A New Experiment Run Group Proposal Submitted to Jefferson Lab PAC44

A Search for Hybrid Baryons in Hall B with CLAS12

Volker Burkert *(Contact Person, Spekesperson)*, Daniel S. Carman, Valery Kubarovsky, Victor Mokeev *(Spokesperson)*, Maurizio Ungaro, Veronique Ziegler
Thomas Jefferson National Accelerator Facility, Newport News, Virginia 23606, USA

Annalisa D'Angelo *(Spokesperson)*, Lucilla Lanza, Alessandro Rizzo
Università di Roma Tor Vergata and INFN Roma Tor Vergata, 00133 Rome, Italy

Gleb Fedotov, Boris Ishkhanov, Evgeny Isupov, Evgeny Golovach *(Spokesperson)*
Skobeltsyn Institute of Physics, Moscow State University, 119234 Moscow, Russia

Ralf Gothe *(Spokesperson)*, Iuliia Skorodumina
University of South Carolina, Columbia, South Carolina 29208, USA

Vincent Mathieu[†], Vladyslav Pauk, Alessandro Pilloni, Adam Szczepaniak[†]
Theory Center, Jefferson Laboratory, Newport News, Virginia 23606, USA
([†]*Joint with Indiana University, Bloomington, Indiana 47405, USA*)

Simon Capstick, Volker Crede
Florida State University, Tallahassee, Florida 32306, USA

Jan Ryckebushch
Ghent University, B-9000 Ghent, Belgium

Michael Döring
The George Washington University, Washington, DC 20052, USA

Philip Cole
Idaho State University, Pocatello, Idaho 83209, USA

Vincenzo Bellini, Francesco Mammoliti, Giuseppe Russo, Concetta Sutera, Francesco Tortorici
INFN, Sezione di Catania, 95125 Catania, Italy

Ilaria Balossino, Luca Barion, Giuseppe Ciullo, Marco Contalbrigo, Paola Lenisa, Aram Movsisyan, Luciano Pappalardo, Mateo Turisini
INFN, Sezione di Ferrara, 44100 Ferrara, Italy

Marco Battaglieri, Andrea Celentano, Raffaella De Vita, Erica Fanchini, Mikhail Osipenko, Marco Ripani, Elena Santopinto, Mauro Taiuti
INFN, Sezione di Genova, 16146 Genova, Italy

Alessandra Filippi
INFN, Sezione di Torino, 10125 Torino, Italy

César Fernández-Ramírez
Universidad Nacional Autónoma de México, 04510 Mexico City, Mexico

Inna Aznauryan
Yerevan Physics Institute, 375036 Yerevan, Armenia

and the CLAS Collaboration

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 ($Q^2 < 0.2$ 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° to 35° 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 and 8.8 GeV to cover the range of invariant mass W up to 3 GeV and Q^2 from 0.05 GeV^2 to 2 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 $Q^2 < 1.0$ 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.

Exclusive events from KY and $\pi^+\pi^-p$ final states will be selected and the unpolarized differential cross sections will be obtained, complemented by measurements of the differential transverse-transverse and transverse-longitudinal interference cross sections. From these data the $\gamma_v pN^*$ electrocouplings will be determined for all possible new states with I=1/2 and I=3/2 and with all possible J^P quantum numbers, and the Q^2 evolution of their helicity amplitudes will then be determined in the low Q^2 range ($Q^2 < 2$ GeV^2) for different reaction channels.

The hybrid baryons will be identified as additional states in the N^*-spectrum beyond the regular three-quark states. Since spin-parities of hybrid baryons are expected to be the same as those for regular three-quark states, the signature of the hybrid-baryon will emerge from the distinctively different low Q^2-evolution of the hybrid-baryon electrocouplings, due to the additional gluonic component in their wave function.

This kinematic range also corresponds to the largest contributions from the meson-baryon cloud, allowing us to improve our knowledge on this component, which is relevant to understand the structure of all N^* states studied so far [,], 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^2. 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.

Contents

General:

- Proposal or proposal
- three-quark state or 3-quark state

1 Introduction

The ongoing program at Jefferson Lab and several other laboratories to study the excitation of nucleons in the so-called nucleon resonance region with real photon and with electron beams has been very successful. Although only a fraction of the data taken during the CLAS run groups g8, g9, g11, and g12 have been analyzed and published, the published data have allowed for very significant advances in light-quark baryon spectroscopy, and led to strong evidence of several new nucleon excitations as listed in the PDG review of 2014 [ ]. These discoveries were possible due to the very high meson production rates recently obtained for energy-tagged photoproduction processes. Furthermore, the use of meson electroproduction has led to completely new insights into the nature of several prominent resonant baryons, e.g. the so-called Roper resonance $N(1440)\frac{1}{2}^+$. This state defied an explanation of its properties, such as mass, transition amplitudes, and transition form factors within the constituent quark model (CQM). The analyses of the new electroproduction data were crucial in dissecting its complex structure and providing a qualitative and quantitative explanation of the space-time evolution of the state [ ]. The Roper was also considered as a candidate for the lowest mass hybrid baryon [ ]. It was only through the meson electroproduction data that this possibility could be dismissed [,].

