北京谱仪实验上轻强子物理研究

房双世

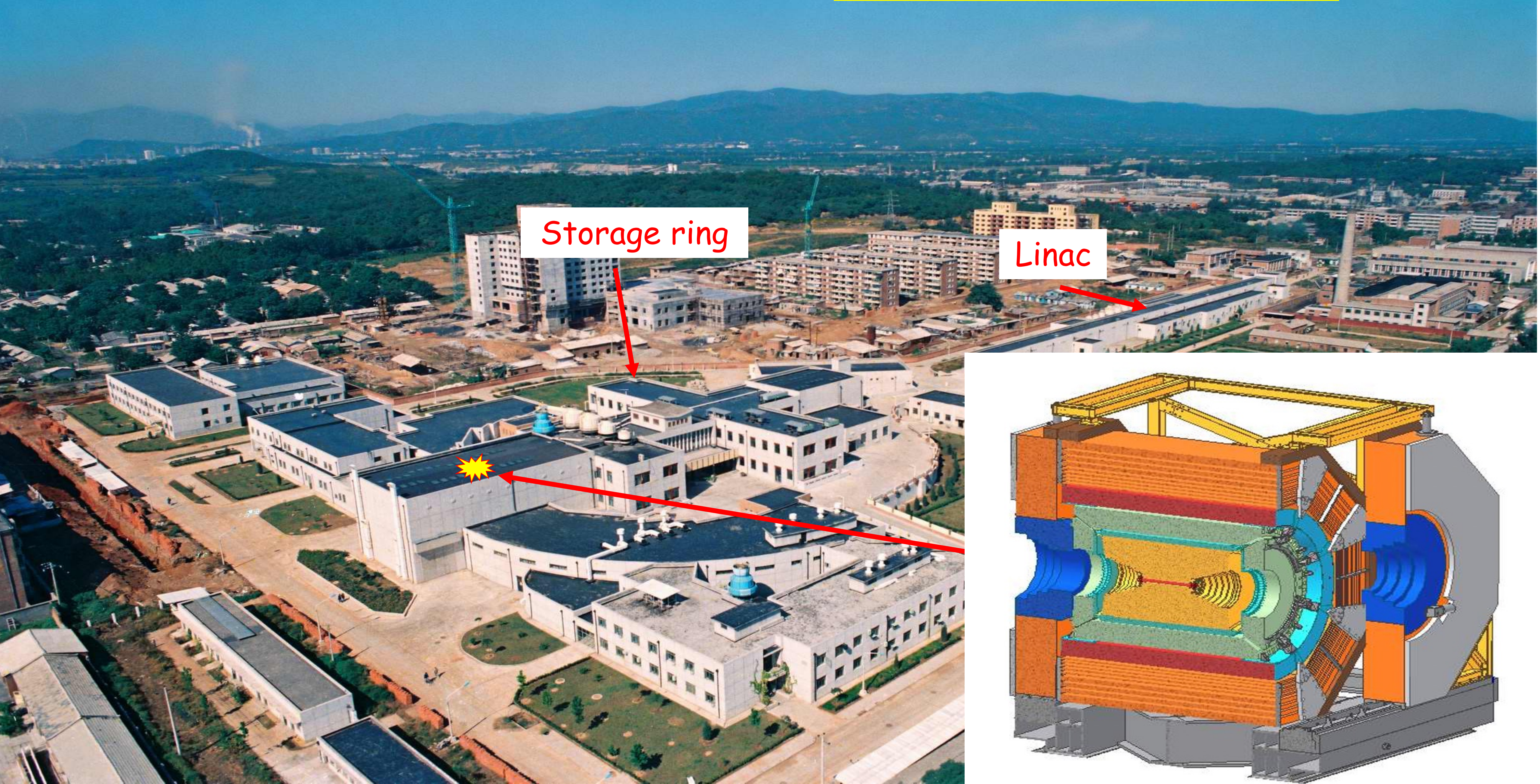
高能物理研究所

河南师范大学，2024年3月23日

Outline

- BEPCII/BESIII
- Light exotics searches
- Light Hyperon physics
- Light meson physics
- Summary

Bird view of BEPCII

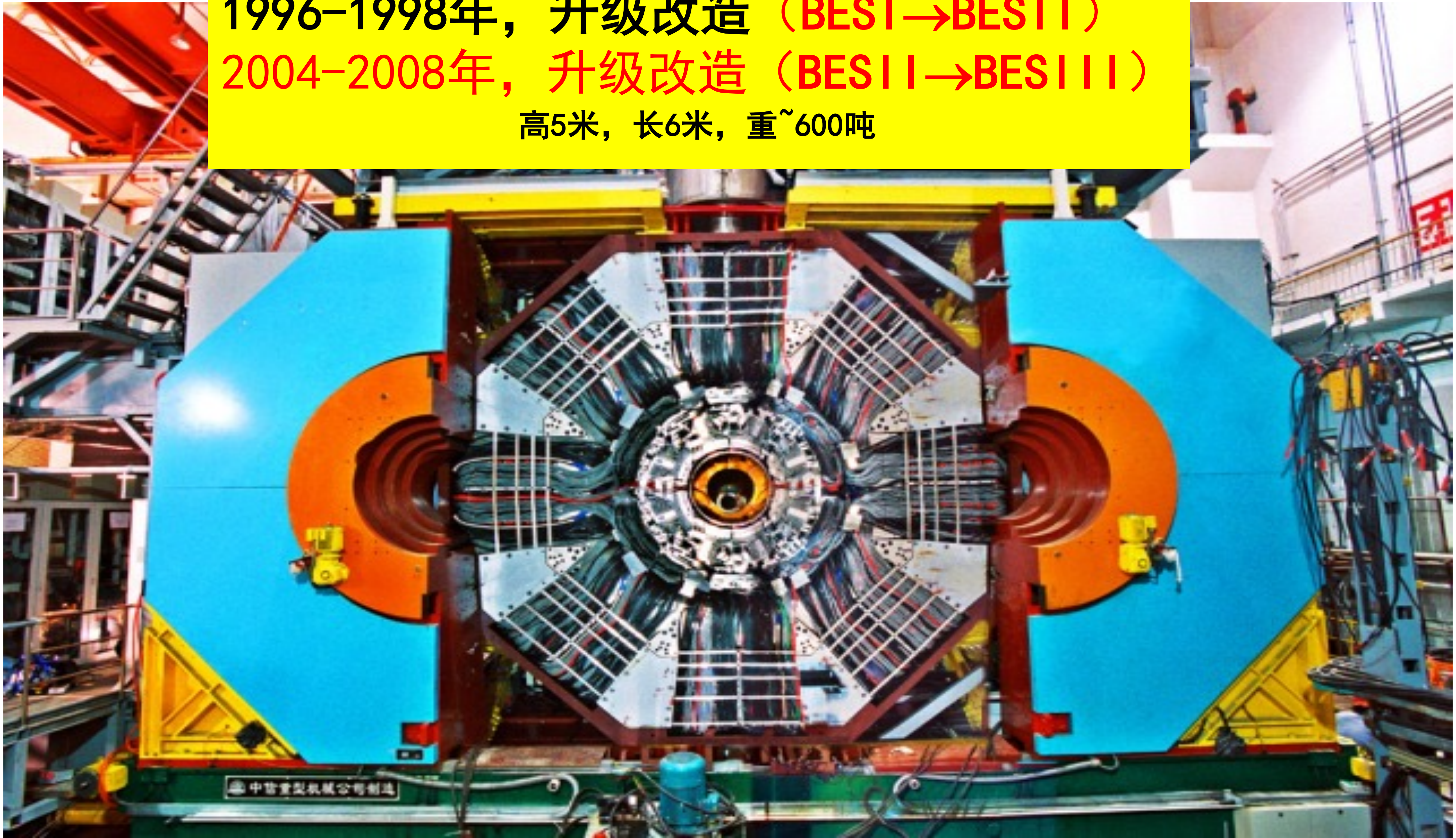


北京谱仪

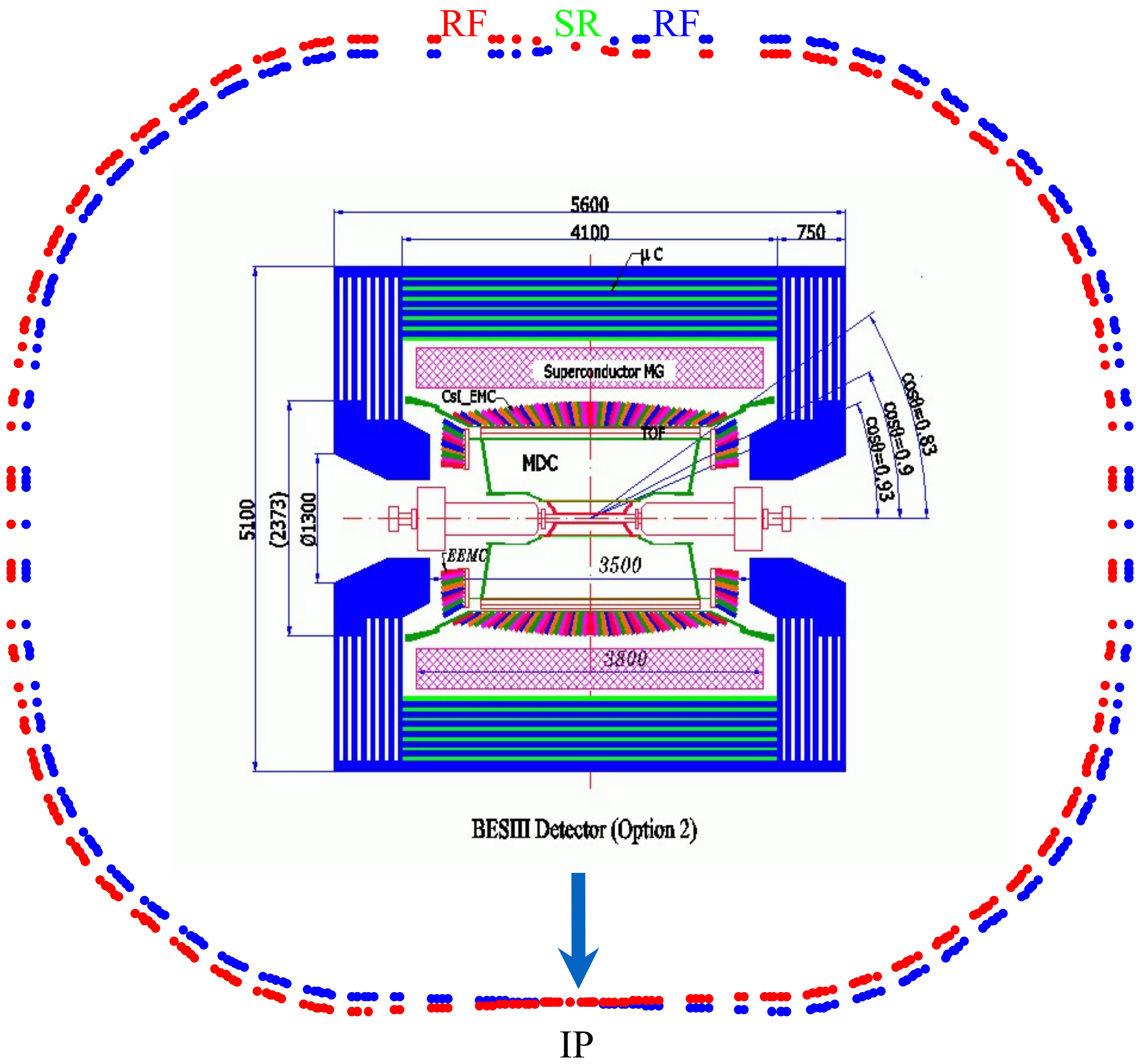
1996-1998年，升级改造（BESI→BESII）

2004-2008年，升级改造（BESII→BESIII）

高5米，长6米，重~600吨



BEPC II Storage ring: Large angle, double-ring



Beam energy: 1-2.5 GeV

Luminosity: 1×10^{33} $cm^{-2}s^{-1}$

Optimum energy: 1.89 GeV

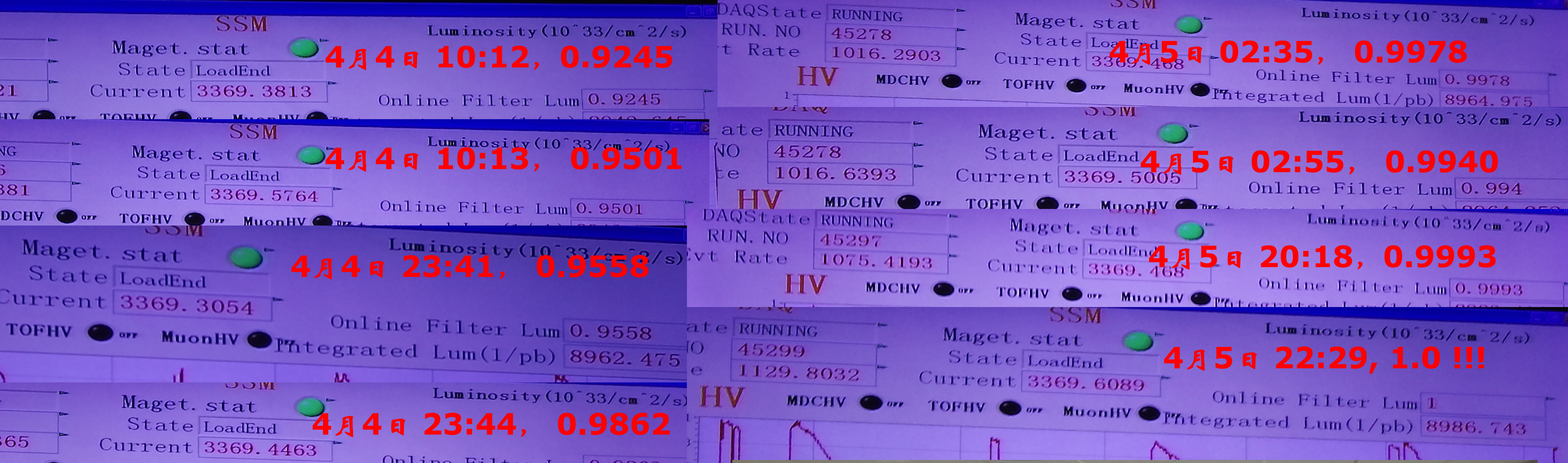
Energy spread: 5.16×10^{-4}

No. of bunches: 93

Bunch length: 1.5 cm

Total current: 0.91 A

SR mode: 0.25A @ 2.5 GeV



4月4日 10:12，0.9245

4月4日 10:13，0.9501

4月4日 23:41，0.9558

4月4日 23:44，0.9862

4月5日 00:46，0.9896

4月5日 02:35，0.9978

4月5日 02:55，0.9940

4月5日 20:18，0.9993

4月5日 22:29，1.0 !!!

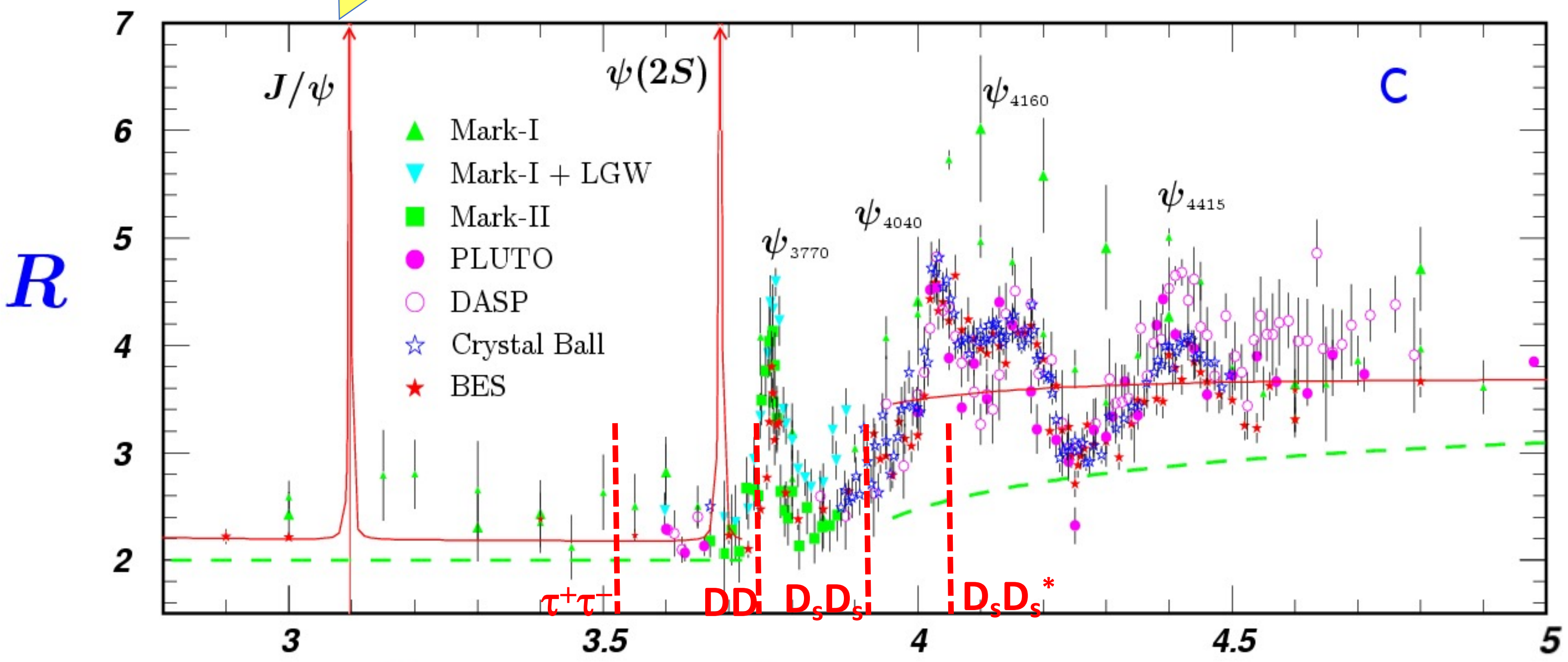
2008-2016年，对撞机设计亮度达标，漫长之路！

说到做到，不欠国家0.001！

2016年4月5日，达到设计亮度：$1\times10^{33}\ cm^{-2}s^{-1}$

World largest data sample directly collected in τ-charm region

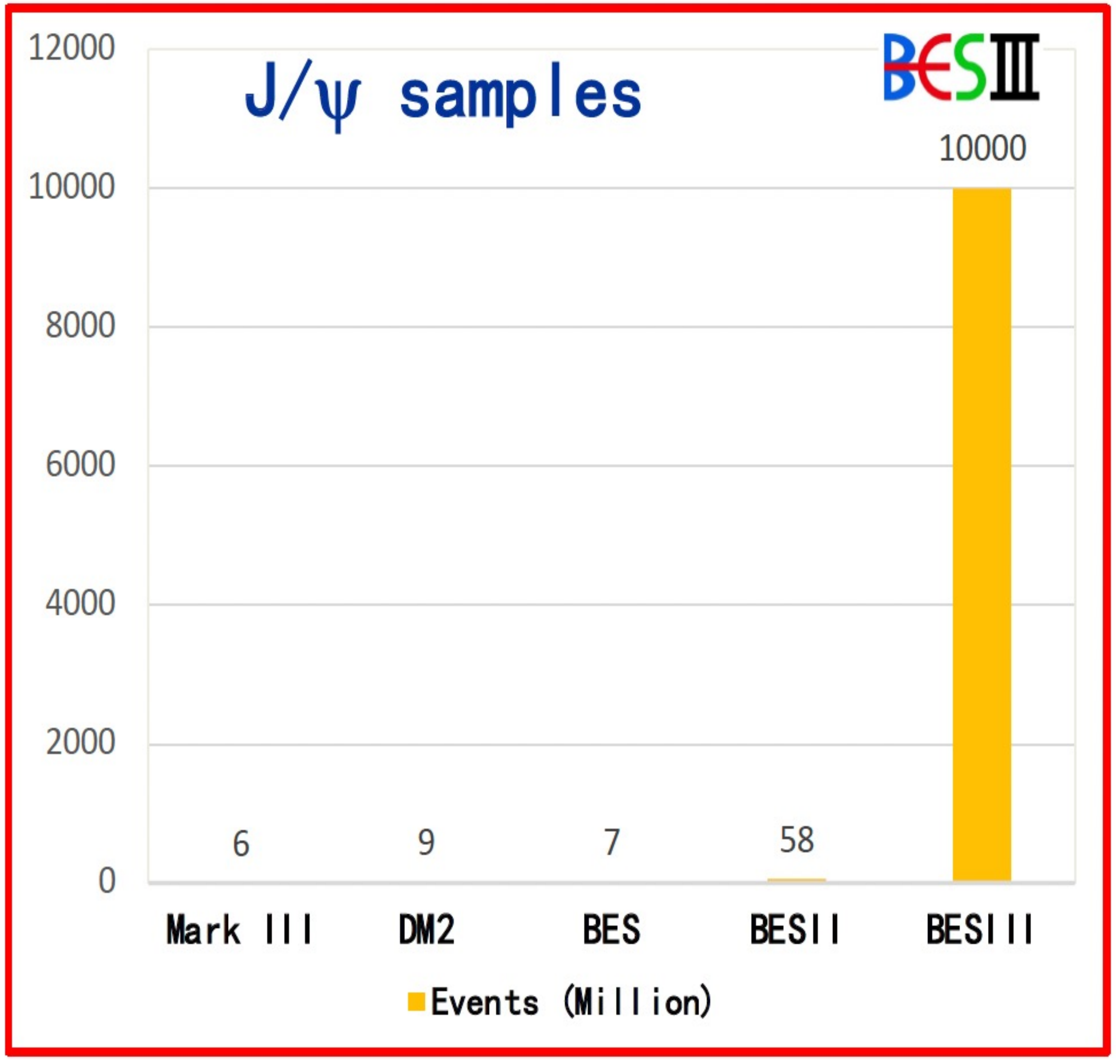
10×10^9 J/ψ
200 × BESII

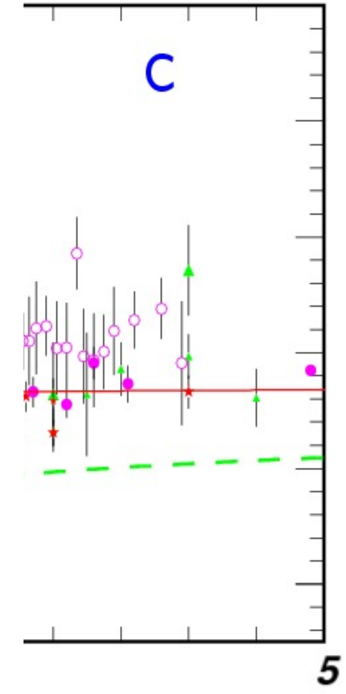


- Light hadron physics
- Charmonium physics
- Charm physics
- R-QCD physics

2008-present: ~50 fb^{-1} data in E_{cm} = 2-4.95 GeV

World largest data sample directly collected in τ-charm region



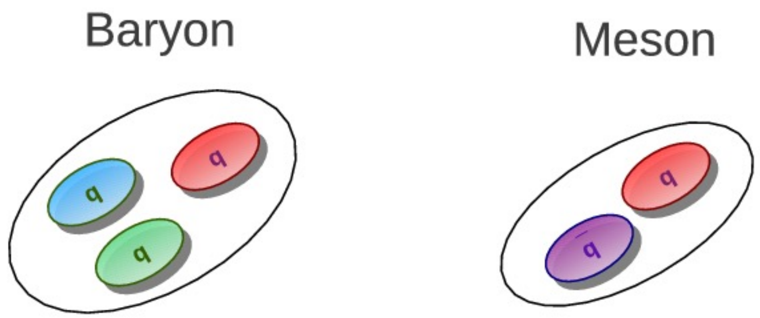


- Light hadron physics
- Charmonium physics
- Charm physics
- R-QCD physics

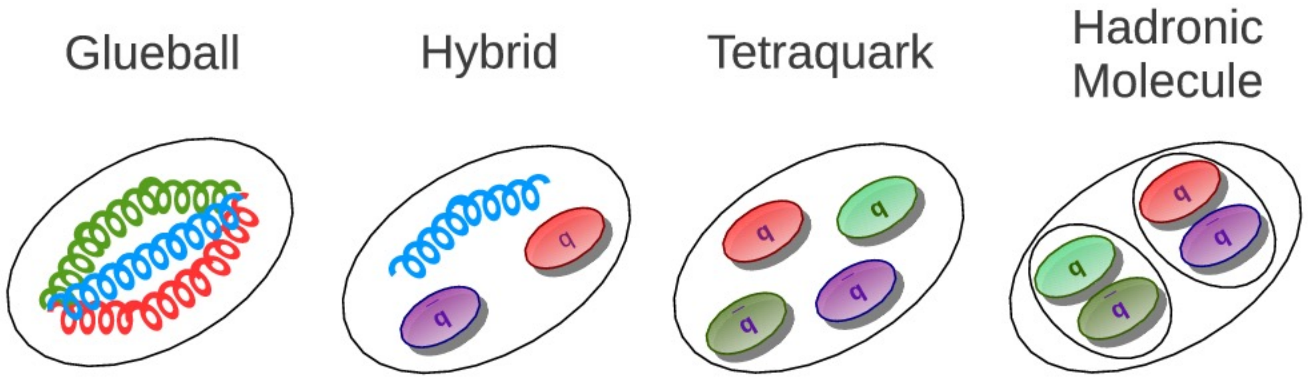
a in E_{cm} = 2-4.95 GeV

Ordinary vs exotic matter

- Conventional hadrons

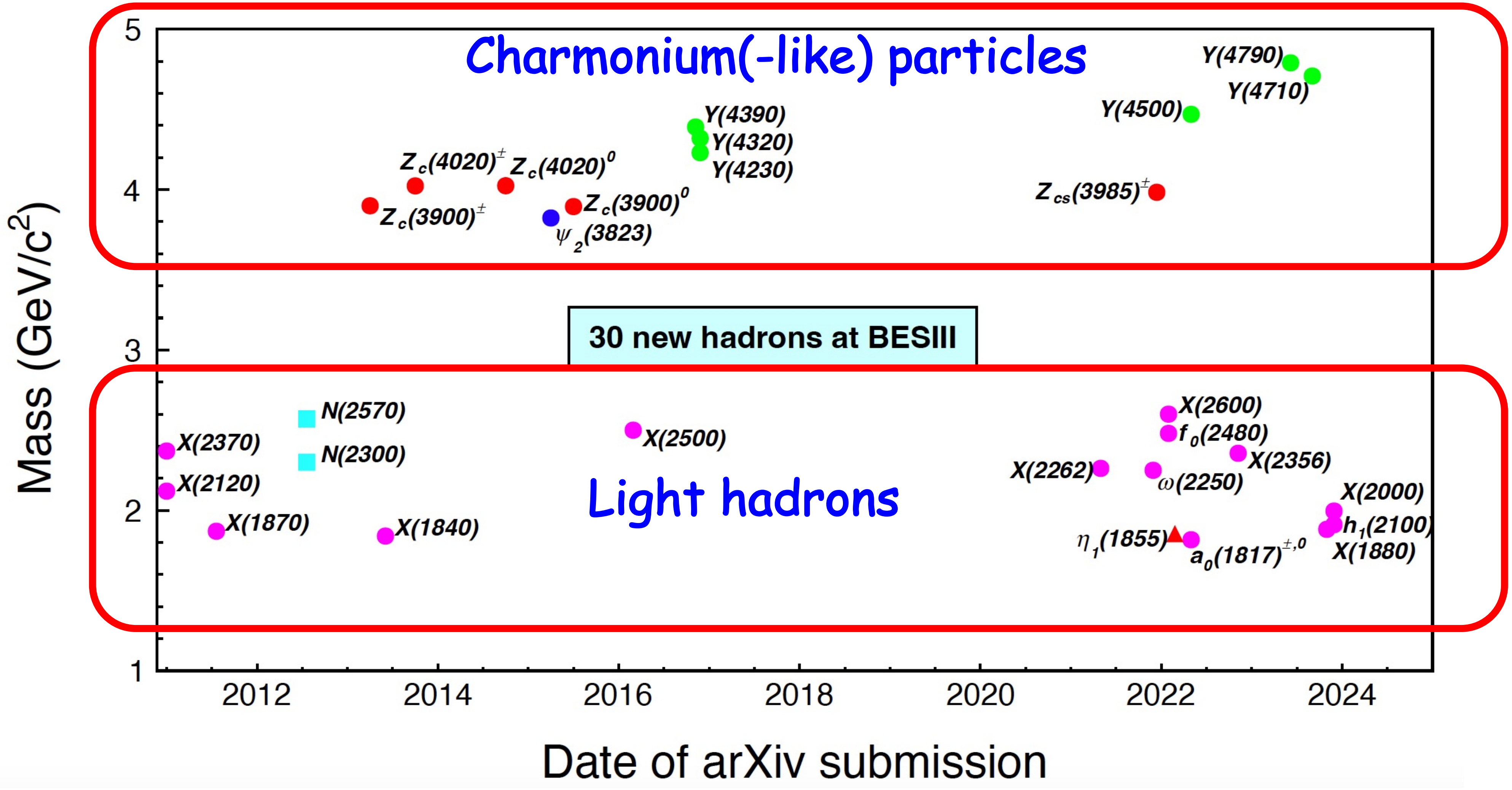


- QCD allows for "exotics"

