Massachusetts Institute of Technology

LNS Laboratory for Nuclear Science

Deeply Virtual Compton Scattering (DVCS) at EIC

EIC User Group Early Career Workshop 2022

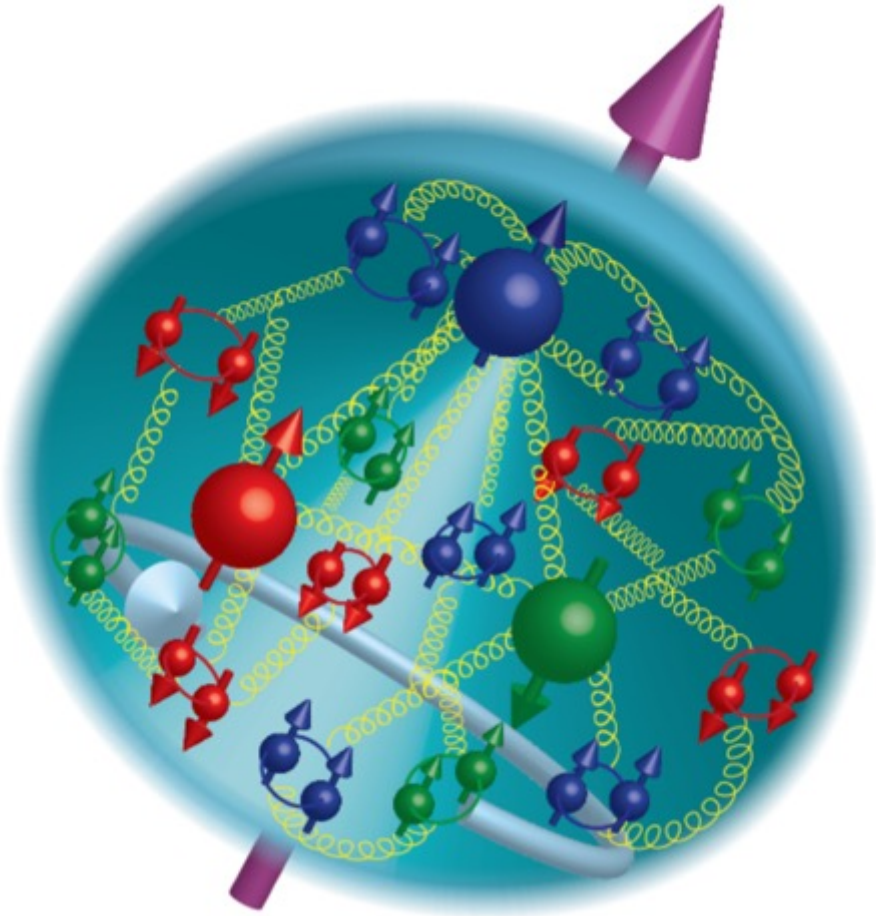
Stony Brook University

Igor Korover

July 24, 2022
Stony Brook

Fundamental Structure of the Nucleon

- Elastic electron scattering determines charge and magnetism of nucleon
- Approx. sphere with <r> ≈ 0.85 Fermi
- The proton contains quarks, as well as dynamically generated quark-antiquark pairs and gluons.
- The proton spin and mass have large contributions from the quark-gluon dynamics.



Nucleon Viewed in High Energy Electron Scattering: 1 Longitudinal Dimension

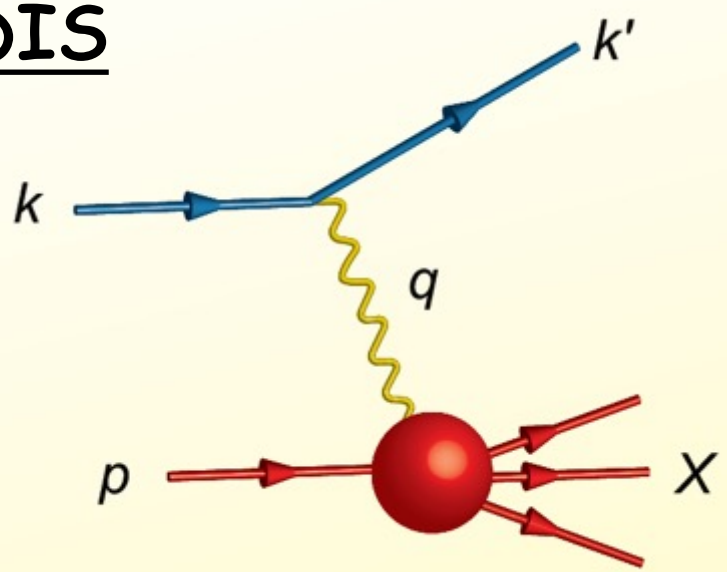
Lorentz Invariants

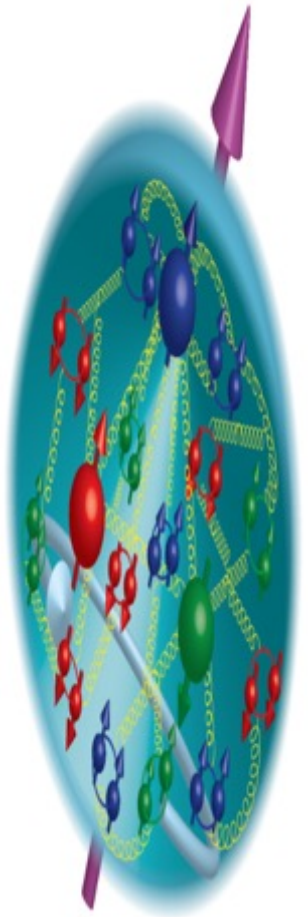
$$E_{cm}^2 = (p + k)^2$$

$$Q^2 = -(k - k')^2$$

$$x = \frac{Q^2}{2p \cdot q}$$

DIS





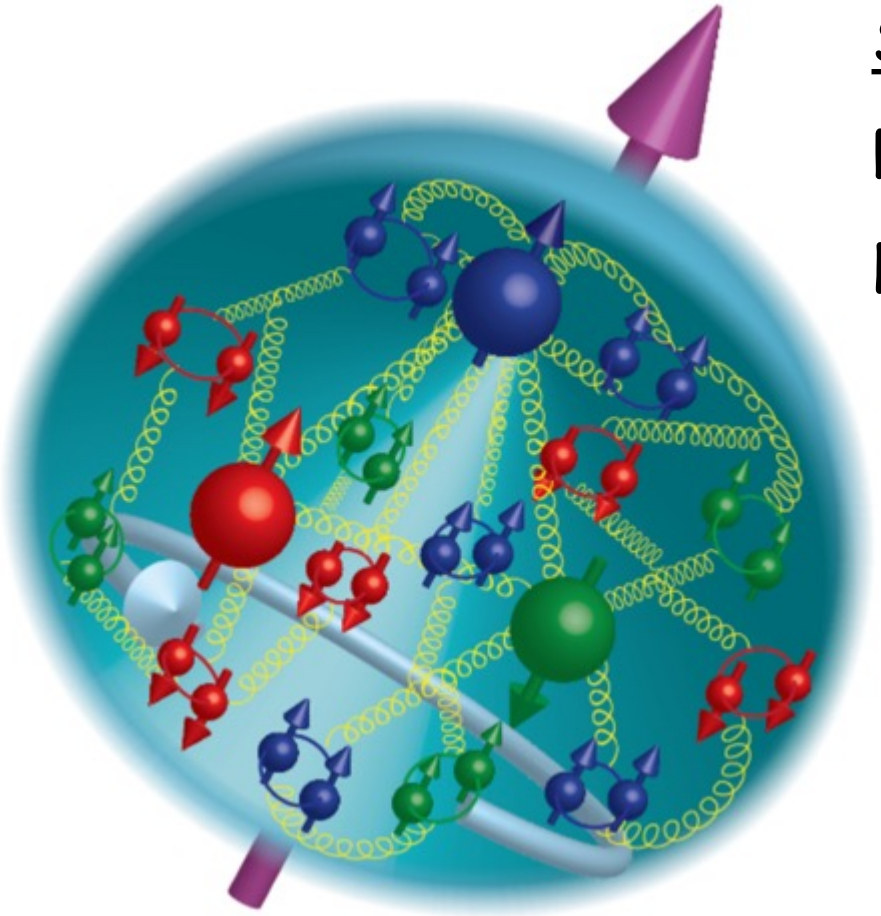
- Viewed from boosted frame, length contracted by

$$\gamma_{Breit} = \sqrt{1 + \frac{Q^2}{4M^2}}$$

- Internal motion of the proton's constituents is slowed down by time dilation – the instantaneous charge distribution of the proton is seen.
- In boosted frame *x* is understood as the longitudinal momentum fraction
  valence quarks: 0.1 < x < 1
  sea quarks: x < 0.1

J. Bjorken, SLAC-PUB-0571
March 1969

Nucleon Tomography:
2 New Dimensions Transverse to Longitudinal Momentum



Structure mapped in terms of

b_T = transverse position

k_T = transverse momentum

Goal:
Unprecedented
21st Century Imaging
of Hadronic Matter

*Direction of longitudinal momentum normal to plane of slide

Valence Quarks: JLab 12 GeV
Sea Quarks and Gluons: EIC

3D Partonic Picture

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

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

Transverse Momentum Dependent distributions

d^3r

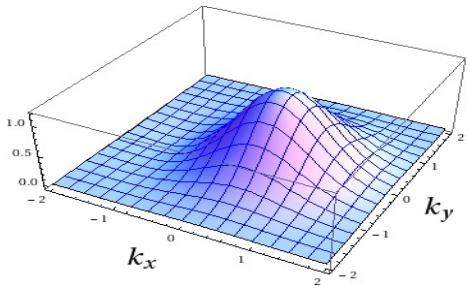
d^3p

Generalized Parton Distributions

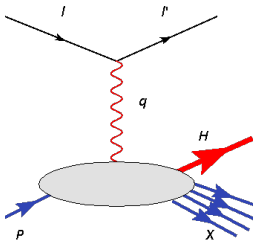
Orbital motion accessible!

$f(x, \mathbf{k}_\perp)$

$H(x, \xi, t)$



SIDIS



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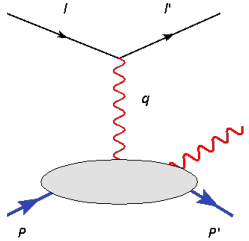
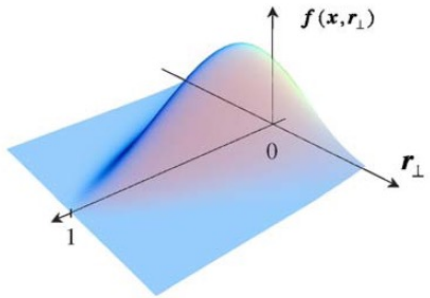
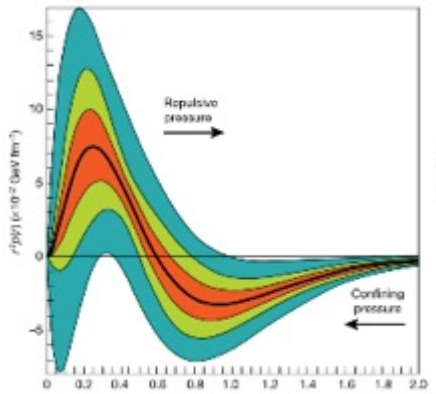


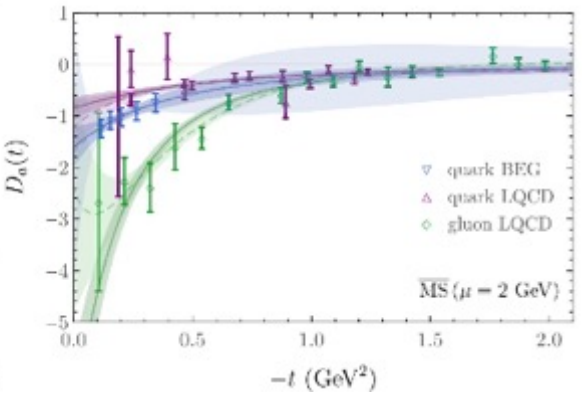


Why GPDs are interesting?

