Light Hadron Spectroscopy at BESIII

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On behalf of BESIII collaboration

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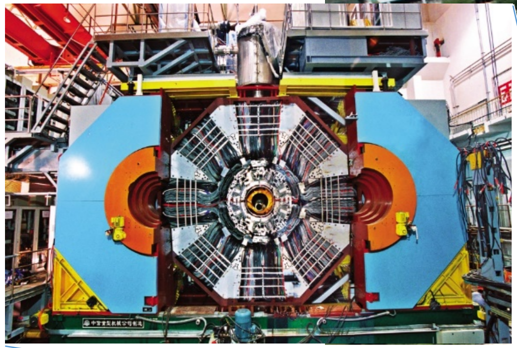
南京大學 NANJING UNIVERSITY

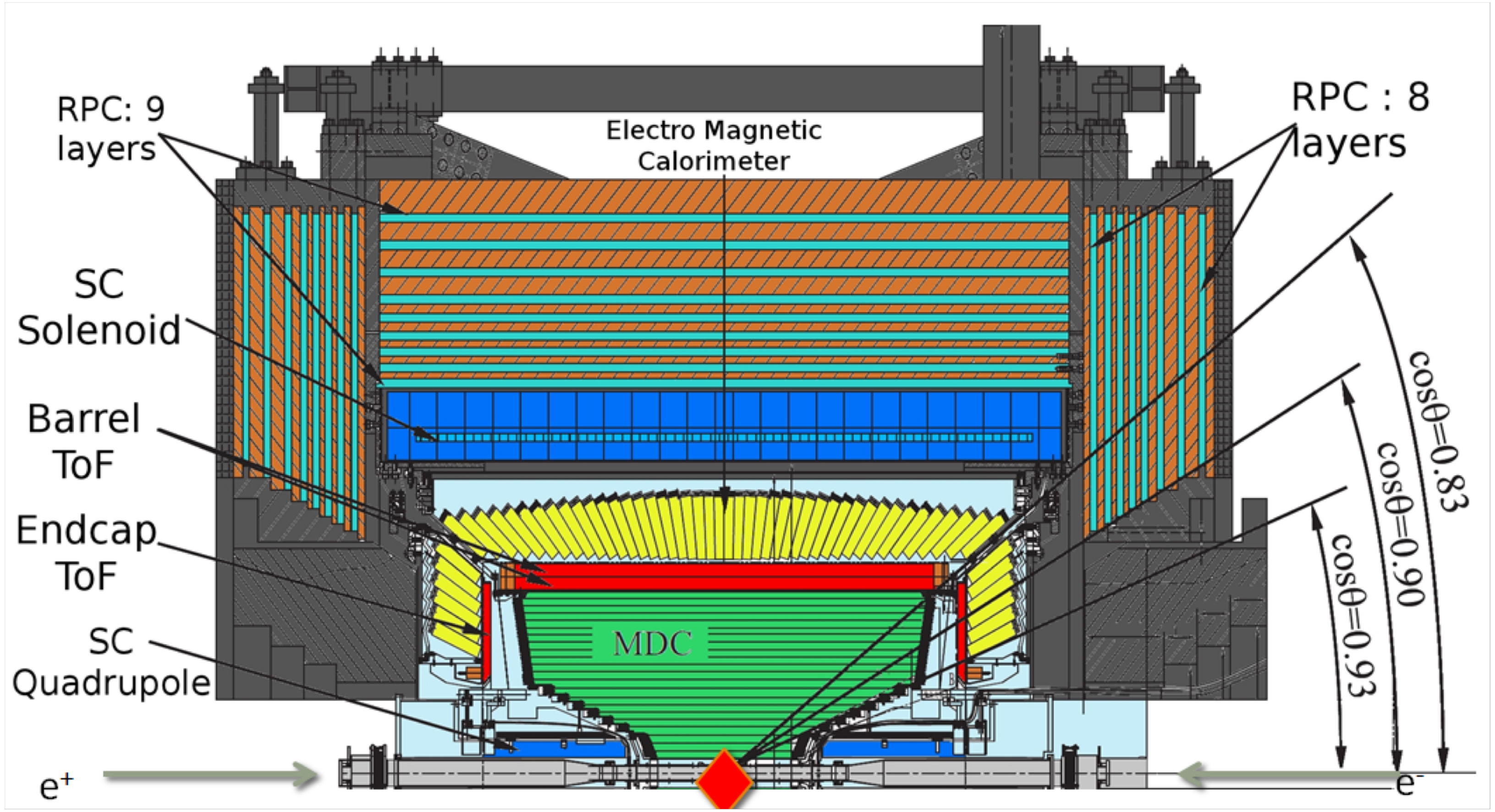
BESIII

BEPCII/BESIII



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

BESIII detector



Main Drift Chamber

σ_P/P = 0.5% @ 1 GeV

$\sigma_{dE/dx}$ = 6%

Time of Flight

σ_T = 90 ps (barrel)

110 ps (endcap)

Super Conducting Solenoid

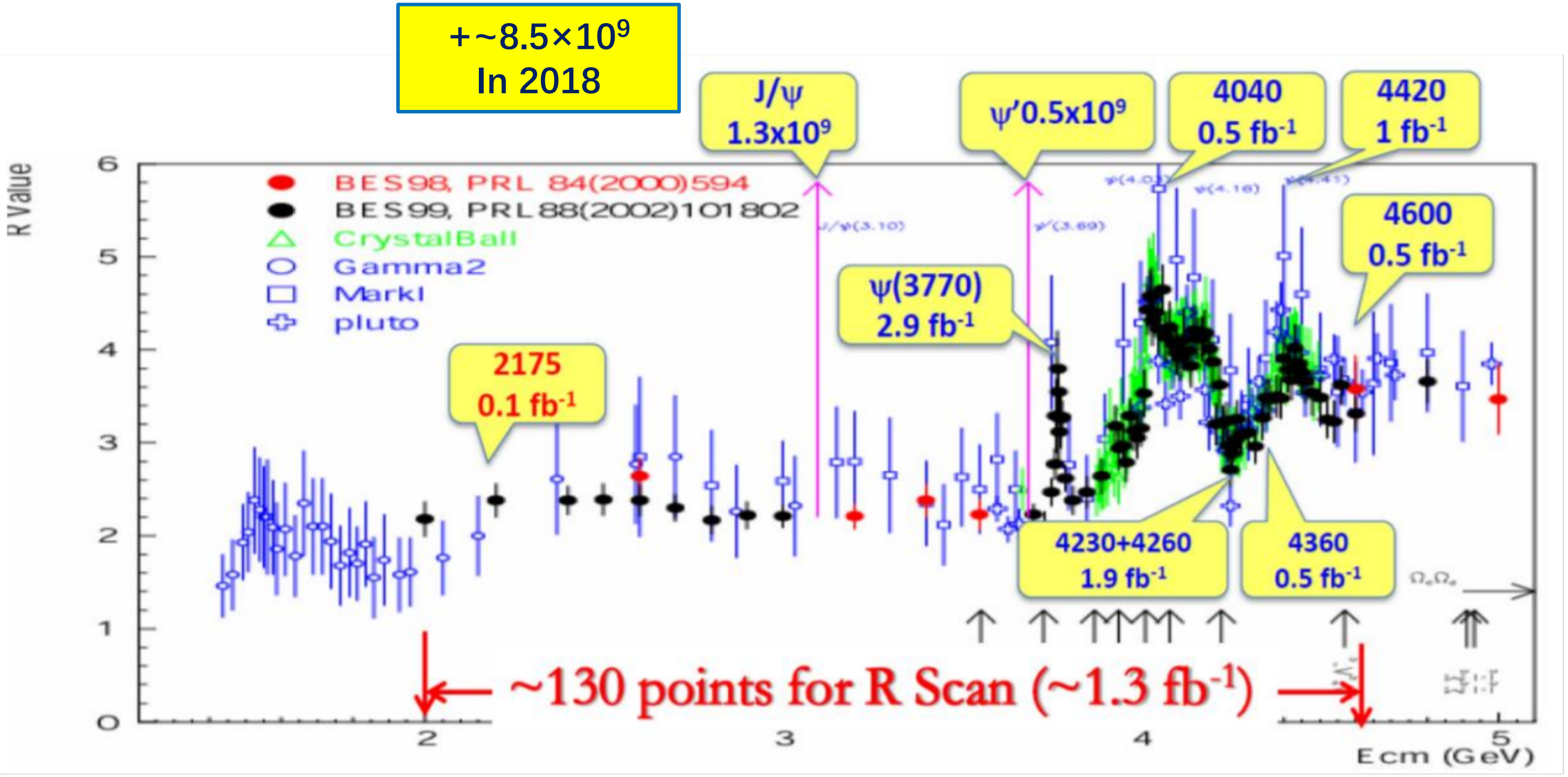
1.0 T (2009)

