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EDITORIAL

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NSTAR 2017

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More than one hundred nuclear and particle physicists from 62 different institutions all around the world, see Fig. 1, participated at the NSTAR2017 conference to present and discuss their latest results. This 11th International Workshop on the Physics of Excited Nucleons took place at the University of South Carolina, Columbia, SC, USA from August 20–23, 2017. The aim of the conference was to develop and push our understanding of strong QCD as it confines quarks and creates nucleons and their excitations from these fundamental building blocks. The covered topics focused hence on: the baryon spectrum through meson photoproduction, baryon resonances in experiments with hadron beams and in the e + e-collisions, baryon resonances in ion collisions and their role in cosmology, the baryon structure through meson electroproduction, transition form factors, and time-like form factors, amplitude analyses and baryon parameter extraction, the baryon spectrum and structure from first principles of QCD, advances in the modeling of baryon spectrum and structure, and future facilities and projects. The detailed program and all presentations can be found at the workshop website: http://nstar2017.physics.sc.edu/. The public lecture, "Laying the God Particle to Rest", by Craig Roberts from the Argonne National Laboratory in Chicago, see Fig. 2, addressed the directly corresponding topic of how mass is generated in our world. Organizing the NSTAR workshop around the total eclipse was evidently a bigger challenge than anticipated four years ago as under the lead of Ralf Gothe (USC) the idea was born, but at the end it was such a special highlight that touched everyone who could experience it in a very profound manner, see Fig. 3.

Studies of the spectrum of excited nucleon (N*) and their structure offer unique opportunities to explore many facets of strong QCD dynamics in generation of various excited nucleons with different quantum numbers of distinctively different structure. Another important part of these efforts is focused on the search for new states of baryon matter expected in approaches with traceable connections to the underlying QCD, but still elusive for experimental detection, the so-called "missing" resonances and hybrid-baryons with glue as the active structural component. For these reasons, the nucleon resonance studies represent a particular important avenue in the challenging adventure of exploring strong interaction dynamics in regime of large quark-gluon running couplings. Fostering the synergistic efforts between experimentalists, phenomenologist and theorists aimed to explore the excited nucleon spectrum and structure and eventually to unravel their emergence from QCD was one of the major workshop objective. The current status of the N* spectrum and structure studies

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Fig. 1 Excited nuclear physicists from across the globe gather together on the rooftop of the Darla Moore School of Business to experience the total solar eclipse during the NSTAR 2017 conference at USC

Fig. 2 Craig Roberts (right) in the W.W. Hootie Johnson Performance Hall of the Darla Moore School of Business just before he was introduced by Ralf Gothe (left) to give his public lecture as part of the Total Eclipse Weekend in Columbia

from experiments with electromagnetic probes, as well as the prospects in this field, in particular in the new era of experiments with the CLAS12 detector in the upgraded Jefferson Lab were reviewed in the experimental keynote talk by Volker Burkert (JLab). The key role of nucleon resonance studies for the understanding of strong QCD dynamics that generates the ground and excited nucleon states, as well as the key open problems in the Standard Model on the mechanisms of hadron mass generation and the nature of quark-gluon confinement were presented in the theoretical keynote talk by C.D. Roberts (ANL). The review of the future developments in hadron physics, presented in the final opening talk by Bob McKeown (JLab), elucidated the opportunities for the N* physics to contribute to the broad research efforts in contemporary hadron physics.

Fig. 3 Conference participants and guests alike enjoyed gazing into the sun, clearly not without the proper ISO 12312-2 protection

The experimental studies of exclusive meson photoproduction off the nucleon at the CLAS, ELSA, and MAMI facilities continuously show rapid progress. These experiments provided detailed information on all exclusive meson photoproduction channels relevant in the resonance region, including differential cross sections and single-, double-, and triple-polarization asymmetries. The most recent advances in experimental studies of exclusive meson photoproduction off protons were presented in talks by V. Crede (FSU), E. Pasyuk (JLab), H. Schmieden (Bonn), V. Sokhoyan (MAMI), and S. Strauch (USC). The data on exclusive photoproduction off bound neutrons keeps growing. These efforts were presented in the talks by A. Sandorfi (JLab), P. Mattione (JLab), and I. Strakovsky (GWU) and in several talks in the parallel session A2. The wealth of the available experimental results opens up new opportunities to determine the pseudo-scalar meson photoproduction amplitudes from the measured observables under minimal model assumptions. New methods to extract reaction amplitudes and resonance parameter from experimental data were presented by A. Svarc (Zargeb). Because of the limited experimental data accuracy, use of constraints imposed by the general reaction amplitude properties such as unitarity and analyticity are particularly important in evaluation of the resonance parameters even in the cases when they can be determined in a nearly model independent way. The development of methods allowing us to build the reaction amplitudes under the aforementioned constraints were discussed by V. Mathieu (JLab) and J. Nys (Ghent). Recent developments in reaction models that account for constraints imposed by unitarity, analyticity, and chiral symmetry capable to treat the triangular singularities were presented by E. Oset (Valencia) elucidating insights into the resonance nature they are providing.

