$\pi°$-electroproduction cross-section (RGA)
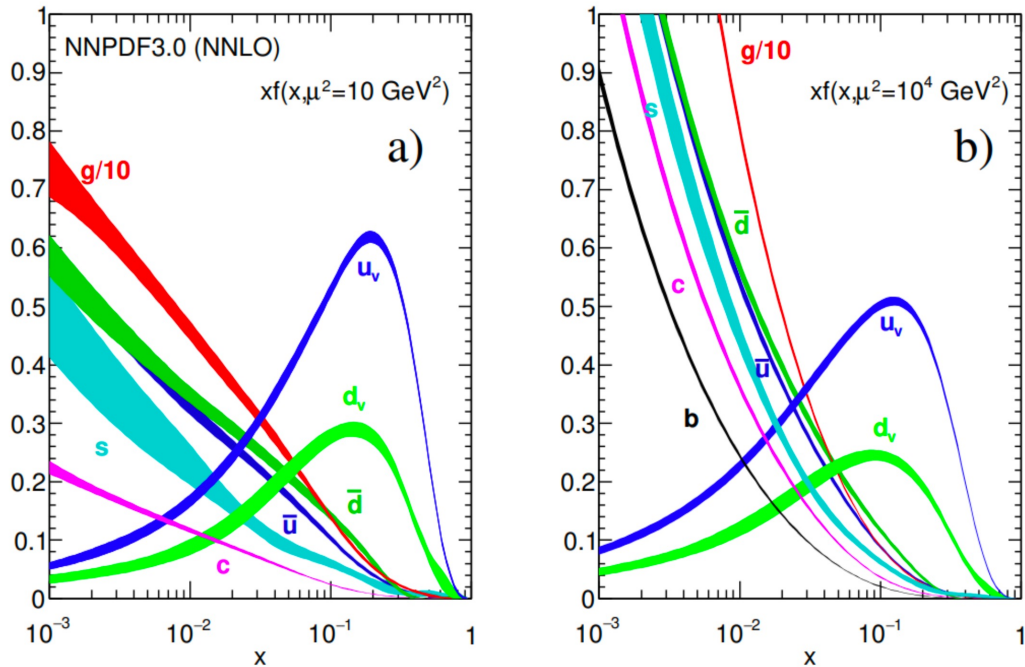
Igor Korover

CLAS collaboration meeting

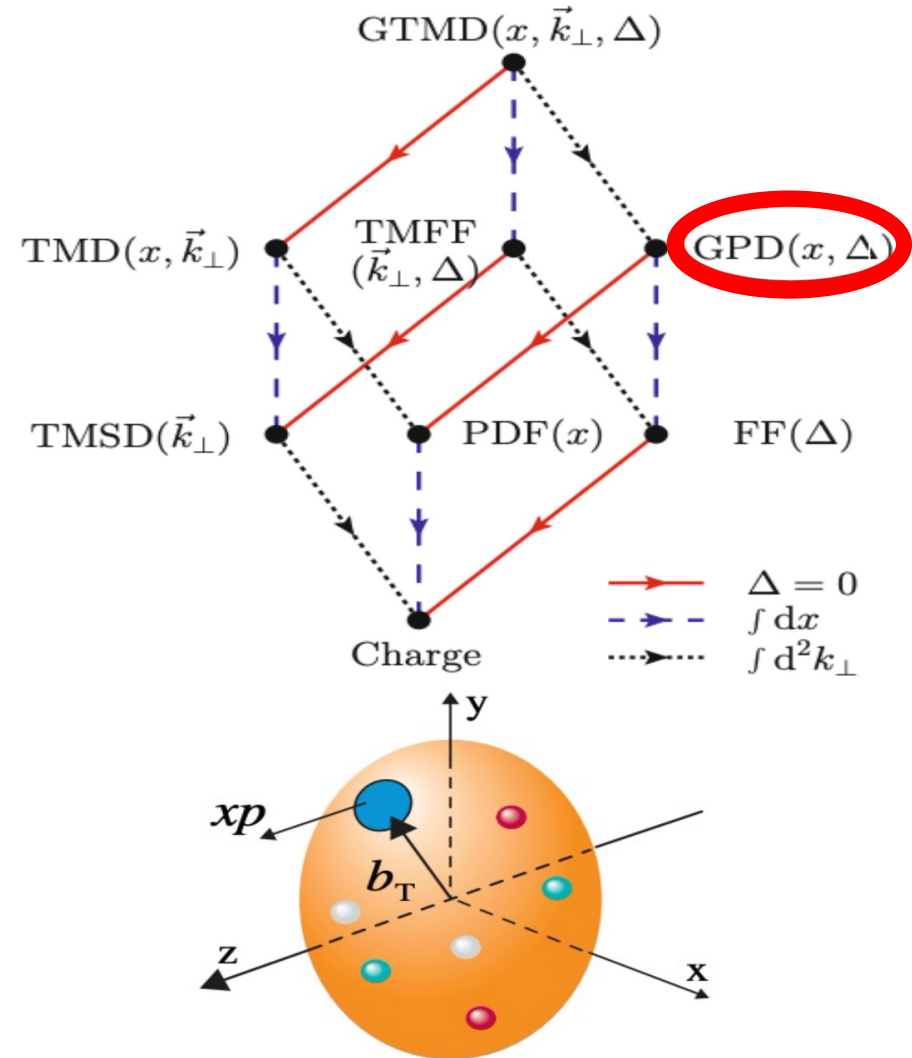March 13, 2024

Jefferson Lab

Motivation

DIS processes (PDF)

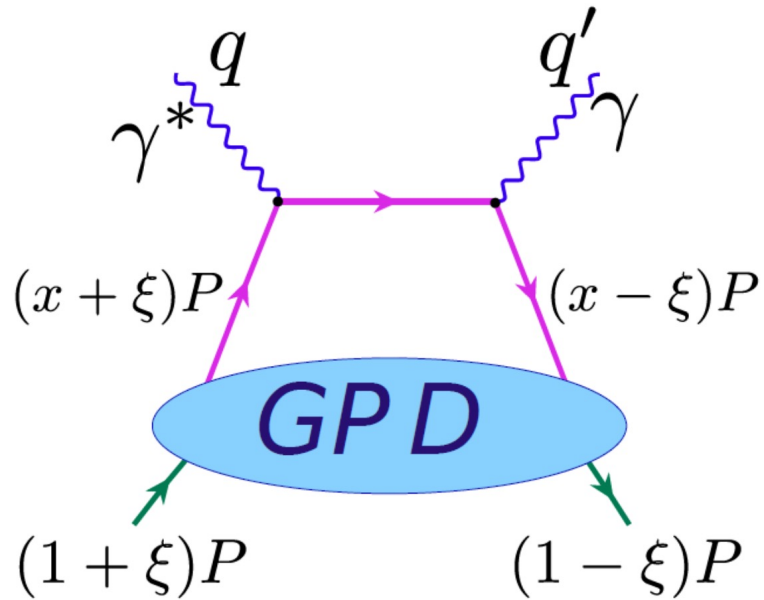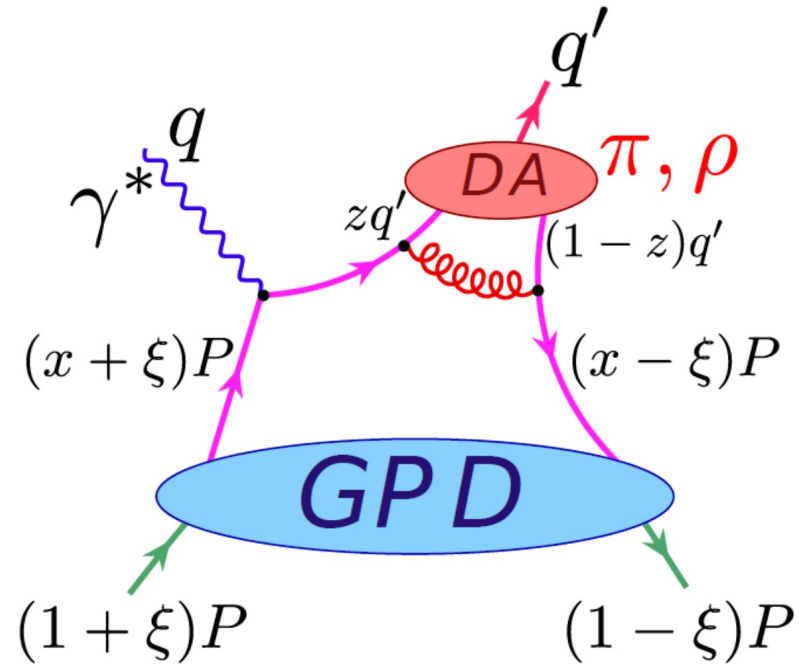

Zyla et al., (2020)

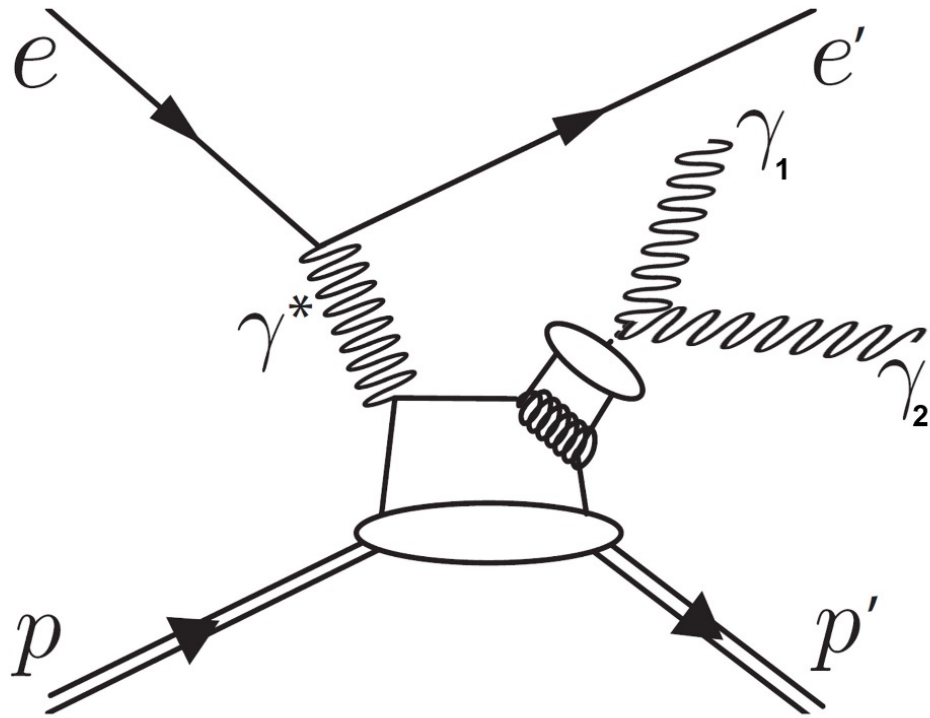## Deeply virtual exclusive processes (DVEP) (GPDs)

DVCS

DV$\pi°$P

DVCS (left) and DVMP Feynman Handbag diagrams
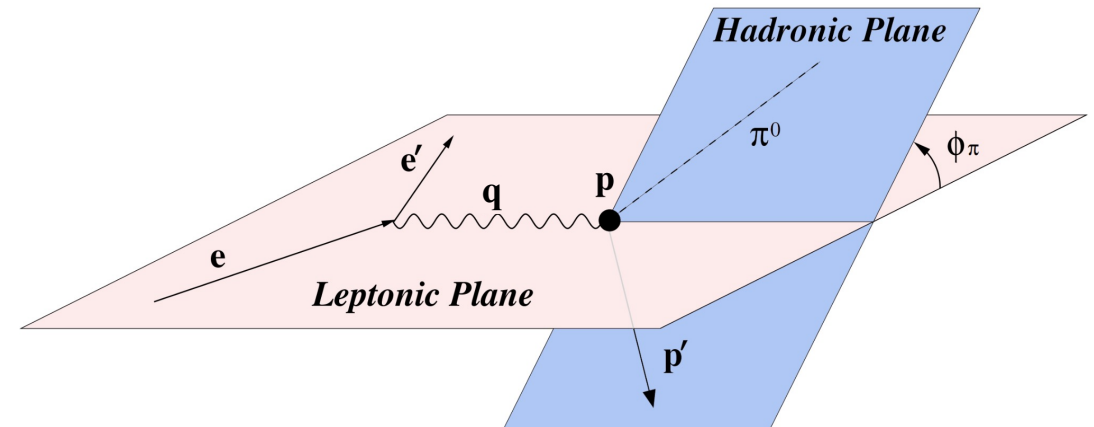
[V. Kubarovsky Nuc Phys B 2011]

$$ep \rightarrow e'\ p'\pi^\circ \rightarrow e'p'\ \gamma_1\ \gamma_2$$

- Virtual photon 4-momentum: $Q^2 = -(e - e')^2$

- Bjorken x: $x_B = \dfrac{Q^2}{2p \cdot q}$

- Momentum transfer: $t = -(p' - p)^2$

- Angle between lepton and hadron planes:
$$\phi = \cos^{-1}\left(\frac{(e \times e') \cdot (p' \times q)}{\|e \times e'\|\ \|p' \times q\|}\right)$$

DV$\pi°$P cross-section

$$\frac{d^4\sigma}{dQ^2 dx_B dt d\phi} \propto \left(\frac{d\sigma_T}{dt} + \epsilon \frac{d\sigma_L}{dt}\right) + \epsilon\cos(2\phi)\frac{d\sigma_{TT}}{dt} + \sqrt{2\epsilon(1+\epsilon)}\cos(\phi)\frac{d\sigma_{LT}}{dt}$$

