Light Hadron Spectroscopy at BESIII

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(On behalf of BESIII collaboration)

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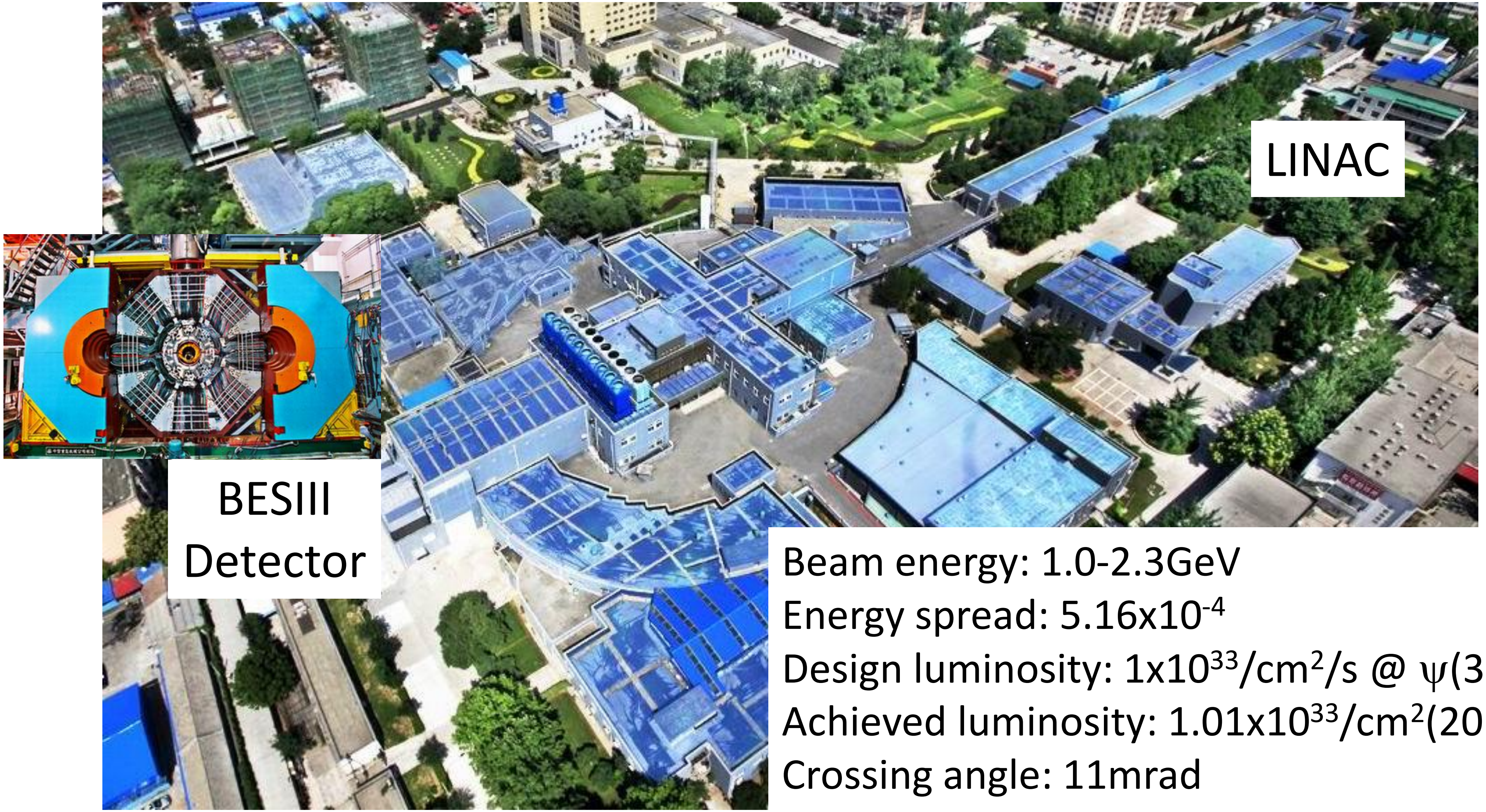
Outline

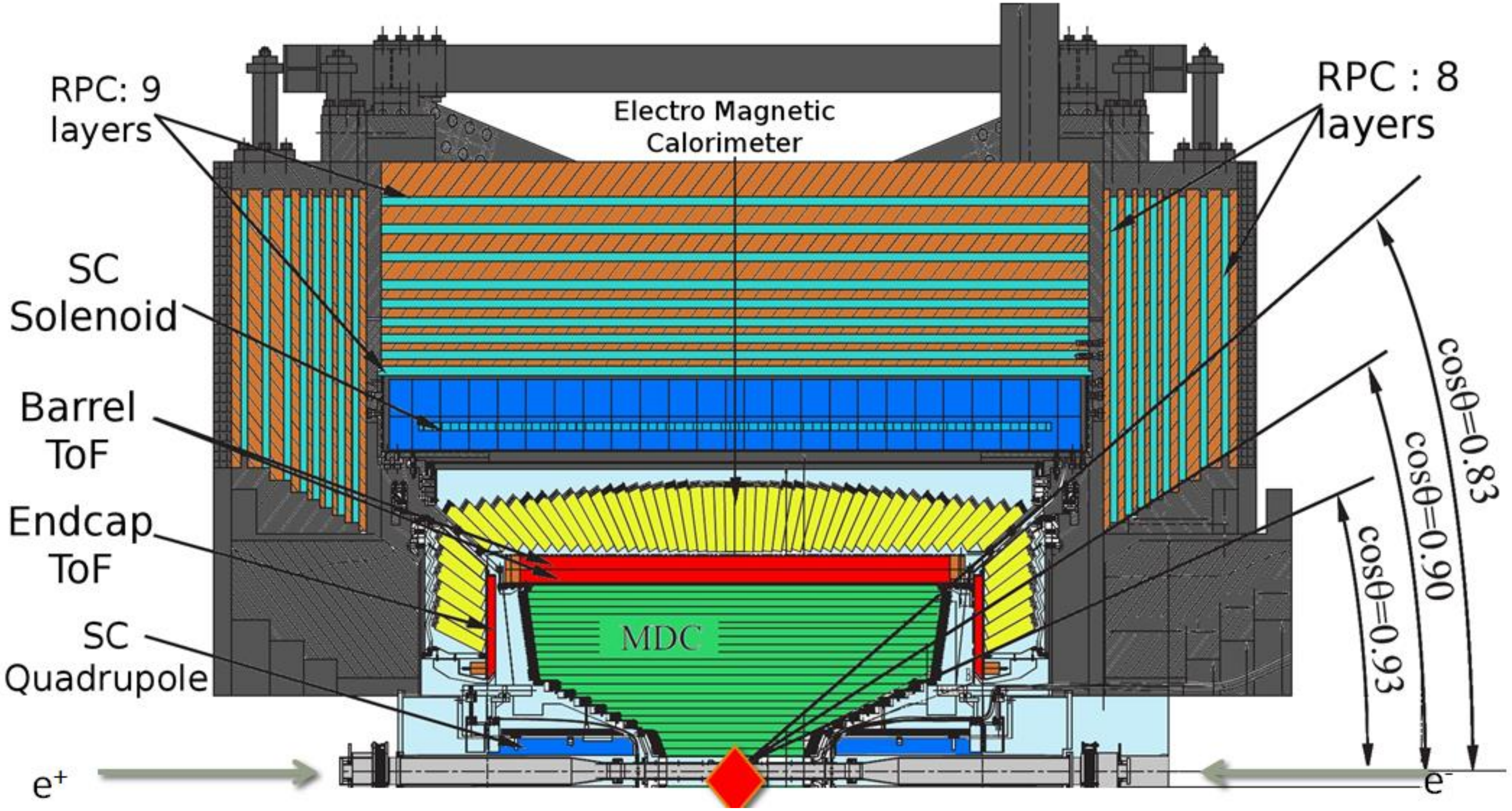
- **Introduction**
- **Selected highlights of BESIII results**
  - ✓ **$p\bar{p}$ threshold enhancement X($p\bar{p}$)/X(1835)**
  - ✓ **Study of the glueball candidates**
  - ✓ **$f_0(980)$-$a_0(980)$ mixing**
- **Summary**

BEPCII



Beam energy: 1.0-2.3GeV
Energy spread: 5.16×10^{-4}
Design luminosity: $1 \times 10^{33}/cm^2/s$ @ $\psi(3770)$
Achieved luminosity: $1.01 \times 10^{33}/cm^2$(2016)
Crossing angle: 11mrad

BESIII detector



Main Drift Chamber

σ_P /P = 0.5% @ 1 GeV

$\sigma_{dE/dX}$ = 5%

Time of Flight

σ_T = 90ps (barrel)

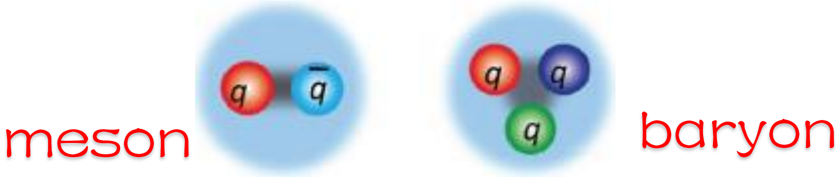
110ps (endcap)

Electromagnetic Calorimeter

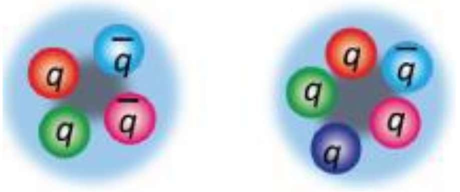
$\sigma_E/\sqrt{E}$= 2.5% @ 1GeV

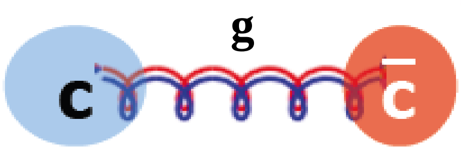
Light hadron spectroscopy at BESIII

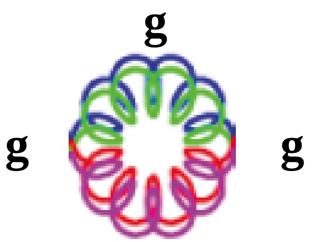
- Conventional hadrons consist of 2 or 3 quarks:

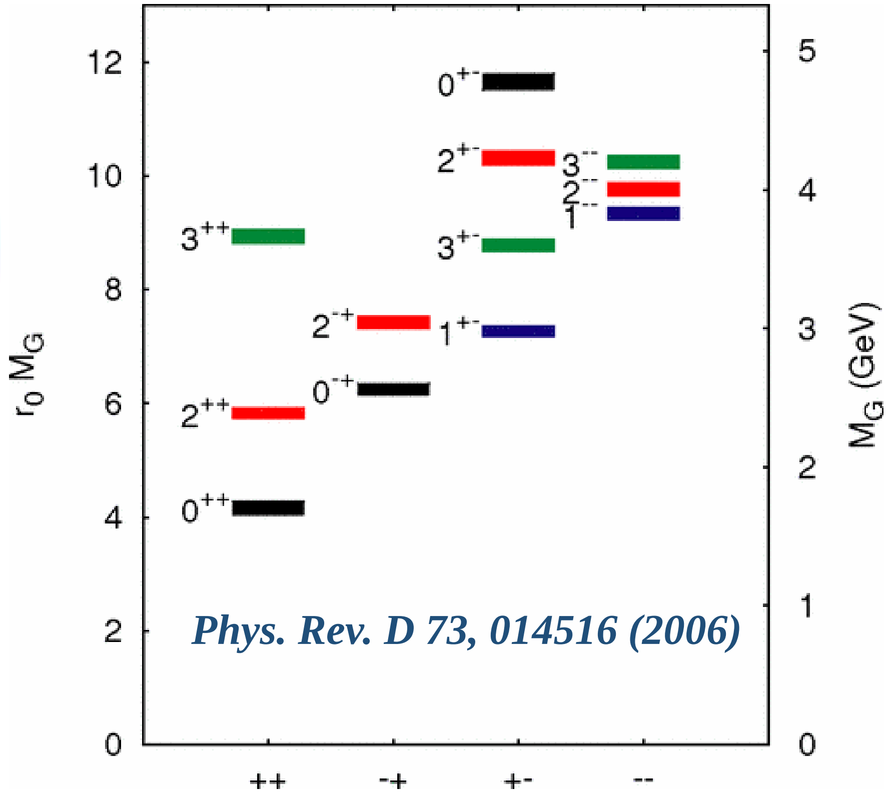


- QCD predicts the new forms of hadrons:
  - ✓ Multi-quark states: Number of quarks ≥ 4
  - ✓ Hybrids: $q\bar{q}g$, $qqqg$ …
  - ✓ Glueballs: gg, ggg …
    - 0^{++} ground state: 1.5~1.7 GeV/c^2
    - 2^{++} ground state: 2.3~2.4 GeV/c^2
    - 0^{-+} ground state: 2.3~2.6 GeV/c^2









Phys. Rev. D 73, 014516 (2006)

None of the new forms of hadrons is settled!

BESIII:

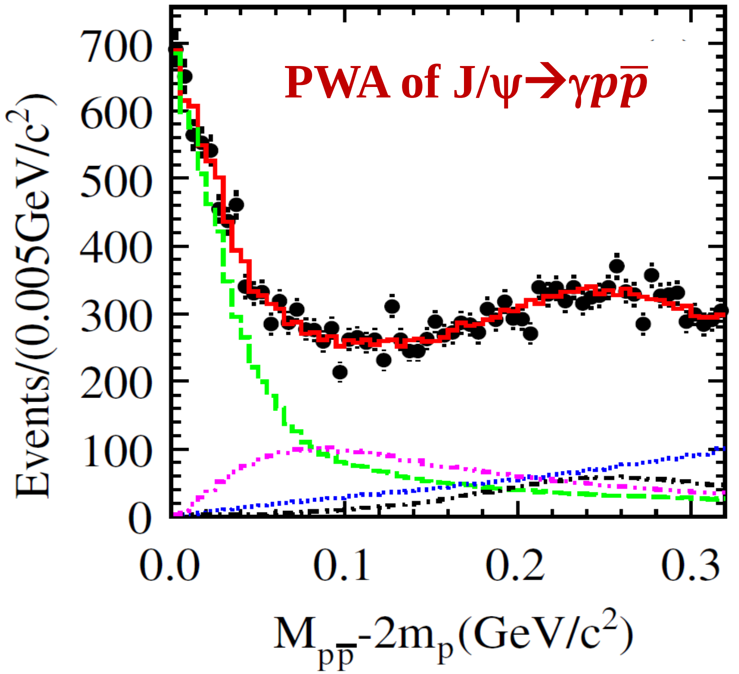
- ✓ World largest J/ψ (1.0×10^{10}), $\psi(3686)$ (4.5×10^{8})
- ✓ Gluon rich processes
- ✓ Clean: produced directly from e^+e^- collision

$p\bar{p}$ threshold enhancement X($p\bar{p}$)/X(1835)

$p\bar{p}$ threshold enhancement X($p\bar{p}$)

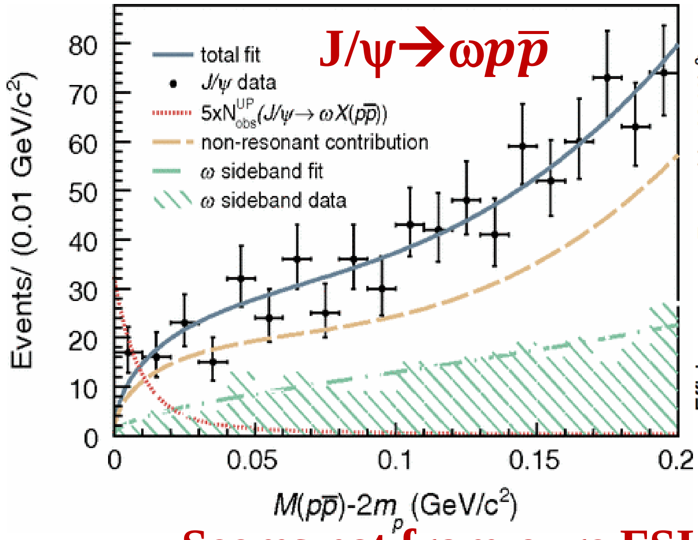
- First observed in J/ψ→$\gamma p\bar{p}$ at BESII. Then confirmed by BESIII and CLEO.
- PWA of J/ψ→$\gamma p\bar{p}$: $J^{PC} = 0^{-+}$
  - ✓ $M = 1836.5^{+19+18}_{-5-17} \pm 19$ MeV/c^2
  - ✓ Width: < 76 MeV/c^2 @ 90% C.L.
  - ✓ A signal model of BW and S-wave FSI factor can well describe $p\bar{p}$ mass threshold structure, the fit quality is much better than that without FSI effect.

Phys. Rev. Lett. 108, 112003 (2012)

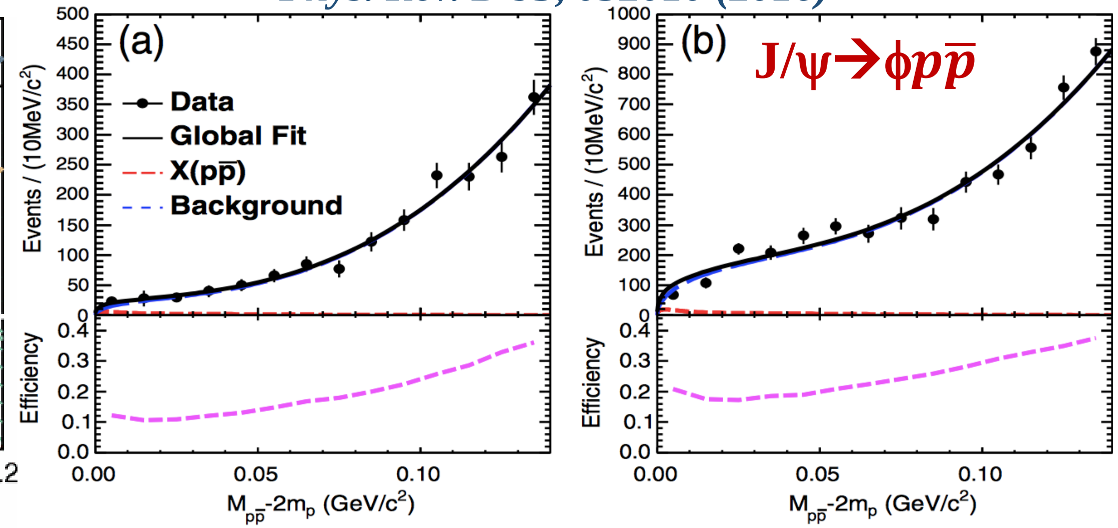


No significant narrow threshold enhancement observed here:

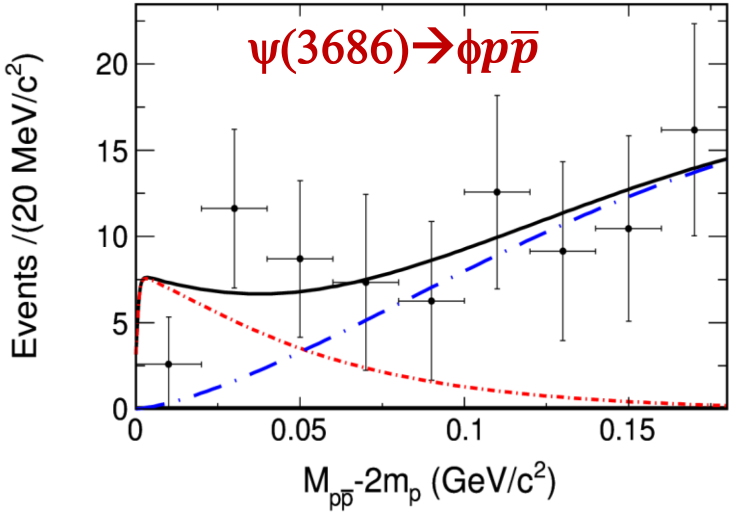
Phys. Rev. D 87, 112014 (2013)



Phys. Rev. D 93, 052010 (2016)



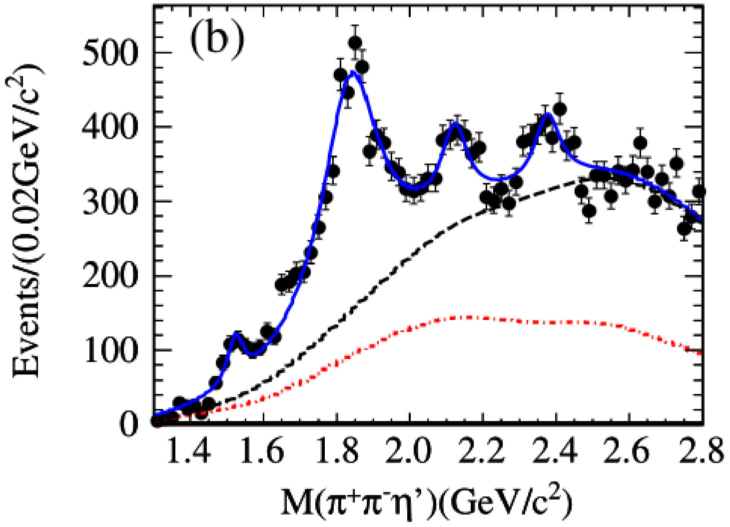
arXiv:1902.09756



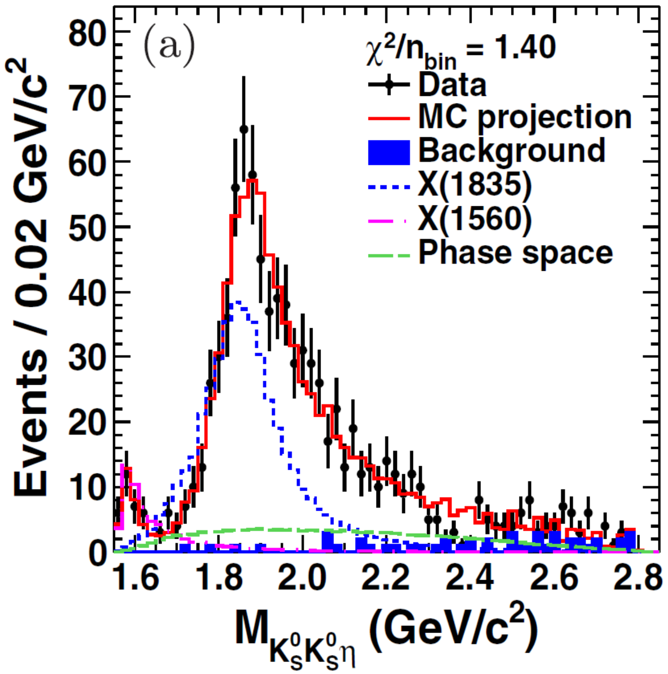
Seems not from pure FSI effect

X(1835)

