Future DVCS in Hall B at Jefferson Lab

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Measuring GPDs through polarization

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

Polarized beam, unpolarized target:

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

Unpolarized beam, longitudinal target:

\[ \Delta \sigma_{UL} \sim \sin \phi \left\{ F_1 H + \xi (F_1 + F_2) \left( H + \frac{\xi}{1+\xi} E \right) \ldots \right\} d\phi \]

Unpolarized beam, transverse target:

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

Kinematically suppressed

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

\[ k = t/4M^2 \]

\[ H(\xi, t) \]

\[ \tilde{H}(\xi, t), H(\xi, t) \]

\[ H(\xi, t), E(\xi, t) \]
Superconducting solenoid

Inner calorimeter (\(\text{PbWO}_4\))

424 crystals, 16 mm long, pointing geometry, \(\sim\) 1 degree/crystal, APD readout

DVCS@CLAS – a dedicated experiment
CLAS Setup for DVCS Experiments

SC Helmholtz magnet especially constructed for this experiment

Inner calorimeter (PbWO₄)

424 crystals, 16 mm long, pointing geometry, ~ 1.2 degree/crystal, APD readout

Calibration via $\pi^0 \rightarrow \gamma\gamma$

$\sigma = 7.5$ MeV

Photon detection in IC and EC (view from target)
Target Spin Asymmetry: $\phi$ Dependence

6 GeV run with NH$_3$ longitudinally polarized target (CLAS + IC) 60 days of beam time

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

A dedicated CLAS experiment with longitudinally polarized target will provide a statistically significant measurement of the kinematical dependences of the DVCS target SSA.


CLAS eg1

CLAS (eg1+IC) projected (experiment planned for 2008)
Target Spin Asymmetry: $Q^2$ Dependence

$x_B=0.3$, $t=0.325\text{ GeV}^2$, $\phi=90^\circ$

![Graph showing $A_{UL}$ as a function of $Q^2$ with data points and curves indicating 'With H-tilde' and 'Without H-tilde'.]
Target Spin Asymmetry: $t$- Dependence

$x_B = .3$, $Q^2 = 2.3 \text{ GeV}^2$, $\phi = 90^\circ$

Higher $t$ values will also be measured. The interpretation within the handbag formalism needs to be clarified.
In the past few years, we were able to glimpse some of the new physics that is accessible through GPDs. However, much more experimental and theoretical work is needed to efficiently unravel the complex structure of the proton.
At 12 GeV, CEBAF will be ideal for GPD studies in valence quark regime.
• **CLAS** will be modified and upgraded to **CLAS12**, which will be worldwide the only large acceptance, multi-purpose detector for fixed target electron scattering experiments.

• **CLAS12** will operate with an upgraded luminosity of $>10^{35}\text{cm}^{-2}\text{s}^{-1}$, more than an order of magnitude increase, and improved particle identification.

• With these capabilities **CLAS12** will support a broad experimental program in fundamental nuclear physics.
Increase luminosity tenfold to $> 10^{35} \text{ cm}^{-2}\text{s}^{-1}$
CLAS12

Central Detector

Solenoid 5T

DC R1, R2, R3

CTOF

SVT

HTCC

FTOF 1

FTOF 2

PCAL

EC

Forward Detector

Forward carriage

TORUS

Jefferson Lab
Deeply Virtual Exclusive Processes
Kinematics Coverage of the 12 GeV Upgrade

Study of high $x_B$ domain requires high luminosity.
DVCS/BH- Beam Asymmetry

$E_e = 11 \text{ GeV}$

With large acceptance, measure large $Q^2$, $x_B$, $t$ ranges simultaneously.

