Recent theoretical progress on $\phi(2170)$/ $Y(2175)$

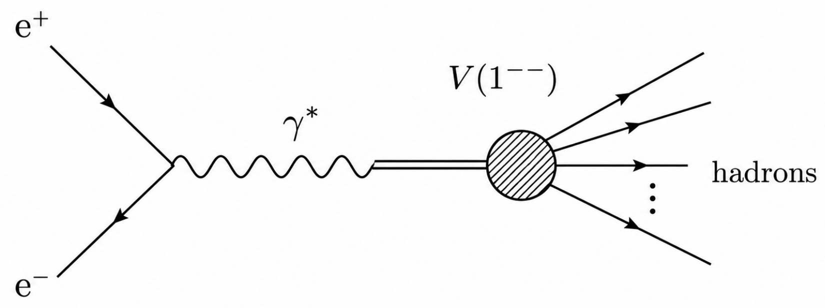
报告人：王俊璋

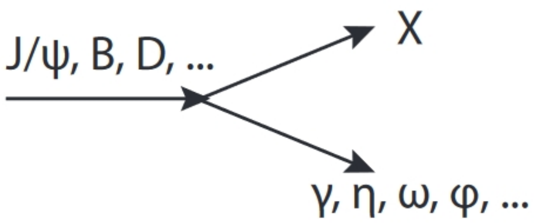
重庆大学

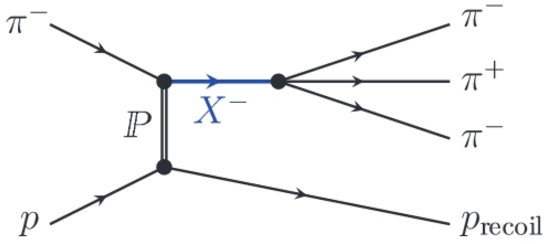
2026.05.15 商丘师范学院@河南商丘

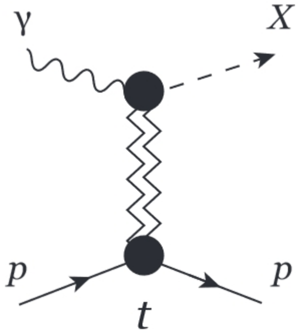
Why vector light mesons?

BESIII, Belle II, COMPASS, GlueX experiment









The vector channel is experimentally special

- Directly accessed in e^+e^- annihilation through γ^*.
- ISR data provide a continuous scan of low-energy hadron spectra.
- Light vector states can also be generated by multiple production modes.

More complicated confinement dynamics

- The confinement regime of the light quark-antiquark interaction is more complicated.
- The relativistic effect is important.

The ϕ-meson family

ρ mesons

$I^G(J^{PC}) = 1^+(1^{--})$

State	Mass	Width
$\rho(770)^0$	775.26 ± 0.23	147.4 ± 0.8
$\rho(770)^\pm$	775.11 ± 0.34	149.1 ± 0.8
$\rho(1450)^*$	1465 ± 25	400 ± 60
$\rho(1570)^\dagger$	$1570 \pm 36 \pm 62$	$144 \pm 75 \pm 43$
$\rho(1700)^*$	1720 ± 20	250 ± 100
$\rho(1900)^\dagger$	$1860 - 1910$	$10 - 160$
$\rho(2150)^\dagger$	$2034 - 2255$	$70 - 460$

MeV

* PDG estimate; † PDG listing omitted from summary table

ω mesons

$I^G(J^{PC}) = 0^-(1^{--})$

State	Mass	Width
$\omega(782)$	782.66 ± 0.13	8.68 ± 0.13
$\omega(1420)^*$	1410 ± 60	290 ± 190
$\omega(1650)^*$	1670 ± 30	315 ± 35
$\omega(2220)^\dagger$	2188 ± 21	105 ± 34

MeV

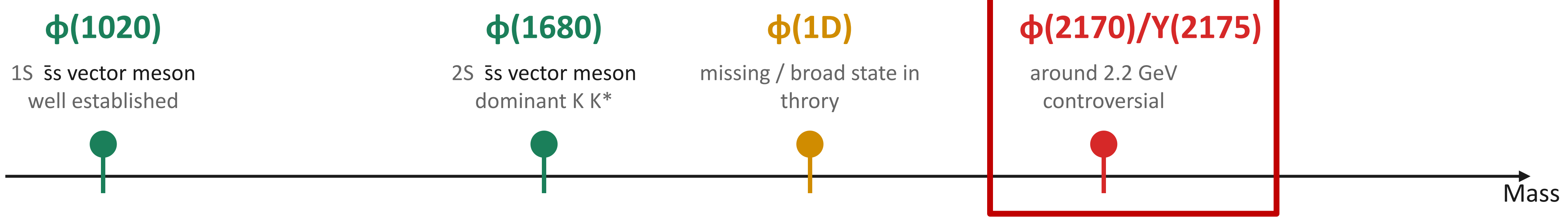
ϕ mesons

$I^G(J^{PC}) = 0^-(1^{--})$

State	Mass	Width
$\phi(1020)$	1019.460 ± 0.016	4.249 ± 0.013
$\phi(1680)^*$	1680 ± 20	150 ± 50
$\phi(2170)$	2164 ± 5	88^{+26}_{-21}

MeV

Listen to Qing-Song Zhou's talk on 17/05



A Structure at 2175-MeV in $e^+e^- \to \phi$ f0(980) Observed via Initial-State Radiation #1

BaBar Collaboration • Bernard Aubert (Barcelona U., ECM) et al. (Oct, 2006)

Published in: *Phys.Rev.D* 74 (2006) 091103 • e-Print: hep-ex/0610018 [hep-ex]

pdf links DOI cite claim reference search **234 citations**

Counted up to 13. 05.2026

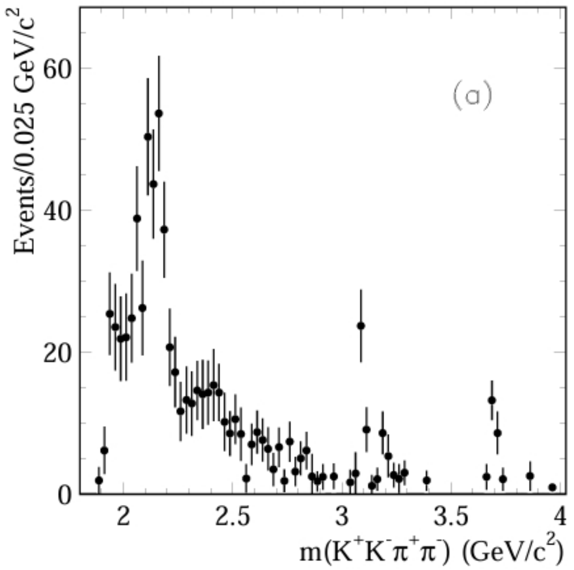
Observation of a broad structure in the $\pi^+\pi^- J/\psi$ mass spectrum around 4.26-GeV/c^2 #16

BaBar Collaboration • Bernard Aubert (Annecy, LAPP) et al. (Jun, 2005)

Published in: *Phys.Rev.Lett.* 95 (2005) 142001 • e-Print: hep-ex/0506081 [hep-ex]

pdf links DOI cite claim reference search **1,126 citations**

Counted up to 13. 05.2026



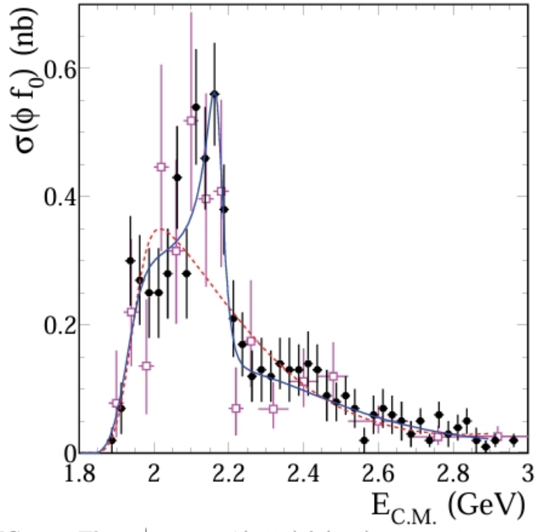
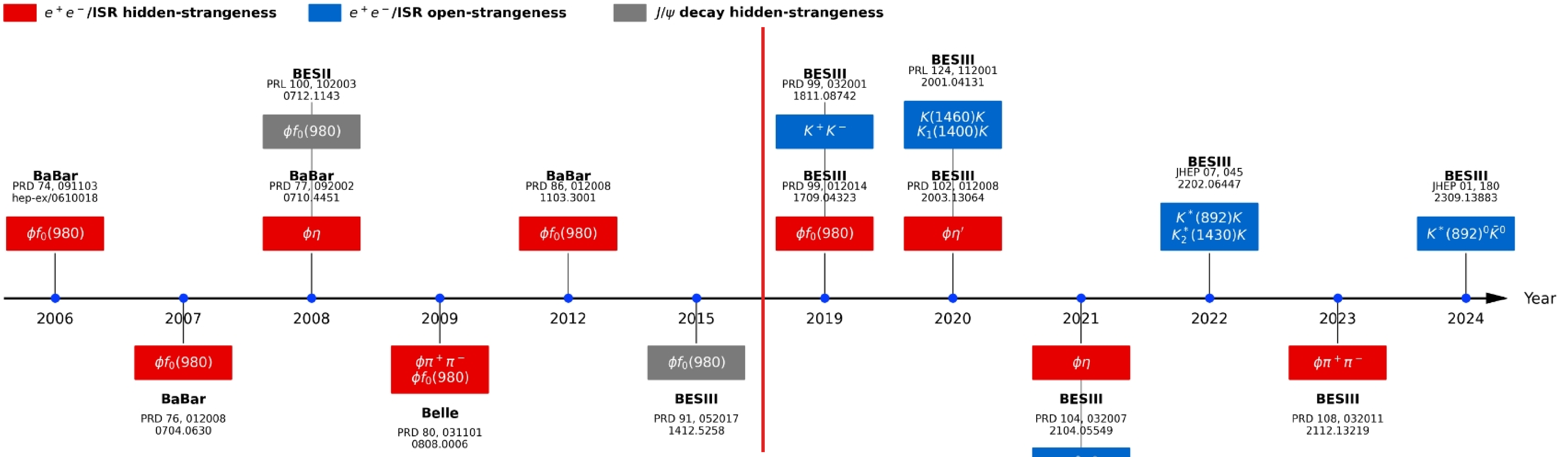
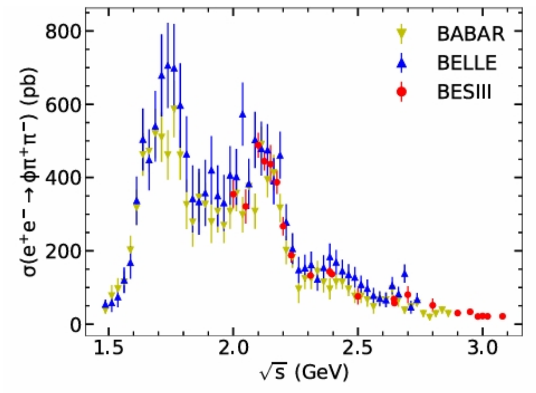


FIG. 6: The $e^+e^- \to \phi(1020)f_0(980)$ cross section, with about 10% of the $\phi\pi\pi$ contribution, obtained via ISR in the $K^+K^-\pi^+\pi^-$ (circles) and $K^+K^-\pi^0\pi^0$ (squares) final states. The curves represent results of the fits described in the text.

