Study of $\phi(2170)$ at BESIII

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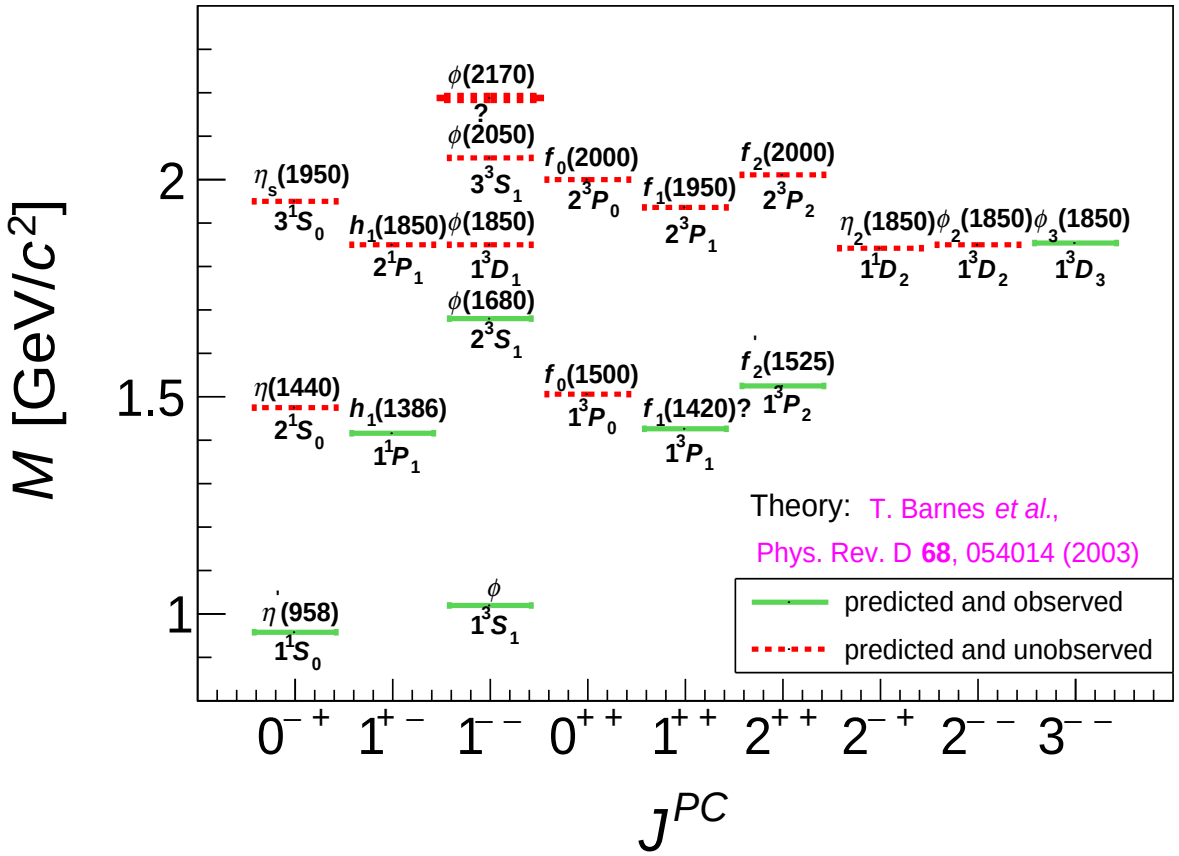
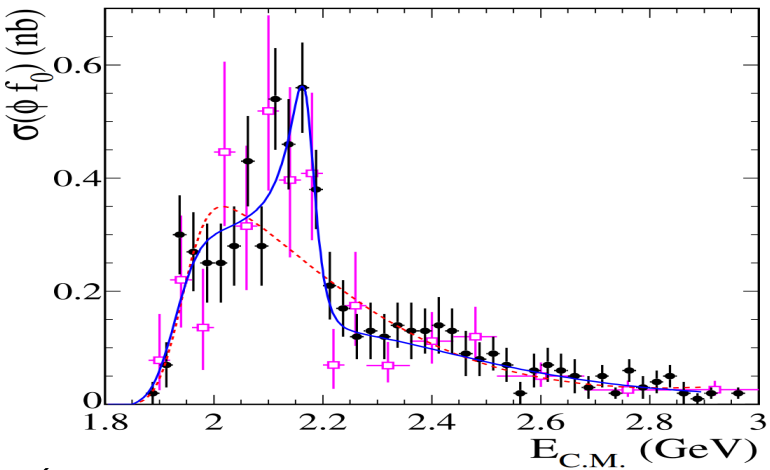
Outline

The strange quarkonium

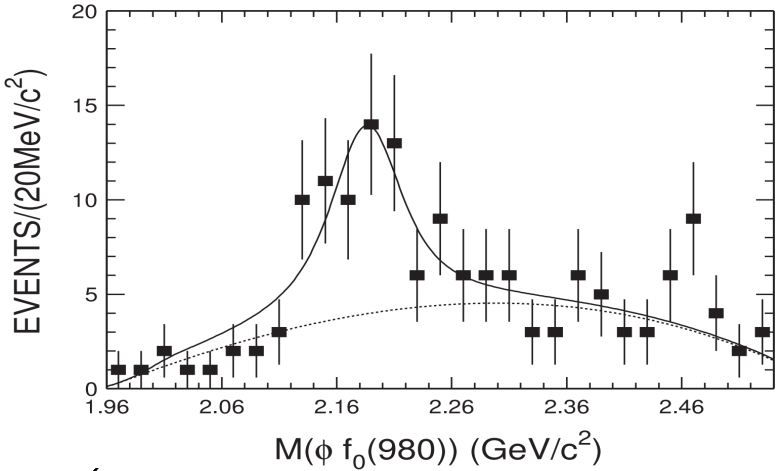


- $s\bar{s}$ analogue of $c\bar{c}$ and $b\bar{b}$, poorly known;
- XYZ particles with strange quark as well?
- A bridge between light and heavy quark.

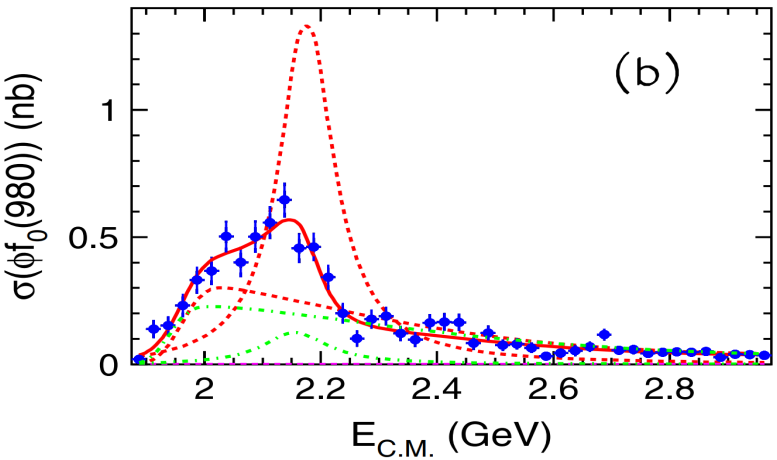
The strange quarkonium



(B. Aubert *et al.* (*BABAR* collaboration), PRD **74**, 091103(R) (2006))



(M. Ablikim *et al.* (BES collaboration), PRL **100**, 102003 (2008))



(C. P. Shen *et al.* (Belle collaboration), PRD **80**, 031101(R) (2009))

- $e^+e^- \Rightarrow$

$$\begin{cases} Y(2175) \to \phi(1020)\pi^+\pi^-, \text{strange} \\ Y(4260) \to J/\psi\pi^+\pi^-, \text{charm} \\ \Upsilon(10860) \to \\ \Upsilon(1S, 2S)\pi^+\pi^-, \text{bottom.} \end{cases}$$

- $\phi(2170)$ as strange analogue of $Y(4220)$?

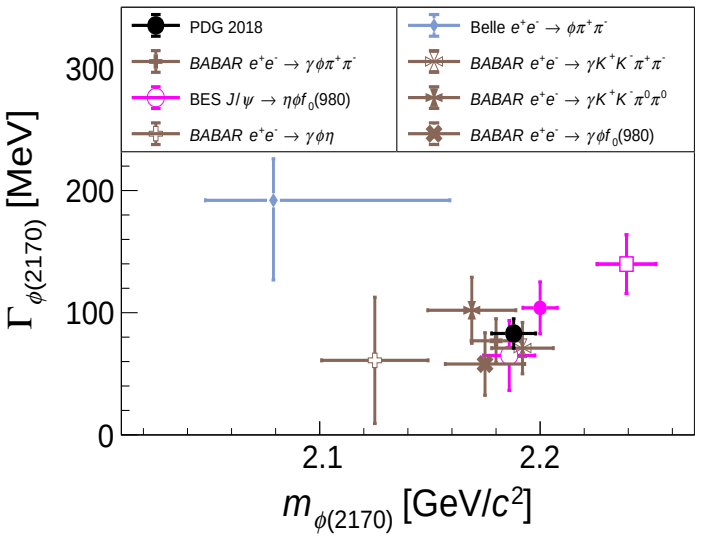
The nature of $\phi(2170)$

- Published measurements:
  - Limited decay modes;
  - Inconsistence on mass and width.
- Theory explanations of $\phi(2170)$:
  - $s\bar{s}g$ hybrid (G. J. Ding *et al.*, PLB **650**, 390 (2007));
  - 2^3D_1 or 3^3S_1 $s\bar{s}$ quarkonium (G. J. Ding *et al.*, PLB **657**, 49 (2007));
  - Tetraquark $s\bar{s}s\bar{s}$ (Z. G. Wang, NP **A791**, 106 (2007));
  - Molecular state $\Lambda\bar{\Lambda}$ (C. F. Qiao, PLB **639**, 263 (2006));
  - $\phi f_0(980)$ resonance with FSI (A. M. Torres *et al.*, PRD **78**, 074031 (2008));
  - Three body system ϕK^+K^- (S. L. Zhu, IJMPE **17**, 283 (2008));

$\phi(2170)$ DECAY MODES

	Mode	Fraction (Γ_i/Γ)
Γ_1	e^+e^-	seen
Γ_2	$\phi\eta$	
Γ_3	$\phi\pi\pi$	
Γ_4	$\phi f_0(980)$	seen
Γ_5	$K^+K^-\pi^+\pi^-$	
Γ_6	$K^+K^-f_0(980) \rightarrow K^+K^-\pi^+\pi^-$	seen
Γ_7	$K^+K^-\pi^0\pi^0$	
Γ_8	$K^+K^-f_0(980) \rightarrow K^+K^-\pi^0\pi^0$	seen
Γ_9	$K^{*0}K^{\pm}\pi^{\mp}$	not seen
Γ_{10}	$K^*(892)^0\overline{K}^*(892)^0$	not seen

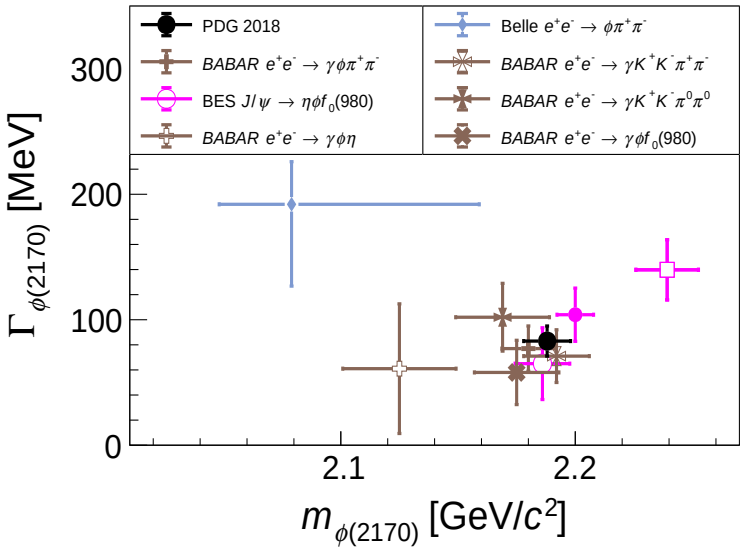
(C. Patrignani *et al.*, (Particle Data Group), CPC **40**, 100001 (2016))



- Not fully understood!

