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<table>
<thead>
<tr>
<th>Published papers</th>
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<tbody>
<tr>
<td>Total number of citations</td>
<td>8,159</td>
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<td>Average citations per published paper</td>
<td>74</td>
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<tr>
<td>Renowned papers (500+)</td>
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<td>Famous papers (250-499)</td>
<td>7</td>
</tr>
<tr>
<td>Very well-known papers (100-249)</td>
<td>12</td>
</tr>
</tbody>
</table>

\[
GPD = (1 + \xi)P - (1 - \xi)P
\]

\[
q \quad q' \quad \gamma^* \quad \gamma
\]

\[
(x + \xi)P \quad (x - \xi)P
\]
Happy Birthday!
Hard Exclusive Reactions at Jlab

Valery Kubarovsky
Jefferson Lab

XIV WORKSHOP ON HIGH ENERGY SPIN PHYSICS DSPIN-11
Dubna, Russia, September 20 - 24, 2011
Outline

• Introduction
• Deeply Virtual Compton Scattering
• Pseudoscalar meson electroproduction
• Vector meson electroproduction
• JLAB 12 upgrade
• Conclusion
Description of hadron structure in terms of GPDs

<table>
<thead>
<tr>
<th><strong>Nucleon form factors</strong></th>
<th><strong>Structure functions</strong></th>
<th><strong>GPDs</strong></th>
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<tbody>
<tr>
<td>transverse charge &amp; current densities</td>
<td>quark longitudinal momentum (polarized and unpolarized) distributions</td>
<td>correlated quark momentum distributions (polarized and unpolarized) in transverse space</td>
</tr>
</tbody>
</table>

- Nucleon form factors
- Structure functions
- GPDs
Generalized Parton Distributions

- There are 4 chiral even GPDs where partons do not transfer helicity $H, \tilde{H}, E, \tilde{E}$
- $H$ and $E$ are “unpolarized” and $\tilde{H}$ and $\tilde{E}$ are “polarized” GPD. This refers to the parton spins.
- 4 chiral odd GPDs flip the parton helicity $H_T, \tilde{H}_T, E_T, \tilde{E}_T$. $H_T$ is connected with transversity

\[
H_T^q(x, 0, 0) = h_1^q(x)
\]
Basic GPD properties

- **Forward limit**
  \[ H^q(x, 0, 0) = q(x) \]
  \[ \tilde{H}^q(x, 0, 0) = \Delta q(x) \]
  \[ H_T^q(x, 0, 0) = h_1^q(x) \]

- **Form factors**
  \[ \int_{-1}^{1} dx \, H^q(x, \xi, t) = F_1^q(t), \quad \int_{-1}^{1} dx \, E^q(x, \xi, t) = F_2^q(t) \]
  \[ \int_{-1}^{1} dx \, \tilde{H}^q(x, \xi, t) = g_A^q(t), \quad \int_{-1}^{1} dx \, \tilde{E}^q(x, \xi, t) = g_P^q(t) \]

- **Angular Momentum**
  \[ J^q(t) = \frac{1}{2} \int_{-1}^{1} dx \, x \left[ H^q(x, \xi, t) + E^q(x, \xi, t) \right] \]
  (Ji’s sum rule)
DVCS and DVMP

- Factorization theorem
- Access to fundamental degrees of freedom

**DVCS:**
- the clearest way to access the GPDs
- Only $\gamma_T$ photons participate in DVCS
- Interference with BH process

**DVMP:**
- Factorization proven only for $\sigma_L$
  \[ \sigma_L \sim 1/Q^6, \quad \sigma_V/\sigma_L \sim 1/Q^2 \]
- Meson distribution amplitude
- Gluon exchange required
- Vector and pseudoscalar meson production allows to separate flavor and separate the helicity-dependent and helicity independent GPDs.
Transversity in hard exclusive electroproduction of pseudoscalar mesons


- The data clearly show that a \textit{leading-twist calculation} of DVMP within the handbag is insufficient. They demand higher-twist and/or power corrections.
- There is a large contribution from the helicity amplitude $M_{0-,++}$. Such contribution is generated by the helicity-flip or transversity GPDs in combination with a twist-3 pion wave function.
- This explanation established an interesting connection to transversity parton distributions. The forward limit of $H_T$ is the transversity

\[ M_{0-,++} \sim H_T \]

\[ H_T^q(x,0,0) = h_1^q(x) \]
Nucleon Tensor Charge from Exclusive $\pi^0$ Electroproduction

