Excited Baryon Program at JLab

A Contribution to the NSAC Long Range Plan

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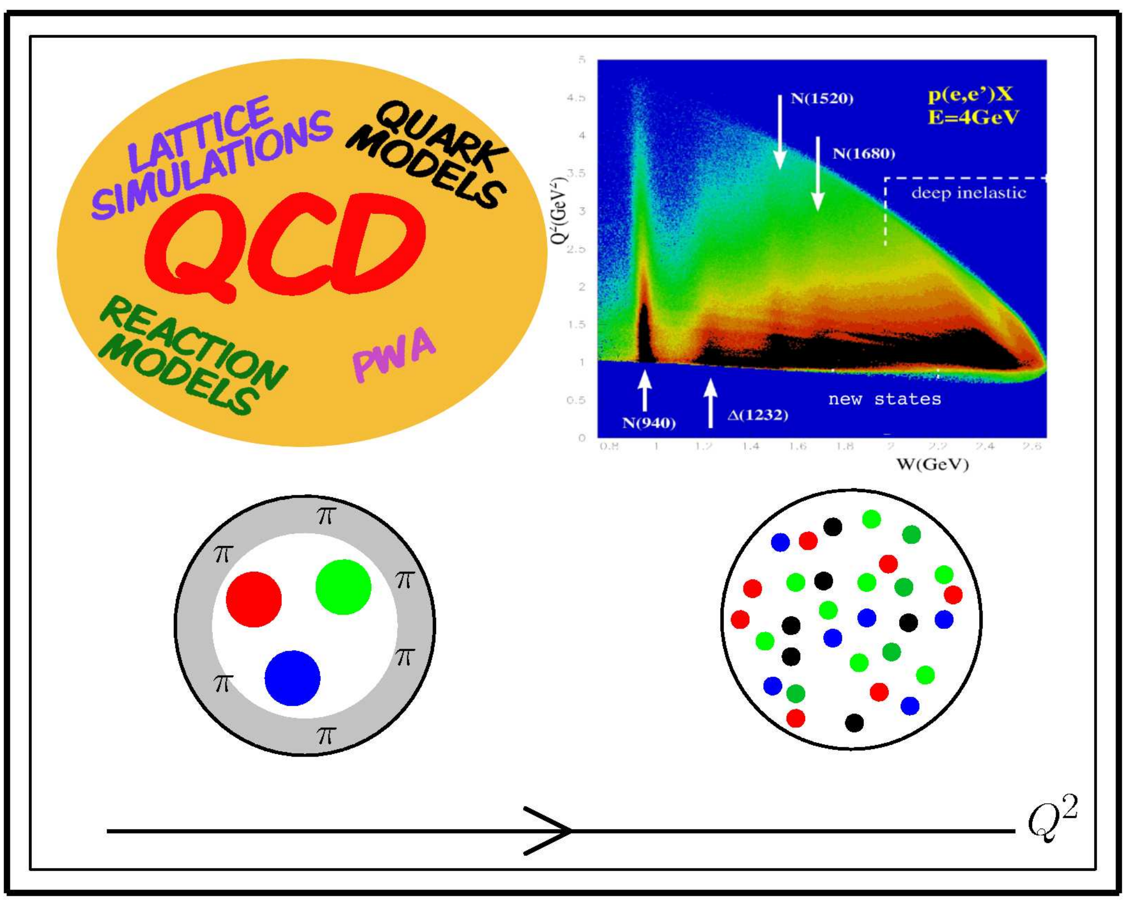

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I. INTRODUCTION AND RECENT PROGRESS

Nucleons make up nearly 100 % of the mass of the visible universe. They are at the core of atoms and nuclei in stars that provide the energy that heat the planets and allow for life to exist on at least one of them, our earth. Understanding their internal structure has been at the center of nuclear and particle physics for decades. The macroscopic properties of the proton and neutron are well known and their ground state charge and current distributions have been measured for more than 50 years. Similar to atomic nuclei, nucleons are complex systems of confined quarks and exhibit characteristic spectra of excited states. Highly excited nucleon states are sensitive to details of quark confinement which is poorly understood within Quantum Chromodynamics (QCD), the fundamental theory of strong interactions. Measurements of excited states are needed to come to a better understanding of how confinement works in nucleons. These excited states couple strongly to the meson-baryon continuum to form nucleon resonances of characteristic masses and decay widths, and can be most effectively investigated by using meson production reactions on the nucleon.

