

Can the X(1750) be a $\phi(1750)$?

 Peter Lichard 

*Institute of Physics and Research Centre for Computational Physics and Data Processing,
Silesian University in Opava, 746 01 Opava, Czech Republic*



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We present the arguments that the X(1750) has the isospin $I = 0$, and as such, it belongs to the ϕ family. We base our argument on the X(1750) appearing in the $e^+e^- \rightarrow K^+K^-$ process as a narrow resonance and not appearing in the $e^+e^- \rightarrow \pi^+\pi^-$ process at all.

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The X(1750) resonance was discovered in 1981 at the CERN Omega Spectrometer [1] with the mass of (1748 ± 11) MeV and the width of (80 ± 30) MeV [2]. Other photoproduction experiments [3] also confirmed its existence. The BESIII Collaboration [4] has recently made an important observation that X(1750) appears together with $\phi(1680)$ in decays of $\psi(2S)$.

The affinity of X(1750) for kaons is obvious from all experiments. With its well-established quantum numbers $J^{PC} = 1^{--}$ the X(1750) should reveal itself in the direct channel of the electron-positron annihilation into K^+K^- .

There are only two datasets on electron-positron annihilation into charged-kaon pairs in the center-of-mass-system (cms) energy region from the threshold to 2 GeV: (i) 2013 data by BABAR Collaboration [5], and (ii) data taken at the SND detector at the VEPP-2000 e^+e^- collider in Novosibirsk published in 2016 [6]. Data from the CMD-3 Collaboration advertised in 2020 [7] have not yet appeared in a final form. In our quest to determine the isospin of the X(1730) resonance, we will use very precise BABAR data [5], which were collected by the initial-state-radiation method [8]. For our fits, we will use 110 data points from the threshold up to 2.2 GeV with statistical errors only.

For the description of the electron-positron annihilation into a K^+K^- pair, we used a vector-meson-dominance (VMD) model with n intermediate vector resonances based on the Feynman diagram depicted in Fig. 1. It provides the cross-section formula

$$\sigma(s) = \frac{\pi\alpha^2}{3s} \left(1 - \frac{4m_K^2}{s}\right)^{3/2} \left| \sum_{j=1}^n \frac{R_j e^{i\delta_j}}{s - M_j^2 + iM_j\Gamma_j} \right|^2, \quad (1)$$

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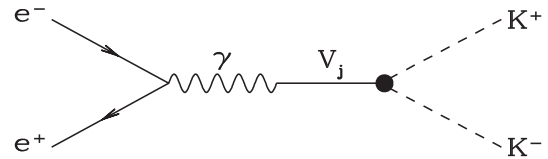


FIG. 1. Feynman diagram of the VMD model.

where M_j and Γ_j are the mass and width of the j th intermediate resonance, respectively. We will treat them as free parameters together with R_j and δ_j (except δ_1 , which is kept at 0).

We first started fitting by assuming three resonances and got a very bad fit: $\chi^2/\text{NDF} = 137.5/99$, confidence level $\text{CL} = 0.6\%$ [9]. The participating resonances were $\phi(1020)$, $\phi(1680)$, and a wide structure with mass of (1040 ± 79) MeV and $\Gamma = (1290 \pm 130)$ MeV representing the background [10].

Then, we included a fourth resonance, and the fit quality improved to $\chi^2/\text{NDF} = 106.3/95$ ($\text{CL} = 20\%$) [11]. The parameters of all resonances are shown in Table I. The newcomer is the X(1750) resonance. The fit is compared with the data in a selected energy region in Fig. 2. Despite statistical significances of $\phi(1680)$ and X(1750) being low (1.7σ and 1σ , respectively), their effect on the shape of the excitation curve between 1.5 and 2 GeV is clearly visible. The reason is their interference with the background, first constructive, then destructive. In order to appreciate the effect better, we show also the model prediction with $\phi(1680)$ and X(1750) switched off.

