

# Study of $\phi(2170)$ at BESIII

张亚腾      郑州大学

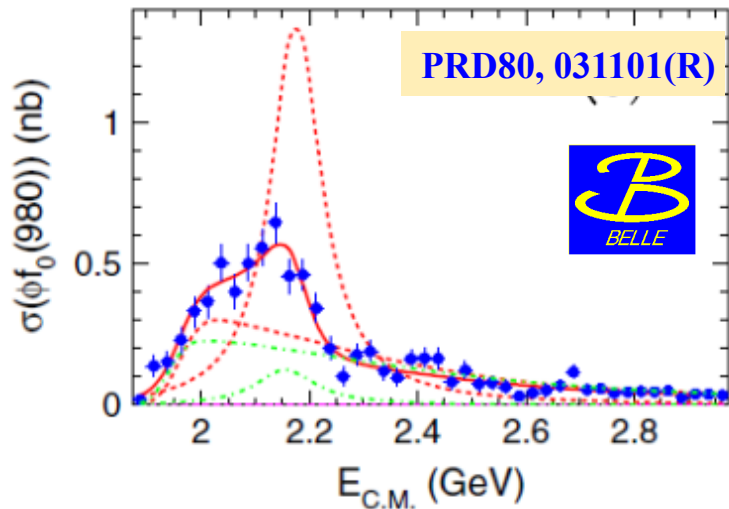
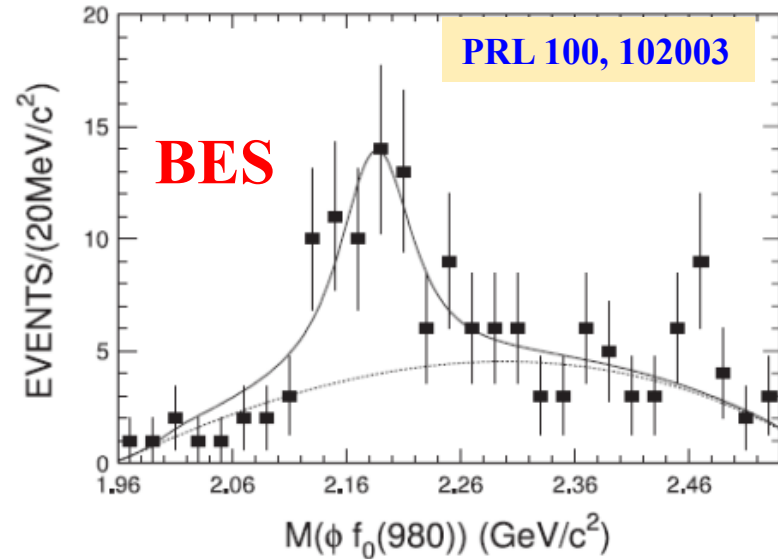
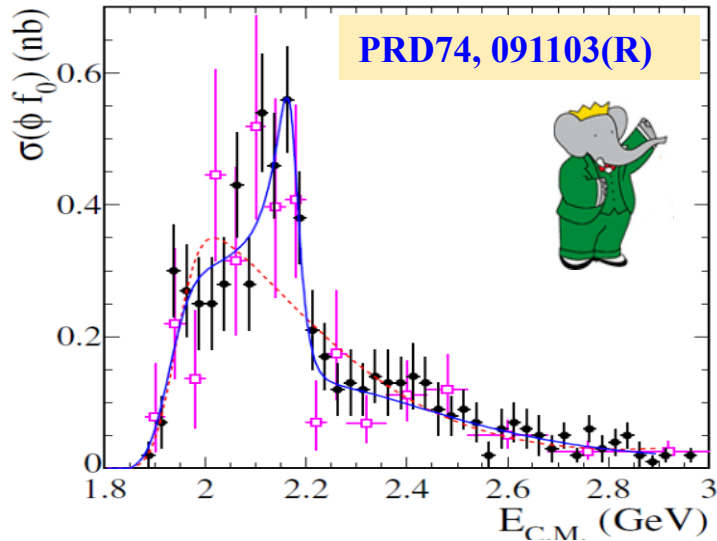
第二届强子与重味物理理论与实验联合研讨会

Lan Zhou, 25-29 March. 2021



BESIII

# $\phi(2170)/Y(2175)$



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

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

# The nature $\phi(2170)$

**PDG**

$\phi(2170)$  DECAY MODES

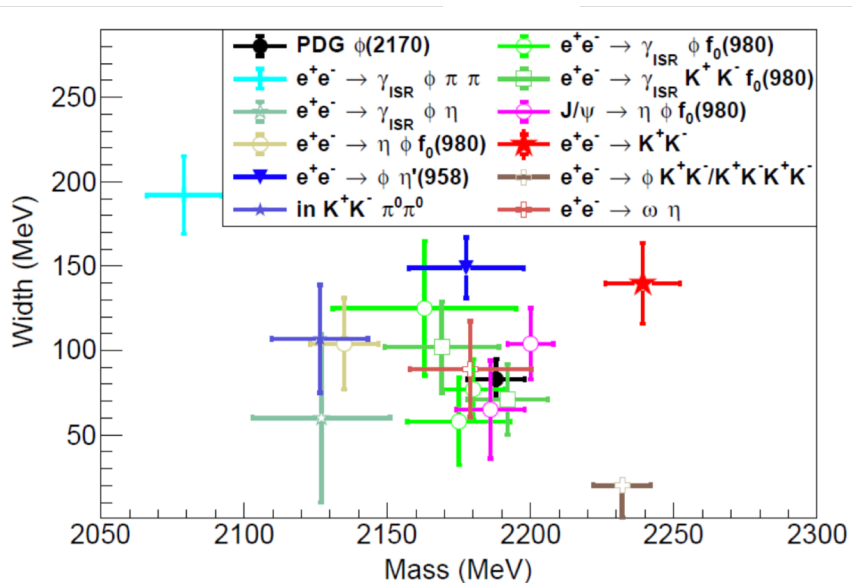
Mode	Fraction ( $\Gamma_i/\Gamma$ )
$\Gamma_1$ $e^+e^-$	seen
$\Gamma_2$ $\phi\eta$	
$\Gamma_3$ $\phi\pi\pi$	
$\Gamma_4$ $\phi f_0(980)$	seen
$\Gamma_5$ $K^+K^-\pi^+\pi^-$	
$\Gamma_6$ $K^+K^-f_0(980) \rightarrow K^+K^-\pi^+\pi^-$	seen
$\Gamma_7$ $K^+K^-\pi^0\pi^0$	
$\Gamma_8$ $K^+K^-f_0(980) \rightarrow K^+K^-\pi^0\pi^0$	seen
$\Gamma_9$ $K^{*0}K^\pm\pi^\mp$	not seen
$\Gamma_{10}$ $K^*(892)^0\bar{K}^*(892)^0$	not seen

