Update of the Proposal PR-09-003 "Nucleon Resonance Studies with CLAS12"

ABSTRACT

Our proposal, Nucleon Resonance Studies with CLAS12, was approved with 60 days of beamtime by the last Program Advisory Committee. By measuring the exclusive single-meson and double-pion electroproduction cross sections produced from a proton target, we seek to extract the electromagnetic transition form factors (electrocouplings) for well-established excited nucleon states in the unexplored domain of Q^2, from 5.0 to 14.0 GeV^2. This cross-correlated information on single- and double-pion channels is vital for reliable electrocoupling measure. Expected data on resonance electrocouplings will allow us systematically exploring how the strong interaction in the non-perturbative regime dresses bare-quarks and how quark cores of the various N^* states emerge from QCD. This experiment is an essential part of the comprehensive program of exclusive electroproduction measurements with CLAS12, in which various channels such as deeply virtual Compton scattering and deeply virtual exclusive meson production, will be measured as well. The close collaboration of experimentalists and theorists, as documented in the full proposal, will allow us to provide high-precision data, high-quality analyses, as well as state-of-the-art modeling of QCD based calculations.

I. INTRODUCTION

For the foreseeable future, the CLAS12 detector will remain the sole facility worldwide capable of delivering information on the $\gamma_v NN^*$ transition helicity amplitudes – and thereby the electrocouplings – at photon virtualities of $Q^2 > 5.0$ GeV^2. These electrocouplings will be extracted from the electroproduction of the primary meson reaction channels, $\pi^+ n$, $\pi^0 p$, and $\pi^+\pi^- p$. Through our recent work [6, 7] for $Q^2 < 5.0$ GeV^2, we have found consistent results on the $\gamma_v NN^*$ electrocouplings, in both the single- and double-pion modes. In that these dominant meson-electroproduction channels possess completely different non-resonant contributions, consistent electrocouplings from these different reaction channels offer compelling evidence in the goodness of this phenomenological result [1]. We expect such analysis of the dominant meson reaction channels $\pi^+ n$, $\pi^0 p$,and $\pi^+\pi^- p$ at photon virtualities of $Q^2 >$ 5.0 GeV^2 will similarly lend strong credence to the reliability of extracting the electrocoupling data. The final results on $\gamma_v NN^*$ electrocouplings will be determined from a simultaneous global analysis of all mentioned above channels within the framework of an advanced dynamical coupled-channel approach, based on the analytical continuation of the reaction amplitudes of multiple reactions channels, which is currently under development by the Excited Baryon Analysis Center, EBAC [2].

Investigating the $\gamma_v NN^*$ electrocouplings Q^2 evolution for well-established excited nucleon states at $5.0 < Q^2 < 10.0$ GeV^2, through a combined and consistent analysis of the single- and double-pion modes, at distance scales, where meson baryon cloud contributions become negligible, for the first time will offer direct access to the quark structure of excited nucleon states. And in conjunction with the results on ground nucleon state structure from the experiments running concurrently with us*reference to experiments running concurrently with us*, will provide for the first time

- access to the dynamics of non-perturbative strong interactions among dressed quarks and shed light on their emergence from QCD – these dynamics being responsible for confinement, the subsequent N* formation;
- information on how the constituent quark mass arises from a cloud of low-momentum gluons, which become attached to the current quarks, i.e. are *getting dressed*. This non-perturbative dynamical chiral-symmetry breaking accounts for more than 97% of the nucleon mass;
- enhanced capabilities for exploring the behavior of the universal QCD β-function in the infrared regime.

We have strong theoretical support for our research program "Nucleon Resonance Studies with CLAS12." In fact, the "Workshop on Electromagnetic Transition Form Factors," which was held at JLab, October 13-15, 2008 [3], owes its genesis to this close collaboration between experimentalists and theorists on our experimental proposal on N^*. As new theoretical developments emerge, we shall certainly follow up on them as we did in documenting the detailed plan on theory support for our proposal in the 62-page White Paper entitled, "Theory Support for the Excited Baryon Program at the JLab 12 GeV Upgrade," which appeared as a preprint [1]. We shall continue disseminate the research activities on the electroproduction of baryon resonances at high Q^2 in dedicated sessions such as "Light Baryons at High Photon Virtualities" which convened within the "Third Workshop of the APS Topical Group in Hadron Physics',' April 29 - May 01,2009, Denver, Colorado [4] and the upcoming workshop, "Exclusive Reaction at High Momentum Transfer IV," May 18-21, 2010,which will take place at Jefferson Lab and where updates on the studies of $\gamma_v NN^*$ electrocouplings will be presented.

To keep abreast of the latest theoretical developments in extracting the $\gamma_v NN^*$ electrocouplings, – which incorporate quark degrees of freedom into the description of the non-resonant mechanisms that become relevant at high Q^2 – we we hold monthly HallB & EBAC Meetings at Jefferson Lab and organize informal seminars and meetings like the "N*-GPD Meeting" at JLab, September 11, 2009 [5]. These meetings provide the backdrop where experimentalists and theorists actively involved in nucleon resonance studies can meet, discuss, and present their research on extracting and interpreting the $\gamma_v NN^*$ electrocouplings at high Q^2.

Given that our proposal was just approved in late January, 2009, we shall focus on our achievements over this past year as described in the following three sections. Starting with Section II, we present several recent theoretical approaches that relate phenomenological information on the Q^2 evolution of the $\gamma_v NN^*$ electrocouplings to the mechanisms that are responsible for N^* formation and thereby shed light on their emergence from QCD. Updates on approaches for extracting $\gamma_v NN^*$ electrocouplings are reported in Section III and a brief update on the development of the experiment is delineated in Section IV.

II. RECENT THEORETICAL DEVELOPMENTS AND APPROACHES IN INTERPRETING THE $\gamma_v NN^*$ ELECTROCOUPLINGS

Through the theoretical interpretation of $\gamma_v NN^*$ electrocouplings, we seek to establish an unambiguous relation between the phenomenologically extracted information and non-perturbative strong interaction mechanisms that are responsible for the baryon formation.

