Observation of an isoscalar resonance with exotic $J^{PC} = 1^{-+}$ quantum numbers in $J/\psi \to \gamma\eta\eta'$

arXiv:2202.00621, 2202.00623

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Hadron Spectroscopy: The Next Big Steps

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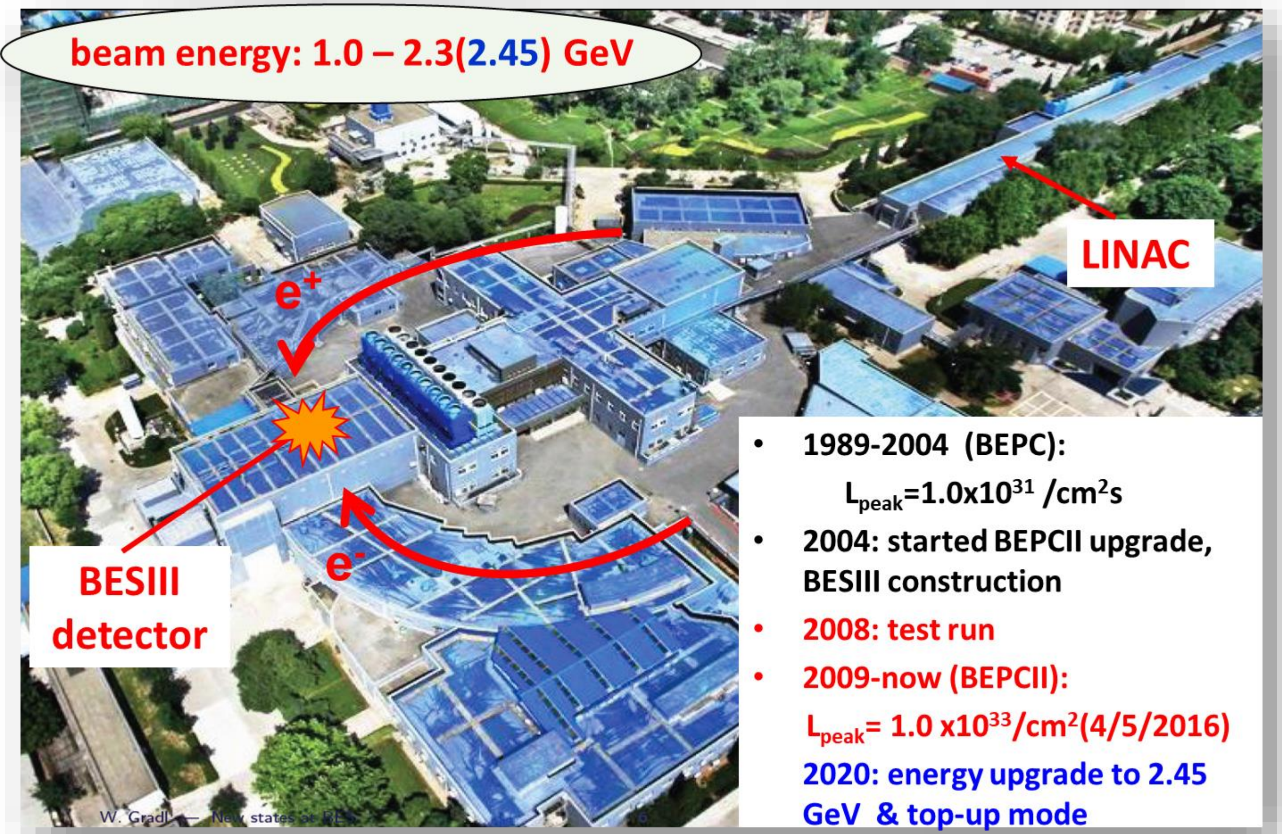
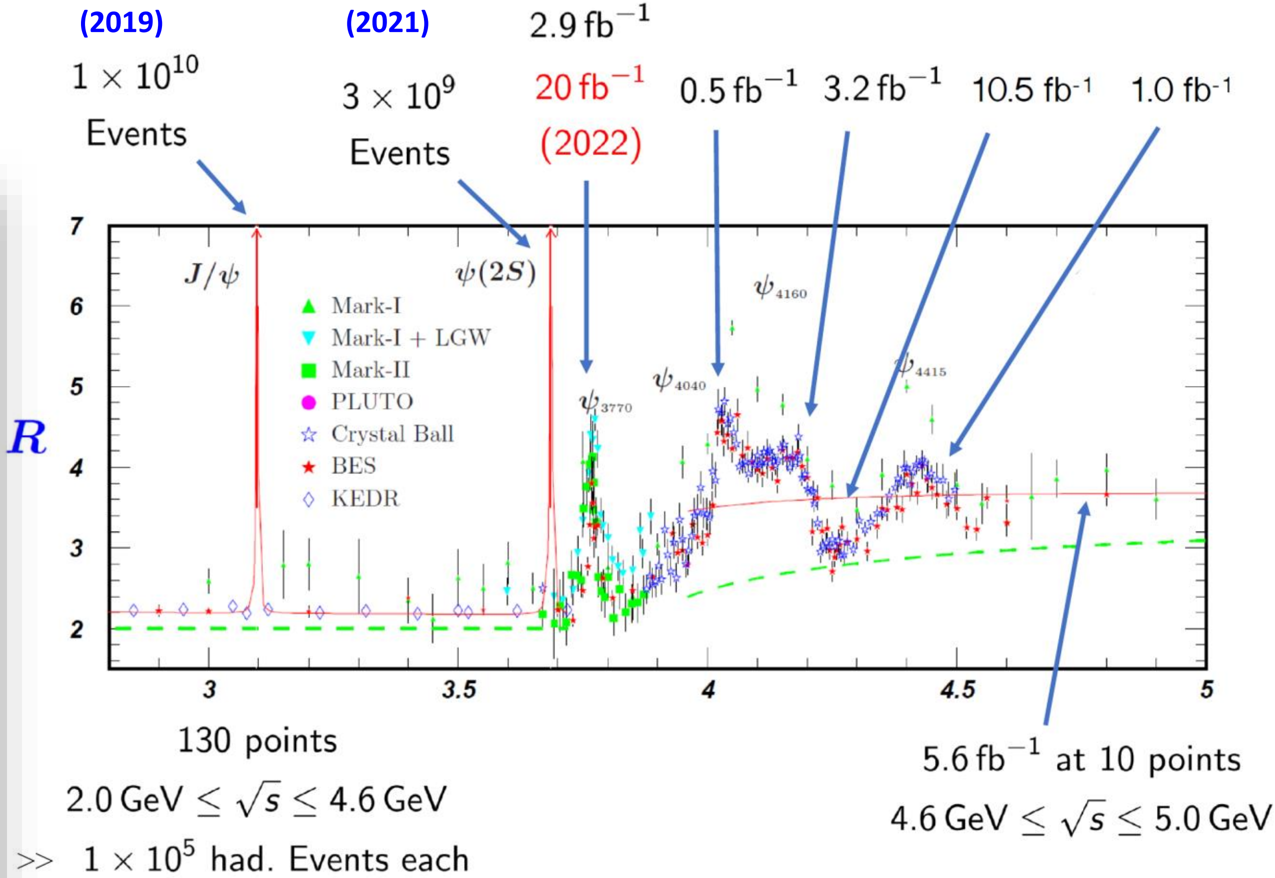
Mainz Institute for Theoretical Physics, Johannes Gutenberg U

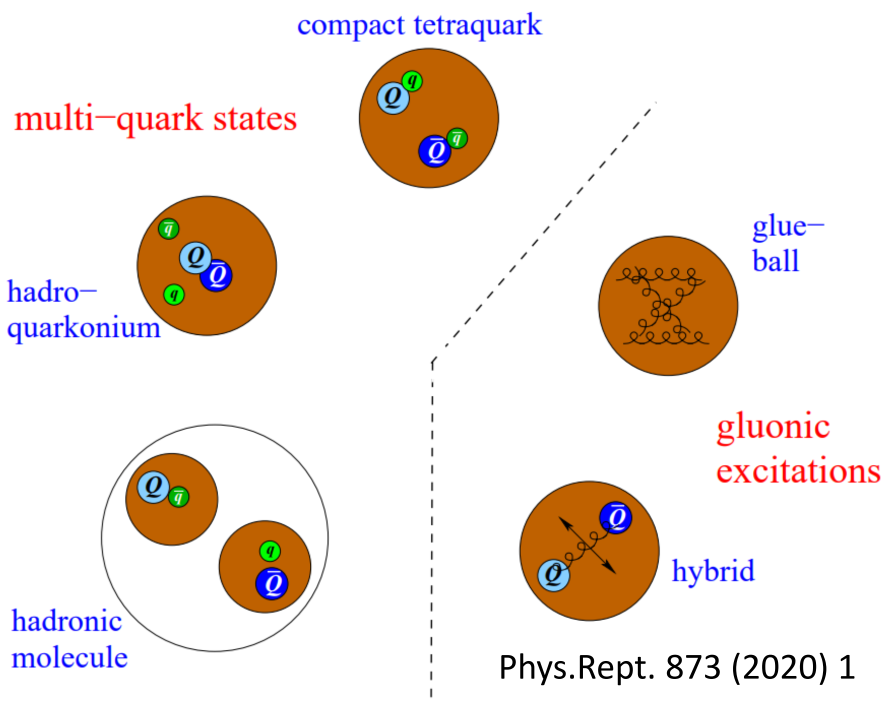
World's largest $\boldsymbol{\tau - \mathrm{charm}}$ data sets in $\mathbf{e^+e^-}$ annihilation

Beijing Electron Positron Collider (BEPCII)





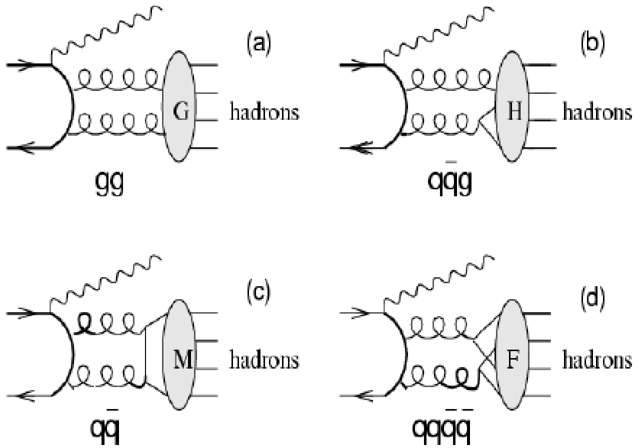
Charmonium decays provide an ideal lab for light hadron physics



Phys.Rept. 873 (2020) 1

What's the role of gluonic excitation and how does it connect to the confinement?

