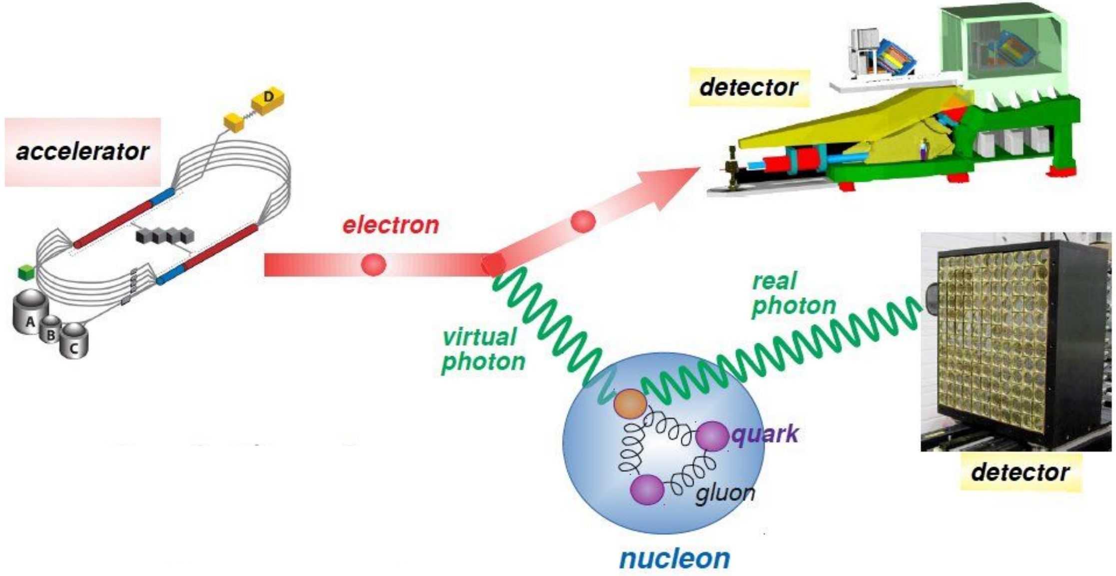
Simultaneous fitting of DVCS cross section:

Extraction of the CFFs, ReH and ReE

Deeply Virtual Compton Scattering (DVCS)

$$ep \to e'p'\gamma$$

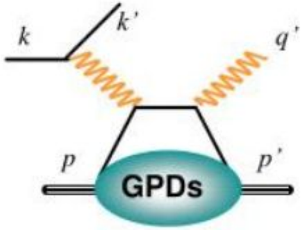


Deeply Virtual Compton Scattering (DVCS)

$$ep \rightarrow e'p'\gamma$$

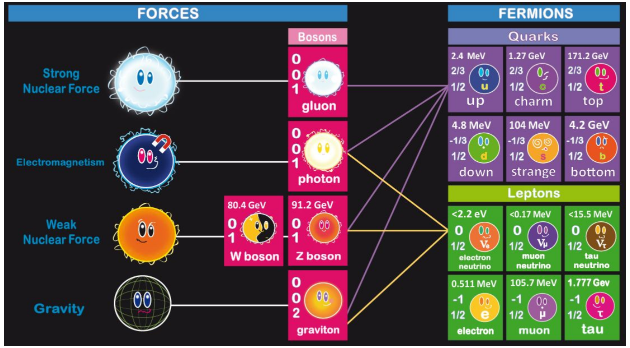
Why?

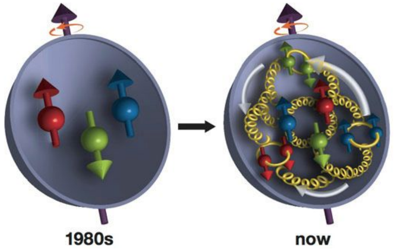
Simplest process involving
Generalized Parton Distribution functions (GPDs)



GPDs Formalism

Force carries and matter particles





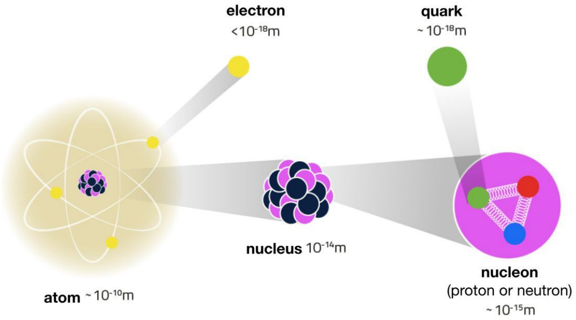
Naive quark model
(only valence quarks)

Surprising data from late 1980s!
Quark contribution is small

➡ Spin crisis

$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + L_z$$

quark spin ($\Delta\Sigma$), gluon spin (ΔG), orbital angular momentum (L_z)



