



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

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## The strange quarkonium



- Compared with cc, ss is poorly known.
- There are XYZ particles with charm & bottom quark, how about strange quark ?
- The strange quark has intermediate mass,  $s\bar{s}$  serves as bridge between light and heavy quark. 2

### **φ(2170)/Y(2175)**



# The nature $\phi(2170)$

 $\Gamma_1$ 

 $\Gamma_5$ 

#### Published measurements

- ✓ Limited decay modes
- ✓ Inconsistence on mass & width  $\begin{bmatrix} r_2 \\ r_3 \\ r_4 \end{bmatrix}$

#### > Theorists explain $\phi(2170)$ as

- $\checkmark 2^{3}D_{1} \text{ or } 3^{3}S_{1} s\bar{s}$
- ✓ ssg hybrid
- ✓ tetraquark
- $\checkmark$  molecular state  $\Lambda\overline{\Lambda}$
- $\checkmark \phi f_0(980)$  resonance with FSI
- ✓ Three body system **φKK**
- Not fully understood

# $\begin{array}{c|c} \phi(2170) \text{ DECAY MODES} \\ \hline \text{Mode} & \text{Fraction } (\Gamma_i/\Gamma) \\ \hline e^+ e^- & \text{seen} \\ \phi \eta & \\ \phi \pi \pi & \\ \phi f_0(980) & \text{seen} \\ K^+ K^- \pi^+ \pi^- & \\ K^+ K^- f_0(980) \rightarrow K^+ K^- \pi^+ \pi^- & \text{seen} \end{array}$

 $\begin{array}{ll} \Gamma_{6} & K^{+}K^{-}f_{0}(980) \rightarrow & K^{+}K^{-}\pi^{+}\pi^{-} & \text{seen} \\ \Gamma_{7} & K^{+}K^{-}\pi^{0}\pi^{0} & & \\ \Gamma_{8} & K^{+}K^{-}f_{0}(980) \rightarrow & K^{+}K^{-}\pi^{0}\pi^{0} & \text{seen} \\ \Gamma_{9} & K^{*0}K^{\pm}\pi^{\mp} & & \text{not seen} \\ \Gamma_{10} & K^{*}(892)^{0}\overline{K}^{*}(892)^{0} & & \text{not seen} \end{array}$ 



# The nature $\phi(2170)$

<b>\$(2170)</b>	Mass (MeV)	Width (MeV)
3 <sup>3</sup> S <sub>1</sub>	2050	378
<b>3</b> 3D		167.21
2° <b>D</b> <sub>1</sub>		211.9
hybrid	2100-2200	148.7
nybrid	2500-2600	155
		120
	$2210 \pm 90$	
sīsīs	$2300 \pm 400$	
	2176	
$\Lambda\overline{\Lambda}$		80.1-95
PDG	$2188 \pm 10$	83±12



