N* Studies in Meson Electroproduction with CLAS

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Jefferson Lab

Hall B Meeting  March 29, 2010
• Introduction

• Analysis tools for evaluation of N* electrocouplings

• New insights into the low lying N* structure from our studies on the Nπ & Nππ CLAS data

• Preliminary results on the studies of high lying proton states (M>1.6 GeV)

• Conclusions and outlook
Primary objectives in the studies of N* structure with CLAS

Our experimental program seeks to determine

\[ \gamma_v NN^* \] transition helicity amplitudes (electrocouplings) at photon virtualities \( 0.2 < Q^2 < 5.0 \text{ GeV}^2 \) for almost all excited proton states analyzing major meson electroproduction channels combined

This comprehensive information allows us to:

- pin-down active degrees of freedom in N* structure at various distances;
- study the non-perturbative strong interactions which are responsible for nucleon formation and their emergence from QCD;
- uniquely access to the origin of more than 97% of nucleon mass generated through dynamical chiral symmetry breaking, and to the behavior of the running strong coupling in the confinement regime.

\[ N^* \] studies are of key importance for the exploration of non-perturbative strong interactions and quark/gluon confinement.
How N* electrocouplings can be accessed

- Isolate the resonant part of production amplitudes by fitting the measured observables within the framework of reaction models, which are rigorously tested against data.
- N* electrocouplings can then be determined from resonant amplitudes under minimal model assumptions.

Consistent results on N* electrocouplings obtained in analyses of various meson channels (e.g. $\pi N$, $\eta p$, $\pi\pi N$) with entirely different non-resonant amplitudes will show that they are determined reliably.

Why \( N\pi/N\pi\pi \) electroproduction channels are important

- \( N\pi/N\pi\pi \) channels are the two major contributors in \( N^* \) excitation region;
- these two channels combined are sensitive to almost all excited proton states;
- they are strongly coupled by \( \pi N \rightarrow \pi\pi N \) final state interaction;
- may substantially affect exclusive channels having smaller cross sections, such as \( \eta p, K\Lambda, \) and \( K\Sigma \).

Therefore knowledge on \( N\pi/N\pi\pi \) electroproduction mechanisms is key for the entire \( N^* \) Program
**Nπ CLAS data at low & high Q^2**

Number of data points > 119,000, W < 1.7 GeV

<table>
<thead>
<tr>
<th>Observable</th>
<th>Q^2 [GeV^2]</th>
<th>Number of Data points</th>
</tr>
</thead>
<tbody>
<tr>
<td>dσ/dΩ(π^0)</td>
<td>0.35-1.6</td>
<td>31 018</td>
</tr>
<tr>
<td>dσ/dΩ(π^+)</td>
<td>0.25-0.65</td>
<td>13 264</td>
</tr>
<tr>
<td></td>
<td>1.7-4.3</td>
<td>33 000</td>
</tr>
<tr>
<td>A_e(π^0)</td>
<td>0.40</td>
<td>956</td>
</tr>
<tr>
<td></td>
<td>0.65</td>
<td>805</td>
</tr>
<tr>
<td>A_e(π^+)</td>
<td>0.40</td>
<td>918</td>
</tr>
<tr>
<td></td>
<td>0.65</td>
<td>812</td>
</tr>
<tr>
<td></td>
<td>1.7 - 4.3</td>
<td>3 300</td>
</tr>
<tr>
<td>dσ/dΩ(η)</td>
<td>0.375</td>
<td>172</td>
</tr>
<tr>
<td></td>
<td>0.750</td>
<td>412</td>
</tr>
</tbody>
</table>

Low Q^2 results:
I. Aznauryan et al., PRC 71, 015201 (2005); PRC 72, 045201 (2005);

High Q^2 results on Roper:
I. Aznauryan et al., PRC 78, 045209 (2008).

Review paper:

full data set in: [http://clasweb.jlab.org/physicsdb/](http://clasweb.jlab.org/physicsdb/)
Non-resonant contributions were described by gauge invariant Born terms:
• pole/reggeized meson $t$-channel exchange;
• $s$- and $u$-nucleon terms.

Final-state $\pi N$ rescattering was taken into account through the K-matrix approximation.