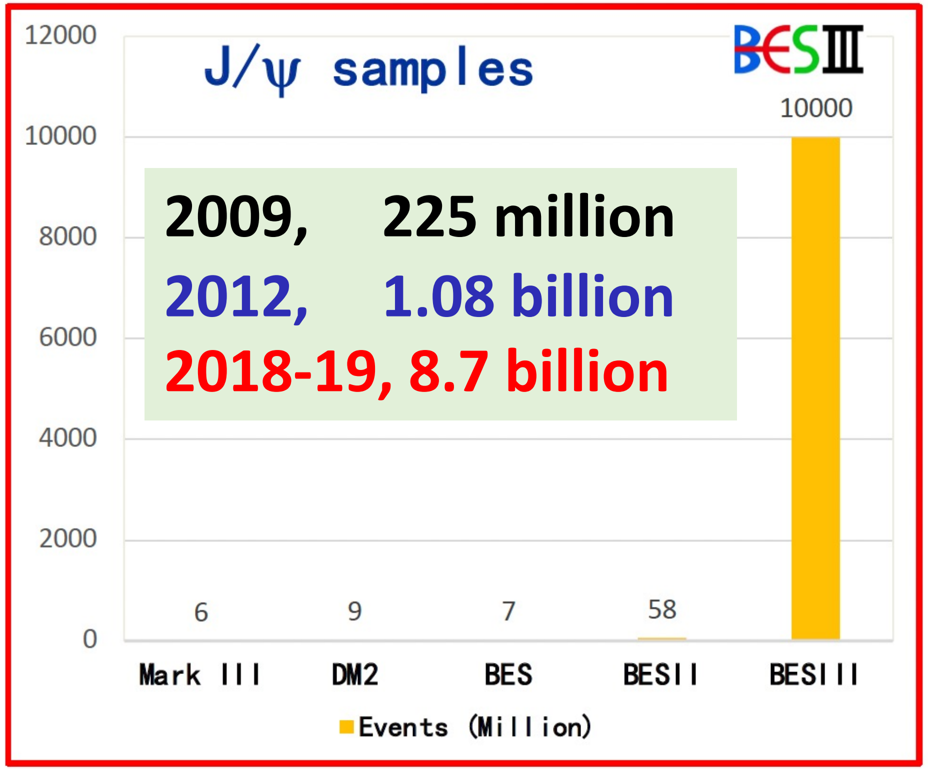


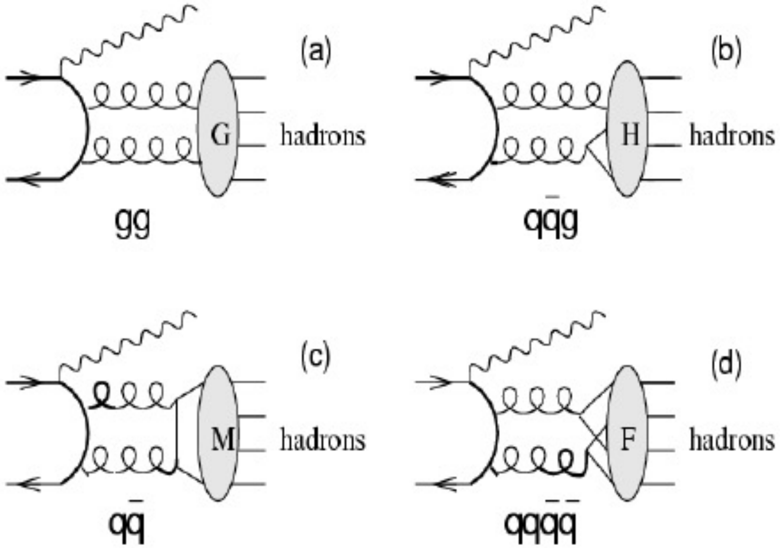
- Searching for those states provides test of QCD

New resonant structures at BESIII



J/ψ : an ideal lab for light hadron spectroscopy



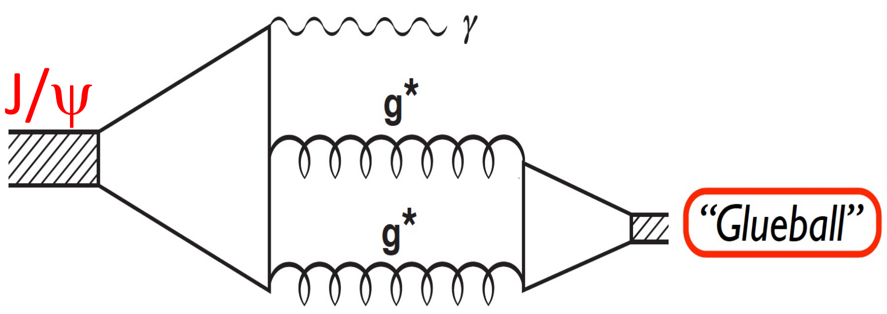


- Especially radiative J/ψ decays : gluon rich production
- Production rates for exotic hadrons is expected to be compatible to the ones for conventional hadrons.

Glueball searches

Two big issues

- What is the production mechanism to utilize?
- What is the mixing with quark model mesons?



Production rate could be calculable in LQCD, but the manifestation of a "glueball" can be tricky!

Chanowitz, Phys.Rev.Lett. 95(2005)172001

Systematic studies needed

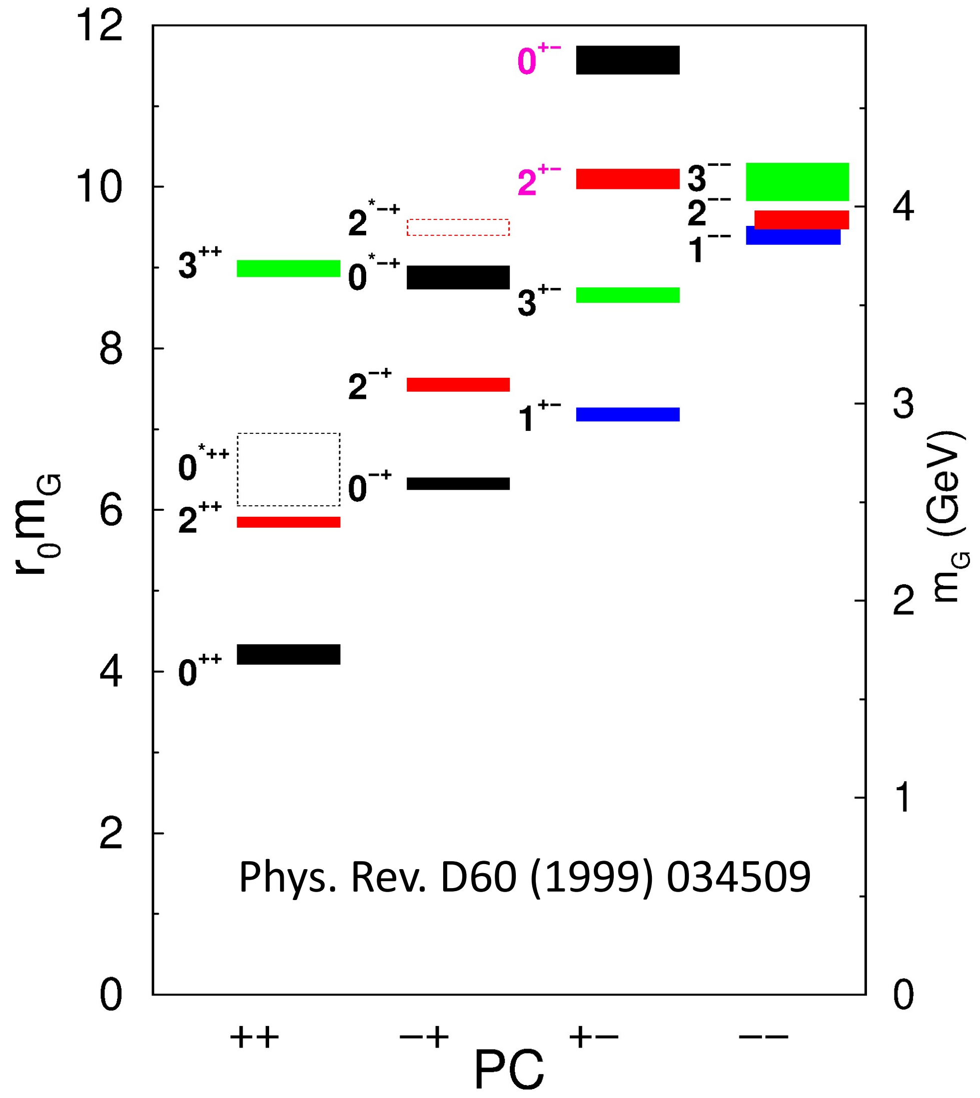
- Outnumbering of conventional QM states
- Abnormal properties ? Eg., small production rate in two photon process

Pseudoscalar glueball searches

Where is the 0^{-+} glueball?

- LQCD：0^{-+}(2.3~2.6 GeV)

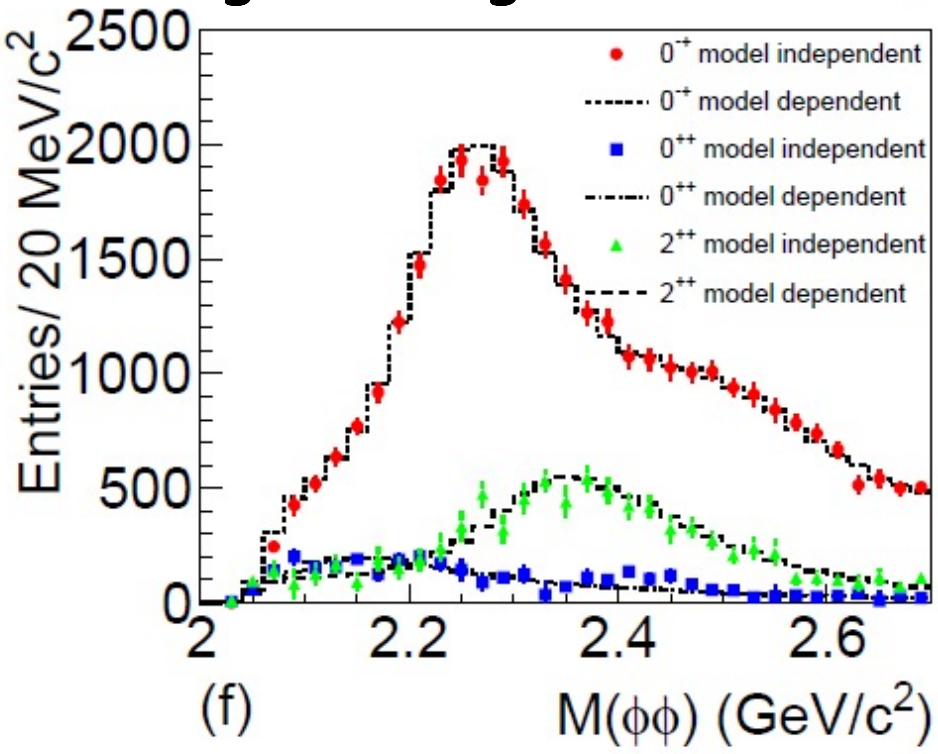
The small number of expected pseudoscalars in the quark model provide a clean and promising environment for the search of glueballs



H.X.Chen, W Chen, X Liu, Y.R. Liu, S.L. Zhu Rept.Prog.Phys. 86 (2023) 2, 026201

Pseudoscalars above 2 GeV

Very little was known for pseudoscalars above 2 GeV. Experimental results are essential for mapping out the pseudoscalar excitations and searching for 0^{-+} glueball

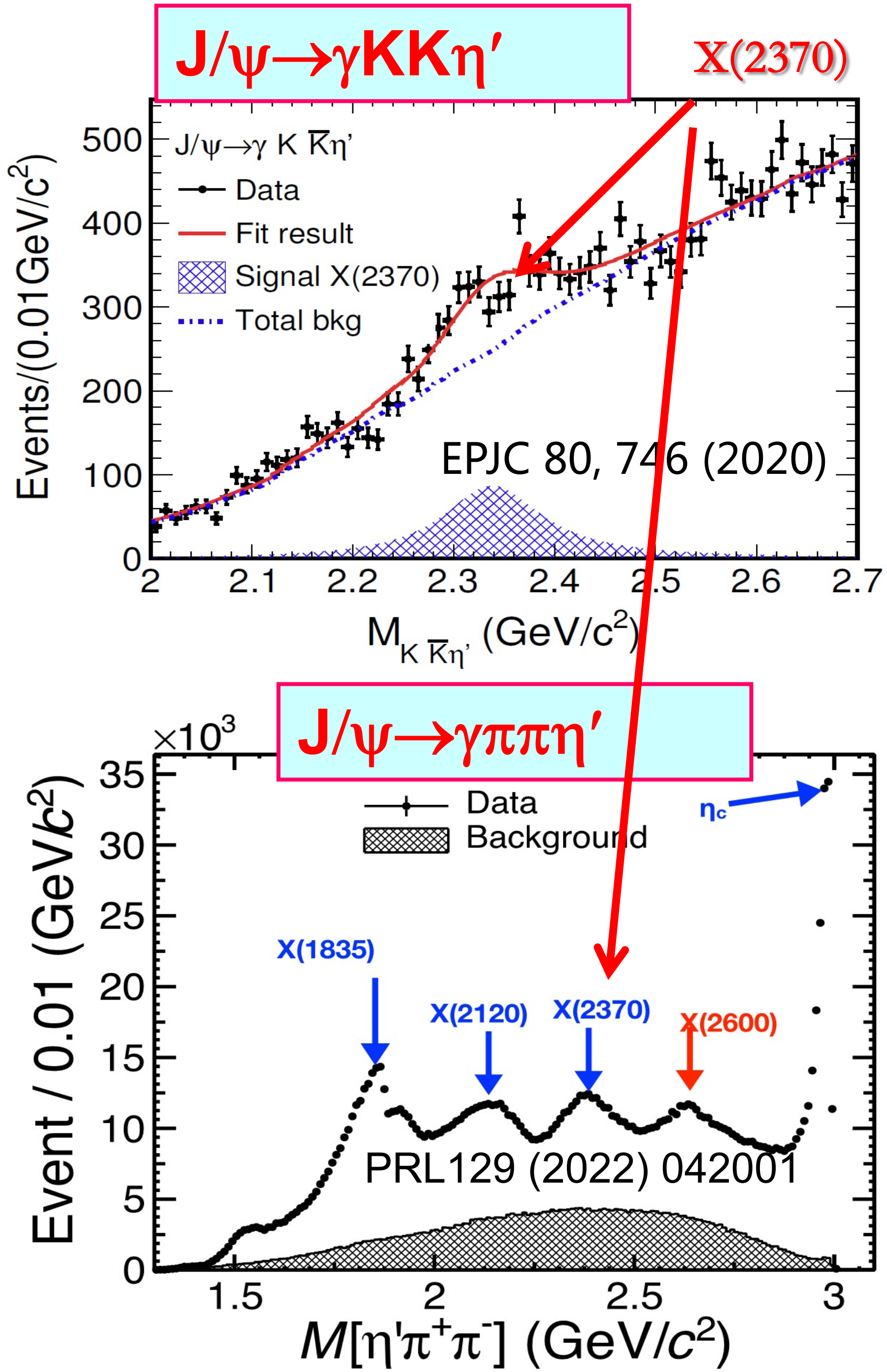


Resonance	$M(MeV/c^2)$	$\Gamma(MeV/c^2)$	B.F.$(\times 10^{-4})$	Sig.
$\eta(2225)$	2216^{+4+18}_{-5-11}	185^{+12+44}_{-14-17}	$(2.40 \pm 0.10^{+2.47}_{-0.18})$	28.1σ
$\eta(2100)$	2050^{+30+77}_{-24-26}	$250^{+36+187}_{-30-164}$	$(3.30 \pm 0.09^{+0.18}_{-3.04})$	21.5σ
$X(2500)$	2470^{+15+63}_{-19-23}	230^{+64+53}_{-35-33}	$(0.17 \pm 0.02^{+0.02}_{-0.08})$	8.8σ
$f_0(2100)$	2102	211	$(0.43 \pm 0.04^{+0.24}_{-0.03})$	24.2σ
$f_2(2010)$	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	$(1.91 \pm 0.07^{+0.72}_{-0.69})$	10.7σ
0^{-+} PHSP			$(2.74 \pm 0.15^{+0.16}_{-1.48})$	6.8σ

Phys. Rev. D97, 051101 (2018)

- Dominant contribution from pseudoscalars: η(2225), η(2100) and X(2500)
- Three tensors $f_2(2010)$, $f_2(2300)$ and $f_2(2340)$

X(2370): new glueball candidate ?



An updated review of the new hadron states

We collect as many theoretical predictions on the pseudoscalar glueball mass as we can, and summarize them in Fig. 71. The average value of the mass predictions obtained after the year 1990 is

$$M_{|gg;0^{-+}\rangle} \sim 2360 \text{ MeV}. \quad (125)$$

Accordingly, the resonance $X(2370)$ first observed in 2010 [880] becomes a possible candidate for the low-lying pseudoscalar glueball, whose mass and width were measured to be [884]:

$$X(2370): M = 2341.6 \pm 6.5 \pm 5.7 \text{ MeV}, \quad \Gamma = 117 \pm 10 \pm 8 \text{ MeV}. \quad (126)$$

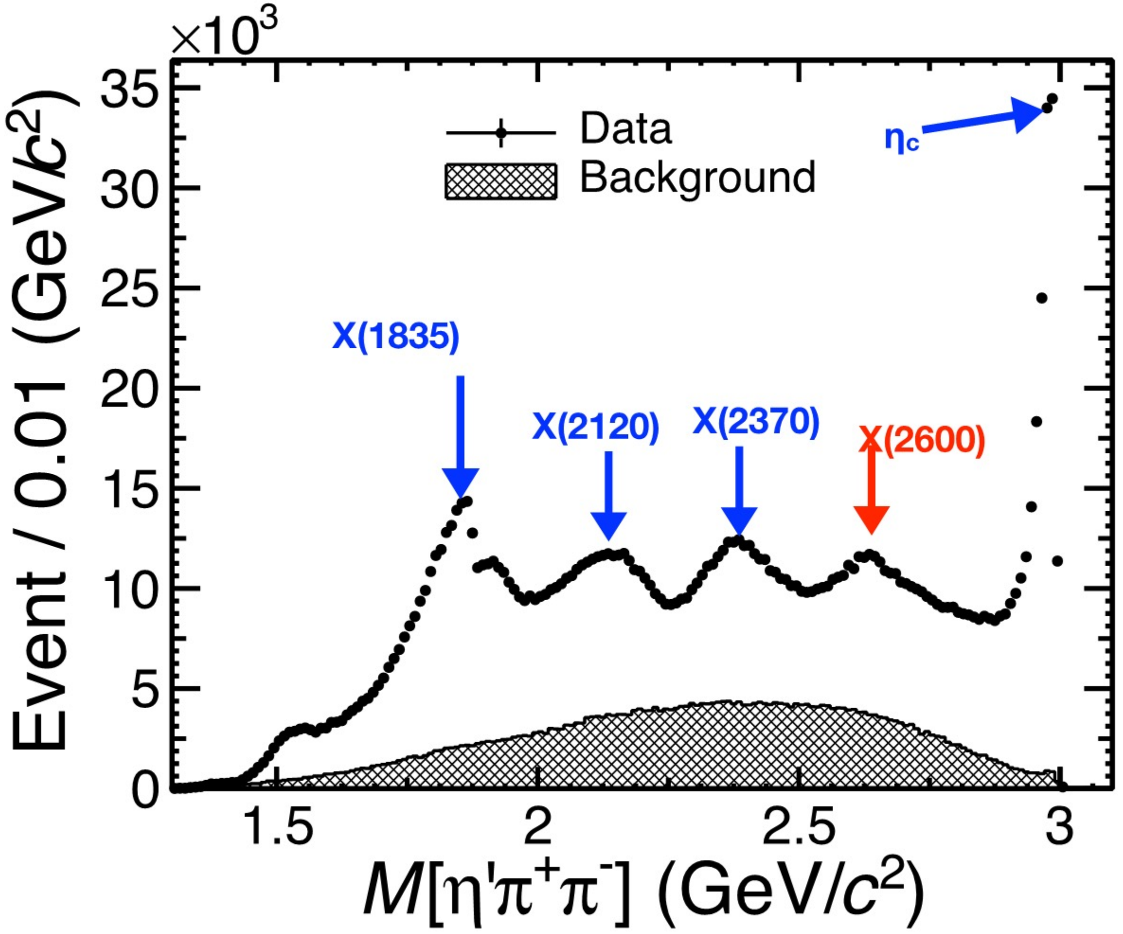
H.X.Chen, W Chen, X Liu, Y.R. Liu, S.L. Zhu Rept.Prog.Phys. 86 (2023) 2, 026201

X(2600): new glueball candidate ?

QCD sum rules

S.Q. Zhang et al, *PRD* 106 (2022) 7, 074010

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



PRL129 (2022) 042001

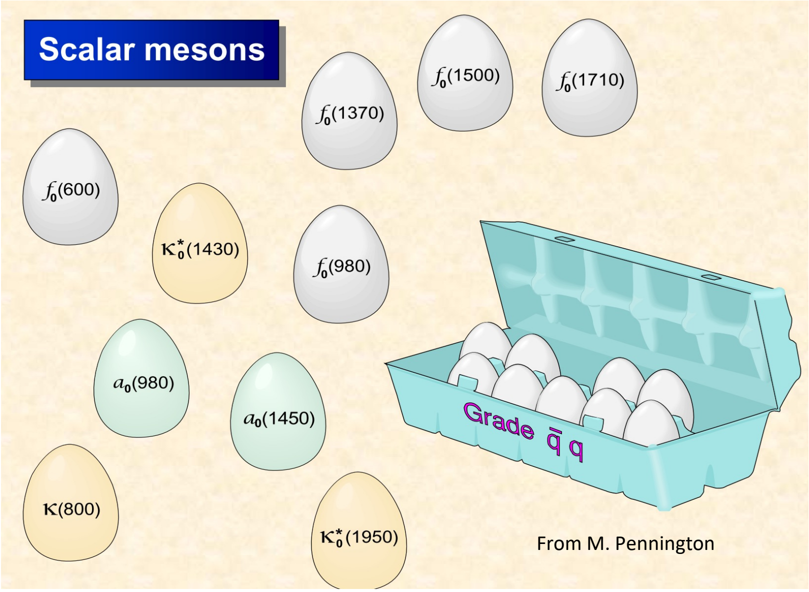
Motivated by the newly observed resonance $X(2600)$ by BESIII Collaboration, we examine the trigluon glueball interpretation for it in the framework of QCD sum rules. We evaluate the mass spectra of the trigluon glueballs with quantum numbers 0^{-+} and 2^{-+} up to dimension 8 condensate in the operator product expansion. Our numerical results indicate that the mass of the 2^{-+} trigluon glueball is about 2.66 ± 0.06 GeV, which is consistent with the mass of the X(2600) within the uncertainties, while 0^{-+} has a mass of 2.01 ± 0.14 GeV. The possible decay channels of the 2^{-+} state are analyzed, which are crucial in decoding $X(2600)$'s internal structure and are hopefully measurable in BESIII, BEllEII, PANDA, and LHCb experiments.

