

Study of $\phi(2170)$ at BESIII

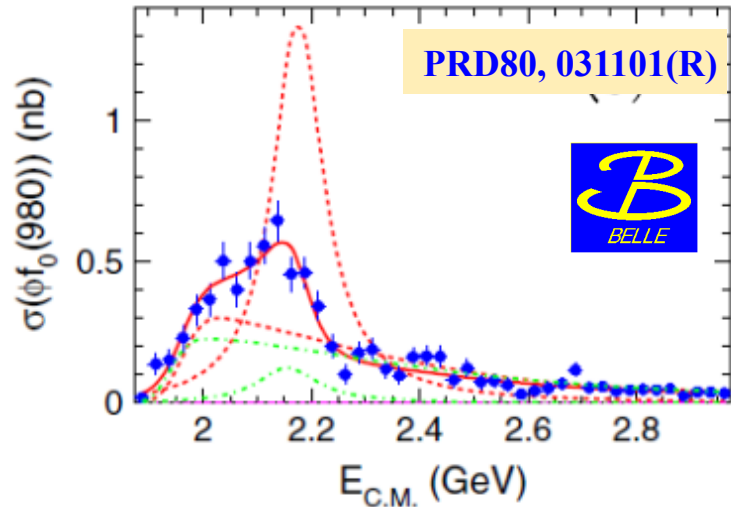
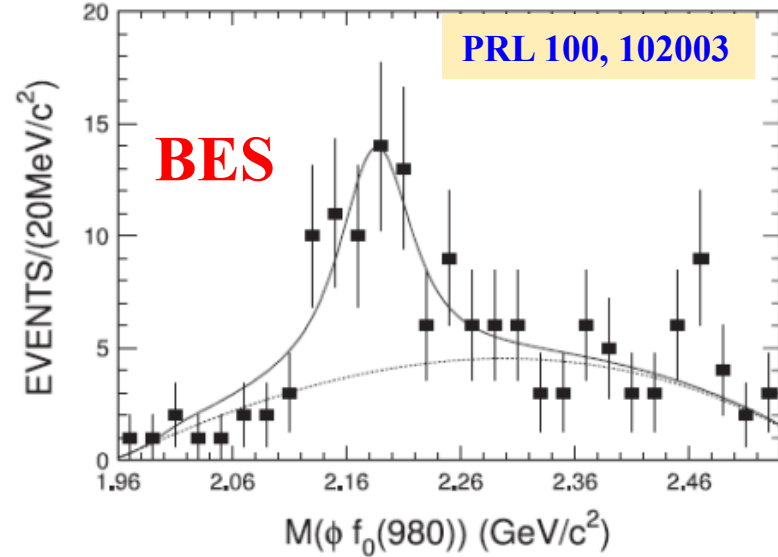
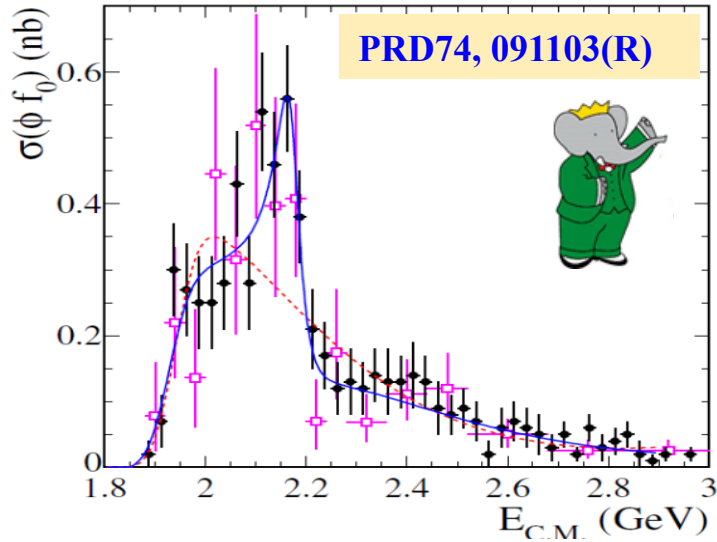
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第7届XYZ粒子研讨会

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



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

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

The nature $\phi(2170)$

PDG

$\phi(2170)$ DECAY MODES

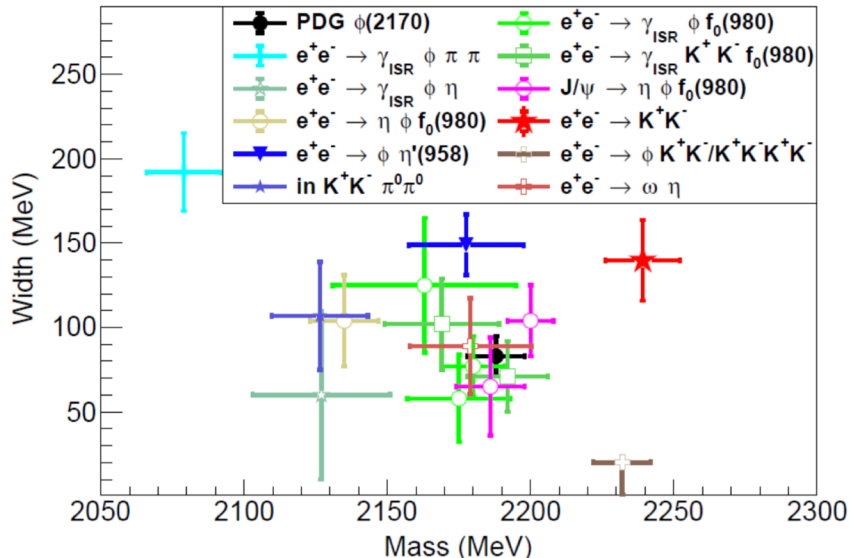
Mode	Fraction (Γ_i/Γ)
Γ_1 e^+e^-	seen
Γ_2 $\phi\eta$	
Γ_3 $\phi\pi\pi$	
Γ_4 $\phi f_0(980)$	seen
Γ_5 $K^+K^-\pi^+\pi^-$	
Γ_6 $K^+K^-f_0(980) \rightarrow K^+K^-\pi^+\pi^-$	seen
Γ_7 $K^+K^-\pi^0\pi^0$	
Γ_8 $K^+K^-f_0(980) \rightarrow K^+K^-\pi^0\pi^0$	seen
Γ_9 $K^{*0}K^\pm\pi^\mp$	not seen
Γ_{10} $K^*(892)^0\bar{K}^*(892)^0$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

