Summary and Remarks

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Problems to solve in N^* Physics

- Need Accurate data for extracting partial-wave amplitudes (PWA) as model independently as possible

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  Perform complete measurements of πN and $\gamma^* N$ reactions

- Fit the extracted PWA/data within a reaction model for extracting resonance poles on complex E-plane.

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  1. Establish baryon spectra
  2. Determine N-N^* transition form factors

- Interpret the extracted resonance parameters

This workshop:

A lot of progress in all three directions have been reported.

Experimental advances

Impressive progress has been made toward complete measurements

Jlab :

- Single and double polarization data of π, $\pi\pi$, $K \cdots$ production have been obtained
- Over-complete measurements of $K^+\Lambda$ will be performed
- Data on polarized "neutron" will be obtained with HD-ICE target

Bonn-ELSA:

- Single and double polarization data of π^0, η, ω, $\pi^0\pi^0$, $\pi^0\eta$ production have been obtained
- More measuements will be performed

Mainz-MAMI:

- Single and double polarization data of π, η, $\pi\pi$ have been obtained
- Complete measurements with Crystal Ball+TAPS will be performed

BES:

- BES-III started July, 2008
- A lot of Ψ, Ψ', Ψ'' have been accumulated for analyzing $\Psi' s \to N^* \bar{N} \cdot \cdot$ to discover higher mass N^*'s

LEPS/Spring-8:

- E_γ is increased to 3.2 GeV
- Polarized HD target will be avalable
- Θ^+ study will be finalized soon.

Julich-COSY:

- Data on $pp \to pK^+Y$ revealed roles of $\Lambda(1405)$, $Y(1480)$ and $\Delta(1620)$
- Data of $pp \to pp\pi^0\pi^0$ disagree with double-Δ mechanisms

Remark:

Obsevables are determined bi-linearly by PWA

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It is not clear how the data from the complete/over-complete measurements can be used to obtain model independent PWA.

Example: scalar-meson scalar-meson elastic scattering

Only one observable, two numbers to be determined

$$\begin{aligned} \frac{d\sigma}{d\Omega} &= |f(\theta)|^2 \\ f(\theta) &= e^{\Phi(\theta)}|f(\theta)| \end{aligned}$$

Data Analysis and Resonance Extractions

1. K-matrix models

- GWU/VPI:
  1. Some 3-stars N^* in PDG are not confirmed
  2. Two poles near $\pi\Delta$ threshold are found in P_{11}

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     can not be parameterized as Briet-Wigner (BW) form

- JLAB:
  1. N-N^* form factors for P_{33} (1232), $S_{11}(1535)$, $D_{13}(1520)$, $D_{33}(1655)$ have been determined
  2. N-N^* form factors for higher mass N^* are being determined.

- Mainz:
  1. 13 N-N^* form factors have been extracted
  2. disagree with JLab results at high Q^2

- Bonn-Catchina :
  1. Very extensive photoproduction data are included in the analysis.
  2. Some new high mass N^* have been proposed.

Remarks:

Extracted N-N^* form factors have very small errors.

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Puzzle:

Any room for improvements when we have data from complete measurements ??

Note :

New double polarization data from Bonn-ELSA disagree with predictions from SAID, MAID, and Bonn-Catchina models

2. Dynamical Models

- EBAC model
  1. Fits to $\pi N \to \pi N, \eta N, \pi\pi N$ data have been obtained
  2. Resonance poles in s, p, d, f waves have been extracted by using analytic continuation method
  3. Fits to π and η photoproduction and electroproduction data have been obtained.
  4. Combined analysis of $\pi N, \gamma^* N \to \pi N, \eta N, \pi\pi N$ is underway
- Julich Model
  1. Resonance poles have been extracted by using analytic continuation method
  2. Procedure for relating to LQCD is being investigated.
  3. Reggy phenomenology is used to constrain the high energy behavior
  4. Results of η' photoproduction are presented.

Remark:

New information for understanding the Roper $N^*(1440)$ have been reported :

- GWU/VPI, Julich, and EBAC all find two poles in P_{11} near $\pi\Delta$ threshold ($\sim$ 1385 MeV)
- N-N^*(1440) form factors extracted by JLab-UIM and Mainz-MAID suggest that $N^*(1440)$ is due to radial excitations of 3-q configuration
- $N^*(1440)$ is clearly seen in BES's data of $\Psi \to N^* \bar{N}$

Interpretations of extracted N^* parameters

- Lattice QCD calculations
  1. Calculations of N^* masses and N-N^* form factors will be improved with petaflop/s computation power
  2. Only the action with chiral symmetry is suitable for investigating N^*
  3. Calculations of N-Δ(1232) and N-$N^*(1440)$ form factors have been performed and are being improved.

- Dyson-Schwinger Equation (DSE) Model
  1. Very successful in describing mesons and nucleon form factors
  2. The only covariant model which has crucial running quark masses for investigating Q^2 dependence of N-N^* form factors.
  3. Calculations of N-Δ (1232) and N-$N^*(1440)$ form factors are underway

- Constituent quark models (CQM)
  1. The N-N^*(1440) form factors extacted by JLab and Mainz agree well with the predictions from relativistic CQM.
  2. Models including $qqqq\bar{q}$ components have been developed to understand N^* properties
  3. Predicted N-N^* couplings have been used to analyze η photoproduction data within EBAC model
- Chiral Unitary Model
  1. 2-mesons + 1-baryon resonances have been predicted and compared with the N^* massess listed by PDG
  2. The hidden gauge approach of Bando is used to include vector mesons for predicting higher mass baryon resonances
  3. Continue to apply the model to investigate reactions induced by π, K and γ.

Remark:

In comparing the predictions from hadron structure calculations with the extracted N^* parameters, one must be careful in examining the dynamical content of the reaction models used in the data analysis.

Note:

N^* parameters extracted from resonance poles and from using Briet-Wigner parameterization can be very different .

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Need some theoretical investigations

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3-ways collaborative efforts:

Hadron structure calculations $\leftrightarrow$ Reaction Models $\leftrightarrow$ Data

Other developments

- N^* project at Lanchow proton facility is being developed :
  Have considered $NN \to NN^* \to \pi NN \cdots$
- New reaction mechanisms of $K\Lambda$ photoproductions have been identified in an effective Lagrangian approach
- Progress in understanding nucleon spins have been reported
- $\cdots$

Concluding remarks

- A lot of progress have been made since the last N^* workshop
- N^* physics is very challenging and needs international collaborations, such as the proposed Pire project for developing US-China collaboration
- This is a very successful meeting with many discussions