- Clean high statistics data samples
- Well defined initial and final states
  - Kinematic constraints
  - $I(J^{PC})$ filter
- "Gluon-rich" process



Scalar glueball candidate: production properties

$$\Gamma(J/\psi \to \gamma G_{0^+}) = \frac{4}{27}\alpha\frac{|p|}{M^2_{J/\psi}}|E_1(0)|^2 = 0.35(8)keV$$
$$\Gamma/\Gamma_{tot} = 0.33(7)/93.2 = 3.8(9)\times 10^{-3}$$

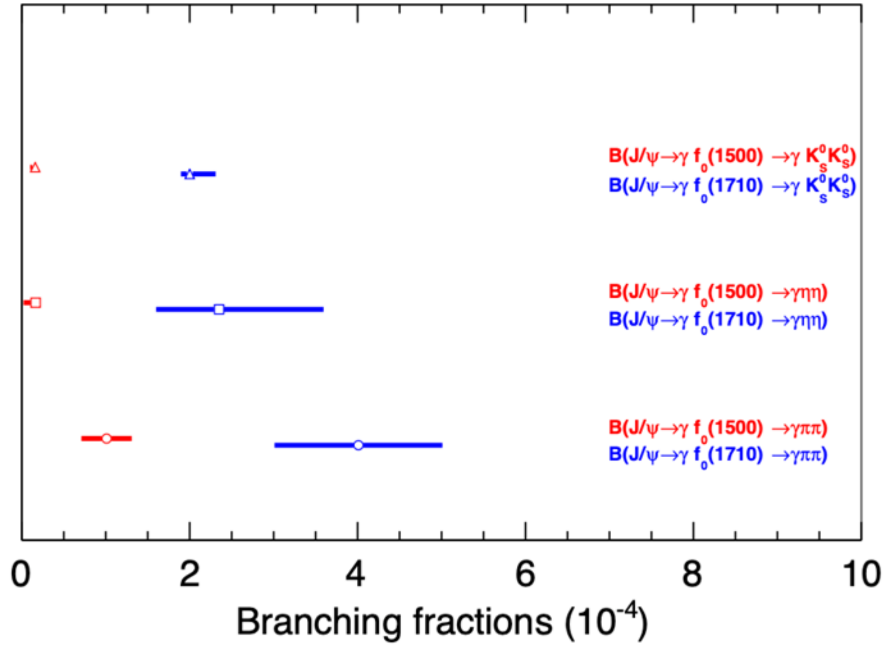
CLQCD, Phys. Rev. Lett. 110, 021601 (2013)

Experimental results

- B(J/ψ → $\gamma f_0(1710)$ → $\gamma K\bar{K}$)=$(8.5^{+1.2}_{-0.9})\times 10^{-4}$
- B(J/ψ → $\gamma f_0(1710)$ → γππ)=$(4.0\pm1.0)\times 10^{-4}$
- B(J/ψ → $\gamma f_0(1710)$ → γωω)=$(3.1\pm1.0)\times 10^{-4}$
- B(J/ψ → $\gamma f_0(1710)$ → γηη)=$(2.35^{+0.13+1.24}_{-0.11-0.74})\times 10^{-4}$

⇒ B(J/ψ → $\gamma f_0(1710)$) > 1.7×10^{-3}

$B(J/\psi \to \gamma f_0(1710))$ is x10 large than that of $f_0(1500)$



$f_0(1710)$ largely overlapped with scalar glueball

Recent coupled channel phenomenology analyses

Phys.Lett.B 816 (2021) 136227 *Eur.Phys.J.C 82 (2022) 1, 80*

Scalar glueball candidate: decay properties

$$\Gamma(G \to \pi\pi : K\bar{K} : \eta\eta : \eta\eta' : \eta'\eta') = 3 : 4 : 1 : 0 : 1$$

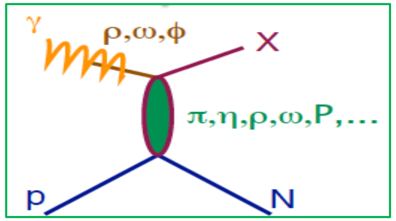
B(G → ηη')/B(G → ππ)<0.04, predicted in Phys. Rev. D 92, 121902

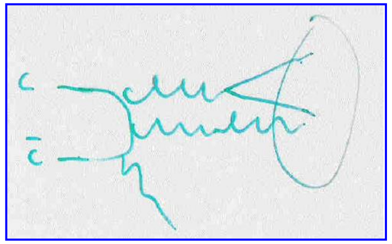
Using 10B of J/ψ events,
J/ψ → γηη′, arXiv:2202.00621, 2202.00623
J/ψ → γη′η′, arXiv:2201.09710

Hybrids: $q\bar{q}g$

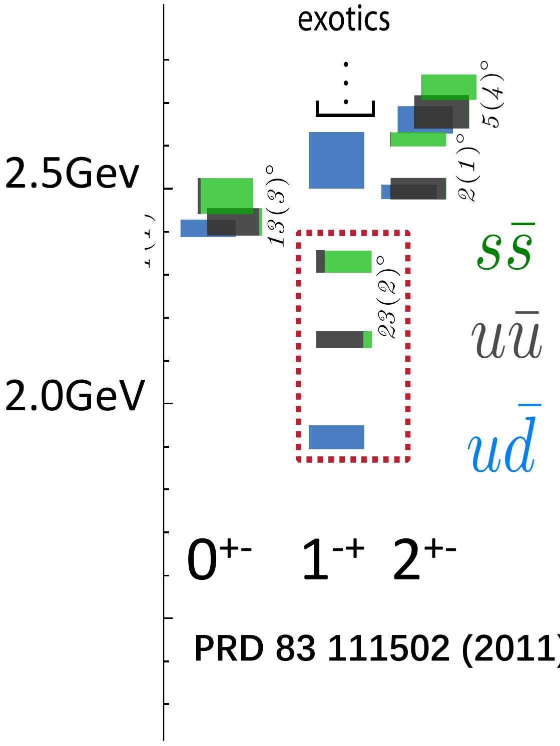
GlueX@JLab

BESIII

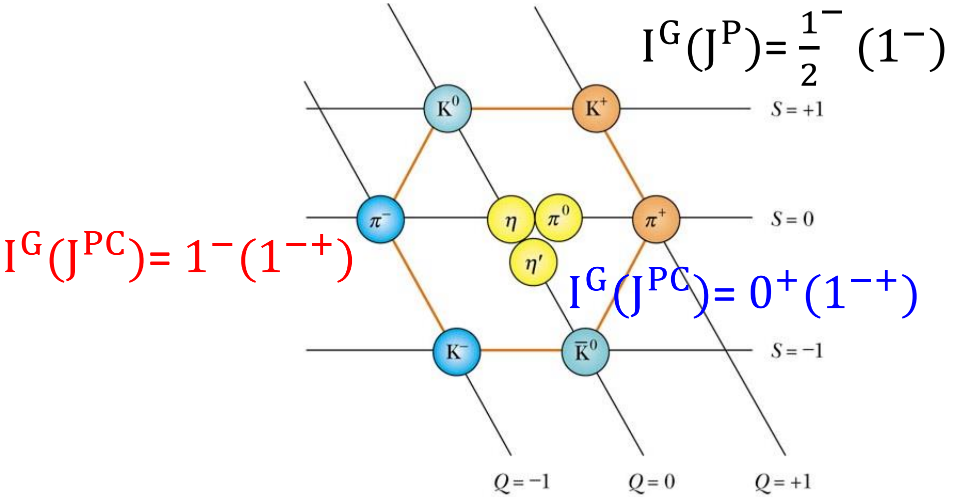




Lattice QCD Predictions:



PRD 83 111502 (2011)

