DVCS @ HERMES

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PacSpin 2011
Deeply Virtual Compton Scattering

- Physics - Interests & Constraints
- HERMES DVCS Measurements
- GPDs & Future Measurements
Deeply Virtual Compton Scattering

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Deeply Virtual Compton Scattering

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Deeply Virtual Compton Scattering

e p \rightarrow e p \gamma
Deeply Virtual Compton Scattering

\[ \frac{d\sigma}{dx_B \, dQ^2 \, dt \, d\phi} = \frac{x_B \, e^6 \, |\tau|^2}{32 \, (2\pi)^4 \, Q^4 \, \sqrt{1 + \epsilon^2}} \]

\[ |\tau|^2 = |\tau_{\text{BH}}|^2 + |\tau_{\text{DVCS}}|^2 + \tau_{\text{BH}}^* \tau_{\text{DVCS}}^* + \tau_{\text{BH}} \tau_{\text{DVCS}}^* \]
Generalised Parton Distributions

\( t \) - Mandelstam variable (squared momentum transfer to nucleon)

\( x \) - Fraction of nucleon's longitudinal momentum carried by active quark

\( \xi \) - half the change in the longitudinal momentum of the active quark.
Generalised Parton Distributions

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GPD Physics

Four distributions of interest: $H, E, \tilde{H}, \tilde{E}$

$H$ and $E$ integrate over quark helicities
$\tilde{H}$ and $\tilde{E}$ are quark helicity difference distributions

$$J_q = \frac{1}{2} \lim_{t \to 0} \int_{-1}^{1} \left[ H^q(x, \xi, t) + E^q(x, \xi, t) \right] x \, dx$$
GPD Physics

Four distributions of interest: $H, E, \tilde{H}, \tilde{E}$

$H$ and $E$ integrate over quark helicities

$\tilde{H}$ and $\tilde{E}$ are quark helicity difference distributions

Nucleon helicity inversion

Nucleon helicity conservation

"Ji’s Relation"

$$J_q = \frac{1}{2} \lim_{t \to 0} \int_{-1}^{1} \left[ H^q (x, \xi, t) + E^q (x, \xi, t) \right] x \, dx$$

GPD Physics

Form Factors (FFs)
Parton Distribution Functions (PDFs)
Generalised Parton Distributions (GPDs)
GPD Physics

H - unpolarised nucleon    ÑH - polarised nucleon
GPDs describe only the soft part of the interaction

Accessed via cross-sections and asymmetries: requires convolution with a hard scattering kernel

\[ H \rightarrow \tilde{H} \quad \tilde{H} \rightarrow \tilde{H} \quad E \rightarrow \tilde{E} \quad \tilde{E} \rightarrow \tilde{E} \]

Results in “Compton Form Factors” accessible through DVCS, which have real and imaginary parts
GPDs describe only the soft part of the interaction

Accessed via cross-sections and asymmetries: requires convolution with a hard scattering kernel

\[ \Im m \mathcal{F}(\xi, t) = F(\xi, \xi, t) \pm F(-\xi, \xi, t), \]
\[ \Re e \mathcal{F}(\xi, t) = \mathcal{P}_C \int_{-1}^{1} \frac{F(x, \xi, t)}{x - \xi} \pm \frac{F(x, \xi, t)}{x + \xi} \, dx \]
GPDs describe only the soft part of the interaction

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\[
\Im m \mathcal{F}(\xi, t) = F(\xi, \xi, t) \pm F(-\xi, \xi, t), \\
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\]

Limited x access
**DVCS @ HERMES**

\[
A_C(\phi) \equiv \frac{d\sigma^+ (\phi) - d\sigma^- (\phi)}{d\sigma^+ (\phi) + d\sigma^- (\phi)} \propto \text{Re}(\mathcal{H})
\]

\[
A_{LU}(\phi) \equiv \frac{\left[ \sigma^{\leftrightarrow}(\phi) + \sigma^{\rightarrow\rightarrow}(\phi) \right] - \left[ \sigma^{\leftrightarrow\leftrightarrow}(\phi) + \sigma^{\leftarrow\rightarrow}(\phi) \right]}{\left[ \sigma^{\rightarrow\leftrightarrow}(\phi) + \sigma^{\rightarrow\rightarrow}(\phi) \right] + \left[ \sigma^{\leftrightarrow\leftrightarrow}(\phi) + \sigma^{\leftarrow\rightarrow}(\phi) \right]} \propto \text{Im}(\mathcal{H})
\]

