Discovery of a Glueball-like Particle X(2370) @ BESIII

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(On behalf of the BESIII Collaboration)

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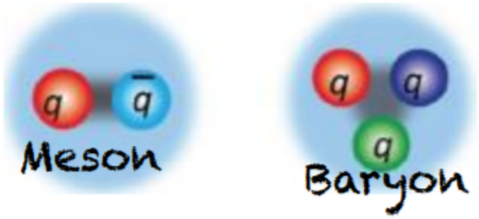
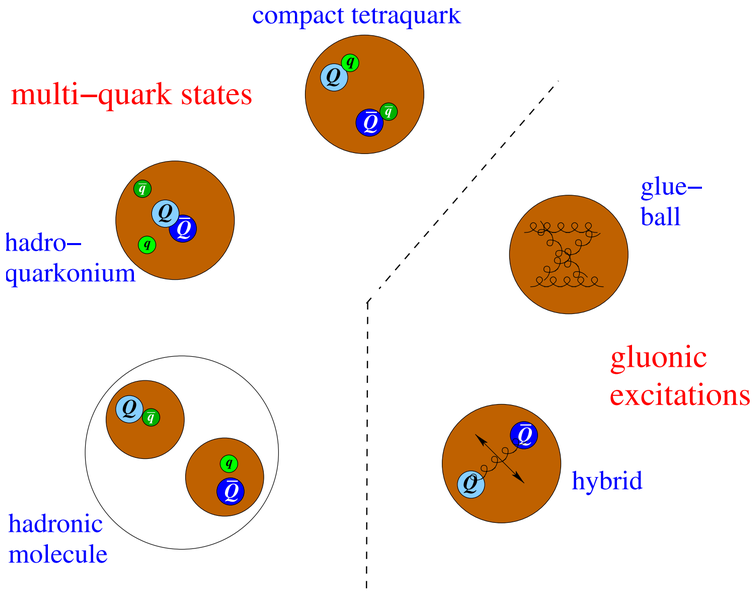
高能物理大会2026

Glueball in QCD

Quark model

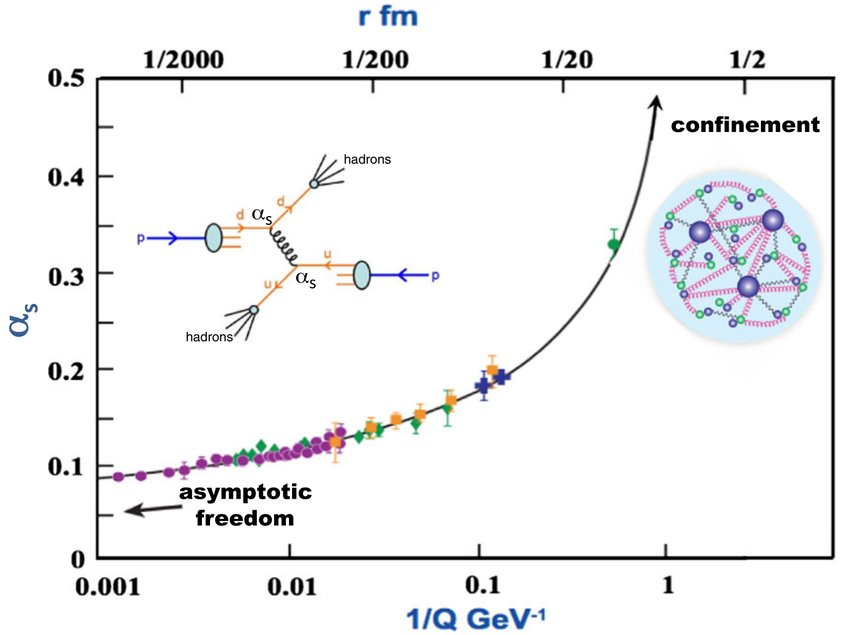


New forms of hadrons



Rev Mod. Phys. 90, 015003

QCD predictions



- ✦ **High Energy:**
  - α_s running, widely confirmed experimentally (Nobel Prize 2004)
- ✦ **Low Energy:**
  - Self-interaction of gluons → **Glueballs**

Glueballs

◈ **Special Importance of Glueballs**： **Glueballs to QCD is just as important as Higgs Boson to EW**

- ✦ **Unique particle made of pure force (bosons)**
- ✦ **Direct proof of self-interactions of gluons — Direct proof of non-Abel gauge interactions of QCD**
- ✦ **Direct proof of origin of mass from strong interactions**

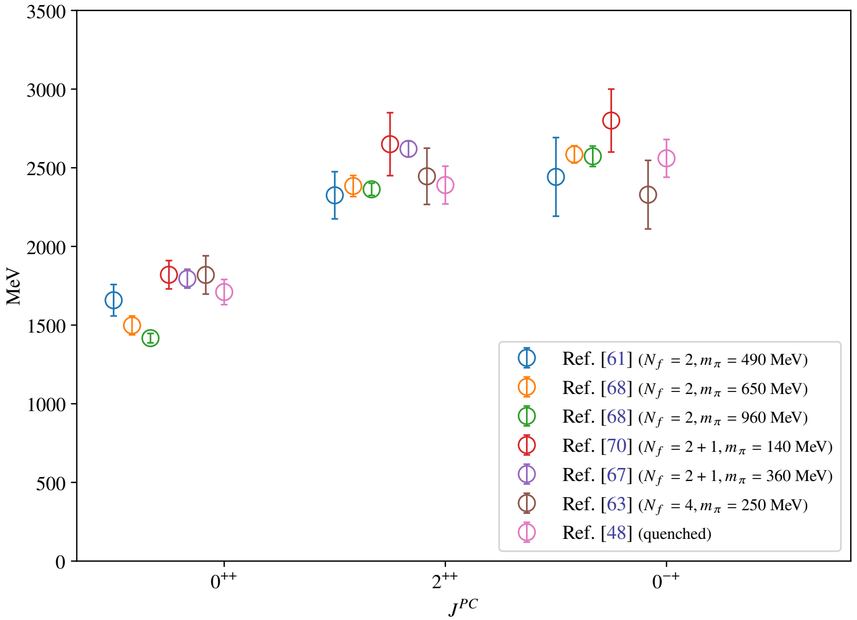
◈ **Lattice QCD** (LQCD) is a non-perturbative method from the first principles in theory.

◈ **Different lattice QCD groups** (including lattice simulations with dynamical quarks)

- ✦ Predictions on **masses and production rates** of pure glueballs
- ✦ Consistent results and expected to be reliable.

