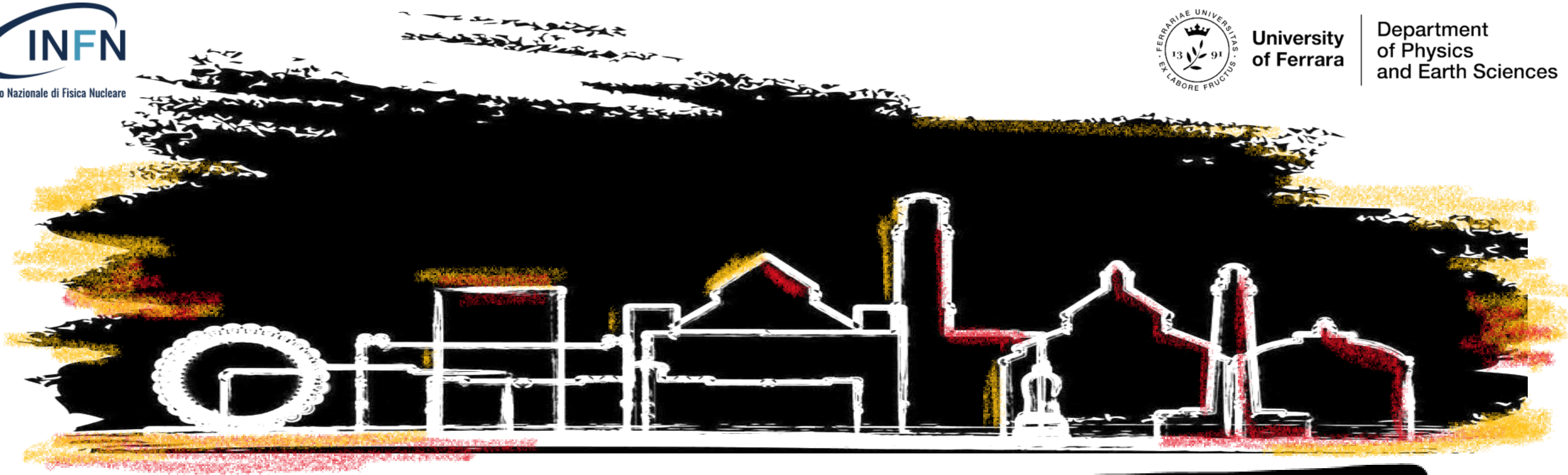


WIFAI 2025 – Fourth Italian Workshop on Physics at High Intensity

Status and perspectives of heavy and light spectroscopy at BESIII

Isabella Garzia, University of Ferrara and INFN
On behalf of the BESIII Collaboration

WIFAI 2025, Centro Polifunzionale per gli Studenti - BARI
11 – 14 Novembre, 2025

Outline

The BESIII experiment

Selection of recent results on light hadron spectroscopy:

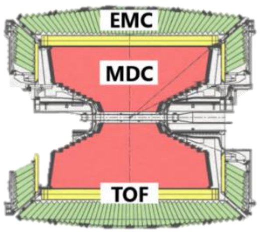
- ***The $\eta_1(1855)$ exotic isoscalar state***
- ***X(2370): glueball-like particle in $J/\psi\to\gamma K^0_S K^0_S \eta'$***
- ***X(1880): a new state observed in $J/\psi\to\gamma(3\pi^+\pi^-)$***
- ***PWA of $J/\psi\to\gamma\gamma\phi$***
- ***Study of $f_1(1420)$ and $\eta(1405)$ in $J/\psi\to\gamma\pi^0\pi^0\pi^0$***
- ***PWA of $\psi(3686)\to\gamma K^0_S K^0_S$***

- Axial-vector strangeonium
  - ***Study of $\psi(3686)\to \phi\pi^0\eta$***
  - ***Study of $\psi(3686)\to \phi\eta\eta'$***
- Charmonium spectroscopy
  - ***Zc±(3900): PWA of $e^+e^-\to \pi^+\pi^- J/\psi$***
  - ***Search for 1^{-+} states in $e^+e^-\to\gamma D_s^+ D_{s1}^-(2536)$***
  - ***Cross section of $e^+e^-\to \pi^+\pi^- h_c$***

Summary and Conclusions

The BESIII experiment @ BEPCII

中国科学院高能物理研究所
Institute of High Energy Physics
Chinese Academy of Sciences



Nucl. Instr. Meth. A614, 345 (2010)

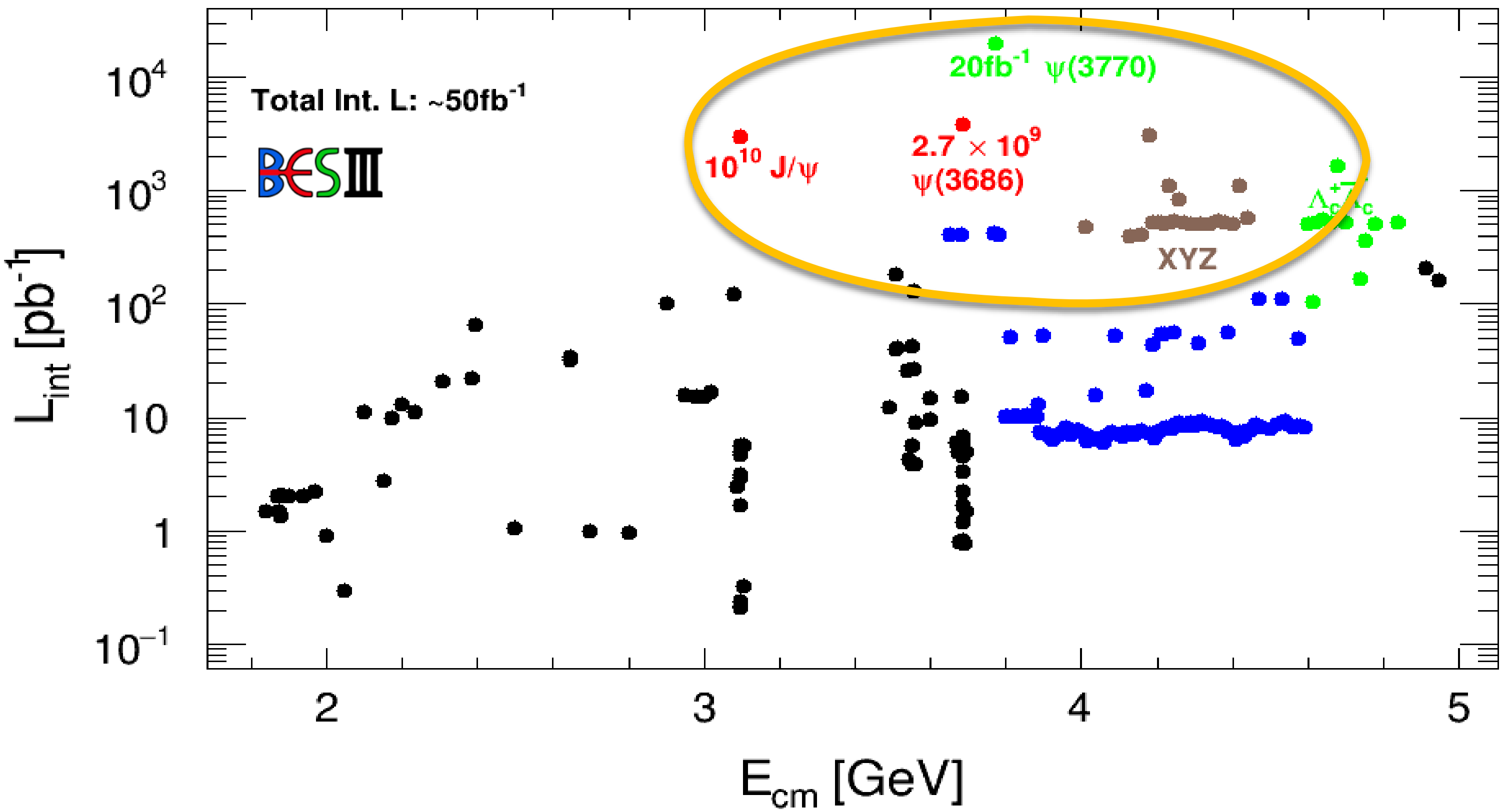
2004: started Beijing Electron Positron Collider II/BESIII construction
- ✓ Double rings
- ✓ Beam energy: 1 - 2.45 GeV
- ✓ Peak luminosity: 1.05×10^{33} cm^{-2}s^{-1} @ $\psi(3770)$, achieved on January 7th, 2023

2009 – today: BESIII physics runs

BESIII dataset and physics program

Optimised for flavour physics in the τ-charm region

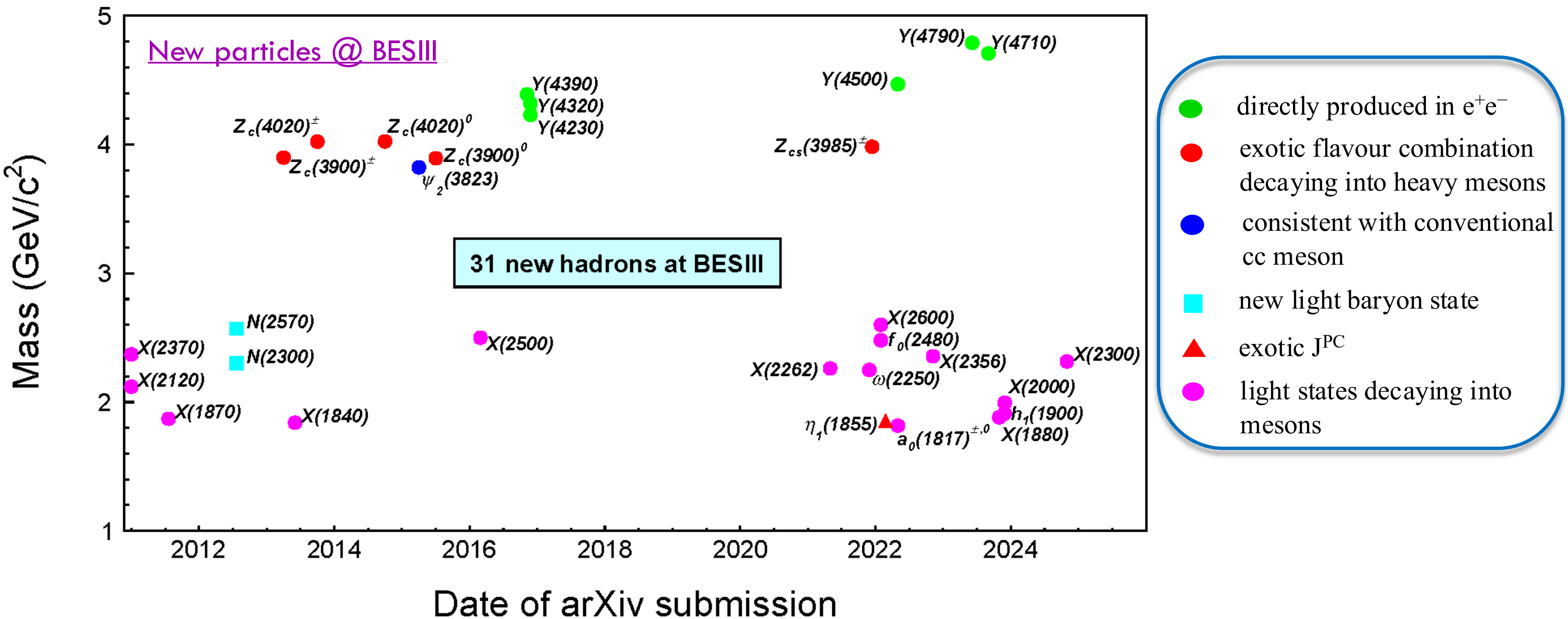
http://english.ihep.cas.cn/bes/ui/ds/202109/t20210923_284001.html



Hadron spectroscopy: establish the spectrum and study the exotic hadrons properties

New discoveries at BESIII

"New hadrons discovered at BESIII," Z. Q. Liu, R. E. Mitchell, Sci.Bull. 68 (2023) 2148-2150

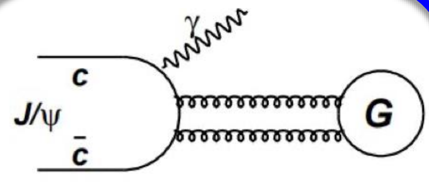


Manifestly exotic
- *Quark contents more than $q\bar{q}$ or qqq*
- *Quantum number J^{PC} not reachable for ordinary mesons or baryons*

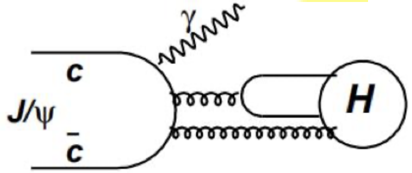
'Cryptoexotic'
- *overpopulation of states*
- *mass/width not fitting in spectra*
- *production and/or decay patterns incompatible with standard mesons/baryons*

Hunting for glueballs and new form of hadrons

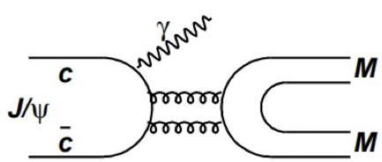
- Charmonium radiative decays is the ideal laboratory for light glueballs and hybrids hadron studies (clean, high statistics and gluon-rich process)



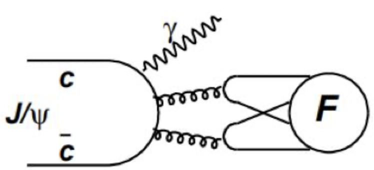
$\Gamma(J/\psi \to \gamma G) \sim O(\alpha\alpha_s^2)$



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

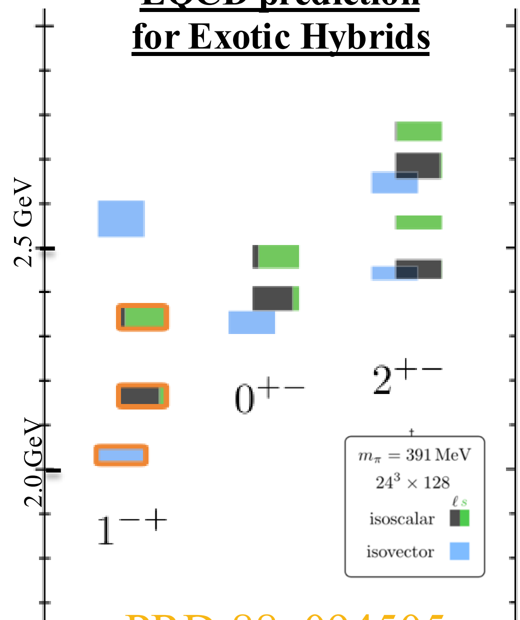


$\Gamma(J/\psi \to \gamma M) \sim O(\alpha\alpha_s^4)$



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

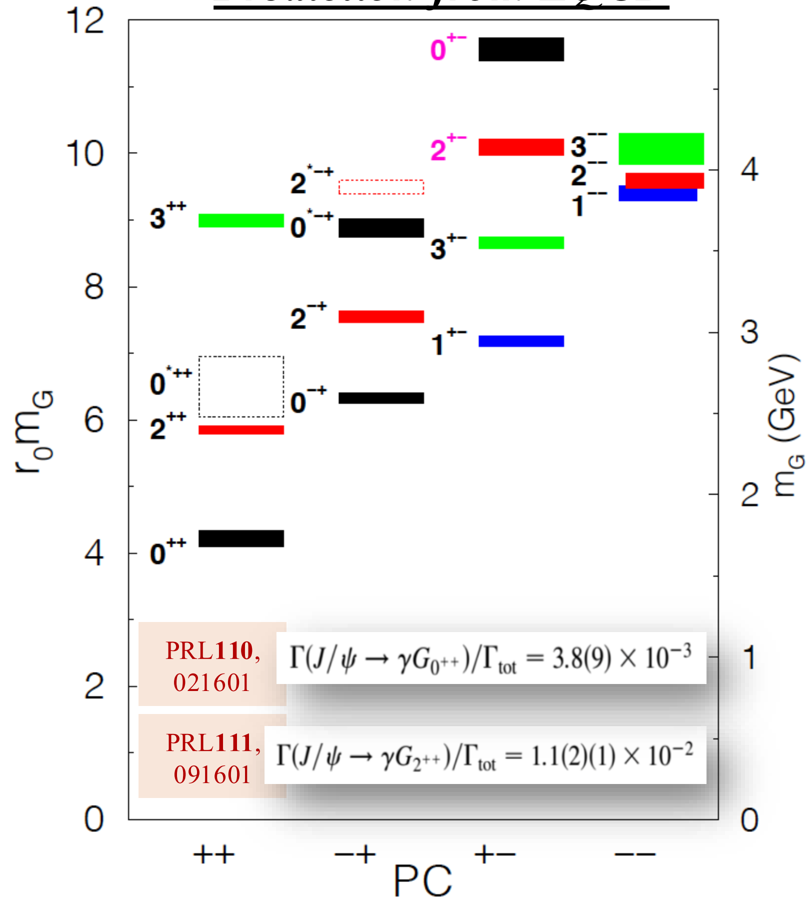
LQCD prediction for Exotic Hybrids



PRD 88, 094505

Glueballs and hybrids are expected to have a larger yield compared to mesons

Prediction from LQCD

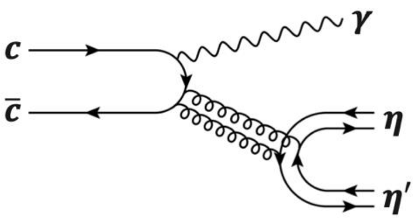


https://doi.org/10.1142/S0218301309012124

Exotic Isoscalar State $\eta_1(1855)$ in $J/\psi \to \gamma\eta\eta'$

Isoscalar 1^{-+} exotic hybrids to establish the hybrid nonet

✓ Can be produced in J/ψ radiative decays and decay to $\eta\eta'$ in P-wave (PRD 83,014021, PRD 83, 014006, Eur.Phys.J.Plus 135, 945)

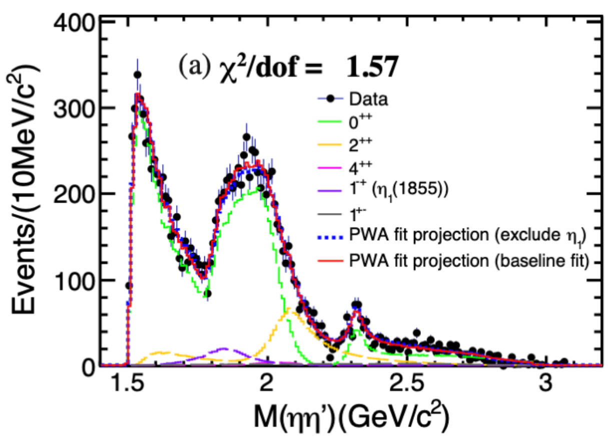


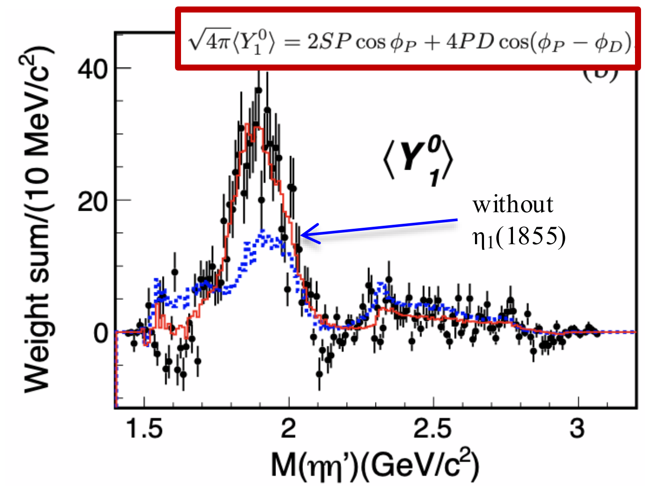
@BESIII: PWA (GPUPWA) of **$J/\psi \to \gamma\eta\eta'$** using 10 Billion of J/ψ data

- $\eta \to \gamma\gamma$ and $\eta' \to \gamma\pi^+\pi^-$/ $\eta\pi^+\pi^-$

PRL **129**, 192002 (2022)
PRD **106**,072012 (2022)
PRD **107**,079901 (2023)

- Isoscalar 1^{-+} state, $\eta_1(1855)$, observed (>19σ)
- Mass is consistent with LQCD calculation for the 1^{-+} hybrid (1.7 – 2.1 GeV/c^2)





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

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

Narrow structure in $\langle Y^0_1\rangle$: $\eta_1(1855)$ P-wave component is needed

Discussion about $f_0(1500)$ and $f_0(1710)$

PRL **129**, 192002 (2022)
PRD **106**,072012 (2022)
*PRD **107**,079901 (2023)

The dominant contributions in the baseline PWA are from scalar resonances:

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

$$\frac{\mathcal{B}(f_0(1500)\to\eta\eta')}{\mathcal{B}(f_0(1500)\to\pi\pi)} = (1.66^{+0.42}_{-0.40}\times 10^{-1})^{*}$$

Consistent with PDG

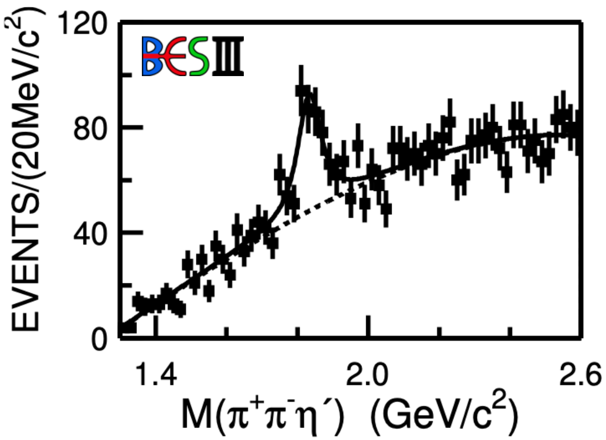
$$\frac{\mathcal{B}(f_0(1710)\to\eta\eta')}{\mathcal{B}(f_0(1710)\to\pi\pi)} < 2.87\times 10^{-3\,*}$$

@90% C.L.