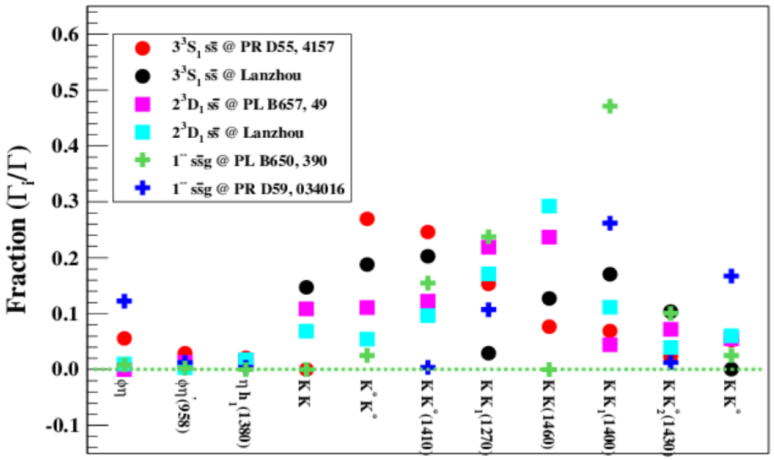
The nature of $\phi(2170)$

$\phi(2170)$	M [MeV/c^2]	Γ [MeV]
3^3S_1	2050	378
	G. J. Ding *et al.*, PLB **657**, 49 (2007)	
2^3D_1		167.21
		211.9
	G. J. Ding *et al.*, PLB **657**, 49 (2007)	
hybrid		148.7
		155
		120
	2100 – 2200	
	2500 – 2600	
	G. J. Ding *et al.*, PLB **650**, 390 (2007)	
$s\bar{s}s\bar{s}$	2210 ± 90	
	2300 ± 400	
	2176	
	Z. G. Wang, NP **A791**, 106 (2007)	
$\Lambda\Lambda$		80.1 – 95
	C. F. Qiao, PLB **639**, 263 (2006)	
PDG	2188 ± 10	83 ± 12
	C. Patrignani *et al.*, (Particle Data Group), CPC **40**, 100001 (2016)	



- Theory models with similar mass and width.
- Inconsistence on mass and width by experiment.
- Test theory models with decay modes.

The nature of $\phi(2170)$

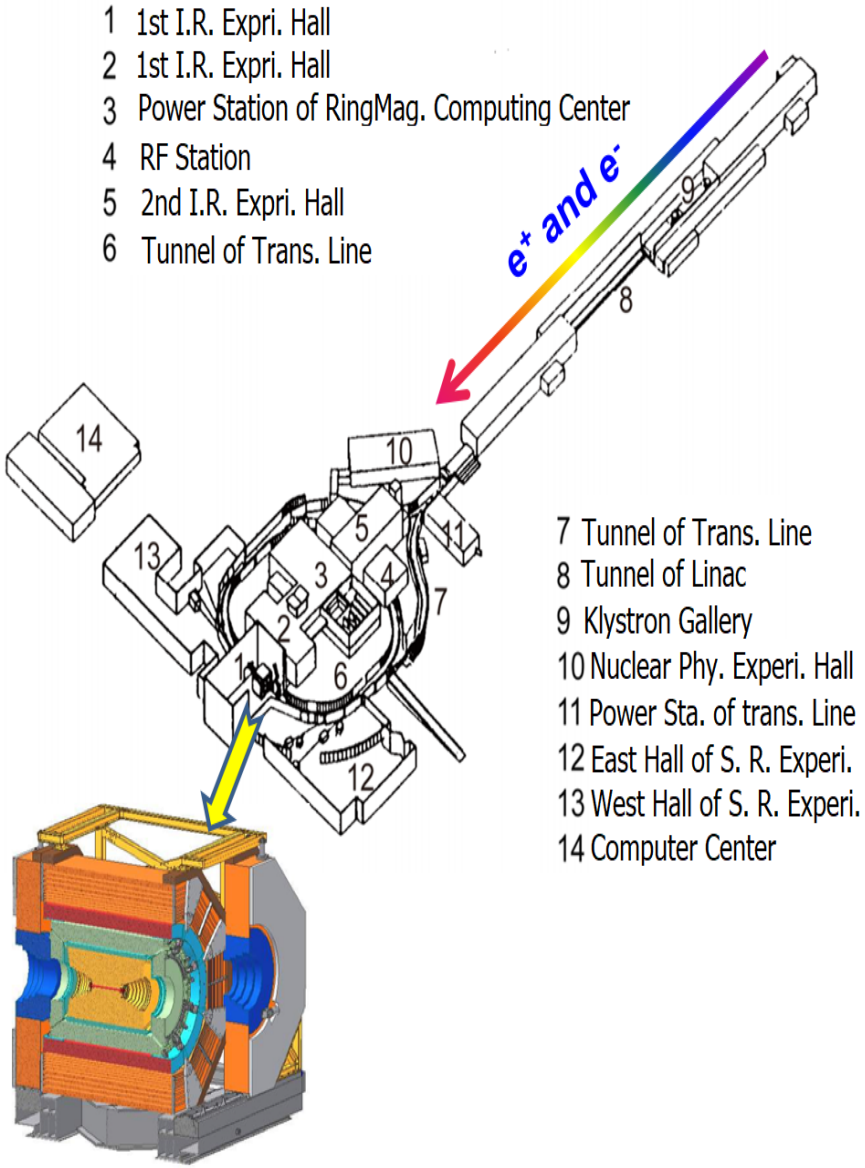


$\phi(2170)$ DECAY MODES

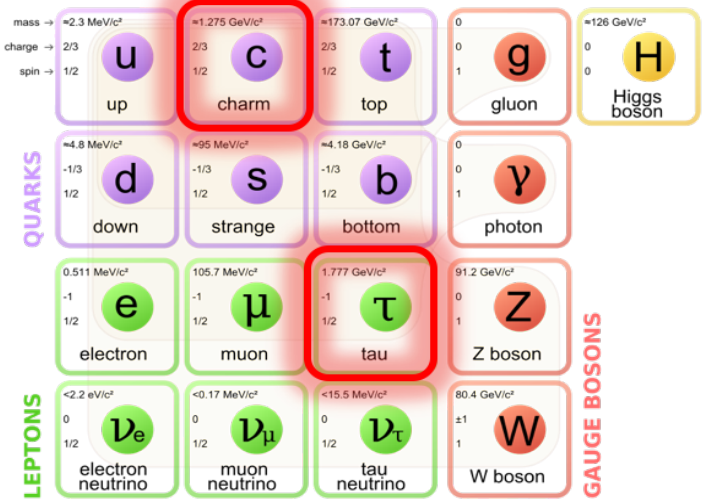
	Mode	Fraction (Γ_i/Γ)
Γ_1	e^+e^-	seen
Γ_2	$\phi\eta$	
Γ_3	$\phi\pi\pi$	
Γ_4	$\phi f_0(980)$	seen
Γ_5	$K^+K^-\pi^+\pi^-$	
Γ_6	$K^+K^-f_0(980) \to K^+K^-\pi^+\pi^-$	seen
Γ_7	$K^+K^-\pi^0\pi^0$	
Γ_8	$K^+K^-f_0(980) \to K^+K^-\pi^0\pi^0$	seen
Γ_9	$K^{*0}K^{\pm}\pi^{\mp}$	not seen
Γ_{10}	$K^*(892)^0\overline{K}^*(892)^0$	not seen

- $KK\pi\pi$: benchmark process
  - K^*K^*: $s\bar{s}g$ (forbidden), 3^3S_1 (favored);
  - $KK_1(1400)$: $s\bar{s}g$ (favored);
  - $KK(1460)$: $s\bar{s}g$ (suppressed), 2^3D_1 (favored);
- $\phi\eta$: 2^3D_1 (suppressed), $s\bar{s}s\bar{s}$ (favored).
- $\eta h_1(1380)$: $s\bar{s}g$ (suppressed).
- K^+K^-: $s\bar{s}g$ (suppressed).