➤ Published experimental information

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

➤ Theorists explain $\phi(2170)$ as

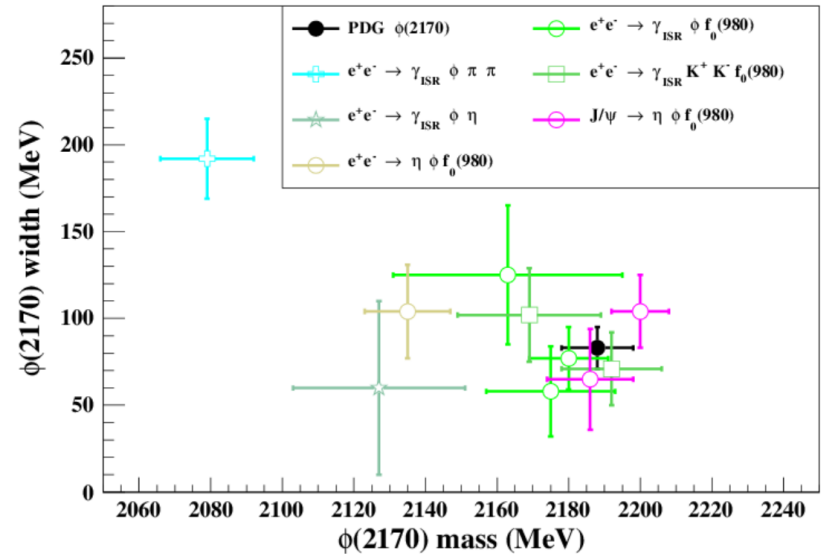
- ✓ $s\bar{s}g$ hybrid
- ✓ 2^3D_1 or 3^3S_1 $s\bar{s}$
- ✓ tetraquark
- ✓ molecular state $\Lambda\bar{\Lambda}$
- ✓ $\phi f_0(980)$ resonance with FSI
- ✓ Three body system ϕKK



Not fully understood

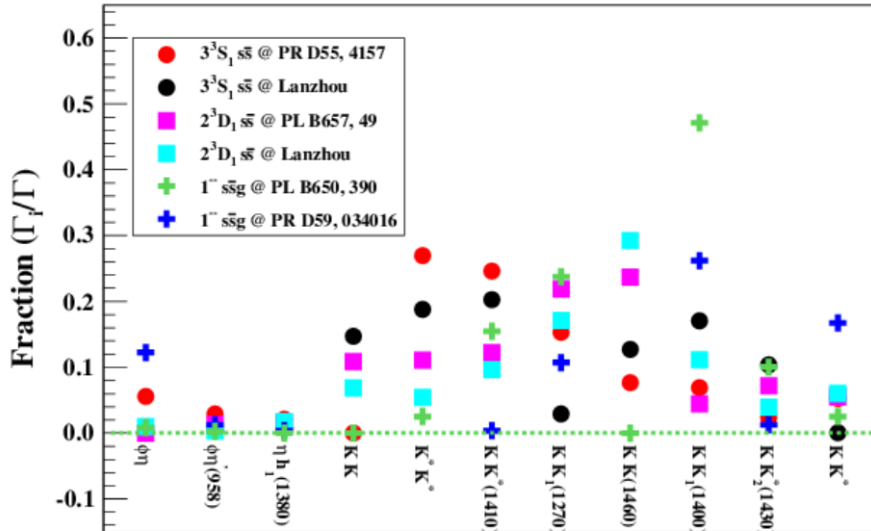
The nature $\phi(2170)$

$\phi(2170)$	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
PDG	2188±10	83±12



- 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

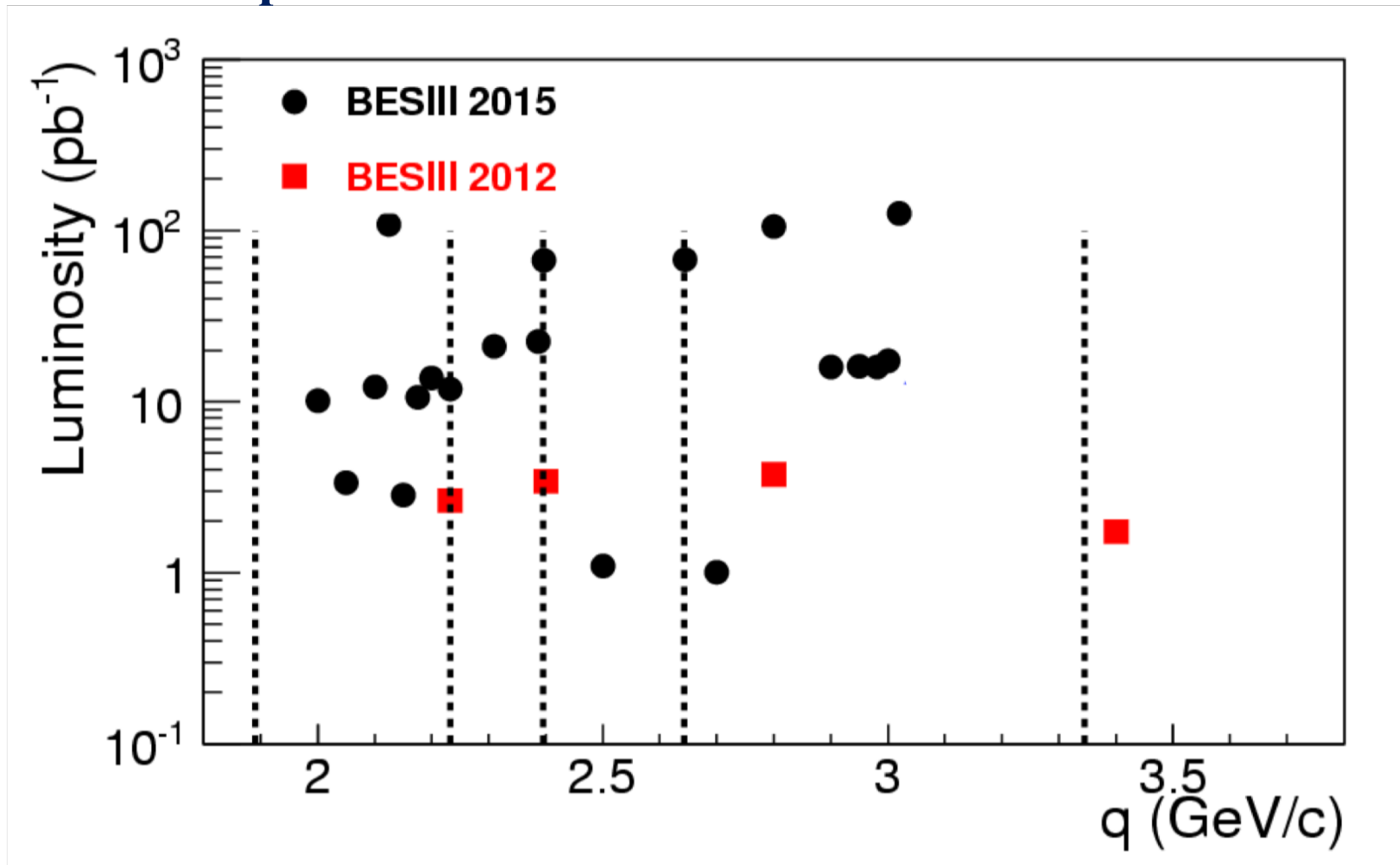
Mode	Fraction (Γ_i/Γ)
Γ_1 $e^+ e^-$	seen
Γ_2 $\phi\eta$	
Γ_3 $\phi\pi\pi$	
Γ_4 $\phi f_0(980)$	seen
Γ_5 $K^+ K^- \pi^+ \pi^-$	
Γ_6 $K^+ K^- f_0(980) \rightarrow K^+ K^- \pi^+ \pi^-$	seen
Γ_7 $K^+ K^- \pi^0 \pi^0$	
Γ_8 $K^+ K^- f_0(980) \rightarrow K^+ K^- \pi^0 \pi^0$	seen
Γ_9 $K^{*0} K^\pm \pi^\mp$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

Need more data !!!