- First observed in $J/\psi \rightarrow \gamma\pi^+\pi^-\eta'$ by BESII and then confirmed by BESIII using the same decay channel with more J/ψ data.
- PWA of $J/\psi \rightarrow \gamma K_S^0 K_S^0 \eta$:
  - ✓ $J^{PC} = 0^{-+}$.
  - ✓ $M = 1844 \pm 9(stat.)^{+16}_{-25}(syst.)$ MeV/c^2
  - ✓ $\Gamma = 192^{+20}_{-17}(stat.)^{+62}_{-43}(syst.)$ MeV
  - ✓ Consistent with X(1835) in $J/\psi \rightarrow \gamma\pi^+\pi^-\eta'$.
  - ✓ B.R.$(\pi^+\pi^-\eta') = 2.87 \pm 0.09^{+0.49}_{-0.52} \times 10^{-4}$
  - ✓ B.R.$(K_S K_S \eta) = 3.31^{+0.33}_{-0.30}{}^{+1.96}_{-1.29} \times 10^{-5}$



Phys. Rev. Lett. 106, 072002 (2011)



Phys. Rev. Lett. 115, 091803 (2015)

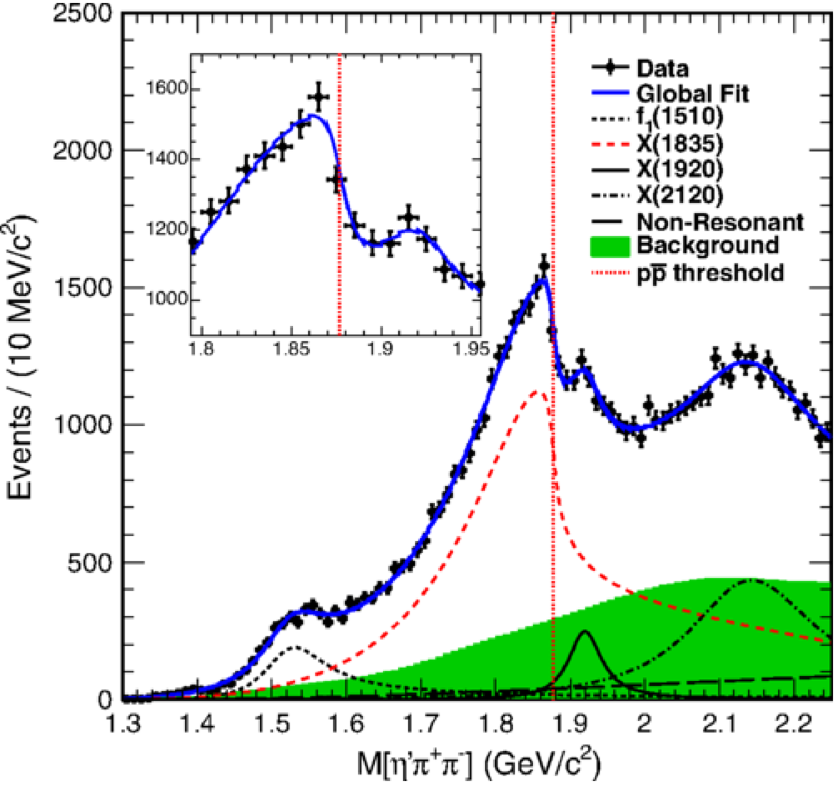
Anomalous line shape of $\pi^+\pi^-\eta'$ near $p\bar{p}$ mass threshold

What causes this distorted line shape?

✓ The opening of X(1835)→$p\bar{p}$?

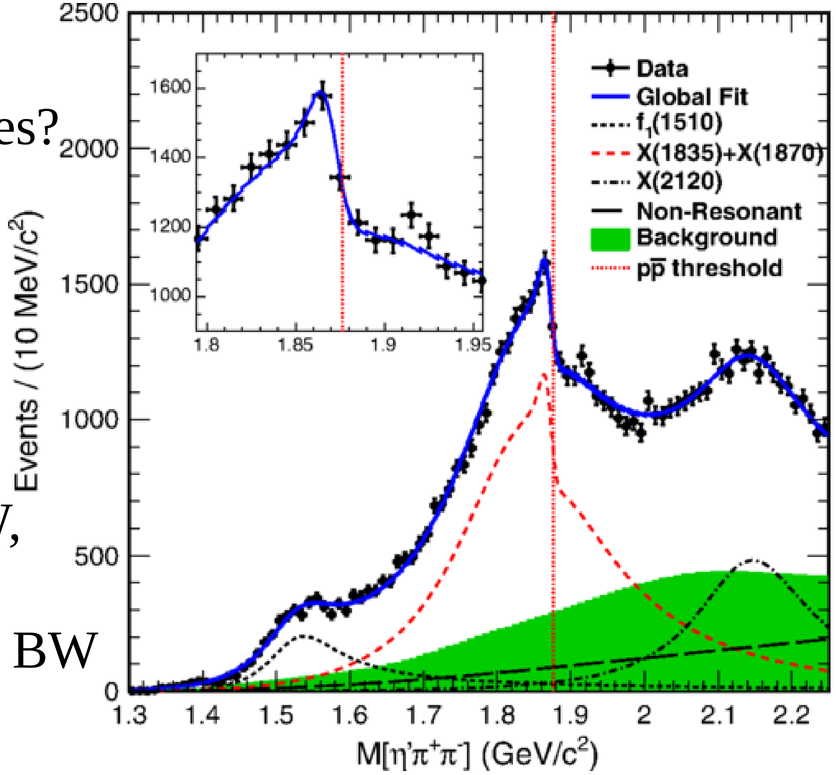
✓ Interference between two resonances?

Phys. Rev. Lett. 117, 042002 (2016)



Model I:
Flatte line shape with strong coupling to $p\bar{p}$ and one additional narrow BW at ~ 1920 MeV/c^2

Model II:
Two coherent BW, X(1835) and one additional, narrow BW at ~ 1870 MeV/c^2 significance > 7σ



- ➢ Both models well describes data with almost equally good fit quality.
- ➢ Suggest the existence of a state, either a broad one with strong couplings to $p\bar{p}$, or a narrow state just below the $p\bar{p}$ mass threshold.
- ➢ Support the existence of a $p\bar{p}$ molecule-like state or bound state.

Search for X(1835)'s other decay modes

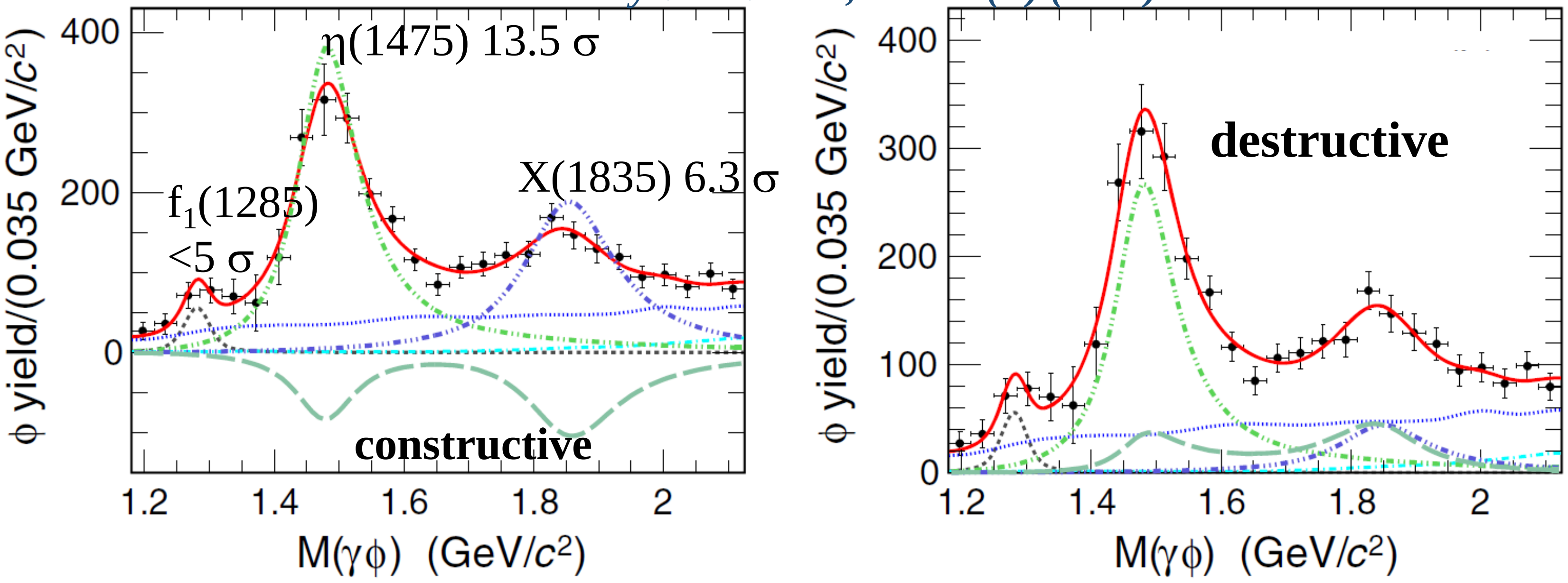
$J/\psi \rightarrow \gamma\gamma\phi$:

- ✓ First observation of $\eta(1475)/X(1835) \rightarrow \gamma\phi$.
- ✓ Angular distribution favor $J^{PC} = 0^{-+}$.
- ✓ Sizeable $s\bar{s}$ components in X(1835): more complicated than a pure $N\bar{N}$ state

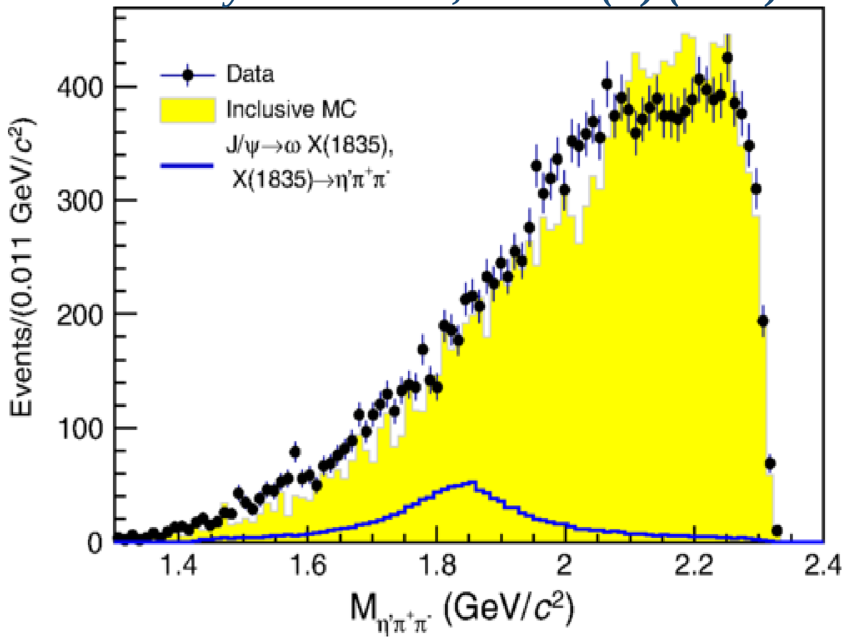
$J/\psi \rightarrow \omega\pi^+\pi^-\eta'$:

- ✓ No obvious signal of X(1835) is found.
- ✓ B.R.< 6.2×10^{-5} @ 90% C. L.