The structure functions can be expressed in terms of GPDs

$$\frac{d\sigma_L}{dt} = \frac{4\pi\alpha}{kQ^2}\left\{(1-\xi^2)|\langle\tilde{H}\rangle|^2 - 2\xi^2\Re\left[\langle\tilde{H}\rangle^*\langle\tilde{E}\rangle\right] - \frac{t'}{4m^2}\xi^2|\langle\tilde{E}\rangle|^2\right\}$$
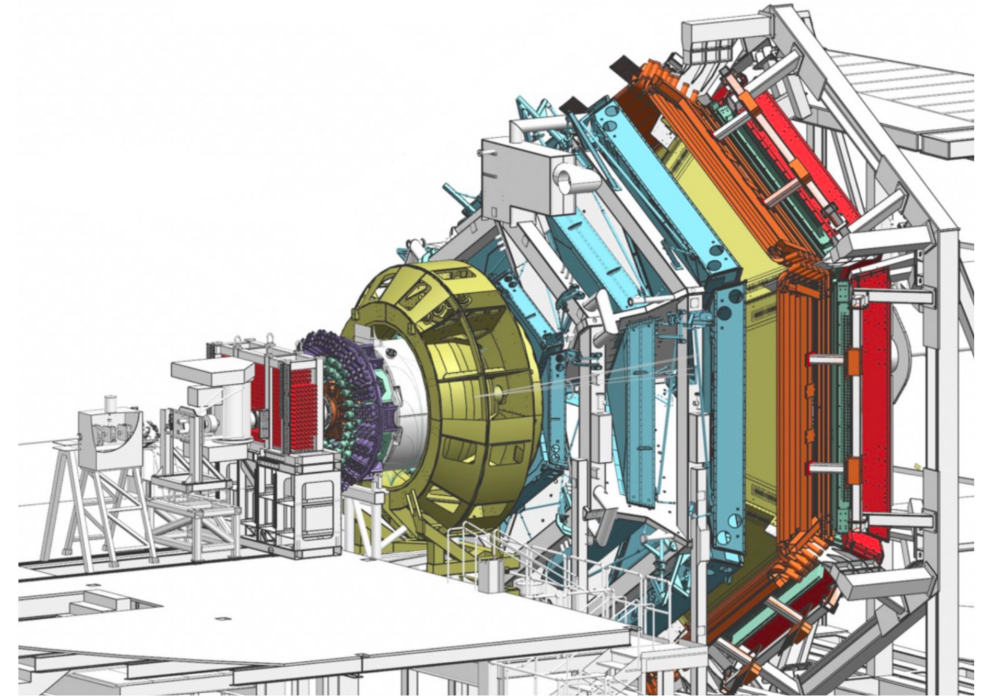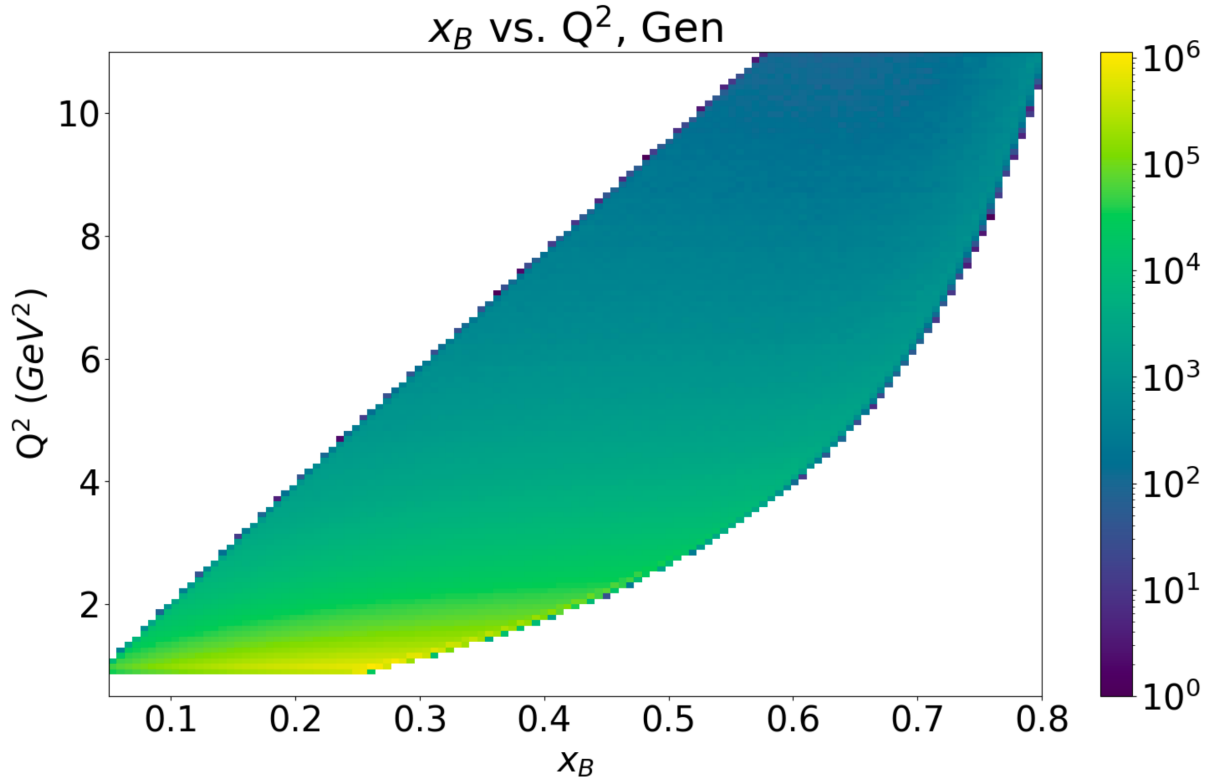
$$\frac{d\sigma_T}{dt} = \frac{2\pi\alpha\mu_\pi^2}{kQ^4}\left\{(1-\xi^2)|\langle H_T\rangle|^2 - \frac{t'}{8m^2}|\langle\bar{E}_T\rangle|^2\right\}$$

$$\frac{d\sigma_{LT}}{dt} = \frac{4\pi\alpha\mu_\pi}{\sqrt{2}kQ^3}\xi\sqrt{1-\xi^2}\frac{\sqrt{-t'}}{2m}\Re\left\{\langle H_T\rangle^*\langle\tilde{E}\rangle\right\}$$

$$\frac{d\sigma_{TT}}{dt} = \frac{4\pi\alpha\mu_\pi^2}{kQ^4}\frac{-t'}{16m^2}\langle\bar{E}_T\rangle^2$$

Experimental setup: unpolarized LH$_2$ target - RGA
Beam: 10.6 GeV

x_B vs. Q^2, Gen

[V. Burkert et al., NIMA, 959, 163419 (2020)]

$$\mathcal{L} = \frac{N_A l \rho Q}{e}$$

Integrated Luminosity:
- Measured from Faraday Cup beam charge
- 5.5 x 10^{40} cm^{-1} from fall 2018 inbending dataset
- 4.6 x 10^{40} cm^{-1} from fall 2018 outbending dataset

Cross-section: Experimental extraction

Number of DVπ°P events

Correction Factors:

$$\frac{d^4\sigma}{dQ^2 dx_B dt d\phi} = \frac{N(Q^2, x_B, t, \phi)}{\mathcal{L}\, \Delta Q^2\, \Delta x_B \Delta t\, \Delta\phi\, Br(\pi^\circ \to \gamma\gamma)} \cdot \frac{1}{\varepsilon_{acc}\, \delta_{RC}\delta_{Norm}}$$

Bin widths

$\mathcal{L}$: Integrated Luminosity

$Br(\pi^\circ \to \gamma\gamma)$: Branching ratio of neutral pions to two photons

δ_{RC} : Radiative correction
ε_{acc} : Acceptance correction
δ_{Norm}: Global normalization

Event selection:

- Particle PID – CLAS12

DIS cuts

- $Q^2 > 1 \, (\mathrm{GeV}/c)^2$

- $W > 2 \, \mathrm{GeV}$

- $\theta_{e'\gamma 1}, \, \theta_{e'\gamma 2} > 4°$

- $E_{\gamma 1}, \, E_{\gamma 2} > 0.15 \, \mathrm{GeV}$

- $\theta_{\gamma 1 \gamma 2} > 1°$

Exclusivity cuts

- $-1.5 \, \mathrm{GeV} < ME_{e'p'\pi^0} < 2 \, \mathrm{GeV}$

- $0 \, \mathrm{GeV} < ME_{e'\gamma} < 2.5 \, \mathrm{GeV}$

- $|MM^2_{e'p'\pi^0}| < 0.1 \, \mathrm{GeV}^2$

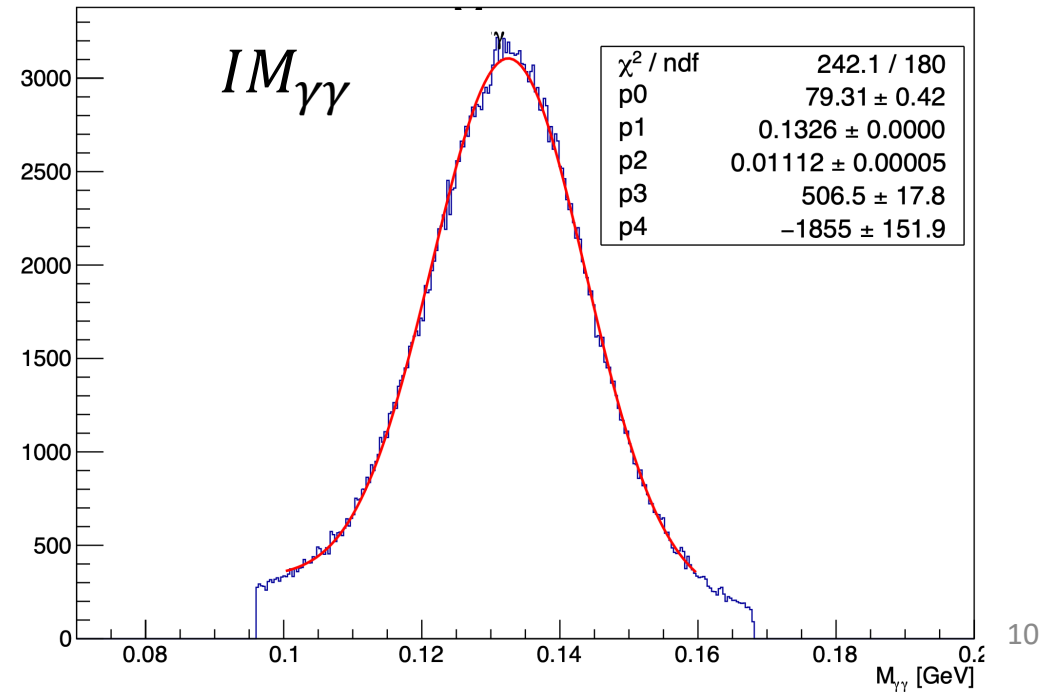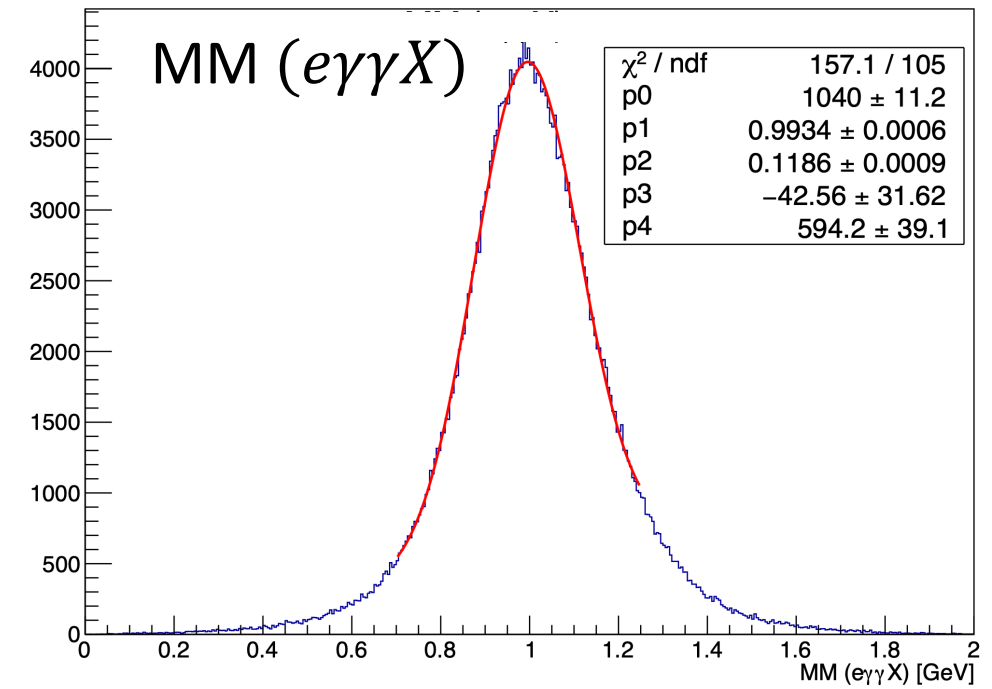- $MP^2_{te'p'\gamma} < 0.75 \, \mathrm{GeV}^2$

Exclusive distributions

Cuts:

- $M_{\gamma\gamma}$

- *Missing* P_t
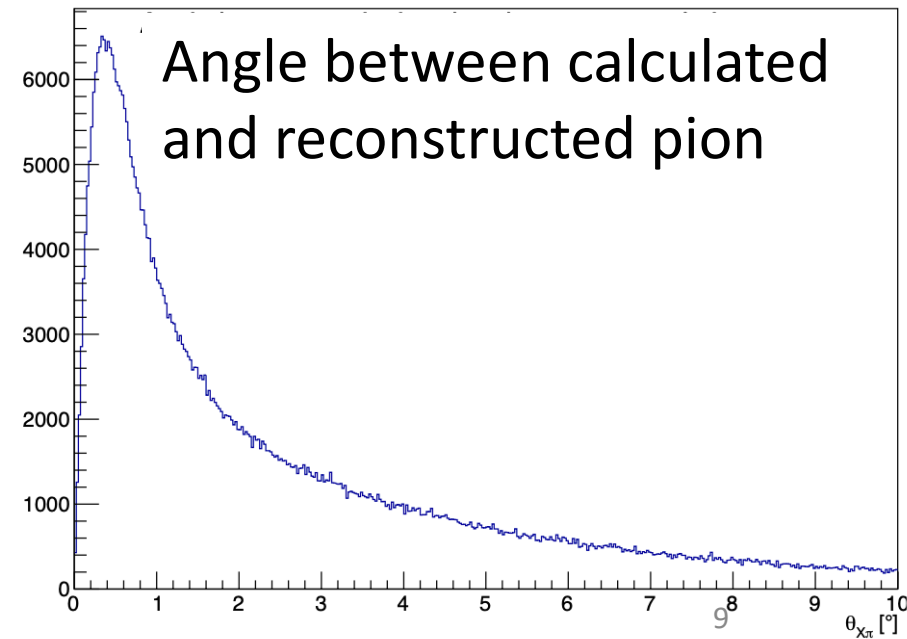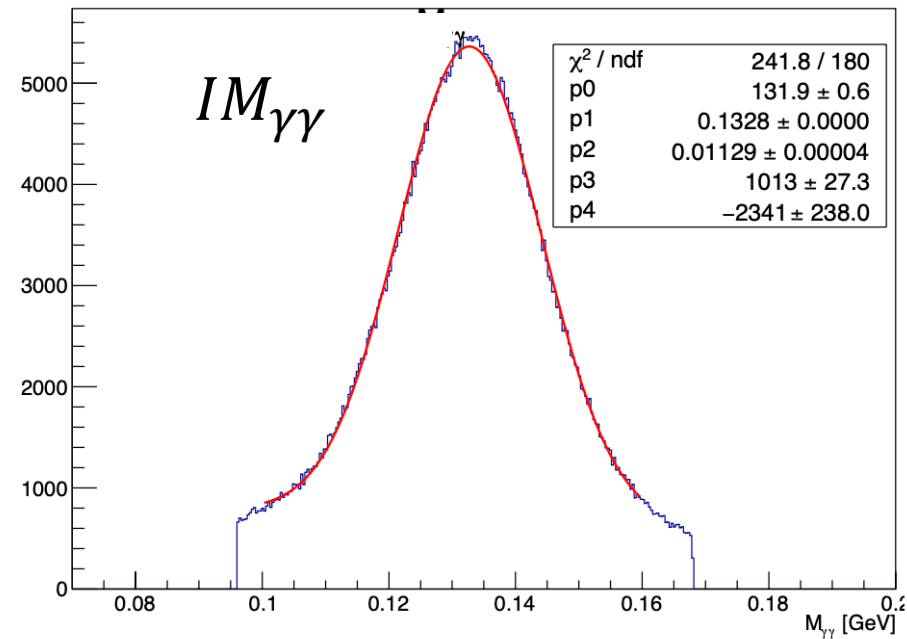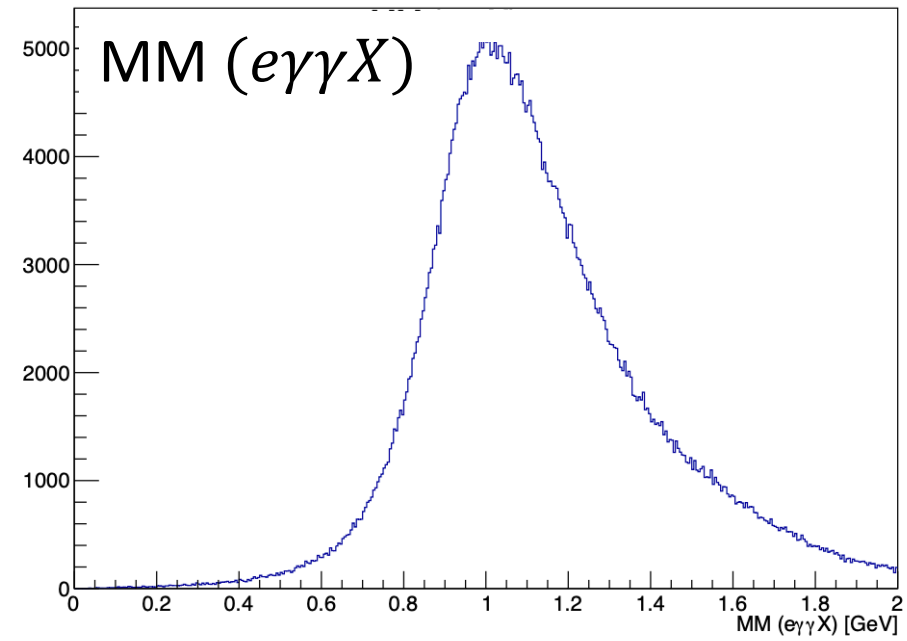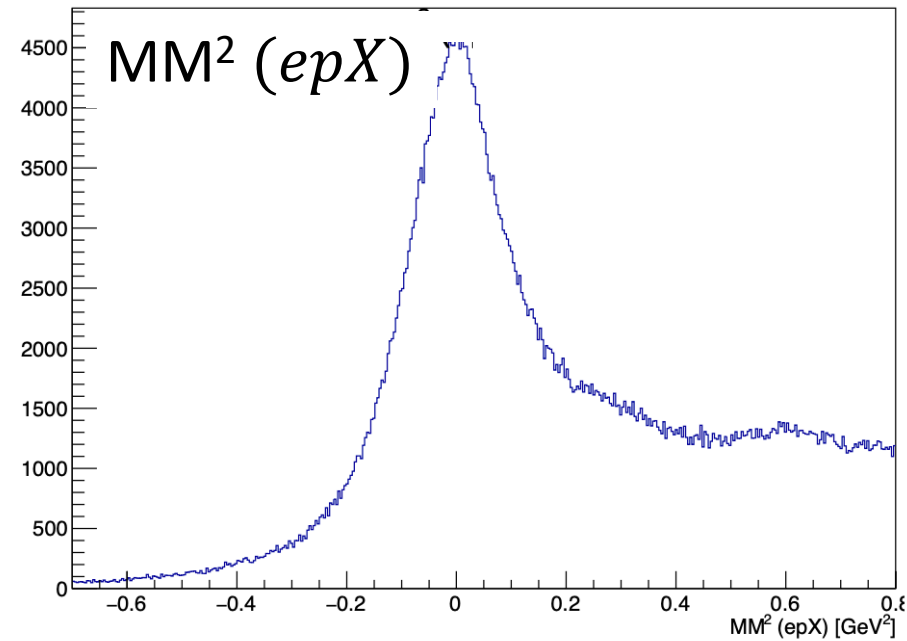
Exclusivity conditions with all cuts
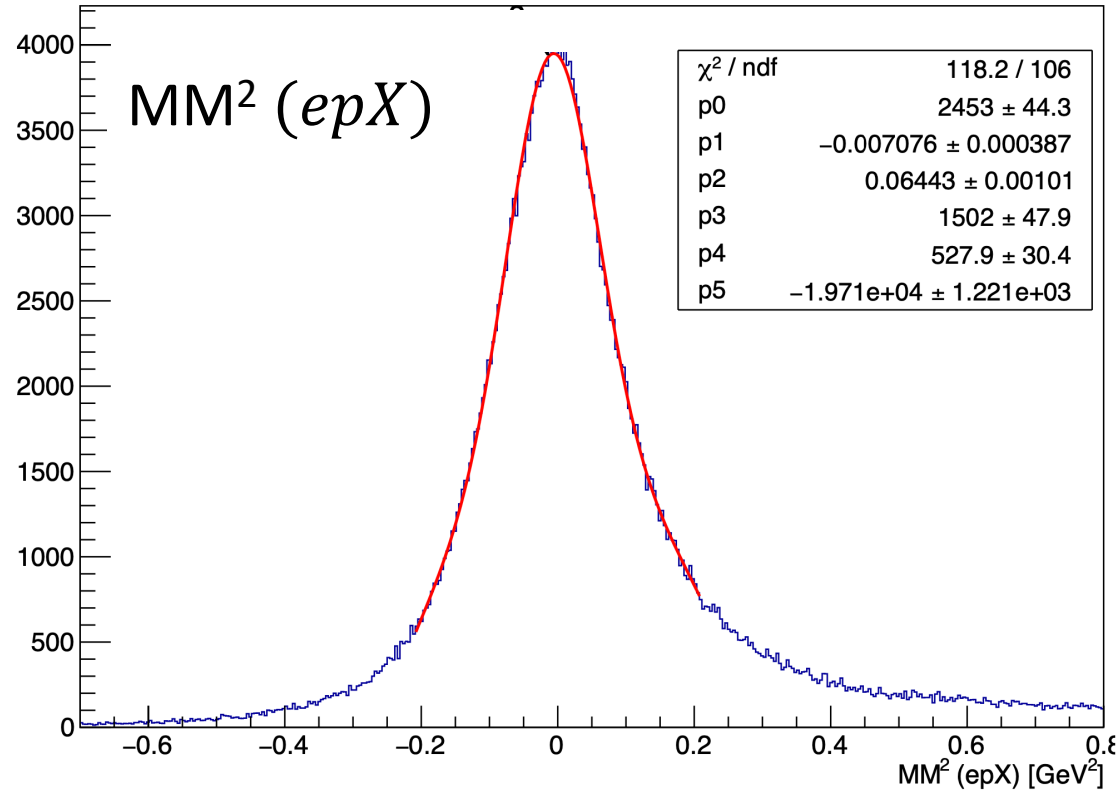
MM² (epX)

χ^2 / ndf	118.2 / 106
p0	2453 ± 44.3
p1	−0.007076 ± 0.000387
p2	0.06443 ± 0.00101
p3	1502 ± 47.9
p4	527.9 ± 30.4
p5	−1.971e+04 ± 1.221e+03

MM ($e\gamma\gamma X$)

χ^2 / ndf	157.1 / 105
p0	1040 ± 11.2
p1	0.9934 ± 0.0006
p2	0.1186 ± 0.0009
p3	−42.56 ± 31.62
p4	594.2 ± 39.1

$IM_{\gamma\gamma}$

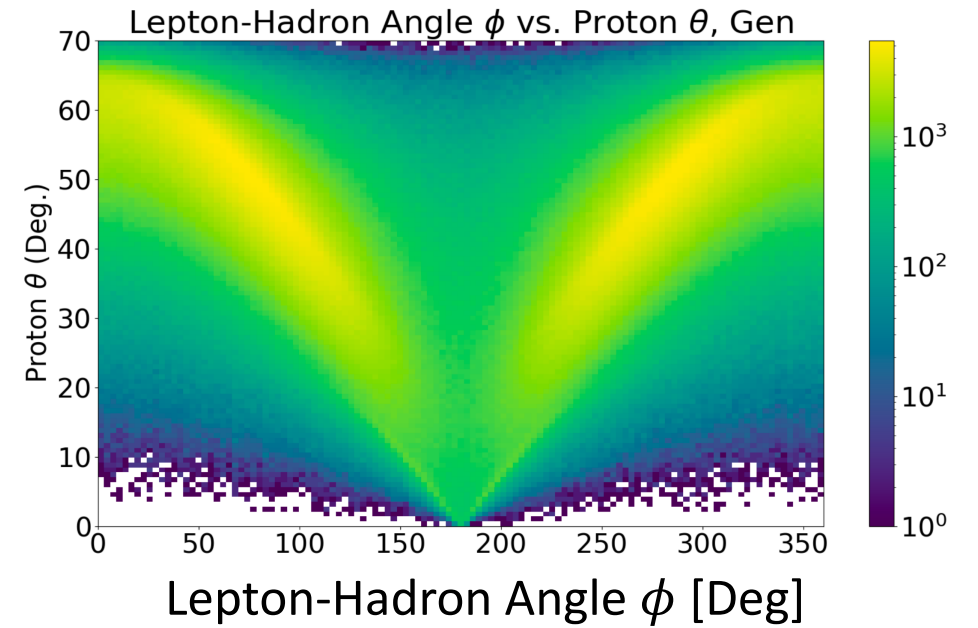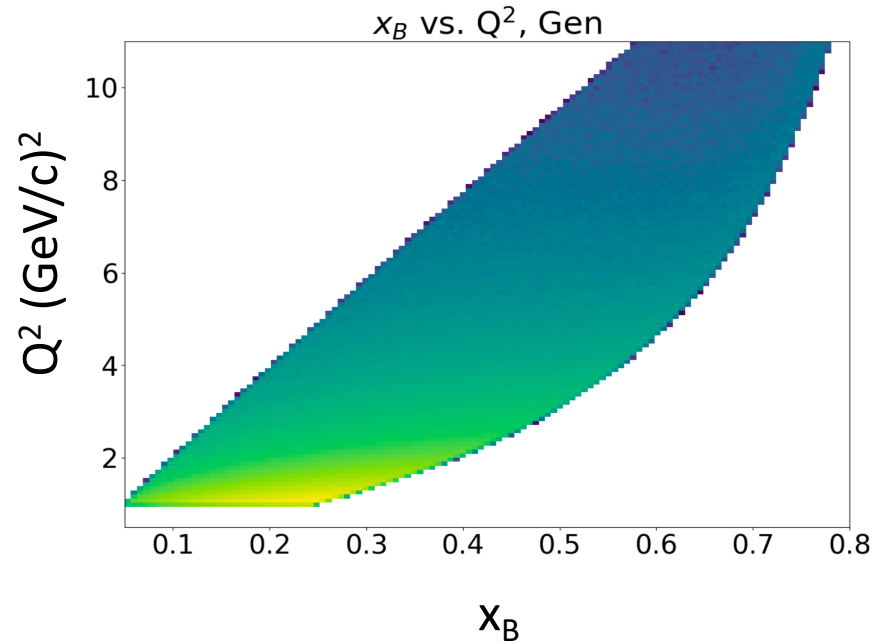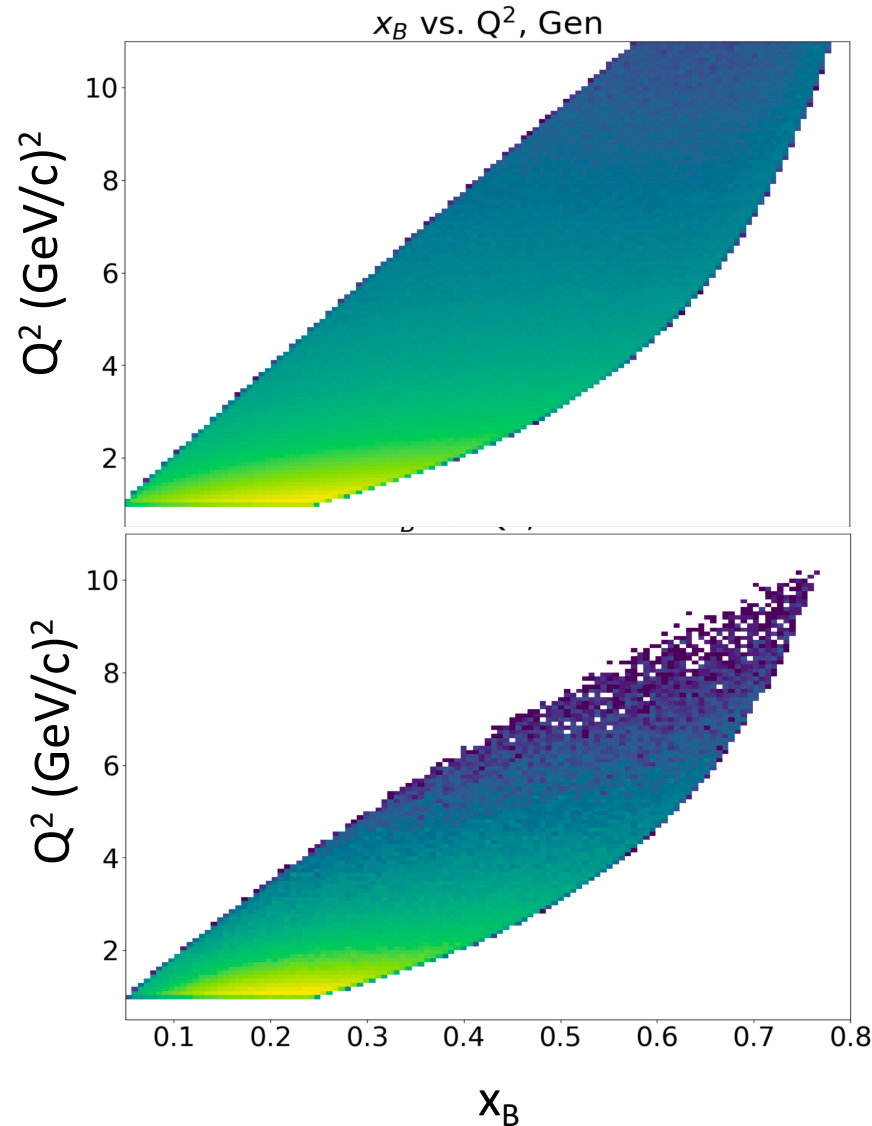| χ^2 / ndf	242.1 / 180
p0	79.31 ± 0.42
p1	0.1326 ± 0.0000
p2	0.01112 ± 0.00005
p3	506.5 ± 17.8
p4	−1855 ± 151.9