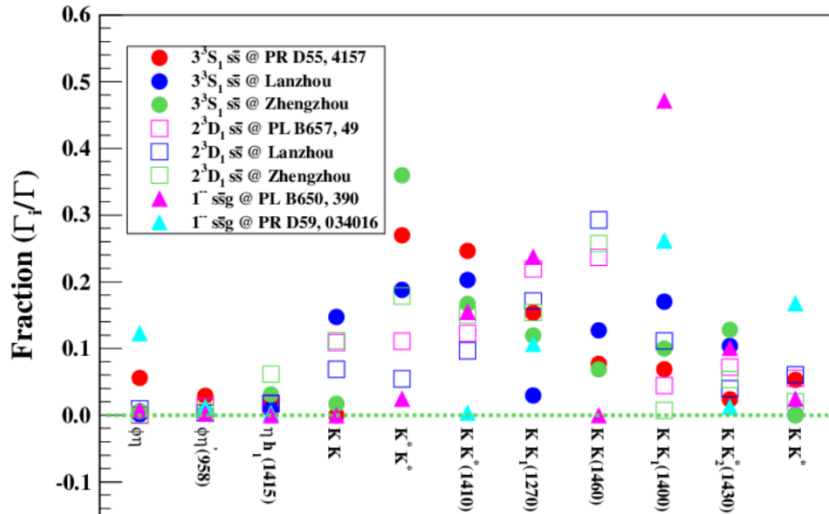
- **$KK\pi\pi$: benchmark process**
 - ✓ **K^*K^* : $s\bar{s}g$ (forbidden), 3^3S_1 (favored)**
 - ✓ **$KK_1(1400)$: $s\bar{s}g$ (favored)**
 - ✓ **$KK(1460)$: $s\bar{s}g$ (suppressed), 2^3D_1 (favored)**
- **$\phi\eta$: 2^3D_1 (suppressed), tetraquark (favored)**
- **$\eta h_1(1380)$: $s\bar{s}g$ (suppressed)**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

Data used in this talk

➤ 650 pb⁻¹ in 2.0 – 3.08 GeV collected in 2015



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



➤ K^+K^- @ $\phi(2170)$

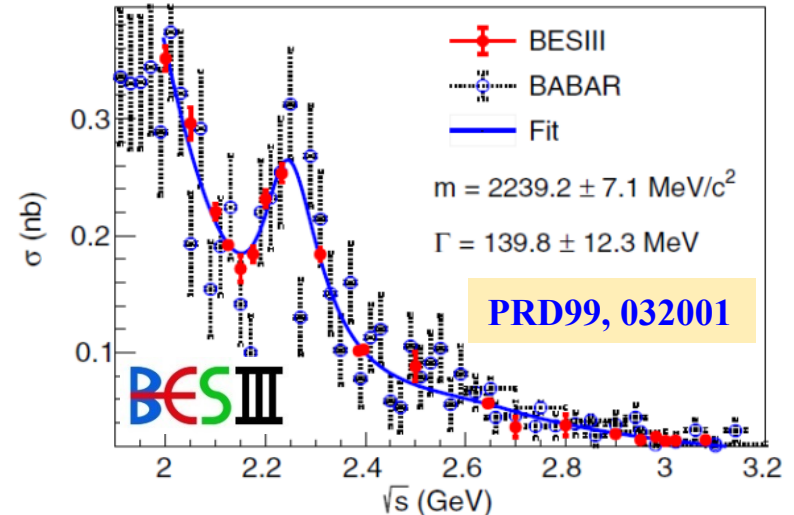
✓ Obvious discrepancy between different theory models

✓ isoscalar: ω^*/ϕ^* ; isovector: ρ^*

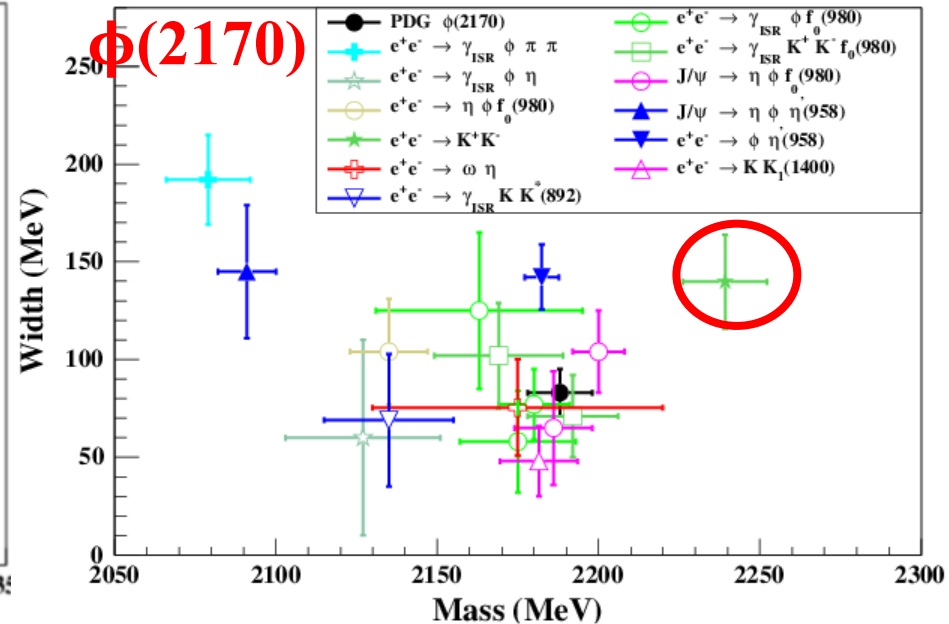
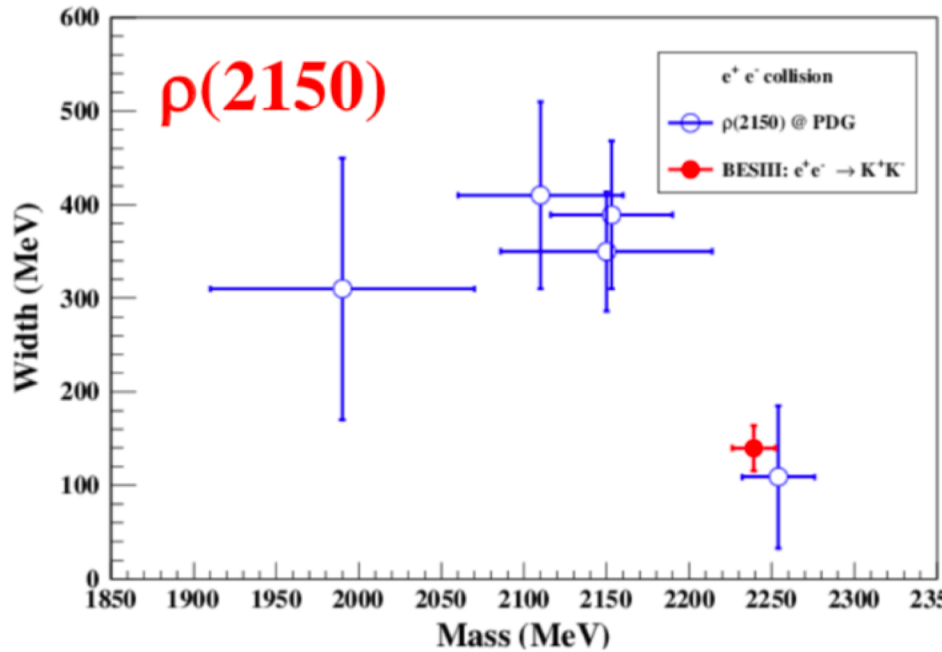
➤ $\sigma(e^+e^- \rightarrow K^+K^-)$ @ [2.0-3.08]GeV

