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V.I. Mokeev for the CLAS Collaboration

Updates on the Studies of N^* Structure with CLAS and the Prospects with CLAS12

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Abstract The recent results on $\gamma_v pN^*$ electrocouplings from analyses of the data on exclusive meson electroproduction off protons measured with the CLAS detector at Jefferson Lab are presented. The impact of these results on the exploration of the excited nucleon state structure and non-perturbative strong interaction dynamics behind its formation is outlined. The future extension of these studies in the experiments with the CLAS12 detector in the upgraded Hall-B at JLab will provide for the first time $\gamma_v pN^*$ electrocouplings of all prominent resonances at the still unexplored distance scales that correspond to extremely low (0.05 GeV^2 $< Q^2 <$ 0.5 GeV^2) and to the highest photon virtualities (5.0 GeV^2 $< Q^2 <$ 12.0 GeV^2) ever achieved in the exclusive electroproduction measurements. The expected results will address the most important open problems of the Standard Model: on the nature of more than 98% of hadron mass, quark-gluon confinement and the emergence of the excited nucleon state structure from the QCD Lagrangian, as well as allowing a search for the new states of hadron matter predicted from the first principles of QCD, the so-called hybrid baryons.

Keywords exclusive meson electroproduction · nucleon resonance structure · non-perturbative strong interaction

1 Introduction

The studies of helicity amplitudes that describe the transitions between the initial real/virtual photon - ground state proton and the final N^*/Δ^* states, the so-called $\gamma_{r,v}pN^*$ photo-/electrocouplings, represent an important and absolutely needed effort in the exploration of non-perturbative strong interaction dynamics behind the generation of the ground and excited nucleon states from quarks and gluons. These studies, carried out in a wide range of photon virtualities Q^2 and over all prominent excited nucleon states, are the only source of information on different manifestations of the non-perturbative strong interaction in the generation of excited nucleons of different quantum numbers [1; 2; 3]. Furthermore, the recent studies of nucleon structure within the framework of the Dyson-Schwinger Equations of QCD (DSEQCD) [4; 5; 6; 7] conclusively demonstrated the critical importance of combined analysis of the data on elastic and transition $p \to N^*$ form factors in order to provide credible access to the momentum dependence of the running dynamical mass of dressed quarks. This fundamental ingredient of the non-perturbative strong interaction elucidates the generation of more than 98% of hadron mass and the emergence of quark-gluon confinement. It makes the studies of the elastic and transition

V.I. Mokeev
Thomas Jefferson National Accelerator Facility, Newport News, VA 23606
Tel.: +1-757-269-6990
Fax: +1-757-269-5800
E-mail: mokeev@jlab.org

$p \to N^*$ form factors, which are directly related to $\gamma_{r,v} p N^*$ photo-/electrocouplings, one of the central focuses of contemporary hadron physics.

In this proceedings we outline the current status in the studies of the $\gamma_v p N^*$ electrocouplings from the data on exclusive meson electroproduction off protons measured with the CLAS detector at JLab [2; 3; 8; 9; 10; 11], as well as the insight to the structure of excited nucleon states offered by these results. We discuss also the prospects for the future extension of the resonance electrocoupling studies in the experiments foreseen with the CLAS12 detector. The results expected from these experiments will address the key open problems of the Standard Model on the nature of more than 98% of the ground and excited nucleon masses, the emergence of quark-gluon confinement and the nucleon spectrum and structure from QCD [12]. Furthermore, they will allow us to search for the new states of baryon matter predicted in the Lattice QCD studies of the N^* spectrum [13], the so-called the hybrid baryons [10; 14].