Phys. Rev. D 97, 051101(R) (2018)



Phys. Rev. D 99, 071101(R) (2019)

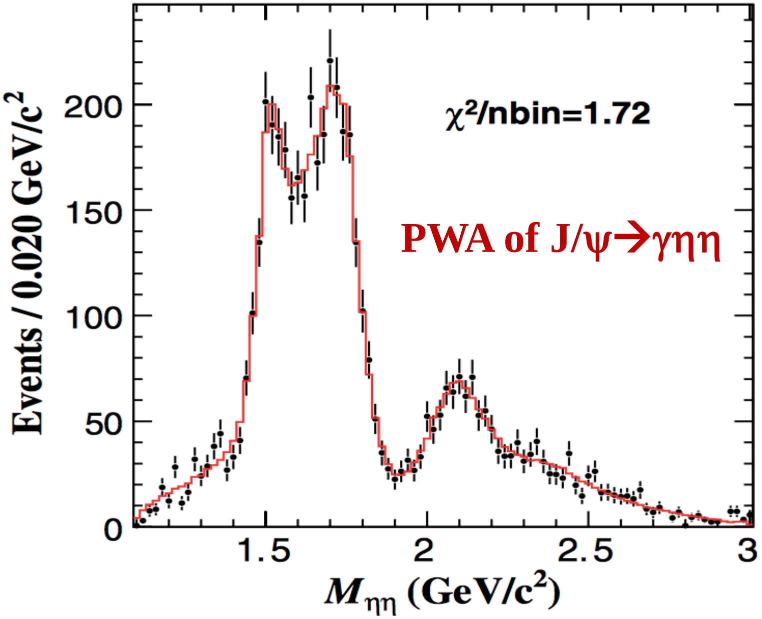


Study of glueball and hybrid candidates

- Searching for glueball provides a direct fundamental test of the QCD theory
- Lattice QCD predicts the lowest lying 0^{-+}, 0^{++}, 2^{++} glueballs have masses below 3 GeV/c^2.
- Radiative J/ψ decays are ideal for searching for glueballs:
  - ✓ 0^{-+} : J/ψ→γPPP, γVV
  - ✓ 0^{++}/ 2^{++} : J/ψ→γPP, γVV

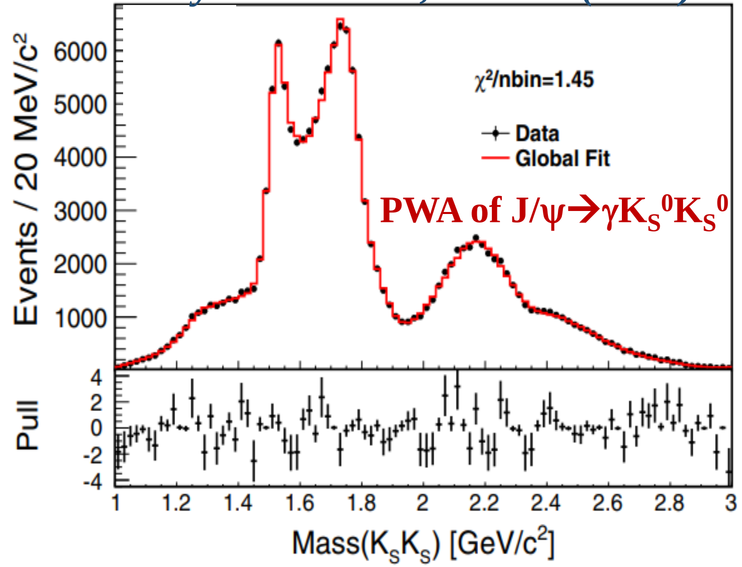
PWA of $J/\psi \rightarrow \gamma\eta\eta / \gamma K_S^0 K_S^0$

Phys. Rev. D 87, 092009 (2013)



Resonance	Mass (MeV/c^2)	Width (MeV/c^2)	$\mathcal{B}(J/\psi \to \gamma X \to \gamma\eta\eta)$	Significance
$f_0(1500)$	1468^{+14+23}_{-15-74}	$136^{+41+28}_{-26-100}$	$(1.65^{+0.26+0.51}_{-0.31-1.40}) \times 10^{-5}$	8.2σ
$f_0(1710)$	$1759 \pm 6^{+14}_{-25}$	$172 \pm 10^{+32}_{-16}$	$(2.35^{+0.13+1.24}_{-0.11-0.74}) \times 10^{-4}$	25.0σ
$f_0(2100)$	$2081 \pm 13^{+24}_{-36}$	273^{+27+70}_{-24-23}	$(1.13^{+0.09+0.64}_{-0.10-0.28}) \times 10^{-4}$	13.9σ
$f_2'(1525)$	$1513 \pm 5^{+4}_{-10}$	75^{+12+16}_{-10-8}	$(3.42^{+0.43+1.37}_{-0.51-1.30}) \times 10^{-5}$	11.0σ
$f_2(1810)$	1822^{+29+66}_{-24-57}	$229^{+52+88}_{-42-155}$	$(5.40^{+0.60+3.42}_{-0.67-2.35}) \times 10^{-5}$	6.4σ
$f_2(2340)$	$2362^{+31+140}_{-30-63}$	$334^{+62+165}_{-54-100}$	$(5.60^{+0.62+2.37}_{-0.65-2.07}) \times 10^{-5}$	7.6σ

Phys. Rev. D 98, 072003 (2018)

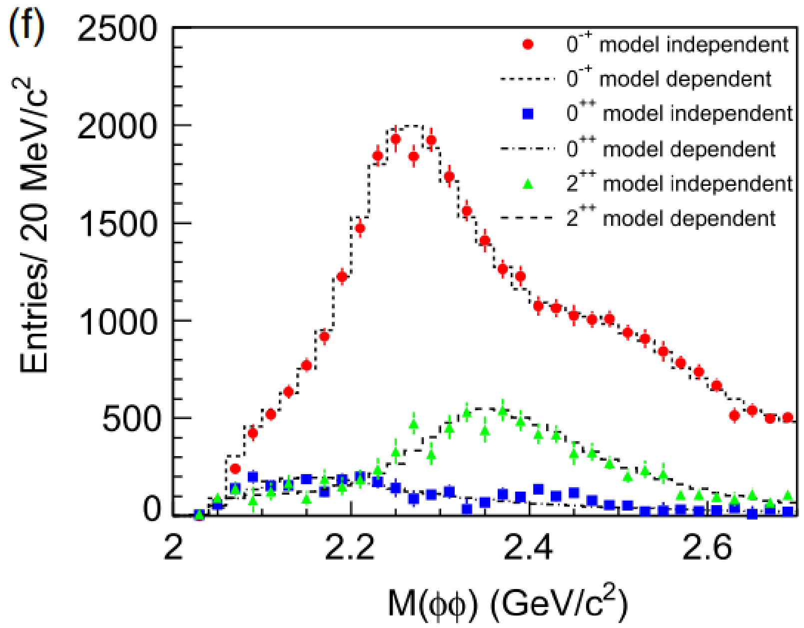


Resonance	M (MeV/c^2)	$M_{\rm PDG}$ (MeV/c^2)	Γ (MeV/c^2)	$\Gamma_{\rm PDG}$ (MeV/c^2)	Branching fraction	Significance
$K^*(892)$	896	895.81 ± 0.19	48	47.4 ± 0.6	$(6.28^{+0.16+0.59}_{-0.17-0.52}) \times 10^{-6}$	35σ
$K_1(1270)$	1272	1272 ± 7	90	90 ± 20	$(8.54^{+1.07+2.35}_{-1.20-2.13}) \times 10^{-7}$	16σ
$f_0(1370)$	$1350 \pm 9^{+12}_{-2}$	1200 to 1500	$231 \pm 21^{+28}_{-48}$	200 to 500	$(1.07^{+0.08+0.36}_{-0.07-0.34}) \times 10^{-5}$	25σ
$f_0(1500)$	1505	1504 ± 6	109	109 ± 7	$(1.59^{+0.16+0.18}_{-0.16-0.56}) \times 10^{-5}$	23σ
$f_0(1710)$	$1765 \pm 2^{+1}_{-1}$	1723^{+6}_{-5}	$146 \pm 3^{+7}_{-1}$	139 ± 8	$(2.00^{+0.03+0.31}_{-0.02-0.10}) \times 10^{-4}$	$\gg 35\sigma$
$f_0(1790)$	$1870 \pm 7^{+2}_{-3}$	...	$146 \pm 14^{+7}_{-15}$	...	$(1.11^{+0.06+0.19}_{-0.06-0.32}) \times 10^{-5}$	24σ
$f_0(2200)$	$2184 \pm 5^{+4}_{-2}$	2189 ± 13	$364 \pm 9^{+4}_{-7}$	238 ± 50	$(2.72^{+0.08+0.17}_{-0.06-0.47}) \times 10^{-4}$	$\gg 35\sigma$
$f_0(2330)$	$2411 \pm 10 \pm 7$	...	$349 \pm 18^{+23}_{-1}$	...	$(4.95^{+0.21+0.66}_{-0.21-0.72}) \times 10^{-5}$	35σ
$f_2(1270)$	1275	1275.5 ± 0.8	185	$186.7^{+2.2}_{-2.5}$	$(2.58^{+0.08+0.59}_{-0.09-0.20}) \times 10^{-5}$	33σ
$f_2'(1525)$	1516 ± 1	1525 ± 5	$75 \pm 1 \pm 1$	73^{+6}_{-5}	$(7.99^{+0.03+0.69}_{-0.04-0.50}) \times 10^{-5}$	$\gg 35\sigma$
$f_2(2340)$	$2233 \pm 34^{+9}_{-25}$	2345^{+50}_{-40}	$507 \pm 37^{+18}_{-21}$	322^{+70}_{-60}	$(5.54^{+0.34+3.82}_{-0.40-1.49}) \times 10^{-5}$	26σ
0^{++} PHSP	...	...	...	...	$(1.85^{+0.05+0.68}_{-0.05-0.26}) \times 10^{-5}$	26σ
2^{++} PHSP	...	...	...	...	$(5.73^{+0.99+4.18}_{-1.00-3.74}) \times 10^{-5}$	13σ

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

Phys. Rev. D 93, 112011 (2016)

- Besides η(2225), the structures in the pseudo-scalar sector above 2 GeV/c^2 are poorly understand.
- $J/\psi \rightarrow \gamma\phi\phi$ provide an opportunity to study 0^{-+} and 2^{++} states above 2 GeV/c^2.
- Dominant contribution from 0^{-+} states
  - ✓ η(2225) is confirmed
  - ✓ Newly observed: η(2100) and X(2500)
- 2^{++} contibutions
  - ✓ $f_2(2010)$, $f_2(2300)$, $f_2(2340)$ observed in $\pi^- p \rightarrow \phi\phi n$ are observed.
  - ✓ Large production rate of $f_2(2340)$
- Model dependent PWA results are well consistent with the results from MIPWA.