Simulation - GEMC

Event generator: **aao_norad**

Nonradiative DV$\pi°$P generator validated on CLAS6 and COMPASS data
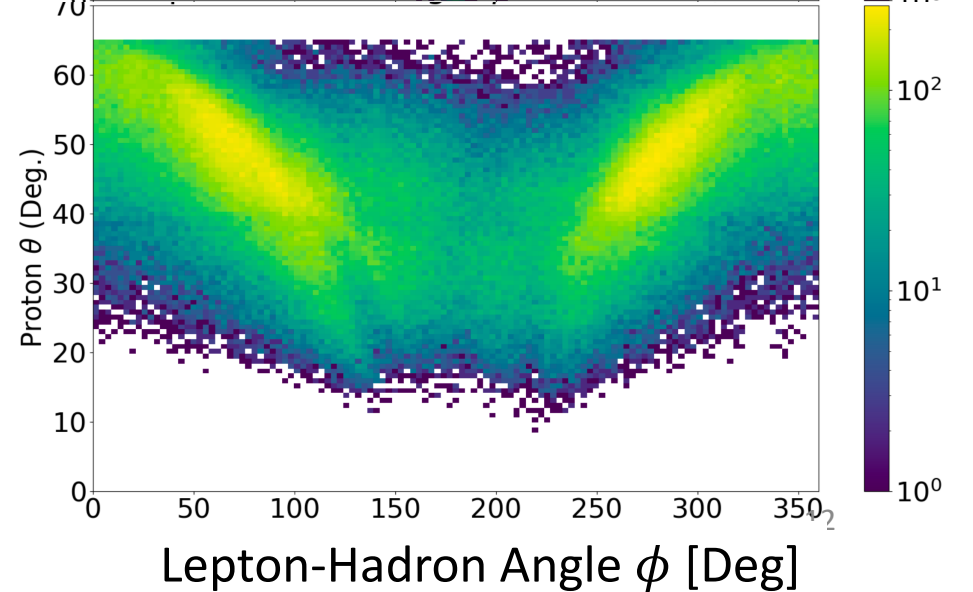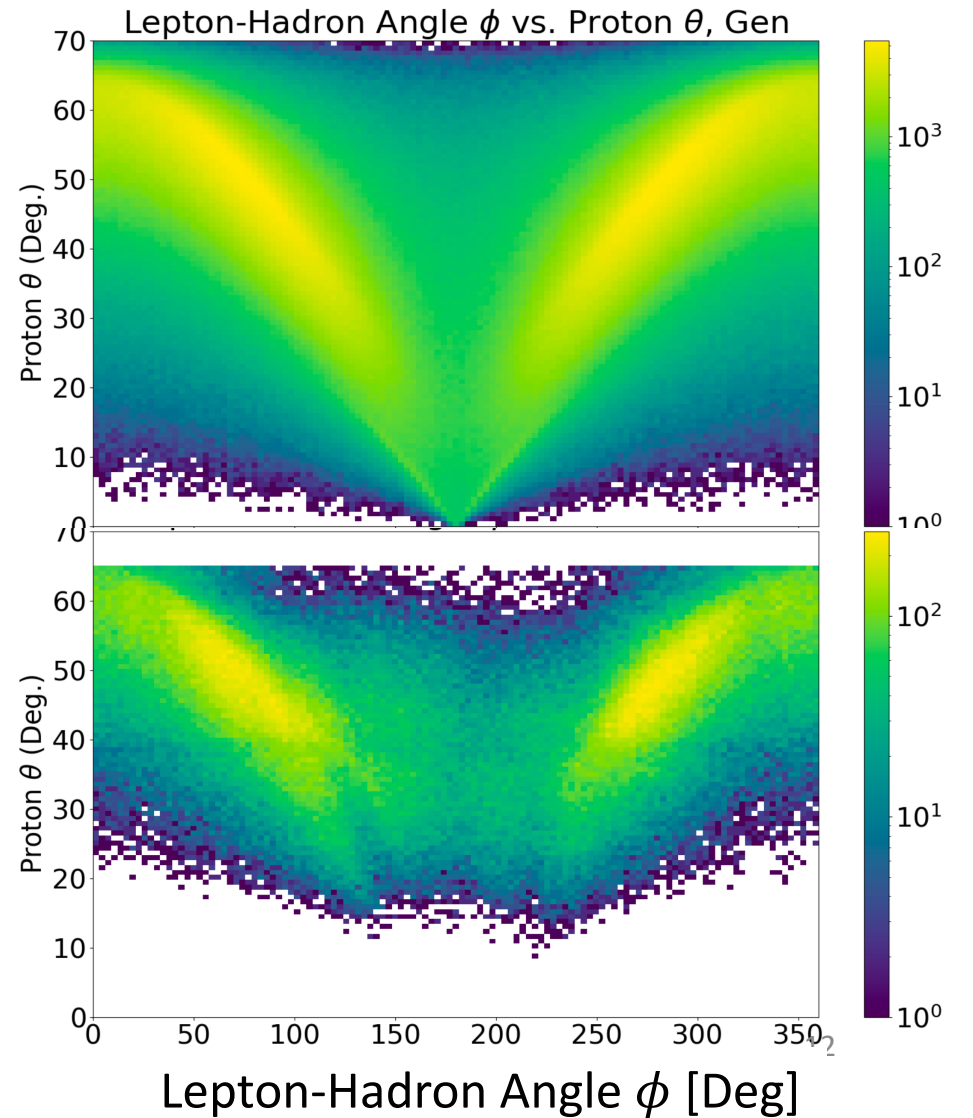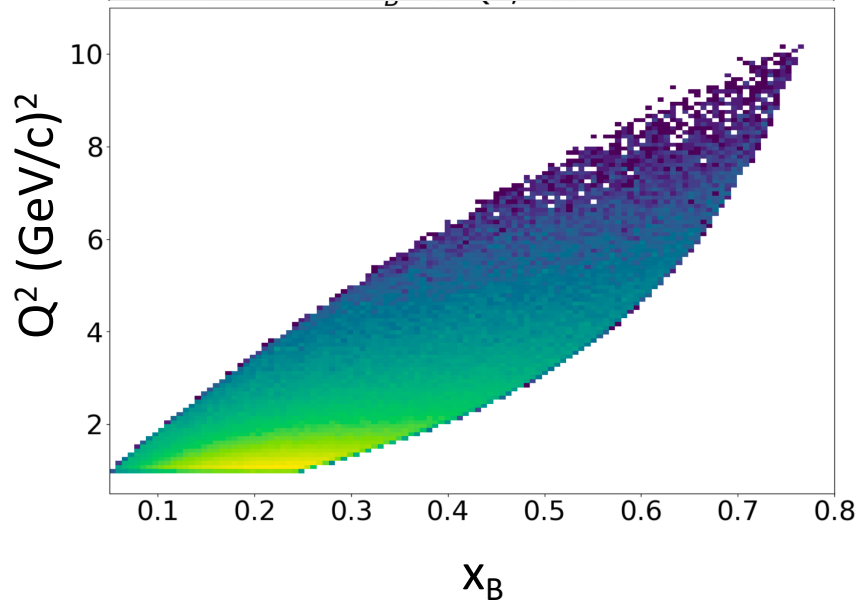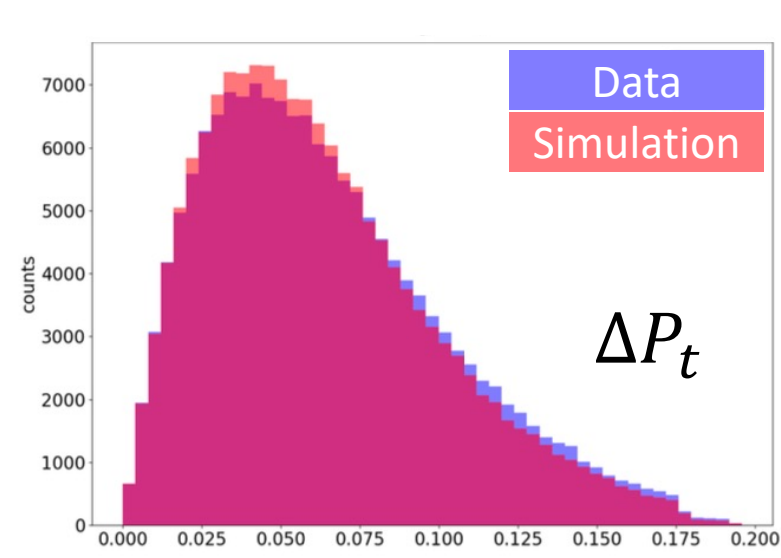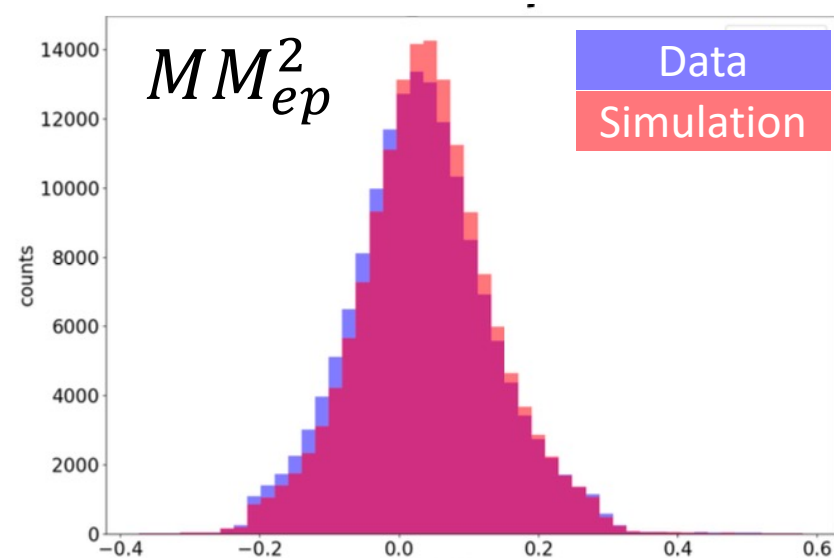
Generated:

Simulation - GEMC

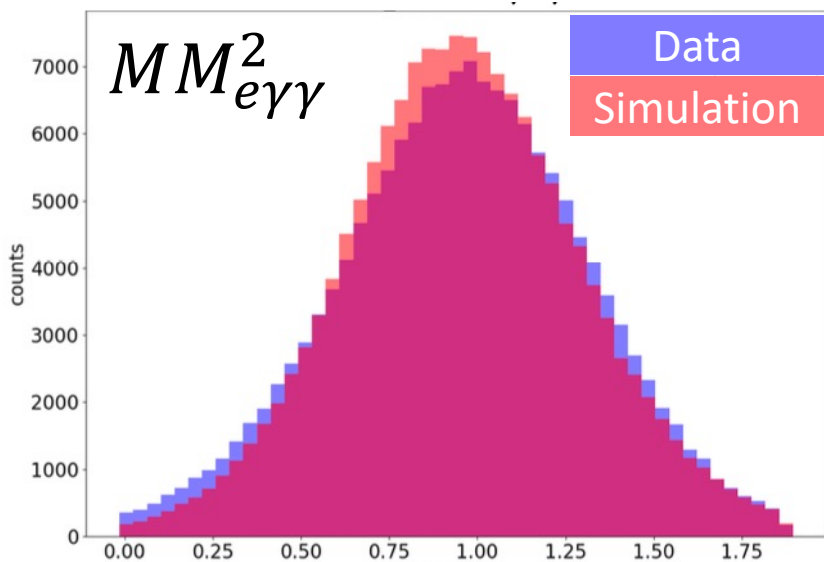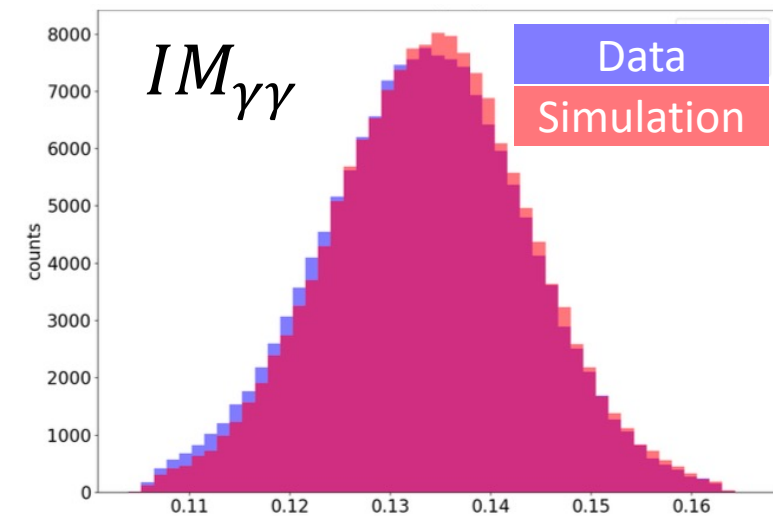Event generator: **aao_norad**