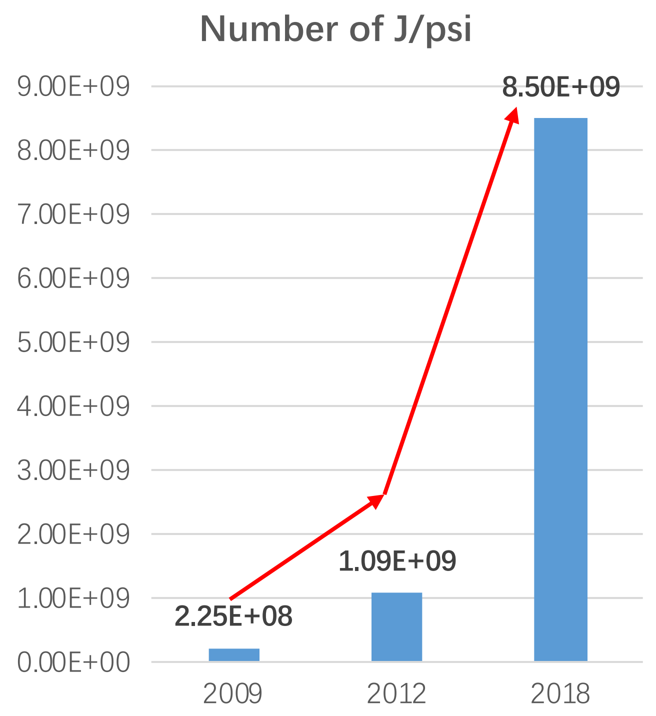
0.9 T (2012)

Electromagnetic Calorimeter

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

BESIII data sets

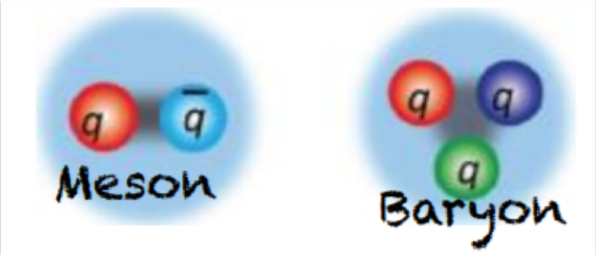


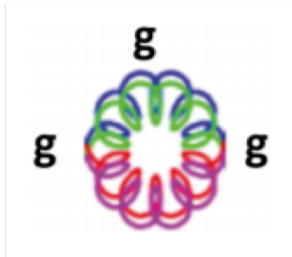


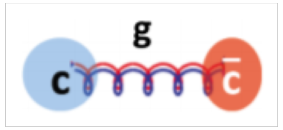
World largest J/ψ, ψ(3686), ψ(3770), … samples

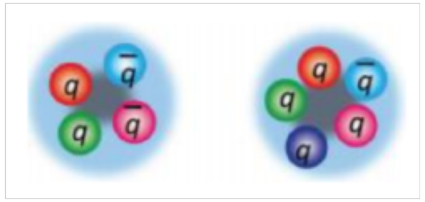
Light hadron spectroscopy at BESIII

- Light hadron spectroscopy is a key tool to study/develop the QCD theory in strong coupling regime
- A major concern: do new forms of hadrons exist?









- BESIII's advantages: the world largest J/ψ, ψ(3686) decay samples
    - Gluon rich processes
    - Kinematic favorable
    - Clean: produced directly from e^+e^- collisions
    - J^{PC}/isospin filter

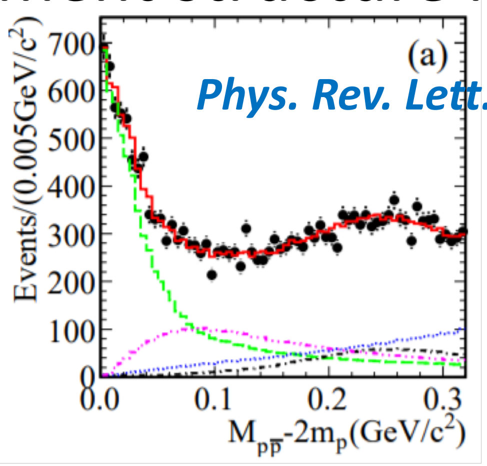
Selected highlights

- X(ppbar)/X(1835)
- Search for glueballs
- $a_0(980)$-$f_0(980)$ mixing

X(ppbar)/X(1835)

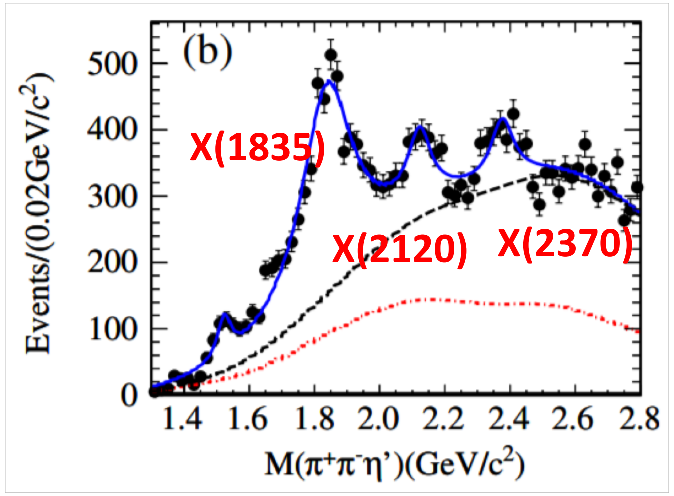
X(ppbar)/X(1835): the same or not?

- X(ppbar): an anomalous strong $p\bar{p}$ threshold enhancement structure in $J/\psi \to \gamma p\bar{p}$, first observed by BESII
  - 0-+
  - Mass = $1836.5^{+19+18}_{-5\ -17} \pm 19$ MeV/c^2
  - Width < 76 MeV/c^2 @ 90% C.L.
  - B.R. = $\left(9.0^{+0.4+1.5}_{-1.1-5.0} \pm 2.3\right) \times 10^{-5}$

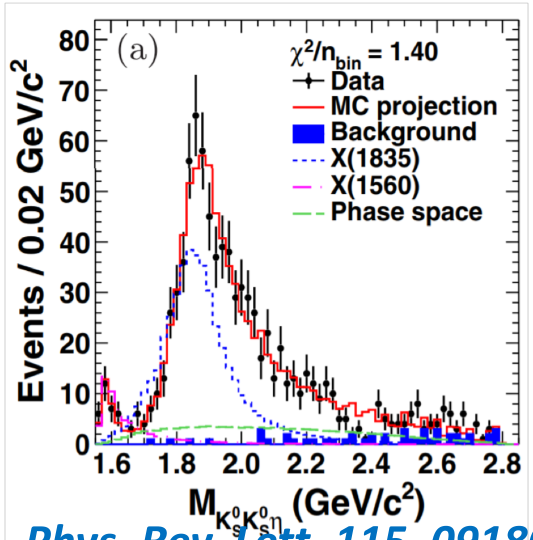


Phys. Rev. Lett. 108, 112003

- X(1835): observed in $J/\psi \to \gamma \eta' \pi^+ \pi^-$ (BESII); also seen in $J/\psi \to \gamma K_S K_S \eta$ (BESIII)
  - 0-+
  - Mass = $1844 \pm 9^{+16}_{-25}$ MeV/c^2
  - Width = 192^{+20+62}_{-17-43} MeV/c^2
  - B.R.($\eta' \pi^+ \pi^-$) = $\left(2.87 \pm 0.09^{+0.49}_{-0.52}\right) \times 10^{-4}$
  - B.R.($K_S K_S \eta$) = $\left(3.31^{+0.33+1.96}_{-0.30-1.29}\right) \times 10^{-5}$



