

Review

Status and Perspectives of the *X*(1750)

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Status and Perspectives of the $X(1750)$

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Abstract

Light mesons serve as a cornerstone in probing symmetry realizations and dynamical breaking mechanisms in the non-perturbative regime of the strong interaction. Among them, a notable case is the $X(1750)$, a 1^{--} state observed in the K^+K^- invariant mass spectrum. It was initially identified as the $\phi(1680)$, but subsequent studies by the FOCUS and BESIII collaborations have unambiguously established it as a distinct new state. FOCUS further showed that interference models cannot reproduce a $\phi(1680)$ -like mass value in its high-statistics data. The absence of the $X(1750)$ in both $s\bar{s}$ and $n\bar{n}$ theoretical spectroscopy renders its internal structure an open and compelling question. This work reviews observations of the $X(1750)$, discusses its possible interpretations, and outlines future prospects for its study, particularly regarding the BESIII experiment.

Keywords: $X(1750)$; light hadron; strangeonium; BESIII

1. Introduction

Hadrons, such as mesons and baryons, are observable manifestations of strong interactions, with their properties deeply rooted in the symmetries of quantum chromodynamics (QCD). Light mesons, in particular, are pivotal in probing the non-perturbative regime of QCD, where phenomena like chiral symmetry breaking and confinement dominate. Their spectrum and decay patterns provide critical insights into how the underlying symmetries are realized or broken. Consequently, light mesons provide an ideal testing ground for the study of strong interactions in the non-perturbative regime.

Many light mesons, such as the ρ , ω , and ϕ states and their excitations, are well established and understood both experimentally and theoretically [1]. Nevertheless, some states remain poorly understood. The $X(1750)$ [1] is one such state that requires further investigation, even though more than forty years have passed since its first observation [2].

In this paper, we review experimental results for the $X(1750)$. Sections 2 and 3 present the early ambiguities regarding whether it was a new state or the photoproduction mode of the $\phi(1680)$ [1], as well as high-statistics results that helped to distinguish it from the $\phi(1680)$. Section 4 compares the mass and width across different $X(1750)$ observations and compares the $X(1750)$ with other nearby vector states. In Section 6, we discuss possible interpretations of the $X(1750)$ and prospects for future studies, particularly in the BESIII experiment [3].

2. The $X(1750)$ in the Early Stages

The first results for the $X(1750)$ were reported in the K^+K^- invariant mass spectrum in the 1980s, although the data were limited by statistics [2,4,5]. As a result, it was difficult



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to distinguish the $X(1750)$ from the $\phi(1680)$, which predominantly decays into K^*K but has a mass close to that of the $X(1750)$.

The $X(1750)$ was first reported as a bump centered at $1.75 \text{ GeV}/c^2$ in the K^+K^- mass spectrum from the photoproduction reaction $\gamma p \rightarrow K^+K^-p$ by Aston D., et al. in 1981 [2]. A fit that included interference between the resonance and a non-resonant contribution that accounted for the ρ , ω , and ϕ tails yielded a mass of $1.69 \pm 0.01 \text{ GeV}/c^2$ and a width of $0.10 \pm 0.04 \text{ GeV}$ [2] (see Figure 4 of [2]).

Given the large statistical uncertainties, these values were consistent with those of the $\phi(1680)$, which may explain why the structure was initially regarded as the photoproduction mode of the $\phi(1680)$, a state more commonly observed in e^+e^- collisions [1]. Notably, an alternative fit without the interference between the Breit–Wigner resonance and non-resonant process was also described in Ref. [2], yielding a mass of $1748 \pm 11 \text{ MeV}/c^2$ and a width of $80 \pm 33 \text{ MeV}$. This already suggested that the structure might be a new state distinct from the $\phi(1680)$.

The evident state in Ref. [2] was also reported in subsequent photoproduction experiments [4,5]. Figure 1 shows the acceptance-corrected K^+K^- mass distribution by the Omega Photon Collaboration [4], where the $X(1750)$ peak is visible. A fit using a Breit–Wigner component and a non-interfering background component yielded a mass of $1.76 \pm 0.02 \text{ GeV}/c^2$ and a width of $0.08 \pm 0.04 \text{ GeV}$ for the signal [4].

