BESIII实验证实胶球存在

Lightest 0^{-+} Glueball as Dominant Constituent of $X(2370)$

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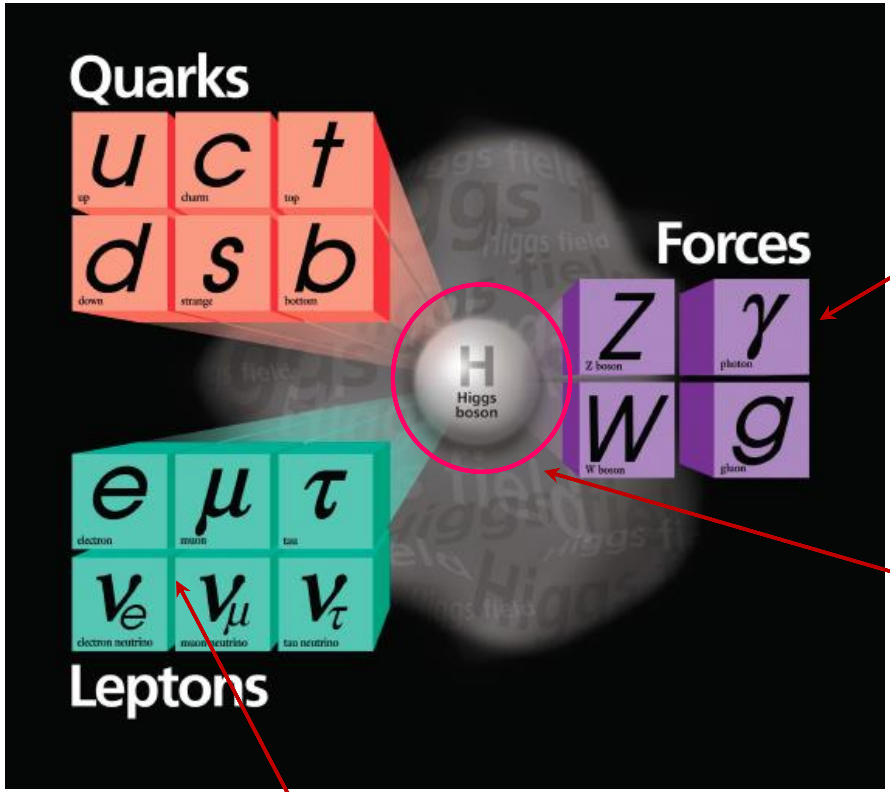
Standard Model （Gauge Theory） describes EW and Strong interactions



EW and strong interactions are mediated by gauge bosons:

- **EW interaction by $\gamma/W/Z$**
- **Strong interaction by Gluons**

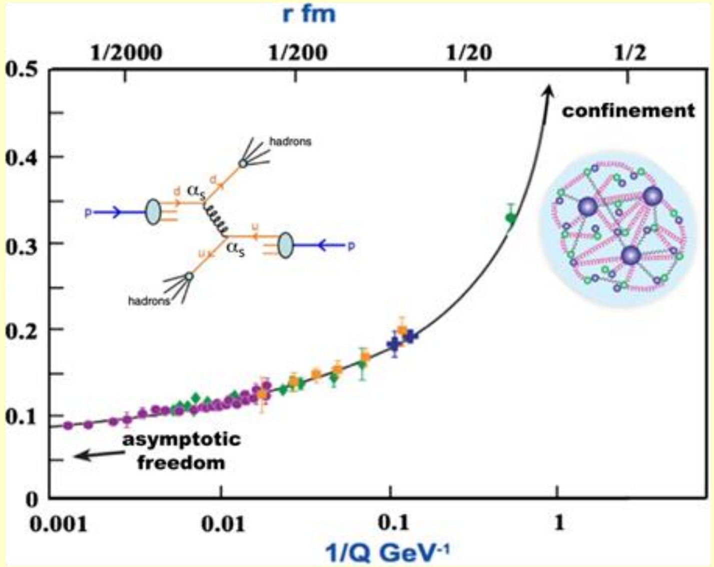
Higgs Boson – origin of mass

Matter is made of leptons and quarks

QCD and its important predictions

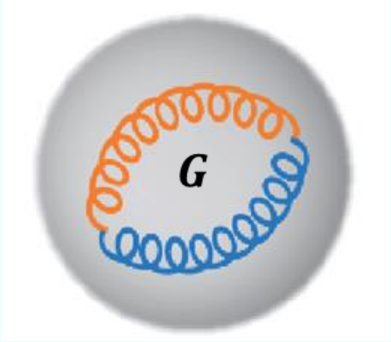
QCD —— SU(3) non-Abelian gauge theory：

At high energy



- α_s running, widely confirmed experimentally (Nobel Prize 2004)

At low energy



- self-interaction of gluons → bound states of gluons —— Glueballs
- Many candidates, not established yet

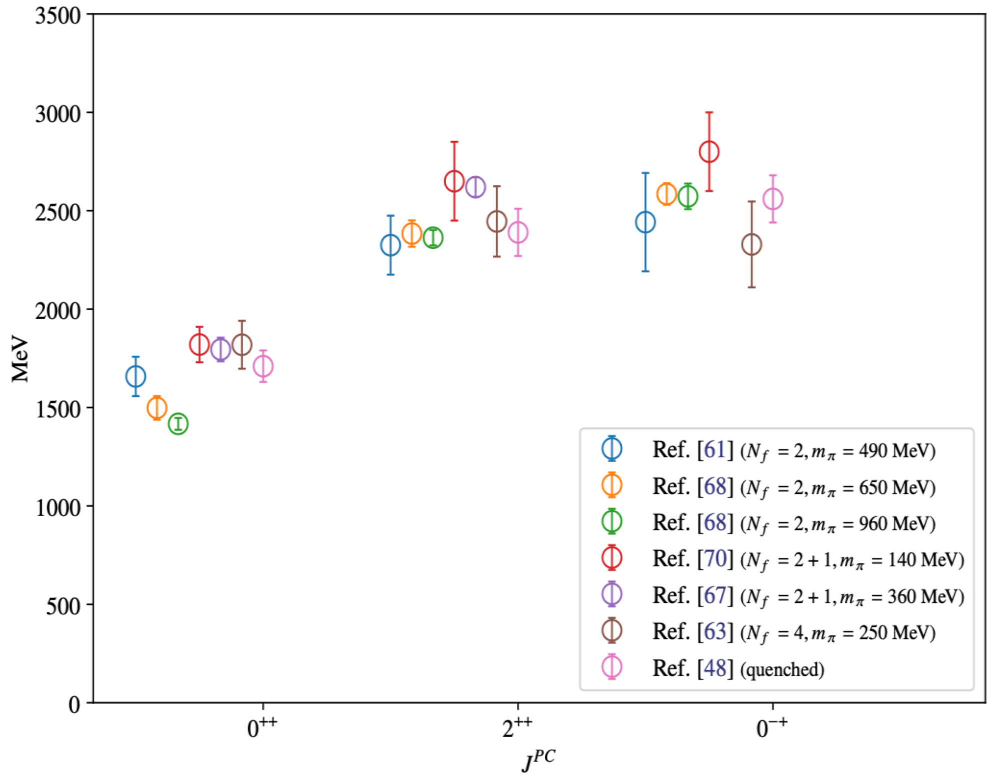
Glueballs

- **Unique particles formed by gauge bosons due to non-Abelian self-interactions**
  - **Unique kind of matter made of pure force (unlike usual matter formed by fermions)**

- **Lattice QCD predictions**
  - $\mathbf{0^{++}}$ **ground state:** $\mathbf{1.3 \sim 2\ GeV}/c^2$
  - $\mathbf{2^{++}}$ **ground state:** $\mathbf{2.3 \sim 2.8\ GeV}/c^2$
  - $\mathbf{0^{-+}}$ **ground state:** $\mathbf{2.3 \sim 3\ GeV}/c^2$

→ All LQCD calculations predict the existence of glueballs.

arxiv:2305.04869



Unique Importance of Glueballs

- Direct proof of self-interactions of gluons — Direct proof of non-Abelian gauge interactions of QCD

- Unique particle/matter made of pure force （bosons）

（ called **‘force particle’,** ‘forcon，力子?’ —— named by Yifang Wang, IHEP former Director）

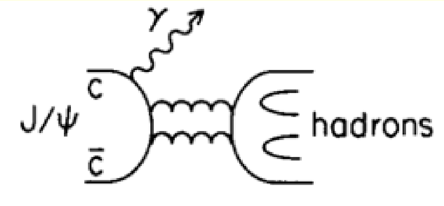
- Direct proof of origin of mass from strong interaction

Glueball production and decays

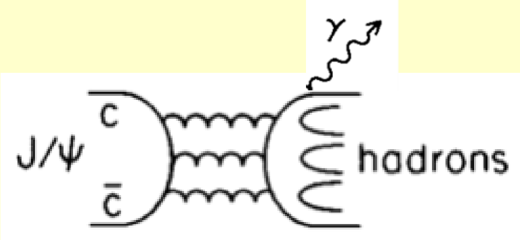
— **Signatures of glueballs**

Glueball production in J/ψ radiative decays

- **Gluon rich environment**



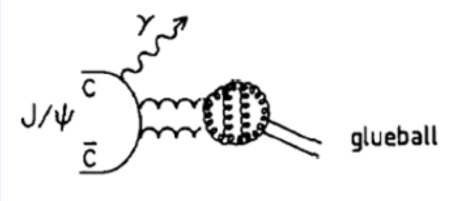
$\sim \alpha\alpha_s^4$



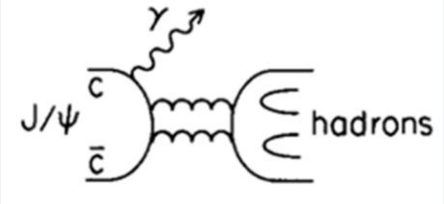
$\sim \alpha\alpha_s^6$

- **Isospin filter:** final states dominated by **I=0** processes
- **Spin-parity filter:** **C parity must be +**, so J^{PC}=$0^{-+}, 0^{++}, 1^{++}, 2^{++}, 2^{-+}$ …
- **Clean environment in e^+e^- collision:** very different from **p-p collision**

- Rich glueball production in J/ψ radiative decays:
  - **Glueball production rate** in J/ψ radiative decays could be **higher** than normal hadrons



$\sim \alpha\alpha_s^2$



$\sim \alpha\alpha_s^4$

→ J/ψ radiative decays are believed to be an ideal/golden place to search for glueballs.

LQCD Predictions on $B(J/\psi \to \gamma G_{0^{-+}})$

LQCD prediction on lightest pseudoscalar glueball:

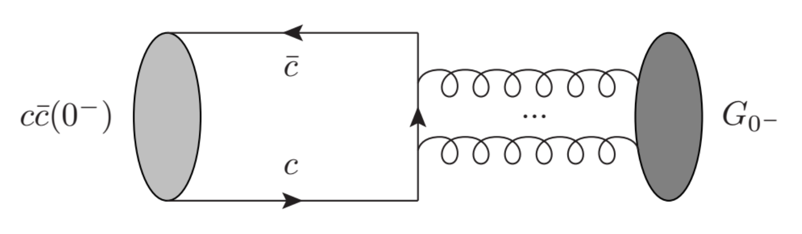
$$\boldsymbol{M = 2395 \pm 14\ \mathrm{MeV}}$$

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

PRD 100 (2019) 054511

- LQCD also predicts the mixing mechanism between 0^{-+} $c\bar{c}$ and 0^{-+} glueball.

PLB 827 (2022) 136960



- Such a mixing mechanism can significantly increase the production rate of the mixture 0^{-+} particle to $\boldsymbol{(2{\sim}20) \times 10^{-3}}$

  even with tiny mixing angle $2^o \sim 5^o$

arXiv: 2605.01757

→ High production rate is expected for 0^{-+} glueball in J/ψ radiative decays.

Glueball Decays ——
flavor-singlet and decay pattern similarities to charmonium decays

No rigorous predictions, but physics pictures are quite clear:

Glueballs contain no quark flavor — **flavor-singlet states**

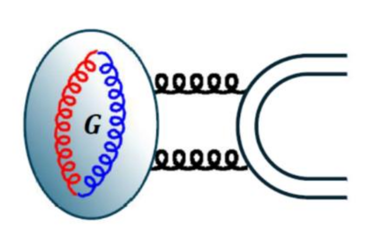
- Most important feature for glueballs
- Flavor symmetric decays into light hadrons
- For 0^{-+} glueball, $\boldsymbol{K^*\bar{K}}$ **mode is forbidden** due to generalized G-parity conservation.

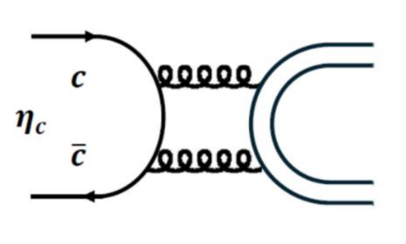
PLB 106 (1981) 114

PLB 109 (1982) 326

Phys. Rep. 454 (2007) 1

The glueball decays should have similar decay patterns to the charmonium families ($0^{++}-\chi_{c0}, 2^{++}-\chi_{c2}, 0^{-+}-\eta_c$) since they all decay via gluons.

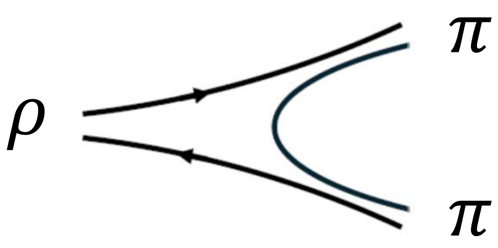




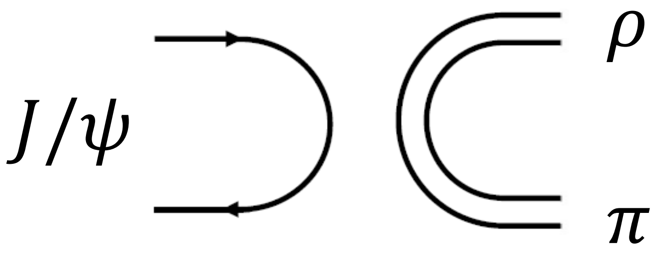
Commun.Theor.Phys. 24 (1995) 373 (hep-ph/9502408)

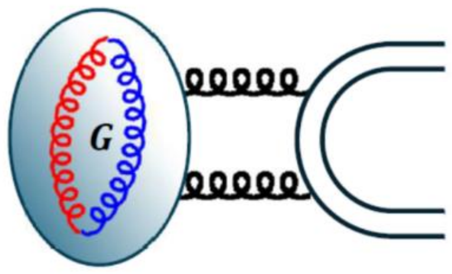
PLB 380 (1996) 189

Glueball Decays —
OZI Forbidden decays and narrow partial widths



OZI allowed decays





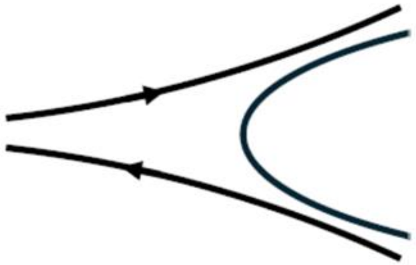
OZI forbidden decays

- Most light meson decays are OZI allowed decays:
  - → Typical partial widths > 100 MeV, and usually have dominant decay modes.
- J/ψ and η_c decays are all OZI forbidden decays:
  - → Partial decay widths should be very **narrow** and have **no dominant** decay modes
    - ➔ signature of gluon decays. ← Glueballs decay similarly

Narrow partial decay width of 0^{-+} glueball

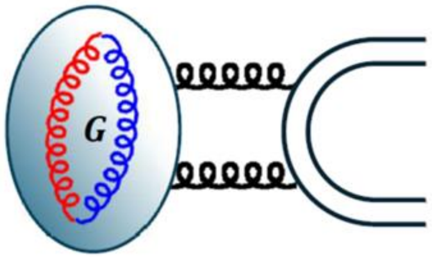
- Glueball width $\sim \sqrt{\text{OZI}}$ rule [Nucl. Phys. B 130 (1977) 328-348]

$$\Gamma(G_{0^{-+}} \to \pi\pi\eta) = \sqrt{\Gamma(\text{OZI allowed}) \times \Gamma(\eta_c \to \pi\pi\eta)}$$
$$= \sqrt{(100\sim200)\ \text{MeV} \times 0.5\ \text{MeV}}$$
$$\sim \text{a few MeV}$$

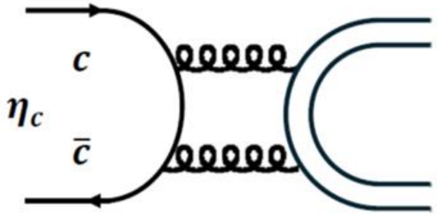


$\alpha_s{}^0$

OZI allowed decays



$\alpha_s{}^2$



$\alpha_s{}^4$

Glueball Decays —
suppressions of $\boldsymbol{G \to \gamma\omega, \gamma\phi}$

- $\gamma\omega, \gamma\phi$ decay modes are regarded as tags of $u\bar{u} + d\bar{d}$ and $s\bar{s}$ contents inside a meson, and are also called flavor filters. (PLB 164 (1985) 379, PRD 67 (2003) 074031)

- Glueballs contain no quarks, and gluons have no direct interaction with photons

  $\mathrm{G} \to \gamma\omega, \gamma\phi$ should be strongly suppressed

- $J/\psi \to \gamma\gamma\omega, \gamma\gamma\phi$ are good places to study this property.

Expected Signatures of Glueball

- Production:

  high production rate in J/ψ radiative decays

- Decay: via gluons
  - flavor-singlet state
  - decay pattern similarities to charmonium decays
  - narrow partial decay width to each mode
  - suppressions of $\gamma\omega, \gamma\phi$ decay modes

The combination of these signatures enable us to identify whether a particle is a glueball or not.

