Recent results on DVCS from Hall A at JLab

Carlos Muñoz Camacho

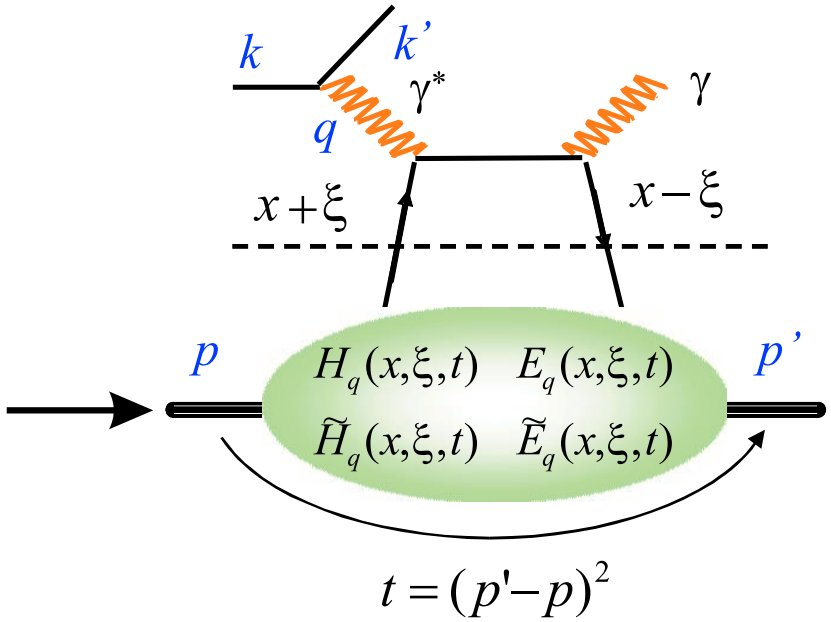
IPN-Orsay, CNRS/IN2P3 (France)

Spatial and Momentum Tomography of Hadrons and Nuclei
INT-17-3 – Sep 5, 2017

Outline

1. Very brief experimental introduction to DVCS
2. Recent DVCS results from Hall A at JLab
   - DVCS: beam energy dependence of the cross section (arxiv:1703.09442)
   - π^O: off the neutron $\rightarrow$ flavor separation (arXiv:1702.00835) $\longrightarrow$ *J. Roche's talk on Thursday*
3. Outlook
   - Jefferson Lab at 12 GeV: Hall A $\rightarrow$ C programs

Deeply Virtual Compton Scattering (DVCS): $\gamma^* p \to \gamma p$



Handbag diagram

High Q^2
Perturbative QCD

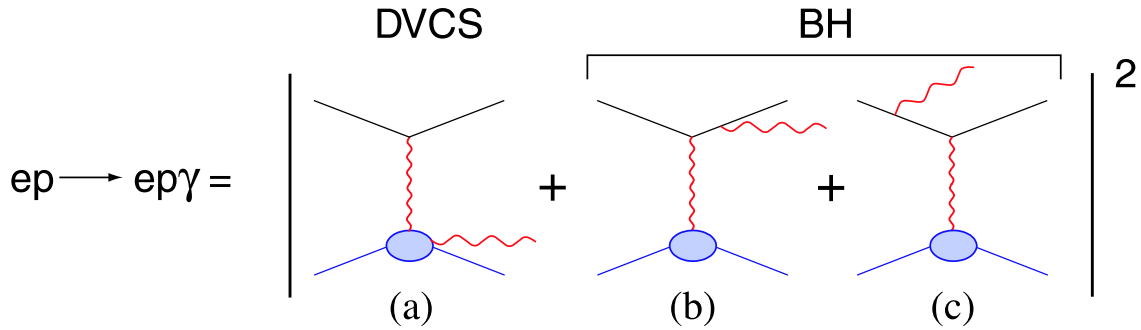
Non-perturbative
GPDs

Bjorken limit:

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

- 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



At leading twist:

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

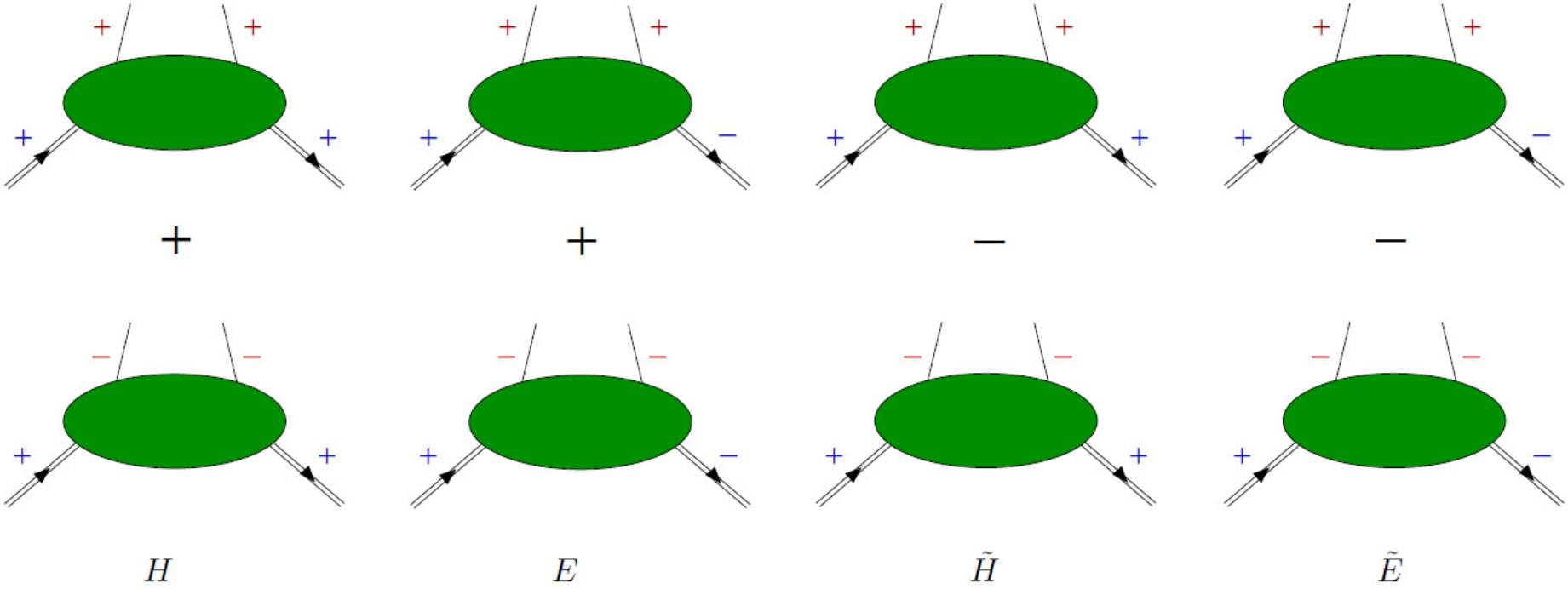
$$d^5\overrightarrow{\sigma} + d^5\overleftarrow{\sigma} = |BH|^2 + 2\,\Re e\left(T^{BH}\cdot T^{DVCS}\right) + |DVCS|^2$$

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

$$\underbrace{\mathcal{P}\int_{-1}^{+1} dx \frac{H(x,\xi,t)}{x-\xi}}_{\text{Access in helicity-independent cross section}} - \underbrace{i\pi\; H(x=\xi,\xi,t)}_{\text{Access in helicity-dependent cross-section}} + \ldots$$

Leading twist GPDs

8 GPDs related to the different combination of quark/nucleon helicities

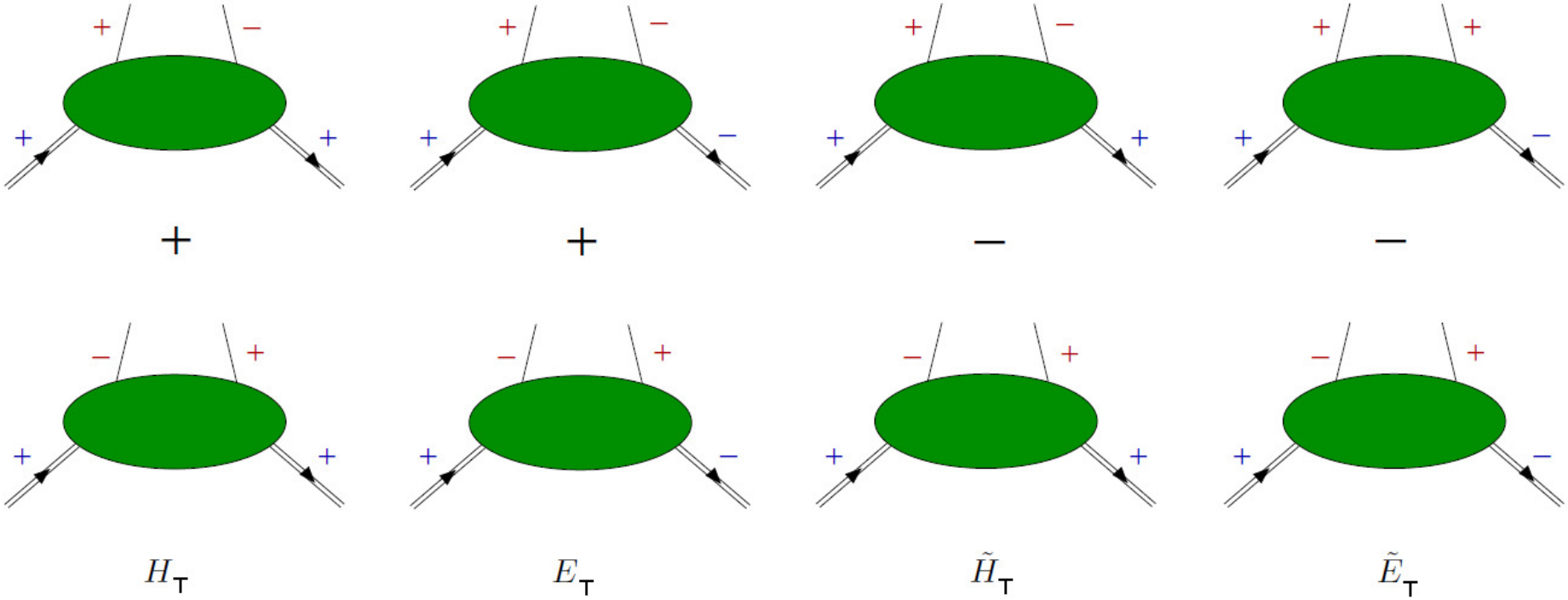


4 chiral-even GPDs: conserve the helicity of the quark

Access through DVCS (and DVMP)