From our analysis of the CLAS data on the Q^2-evolution of the $\gamma_v NN^*$ electrocouplings, the resonance structures are a result of quark degrees of freedom confined in internal quark core and surrounding meson baryon cloud originated by the reaction mechanisms as indicated in Fig. 1. Due to the kinematical reach attained by the 6.0-GeV electron beam, there is not much data at higher photon virtualities , but analysis of available data clearly show for $Q^2 > 5.0$ GeV^2 the quark degrees of freedom are expected to be dominant. This is to say, higher photon virtualities gives access to the desirable kinematic region where $\gamma_v NN^*$ electrocouplings are described in terms of quark degrees of freedom.

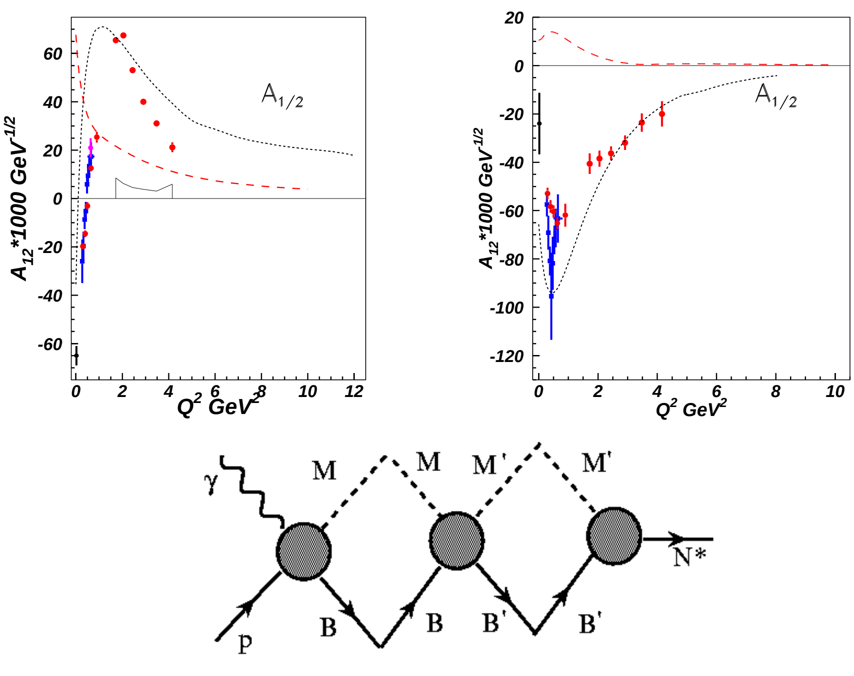

FIG. 1: The contributions from quark degrees of freedom and meson-baryon dressing to the $A_{1/2}$ electrocouplings of the $P_{11}(1440)$ (top left) and $D_{13}(1520)$ (top right) states. The CLAS data from analyses of $N\pi$ [6] and $\pi^+\pi^-p$ [7] electroproduction are shown in red and in blue, respectively. The contributions from the quark core estimated within the framework of relativistic quark models [8, 9] are given by the dotted lines, and the contributions from meson-baryon dressing, obtained within the framework of the EBAC-DCC approach [10], are represented by the dashed red lines. A diagram illustrating the meson-baryon dressing is shown in the bottom part.

Shown above in Fig. 1 are the CLAS helicity amplitude data for both single- and double-pion reactions for the two excited-baryon states. Superimposed are the contributions from the quark degrees of freedom, estimated within the framework of quark models [8, 9], and from meson baryon dressing to the electrocouplings of the $P_{11}(1440)$ and $D_{13}(1520)$ states, estimated within the framework of the Dynamical Coupled Channel (DCC) analysis from EBAC or EBAC-DCC. [10], These models find that the meson-baryon dressing contributions are substantial, particularly at Q^2<1.0 GeV^2, and are quite complex, thus making it difficult to access quark degrees of freedom unambiguously. A recent EBAC-DCC analysis of the world's πN scattering data [11] indicates that a common quark core may create multiple resonance poles in the scattering amplitudes. For the P_{11} wave they find two poles in a complex energy plane near the corresponding PDG values for the $P_{11}(1440)$ state and a third one at (1820,-248) GeV; all three originate from a common quark core at a mass of 1.76 GeV (see Fig. 2).

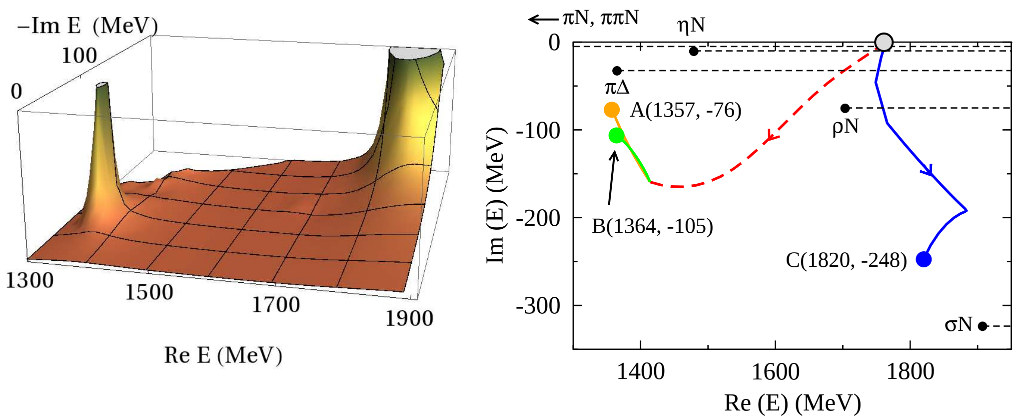

FIG. 2: Right: P_{11} resonances in the complex energy plane, extracted [11] within EBAC-DCC model [12]. The vertical axis (arbitrary unitS) measures the absolute value of the calculated πN scattering amplitude. Left: trajectories of the evolution of three extracted P_{11} resonance poles, indicated by A, B, and C, from the bare three-quark state at 1.76 GeV in the complex energy plane.