Cases	Possible decay channels	
0^{-+} two-gluon glueball $\to$	$a_0(980) + \pi$	$\{f_0(500),\ f_0(980)\} + \eta$
0^{-+} trigluon glueball $\to$	$\{f_0(500),\ f_0(980),\ f_0(1370),\ f_0(1500)\} + \eta$ $f_0(500) + f_0(980) + \eta$ $f_0(500) + f_0(500) + \{\eta,\ \eta'\}$ $\{f_0(500),\ f_0(980)\} + a_0(980) + \pi$	$\eta\eta\eta,\ \eta\eta\eta',\ \{\eta,\ \eta'\} + \pi + \pi$ $\{\omega\omega,\ \rho\rho\} + f_0(500)$ $N\bar{N}$
2^{-+} two-gluon glueball $\to$	$a_2(1320) + \pi$ $f_2(1270) + \eta$	$f_0(500) + f_1(1285)$
2^{-+} trigluon glueball $\to$	$\eta_2(1645) + f_0(500)$ $\{f_2(1270),\ f_2'(1525)\} + \{\eta,\ \eta'\}$ $a_2(1320) + f_0(500) + \pi$ $\{f_2(1270),\ f_2'(1525)\} + f_0(500) + \eta$ $\{f_2(1270),\ f_2'(1525)\} + a_0(980) + \pi$ $\omega + \phi + \eta,\ \{\pi\pi,\ \omega\omega,\ \rho\rho\} + \{\eta,\ \eta'\}$	$2f_1(1285),\ 2a_1(1260),\ 2h_1(1170)$ $\rho + \rho + f_0(980)$ $\{\omega\omega,\ \rho\rho,\ \omega + \phi\} + f_0(500)$ $h_1(1170) + \omega + \eta$ $\{h_1(1170),\ h_1(1415)\} + \rho + \pi$ $N\bar{N},\ \Lambda\bar{\Lambda},\ \Sigma\bar{\Sigma},\ \Xi\bar{\Xi}$

Scalar glueball searches

- Why light scalar mesons are interesting?
  - There have been hot debates on **the existence of** **σ and κ**
  - **σ, κ and $f_0(980)$ are also possible mutiquark states.** **They are all near threshold.**
  - Lattice QCD predicts the 0^{++} **scalar glueball mass ~ 1.6 GeV.** $f_0(1500)$ and $f_0(1710)$ are good candidates.

Overpopulated!



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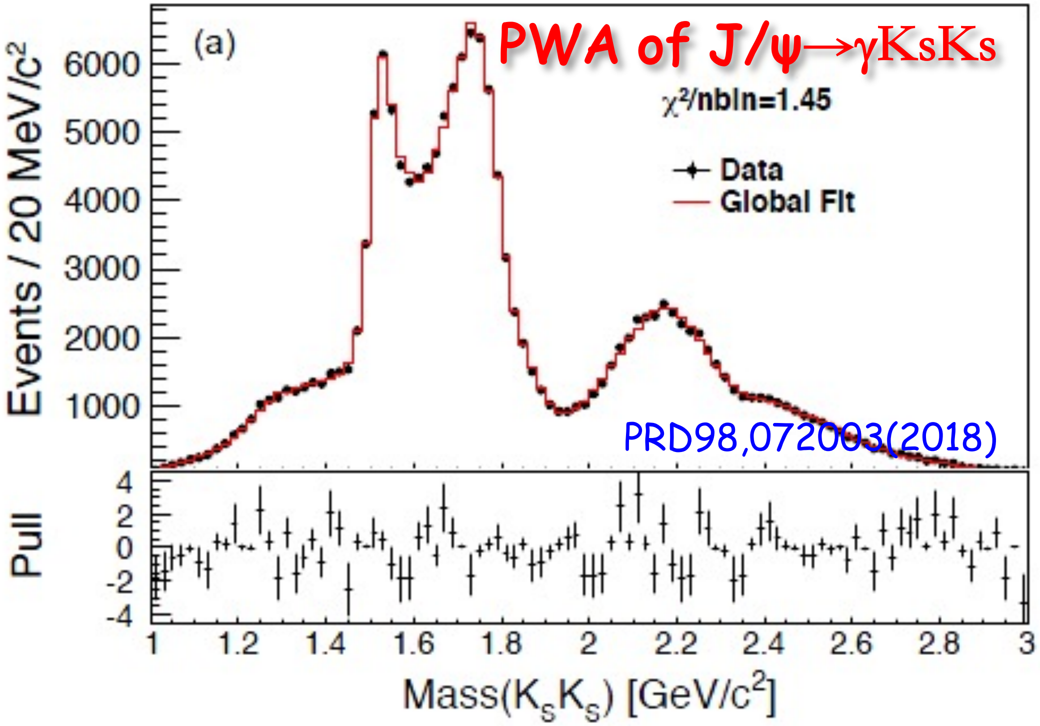
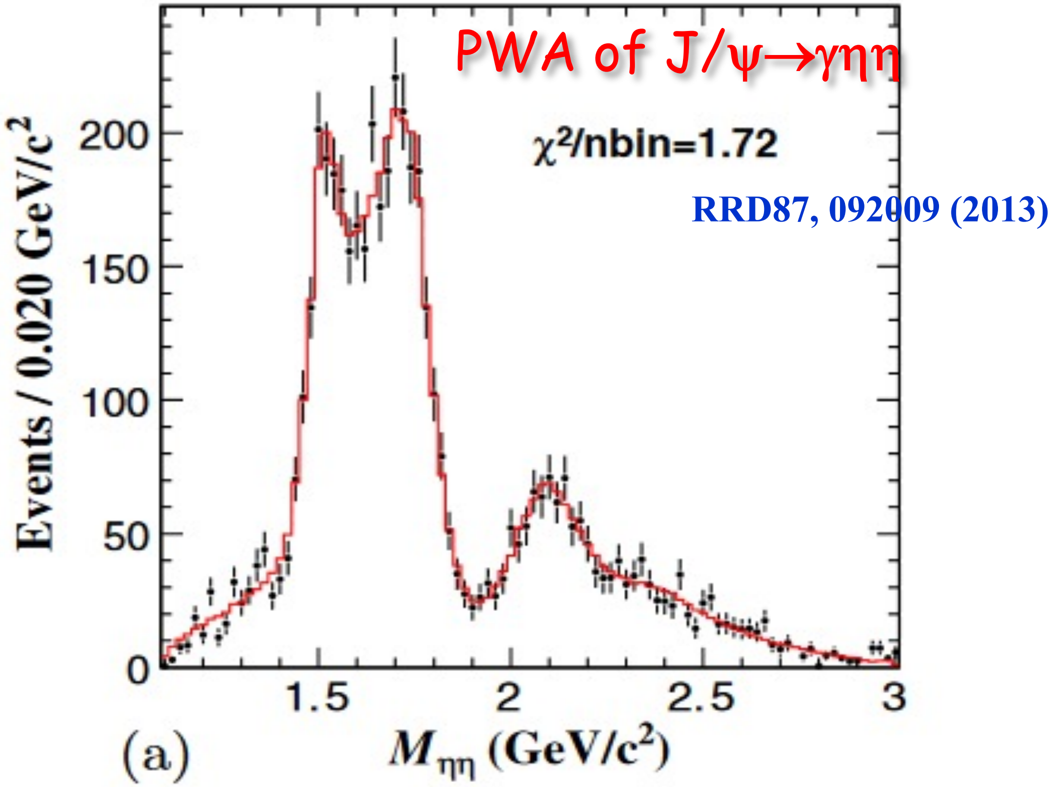
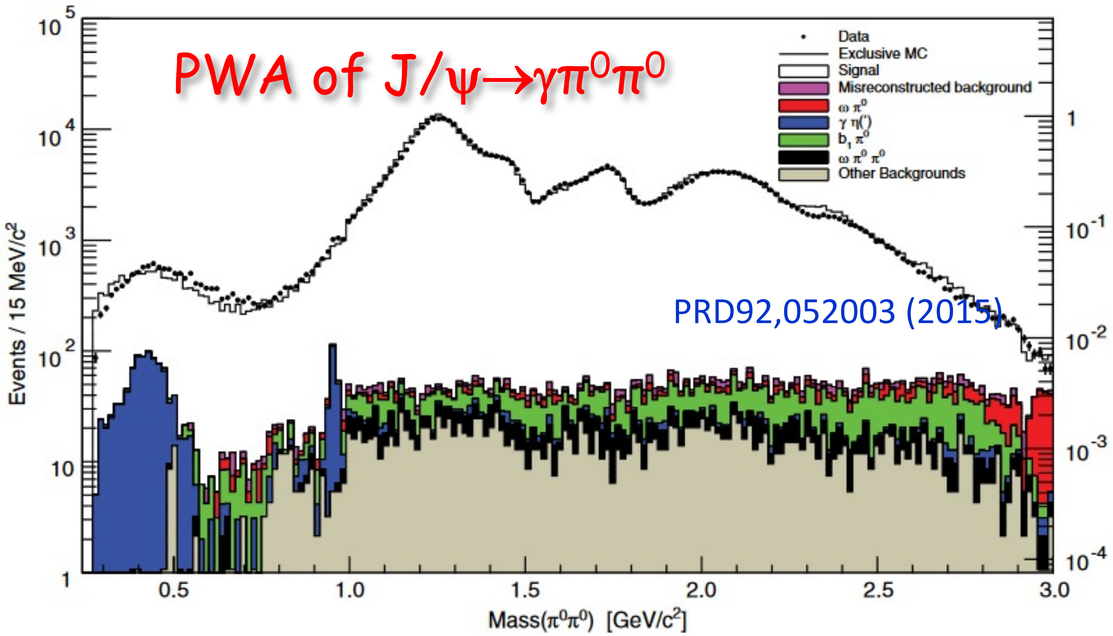






- $f_0(1710)$ and $f_0(1500)$ are dominant
- $f_2'(1525)$ also seen
- Broad bump above 2 GeV, contributions from scalar and tensor

Scalar glueball candidate: $f_0(1710)$

$$\Gamma(J/\psi \to \gamma G_{0^+}) = \frac{4}{27}\alpha\frac{|p|}{M^2_{J/\psi}}|E_1(0)|^2 = 0.35(8)keV$$

$$\Gamma/\Gamma_{tot} = 0.33(7)/93.2 = 3.8(9)\times 10^{-3}$$

CLQCD, Phys. Rev. Lett. 110, 021601 (2013)

Experimental results

- $B(J/\psi \to \gamma f_0(1710) \to \gamma K\bar{K}) = (8.5^{+1.2}_{-0.9})\times 10^{-4}$
- $B(J/\psi \to \gamma f_0(1710) \to \gamma\pi\pi) = (4.0\pm1.0)\times 10^{-4}$
- $B(J/\psi \to \gamma f_0(1710) \to \gamma\omega\omega) = (3.1\pm1.0)\times 10^{-4}$
- $B(J/\psi \to \gamma f_0(1710) \to \gamma\eta\eta) = (2.35^{+0.13+1.24}_{-0.11-0.74})\times 10^{-4}$

$\Rightarrow$ $B(J/\psi \to \gamma f_0(1710)) > 1.7\times 10^{-3}$

Flavor-blindness of glueball decays

$$\frac{1}{P.S.}\Gamma(G \to \pi\pi : K\overline{K} : \eta\eta : \eta\eta' : \eta'\eta') = 3:4:1:0:1$$

*with chiral suppression

PRL 98 149103

$$\Gamma(G \to \pi\pi)/\Gamma(G \to K\bar{K}) \approx \frac{f_\pi^4}{f_K^4} \approx 0.48$$

$$\frac{1}{P.S.}\Gamma(G \to \pi\pi : K\bar{K} : \eta\eta) \approx 1.3 : 3.16 : 1$$

$f_0(1710)$ largely overlapped with scalar glueball

Tensor glueball searches

$$\Gamma(J/\psi \to \gamma G_{2+}) = 1.01(22) keV$$

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

CLQCD, Phys. Rev. Lett. 111, 091601 (2013)

BESIII results

$$Br(J/\psi \to \gamma f_2(2340) \to \gamma\eta\eta) = (3.8^{+0.62+2.37}_{-0.65-2.07}) \times 10^{-5}$$

Phys.Rev. D87, 092009 (2013)

$$Br(J/\psi \to f_2(2340) \to \gamma\phi\phi) = (1.91 \pm 0.14^{+0.72}_{-0.73}) \times 10^{-4}$$

Phys.Rev. D93, 112011 (2016)

$$Br(J/\psi \to \gamma f_2(2340) \to \gamma K_S K_S) = (5.54^{+0.34+3.82}_{-0.40-1.49}) \times 10^{-5}$$

Phys.Rev. D98, 072003 (2018)

6 Glueballs and light hybrid mesons

Rept.Prog.Phys. 86 (2023) 2, 026201

$f_2(2010)$, $f_2(2300)$ and $f_2(2340)$ are observed with a strong production of $f_2(2340)$; consist with central production and pp-bar annihilations

It is desirable to search for more decay modes!

Landscape of light glueball has updated

Scalar : Overpopulation

- LQCD : ground state 0^+ glueball ~1.7 GeV, first excitation ~2.1 GeV

➡

✓ **Strong production of $f_0(1710)/f_0(2100)$ in $J/\psi \to \gamma\, \eta\eta/KK/\pi\pi$**, the pattern consists with LQCD's prediction

Tensor : large uncertainty

- LQCD : 2^{++}(2.3~2.4 GeV)

➡

✓ **Strong production of $f_2(2340)$ in $J/\psi \to \gamma\eta\eta/KK/\pi\pi/\phi\phi$** ; consists with LQCD's prediction

Pseudoscalar : very little known above 2 GeV, puzzles in low mass region

- LQCD : 0^{-+}(2.3~2.6 GeV)

➡

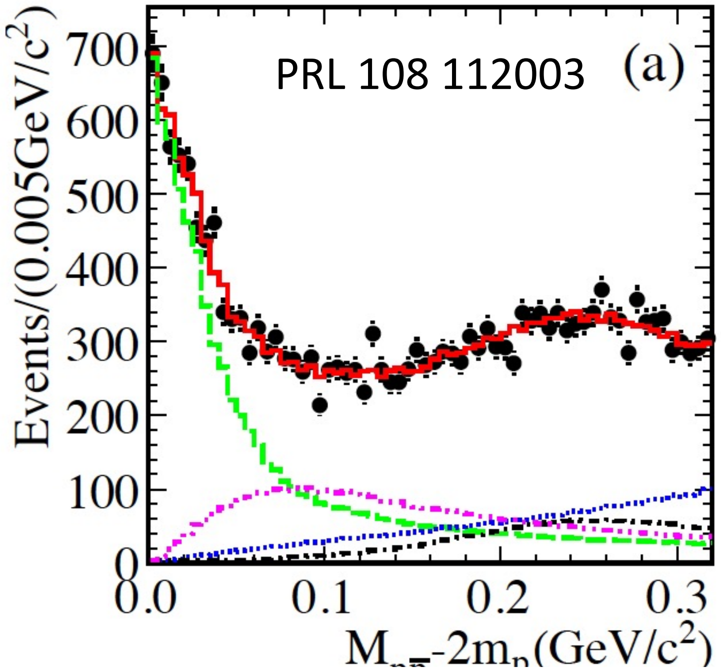
✓ **Trajectory :**

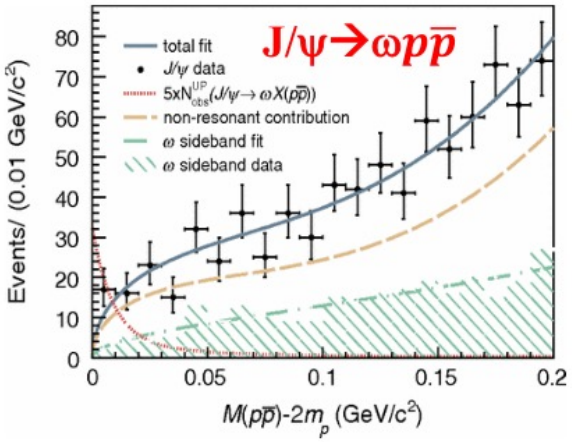
- **$f_1(1285)$, no $\eta(1295)$**
- **$\eta(1405)$ /$\eta(1475)$ can be one resonance**

□ **Above 2 GeV: X(2370)?**

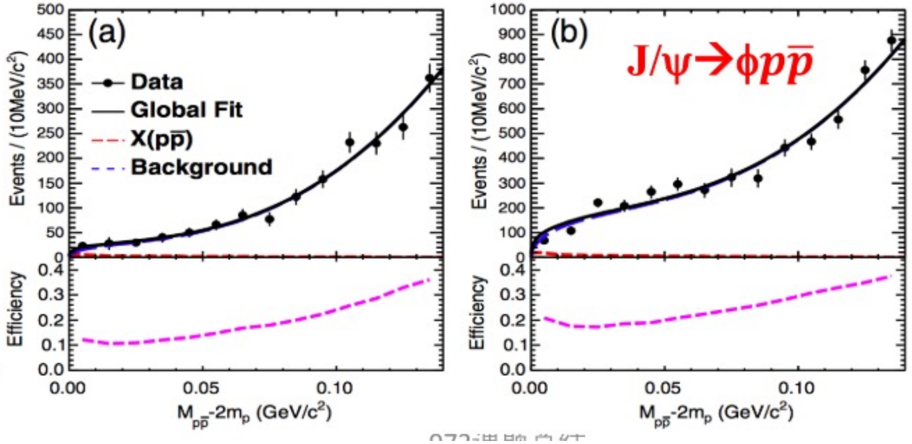
$p\bar{p}$ threshold enhancement $X(p\bar{p})$: Baryonium state?

- First observed in $J/\psi \to \gamma p\bar{p}$ at BESII, confirmed by BESIII and CLEO-c
- PWA of $J/\psi \to \gamma p\bar{p}$: $J^{PC} = 0^{-+}$
  - The fit with a BW and S-wave FSI (I=0) factor can well describe $p\bar{p}$ mass threshold structure
- Non-observation in hadronic decays: not from pure FSI

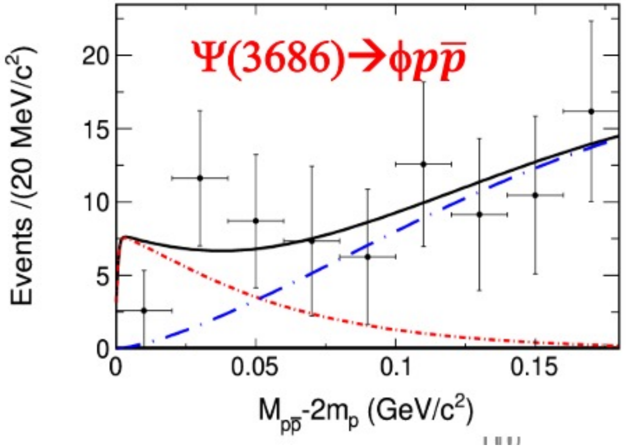




PRD87,112014(2013)

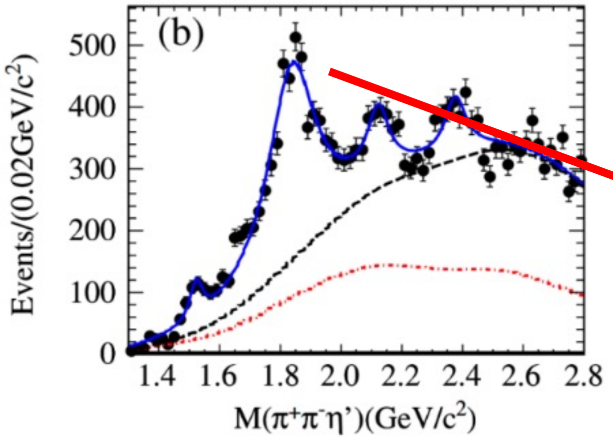


PRD93,052010(2016)



PR D99 112010(2019)

Anomalous line shape of η′π⁺π⁻ near $p\bar{p}$ mass threshold



X(1835) observed in $J/\psi \to \gamma\eta'\pi^+\pi^-$

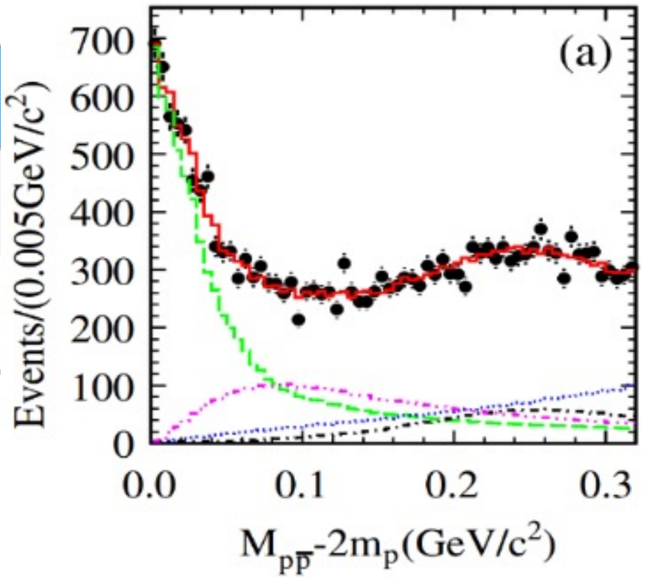
X(1835) $J^{PC}=0^{-+}$
$M = 1844 \pm 9^{+16}_{-25}$ MeV/c^2
$\Gamma = 192^{+20+62}_{-17-43}$ MeV/c^2

PRL 106, 072002 (2011)

X($p\bar{p}$) observed in $J/\psi \to \gamma p\bar{p}$

X($p\bar{p}$) $J^{PC}=0^{-+}$
$M = 1832^{+19}_{-5}{}^{+18}_{-17} \pm 19$ MeV/c^2
$\Gamma = 13 \pm 19$ MeV/c^2 (< 76 MeV/c² @ 90% C.L.)

PRL 108, 112003 (2012)

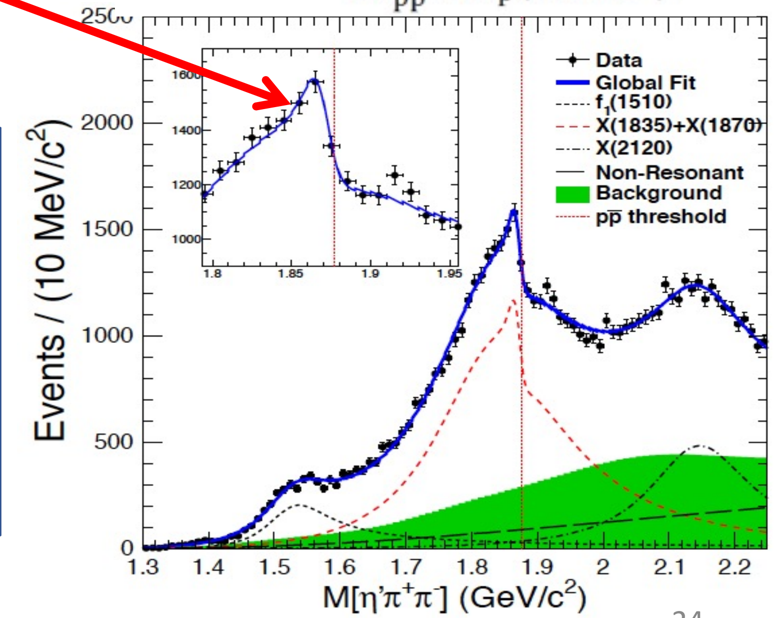


connection between X(1835) and X($p\bar{p}$)

The anomalous line shape :

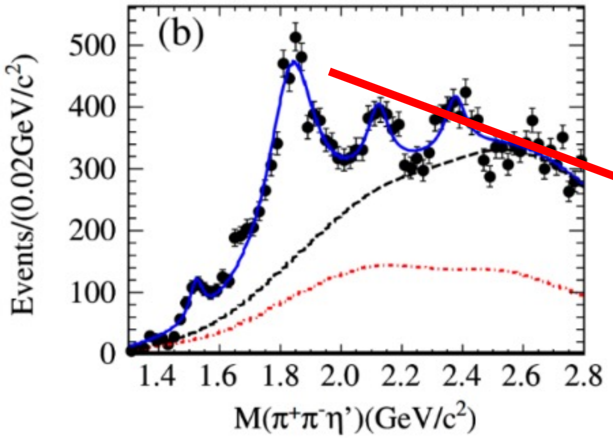
-- Suggest the existence of a state, either a broad state with strong couplings to $p\bar{p}$, or a narrow state just below the $p\bar{p}$ mass threshold

-- Support the existence of a $p\bar{p}$ molecule-like state or bound state



PRL 117, 042002 (2016)

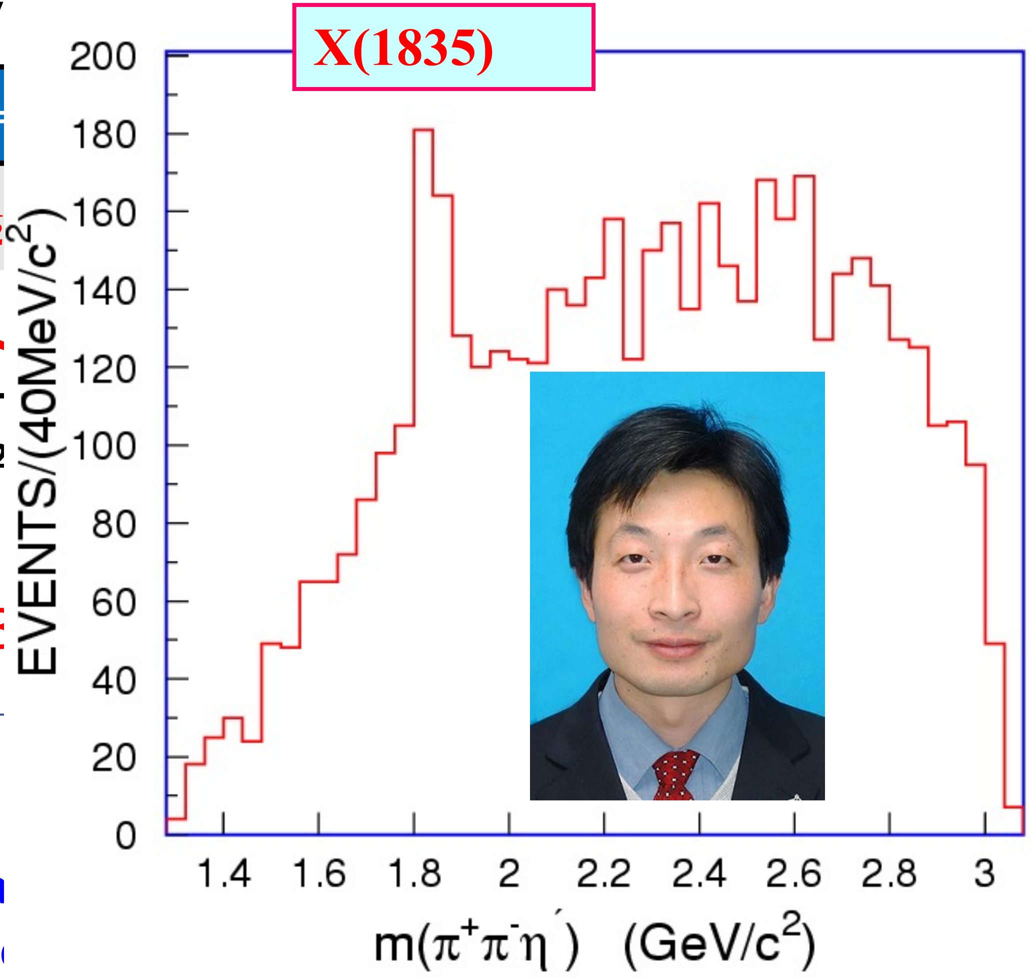
Anomalous line shape of $\eta'\pi^+\pi^-$ near $p\bar{p}$ mass threshold