◈ **Lattice QCD predictions on pure glueball masses:**

- ✦ **0^{++} ground state:** 1.5 - 1.7 GeV/c^2
- ✦ **2^{++} ground state:** 2.3 - 2.4GeV/c^2
- ✦ **0^{-+} ground state:** 2.3 - 2.6GeV/c^2



arxiv:2305.04869

Historical Glueball Candidates

Scalar $f_0(1710)$

- High production rate in $J/\psi \to \gamma\pi\pi/KK$, but flavor asymmetric(mixing scheme)
- Decay suppression in $f_0(1710)$→ ηη'

➡ A scalar glueball/large glueball content with some controversies

Tensor ξ(2230)

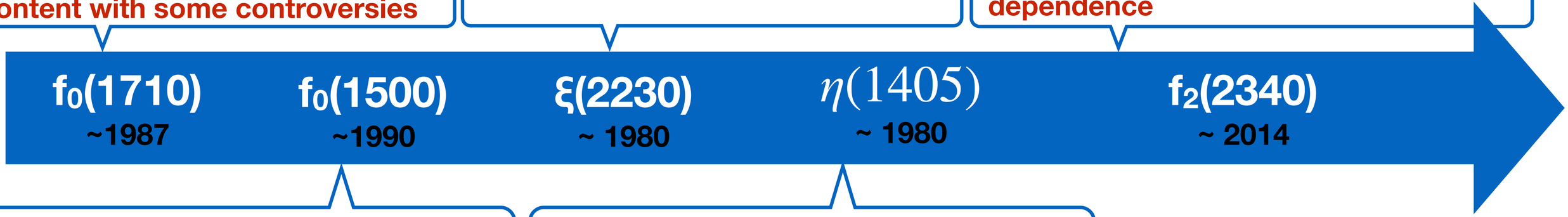
- Observed in J/ψ → γKK, γππ, $\gamma p\bar{p}$
- Not confirmed with higher statistics data

➡ Fluctuation effect

Tensor $f_2(2340)$

- High production rate in J/ψ→γ(KK/ηη/η'η'/φφ) but lower than LQCD prediction
- Large overlap among different wide tensor structure

➡ Hard to interpret for the strong model dependence



Scalar $f_0(1500)$

- High production rate in $J/\psi \to \gamma\pi\pi/KK$ but lower than $f_0(1710)$
- No suppression in $f_0(1500)$→ ηη'

➡ Can not be a scalar glueball

Pseudo-scalar $\eta(1405)$

- Rich production in J/ψ radiative decay
- But far way from mass prediction from LQCD

➡ Can not be a scalar glueball

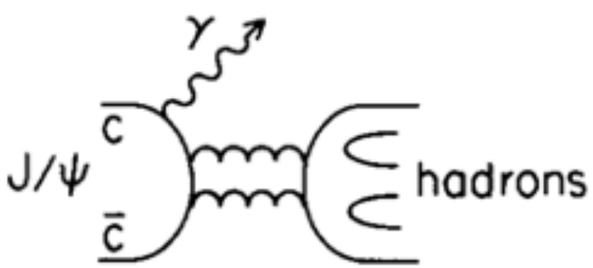
X(2370)

➡ Glueball-like particle

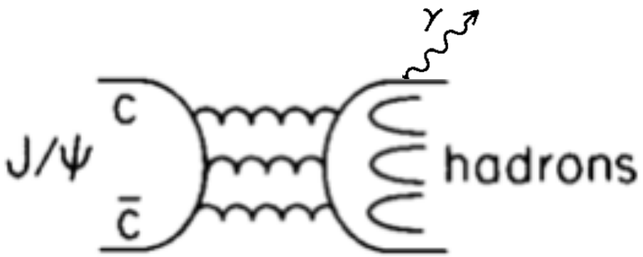
【IJMPA Vol: 40 Iss: 19, 2530007 (2025)】

Glueball production in J/ψ Radiative decay

◈ **Gluon rich environment**



$\sim \alpha\alpha_s^4$



$\sim \alpha\alpha_s^6$

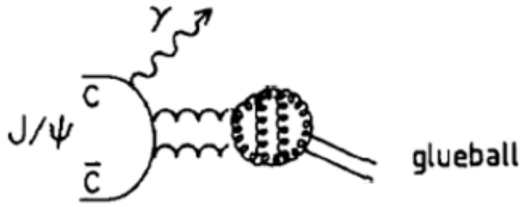
◈ **Isospin filter:** final states dominated by **I=0** processes

◈ **Spin-parity filter:** **C parity must be +**, so $J^{pc}=0^{-+}, 0^{++}, 1^{++}, 2^{++}, 2^{-+}$ …

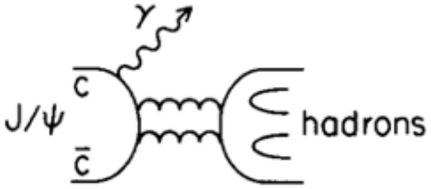
◈ **Clean environment in e^+e^- collision:** very different from **p-p collision**

◈ **Rich glueball production in J/ψ radiative decays:**

✦ **Glueball production rate** in J/ψ radiative decays could be **higher** than normal hadrons



$\sim \alpha\alpha_s^2$

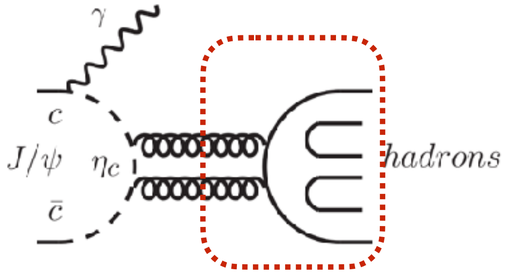


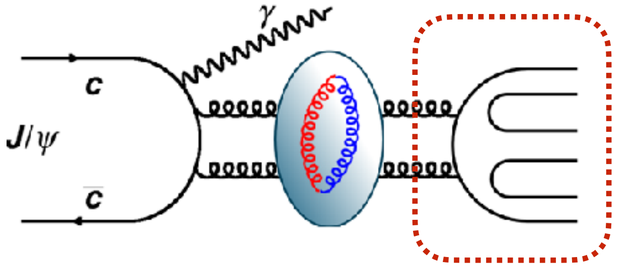
$\sim \alpha\alpha_s^4$

➡ **J/ψ Radiative decay is an ideal place to search for glueballs**

Glueball Decays

- **Flavor symmetric decays**
- **No rigorous predictions on decay patterns and their branching ratios**
- The glueball decays could be the analogy to **Charmonium decays** since they all decay via gluons (OZI suppression) [PLB 380 189(1996), Commu. Theor. Phys. 23.373 (1995)]
  - e.g. the 0^{-+} glueball could have similar decays of η_c