This suppressed decay rate supports the hypothesis that the $f_0(1710)$ has a large overlap with the ground state scalar glueball (PRD 92,121902)

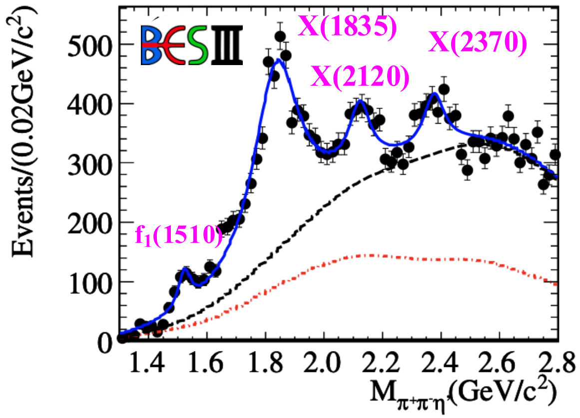
Glueball candidates in radiative ψ decays

PRL 95, 262001 (2005)



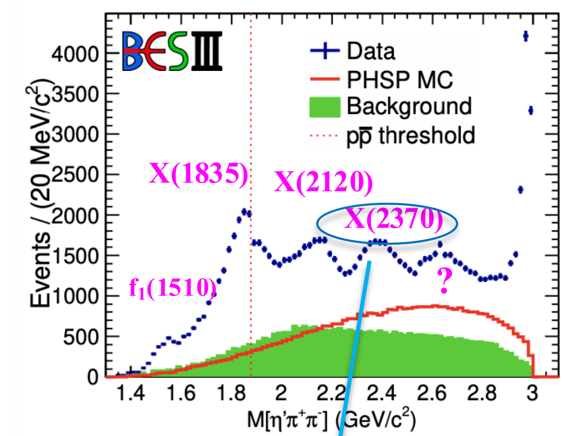
$58 \times 10^6\ J/\psi$ events

PRL 106, 072002 (2011)



$225.2 \times 10^6\ J/\psi$ events

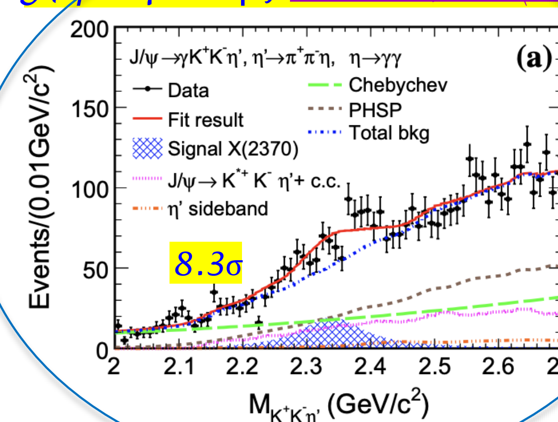
PRL 117, 042002 (2016)



$1090 \times 10^6\ J/\psi$ events

- Structure just at or below $p\bar{p}$ threshold: X(1835)
  - Non-trivial line shape: try to fit with Flatté or sum of interfering BWs
- Additional structures: X(2120), X(2370), ?

$J/\psi \to \gamma K K \eta'$, EPJC80, 746(2020)



$X(2370)$: Glueball-like particle in $J/\psi \to \gamma K_S^0 K_S^0 \eta'$

PWA using 10 Billion of J/ψ data @ BESIII

PRL 132, 181901 (2024)

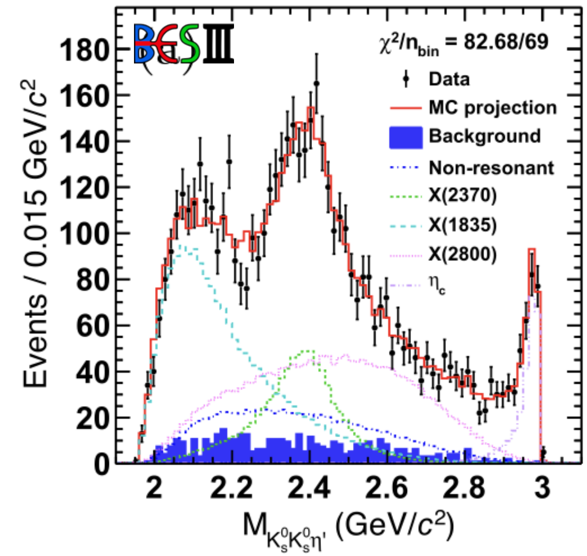
- Main backgrounds ($J/\psi \to \pi^0 K_S^0 K_S^0 \eta'$ and $J/\psi \to K_S^0 K_S^0 \eta'$) are forbidden by exchange symmetry and CP conservation
- $M(K^0_S K^0_S) < 1.1$GeV to select the $f_0(980)$

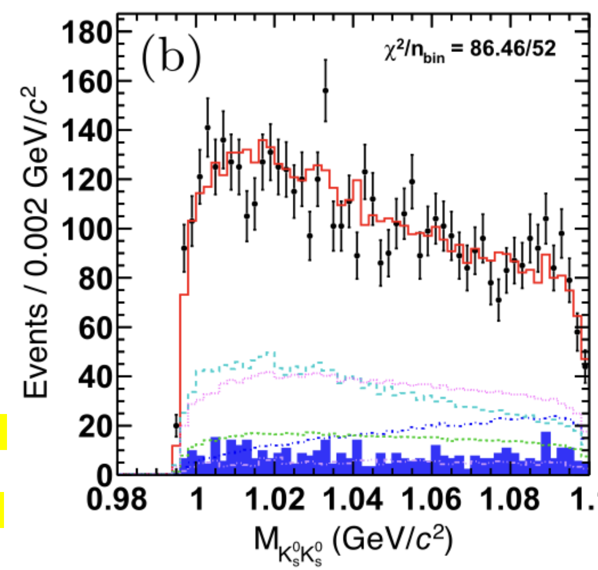
state	J^{PC}	Decay mode	Mass (MeV/c^2)	Width (MeV/c^2)	Significance
X(2370)	0^{-+}	$f_0(980)\eta'$	2395^{+11}_{-11}	188^{+18}_{-17}	14.9σ
X(1835)	0^{-+}	$f_0(980)\eta'$	1844	192	22.0σ
X(2800)	0^{-+}	$f_0(980)\eta'$	2799^{+52}_{-48}	660^{+180}_{-116}	16.4σ
η_c	0^{-+}	$f_0(980)\eta'$	2983.9	32.0	$> 20.0\sigma$
PHSP	0^{-+}	$\eta'(K_S^0K_S^0)_{S-wave}$	− − −	− − −	9.0σ
		$\eta'(K_S^0K_S^0)_{D-wave}$	− − −	− − −	16.3σ

- Spin parity of X(2370) is determined to be 0^{-+} for the first time with significance greater than 10σ
- X(2800): broad structure to describe the effective contributions from possible high mass resonances (X(2600)) and the tail of the η_c line shape

$$M(X(2370)) = 2395 \pm 11^{+26}_{-94}\ \ \mathrm{MeV/c^2}$$
$$\Gamma(X(2370)) = 118^{+18}_{-17}(\mathrm{stat})^{+124}_{-33}(\mathrm{sist})\ \ \mathrm{MeV}$$

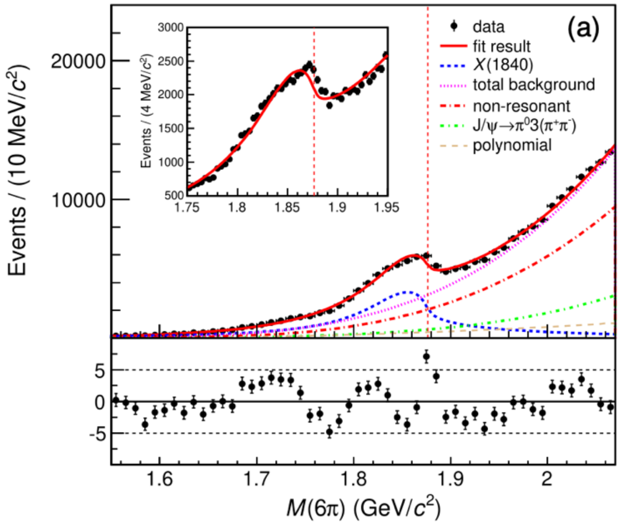
Good agreement with LQCD prediction of lightest pseudoscalar glueball

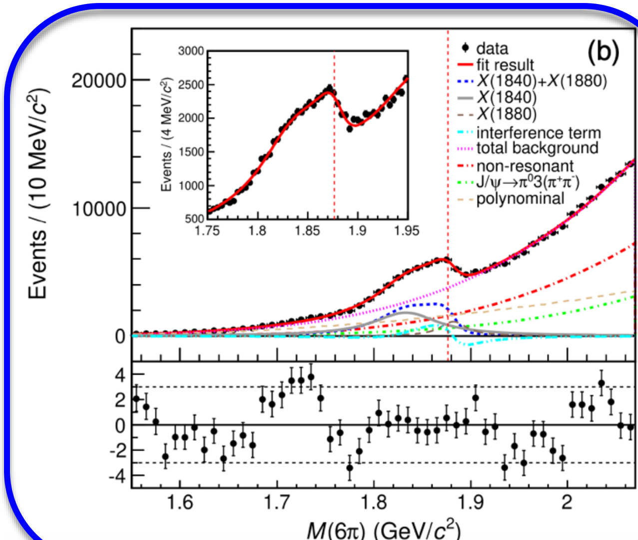




X(1880): A New State Observed in $J/\psi \to \gamma 3(\pi^+\pi^-)$

BESIII





PRL **132**,151901 (2024)

10 Billion of J/ψ data @ BESIII

(45 times larger than the sample previously analyzed)

- Study the line shape around the $p\bar{p}$ threshold
- Understand the nature of the X(1840) previously observed in the $J/\psi \to \gamma 3(\pi^+\pi^-)$ [PRD88,091502]
- An anomalous line shape near the pp mass threshold is clearly observed
- Two models:
  1. opening of the $X(1840) \to p\bar{p}$ decay
  2. **interference between two resonances**

Parameters	Solution I	Solution II
$M_{X(1840)}$ (MeV/c^2)	$1832.5 \pm 3.1 \pm 2.5$	
$\Gamma_{X(1840)}$ (MeV)	$80.7 \pm 5.2 \pm 7.7$	
$\mathcal{B}_{X(1840)} (\times 10^{-5})$	$1.19 \pm 0.30 \pm 0.15$	$2.07 \pm 0.50 \pm 0.36$
$M_{X(1880)}$ (MeV/c^2)	$1882.1 \pm 1.7 \pm 0.7$	
$\Gamma_{X(1880)}$ (MeV)	$30.7 \pm 5.5 \pm 2.4$	
$\mathcal{B}_{X(1880)} (\times 10^{-5})$	$0.29 \pm 0.20 \pm 0.09$	$1.19 \pm 0.31 \pm 0.18$

much narrower than X(1835)

Observed line shape consistent with two overlapping resonant structure: X(1840) and X(1880) (10σ)

→ complex resonant structures near the $p\bar{p}$ threshold

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

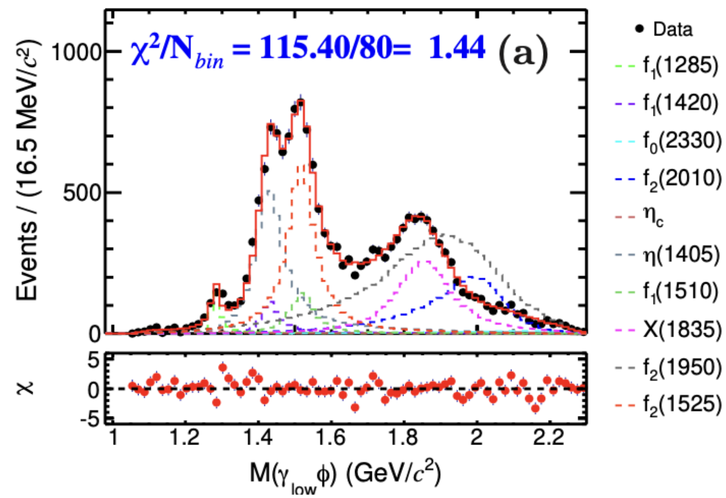
PRD **111**, 052011(2025)

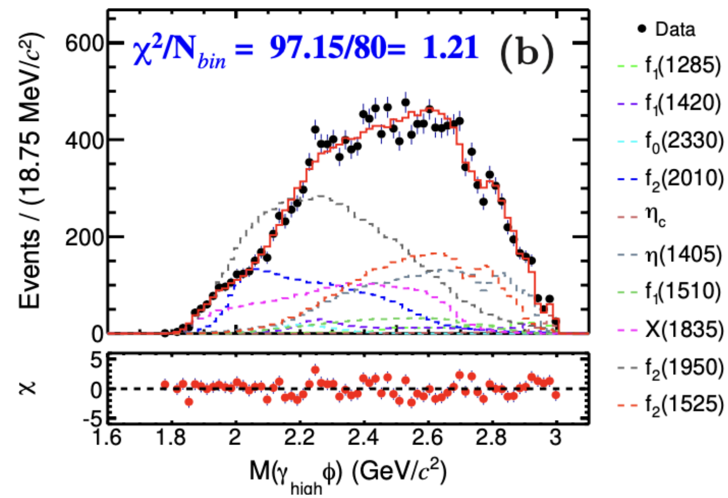
The decays $J/\psi\to\gamma X$, $X\to\gamma V$ ($V = \rho, \omega, \phi$) serve as flavor filter

- unravelling quark contents of the intermediate resonances

GPUPWA framework used to disentangle the structures

Resonance	M (MeV/c^2)	Γ (MeV)	$\mathcal{B}(\times10^{-6})$	Significance
$f_1(1285)$	1281.9	22.7	$0.29\pm0.03^{+0.11}_{-0.09}$	17.3σ
$f_1(1420)$	1426.3	54.5	$0.55\pm0.07^{+0.18}_{-0.17}$	9.0σ
$\eta(1405)$	$1422.0\pm2.1^{+5.9}_{-7.8}$	$86.3\pm2.7^{+6.6}_{-17.4}$	$3.57\pm0.18^{+0.59}_{-0.61}$	18.9σ
$f_1(1510)$	1518.0	73.0	$0.78\pm0.09^{+0.34}_{-0.30}$	5.3σ
$f_2(1525)$	1517.4	86.0	$2.76\pm0.18^{+0.90}_{-0.61}$	16.4σ
$X(1835)$	$1849.3\pm3.0^{+7.6}_{-10.0}$	$179.6\pm8.7^{+22.5}_{-27.9}$	$3.37\pm0.19^{+0.78}_{-1.10}$	15.3σ
$f_2(1950)$	1936.0	464.0	$9.96\pm0.60^{+3.44}_{-2.13}$	13.1σ
$f_2(2010)$	2011.0	202.0	$4.63\pm0.43^{+1.42}_{-1.46}$	11.3σ
$f_0(2200)$	2187.0	207.0	$0.20\pm0.04^{+0.05}_{-0.07}$	6.3σ
η_c	2983.9	32.0	$0.21\pm0.03^{+0.05}_{-0.07}$	12.9σ





- $\eta(1405)$ and $f_1(1420)$ are needed to describe the structure with mass around 1.4 GeV
- X(1835) is confirmed to be 0^{-+} with a sizable ss component
- $\eta_c\to\gamma\phi$ observed for the first time
- No significant signals are observed for $\eta(1295)$, $\eta(1475)$, $\eta_1(1855)$ and X(2370)

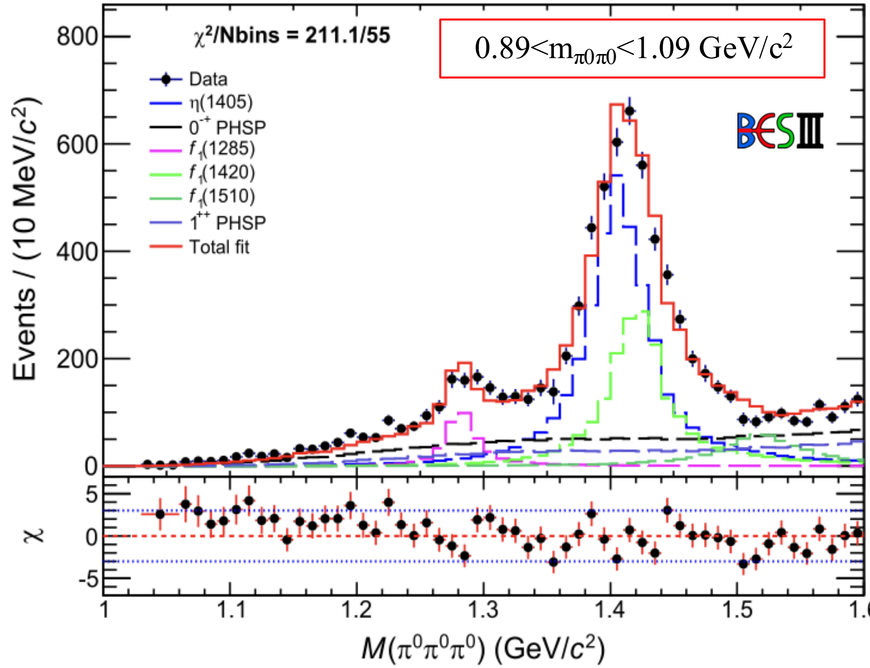
Study of $f_1(1420)$ and $\eta(1405)$ $J/\psi\to\gamma\pi^0\pi^0\pi^0$

PRD **112**,032007 (2025)

10 Billion of J/ψ data @ BESIII

Learn more about the nature of the η(1405) and η(1475), and investigate the properties of pseudoscalar and axial vectors around 1.3 and 1.4 GeV/c^2

- PWA using GPUPWA framework
  - $\pi^0\pi^0$ system: contributions from $f_0(980)$ and 0^{++} PHSP
  - Three axial vectors observed in the $3\pi^0$ for the first time
- Qualitative agreement between Mass-Indipendent in and Mass-dependent PWA
- Difficult to resolve the η(1405) and η(1475) structures
  - introduce large uncertainties



Resonance	M (MeV/c^2)	Γ (MeV)	$\mathcal{B}$	Significance (σ)
$\eta(1405)$	$1404^{+0.8}_{-1.5}{}^{+2.0}_{-8.1}$	$46^{+1.8}_{-2.0}{}^{+4.2}_{-0.0}$	$(4.62\pm0.15^{+5.08}_{-0.18})\times10^{-6}$	19.1
0^{-+} PHSP	$\cdots$	$\cdots$	$(3.24\pm0.08^{+0.41}_{-1.54})\times10^{-5}$	24.8
$f_1(1285)$	1281.9	22.7	$(5.64\pm0.45^{+0.74}_{-3.05})\times10^{-7}$	13.3
$f_1(1420)$	$1418^{+1.7}_{-2.1}{}^{+2.0}_{-2.2}$	$46^{+3.4}_{-2.3}{}^{+6.1}_{-11.0}$	$(2.23\pm0.16^{+0.20}_{-1.20})\times10^{-6}$	13.7
$f_1(1510)$	1518	73	$(7.91\pm1.20^{+0.74}_{-3.83})\times10^{-7}$	8.8
1^{++} PHSP	$\cdots$	$\cdots$	$(2.60\pm0.08^{+1.48}_{-1.66})\times10^{-5}$	13.3

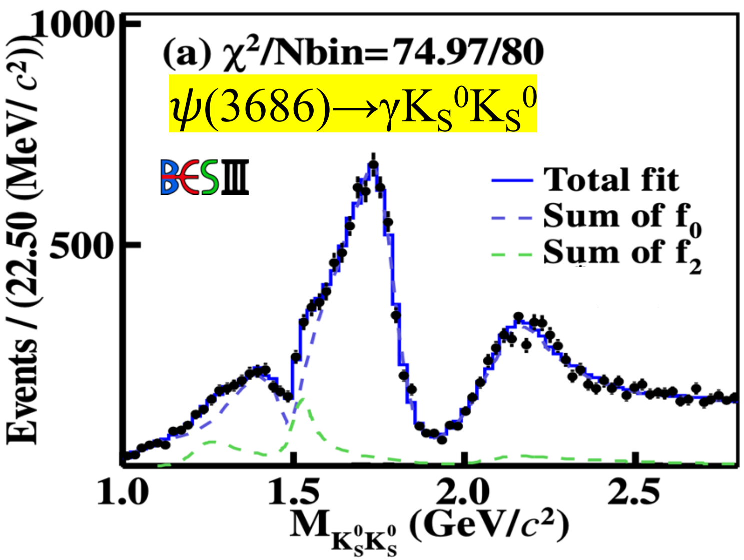
first obs. in the decay of $3\pi^0$

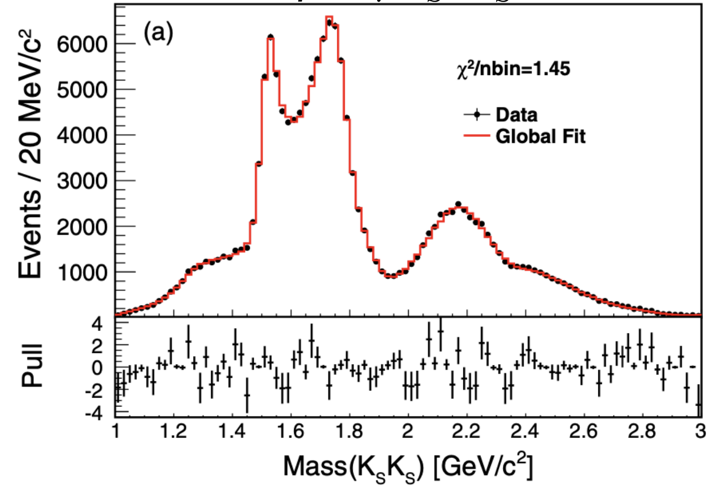
PWA of $\psi(3686)\to\gamma K_S^0K_S^0$

e-Print: 2502.13540 [hep-ex]

