Generalized Parton Distributions and Global Analysis
12-14 June 2023

DVCS EXPERIMENTS FROM JEFFERSON LAB TO THE EIC

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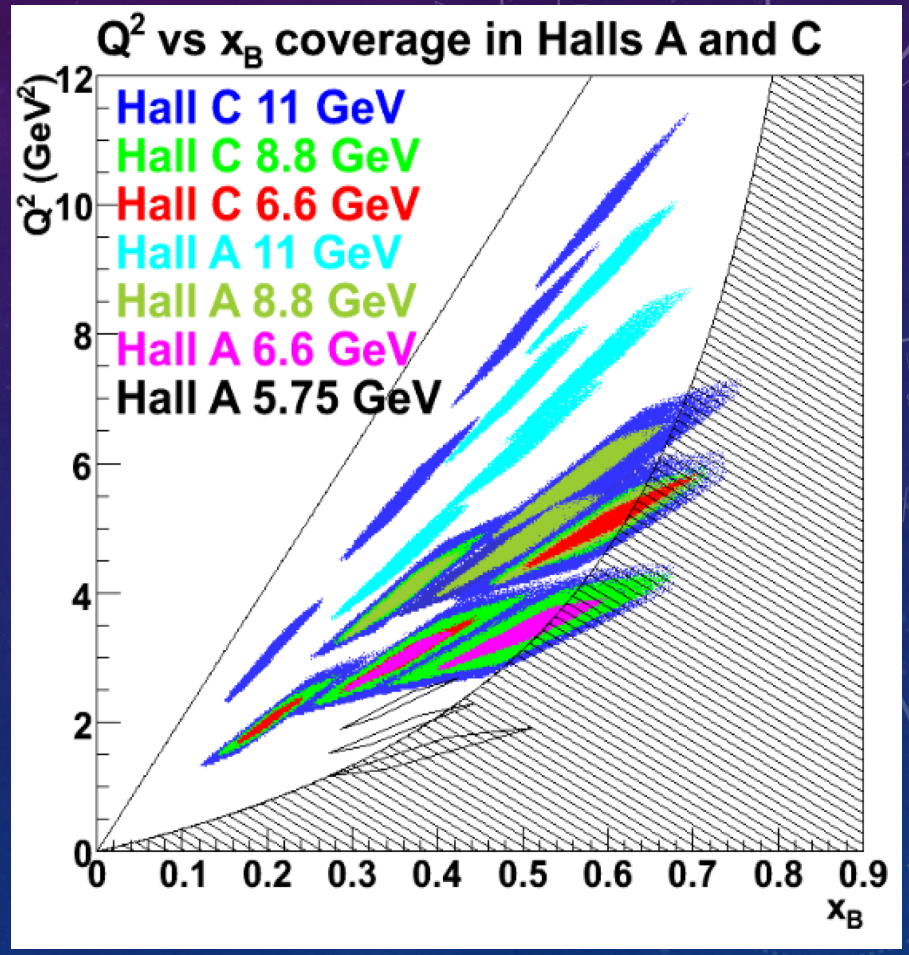
HALL A/C DVCS & π^0 AT 12 GEV

- E12-06-114
  - DVCS: F.Georges et al, *Phys.Rev.Lett.* **128** (2022) 25, 252002
  - Deep π^0 *Phys.Rev.Lett.* **127** (2021) 15, 152301
  - 50% complete, 38 PAC days added to Hall-C NPS in Jeopardy review
- NPS Run August 2023-March 2024
  - E12-13-010 Hydrogen (53 days)
  - E12-22-006: Deuterium (44 days)
- Future NPS runs on Wide Angle (real) Compton Scattering

HALL A/C PAST, PRESENT, and FUTURE DVCS

- Mostly to be completed by 2024
  - Possibly ~40 days still pending after first NPS run.
- Some kinematic adjustments for actual beam energies (e.g. 10.4, 10.6 GeV, rather than 11 GeV)



HALL A 12 GEV DVCS RESULTS:
F.Georges et al, *Phys.Rev.Lett.* **128** (2022) 25, 252002

- Analyzed in terms of W.Braun, *et al* formalism.
  - Light cone defined by q & q' (virtual photon and emitted real photon)
  - Helicity CFFs: $H_{\lambda',\lambda}.\ E_{\lambda',\lambda}.\ \tilde{H}_{\lambda',\lambda}.\ \tilde{E}_{\lambda',\lambda}$
  - Hypothesis: at fixed x_B, each CFF is independent of Q^2
    - Neglect QCD evolution
    - All higher-twist effects are contained in helicity flip CFFs:
    - Real & Imaginary parts of CFFs extracted from E_e, Q^2, $\phi_{\gamma\gamma}$ dependence of kinematic factors at fixed x_B

HALL A DVCS RESULTS @12 GEV

PHYSICAL REVIEW LETTERS **128,** 252002 (2022)

TABLE I. Main kinematic variables for each of the nine (Q^2, x_B) settings where the DVCS cross section is reported. E_b is the incident electron energy, E_γ and $-t_{\min}$ correspond to a final state photon emitted parallel to $\mathbf{q} = \mathbf{k} - \mathbf{k}'$ at the nominal Q^2, x_B values listed. For each setting, the cross section is measured as a function of t (3 to 5 bins depending on the setting) and in 24 bins in ϕ. The accumulated charge, corrected by the acquisition dead time, is listed in the row labeled $\int Qdt$. The last row of the table indicates the number of statistically independent measurements (bins) for each x_B setting, including helicity dependence.

