High-$t$ meson electroproduction. Experimental status and prospects

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Newport News
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CLAS6: lots of data.
CLAS12: Exp. # E12-06-108

New proposal being prepared for PAC 38
Deeply Virtual Meson Electroproduction

- High $Q^2$ - Low -$t$
  Complement DVCS experiment.
  Unique access to spin dependent GPDs

- Low $Q^2$ - High -$t$
  New form factors related to $1/x$ moments of GPDs

- High $Q^2$ - High -$t$
  Region never accessed.

$\pi^0, \eta, \rho^0, \omega, \phi...$
## Kinematic regions in meson electroproduction

<table>
<thead>
<tr>
<th>Region</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$W &gt; 2$ GeV, High $Q^2$, Low $-t$</td>
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<td>$W &gt; 2$ GeV, High $Q^2$, High $-t$</td>
<td>Region never before accessed. Small initial configurations and small reaction size.</td>
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Factorization theorem states that in the limit $Q^2 \to \infty$ exclusive electroproduction of mesons is described by hard rescattering amplitude, generalized parton distributions (GPDs), and the distribution amplitude $\Phi(z)$ of the outgoing meson.

• The prove applies only to the case when the virtual photon has **longitudinal polarization**

• $Q^2 \to \infty \sigma_L \sim 1/Q^6$, $\sigma_T/\sigma_L \sim 1/Q^2$
How are the proton’s charge densities related to its quark momentum distribution?

M. Burkardt, A. Belitsky… Interpretation in impact parameter space

Proton form factors, **transverse** charge & current densities

Correlated quark momentum and helicity distributions in transverse space - **GPDs**

Structure functions, quark **longitudinal** momentum & spin distributions
GPDs

- GPD is Fourier Transform of matrix elements
- $t$-dependence of GPDs maps transverse position of quarks
- GPDs at zero skewedness ($\xi=0$) is the probability to find quark with momentum $x$ and impact parameter $b_x$
- Generalize at $\xi \neq 0$ → Quantum femtophotography
- DGLAP region ($x > \xi$) – quark femtophotography
- ERBL region ($x < \xi$) – quark-antiquark femtophotography pair of the size $1/Q$
Deeply Virtual Meson production

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

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

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

<table>
<thead>
<tr>
<th>Meson</th>
<th>GPD flavor composition</th>
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<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>
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</table>

- DVCS is the cleanest way of accessing GPDs. However, it is difficult to perform a flavor separation.
- Vector and pseudoscalar meson production allows one to separate flavor and isolate the helicity-dependent GPDs.
**π^0 electroproduction**

**Handbag predictions**


\[ \sigma_T + \varepsilon \sigma_L \]

\[ \sigma_T \]

\[ \sigma_{LT} \]

Predictions for the cross section (left) and \( A_{UT} \) (right) for the \( π^0 \) electroproduction versus \( -t \). The unseparated\( (\sigma_L, \sigma_T) \) cross section was calculated as well as \( \sigma_T \) and \( \sigma_{LT} \). At \( W=2.2 \text{ GeV} \) the cross section will be a factor of 10 larger. We can check it at Jlab.
Transition from “hadronic” to the partonic degrees of freedom
Regge Model

J.M. Laget 2010

(a) Regge poles (vector and axial vector mesons)
(b) and (c) pion cuts

Vector meson cuts

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

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

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

\[ Q^2 = 1.75 \]
\[ x_B = 0.22 \]
Comparison with J.M. Laget Regge model

- Extracted reduced cross sections were compared with predictions of J.M. Laget Regge Model
Q2-dependence
$x_B$ dependence
W-dependence

$\gamma^* p \rightarrow p\pi^0$
t - distribution

\[ \frac{d\sigma}{dt} \propto e^{B(x_B,Q^2) t} \]

\[ \gamma^* p \rightarrow p\pi^0 \]
t-Slope Parameter as a Function of $x_B$ and $Q^2$

$$\frac{d\sigma}{dt} \propto e^{B(x_B, Q^2)t}$$

\[ B(x) = 2\alpha' \ln(1/x) \]

This is not fit of data. This is GPD predictions with Regge inspired t-dependence $x^{\alpha t}$

$B(x_b, Q^2)$ is almost independent of $Q^2$

$B(x_b)$ is decreasing with increasing $x_b$
Preliminary data on the ratio $\eta/\pi^0$ as a function of $x_B$ for different bins in $t$.

The dependence on the $x_B$ and $Q^2$ is very weak.