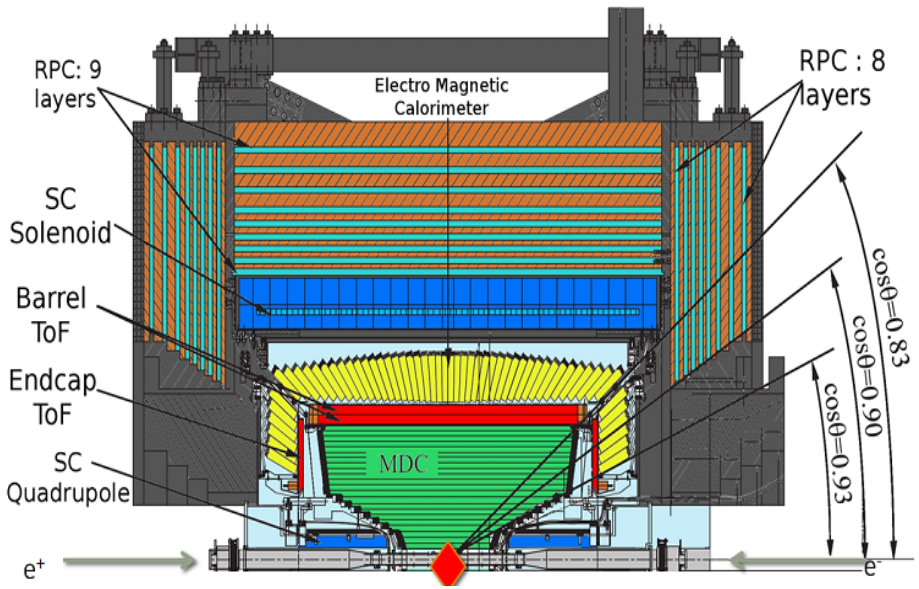
Beijing Electron Positron Collider II



- E_{beam}: 1.00-2.48 GeV;
- Double storage ring: e^+ and e^-;
- No. of bunches: 93;
- Luminosity: 1.0×10^{33} cm^{-2}s^{-1} @3770MeV

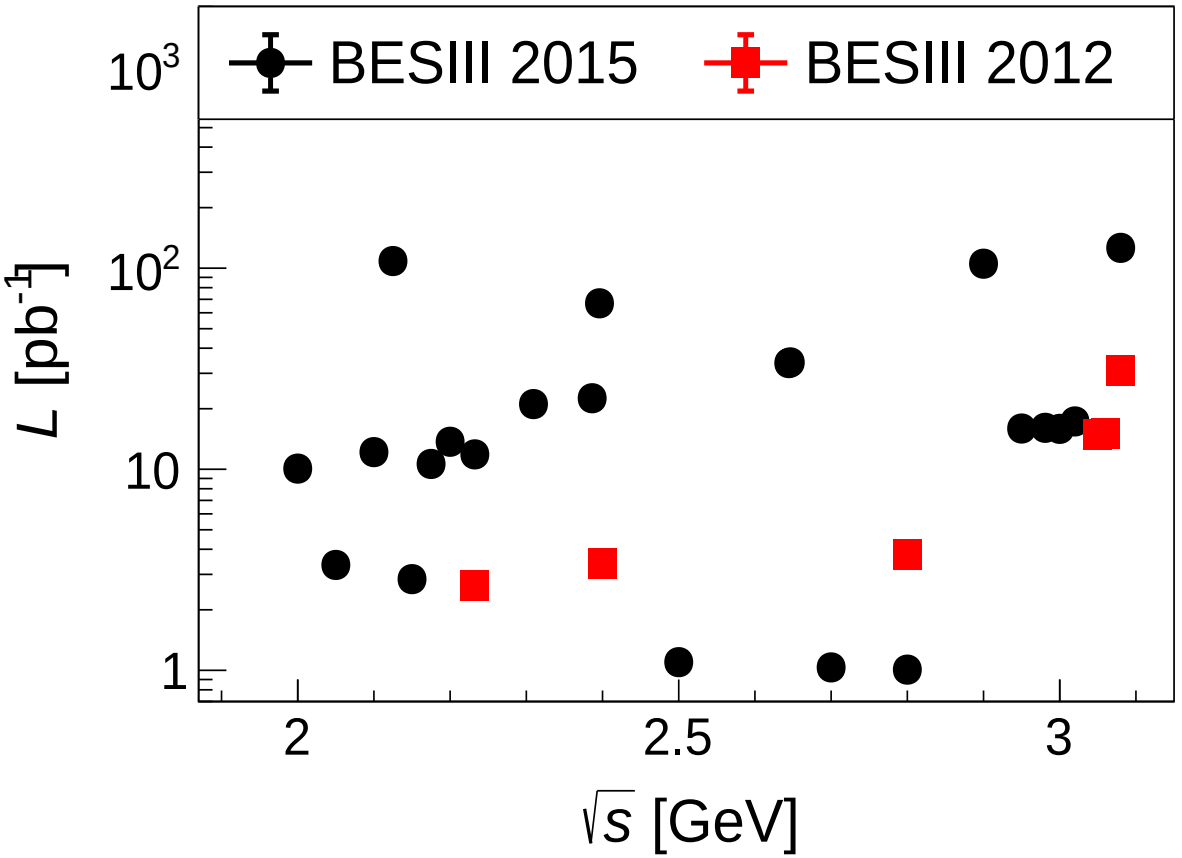


BEijing Spectrometer III



- Main Drift Chamber (MDC): (He/C_3H_8=60/40)
  - σ_{xy}≈130 μm, dE/dx ∼6%;
  - σ_p/p≈0.5% at 1 GeV.
- Time Of Flight (TOF): (Barrel: plastic scintillator, endcap: MRPC)
  - σ_{time}(barrel)≈80 ps,
  - σ_{time}(endcap)≈65 ps.
- ElectroMagnetic Calorimeter (EMC): (CsI(Tl))
  - σ_E/E(barrel)≈2.5% at 1 GeV,
  - σ_E/E(endcap)≈5% at 1 GeV.
- Superconducting Magnet: B =1 T.
- Muon Counter: Resistive Plate Chambers (RPC):
  - barrel: 9 layers;
  - endcap: 8 layers.
  - $\sigma_{spatial}$=2 cm.

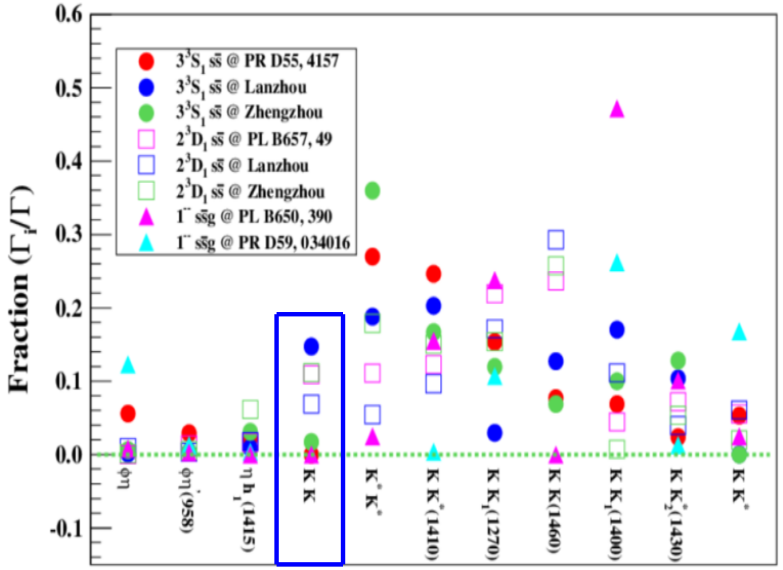
Data used in this talk



- 650 pb^{-1} in 2.00-3.08 GeV collected in 2015.

Recent results

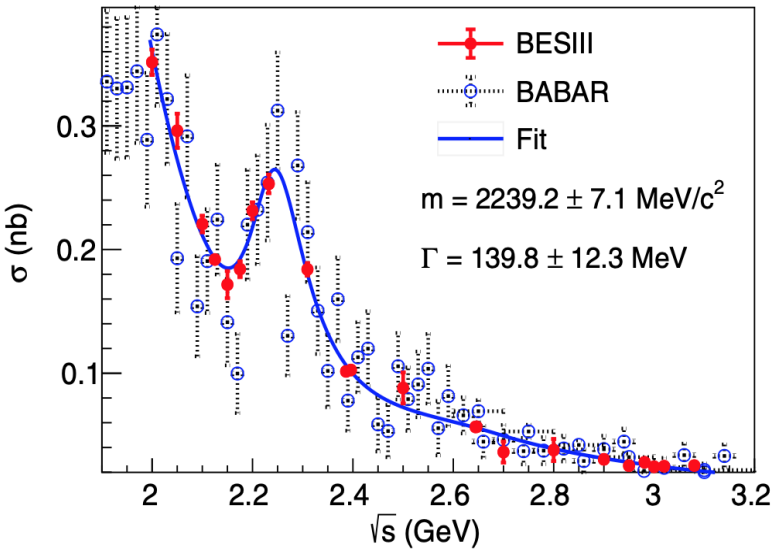
$e^+e^- \to K^+K^-$



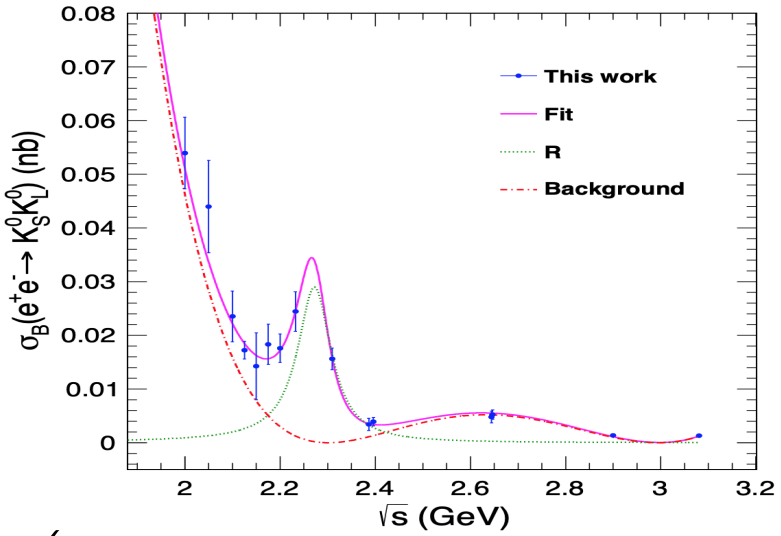
(Y. B. Dong *et al.*, PRD **96**, 074027 (2017))

$\phi(2170)$ decay	This work $^3S_1$ $\Lambda\bar{\Lambda}$	$^3P_0$ with $s\bar{s}$	Data
KK	$73.8 - 87.7$	...	...
$\phi f_0(980)$	$0.25 - 0.3$	< 10	Seen
$\omega\sigma$	$4.2 - 4.9$	...	...
$K*K_0^*(800)$	$1.8 - 2.1$	...	...
Total	$80.1 - 95$		83 ± 12

- K^+K^- at $\phi(2170)$:
  - Controversial in theory;
  - isoscalar: ω^*/ϕ^*;
  - isovector: ρ^*.
- $\sigma^{\text{Born}}_{K^+K^-}(s)$ at $2.00 - 3.08$ GeV (M. Ablikim *et al.* (BESIII collaboration), PRD **99**, 032001 (2019)).
  - $m_{\phi(2170)} = (2239.2 \pm 7.1)$ MeV/c^2;
  - $\Gamma = (139.8 \pm 12.3)$ MeV.