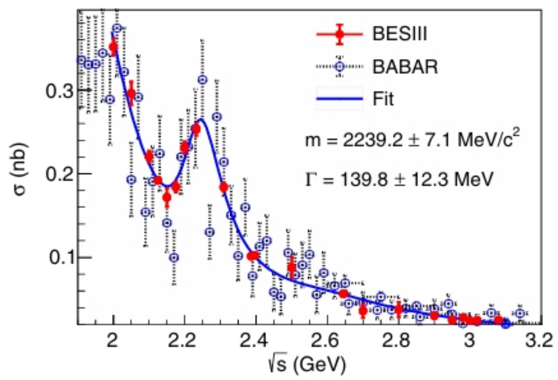
[BaBar], Phys. Rev. D 74, 091103 (2006)

Experimental overview of Y(2175)

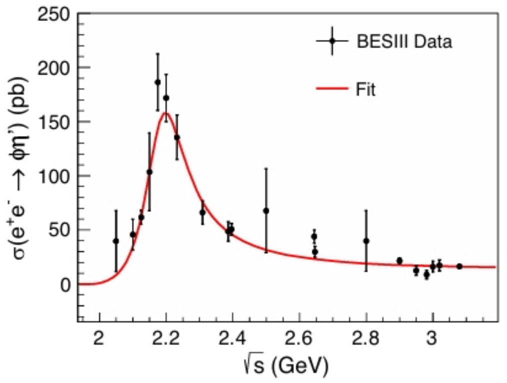




[BESIII], Phys. Rev. D 108, 032011 (2023)



[BESIII], Phys.Rev.D 99 (2019) 3, 032001



[BESIII], Phys.Rev.D 102 (2020) 1, 012008

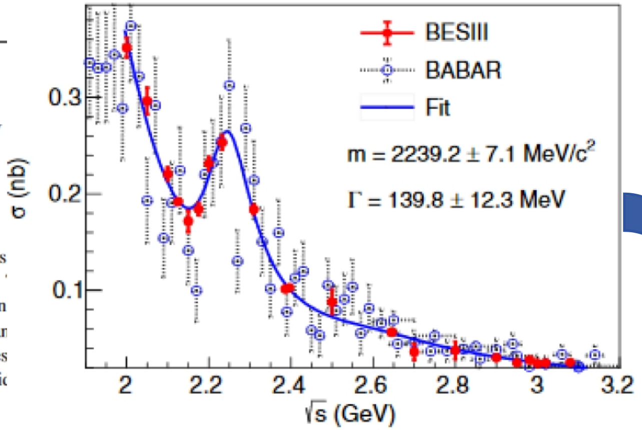
Puzzle I : extracted resonance parameters are channel dependent

PHYSICAL REVIEW D **99,** 032001 (2019)

Measurement of $e^+e^- \to K^+K^-$ cross section at $\sqrt{s} = 2.00-3.08$ GeV

(BESIII Collaboration)

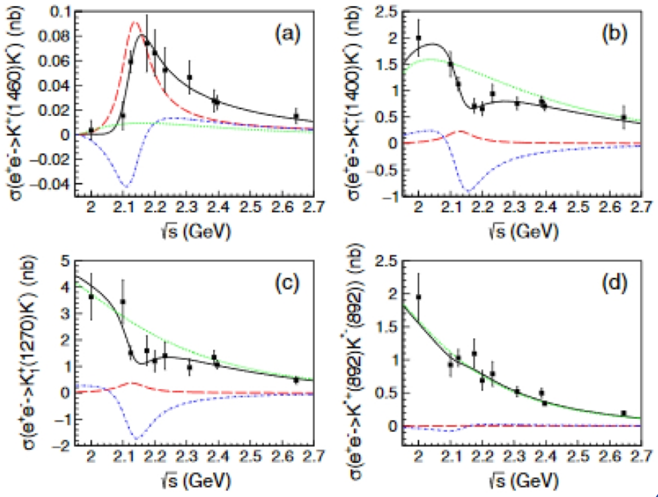
The cross section of the process $e^+e^- \to K^+K^-$ is measured at a number of center-of-mass energies from 2.00 to 3.08 GeV with the BESIII detector at the Beijing Electron Positron Collider (BEPCII). ' results provide the best precision achieved so far. A resonant structure around 2.2 GeV is observed in cross section line shape. A Breit-Wigner fit yields a mass of $M = 2239.2 \pm 7.1 \pm 11.3$ MeV/c^2 ar width of $\Gamma = 139.8 \pm 12.3 \pm 20.6$ MeV, where the first uncertainties are statistical and the second ones systematic. In addition, the timelike electromagnetic form factor of the kaon is determined at the indivic center-of-mass energy points.



PHYSICAL REVIEW LETTERS **124,** 112001 (2020)

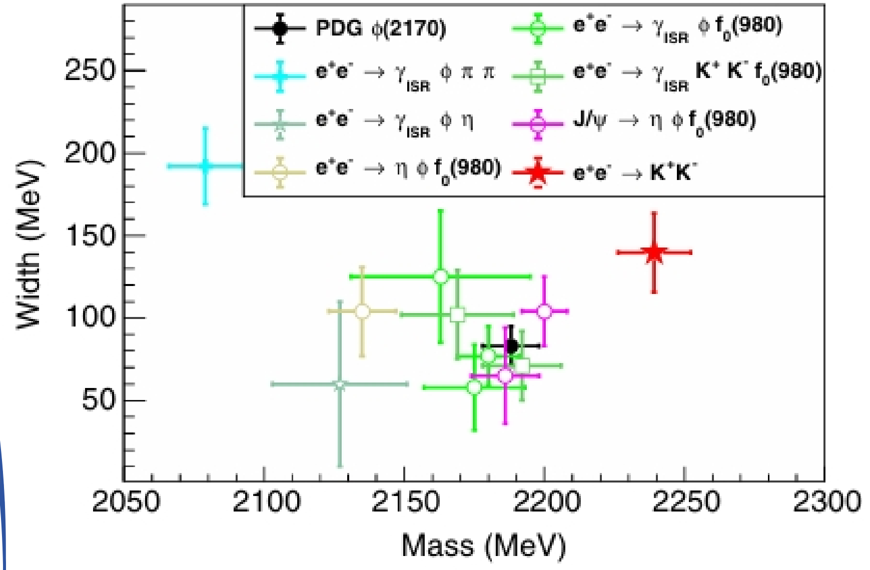
Observation of a Resonant Structure in $e^+e^- \to K^+K^-\pi^0\pi^0$

(BESIII Collaboration)



$(2126.5 \pm 16.8 \pm 12.4)$ MeV$/c^2$ and width $\Gamma = (106.9 \pm 32.1 \pm 28.1)$ MeV

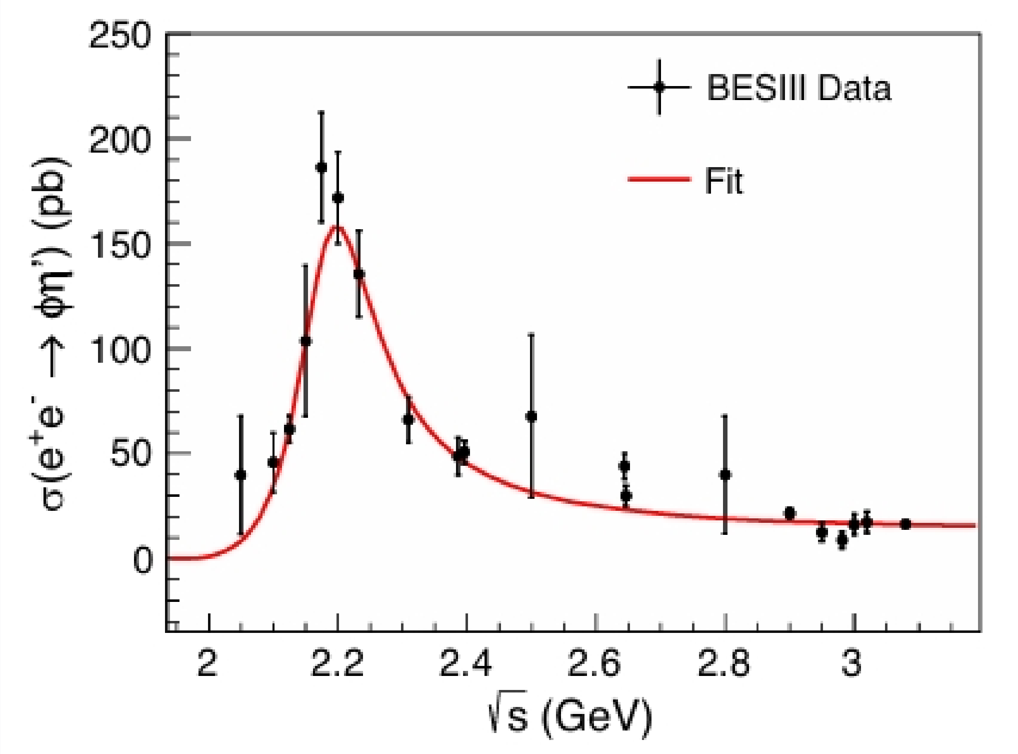
100 MeV mass discrepancy!



several nearby resonances?
strong channel dynamics?

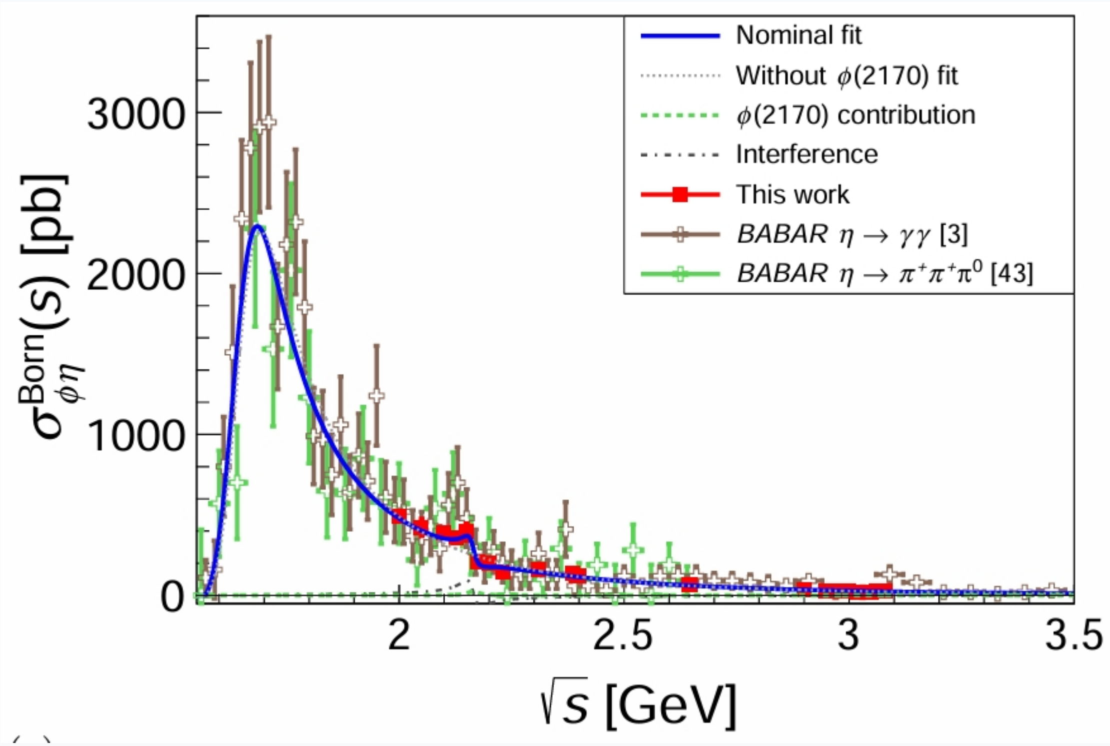
Puzzle II : why does ϕη′ look so prominent?

BESIII ϕη′ cross section



[BESIII], Phys.Rev.D 102 (2020) 1, 012008

ϕη cross section



[BESIII], Phys.Rev.D 104 (2021) 3, 032007

Puzzle II : why does φη′ look so prominent?

this width is consistent with the Y(2175) structre in open-charm channels and ϕf_0

BESIII φη′ cross section

Parameter	Solution I	Solution II
M_R (MeV/c^2)	$2177.5 \pm 4.8(\text{stat}) \pm 19.5(\text{syst})$	
Γ^R_{tot} (MeV)	$149.0 \pm 15.6(\text{stat}) \pm 8.9(\text{syst})$	
$\mathcal{B}_\mathcal{R}\Gamma^R_{e^+e^-}$ (eV)	$7.1 \pm 0.7(\text{stat}) \pm 0.7(\text{syst})$	
φ (rad)	3.13 ± 2.01	-0.01 ± 2.36

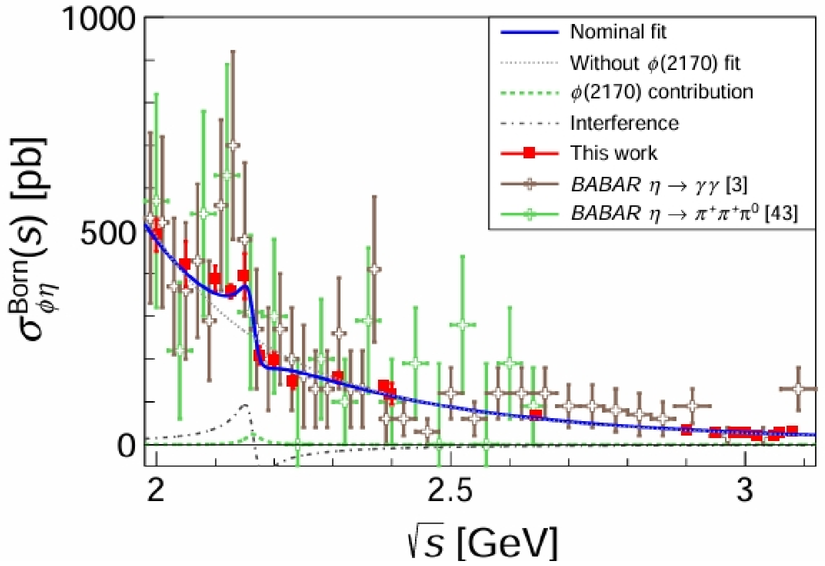
$$R^{\text{exp}}_{\eta/\eta'} = \begin{cases} 0.034^{+0.018}_{-0.011} \text{ solution I,} \\ 1.42^{+0.58}_{-0.48} \text{ solution II,} \end{cases}$$

The broad state is missing for the φη channel

Ratio of phase space is about 4.3

BESIII φη cross section

Parameter	Solution I	Solution II
χ^2/n.d.f	$86.8/97$	
a_0	$-0.11^{+0.09}_{-0.22}$	-0.24 ± 0.58
a_1	$1.91^{+0.61}_{-0.76}$	$2.54^{+2.86}_{-1.55}$
$\mathcal{B}^{\phi(2170)}_{\phi\eta}\Gamma^{\phi(2170)}_{e^+e^-}$	$0.24^{+0.12}_{-0.07}$ eV	$10.11^{+3.87}_{-3.13}$ eV
$m_{\phi(2170)}$	2163.5 ± 6.2 MeV/c^2	
$\Gamma_{\phi(2170)}$	$31.1^{+21.1}_{-11.6}$ MeV	
$\Phi_{\phi(2170)}$	$1.82^{+0.35}_{-0.31}$	$-2.92^{+0.05}_{-0.06}$



Theoretical interpretations before the new open-strange constraints

Conventional $\bar{s}s$

$\phi(3S)$ or $\phi(2D)$; strong-decay pattern is the central test.

