Massachusetts Institute of Technology

LNS Laboratory for Nuclear Science

DVCS study toward forthcoming EIC

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CFNS Postdoc meeting

December 9, 2022

Stony Brook University

Theorists have developed a powerful formalism for studying the 3D partonic picture of the nucleon and the nucleus. It is encoded in Generalized Parton Distributions (GPDs) and Transverse Momentum Dependent Distributions

Wigner distribution

$W(\mathbf{p}, \mathbf{x})$

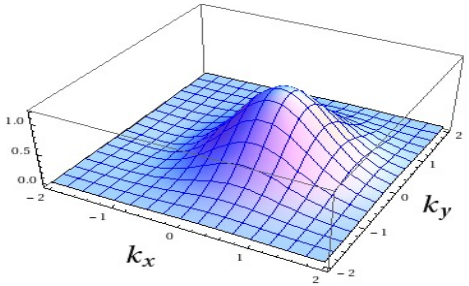
d^3r → $f(x, \mathbf{k}_\perp)$

d^3p → $H(x, \xi, t)$

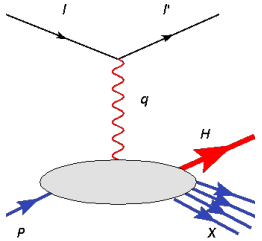
Transverse Momentum Dependent distributions

Generalized Parton Distributions

Orbital motion accessible!



SIDIS



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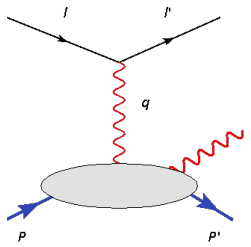
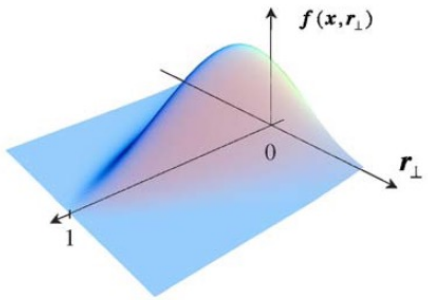
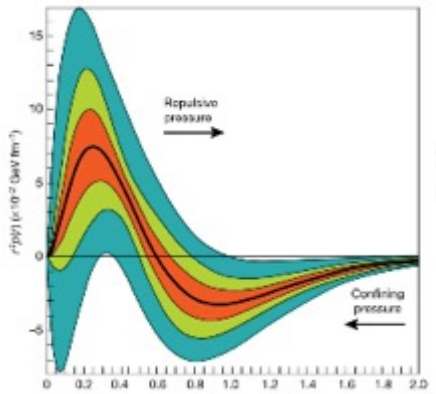


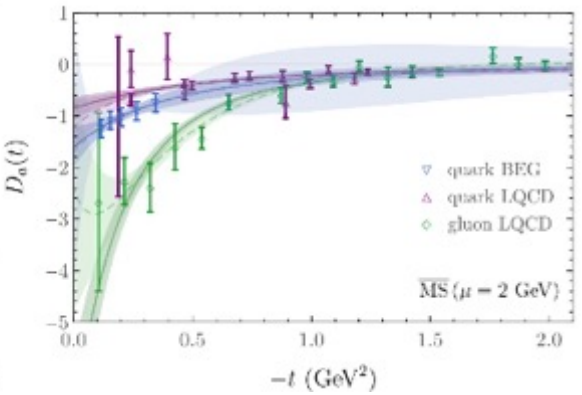


Why GPDs are interesting?

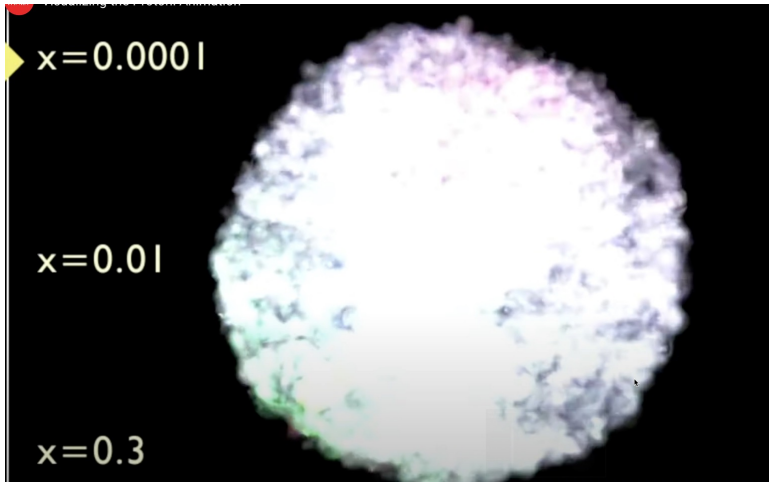
- Imaging of the nucleon
- Spin decomposition of the nucleon
- Mass origin of the nucleon
- Dynamic properties of the nucleon

R. G. Milner and R. Ent, Visualizing the Proton (2022)





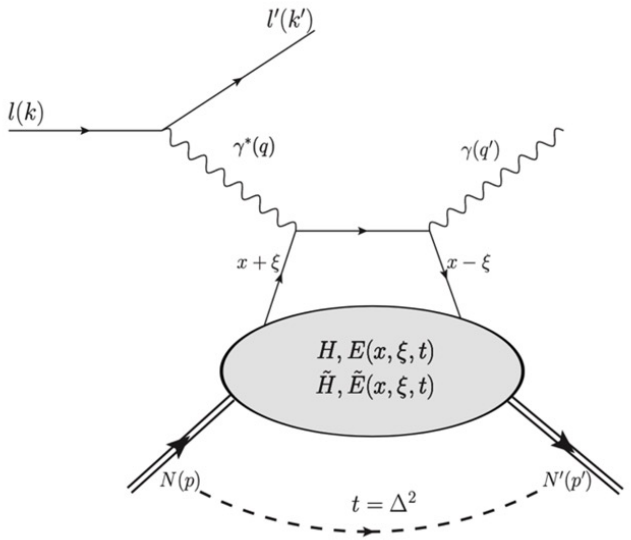
V. D. Burkert, L. Elouadrhiri and F. X. Girod, (2018)
P. E. Shanahan and W. Detmold (2019)



Deeply virtual exclusive scattering

DVCS

$$e + p \to e' + p' + \gamma$$



$$\frac{P^+}{2\pi}\int dy^-\, e^{ixP^+y^-}\,\langle p'|\bar{\psi}_q(0)\gamma^+(1+\gamma^5)\psi(y)|p\rangle$$

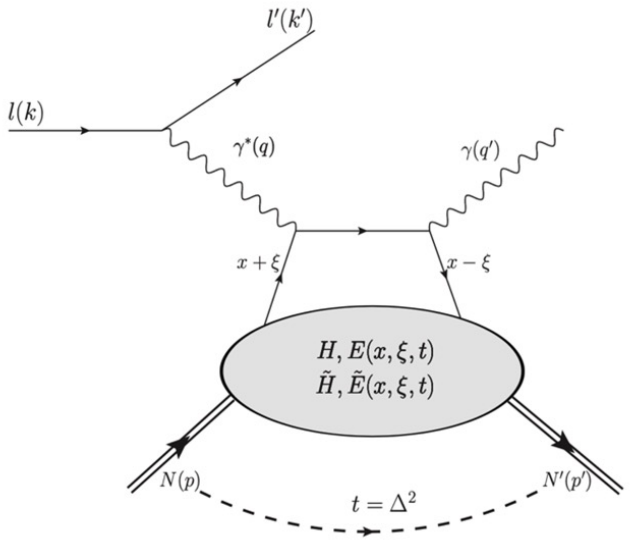
$$= \bar{N}(p')\left[H^q(x,\xi,t)\gamma^+ + E^q(x,\xi,t)i\sigma^{+\nu}\frac{\Delta_\nu}{2M}\right.$$

$$\left. + \tilde{H}^q(x,\xi,t)\gamma^+\gamma^5 + \tilde{E}^q(x,\xi,t)\gamma^5\frac{\Delta^+}{2M}\right]N(p)$$

Deeply virtual exclusive scattering

DVCS

$$e + p \to e' + p' + \gamma$$



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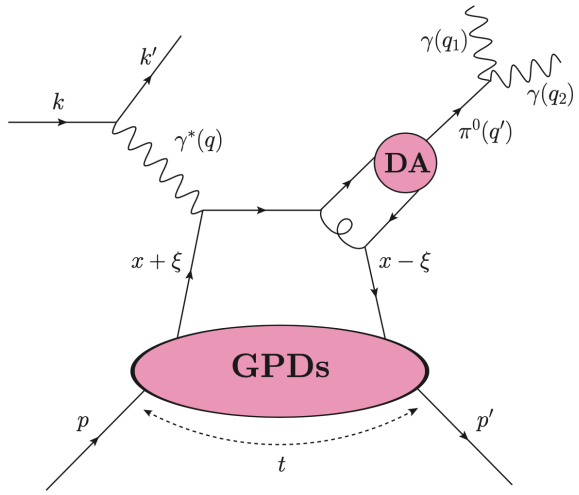
DVπ^0

$$e + p \to e' + p' + \pi^0$$



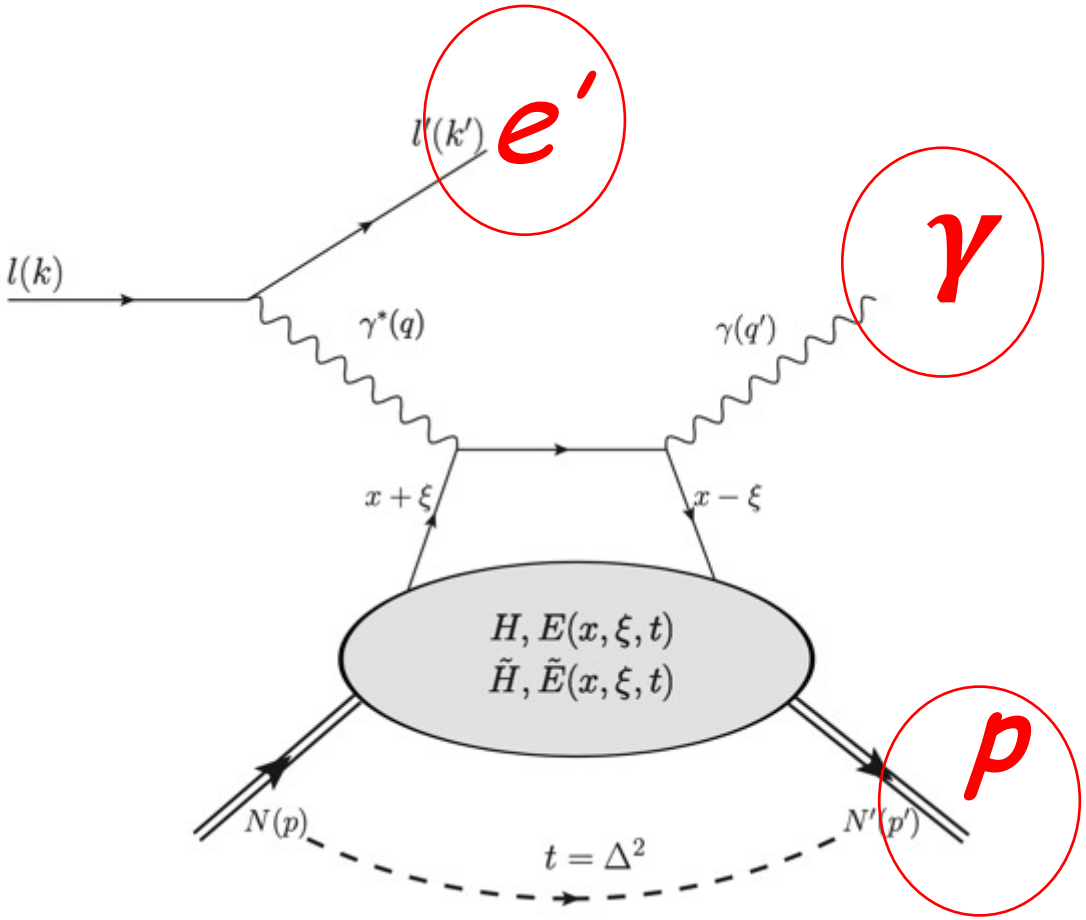
$$\frac{d\sigma_L}{dt} = \frac{4\pi\alpha}{kQ^2}\left\{(1-\xi^2)\,|\langle\tilde{H}\rangle|^2 - 2\xi^2\Re\left[\langle\tilde{H}\rangle^*\langle\tilde{E}\rangle\right] - \frac{t'}{4m^2}\xi^2|\langle\tilde{E}\rangle|^2\right\}$$