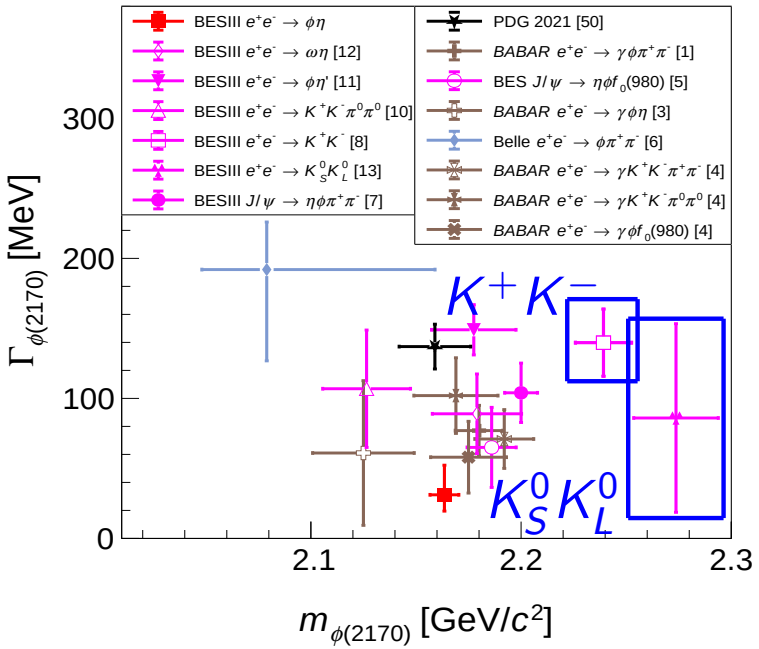


$e^+e^- \to K^0_SK^0_L$



(M. Ablikim *et al.* (BESIII collaboration), arXiv:2105.13597)

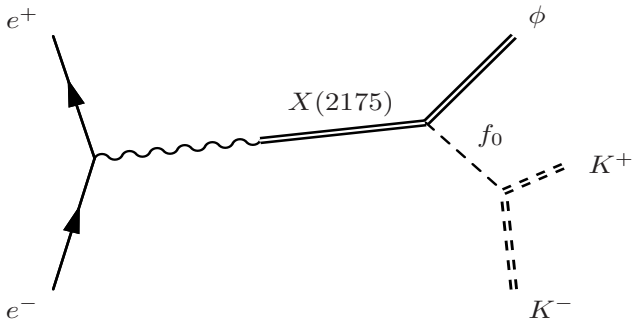
- $\sigma^{\rm Born}_{K^0_SK^0_L}(s)$ at $2.00-3.08$ GeV:
  - $m_{\phi(2170)} = (2273.7 \pm 5.7 \pm 19.3)$ MeV/c^2;
  - $\Gamma = (86 \pm 44 \pm 51)$ MeV;
  - $\mathcal{B}^{\phi(2170)}_{K^0_SK^0_L}\Gamma^{\phi(2170)}_{e^+e^-} = (0.9 \pm 0.6 \pm 0.7)$ eV.
- Discrepancy: mass higher, width much larger than $\phi(2170)$.



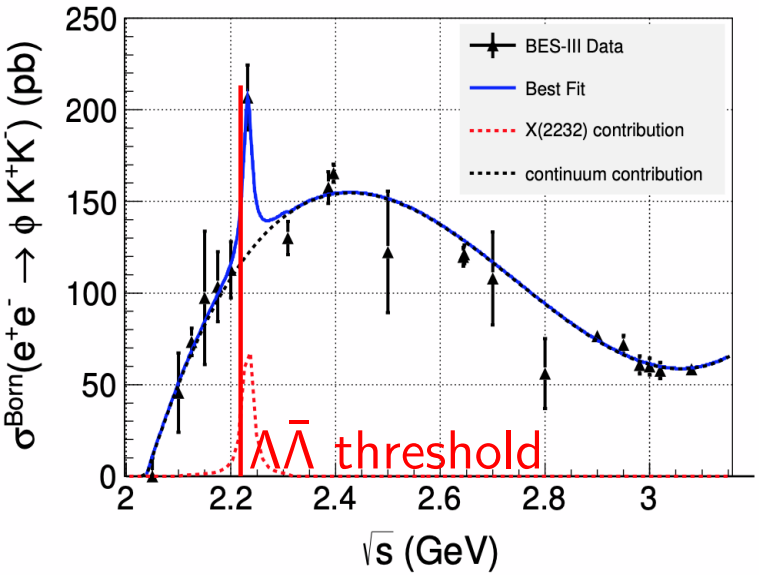
- $K^0_SK^0_L$ at $\phi(2170)$:
  - Controversial in theory;
  - isoscalar: ω^*/ϕ^*;
  - isovector: ρ^*.
- Resonance also exist in $\pi^+\pi^-$ process, maybe $\rho(2150)$, $\phi(2170)$, or mixture?

$e^+e^- \to \phi K^+K^-$ and $K^+K^-K^+K^-$

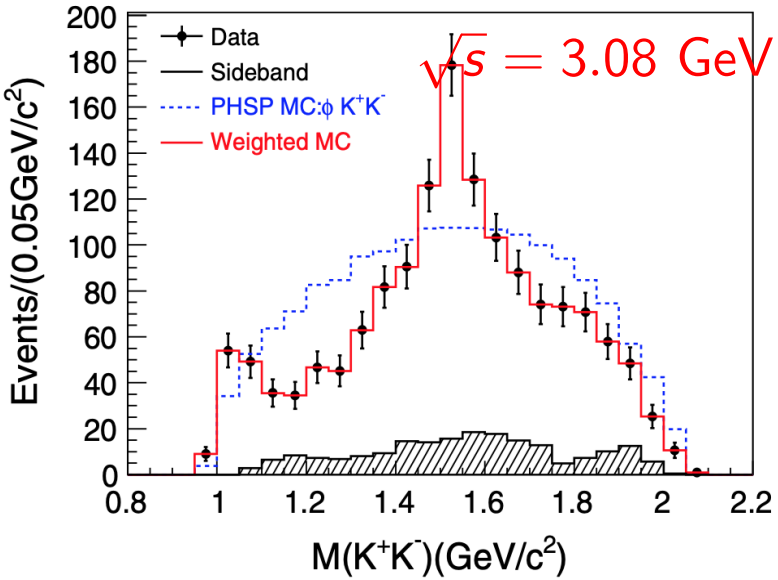
- $\phi(2170)$: resonant of ϕK^+K^-.



(S. Gómez-Avila *et al.*, PRD **79**, 034018 (2009)).

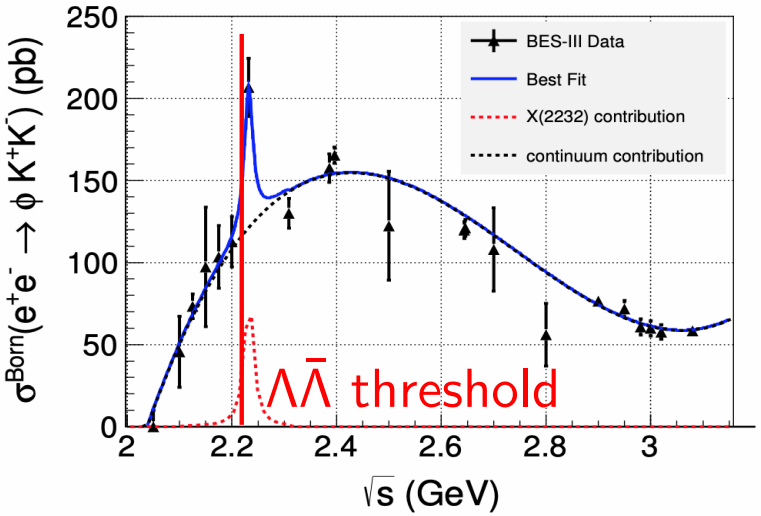


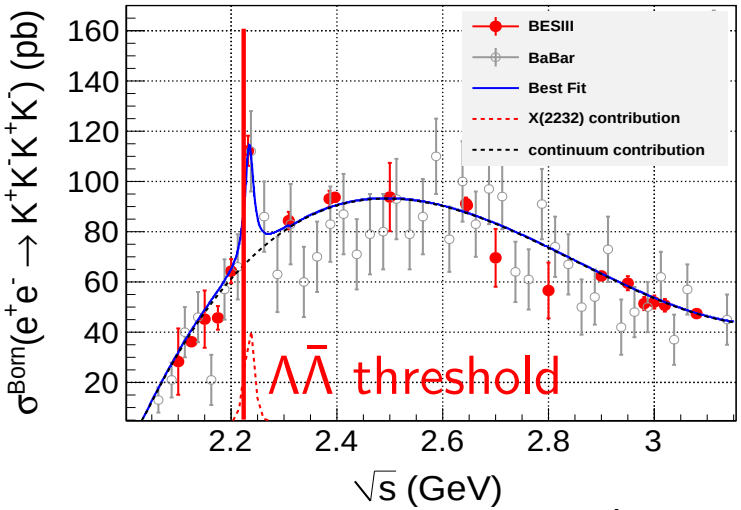
(M. Ablikim *et al.* (BESIII collaboration), PRD **100**, 022009 (2019))



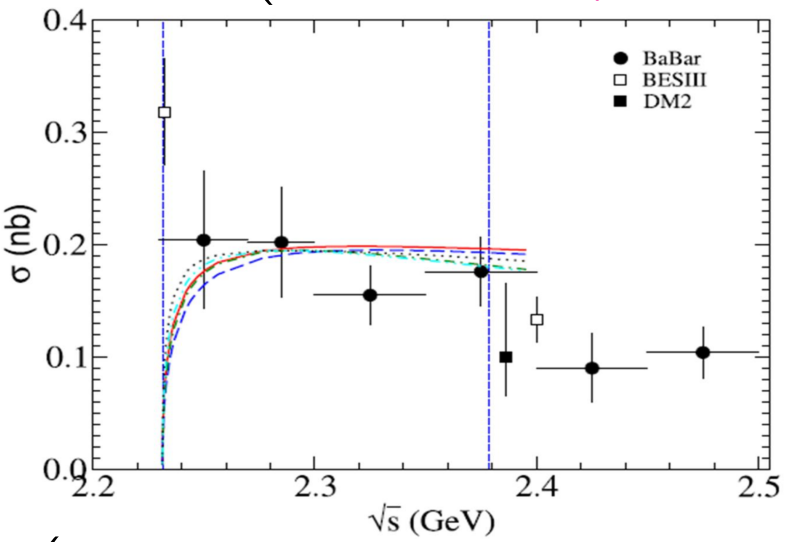
- A hint for a resonance around $\Lambda\bar{\Lambda}$ threshold:
  - $m_{\phi(2170)} = (2232.0 \pm 3.5\ \mathrm{MeV}/c^2)$;
  - $\Gamma < 20$ MeV.
- Three-body system $\phi K + K^-$?