2 Evaluation of $\gamma_v p N^*$ electrocouplings from the CLAS data on exclusive meson electroproduction off protons

The CLAS detector has contributed the lion's share of the world data on all essential exclusive meson electroproduction channels in the resonance excitation region including πN, ηp, KY, and $\pi^+\pi^- p$ electroproduction off protons with nearly complete coverage of the final hadron phase space [8]. The observables measured with the CLAS detector are stored in the CLAS Physics Data Base [15]. The available observables in the resonance excitation region are listed in Table 1. In the near future the data in the resonance region will be extended by new results on $\pi^+ n$, $\pi^0 p$, and $\pi^+\pi^- p$ exclusive electroproduction at $W < 1.9$ GeV and 0.3 GeV^2 $< Q^2 < 1.0$ GeV^2. The new data on $\pi^+\pi^- p$ electroproduction off protons at $W < 2.0$ GeV will become available in the Q^2 range from 2.0 GeV^2 to 5.0 GeV^2.

So far, most of the results on the $\gamma_v p N^*$ electrocouplings have been extracted from independent analyses of $\pi^+ n$, $\pi^0 p$, and $\pi^+\pi^- p$ exclusive electroproduction data off the proton. A total of nearly 160,000 data points (d.p.) on unpolarized differential cross sections, longitudinally polarized beam asymmetries, and longitudinal target and beam-target asymmetries for πN electroproduction off protons were obtained with the CLAS detector at $W < 2.0$ GeV and 0.2 GeV^2 $< Q^2 < 6.0$ GeV^2. The data have been analyzed within the framework of two conceptually different approaches: a unitary isobar model (UIM) and dispersion relations (DR) [16; 17]. The UIM describes the πN electroproduction amplitudes as a superposition of N^* electroexcitations in the s-channel, non-resonant Born terms, and ρ- and ω- t-channel contributions. The latter are reggeized, which allows for a better description of the data in the second- and third-resonance regions. The final-state interactions are treated as πN rescattering in the K-matrix approximation [16]. In the DR approach, dispersion relations relate the real to the imaginary parts of the invariant amplitudes that describe the πN electroproduction. Both approaches provide a good and consistent description of the πN data in the range of $W < 1.7$ GeV and $Q^2 < 5.0$ GeV^2, resulting in $\chi^2/d.p. < 2.9$.

The $\pi^+\pi^- p$ electroproduction data from CLAS [18; 19] provide information for the first time on nine independent single-differential and fully-integrated cross sections binned in W and Q^2 in the mass range $W < 2.0$ GeV and at photon virtualities of 0.25 GeV^2 $< Q^2 < 1.5$ GeV^2. The analysis of the data have allowed us to develop the JM reaction model [3; 20; 21] with the goal of extracting resonance electrocouplings, as well as $\pi\Delta$ and ρp hadronic decay widths. This model incorporates all relevant reaction mechanisms in the $\pi^+\pi^- p$ final-state channel that contribute significantly to the measured electroproduction cross sections off protons in the resonance region, including the $\pi^-\Delta^{++}$, $\pi^+\Delta^0$, $\rho^0 p$, $\pi^+ N(1520)\frac{3}{2}^-$, $\pi^+ N(1685)\frac{5}{2}^+$, and $\pi^-\Delta(1620)\frac{3}{2}^+$ meson-baryon channels, as well as the direct production of the $\pi^+\pi^- p$ final state without formation of intermediate unstable hadrons. In collaboration with JPAC [22] a special approach has been developed allowing us to remove the contributions from the s-channel resonances to the reggeized t-channel non-resonant terms in the $\pi^-\Delta^{++}$, $\pi^+\Delta^0$, $\rho^0 p$ electroproduction amplitudes. The contributions from well established N^* states in the mass range up to 2.0 GeV were included into the amplitudes of the $\pi\Delta$ and ρp meson-baryon channels by employing a unitarized version of the Breit-Wigner ansatz [20]. The JM model provides a good description of the $\pi^+\pi^- p$ differential cross sections at $W < 1.8$ GeV and 0.2 GeV^2 $< Q^2 < 1.5$ GeV^2 with $\chi^2/d.p. < 3.0$. The quality for the description of the CLAS data suggests the unambiguous and credible separation between the resonant/non-resonant contributions achieved fitting the CLAS data [3]. The credible isolation of the resonant contributions makes it possible to determine the resonance electrocouplings, along with the $\pi\Delta$, and ρN decay widths from the resonant contributions employing for their description the amplitudes of the unitarized Breit-Wigner ansatz [20] that fully accounts for the unitarity restrictions on the resonant amplitudes.

