New Deeply Virtual Compton Scattering results from Jefferson Lab

Carlos Muñoz Camacho
IPN-Orsay, CNRS/IN2P3 (France)

25th International Workshop on Deep Inelastic Scattering
April 3–7, 2017
Outline

1. (Very) brief experimental introduction to DVCS

2. Recent DVCS results from Hall A at JLab:
   - Reminder of latest published data (late 2015)
   - New results (released last week)

3. Outlook:
   - Jefferson Lab at 12 GeV: Hall A and Hall C program
Deeply Virtual Compton Scattering (DVCS): $\gamma^* p \rightarrow \gamma p$

Handbag diagram

**Motivation**

Deeply Virtual Compton Scattering (DVCS): $\gamma^* p \rightarrow \gamma p$

- **Handbag diagram**
- **High $Q^2$**
- **Perturbative QCD**
- **Non-perturbative GPDs**

**Bjorken limit:**

$$Q^2 = -q^2 \rightarrow \infty \quad \nu \rightarrow \infty \quad x_B = \frac{Q^2}{2M\nu} \text{ fixed}$$

- GPDs accessible through DVCS *only* at $Q^2 \rightarrow \infty$
- Actual value of $Q^2$ *must* be tested and established by experiment
**DVCS experimentally: interference with Bethe-Heitler**

At leading twist:

\[
\begin{align*}
\frac{d^5}{\sigma} \rightarrow \frac{d^5}{\sigma} & = 2 \Im \langle T^{BH} \cdot T^{DVCS} \rangle \\
\frac{d^5}{\sigma} \rightarrow \frac{d^5}{\sigma} & = |BH|^2 + 2 \Re \langle T^{BH} \cdot T^{DVCS} \rangle + |DVCS|^2
\end{align*}
\]

\[
\tau^{DVCS} = \int_{-1}^{+1} dx \frac{H(x, \xi, t)}{x - \xi + i\epsilon} + \cdots = \\
\mathcal{P} \int_{-1}^{+1} dx \frac{H(x, \xi, t)}{x - \xi} - i\pi H(x = \xi, \xi, t) + \cdots
\]

Access in **helicity-independent cross section**

Access in **helicity-dependent cross-section**
DVCS cross sections: azimuthal analysis

\[ Q^2 = 2.36 \text{ GeV}^2, \, x_B = 0.37, \, -t = 0.32 \text{ GeV}^2 \]

\[ d^4\sigma = \mathcal{T}_{BH}^2 + \mathcal{T}_{BH} \mathcal{R}(\mathcal{T}_{DVCS}) + \mathcal{T}_{DVCS}^2 \]

\[ \mathcal{R}(\mathcal{T}_{DVCS}) \sim c_0^T + c_1^T \cos \phi + c_2^T \cos 2\phi \]

\[ \mathcal{T}_{DVCS}^2 \sim c_0^{DVCS} + c_1^{DVCS} \cos \phi \]

\[ \Delta^4\sigma = \frac{d^4\sigma - d^4\bar{\sigma}}{2} = \mathcal{I}m(\mathcal{T}_{DVCS}) \]

\[ \mathcal{I}m(\mathcal{T}_{DVCS}) \sim s_1^T \sin \phi + s_2^T \sin 2\phi \]


Carlos Muñoz Camacho (IPN-Orsay)
DVCS cross sections: $Q^2$–dependance

No $Q^2$-dependance within limited range $\Rightarrow$ leading twist dominance
DVCS cross sections: higher twist corrections

KM10a: global fit to HERA x-sec & HERMES + CLAS spin asymmetries

Kumericki and Mueller (2010)
**DVCS cross sections: higher twist corrections**

- **KM10a**: global fit to HERA x-sec & HERMES + CLAS spin asymmetries
  
  Kumericki and Mueller (2010)

- **Target-mass corrections (TMC)**: \( \sim \mathcal{O}(M^2/Q^2) \) and \( \sim \mathcal{O}(t/Q^2) \)
  
  Braun, Manashov, Mueller and Pirnay (2014)

---

**Kin2**

- \( x_B = 0.34 - 0.38 \)
- \( Q^2 = 1.8 - 2.0 \text{ GeV}^2 \)

- **Bethe-Heitler**
- **KM10a**
- **KM10a + TMC**

Braun et al., Phys. Rev. D89, 074022

Carlos Muñoz Camacho (IPN-Orsay)
Rosenbluth-like separation of the DVCS cross section

$$\sigma(ep \to ep\gamma) = \left|BH\right|^2 + \mathcal{I}(BH \cdot DVCS) + \left|DVCS\right|^2$$