Access to Lz

It is necessary to have *transverse* information.
Coordinate space: GPDs

Gain insight of the structure of quarks and qluons inside the proton

3D imaging of the proton

GPDs Formalism

GPDs provide correlated information on transverse spatial and longitudinal momentum distributions of partons.

$$GPD(x, \xi, t = \Lambda^2)$$

Longitudinal momentum fractions

- x is integrated over in the scattering amplitude
- ξ is fixed by the process kinematics.

$$\xi = \frac{x_B}{2 - x_B}$$

x_B Bjorken variable

Squared momentum transfer to the proton

- $$t = (p' - p)^2$$

In terms of the transverse momentum transfer $\Delta_T = p'_T - p_T$

$$t = \frac{-(\Delta_T^2 + 4\xi^2 M^2)}{(1 - \xi^2)}$$

DVCS cross section

Measure of the probability that two particles will collide and react in a specific process.

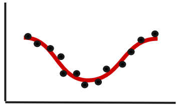
$$ep \rightarrow e'p'\gamma$$

Experiment
$d\sigma_{exp}$

Theoretical Model
$d\sigma_{theory}$

Jefferson Lab Hall A
6 GeV

Extraction of Generalized Parton Distribution Observables from Deeply Virtual Electron Proton Scattering Experiments
arXiv:1903.05742v3



Extract $\Re e\mathcal{H}$ and $\Re e\mathcal{E}$ from fit parameters

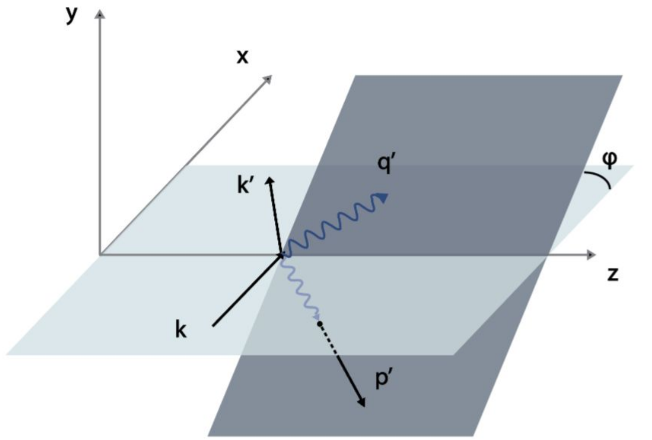
Connected to GPDs

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

DVCS cross section

- *Kinematic settings*

$$ep \to e'p'\gamma$$



4-momentum vectors

k incoming electron
k' outgoing electron
q virtual exchange photon
q' outgoing photon
p' outgoing proton

$$d\sigma(k, x_B, t, Q^2, \phi)$$

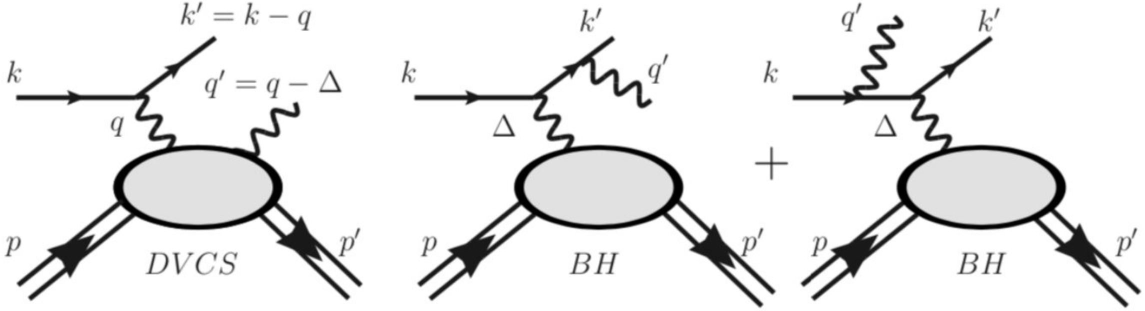
- k Energy of the incoming electron
- Q^2 Electron squared momentum transfer $-(k-k')^2$
- t Squared momentum transfer to the proton $(p'-p)^2$
- x_B Bjorken variable

$$x_B = \frac{Q^2}{2(pq)}$$

Determines the momentum fraction of the quark or gluon on which the photon scatters.