Setting	Kin-36-1	Kin-36-2	Kin-36-3	Kin-48-1	Kin-48-2	Kin-48-3	Kin-48-4	Kin-60-1	Kin-60-3
x_B		0.36				0.48			0.60
E_b (GeV)	7.38	8.52	10.59	4.49	8.85	8.85	10.99	8.52	10.59
Q^2 (GeV^2)	3.20	3.60	4.47	2.70	4.37	5.33	6.90	5.54	8.40
E_γ (GeV)	4.7	5.2	6.5	2.8	4.7	5.7	7.5	4.6	7.1
$-t_{\min}$ (GeV^2)	0.16	0.17	0.17	0.32	0.34	0.35	0.36	0.66	0.70
$\int Qdt$ (C)	1.2	1.7	1.3	2.2	2.2	3.7	5.7	6.4	18.5
Number of data bins		672			912			480	

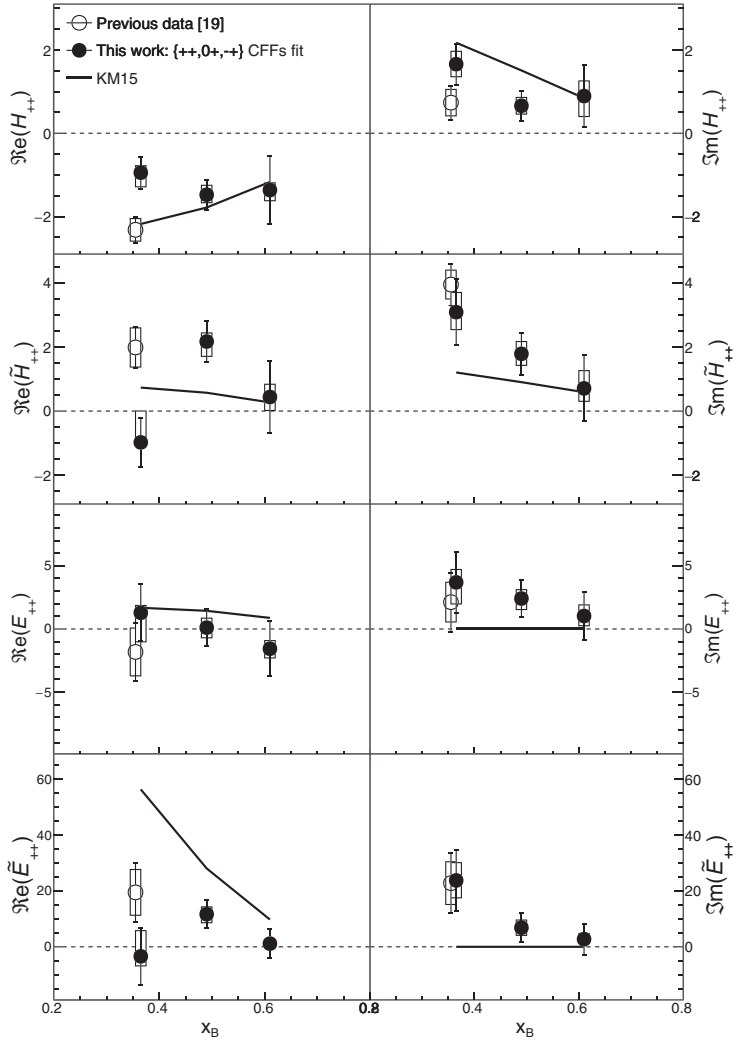


FIG. 4. Values of the helicity-conserving CFFs, averaged over t, as a function of x_B. Bars around the points indicate statistical uncertainty and boxes show the total systematic uncertainty. The fit results of previous data [19] at $x_B = 0.36$ are displayed with the open markers. The average t values are -0.281 GeV^2 [19] and -0.345, -0.702, -1.050 GeV^2 at $x_B = 0.36$, 0.48, 0.60, respectively. The solid lines show the KM15 model [29].

- Helicity conserving terms *e.g.* $\mathcal{H}_{++}$ shown, error bands include effects of $\mathcal{H}_{0+}$ and $\mathcal{H}_{-+}$

DEEP π^0

- Hall A 6 GeV L/T separations show Transverse-dominance
  - T-enhancement from χSB: Liutti et al, Goloskokov &Kroll
    - Access to Transversity GPDs
  - Supported by $\varepsilon\sigma_L+\sigma_T$, σ_{TL} , σ_{TT} results from CLAS
  - 12 GeV L/T separations planned with NPS run 2023-2024
- Flavor separations from D + H data and η-production (CLAS)