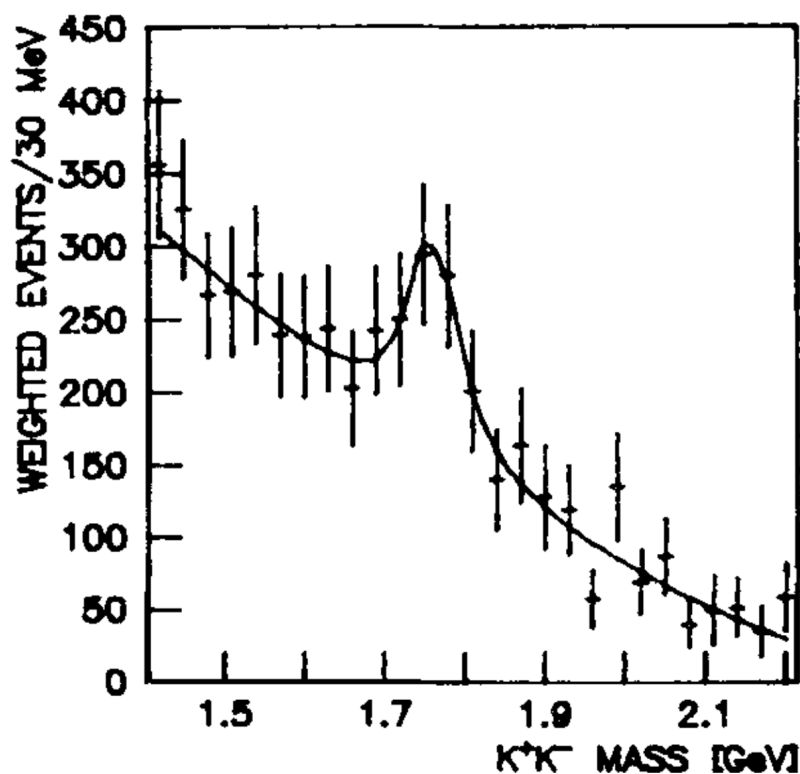


Figure 1. Acceptance-corrected K^+K^- mass distribution from Ref. [4].

The K^+K^- mass distribution by Busenitz J. et al. in 1989 [5] also shows a similar structure, around $1.75 \text{ GeV}/c^2$, as shown in Figure 2. A fit without interference gave a mass of $1.726 \pm 0.022 \text{ GeV}/c^2$ and a width of $0.121 \pm 0.047 \text{ GeV}$. Although Ref. [5] noted that the observation was consistent with Ref. [2], the low statistics and large uncertainties meant that the Particle Data Group (PDG) at the time still classified these $X(1750)$ signals as the ‘photoproduction of the $\phi(1680)$ ’.