- �� Azimuthal angle between the hadron plane formed by the outgoing proton and photon and the lepton plane

DVCS $d\sigma_{theory}$ fit function



$$\sigma_{UU} = \sigma_{UU}^{DVCS} + \sigma_{UU}^{BH} + \sigma_{UU}^{\mathcal{I}}$$

DVCS $d\sigma_{theory}$ fit function

$$\sigma_{UU} = \sigma_{UU}^{DVCS} + \sigma_{UU}^{BH} + \sigma_{UU}^{\mathcal{I}}$$

Fitting parameter

$$\sigma_{UU}^{BH} = \frac{\Gamma}{t}\left[A_{UU}^{BH}\left(F_1^2 + \tau F_2^2\right) + B_{UU}^{BH}\tau G_M^2(t)\right]$$

Elastic Form Factors

$$F_1 = \frac{2.7928}{(1-1.40716\,t)^2} - F_2 \qquad F_2 = \frac{1.7928}{(1-1.40716\,t)^2\left(1-\frac{t}{4M^2}\right)}$$

$$A_{UU}^{BH} = \frac{16\,M^2}{t(kq')(k'q')}\left[4\tau\left((kP)^2 + (k'P)^2\right) - (\tau+1)\left((k\Delta)^2 + (k'\Delta)^2\right)\right]$$

$$B_{UU}^{BH} = \frac{32\,M^2}{t(kq')(k'q')}\left[(k\Delta)^2 + (k'\Delta)^2\right]$$

$$\sigma_{UU}^{\mathcal{I}} = \frac{\Gamma}{Q^2(-t)}\left[A_{UU}^{\mathcal{I}}\left(F_1\,\Re e\mathcal{H} + \tau F_2\,\Re e\mathcal{E}\right) + B_{UU}^{\mathcal{I}} G_M\left(\Re e\mathcal{H} + \Re e\mathcal{E}\right) + C_{UU}^{\mathcal{I}} G_M \Re e\widetilde{\mathcal{H}}\right]$$

Compton Form Factors (CFFs)

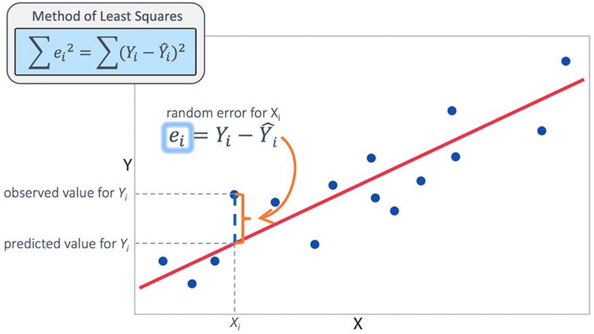
Fitting parameters

~small

$$A_{UU}^{\mathcal{I}} = -\frac{4}{(kq')(k'q')}\Big\{(Q^2+t)\Big[2((kP)+(k'P))(kk)_T + (Pq)(kq')_T + 2(k'P)(kq') - 2(kP)(k'q') + (k'q')(kP)_T + (kq')(k'P)_T - 2(kk')(kP)_T\Big] + (Q^2 - t + 4(k\Delta))\Big[(Pq')((kk')_T + (kq')_T - 2(kk')) + 2(kk')(Pq')_T - (k'q')(kP)_T - (kq')(k'P)_T\Big]\Big\}\cos\phi$$

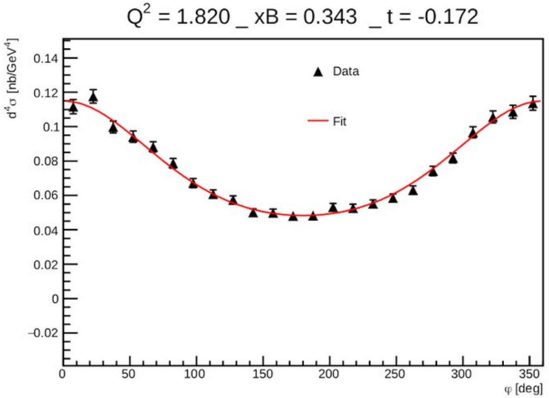
$$B_{UU}^{\mathcal{I}} = \frac{2\xi}{(kq')(k'q')}\Big\{(Q^2+t)\Big[2(kk)_T((k\Delta)+(k'\Delta)) + (kq')_T\Big((q\Delta) - (kq') - (k'q') + 2(kk')\Big) + 2(kq')(k'\Delta) - 2(k'q')(k\Delta)\Big] + (Q^2 - t + 4(k\Delta))\Big[((kk)_T - 2(kk'))(q'\Delta) - (kk')\Delta_T^2 - 2(k\Delta)_T(kq')\Big]\Big\}\cos\phi$$

