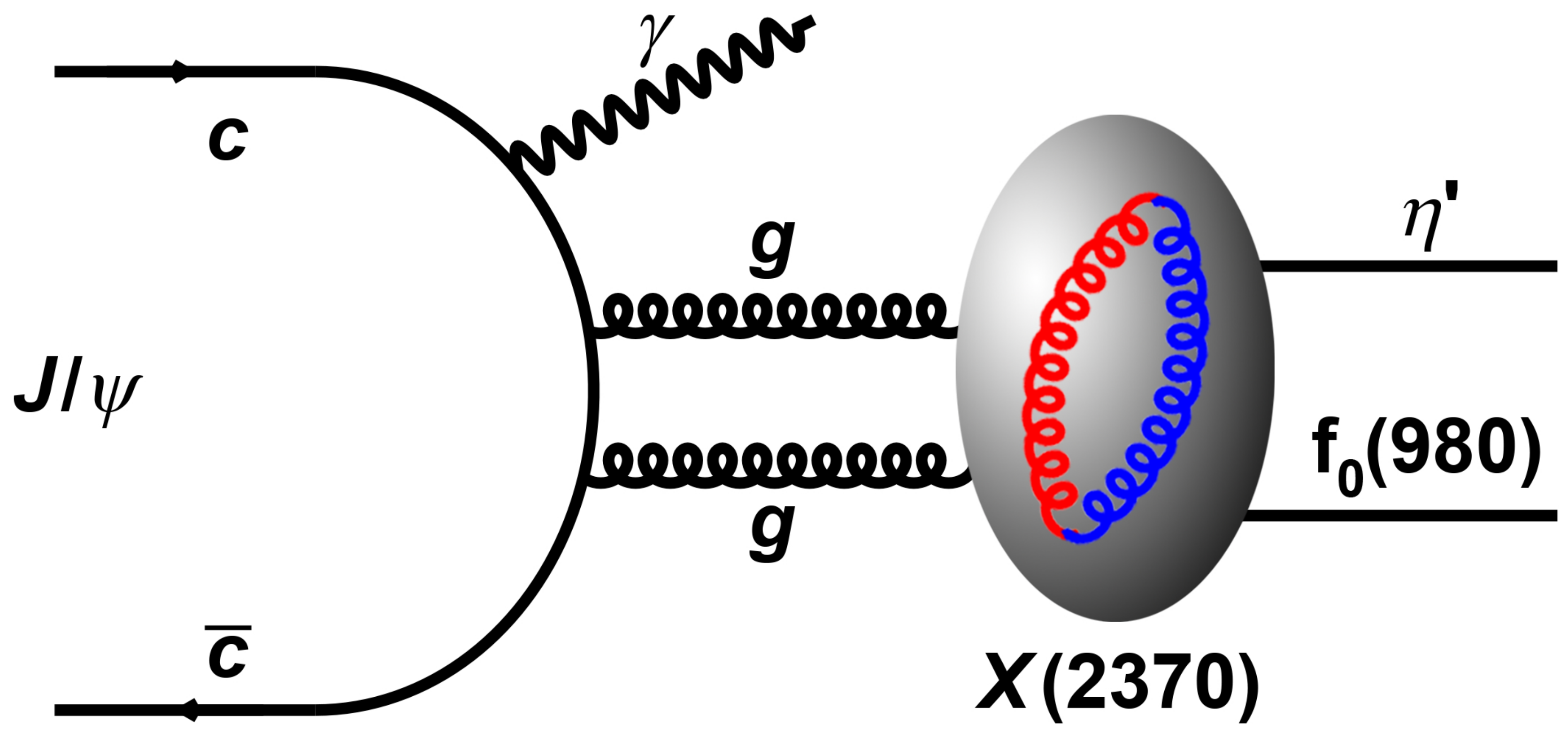
Discovery of a Glueball-like particle X(2370) @ BESIII



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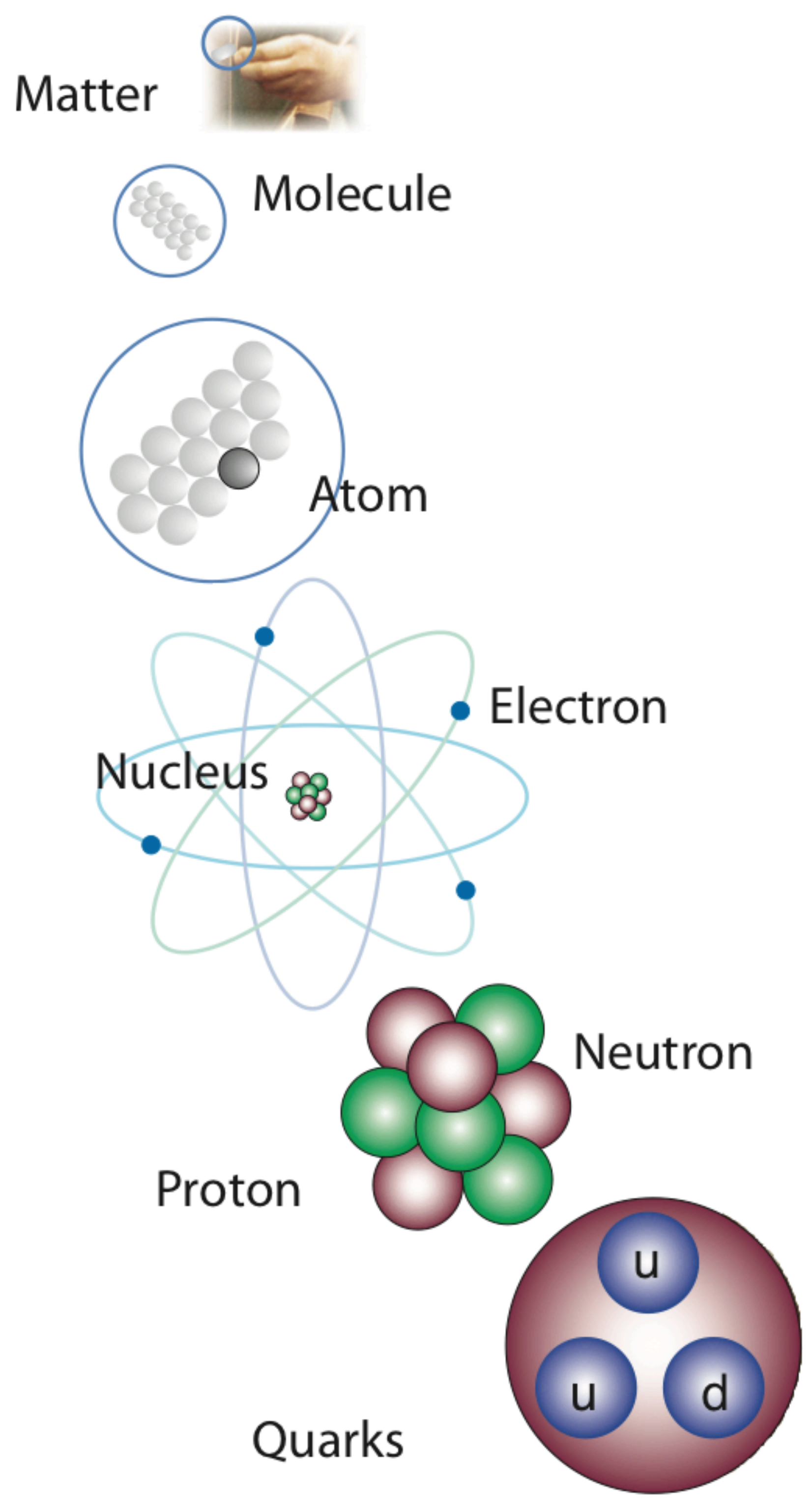
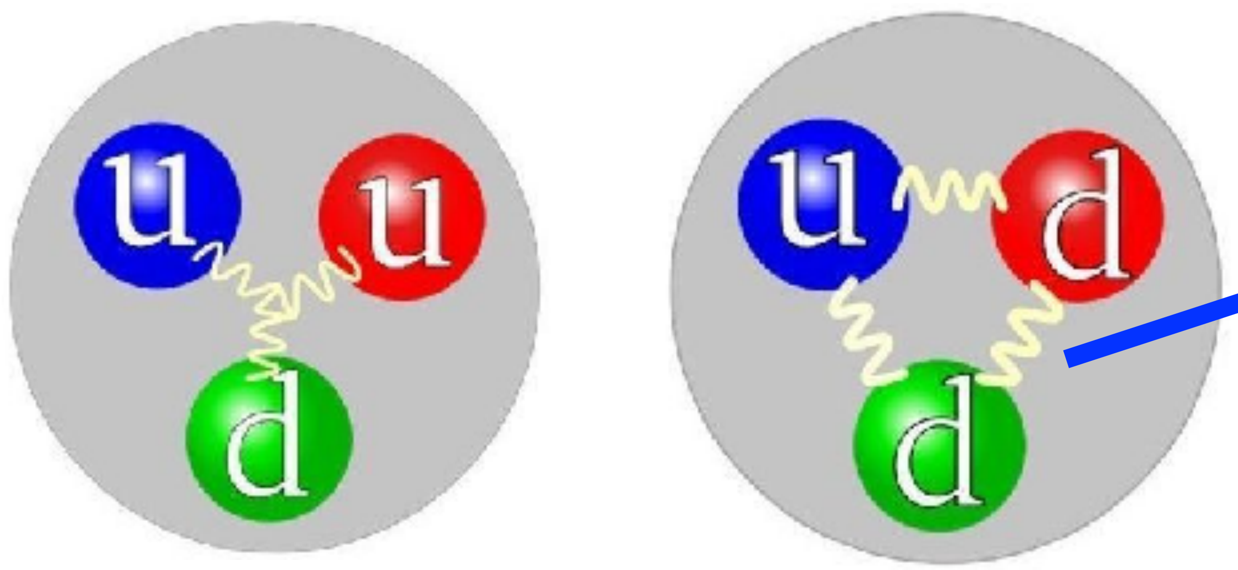
(On behalf of the BESIII Collaboration)

CERN Seminar, May 21st, 2024

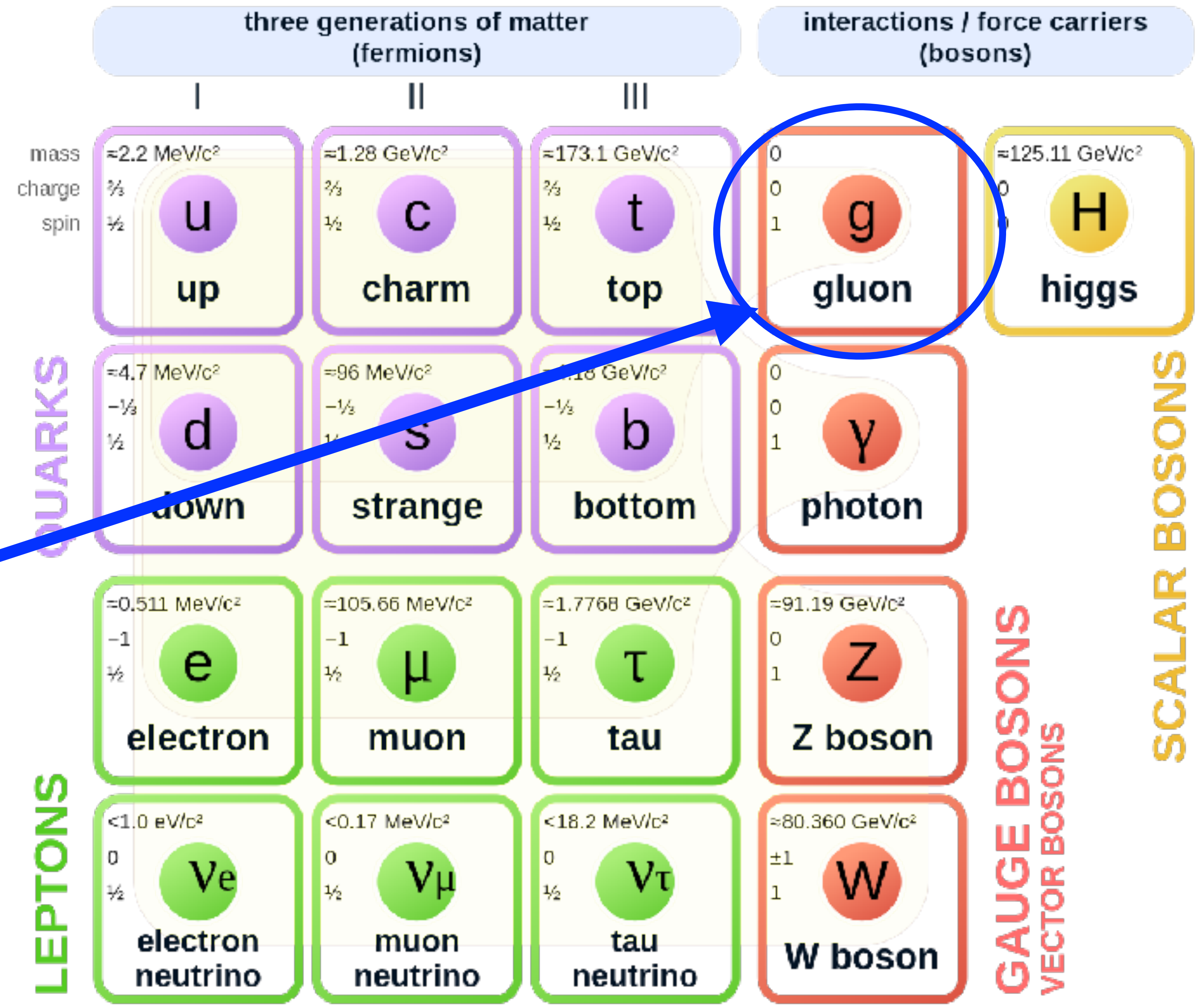
All matters are made out of quarks and leptons



Proton: uud Neutron: udd



Standard Model of Elementary Particles



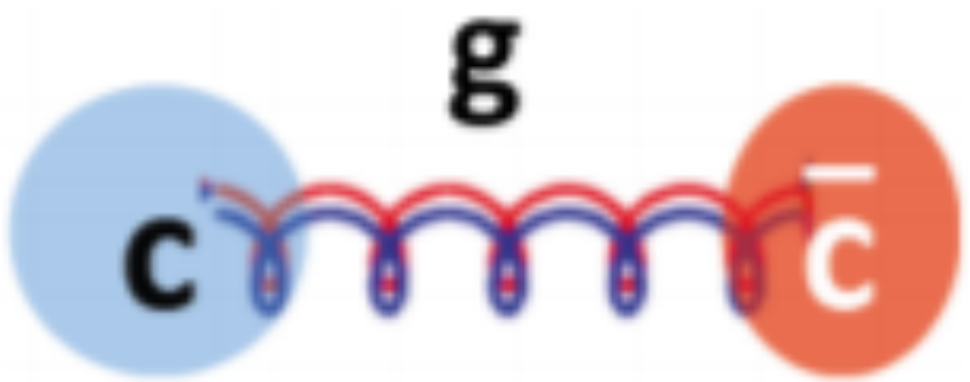
- The basic theory for strong interactions is quantum chromodynamics (QCD)
  - **Gluons are the force carriers of the strong interactions**
  - **Gluon self-interaction:** prediction of non-Abelian Gauge SU(3) QCD theory

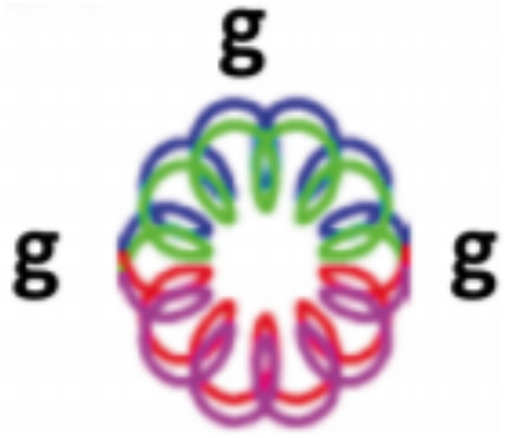
Forms of hadrons

◈ **In quark model:**

◈ **Other forms of hadrons：**

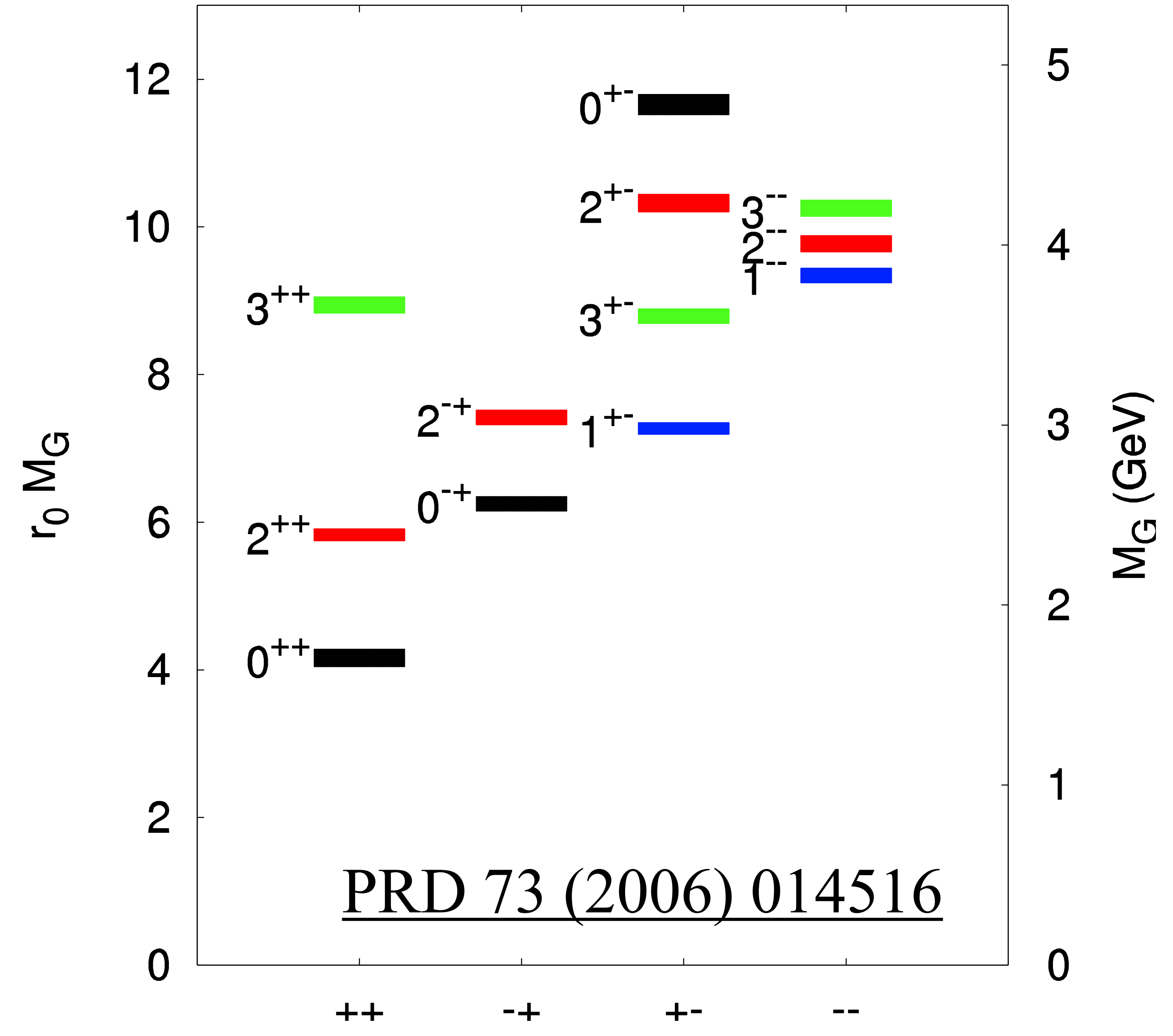
- ✦ **Multi-quark:** quark number >= 4
- ✦ **Hybrid state:** the mixture of quark and gluon
- ✦ **Glueball:** composed of gluons (**gg, ggg, gggg ….**)