Resonance	M (MeV/c^2)	Γ (MeV/c^2)	B.F. ($\times 10^{-4}$)	Sig.
η(2225)	2216^{+4+21}_{-5-11}	185^{+12+43}_{-14-17}	$(2.40 \pm 0.10^{+2.47}_{-0.18})$	28σ
η(2100)	2050^{+30+75}_{-24-26}	$250^{+36+181}_{-30-164}$	$(3.30 \pm 0.09^{+0.18}_{-3.04})$	22σ
X(2500)	$2470^{+15+101}_{-19-23}$	230^{+64+56}_{-35-33}	$(0.17 \pm 0.02^{+0.02}_{-0.08})$	8.8σ
$f_0(2100)$	2101	224	$(0.43 \pm 0.04^{+0.24}_{-0.03})$	24σ
$f_2(2010)$	2011	202	$(0.35 \pm 0.05^{+0.28}_{-0.15})$	9.5σ
$f_2(2300)$	2297	149	$(0.44 \pm 0.07^{+0.09}_{-0.15})$	6.4σ
$f_2(2340)$	2339	319	$(1.91 \pm 0.14^{+0.72}_{-0.73})$	11σ
0^{-+} PHSP			$(2.74 \pm 0.15^{+0.16}_{-1.48})$	6.8σ

Scalar/tensor glueball candidate ($0^{++}/2^{++}$)

Decay rate of pure glueball from LQCD:

$$\Gamma(J/\psi \to \gamma G_{0^+}) = \frac{4}{27}\alpha\frac{|p|}{M_{J/\psi}^2}|E_1(0)|^2 = 0.35(8)keV$$

$$\Gamma/\Gamma_{tot} = 0.33(7)/93.2 = 3.8(9)\times 10^{-3}$$

Phys. Rev. Lett. 110, 021601 (2013)

$$\Gamma(J/\psi \to \gamma G_{2^+}) = 1.01(22)keV$$

$$\Gamma(J/\psi \to \gamma G_{2^+})/\Gamma_{tot} = 1.1\times 10^{-2}$$

Phys. Rev. Lett. 111, 091601 (2013)

Experimental results from J/ψ radiative decays to scalars or tensors:

- $B(J/\psi \to \gamma f_0(1710) \to \gamma K\bar{K}) = (8.5^{+1.2}_{-0.9})\times 10^{-4}$
- $B(J/\psi \to \gamma f_0(1710) \to \gamma\pi\pi) = (4.0\pm1.0)\times 10^{-4}$
- $B(J/\psi \to \gamma f_0(1710) \to \gamma\omega\omega) = (3.1\pm1.0)\times 10^{-4}$
- $B(J/\psi \to \gamma f_0(1710) \to \gamma\eta\eta) = (2.35^{+0.13}_{-0.11}{}^{+1.24}_{-0.74})\times 10^{-4}$
- $B(J/\psi \to \gamma f_2(2340) \to \gamma\eta\eta) = (5.60^{+0.62}_{-0.65}{}^{+2.37}_{-2.07})\times 10^{-5}$
- $B(J/\psi \to \gamma f_2(2340) \to \gamma\phi\phi) = (1.91 \pm 0.14^{+0.72}_{-0.73})\times 10^{-4}$
- $B(J/\psi \to \gamma f_2(2340) \to \gamma K_S^0 K_S^0) = (5.54^{+0.34}_{-0.40}{}^{+3.28}_{-1.49})\times 10^{-5}$

$\Rightarrow B(J/\psi \to \gamma f_0(1710)) > 1.7\times 10^{-3}$

$f_0(1710)$ / $f_2(2340)$: The candidate of the scalar/ tensor glueball ?

$a_0(980)$-$f_0(980)$ mixing

- Mixing intensity provides important information in understanding the nature of $a_0(980)$ and $f_0(980)$.
- To better determine relevant parameters for $f_0(980)$
- And $a_0(980)$ need to take both ways into account.

$$\xi_{fa} = \frac{Br(J/\psi \to \phi f_0(980) \to \phi a_0^0(980) \to \phi \eta \pi^0)}{Br(J/\psi \to \phi f_0(980) \to \phi \pi\pi)}$$

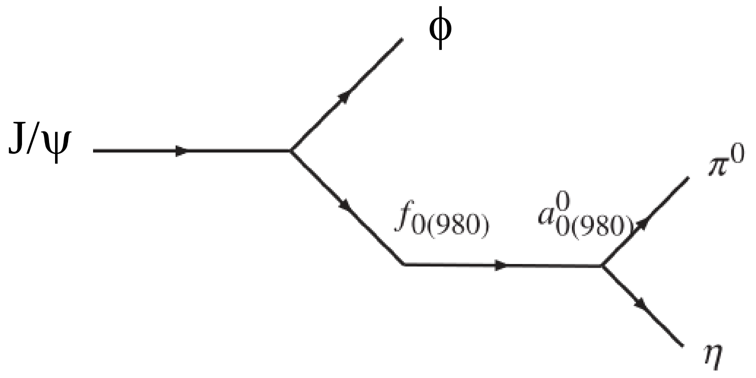
$$\xi_{af} = \frac{Br(\psi' \to \gamma \chi_{c1} \to \gamma \pi^0 a_0^0(980) \to \gamma \pi^0 f_0(980) \to \gamma \pi^0 \pi^+ \pi^-)}{Br(\psi' \to \gamma \chi_{c1} \to \gamma \pi^0 a_0^0(980) \to \gamma \pi^0 \pi^0 \eta)}$$

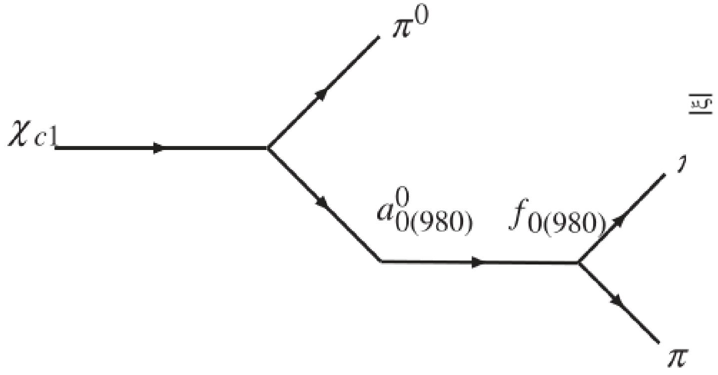
- Narrow peak (8 MeV) at around 980 MeV can be expected in $\eta\pi^0$ ($J/\psi \to \phi f_0(980) \to \phi a_0(980) \to \phi \eta \pi^0$) or $\pi^+\pi^-$($\chi_{c1} \to a_0(980)\pi^0 \to f_0(980)\pi^0 \to \pi^+\pi^-\pi^0$) invariant mass spectra.

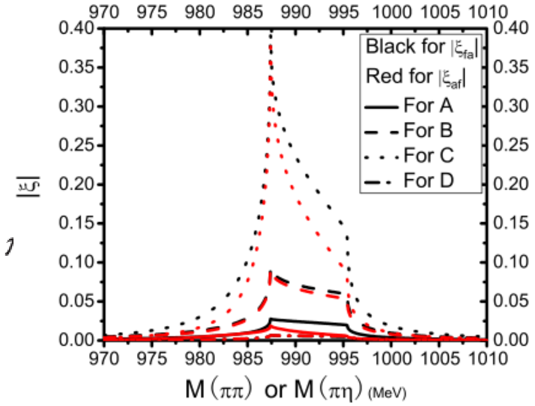
J.Wu, Q.Zhao, B.Zou Phys.Rev. D 75, 114012

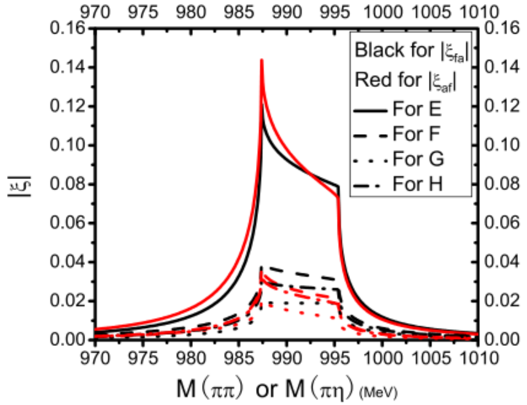
C. Hanhart etc. Phys. Rev. D 76, 074028

J.Wu, B.Zou Phys.Rev. D 78, 074017









Predictions for mixing intensity from various models and experiments.

Observation of $a_0(980)$-$f_0(980)$ mixing

- Using 1.3 billion J/ψ events,

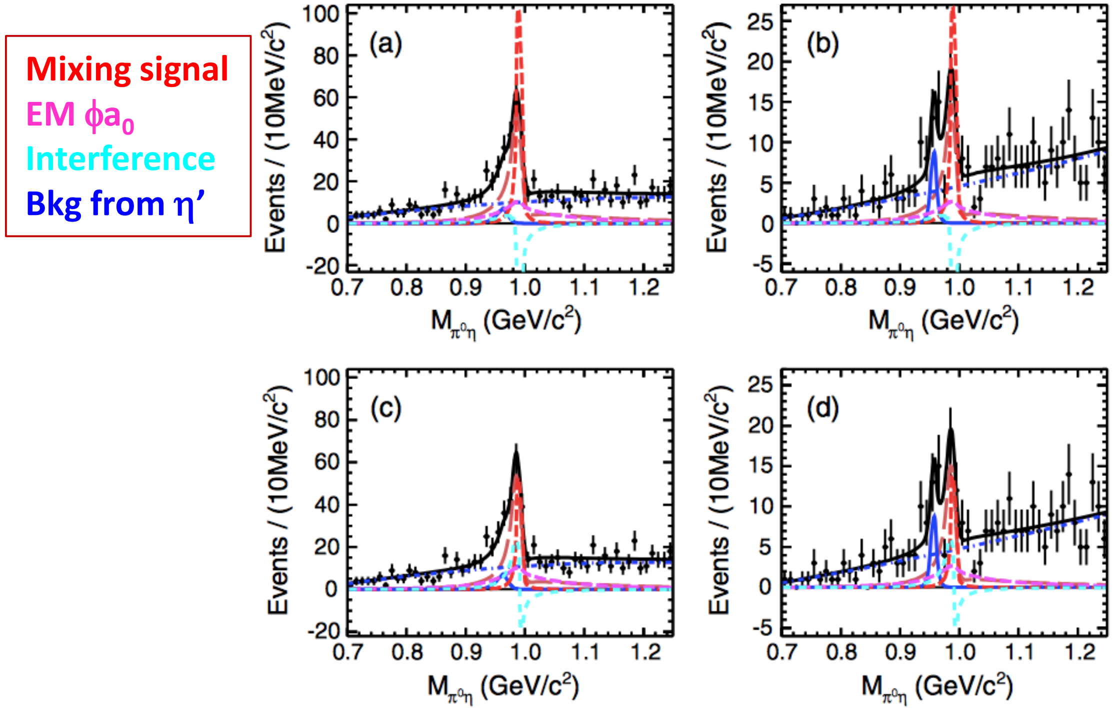
  $f_0(980)$-$a_0(980)$ is observed in the isospin violating

  $J/\psi \to \phi f_0(980) \to \phi a_0(980) \to \phi \eta \pi^0$ (7.4 σ)