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

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

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

DVCS process

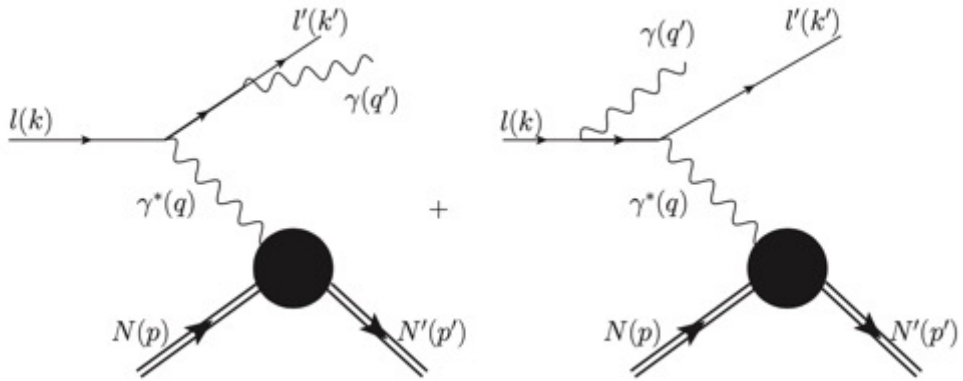


$$e + p \rightarrow e' + p' + \gamma$$

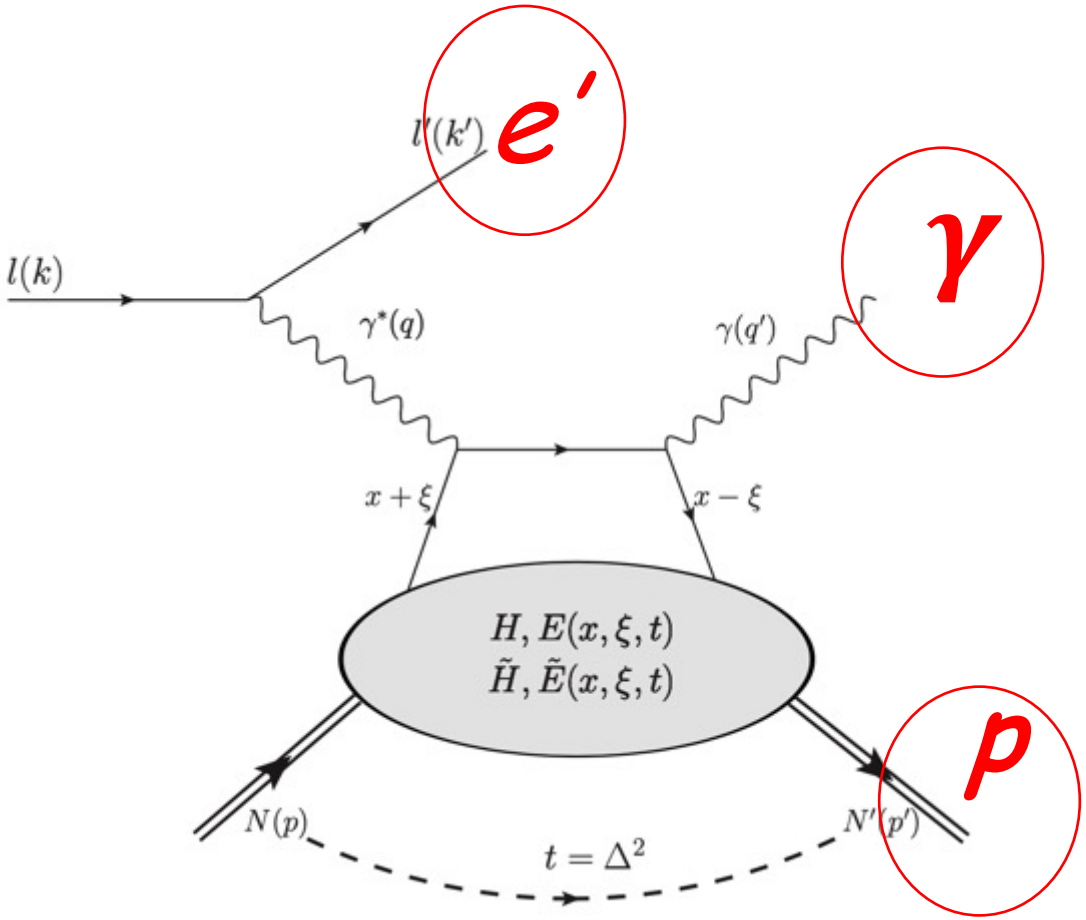
Pure QED

Bethe-Heitler

<u>Irreducible Background</u>



DVCS process



$$e + p \rightarrow e' + p' + \gamma$$

$$\frac{d\sigma}{dx_B dQ^2 d|t| d\phi} = \Gamma \times |\mathcal{T}_{\mathrm{BH}} + \mathcal{T}_{\mathrm{DVCS}}|^2$$

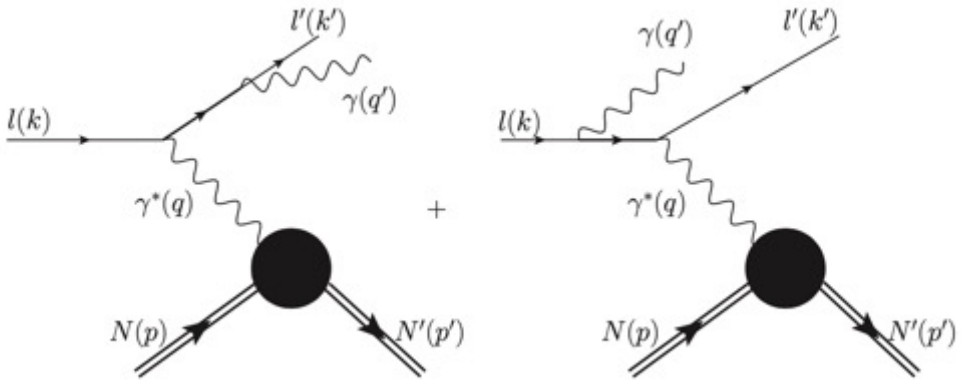
$$= \Gamma \times (|\mathcal{T}_{BH}|^2 + |\mathcal{T}_{DVCS}|^2 + \mathcal{I})$$

$$\mathcal{T}_{\mathrm{BH}} \propto \mathrm{FF}, \quad \mathcal{T}_{\mathrm{DVCS}} \propto \mathrm{CFF}$$