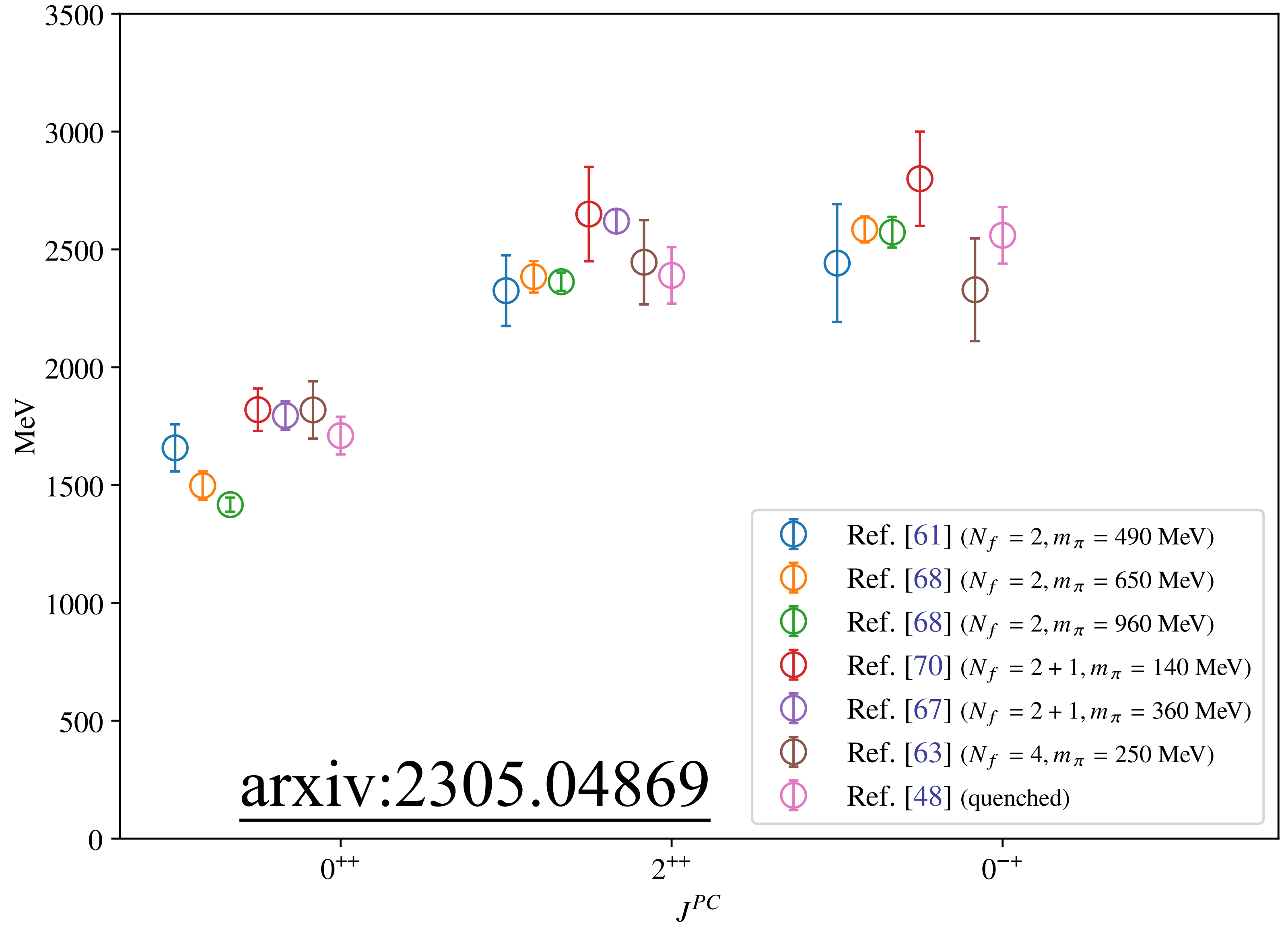




Glueballs are unique particles formed by gluons (force carriers) due to non-Abelian gauge self-interactions of gluons

Theory Prediction





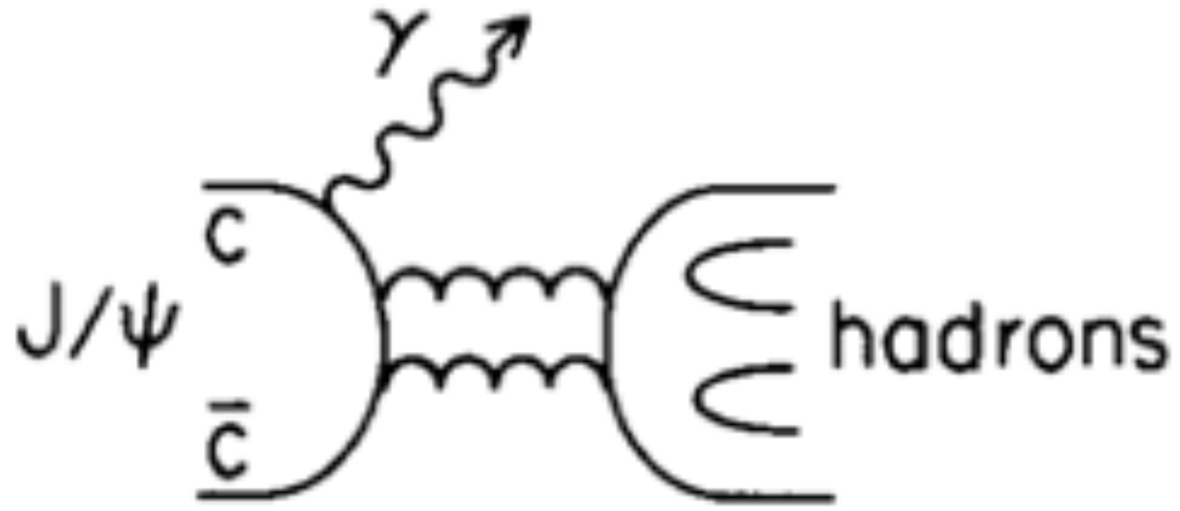
- ◈ **Quenched lattice QCD** is the non-perturbative method for this theory from the first principles.
- ◈ The predictions of **masses and production rates** of pure glueballs are expected to be reliable.
- ◈ Lattice QCD predictions:
  - ✦ **0^{++} ground state:** 1.5 - 1.7 GeV/c^2
  - ✦ **2^{++} ground state:** 2.3 - 2.4GeV/c^2
  - ✦ **0^{-+} ground state:** 2.3 - 2.6GeV/c^2

Glueball Search

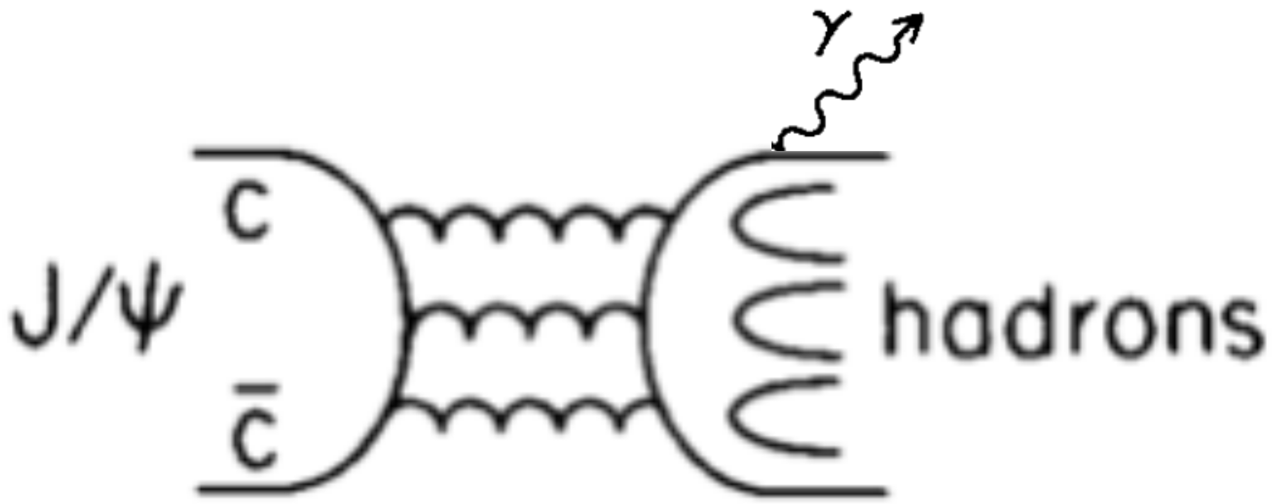
- **Many experiments searched for glueballs over the past 4 decades,** mostly in J/ψ radiative decays from electron-positron collision
  - The advantage for **glueball searches via J/ψ radiative decays from electron-positron collision**
  - **Glueball production in J/ψ radiative decays**
  - **Glueball decays**
  - **Many historical glueball candidates**, but also some **difficulties**

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 $J^{PC}=0^{-+}, 0^{++}, 1^{++}, 2^{++}, 2^{-+} \ldots$

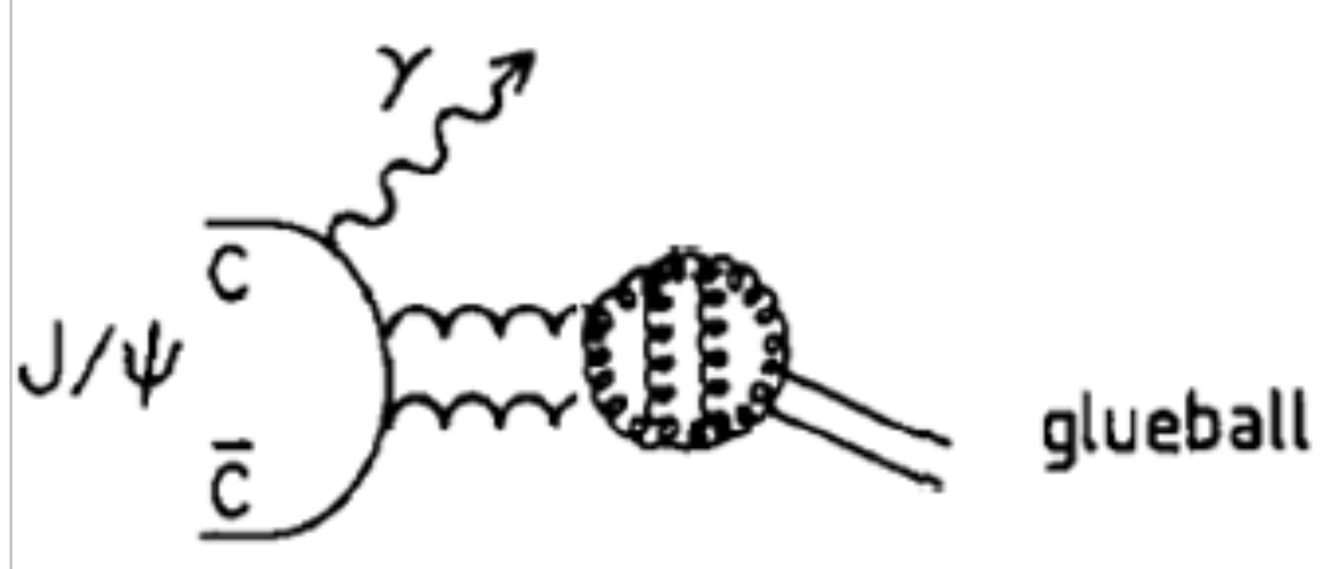
- **Clean environment in electron-positron collision:** very different from **proton-antiproton collision**

➡ **Ideal place to search for glueballs**

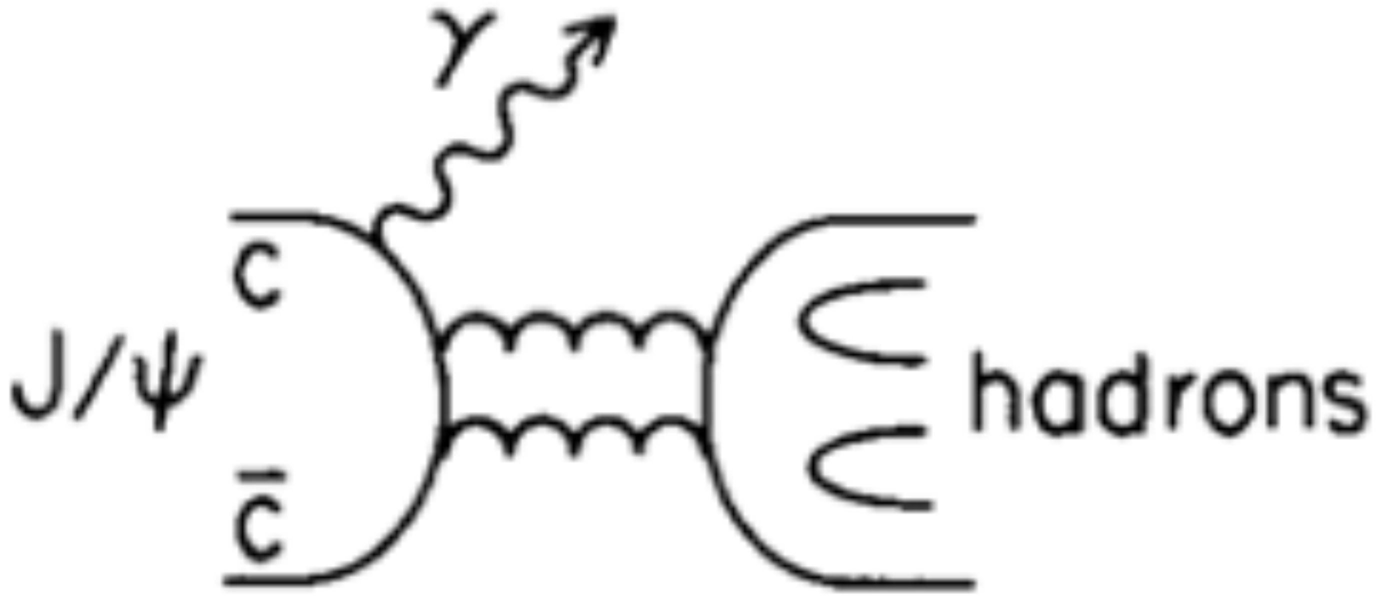
Glueball Production in J/ψ radiative decays

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

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



$\sim\alpha\alpha_s^2$



$\sim\alpha\alpha_s^4$

Glueball Decays

- **Flavor symmetric decays**
- **No rigorous predictions on decay patterns and their branching ratios**
- The glueball decays could have **similar decays to the Charmonium families** since both of them can only decay via gluons
  - e.g. the 0^{-+} glueball could have similar decays of η_c
  - One of the favorite decays modes of η_c is $\pi\pi\eta'$, so $J/\psi \to \gamma\, \pi\pi\eta'$ could be a good place to search for the 0^{-+} glueball

Historical Glueball Candidates — 0^{++} scalar Glueball

- **$f_0(1710)$:** discovered by MarkII in 1980's as $\theta_2(1720)$ and $J^{pc} = 2^{++}$ from a simple fit to the angular distribution. Lots of studies at MarkII, DM2, BESI,BESII, BESIII
  - **J^{pc} was firstly changed to 0^{++}** on a full PWA of J/ψ→ γKK @ BESII
  - The high production rate of J/ψ→ $\gamma f_0(1710)$ and the suppression of $f_0(1710)$→ ηη' strongly support its interpretation:
    - **A scalar glueball or large glueball content if it is a mixture of glueball and normal meson**
  - **With PS subtracted, $\Gamma(f_0(1710)\to\pi\pi:KK)$=1:2.43, which should be 1:1 for a pure glueball decays**
  - **Difficulty:** What causes the **flavor symmetric breaking** needs to be understood from first principle of QCD (not just phenomenological understanding).

- $B[J/\psi \to \gamma f_0(1710) \to \gamma\pi\pi] = (4.01 \pm 1.0)\times10^{-4}$
  - BESII: PLB 642 441 (2006)
- $B[J/\psi \to \gamma f_0(1710) \to \gamma K_S^0 K_S^0] = (2.00^{+0.03+0.31}_{-0.02-0.10})\times10^{-4}$
  - BESIII: PRD 98 072003 (2018)

$B[f_0(1500) \to \eta\eta']/B[f_0(1500) \to \pi\pi] = (1.66^{+0.42}_{-0.40})\times10^{-1}$

$B[f_0(1710) \to \eta\eta']/B[f_0(1710) \to \pi\pi] < (2.9^{+1.1}_{-0.9})\times10^{-3}$

- BESIII: PRD 106 072012 (2022)

A lot of studies from BES in J/ψ → γKK, γππ, γηη, γηη'

Historical Glueball Candidates — 0^{++} scalar Glueball

- **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:

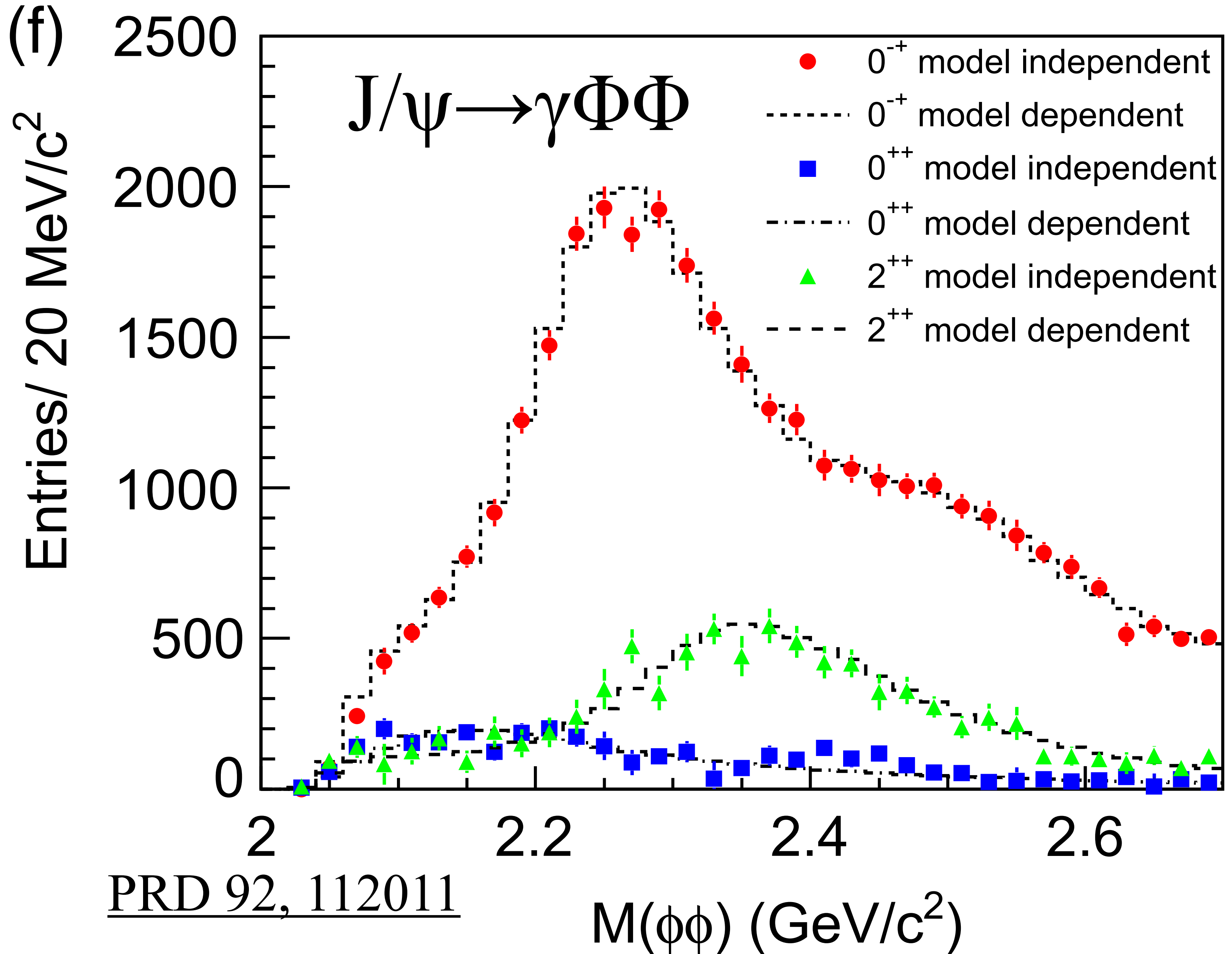
$$B(J/\psi \to \gamma f_0(1500)) \sim 0.29 \times 10^{-3}$$
$$B(J/\psi \to \gamma f_0(1710)) \sim 2.2 \times 10^{-3}$$

Historical Glueball Candidates — 2^{++} Tensor Glueball

- ξ(2230)
  - First observed by MarkIII is J/ψ→ γKK in 1980's, then by BESI in 1990's in J/ψ → γKK, γππ, γppbar 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 with much higher statistics.

