Experimental study of ϕ(2170)

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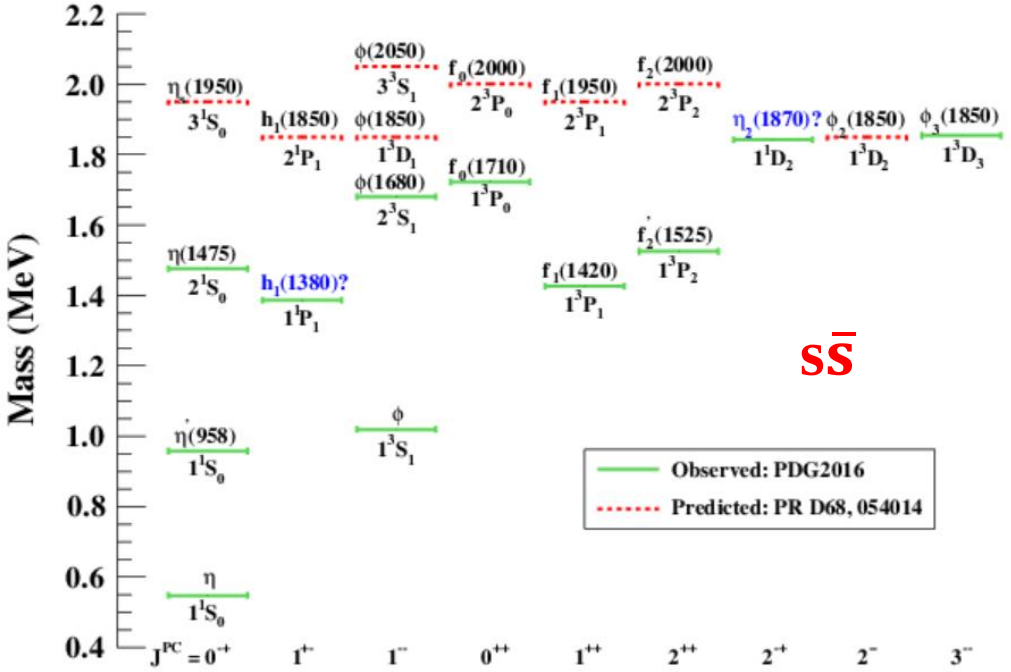
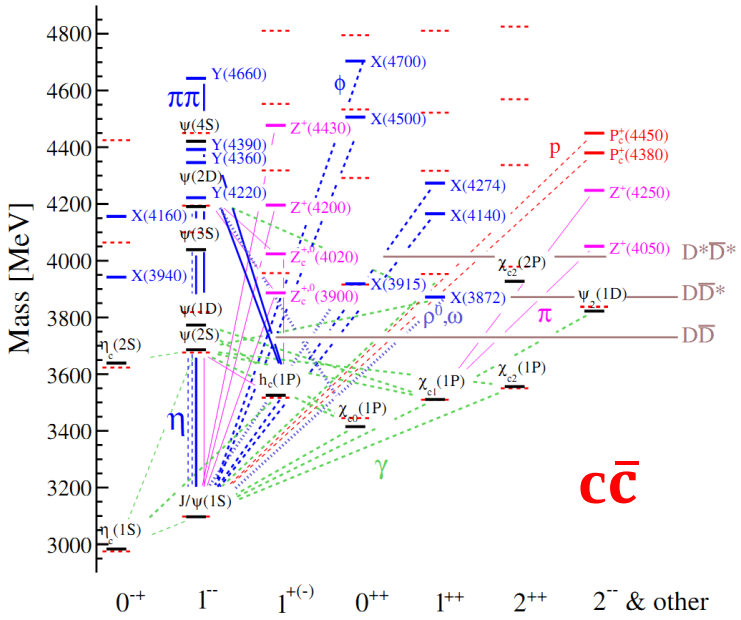
For BESIII Collaboration

- **Why do we study ϕ(2170) ?**
- **How to study ϕ(2170) ?**
- **Status of ϕ(2170) @ experiment**
- **Summary and outlook**

中国物理学会高能物理分会第十届全国会员代表大会暨学术年会

Strange quarkonium



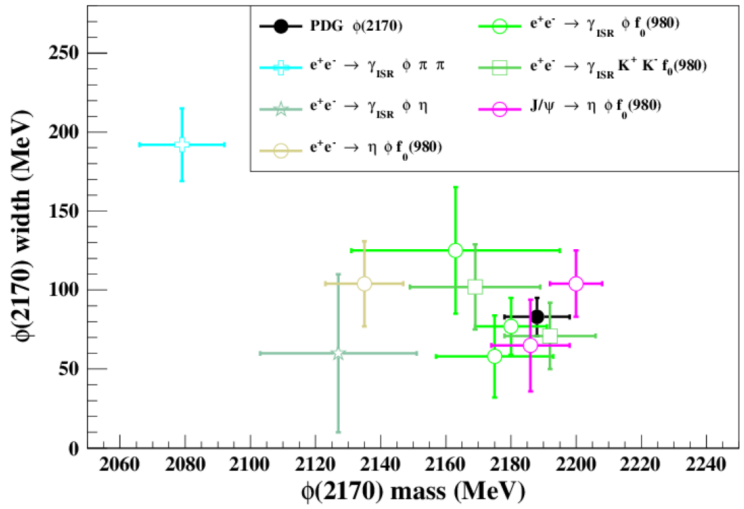


- Compared with $c\bar{c}$ and $b\bar{b}$, $s\bar{s}$ is a terra incognita
- Strange quarkonium is the bridge between lighter quark sector and charmonium & bottonium
- Difficulty: small mass, $s\bar{s}$ and $n\bar{n}$