➤ Published experimental information

- ✓ Limited decay modes
- ✓ Inconsistence on mass & width

➤ Theorists explain  $\phi(2170)$  as

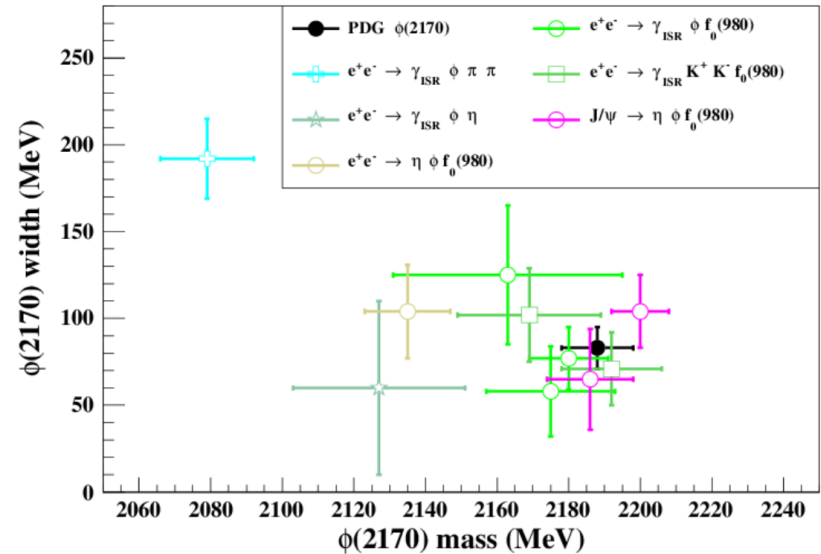
- ✓  $s\bar{s}g$  hybrid
- ✓  $2^3D_1$  or  $3^3S_1$   $s\bar{s}$
- ✓ tetraquark
- ✓ molecular state  $\Lambda\bar{\Lambda}$
- ✓  $\phi f_0(980)$  resonance with FSI
- ✓ Three body system  $\phi KK$



**Not fully understood**

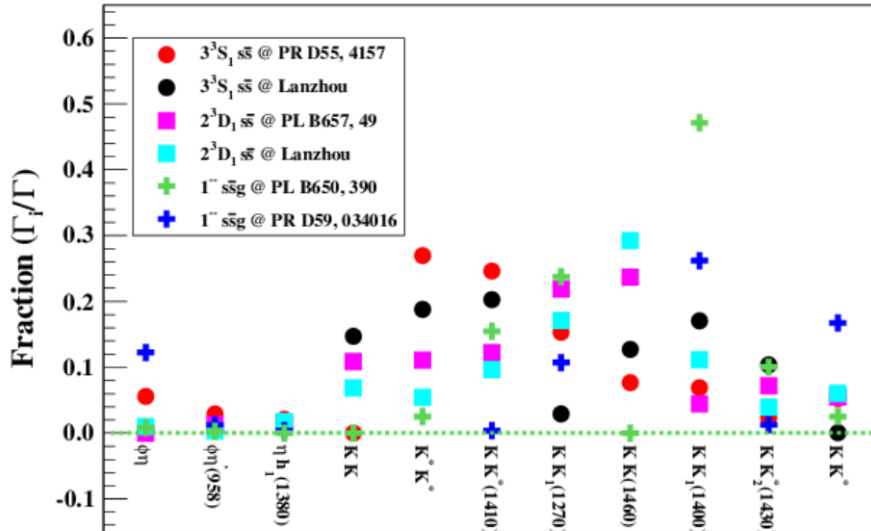
# The nature $\phi(2170)$

$\phi(2170)$	Mass (MeV)	Width (MeV)
$3^3S_1$	2050	378
$2^3D_1$		167.21
		211.9
hybrid		148.7
		155
		120
	2100-2200	
	2500-2600	
$s\bar{s}s\bar{s}$	2210±90	
	2300±400	
	2176	
$\Lambda\bar{\Lambda}$		80.1-95
<b>PDG</b>	<b>2188±10</b>	<b>83±12</b>



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

# The nature $\phi(2170)$



**PDG**

$\phi(2170)$  DECAY MODES

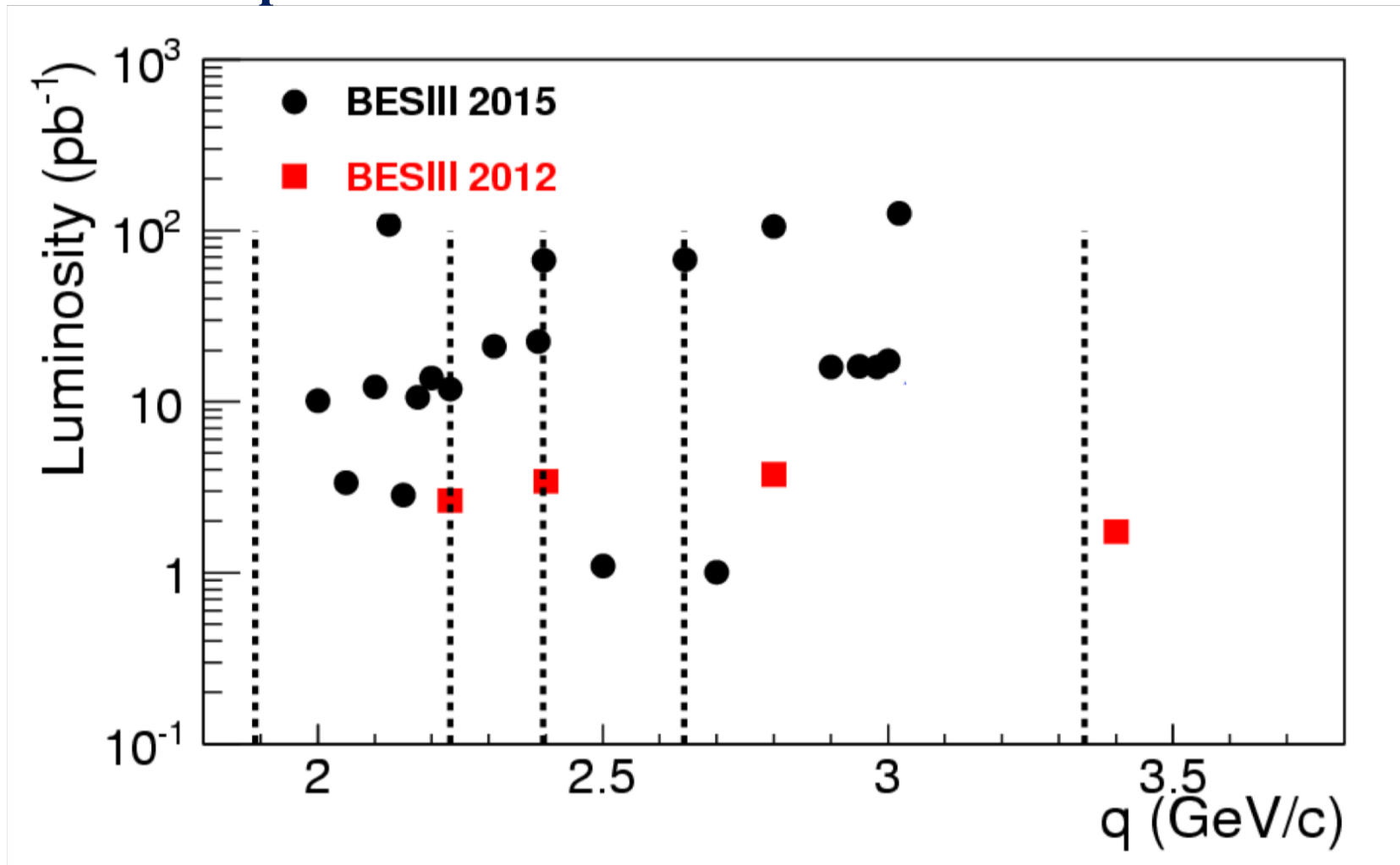
Mode	Fraction ( $\Gamma_i/\Gamma$ )
$\Gamma_1$ $e^+ e^-$	seen
$\Gamma_2$ $\phi\eta$	
$\Gamma_3$ $\phi\pi\pi$	
$\Gamma_4$ $\phi f_0(980)$	seen
$\Gamma_5$ $K^+ K^- \pi^+ \pi^-$	
$\Gamma_6$ $K^+ K^- f_0(980) \rightarrow K^+ K^- \pi^+ \pi^-$	seen
$\Gamma_7$ $K^+ K^- \pi^0 \pi^0$	
$\Gamma_8$ $K^+ K^- f_0(980) \rightarrow K^+ K^- \pi^0 \pi^0$	seen
$\Gamma_9$ $K^{*0} K^\pm \pi^\mp$	not seen
$\Gamma_{10}$ $K^*(892)^0 \bar{K}^*(892)^0$	not seen