The excited baryon program has two main components. The first one is to establish the systematics of the spectrum, which provides information on the nature of the effective degrees of freedom in strong QCD. These studies are carried out with hadronic and electromagnetic probes. The second component is to probe resonance transitions at different distance scales. Electron beams are ideal to measure the resonance transition form factors from the nucleon ground state to the excited baryon states, and with varying spatial resolution of the probe. These measurements probe the internal structure of excited states and provide information about the confining forces of the 3-quark system. With concerted efforts in analyzing very extensive data from Jefferson Laboratory (JLab) and other electron facilities, significant progress has been made in the past few years. The contribution of mesons to the structure of the Δ (1232) resonance has been explored up to $Q^2 = 6$ (GeV)^2, as illustrated in Fig.1. The N-Δ transition form factors are now considered along with the nucleon form factors as the benchmark data challenging the theoretical community. Progress in understanding these data with Lattice QCD (LQCD) calculations has been made[2]. Moreover, accurate data of the transition form factors for several higher mass N^* have been extracted in the past two years. The example of the transition form factor for the Roper resonance, shown in Fig.2, demonstrates the sensitivity of these measurements to the baryon structure. The

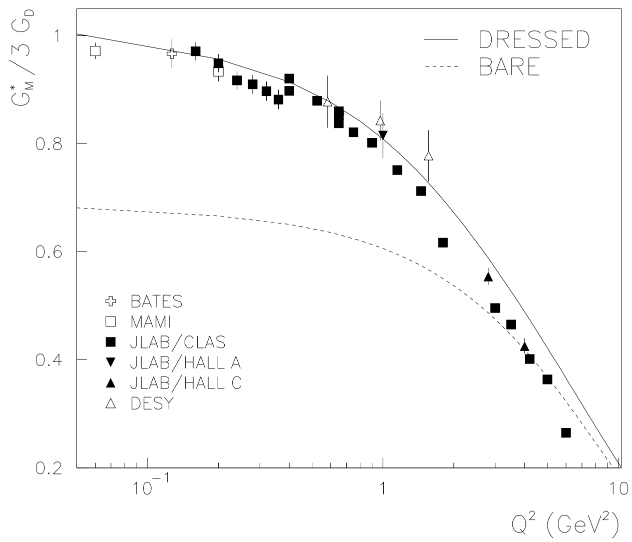

FIG. 1: Magnetic M1 form factor G^*_M for $\gamma N \to \Delta(1232)$, normalized to the elastic dipole G_d. Data points were obtained from Unitary Isobar Model analysis of the exclusive $p(e, e'p)\pi^o$ reaction. Curves are from a dynamical model calculations described in Ref.[1]. The dashed curve is obtained from turning off meson cloud effects.

comparison with the relativistic quark model calculations shows that the state has a quark substructure at small distances eliminating models of this state as a hybrid baryon or a meson-baryon molecule. This conclusion is consistent with LQCD calculations that also show a valence quark structure for this state. These developments mark a major advance in our understanding of the baryon structure. In addition, candidates for new baryon states have been found in various channels for further confirmation with experiments to be performed with polarized beams and polarized targets. For example, the very accurate two-pion electro-production data prove to be very effective in the search for baryon states which decay primarily into resonant $\pi\Delta$ or ρN channels. As illustrated in Fig.3, the analysis of the $\pi^+\pi^-$ electro-production data from JLab show evidence for a $J^P = \frac{3}{2}^+$ state at 1720 MeV which decays strongly into $\pi\Delta$. This state could be different from the conventional $N^*(P_{13}, 1720)$ state which decays predominantly into ρN, as listed by the Particle Data Group in 2006.

Despite these successes, the study of excited baryons continues to be a challenge in hadron

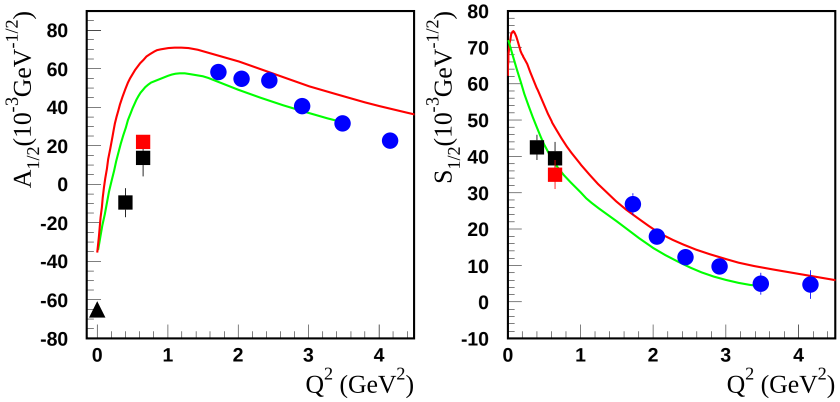

FIG. 2: The extracted $\gamma N \rightarrow N^*(1440)$ form factors are compared with the results from relativistic quark model calculations; red curves [3], green curves[4].