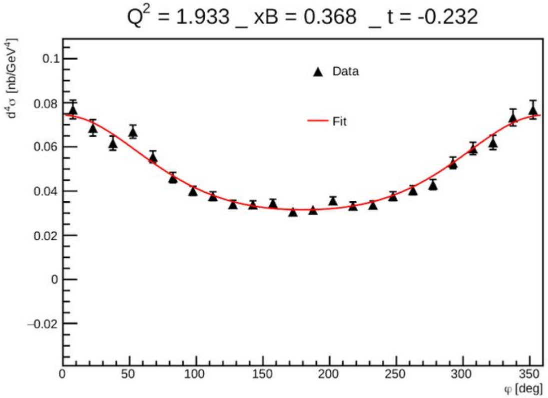
Local Fit



Jefferson Lab Hall A
E00-110 experiment
6 GeV

20 kinematic bins



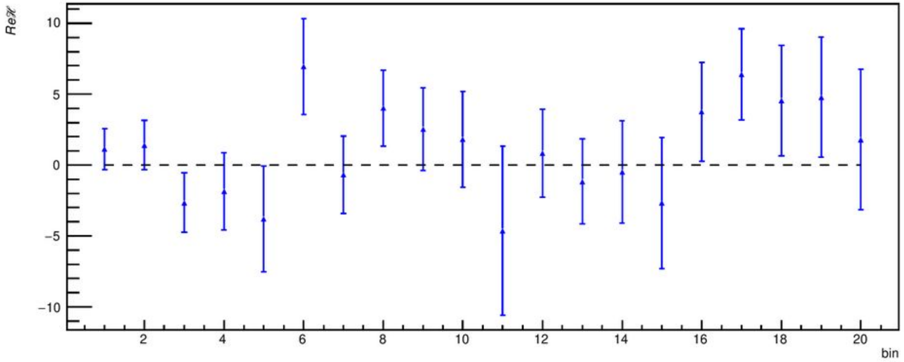


CFFs are free parameters of the fit

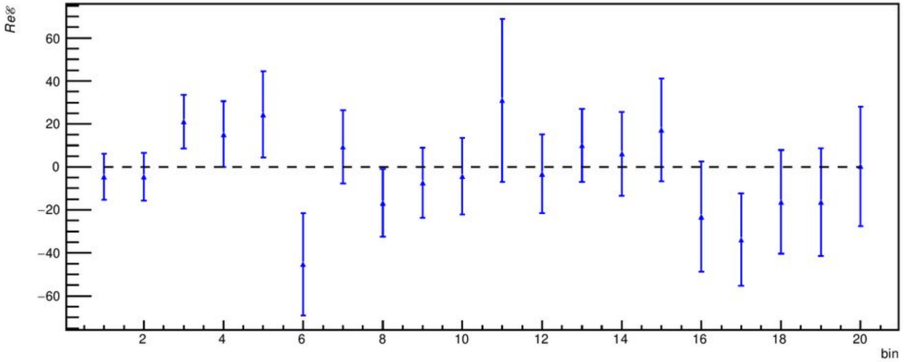
Local Fit

- *Results*

$\Re e \mathcal{H}$

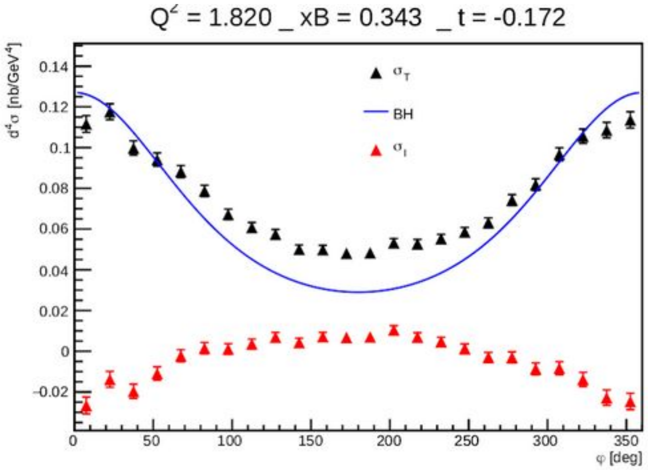


$\Re e \mathcal{E}$



KL Separation

- *Transform the cross section into a line space.*



$$\sigma_{UU} = \sigma_{UU}^{DVCS} + \sigma_{UU}^{BH} + \underline{\sigma_{UU}^{\mathcal{I}}}$$

Term with CFFS

$$\sigma_{UU}^{\mathcal{I}} = \sigma_{UU} - \sigma_{UU}^{DVCS} - \sigma_{UU}^{BH}$$

data

Fit parameter from the local fit

$$\sigma_{UU}^{\mathcal{I}} = \frac{\Gamma}{Q^2(-t)}\left[A_{UU}^{\mathcal{I}}\left(F_1\Re e\mathcal{H} + \tau F_2\Re e\mathcal{E}\right) + B_{UU}^{\mathcal{I}}G_M\left(\Re e\mathcal{H} + \Re e\mathcal{E}\right) + C_{UU}^{\mathcal{I}}G_M\Re e\widetilde{\mathcal{H}}\right]$$

The coefficients can be written in the form:

$$\frac{Acos^2(\phi) + Bcos(\phi) + C}{Dcos^2(\phi) + Ecos(\phi) + F} \quad cos(\phi)$$