$\phi(2170)$ 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 ± 12

PRD96, 074027



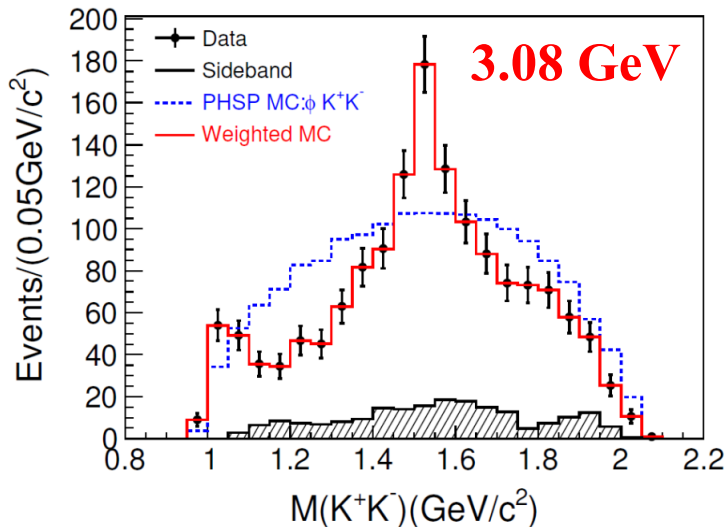
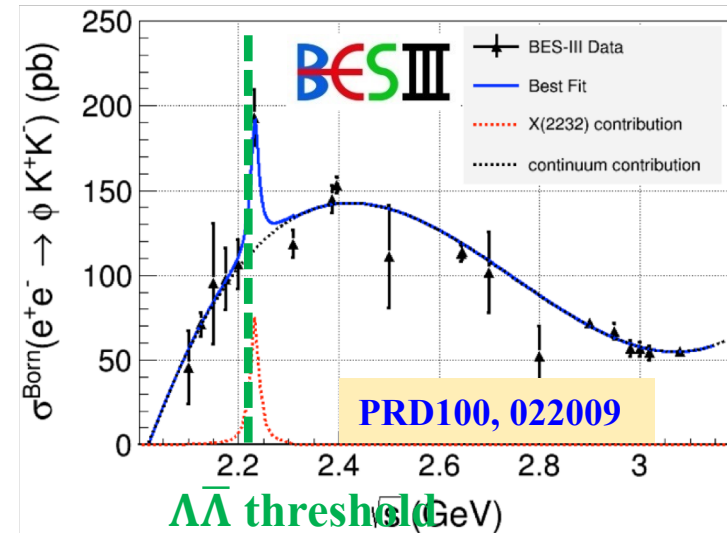
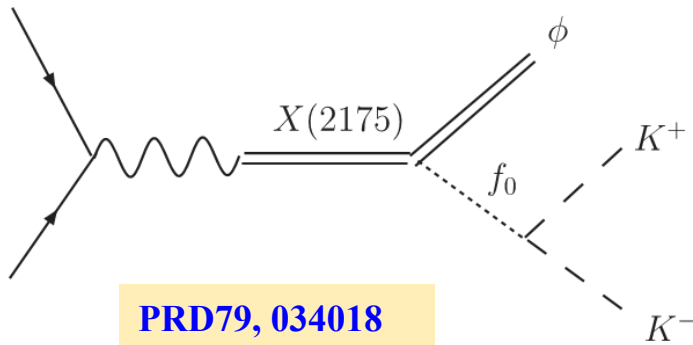
$$e^+ e^- \rightarrow K^+ K^-$$



- Large discrepancy with other decay models
- $K^+ K^-$ resonance maybe a $\rho(2150)$

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

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



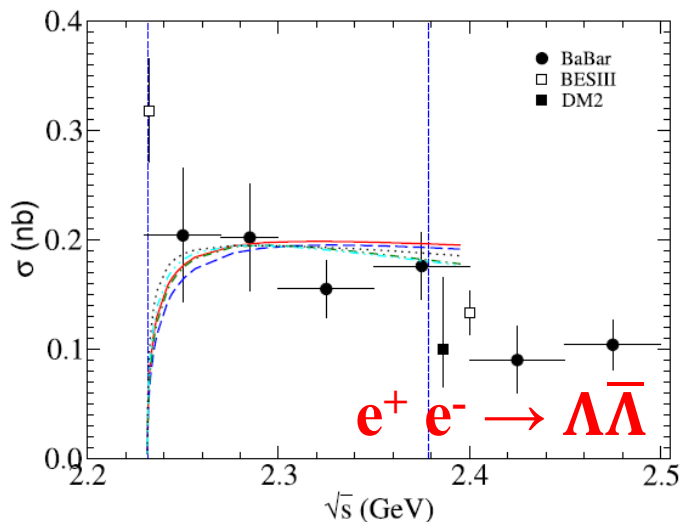
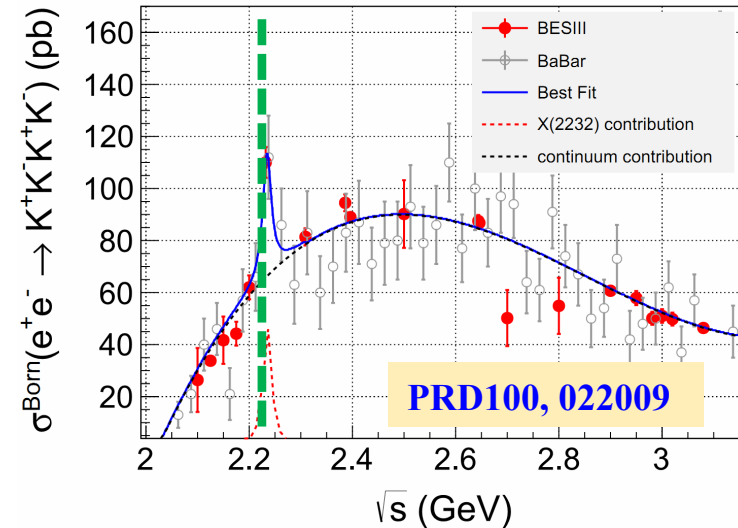
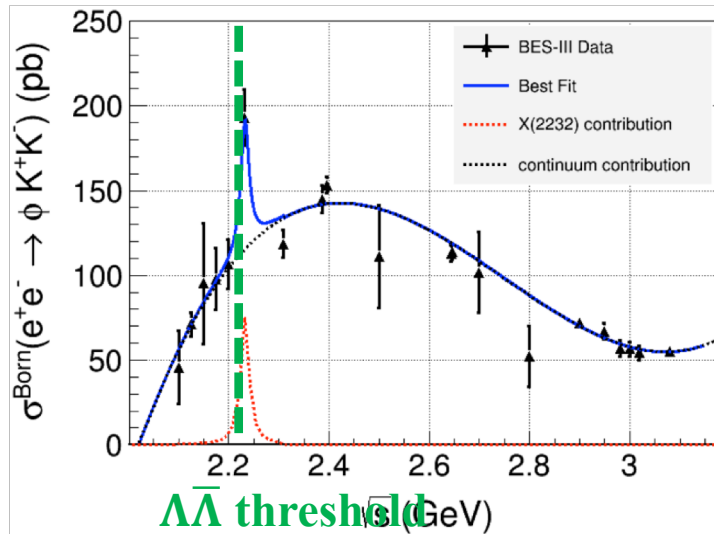
➤ A hint for a resonance around $\Lambda\bar{\Lambda}$ threshold

