Highlights of Recent BESIII Results

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Outline

- **Status of BEPC-II and BESIII**
- **R-Value measurement** PRL 128, 062004 (2022)
- **Results from radiative J/ψ decays**
  - **New discovery of X(2600) in $J/\psi \to \gamma\pi^+\pi^-\eta'$** PRL 129, 042001 (2022)
  - **EM Dalitz decay $J/\psi \to e^+e^-\pi^+\pi^-\eta'$** PRL 129, 022002 (2022)
  - **Light Higgs boson A^0 search** PRD 105, 012008 (2022)
- **Observation of $D^0 \to \omega\phi$** PRL 128, 011803 (2022)
- **Summary and outlook**

Beijing Electron Positron Collider II

https://english.ihep.ac.cn/

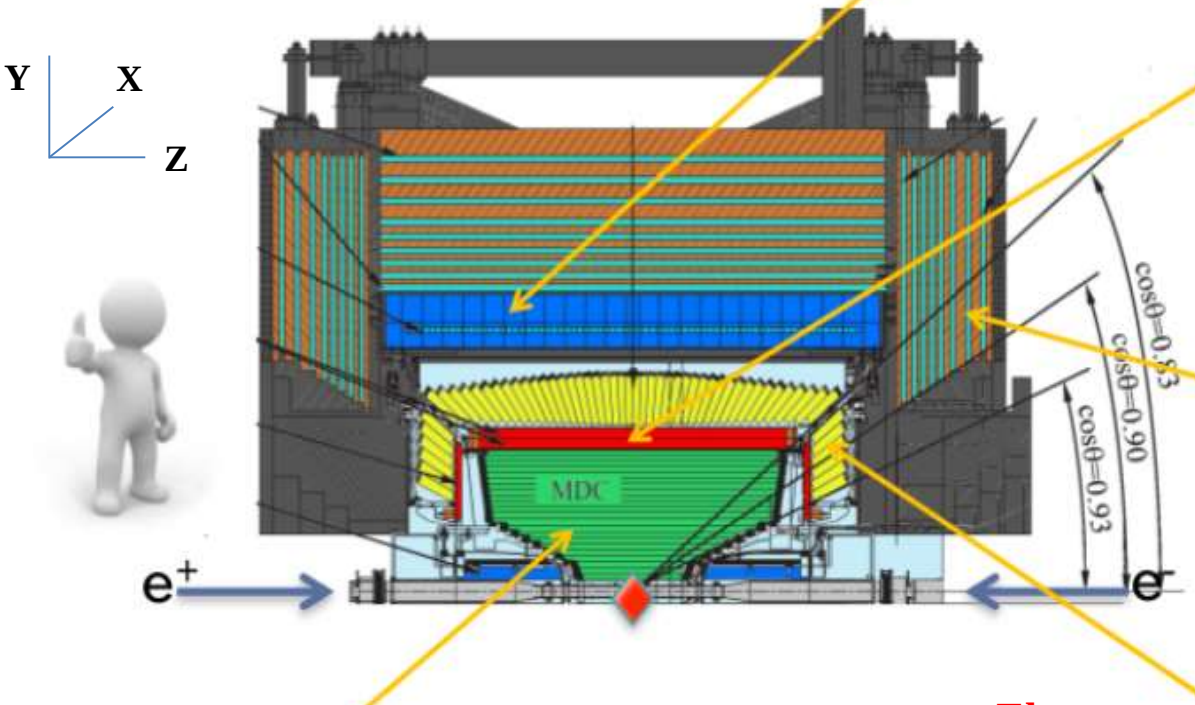
2004: started BEPCII/BESIII construction

- ✓ **Double rings**
- ✓ **Beam energy: 1-2.45 GeV**
- ✓ **Design luminosity: 1×10^{33} $cm^{-2}s^{-1}$ @ $\psi(3770)$, achieved in 2016**

2009 – today: BESIII physics runs

BESIII Experiment

BESIII experiment is a symmetric electron positron collider running at tau-charm region.



Super conducting magnet

✓ 1 Tesla

[Nucl. Instrum. Meth. A614, 345-399 (2010)]

Time of Flight (TOF)

- 2 layer plastic scintillators
- $\sigma_T \approx 80$ ps (barrel)
- $\sigma_T \approx 110$ ps (endcap) (~65 ps after upgradation with MRPC)
- Particle id

Muon system

- 9 layers of RPC
- P > 400 MeV/c
- $\delta R\phi \approx 1.4 - 1.7$ cm

Multilayer drift chamber (MDC)

- He/C_3H_8 (60/40)
- 43 layers
- Momentum resolution $\sigma_p/p \approx 0.5\%$ @ 1 GeV
- Spatial resolution $\sigma_{xy} \approx 130$ μm.

Electromagnetic calorimeter (EMC) (CsI(Tl))

→ 6240 crystals overall

- $\sigma(E)/E \approx 2.5\%$
- $\sigma_{Z,\phi}(E) \approx$ 0.5 – 0.7 cm

**Will replace the inner part of the drift chamber by the three layers of CGEM detector during Jan-Jun., 2024

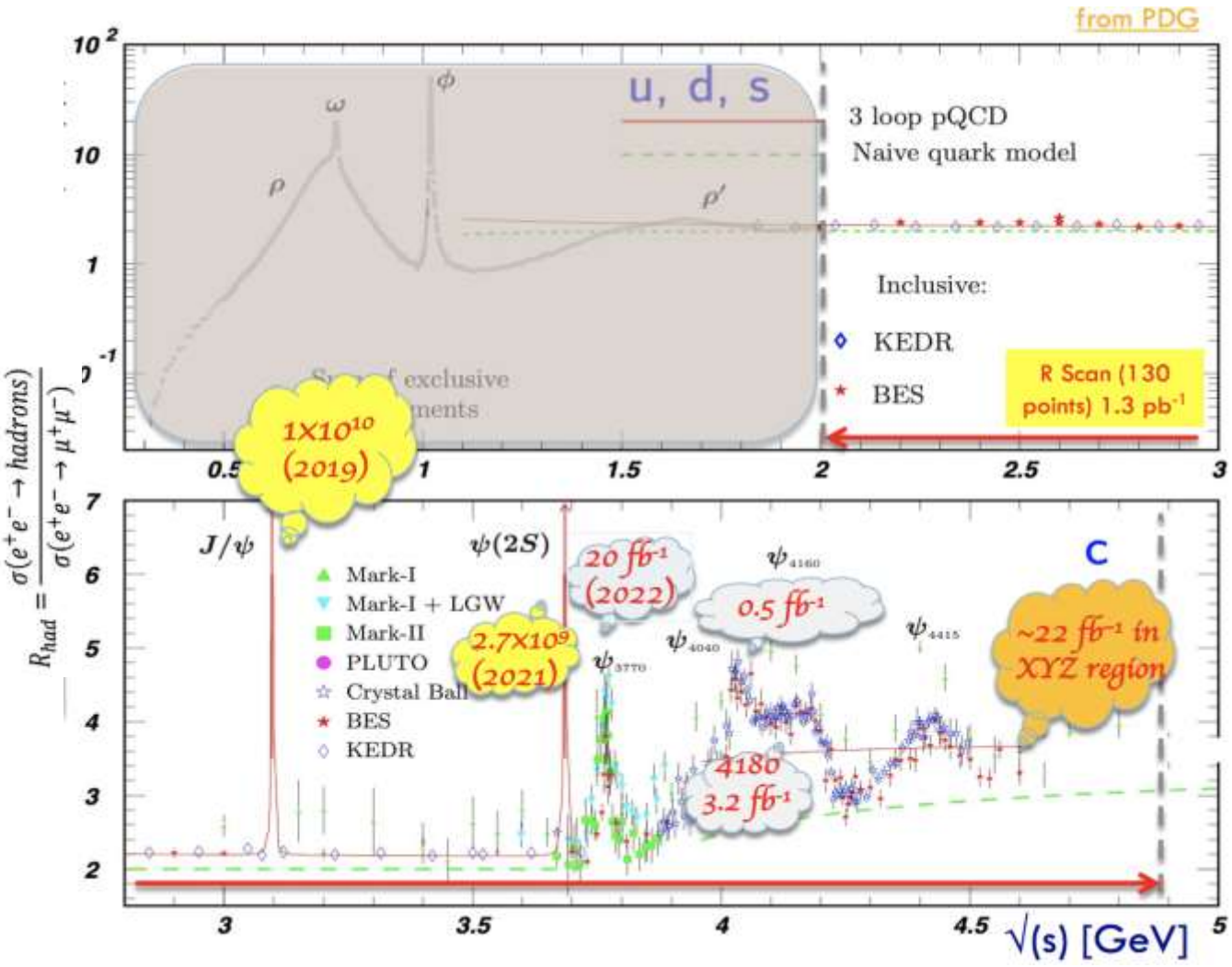
BESIII Data-set

- 130 points between 2 and 4.6 GeV (715 pb^{-1} up to 3.08 GeV for ρ, ω, ϕ studies.

