Dynamical coupled-channels study of photo- and electro-production reactions

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in collaboration with
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Joint DNP/JPS meeting Oct. 13-17
1. Excited Baryon Analysis Center (EBAC) @JLab

2. Recent results from EBAC-DCC analysis of $ep \rightarrow e'\pi N$ reactions

3. Current work on “Complete Experiment” of pseudoscalar meson photoproduction reactions
Excited Baryon Analysis Center @ Jefferson Lab

Objectives and goals:

Through the comprehensive analysis of world data of $\pi N$, $\gamma N$, $N(e,e')$ reactions,

- Determine $N^*$ spectrum (masses, widths)
- Extract $N^*$ form factors, in particular the $N$-$N^*$ electromagnetic transition form factors
- Develop a method to connect with hadron structure calculations and deduce the structure of $N^*$ states

Reaction Data

$\pi N \rightarrow \pi N, \eta N, \pi\pi N, KY, \omega N...

\gamma^{(*)} N \rightarrow \pi N, \eta N, \pi\pi N, KY, \omega N...

Dynamical Coupled-Channels Analysis @ EBAC

Hadron Models

Lattice QCD

QCD

Founded in January 2006

http://ebac-theory.jlab.org/
Dynamical coupled-channels model @ EBAC


✓ Partial wave (LSJ) amplitude of a → b reaction:

\[
T^{(LSJ)}_{a,b}(p_a, p_b; E) = V^{(LSJ)}_{a,b}(p_a, p_b) + \sum_c \int_0^\infty q^2 dq V^{(LSJ)}_{a,c}(p_a, q)G_c(q; E)T^{(LSJ)}_{c,b}(q, p_b; E)
\]

coupled-channels effect

✓ Reaction channels:

\[
a, b, c = (\gamma^{(*)}N, \pi N, \eta N, \pi\Delta, \sigma N, \rho N, K\Lambda, K\Sigma, \omega N)
\]

\[
\pi\pi N
\]

✓ Potential:

\[
V_{a,b} = v_{a,b} + \sum_{N^*} \frac{\Gamma_{N^*,a}^{\dagger} \Gamma_{N^*,b}}{E - M_{N^*}}
\]

ground meson-baryon exchange

bare N* state
2. Single pion electroproduction ($Q^2 > 0$)

Fit to the structure function data from CLAS

$$\frac{d\sigma^{5}}{dE_{e}d\Omega_{e}d\Omega_{\pi}^*} = \Gamma_{\gamma} \left[ \sigma_{T} + c\sigma_{L} + \sqrt{2c(1+c)}\sigma_{LT}\cos\phi_{\pi}^* + c\sigma_{TT}\cos2\phi_{\pi}^* + h_{e}\sqrt{2c(1-c)}\sigma_{LT'} \sin\phi_{\pi}^* \right].$$

$Q^2 = 0.4 \text{ (GeV/c)}^2$

$Q^2 = 1.45 \text{ (GeV/c)}^2$

$W < 1.6 \text{ GeV}$

$Q^2 < 1.5 \text{ (GeV/c)}^2$

$\Gamma_{\gamma N \rightarrow N^*}$ is determined at each $Q^2$. 

p (e,e' $\pi^0$) p
$\gamma^* N \rightarrow \Delta(1232)$ form factors

- $G_M^*$
- $G_E^*$
- $G_C^*$

- Full results
- $\Delta(1232)$ form factors

- Meson cloud
“Complete Experiment” of pseudoscalar meson photoproduction reactions

“Complete Experiment” = Measure ALL polarization observables needed to determine amplitudes (up to overall phase)

- unpolarized diff. crs. sec.
  → \( d\sigma /d\Omega \)

- single spin
  → \( P, \Sigma, T \)

- beam-target
  → \( E, F, G, H \)

- beam-recoil
  → \( C_{x'}, C_{z'}, O_{x'}, O_{z'} \)

- target-recoil
  → \( T_{x'}, T_{z'}, L_{x'}, L_{z'} \)

✓ Measurement of \( \gamma N \to KY \) pol. obs. is very active.

✓ OVER-COMPLETE experiment planned by CLAS for \( \gamma p \to K^+ Y, \gamma n \to KY \).

Provides critical information on \( N^* \to KY \) decays!!
**“Complete Experiment” of pseudoscalar meson photoproduction reactions**

“Complete Experiment” = Measure **ALL** polarization observables needed to determine amplitudes (up to overall phase)

unpolarized diff. crs. sec.
→ \(d\sigma/d\Omega\)

single spin
→ \(A_{1}\)

beam-target
→ \(C_{X'}, C_{Z'}, O_{X'}, O_{Z'}\)

beam-recoil
→ \(T_{X'}, T_{Z'}, L_{X'}, L_{Z'}\)

target-recoil

How much critical are the polarization observables on constraining reaction models and extracting N* parameters?

8 /16 observables needed!
Chiang, Tabakin PRC55 2054 (1997)

Provides critical information on N* \(\rightarrow\) KY decays!!
Comparison of all $\gamma N \rightarrow \pi N$ observables

$\gamma p \rightarrow \pi^0 p$

$W = 1232$ (MeV)

$W = 1481$ (MeV)

EBAC  SAID  MAID

Thomas Jefferson National Accelerator Facility
Polarization observables of $K^+$ Lambda photoproduction

Sandorfi, Hoblit, Kamano, Lee, in preparation


- The $\pi N$, $\gamma N \to KY$ data before 2006 are used for the model construction

- Necessity of new $N^*$ states for explaining the data: D13, S11, P13 with mass 1800-1950 MeV
Polarization observables of \( K^+ \) Lambda photoproduction

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- The \( \pi N, \gamma N \rightarrow KY \) data before 2006 are used for the model construction
- Necessity of new \( N^* \) states for explaining the data: D13, S11, P13 with mass 1800-1950 MeV

\[ \gamma p \rightarrow K^+ \Lambda \]
Summary

✓ Presented our recent analysis of $ep \rightarrow e'\pi N$ reaction.
  - Our model successfully describes the reaction at $Q^2 < 1.5 \text{ (GeV/c)}^2$.
  - N-N* e.m. transition form factors are extracted for the N* states up to the second resonance region.

✓ Examined significance of the polarization observables for construction of reaction models and extraction of N* parameters.
  - $\gamma p \rightarrow \pi N$ reaction:
    Provides useful information on constraining reaction models beyond the $\Delta(1232)$.
  - $\gamma p \rightarrow KY$ reaction:
    Will be crucial for extracting $N* \rightarrow KY$ information including recently suggested new N* states around 1.9 GeV.