**Need more data !!!**

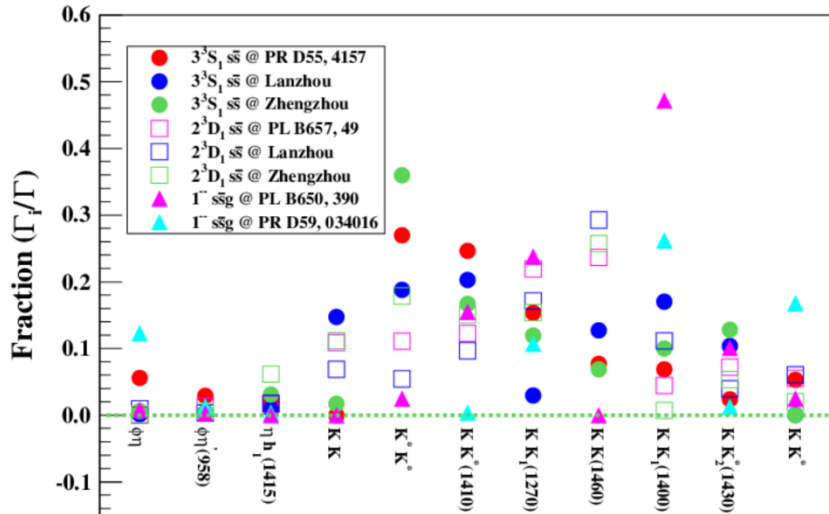
- **$KK\pi\pi$ : benchmark process**
  - ✓  **$K^*K^*$ :  $s\bar{s}g$  (forbidden),  $3^3S_1$  (favored)**
  - ✓  **$KK_1(1400)$ :  $s\bar{s}g$  (favored)**
  - ✓  **$KK(1460)$ :  $s\bar{s}g$  (suppressed),  $2^3D_1$  (favored)**
- **$\phi\eta$ :  $2^3D_1$  (suppressed), tetraquark (favored)**
- **$\eta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

# Data used in this talk

➤ 650 pb<sup>-1</sup> in 2.0 – 3.08 GeV collected in 2015



$$e^+ e^- \rightarrow K^+ K^-$$



➤  $K^+K^-$  @  $\phi(2170)$

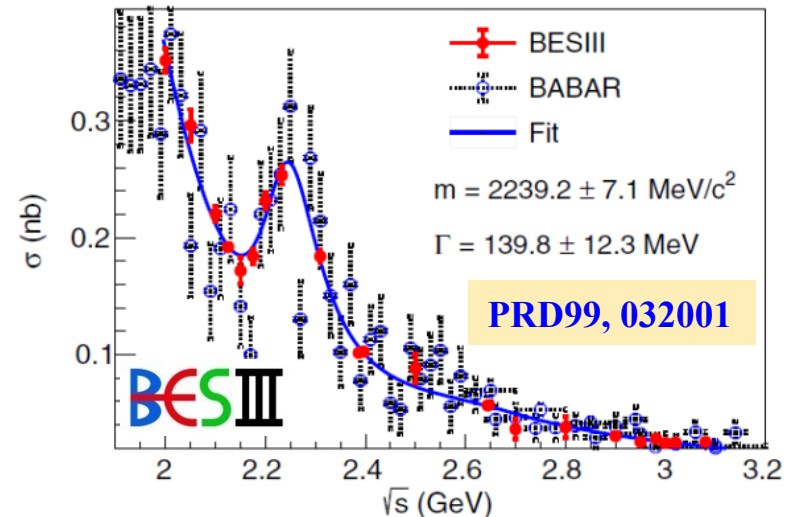
✓ Obvious discrepancy between different theory models