✓ Mass = $2232 \pm 3.5 \text{ MeV}$

✓ Width < 20 MeV

➤ Three body system $\phi K K$?

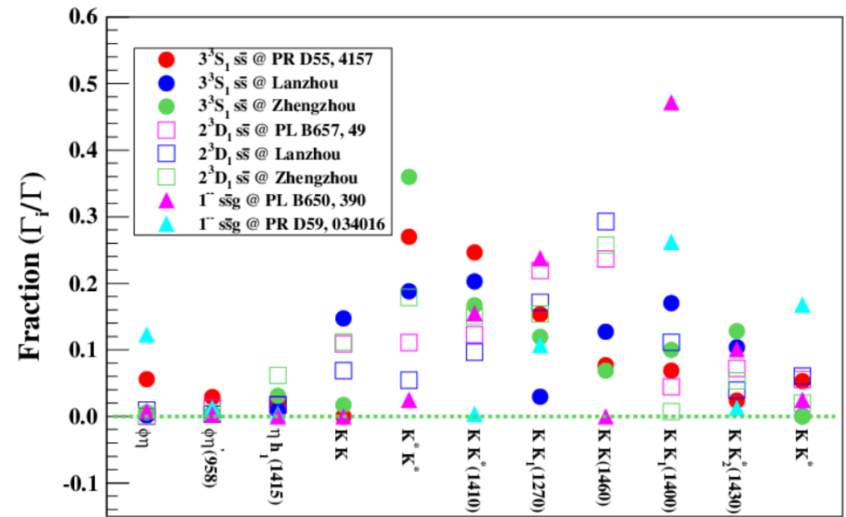
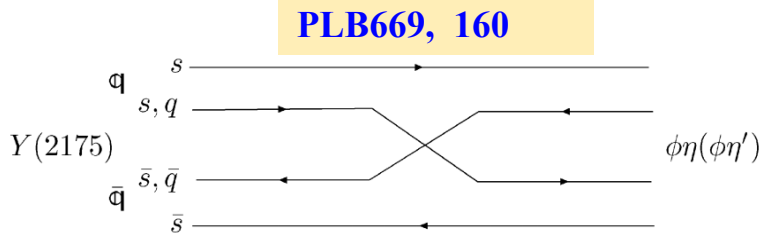
$e^+e^- \rightarrow 2(K^+K^-)$



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

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

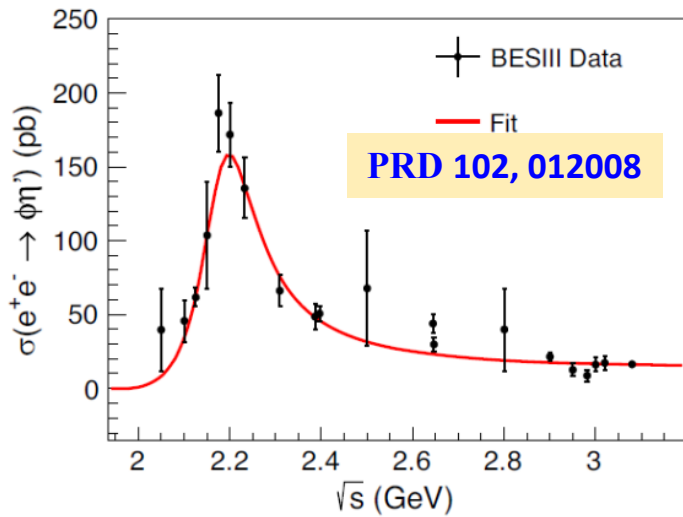
- $\phi\eta$ and $\phi\eta'$ modes: isoscalar
 - ✓ ϕ^* and ω^* (OZI suppressed)
 - ✓ useful to measure parameters
- Tetraquark favorites $\phi\eta$ and $\phi\eta'$



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

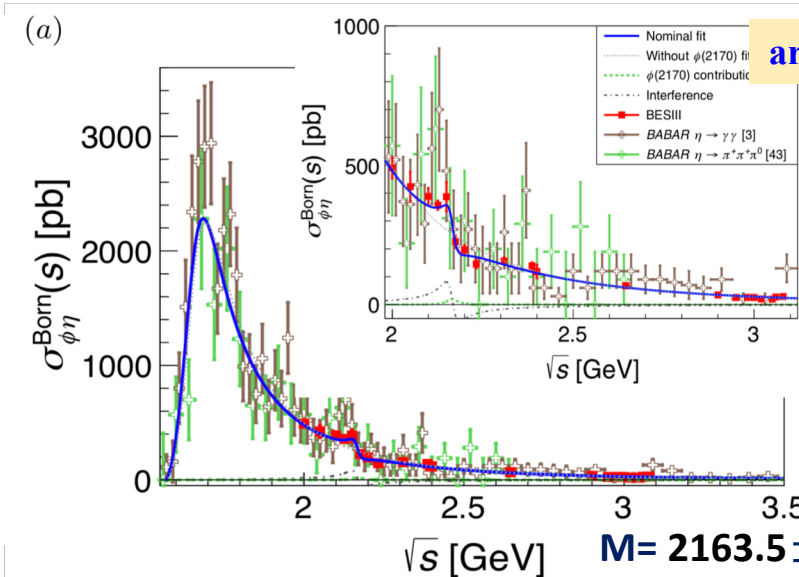
$1^- s\bar{s}g$	alt	2.2GeV	standard	IKP	Ding
	PRD59, 034016				PLB650,390
$\phi\eta$	2	19	11	3	1.2
$\phi\eta'$	0.01	2	0.1	0.02	0.4
$\text{Br}(\phi\eta)/\text{Br}(\phi\eta')$	200	9.5	110	150	3