physics. Most known non-strange baryon states have been discovered using elastic $\pi N \rightarrow \pi N$ scattering analysis before 1980. The widely accepted symmetric constituent quark model based on broken spin-flavor SU(6) and orbital excitation O(3) symmetry reproduces well the excitation spectrum for masses up to 1.8 GeV. However, a large number of higher mass states predicted in this model have no clear correspondence in experiments. As alternatives, it has been shown that the well established baryon states fit also in other symmetry schemes, such as the diquark-quark models, which predict a much reduced number of excited states. The current challenge is to identify some of the higher lying baryon states with masses of 1.7 to 2.2 GeV. These states could couple strongly with several meson-baryon channels, in particular the complex two-pion channels, to form resonances with energies which are not related trivially to the positions predicted by the constituent quark models as well as the current LQCD calculations. The identifications of these states require precise measurements of several channels and theoretically sound data analysis methods which account for the channel coupling effects resulting from the unitarity conditions and the reaction mechanisms at short distances where we want to map out the internal structure of baryons. A large experimental effort is currently underway and planned for the next several years at Jefferson Lab using the CLAS detector in conjunction with polarized hydrogen and deuterium targets to search for some of these states with linearly or circularly polarized photon beams.

To analyze the already collected and forthcoming very extensive data, efficient and sound methods for performing empirical amplitude analysis have been developed by several groups with continuing improvements. To strengthen this effort and to also interpret the extracted resonance parameters, the Excited Baryon Analysis Center (EBAC) was established at Jefferson Laboratory in January, 2006.

II. EXPERIMENTAL DEVELOPMENTS

In the past few years, extensive data of photo- and electro-production of pseudo-scalar mesons $(\pi, 2\pi, \eta, K)$ and vector mesons (ω, ϕ) have been accumulated at JLab, MAMI, ELSA, GRAAL, and Spring-8. These data have been analyzed to identify candidates for new excited baryon states and extract N-N^* transition form factors for several known resonances. The current effort is to utilize highly polarized hydrogen and deuterium targets and polarized photon beams toward complete measurements of a large number of reaction channels, and to measure the polarization of recoil hyperons through their weak decays. These data, together with the already collected unpolarized cross sections, will form the basis for a much

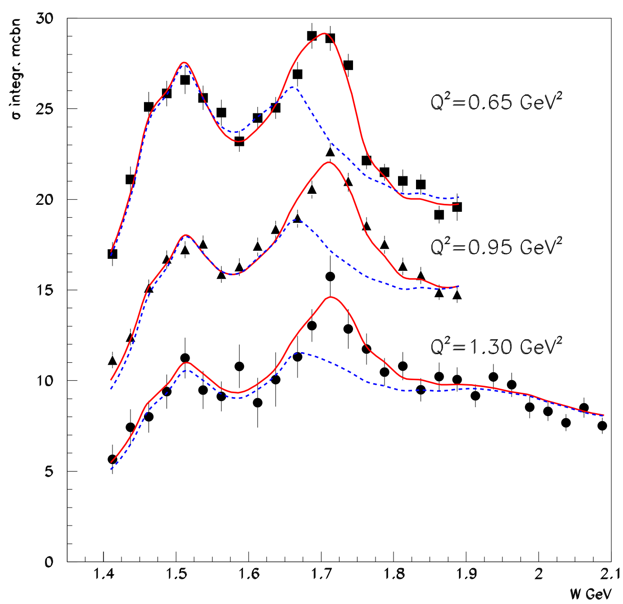

FIG. 3: Integrated cross section for the process $\gamma p \to \pi^+\pi^- p$ as function of the invariant hadronic mass. The solid curves are from fits using the JM06 model [7]. The dashed curves are obtained when the contributions of a $J^P = \frac{3}{2}^+$ candidate state at 1.72 GeV are turned off.

more efficient and much less ambiguous search for new baryon states than has been possible to date. In a coupled channel analysis these data will allow extraction of N* resonance parameters even of the well known states with much improved accuracy.

The photon beam facilities in experimental Hall B at JLab provide energy-marked unpolarized and polarized bremsstrahlung photon beams with energies up to 5.5 GeV, accessing invariant hadronic masses up to 3 GeV. These facilities, in combination with the CEBAF Large Acceptance Spectrometer (CLAS), makes JLab a unique place for photo-production experiments. The first CLAS experiments using unpolarized photon beams and unpolarized hydrogen or deuterium targets have measured the differential cross sections of various pseudo-scalar meson production channels. Subsequent experiments have used a linearly polarized photon beam to measure the beam asymmetries Σ. In addition to single meson production, the two charged pion photo-production is studied.

