New Deeply Virtual Compton Scattering results from Jefferson Lab
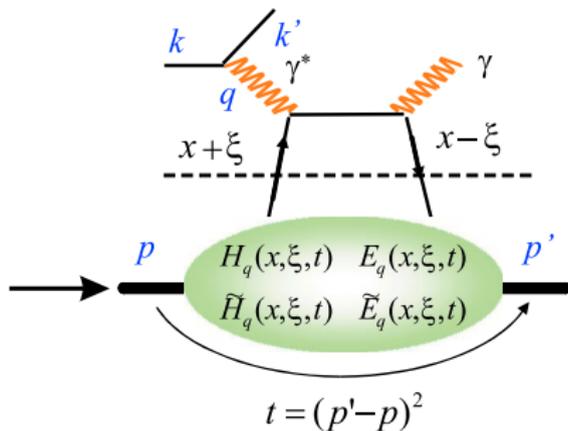
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Outline

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): $\gamma^* p \to \gamma p$
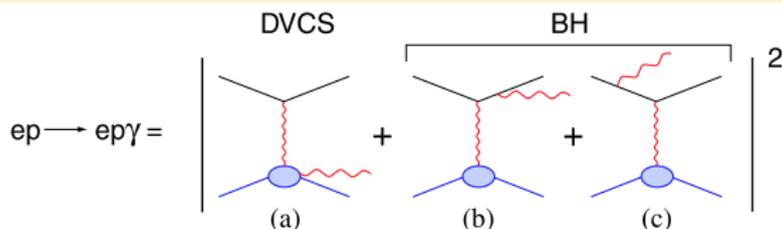

High Q^2
Perturbative QCD

Non-perturbative
GPDs

Handbag diagram

Bjorken limit:

$$Q^2 = \begin{array}{rcl} -q^2 & \to & \infty \\ \nu & \to & \infty \end{array} \Bigg\} \quad x_B = \frac{Q^2}{2M\nu} \text{ fixed}$$

- GPDs accesible through DVCS *only* at $Q^2 \to \infty$
- Actual value of Q^2 *must* be tested and established **by experiment**

DVCS experimentally: interference with Bethe-Heitler

$$ep \longrightarrow ep\gamma = \left| \underbrace{}_{\text{(a)}}^{\text{DVCS}} + \overbrace{\underbrace{}_{\text{(b)}} + \underbrace{}_{\text{(c)}}}^{\text{BH}} \right|^2$$

At leading twist:

$$d^5 \overset{\rightarrow}{\sigma} - d^5 \overset{\leftarrow}{\sigma} = 2 \,\Im m \left(T^{BH} \cdot T^{DVCS} \right)$$

$$d^5 \overset{\rightarrow}{\sigma} + d^5 \overset{\leftarrow}{\sigma} = |BH|^2 + 2 \,\Re e \left(T^{BH} \cdot T^{DVCS} \right) + |DVCS|^2$$

$$\mathcal{T}^{DVCS} = \int_{-1}^{+1} dx \frac{H(x, \xi, t)}{x - \xi + i\epsilon} + \cdots =$$

$$\mathcal{P} \int_{-1}^{+1} dx \frac{H(x, \xi, t)}{x - \xi} \qquad - \qquad i\pi \; H(x = \xi, \xi, t) \qquad + \ldots$$

Access in helicity-independent cross section   Access in helicity-dependent cross-section

DVCS cross sections: azimuthal analysis

$Q^2 = 2.36$ GeV^2, $x_B = 0.37$, $-t = 0.32$ GeV^2

$$d^4\sigma = \mathcal{T}_{\mathsf{BH}}^2 + \mathcal{T}_{\mathsf{BH}}\mathcal{Re}(\mathcal{T}_{\mathsf{DVCS}}) + \mathcal{T}_{\mathsf{DVCS}}^2$$