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

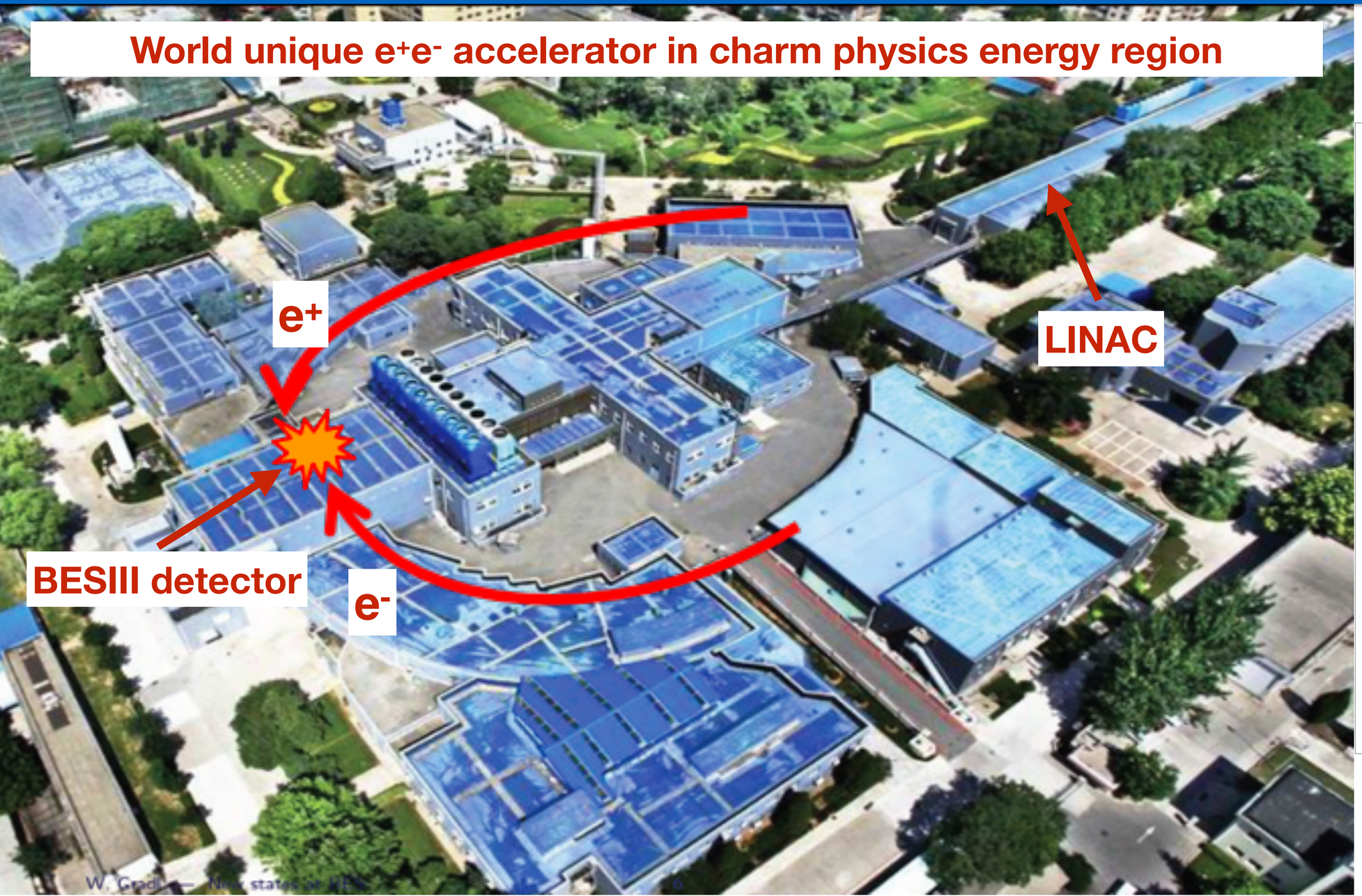
Decays involving hadronic resonances

Γ_1	$\eta'(958)\pi\pi$	(1.87±0.26) %
Γ_2	$\eta'(958)K\overline{K}$	(1.61±0.25) %

Decays into stable hadrons

Γ_{34}	$K\overline{K}\pi$	(7.0 ±0.4) %
Γ_{35}	$K\overline{K}\eta$	(1.32±0.15) %
Γ_{36}	$\eta\pi^+\pi^-$	(1.7 ±0.5) %

Beijing Electron Positron Collider (BEPCII)



2004: Construction

- Double rings
- Beam energy:

  1.0 - 2.3 (2.45)GeV
- Designed luminosity:

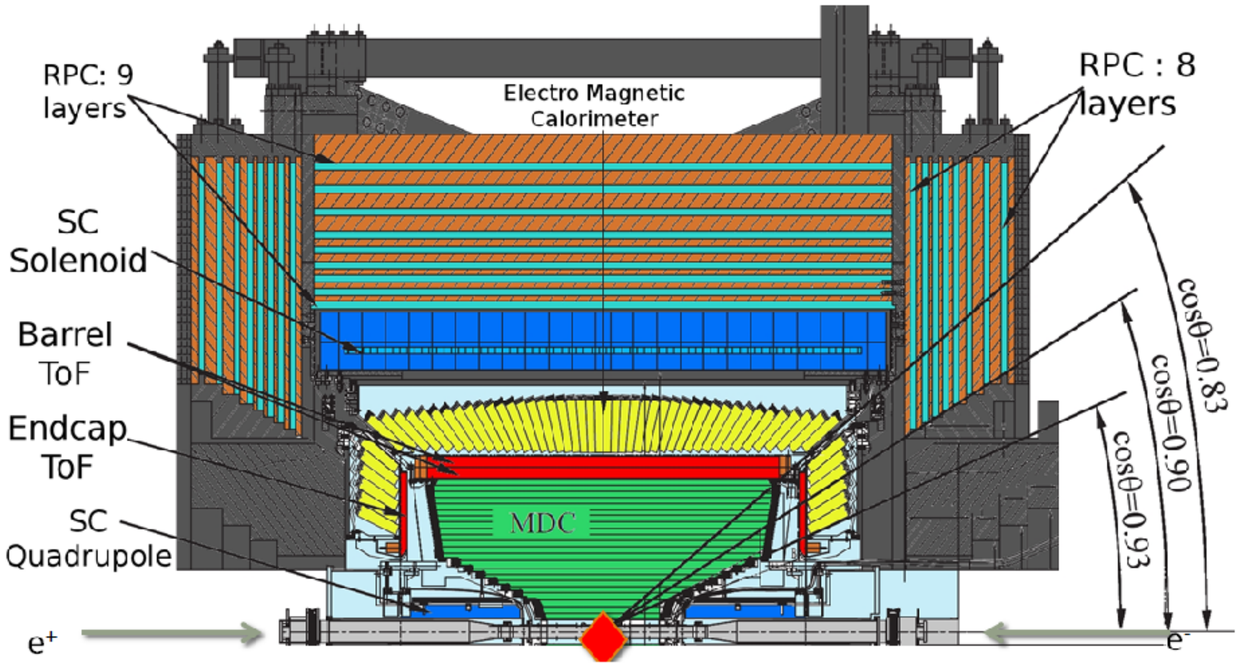
  1×10^{33} cm^{-2} s^{-1}

2008：test run

2009-now: BESIII physics runs

BESIII detector

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



Total weight 730 ton,
~40,000 readout channel
Data rate: 5kHz, 50Mb/s

- Magnet: 1T Superconducting
- 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
  - ΔE/E = 2.5% @ 1GeV - Barrel
  - ΔE/E = 5% @ 1GeV - Endcap
- Muon ID: 9 layer RPC

Has been in full operation since 2008, all sub-detectors are in a very good status!