- Using 450 million $\psi(3686)$ events,

  $a_0(980)$-$f_0(980)$ is observed in the isospin violating

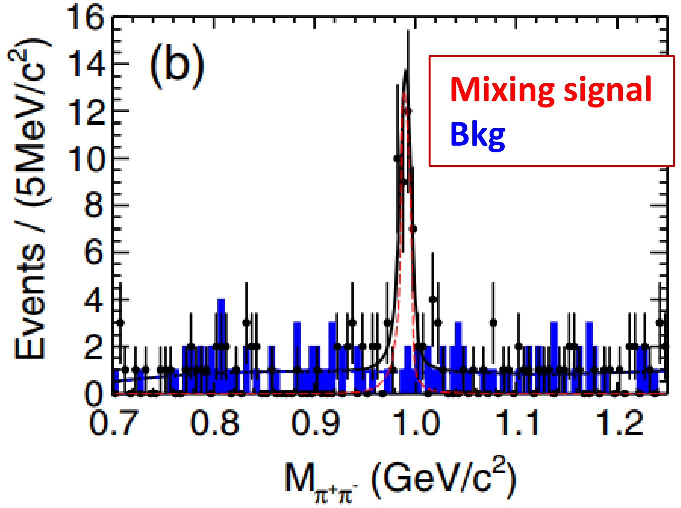
  $\chi_{c1} \to a_0(980)\pi^0 \to f_0(980)\pi^0 \to \pi^+\pi^-\pi^0$ (5.5 σ)



Phys. Rev. Lett. 121, 022001 (2018)

Channel	$f_0(980) \to a_0^0(980)$ Solution I	$f_0(980) \to a_0^0(980)$ Solution II	$a_0^0(980) \to f_0(980)$
$\mathcal{B}$ (mixing) (10^{-6})	$3.18 \pm 0.51 \pm 0.38 \pm 0.28$	$1.31 \pm 0.41 \pm 0.39 \pm 0.43$	$0.35 \pm 0.06 \pm 0.03 \pm 0.06$
$\mathcal{B}$ (EM) (10^{-6})	$3.25 \pm 1.08 \pm 1.08 \pm 1.12$	$2.62 \pm 1.02 \pm 1.13 \pm 0.48$	...
$\mathcal{B}$ (total) (10^{-6})	$4.93 \pm 1.01 \pm 0.96 \pm 1.09$	$4.37 \pm 0.97 \pm 0.94 \pm 0.06$	...
ξ (%)	$0.99 \pm 0.16 \pm 0.30 \pm 0.09$	$0.41 \pm 0.13 \pm 0.17 \pm 0.13$	$0.40 \pm 0.07 \pm 0.14 \pm 0.07$

7.4σ　　5.5σ



Summary

- A set of interesting and important results from the light hadron spectroscopy achieved:
  - ✓ Both X(1835) and $p\bar{p}$ are confirmed by BESIII.
    - J^{PC} (X(1835)/X($p\bar{p}$))= 0^{-+};
    - Anomalous line shape of $\pi^+\pi^-\eta'$ near $p\bar{p}$ mass threshold is observed.
  - ✓ 0^{++} and 2^{++} structures are studied from J/ψ radiative decays:
    - Strong production of $f_0(1710)$ in $J/\psi \to \gamma\eta\eta/\gamma K_S^0 K_S^0$,

      production rate of $f_0(1710)$ is about 1 order of magnitude larger than that of $f_0(1500)$.
    - Strong production of $f_2(2340)$ in $J/\psi \to \gamma\eta\eta/\gamma K_S^0 K_S^0/\gamma\phi\phi$;

      could be a candidate for the lowest lying tensor glueball?
  - ✓ First observation of $a_0(980)$-$f_0(980)$ mixing.
- With 10 billion J/ψ events, more interesting results are expected in the near future.

Thanks!

Back up

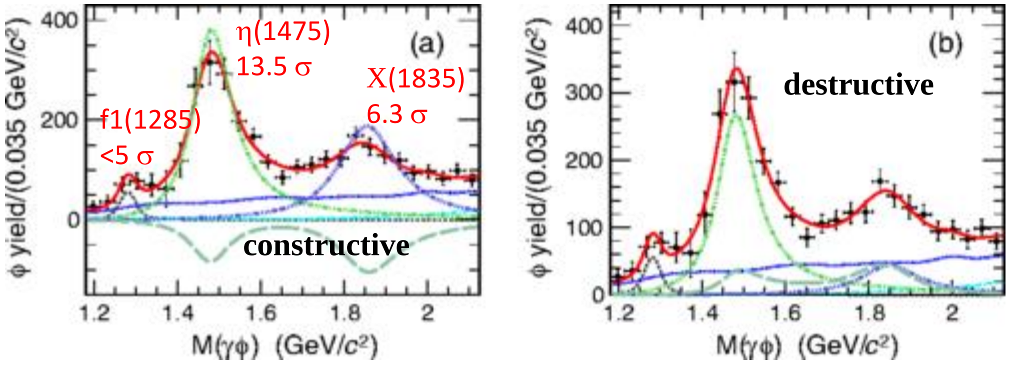
$X(p\bar{p})$/ X(1835)

$X(p\bar{p})$	X(1835)
0^{-+}	0^{-+}
M = $1832^{+19}_{-5}{}^{+19}_{-17} \pm 19$ MeV/c^2	M = $1844 \pm 9^{+16}_{-25}$ MeV/c^2
$\Gamma = 13 \pm 19$ MeV (<76 MeV @ 90% C.L.)	$\Gamma = 192^{+20}_{-17}{}^{+62}_{-43}$ MeV
$p\bar{p}$ bound state? …	$p\bar{p}$ bound state? η′ excitation? glueball? …
The SAME state?	

Search for X(1835) through other decay modes

Observation of η(1475) and X(1835) in J/ψ→γγϕ

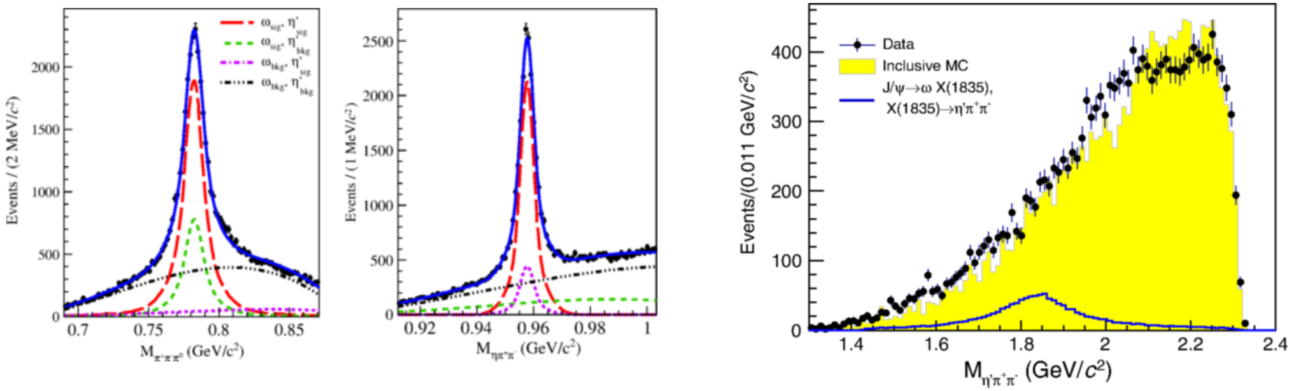
Phys. Rev. D 97, 051101(R) (2018)



- ✓ First observation of η(1475)/X(1835)→γϕ.
- ✓ Angular distribution favor $J^{PC} = 0^{-+}$.
- ✓ Sizeable $s\bar{s}$ components in X(1835): more complicated than a pure $N\bar{N}$ bound state.
- ✓ One state assumption: $R = \frac{\Gamma_{\eta(1405)/\eta(1475)\to\gamma\rho}}{\Gamma_{\eta(1405)/\eta(1475)\to\gamma\phi}}$ is slightly larger than the prediction[1].
- ✓ Two states assumption: η(1475) could be the radial excitation of the η'.

Search for X(1835) in J/ψ→ωπ⁺π⁻η'

Phys. Rev. D 99, 071101(R) (2019)

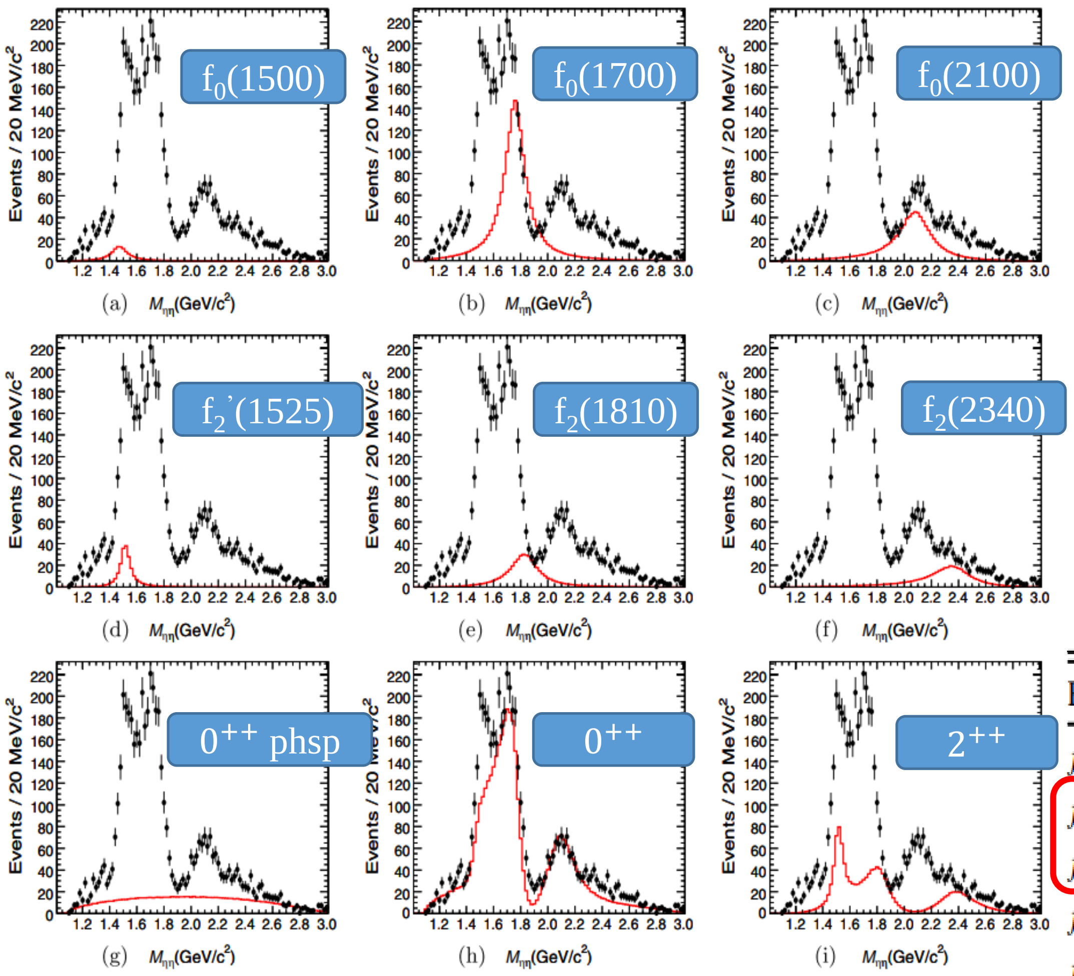


- ✓ 2-dimentional fit is used for the signal extraction.
- ✓ No obvious sign of X(1835) is found.
- ✓ Estimate the upper limit on the branching fraction at 90% C. L., B(J/ψ→ωX(1835)→ωπ⁺π⁻η') < 6.2×10⁻⁵.