Phys. Rev. Lett. 106, 072002

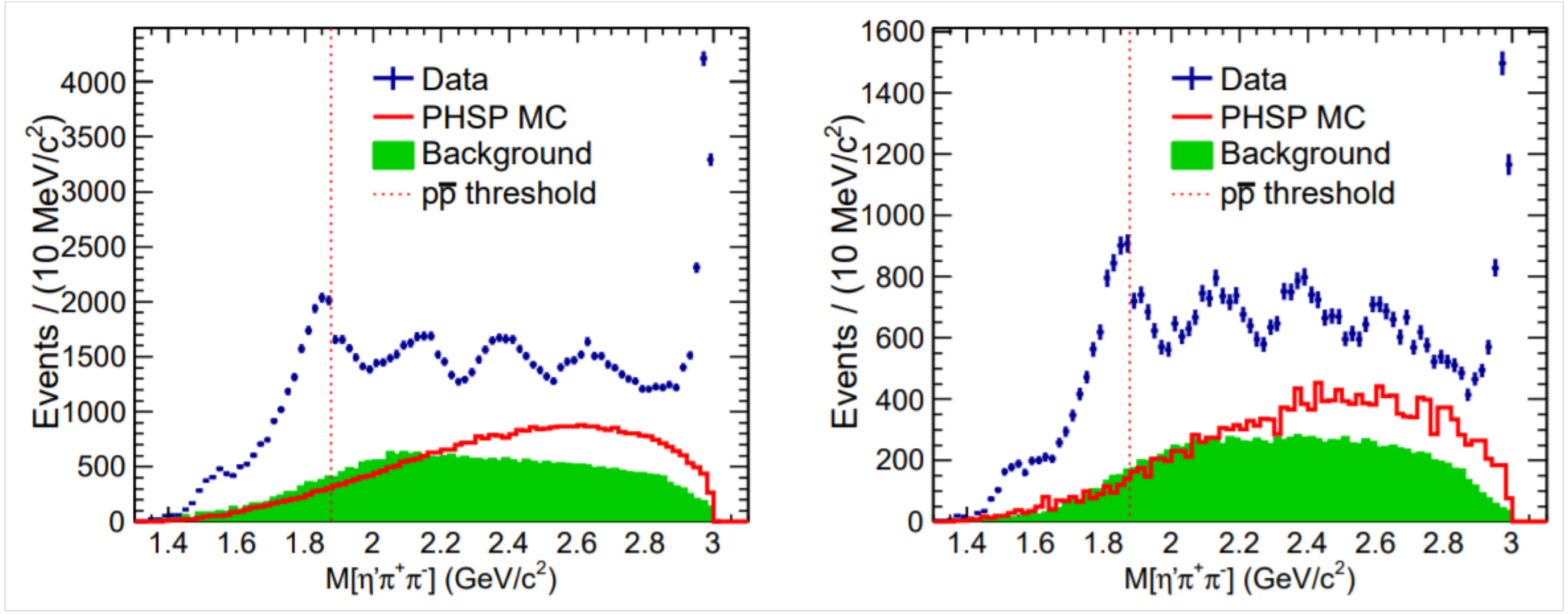


Phys. Rev. Lett. 115, 091803

Anomalous $\eta'\pi^+\pi^-$ line shape near ppbar mass threshold in $J/\psi\to\gamma\eta'\pi^+\pi^-$

Phys. Rev. Lett. 117, 042002

- Re-study using high statistics J/ψ decay sample
- Clear signal of X(1835), X(2120), X(2370), and a structure near 2.65 GeV/c^2
- Significant distortion near ppbar mass threshold
  - Seen in both η′ decay modes



What causes this distorted line shape?

- ☐ The opening of X(1835)→pp̄?
- ☐ Interference between two resonances?

Anomalous $\eta'\pi^+\pi^-$ line shape near ppbar mass threshold in $J/\psi\to\gamma\eta'\pi^+\pi^-$

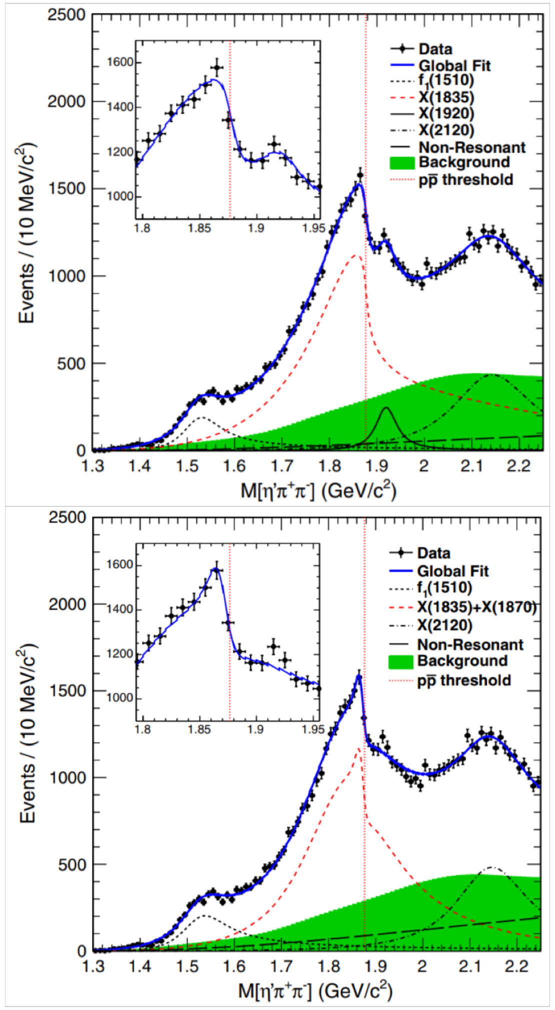
- Model I: Flatte formula
  - Strongly couples to proton-antiproton, significance > 7σ
  - $M_{pole} = 1909.5 \pm 15.9^{+9.4}_{-27.5}$ MeV/c²
  - $\Gamma_{pole} = 273.5 \pm 21.4^{+6.1}_{-64.0}$ MeV/c²

A ppbar molecule state?

- Model II: two coherent Breit-Wigner
  - A broad resonance, whose mass/width are consistent with the X(1835)
  - A narrow resonance just below the ppbar mass threshold, significance > 7σ
    - Mass = $1870.2 \pm 2.2^{+2.3}_{-0.7}$ MeV/c²
    - Width = $13.0 \pm 6.1^{+2.1}_{-3.8}$ MeV/c²

A ppbar bound state?

Phys. Rev. Lett. 117, 042002



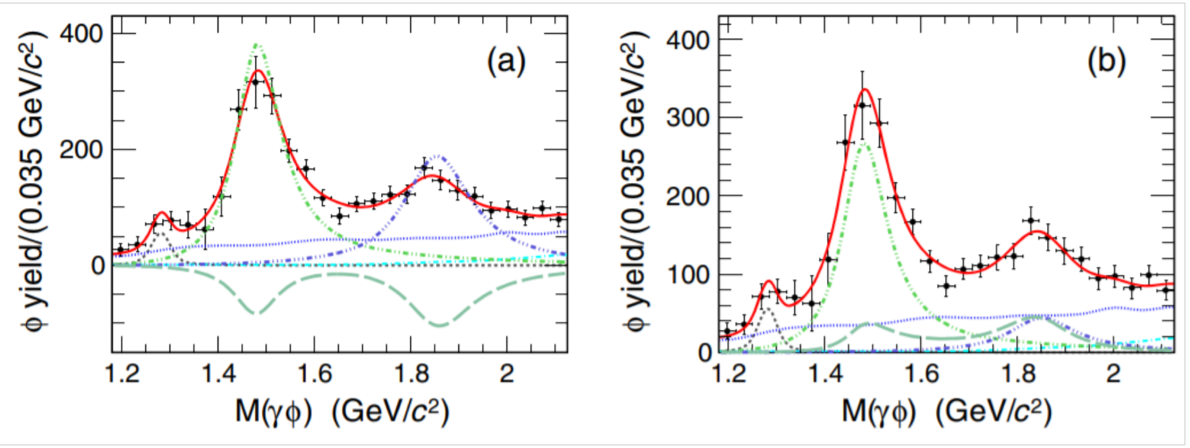
Both models well describes data with almost equally good fit quality

Either there is a ppbar molecule state or there is a ppbar bound state!

Search for X(1835)'s other decay modes

- $J/\psi \to \gamma\gamma\phi$: first observation of $X(1835) \to \gamma\phi$
  - Sizeable $s\bar{s}$ components in X(1835): more complicated than a pure $N\bar{N}$ state
  - B.R. = $(1.77 \pm 0.35 \pm 0.25) \times 10^{-6}$ or $(8.09 \pm 1.99 \pm 1.35) \times 10^{-6}$