- Light Hadron Spectroscopy
- η/η' decays
- Hyperon physics
- Charmonium transitions
- New physics

- Charm physics
- ISR processes

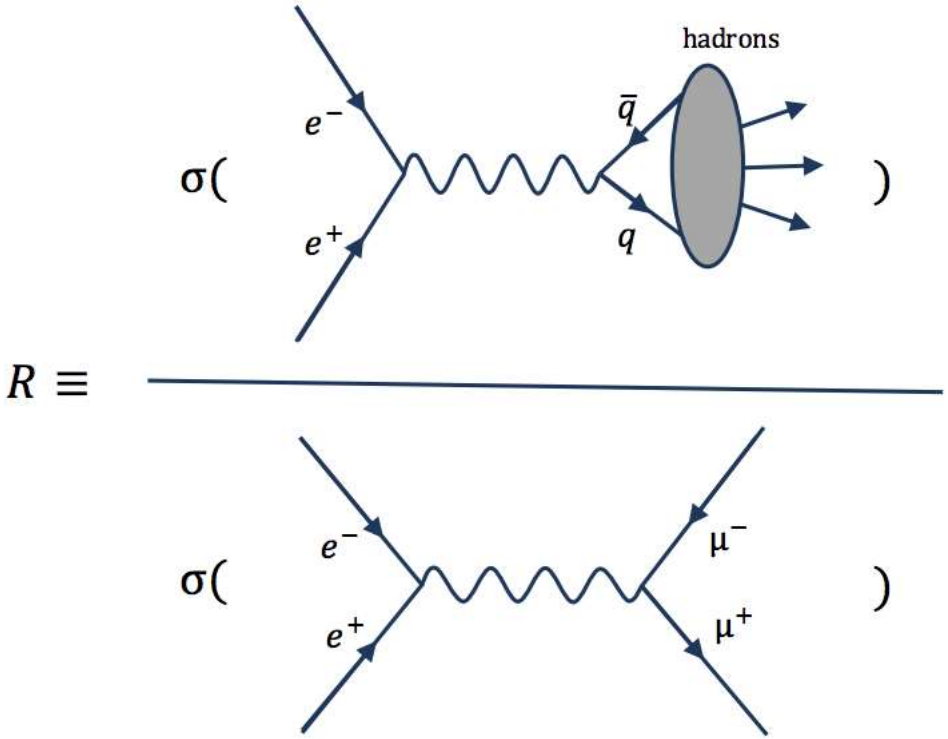
- XYZ physics and spectroscopy.
- Open charm production
- Charmed baryons



First data at higher CM energies is now available at ($4.7 < \sqrt{s} < 4.94$ GeV)

R-Value Measurement

PRL 128, 062004 (2022)



http://bes3.ihep.ac.cn/hi/202203/t20220301_301719.html

R-Value Measurement

PRL 128, 062004 (2022)

- R-Value is the ratio of leading-order production cross sections of hadrons and muon-pairs in e^+e^- collisions

$$R \equiv \frac{\sigma^0(e^+e^- \to \text{hadrons})}{\sigma^0(e^+e^- \to \mu^+\mu^-)} \equiv \frac{\sigma^0_{\text{had}}}{\sigma^0_{\mu\mu}}$$

With $\sigma^0_{\mu\mu}$ directly from QED: $\sigma^0_{\mu\mu} = \frac{4\pi\alpha}{3s}\frac{\beta_\mu(3-\beta\mu^2)}{2}$, with $\beta_\mu = \sqrt{1-\frac{4m_\mu^2}{s}}$

- Important input to current tests of Standard Model

Running of the Fine Structure Constant $\Delta\alpha_{em}$

$\alpha(m_Z^2)$ one of three essential observables for electroweak precision physics

$$\Delta\alpha = 1 - \frac{\alpha(0)}{\alpha(s)} = \Delta\alpha_{\text{lepton}}(s) + \Delta\alpha^{(5)}_{\text{had}}(s) + \Delta\alpha_{\text{top}}(s)$$

From perturbation theory

Hadronic Vacuum Polarization contribution

top quark contribution

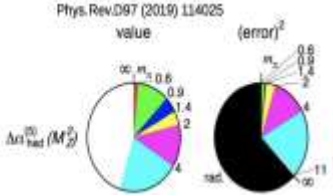
$$\Delta\alpha^{(5)}_{\text{had}}(s) = -\frac{\alpha s}{3\pi}\text{Re}\int_{E_{th}}^{\infty} ds' \frac{R(s')}{s'(s'-s-i\varepsilon)}$$

R-Value over wide energy range important input: $\Delta\alpha^{(5)}_{\text{had}}(M_Z^2)$

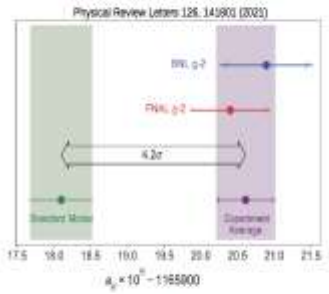
Source	Contribution ($\times 10^{-4}$)
$\Delta\alpha_{\text{lepton}}(M_Z^2)$	314.979 ± 0.002
$\Delta\alpha^{(5)}_{\text{had}}(M_Z^2)$	276.0 ± 1.0
$\Delta\alpha_{\text{top}}(M_Z^2)$	-0.7180 ± 0.0054

Eur.Phys.J. 80 (2020) 241

Phys.Rev.D97 (2019) 114025



Anomalous Magnetic Moment of the Muon



Muon anomaly $a_\mu = \frac{g_\mu - 2}{2}$

- Less than 0.5 ppm accuracy in experiment and theory
  - Exp: $116\,592\,061(41) \times 10^{-11}$ (Physical Review Letters 126, 141801 (2021))
  - SM: $116\,591\,810(43) \times 10^{-11}$ (Physics Reports 887 (2020) 1–16)
- Discrepancy between SM prediction and experiment
- Hadronic contributions dominate uncertainty of a_μ^{SM}

Hadronic Vacuum Polarization contribution:

- Dispersion integral
- R-Value as experimental input

$$a_\mu^{HVP} = \left(\frac{\alpha m_\mu}{3\pi}\right)^2 \int_{2m_\pi}^{\infty} ds \frac{R(s)K(s)}{s^2}$$

- Tension with latest Lattice QCD calculations

R-Value determination

PRL 128, 062004 (2022)

- Used 14 center-of-mass energy points: $\sqrt{s} = [2.2324, 3.6710]$ GeV

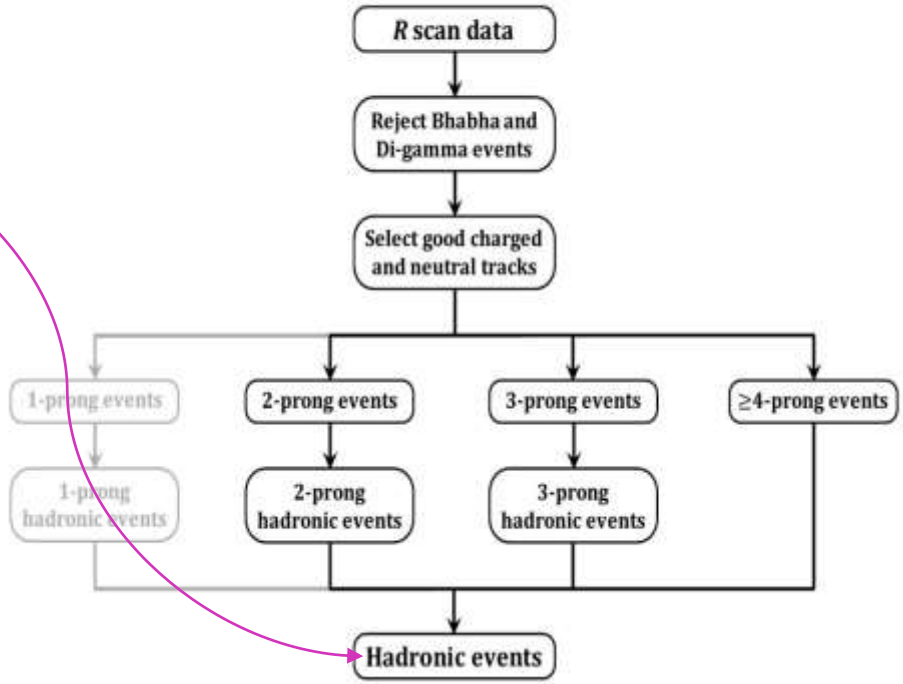
- Experimentally, the R value is determined by

$$R = \frac{N_{\text{had}}^{\text{obs}} - N_{\text{bkg}}}{\sigma_{\mu\mu}^{0}\mathcal{L}_{\text{int.}}\varepsilon_{\text{trig}}\varepsilon_{\text{had}}(1+\delta)}$$

LUARLW model, developed to simulate inclusive hadronic events, to estimate the hadronic detection efficiency.