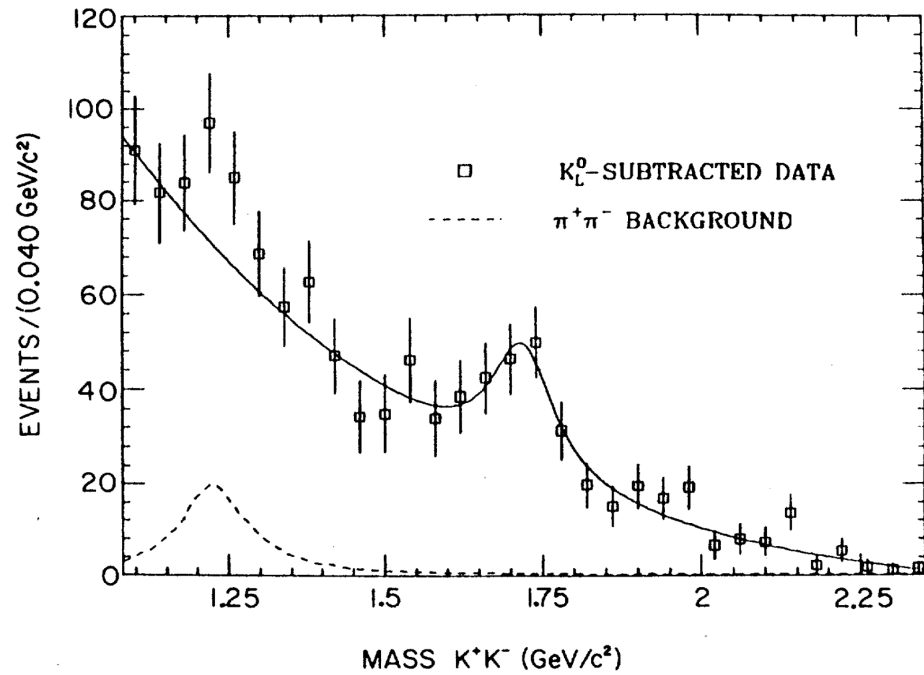


Figure 2. K^+K^- mass distribution from Ref. [5].

3. The X(1750) in High-Statistics Data

3.1. The FOCUS Results

The FOCUS collaboration was the first to report the X(1750) with high statistics (significance well above 5σ) in the K^+K^- mass spectrum from a photoproduction process [6]. A distinct peak corresponding to the X(1750) is visible in Figure 3a of Ref. [6].

The mass and width reported by FOCUS are $1753.5 \pm 1.5 \pm 2.3$ MeV/ c^2 and $122.2 \pm 6.2 \pm 8.0$ MeV, respectively, with very small uncertainties. These values differ significantly from those of the $\phi(1680)$ [1]. Furthermore, FOCUS searched for the X(1750) in the K^*K mass spectrum—the dominant decay mode of the $\phi(1680)$ —and found no signal [6]. Based on the clear differences in resonance parameters and decay modes, the FOCUS collaboration concluded that the X(1750) is a new state distinct from the $\phi(1680)$.

3.2. The X(1750) at BESIII

A key result came from the BESIII collaboration, which reported the first simultaneous observation of both the X(1750) and the $\phi(1680)$ in the same K^+K^- mass distribution, with each having significance exceeding 5σ [7]. This observation unambiguously confirms that the two are distinct states. Through a partial wave analysis (PWA; an introduction can be found in Ref. [8]), BESIII not only determined the mass and width of the X(1750) but also established its spin parity as 1^{--} , the same as that of the $\phi(1680)$. Figure 3 shows the fit projection of the K^+K^- mass spectrum, where the X(1750) is represented by the pink dashed line and the $\phi(1680)$ by the red dash-dotted line [7]. Interestingly, the X(1750) does not appear as a peak; instead, a significant dip around 1.7 GeV/ c^2 is observed due to the interference between the X(1750) and the $\phi(1680)$. The mass and width of the X(1750) from this analysis are 1784^{+12+0}_{-12-27} MeV/ c^2 and 106^{+22+8}_{-19-36} MeV, respectively [7].