PPP Modes — Golden Decay Modes for 0^{-+} Glueball Searches

- Typically, PPP (3 pseudoscalar mesons, such as $\pi\pi\eta, \pi\pi\eta', K\bar{K}\pi$) modes are believed as golden decay modes in 0^{-+}glueball searches.
  - S –wave decays for 0^{-+} mesons, no suppression factor, major decay modes
  - PPP modes are either forbidden or strongly suppressed in 0^{++}or 2^{++} mesons decays — spin-parity filter
- PP (2 pseudoscalar mesons) modes are forbidden for 0^{-+} mesons
- VV modes (2 vector mesons, such as $\omega\omega, \phi\phi, \rho\rho, K^*K^*$)
  - P-wave decays for 0^{-+} mesons — suppressed near mass threshold
  - All J^{PC} mesons allowed, not a spin-parity filter
- Baryon modes
  - All J^{PC} mesons allowed, not a spin-parity filter
- Multi-pion modes
  - All J^{PC} mesons allowed, not a spin-parity filter
  - 0^{-+} mesons decay mainly via two-body sequential decays, i.e., mainly via $f_2(1270)$, $a_1(1260)$ pair intermediate states — 0^{-+} glueball mass may not be high enough, i.e., PS is not allowed.

Low Sensitivity

Historical Glueball Candidates

- 0^{++} scalar glueball candidates
  - $f_0(1710)$
    - Discovered by MarkII in 1980's as $\theta_2(1720)$ at beginning, only based on a fit to the angular distribution. Lots of studies at MarkII, DM2, BESI.
    - J^{PC} was firstly changed to 0^{++} at BESII based on a full PWA in $J/\psi \to \gamma K\bar{K}$
    - With PWA, it was carefully studied at BESIII in $J/\psi \to \gamma K\bar{K}, \gamma\pi\pi, \gamma\eta\eta, \gamma\eta\eta'$.
    - The high production rate of $J/\psi \to \gamma f_0$ (1710) and the suppression of f_0 (1710) $\to \gamma\eta\eta'$ measured from BESIII strongly support its interpretation as a scalar glueball or it has large glueball content if it is a mixture of glueball and normal meson.
    - Difficulty: With phase space subtracted, from BESII and BESIII measurements, we obtained $\Gamma(f_0(1710)$

- $B(J/\psi \to \gamma f_0(1710) \to \gamma\pi\pi) = (4.01 \pm 1.0) \times 10^{-4}$
  BESII: PLB 642 441 (2006)
- $B(J/\psi \to \gamma f_0(1710) \to \gamma K_s K_s) = (2.00^{+0.03+0.31}_{-0.02-0.10}) \times 10^{-4}$
  BESIII: PRD 98 072003 (2018)
- $B(f_0(1500) \to \eta\eta')/B(f_0(1500) \to \pi\pi) = (1.66^{+0.42}_{-0.40}) \times 10^{-1}$
- $B(f_0(1710) \to \eta\eta')/B(f_0(1710) \to \pi\pi) < (2.9^{+1.1}_{-0.9}) \times 10^{-3}$
  BESIII: PRD 106 072012(2022)

Main Difficulties:

1. Mixing with nearby f_0's

2. Hard to exclude other interpretations

Historical Glueball Candidates

- 0^{++} scalar glueball candidates
  - $f_0(1500)$
    - Discovered by Crystal Barrel in 1990's as a unique 0^{++} candidate since $f_0(1710)$ was f_2 at that time.
    - Difficulty: compared with $f_0(1710)$, much lower production rate than $f_0(1710)$ disfavors its interpretation as a scalar glueball.
  - Mixing between $f_0(1500)$ / $f_0(1710)$, or even with $f_0(1790)$?
    - Difficulty: dynamic mixing mechanism needs to be understood from the first principle of QCD (not just phenomenological understanding).

BESIII:

$$B\left(J/\psi \to \gamma f_0(1500)\right) \sim 0.29 \times 10^{-3}$$
$$B\left(J/\psi \to \gamma f_0(1710)\right) \sim 2.2 \times 10^{-3}$$

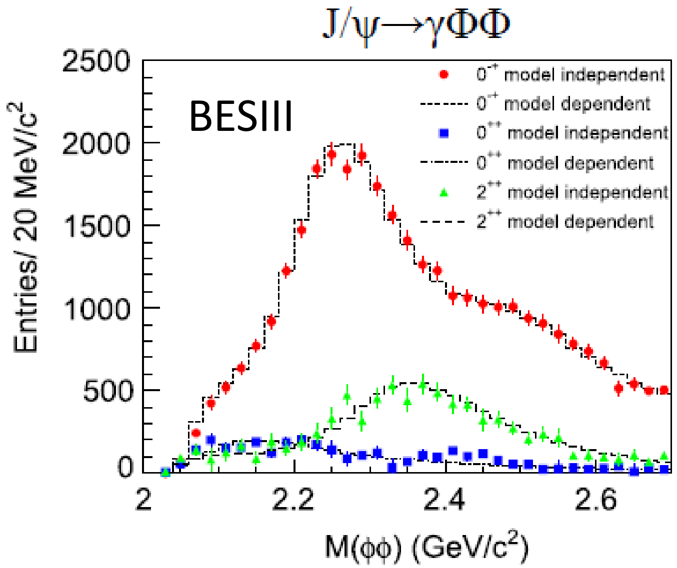
Main Difficulties:

1. Mixing with nearby f0's

2. Hard to exclude other interpretations

Historical Glueball Candidates

- 2^{++} Tensor Glueball Candidates
  - $\xi(2230)$
    - First observed by MarkIII is $J/\psi \to \gamma K\bar{K}$ in 1980's, then by BESI in 1990's in $J/\psi \to \gamma K\bar{K}, \gamma\pi\pi, \gamma p\bar{p}$ with very narrow mass peak.
    - It was a tensor glueball candidate due to good flavor symmetric decay property.
    - Difficulty: it was not confirmed by BESII, nor BESIII.
  - $f_2(2340)$
    - Many wide f_2 mesons in the mass region of 2.3 GeV from the LQCD predictions
    - Difficulty: no clear mass peak of these f_2 mesons can be directly observed in J/ψ radiative decays due to large overlaps among various wide resonances. They can only be seen as PWA components.
    - $f_2(2340)$: its large production rate in J/ψ radiative decays favors its interpretation as a tensor glueball candidate.
    - More PWA studies are needed to check the consistency among various decays modes. However, due to large overlaps again, no independent mass and width scan can be performed in PWA, i.e., the masses and widths of these f_2 mesons have to be fixed to previous measurements.



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

Main difficulties: two many 2^{++} nearby, hard to distinguish from other interpretations

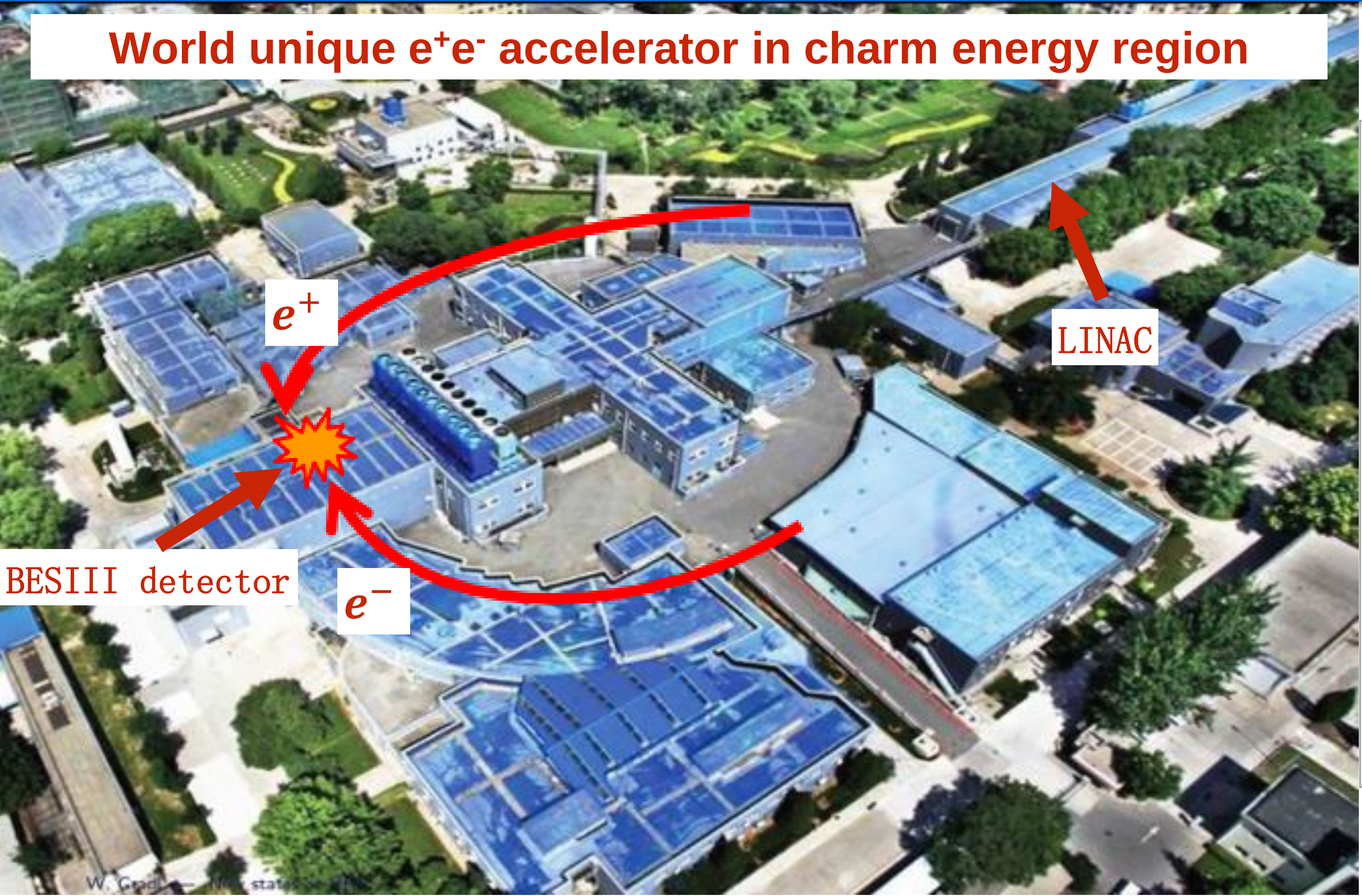
Historical Glueball Candidates

- 0^{-+} Pseudoscalar Glueball Candidate
  - $\eta(1405)$ first discovered by MarkII in 1980's, named as $\iota(1440)$ with complicated structures. Lots of studies at MarkII, MarkIII, DM2 and BES.
  - Believed as the first glueball candidate due to its large production rate in J/ψ radiative decays and lack of reliable LQCD predictions in 1980's
  - No longer to be believed as 0^{-+} glueball candidate due to its large different mass from LQCD prediction.

Until 2011， no good 0^{-+} glueball candidate observed above 2.3 GeV

BESIII Studies on $X(2370)$

Beijing Electron Positron Collider (BEPCII)



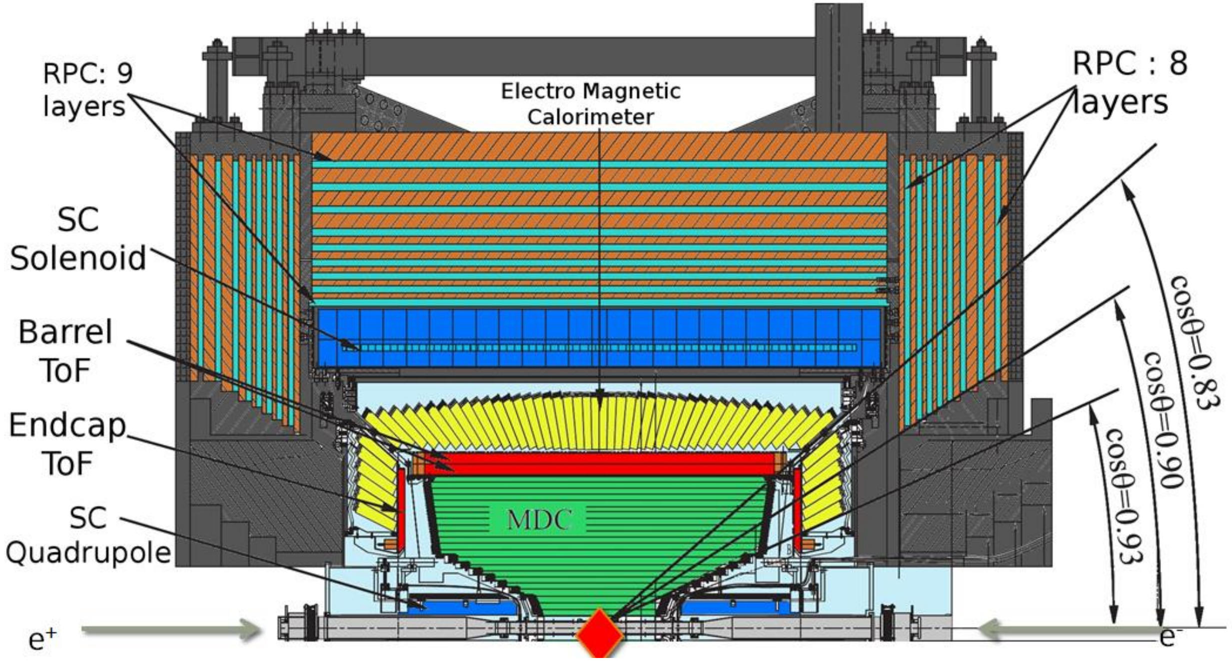
2004-2008: Construction

- Double rings
- Beam energy: 1.0 - 2.3 (2.45) GeV
- Designed luminosity: 1×10^{33} cm^{-2} s^{-1}

2009-now: BESIII physics runs

BESIII detector

Designed for neutral and charged particles with excellent resolution, PID, and large coverage



Total weight 730 tons,
~40,000 readout channels
Data rate: 5k Hz, 50 Mb/s

- MDC: small cell & He gas
  - σ_{xy} = 130 μm
  - σ_p/p=0.5% @1GeV
  - dE/dx = 6%
- TOF: plastic scintillator/MRPC
  - σ_T = 80 ps Barrel
  - σ_T = 110 (60) ps Endcap
- EMC: CsI crystals
  - $\Delta E/E$ = 2.5% @ 1GeV - Barrel
  - $\Delta E/E$ = 5% @ 1GeV - Endcap
- Muon ID: 9 layer RPC
- Magnet: 1T Superconducting

In full operation since 2008, all sub-detectors are in a very good condition!

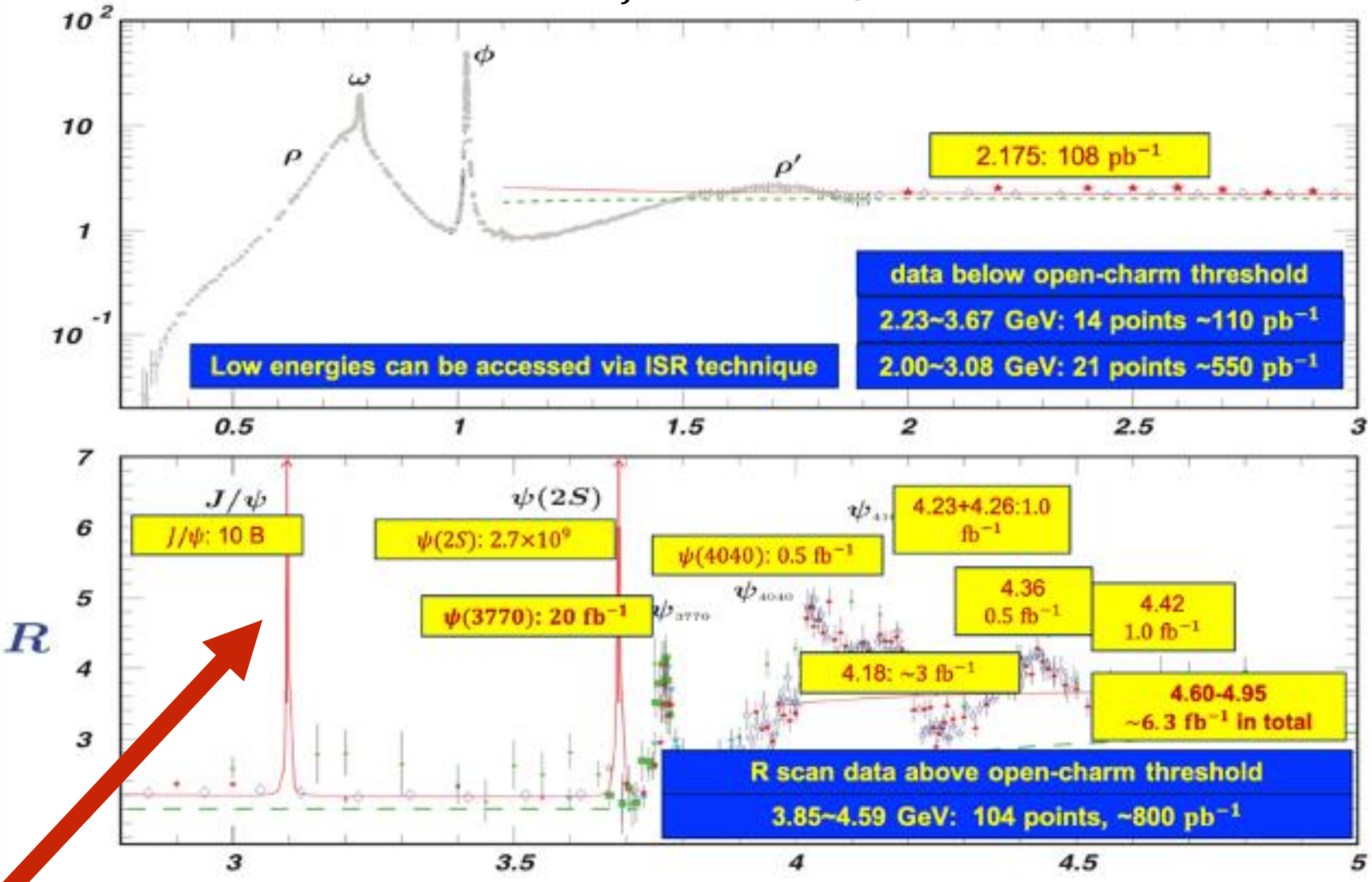
BESIII Data samples

Data sets collected so far:

- ✦ 10×10^9 J/ψ events
- ✦ 2.7×10^9 $\psi(2S)$ events
- ✦ 20 fb^{-1} $\psi(3770)$
- ✦ Scan data between 1.8 and 3.08 GeV, and above 3.74 GeV
- ✦ Large datasets for XYZ studies:

Scan with >500 pb^{-1} per energy point space 10–20 MeV apart

Totally about $50fb^{-1}$ integrated luminosity



Huge J/ψ data sample : ~10 billion

Key scientific question to be answered at BESIII: Glueballs exist or not?