[arXiv:hep-ph/9910285]

Analysis Stategy



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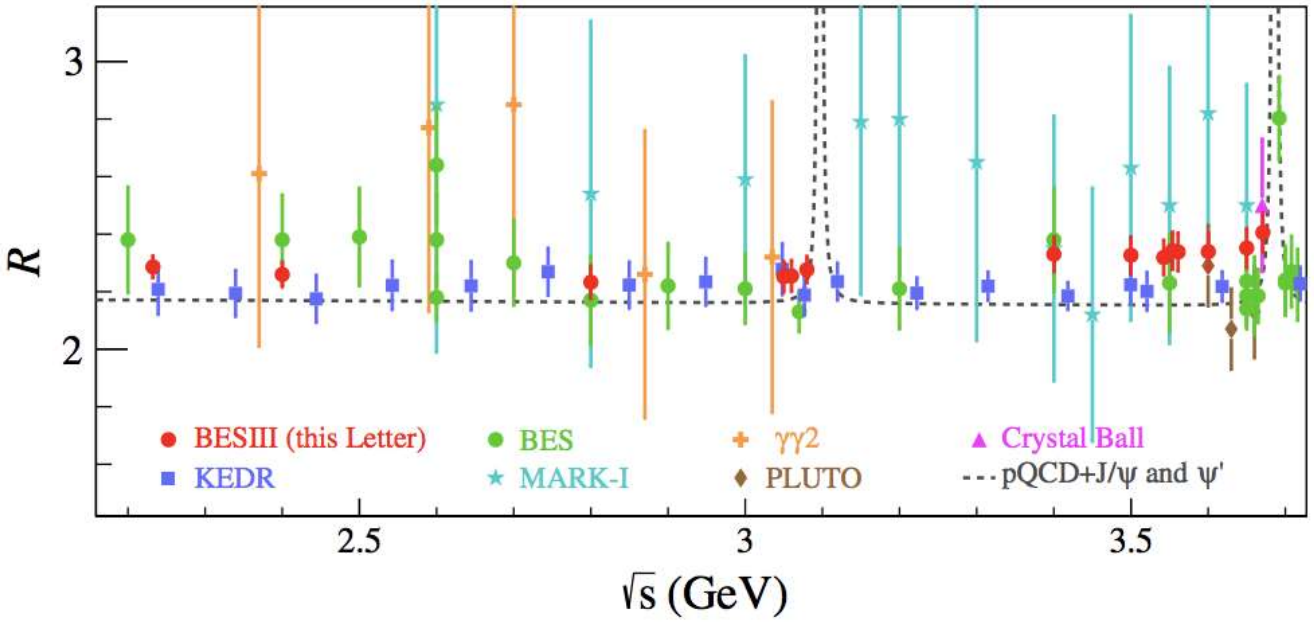


$\sqrt{s}$ (GeV)	N_{had}^{obs}	N_{bkg}	$\sigma_{\mu\mu}^{0}$ (nb)	$\mathcal{L}_{int}$ (pb^{-1})	ε_{had} (%)	$1+\delta$	R
2.2324	83 227	2041	17.427	2.645	64.45	1.195	$2.286 \pm 0.008 \pm 0.037$
2.4000	96 627	2331	15.079	3.415	67.29	1.204	$2.260 \pm 0.008 \pm 0.042$
2.8000	83 802	2075	11.078	3.753	72.25	1.219	$2.233 \pm 0.008 \pm 0.055$
3.0500	283 822	7719	9.337	14.89	73.91	1.193	$2.252 \pm 0.004 \pm 0.052$
3.0600	282 467	7683	9.276	15.04	73.88	1.183	$2.255 \pm 0.004 \pm 0.054$
3.0800	552 435	15 433	9.156	31.02	73.98	1.123	$2.277 \pm 0.003 \pm 0.046$
3.4000	32 202	843	7.513	1.733	74.81	1.382	$2.330 \pm 0.014 \pm 0.058$
3.5000	62 670	1691	7.090	3.633	75.32	1.351	$2.327 \pm 0.010 \pm 0.062$
3.5424	145 303	3872	6.921	8.693	75.58	1.341	$2.319 \pm 0.006 \pm 0.060$
3.5538	92 996	2469	6.877	5.562	75.50	1.338	$2.342 \pm 0.008 \pm 0.064$
3.5611	64 650	2477	6.849	3.847	75.50	1.337	$2.338 \pm 0.010 \pm 0.066$
3.6002	159 644	9817	6.701	9.502	75.73	1.328	$2.339 \pm 0.006 \pm 0.065$
3.6500	78 730	6168	6.519	4.760	76.00	1.308	$2.352 \pm 0.009 \pm 0.067$
3.6710	75 253	6461	6.445	4.628	76.11	1.260	$2.405 \pm 0.010 \pm 0.067$

Accuracy ~2.6% @ √s < 3.1 GeV and ~3.0% @ √s > 3.1 GeV

R-Value consistent with KEDR result [Phys. Lett. B 788, 42 (2019)] and QCD prediction [Phys. Lett. B 714, 62 (2012)]

Radiative J/ψ decays

- **New discovery of X(2600) in $J/\psi \to \gamma\pi^+\pi^-\eta'$** PRL 129, 042001 (2022)

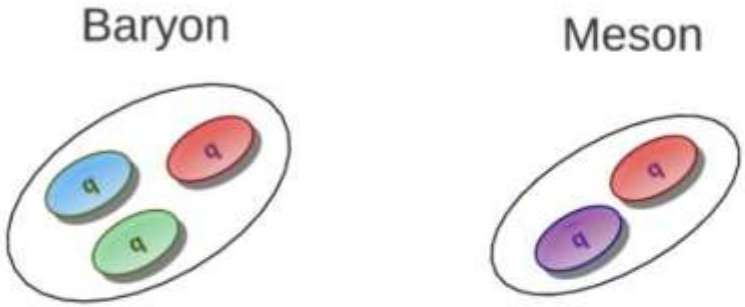
  http://bes3.ihep.ac.cn/hi/202207/t20220720_308453.html

- **EM Dalitz decay $J/\psi \to e^+e^-\pi^+\pi^-\eta'$** PRL 129, 022002 (2022)

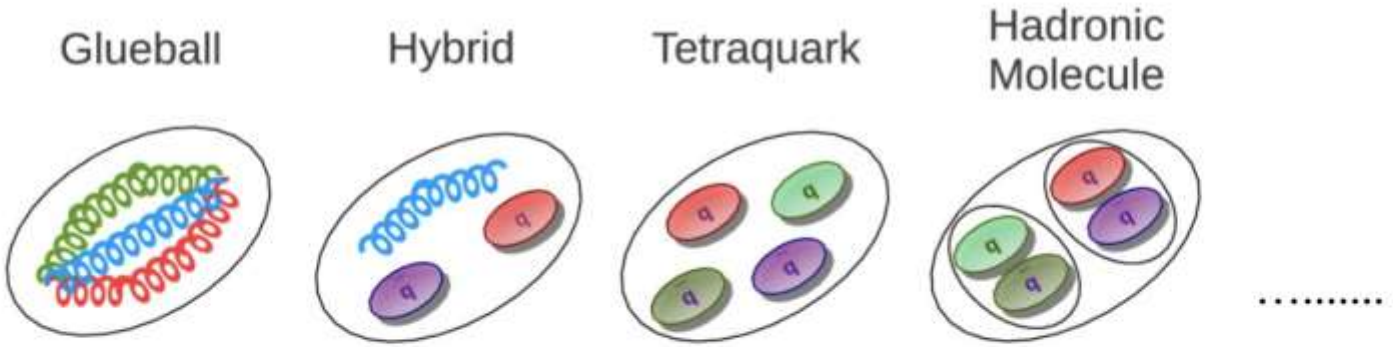
- **Light Higgs boson A^0 search** PRD 105, 012008 (2022)

Hadron spectrum

Naïve Quark Model:
conventional hadrons
contain two or three quarks



… ***but*** QCD allows also different combinations of quarks and gluons: ***EXOTIC*** hadrons



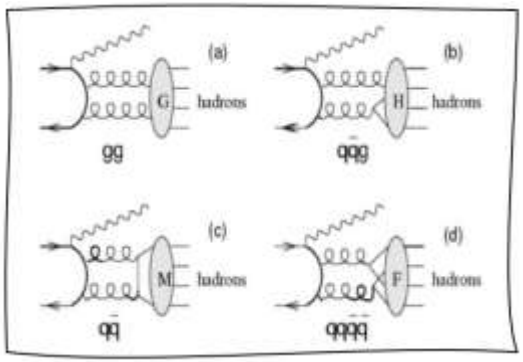
A lot of exotic states observed experimentally, but their nature is still far from being understood!!!