 TABLE I. Resonances appearing in the fit to the BABAR data [5] over the 0.98–2.20 GeV range using Eq. (1) with $n = 4$.

	M (MeV)	Γ (MeV)	Significance
$\phi(1020)$	1019.072(16)	4.284(35)	87σ
$\phi(1680)$	1677 ± 14	95 ± 19	1.7σ
X(1750)	1753 ± 21	77 ± 18	1.0σ
Background	1167 ± 47	1040 ± 89	4.9σ

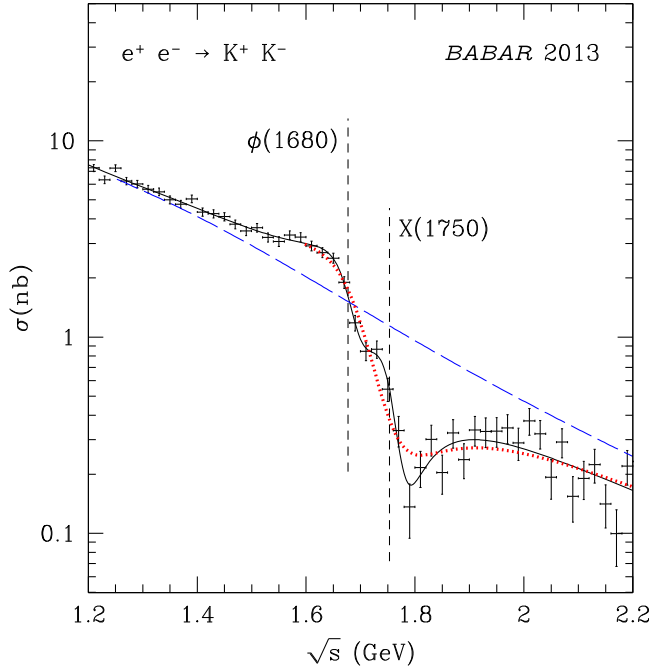


FIG. 2. Behavior in a selected region of the three-resonance (dots) and four-resonance (full) fits compared to the *BABAR* data [5]. The positions of $\phi(1680)$ and $X(1750)$ are marked with vertical lines. The dashes show the model curve without those two resonances.

We did not continue adding further resonances because our main aim was not to get a perfect fit and find all resonances but to prove that the $X(1750)$ is produced in the $e^+e^- \rightarrow K^+K^-$ process. The latter aim we have just accomplished.

In the next step, we explored very precise $e^+e^- \rightarrow \pi^+\pi^-$ data of the *BABAR* Collaboration [12] in the same energy range. We got a perfect fit with six resonances: $\chi^2/\text{NDF} = 227.6/303$ (CL = 100%). With such a perfect fit, displayed in Fig. 3, we can be almost sure that no resonance escaped our attention.

The resonances found were $\rho(770)$, $\omega(782)$, $\rho(1450)$, $\rho(1900)$, and two resonances from the ϕ family: $\phi(1020)$ with statistical significance 0.2σ and $\phi(1680)$ with 0.3σ . We conclude that $X(1750)$ production in the $e^+e^- \rightarrow \pi^+\pi^-$ process is negligible.

The resonances of the ϕ family are characterized by the quantum numbers $I^G(J^{PC}) = 0^-(1^{--})$. What concerns the e^+e^- annihilation is that they are copiously produced in the K^+K^- channel. However, in the $\pi^+\pi^-$ one, they appear at most at the level corresponding to the violation of the isospin