Table 1 Observables for exclusive meson electroproduction off protons that have been measured with the CLAS detector in the resonance excitation region and stored in the CLAS Physics Data Base [15]: CM-angular distributions for the final mesons ($\frac{d\sigma}{d\Omega}$); beam, target, and beam-target asymmetries ($A_{LT'}$, A_t, A_{et}); and recoil hyperon polarizations (P', P^0).

Hadronic final state	W-range GeV	Q^2-range GeV^2	Measured observables
$\pi^+ n$	1.10-1.38	0.16-0.36	$\frac{d\sigma}{d\Omega}$
	1.10-1.55	0.30-0.60	$\frac{d\sigma}{d\Omega}$
	1.10-1.70	1.70-4.50	$\frac{d\sigma}{d\Omega}$, $A_{LT'}$
	1.60-2.00	1.80-4.50	$\frac{d\sigma}{d\Omega}$
$\pi^0 p$	1.10-1.38	0.16-0.36	$\frac{d\sigma}{d\Omega}$
	1.10-1.68	0.40-1.15	$\frac{d\sigma}{d\Omega}$, $A_{LT'}$, A_t, A_{et}
	1.10-1.39	3.00-6.00	$\frac{d\sigma}{d\Omega}$
ηp	1.50-2.30	0.20-3.10	$\frac{d\sigma}{d\Omega}$
$K^+\Lambda$	1.62-2.60	1.40-3.90	$\frac{d\sigma}{d\Omega}$
	1.62-2.60	0.70-5.40	P', P^0
$K^+\Sigma^0$	1.62-2.60	1.40-3.90	$\frac{d\sigma}{d\Omega}$
	1.62-2.60	0.70-5.40	P'
$\pi^+\pi^- p$	1.30-1.60	0.20-0.60	Nine single-differential cross sections
	1.40-2.10	0.50-1.50	

Electrocouplings of nucleon resonances and their KY hadronic decay widths can also be determined from analyses of the CLAS data on exclusive KY electroproduction off protons [23]. Future analyses of the large body of these data (Table 1) will improve the knowledge on electrocouplings and KY hadronic decay widths of high-lying N^* states with masses above 1.6 GeV. The decay to the πN final state for many of these resonances are suppressed. Currently, the preliminary results on the electrocouplings of these states are available from the studies of $\pi^+\pi^- p$ electroproduction off protons only [11; 24]. Consistent results on $\gamma_v p N^*$ electrocouplings of the aforementioned resonances obtained in independent analyses of KY electroproduction will validate credible extraction of these fundamental quantities. The development of the analysis tools for extraction of the resonance parameters from KY electroproduction data measured with CLAS is urgently needed.

