Deeply Virtual Compton Scattering at JLab 12GeV

First Studies of the Fall 2014 Run at Hall A

Marco Carmignotto

JLab Hall A DVCS Collaboration

6th Workshop of the APS Topical GHP - April 11–14, 2015; Baltimore, Maryland
Topics

- Generalized Parton Distributions and Deeply Virtual Compton Scattering
- DVCS at Jefferson Laboratory, Hall A

Instrumentation:
- Hall A spectrometers
- DVCS: dedicated calorimeter FPGA based data acquisition

Preliminary studies:
- Data acquisition deadtimes monitoring
- Detector efficiencies
- Preliminary missing mass checks: DVCS and $\pi^0$
Generalized Parton Distributions (GPD) encode information on the distribution of partons both in the transverse plane and in the longitudinal direction.

Nucleon structure described by 4 GPDs: $H, E$ (unpolarized), $\bar{H}, \bar{E}$, polarized)

Quark GPDs $E$ and $H$ are connected to the elastic form factors:

$$\int_0^1 dx \, H^q(x, \xi, t, \mu^2) = F_1^q(t)$$

$$\int_0^1 dx \, E^q(x, \xi, t, \mu^2) = F_2^q(t)$$

And also to usual PDFs.

GPDs describe the soft part, i.e., with non-perturbative functions.
Accessing GPDs experimentally

We can access GPDs through hard exclusive reactions

Deeply Virtual Compton Scattering (DVCS)  Deeply virtual meson production (DVMP)

- Simplest and cleanest way to access GPDs experimentally. The spin asymmetry studies in DVCS give access to imaginary part of the scattering amplitude.
- DVCS (flavor blind) probes GPD $H$ and provides additional information on singlet quarks
- Mesons select definite charge, spin, flavor component of GPD
- Quantum numbers in DVMP probe individual GPD components selectively
- Need good understanding of reaction mechanism
  - QCD factorization for mesons is complex (additional interaction of the produced meson)

Images: https://www.jlab.org/highlights/images/physics/dvcs.jpg
Accessing GPDs with DVCS

DVCS amplitudes interfere with E&M Bethe-Heitler:

Interference term:

\[
I = \frac{e^6}{x_B y^3 \mathcal{P}_1(\phi_{\gamma\gamma}) \mathcal{P}_2(\phi_{\gamma\gamma}) t} \left\{ c_0^\gamma \sum_{n=1}^{3} (-1)^n \left[ c_n^\gamma(n) \cos(n\phi_{\gamma\gamma}) - \lambda_{n,\alpha}^\gamma \sin(n\phi_{\gamma\gamma}) \right] \right\}
\]

DVCS\(^2\) term:

\[
|I_{\text{DVCS}}(\lambda)|^2 = \frac{e^6}{y^2 Q^2} \left\{ c_0^\text{DVCS} + \sum_{n=1}^{2} (-1)^n c_n^\text{DVCS} \cos(n\phi_{\gamma\gamma}) + \lambda_{1,\alpha}^\text{DVCS} \sin(n\phi_{\gamma\gamma}) \right\}
\]

Encodes GPDs
DVCS at JLab Hall A - 6 GeV

6 GeV

DVCS helicity-dependent ($d^4\Sigma$) and helicity-independent ($d^4\sigma$) cross sections measured in E00-110 for $Q^2 = 2.3$ GeV$^2$ and $t = -0.28$ GeV$^2$.

Some Fourier coefficients measured

[C. Munoz Camacho et al., 2005]
\[ \pi^0 \] electroproduction

Measurements of the same final state particles: e\(^-\) and photon

Cross section measured at same Q\(^2\), but different epsilon, allow for L/T separation.

\[
\frac{d\sigma}{d\Omega_{\pi}} \mid_{\text{unpol}} = \frac{d\sigma_T}{d\Omega_{\pi}} + \epsilon_L \frac{d\sigma_L}{d\Omega_{\pi}} + \sqrt{2\epsilon_L(1+\epsilon)} \frac{d\sigma_{TL}}{d\Omega_{\pi}} \cos \phi_{\pi} + \epsilon \frac{d\sigma_{TT}}{d\Omega_{\pi}} \cos 2\phi_{\pi}
\]