Pure QED

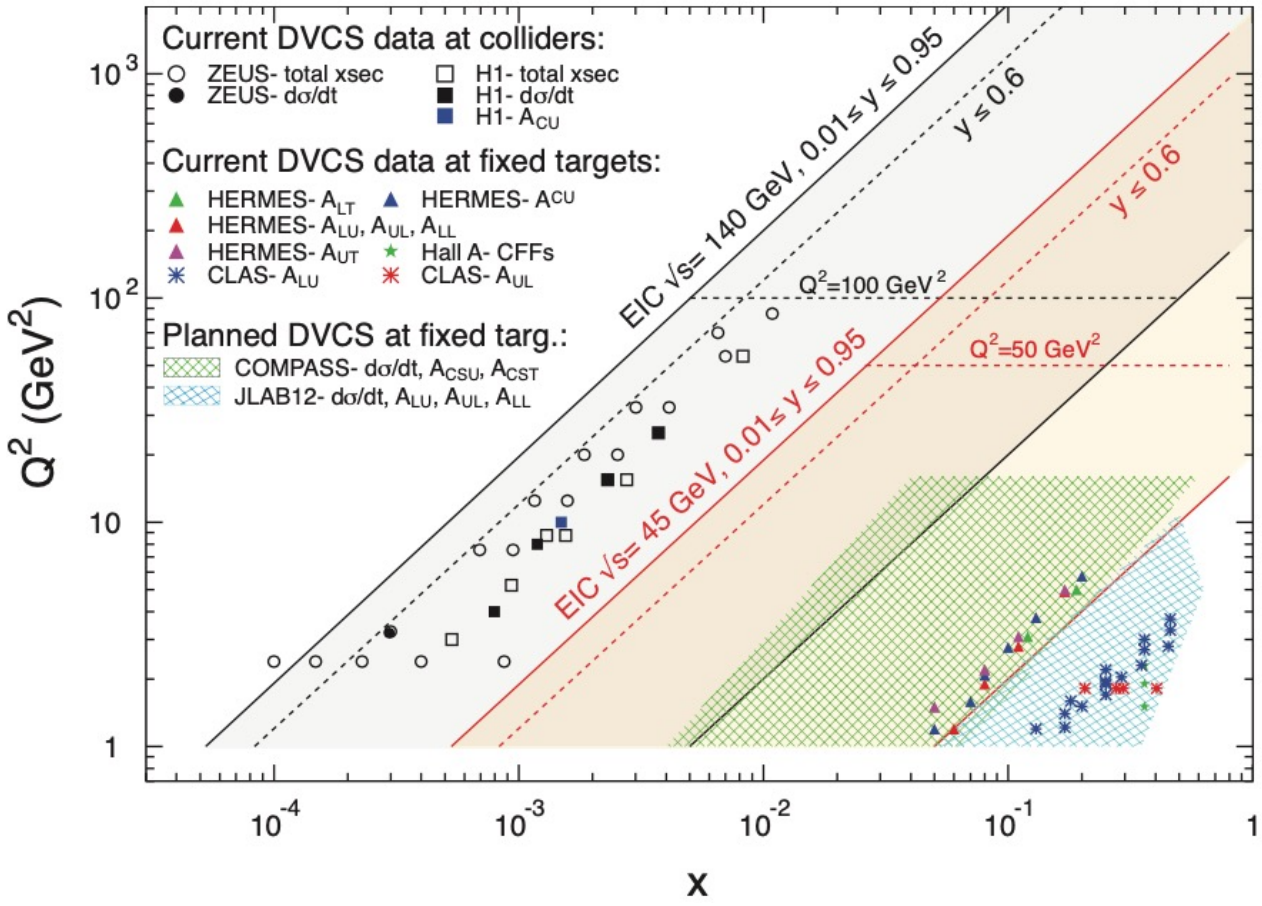
Bethe-Heitler

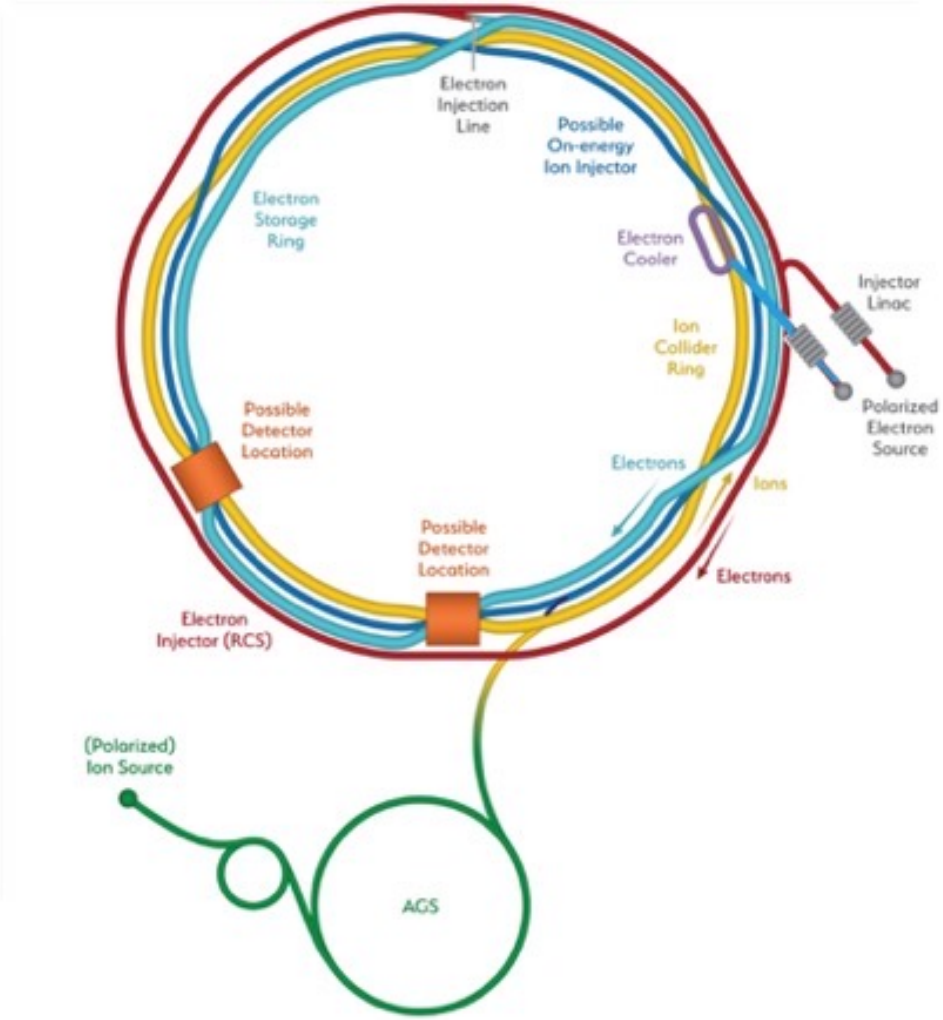
Irreducible Background



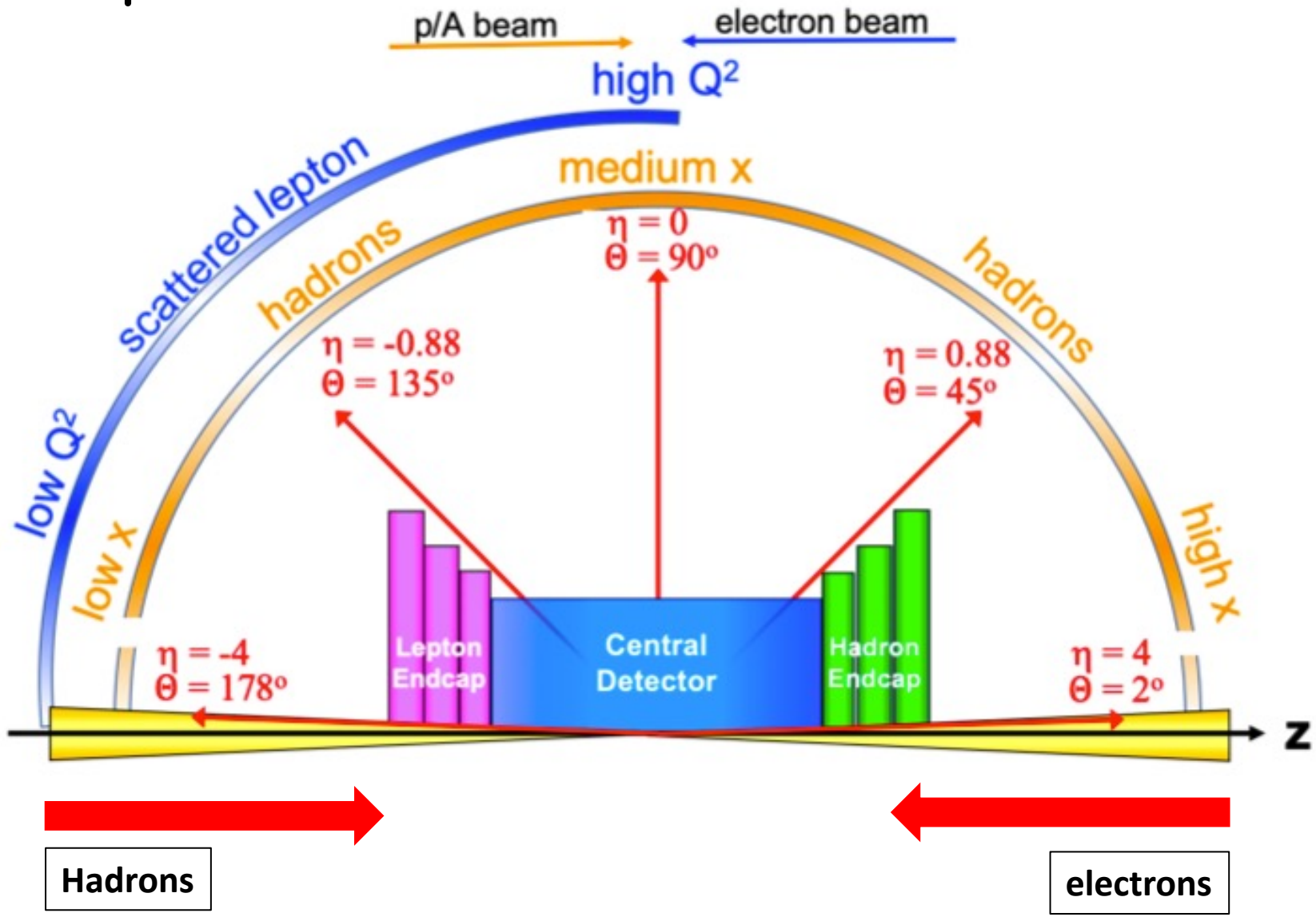
DVCS at EIC

arXiv:1304.0077v2





EIC detector concept



Simulation tool:
MILOU (3D) - generator

https://arxiv.org/pdf/hep-ph/0411389v1.pdf

Used for Yellow report arXiv:2103.05419

3D – lookup tables (Q^2,x_B,t)

KM20 – implemented in GeParD (Nucl.Phys.B794:244-323,2008)

GK – implemented in PARTONS ((arXiv:1512.06174)

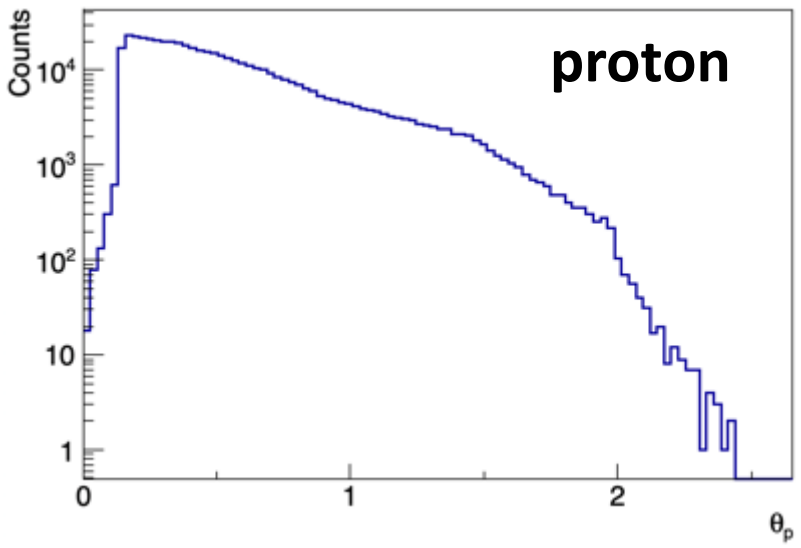
Account for an interplay between all three variables

New EPIC generator based on PARTONS framework

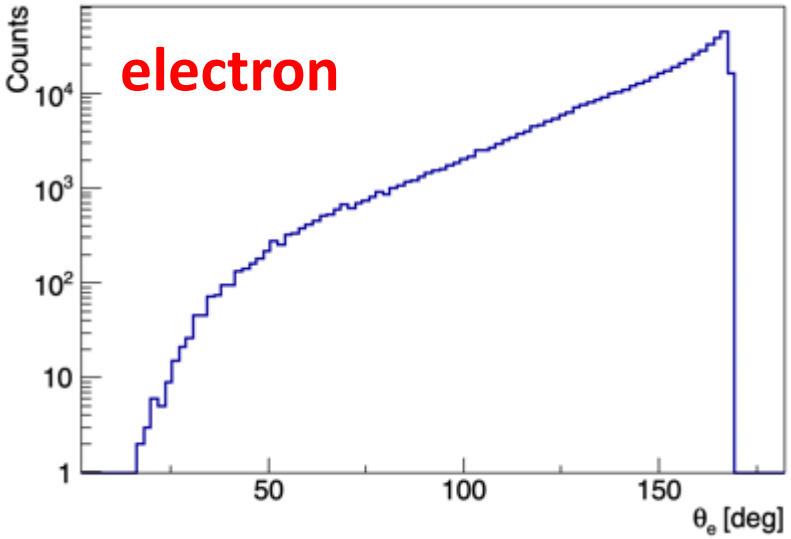
Eur. Phys. J. C **82**, 819 (2022)