Leading twist GPDs

8 GPDs related to the different combination of quark/nucleon helicities



4 chiral-odd GPDs: flip helicity of the quark

"transversity GPDs"

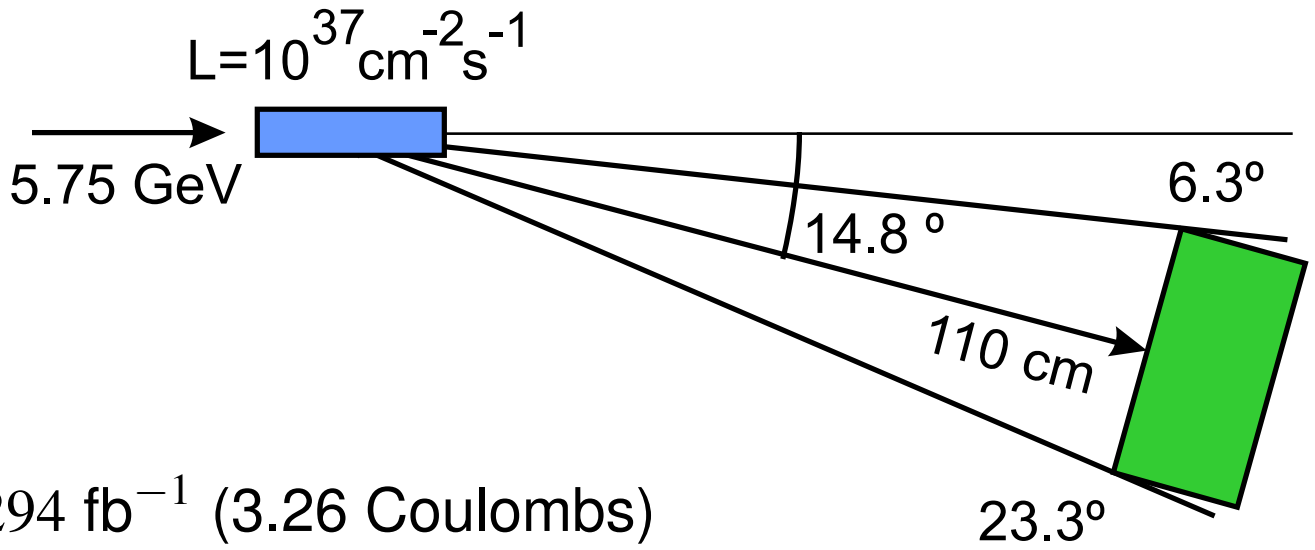
Experimental access more complicated (π^0 electroproduction?)

Ahmad, Goldstein, Liuti (2009)

Goloskokov, Kroll (2011)

Kinematic settings: testing Q^2–dependance

Kin	Q^2 (GeV^2)	x_B	θ_e (deg.)	θ_{γ^*} (deg.)	P_e (GeV)
1	**1.5**	0.36	15.6	**22.3**	3.6
2	**1.9**	0.36	19.3	**18.3**	2.9
3	**2.3**	0.36	23.9	**14.8**	2.3

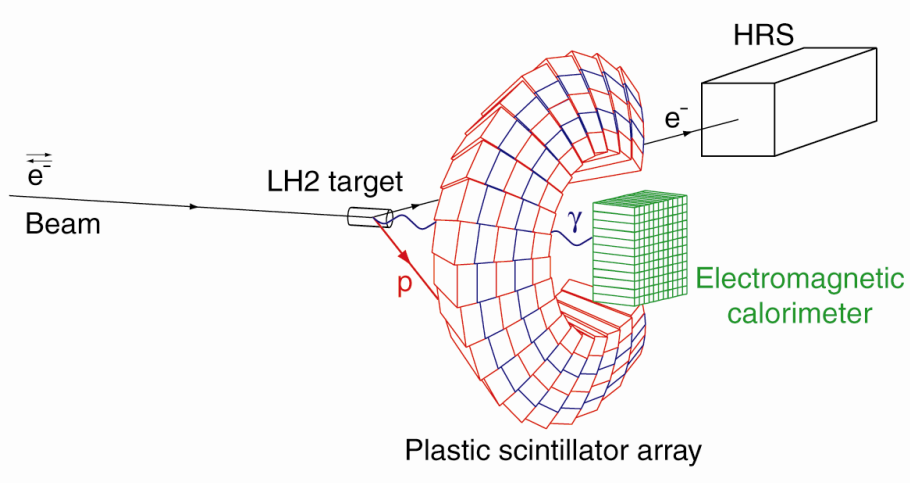


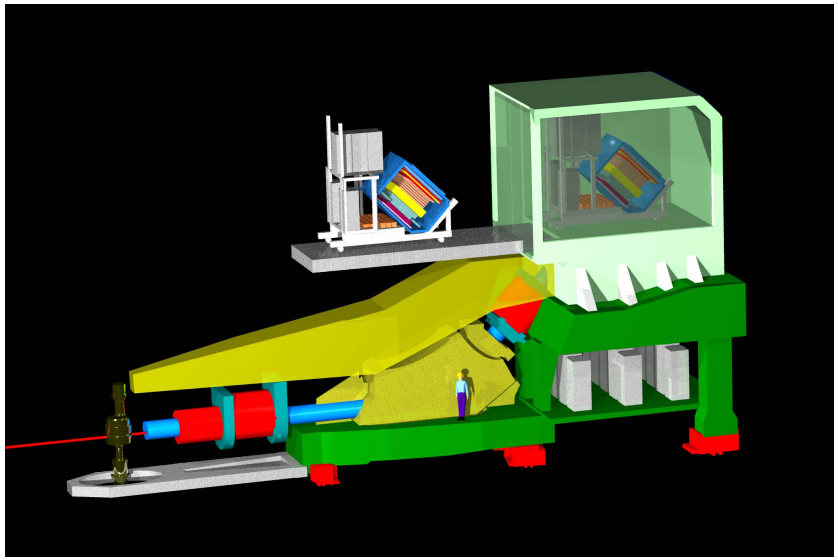
$\mathcal{P} = 75.3\%$

$\int \mathcal{L}\, dt = 13294$ fb^{-1} (3.26 Coulombs)

