Partial wave analysis of meson resonances that decay $K^*\bar{K}$ using data from the GlueX experiment

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Currently, particle physicists are attempting to map the light meson spectrum in order to contribute to the Standard Model of particle physics by strengthening our understanding of the strong interaction. The GlueX experiment at the Thomas Jefferson National Laboratory is contributing to these efforts through photoproduction of hadronic forms of matter. Using a 12 GeV linearly polarized photon beam, GlueX hopes to identify meson states forbidden by the Constituent Quark Model. As a main research objective, the GlueX collaboration is searching for hybrid $q\bar{q}g$ meson states that exhibit exotic quantum numbers. The Arizona State University (ASU) Meson Physics Group is contributing to the GlueX efforts by analyzing $\gamma p \to pK^+K^-\gamma\gamma$ events. Specifically, we are interested in identifying meson states that decay $K^*\bar{K}$, $a_0\pi^0$, $\phi\pi^0$, and $K^+K^-\pi^0$. To accomplish this task, a partial wave analysis is necessary to separate the overlapping states with different J^{PC} quantum number. I focused my analysis efforts on building the tools to perform a partial wave analysis for the ASU Meson Physics Group with the hope of identifying meson states that decay $K^*\bar{K}$. The reasons for focusing on this decay are twofold:

1. The 1400 MeV mass region is filled with controversy regarding two pseudoscalar mesons, the $\eta(1405)$ and $\eta(1475)$, two axial vector mesons, the $f_1(1420)$ and $f_1(1510)$, and possible tensor mesons.

2. One predicted meson with exotic quantum numbers is the η_1' hybrid meson candidate, which is predicted to decay to $K^*\bar{K}$ and have a mass near 2.3 GeV.

What meson states exist in the 1400 MeV mass region has been subject to controversy since the 1960s with the discovery of a meson state near ∼1420 MeV. Over the years, multiple experiments performed spin-parity analyses of events in this mass region produced differing results. Some experiments identified meson states with 0^{-+} and 1^{++} J^{PC} quantum numbers decaying $K^+K^-\pi^0$. These states became known as the ι and E mesons, respectively, and the controversy over what was believed to be a single meson became known as the E/ι puzzle. As of the late 1990s, it was generally accepted that it was in fact two meson states the ι meson being the $\eta(1405)$ pseudoscalar meson and the E meson being the $f_1(1420)$ axial vector meson. However, the controversy did not end with the resolution of the E/ι puzzle.

The meson states that contribute to the 1400 MeV mass region continues to be a topic of debate. One major issue involves the existence of two pseudoscalar mesons decaying $K^*\bar{K}$ or $a_0\pi^0$, the $\eta(1405)$ and $\eta(1475)$. The MARKIII, DM2, BESIII, OBELIX and other collaborations have performed spin-parity analyses producing evidence for the existence of two pseudoscalar mesons in pp and πp central production, and J/ψ radiative and hadronic decays. However, the L3 collaboration only reports the existence of the $\eta(1475)$ in $\gamma\gamma$ collisions. The contradictory results of these experiments does not negate the existence of two pseudoscalar mesons in this mass region, but points to the possible quark-gluonic contributions to the states. Since the $\eta(1405)$ is not identified in $\gamma\gamma$ collisions, it may have large gluonic content, making it a 0^{-+} glueball. Furthermore, the $\eta(1295)$ and $\eta(1475)$ would be the first radial excitation of the η and η', respectively. These conclusions are supported by the flux tube model, but not lattice gauge theory.

The issue of two pseudoscalar mesons in the 1400 MeV mass region is not the only doubling of meson states with the same J^{PC} quantum numbers in this mass region. Two axial vector mesons have been identified, specifically the $f_1(1420)$ and $f_1(1510)$. The ground state 1^{++} axial vector meson nonet has the $f_1(1420)$ as the $s\bar{s}$ contribution. With the existence of multiple axial vector mesons in this mass region, it is unclear that this is the correct quark content for the $f_1(1420)$.

Our interests do not only lie with this mass region, but also with a search for the η_1' hybrid meson candidate decaying $K^*\bar{K}$. To accomplish this goal, the focus has been on the 1400 MeV mass region to add to the debate regarding the pseudoscalar and axial vector mesons, and to establish the tools necessary to identify meson states with masses greater than 2.0 GeV. It is necessary to perform a partial wave analysis (PWA) to extract the identities of the meson states decaying $K^*\bar{K}$ in $\gamma p \to pK^+K^-\gamma\gamma$ events from the GlueX experiment. My work provides the PWA tool to perform a PWA of $\gamma p \to pK^*\bar{K}$ with preliminary results for the identity of meson states decaying $K^*\bar{K}$.

To conduct the PWA, two sets of angular distributions for $\gamma p \to pK^*\bar{K}$ are produced. The first set includes the polar and azimuthal angles of the K^* meson decaying from the meson resonance in the resonance helicity frame. The second set includes the polar and azimuthal angles of the K decaying from the K^* in the K^* helicity frame. With these angular distributions, an unbinned extended maximum likelihood fit is performed for 20 MeV mass bins from 1.34 to 1.58 GeV using an intensity function dependent on the determined angles. The intensity function is built using partial waves defined by Wigner-D functions, which act as the spherical harmonics for the meson, and has fitting parameters that are dependent on the J^P quantum numbers. The fitting parameters provide the number of events with a given angular momentum. Furthermore, the $\gamma p \to pK^*\bar{K}$ is divided into eight subsets, one for each polarization direction and charged state of the $K^*\bar{K}$ ($K^{*\pm}K^{\mp}$). Identical fit parameters of the intensity function are constrained between the eight subsets of the data. From the fit parameters for each 20 MeV mass bin, invariant mass distributions for $K^*\bar{K}$ for particles with $J = 0$, 1, and 2 are produced from which possible particle identities are determined.

Preliminary results from the PWA provide evidence for two pseudoscalar mesons, two axial vector mesons, and two tensor mesons in the 1400 to 1600 MeV mass region. The two pseudoscalar mesons are consistent with the $\eta(1405)$ and $\eta(1475)$. Since these were produced through photoproduction, we establish further uncertainty in the gluonic content of the $\eta(1405)$. This may be remedied by pomeron exchange, which is supported by the large $|t|$-slope for this mass region. The identities of the two axial vector mesons could be the $f_1(1420)$ and $f_1(1510)$. If these results are confirmed, then the $f_1(1420)$ may not be the $s\bar{s}$ contribution to the ground state axial vector nonet. Finally, two possible tensor mesons are discernible which may have $f_2(1430)$ and $f_2(1525)$ identities. These results would be analogous with the pseudoscalar and axial vector mesons with respect to the quantity of the meson states of each type in the mass region. Furthermore, confirmation of the $f_2(1430)$ would assist in establishing the state and provide a new decay mode.

More work is necessary to finalize the identity of the meson states decaying $K^*\bar{K}$ in GlueX $\gamma p \to pK^+K^-\gamma\gamma$ events. To assist in determining the quark gluonic content for these mesons, the K_L experiment can perform a similar analysis because meson states without strange quark contributions will be heavily suppressed. Efforts are being made to expand the PWA to include $a_0\pi^0$, which will assist in identifying states in this mass region, as well as in the 1200 MeV mass region. As of now, the work is consistent with previous experiments, which lends credence to the used PWA tools. Further analysis efforts will only improve the tools and results leading to a search for the η_1' hybrid meson candidate by the ASU Meson Physics Group.