Phys. Rev. D 87, 014023 (2013)

PWA of J/ψ→γηη

Phys. Rev. D 87, 092009 (2013)

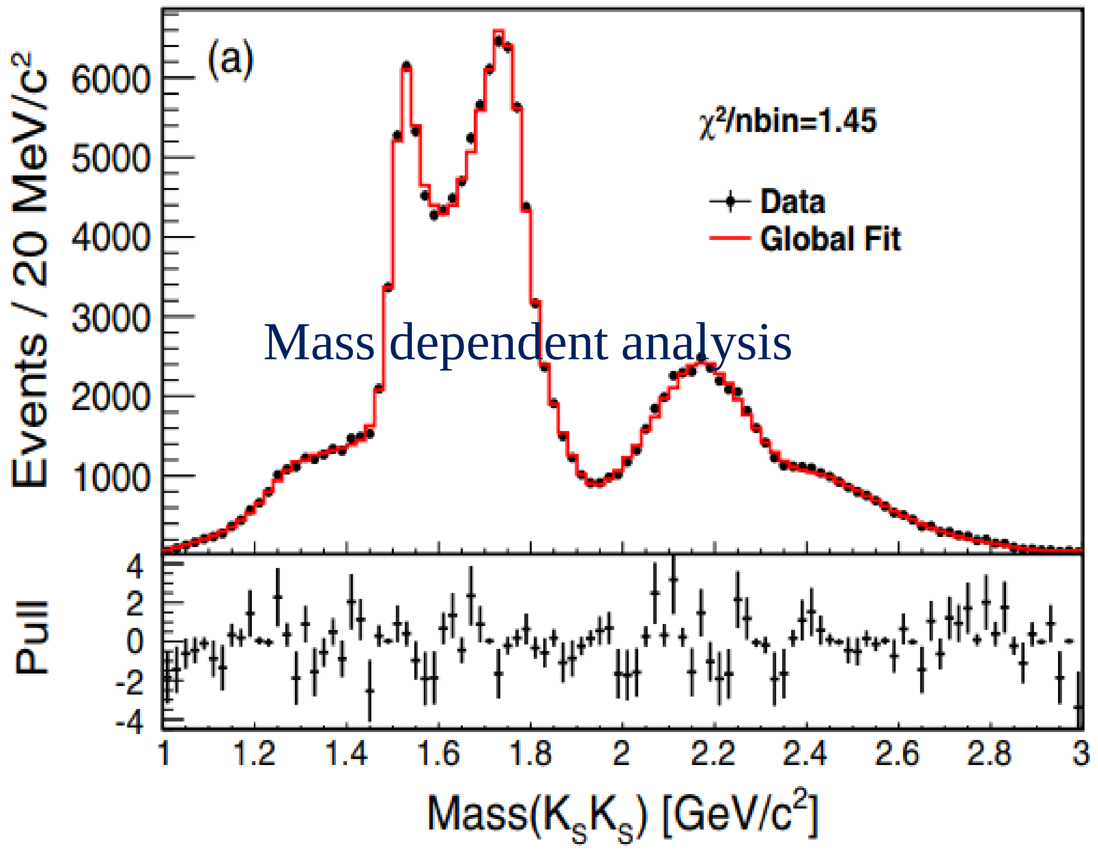


- J/ψ→γηη: a good channel to study 0^{++} and 2^{++} states
- Production rate of J/ψ radiative decays to $f_0(1710)$ is compatible with LQCD prediction for a pure gauge scalar glueball.
  →suggest possible large overlap with LQCD predictions of 0^{+}glueball.
- Production rate of $f_0(1710)$ and $f_0(2100)$ are both about 1 order of magnitude larger than that of $f_0(1500)$.
- A strong contribution from $f_2(2340)$:
  candidate for the lowest lying tensor glueball.

Resonance	Mass (MeV/c^2)	Width (MeV/c^2)	$\mathcal{B}(J/\psi \to \gamma X \to \gamma\eta\eta)$	Significance
$f_0(1500)$	1468^{+14+23}_{-15-74}	$136^{+41+28}_{-26-100}$	$(1.65^{+0.26+0.51}_{-0.31-1.40}) \times 10^{-5}$	8.2σ
$f_0(1710)$	$1759 \pm 6^{+14}_{-25}$	$172 \pm 10^{+32}_{-16}$	$(2.35^{+0.13+1.24}_{-0.11-0.74}) \times 10^{-4}$	25.0σ
$f_0(2100)$	$2081 \pm 13^{+24}_{-36}$	273^{+27+70}_{-24-23}	$(1.13^{+0.09+0.64}_{-0.10-0.28}) \times 10^{-4}$	13.9σ
$f_2'(1525)$	$1513 \pm 5^{+4}_{-10}$	75^{+12+16}_{-10-8}	$(3.42^{+0.43+1.37}_{-0.51-1.30}) \times 10^{-5}$	11.0σ
$f_2(1810)$	1822^{+29+66}_{-24-57}	$229^{+52+88}_{-42-155}$	$(5.40^{+0.60+3.42}_{-0.67-2.35}) \times 10^{-5}$	6.4σ
$f_2(2340)$	$2362^{+31+140}_{-30-63}$	$334^{+62+165}_{-54-100}$	$(5.60^{+0.62+2.37}_{-0.65-2.07}) \times 10^{-5}$	7.6σ

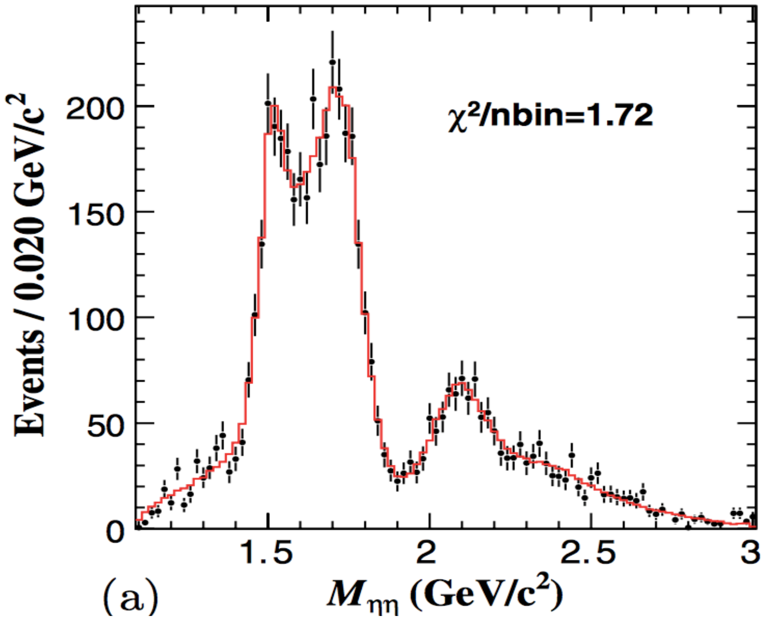
PWA of $J/\psi \rightarrow \gamma K_S^0 K_S^0$

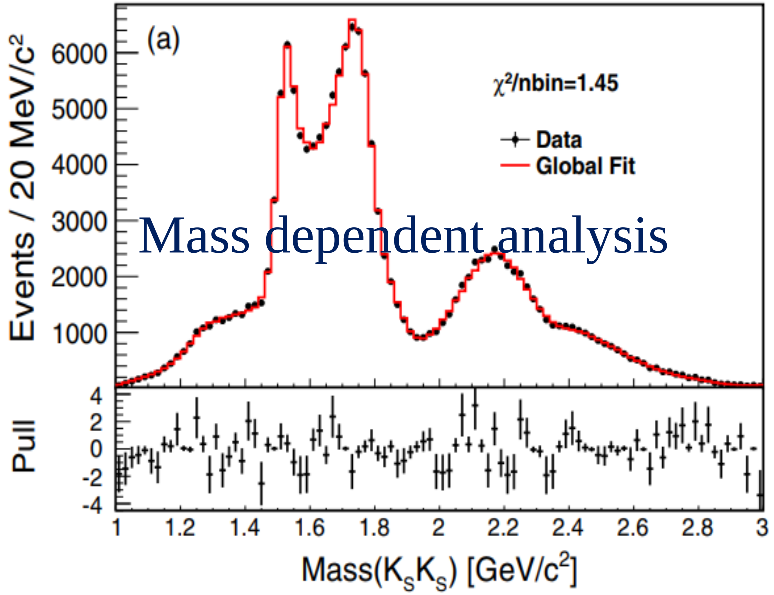
Phys. Rev. D 98, 072003 (2018)



- Dominant scalars: $f_0(1710)$, $f_0(2200)$
- Dominant scalars: $f_2^{'}(1525)$, $f_0(2340)$
- $B(J/\psi \rightarrow \gamma f_0(1710))$ is one order of magnitude larger than $B(J/\psi \rightarrow \gamma f_0(1500))$

PWA of $J/\psi \rightarrow \gamma\eta\eta / \gamma K_S^0 K_S^0$





- $B(J/\psi \rightarrow \gamma f_0(1710))$ is compatible with LQCD prediction for a pure gauge scalar glueball.

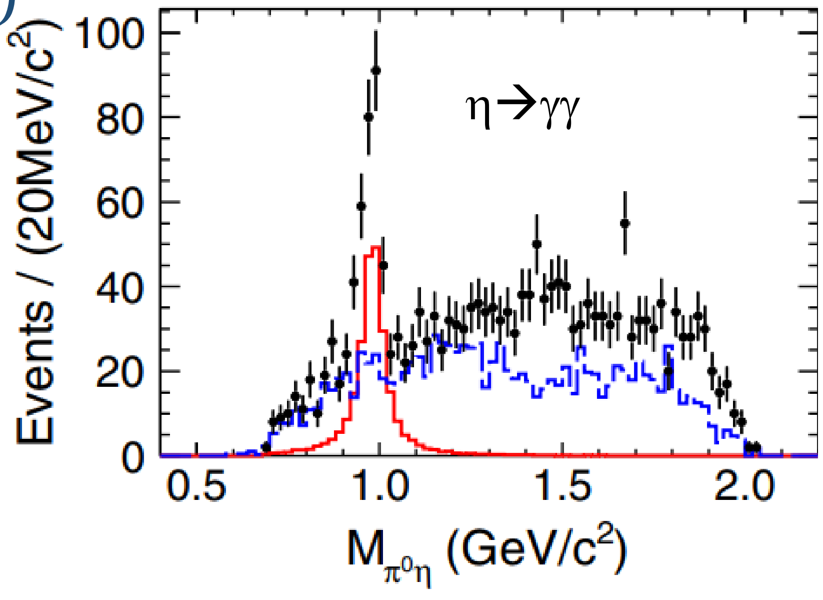
  →suggest possible large overlap with LQCD predictions of 0^+ glueball.
- Production rate of $f_0(1710)$ and $f_0(2100)$ are both about 1 order of magnitude larger than that of $f_0(1500)$.
- A strong contribution from $f_2(2340)$.