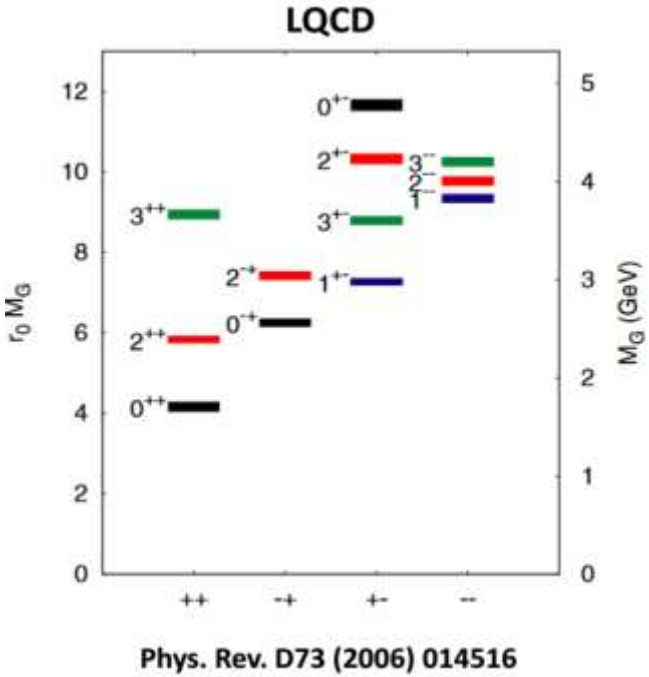
Hadron spectroscopy: establish the spectrum and study the exotic hadrons properties

Radiative J/ψ decays

- Charmonium radiative decays provide ideal laboratory for light glueballs and hybrids studies

  - ✓ Gluon-rich process
  - ✓ Clean process
  - ✓ High statistics





Phys. Rev. D73 (2006) 014516

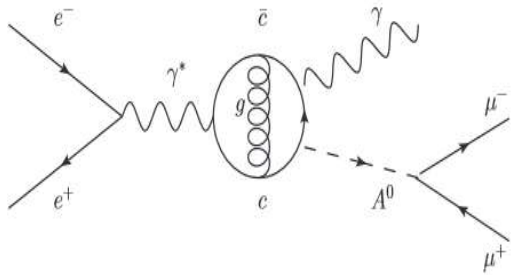
- Glueballs can mix with ordinary $q\bar{q}$ states

  Predicted large branching fractions for glueballs in J/ψ radiative decays

PRL110, 021601 $\Gamma(J/\psi \to \gamma G_{0^{++}})/\Gamma_{tot} = 3.8(9) \times 10^{-3}$

PRL111, 091601 $\Gamma(J/\psi \to \gamma G_{2^{++}})/\Gamma_{tot} = 1.1(2)(1) \times 10^{-2}$

- Radiative J/ψ decays can also be utilized to search for a CP-odd light Higgs boson (A^0)

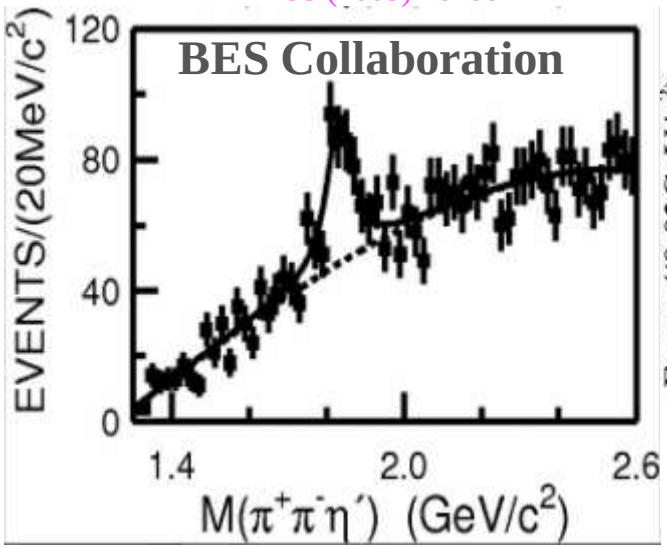


Phys. Rev. Lett. **39**, 1304 (1977)

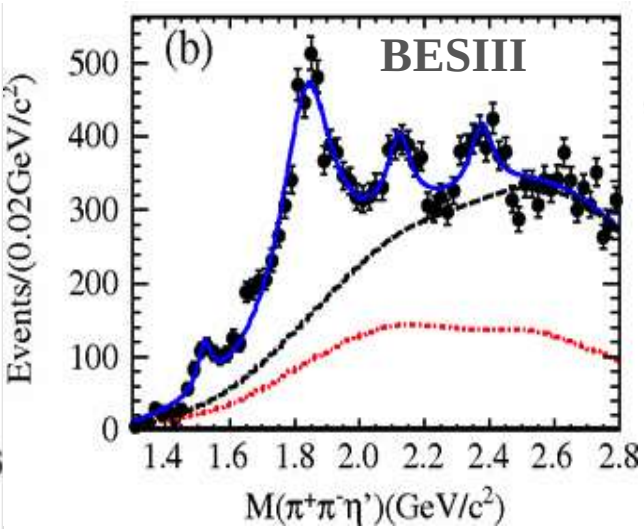
Past observations of X(1835), X(2120), X(2370) in $J/\psi \to \gamma\pi^+\pi^-\eta'$

The $J/\psi \to \gamma\pi^+\pi^-\eta'$ has already lead to discovery of three states

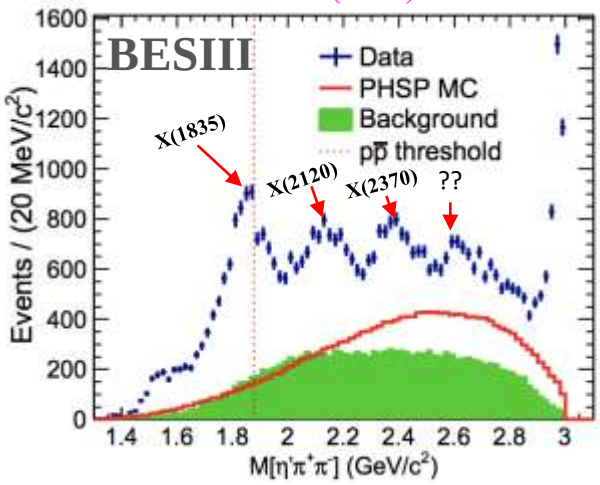
PRL 95 (2005) 262001



PRL 106 (2011) 072002



PRL 117 (2016) 042002



58×10^6 J/ψ → 225×10^6 J/ψ → 1.3×10^9 J/ψ

Past observations of X(1835), X(2120), X(2370) in $J/\psi \to \gamma\pi^+\pi^-\eta'$

PRL 129, 042001 (2022)

