Extraction of CFFs observables from DVCS

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2021 - DNP Meeting

October 14^{th} 2021

Introduction Generalized Parton Distributions

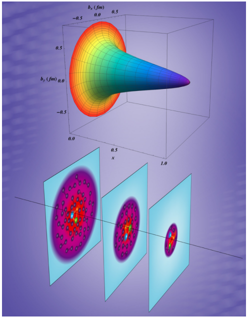
GPDs provide correlated information of the **transverse position** and the **longitudinal momentum** distributions of partons.

$$GPDs\,(\underbrace{x,\ \xi}_{},\ t\ =\ \Lambda^2)$$

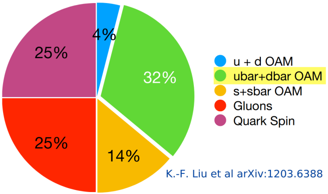
2 longitudinal momentum fractions

squared momentum transfer to the proton

$$t \rightarrow \Delta_T \xrightarrow{Fourier\ transform} \mathbf{b}\,(transverse\ position)$$



R. Dupre et al arXiv:1704.07330



K.-F. Liu et al arXiv:1203.6388

Proton spin contributions from Lattice QCD

Access form factors of energy-momentum tensor:

$$\int_{-1}^{+1} dx x H^q(x,\xi,t) = A(t) + \xi^2 C(t)$$

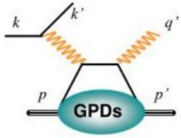
$$\int_{-1}^{+1} dx x E^q(x,\xi,t) = B(t) - \xi^2 C(t)$$

Ji's angular momentum sum rule

$$\int_{-1}^{+1} dx x \left\{H^q(x,\xi,0) + E^q(x,\xi,0)\right\} = A(0) + B(0) = 2J^q$$

- **CFFs are directly linked to the tomography of the proton.**
- **CFFs give insights on: Spin structure, energy-momentum structure**

Deep Virtual Compton Scattering (DVCS) is the simplest process involving Generalized Parton Distribution functions (GPDs).



$$ep \longrightarrow e^{'}p^{'}\gamma$$

Twist-2

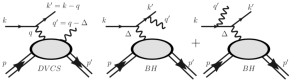
Chiral even GPDs: quark helicity is conserved

	conserve nucleon helicity	flip of the nucleon helicity
averages over quark helicities "unpolarized"	H	E
differences of quark helicities "polarized"	$\widetilde{H}$	$\widetilde{E}$

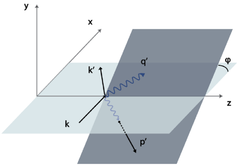
Accesing GPDs through DVCS

DVCS cross section is parametrized in terms of the Comptom Form Factors (CFFs). At twist-2 there are 8 CFFs $(\mathcal{H}, \mathcal{E}, \widetilde{\mathcal{H}}, \widetilde{\mathcal{E}})$ considering their $\Re e$ and $\Im m$ parts, that are given by the convolution of GPDs:

$$\mathcal{H}\left(x_B,\, t,\, Q^2\right) = \int_{-1}^{1} dx \left[\frac{1}{\xi - x - i\epsilon} - \frac{1}{\xi + x - i\epsilon}\right] H\left(x,\, \xi,\, t,\, Q^2\right)$$



$$\underbrace{\frac{d^5\sigma}{dx_{Bj}dQ^2d|t|d\phi d\phi_S} = \frac{\alpha^3 x_B y^2}{16\pi^2 Q^4\sqrt{1+\epsilon^2}}\frac{1}{e^6}\left[|\mathcal{T}^{BH}|^2+|\mathcal{T}^{DVCS}|^2+\mathcal{I}\right]}_{f(k,Q^2,x_B,t,\phi)} \, .$$



[B. Kriesten, S. Liuti, et al arXiv:1903.05742]

DVCS cross section formulations

- VA [B. Kriesten, S. Liuti, et al arXiv:1903.05742]
  - Written in terms of helicity amplitudes.
  - Covariant description
- BKM (2002) [A.V. Belitsky, D. Muller, A. Kirchner arXiv:0112108v2]
  - Written in terms of harmonics of the azimuthal angle, ϕ, and in kinematic powers of 1/Q.