So far, the multi-channel coupled channel approaches represent the most advanced approach of the reaction models to extract resonance parameters from combined global analyses of all available data on exclusive meson photo- and hadroproduction. Recent advances in the development and application of the coupled channel approaches to analyze exclusive meson photoproduction data were presented by M. Doering (GWU), M. Mai (GWU), and S. Nakamura (Cruzeiro do Sul). Such analyses of exclusive meson photoproduction data within the coupled channel approaches considerably extended our knowledge of the N* spectrum. V. Burkert (JLab) emphasized this important achievement in the opening talk. In particular, the Bonn–Gatchina coupled channel analysis revealed several N* candidate states that have been included in the 2014 edition of the PDG as an outcome of these efforts. The next important step should be the extension of the coupled channel approaches for the studies of exclusive electroproduction data with a kinematic coverage over full, or at least the biggest, part of the resonance excitation region. The manifestation of new candidate-states in exclusive electroproduction with Q^2-independent masses and total and partial hadronic decay widths will validate the existence of new baryon state in a nearly model independent way allowing us to complete the long-term effort on the search for the "missing"-baryon states. The extension of the coupled channel approaches to exclusive electroproduction is also of key importance for the hybrid-baryon search in the upcoming experiments with the CLAS12 detector at Jefferson Lab. These states were predicted in the recent Lattice QCD studies of hadron spectrum and independently supported by various quark models, but were never observed so far. The unique combination of the 11-GeV continuous electron beam and the CLAS12 detector with an almost 4π acceptance will allow us to search for these states in exclusive $\pi^+\pi^-p$, $K\Lambda$, and $K\Sigma$ electroproduction channels, scanning for the first time the mass range from 1.8 to 3.0 GeV, where the lightest hybrid-baryons should be located according to theory expectations. The characteristic Q^2-evolution of the resonance electroexcitation amplitudes will reveal the signature for glue contributions. This research activity was reviewed in the talk by A. D'Angelo (INFN).

Results on the evolution of the N* electroexcitation amplitudes ($\gamma_v NN^*$ electrocouplings) in dependence of the photon virtuality Q^2, obtained from the data on exclusive meson electroproduction off nucleons, offer access to the internal structure of all prominent resonances. They shed light on the strong QCD dynamics as it generates the full spectrum of excited nucleon states as the bound systems of quarks and gluons. The CLAS detector at JLab has produced the dominant part of the available worldwide data on all relevant meson electroproduction channels off nucleons in the resonance region for Q^2 up to 5.0 GeV^2. The experimental results from the meson electroproduction off protons were presented by D. Carman (JLab), K. Park (JLab), and P. Cole (Lamar). First results on π^-p electroproduction off bound neutrons were presented by Y.Tian (Syracuse). Further experimental results on $N\pi$, $\pi^+\pi^-p$, ωp exclusive electroproduction off free protons and bound nucleons keep growing with a focus on the studies of high mass region of $W > 1.6$ GeV and with extended coverage over photon virtualitues up to 5.0 GeV^2. The advances in these efforts were discussed in two special sessions, A4 and A5.

All currently available results on $\gamma_v NN^*$ electrocouplings were obtained from fits to measured meson electroproduction observables within the framework of phenomenological reaction models. The MAID approach represents one of the major tools that has successfully been used worldwide over the last decades for the extraction of resonance parameters from exclusive $N\pi$ and $N\eta$ electroproduction. The MAID approach legacy and future were presented by L. Tiator (Mainz). The efforts on the extraction of the $\gamma_v NN^*$ electrocouplings from the CLAS data were reviewed by V. Mokeev (JLab). These analyses of the $N\pi$, $N\eta$, and $\pi^+\pi^-p$ exclusive electroproduction data have provided the only results available worldwide on the Q^2 evolution of resonance electrocouplings for most excited nucleon states in the mass range up to 1.8 GeV and at photon virtualities up to 5.0 GeV^2 (for Δ (1232)$3/2^+$ up to 7.5 GeV^2 and for N(1535)$1/2^-$ up to 7.05 GeV^2). Current results are openly accessible[1] and show high consistency in the results on the resonance electrocouplings obtained independently from analyses of different exclusive channels with entirely different non-resonant contributions, offering sound evidence for credible extraction of these fundamental quantities. In the near term future electrocouplings up to 5.0 GeV^2 of most excited nucleon states in mass range up to 2.0 GeV will become available from independent analyses of the CLAS data on exclusive $N\pi$ and $\pi^+\pi^-p$ electroproduction off protons. The Argonne-Osaka collaboration for the first time provided preliminary results on electrocouplings of Δ (1232) $3/2^+$ and N(1440)$1/2^+$ resonances determined from global multi-channel analysis of eight meson-baryon photo-, electro-, and hadroproduction channels within their advanced coupled channel approach that accounts for the restrictions imposed both by two- and three-body unitarity conditions. This significant achievement in resonance electrocoupling extraction was reported by H. Kamano (KEK). The corresponding coupled channel results on extraction of the resonance parameters from exclusive meson electroproduction off bound nucleons was presented by T. Sato (Osaka) and S. Nakamura (Cruzeiro do Sul). The roadmap for the implementation of quark degrees of freedom into the reaction models for extraction of $\gamma_v NN^*$ electrocouplings at high photon virtualities up to 12 GeV^2 as they are expected from CLAS12 was outlined by G. Eichmann (IST).