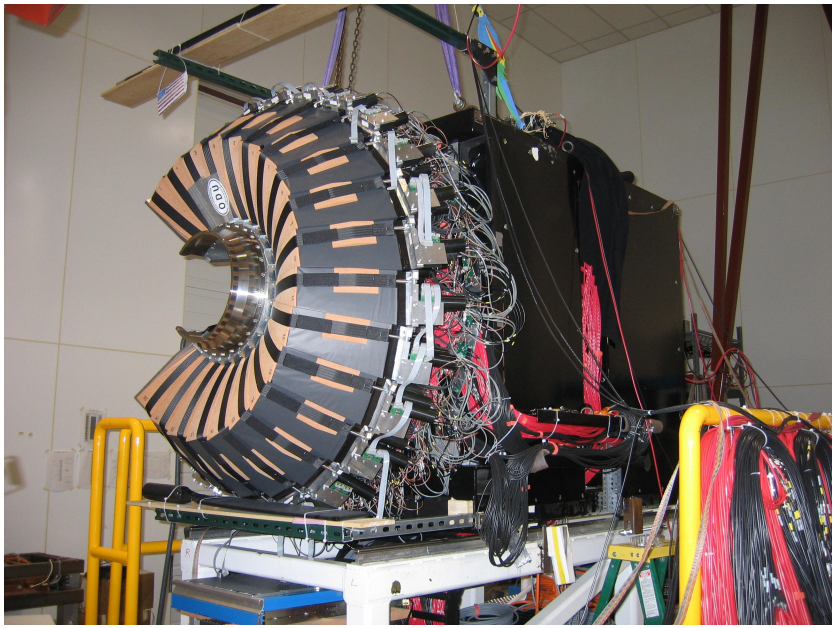
E00-110 experimental setup

High Resolution Spectrometer

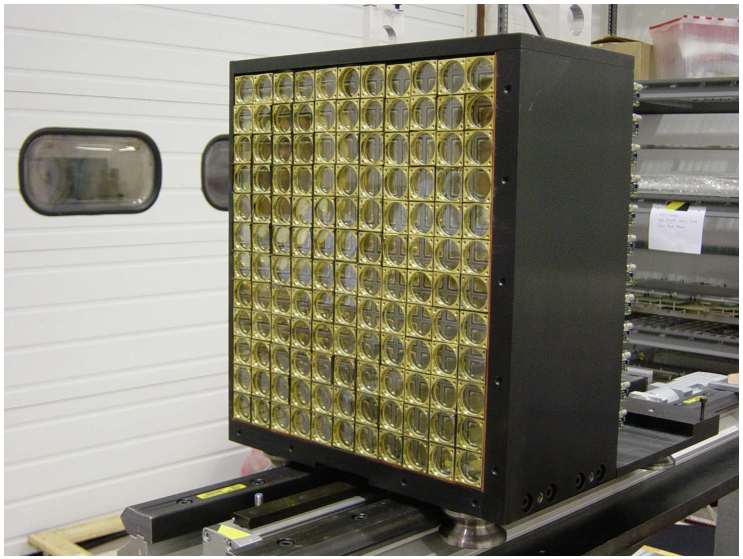




100-channel scintillator array

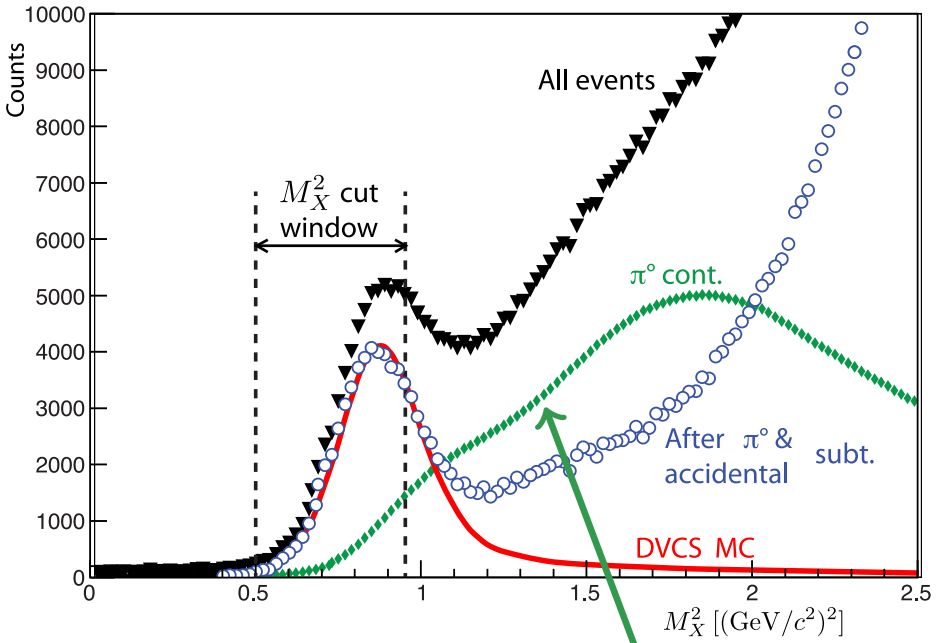


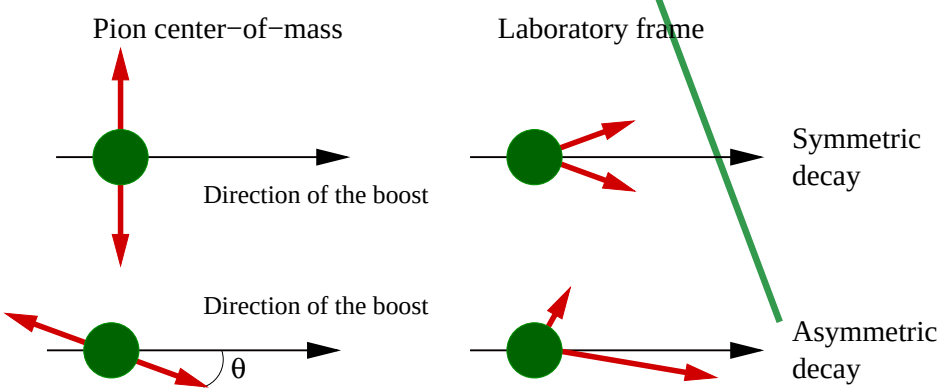
PbF_2 electromagnetic calorimeter

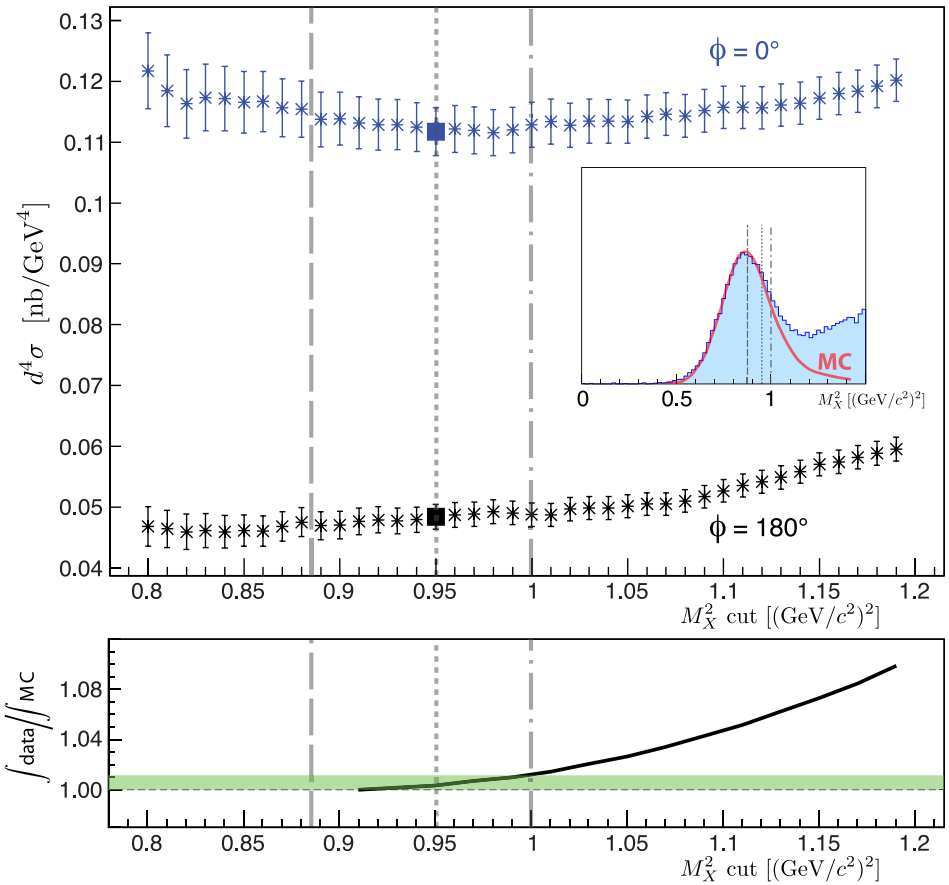


Data analysis: exclusivity and background subtraction

$ep \rightarrow e\gamma X$ missing mass squared



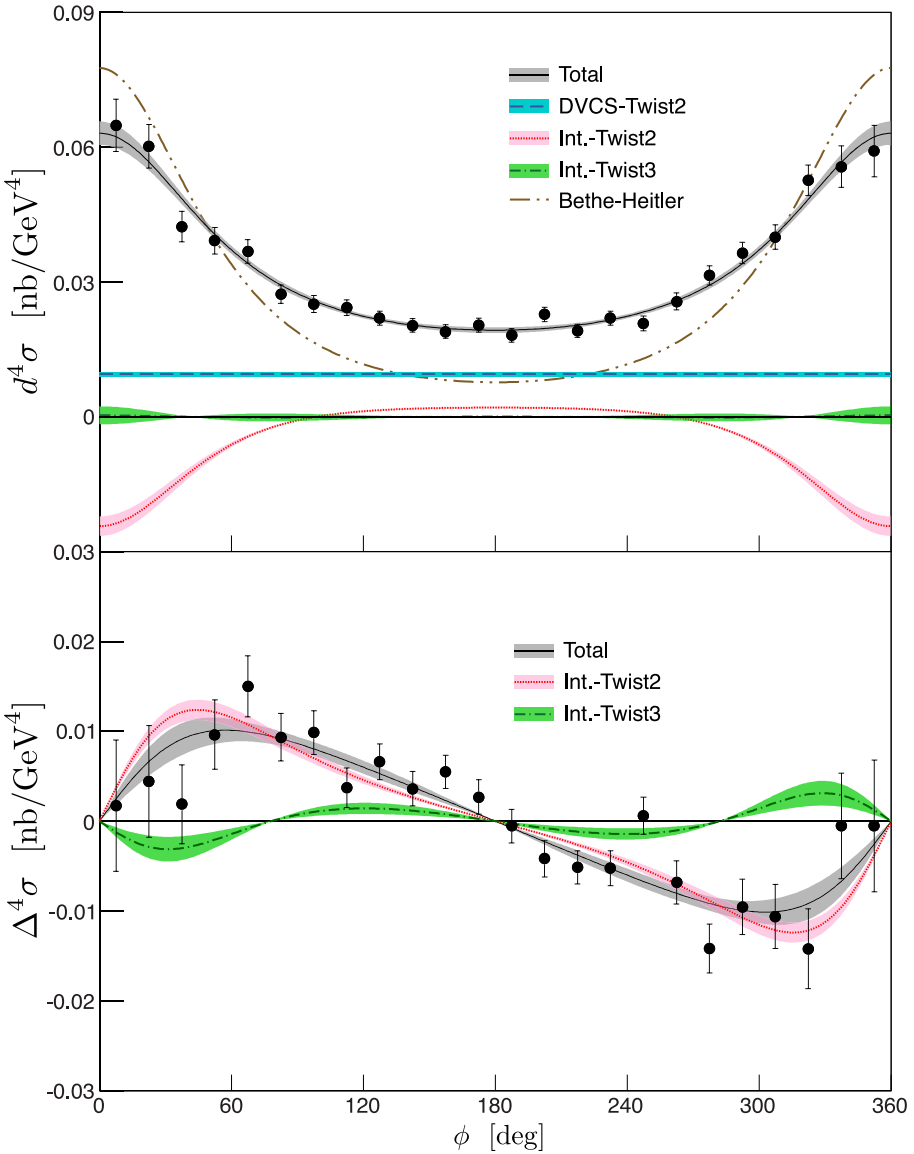


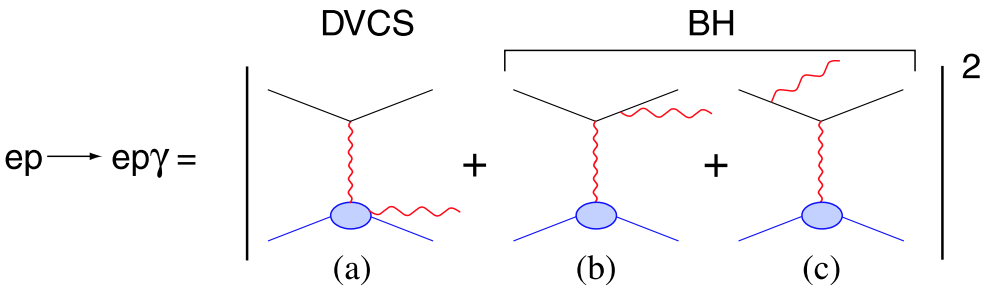


- Only e' & γ detected + M_X^2-cut
- 2-3% uncertainty on exclusivity