Angular distributions for DVCS

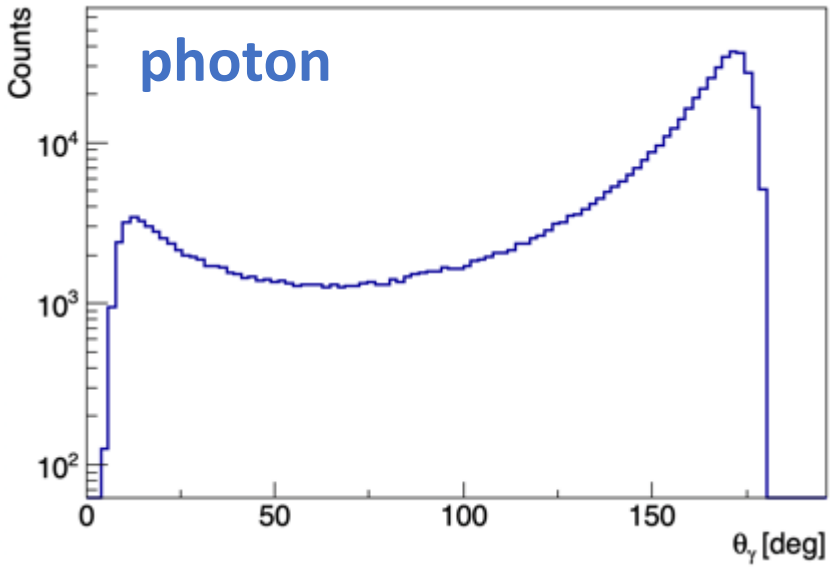
5x41 GeV



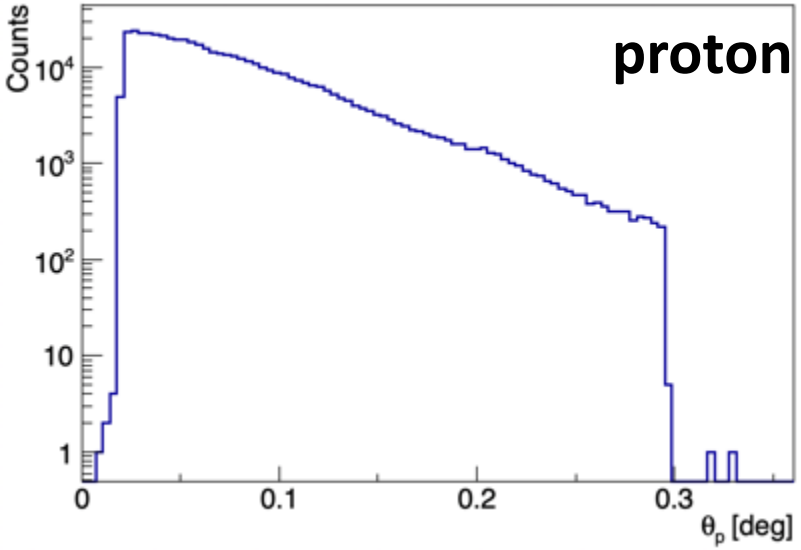
5x41 GeV



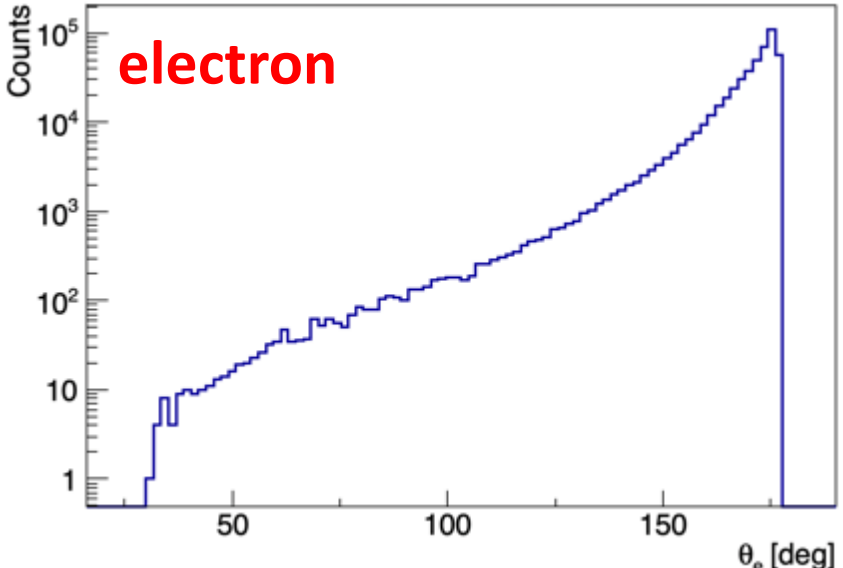
5x41 GeV



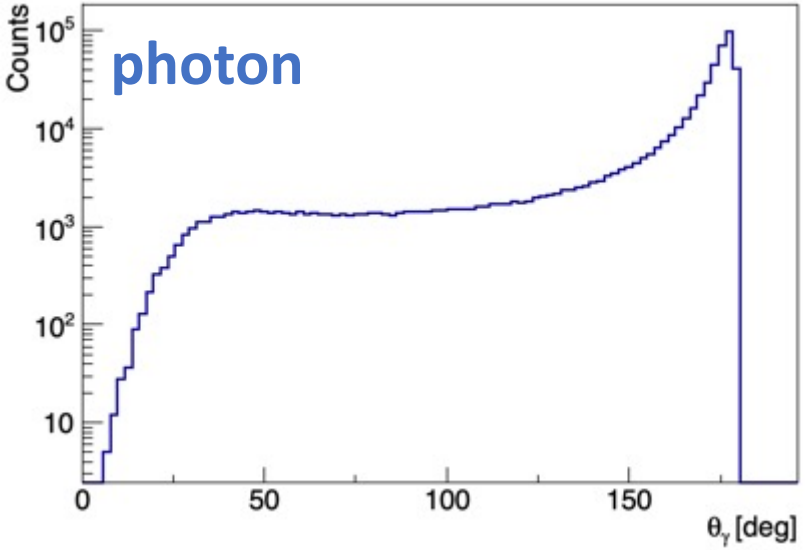
18x275 GeV



18x275 GeV



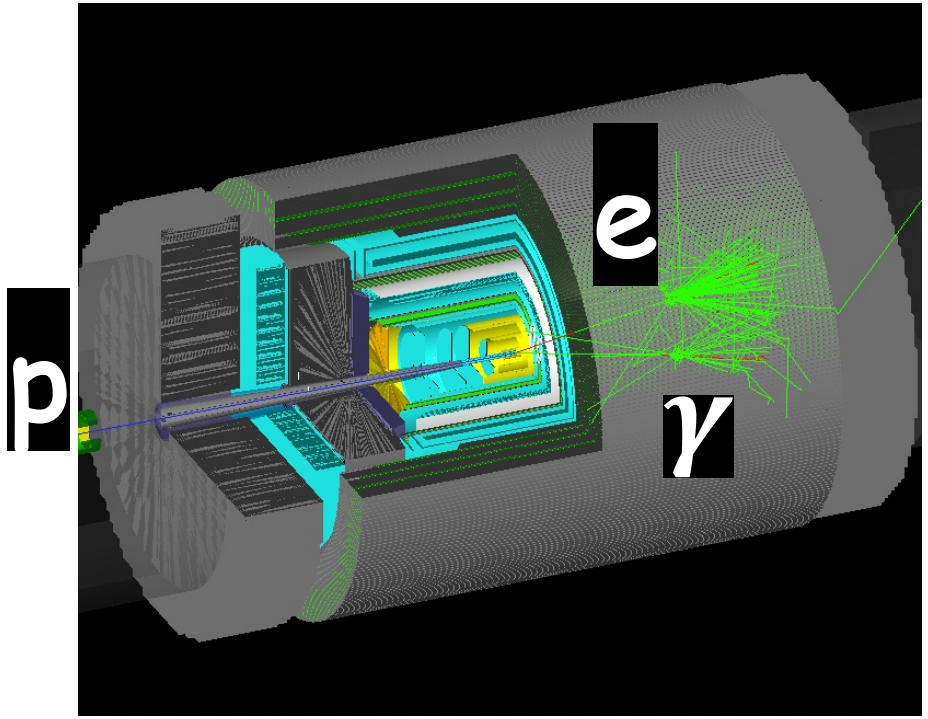
18x275 GeV



DVCS kinematics

Electron and photon

detected in main barrel



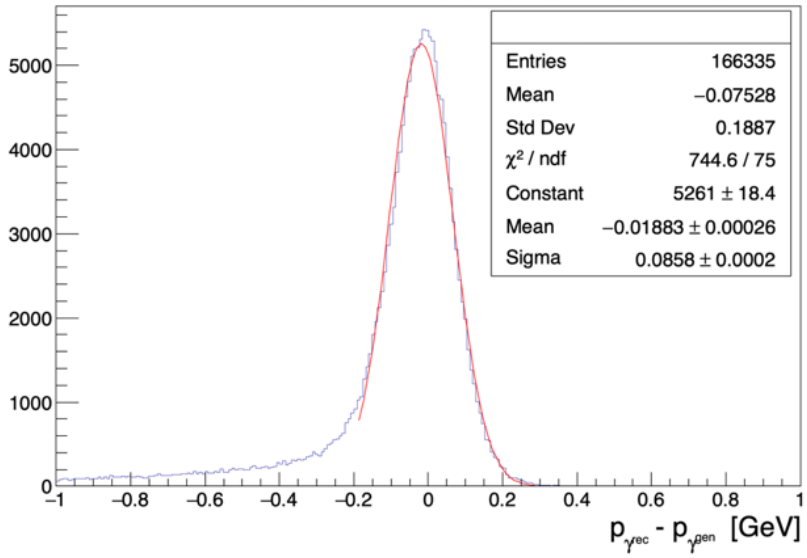
(Fun4All)