$$\mathcal{Re}(\mathcal{T}_{\mathsf{DVCS}}) \sim c_0^{\mathcal{I}} + c_1^{\mathcal{I}}\cos\phi + c_2^{\mathcal{I}}\cos 2\phi$$
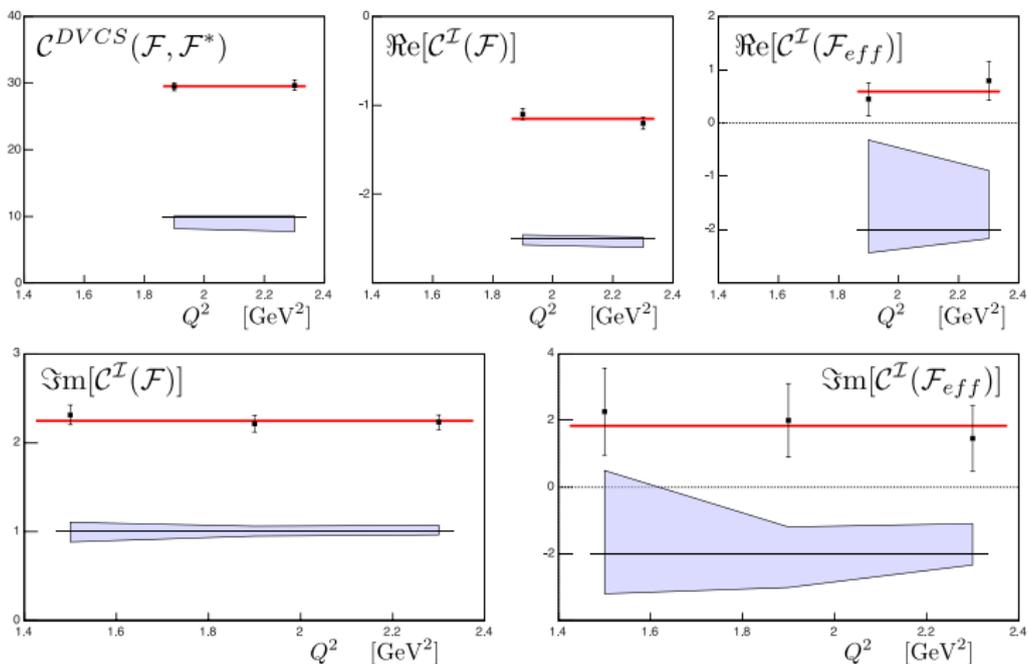
$$\mathcal{T}_{\mathsf{DVCS}}^2 \sim c_0^{\mathsf{DVCS}} + c_1^{\mathsf{DVCS}}\cos\phi$$

$$\Delta^4\sigma = \frac{d^4\overrightarrow{\sigma} - d^4\overleftarrow{\sigma}}{2} = \mathcal{Im}(\mathcal{T}_{\mathsf{DVCS}})$$