Fixed-$t$ Dispersion Relations for invariant Ball amplitudes (Devenish & Lyth)

\[ \gamma^* p \rightarrow N\pi \]

Dispersion relations for 6 invariant Ball amplitudes:

17 Unsubtracted Dispersion Relations

\[
ReB_i^{(\pm,0)}(s, t, Q^2) \left[ ReB_3^{(+,0)}(s, t, Q^2) \right] = R_i^{(v,s)}(Q^2) \left( \frac{1}{s - m_N^2} + \frac{\eta_i \eta^{(+,-,0)}}{u - m_N^2} \right) \\
+ \frac{P}{\pi} \int_{s_{thr}}^\infty ImB_i^{(\pm,0)}(s', t, Q^2) \left( \frac{1}{s' - s} + \frac{\eta_i \eta^{(+,-,0)}}{s' - u} \right) ds'
\]

(i=1,2,4,5,6)

1 Subtracted Dispersion Relation

\[
ReB_3^{(-)}(s, t, Q^2) = R_3^{(v)}(Q^2) \left( \frac{1}{s - m_N^2} + \frac{1}{u - m_N^2} \right) - eg \frac{F_\pi(Q^2)}{t - m_N^2} + f_{sub}(t, Q^2) \\
+ \frac{P}{\pi} \int_{s_{thr}}^\infty ImB_3^{(-)}(s', t, Q^2) \left( \frac{1}{s' - s} + \frac{1}{s' - u} \right) ds'
\]
Fits to $N\pi$ diff. cross sections & structure functions

$Q^2=2.05 \text{ GeV}^2$
- DR
- DR w/o P11
- UIM

$Q^2=2.44 \text{ GeV}^2$
- DR
- UIM
The CLAS data on $\pi^+\pi^-p$ differential cross sections and the description within the JM model

G.V. Fedotov et al, PRC 79 (2009), 015204

M. Ripani et al, PRL 91 (2003), 022002
JLAB-MSU meson-baryon model (JM) for $N\pi\pi$ electroproduction.

**3-body processes:**

Isobar channels included:

- $\pi^-\Delta^{++}$
  - All well established $N^*$s with $\pi\Delta$ decays and $3/2^+(1720)$ candidate.
  - Reggeized Born terms with effective FSI & ISI treatment.
  - Extra $\pi\Delta$ contact term.

- $\rho^0p$
  - All well established $N^*$s with $\rho p$ decays and $3/2^+(1720)$ candidate.
  - Diffractive ansatz for non-resonant part and $\rho$-line shrinkage in $N^*$ region.

**JM09 version:** Unitarized BW ansatz for resonant amplitudes:

I.J.R.Aitchison NP A189 (1972), 417
3-body processes:

\[ \gamma \rightarrow \pi^+ (\pi^-) \]
\[ (P^{++}33(1640)) \]
\[ F^0_{15}(1685) \]
\[ \pi^- (\pi^+) \]
\[ D{13}(1520) \]

Isobar channels included:

- \( \pi^+D^0_{13}(1520) \)
- \( \pi^+F^0_{15}(1685) \)
- \( \pi^-P^{++}_{33}(1640) \)

Isobar channels; observed for the first time in the CLAS data at \( W > 1.5 \) GeV.

Direct 2\( \pi \) production required by unitarity and confirmed in analysis of the CLAS \( \pi^+\pi^-p \) data.

V. Mokeev, V. Burkert, J. Phys. 69, 012019 (2007);
Resonant & non-resonant parts of $N\pi\pi$ cross sections as determined from the CLAS data fit within the framework of JM model.
Meson-baryon dressing vs Quark core contribution in $\Delta$N Transition Form Factor – $G_M$. EBAC analysis.

One third of $G_M^*$ at low $Q^2$ is due to contributions from meson-baryon (MB) dressing:

Within the framework of relativistic QM [B.Julia-Diaz et al., PRC 69, 035212 (2004)], the bare-core contribution is very well described by the three-quark component of the wf.

$$G_M^* = \frac{1}{3} (1 + Q^2/0.71)^2$$
Q² dependence of NΔ Transition amplitudes

- No sign for onset of asymptotic behavior, \( R_{EM} \rightarrow +100\% \), \( R_{SM} \rightarrow \text{const.} \)
- \( R_{EM} \) remains negative and small, \( R_{SM} \) becoming more negative with \( Q^2 \).
- Meson-baryon contributions needed to describe multipoles.
- LQCD shows same trend as data but discrepancies for \( R_{SM} \) at low \( Q^2 \)
$P_{11}(1440)$ electrocouplings from the CLAS data on $N\pi/N\pi\pi$ electroproduction

- **$N\pi\pi$ preliminary**
- **$N\pi$**


Light front models:
- I. Aznauryan
- S. Capstick
- hybrid $P_{11}(1440)$

- Good **agreement** between the electrocouplings obtained from the $N\pi$ and $N\pi\pi$ channels: Reliable measurement of the electrocouplings.

