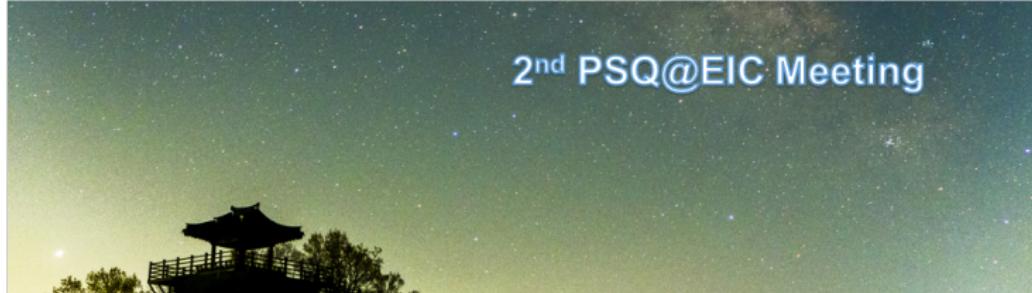


Connecting DVCS at low and high energies for precision imaging

F.-X. Girod

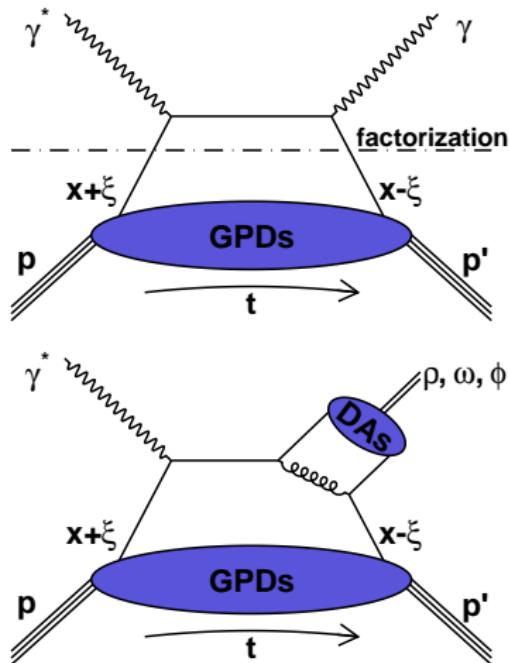
University of Connecticut & George Washington

Jul 20th 2021



Deep Exclusive Scattering

Generalized Parton Distributions



$\gamma^* p \rightarrow \gamma p'$, $\gamma^* p \rightarrow \rho p'$, $\omega p'$, $\phi p'$

Bjorken regime :

$Q^2 \rightarrow \infty$, x_B fixed

t fixed $\ll Q^2$, $\xi \rightarrow \frac{x_B}{2-x_B}$

F. M. Dittes et al PL B209 (1988) 325
X. Ji, PRL78 (1997) 610

$$\begin{aligned} & \frac{P^+}{2\pi} \int dy^- e^{ixP^+y^-} \langle p' | \bar{\psi}_q(0) \gamma^+ (1 + \gamma^5) \psi(y) | p \rangle \\ &= \bar{N}(p') \left[H^q(x, \xi, t) \gamma^+ + E^q(x, \xi, t) i \sigma^{+\nu} \frac{\Delta_\nu^+}{2M} \right. \\ & \quad \left. + \tilde{H}^q(x, \xi, t) \gamma^+ \gamma^5 + \tilde{E}^q(x, \xi, t) \gamma^5 \frac{\Delta^+}{2M} \right] N(p) \end{aligned}$$

spin	N no flip	N flip
q no flip	H	E
q flip	\tilde{H}	\tilde{E}

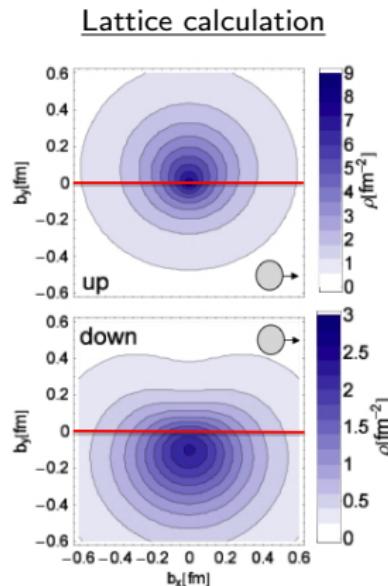
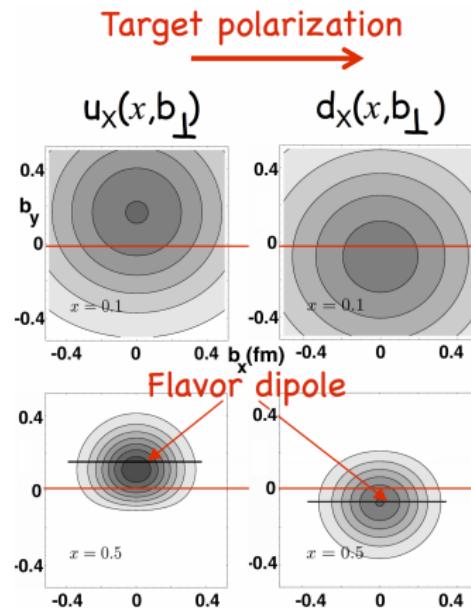
3-D Imaging conjointly in transverse impact parameter and longitudinal momentum

GPDs and Transverse Imaging

(x_B, t) correlations

$$q_X(x, \vec{b}_\perp) = \int \frac{d^2 \vec{\Delta}_\perp}{(2\pi)^2} \left[H(x, 0, t) - \frac{E(x, 0, t)}{2M} \frac{\partial}{\partial b_y} \right] e^{-i \vec{\Delta}_\perp \cdot \vec{b}_\perp}$$

M. Burkardt PR D62 (2000) 071503



GPDs and Energy Momentum Tensor (x, ξ) correlations

Form Factors accessed via second x-moments :

$$\langle p' | \hat{T}_{\mu\nu}^q | p \rangle = \bar{N}(p') \left[M_2^q(t) \frac{P_\mu P_\nu}{M} + J^q(t) \frac{i(P_\mu \sigma_{\nu\rho} + P_\nu \sigma_{\mu\rho}) \Delta^\rho}{2M} + d_1^q(t) \frac{\Delta_\mu \Delta_\nu - g_{\mu\nu} \Delta^2}{5M} \right] N(p)$$

Angular momentum distribution

$$J^q(t) = \frac{1}{2} \int_{-1}^1 dx x [H^q(x, \xi, t) + E^q(x, \xi, t)]$$

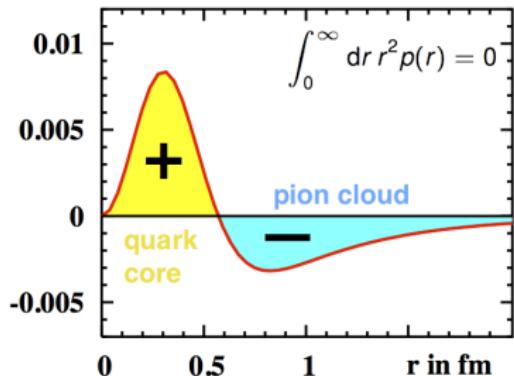
Mass and force/pressure distributions

$$M_2^q(t) + \frac{4}{5} d_1(t) \xi^2 = \frac{1}{2} \int_{-1}^1 dx x H^q(x, \xi, t)$$

$$d_1(t) = 15M \int d^3 \vec{r} \frac{j_0(r\sqrt{-t})}{2t} p(r)$$

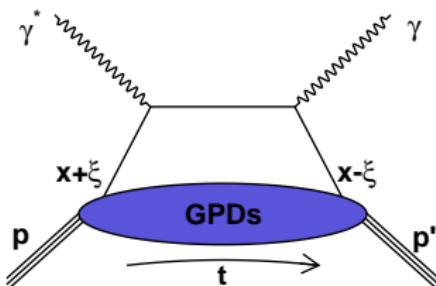
H. Page, PR 144 (1966) 1250
X. Ji, PRL78 (1997) 610
M.V. Polyakov PL B555 (2003) 57
K. Goeke et al PR D75 (2007) 094021

$r^2 p(r)$ in GeV fm^{-1}



Deeply Virtual Compton Scattering

The cleanest GPD probe at low and medium energies



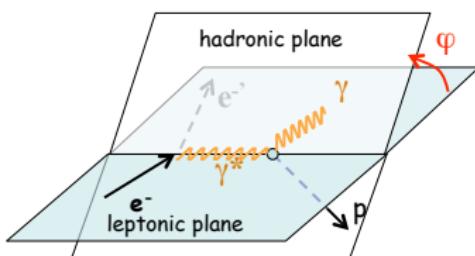
$$ep \rightarrow ep\gamma$$

DVCS BH

$$\sigma(ep \rightarrow ep\gamma) \propto \left| \begin{array}{c} \text{(a)} \\ \text{(b)} \\ \text{(c)} \end{array} \right| + \left| \begin{array}{c} \text{(a)} \\ \text{(b)} \\ \text{(c)} \end{array} \right| + \left| \begin{array}{c} \text{(a)} \\ \text{(b)} \\ \text{(c)} \end{array} \right| \right|^2$$