Moreover, the combined analysis of the elastic πN scattering data and the recent single-pion electroproduction data, as performed within the framework of extended analytical continuation method [13], has revealed large imaginary parts in $\gamma_v NN^*$ transition helicity amplitudes, where two of the three poles lie close to $P_{11}(1440)$ state. Earlier approaches for quark core contribution predicted electrocouplings that have no imaginary components. Such complications make it nearly impossible for a direct comparison between $\gamma_v NN^*$ electrocouplings and predictions of the models, that take into account only the contributions from quark degrees of freedom.

On the other hand, the EBAC results (cf. Fig. 1) have shown that absolute and relative contributions from meson-baryon cloud decreases with increasing Q^2 and meson-baryon dressing becomes negligible at Q^2>5.0 GeV^2. It is at these distance scales quark degrees of freedom are expected to dominate. The data on $\gamma_v NN^*$ electrocouplings at 5.0 <Q^2 < 14.0 GeV^2, expected from our proposed experiment will afford direct access to quark degrees of freedom, thereby allowing us to avoid aforementioned complications caused by the meson-baryon dressing at lower photon virtualities.

We shall make use of several theoretical approaches towards the goal of understanding the strong-interaction mechanisms that create N^* from the underlying quarks and gluons based on the phenomenological information on the Q^2 evolution of $\gamma_v NN^*$ electrocouplings . Among the approaches we shall employ are: a) Lattice QCD; b) the formalism based on Dyson-Schwinger equations of QCD c) light-cone sum rules and c) quark models; the latest being the only currently available tool for analysis of electrocouplings of majority of excited proton states. Accounting for meson-baryon dressing is still beyond the scope of all these approaches. Therefore, they can only be efficiently applied in the analysis of $\gamma_v NN^*$ electrocouplings at Q^2 > 5.0 GeV^2, which is exactly within the expected kinematic reach of our approved experiment. .

This year (2009) the first LQCD calculations of the highly excited state spectrum of the nucleon, delta and meson spectrum were made with three flavors of dynamical fermions. A significant step in these calculations is the determination of the spin content of the states [14, 15]. The number of states that are well determined is far beyond any previous LQCD calculations. However, a full study will need to include multi-particle operator constructions which will couple to decaying states, for example the $P_{11}(1440)$. Already, though, some information as to the content of the states can be gleamed from wavefunction overlaps, such as mixing angles. The decay of these states via radiative transitions determines the electro couplings. This year, the first LQCD calculations [16, 17] of the $P - P_{11}(1440)$ transition electromagnetic form factors F_1 and F_2 were extended, the results of which were calculated for several pion masses as shown in Fig. 3. The LQCD calculations were carried out for relatively large pion masses, with three flavors dynamical fermions, but used a very simple basis of projection operators. Nonetheless, despite all these simplifications, the calculation reproduces major features in form factor behavior at $Q^2 > 1.0$ GeV^2.

By the time of 12 GeV Upgrade the Theory Division at JLab [1], plans to have ready the excited proton states of minimal masses in each partial wave for the $\gamma_v NN^*$ electrocouplings at Q^2 up to 10 GeV^2, which will be evaluated at the physical pion mass and employing a full basis of nucleon operators.

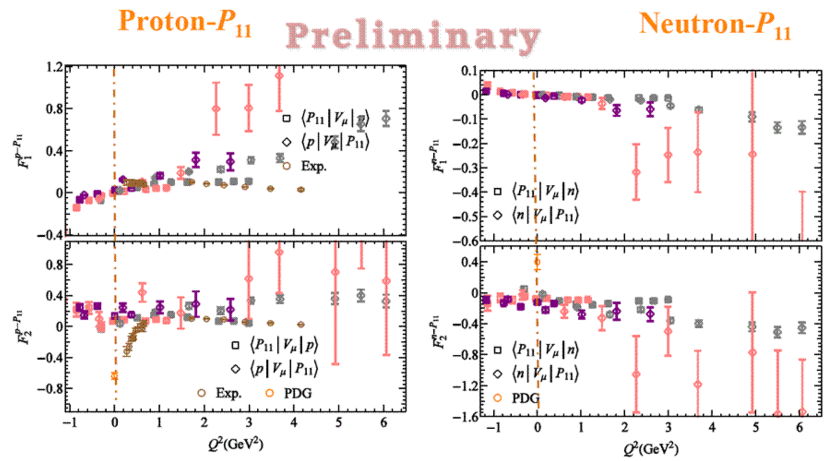

FIG. 3: Transition $P - P_{11}(1440)$ electromagnetic form factors F_1 (top) F_2 (bottom). Experimental CLAS data are shown in gold. JLAB Theory Center LQCD results [17] for various pion masses are shown in magenta ($m_\pi = 743 MeV$), in gray ($m_\pi = 580 MeV$) and in red ($m_\pi = 450 MeV$).

The University of Regensburg group are collaborating with us in the theoretical interpretation of $\gamma_v NN^*$ electrocouplings, where they are developing a combined approach, incorporating LQCD and light-cone sum rules (LCSR). In this approach several moments of quark distribution amplitudes (DAs) are derived from QCD Lagrangian within the framework of LQCD. In the second step $\gamma_v NN^*$ electrocouplings are determined from quark distribution amplitudes using light cone sum rules [1, 18]. The crucial advantage of such a synthetic approach is that the form factors are calculated in terms of well-defined DAs which correspond to hadron (N or N^*) wave functions at small transverse separations. This approach has already provided results on the Q^2 evolution of $S_{11}(1535)$ electrocouplings almost within the entire area of photon virtualities covered by our approved experiment (Q$^2 < 12$ GeV^2) as shown in Fig. 4.