Historical Glueball Candidates — 2^{++} Tensor Glueball

- $f_2(2340)$
  - **Its large production rate** in $J/\psi \to \gamma$**(KK/ηη/η'η'/ϕϕ)** favors its interpretation as a **tensor glueball** .
  - **Many wide f_2 mesons in the mass region of 2.3GeV** of 2^{++} glueball mass from the LQCD predictions
  - **Difficulty: no clear mass peak of these f_2 mesons** due to large overlaps among various wide resonances. (PWA components)
    - **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.



PRD 92, 112011

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

Historical Glueball Candidates — 0^{-+} Pseudoscalar Glueball

- η(1405)
  - first discovered by MarkII in 1980's, named as η(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 0^{-+} glueball candidate due to its large different mass from LQCD prediction.

Historical Difficulties in Glueball Searches

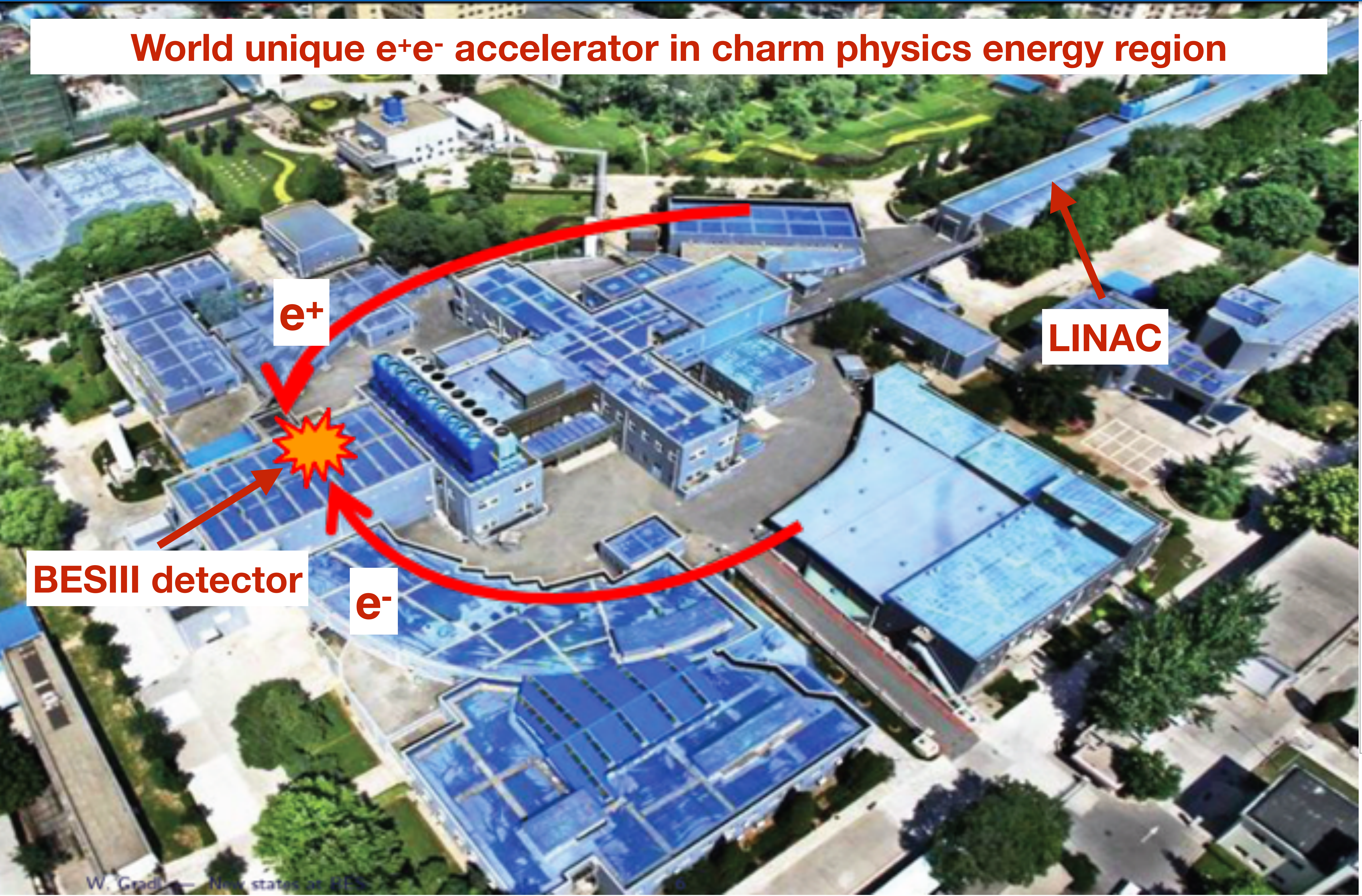
◈ **Theoretically:**

- **No prediction on the decay branch ratios** so far (even the order)
- **Very rare prediction on the glueball production rate** $\Gamma(J/\psi \to \gamma G)$
- **Mix** with qqbar mesons or even with 4q, qqg, mesons? **Mixing dynamics**?

◈ **Experimentally:**

- Data sample was not big enough
- No good way **modeling background** in many cases.
- **Interference among mesons** makes the analysis more complicated:
  - **PWA is a must, but it is complicated and takes a quite long time.**

Beijing Electron Positron Collider (BEPCII)



2004: Construction

- Double rings
- Beam energy:

  1.0 - 2.3 (2.45)GeV
- Designed luminosity:

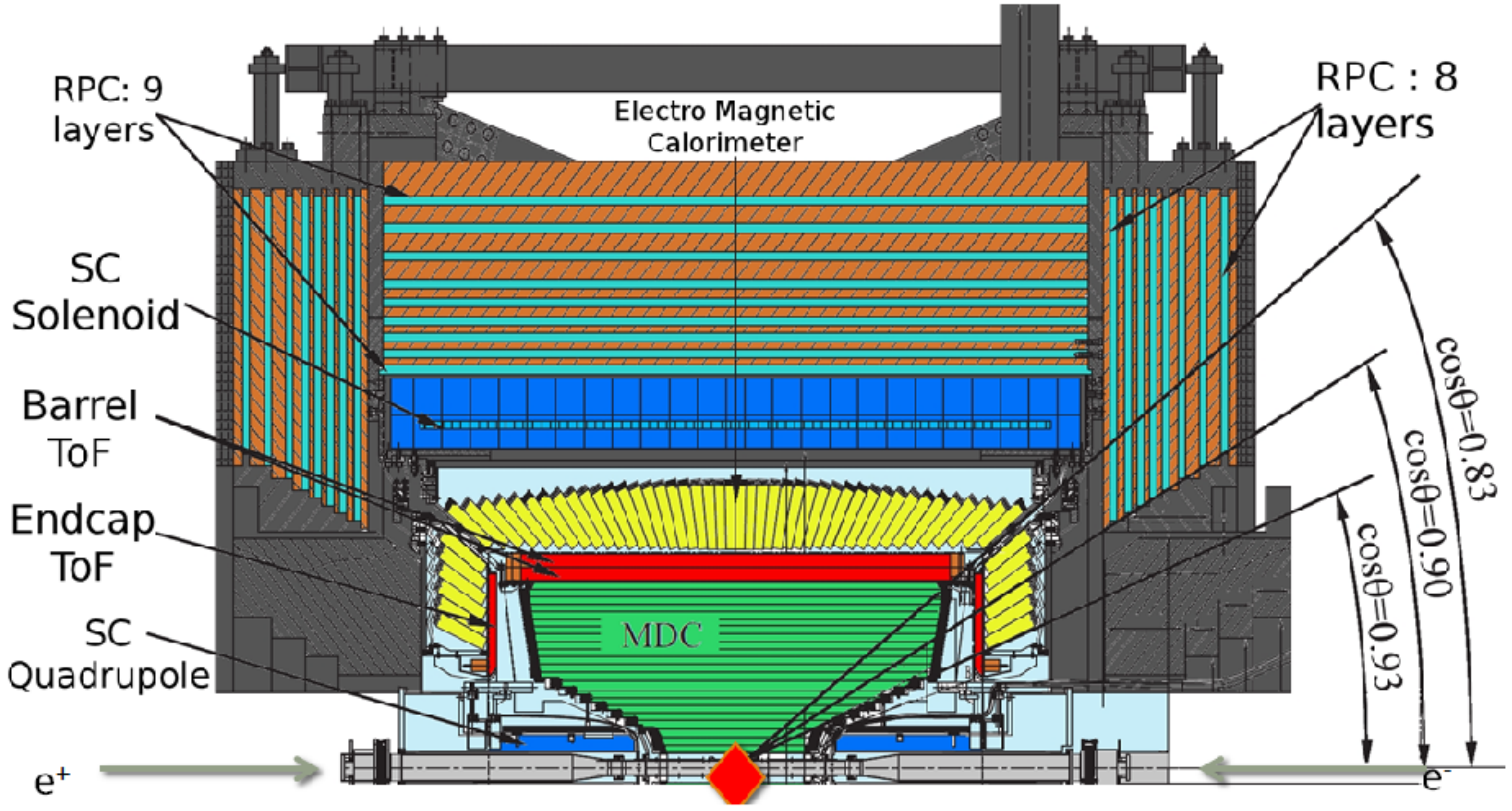
  1×10^{33} cm^{-2} s^{-1}

2008： test run

2009-now: BESIII physics runs

BESIII detector

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

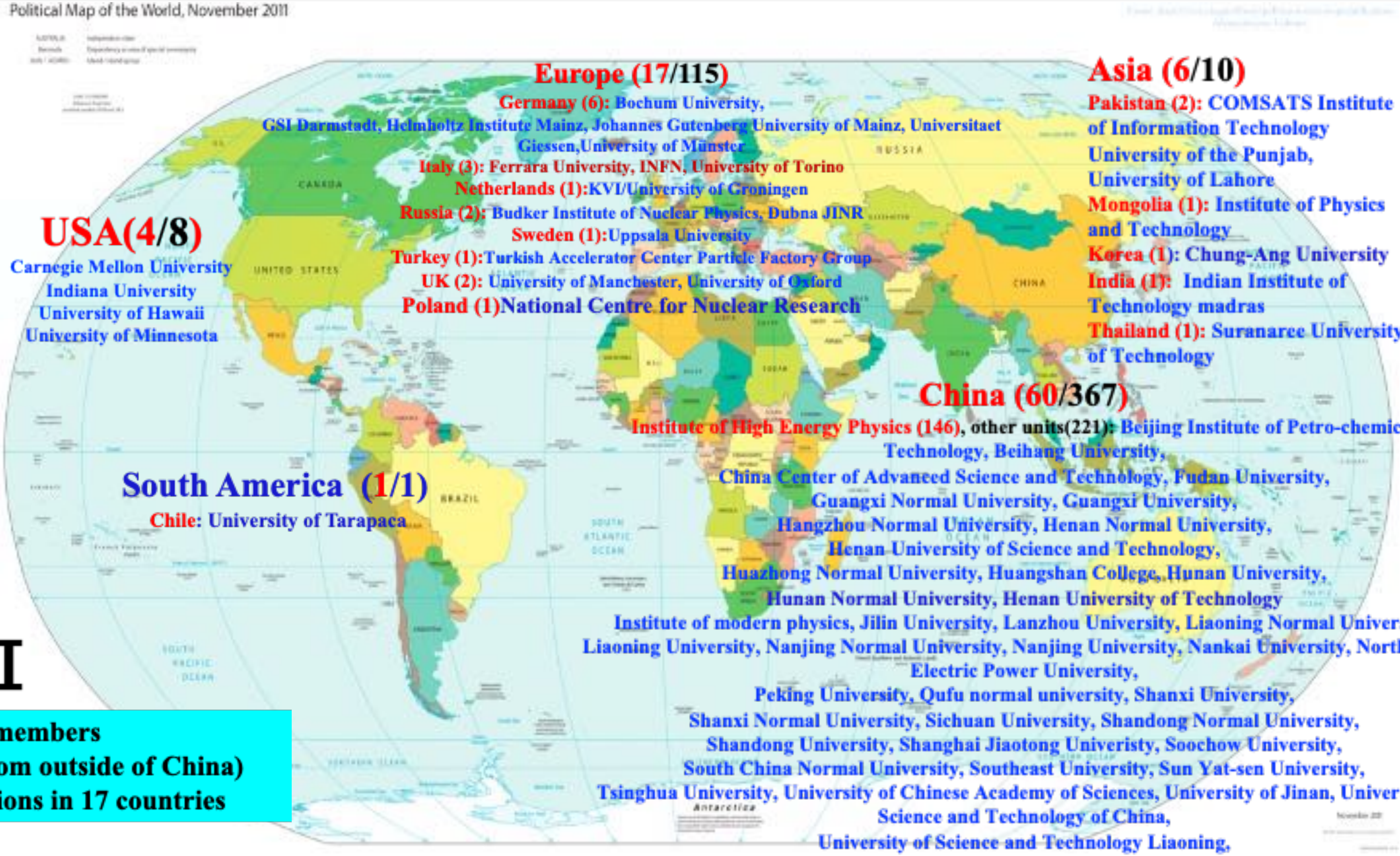


Total weight 730 ton,
~40,000 readout channel
Data rate: 5kHz, 50Mb/s

- Magnet: 1T Super conducting
- 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 very good status!

BESIII Collaboration



Europe (17/115)

Germany (6): Bochum University, GSI Darmstadt, Helmholtz Institute Mainz, Johannes Gutenberg University of Mainz, Universitaet Giessen, University of Münster
Italy (3): Ferrara University, INFN, University of Torino
Netherlands (1): KVI/University of Groningen
Russia (2): Budker Institute of Nuclear Physics, Dubna JINR
Sweden (1): Uppsala University
Turkey (1): Turkish Accelerator Center Particle Factory Group
UK (2): University of Manchester, University of Oxford
Poland (1) National Centre for Nuclear Research

Asia (6/10)

Pakistan (2): COMSATS Institute of Information Technology
University of the Punjab, University of Lahore
Mongolia (1): Institute of Physics and Technology
Korea (1): Chung-Ang University
India (1): Indian Institute of Technology madras
Thailand (1): Suranaree University of Technology

USA (4/8)

Carnegie Mellon University
Indiana University
University of Hawaii
University of Minnesota

South America (1/1)

Chile: University of Tarapaca

China (60/367)

Institute of High Energy Physics (146), other units (221): Beijing Institute of Petro-chemical Technology, Beihang University, China Center of Advanced Science and Technology, Fudan University, Guangxi Normal University, Guangxi University, Hangzhou Normal University, Henan Normal University, Henan University of Science and Technology, Huazhong Normal University, Huangshan College, Hunan University, Hunan Normal University, Henan University of Technology Institute of modern physics, Jilin University, Lanzhou University, Liaoning Normal University, Liaoning University, Nanjing Normal University, Nanjing University, Nankai University, North China Electric Power University, Peking University, Qufu normal university, Shanxi University, Shanxi Normal University, Sichuan University, Shandong Normal University, Shandong University, Shanghai Jiaotong Univeristy, Soochow University, South China Normal University, Southeast University, Sun Yat-sen University, Tsinghua University, University of Chinese Academy of Sciences, University of Jinan, University of Science and Technology of China, University of Science and Technology Liaoning, University of South China, Wuhan University, Xinyang Normal University, Zhejiang University, Zhengzhou University, YunNan University, China University of Geosciences

~600 members
(more than 130 from outside of China)
From 89 institutions in 17 countries

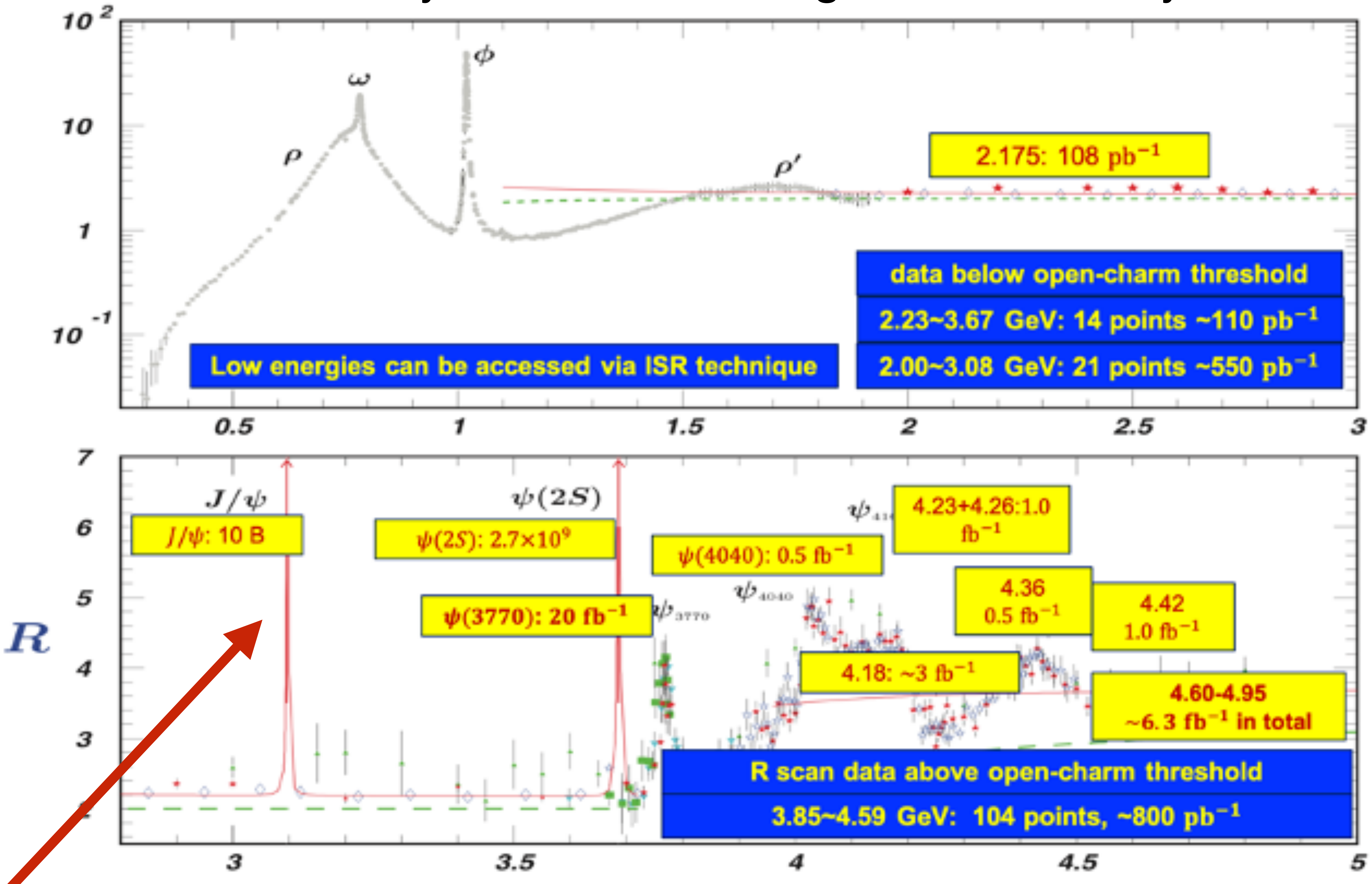
BESIII Data samples

Data sets collected so far include

- 10×10⁹ J/ψ events
- 2.7×10⁹ ψ(2S) events
- 20 fb^{-1} ψ(3770)
- Scan data between 2.0 and 3.08 GeV, and above 3.74GeV
- Large datasets for XYZ studies:

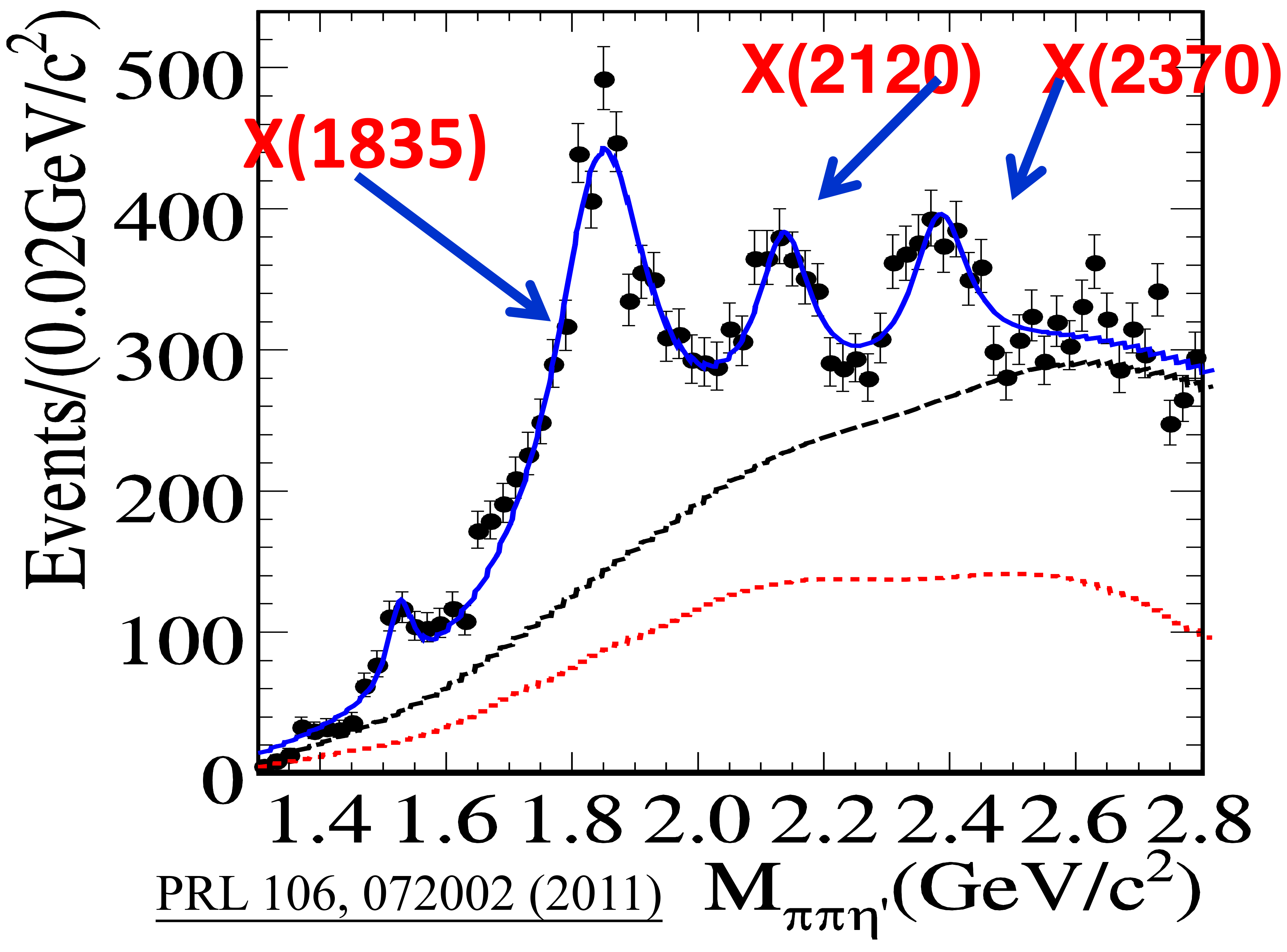
  Scan with >500pb-1 per energy point space 10-20MeV apart

Totally about 50fb^{-1} integrated luminosity



World largest J/ψ data sample : ~10 billion

Observation of the X(2370) in 2011



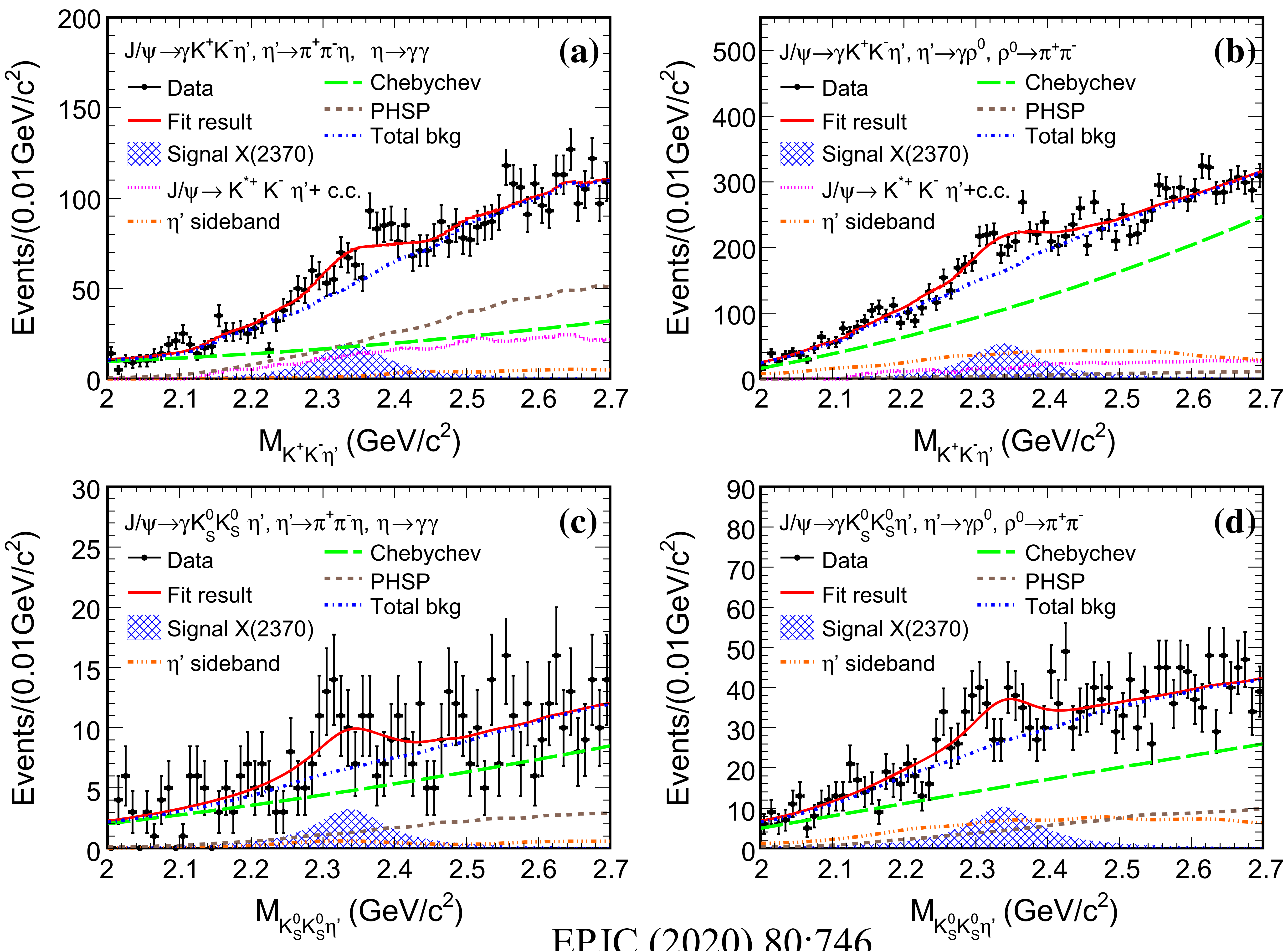
PRL 106, 072002 (2011)

$J/\psi \to \gamma \pi^+ \pi^- \eta'$ With ~225M J/ψ events

	M(MeV/c²)	Γ(MeV/c²)	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

- ◈ **Discovery of X(2370) in $J/\psi \to \gamma \pi^+ \pi^- \eta'$ with the statistic significance of 6.4σ**
- ◈ **First observation of one particle: a good candidate for 0^{-+} glueball**
  - ✦ **Mass, production and decay property are consistent with the LQCD prediction**

Confirmation of the X(2370) in J/ψ→γKKη’



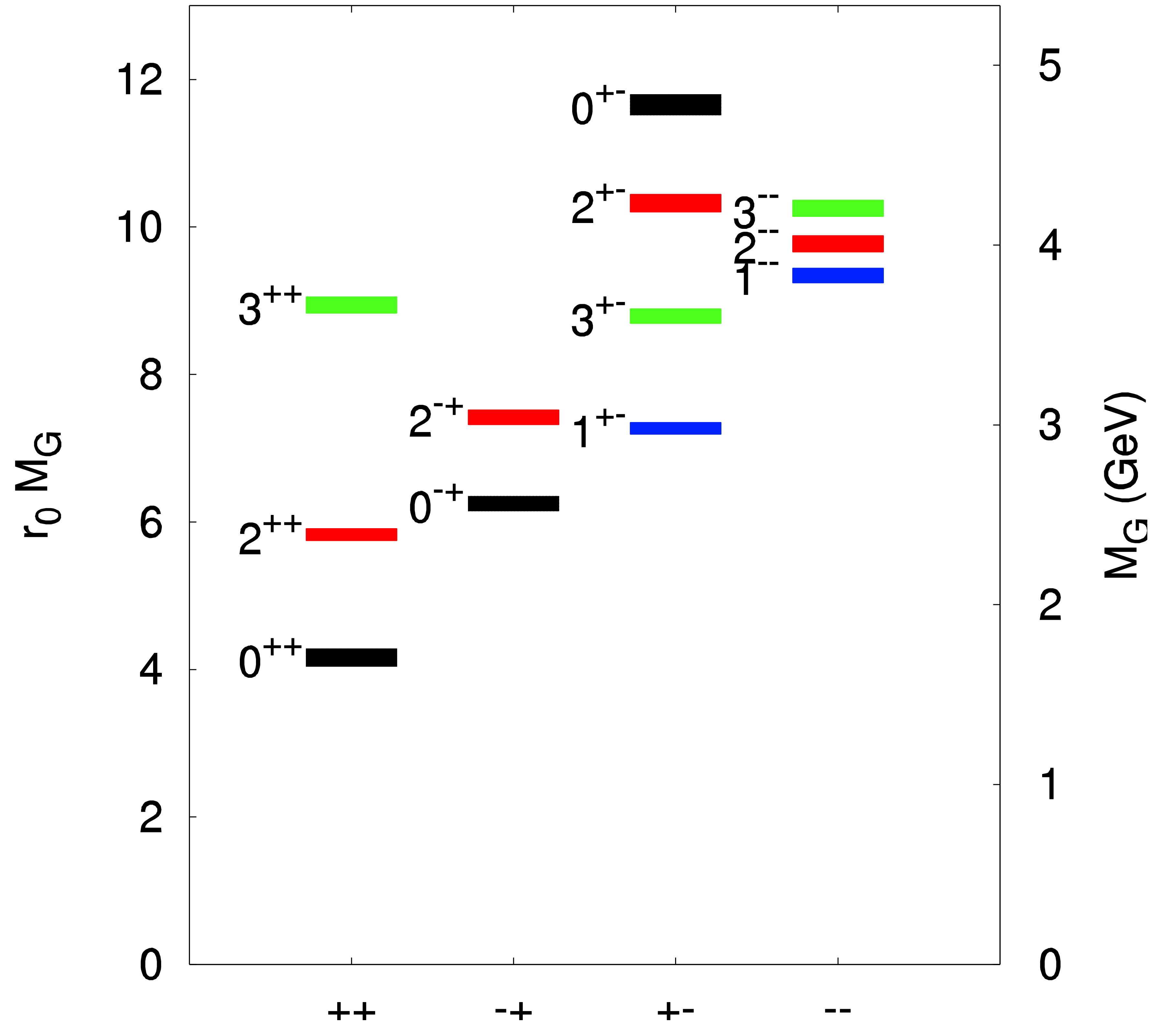
EPJC (2020) 80:746

- **Combination with 1.31×10⁹ J/ψ events**
  - **J/ψ→γK⁺K⁻η’ and J/ψ→γKₛKₛη’**
  - **η’ →γππ and η’→ππη**
- **Confirmation of the X(2370) with 8.3σ**
  - **M = 2341.6±6.5(stat.)±5.7(syst.) MeV**
  - **Γ = 117±10(stat.)±8(syst.) MeV**
  - **Br(J/ψ→γX(2370)→γK⁺K⁻η’)=(1.79±0.23±0.65)×10⁻⁵**
  - **Br(J/ψ→γX(2370)→γKsKsη’)=(1.18±0.32±0.39)×10⁻⁵**

Observation: X(2370) new decay mode of KKη’

X(2370) - good candidate of 0^{-+} glueball

- Its mass is consistent with LQCD prediction on the 0^{-+} glueball
- Observed in flavor symmetric decay modes of $\pi^+\pi^-\eta'$ and $KK\eta'$ — favorite decay modes of 0^{-+} glueball
- We need to know its spin-parity



Improved situation in Glueball Searches

- **Theoretically:**
  - **Guidance from η_c decays**
  - Now we have prediction on **glueball production rate from LQCD:** $B(J/\psi \to \gamma G_{0^{-+}}) = 2.31 \pm 0.80 \times 10^{-4}$
  - Luckily, for the X(2370), there is **no other 0^{-+} resonance nearby** (in ~200MeV range) in J/ψ radiative decays
- **Experimentally:**
  - **World largest J/ψ data sample : ~10 billion**
  - **Physics channels with few background**
  - **GPU technique helps to speed up PWA** [J.Phys.Conf. Ser. 219, 042031]
    - It takes a long time in PWA for the complicated interference and comprehensive test of different combinations

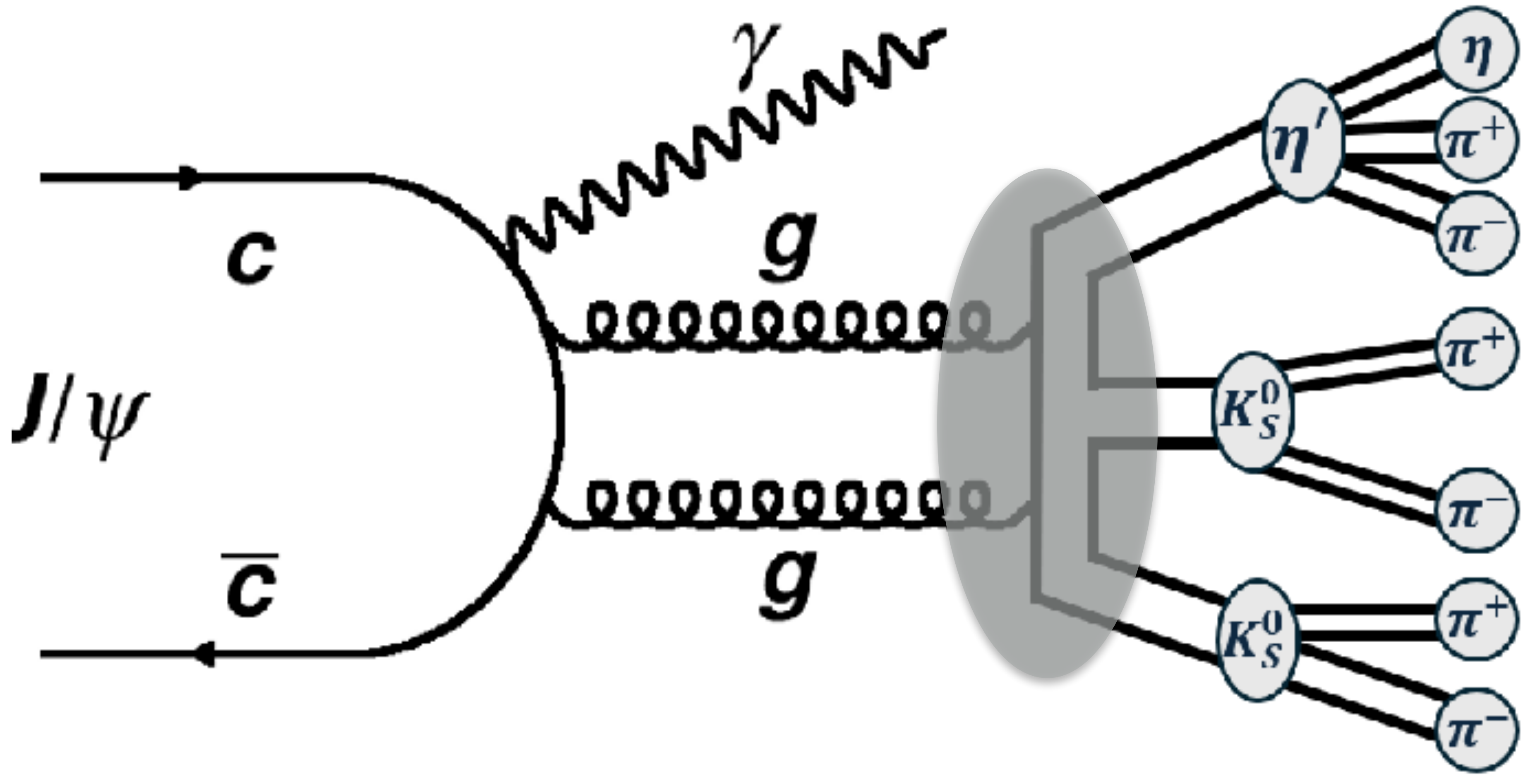
Spin-Parity determination of the X(2370) in $J/\psi \to \gamma K^0_s K^0_s \eta'$