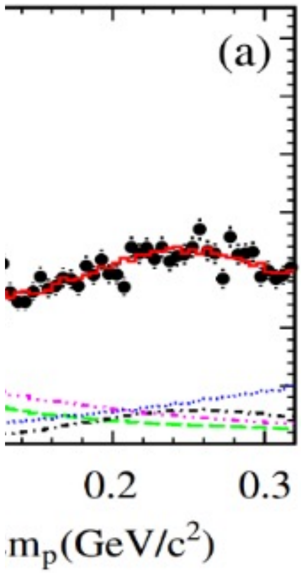


X(1835) observed in J/

X(1835) J^{PC}=
$M = 1844 \pm 9^{+1}_{-2}$
$\Gamma = 192^{+20+62}_{-17-43}$

PRL 106, 072002



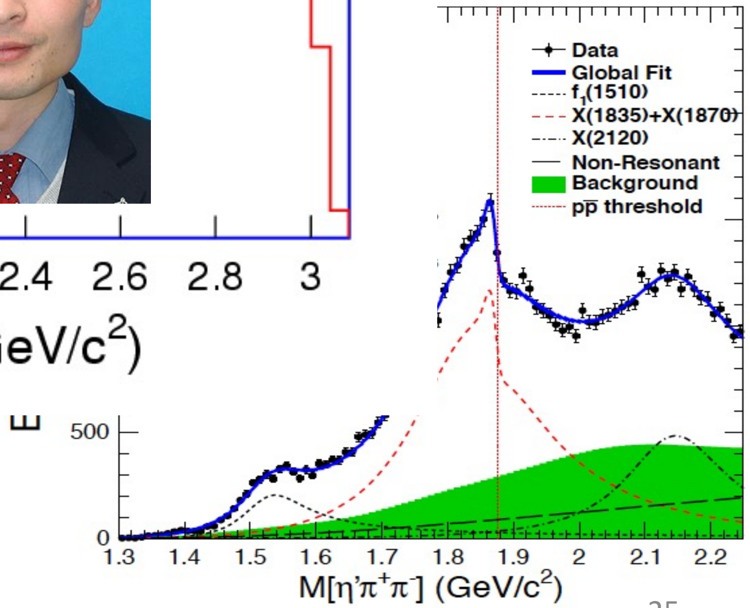


connection between X(18

The anomalous line shape :

-- Suggest the existence of a state, either a
couplings to $p\bar{p}$, or a narrow state just bel

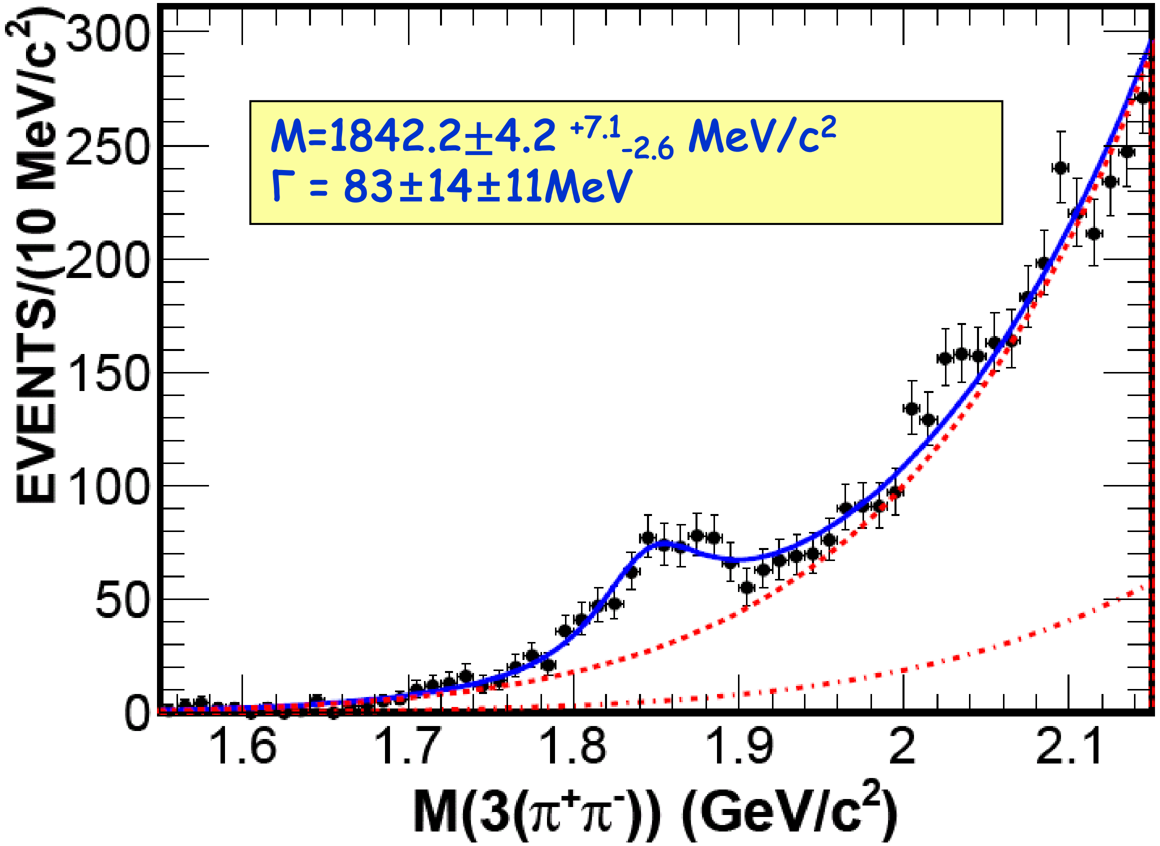
-- Support the existence of a $p\bar{p}$ molecule-like state or bound state



PRL 117, 042002 (2016)

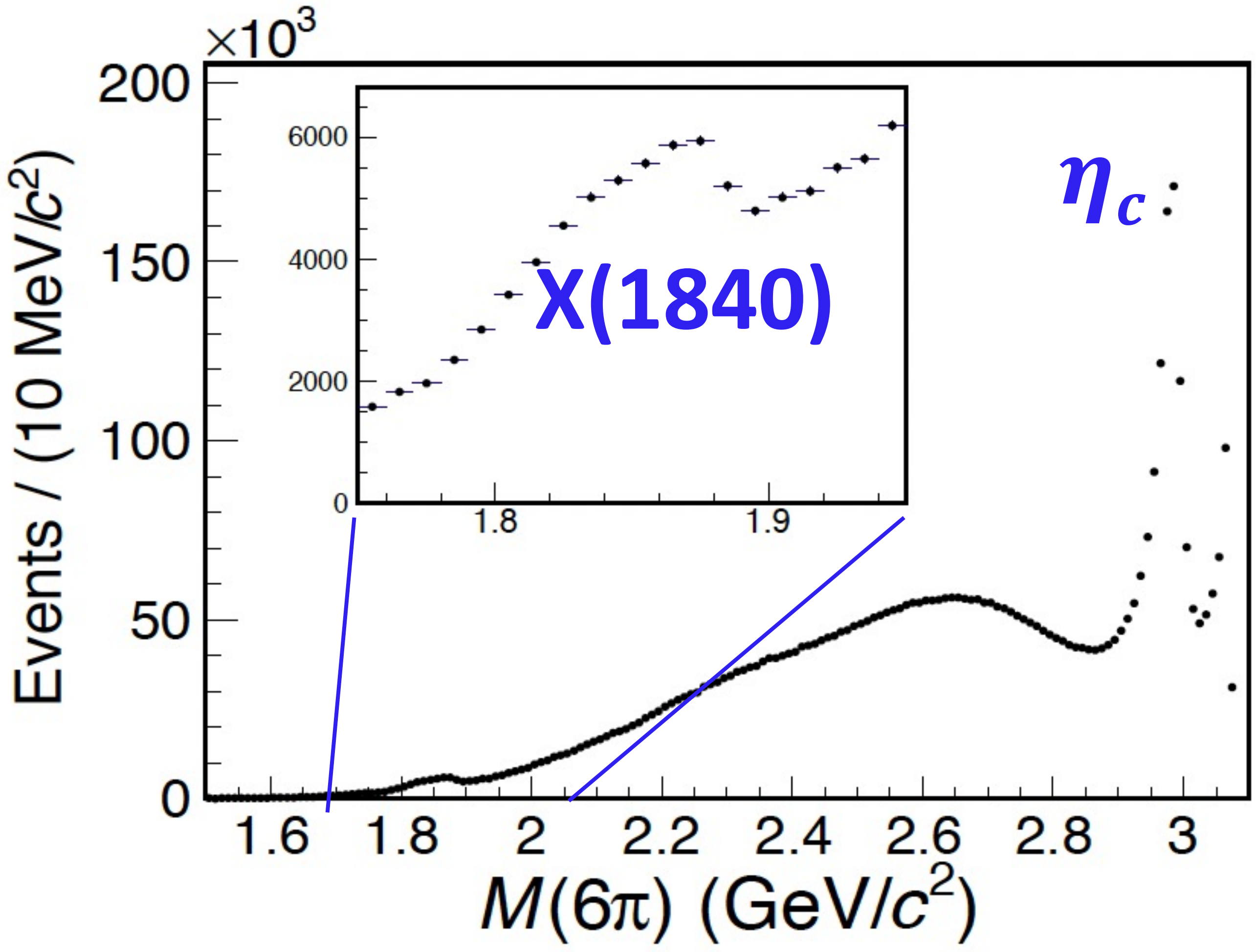
Observation of X(1840) in $J/\psi \rightarrow \gamma 3(\pi^+\pi^-)$（张金国）

PRD 88, 091502 (2013)



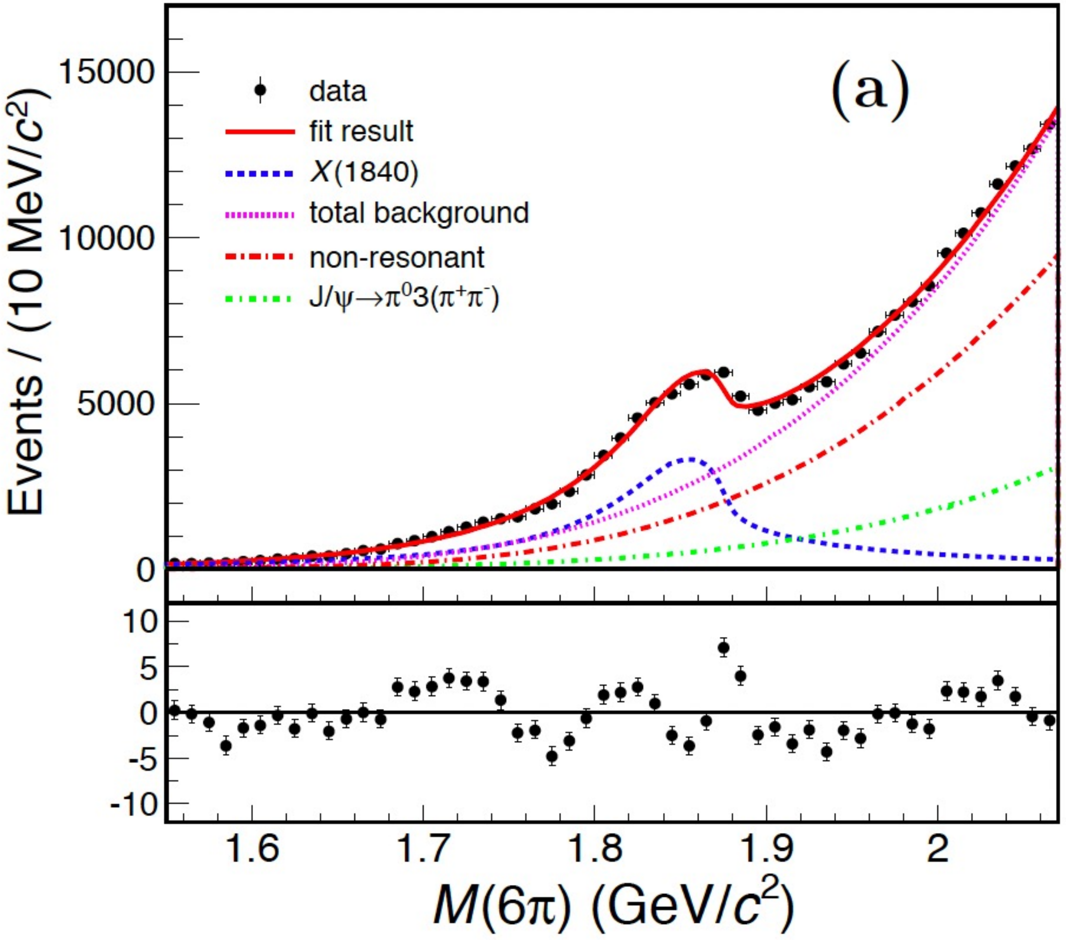
- Mass is consistent with that of X(1835), but the width is much smaller than $\Gamma_{X(1835)} = 190.1 \pm 9.0^{+38}_{-36}$ MeV
- A new decay modes of X(1835)?

Anomalous line-shape of $3(\pi^+\pi^-)$ in $J/\psi\to\gamma\,3(\pi^+\pi^-)$

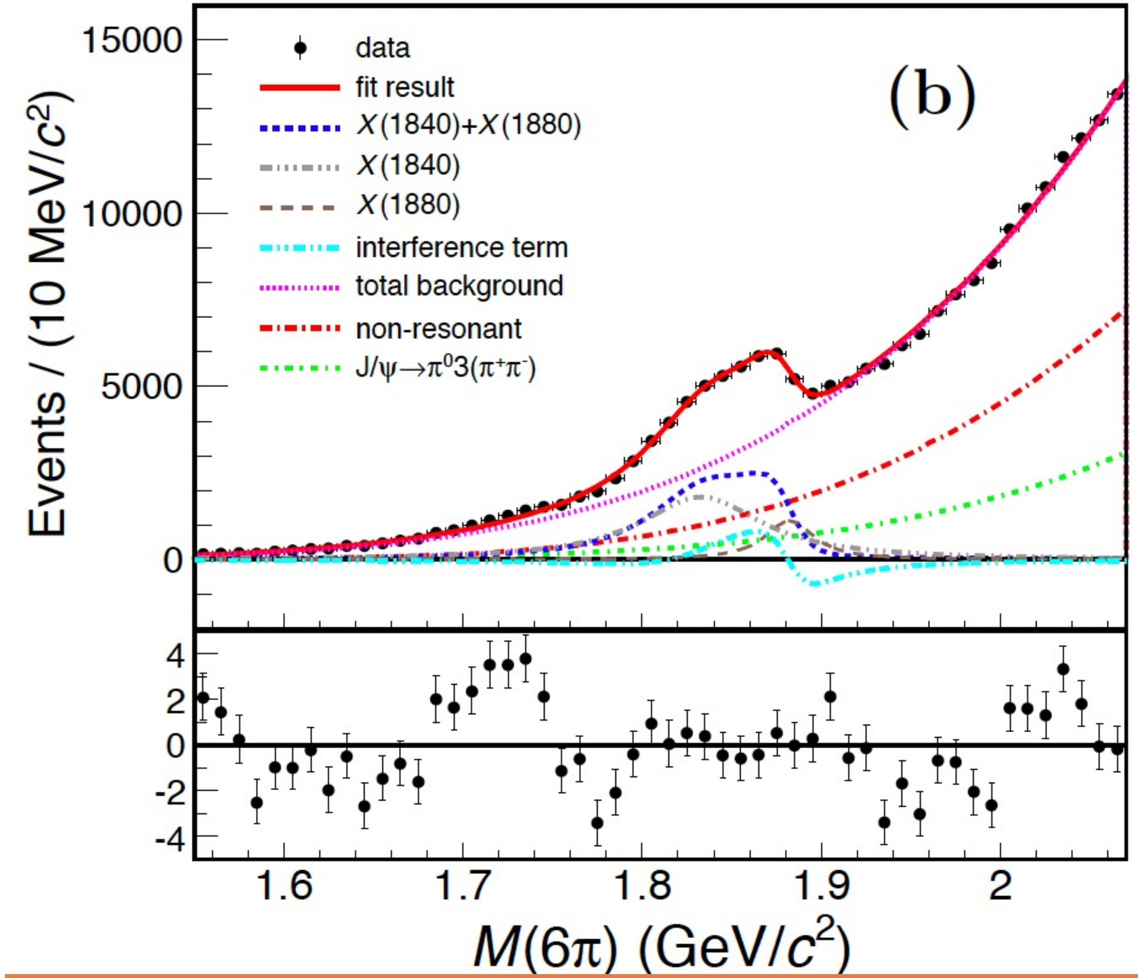


arXiv:2310.17937, accepted by PRL

Flatte function

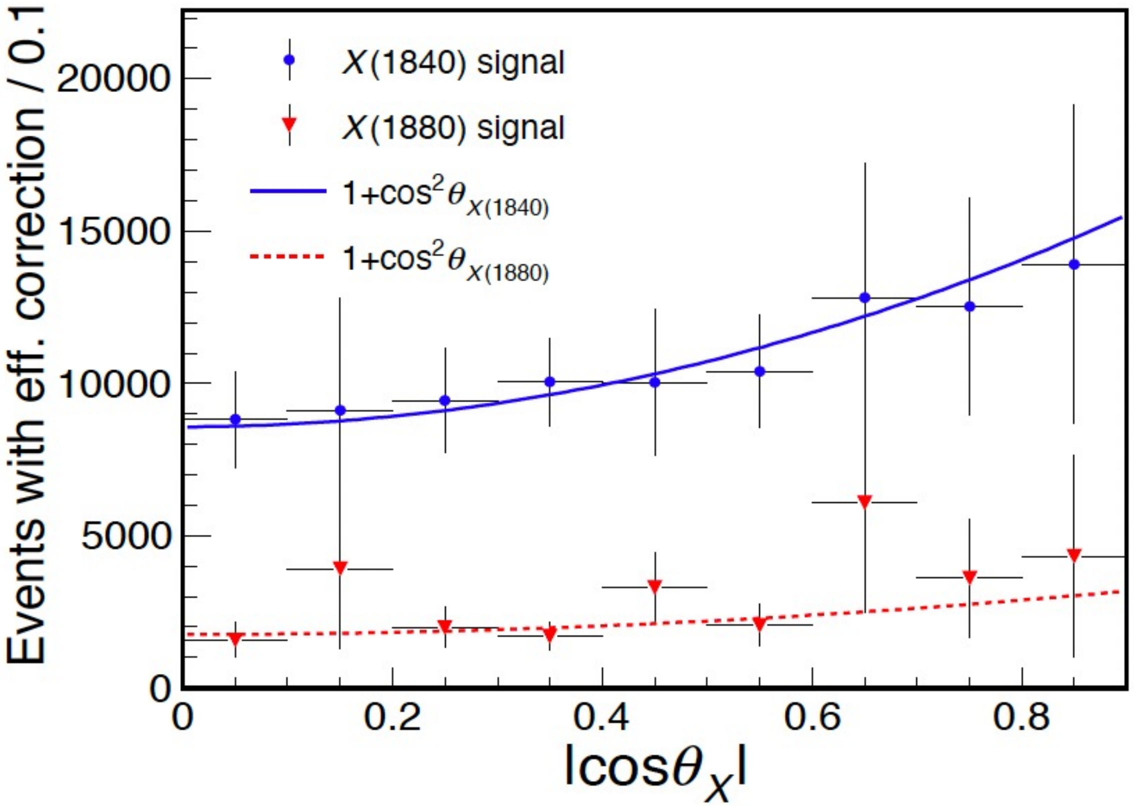


Two BWs



Resonance	M(MeV/c^2)	Γ(MeV/c^2)
X(1880)	1882.1±1.7±0.7	30.7±5.5±2.4
X(1840)	1832.5±3.1±2.5	80.7±5.2±7.7

Consistent with pseudoscalars



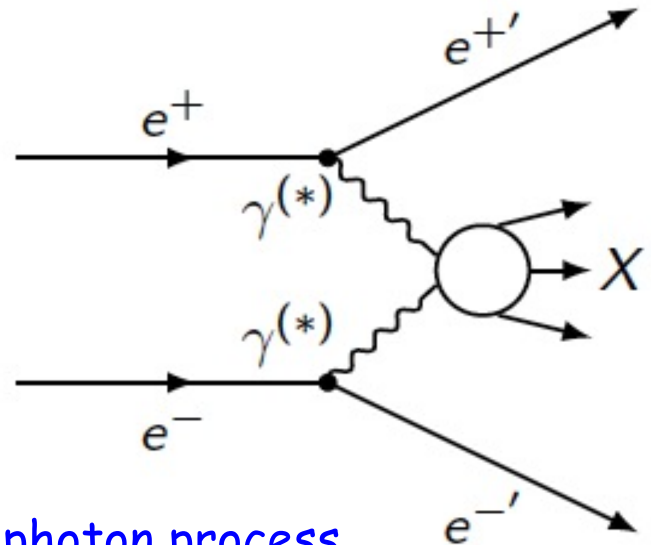
narrow state below $p\bar{p}$ threshold !

Prospects: 10B J/ψ and 2.7B $\psi(2S)$ provide great opportunities

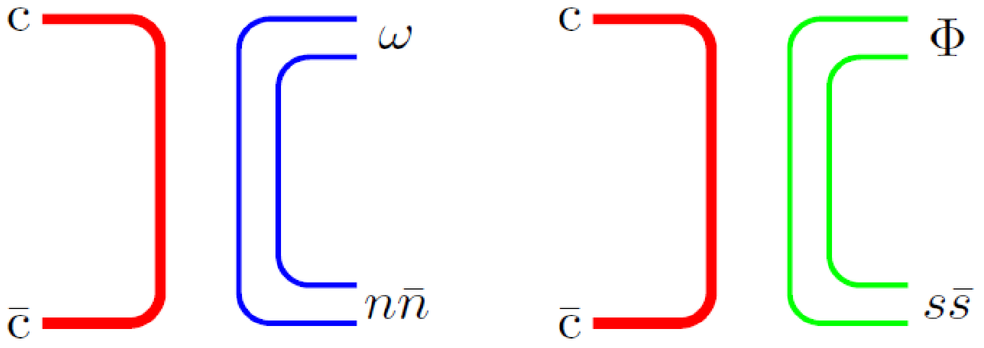
	0^+	2^+	0^-
$J/\psi\to\gamma PP$			
$J/\psi\to\gamma VV$			
$J/\psi\to\gamma PPP$			
$J/\psi\to\gamma PPPP$			

- 0^+, 2^+ : coupled channel analysis
  - $J/\psi\to\gamma PP$
  - $J/\psi\to\omega/\varphi + X$
- 0^- : trajectory >2 GeV, X(2370)
  - $J/\psi\to\gamma PPP$
  - $J/\psi\to\gamma\gamma V$
- 1^{-+}
  - $J/\psi\to\gamma\eta_1^{(\prime)}$
  - $\chi_{c1}\to\eta\eta_1^{(\prime)},\pi\pi_1$

Anti filter:



Two photon process



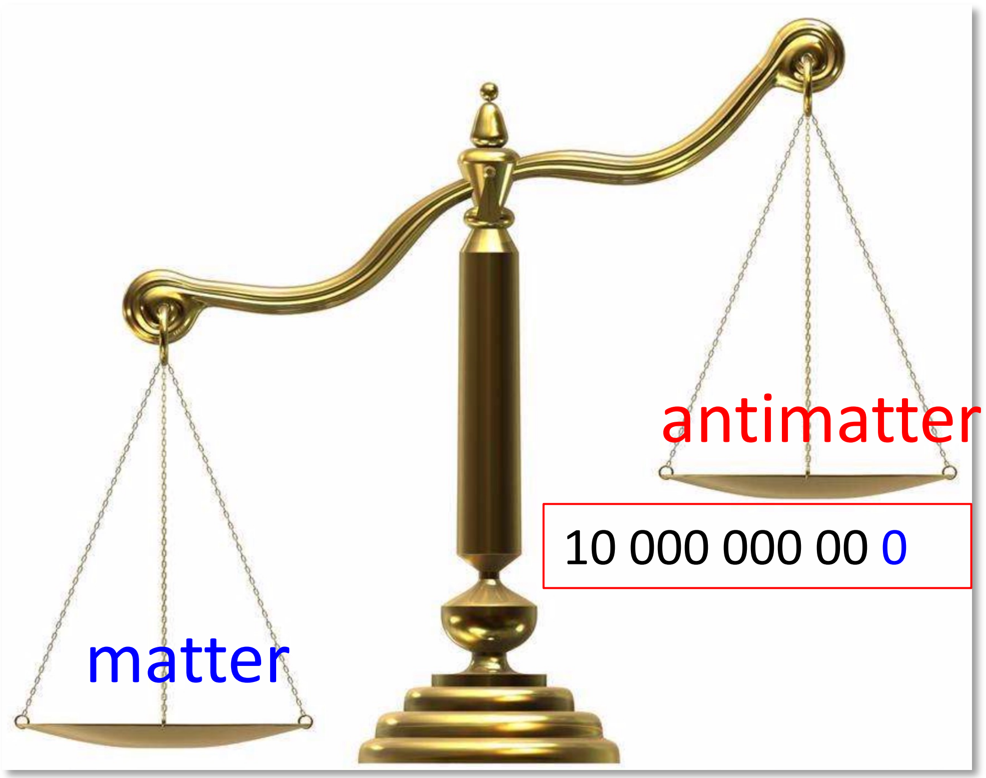
Flavor Filters : $J/\psi\to\omega/\phi + X$

Hyperon Physics

- CP violation: K (1964), B(2001), D(2019)
- Not enough !

