DVCS cross sections from CLAS

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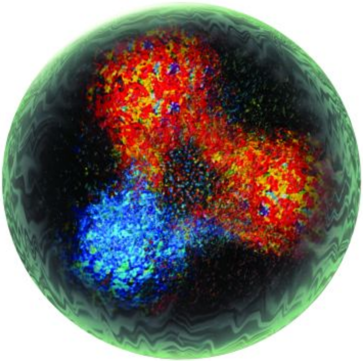
Examining a Nucleon

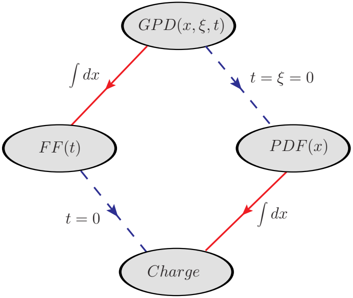
Gazing into a Nucleon



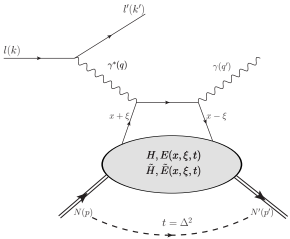
- What does the interior of a nucleon look like?
- What is its spin structure?
- Historically, we have answered the structure question in terms of Form Factors (FFs) and Parton Distribution Functions (PDFs)
- The spin structure is still quite a puzzle

Generalized Parton Distributions (GPDs)

- X. Ji, D. Müller, A. Radyushkin
- GPDs: Extension of FF and PDF concept
- Allows for simultaneous access of three dimensional picture
- GPDs may be accessed:
  - Deeply Virtual Compton Scattering (DVCS)
  - Deeply Virtual Meson Production (DVMP)



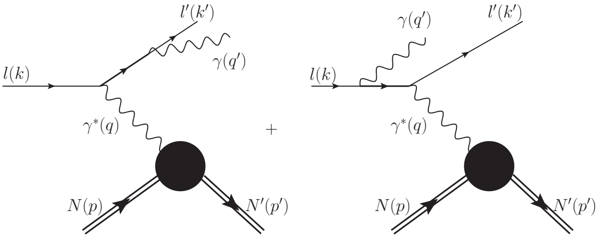
Accessing via DVCS - The Handbag Diagram



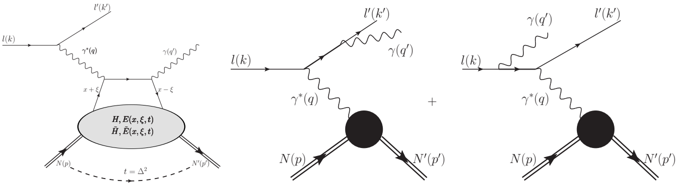
- GPDs can be accessed via DVCS
- X. Ji showed that the DVCS handbag diagram can be factorized into hard QED and soft QCD components
- The parametrizations of the QCD part are the GPDs
- Integrals over GPDs (Compton Form Factors (CFFs)) are accessed by measuring DVCS cross sections

Bethe-Heitler

- When measuring the $e + p \to e' + p' + \gamma$ reaction, Bethe-Heitler is also inseparably measured.
- It is a known QED process



DVCS Cross Section



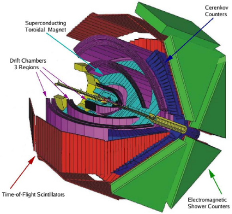
$$
\begin{aligned}
\sigma_{unp} &\propto |\mathcal{M}_{BH}|^2 + 2\,\mathcal{M}_{BH}\,Re(\mathcal{M}_{DVCS}) + |\mathcal{M}_{DVCS}|^2 \\
\sigma_{pol} &\propto 2\,\mathcal{M}_{BH}\,Im(\mathcal{M}_{DVCS}) \qquad (1)
\end{aligned}
$$

Jefferson Laboratory

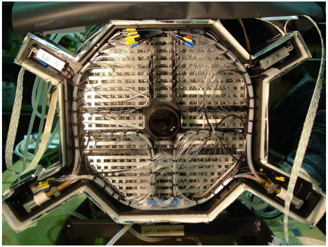
- Electron accelerator
- Newport News, VA, USA
- 6 GeV era experiment