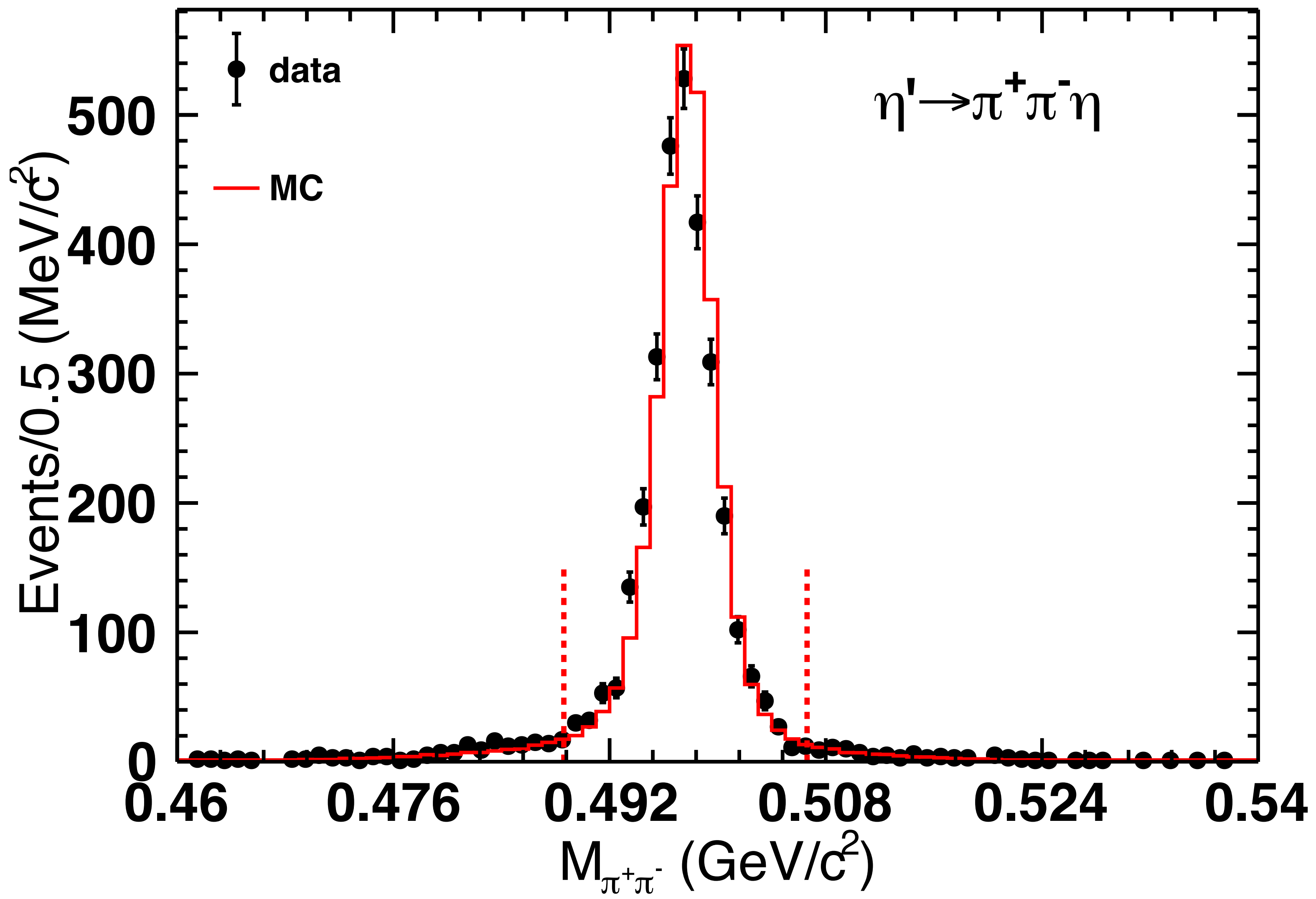
Make use of three advantages:

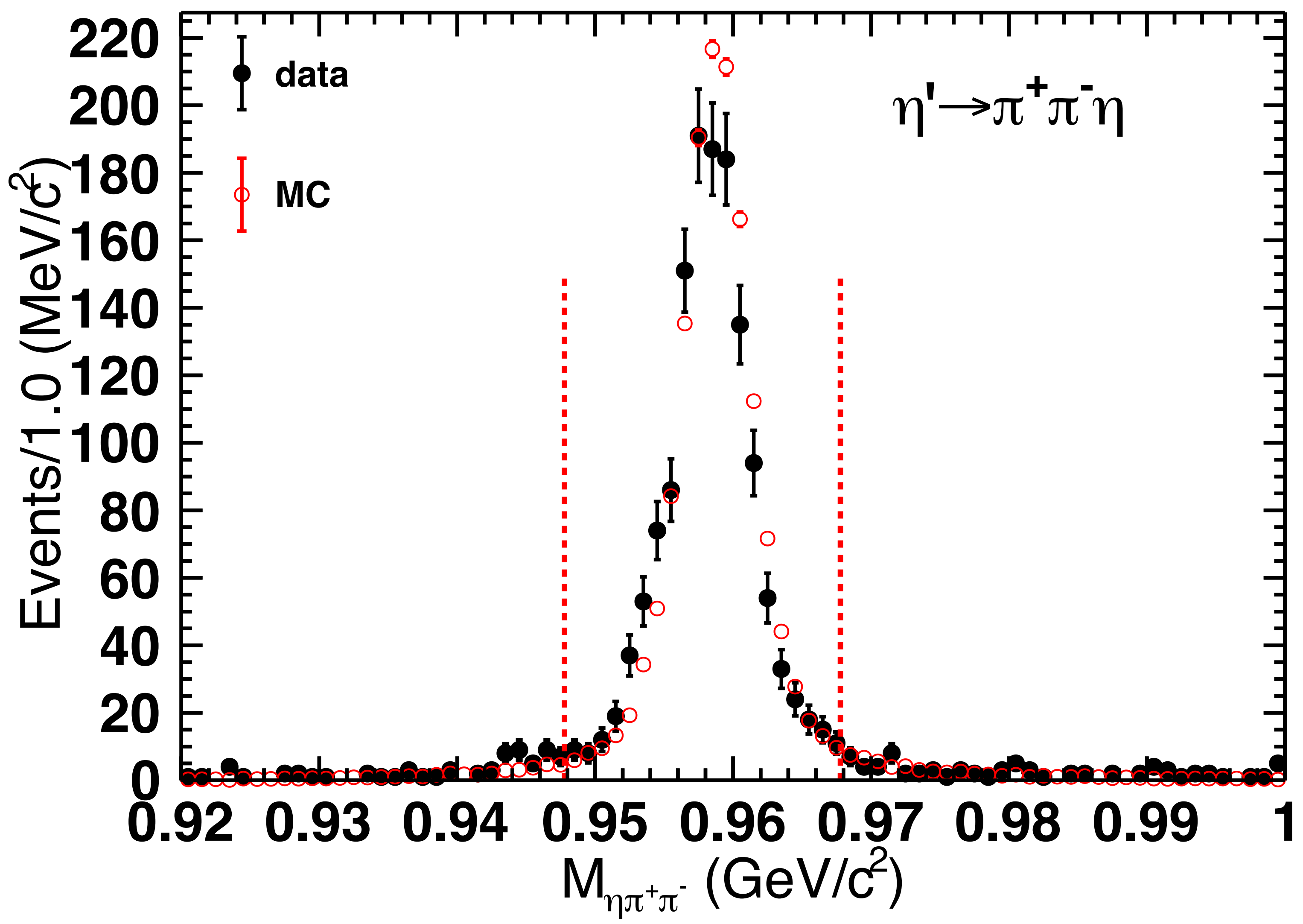
- **Clean $J/\psi \to \gamma K^0_s K^0_s \eta'$ process**
  - **Almost no background:** possible dominant background processes of $J/\psi \to \pi^0 K^0_s K^0_s \eta'$ and $J/\psi \to K^0_s K^0_s \eta'$ are forbidden by **exchange symmetry and C-parity conservation.**
- **~10B clean J/ψ events**
- **High-precision efficiency and resolution of charged particles and photons:** good reconstruction for K^0_s/η'

Selection for $J/\psi \to \gamma K^0_S K^0_S \eta'$, $\eta' \to \pi^+\pi^-\eta$

- **Signal selection:**
  - At least 3 charged pairs + 3 photons
  - Constraint kinematic fit with energy-momentum conservation
  - K^0_S reconstruction: $|M_{\pi\pi} - m_{K_S}| < 9$ MeV/c^2
  - η' reconstruction: $|M_{\pi\pi\eta} - m_{\eta'}| < 10$ MeV/c^2
- **Background veto:**
  - π^0 veto: $|M_{\gamma\gamma} - m_{\pi 0}| > 20$MeV/$c^2$



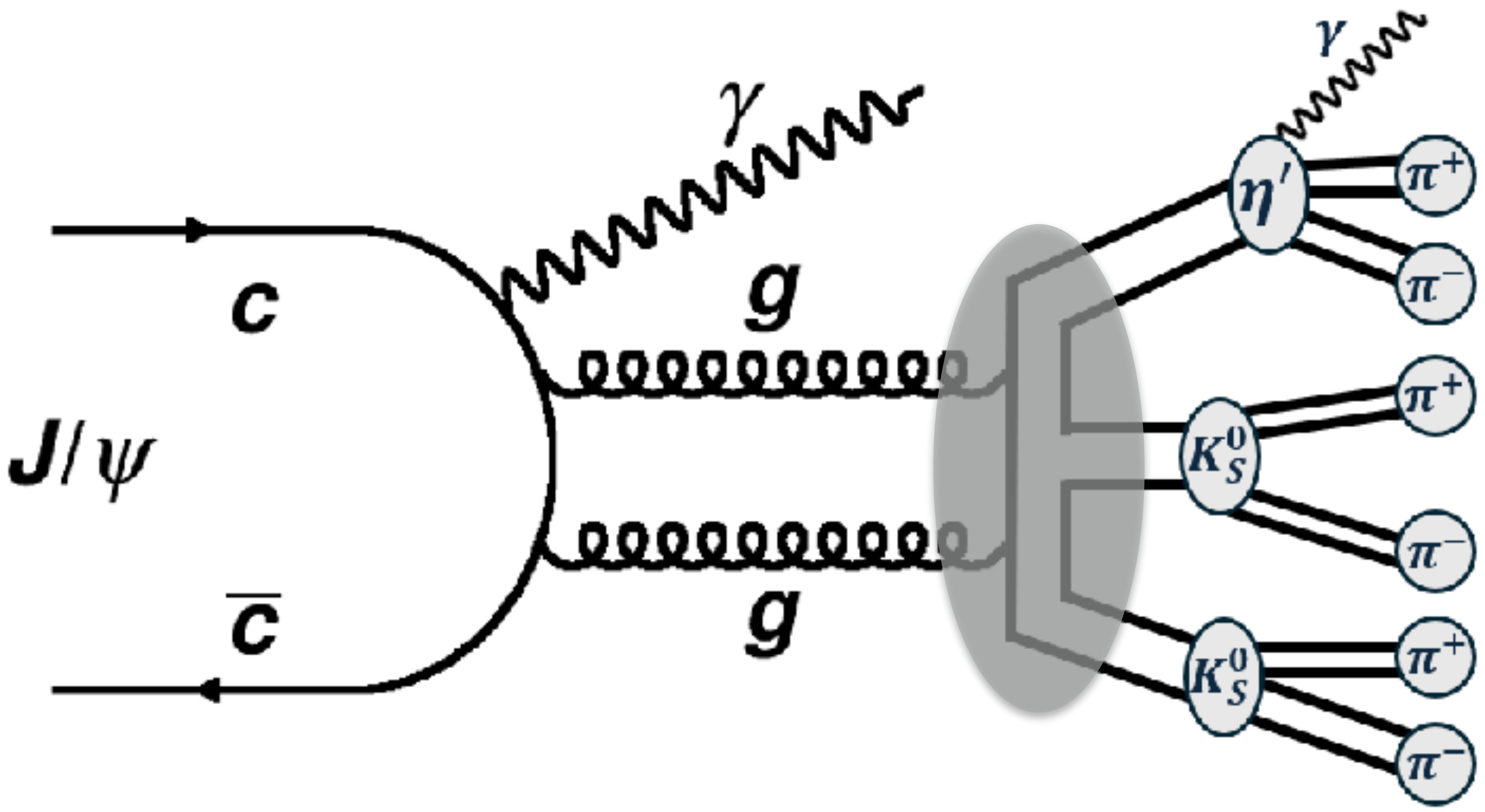


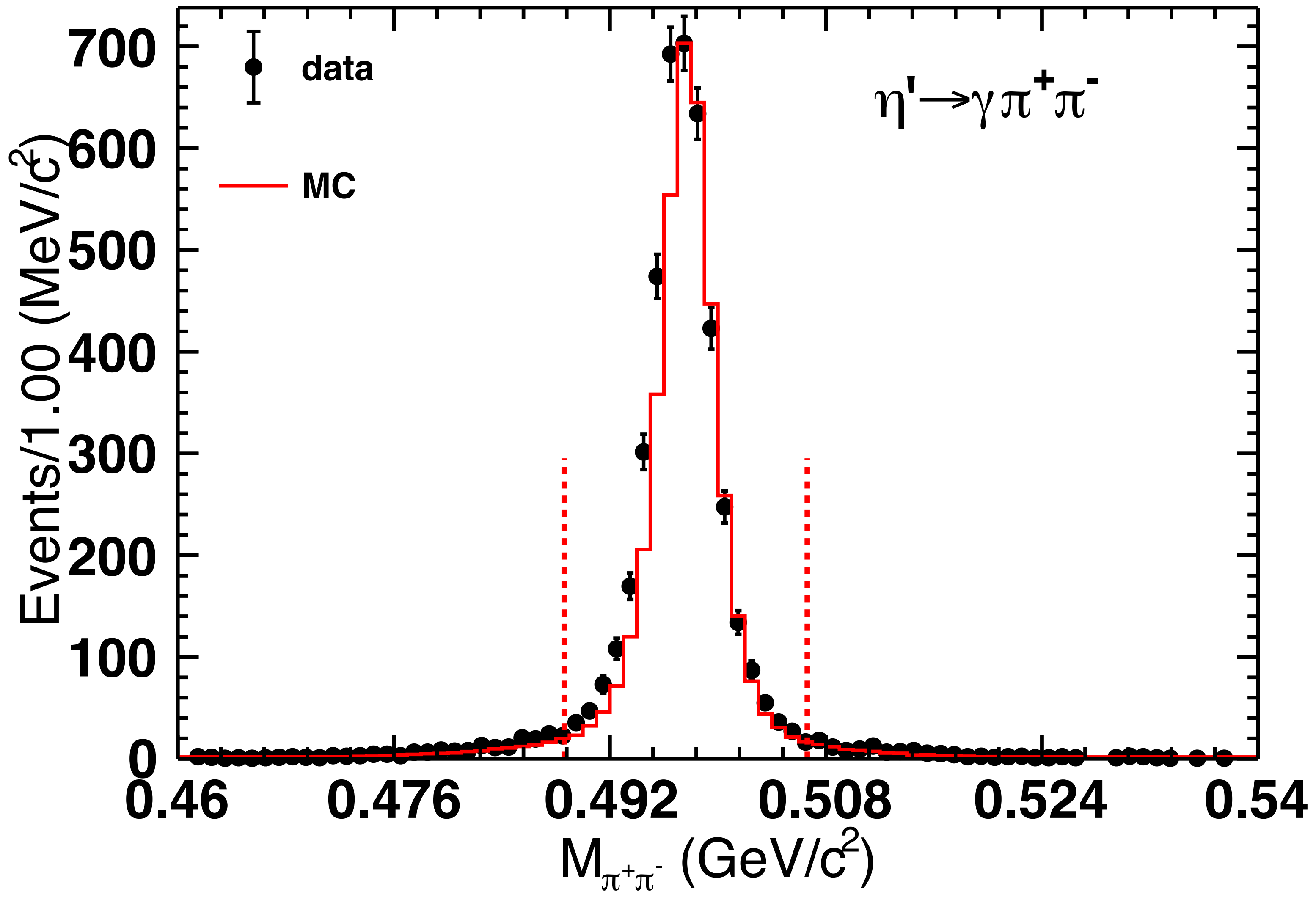


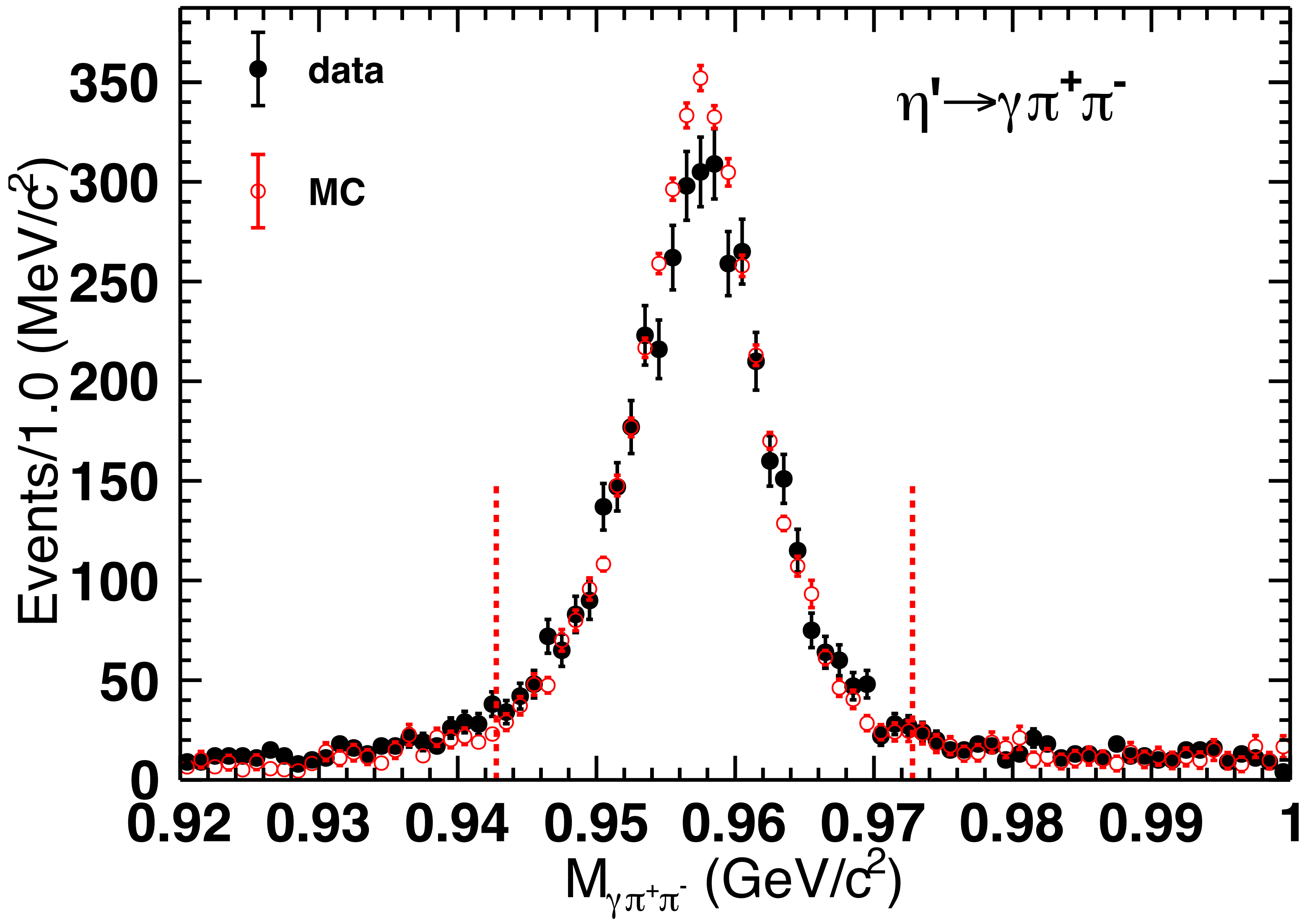
Clean K^0_S and η' Signal

Selection for $J/\psi\to\gamma K^0_S K^0_S \eta'$, $\eta'\to\gamma\pi^+\pi^-$

- **Signal selection:**
  - At least 3 charged pairs + 2 photons
  - Constraint kinematic fit with energy-momentum conservation
  - K^0_S reconstruction: $|M_{\pi\pi} - m_{K_S}| < 9$ MeV/c^2
  - η' reconstruction: $|M_{\pi\pi\eta} - m_{\eta'}| < 15$ MeV/c^2
- **Background veto:**
  - π^0/η veto: $|M_{\gamma\gamma} - m_{\pi0}| > 20$MeV/$c^2$, $|M_{\gamma\gamma} - m_{\eta}| > 30$MeV/$c^2$