Nonradiative DVπ°P generator validated on CLAS6 and COMPASS data
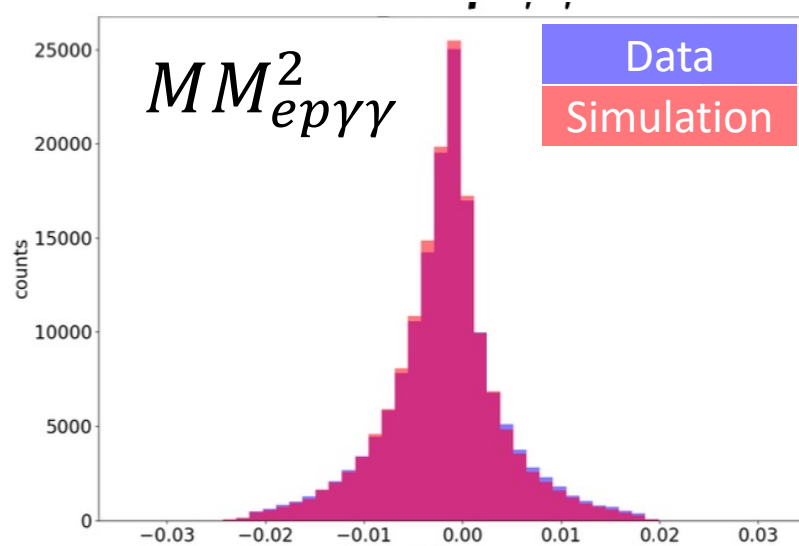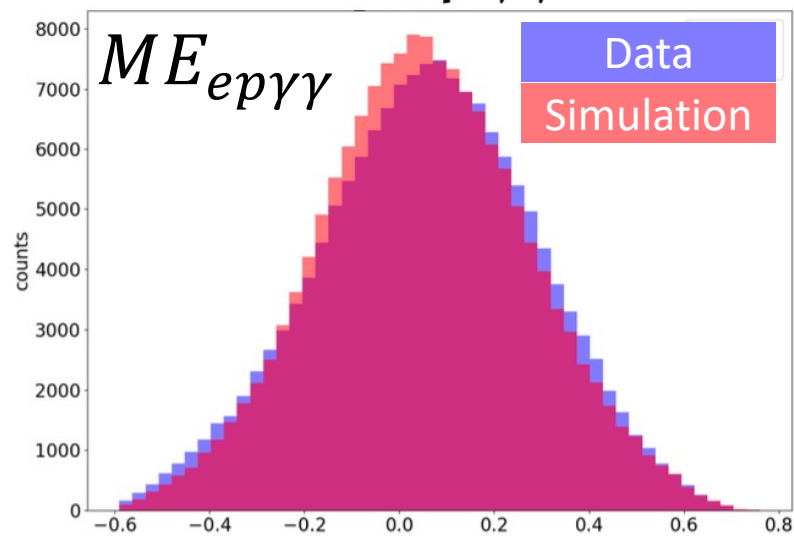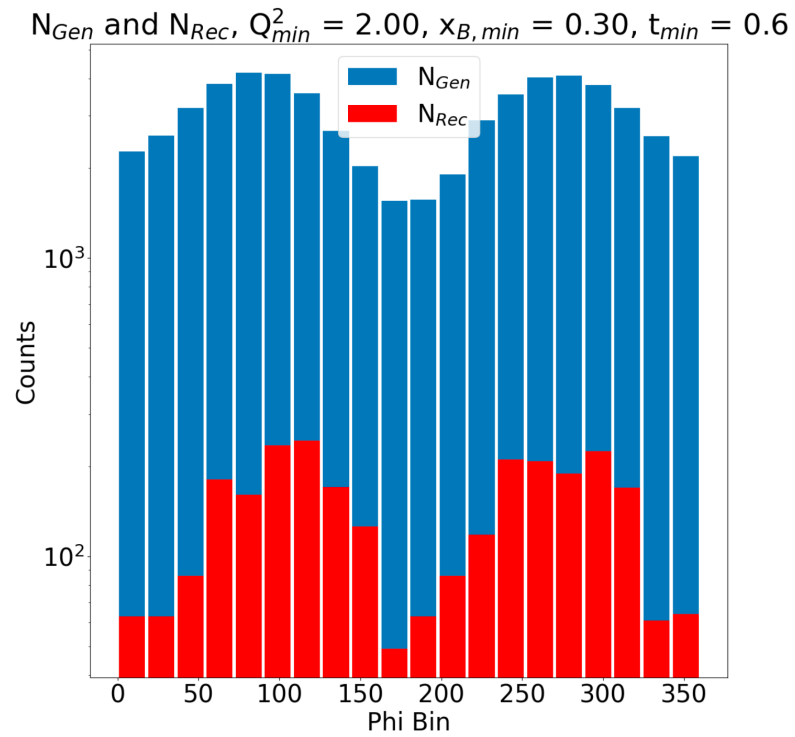
Generated:

Reconstructed:

Data and simulation comparison

Acceptance correction

$$\epsilon_{acc} = \frac{N_{detected,experiment}}{N_{truth}} \approx \frac{N_{detected,simulation}}{N_{truth,simulation}} \equiv \frac{N_{sim}}{N_{gen}}$$

N_{Gen} and N_{Rec}, $Q^2_{min} = 2.00$, $x_{B,min} = 0.30$, $t_{min} = 0.6$
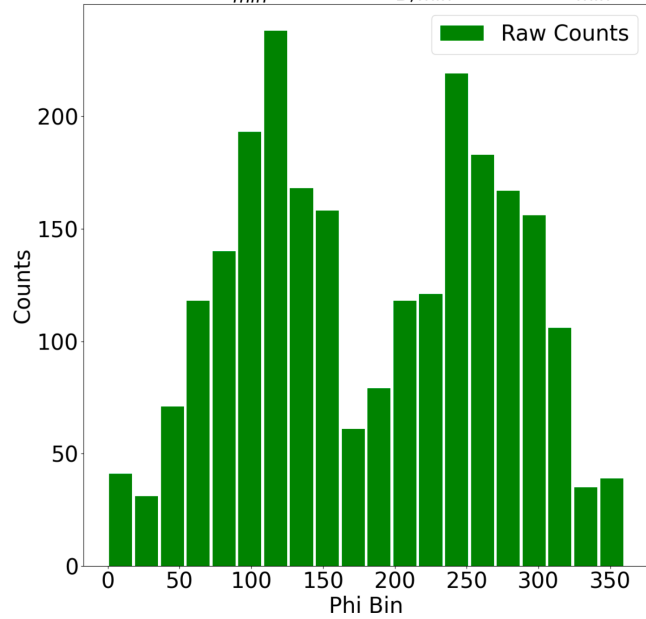
Acceptance correction

$$\epsilon_{acc} = \frac{N_{detected,experiment}}{N_{truth}} \approx \frac{N_{detected,simulation}}{N_{truth,simulation}} \equiv \frac{N_{sim}}{N_{gen}}$$

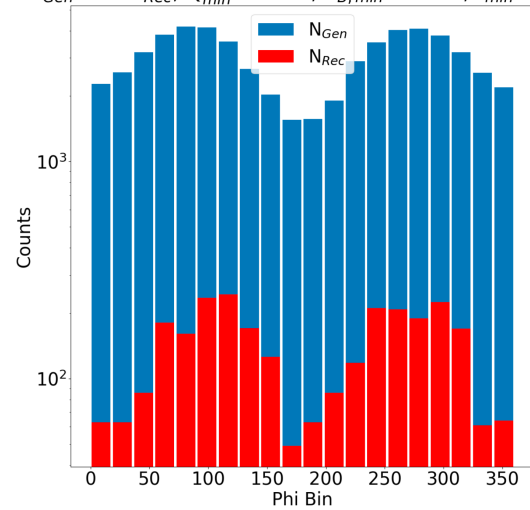Raw Counts, $Q^2_{min} = 2.00$, $x_{B,min} = 0.30$, $t_{min} = 0.6$

N_{Gen} and N_{Rec}, $Q^2_{min} = 2.00$, $x_{B,min} = 0.30$, $t_{min} = 0.6$

Acc. Corrected Counts, $Q^2_{min} = 2.00$, $x_{B,min} = 0.30$, $t_{min} = 0.6$
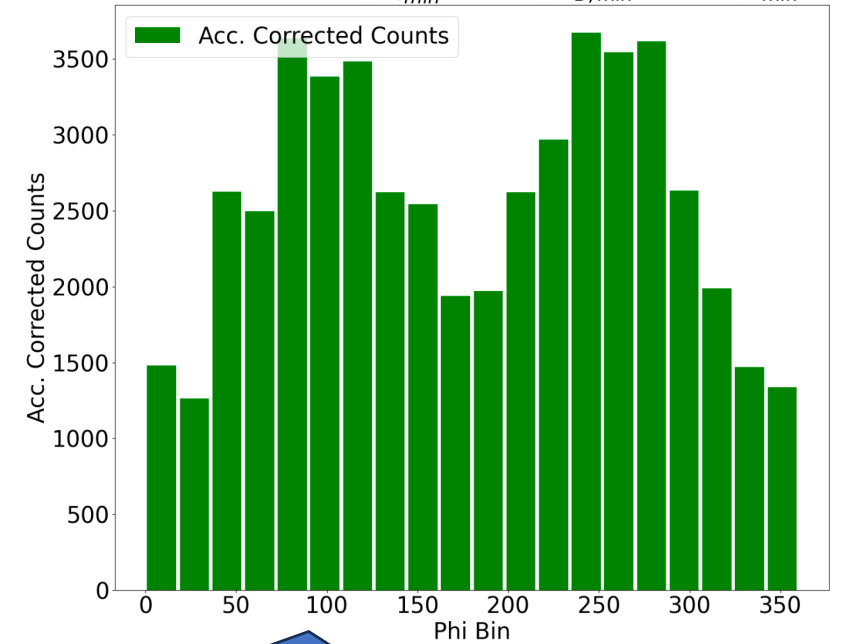
Acceptance Correction Factor for All Bins
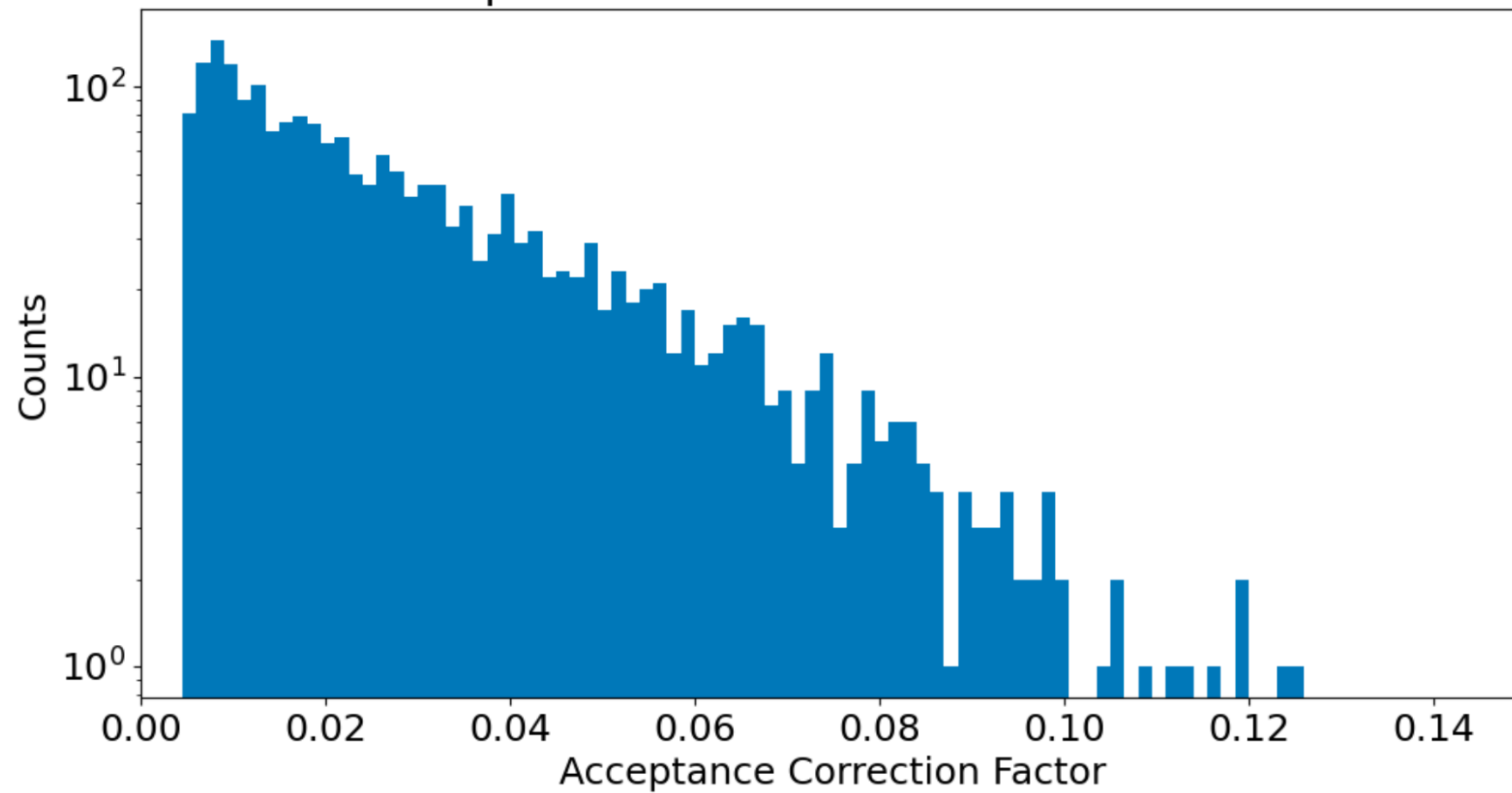
Additional corrections