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

# The nature $\phi(2170)$

#### **Decay Mode**





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

#### φ(2170) MASS

VALUE (MeV	)	EVTS	DOCUMENT ID		TECN	COMMENT
2159 ±17	OUR /	AVERAGE	Error includes sca	le fac	tor of 1.	4. See the ideogram below
$2176 \pm 24$	↓ ± 3		<sup>1</sup> ABLIKIM	21A	BES3	$e^+e^- \rightarrow \omega \eta$
$2177.5\pm4$	$1.8 \pm 19.5$		<sup>2</sup> ABLIKIM	20M	BES3	$e^+e^- \rightarrow \eta' \phi$
$2126.5 \pm 16$	$5.8 \pm 12.4$		<sup>3</sup> ABLIKIM	20s	BES3	$e^+e^- \rightarrow K^+K^-\pi^0\pi^0$
• • • We	do not us	e the follov	ving data for averag	ges, fi	ts, limits	, etc. ● ● ●
2135 ± 8	$3 \pm 9$	95	ABLIKIM	19	BES3	$e^+e^- \rightarrow \eta \phi f_0(980)$
2239.2± 7	7.1±11.3		<sup>4</sup> ABLIKIM	19L	BES3	$e^+e^- \rightarrow K^+K^-$
$2200 \pm 6$	$5 \pm 5$	471	ABLIKIM	15H	BES3	$J/\psi \rightarrow \eta \phi \pi^+ \pi^-$
$2180 \pm 8$	$3 \pm 8$		<sup>5,6</sup> LEES	12F	BABR	10.6 $e^+e^- \rightarrow$
						$\phi \pi^+ \pi^- \gamma$
$2079 \pm 13$	$^{+79}_{-28}$	4.8k	<sup>7</sup> SHEN	09	BELL	10.6 $e^+e^- \rightarrow$
0106 1 10		50		00-	DEC	$K^+K^-\pi^+\pi^-\gamma$
$2180 \pm 10$	$1 \pm 6$	52	ABLIKIM	08F	BES	$J/\psi \rightarrow \eta \phi f_0(980)$
$2125 \pm 22$	$2 \pm 10$	483	AUBERT	08S	BABR	10.6 $e^+e^- \rightarrow \phi \eta \gamma$
$2192 \pm 14$	ļ	116	<sup>8</sup> AUBERT	07Ak	BABR	10.6 $e^+e^- \rightarrow$
						$K^+K^-\pi^+\pi^-\gamma$
$2169 \pm 20$	)	149	<sup>8</sup> AUBERT	07AF	BABR	$10.6 e^+ e^- \rightarrow \mu^+ \mu^- = 0 = 0 = 0$
2175 + 10	) + 15	201	6.9 ALIBERT RE	060	BABB	$10.6 e^{\pm}e^{-} \rightarrow$
2113 110	, 11	201	AUDENT, DE	000	DADK	$K^+K^-\pi\pi\gamma$

Pr	rocess	ssg	3 <sup>3</sup> S <sub>1</sub>	$2^{3}D_{1}$	tetraquark
	<b>K</b> * <b>K</b> *	forbidden	favored		
ΚΚππ	<b>KK</b> <sub>1</sub> (1400)	favored			
	<b>KK(1460)</b>	suppressed		favored	
	φη			suppressed	favored
ηh <sub>1</sub>	(1380)	suppressed			
]	KK	suppressed			

#### Data used in this talk



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



 $\succ$  1<sup>--</sup> ssg hybrid has large  $\Gamma_{\phi_{\eta}}$  and smaller  $\Gamma_{\phi_{\eta'}}$ 

1- s <b>⊽</b> g	alt	2.2GeV	standard	IKP	Ding
		PRD59	9, 034016		PLB650,390
Φη	2	19	11	3	1.2
<b>Φ</b> η′	0.01	2	0.1	0.02	0.4
$Br(\varphi\eta)/Br(\varphi\eta')$	200	9.5	110	150	3

8

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





🔶 ф(2170)@фη

- $\checkmark$  M= 2163.5  $\pm$  6.2  $\pm$  3.0 MeV/c<sup>2</sup>
- ✓ Γ= 31. 1<sup>+21.1</sup><sub>-11.6</sub>±1.1 MeV
- ✓ Significance:  $6.9\sigma$
- ✓ M= 2177.5±4.8±19.5 MeV/c<sup>2</sup>
   Γ= 149.0±15.6±8.9 MeV
- ✓ Significance: >  $10\sigma$

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

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

> If we observed  $\phi(2170)$  in e<sup>+</sup> e<sup>-</sup>  $\rightarrow \phi \eta', \phi(2170)$  as a 1<sup>--</sup> s $\overline{s}g$ ?