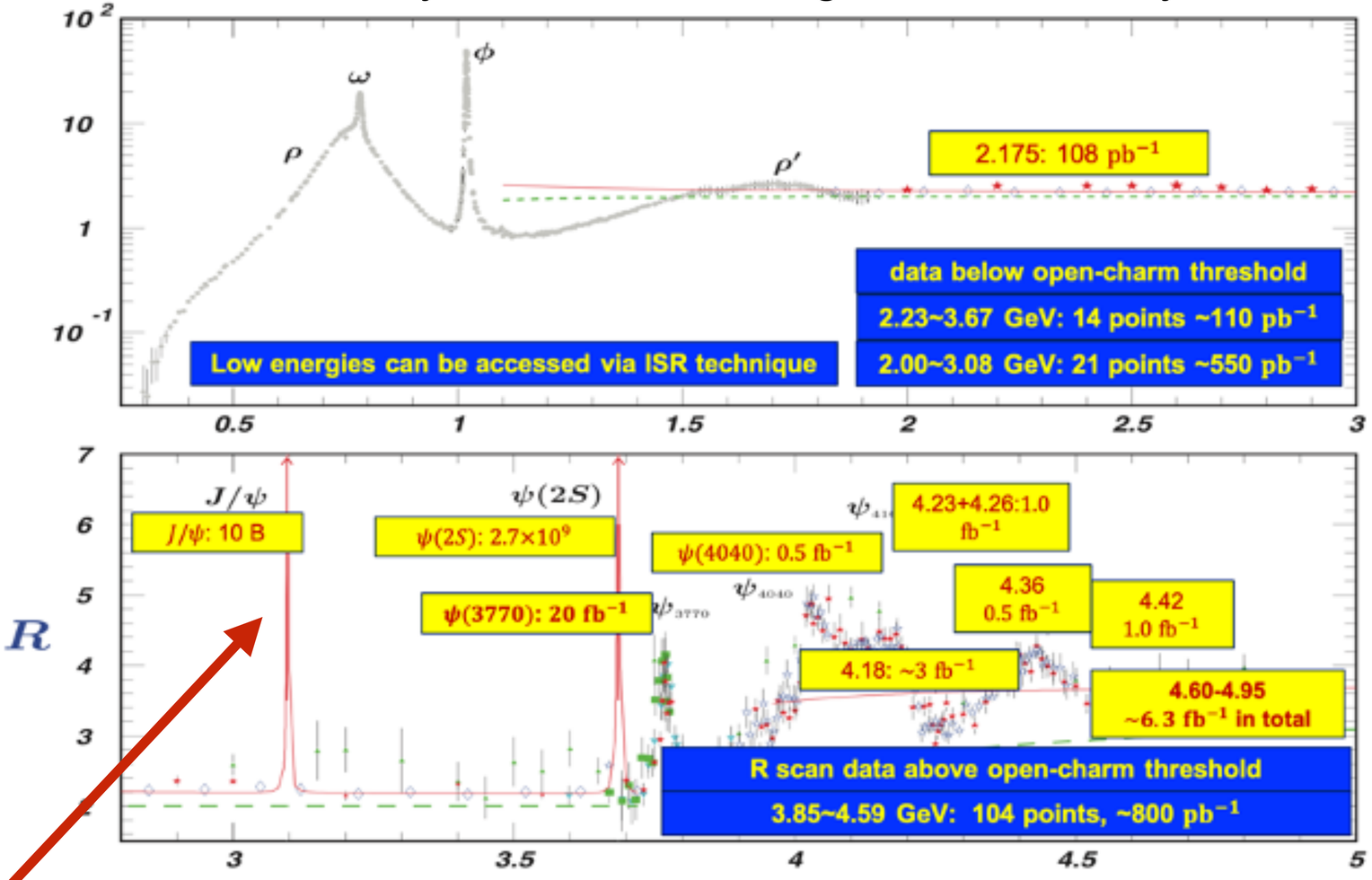
BESIII Data samples

Totally about 50fb^{-1} integrated luminosity

Data sets collected so far include

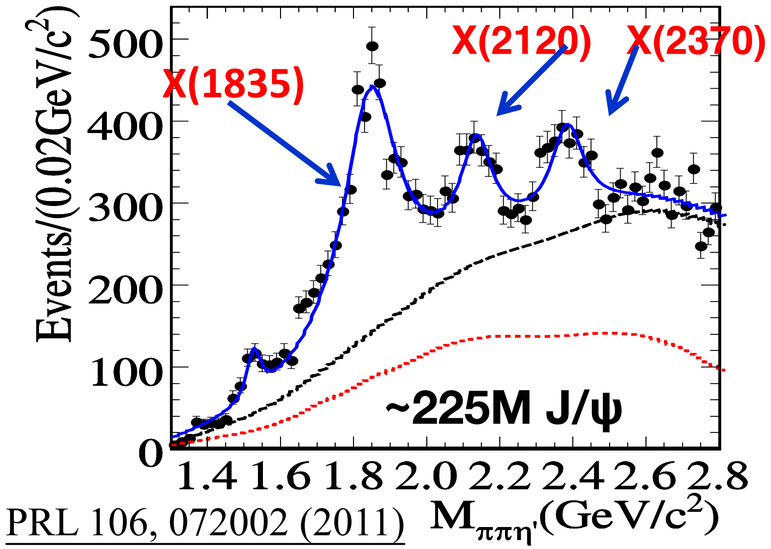
- 10×10^9 J/ψ events
- 2.7×10^9 ψ(2S) events
- 20 fb^{-1} ψ(3770)
- Scan data between 1.8 and 3.08 GeV, and above 3.74GeV
- Large datasets for XYZ studies:

  Scan with >500pb-1 per energy point space 10-20MeV apart

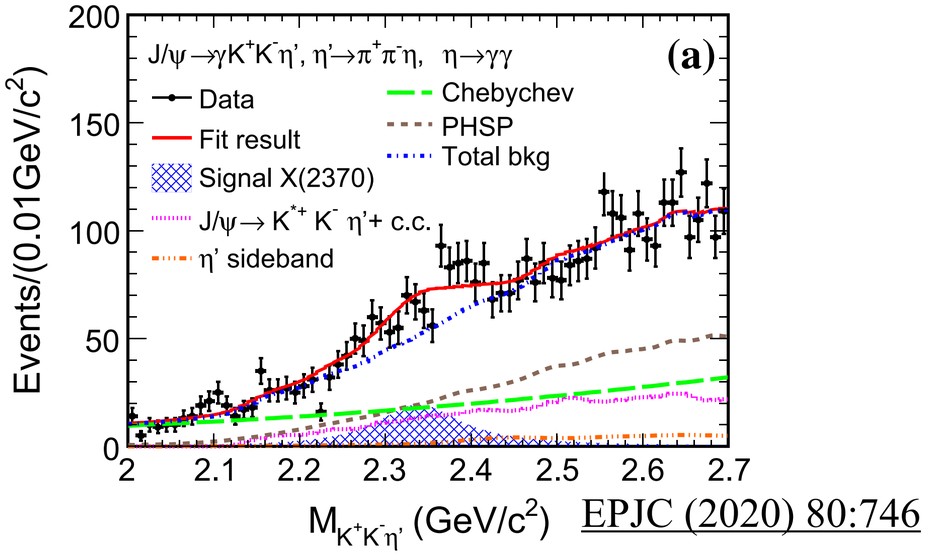


World largest J/ψ data sample : ~10 billion

X(2370)



