DVCS @ HERMES
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GPD 2010
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_{BH}|^2 + |\tau_{DVCS}|^2 + \tau_{BH} \tau_{DVCS}^* + \tau_{BH}^* \tau_{DVCS}

\[\mathcal{I}\]

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deeply virtual compton scattering diagram

- e (k) → e (k')
- γ (q) → γ* (q')
- p (p) → p (p')
Generalised Parton Distributions

t - Mandelstam variable (squared momentum transfer to nucleon)

x - Fraction of nucleon’s longitudinal momentum carried by active quark

ξ - half the change in the longitudinal momentum of the active quark.
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: $H$, $E$, $\tilde{H}$, $\tilde{E}$

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Nucleon helicity inversion

Nucleon helicity conservation

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

“Ji’s Relation”

*Phys. Rev. Lett. 78:610, 1997*
GPD Physics

Form Factors (FFs)

Parton Distribution Functions (PDFs)

Generalised Parton Distributions (GPDs)
GPD Physics

\( p_z \rightarrow \infty \)

Form Factors (FFs)

Parton Distribution Functions (PDFs)

Generalised Parton Distributions (GPDs)

\( H \) - unpolarised nucleon  \( \tilde{H} \) - 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

\[
\text{Im } F(\xi, t) = F(\xi, \xi, t) \pm F(-\xi, \xi, t), \\
\text{Re } F(\xi, t) = \mathcal{P}_C \int_{-1}^{1} \frac{F(x, \xi, t)}{x - \xi} \pm \frac{F(x, \xi, t)}{x + \xi} \, dx
\]
GPD Physics

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\[ \Im \mathcal{F}(\xi, t) = F(\xi, \xi, t) \pm F(-\xi, \xi, t), \]
\[ \Re \mathcal{F}(\xi, t) = \mathcal{P}_C \int_{-1}^{1} \frac{F(x, \xi, t)}{x - \xi} \pm \frac{F(x, \xi, t)}{x + \xi} \, dx \]

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

\[ A_{LU}(\phi) \equiv \frac{[\sigma^{\to \leftarrow}(\phi) + \sigma^{\to \Rightarrow}(\phi)] - [\sigma^{\leftarrow \leftarrow}(\phi) + \sigma^{\leftarrow \Rightarrow}(\phi)]}{[\sigma^{\to \leftarrow}(\phi) + \sigma^{\to \Rightarrow}(\phi)] + [\sigma^{\leftarrow \leftarrow}(\phi) + \sigma^{\leftarrow \Rightarrow}(\phi)]} \propto \text{Im}(\mathcal{H}) \]

\[ A_{UL}(\phi) \equiv \frac{[\sigma^{\leftarrow \rightarrow}(\phi) + \sigma^{\to \Rightarrow}(\phi)] - [\sigma^{\leftarrow \leftarrow}(\phi) + \sigma^{\rightarrow \leftarrow}(\phi)]}{[\sigma^{\leftarrow \rightarrow}(\phi) + \sigma^{\to \Rightarrow}(\phi)] + [\sigma^{\leftarrow \leftarrow}(\phi) + \sigma^{\rightarrow \leftarrow}(\phi)]} \propto \text{Im}(\bar{\mathcal{H}}) \]

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

\[ \vec{k}, \vec{k}', \vec{q}, \vec{p}_\gamma, \phi \]
DVCS @ HERMES

\[ \langle Q^2 \rangle \approx 2.4 \text{ GeV}^2 \]
\[ \langle x_B \rangle \approx 0.1 \]
\[ \langle -t \rangle \approx 0.1 \text{ GeV}^2 \]

- \[ 1 \text{ GeV}^2 < Q^2 \equiv -q^2 < 10 \text{ GeV}^2 \]
- \[ 0.03 < x_B < 0.3 \]
- \[ 0 \text{ GeV}^2 < -t \equiv -(p-p')^2 < 0.7 \text{ GeV}^2 \]

Forward spectrometer \(\Rightarrow\) measure asymmetries directly
DVCS @ HERMES

Forward spectrometer ⇒ measure asymmetries directly

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DVCS @ HERMES

![Graph showing data and distributions for different processes: Data, MC Sum, BH/DVCS, Resonance Production, SIDIS Production, and Exclusive π^0 Production. The graph plots 1000*N/N_DiS against M_x^2 in GeV^2.]
**DVCS @ HERMES**

- Wanted Signal
- BH/DVCS from $\Delta$, e.g.
  - $e \Delta \rightarrow e \Delta \gamma \rightarrow e p \pi^0 \gamma$
  - $e p \rightarrow e X \gamma$
  - $e p \rightarrow e p \pi^0$
Beam Asymmetries

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

Beam Helicity Asymmetries access Im(\mathcal{H}) Larger values for the BHA than BCA - node in the small-x region near to the HERMES kinematics?
Target Asymmetries

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

http://arxiv.org/abs/1004.0177

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

VGG Model:

Double Spin Asymmetries

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

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

Interference + $|DVCS|^2$ where $t < t_{coh.}$.

The data shows no significant difference between coherent and incoherent DVCS processes.


Nuclear Mass Dependence


Beam Charge Asymmetries are essentially 0 for coherent scattering

Consistent with the Proton asymmetry for heavier targets
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

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

Recoil Detector - **True Exclusivity!**

Almost pure BH/DVCS signal - background <1%

Potential for measuring other exclusive physics processes - $\Delta$-DVCS, HEMP physics, DVCS on neutron...
Future DVCS Data

Calibrations finalised

Kinematic Fitting routines implemented

Event selection method finalised - asymmetry extraction techniques to be finalised and systematic studies still to be completed.
Future DVCS Data

- Significant improvement in the purity of signal
- No hard-and-fast idea on the feasibility of a Δ-DVCS measurement
- Expect first publicly-available results in Q2 2011
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 clearly correct idea about how the nuclear medium modifies GPD-dependent behaviour. More data?

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

- Experimental extractions of GPDs and related physical quantities can work in harmony with Lattice QCD.