$$\mathcal{Im}(\mathcal{T}_{\mathsf{DVCS}}) \sim s_1^{\mathcal{I}}\sin\phi + s_2^{\mathcal{I}}\sin 2\phi$$
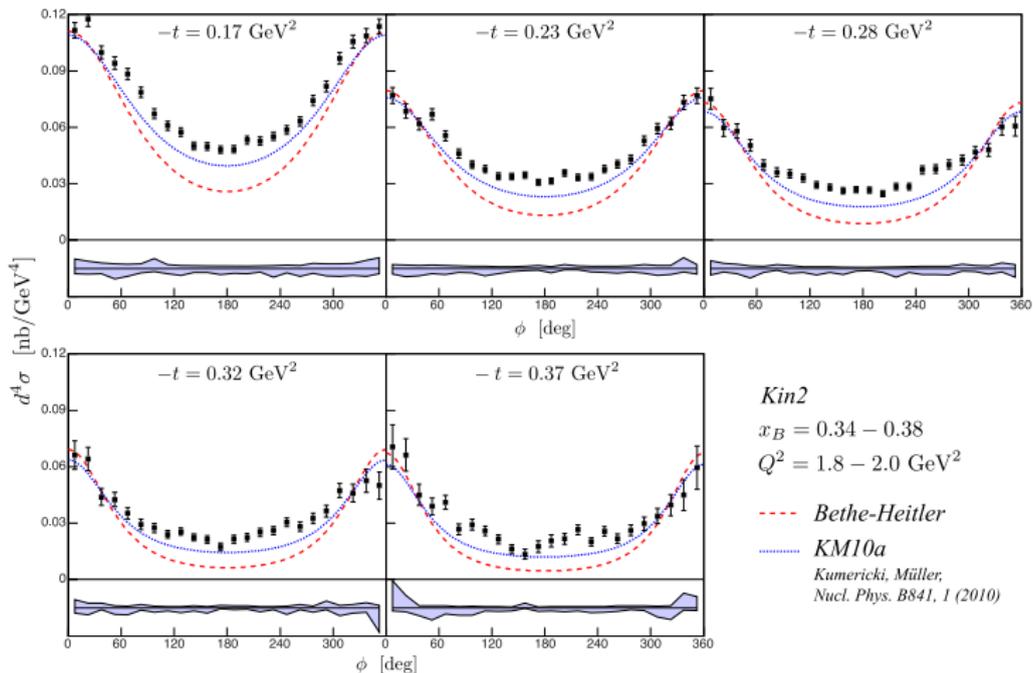
M. Defurne *et al.* Phys. Rev. C 92, 055202 (2015)
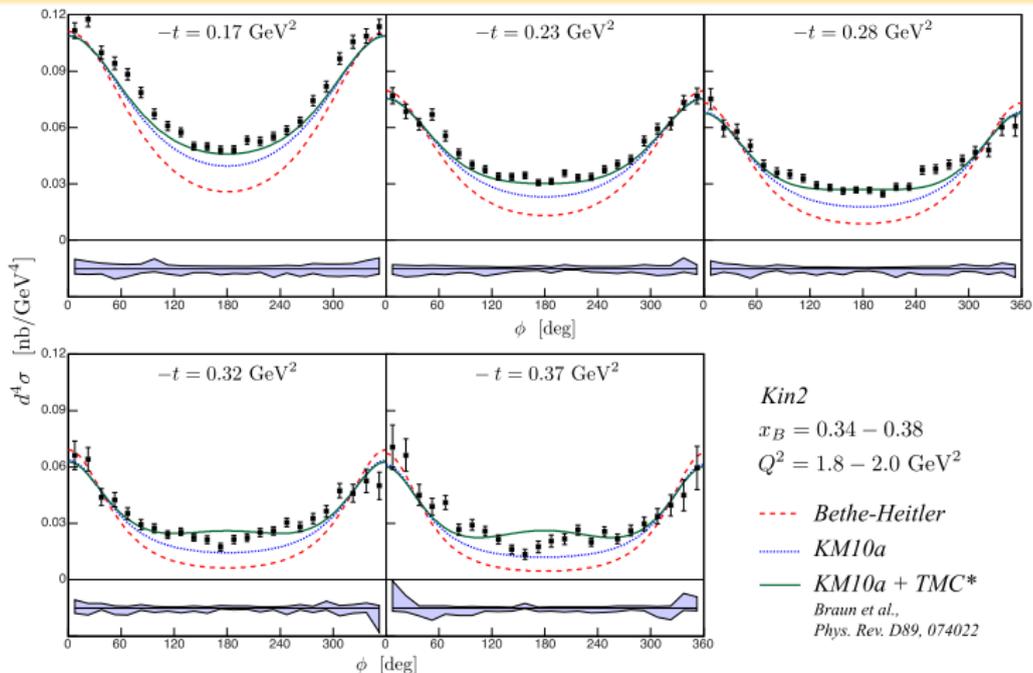
DVCS cross sections: Q^2–dependance

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

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

- 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)

Rosenbluth-like separation of the DVCS cross section

$$\sigma(ep \rightarrow ep\gamma) = \underbrace{|BH|^2}_{\text{Known to} \sim 1\%} + \underbrace{\mathcal{I}(BH \cdot DVCS)}_{\text{Linear combination of GPDs}} + \underbrace{|DVCS|^2}_{\text{Bilinear combination of GPDs}}$$