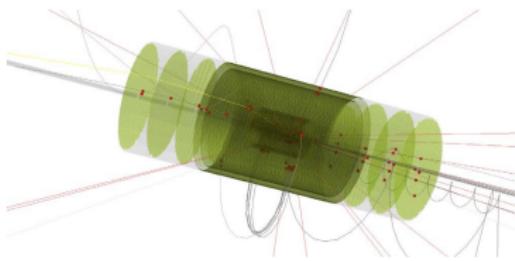
Diehl, Gousset, Pire, Ralston (1997)

Belitsky, Müller, Kirchner (2002, 2010)

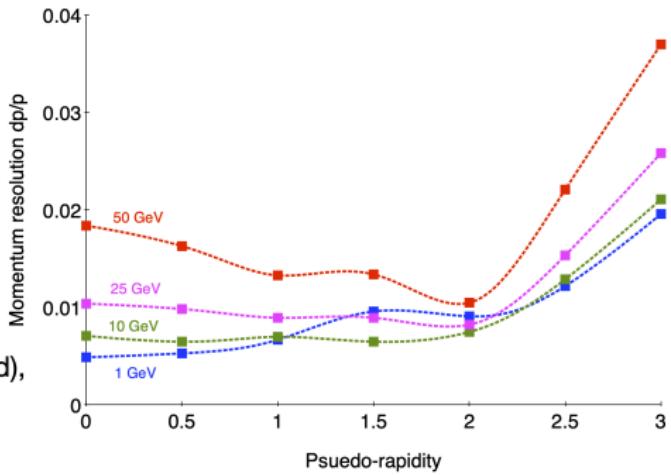


$$A_{LU} = \frac{d^4\sigma^\rightarrow - d^4\sigma^\leftarrow}{d^4\sigma^\rightarrow + d^4\sigma^\leftarrow} \stackrel{\text{twist-2}}{\approx} \frac{\alpha \sin \phi}{1 + \beta \cos \phi}$$
$$\alpha \propto \text{Im} \left(F_1 \mathcal{H} + \xi G_M \tilde{\mathcal{H}} - \frac{t}{4M^2} F_2 \mathcal{E} \right)$$
$$\mathcal{H}(\xi, t) = i\pi H(\xi, \xi, t) + \mathcal{P} \int_{-1}^1 dx \frac{H(x, \xi, t)}{x - \xi}$$
$$A_{UL} \propto \text{Im} \left(F_1 \tilde{\mathcal{H}} + \xi G_M \mathcal{H} + G_M \frac{\xi}{1 + \xi} \mathcal{E} + \dots \right) \sin \phi$$

EIC Si Tracker Concept



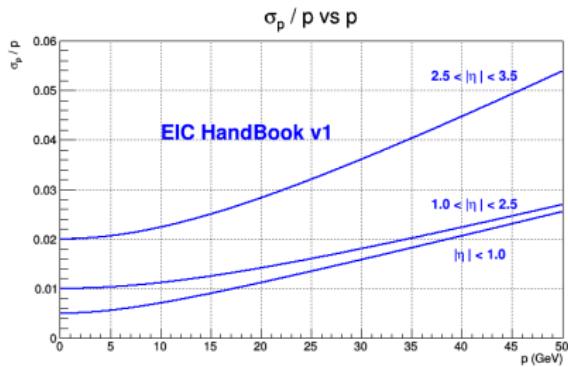
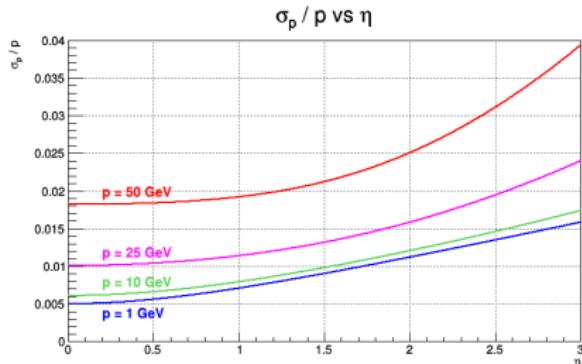
- 6 barrel layers,
- 6 tapered disks x 2 (forward, backward),
- $r_{outer} \sim 0.45\text{m}$, $-1.22\text{m} < z < 1.22\text{m}$,
- $\sim 15\text{m}^2$ area; $\sim 10\text{m}^2$ barrel, $\sim 5\text{m}^2$ disks



April 9, 2020 - JLab-LBNL EIC discussion

Ernst Sichtermann

Si Tracker Resolutions Parameterization



EIC Handbook Parameterizations:

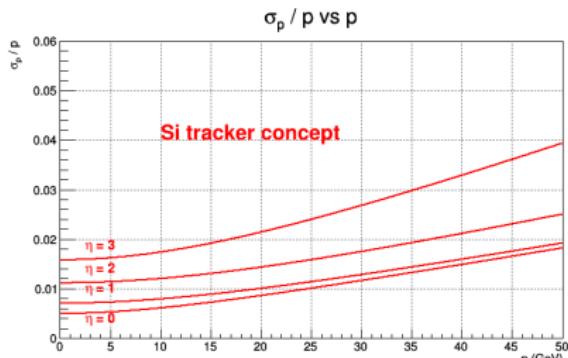
$$2.5 < |\eta| < 3.5 \implies \frac{\sigma_p}{p} = 0.1\%p \oplus 2\%$$

$$1.0 < |\eta| < 2.5 \implies \frac{\sigma_p}{p} = 0.05\%p \oplus 1\%$$

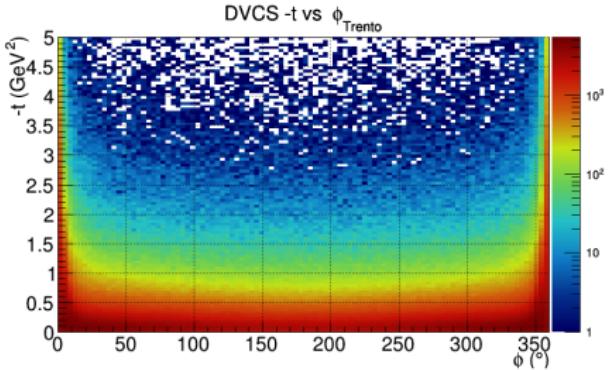
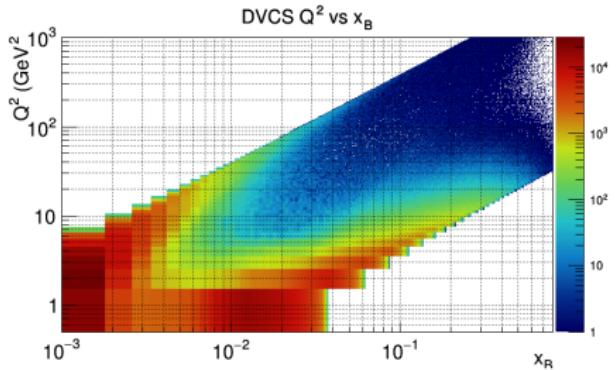
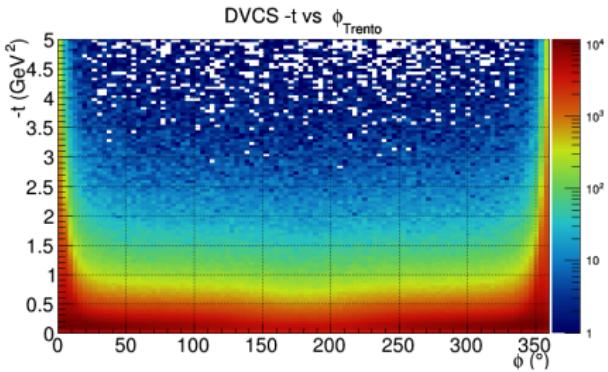
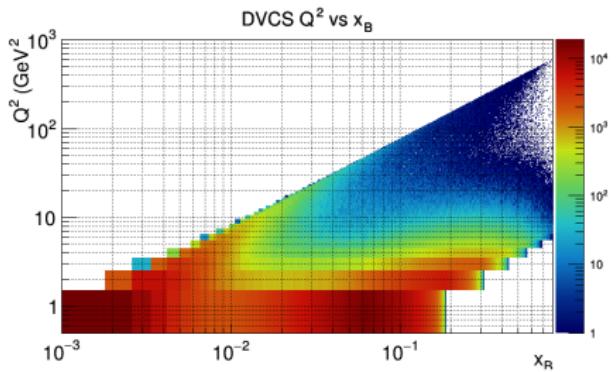
$$|\eta| < 1.0 \implies \frac{\sigma_p}{p} = 0.05\%p \oplus 0.5\%$$

Si concept Parameterization:

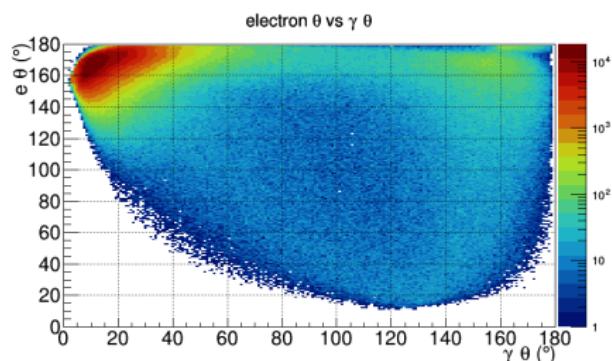
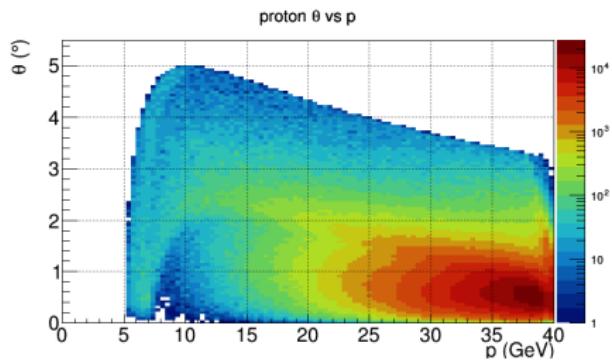
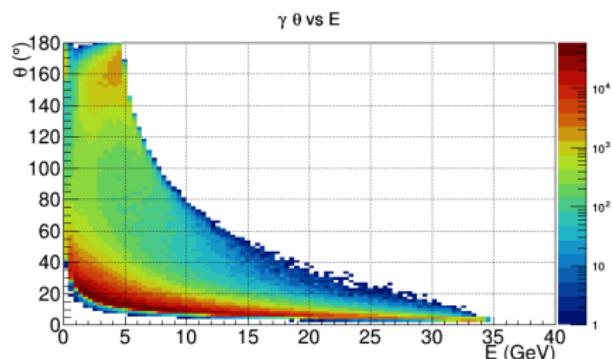
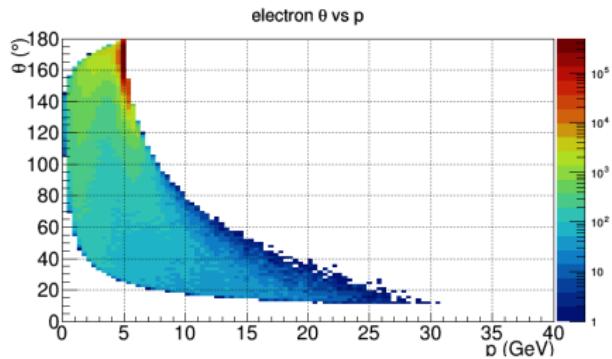
$$\frac{\sigma_p}{p} = 0.5\% \oplus 0.0035\%p \oplus 0.5\%\eta \oplus 7 \times 10^{-5} p\eta^2$$



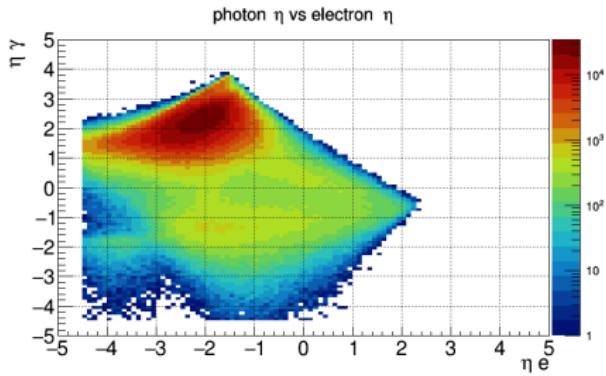
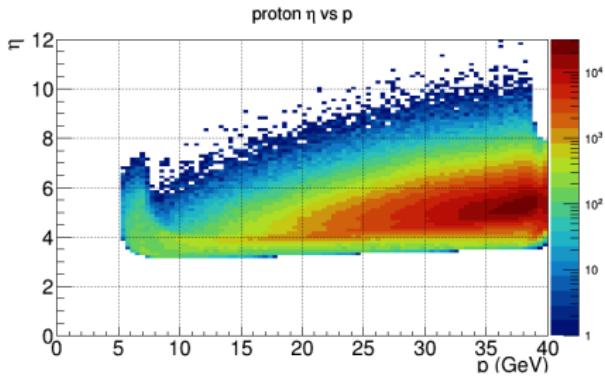
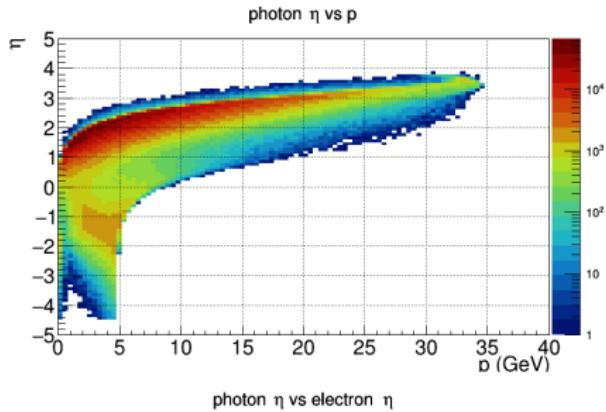
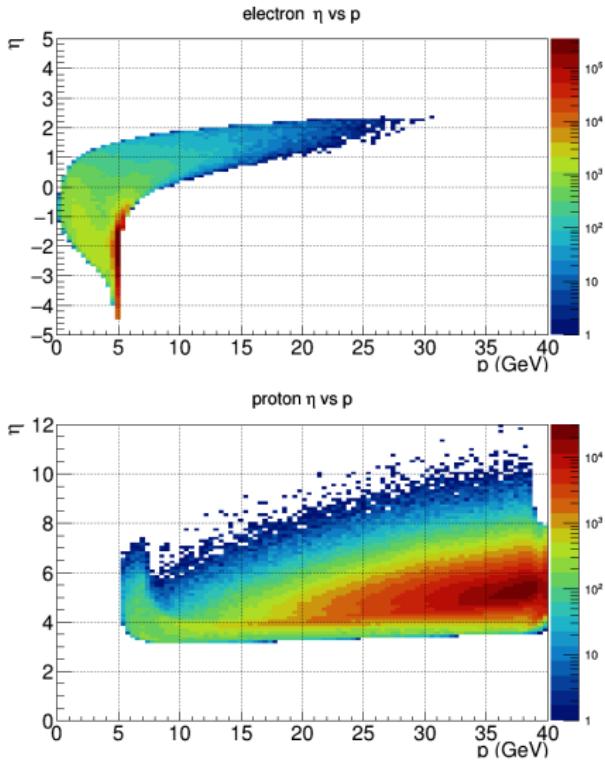
Coverage $5 \times 40 \text{ GeV}^2$ and $10 \times 100 \text{ GeV}^2$



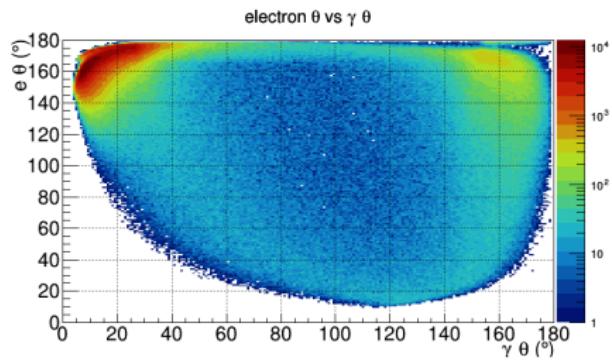
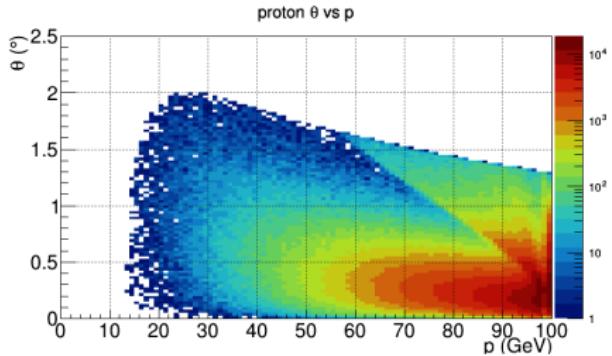
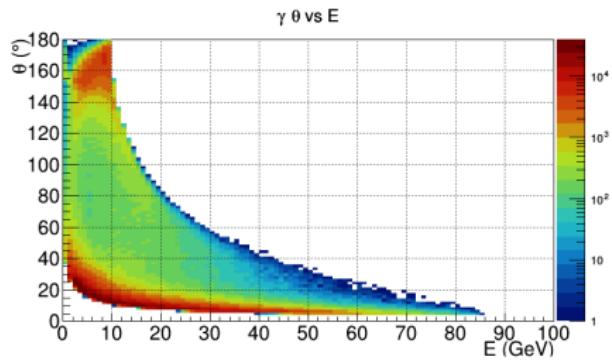
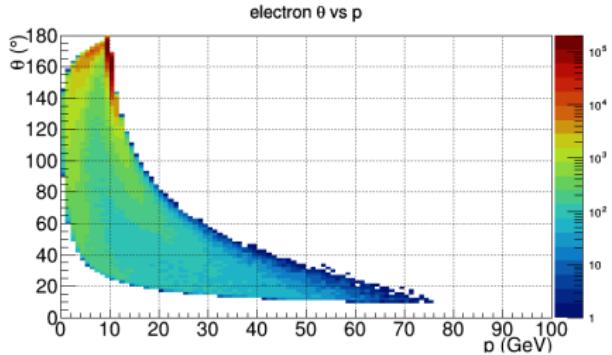
Kinematics 5×40 GeV 2