The theory of the strong interactions, QCD, not only allows for the existence of baryons with dominant gluonic contributions (hybrid baryons), but Lattice QCD calculations now predict several baryon states with dominant gluonic admixture to the wave function, and with the lowest mass hybrids approximately 1.3 GeV above the nucleon ground state of 0.94 GeV [ ], i.e. **in the range** $W = 2.1 - 2.5$ **GeV**. In the meson sector, exotic states (hybrid mesons) are predicted with quantum numbers that cannot be obtained in a pure $q\bar{q}$ configuration. The selection of mesons with such exotic quantum numbers provides a convenient way to identify candidates for gluonic mesons. In contrast to the meson sector hybrid baryons have quantum numbers that are also populated by ordinary excited 3-quark states. Hybrid baryons hence mix with these 3-quark excited states or with dynamically generated states making the identification of gluonic baryons more difficult. An important question is therefore: How can we distinguish gluonic excitations of baryons from their ordinary quark excitations? Another question is the mass range in which we may expect hybrid baryons to occur.

Mapping out the nucleon spectrum and the excitation strengths of individual resonances is a powerful way to answer a central question of hadron physics: "What are the effective degrees of freedom as the excited states are probed at different distance scales?". Previous analyses of meson electroproduction have shown to be most effective in providing answers **in several cases of excited states:** $\Delta(1232)\frac{3}{2}^+$, $N(1440)\frac{1}{2}^+$, $N(1520)\frac{3}{2}^-$, $N(1535)\frac{1}{2}^-$, $\Delta(1620)\frac{1}{2}^-$ $N(1680)\frac{5}{2}$ **and** $N(1710)1/2^+$.

The experimental program outlined in this proposal is meant to vastly improve upon the available information and extend the reach of meson electroproduction to cover the full nucleon resonance mass range up to 3 GeV and a larger low-Q^2 range from 0.05 to 2 GeV^2, using electron beam energies of 6.6 GeV and 8.8 GeV. The unpolarized differential cross sections will be resumed for KY and $\pi^+\pi^-p$ exclusive channels, complemented by measurements of the differential transverse-transverse and transverse-longitudinal interference cross sections.

From these data the $\gamma_v pN^*$ 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 πN [,] and KY [ ], as well as **the JLab-Moscow (JM) meson-baryon reaction model for $\pi^+\pi^-p$ electroproduction** [,], multi-channel partial wave techniques employing both the Bonn-Gatchina [ ] and GWU [ ] approaches, and approaches starting from the Veneziano model and Regge phenomenology [ ] 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=1/2 and I=3/2 and with all possible J^P 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 values of 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 $\gamma_v pN^*$ 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 $\Delta(1232)3/2^+$, the $N(1440)1/2^+$ and the $N(1535)1/2^-$ [,]. These and many other results are included in the review of the N^* and Δ^* states in the latest edition of the PDG [ ].

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 [ ]. Since spin-parities of hybrid baryons are expected to be the same as those for regular three-quark states, information on the $\gamma_v pN^*$ electrocoupling evolution with Q^2 becomes critical in the search for hybrid baryons. A distinctively different Q^2-evolution of the hybrid-baryon electrocouplings is expected considering the different color-multiplet assignments for the quark-core in a regular versus a hybrid baryon, i.e. a color singlet and octet, respectively. Low photon virtualities offer a preferential regime for the studies of hybrid-baryon electrocouplings.

In conjunction with experiment E12-09-003, which focuses on the highest Q^2, as well as E12-06-108A, which explores $K^+\Lambda$ production, the proposed experiment will provide a complete program of nucleon resonance electroexcitation.

2 Theoretical Studies of Hybrid Baryons

2.1 Model projections

In an extension of the MIT bag model, gluonic excitations of the nucleon, to states where a constituent gluon in the lowest energy transverse electric mode combines with three quarks in a color octet state to form a colorless state in the mass range of 1.600 ± 0.100 GeV, have been broadly discussed since 1983 [ ].

The gluon flux-tube model applied to hybrid baryons [,] came up with similar quantum numbers of the hybrid states, but predicted considerably higher masses than the bag model. For the lowest mass flux-tube hybrid baryon a mass of 1.870 ± 0.100 GeV was

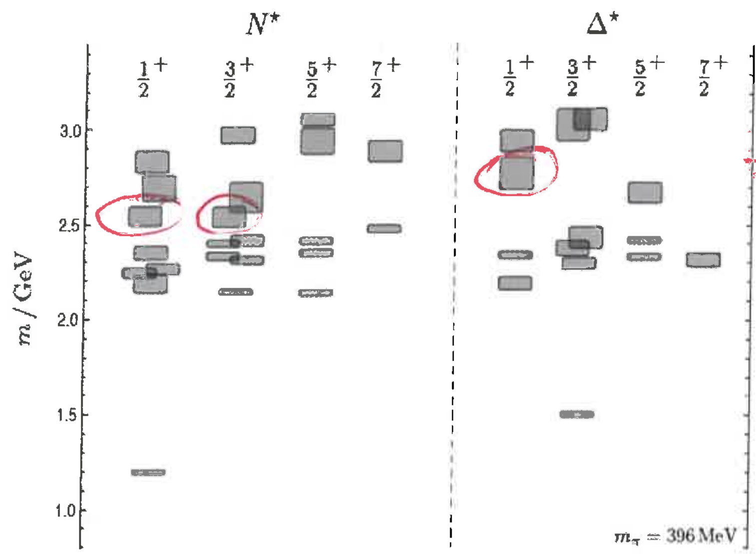

Figure 1: The light-quark baryon spectrum predicted in Lattice QCD at a pion mass of 396 MeV. The blue shaded boxes indicate states with dominant gluonic contributions. Note that both the mass of the nucleon ground state and of the $\Delta(1232)$ are shifted by nearly 300 MeV to higher masses.

found. In all cases the lowest mass hybrid baryon was predicted as a $J^P = 1/2^+$ state, i.e. a nucleon-like or Roper-like state. Hybrid baryons were also discussed in the Large N_c approximation of QCD for heavy quarks [ ], which also led to the justification of the constituent glue picture used in the models. The high energy behavior of hybrid baryons was discussed in [ ]. However, in contrast to hybrid meson production, which has received great attention both in theory and in experiments, the perceived difficulties of isolating hybrid baryon states from ordinary quark states led this part of the field to remain dormant for a decade.