DVCS cross sections: azimuthal analysis

$Q^2 = 2.36\ \text{GeV}^2,\ x_B = 0.37,\ -t = 0.32\ \text{GeV}^2$





$$d^4\sigma = \mathcal{T}^2_{\text{BH}} + \mathcal{T}_{\text{BH}}\mathcal{R}e(\mathcal{T}_{\text{DVCS}}) + \mathcal{T}^2_{\text{DVCS}}$$

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

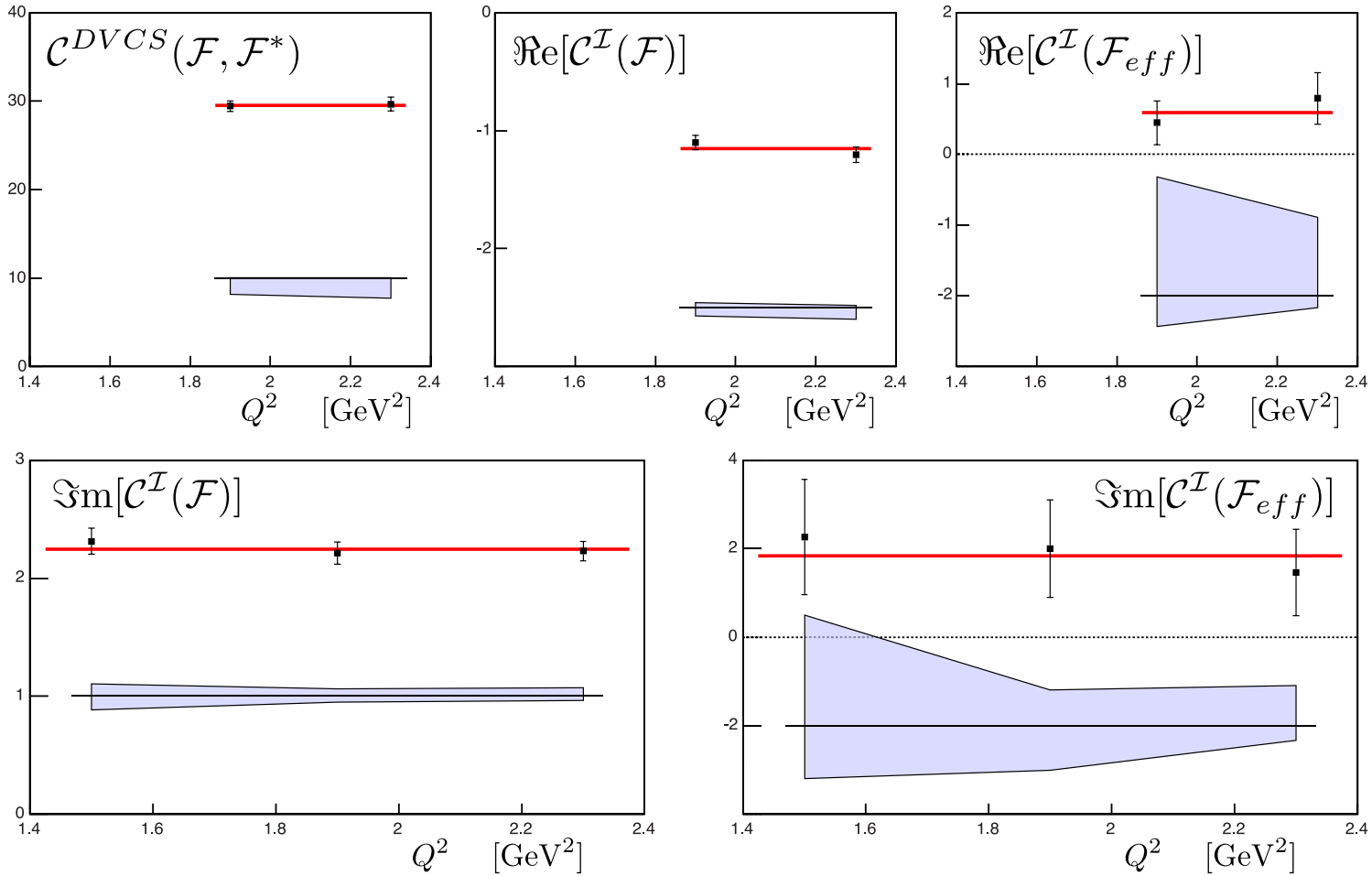
$$\mathcal{T}^2_{\text{DVCS}} \sim c_0^{\text{DVCS}} + c_1^{\text{DVCS}}\cos\phi$$

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

$$\mathcal{I}m(\mathcal{T}_{\text{DVCS}}) \sim s_1^{\mathcal{I}}\sin\phi + s_2^{\mathcal{I}}\sin 2\phi$$