The data for hyperon production have increased dramatically in recent years. Since Λ polarization can be measured by using its self-analyzing decay distribution, it is possible to extract double and triple polarization observables and measure spin transfer from the photon to the hyperon. One surprising result[6] is that Λ's appear to be 100% polarized if produced by circularly polarized photons, independent of the photon energy and scattering angle.

The next generation of CLAS photo-production experiments will use polarized targets to investigate double polarization observable more generally on both hydrogen and deuterium. The polarized Frozen Spin Target (FROST) is in the final testing phase at JLab and will be used to measure all beam-target double polarization observables for a large number of final states. In case of hyperon production, additional triple polarization observables are accessible which, for the first time, allow the measurement of all observables needed for an unambiguous model independent determination of the reaction amplitudes. These experiments are scheduled to begin in 2007 and many of the accessible observables will be measured for the first time. To study the isospin decomposition of the resonance amplitudes the measurements off polarized protons provided by FROST will be complemented with those off polarized neutrons provided by the HD polarized target, built at BNL and planned to be transferred to JLab for data taking in 2009/2010. To measure such an extensive and nearly complete set of observables with unprecedented accuracy, the CLAS collaboration has developed a comprehensive experimental program to carry out these forthcoming experiments.

The projected accuracy of the new measurements for various polarization observables are displayed in Figs.4 and 5 for FROST program and HD program, respectively.

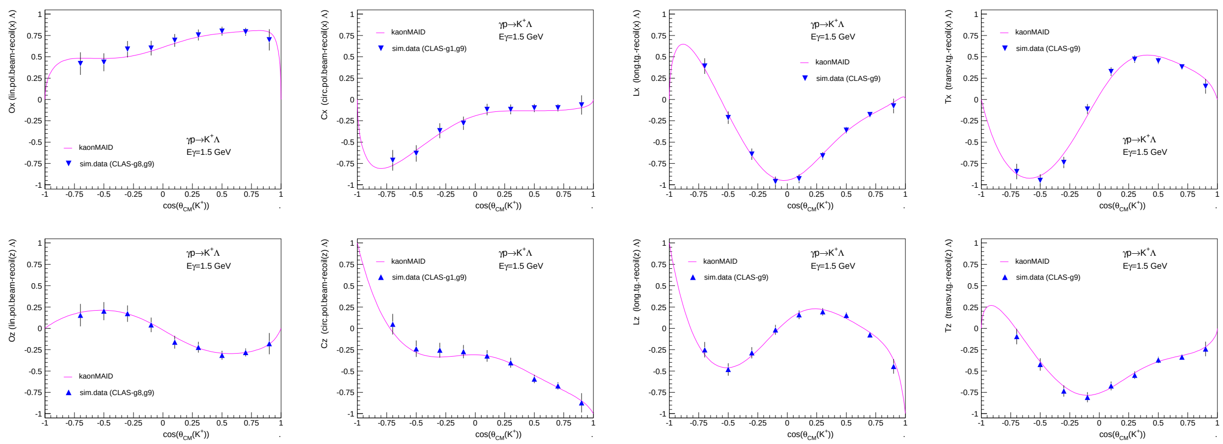

FIG. 4: The projected accuracy of some of the spin observables of $\gamma p \to K^+\Lambda$ to be measured under JLab's FROST program. The curves are generated from KaonMAID[16].

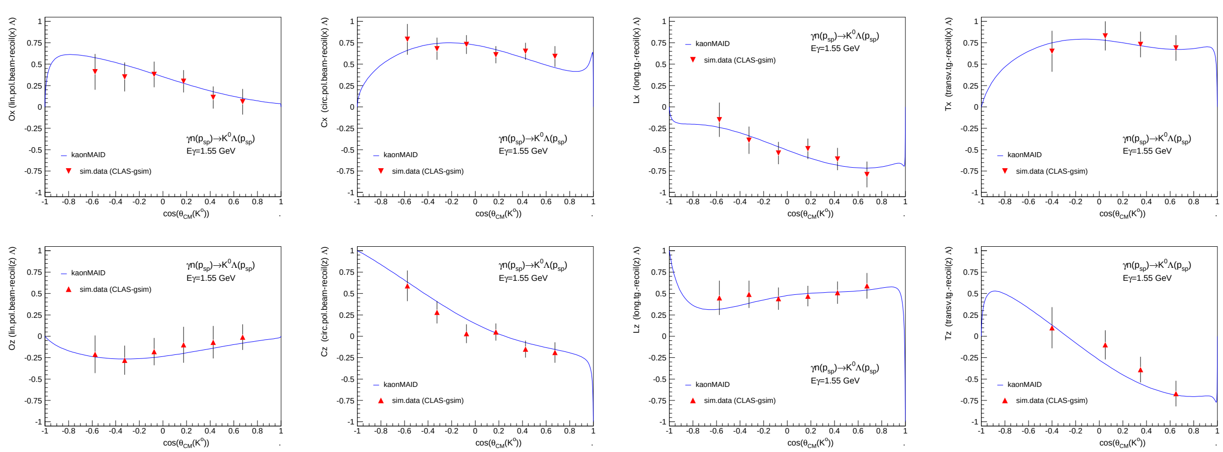

FIG. 5: The projected accuracy of some of the spin observables $\gamma n \to K^0\Lambda$ with proton as a spectator to be measured using the HD target. The curves are from KaonMAID[16]