$A(Q^2,x_B,t)$

$\Delta \sigma(Q^2,x_B,t)$

$\sigma(Q^2,x_B,t)$
CLAS12 - DVCS/BH - Beam Asymmetry

$Luminosity = 720 fb^{-1}$

$E_e = 11 GeV$

$Q^2 = 5.5 GeV^2$

$x_B = 0.35$

$-t = 0.25 GeV^2$
CLAS12 - DVCS/BH Beam Asymmetry

$\vec{e} p \rightarrow e p \gamma$

$E = 11$ 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$^2$
$\Delta x = 0.05$
\( e \vec{p} \rightarrow e p\gamma \)

Longitudinally polarized target

\[ \Delta \sigma \sim \sin \phi \Im \{F_1 \tilde{H} + \xi (F_1 + F_2) H \ldots \} d\phi \]

\[
\begin{align*}
E &= 11 \text{ GeV} \\
Q^2 &= 2.2, x_p = 0.25 \\
Q^2 &= 3.5, x_p = 0.25 \\
Q^2 &= 4.5, x_p = 0.25 \\
Q^2 &= 2.2, x_p = 0.35 \\
Q^2 &= 3.5, x_p = 0.35 \\
Q^2 &= 5.5, x_p = 0.35 \\
Q^2 &= 2.2, x_p = 0.45 \\
Q^2 &= 3.5, x_p = 0.45 \\
Q^2 &= 5.5, x_p = 0.45
\end{align*}
\]

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

\( T = 1000 \text{ hrs} \)

\( \Delta Q^2 = 1 \text{ GeV}^2 \)

\( \Delta x = 0.05 \)
CLAS12 - DVCS/BH Target Asymmetry

\[ e \uparrow p \rightarrow ep\gamma \quad E = 11 \text{ GeV} \]

Transverse polarized target

\[ \Delta \sigma \sim \sin \phi \Im \{k_1(F_2H - F_1E) + \ldots\}\,d\phi \]

\( A_{UTx} \) Target polarization in the scattering plane

\( A_{UTy} \) Target polarized perpendicular to the scattering plane

- Asymmetries are highly sensitive to the u-quark contributions to the proton spin.

Sample kinematics

\( Q^2=2.2 \text{ GeV}^2, x_B = 0.25, -t = 0.5\text{GeV}^2 \)
Double DVCS (DDVCS)

DDVC rates reduced by factor > 200!

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

Cross section

\( H(x, \xi, 0) \)

DVCS asymmetry

DDVCS
Conclusions

• With QCD as the theoretical framework, and the handbag mechanism and GPDs as tools the proton (and neutron) structure can be accessed systematically.

• First experiments demonstrate the applicability of the basic “handbag” mechanism at moderate (Jlab) energies.

• The JLab energy upgrade and new equipment provide the means to explore the complex proton structure in the full valence quark regime.
Deeply Virtual Compton Scattering (DVCS)

GPDs depend on 3 variables, e.g. \( H(x, x, t) \). They probe the quark structure at the amplitude level.

\[
\xi = \frac{x_B}{2-x_B}
\]
Target Spin Asymmetry: \( Q^2 \)- Dependence

\[ x_B = 0.3, \ t = 0.325 \ \text{GeV}^2, \ \phi = 90^\circ \]

- \( \xi \)-independent
- \( \xi \)-dependent
- \( \xi \)-dep.+D-term

CLAS Eg1
First DVCS measurement with spin-aligned target

Unpolarized beam, longitudinally spin-aligned target:

\[ \Delta \sigma_{UL} \sim \sin \phi \text{Im}\{F_1 \tilde{H} + \xi (F_1 + F_2) H + \ldots \}d\phi \]

\[ \alpha = 0.252 \pm 0.042 \]
\[ \beta = -0.022 \pm 0.045 \]

Planned experiment in 2008 will improve accuracy dramatically.

Increase luminosity tenfold to $> 10^{35} \text{ cm}^{-2}\text{s}^{-1}$
Target Spin Asymmetry: $t$-Dependence

$x_B = 0.3$, $Q^2 = 2.3$ GeV$^2$, $\phi = 90^\circ$

$A_{UL}$

- $\xi$-independent
- $\xi$-dependent
- $\xi$-dep. + D-term

$0 \leq t (\text{GeV}^2) \leq 1$
Target Spin Asymmetry: $x$-Dependence

$t = 0.325 \text{ GeV}^2$, $Q^2 = 2.3 \text{ GeV}^2$, $\phi = 90^\circ$

$A_{UL}$ versus $x$ with different models:
- $\xi$-independent
- $\xi$-dependent
- $\xi$-dep. + D-term

CLAS Eg1