$\phi(2170)$

PDG $\phi(2170)$ DECAY MODES

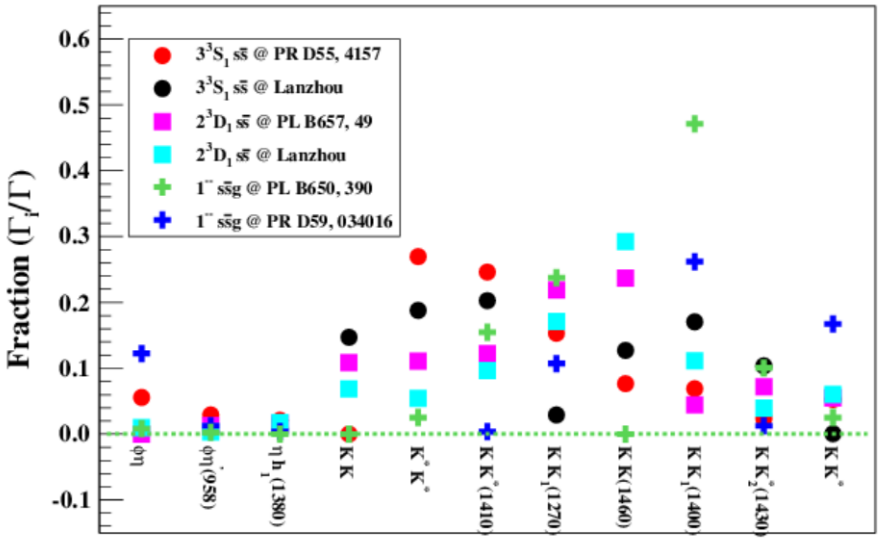
	Mode	Fraction (Γ_i/Γ)
Γ_1	e^+e^-	seen
Γ_2	$\phi\eta$	
Γ_3	$\phi\pi\pi$	
Γ_4	$\phi f_0(980)$	seen
Γ_5	$K^+K^-\pi^+\pi^-$	
Γ_6	$K^+K^-f_0(980) \rightarrow K^+K^-\pi^+\pi^-$	seen
Γ_7	$K^+K^-\pi^0\pi^0$	
Γ_8	$K^+K^-f_0(980) \rightarrow K^+K^-\pi^0\pi^0$	seen
Γ_9	$K^{*0}K^{\pm}\pi^{\mp}$	not seen
Γ_{10}	$K^*(892)^0\overline{K}^*(892)^0$	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**
- **aspects of $\phi(2170)$ are still not fully understood.**

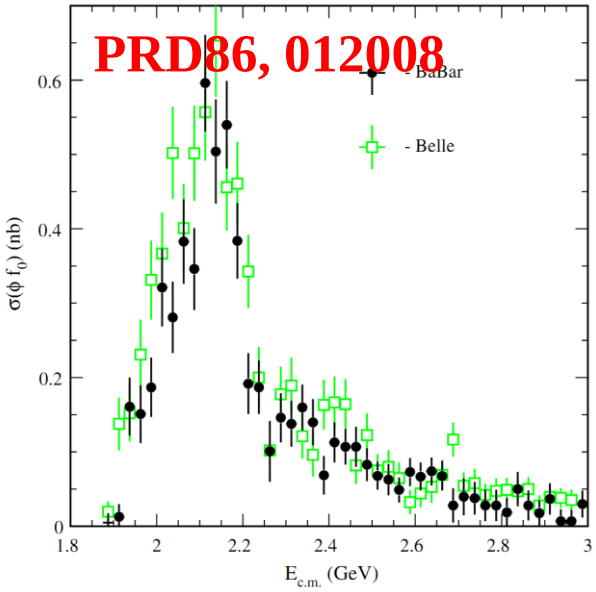
$\phi(2170)$

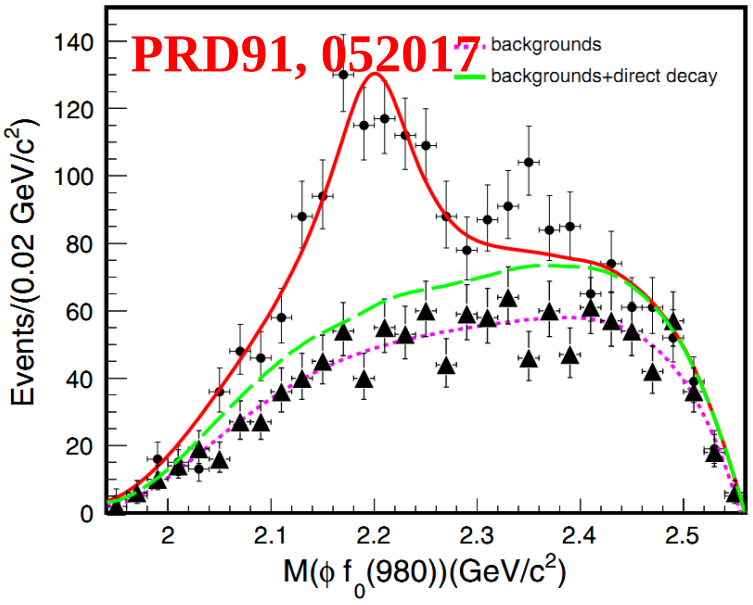
$\phi(2170)$	Mass (MeV)	Width (MeV)
3^3S_1	2050	378
2^3D_1		167.21
		211.9
hybrid		148.7
		155
		120
	2100-2200	
	2500-2600	
$s\bar{s}s\bar{s}$	2210±90	
	2300±400	
	2176	
$\Lambda\bar{\Lambda}$		80.1-95
PDG	2188±10	83±12

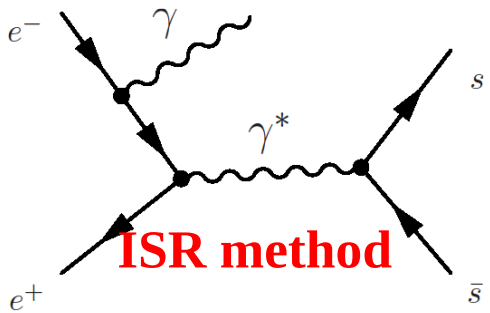


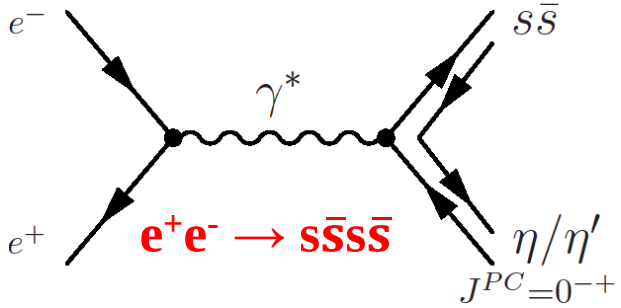
- KK$\pi\pi$: benchmark process
  - ✓ K*K*: s$\bar{s}$g (forbidden), 3^3S_1 (favored)
  - ✓ KK$_1$(1400): s$\bar{s}$g (favored)
  - ✓ KK(1460): s$\bar{s}$g (forbidden), 2^3D_1 (favored)
- $\phi\eta$: 2^3D_1 (forbidden), tetraquark (favored)
- $\Phi\eta$': tetraquark (favored)
- $\eta h_1(1380)$: s$\bar{s}$g (forbidden)
- KK: s$\bar{s}$g (forbidden), $^3S_1\Lambda\bar{\Lambda}$ (favored)