- Searching for glueballs has been the **top physics goal** of BEPC and BEPCII **for about 40 years!**

- With 10 billion J/ψ data, we should be able to answer this key question — either we find them, or exclude them.
  - BESIII Physics Yellow Book

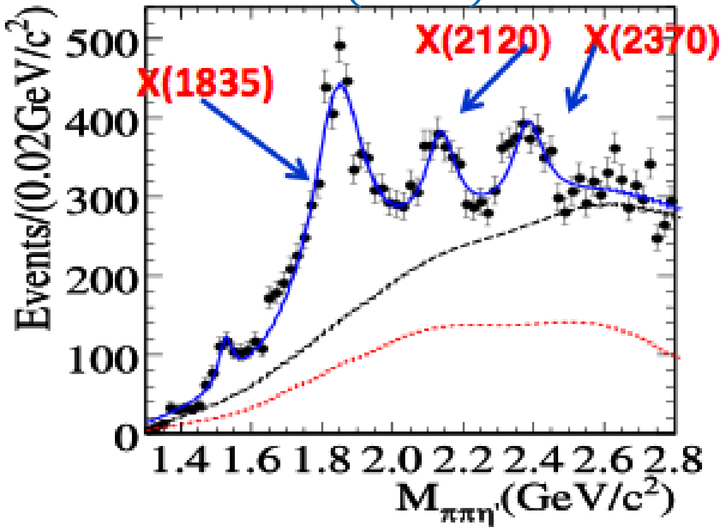
→ We started to find the answer…

Discovery of $X(2370)$

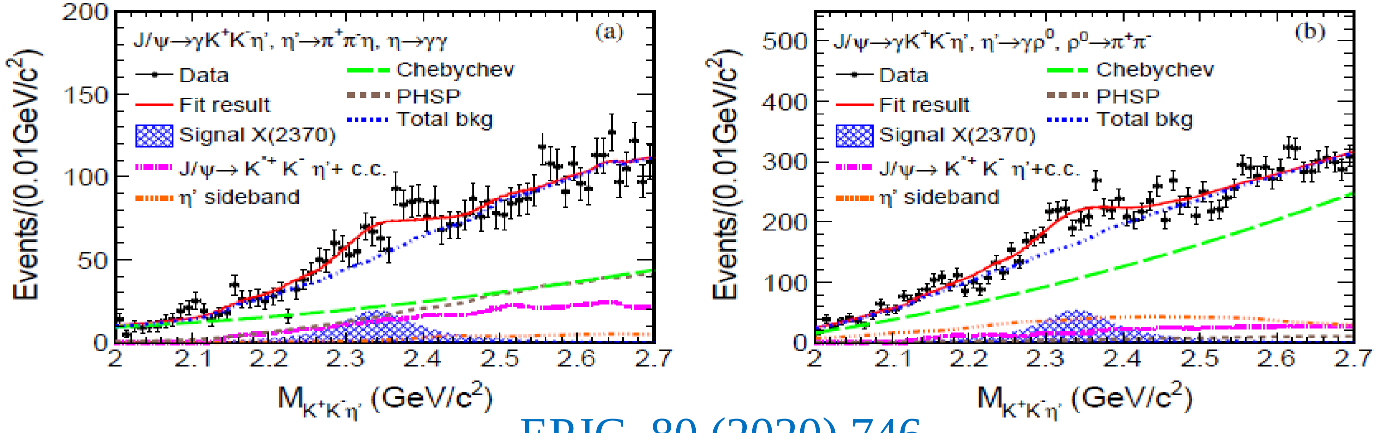
- **Discovered by BESIII in $J/\psi \to \gamma\pi^+\pi^-\eta'$ in 2011.**

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

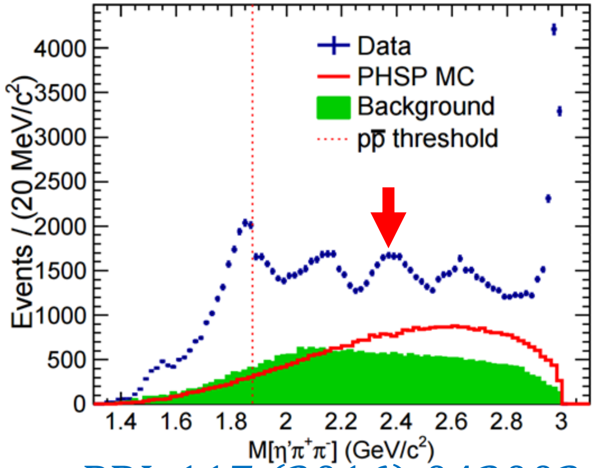
PRL106 (2011) 072002



- **Confirmed by BESIII in $J/\psi \to \gamma\pi^+\pi^-\eta', \gamma K\bar{K}\eta'$ (more data & new mode)**

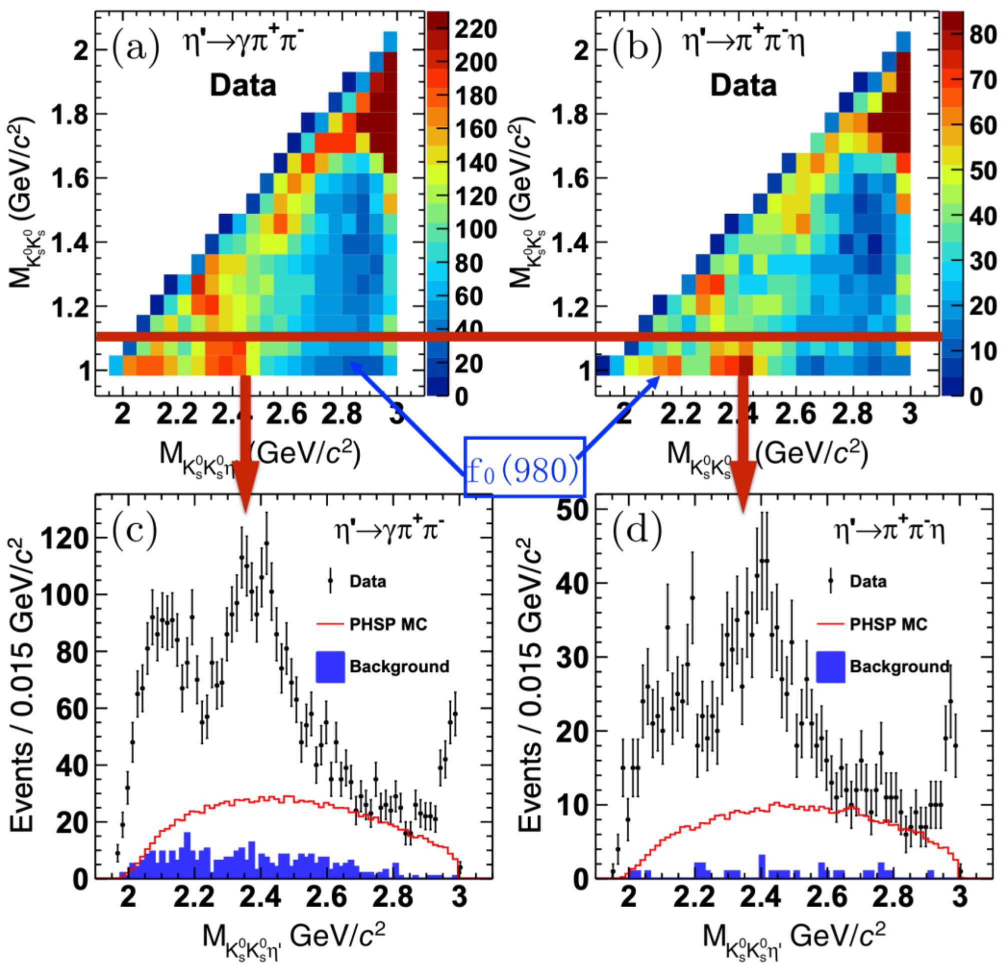


EPJC 80 (2020) 746



PRL 117 (2016) 042002

Spin-parity Determination of $X(2370)$ in $J/\psi \to \gamma K_S^0 K_S^0 \eta'$



[PRL 132 (2024) 181901]

- Almost background free channel
- 10 billion J/ψ data
- Very good BESIII detector performance

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

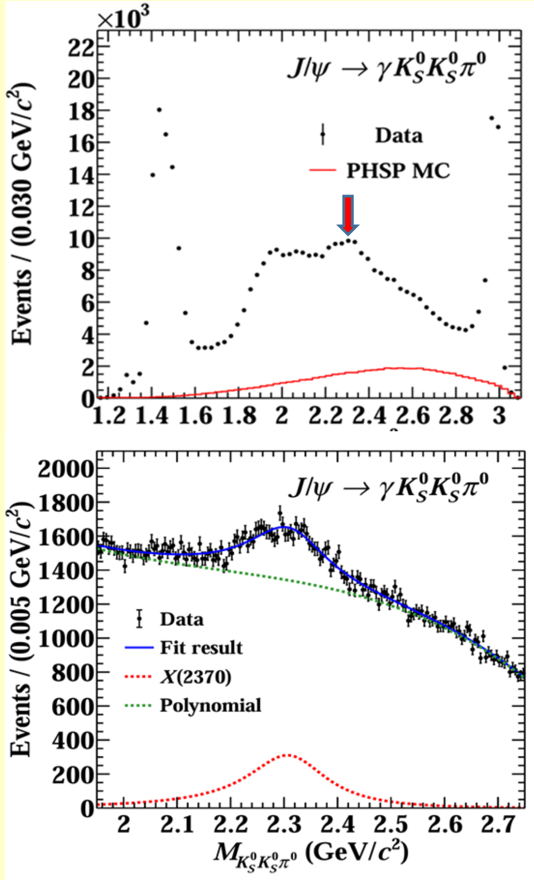
$M = 2395 \pm 11^{+26}_{-94}$ MeV

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

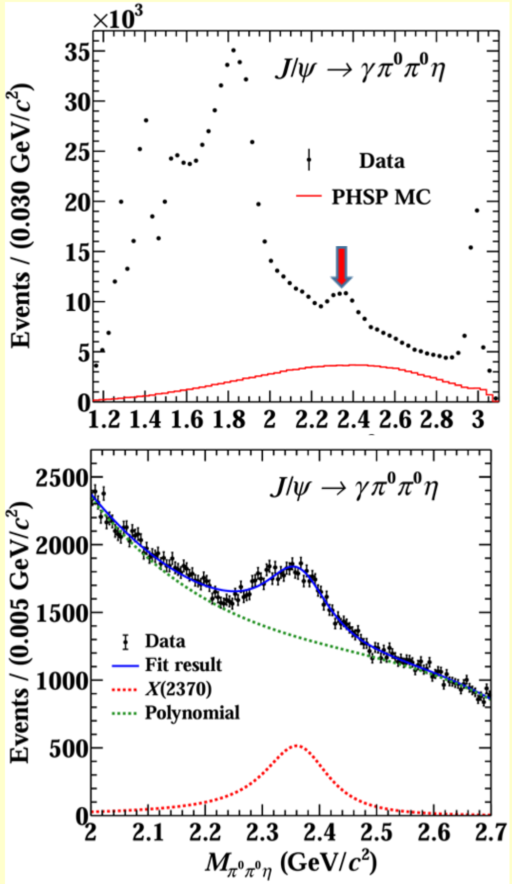
$B(J/\psi \to \gamma X(2370)) \times B(X(2370) \to f_0(980)\eta')$
$\times B(f_0(980) \to K_S^0 K_S^0)$
$= (1.31 \pm 0.22\ {}^{+2.85}_{-0.84}) \times 10^{-5}$

New decay modes: $X(2370) \to K_S^0 K_S^0 \pi^0,\ \pi^0\pi^0\eta, a_0(980)\pi^0$

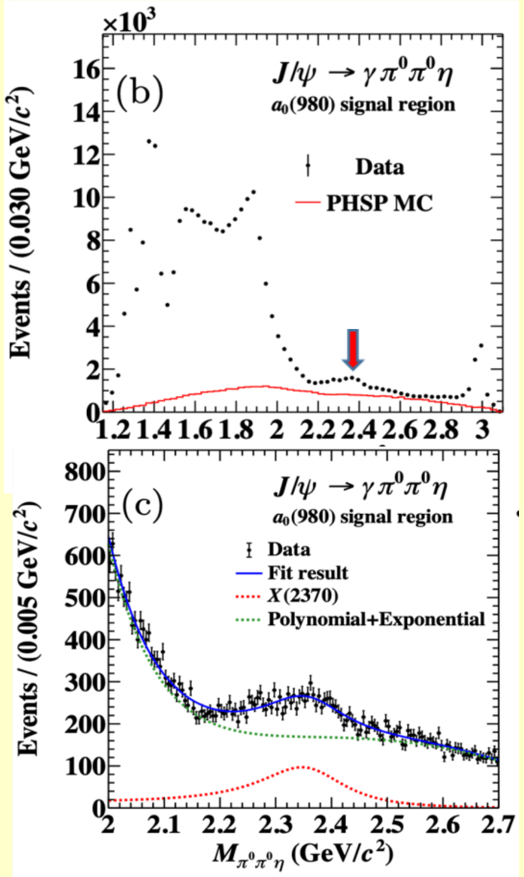
Observed $X(2370)$ decay modes show strong similarities to those of η_c



$X(2370) \to K_S^0 K_S^0 \pi^0\ (> 14\sigma)$



$X(2370) \to \pi^0\pi^0\eta\ (> 20\sigma)$

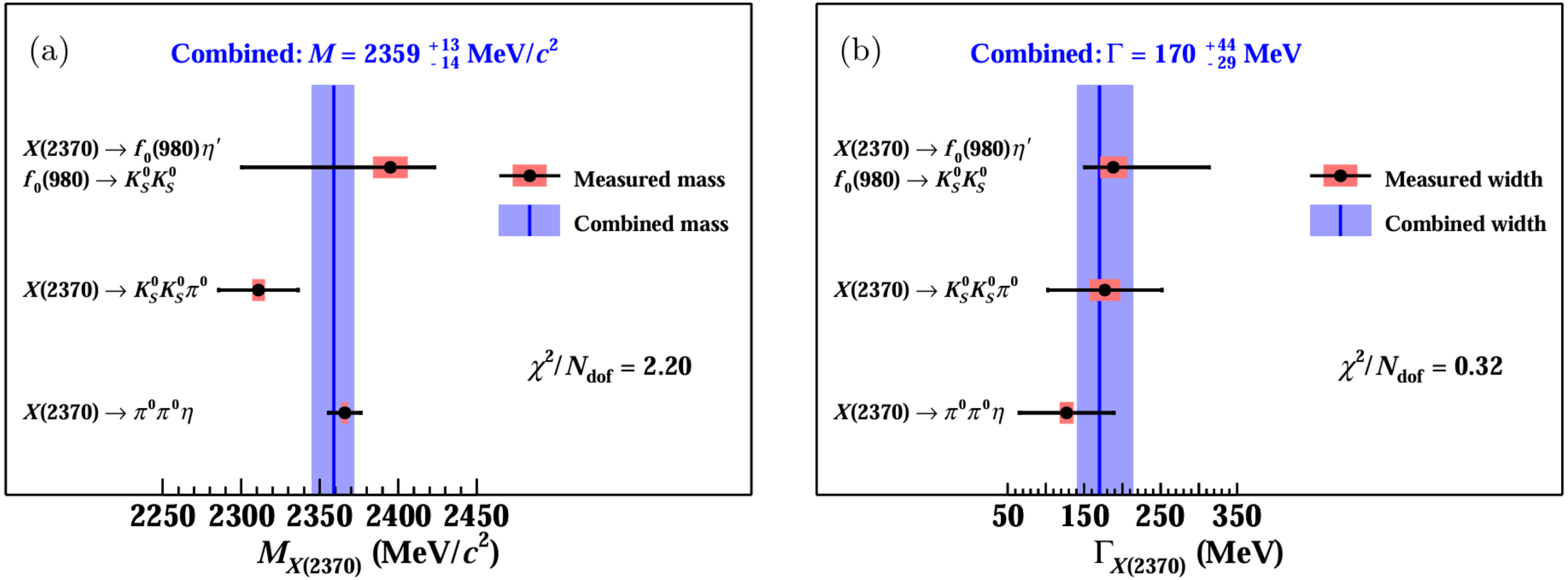


$X(2370) \to a_0(980)\pi^0\ (> 9\sigma)$

arxiv:2605.26495

$X(2370)$ Combined Mass and Width

arxiv： 2605.26495



Combined result:

$$M_{X(2370)} = 2359^{+13}_{-14}\mathrm{MeV}/c^2$$

$$\Gamma_{X(2370)} = 170^{+44}_{-29}\mathrm{MeV}$$

High production rate of $B(J/\psi \to \gamma X(2370))$

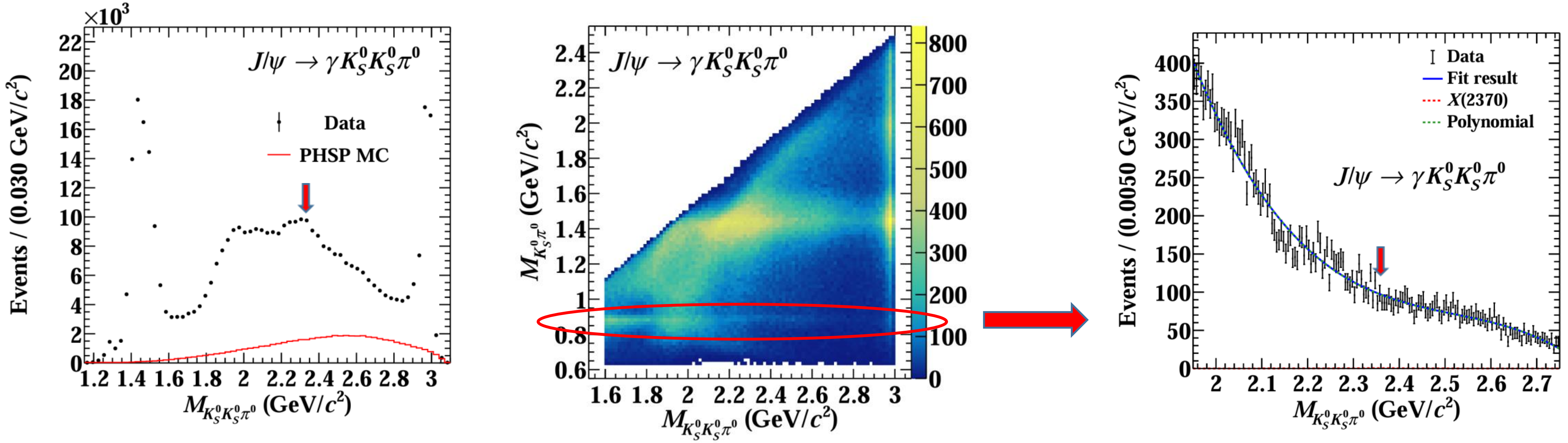
Decay channel	$\mathcal{B}\ (\times 10^{-4})$
$J/\psi \to \gamma X(2370) \to \gamma K \bar{K} \pi$	$3.25 \pm 0.25^{+0.73}_{-0.75}$
$J/\psi \to \gamma X(2370) \to \gamma \pi \pi \eta$	$3.2 \pm 0.1^{+0.9}_{-1.0}$
$J/\psi \to \gamma X(2370) \to \gamma \pi \pi \eta'$	$1.94 \pm 0.04^{+0.33}_{-0.88}$
$J/\psi \to \gamma X(2370) \to \gamma K \bar{K} \eta'$	$0.39 \pm 0.05 \pm 0.10$