Programs for measuring single and double polarization observables have also been planned for 2007 with the Crystal Barrel detector at ELSA (and photon energies up to 3.1 GeV) and with the Crystal Ball at MAMI (with photon energies up to 1.4 GeV). Both detectors are electromagnetic calorimeters with high granularity and good energy resolution, and are optimized for the detection of mesons with large branching ratios to photon final states. These experiments will complement the JLab program which emphases the detection of charged particles in the final state. In particular, a combined analysis of both the $\pi^+\pi^-$ production data from JLab and the $\pi^0\pi^0$ and $\pi^0\eta$ production data from ELSA and/or MAMI will be necessary to distinguish nucleon resonances which decay primarily into $\pi\Delta$ or ρN channels.

The real photon data at $Q^2 = 0$ anchor the analyses of the electro-production data which have been accumulated up to $Q^2 \sim 6$ (GeV/c)^2 in recent years. The multipole decomposition of electro-production data can be used to extract the electromagnetic N-N^* transition form factors which encode the spatial and spin structure of the nucleon and its excited states and hence are sensitive to the nature of the effective degrees of freedom that characterize baryon structure at different distance scales. Transition form factors for several low-lying states have already been extracted, as illustrated in Figs.(1)-(2).

The pion electro-production database up to W = 2.5 GeV and $Q^2 = 6$ GeV^2 is growing rapidly. JLab has already contributed 75 % of all the available data to the current world database. Measurements of the two-pion decay channels complement the single pion results, and are especially important for the higher mass states. A full set of unpolarized $2\pi N$ final state observables has been obtained for the first time with the CLAS detector. In a combined analysis of single and double pion electro-production data, results on the Q^2 evolution of the transition form factors have been obtained for many of the well established excited states.

Although the focus of the current program is on strangeness S = 0 baryons, with the CLAS detector hyperon states with S = -1, and cascade states with S = -2 can also be accessed using double kaon photo-production reactions. Cascade baryons are of special interest, as they are predicted to have narrow widths and can more easily be separated from non-resonant production mechanisms. They can be more effective in distinguishing hadron structure models in terms of constituent quark degrees of freedom. Furthermore it is easier to make predictions within LQCD. The results of an exploratory experiment performed recently[9] shows the high potential of CLAS to study strange baryon spectroscopy. An experimental program along these lines is being formed at JLab.

III. REACTION MODELS FOR DATA ANALYSES

The developments described above are creating a more complete data base for the theoretical analysis. Ideally, one would like to study the N^* structure by analyzing the meson-baryon reaction data completely within QCD. This however is far from our reach. To make progress, the data analyses are being performed in two steps. First, reaction models are developed to extract the N^* parameters from the data. The next step is to develop interpretations of the extracted N^* parameters in terms of effective degrees of freedom. In the past few years, a lot of progress has been made in this direction and we are now armed with well-developed models to analyze and interpret the very large amount of data from JLab and other facilities.

Most of the known baryon resonances have been identified by applying the model based on dispersion relations[10] to analyze the πN elastic scattering data. However this approach has its limitations. It is applicable[11] to electromagnetic pion production only within a range of Q^2. Furthermore, it becomes very difficult and impractical for analyzing the data of two-pion production reactions which are crucial in identifying new resonances with large widths of decays into $\pi\Delta$ and ρN states. Alternative reaction models have therefore been developed in recent years to analyze the new data of electromagnetic meson production reactions.

The Partial Wave Analysis (PWA) by the GWU/VPI group continues to make progress[12] by carrying out analyses using the baryon spectroscopy database that is still dominated by πN scattering and covers invariant masses up to W = 2.5 GeV. Their K-matrix analysis of pion photo-production has been extended to analyze the electro-production data. Plans are being developed to revise the isobar model analysis[13] of $\pi N \to \pi\pi N$ data accumulated in 1970's, and to include the recent data from TRIUMF and BNL in the analysis.