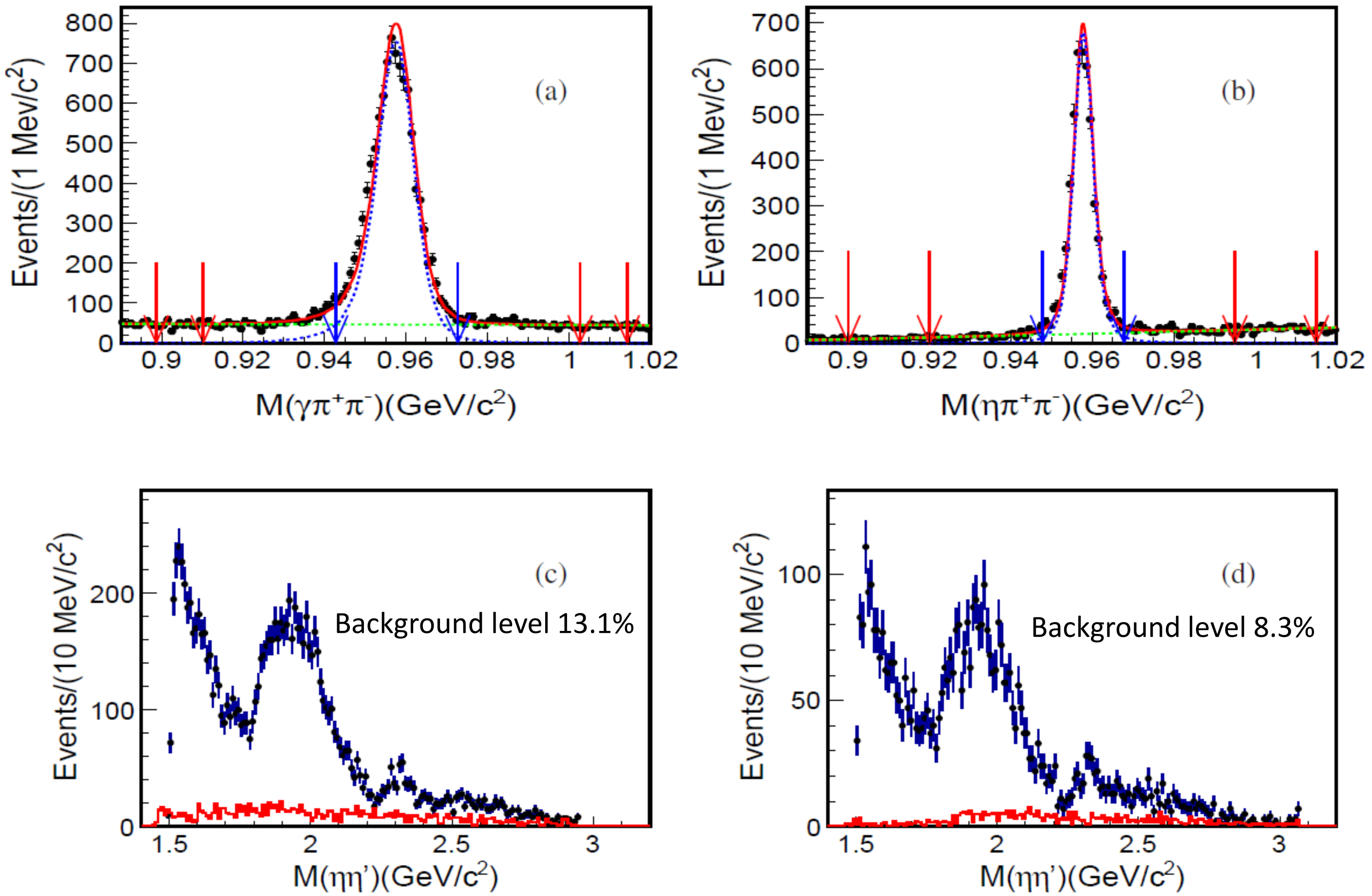


Only I=1 candidates π_1 have been observed yet

- Isoscalar 1^{-+} is critical to establish the hybrid nonet
- Can be produced in the gluon-rich charmonium decays
  - Can decays to $\eta\eta'$ in P-wave, PRD 83, 014021 (2011), PRD 83, 014006 (2011)

Event selection

- $J/\psi \to \gamma\eta\eta', \eta \to \gamma\gamma, \eta' \to \eta\pi^+\pi^- / \gamma\pi^+\pi^-,$



- Potential backgrounds are studied using an inclusive MC sample of 10B J/ψ decays
- No significant peaking background is observed in the invariant mass distribution of the η′
- Backgrounds are estimated by the η′ sidebands in the data

Partial wave analysis

- Similar as the analyses of $J/\psi \rightarrow \gamma\eta\eta$ [Phys.Rev. D 87, 092009]and $J/\psi \rightarrow \gamma K_S K_S$ [Phys.Rev. D 98, 072003], based on the covariant tensor amplitudes [Eur. Phys. J. A 16, 537] and the GPUPWA framework [J. Phys. Conf. Ser. 219, 042031]
  - Isobars in $J/\psi \rightarrow \gamma X, X \rightarrow \eta\eta'$ and $J/\psi \rightarrow \eta X, X \rightarrow \gamma\eta'$ and $J/\psi \rightarrow \eta' X, X \rightarrow \gamma\eta$. X: constant-width, relativistic BW
- A combined unbinned maximum likelihood fit is performed for the two decay channels of η'
  - sharing the same set of masses, widths, relative magnitudes, and phases
- Backgrounds estimated by η' sidebands are subtracted

$$S = -(\ln\mathcal{L}_{data} - \sum_i \omega_i \cdot \ln\mathcal{L}_{background})$$

All kinematically allowed known resonances with 0^{++}, 2^{++}, and $4^{++}(\eta\eta')$ and 1^{+-} and $1^{--}(\gamma\eta('))$ are considered

Decay mode	0^{++}	2^{++}	4^{++}
$J/\psi \to \gamma X \to \gamma\eta\eta'$	$f_0(1500)$	$f_2(1525)$	$f_4(2050)$
	$f_0(1710)$	$f_2(1565)$	$f_4(2300)$
	$f_0(1810)$[58]	$f_2(1640)$	$f_4(2283)$[57]
	$f_0(2020)$	$f_2(1810)$	
	$f_0(2100)$	$f_2(1910)$	
	$f_0(2200)$	$f_2(1950)$	
	$f_0(2330)$	$f_2(2010)$	
	$f_0(2102)$[57]	$f_2(2150)$	
	$f_0(2330)$[57]	$f_2(2220)$	
		$f_2(2300)$	
		$f_2(2340)$	
		$f_2(2240)$[57]	

	1^{--}	1^{+-}
$J/\psi \to \eta^{(\prime)} X \to \gamma\eta\eta'$	$\omega(1420)$	$h_1(1415)$
	$\omega(1650)$	$h_1(1595)$
	$\phi(1680)$	
	$\phi(2170)$	
	$\rho(1450)$	
	$\rho(1700)$	
	$\rho(1900)$	

PDG and

[57] $\bar{p}p$ reactions at Crystal Barrel and PS172, Phys. Rept. 397, 257

[58] $J/\psi \to \gamma\phi\omega$ at BESIII, Phys. Rev. D 87,032008

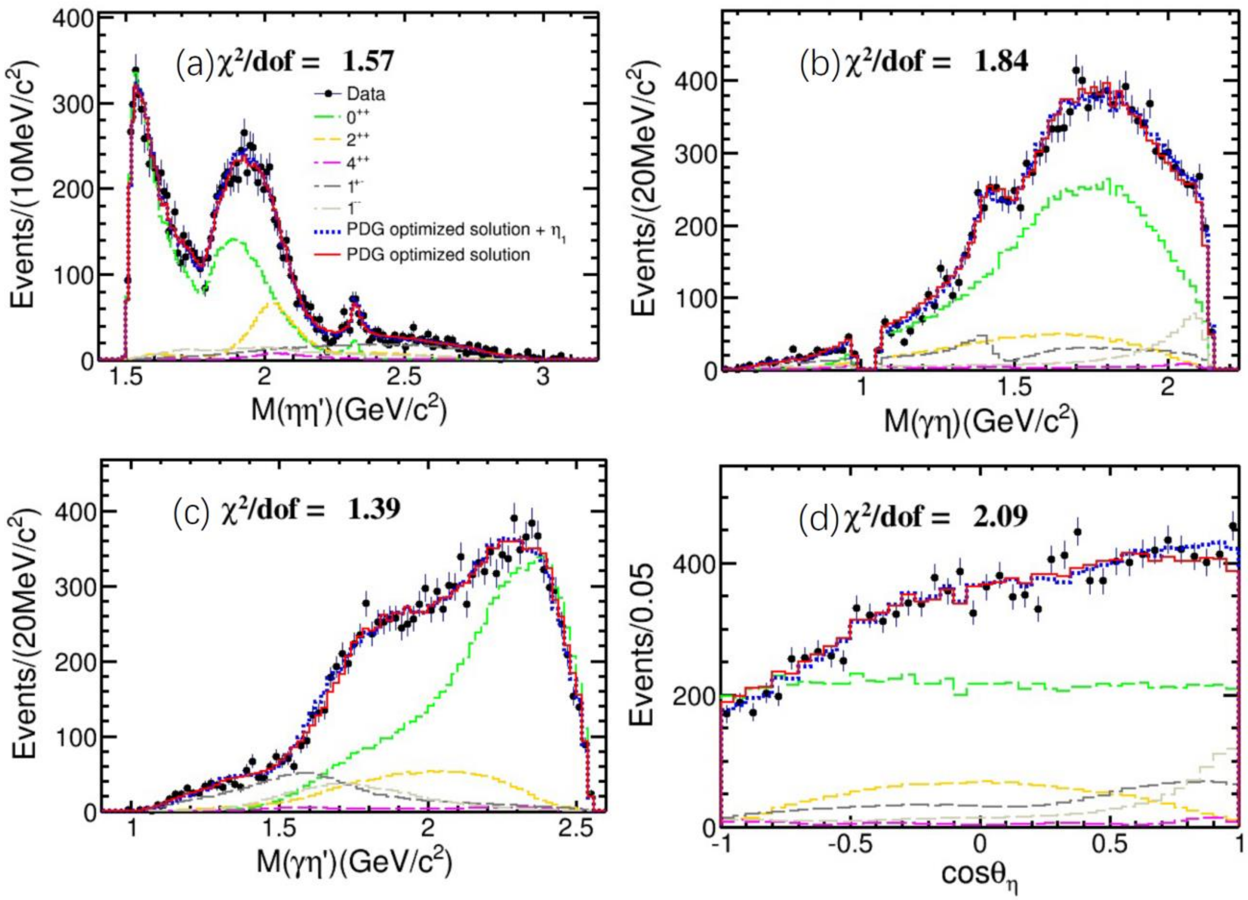
PDG-optimized set of amplitudes

Decay mode	Resonance	M (MeV/c^2)	Γ (MeV)	M_{PDG} (MeV/c^2)	Γ_{PDG} (MeV)	B.F. ($\times 10^{-5}$)	Sig.
$J/\psi \to \gamma X \to \gamma\eta\eta'$	$f_0(1500)$	1506	112	1506	112	3.05±0.07	$\gg 30\sigma$
	$f_0(1810)$	1795	95	1795	95	0.07±0.01	7.6σ
	$f_0(2020)$	1935±5	266±9	1992	442	1.67±0.07	11.0σ
	$f_0(2100)$	2109±11	253±21	2086	284	0.33±0.03	5.2σ
	$f_0(2330)$	2327±4	44±5	2314	144	0.07±0.01	8.5σ
	$f_2(1565)$	1542	122	1542	122	0.20±0.03	6.2σ
	$f_2(1810)$	1815	197	1815	197	0.37±0.03	7.0σ
	$f_2(2010)$	2022±6	212±8	2011	202	1.36±0.10	8.8σ
	$f_2(2340)$	2345	322	2345	322	0.25±0.04	6.5σ
	$f_4(2050)$	2018	234	2018	234	0.11±0.02	5.6σ
$J/\psi \to \eta' X \to \gamma\eta\eta'$	$h_1(1415)$	1416	90	1416	90	0.14±0.01	10.3σ
	$h_1(1595)$	1584	384	1584	384	0.41±0.04	9.7σ
	$\phi(2170)$	2160	125	2160	125	0.24±0.03	5.6σ
$J/\psi \to \eta X \to \gamma\eta\eta'$	$h_1(1595)$	1584	384	1584	384	0.50±0.03	11.0σ
	$\rho(1700)$	1720	250	1720	250	0.22±0.03	8.8σ

The masses and widths of the resonances near ηη′ threshold ($f_0(1500)$, $f_2(1525)$, $f_2(1565)$ and $f_2(1640)$) as well as those with small fit fractions (<3%) are always fixed to the PDG values