✓ isoscalar:  $\omega^*/\phi^*$ ; isovector:  $\rho^*$

➤  $\sigma(e^+e^- \rightarrow K^+K^-)$  @ [2.0-3.08]GeV

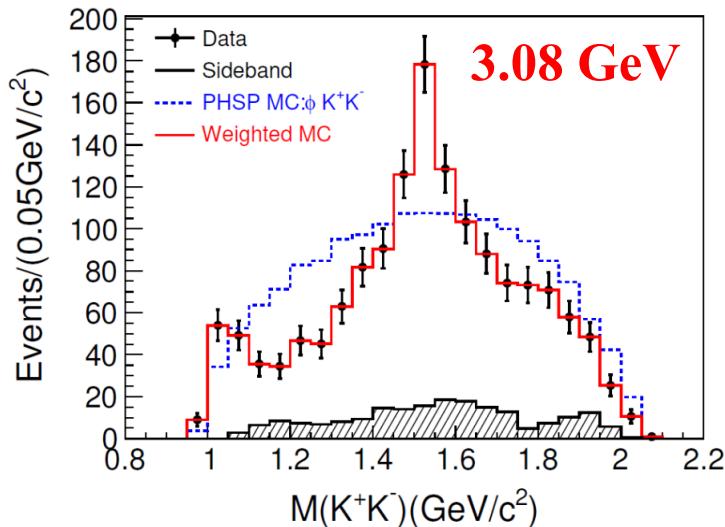
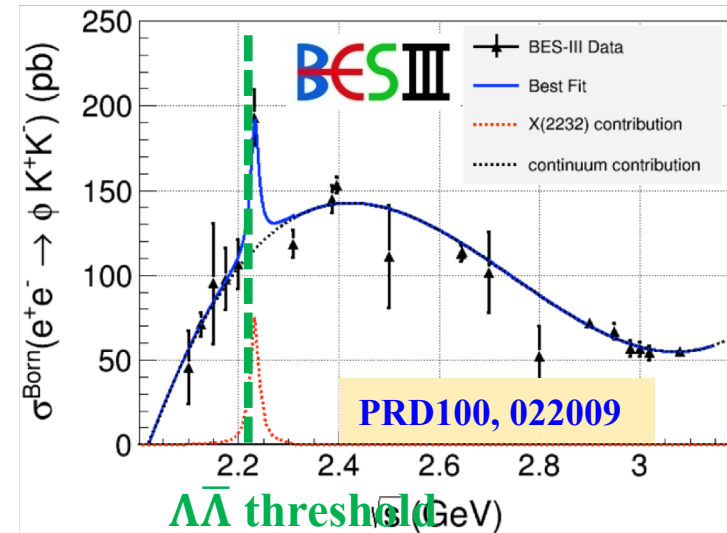
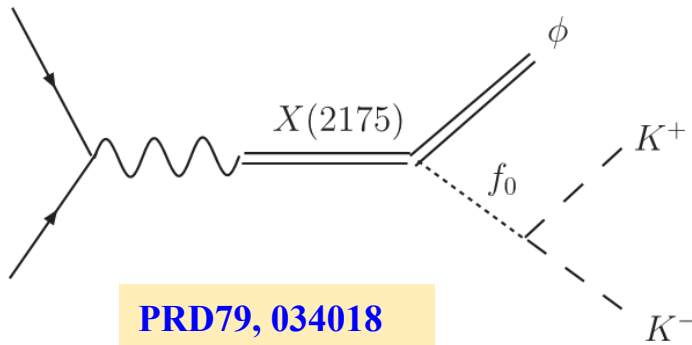
$\phi(2170)$ decay	This work	$^3P_0$ model	Data [5]
	$^3S_1 \Lambda \bar{\Lambda}$	within $s\bar{s}$ [10]	
$KK$	73.8–87.7	...	...
$\phi f_0(980)$	0.25–0.3	< 10	Seen
$\omega\sigma$	4.2–4.9		
$K^*K_0^*(800)$	1.8–2.1		
Total	80.1–95		$83 \pm 12$

PRD96, 074027



$$e^+ e^- \rightarrow \phi K^+ K^-$$

➤  $\phi(2170)$ : resonant of  $\phi K K$



➤ A hint for a resonance around  $\Lambda\bar{\Lambda}$  threshold

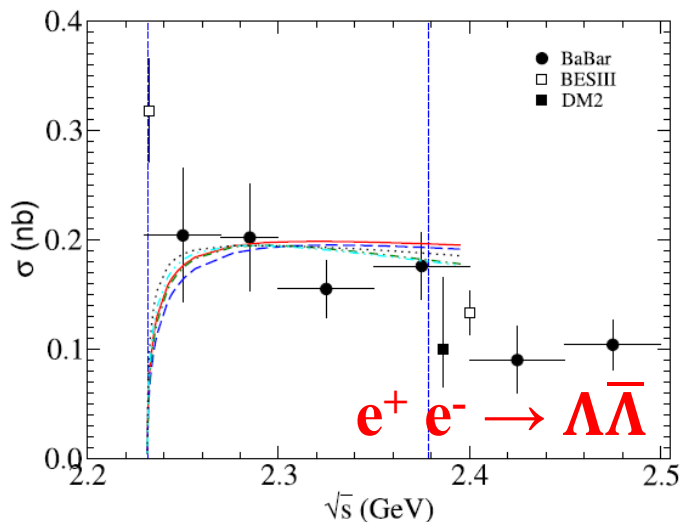
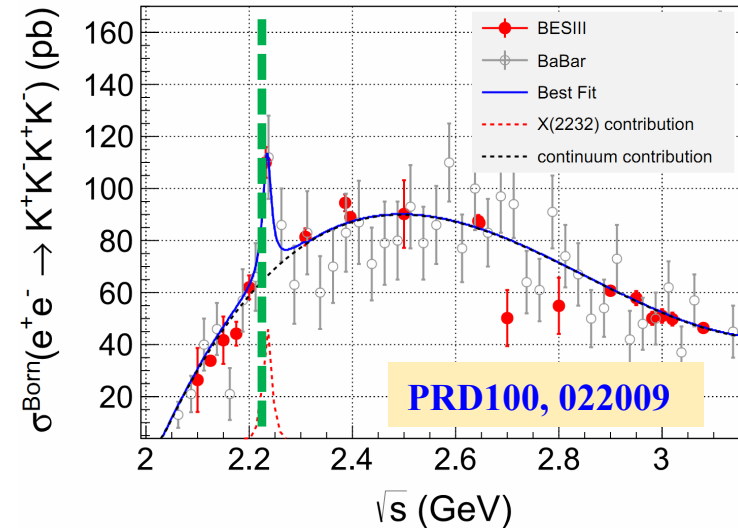
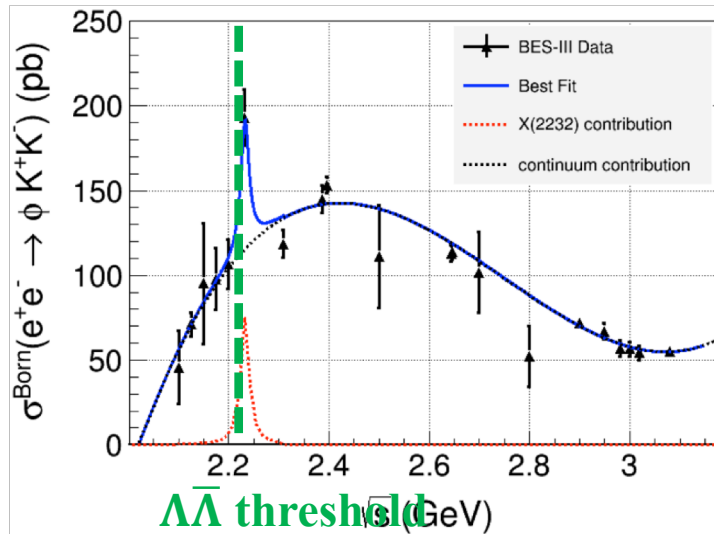
✓ Mass =  $2232 \pm 3.5 \text{ MeV}$