- The total sum from the left table is $\sim 0.9 \times 10^{-3}$
- Considering other unmeasured decay modes, it is reasonable to conclude:

  $B(J/\psi \to \gamma X(2370)) > 1 \times 10^{-3}$

Flavor-singlet state: non-observation of $X(2370) \to K^*(892)\bar{K} + \text{c.c.}$

Forbidden by Generalized G-parity conservation



Significance of the $X(2370) = 0.1\sigma$

$$\mathcal{B}[J/\psi \to \gamma X(2370)] \times \mathcal{B}\left[X(2370) \to K^*(892)^0 K^0_S + \text{c.c.} \to K^0_S K^0_S \pi^0\right] < 2.7 \times 10^{-6} \text{ @90\% C.L.}$$

$$\frac{\mathcal{B}[X(2370) \to K^*(892)^0 K^0_S + \text{c.c.} \to K^0_S K^0_S \pi^0]}{\mathcal{B}[X(2370) \to K^0_S K^0_S \pi^0]} < 0.081 \text{ @90\% C.L.}$$

$X(2370)$ is a flavor-singlet state, the first observed above 1 GeV.

Narrow partial decay widths of $X(2370)$

Decay channel	$\mathcal{B}$ $(\times 10^{-4})$
$J/\psi \to \gamma X(2370) \to \gamma K\bar{K}\pi$	$3.25 \pm 0.25^{+0.73}_{-0.75}$
$J/\psi \to \gamma X(2370) \to \gamma\pi\pi\eta$	$3.2 \pm 0.1^{+0.9}_{-1.0}$
$J/\psi \to \gamma X(2370) \to \gamma\pi\pi\eta'$	$1.94 \pm 0.04^{+0.33}_{-0.88}$
$J/\psi \to \gamma X(2370) \to \gamma K\bar{K}\eta'$	$0.39 \pm 0.05 \pm 0.10$

- These processes are dominated by S-wave two-body decay process, with flavor symmetry

a) $K\bar{K}\eta'$: $f_0(980)\eta'$

b) $\pi\pi\eta'$: $f_0(980)\eta'$, $f_0(500)\eta'$

c) $\pi\pi\eta$: $a_0(980)\pi^0$, $f_0(500)\eta$, $f_0(1500)\eta$, $f_0(1710)\eta$

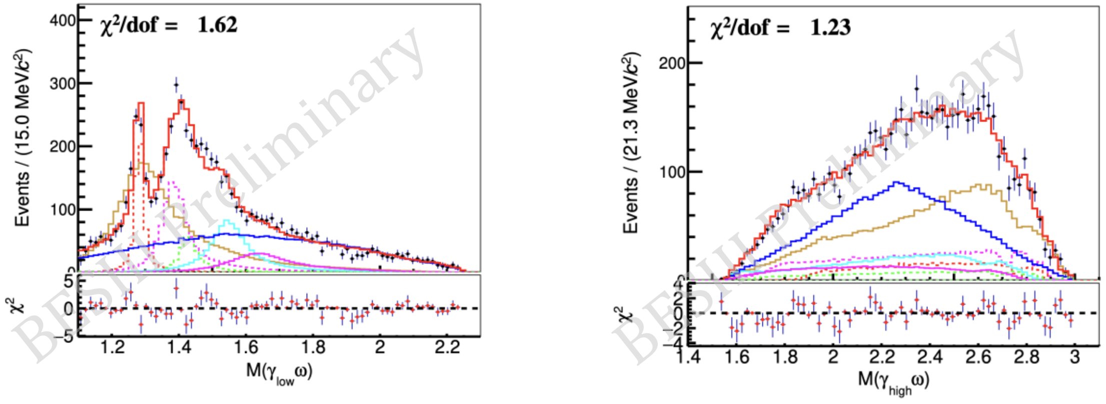
d) $K\bar{K}\pi$: $K_0^*(1430)\bar{K}$, $K_0^*(800)\bar{K}$, $a_0(980)\pi^0$, many more isospin combinations

- There may be other unmeasured decay modes of $X(2370)$, such as VV, multi-pion modes

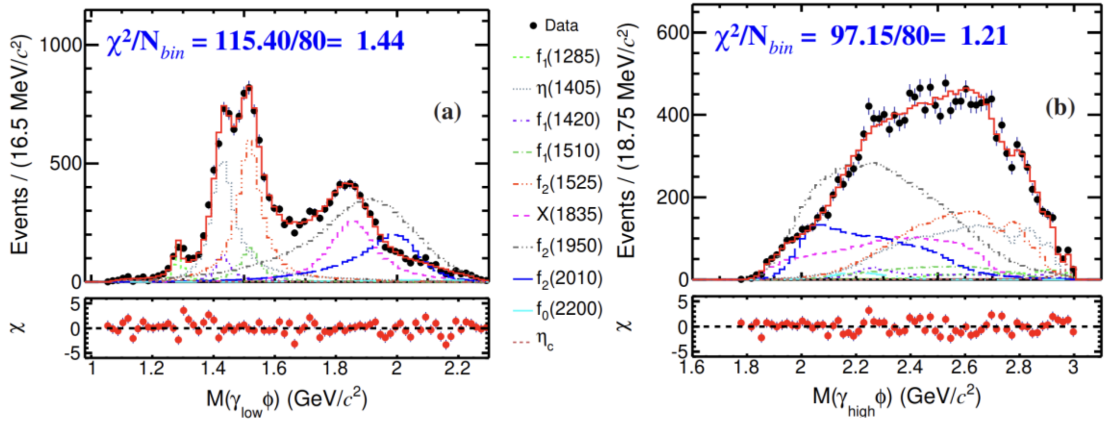
→ Each above S-wave two-body decay mode has a BR 1~10%, corresponding to a partial width ~ a few MeV, since $X(2370)$ total width is only ~150MeV

Suppressions of X(2370) $\to \gamma\omega, \gamma\phi$

$J/\psi \to \gamma\gamma\omega$



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



PRD 111(2025) 052011

- $J/\psi \to \gamma\gamma\omega, \gamma\gamma\phi$ have been studied with amplitude analysis at BESIII

Resonance R	$J/\psi \to \gamma R \to \gamma\gamma\omega$ $(\times 10^{-6})$ [29]	$J/\psi \to \gamma R \to \gamma\gamma\phi$ $(\times 10^{-6})$ [30]
$\eta(1405)$	$3.54 \pm 0.20^{+0.65}_{-0.24}$	$3.57 \pm 0.18^{+0.59}_{-0.61}$
$X(1835)$	< 0.11	$3.37 \pm 0.19^{+0.78}_{-1.10}$
$X(2370)$	< 0.04	< 0.11

- With $B\big(J/\psi \to \gamma X(2370)\big) > 1 \times 10^{-3}$, these suppressions are very strong

Comparisons of decay widths of $\gamma\omega, \gamma\phi$ (I)

We did not observe $X(2370)$ in the amplitude analyses on $J/\psi \to \gamma\gamma\omega, \gamma\gamma\phi$, and we obtain the upper limits on product BRs:

- $\mathcal{B}[J/\psi \to \gamma X(2370) \to \gamma\gamma\omega] < 0.04 \times 10^{-6}$ @ 90% C.L.
- $\mathcal{B}[J/\psi \to \gamma X(2370) \to \gamma\gamma\phi] < 0.11 \times 10^{-6}$ @ 90% C.L.

From our paper, we have $\mathcal{B}[J/\psi \to \gamma X(2370)] > 1 \times 10^{-3}$, so we have:

- $\mathcal{B}[X(2370) \to \gamma\omega] < 4 \times 10^{-5}$
- $\mathcal{B}[X(2370) \to \gamma\phi] < 1 \times 10^{-4}$

With $X(2370)$ width 170 MeV $= 1.7 \times 10^{5}\ keV$, we have:

- partial width of $X(2370) \to \gamma\omega < 6.8$ keV
- partial width of $X(2370) \to \gamma\phi < 17$ keV

Actually, given large P-wave phase spaces of high mass resonance decaying into $\gamma\omega$ and $\gamma\phi$, the above partial widths are very small, see below.

Comparisons of decay widths of gamma omega, gamma phi (II)

In our paper, we compare them with the $\eta(1405)/\eta(1475)$ and $X(1835)$. From amplitude analyses, we have:

- $\mathcal{B}[J/\psi \to \gamma\eta(1405)/\eta(1475) \to \gamma\gamma\omega] = 3.5 \times 10^{-6}$.
- $\mathcal{B}[J/\psi \to \gamma\eta(1405)/\eta(1475) \to \gamma\gamma\phi] = 3.6 \times 10^{-6}$.
- $\mathcal{B}[J/\psi \to \gamma X(1835) \to \gamma\gamma\phi] = 3.4 \times 10^{-6}$.

With $\mathcal{B}[J/\psi \to \gamma\eta(1405)/\eta(1475)\,] \sim 5 \times 10^{-3}$ and $\mathcal{B}[J/\psi \to \gamma X(1835)] \sim (4-8) \times 10^{-4}$, we have:

- $\mathcal{B}[\eta(1405)/\eta(1475) \to \gamma\omega] = 7 \times 10^{-4}$
- $\mathcal{B}[\eta(1405)/\eta(1475) \to \gamma\phi] = 7.2 \times 10^{-4}$
- $\mathcal{B}[X(1835) \to \gamma\phi] = (4-8) \times 10^{-3}$

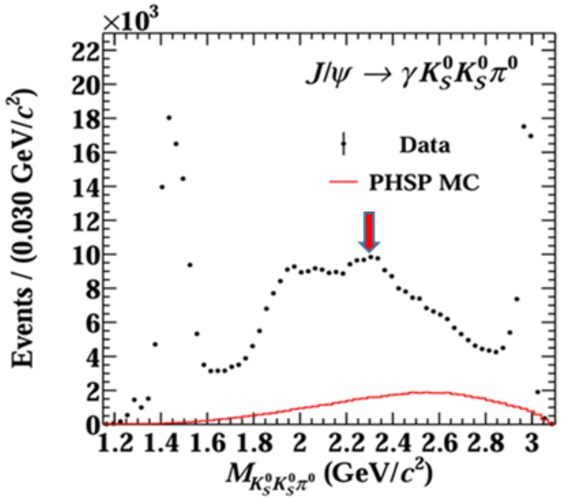
Then from above BRs and the widths of $\eta(1405)/\eta(1475)$ ~50-90 MeV $=5-9 \times 10^4$ keV , and width of $X(1835)$ $= 130$ MeV $= 1.3 \times 10^5$ keV, we have:

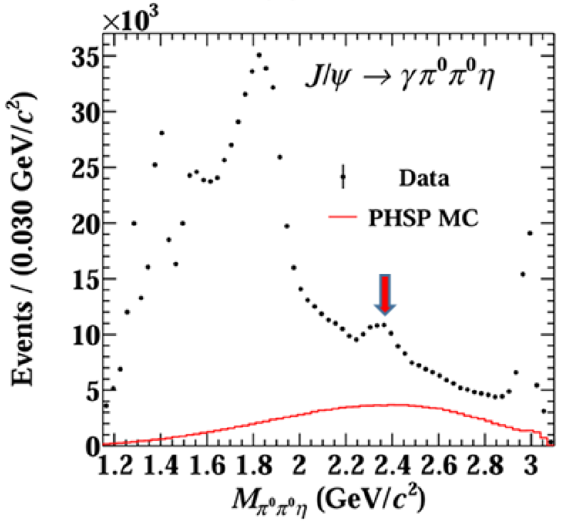
- partial width of $\eta(1405)/\eta(1475) \to \gamma\omega$ ~35-63 keV
- partial width of $\eta(1405)/\eta(1475) \to \gamma\phi$ ~36-65 keV
- partial width of $X(1835) \to \gamma\phi \sim$ 500-1000 keV

From all above numbers, compared with $\eta(1405)/\eta(1475)$, with further considering ~10 times larger P-wave phase spaces of $X(2370) \to \gamma\omega, \gamma\phi$ than those of $\eta(1405)/\eta(1475)$, the decays of $X(2370) \to \gamma\omega$, $\gamma\phi$ are strongly suppressed.

Examine consistencies of $X(2370)$ with glueballs and other interpretations

High production rate of $B(J/\psi \to \gamma X(2370))$





$B(J/\psi \to \gamma X(2370)) > 1 \times 10^{-3}$

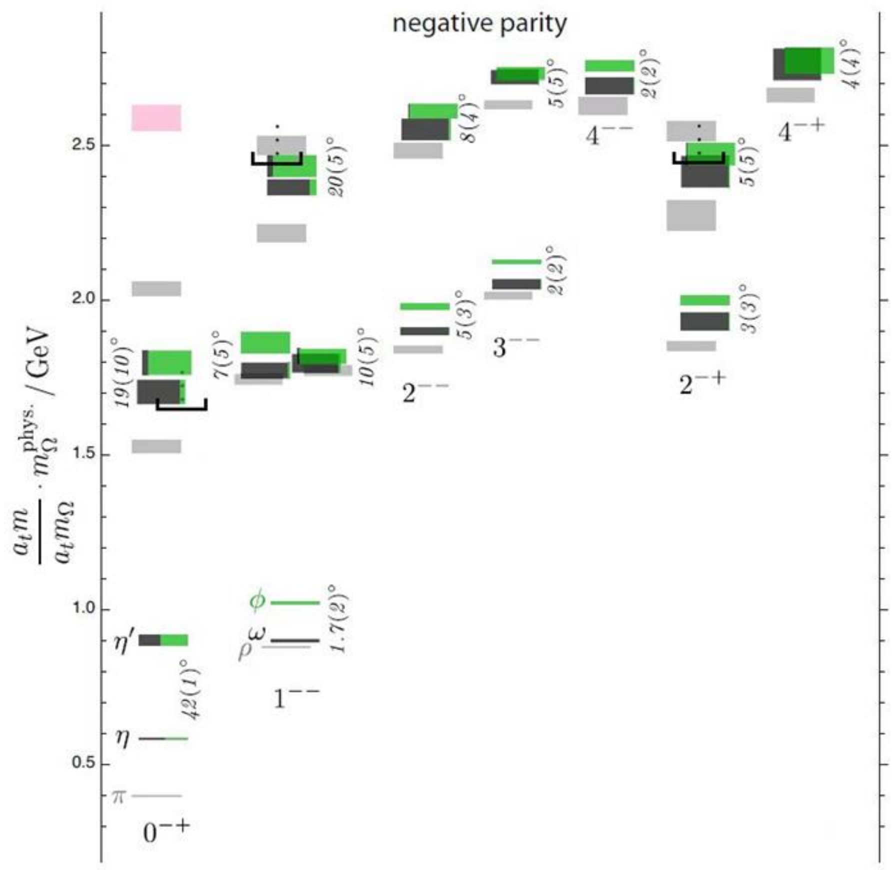
- High production rate is expected by glueball+$c\bar{c}$ mixing mechanism

- $X(2370)$ is unique between 2.3 GeV and η_c as seen in left plots

→Other 0^{-+} mesons either with much lower production rates or with much broader widths than $X(2370)$

- Disfavor baryonium-like states, given (PDG 2026):
  - $B(J/\psi \to \gamma \Lambda\bar{\Lambda}) < 1.3 \times 10^{-4}$ @ 90% C. L.
  - $B(J/\psi \to \gamma p\bar{p}) = (3.8 \pm 1.0) \times 10^{-4}$

$X(2370)$ is flavor-singlet



PRD 83 (2011) 111502

Most important glueball expectation

Disfavor $q\bar{q}$ interpretation

- LQCD prediction: no flavor-singlet from $u\bar{u} + d\bar{d}$ and $s\bar{s}$ mixing above 1 GeV
    - PDG data support this prediction

Hybrid and multiquark states can hardly form flavor-singlet states

Multiquark flavor-singlet?

- $uu\bar{u}\bar{u}+dd\bar{d}\bar{d}+uu\bar{d}\bar{d}+dd\bar{u}\bar{u}+uu\bar{s}\bar{s}+dd\bar{s}\bar{s}+ss\bar{s}\bar{s}+$…mixing to form flavor-singlet?

→Maybe, but quite un-natural

→Not seen even any candidate-like in PDG

$X(2370)$ decays similar to η_c

- Expected for 0^{-+} glueball

- Other interpretations can hardly explain this, e.g., full strange tetraquark states cannot have such similarities.