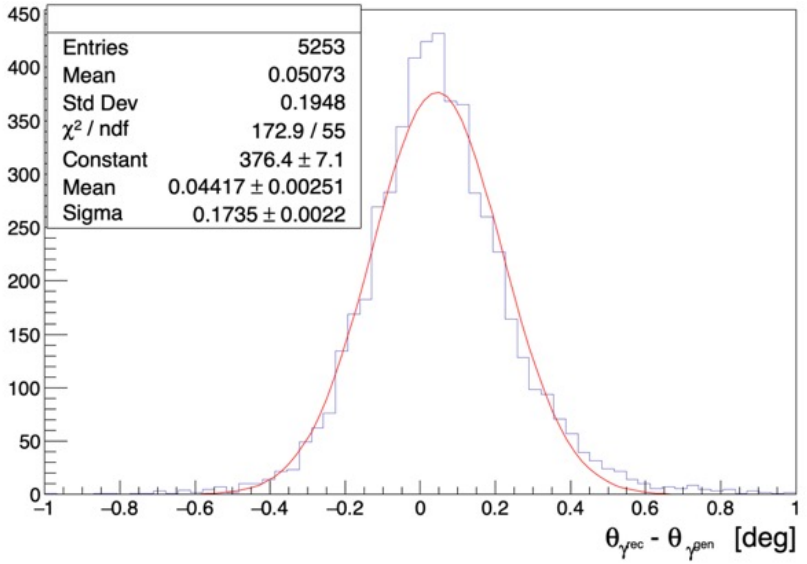
Momentum Resolution

~ 0.1 GeV

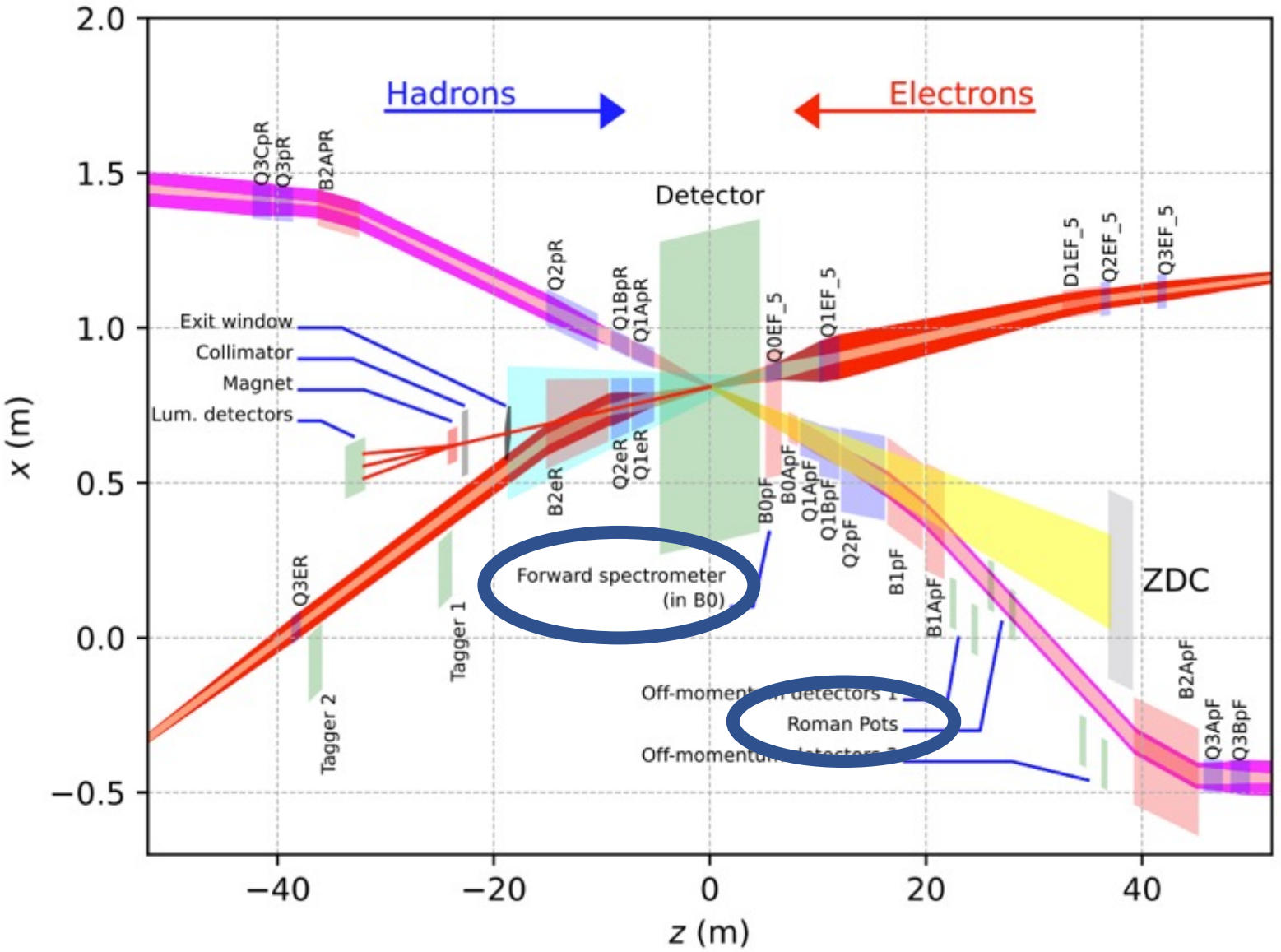
Angular resolution

< 0.5 deg

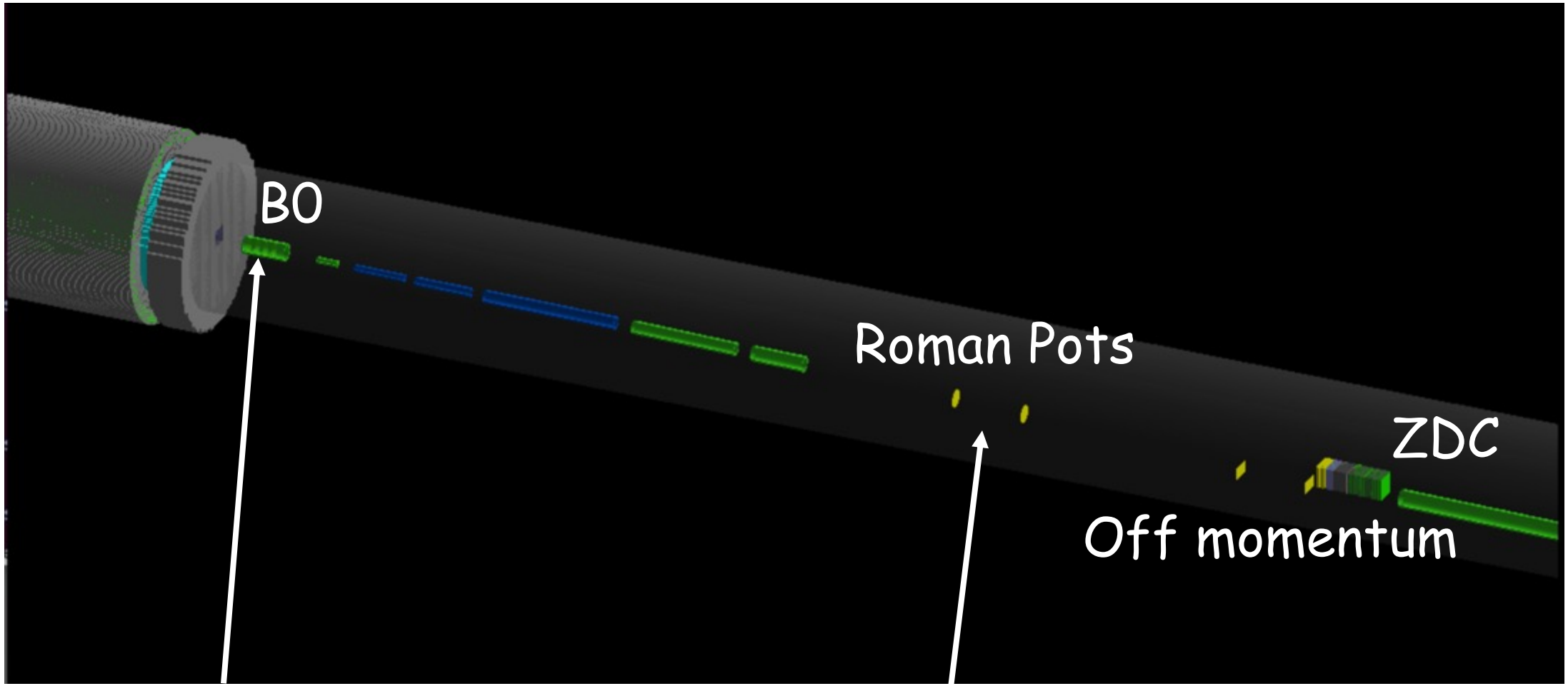




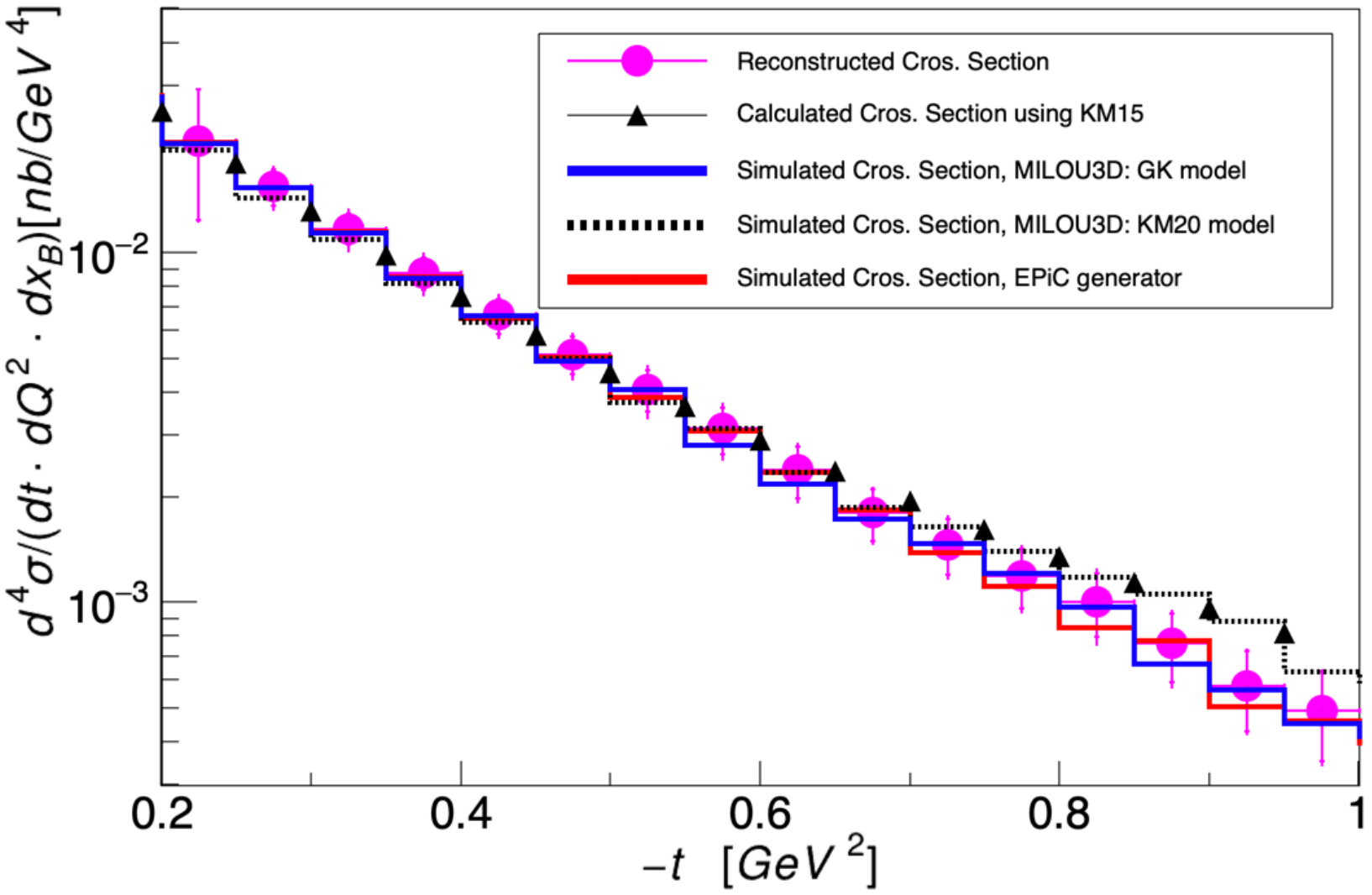
Detection of scattered protons in Far Forward region



Far-Forward simulation (Fun4All)