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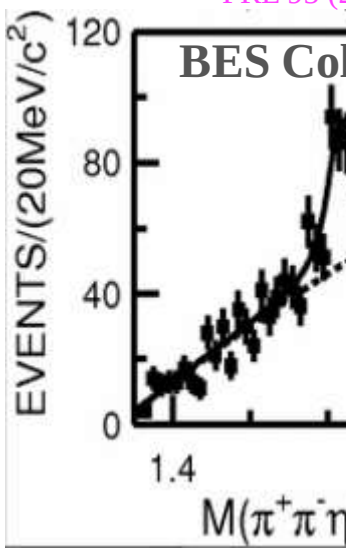
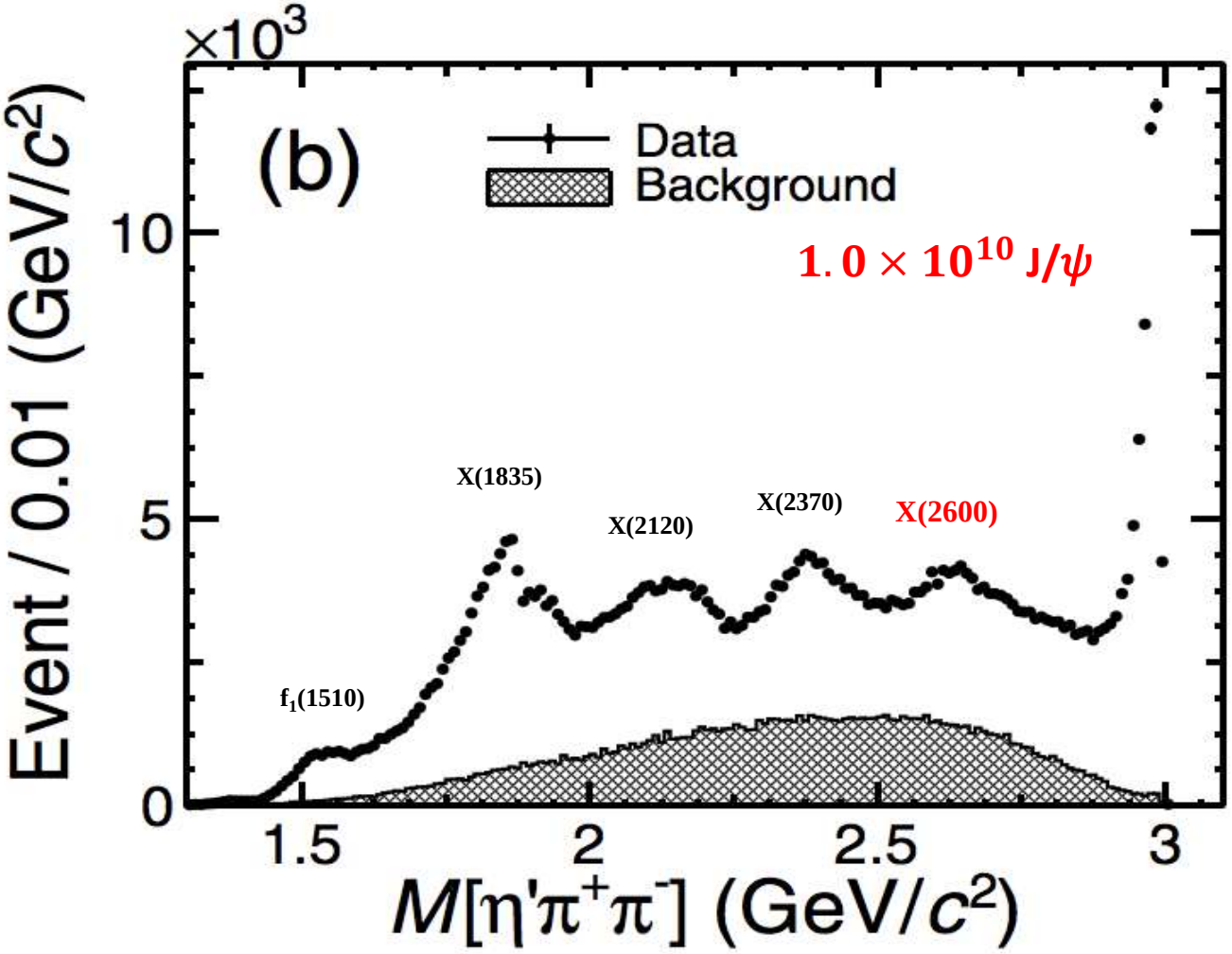
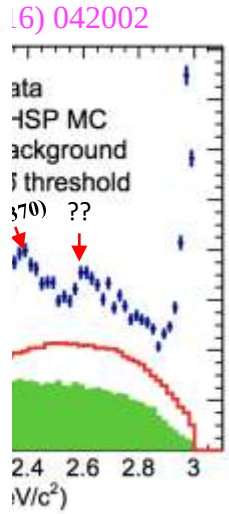


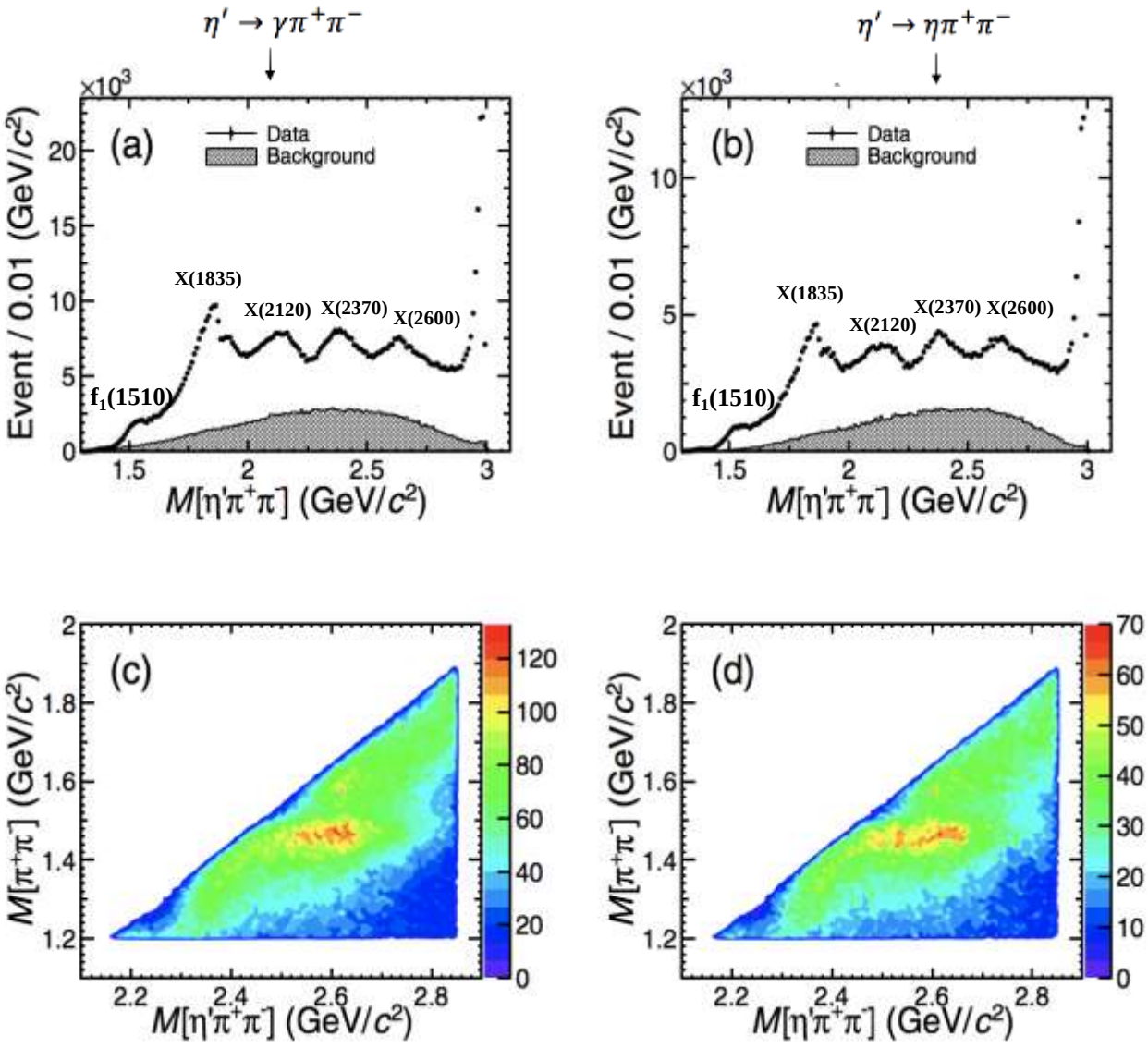




New discovery of X(2600) in $J/\psi \to \gamma\pi^+\pi^-\eta'$

PRL 129, 042001 (2022)

- Confirmation of X(1835), X(2120) and X(2370)
- New structure X(2600)
- Correlation with $M_{\pi^+\pi^-} \approx$ 1.5 GeV