Ahmad, Goldstein, Lui, Phys. Rev. D 79, 054014 (2009), arXiv:1104.5682v1

- The quantum numbers and Dirac structure of $\pi^0$ electroproduction restrict the possible contributions to the 4 chiral odd GPDs, one of which, $H_T$, is related to the transversity distribution and the tensor charge.
- This differs from DVCS and both vector and charge $\pi^{+/-}$ electroproduction, where the axial charge can enter the amplitudes.
- Contrary the tensor charge enters the $\pi^0$ process.

partonic degrees of freedom interpretation; t-channel exchange diagram
JLab Site: The 6 GeV Electron Accelerator

- 3 independent beams with energies up to 6 GeV
- Dynamic range in beam current: $10^6$
- Electron polarization: 85%
CEBAF Large Acceptance Spectrometer CLAS

CLAS Lead Tungstate Electromagnetic Calorimeter

424 crystals, 18 RL, Pointing geometry, APD readout
Accessing GPDs through polarization

\[ A = \frac{\sigma^+ - \sigma^-}{\sigma^+ + \sigma^-} = \frac{\Delta \sigma}{2\sigma} \]

Polarized beam, unpolarized proton target:

\[ \Delta \sigma_{LU} \sim \sin \phi \{ F_1 \mathcal{H} + \xi (F_1 + F_2) \tilde{\mathcal{H}} + k F_2 \mathcal{E} \} d\phi \]

Kinematically suppressed

Unpolarized beam, longitudinal proton target:

\[ \Delta \sigma_{UL} \sim \sin \phi \{ F_1 \tilde{\mathcal{H}} + \xi (F_1 + F_2) ( \mathcal{H} + \xi/(1+\xi) \mathcal{E} ) - \ldots \} d\phi \]

Kinematically suppressed

Unpolarized beam, transverse proton target:

\[ \Delta \sigma_{UT} \sim \cos \phi \{ k (F_2 \mathcal{H} - F_1 \mathcal{E}) + \ldots \} d\phi \]

Kinematically suppressed

\( \xi \approx x_B/(2-x_B) \)

\( k = t/4M^2 \)

\( \mathcal{H}(\xi,t) \)

\( \tilde{\mathcal{H}}(\xi,t) \)

\( \mathcal{H}(\xi,t), \mathcal{E}(\xi,t) \ldots \) are CFF
### DVCS kinematics

<table>
<thead>
<tr>
<th></th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>$Q^2$</td>
<td>1 GeV$^2$</td>
<td>5 GeV$^2$</td>
</tr>
<tr>
<td>$x_B$</td>
<td>0.1</td>
<td>0.6</td>
</tr>
<tr>
<td>$-t$</td>
<td>$t_{min}$</td>
<td>1 GeV$^2$</td>
</tr>
<tr>
<td>$W$</td>
<td>2 GeV</td>
<td>3 GeV</td>
</tr>
</tbody>
</table>
• **VGG** parameterization reproduces \(-t > 0.5\text{GeV}^2\) behavior, and overshoots asymmetry at small \(t\).

• The latter could indicate that **VGG** misses some important contributions to the DVCS cross section.

• Regge model (J-M Laget) is in fair agreement in some kinematic bins with our results.

• The Regge mode seems to be working at low \(Q^2\) while the GDP approach gets better at larger \(Q^2\). This is expected.

\[
A_{LU} = \frac{\sigma^+ - \sigma^-}{\sigma^+ + \sigma^-} = \frac{\Delta\sigma}{2\sigma}
\]

F.-X. Girod et al., PRL 100 (2008) 162002
Extraction of Compton Form Factors from CLAS DVCS data

- $A_{LU}$ and $A_{UL}$ CLAS results only
- $\text{Im } H(t)$ $\text{Im } \tilde{H}(t)$ are extracted
- $\text{Im } \tilde{H}(t)$ flatter than $\text{Im } H(t)$


The fact that $\tilde{H}$ is "flatter" in $t$ than $H$, hints that the axial charge of the nucleon is more concentrated than the electromagnetic charge. This is related to the fact that the axial form factor is also flatter than the EM form factors. We see that via different formalism (GDPS vs FFs) and reaction (DVCS vs elastic), one reaches the same conclusions.
DVCS x-sections from CLAS

