Discrepancy of $\phi(1680)$ properties and observation of the $X(1750)$

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The predicated $s\bar{s}$ spectroscopy

- Strangeonia ($s\bar{s}$) has been studies in theory in the paper PRD68,054014
- While there are only limited number of states which are well established in experiments, for example, the $\phi(1680)$

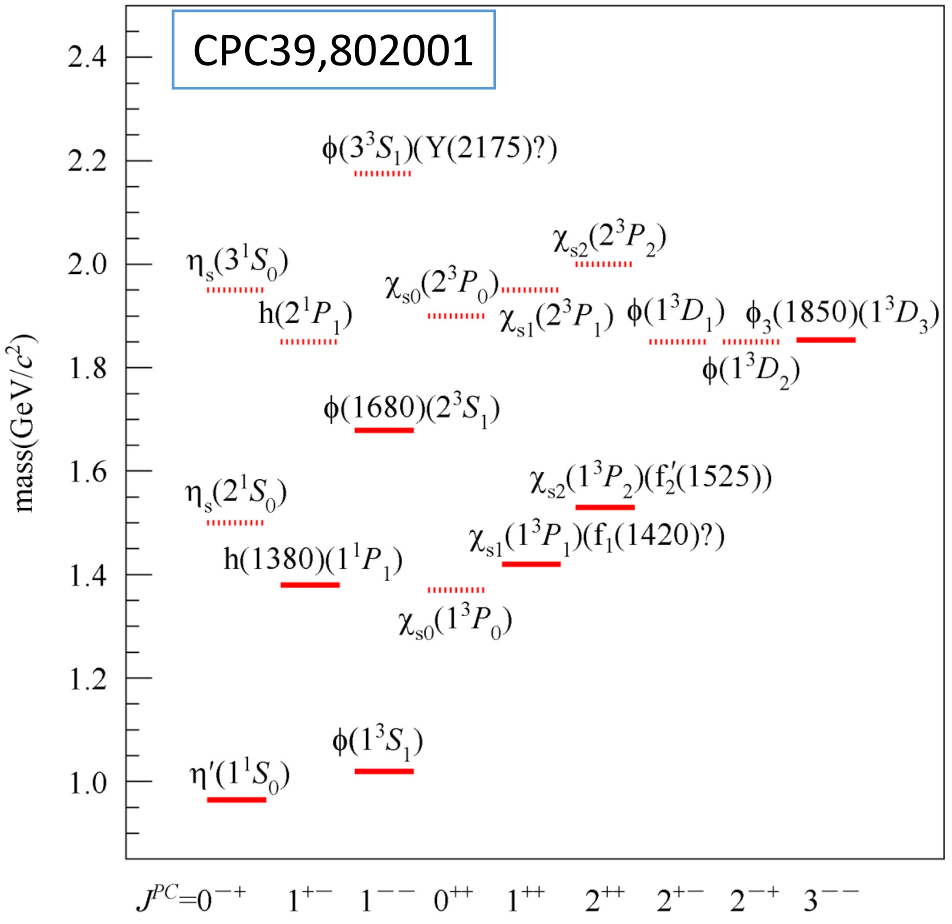


Fig. 1. The strangeonium family.

$\phi(1680)$: candidate of 2^3S_1 state

- $\phi(1680)$ is a natural candidate for the $s\bar{s}$ radial excitation of the $\phi(1020)$
- A $s\bar{s}$ state prefers to decay into strange mesons (OZI rule)
- $\phi(1680)$ is observed in KK, KK^* and $KK\pi\pi$ modes
- And no observation of $\phi(1680)$ in $\omega\pi\pi$ mode

Decay Modes

Mode		Fraction (Γ_i / Γ)	Scale Factor/ Conf. Level	P (MeV/c)
Γ_1	$K\overline{K}^*(892)$ + c.c.	seen		462
Γ_2	$K_S^0 K\pi$	seen		621
Γ_3	$K\overline{K}$	seen		680
Γ_4	$K_L^0 K_S^0$			677
Γ_5	e^+e^-	seen		840
Γ_6	$\omega\pi\pi$	not seen		623
Γ_7	$\phi\pi\pi$			482
Γ_8	$K^+K^-\pi^+\pi^-$	seen		544
Γ_9	$\eta\phi$	seen		290
Γ_{10}	$K^+K^-\eta$			329
Γ_{11}	$\eta\gamma$	seen		751
Γ_{12}	$K^+K^-\pi^0$			623

PDGLive (PDG2020)

Discrepancy of $\phi(1680)$ properties

- Even for the well established $\phi(1680)$, there are remained questions
- $\phi(1680)$ is expected in both e^+e^- production and photoproduction
- The mass and width observed in e^+e^- production and photoproduction are not consistent