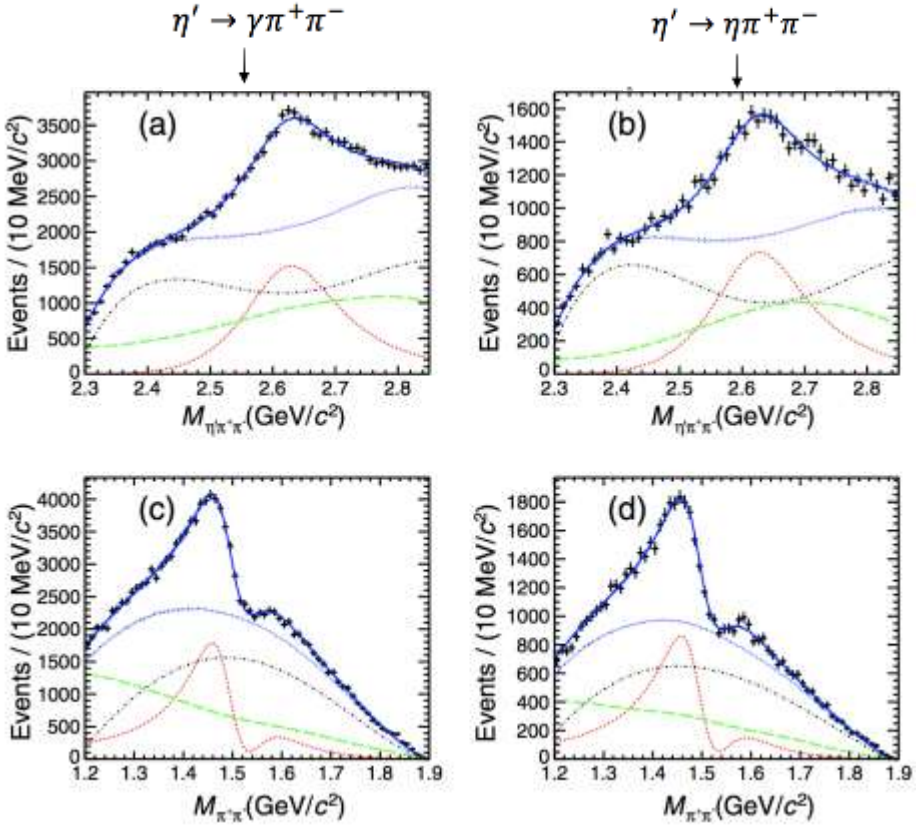


New discovery of X(2600) in $J/\psi \to \gamma\pi^+\pi^-\eta'$

PRL 129, 042001 (2022)

- Confirmation of X(1835), X(2120) and X(2370)
- New structure X(2600)
- Correlation with $M_{\pi^+\pi^-} \approx 1.5$ GeV
- Complicated pattern in $M_{\pi^+\pi^-}$ interference between $f_0(1500)$ and X(1540)

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

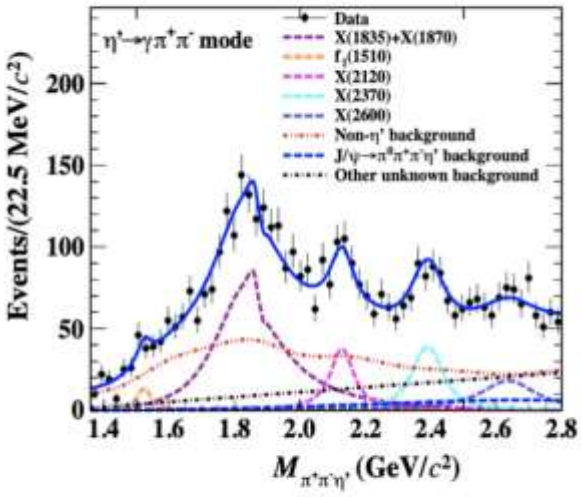


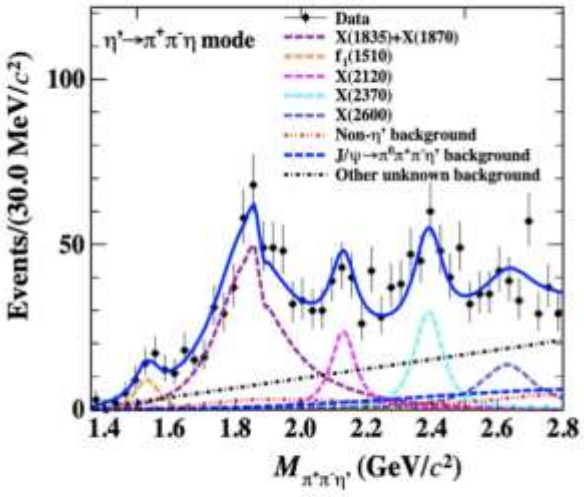
More studies (including J^{PC} determination) is necessary to fully understand the nature of X(2600).

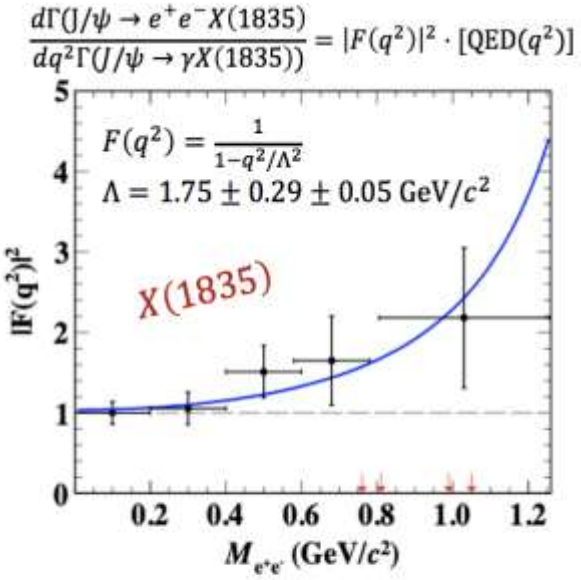
Same structures in EM Dalitz decay $J/\psi \to e^+e^-\pi^+\pi^-\eta'$

PRL 129, 022002 (2022)

- same structures in EM Dalitz decay $J/\psi \to e^+e^-\eta'\pi^+\pi^-$







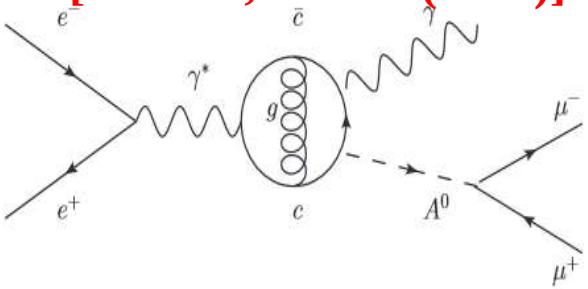
- additional input to model calculations regarding nature of these states

Light Higgs boson A^0 search in radiative J/ψ decay

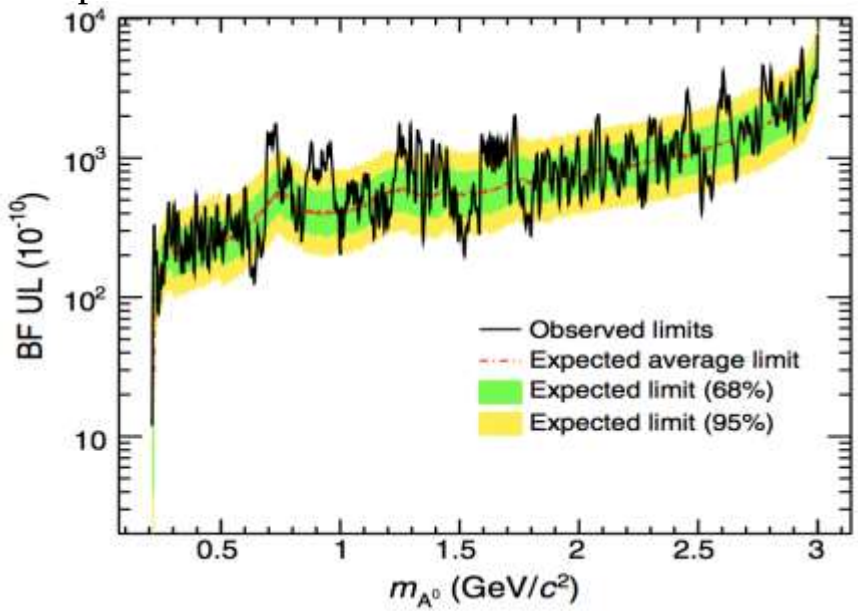
PRD 105, 012008 (2022)

Expected $B(J/\psi \to \gamma A^0) \sim 10^{-9} - 10^{-7}$

[PRD 76, 051105 (2007)]



- No evidence of A^0 production is found and set 90% confidence level upper limits on product BFs .

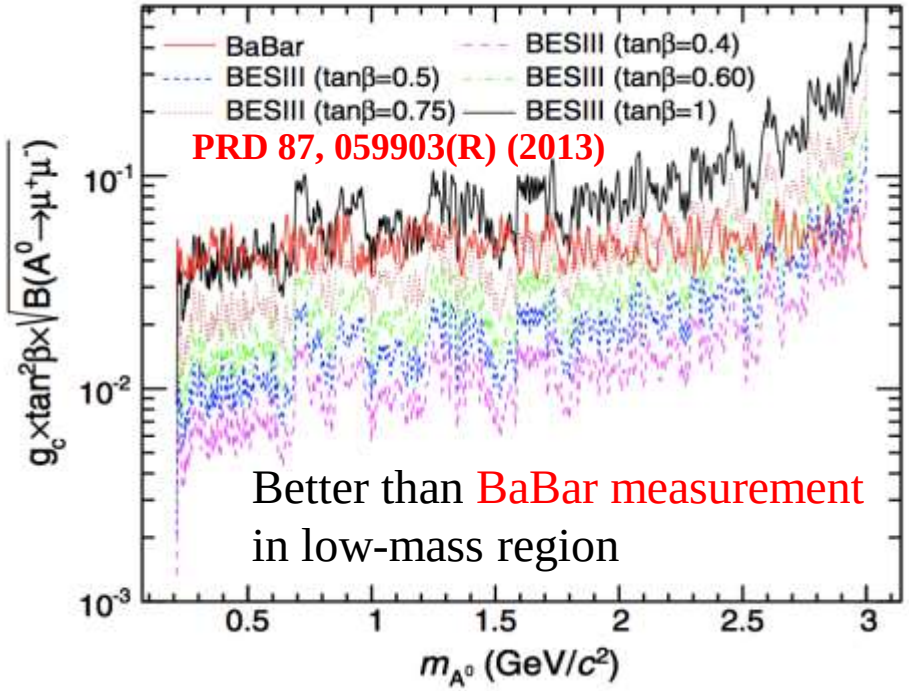


- Use 9 billion J/ψ events collected by BESIII experiment to perform this study.