Known to \(\sim 1\%\)

Linear combination of GPDs

Bilinear combination of GPDs

$$\mathcal{I} \propto 1/y^3 = (k/\nu)^3,$$

$$\left|\mathcal{T}^{DVCS}\right|^2 \propto 1/y^2 = (k/\nu)^2$$

BKM-2010 – at leading twist → 7 independent GPD terms:

$$\{\text{Re}, \text{Im} \left[ C^I, C^{I,V}, C^{I,A} \right] (F) \}$$

and

$$C^{DVCS}(F, F^*)$$

\(\varphi\)-dependence provides 5 independent observables:

$$\sim 1, \sim \cos \varphi, \sim \sin \varphi, \sim \cos(2\varphi), \sim \sin(2\varphi)$$

The measurement of the cross section at two or more beam energies for exactly the same \(Q^2, x_B, t\) kinematics, provides the additional information in order to extract all leading twist observables independently.
E07-007: DVCS beam-energy dependence

- Cross section measured at 2 beam energies and constant $Q^2$, $x_B$, $t$
  
  $E = 4.5$ GeV
  
  $E = 5.6$ GeV

- Leading-twist and LO simultaneous fit of both beam energies (dashed line) does not reproduce the data

Light-cone axis in the $(q,q')$ plane (Braun et al.): $H_{++}$, $\tilde{H}_{++}$, $E_{++}$, $\tilde{E}_{++}$
Beyond Leading Order (LO) and Leading Twist (LT)

Two fit-scenarios:

Light-cone axis in the \((q,q')\) plane (Braun et al.)

LO/LT + HT

\(\mathbb{H}^{++}, \tilde{\mathbb{H}}^{++}, \mathbb{H}_0^+, \tilde{\mathbb{H}}_0^+\)

LO/LT + NLO

\(\mathbb{H}^{++}, \tilde{\mathbb{H}}^{++}, \mathbb{H}^{-+}, \tilde{\mathbb{H}}^{-+}\)
E07-007: DVCS beam-energy dependence

- Cross section measured at 2 beam energies and constant $Q^2$, $x_B$, $t$

- Leading-twist and LO simultaneous fit of both beam energies (dashed line) does not reproduce the data

- Including either NLO or higher-twist effects (dark solid line) satisfactorily reproduce the angular dependence
**DVCS^2 and I (DVCS·BH) separation**

DVCS^2 and I (DVCS·BH) separated in NLO and higher-twist scenarios.

- **DVCS^2 & I** significantly different in each scenario.
- Sizeable DVCS^2 contribution in the higher-twist scenario in the helicity-dependent cross section.

M. Defurne et al., arxiv:1703.09442

Carlos Muñoz Camacho (IPN-Orsay)  
New DVCS results
**E12-06-114: JLab Hall A at 11 GeV**

JLab12 with 3, 4, 5 pass beam  
(6.6, 8.8, 11.0 GeV beam energy)

88 days  
250k events/setting
1st Hall A experiment after the Upgrade (2014–2016)

Scaling tests of the DVCS cross section

Identification of DVCS events:
online $ep \rightarrow e\gamma X$ missing mass squared

$\sim 50\%$ of the required beamtime completed

Data analysis underway...
E12-13-010: DVCS in Hall C

- HMS ($p < 7.3 GeV$): scattered electron
- PbWO$_4$ calorimeter: $\gamma/\pi^0$ detection
- Sweeping magnet
E12-13-010: beam energy separation in Hall C

\[ Q^2 \text{ vs } x_B \text{ coverage in Halls A and C} \]

- Hall C 11 GeV
- Hall C 8.8 GeV
- Hall C 6.6 GeV
- Hall A 11 GeV
- Hall A 8.8 GeV
- Hall A 6.6 GeV
- Hall A 5.75 GeV

Inaccessible with \( E_b < 11 \text{ GeV} \)

Resonance region \( W < 2 \text{ GeV} \)

Approved by the PAC, possible running in \( \gtrsim 2020 \)
Summary

1. Recent high precision DVCS cross sections from Hall A at Jefferson Lab

2. Need of higher twist and/or NLO contributions to fully describe the data (eg. in global GPD fits)

3. First separation of $\text{DVCS}^2$ and BH-DVCS interference in the $ep \rightarrow e\gamma p$ cross section

4. Approved program of experiments in Hall A and C to continue these high precision DVCS measurements at 12 GeV