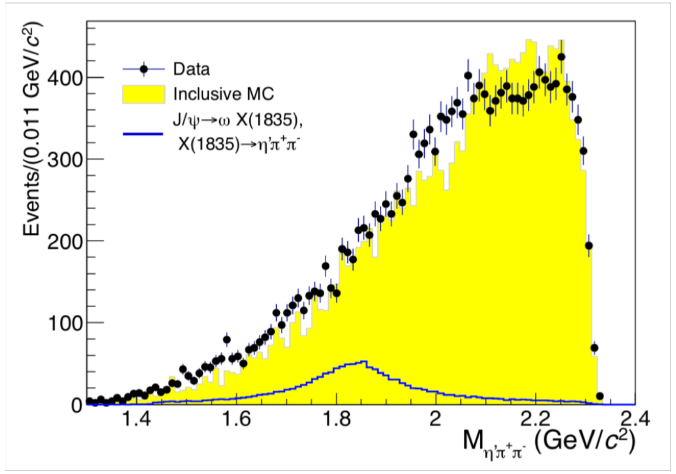
Phys. Rev. D 97, 051101



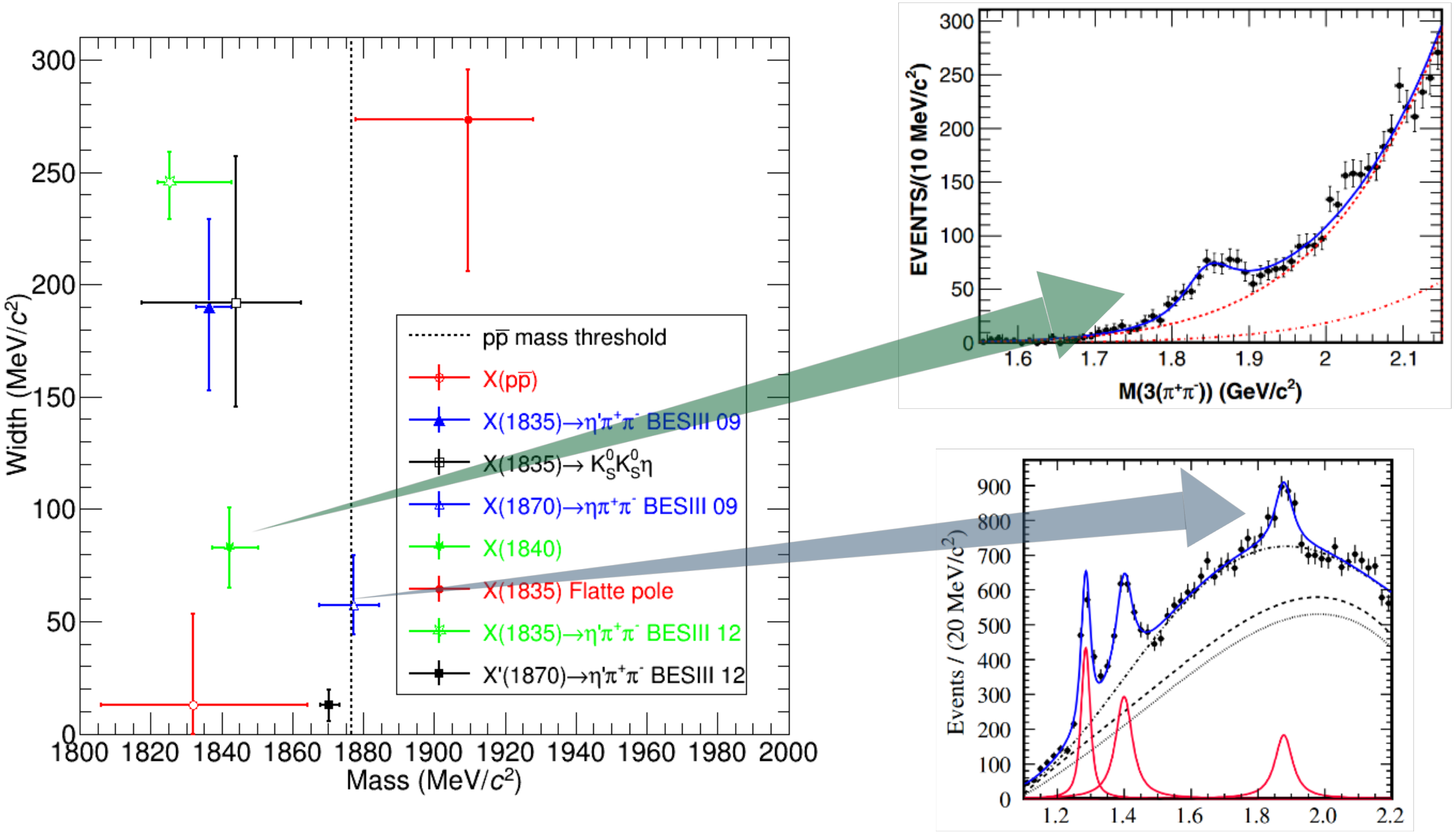
- $J/\psi \to \omega\eta'\pi^+\pi^-$: no obvious sign of X(1835)'s existence
  - B.R. < 6.2×10^{-5} @ 90% C.L.
  - Strong coupling with di-gluon?

	$J/\psi \to \gamma X$	$J/\psi \to \omega X$
$X(1835) \to \eta'\pi^+\pi^-$	$3\times10^{-4} \sim 4\times10^{-4}$	$<6.2\times10^{-5}$ (90%)
$X(p\bar{p}) \to p\bar{p}$	9×10^{-5}	$<3.9\times10^{-6}$ (90%)

arXiv:1902.04862 [hep-ex]



States between 1.8-1.9 GeV/c^2 at BESIII



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

Phys. Rev. D 88, 091502(R)