Ding, Yan, PLB 657, 49 (2007)

Wang et al., PRD 85, 074024 (2012)

Coito et al., PRD 80, 094011 (2009)

Pang, PRD 99, 074015 (2019)

Hybrid $\bar{s}sg$

Selection-rule expectations; open-strange channels are decisive.

Ding, Yan, PLB 650, 390 (2007)

Ding, Yan, PLB 657, 49 (2007)

Ho et al., PRD 100, 034012 (2019)

Tetraquark

Mass can be accommodated

Z. G. Wang, NPA 791, 106 (2007)

Chen et al., PRD 78, 034012 (2008)

Drenska et al., PLB 669, 160 (2008)

Ke, Li, PRD 99, 036014 (2019)

Agaev et al., PRD 101, 074012 (2020)

Two-body molecules

ϕf_0 or $\Lambda\bar{\Lambda}$ components

Napsuciale et al., PRD 76, 074012 (2007)

Alvarez-Ruso et al., PRD 80, 054011 (2009)

Zhao et al., PRD 87, 054034 (2013)

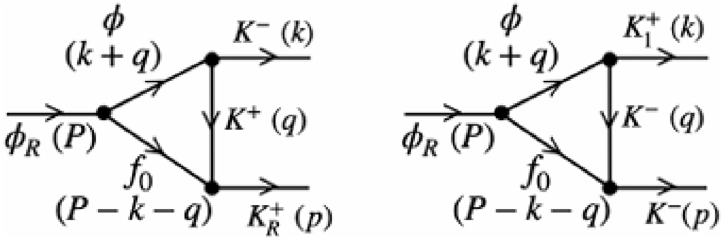
Dong et al., PRD 96, 074027 (2017)

Three-body molecule

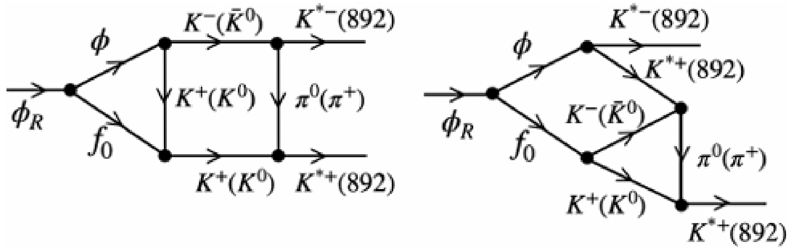
$\phi K \bar{K}$ Faddeev dynamics predicts ϕf_0-like structure around 2.15 GeV.

Martínez Torres et al., PRD 78, 074031 (2008)

Recent theoretical researches: ϕf₀ or ϕK K̄



		B_1
Our results	Model B	0.62 ± 0.20
	Model C	0.11 ± 0.04
Experiment	Solution 1	0.64 ± 0.92
	Solution 2	0.03 ± 0.04



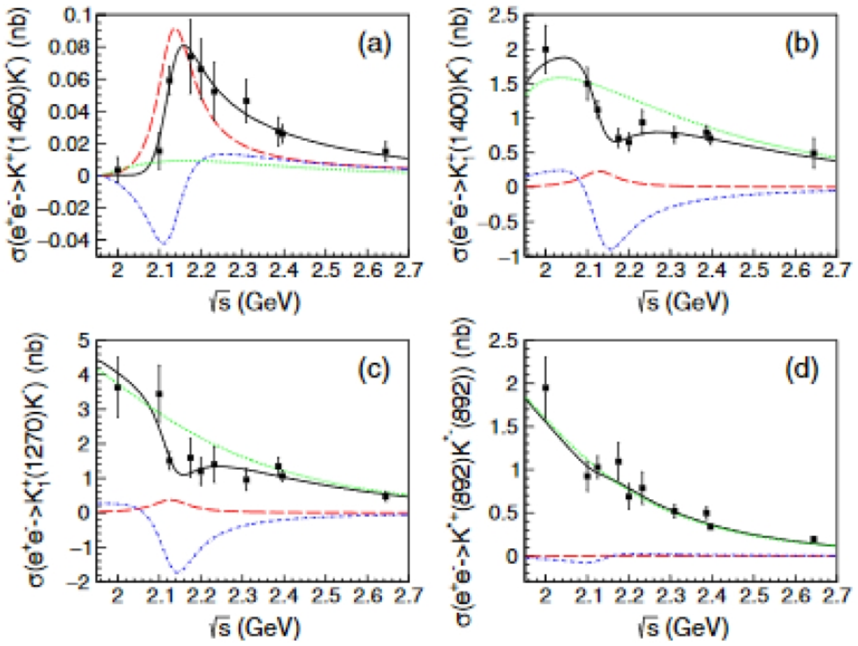
$$B_1 \equiv \frac{\Gamma_{\phi_R \to K^+(1460)K^-}}{\Gamma_{\phi_R \to K_1^+(1400)K^-}} = \frac{\mathcal{B}r[\phi_R \to K^+(1460)K^-]}{\mathcal{B}r[\phi_R \to K_1^+(1400)K^-]},$$

$$B_2 \equiv \frac{\Gamma_{\phi_R \to K^+(1460)K^-}}{\Gamma_{\phi_R \to K_1^+(1270)K^-}} = \frac{\mathcal{B}r[\phi_R \to K^+(1460)K^-]}{\mathcal{B}r[\phi_R \to K_1^+(1270)K^-]},$$

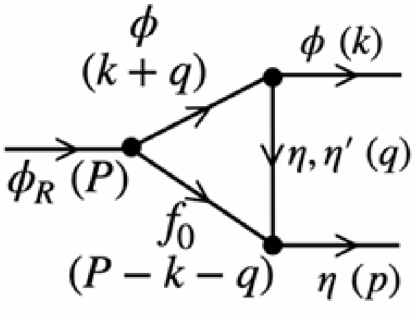
$$B_3 \equiv \frac{\Gamma_{\phi_R \to K_1^+(1270)K^-}}{\Gamma_{\phi_R \to K_1^+(1400)K^-}} = \frac{\mathcal{B}r[\phi_R \to K_1^+(1270)K^-]}{\mathcal{B}r[\phi_R \to K_1^+(1400)K^-]},$$

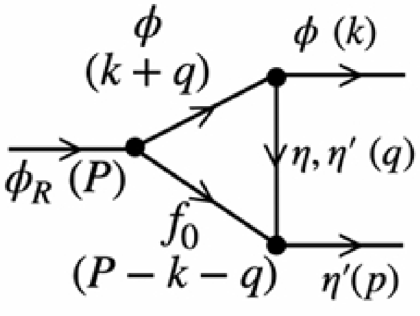
		B_2	
Our results	Model A	1.3 ± 0.4	(Poles z_1, z_2)
		3.6 ± 1.2	(Pole z_1)
		8.8 ± 2.8	(Pole z_2)
	Model B	16 ± 6	
		1.2 ± 0.4	(Solution $\mathbb{S}_1$)
	Model C	0.12 ± 0.04	(Solution $\mathbb{S}_2$)
		0.05 ± 0.02	(Solution $\mathbb{S}_3$)
Experiment	Solution 1	0.40 ± 0.54	
	Solution 2	0.02 ± 0.03	

		B_3	
Our results	Model B	0.04 ± 0.01	
		0.09 ± 0.02	(Solution $\mathbb{S}_1$)
	Model C	0.96 ± 0.16	(Solution $\mathbb{S}_2$)
		2.40 ± 0.40	(Solution $\mathbb{S}_3$)
Experiment	Solution 1	1.62 ± 1.38	
	Solution 2	1.55 ± 0.19	



Malabarba, Ren, Khemchandani and Martinez Torres, Phys. Rev. D 103, 016018 (2021)





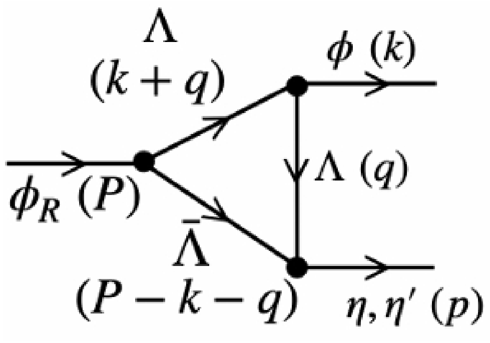
		-15	-19.47	-22
β (Degree)				
$\Gamma^{\phi(2170)}_{\phi\eta}$	LI	4.30 ± 0.93	3.27 ± 0.71	2.76 ± 0.60
	GI	5.14 ± 1.11	3.91 ± 0.85	3.29 ± 0.71
	LII	3.38 ± 0.73	2.59 ± 0.56	2.20 ± 0.48
	GII	4.17 ± 0.91	3.20 ± 0.69	2.71 ± 0.59
$\Gamma^{\phi(2170)}_{\phi\eta'}$	LI	0.84 ± 0.18	0.83 ± 0.18	0.81 ± 0.18
	GI	0.94 ± 0.20	0.93 ± 0.20	0.91 ± 0.20
	LII	0.80 ± 0.18	0.80 ± 0.17	0.79 ± 0.17
	GII	0.95 ± 0.21	0.94 ± 0.20	0.93 ± 0.20

$$R_{\eta/\eta'} = 3.9 \pm 1.3.$$

$$|\eta\rangle = \cos\beta|\eta_8\rangle - \sin\beta|\eta_1\rangle,$$
$$|\eta'\rangle = \sin\beta|\eta_8\rangle + \cos\beta|\eta_1\rangle,$$

$$\mathbb{P} = \begin{pmatrix} A(\beta)\eta + B(\beta)\eta' + \frac{\pi^0}{\sqrt{2}} & \pi^+ & K^+ \\ \pi^- & A(\beta)\eta + B(\beta)\eta' - \frac{\pi^0}{\sqrt{2}} & K^0 \\ K^- & \bar{K}^0 & C(\beta)\eta + D(\beta)\eta' \end{pmatrix},$$