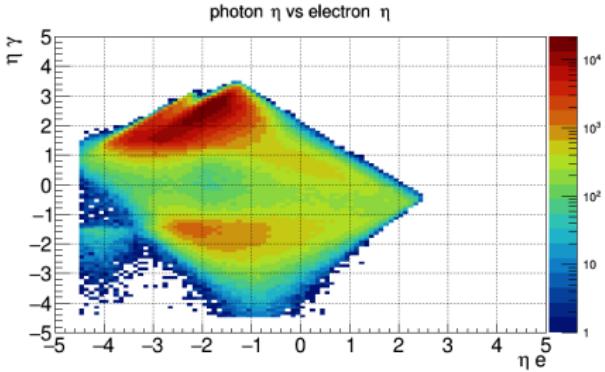
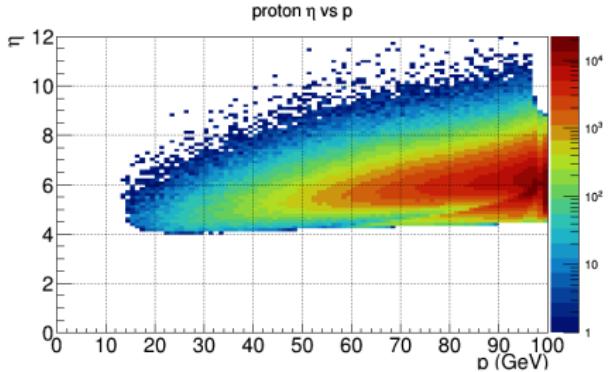
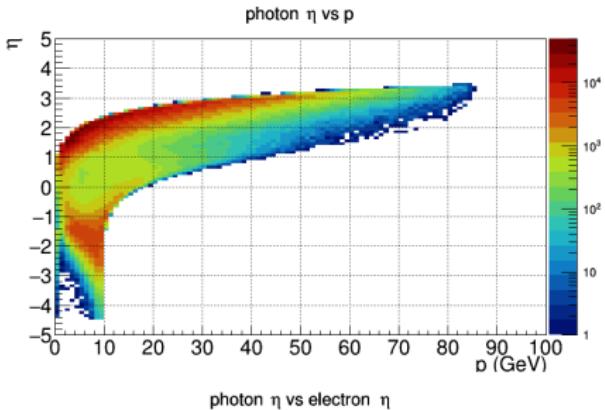
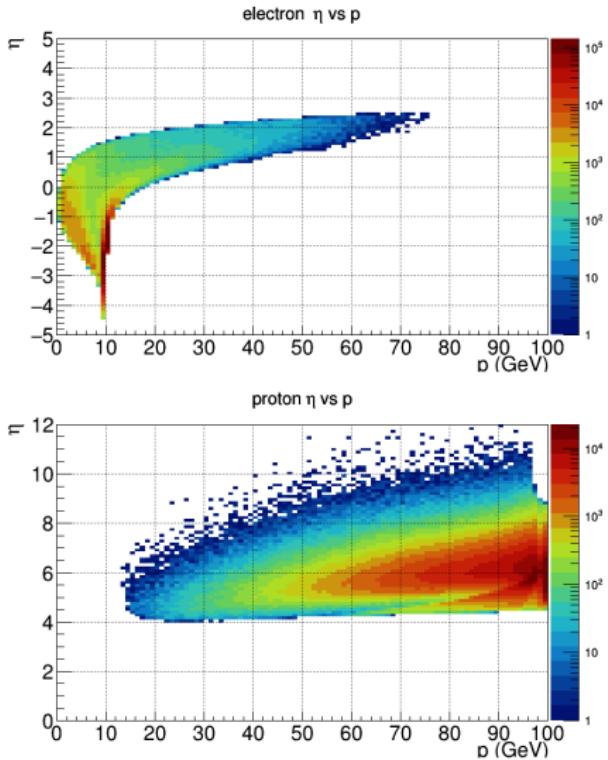
Kinematics 5×40 GeV 2



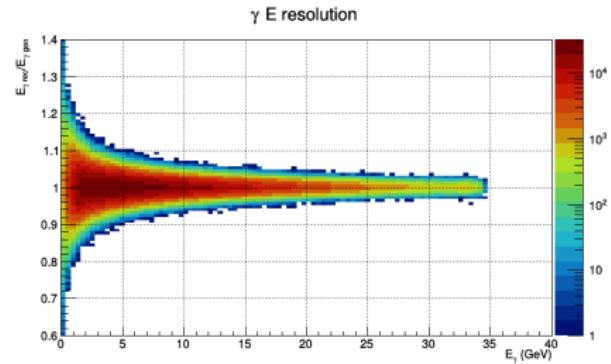
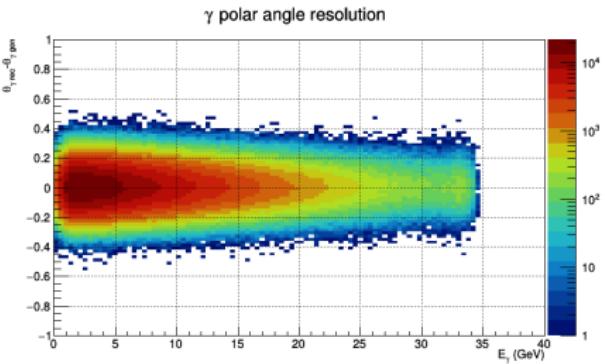
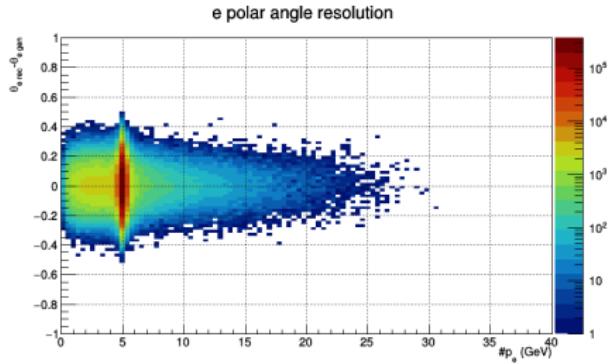
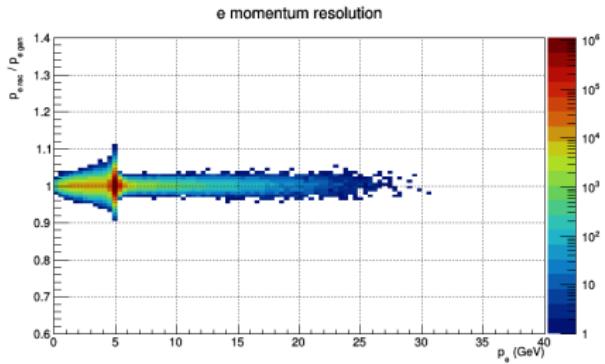
Kinematics 10×100 GeV 2



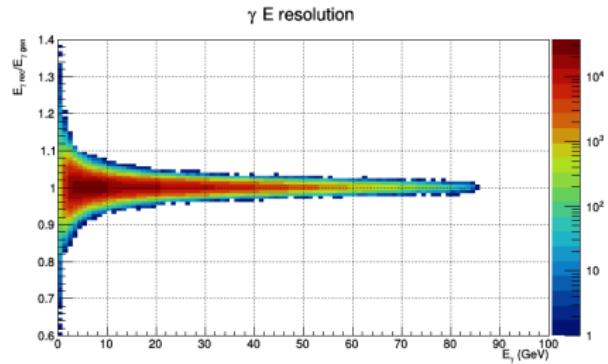
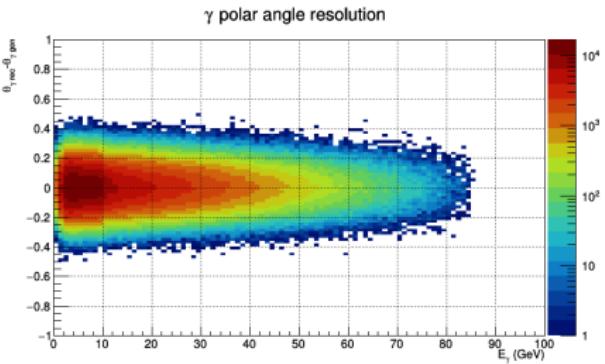
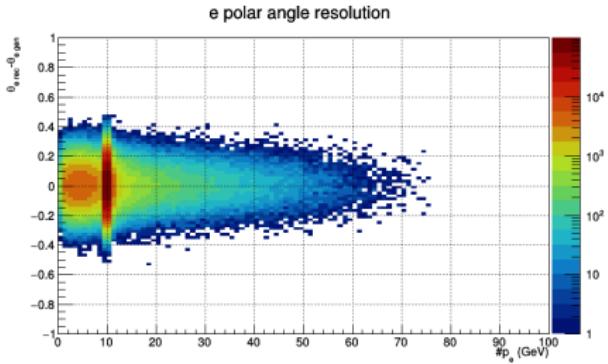
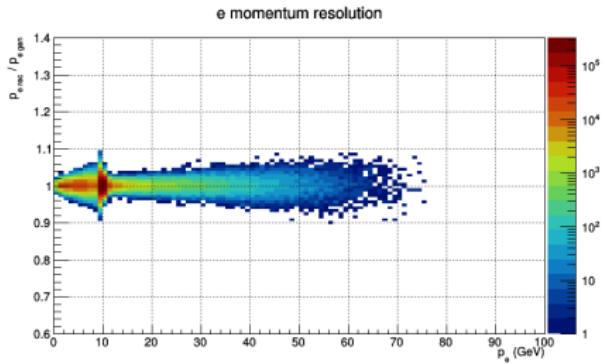
Kinematics 10×100 GeV 2