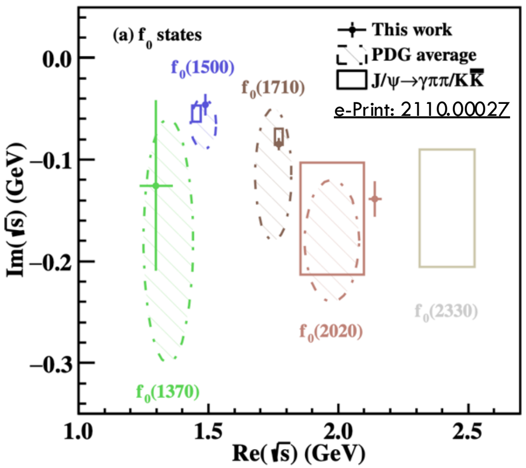
~ 2700×10^6 ψ(3686) events

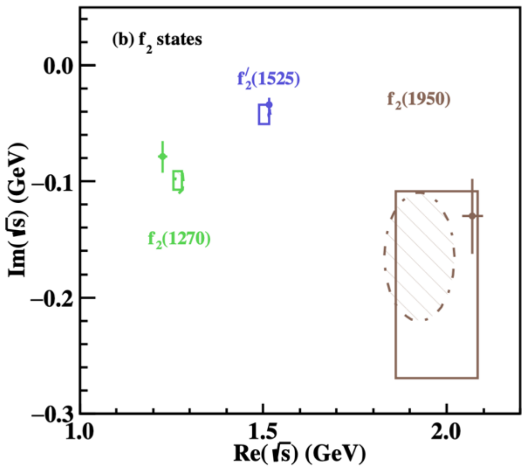
Further investigation on the f_0 and f_2 states





PRD 98,072003 (2018)

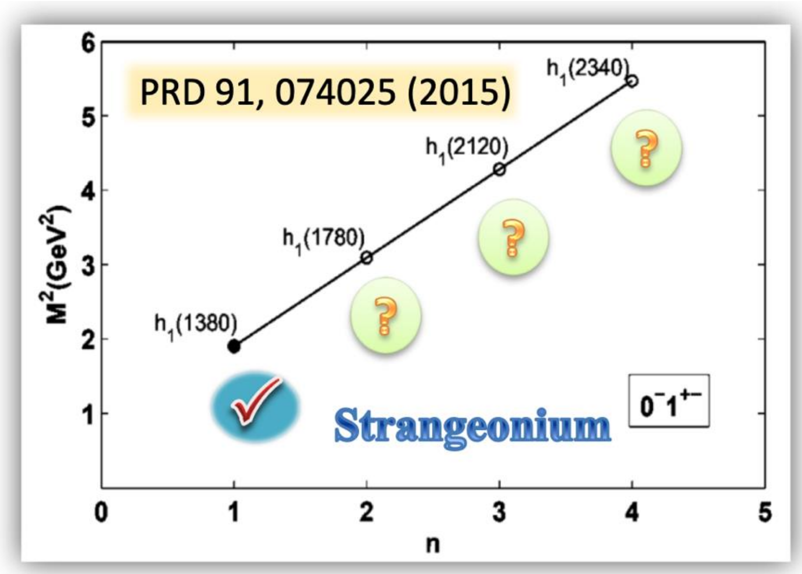




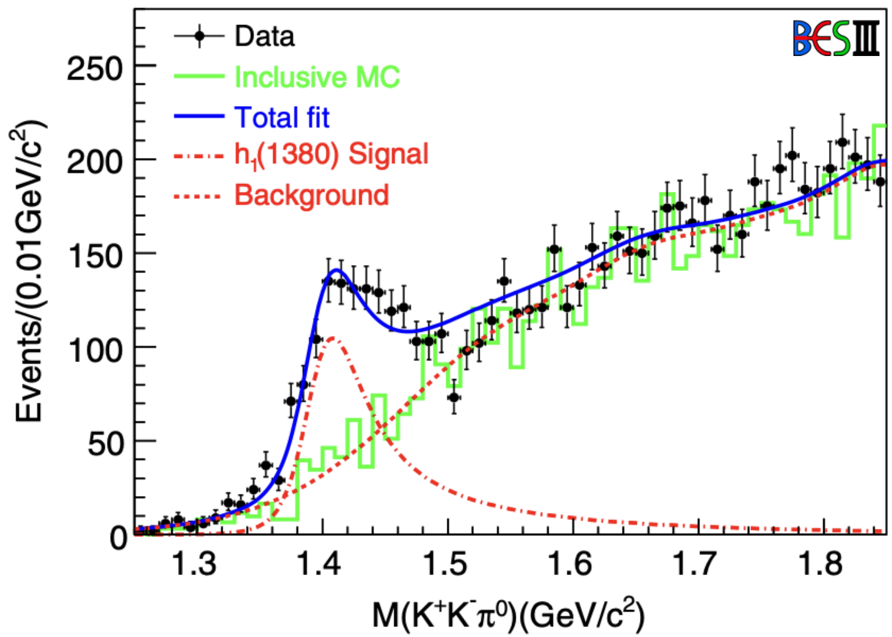
- Data well described with **four** poles for the f_0-wave and **three** poles for the f_2-wave
  - masses and widths consistent between J/ψ and ψ(2S) decays
- f_0(2330) not observed this BESIII analysis

$$\frac{\mathcal{B}(\psi(3686)\to\gamma gg)}{\mathcal{B}(J\psi\to\gamma gg)}=(11.7\pm3.6)\%$$

Axial-Vector Strangeonium

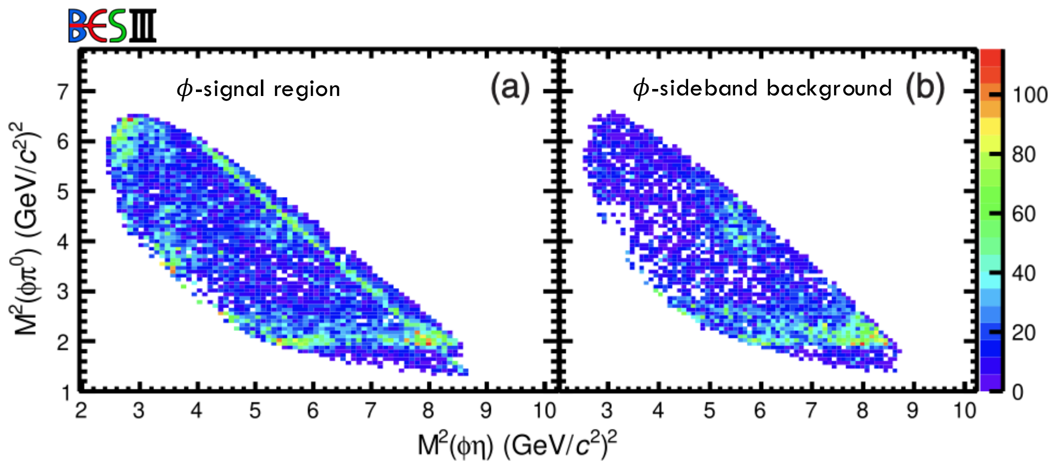


Observation of $h_1(1380)$ in the $J/\psi \rightarrow \eta`KK\pi$ decay
PRD 98, 072005 (2018)



- Only the ground axial-vector state **$h_1(1380)$** (**$h_1(1415)$** PDG) has been confirmed
  - Observed about 35 years ago by fixed target experiments
  - Observed by BESIII in the M(KKπ) in the $J/\psi \rightarrow \eta`KK\pi$ decay using 1.31×10^9 J/ψ events
- Exited states (**$h_1(2P)$** and **$h_1(3P)$**) have been predicted by theory, but still not confirmed experimentally
- Fully-strange tetraquarks predicted in the same mass region and decay in the same final states

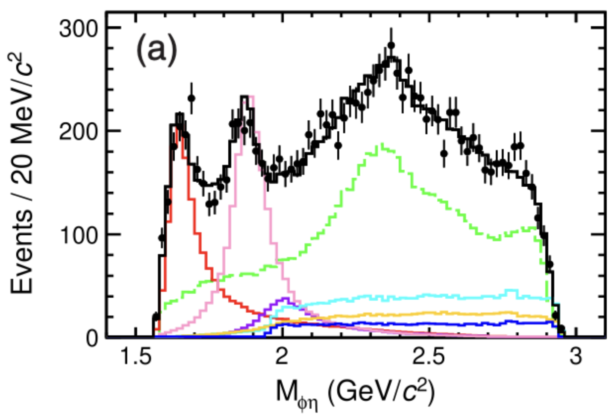
Study of the decay $J/\psi \to \phi\pi^0\eta$

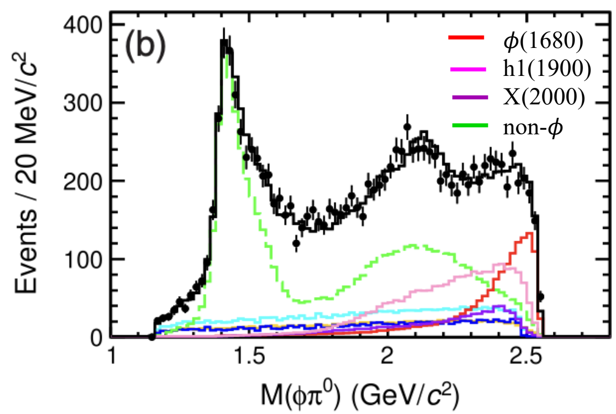


PRD 110, 112014 (2024)

10 Billion of J/ψ data @ BESIII

- PWA analysis based on GPUPWA framework
- Improve the understanding of the h_1 family
- Improved precision of the $a_0(980)$-$f_0(980)$ mixing





- ➢ $\phi(1680)$ established vector strangeonium meson
- ➢ Two new resonances in the $M(\phi\eta)$ observed for the first time

$$M_{h_1(1900)} = 1908 \pm 6^{+8}_{-4}\ \mathrm{MeV/c^2}$$
$$\Gamma_{h_1(1900)} = 175 \pm 13^{+7}_{-16}\mathrm{MeV}$$

$h_1(1900)$ (1^{+-}) consistent with **$h_1(2P)$** strangeonium state

$$M_{X(2000)} = 1992 \pm 12^{+15}_{-6}\ \mathrm{MeV/c^2}$$
$$\Gamma_{X(2000)} = 132 \pm 22^{+17}_{-4}\mathrm{MeV}$$

$X(2000)$ (1^{--}) mass and width disagree with $\phi(3S/2D)$ predictions

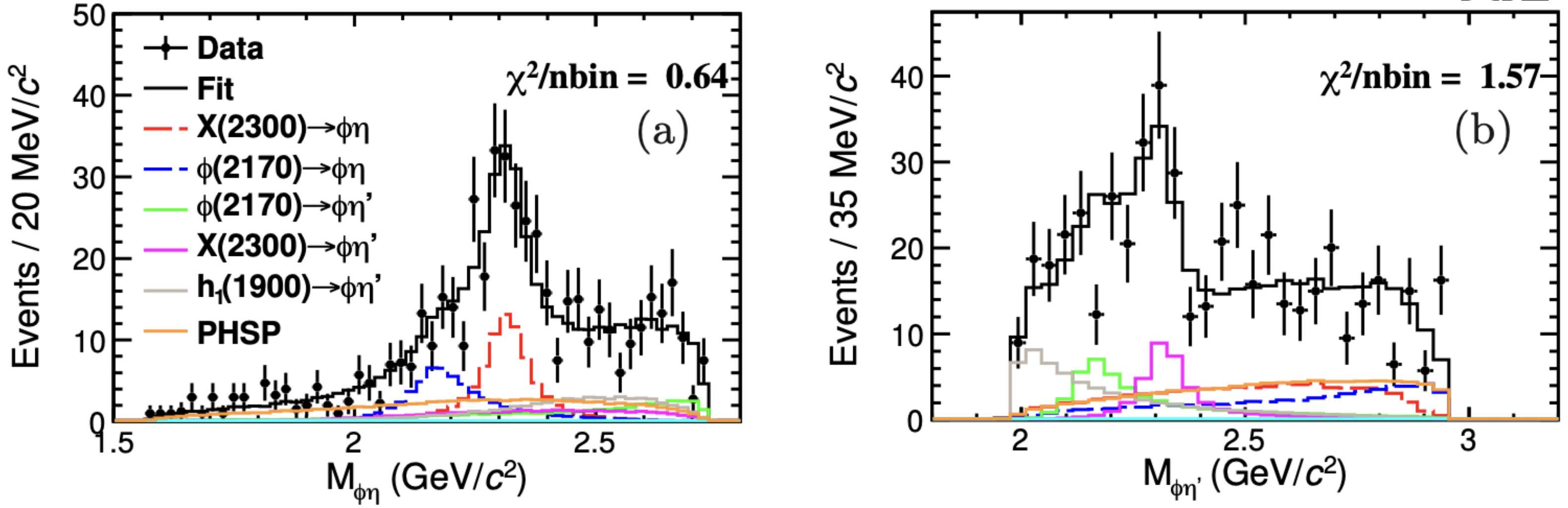
The structure around 1.4 GeV/c^2 in the $\phi\pi^0$ invariant mass spectra is well described by non-ϕ background

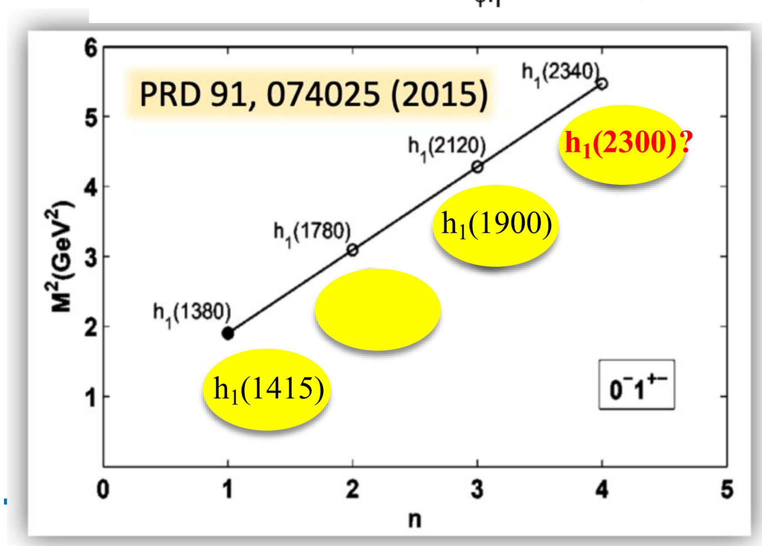
Study of $\psi(3686)\to\phi\eta\eta'$

Amplitude analysis based on ~ 2700×10^6 $\psi(3686)$ events

e-Print: 2410.05736 [hep-ex]

- ➢ Well established $\phi(2170)$ and $h_1(1900)$ states observed
- ➢ An axial-vector state in the $M(\phi\eta)$ observed for the first time



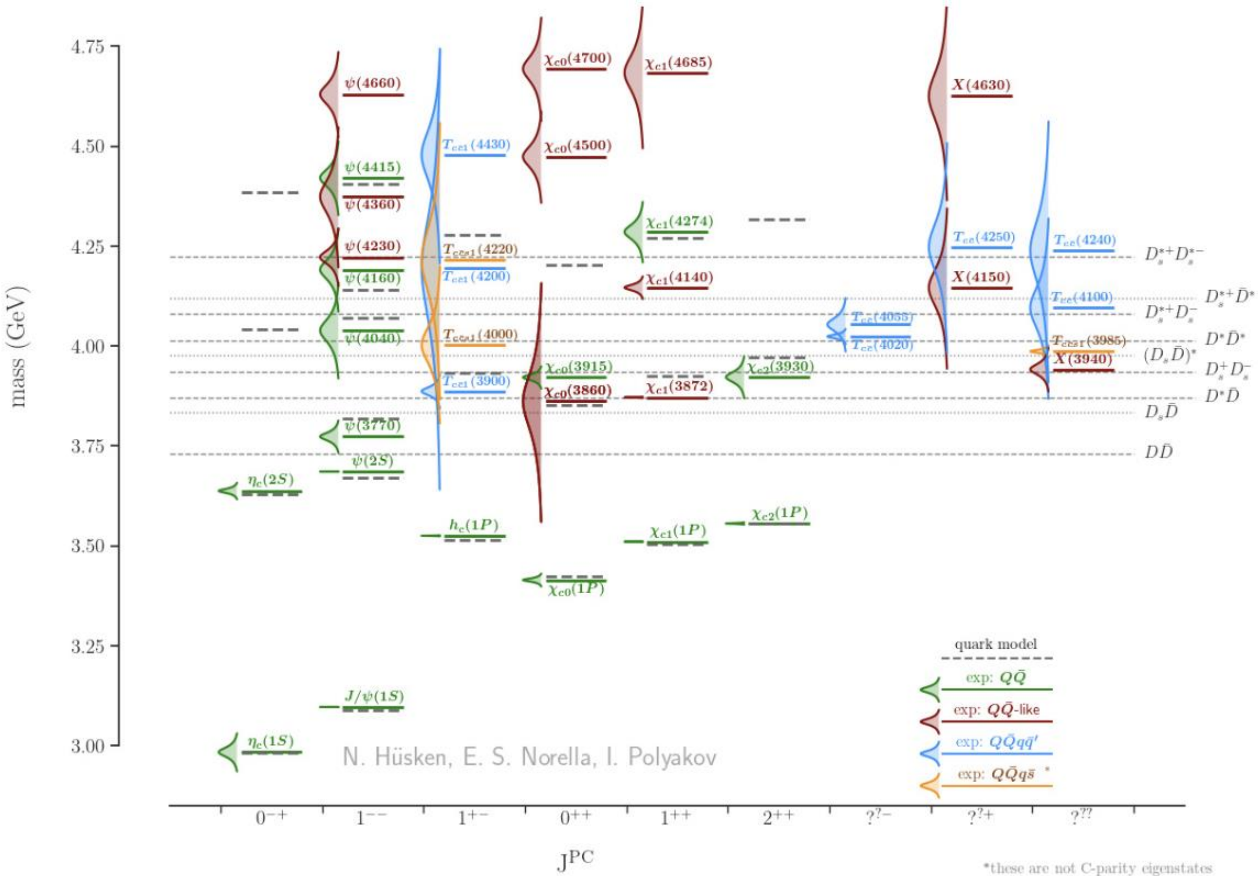


$X(2300)\to h_1(2300)$? (1^{+-})

$$M_{X(2300)} = 2316 \pm 9 \pm 30\ \mathrm{MeV/c^2}$$

$$\Gamma_{X(2300)} = 89 \pm 15 \pm 26\mathrm{MeV}$$

- ✓ The mass of the observed resonance deviates systematically from the $h_1(3P)$ predictions
- ✓ More theoretical calculations needed to test the $T_{(ss\bar{s}\bar{s})1+-}$ hypothesis