M. Defurne *et al.* Phys. Rev. C 92, 055202 (2015)

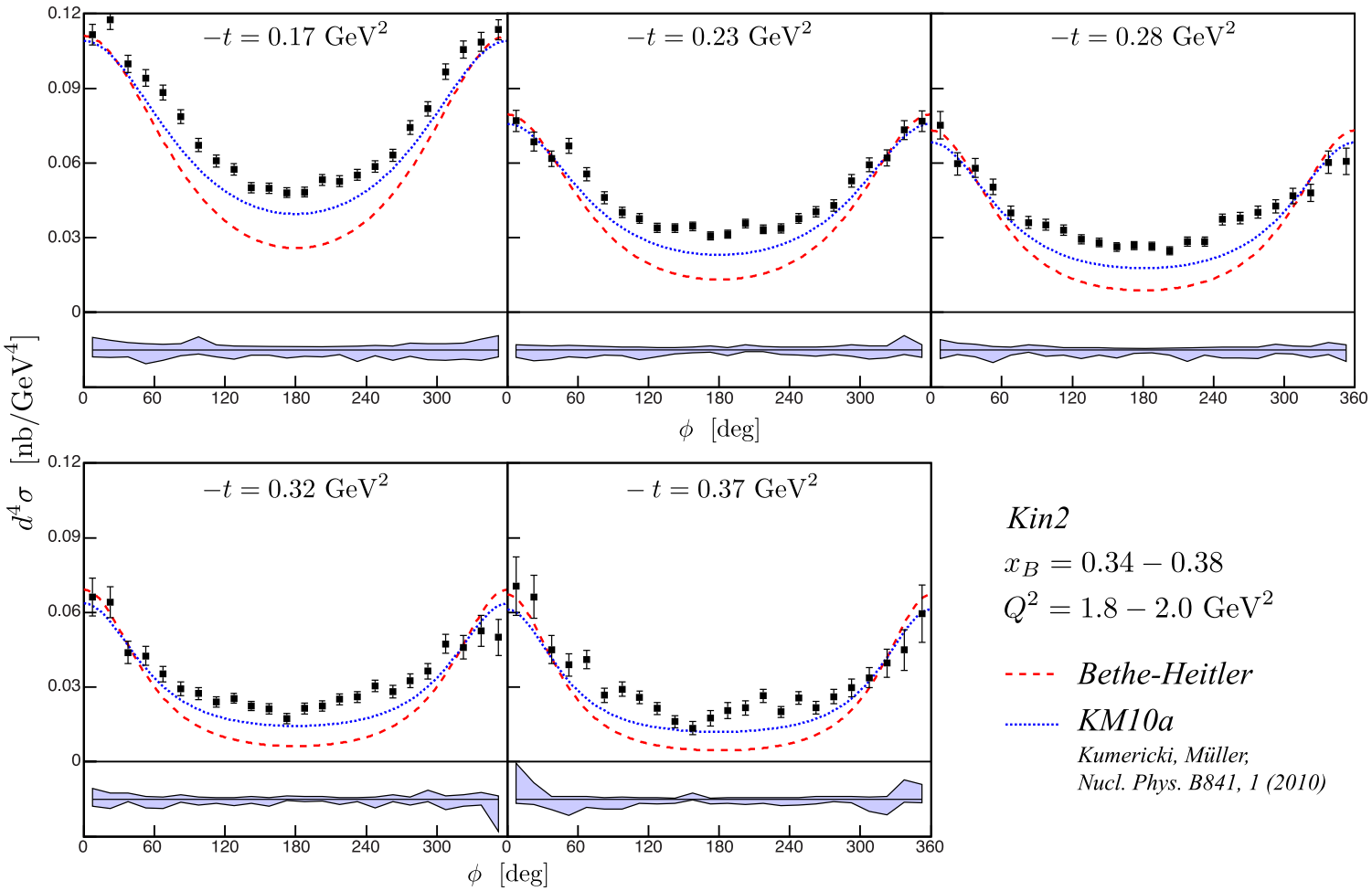
DVCS cross sections: Q^2–dependance



No Q^2-dependance within limited range $\Rightarrow$ leading twist dominance

Phys. Rev. **C92** (2015) 055202

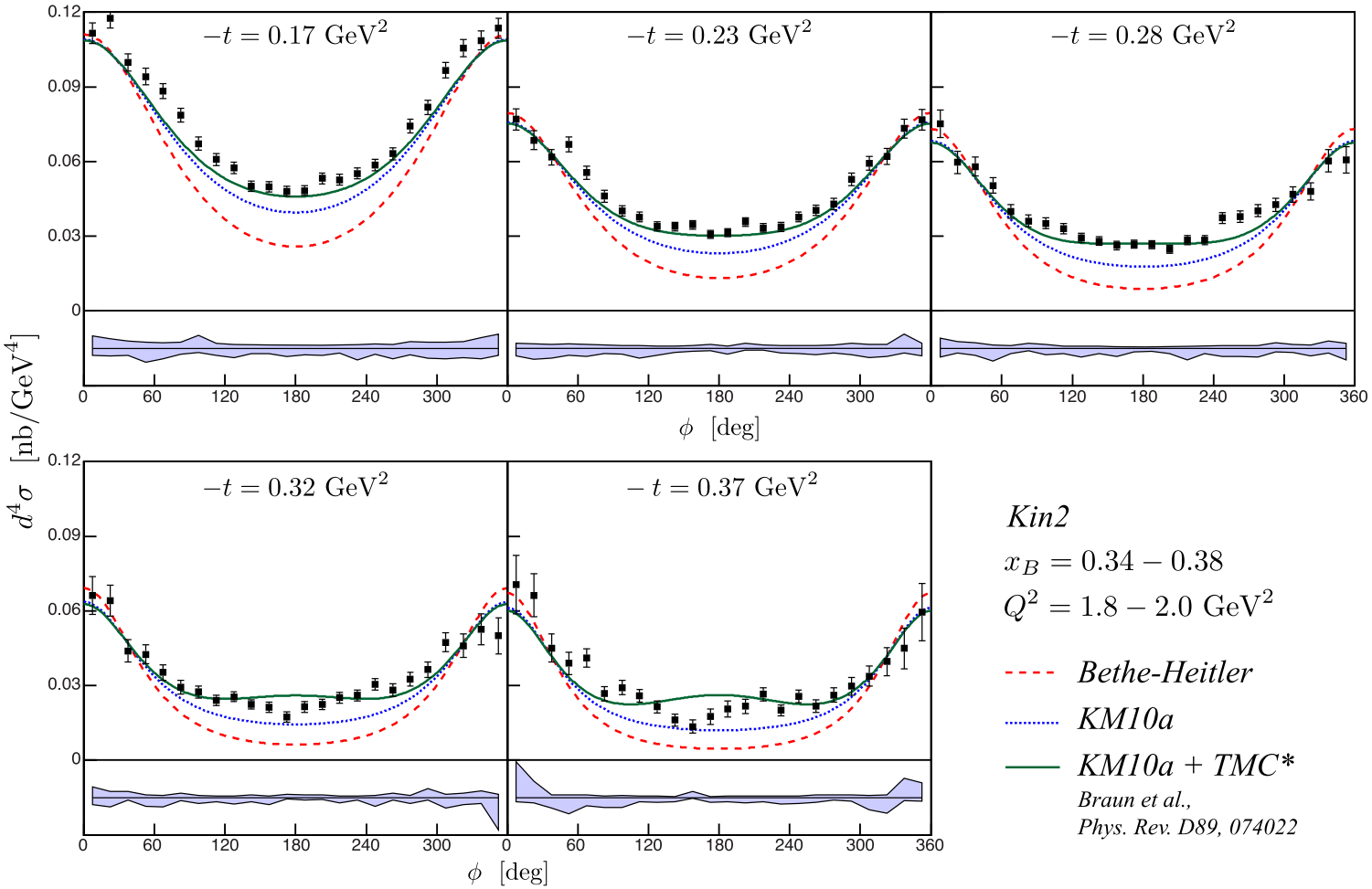
DVCS cross sections: higher twist corrections



- KM10a: global fit to HERA x-sec & HERMES + CLAS spin asymmetries

  Kumericki and Mueller (2010)

DVCS cross sections: higher twist corrections



- 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)

DVCS process: leading twist ambiguity

- DVCS defines a preferred axis: light-cone axis
- At finite Q^2 and non-zero t, there is an ambiguity:
  1. Belitsky et al. ("BKM", 2002–2010): light-cone axis in plane (q,P)
  2. Braun et al. ("BMP", 2014): light-cone axis in plane (q,q') easier to account for kin. corrections $\sim \mathcal{O}(M^2/Q^2)$, $\sim \mathcal{O}(t/Q^2)$

$$\left.\begin{array}{rl} \mathcal{F}_{++} = & \mathbb{F}_{++} + \frac{\chi}{2}\left[\mathbb{F}_{++} + \mathbb{F}_{-+}\right] - \chi_0 \mathbb{F}_{0+} \\ \mathcal{F}_{-+} = & \mathbb{F}_{-+} + \frac{\chi}{2}\left[\mathbb{F}_{++} + \mathbb{F}_{-+}\right] - \chi_0 \mathbb{F}_{0+} \\ \mathcal{F}_{0+} = & -(1+\chi)\mathbb{F}_{0+} + \chi_0\left[\mathbb{F}_{++} + \mathbb{F}_{-+}\right] \end{array}\right\} \xrightarrow[\mathbb{F}_{0+}=0]{\mathbb{F}_{-+}=0} \left\{\begin{array}{ll} \mathcal{F}_{++} & = (1+\frac{\chi}{2})\mathbb{F}_{++} \\ \mathcal{F}_{-+} & = \frac{\chi}{2}\mathbb{F}_{++} \\ \mathcal{F}_{0+} & = \chi_0 \mathbb{F}_{++} \end{array}\right.$$

(eg. $\chi_0 = 0.25$, $\chi = 0.06$ for $Q^2 = 2$ GeV^2, $x_B = 0.36$, $t = -0.24$ GeV^2)

Rosenbluth-like separation of the DVCS cross section

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

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

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

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

$$\left\{\Re\mathrm{e}, \Im\mathrm{m}\left[\mathcal{C}^{\mathcal{I}}, \mathcal{C}^{\mathcal{I},V}, \mathcal{C}^{\mathcal{I},A}\right](\mathcal{F})\right\}, \quad \text{and} \quad \mathcal{C}^{DVCS}(\mathcal{F}, \mathcal{F}*).$$

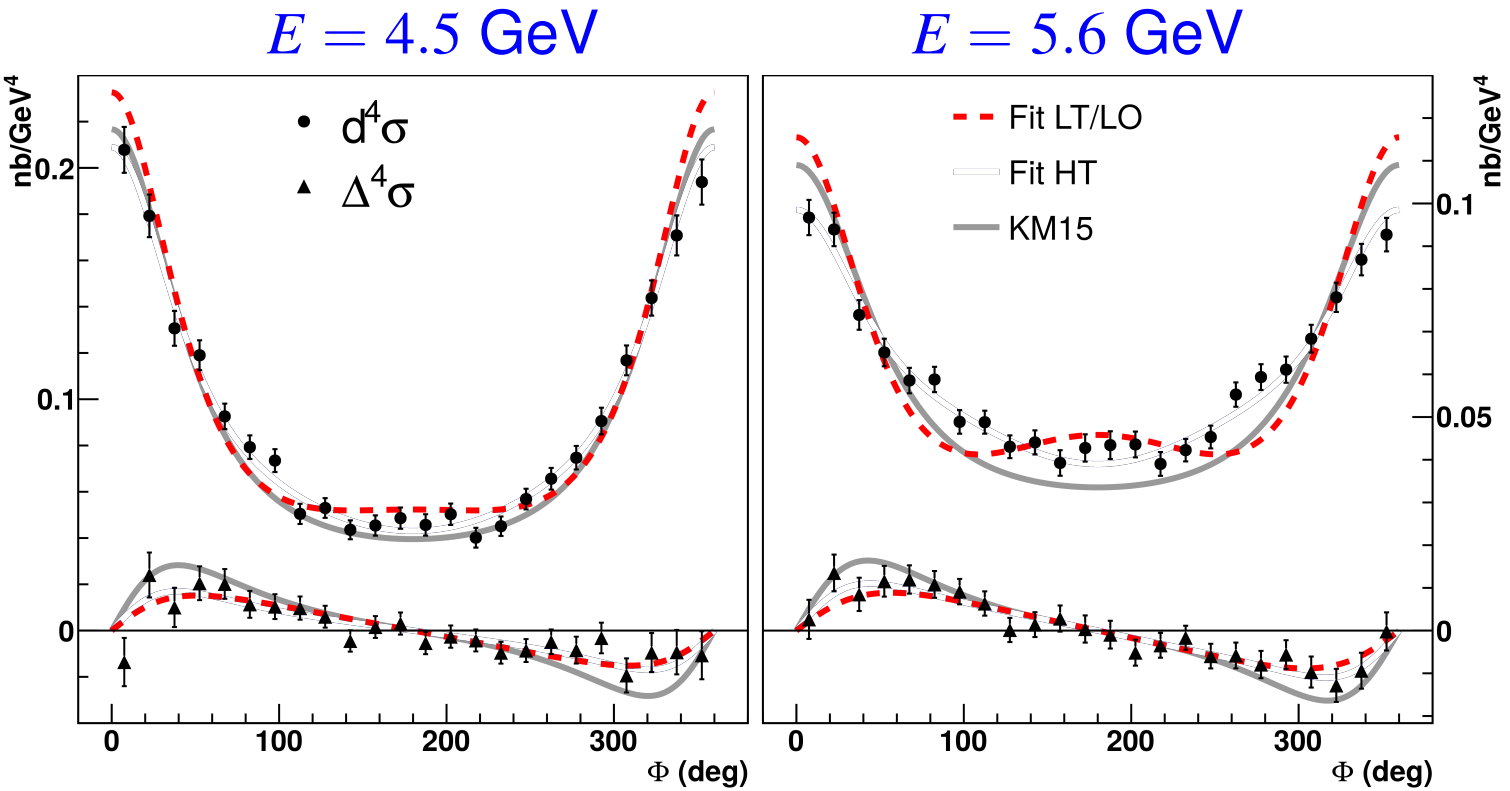
φ-dependence provides 5 independent observables:

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

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.*): $\mathbb{H}_{++}$, $\widetilde{\mathbb{H}}_{++}$, $\mathbb{E}_{++}$, $\widetilde{\mathbb{E}}_{++}$

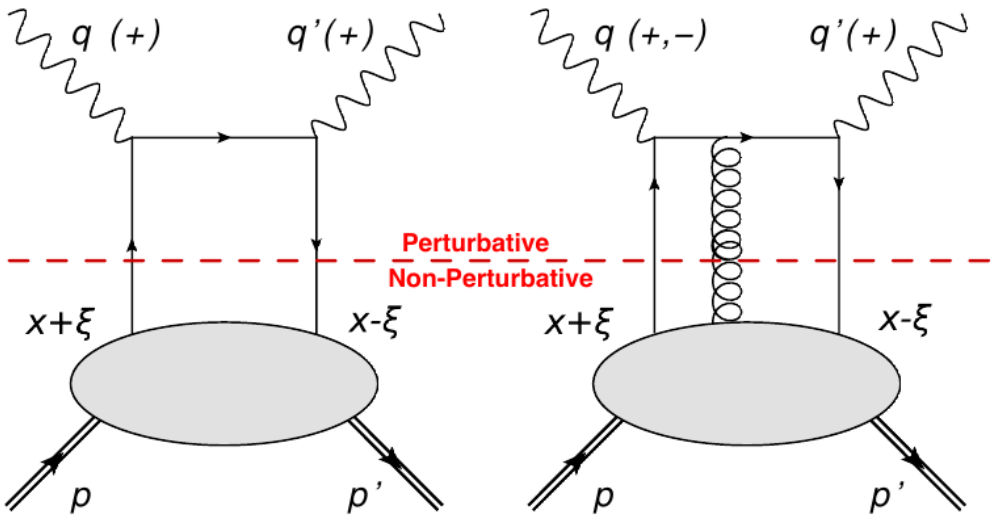
Beyond Leading Order (LO) and Leading Twist (LT)

Two fit-scenarios:

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

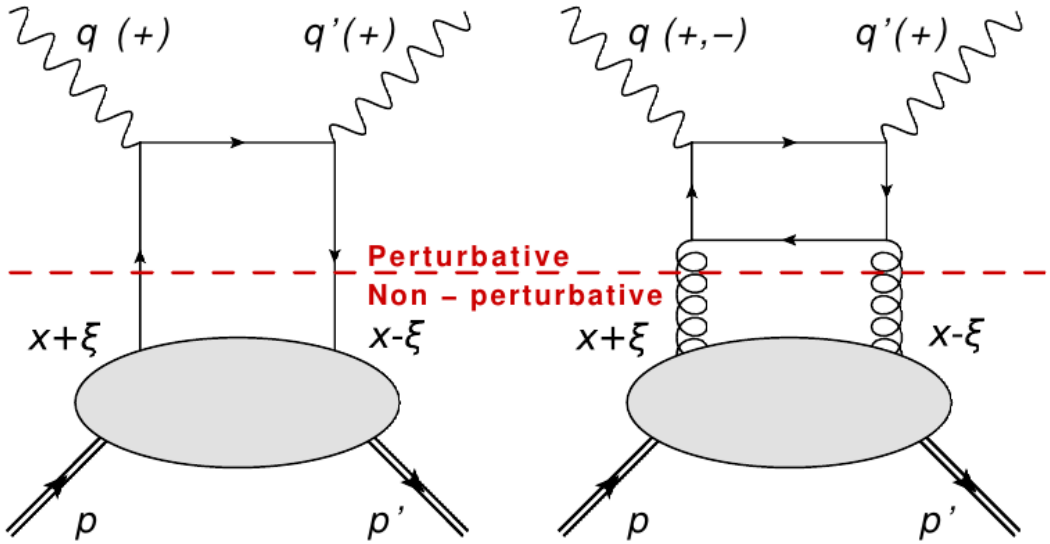
LO/LT + HT

$\mathbb{H}_{++}$, $\widetilde{\mathbb{H}}_{++}$, $\mathbb{H}_{0+}$, $\widetilde{\mathbb{H}}_{0+}$



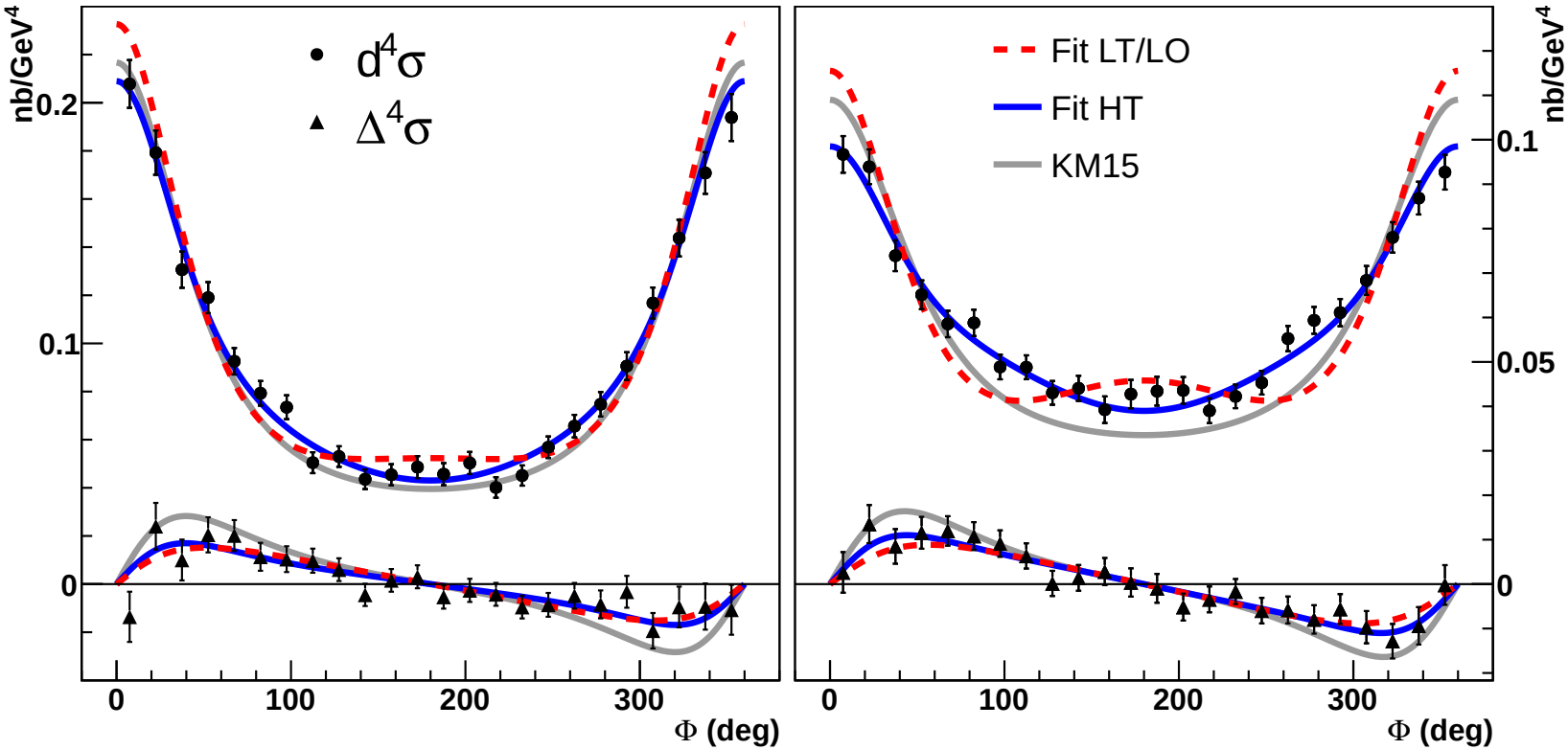
LO/LT + NLO

$\mathbb{H}_{++}$, $\widetilde{\mathbb{H}}_{++}$, $\mathbb{H}_{-+}$, $\widetilde{\mathbb{H}}_{-+}$