ϕ(2170) @ ISR method

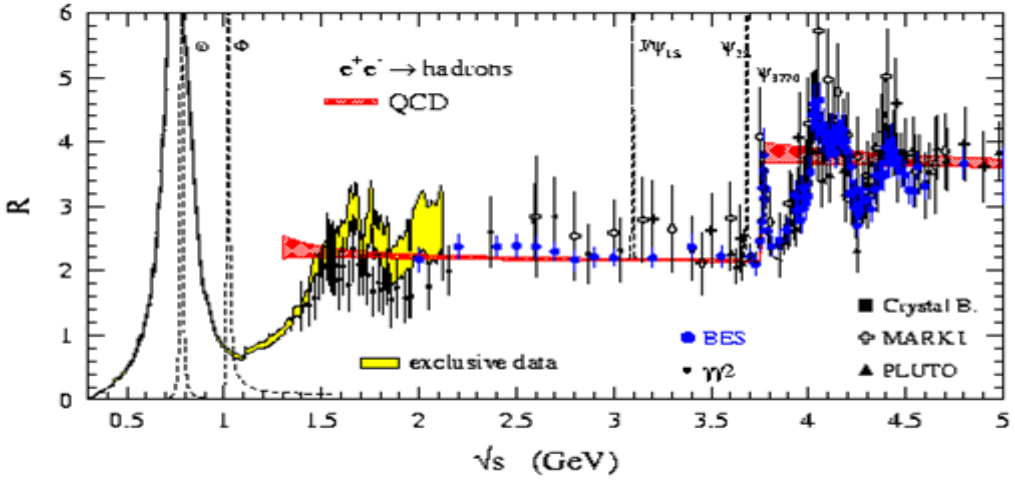


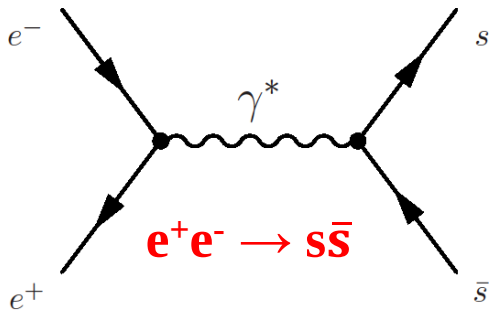


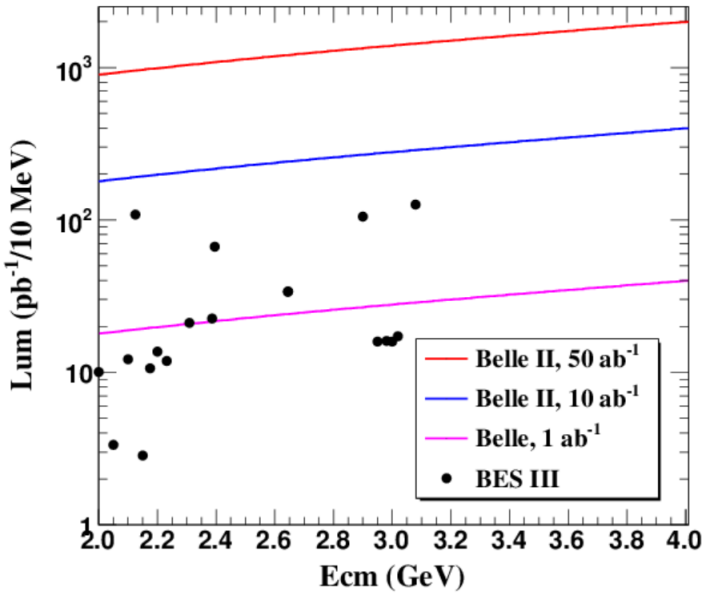




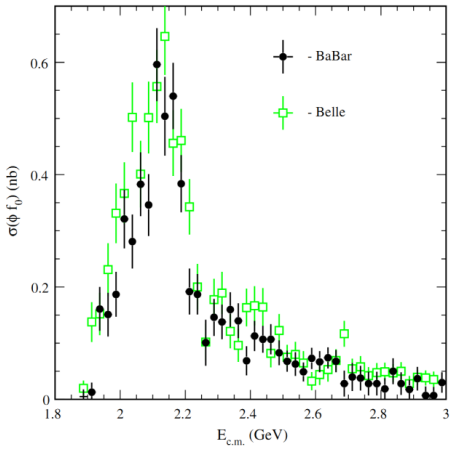
ϕ(2170) @ energy scan method

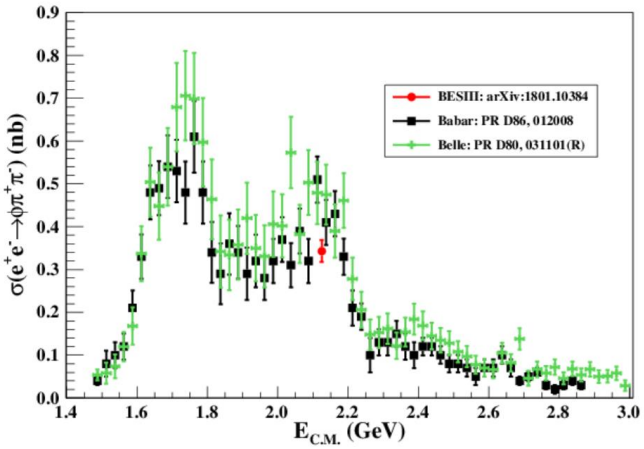


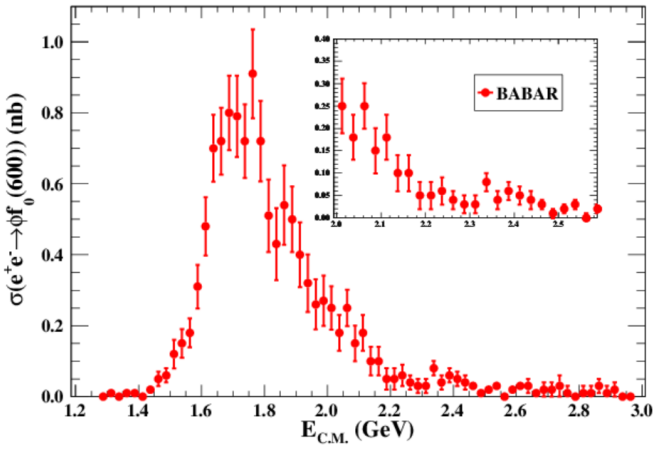




$e^+ e^- \to \phi f_0(980), \phi\pi\pi, \phi f_0(600)$

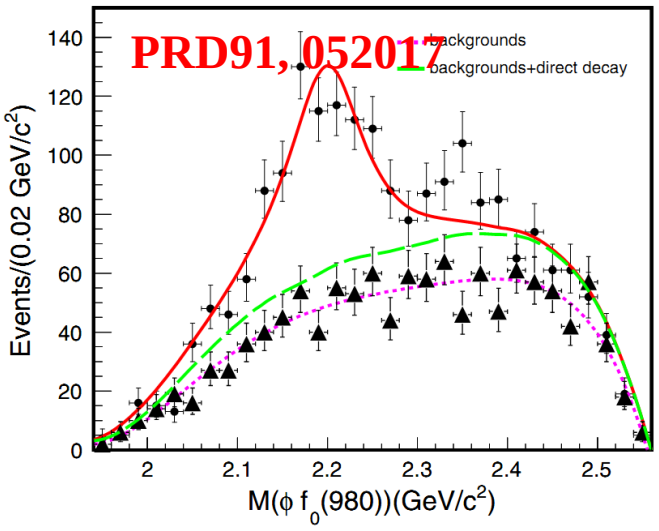


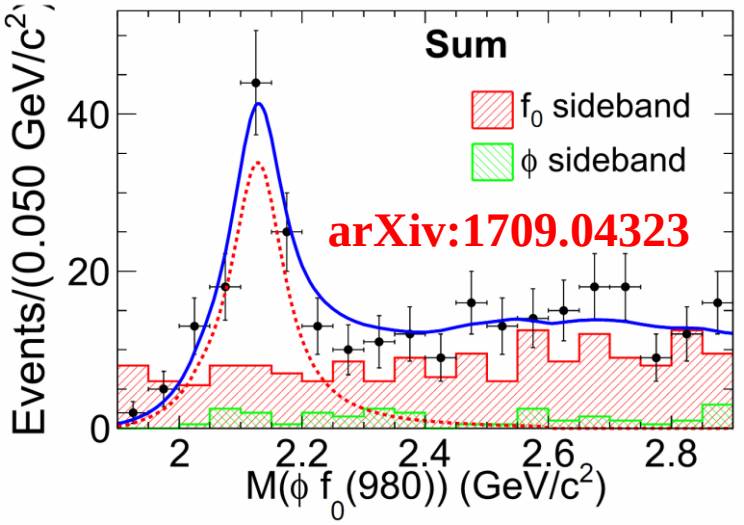




- Select $f_0(980)$ by $0.85 < m_{\pi\pi} < 1.1$GeV