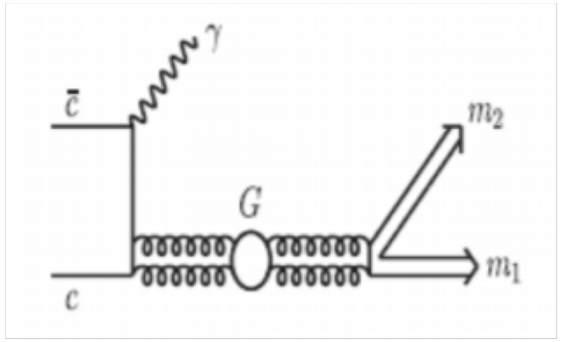
$J/\psi \to \omega\eta\pi^+\pi^-$

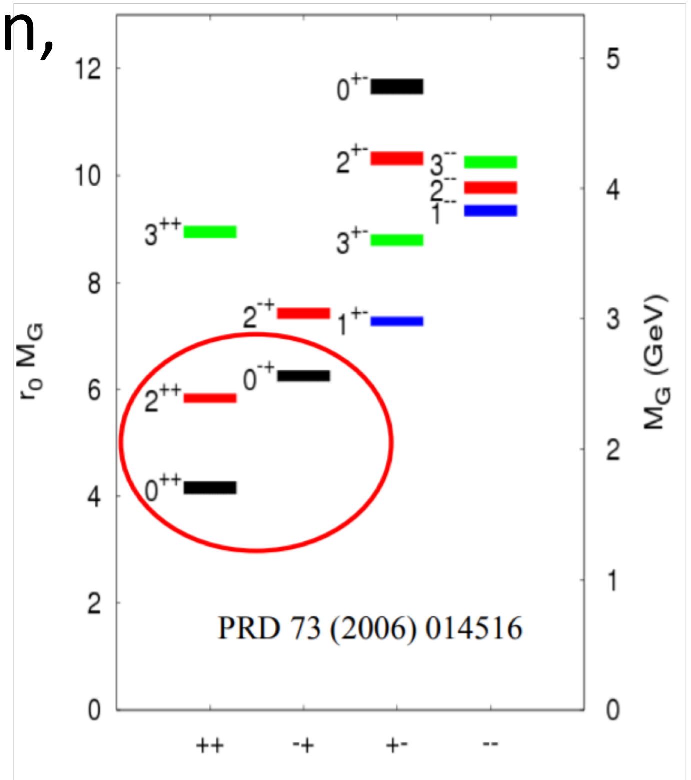
Phys. Rev. Lett. 107, 182001

Search for glueballs

Search for glueball at BESIII

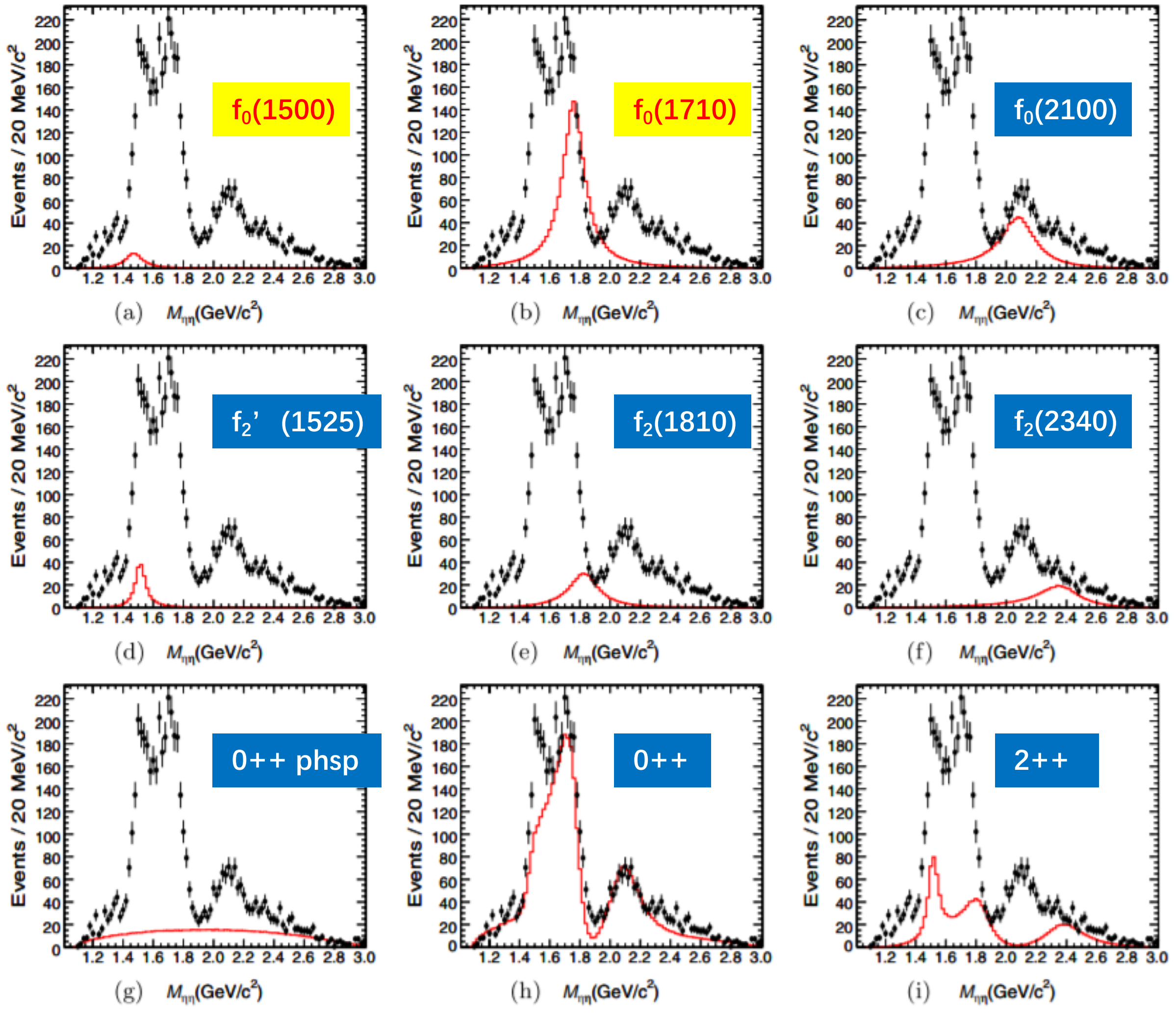
- Glueball is formed by non-abelian gluon-gluon interaction, searching for glueball provides a direct fundamental test of the QCD theory
- Lattice QCD predicts the lowest lying 0-+, 0++, 2++ glueballs have masses below 3 GeV/c^2
- Radiative J/ψ decays are ideal for searching for glueballs
  - 0-+: J/ψ→γPPP, γVV
  - 0++/2++: J/ψ→γPP, γVV





PWA of J/ψ→γηη

- J/ψ→γηη: a good channel to study 0++ and 2++ states
  - Production rate of $f_0(1710)$ is compatible with LQCD prediction for a pure scalar glueball –> **large overlap between $f_0(1710)$ and a 0++ glueball?**

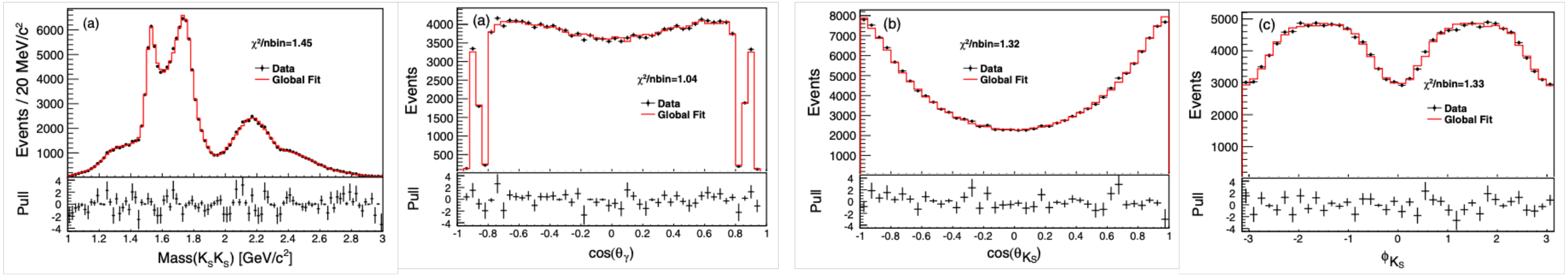


Resonance	Mass (MeV/c^2)	Width (MeV/c^2)	$\mathcal{B}(J/\psi \to \gamma X \to \gamma\eta\eta)$	Significance
$f_0(1500)$	1468^{+14+23}_{-15-74}	$136^{+41+28}_{-26-100}$	$(1.65^{+0.26+0.51}_{-0.31-1.40}) \times 10^{-5}$	8.2σ
$f_0(1710)$	$1759 \pm 6^{+14}_{-25}$	$172 \pm 10^{+32}_{-16}$	$(2.35^{+0.13+1.24}_{-0.11-0.74}) \times 10^{-4}$	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

Phys. Rev. D 87, 092009

2++ components above 2 GeV is well described by a single $f_2(2340)$ with fairly large production rate → $f_2(2340)$ could be a good candidate for the lowest lying tensor glueball

PWA of J/ψ→γ$K_S K_S$



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

B.R.[J/ψ→γf_0(1710)] is one-order of magnitude larger than B.R.[J/ψ→γf_0(1500)]

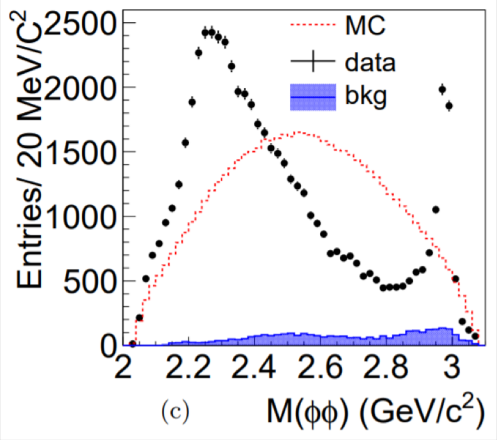
Tensor contribution above 2 GeV is dominantly f_2(2340)

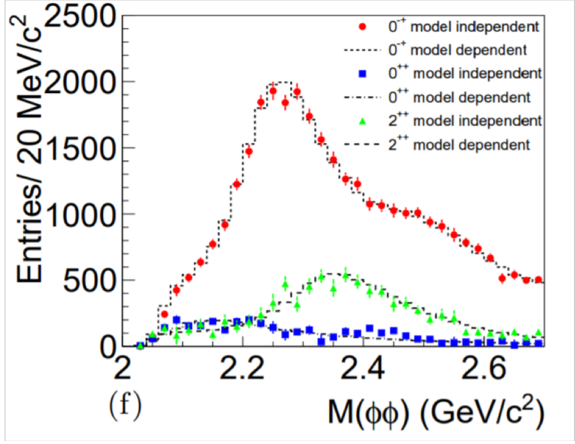
Phys. Rev. D 98, 072003

PWA of J/ψ→γϕϕ

Phys. Rev. D 93, 112011

- Provides an opportunity to study 0-+ and 2++ states above 2 GeV/c^2
- 0-+ contributions
  - η(2225) is confirmed
  - Newly observed: η(2100) and X(2500)
- 2++ contributions
  - f_2(2010), f_2(2300), f_2(2340)
  - **Large production rate of f_2(2340)**





Resonance	M(MeV/c^2)	Γ(MeV/c^2)	B.F.($\times 10^{-4}$)	Sig.
$\eta(2225)$	2216^{+4+18}_{-5-11}	185^{+12+44}_{-14-17}	$(2.40 \pm 0.10^{+2.47}_{-0.18})$	28.1σ
$\eta(2100)$	2050^{+30+77}_{-24-26}	$250^{+36+187}_{-30-164}$	$(3.30 \pm 0.09^{+0.18}_{-3.04})$	21.5σ
X(2500)	2470^{+15+63}_{-19-23}	230^{+64+53}_{-35-33}	$(0.17 \pm 0.02^{+0.02}_{-0.08})$	8.8σ
$f_0(2100)$	2102	211	$(0.43 \pm 0.04^{+0.24}_{-0.03})$	24.2σ
$f_2(2010)$	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	$(1.91 \pm 0.07^{+0.72}_{-0.69})$	10.7σ
0^{-+} PHSP			$(2.74 \pm 0.15^{+0.16}_{-1.48})$	6.8σ

Again, it seems f2(2340) could be a good tensor glueball candidate!