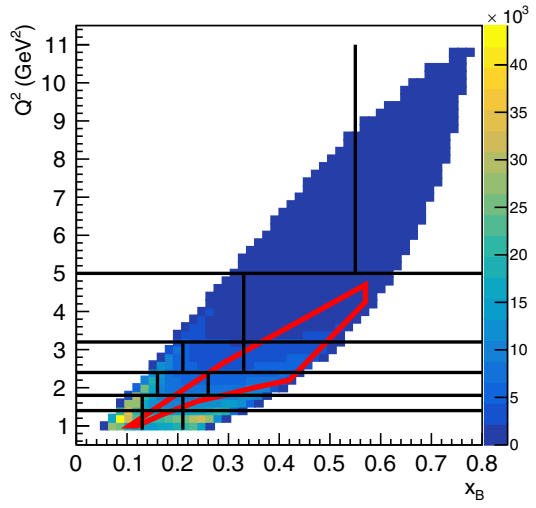
DVCS @ CLAS12

- RG-A Hydrogen Target (200 days approved, plus RG-K)
  - ~50% of data acquired
- RG-B Deuterium Target (90 days approved)
  - ~50% of data acquired
- RG-C Longitudinally polarized LH_3 and LD_3 (80 days approved).
  - 100% data taking completed March 2023