This year (2009) a new computer code was developed. It is somewhat more general and has been used on new lattices of size 24^3 and 32^3 at a pion mass of 275 MeV, which is significantly closer to the physical pion mass as compared to previous calculations. Fig. 5 shows the present status of the Regensburg results for f_N, nucleon wave function at the origin. An improved projection operator was implemented in order to obtain a cleaner separation of the states with opposite parities. The analysis of the data at $m_\pi = 0.275$ GeV is not yet finished and it is to be expected that the $N^*(1535)$ results will profit at least as much from the various improvements as the nucleon data [19]. These new results will be used to update our previous calculation of the $\gamma_v NN^*$ electrocouplings shown in Fig. 4. By the time of the 12 GeV Upgrade, the combined LQCD & LCSR approach will provide predictions on the Q^2 evolution of electrocouplings for several parity doublet pairs [1]. The LQCD calculations will be carried out at the physical pion mass and the LCSR approach used to obtain predictions in the entire Q^2 area covered by the proposed experiment. Moreover, LCSR will be advanced to next-to-leading order. Employing the improved LCSR will allow one to obtain the information on quark DAs in N* quark cores from the $\gamma_v NN^*$ electrocoupling data and explore how different are the distribution amplitudes in ground and excited nucleon states of various spins and parities.

In addition to the LQCD calculations delineated above, the Dyson-Schwinger equations of QCD (DSEs) provide a powerful complementary approach. Formulated in the continuum and providing direct access to properties of hadrons constituted from QCD's lightest quarks, the DSEs enable observable information on $\gamma_v NN^*$ electrocouplings to be related to QCD itself. In this approach, dressed-quark propagators and scattering amplitudes are computed from QCD via a systematic and symmetry preserving truncation scheme, and one obtains gauge-invariant observables expressed as contractions of gauge-covariant Schwinger functions. In particular, the $\gamma_v NN^*$ electrocouplings can be obtained by combining results from the gap-, Bethe-Salpeter- and Faddeev-equations of QCD, to arrive at a Poincaré-invariant description of baryons, which are constituted from dressed-quarks and -gluons bound by interactions that are

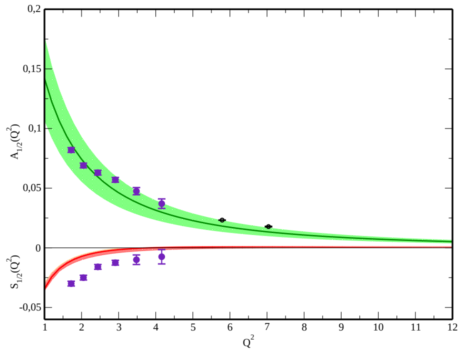

FIG. 4: Prediction on Q^2 evolution of $S_{11}(1535)$ electrocouplings obtained within the framework of combined LQCD & LCSR approach [1, 18] (shadowed areas) in comparison with the CLAS data [6] (points with error bars).

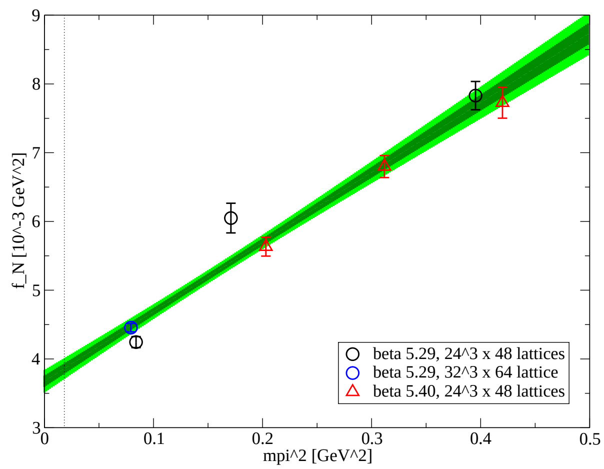

FIG. 5: Nucleon wave function at the origin, f_N, as a function of the pion mass m_π^2.

systematically connected with QCD [1, 20, 21]. The DSE framework is especially useful in elucidating nonperturbative manifestations of strong interaction physics, such as dynamical chiral symmetry breaking and quark confinement. This is emphasized in Fig. 6, which depicts LQCD and DSE results on the momentum-dependence of the dynamically-generated dressed-quark mass function.

It will be apparent in the figure that for momenta larger than 2 GeV, the mass function describes a current-quark, propagating almost like a single parton. However, for momenta less than this transition boundary, the mass function rises sharply, reaching the constituent-quark mass-scale in the infrared. On this domain, the dressed-quark is far from a single parton: the effect evident in this figure owes to a cloud of low-momentum gluons attaching themselves to the current-quark. This is the phenomenon of dynamical chiral symmetry breaking. It is essentially nonperturbative and, even were the Standard Model Lagrangian to possess massless quarks, this effect would make them massive. Dynamical chiral symmetry breaking is responsible for more than 97% of the nucleon's mass. Contemporary theory suggests that dynamical chiral symmetry breaking is an unavoidable consequence of confinement but that remains to be conclusively proven. Certain, however, is that the momentum-dependence of the mass function is directly tied to the behavior of QCD's β-function, and that this momentum-dependence produces effects that are unambiguously observable in experiment. For example and of immediate relevance, the transition from current-quark to nonperturbative dressed-quark can be observed in the Q^2 evolution of hadron elastic and transition form factors.