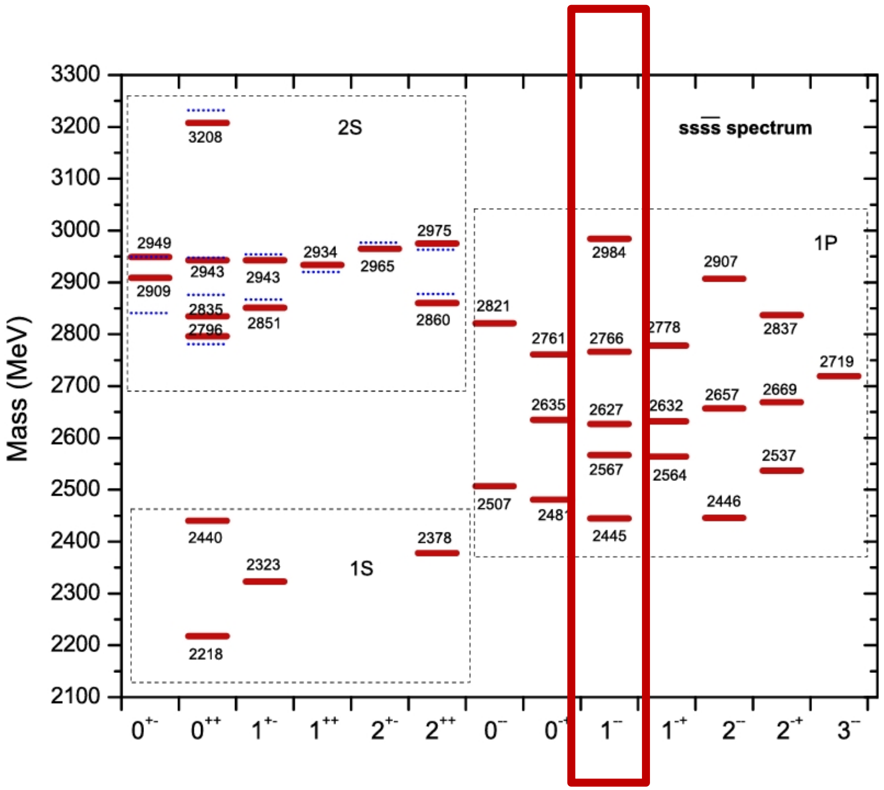
$$A(\beta) = -\frac{\sin\beta}{\sqrt{3}} + \frac{\cos\beta}{\sqrt{6}},$$
$$B(\beta) = \frac{\sin\beta}{\sqrt{6}} + \frac{\cos\beta}{\sqrt{3}},$$
$$C(\beta) = -\frac{\sin\beta}{\sqrt{3}} - \sqrt{\frac{2}{3}}\cos\beta,$$
$$D(\beta) = -\sqrt{\frac{2}{3}}\sin\beta + \frac{\cos\beta}{\sqrt{3}},$$



$$R_{\eta/\eta'} \simeq 0.43 - 0.86$$

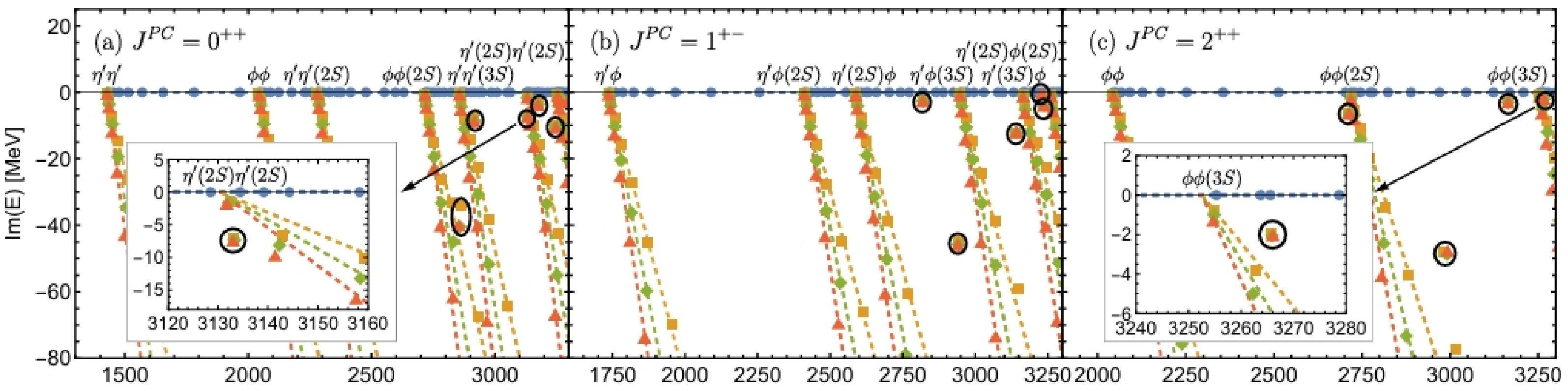
Malabarba, Khemchandani and Torres, Phys. Rev. D 108, 036010 (2023)

Recent theoretical researches: fully-strange tetraquark



Non-relativistic potential model within diquark-antidiquark approximation

Liu, Liu, Zhong and Zhao, Phys. Rev. D 103, 016016 (2021)

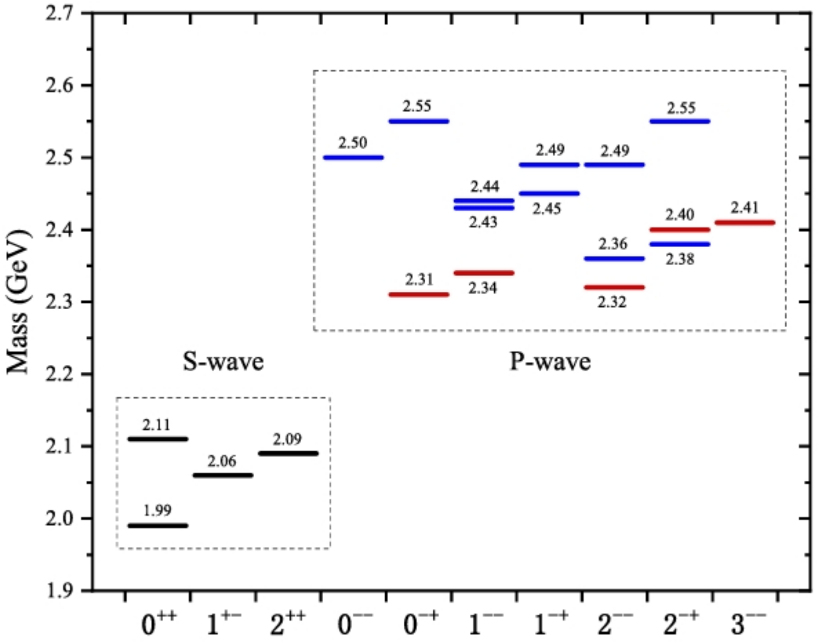


Constituent quark potential model, by solving the full four-body Schrodinger equation and using the complex scaling method to identify resonant states

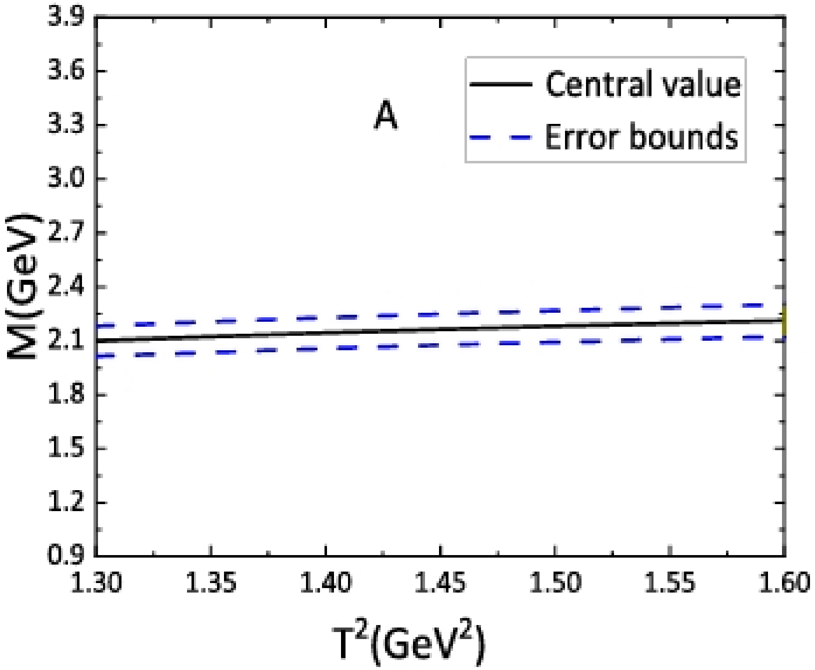
Ma, Wu, Meng, Chen and Zhu, Phys. Rev. D 110, 074026 (2024)

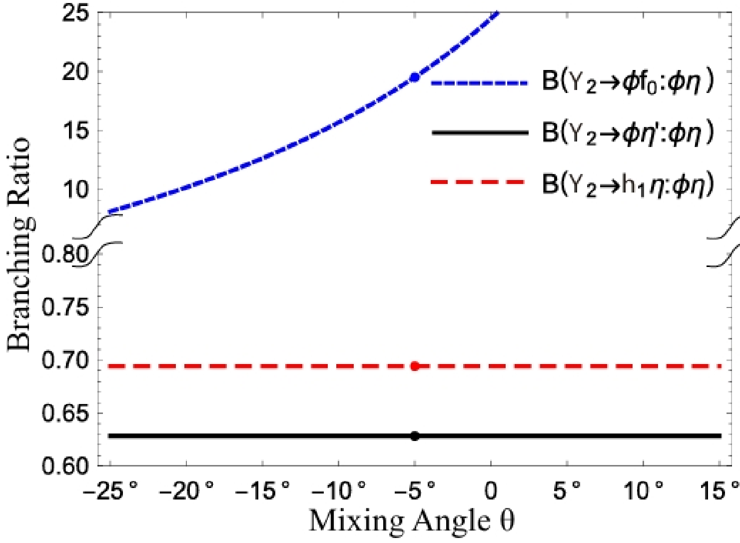
Recent theoretical researches: fully-strange tetraquark

$$M_{Y_2} = 2.34 \pm 0.17 \text{ GeV}.$$



$$2.16 \pm 0.14 \text{ GeV}$$





the Fierz rearrangement

QCD sum rule method within diquark-antidiquark picture

$$\mathcal{B}(Y_2 \to \phi\eta : \phi\eta' : \phi f_0 : h_1(1415)\eta) = 1 : 0.63^{+0.19}_{-0.27} : 19.52^{+6.05}_{-5.51} : 0.69^{+0.09}_{-0.14}.$$

Su and Chen,
Phys. Rev. D 106, 014023 (2022)

Xin and Wang,
Chin.Phys.C 48 (2024) 3, 033104

Jiang, Tan, Chen and Cui,
Symmetry 16, 1021 (2024)

Recent theoretical researches: strangeonium hybrid

Table 4. The fitted masses m_n of the 1^{--} states for two different types of operators and different time windows $[t_{\min}, t_{\max}]$ and χ^2 per degree of freedom (χ^2/dof) for the $\beta = 2.4$ and $\beta = 2.8$ lattices. All the masses are converted to values in physical units using the lattice spacing a_s in Table 1.

$t_{\min}$	χ^2/dof	m_1 /GeV	m_2 /GeV	m_3 /GeV
	$\beta = 2.4$	$t_{\max} = 40$	$(s\bar{s})$	
8	0.84	1.013(1)	1.753(77)	2.16(22)
7	0.81	1.013(1)	1.787(93)	2.08(19)
6	0.83	1.014(1)	1.732(47)	2.13(12)
5	0.92	1.015(1)	1.709(36)	2.11(08)
	$\beta = 2.4$	$t_{\max} = 45$	$(s\bar{s}g)$	
16	1.40	1.011(1)	1.72(12)	—
15	1.42	1.011(1)	1.66(10)	—
14	1.42	1.009(1)	1.77(08)	—
13	1.67	1.007(1)	1.83(06)	—
	$\beta = 2.8$	$t_{\max} = 30$	$(s\bar{s})$	
10	1.93	1.001(5)	1.634(114)	2.17(29)
9	1.97	1.003(4)	1.633(86)	2.02(18)
8	2.11	0.999(3)	1.665(81)	2.30(20)
7	2.39	0.998(3)	1.668(52)	2.34(17)
	$\beta = 2.8$	$t_{\max} = 45$	$(s\bar{s}g)$	
19	1.17	1.006(4)	1.51(6)	—
18	1.39	1.003(3)	1.55(6)	—
17	1.50	1.005(3)	1.51(5)	—
16	1.45	0.998(2)	1.58(4)	—

$$\frac{\Gamma(\phi(2170) \to \phi\eta)}{\Gamma(\phi(2170) \to \phi\eta')} = \tan^2\theta \left(\frac{k_\eta}{k_{\eta'}}\right)^3,$$

lattice QCD in the quenched approximation

Ma, Chen, Gong and Liu, Chin. Phys. C 45, 013112 (2021)

Recent theoretical researches: strangeonium hybrid

(NLO) QCD sum rule analysis for light hybrid mesons

Parameters	NLO		LO	
	$s\bar{s}g$	$u\bar{u}g$	$s\bar{s}g$	$u\bar{u}g$
$\overline{\chi^2_{\rm min}}$	1.17×10^{-5}	2.32×10^{-5}	5.99×10^{-5}	4.83×10^{-5}
$s_0(\mathrm{GeV}^2)$	6.15 ± 1.21	5.85 ± 1.21	8.91 ± 1.43	8.45 ± 1.52
$m(\mathrm{GeV})$	2.31 ± 0.23	2.25 ± 0.23	2.77 ± 0.22	2.70 ± 0.24

Table 2. Single-resonance GSR fitting results in different scenarios. The values shown are determined via a Monte Carlo uncertainty analysis (the $\langle \bar{q}q \rangle$ and $\langle \bar{s}s \rangle$ are assumed to have a 10% uncertainties). The $\overline{\chi^2_{\rm min}}$ denotes the average minimum χ^2.