Discrepancy of $\phi(1680)$ properties

- $\phi(1680)$ is well established in both e^+e^- production

$\phi(1680)$ **MASS** PDGLive

e^+e^- **PRODUCTION**

VALUE (MeV)	*EVTS*	*DOCUMENT I*
1680 ± 20	**OUR ESTIMATE**	
• • • We do not use the following data for averages, fits, limi		
$1641\ ^{+24}_{-18}$		ACHASOV
$1667 \pm 5 \pm 11$	3k	1 IVANOV
1700 ± 23	2k	2 ACHASOV
$1674 \pm 12 \pm 6$	6.2k	3 LEES
$1733 \pm 10 \pm 10$		4 LEES
$1689 \pm 7 \pm 10$	4.8k	5 SHEN
$1709 \pm 20 \pm 43$		6 AUBERT
1623 ± 20	948	7 AKHMETSHIN
$\sim$ 1500		8 ACHASOV
$\sim$ 1900		9 ACHASOV
1700 ± 20		10 CLEGG
1657 ± 27	367	BISELLO
1655 ± 17		11 BISELLO
1680 ± 10		12 BUON
1677 ± 12		13 MANE

$\phi(1680)$ **WIDTH** PDGLive

e^+e^- **PRODUCTION** INSPIRE search

VALUE (MeV)	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
150 ± 50	**OUR ESTIMATE** This is only an educated guess; the error given is larger than the error on the average of the published values.				
• • • We do not use the following data for averages, fits, limits, etc. • • •					
$103\ ^{+26}_{-24}$		ACHASOV	2019	SND	$e^+ e^- \to \pi^+\pi^-\pi^0\eta$
$176 \pm 23 \pm 38$	3k	1 IVANOV	2019A	CMD3	$1.59 - 2.007\ e^+ e^- \to K^+K^-\eta$
300 ± 50	2k	2 ACHASOV	2018A	SND	$1.3 - 2.0\ e^+ e^- \to K^0_S K^0_L \pi^0$
$165 \pm 38 \pm 70$	6.2k	3 LEES	2014H	BABR	$e^+ e^- \to K^0_S K^0_L \gamma$
$300 \pm 15 \pm 37$		4 LEES	2012F	BABR	$10.6\ e^+ e^- \to \phi\pi^+\pi^-\gamma$
$211 \pm 14 \pm 19$	4.8k	5 SHEN	2009	BELL	$10.6\ e^+ e^- \to K^+K^-\pi^+\pi^-\gamma$
$322 \pm 77 \pm 160$		6 AUBERT	2008S	BABR	$10.6\ e^+ e^- \to$ hadrons
139 ± 60	948	7 AKHMETSHIN	2003	CMD2	$1.05 - 1.38\ e^+ e^- \to K^0_L K^0_S$
300 ± 60		8 CLEGG	1994	RVUE	$e^+ e^- \to K^+K^-\ ,\ K^0_S K\pi$
146 ± 55	367	BISELLO	1991C	DM2	$e^+ e^- \to K^0_S K^\pm\pi^\mp$
207 ± 45		9 BISELLO	1988B	DM2	$e^+ e^- \to K^+K^-$
185 ± 22		10 BUON	1982	DM1	$e^+ e^- \to$ hadrons
102 ± 36		11 MANE	1982	DM1	$e^+ e^- \to K^0_S K\pi$

Discrepancy of $\phi(1680)$ properties

- $\phi(1680)$ is observed in consistent photoproduction measurements

$\phi(1680)$ MASS PDGLive

PHOTOPRODUCTION

VALUE (MeV)	*DOCUMENT*
• • • We do not use the following data for averages	
1753 ± 3	1 LINK
1726 ± 22	1 BUSENITZ
1760 ± 20	1 ATKINSON
1690 ± 10	1 ASTON

$\phi(1680)$ WIDTH PDGLive

PHOTOPRODUCTION

INSPIRE search

VALUE (MeV)	*DOCUMENT ID*		*TECN*	*COMMENT*
• • • We do not use the following data for averages, fits, limits, etc. • • •				
122 ± 63	1 LINK	2002K	FOCS	$20 - 160\ \gamma\ p \to K^+ K^- p$
121 ± 47	1 BUSENITZ	1989	TPS	$\gamma\ p \to K^+ K^-$ X
80 ± 40	1 ATKINSON	1985C	OMEG	20–70 $\gamma\ p \to K\overline{K}$ X
100 ± 40	1 ASTON	1981F	OMEG	25–70 $\gamma\ p \to K^+ K^-$ X

Discrepancy of $\phi(1680)$ properties

- But the measured mass and width of the $\phi(1680)$ are **different** in e^+e^- **production** and **photoproduction**