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

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

BKM-2010 – at leading twist $\rightarrow$ 7 independent GPD terms:

$$\left\{\Re\mathrm{e}, \Im\mathrm{m} \left[\mathcal{C}^{\mathcal{I}}, \mathcal{C}^{\mathcal{I},V}, \mathcal{C}^{\mathcal{I},A}\right] (\mathcal{F})\right\}, \qquad \text{and} \qquad \mathcal{C}^{DVCS}(\mathcal{F}, \mathcal{F}*).$$
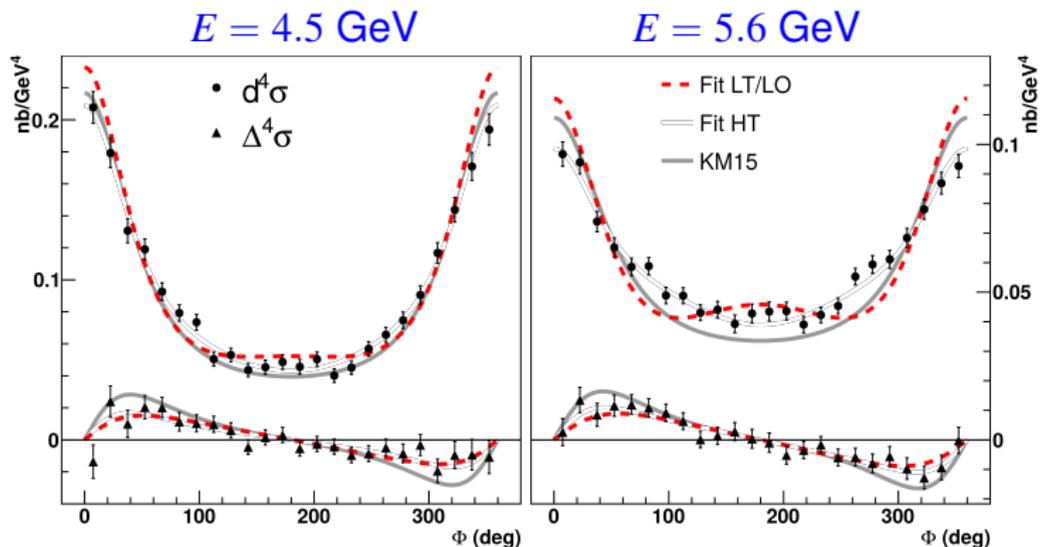
φ-dependence provides 5 independent observables:

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

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

- 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.*): $\mathbb{H}_{++}$, $\widetilde{\mathbb{H}}_{++}$, $\mathbb{E}_{++}$, $\widetilde{\mathbb{E}}_{++}$
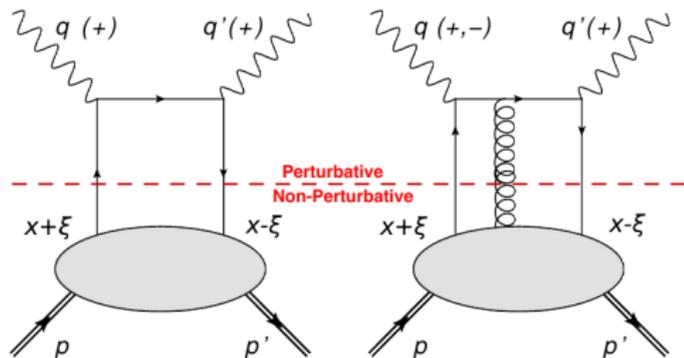
Beyond Leading Order (LO) and Leading Twist (LT)

Two fit-scenarios:

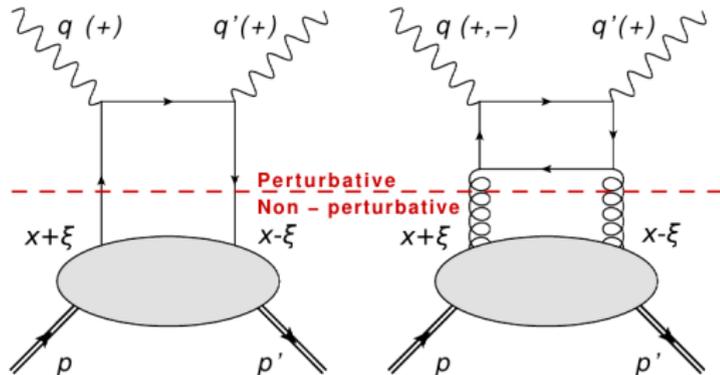**Light-cone axis in the (q,q') plane** (Braun *et al.*)