  - ✓ About 10% non-$\phi f_0(980)$ count as $\phi f_0(980)$ signal
- $\phi(2170)$ mass & width
  - ✓ $\phi\pi\pi$: M=2.079 ± 0.013 GeV; Γ =0.192 ± 0.023GeV
  - ✓ $\phi f_0(980)$: M=2.163 ± 0.032 GeV; Γ =0.125 ± 0.040GeV
- select $f_0(600)$ with $m_{\pi\pi} < 0.85$ GeV
  - ✓ $\phi(1680) \to \phi f_0(600)$: Yes; $\phi(2175) \to \phi f_0(600)$: No

$e^+ e^- \to \eta \phi f_0(980)$

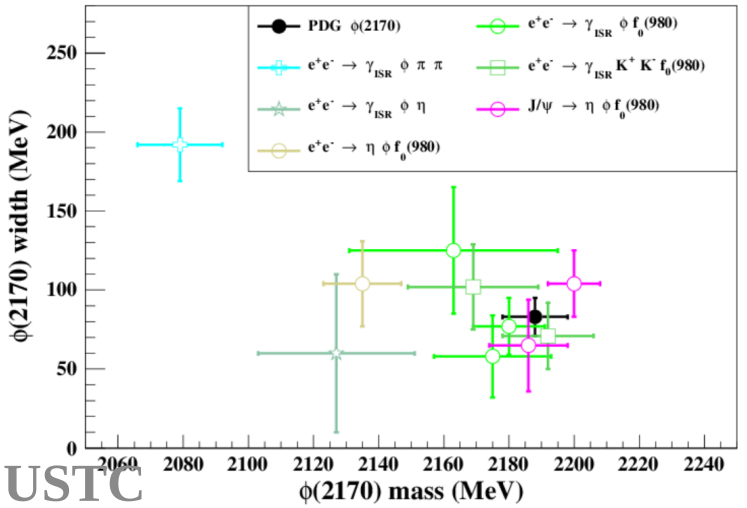




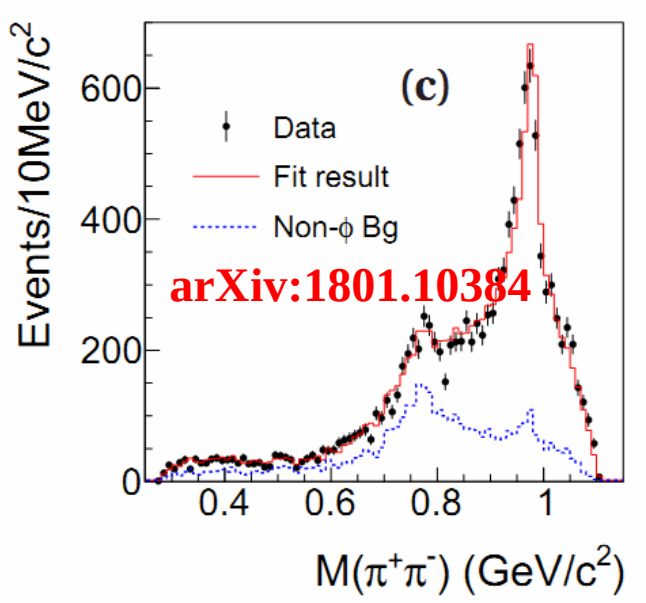
- $\phi f_0(980)$ @ $J/\psi \to \eta \phi f_0(980)$
- $\phi f_0(980)$ @ $e^+ e^- \to \eta \phi f_0(980)$