2.2 Lattice QCD predictions

The first quenched calculations on the lattice came in 2003 [ ], when the lowest gluonic 3-quark hybrid system was projected at a mass of 1 GeV above the nucleon mass, placing the lowest hybrid baryon at a mass around 2 GeV. The first LQCD calculation of the full light-quark baryon spectrum with unquenched quarks occurred in 2012 that included the projections of the hybrid nucleon N_G states and hybrid Δ_G states [ ]. Figure 1 shows the projected light quark baryon spectrum in the lower mass range.

At the pion mass of 396 MeV used in this projection, the prediction for the nucleon mass is shifted by nearly 300 MeV to higher masses. In the following we take this shift into account by subtracting 300 MeV from the masses of the excited states in Fig. 1. As stated in [ ], the lowest hybrid baryons, shown in Fig. 1 in blue, were identified as states with leading gluonic contributions. If hybrid baryons are not too wide, we might expect the lowest hybrid baryon

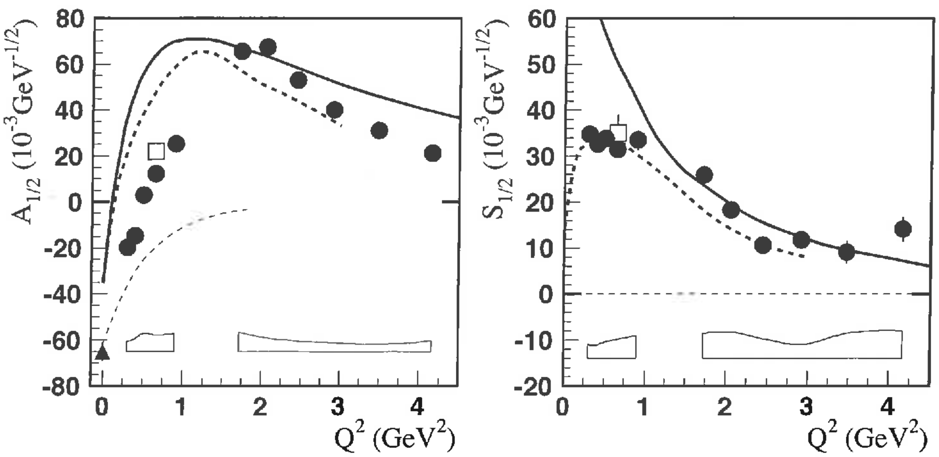

Figure 2: Electrocoupling amplitudes of the Roper resonance $N(1440)\frac{1}{2}^+$. The thin dashed lines are the constituent quark-glue model predictions for the gluonic Roper

to occur at masses of about 1.3 GeV above the ground state, i.e. in a mass range of 2.2 – 2.3 GeV, a few hundred MeV above the band of radially excited $J^P = \frac{1}{2}^+$ 3-quark nucleon excitations of isospin 1/2 and thus possibly well separated from other states.

In this computation the lowest $J^P = \frac{3}{2}^+$ gluonic states are nearly mass degenerate with the corresponding $J^P = \frac{1}{2}^+$ gluonic states generating a glue-rich mass range of hybrid nucleons. If these projections hold up with LQCD calculations using near physical pion masses, one should expect a band of the lowest mass hybrid baryon states with spin-parity $\frac{1}{2}^+$ and $\frac{3}{2}^+$ to populate a relatively narrow mass band of 2.2 – 2.5 GeV. Note, that these states fall into a mass range where no 3-quark nucleon excitations are predicted to exist from these calculations. The corresponding negative parity hybrid states, which are expected to occur at much higher masses, are not included in this graph and are not further considered here; although they may be subject of analysis, should they appear within the kinematic range covered by this Proposal.

2.3 Hadronic couplings

Very little is known about possible hadronic couplings of hybrid baryons. One might expect an important role for final states with significant gluonic admixture, e.g. $B_G \rightarrow N\eta'$ [ ], or final states containing $s\bar{s}$ contributions due to the coupling $G \rightarrow s\bar{s}$, e.g. $B_G \rightarrow K^+\Lambda$, $B_G \rightarrow N^*(1535)\pi \rightarrow N\eta\pi$, $B_G \rightarrow N\pi\pi$, $B_G \rightarrow \phi(1020)N$, and $B_G \rightarrow K^*\Lambda$. Quark-model estimates of the hadronic couplings would be helpful in selecting the most promising final state for the experimental evaluation. As long as such estimates are not available we will use a range of assumptions on the hadronic couplings to estimate the sensitivity required for definitive measurements. Assuming hadronic couplings of a few percent in the less complex final states, e.g. $K^+\Lambda$, $K^*\Lambda$, or $N\pi\pi$, we should be able to identify these states and proceed to experimentally establish their electromagnetic couplings and Q^2 dependences. **We included into our Proposal those of the aforementioned channels which we already studied in details previously and included into the future N^* studies with the CLAS12**

[,], i.e. $K^+\Lambda$, $K^+\Sigma$ and $\pi^+\pi^-p$. Later on these studies may be extended by the exploration of other electroproduction channels such as $\phi(1020)N$, $K^*\Lambda$.

