Single π^0 Electroproduction in the Resonance Region with CLAS

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Electromagnetic Excitation of N^*

- Allows to address the central question:
**What are the relevant degrees-of-freedom
at varying distance scale?**

Electromagnetic Excitation of N^* 's

The experimental N^* Program has two major components:

- 1) Accurate measurements of transition form factors ($A_{3/2}$, $A_{1/2}$, $S_{1/2}$) of known states as photon virtuality (Q^2) to probe their internal structure and confining mechanism

- 2) Search for undiscovered new baryon states.

Both parts of the program are being pursued in various decay channels, e.g. $N\pi$, $p\eta$, $p\pi^+\pi^-$, $K\Lambda$, $K\Sigma$, $p\omega$, pp^0 using cross sections and polarization observables.

SU(6) $\times$ O(3) Classification of Low Lying N*

Exclusive Processes in N^* Studies

Transition Form Factors of Low Lying N* States

$p\pi^0$ channel is important to study:

The $\gamma^*N\Delta(1232)$ Quadrupole Transition

N* Transition Form Factors in the 2nd
Resonance Region -

“Roper” $P_{11}(1440)$, $S_{11}(1535)$, $D_{13}(1520)$

The $\gamma^* N \Delta(1232)$ Quadrupole Transition

SU(6): $E_{1+} = S_{1+} = 0$

		E/M	S/M
	pion cloud	~ -0.03	-0.1
	one-gluon exch.	~ 0.01	
	pQCD	$+1$	const.

Shape at low Q^2

$\gamma^* N \Delta$ Multipole Ratios R_{EM} , R_{SM} before JLab

$$R_{EM} = E_{1+} / M_{1+}$$
$$R_{SM} = S_{1+} / M_{1+}$$

← Sign @ $Q^2 > 0$?

← Q^2 dependence?

$\gamma^*N\Delta$ Multipole Ratios R_{EM} , R_{SM} with JLab

- $R_{EM} = -2$ to -4% at $0 \leq Q^2 \leq 6 \text{ GeV}^2$.
- $R_{SM} < 0$, increasing in magnitude.
- $R_{EM} < 0$ favors oblate shape of $\Delta(1232)$.
- Pion contributions needed to explain shape, magnitude.
- No trend towards asymptotic behavior $R_{EM} \rightarrow +100\%$.

N* Transition Form Factors in the 2nd Resonance Region

$P_{11}(1440)$

Poorly understood in nrCQMs.

Other models:

- Hybrid baryon with gluonic excitation $|q^3G\rangle$
- Quark core with large meson cloud $|q^3m\rangle$
- Nucleon-sigma molecule $|N\sigma\rangle$
- Dynamically generated resonance

$S_{11}(1535)$

Hard form factor (slow fall off with Q^2)

Not a quark resonance, but $K\Sigma$ dynamical system?

$D_{13}(1520)$

Change of helicity structure with increasing Q^2 from $\lambda=3/2$ dominance to $\lambda=1/2$ dominance, predicted in nrCQMs, pQCD.

Roper $P_{11}(1440)$ Helicity amplitudes

1. Weber, PRC41(1990)2783 2. Capstick, PRD51(1995)3598
 3. Simula, PLB397 (1997)13 4. Riska, PRC69(2004)035212
 5. Aznauryan, PRC76(2007)025212 6. Cano, PL B431(1998)270

I. G. Aznauryan et al. (CLAS), arXiv:080447 [nucl-ex]

Transverse amplitudes for $\gamma^*p \rightarrow D_{13}(1520)$

CLAS Single Pion Electro-production Data

Data in the $\Delta(1232)$ region up to $W = 1.4$ GeV

JLab/Hall C	Frolov	1999	$p\pi^0$	$Q^2 = 2.5 - 4.3 \text{ GeV}^2$
Bates	Mertz et al.	2001	$p\pi^0$	$Q^2 = 0.127 \text{ GeV}^2$
Mainz	Pospischil et al.	2001	$p\pi^0$	$Q^2 = 0.127 \text{ GeV}^2$
JLab/CLAS	Joo et al.	2002	$p\pi^0$	$Q^2 = 0.4 - 1.8 \text{ GeV}^2$
Bonn	Bantes, Gothe	2002	$p\pi^0$	$Q^2 = 0.6 \text{ GeV}^2$
JLab/CLAS	Egiyan et al.	2006	$n\pi^+$	$Q^2 = 0.3 - 0.6 \text{ GeV}^2$
Mainz	Elsner et al. / Stave et al.	2006	$p\pi^0$	$Q^2 = 0.05-0.2 \text{ GeV}^2$
Jlab/CLAS	Ungaro et al.	2006	$p\pi^0$	$Q^2 = 3.0 - 6.0 \text{ GeV}^2$
JLab/Hall A	Kelly et al.	2007	$p\pi^0$	$Q^2 = 1.0 \text{ GeV}^2$
JLab/CLAS	Park et al.	2008	$n\pi^+$	$Q^2 = 3.0 - 6.0 \text{ GeV}^2$