with $\sqrt{s}$ = [3.773, 4.600]GeV

- apply sideband method for non- $\phi f_0(980)$ events



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

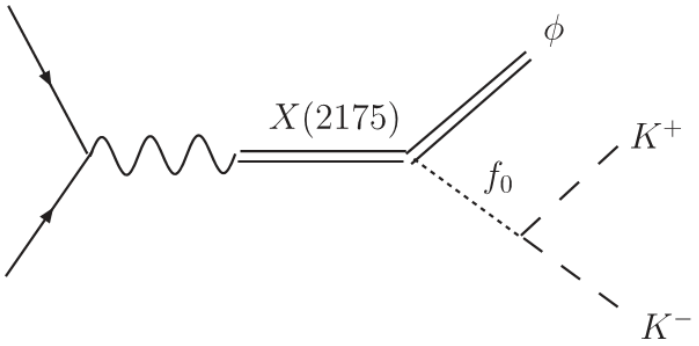


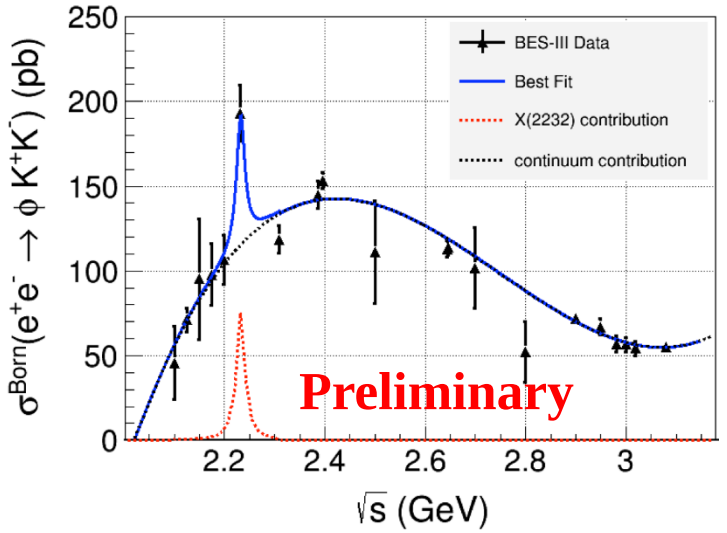
Data set	$\sqrt{s}$ (GeV)	Luminosity (pb^{-1})
1	2.0000	10.074
2	2.0500	3.343
3	2.1000	12.167
4	2.1250	108.490
5	2.1500	2.841
6	2.1750	10.625
7	2.2000	13.699
8	2.2324	11.856
9	2.3094	21.089
10	2.3864	22.549
11	2.3960	66.869
12	2.6444	33.722
13	2.6464	34.003
14	2.9000	105.253
15	2.9500	15.942
16	2.9810	16.071
17	3.0000	15.881
18	3.0200	17.290
19	3.0800	126.185

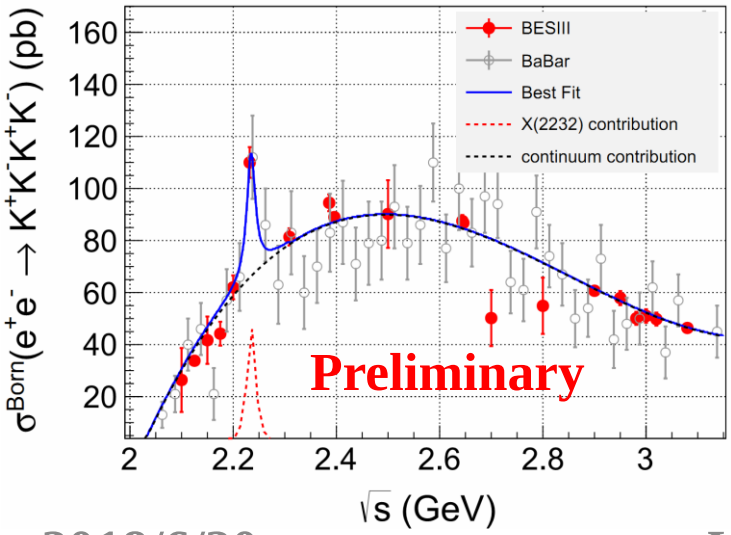
- **$\phi\,\pi\,\pi$ @ $\sqrt{s}$ = 2.125GeV for Z_s**
- **$\pi\,\pi$ invariant mass: $f_0(600)$, $f_0(800)$, tail from $f_0(1370)$, $f_2(1270)$**
- **PWA of $\phi\,\pi\,\pi$ @ [2.00, 3.08] GeV**

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

- **$\phi(2170)$: resonant of ϕKK**

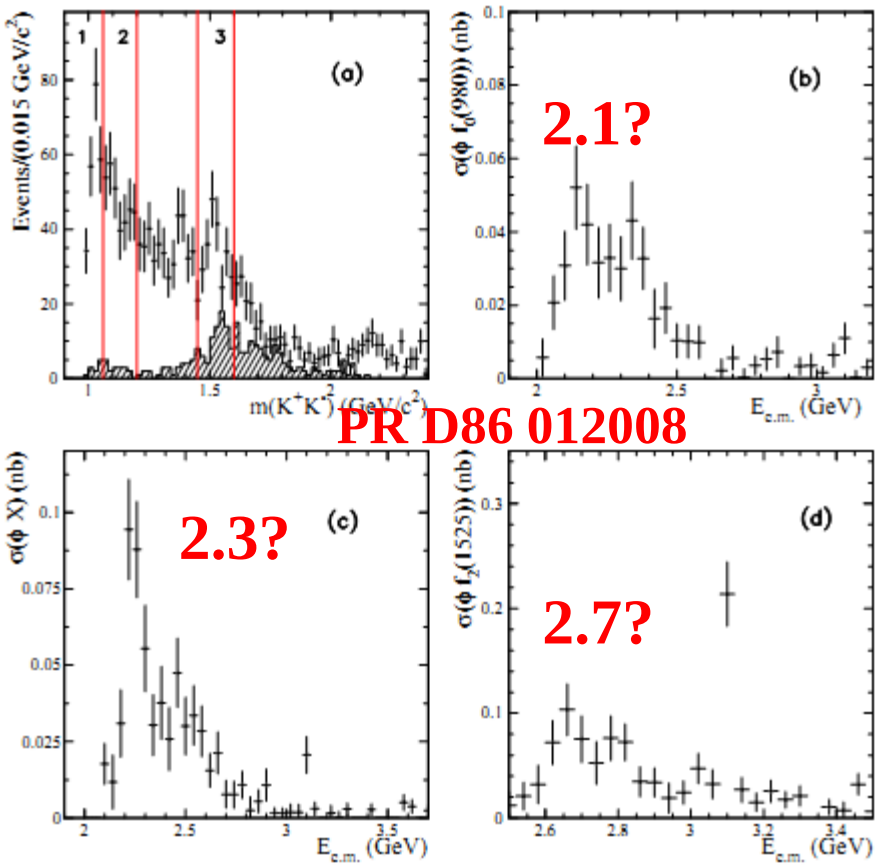






- **A hint for a resonance around $\Lambda\bar{\Lambda}$ threshold**
  - ✓ **Mass = 2232±3.5MeV;**
  - ✓ **Width = 7.5(+13.5) MeV**
- **Three body system ϕKK: ×**