This fact has recently been demonstrated very forcefully in connection with the pion's electromagnetic form factor [27]. In Fig. 7 we present a comparison between experimental data on the pion electromagnetic form factor and calculations conducted under two different assumptions for the dressed-quark propagator: the *solid-curve* is obtained with a momentum independent constituent-quark mass, generated by a contact interaction; whereas the *dashed-curve* is the DSE result obtained with a momentum-dependent mass-function of the type generated by QCD [26]. It is plain that only by accounting fully and correctly for the behavior of $M(p^2)$ can one hope to explain and understand extant and forthcoming data on the pion electromagnetic form factor. Studies are currently underway, aimed at identifying

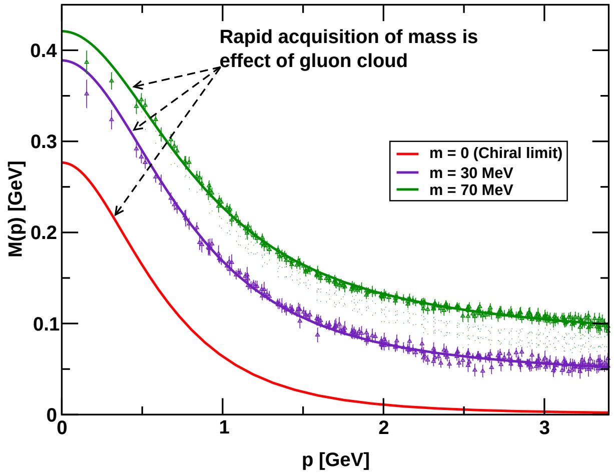

FIG. 6: Dressed quark mass function, M(p), for light-quarks, obtained in Landau gauge: solid curves DSE results, including the chiral-limit [22, 23]; points with error bars are the results from unquenched LQCD [24]. The data for our approved experiment will, for the first time , allow to study the kinematic regime for momenta running over the quark propagator for momenta $p < 1.1$ GeV, which spans the transition from almost-completely dressed constituent quark to the almost-completely undressed current quark. It is important to bear in mind that the dressed-quark propagator is gauge-covariant and hence the features evident in this figure have a genuinely measurable impact on observables.

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analogous signals for the running of the dressed quark in the Q^2-evolution of proton elastic form factors and the $N - P_{33}(1232)$ and $N - P_{11}(1440)$ transition electromagnetic form factors.

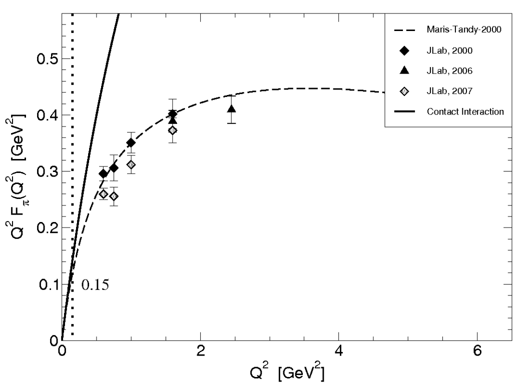

FIG. 7: Description of experimental data on pion electromagnetic form factor with momentum independent quark mass (solid line) and full DSE prediction (dashed line) [25, 27] with dynamical quark mass shown in Fig. 6.

The 12 GeV Upgrade will, for the first time, provide beams capable of generating momentum transfers in a domain that will enable experiment to be sensitive to the evolution of the mass function on $0 < p < 1.1$ GeV; namely, to probe the mass function on the domain within which the transition from nonperturbative to perturbative behavior takes place (see Fig. 6). Therefore, analysis of the data on $\gamma_v NN^*$ electrocouplings obtained in the proposed experiment within the framework of QCD's DSEs will uniquely enable us to verify experimentally that dynamical chiral symmetry breaking in QCD is the origin of the vast bulk of the mass of observable matter in the universe. Moreover, the feedback between experiment and theory that must naturally follow, will provide the means to chart the behavior of QCD's β-function at infrared momenta. There is no greater challenge in the Standard Model, and few in physics, than learning to understand the truly nonperturbative long-range behavior of the strong interaction. In this connection, studies of excited states of the nucleon are especially useful because their properties are determined by the interactions between dressed-quarks at distances larger than those most important to the structure of ground states [1].

Finally we should mention several developments in quark models, that currently represent the only available tool for analysis of majority of nucleon excitations. The $q\bar{q}$ pair production and the quark form factors presumably will both play a key role in the description of the baryon excitation in the Q^2 range accessible with 12 GeV electrons. The presence of $q\bar{q}$ effects points towards the need of unquenching the quark models [28]. This problem has been addressed recently for the baryon sector [29]. With the availability of unquenched CQM both the electromagnetic and strong decay of the resonances will be described in a consistent way. With increasing momentum transfer the excitation of resonances will also allow testing the short distance behavior of the $q\bar{q}$ production mechanism and, in particular, of the meson production.

The phenomenological quark form factors which have been introduced up to now contain and mix contributions from both the structure of the effective (constituent) quarks and from the dynamics not explicitly included in CQM, such as the $q\bar{q}$ pair creation or meson production effects. By unquenching the CQM, it will be possible to disentangle the quark form factors and test the onset of the transition to the asymptotic QCD current quarks.

In closing we emphasize that the proposed experiment is the only one in the foreseeable future that can provide data on $\gamma_v NN^*$ electrocouplings at $Q^2 > 5.0$ GeV^2, data which is vital to reaching an understanding of two truly novel phenomena in the Standard Model; namely, the essentially nonperturbative physics of confinement and dynamical chiral symmetry breaking in QCD.