$\phi(1680)$ MASS

PDGLive

e^+e^- PRODUCTION

VALUE (MeV)	*EVTS*
1680 ± 20	**OUR ESTIMATE**
• • • We do not use the following da	
$1641 ^{+24}_{-18}$	
$1667 \pm5 \pm11$	3k
1700 ± 23	2k
$1674 \pm12 \pm6$	6.2k

~1680 MeV

$\phi(1680)$ MASS

PDGLive

PHOTOPRODUCTION

VALUE (MeV)	
• • • We do not use the following data	
1753 ± 3	1
1726 ± 22	1
1760 ± 20	1
1690 ± 10	1

~1750 MeV

$\phi(1680)$ WIDTH

PDGLive

e^+e^- PRODUCTION

VALUE (MeV)	*EVTS*
150 ± 50	**OUR ESTIMATE** Th published values.
• • • We do not use the following data f	
$103 ^{+26}_{-24}$	
$176 \pm23 \pm38$	3k
300 ± 50	2k
$165 \pm38 \pm70$	6.2k

~150 MeV

$\phi(1680)$ WIDTH

PDGLive

PHOTOPRODUCTION

VALUE (MeV)		*DOCUMENT ID*		*TECN*
• • • We do not use the following data for averages, fits, limits, etc. • • •				
122 ± 63	1	LINK	2002K	FOCS
121 ± 47	1	BUSENITZ	1989	TPS
80 ± 40	1	ATKINSON	1985C	OMEG
100 ± 40	1	ASTON	1981F	OMEG

~120 MeV

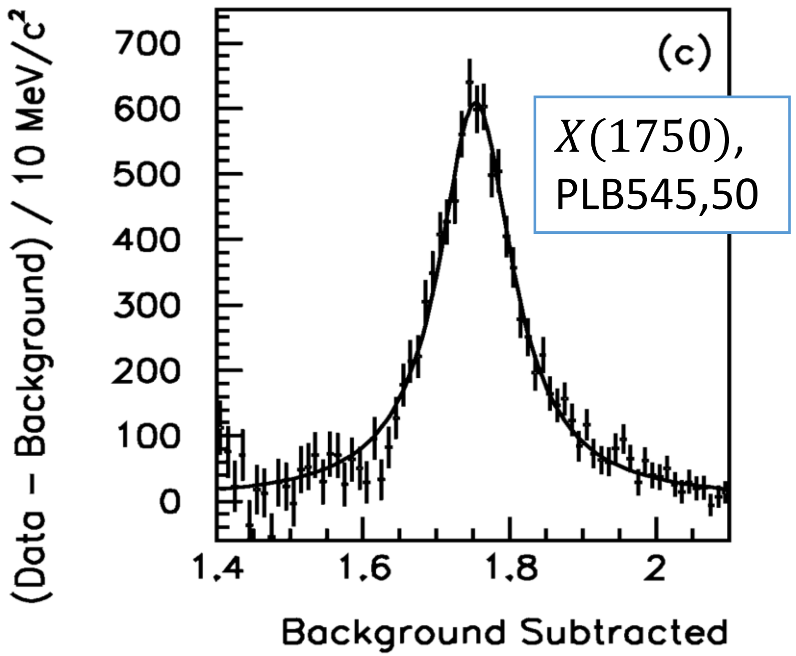
Discrepancy of $\phi(1680)$ properties

- An interpretation of the discrepancy is the interference between $\phi(1680)$ and nearby states
  - But interference can occur in both e^+e^- production and photoproduction
  - If interference is negligible, the measured parameters should consistent with those measured including interference
- Another solution is that the observations in e^+e^- production and photoproduction are different states
  - The one in e^+e^- production is the $\phi(1680)$
  - The one in photoproduction is the $X(1750)$