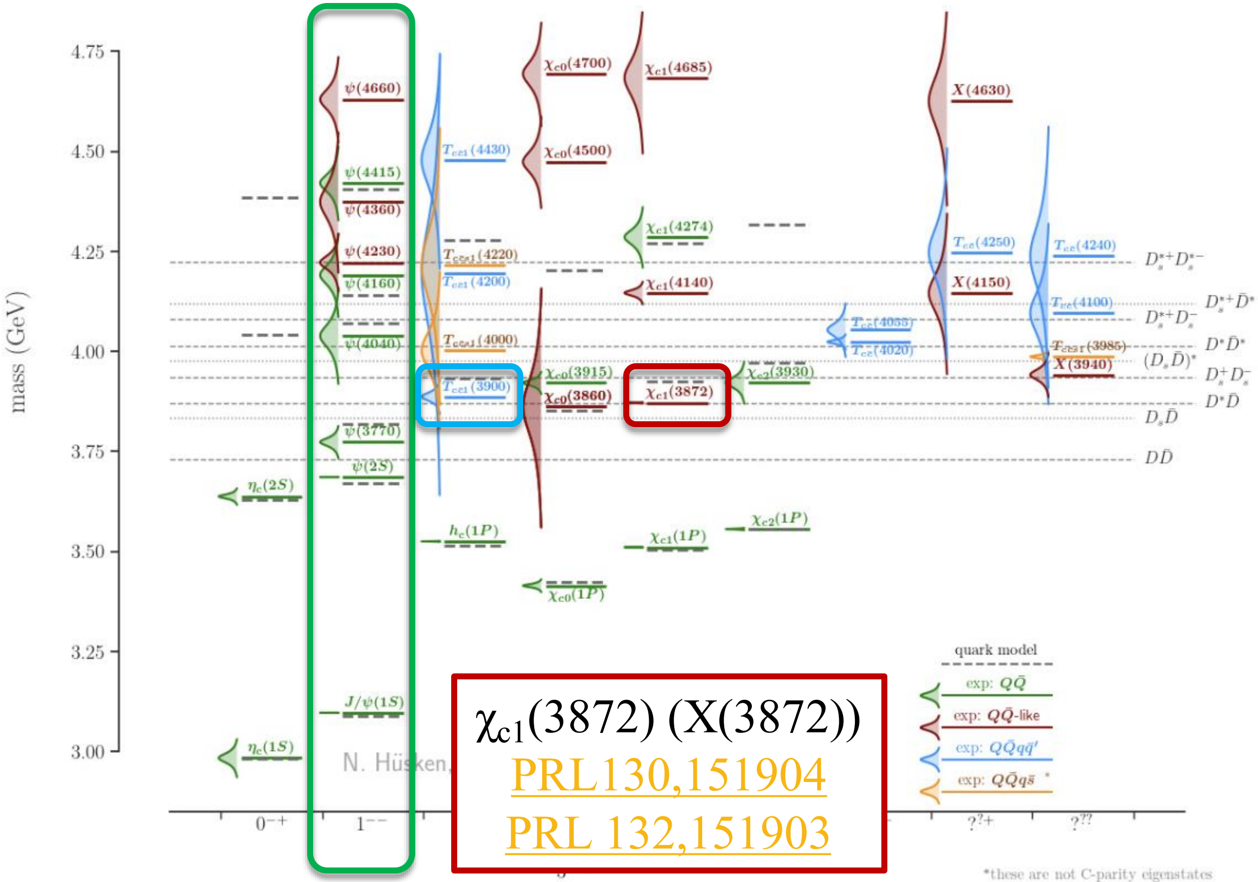
- Conventional charmonia fit well with potential model calculations

$$V_{c\bar{c}} = -\frac{4}{3}\cdot\frac{\alpha_s(r)}{r} + k\cdot r$$

+ spin-dependent terms

- good agreement with experiments
- Many other states seen in experiments like BaBar, Belle, BESIII, LHCb, …

Charmonium Spectroscopy



$\chi_{c1}(3872)$ (X(3872))
PRL130,151904
PRL 132,151903

- Conventional charmonia fit well with potential model calculations

$$V_{c\bar{c}} = -\frac{4}{3}\cdot\frac{\alpha_s(r)}{r} + k\cdot r$$

+ spin-dependent terms

- good agreement with experiments
- Many other states seen in experiments like BaBar, Belle, BESIII, LHCb, …

vector states (Y); commonly identified as ψ

$T_{c\bar{c}1}(3900)/Z_c(3900)$
Z: isospin $\neq 0$

X: remined states (non Y and non Z)

$Z_c^{\pm}(3900)$: PWA of $e^+e^- \to \pi^+\pi^- J/\psi$

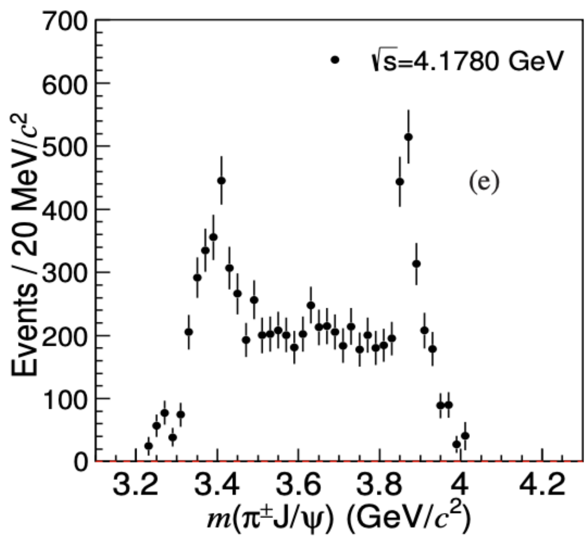
https://arxiv.org/pdf/2505.13222

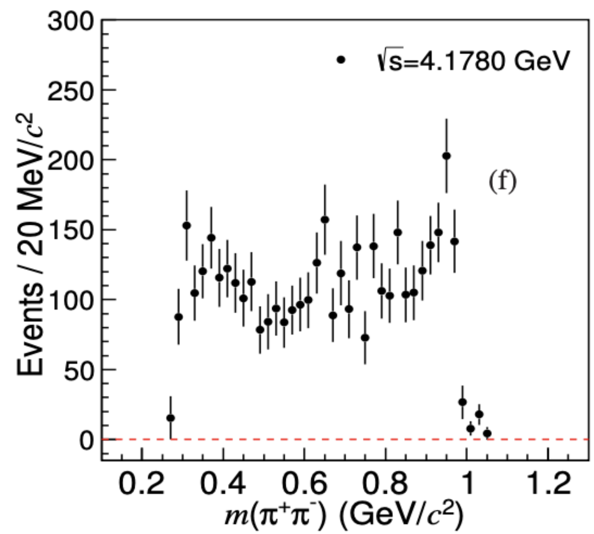
$Z_c(3900)$ ($T_{c\bar{c}1}(3900)$)

- Observed in the invariant mass distribution of $J/\psi\pi^{\pm}$ by BESIII and Belle, and confirmed by CLEO-c
- Its internal structure is still unclear
- May be strongly correlated with the Y(4230)

➢ PWA of 17 data sample (12 fb^{-1}): $\sqrt{s}$ = 4.13 - 4.36 GeV
  - ➢ helicity-covariant method
  - ➢ Two models:

1. $f_0(980)$ as Flatté, $\sigma(500)$, $f_0(1370)$, $f_2(1270)$ and $Z_c(3900)$ as Breit-Wigner
2. $\sigma(500)$, $f_0(1370)$, $f_2(1370)$ with K-matrix, $f_2(1270)$ and $Z_c(3900)$ as Breit-Wigner

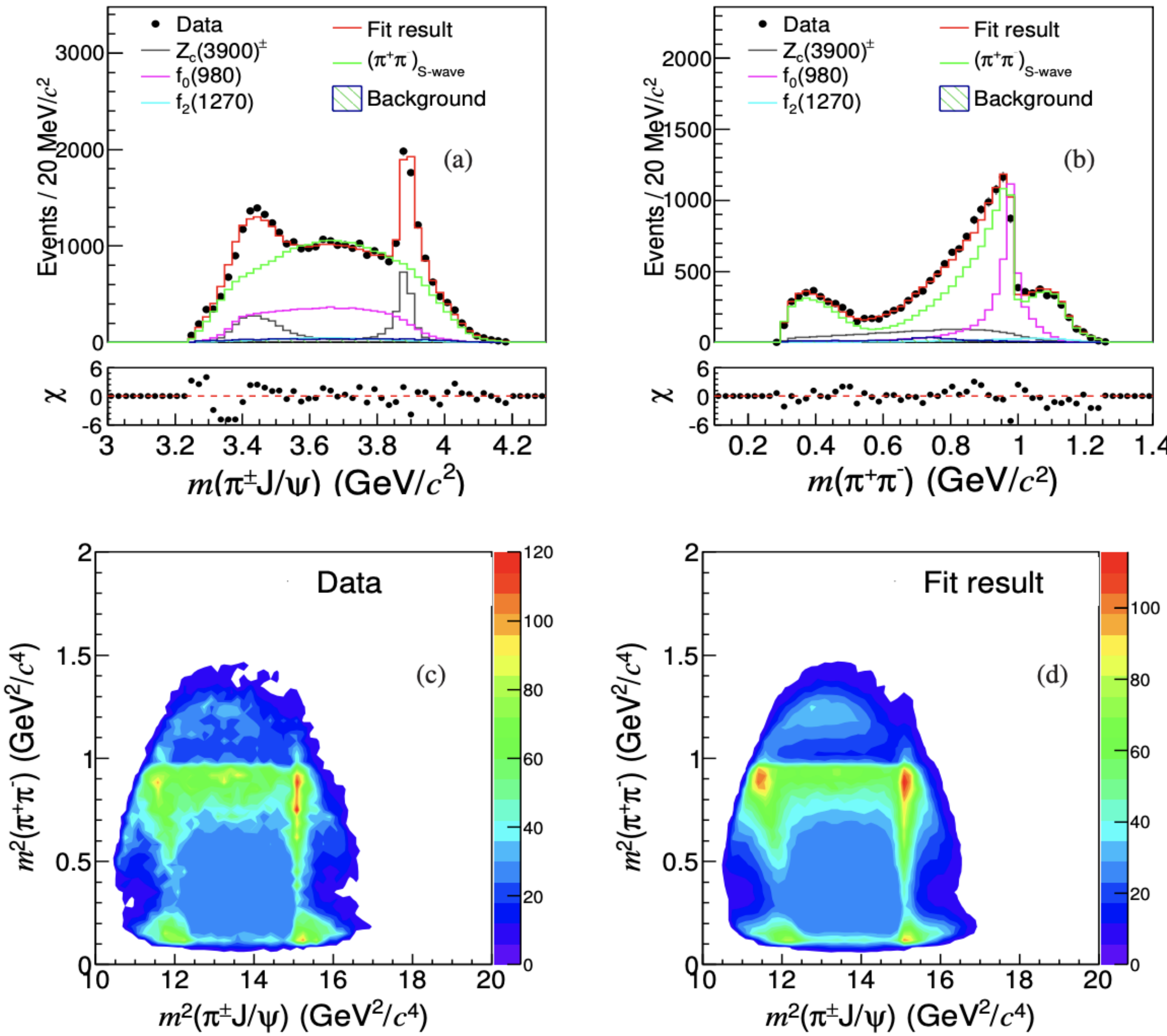




$Z_c^{\pm}(3900)$: PWA of $e^+e^- \to \pi^+\pi^- J/\psi$

https://arxiv.org/pdf/2505.13222

Sum over all center-of-mass energies



$\pi^+ Z_c^-(3900)$, $f_j J/\psi$ ($f_j = f_0(500), f_0(980), f_0(1370), f_2(1270)$)

Further studies are ongoing to better describe the region around 3.3 GeV/c² in the $\pi J/\psi$ invariant mass spectrum

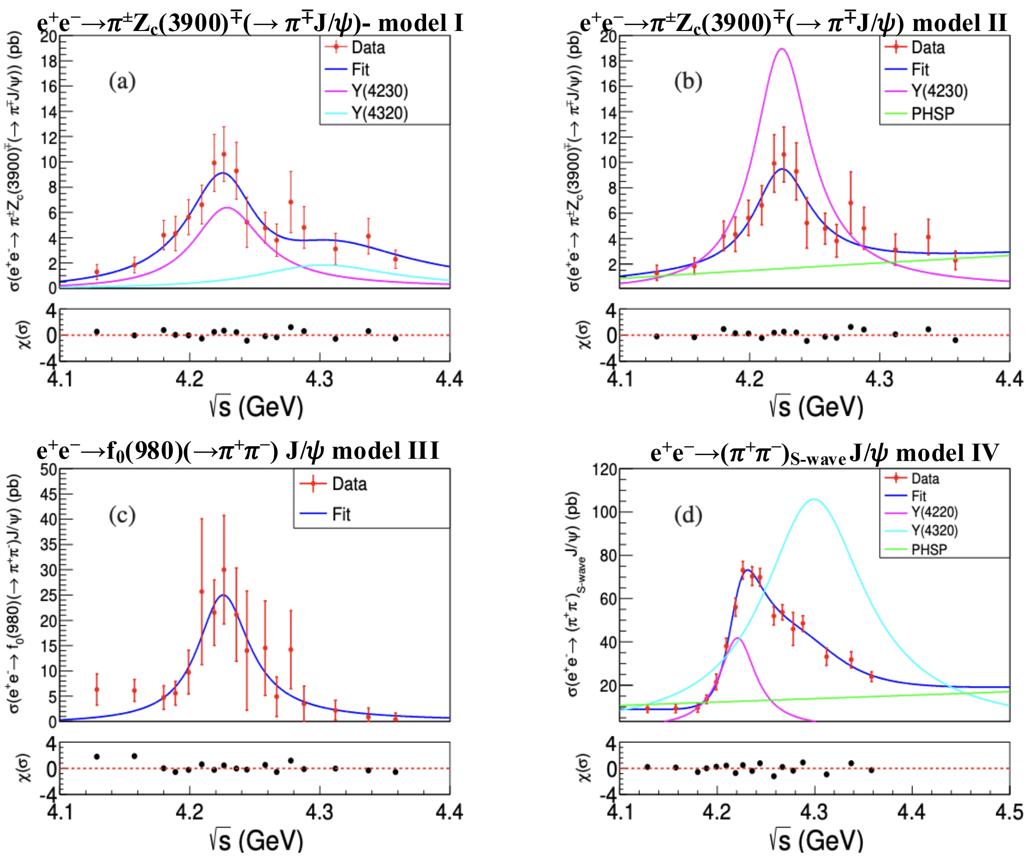
Mass and width of $Z_c(3900)^{\pm}$ from simultaneous fit

Sample	M (MeV/c^2)	Γ (MeV)
4.1567 − 4.1989	3883.5 ± 1.6	38.6 ± 3.6
4.2091 − 4.2357	3884.0 ± 1.0	37.8 ± 1.6
4.2438 − 4.2776	3884.9 ± 1.8	34.2 ± 3.3
4.2866 − 4.3583	3890.0 ± 2.3	36.1 ± 4.2
Average	3884.6 ± 0.7 ± 3.3	37.2 ± 1.3 ± 6.6

$Z_c^{\pm}(3900)$: PWA of $e^+e^- \to \pi^+\pi^- J/\psi$

https://arxiv.org/pdf/2505.13222

	Process	$Y(4220)$		$Y(4320)$
		M (MeV/c^2)	Γ (MeV)	Significance
(a)	$\pi^{\pm}Z_c(3900)^{\mp}$ (model I)	$4227.0 \pm 7.0 \pm 6.1$	$64.4 \pm 17.2 \pm 22.3$	2.1σ
(b)	$\pi^{\pm}Z_c(3900)^{\mp}$ (model II)	$4223.5 \pm 6.6 \pm 0.6$	$52.8 \pm 20.2 \pm 0.3$	1.9σ
(c)	$f_0(980)J/\psi$ (model III)	$4224.6 \pm 4.5 \pm 0.6$	$46.4 \pm 8.0 \pm 0.2$	0.3σ
(d)	$(\pi^+\pi^-)_{\text{S-wave}}J/\psi$ (model IV)	$4220.6 \pm 3.2 \pm 12.7$	$45.4 \pm 5.8 \pm 6.3$	12.2σ
	$Y(4220)^{\text{ave}}$	$4225.8 \pm 4.2 \pm 3.1$	$55.3 \pm 9.5 \pm 11.1$	



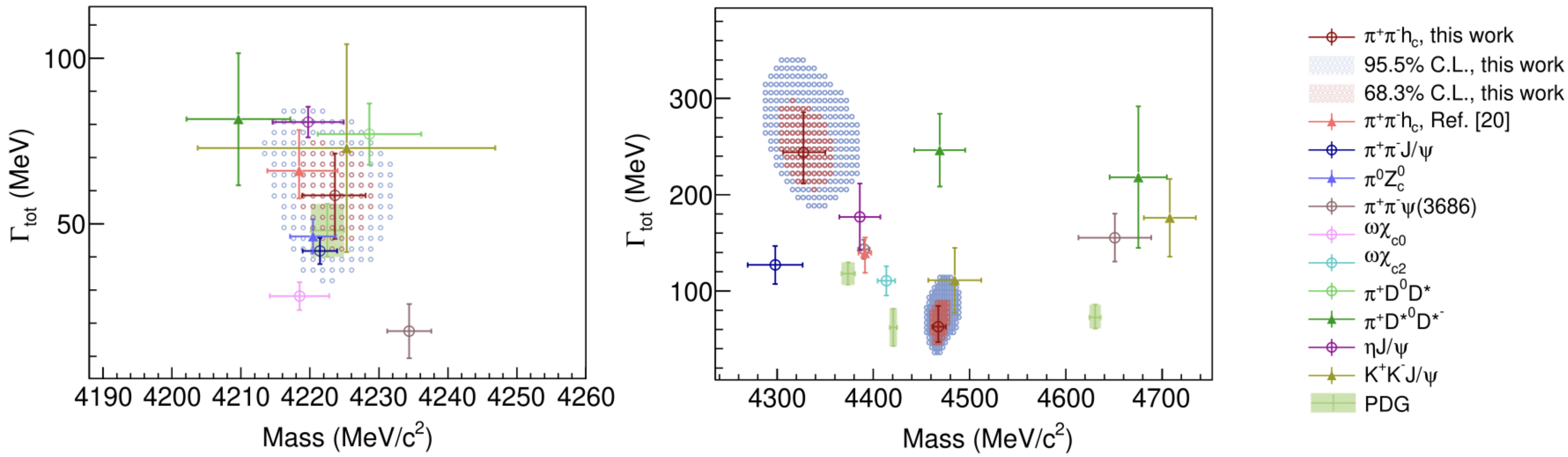
- Model I: coherent sum of two BW functions
- Model II: one BW and a two-body PHSP functions
- Model III: one BW function
- Model IV: coherent sum of two BW functions and two-body PHSP function

- Dominant contribution from $(\pi+\pi-)_{\text{S-wave}}J/\psi$
- The cross sections with Y(4220) and Y(4320) decaying into different final states appear to have different distributions
- $f_0(980)J/\psi$ process well described by one BW (parameters consistent with those of the Y(4220))

Cross section of $e^+e^-\to\pi^+\pi^- h_c$

PRL 135, 071901(2025)

- Overpopulation of vector charmonium-like states

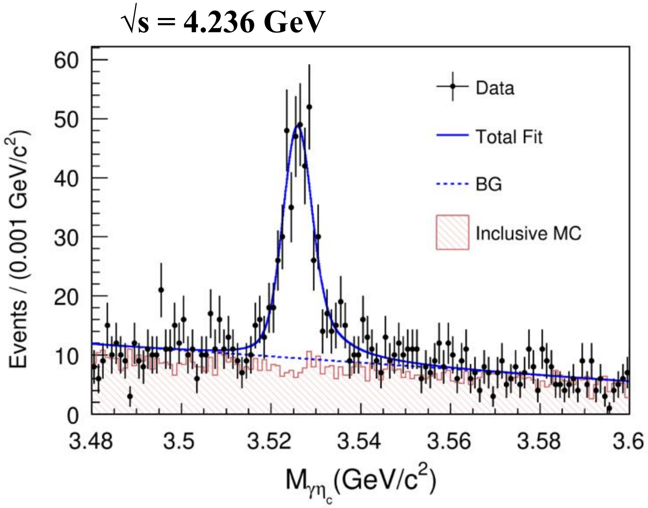


- The transition between vector charmonium states and h_c are expected to be suppressed due to heavy quark spin symmetry
- 4S-3D and 5S-4D mixing charmonium states are predicted to lie between 4.2 and 4.5 GeV/c^2
  - $e^+e^-\to\pi^+\pi^-h_c$ at $\sqrt{s}$ from 4.009 to 4.950 GeV

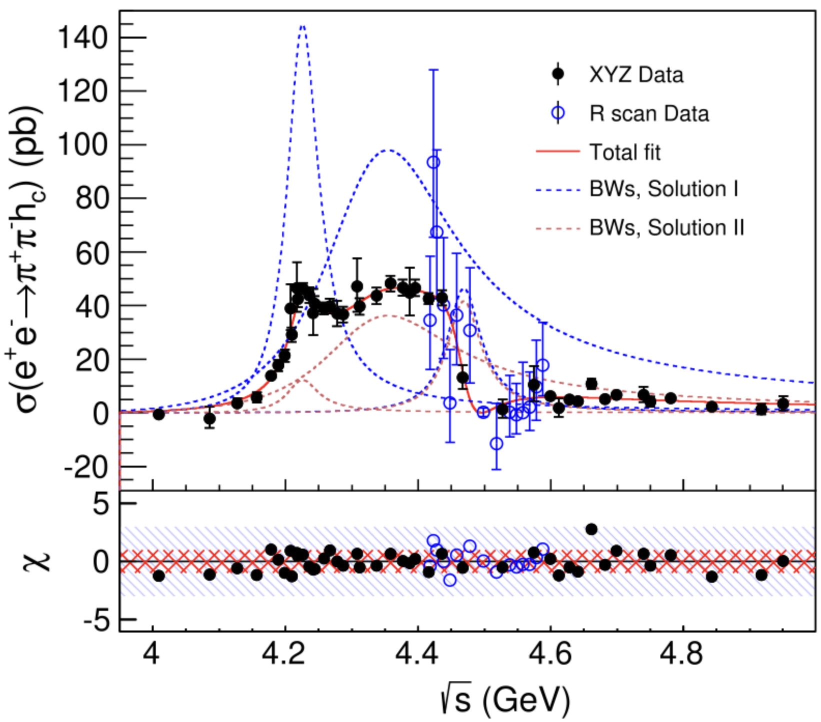
1. XYZ-I: 19 energy points with large statistics → large statistic
2. XYZ-II: 25 energy points with lower statistics → medium statistics
3. R-scan: 15 energy points each with 8 pb^{-1} → least statistics

Cross section of $e^+e^- \to \pi^+\pi^- h_c$

PRL 135, 071901(2025)



- $h_c \to \gamma\eta_c$, with η_c reconstructed in 16 exclusive hadronic final states
- Signal yield is determined by performing an unbinned maximum likelihood fit to $M(\gamma\eta_c)$