✓ Width < 20 MeV

➤ Three body system  $\phi K K$



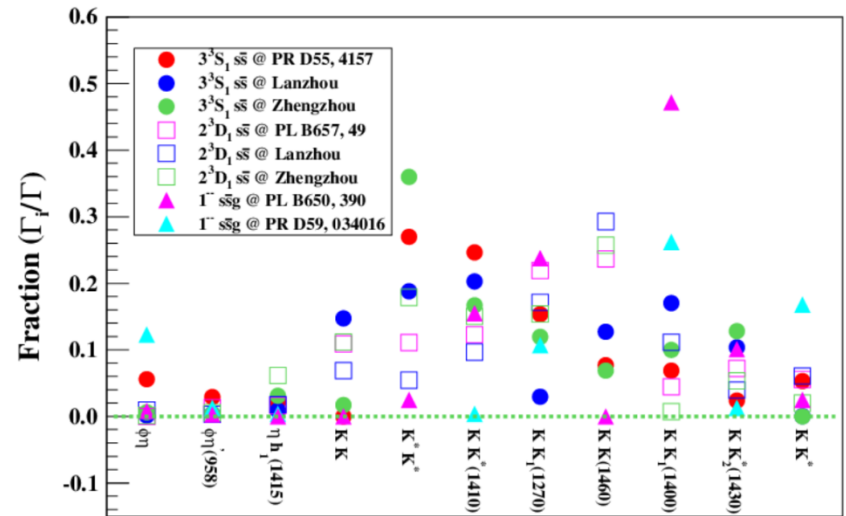
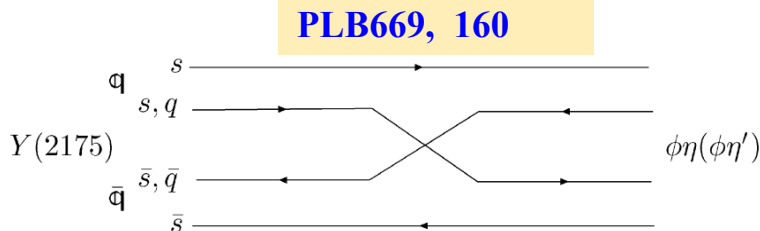
# $e^+e^- \rightarrow 2(K^+K^-)$



- $\phi K^+K^-$  and  $2(K^+K^-)$  have similar enhancement around 2.2324 GeV
- $\Lambda\bar{\Lambda}$  threshold ?
- More ideas ?

# $e^+e^- \rightarrow \phi\eta$ and $\phi\eta'$

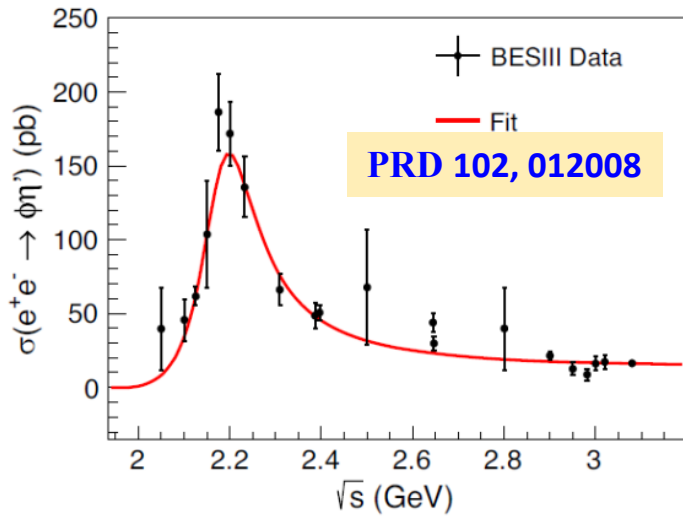
- $\phi\eta$  and  $\phi\eta'$  modes: isoscalar
  - ✓  $\phi^*$  and  $\omega^*$  (OZI suppressed)
  - ✓ useful to measure parameters
- Tetraquark favorites  $\phi\eta$  and  $\phi\eta'$



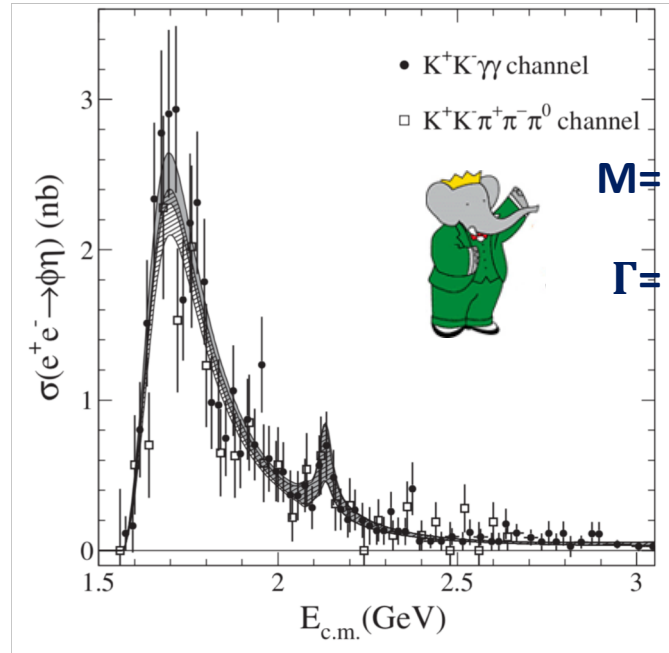
- $1^- s\bar{s}g$  hybrid has large  $\Gamma_{\phi\eta}$  and smaller  $\Gamma_{\phi\eta'}$

$1^- s\bar{s}g$	alt	2.2GeV	standard	IKP	Ding
	PRD59, 034016				PLB650,390
$\phi\eta$	2	19	11	3	1.2
$\phi\eta'$	0.01	2	0.1	0.02	0.4
$\text{Br}(\phi\eta)/\text{Br}(\phi\eta')$	200	9.5	110	150	3

# $e^+e^- \rightarrow \phi\eta$ and $\phi\eta'$



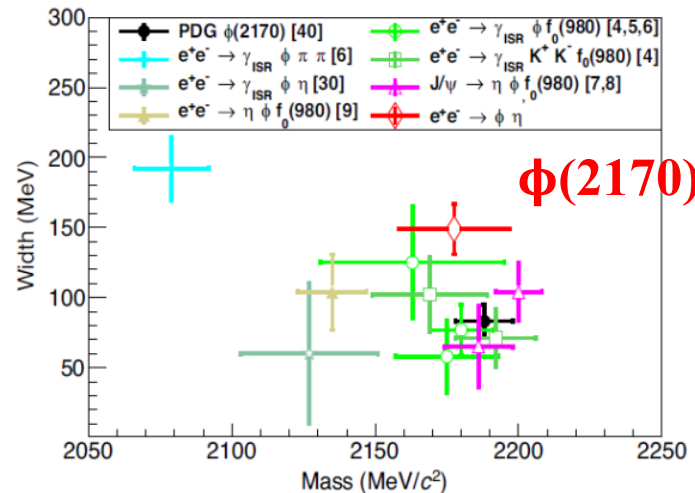
$M = 2177.5 \pm 4.8 \pm 19.5 \text{ MeV}/c^2$   
 $\Gamma = 149.0 \pm 15.6 \pm 8.9 \text{ MeV}$



$M = 2125 \pm 22 \text{ MeV}/c^2$

$\Gamma = 61 \pm 50 \text{ MeV}$

➤  $\phi(2170)$  @  $\phi\eta'$  and  $\phi\eta$ ?