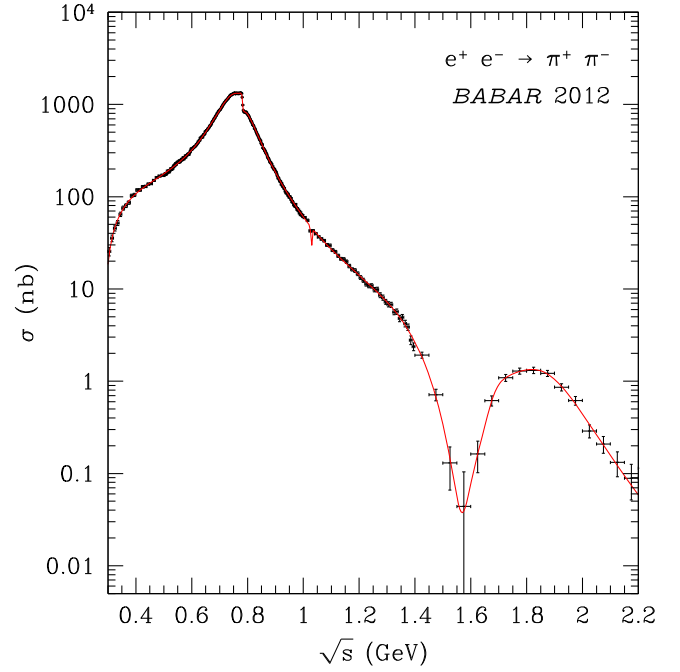


FIG. 3. Fit to the *BABAR* data [12] using Eq. (1) with six resonances. Only statistical errors were considered. Quality of the fit is characterized by $\chi^2/\text{NDF} = 227.6/303$, CL = 100%.

(G parity) symmetry [13]. That is precisely what the $X(1750)$ does. Therefore, we suggest assigning isospin zero to it.

This Letter hints at the e^+e^- annihilation as another process in addition to the photoproduction and the decay of charmonium, where the $X(1750)$ is produced. Further experimental investigation would be worthwhile of this and other processes where quantum numbers $I^G(J^{PC}) = 0(1^{--})$ permit the $X(1750)$ to participate.

The parameters of $\phi(1750)$ found by analyzing the $e^+e^- \rightarrow K^+K^-$ process, $M = (1753 \pm 21)$ MeV and $\Gamma = (77 \pm 18)$ MeV, are compatible with those found in the other processes.

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Data availability. No data were created or analyzed in this study.

- [1] D. Aston *et al.*, *Phys. Lett.* **104B**, 231 (1981).
- [2] These values can be found in the original paper [1] on page 232. The authors presented the discovery of $\phi(1680)$ as the main result and somewhat sidelined the first appearance of X(1750).
- [3] M. Atkinson *et al.* (Omega Photon Collaboration), *Z. Phys. C* **27**, 233 (1985); J. Busenitz *et al.*, *Phys. Rev. D* **40**, 1 (1989); J. M. Link *et al.* (FOCUS Collaboration), *Phys. Lett. B* **545**, 50 (2002).
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- [7] V. L. Ivanov (for the CMD-3 Collaboration), *Yad. Fiz.* **83**, 444 (2020) [*Phys. At. Nucl.* **83**, 731 (2020)].
- [8] The BABAR detector was situated at the PEP-II e^+e^- collider operating at the cms energy of 10.58 GeV. Experimentalists investigated the process $e^+e^- \rightarrow K^+K^-\gamma$ in which the photon carried away some energy, so the invariant energy of the K^+K^- system varied in a wide range, and the corresponding $e^+e^- \rightarrow K^+K^-$ cross sections were extracted.
- [9] As always, we find the program MINUIT by F. James and M. Roos [*Comput. Phys. Commun.* **10**, 343 (1975)] to be extremely useful.
- [10] The minimalization program offered us this background description, which we found acceptable.
- [11] If adding systematic errors to the statistical ones quadratically, the result would be $\chi^2/\text{NDF} = 93.7/95$ (CL = 52%).
- [12] J. P. Lees *et al.* (BABAR Collaboration), *Phys. Rev. D* **86**, 032013 (2012).
- [13] Notice the trace of $\phi(1020)$ in Fig. 3, as an example.