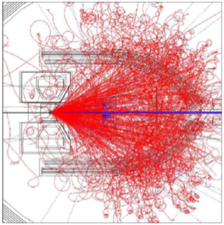
Hall B, CLAS

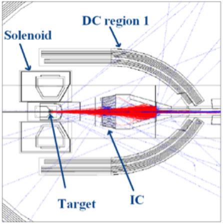
- CLAS detector was used for e1-dvcs1 and 2
- Designed to have very large acceptance



e1-dvcs2 experiment







- 5.88 GeV
- Inner Calorimeter (IC) used for forward DVCS photons
- 424 $PbWO_4$ crystals
- $4^\circ - 12^\circ$ polar acceptance
- LH2 (proton!) target, 19K, 5 cm

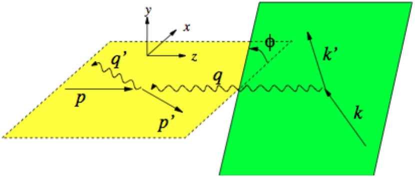
Steps to Obtain Cross Sections

- Particle Identification
- Define Kinematic Bins
- Exclusivity Cuts
- Construct Cross Sections

$$\frac{\mathrm{d}^4\sigma_{unp}}{\mathrm{d}Q^2\mathrm{d}t\mathrm{d}x_B\mathrm{d}\Phi} = \frac{\left(N_{e+p+\gamma} - N_{e+p+\pi^0(1\gamma)}\right)}{\mathcal{L}_{\text{int}} A \Delta V F_{\text{rad}}}, \quad (2)$$

$$\frac{\mathrm{d}^4\sigma_{\text{pol}}}{\mathrm{d}Q^2\mathrm{d}t\mathrm{d}x_B\mathrm{d}\Phi} = \frac{1}{2P}\left(\frac{\mathrm{d}^4\sigma_{+}}{\mathrm{d}Q^2\mathrm{d}t\mathrm{d}x_B\mathrm{d}\Phi} - \frac{\mathrm{d}^4\sigma_{-}}{\mathrm{d}Q^2\mathrm{d}t\mathrm{d}x_B\mathrm{d}\Phi}\right) \quad (3)$$

Cross Section Variables



- $Q^2 = -q \cdot q = -(p_e - p'_e)^2$
- $x_B = \frac{Q^2}{2p_p \cdot q}$
- $t = (p_p - p'_p)^2$
- ϕ angle between leptonic and hadronic plane

Particle Identification

Electrons

- Triggered on Cherenkov detector
- Separated from MIPs with sampling fraction cut in CLAS electromagnetic calorimeters

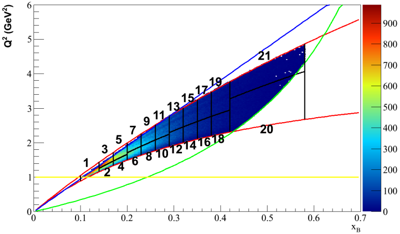
Protons

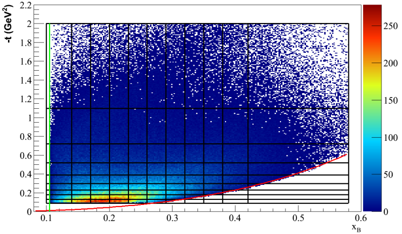
- Separated from other positive charged particles by time-of-flight-cut, $\Delta\beta = \beta_{TOF} - \beta_{DC}$