E07-007: DVCS beam-energy dependence

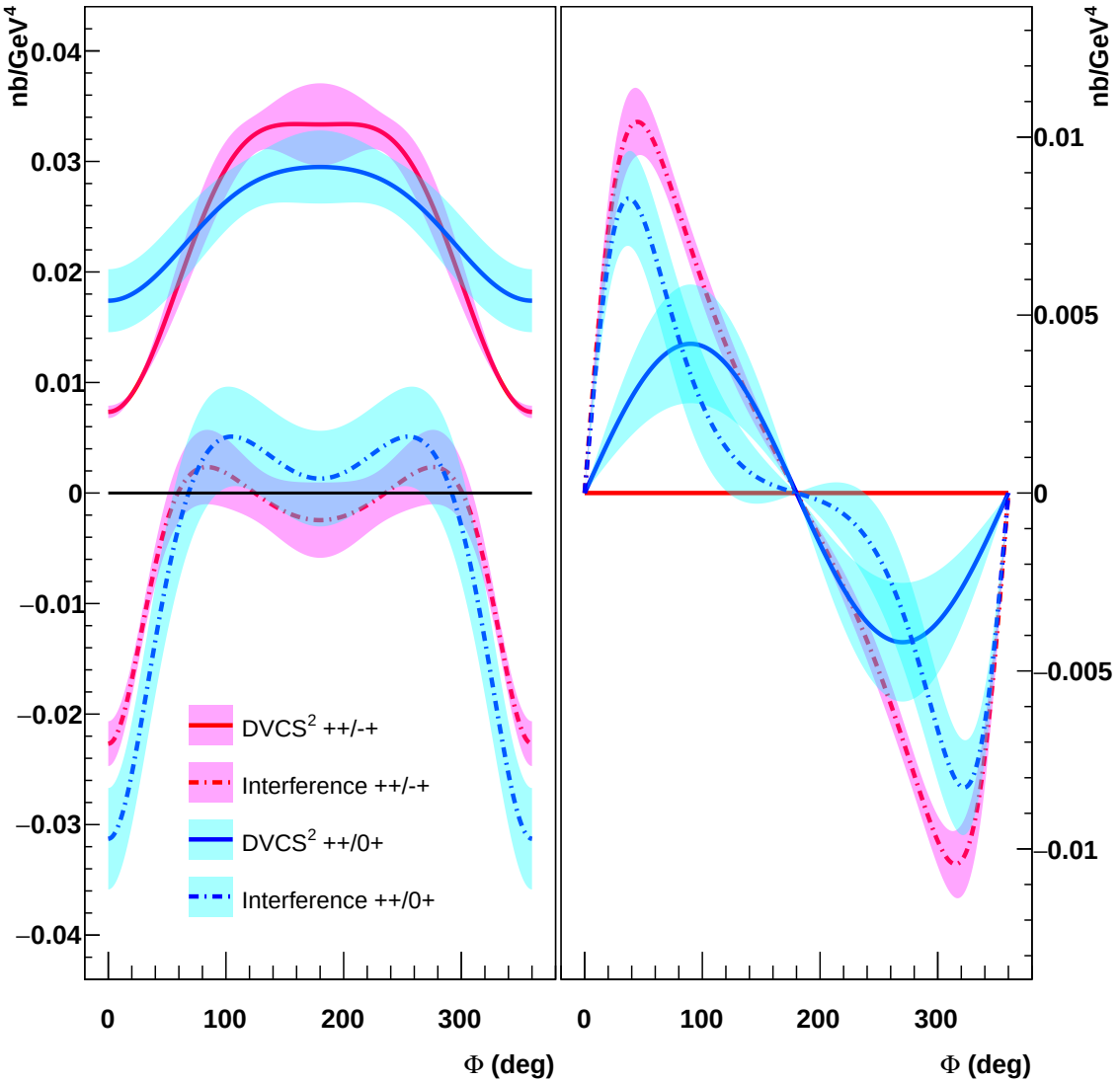
- Cross section measured at 2 beam energies and constant Q^2, x_B, t



- 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

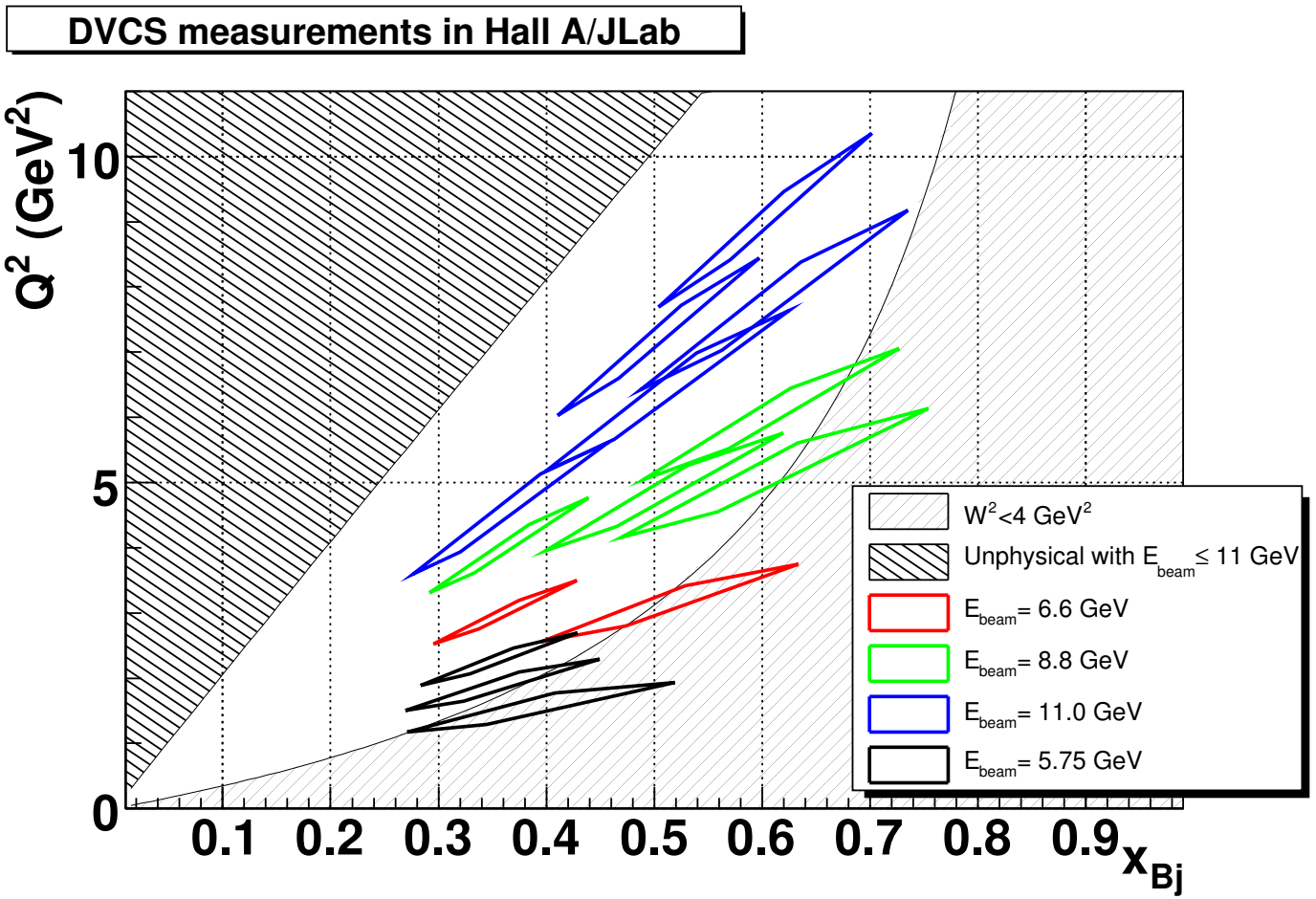


- $DVCS^2$ & $\mathcal{I}$ significantly different in each scenario
- Sizeable $DVCS^2$ contribution in the higher-twist scenario in the helicity-dependent cross section

arXiv:1703.09442

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

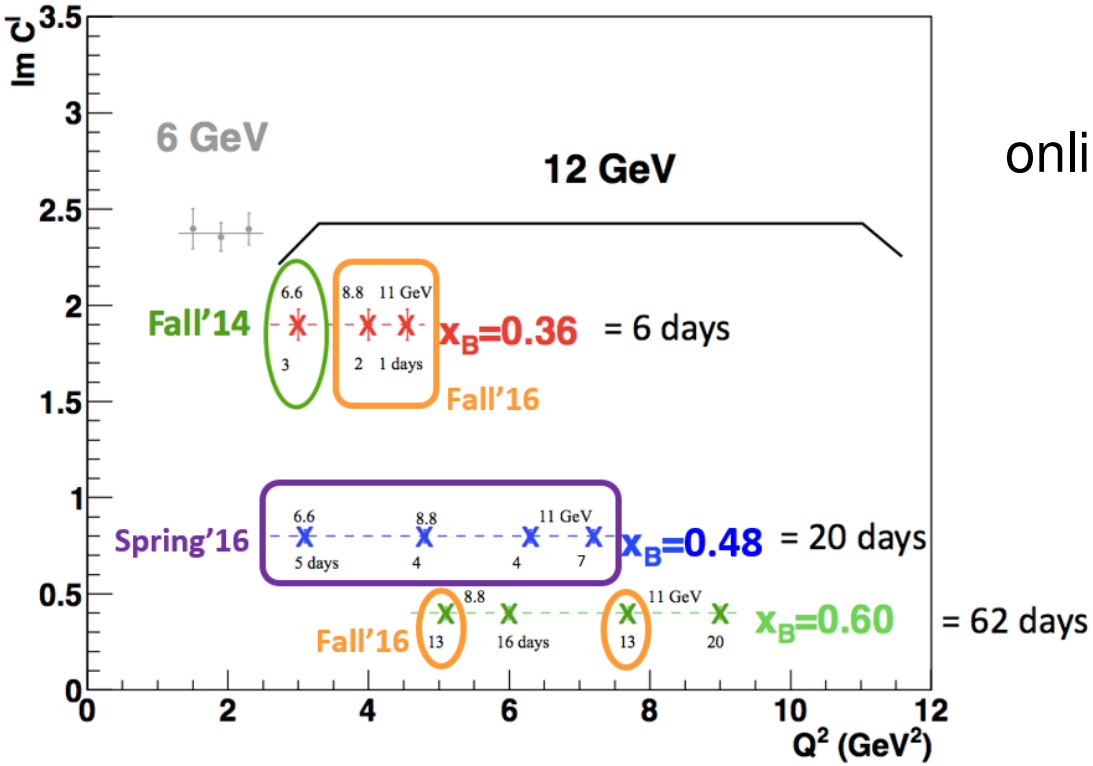
JLab12 with 3, 4, 5 pass beam
(6.6, 8.8, 11.0 GeV beam energy)