Narrow partial decay widths of $X(2370)$

- Expected for glueball decays
  - Estimated from $\sqrt{\mathrm{OZI}}$ rule $\sim$ a few MeV

- Disfavor $q\bar{q}$, multi-quark or hybrid states (with $q\bar{q}$ inside them)
  - They are all dominated by OZI allowed decays (typical decay width $\sim$ 100 MeV)

Strong suppressions of $X(2370) \to \gamma\omega, \gamma\phi$

- Expected for 0^{-+} glueball

- Light $q\bar{q}$ content inside $X(2370)$ should be very small

Discussion on $\Sigma\bar{\Sigma}$ baryonium（I）

- High production rate of $B(J/\psi \to \gamma X(2370)) > 1 \times 10^{-3}$ disfavor this interpretation.
  - With phase space corrections ($B(J/\psi \to \gamma X)$)~E_g^3), X(2370) has the STRONGEST coupling to gluons among ALL 0^{-+} particles !!!

- $B(J/\psi \to \Sigma\bar{\Sigma}) \sim 10^{-3}$, $B(\eta_c \to \Sigma\bar{\Sigma}) \sim 10^{-3}$
  - Typically one oder lower than meson productions

→PDG shows NO evidence that $\Sigma\bar{\Sigma}$ pair may have strong coupling with gluons!

Discussion on $\Sigma\bar{\Sigma}$ baryonium（II）

- $\Sigma\bar{\Sigma}$ is not a flavor-singlet state.
  - Many six-quark mixing states

    ($uuu\bar{u}\bar{u}\bar{u} + uud\bar{u}\bar{u}\bar{d} + uds\bar{u}\bar{d}\bar{s} + uss\bar{u}\bar{s}\bar{s} + \ldots$ ... mixing?)
  - Quite un-natural, even if it exists, its mass can hardly be at $\Sigma\bar{\Sigma}$ mass threshold anymore

- $\Sigma\bar{\Sigma} \rightarrow K^*\bar{K}$ may be suppressed (6 quark→4 quark)
  - But NOT forbidden!

- Keep in mind: "suppression" is different from "forbidden"

  (more data is needed, of course difficult to conclude "forbidden")

Discussion on $\Sigma\bar{\Sigma}$ baryonium（III）

- $\Sigma\bar{\Sigma}$ has NO $X(2370) - \eta_c$-like decay pattern

- $\Sigma\bar{\Sigma}$: 6 quark → 3 body decays to $K\bar{K}\pi, \pi\pi\eta, \pi\pi\eta', K\bar{K}\eta'$... dominant

- $X(2370), \eta_c \rightarrow K\bar{K}\pi, \pi\pi\eta, \pi\pi\eta', K\bar{K}\eta'$... all dominant by 2-body decays, almost no 3-body decays

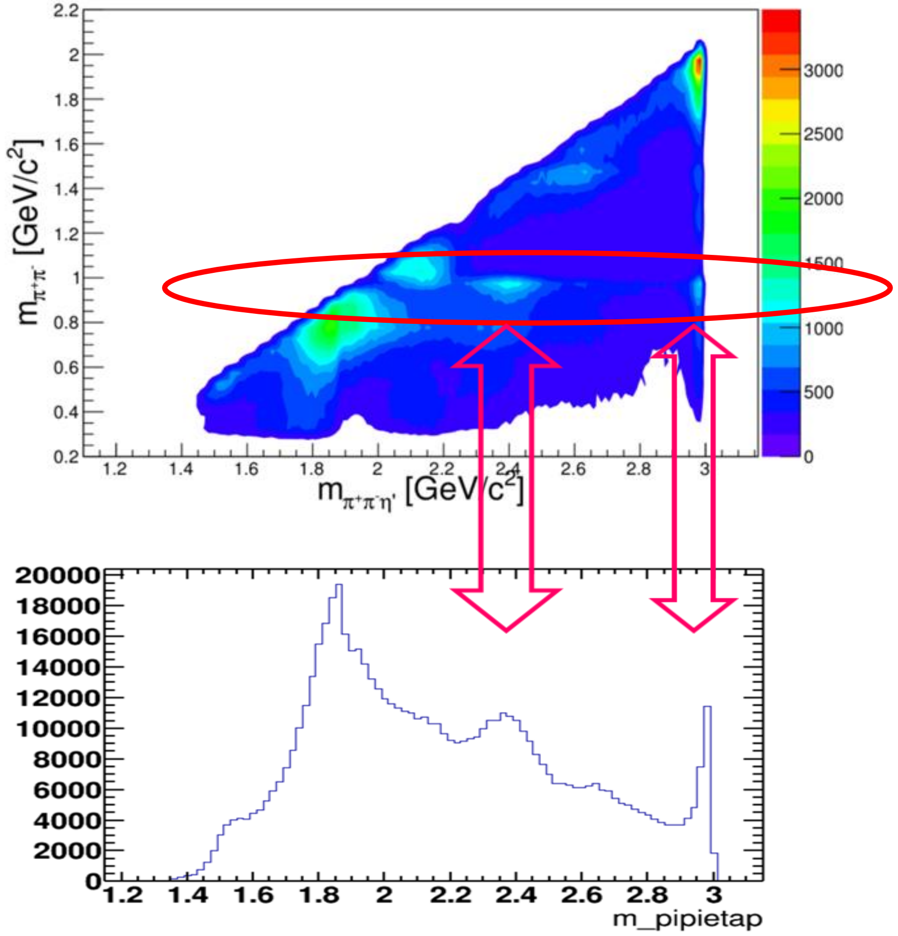
$\Sigma\bar{\Sigma}$ has completely different decay pattern from $X(2370)$

→ IT CANNOT BE $X(2370)$!

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

- $\pi^+\pi^-\eta'$ is the first mode to discover the $X(2370)$
- In the 2D plot of $M_{\pi\pi}$ vs. $M_{\pi\pi\eta'}$, in the $f_0(980)$ mass band, clear signals of both $X(2370)$ and η_c
- Additional important information:
  - $X(2370) \to \pi\pi\eta'$ almost 100% via $f_0(980)\eta'$
  - $\eta_c \to \pi\pi\eta'$ dominantly via $X(1800)\eta'$
  - NO phase space for $X(2370) \to X(1800)\eta'$

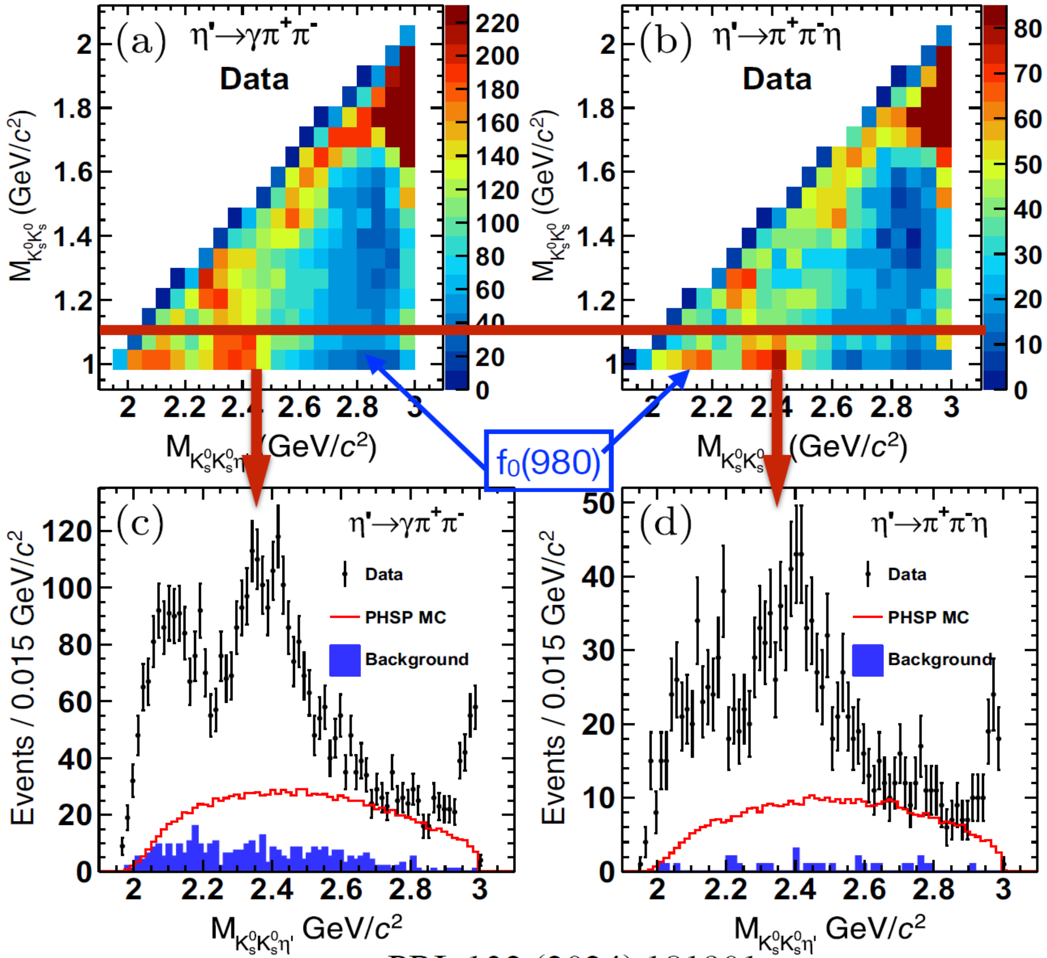
$M_{\pi^+\pi^-}$vs $M_{\pi^+\pi^-\eta'}$



$M_{\pi^+\pi^-}$ < 1.0 GeV

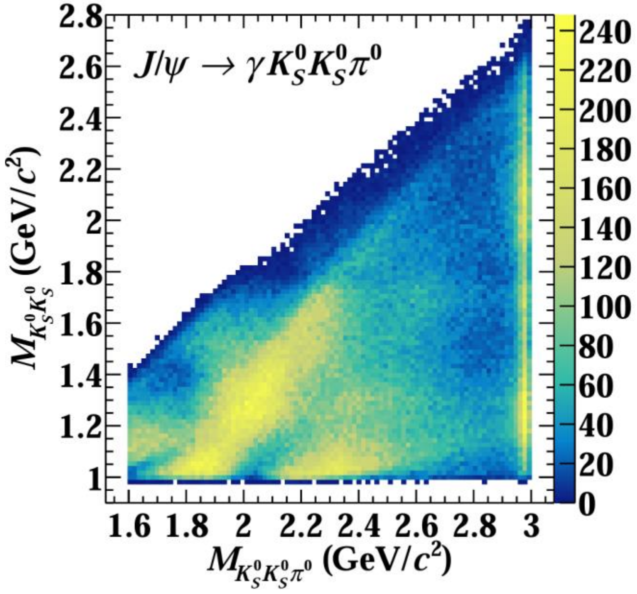
$J/\psi \to \gamma K_S^0 K_S^0 \eta'$

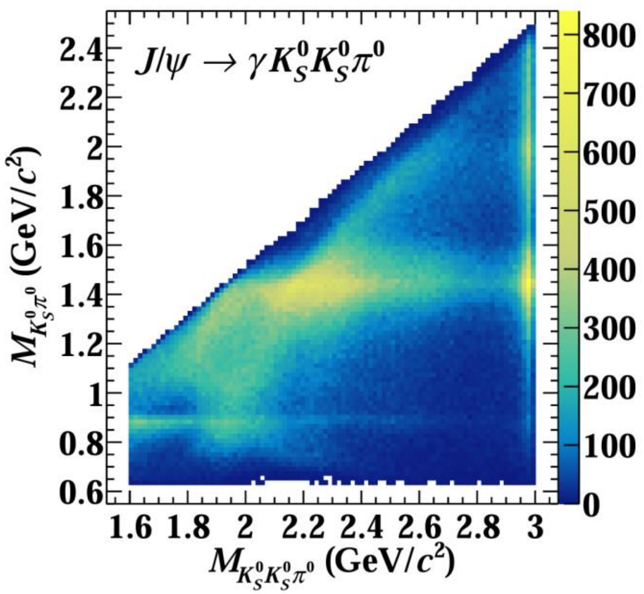
- In the $f_0(980)$ mass band of $K_S^0 K_S^0$ mass, clear signals of both $X(2370)$ and η_c
- Additional important information:
  - $X(2370) \to K\bar{K}\eta'$ almost 100% via $f_0(980)\eta'$
  - $\eta_c \to K\bar{K}\eta'$ dominantly via $X(1800)\eta'$
  - NO phase space for $X(2370) \to X(1800)\eta'$

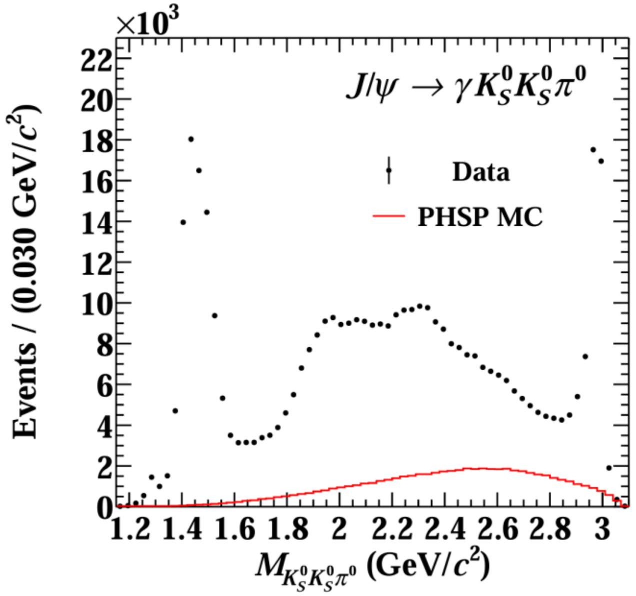


PRL 132 (2024) 181901

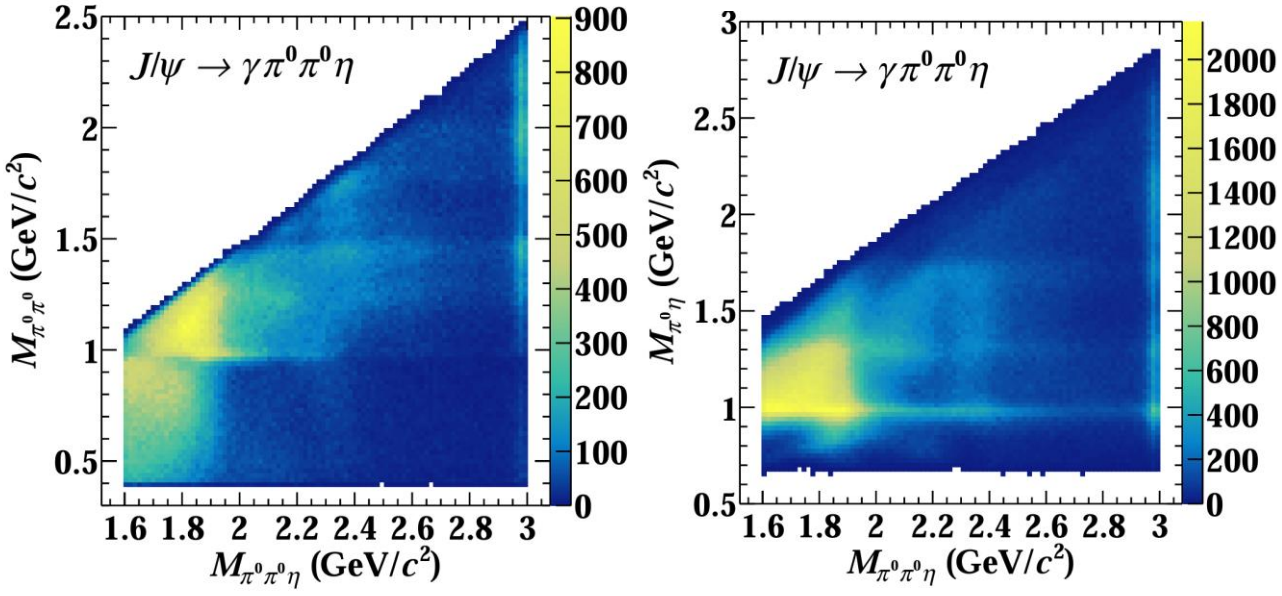
$J/\psi \to \gamma K_S^0 K_S^0 \pi^0$

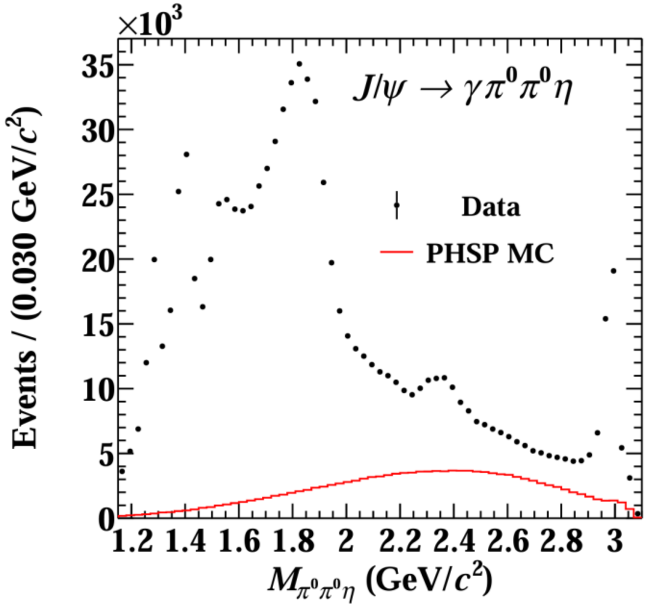






$J/\psi \to \gamma\pi^0\pi^0\eta$





Evidence of X(2370) in $J/\psi \to \gamma K_S^0 K_S^0 \eta$

In the 2D mass plot of $M_{K_S^0 K_S^0}$ $vs.$ $M_{K_S^0 K_S^0 \eta}$ in the BESIII paper on the spin-parity determination of the $X(1835)$, qualitatively, we can clearly observe:

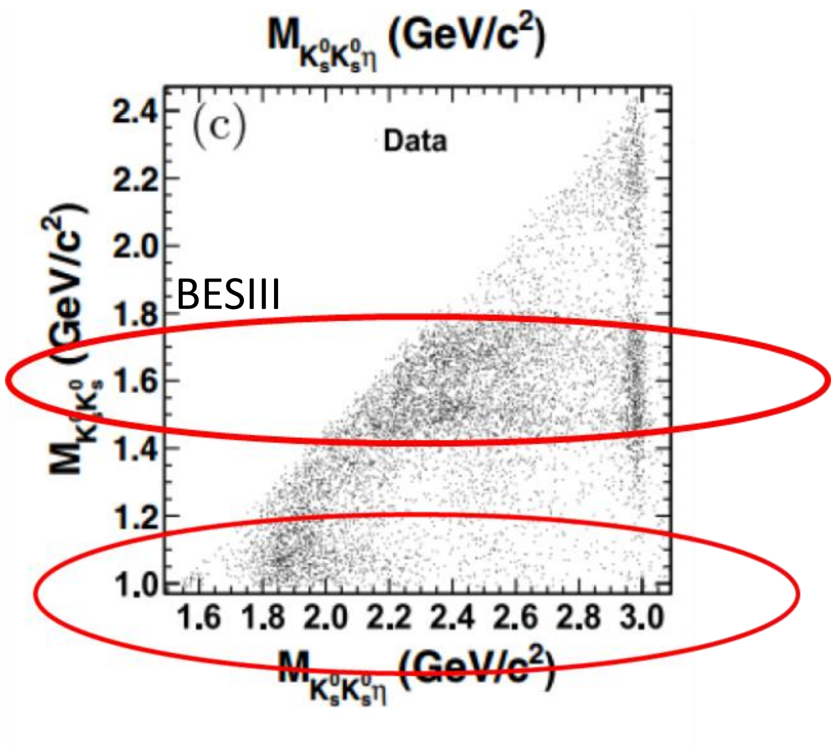
- In the upper $M_{K_S^0 K_S^0}$ mass band of $1.5 - 1.7$ GeV range, clear signals of both $X(2370)$ and η_c.