Radiative corrections

$(x_{B,min}Q^2_{min}t_{min})$=(0.3, 1.5, 0.2)
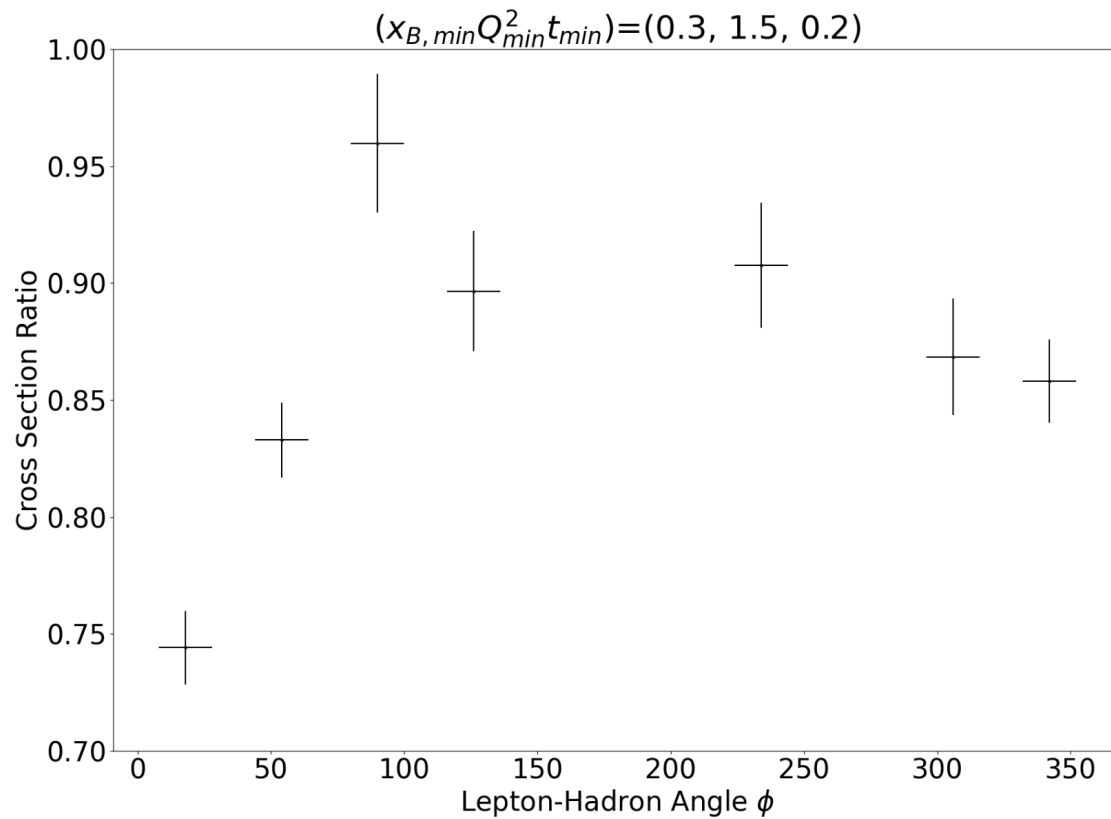
Binning corrections

- Finite bin size
- Bin Migration effects

Overall Normalization

Experimental phase space

x_B vs Q^2, Exp. Outbend.

ϕ vs Momentum Transfer t, Exp. Outbend.

Experimental phase space

x_B vs Q^2, Exp. Outbend.
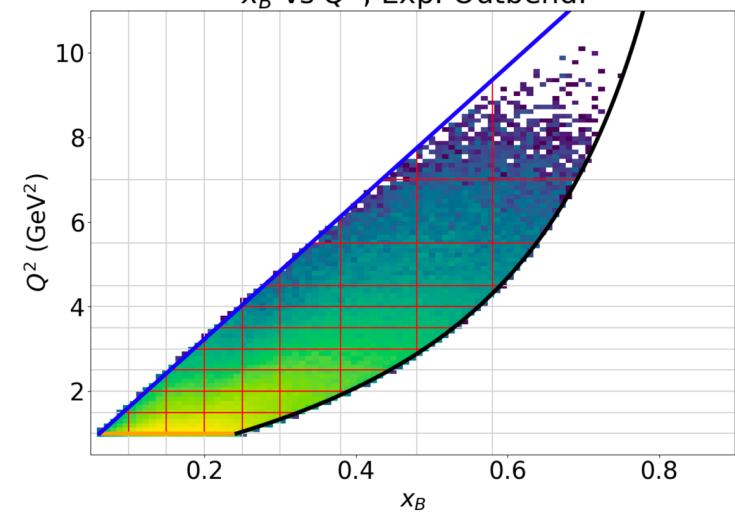
ϕ vs Momentum Transfer t, Exp. Outbend.
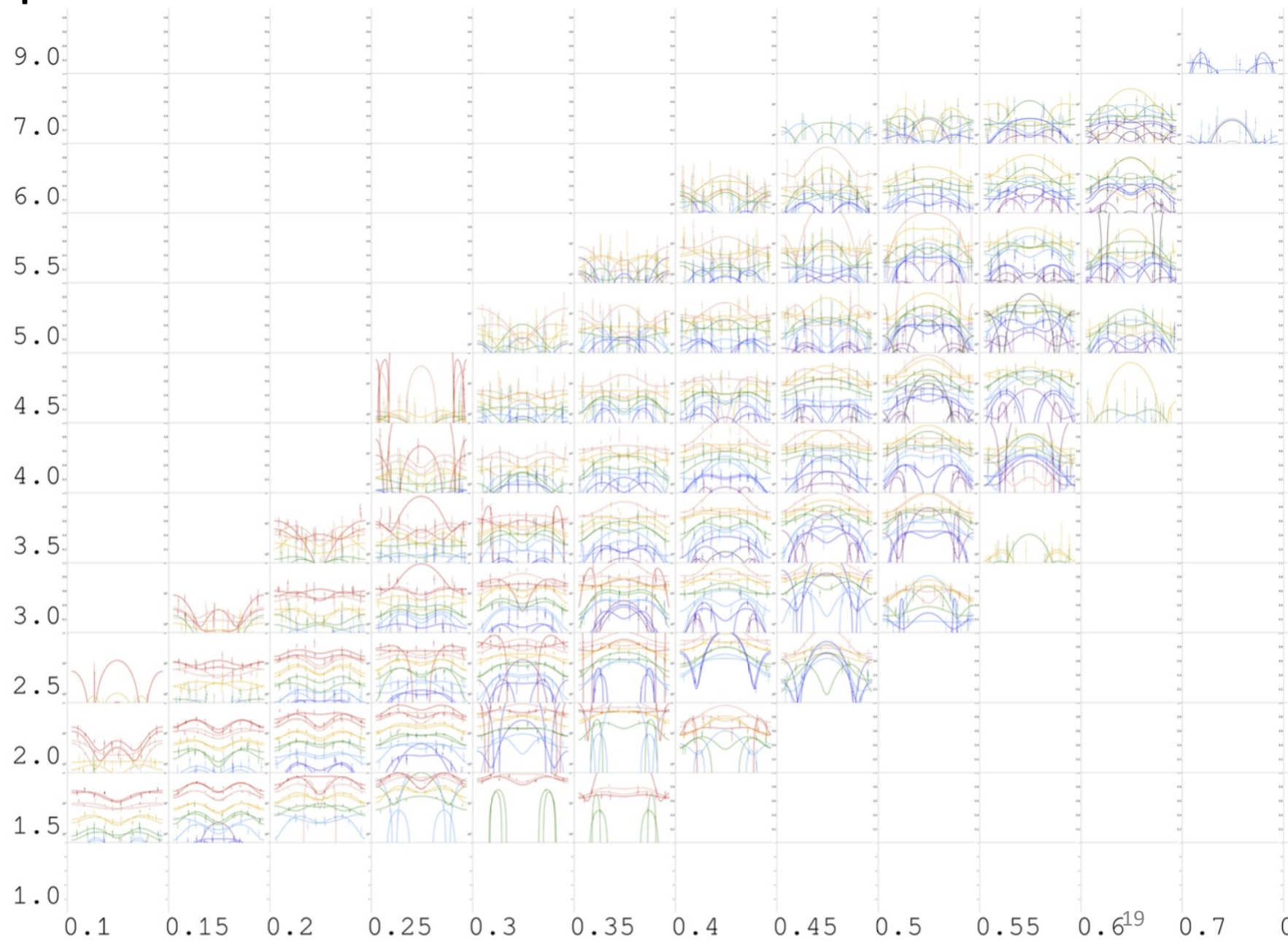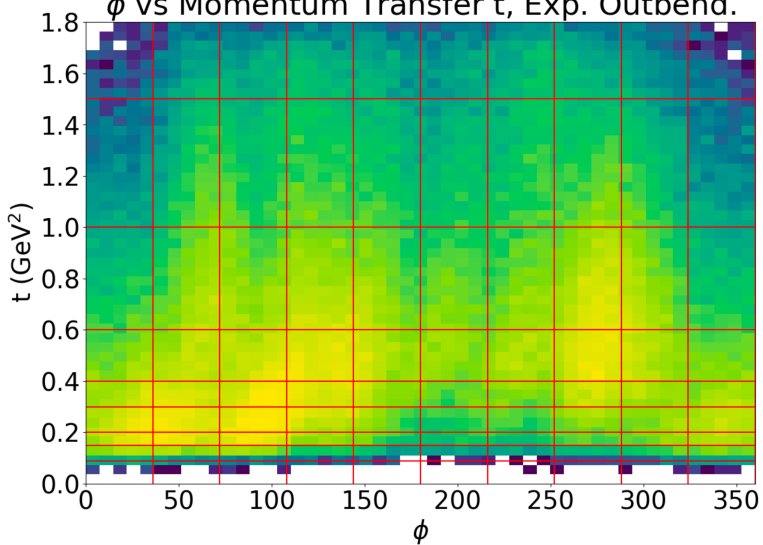
Preliminary results

$$< Q^2 > = 1.61 \, (\frac{GeV}{c})^2$$

$$< x_B > = 0.19 \qquad < t > = 0.2$$

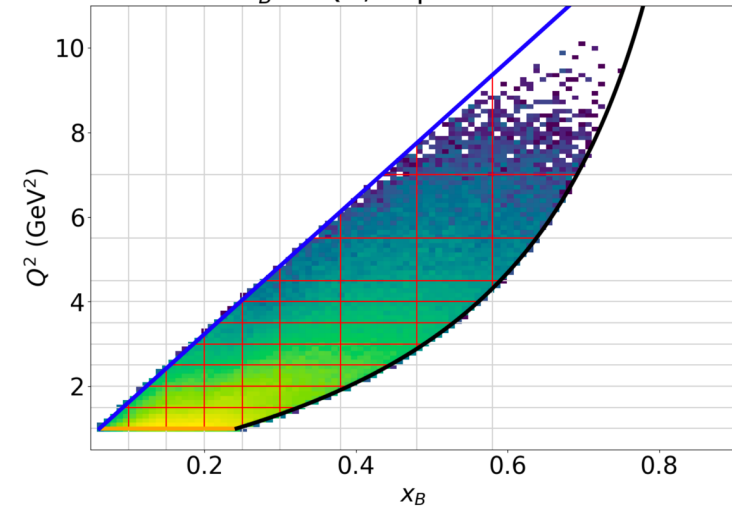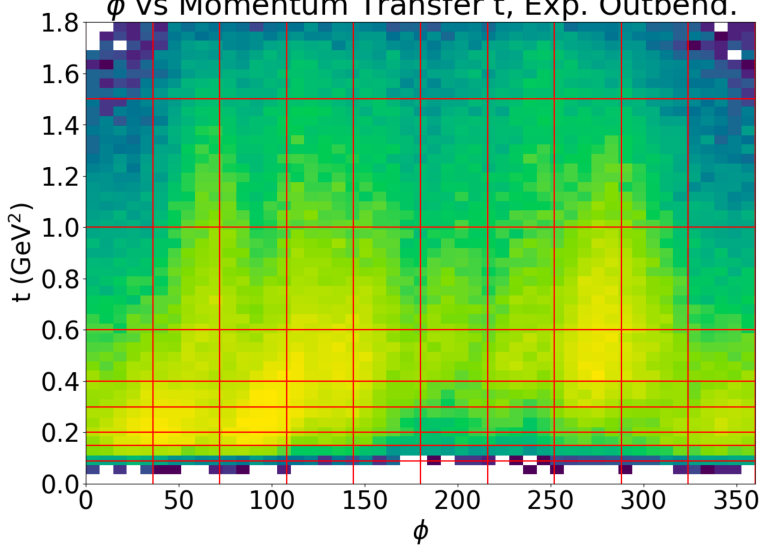$$< Q^2 > = 5.75 \, (\frac{GeV}{c})^2$$