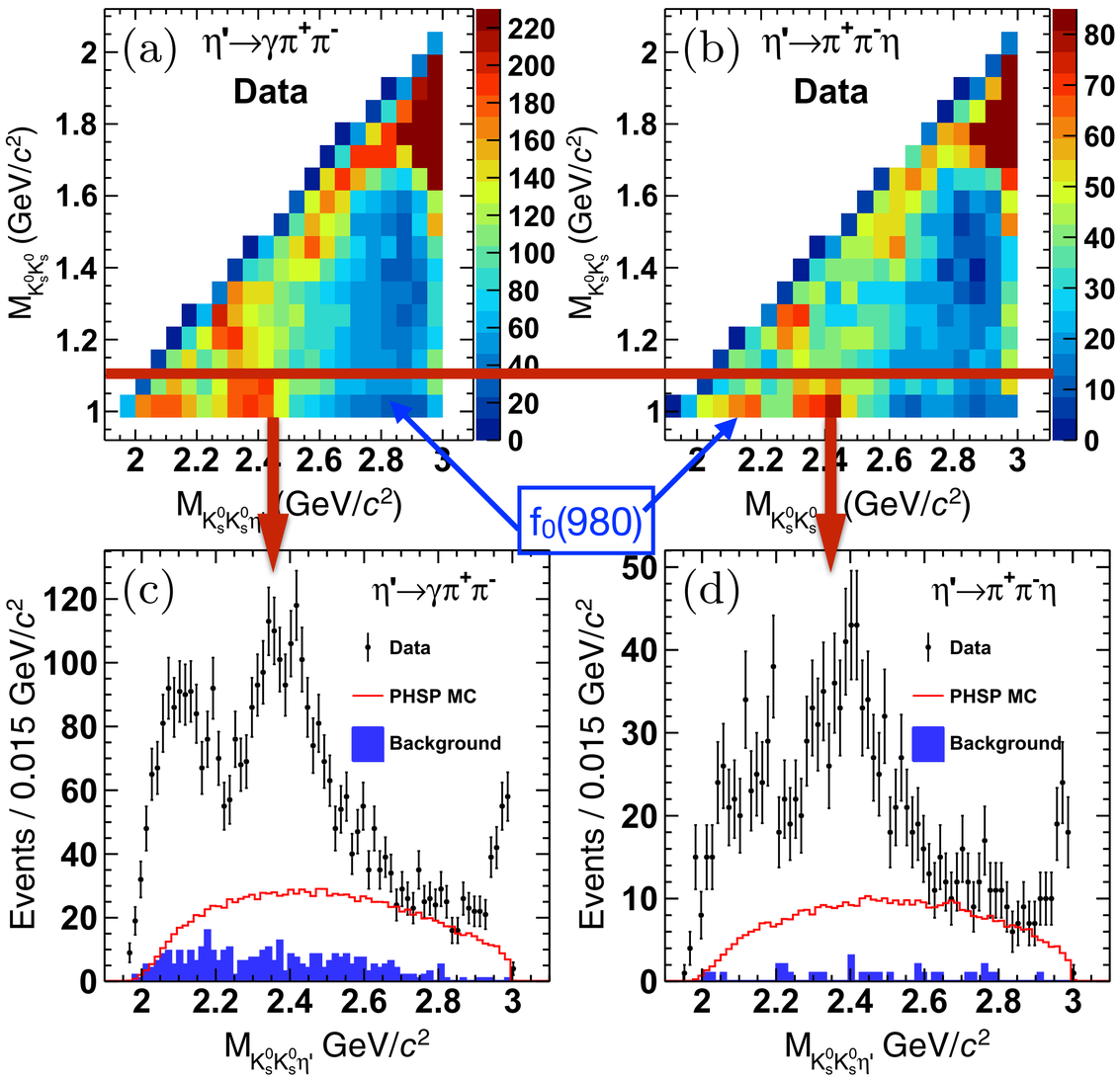
PRL 106, 072002 (2011)



EPJC (2020) 80:746

- Discovered (6.4σ) by BESIII in $J/\psi \to \gamma\pi^+\pi^-\eta'$ in 2011
  - Produced in the gluon-rich J/ψ radiative decays
  - Its mass is consistent with LQCD prediction on the 0^{-+} glueball
- Observed in flavor symmetric decay modes of $\pi^+\pi^-\eta'$ and $K\bar{K}\eta'$ — favorite decay modes of 0^{-+} glueball
- Determination of its spin-parity is crucial

Spin-Parity determination of the X(2370) in $J/\psi\to\gamma K^0_S K^0_S \eta'$



PRL 132 (2024) 181901

- Analysis advantage of $J/\psi\to\gamma K^0_S K^0_S \eta'$:
  - Almost background free channel (exchange symmetry and C-parity conservation)
  - 10billion J/ψ data
  - Very good BESIII detector performance
- Similar structures in $\eta'\to\pi^+\pi^-\eta$ / $\gamma\pi^+\pi^-$ modes:
  - Evident $f_0(980)$ in $K^0_S K^0_S$ mass threshold
  - Clear signal of X(1835),X(2370),η_c with $f_0(980)$ selection
- Best PWA fit can well describe the data:
  - **Spin-parity of the X(2370) is determined to be 0^{-+}** with significance larger than **9.8σ w.r.t. other J^{PC} assumptions**

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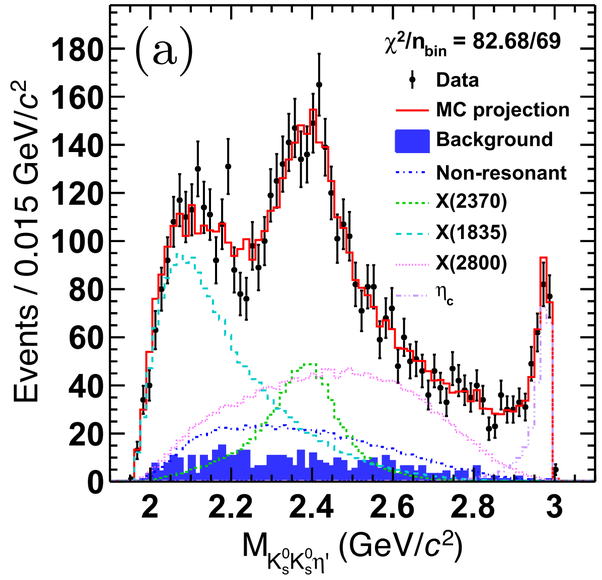

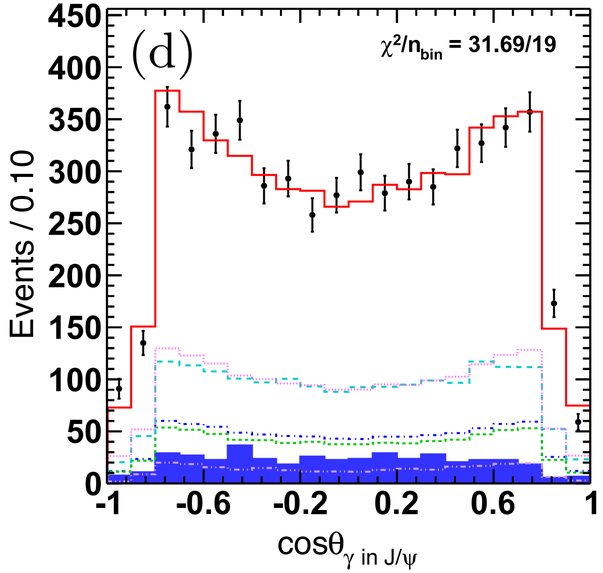

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Compared with LQCD prediction on Lightest 0^{-+} Glueball

X(2370) measurements: PRL 132 (2024) 181901

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

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

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

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

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 good 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 good 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, $B(J/\psi\to\gamma X(2370)) = (10.7^{+22.8}_{-7})\times 10^{-4}$)