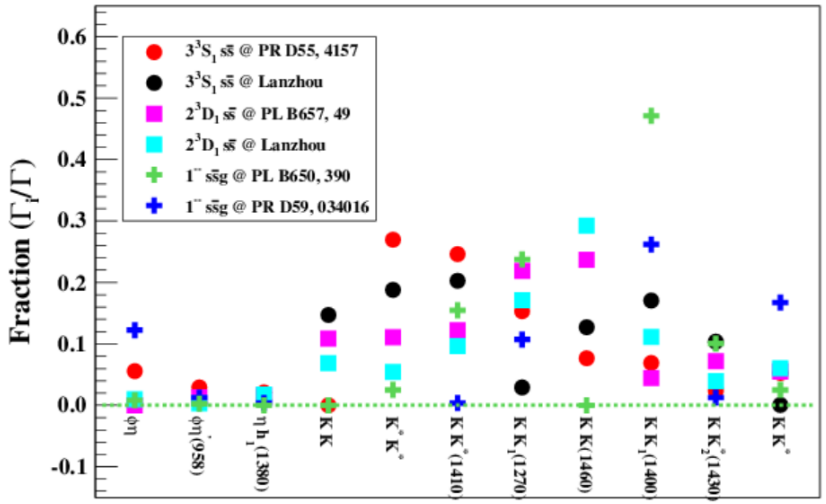
$e^+ e^- \to \phi K^+ K^-$



PR D86 012008

- m_{KK} @ ϕK+K-
  - ✓ (b) $m_{KK} < 1.06$GeV
  - ✓ (c) $1.06 < m_{KK} < 1.45$GeV
  - ✓ (d) $1.45 < m_{KK} < 1.6$GeV
- $\phi f_0(1370)$ and $\phi f_2'(1525)$
  - ✓ $\phi f_0(600)$: $\phi(1680)$
  - ✓ $\phi f_0(980)$: $\phi(2170)$

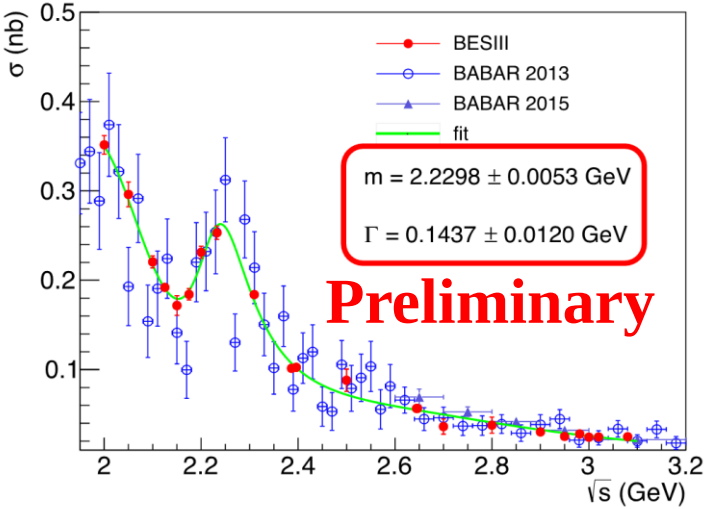
$e^+ e^- \rightarrow K^+ K^-$



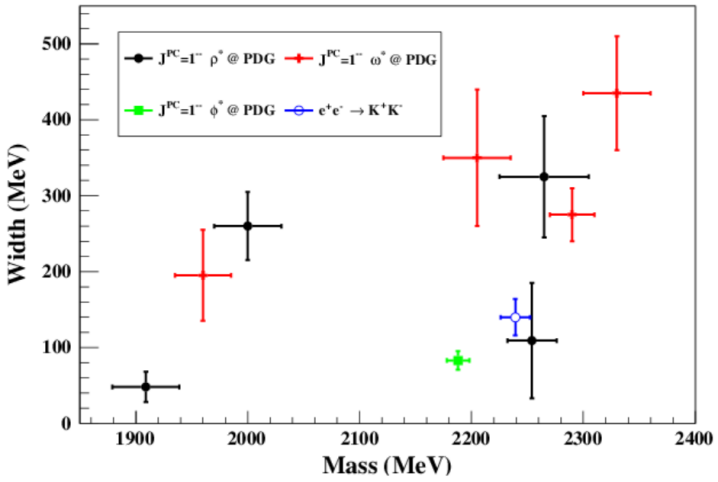
- K^+K^- @ $\phi(2170)$
  - ✓ Obvious discrepancy between different theory models
  - ✓ isoscalar: ω^*/ϕ^*; isovector: ρ^*
- $\sigma(e^+e^- \rightarrow K^+K^-)$ @ [2.0-3.08]GeV

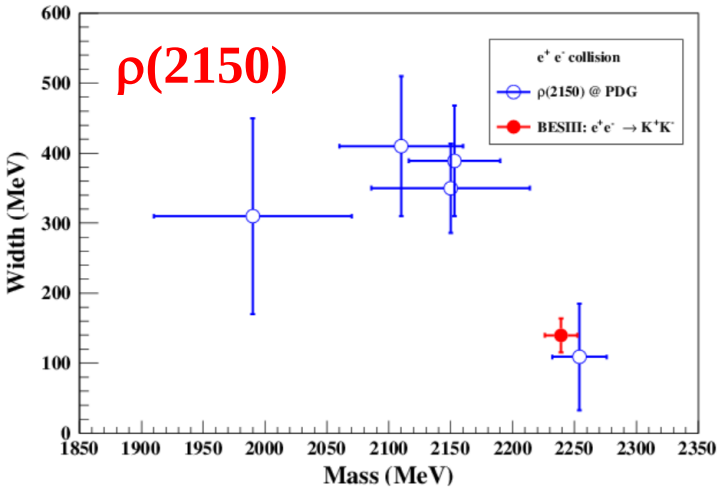
$\phi(2170)$ decay	This work $^3S_1\Lambda\bar{\Lambda}$	$^3P_0$ model within $s\bar{s}$ [10]	Data [5]
KK	73.8–87.7	...	...
$\phi f_0(980)$	0.25–0.3	<10	Seen
$\omega\sigma$	4.2–4.9	...	...
$K^*K_0^*(800)$	1.8–2.1	...	...
Total	80.1–95		83 ± 12