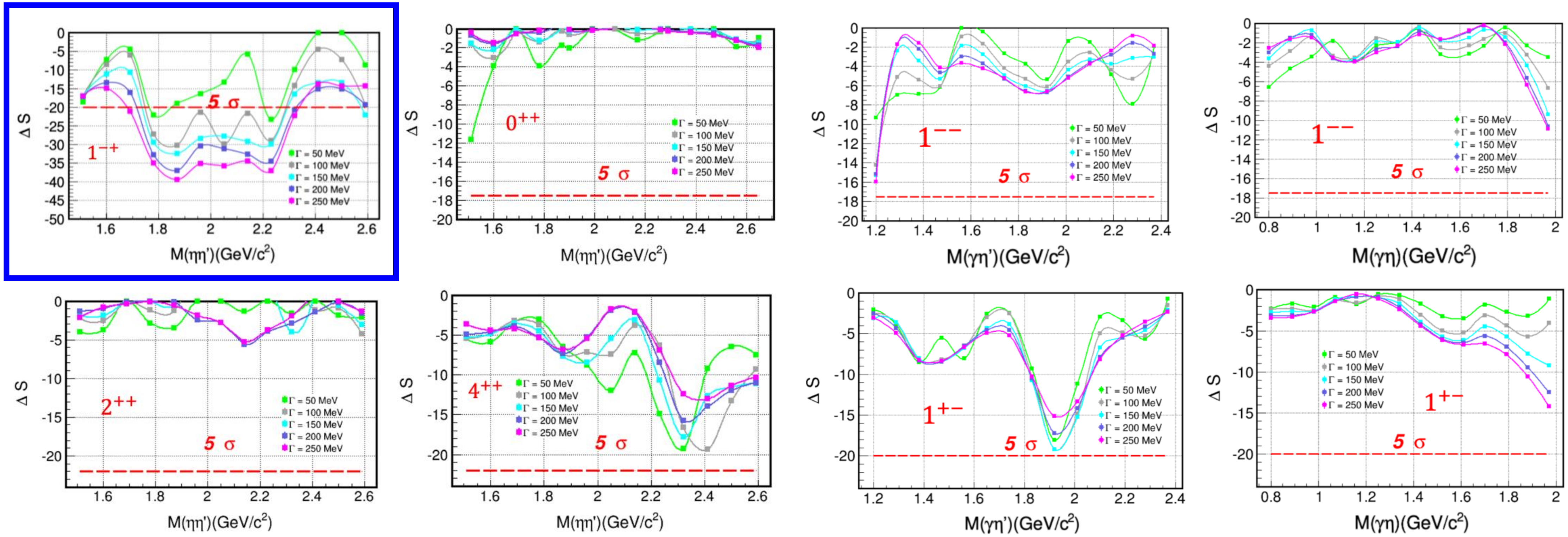
Components with statistical significance larger than 5σ

PWA projections for PDG-optimized set



Search for new resonances

scans of additional resonance with different J^{PC}, masses and widths



Baseline set of amplitudes by adding the η_1 state

Decay mode	Resonance	M (MeV/c^2)	Γ (MeV)	M_{PDG} (MeV/c^2)	Γ_{PDG} (MeV)	B.F. ($\times 10^{-5}$)	Sig.
$J/\psi \to \gamma X \to \gamma\eta\eta'$	$f_0(1500)$	1506	112	1506	112	$1.81\pm0.11^{+0.19}_{-0.13}$	$\gg 30\sigma$
	$f_0(1810)$	1795	95	1795	95	$0.11\pm0.01^{+0.04}_{-0.03}$	11.1σ
	$f_0(2020)$	$2010\pm6^{+6}_{-4}$	$203\pm9^{+13}_{-11}$	1992	442	$2.28\pm0.12^{+0.29}_{-0.20}$	24.6σ
	$f_0(2330)$	$2312\pm7^{+7}_{-3}$	$65\pm10^{+3}_{-12}$	2314	144	$0.10\pm0.02^{+0.01}_{-0.02}$	13.2σ
	$\eta_1(1855)$	$1855\pm9^{+6}_{-1}$	$188\pm18^{+3}_{-8}$	-	-	$0.27\pm0.04^{+0.02}_{-0.04}$	21.4σ
	$f_2(1565)$	1542	122	1542	122	$0.32\pm0.05^{+0.12}_{-0.02}$	8.7σ
	$f_2(2010)$	$2062\pm6^{+10}_{-7}$	$165\pm17^{+10}_{-5}$	2011	202	$0.71\pm0.06^{+0.10}_{-0.06}$	13.4σ
	$f_4(2050)$	2018	237	2018	237	$0.06\pm0.01^{+0.03}_{-0.01}$	4.6σ
	0^{++} PHSP	-	-	-	-	$1.44\pm0.15^{+0.10}_{-0.20}$	15.7σ
$J/\psi \to \eta' X \to \gamma\eta\eta'$	$h_1(1415)$	1416	90	1416	90	$0.08\pm0.01^{+0.01}_{-0.02}$	10.2σ
	$h_1(1595)$	1584	384	1584	384	$0.16\pm0.02^{+0.03}_{-0.01}$	9.9σ

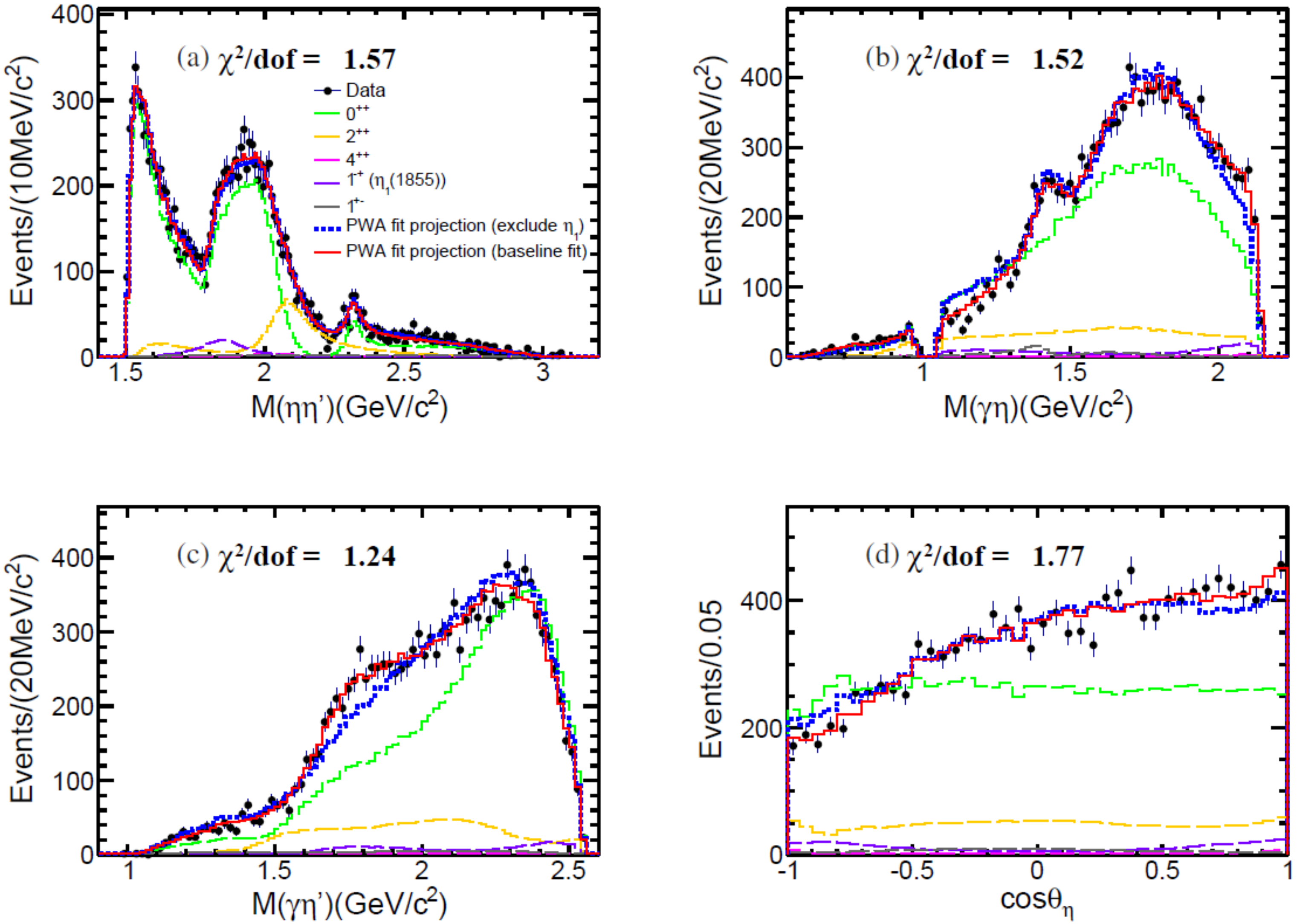
Comparing to the PDG-optimized set, ln L of the baseline set is improved by 32 and the number of free parameters is reduced by 16

Contributions from the $f_0(2100)$, $h_1(1595)(\gamma\eta')$, $\rho(1700)(\gamma\eta')$, $\phi(2170)(\gamma\eta)$, $f_2(1810)$, and $f_2(2340)$, in the PDG-optimized set become insignificant (< 3σ), omitted

Significance of the $f_4(2050)$ is reduced from 5.6σ to 4.6σ, but is still retained