Clean K^0_S and η' Signal

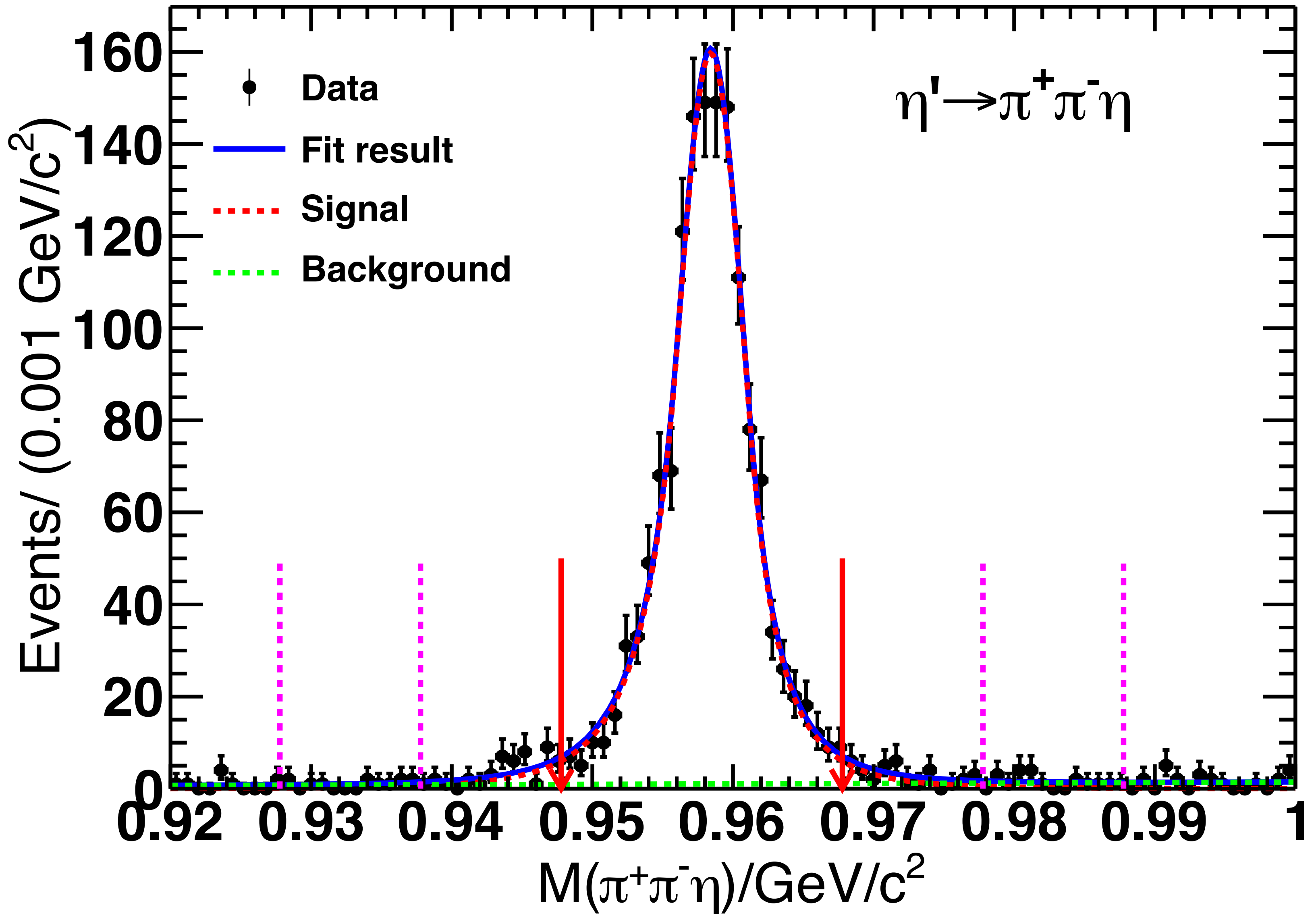
Background estimation

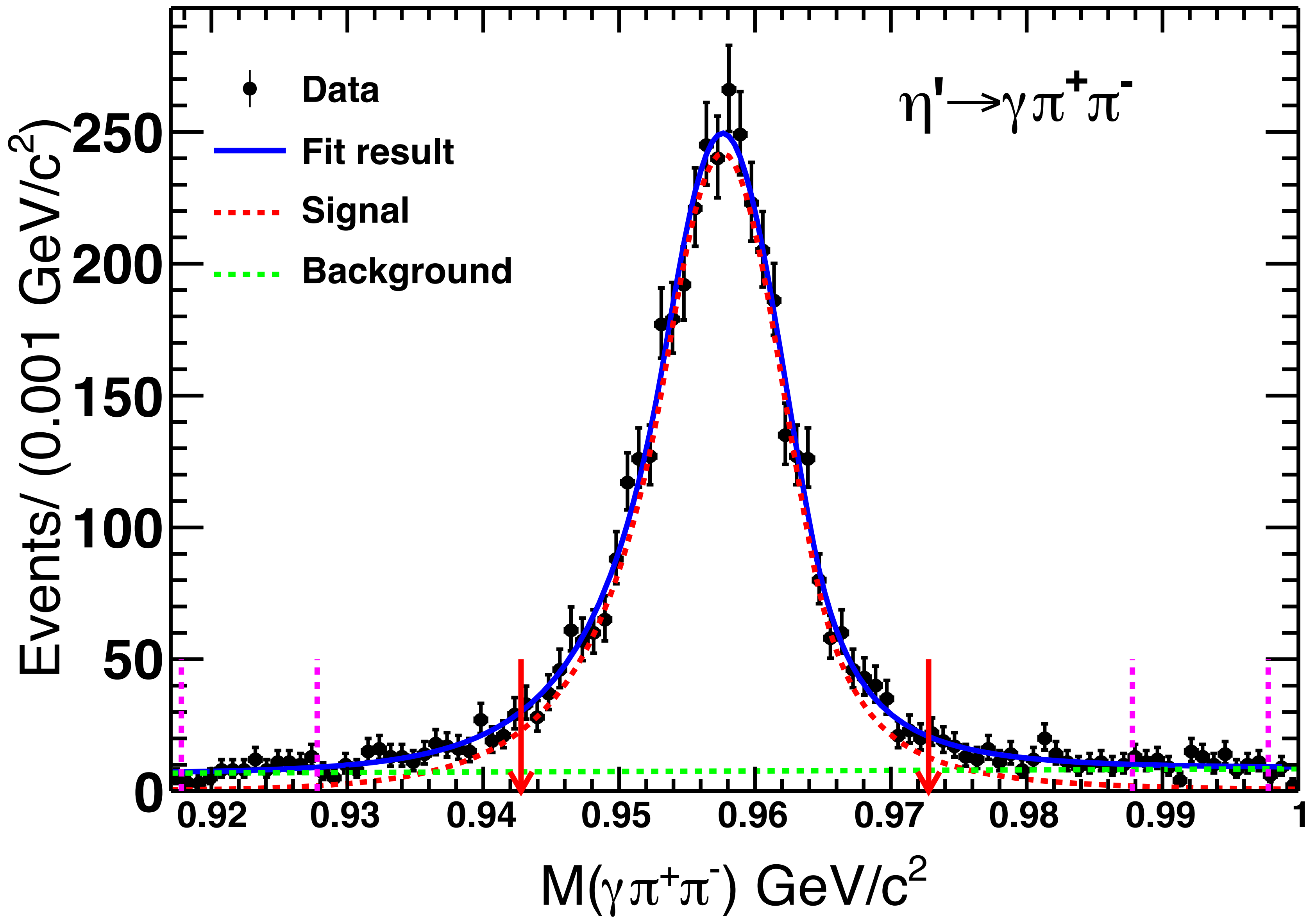
◈ **Negligible mis-combination for K^0_s reconstruction (<0.1%)**

◈ **No background from $J/\psi \to \pi^0 K^0_s K^0_s \eta'$:** further validation directly from data

◈ **Little background from non-η' processes:** estimated directly from η' mass sideband region:

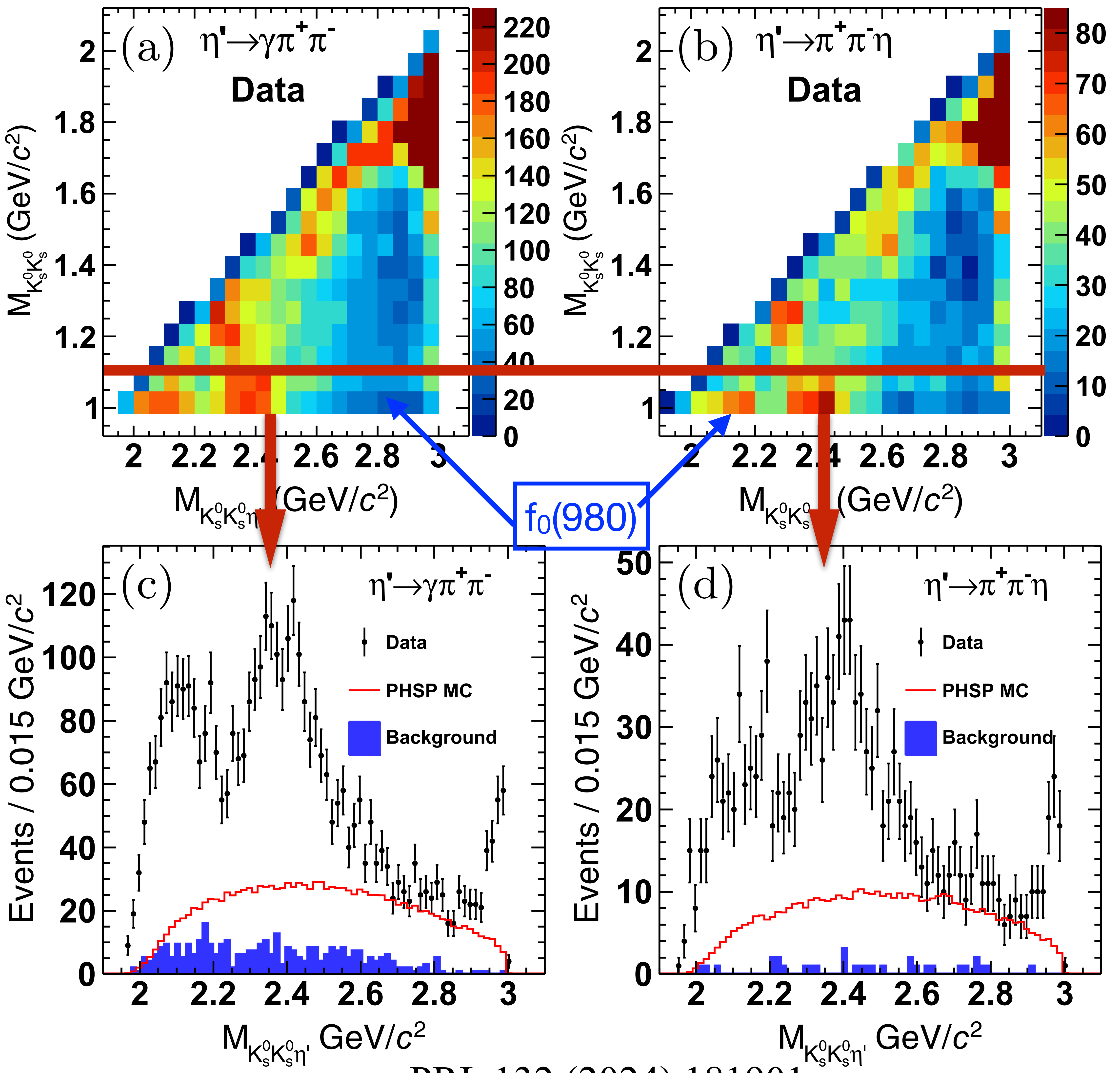
- ✦ No peaking background
- ✦ **Non-η' background fraction: 1.8% for $\eta' \to \pi^+\pi^-\eta$ 6.8% for $\eta' \to \gamma\pi^+\pi^-$**





The process with almost no background is good for the PWA

Mass spectrum after final selection



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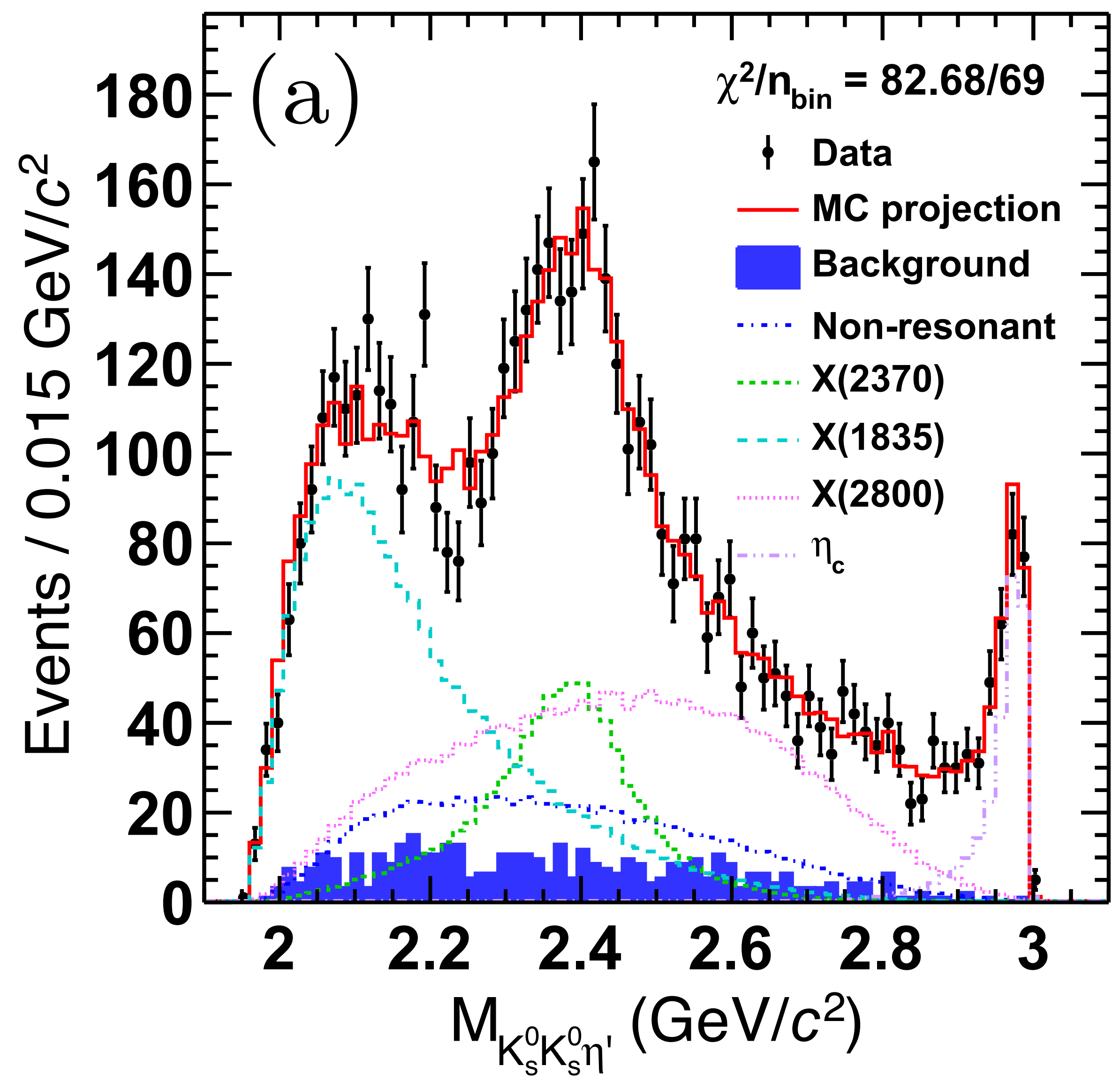
- **Similar structures in $\eta' \to \pi^+\pi^-\eta$ / $\gamma\pi^+\pi^-$ modes:**
  - Evident $f_0(980)$ in $K^0_sK^0_s$ mass threshold
  - **A clear connection between the $f_0(980)$ and X(2370)**
- **$f_0(980)$ selection with $M(K^0_sK^0_s)$ <1.1GeV/c^2**
  - Clear signal of the X(2370) and η_c
  - Reduce PWA complexities from additional intermediate processes

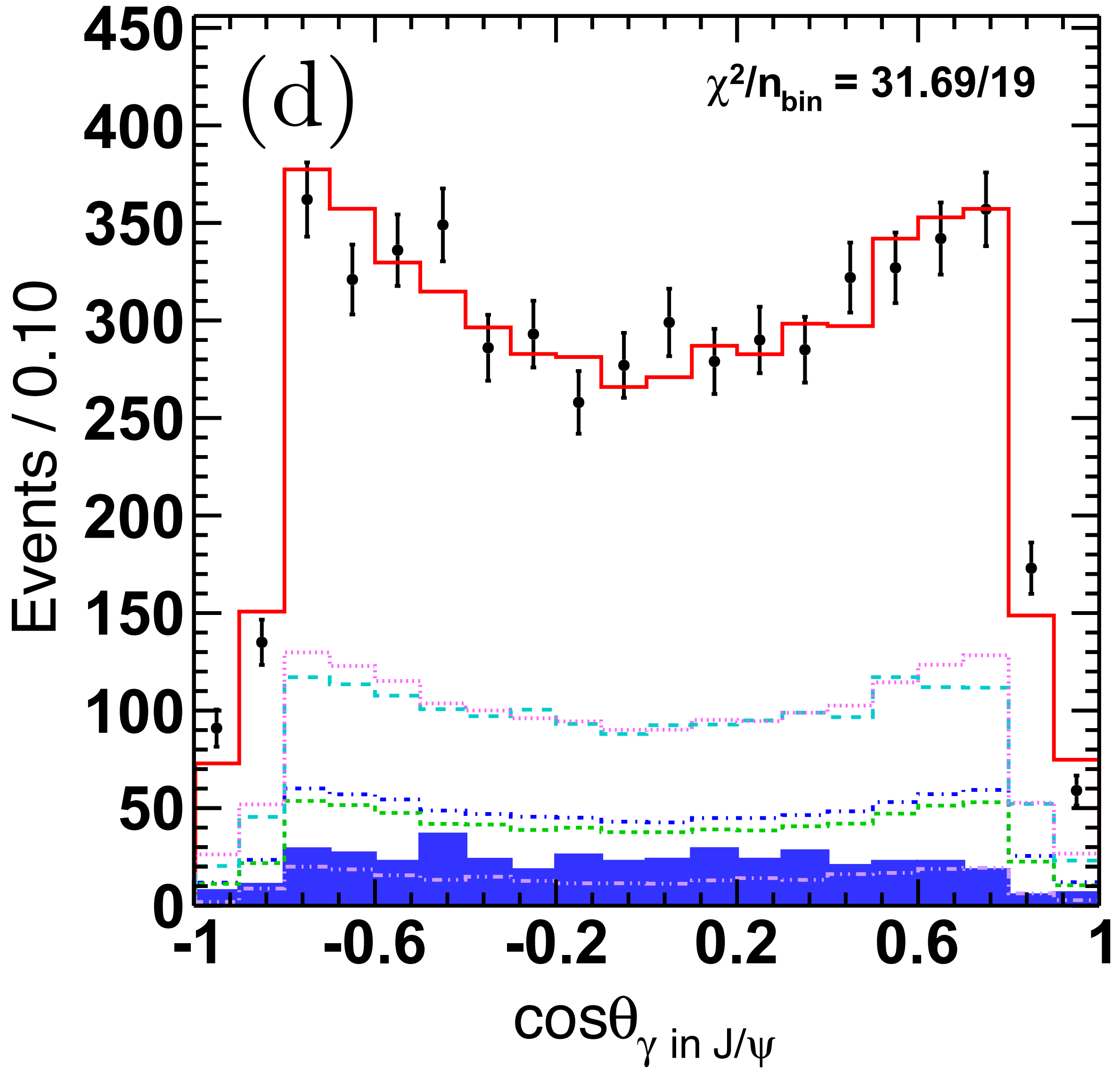
Partial wave analysis

- It is necessary to perform partial wave analysis：
  - To determine quantum numbers and interferences
- Amplitude construction with **covariant tensor formalism** [EPJA 16 (2003) 537]
- **Parametrization with quasi-sequential two-body decays (only spin J(X)<3 states):**
  - $J/\psi \to \gamma X$, $X \to Y\eta'$: Y represent $K^0_S K^0_S$
  - $J/\psi \to \gamma X$, $X \to Z K^0_S$: Z represent $K^0_S\ \eta'$
- **An un-binned maximum likelihood fit** on the combination of $\eta' \to \pi^+\pi^-\eta$ / $\gamma\pi^+\pi^-$ modes:
  - Non-η' background subtraction with the NLL values of events from η' sideband region

$$S = (-\ln \mathcal{L})_{data} - (-\ln \mathcal{L})_{bg} = -\left(\sum_{i=1}^{N_{data}} \ln \frac{\omega(\xi_i)}{\sigma}\right) + f_{norm} \cdot \left(\sum_{i=1}^{N_{sideband}} \ln \frac{\omega(\xi_i)}{\sigma}\right)$$