III. RECENT DEVELOPMENTS IN REACTION MODELS FOR EXTRACTION OF $\gamma_v NN^*$ ELECTROCOUPLING FROM THE OBSERVABLES OF THE PROPOSED EXPERIMENT

For evaluation of $\gamma_v NN^*$ electrocouplings from the data of the proposed experiment we are going to utilize: a) independent analyses of $N\pi$ and $\pi^+\pi^-p$ electroproduction channels within the framework of phenomenological reaction models checked against variety of available observables[6, 30, 31]; b)combined analysis of the $N\pi$ and $\pi^+\pi^-p$ exclusive channels within the framework of EBAC-DCC coupled channel approach [1, 2]. Independent analyses of $N\pi$ and $\pi^+\pi^-p$ electroproduction channels within the framework of phenomenological reaction models will allow us to check and to establish all relevant contributing mechanisms and to isolate resonant parts in observables, needed for evaluation of $\gamma_v NN^*$ electrocouplings. Consistent results on $\gamma_v NN^*$ electrocouplings from two major meson electroproduction channels $N\pi$ and $\pi^+\pi^-p$ with completely different non resonant mechanisms will provide a compelling evidence for reliable electrocoupling measure. The final results on $\gamma_v NN^*$ electrocouplings will be obtained in a combined analysis of $N\pi$ and $\pi^+\pi^-p$ electroproduction data within the framework of EBAC-DCC coupled channel approach. This formalism will allow us to account explicitly for the hadronic final state interactions, that play a substantial role for the $N\pi$ and $\pi^+\pi^-p$ final state, rigorously maintain the constraints imposed by unitarity. EBAC-DCC approach will allow us to determine $\gamma_v NN^*$ electrocouplings from residues at the poles in complex energy plane, utilizing analytical continuation method [13]. In turn, the phenomenological reaction models [6, 30, 31] will provide information on cross section/amplitudes of various contributing processes obtained from the data fit. This information is of particular importance for the studies of complex $\pi^+\pi^-p$ electroproduction channel.

In 2009 substantial progress was achieved in extraction of $\gamma_v NN^*$ electrocouplings in independent analyses of $N\pi$ and $\pi^+\pi^-p$ electroproduction within the framework of reaction models [6, 30] and [31], respectively.

The CLAS data extended considerably available information on $N\pi$ electroproduction observables. For the first time data on differential cross sections, longitudinally polarized beam asymmetries and longitudinal target and beam-target asymmetries for π electroproduction off protons becomes available from CLAS with almost 4π coverage in a wide kinematical area W < 1.7 GeV and $0.15 < Q^2 < 5.0$ GeV^2. Combined analysis of all this data was completed in 09' and published in the paper [6]. A total of about 119000 data points were included in analysis within the framework of two conceptually different approaches - fixed-t dispersion relations and a unitary isobar model- allowing us to draw conclusions on the model sensitivity of obtained electrocouplings. We have put significant effort into accounting for model and systematical uncertainties. All transverse and longitudinal $\gamma_v NN^*$ electrocouplings were determined for $P_{33}(1322)$ state at $0.16 < Q^2 < 6.0$ GeV^2 and for $P_{11}(1440)$ $D_{13}(1520)$, $S_{11}(1535)$ at $0.3 < Q^2 < 4.5$ GeV^2. Thanks to the CLAS measurements longitudinal electrocouplings of $P_{11}(1440)$ $D_{13}(1520)$, $S_{11}(1535)$ were determined for the first time. Examples of extracted electrocouplings are shown in Fig. 8, 9.

Recent analysis [6] clearly showed that fit of all available $N\pi$ electroproduction observables combined within the framework or reaction models [6, 30] allowed us to determine $\gamma_v NN^*$ electrocouplings in full area of photon virtualities covered with 6.0 GeV beam.

The CLAS data on $\pi^+\pi^-p$ electroproduction [34, 35] for the first time provided information on nine independent single differential cross section in each bin of W and Q^2 covered by measurements in a kinematical area 1.4$<$ W $<$ 2.1 GeV and $0.25 < Q^2 < 1.5$ GeV^2. Recent results were published in 09' [35]. Detailed experimental information for the first time available from CLAS makes it possible to establish all essential contributing mechanisms from their manifestations in observables. Analysis of the CLAS data allowed us to develop phenomenological reaction model JM for description of $\pi^+\pi^-p$ electroproduction [7, 31] with a primary objective to determine $\gamma_v NN^*$ electrocouplings

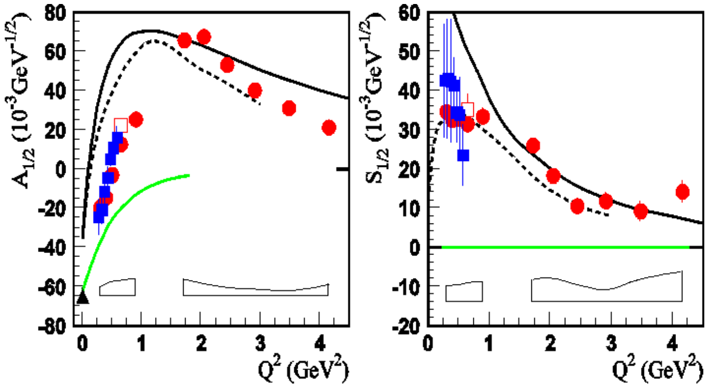

FIG. 8: Electrocouplings for $P_{11}(1440)$ state determined from the CLAS data on $N\pi$ electroproduction [6] (red point) and preliminary results from the CLAS data on $\pi^+\pi^-p$ channel [7] (blue point). Black solid and dashed lines represent light front quark model calculation [8, 32] for $P_{11}(1440)$ as first radial excitation of three quark in the ground state. Green lines correspond to electrocouplings calculated in assumption that $P_{11}(1440)$ represent a hybrid 3qG state [33].