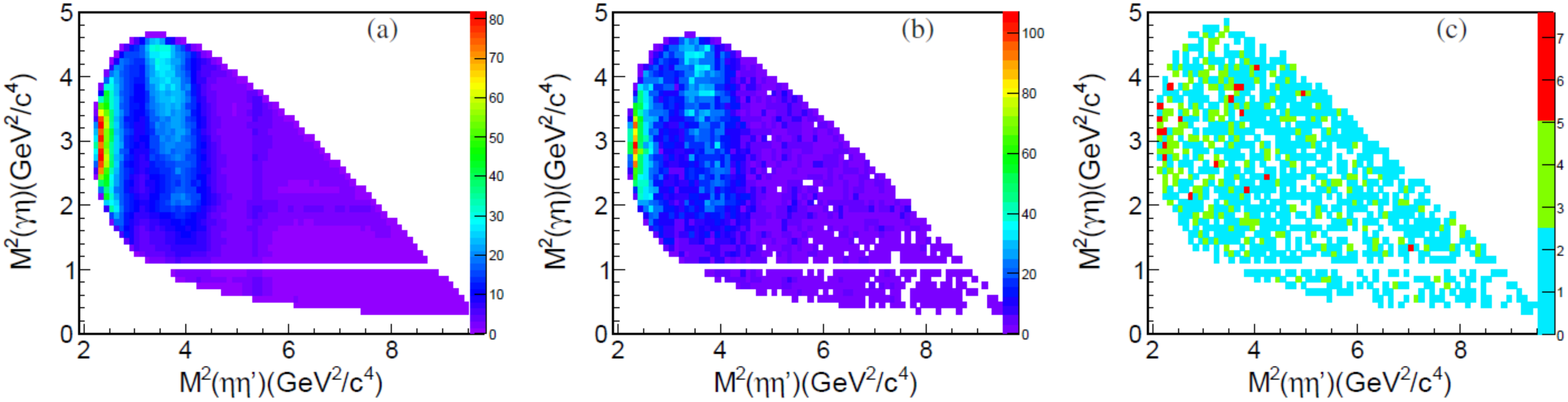
Baseline set of amplitudes

PWA fit projections



Baseline set of amplitudes

PWA fit projections



PWA result Data Sideband

Baseline set of amplitudes

Fit fractions in the PWA fit with the baseline set of amplitudes

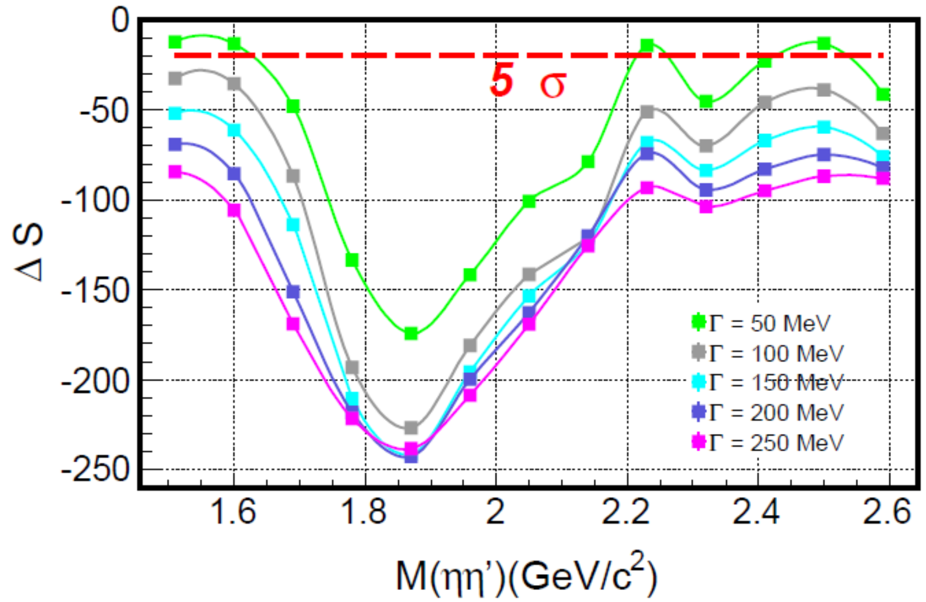
Resonance	$f_0(1500)$	$f_0(1810)$	$f_0(2020)$	$f_0(2330)$	$h_1(1415)(\gamma\eta)$	$h_1(1595)$	$\eta_1(1855)$	$f_2(1565)$	$f_2(2010)$	$f_4(2050)$	0^{++} PHSP
$f_0(1500)$	21.9±1.4	−4.3±0.4	16.2±0.5	−1.0±0.1	1.6±0.2	−1.6±0.9	0.2±0.0	0.2±0.1	0.6±0.1	0.0±0.0	13.4±1.1
$f_0(1810)$		1.4±0.1	−5.6±0.6	0.4±0.0	−0.1±0.0	0.6±0.1	0.0±0.0	−0.2±0.0	0.1±0.0	0.0±0.0	2.0±0.3
$f_0(2020)$			29.5±1.6	−3.7±0.5	0.0±0.2	−3.6±0.4	0.2±0.0	1.1±0.1	0.1± 0.1	0.1±0.0	−15.9±1.8
$f_0(2330)$				1.4±0.2	0.1±0.0	0.3±0.1	0.0±0.0	−0.1±0.0	−0.2± 0.0	0.0±0.0	2.6±0.3
$h_1(1415)$					1.1±0.2	−1.1±0.3	−0.2±0.1	0.1±0.1	0.2±0.1	0.0±0.0	2.3±0.3
$h_1(1595)$						2.1±0.3	0.5±0.1	−0.3±0.3	0.0±0.2	0.1±0.0	2.3±1.0
$\eta_1(1855)$							3.5±0.5	0.0±0.0	−0.1±0.0	0.0±0.0	0.1±0.0
$f_2(1565)$								4.6±0.7	−0.6±0.8	0.0±0.0	−0.9±0.1
$f_2(2010)$									10.2±0.8	−0.1±0.1	0.2±0.1
$f_4(2050)$										0.8±0.2	0.0±0.0
0^{++} PHSP											18.5±1.9

Significance for additional resonances

Decay mode	Resonance	J^{PC}	ΔS	ΔNdof	Sig.
$J/\psi \to \gamma X \to \gamma\eta\eta'$	$f_2(1525)$	2^{++}	6.3	6	1.9σ
	$f_2(1810)$	2^{++}	2.7	6	0.7σ
	$f_0(1710)$	0^{++}	3.4	2	2.1σ
	$f_2(1910)$	2^{++}	3.9	6	1.1σ
	$f_2(1950)$	2^{++}	2.6	6	0.6σ
	$f_0(2100)$	0^{++}	1.1	2	1.1σ
	$f_2(2150)$	2^{++}	2.3	6	0.5σ
	$f_0(2200)$	0^{++}	0.4	2	0.4σ
	$f_2(2220)$	2^{++}	8.6	6	2.6σ
	$f_2(2300)$	2^{++}	7.2	6	2.2σ
	$f_4(2300)$	4^{++}	2.3	6	0.5σ
	$f_0(2330)$	0^{++}	1.5	2	1.2σ
	$f_2(2340)$	2^{++}	6.3	6	1.9σ
	$f_0(2102)$[57]	0^{++}	0.1	2	0.2σ
	$f_2(2240)$[57]	2^{++}	2.9	6	0.7σ
	$f_2(2293)$[57]	2^{++}	4.1	6	1.2σ
	$f_4(2283)$[57]	4^{++}	0.9	6	0.1σ
$J/\psi \to \eta' X \to \gamma\eta\eta'$	$\rho(1450)$	1^{--}	3.4	2	2.1σ
	$\rho(1700)$	1^{--}	0.8	2	0.7σ
	$\rho(1900)$	1^{--}	0.0	2	0σ
	$\omega(1420)$	1^{--}	5.3	2	2.8σ
	$\omega(1650)$	1^{--}	2.6	2	1.7σ
	$\phi(1680)$	1^{--}	4.3	2	2.5σ
	$\phi(2170)$	1^{--}	0.4	2	0.4σ
$J/\psi \to \eta X \to \gamma\eta\eta'$	$h_1(1415)$	1^{+-}	1.3	4	0.5σ
	$h_1(1595)$	1^{+-}	8.1	4	2.9σ
	$\rho(1450)$	1^{--}	1.3	2	1.1σ
	$\rho(1700)$	1^{--}	3.1	2	2.0σ
	$\rho(1900)$	1^{--}	6.1	2	3.0σ
	$\omega(1420)$	1^{--}	2.5	2	1.7σ
	$\omega(1650)$	1^{--}	0.8	2	0.7σ
	$\phi(1680)$	1^{--}	2.1	2	1.5σ
	$\phi(2170)$	1^{--}	0.1	2	0.1σ

all insignificant (< 3σ)

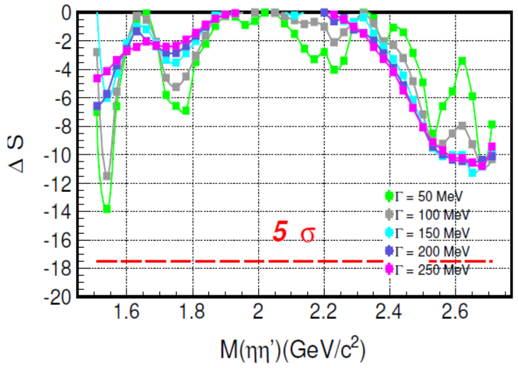
- Assuming $\eta_1(1855)$ is an additional resonance, scans of with different masses and widths



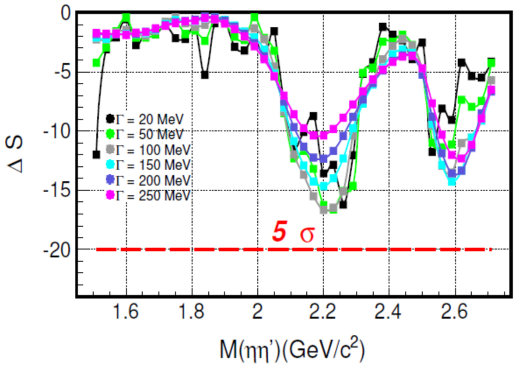
- The most significant additional contribution (4.4σ) comes from another exotic 1^{-+} component around 2.2 GeV with a very small fit fraction

Baseline set of amplitudes

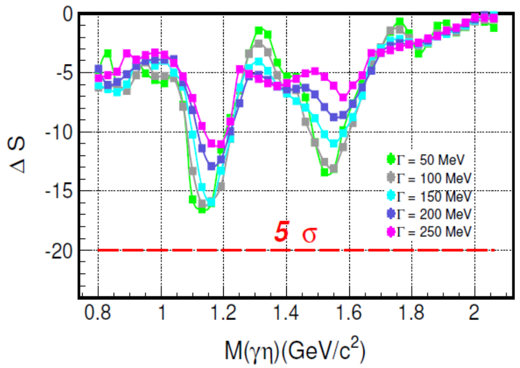
No significant contributions from additional resonances