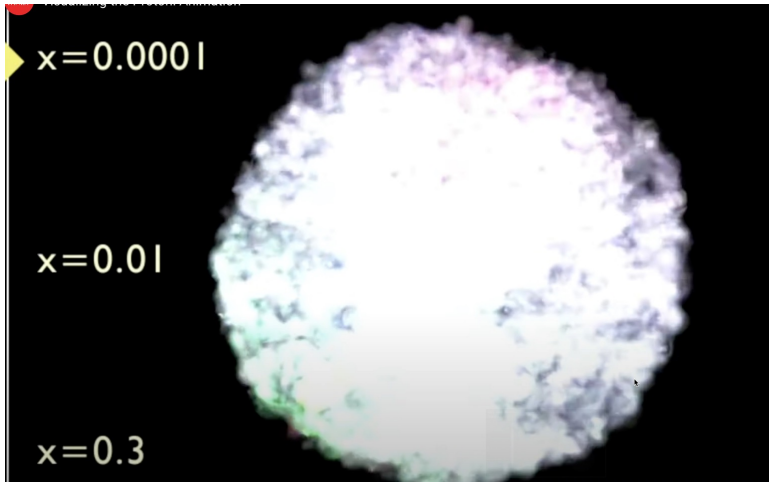
- Imaging of the nucleon
- Spin decomposition of the nucleon
- Mass origin of the nucleon
- Dynamic properties of the nucleon

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



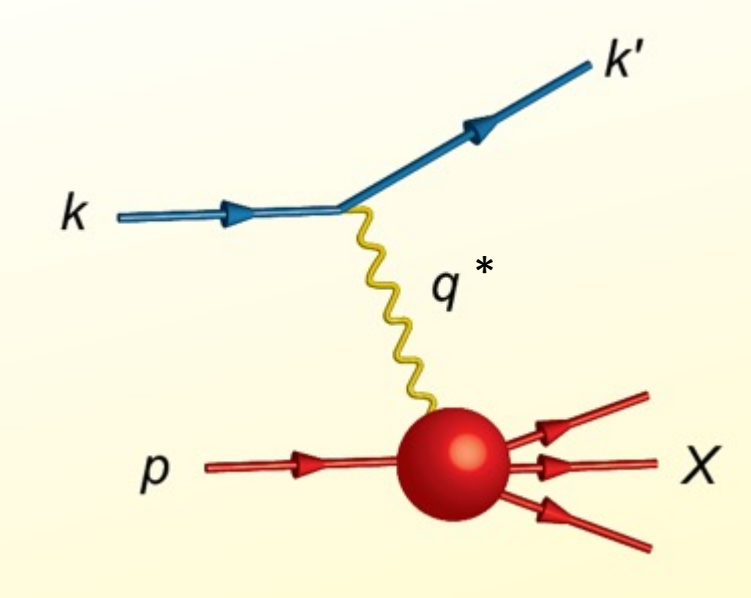


V. D. Burkert, L. Elouadrhiri and F. X. Girod, (2018)
P. E. Shanahan and W. Detmold (2019)



DIS

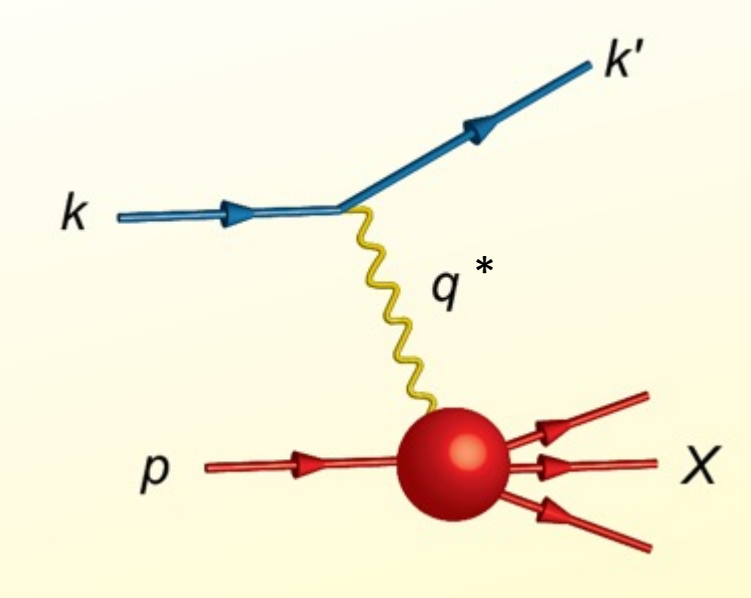
$$ep \rightarrow e'X$$



Proton is destroyed

DIS

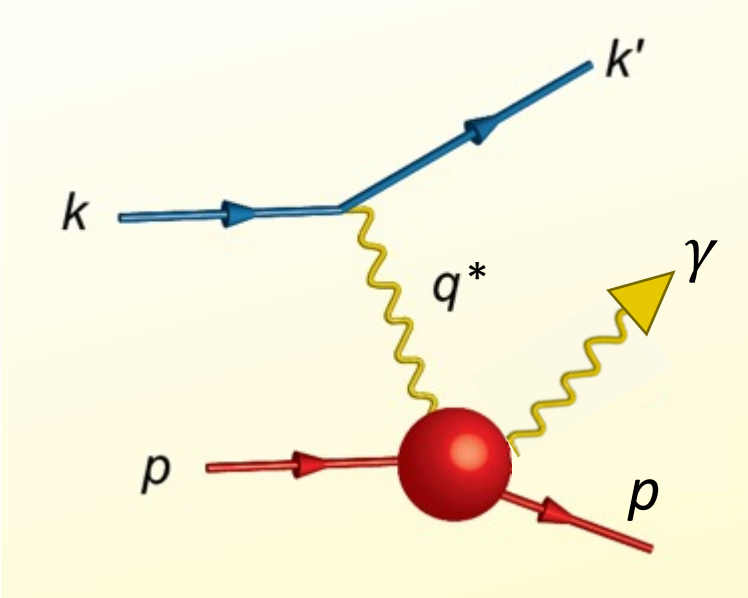
$ep \rightarrow e'X$



Proton is destroyed

DES

$ep \rightarrow e'p'\gamma$



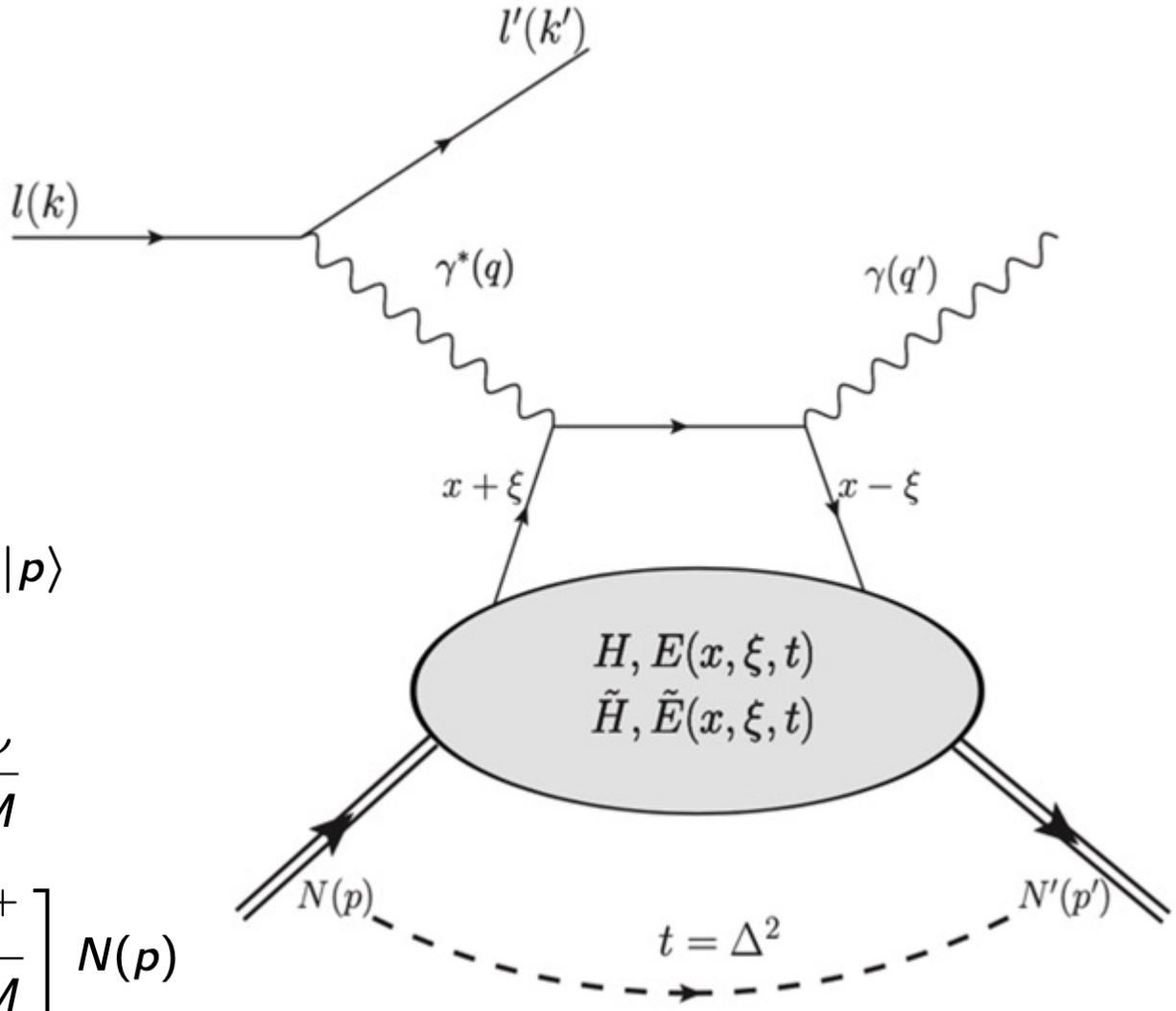
Keeping proton intact

"excitation of the proton constituents"

Additional particle: photon, (meson…)

Deeply Virtual Compton Scattering

$$(ep \to e'p'\gamma)$$



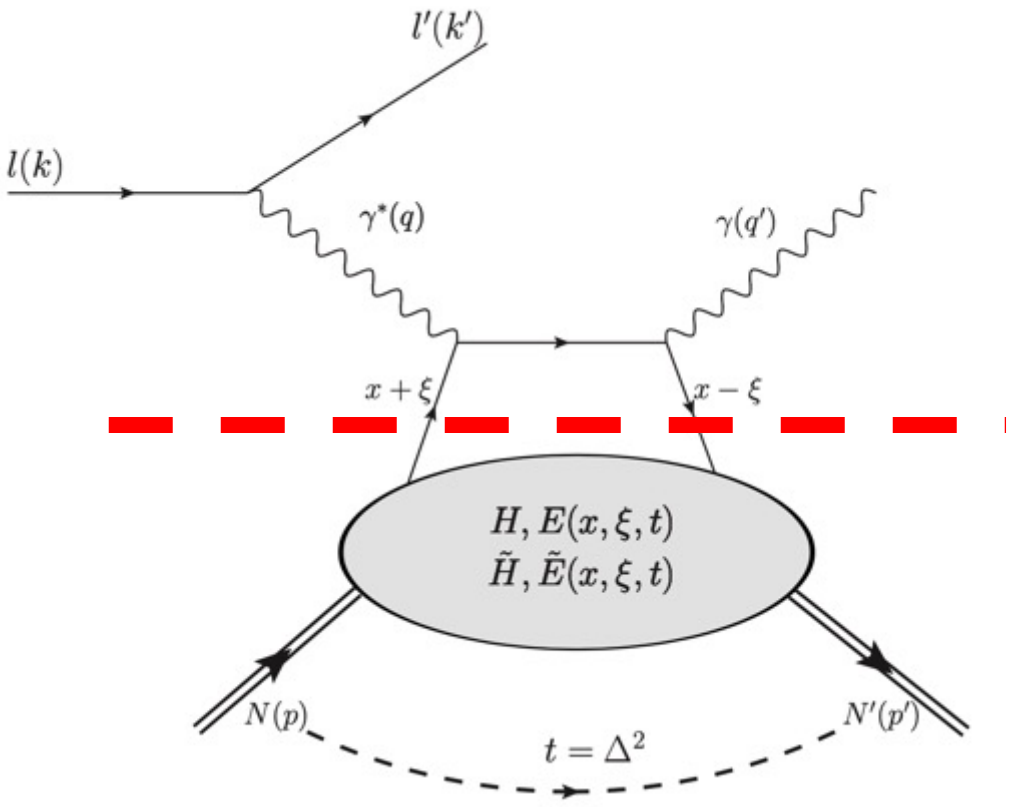
Three particles in Final State

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

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

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

DVCS process



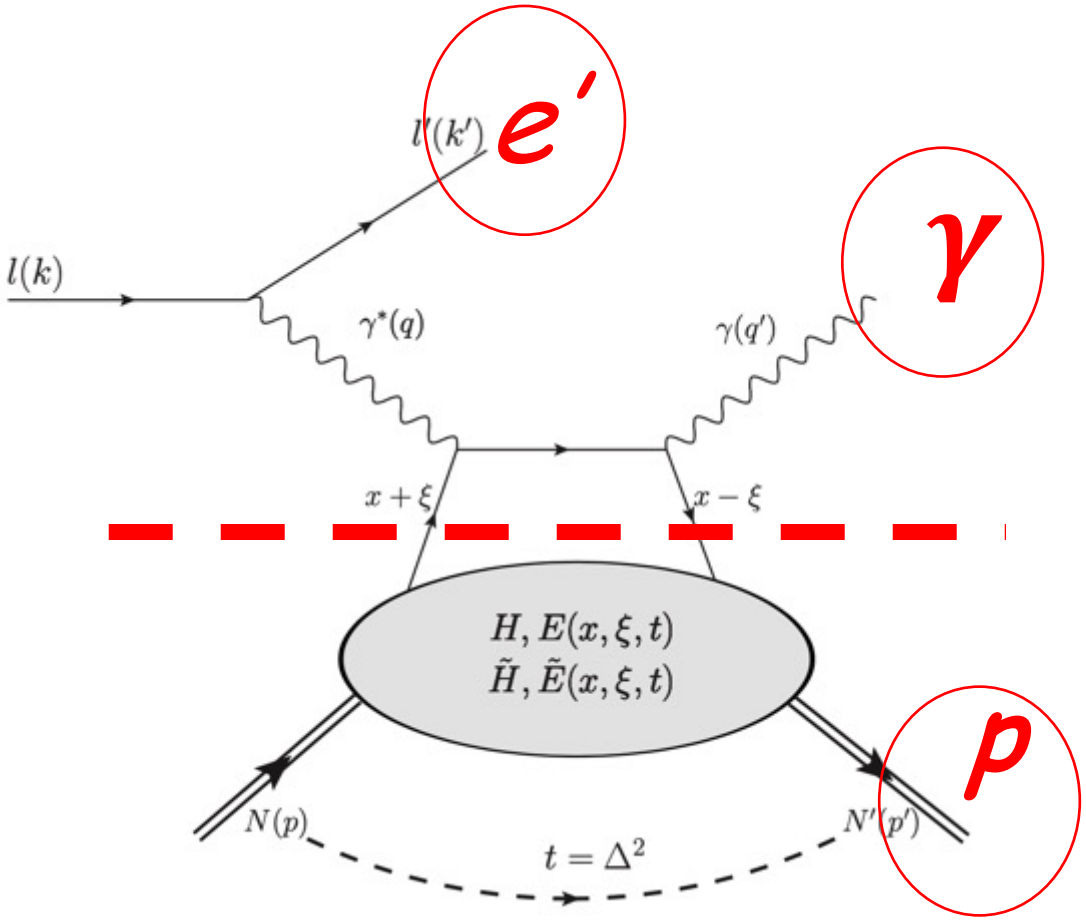
$$\sigma \propto H \times S$$

Hard

Soft

- Proof of factorization for the DVCS
  - at Bjorken limit
    - X. Ji and J. Osborne (1998)
    - J. C. Collins and A. Freund (1999)
  - proof simplified w/ EFT technique
    - CB, SF, DP, IR, I. Stewart (2002)
  - experimental tests
    - HERA, Jefferson Lab, Compass, …