Evidence of $X(2370)$, $\eta_c \to f_0(1500)\eta$, $f_0(1710)\eta$

- In the lower $M_{K_S^0 K_S^0}$ mass band of $f_0(980)$, no $X(2370)$, nor η_c.

Suppressions of $X(2370)$, $\eta_c \to f_0(980)\eta$

→High similarities between $X(2370)$ and η_c decays!



PRL 115, 091803 (2015)

Discussion on $\Sigma\bar{\Sigma}$ baryonium（IV）

- $\Sigma\bar{\Sigma}$ cannot have narrow partial width to $K\bar{K}\pi, \pi\pi\eta, \pi\pi\eta', K\bar{K}\eta'$...

  They are all OZI allowed decays, no ANY suppression factors

Discussion on $\Sigma\bar{\Sigma}$ baryonium（V）

- In $X(2370)$ mass lineshap, NO "fast drop" distortion at $\Sigma\bar{\Sigma}$ mass threshold
  - c.f.: $f_0(980), X(1835)$

→$X(2370)$ has NO strong coupling with $\Sigma\bar{\Sigma}$

Summarize ALL above discussions:

$X(2370)$ STRONGLY DISFAVOR a $\Sigma\bar{\Sigma}$ state

Examination of Possible Interpretations of $X(2370)$

Qualitative compatibility of each interpretation with observed $X(2370)$ properties

Possible interpretation	High production in J/ψ radiative decays	Flavor-singlet / suppressed $K^*(892)\bar{K}$	η_c-like decay pattern	Narrow partial widths	Strong suppression of $\gamma\omega$, $\gamma\phi$	Overall consistency
Glueball-dominant $X(2370)$	✓	✓	✓	✓	✓	✓
Conventional $q\bar{q}$ pseudoscalar excitation (η/η'-like)	×	×	×	×	×	×
$\Sigma\bar{\Sigma}$ /baryonium / six quark state	×	×/?	×	×	?	×
Tetraquark state	×	×/?	×	×	×	×
Hybrid meson ($q\bar{q}g$)	?	×	×	×	?	×

Legend: ✓ = naturally compatible / can explain; × = in tension / not naturally explained. This is a qualitative synthesis, not a single-observable exclusion test.

Main message: the glueball-dominant constituent is essential because it explains the combined pattern, not merely one isolated property.

Summary

- Properties of $X(2370)$:
  - high production rate in J/ψ radiative decays
  - flavor-singlet state
  - decay pattern similarities to η_c
  - narrow partial decay widths
  - strong suppressions of $\gamma\omega, \gamma\phi$ decays
- These properties are fully consistent with the expected signatures of glueball.
  - Other interpretations can hardly explain all of them **simultaneously**
- The lightest 0^{-+} glueball is needed for a natural and complete explanation of $X(2370)$ properties measured by BESIII.

→ The lightest $\mathbf{0^{-+}}$ glueball is the dominant constituent of $\boldsymbol{X(2370)}$

- 文章introduction里清楚地写了：

  认证胶球占主导成分的混合粒子是对胶球存在的明确证明

ball and the $c\bar{c}$ component [11]. Such a mixing mechanism means that 0^{-+} glueball might only be found in the 0^{-+} glueball and $c\bar{c}$ mixture, i.e., identification of the 0^{-+} glueball dominant mixture particle should be an unambiguous proof of the existence of the 0^{-+} glueball.

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NEWS | PHYSICS

Behold the 'glueball,' a strange new form of matter

Collider in China forges elusive particle, made of force-carrying gluons

11 AUG 2026 · 3:50 PM ET · BY JULIA VAZ

Colin Morningstar 教授 (Carnegie Mellon大学 胶球权威专家)：这是实验上的一次胜利。这一发现是基础物理的纪念碑级成就。

It' s an experimental triumph. The finding is a monumental achievement for fundamental physics

William Detmold 教授 (MIT 核物理专家)：胶球寻找有很长的历史，大部分都没有结论。但是新的结果确实在所有方面都符合。

Detmold adds that the history of glueball searches has been long and mostly inconclusive. But the new result "is really ticking all the boxes", he says.

英国《自然》杂志报道

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NEWS | 12 August 2026

A particle made of force: physicists say they've found mysterious 'glueball'

Scientists have predicted the existence of a particle made of gluons for a long time, but detecting it has taken decades.

Ulrik Egede教授 (Monash大学 实验粒子物理专家)：这是非常令人信服的证据

It is quite convincing evidence.

Bruce Yabsley教授 (Sydney大学 粒子物理专家)：当前的发现非常有说服力。这是通往理解胶球的起点。

The current finding quite persuasive. This is the beginning of the road to understanding glueballs.

特别感谢

- BEPC加速器团队，国家数据中心/高能所计算中心
- 国内理论家的联合讨论（五次）

BESIII文章中都予以了致谢！

backup

2011年，“意外”发现$X(2370)$ 新粒子

我指导黄燕萍完成博士论文成果——中科院优秀博士论文奖

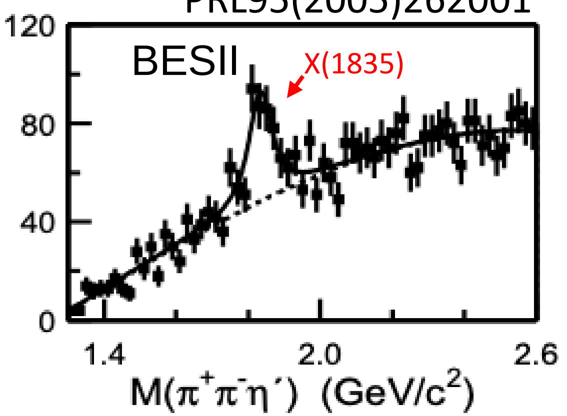
- BESIII在 $J/\psi \rightarrow \gamma\pi^+\pi^-\eta'$ 发现$X(2370)$新粒子

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

- X(1835) — BEPC发现的第一个新粒子
- 在确认$X(1835)$粒子的过程中，“意外”发现$X(2370)$新粒子

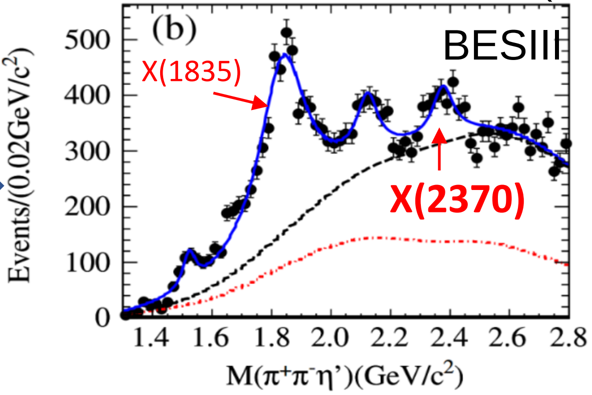
58M J/ψ

PRL95(2005)262001



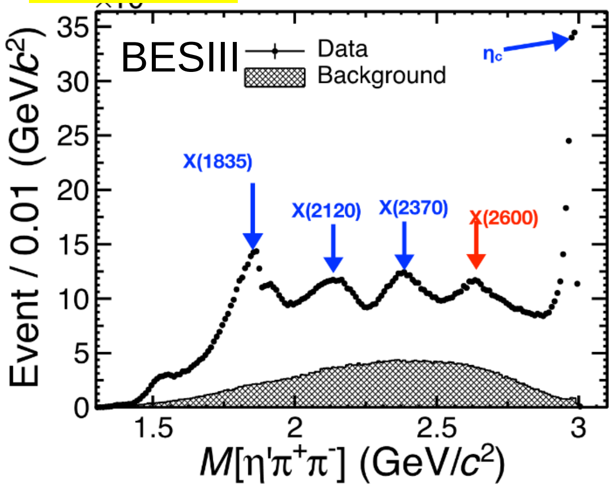
220 M J/ψ

PRL106, 072002 (2011)



10 B J/ψ

PRL129 (2022) 042001



BESIII测量的$X(2370)$性质总结

- 质量和自旋等量子数与格点QCD预言一致（LQCD计算陈莹等）

- $X(2370)$粒子的产额与格点QCD预言一致（LQCD计算陈莹等）

  J/ψ 粒子衰变中丰富产生

- $X(2370)$粒子衰变性质：
  - 味单态
  - 胶子特殊的衰变模式 —— 与η_c衰变的相似性（理论赵光达、黄涛）
  - 到每一个特定衰变末态的衰变分宽度很小（理论赵光达、黄涛）
  - 辐射衰变到普通粒子被压低

与胶球的预期信号完全一致，而以上其他类型的粒子都<u>很难同时</u>解释所有性质

→不支持其他所有可能类型粒子的解释

Estimation of constraint on normal $q\bar{q}$ contribution inside $X(2370)$ based on $K^*\bar{K}$ upper limit （suggestion from F.-K. Guo）

- Theoretical calculations on the partial width of normal $q\bar{q} \to K^*\bar{K}$ is about 20~200 MeV
- $Br(X(2370) \to K^*\bar{K} + \mathrm{c.c.})/Br(X(2370) \to K\bar{K}\pi) < 0.08$
- Reasonable assumption: $Br(X(2370) \to K\bar{K}\pi) < 10\%$
- Then we have $Br(X(2370) \to K^*\bar{K} + \mathrm{c.c.}) < 0.008$

  → partial width of $X(2370) \to K^*\bar{K} < 2MeV$

So the normal $q\bar{q}$ contribution in $X(2370) < 10\%$~1%

→ normal $q\bar{q}$ contribution inside $X(2370)$ is very small!

结　论
胶球存在！

- 必须存在胶球才能自然、完全地解释BESIII测量到的$X(2370)$粒子的所有性质

- 文章中严谨的表述：胶球是$X(2370)$粒子的主导成分
    - 实际上非胶球成分应该非常小（<10%）
    - 逻辑上该表述明确包含了“确认胶球存在”

    （逻辑简单清楚：必须首先有胶球存在才能有“主导”）

→非100%胶球含量的$X(2370)$粒子100%地证明了胶球的存在！

对比：质子

- 夸克模型建立时，质子由uud夸克组成

- 现在我们知道，质子不是100%由纯uud夸克组成

- uud重子存在没有异议

→强子中mixing是自然现象

Evidence of X(2370) in $J/\psi \to \gamma K_S^0 K_S^0 \eta$

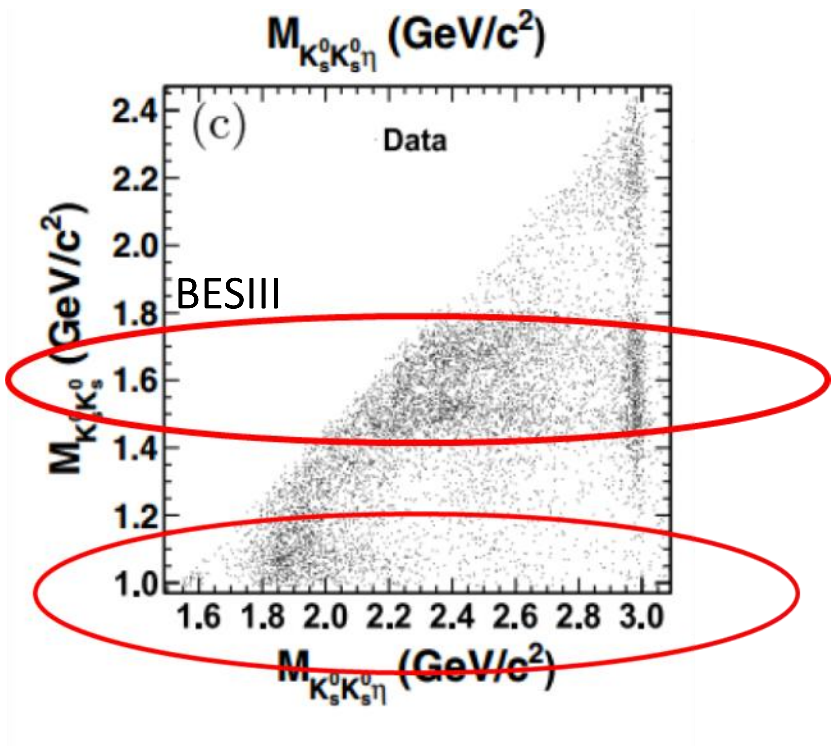
In the 2D mass plot of $M_{K_S^0 K_S^0}$ $vs.$ $M_{K_S^0 K_S^0 \eta}$ in the BESIII paper on the spin-parity determination of the $X(1835)$, qualitatively, we can clearly observe:

- In the upper $M_{K_S^0 K_S^0}$ mass band of $1.5 - 1.7$ GeV range, clear signals of both $X(2370)$ and η_c.

Evidence of $X(2370)$, $\eta_c \to f_0(1500)\eta$, $f_0(1710)\eta$

- In the lower $M_{K_S^0 K_S^0}$ mass band of $f_0(980)$, no $X(2370)$, nor η_c.

Suppressions of $X(2370)$, $\eta_c \to f_0(980)\eta$



PRL 115, 091803 (2015)

→High similarities between $X(2370)$ and η_c decays!

5 major η_c decay modes（from PDG）— 5 "Golden" modes in 0^{-+} glueball traditional searches

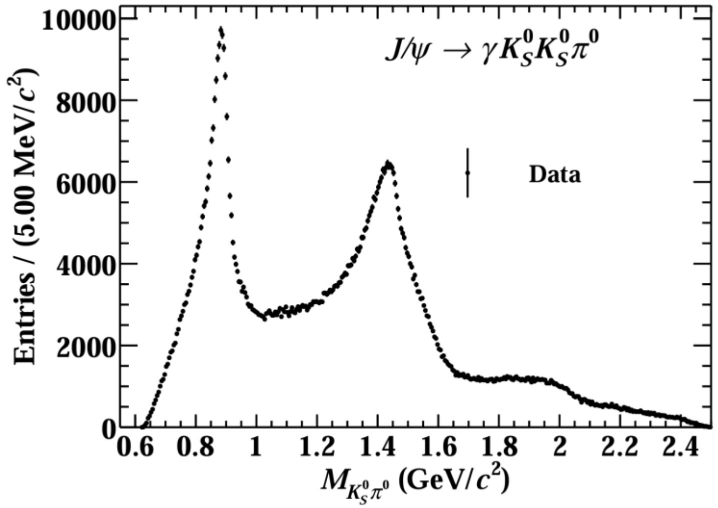
Decays involving hadronic resonances	
$\eta'(958)\pi\pi$	$(2.0 \pm 0.4)\ \%$
$\eta'(958)K\overline{K}$	$(1.73 \pm 0.35)\ \%$

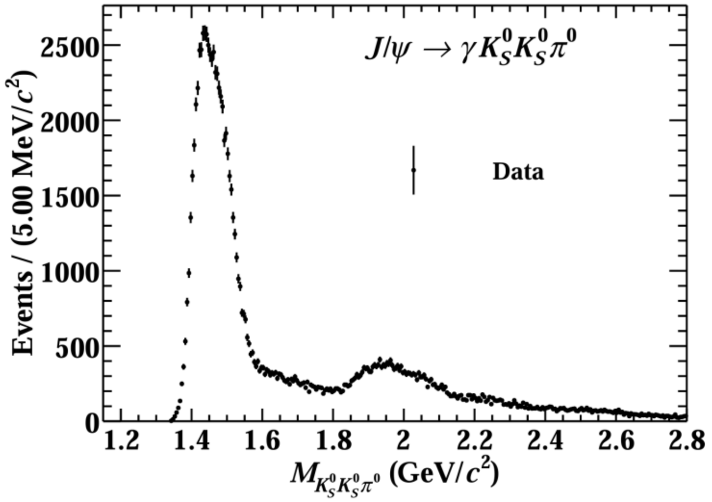
Decays into stable hadrons	
$K\overline{K}\pi$	$(7.1 \pm 0.4)\ \%$
$K\overline{K}\eta$	$(1.32 \pm 0.15)\ \%$
$\eta\pi^+\pi^-$	$(1.6 \pm 0.4)\ \%$