- Best fit model: coherent sum of 3 BW functions (needed to describe the dip at 4.5 GeV)

$$|BW_1(\sqrt{s}) + e^{i\phi_2} BW_2(\sqrt{s}) + e^{i\phi_3} BW_3(\sqrt{s})|^2.$$

$$\frac{M_k}{\sqrt{s}} \cdot \frac{\sqrt{12\pi(\Gamma_{ee}\mathcal{B}(R_k \to \pi^+\pi^- h_c))_k \Gamma_k}}{s - M_k^2 + iM_k\Gamma_k} \cdot \sqrt{\frac{PS(\sqrt{s})}{PS(M_k)}}$$

- First resonance consistent with those reported for Y(4220) by BESIII
- Significance of R3 > 5σ
- Mass of R2 consistent with the $\psi(4360)$ but the width is 100 MeV broader
- Width of R3 consistent with the $\psi(4500)$ but the mass is 40 MeV higher

Search for 1^{-+} states in $e^+e^- \to \gamma D^+_s D^-_{s1}(2536)$

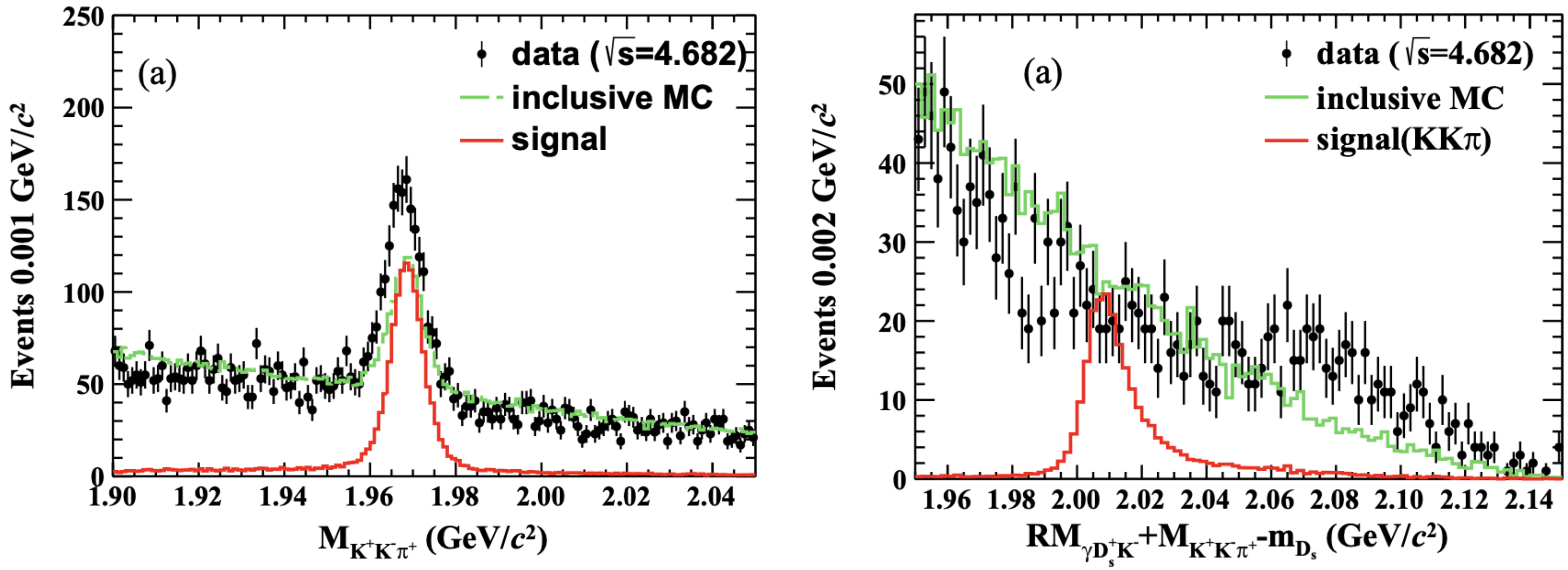
Search for states with exotic quantum number $J^{PC}=1^{-+}$

PRD 112, 032002 (2025)

- no evidence in the charmonium energy region
- Q. Wang [PRD 89, 114013] predicts 1^{-+} molecule state $DD_1(2420)$
  - Extend to D meson with strange quark $D_s^+D_{s1}^-(2536)$
- Data sample (5.8 fb^{-1}): $\sqrt{s}$ = 4.61 - 4.95 GeV

Partial reconstruction method:

$$e^+e^- \to \gamma D_s^+ D_{s1}^-(2536);\ D_s^+ \to K^+K^-\pi^+;\ D_{s1}^-(2536) \to K^-\bar{D}^{*0}$$
$$e^+e^- \to \gamma D_s^+ D_{s1}^-(2536);\ D_s^+ \to K_S^0\pi^+;\ D_{s1}^-(2536) \to K^-\bar{D}^{*0}$$

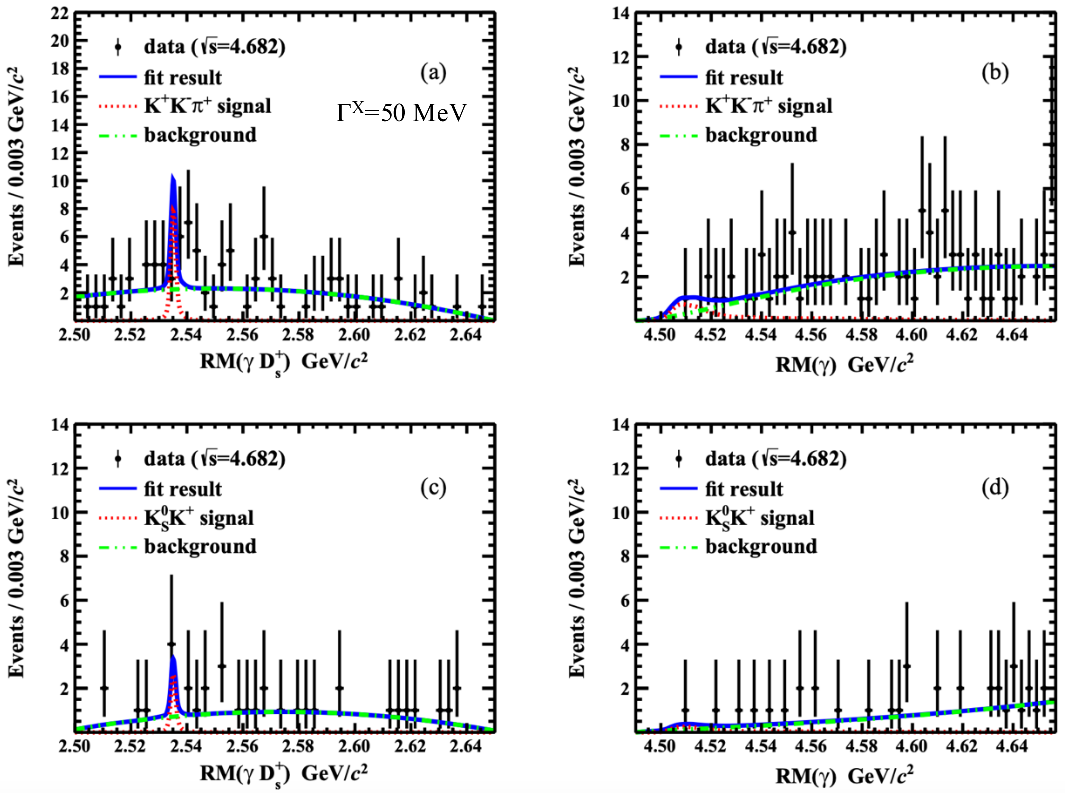


Clear D_s are observed, but no significant $\bar{D}^{*0}$

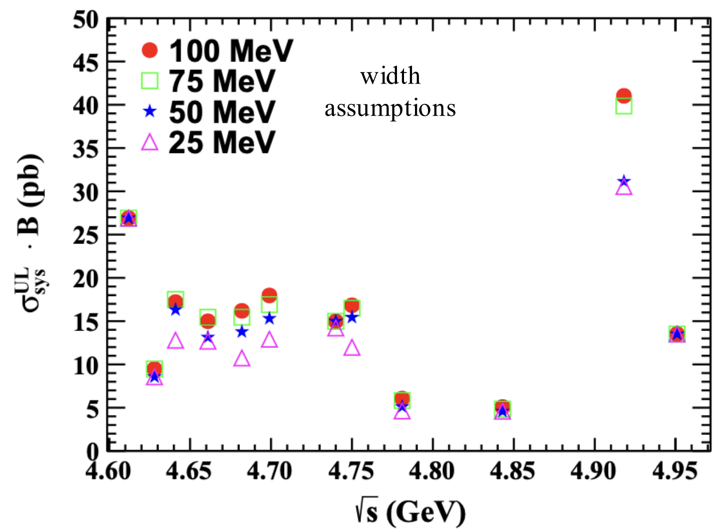
Search for 1^{-+} states in $e^+e^- \to \gamma D^+_s D^-_{s1}(2536)$

PRD 112, 032002 (2025)

Unbinned two-dimensional simultaneous fit



$$\sigma^{UL} \cdot \mathcal{B} = \frac{N^{UL}_{KK\pi}}{\mathcal{L}_{int} \cdot (1+\delta) \cdot \frac{1}{|1-\Pi|^2} \cdot \epsilon_{KK\pi} \cdot \mathcal{B}_1 \cdot \mathcal{B}_2}$$



No significant signal is observed and the ULs of σ($e^+e^- \to \gamma X$)*B($X \to D_s^+ D_{s1}^-(2536)$) are determined at 90% CL by means of Bayesian method, assuming M_X = 4.503 GeV/c2 and ΓX=25, 50, 75 or 100 MeV

Status and Perspectives

e^+e^- offers a particularly clean environment and high-statistics data samples, making it an excellent laboratory for detailed spectroscopy studies.

Light hadron spectroscopy

- ***Exotic state and glueball-like particle J/ψ radiative decays***
- ***Observation of new states***
- ***PWA analysis studies***

Axial-vector strangeonium

- ***Search for exited axial vector strangeonium states and fully strange tetraquarks***

Charmonium spectroscopy

- ***Study the nature of XYZ states***
- ***Search for new decay modes and charged/neutral partner***
- ***Test tetraquark hypothesis, threshold effect, kinematic reflection, ...***

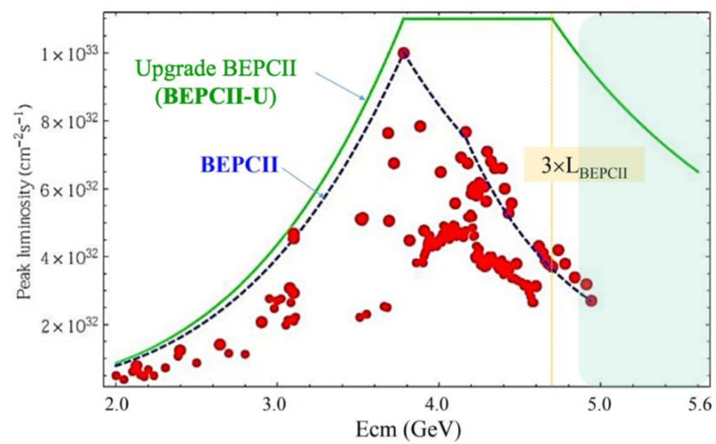
Ongoing studies:

- ✓ $\mathbf{J/\psi\to\gamma K^0_S K^0_S \pi^0}$ and $\mathbf{J/\psi\to\gamma\,\pi^0\pi^0\eta}$ preliminary results on the X(2370)
- ✓ Advanced analysis techniques
  - ✓ PWA, improved parameterized methods like the K-matrix approach, line shape studies …
- ✓ Coupled channel approaches are required – and are being developed — both for **light-hadron** and **charmonium spectroscopy**
  - ✓ $T_{c\bar{c}}(4020)^- \to D^{*0}D^{*-}$, $\pi^- J/\psi$, and $\pi^- h_c$
  - ✓ ….

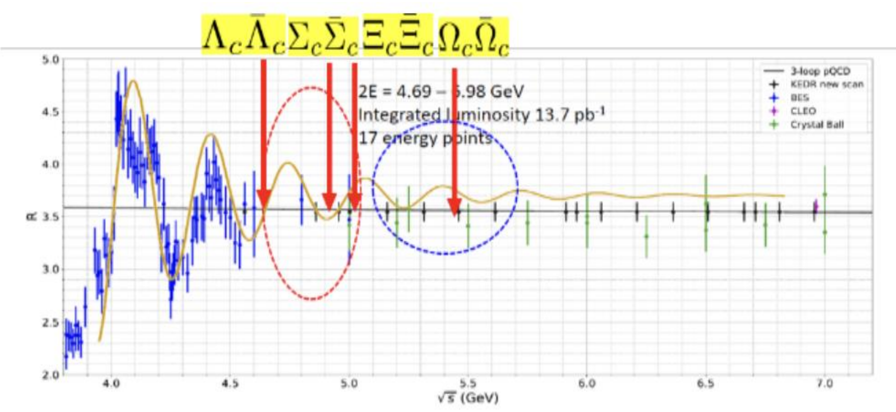
Status and Perspectives

2024/2025: Detector and BEPCII upgrade

- Upgrade in energy (5.6 GeV) and luminosity (BEPCII-U, 3x)
  - precision XYZ physics
  - fine energy scans to study cross sections
  - large datasets at single √s to study X, Z_c lineshapes
- A new inner tracker (CGEM) was installed
- Opportunities to study other charmed baryons (Σ_c, Ξ_c, Ω_c) in the BEPCII-U



Above the $J/\psi p\bar{p}$ threshold, can we produce pentaquarks?



Status and Perspectives

BEPCII-U Operation plan

- Jul. 2024 – Dec. 2024 — Summer shutdown for installation
- Jan. 2025 – Jul. 2025 — Commissioning & Data taking @1.843GeV ψ (3686)
- Aug. 2025 — Summer shutdown
- Sep. 2025 – Jul. 2026 — Data taking @1.843GeV & 2.35GeV (project test)
- Aug. 2026 – Sep. 2026 — Summer shutdown & LINAC final upgrade
- Oct. 2026 – Sep. 2028 — Data taking within beam energy 2.1-2.5GeV
- Sep. 2028 – Jul. 2030 — Data taking within beam energy 2.5-2.8GeV

C.H. Yu @ BESIII 2025 summer Col. meeting

- **2025/26** (round 19) — allocation not final
  BEPCII-U: demonstrate operation at high energy, show gain in luminosity
  Run at 4680 MeV — start collecting $\Lambda_c^+\overline{\Lambda}_c^-$ sample (requested total of 9 fb^{-1})
  Scans around $X(3872)$ and χ_{c2} (about one month each)

Conclusions

- Both light and heavy hadron spectroscopy have made remarkable progress, with several new and intriguing states observed

BUT

- Many open questions remain — concerning their nature, internal structure, and possible exotic configurations

- **Future analyses**, including coupled-channel and amplitude studies, together with **new data from BESIII and upcoming experiments**, will be crucial to deepen our understanding of strong interactions in the non-perturbative regime

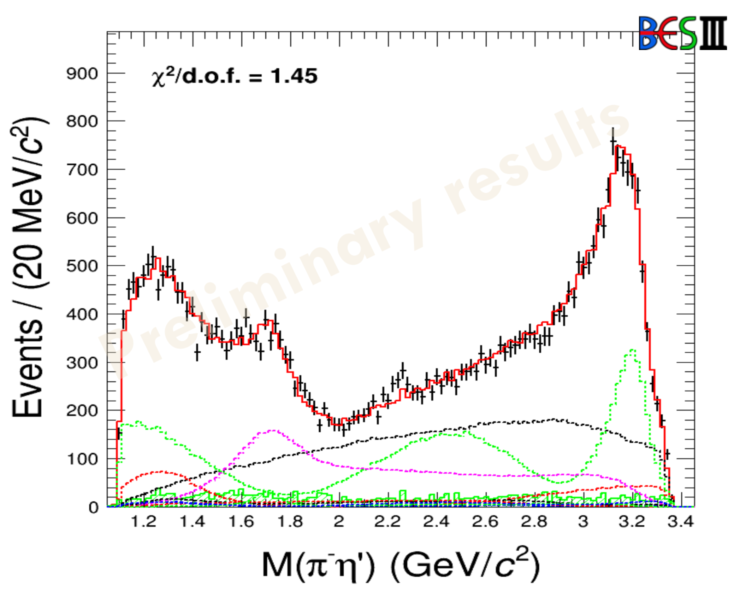
Thank you for your attention

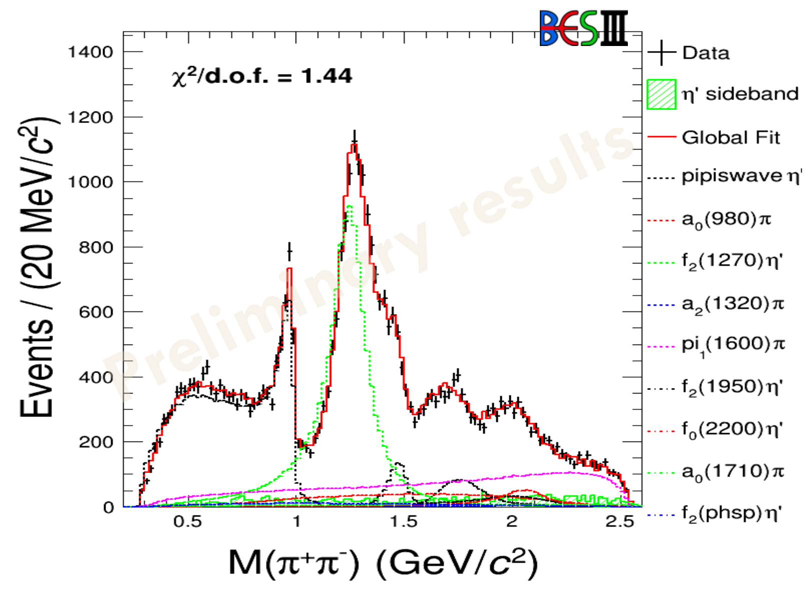
Back-up slides

The $\pi_1(1600)$ in χ_{c1} decays

Based on ~ 2700×10^6 $\psi(3686)$ events a PWA is performed on the $\psi(2S) \to \gamma\chi_{c1}$, $\chi_{c1} \to \pi^+\pi^-\eta'$ (a factor of 100 more statistics than CLEOc)

- Opportunity to search for $J^{PC} = 1^{-+}$ exotics in the $\eta'\pi$ systems
- 1^{-+} hybrid experimental candidates: $\pi_1(1400)$, $\pi_1(1600)$, $\pi_1(2015)$
- Studies claimed that the $\pi_1(1400)$ and $\pi_1(1600)$ might originate from a same pole (Eur.Phys.J.C 81 (2021) 12, 1056, Phys.Rev.Lett. 122 (2019) 4, 042002)





- ✓ $\pi_1(1600)$ is first observed in $\chi_{c1} \to \pi^+\pi^-\eta'$ process with well over 10σ significance
- ✓ The J^{pc} of $\pi_1(1600)$ is measured to be exotic 1^{-+} with over 10σ

X(2370)

X(2370) measurements:

$J^{PC} = 0^{-+}$ with significance >9.8σ

$M = 2395 \pm 11^{+26}_{-94}$ MeV

$\Gamma = 188^{+18}_{-17}{}^{+124}_{-33}$ MeV

$B(J/\psi \to \gamma X(2370)) B(X(2370) \to f_0(980)\eta') B(f_0(980) \to K^0_S K^0_S)$
$= 1.31 \pm 0.22^{+2.85}_{-0.84} \times 10^{-5}$

PRL 132 (2024) 181901

LQCD prediction on lightest pseudoscalar glueball:

$J^{PC} = 0^{-+}$

$M = 2395 \pm 14$ MeV

$B(J/\psi \to \gamma G_{0-+}) = 2.31 \pm 0.80 \times 10^{-4}$

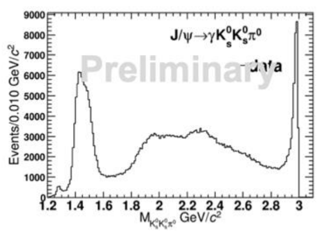
PRD 100 (2019) 054511

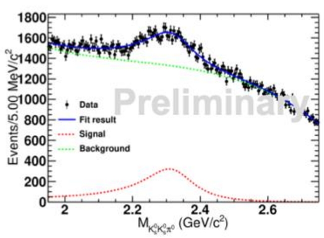
- The measurements are in a agreement with the predictions on lightest pseudoscalar glueball
  - **The spin-parity of the X(2370) is determined to be 0^{-+} for the first time**
  - **Mass is in a agreement with LQCD predictions**
  - The estimation on $B(J/\psi \to \gamma X(2370))$ and prediction on $B(J/\psi \to \gamma G_{0-+})$ are consistent within errors (assuming ~5% decay rate, $B(J/\psi \to \gamma X(2370)) = 10.7^{+22.8}_{-7} \times 10^{-4}$)

Courtesy of **Yanping Huang**

X(2370)

- **Observation of X(2370) in $J/\psi \to \gamma K_S^0 K_S^0 \pi^0$**
  - ✓ Almost background free channel