PRD96, 074027

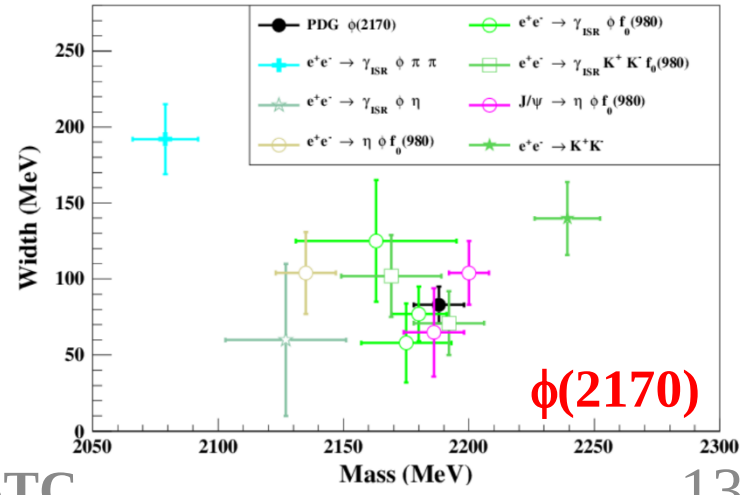


$e^+ e^- \rightarrow K^+ K^-$



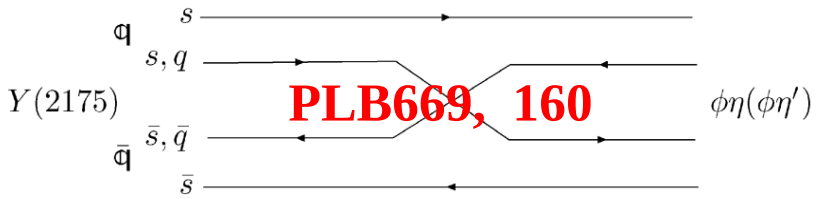


- Compare K^+K^- resonance
  - ✓ $J^{PC}=1^{--}$ vector: ω*/ϕ*/ρ*
  - ✓ ρ(2150) @ e^+e^- collision
  - ✓ ϕ(2150) experimental results
- K^+K^- resonance maybe a ρ(2150)
- ϕ(2170) → K^+ K^-: **NO**



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

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



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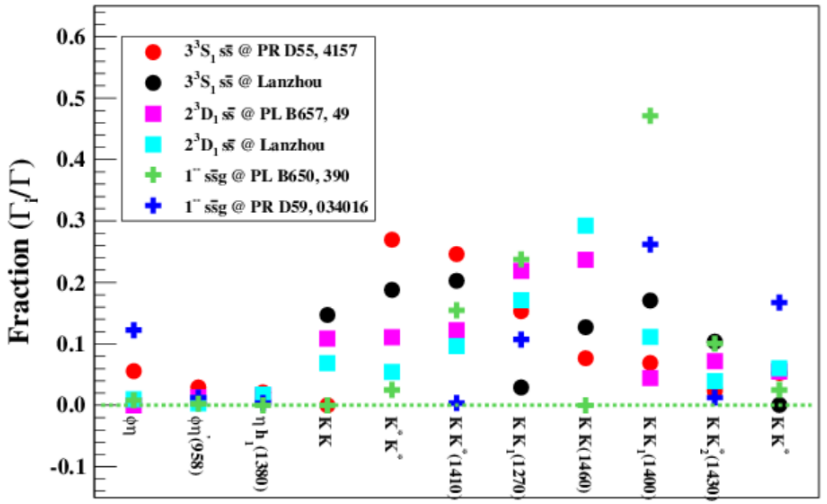
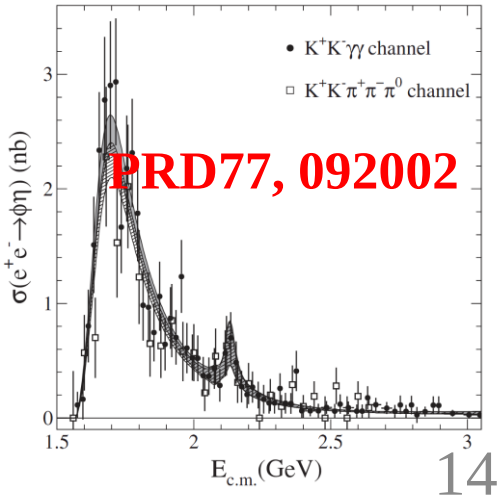


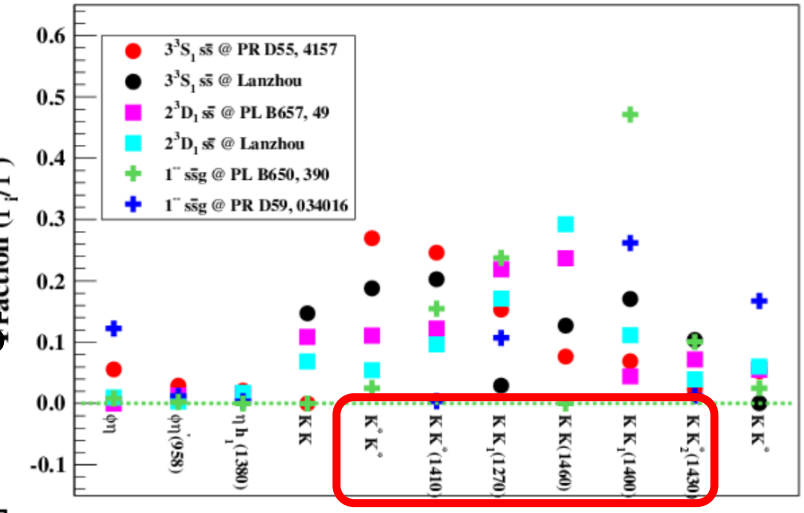
- BABAR measured $\phi\eta$ mode
  - ✓ ~50% stat. uncertainty around 2.2GeV
  - ✓ $Br_{\phi\eta}\Gamma_{ee}$ = 1.7±0.7±1.3eV
  - ✓ $Br_{\phi f0(980)}\Gamma_{ee}$ = 2.5±0.8±0.4eV
- Reviewd $\phi\eta$ and $\phi\eta'$ inside BESIII