3 Selected results on resonance electrocouplings and their impact on the insight into N^* structure

Resonance electrocouplings have been obtained from various CLAS data in the exclusive channels: $\pi^+ n$ and $\pi^0 p$ at $Q^2 < 5.0$ GeV^2 in the mass range up to 1.7 GeV, ηp at $Q^2 < 4.0$ GeV^2 in the mass range up to 1.6 GeV, and $\pi^+\pi^- p$ at $Q^2 < 1.5$ GeV^2 in the mass range up to 1.8 GeV [3; 8; 16; 17; 20; 24]. The studies of the $N(1440)1/2^+$ and $N(1520)3/2^-$ resonances with the CLAS detector [3; 16; 20] have provided the dominant part of the information available worldwide on their electrocouplings in a wide range of photon virtualities 0.25 GeV^2 $< Q^2 <$ 5.0 GeV^2. Currently the $N(1440)1/2^+$ and $N(1520)3/2^-$ states, together with the $\Delta(1232)3/2^+$ and $N(1535)1/2^-$ resonances [8], represent the most explored excited nucleon states. Furthermore, results on the $\gamma_v p N^*$ electrocouplings for the high-lying $N(1675)5/2^-$, $N(1680)5/2^+$, and $N(1710)1/2^+$ resonances have been determined for the first time from the CLAS πN data at 1.5 GeV^2 $< Q^2 <$ 4.5 GeV^2 [17]. The first results on the electrocouplings of $\Delta(1620)1/2^-$ resonance that preferentially decays to the $N\pi\pi$ final states have recently become available from analysis of the CLAS data on $\pi^+\pi^- p$ electroproduction off protons. The up to date numerical results on electrocouplings of most nucleon resonances in the mass range up to 1.8 GeV available from the exclusive electroproduction data from CLAS and elsewhere are maintained on our web page [24].

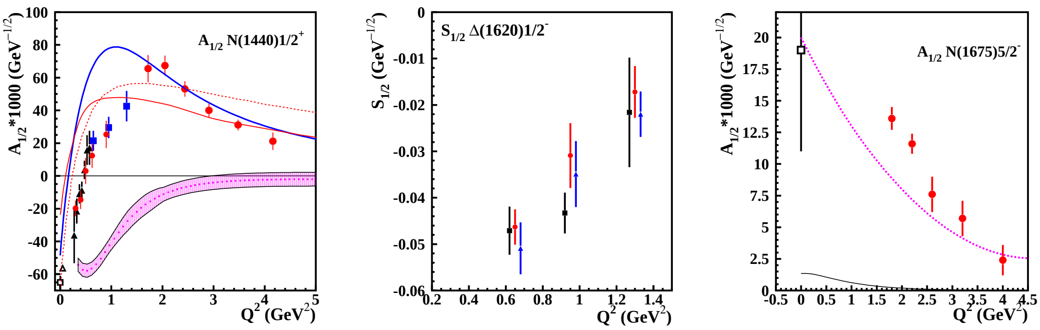

Fig. 1 (Color Online) $A_{1/2}$ $\gamma_v pN^*$ electrocouplings of the $N(1440)1/2^+$ (left), $N(1675)5/2^-$ (right), and $S_{1/2}$ $\gamma_v pN^*$ electrocouplings of the $\Delta(1620)1/2^-$ (center) resonances from analyses of the CLAS electroproduction data off protons in the πN - [16; 17] (red circles in the left and right panels) and $\pi^+\pi^-p$ channels [20] (black triangles in the left panel), with new results from the $\pi^+\pi^-p$ channel [3] (blue squares in the left panel). The central panel shows the $\Delta(1620)1/2^-$ electrocouplings obtained from analyses of $\pi^+\pi^-p$ electroproduction data off protons [3] carried out independently in three intervals of W: 1.51 GeV $\rightarrow$ 1.61 GeV (black squares), 1.56 GeV $\rightarrow$ 1.66 GeV (red circles), and 1.61 GeV $\rightarrow$ 1.71 GeV (blue triangles). Photocouplings are taken from the RPP [25] (open squares) and the CLAS data analysis [26] of πN photoproduction (open triangles). The electrocoupling results in the left panel are shown in comparison with the DSEQCD - [4] (blue thick solid) and constituent quark model calculations [27] (thin red solid), [28] (thin red dashed). The meson-baryon cloud contributions, determined as described in Section 3, are shown by the magenta area. For the case of the $N(1675)5/2^-$ resonance (right), the absolute values of the meson-baryon cloud amplitudes at the resonance poles taken from Argonne-Osaka coupled channel analysis [29] are shown by dashed magenta line together with the estimate for the quark core contribution from a quark model [30] (black solid line).