# $e^+ e^- \rightarrow \phi\eta$ and $\phi\eta'$

➤  $e^+ e^- \rightarrow \phi\eta$  and  $\phi\eta'$

✓ **BarBar  $\phi\eta$ :  $1.7 \pm 0.7 \pm 1.3$  eV**

$$\frac{\text{Br}[\phi(2170) \rightarrow \phi\eta] \cdot \Gamma_{ee}}{\text{Br}[\phi(2170) \rightarrow \phi\eta'] \cdot \Gamma_{ee}} = \mathbf{0.23 \pm 0.10 \pm 0.18}$$

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

$1^- s\bar{s}g$	alt	2.2GeV	standard	IKP	Ding
	PRD59, 034016				PLB650,390
$\phi\eta$	2	19	11	3	1.2
$\phi\eta'$	0.01	2	0.1	0.02	0.4
$\text{Br}(\phi\eta)/\text{Br}(\phi\eta')$	200	9.5	110	150	3

# $e^+e^- \rightarrow \text{KK}\pi\pi$

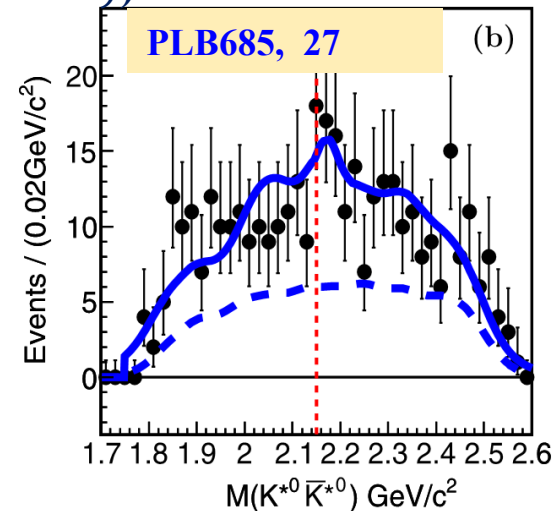
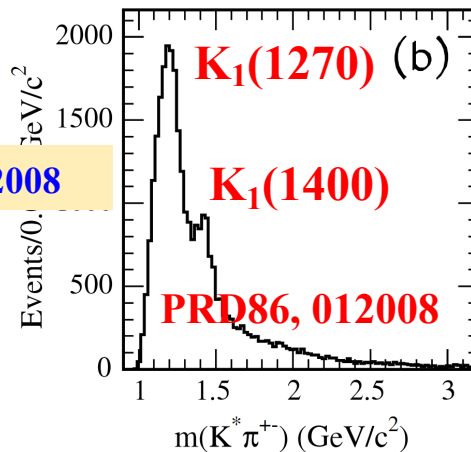
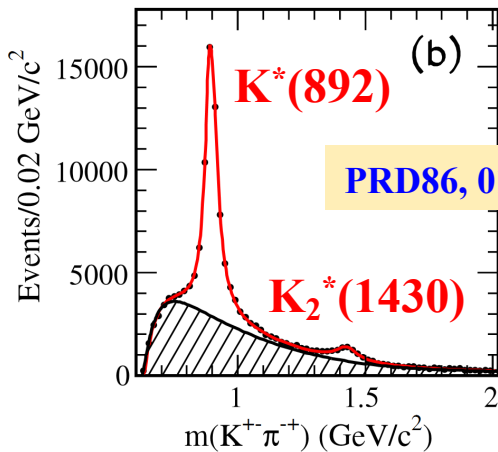
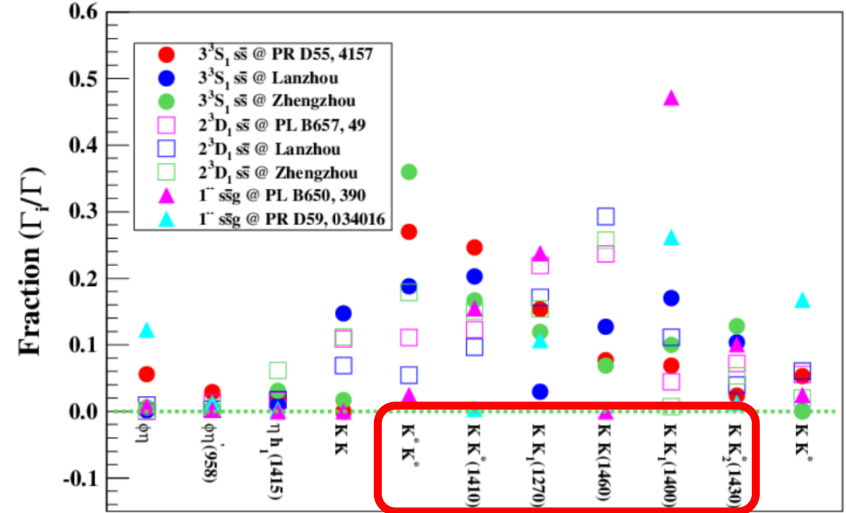
➤  $e^+e^- \rightarrow \text{KK}\pi\pi$ : important to distinguish  $\phi(2170)$  theory models

- ✓  $\text{K}^*\text{K}^*$ :  $s\bar{s}g$  (unfavored),  $3^3\text{S}_1$  (favored)
- ✓  $\text{KK}_1(1400)$ :  $s\bar{s}g$  (favored)
- ✓  $\text{KK}(1460)$ :  $s\bar{s}g$  (unfavored),  $2^3\text{D}_1$  (favored)

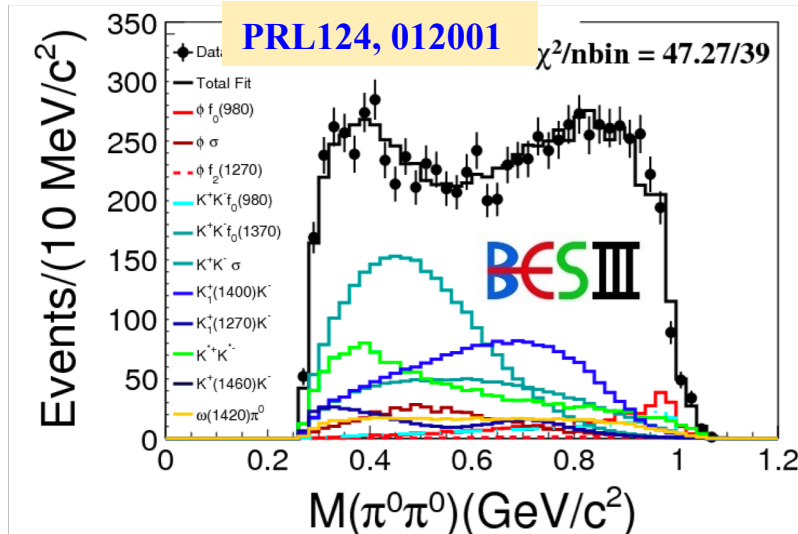
➤ BaBar:  $\text{K}^*(892)$ ,  $\text{K}_2^*(1430)$ ,  $\text{K}_1(1270)$  and  $\text{K}_1(1400)$