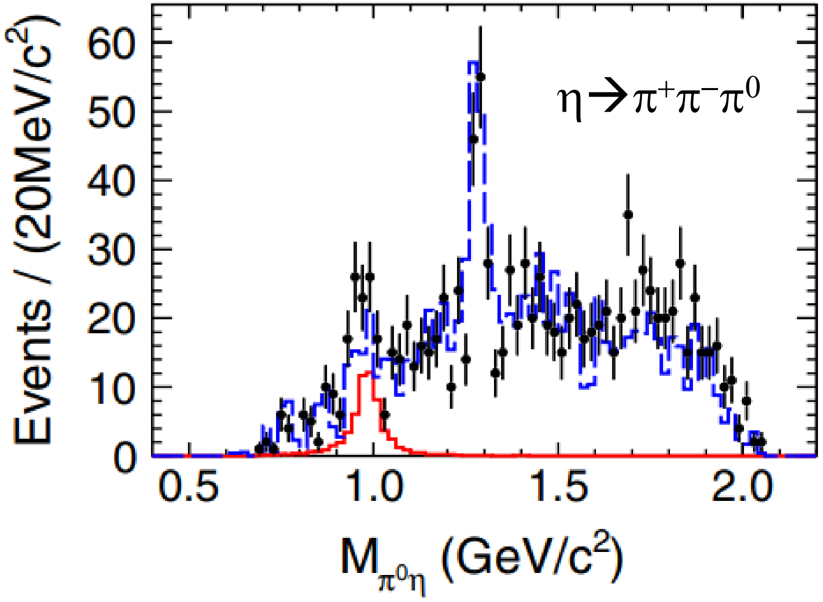
- Dominant scalars: $f_0(1710)$, $f_0(2200)$
- Dominant scalars: $f_2'(1525)$, $f_0(2340)$
- $B(J/\psi \rightarrow \gamma f_0(1710))$ is one order of magnitude larger than $B(J/\psi \rightarrow \gamma f_0(1500))$

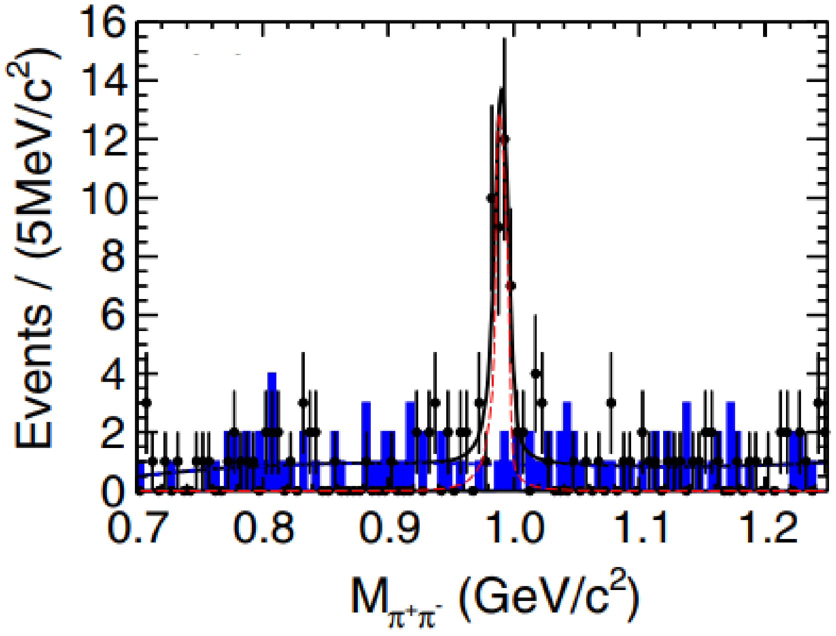
Observation of $a_0(980)$-$f_0(980)$ mixing

Phys. Rev. Lett. 121, 022001 (2018)

- Using 1.3 billion J/ψ events, $f_0(980)$-$a_0(980)$ is observed in the isospin violating $J/\psi \to \phi f_0(980) \to \phi a_0(980) \to \phi\eta\pi^0$ (7.4 σ)



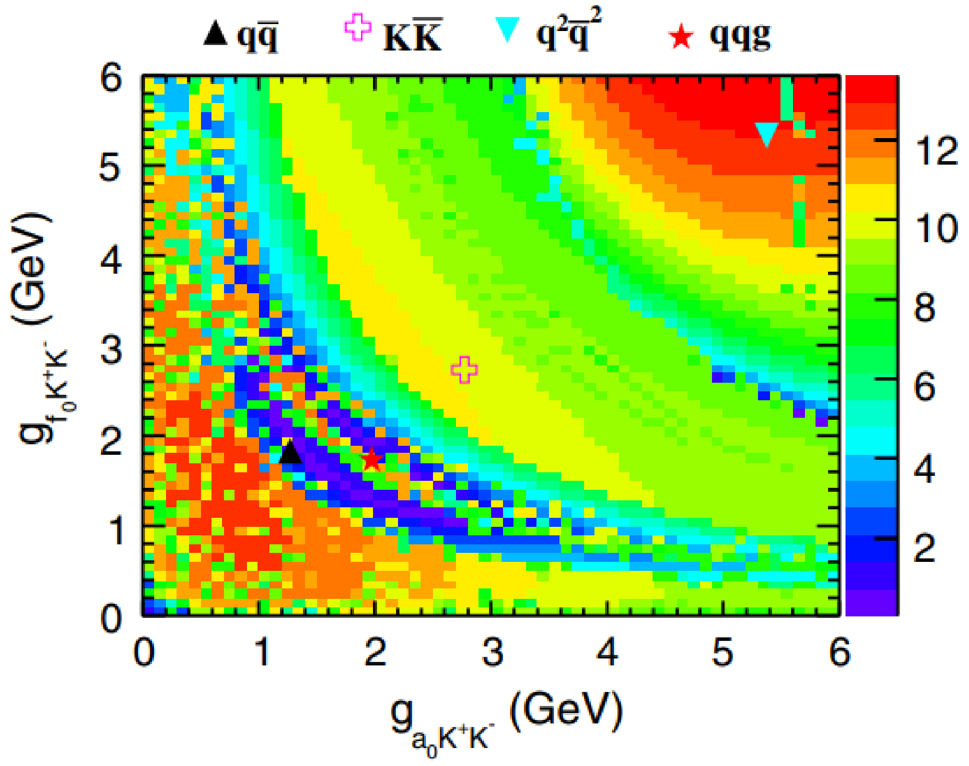




- Using 450 million ψ(3686) events, $a_0(980)$-$f_0(980)$ is observed in the isospin violating $\chi_{c1} \to a_0(980)\pi^0 \to f_0(980)\pi^0 \to \pi^+\pi^-\pi^0$ (5.5 σ)

Observation of $a_0(980)$-$f_0(980)$ mixing

- ✓ The statistical significance of the mixing signal scanned in the 2D space of $g_{f_0 \to K^+K^-}$ and $g_{a_0 \to K^+K^-}$
- ✓ The region with higher significance indicate the larger probability
- ✓ The markers indicate predictions from various theoretical models (without uncertainties of model)



Comparison among BESIII results

0++	$\eta\eta$			K_SK_S		
	M (MeV/c²)	Γ (MeV/c²)	B.R. (x10⁻⁵)	M (MeV/c²)	Γ (MeV/c²)	B.R. (x10⁻⁵)
$f_0(1370)$	-	-	-	$1350 \pm 9^{+12}_{-2}$	$231 \pm 21^{+28}_{-48}$	$1.07^{+0.08+0.36}_{-0.07-0.34}$
$f_0(1500)$	1468^{+14+23}_{-15-74}	$136^{+41+28}_{-26-100}$	**$1.65^{+0.26+0.51}_{-0.31-1.40}$**	1505	109	**$1.59^{+0.16+0.18}_{-0.16-0.56}$**
$f_0(1710)$	$1759 \pm 6^{+14}_{-25}$	$172 \pm 10^{+32}_{-16}$	**$23.5^{+1.3+12.4}_{-1.1-7.4}$**	$1765 \pm 2^{+1}_{-1}$	$146 \pm 3^{+3}_{-1}$	**$20.0^{+0.3+3.1}_{-0.2-1.0}$**
$f_0(1790)$	-	-	-	$1870 \pm 7^{+2}_{-3}$	$146 \pm 14^{+7}_{-15}$	$1.11^{+0.06+0.19}_{-0.06-0.32}$
$f_0(2100)$	$2081 \pm 13^{+24}_{-36}$	273^{+27+70}_{-24-23}	$11.3^{+0.9+6.4}_{-1.0-2.8}$	-	-	-
$f_0(2200)$	-	-	-	$2184 \pm 5^{+4}_{-2}$	$364 \pm 9^{+4}_{-7}$	$27.2^{+0.8+1.7}_{-0.6-4.7}$
$f_0(2330)$	-	-	-	$2411 \pm 10^{+7}_{-7}$	$349 \pm 18^{+23}_{-1}$	$4.95^{+0.21+0.66}_{-0.21-0.72}$

2++	$\eta\eta$			K_SK_S			$\phi\phi$		
	M (MeV/c²)	Γ (MeV/c²)	B.R. (x10⁻⁵)	M (MeV/c²)	Γ (MeV/c²)	B.R. (x10⁻⁵)	M (MeV/c²)	Γ (MeV/c²)	B.R. (x10⁻⁵)
$f_2(1525)$	$1513 \pm 5^{+4}_{-10}$	75^{+12+16}_{-10-8}	$3.42^{+0.43+1.37}_{-0.51-1.30}$	1516 ± 1	$75 \pm 1 \pm 1$	$7.99^{+0.03+0.69}_{-0.04-0.50}$	-	-	-
$f_2(2340)$	$2362^{+31+140}_{-30-63}$	$334^{+62+165}_{-54-100}$	**$5.60^{+0.62+2.37}_{-0.65-2.07}$**	$2233 \pm 34^{+9}_{-25}$	$507 \pm 37^{+18}_{-21}$	**$5.54^{+0.34+3.82}_{-0.40-1.49}$**	2339	319	**$19.1 \pm 0.7^{+7.2}_{-6.9}$**

Search for glueball at BESIII

- 0^{++} sector
  - ✓ The production rate of $f_0(1710)$ is compatible with LQCD prediction for a pure gauge scalar glueball
- 2^{++} sector
  - ✓ f2(2340) seems to be a good candidate for its large production rate in radiative J/ψ decays
- 0^{-+} sector
  - ✓ X(2370) could be a candidate for 0^{-+} glueball
  - ✓ X(2500) observed in J/ψ→γϕϕ and the structure around 2.6 GeV/c^2 observed in $J/\psi \to \gamma\eta'\pi^+\pi^-$.

J/ψ→γPP	J/ψ→γVV	J/ψ→γPPP
J/ψ→γηη	J/ψ→γωϕ	J/ψ→γKKη′
$J/\psi \to \gamma\pi^0\pi^0$	J/ψ→γϕϕ	$J/\psi \to \gamma\eta\pi^0\pi^0$
$J/\psi \to \gamma K_S K_S$	J/ψ→γωω	…
J/ψ→γηη′	…	…
J/ψ→γη′η′	…	…
…	…	…

Published
Release is in schedule
Ongoing