Consistent results for the $\gamma_v pN^*$ electrocouplings of the $N(1440)1/2^+$ and $N(1520)3/2^-$ resonances, which have been determined in independent analyses of the dominant meson electroproduction channels, πN and $\pi^+\pi^-p$ shown in Fig. 1 (left) and in Fig. 2 (left), demonstrate that the extraction of these fundamental quantities is reliable, since a good data description is achieved in the major electroproduction channels having quite different background contributions. We have developed special procedures to test the reliability of the resonance $\gamma_v pN^*$ electrocouplings extracted from the charged double pion electroproduction data only. In this case, we carried out the extraction of the resonance parameters independently, fitting the CLAS $\pi^+\pi^-p$ electroproduction data [18] in overlapping intervals of W. The non-resonant amplitudes in each of the presented in Fig 1 (center) W-intervals are different, while the resonance parameters should remain the same as they are determined from the data fit in different W-intervals. The electrocouplings of the $\Delta(1620)1/2^-$ state determined in this procedure are shown in the center of Fig. 1. The consistent results on these electrocouplings from the independent analyses of different W-intervals strongly support their reliable extraction. The tests described above demonstrated the capability of the models outlined in Section 2 to provide reliable information on the $\gamma_v pN^*$ resonance electrocouplings from independent analyses of the data on exclusive πN and $\pi^+\pi^-p$ electroproduction.

Experimental results on $\gamma_v pN^*$ electrocouplings offer insight into the non-perturbative strong interaction dynamics behind the emergence of the N^* structure from the QCD Lagrangian. Two conceptually different approaches have been developed that allow us to relate the information on the Q^2 evolution of the resonance electrocouplings to the first principles of QCD.

Due to the rapid progress in the field of DSEQCD studies of excited nucleon states [4; 5; 6; 31], the first evaluations of the transition $p \rightarrow \Delta(1232)3/2^+$ form factors and the $N(1440)1/2^+$ resonance electrocouplings starting from the QCD Lagrangian have recently become available. The $A_{1/2}$ electrocouplings of the $N(1440)1/2^+$ resonance computed in [4] are shown in Fig. 1 (left) by the solid blue lines. The evaluation [4] is applicable at photon virtualities $Q^2 > 2.0$ GeV^2 where the contributions of the inner quark core to the resonance electrocouplings are much larger than from the external meson baryon cloud. In this range of photon virtualities, the evaluation [4] offers a good description of the experimental results on the transition $p \to \Delta(1232)3/2^+$ form factors and the $N(1440)1/2^+$ resonance electrocouplings achieved with a momentum dependence of the dressed quark mass that is *exactly the same* as the one employed in the previous evaluations of the elastic electromagnetic nucleon form factors [5]. This success strongly supports: a) the relevance of dynamical dressed quarks, with properties predicted by the DSEQCD approach [12], as constituents of the quark core in the structure of the ground and excited nucleon states; and b) the capability of the DSEQCD approach [4; 5] to map out the dressed quark mass function from the experimental results on the Q^2-evolution of the nucleon elastic - and $p \to N^*$ electromagnetic transition form factors or rather $\gamma_v pN^*$ electrocouplings.