➤  $\text{J}/\psi \rightarrow \eta\phi(2170) \rightarrow \eta\text{K}^*\text{K}^*$

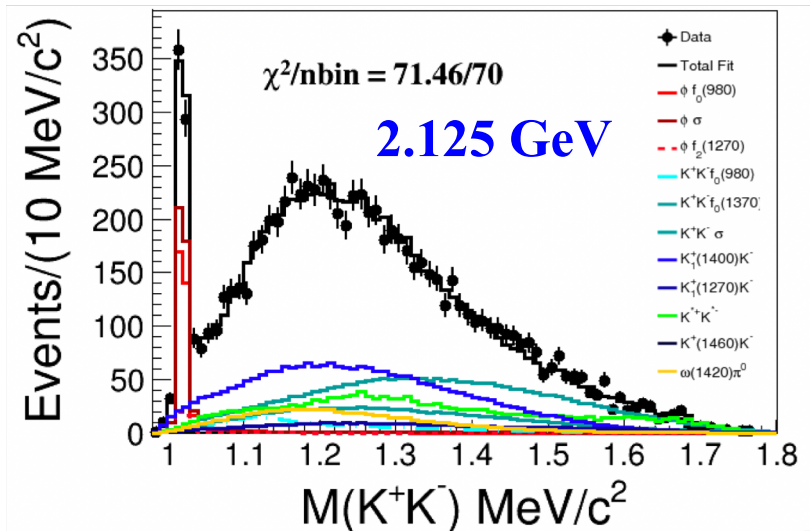
- ✓ BES: 58M  $\text{J}/\psi$ , an upper limit of  $\text{Br}(\text{J}/\psi \rightarrow \eta\phi(2170))$ .



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

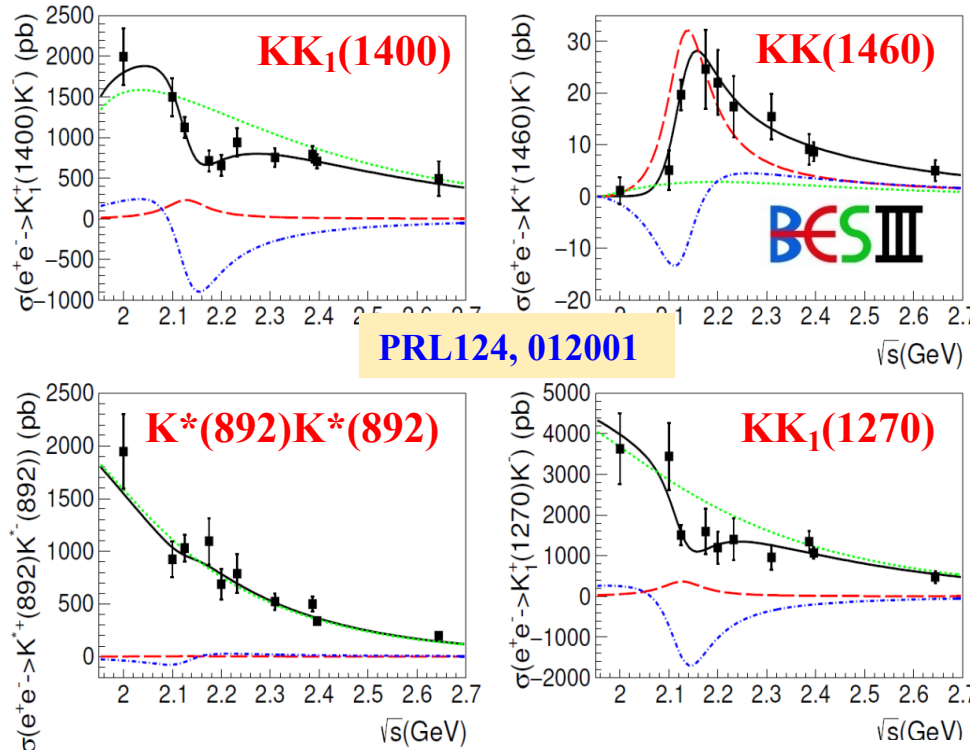


process	Significance (2.1250 GeV)	Significance (2.3960 GeV)
$\phi f_0(980)$	$>8.0 \sigma$	$>8.0 \sigma$
$\phi \sigma$	$>8.0 \sigma$	–
$\phi f_2(1270)$	$5.0 \sigma$	–
$\phi f_0(1370)$	–	$6.9 \sigma$
$K^{*+}(892)K^{*-}(892)$	$>8.0 \sigma$	$>8.0 \sigma$
$K^+(1460)K^-$	$>8.0 \sigma$	$6.4 \sigma$
$K_0^{*+}(1430)K^{*-}(892)$	$>8.0 \sigma$	$7.5 \sigma$
$K_2^{*+}(1430)K^{*-}(892)$	–	$6.4 \sigma$
$K_1^+(1400)K^-$	$>8.0 \sigma$	$>8.0 \sigma$
$K_1^+(1270)K^-$	$>8.0 \sigma$	$>8.0 \sigma$
$K^{*+}(892)K^-\pi^0$	–	$5.4 \sigma$
$K^+K^-f_0(980)$	$6.2 \sigma$	$>8.0 \sigma$
$K^+K^-\sigma$	$>8.0 \sigma$	$>8.0 \sigma$
$K^+K^-f_0(1370)$	$>8.0 \sigma$	$7.4 \sigma$
$\omega(1420)\pi^0$	$>8.0 \sigma$	$5.2 \sigma$



- A PWA for multi-energy points @ [2.0, 2.644] GeV
- There is **no significant signal of  $e^+e^- \rightarrow KK^*(1410)$**
- Extract Born cross section of intermediate states