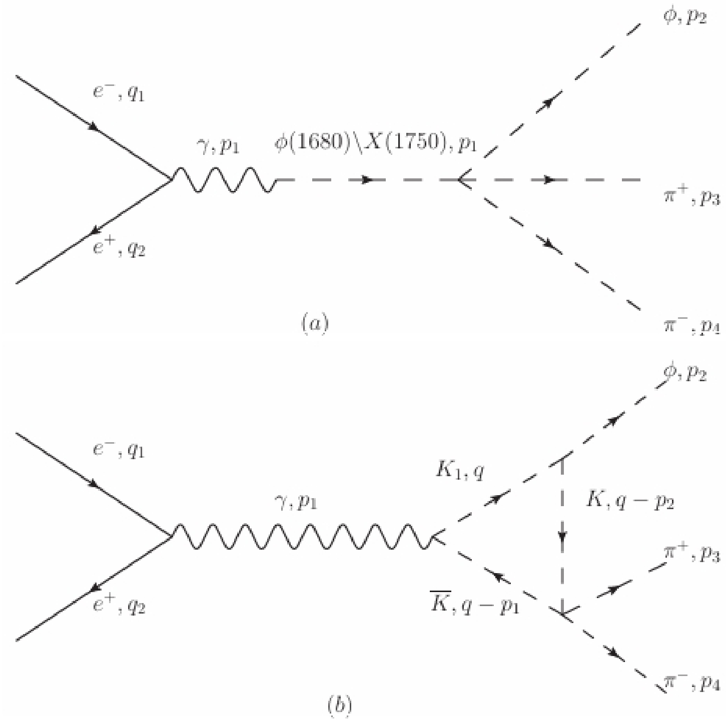
Parameters	$\kappa_6 = 3,\ \kappa_8 = 2$		$\kappa_6 = 3,\ \kappa_8 = 5$	
	$s\bar{s}g$	$u\bar{u}g$	$s\bar{s}g$	$u\bar{u}g$
$\overline{\chi^2_{\rm min}}$	2.85×10^{-5}	7.28×10^{-5}	1.74×10^{-4}	4.30×10^{-4}
$s_0(\mathrm{GeV}^2)$	6.03 ± 1.21	6.02 ± 1.31	6.40 ± 1.60	7.03 ± 2.16
$m(\mathrm{GeV})$	2.29 ± 0.23	2.28 ± 0.24	2.34 ± 0.28	2.43 ± 0.37

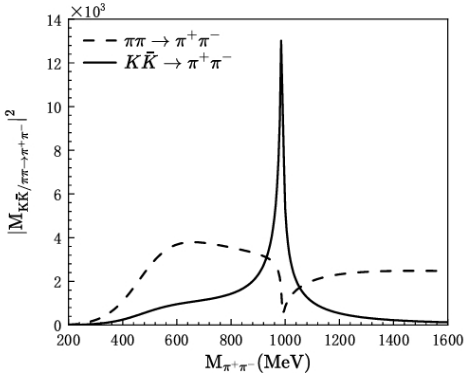
Table 3. Single-resonance NLO GSR fitting results for different factorization deviation factors. Obtained in a same way as in table 2.

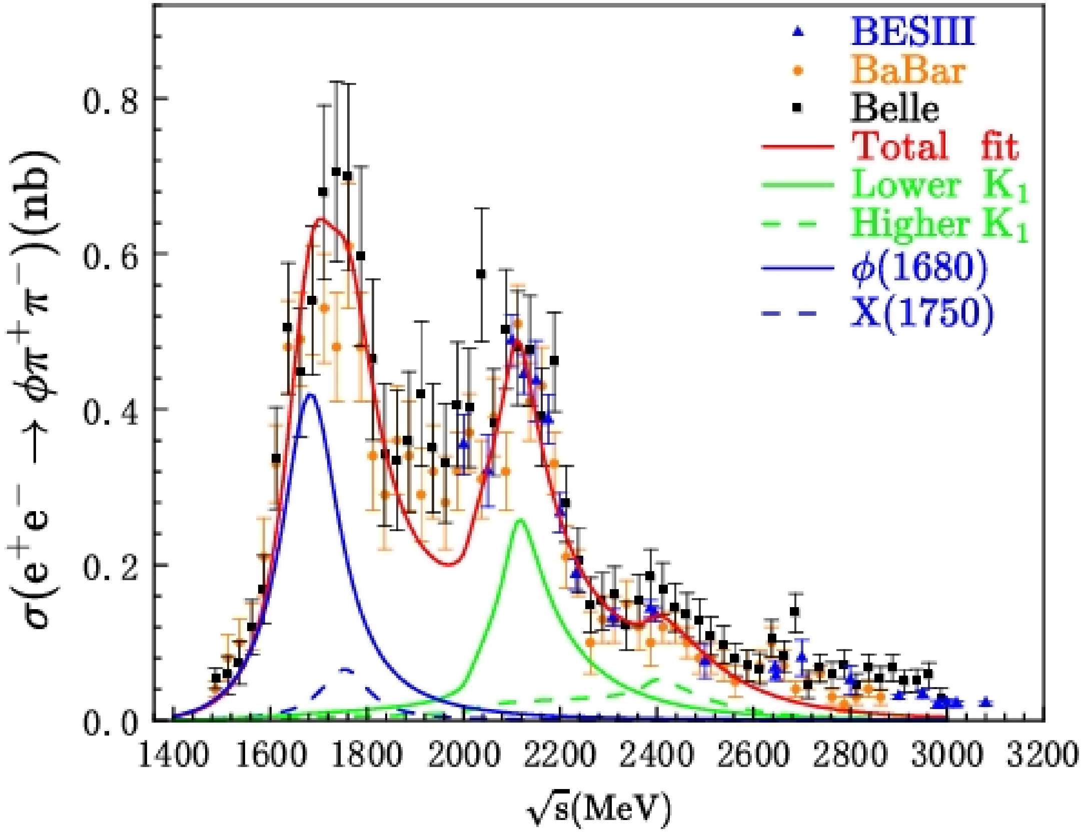
Listen to Zhuo-Ran Huang's talk on 17/05

Li, Huang, Chen and Jin, JHEP 03, 087 (2026)

Recent theoretical researches: triangular singularity







Wei, Shen, Liu and Xie, Phys. Rev. D 113, 014022 (2026)

Recent theoretical researches: interference effect from strangeonium 3S and 1D

the strangeonium hybrid and excited strangeonium ϕ(3S) and ϕ(2D) should dominantly decay into open-strange modes, so the newly observed structure around 2.2 GeV in open-strange processes should be good candidate of hybrid and excited ϕ mesons.

Strangeonium hybrid ⊗

G. J. Ding and M. L. Yan, $Y(2175)$: Distinguish Hybrid State from Higher Quarkonium, Phys. Lett. B **657**, 49-54 (2007).

The observation of a vector structure around 2.2 GeV in KK and KK(1460) channel does not favor the hybrid explanation, but no signal in K*K* is consistent with expectation of hybrid configuration.

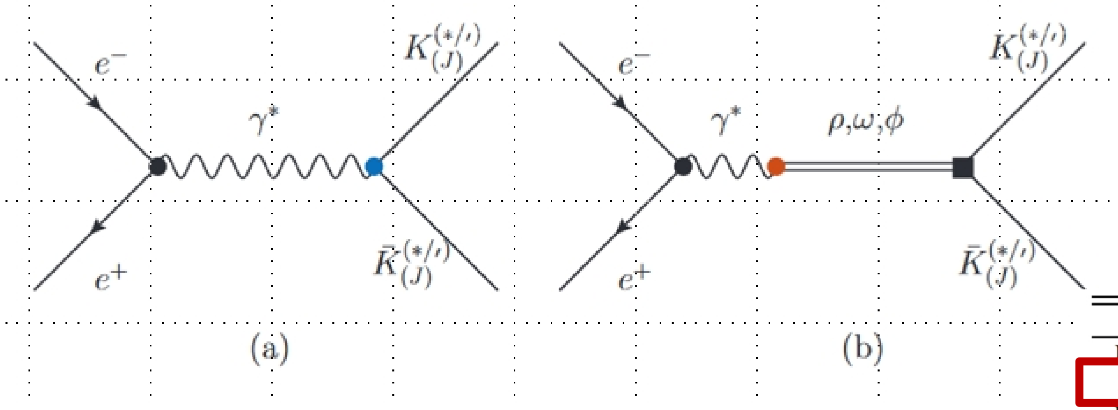
ϕ(3S) and ϕ(2D)⊗

K1(1270)K and K∗K∗ were predicted to be dominant decay channels of ϕ(3S) and ϕ(2D), so the BESIII data does not support these theoretical predictions.

T. Barnes, N. Black and P. R. Page, Strong decays of strange quarkonia, Phys. Rev. D **68**, 054014 (2003).
C. Q. Pang, Excited states of ϕ meson, Phys. Rev. D **99**, no.7, 074015 (2019).

Understanding the puzzle of inconsistent resonance parameter of Y(2175)

Recent theoretical researches: interference effect from strangeonium 3S and 1D



There are $\boldsymbol{\rho(2000)}$, $\boldsymbol{\rho(2150)}$ and $\boldsymbol{\rho(2270)}$(3 $\boldsymbol{\omega}$ partner states) and $\boldsymbol{\varphi(3S)}$ and $\boldsymbol{\varphi(2D)}$ states around 2.0 GeV, so it should be very difficult to analyze the open-strange processes above 2.0 GeV

The scattering amplitude

$$\mathcal{M}^{KK^{(\prime)}}_{\mathrm{Dir}} = [\bar{v}(k_2) ie\gamma^{\mu} u(k_1)] \frac{-g_{\mu\nu}}{q^2} [-e(p_4^{\nu} - p_3^{\nu}) F_{KK^{(\prime)}}(q^2)],$$

$$\mathcal{M}^{KK^{(\prime)}}_{\mathcal{V}} = [\bar{v}(k_2) ie\gamma_{\mu} u(k_1)] \frac{-g^{\mu\rho}}{q^2} \frac{-em_{\mathcal{V}}^2}{f_{\mathcal{V}}} \frac{-g_{\rho\nu} + q_{\rho}q_{\nu}/m_{\mathcal{V}}^2}{q^2 - m_{\mathcal{V}}^2 + im_{\mathcal{V}}\Gamma_{\mathcal{V}}} \times [-g_{\mathcal{V}KK^{(\prime)}}(p_4^{\nu} - p_3^{\nu})], \quad (3)$$

$$\mathcal{M}^{KK^*}_{\mathrm{Dir}} = [\bar{v}(k_2) ie\gamma^{\mu} u(k_1)] \frac{-g_{\mu\nu}}{q^2} [e\varepsilon^{\alpha\nu\rho\sigma} q_{\alpha} p_{4\rho} \epsilon^*_{K^*\sigma} F_{KK^*}(q^2)],$$