0-+ around 2.5 GeV is close to the predicted mass for pseudoscalar glueball

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
  - $f_2(2340)$ 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

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

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

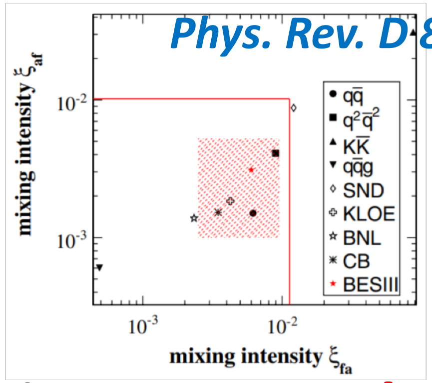
- Theorists proposed $a_0(980)$-$f_0(980)$ mixing mechanism ~40 years ago, to clarify the nature of these two states
- BESIII observed evidence of $a_0(980)$-$f_0(980)$ mixing using 225 million J/ψ events and 106 million ψ′ events

$$\xi_{fa} = \frac{\mathcal{B}[J/\psi \to \phi f_0(980) \to \phi a_0^0(980) \to \phi\eta\pi^0]}{\mathcal{B}[J/\psi \to \phi f_0(980) \to \phi\pi\pi]},$$

3.4σ
< 1.1% @ 90% C.L.

$$\xi_{af} = \frac{\mathcal{B}[\chi_{c1} \to \pi^0 a_0^0(980) \to \pi^0 f_0(980) \to \pi^0\pi^+\pi^-]}{\mathcal{B}[\chi_{c1} \to \pi^0 a_0^0(980) \to \pi^0\pi^0\eta]}.$$

1.9σ
< 1.0% @ 90% C.L.



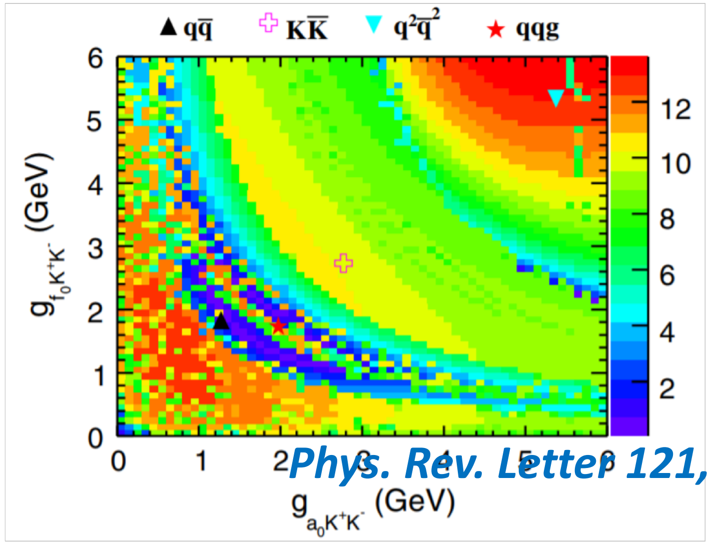
Phys. Rev. D 83, 032003

- By analyzing 1.3 billion J/ψ and 450 million ψ′ collected by BESIII, **$a_0(980)$-$f_0(980)$ mixing is finally confirmed**

TABLE II. The branching fractions ($\mathcal{B}$) and the intensities (ξ) of the $a_0^0(980)$-$f_0(980)$ mixing. The first uncertainties are statistical, the second ones are systematic, and the third ones are obtained using different parameters for $a_0^0(980)$ and $f_0(980)$ as described in the text.

	$f_0(980) \to a_0^0(980)$		
Channel	Solution I	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



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Summary

- BESIII has obtained many results in light hadron spectroscopy since its first physics run started from 2009
  - There are X(ppbar) and X(1835), now we have established connection between them! **Either a proton-antiproton molecule state or bound state exists**
  - X(1840) and X(1870) - it's very strange/interesting to see so many states with similar properties (mass/width/decay modes/…) in this region
  - **Extensive and systematic searching for glueballs**: $f_0(1710)$, $f_2(2340)$, X(2370), X(2500), and X(26??), …
  - **First observation of $a_0(980)$-$f_0(980)$ mixing**. Many unexpected/interesting phenomena: narrow $f_0(980)$, large isospin breaking rate, …
- After 2018's J/ψ data taking, the amount of total J/ψ events has increased from 1.3 billion to 10 billion. More and more interesting results are expected in the near future.

Thanks!

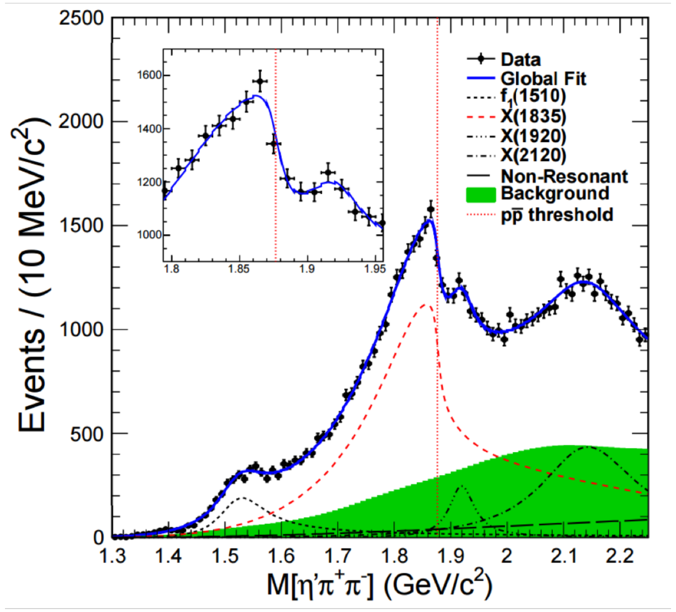
Anomalous line shape of η′π⁺π⁻ near $p\bar{p}$ mass threshold in J/ψ→γη′π⁺π⁻

- Use the Flatté formula for the line shape
  - $T = \frac{\sqrt{\rho_{out}}}{\mathcal{M}^2 - s - i\sum_k g_k^2 \rho_k}$
    - $\sum_k g_k^2 \rho_k \simeq g_0^2(\rho_0 + \frac{g_{p\bar{p}}^2}{g_0^2}\rho_{p\bar{p}})$
    - $g_{p\bar{p}}^2/g_0^2$ is the ratio between the coupling strength to the $p\bar{p}$ channel and the summation of all other channels

The state around 1.85 GeV/c^2	
$\mathcal{M}$ (MeV/c^2)	$1638.0\ ^{+121.9}_{-121.9}\ ^{+127.8}_{-254.3}$
g_0^2 ((GeV/c^2)^2)	$93.7\ ^{+35.4}_{-35.4}\ ^{+47.6}_{-43.9}$
$g_{p\bar{p}}^2/g_0^2$	$2.31\ ^{+0.37}_{-0.37}\ ^{+0.83}_{-0.60}$
M_{pole} (MeV/c^2) *	$1909.5\ ^{+15.9}_{-15.9}\ ^{+9.4}_{-27.5}$
Γ_{pole} (MeV/c^2) *	$273.5\ ^{+21.4}_{-21.4}\ ^{+6.1}_{-64.0}$
Branching Ratio	$(3.93\ ^{+0.38}_{-0.38}\ ^{+0.31}_{-0.84})\times 10^{-4}$

* The pole nearest to the $p\bar{p}$ mass threshold

A $p\bar{p}$ molecule-like state?



$\log\mathcal{L}$ = 630549.5

Significance of $g_{p\bar{p}}^2/g_0^2$ being non-zero is larger than 7σ

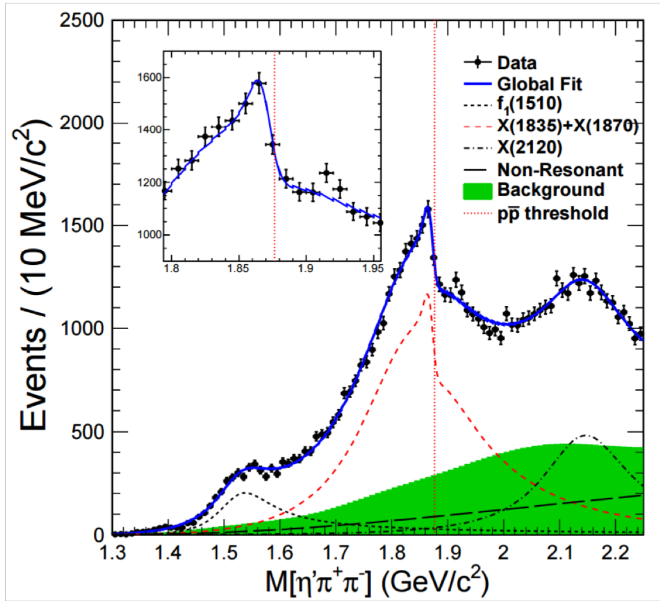
X(1920) is needed with 5.7σ

Anomalous line shape of $\eta'\pi^+\pi^-$ near $p\bar{p}$ mass threshold in $J/\psi \to \gamma\eta'\pi^+\pi^-$

- Use coherent sum of two Breit-Wigner amplitudes
  - $T = \frac{\sqrt{\rho_{out}}}{M_1^2 - s - iM_1\Gamma_1} + \frac{\beta \cdot e^{i\theta} \cdot \sqrt{\rho_{out}}}{M_2^2 - s - iM_2\Gamma_2}$