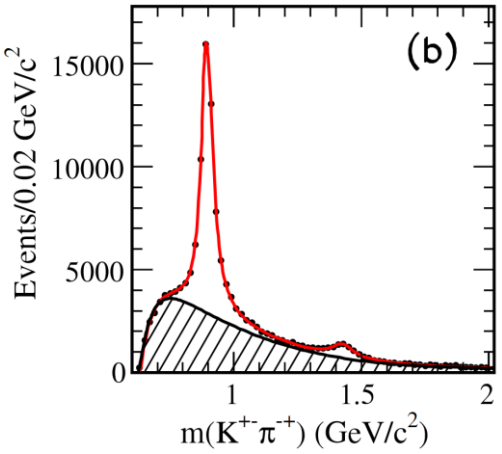


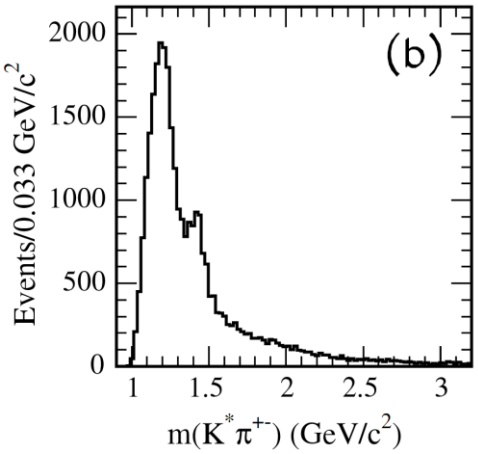
PRD77, 092002

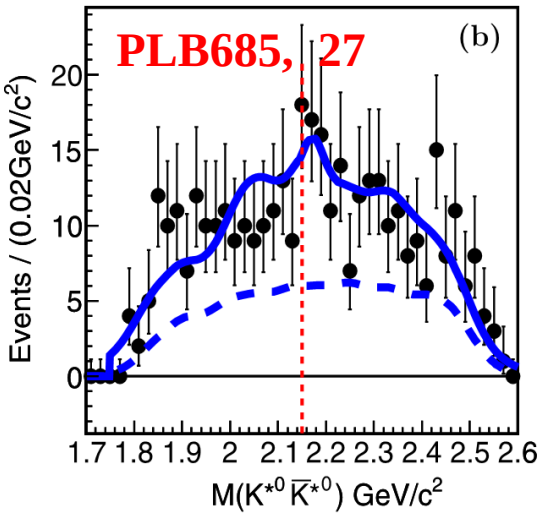
$e^+ e^- \to K K \pi \pi$

- $e^+e^- \to KK\pi\pi$: important to distinguish $\phi(2170)$ theory models
- BABAR: $K^*(892)$, $K_2^*(1430)$, $K_1(1270)$ and $K_1(1400)$
- $J/\psi \to \eta\phi(2170) \to \eta K^*K^*$ @ BES
- Broad K*, PWA @ R scan data









Analysis topics

Decay modes	
KK	$KK_2^*(1430)$
K^*K	$\phi\eta$
K^*K^*	$\phi\eta'$
KK(1460)	$h_1(1380)\eta$
$KK^*(1410)$	$\omega\eta$
$KK_1(1270)$	$\omega\eta'$
$KK_1(1400)$	$\rho\eta$

- Your suggestions are welcomed

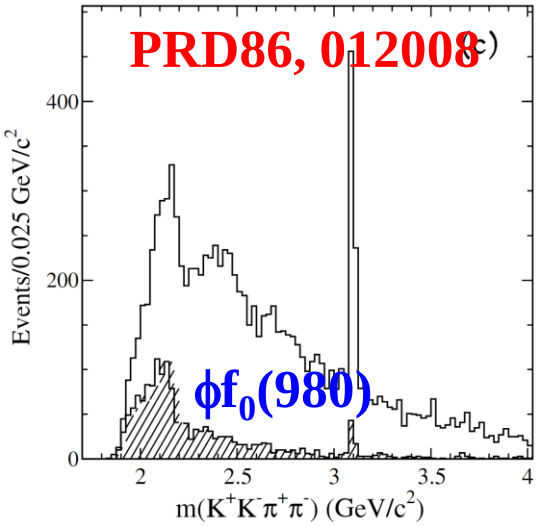
Summary and outlook

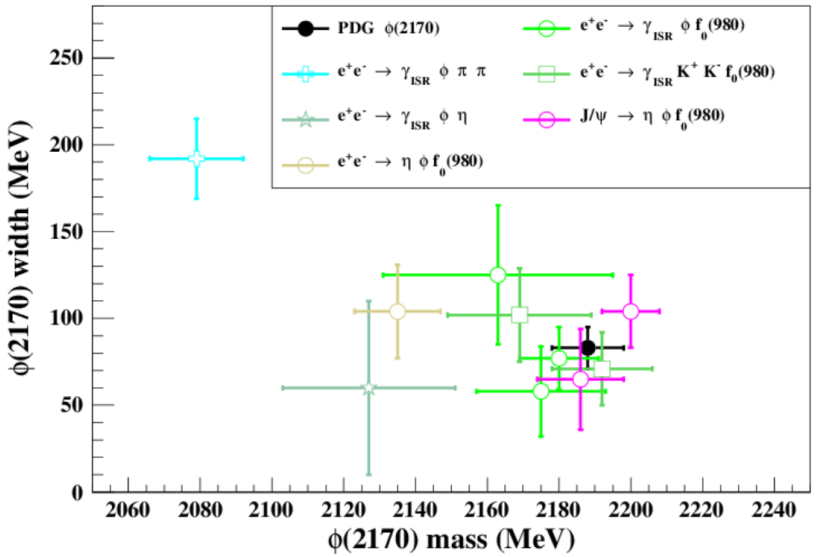
- Compared with $c\bar{c}$ and $b\bar{b}$, $s\bar{s}$ is a terra incognita
- Aspects of $\phi(2170)$ are still not fully understood
- Using BESIII R scan data, we are extensively studying $\phi(2170)$

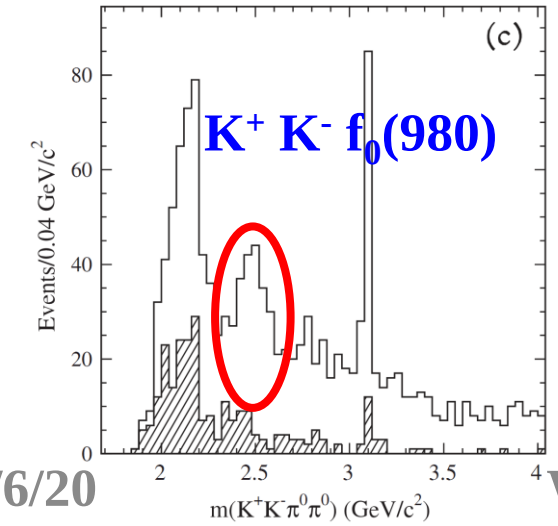
modes	$2^3D_1\ s\bar{s}$			$3^3S_1\ s\bar{s}$		$1^{--}\ s\bar{s}g$
MeV	$^3P_0$ model	Flux tube	Lanzhou	$^3P_0$ model	Lanzhou	Flux tube
KK	9.8	23.1	40.8	0	35.8	0
K^*K	1.3	11.7	35.8	20	0.1	3.7
K^*K^*	18.11	23.5	32.2	102	45.7	0
KK(1460)	58.3	50.2	173.5	29	30.9	0
$KK^*(1410)$	31.9	26.0	57.3	93	49.3	23
$KK_1(1270)$	21.9	46.4	101.5	58	7.1	35.3
$KK_1(1400)$	8.6	9.4	65.9	26	41.4	70.1
$KK_2^*(1430)$	10.8	15.3	23.3	9.0	25.2	15.0
$\phi\eta$	0	0	5.7	21	0.3	1.2
$\phi\eta'$	2.9	2.8	1.8	11	0.8	0.4
$h_1(1380)\eta$	3.6	3.5	10.4	0	2.2	0
Width	167	212	593	378	243	149

Theoretical models will be estimated or ruled out at near future

$e^+ e^- \to K^+ K^- f_0(980)$







- $\phi(2170)$ @ $K^+ K^- f_0(980)$
- Structure around 2.5GeV ?