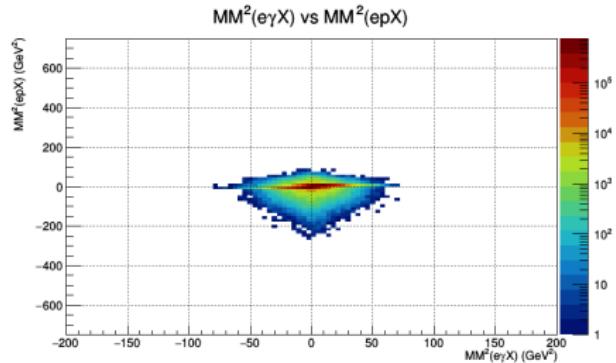
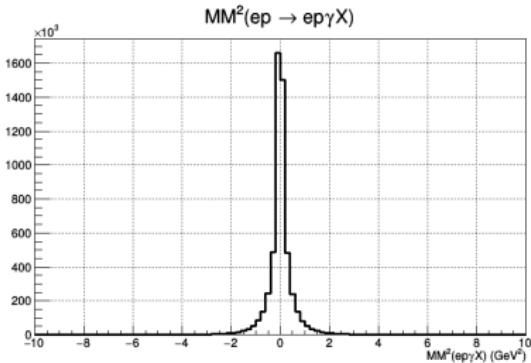
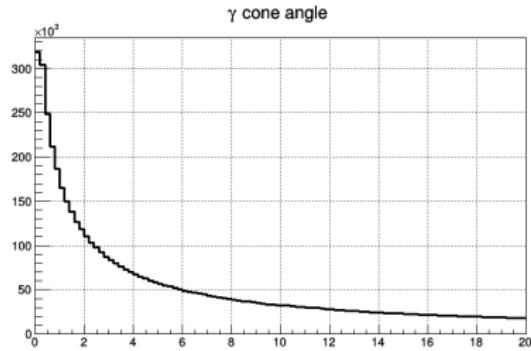
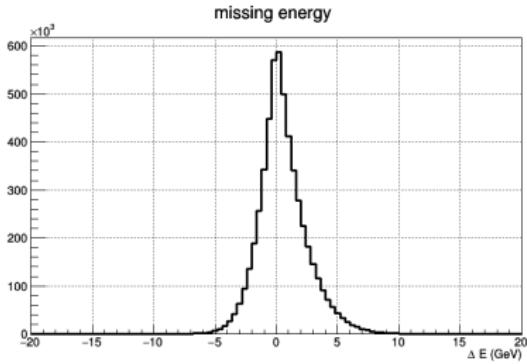
Input Resolutions $5 \times 40 \text{ GeV}^2$



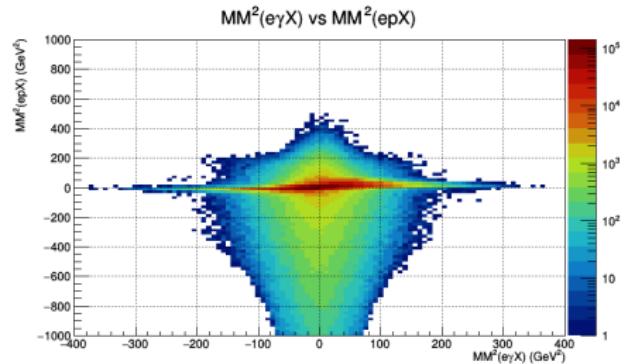
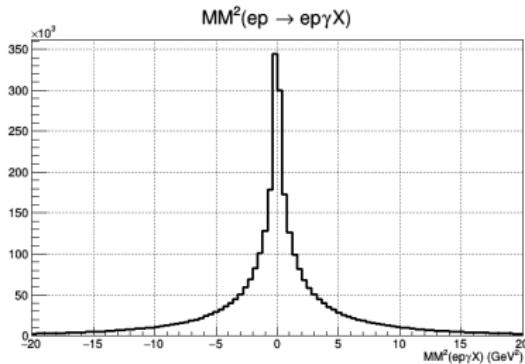
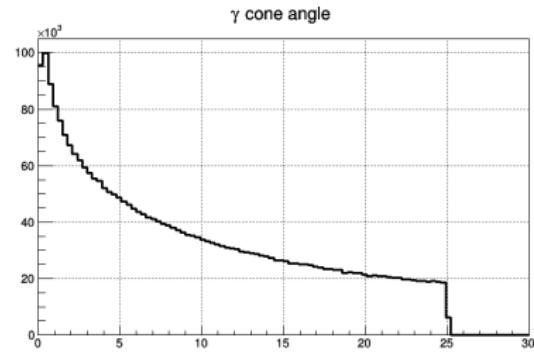
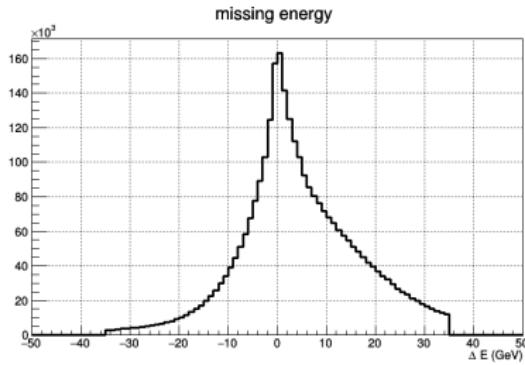
Input Resolutions 10×100 GeV 2