X(1835)	
M (MeV/c^2)	$1825.3\ ^{+2.4}_{-2.4}\ ^{+17.3}_{-2.4}$
Γ (MeV/c^2)	$245.2\ ^{+14.2}_{-12.6}\ ^{+4.6}_{-9.6}$
B.R. (constructive interference)	$(3.01\ ^{+0.17}_{-0.17}\ ^{+0.26}_{-0.28}) \times 10^{-4}$
B.R. (destructive interference)	$(3.72\ ^{+0.21}_{-0.21}\ ^{+0.18}_{-0.35}) \times 10^{-4}$
X(1870)	
M (MeV/c^2)	$1870.2\ ^{+2.2}_{-2.3}\ ^{+2.3}_{-0.7}$
Γ (MeV/c^2)	$13.0\ ^{+7.1}_{-5.5}\ ^{+2.1}_{-3.8}$
B.R. (constructive interference)	$(2.03\ ^{+0.12}_{-0.12}\ ^{+0.43}_{-0.70}) \times 10^{-7}$
B.R. (destructive interference)	$(1.57\ ^{+0.09}_{-0.09}\ ^{+0.49}_{-0.86}) \times 10^{-5}$

A $p\bar{p}$ bound state?



log$\mathcal{L}$ = 630540.3

Significance of X(1870) is larger than 7σ

X(1920) is not significant

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

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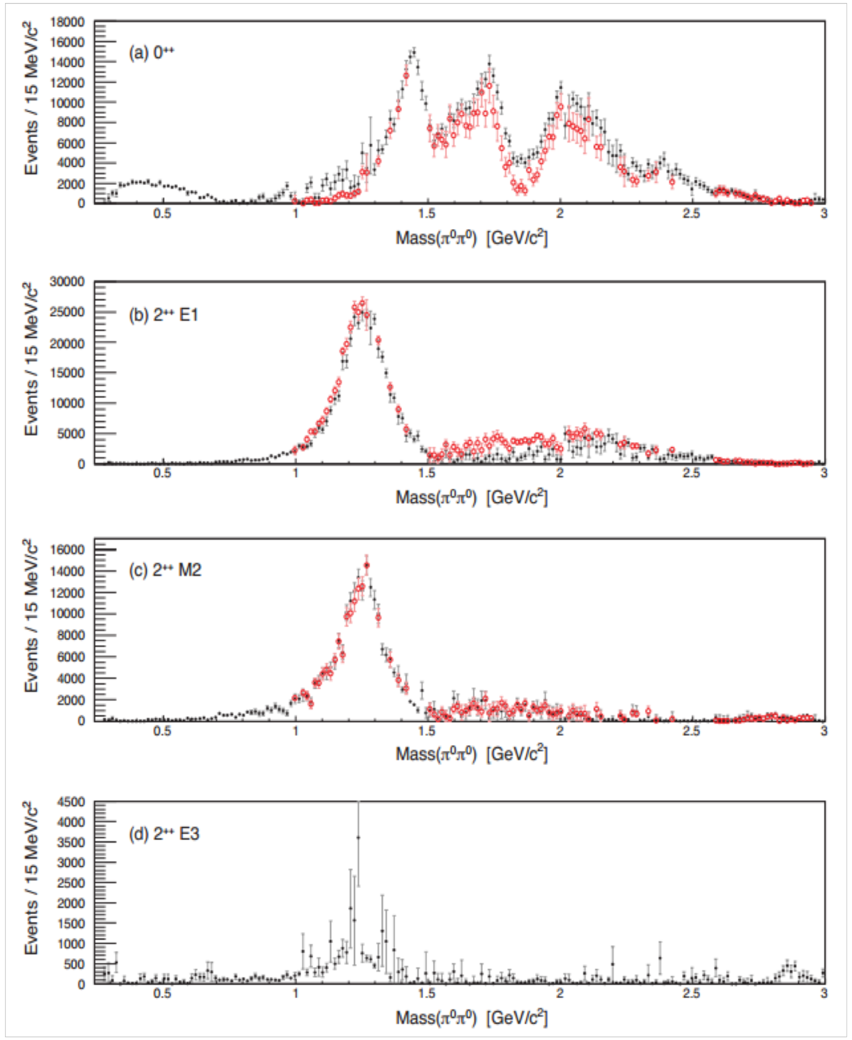
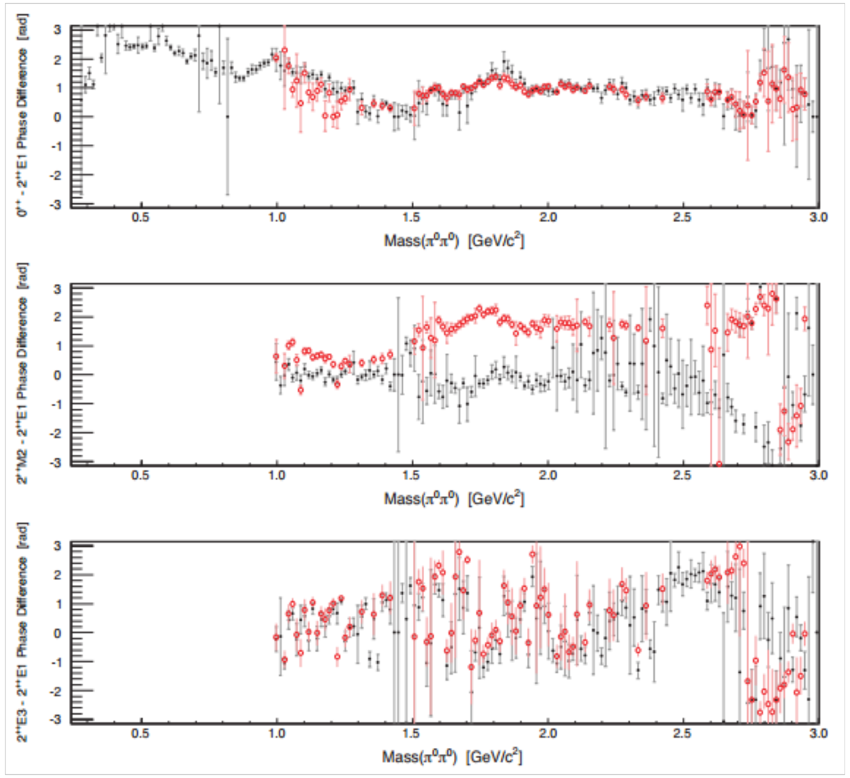
Extracted intensity