$e^+e^- \to \phi K^+K^-$ and $K^+K^-K^+K^-$





(M. Ablikim *et al.* (BESIII collaboration), PRD **100**, 022009 (2019))

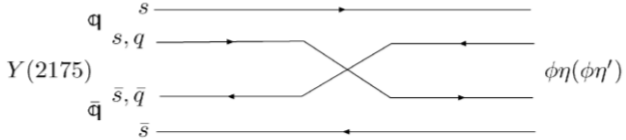


(M. Ablikim *et al.* (BESIII collaboration), PRD **97**, 032013 (2018))

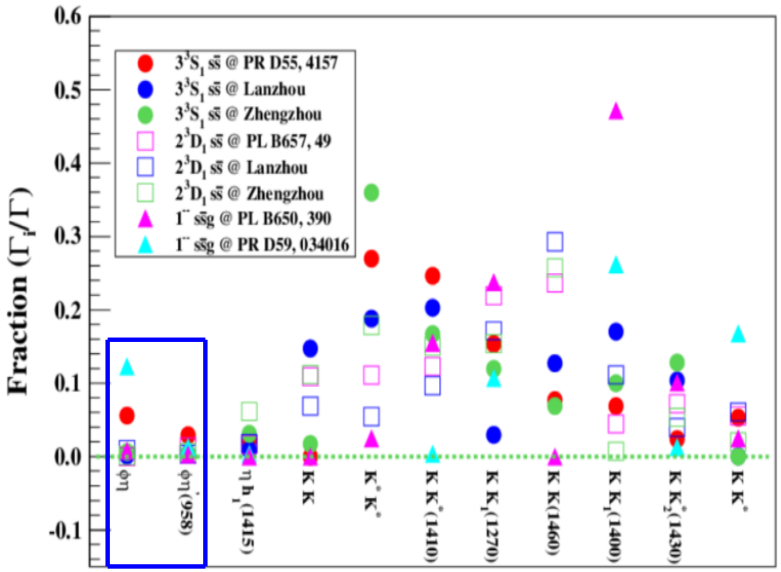
- Both ϕK^+K^- and $K^+K^-K^+K^-$ show similar enhancement around 2.2324 GeV;
- $\Lambda\bar{\Lambda}$ threshold effect?
- Any other explanations?

$e^+e^- \to \phi\eta$ and $\phi\eta'$

- $\phi\eta/\phi\eta'$ modes: isoscalar.
  - ϕ^* or ω^* (OZI suppressed);
  - Parameter info helpful.
- Tetraquark favors $\phi\eta$ and $\phi\eta'$.



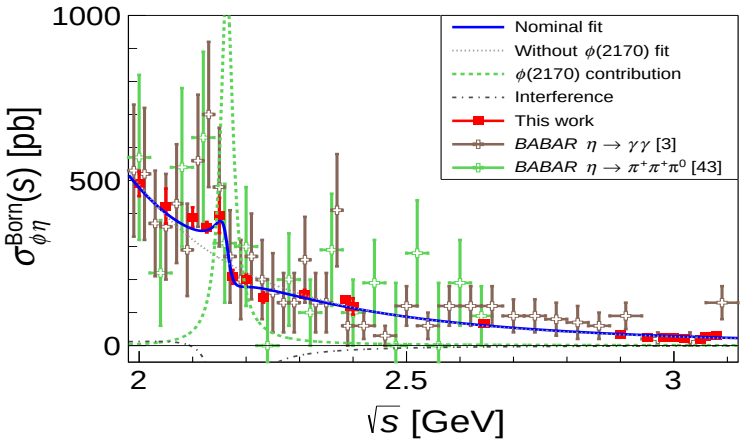
(N. V. Drenska *et al.*, PLB **669**, 160 (2008)).



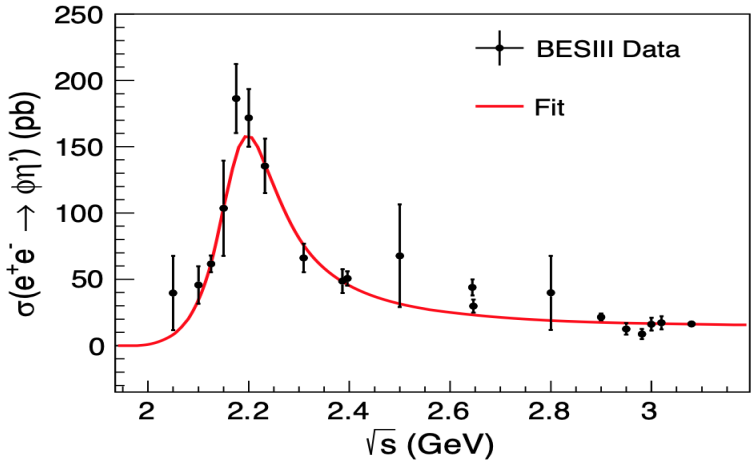
- 1^{--} $s\bar{s}g$ hybrid has large $\Gamma_{\phi\eta}$ and smaller $\Gamma_{\phi\eta'}$.

1^{--} $s\bar{s}g$	alt	2.2 GeV	standard	IKP	Ding
	A. M. Torres *et al.*, PRD **59**, 034016 (1999)				G. J. Ding *et al.*, PLB **650**, 390 (2007)
$\phi\eta$	2	19	11	3	1.2
$\phi\eta'$	0.01	2	0.1	0.02	0.4
$\frac{\mathcal{B}^{\phi(2170)}_{\phi\eta}\Gamma^{\phi(2170)}_{e^+e^-}}{\mathcal{B}^{\phi(2170)}_{\phi\eta'}\Gamma^{\phi(2170)}_{e^+e^-}}$	200	9.5	110	150	3

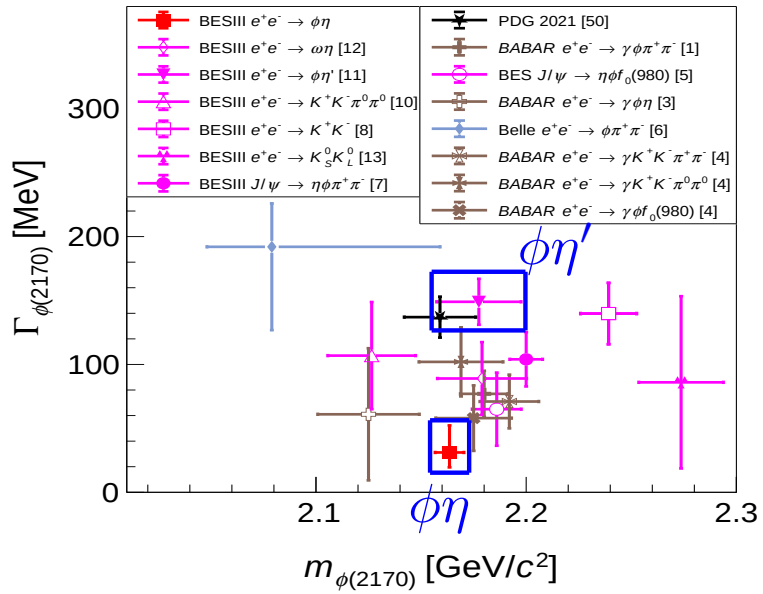
$e^+e^- \to \phi\eta$ and $\phi\eta'$



(M. Ablikim *et al.* (BESIII collaboration), arXiv:2104.05549)



(M. Ablikim *et al.* (BESIII collaboration), PRD **102**, 012008 (2020))



- $\phi(2170)$ at $\phi\eta$
  - $m_{\phi(2170)} = (2163.5 \pm 6.2 \pm 3.0)$ MeV/c^2;
  - $\Gamma = (31.1^{+21.1}_{-11.6} \pm 1.1)$ MeV.
- $\phi(2170)$ at $\phi\eta'$
  - $m_{\phi(2170)} = (2177.5 \pm 4.8 \pm 19.5)$ MeV/c^2;
  - $\Gamma = (149.0 \pm 15.6 \pm 8.9)$ MeV.

$e^+e^- \to \phi\eta$ and $\phi\eta'$

- $e^+e^- \to \phi\eta$ and $\phi\eta'$
  - $\mathcal{B}^{\phi(2170)}_{\phi\eta}\Gamma^{\phi(2170)}_{e^+e^-} = (0.24^{+0.12}_{-0.07})$ eV or $(10.11^{+3.87}_{-3.13})$ eV;
  - $\mathcal{B}^{\phi(2170)}_{\phi\eta'}\Gamma^{\phi(2170)}_{e^+e^-} = (7.1 \pm 0.7)$ eV;

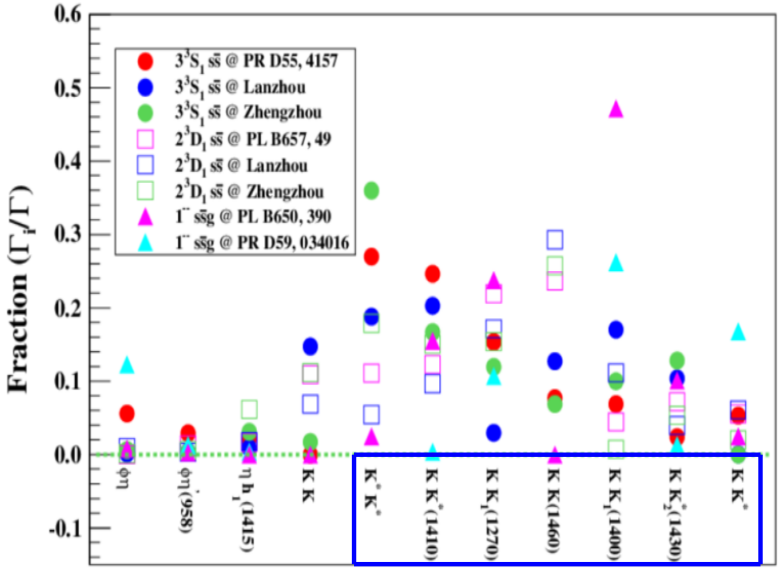
$$\frac{\mathcal{B}^{\phi(2170)}_{\phi\eta}\Gamma^{\phi(2170)}_{e^+e^-}}{\mathcal{B}^{\phi(2170)}_{\phi\eta'}\Gamma^{\phi(2170)}_{e^+e^-}} = (0.03^{+0.02}_{-0.01}) \text{ or } (1.42^{+0.56}_{-0.46}).$$

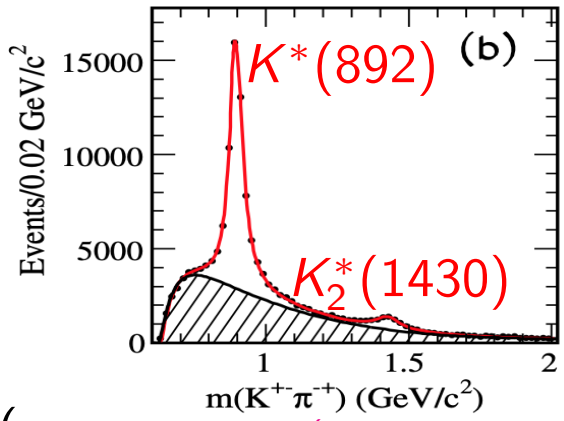
- If we observed $\phi(2170)$ in $e^+e^- \to \phi\eta'$, $\phi(2170)$ as an 1^{--} $s\bar{s}g$?