- RG-L “ALERT” active and/or spectator tagging for n/p DVCS and coherent DVCS on D, He targets.

CLAS12: RUN GROUP A:

- H(e,e'pγ)
- ~50% of available statistics, ~25% of total projected statistics

CLAS 12 phase space and relative count rate. (6 GeV in red)



PHYSICAL REVIEW LETTERS **130,** 211902 (2023)

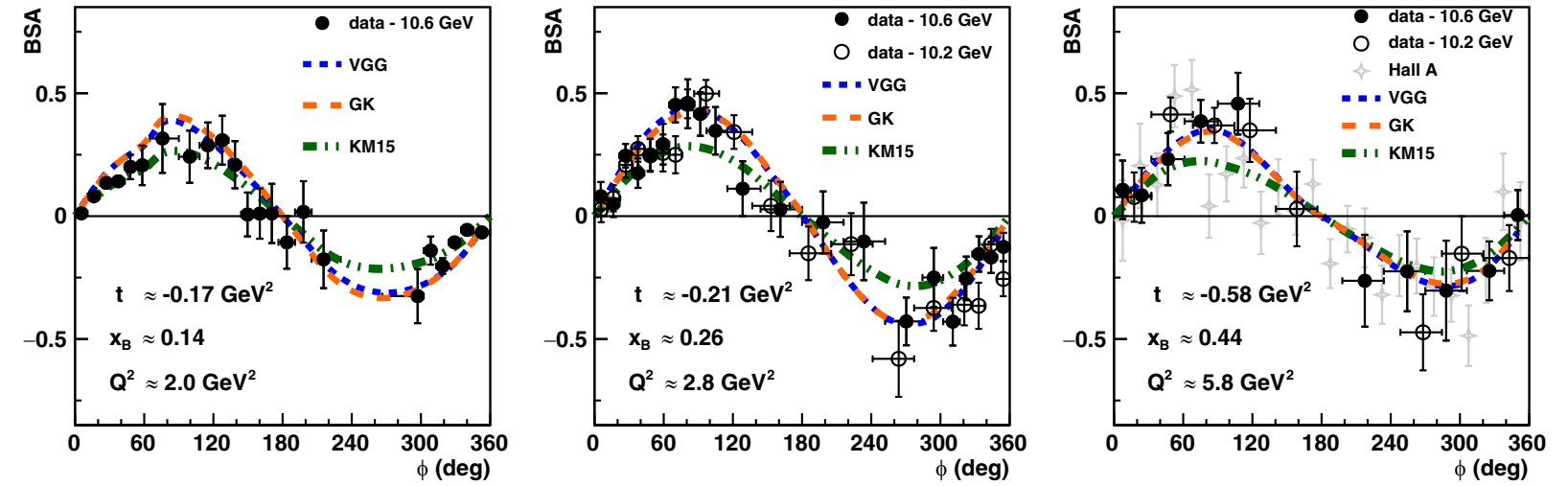
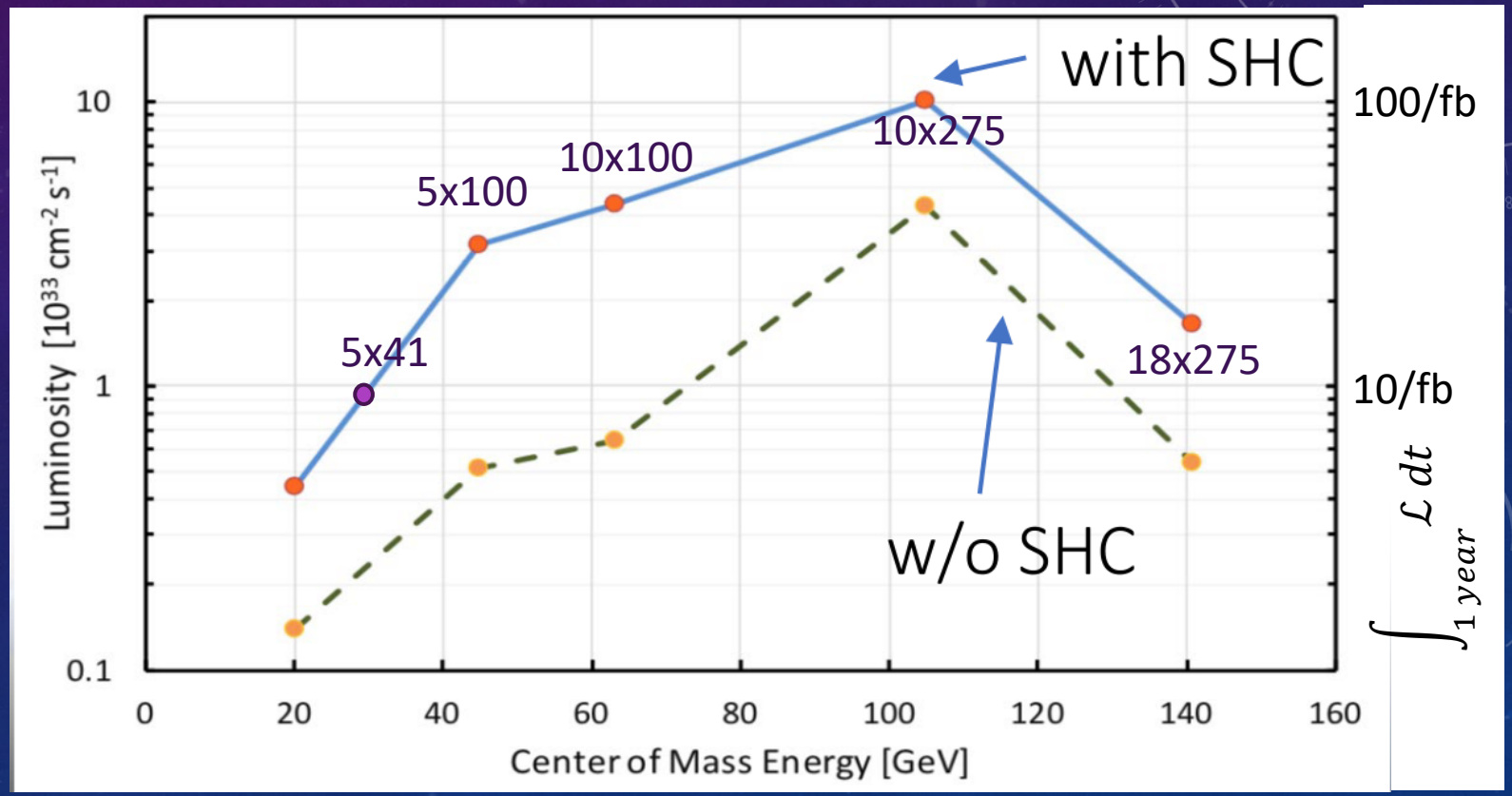


