Letter of Interest: Hadron Spectroscopy at the Electron Ion Collider

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Abstract

Recent observations in heavy-quark spectroscopy have provided numerous candidates for hadronic resonances which are exotic in nature. The Electron Ion Collider (EIC) has the potential to produce such resonances in photoproduction reactions, which would confirm the observations in previous experiments and provide complementary insight into their composition. This opportunity has inspired recent work on theoretical models for exclusive production of so-called XYZ states in electron-hadron collisions as well as detector simulations to meet the requirements of such a program at the EIC.

Considerable progress in hadron spectroscopy has been made in recent years through many unexpected observations in the heavy quark sector including the proliferation of so-called XYZ states, charmed pentaquark P_c candidates and more (see reviews Ref. [1–4]). Relatively early in the XYZ discoveries in e^+e^- colliders and $b-$hadron decays it was recognized that they could be studied in alternative processes, such as photoproduction, with many calculations for individual reactions over the years, for example Refs. [5–8].

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Fixed target experiments using the Jefferson Lab 12 GeV electron beam, such as GlueX [9] or CLAS12 [10], provide access to the light-quark regime and s-channel production of P_c states discovered by LHCb [11], however they do not have sufficient energies to produce XYZ states *via* t-channel exchange. Previous measurements in ep collistions at HERA, however, have demonstrated the ability to study heavy quarkonia through photoproduction, particularly the well known vector $c\bar{c}$ and $b\bar{b}$ states [12–15]. The COMPASS collaboration has studied muonproduction of the $J/\psi\pi^+\pi^-p$ final state finding an indication of a new state $\widetilde{X}(3872)$ [16] and also set limits on Z_c photoproduction in the $J/\psi\pi^+n$ final state [17].

The Electron Ion Collider (EIC) is a high-luminosity polarized ep and eA collider with variable center-of-mass energies from 20-140 GeV. A broad physics program is outlined in the EIC white paper [18] including key questions in particle and nuclear physics on the 3-dimensional structure of the nucleon and high parton densities in nuclei. This Letter of Interest is part of an expansion of that physics program to include opportunities in hadron spectroscopy provided by this unique facility. The integrated luminosities expected for the EIC, on the order of 1-10 fb^{-1}, provide the opportunity to study rare exclusive processes not accessible at HERA.

Recent predictions from the JPAC Collaboration [19] provide a comprehensive assessment of the exclusive cross sections for several XYZ states. With expected cross sections at the $\sim$1-10 nb level the statistics available for some of these reactions are comparable to current measurements of similar states in e^+e^- machines and heavy flavor decays.

In addition, measurements of conventional quarkonium states have shown that nuclear breakup effects are dependent on the radius of the observed state [20–22]. It is anticipated that similar suppression effects for exotic hadrons can be used to discriminate between compact multiquark and molecular models of their structure. This has been studied in heavy-ion collisions [23–27] and could continue in eA collisions with varying target nuclei at the EIC.

The EIC detector concepts are already well-suited for hadron spectroscopy, due to their large angular coverage and electron, hadron particle identification capabilities. In addition, the exclusive detection of these final states will be enhanced by complete detectors which measure the forward scattered electron or recoiling nucleon near their respective beamlines. Simulations of the detector requirements for these reactions are ongoing to refine the detector concepts as part of the year-long EIC Yellow Report process [28].

Additional opportunities which may be available at the EIC include:

- Exclusive production of conventional charmonia and bottomonia,
- Semi-inclusive production of XYZ states,
- Potential access to charmonium hybrids predicted by Lattice QCD [29]

In summary, there are exciting prospects for a unique hadron spectroscopy program at the EIC which are actively being pursued and could provide critical new information on the nature of recent observations in the heavy quark sector.

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