PWA Fit





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- Best fit can well describe the data including resonances (>5σ): **X(1835), X(2370), X(2800), η_c**
  - **Spin-parity of the X(2370) is determined to be 0^{-+}** with significance larger than 9.8σ w.r.t. other J^{PC} assumptions
  - X(2800): a broad structure for the effective contributions from possible high mass resonances and the tail of η_c lineshape

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^{-+}	$\eta'(K_S^0 K_S^0)_{S-wave}$	− − −	− − −	9.0σ
		$\eta'(K_S^0 K_S^0)_{D-wave}$	− − −	− − −	16.3σ

PWA Validations

- **Additional decay modes: significance <3σ and impact is ignored**
  - **J^{PC} and decay modes for each components**: $f_0(1500)\eta'$, $f_2(1270)\eta'$, $K^*(1410)K_s^0$, $K_0^*(1430)K_s^0$, $K_0^*(1430)K_s^0$, $K_2^*(1430)K_s^0$, $K_0^*(1680)K_s^0$, $(K_s^0K_s^0)_S\eta'$, $(K_s^0K_s^0)_D\eta'$, $(K_s^0\eta')_PK_s^0$, $(K_s^0\eta')_DK_s^0$
- **Additional resonance checks: significance <5σ**
  - No evidence of the **X(2120)** in the K_sK_s mass threshold region for $J/\psi\to\gamma K_sK_s\eta'$ only
  - The significance of **$X(2600)\to f_0(980)\eta'$** is 4.2σ
  - Impact from the X(2120) and X(2600) is taken into account as systematic uncertainty
- **The X(2800)** with a mass of 2799 MeV and width of 660 MeV:
  - Used to described effective contributions from high mass region
  - **Strongly reply on the description of η_c lineshape:** different variations are included into the systematic uncertainty
  - Statistical uncertainties of the X(2800) mass and width are included in the systematic uncertainties on the X(2370) measurements

Final results

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

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

M = 2395 ±11$^{+26}_{-94}$ MeV

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

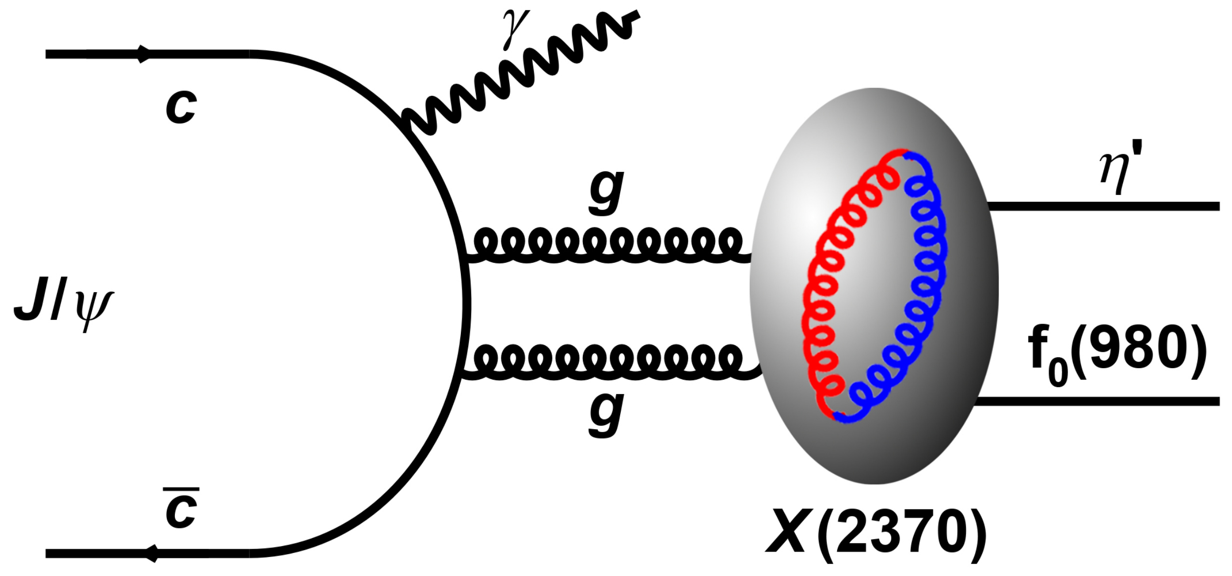
$B(J/\psi\to\gamma X(2370))B(X(2370)\to f_0(980)\eta')B(f_0(980)\to K^0_S K^0_S)$
$= 1.31 \pm 0.22^{+2.85}_{-0.84} \times 10^{-5}$

LQCD prediction on lightest pseudoscalar glueball:

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

M = 2395 ±14 MeV

$B(J/\psi\to\gamma G_{0-+}) = 2.31 \pm 0.80 \times 10^{-4}$ PRD 100 (2019) 054511

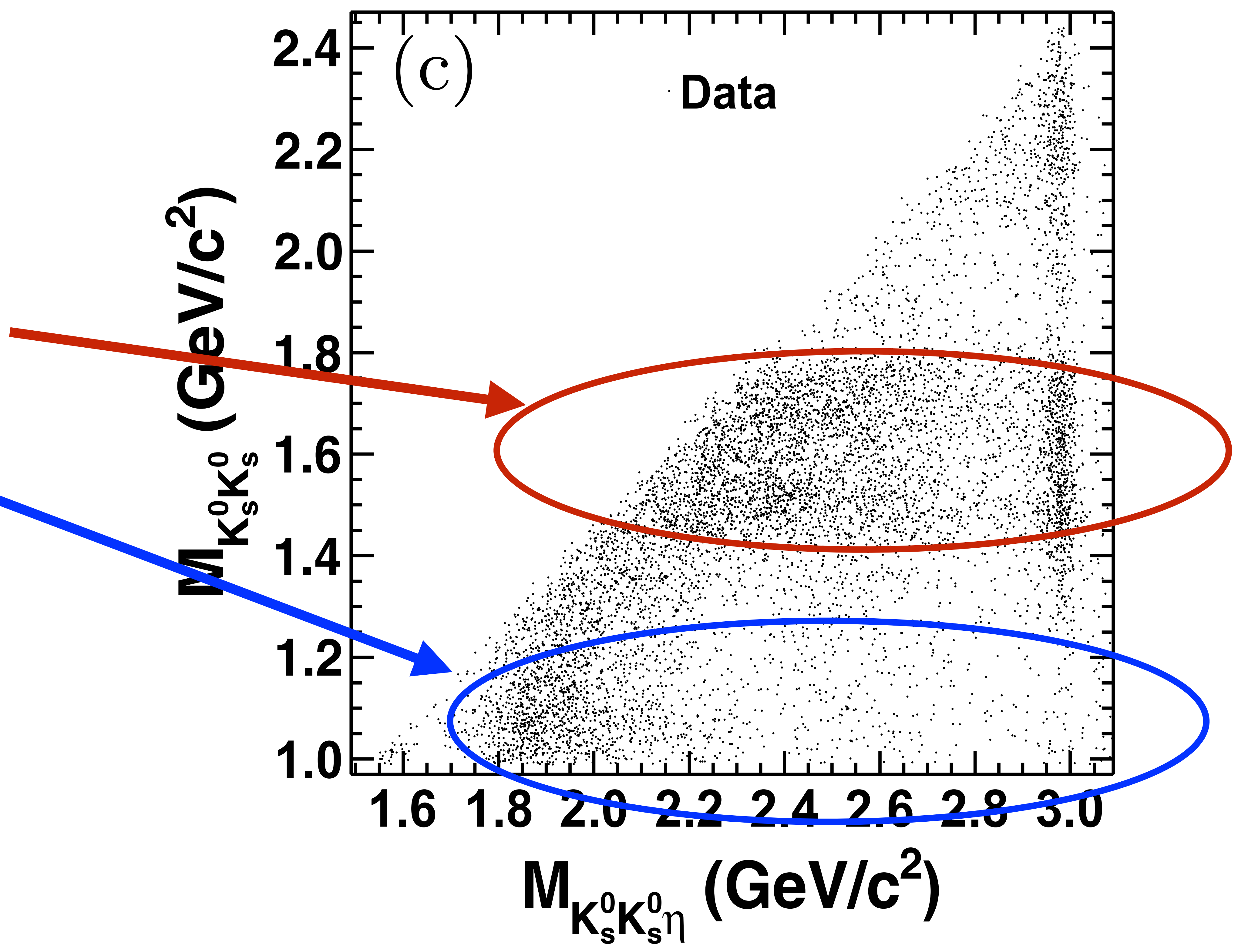


- The measurements are in a agreement with the predictions on **lightest pseudoscalar glueball**
  - **The spin-parity of the X(2370) is determined to be 0^{-+} for the first time**
  - **Mass is in a good agreement with LQCD predictions**
  - The estimation on $B(J/\psi\to\gamma X(2370))$ and prediction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

Study 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:
  - **In the upper M_{KK} mass band of 1.5-1.7GeV range, clear signals of both X(2370) and η_c**
  - **In the lower M_{KK} mass band of $f_0(980)$, no X(2370), nor η_c.**
- Such high similarity between X(2370) and η_c decay modes also strongly supports the glueball interpretation of the X(2370).



PRL 115 (2015) 091803

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) is the first particle that matches the theoretical expectations for a glueball**
  - **Spin-parity quantum numbers** are determined to be $J^{pc} = 0^{-+}$
  - Measurements and predictions on **mass and production rate** are consistent within errors
  - **production and decay properties:** the X(2370) is observed in J//ψ radiative decay and flavor symmetric decay modes (favorite decay modes of 0^{-+} glueball)

— Glueball-like particle, X(2370) is discovered by BESIII

Many thanks to the efficient work:
The BESIII detector maintenance and offline software teams, computing center
The BEPCII accelerator operation team which provide stable detector operation

Prospects

- **More decay modes of the X(2370) will be studied at BESIII**
  - Including KKπ, ππη
  - To check their similarities with η_c, and to understand the decay pattern of this glueball-like particle
- **Improve the measurements on the mass, width, branching ratio and production rates of the X(2370)**
  - Need to have better ways to understand and control the interferences in PWA.
- **Looking forward to more reliable LQCD studies on the glueball properties**

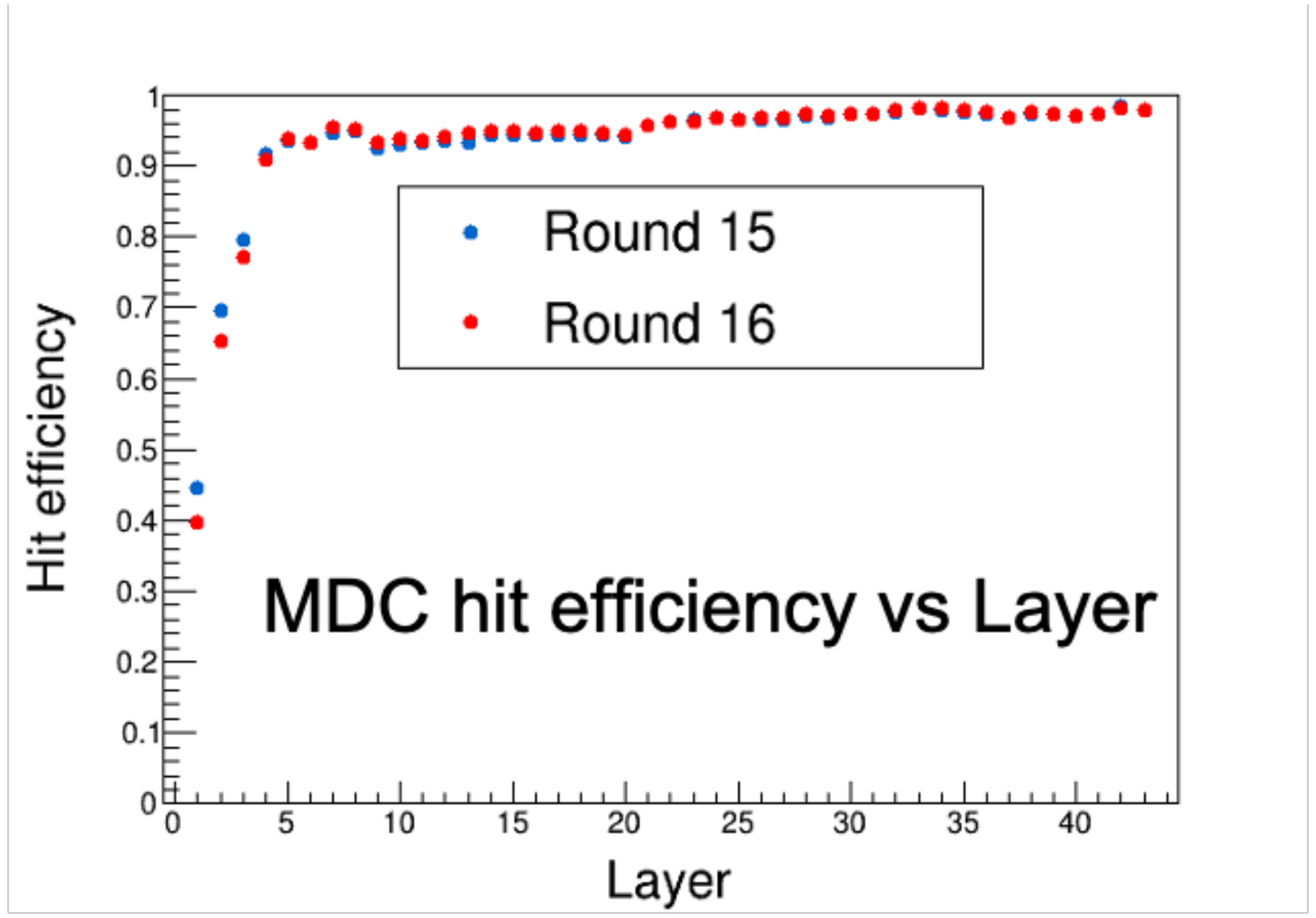
Back-up

Exps.	MDC Wire reso.	MDC dE/dx Reso.	EMC Energy reso.
CLEO	110 μm	5%	2.2-2.4 %
Babar	125 μm	7%	2.67 %
Belle	130 μm	5.6%	2.2 %
BESIII	115 μm	<5% (Bhabha)	2.3%

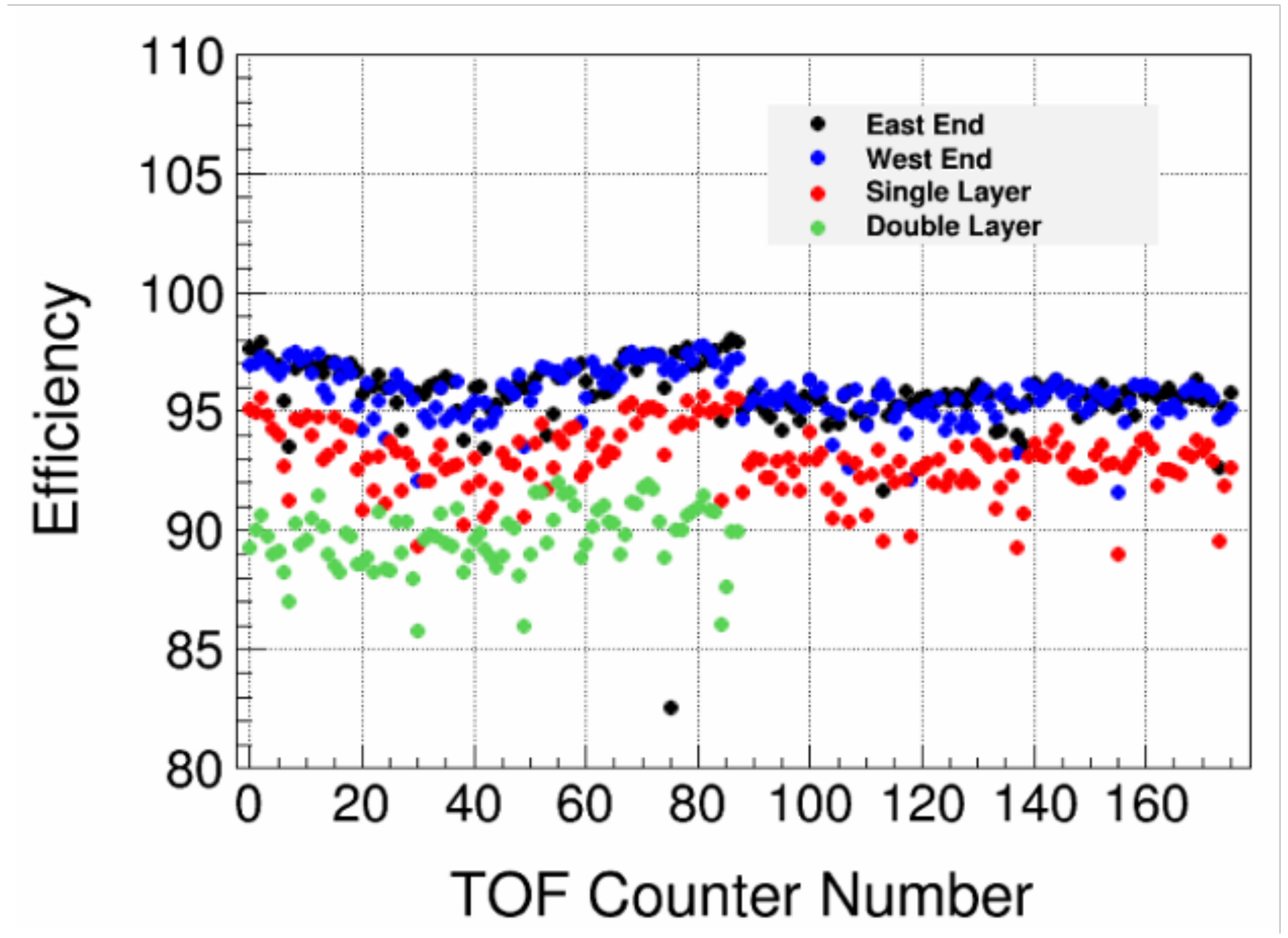
Exps.	TOF time reso.
CDFII	100 ps
Belle	90 ps
BESIII	68 ps (Barrel) 98 ps (Endcap) 60 ps(Endcap, MRPC)