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



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

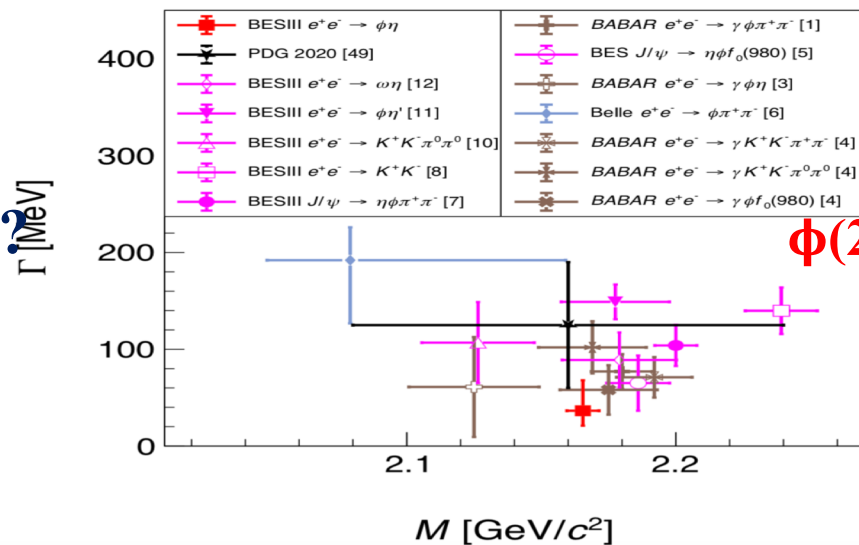
$$\Gamma = 149.0 \pm 15.6 \pm 8.9 \text{ MeV}$$



$$M = 2163.5 \pm 6.2 \pm 3.0 \text{ MeV}/c^2$$

$$\Gamma = 31.1^{+21.1}_{-11.6} \pm 1.1 \text{ MeV}$$

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



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

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

✓ $\text{Br} \cdot \Gamma_{e^+e^-}(\phi\eta): 0.23^{+0.37}_{-0.06} \text{ eV}$

✓ $\text{Br} \cdot \Gamma_{e^+e^-}(\phi\eta'): 7.1 \pm 0.7 \text{ eV}$

$$\frac{\text{Br}[\phi(2170) \rightarrow \phi\eta] \cdot \Gamma_{ee}}{\text{Br}[\phi(2170) \rightarrow \phi\eta'] \cdot \Gamma_{ee}} = 0.03^{+0.02}_{-0.01}$$

➤ 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
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$\text{Br}(\phi\eta)/\text{Br}(\phi\eta')$	200	9.5	110	150	3

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

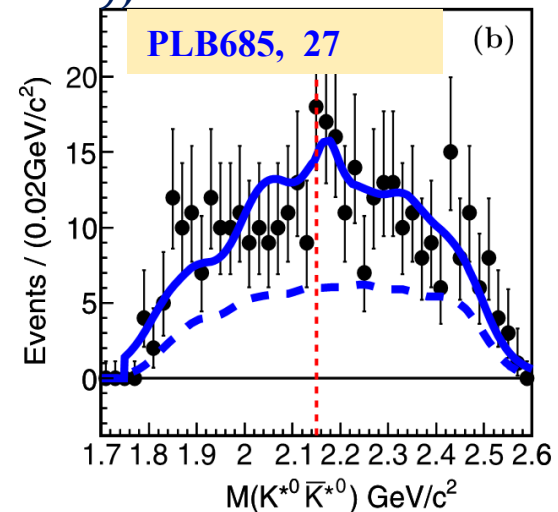
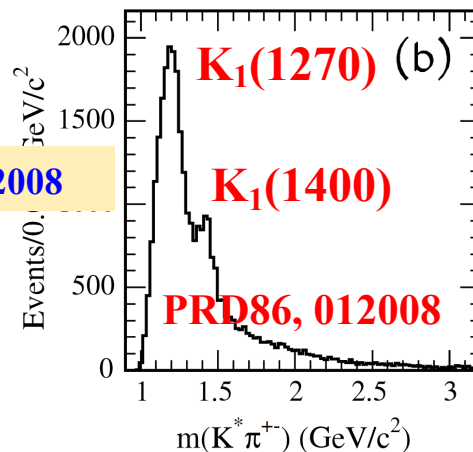
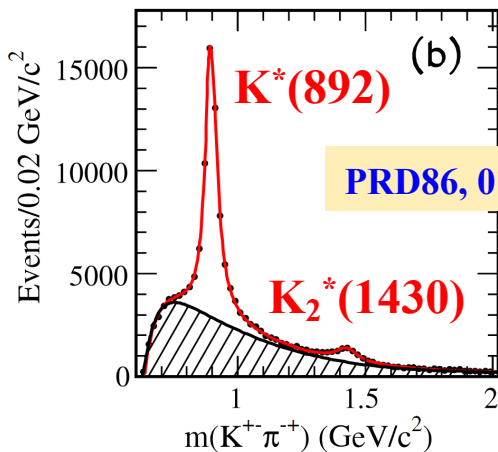
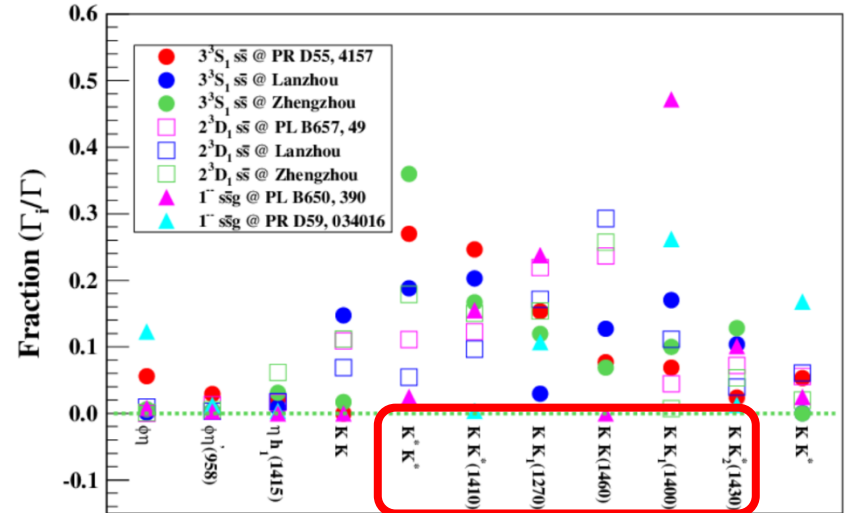
➤ $e^+e^- \rightarrow \text{KK}\pi\pi$: important to distinguish $\phi(2170)$ theory models

- ✓ K^*K^* : $s\bar{s}g$ (unfavored), 3^3S_1 (favored)
- ✓ $\text{KK}_1(1400)$: $s\bar{s}g$ (favored)
- ✓ $\text{KK}(1460)$: $s\bar{s}g$ (unfavored), 2^3D_1 (favored)