1^{--} $s\bar{s}g$	alt	2.2 GeV	standard	IKP	Ding
	A. M. Torres *et al.*, PRD **59**, 034016 (1999)				G. J. Ding *et al.*, PLB **650**, 390 (2007)
$\phi\eta$	2	19	11	3	1.2
$\phi\eta'$	0.01	2	0.1	0.02	0.4
$\frac{\mathcal{B}^{\phi(2170)}_{\phi\eta}\Gamma^{\phi(2170)}_{e^+e^-}}{\mathcal{B}^{\phi(2170)}_{\phi\eta'}\Gamma^{\phi(2170)}_{e^+e^-}}$	200	9.5	110	150	3

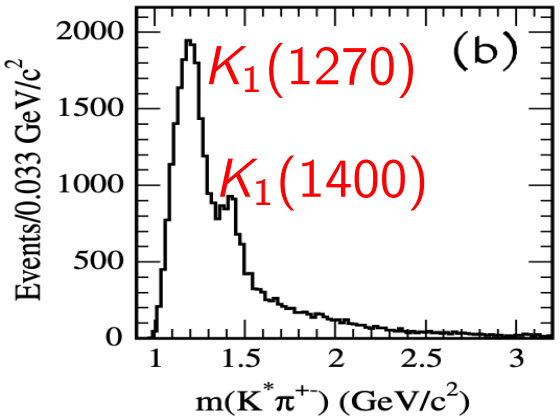
$e^+e^- \to KK\pi\pi$

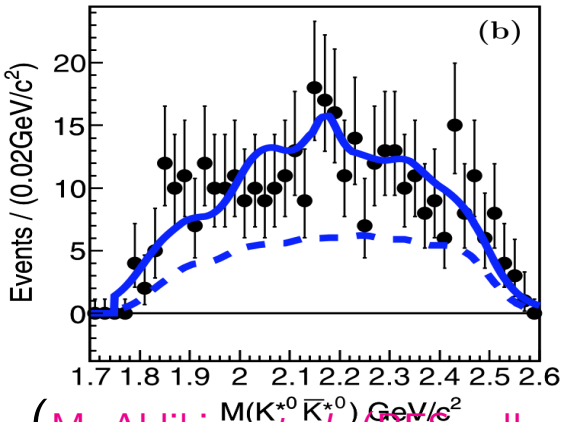
- $e^+e^- \to KK\pi\pi$ paramount to distinguish $\phi(2170)$ theory models:
  - K^*K^*: $s\bar{s}g$ (unfavored), 3^3S_1 (favored);
  - $KK_1(1400)$: $s\bar{s}g$ (favored);
  - $KK(1460)$: $s\bar{s}g$ (unfavored), 2^3D_1 (favored).
- *BABAR*: $K^*(892)$, $K_2^*(1430)$, $K_1^*(1270)$ and $K_1(1400)$.
- $J/\psi \to \eta\phi(2170) \to \eta K^*K^*$.
  - BES: 58 M J/ψ, an upper limit of $\mathcal{B}(J/\psi \to \eta\phi(2170))$.





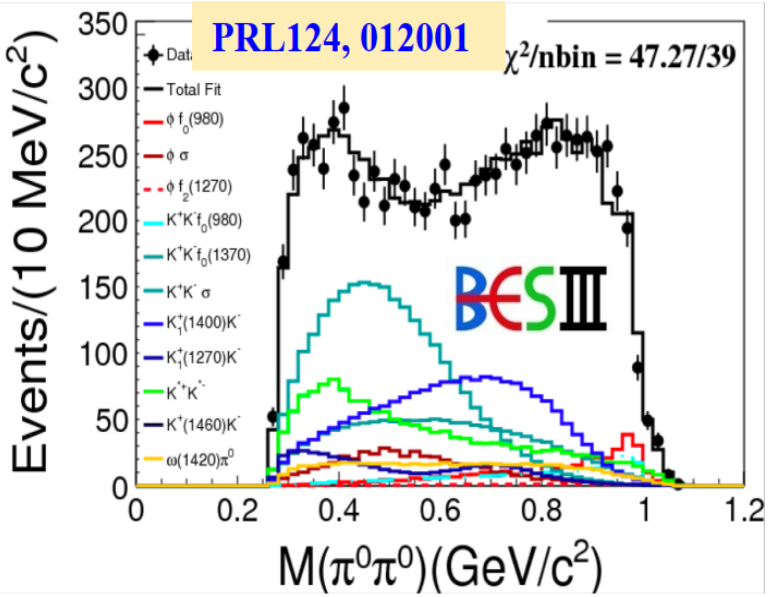
(B. Aubert *et al.* (*BABAR* collaboration), PRD **86**, 012008 (2012))

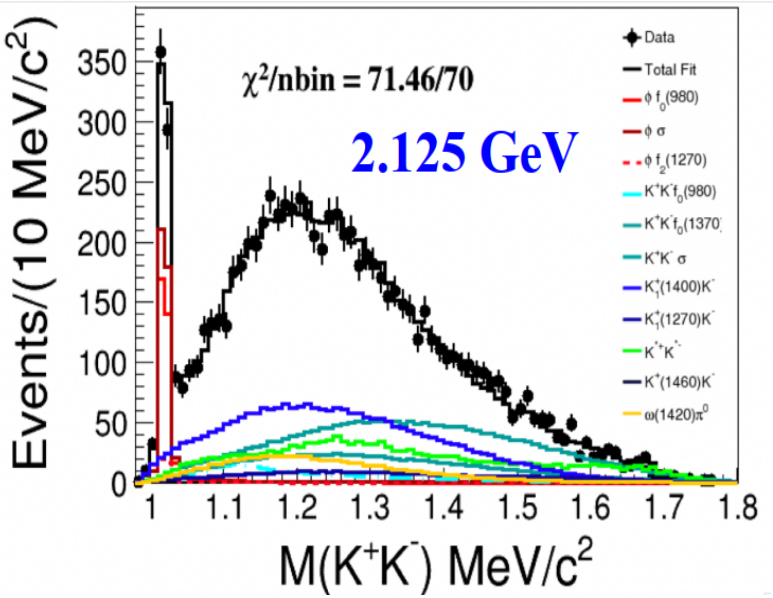




(M. Ablikim *et al.* (BES collaboration), PLB **685**, 27 (2010))

$e^+e^- \to K^+K^-\pi^0\pi^0$



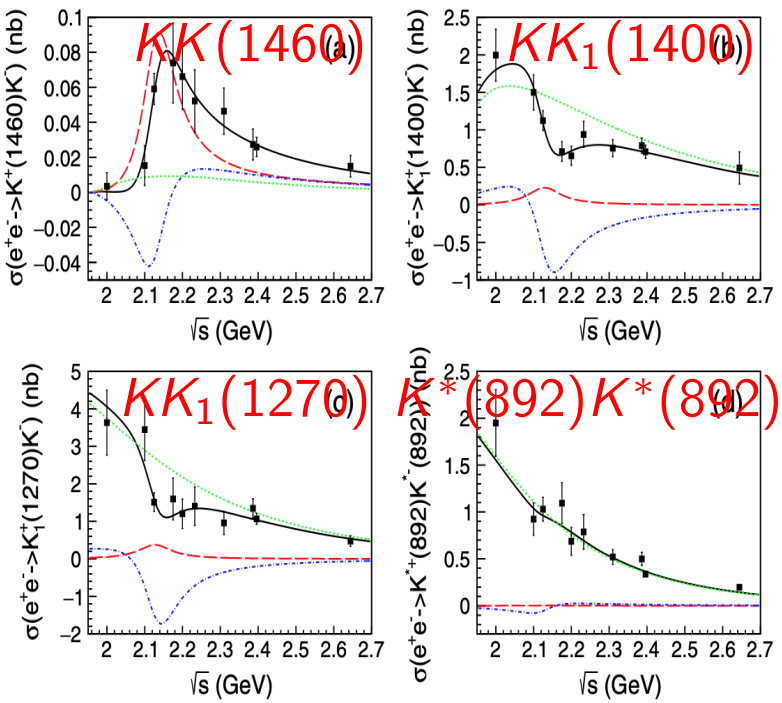


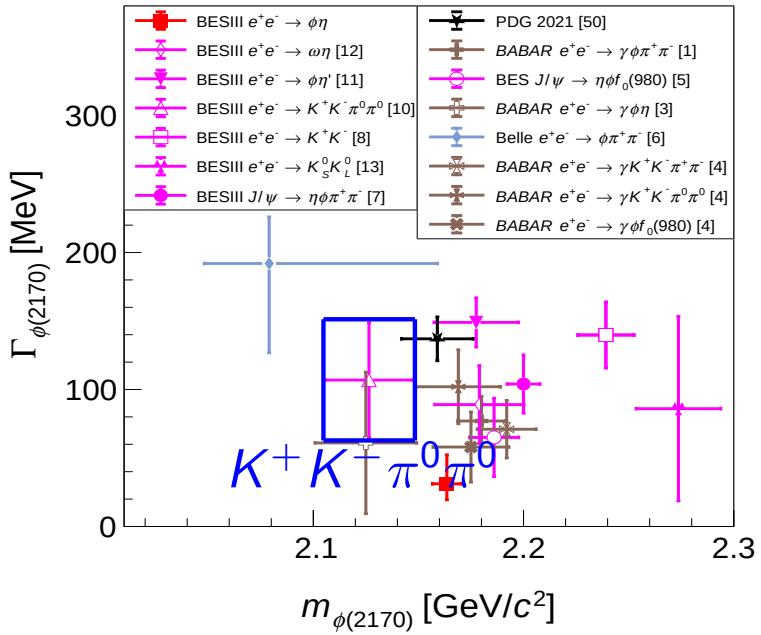
(M. Ablikim *et al.* (BESIII collaboration), PRL **124**, 012001 (2020))

process	significance at 2.125 GeV	significance at 2.396 GeV
$\phi f_0(980)$	$> 8.0\ \sigma$	$> 8.0\ \sigma$
$\phi\sigma$	$> 8.0\ \sigma$	...
$\phi f_2(1270)$	$5.0\ \sigma$	...
$\phi f_0(1370)$	...	$6.9\ \sigma$
$K^{*+}(892)K^{*-}(892)$	$> 8.0\ \sigma$	$> 8.0\ \sigma$
$K^+(1460)K^-$	$> 8.0\ \sigma$	$6.4\ \sigma$
$K_0^{*+}(1430)K^{*-}(892)$	$> 8.0\ \sigma$	$7.5\ \sigma$
$K_2^{*+}(1430)K^{*-}(892)$	...	$6.4\ \sigma$
$K_1^+(1400)K^-$	$> 8.0\ \sigma$	$> 8.0\ \sigma$
$K_1^+(1270)K^-$	$> 8.0\ \sigma$	$> 8.0\ \sigma$
$K^{*+}(892)K^-\pi^0$	...	$5.4\ \sigma$
$K^+K^-f_0(980)$	$6.2\ \sigma$	$> 8.0\ \sigma$
$K^+K^-\sigma$	$> 8.0\ \sigma$	$> 8.0\ \sigma$
$K^+K^-f_0(1370)$	$> 8.0\ \sigma$	$7.4\ \sigma$
$\omega(1420)\pi^0$	$> 8.0\ \sigma$	$5.2\ \sigma$

- Partial Wave Analysis at multiple energies in $2.000 - 2.644$ GeV.
- No significant signal observed for $e^+e^- \to KK^*(1410)$.
- Born cross section measured for intermediate states as well.