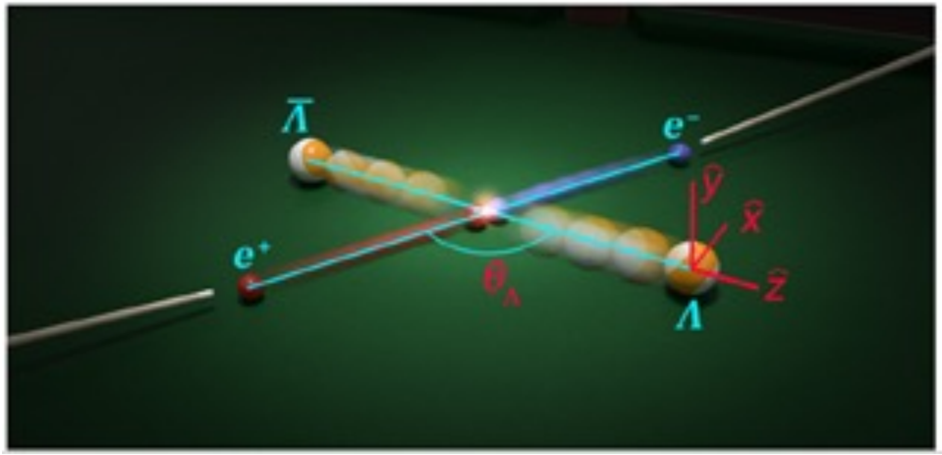
  CP asymmetry : 10^{-10} → present universe

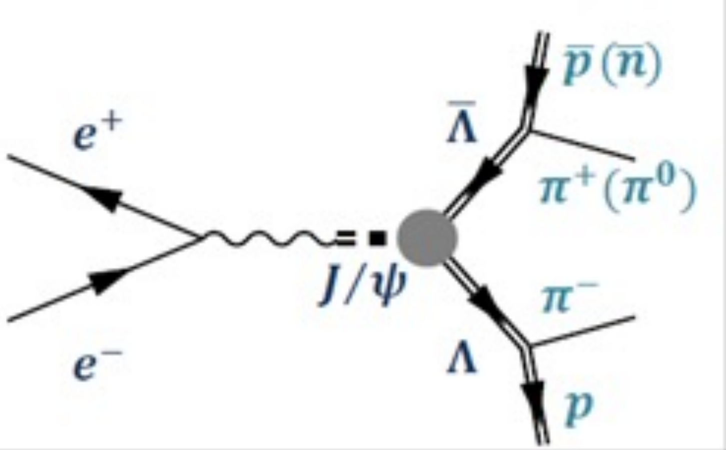
  CP asymmetry in SM : $10^{-20} \sim 10^{-16}$

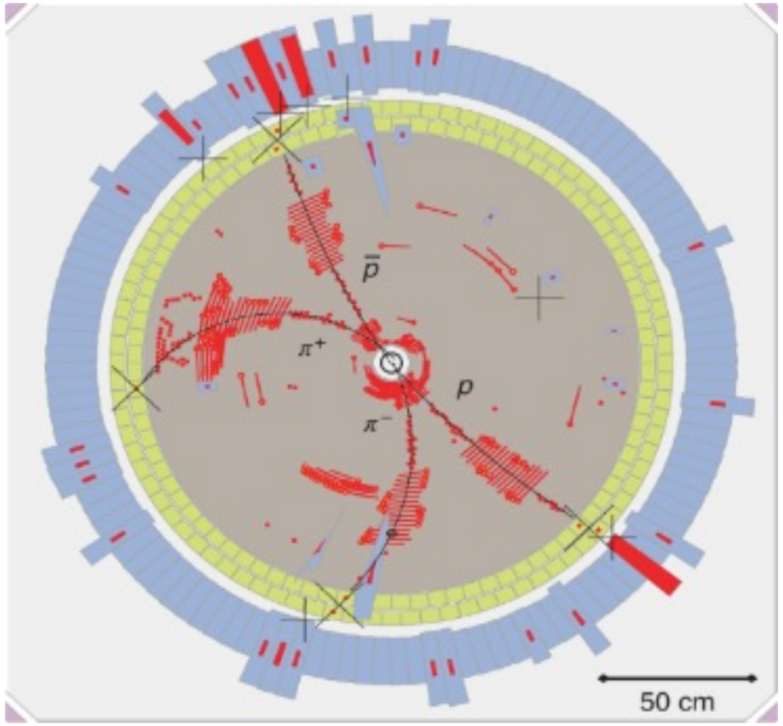


New source for CP asymmetry ?

Huge amount Hyperon pairs produced in J/ψ decays







Decay mode	$\mathcal{B}(\times 10^{-3})$	$N_\mathcal{B}$ $(\times 10^6)$
$J/\psi \to \Lambda\bar{\Lambda}$	1.61 ± 0.15	16.1 ± 1.5
$J/\psi \to \Sigma^0\bar{\Sigma}^0$	1.29 ± 0.09	12.9 ± 0.9
$J/\psi \to \Sigma^+\bar{\Sigma}^-$	1.50 ± 0.24	15.0 ± 2.4
$J/\psi \to \Sigma(1385)^-\bar{\Sigma}^+$ (or c.c.)	0.31 ± 0.05	3.1 ± 0.5
$J/\psi \to \Sigma(1385)^-\bar{\Sigma}(1385)^+$ (or c.c.)	1.10 ± 0.12	11.0 ± 1.2
$J/\psi \to \Xi^0\bar{\Xi}^0$	1.20 ± 0.24	12.0 ± 2.4
$J/\psi \to \Xi^-\bar{\Xi}^+$	0.86 ± 0.11	8.6 ± 1.0
$J/\psi \to \Xi(1530)^0\bar{\Xi}^0$	0.32 ± 0.14	3.2 ± 1.4
$J/\psi \to \Xi(1530)^-\bar{\Xi}^+$	0.59 ± 0.15	5.9 ± 1.5
$\psi(2S) \to \Omega^-\bar{\Omega}^+$	0.05 ± 0.01	0.15 ± 0.03

If $\Delta\Phi \neq 0$, Λ are transversely polarized

Correlated 5-dim. angular distribution $e^+e^- \to J/\psi \to \Lambda\bar{\Lambda}$

$$\mathcal{W}(\xi;\alpha_\psi,\Delta\Phi,\alpha_-,\alpha_+) = 1 + \alpha_\psi \cos^2\theta_\Lambda$$

Unpolarized part

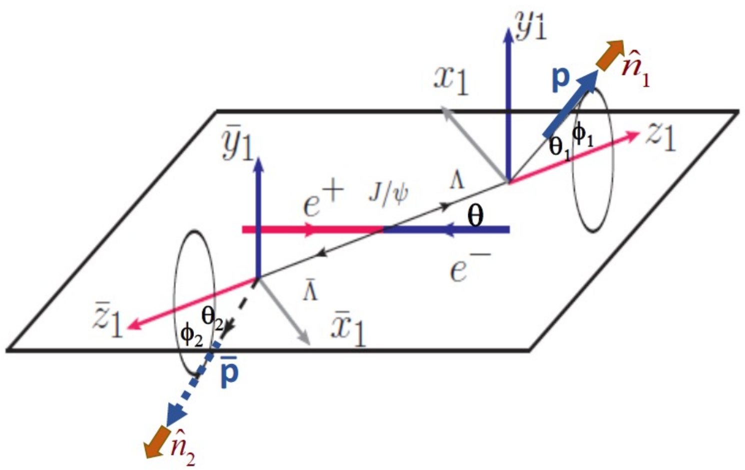
Entangled part

$$+\alpha_-\alpha_+\left[\sin^2\theta_\Lambda\left(n_{1,x}n_{2,x} - \alpha_\psi n_{1,y}n_{2,y}\right) + \left(\cos^2\theta_\Lambda + \alpha_\psi\right) n_{1,z}n_{2,z}\right]$$

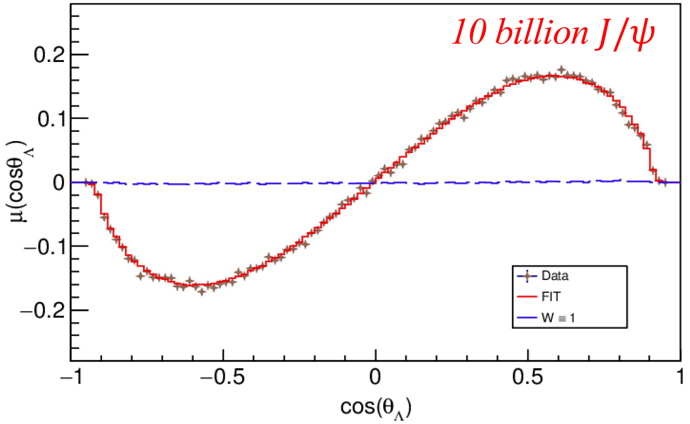
$$+\alpha_-\alpha_+\sqrt{1-\alpha_\psi{}^2}\cos(\Delta\Phi)\sin\theta_\Lambda\cos\theta_\Lambda\left(n_{1,x}n_{2,z} + n_{1,z}n_{2,x}\right)$$

$$+\sqrt{1-\alpha_\psi{}^2}\sin(\Delta\Phi)\sin\theta_\Lambda\cos\theta_\Lambda\left(\alpha_- n_{1,y} + \alpha_+ n_{2,y}\right),$$

Polarized part



Polarization-term can be used to determine a_- and a_+ simultaneously



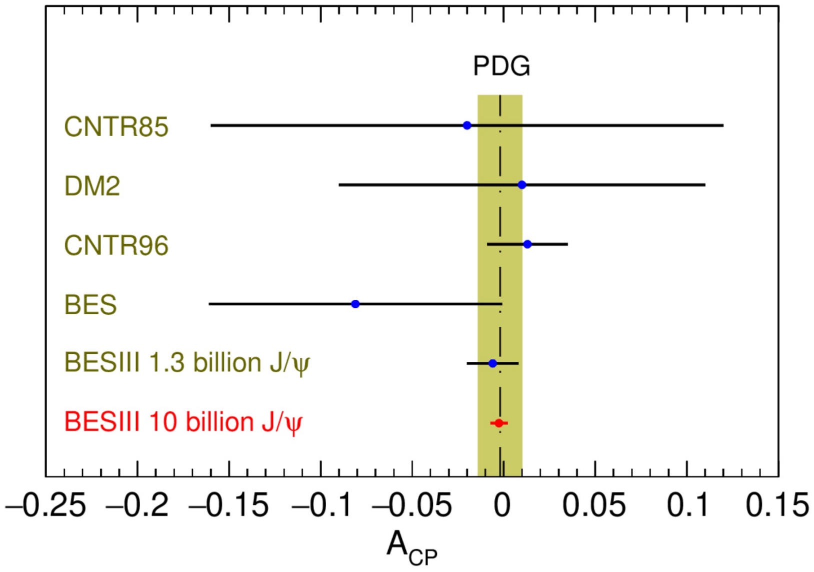
Λ

$$P_y(\cos\theta_\Lambda) = \frac{\sqrt{1-\alpha_\psi^2}\,\sin(\Delta\Phi)\cos\theta_\Lambda\sin\theta_\Lambda}{1+\alpha_\psi\cos^2\theta_\Lambda}$$

PRL. 129, 131801 (2022)

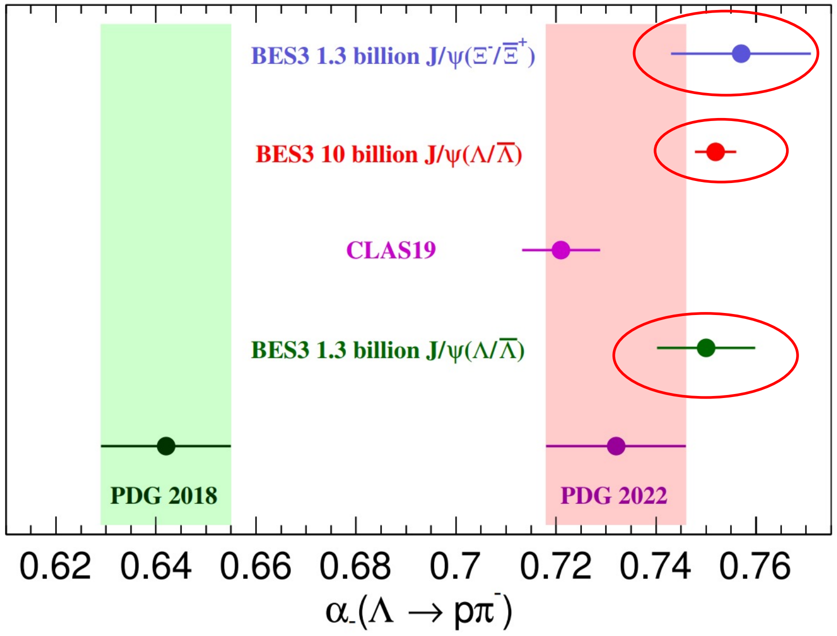
Nat. Phys. 15, 631 (2019)

The most precise *CP test in* Λ and $\bar{\Lambda}$ decay



Standard mode prediction : A_{CP}~ 10^{-4} (PRD 34, 833 (1986))

More than standard d… shift from a… previous measurem…



Summary

Extraction of the N^* and Δ spectrum from experimental data:

- new informati…
- also electropr…
- recent results…

第12届核子激发态国际会议
2019-6月10日-14日，波恩，德国

Jülich-Bonn model:

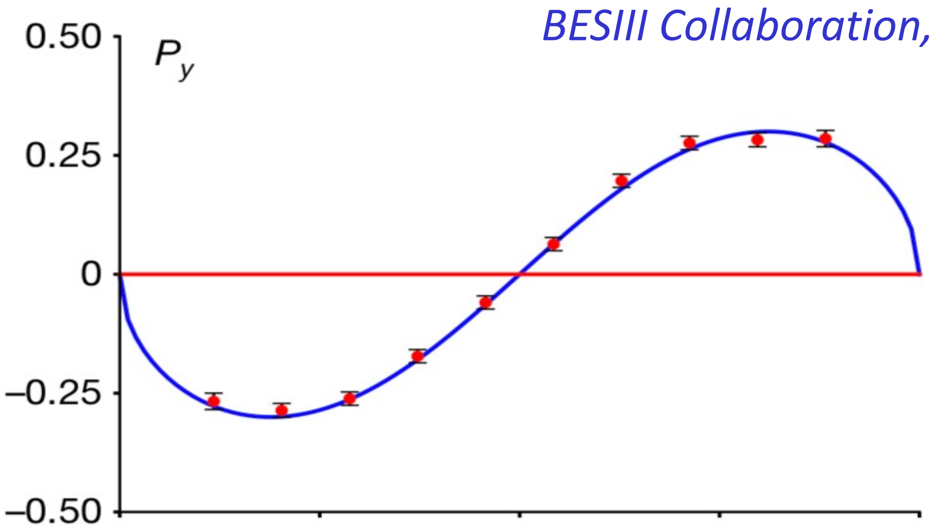
- extension of the coupled-channel approach to kaon photoproduction
- $\gamma p \to K\Sigma$ especially interesting for $I = 3/2$ states
- impact of a new value of the Λ decay parameter α_-:
  - many resonances more or less stable
  - some exceptions with major changes in the resonance parameters
  - photo couplings at the pole more sensitive than other parameter

Future plans JüBo:

- electroproduction (already in progress)
- inclusion of the further channels, e.g. photoproduction on the neutron

Probe CP asymmetry and weak phase in $J/\psi \to \Xi \bar{\Xi}$.(王雄飞)

BESIII Collaboration, Nature 606,64 (2022)



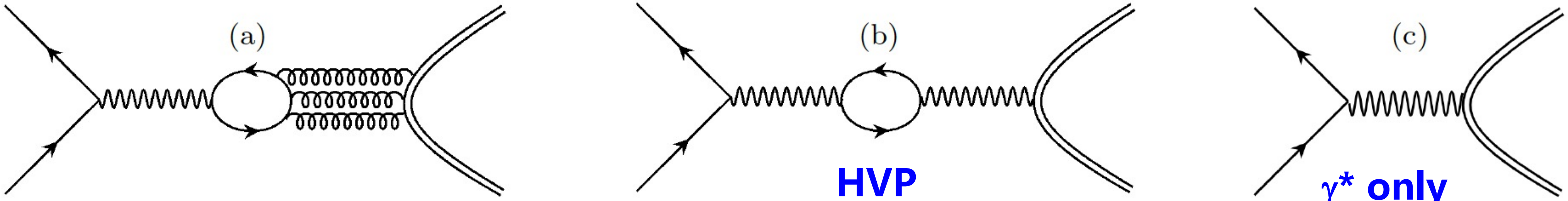
First measurement of weak and strong phase in $\Xi^- \to \Lambda\pi$

$\xi_P - \xi_S$	$(1.2 \pm 3.4 \pm 0.8) \times 10^{-2}$ rad
$\delta_P - \delta_S$	$(-4.0 \pm 3.3 \pm 1.7) \times 10^{-2}$ rad
A_{CP}^{Ξ}	$(6 \pm 13 \pm 6) \times 10^{-3}$
$\Delta\phi_{CP}^{\Xi}$	$(-5 \pm 14 \pm 3) \times 10^{-3}$ rad
A_{CP}^{Λ}	$(-4 \pm 12 \pm 9) \times 10^{-3}$
$\langle\phi_{\Xi}\rangle$	$0.016 \pm 0.014 \pm 0.007$ rad

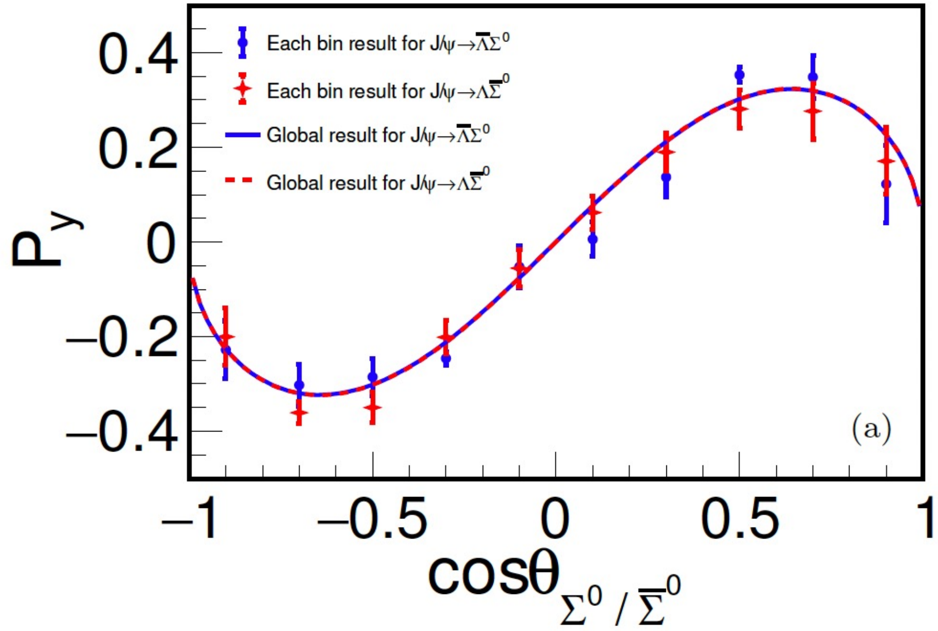
Open a new window for exploring CP asymmetry!

Observation of polarizations in $J/\psi\to\Lambda\bar{\Sigma}$ （郑文静）

arXiv:2309.04139, submitted to Nature Physics



Strong Int. **HVP** **γ^* only**

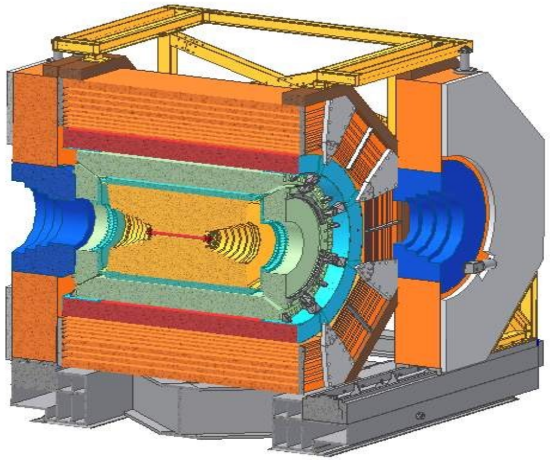


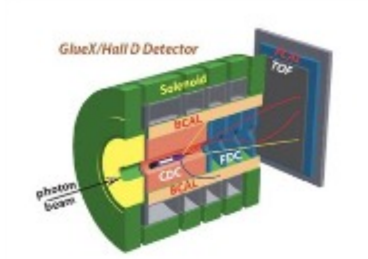
Form factor ratio:
G_E/G_M=0.860±0.029±0.010

$\Delta\phi_1+\Delta\phi_2$ =3.139±0.133±0.014
in good agreement with zero: no direct CP violation

Light meson physics

- Rich physics in the light meson decays
  - Test ChPT predictions
  - Form factors
  - Test fundamental symmetries
- BESIII: a light meson factory
  - $J/\psi \to \gamma\eta/\eta' \to 1\times10^{7}\ \eta,\ 5.2\times10^{7}\ \eta'$





BESIII: an important role in η/η′ decays

(27 publications since 2011)

What is "NEW" at BESIII ?

- New decays
- New decay mechanisms
- New approaches
- New tests for fundamental symmetries

$\eta'(958)$ REFERENCES

ABLIKIM	21I	PR D103 072006	M. Ablikim *et al.*	(BESIII Collab.)
ABLIKIM	21J	PR D103 092005	M. Ablikim *et al.*	(BESIII Collab.)
ABLIKIM	20E	PR D101 032001	M. Ablikim *et al.*	(BESIII Collab.)
ABLIKIM	19AW	PR D100 052015	M. Ablikim *et al.*	(BESIII Collab.)
~~ABLIKIM~~	~~19T~~	~~PRL 122 142002~~	~~M. Ablikim *et al.*~~	(BESIII Collab.)
ABLIKIM	18	PR D97 012003	M. Ablikim *et al.*	(BESIII Collab.)
~~ABLIKIM~~	~~18C~~	~~PRL 120 242003~~	~~M. Ablikim *et al.*~~	(BESIII Collab.)
ADLARSON	18A	PR D98 012001	P. Adlarson *et al.*	(A2 Collab. at MAMI)
GONZALEZ-S...	18A	EPJ C78 758	S. Gonzalez-Solis, E. Passemar	(BEIJ, IND+)
AAIJ	17D	PL B764 233	R. Aaij *et al.*	(LHCb Collab.)
~~ABLIKIM~~	~~17~~	~~PRL 118 012001~~	~~M. Ablikim *et al.*~~	(BESIII Collab.)
ABLIKIM	17T	PR D96 012005	M. Ablikim *et al.*	(BESIII Collab.)
ABLIKIM	16M	PR D93 072008	M. Ablikim *et al.*	(BESIII Collab.)
ABLIKIM	15AD	PR D92 051101	M. Ablikim *et al.*	(BESIII Collab.)
ABLIKIM	15G	PR D92 012014	M. Ablikim *et al.*	(BESIII Collab.)
ABLIKIM	15O	PR D92 012001	M. Ablikim *et al.*	(BESIII Collab.)
ABLIKIM	15P	PR D92 012007	M. Ablikim *et al.*	(BESIII Collab.)
ACHASOV	15	PR D91 092010	M.N. Achasov *et al.*	(SND Collab.)
AKHMETSHIN	15	PL B740 273	R.R. Akhmetshin *et al.*	(CMD-3 Collab.)
PDG	15	RPP 2015 at pdg.lbl.gov		(PDG Collab.)
ABLIKIM	14M	PRL 112 251801	M. Ablikim *et al.*	(BESIII Collab.)
~~DONSKOV~~	~~14~~	~~MPL A29 1450213~~	~~S. Donskov *et al.*~~	(GAMS-4π Collab.)
PDG	14	CP C38 070001	K. Olive *et al.*	(PDG Collab.)
ABLIKIM	13	PR D87 012009	M. Ablikim *et al.*	(BESIII Collab.)
ABLIKIM	13G	PR D87 032006	M. Ablikim *et al.*	(BESIII Collab.)
ABLIKIM	13O	PR D87 092011	M. Ablikim *et al.*	(BESIII Collab.)
ABLIKIM	13U	PR D88 091502	M. Ablikim *et al.*	(BESIII Collab.)
~~ABLIKIM~~	~~12E~~	~~PRL 108 182001~~	~~M. Ablikim *et al.*~~	(BESIII Collab.)
PDG	12	PR D86 010001	J. Beringer *et al.*	(PDG Collab.)
ABLIKIM	11	PR D83 012003	M. Ablikim *et al.*	(BESIII Collab.)
ABLIKIM	11G	PR D84 032006	M. Ablikim *et al.*	(BESIII Collab.)