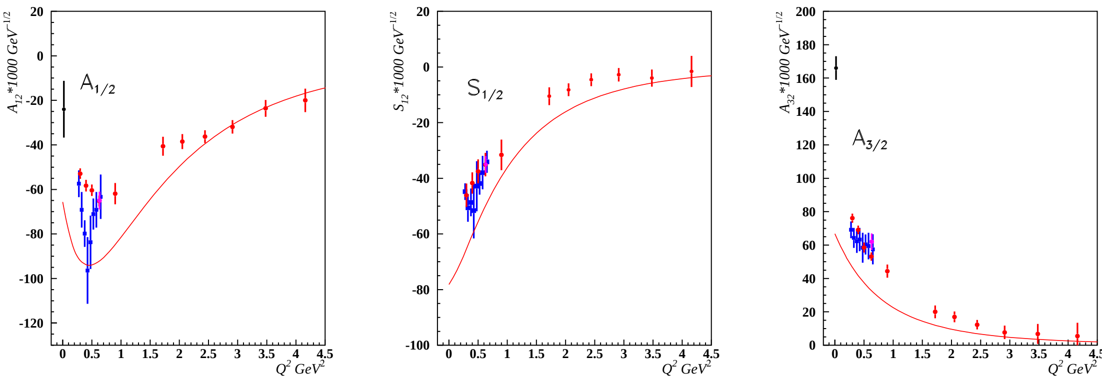

FIG. 9: Electrocouplings for $D_{13}(1520)$ state determined from the CLAS data on $N\pi$ electroproduction [6] (red point) and preliminary results from the CLAS data on $\pi^+\pi^-p$ channel (blue point) [7]. Difference between the data and quark model [9] calculations at $Q^2 < 1.0$ GeV^2 indicates for possible contributions from meson-baryon dressing.

from combined fit of all observables. The JM model [31] was successfully applied for analysis of recent CLAS data [35]. In 09' kinematical coverage of JM model was extended. Successful description of nine single differential cross sections was achieved in kinematic area 1.4< W < 2.1 GeV and $0.25 < Q^2 < 1.5$ GeV^2 allowing us to isolate resonant contributions to observables, needed for extraction of $\gamma_v NN^*$ electrocouplings. Preliminary results on electrocouplings of almost all N^* states with masses < 1.8 GeV were obtained in a wide Q^2 area $0.25 < Q^2 < 1.5$ GeV^2.

Comparison between electrocouplings of $P_{11}(1440)$ and $D_{13}(1520)$ states obtained from analyses of $N\pi$ and $\pi^+\pi^-p$ exclusive channels is shown in Fig. 8, 9. Consistent results on electrocouplings obtained from analysis of two major meson electroproduction channel with completely different non resonant mechanisms offer a compelling evidence for their reliable measure, as well as for reliability of reaction models developed for analyses of $N\pi$ and $\pi^+\pi^-p$ electroproduction.

The data on $\pi^+\pi^-p$ electroproduction cross sections at 1.4< W < 2.1 GeV and $2.0 < Q^2 < 5.$ GeV^2 are close to completion. In Fig 10 we show fully integrated cross section in this kinematics area with pronounced signals from N^* Forthcoming analysis of these new data within the framework of JM model will allow us to obtain electrocouplings for major part of excited proton states at photon virtualities up to 5.0 GeV^2.

In 09' we have initiated effort on implementation of quark degrees of freedom in description of non-resonant mechanisms of $N\pi$ and $\pi^+\pi^-p$ electroproduction channels. The research effort by Universitaet Wuppertal and JINR at Dubna is in progress on implementation of quark degrees of freedom in description of non-resonant parts for $N\pi$ electroproduction channels within the framework of hand bag approach developed in [36]. Extension of this approach toward N* excitation region requires GPD modeling at large x_b. > 0.6 It is a new step in the GPD studies. First results are expected by the end of 2010. Next step will be implementation of quark degrees of freedom to biggest in

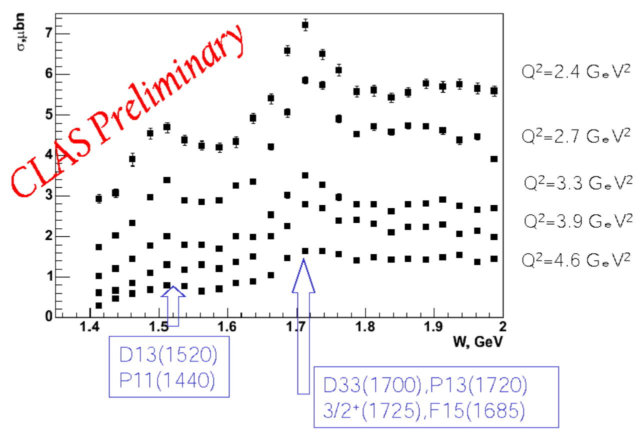

FIG. 10: Preliminary CLAS data on fully integrated $\pi^+\pi^-p$ cross sections at high photon virtualities

N* excitation region $\pi\Delta$ isobar channel in $\pi^+\pi^-p$ electroproduction. Therefore, the proposed experiment has already initiated further extension in the GPD studies.

Substantial progress was achieved in development EBAC-DCC coupled channel analysis [2]. As it was mentioned above, this approach is of particular interest for the proposed experiment.

As the initial step to analyze the data of electromagnetic production of πN, $\pi\pi N$, ηN, $K\Lambda$, $K\Sigma$, and ωN, the hadronic parameters of the EBAC-DCC model should be determined by analyzing the available πN reaction data. This was completed [12] with accurate descriptions of *all* available πN elastic scattering data. Employing analytical continuation method, resonance pole position for 14 well established N* were extracted.

With the hadronic parameters determined in our analysis of πN reactions, fit of the CLAS/world $N\pi$ electroproduction data was carried out. In fitting these data only free parameters are the bare $\gamma_v NN^*$ electrocouplings. It was found [11, 37, 38] that fit offers a good description of the available data at $W \leq$ about 1.65 GeV. In Fig.11 we show one of our results in fitting the CLAS data of the structure functions of $p(e, e'\pi^0)p$

Therefore EBAC has developed all needed machinery in order to determine $\gamma_v NN^*$ electrocouplings in coupled channel analysis of $\pi N, \gamma^* N \to \pi N, \eta N$, reactions. The EBAC highest priority for the next three years is to complete a *combined* simultaneous coupled-channel analysis of all the world's data on $\pi N, \gamma^* N \to \pi N, \eta N, \pi\pi N$ reactions [2]. In this effort information on the cross sections/amplitudes of contributing processes derived from analysis of the CLAS data within the framework of phenomenological reaction model will be helpful, in particular, for implementation of complex $\pi^+\pi^-p$ electroproduction channel.