2.4 Electromagnetic couplings

Studies of excited nucleon state electrocouplings in a wide range of photon virtualities is proven to be the effective tools in establishing the active degrees of freedom contributing to the N* structure at different distances [, , –]. The information on the $\gamma_v NN^*$ electrocoupling evolution with Q^2 becomes critical in the search for hybrid baryons. The distinctively different Q^2 evolution of the hybrid-baryon electrocouplings is expected considering the different color-multiplet assignments for the quark-core in a regular versus a hybrid baryon, i.e. a color singlet and octet, respectively. Electromagnetic couplings have been studied within a non-relativistic constituent quark-gluon model, but only for two possible hybrid states, the Roper $N_G(1440)\frac{1}{2}^+$ and the $\Delta_G(1600)\frac{3}{2}^+$. In reference [ ] the photoexcitation of the hybrid Roper resonance $N(1440)\frac{1}{2}^+$ was studied, and in reference [ ] the electroproduction transition form factors of a hybrid Roper state were evaluated. The latter was essential in eliminating the Roper resonance as a candidate for a hybrid state, both due to the transverse helicity amplitude and its Q^2 dependence and the prediction of $S_{1/2}(Q^2) = 0$ at all Q^2. It also showed that a hybrid Roper transition amplitude $A_{1/2}$ should behave like the $A_{1/2}$ of the ordinary $\Delta(1232)$. Clearly the $S_{1/2}$ behaves differently and the $A_{3/2}$ does not exist for the Roper. Recent measurements of the electrocoupling transition amplitudes are shown in Fig. 6. Both amplitudes exhibit a Q^2 dependence that is distinctively different from the hybrid baryon prediction. Especially the scalar amplitude $S_{1/2}(Q^2)$ was found to be large while it is predicted to be suppressed in leading order for the lowest mass $\frac{1}{2}^+$ hybrid state.

The aforementioned predictions should apply to each lowest mass hybrid state with $J^P = \frac{1}{2}^+$ and $\frac{3}{2}^+$. One may ask about the model-dependence of this prediction. The transverse amplitude has model sensitivity in its Q^2 dependence and it depends on model ingredients, however, there are no ordinary 3-quark model predictions that would come even close to the predictions of the hybrid quark-gluon model. The radial excitation of the Roper resonance gives a qualitatively different prediction for $A_{1/2}(Q^2)$ compared to the hybrid excitation, where the 3-quark component remains in the ground state with only a spin-flip occurring (just as for the $N-\Delta(1232)$ transition). The suppression of the longitudinal coupling is a property of the γqG vertex and is largely independent of specific model assumptions.

The other state, $\Delta(1600)\frac{3}{2}^+$, was considered as a candidate for the lowest mass gluonic Δ_G. A result similar to the one for the hybrid Roper is found in [ ] for a hybrid $\Delta_G(1600)\frac{3}{2}^+$, i.e. a fast falling $A_{1/2}(Q^2)$ and $S_{1/2}(Q^2) \approx 0$. The amplitudes at the photon point are not inconsistent with the ordinary 3-quark model calculation but are inconsistent with the hybrid baryon hypothesis. On the other hand this result is also in line with the expectation that the lowest mass hybrid states should have considerably higher masses than the first radially excited quark states. Note that there are currently no experimental results for the Q^2 dependence of the $A_{1/2}$ and $S_{1/2}$ amplitudes of this state.

Based on quark counting rules [?], we expect that electrocouplings of hybrid baryons should decrease with photon virtuality Q^2 more rapidly than for the reg-

ular three-quark nucleon resonance because of the extra constituent. So, the low photon virtualities offer a preferential regime for the studies of hybrid-baryons. In our Proposal we are planning to explore the range of $Q^2 < 2.0$ GeV^2 with particular focus for hybrid baryon search at $Q^2 < 1.0$ GeV^2. In order to identify hybrid-baryon we are looking for its electrocouplings behavior which should have distinctively different features in comparison with already established from the CLAS results [ ]. electrocouplings of three-quark resonances of $J^P = \frac{1}{2}^+$ shown in Fig 5,6 and of $J^P = \frac{3}{2}^+$ shown in Fig 7,8. If hybrid baryons will be established in the proposed experiment, further studies of their electrocouplings can be extended towards higher photon virtualities from the data of the approved experiments with the CLAS12 [,]

3 Strategies for identifying Hybrid- and three-quark new baryon states

In this section we address the question if and how gluonic hybrid baryons are distinct from ordinary quark excitations. We will also elucidate the additional opportunities offered by the studies of exclusive electroproduction processes at different photon virtualities for the search of new baryon states both hybrid-baryons and regular three-quark so-called "missing" resonances.

3.1 Search for the hybrid baryon states

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Old version: In this section we address the question if and how gluonic hybrid baryons are distinct from ordinary quark excitations. As discussed in section 2.2 the lowest hybrid baryons should have isospin $I = \frac{1}{2}$ and $J^P = \frac{1}{2}^+$ or $J^P = \frac{3}{2}^+$, and their masses should be in the range of 2.20 to 2.50 GeV. This mass range must be verified once LQCD calculations with physical pion masses become available, as masses may shift with more realistic pion masses, likely to the lower mass range. Four states with $I = \frac{1}{2}$ and $J^P = \frac{1}{2}$ are predicted with dominant quark contributions and with masses below the mass of the lowest LQCD hybrid states. Of these four states two are the well known $N(1440)\frac{1}{2}^+$ and $N(1710)\frac{1}{2}^+$, and two are the less well established $N(1880)\frac{1}{2}^+$ and $N(2100)\frac{1}{2}^+$ with 2* and 1* ratings, respectively. Another state $N(2300)$ has a 2* rating and falls right into the lowest hybrid mass band projected by LQCD. This state, if confirmed, could be a candidate for the predicted lowest LQCD hybrid state.