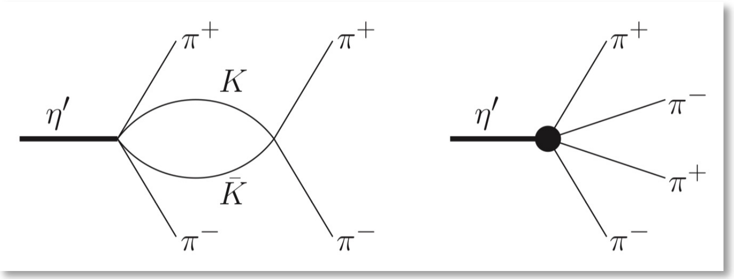
PDG2022

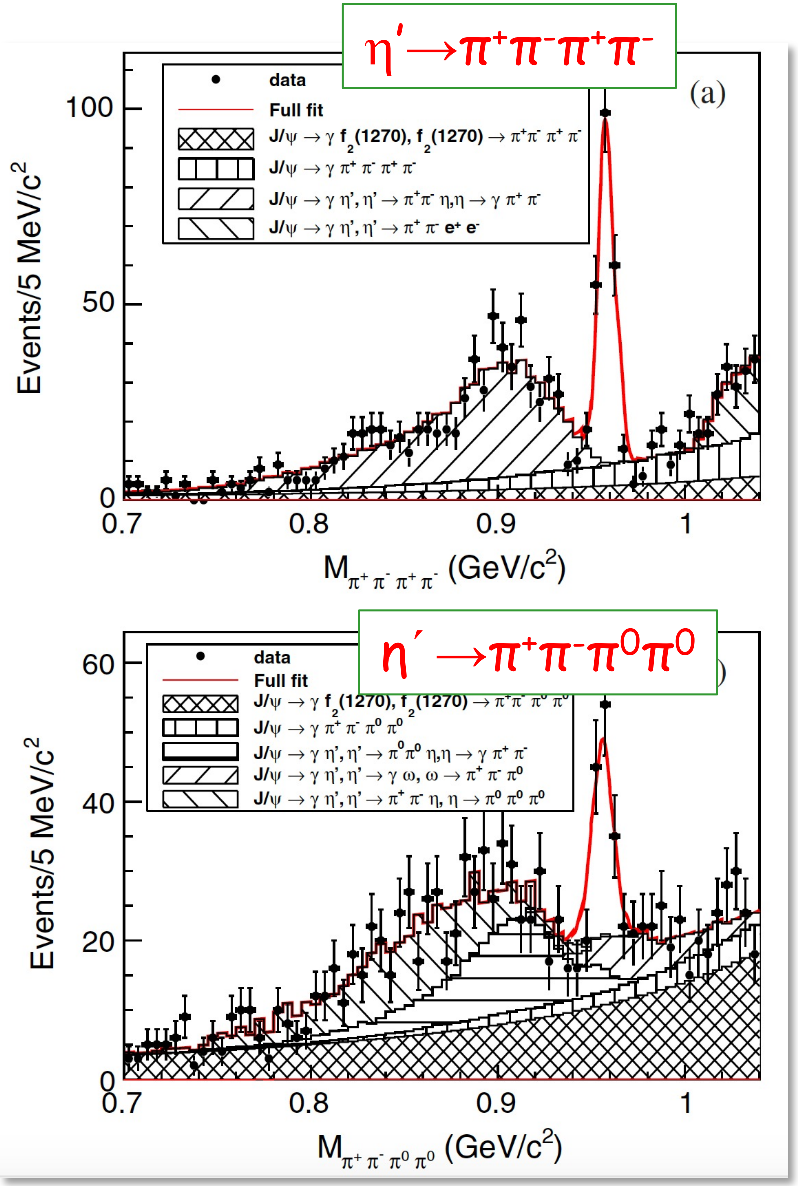
New decays

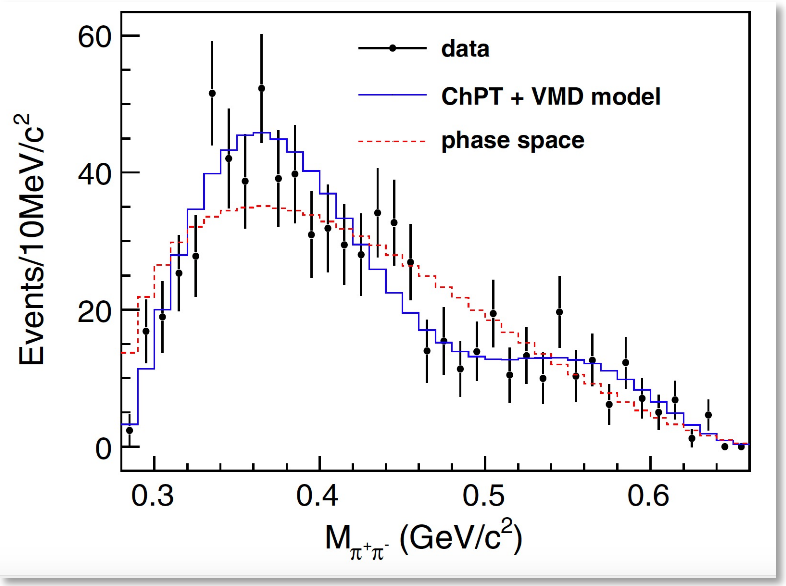
$\eta' \to 2(\pi^+\pi^-), \pi^+\pi^-\pi^0\pi^0$	PRL112, 251801(2014)
$\eta' \to \gamma e^+e^-$	PRD92, 012001(2015)
$\eta' \to \omega e^+e^-$	PRD92, 051101(2015)
$\eta' \to \rho\pi$	PRL118, 012001(2017)
$\eta' \to \gamma\gamma\pi^0$	PRD96, 012005(2017)
$\eta' \to \pi^+\pi^- u^+ u^-$	PRD103, 072006(2021)
$\eta' \to e+e-e+e-$	PRD105,112010(2022)

Observation of η′ →π+π-π+π-,π+π-π0π0 (李会娟)

PRL112,251801(2014)







ChPT+VMD:
only occur at $O(p^6)$

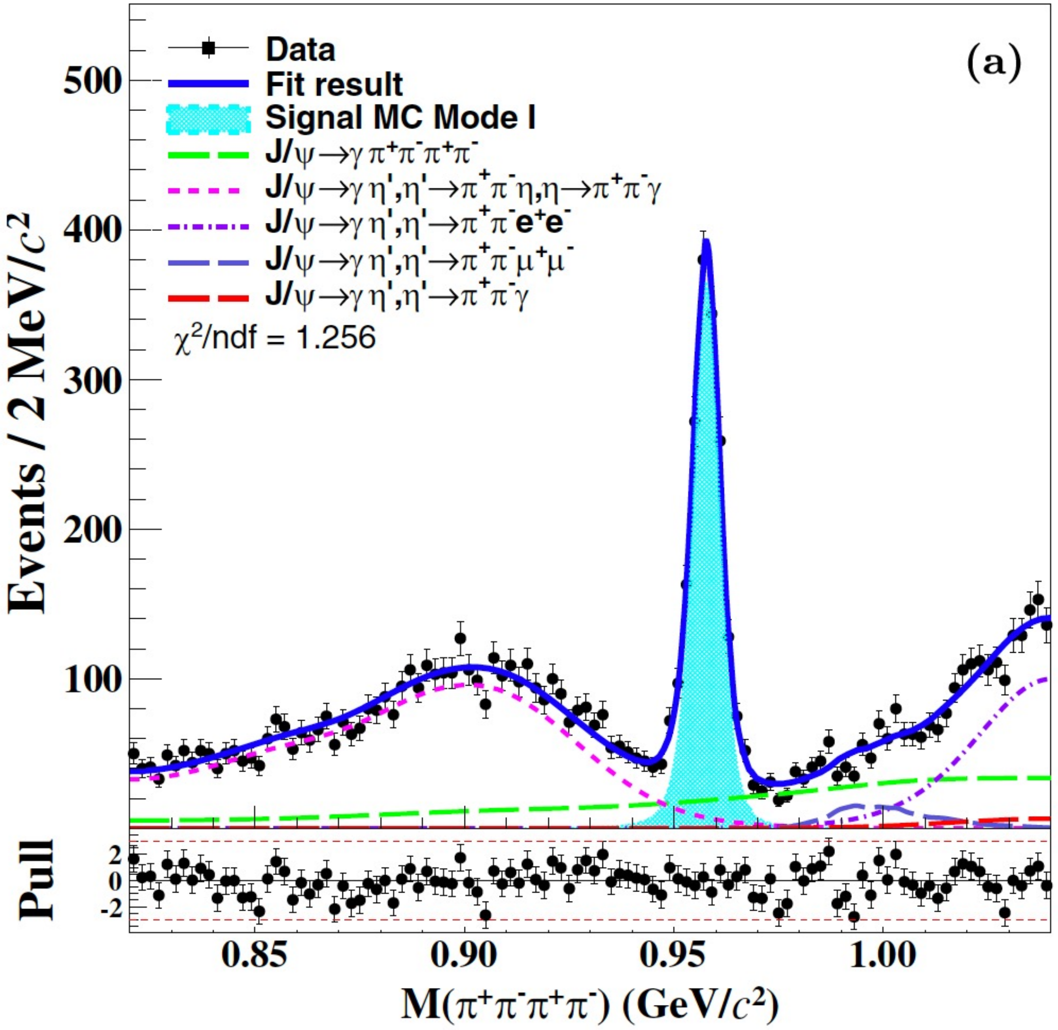
$B(\eta'\to\pi^+\pi^-\pi^+\pi^-)=(1.0\pm0.3)\times10^{-4}$
$B(\eta'\to\pi^+\pi^-\pi^0\pi^0)=(2.4\pm0.7)\times10^{-4}$

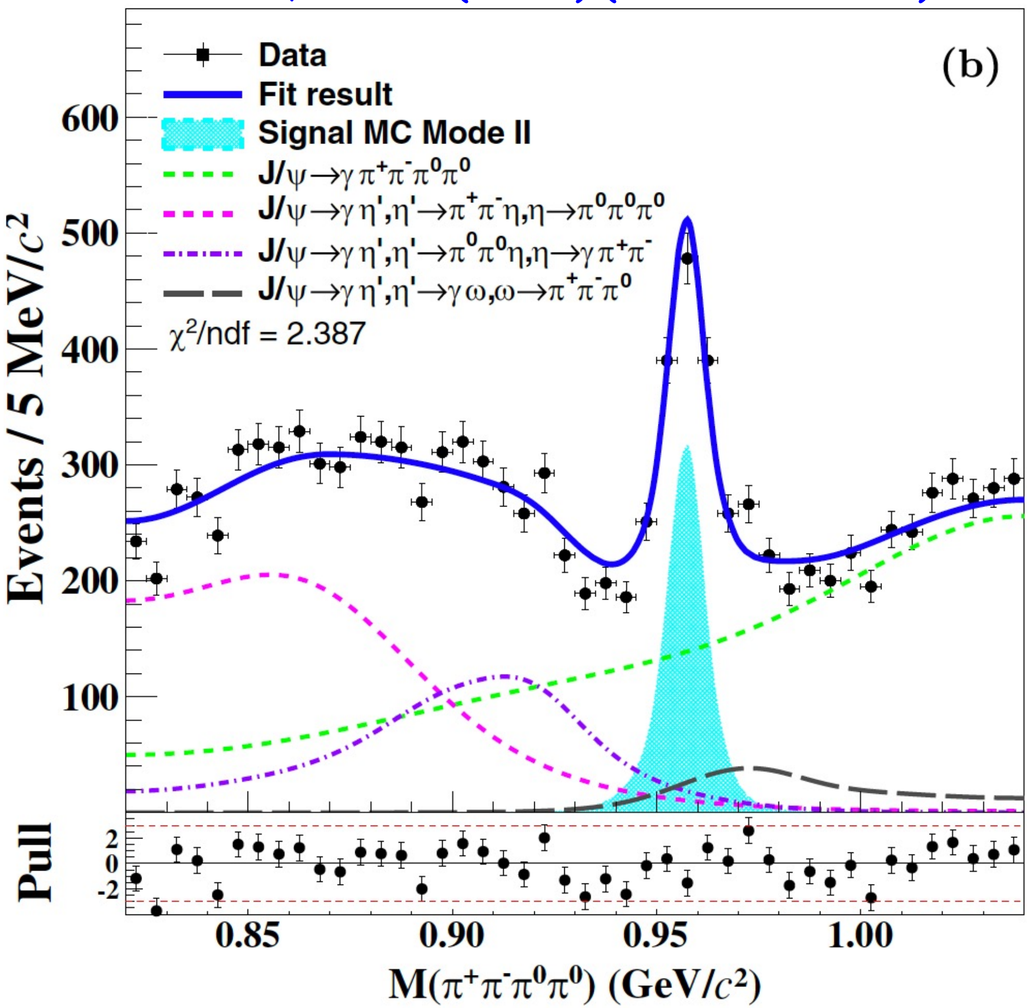
F.K. Guo et al ,PRD 85,014014 (2012)

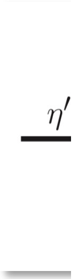
$B(\eta'\to\pi^+\pi^-\pi^+\pi^-)=(8.63\pm0.69\pm0.64)\times10^{-5}$
$B(\eta'\to\pi^+\pi^-\pi^0\pi^0)=(1.82\pm0.35\pm0.18)\times10^{-4}$

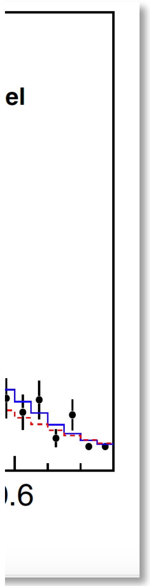
Observation of $\eta' \to \pi^+\pi^-\pi^+\pi^-, \pi^+\pi^-\pi^0\pi^0$ (李会娟)

PRD109,032006(2024) (赵子涵，郑文静)





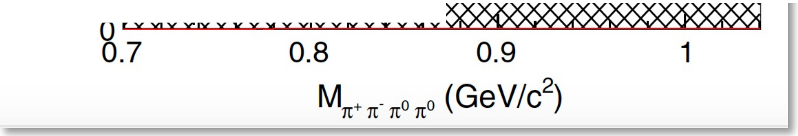




B

B

F.K. Guo et al ,PRD 85,014014 (2012)



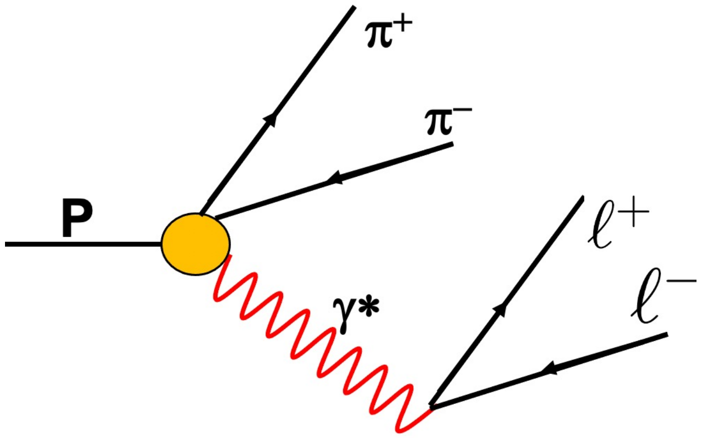
4)

54)×10^{-5}

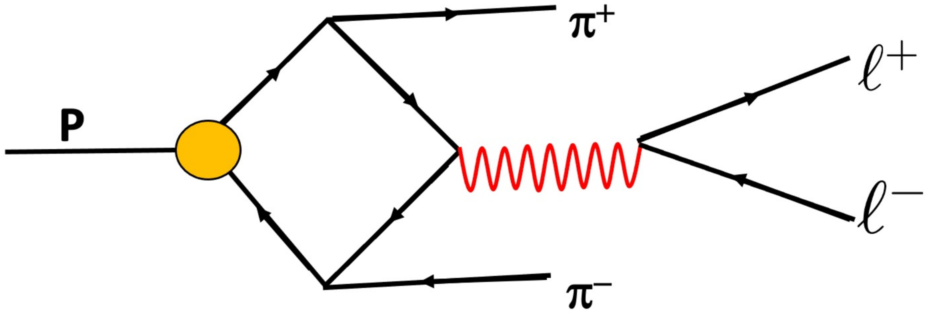
18)×10^{-4}

$\eta' \to \pi^+\pi^- l^+ l^-$

- Box anomaly
- Form factor → $(g-2)_\mu$
- Test the CP symmetry



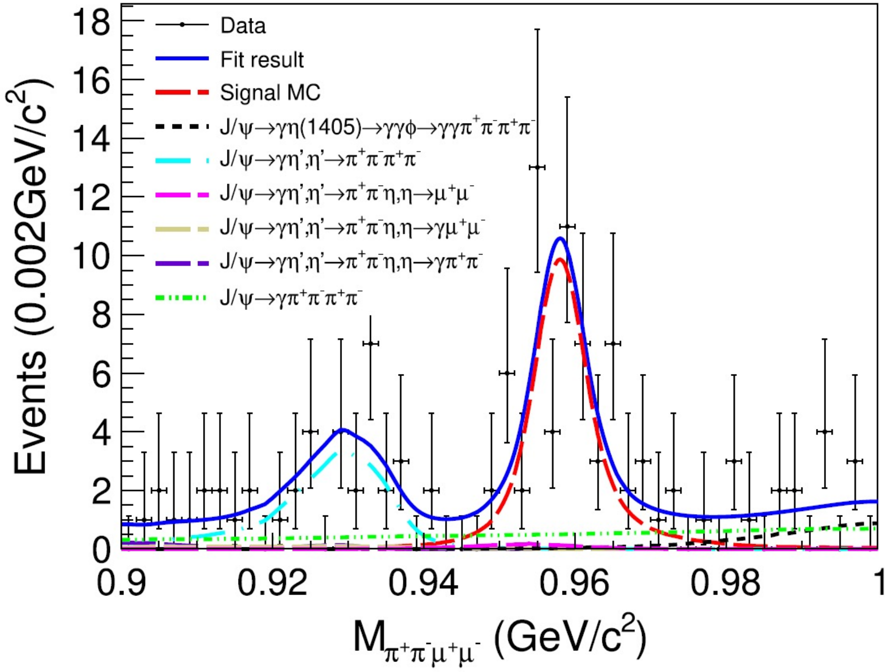
VMD



Box-anomaly

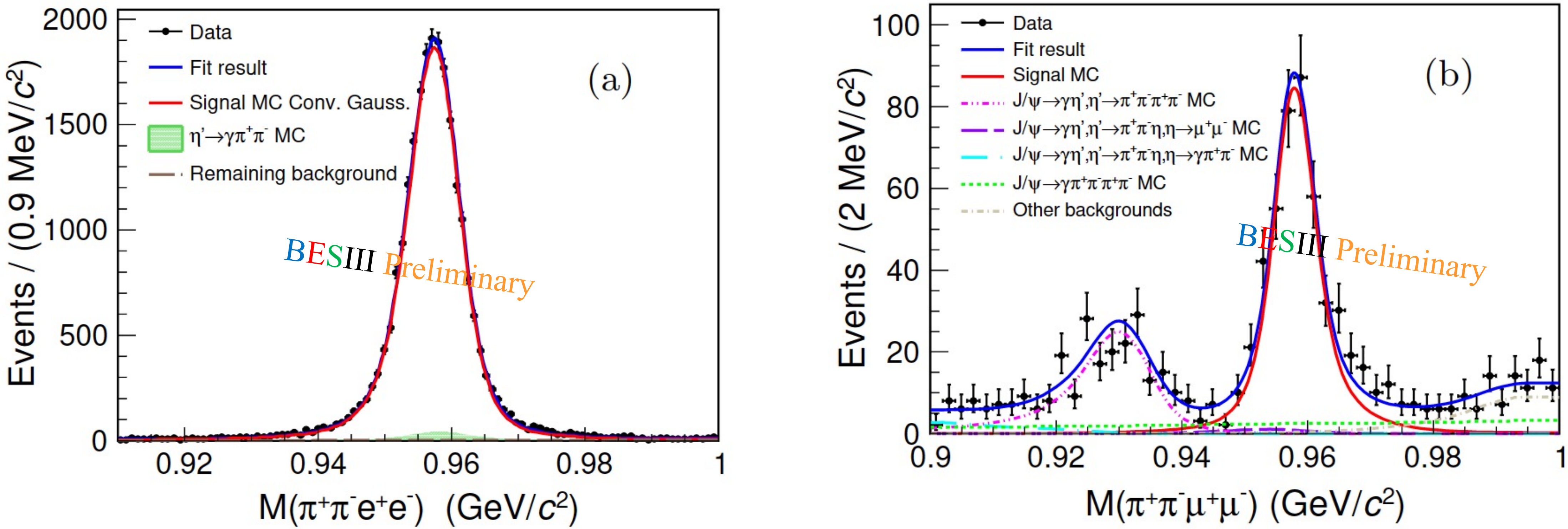
	$\mathcal{B}(\eta' \to \pi^+\pi^- e^+e^-)$ (10^{-3})	$\mathcal{B}(\eta' \to \pi^+\pi^- \mu^+\mu^-)$ (10^{-5})
Hidden gauge*	2.17 ± 0.21	2.20 ± 0.30
Unitary χPT*	$2.13^{+0.17}_{-0.31}$	$1.57^{+0.96}_{-0.75}$
VMD*	2.27 ± 0.13	2.41 ± 0.25
BESIII (2013)◇	$2.11 \pm 0.12 \pm 0.15$	< 2.9
BESIII (2021)◇	$2.42 \pm 0.05 \pm 0.08$	$1.97 \pm 0.33 \pm 0.19$
CLEO◇	$2.50^{+1.2}_{-0.9} \pm 0.5$	< 24

A. Faessler, C. Fuchs, and M. I. Krivoruchenko, PRC 61, 035206 (2000).
B. Borasoy and R. Nissler, EPJA 33, 95 (2007).
T. Petri, arXiv:1010.2378



PRD103,072006(2021) (吉钰瑶)

BFs of $\eta' \to \pi^+\pi^-l^+l^-$



Decay Mode	N_{sig}	$\varepsilon(\%)$	Branching fraction
$\eta' \to \pi^+\pi^-e^+e^-$	22725±155	17.49±0.04	$(2.45 \pm 0.02(stat))\times 10^{-3}$
$\eta' \to \pi^+\pi^-\mu^+\mu^-$	434±25	37.95±0.07	$(2.16 \pm 0.12(stat))\times 10^{-5}$

Decay Amplitude

T. Petri, arXiv:1010.2378

- ✓ Decay amplitude

$$\overline{\left|\mathcal{A}_{\eta'\to\pi^+\pi^-l^+l^-}\right|^2}(s_{\pi\pi}, s_{ll}, \theta_\pi, \theta_1, \varphi) = \frac{e^2}{8k^2}|M(s_{\pi\pi}, s_{ll})|^2 \times \lambda\left(m_{\eta'}^2, s_{\pi\pi}, s_{ll}\right) \times [1 - \beta_1^2 \sin^2\theta_1 \sin^2\varphi] s_{\pi\pi}\beta_\pi^2 \sin^2\theta_\pi$$

- ✓ $M(s_{\pi\pi}, s_{ll})$ contains the information of the decaying particle and the VMD input ,

$$M(s_{\pi\pi}, s_{ll}) = \frac{e}{8\pi^2 f_\pi^3}\frac{1}{\sqrt{3}}\left(\frac{f_\pi}{f_8} sin\theta_{mix} + 2\sqrt{2}\frac{f_\pi}{f_0} cos\theta_{mix}\right) \times VMD(s_{\pi\pi}, s_{ll})$$

constant

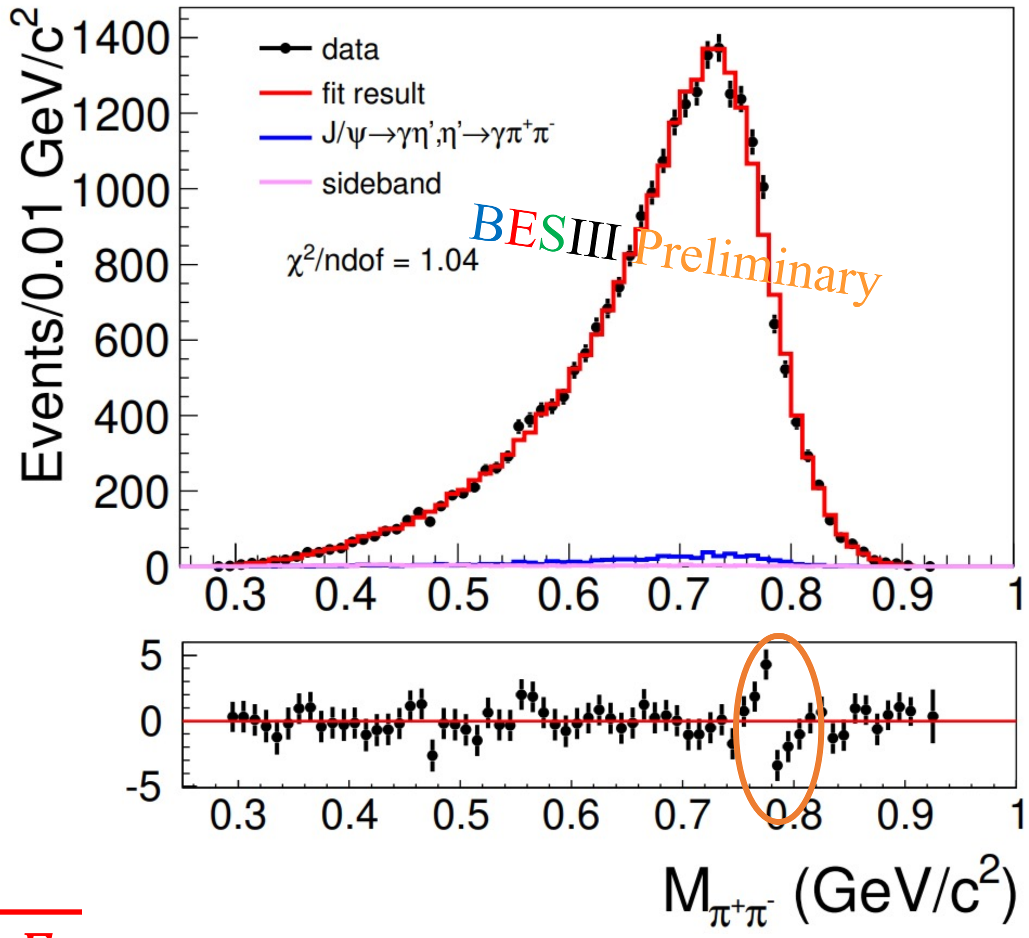
- ✓ Form Factor:

$$VMD(s_{\pi\pi}, s_{ll}) = 1 - \frac{3}{4}(c_1 - c_2 + c_3) + \frac{3}{4}(c_1 - c_2 - c_3)\frac{m_V^2}{m_V^2 - s_{ll} - i m_V \Gamma(s_{ll})} + \frac{3}{2}c_3 \frac{m_V^2}{m_V^2 - s_{ll} - i m_V \Gamma(s_{ll})}\frac{m_{V,\pi}^2}{m_{V,\pi}^2 - s_{\pi\pi} - i m_{V,\pi}\Gamma(s_{\pi\pi})}$$

Box anomaly **VMD contribution** **VMD contribution**

✓ VMD models:

- Hidden gauge model (Model I): $c_1 - c_2 = c_3 = 1$
- Full VMD model (Model II): $c_1 - c_2 = 1/3,\ c_3 = 1$
- Modified VMD model (Model III): $c_1 - c_2 \neq c_3$



✓ ρ^0 only can not describe data

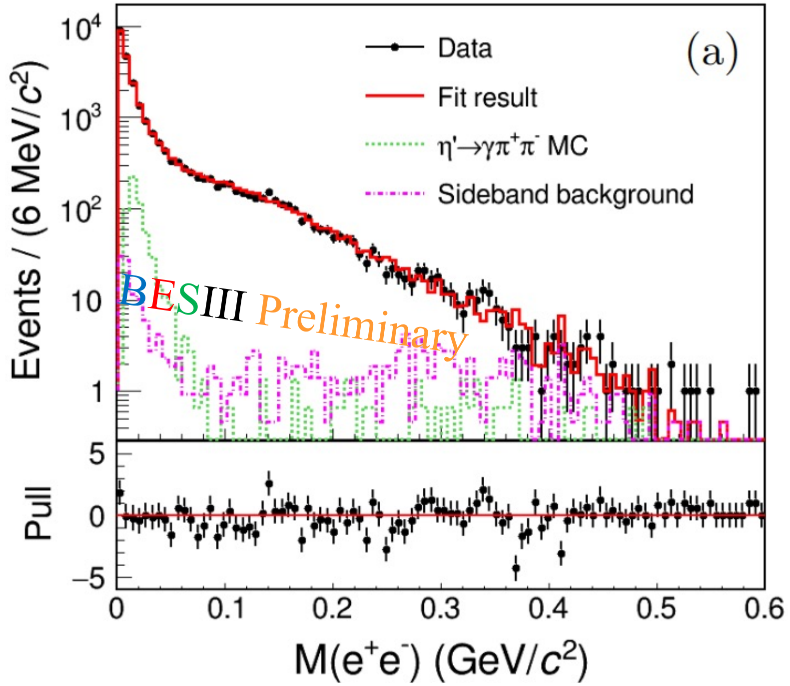
✓ $\omega \to \pi^+\pi^-$ decay is necessary !