FIG. 5. Beam-spin asymmetries for bins only reachable with a ~10 GeV electron beam, compared with the KM15, GK, and VGG GPD models. The kinematics listed are approximate; point-by-point kinematics are available in the tables of the Supplemental Material for the full dataset [40]. In the last bin, Hall A asymmetries have been computed from the data published in [22] at $Q^2 = 5.36$ GeV^2, $x_B = 0.48$, and $t = -0.51$ GeV^2.

EIC DESIGN *ep* LUMINOSITY

- Full Luminosity with Strong Hadron Cooling (SHC)
- https://doi.org/10.18429/JACoW-IPAC2022-WEIXGD1 "Collisions will occur at a range of center-of-mass energies between 29 GeV and 140 GeV"

D.Xu, *et al*, https://doi:10.18429/JACoW-IPAC2022-WEIXGD1



PROTON DVCS @ EIC

- ECCE Simulations ep→epγ
  - Acceptance in $-t<0.25$ GeV^2 is achieved with special "high acceptance" tune (larger β^*) to reduce angular spread at target. Factor of ≥2 lower Lumi.
- To my knowledge, no detailed simulations of CFF sensitivity yet.
- Longitudinally & transversely polarized protons!

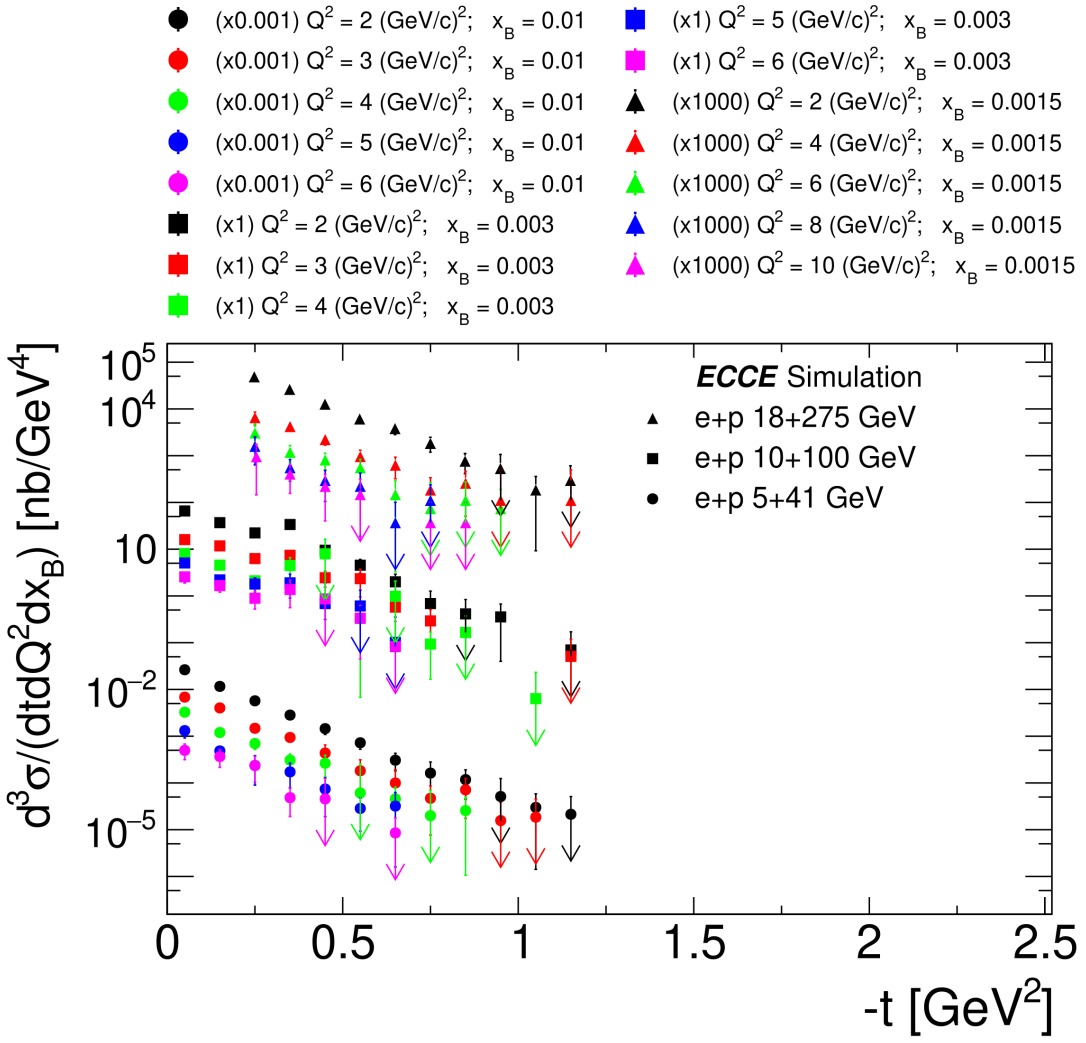


Figure 33: Projected DVCS differential cross-section measurements as a function of the momentum transfer $-t$ for different bins in Q^2 and x_B. The assumed integrated luminosity is 10 fb $^{-1}$ for each beam energy configuration.

EIC *ep* and *eA* LUMINOSITY

- W.Fischer, IPAC2021
  "High Acceptance" tune require to achieve low-t acceptance for DVCS