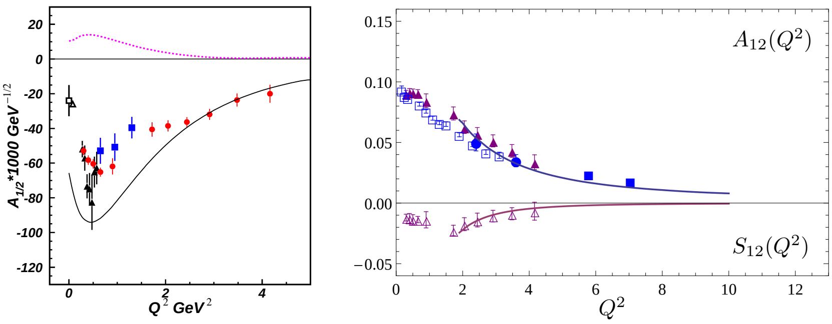

Fig. 2 (Color Online) $A_{1/2}$ photo-/electrocouplings of the $N(1520)3/2^-$ (left) and $N(1535)1/2^-$ (right) resonances from analyses of the CLAS electroproduction data off protons [3; 16; 20; 32]. The symbol meaning in the left panel is the same as in Fig. 1 (left). The $N(1535)1/2^-$ electrocouplings in the right panel from πN [16] and ηN [32] electroproduction are shown by the triangles and rectangles, respectively. The analysis [32] of the ηN data was carried out assuming $S_{1/2}$=0. The electrocoupling results for the $N(1520)3/2^-$ are shown in comparison with the model estimates for the quark core [30] (black solid). The meson-baryon cloud contributions taken from the Argonne-Osaka coupled channel analysis [29] are shown by the magenta dashed line. In case of the $N(1535)1/2^-$ resonance (right) the data are compared with the results of the LCSR model [1] with the quark DA normalization parameters from the LQCD results obtained starting from the QCD Lagrangian [33].

The model [1] employs the light cone some rules (LCSR) in order to relate the quark distribution amplitudes (DA) of the excited nucleon states to the Q^2 evolution of their electrocouplings. Analysis of the $N(1535)1/2^-$ $\gamma_v pN^*$ electrocouplings from CLAS within the framework of this model has provided access to the quark DA's of excited nucleons for the first time. The model [1] describes successfully the CLAS results shown in Fig. 2 (right) at $Q^2 > 2.0$ GeV^2 where LCSR's are applicable, with the values of the normalization parameters for the leading twist $N(1535)1/2^-$ quark DA obtained from the QCD Lagrangian within the framework of lattice QCD [33]. The results on the $N(1535)1/2^-$ electrocouplings in the much broader range of photon virtualities up to 12 GeV^2 expected from the future N^* studies with the CLAS12 detector in Hall B [23; 34; 35] will considerably improve knowledge of the $N(1535)1/2^-$ quark DA, allowing us to determine from electrocoupling data not only the normalization parameters, but also most of the shape parameters of the quark DA's. These studies will be extended by analyses of other excited nucleon states. Confronting the quark DA's of excited nucleon states determined from the experimental results on $\gamma_v pN^*$ electrocouplings to the lattice QCD expectations, offers an alternative way with respect to DSEQCD approaches to study the emergence of the resonance structure from the first principles of the QCD.

The quark DA's of excited nucleon states are also expected from the future DSEQCD studies [7]. Consistency between the expectations for the N^* quark DA parameters obtained within the framework of LQCD/DSEQCD and their values from the fit to the data on resonance electrocouplings within the framework of LCSR will validate credible access to the fundamental ingredients of the non-perturbative strong interaction behind the emergence of the N^* structure from the QCD Lagrangian.

Analysis of the CLAS results on the $\gamma_v pN^*$ electrocouplings over most excited nucleon states in the mass range up to 1.8 GeV has revealed the N^* structure for $Q^2 < 5.0$ GeV^2 as a complex interplay between an inner core of three dressed quarks and an external meson-baryon cloud. The two extended quark models [27; 28], that account for the meson-baryon cloud and the quark core contributions combined, provided a better description of the $N(1440)1/2^+$ electrocouplings shown in Fig. 1