Within the K-matrix formulation, the Mainz group[14] and JLab-Yeveran group[15] have developed the Unitary Isobar Model (UIM) to analyze very extensive pion photo- and electro-production data. The $\gamma N \to N^*$ form factors with unprecedented precision have been extracted for the known low-lying N^* states. In a collaboration with EBAC, the JLab-Yeveran analyses are being refined by including the coupled-channel effects.

The coupled-channel K-matrix models have been developed by the Giessen group[17], GWU group[18], KVI group[19], and Bonn-Gatchina group[20]. Their analyses have revealed the importance of coupled-channel effects in extracting N^* parameters and have identified several new N^* candidate states from analyzing the data of ω, η, and K production. These findings will be further examined by using the forthcoming data of polarization observables, as described in the previous section. All groups are improving their analysis methods to cover more channels and use better theoretical input to define non-resonant reaction mechanisms.

A partial-wave analysis tool set has recently been developed by the Carnegie Mellon group [21]. The tool kit supports both event based maximum likelihood fitting as well as simple fits to cross sections and allows for easy coupling of many different data sets into the same fit. This has been well tested and is currently being applied in the analysis of photo-production data from the CLAS experiment at JLab. These data currently include the photo production of πN, ωN, ηN, $\eta' N$, $K\Lambda$, $K\Sigma^0$ and $2\pi N$.

The JLab-MSU collaboration has developed[7] an isobar model (JM06) with tree-diagram mechanisms and additional phenomenological terms to analyze very extensive $\pi^+\pi^-$ photo- and electro-production data from JLab. All significant 2π contributions have been identified in the analysis. The JM06 model has been instrumental in identifying nucleon resonances in the 2π exclusive channel, with masses heavier than 1.6 GeV. For the first time preliminary data on Q^2 evolution for electro-couplings of $S_{31}(1620)$, $P_{13}(1720)$, $D_{13}(1700)$, and $D_{33}(1700)$ states, which decay mostly with two pion emission have become available. In a collaboration with EBAC, the analyses with JM06 model are being refined by including the coupled-channel effects.

A number of dynamical models[22–27] have been developed in recent years to analyze both the πN elastic scattering and electromagnetic pion production data. These models differ from the K-matrix models described above by accounting for the off-shell scattering mechanisms. Hence they are more directly related to hadron structure calculations and can be used to develop theoretical interpretations of the extracted N^* parameters. The models of Refs.[22, 23] have been instrumental in revealing the important pion cloud contribution to the $\gamma N \rightarrow \Delta$ form factors. Progress in understanding these data with Lattice QCD calculations has been made[2]. Accordingly, the effective field theory approach[28] has been applied to investigate the chiral extrapolation which is needed to obtain realistic N-Δ form factors from the current LQCD calculations with very large pion mass. To investigate higher mass nucleon resonances, dynamical coupled-channel models with all relevant reaction channels are being developed at EBAC[29] and also by the Julich Group[27], aiming at a comprehensive analysis of the data of π, η, ω, K, and 2π production.

IV. EXCITED BARYON ANALYSIS CENTER

The Excited Baryon Analysis Center (EBAC) was established at JLab in January, 2006 to provide theoretical support to the excited baryon program. EBAC's program has two components. The first one is to identify new baryon states and extract the N^* parameters from the meson production data. The second one is to develop interpretations of the extracted N^* parameters. This requires a full understanding of the coupled-channel effects resulting from the unitarity conditions and the reaction mechanisms in the short range (off-shell) region where we want to map out the structure of baryons. To achieve these two goals, a dynamical coupled-channel reaction model has been developed at EBAC and is being used to perform analyses of the meson production data from JLab and other facilities.

EBAC's dynamical coupled-channel model[29] is obtained by extending a well-tested dynamical model[22] in the $\Delta(1232)$ region to include all relevant meson-baryon channels and the excitations of higher mass baryon resonances. The channels considered are $\gamma N, \pi N, \eta N$, ωN, and the three-particle $\pi\pi N$ continuum which has $\pi\Delta, \rho N$, and σN resonant components. The model satisfies the unitarity conditions and accounts for the reaction mechanisms in the short-range region by generating the reaction amplitudes from solving coupled-channel integral equations with $\pi\pi N$ unitarity cuts. This model is now being used to analyze the π, η, ω, and 2π production data. An extension of the investigation to include the strangeness production channels, $K\Lambda$ and $K\Sigma$, is also in progress. First results are expected in the summer of 2007 and a complete analysis of nucleon resonances with mass below 2 GeV is expected in 2009 to meet one of the milestones of the last NSAC long-range plan.