Physics analyses such as these have already a profound impact on the contemporary understanding of strong QCD dynamics. The Dyson–Schwinger Equations of QCD (DSEQCD) successfully describes the data on elastic and transition ($N \rightarrow \Delta$ (1232)$3/2^+$, $N \rightarrow$ N(1440)$1/2^+$) form factors from CLAS for $Q^2 > 2.5$ GeV^2 with the same momentum-dependent dressed quark running mass, which turns out to coincide with those used for successful description of pion elastic form factor. These breakthrough results reported by J. Segovia (Munich) demonstrated that constituent quarks with a momentum-dependent mass, that is inferred from the QCD Lagrangian within DSEQCD, represent the relevant structural component for the ground and excited nucleon states. Furthermore, this success offers the strong evidence for capability to explore the mechanisms behind the generation of $> 98\%$ of hadron mass based on the experimental results on Q^2-evolution of resonance electrocouplings. This is one of the most important achievements of the synergistic efforts between experimentalists, phenomenologists, and theorists in hadron physics. Still, it needs to be further validated in the future DSEQCD analyses of experimental results on the N* structure of various excited states. The evaluation of the orbital-excited N(1535)$1/2^-$ resonance electrocouplings within DSEQCD presented

[1] Electrocoupling data access via https://userweb.jlab.org/~mokeev/resonance_electrocouplings/.

by A. Bashir (Michoacan) represents the first step in this direction. Consistent results on the momentum-dependent running quark mass from the data on the Q^2-evolution of different resonance electrocouplings, studied independently for all prominent excited nucleon states as well as the electromagnetic nucleon and pion elastic form factors, are critical in order to validate the access to the mechanisms behind the hadron mass generation and quark-gluon confinement emergence that are encoded in the quark mass momentum dependence. New ideas on a connection between nucleon elastic and transition form factors and QCD's process-independent effective charge were presented by J. Rodríguez-Quintero (Huelva).

So far, quark models represent the only available tool for the studies of nucleon resonance electrocouplings over full spectrum of excited nucleon states. Moreover, they are capable to account for the contributions from both meson-baryon and quark degrees of freedom. New ideas on the application of the light-front holography and superconformal quantum mechanics to analyses of the N* spectrum and structure were presented by S. Brodsky (SLAC). The current status and the prospects of different quark models as they describe the resonance structure were presented by G. Ramanlo (Cruzeiro do Sul) and E. Santopinto (Genova). The evaluation of the $\gamma_v NN^*$ electrocouplings over the full spectrum of excited nucleon states at photon virtuality up to 12 GeV^2 represents a task of particular importance for theory support of the future studies of the nucleon resonance structure with the CLAS12 detector. Quark models are important in providing support for the QCD-rooted approaches. Remarkably, strong evidence for a momentum-dependent constituent quark mass was also obtained in the analysis of the CLAS results on electrocouplings of all low-lying resonances in mass range up to1.6 GeV within the framework of novel light-front quark model as shown by V. Burkert (JLab) in a presentation from I. Aznauryan (Yerevan).

Lattice QCD is making steady progress towards the evaluation of the nucleon resonance electrocouplings from the first principles of QCD and accounting for full complexity of all strong QCD mechanisms relevant for the generation of the N* structure. These innovative studies were discussed in two focused sessions, B1 and B2. An overview of the Lattice QCD efforts in the studies of the N* spectrum and structure was presented by J. Wu (Adelaide) and R. Briceno (JLab).

Input on strong QCD dynamics through studies of the nucleon resonance electrocouplings can be used in exploration of quark-gluon confinement from the results on the 3D-structure of the ground nucleons within GPD framework. These efforts that constitute flagship experiments with the CLAS12 detector at Jefferson Lab were presented by L. Elouadrhiri (JLab) and discussed in the parallel session C1. Furthermore, experimental results on resonance electrocouplings are of particular importance in the studies of quark-hadron duality as discussed in the parallel session A1 and reviewed by W. Melnitchouk (JLab). The initiation of new joint efforts between experimentalists, phenomenologist, and theorists to study strong QCD dynamics through the exploration of the resonance spectrum and structure accessible via exclusive meson electroproduction in the resonance region and DIS-processes was one of the most important outcomes of NSTAR17 conference.

Courtesy of Lothar Tiator, participant of the NSTAR 2017 workshop in Columbia.