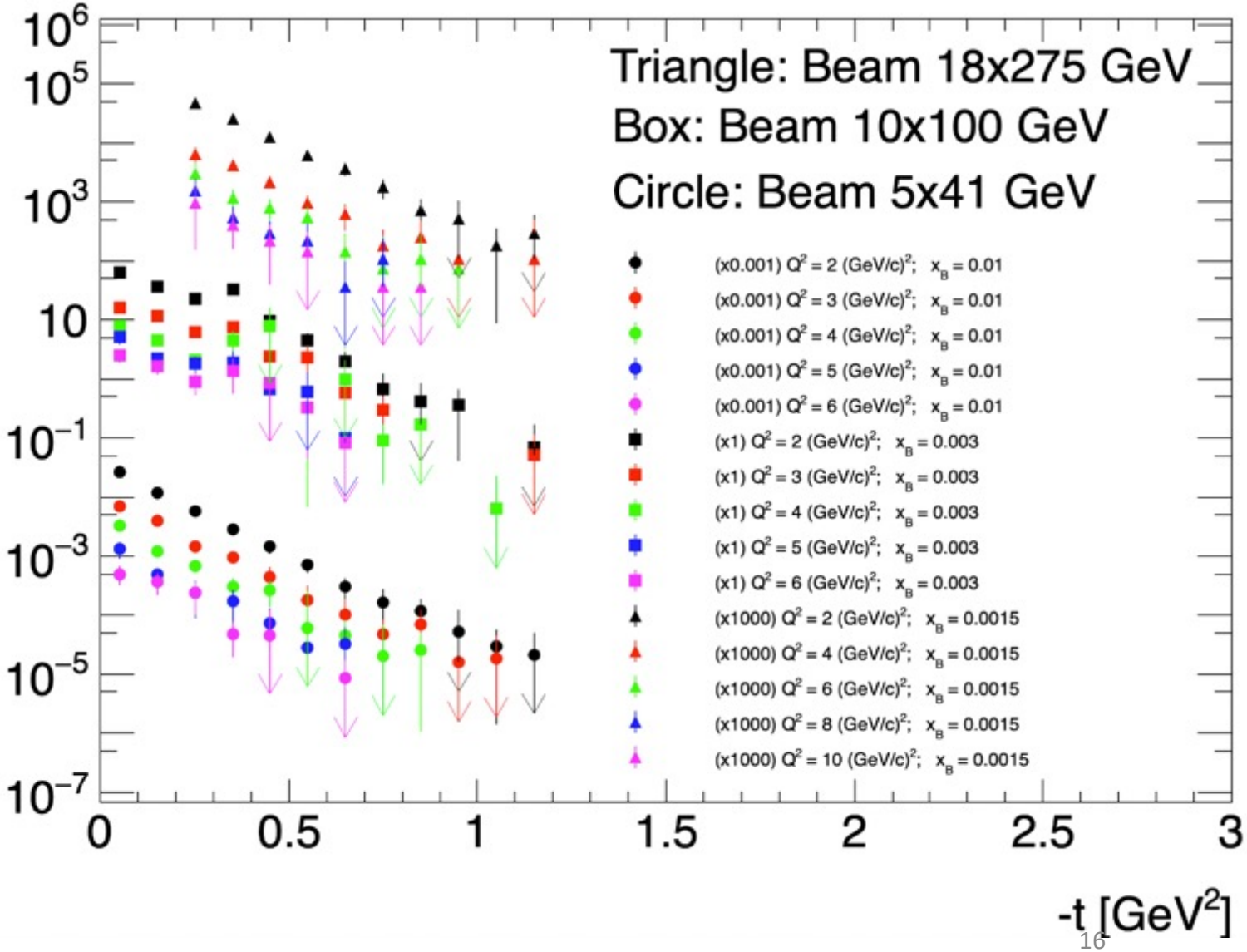
Consistency check



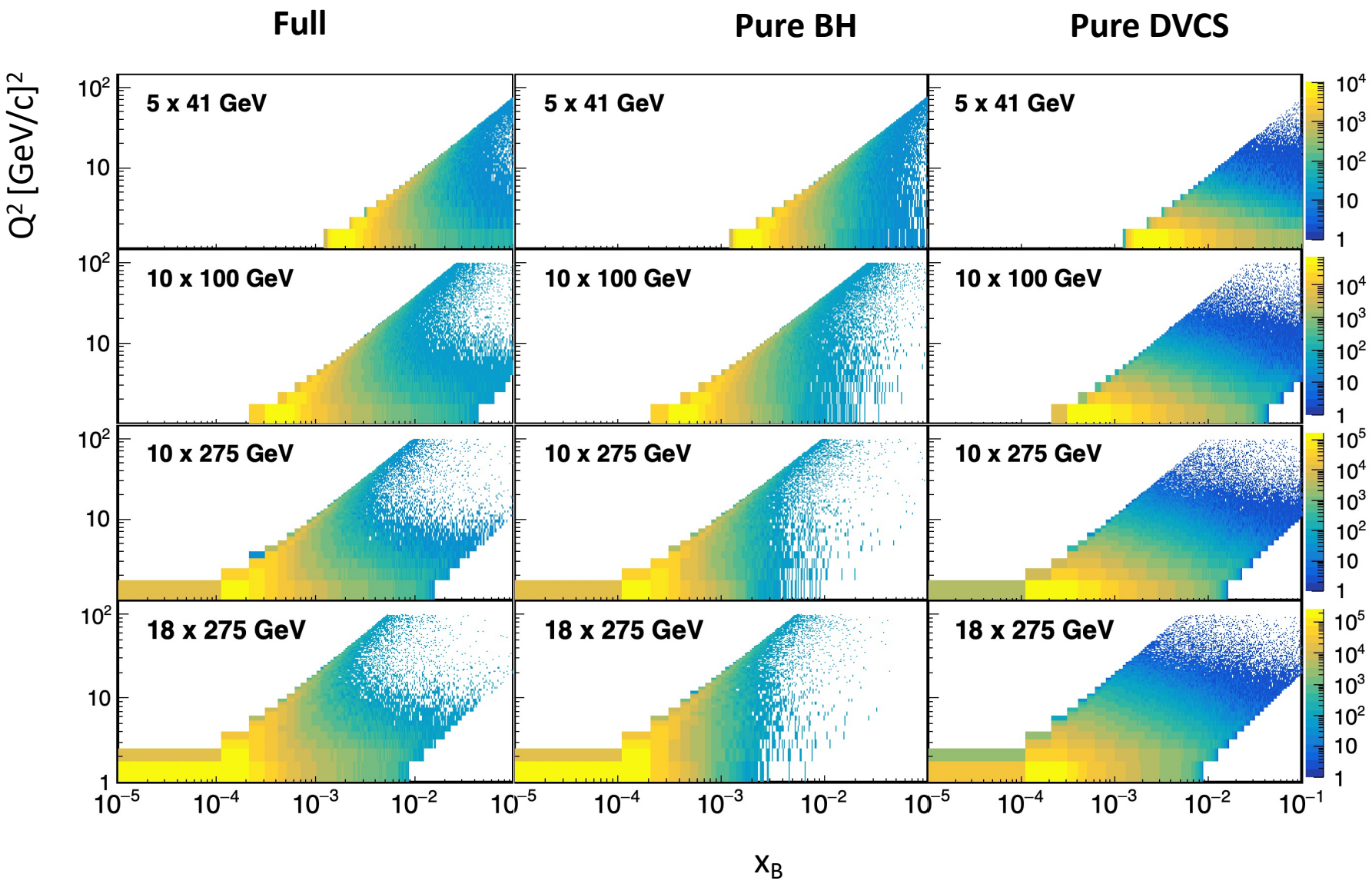
Cross section

$d\sigma$

- Corrected to acceptance
- Bin Volume
- Integrated luminosity 10 fb^{-1}



Kinematical Coverage of EIC for different beam energies

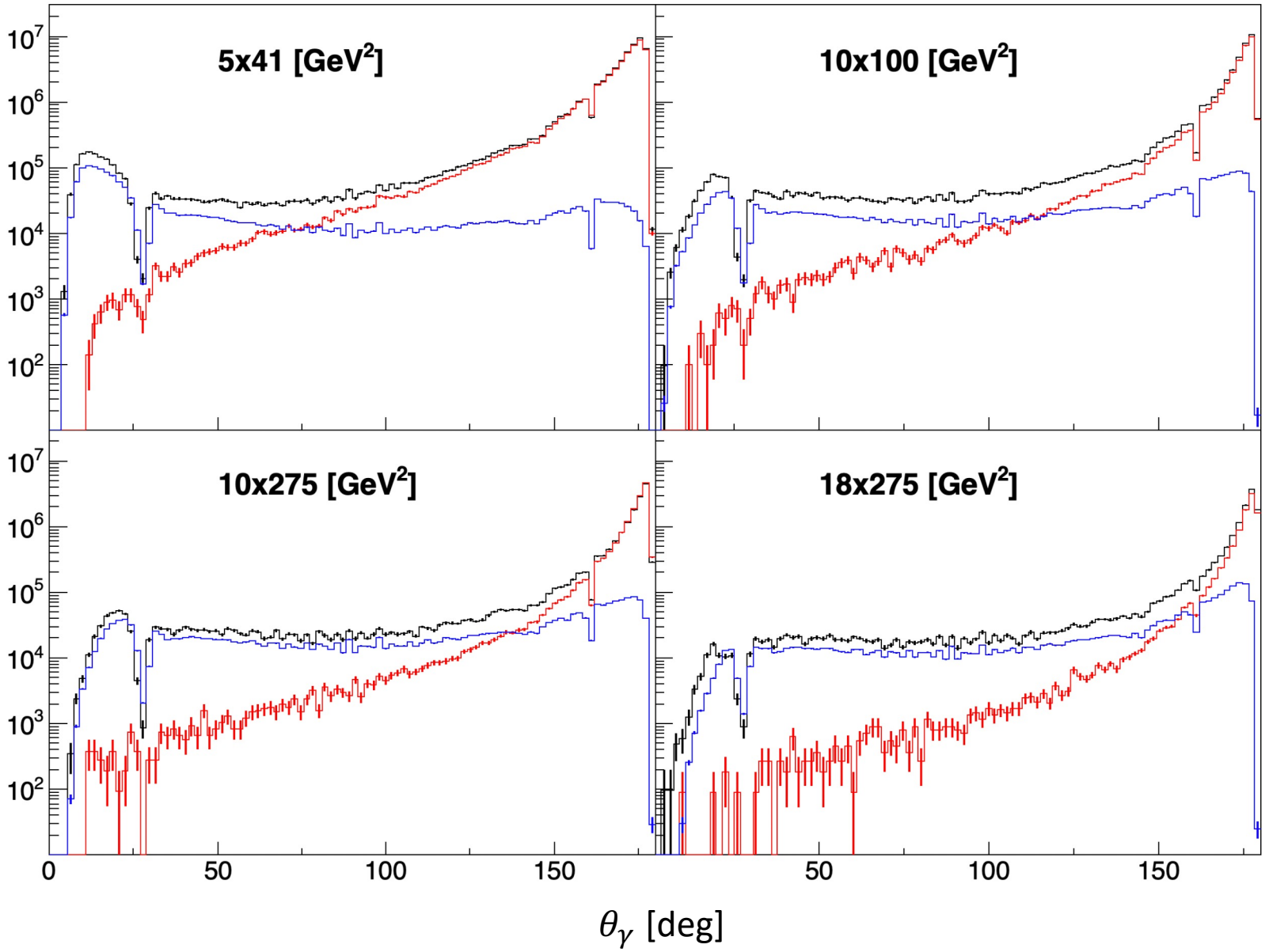


DVCS photons

Red – BH

Blue – pure DVCS

Black - Full



DVCS photons

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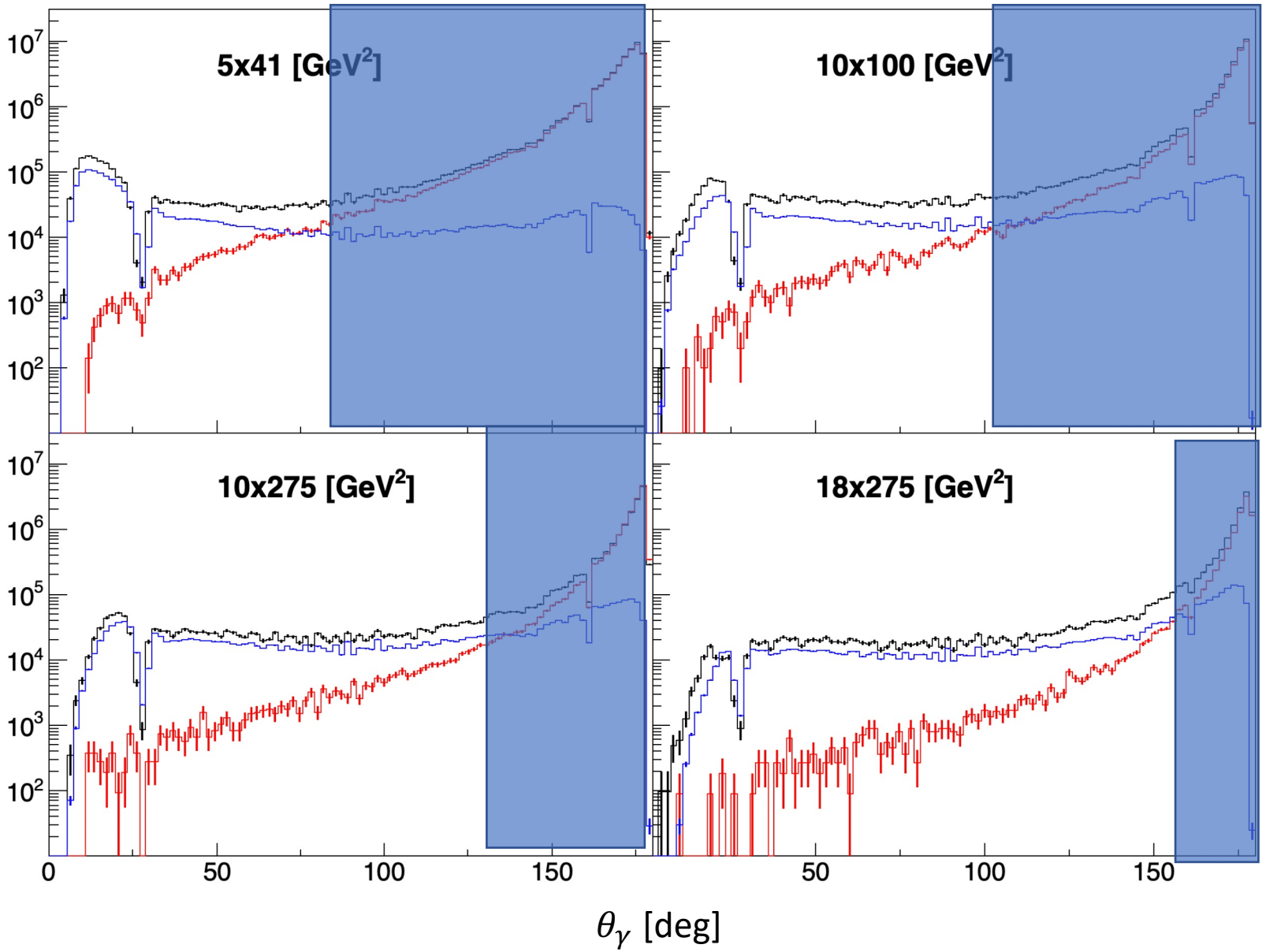
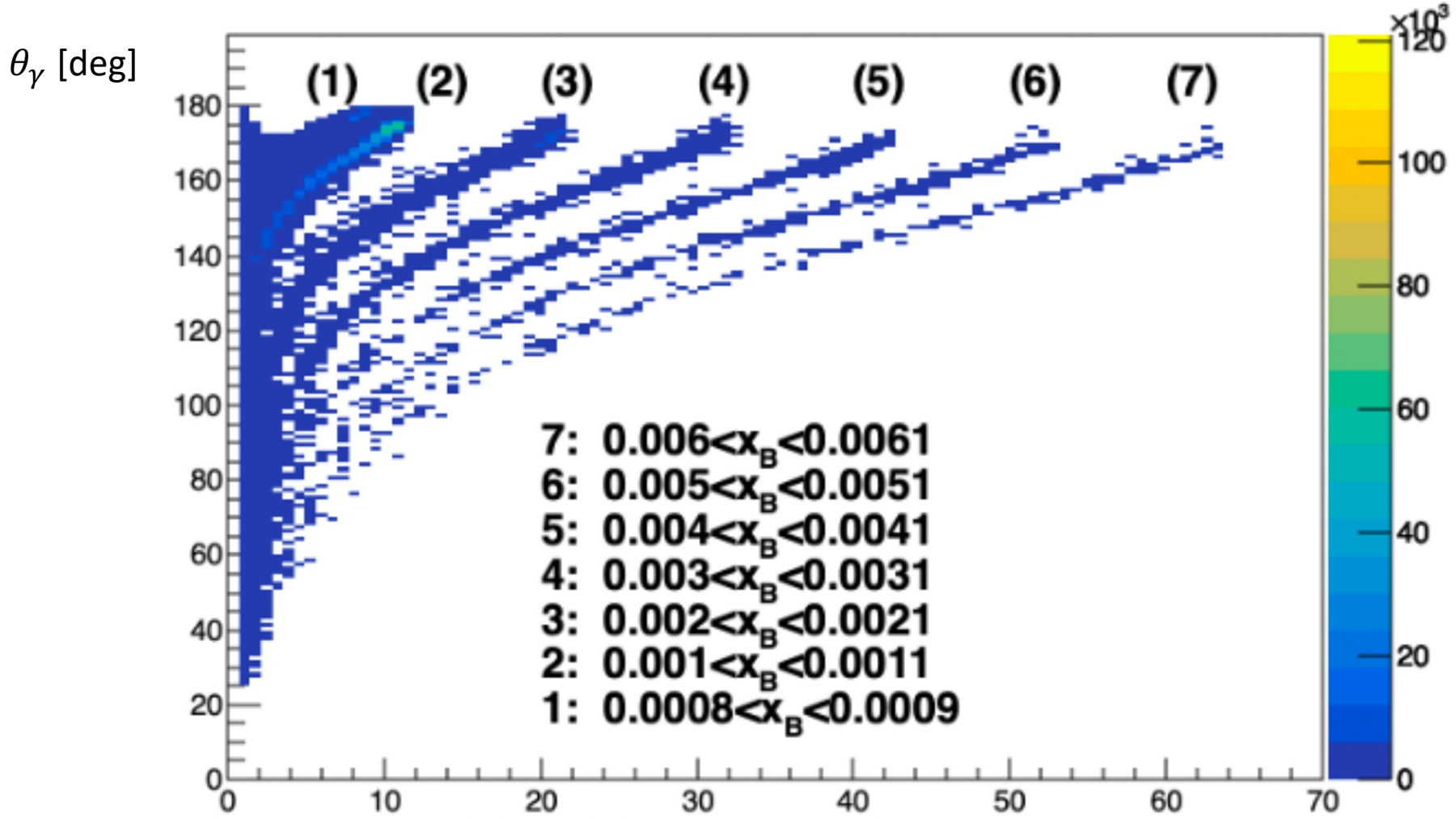


DVCS photons

Beam: 10 x 100 GeV

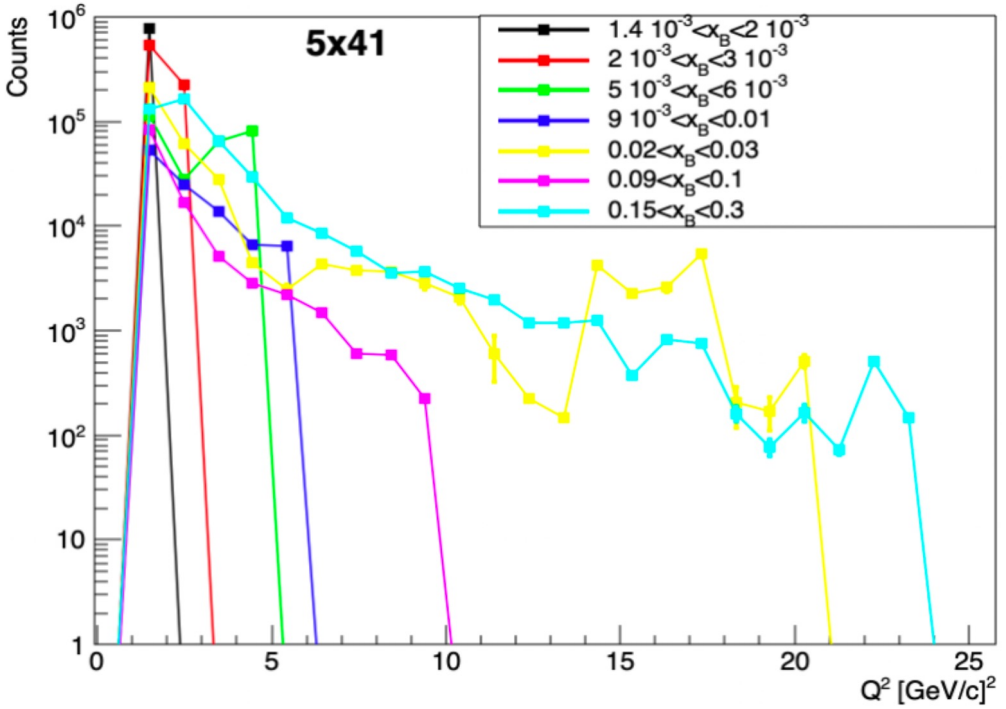


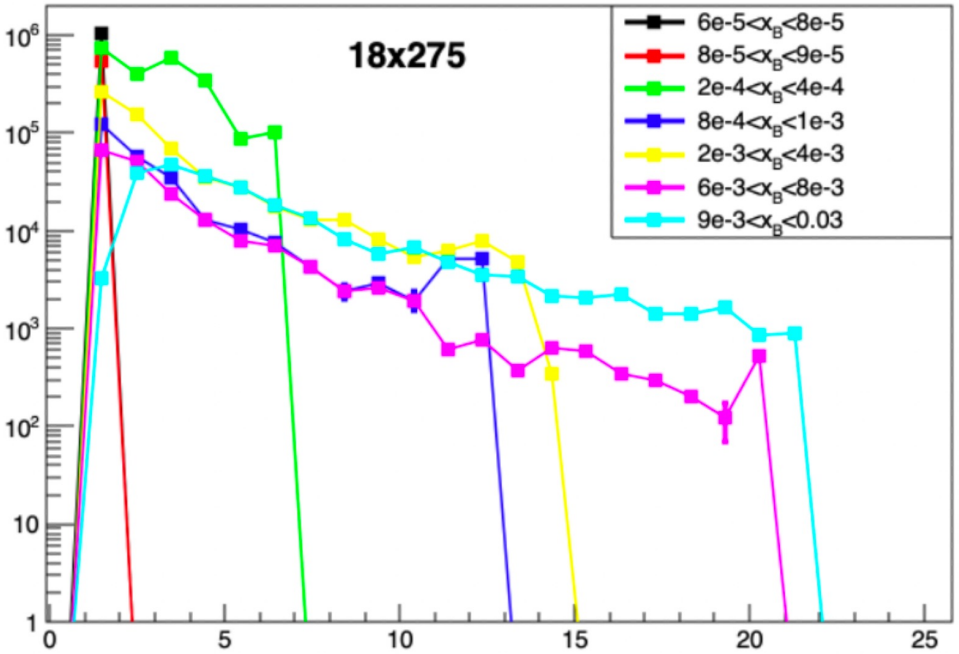
Number of DVCS events

#DVCS = #Total - #BH

Approximal Limit* to measure DVCS:

$Q^2 \sim 20\ (GeV/c)^2$





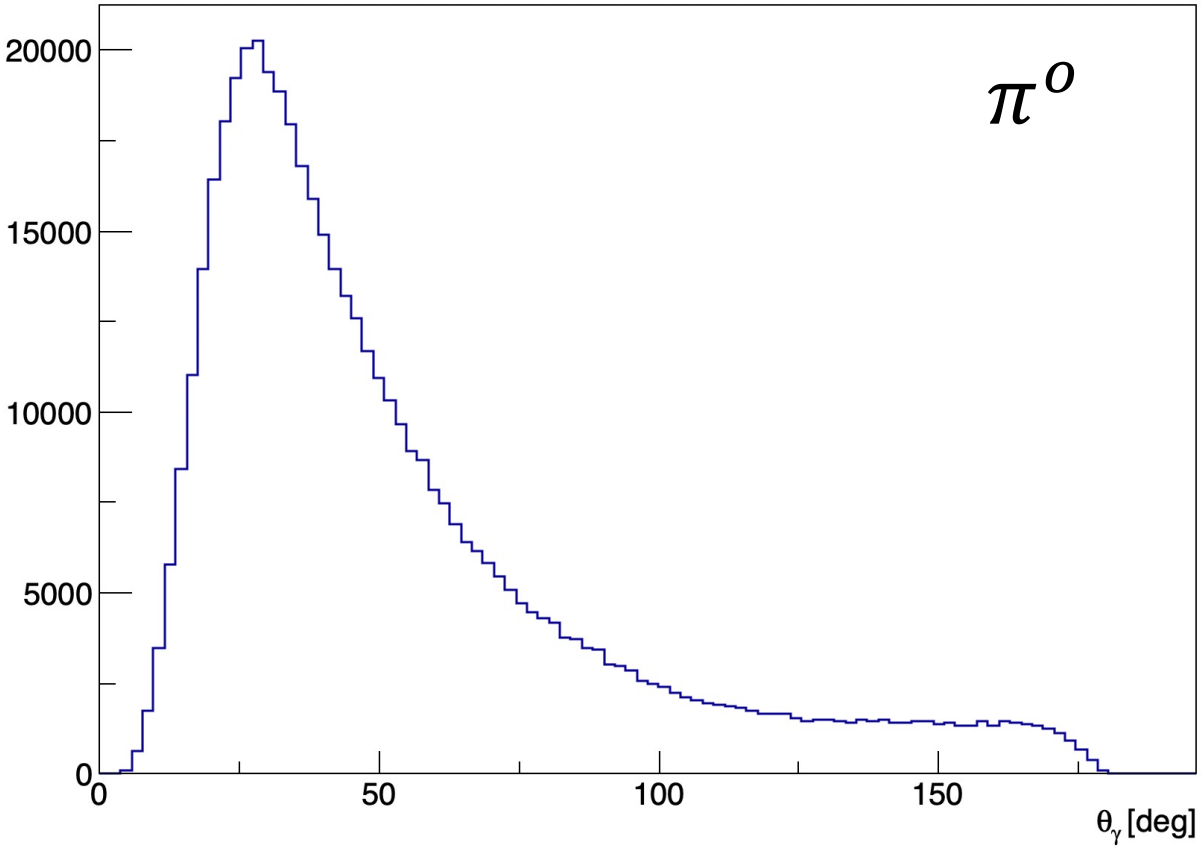
** - absolute cross section and without additional angular dependence study*

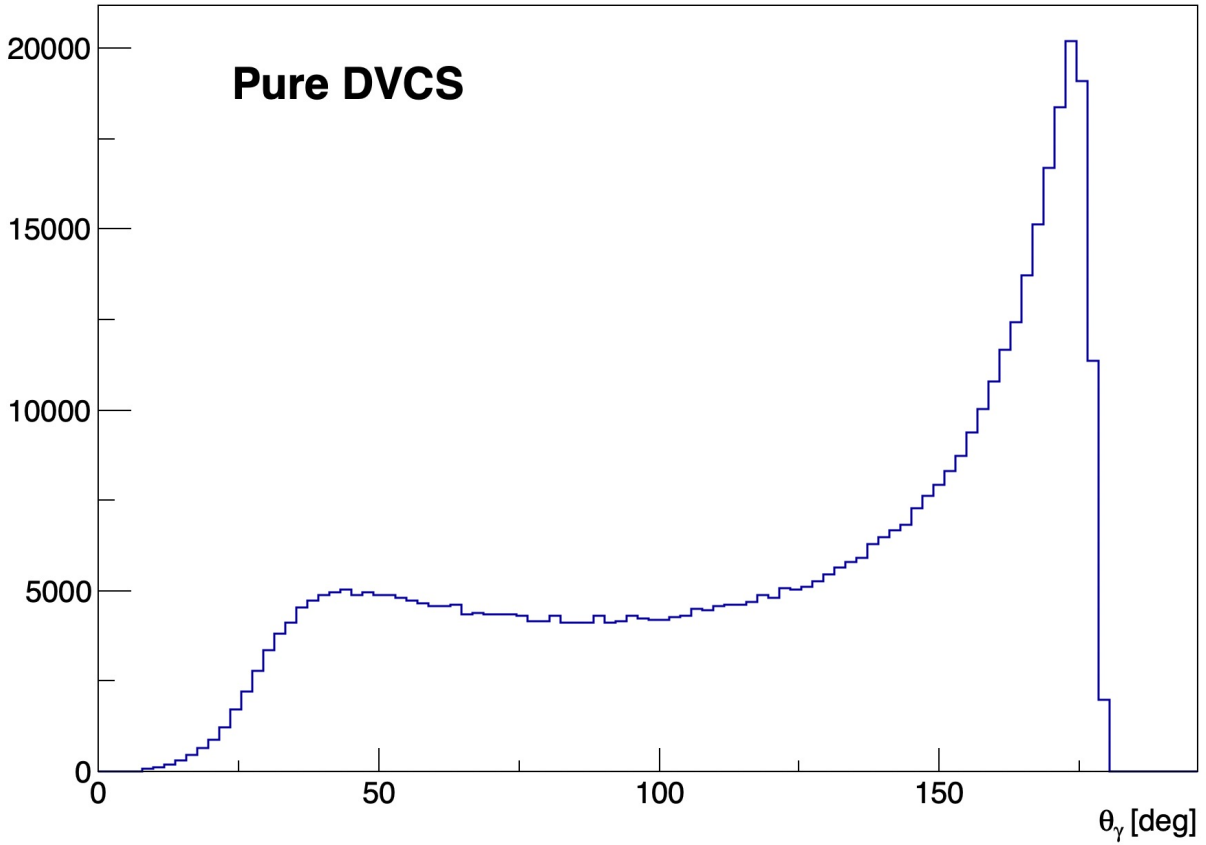
What about Background

Beam setup 18x275 GeV

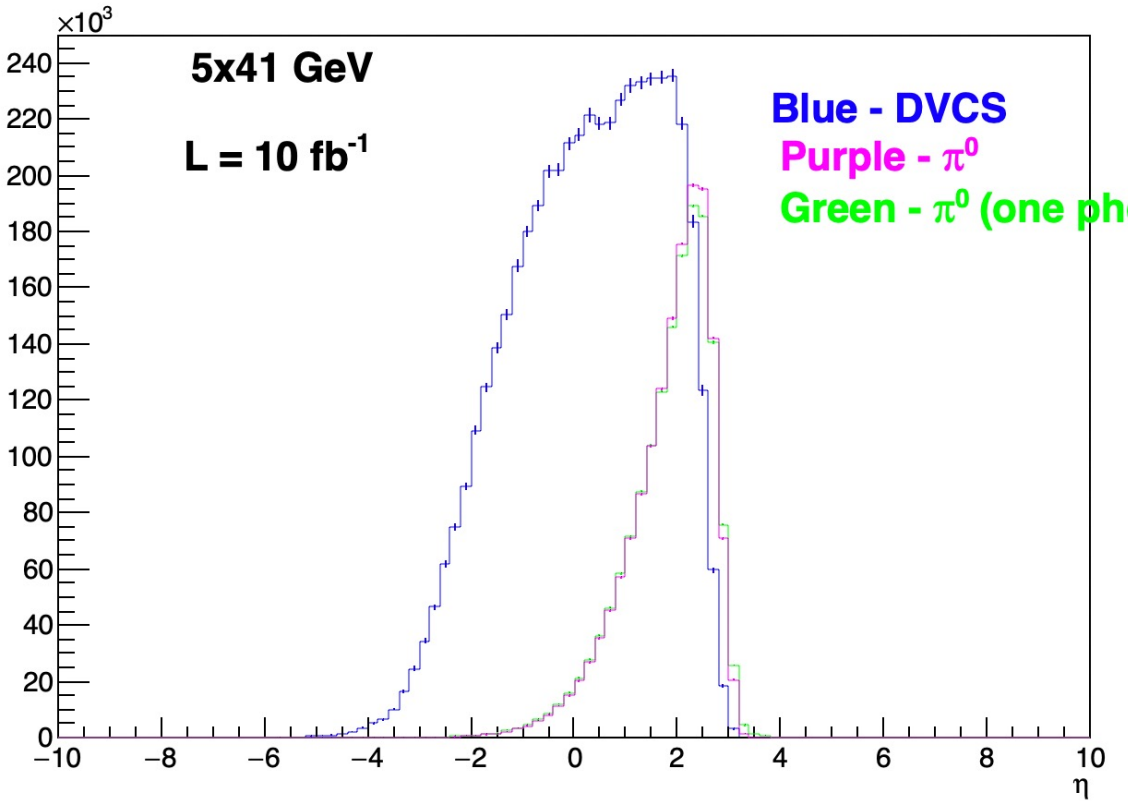
$$ep \rightarrow e'p'\pi^o \rightarrow e'p'\boldsymbol{\gamma\gamma}$$

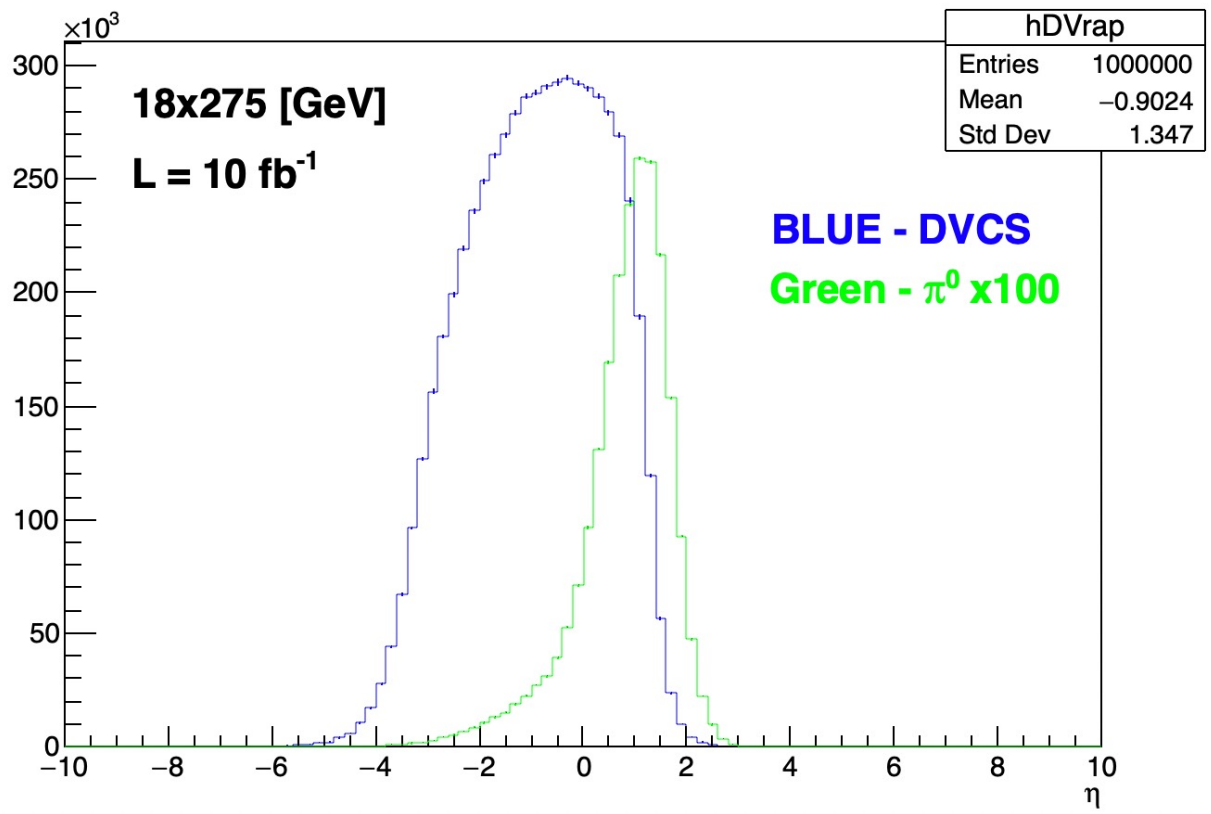
$$ep \rightarrow e'p'\boldsymbol{\gamma}$$