(left) at $Q^2 < 2.0$ GeV^2, demonstrating the increasing importance of the meson-baryon contributions as Q^2 decreases. The credible DSEQCD evaluation of the quark core contributions to the electrocouplings of the $N(1440)1/2^+$ state has allowed us to derive the meson-baryon cloud contributions to this resonance as the difference between the experimental data on resonance electrocouplings and the quark core electroexcitation amplitudes from DSEQCD [4] shown by the blue line in Fig 1 (left). The obtained meson-baryon cloud contributions are presented in Fig. 1 (left) by magenta dashed area. The relative contributions of the quark core and the meson-baryon cloud depend strongly on the quantum numbers of the excited nucleon state. The quark core becomes the dominant contributor to the $A_{1/2}$ electrocouplings of the $N(1440)1/2^-$ and $N(1520)3/2^-$ resonances at $Q^2 > 2.0$ GeV^2, as can be seen in Fig. 1 (left) and Fig. 2 (left), respectively. The results on these state electrocouplings offer almost direct access to the dressed quark contributions for $Q^2 > 2.0$ GeV^2. Instead, electrocouplings of the $N(1675)5/2^-$ state, shown in Fig 1 (right), are dominated by meson-baryon cloud, allowing us to explore this component from the electrocoupling data. The relative contributions of the meson-baryon cloud to the electrocouplings of all resonances studied with the CLAS decrease with Q^2 in gradual transition towards quark core dominance at photon virtualities above 5.0 GeV^2.

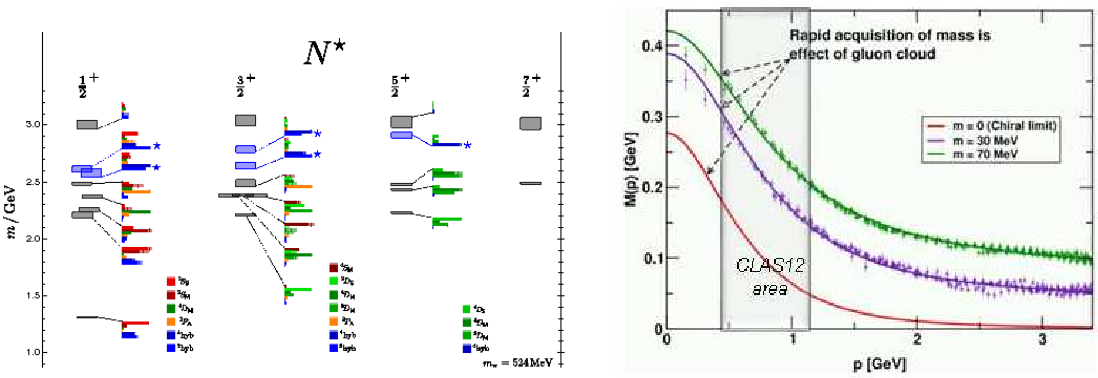

Fig. 3 (Color Online) Left: Spectrum of N^* states computed in LQCD starting from the QCD Lagrangian [13] will be mapped out with CLAS12 with the primary objective of the hybrid baryon search [10; 36]. The contributions from the relevant quark and glue configurations to the resonance structure are shown by the horizontal bars connected by dashed lines to the boxes showing the N^* masses and full widths with a pion mass of 524 MeV. The expected hybrid baryons with dominant contributions from glue are shown by the blue boxes. Right: Momentum dependencies of the running dressed quark mass from LQCD at two values of the bare quark masses, 30 MeV and 70 MeV, are shown by points with error bars [37] in comparison with the DSEQCD results (green and magenta lines) [12] for the same bare quark masses as in the LQCD studies. Evaluations in the chiral limit of massless bare quarks, which are close to the bare masses of the light u and d quarks, are currently available from DSEQCD only and shown by the red line [12]. The dressed quark mass function in the momentum range that will be accessible for the first time from the studies of the Q^2 evolution of the resonance electrocouplings from exclusive meson electroproduction data with CLAS12 [23; 34] is shown in the shadowed area, allowing us to explore the nature of >98% of hadron mass, quark gluon confinement, and the emergence of the nucleon resonance structure from QCD [9].

4 Prospects for the future studies of excited nucleon states with the CLAS12

After completion of the Jefferson Lab 12 GeV Upgrade Project, the CLAS12 detector in the upgraded Hall B will be the only foreseen facility worldwide capable of studying nucleon resonances at the still unexplored ranges of the smallest photon virtualities 0.05 GeV^2 $< Q^2 <$ 0.5 GeV^2 and the highest photon virtualities ever achieved in exclusive reaction measurements up to 12 GeV^2 [9; 10; 34].