LO/LT + HT
$\mathbb{H}_{++}, \widetilde{\mathbb{H}}_{++}, \mathbb{H}_{0+}, \widetilde{\mathbb{H}}_{0+}$
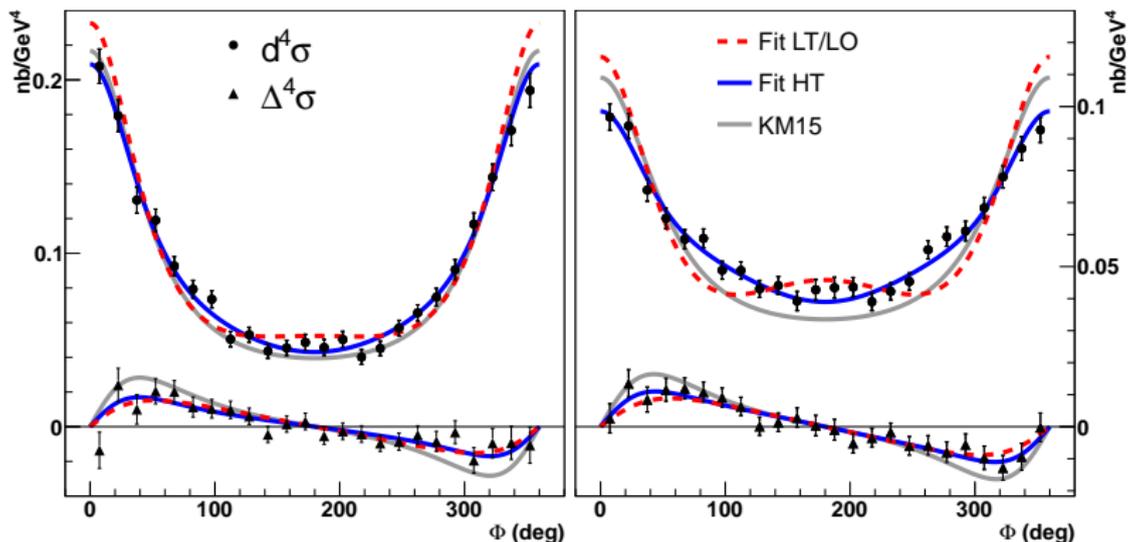

LO/LT + NLO
$\mathbb{H}_{++}, \widetilde{\mathbb{H}}_{++}, \mathbb{H}_{-+}, \widetilde{\mathbb{H}}_{-+}$
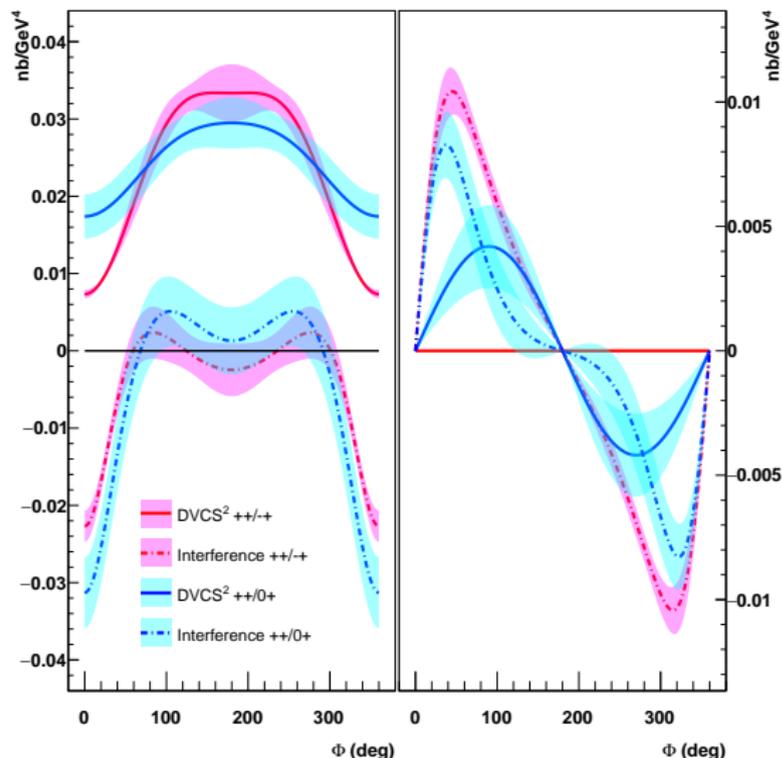
E07-007: DVCS beam-energy dependence

