Search for Strangeonia in Photoproduction using CLAS

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Abstract.
The HyCLAS experiment at Jefferson Lab is a program to search for new and unusual mesons produced via photoproduction. The strangeonia sector is poorly known and a main component of this program is a search for new strangeonium states. The reaction \( \gamma p \rightarrow p \phi \eta \) is an ideal channel to look for strangeonium states due to the strangeness content of both the \( \phi \) and \( \eta \). The data was acquired at the JLAB CLAS facility using a 4 - 5.5 GeV tagged photon beam. The \( \phi \) meson is identified via the \( K^+ K^- \) decay. The recoil proton is observed in the CLAS spectrometer and the \( \eta \) meson is identified through the missing mass. Also of interest is the search for strangeonia decaying to \( \phi \pi^0 \) and \( \phi \omega \). These channels are OZI suppressed for \( q \bar{q} \) mesons and an observation of a meson decaying to these channels would provide a strong evidence of mesons beyond \( q \bar{q} \). Preliminary results describing the data quality, kinematics and dynamics will be shown.

Keywords: strangeonia, photoproduction, meson, spectroscopy, exotic, gluonic

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INTRODUCTION

We propose to study the strong decay amplitudes, partial widths and production channels of strangeonia from the CLAS g12 dataset obtained during the HyCLAS [1] experiment conducted using CLAS detector [2] at Jefferson Lab. HyCLAS ran as part of a larger run-period with multiple experiments in April of 2008. The experiment was designed and conducted to search and observe new forms of hadronic matter through photoproduction. HyCLAS was motivated by recent experimental results for gluonic hybrid meson candidates and theoretical Lattice QCD and Flux-tube Model calculations[3][4][5][6]. Crucial among the various channels to be explored in HyCLAS are those for strangeonia, resonances such as \( \phi(1680) \), \( X(1750) \) and \( \phi_3(1850) \) decaying to \( \eta \phi \). This decay channel is the signature that will unequivocally identify a strangeonium (\( s \bar{s} \)) state [7] and will be a main focus of this study. \( \eta \phi \), \( \eta' \phi \) are \( s \bar{s} \) signature decay modes due to their negligible interference with non-strange \( n \bar{n} \) vector decay modes. \( \phi(1020) \) is a \( s \bar{s} \) vector meson and the \( \eta \) meson wave-function has a strong component of \( s \bar{s} \) in it. Also of interest is the decay channel \( \phi \pi^0 \) which is an exotic channel due to its OZI suppression. Observation of a resonance decaying to \( \phi \pi^0 \) would provide a strong evidence of mesons beyond \( q \bar{q} \). The data for the proposed analysis comes from the aforementioned HyCLAS experiment. A final state of proton, \( K^+ \) and \( K^- \) will be selected from the dataset. An intermediate \( \phi \) state will be identified by its decay to \( K^+ K^- \). Using energy-momentum conservation, missing mass in an event is calculated. A cut for the missing \( \eta \) or the \( \pi^0 \) mass in their respective mass range will be implemented to identify the missing particle \( (\gamma p \rightarrow p K^+ K^- \eta/\pi^0) \). Invariant mass for the \( \phi \) and the missing \( \eta/\pi^0 \) system will be reconstructed to observe possible resonances. We will study the expected decay channels and widths predicted from various theoretical models and compare them to our experiment wherever possible.

STRANGEONIA

Strangeonia are unflavored \( s \bar{s} \) mesons primarily associated with the excited radial and orbital states of the ground state \( s\bar{s} \). The study of strangeonium states can serve as a bridge between short and large distance behavior of the QCD confinement potential because of the intermediate mass of the strange quarks between light mesons and the charmonium sector. Excitations of \( s\bar{s} \) provide a range of quark separations, where the confinement potential can be studied from the perturbative to the non-perturbative regime (from high momentum \( q^2 \) to low momentum \( q^2 \) transfer). Understanding of the \( s\bar{s} \) spectrum will help us bridge the gap between Heavy Quark Effective Theory and the abundant light quarks around us. Of the 22 expected strangeonia below 2.2 GeV, only 7 probable resonances - \( \eta \eta' \), \( \phi(1020) \),
FIGURE 1. Reconstructed Invariant Mass for $K^+K^-$ events with peak for the $\phi$ meson visible

$h_1(1386)$, $f_1(1426)$, $f_2(1525)$. $\phi(1680)$ and $\phi_3(1854)$ are well identified where we count the maximally mixed $\eta\eta'$ as one resonance [7]. Of these, the $h_1(1386)$ still needs additional confirmation.

Photoproduction of mesons occur primarily through Vector Meson Dominance where a photon becomes a $q\bar{q}$ pair conserving its spin parity $J^P = 1^-$. Hence we consider the vector photon as a vector meson ($\rho$, $\omega$, $\phi$) with a high content of $s\bar{s}$ and we expect to observe a radial excitation $\phi(1680)$ of the ground state $s\bar{s}$ vector meson $\phi(1020)$. This state has been observed in $e^+e^-$ production and disputed in photoproduction [8] [9].