$$< x_B > = 0.69 \qquad < t > = 1.7$$

Reduced Cross Section Fit Over Phi, Q^2 = 1.61, x_B = 0.19, t = 0.2

Reduced Cross Section Fit Over Phi, Q^2 = 5.75, x_B = 0.62, t = 1.7
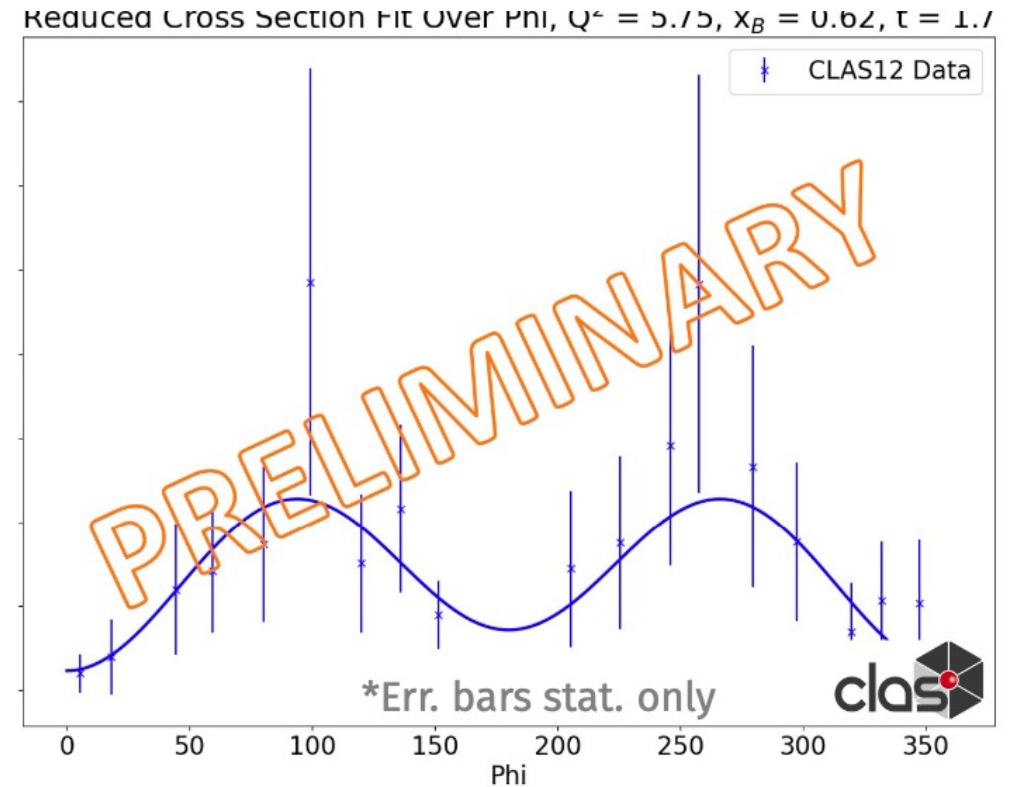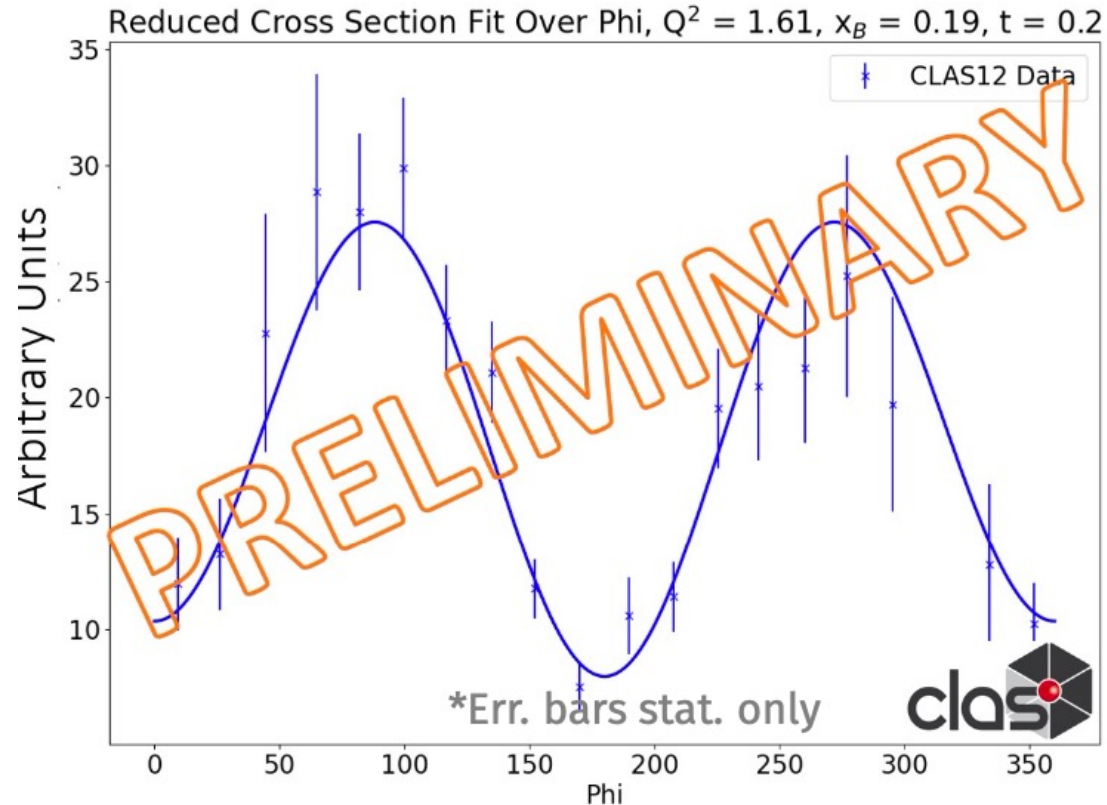
$$\frac{d^4\sigma}{dQ^2 dx_B dt d\phi} \propto A + \epsilon \cos(2\phi) \, B + \sqrt{2\epsilon(1+\epsilon)} \cos(\phi) \, C$$

Comparison with CLAS6 data

Reduced Cross Section at $1.5 < Q^2 < 2$, $0.2 < x_B < 0.25$, $0.2 < t < 0.3$

Legend:
- CLAS6 Data Fit Weighted
- GK Model 5.75 GeV Beam
- CLAS12 Data Fit Weighted
- GK Model 10.6 GeV Beam
- CLAS6 Data
- CLAS12 Data

CLAS6 Kinematic Coverage
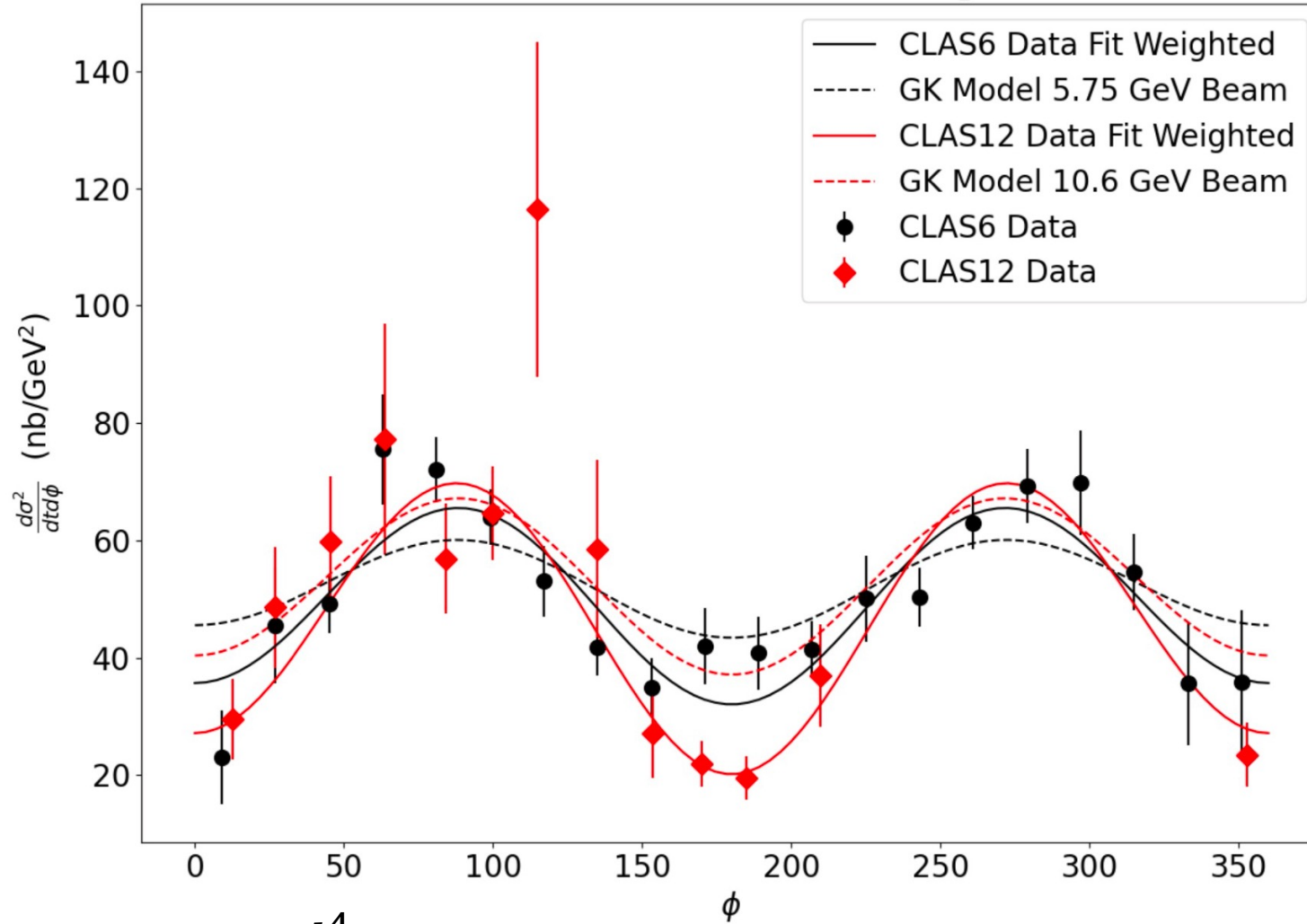
$$\frac{d^4\sigma}{dQ^2 dx_B dt d\phi} \propto A + \epsilon \cos(2\phi)\, B + \sqrt{2\epsilon(1+\epsilon)} \cos(\phi)\, C$$

Extraction of structure functions

$\langle x_B \rangle = 0.23$, $\langle Q^2 \rangle = 2.23$ GeV^2

$<x_B> = 0.23$
$<Q^2> = 2.23\ GeV^2$

$\langle x_B \rangle = 0.43$, $\langle Q^2 \rangle = 3.72$ GeV^2
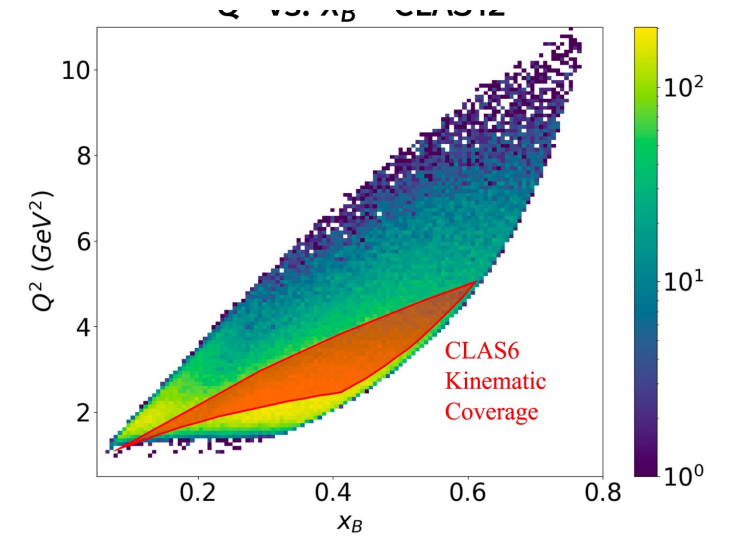
$<x_B> = 0.23$
$<Q^2> = 1.79\ GeV^2$
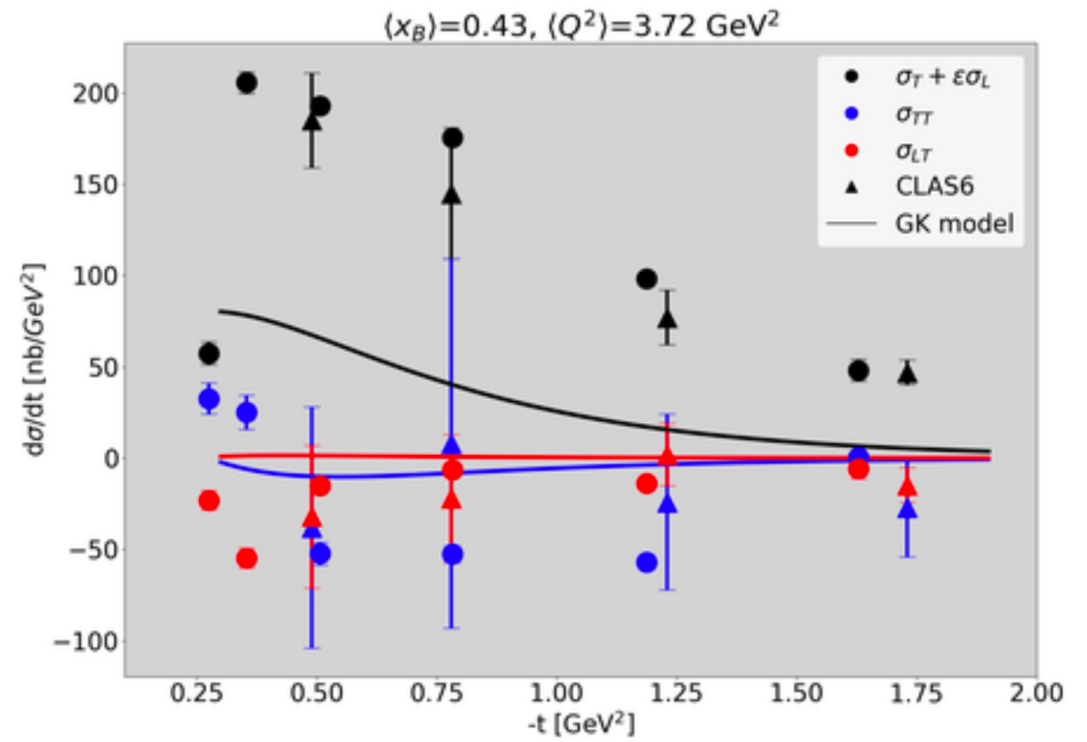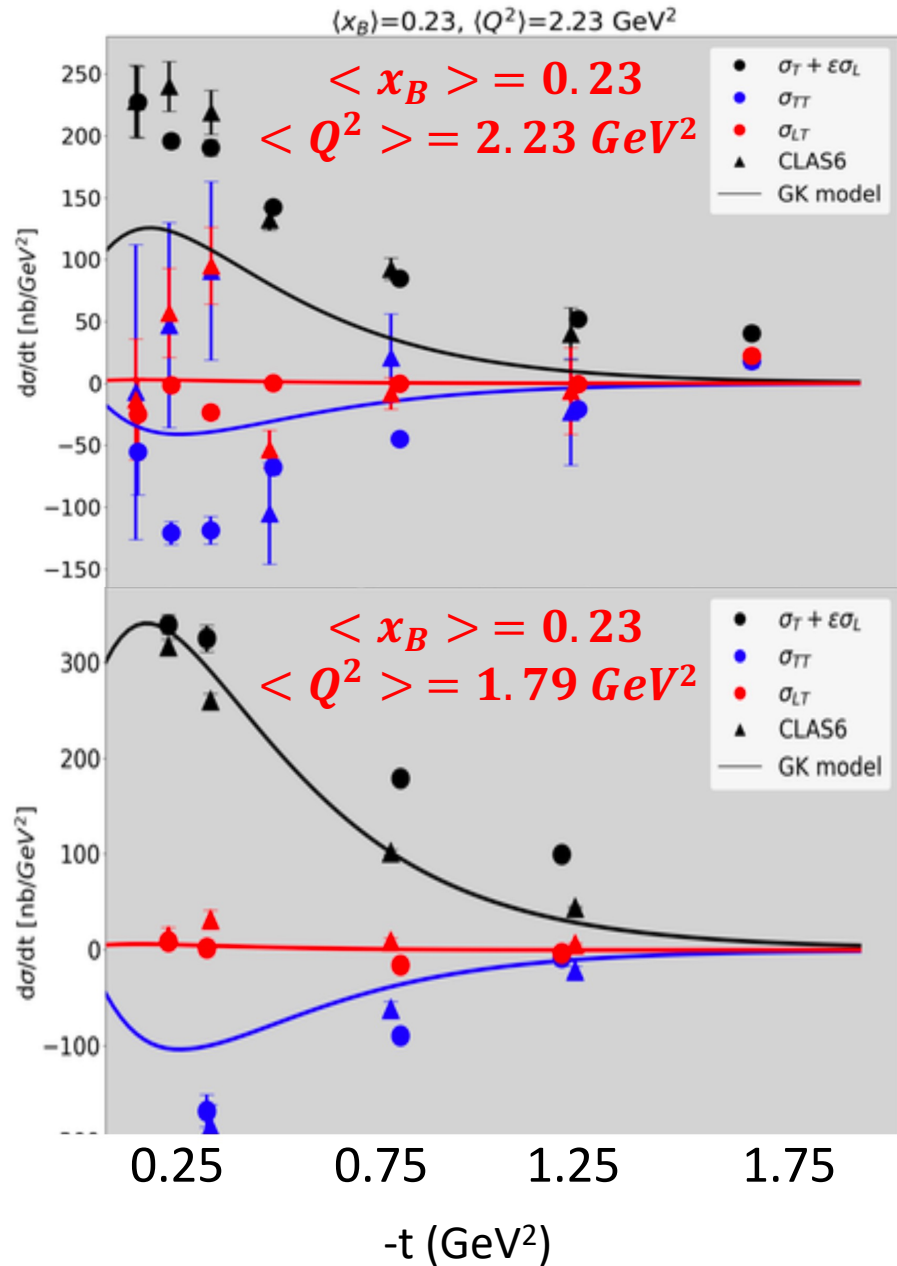
$$\bullet \left(\frac{d\sigma_T}{dt} + \epsilon\, \frac{d\sigma_L}{dt} \right),\ \bullet\ \frac{d\sigma_{TT}}{dt}\ ,\bullet\ \frac{d\sigma_{LT}}{dt}$$