Input Resolutions $5 \times 40 \text{ GeV}^2$

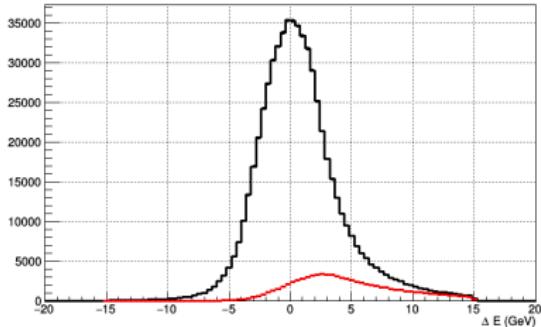


Input Resolutions $10 \times 100 \text{ GeV}^2$

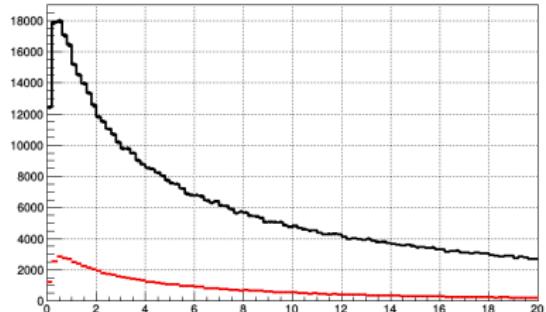


DVCS π^0 separation 5 GeV \times 40 GeV

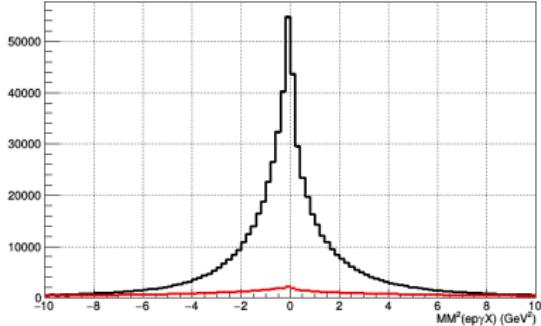
missing energy



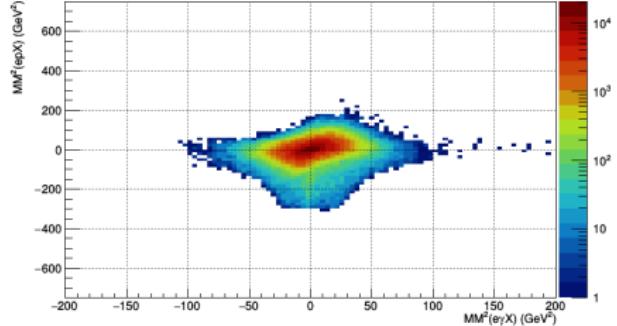
γ cone angle



$MM^2(ep \rightarrow ep\gamma X)$

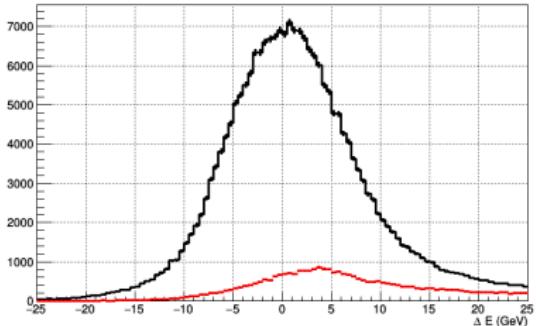


$MM^2(e\gamma X)$ vs $MM^2(epX)$

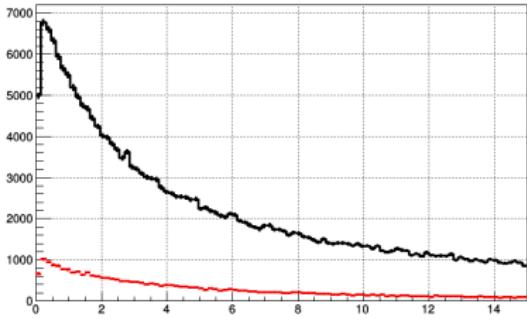


DVCS π^0 separation 10 GeV \times 100 GeV

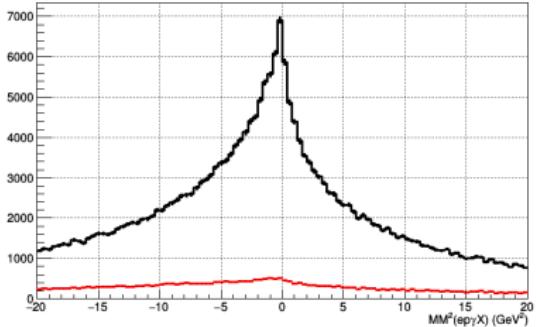
missing energy



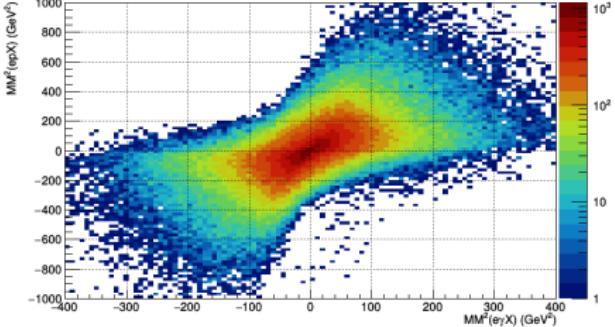
γ cone angle



$MM^2(ep \rightarrow ep\gamma X)$

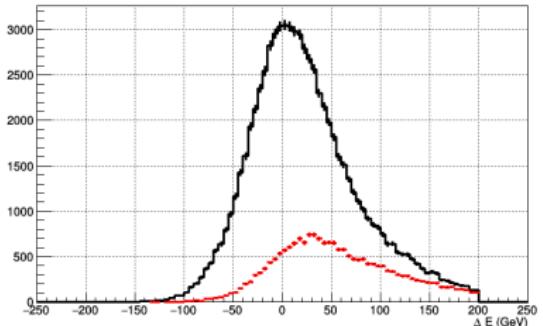


$MM^2(ep\gamma X)$ vs $MM^2(epX)$

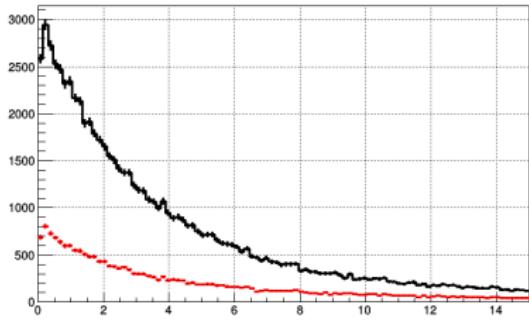


DVCS π^0 separation 18 GeV \times 275 GeV

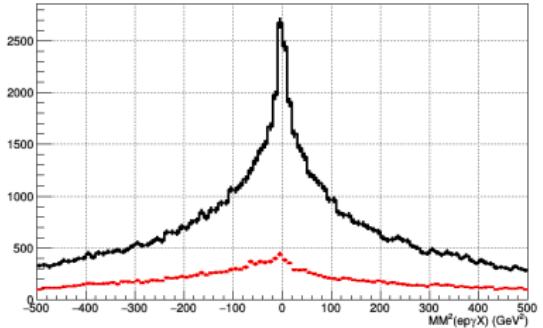
missing energy



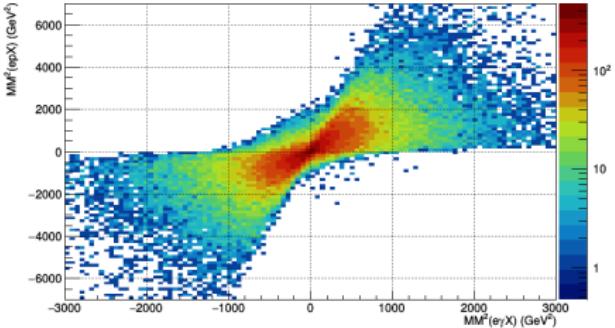
γ cone angle



$MM^2(ep \rightarrow ep\gamma X)$



$MM^2(ep\gamma X)$ vs $MM^2(epX)$



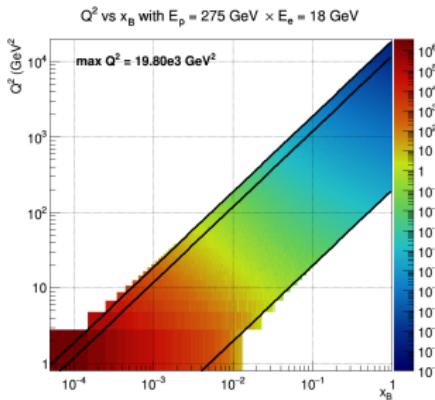
EIC proton DVCS Observables

Lept	Hadr	$\int \mathcal{L} \text{fb}^{-1}$	Observables	$A_{e,p}$
L	u	200	σ	A_{LU}
L	L	100	A_{UL}	A_{LL}
L	T	100	A_{UTx}	A_{UTy}
Le^+	u	100	A^C	A_{LU}^C

$$N_{\text{events}} = \int \mathcal{L} \times \sigma \times KPS$$

$$KPS = \Delta x_B \Delta Q^2 \Delta t \Delta \phi$$

$$\frac{\Delta \sigma}{\sigma} = \frac{1}{\sqrt{N_{\text{events}}}} \oplus 5\%$$



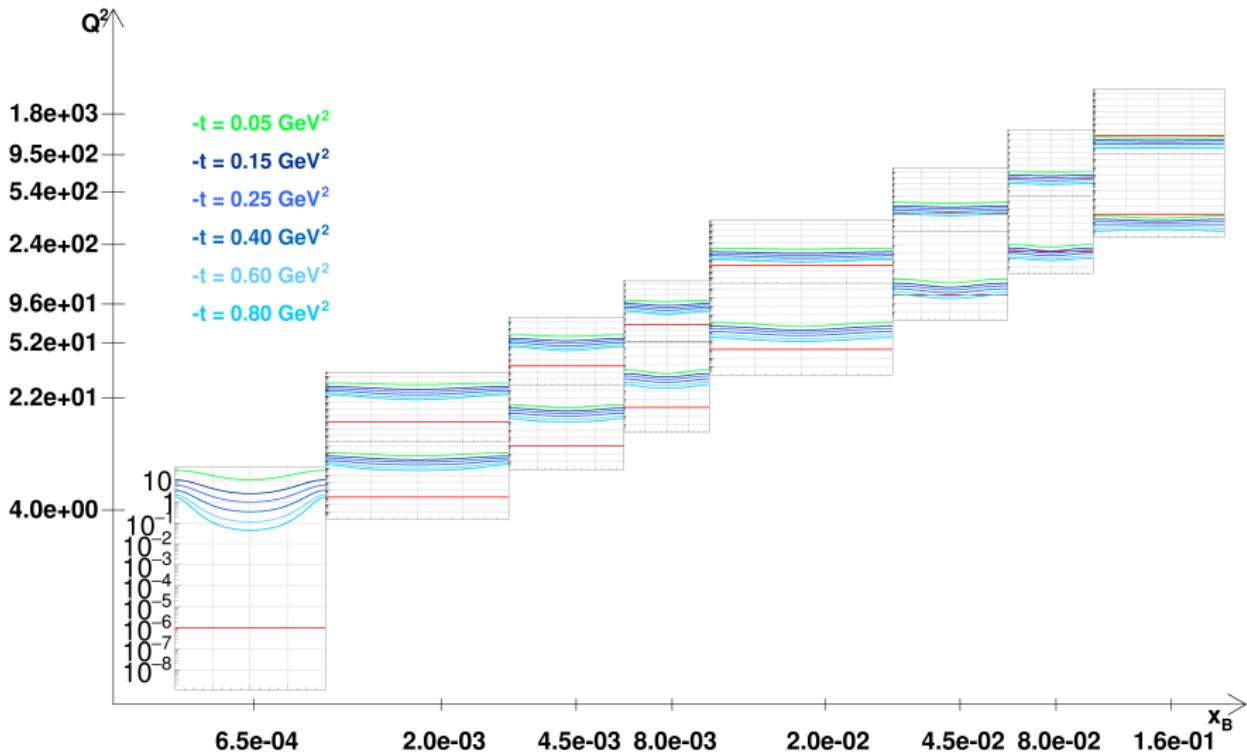
$$\Delta A_{LU} = \frac{1}{P_e} \sqrt{\frac{1 - P_e^2 A_{LU}^2}{N}} \oplus 3\%_{\text{relative}} \quad P_e = 70\%$$