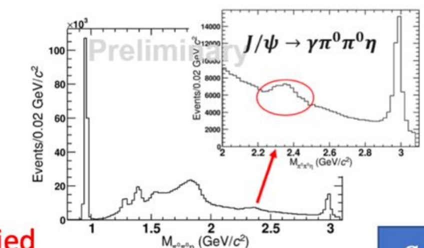


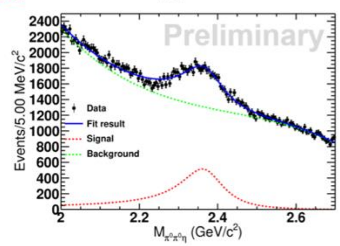


Statistical significance: >> 5σ

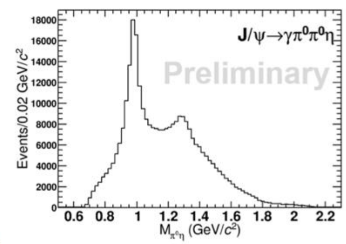
- More decay mode studied
- Highly similarity to η_c

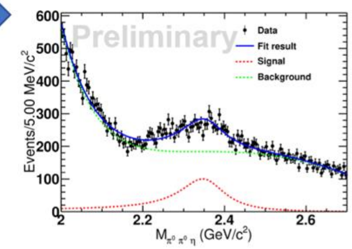
- **Observation of X(2370) in $J/\psi \to \gamma \pi^0 \pi^0 \eta$**
  - ✓ Almost background free channel





$a_0(980)$ region

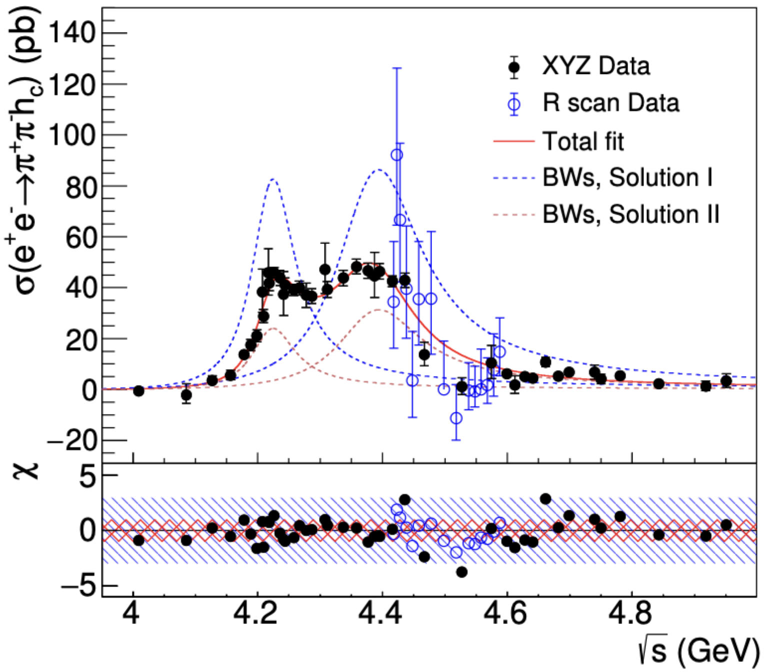




Statistical significance: >> 5σ

Cross section of $e^+e^-\to\pi^+\pi^-h_c$

PRL 135, 071901(2025)



- 2 BW fit results

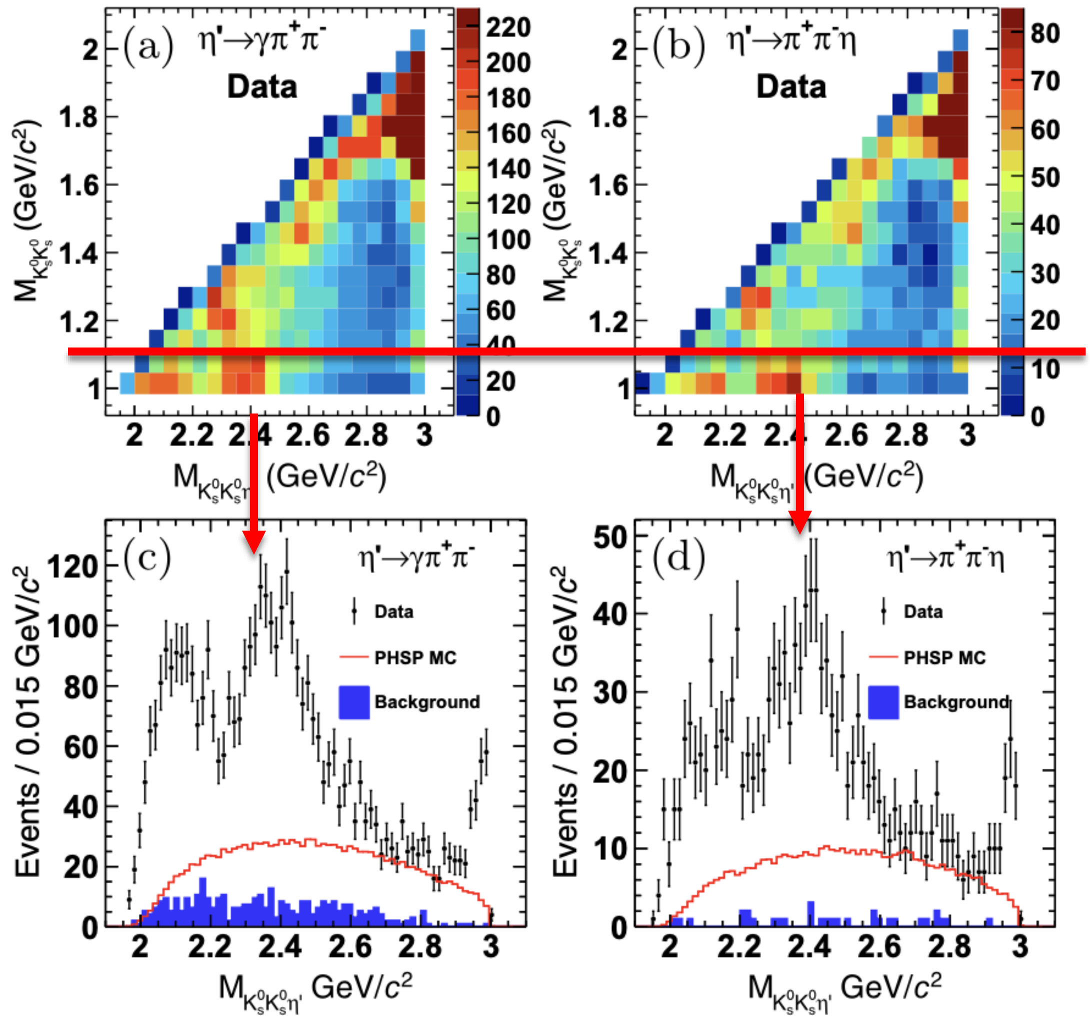
Parameter	R_1	R_2	R_3
M (MeV/c^2)	$4223.6^{+3.6+2.6}_{-3.7-2.9}$	$4327.4^{+20.1+10.7}_{-18.8-9.3}$	$4467.4^{+7.2+3.2}_{-5.4-2.7}$
Γ (MeV)	$58.5^{+10.8+6.7}_{-11.4-6.5}$	$244.1^{+34.0+24.2}_{-27.1-18.3}$	$62.8^{+19.2+9.9}_{-14.4-7.0}$
$\Gamma_{ee}\cdot\mathcal{B}(R\to\pi^+\pi^-h_c)$ (eV)	$10.2^{+1.2+1.4}_{-1.5-1.4}$ $(0.9^{+0.4+0.3}_{-0.4-0.2})$	$29.1^{+5.7+4.4}_{-3.9-3.4}$ $(10.8^{+2.5+1.9}_{-1.8-1.5})$	$3.9^{+3.5+1.7}_{-1.7-0.5}$ $(3.5^{+3.0+1.5}_{-1.6-0.7})$
ϕ (rad)	...	$3.6^{+0.1+0.1}_{-0.1-0.1}$ $(0.7^{+0.3+0.2}_{-0.3-0.2})$	$0.7^{+0.3+0.1}_{-0.3-0.2}$ $(-2.2^{+0.3+0.2}_{-0.3-0.1})$

X(2370): Glueball-like particle in $J/\psi\to\gamma K_S^0K_S^0\eta'$

PRL 132, 181901 (2024)

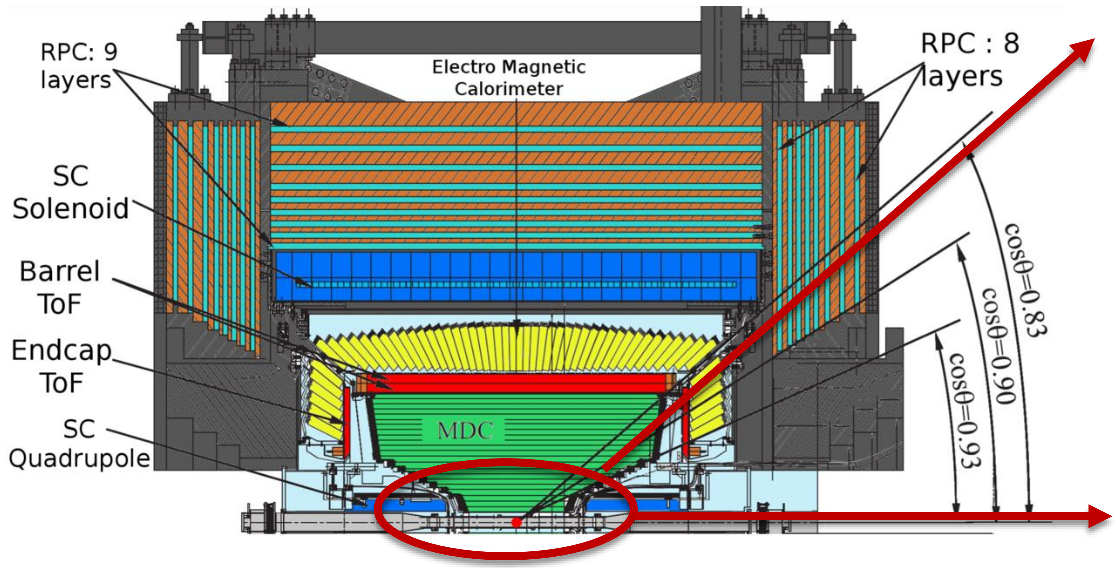
PWA using 10 Billion of J/ψ data @ BESIII

- Minimal background contribution: $J/\psi\to\pi^0K_S^0K_S^0\eta'$ and $J/\psi\to K_S^0K_S^0\eta'$ since they are forbidden by exchange symmetry and CP conservation
- $\eta'\to\gamma\pi^+\pi^-/\eta\pi^+\pi^-$; $K_S^0\to\pi^+\pi^-$

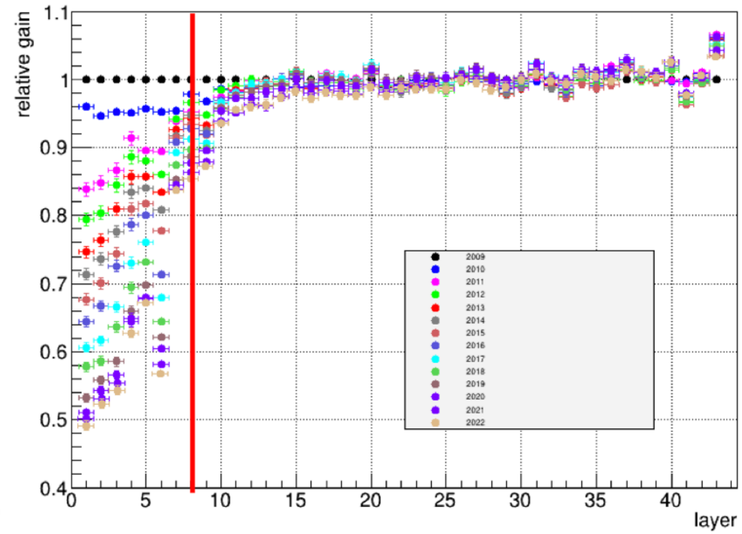


- Strong enhancement near $K^0_SK^0_S$ mass threshold from $f_0(980)$
- Clear connection between $f_0(980)$ and the structure around 2.4 GeV
- $M(K^0_SK^0_S)$ <1.1GeV to select the $f_0(980)$

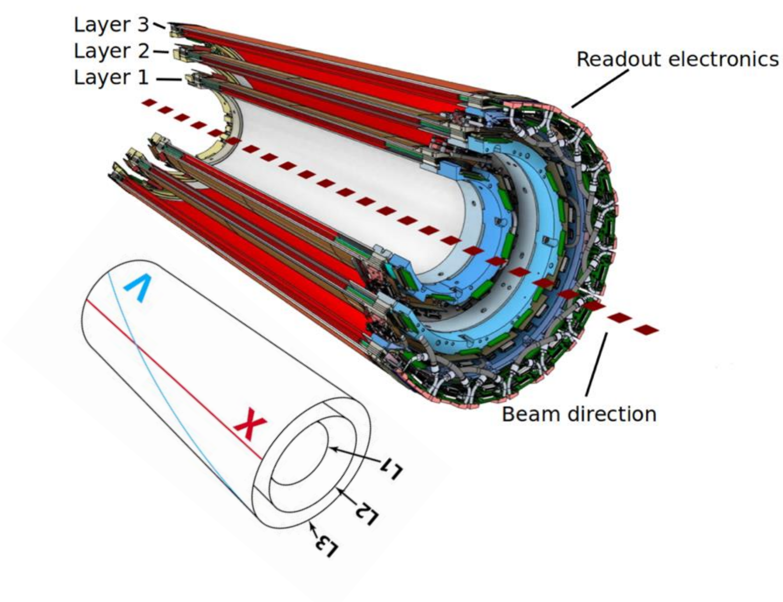
Why CGEM-IT ?



Gain loss of the inner MDC



Gain loss per year ~ 4 %

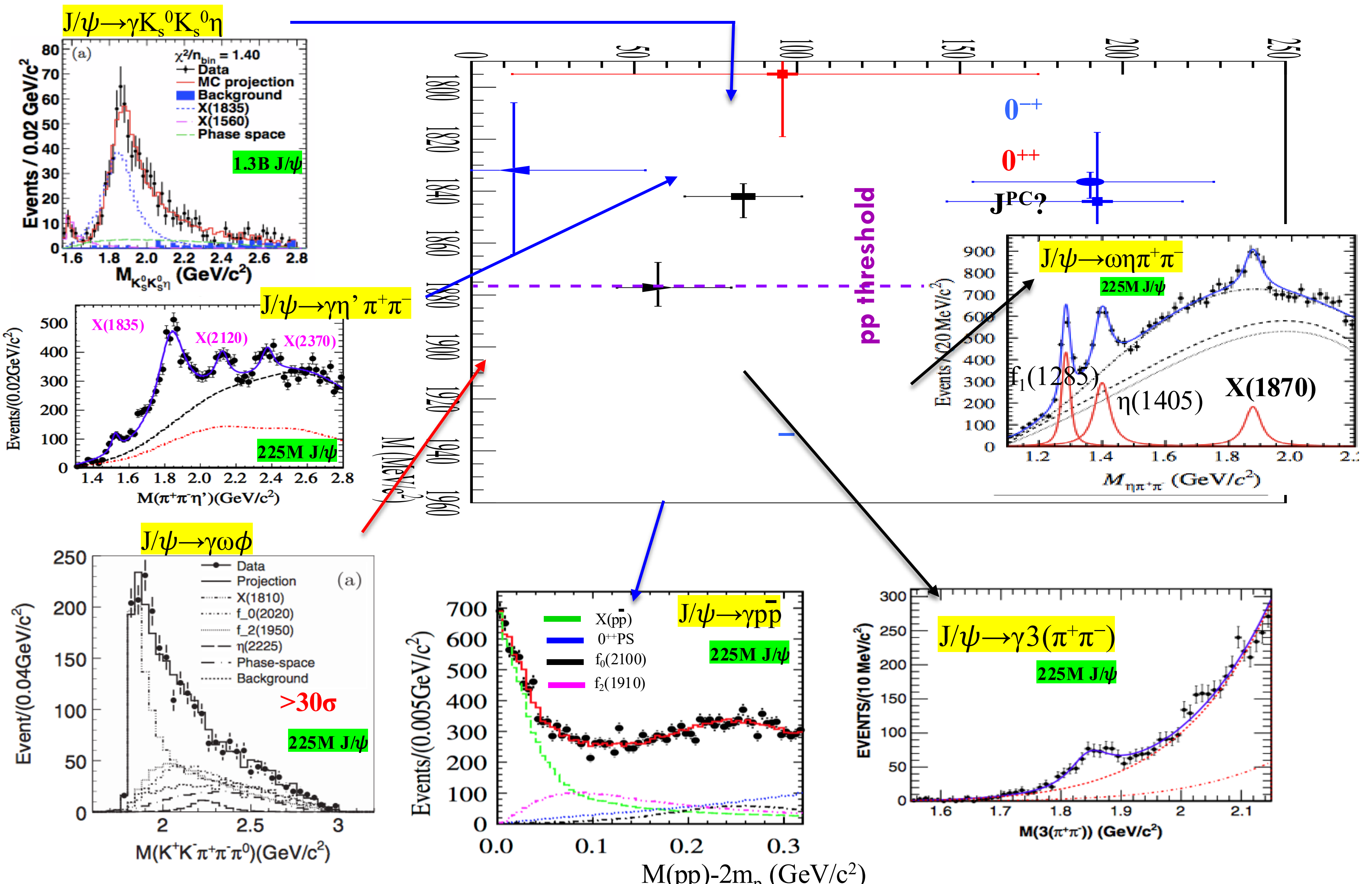


- Replace the inner MDC with 3 layers of cylindrical triple-GEM detectors
- Improve rate capability, aging and secondary vertex reconstruction, while retaining the current momentum and tracking performance

Main system requirements:

- Low Material budget ~1.5% of X_0 in total
- Spatial resolution of 130-150 μm with charge and time readout

Structures between 1.8 -1.9 GeV

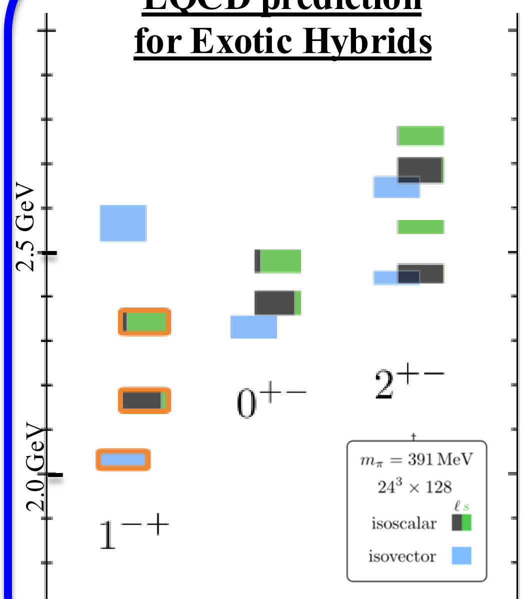


Hunting for glueballs and new form of hadrons

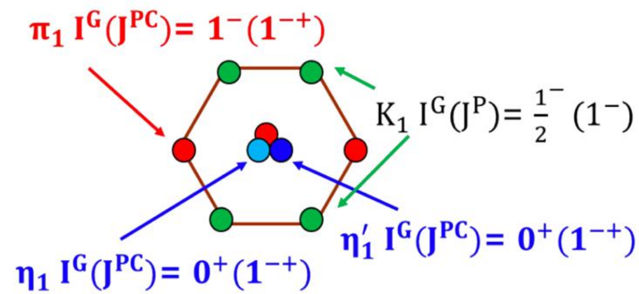
- Charmonium radiative decays is the ideal laboratory for light glueballs and hybrids hadron studies (clean, high statistics and gluon-rich process)

- **Exotic Hybrids**: $J^{PC} = 0^{+-}, 1^{-+}, 2^{+-}$ (forbidden in the conventional QCD scheme)
- The exotic $J^{PC} = 1^{-+}$ nonet of hybrids is predicted to be the lightest
- Only isovector candidate observed yet: $\pi_1(1400)$, $\pi_1(1600)$ [the most extensively studied], $\pi_1(2015)$

LQCD prediction for Exotic Hybrids



PRD 88, 094505



BESIII experiment offers the ideal environment for this search $J/\psi \to \gamma\eta\eta'$

- Isoscalar 1^{-+} hybrids is important to establish the hybrid nonet
  - Can be produced in J/ψ radiative decays
  - Can decay to $\eta\eta'$ in P-wave (PRD 83,014021, PRD 83, 014006, Eur.Phys.J.Plus 135, 945)