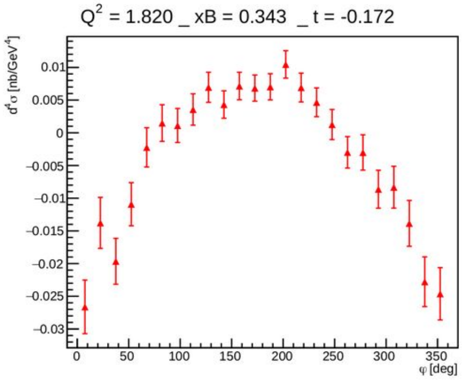
KL Separation

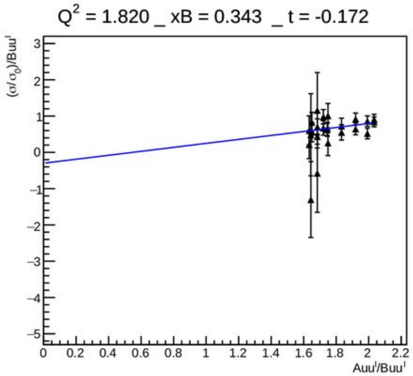
- *Transform the cross section into a line space.*

$$\sigma^{\mathcal{I}}_{UU} = \frac{\Gamma}{Q^2(-t)}\left[A^{\mathcal{I}}_{UU}\left(F_1\,\Re e\mathcal{H} + \tau F_2\,\Re e\mathcal{E}\right) + B^{\mathcal{I}}_{UU} G_M\left(\Re e\mathcal{H} + \Re e\mathcal{E}\right) + C^{\mathcal{I}}_{UU} G_M \Re e\widetilde{\mathcal{H}}\right]$$

Express the cross section as a linear function of the ration of the coefficients A_{UU}^{1}, B_{UU}^{1} and C_{UU}^{1}

$$\frac{Q^2(-t)}{B^{\mathcal{I}}_{UU}\Gamma}\,\sigma^{\mathcal{I}}_{UU} = \frac{A^{\mathcal{I}}_{UU}}{B^{\mathcal{I}}_{UU}}\underbrace{\left(F_1\,\Re e\mathcal{H} + \tau F_2\,\Re e\mathcal{E}\right)}_{\text{slope}} + \underbrace{G_M\left(\Re e\mathcal{H} + \Re e\mathcal{E}\right)}_{\text{intercept}}$$





KL Separation

$$\sigma^{\mathcal{I}}_{UU} = \frac{\Gamma}{Q^2(-t)}\left[A^{\mathcal{I}}_{UU}\left(F_1\,\Re e\mathcal{H} + \tau F_2\,\Re e\mathcal{E}\right) + B^{\mathcal{I}}_{UU} G_M\left(\Re e\mathcal{H} + \Re e\mathcal{E}\right) + C^{\mathcal{I}}_{UU} G_M\,\Re e\widetilde{\mathcal{H}}\right]$$

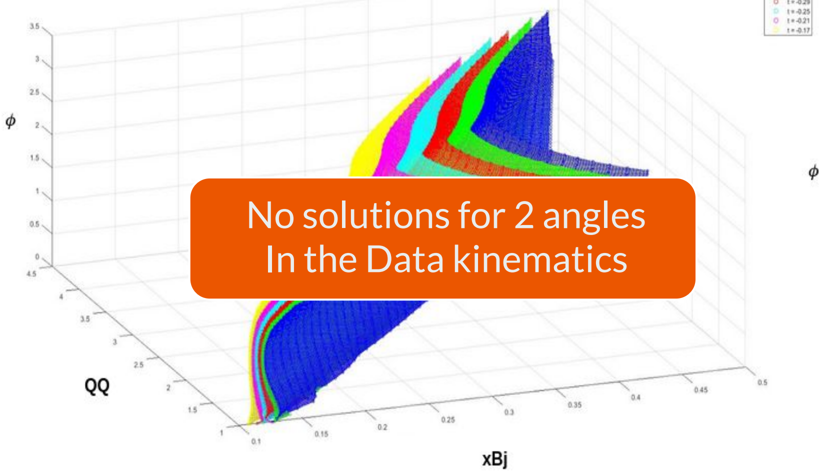
Neglected

- There must be at least 2 angles at which either of the coefficients is zero.