Radiative corrections and $\pi^0$ contamination accounted
Hall A

• Proton DVCS, helicity dependent and independent cross sections were measured at
  \[ Q^2=(1.5, 1.9, 2.3) \text{ GeV}^2 \]
  \[ -t=(0.17, 0.23, 0.28, 0.33) \text{ GeV}^2 \]
  \[ x_B=0.36 \]

• Neutron DVCS, helicity dependent cross section on deuterium. Sensitive to \( E(\xi, t) \)
  \[ Q^2=1.9 \text{ GeV}^2 \]
  \[ x_B=0.36 \]

• Completed data taking at 2010, which included measurements of DVCS on proton and deuterium at two different energies with the aim to separate Re \([DVCS*BH]\) and \(|DVCS|^2\) terms.
Imaginary Part of the Interference Term

- VGG model agrees in slope with the data but lies 30% above
- $Q^2$ independent in all $t$ bins
- Provide support for the factorization at $Q^2 > 2$ GeV$^2$
Constraint on $J_d$ and $J_u$

Helicity-dependent Jlab Hall-A neutron and HERMES transversity polarized proton data constrain in a model dependent way on the total up and down quark contributions to the proton spin.

\[ J_q = \frac{1}{2} \Delta \Sigma_q + L_q = \frac{1}{2} \int_{-1}^{1} x[H_q(x, \xi, t = 0) + E_q(x, \xi, t = 0)] dx \]
Exclusive Meson Production
Pseudoscalar mesons

\[ ep \to en\pi^+ \]
\[ ep \to ep\pi^0, \quad \pi^0 \to \gamma\gamma \]
\[ ep \to ep\eta, \quad \eta \to \gamma\gamma \]

Vector mesons

\[ ep \to en\rho^+, \quad \rho^+ \to \pi^+\pi^0 \]
\[ ep \to ep\rho^0, \quad \rho^0 \to \pi^+\pi^- \]
\[ ep \to ep\omega, \quad \omega \to \pi^+\pi^-\pi^0 \]
\[ ep \to ep\phi, \quad \phi \to K^+K^- \]
Deeply Virtual Meson Production

CLAS results

\[ ep \rightarrow ep\pi^0, \quad \pi^0 \rightarrow \gamma\gamma \]

\[ ep \rightarrow ep\eta, \quad \eta \rightarrow \gamma\gamma \]

\[ ep \rightarrow en\rho^+, \quad \rho^+ \rightarrow \pi^+\pi^0 \]

<table>
<thead>
<tr>
<th>Meson</th>
<th>GPD flavor composition</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\pi^+)</td>
<td>(\Delta u - \Delta d)</td>
</tr>
<tr>
<td>(\pi^0)</td>
<td>(2\Delta u + \Delta d)</td>
</tr>
<tr>
<td>(\eta)</td>
<td>(2\Delta u - \Delta d)</td>
</tr>
<tr>
<td>(\rho^0)</td>
<td>(2u + d)</td>
</tr>
<tr>
<td>(\rho^+)</td>
<td>(u - d)</td>
</tr>
<tr>
<td>(\omega)</td>
<td>(2u - d)</td>
</tr>
</tbody>
</table>

Flavor separation
Access to polarized GPDs
Access to transversity GPDs
4 Dimensional Grid

Rectangular bins are used.
- $Q^2$ - 7 bins (1.0-4.5 GeV$^2$)
- $x_B$ - 7 bins (0.1-0.58)
- $t$ - 8 bins (0.09-2.0 GeV)
- $\phi$ - 20 bins (0-360°)
- $\pi^0$ data ~2000 points
- $\eta$ data ~1000 points
Monte Carlo

• Empirical model for the structure cross sections was used for the MC simulation and radiative corrections
• This model is based on CLAS data
• MC simulation included the radiative effects and used empirical model for the Born term.
• 100 M events were simulated with GSIM program.
Radiative Corrections

- Radiative Corrections were calculated using Exclurad package with structure cross sections described by our empirical cross section.