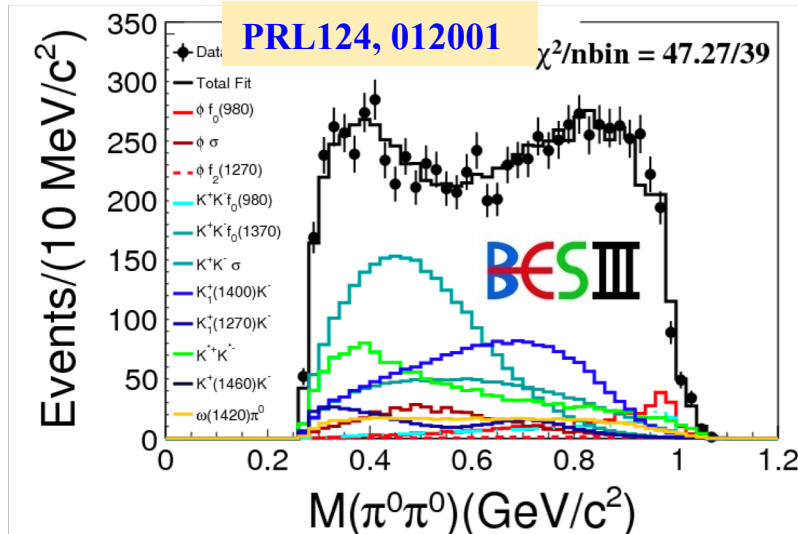
➤ BaBar: $\text{K}^*(892)$, $\text{K}_2^*(1430)$, $\text{K}_1(1270)$ and $\text{K}_1(1400)$

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

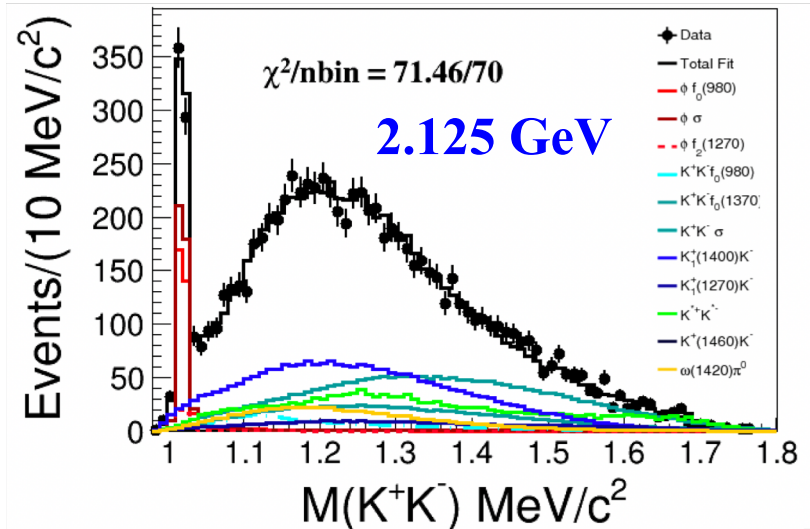
- ✓ BES: 58M J/ψ , an upper limit of $\text{Br}(\text{J}/\psi \rightarrow \eta\phi(2170))$.



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

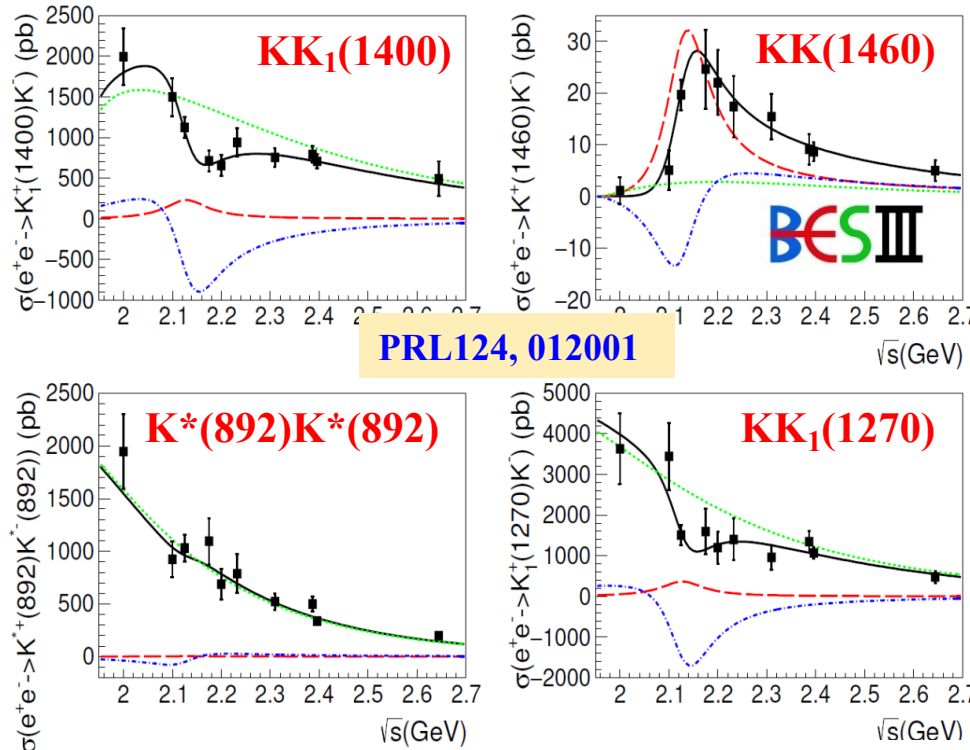


process	Significance (2.1250 GeV)	Significance (2.3960 GeV)
$\phi f_0(980)$	$>8.0 \sigma$	$>8.0 \sigma$
$\phi \sigma$	$>8.0 \sigma$	–
$\phi f_2(1270)$	5.0σ	–
$\phi f_0(1370)$	–	6.9σ
$K^{*+}(892)K^{*-}(892)$	$>8.0 \sigma$	$>8.0 \sigma$
$K^+(1460)K^-$	$>8.0 \sigma$	6.4σ
$K_0^{*+}(1430)K^{*-}(892)$	$>8.0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



- 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

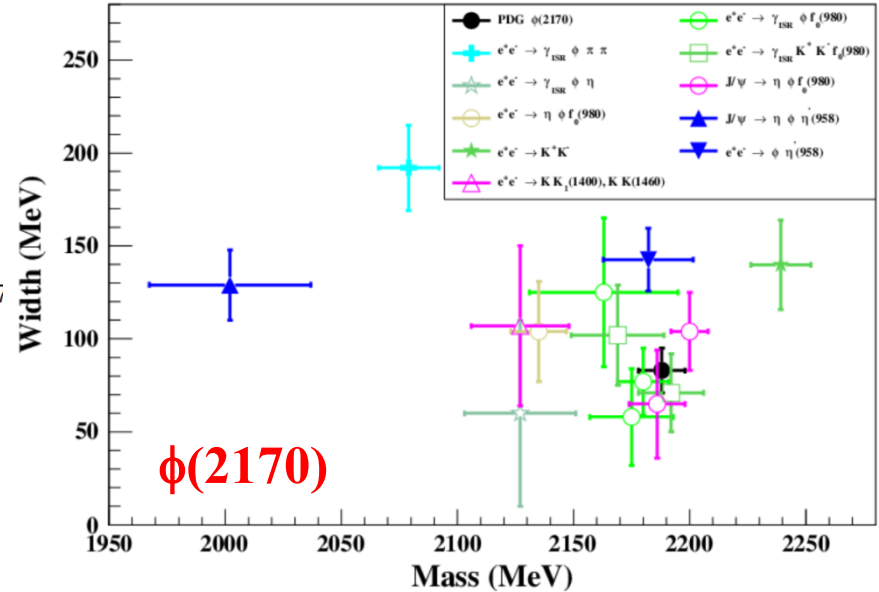


Table 22: Fitting parameters.