The EBAC's dynamical coupled-channel calculations are also aimed at complementing the empirical amplitude analyses described in the previous sections. To process a large amount of the data to obtain the first-run information about the N^* excitations, these analyses, mostly based on the K-matrix approach, must be efficient numerically and hence are forced to make approximations in treating the reaction mechanisms. To establish and also develop theoretical interpretations of the extracted N^* parameters, the approximations used in such analyses must be examined. The validity of the often used speed-plot or time-delayed plot methods in extracting the N^* parameters from the determined partial-wave amplitudes should also be studied. These theoretical issues are being investigated at EBAC in order to provide information for improving the current empirical amplitude analyses. As a first step, EBAC is collaborating with the CLAS collaboration to refine their isobar model analyses of pion electro-production data by including the coupled-channel effects. Collaborations with other empirical analysis groups will be developed.

The main challenge to EBAC is to develop a way to confront the extracted N^* parameters directly with LQCD calculations. Progress has been made[1, 2] in this direction for the Δ (1232) resonance. However, many open questions remain to be investigated[28] before meaningful comparisons can be made. EBAC is planning to work with the LQCD groups to explore the connections between LQCD and results obtained from the analysis using the approach described above.

V. OUTLOOK WITH 12 GEV UPGRADE

The measurements of transition form factors for the identified baryon states require electron beams of sufficiently large energy span to probe the long and short distance structure of the nucleon. The program has started with energies from 1 to 6 GeV, and requires the energy doubling of the JLab accelerator to 12 GeV to allow probing the nucleon core at distance scales where contributions from the bare quarks may become important. Jefferson Laboratory is the only place where these experiments can be carried out at modest Q^2 with CLAS, and after the 12 GeV upgrade at high Q^2 with *CLAS12*. An example of the kinematics range covered with the 12 GeV JLab upgrade is shown in Fig.6

The N^* program can be complementary to the Generalized Parton Distributions (GPD) program at JLab. Progress in this direction is being made[32] by exploring the relations between GPDs, introduced[30, 31] in 1990's, and the N-N^* transition form factors. Transition GPDs can be accessed experimentally for example in Deeply Virtual Compton Scattering where a high energy photon is generated together with a recoil excited baryon in the final state. Such studies will be part of future experiments at the 12 GeV upgrade using the upgraded *CLAS12* detector.

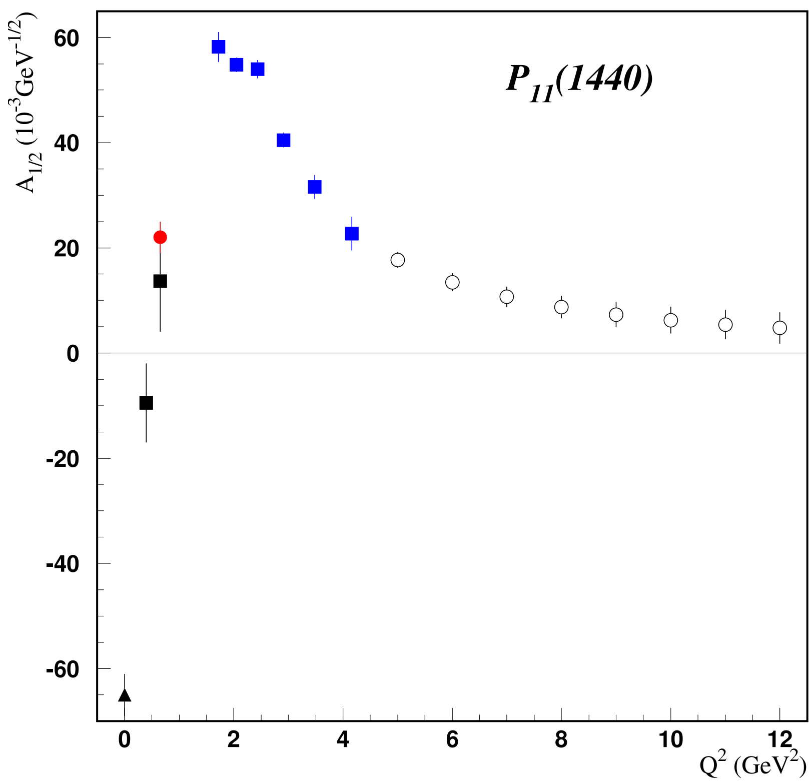

FIG. 6: The transverse transition amplitude for the Roper resonance $P_{11}(1440)$ with projections for the JLab 12 GeV upgrade using the *CLAS12* detector (open circles).

VI. ACKNOWLEDGMENT

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[1] B. Julia-Diaz, T.-S. H. Lee, T. Sato, and L.C. Smith, nucl-th/0611033, to appear in Phys. Rev. C.

[2] C. Alexandrou, P. de Forcrand, H. Neff, J. W. Negele, W. Schroers and A. Tsapalis, Phys. Rev. Lett. **94**, 021601 (2005); C. Alexandrou, T. Leontiou, J. W. Negele and A. Tsapalis, hep-lat/0607030.