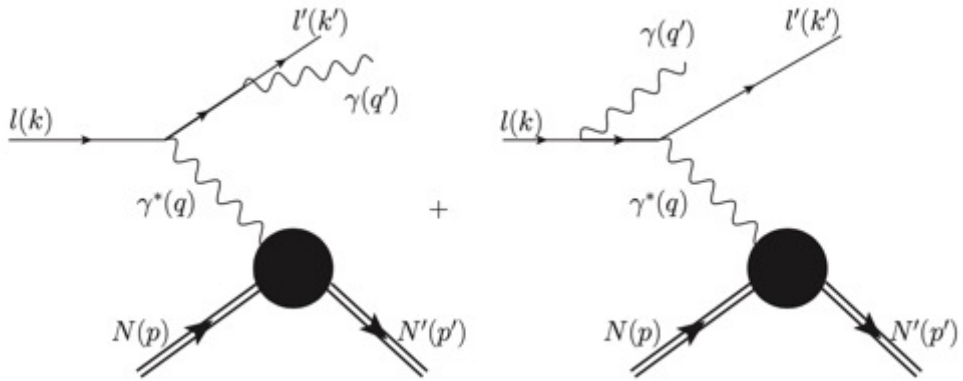
DVCS process



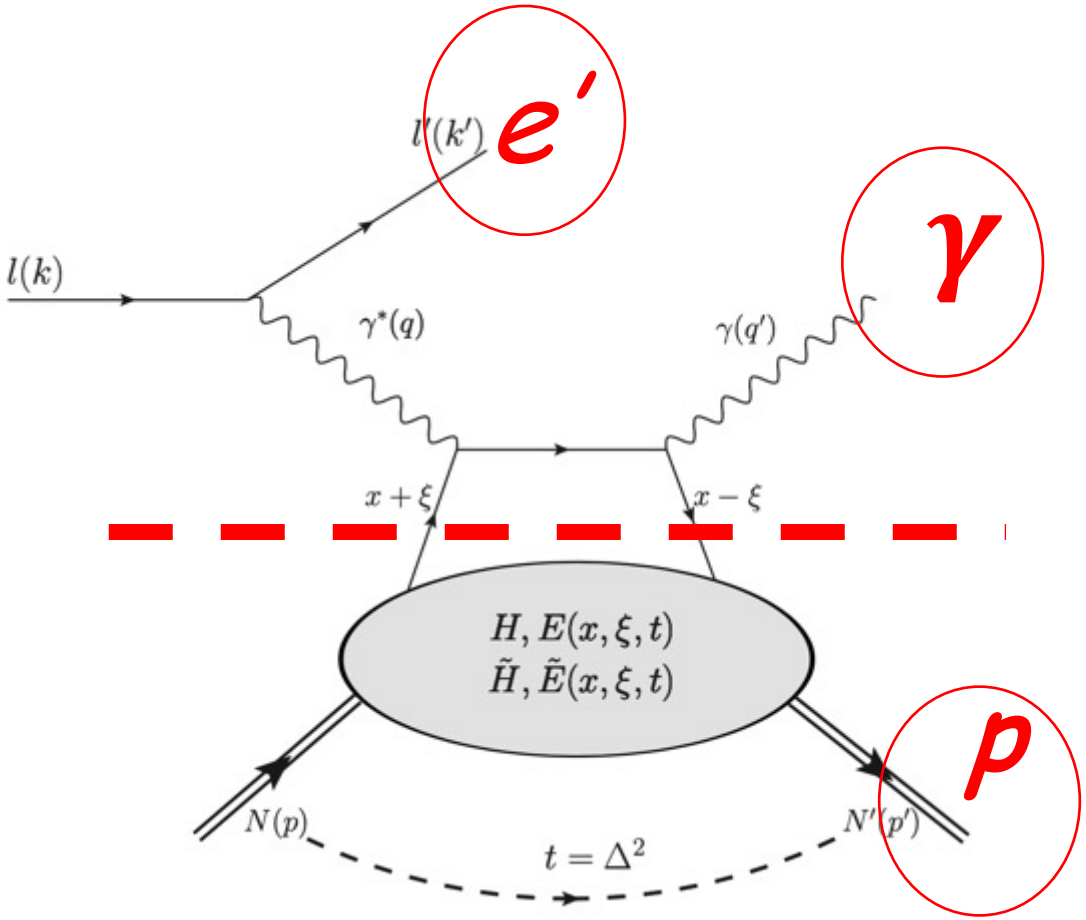
Pure QED

Bethe-Heitler

<u>Irreducible Background</u>



DVCS process

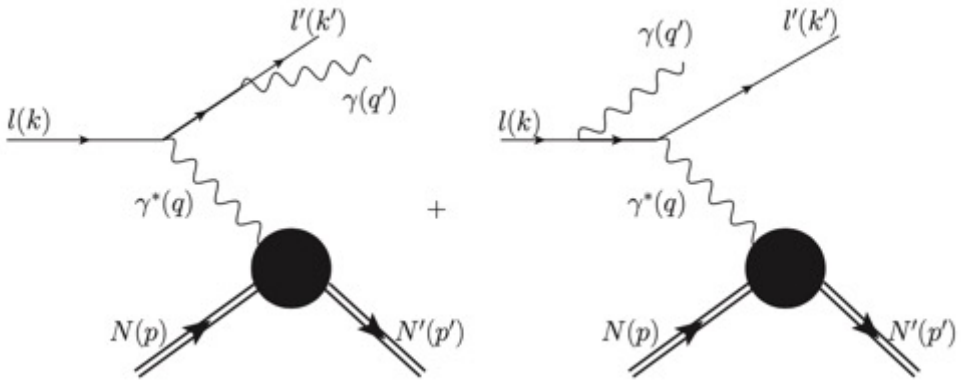


$$\frac{d\sigma}{dx_B dQ^2 d|t| d\phi} = \Gamma \times |\mathcal{T}_{\rm BH} + \mathcal{T}_{\rm DVCS}|^2$$
$$= \Gamma \times (|\mathcal{T}_{BH}|^2 + |\mathcal{T}_{DVCS}|^2 + \mathcal{I})$$
$$\mathcal{T}_{\rm BH} \propto {\rm FF}, \quad \mathcal{T}_{\rm DVCS} \propto {\rm CFF}$$

