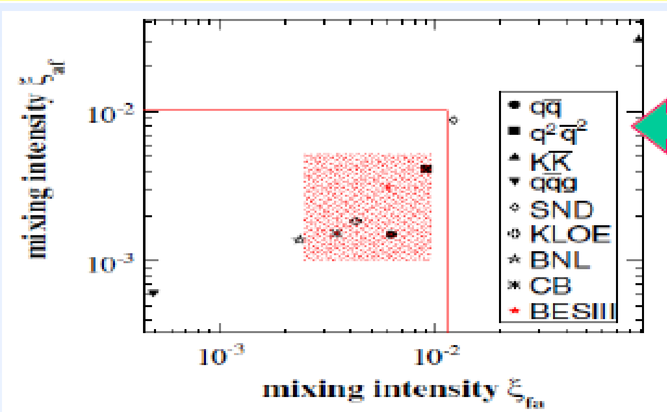
.... Mixing signal
--- $f_0(980)$ contribution from other processes
--- Background polynomial

$$Br(\psi' \to \gamma\chi_{c1} \to \gamma\pi^0 a_0^0(980) \to \gamma\pi^0 f_0(980) \to \gamma\pi^0\pi^+\pi^-)$$
$$= (2.7 \pm 1.4(stat) \pm 0.7(syst) \pm 0.3(para)) \times 10^{-7}$$
$$(< 6.0 \times 10^{-7} @ 90\% C.L.)$$

Mixing Intensity:

$$\xi_{af} = \frac{Br(\psi' \to \gamma\chi_{c1} \to \gamma\pi^0 a_0^0(980) \to \gamma\pi^0 f_0(980) \to \gamma\pi^0\pi^+\pi^-)}{Br(\psi' \to \lambda\varphi_{c1} \to \gamma\pi^0 a_0^0(980)\gamma\pi^0\pi^0\eta)}$$
$$= (0.31 \pm 0.16(stat) \pm 0.14(syst) \pm 0.03(para))\%$$
$$(< 1.0\% @ 90\% C.L.)$$

Mixing intensitity ξ_{af} vs. ξ_{fa}



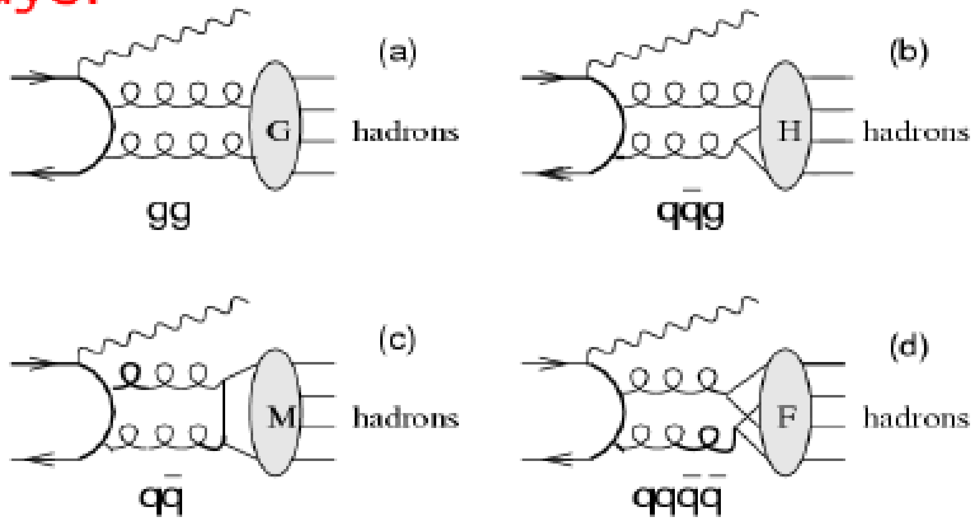
Shade region: BESIII measurements
Red line: BESIII upper limit
Dots: various predictions

Very Useful in pinning down the resonance parameters of $a_0^0(980)$ and $f_0(980)$

Glueball signatures

- Enhanced production in gluon rich processes such as pp central production, J/ψ radiative decays and $p\bar{p}$ annihilation.

J/ψ decays:



$$\Gamma(J/\psi \to \gamma G) \sim O(\alpha\alpha_s^2), \Gamma(J/\psi \to \gamma H) \sim O(\alpha\alpha_s^3),$$

$$\Gamma(J/\psi \to \gamma M) \sim O(\alpha\alpha_s^4), \Gamma(J/\psi \to \gamma F) \sim O(\alpha\alpha_s^4)$$

Baryon Summary Table (J^P and status are listed)

Status:

******** **Existence is certain, and properties are at least fairly well explored.**

******* **Existence is very likely but further confirmation of quantum numbers and branching fractions is required.**

****** **Evidence of existence is only fair.**

***** **Evidence of existence is poor.**

Resonance	Mass(MeV)	Width(MeV)	J^P	C.L.
N(1440)	1440	350	$1/2^+$	****
N(1520)	1520	125	$3/2^-$	****
N(1535)	1535	150	$1/2^-$	****
N(1650)	1650	150	$1/2^-$	****
N(1675)	1675	145	$5/2^-$	****
N(1680)	1680	130	$5/2^+$	****
N(1700)	1700	100	$3/2^-$	***
N(1710)	1710	100	$1/2^+$	***
N(1720)	1720	150	$3/2^+$	****
N(1885)	1885	160	$3/2^-$	'Missing' N*
N(1900)	1900	498	$3/2^+$	**
N(2000)	2000	300	$5/2^+$	**
N(2065)	2065	150	$3/2^+$	'Missing' N*
N(2080)	2080	270	$3/2^-$	**
N(2090)	2090	300	$1/2^-$	*
N(2100)	2100	260	$1/2^+$	*
N(2200)	2200	300	$5/2^-$	**

N* with spin 7/2 or larger is not shown here.