Photons

- Detected both in IC and CLAS electromagnetic calorimeters

Kinematical Domain



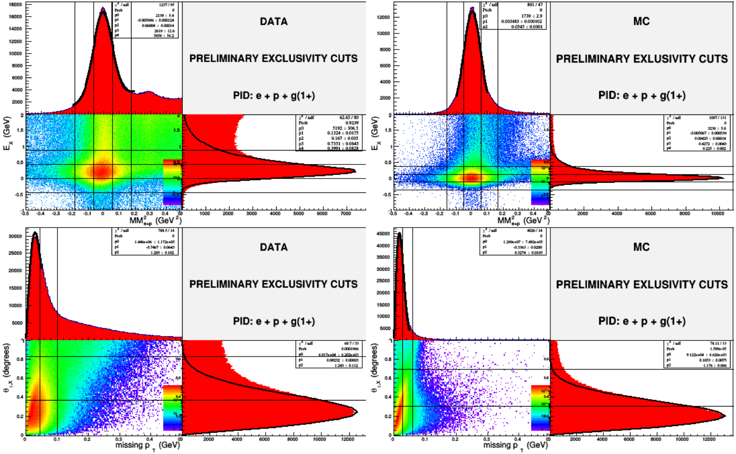


- 21 bins in x_B and Q^2
- 9 bins in t
- 24 bins in ϕ

Event Selection, Exclusivity Cuts

1. p_T: the perpendicular component of missing momentum in the $ep \rightarrow e'p'\gamma X$ reaction,
2. E_X: the missing energy in the $ep \rightarrow e'p'\gamma X$ reaction,
3. $MM^2_{e'+p'}$: the squared missing mass of the $ep \rightarrow e'p'X$ system,
4. $\theta_{X,\gamma}$: the difference between the calculated polar angle of the photon from the scattered electron and recoil proton measured kinematics $ep \rightarrow e'p'X$ and the detected one $ep \rightarrow e'p'\gamma$,
5. $\Delta\phi$: the coplanarity of the virtual photon, the real photon and the recoil proton.

Event Selection, Exclusivity Cuts

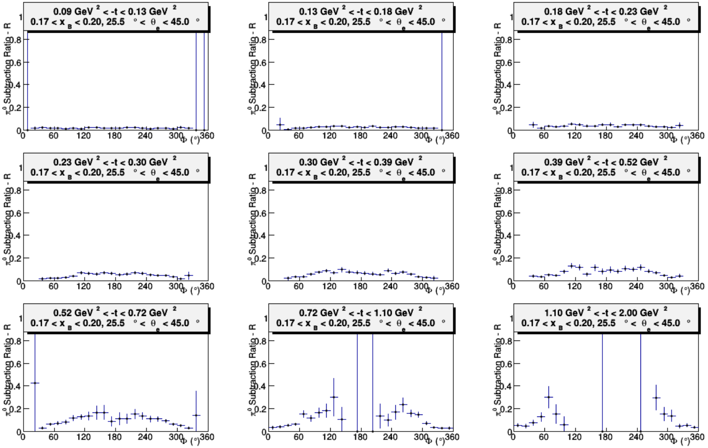


Neutral Pion Contamination, Removal

- Pion contamination occurs in the form of π_0 decaying, and one photon entering into CLAS or IC
- We cannot distinguish this from DVCS in experiment
- An estimation of the contamination can be made by using simulation
- We can calculate the ratio of $e + p + \pi_0(\gamma)$ to $e + p + \pi_0(\gamma\gamma)$ in simulation
- The ratio is the same in experiment, therefore one needs only $e + p + \pi_0(\gamma\gamma)$ in experiment

$$N_{\pi^0}^{\gamma} = N_{\pi^0}^{\gamma\gamma} \frac{N_{\pi^0,\mathrm{sim}}^{\gamma}}{N_{\pi^0,\mathrm{sim}}^{\gamma\gamma}},$$

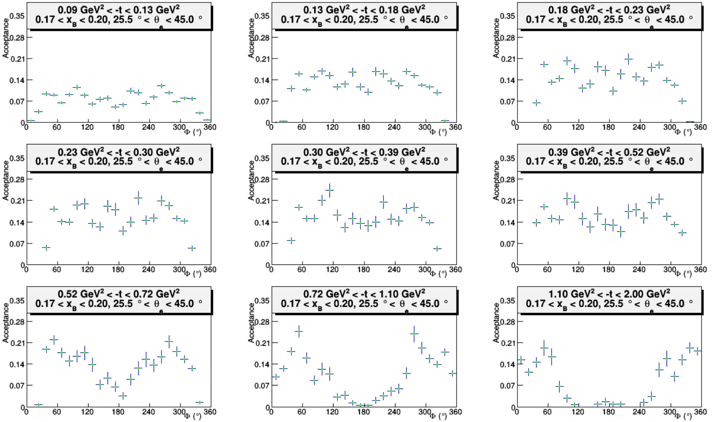
Neutral Pion Contamination, Removal



Acceptance, Simulation

- The acceptance of CLAS is calculated as $\frac{N_{rec}}{N_{gen}}$
- N_{gen} is the number of generatred events bin per bin
- N_{rec} is the number of reconstructed events bin per bin
- By reconstructed, we mean that they are simulated events that pass all PID and channel selection cuts