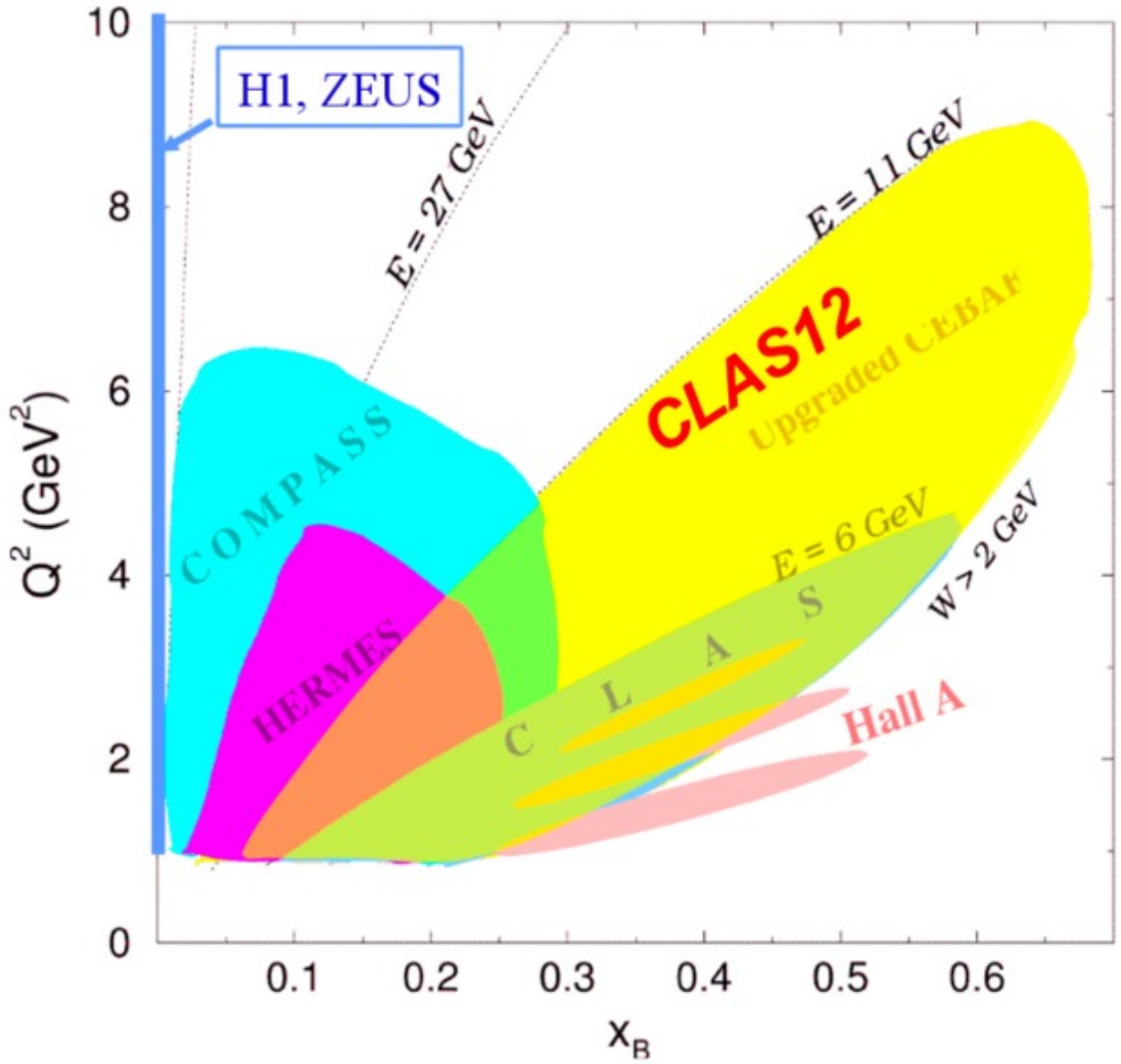
Pure QED

Bethe-Heitler

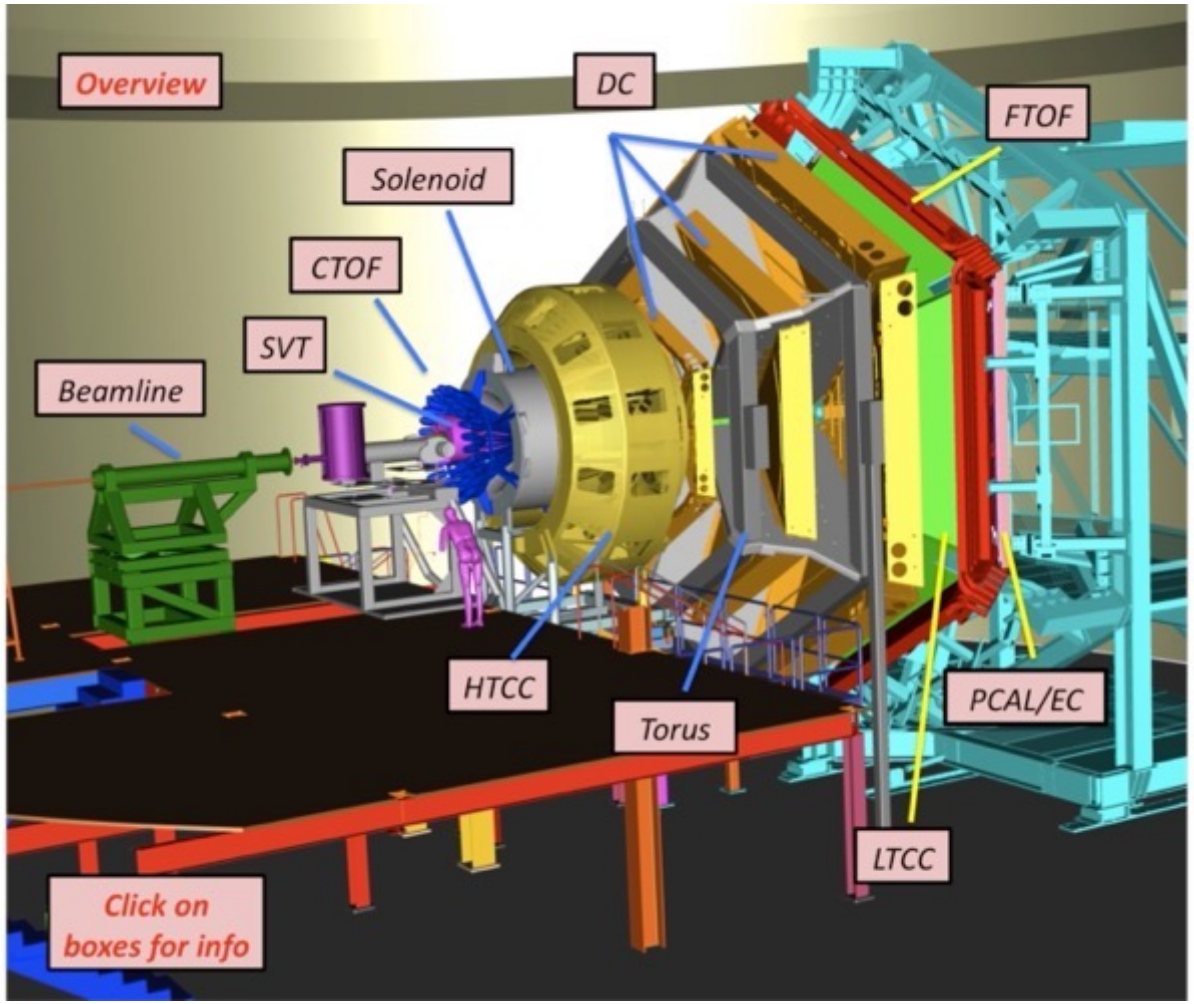
Irreducible Background

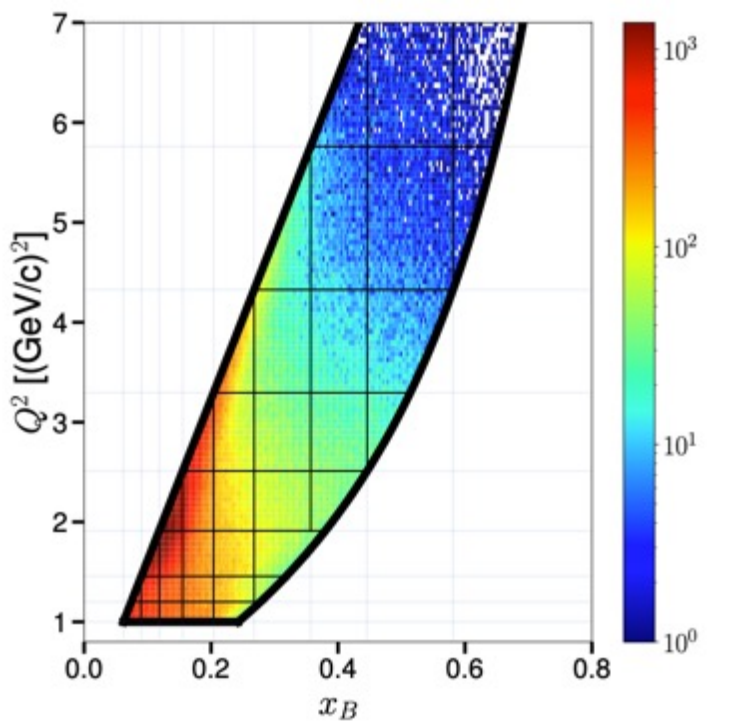


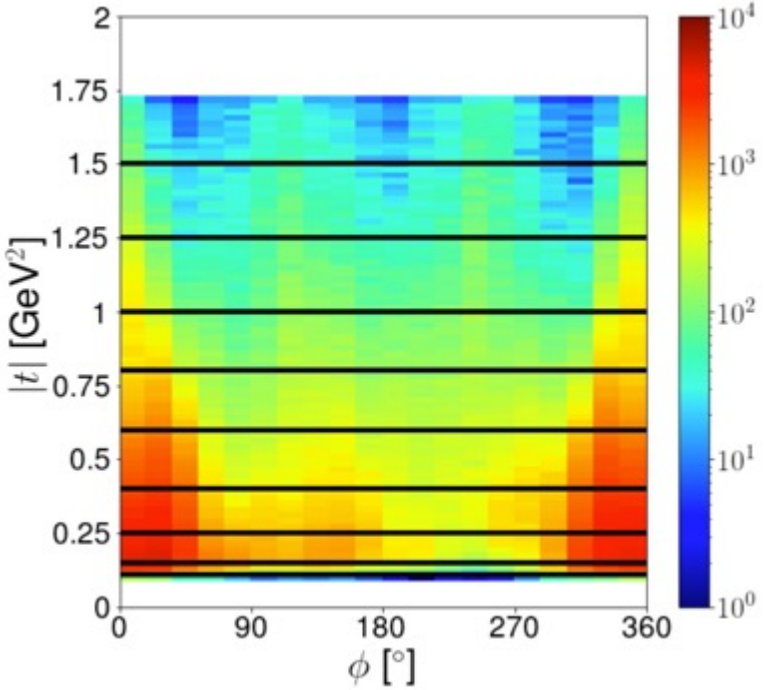
DVCS landscape

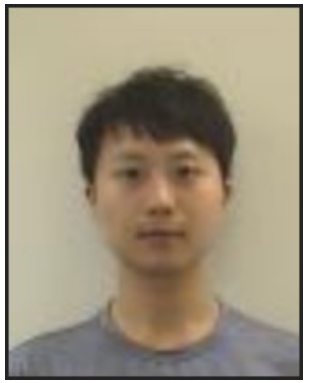


Jefferson Lab - CLAS12



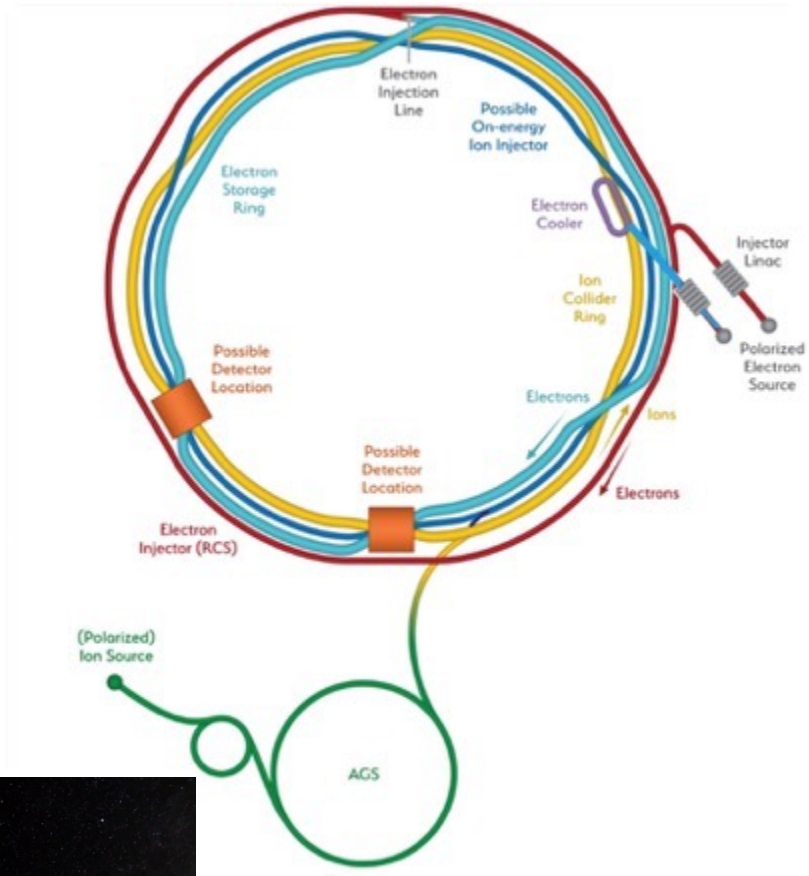


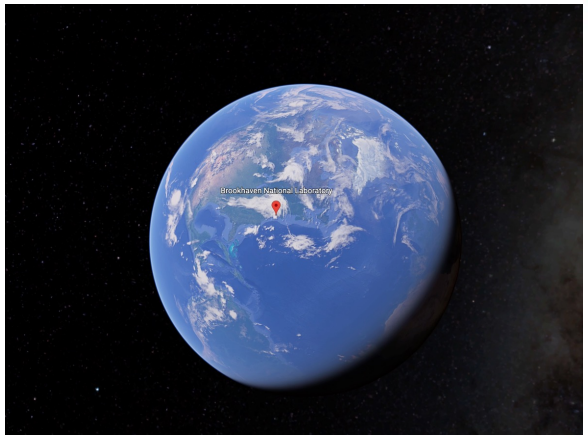




Sangbaek Lee

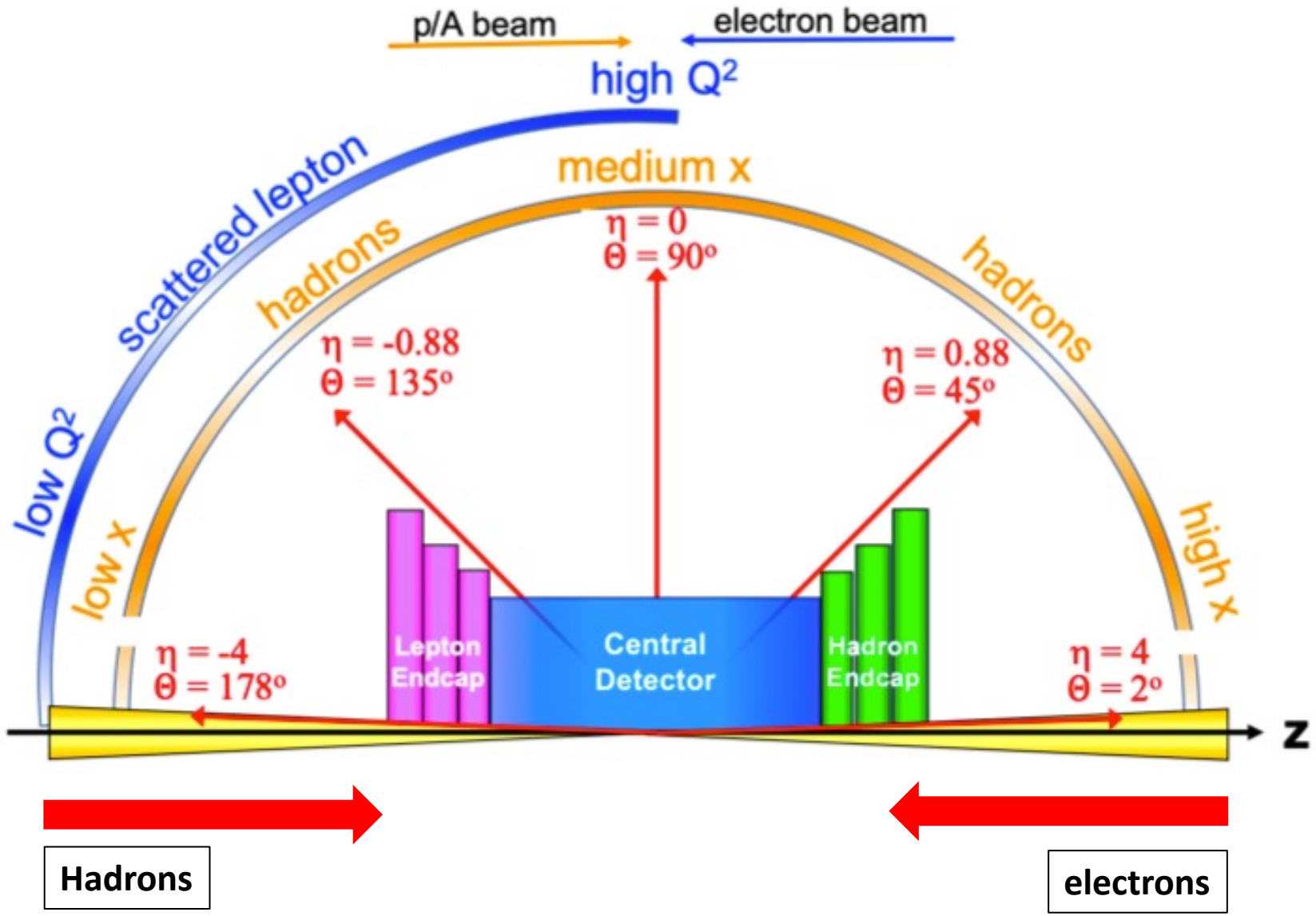
Electron-Ion Collider





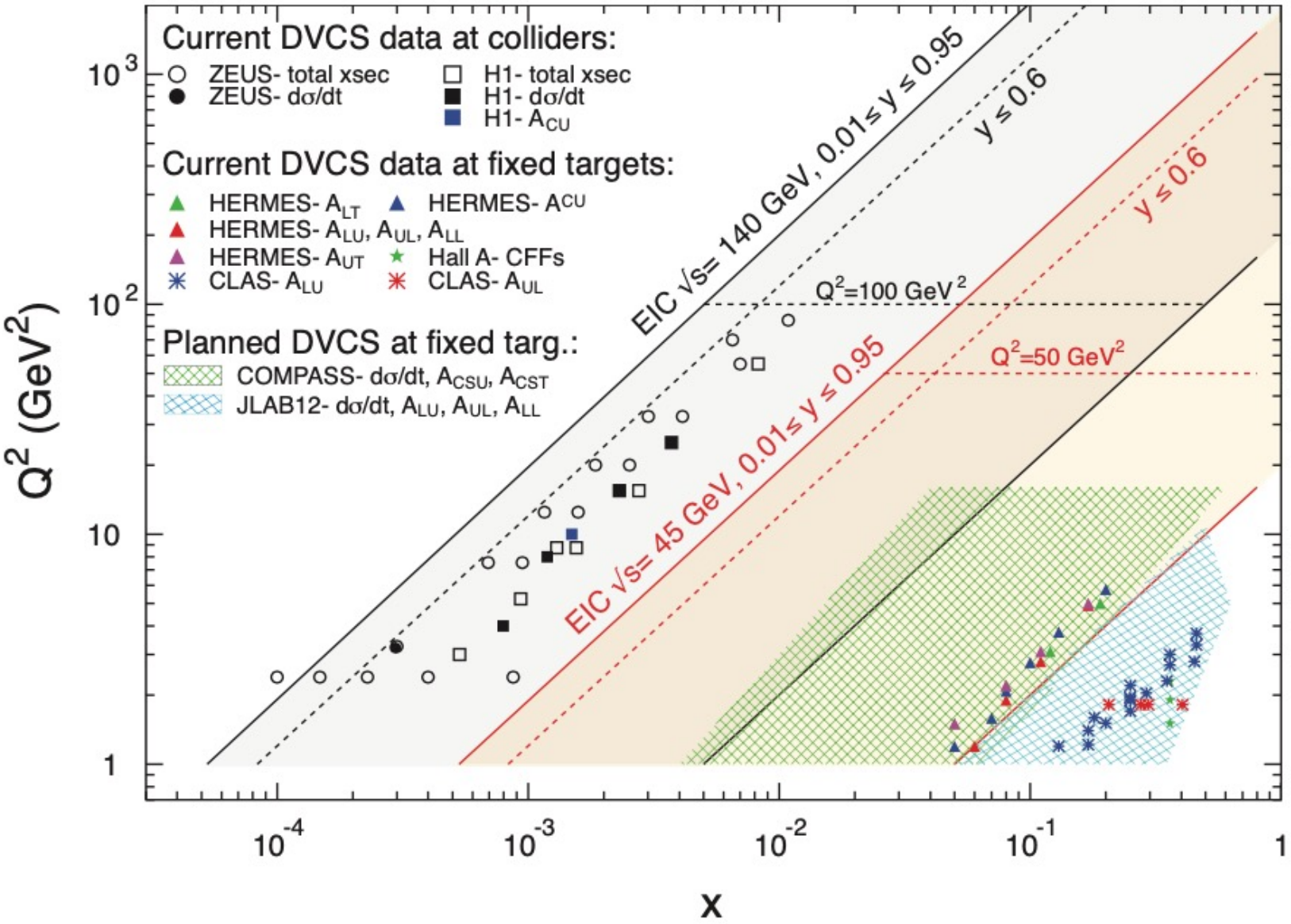
- 275 GeV/nucleon max. on 18 GeV e-beam
- High luminosity: 10^{34} e-nucleon $cm^{-2}s^{-1}$
- 70% polarized electron, nucleon beams