\[ \text{RadCor} = \frac{\sigma_{\text{Rad}}}{\sigma_{\text{Born}}}, \]

\[ Q^2 = 1.15 \text{ GeV}^2 \quad x_B = 0.13 \quad -t = 0.1 \text{ GeV}^2 \]
Structure Functions

\[ \sigma_T + \varepsilon \sigma_L \quad \sigma_{TT} \quad \sigma_{LT} \]

\[
\frac{d\sigma}{dt d\phi} (Q^2, x, t, \phi) = \frac{1}{2\pi} \left( \frac{d\sigma_T}{dt} + \varepsilon \frac{d\sigma_L}{dt} \right) + \varepsilon \frac{d\sigma_{TT}}{dt} \cos 2\phi + \sqrt{2\varepsilon (\varepsilon + 1)} \frac{d\sigma_{LT}}{dt} \cos \phi
\]

\[ \gamma^* p \rightarrow p\pi^0 \]

\[ \phi \text{ distribution} \]

GM Laget Regge model
\[ \sigma_U = \sigma_T + \varepsilon \sigma_L \]  

**W dependence**

- \( \sigma_U \) decreases with \( W \) at Jlab kinematics
- This behavior is typical for Regge model
- Difficult to get such dependence with conventional GPD models

\[ \sigma_U \sim 1/W^{1.5-2} \]
\[ \sigma_U = \sigma_T + \epsilon \sigma_L \] 

\( x_B \) dependence

- Another way to view the cross section as a function of \( x_B \)
- \( \sigma_U \) increases with \( x_B \)
- \( W=Q^2(1/x-1) \)
\[ d\sigma_{U}/dt \]

\[ \frac{d\sigma}{dt}(\gamma^* p \rightarrow ep\pi^0) \propto e^{bt} \]

\[ \gamma^* \rightarrow \pi, \rho, \ldots \]

\[ q \]

\[ q' \]

\[ (1 + \xi)P \]

\[ (1 - \xi)P \]

\[ (x + \xi)P \]

\[ (x - \xi)P \]

\[ GPD \]

\[ Q^2 \]

\[ x_B \]

\[ P1 \]

\[ P2 \]

\[ P1 \]

\[ P2 \]

\[ P1 \]

\[ P2 \]

\[ P1 \]

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\[ P2 \]
The slope parameter is decreasing with increasing $x_B$. Looking to this picture we can say that the perp width of the partons with $x \rightarrow 1$ goes to zero.
Transversity in $\pi^0$ electroproduction


$Q^2=2.71$ GeV$^2$

$x_B=0.34$

Transvers cross section dominates in this model

Theory: Goloskokov&Kroll

Data: CLAS (preliminary)
Transversity in $\pi^0$ electroproduction


- Include *transversity* GPDs $H_T$ and $E_T = 2\tilde{H}_T + E_T$ Dominate in CLAS kinematics.
- The model was optimized for low $x_B$ and high $Q^2$. The corrections $t/Q^2$ were omitted.
- Nevertheless the model successfully described CLAS data even at low $Q^2$.
- Pseudoscalar meson production provides unique possibility to access the transversity GPDs.

![Graphs showing $d^2\sigma/dt^2$ vs. $-t/Q^2$ for different $Q^2$ and $x_B$ values.](image-url)
Goldstein and Liuti GPD$_T$ model

Data – CLAS6

We are looking forward to extend the comparison with GPD-based model in the full kinematic domain of CLAS
Beam Spin Asymmetry

Ahmad, Goldstein, Luiti, 2009

- Data CLAS
- Blue – Regge model
- Red – GPD predictions
- tensor charges
  \( \delta u = 0.48 \),
  \( \delta d = -0.62 \)
- transverse anomalous magnetic moments
  \( \kappa_{u_T} = 0.6 \),
  \( \kappa_{d_T} = 0.3 \).
$\eta/\pi^0$ Ratio

- The dependence on the $x_B$ and $Q^2$ is very week.
- The ratio in the photoproduction is near 0.2-0.3 (very close to what we have at our smallest $Q^2$).
- Conventional GPD models predict this ratio to be around 1 (at low $-t$).
- KG model predicts this ratio to be $\sim 1/3$ at CLAS values of $t$.

\[ \frac{\sigma(ep \rightarrow ep\eta)}{\sigma(ep \rightarrow ep\pi^0)} \]

\[ \overline{E}_T = 2\overline{H}_T + E_T \]