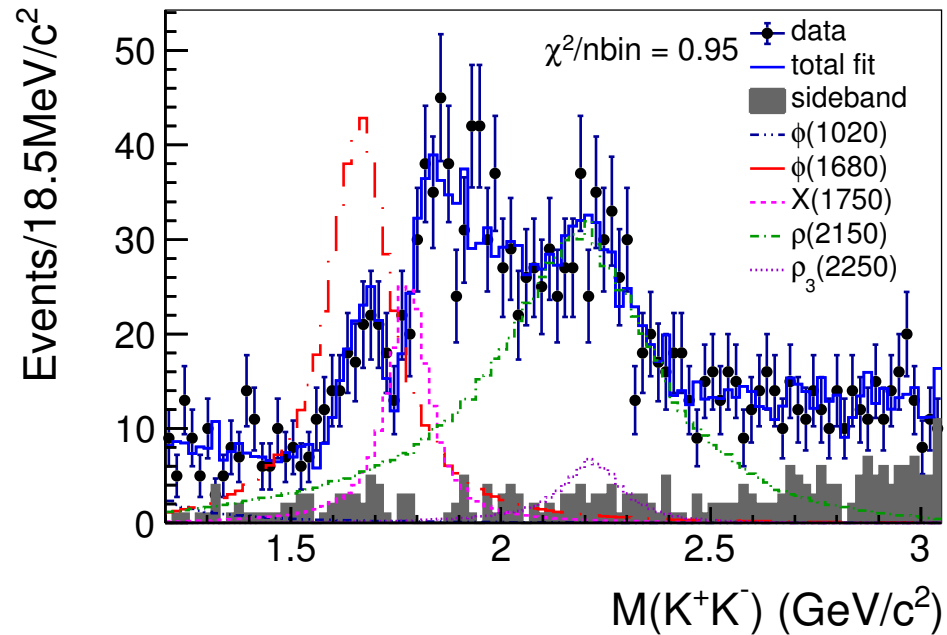


Figure 3. K^+K^- mass distribution of $\psi(2S) \rightarrow K^+K^-\eta$ from Ref. [7]. The $X(1750)$ is represented by the pink dashed line and the $\phi(1680)$ by the red dash-dotted line.

4. Comparison of $X(1750)$ Observations and Other Nearby Vector States

For ease of comparison, Table 1 summarizes measurements of the $X(1750)$ from different experiments alongside other nearby vector states. Figure 4 displays the masses and widths of these observations and states.

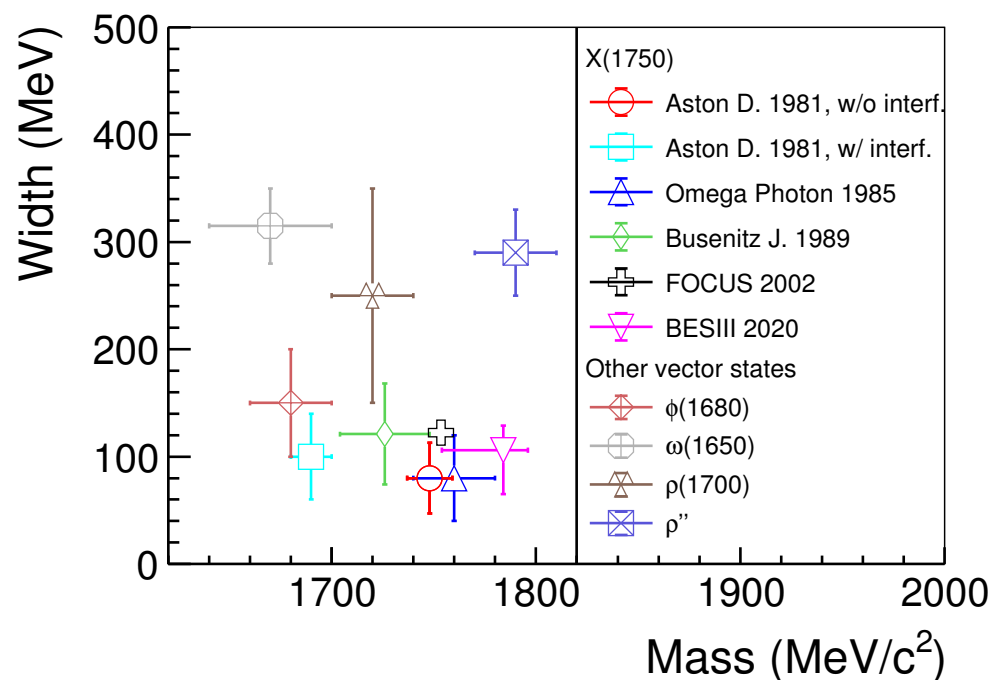


Figure 4. Comparison of the mass and width of the $X(1750)$ [2,4–7] and other nearby vector states [1,9]. Uncertainties for points from FOCUS 2002 [6], BESIII 2020 [7], and for ρ'' [9] are the quadrature sum of statistical uncertainty and systematic uncertainty; for other points, only statistical uncertainties are shown.