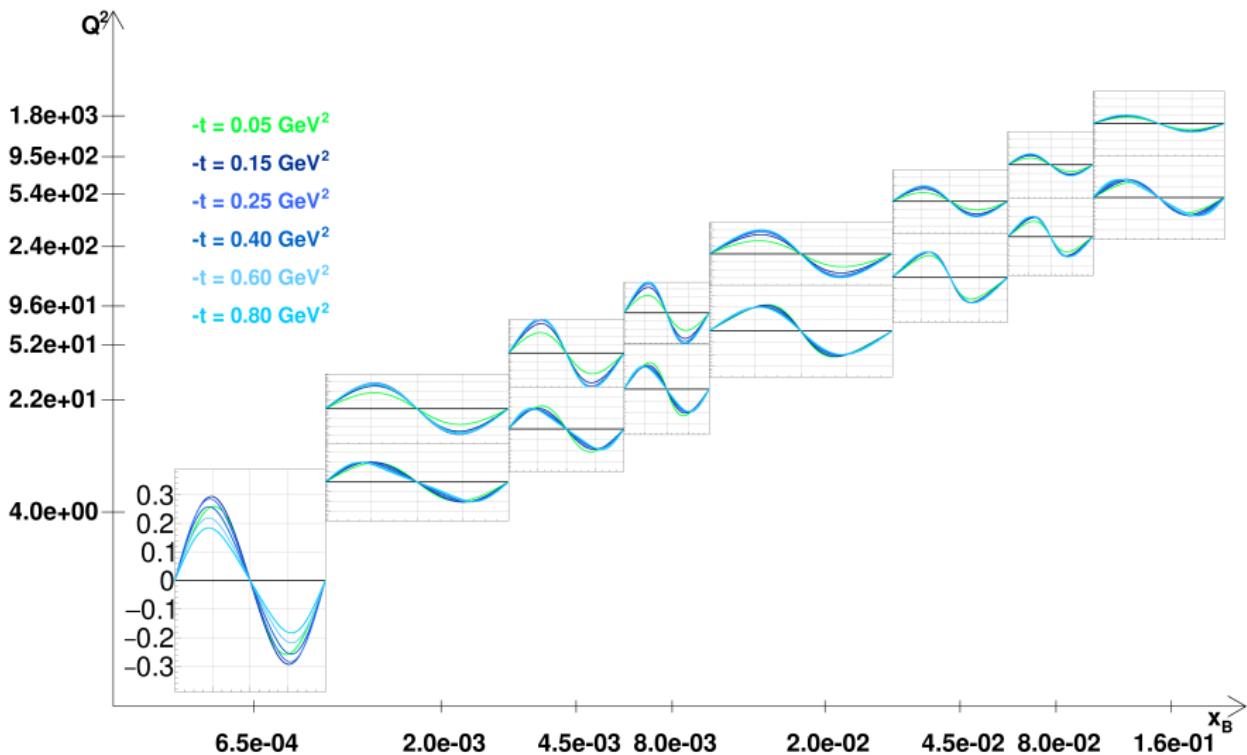
$$\Delta A_{UL} = \frac{1}{P_p} \sqrt{\frac{1 - P_p^2 A_{UL}^2}{N}} \oplus 3\%_{\text{relative}} \quad P_p = 70\%$$

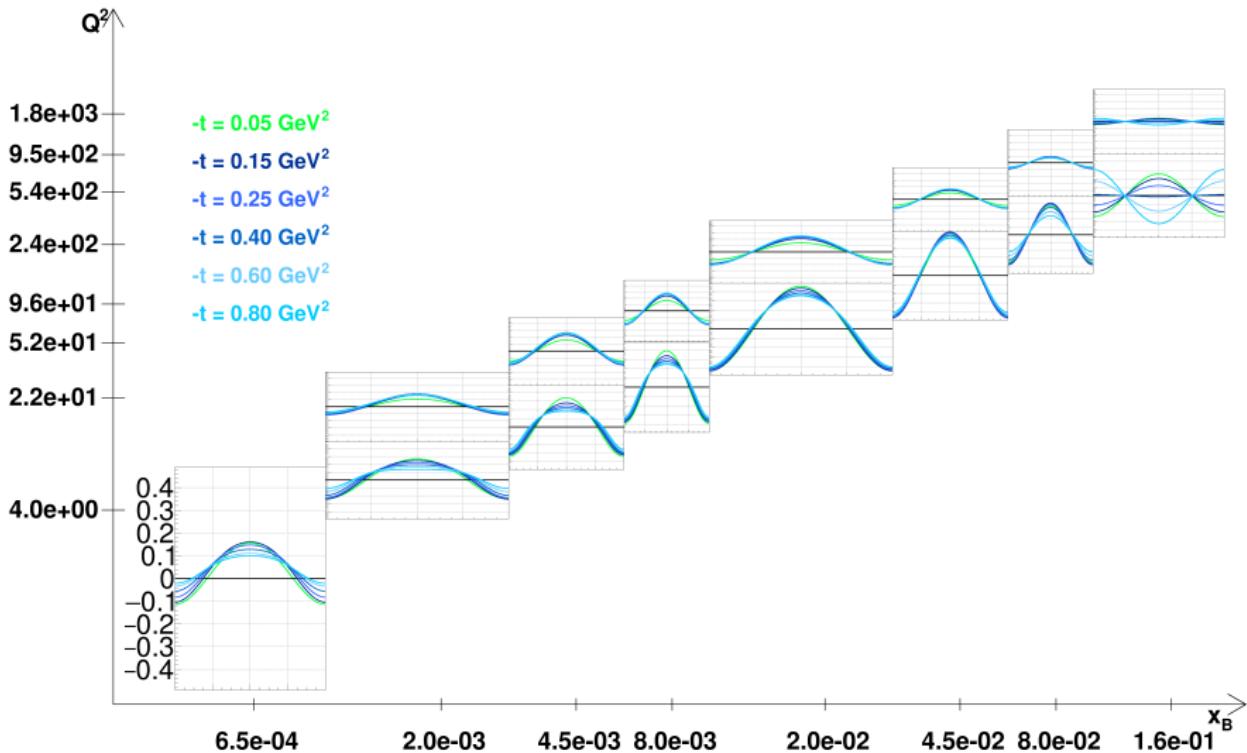
$$\Delta A_{LL} = \frac{1}{P_e P_p} \sqrt{\frac{1 - P_e^2 P_p^2 A_{LL}^2}{N}} \oplus 3\%_{\text{relative}} \oplus 3\%_{\text{relative}}$$

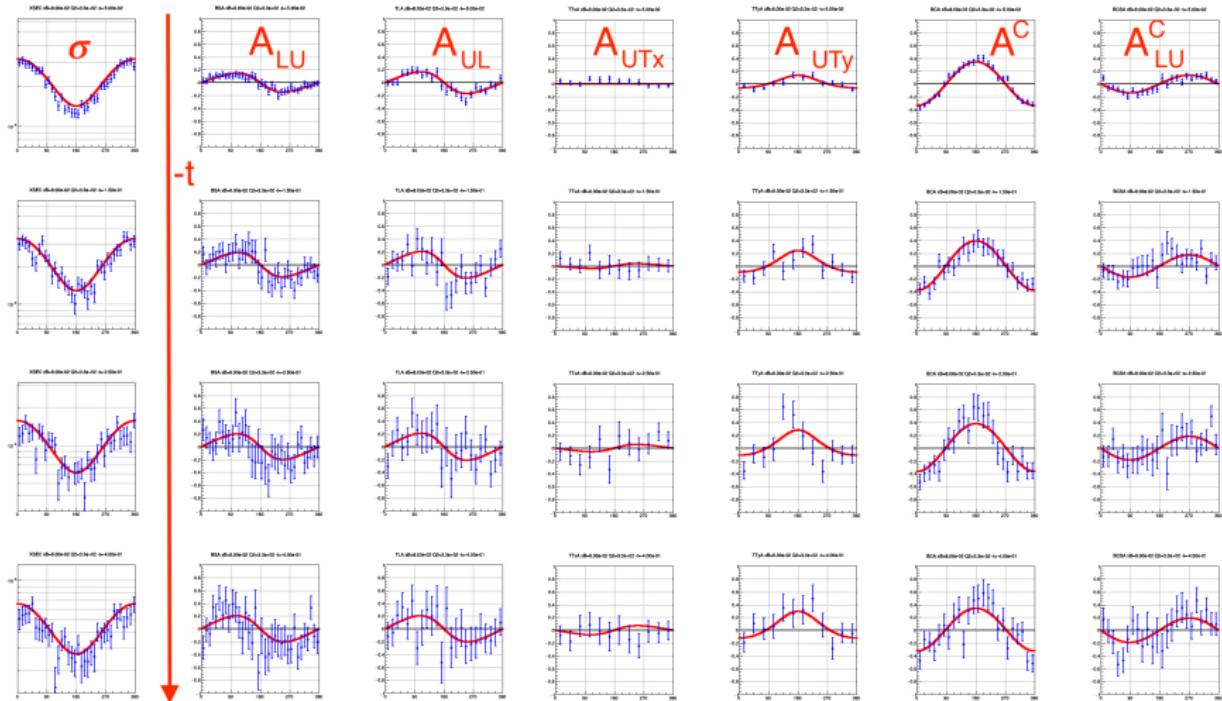
$$\Delta A_C = \sqrt{\frac{1 - A_C^2}{N}} \oplus 3\%_{\text{relative}}$$

$$\Delta A_{LC} = \frac{1}{P_{e+}} \sqrt{\frac{1 - P_{e+}^2 A_{LC}^2}{N}} \oplus 3\%_{\text{relative}} \quad P_{e+} = 70\%$$