88 days
250k events/setting

1st Hall A experiment after the Upgrade (2014–2016)

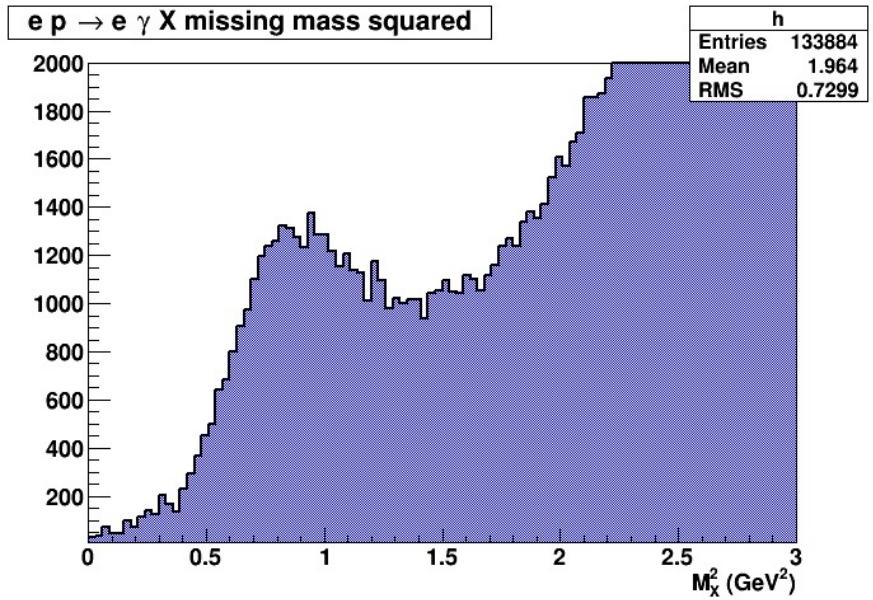
Scaling tests of the DVCS cross section



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

Identification of DVCS events:

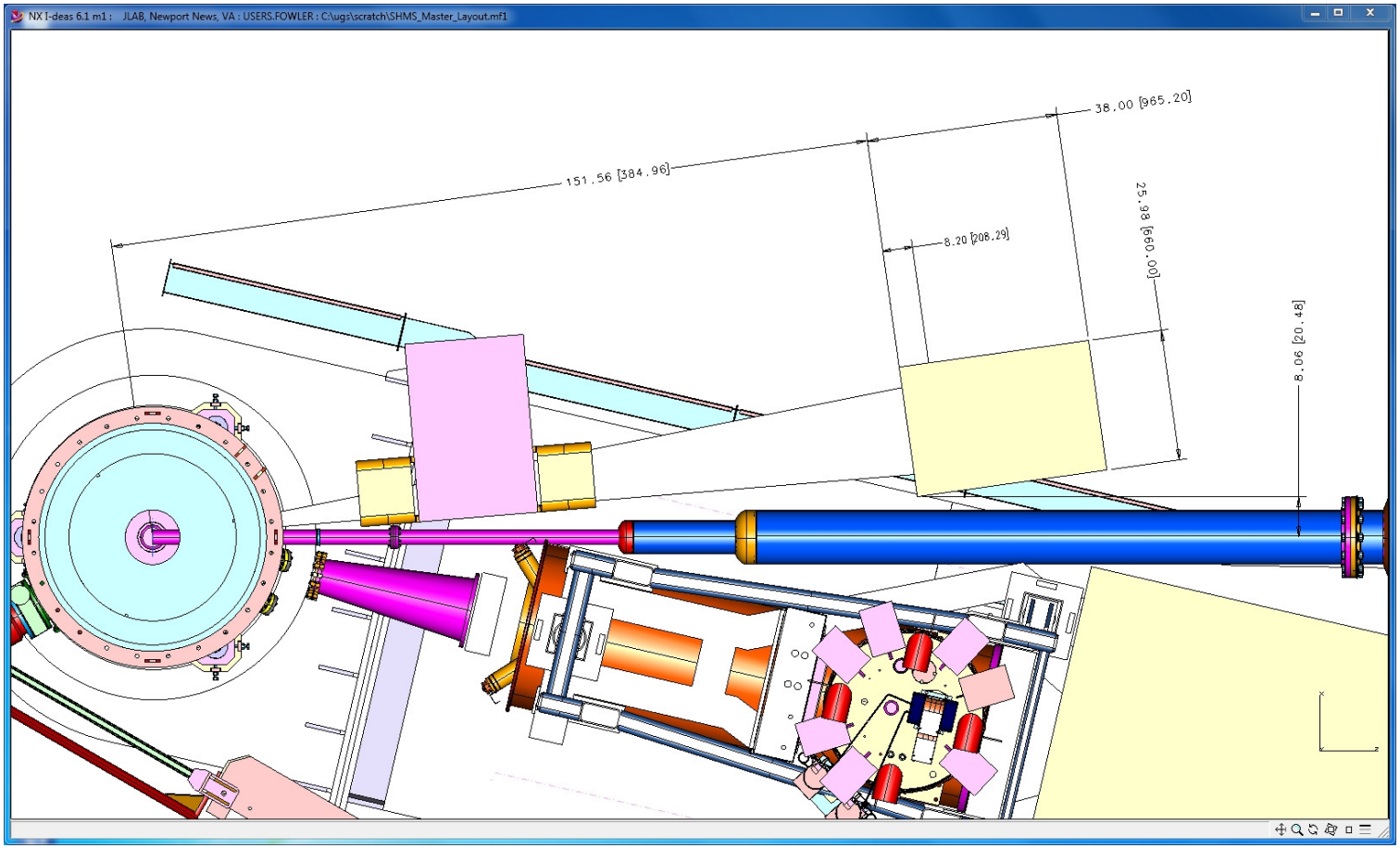
online $ep \to e\gamma X$ missing mass squared



Data analysis underway...

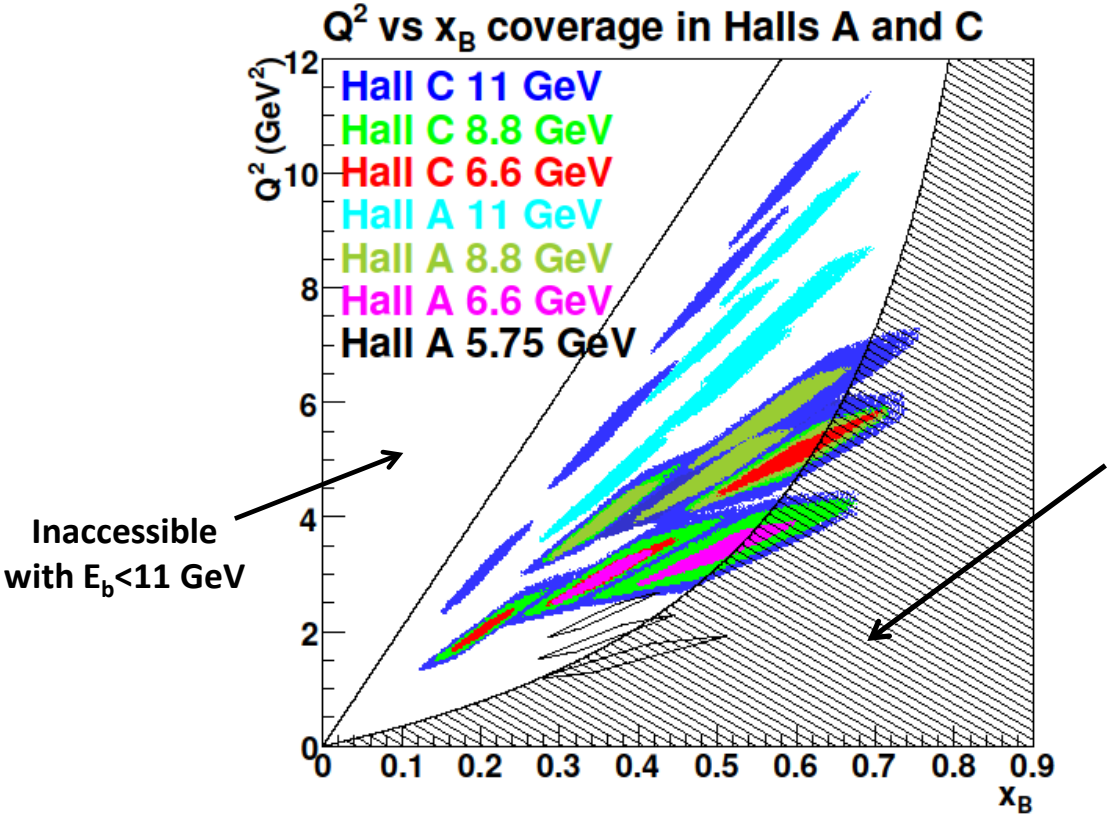
E12-13-010: DVCS in Hall C

- HMS ($p < 7.3GeV$): scattered electron
- $PbWO_4$ calorimeter: γ/π^0 detection
- Sweeping magnet



11 (and 8.8 and 6.6) GeV program in Halls A & C

- Approved high precision DVCS & π^0 programs in Halls A & C



- **Hall A** 50% of data already collected (2014–2016):
  analysis underway. . .
- **Hall C** program could start ∼2019–2020:
  Neutral Particle Spectrometer (NPS) under construction

Summary

- Recent high precision DVCS cross sections from Hall A at JLab
- Need of higher twist and/or NLO contributions to fully describe the data (eg. in global GPD fits)
- First separation of DVCS^2 and BH-DVCS interference in the $ep \to e\gamma p$ cross section
- Approved program of experiments in Hall A and C to continue these high precision DVCS measurements at 12 GeV

Back-up