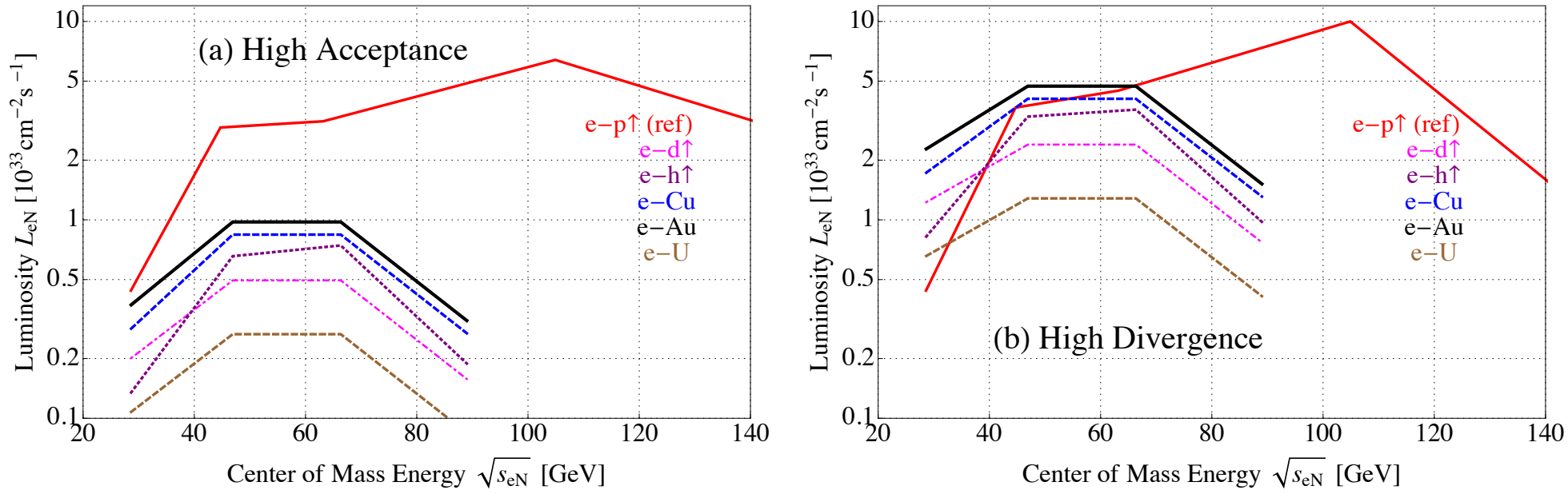


Figure 1: EIC e-A luminosity L_{eN} for N = p, d, h, Cu, Au and U beams, all with Strong Hadron Cooling. Part (a) shows the luminosities for the High Acceptance limits imposed on the angular beam spreads $\sigma'_{A,x,y,\max}$ at the Interaction Point (Table 2), and part (b) for the High Divergence limits. With Strong Hadron Cooling the peak and average store luminosity are close. The e-p reference case data are taken from Ref. [1].

NEUTRON DVCS @ EIC

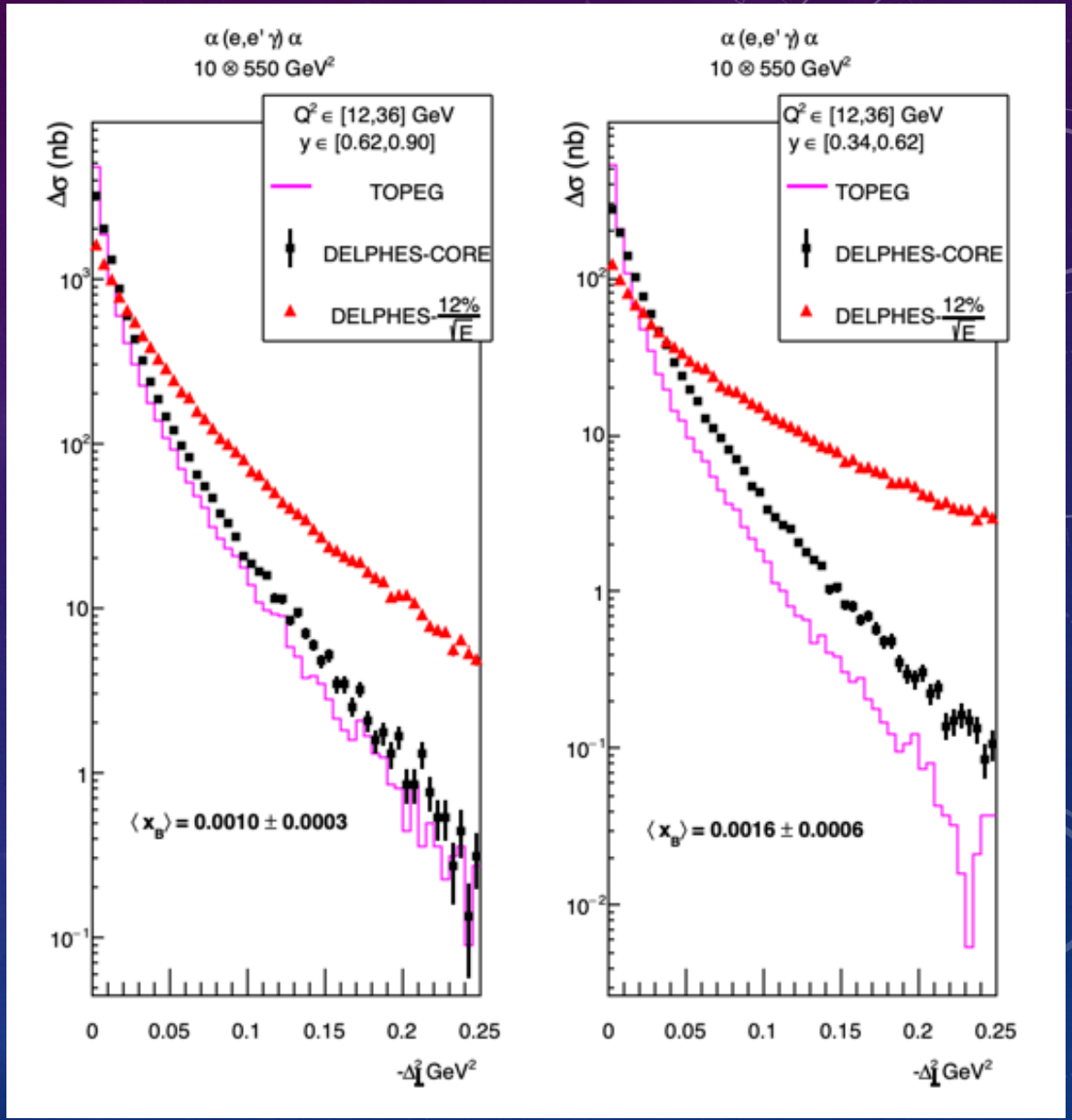
- Polarized ^{3}He (longitudinal & transverse, ~80%)
  - Di-proton spectators from neutron DVCS in ^{3}He emerge near 0deg with rigidity (P/Q) = 66% of beam→detected in “Off Momentum Trackers in far-forward region ≥ 20m from IP
  - Active neutron detectable in ~4mr cone --> -D2<0.5 GeV2 at 183 GeV/n. Possible veto of breakup channels.
- Un-polarized deuteron beams are a day-one feature
  - Polarized *d* is an upgrade dream, but not impossible.