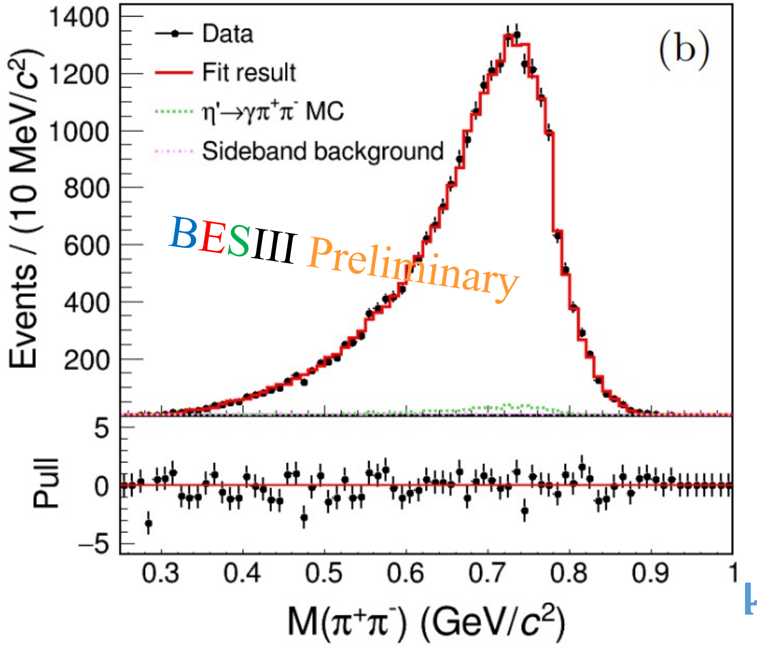
$$\frac{m_{V,\pi}^2}{m_{V,\pi}^2 - s_{\pi\pi} - i m_{V,\pi}\Gamma(s_{\pi\pi})} + \beta e^{i\theta} \frac{m_\omega^2}{m_\omega^2 - s_{\pi\pi} - i m_\omega \Gamma_\omega}$$

box-anomaly?

Amplitude analysis results

$\eta' \to \pi^+\pi^-e^+e^-$	Model I	Model II	Model III
	$c_1 - c_2 = c_3 = 1$	$c_1 - c_2 = 1/3, c_3 = 1$	$c_1 - c_2 \neq c_3$
$m_V\,(\mathrm{MeV}/c^2)$	954.26 ± 82.53	857.37 ± 74.31	787.53 ± 137.90
$m_{V,\pi}\,(\mathrm{MeV}/c^2)$	765.32 ± 1.12	765.35 ± 1.12	764.75 ± 1.25
$m_\omega\,(\mathrm{MeV}/c^2)$	778.69 ± 1.26	778.70 ± 1.26	778.70 ± 1.36
$\beta(10^{-3})$	8.53 ± 1.40	8.52 ± 1.40	8.11 ± 1.43
θ	1.43 ± 0.31	1.43 ± 0.31	1.44 ± 0.35
$c_1 - c_2$	1	1/3	-0.03 ± 0.87
c_3	1	1	1.03 ± 0.02





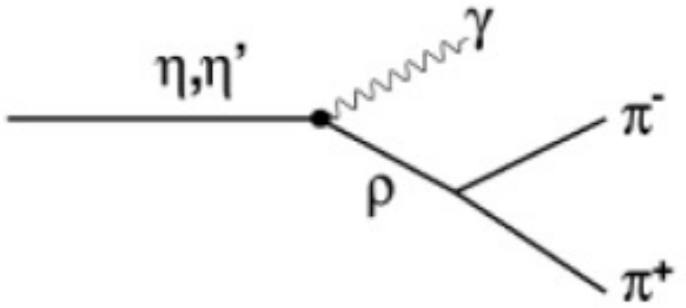
- ✓ All the above cases provide good description of data
- ✓ Limited statistics at the high e^+e^- mass region
  → Large statistical uncertainty
- ✓ A test with $c_1 - c_2 = c_3$ gives $c_1 - c_2 = c_3 = 1.03 \pm 0.02$, which is consistent with Model I.

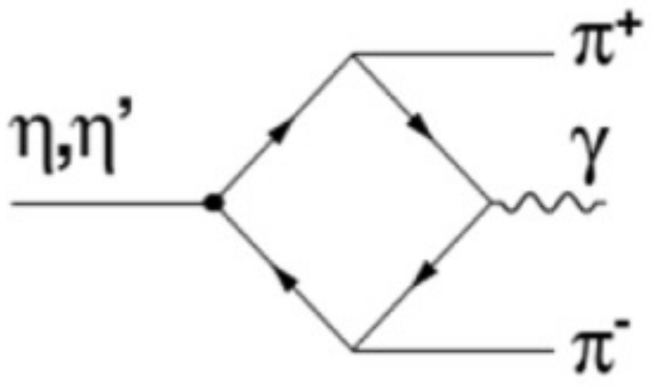
New decay mechanisms

Precision study of $\eta' \to \gamma\pi^+\pi^-$ PRL120, 242003(2018)

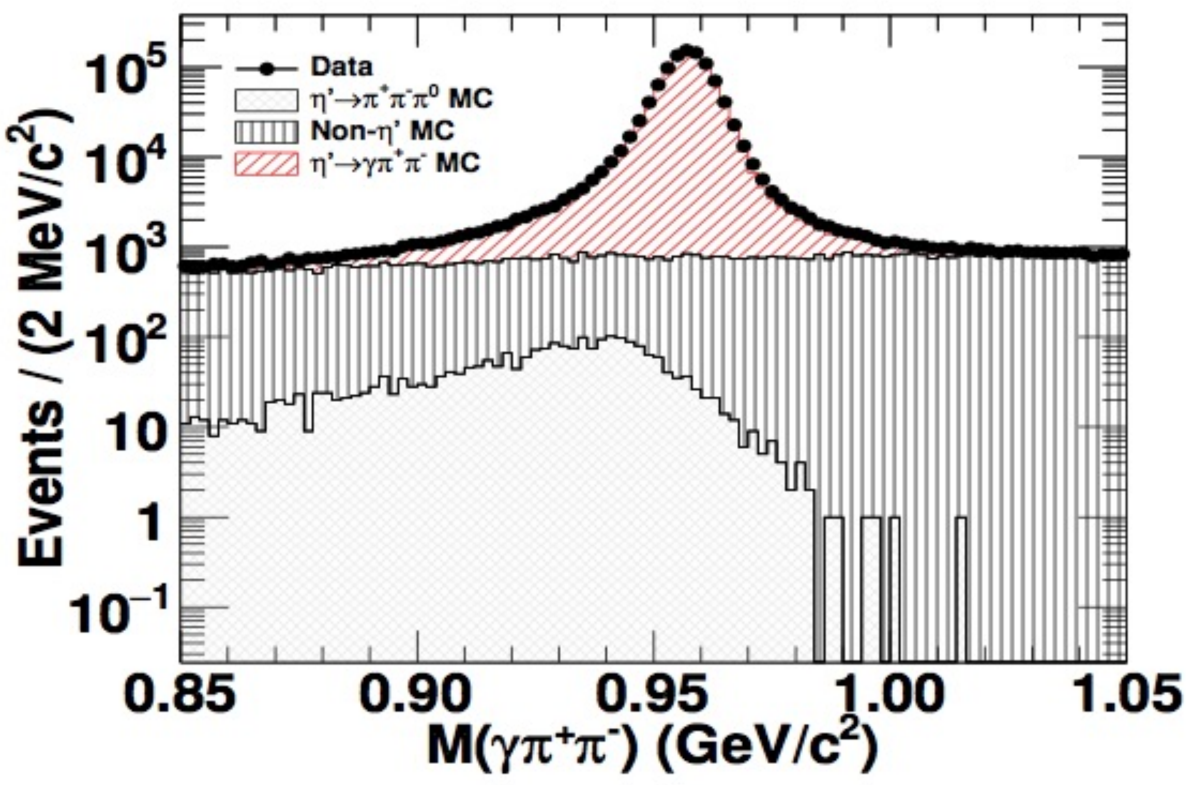
Evidence of cusp effect in $\eta' \to \pi^0\pi^0\eta$ PRL130, 081901(2023)

$\eta' \to \gamma\pi^+\pi^-$ decay dynamics





~0.9M events



high term of ChPT→ box anomaly

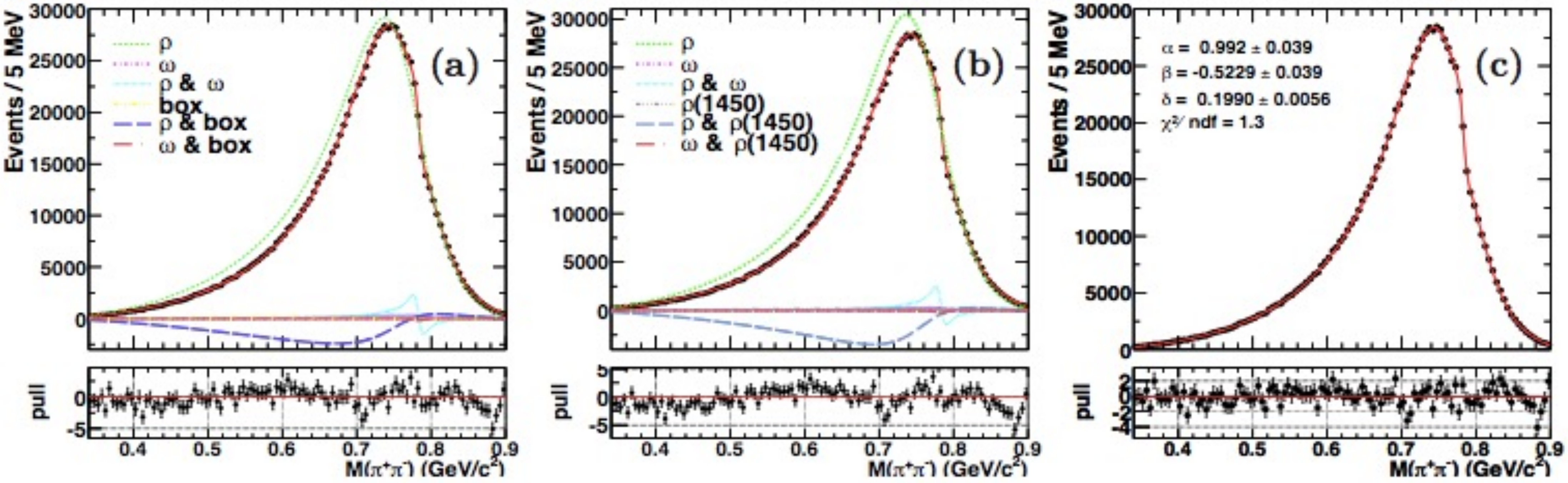
PRL120,242003(2018)

Model-(in)dependent fit

fit with ρ(770)-ω-box anomaly

fit with ρ(770)-ω-ρ(1450)

$P(s_{\pi\pi}) = 1 + \alpha\, s_{\pi\pi} + \beta\, O(s^2_{\pi\pi}) + \delta\, BW_\omega$

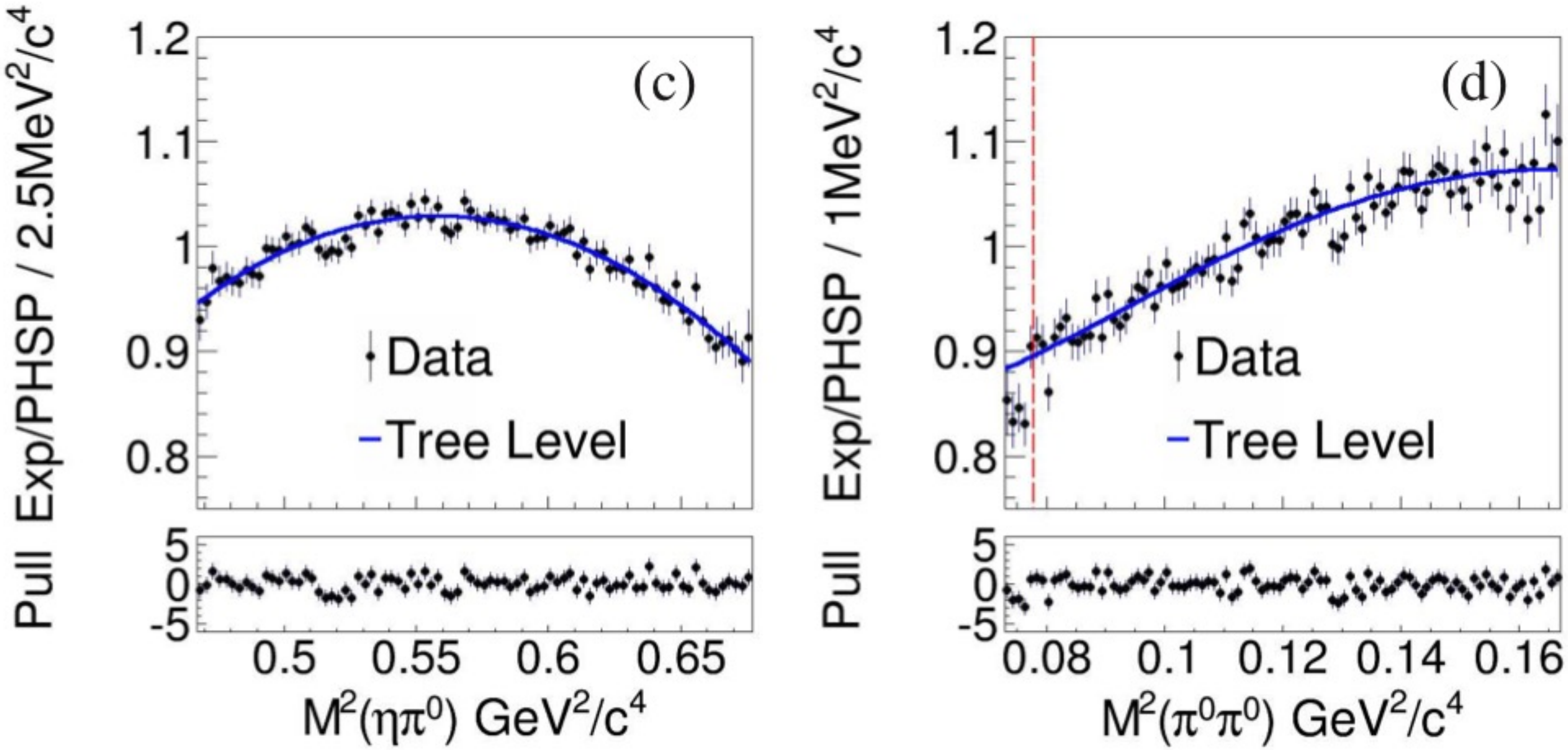


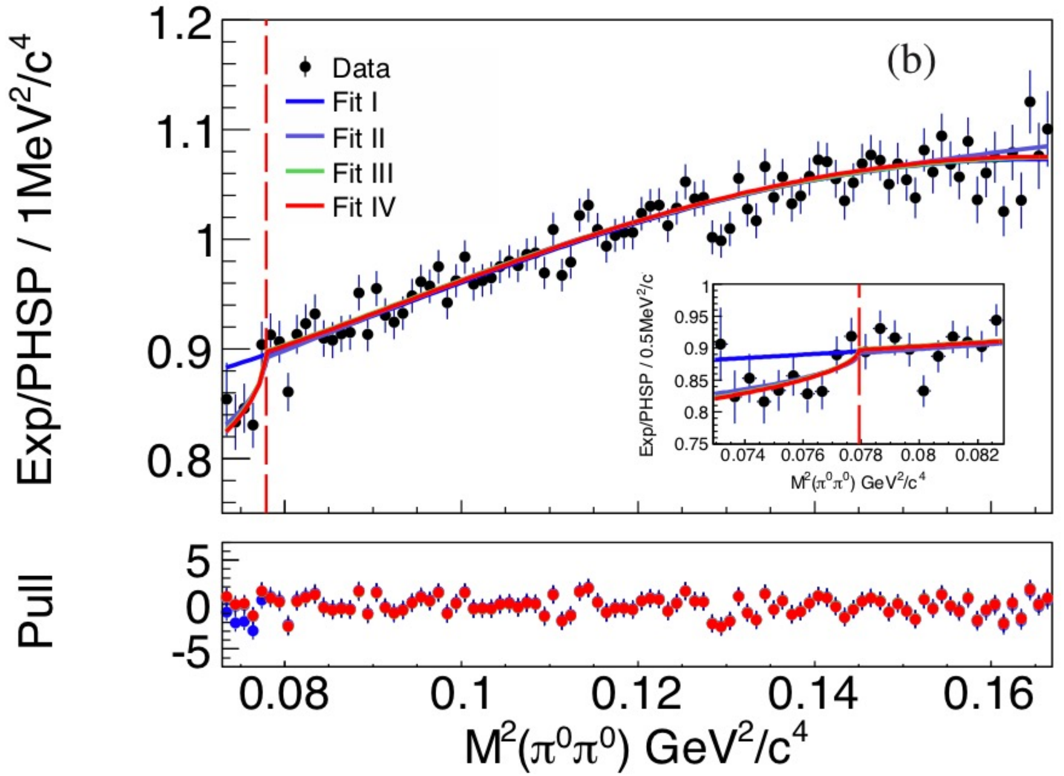
- ✓ ρ(770)-ω cannot describe data well
- ✓ Extra contribution (maybe ρ(1450) or box-anomaly) is also necessary

Evidence of the cusp effect in $\eta' \to \pi^0\pi^0\eta$

PRL130,081901(2023)

- Investigation on ππ and πη final interactions
- The cusp effect is sizeable in this decay





- Non-relativistic effective field theory
  B. Kubis and S. P. Schneider, EPJC 62, 511 (2009)
- Fits at different cases
- Evidence of the cusp effect @ 3.5σ !

Parameters	Fit I	Fit II	Fit III	Fit IV
a	$-0.075 \pm 0.003 \pm 0.001$	-0.207 ± 0.013	-0.143 ± 0.010	$-0.077 \pm 0.003 \pm 0.001$
b	$-0.073 \pm 0.005 \pm 0.001$	-0.051 ± 0.014	-0.038 ± 0.006	$-0.066 \pm 0.006 \pm 0.001$
d	$-0.066 \pm 0.003 \pm 0.001$	-0.068 ± 0.004	-0.067 ± 0.003	$-0.068 \pm 0.004 \pm 0.001$
$a_0 - a_2$	-	0.174 ± 0.066	0.225 ± 0.062	$0.226 \pm 0.060 \pm 0.012$
a_0	-	0.497 ± 0.094	-	-
a_2	-	0.322 ± 0.129	-	-
Statistical Significance	-	3.4σ	3.7σ	3.6σ

Few results on η decays at BESIII !

η REFERENCES

ABLIKIM	21AM	PR D104 092004	M. Ablikim *et al.*	(BESIII Collab.)
BABUSCI	20A	JHEP 2010 047	D. Babusci *et al.*	(KLOE-2 Collab.)
ZHEVLAKOV	19	PR D99 031703	A.S. Zhevlakov *et al.*	(TMSK, MAINZ, TUBIN+)
ACHASOV	18B	PR D98 052007	M.N. Achasov *et al.*	(SND Collab.)
ADLARSON	18C	PL B784 378	P. Adlarson *et al.*	(WASA-at-COSY Collab.)
PRAKHOV	18	PR C97 065203	S. Prakhov *et al.*	(A2 Collab. at MAMI)
AAIJ	17D	PL B764 233	R. Aaij *et al.*	(LHCb Collab.)
ADLARSON	17B	PR C95 035208	P. Adlarson *et al.*	(A2 Collab. at MAMI)
ANASTASI	16A	JHEP 1605 019	A. Anastasi *et al.*	(KLOE-2 Collab.)
ARNALDI	16	PL B757 437	R. Arnaldi *et al.*	(NA60 Collab.)
ABLIKIM	15G	PR D92 012014	M. Ablikim *et al.*	(BESIII Collab.)
ADLARSON	14A	PR C90 045207	P. Adlarson *et al.*	(WASA-at-COSY Collab.)
AGAKISHIEV	14	PL B731 265	G. Agakishiev *et al.*	(HADES Collab.)
NEFKENS	14	PR C90 025206	B.M.K. Nefkens *et al.*	(A2 Collab. at MAMI)
NIKOLAEV	14	EPJ A50 58	A. Nikolaev *et al.*	(MAMI-B, MAINZ, BONN)
ABLIKIM	13	PR D87 012009	M. Ablikim *et al.*	(BESIII Collab.)
ABLIKIM	13G	PR D87 032006	M. Ablikim *et al.*	(BESIII Collab.)
BABUSCI	13	PL B718 910	D. Babusci *et al.*	(KLOE/KLOE-2 Collab.)
BABUSCI	13A	JHEP 1301 119	D. Babusci *et al.*	(KLOE-2 Collab.)
AGAKISHIEV	12A	EPJ A48 64	G. Agakishiev *et al.*	(HADES Collab.)
GOSLAWSKI	12	PR D85 112011	P. Goslawski *et al.*	(COSY-ANKE Collab.)
ABLIKIM	11G	PR D84 032006	M. Ablikim *et al.*	(BESIII Collab.)

$\eta'(958)$ REFERENCES

ABLIKIM	21I	PR D103 072006	M. Ablikim *et al.*	(BESIII Collab.)
ABLIKIM	21J	PR D103 092005	M. Ablikim *et al.*	(BESIII Collab.)
ABLIKIM	20E	PR D101 032001	M. Ablikim *et al.*	(BESIII Collab.)
ABLIKIM	19AW	PR D100 052015	M. Ablikim *et al.*	(BESIII Collab.)
ABLIKIM	19T	PRL 122 142002	M. Ablikim *et al.*	(BESIII Collab.)
ABLIKIM	18	PR D97 012003	M. Ablikim *et al.*	(BESIII Collab.)
ABLIKIM	18C	PRL 120 242003	M. Ablikim *et al.*	(BESIII Collab.)
ADLARSON	18A	PR D98 012001	P. Adlarson *et al.*	(A2 Collab. at MAMI)
GONZALEZ-S...	18A	EPJ C78 758	S. Gonzalez-Solis, E. Passemar	(BEIJ, IND+)
AAIJ	17D	PL B764 233	R. Aaij *et al.*	(LHCb Collab.)
ABLIKIM	17	PRL 118 012001	M. Ablikim *et al.*	(BESIII Collab.)
ABLIKIM	17T	PR D96 012005	M. Ablikim *et al.*	(BESIII Collab.)
ABLIKIM	16M	PR D93 072008	M. Ablikim *et al.*	(BESIII Collab.)
ABLIKIM	15AD	PR D92 051101	M. Ablikim *et al.*	(BESIII Collab.)
ABLIKIM	15G	PR D92 012014	M. Ablikim *et al.*	(BESIII Collab.)
ABLIKIM	15O	PR D92 012001	M. Ablikim *et al.*	(BESIII Collab.)
ABLIKIM	15P	PR D92 012007	M. Ablikim *et al.*	(BESIII Collab.)
ACHASOV	15	PR D91 092010	M.N. Achasov *et al.*	(SND Collab.)
AKHMETSHIN	15	PL B740 273	R.R. Akhmetshin *et al.*	(CMD-3 Collab.)
PDG	15	RPP 2015 at pdg.lbl.gov		(PDG Collab.)
ABLIKIM	14M	PRL 112 251801	M. Ablikim *et al.*	(BESIII Collab.)
DONSKOV	14	MPL A29 1450213	S. Donskov *et al.*	(GAMS-4π Collab.)
PDG	14	CP C38 070001	K. Olive *et al.*	(PDG Collab.)
ABLIKIM	13	PR D87 012009	M. Ablikim *et al.*	(BESIII Collab.)
ABLIKIM	13G	PR D87 032006	M. Ablikim *et al.*	(BESIII Collab.)
ABLIKIM	13O	PR D87 092011	M. Ablikim *et al.*	(BESIII Collab.)
ABLIKIM	13U	PR D88 091502	M. Ablikim *et al.*	(BESIII Collab.)
ABLIKIM	12E	PRL 108 182001	M. Ablikim *et al.*	(BESIII Collab.)
PDG	12	PR D86 010001	J. Beringer *et al.*	(PDG Collab.)
ABLIKIM	11	PR D83 012003	M. Ablikim *et al.*	(BESIII Collab.)
ABLIKIM	11G	PR D84 032006	M. Ablikim *et al.*	(BESIII Collab.)