- Full range of ions: p to U
- Two collider detectors
- Project officially launched by US DOE in January 2020
- Present schedule: accelerator turn-on 2031
- Project cost: $ 2 billion approx.

Kinematic coverage



Kinematical coverage of EIC

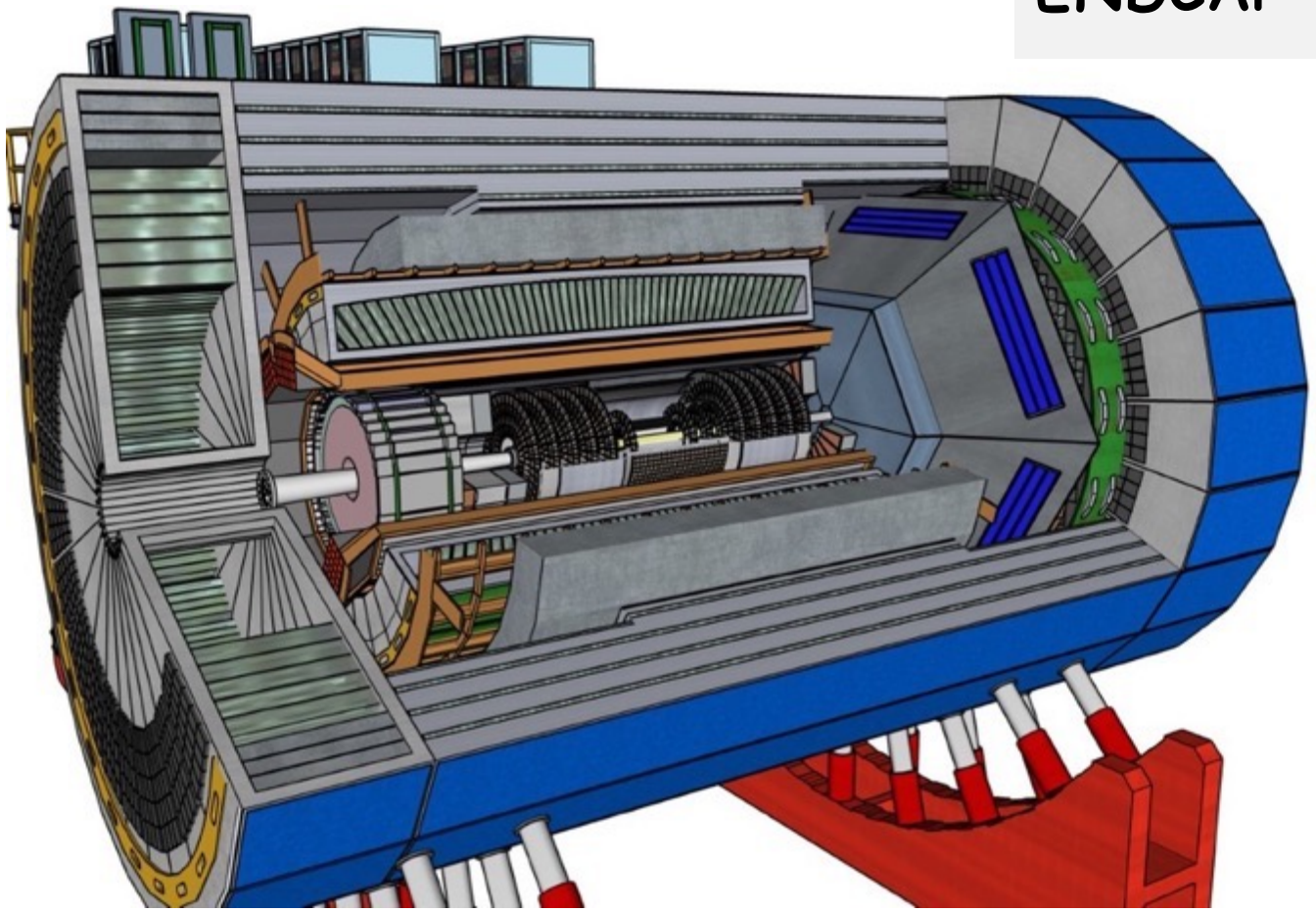
arXiv:1304.0077v2



Main detector

HADRON ENDCAP

ELECTRON ENDCAP



CENTRAL BARREL

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)

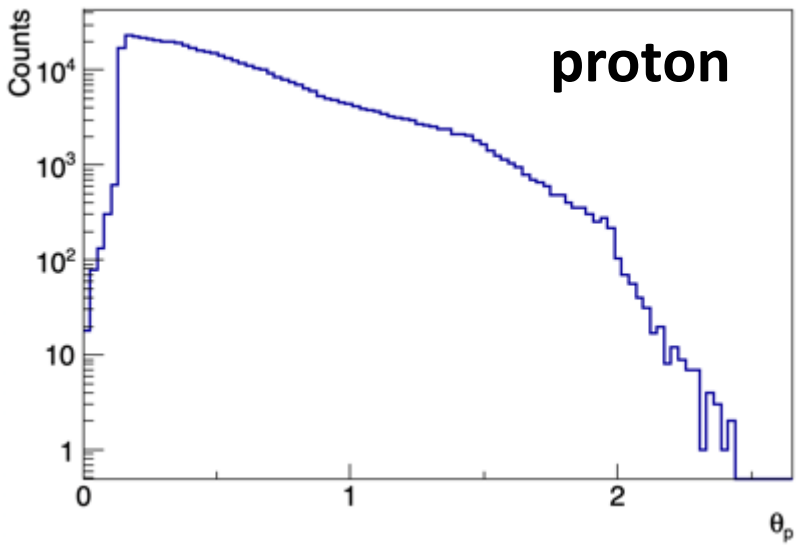
KM20 – implemented in GeParD (Nucl.Phys.B794:244-323,2008)

GK – implemented in PARTONS ((arXiv:1512.06174)

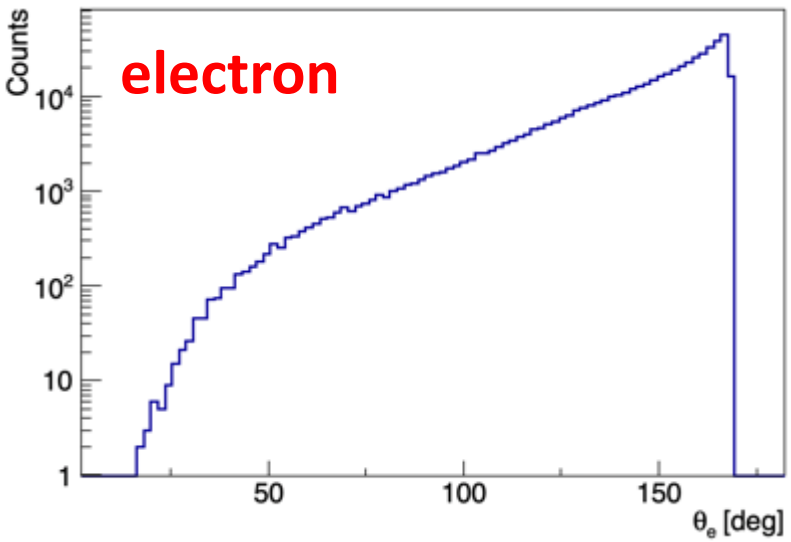
Account for an interplay between all three variables