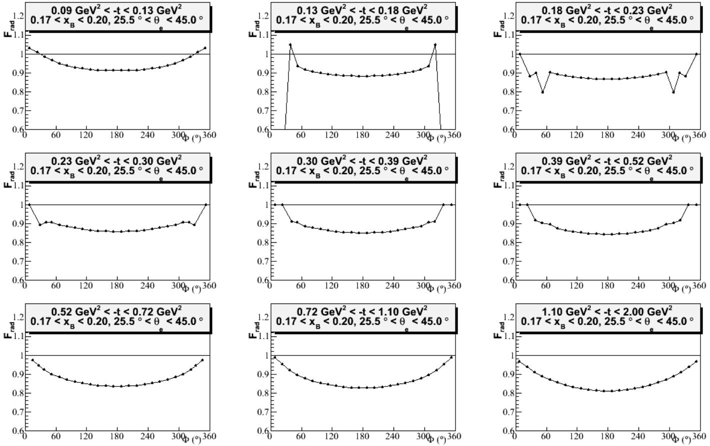
Acceptance, Simulation



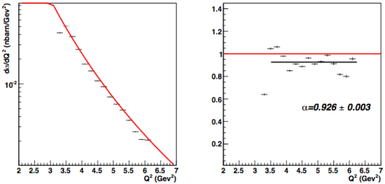
Radiative Corrections

- Radiative effects, both internal and external, are present in experiment
- In order to make the connection between the cross section describe in the theory section (the Born term), we must determine the ratio between the all-radiative-included cross section, and the Born cross section
- This has been done by several people
- The radiative corrections used in this analysis are performed by I. Akushevich

Radiative Corrections



Elastic Normalization



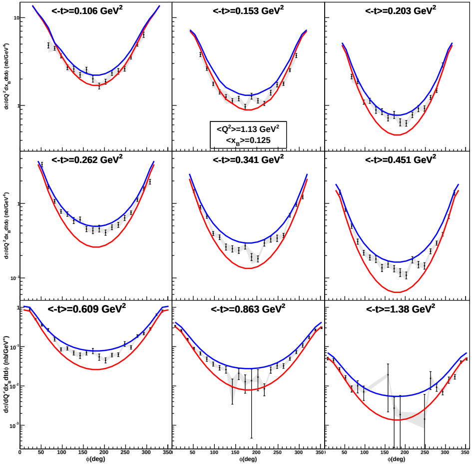
- CLAS requires an overall normalization factor
- E.g., the elastic cross section results in an overall lower cross section value than literature
- This is due to electron and proton detection/acceptance
- Photons do not suffer from this difficulty
- Therefore, the overall normalization based on the elastic channel is taken

Systematic Uncertainties

Systematic Uncertainties

Source	Error (%)
Global Normalization	5
Exclusivity Cuts	5.5
Fiducial Cuts	4.2
Radiative Corrections	3
Total Estimate	10.3

Final Extraction of Cross Sections



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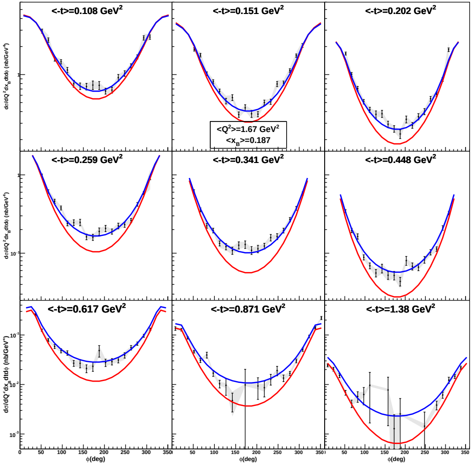