It is evident that the mass and width of the $X(1750)$ differ from those of the $\phi(1680)$, even in the early results with large statistical uncertainties. The only exception arises from an interference fit in Ref. [2], which modeled interference between the signal resonance and a non-resonant contribution accounting for the ρ , ω , and ϕ tails. In this specific model, the extracted mass and width of the $X(1750)$ appear closer to those of the $\phi(1680)$. Given the significant role of interference, the FOCUS collaboration investigated fit models incorporating interference between the resonance and a K^+K^- continuum, as well as between the resonance and a second, lower-mass resonance. Crucially, in all scenarios tested by FOCUS, the mass of the $X(1750)$ consistently exceeded $1747 \text{ MeV}/c^2$ [6]. This investigation suggests that the $\phi(1680)$ -like parameters obtained in the interference model of Ref. [2] result not only from the interference effects but also from the limited statistics of the data.

Table 1. Masses and widths of the $X(1750)$ and other nearby vector states.

State	M (MeV/ c^2)	Γ (MeV)	Source	Comment
$X(1750)$	1690 ± 10	100 ± 40	Ref. [2]	Mass fit; with interference with ρ, ω, ϕ tails
	1748 ± 11	80 ± 33	Ref. [2]	Mass fit; without interference
	1760 ± 20	80 ± 40	Ref. [4]	Mass fit; without interference
	1726 ± 22	121 ± 47	Ref. [5]	Mass fit; without interference
	$1753.5 \pm 1.5 \pm 2.3$	$122.2 \pm 6.2 \pm 8.0$	Ref. [6]	Mass fit; without interference
	$1784_{-12}^{+12+0}_{-27}$	$106_{-19}^{+22+8}_{-36}$	Ref. [7]	PWA; with interference
$\omega(1650)$	1670 ± 30	315 ± 35	Ref. [1]	PDG
$\phi(1680)$	1680 ± 20	150 ± 50	Ref. [1]	PDG
$\rho(1700)$	1720 ± 20	250 ± 100	Ref. [1]	PDG
ρ''	1790 ± 20	290 ± 40	Ref. [9]	Mass fit; with interference

5. Other Related Experiments

As a 1^{--} state, the $X(1750)$ can be produced directly in e^+e^- collisions. Consequently, it could potentially be observed in the cross-section for $e^+e^- \rightarrow K^+K^-$, provided that the production rate and dataset are sufficiently large.

The BABAR collaboration studied the $e^+e^- \rightarrow K^+K^-(\gamma)$ process using the initial state radiation method and found that the data were well described without any additional contribution from the $X(1750)$ [10]. Similarly, recent results from the SND [11] and CMD-3 collaborations [12], obtained via the energy scan method, also show no essential contribution from the $X(1750)$.

The absence of the $X(1750)$ in $e^+e^- \rightarrow K^+K^-$ data may indicate a small production rate, which could be related to its specific quark content.

6. Discussion and Perspectives

6.1. Possible Theoretical Interpretations

The $X(1750)$ has been observed in the K^+K^- mass spectrum across multiple experiments [2,4–7]. This makes it a natural candidate for a strangeonium state ($s\bar{s}$).

Strangeonium spectroscopy was first systematically studied in Ref. [13] within the framework of the relativistic quark model with QCD in Ref. [14], which successfully predicted the $\phi(1680)$ but did not anticipate the $X(1750)$: the predicted $1^{--} s\bar{s}$ states are $\phi(1020)$, $\phi(1680)$, unobserved $\phi(1850)$, and unobserved $\phi(2050)$. More recent theoretical studies on strangeonia and their decay properties [15,16] obtained similar results for the 1^{--} strangeonia and did not predict a strangeonium with a mass of around $1750 \text{ MeV}/c^2$. Consequently, the $X(1750)$ is incompatible with the current spectrum of conventional strangeonium states.