CLAS6: I. Bedlinskiy et al. (2014)

Extraction of structure functions

$\langle x_B \rangle = 0.28$, $\langle Q^2 \rangle = 3.21$ GeV^2

$\langle x_B \rangle = 0.44$, $\langle Q^2 \rangle = 5.97$ GeV^2

Legend:
- $\sigma_T + \varepsilon\sigma_L$
- σ_{TT}
- σ_{LT}
- CLAS6
- GK model
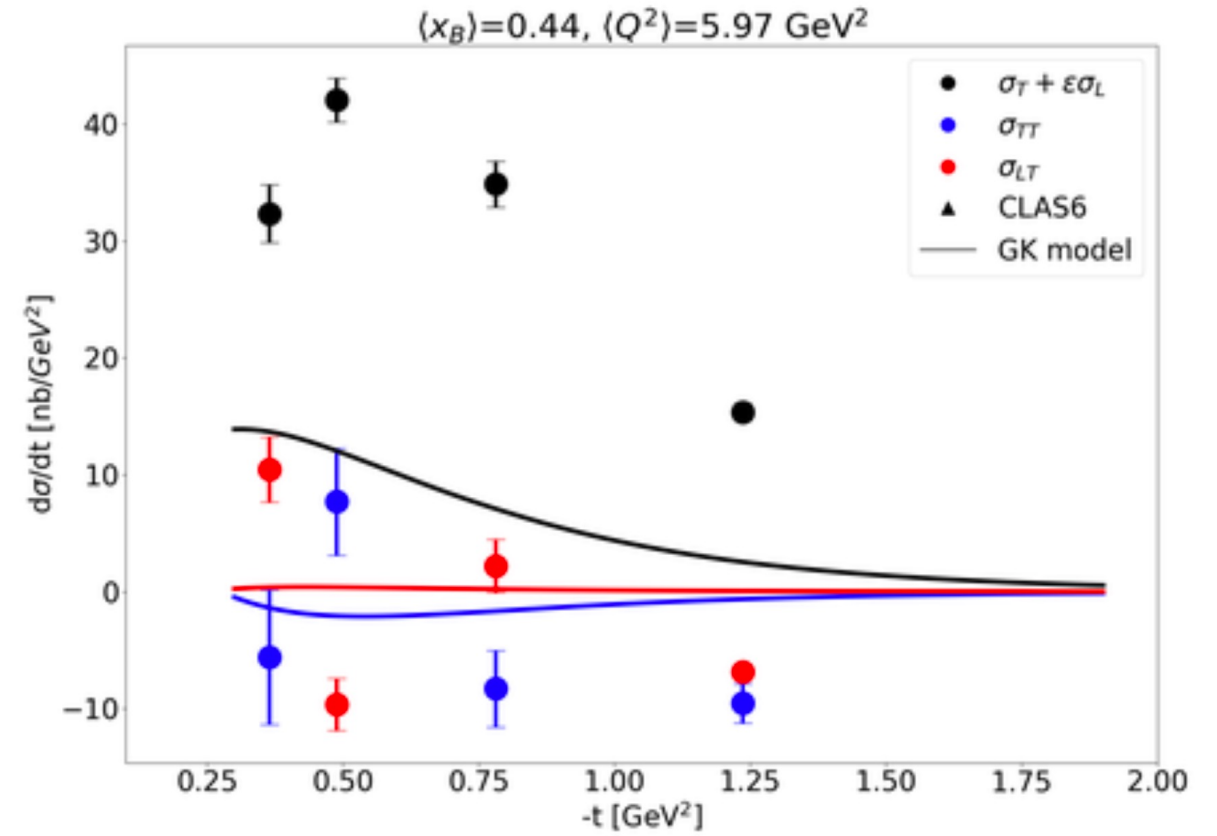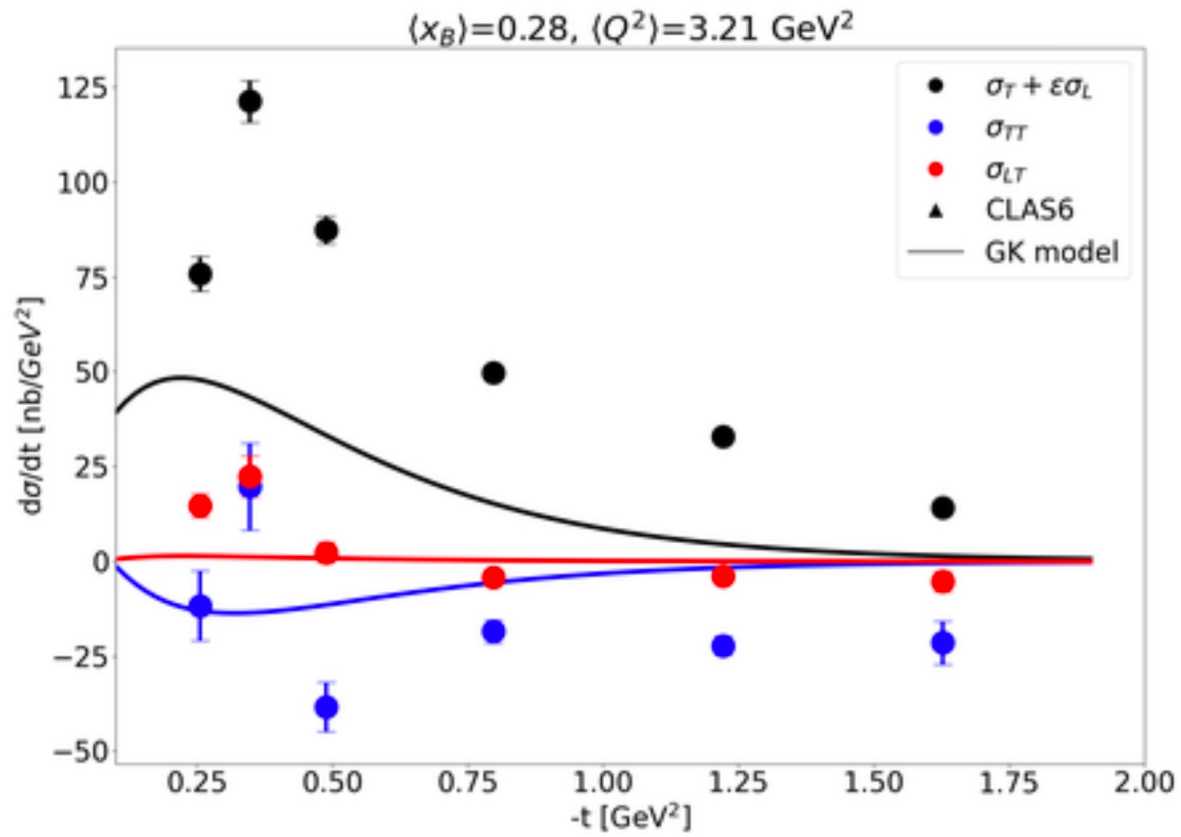
Impact Parameter and t Dependence

$$\frac{d\sigma_U}{dt} = \int \frac{d^2\sigma}{dt\, d\phi} d\phi$$

Cross Section fit with:

$$\propto A e^{-bt}$$

B Parameter of Exp. Fit to t Dependence of CLAS12 and CLAS6 Cross Sections

Systematic uncertainty budget:

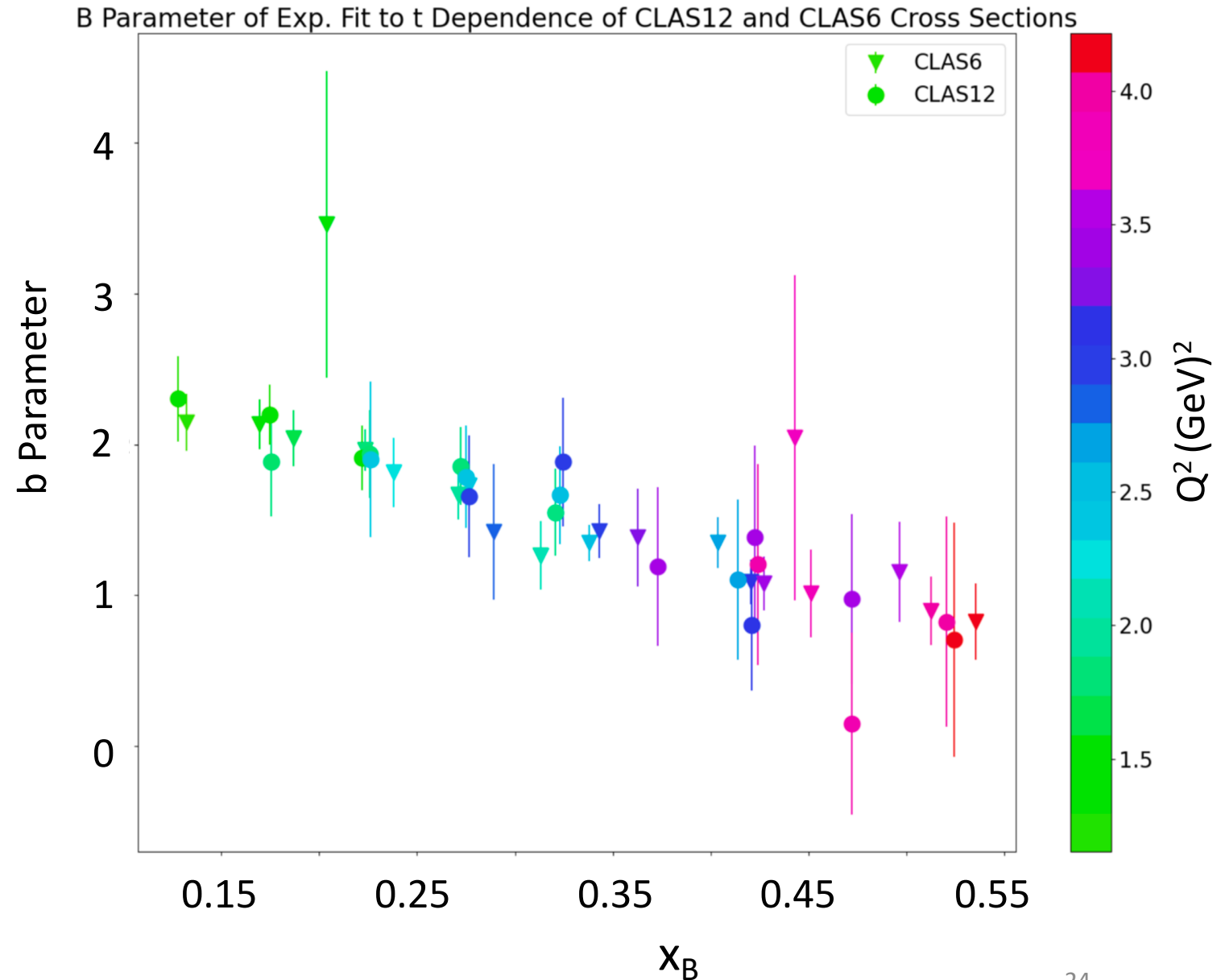| Systematic Uncertainty	Median Percent Value	Bin or Overall
Fiducial Cuts / PID	12.3 %	Bin-by-bin
Reconstruction Efficiency	8.0 %	Bin-by-bin
Simulation Resolution Matching	8.6 %	Bin-by-bin
Exclusivity Cuts	12.4 %	Bin-by-bin
Acceptance Correction	9.8 %	Bin-by-bin
Radiative Correction	5.1 %	Bin-by-bin
Finite Bin Width	3.2 %	Bin-by-bin
Unfolding Methods	13.4 %	Bin-by-bin
Accumulated Beam Charge	<1 %	Overall
Physical Target Properties	<1%	Overall
Absolute Normalization	13%	Overall
Total (quadrature)	30%	Bin-by-bin

Summary

- Large phase space coverage: multi-bin extraction cross-section for the GPD program.

- The DVπ^oP cross-section is in agreement with the theoretical parametrization at low Q^2.

- Agreement with previous measurements at CLAS6.

- Deviations from the model as Q^2 increases.

- Analysis note in final preparations.

Thank you for you attention