Past photoproduction experiments have observed the mass of a resonance near $1750\text{ MeV}/c^2$ as an enhancement in the mass of $K^+K^-$ [10]. Majority of the experiments suffered from low statistics with about few hundred events at best. These experiments also assumed that any observed state was a diffractively photoproduced vector meson. Hence an observation near $1750\text{ MeV}/c^2$ was identified with the $\phi(1680)$ from the $e^+e^-$ experiments [9]. In $e^+e^-$ production the $\phi(1680)$ mass averages nearer to $1680\text{ MeV}/c^2$ while in photoproduction the mass for the same (assumed) resonance is closer to $1750\text{ MeV}/c^2$. It was originally thought that these observations were of the same resonance with the mass shift due to interference effects with other decay channels. The FOCUS experiment at Fermilab recently claimed that the structure in photoproduction at $1750\text{ MeV}/c^2$ is a different resonance [8]. The $\phi(1680)$ resonance has been clearly established in $e^+e^-$ production with the dominant decay channel being $KK^*$ ($e^+e^- \rightarrow K_sK\pi$). Meanwhile FOCUS measured the $\phi(1750)/X(1750)$ mass to be $1753\text{ MeV}/c^2$ with its dominant decay mode being $K^+K^-$. FOCUS found no photoproduced enhancement in the sample for $KK^*$ corresponding to the $1750\text{ MeV}/c^2$ state in $K^+K^-$. They state that interference effects could be possible but an unlikely reason for this resonance and they claim $\phi(1750)$ to be a new state, different from the $\phi(1680)$.

The $\phi(1680)$ resonance either behaves differently based on its production mechanism or its an altogether different resonance [8]. This issue is still an open question. The FOCUS observation is cited under and included with the $\phi(1680)$ in PDG and is not as of yet listed as a separate state [9]. Recently, it was proposed that a structure observed at $2175\text{ MeV}$ by the Babar Collaboration is a $1^{--}$ strangeonium hybrid [11] [12]. Also open to being observed in our dataset is the possibility of $\phi_3(1850)$ resonance claimed to have been seen in earlier experiments, though these resonances are at the edge of our observational range.
A Preliminary analysis of the data obtained from our g12 run-period is presented. We study the final state $\gamma p \rightarrow pK^+K^-[X]$ (1) where an additional neutral particle such as $\pi^0$, $\eta$ or a possible $\omega$ (2) will be identified by energy momentum conservation. Identifying an intermediate $\phi$ meson (1) allows us access to study the $\phi\eta$ (3), $\phi\pi^0$ (4) and possible $\phi\omega$ states. Of these, the $\phi\eta$ channel can only arise from an initial $s\bar{s}$ state in accordance with Zweig rule and thus is free from interference effects with $n\bar{n}$ ($u\bar{u} + d\bar{d}$) states. Hence, our analysis should be able to help clarify the issue of $\phi(1680)/\phi(1750)$ further.

Events with at least three charged tracks are selected so as to have an inclusive sample of $pK^+K^-$ events. Only events with beam photon energy greater than 4.4 GeV are selected to remove the low energy events. Cuts are applied on the event vertex to make sure the event originates inside the target. Timing cut on the interaction time ($\pm 1$ ns) is applied using the start counter and the RF to ensure that the right photon is selected. In order to identify peripheral meson production, cuts are applied on the missing momentum ($p_z, p_t \leq (0.1, 0.05)$).

For the $\phi\eta$ system, we analyse the channel $\gamma p \rightarrow pK^+K^-[\eta]$ (1), where we expect the proton to act as a spectator in a low momentum transfer, low $t$ channel reaction. Final state of proton, $K^+$ and $K^-$ is selected and an intermediate $\phi$ state identified by selecting on the invariant mass of the $K^+K^-$ system (1). The $\phi$ meson is clearly observed at the low mass end of the $K^+K^-$ invariant mass spectrum. Using energy-momentum conservation, a missing eta (2) is identified and the invariant mass for the $\phi$ and the missing $\eta$ system (3) is reconstructed to observe possible resonances. Similar techniques will also be used to look for other decays in various channels like the exotic $\gamma p \rightarrow pK^+K^-[\pi^0]$ (1) (4) and
FIGURE 4. Invariant mass for events with $\phi \pi^0$ and proton $\pi^0$ identified using cuts on missing mass.

$\gamma p \rightarrow pK^+K^- [\omega]$. Both $\phi \pi^0$ and $\phi \omega$ channels are exotic as they are OZI suppressed decays for $q\bar{q}$ mesons [13] [14]. These events will be further analysed to observe and isolate possible resonances.

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REFERENCES

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