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Summary *

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Abstract A summary of the contributions to this workshop is given. The status and future development of N^* physics are discussed.

Key words

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1 Introduction

The investigation of excited baryons (N^*) has three main components:

1. We need to perform experiments to obtain extensive and accurate data for extracting the partial-wave amplitudes (PWA) of meson-baryon reactions as model independent as possible.

2. We need to analyze the resulting PWA within a reaction model for extracting the resonance parameters by using either the method of analytic continuation to complex energy plane or by the fits based on the Breit-Wigner parameterization.

3. We need to interpret the extracted resonance parameters for establishing the baryon spectrum and understanding the structure of N^* states.

In this workshop, a lot of progress in all of these three subjects have been reported. In the following three sections, the main advances in each of them will be summarized. It is not possible, and perhaps also not necessary, to cover all of the contributions to this workshop which can be found in this proceeding. Some concluding remarks are given in section **5**.

2 Experimental Developments

It has been well recognized that the complete or over-complete measurements of meson-baryon reactions are needed for extracting accurate PWA from data. Impressive progress in this direction has been made at Jefferson Lab (JLab), Bonn-ELSA, and Mainz-MAMI.

At JLab, single and double polarization data of π, 2π and K production have been obtained and are being analyzed. In the next few years, an over-complete measurement of $K\Lambda$ and $K\Sigma$ photoproduction will be performed at Hall B. Accordingly, the strategy for extracting the multipole amplitudes of $\gamma N \rightarrow K\Lambda, K\Sigma$, as model independent as possible, from these upcoming data are being developed in a joint effort of the CLAS collaboration and EBAC. Progress is also being made at JLab to install the HD-ICE target such that the data on polarized neutrons can also be obtained.

At Bonn-ELSA, single and double polarization data of π^0, η, ω, $\pi^0\pi^0$ and $\pi^0\eta$ photoproduction have been obtained and included in their coupled-channel analysis. Equipments for obtaining more polarization observables are being developed.

At Mainz-MAMI, single and double polarization data of π, η, $\pi\pi$ photoproduction have been obtained and are being analyzed. With the combination of Crystal Ball and TAPS, complete measurements will be performed in the near future.

In addition to the above advances toward performing complete measurements, several important

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experimental developments have been reported. With the excellent performance of BES-III at the Institute of High Energy Physics at Beijing, a lot of Ψ, Ψ', Ψ'' production data have been accumulated and are being analyzed for identifying higher mass N^* states from the decays of these particles into $N^*\bar{N}$. At LEPS/SPring-8, the polarized photon energy has been increased to 3.2 GeV and polarized HD target will be available very soon for double polarization measurements. The data of $pp \to pK^+Y$ from Jülich-COSY have revealed roles of $\Lambda(1405)$, $\Sigma(1480)$ and $\Delta(1620)$. The data of $pp \to pp\pi^0\pi^0$ are found to disagree with the predictions from the double-Δ production mechanisms. At the Lanchow proton facility in China, a project for investigating N^* in nucleon-nucleon collisions is being developed.

3 Data Analysis and Resonance Extractions

3.1 K-matrix models

The K-matrix models continue to be very productive in extracting N^* parameters. The GWU/VPI group has recently found that some 3-stars N^* states listed by the Particle Data Group (PDG) are not confirmed in their analysis. They also point out that the P_{11} πN amplitude has two poles near the $\pi\Delta$ threshold and therefore can not be parameterized as the Breit-Wigner form. They have also made progress in analyzing the data of pion electroproduction reactions.

The JLab-UIM analysis has extracted $\gamma^* N \to N^*$ form factors for $P_{33}(1232)$, $P_{11}(1440)$, $S_{11}(1535)$, $D_{13}(1520)$ and $D_{33}(1700)$. They are making progress in extracting form factors for higher mass N^* states.

The Mainz-UIM analysis (MAID) has extracted 13 $\gamma^* N \to N^*$ form factors. Their results for few N^* states are in fair agreement with the results from a recent constituent quark model calculation. At high Q^2 region, their results differ from JLab's significantly.

The Bonn-Gatchina analysis has included very extensive photoproduction data of single and double meson photoproduction data. They have proposed some new high mass N^* states.

3.2 Dynamical models

The development of dynamical models has made significant progress in the past two years. At EBAC, the data of $\pi N \to \pi N, \eta N, \pi\pi N$ have been analyzed for determining the hadronic parameters of their dynamical coupled-channel model. An analytic continuation method has been developed for extracting the resonances positions from the predicted coupled-channel reaction matrix elements. All of the resonances identified within their reaction model consist of a bare state and meson cloud. The model has been applied to analyze single pion photoproduction and electroproduction data to obtain preliminary values of $\gamma N \to N^*$ form factors. Their current focus is to perform a very challenging combined analysis of $\pi N, \gamma^* N \to \pi N, \eta N, \pi\pi N$. This is needed to finalize their extraction of resonance parameters and a necessary step to discover new resonances states at higher mass region using the data of KY and ωN production, in particular the data from the forthcoming over complete measurements of $\gamma p \to K^+\Lambda$.