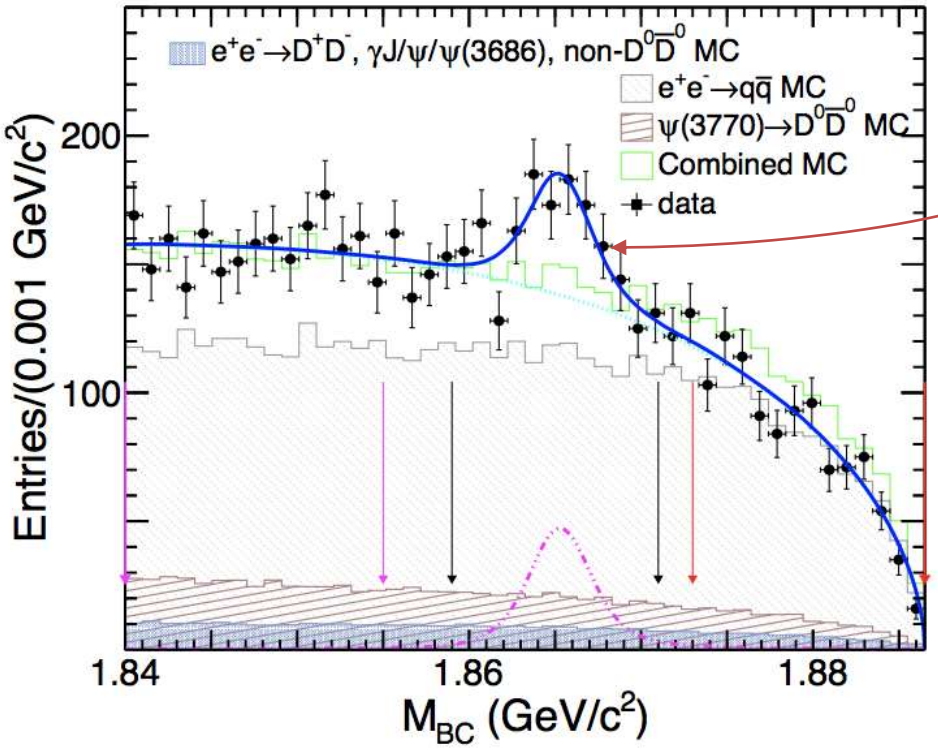
$$\frac{\mathcal{B}(V \to \gamma A^0)}{\mathcal{B}(V \to l^+ l^-)} = \frac{G_F m_q^2 g_q^2 C_{\mathrm{QCD}}}{\sqrt{2}\pi\alpha}\left(1 - \frac{m_{A^0}^2}{m_V^2}\right)$$

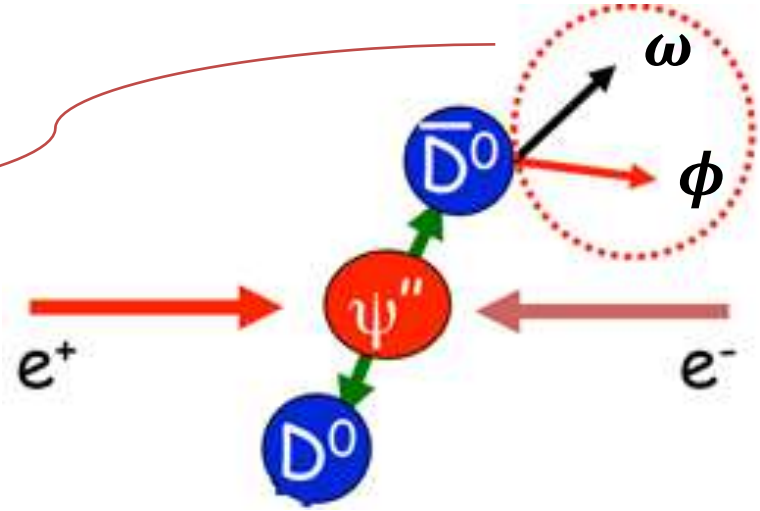
In Next-to-Minimal Supersymmetric Model (NMSSM), $g_c = cos\theta_A / tan\beta$ for Charm quark and $g_b = cos\theta_A tan\beta$ for bottom quark.

Annu. Rev. Nucl. Part. Sci. 70, 197 (2020)



Observation of $D^0 \to \omega\phi$ with 2.93 fb^{-1} of BESIII $\psi(3773) \to D\bar{D}$ $(D = D^0, D^+)$ data





PRL 128, 011803 (2022)

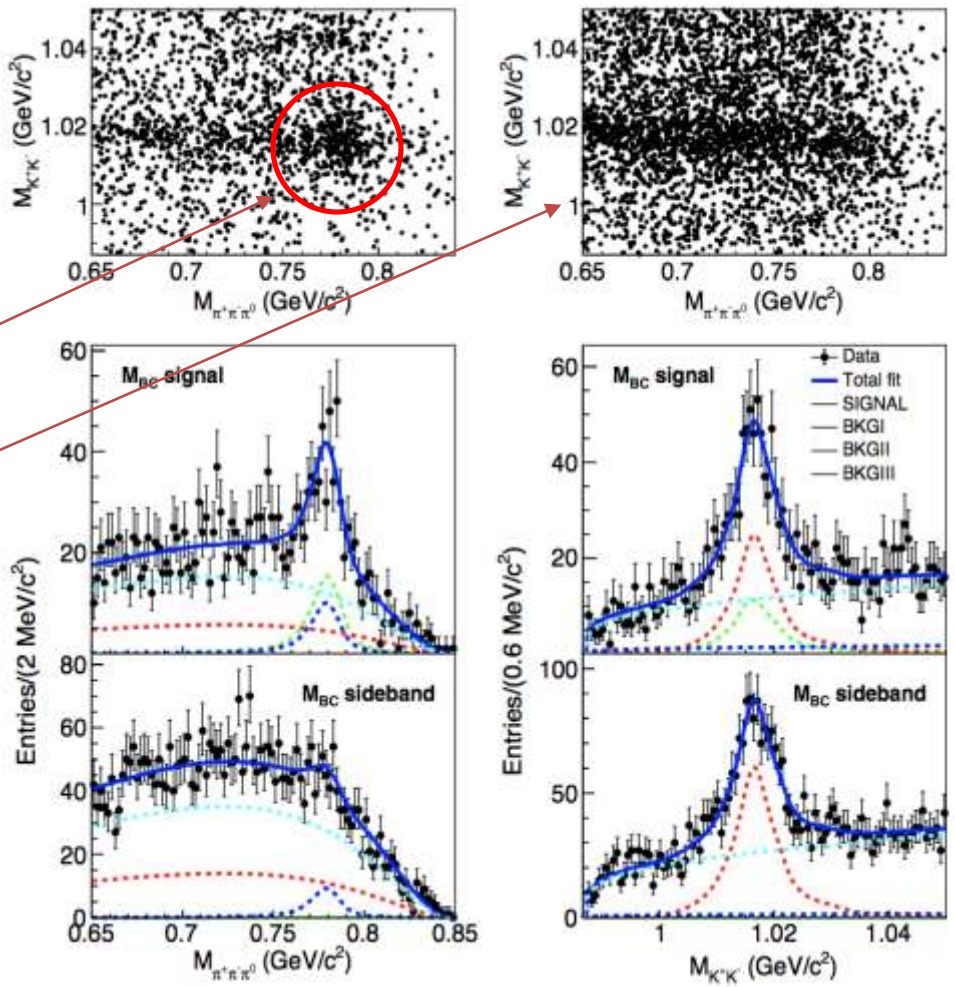
Observation of $D^0 \to \omega\phi$

PRL 128, 011803 (2022)