NUCLEAR DVCS @ EIC

- The EIC ion storage ring determines the magnetic rigidity P_0 of a stored ion.
  - Total ion momentum is ZP_0
  - Final focus quads & emittance determine angular spread $\sigma(\theta) \approx 0.3$ mrad at IP.
  - Ion rms $P_T = ZP_0\,\sigma(\theta)$: Completely washes out diffraction patterns of nuclei.
  - Reconstruct momentum transfer to nucleus without nuclear detection.
  - Rapidly lose ability to detect recoil nuclei at reasonable Δ^2 values
- Exclusive Vector meson production. Channels with all charged particles:
  - (e,e' $\boldsymbol{\rho}\rightarrow\pi^+\pi^-$), (e,e' $\phi\rightarrow K^+K^-$), (e,e'J/$\Psi\rightarrow e^+e^-$ or $\mu^+\mu^-$)
  - Directly measure $\Delta^\mu=(k-k'-V)^\mu$ with central tracker
- DVCS: ${}^A\mathrm{Z}(e,e'\gamma)\,{}^A\mathrm{Z}$ feasible only with excellent γ-resolution

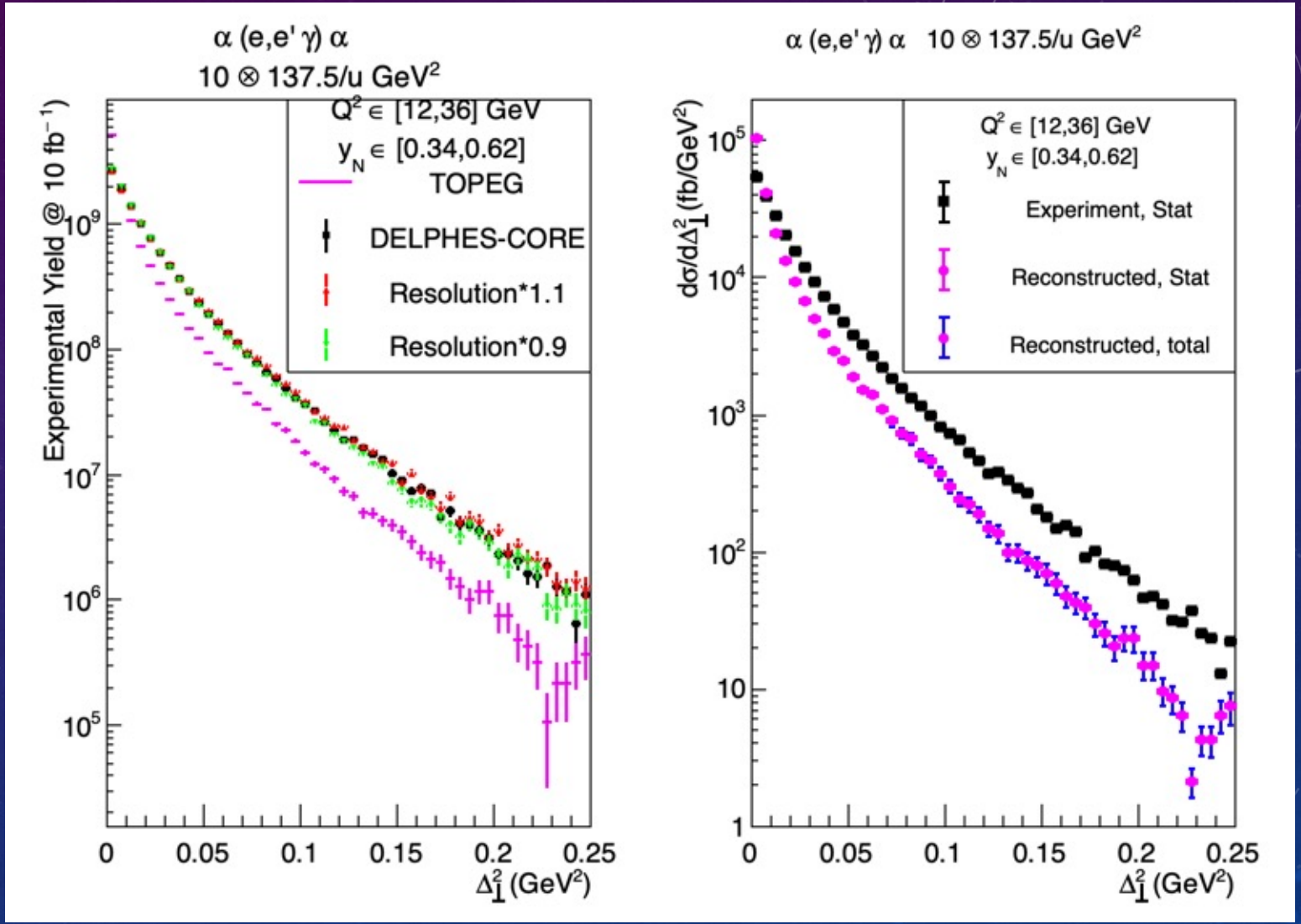
NUCLEAR DVCS WITH A 2ND EIC DETECTOR

- Downstream focus in ion beam line enables tagging/veto of all possible breakup nuclei of beams from D to Zr, and all A-2 daughters up to U.
- 2nd detector offers opportunity for high resolution EMCal in barrel
  - Black points show $PbWO_4$ resolution