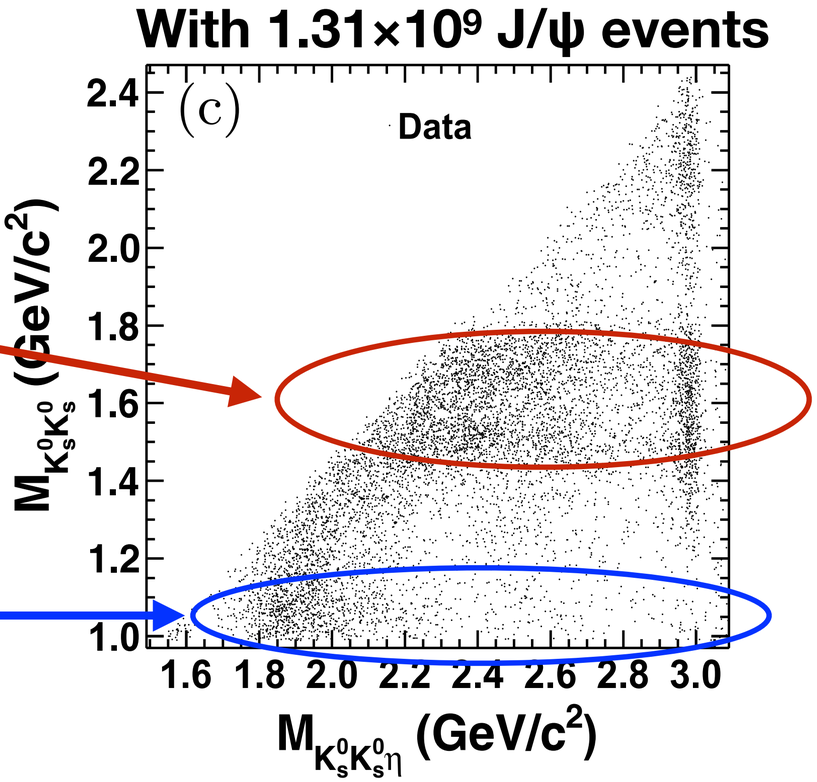
X(2370) in $J/\psi \to \gamma K^0_s K^0_s \eta$

Observation and Spin-Parity Determination of the $X(1835)$ in $J/\psi \to \gamma K^0_S K^0_S \eta$

Qualitatively, we can clearly observe: similar decay patterns of the X(2370) and η_c if phase space allows

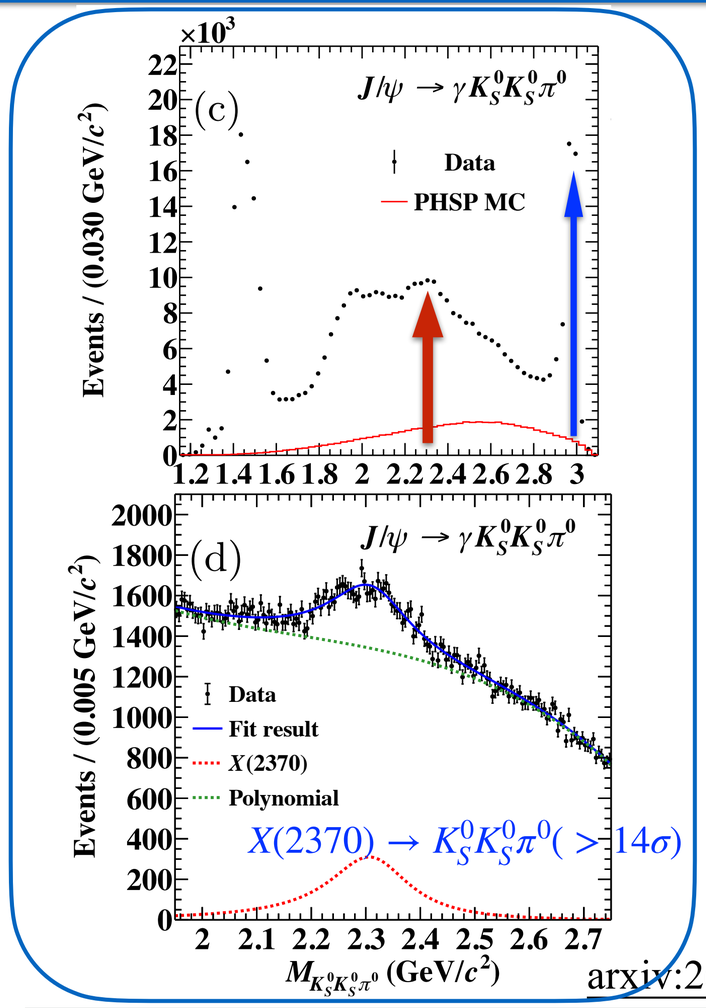
In the upper KK mass band of 1.5-1.7GeV range, clear signals of both X(2370) and η_c