- 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 $\mathcal{I}$ (DVCS·BH) separation

DVCS^2 and $\mathcal{I}$ (DVCS·BH) separated in NLO and higher-twist scenarios

- DVCS^2 & $\mathcal{I}$ significantly different in each scenario

- Sizeable DVCS^2 contribution in the higher-twist scenario in the helicity-dependent cross section
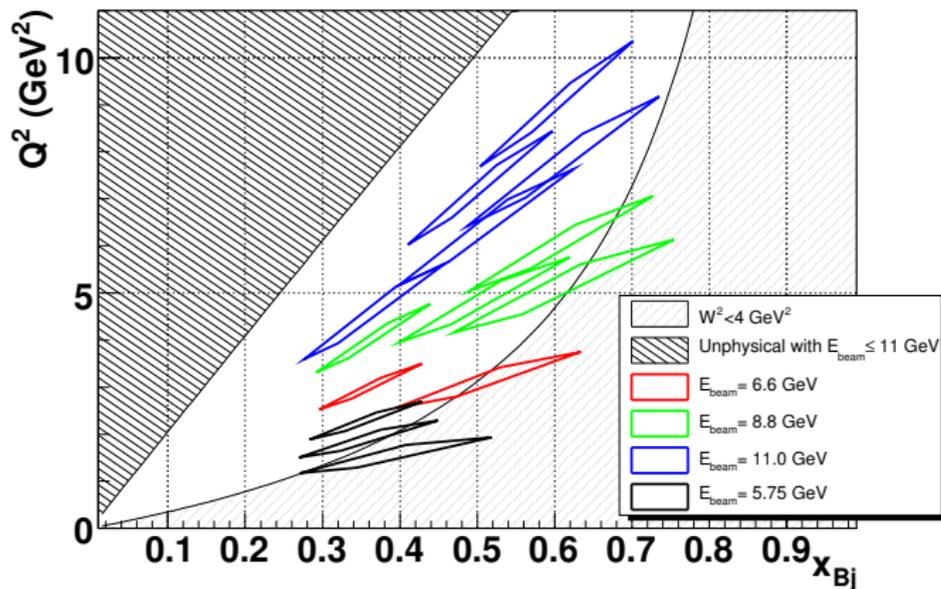
M. Defurne et al., arxiv:1703.09442