New approach to investigate η decays with $\eta' \to \pi^+\pi^-\eta$

η REFERENCES

ABLIKIM	21AM	PR D104 092004	M. Ablikim *et al.*	(BESIII Collab.)
BABUSCI	20A	JHEP 2010 047	D. Babusci *et al.*	(KLOE-2 Collab.)
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PRAKHOV	18	PR C97 065203	S. Prakhov *et al.*	(A2 Collab. at MAMI)
AAIJ	17D	PL B764 233	R. Aaij *et al.*	(LHCb Collab.)
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BABUSCI	13A	JHEP 1301 119	D. Babusci *et al.*	(KLOE-2 Collab.)
AGAKISHIEV	12A	EPJ A48 64	G. Agakishiev *et al.*	(HADES Collab.)
GOSLAWSKI	12	PR D85 112011	P. Goslawski *et al.*	(COSY-ANKE Collab.)
ABLIKIM	11G	PR D84 032006	M. Ablikim *et al.*	(BESIII Collab.)

- Production rate lower than η′
- Background from QED and J/ψ decays

ABLIKIM	18	PR D97 012003	M. Ablikim *et al.*	(BESIII Collab.)
ABLIKIM	18C	PRL 120 242003	M. Ablikim *et al.*	(BESIII Collab.)

$J/\psi \to \gamma\eta$ → 1×10^7 η

$J/\psi \to \gamma\eta'$, $\eta' \to \pi^+\pi^-\eta$ → 2.2×10^7 η

ABLIKIM	15P	PR D92 012007	M. Ablikim *et al.*	(BESIII Collab.)
ACHASOV	15	PR D91 092010	M.N. Achasov *et al.*	(SND Collab.)
AKHMETSHIN	15	PL B740 273	R.R. Akhmetshin *et al.*	(CMD-3 Collab.)
PDG	15	RPP 2015 at pdg.lbl.gov		(PDG Collab.)
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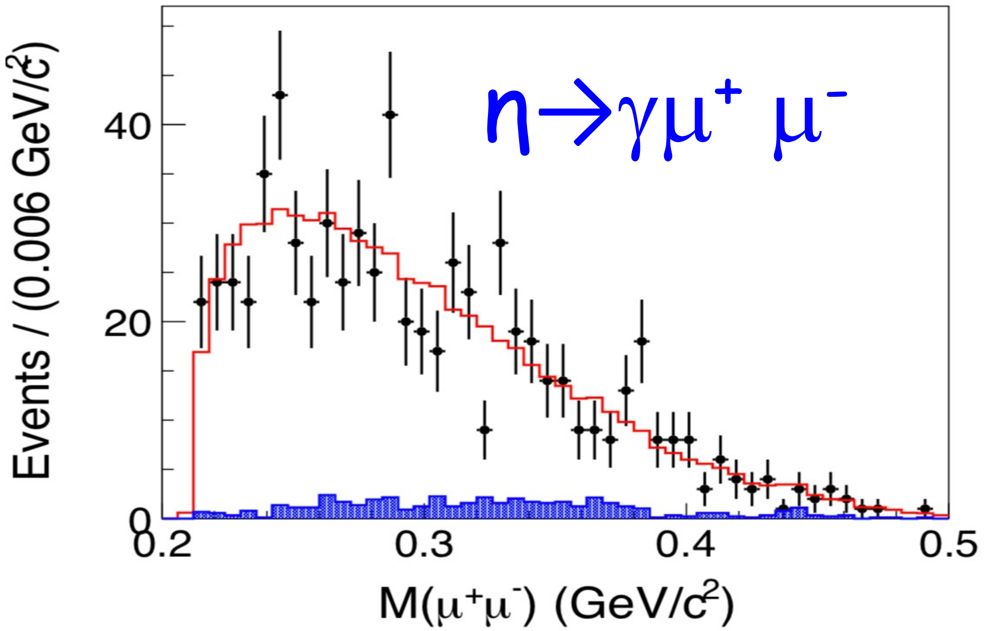
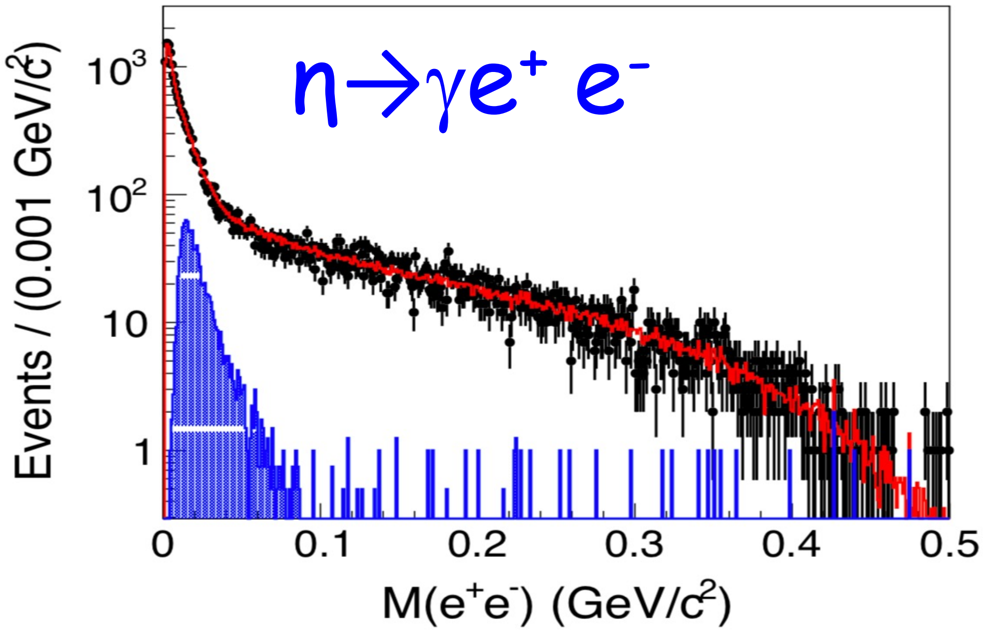
ABLIKIM	13G	PR D87 032006	M. Ablikim *et al.*	(BESIII Collab.)
ABLIKIM	13O	PR D87 092011	M. Ablikim *et al.*	(BESIII Collab.)
ABLIKIM	13U	PR D88 091502	M. Ablikim *et al.*	(BESIII Collab.)
ABLIKIM	12E	PRL 108 182001	M. Ablikim *et al.*	(BESIII Collab.)
PDG	12	PR D86 010001	J. Beringer *et al.*	(PDG Collab.)

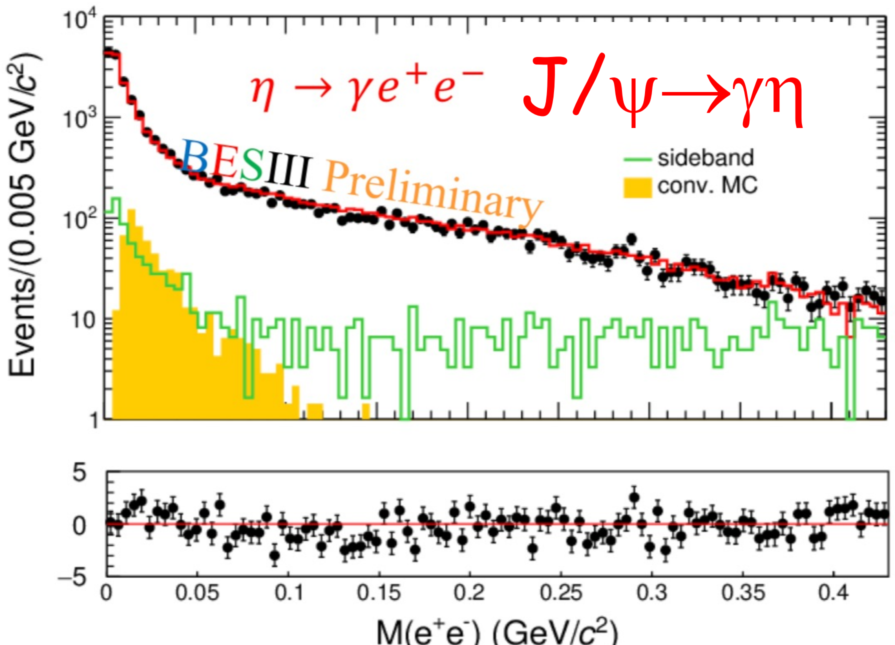
One more η′ constraint to suppress the background events !

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





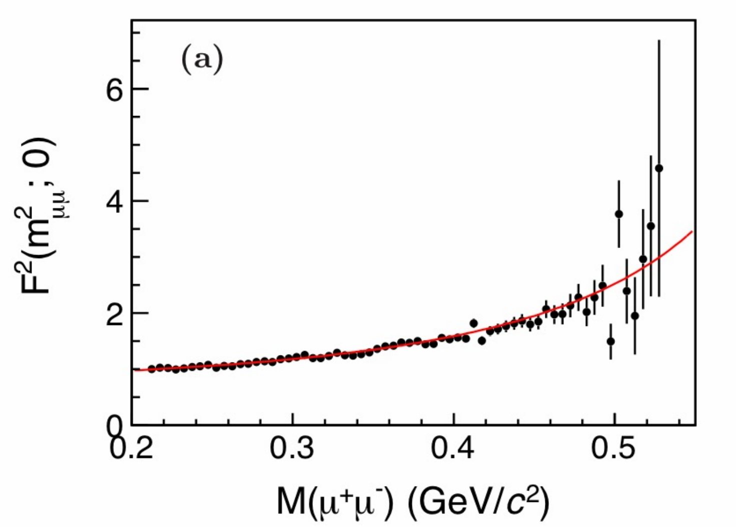
- Help distinguish muons from pions
- Background level is low

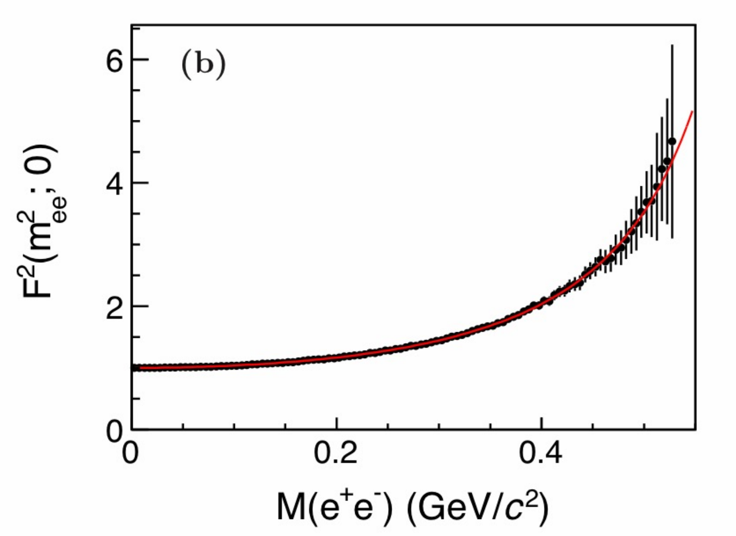


Feasibilities at SCTF

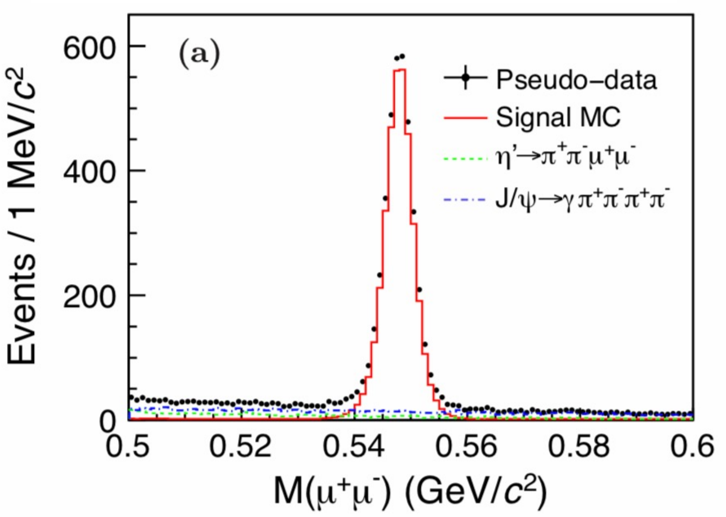
PRD108,014038(2023)

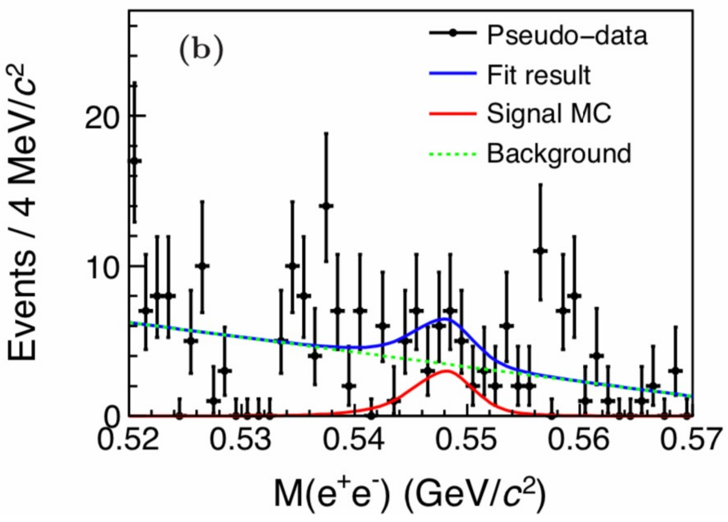
$\eta \to \gamma e^+ e^-$ **AND** $\eta \to \gamma \mu^+ \mu^-$



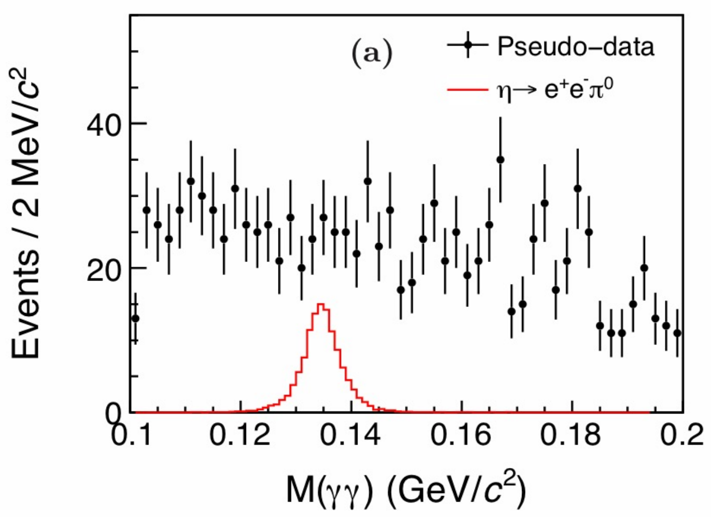


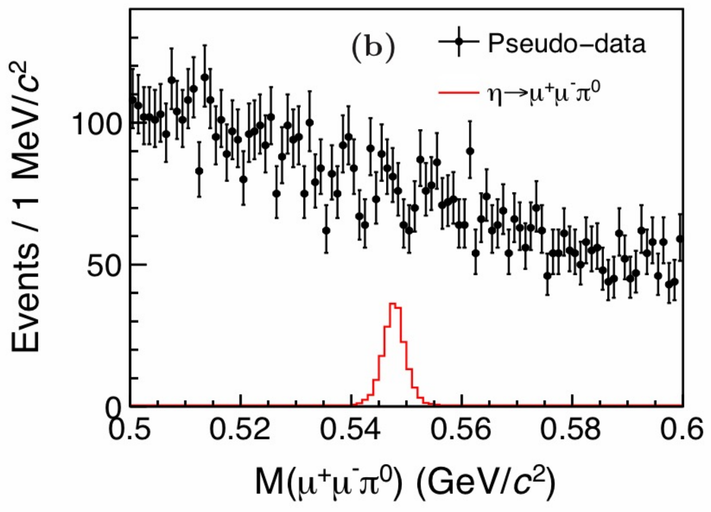
$\eta \to e^+ e^-$ **AND** $\eta \to \mu^+ \mu^-$





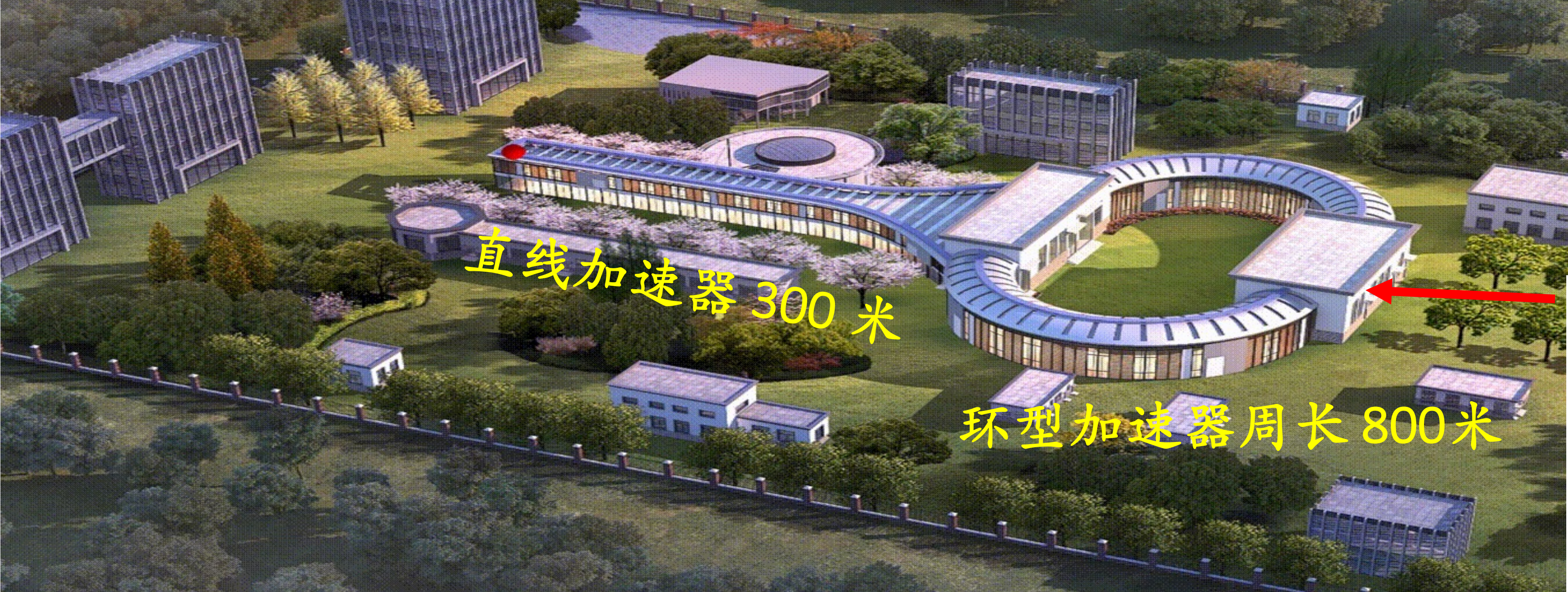
$\eta \to \pi^0 e^+ e^-$ **AND** $\eta \to \pi^0 \mu^+ \mu^-$

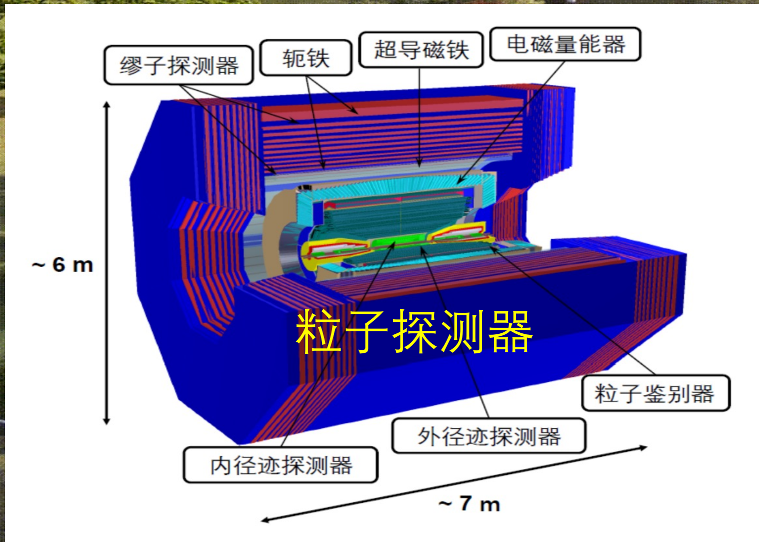




高亮度：超级陶粲工厂(STCF)

- 能量: 2-7 GeV, 亮度: > 0.5×10^{35} cm^{-2} s^{-1}m
- 经费: 预研4.2 亿, 建造45 亿
- 时间: 预研 **4**年, 建造**7** 年, 运行 **10** 年, 升级改造 **2** 年, 再运行**10** 年

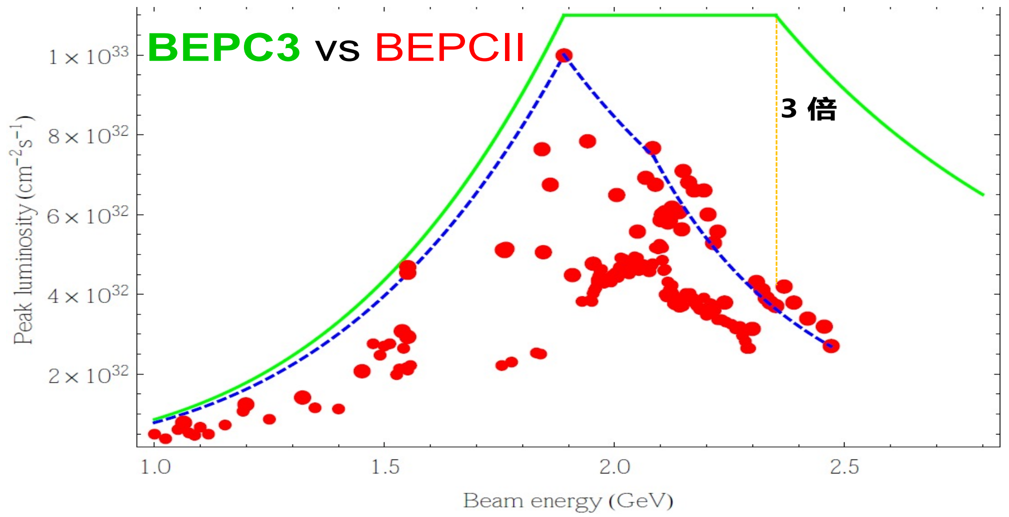




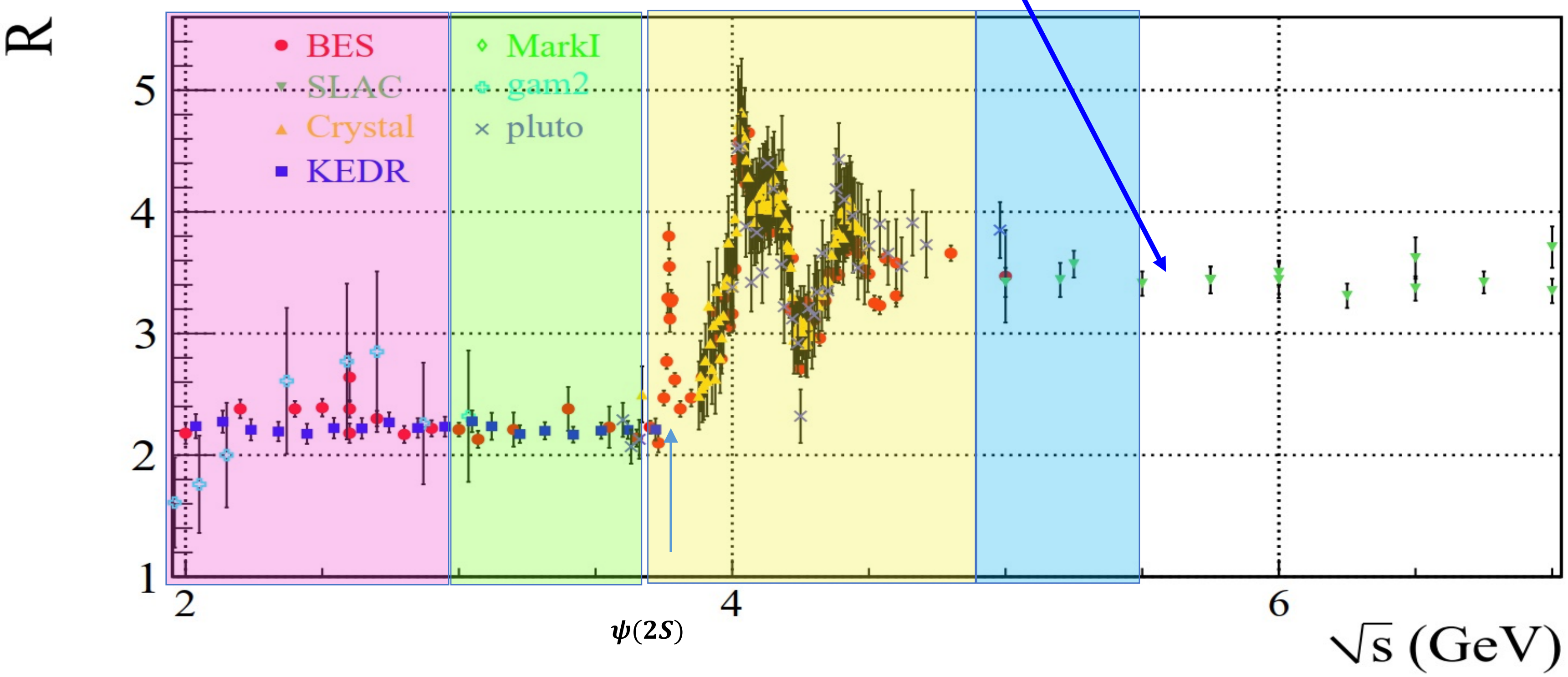
- 强相互作用的本质和强子结构
- 奇特物资与正反物质不对称
- 寻找新物理现象(暗物质粒子，暗光子，对称性破缺...)

Plan of BEPCII/BESIII upgrade

- **Optimize E_{cm} at 4.7 GeV with luminosity 3 times higher than the current BEPCII → more effective data taking**



Extend the maximum E_{cm} up to 5.6 GeV → more physics opportunity



Nearly blank at 5-7GeV

Summary

- Data with unprecedented statistical accuracy from BESIII provides great opportunities to investigate the light hadron physics
- Significant progresses achieved:
  - Exotics searches
  - Hyperon physics
  - Light meson physics
- BEPCII/BESIII upgrades in 2024, then continues to take data till ~2030

非常感谢!