Relative normalization

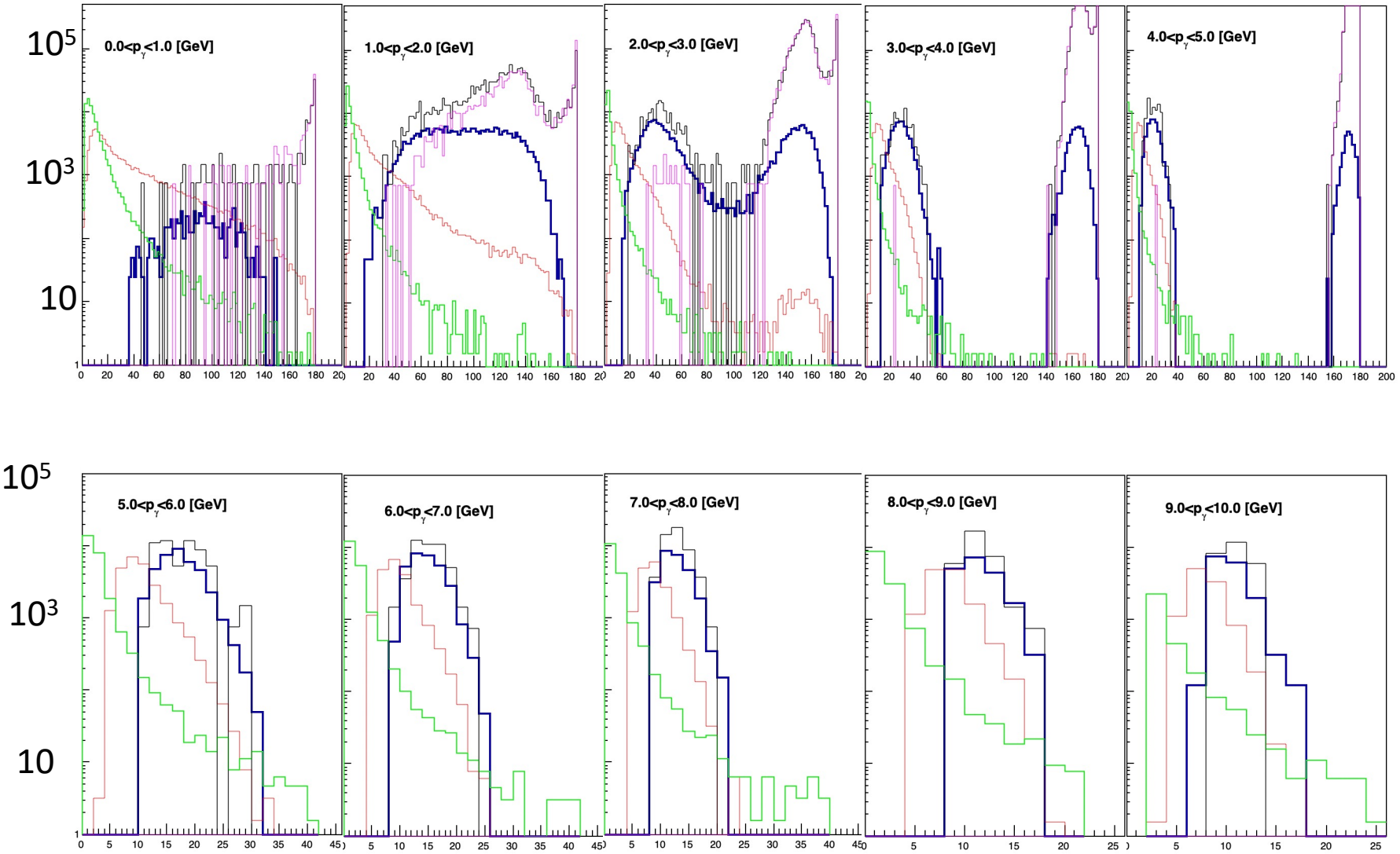




π^0 Background expected is not significant

Photon contamination study

Beam Energy 5x41 GeV Integrated: $\mathcal{L} = 10\ fb^{-1}$



Black – DVCS + BH + Int.

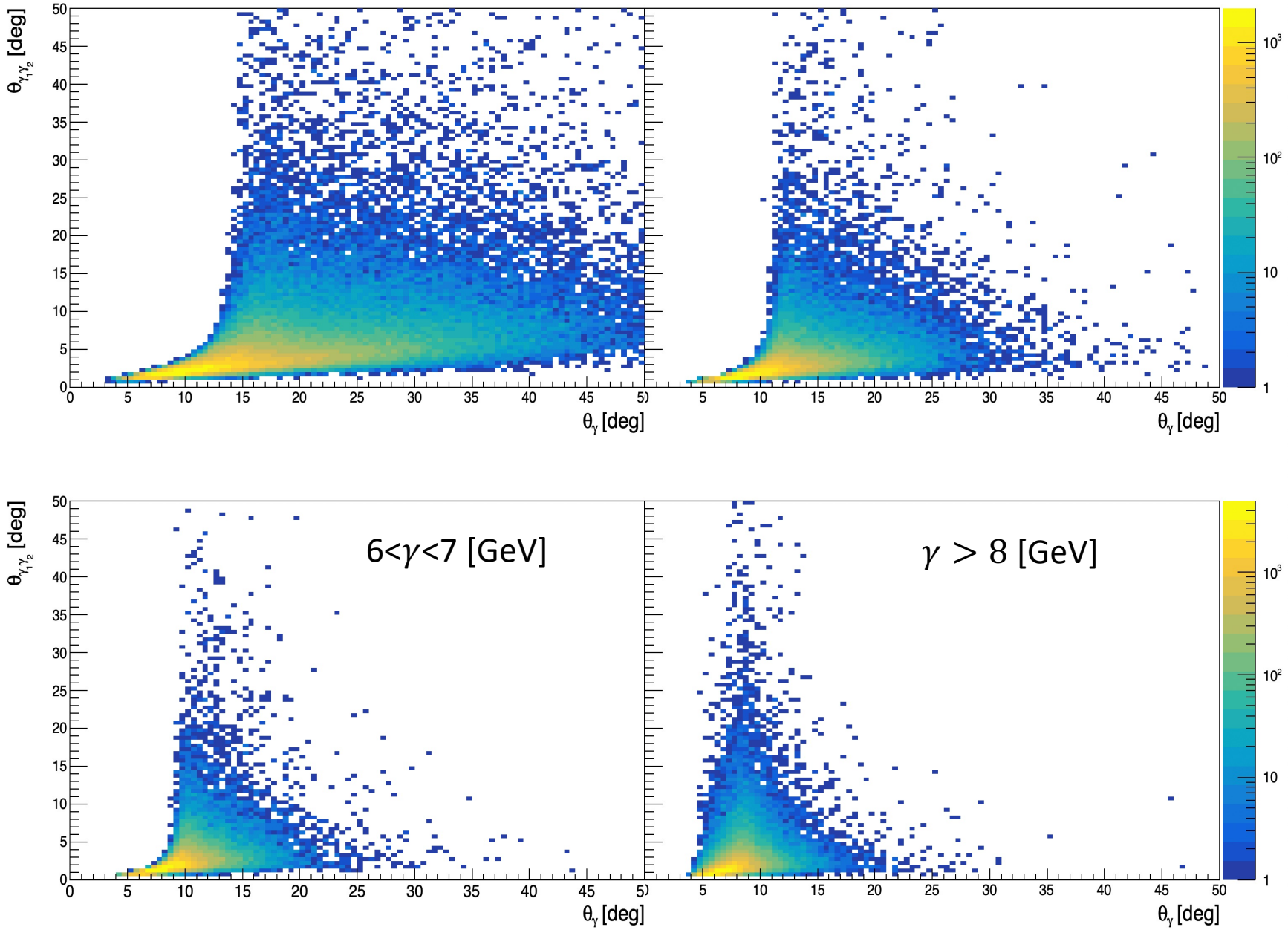
Purple – pure BH

Blue – pure DVCS

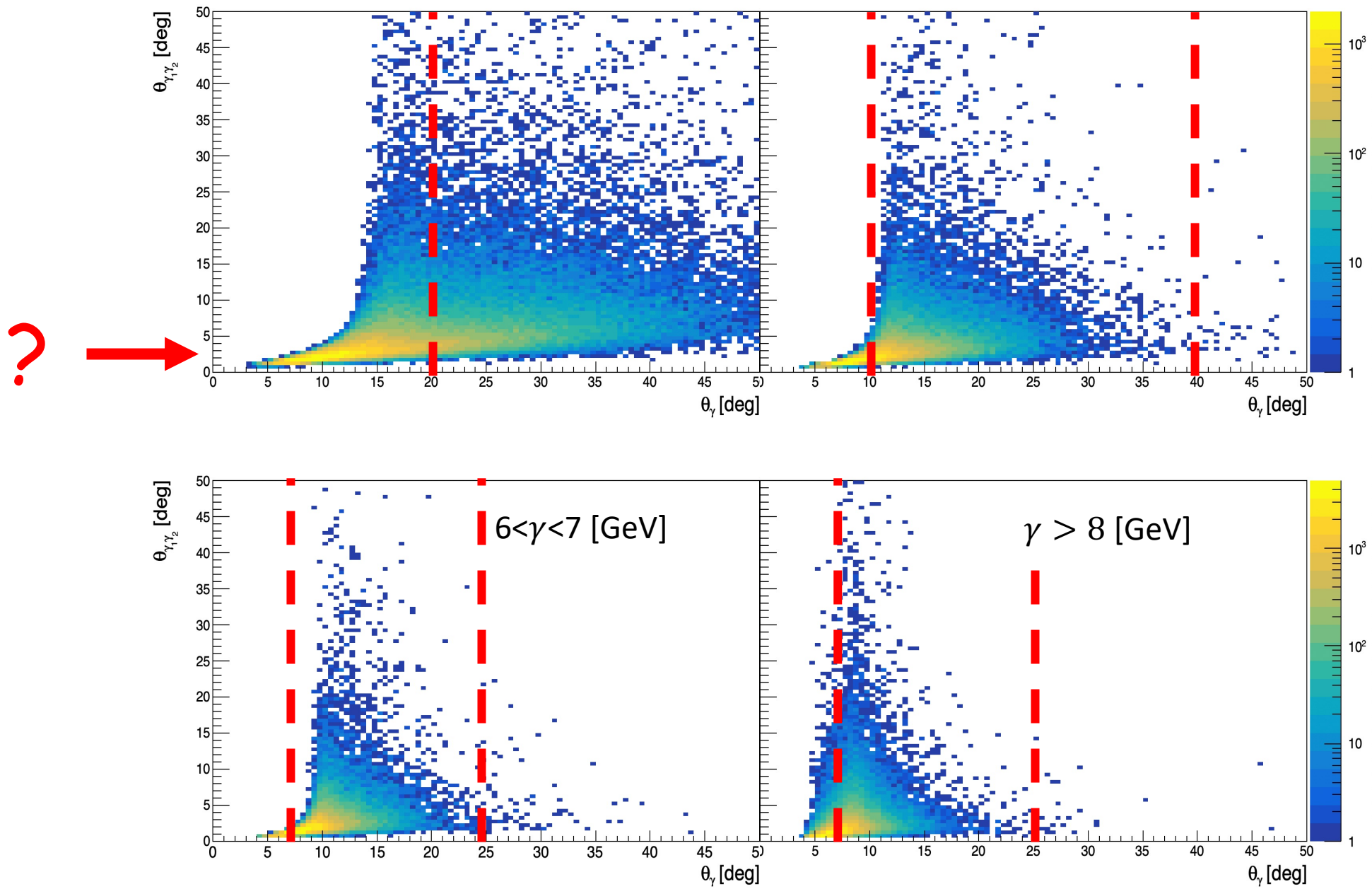
Red – gamma from π^0

Green - $\theta_{\gamma\gamma}$ from π^0

Photon contamination study



Photon contamination study



Summary and outlook

- Deeply virtual exclusive reaction are crucial to study the GPDs.
- EIC will provide a wide phase space for DVCS study.
- High precision data is expected over the wide kinematical range.
- Significant attention must be devoted to far forward region (proton detection).
- High acceptance and efficiency will enable removal of neutral pion background.
- Extension to asymmetries study planed with the use of novel EPIC generator.
- Realistic reconstruction based on the detector development.

Thank you!