$e^+e^- \to K^+K^-\pi^0\pi^0$



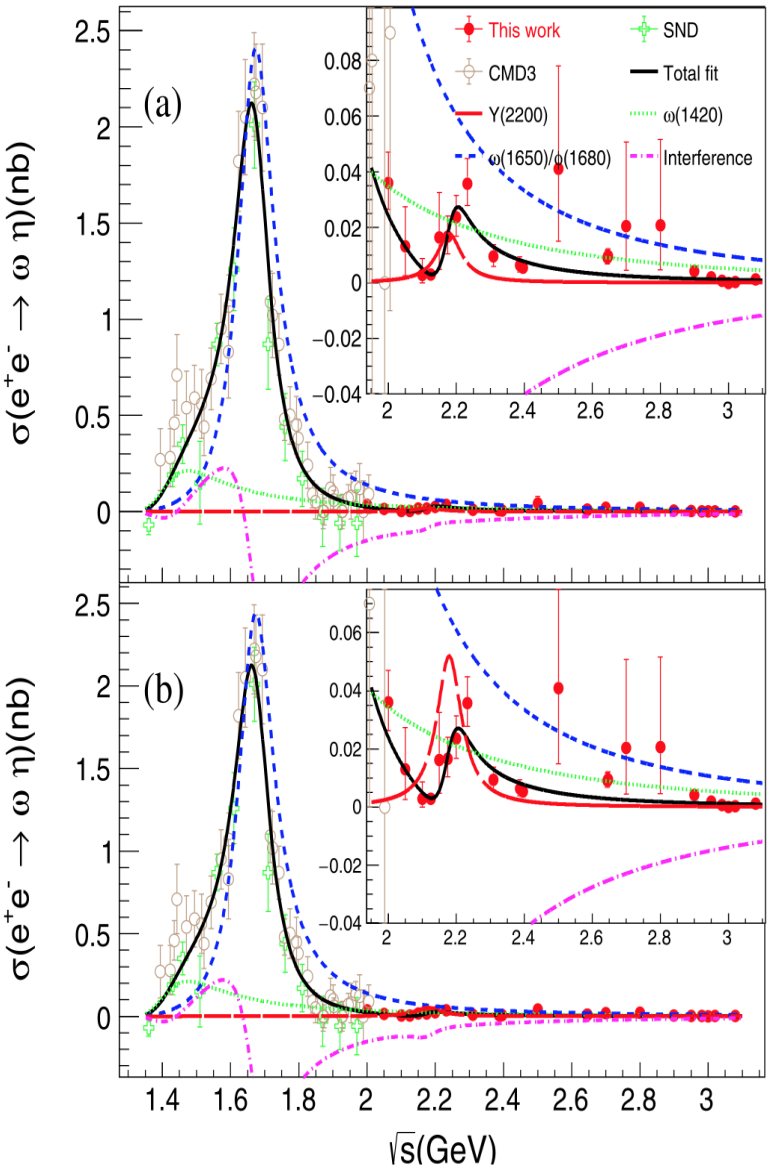


- Dots: BESIII data;
- Black curves: fit results;
- Red long-dashed: $\phi(2170)$;
- Green shot-dashed: $1/s^n$;
- Blue dash-dotted: interference.

Channel	$e^+e^- \to K_1^+(1400)K^-$		$e^+e^- \to K^+(1460)K^-$	$e^+e^- \to K_1^+(1270)K^-$		$e^+e^- \to K^{*+}K^{*-}$
Mass [MeV/c^2]	2126.5 ± 16.8					
Width [MeV]	106.9 ± 32.1					
	Solution I	Solution II		Solution I	Solution II	
$\mathcal{B}_R\Gamma^{e^+e^-}$	7.6 ± 3.7	152.6 ± 14.2	1.0 ± 1.3	4.7 ± 3.3	98.8 ± 7.8	0.04 ± 0.2
Φ [rad]	3.7 ± 0.4	4.5 ± 0.3	5.6 ± 1.5	4.0 ± 0.2	4.5 ± 0.1	5.8 ± 1.9
Significance [σ]	4.8		4.5	1.4		1.2

- $\phi(2170) \to KK_1(1400)$ and $KK(1460)$: Yes!.

$e^+e^- \to \omega\eta$



(M. Ablikim *et al.* (BESIII collaboration), PLB **813**, 136059 (2021))

- The η has $s\bar{s}$ component:
  - Isospin zero: ω^* and ϕ^*;
  - $\phi(2170) \to \omega\eta$: Yes!

Parameter	Solution I	Solution II
$m_{Y(2180)}$ [MeV/c^2]	2179 ± 21 MeV/c^2	
$\Gamma_{Y(2180)}$ [MeV]	89 ± 28	
$\mathcal{B}^{Y(2180)}_{\omega\eta}\Gamma^{Y(2180)}_{e^+e^-}$ [eV]	0.50 ± 0.16	1.50 ± 0.44
$\Phi_{Y(2180)}$	2.7 ± 0.3	1.9 ± 0.2
Significance [σ]	6.1	

PDG	Mass [MeV/c^2]	Width [MeV]
$\omega(2205)$	2205 ± 30	350 ± 90
$\omega(2290)$	2290 ± 20	375 ± 35
$\omega(2330)$	2330 ± 30	435 ± 75

Summary

Summary of $\mathcal{B}^R\Gamma^R_{e^+e^-}$

Decay modes	Experimental Results
K^+K^-	...
$K^0_SK^0_L$	$0.9 \pm 0.6 \pm 0.7$
ϕK^+K^-	...
$\phi\eta$	$0.24^{+0.12}_{-0.07}/10.11^{+3.87}_{-3.13}$
$\phi\eta'$	7.1 ± 0.7
$K^*(892)K^*(892)$	0.04 ± 0.2
$KK(1460)$	1.0 ± 1.3
$KK^*(1410)$	...
$KK_1(1270)$	$4.7 \pm 3.3/98.8 \pm 7.8$
$KK_1(1400)$	$7.6 \pm 3.4/152.6 \pm 14.2$
$KK^*_2(1430)$	...
$\omega\eta$	$0.50 \pm 0.16/1.9 \pm 0.2$

$\phi(2170)$ as pure $3^3S_1s\bar{s}$?

Decay modes	$3^3S_1s\bar{s}$	
	$^3P_0$ model	Lanzhou
$\phi\eta$	21	0.3
$\phi\eta'$	11	0.8
KK	0	35.8
$K^*(892)K^*(892)$	102	45.7
$KK(1460)$	29	30.9
$KK^*(1410)$	93	49.3
$KK_1(1270)$	58	7.1
$KK_1(1400)$	26	41.4
$KK_2^*(1430)$	9.0	25.2

- Reduction to Absurdity:
  - $3^3S_1s\bar{s}$: $\Gamma_{K^*(892)K^*(892)} > \Gamma_{KK_1(1400)}$;
  - Exp. $\phi(2170)$ at $KK_1(1400)$;
  - Exp. no $\phi(2170)$ at $K^*(892)K^*(892)$;
  - Exp. similar $\epsilon_{\rm eff}$;
- Similar check for several modes:
  - $KK^*(1410)$: No $\phi(2170)$;
  - $KK(1460)$: Yes $\phi(2170)$;
- $\phi(2170)$ as pure $3^3S_1s\bar{s}$: No.

- No $\phi(2170)$ at $K^*(892)K^*(892)$ and $KK^*(1410)$.
- Yes $\phi(2170)$ at $KK(1460)$ and $KK_1(1400)$.

$\phi(2170)$ as pure $2^3D_1s\bar{s}$?

Decay modes	$2^3D_1s\bar{s}$			$\phi(2170)$
	$^3P_0$ model	Flux tube	Lanzhou	BESIII
$\phi\eta$	0	0	5.7	Yes
$\phi\eta'$	2.9	2.8	1.8	Yes
KK	9.8	23.1	40.8	No
$K^*(892)K^*(892)$	18.11	23.5	32.2	No
$KK(1460)$	58.3	50.2	173.5	Yes
$KK^*(1410)$	31.9	26.0	57.3	No
$KK_1(1270)$	21.9	46.4	101.5	?
$KK_1(1400)$	8.6	9.4	65.9	Yes
$KK_2^*(1430)$	10.8	15.3	23.3	Not yet

- No $\phi(2170)$ at KK, $K^*(892)K^*(892)$ and $KK_1(1270)$.
- Yes $\phi(2170)$ at $KK_1(1400)$.

$\phi(2170)$ as pure $1^{--}s\bar{s}$?

Decay modes	$1^{--}s\bar{s}$				$\phi(2170)$
	Ding	IKP	standard	2.2 GeV	BESIII
$\phi\eta$	1.2	3	11	19	Yes
$\phi\eta'$	0.4	0.02	0.1	2	Yes
KK	0				No
$K^*(892)K^*(892)$	0				No
$KK(1460)$	0				Yes
$KK^*(1410)$	23	9	11	55	No
$KK_1(1270)$	35.3	26	18.1	16.6	?
$KK_1(1400)$	70.1	63.7	32.04	40.6	Yes
$KK_2^*(1430)$	15.0	2	0.07	2	Not yet

- No $\phi(2170)$ at $KK^*(1410)$.
- Yes $\phi(2170)$ at $KK(1460)$.
- Small $\frac{\mathcal{B}^{\phi(2170)}_{\phi\eta}\Gamma^{\phi(2170)}_{e^+e^-}}{\mathcal{B}^{\phi(2170)}_{\phi\eta'}\Gamma^{\phi(2170)}_{e^+e^-}}$.