- The data are sensitive to quark model expectations, allowing us to rule out hypothesis of hybrid nature of $P_{11}(1440)$. 
Valence quark distribution for $\gamma_vp \to P_{11}(1440)$


- Use valence quark model; based on covariant spectator formalism (F. Gross). Baryon is described as a quark-diquark system with the 0 and 1 spin states (consistent with DSE kernel), and acts as spectator. Photon interacts with isolated quark in impulse approximation.
- Model parameter adjusted to fit the nucleon form factor and Delta data. No new parameter adjusted for the NP$_{11}(1440)$ transition form factors.
- Agreement at high $Q^2$ where meson cloud should be small, support the structure of P11(1440) core as three quarks in first radial excitation.
Meson-baryon dressing / Quark core contributions in the $A_{1/2}$ electrocouplings of the $P_{11}(1440)$ & $D_{13}(1520)$ states.

Estimates from EBAC for the MB dressing (absolute values): B.Julia-Diaz et al., PRC 76, 5201 (2007).

- MB dressing effects have substantial contribution to N* electrocouplings at $Q^2<1.0$ GeV$^2$ and gradually decrease with $Q^2$;
- Contribution from dressed quarks increases with $Q^2$ and are expected to be dominant at $Q^2>5.0$ GeV$^2$;
- $A_{1/2}$ amplitude of $D_{13}(1520)$ state is dominated by quark contributions at $Q^2>2.0$ GeV$^2$. These data can be used, e.g., together with DSE analyses in order to chart momentum dependence of running dressed quark mass.
Impact of MB dressing on spectrum of $P_{11}$ excited proton states. EBAC global analysis.

Single bare pole or quark core creates three resonant poles being dressed by MB cloud. Two of them at lower masses correspond to $P_{11}(1440)$, third generates resonance $\sim 1.8$ GeV mass.

Puzzle with $P_{11}(1440)$ mass in quark models is solved? DSE evaluation of bare $P_{11}(1440)$ mass are in progress by I.Cloet and C.Roberts

N.Suzuki et al., PRL 104, 043202 (2010)
$\gamma_v N P_{11}(1440)$ electrocouplings from LQCD. Lattice group at JLAB Theory Center

Trend in the data behavior is well reproduced by LQCD with $m_\pi = 450$ MeV (red points), except $F_2$ form factor at $Q^2 < 1.0$ GeV$^2$
D_{13}(1520) electrocouplings from the CLAS data on Nπ/Nππ electroproduction

- electrocouplings as determined from the Nπ & Nππ channels are in good agreement overall
- indications for contributions from both quark core and MB cloud

\[ A_{\text{hel}} = \frac{(A_{1/2})^2 - (A_{3/2})^2}{(A_{1/2})^2 + (A_{3/2})^2} \]

error bars include systematic uncertainties

M. Giannini/
E. Santopinto
hyper-centric
CQM
γpN(1535)S_{11} electrocouplings

Analysis of pη channel assumes S_{1/2}=0
Branching ratios: β_{Nπ} = β_{Nη} = 0.45

- A_{1/2}(Q^2) from Nπ and pη are consistent
- First extraction of S_{1/2}(Q^2) amplitude
- QCD-based LQCD & LCSR calculations (black solid lines) by Regensburg Univ. Group reproduces data trend at Q^2>2.0 GeV^2
High lying resonance electrocouplings from $N\pi\pi$ CLAS data analysis

$N\pi\pi$ CLAS preliminary:

- Unitarized BW ansatz
- Regular BW ansatz

$N\pi$ world

$N\pi$ CLAS $Q^2=0$
High lying resonance electrocouplings from $N\pi\pi$ CLAS data analysis

The amplitudes of unitarized BW ansatz

The CLAS $\pi^+\pi^-p$ data offer sufficient constraints for the extraction of $\gamma_v NN^*$ electrocouplings.
# 1st through 3rd nucleon resonance regions