A_{UU}^{I}

No solutions

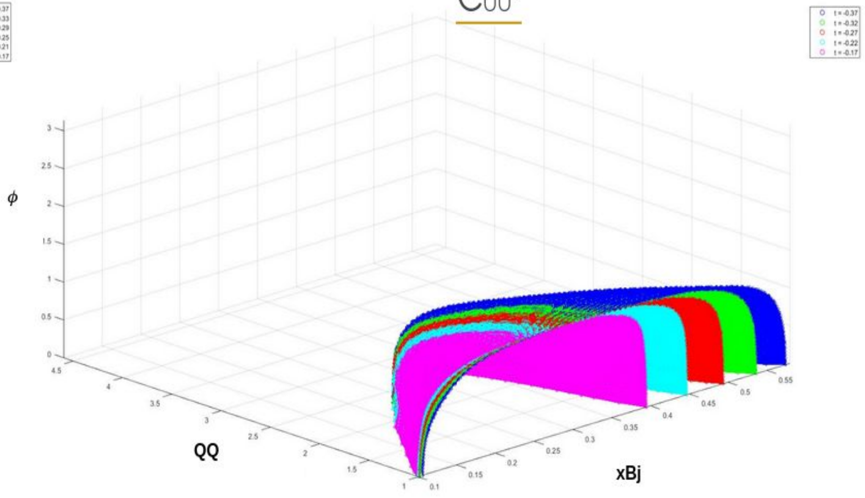
B_{UU}^{I}



No solutions for 2 angles
In the Data kinematics

2 solutions

C_{UU}^{I}



1 solution

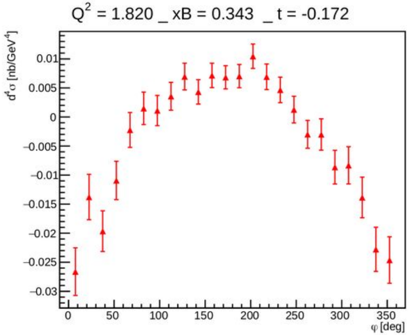
KL Separation

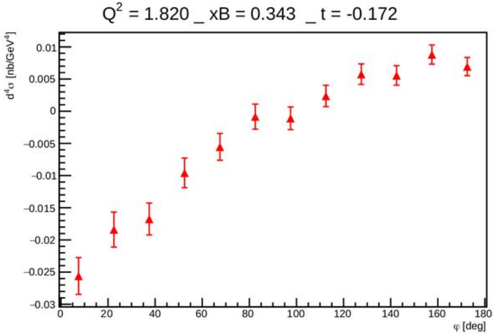
- *Transform the cross section into a line space.*

$$\sigma^{\mathcal{I}}_{UU} = \frac{\Gamma}{Q^2(-t)}\left[A^{\mathcal{I}}_{UU}\left(F_1\,\Re e\mathcal{H} + \tau F_2\,\Re e\mathcal{E}\right) + B^{\mathcal{I}}_{UU}G_M\left(\Re e\mathcal{H} + \Re e\mathcal{E}\right)\right]$$

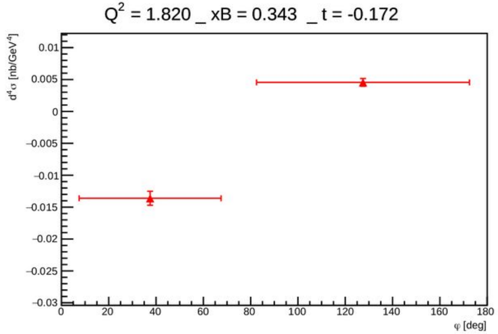
Rebinning the data

Symmetric coefficients





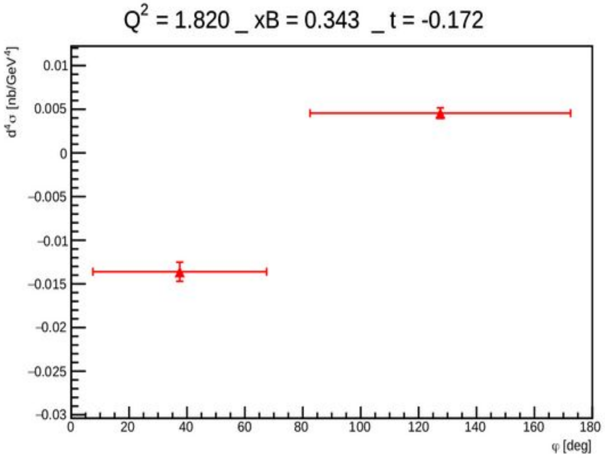
Reduced Statistical errors

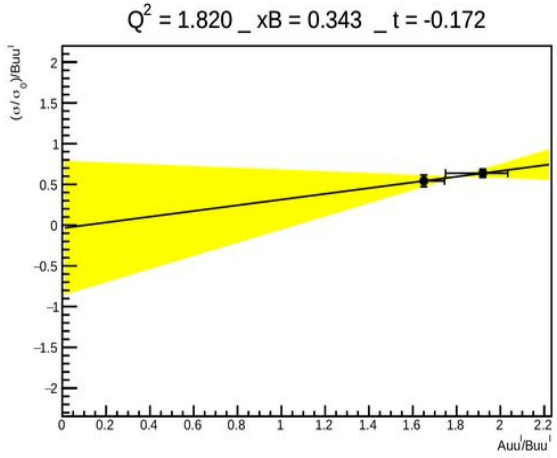


KL Separation

- *Transform the cross section into a line space.*

$$\frac{\sigma_r^{\mathcal{I}}}{B_{UU}^{\mathcal{I}}} = \frac{A_{UU}^{\mathcal{I}}}{B_{UU}^{\mathcal{I}}} \left(F_1 \Re e\mathcal{H} + \tau F_2 \Re e\mathcal{E} \right) + G_M \left(\Re e\mathcal{H} + \Re e\mathcal{E} \right)$$