Summary

$\phi(2170)$ DECAY MODES

	Mode	Fraction (Γ_i/Γ)
Γ_1	e^+e^-	seen
Γ_2	$\phi\eta$	
Γ_3	$\phi\pi\pi$	
Γ_4	$\phi f_0(980)$	seen
Γ_5	$K^+K^-\pi^+\pi^-$	
Γ_6	$K^+K^-f_0(980) \rightarrow K^+K^-\pi^+\pi^-$	seen
Γ_7	$K^+K^-\pi^0\pi^0$	
Γ_8	$K^+K^-f_0(980) \rightarrow K^+K^-\pi^0\pi^0$	seen
Γ_9	$K^{*0}K^{\pm}\pi^{\mp}$	not seen
Γ_{10}	$K^*(892)^0\overline{K}^*(892)^0$	not seen

$\phi(2170)$ $I^G(J^{PC}) = 0^-(1^{--})$

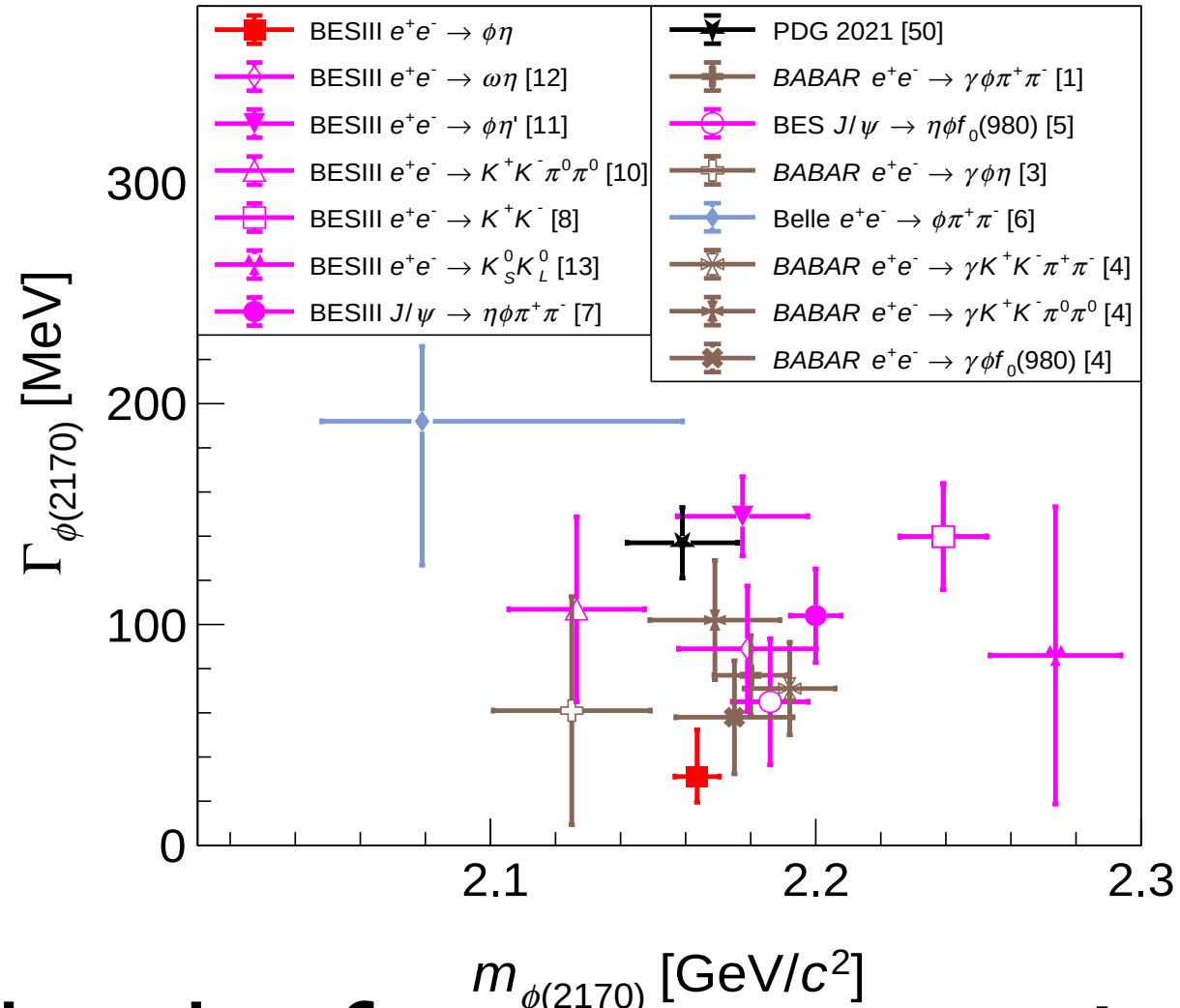
$\phi(2170)$ MASS

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	COMMENT
2159 ±17 OUR AVERAGE		Error includes scale factor of 1.4. See the ideogram below.			
2176 ±24 ± 3		[1] ABLIKIM	21A	BES3	$e^+e^- \rightarrow \omega\eta$
2177.5± 4.8±19.5		[2] ABLIKIM	20M	BES3	$e^+e^- \rightarrow \eta'\phi$
2126.5±16.8±12.4		[3] ABLIKIM	20S	BES3	$e^+e^- \rightarrow K^+K^-\pi^0\pi^0$
• • • We do not use the following data for averages, fits, limits, etc. • • •					
2135 ± 8 ± 9	95	ABLIKIM	19I	BES3	$e^+e^- \rightarrow \eta\phi f_0(980)$
2239.2± 7.1±11.3		[4] ABLIKIM	19L	BES3	$e^+e^- \rightarrow K^+K^-$
2200 ± 6 ± 5	471	ABLIKIM	15H	BES3	$J/\psi \rightarrow \eta\phi\pi^+\pi^-$
2180 ± 8 ± 8		[5,6] LEES	12F	BABR	10.6 $e^+e^- \rightarrow \phi\pi^+\pi^-\gamma$
2079 ±13 $^{+79}_{-28}$	4.8k	[7] SHEN	09	BELL	10.6 $e^+e^- \rightarrow K^+K^-\pi^+\pi^-\gamma$
2186 ±10 ± 6	52	ABLIKIM	08F	BES	$J/\psi \rightarrow \eta\phi f_0(980)$
2125 ±22 ±10	483	AUBERT	08S	BABR	10.6 $e^+e^- \rightarrow \phi\eta\gamma$
2192 ±14	116	[8] AUBERT	07AK	BABR	10.6 $e^+e^- \rightarrow K^+K^-\pi^+\pi^-\gamma$
2169 ±20	149	[8] AUBERT	07AK	BABR	10.6 $e^+e^- \rightarrow K^+K^-\pi^0\pi^0\gamma$
2175 ±10 ±15	201	[6,9] AUBERT,BE	06D	BABR	10.6 $e^+e^- \rightarrow K^+K^-\pi\pi\gamma$

Summary

- Strangenium $s\bar{s}$ is a terra incognita to be explored.
- BESIII provides experimental data on $\phi(2170)$.
- Lots of progress in study $\phi(2170)$ at BESIII:
  - $e^+e^- \to K^+K^-$;
  - $e^+e^- \to \phi K^+K^-$ and $K^+K^-K^+K^-$;
  - $e^+e^- \to \phi\eta$ and $\phi\eta'$;
  - $e^+e^- \to KK\pi\pi$;
  - $e^+e^- \to \omega\eta$.
- May help to resolve the property of $\phi(2170)$:
  - Pure 3^3S_1 $s\bar{s}$?
  - Pure 2^3D_1 $s\bar{s}$?
  - Molecular state $\Lambda\bar{\Lambda}$?
  - Three-body system ϕKK?
  - 1^{--} $s\bar{s}g$ hybrid?
  - Tetraquark?
  - Mixing state?
- Aspects of $\phi(2170)$ are still not fully understood. More studies needed, some ongoing at BESIII.
- Revisits/Inputs from theory are highly desired!

Results in a glance



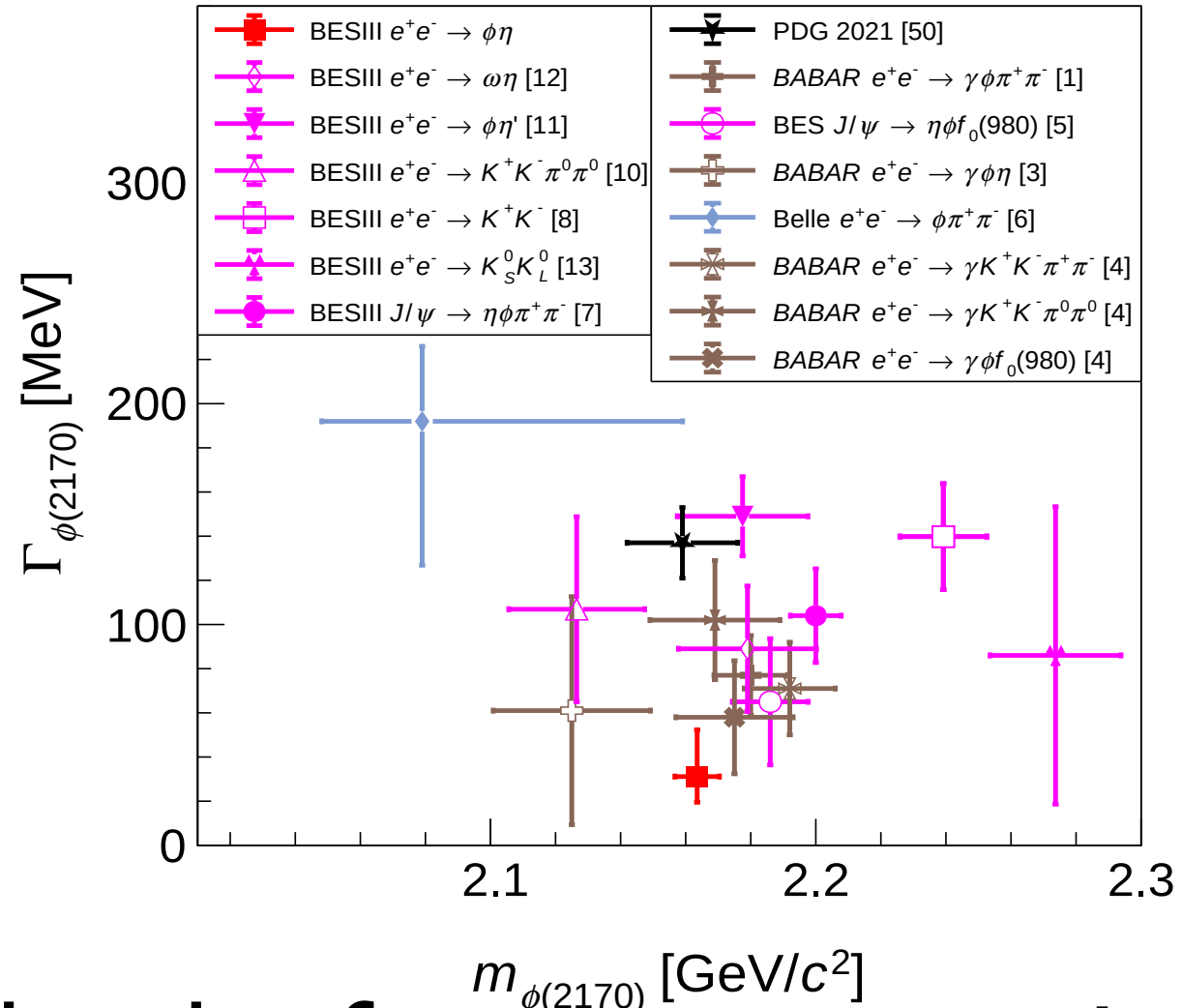
Thanks for your attention!

Great era, best scientists

- We are living in a great era, because this era have the best scientists, Simon Eidelman, Steven Weinberg and Toshihide Maskawa.



Results in a glance



Thanks for your attention!