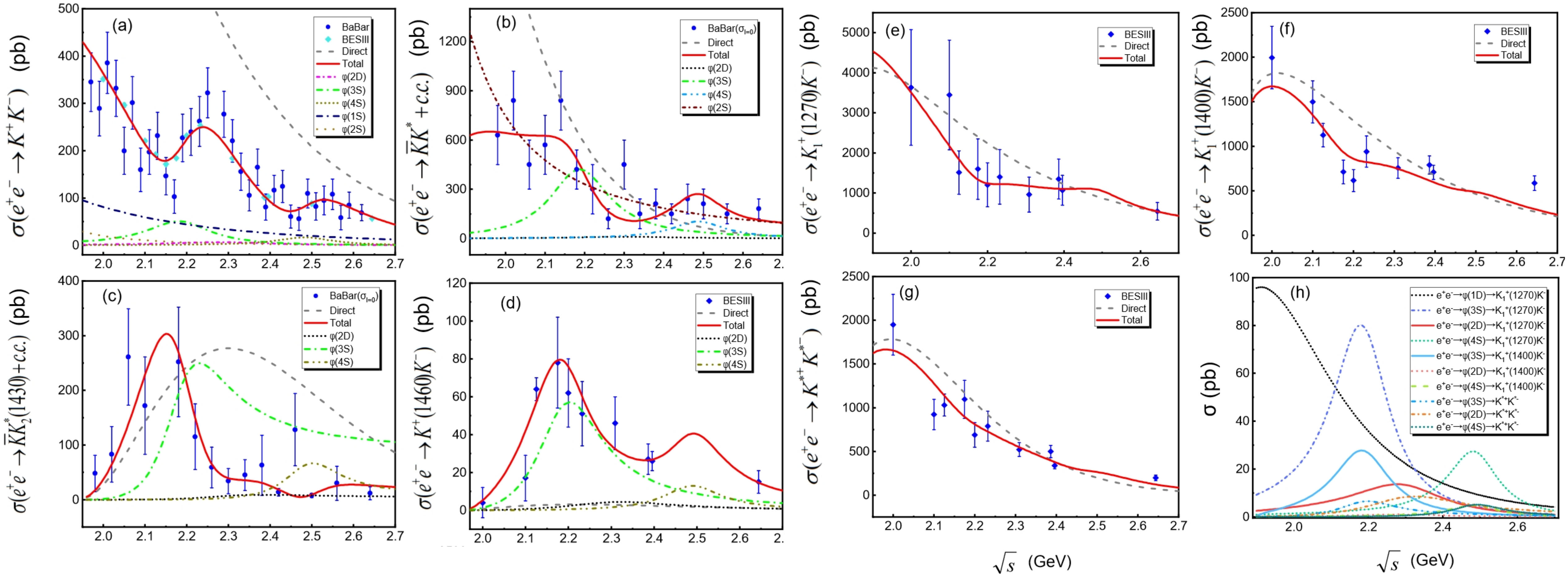
$$\mathcal{M}^{KK^*}_{\mathcal{V}} = [\bar{v}(k_2) ie\gamma_{\mu} u(k_1)] \frac{-g^{\mu\rho}}{q^2} \frac{-em_{\mathcal{V}}^2}{f_{\mathcal{V}}} \frac{-g_{\rho\nu} + q_{\rho}q_{\nu}/m_{\mathcal{V}}^2}{q^2 - m_{\mathcal{V}}^2 + im_{\mathcal{V}}\Gamma_{\mathcal{V}}} \times [g_{\mathcal{V}KK^*} \varepsilon^{\alpha\nu\omega\sigma} q_{\alpha} p_{4\omega} \epsilon^*_{K^*\sigma}], \quad (4)$$

Wang, Wang, Liu and Matsuki,
Phys. Rev. D 104, 054045 (2021)

States	$\rho(2D)$	$\rho(4S)$	$\rho(3D)$	$\rho(5S)$	$\omega(2D)$	$\omega(4S)$	$\omega(3D)$	$\omega(5S)$
Mass (GeV)	2.003	2.180	2.283	2.422	2.003	2.180	2.283	2.422
$\Gamma_{e^+e^-}$ (keV)	0.020	0.063	0.016	0.036	0.0022	0.007	0.0018	0.004
Γ_{Total} (MeV)	179	102	158	80	181	104	94	69
$\mathcal{B}(KK)$	0.006	0.002	0.002	···	0.006	0.002	0.003	···
$\mathcal{B}(KK^*)$	0.001	···	···	···	0.001	···	···	···
$\mathcal{B}(K^*K^*)$	···	0.003	···	0.003	···	0.003	0.001	0.003
$\mathcal{B}(KK_1(1270))$	···	0.010	···	0.004	···	0.010	···	0.005
$\mathcal{B}(KK^*(1410))$	···	0.001	···	···	···	0.001	···	···
$\mathcal{B}(K^*K_1(1270))$	···	0.004	···	0.004	···	0.004	···	0.005
$\mathcal{B}(KK(1460))$	0.002	0.003	0.003	0.001	0.002	0.002	0.005	0.001

States	$\phi(1D)$	$\phi(3S)$	$\phi(2D)$	$\phi(4S)$	$\phi(3D)$
Mass (GeV)	1.860	2.103	2.236	2.423	2.519
$\Gamma_{e^+e^-}$ (keV)	0.063	0.106	0.017	0.050	0.010
Γ_{Total} (MeV)	515	156	265	140	171
$\mathcal{B}(KK)$	0.076	0.059	0.087	0.047	0.084
$\mathcal{B}(KK^*)$	0.100	0.242	0.067	0.145	0.050
$\mathcal{B}(K^*K^*)$	0.016	0.007	0.105	0.014	0.139
$\mathcal{B}(KK^*(1410))$	···	0.180	0.080	0.142	0.052
$\mathcal{B}(KK^*(1680))$	···	···	···	0.004	0.003
$\mathcal{B}(K^*K^*(1410))$	···	···	···	···	0.045
$\mathcal{B}(KK_2^*(1430))$	···	0.115	0.043	0.091	0.043
$\mathcal{B}(K^*K_2^*(1430))$	···	···	···	0.057	0.047
$\mathcal{B}(KK_1(1270))$	0.799	0.185	0.356	0.154	0.293
$\mathcal{B}(K^*K_1(1270))$	···	···	0.110	0.018	0.095
$\mathcal{B}(KK_1(1400))$	···	0.064	0.026	0.027	0.015
$\mathcal{B}(K^*K_1(1400))$	···	···	···	0.126	0.003
$\mathcal{B}(KK(1460))$	···	0.127	0.112	0.073	0.101
$\mathcal{B}(K^*K(1460))$	···	···	···	0.013	0.005
$\mathcal{B}(K^*K_0(1430))$	···	···	···	0.049	···
$\mathcal{B}(KK_3^*(1780))$	···	···	···	0.021	0.014

Recent theoretical researches: interference effect from strangeonium 3S and 1D



Wang, Wang, Liu and Matsuki, Phys. Rev. D 104, 054045 (2021)

Recent theoretical researches: understanding the puzzle phenomenon associated with ϕη and ϕη′

Predicted ratio for $\phi(2170) \to \phi\eta$ and $\phi\eta'$

$R_{\eta/\eta'} \equiv \Gamma[\phi(2170) \to \phi\eta]/\Gamma[\phi(2170) \to \phi\eta']$

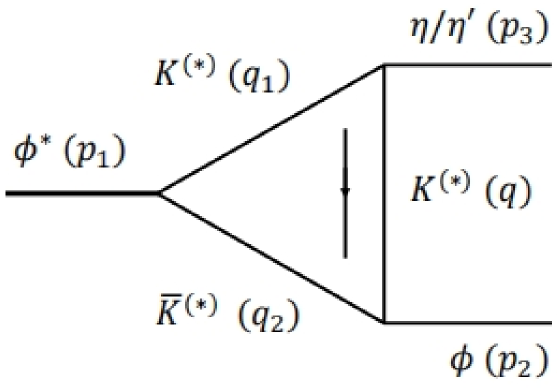
Assignment	Decay model	Reference	$R_{\eta/\eta'}$
$s\bar{s}\ 3\,^3S_1$	$^3P_0$ model SHO wave functions	Barnes, Black, Page PRD 68, 054014 (2003)	**1.91**
$s\bar{s}\ 3\,^3S_1$	$^3P_0$ model modified GI wave functions	Pang PRD 99, 074015 (2019)	**77**
$s\bar{s}\ 2\,^3D_1$	$^3P_0$ model modified GI wave functions	Pang PRD 99, 074015 (2019)	**9.9**
$s\bar{s}\ 3\,^3S_1$	nonrelativistic linear-potential quark model	Li, Gui, Liu, Lü, Zhong CPC 45, 023116 (2021)	**25**
$s\bar{s}\ 2\,^3D_1$	nonrelativistic linear-potential quark model	Li, Gui, Liu, Lü, Zhong CPC 45, 023116 (2021)	**1.13**
$s\bar{s}g$ **hybrid**	flux-tube / hybrid decay model	Page, Swanson, Szczepaniak PRD 59, 034016 (1999)	**9.5–200**
$s\bar{s}g$ **hybrid**	hybrid interpretation of $Y(2175)$	Ding, Yan PLB 650, 390 (2007)	**3**

Ratio of phase space is about 4.3

Recent theoretical researches: understanding the puzzle phenomenon associated with ϕη and ϕη′

Parameters	$\phi(2S)$	$\phi(2D)$	$\phi(3S)$	$Y(2175)$(Hybrid)
Mass (MeV)	1680 ± 20	2183 ± 1	2290 ± 3	2175 ± 10 ± 15
Γ_{Total} (MeV)	150 ± 50	185 ± 4	312 ± 6	148.7
$\Gamma_{e^+e^-}$ (eV)	285	106	17	?
$\mathcal{B}(KK)$	0.108	0.059	0.087	0.237
$\mathcal{B}(K^*K)$	0.851	0.242	0.067	0.025
$\mathcal{B}(K^*K^*)$	...	0.007	0.105	
$\mathcal{B}(KK_1(1270))$	...	0.185	0.356	0.237
$\mathcal{B}(KK_1(1400))$	...	0.064	0.026	0.471
$\mathcal{B}(\phi\eta)$	0.041	0.011	0.003	0.0081
$\mathcal{B}(\phi\eta')$	...	0.0003	0.0001	0.0026

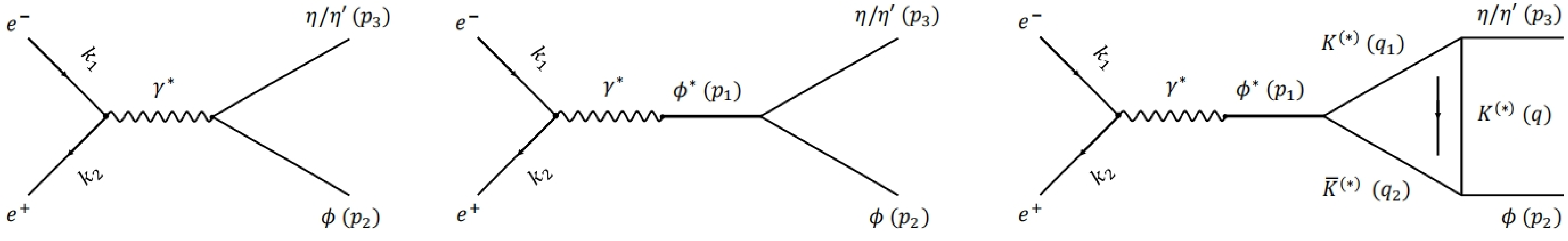
The resonance parameters are very reliable from the fit to the cross section of multiple open-charm channels



$$g_{\phi K^*K} = g_{VVP}, \qquad g_{\phi K^*K^*} = g_{\phi KK},$$
$$g_{K^*K\eta} = (\alpha+\gamma)g_{\phi KK}, \qquad g_{K^*K\eta'} = (\beta+\delta)g_{\phi KK},$$
$$g_{K^*K^*\eta} = (\alpha+\gamma)g_{VVP}, \qquad g_{K^*K^*\eta'} = (\beta+\delta)g_{VVP},$$

$$\alpha = \frac{\cos\theta - \sqrt{2}\sin\theta}{\sqrt{6}}, \qquad \beta = \frac{\sqrt{2}\cos\theta + \sin\theta}{\sqrt{6}},$$
$$\gamma = \frac{-2\cos\theta - \sqrt{2}\sin\theta}{\sqrt{6}}, \qquad \delta = \frac{\sqrt{2}\cos\theta - 2\sin\theta}{\sqrt{6}}$$

$$\frac{g_{K^{(*)}_{(J)}K^{(*)}_{(J)}\eta}}{g_{K^{(*)}_{(J)}K^{(*)}_{(J)}\eta'}} = \frac{-\cos\theta - 2\sqrt{2}\sin\theta}{2\sqrt{2}\cos\theta - \sin\theta} \approx -0.094$$



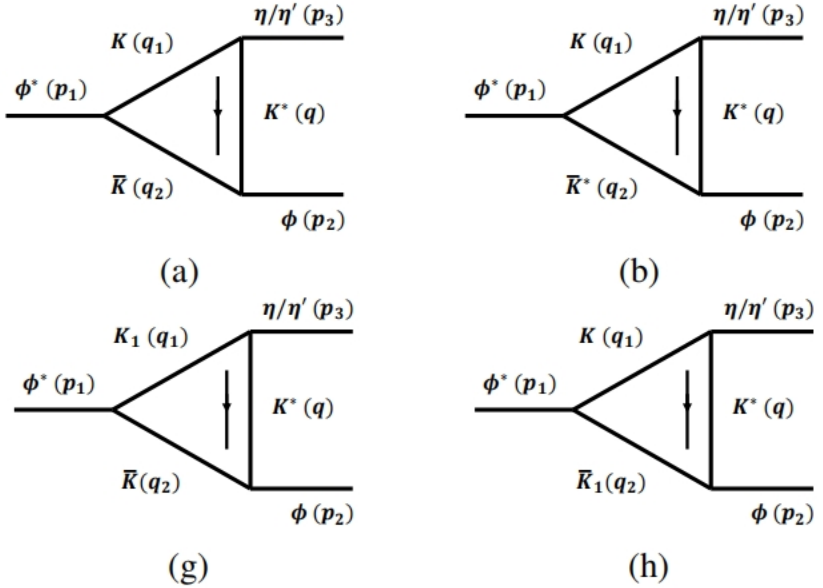
(a) (b) (c)