In the lower KK mass band of $f_0(980)$, no X(2370), nor η_c

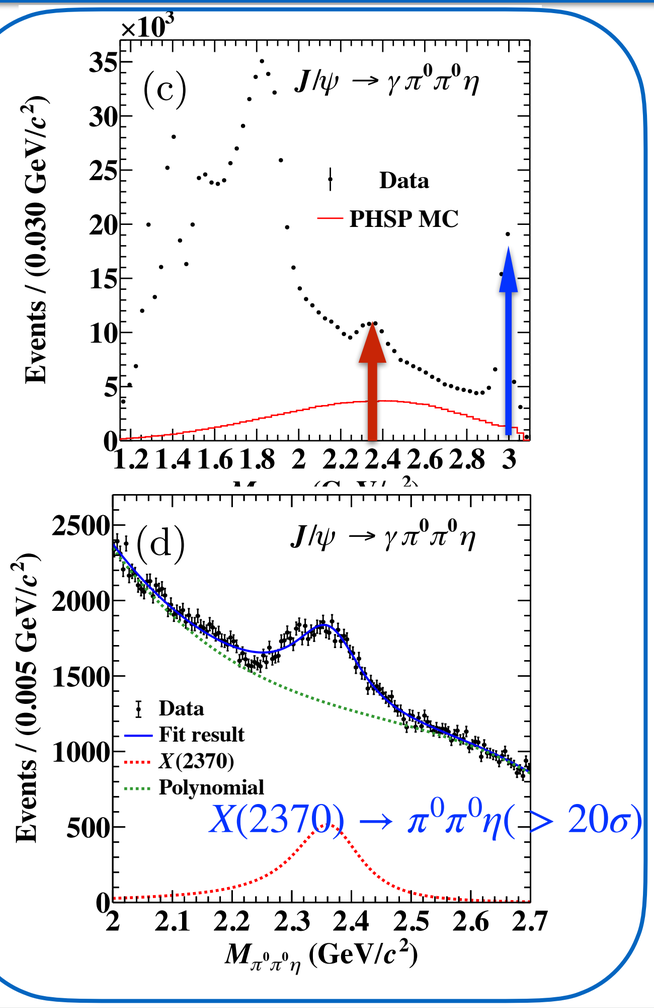


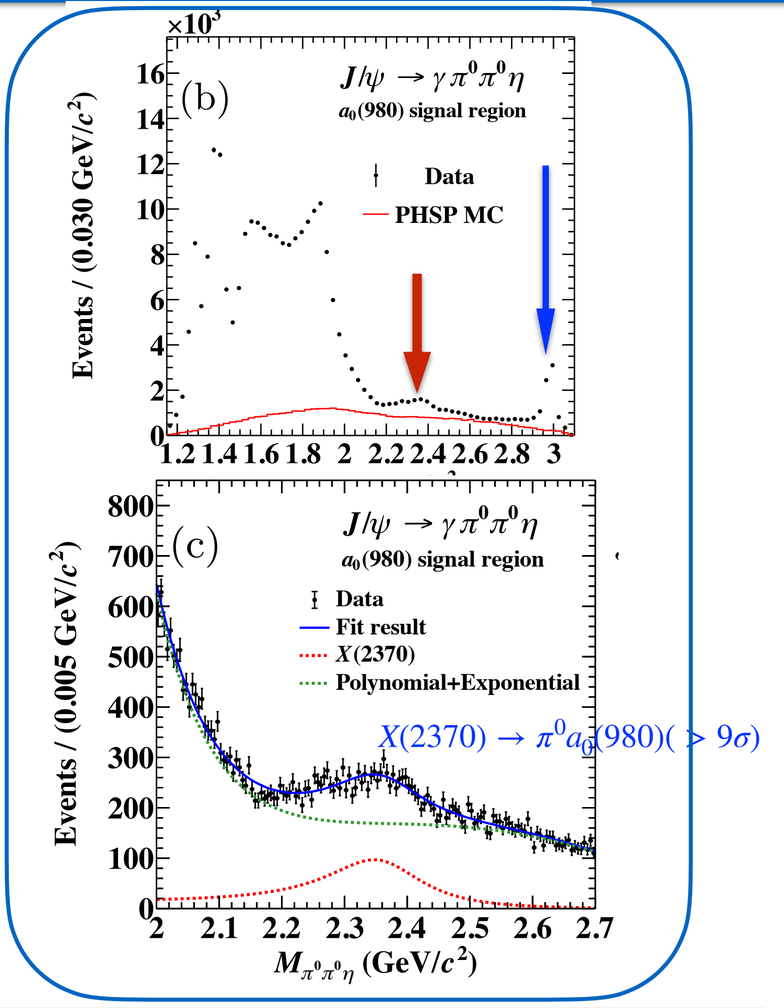
PRL 115 (2015) 091803

Observation of the X(2370) in $K_S^0K_S^0\pi^0$ and $\pi^0\pi^0\eta$



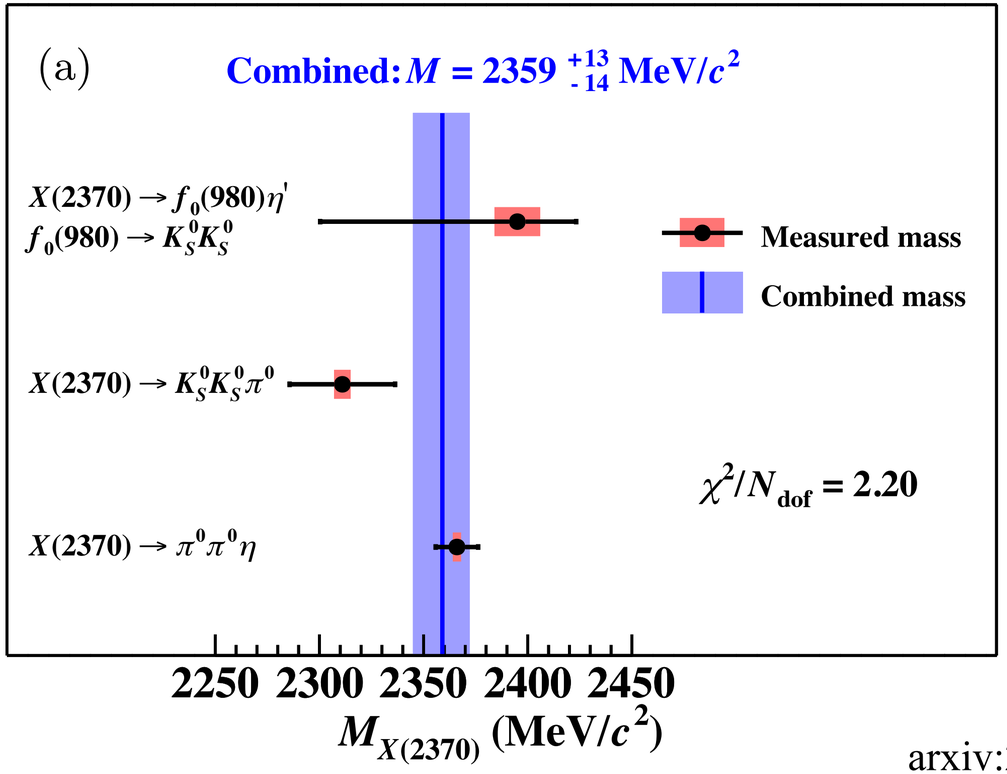
arxiv:2605.26495

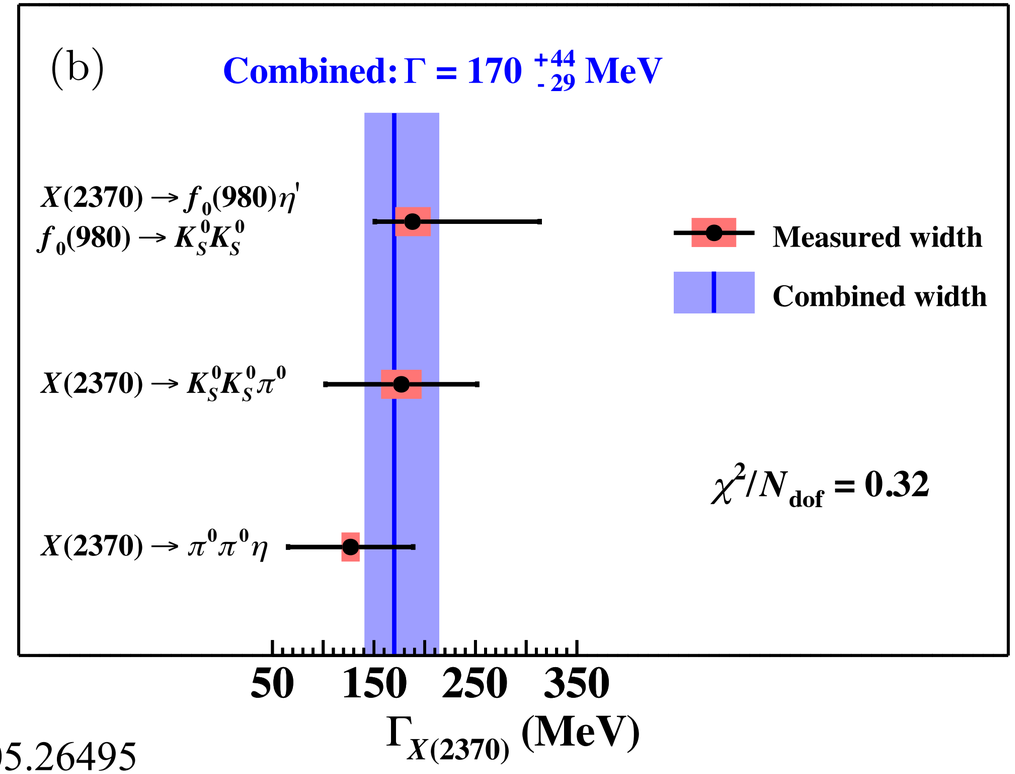




- **Decay modes of X(2370)$\to \pi\pi\eta', K\bar{K}\eta', K\bar{K}\pi, \pi\pi\eta$, $K\bar{K}\eta$, $a(980)\pi$ observed**
- **Such high similarity between the X(2370) and η_c decay modes strongly supports the glueball interpretation of the X(2370)**