JLab Hall A @ 6 GeV

- Unpolarized beam
- Unpolarized H_2 target
- 20 kinematic sets in x_B, t, Q^2
- $Q^2[1.453, 2.375]GeV^2$
- $t[-0.121, -0.4]GeV^2$
- $x_B[0.336, 0.401]$

Unpolarized Twist-2 → $\Re e\mathcal{H}$, $\Re e\mathcal{E}$, $\Re e\widetilde{\mathcal{H}}$

Extraction Methods ϕ space fit

$$\frac{d^5\sigma}{dx_{Bj}dQ^2d|t|d\phi d\phi_S} = \frac{\alpha^3 x_B y^2}{16\pi^2 Q^4\sqrt{1+\epsilon^2}}\frac{1}{e^6}\left[\underbrace{|\mathcal{T}^{BH}|^2}_{\substack{\text{Exact (QED)}\\ \text{FFs: } F_1,\, F_2}} + \underbrace{|\mathcal{T}^{DVCS}|^2}_{\phi\text{-indep}} + \underbrace{\mathcal{I}}_{\text{3 CFFs}}\right].$$

V A

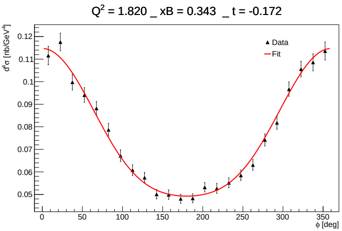
$$|\mathcal{T}_{DVCS}|^2 = \frac{1}{Q^2(1-\epsilon)}\underbrace{F_{UU,T}}_{\text{8 CFFs}}$$

$$\mathcal{I}^{VA} = \frac{1}{Q^2|t|}\left[A^{VA}_{UU}\left(F_1\Re e\mathcal{H} - \frac{t}{4M^2}F_2\Re e\mathcal{E}\right) + B^{VA}_{UU}G_M\left(\Re e\mathcal{H} + \Re e\mathcal{E}\right) + C^{VA}_{UU}G_M\Re e\widetilde{\mathcal{H}}\right]$$

B K M

$$|\mathcal{T}_{DVCS}|^2 = \frac{e^6}{y^2Q^2}\left\{2(2-2y-y^2)\right\}\underbrace{C^{DVCS}_{unp}(\mathcal{F},\mathcal{F}^*)}_{\text{8 CFFs}}$$

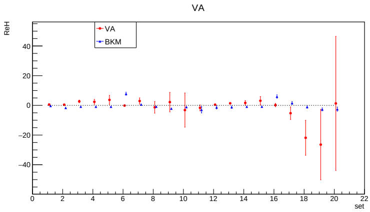
$$\mathcal{I}^{BMK} = \frac{e^6}{x_B y^3 t\mathcal{P}_1(\phi)\mathcal{P}_2(\phi)}\left[A^{BKM}_{UU}\left(F_1\Re e\mathcal{H} - \frac{t}{4M^2}F_2\Re e\mathcal{E}\right) + B^{BKM}_{UU}G_M\left(\Re e\mathcal{H} + \Re e\mathcal{E}\right) + C^{BKM}_{UU}G_M\Re e\widetilde{\mathcal{H}}\right]$$

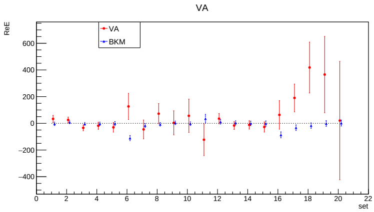


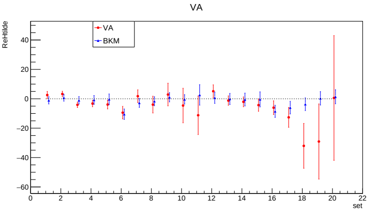
4 fit parameters:

$\Re e\mathcal{H}$, $\Re e\mathcal{E}$, $\Re e\widetilde{\mathcal{H}}$, pure DVCS

Extraction Methods ϕ space fit







$k = 5.75GeV$

$Q^2[1.453, 2.375]GeV^2$

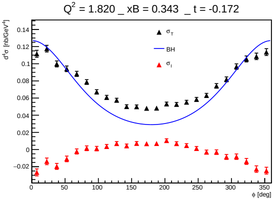
$t[-0.121, -0.4]GeV^2$

$x_B[0.336, 0.401]$

Improve results by imposing fit constraints.

Extraction Methods A_{UU}/B_{UU} space fit

VA Linear Method [B. Kriesten, S. Liuti, et al arXiv:1903.05742]



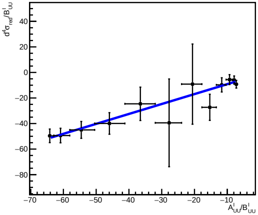
Change of variables

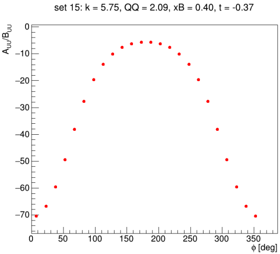
$$\phi \longrightarrow \frac{A^I_{UU}}{B^I_{UU}}$$