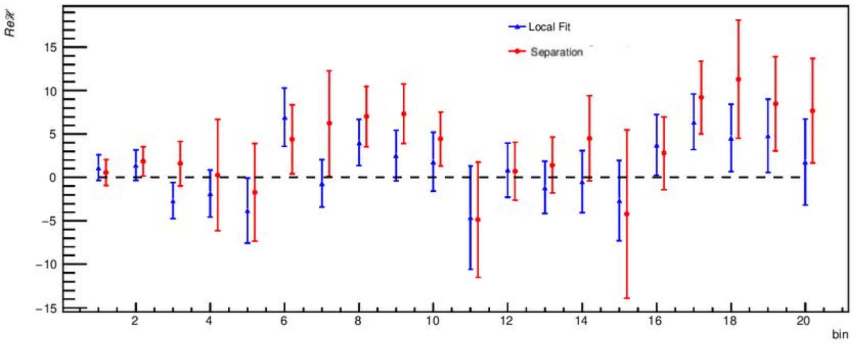




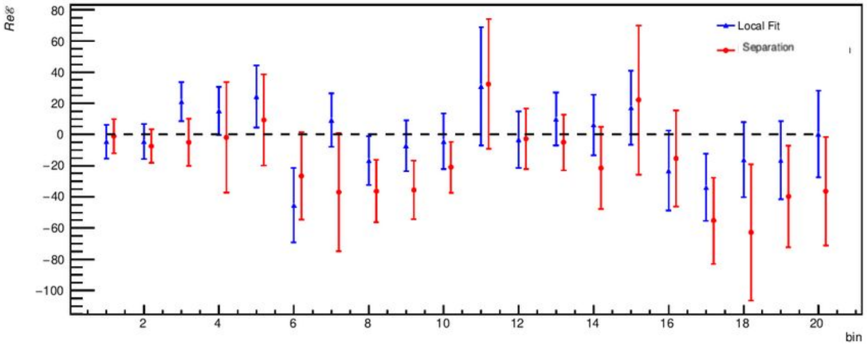
KL Separation

- *Results*

$\Re e\mathcal{H}$

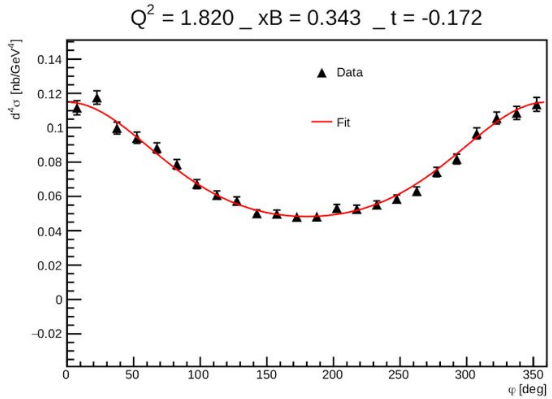


$\Re e\mathcal{E}$



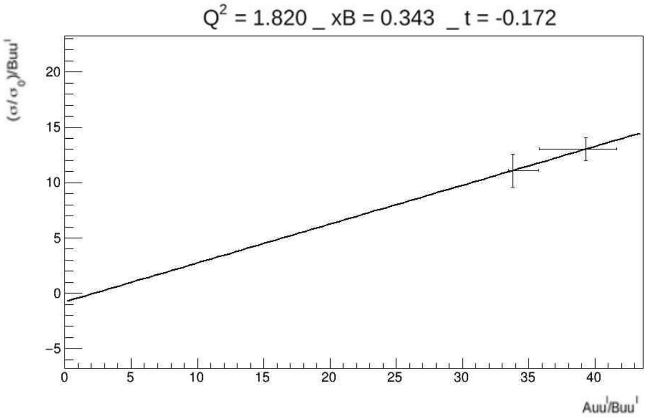
Simultaneous Fit

ϕ space



$$\sigma_{UU}^{DVCS} + \sigma_{UU}^{BH} + \frac{\Gamma}{Q^2(-t)}\left[A_{UU}^{\mathcal{I}}\left(F_1 \Re e\mathcal{H} + \tau F_2 \Re e\mathcal{E}\right) + B_{UU}^{\mathcal{I}} G_M \left(\Re e\mathcal{H} + \Re e\mathcal{E}\right)\right]$$