<table>
<thead>
<tr>
<th>State</th>
<th>$\beta_{N\pi}$</th>
<th>$\beta_{N\eta}$</th>
<th>$\beta_{N\pi\pi\pi}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Delta(1232) P_{33}$</td>
<td>0.995</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$N(1440) P_{11}$</td>
<td>0.55-0.75</td>
<td></td>
<td>0.3-0.4</td>
</tr>
<tr>
<td>$N(1520) D_{13}$</td>
<td>0.55-0.65</td>
<td></td>
<td>0.4-0.5</td>
</tr>
<tr>
<td>$N(1535) S_{11}$</td>
<td>0.35-0.55</td>
<td>0.45-0.60</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td>$N(1620) S_{31}$</td>
<td>0.20-0.30</td>
<td></td>
<td>0.7-0.8</td>
</tr>
<tr>
<td>$N(1650) S_{11}$</td>
<td>0.60-0.95</td>
<td>0.03-0.10</td>
<td>0.1-0.2</td>
</tr>
<tr>
<td>$N(1685) F_{15}$</td>
<td>0.65-0.70</td>
<td></td>
<td>0.3-0.4</td>
</tr>
<tr>
<td>$\Delta(1700) D_{33}$</td>
<td>0.1-0.2</td>
<td></td>
<td>0.8-0.9</td>
</tr>
<tr>
<td>$N(1720) P_{13}$</td>
<td>0.1-0.2</td>
<td>0.01-0.15</td>
<td>&gt;0.7</td>
</tr>
</tbody>
</table>

- $N\pi$ and $N\pi\pi$ for $P_{11}(1440), D_{13}(1520), S_{11}(1650), F_{15}(1685)$
- $N\pi$ and $N\eta$ for $S_{11}(1535)$
- $N\pi\pi\pi$ for $S_{31}(1620), D_{33}(1700)$ and $P_{13}(1720)$
**N* hadronic parameters derived from the CLAS $\pi^+\pi^-p$ data fit**

### $P_{13}(1720)$

<table>
<thead>
<tr>
<th></th>
<th>$\Gamma_{tot}$, MeV</th>
<th>$\Gamma_{\pi\Delta}$, MeV</th>
<th>$\Gamma_{\rho\rho}$, MeV</th>
<th>$M$, GeV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regular BW ansatz</td>
<td>135±12</td>
<td>1.53±1.05</td>
<td>114±12</td>
<td>1.743±0.006</td>
</tr>
<tr>
<td>Unitarized BW ansatz before improvements</td>
<td>176±19</td>
<td>26±3.78</td>
<td>131±21</td>
<td>1.745±0.004</td>
</tr>
<tr>
<td>Unitarized BW ansatz after improvements</td>
<td>113±3.4</td>
<td>10.9±1.40</td>
<td>82.9±3.26</td>
<td>1.744±0.007</td>
</tr>
</tbody>
</table>

### $3/2^+(1720)$ candidate state

<table>
<thead>
<tr>
<th></th>
<th>$\Gamma_{tot}$, MeV</th>
<th>$\Gamma_{\pi\Delta}$, MeV</th>
<th>$\Gamma_{\rho\rho}$, MeV</th>
<th>$M$, GeV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regular BW ansatz</td>
<td>86±5</td>
<td>44±5.5</td>
<td>6.25±1.62</td>
<td>1.727±0.003</td>
</tr>
<tr>
<td>Unitarized BW ansatz before improvements</td>
<td>86±11</td>
<td>44±11</td>
<td>5.85±1.27</td>
<td>1.727±0.004</td>
</tr>
<tr>
<td>Unitarized BW ansatz after improvements</td>
<td>107±12</td>
<td>61±12</td>
<td>0.63±0.21</td>
<td>1.725±0.006</td>
</tr>
</tbody>
</table>
Electrocouplings of \([70,1\text{-}] \text{SU}_{\text{sf}}(6)\)-plet states from \(N\pi/N\pi\pi\) CLAS data and their description in SQTM approach

- SU(6) spin-flavor symmetry for quark binding interactions
- Dominant contribution from single quark transition operator:

\[ A L_+ + B L_0 \sigma_+ + C \sigma_0 L_+ + D \sigma_- L_+ L_+ \]

World data before CLAS measurements on transverse electrocouplings of \(D_{13}(1520)\) and \(S_{11}(1535)\) states (the areas between solid lines) allowed us to predict transverse electrocouplings for others \([70,1\text{-}]\) states (the areas between solid lines on the next slide), utilizing SU(6) symmetry relations.