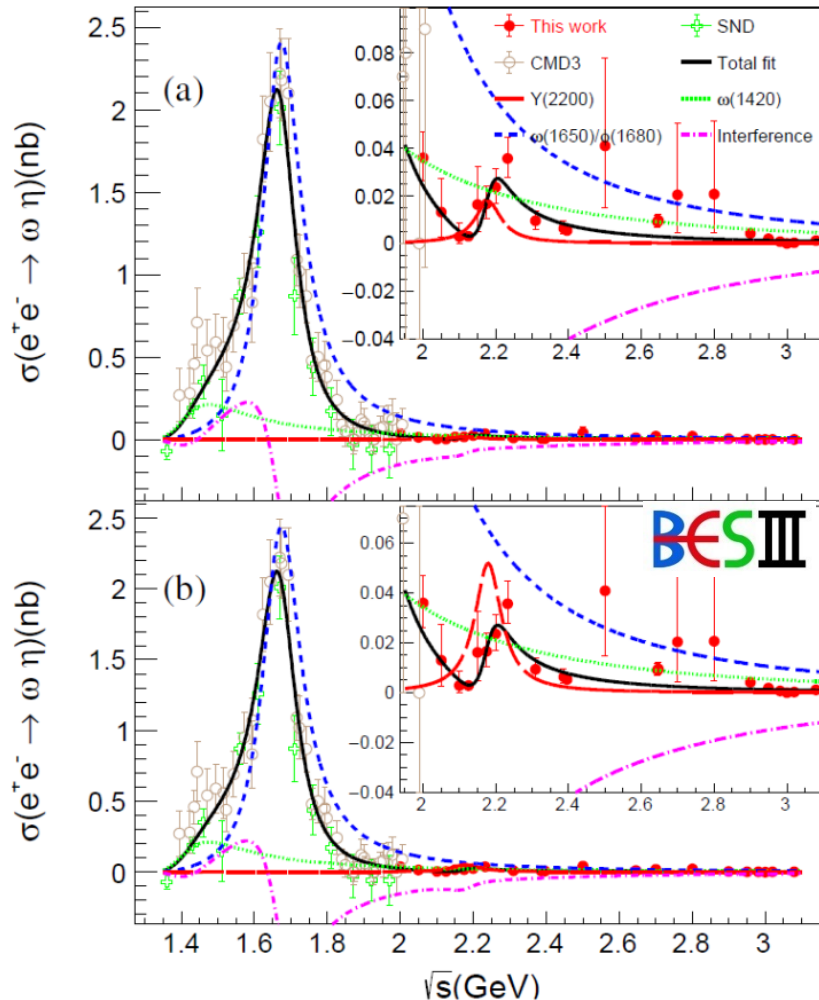
channel	$e^+e^- \rightarrow K_1^+(1400)K^-$	$e^+e^- \rightarrow K^+(1460)K^-$	$e^+e^- \rightarrow K_1^+(1270)K^-$	$e^+e^- \rightarrow K^{*+}K^{*-}$
Mass (MeV/c ²)	2126.5 ± 16.8			
Width (MeV)	106.9 ± 32.1			
	Solution1	Solution2	Solution1	Solution2
$\mathcal{B}_R \Gamma^{e^+e^-}$ (eV)	7.6 ± 3.7	152.6 ± 14.2	4.7 ± 3.3	98.8 ± 7.8
ϕ (rad)	3.7 ± 0.4	4.5 ± 0.3	4.0 ± 0.2	4.5 ± 0.1
Significance(σ)	4.8		1.4	
			1.2	

- ✓ 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)



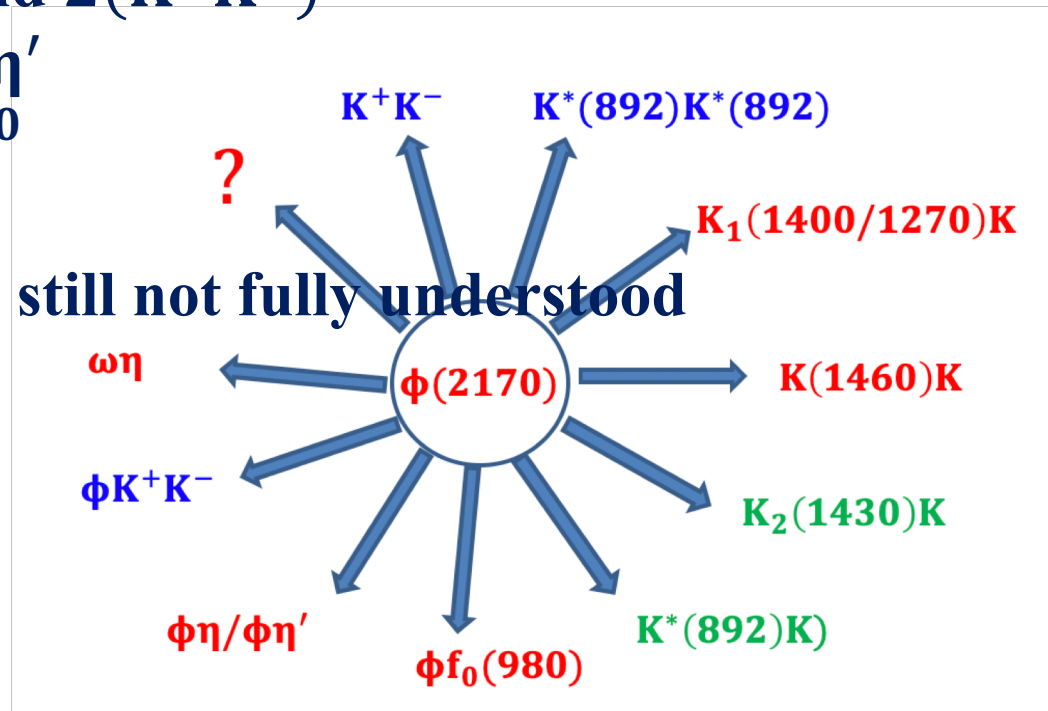
- The η has $s\bar{s}$ component
- ✓ Isospin zero: ω^* and ϕ^*
- ✓ $\phi(2170) \rightarrow \omega\eta$: **Yes ?**

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

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



Back up