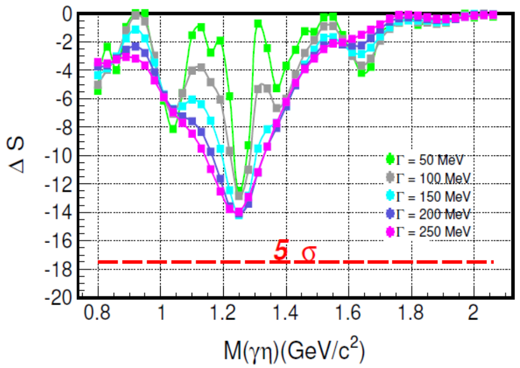
(a) Additional 0^{++} state scan in $\eta\eta'$



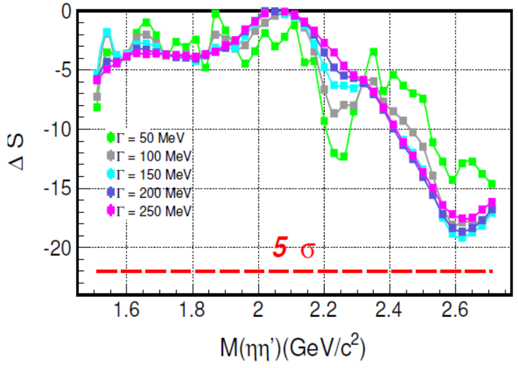
(b) Additional 1^{-+} state scan in $\eta\eta'$



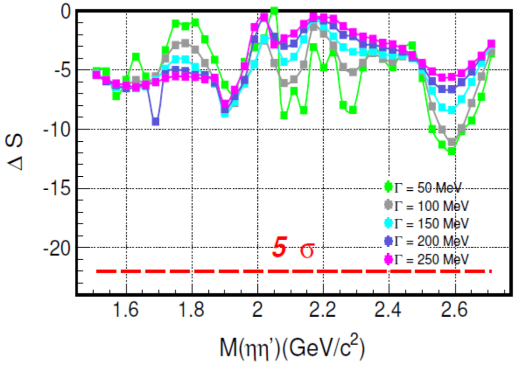
(e) Additional 1^{+-} state scan in $\gamma\eta$



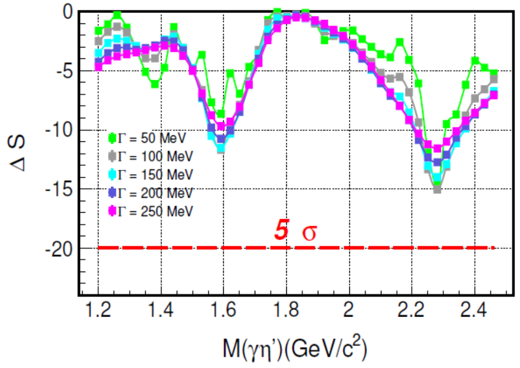
(f) Additional 1^{--} state scan in $\gamma\eta$



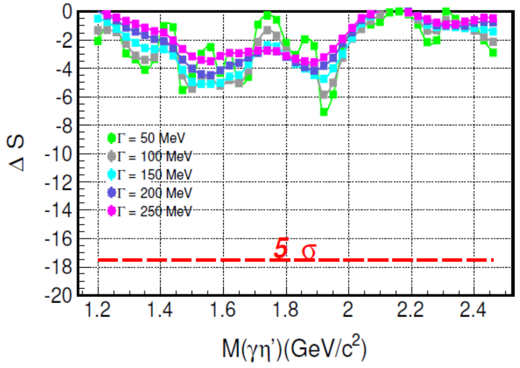
(c) Additional 2^{++} state scan in $\eta\eta'$



(d) Additional 4^{++} state scan in $\eta\eta'$



(g) Additional 1^{+-} state scan in $\gamma\eta'$



(h) Additional 1^{--} state scan in $\gamma\eta'$

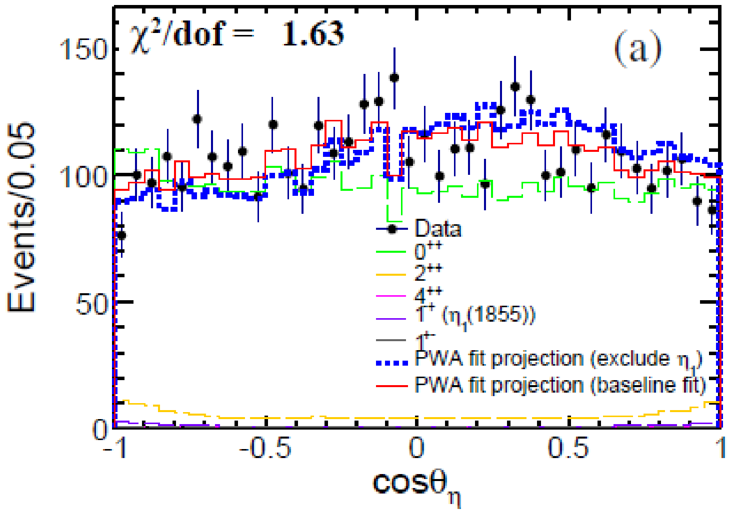
Further checks on the 1^{-+} state $\eta_1(1855)$

- Changing the J^{PC} to the $\eta_1(1855)$, and the log-likelihoods are worse by at least 235 units
- BW Phase motion of $\eta_1(1855)$

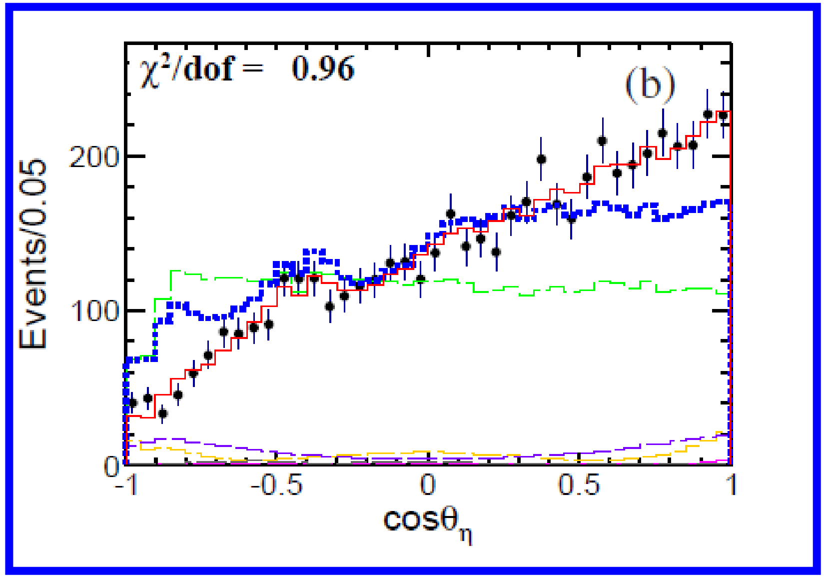
$$\text{from } \frac{1}{M^2-s-iM\Gamma} \text{ to } \sqrt{\frac{1}{(M^2-s)^2+M^2\Gamma^2}}$$

→ln L worsen by 43 units

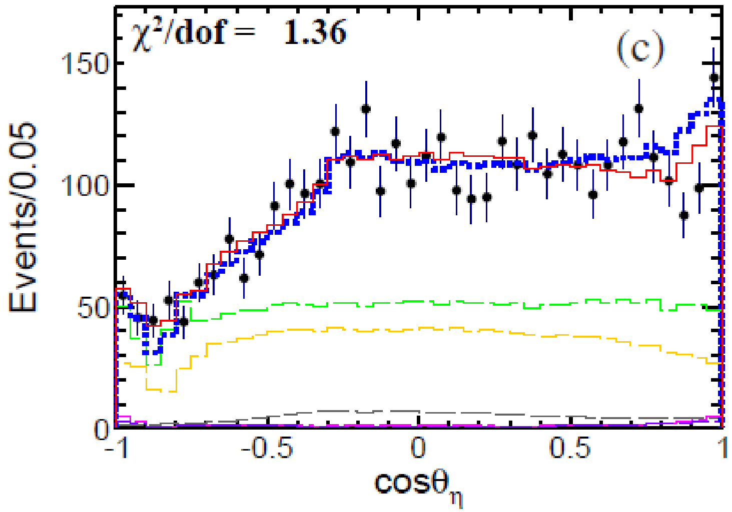
Further checks on the 1^{-+} state $\eta_1(1855)$



$[1.5,1.7]\ \mathrm{GeV}/c^2$



$[1.7,2.0]\ \mathrm{GeV}/c^2$



$[2.0,3.2]\ \mathrm{GeV}/c^2$

a clear asymmetry largely due to $\eta_1(1855)$ signal

Further checks on the 1^{-+} state $\eta_1(1855)$

Angular distribution as a function of $M(\eta\eta')$ can be expressed model-independently in terms of Legendre polynomial moments

$$\langle Y_l^0 \rangle \equiv \sum_{i=1}^{N_k} W_i Y_l^0(\cos\theta_\eta^i)$$

- for data, W_i is to implement background subtraction
- for MC, W_i is intensity for each event calculated in the PWA

The moments are related to the spin-0 (S), spin-1 (P) and spin-2 (D) amplitudes by