- Long-distance contributions to $D^0 - \bar{D}^0$ mixing arise in $D^0 \to VV$ decays.
- Used 2.93 fb^{-1} of $\psi(3770)$ data.
- Single-tag method with $\phi \to K^+K^-$ and $\omega \to \pi^+\pi^-\pi^0$
- Signal: 1.859 < MBC < 1.871 GeV/c^2
- Sideband: (1.84,1.855) U (1.873, 1.890) GeV/c^2
- First Observation:

$$\mathcal{B} = \frac{N_{\rm sig}^{\rm ST}}{2.N_{D^0\bar{D}^0}.\epsilon.\mathcal{B}_{sub}} = (6.48 \pm 0.96 \pm 0.40) \times 10^{-4}$$

with 6.3σ significance



Consistent with factorization model predictions in [PRD 81, 114020 (2010); PRD 43, 843 (1991)], inconsistent with those based on SU(3) symmetry [PRD 43, 843 (1991); CPC 42, 063101 (2018); PRD 56, 7207 (1997)]

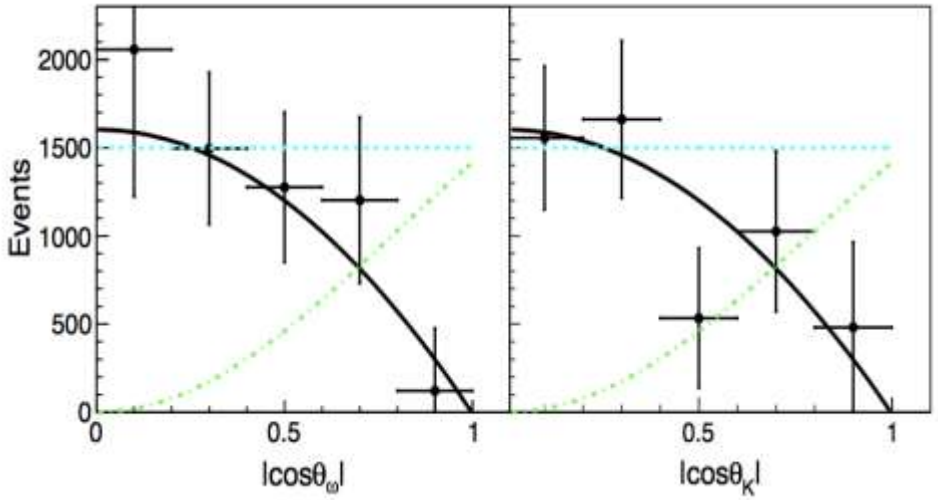
Polarization in $D^0 \to \omega\phi$

PRL 128, 011803 (2022)

— Fit

..... Longitudinal hypothesis

$$\frac{1}{\Gamma}\frac{d\Gamma}{d\cos\theta} = \frac{3}{2}\left\{\frac{1}{2}(1-f_L)\sin^2\theta + f_L\cos^2\theta\right\}$$

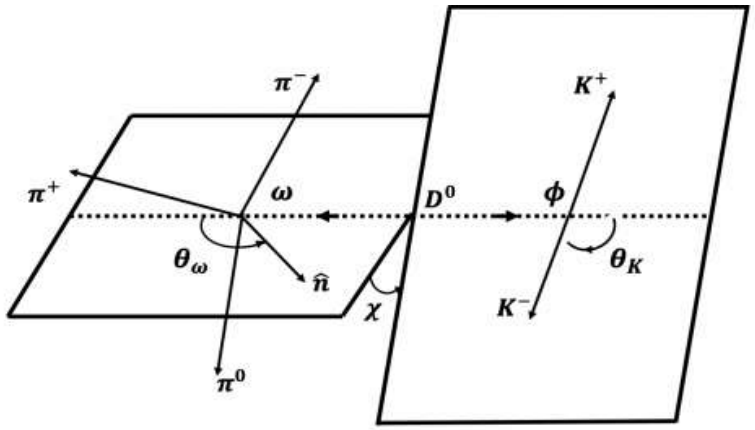


- $f_L < 0.24$ at 95% CL
- ω and ϕ found to be transversely polarized
- Contradicts model based predictions

— Factorization model: $f_L \sim 0.5$

[Phys. Rev. D 59, 114013 (1999)]

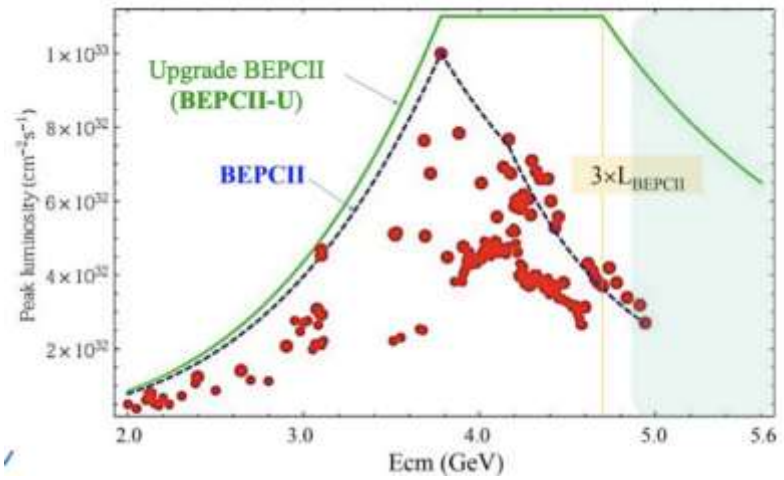
— Lorentz invariant-based symmetry model: $f_L \sim 0.33$



[JHEP 03, 042 (2014)]

Summary and outlook

- BESIII is an experiment of tau-charm factory.
- This talk mainly covers the results of light QCD, light hadron spectroscopy, New physics and charm physics.
  - Improved the precision of R measurement — **PRL 128, 062004 (2022)**
  - First observation of X(2600) — **PRL 129, 042001 (2022)**
  - Set stringent upper limits on light CP-odd Higgs boson search — **PRD 105, 012008 (2022)**
  - First polarization measurement in $D^0 \to \omega\phi$ — **PRL 128, 011803 (2022)**
- Many analyses in progress!
- Further upgrade in energy (5.6 GeV) and luminosity (BEPCII-U, 3x) planned for the next year



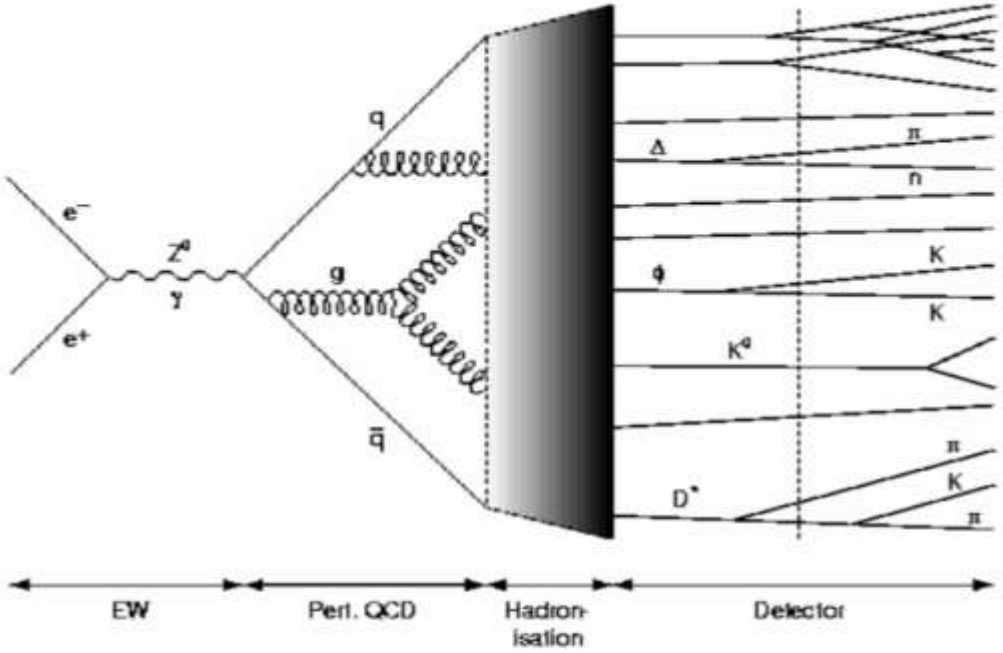
Thanks!

Back-up slide

R-Value Measurement

PRL 128, 062004 (2022)

Hadronization procedure in electron-positron annihilation:



Main features of the LUARLW model:

- A self-consistent inclusive generator developed based on JETSET.
- Initial-state radiation (ISR) process is implemented from $2m_\pi$ to $\sqrt{s}$.
- Kinematic quantities of initial hadrons are sampled by the Lund area law.
- Phenomenological parameters are tuned based on comparisons between data and MC.