Probably we have small positive slope. The ratio in the photoproduction is near 0.2-0.3 (very close to what we have at our smallest $Q^2$).
Vector Mesons
Quark and Gluon GPDs

\[ \gamma^* p \rightarrow np^+ \]
\[ \gamma^* p \rightarrow pp^0 \]
\[ \gamma^* p \rightarrow p\omega \]
\[ \gamma^* p \rightarrow p\phi \]

\[ \begin{array}{c|c}
\hline
\text{p}^0 & e_u H^u - e_d H^d \\
\hline
\text{H} & e_u E^u - e_d E^d \\
\hline
\text{p}^+ & H^u - H^d \\
\hline
\end{array} \]
Slope parameter is decreasing similar to $\pi_0$.
Vector mesons b-slope parameter
σ_L σ_T separation
SCHC  S-channel helicity conservation

\[ \gamma_L p \rightarrow n \rho^+ \]

CLAS data

GPD fails to describe data by more than order of magnitude
\( \gamma_L^* p \rightarrow p \rho^0 \)

Fails to describe data \( W < 5 \text{ GeV} \)  
Describes well for \( W > 5 \text{ GeV} \)

\[ \sigma_L \]

VGG model  
GK model
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, adding the so called generalized D-term (M. Guidal) together with standard VGG model successfully describes data.
• φ mesons - gluon GPD are dominant
• ρ^0 and ω - sea quarks and/or gluons dominant.

GPD approach describes well data for W>5 GeV
Large angle (high -t), relatively small $Q^2$
(Analog to WACS where handbag works very well)

\[
\frac{d\sigma_L^M}{dt} \propto \int_0^1 d\tau \phi(\tau) R(t, \tau) \quad R(t) \rightarrow R_V^M R_V^{MS} R_A^M R_V^M
\]

\[R_V^M (t) = \int \sum_q \frac{dx}{x} H^q (x, t) \quad R_T^M (t) = \int \sum_q \frac{dx}{x} E^q (x, t) \quad R_A^M (t) = \int \sum_q \frac{dx}{x} H^q (x, t)\]

CLAS data: Kubarovsky
GPD model: Huang and Kroll
High-\textit{t}, Large $Q^2$

From GPDs to TDAs

- GPDs are not the adequate tool for describing \textit{backward} hard electroproduction
- Basic difference forward vs backward is the exchange of $q\bar{q}$ vs $qqq$
TDAs: Transition distribution amplitudes

• In backward meson electroproduction there is factorization of a non-perturbative part describing a baryon to meson transition and perturbative part $\gamma^*qqq \rightarrow qqq$ transition

• TDAs provide information on Fock state of the proton with small $b_T$ for quark triplet or how to find a meson in a proton.

• As for GPDs, the $t$ dependence of TDAs maps the transverse position $b_T$ of quarks
Q<sup>2</sup> > 1 GeV<sup>2</sup>
W > 2 GeV
x<sub>B</sub> > 0.1
JLab 12 GeV Upgrade

**CLAS12**
- High luminosity
- Large acceptance
- Wide kinematic coverage
- High precision
Kinematics coverage for deeply exclusive experiments

- No overlap with other existing experiments
- Complementary & unique

- Jlab @ 12GeV
- COMPASS
- HERMES
- Upgraded CEBAF
- Hall A
Projected measured cross sections.

\[ ep \rightarrow ep\pi^0 \]
New PAC38 Proposal (2011)

Deep Virtual Exclusive Vector Meson Electroproduction

\[ ep \to e\phi, \quad \phi \to K^+K^- \quad ep \to e\rho^0, \quad \rho^0 \to \pi^+\pi^- \]
\[ ep \to e\omega, \quad \omega \to \pi^+\pi^-\pi^0 \quad ep \to e\rho^+, \quad \rho^+ \to \pi^+\pi^0 \]

- Kinematics:
  - \( Q^2 \) from 3 – 10 GeV
  - \(-t\) from .5 to 10 GeV
  - \( W \) from 2-4 GeV

- Run simultaneously with DVCS

- Simulations for \( \phi, \rho^0, \rho^+, \omega \) are beginning.

- Isolating K’s over entire kinematic range.
Summary

- Deeply Virtual Meson Production has the potential to probe the nucleon structure at the parton level, as described by Generalized Parton distributions (GPDs).
- The most extensive set of $\pi^0, \eta, \rho^+, \rho^0, \omega$, and $f$ electroproduction to date has been obtained with the CLAS spectrometer.
- The approach to the hard regime can be studied experimentally using model-independent tests which probe qualitative features like $t$-slope as function of $Q^2$ and $x_B$.
- CLAS12 program of pseudoscalar and vector electroproduction will provide unique information about the:
  - transition between soft long-range phenomena and hard short range.
  - quark momentum and spin distributions of the nucleons.
  - gluon and quark GPDs.

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