The $X(1750)$ from FOCUS

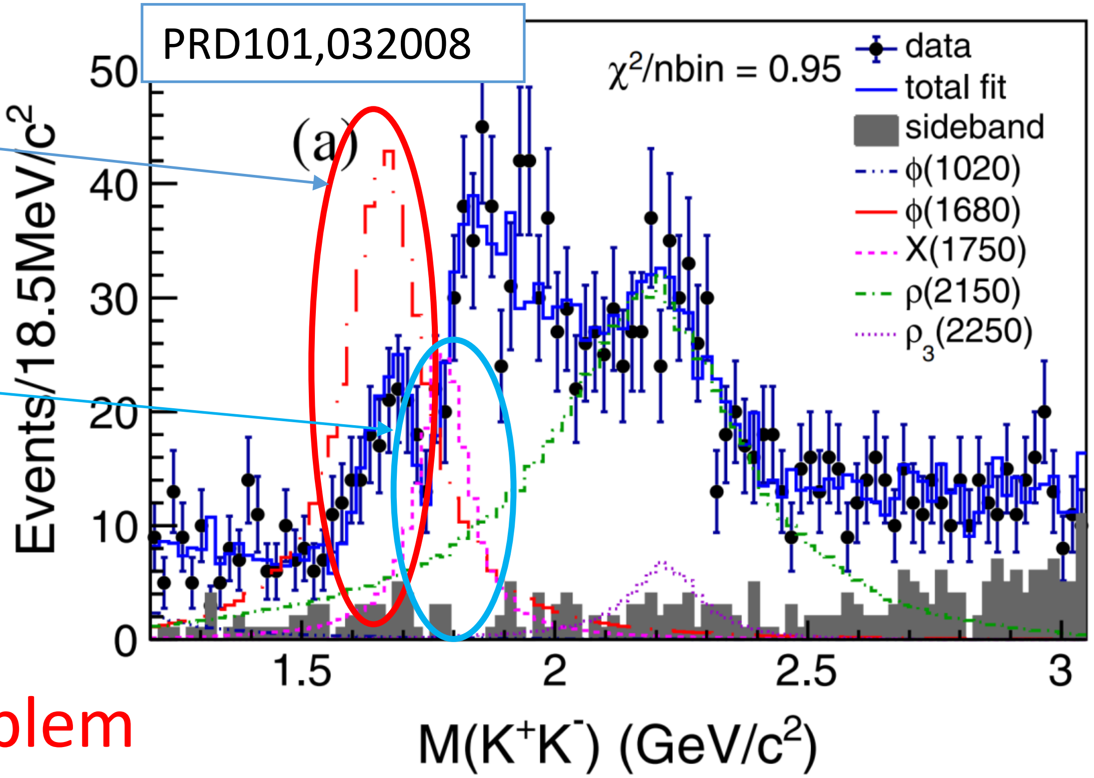
- Observations in different photoproduction experiments are consistent
- Low statistics for the early stage results
- FOCUS presented the latest result in 2002 using $\gamma p \rightarrow K^{+}K^{-}p$ (PLB545,50)

  - $M = 1753.5\ \mathrm{MeV/c^2}, \Gamma = 122.2\ \mathrm{MeV}$ significantly differs to $\phi(1680)$
  - Fit including interference doesn't change mass very much.
  - No $X \rightarrow K^{*}K$ (dominant mode of $\phi(1680)$)
  - The $X(1750)$ may be a new state



Simultaneous observation of $\phi(1680)$ and $X(1750)$

- BESIII performed a partial wave analysis of $\psi(3686) \to K^+K^-\eta$ (PRD101,032008) [my work ☺]
- Both $\phi(1680)$ and $X(1750)$ are observed in K^+K^- simultaneously
- $\phi(1680)$:
  - $M = 1680\ \mathrm{MeV/c^2}$,
  - $\Gamma = 185\ \mathrm{MeV}$
- $X(1750)$:
  - $M = 1784\ \mathrm{MeV/c^2}$,
  - $\Gamma = 106\ \mathrm{MeV}$
- The simultaneous observation clearly shows that they are two different states and naturally solved the discrepancy problem



The new question: the nature of X(1750)

- Observations in e^+e^- production and in photoproduction are different states: solved the discrepancy problem naturally
- Then another question arises:
- $\phi(1680)$ is a candidate of 2^3S_1 (PRD68,054014)
- What about the $X(1750)$?
    - Only observed in K^+K^- final states up to date →likely a $s\bar{s}$ state (search of non-$s\bar{s}$ decays can make further confirmation)
    - Spin-parity is 1^{--} (PRD101,032008)
    - K^+K^- dominance disagreement with the 2^3S_1 predication, and no predicated state with similar mass/width and spin-parity (PRD68,054014)
    - Need theorists to help interpret the $X(1750)$

Summary

- The $X(1750)$ is confirmed in experiments, and it is NOT the $\phi(1680)$
- The nature of the $X(1750)$ is not clear
- Not fit into the theoretical predication of the $s\bar{s}$ spectroscopy
- To understand the nature of the $X(1750)$ in experiment side
  - One can study the $K^+K^-\eta/\eta'$ system in J/ψ and $\psi(3686)$ decays
  - Study $\phi\eta/KK^*$ final states and search $X(1750)$ in non-$s\bar{s}$ final states
  - BESIII has ~10 Billion J/ψ events and will have ~3 Billion $\psi(3686)$ events, which provide good opportunities to study these processes and the $X(1750)$
- Need theorists' efforts to interpret and understand the $X(1750)$

Thanks!