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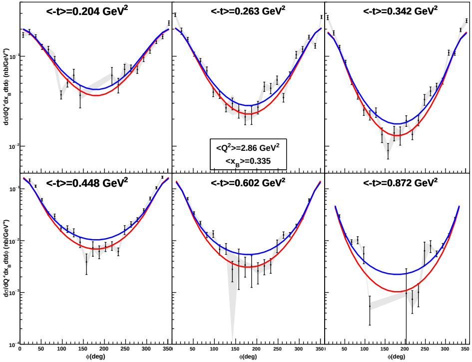
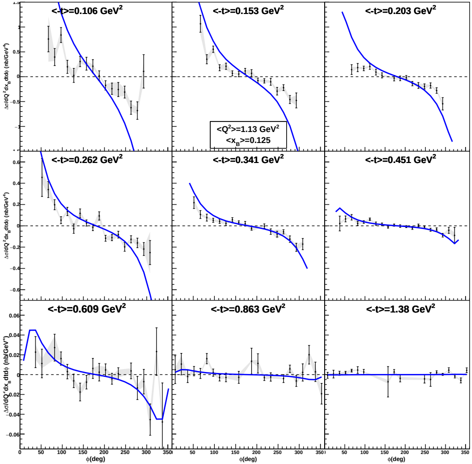


Final Extraction of Cross Section Differences



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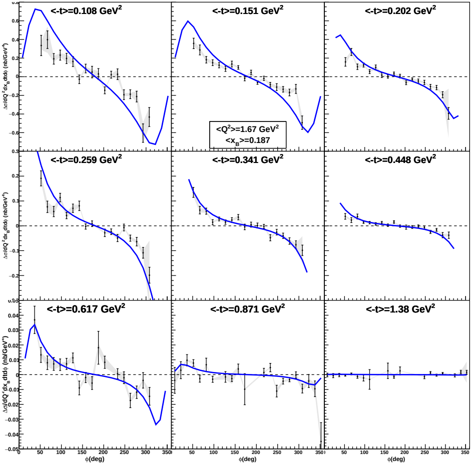

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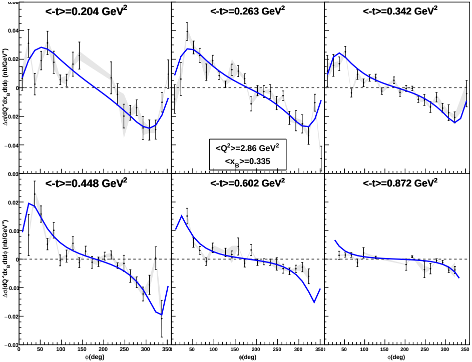
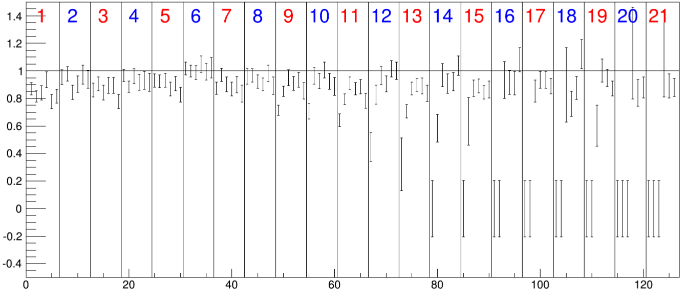


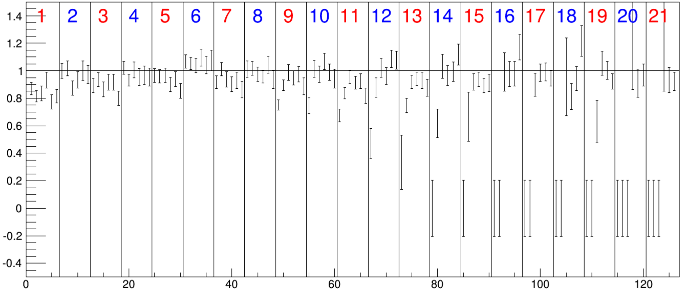
Comparison with e1-dvcs1

- Experiments are at different kinematics
- Beam energies are different
- Target and geometry are different



Comparison with e1-dvcs1, with beam corrections

- A correction was worked out to take into account the different in beam energy between e1-dvcs1 and 2
- A substantial improvement results



Status of Publication

- We plan to submit to Physics Review C
- Internal analysis review - *complete*
- Ad Hoc review - *in progress*
- Collaboration wide review - *to do*
- Journal submission - *to do*

Questions?