In order to address this question, it is necessary to confirm (or refute) the existence of the 2* state $N(1880)$ and of the 1* state $N(2100)$, and to measure the electromagnetic couplings of $N(2300)$ and their Q^2 dependence. Improved information on the lower mass states should become available in the next one or two years, when the new high-statistics single- and double-polarization data from CLAS have been included into the multi-channel analysis frameworks such as the Bonn-Gatchina or Jülich/GWU approaches. Should these two states be confirmed, then any new nucleon state with $J^P = \frac{1}{2}^+$, which happens to be in the right mass range, could be a candidate for the lowest mass hybrid baryon. The

$N(2300)\frac{1}{2}^+$ state has been seen at BES III only in the invariant mass $M(p\pi^\circ)$ of $\Psi(2S) \to p\bar{p}\pi^\circ$ events. In this case the production of $N(2300)$ occurs at very short distances as it emerges from heavy quark flavor $c\bar{c}$ decay. Hence the state may even be observable in single pion electroproduction $ep \to e'\pi^+n$ and $ep \to e'p'\pi^\circ$, if it couples to photons with sufficient strength to be measurable.

In the $J^P = \frac{3}{2}^+$ sector the situation is more involved. There are two hybrid states predicted in the mass range 2.2 to 2.4 GeV, with masses above five quark model states at same J^P. Of the five states, two are well known 4* and 3* states, the $N(1720)\frac{3}{2}^+$ and the $N(1900)\frac{3}{2}^+$, respectively, and one state, the $N(2040)\frac{3}{2}^+$, has a 1* rating. Here we will have to confirm (or refute) the 1* star state and find two or three (if $N(2040)$ does not exist) more quark model state with the same quantum numbers in the mass range 1.7 to 2.1 GeV. There is one candidate $\frac{3}{2}^+$ state with mass near 1.72 GeV seen in $p\pi^+\pi^-$ electroproduction [ ], whose status we will be able to pin down with the expected very high statistics data.

Possible signatures of the lowest mass hybrid baryons are:

- Resonance masses in the range 2.0 GeV $\leq W \leq 2.5$ GeV with $I = 1/2$, and $J^P = \frac{1}{2}^+$ or $J^P = \frac{3}{2}^+$. **Presence of almost the same masses $J^P = \frac{1}{2}^+$ and $J^P = \frac{3}{2}^+$ states with no regular 3-quark states observed in the mass range of the lowest hybrids.**

- Q^2 dependence of the transverse helicity amplitude $A_{1/2}(Q^2)$ similar to the $\Delta(1232)\frac{3}{2}^+$ but dissimilar to **3-quark excited states of same J^P seen in the CLAS results**, and

- a strongly suppressed helicity amplitude $S_{1/2}(Q^2) \approx 0$ in comparison to other ordinary 3-quark states or meson-baryon excitations.

This list of expected resonance properties may provide some initial guidance when examining new baryon states for signatures of large gluonic components, they are however not sufficient to firmly establish the hybrid nature of a state. To achieve this goal, improved modeling of other degrees-of-freedom such as meson-baryon contributions and direct calculations of electrocouplings from LQCD will be needed. The expected high statistics data will be used to identify any new or poorly known state, whether or not it is a candidate for a hybrid baryon state. This will aid in the identification of the effective degrees of freedom underlying the resonance excitation of all states that couple to virtual photons. Old: check for repetitions

Besides the search for hybrid baryon states, there are many open issues in our knowledge of the structure of ordinary baryon excitations, that can be addressed with data taken in parallel from the same experiment. As an example we show in Fig. 3 the electrocouplings of the $N(1680)\frac{5}{2}^+$ resonance, the strongest state in the third nucleon resonance region. With the exception of the real photon point, the data are quite sparse for $Q^2 \leq 1.8$ GeV^2 and the high statistics data expected from this project would remedy the lack of experimental information and address similar situations for other states as well. Note that the very high-Q^2 part will be covered by the approved JLab experiment E12-09-003.

An even more compelling example is the $N(1675)\frac{5}{2}^-$ state, where data at $Q^2 > 1.8$ GeV^2 have been published recently by the CLAS Collaboration [ ]. Figure 4 shows the measured helicity amplitudes. Low Q^2 data are very important here, as for this state the quark

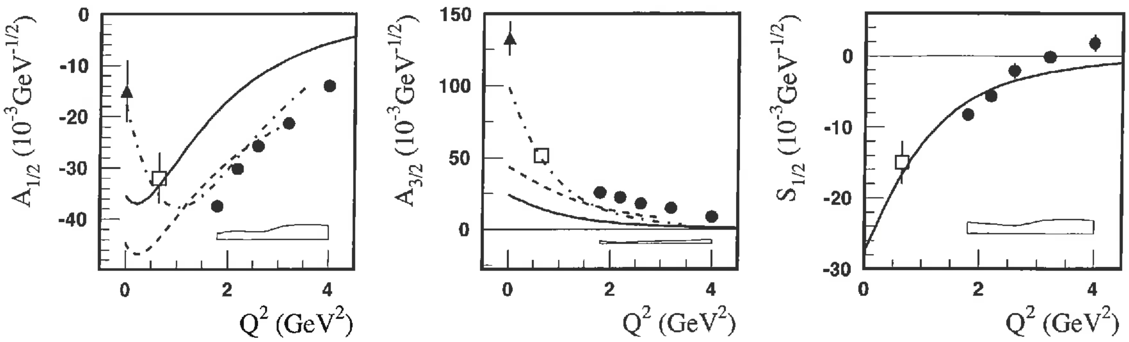

Figure 3: Electrocoupling amplitudes of the $N(1680)\frac{5}{2}^+$ resonance.