[3] S. Capstick and B.D. Keister, Phys. Rev. **D51**, 3598 (1995)

[4] I. G. Aznauryan and A.S. Bagdasaryan, Yad. Fiz. **41**, 249 (1985); I. G. Aznauryan, e-archiv:

nucl-th/0701012 (2006).

[5] W.-M. Yao et al. (RPP) J. Phys. G 33, 1 (2006)

[6] R. Bradford et al. (CLAS), nucl-ex/0611034 (2006)

[7] V. I. Mokeev, V. D. Burkert, et. al., Proceedings of the Workshop on Physics of Excited Nucleons NSTAR2005, ed. by S.Capstick, V.Crede, P.Eugenio, p. 47-56.

[8] I. G. Aznauryan et. al., Phys. Rev **C72**, 045201 (2005).

[9] J. Price et al., Phys. Rev. **C71**, 058201 (2005); L. Guo and D. Weygand, hep-ex/0601010, hep-ex/0601011.

[10] G. Hohler, F. Kaiser, R. Koch, Pietarinen, **Handbook of Pion-Nucleon Scattering**, Physics Data 12-1, Karlsruhe (1979)

[11] A. Donnachie, in **High Energy Physics**, ed. E. Burhop, Vol. 5 (Academic Press NY 1972), page 1.

[12] R.A. Arndt, W.J. Briscoe, I.I. Strakovsky, and R.L. Workman, Phys. Rev. C 74, 045205 (2006)

[13] D.M. Manley, R.A. Arndt, Y. Goradia, and V. Teplitz, Phys. Rev. D 30, 904 (1984).

[14] D. Drechsel, O. Hanstein, S.S. Kamalov, and L. Tiator, Nucl. Phys. **A645**, 145 (1999)

[15] I.G.Aznauryan, V.D.Burkert, H.Egiyan et al., Phys.Rev. C71, 015201 (2005).

[16] T. Mart, C. Bennhold, H. Haberzettl, and L. Tiator, "KaonMaid 2000" at http://www.kph.uni-mainz.de/MAID/kaon/.

[17] V. Shklyar, H. Lenske, U. Mosel, G. Penner, Phys. Rev. **C71**, 055206 (2005)

[18] A. Waluyo and C. Bennhold, International Workshop on the Physics of Excited Baryons (NSTAR 05), Tallahassee, Florida, 10-15 Oct 2005.

[19] A. Usov and O. Scholten, Phys. Rev. **c72**, 025205 (2005)

[20] A. Anisovich, E. Klempt, A. Sarantsev, U. Thoma, Eur.Phys.J. **A24**, 111 (2005)

[21] Matt Bellis, et. al. Proceeding of the meeting of the Topical Group on Hadronic Physics, October 2006, Nashville TN, and on http://www-meg.cmu.edu/pwa.

[22] T. Sato and T.-S. H. Lee, Phys. Rev. **C 54**, 2660 (1996); Phys. Rev. **C63**, 055201 (2001).

[23] Kamalov and S.N. Yang, Phys. Rev. Lett. **83**, 4494 (1999); S.S. Kamalov, S. N. Yang, D. Drechsel, O. Hanstein, and L. Tiator, Phys, Rev, **C64**, 032201(R) (2001),

[24] G.L. Cala, V. Pascalutsa, J.A. Tjon, and L.E. Wright, Phys. Rev. **C70**, 032201 (2004)

[25] M.G. Fuda and H. Alharbi, Phys. Rev. **C68**, 064002 (2003)

[26] F. Gross and Y.Surya, Phys. Rev. **C47**, 703 (1993); Y.Surya and F. Gross, Phys. Rev. **C 53**,

2422 (1996).

[27] H. Haberzettl, K. Nakayama, and S. Krewald, Phys.Rev. **C74**, 045202 (2006).

[28] Vladimir Pascalutsa and Marc Vanderhaeghen, Phys.Rev. **D73**, 034003 (2006).

[29] A. Matsuyama, T. Sato, and T.-S. H. Lee, to appear in Phys. Rept., e-Print Archive: nucl-th/0608051

[30] A. Radyushkin, Phys. Lett **B380**, 417 (1996); **385**, 333 (1996) ;Phys. Rev. **D56**, 5524 (1997)

[31] X. Ji, Phys. Rev. Lett **78**, 610 (1997); Phys. rev. **D55**, 7114 (1997)

[32] L. Frankfurt et al., Phys. Rev. Lett **84**, 2589 (2000); Goeke et al., Prog. Part. Nucl. Phys. **47**, 401 (2001); V. Pascalutsa and M. Vanderhaeghen, hep-ph/0611050.