Observation of the X(2370) in $K_S^0K_S^0\pi^0$ and $\pi^0\pi^0\eta$



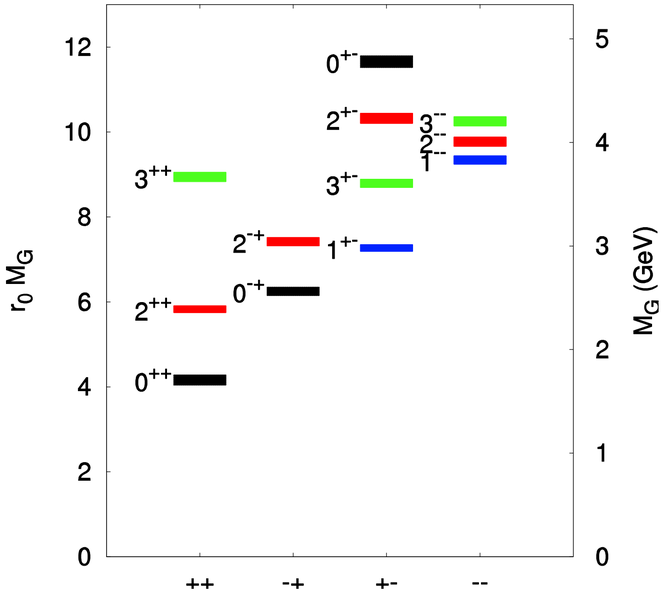


arxiv:2605.26495

More details in Shuo Han's Poster:

"observation of the X(2370) in J/ψ to $\gamma K_S^0K_S^0\pi^0$ and $\gamma\pi^0\pi^0\eta$"

Recap on the X(2370) Measurements



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

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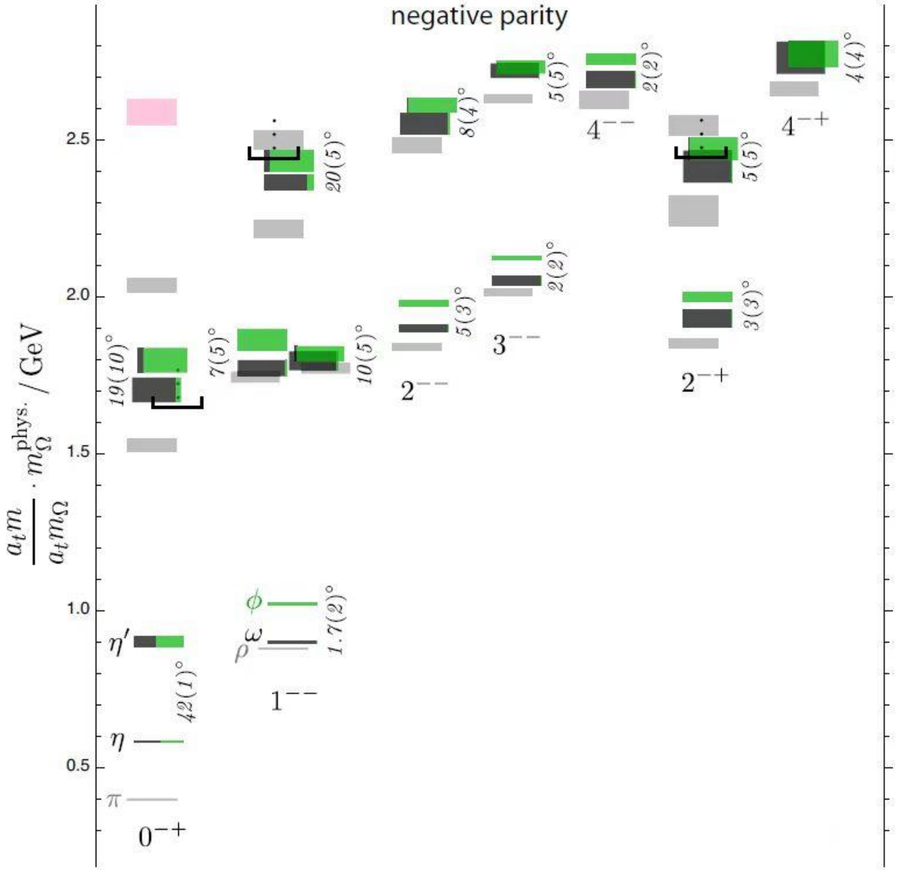
◈ Consistent with the features of a pseudoscalar glueball

- ✦ The spin-parity is determined to be 0^{-+}
- ✦ Its mass is consistent with LQCD prediction on the 0^{-+} glueball
- ✦ High Production in the gluon-rich J/ψ radiative decays
- ✦ Observation in the 5 "Golden" modes: Flavor symmetric decay property

Discussion on X(2370) decay properties

- **Normal $q\bar{q}$ mesons, hybrids and multiquark states can hardly explain all 5 decay modes ($\pi\pi\eta'$, $KK\eta'$, $\pi\pi\eta$, $KK\eta$,$KK\pi$) with different quark flavor combinations.**
  - e.g., LQCD calculation shows that mixing between $u\bar{u} + d\bar{d}$ and $s\bar{s}$ components should be very small for 0^{-+} $q\bar{q}$ meson at ~ 2GeV
- **The high similarities between X(2370) and η_c decay modes strongly suggest it decays via gluons**



PRD 83 (2011) 11502

Narrow Decay Partial Widths of the X(2370)

- **For 5 golden PPP decay modes: similar number of events under the X(2370) peak**
  - **No dominant decay modes, similar to η_c**

- **Naive estimation on the BR of each mode ~5-10%, i.e., partial width of each decay modes is ~10MeV**

- **This would be very hard to be explained if there were quark content ($q\bar{q}$, qqg, multiquark) in X(2370) for OZI allowed decays**

  - Typically OZI allowed decay partial width ~100MeV

  - OZI allowed decays usually have dominant decay modes

- **X(2370) decays should be OZI suppressed decays as η_c, i.e., via gluons!**

Discussion on X(2370) properties — Production

- Richly produced in J/ψ radiative decays — just as glueball expectation

- In the above 2.3GeV mass region as LQCD 0^{-+} glueball prediction, X(2370) is the unique 0^{-+} particle produced in these “5 golden modes” and in J/ψ radiative decays, i.e., no other 0^{-+} particles in this mass region can be called as “richly produced” if they have not shown up in 10 billion such a huge J/ψ data sample.

  - **The production property shows that we only have one qualified candidate X(2370) for 0^{-+} glueball**

  - **We are facing a situation: Either we finally identify X(2370) as 0-+ glueball, or LQCD may face a big challenge in the glueball predictions —— similar to the situation before the Higgs boson discovery**

Summary

- **Glueballs are important predictions from LQCD:**
  - **Unique particles formed** by gluons (force carriers) due to non-Abelian Gauge self-interactions of gluons
- **The X(2370) observed in J/ψ radiative decays is the first particle consistent with 0^{-+} glueball**
  - **Spin-parity quantum numbers** are determined to be $J^{PC} = 0^{-+}$
  - Measurements and predictions on **mass and rich production rate** are consistent within errors
  - **Decay properties:** observation of 5 golden decay modes of $\pi\pi\eta', K\bar{K}\eta', K\bar{K}\pi, \pi\pi\eta, K\bar{K}\eta, a(980)\pi$ (in analogy to η_c)
    - **Glueball-like particle, X(2370) is discovered by BESIII**

More comprehensive measurement on X(2370) is coming soon