Alternatively, the $X(1750)$ could be an excited state of the ρ or ω mesons, with sufficient mass to decay into K^+K^- . The nearest known 1^{--} state in this sector is the $\rho(1700)$, with a mass of $1720 \pm 20 \text{ MeV}/c^2$ and a width of $250 \pm 100 \text{ MeV}$ [1]. Recent theoretical studies on ρ/ω excitations obtained a state corresponding to the $\rho(1700)$ [17–19], but they do not predict a state with a mass similar to the $X(1750)$. The $\rho(1700)$ mainly decays into 4π and 2π final states [1], which is different from the $X(1750)$. Thus, the significant differences in both the decay patterns and resonance parameters (mass and width) strongly prohibit the identification of the $X(1750)$ as the $\rho(1700)$, despite the fact that this possibility cannot be entirely excluded due to the sizeable experimental uncertainties regarding the $\rho(1700)$'s properties.

Given the difficulties in accommodating the $X(1750)$ within the conventional quark model, exotic interpretations such as tetraquark states and hybrid states become compelling. However, theoretical studies on light hybrid states [20,21] and light tetraquark states [22,23] show a large difference between the $X(1750)$ and these 1^{--} hybrid and tetraquark states: hybrid states have a mass greater than $2.3 \text{ GeV}/c^2$ [20,21], and tetraquark states have a mass greater than $1.9 \text{ GeV}/c^2$ [22,23]. Therefore, while its conventional nature is challenged, the $X(1750)$ also does not readily fit into the predicted spectra of light exotics, calling for further theoretical scrutiny of its internal structure.

6.2. Future Experimental Prospects

The absence of the $X(1750)$ in the predictions from both $s\bar{s}$ and $n\bar{n}$ quarkonia spectroscopy underscores the need for further theoretical and experimental efforts.

Most observations of the $X(1750)$ come from photoproduction experiments. Recently, the exclusive photoproduction of vector mesons in the mass region around $1.7 \sim 1.8 \text{ GeV}/c^2$ has been reported by the ALICE and LHCb collaborations in ultraperipheral heavy-ion collisions (UPCs) [9,24]. Notably, LHCb observed the photoproduction of a ρ'' state with a mass of $1790 \pm 20 \text{ MeV}/c^2$ and a width of $290 \pm 40 \text{ MeV}$ in the $\pi^+\pi^-$ final state [9].

The ρ'' observed by LHCb in $\pi^+\pi^-$ as well as the $\rho(1700)$ could also decay into K^+K^- . Given the unclear quark content of the $X(1750)$, a possible connection to these ρ -like states warrants consideration. Although current measurements of their masses and widths suggest that they are distinct, the sizeable uncertainties preclude a definitive conclusion. Further comparative studies of the $X(1750)$ and the ρ -like states, such as precise measurements of their masses and widths, and a direct search for $X(1750)$ in $\pi^+\pi^-$, could help to clarify whether they are distinct states.

The future Electron–Ion Collider (EIC) will provide another opportunity to study the photoproduction of the $X(1750)$ with high precision. Recent simulation studies [25] demonstrate that vector mesons in this mass range can be efficiently reconstructed in e^-p collisions. A dedicated search for the $X(1750)$ in both $\pi^+\pi^-$ and K^+K^- final states, accompanied by the measurement of their relative branching fractions, would provide direct insight into its quark content.

On the other hand, charmonium decays such as those of J/ψ and $\psi(2S)$, produced in e^+e^- collisions, provide a clean environment for the study of the $X(1750)$. The BESIII

experiment [3] has collected the world's largest dataset of J/ψ and $\psi(2S)$ decays, offering excellent opportunities to investigate the properties of the $X(1750)$ and clarify its nature. BESIII has observed the $X(1750)$ in $\psi(2S) \rightarrow K^+K^-\eta$ using a portion of its $\psi(2S)$ data [7]. Further studies of processes like $J/\psi, \psi(2S) \rightarrow K^+K^-\eta/\pi^0$ and $J/\psi, \psi(2S) \rightarrow K_S^0K^\pm\pi^\mp$, $J/\psi, \psi(2S) \rightarrow K^+K^-\eta/\eta'$, and $J/\psi, \psi(2S) \rightarrow \pi^+\pi^-\eta/\eta'$ could help to determine the isospin and quark content of the $X(1750)$.

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