MUC: Eff. ~ 96%

Noise: < 0.04 Hz/cm^2(Barrel), < 0.1 Hz/cm^2(Endcap)



Round 15
Round 16
MDC hit efficiency vs Layer
Hit efficiency
Layer



East End
West End
Single Layer
Double Layer
Efficiency
TOF Counter Number

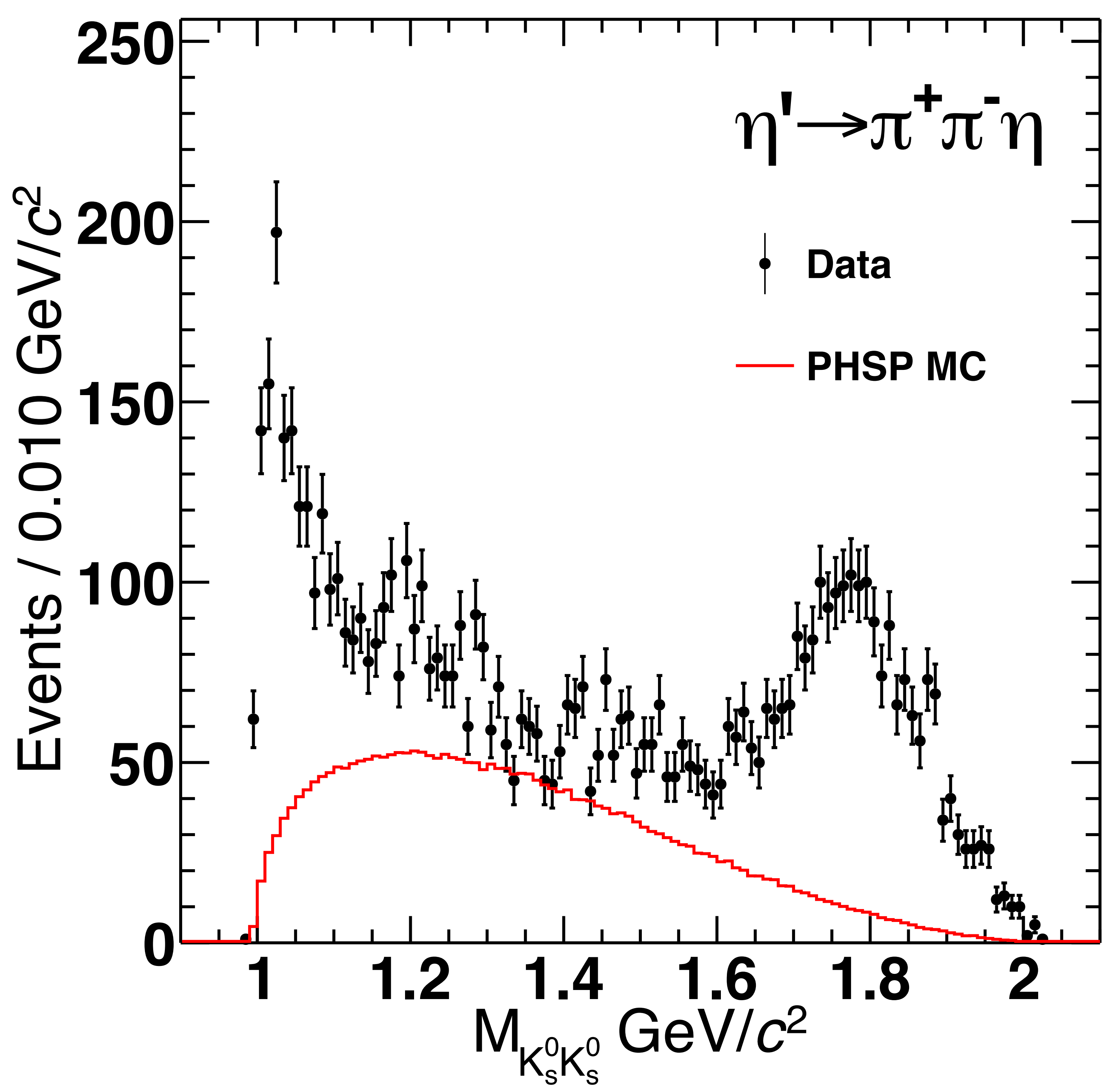
LQCD prediction

By applying the variational method to a large operator set, we obtain an optimal operator which couples predominantly to the ground state pseudoscalar glueball G. In this work, m_G is determined to be 2.395(14) GeV, and the on-shell form factor of $J/\psi \to \gamma G$ is derived as $\hat{V}(0) = 0.0246(43)$, in the continuum limit, from which we obtain the following partial decay width and the production rate

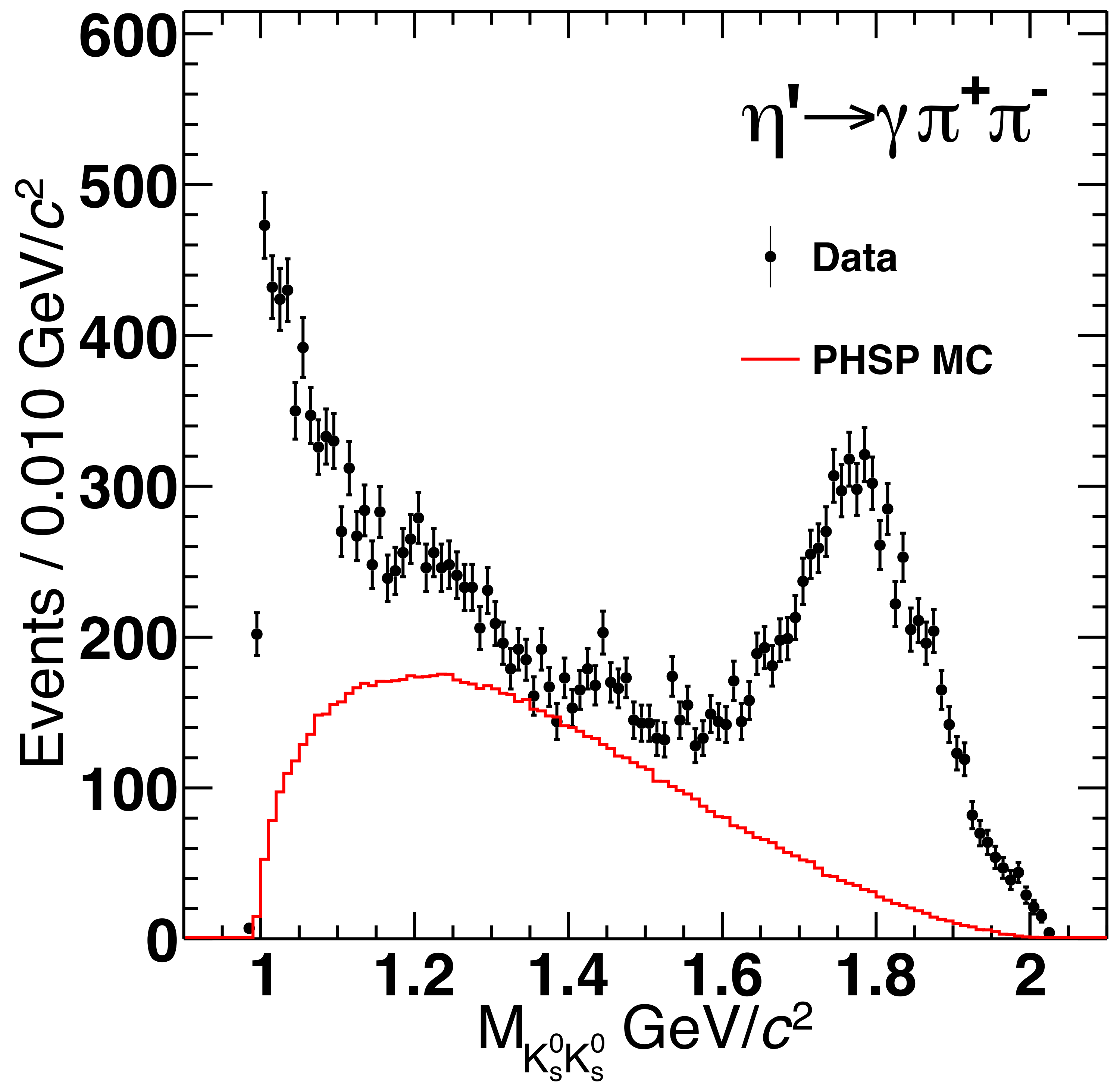
$$\Gamma(J/\psi \to \gamma G_{0^{-+}}) = 0.0215(74)\ \text{keV}$$
$$\text{Br}(J/\psi \to \gamma G_{0^{-+}}) = 2.31(80) \times 10^{-4}. \qquad (32)$$

We introduce an effective coupling g_X to describe the interaction between the pseudoscalar X and the gluonic intermediate states in the processes $J/\psi \to \gamma X$, as defined in Eq. (30). It is interesting to see that all the g_X's are comparable for the pseudoscalar glueball and the non-flavored $q\bar{q}$ pseudoscalars (η states). We tentatively attribute the large production rates of the η states to the QCD $U_A(1)$ anomaly which is totally a nonperturbative effect.

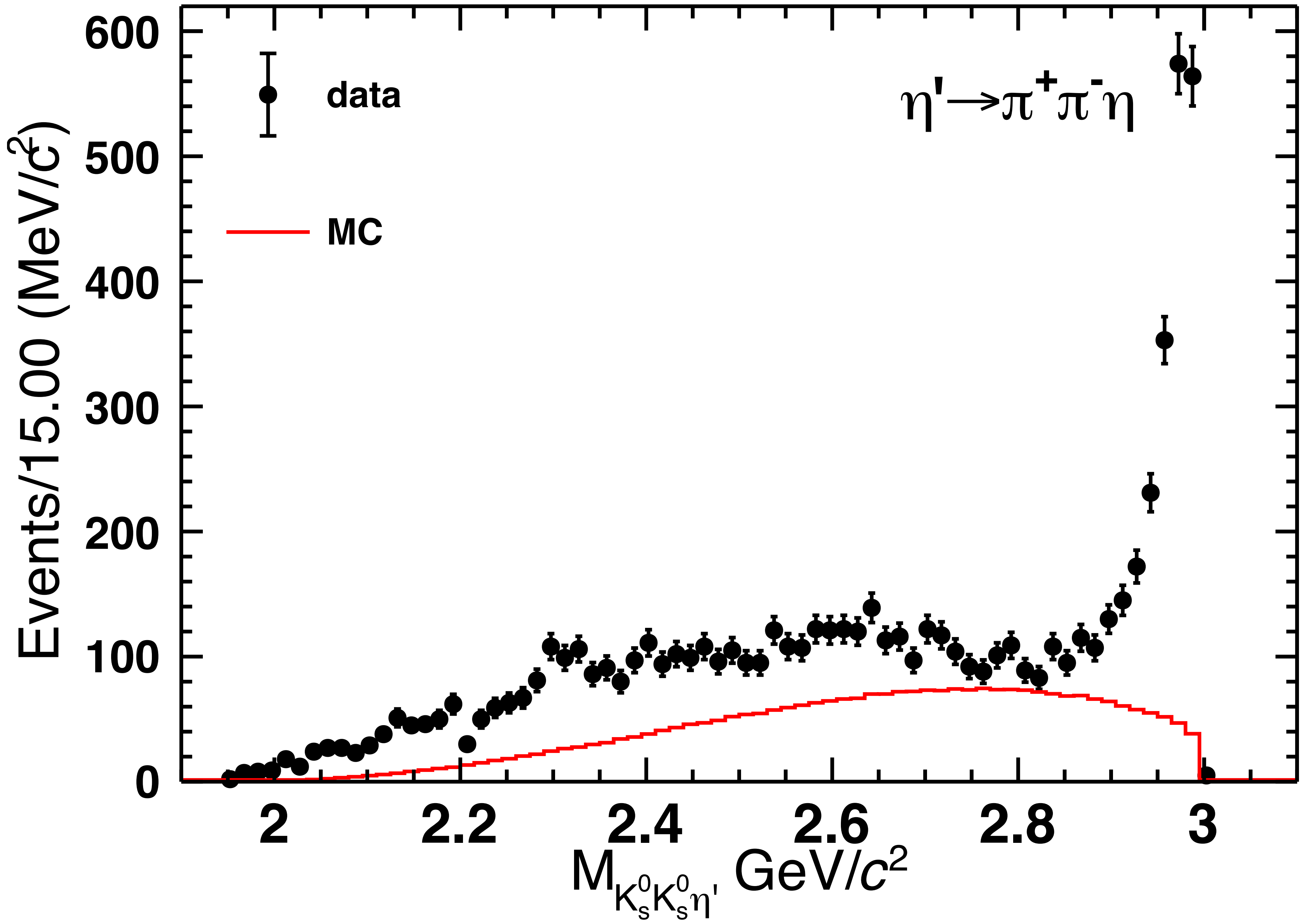
Even though this study is performed in the quenched approximation and the uncertainty in the presence of dynamical quarks is not controlled, we hope our result can provide useful theoretical information for experiments to unravel the properties of the possible pseudoscalar glueball.

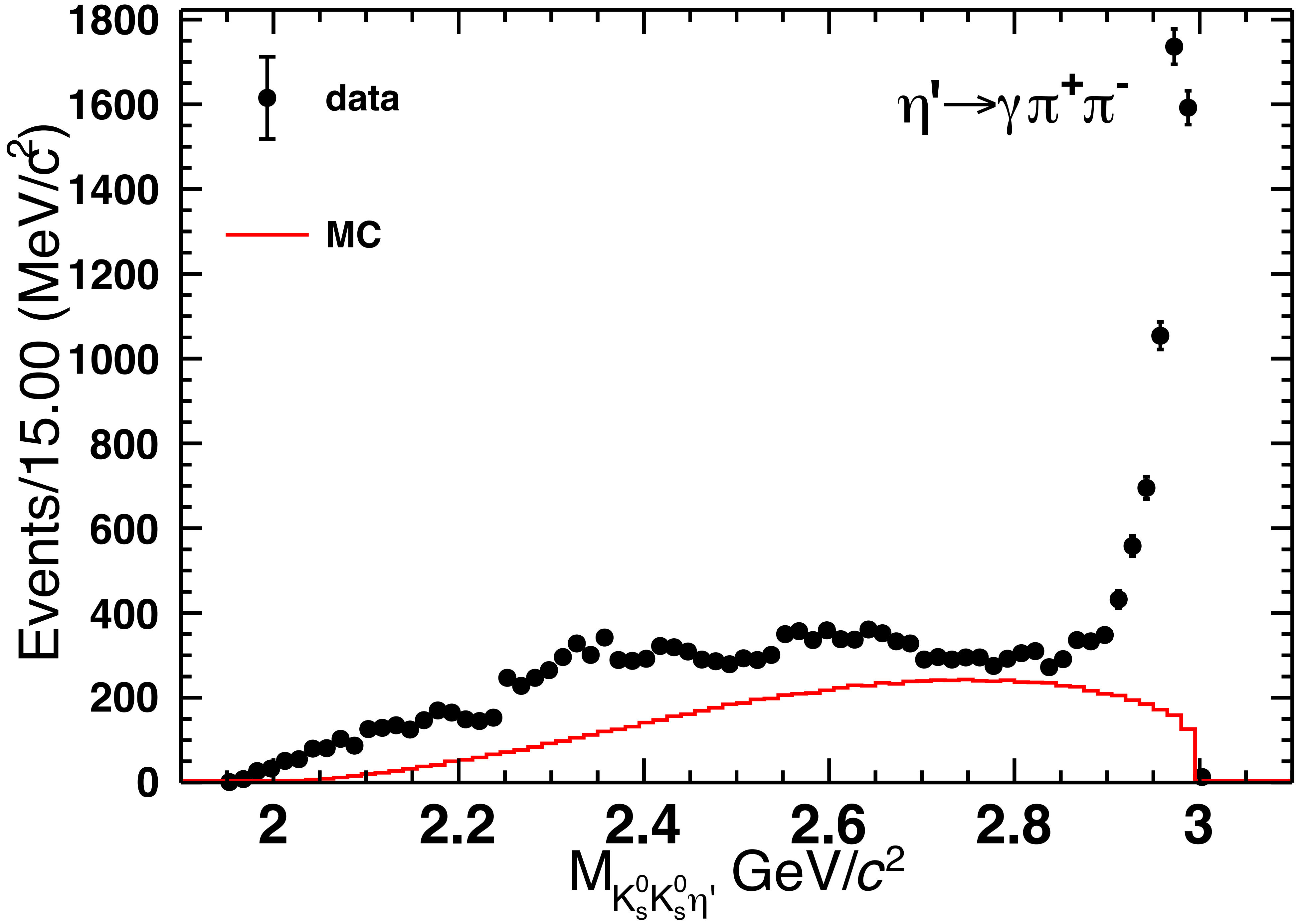


η'→π+π-η
Data
PHSP MC
Events / 0.010 GeV/c2
0
50
100
150
200
250
1
1.2
1.4
1.6
1.8
2
MKs0Ks0 GeV/c2



η'→γπ+π-
Data
PHSP MC
Events / 0.010 GeV/c2
0
100
200
300
400
500
600
1
1.2
1.4
1.6
1.8
2
MKs0Ks0 GeV/c2


data
MC
η'→π+π-η
Events/15.00 (MeV/c2)
M K0sK0sη' GeV/c2


data
MC
η'→γπ+π-
Events/15.00 (MeV/c2)
M K0sK0sη' GeV/c2

Sources	ΔM (MeV/c^2)	$\Delta\Gamma$ (MeV)	$\Delta\mathcal{B}/\mathcal{B}(\%)$
Event selection	$\cdots$	$\cdots$	± 4.8
Background estimation	$+2$	$^{+4}_{-4}$	$^{+3.7}_{-5.1}$
$f_0(980)$ parametrization	-6	$+7$	± 5.3
X(1835) parametrization	$^{+15}_{-12}$	$^{+24}_{-11}$	$^{+20.2}_{-8.3}$
η_c parametrization	-13	-8	-14.5
Breit-Wigner formula	-1	$+6$	-8.3
Broad 0^{-+} structure	-88	$^{+111}_{-21}$	$^{+211.8}_{-56.5}$
Additional resonances	$^{+22}_{-25}$	$^{+48}_{-21}$	$^{+41.9}_{-20.8}$
Total	$^{+26}_{-94}$	$^{+124}_{-33}$	$^{+217.0}_{-63.7}$

component	$X(2370)\to f_0(980)\eta'$	$X(1835)\to f_0(980)\eta'$	$X(2800)\to f_0(980)\eta'$	$\eta_c\to f_0(980)\eta'$	$PHSP\to\eta'(K_S^0K_S^0)_{S-wave}$	$PHSP\to\eta'(K_S^0K_S^0)_{D-wave}$
$X(2370)\to f_0(980)\eta'$	1.00	1.12	1.15	0.08	-1.23	0.02
$X(1835)\to f_0(980)\eta'$		1.00	0.32	-0.07	-1.41	0.01
$X(2800)\to f_0(980)\eta'$			1.00	0.33	-1.18	0.02
$\eta_c\to f_0(980)\eta'$				1.00	0.11	0.00
$PHSP\to\eta'(K_S^0K_S^0)_{S-wave}$					1.00	-0.02
$PHSP\to\eta'(K_S^0K_S^0)_{D-wave}$						1.00