# $e^+e^- \rightarrow K^+K^-\pi^0\pi^0$



PRL124, 012001

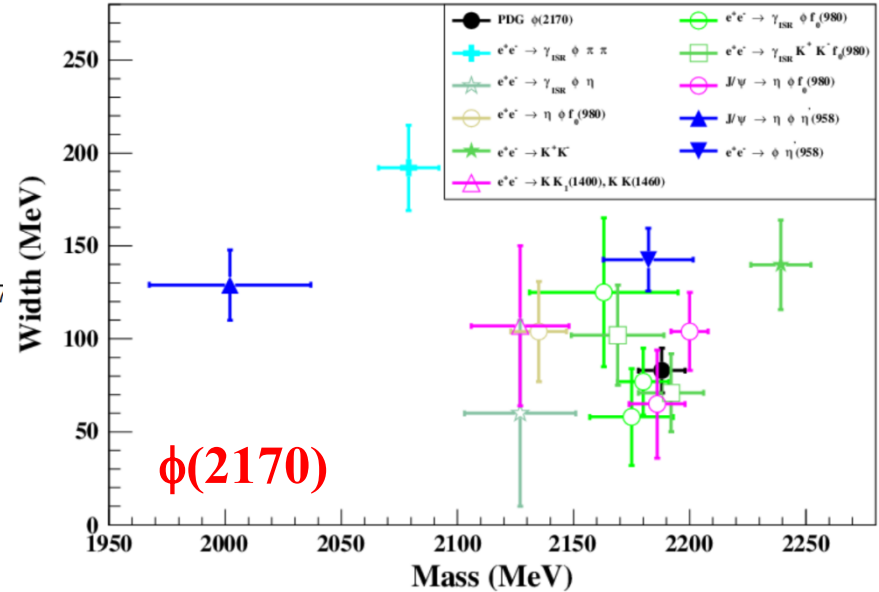


Table 22: Fitting parameters.

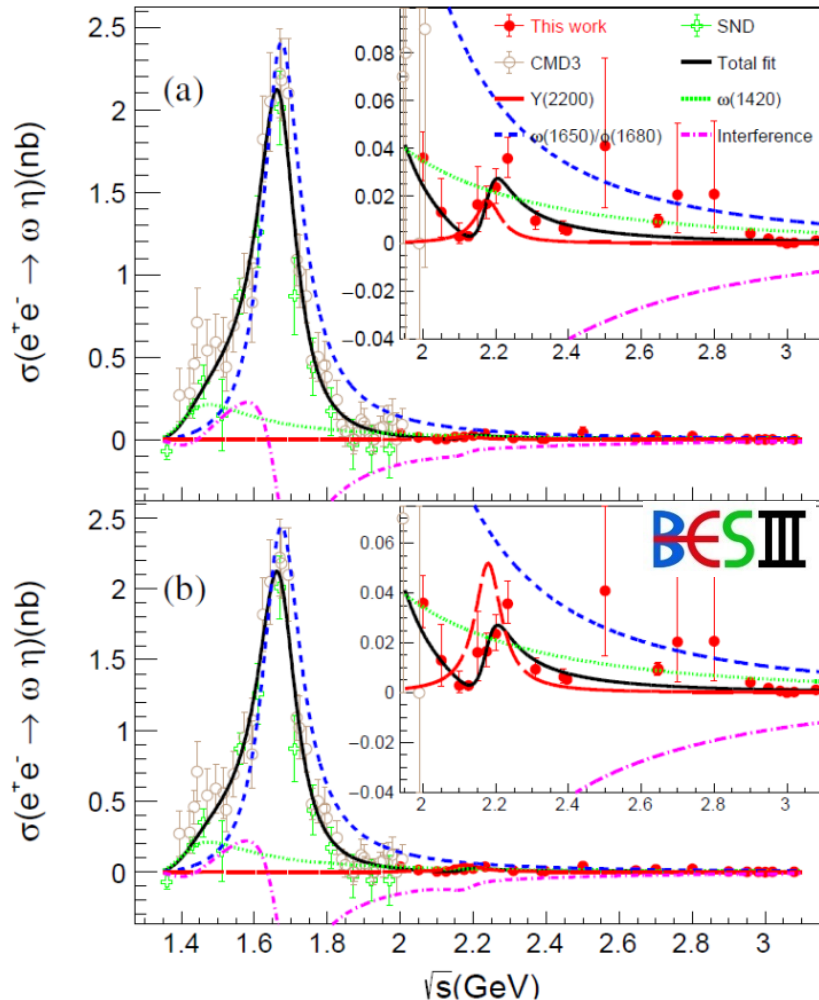
channel	$e^+e^- \rightarrow K_1^+(1400)K^-$	$e^+e^- \rightarrow K^+(1460)K^-$	$e^+e^- \rightarrow K_1^+(1270)K^-$	$e^+e^- \rightarrow K^{*+}K^{*-}$	
Mass (MeV/ $c^2$ )	$2126.5 \pm 16.8$				
Width (MeV)	$106.9 \pm 32.1$				
	Solution1	Solution2		Solution1	Solution2
$\mathcal{B}_R \Gamma^{e^+e^-}$ (eV)	$7.6 \pm 3.7$	$152.6 \pm 14.2$	$1.0 \pm 1.3$	$4.7 \pm 3.3$	$98.8 \pm 7.8$
$\phi$ (rad)	$3.7 \pm 0.4$	$4.5 \pm 0.3$	$5.6 \pm 1.5$	$4.0 \pm 0.2$	$4.5 \pm 0.1$
Significance( $\sigma$ )	4.8		4.5	1.4	

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

➤  $\phi(2170) \rightarrow K K_1(1400)$  and  $K K(1460)$ : **Yes ?**

# $e^+e^- \rightarrow \omega\eta$

PLB 813, 136059 (2021)



- The  $\eta$  has  $s\bar{s}$  component
- ✓ Isospin zero:  $\omega^*$  and  $\phi^*$
- ✓  $\phi(2170) \rightarrow \omega\eta$ : **Yes ?**

parameters	solution I	solution II
$m_{Y(2180)} (\text{MeV}/c^2)$	$2179 \pm 21$	
$\Gamma_{Y(2180)} (\text{MeV})$	$89 \pm 28$	
$\Gamma^{ee} \cdot B^{\omega\eta} (\text{eV})$	$0.50 \pm 0.16$	$1.50 \pm 0.44$
$\varphi$	$2.7 \pm 0.3$	$1.9 \pm 0.2$
significance	$6.1\sigma$	

PDG	Mass	Width
$\omega(2205)$	$2205 \pm 30$	$350 \pm 90$
$\omega(2290)$	$2290 \pm 20$	$375 \pm 35$
$\omega(2330)$	$2330 \pm 30$	$435 \pm 75$



# Summary and outlook

- Compared with  $c\bar{c}$  and  $b\bar{b}$ ,  $s\bar{s}$  is a terra incognita
- Lots of progress in study  $\phi(2170)$  at BESIII
  - ✓  $e^+e^- \rightarrow K^+K^-$
  - ✓  $e^+e^- \rightarrow \phi K^+K^-$  and  $2(K^+K^-)$
  - ✓  $e^+e^- \rightarrow \phi\eta$  and  $\phi\eta'$
  - ✓  $e^+e^- \rightarrow K^+K^-\pi^0\pi^0$
  - ✓  $e^+e^- \rightarrow \omega\eta$
- Aspects of  $\phi(2170)$  are still not fully understood