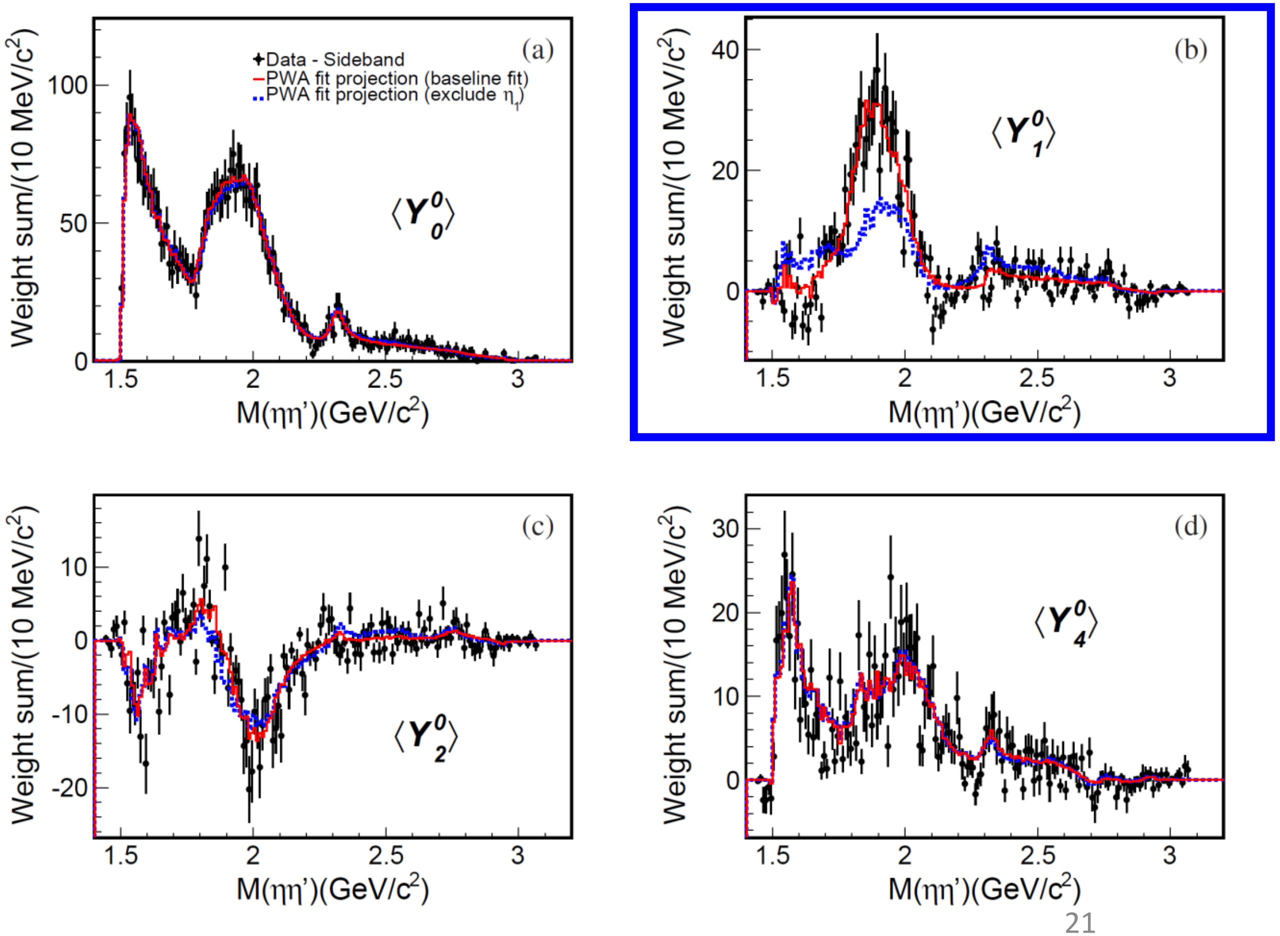
$$\sqrt{4\pi}\langle Y_0^0 \rangle = S^2 + P^2 + D^2$$

$$\sqrt{4\pi}\langle Y_1^0 \rangle = 2SP\cos\phi_P + 4PD\cos(\phi_P - \phi_D)$$

$$\sqrt{4\pi}\langle Y_2^0 \rangle = \frac{2}{\sqrt{5}}P^2 + \frac{2\sqrt{5}}{7}D^2 + 2SD\cos\phi_D$$

$$\sqrt{4\pi}\langle Y_4^0 \rangle = \frac{6}{7}D^2$$

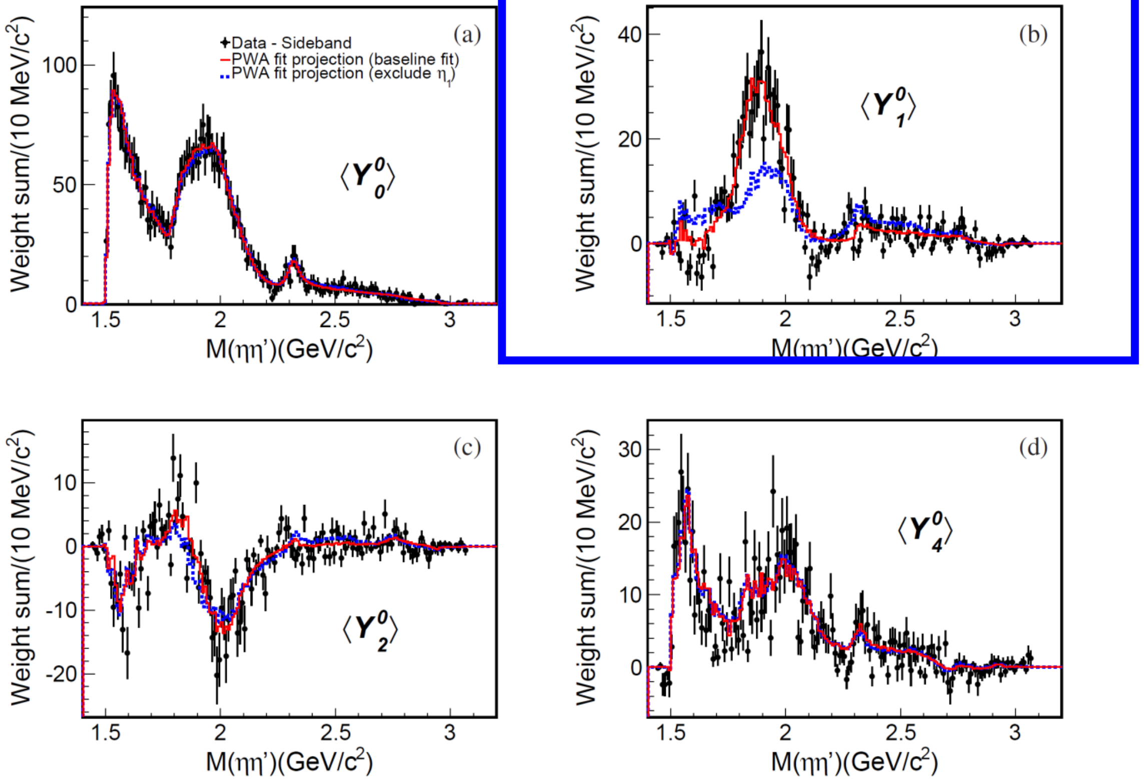
need for the $\eta_1(1855)$ P-wave



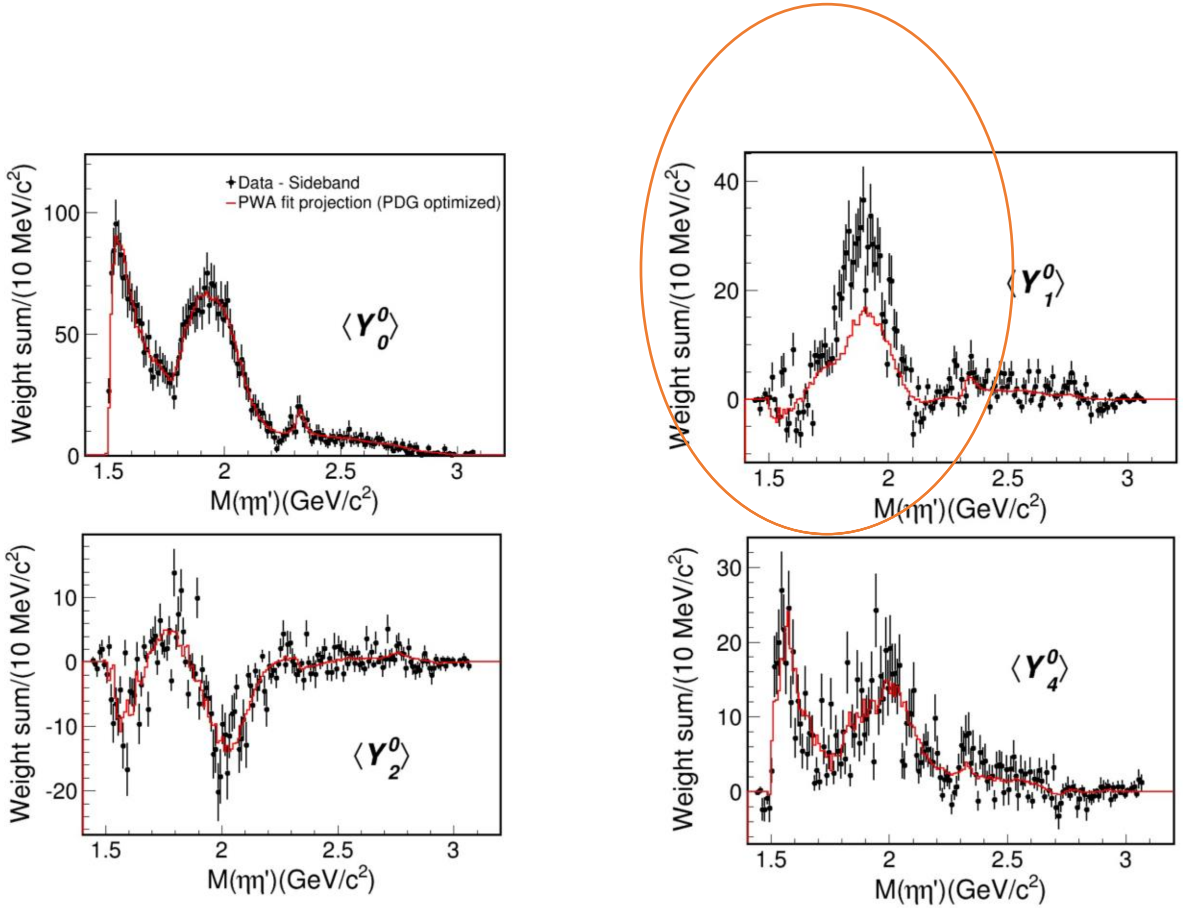
For comparison

Can not be described only with 1^{+-} and 1^{--} states in $\gamma\eta(')$

need for the $\eta_1(1855)$ P-wave



Baseline set of amplitudes



PDG-optimized set of amplitudes

Systematic uncertainties (event selection)

Common systematic uncertainties		
Sources	$\eta' \to \eta\pi^+\pi^-$	$\eta' \to \gamma\pi^+\pi^-$
Pion tracking	2	
Four photon detection	4	
Number of J/ψ events	0.43	
$\mathcal{B}(\eta \to \gamma\gamma)$	0.2	
Total	4.5	
Independent systematic uncertainties		
Sources	$\eta' \to \eta\pi^+\pi^-$	$\eta' \to \gamma\pi^+\pi^-$
Another photon detection	1	-
Kinematic fit	1.5	2.6
η' mass resolution	0.3	0.2
$\mathcal{B}(\eta' \to \eta\pi^+\pi^-)$	0.5	-
$\mathcal{B}(\eta' \to \gamma\pi^+\pi^-)$	-	0.4
$\mathcal{B}(\eta \to \gamma\gamma)$ for another one	0.2	-
Total	1.9	2.6
Combined result	4.8	