$X(2370)$ is observed in all 5 modes

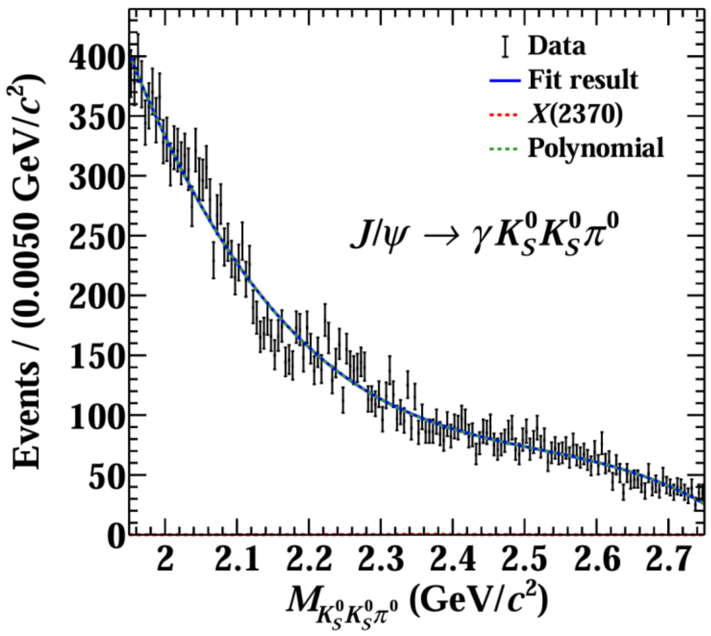
→ High similarities between $X(2370)$ and η_c decays

Searching for $X(2370) \to K^*(892)\bar{K} + \text{c.c.} \to K_S^0 K_S^0 \pi^0$





Significance of the $X(2370) = 0.1\sigma$



$$\mathcal{B}[J/\psi \to \gamma X(2370)] \times \mathcal{B}[X(2370) \to K^*(892)^0 K_S^0 + \text{c.c.} \to K_S^0 K_S^0 \pi^0] = (0.1 \pm 1.2(\text{stat}) \pm 1.1(\text{syst})) \times 10^{-6}$$

$$\mathcal{B}[J/\psi \to \gamma X(2370)] \times \mathcal{B}\left[X(2370) \to K^*(892)^0 K_S^0 + \text{c.c.} \to K_S^0 K_S^0 \pi^0\right] < 2.7 \times 10^{-6} \ @90\% \text{ C.L.}$$

$$\frac{\mathcal{B}[X(2370) \to K^*(892)^0 K_S^0 + \text{c.c.} \to K_S^0 K_S^0 \pi^0]}{\mathcal{B}[X(2370) \to K_S^0 K_S^0 \pi^0]} = 0.003 \pm 0.040(\text{stat}) \pm 0.026(\text{syst})$$

$$\frac{\mathcal{B}[X(2370) \to K^*(892)^0 K_S^0 + \text{c.c.} \to K_S^0 K_S^0 \pi^0]}{\mathcal{B}[X(2370) \to K_S^0 K_S^0 \pi^0]} < 0.081 \ @90\% \text{ C.L.}$$

Estimation of constraint on normal $q\bar{q}$ contribution inside $X(2370)$ based on $K^*\bar{K}$ upper limit

- Theoretical calculations on the partial width of normal $q\bar{q} \to K^*\bar{K}$ is about 20~200 MeV
- $Br(X(2370) \rightarrow K^*\bar{K} + \mathrm{c.c.})/Br(X(2370) \rightarrow KK\pi) < 0.08$
- Reasonable assumption: $Br(X(2370) \rightarrow KK\pi) < 10\%$
- Then we have $Br(X(2370) \rightarrow K^*\bar{K} + \mathrm{c.c.}) < 0.008$

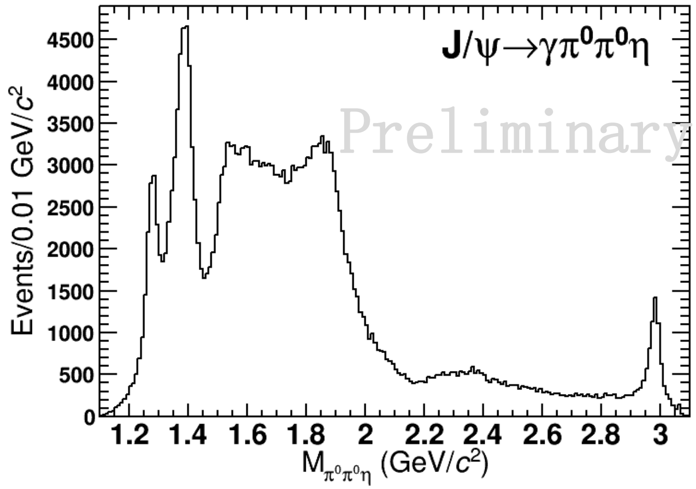
  → partial width of $X(2370) \rightarrow K^*\bar{K} < 2MeV$

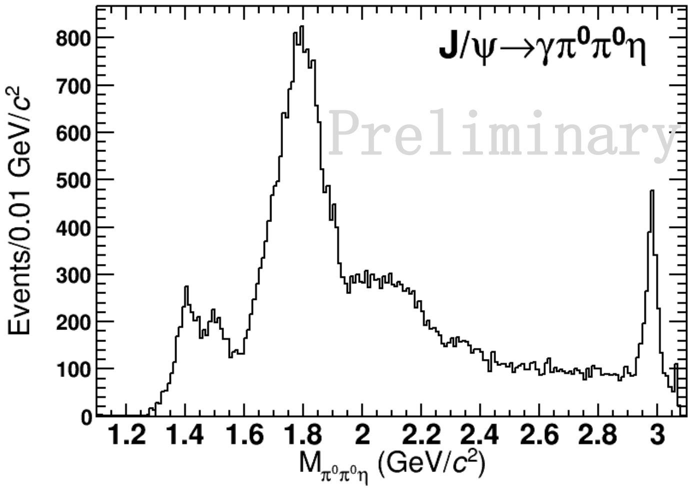
So the normal $q\bar{q}$ contribution in $X(2370) < 10\%{\sim}1\%$

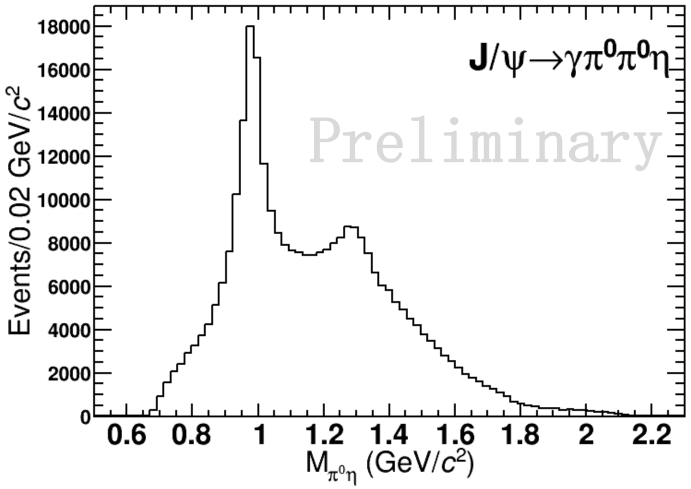
→ normal $q\bar{q}$ contribution inside $X(2370)$ is very small!

$\pi^0\pi^0\eta$ invariant mass spectrum in $a_0(980)$ signal region

- After requiring $|m_{\pi^0\pi^0} - 1.5| > 0.15$ GeV to veto $f_0(1500)$ signal, there is the clear $X(2370)$ signal in the $a_0(980)$ signal region, but not in the $a_0(980)$ sideband region.







$a_0(980)$ signal region
$|m_{\pi^0\eta} - 0.98| < 0.05$ GeV

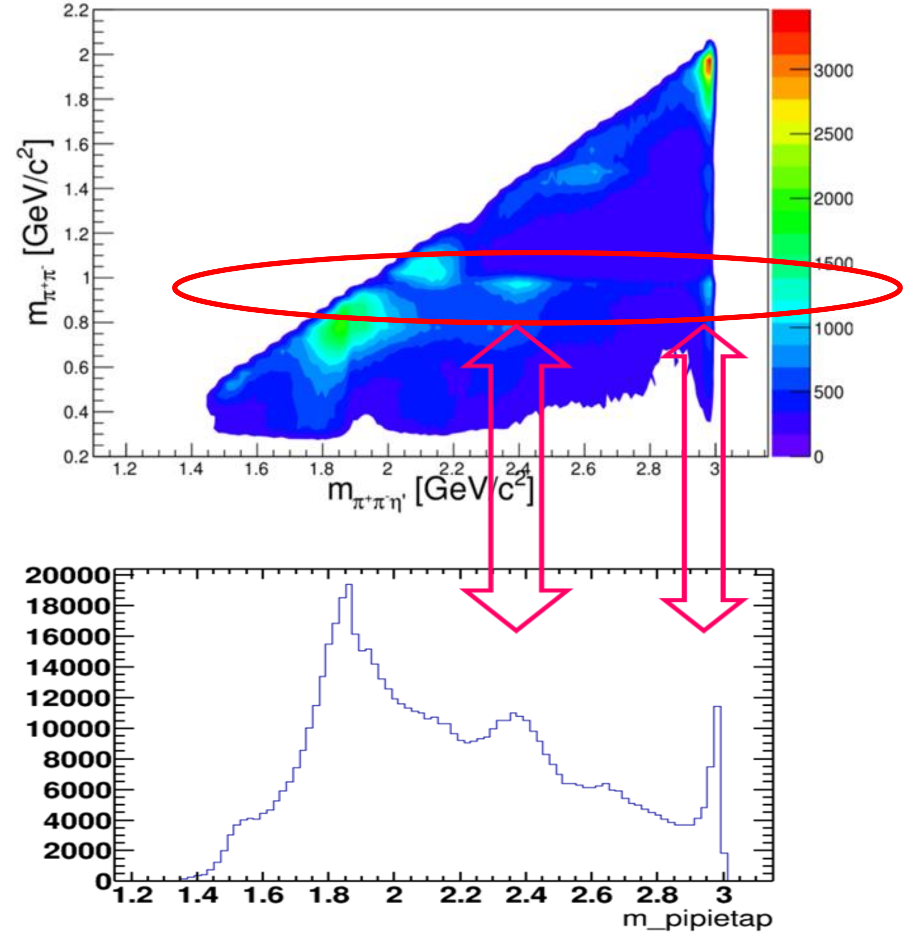
$a_0(980)$ sideband region
$0.2 < |m_{\pi^0\eta} - 0.98| < 0.25$ GeV

$M(\pi^0\pi^0\eta) > 2$ GeV

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

- $\pi^+\pi^-\eta'$ is the first mode to discover the $X(2370)$
- In the 2D plot of $M_{\pi\pi}$ vs. $M_{\pi\pi\eta'}$, in the $f_0(980)$ mass band, clear signals of both $X(2370)$ and η_c
- Additional important information:
  - $X(2370) \to \pi\pi\eta'$ almost 100% via $f_0(980)\eta'$
  - $\eta_c \to \pi\pi\eta'$ dominantly via $X(1800)\eta'$
  - NO phase space for $X(2370) \to X(1800)\eta'$

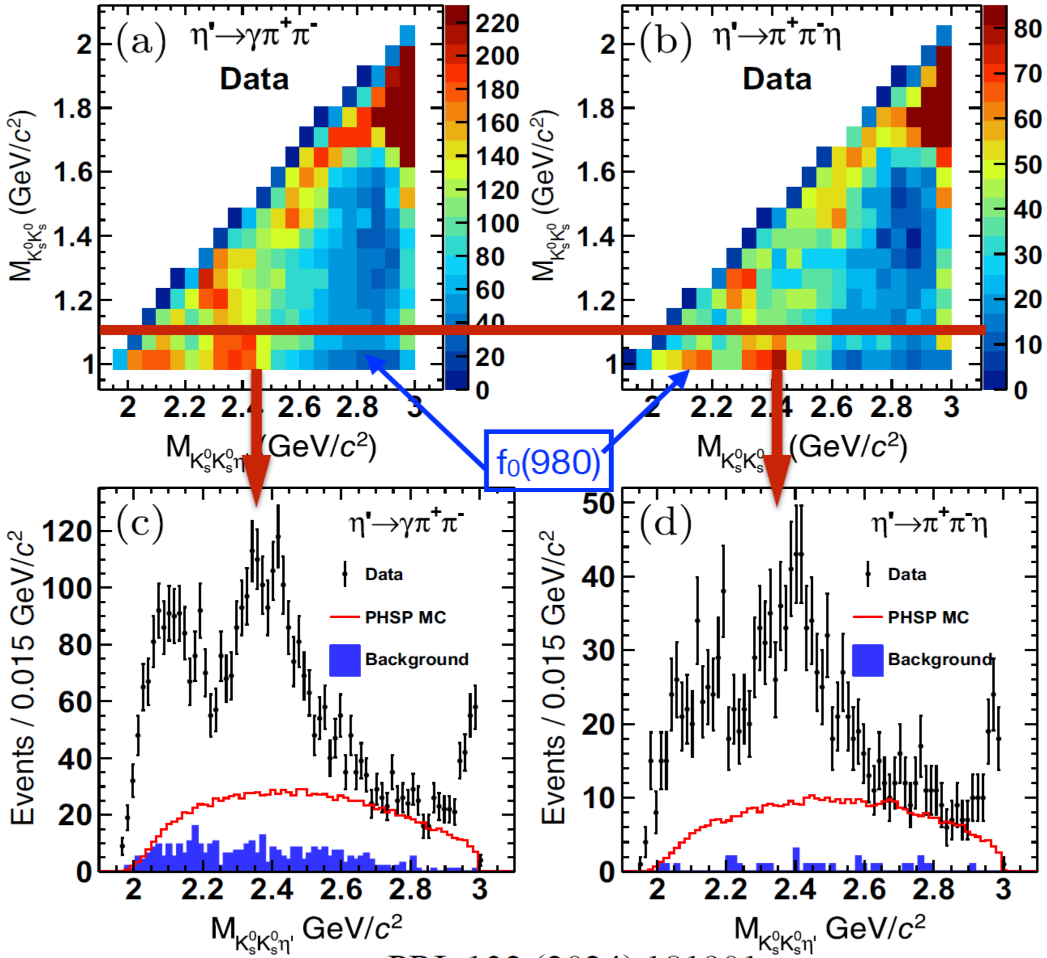
$M_{\pi^+\pi^-}$vs $M_{\pi^+\pi^-\eta'}$



$M_{\pi^+\pi^-}$ < 1.0

$J/\psi \to \gamma K_S^0 K_S^0 \eta'$

- In the $f_0(980)$ mass band of $K_S^0 K_S^0$ mass, clear signals of both $X(2370)$ and η_c
- Additional important information:
  - $X(2370) \to K\bar{K}\eta'$ almost 100% via $f_{0(980)}\eta'$
  - $\eta_c \to KK\eta'$ dominantly via $X(1800)\eta'$
  - NO phase space for $X(2370) \to X(1800)\eta'$



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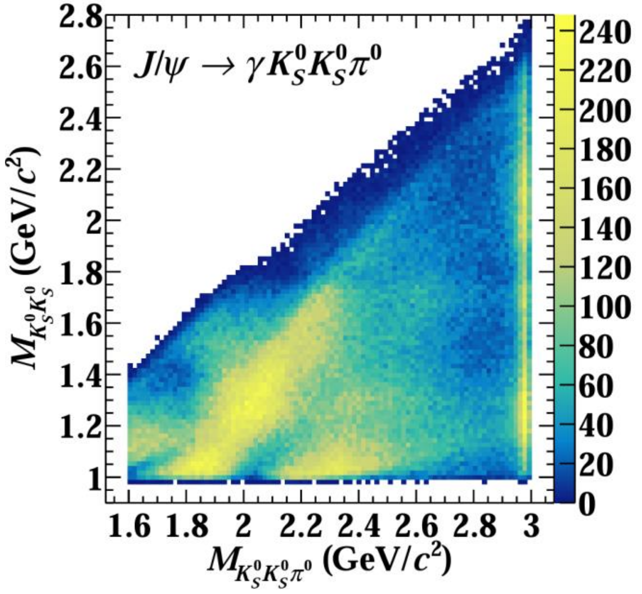
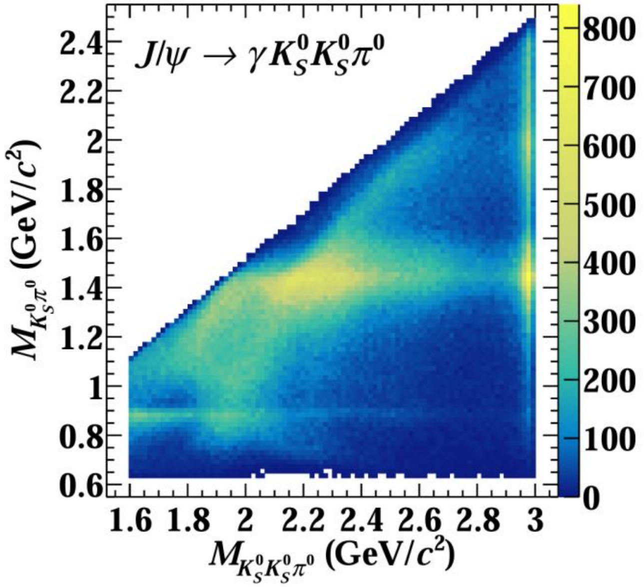
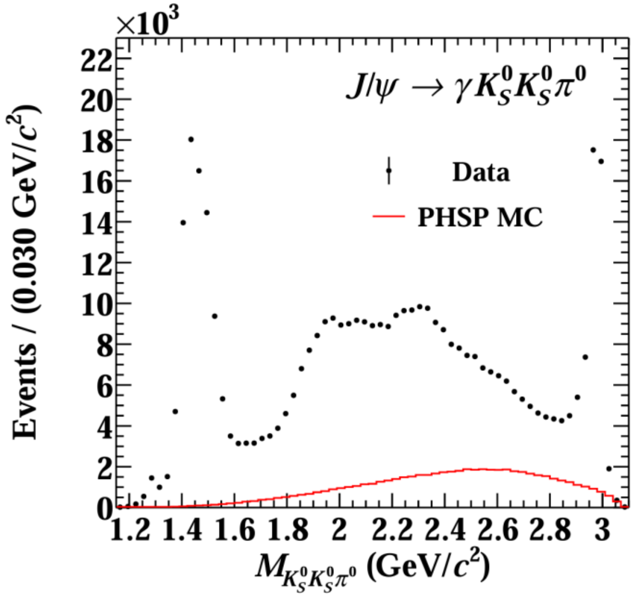
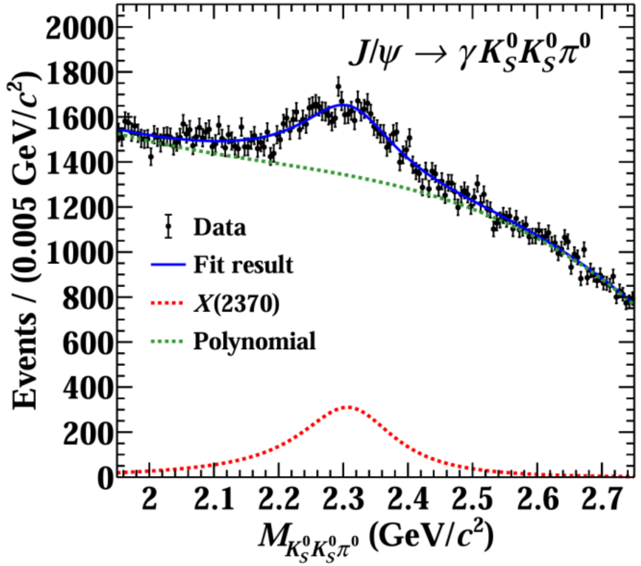
$J/\psi \to \gamma K_S^0 K_S^0 \pi^0$