Electrocouplings of $[70,1-]$ $SU_{sf}(6)$-plet states from $N\pi/N\pi\pi$ CLAS data and their description in SQTM approach

SQTM predictions are consistent with major features in $Q^2$ evolution of $[70,1-]$ state electrocouplings, offering an indication for:

- relevance of quark degrees of freedom and substantial contribution to quark binding from $qq$ interactions that poses $SU(6)$ spin-flavor symmetry

- these data offer an additional insight into the nature of interactions between dressed quarks
Conclusions and outlook

• Phenomenological analyses of a large body of observables measured in $\pi^+n$, $\pi^0p$, $\eta p$ and $\pi^+\pi^-p$ electroproduction channels allowed us to determine electrocouplings for almost all well established N*’s with masses <1.8 GeV. Electrocouplings of low lying N*’s ($M<1.6$ GeV) were obtained at photon virtualities $0.2<Q^2<5.0$ GeV$^2$ from $N\pi$ channels and at $Q^2<0.6$ GeV$^2$ also from $\pi^+\pi^-p$ channel, while for high lying states ($M>1.6$ GeV) they were determined at $0.5<Q^2<1.5$ GeV$^2$ from $\pi^+\pi^-p$ channel.

• Consistent results on $\gamma_v NN^*$ electrocouplings obtained from various meson electroproduction channels with entirely different non-resonant contributions offer an evidence for reliable electrocoupling measure and for credible evaluation of resonant/non-resonant contributions.

• In near term future $\pi^+\pi^-p$ electroproduction data will be available at $2.0<Q^2<5.0$ GeV$^2$, allowing us to determine electrocouplings for a major part of excited proton states up to highest photon virtualities accessible with 5 GeV beam. $g_{11} \pi^+\pi^-p$ photoproduction data will extend considerably our knowledge of mechanisms contributing to this exclusive channel.
Conclusions and outlook

- Derived from the data fit information on amplitudes/cross sections of various mechanisms in $N\pi$ & $N\pi\pi$ electroproduction will be utilized in a global coupled channel analysis developing by EBAC.

- Phenomenological analyses of $\gamma_v NN^*$ electrocouplings at $Q^2<5.0$ GeV$^2$ revealed substantial contributions from both meson-baryon and quark degrees of freedom. MB dressing of $N^*$’s were determined by EBAC from a global fit of $\pi N$ scattering and $N\pi$ electroproduction reactions. MB contributions decrease with $Q^2$ and at $Q^2>5.0$ GeV$^2$ quark degrees of freedom are expected to dominate.

- First exploratory attempts to describe $\gamma_v NN^*$ electrocouplings within the LQCD framework (JLAB Lattice Group, Univ. of Regensburg) showed promising potential for LQCD to understand $N^*$ formation in non-perturbative quark/gluon interactions starting from the QCD Lagrangian.
Conclusions and outlook

- Analyses of $\gamma vNN^*$ electrocouplings at $Q^2 > 2.0$ GeV$^2$ within the framework of DSE approaches (ANL, Univ. of Washington) will allow us to address two central issues in the physics of non-perturbative strong interactions: a) generation of $> 97\%$ of nucleon/N* masses through dynamical chiral symmetry breaking; b) explore a behavior of QCD $\beta$-function in confinement regime

Hall B at Jefferson Lab has unique, best in the world opportunities to explore non-perturbative strong interactions at large and intermediate $x_B$ and their emergence from QCD through combined analysis of the data on $\gamma vNN^*$ electrocouplings and comprehensive experimental information on the ground state structure from DIS inclusive and semi-inclusive and from fully exclusive GPD ‘s structure functions. LQCD and DSE offer two independent and complementary QCD-based theoretical frameworks allowing us to achieve these challenging objectives.
Back-up
Resonance signals in $2\pi$ electroproduction at high $Q^2$.

After 12 GeV Upgrade CLAS12 will be only facility foreseen worldwide, capable to study electrocouplings for full spectrum of N*'s at $Q^2$ from 5.0 to 10 GeV².