Angular distributions for DVCS

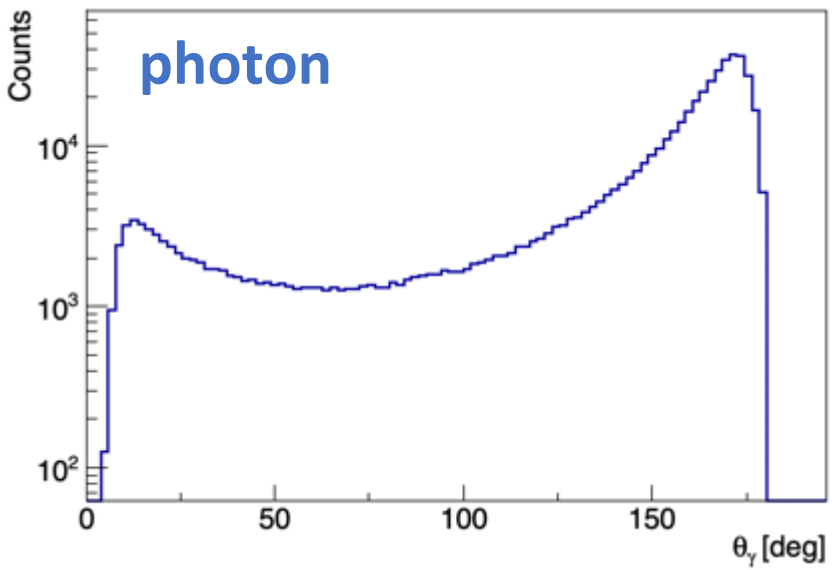
5x41 GeV



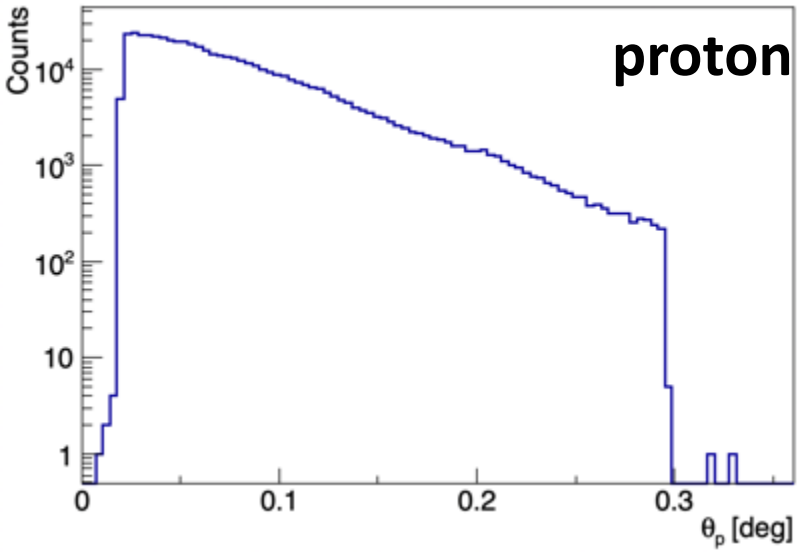
5x41 GeV



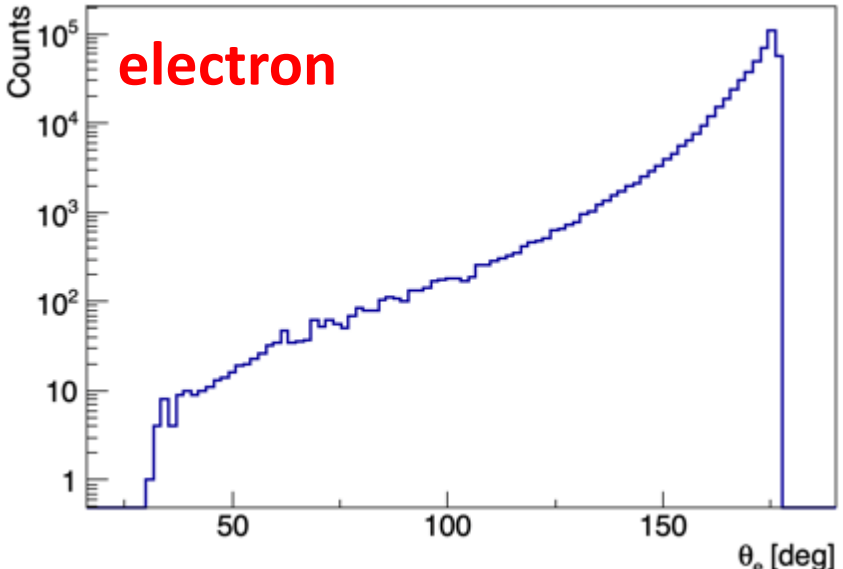
5x41 GeV



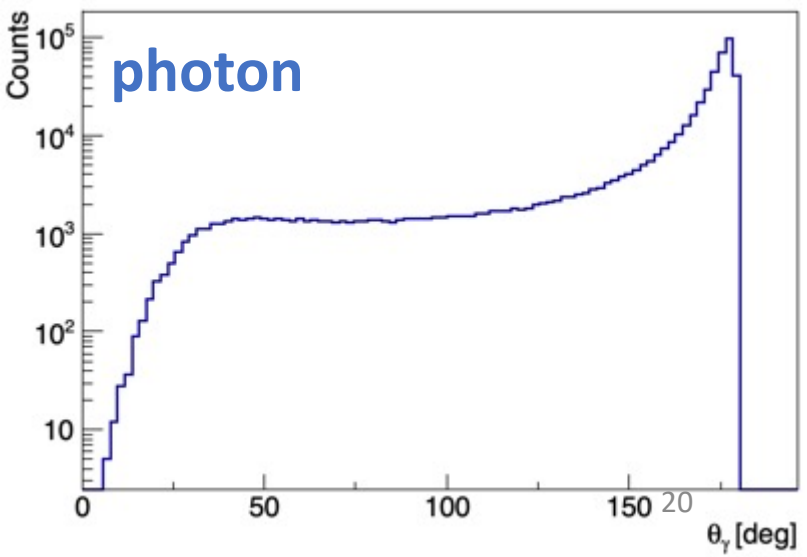
18x275 GeV



18x275 GeV



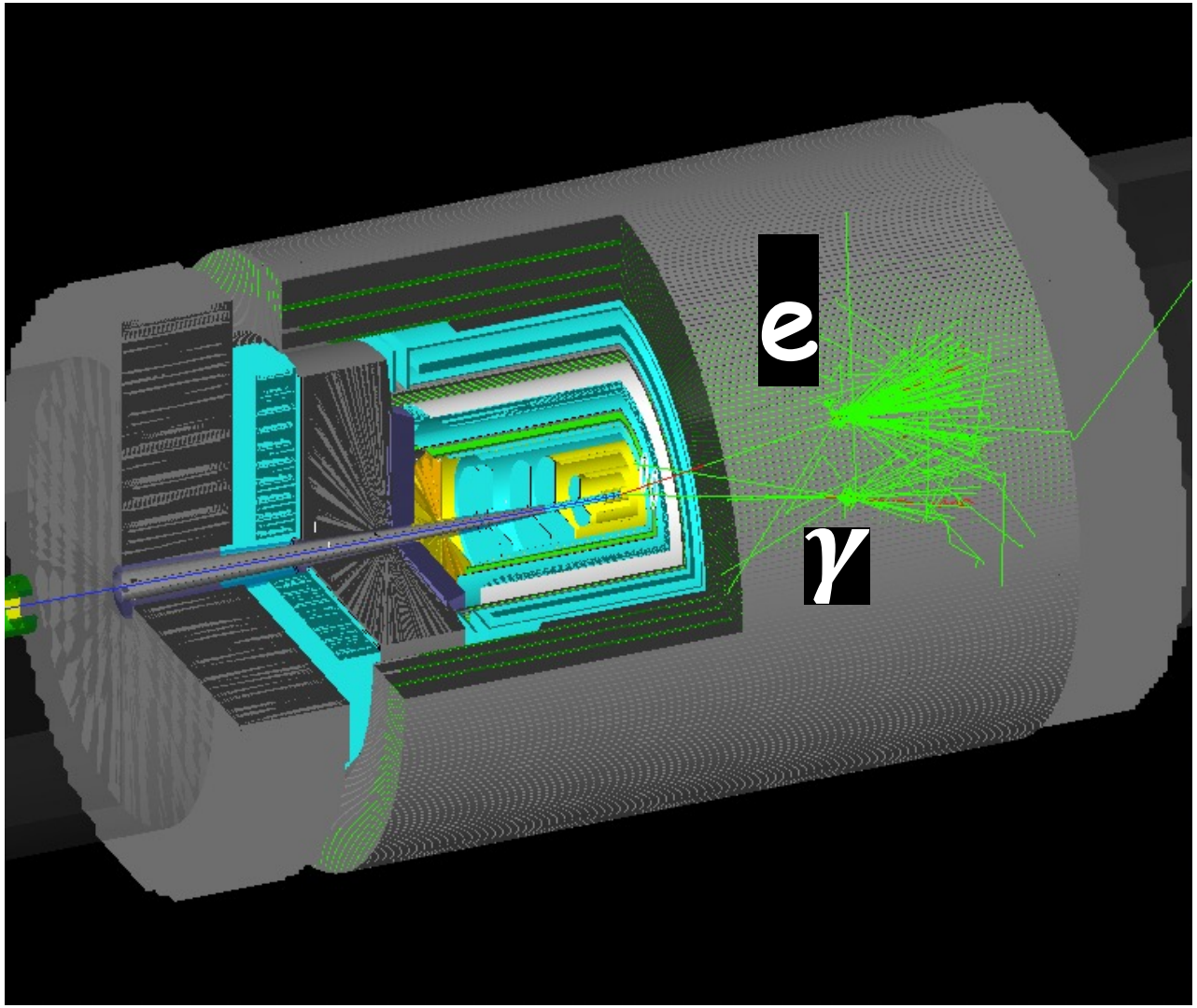
18x275 GeV



DVCS kinematics

Electron and photon

detected in main barrel



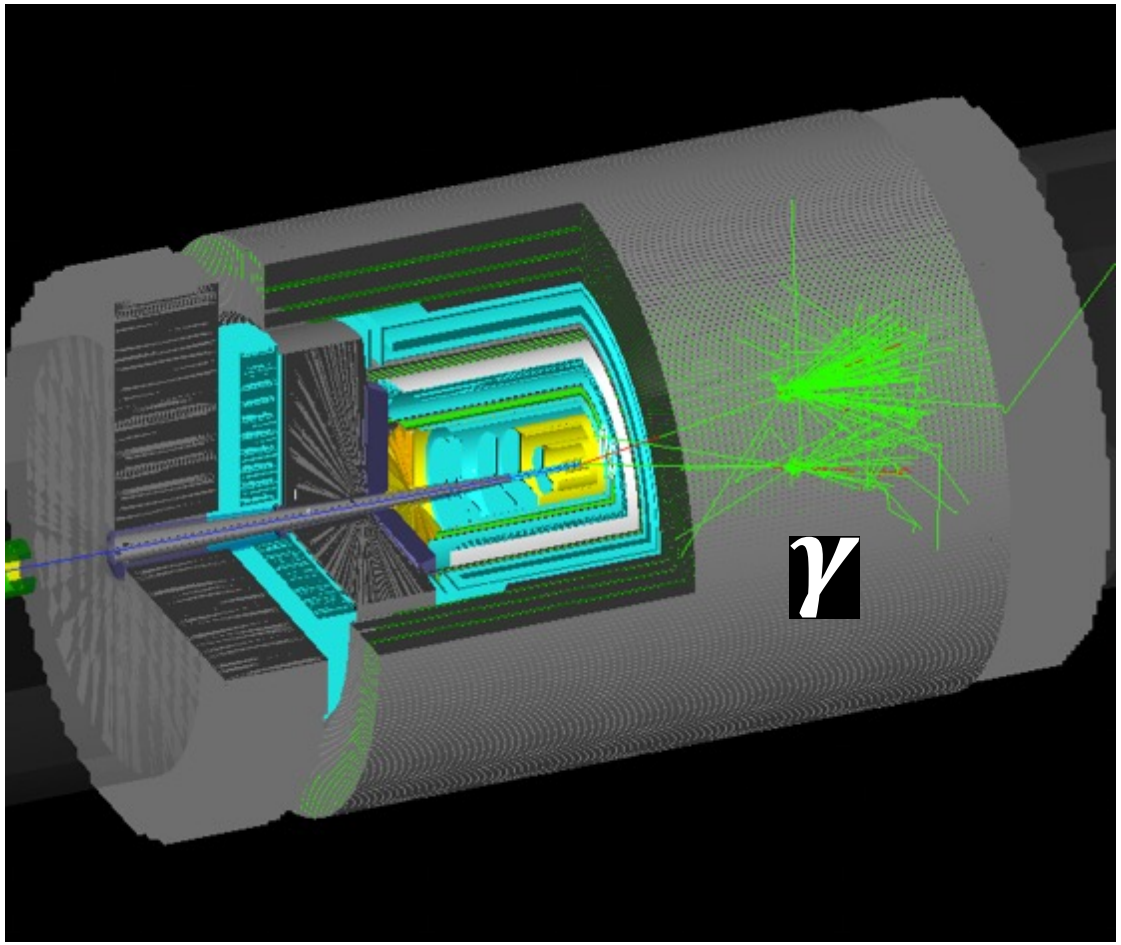
Photon detection

Extraction of photon energy from clusters in EM calorimeters.

Vertex position is based on electron track.