Indication of large contributions from the GPD $\overline{E}_T$ with the same sign for $u$ and $d$-quark parts.
Vector Mesons
Quark and Gluon GPDs

$$\gamma^* p \rightarrow n\rho^+$$

$$\gamma^* p \rightarrow p\rho^0$$
$$\gamma^* p \rightarrow p\omega$$

$$\gamma^* p \rightarrow p\phi$$

<table>
<thead>
<tr>
<th>$\rho^0$</th>
<th>$e_u H^u - e_d H^d$</th>
<th>$e_u E^u - e_d E^d$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\omega$</td>
<td>$e_u H^u + e_d H^d$</td>
<td>$e_u E^u + e_d E^d$</td>
</tr>
<tr>
<td>$\rho^+$</td>
<td>$H^u - H^d$</td>
<td>$E^u - E^d$</td>
</tr>
</tbody>
</table>
\[
\frac{d\sigma}{dt}(\gamma^* p \to en\rho^+) \propto \sqrt{-t} e^{bt}
\]

CLAS data. The first measurement of the $\rho^+$ exclusive electroproduction
\[ \rho^+ \text{ t-slope parameter} \]

Slope parameter is decreasing with \( x_B \). This indicates that the size of the interaction region decreases as \( x_B \to 1 \).

\[ \frac{d\sigma}{dt}(\gamma^* p \rightarrow e n \rho^+) \propto \sqrt{-t} e^{b t} \]
Vector mesons t-slope parameter

\[ W^2 = Q^2 \left( \frac{1}{x_B} - 1 \right) + m_N^2 \]

- \( b \) increases with \( W \): the size of the nucleon increases as one probes the high \( W \) values (i.e. the sea quarks). Sea quarks tend to extend to the periphery of the nucleon.
Popular GK and VGG models can not provide the right $W$-dependence of the cross-section.

This does not mean that we can’t access GPD in vector meson electroproduction.

For example, model with the addition of $q$-$qbar$ exchange (M.Guidal) together with standard VGG model successfully describes data.
\( \gamma_L p \rightarrow p\phi \)

\( \phi \) and \( \rho^0 \)

- \( \phi \) mesons - gluon GPD are dominant
- \( \rho^0 \) and \( \omega \) - sea quarks and/or gluons dominant.

GPD approach describes well data for \( W > 5 \) GeV
Hall B 12GeV upgrade overview from **CLAS** to **CLAS12**

**CLAS** will be replaced with **CLAS12**

**CLAS12** is designed to operate with order of magnitude higher luminosity.

**CLAS12** designed to accommodate polarized solid state targets NH$_3$, ND$_3$ and HD.
Jlab Upgrade Program

Deeply Virtual Exclusive Meson Electroproduction

\[
\begin{align*}
ep & \rightarrow ep\pi^0 & ep & \rightarrow ep\eta \\
ep & \rightarrow ep\phi & ep & \rightarrow ep\rho^0 \\
ep & \rightarrow ep\omega & ep & \rightarrow ep\rho^+
\end{align*}
\]

Deeply Virtual Compton Scattering

\[
\begin{align*}
ep & \rightarrow ep\gamma & en & \rightarrow en\gamma
\end{align*}
\]

- Kinematics:
  \(Q^2\) from 3 – 10 GeV\(^2\)
  \(-t\) from .5 to 10 GeV\(^2\)
  \(W\) from 2-4 GeV
Kinematic reach of the 12 GeV Upgrade

Exclusive Processes

Study of high $x_B$ domain requires high luminosity
With large acceptance, measure large $Q^2$, $x_B$, $t$ ranges simultaneously.

$A_{LU}$

$A(Q^2, x_B, t)$
$\Delta\sigma(Q^2, x_B, t)$
$\sigma(Q^2, x_B, t)$
Luminosity = 720 fb$^{-1}$

$Q^2 = 5.5 \text{GeV}^2$

$x_B = 0.35$

$-t = 0.25 \text{GeV}^2$
CLAS12 - DVCS/BH Beam Asymmetry

$e \, p \rightarrow ep\gamma$

$E = 11$ GeV

$\Delta\sigma_{LU} \sim \sin\phi \text{Im}\{F_1 H^+\} d\phi$

Selected Kinematics

$L = 1 \times 10^{35}$
$T = 2000$ hrs
$\Delta Q^2 = 1$ GeV$^2$
$\Delta x = 0.05$
$E = 11 \text{ GeV}$

e $p \rightarrow e p \gamma$

$\Delta \sigma \sim \sin \phi \text{Im}\{F_1H + \xi(F_1 + F_2)H \ldots\}d\phi$

$L = 2 \times 10^{35} \text{ cm}^{-2} \text{s}^{-1}$

$T = 1000 \text{ hrs}$

$\Delta Q^2 = 1 \text{ GeV}^2$

$\Delta x = 0.05$
Asymmetries highly sensitive to the u-quark contributions to the proton spin.
CLAS12 – DVCS/BH beam spin asymmetry on neutrons

DVCS on the neutron

This program requires adding a Central Neutron Detector (CDN) to the CLAS12 base equipment.

