

## A Search for Hybrid Baryons in Hall B with CLAS12

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## ABSTRACT

This proposal aims to establish a program to search for new excited baryon states in the mass range from 1.8 GeV to 3 GeV, as well as to explore for the first time the behavior of resonance electrocouplings over the full spectrum of excited proton states at photon virtualities  $Q^2$  approaching the photon point ( $Q^2 < 0.2 \text{ GeV}^2$ ). This work focuses on measuring  $K^+\Lambda$ ,  $K^+\Sigma^0$ , and  $\pi^+\pi^-p$  exclusive final states in CLAS12 and detecting the scattered electrons in the angular range from  $2.5^\circ$  to  $35^\circ$  using the electron detection capabilities of the Forward Tagger and the CLAS12 detector. The experiment will use longitudinally polarized electron beams of 6.6 GeV (30 days) and 8.8 GeV (30 days) to cover the range of invariant mass  $W$  up to 3 GeV and  $Q^2$  from  $0.05 \text{ GeV}^2$  to  $2 \text{ GeV}^2$ . The main aspects of the proposal are to:

- search for new hybrid baryon states with the glue as an extra constituent component beyond the three constituent quarks by focusing measurements at  $Q^2 < 1.0 \text{ GeV}^2$  where the expected magnitudes of the hybrid electroexcitation amplitudes are maximal;
- search for three-quark “missing” resonances in the electroproduction of different hadronic final states with the highest fluxes of virtual photons ever achieved in exclusive meson electroproduction experiments;
- study the structure of prominent nucleon resonances in the mass range up to 3 GeV in the regime of large meson-baryon cloud contributions and explore the  $N^*$  longitudinal electroexcitation approaching the photon point.

The  $KY$  final states will be measured in topologies where the scattered electron and  $K^+$  are detected, while the four-momentum of the hyperon will be reconstructed employing energy-momentum conservation and complemented by the data when the electroproduced  $K^+$  and the  $p$  from the hyperon decay will be measured (thus allowing for measurements

of the hyperon polarization). For the  $\pi^+\pi^-p$  channel the observables will be obtained from the combination of all possible event topologies where the scattered electron and all final hadrons are detected, as well as when only two of three final state hadrons are detected, with the four-momentum of the third hadron reconstructed from energy-momentum conservation. The unpolarized differential cross sections will be obtained for the aforementioned exclusive channels and complemented by measurements of the differential transverse-transverse and transverse-longitudinal interference cross sections.

From these data the  $\gamma_v p N^*$  electrocouplings will be determined employing the well known unitary isobar models and dispersion relation approaches that have proven very effective for the study of two-body final states such as  $\pi N$  [1, 2] and  $KY$  [3], as well as the JM meson-baryon reaction model for  $\pi^+\pi^-p$  electroproduction [2, 4], multi-channel partial wave techniques employing both the Bonn-Gatchina [5] and GWU [6] approaches, and approaches starting from the Veneziano model and Regge phenomenology [7] that are applicable at higher energies where many hadron channels open in the final state interactions.

The program will search for all possible new states with  $I = \frac{1}{2}$  and  $I = \frac{3}{2}$  and with all possible  $J^\pi$  quantum numbers. As new states are identified using the high event rates at very small  $Q^2$  values (“quasi-real” photoproduction), the  $Q^2$  dependence of their helicity amplitudes will be determined. The results at different  $Q^2$  from the different exclusive channels will substantially enhance our capability for the discovery of new baryon states. Consistent results on resonance masses and  $\gamma_v p N^*$  electrocouplings from the different exclusive decay channels, as well as  $Q^2$ -independent partial hadronic decay widths over the full  $Q^2$ -range, will offer convincing evidence for the existence of new states and the reliable extraction of their parameters. This approach has been highly effective in determining the  $Q^2$  dependence of the  $A_{1/2}$ ,  $A_{3/2}$ , and  $S_{1/2}$  helicity amplitudes for several of the lower mass baryons, such as the  $\Delta(1232)\frac{3}{2}^+$ , the  $N(1440)\frac{1}{2}^+$  and the  $N(1535)\frac{1}{2}^-$  [1, 4]. These and many other results are included in the review of the  $N^*$  and  $\Delta^*$  states in the latest edition of the PDG [8].

The hybrid baryons will be identified as additional states in the  $N^*$ -spectrum beyond the regular three-quark states as was predicted in recent LQCD studies of the baryon spectrum [9] that demonstrated the emergence of hybrid baryons from the QCD-Lagrangian. Unfortunately, the spins and parities of hybrid baryons are expected to be the same as those for regular three-quark states. However the presence of explicit gluonic degrees of freedom in the hybrid baryon wave function implies different color-multiplet assignments for the quark-

core: color octet for the hybrid states versus color singlet for the regular states. This results in a distinctively different  $Q^2$ -evolution of the hybrid-baryon electrocouplings, especially at  $Q^2$  values lower than 2 GeV<sup>2</sup>.

Since the lowest hybrid baryons with spin-parity assignments of  $J^\pi = \frac{1}{2}^+$  and  $J^\pi = \frac{3}{2}^+$  are predicted to cover the mass range of 2.2 - 2.3 GeV, and they are expected to decay into final states with significant  $s\bar{s}$  content such as  $KY$  and  $\pi\pi N$ , the new information on the  $\gamma_v p N^*$  electrocoupling evolution with  $Q^2$  in the proposed kinematics will substantially enhance our capability of discovering new baryon states.

Moreover, this kinematic range corresponds to the largest contributions from the meson-baryon cloud, allowing us to improve considerably our knowledge on this component, which is relevant to understand the structure of all  $N^*$  states studied so far [1, 4], as well as to explore the longitudinal  $N^*$  electroexcitations as the photon virtuality goes to zero.

This program adds an important new physics component to the existing CLAS12  $N^*$  program at 11 GeV, which aims to measure the transition form factors for all prominent  $N^*$  states up to the highest photon virtualities ever probed in exclusive reactions  $Q^2 < 12$  GeV<sup>2</sup>. The study of the spectrum and structure of excited nucleon states at distance scales from low to high  $Q^2$ , encompassing the regime where low-energy meson-baryon degrees of freedom dominate to the regime where quark degrees of freedom dominate, allows for the opportunity to better understand how the strong interaction of dressed quarks and gluons gives rise to the spectrum and structure of excited nucleon states and how these states emerge from QCD.

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