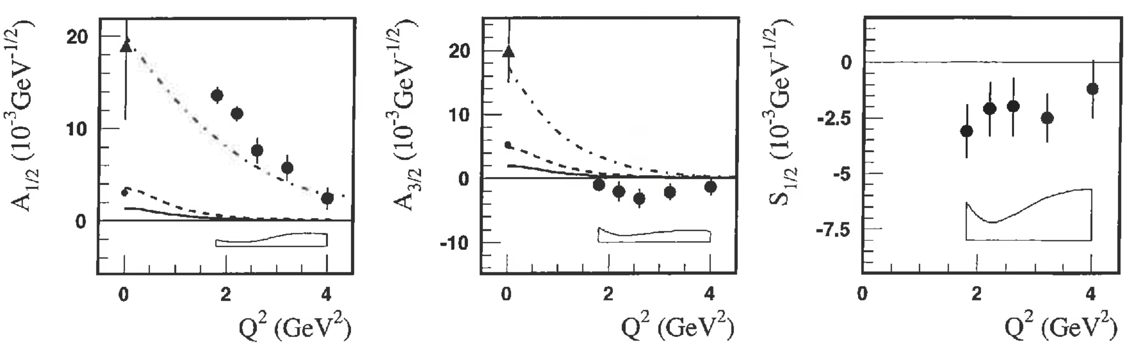

Figure 4: Electrocoupling amplitudes of the $N(1675)\frac{5}{2}^-$ resonance. Quark models predict the transverse amplitudes to be suppressed. The significant deviation of the $A_{1/2}$ amplitudes is consistent with meson-baryon contributions to the excitation strength (dashed-dotted lines).

transitions are strongly suppressed by the Moorhouse selection rule, and therefore, any non-zero value of the electrocoupling amplitudes will directly measure the strength of the meson-baryon contributions. The main data needed are single pion production $ep \to e'\pi^+n$ and $ep \to e'\pi^0p$. These processes can be accumulated with sufficiently high event rates, even with a pre-scale factor of 10 or more on the FT, should the overall event rate be too high in this 2-prong topology.

The recent combined analysis [ ] of the CLAS $\pi^+\pi^-p$ photo- [ ] and electro-production [ ] data revealed further convincing evidence for new baryon state $N'(1720)3/2^+$. This state has the same spin-parity and almost the same mass and total decay width as the conventional $N(1720)3/2^+$, but distinctively different Q^2 evolution of the resonance electrocouplings (see Fig. 7, 8) and the partial hadronic decay widths to the $\pi\Delta$ and ρp final states. Right now, beside the photon point the electrocouplings of new $N'(1720)3/2^+$ state are available in the limited range of Q^2 from 0.5 to 1.5 GeV^2. As it is shown in Fig 7, 8 the $A_{1/2}(Q^2)$ electrocouplings of $N(1720)3/2^+$ and $N'(1720)3/2^+$ states evolve at $Q^2 < 0.5$ GeV^2 completely different. The $A_{1/2}(Q^2)$ of the conventional $N(1720)3/2^+$ baryon state decreases with Q^2, while for the new $N'(1720)3/2^+$ it incareses in the range of $Q^2 < 0.5$ GeV^2. Therefore, the future results on $N(1720)3/2^+$ and $N'(1720)3/2^+$ electrocouplings from the data on exclusive $\pi^+\pi^-p$ electroproduction off protons

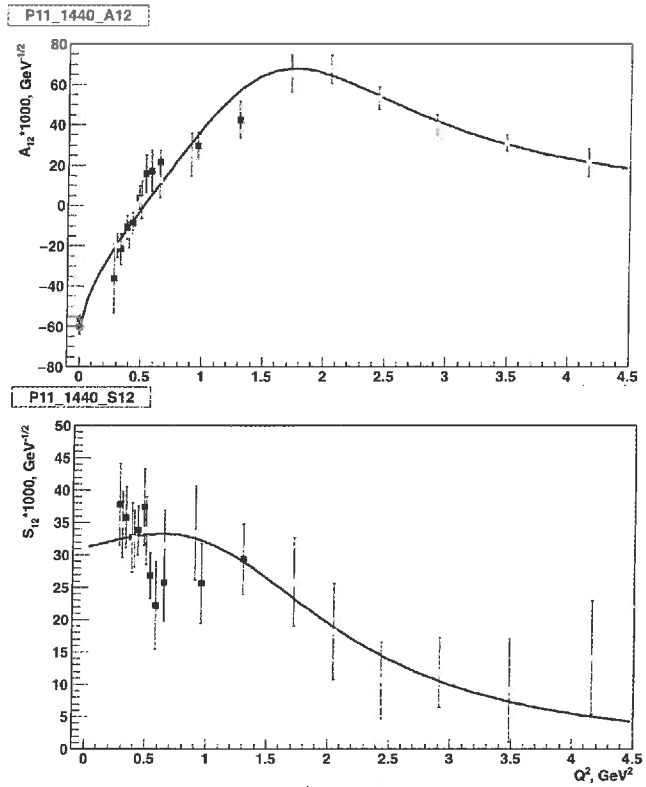

Figure 5: Interpolation of the $N(1440)1/2^+$ electrocouplings from the CLAS data on $N\pi$ (green circles) [ ] and $\pi^+\pi^-p$ [,] (black and blue squares) exclusive electroproduction off protons. The results at the photon point are taken from [,]

at small Q^2 will shed light on the differences in the structure of the conventional and the so-called "missing" baryon states.