Combined with the weighted least squares method

Systematic uncertainties (PWA)

- BW parametrization for $\mathrm{f}_0(1500)$
  - replace the BW with a Flatte-like form

$$\Gamma(s) = g\Gamma(\frac{M^2}{s})(\frac{\rho(s)}{\rho(M^2)})^{2l+1} + (1-g)\Gamma_0$$, g ~0.02

- Fixed resonance parameters
  - varying within 1 σ of the PDG values
- Background uncertainty
  - different sideband regions and normalization factors
- Additional resonances
  - adding the most significant additional resonances for each possible J^{PC} into the baseline fit individually

Sources	$f_0(2020)$		$f_0(2330)$		$\eta_1(1855)$		$f_2(2010)$	
	ΔM	$\Delta\Gamma$	ΔM	$\Delta\Gamma$	ΔM	$\Delta\Gamma$	ΔM	$\Delta\Gamma$
Breit-Wiger formula	-1	$+10$	-1	$+1$	-1	$+2$	-4	$+3$
Resonance parameters	$+1$	-10	-3	$+2$	$+2$	-1	0	-2
Extra resonances	$^{+4}_{-2}$	$^{+9}_{-2}$	$+7$	$^{+1}_{-9}$	$+4$	$^{+1}_{-6}$	$^{+10}_{-5}$	$+10$
Backgroud uncertainty	-1	-4	$+3$	$^{+1}_{-7}$	$+3$	$^{+1}_{-5}$	-1	-5
Total	$^{+4}_{-3}$	$^{+13}_{-11}$	$^{+7}_{-3}$	$^{+3}_{-12}$	$^{+6}_{-1}$	$^{+3}_{-8}$	$^{+10}_{-7}$	$^{+10}_{-5}$

Sources	$f_0(1500)$	$f_0(1810)$	$f_0(2020)$	$f_0(2330)$	$\eta_1(1855)$	$f_2(1565)$	$f_2(2010)$	$f_4(2050)$	0^{++}PHSP	$h_1(1415)(\gamma\eta)$	$h_1(1595)(\gamma\eta)$
Event selection	±4.8										
Breit-Wigner formula	-1.7	$+11.6$	$+6.9$	$+3.2$	-1.1	$+17.8$	$+0.2$	$+4.2$	-0.6	-8.2	-4.1
Extra resonances	$^{+9.4}_{-1.0}$	$^{+30.4}_{-8.4}$	$+10.0$	$^{+7.8}_{-13.4}$	$^{+3.5}_{-10.4}$	$^{+31.5}_{-2.7}$	$^{+12.9}_{-6.5}$	$^{+44.4}_{-4.7}$	$^{+5.1}_{-12.2}$	$^{+11.0}_{-9.1}$	$^{+16.2}_{-2.2}$
Resonance parameters	-4.8	-25.6	-6.5	$+3.6$	-6.1	$+5.5$	$+0.2$	-1.4	-4.6	-11.4	-4.3
Backgroud uncertainty	$^{+0.5}_{-0.6}$	$^{+0.4}_{-7.5}$	$^{+0.8}_{-3.4}$	$^{+0.3}_{-10.4}$	$^{+0.2}_{-1.1}$	$+11.0$	-2.7	$^{+31.9}_{-6.5}$	-1.8	-8.8	$^{+8.4}_{-0.6}$
Total	$^{+10.6}_{-7.1}$	$^{+32.9}_{-28.4}$	$^{+13.1}_{-8.8}$	$^{+10.3}_{-17.6}$	$^{+5.9}_{-13.1}$	$^{+38.5}_{-5.5}$	$^{+13.7}_{-8.5}$	$^{+55.0}_{-9.5}$	$^{+7.0}_{-14.0}$	$^{+12.0}_{-19.5}$	$^{+18.8}_{-8.0}$

The statistical significance of the $\eta_1(1855)$ is recalculated in every variation. >19 σ

Summary and prospects

- An isoscalar 1^{-+} , $\eta_1(1855)$, has been observed in $J/\psi \to \gamma\eta\eta'$ (>19σ)

  $M = (1855 \pm 9^{+6}_{-1})\ \mathrm{MeV/c^2}, \Gamma = (188 \pm 18^{+3}_{-8})\ \mathrm{MeV/c^2}$

  $$B(J/\psi \to \gamma\eta_1(1855) \to \gamma\eta\eta') = \left(2.70 \pm 0.41^{+0.16}_{-0.35}\right) \times 10^{-6}$$

  arXiv:2202.00621, 2202.00623

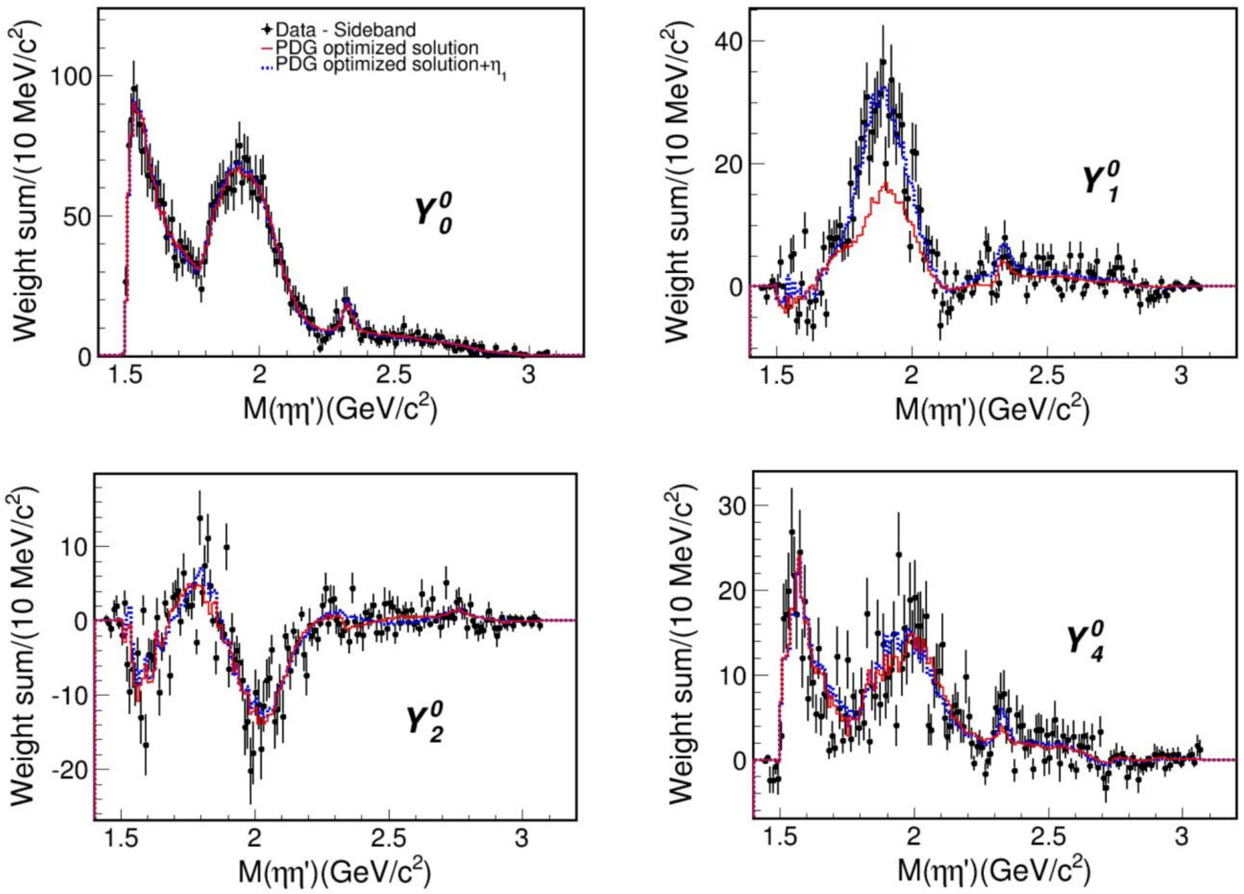
  - Hybrid? Molecule? Tetraquark?
  - Investigate production/decay mechanism and search for other partners in more reactions

- Further more, significant $J/\psi \to \gamma f_0(1500) \to \gamma\eta\eta'$ has been observed, while $f_0(1710)$ is insignificant
  - $B(f_0(1710) \to \eta\eta')/ B(f_0(1710) \to \pi\pi)< 1.61 \times 10^{-3}$ @90% C.L. , which further supports the f(1710) has a large overlap with glueball

  Glueball → ηη' is expected to be suppressed

Thank you

Angular moments for PDG-optimized set



Event selection

- $J/\psi \to \gamma\eta\eta'$, $\eta \to \gamma\gamma$, $\eta' \to \eta\pi^+\pi^-$
- $\chi^2_{6C}(J/\psi \to \gamma\eta\eta\pi^+\pi^-)$<30
- $\chi^2_{4C}(J/\psi \to 5\gamma\pi^+\pi^-)$<$\chi^2_{4C}(J/\psi \to 4\gamma\pi^+\pi^-)$, $\chi^2_{4C}(J/\psi \to 5\gamma\pi^+\pi^-)$<$\chi^2_{4C}(J/\psi \to 6\gamma\pi^+\pi^-)$
- Select η'
- Veto $J/\psi \to \phi\eta'$
- Veto mis-reconstructed π^0, η

- $J/\psi \to \gamma\eta\eta'$, $\eta \to \gamma\gamma$, $\eta' \to \gamma\pi^+\pi^-$
- $\chi^2_{5C}(J/\psi \to \gamma\gamma\eta\pi^+\pi^-)$<20
- $\chi^2_{4C}(J/\psi \to 4\gamma\pi^+\pi^-)$<$\chi^2_{4C}(J/\psi \to 3\gamma\pi^+\pi^-)$, $\chi^2_{4C}(J/\psi \to 4\gamma\pi^+\pi^-)$<$\chi^2_{4C}(J/\psi \to 5\gamma\pi^+\pi^-)$
- Select η'
- Veto $J/\psi \to \phi\eta'$
- Veto mis-reconstructed π^0, η
- Veto fake-photon bkg $J/\psi \to \eta\pi^+\pi^-$