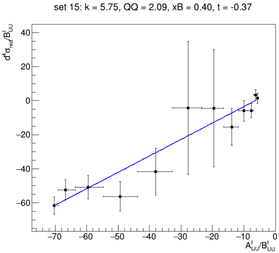
$$d^4\sigma^I_{UU} = d^4\sigma^T_{data} - d^4\sigma^{BH} - d^4\sigma^{DVCS}$$

$$\frac{Q^2(-t)}{B^I_{uu}\Gamma} d^4\sigma^I_{UU} = \frac{A^I_{uu}}{B^I_{uu}} \underbrace{(F_1 \Re e\mathcal{H} + \tau F_2 \Re e\mathcal{E})}_{slope} + \underbrace{G_M(\Re e\mathcal{H} + \Re e\mathcal{E})}_{intercept}$$

$$+ \underbrace{\frac{C^I_{uu}}{B^I_{uu}}}_{\sim small} G_M \Re e\widetilde{\mathcal{H}}$$







- Weighted average of symmetric points.
- $\frac{A_{UU}}{B_{UU}}(\phi)$ is not linear

$$\Downarrow$$

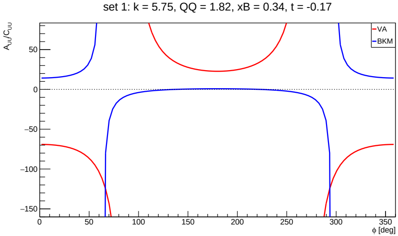
Asymmetric bins in $\frac{A_{UU}}{B_{UU}}$

Extraction Methods

Pseudo-data study

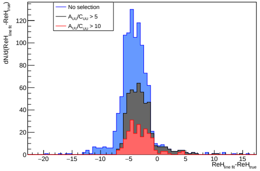
$\frac{A_{UU}}{B_{UU}}$ systematic

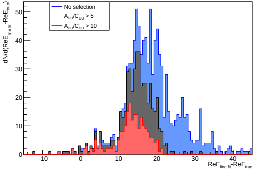
$$\frac{Q^2(-t)}{B^I_{uu}\Gamma} d^4\sigma^I_{UU} = \frac{A^I_{uu}}{B^I_{uu}} \underbrace{(F_1 \Re e\mathcal{H} + \tau F_2 \Re e\mathcal{E})}_{slope} + \underbrace{G_M(\Re e\mathcal{H}+\Re e\mathcal{E})}_{intercept} + \underbrace{\frac{C^I_{uu}}{B^I_{uu}}}_{\sim small} G_M \Re e\widetilde{\mathcal{H}}$$



$\frac{C^I_{uu}}{B^I_{uu}}$ is generally small. BKM has a larger plateau around the largest values of the $\frac{C^I_{uu}}{B^I_{uu}}$. This behavior depends on the kinematic settings.

To account for the effect of this approximation, pseudo-data is generated at the HallA kinematics.





VA Pseudo-data

Toy Model

Higher ϕ resolution

Large kinematic range

1058 sets

ϕ-fit and VA line fit comparison

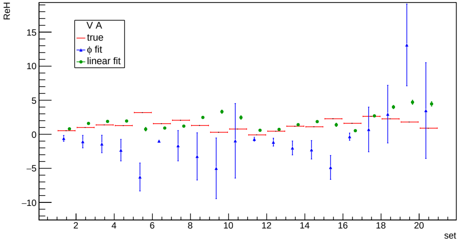
VA Pseudo-data

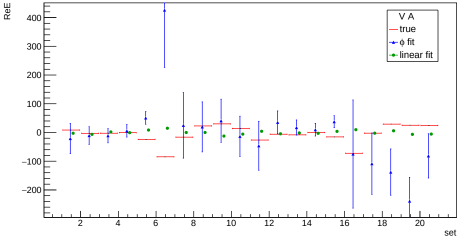
20 kinematics sets of the HallA data.

$k = 5.75 GeV$
$Q^2[1.453, 2.375]GeV^2$
$t[-0.121, -0.4]GeV^2$
$x_B[0.336, 0.401]$

CFFs set at the values obtained from the data ϕ fit.

Cross sections with 5% variation.





VA linear method greatly improve the extraction of the $\Re e\mathcal{H}$ and $\Re e\mathcal{E}$ CFFs at the HallA kinematics.

Results will be reported using the **linear fit** method for the **VA formulation**.

Extraction Methods

Pseudo-data study

ϕ-fit and VA line fit comparison

BKM Pseudo-data

20 kinematics sets of the HallA data.

$k = 5.75 GeV$

$Q^2[1.453, 2.375] GeV^2$

$t[-0.121, -0.4] GeV^2$

$x_B[0.336, 0.401]$

CFFs set at the values obtained from the data ϕ-fit.