\[
A_{UL}(\phi) \equiv \frac{\left[ \sigma^{\leftrightarrow}(\phi) + \sigma^{\rightarrow\rightarrow}(\phi) \right] - \left[ \sigma^{\leftrightarrow\rightarrow\leftrightarrow}(\phi) + \sigma^{\rightarrow\leftarrow}(\phi) \right]}{\left[ \sigma^{\rightarrow\leftrightarrow}(\phi) + \sigma^{\rightarrow\rightarrow}(\phi) \right] + \left[ \sigma^{\leftrightarrow\rightarrow\leftrightarrow}(\phi) + \sigma^{\rightarrow\leftarrow}(\phi) \right]} \propto \text{Im}(\mathcal{H})
\]

\[
A_{LL}(\phi) \equiv \frac{\left[ \sigma^{\rightarrow\rightarrow}(\phi) + \sigma^{\leftrightarrow\leftrightarrow}(\phi) \right] - \left[ \sigma^{\rightarrow\leftrightarrow}(\phi) + \sigma^{\rightarrow\rightarrow}(\phi) \right]}{\left[ \sigma^{\rightarrow\rightarrow}(\phi) + \sigma^{\leftrightarrow\leftrightarrow}(\phi) \right] + \left[ \sigma^{\rightarrow\leftrightarrow}(\phi) + \sigma^{\rightarrow\rightarrow}(\phi) \right]} \propto \text{Re}(\mathcal{\bar{H}})
\]
DVCS @ HERMES

\[ \langle Q^2 \rangle \approx 2.4 \text{ GeV}^2 \]
\[ \langle x_B \rangle \approx 0.1 \]
\[ \langle -t \rangle \approx 0.1 \text{ GeV}^2 \]
\[ 1 \text{ GeV}^2 < Q^2 \equiv -q^2 < 10 \text{ GeV}^2 \]
\[ 0.03 < x_B < 0.3 \]
\[ 0 \text{ GeV}^2 < -t \equiv -(p-p')^2 < 0.7 \text{ GeV}^2 \]
DVCS @ HERMES

Data
MC Sum
BH/DVCS
Resonance Production
SIDIS Production
Exclusive $\pi^0$ Production
DVCS @ HERMES

Wanted Signal

BH/DVCS from $\Delta$, e.g

$e\Delta \rightarrow e\Delta \gamma \rightarrow e\, p\, \pi^0\, \gamma$

$e\, p \rightarrow e\, X\, \gamma$

$e\, p \rightarrow e\, p\, \pi^0$
<table>
<thead>
<tr>
<th>HERMES DVCS</th>
<th>Hydrogen</th>
<th>Deuterium</th>
<th>Hydrogen Preliminary</th>
</tr>
</thead>
<tbody>
<tr>
<td>$A_C^{\cos(0\phi)}$</td>
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<tr>
<td>$A_C^{\cos \phi}$</td>
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<td>$A_C^{\cos(2\phi)}$</td>
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<td>$A_C^{\cos(3\phi)}$</td>
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<tr>
<td>$A_C^{\sin \phi}$</td>
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<tr>
<td>$A_{LU,I}^{\sin \phi}$</td>
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<tr>
<td>$A_{LU,DVCS}^{\sin \phi}$</td>
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<tr>
<td>$A_{LU,I}^{\sin(\phi - \phi_s)}$</td>
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<tr>
<td>$A_{LT,I}^{\cos(\phi - \phi_s)}$</td>
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<tr>
<td>$A_{LT,I}^{\cos(\phi - \phi_s) \sin \phi}$</td>
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<td>$A_{UL}^{\sin \phi}$</td>
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<td>$A_{UL}^{\sin(2\phi)}$</td>
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Amplitude Value

-0.3 -0.2 -0.1 0 0.1 0.2 0.3

Tuesday, 21 June 2011
Beam Asymmetries

Beam Charge Asymmetries access $\text{Re}(\mathcal{H})$

$\Delta$-resonance
Beam Asymmetries

Beam Helicity Asymmetries access $\text{Im}(\mathcal{H})$

Larger values for the BHA than BCA - correlated to the difference in the CFF access?
Target Asymmetries

Long. Pol. target asymmetries access $\text{Im}(\bar{H})$

http://arxiv.org/abs/1004.0177

A. Airapetian et al, JHEP 06 (2010) 019

VGG Model:


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Double Spin Asymmetries

Long. Pol. target / Long. Pol. Beam access Re(\tilde{\mathcal{H}})

Caveat! Relatively large BH contribution to these asymmetries!

http://arxiv.org/abs/1004.0177

A. Airapetian et al, JHEP 06 (2010) 019
Beam Asymmetries


Deuterium is governed by different GPDs - but the asymmetry data is not so different!

http://www.arxiv.org/abs/0911.0095
Target Asymmetries

No good idea how to model long. pol. deuterium GPDs. Currently use a proton/neutron hybrid

http://www.arxiv.org/abs/1008.3996

Nuclear-Mass Dependence

Nuclear-Binding models expected the DVCS asymmetry for nuclear targets to be ~2x that of the Hydrogen asymmetry.
Nuclear Mass Dependence

http://arxiv.org/abs/0911.0091


The data shows no significant difference between coherent and incoherent DVCS processes.
\[ \langle Q^2 \rangle \approx 2.4 \text{ GeV}^2 \]
\[ \langle x_B \rangle \approx 0.1 \]
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DVCS @ HERMES

Recoil Detector

Target Cell

Steel Plate

DVC

SILICON
HODOSCOPE H0

FIELD CLAMPS

DRIFT CHAMBERS

PROP. CHAMBERS

MC 1–3

BC 1/2

RICH

TRIGGER HODOSCOPE H1

PRESHOWER (H2)

LUMINOSITY MONITOR 27.5 GeV

CALORIMETER 140 mrad

270 mrad

MAGNET

BC 3/4

TRD

270 mrad

140 mrad

0 1 2 3 4 5 6 7 8 9 10 m

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Significant improvement in the purity of the signal

Current DVCS Data

Sum

Track in the Recoil Detector

Kin. Fit says probably DVCS

Kin. Fit says probably not DVCS
Current DVCS Data

HERMES PRELIMINARY 2006/07 data

3.4% scale uncertainty

\( e^+ p \rightarrow e^+ p \gamma \)

\( A_{LU}^{\sin \phi} \)

\( A_{LU}^{\sin (2\phi)} \)

Overall

\( -t [\text{GeV}^2] \)

\( 10^{-1} \)

\( 10^{-1} x_B \)

\( 1 \)

\( Q^2 [\text{GeV}^2] \)

\( 10 \)

without Recoil Det.

with Recoil Det.

in Recoil Det. accept.
Current DVCS Data

HERMES PRELIMINARY 2006/07 data

Overall data

\[ \phi \sin (2\, \theta_A) \]

3.4\% scale uncertainty

Overall

\[ e^+ p \rightarrow e^+ p \gamma \]

\[ B_x \]

\[ -10^2 \ to \ 10^2 \ [\text{GeV}^2] \]

\[ -10^{-1} \ to \ 10^{-1} \ [\text{GeV}^2] \]

\[ 1 \ to \ 10 \ [\text{GeV}^2] \]

Elastic Assoc.

with Recoil Det.
in Recoil Det. accept.

without Recoil Det.

Process fractions

overall

\[ -t [\text{GeV}^2] \]

\[ x_B \]

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

Tuesday, 21 June 2011
GPD Discovery

New CFF Fit Result incorporating A_{UL} moments

Postulate GPDs from first principle models

http://arxiv.org/abs/0904.0458
Kumerički and Müller

http://arxiv.org/abs/1005.4922
M. Guidal

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New CFF Fit Result incorporating A_{UL} moments

Postulate GPDs from first principle models

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Kumerički and Müller
Measurements of the dvcs cross-section can help determine $x$ and $t$ entanglement.

All four GPDs will be accessed in proposed measurements at JLab and COMPASS.
Meson Data

Meson data can also play a vital role in accessing GPDs - especially the “polarised” GPDs $\tilde{H}$ and $\tilde{E}$!

Extraction of SDMES and Helicity Amplitude Ratios at HERMES for $\rho$ mesons have shown that the handbag approximation is insufficient!
Throughout the majority of exclusive physics data from HERMES we see that there is very little difference between protons and deuterons!!!
Conclusions

- **DVCS** can be used to access information on Generalised Parton Distributions
- That information can tell us unique things about nucleon structure
- **HERMES** has the most diverse DVCS measurements of any experiment.
Conclusions

• There is still no clear idea about how the nuclear medium modifies GPD-dependent behaviour.

• Already, GPDs can be constrained - but there is much left to do!

• DVCS and DVMP both seem to show that there is little difference between proton and deuteron data!!!