The reaction amplitude

$$\mathcal{M}_{\rm Dir} = \bar{v}(k_2)(ie\gamma_\rho)u(k_1)\frac{-g^{\rho\nu}}{p_1^2}g_{\gamma\phi\eta^{(\prime)}}\varepsilon_{\mu\nu\alpha\beta}(-ip_1^\mu)(ip_2^\alpha)\varepsilon^{*\beta}(p_2).$$

$$\mathcal{M}_{\rm Tree}^{\phi_i^*} = \bar{v}(k_2)(ie\gamma_\xi)u(k_1)\frac{-g^{\xi\zeta}}{p_1^2}\frac{-em_{\phi^*}^2}{f_{\phi^*}}\frac{\tilde{g}_{\zeta\mu}(p_1)}{p_1^2-m_{\phi^*}^2+im_{\phi^*}\Gamma_{\phi^*}} \times g_{\phi_i^*\phi\eta^{(\prime)}}\varepsilon_{\mu\nu\alpha\beta}(-ip_1^\mu)(ip_2^\alpha)\varepsilon^{*\beta}(p_2).$$

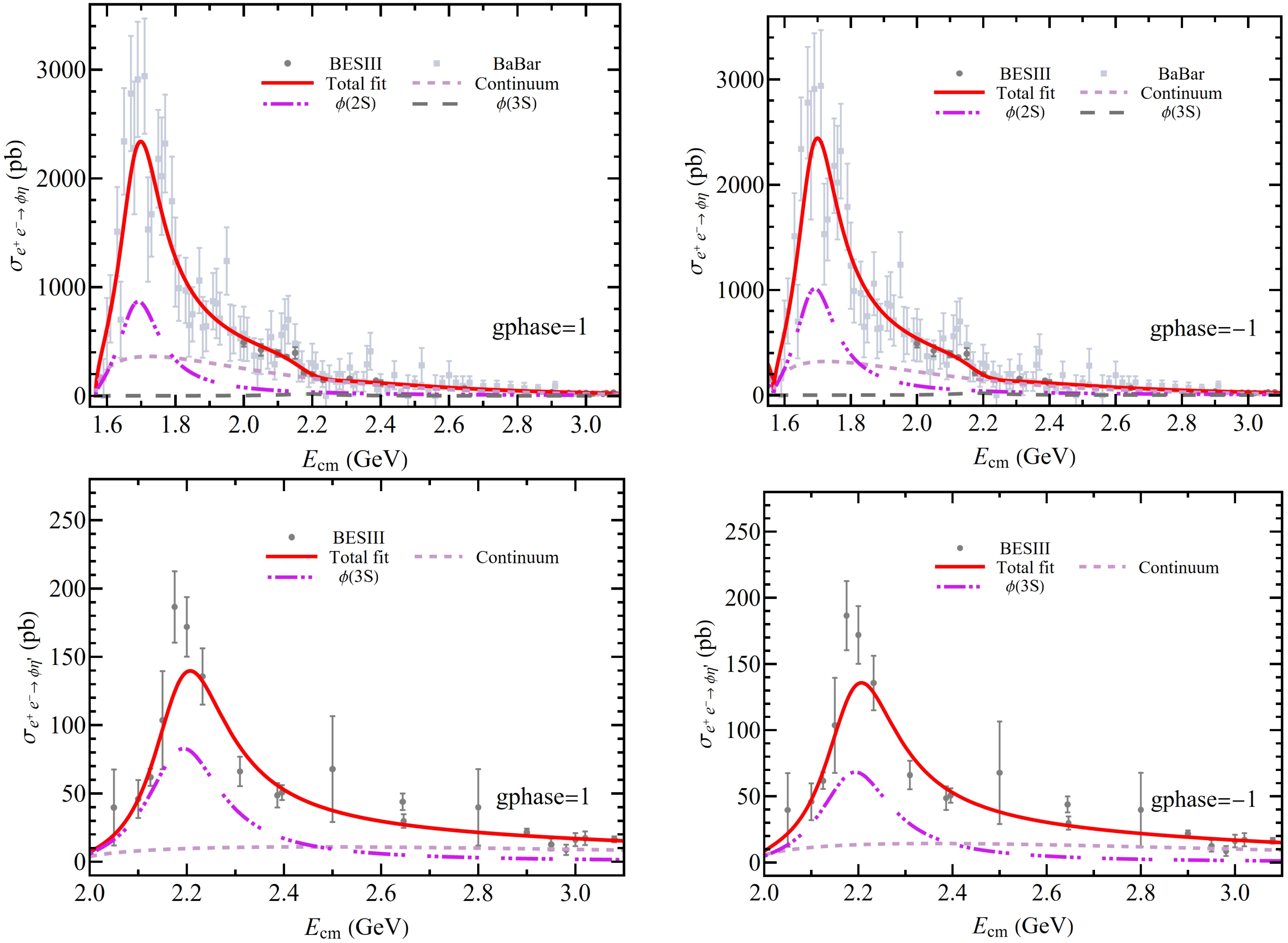
$$\mathcal{M}_{\rm Loop}^{\phi_i^*} = 4\times\left(\sum_{j=1}^{6}\mathcal{M}^j + g_{\rm phase}\sum_{j=7}^{10}\mathcal{M}^j\right)$$



Recent theoretical researches: understanding the puzzle phenomenon associated with ϕη and ϕη′

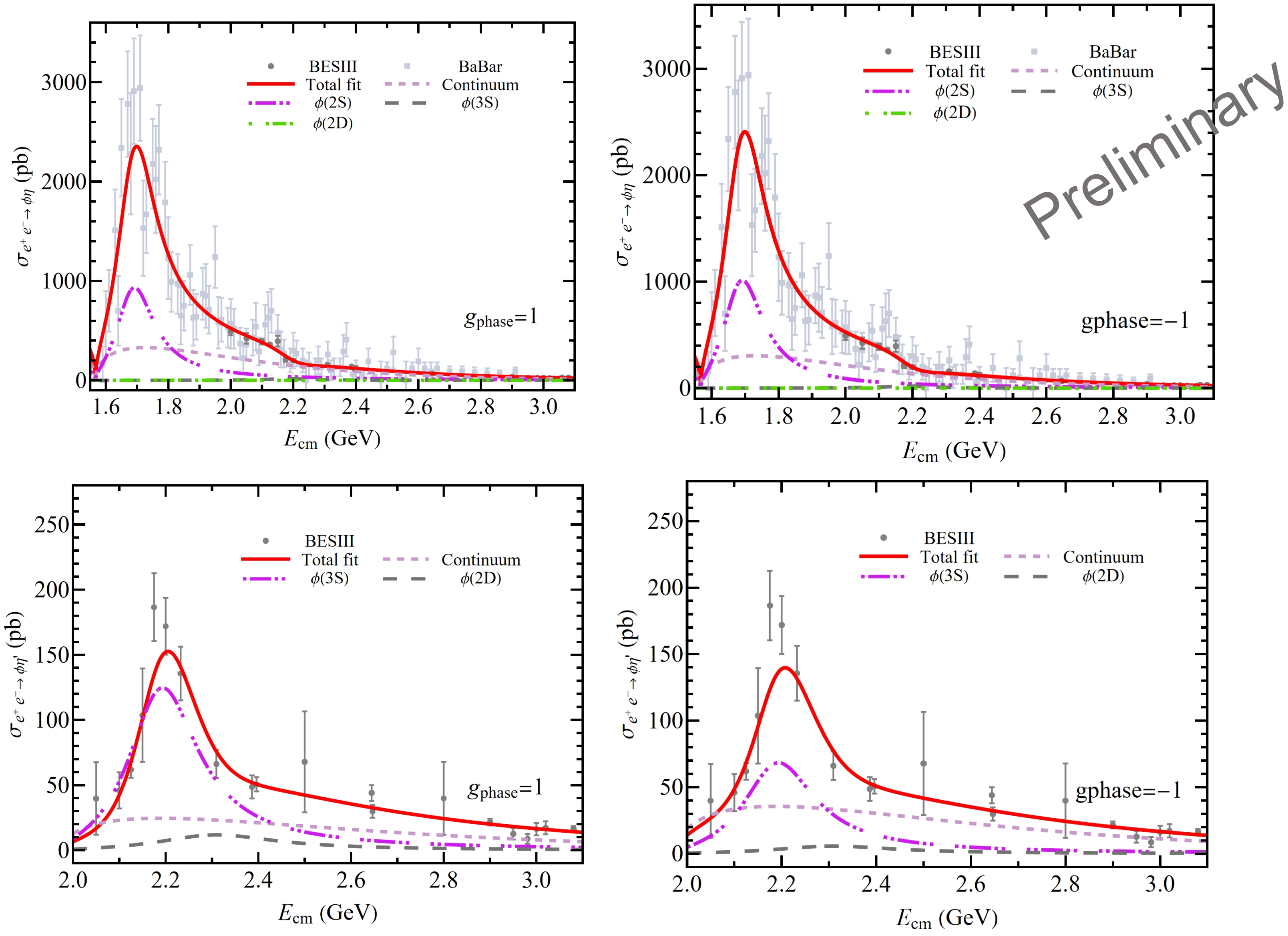
Preliminary

Parameters	$g_{\text{phase}} = 1$	$g_{\text{phase}} = -1$
C_1 $(^{-3})$	2.14 ± 0.02	2.00 ± 0.02
n_1 (GeV^{-2})	1.68 ± 0.01	1.67 ± 0.01
ϕ_{11} (rad)	1.16 ± 0.03	1.09 ± 0.04
ϕ_{12} (rad)	4.00 ± 0.07	4.00 ± 0.07
C_2 $(^{-3})$	0.26 ± 0.01	0.31 ± 0.01
n_2 (GeV^{-2})	0.57 ± 0.05	0.71 ± 0.05
ϕ_{22} (rad)	0.80 ± 0.11	0.93 ± 0.10
α	3.62 ± 0.08	5.00 (upper limit)
χ^2/n.d.f	1.08	1.08
$\Gamma_{\text{Loop}}(\phi(2S) \to \phi\eta)$ (MeV)	0.79	1.82
$\Gamma_{\text{Total}}(\phi(2S) \to \phi\eta$ (MeV)	9.23	10.79
$\Gamma_{\text{Loop}}(\phi(3S) \to \phi\eta)$ (MeV)	0.23	0.26
$\Gamma_{\text{Total}}(\phi(3S) \to \phi\eta)$ (MeV)	1.75	1.97
$\Gamma_{\text{Loop}}(\phi(3S) \to \phi\eta')$ (MeV)	7.97	6.79
$\Gamma_{\text{Total}}(\phi(3S) \to \phi\eta')$ (MeV)	8.57	7.06



Recent theoretical researches: understanding the puzzle phenomenon associated with φη and φη′