1 s <b>⊽</b> g	alt	2.2GeV	standard	IKP	Ding
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≻ KK @ φ(2170)

- ✓ Obvious discrepancy between different theory models
- ✓ isoscalar:  $\omega^*/\phi^*$ ; isovector:  $\rho^*$

#### PRD96, 074027

$\phi(2170)$ decay	This work	${}^{3}P_{0}$ model	Data [5]
	${}^{3}S_{1}\Lambda\Lambda$	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		$83 \pm 12$



M =2239.2  $\pm$  7.1  $\pm$  11.3 MeV/c<sup>2</sup>  $\Gamma$  =139.8  $\pm$  12.3  $\pm$  20.6 MeV

M =2273.7  $\pm$  5.7  $\pm$  19.3 MeV/c<sup>2</sup>  $\Gamma$  =86  $\pm$  44  $\pm$  51 MeV Significance: 7.5 $\sigma$ 

The mass and width are consistent within errors!

# $e^+e^- \rightarrow K^+K^-/K_SK_L$



Large discrepancy with other decay models
 K<sup>+</sup>K<sup>-</sup> resonance maybe a ρ(2150)

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

# → e<sup>+</sup>e<sup>-</sup> → KKππ: important to distinguish $\phi(2170)$ theory models <br/> ✓ K\*K\*: ss̄g (unfavored), 3<sup>3</sup>S<sub>1</sub> (favored) <br/> ✓ KK<sub>1</sub>(1400): ss̄g (favored) <br/> ✓ KK(1460): ss̄g (unfavored), 2<sup>3</sup>D<sub>1</sub> (favored) <br/> ✓ BaBar: K\*(892), K<sub>2</sub>\*(1430), <br/> K<sub>1</sub>(1270) and K<sub>1</sub>(1400) <br/> </br>



 $\searrow J/\psi \to \eta \phi(2170) \to \eta K^* K^*$  $\checkmark$  BES: 58M J/ $\psi$ , an upper limit of Br(J/ $\psi \to \eta \phi(2170)$ ).



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



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 <i>σ</i>

- A PWA for multi-energy points
  @ [2.0, 2.644]GeV
- ➤ There is no significant signal of e<sup>+</sup>e<sup>-</sup>→KK<sup>\*</sup>(1410)

Extract Born cross section of intermediate states

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



✓ Blue dash-dotted: interference

φ(2170) -> K K<sub>1</sub>(1400) and K K(1460): Yes ? <sup>16</sup>

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



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



0.1

 $0.0^{E}_{2.2}$ 

**e**<sup>+</sup>

 $\sqrt{s}$  (GeV)

2.4

2.5

2.3

> More ideas ?

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



# ➤ The η has ss component ✓ Isospin zero: $ω^*$ and $φ^*$ ✓ φ(2170) → ω η: Yes ?

Parameters	Solution I	Solution II
$m_{Y(2180)} (MeV/c^2)$	2176	$\pm 24$
$\Gamma_{Y(2180)}$ (MeV)	89 =	± 50
$\Gamma^{ee} \cdot B^{\omega\eta}$ (eV)	$0.43\pm0.15$	$1.25\pm0.48$
arphi	$2.6\pm0.3$	$1.9\pm0.2$
significance	6.2	2σ

PDG	Mass [MeV/ $c^2$ ]	Width [MeV]
$\omega(2205)$	$2205\pm30$	$350\pm90$
$\omega(2290)$	$2290\pm20$	$375\pm35$
$\omega$ (2330)	$2330\pm30$	$435\pm75$

### **Summary and outlook**

- > Compared with  $c\bar{c}$ ,  $s\bar{s}$  is a terra incognita
- > Lots of progress in study  $\phi(2170)$  at BESIII
  - $\checkmark e^+e^- \rightarrow K^+K^-/K_SK_L$
  - $\checkmark e^+e^- \rightarrow \varphi K^+K^-$  and  $2(K^+K^-)$
  - $\checkmark e^+e^- \rightarrow \varphi \eta$  and  $\varphi \eta'$
  - $\checkmark e^+e^- \rightarrow K^+K^-\pi^0\pi^0$
  - $\checkmark e^+e^- \rightarrow \omega \eta$

Aspects of φ(2170) are still not fully understood. More studies needed, some ongoing at BESIII.



Thanks for your attention !

#### Back up