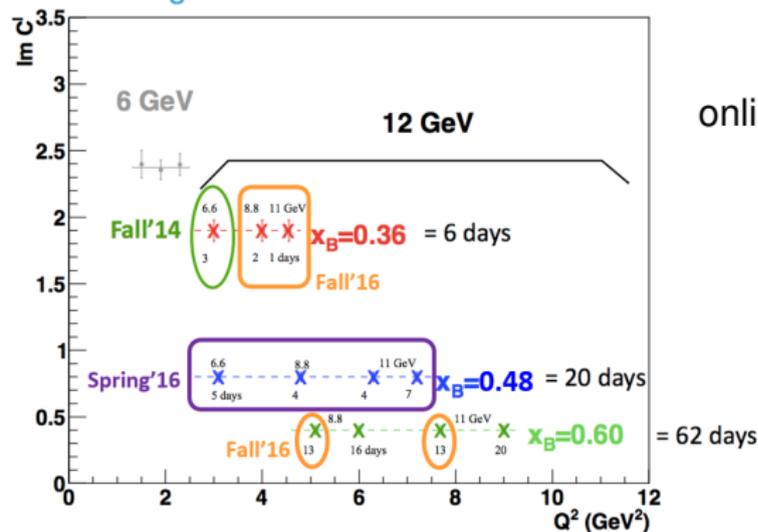# E12-06-114: JLab Hall A at 11 GeV

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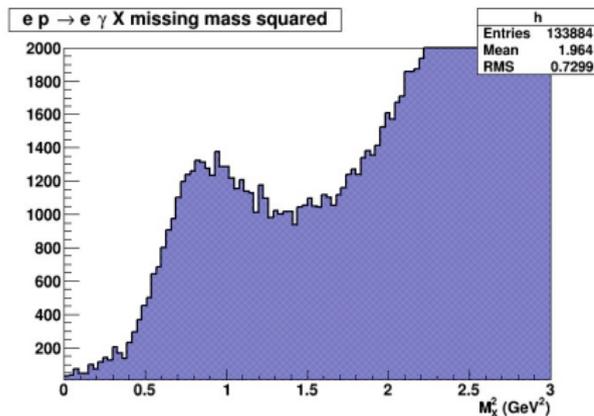(6.6, 8.8, 11.0 GeV beam energy)

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

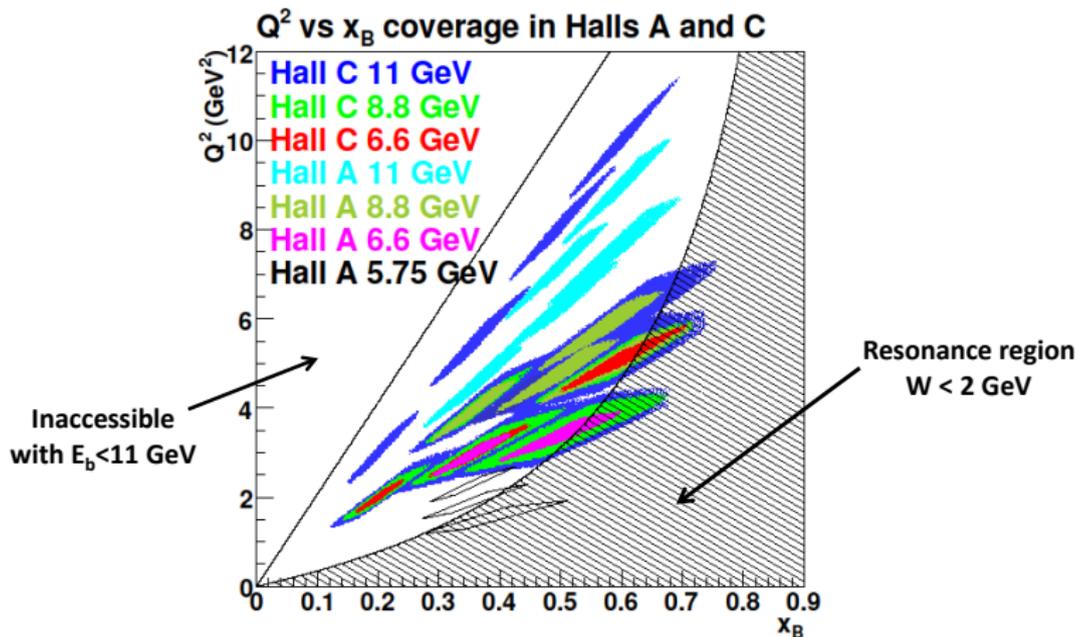$\sim 50\%$ of the required beamtime completed

Data analysis underway...

E12-13-010: DVCS in Hall C

- HMS ($p < 7.3 GeV$): scattered electron
- PbWO$_4$ calorimeter: γ/π^0 detection
- Sweeping magnet

E12-13-010: beam energy separation in Hall C

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 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