IV. RECENT DEVELOPMENTS OF THE EXPERIMENT AND THE BEAMTIME REQUEST

Many of the spokespersons are also PIs for the development and construction of key elements of the CLAS12 baseline equipment: Forward Time-of-Flight Detector (University of South Carolina), Silicon Vertex Tracker (Moscow State University), High Threshold Cerenkov Detector (Rensselaer Polytechnic Institute and University of Connecticut), and Region 1 Drift Chambers (Idaho State University). All these design and construction efforts have now been successfully reviewed by international technical committees of leading experts in their fields and all detector developments that we push fulfill or surpass the design requirements. The overall development of the CLAS12 baseline equipment, that is needed to run our proposed experiment, is on track. There are no updates to be reported beyond the recent full simulation that demonstrates the feasibility of the experiment, as documented in our proposal PR-09-003.

Within the total requested beam time of 60 days at 11 GeV electron beam energy with the highest possible electron beam polarization, the estimated collected statistics in most of the Q^2 and W bins will be higher and for the highest Q^2 bins comparable to the statistics accumulated in the previous e1 and e1-6 run periods. Furthermore the new results show that the overall resonance to background ratio increases with increasing Q^2. Therefore we are confident that we will be able to extract the resonance electrocoupling amplitudes up to typically 10 GeV^2 with an equivalent or better accuracy than up to 4 GeV^2 (see Fig. 12) by using the established and currently developed model approaches applied to the same number of measured observables, which have been shown to be sufficient for

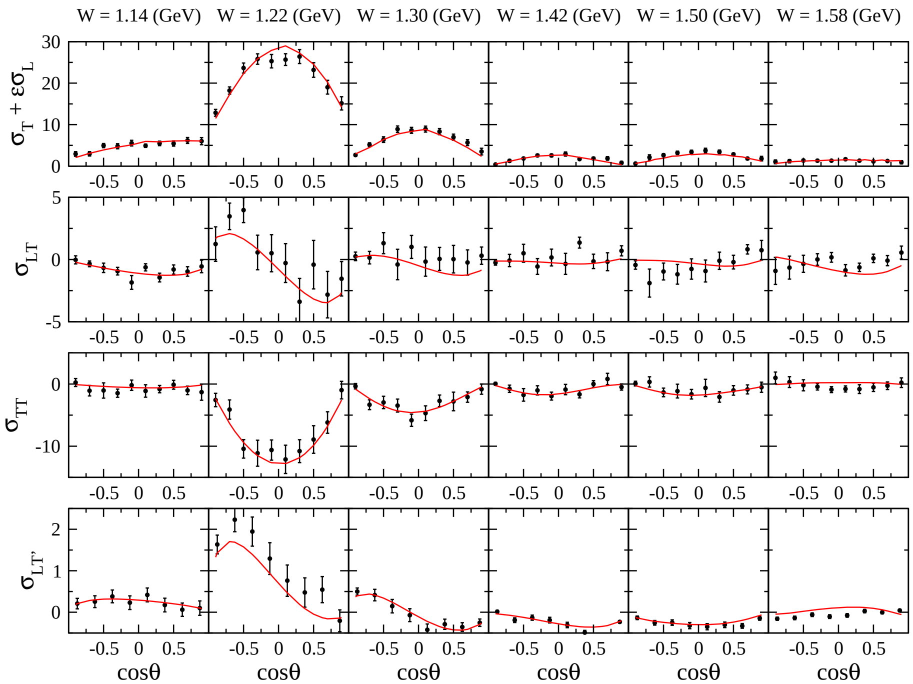

FIG. 11: Structure functions of $p(e,e'\pi^0)p$ at $Q^2 = 0.4$ (GeV/c0^2 and $W \leq 1.65$ geV. Solid curves are from EBAC-DCC analysis[38].

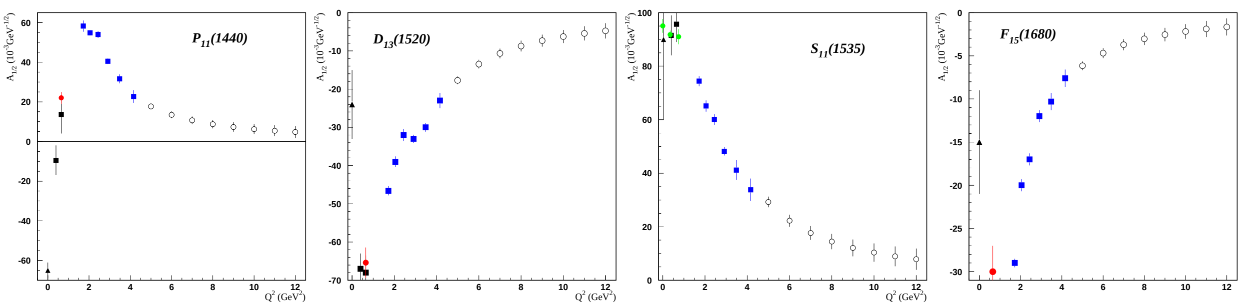

FIG. 12: Projected $A_{1/2}$ helicity amplitudes for the electroexcitation of the resonances $P_{11}(1440)$, $D_{13}(1520)$, $S_{11}(1535)$, and $F_{15}(1680)$, as expected from our proposed experiment (open circles with error bars). Also shown are the corresponding electrocouplings, as extracted from the available CLAS data on 1π electroproduction [6, 39] (black filled squares), data from the analysis of e1-6 run [40] (blue filled squares), and the results from a combined analysis of the 1π and 2π electroproduction channels [41].

this analysis (see Sec. III).

Beam Time Request	Beam	Beam Energy	Luminosity	Target	Detector
60 *days*	*polarized* e^-	11 *GeV*	$10^{35}\ cm^{-2}s^{-1}$	LH_2	*base equipment*

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