Letter of Interest: Hadron Spectroscopy with the GlueX Experiment

The GlueX Collaboration

Abstract

The primary goal of the GlueX Experiment is the search for mesons in which the confining gluonic field is excited, the so-called hybrid mesons, the identification of which would yield new insight into non-perturbative QCD and the contribution of gluonic fields to the hadron spectrum. The photoproduction data that is being acquired is of unprecedented statistics and quality, and will allow the study of many aspects of hadron spectroscopy. The currently planned GlueX program is expected to run through 2025, and opportunities for the future experimental program are being developed. The GlueX Collaboration will contribute a description of our plan to search for exotic hadrons, a summary of the current progress, and goals for the future.

Contacts: Sean Dobbs[1], Matt Shepherd, Justin Stevens

A major goal of hadron spectroscopy is understanding how the underlying quark and gluon degrees of freedom manifest themselves in the observed hadron spectrum. One type of state with explicit gluonic content are the so-called "hybrid mesons", in which the gluonic field binding the quark-antiquark pair is itself excited [1, 2]. Of particular interest are the exotic-quantum-number hybrid mesons, which are hybrids with J^{PC} quantum numbers that are not allowed J^{PC} of conventional $q\bar{q}$ mesons: 0^{--}, 0^{+-}, 1^{-+}, 2^{+-}, ... Lattice QCD calculations predict several nonets of exotic and conventional quantum number hybrid mesons in the $1-2$ GeV range [3, 4], which can be produced in photoproduction with simple t-channel exchanges. Most searches for hybrid mesons so far have focused on the search for the lightest $J^{PC} = 1^{-+}$ state, the π_1, in pion production, with the most recent results coming from the COMPASS experiment in the $\pi^+\pi^-\pi^-$ [5, 6] and $\eta(')\pi^-$ [7, 8, 9] final states, and the Crystal Ball experiment using the $\pi^0\pi^0\eta$, $\pi^0\eta\eta$, and $K^+K^-\pi^0$ channels [10, 11].

The primary goal of the GlueX Experiment is to identify and study the spectrum of light quark hybrid mesons through photoproduction [12], which will require an extensive study of the meson spectrum in the $1-2$ GeV mass range. The large photoproduction data set collected by GlueX will also allow us to carry out a broad program of hadron spectroscopy and address other issues in hadron physics. For example, the recently installed DIRC detector will provide enhanced sensitivity to mesons and baryons containing strange quarks. The available beam energies also allow the study of charmonium production in the near-threshold region, including the production of charmonium+proton resonances in the s-channel.

The GlueX Experiment is located in Hall D at the Thomas Jefferson National Accelerator Facility (Jefferson Lab). The experiment combines a linearly polarized, multi-GeV photon beam with a large acceptance spectrometer optimized for hadronic spectroscopy with the ability to reconstruct and identify charged and neutral particles. The GlueX beamline and detector have been described in detail in Ref. [13]. The first GlueX physics run covered 2017–2018, where 4 PB of data corresponding to a luminosity of 320 pb^{-1} collected, and the full data were available for analysis in Fall 2019. A vigorous program of study of meson photoproduction processes using a portion of this data has resulted in several publications to date [14, 15, 16]. Following this run, a DIRC system for improved charged hadron identification in the forward region was installed, and the second GlueX run started in early 2020 and is still ongoing. This second run is expected to continue to 2025, depending on the accelerator availability and schedule of other approved experiments in Hall D, and yield an increase in statistics of roughly a factor 5.

[1]Corresponding author: `sdobbs@fsu.edu`

The current hybrid searches are focused on several "golden channels" with sufficiently large cross sections and clean signals , including $\eta\pi$, $\eta'\pi$, $\eta\pi\pi$, $\omega\pi\pi$, and K^*K. The full data from the first physics run are now available, representing the first high statistics photoproduction data set with neutral particle reconstruction that covers the full light meson mass range, which provides statistics in many hybrid channels that are equal to or larger than those used in other searches. This data corresponds to the first high-statistics The current focus is on the study of well-known mesons, studies of important background reactions, and the development and validation of the reaction models needed to perform the amplitude analyses required for these searches. These models are crucial in controlling the systematic effects in our amplitude analyses, and we are developing them in collaboration with several groups of theorists, including the The Joint Physics Analysis Center (JPAC) [17, 18, 19, 20, 21].

The potential future physics program was discussed in several meetings over the past two years, and a White Paper briefly describing these opportunities was written last year [23]. The first physics run provides a photoproduction data set several orders of magnitude over what currently exists at these energies and a world-leading set of data for several key hybrid meson search channels, and the current run is extending this reach into the strange-quark hadron sector. However, some of the exotic states we are searching for may have small production cross sections, so to reach the ultimate sensitivity of the experiment and to accomplish the goal of mapping the light meson spectrum, it is expected that additional running time may be requested depending on the results of the analysis of the data that is currently being collected.

GlueX also has the ability to study the production of charmonium, as illustrated by the first measurements of the energy dependence of the J/ψ photoproduction cross section in the near-threshold region [22]. While the study of this reaction can provide insight into the gluonic content of the proton, it also allows for the search for $s-$channel production of resonances decaying to the $J/\psi+$ proton final state, such as the P_c^+ states. While the larger future data sets will allow us to perform more sensitive searches for these states, it will also allow us to extend these studies to other interesting final states, spectroscopically or otherwise, such as $\eta_c p$, $\chi_{c1}p$, $h_c p$, and hopefully even $D^{(*)0}\Lambda_c^+$. Future experimental conditions can also be optimized to enhance the production of these states, and the available beam polarization in the corresponding energy range.

Running GlueX under other conditions could also provide unique data sets, and future plans will evolve depending on what we find in the data. Several possible scenarios have been described in the Future Physics White Paper. For example, it could be interesting to study the energy dependence of hybrid meson production cross sections, which would require taking data with different beam conditions. If we see isovector hybrids in a charge exchange reaction, it could be interesting to take data using a deuterium target. The observation of strange-quark counterparts to the charmonium-like X/Y/Z states could also motivate additional running with new detector modifications. Physics programs for nuclear or polarized targets are also being developed.

Preparations for an upgrade to the forward lead-glass calorimeter by replacing the inner section by $PbWO_4$ is in progress, and it is expected be completed by 2024. Other potential detector upgrades are being studied, and it is expected that many detector components will be needed to be upgraded or replaced by the latter half of the decade.

As described above, the GlueX Experiment will provide a large unique data set, and we will explore and discuss the prospects and plans for establishing the liqht-quark hybrid meson spectrum and addressing other problems and current issues in hadron spectroscopy, in combination with the theoretical community and other experimental efforts.

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