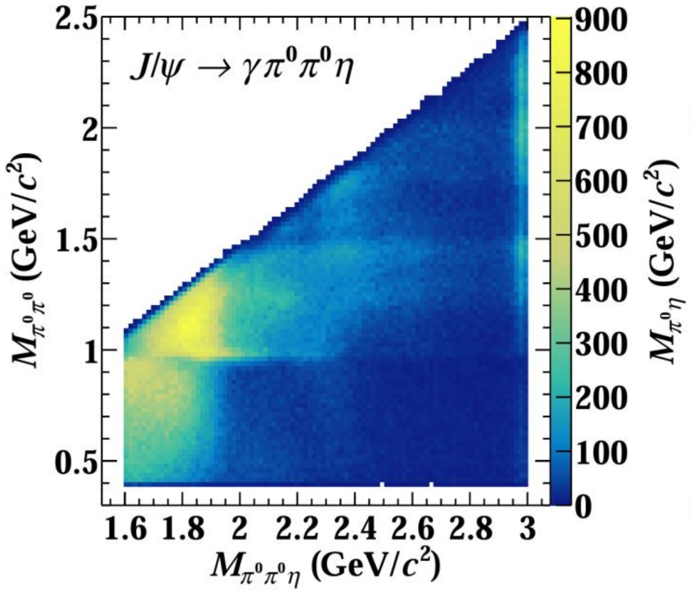
Final result:

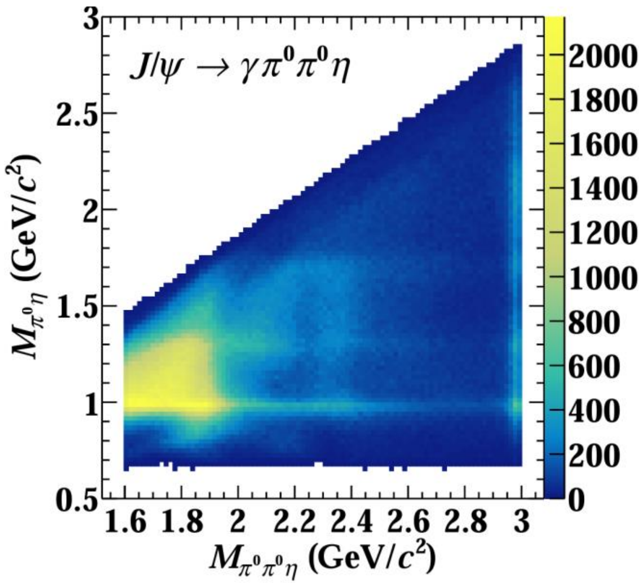
$M_{X(2370)} = 2311 \pm 4(\text{stat}) \pm 25(\text{syst})$ MeV/c^2

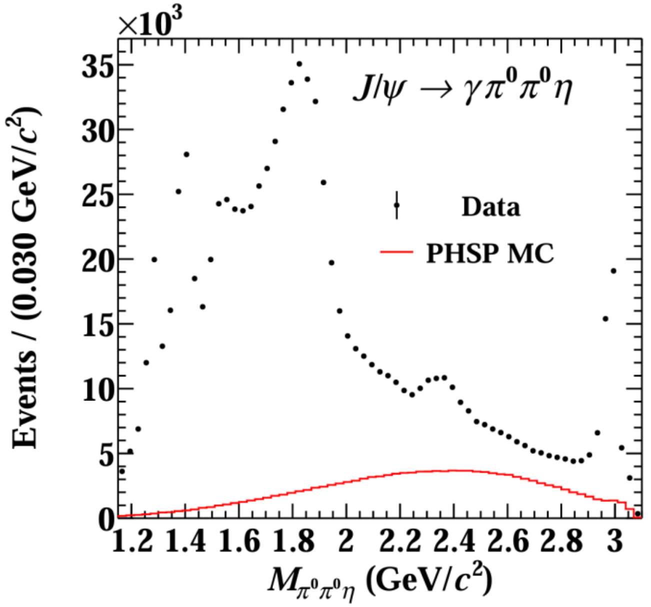
$\Gamma_{X(2370)} = 177 \pm 20(\text{stat}) \pm 72(\text{syst})$ MeV

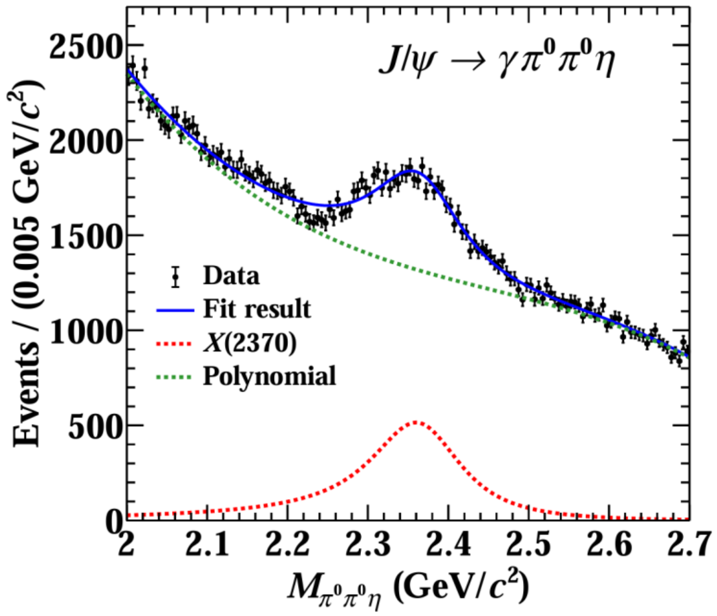
Significance of the $X(2370) > 14\sigma$

$J/\psi \to \gamma\pi^0\pi^0\eta$









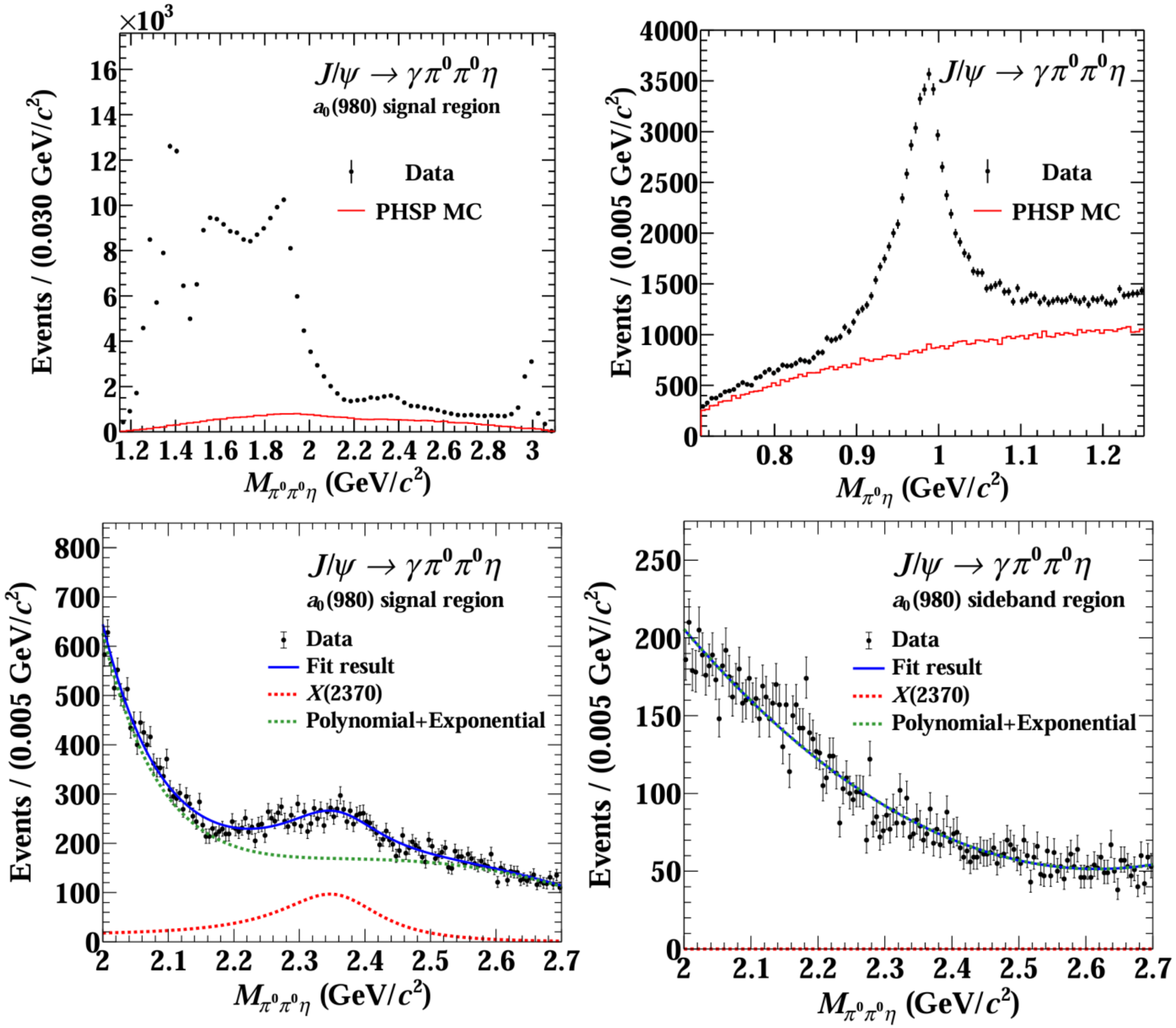
Final result:

$M_{X(2370)} = 2366 \pm 2(\text{stat}) \pm 10(\text{syst})$ MeV/c^2

$\Gamma_{X(2370)} = 127 \pm 9(\text{stat}) \pm 61(\text{syst})$ MeV

Significance of the $X(2370) > 20\sigma$

$J/\psi \to \gamma a_0^0 \pi^0 \to \gamma \pi^0 \pi^0 \eta$



Final result:

$M_{X(2370)} = 2358 \pm 5(\text{stat}) \pm 9(\text{syst})\ \text{MeV}/c^2$

$\Gamma_{X(2370)} = 180 \pm 20(\text{stat}) \pm 58(\text{syst})\ \text{MeV}$

Significance of the $X(2370) > 9\sigma$

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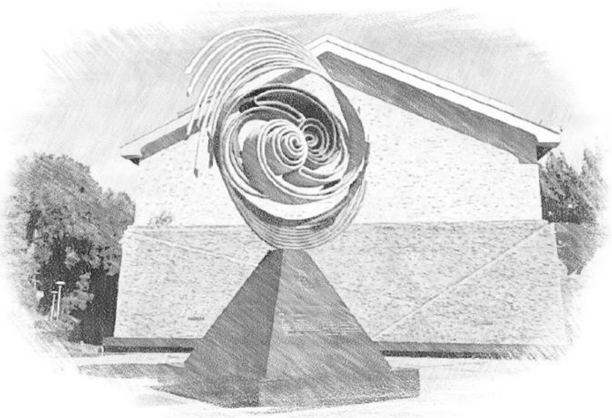
Institute of High Energy Physics
Chinese Academy of Sciences



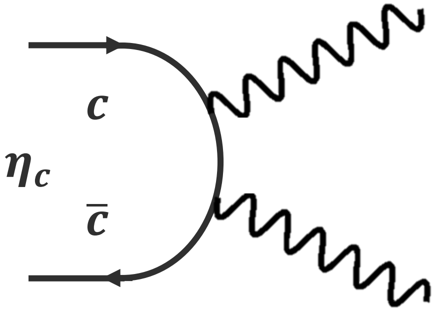
中国高等科学技术中心
China Center of Advanced Science and Technology

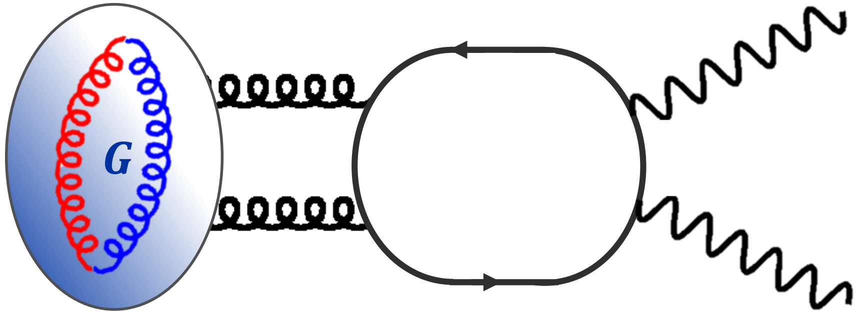
BESIII

Search for the $X(2370)$ in $\gamma\gamma \to \pi^+\pi^-\eta'$ using Belle data

Feynman diagram of the two-photon process

- The η_c and glueball decay to two photons





Compared with η_c suppressed: α_s^2 ~0.1

$$\frac{\Gamma_{X(2370)\to\gamma\gamma}}{\Gamma_{\eta_c\to\gamma\gamma}} \sim 0.1$$

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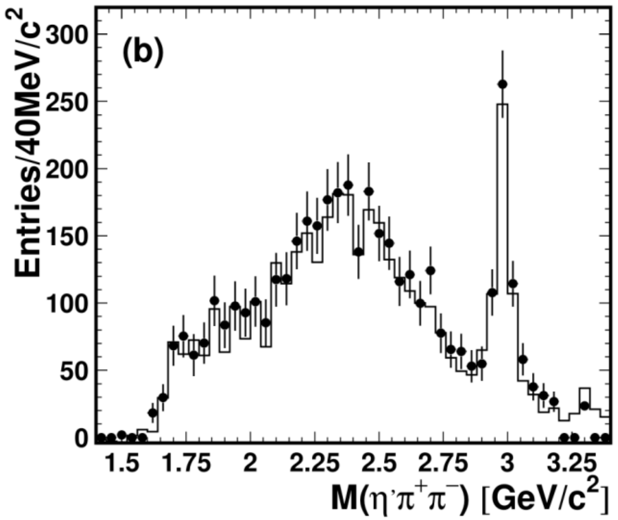
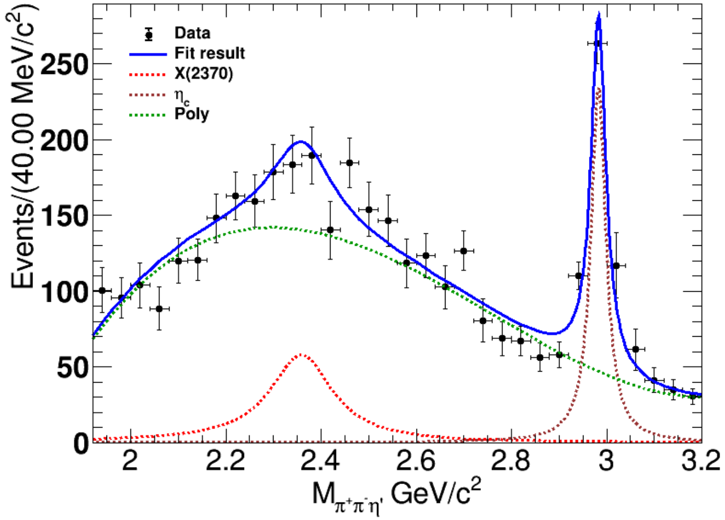
Chinese Academy of Sciences
BESIII

Search for $\gamma\gamma \to X(2370)$ with $\pi^+\pi^-\eta'$ final state

- Perform a χ^2 fit to the $\pi^+\pi^-\eta'$ mass spectrum extracted from PRD 86, 052002 (2012)
  - No PWA yet. Conservatively assuming that all events in the plot are from 0-+, fix the X (2370) peak and width to BESIII value
  - Significance of the $X(2370)$ ~3σ



PRD 86, 052002 (2012)
(Belle Data)



N_{η_c} = 330 ± 21
$N_{X(2370)}$ = 324 ± 101
$N_{X(2370)}/N_{\eta_c}$ = 0.98 ± 0.33

$Event\ rate\ and\ \Gamma_{X(2370)\to\gamma\gamma}/\Gamma_{\eta_c\to\gamma\gamma}$

- For two photon process

$$\frac{N_{X(2370)}}{N_{\eta_c}} = \frac{\Gamma_{X(2370)\to\gamma\gamma} B[X(2370)\to\pi^+\pi^-\eta']}{\Gamma_{\eta_c\to\gamma\gamma} B[\eta_c\to\pi^+\pi^-\eta']}$$

- Since η_c has much larger phase space than X(2370) so as to have many more decay modes than X(2370), so naively, we may have $B[X(2370) \to \pi^+\pi^-\eta']/B[\eta_c \to \pi^+\pi^-\eta']$ ~5-10

- So, $\dfrac{\Gamma_{X(2370)\to\gamma\gamma}}{\Gamma_{\eta_c\to\gamma\gamma}} = (1/5\text{-}1/10) * \dfrac{N_{X(2370)}}{N_{\eta_c}} = (0.1\text{-}0.2)*(0.98+/-0.33) \sim 0.1\text{-}0.2$, as expected from α_s^2 ~0. 1

- Without considering sys. errors, $\Gamma_{X(2370)\to\gamma\gamma}$ rate is not inconsistent with glueball within 2 σ