The Jülich group has applied an analytic continuation method to extract resonances from their coupled-channel model of πN scattering. They are working on a model to constraint the amplitudes at high energies by Regge phenomenology and low energies by the chiral perturbation theory. They are also investigating the procedures for relating reaction models to Lattice QCD (LQCD). An extension of their model to investigate η' photoproduction has been reported.

4 Interpretations of Extracted N^* parameters

Theoretical effort to interpret the N^* parameters is also advancing significantly in several directions. The LQCD calculations of the N^* masses and N-N^* form factors will be improved with petaflop/second computation power. Calculations of N-Δ (1232) and N-$N^*(1440)$ form factors have been performed and are being improved.

The Dyson-Schwinger Equation (DSE) model, which is the only covariant model with crucial running quark masses and has been very successful in describing mesons and nucleon form factors, is emerging as a very important tool for interpreting N^* parameters up to the high Q^2 region accessible to JLab's 12 GeV upgrade. The DSE calculations of N-$\Delta(1232)$ and N-$N^*(1440)$ form factors are underway.

Within the constituent quark model (CQM), it was reported that the N-N^* form factors extracted by Mainz and JLab analysis are in good agreement with the recent calculations, in particular the change of sign of N-$N^*(1440)$ form factor at low Q^2 region. Models including $qqqq\bar{q}$ components have been developed to interpret some N^* parameters. The CQM predictions of N-N^* couplings have been used as initial parameters in applying EBAC's dynamical coupled-channel model to analyze the η photoproduction data.

The Chiral Unitary Model (CUM), which describes hadron resonances in terms of hadron-hadron coupled-channel interactions, has been used to describe N^* masses as 2-mesons + 1-baryon states. Effort is continued to apply CUM to investigate reactions induced by π, K, and γ.

Other interesting reports are on the understanding nucleon spins and the new mechanisms of $K\Lambda$ photoproduction in an effective Lagrangian approach.

5 Concluding Remarks

It is common to expect that we will be able to obtain model independent PWA from the data of complete observables; 8 for pseudoscalar meson photoproduction and 12 for electroproduction. This however is not so obvious simply because the observables are determined bi-linearly by PWA. As an example, let us consider elastic scattering of two scalar mesons. There is only one observable : differential cross section $d\sigma/d\Omega = |f(\theta)|^2$. The complex amplitude $f(\theta) = e^{i\phi(\theta)}|f(\theta)|$ clearly can not be determined by one real number $d\sigma/d\Omega$. Only at very specific kinematic region, such as at low energies where only few partial waves are relevant, the amplitude can be determined by the complete data of $d\sigma/d\Omega$. For the N^* studies, we are facing a much more complex coupled-channel situation. We need to start to develop strategies to extract PWA from the forthcoming data from the complete/over-complete measurements.

The extracted $\gamma^* N \rightarrow N^*$ form factors presented at this workshop appear to have small errors. Since only few of the complete observables are used in the analysis, these results must be re-examined, in particular their relative signs between different multipole amplitudes and between different Q^2 regions, by the analysis including more polarization data. At this workshop we have already learned from one report that the new double polarization data from Bonn-ELSA disagree with the predictions calculated from using the amplitudes of SAID, MAID, and Bonn-Gatchina analysis. The determination of $\gamma^* N \rightarrow N^*$ form factors can be finalized only when the data from the forthcoming complete measurements are included in the analysis.

An interesting development is that new information for understanding the Roper $N^*(1440)$ have been reported. Two resonance poles near the $\pi\Delta$ threshold (~ 1385 MeV) in P_{11} amplitude have been found independently within the coupled-channels analysis of GWU/VPI, EBAC, and Jülich. In the EBAC analysis, these two poles as well as a pole near 1.8 GeV are found to evolve from the same bare state with a mass of 1.736 GeV. In the JLab-UIM and Mainz-MAID single-channel K-matrix analysis, the extracted $\gamma^* N \rightarrow N^*(1440)$ is consistent with the radial excitation of 3-quark configuration within the constituent quark model. It has been reported in the BES-II experiment that a clear peak in the πN invariant mass distributions of $\Psi \rightarrow \bar{N} N \pi$ decays can be seen in the πN invariant mass around the $N^*(1440)$ energy. All of these developments have provided new information for understanding the mysterious Roper resonance.

In most of the hadron structure calculations, it is custom to compare the results with the N^* parameters listed by PDG or recent analysis. It is important to note that the data used in extracting N^* parameters are not complete so far and each analysis involves some assumptions. For example, the N^* parameters extracted at resonance poles using analytic continuation and those from Breit-Wigner parameterization can be very different. Such differences must be understood within reaction theories before the hadron structure calculations can be sensibly tested.

In conclusion, this has been a very successful workshop. Many important developments have been reported and discussions have been very extensive and fruitful. It has defined several new directions for the investigation of N^* physics.