The studies of nucleon resonances at small photon virtualities are driven by the search for new states of baryon matter, the so-called hybrid-baryons [36]. Small Q^2 is preferential for the observation of these new states that contain three dressed quarks and, in addition, glue as the structural component. The LQCD studies of the N^* spectrum starting from the QCD Lagrangian [13] predict several such states of the positive parities shown in Fig. 3 (left). The evaluations [13] were carried with much higher quark mass than needed to reproduce the pion mass. In order to estimate the physics masses of hybrid states we corrected the results of [13] reducing the predicted hybrid mass values by the differences between the experimental results on the masses of the known lightest N^* of the same spin-parities as for the expected hybrid baryons and their values from LQCD. In the experiment with CLAS12 we will search for the hybrid signal as the presence of extra states in the conventional resonance spectrum of J^P=1/2$^+$, 3/2$^+$ in the mass range from 2.0 GeV to 2.5 GeV from the data of exclusive KY and $\pi^+\pi^-p$ electroproduction off protons [36]. The hybrid nature of the new baryon states will be identified looking for the specific Q^2 evolution of their electrocouplings. We expect the specific behavior of the hybrid state electrocouplings with Q^2 because one might imagine that the three quarks in a hybrid baryon should be in a color-octet state in order to create a colorless hadron in combination with the glue constituent in a color-octet state. Instead, in regular baryons, constituent quarks should be in color-singlet state. So pronounced differences for quark configurations in the structure of conventional and hybrid baryons should results in a peculiar Q^2 evolution of hybrid baryon electrocouplings. The studies on the N^* structure at low Q^2 over spectrum of all prominent resonances will also extend our knowledge on the meson-baryon cloud in the resonance structure and will offer unique information on the N^* excitations by longitudinal photons as $Q^2 \to 0$. The extension of amplitude analysis [38; 39; 40] and coupled channel analysis [41; 42] methods, which were employed successfully in the studies of exclusive meson photoproduction, for electroproduction off protons at small photon virtualities is of particular importance for the success of the aforementioned efforts.

The experiments on the studies of excited nucleon state structure in exclusive πN, KY, and $\pi^+\pi^-p$ electroproduction off protons at 5.0 GeV^2 $< Q^2 <$ 12.0 GeV^2 [23; 35] are scheduled in the first year of running with the CLAS12 detector. For the first time electrocouplings of all prominent nucleon resonances will become available at the highest photon virtualities ever achieved in the exclusive electroproduction studies. These distance scales correspond to the still unexplored regime for the N^* electroexcitation where the resonance structure is dominated by the quark core with almost negligible meson-baryon cloud contributions. The foreseen experiments offer almost direct access to the properties of dressed quarks inside N^* states of different quantum numbers. Consistent results on the dressed quark mass function derived from independent analyses of the data on the $\gamma_v pN^*$ electrocouplings of the resonances of distinctively different structure, such as radial excitations, spin-flavor flip, orbital excitations, will validate credible access to this fundamental ingredient of the non-perturbative strong interaction supported by the experimental data. The expected data on the $\gamma_v pN^*$ electrocouplings will provide for the first time access to the dressed quark mass function in the range of momenta/distance scales where the transition from the quark-gluon confinement to the pQCD regimes of strong interaction takes full effect, as is shown in Fig. 3 (right). Exploring the dressed quark mass function at these distances will allow us to address the most challenging open problems of the Standard Model: on the nature of >98% of hadron mass, quark-gluon confinement, and the emergence of the N^* structure from the QCD Lagrangian [6; 9; 43; 44].

In order to provide reliable evaluation of resonance electrocouplings at high photon virtualities, the reaction models for resonance electrocoupling extraction should be further developed, implementing explicitly quark degrees of freedom in the description of the non-resonant amplitudes. The efforts on implementation of the hand-bag diagrams for the part of non-resonant amplitudes in πN electroproduction off protons in the N^* region are underway [45].

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