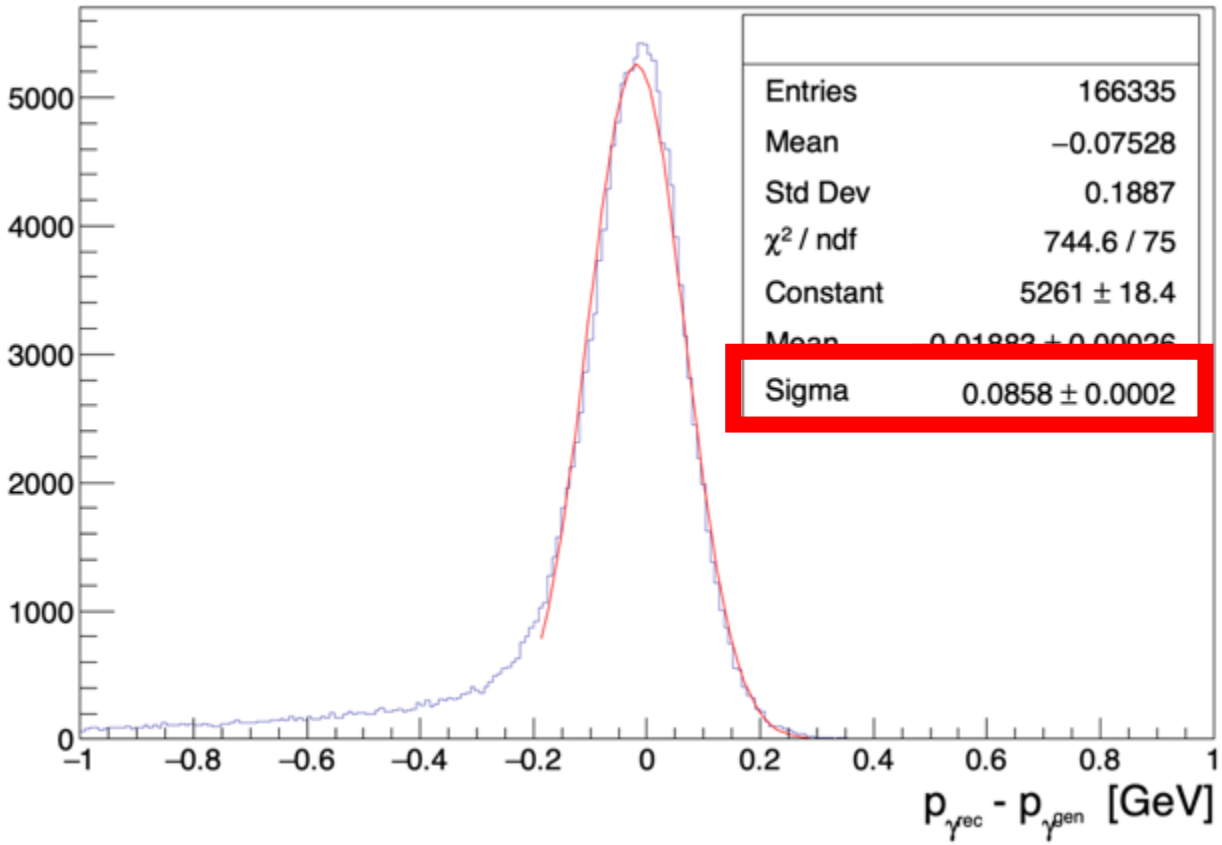
Angular resolution: < 0.5 deg

Energy resolution: ~ 0.1 GeV

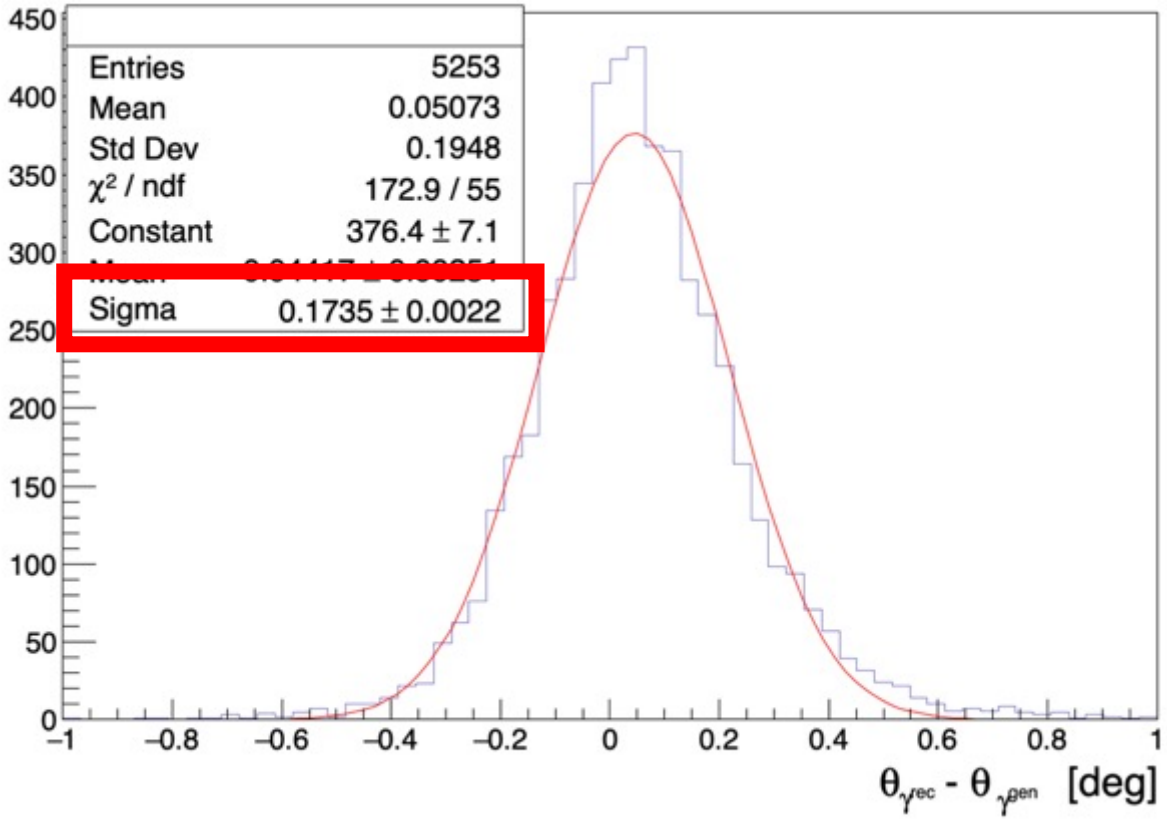


Photons

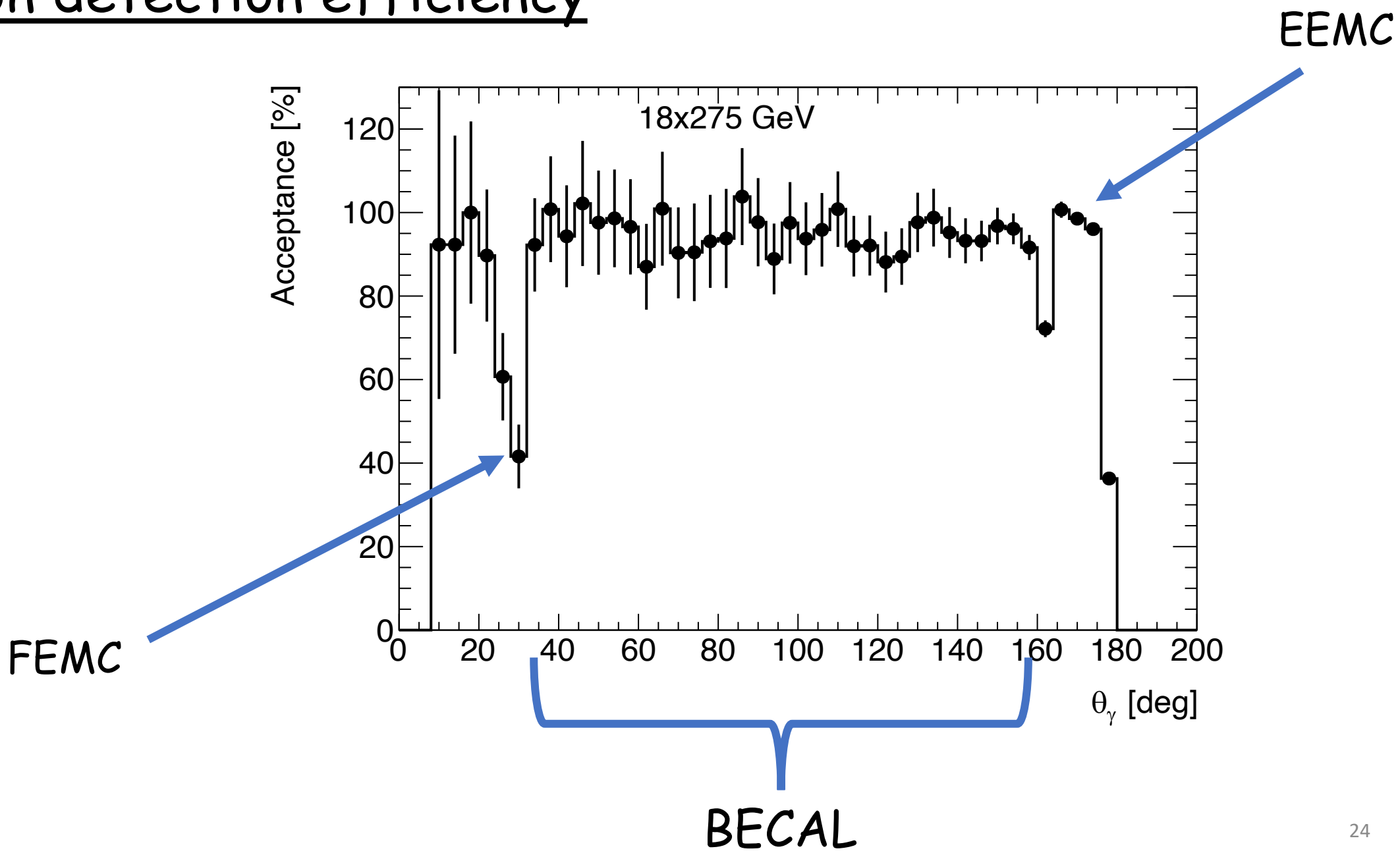
Momentum Resolution



Angular resolution

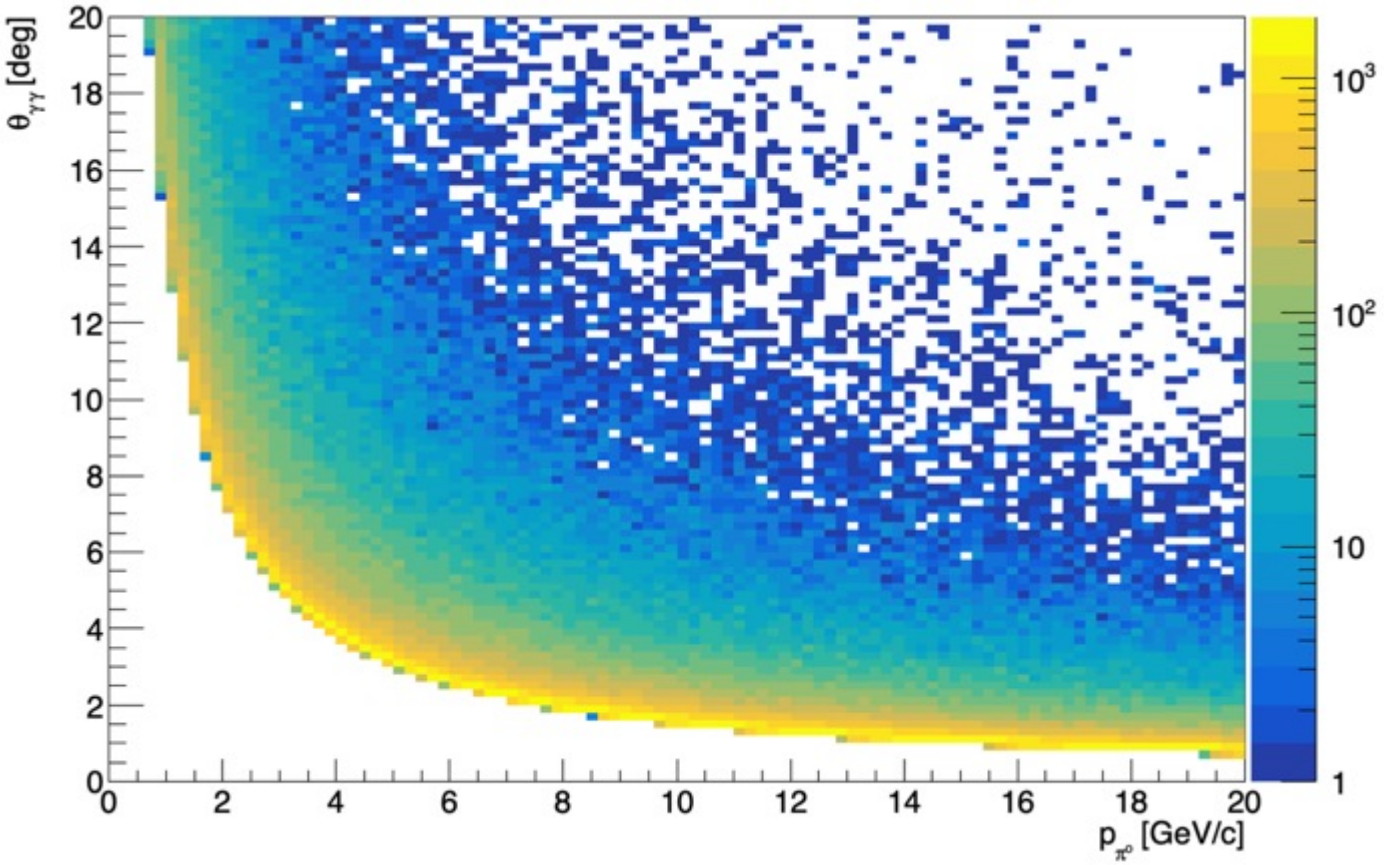


Photon detection efficiency

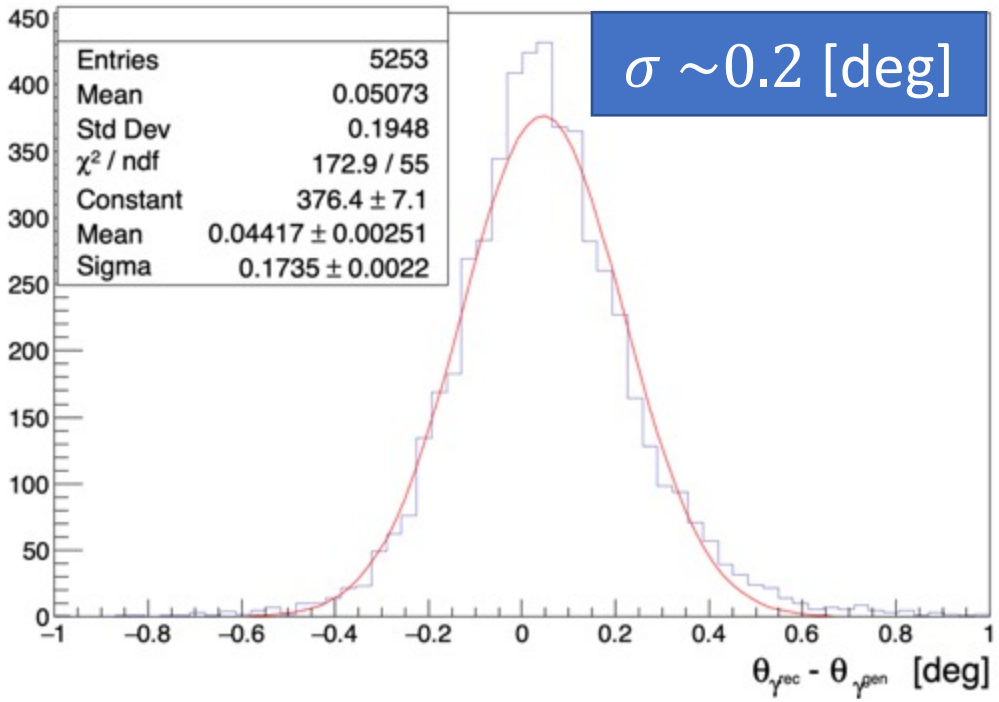