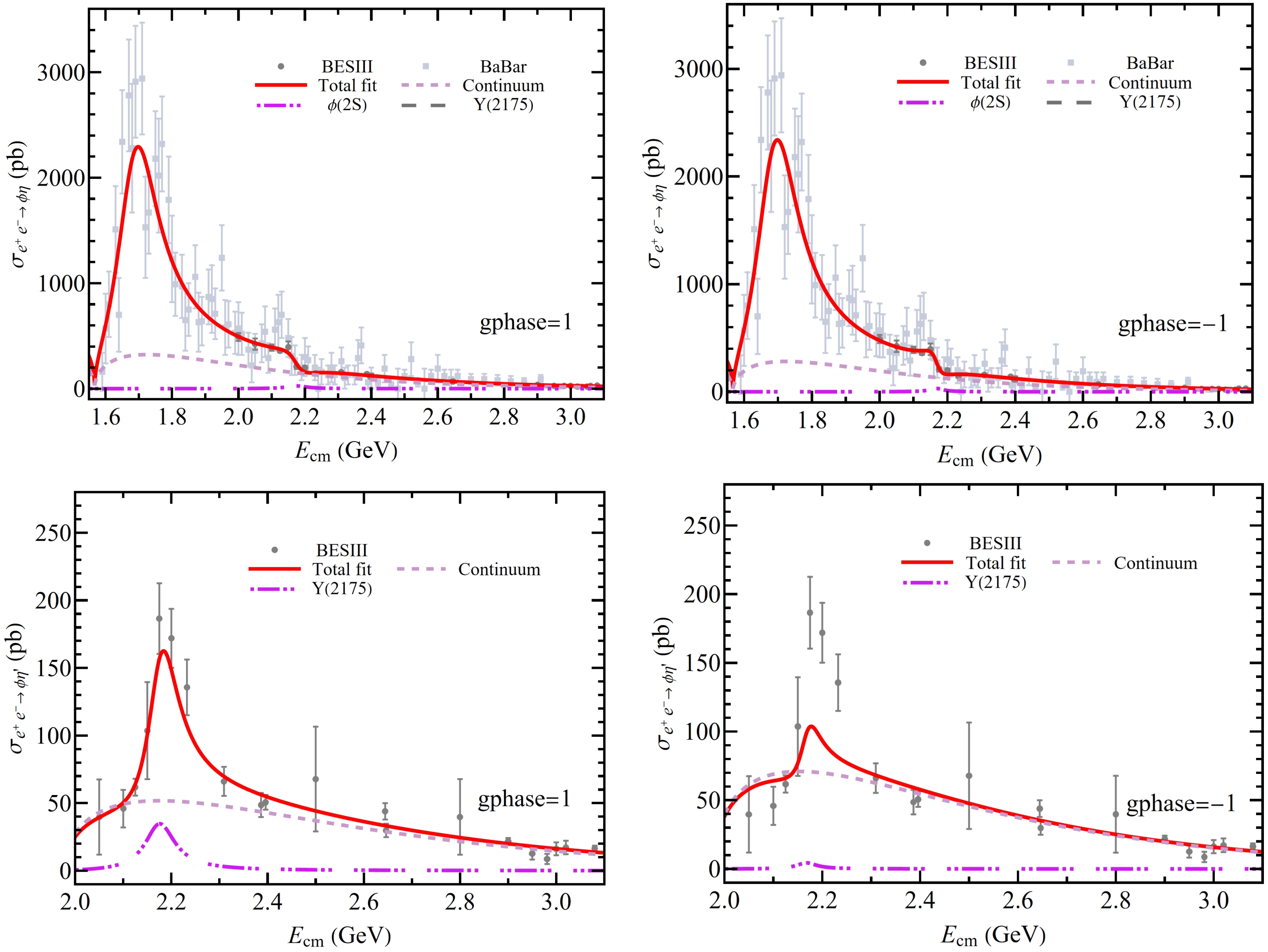
Parameters	$g_{phase}=1$	$g_{phase}=-1$
C_1 $(^{-3})$	2.03 ± 0.03	1.95 ± 0.03
n_1 (GeV^{-2})	1.67 ± 0.01	1.65 ± 0.02
ϕ_{11} (rad)	1.14 ± 0.04	1.11 ± 0.04
ϕ_{12} (rad)	3.98 ± 0.08	3.97 ± 0.08
ϕ_{13} (rad)	1.87 ± 0.65	1.79 ± 0.47
C_2 $(^{-3})$	0.48 ± 0.02	0.58 ± 0.02
n_2 (GeV^{-2})	1.24 ± 0.05	1.26 ± 0.04
ϕ_{22} (rad)	0.60 ± 0.07	0.77 ± 0.07
ϕ_{23} (rad)	4.69 ± 0.11	4.54 ± 0.18
α	4.27 ± 0.39	5.00 (upper limit)
χ^2/n.d.f	0.99	1.02
$\Gamma_{Loop}(\phi(2S)\to\phi\eta)$ (MeV)	1.21	1.82
$\Gamma_{Total}(\phi(2S)\to\phi\eta)$ (MeV)	9.93	10.79
$\Gamma_{Loop}(\phi(3S)\to\phi\eta)$ (MeV)	0.36	0.26
$\Gamma_{Total}(\phi(3S)\to\phi\eta)$ (MeV)	1.69	1.97
$\Gamma_{Loop}(\phi(3S)\to\phi\eta')$ (MeV)	12.09	6.79
$\Gamma_{Total}(\phi(3S)\to\phi\eta')$ (MeV)	12.89	7.06
$\Gamma_{Loop}(\phi(2D)\to\phi\eta)$ (MeV)	0.35	0.31
$\Gamma_{Total}(\phi(2D)\to\phi\eta)$ (MeV)	0.29	0.52
$\Gamma_{Loop}(\phi(2D)\to\phi\eta')$ (MeV)	18.95	9.71
$\Gamma_{Total}(\phi(2D)\to\phi\eta')$ (MeV)	23.72	11.39



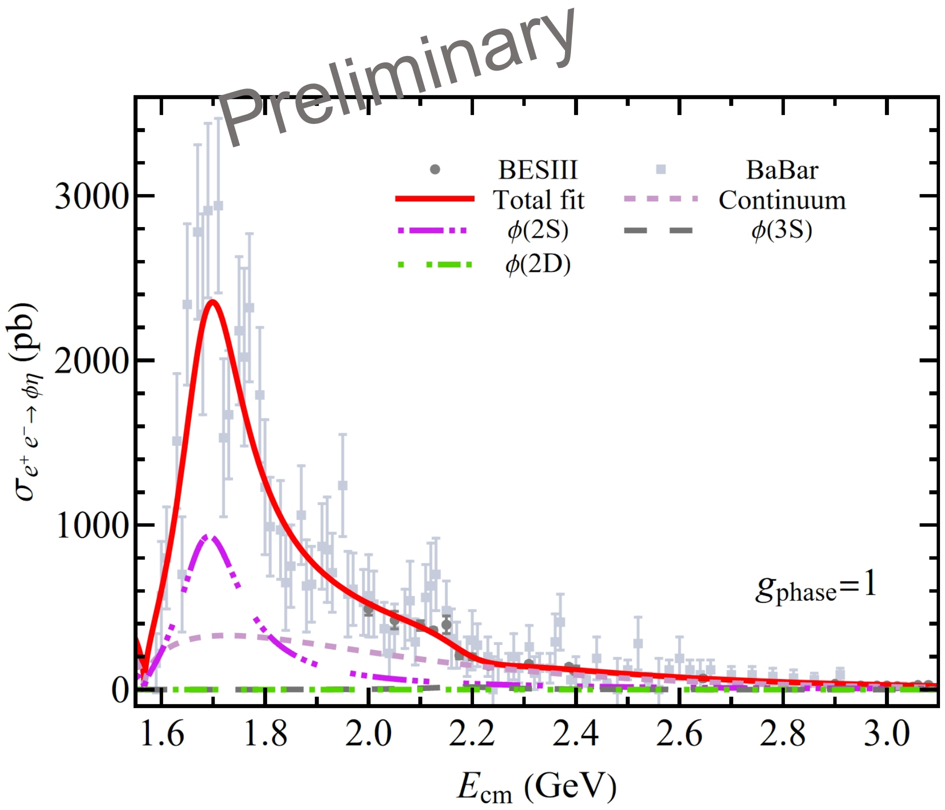
Recent theoretical researches: understanding the puzzle phenomenon associated with $\phi\eta$ and $\phi\eta'$

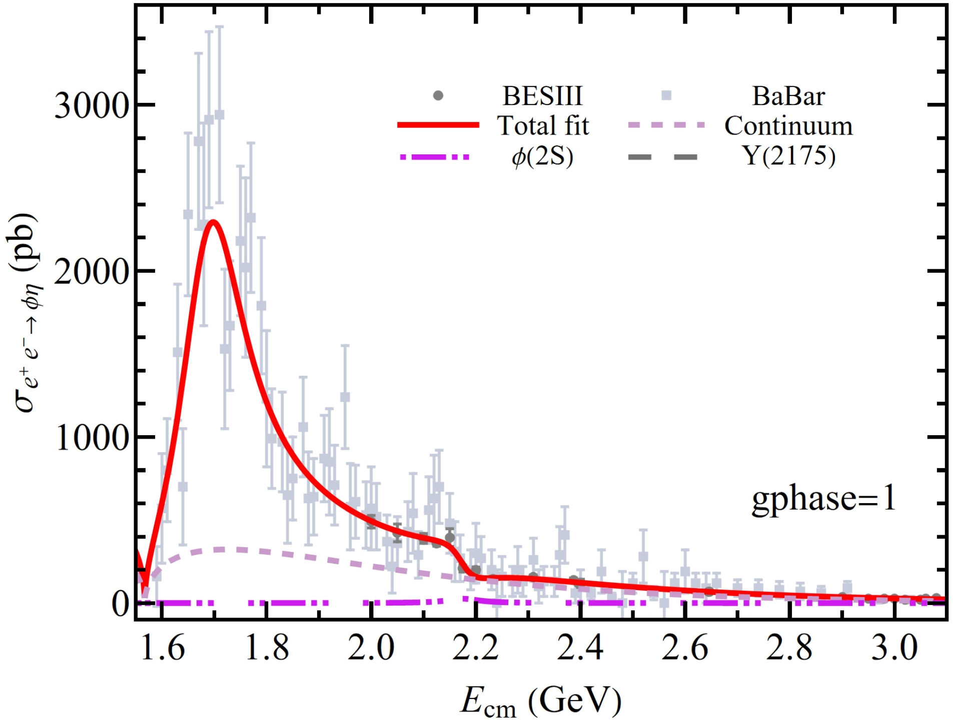
Preliminary

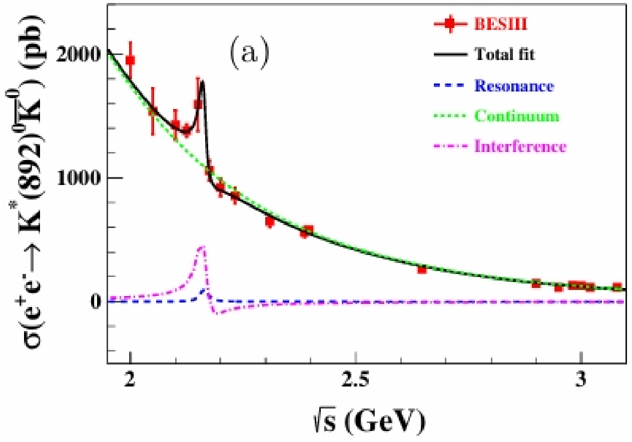
Parameters	$g_{\rm phase} = 1$	$g_{\rm phase} = -1$
C_1 ($^{-3}$)	2.01 ± 0.03	1.89 ± 0.10
n_1 (GeV^{-2})	1.69 ± 0.01	1.69 ± 0.06
ϕ_{11} (rad)	1.17 ± 0.04	1.12 ± 0.15
ϕ_{14} (rad)	3.80 ± 0.09	3.56 ± 0.19
C_2 ($^{-3}$)	0.70 ± 0.02	0.85 ± 0.04
n_2 (GeV^{-2})	1.32 ± 0.04	1.48 ± 0.07
$\Gamma^{e^+e^-}_{Y(2175)}$ (eV)	83.65 ± 11.79	47.57 ± 11.38
$M_{Y(2175)}$ (MeV)	2174.20 ± 3.63	2167.95 ± 4.77
$\Gamma^{\rm Total}_{Y(2175)}$ (MeV)	75.54 ± 9.92	50 (lower limit)
ϕ_{24} (rad)	0.95 ± 0.10	0.70 ± 0.29
α	3.99 ± 0.11	5.00 (upper limit)
χ^2/n.d.f	0.98	1.22
$\Gamma_{\rm Loop}(\phi(2S) \to \phi\eta)$ (MeV)	1.02	1.82
$\Gamma_{\rm Total}(\phi(2S) \to \phi\eta$ (MeV)	9.62	10.79
$\Gamma_{\rm Loop}(Y(2175) \to \phi\eta)$ (MeV)	0.03	0.02
$\Gamma_{\rm Total}(Y(2175) \to \phi\eta)$ (MeV)	0.57	0.52
$\Gamma_{\rm Loop}(Y(2175) \to \phi\eta')$ (MeV)	1.05	0.18
$\Gamma_{\rm Total}(Y(2175) \to \phi\eta')$ (MeV)	1.24	0.12



Recent theoretical researches: understanding the puzzle phenomenon associated with ϕη and ϕη′







Parameter	Solution 1	Solution 2
M_Y(MeV/c^2)	$2164.7 \pm 9.1 \pm 3.1$	
Γ_Y(MeV)	$32.4 \pm 21.0 \pm 1.8$	
$\Gamma_Y^{e^+e^-}\mathcal{B}$(eV)	$1.0 \pm 0.2 \pm 0.1$	$73.6 \pm 4.4 \pm 2.0$
ϕ_Y(rad)	$2.5 \pm 0.5 \pm 0.1$	$-1.7 \pm 0.1 \pm 0.1$
Significance	3.2σ	

[BESIII], JHEP01(2024)180

The existence of two Y(2175) around 2170 MeV? (a narrow state and a broad state, and the former may a good candidate of exotic vector light hadron)

Summary

- **We reviewed the experimental and theoretical progress on ϕ(2170), with emphasis on the new constraints from hidden- and open-strangeness channels after 2019.**

- **We proposed a unified interpretation of two central puzzles: the channel-dependent resonance parameters and the unexpected enhancement in ϕη′. Both can be understood from the interference of spectroscopically supported 3S and 2D strangeonium states, with the ϕη′ enhancement naturally driven by kaon meson-loop effects.**

- **Although the present ϕη and ϕη′ cross sections can be well described, the data may indicate an additional narrow vector structure. If confirmed, such a state would be a promising exotic candidate in the light vector sector.**

Thanks for your attention!