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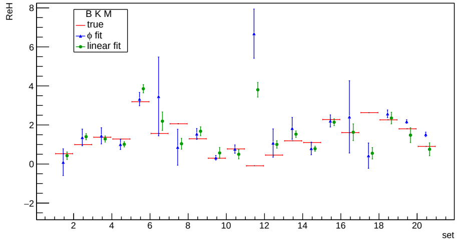
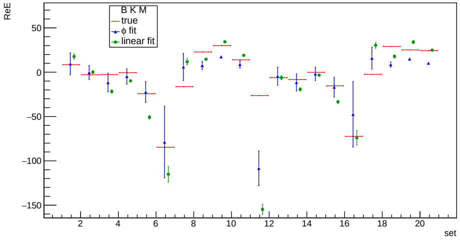




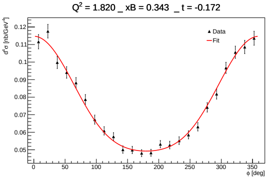
There are no marked improvements applying the VA linear method fit for the extraction of CFFs $\Re e\mathcal{H}$ and $\Re e\mathcal{E}$ at the HallA kinematics.

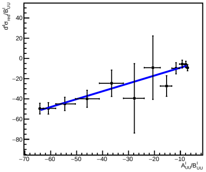
Results will be reported using the ϕ**-fit** for the **BKM formulation**.

Extraction Methods   Simultaneous fit

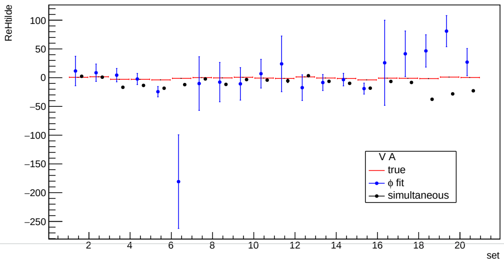
$\Re e\widetilde{\mathcal{H}}$ cannot be extracted from VA linear method.

Set constraints to extract $\Re e\widetilde{\mathcal{H}}$ by performing a simultaneous fit:





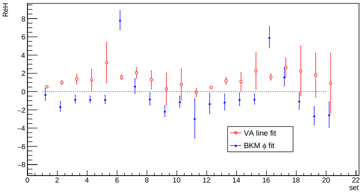
Simultaneous $\chi^2 = \chi^2_{\phi space} + \chi^2_{A_{UU}/B_{UU} space}$

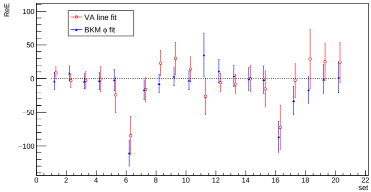


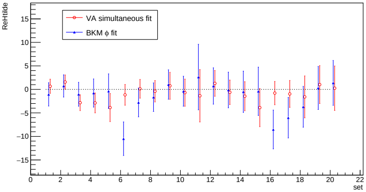
The results for the extraction of $\Re e\widetilde{\mathcal{H}}$ from the VA formalism are reported performing a **simultaneous** fit.

CFFs extraction with BKM formalism are shown with the ϕ results since the extraction does not improve with the VA line method.

Results







$k = 5.75 GeV$

$Q^2[1.453, 2.375]GeV^2$

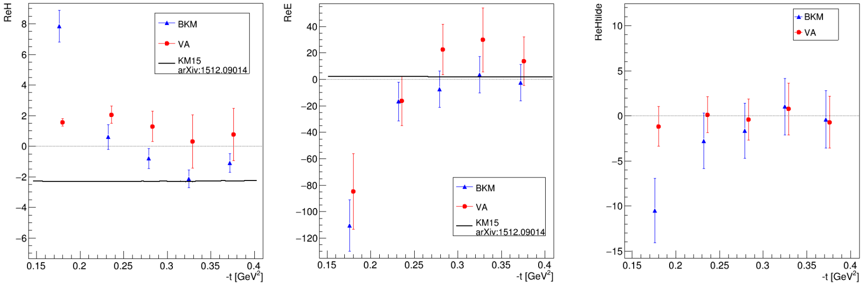
$t[-0.121, -0.4]GeV^2$

$x_B[0.336, 0.401]$

Results

CFFs vs t

Kin 3: $x_B[0.345, 0.373]$, $Q^2[2.218, 2.375]GeV^2$



Summary and Future Work

- The CFFs $\Re e\mathcal{H}$, $\Re e\mathcal{E}$ and $\Re e\widetilde{\mathcal{H}}$ were extracted from the JLab Hall A @ 6 GeV DVCS data using the VA and BKM(2002) model fit.
- The obtained CFFs are consistent in the 2 formulation within the errors for all kinematic settings, except for $\Re e\mathcal{H}$ that displays a different sign behavior.
- Use additional constraints with Artificial Neural Network to optimize the CFFs extraction.
- Study the systematic limits of the extraction in the A_{UU}/B_{UU}-space.

THANK YOU!