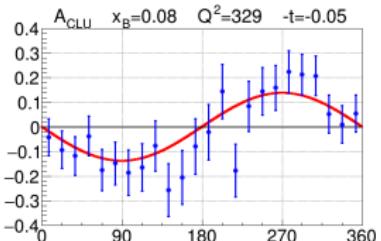
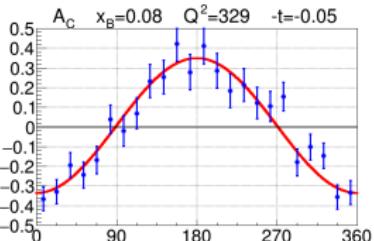
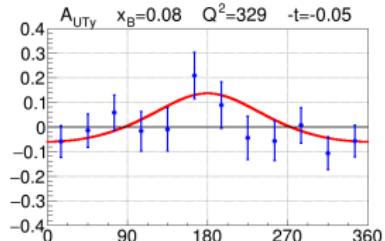
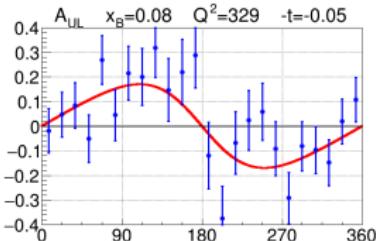
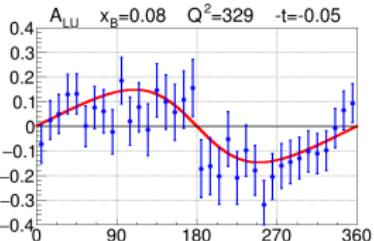
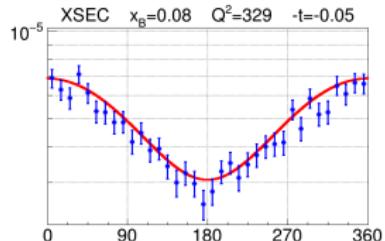






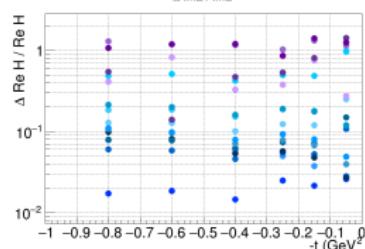
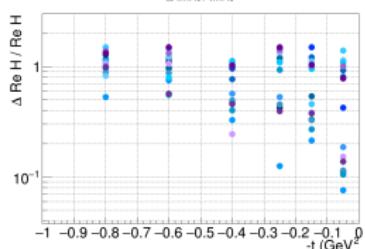
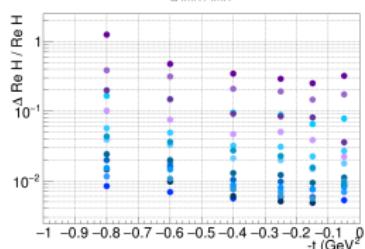
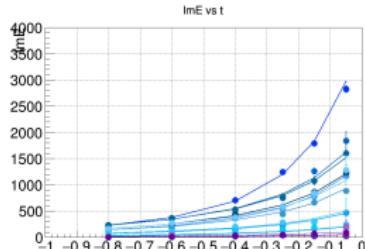
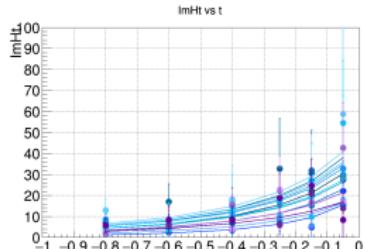
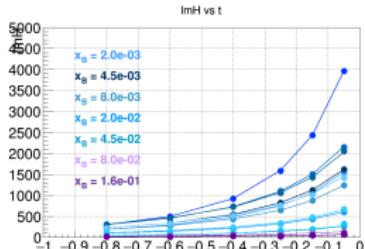


Not shown here: A_{LL} A_{LTx} A_{LTy} are small

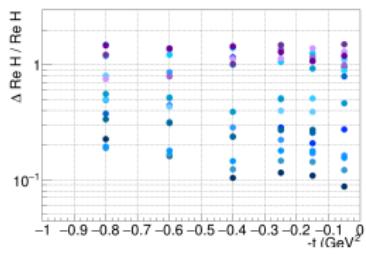
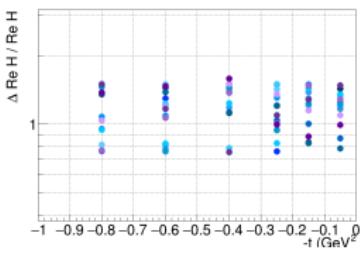
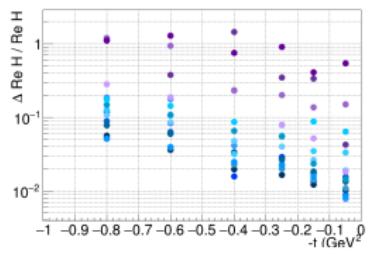
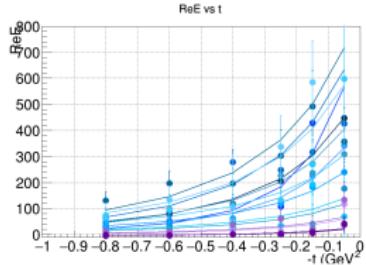
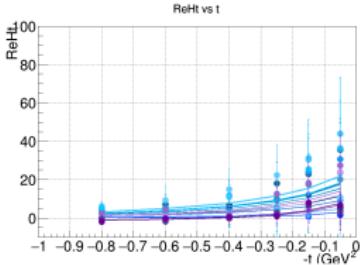
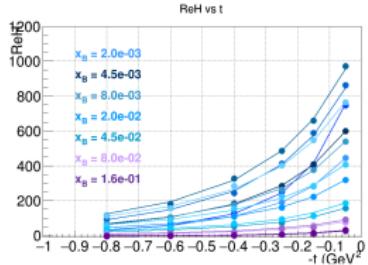


Smeared both statistics and systematics
Fit CFF wth/without to estimate systematics

Locally extracted Im CFF 275×18 GeV 2



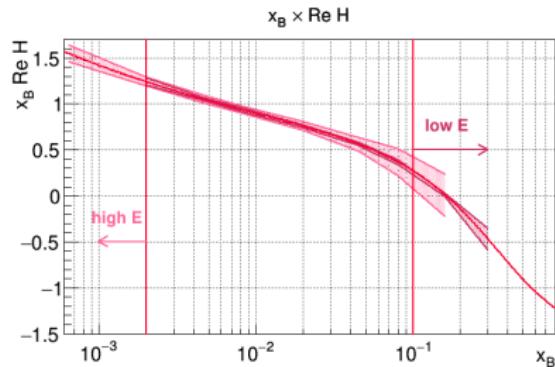
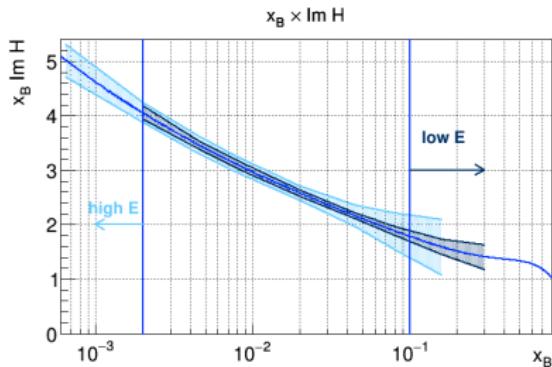
Locally extracted Re CFF $275 \times 18 \text{ GeV}^2$



High and Low energies runs

Kinematical coverage complementarity

Local extraction results:



Entering the GPD extraction Precision Era!

Towards Ji's sum rule

$$J^q(t) = \frac{1}{2} \int_{-1}^1 dx x [H^q(x, \xi, t) + E^q(x, \xi, t)]$$

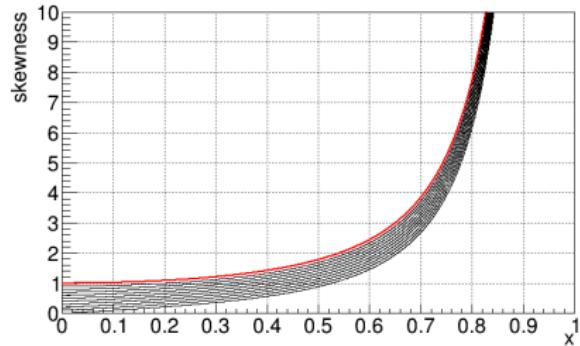
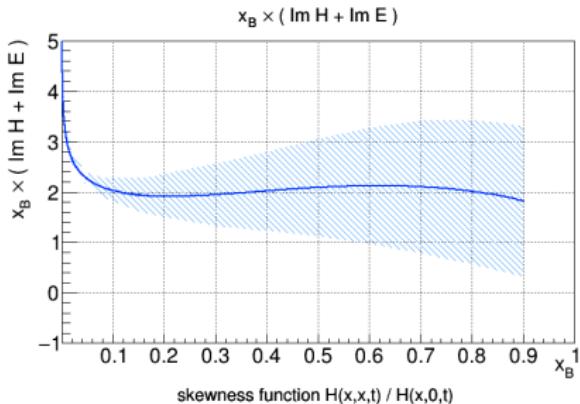
independent of ξ but at fixed ξ

DVCS measures

$$\text{Im}\mathcal{H}(\xi, t) = \pi H(\xi, \xi, t)$$

need another process to access the skewness
→ especially crucial at large x_B

DDVCS?
JLab 12 luminosity upgrade?



Summary, Outlook

- Complementarity between High and Low energies runs
- Separation signal and background: resolutions requirements
- Local CFF extraction fits with $\int \mathcal{L} = 100 \text{ fb}^{-1}$ per configuration
- Potential physics extension with polarized positron source
- Next Step: implement dispersion relation global fit