In general, the studies of resonance electrocouplings at small photon virtualities in the proposed experiment for the first time will allow us to explore their Q^2-evolution at the distances where the meson-baryon cloud contributions are expected to be biggest, offering the preferential condition for exploration of this component of the N*-structure. The recent advances in the studies of the nucleon structure within the framework of the based on QCD Dyson-Schwinger Equations [,], makes it increasingly clear, that the systematic information on meson-baryon cloud for the excited nucleon states of different quantum numbers is of particular importance in order to understand how the confined in the ground/excited nucleon core dressed quarks and gluons eventually evolve into the external deconfined mesons and baryons. Therefore, the proposed studies will address the challenging open problem in the hadron physics on the transition from quark-gluon confinement to the regime of strong interaction between the color-neutral mesons and baryons.

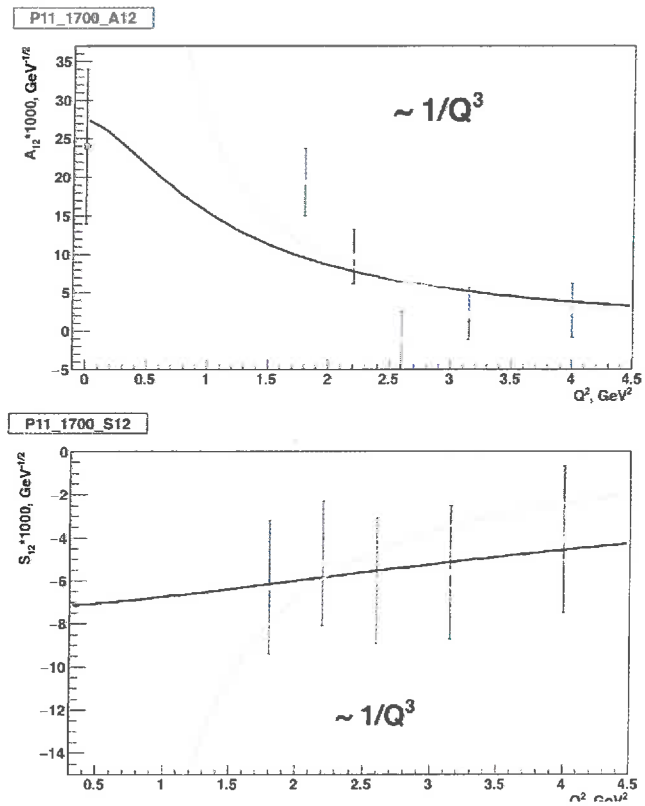

Figure 6: Interpolation of the $N(1710)1/2^+$ electrocouplings from the CLAS data on $N\pi$ (green circles) [ ] exclusive electroproduction off protons. The results at the photon point are taken from [,]

3.2 Search for the three-quark new baryon states

Advanced studies of the data on exclusive meson photoproduction off protons carried out within the framework of the global multi-channel amplitude analysis developed by the Bonn-Gatchina group [–] revealed the signals from many new baryon states in the mass range from 1.7 GeV to 2.5 GeV. These states were included to the PDG [ ] with the status from one to three star states. Notably, the most prominent signals from new states come from analyses of the CLAS [–], ELSA [ ], MAMI [ ] and GRAAL [?] data on KY electroproduction. Studies of KY as well as $\pi^+\pi^-p$ exclusive electroproduction channels extend considerably our capability in establishing of the excited nucleon state spectrum, including both regular three-quark and exotic hybrid states.

The new baryon states, if they are excited in s-channel should be seen in exclusive reactions both with the real and virtual photons in the same final states. Furthermore, their masses, total decay widths, partial decay widths to different final states should be Q^2-independent. The values of $\gamma_v pN^*$ electrocouplings obtained independently from analyses of different exclusive channels with completely different non-resonant contributions should be the same. Consistent results on resonance masses, $\gamma_v pN^*$ electrocouplings for all exclusive decay channels under study, and Q^2-independent partial hadronic decay widths, over the