Further Checks on the $\eta_1(1855)$

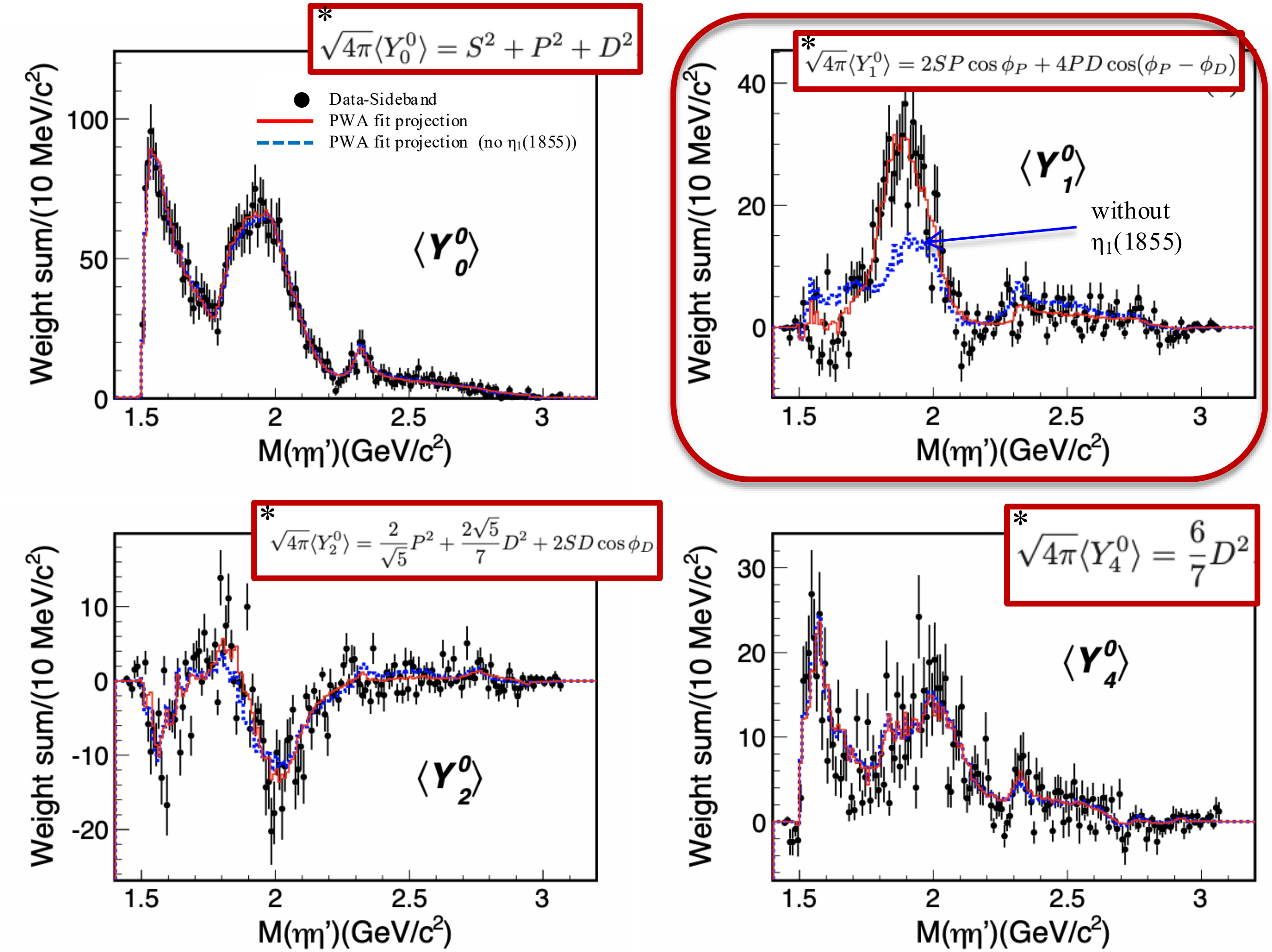
PRL 129, 192002 (2022)
PRD 106,072012 (2022)

The $\cos(\theta_\eta)$ distribution can be expressed as an expansion in terms of Legendre polynomials; the coefficients (unnormalized moments of expansion) characterize the spin of the ηη' resonances

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

- Neglecting resonance contributions in the γη(') subsystem and amplitude with spin greater than 2, the moments are related to the spin-0 (S), spin-1 (P) and spin-2 (D) amplitudes

- Good data/PWA consistency
- Narrow structure in $\langle Y^0_1 \rangle$: $\eta_1(1855)$ P-wave component is needed



*Assuming ηη' system has zero helicity

J/ψ radiative decay: PWA status in a nutshell

	0+	2+	0−
$J/\psi\to\gamma PP$	$J/\psi\to\gamma\eta\eta$ (PRD87,092009) $J/\psi\to\gamma\pi^0\pi^0$ (PRD92,052003) $J/\psi\to\gamma K_S K_S$ (PRD98,072003) $J/\psi\to\gamma\eta\eta'$ (PRL129,192002) $J/\psi\to\gamma\eta'\eta'$ (PRD105,072002)		
$J/\psi\to\gamma VV$			$J/\psi\to\gamma\omega\phi$ (PRD87,032008) $J/\psi\to\gamma\phi\phi$ (PRD93,112011) $J/\psi\to\gamma\omega\omega$ (PRD100,052012)
$J/\psi\to\gamma PPP$			$J/\psi\to\gamma\eta'\pi\pi$ (PRL106,072002, noPWA) $J/\psi\to\gamma K_S K_S\eta$ (PRL115,091803) $J/\psi\to\gamma K_S K_S\pi^0$ (JHEP 03,121)

- **$J/\psi\to\gamma PP$: 0^{++}, 2^{++}, …**
- **$J/\psi\to\gamma PPP$, γVV: 0^{-+}**
- Neutral channel is much cleaner than the charged ones

Amplitude Analysis: toll to extract the complex amplitudes from experimental data

- Models with free parameters
- Consider the kinematic of final states particles
- Vary the parameters to maximize the likelihood

- **Mass Dependent (MD) PWA**: model the dynamics of particle interactions as coherent sum of resonances
- **Mass Independent (MI) PWA**: make minimal model assumptions and measure the dynamical amplitudes independently in small regions of two-meson invariant mass (JHEP 03,121 (2023))

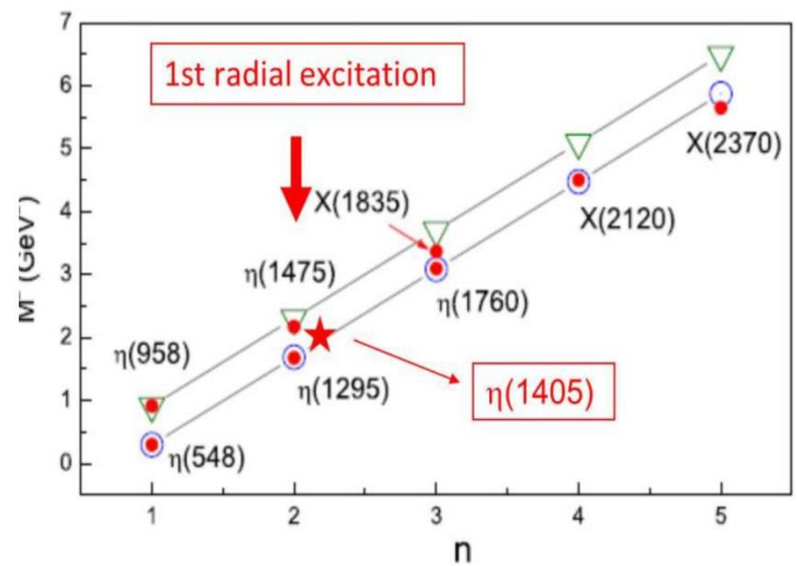
Toward the η(1405)/η(1475) puzzle solving

JHEP03(2023)121

What's the nature of pseudoscalar structure with a mass around 1.4 GeV/c^2 (the so called "ι" state) ?

- Observed first in the J/ψ radiative decay to the $K\bar{K}\pi$ final state in the early 1980s by the Crystal Barrel [PHL 97, 328] and Mark II [PRL 49, 259]

- Quark model predicts only one pseudoscalar meson near 1.4 GeV
- Theoretical interpretation:
  - η(1475): first radial excitation of η'
  - η(1405): glueball candidate
- LQCD prediction for the 0^{-+} lightest glueball candidate: [2.3-2.6] GeV



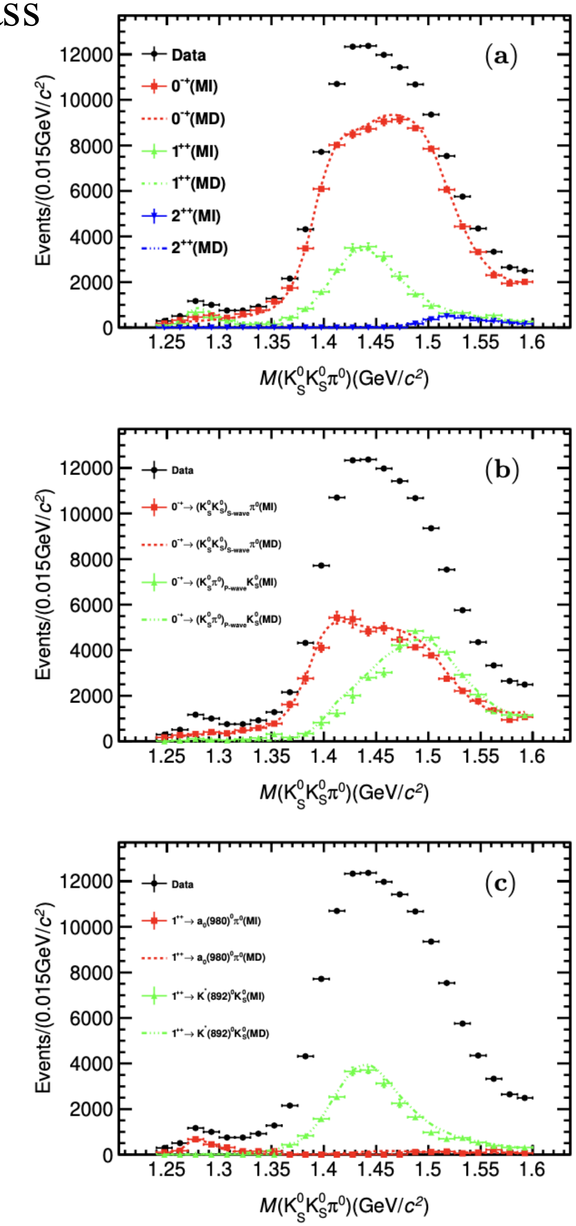
η(1405) and η(1475) are two separate states or just one pseudoscalar state, namely η(1440), in different decay mode?

What's the nature of the outnumbered η(1405)?

$J/\psi \to \gamma K^0_S K^0_S \pi^0$ - Mass Independent PWA

JHEP03(2023)121

- Mass independent fit by scanning the invariant $K^0_S K^0_S \pi^0$ mass
  - identification of the strongest waves
- The pseudoscalar component is the dominant contribution
  - relatively constant around 1.4 GeV/c^2
  - $(K^0_S K^0_S)_{S\text{-wave}}\pi^0$ and $(K^0_S \pi^0)_{P\text{-wave}} K^0_S$ partial waves are of comparable magnitude, but with different line shapes and peaks
  - two resonances parameterization needed
- Axial vector component peaking at 1.28 GeV/c^2 and 1.42 GeV/c^2; Tensor component around 1.52 GeV/c^2 decaying into $K^*(892)^0 K^0_S$ observed for the first time



Resonance	$M(\mathrm{MeV}/c^2)$	$\Gamma(\mathrm{MeV})$
$\eta(1405)$	$1391.7 \pm 0.7^{+11.3}_{-0.3}$	$60.8 \pm 1.2^{+5.5}_{-12.0}$
$\eta(1475)$	$1507.6 \pm 1.6^{+15.5}_{-32.2}$	$115.8 \pm 2.4^{+14.8}_{-10.9}$
$f_1(1285)$	$1280.2 \pm 0.6^{+1.2}_{-1.5}$	$28.2 \pm 1.1^{+5.5}_{-2.9}$
$f_1(1420)$	$1433.5 \pm 1.1^{+27.9}_{-0.7}$	$95.9 \pm 2.3^{+13.6}_{-10.9}$
$f_2(1525)$	$1515.4 \pm 2.5^{+3.2}_{-7.6}$	$64.0 \pm 4.3^{+2.0}_{-6.1}$

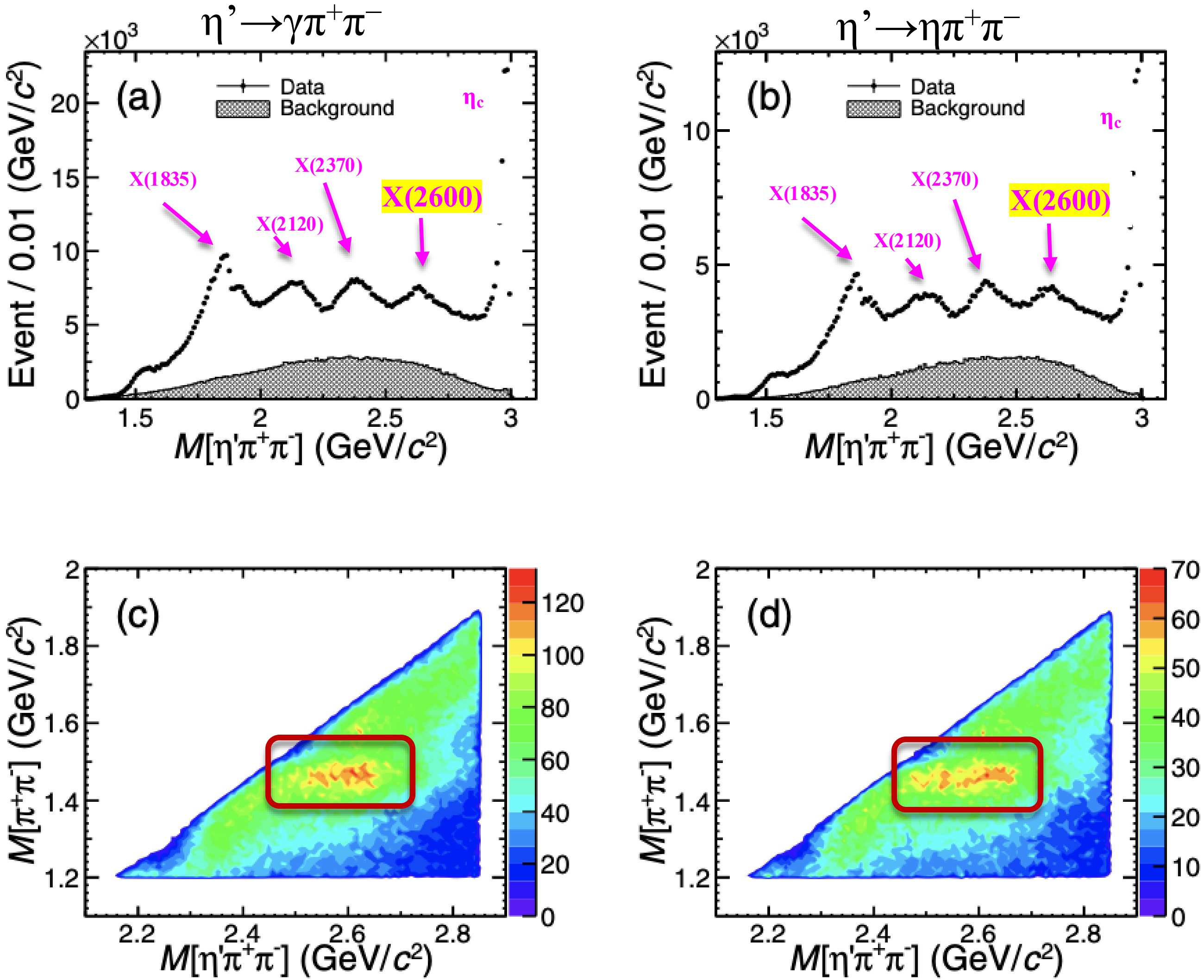
Consistency between MI and MD results

Theorists attempt to reveal the η(1405)/η(1475) pole structure [PRD107, L091505]

X(2600): A New State Observed in $J/\psi \to \gamma\pi^+\pi^-\eta'$

10 Billion of J/*ψ* data @ BESIII ($\eta' \to \gamma\pi^+\pi^- / \eta\pi^+\pi^-$)

PRL 129, 042001 (2022)



A new state in $M(\eta'\pi^+\pi^-)$ invariant mass is observed around 2.6 GeV/c^2, which is correlated to a structure in $M(\pi^+\pi^-)$ @ 1.5 GeV/c^2

X(2600): A New State Observed in $J/\psi \to \gamma\pi^+\pi^-\eta'$

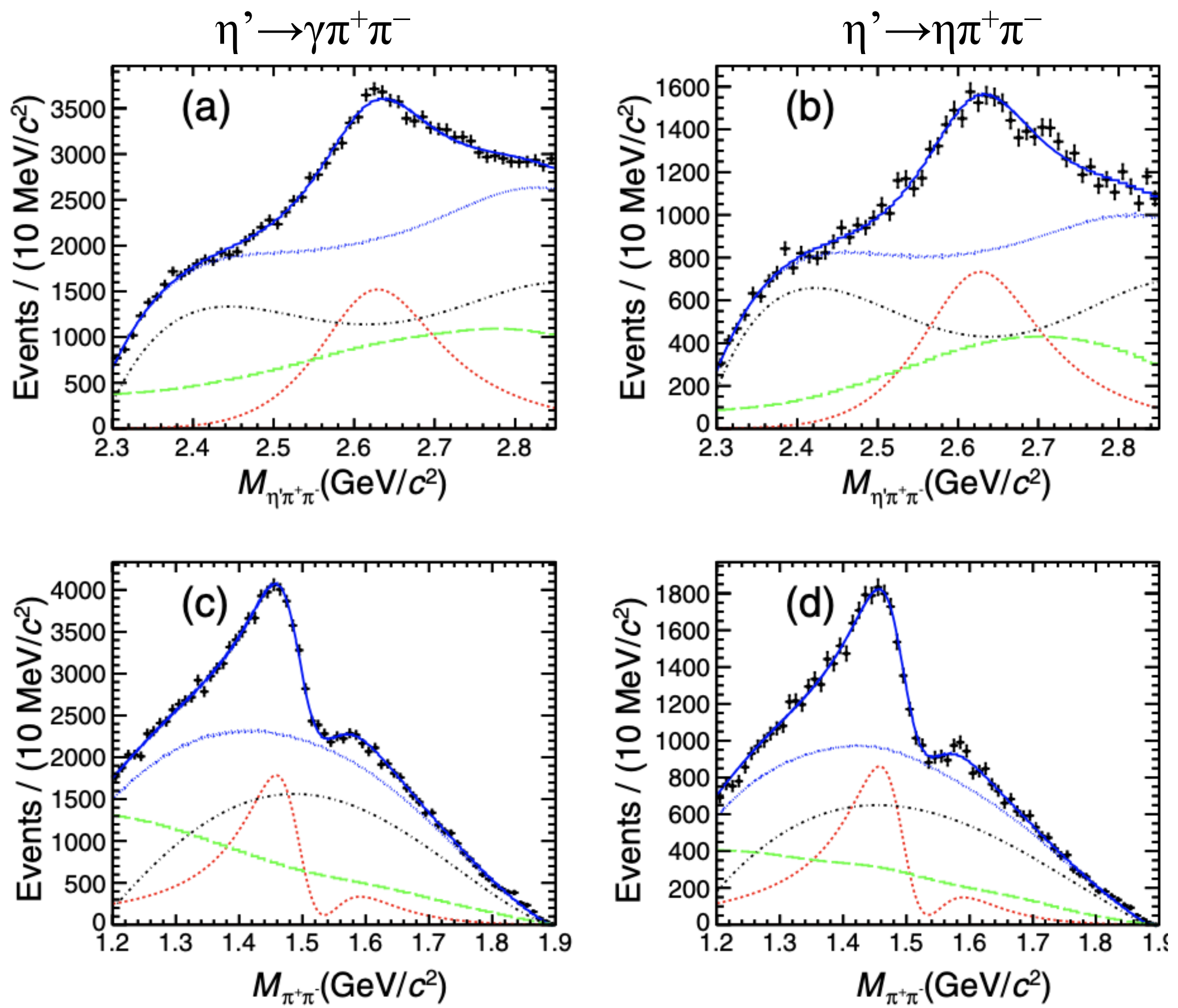
PRL 129, 042001 (2022)

- Simultaneous fit to $\eta'\pi^+\pi^-$ and $\pi^+\pi^-$ mass spectra is performed

Resonance	Mass (MeV/c^2)	Width (MeV)
$f_0(1500)$	$1492.5 \pm 3.6^{+2.4}_{-20.5}$	$107 \pm 9^{+21}_{-7}$
$X(1540)$	$1540.2 \pm 7.0^{+36.3}_{-6.1}$	$157 \pm 19^{+11}_{-77}$
$X(2600)$	$2618.3 \pm 2.0^{+16.3}_{-1.4}$	$195 \pm 5^{+26}_{-17}$