For example, 6 GeV analysis:

\[ [e p \rightarrow e \pi^0 X] = \]

\[ [\pi^0 \rightarrow 2\gamma] = \]

\[ \pi^0 \] events are in the acceptance:

We will measure the \[ \pi^0 \] electroproduction cross section in the same kinematics, that may allow for L/T separation
DVCS kinematics: JLab @ 12 GeV

- Scaling test of DVCS cross-sections to 5% precision over large arm in $Q^2$
- Separation of $Re$ and $Im$ part of DVCS amplitude (polarized and total cross section)

We have a hint for leading order domination. We will expand the $Q^2$ and $x_{Bj}$ scan to nail that down.

3rd generation of DVCS experiments at JLab Hall A

Planned scans in $Q^2$ and $x_{Bj}$

JLab at 12 GeV and DVCS instrumentation
Jefferson Laboratory at 12 GeV

JLab during the upgrade Commissioning phase now!

Added new cryomodules to double the electron beam energy

Upgrades:

- Upgraded equipment of existing Halls
- Built Hall D (GlueX)
- ...

- Commissioning phase
JLab Hall A

Existing two High Resolution Spectrometers (HRS)

DVCS:
We use the Left HRS to detect

- s2m and s0: scintillators pannels for triggering
- PID: Gas Cherenkov, Pion Rejector calorimeter
- Drift chamber, FPP chamber
Dedicated detector for DVCS

DVCS calorimeter

208 PbF$_2$ blocks calorimeter
Resolution: 3% ~ modest

LH2 Target

Hall A Left HRS

Beam dump

Calorimeter photon energy resolution is our limiting factor in the missing mass reconstruction
Dedicated FPGA electronics for trigger and signal sampling

- 208 channels
- 1 GHz sampling rate
- Digitalization of 128 ns window

Allows for waveform analyses and better separate pile-up events off-line
Sampling and disentangling pile-up events

Two actual examples of pile up events
Taken few days ago, during a production run

Algorithm built to fit and disentangle these events
Preliminary studies
Production runs:
Monitoring deadtimes closely

- DAQ deadtime is a direct normalization factor to the cross sections extractions

- Monitoring of DAQ deadtimes during the runs, for the calculation of deadtime weighted beam current

- In the example, a run taken at with several beam currents for deadtime studies.

- Few beam trips observed (will be removed later for the analysis)

- Mean deadtime of ~5% in a production run

\[
Yield = \frac{N_{\text{events}}}{Q \cdot DAQ_{\text{LIVE}} \cdot \text{eff}}
\]
Monitoring details of the DAQ: Trigger efficiencies

Detector efficiencies are also a direct normalization factor to the cross sections extractions.

- Monitoring trigger efficiencies for the different kinematics of the experiment
Very preliminary first data analysis
2 clusters events

- Invariant mass reconstruction of 2 clusters events
- $\pi^0$ peaks at slightly shifted mass, since we still didn’t tune all the calibration coefficients

![Graph showing invariant mass distribution for 2 clusters events.](chart.png)

Calorimeter energy not fully calibrated yet
Very preliminary analysis:
One cluster events

Some preliminary cuts applied:

- Vertex reconstructed in the target
- Photon energy above 0.6 GeV (expected DVCS range)
- PID: pion rejection
- Time of event at the calorimeter

Cut example: time of event in the calorimeter

Exclusive peak in missing mass
DVCS events

![Graph showing DVCS events and cuts applied](image)
2014/2015 data taking continues...

- Running the experiment together with the JLab 12 GeV commissioning
- 100 days approved to run the DVCS experiment at JLab Hall A
- Run time already scheduled/planned for 2016
- Scaling test of DVCS cross section for leading order factorization confirmation
- Extraction of \( t \)-dependent polarized and unpolarized DVCS cross section (and \( \pi^0 \) electroproduction) over a wide kinematic range
  - \( Q^2 \) from 2 to 9 GeV²
  - \( x_B = 0.36, 0.5, \) and 0.6

Thank you!

More about DVCS at Hall A at the APS meeting:
Lee Allison, “The Spring 2015 JLab Hall A Deeply Virtual Compton Scattering Run”
Sunday, April 12, 2015 - 1:30PM