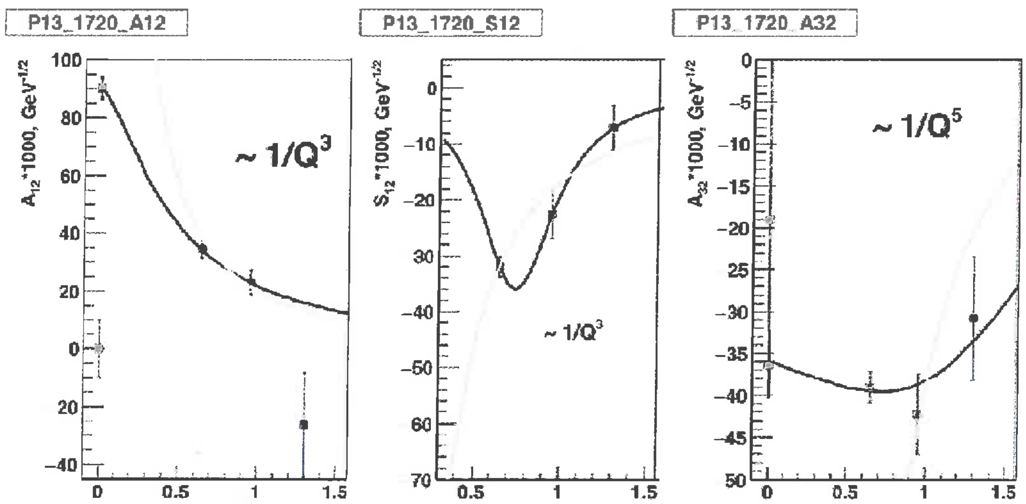

Figure 7: Interpolation of the $N(1720)3/2^+$ electrocouplings from the CLAS data on $\pi^+\pi^-p$ [ ] exclusive electroproduction off protons [ ]. The results at the photon point are taken from [,]

full covered Q^2-range, will offer convincing evidence for the existence of new states. These studies offer model independent way to prove not only the existence of new excited nucleon states but also their nature as the s-channel resonances eliminating the alternative interpretations for the structures observed in the kinematics dependencies of the observables as complex coupled channel effects, dynamical singularities for the non-resonant amplitudes, kinematic reflections, etc.

This strategy was successfully employed in the recent analysis of the $\pi^+\pi^-p$ preliminary photo- and electroproduction cross sections [ ] from the CLAS carried out combined within the framework of meson-baryon reaction model JM [ ]. It was found that in order to describe both photo- and electroproduction data at W around 1.7 GeV keeping $\pi\Delta$ and ρp hadronic decay widths of all contributing resonances Q^2-independent, new baryon state $N'(1720)3/2^+$ state is needed with almost the same mass, total widths and the same spin-parity as for the conventional $N(1720)3/2^+$ resonances, but with completely different branching fractions for the hadronic decay to the $\pi\Delta$ and ρp final state and Q^2-evolution of its $\gamma_v pN^*$ electrocouplings.

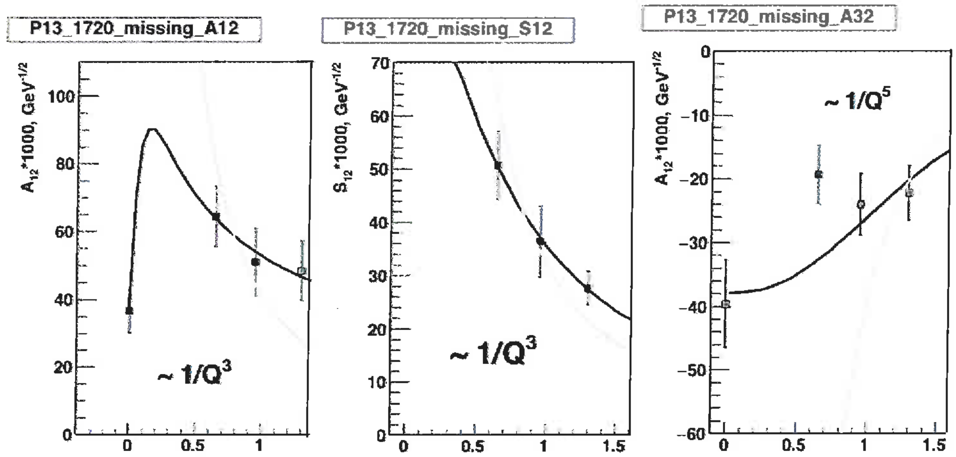

Figure 8: Interpolation of the $N'(1720)3/2^+$ electrocouplings from the CLAS data on $\pi^+\pi^-p$ [ ] exclusive electroproduction off protons [ ]. The results at the photon point are taken from [,]

The studies of exclusive KY, $\pi^+\pi^-p$ electroproduction channels at $Q^2 < 2.0$ GeV^2 with maximal virtual photon flux ever achieved in exclusive electroproduction will allow us to solidify the results on the spectrum of excited nucleon states, confirming or ruling out the signal of "missing" resonances observed in exclusive photoproduction. Furthermore, for the first time the information on $\gamma_v pN^*$ electrocouplings of new baryon states will become available offering an access to the structure of "missing" resonances elucidating their differences from the conventional resonances. Finally we want to note that the studies of two major exclusive $N\pi$ and $\pi^+\pi^-p$ electroproduction channels with CLAS revealed the relative growth of the resonant contributions with Q^2 in both channels. So, use of the high intensity virtual photon flux of the proposed experiment may be even preferential for new baryon state search in comparison with the photoproduction. It still remain to be seen which range of photon virtualities is the most suitable for the discovery of new excited nucleon states.

3.3 Amplitude analyses of measured observables in a search for new baryon states.

In the analyses of the future experimental data we will apply the amplitude analyses methods for the resonance search and extraction of the resonance parameters. We will employ the global fit of all exclusive channels studied with the CLAS12 in the kinematics of out interest with a focus on new baryon state search within the framework of coupled channel approaches. We also planning to extract of the resonance parameters from the independent analyses of KY, $\pi^+\pi^-p$ exclusive electroproduction off protons carried our within the framework of the reaction models for description of these exclusive channels. Consistent results on the resonant parameters determined from independent analyses of different exclusive meson electroproduction channels and extracted from the global multi-channel fit of all available