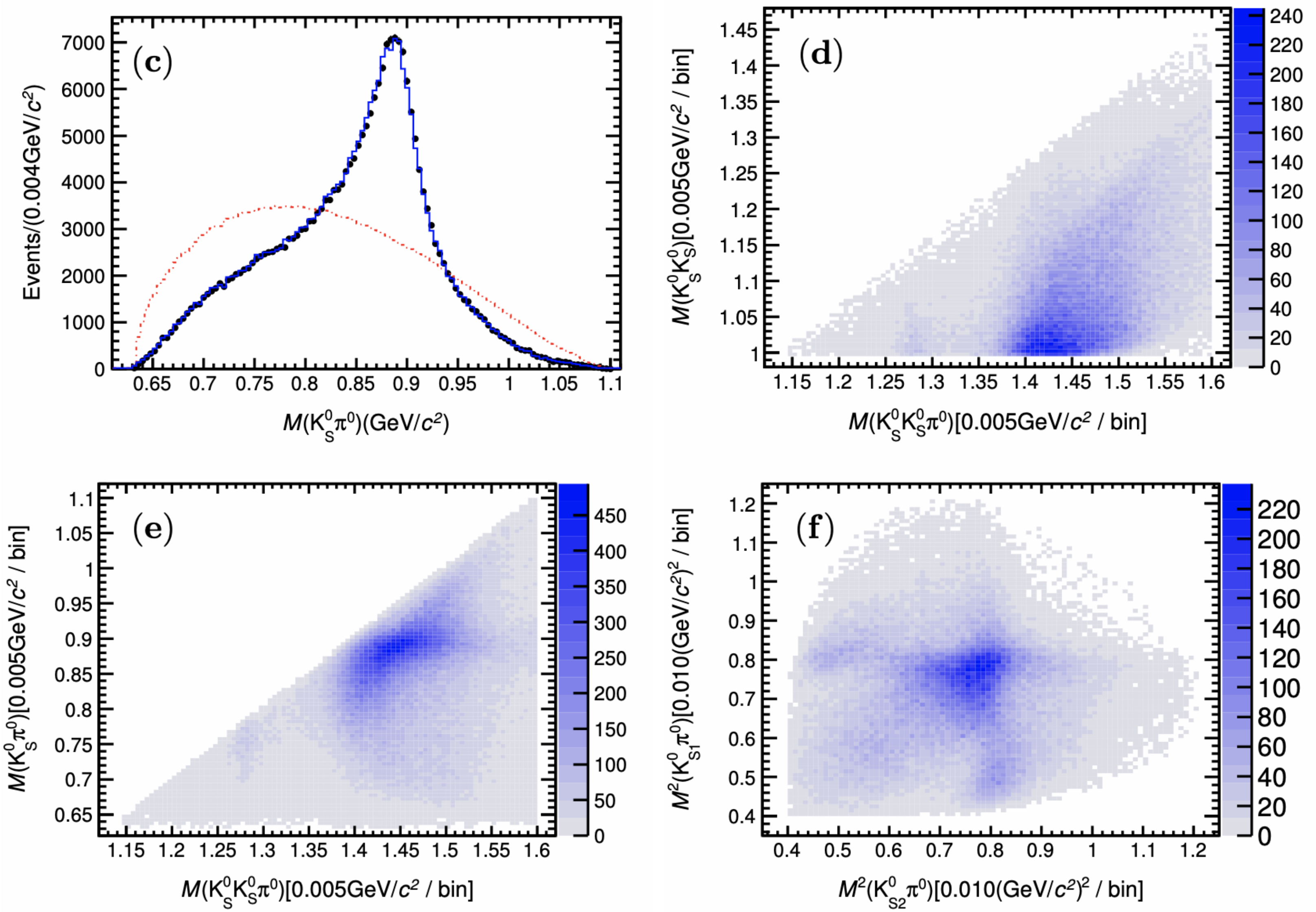
- X(2600) resonance observed for the first time with a statistical significance greater than 20σ

- The structure in $M(\pi^+\pi^-)$ around 1.5 GeV/c^2 can be well described with the interference between $f_0(1500)$ and the X(1540) resonances



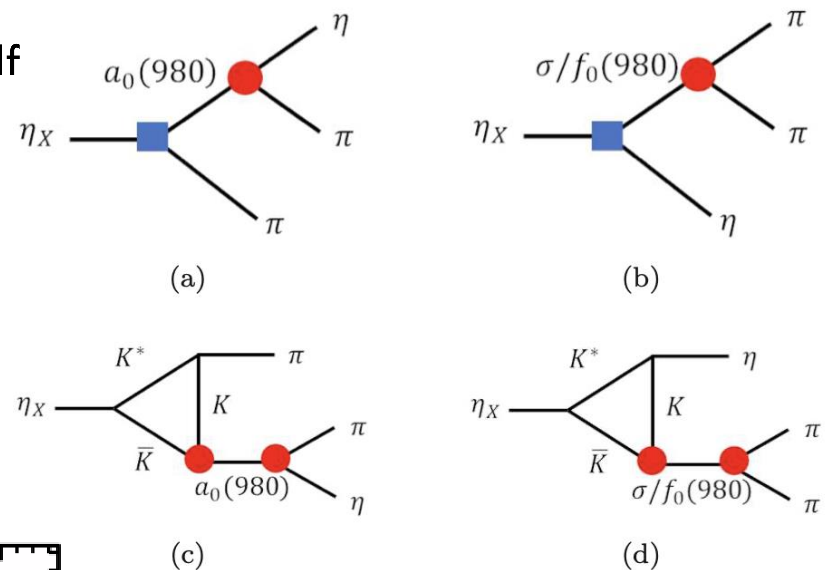
Dalitz Plot - $J/\psi \to \gamma K^0_S K^0_S \pi^0$

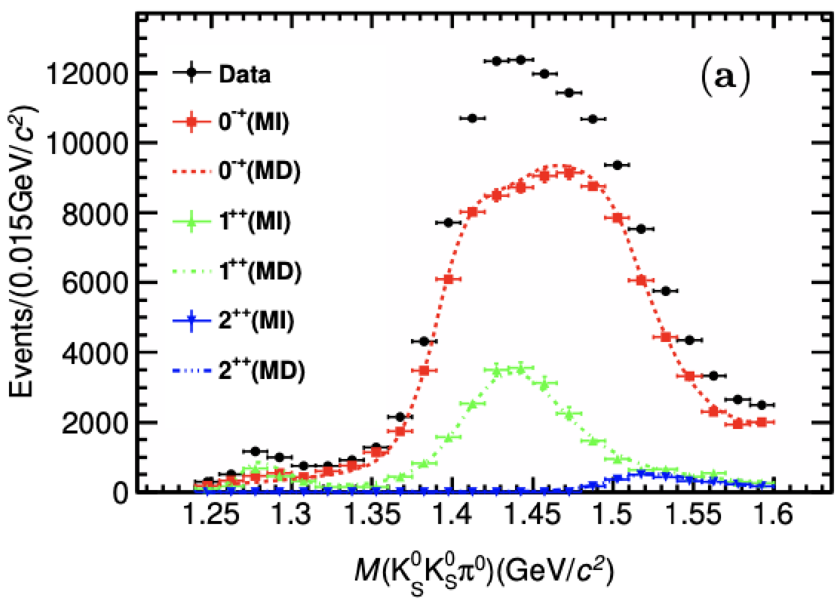
JHEP03(2023)121



Dalitz Plot - $J/\psi \to \gamma K^0_S K^0_S \pi^0$

https://arxiv.org/pdf/2302.01210.pdf





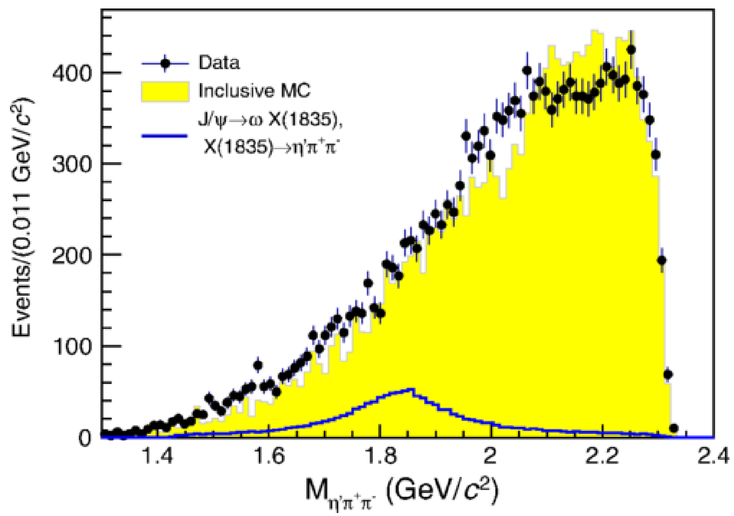
JHEP03(2023)121

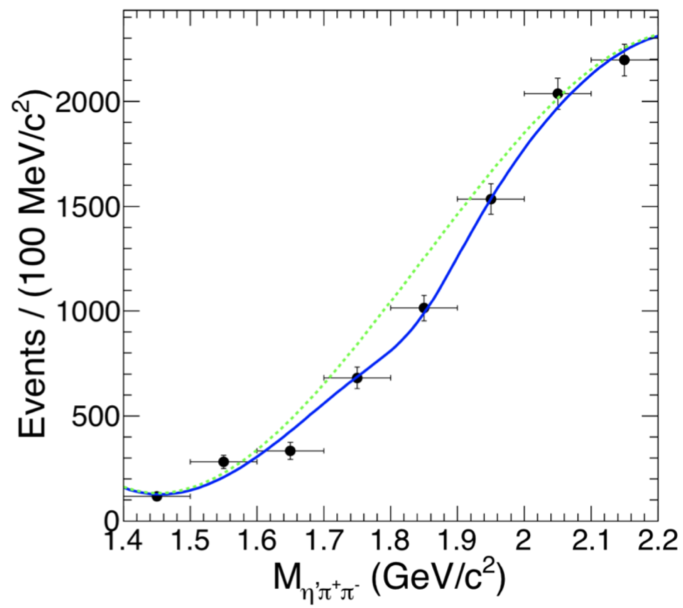
Search for X(1835) in other decay modes

- $J/\psi \to \omega\eta'\pi^+\pi^-$ hadronic decay and search for $X(1835) \to \eta'\pi^+\pi^-$

PRD **99**, 071101 (R) (2019)

1.3×10⁹ J/ψ @ BESIII





- No obvious sign of X(1835)'s existence
- Large gluon component? [PRD74,034019]

$$\mathcal{B}(J/\psi \to \omega\eta'\pi^+\pi^-) = (1.12 \pm 0.02 \pm 0.13) \times 10^{-3}$$
$$\mathcal{B}(J/\psi \to \omega X(1835),\ X(1835) \to \eta'\pi^+\pi^-) < 6.2 \times 10^{-5}$$

@ 90% C.L.

The puzzle is still not complete ….

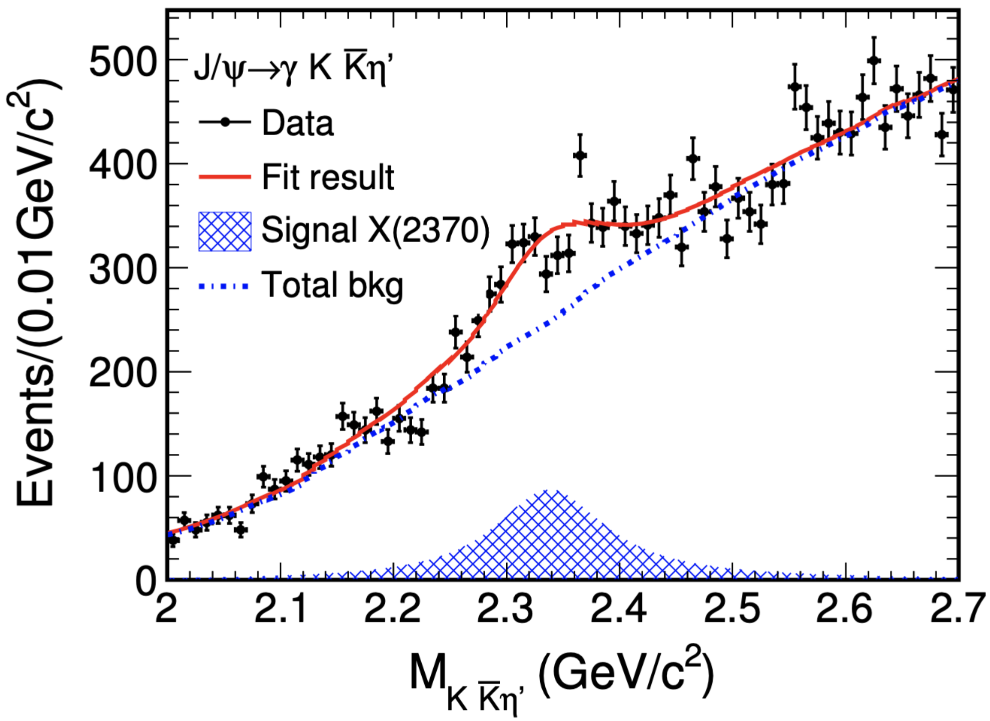
First Observation of X(2370) in $J/\psi\to\gamma K\bar{K}\eta'$

1.3×10⁹ J/ψ @ BESIII

EPJC **80**, 746 (2020)

- X(2120) and X(2370) states observed in the $\pi^-\pi^+\eta'$ invariant mass spectra (PRL**106**,072002)
- The **X(2370)** measured mass is consistent with the pseudoscalar glueball candidate predicted by LQCD calculation (PRD**73**,014516)

➢ Simulataneus fit performed for two decay η' modes



➢ **No evidence of X(2120) is found**

$\mathcal{B}(J/\psi \to \gamma X(2120) \to \gamma K^+K^-\eta') < 1.49 \times 10^{-5}$

$\mathcal{B}(J/\psi \to \gamma X(2120) \to \gamma K^0_S K^0_S\eta') < 6.38 \times 10^{-6}$

➢ **Clear X(2370) signal observed with significance of about 8.3σ**

$$M_{X(2370)} = 2341.6 \pm 6.5 \pm 5.7\ \mathrm{MeV}/c^2 \quad \Gamma_{X(2370)} = 117 \pm 10 \pm 8\ \mathrm{MeV}$$

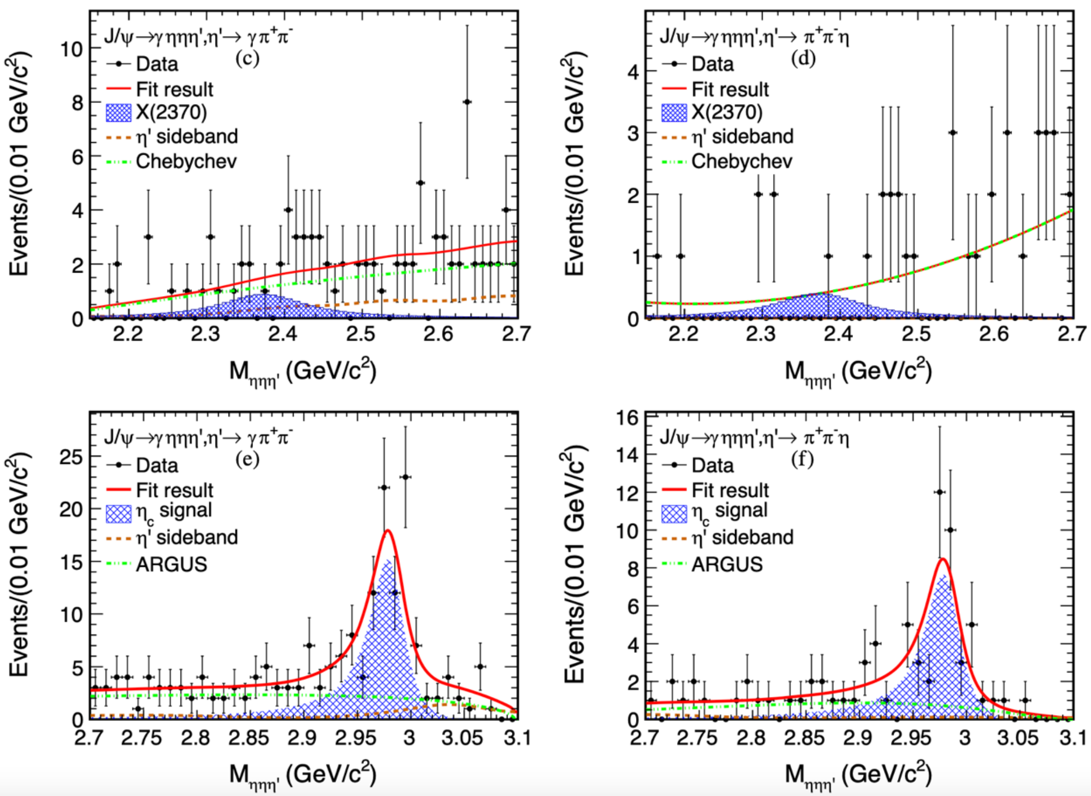
$$\mathcal{B}(J/\psi \to \gamma X(2370) \to \gamma K^+K^-\eta') = (1.79 \pm 0.23 \pm 0.65) \times 10^{-5}$$

$$\mathcal{B}(J/\psi \to \gamma X(2370) \to \gamma K^0_S K^0_S\eta') = (1.18 \pm 0.32 \pm 0.39) \times 10^{-5}$$

Search for X(2370) in $J/\psi \to \gamma\eta\eta\eta'$

PRD **103**, 012009 (2021)

1.3×10^9 J/ψ @ BESIII



Branching ratios prediction for the decay of pseudoscalar glueball with M~2.37 GeV into three pseudoscalar mesons (PRD **87**,054036 (2013))

$$\Gamma_{G\to\eta\eta\eta'}/\Gamma_G^{tot} = 0.00082$$

$$\Gamma_{G\to KK\eta'}/\Gamma_G^{tot} = 0.011$$

$$\Gamma_{G\to\pi\pi\eta'}/\Gamma_G^{tot} = 0.090$$

- **No obvious signal of X(2370)**

Simultaneous unbinned maximum likelihood fit to the ηηη' is performed and the 90% C.L. upper limit is calculated

$$\mathcal{B}(J/\psi \to \gamma X(2370) \to \gamma\eta\eta\eta') < 9.2\times10^{-6}$$

(it does not contradict PRD **87**,054036)

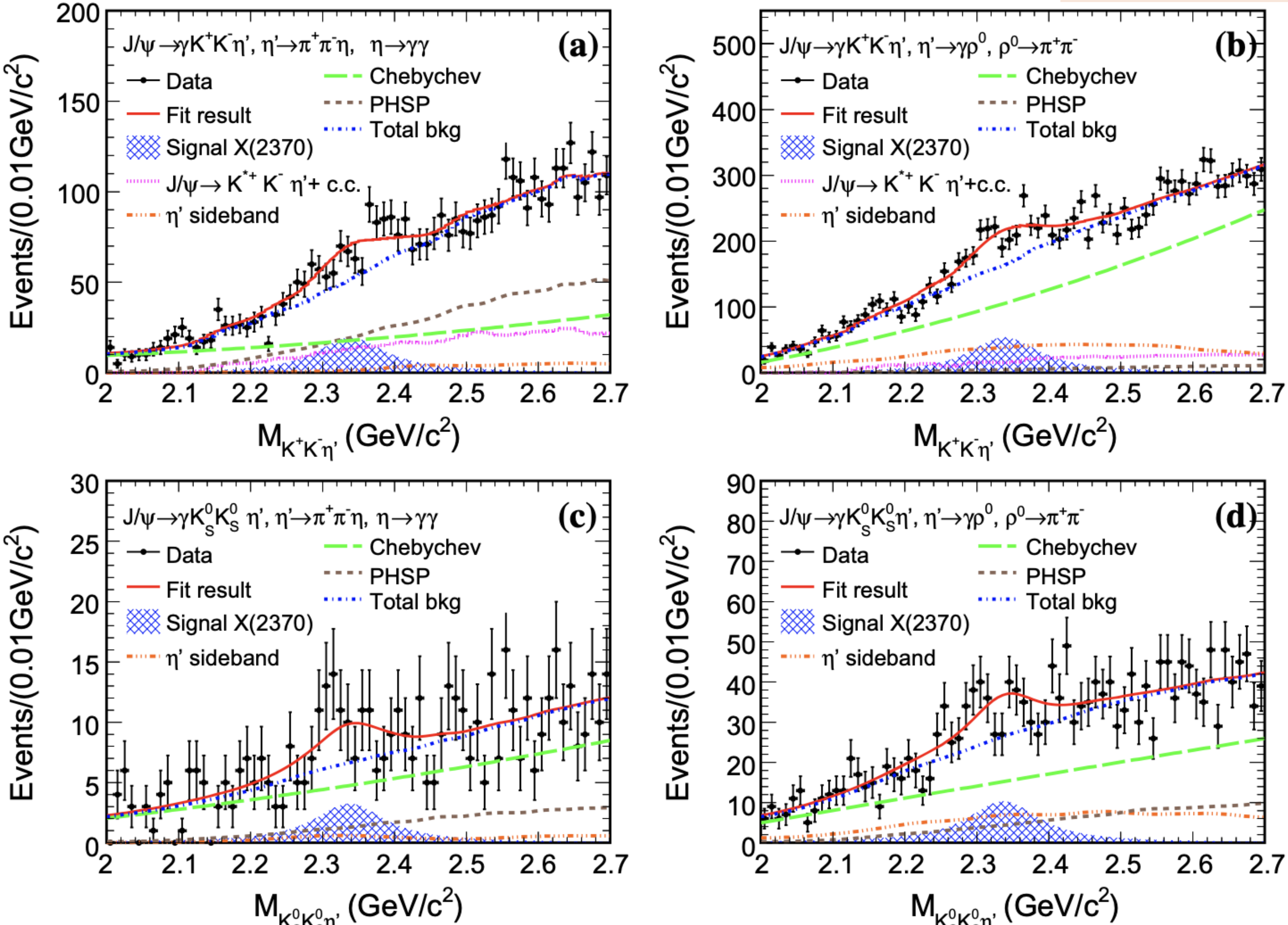
$$\mathcal{B}(J/\psi \to \gamma\eta_c)\cdot\mathcal{B}(\eta_c \to \eta\eta\eta') = (4.86\pm0.62\pm0.45)\times10^{-5}$$

FIRST OBSERVATION in the ηηη' invariant mass spectra

First Observation of X(2370) in $J/\psi \to \gamma K\bar{K}\eta'$

1.3×10^9 J/ψ @ BESIII

EPJC **80**, 746 (2020)



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

PRD **111**, 052011(2025)

The decays $J/\psi \to \gamma X$, $X \to \gamma V$ ($V = \rho, \omega, \phi$) serve as flavor filter

- unravelling quark contents of the intermediate resonances

GPUPWA framework used to disentangle the structures in the Dalitz plot