DVCS on neutrons is sensitive to GPD $E_n$ and the d-quark content of the nucleon spin.

European Initiative led by: Orsay University
Forward Detector:
- TORUS magnet
- Forward SVT tracker
- HT Cherenkov Counter
- Drift chamber system
- LT Cherenkov Counter
- Forward ToF System
- Preshower calorimeter
- E.M. calorimeter

Central Detector:
- SOLENOID magnet
- Barrel Silicon Tracker
- Central Time-of-Flight
- Polarized target (NSF)

Proposed upgrades:
- Micromegas (CD)
- Neutron detector (CD)
- RICH detector (FD)
- Forward Tagger (FD)
CLAS12 in construction - examples

1. Super Conducting Magnets
   - Conductor ready
   - Torus Coil case being prepared for coil winding

2. Silicon Vertex Tracker
   - Testing of the readout chip
   - Sensor testing

3. Forward Time of Flight
   - PMT testing at USC
   - Scintillator testing at USC
CLAS12 Under Construction - Examples

1. Drift Chambers
   - Wire stringing of RI at JLab
   - Wire stringing of RII at ODU

2. High Threshold Cerenkov
   - Mirror fabrication in the JLab Clean room
   - Mirror trimming at JLab Machine shop

3. Pre-Shower Calorimeter (MRI/NSF)
   - Module assembly
   - Fibers QA
Two short parasitic installation periods in FY10

6-month installation
May-Oct 2011

12-month installation
May 2012-May 2013

Hall A commissioning start
October 2013

Hall D commissioning start
April 2014

Halls B & C commissioning start
October 2014

Project Completion June 2015
Arizona State University, Tempe, AZ
University of Bari, Bari, Italy
University of California, Los Angeles, CA
California State University, Dominguez Hills, CA
Carnegie Mellon University, Pittsburgh, PA
Catholic University of America
CEA-Saclay, Gif-sur-Yvette, France
Christopher Newport University, Newport News, VA
University of Connecticut, Storrs, CT
Edinburgh University, Edinburgh, UK
University Ferrara, Ferrara, Italy
Florida International University, Miami, FL
Florida State University, Tallahassee, FL
George Washington University, Washington, DC
University of Glasgow, Glasgow, UK

University of Grenoble, Grenoble, France
Idaho State University, Pocatello, Idaho
INFN, Laboratori Nazionali di Frascati, Frascati, Italy
INFN, Sezione di Genova, Genova, Italy
Institut de Physique Nucléaire, Orsay, France
ITEP, Moscow, Russia
James Madison University, Harrisonburg, VA
Kyungpook University, Daegu, South Korea
University of Massachusetts, Amherst, MA
Moscow State University, Moscow, Russia
University of New Hampshire, Durham, NH
Norfolk State University, Norfolk, VA
Ohio University, Athens, OH
Old Dominion University, Norfolk, VA
Rensselaer Polytechnic Institute, Troy, NY
Rice University, Houston, TX
University of Richmond, Richmond, VA
University of Rome Tor Vergata, Italy
University of South Carolina, Columbia, SC
Thomas Jefferson National Accelerator Facility, Newport News, VA
Union College, Schenectady, NY
University of Santa Maria, Valparaiso, Chile
Virginia Polytechnic Institute, Blacksburg, VA
University of Virginia, Charlottesville, VA
College of William and Mary, Williamsburg, VA
Yerevan Institute of Physics, Yerevan, Armenia
Brazil, Germany, Morocco and Ukraine,
, have individuals or groups involved with CLAS,
but with no formal collaboration at this stage.
Summary

— The discovery of Generalized Parton Distributions has opened up a new and exciting avenue of hadron physics that needs exploration in dedicated experiments.

— Moderate to high energy, high luminosity, and large acceptance spectrometers are needed to measure GPDs in deeply virtual exclusive processes.

— The JLab 12 GeV Upgrade provides the tools to do this well and explore the nucleon at a much deeper level.
The Fin