CLAS Single Pion Electro-production Data

Data up to the 3rd resonance region up to $W = 1.7 \text{ GeV}$

JLab/CLAS	Joo et al. (A_e only)	2003	$p\pi^0$	$Q^2 = 0.4 - 0.65 \text{ GeV}^2$
JLab/CLAS	Joo et al. (A_e only)	2004	$n\pi^+$	$Q^2 = 0.4 - 0.65 \text{ GeV}^2$
JLab/Hall A	Laveissiere et al.	2004	$p\pi^0$	$Q^2 = 1.0 \text{ GeV}^2$
JLab/CLAS	Egiyan et al.	2006	$n\pi^+$	$Q^2 = 0.3 - 0.6 \text{ GeV}^2$
JLab/CLAS	Park et al.	2008	$n\pi^+$	$Q^2 = 1.7 - 4.5 \text{ GeV}^2$

CLAS Single π^0 Electro-production Data Analysis

- E1E:
 - Beam Energy: 1 GeV and 2 GeV
 - Low Q^2 up to 1.5 GeV, and W up to 1.7 GeV
- E1-6:
 - Beam Energy: 5.75 GeV
 - Low Q^2 , up to 4.5 GeV and W up to 2.0 GeV
- Beam polarization: $\sim 70 - 80 \%$
- Target: Liquid Hydrogen

CEBAF at Jefferson Lab

E_{max}	$\sim 6 \text{ GeV}$
I_{max}	$\sim 200 \mu\text{A}$
Duty Factor	$\sim 100\%$
σ_E/E	$\sim 2.5 \cdot 10^{-5}$
Beam P	$\sim 80\%$
$E_{\gamma_0}(\text{tagged})$ GeV	$\sim 0.8 - 5.5$

CLAS

CEBAF Large Acceptance Spectrometer (CLAS)

- Six identical sectors
- 5 T toroidal B-field
- $\Delta\theta = 15-140$ degrees
- $\Delta\phi = 0-50$ degrees
- $\Delta p/p = 10^{-2}-10^{-3}$

Electron PID

- Number of photo-electrons ($nphe$) in the Čerenkov detector
- EC Threshold
- EC Sampling Fraction
- Track Coordinates in the EC plane
- Minimum Ionizing Particles rejection
- Electromagnetic Shower Shape

Electron PID

Proton PID

Use TOF timing and DC momentum of positive tracks

π^0 selection

$e + p \rightarrow e' + p + X$ on $\Delta(1232)$
resonance region from 5.7 GeV

M_X^2 from $e + p \rightarrow e' + p + X$
on $\Delta(1232)$ resonance region from
2.0 GeV

π^0 selection (E1-6)

M_X^2 from $e + p \rightarrow e' + p + X$
for $1.1 < W < 2.0$ GeV

Entries 1932129

Currently working on bench-mark
studies on $\Delta(1232)$ region
with/without tagging π^0

Entries 190785

Entries 190785

Typical $ep \rightarrow e'p\pi^0$ cross sections vs $\cos \theta^*$ and φ^*

$Q^2 = 0.2 \text{ GeV}^2$ $W=1.22 \text{ GeV}$

π^+ electroproduction at $Q^2=0.20 \text{ GeV}^2$ using CLAS

Differential Cross section from 2.0 GeV

$$0.6 < Q^2 < 0.7, 1.3 < W < 1.35$$

Very preliminary

Legendre Moment

$$\sigma_T + \varepsilon \sigma_L = \sum_{i=0}^{i=2} A_i P_i(\cos \theta)$$

$$0.6 < Q^2 < 0.7$$

E1+/M1+ and S1+/M1+

CLAS e1e UIM Fit

- $p\pi^0$ only
- $n\pi^+$ only
- $p\pi^0$ and $n\pi^+$

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CLAS12 - Detector

Projections for N^* Transition Amplitudes @ 12 GeV

Probe the transition from effective degrees of freedom, e.g. constituent quarks, to elementary quarks, with characteristic Q^2 dependence.

Summary

- Single π^0 electro-production analysis is under way for low and high Q^2 range up to 2.0 GeV in W.
- Able to perform combined analysis with $n\pi^+$ and two pion channels
- $p\pi^0$ channel is an important part of 12 GeV N^* program with CLAS12.
- Current $p\pi^0$ analysis measuring all final states will provide an important step for 12 GeV N^* program.