αDVCS

- TOPEG event generator
  https://gitlab.in2p3.fr/dupre/nopeg
  10 GeV $e^- \otimes$ *137.5 GeV per nucleon*
- DELPHES FastMC: hypothetical $PbWO_4$ EMCal for $\eta<0$
- Systematic uncertainty in reconstructed cross section estimated by varying EMCal resolution by ±10%
- Error bars from uncertainty of bin-migration remain small.



NUCLEAR DVCS SIMULATIONS

- Need new MC event generators
  - TOPEG is great, but infinitely slow if Re[CFF] is included
- Need generators (even simplistic) for a range of nuclei
  - ^{12}C, ^{16}O, … ^{40,48}Ca, … Zr, Pb
  - The significance of the veto powers of the 2nd focus in IR-8 (2nd Detector) grows rapidly with *Z*.

DOUBLE DVCS

- Severely Count Rate limited
  - Best case (my opinion) low Q^2, “measure” slightly off diagonal, *i.e.* x=±(ξ-ε): $GPD(\xi^-, \xi, t) \pm GPD(-(\xi^-), -\xi, t)$
  - GPD has discontinuity in slope at x=±ξ (D-term)

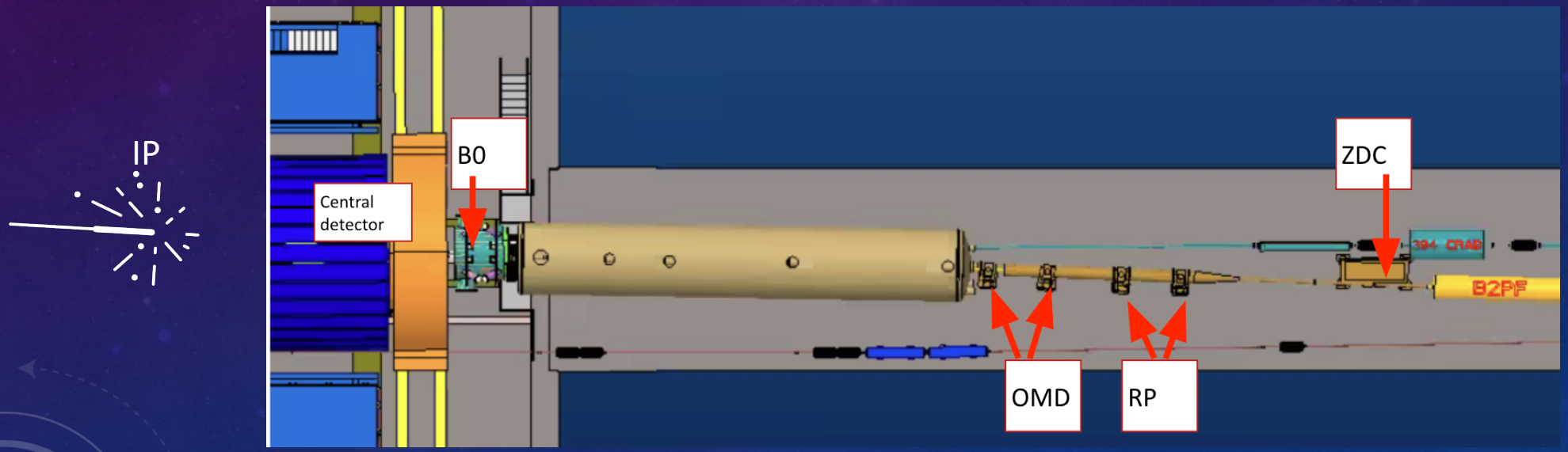
CONCLUSIONS

- Need to understand/control impact of higher-twist observables
- We will always only have a discrete number of local averages of CFFs from experiments
  - Need a realistic assessment of possible constraints on GPDs from data, Lattice QCD, *etc.*
  - Also consider the physics content of the CFFs themselves*:*
    Transitions amplitudes (not probabilities) of $x+\xi \rightarrow x-\xi$

MORE SLIDES

FORWARD TAGGING IN EPIC

- Proton DVCS detected by insertable `Roman Pot' (RP) trackers, fixed `Off Momentum Detectors' (OMD), and/or B0 (dipole) tracker
- Spectator protons from *e.g.* ^{3}He in RP or OMD



Hall A 12 GeV DVCS: cross sections

- Dataset sample - multidimensional binning:
  3 x_B bins ×
  2-4 Q^2 bins ×
  3-5 t bins ×
  24 ϕ bins
- More than 2000 data points in Q^2, x_B, t and ϕ

x_B=0.36	x_B=0.48	x_B=0.60