Relative phase



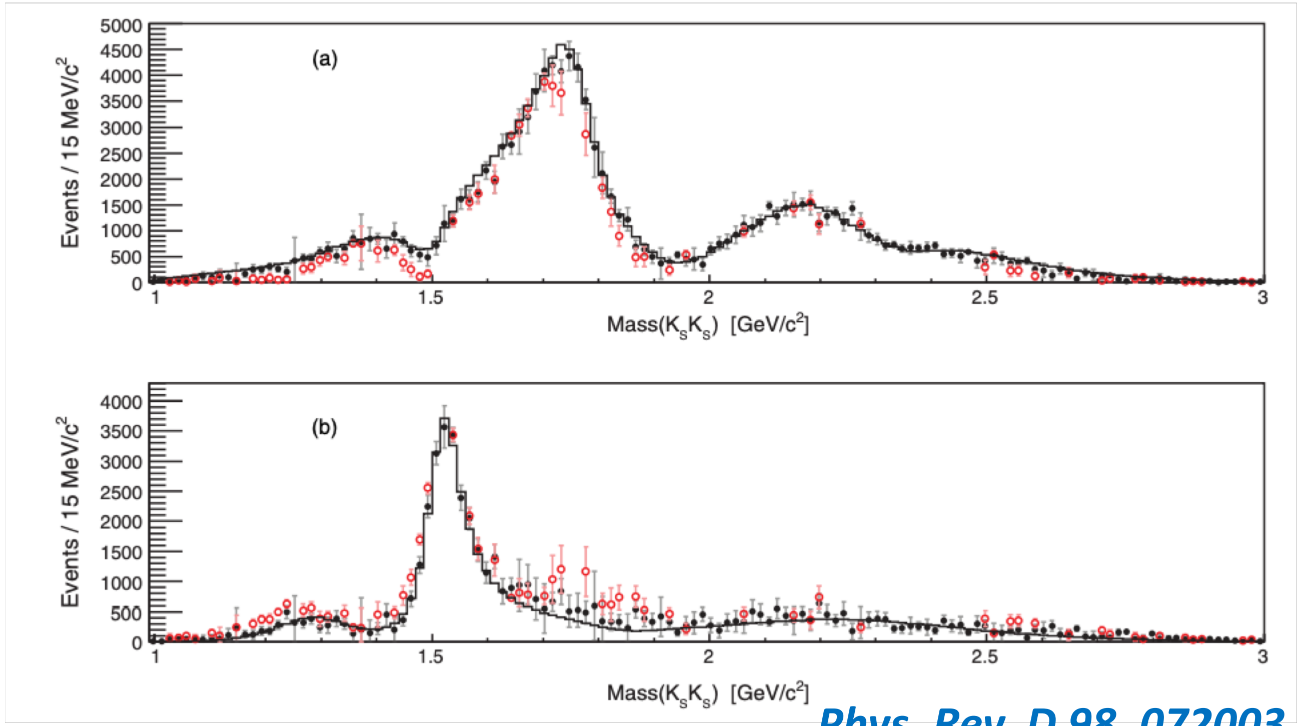
- Nominal Solution
- Ambiguous Solution

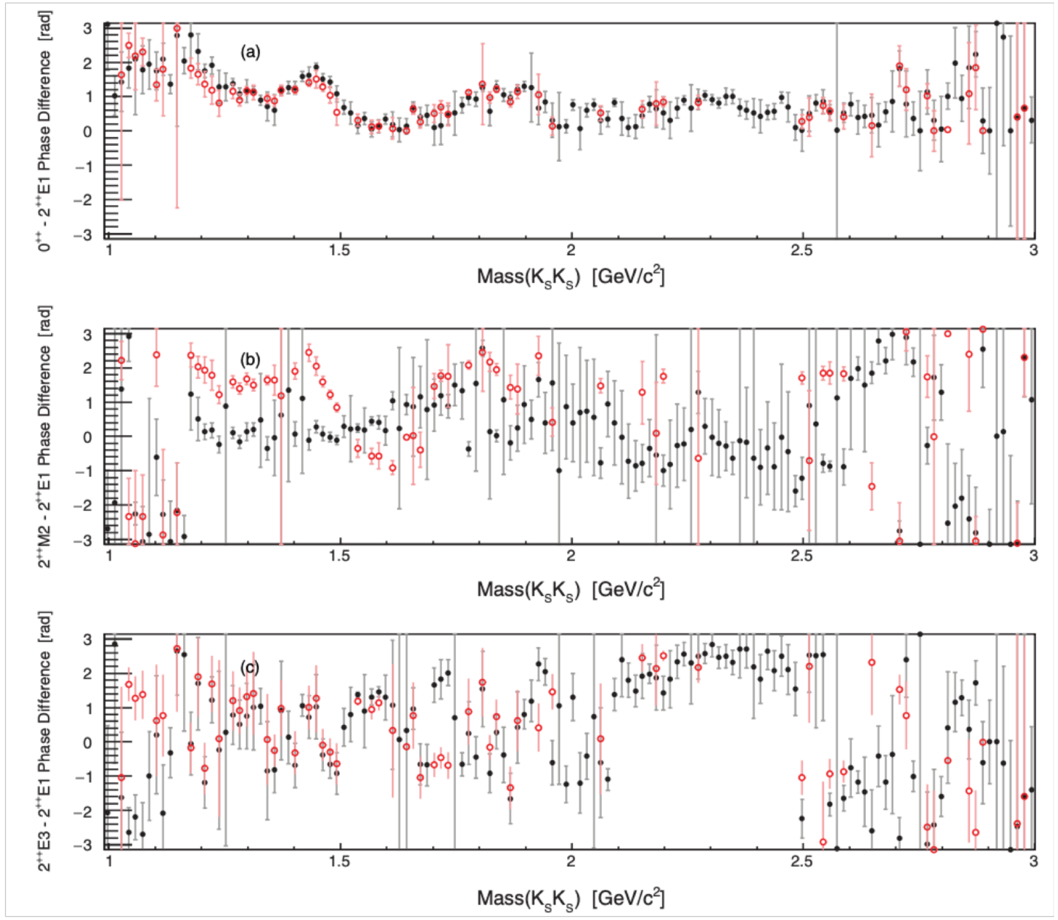
✓ A piecewise function that describes the dynamics of the $\pi^0\pi^0$ system is determined as a function of $M(\pi^0\pi^0)$

✓ Significant features of the scalar spectrum includes structures near 1.5, 1.7 and 2.0 GeV/c^2

✓ Ambiguities present above $K\bar{K}$ threshold

PWA of $J/\psi \rightarrow \gamma K_S K_S$ (model independent)





Phys. Rev. D 98, 072003

- Nominal Solution
- Ambiguous Solution

✓ Significant features of the scalar spectrum includes structures near 1.7 and above 2.0 GeV/c^2

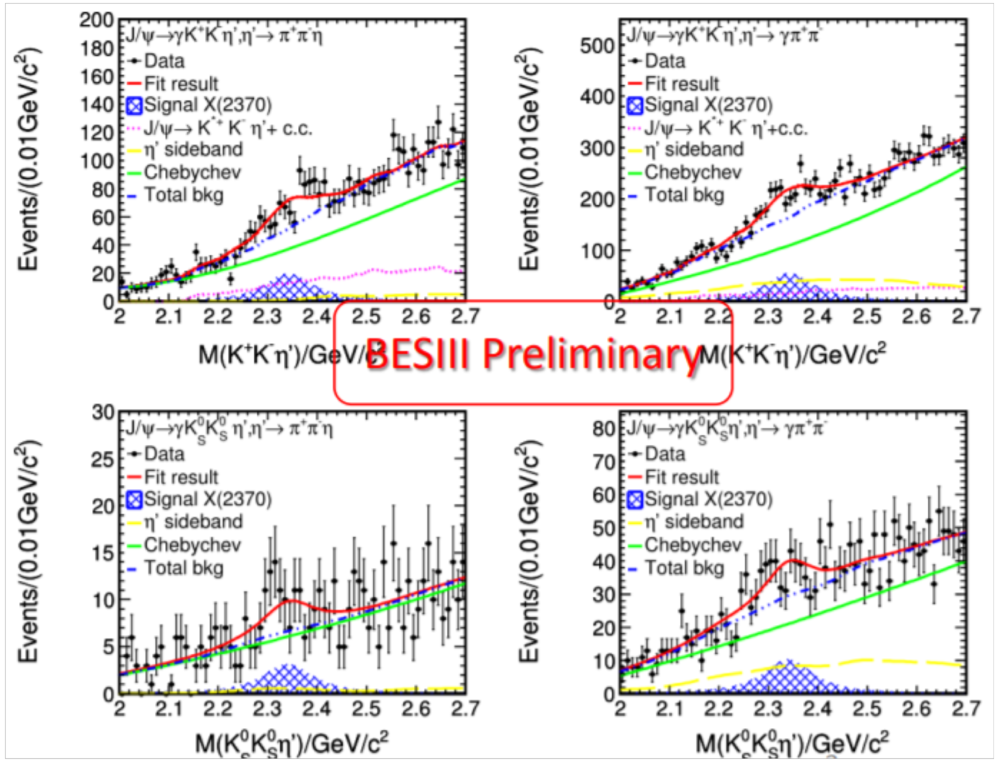
✓ Good agreement with results of model dependent PWA

✓ Ambiguities exist in model independent PWA

Observation of X(2370) in J/ψ→γKKη′

- X(2120) and X(2370) were first observed by the BESIII in $J/\psi \to \gamma \eta' \pi^+ \pi^-$
  - LQCD predicts the lowest lying 0-+ glueball has mass between 2.3-2.6 GeV/c^2
  - X(2120) and X(2370) are candidates?
- Combined study of $J/\psi \to \gamma K^+ K^- \eta' / \gamma K_S K_S \eta'$
  - First observation of X(2370) in this process

	combined results
M (MeV/c^2)	$2343.91 \pm 6.88(stat.) \pm 1.23(sys.)$
Γ (MeV)	$117.73 \pm 12.75(stat.) \pm 4.14(sys.)$
$B(J/\psi \to \gamma X(2370) \to \gamma K^+ K^- \eta')$	$(1.86 \pm 0.39\ (stat.) \pm 0.29\ (sys.)) \times 10^{-5}$
$B(J/\psi \to \gamma X(2370) \to \gamma K_S^0 K_S^0 \eta')$	$(1.19 \pm 0.37\ (stat.) \pm 0.18\ (sys.)) \times 10^{-5}$



- Mass/width are consistent with X(2370) in $J/\psi \to \gamma \eta' \pi^+ \pi^-$
- Br[X(2370)→KKη′]/Br[X(2370)→η′π⁺π⁻] ~ 1/15
- A theoretical work predicts **$\Gamma_{G \to KK\eta'}/\Gamma_G = 0.011$** and **$\Gamma_{G \to \eta'\pi\pi}/\Gamma_G = 0.090$** for $M_G = 2.37$ GeV/c^2 (PRD 87, 054036)

- No clear signal of X(2120)

Spin-parity is not yet determined