Access to constituent quark structure and interactions through quark core excitation in N*'s for the first time.
Input for $N\pi/N\pi\pi$ coupled channel analysis: partial waves of total spin $J$ for non-resonant helicity amplitudes in $\pi^-\Delta^{++}$ isobar channel

\[
\begin{align*}
\langle \lambda_f | T^J | \lambda_y \lambda_p \rangle &= \\
\int \frac{2J + 1}{2} \langle \lambda_f | T | \lambda_y \lambda_p \rangle &\cdot \\
d^J_{\mu\nu}(\theta_f) \sin \theta_f d\theta_f
\end{align*}
\]

Will be used for $N^*$ studies in coupled channel approach developing by EBAC.
Ground state and P11(1440) electrocouplings & quark model expectations

S. Capstick
light cone (LC) model

B. Metsch
Bethe-Salpeter model

I. Aznauryan
LC model

M. Giannini/
E. Santopinto
hyper-centric CQM

P11(1440) electrocouplings at $Q^2>2.0$ GeV$^2$ are consistent with substantial contribution from 3-quarks in first radial excitation, while at $Q^2<0.6$ GeV$^2$ additional contributions become evident.
New regime in $N^*$ excitation at high $Q^2$

- the photons of high virtuality penetrate meson-baryon cloud and interact mostly to quark core

- data on $N^*$ electrocouplings at high $Q^2$ allow us to access quark degrees of freedom, getting rid of meson-baryon cloud.

- can be obtained at $5<Q^2<10$ GeV$^2$ after 12 GeV Upgrade with CLAS12 for majority of $N^*$ with masses less than 3.0 GeV

EBAC calculations for meson-baryon cloud of low lying $N^*$'s.

For the foreseeable future, CLAS12 will be the only facility worldwide, which will be able to access the N* electrocouplings in the $Q^2$ regime of 5 GeV$^2$ to 10 GeV$^2$, where the quark degrees of freedom are expected to dominate.
Physics objectives in the N* studies with CLAS12

- explore the interactions between the dressed quarks, which are responsible for the formation for both ground and excited nucleon states.
- probe the mechanisms of light current quark dressing, which is responsible for >97% of nucleon mass.


Parallel sessions #9,13 of GHP09 Workshop

\[ Q^2 = 10 \text{ GeV}^2 \]

DSE: lines and LQCD: triangles

\[ Q^2 = 10 \text{ GeV}^2 = (p \times \text{number of quarks})^2 \rightarrow p = 1.05 \text{ GeV} \]
Nucleon Resonance Studies with CLAS12

R. Arndt\(^4\), H. Avakian\(^6\), I. Aznauryan\(^{11}\), A. Biselli\(^3\), W.J. Briscoe\(^4\), V. Burkert\(^6\), V.V. Chesnokov\(^7\), P.L. Cole\(^5\), D.S. Dale\(^5\), C. Djalali\(^{10}\), L. Elouadrhiri\(^6\), G.V. Fedotov\(^7\), T.A. Forest\(^5\), E.N. Golovach\(^7\), R.W. Gothe\(^*^{10}\), Y. Ilieva\(^{10}\), B.S. Ishkhanov\(^7\), E.L. Isupov\(^7\), K. Joo\(^9\), T.-S.H. Lee\(^1,2\), V. Mokeev\(^*^{6}\), M. Paris\(^4\), K. Park\(^{10}\), N.V. Shvedunov\(^7\), G. Stancari\(^5\), M. Stancari\(^5\), S. Stepanyan\(^6\), P. Stoler\(^8\), I. Strakovsky\(^4\), S. Strauch\(^{10}\), D. Tedeschi\(^{10}\), M. Ungaro\(^9\), R. Workman\(^4\), and the CLAS Collaboration

**JLab PAC 34, January 26-30, 2009**

Approved for 60 days beamtime

[http://www.physics.sc.edu/~gothe/research/pub/nstar12-12-08.pdf](http://www.physics.sc.edu/~gothe/research/pub/nstar12-12-08.pdf).

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Spokesperson

Contact Person*
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JLab PAC 34, January 26-30, 2009

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Jefferson Lab (VA, USA)\(^5\),
University of Genova (Italy)\(^7\),
University of Regensburg (Germany)\(^8\),
and University of Washington (WA, USA)\(^9\)

Open invitation.
List is open to any and all who wish to participate!