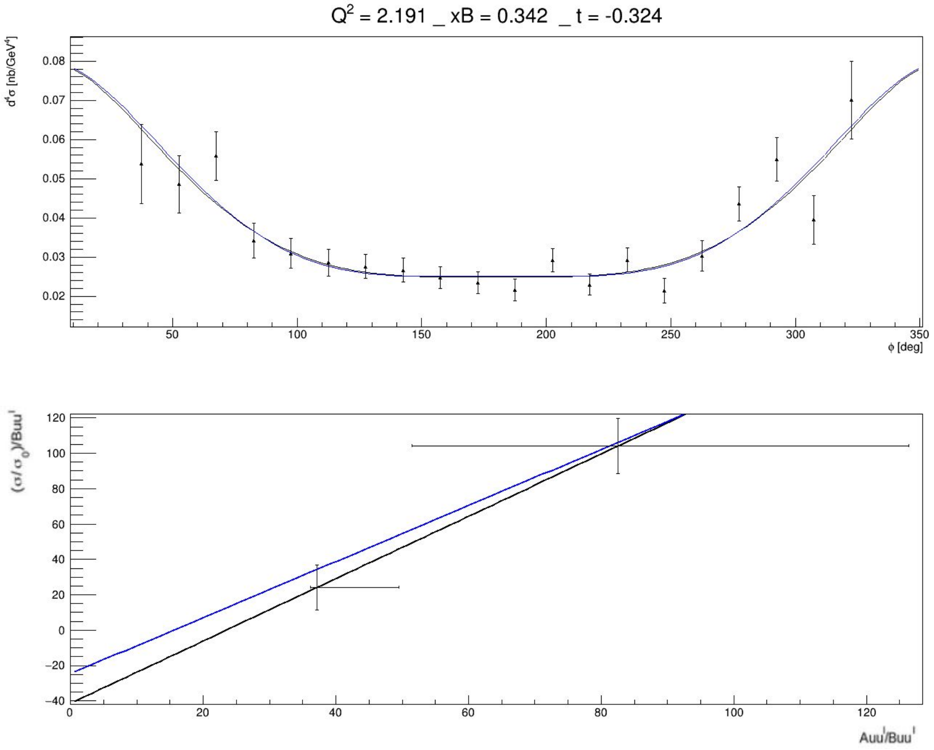
A_{UU}^{I}/B_{UU}^{I} space



$$\frac{A_{UU}^{\mathcal{I}}}{B_{UU}^{\mathcal{I}}}\left(F_1 \Re e\mathcal{H} + \tau F_2 \Re e\mathcal{E}\right) + G_M \left(\Re e\mathcal{H} + \Re e\mathcal{E}\right)$$

Least-Squares Minimization

Simultaneous Fit



Chi2/ndf = 1.47

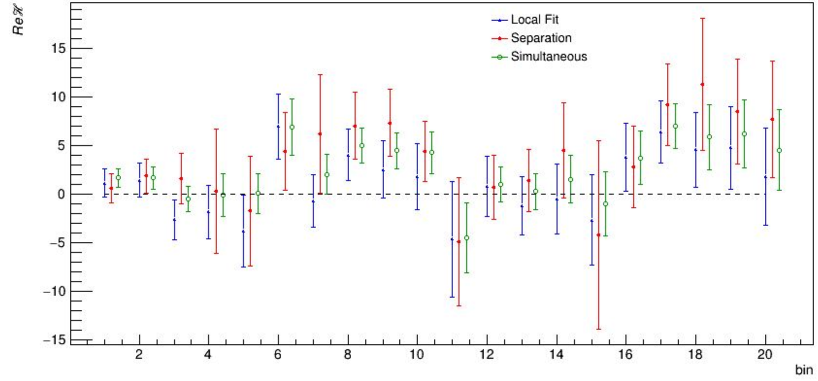
ReH = 6.17769 +/- 3.51418

ReE = -24.8391 +/- 20.5093

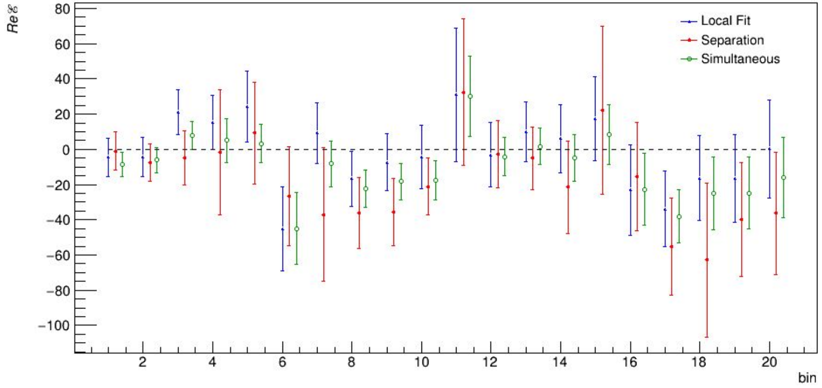
Simultaneous Fit

- *Results*

$\Re e\mathcal{H}$



$\Re e\mathcal{E}$



Simultaneous Fit

Smaller errors