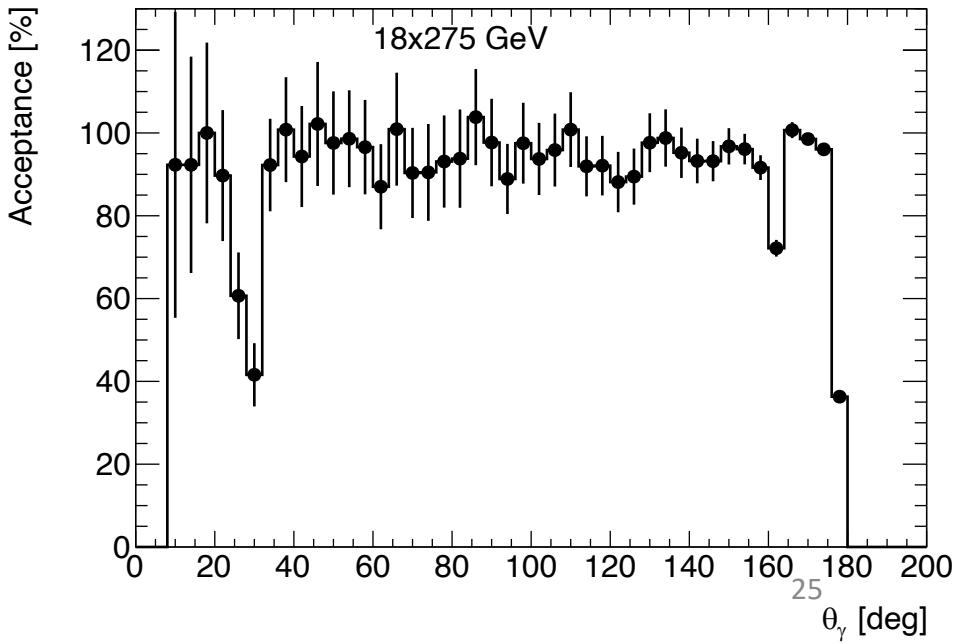
Photon resolution and separation between photon

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



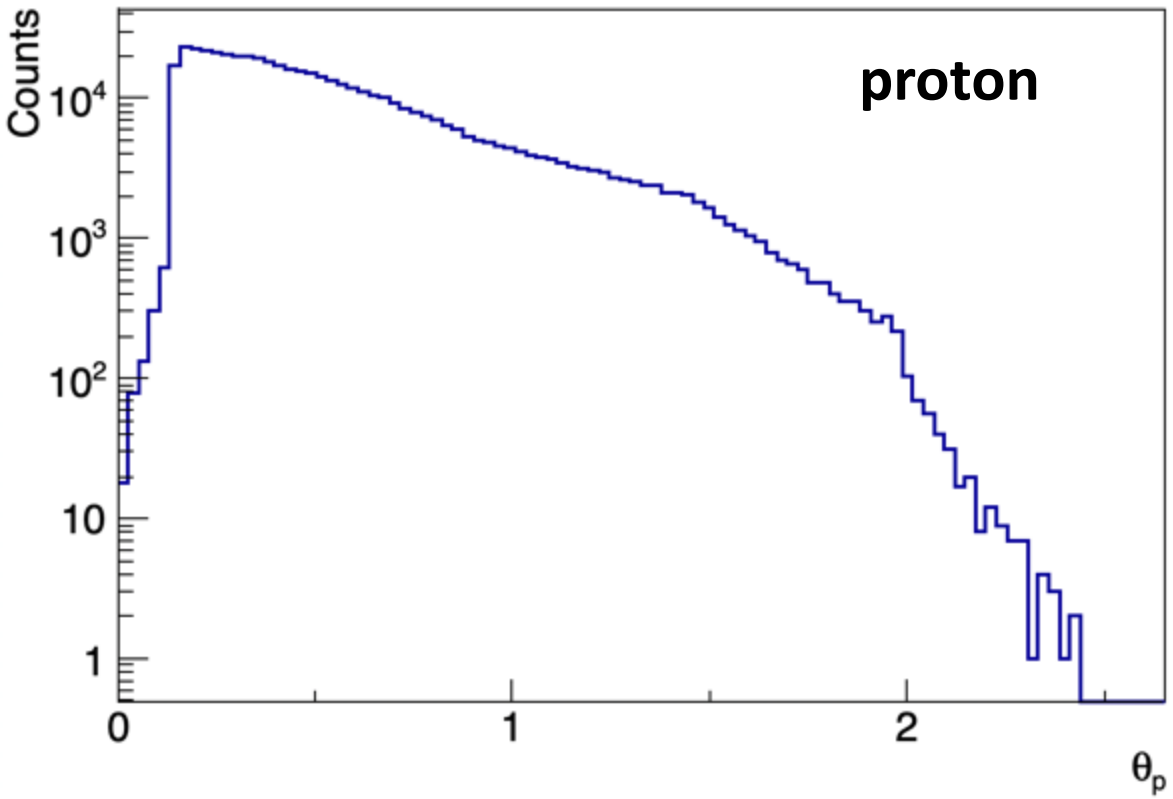
Beam setup 18x275 GeV



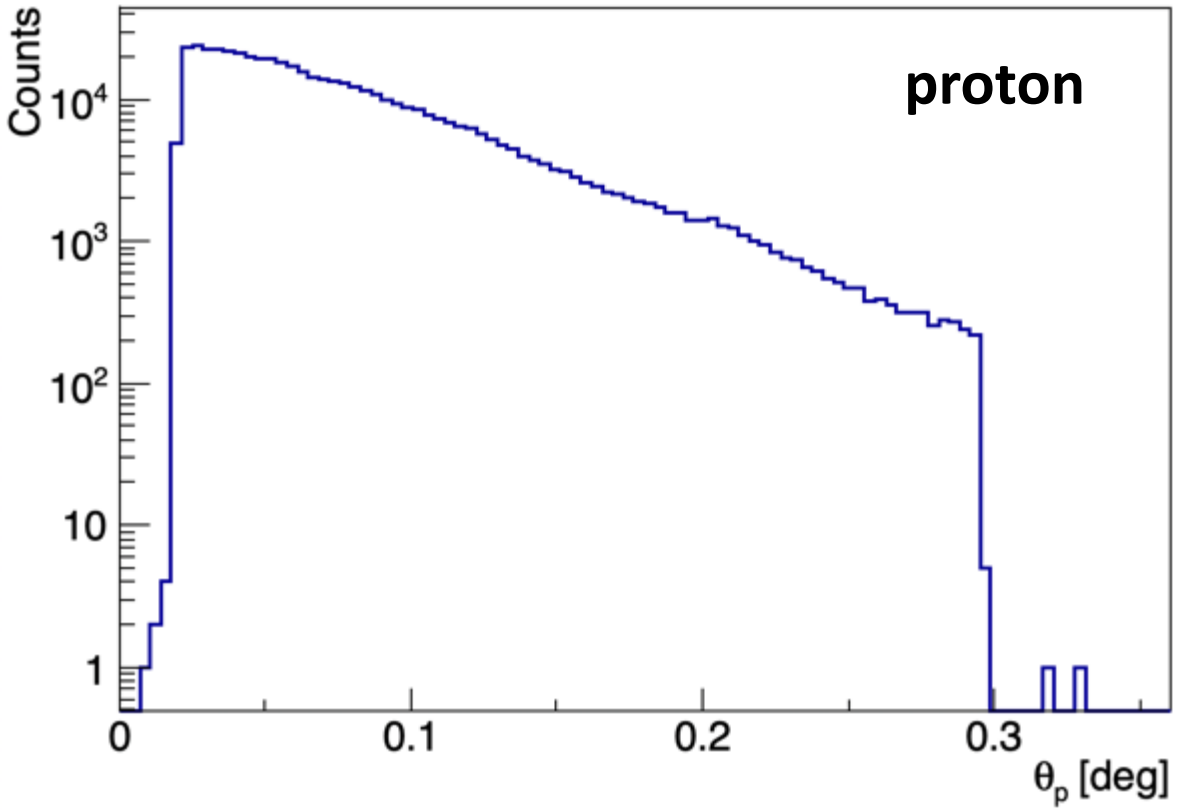


DVCS protons

5x41 GeV

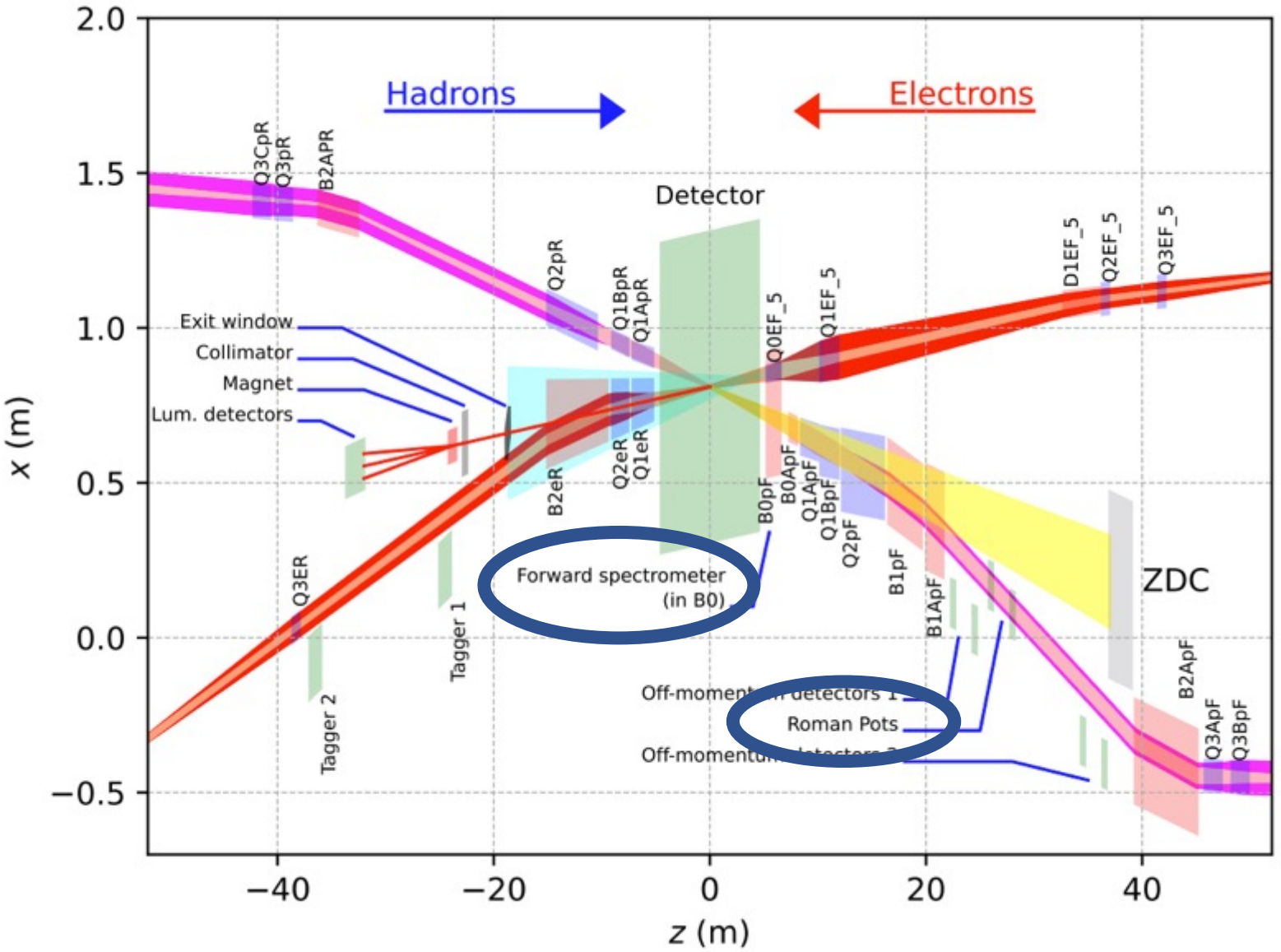


18x275 GeV

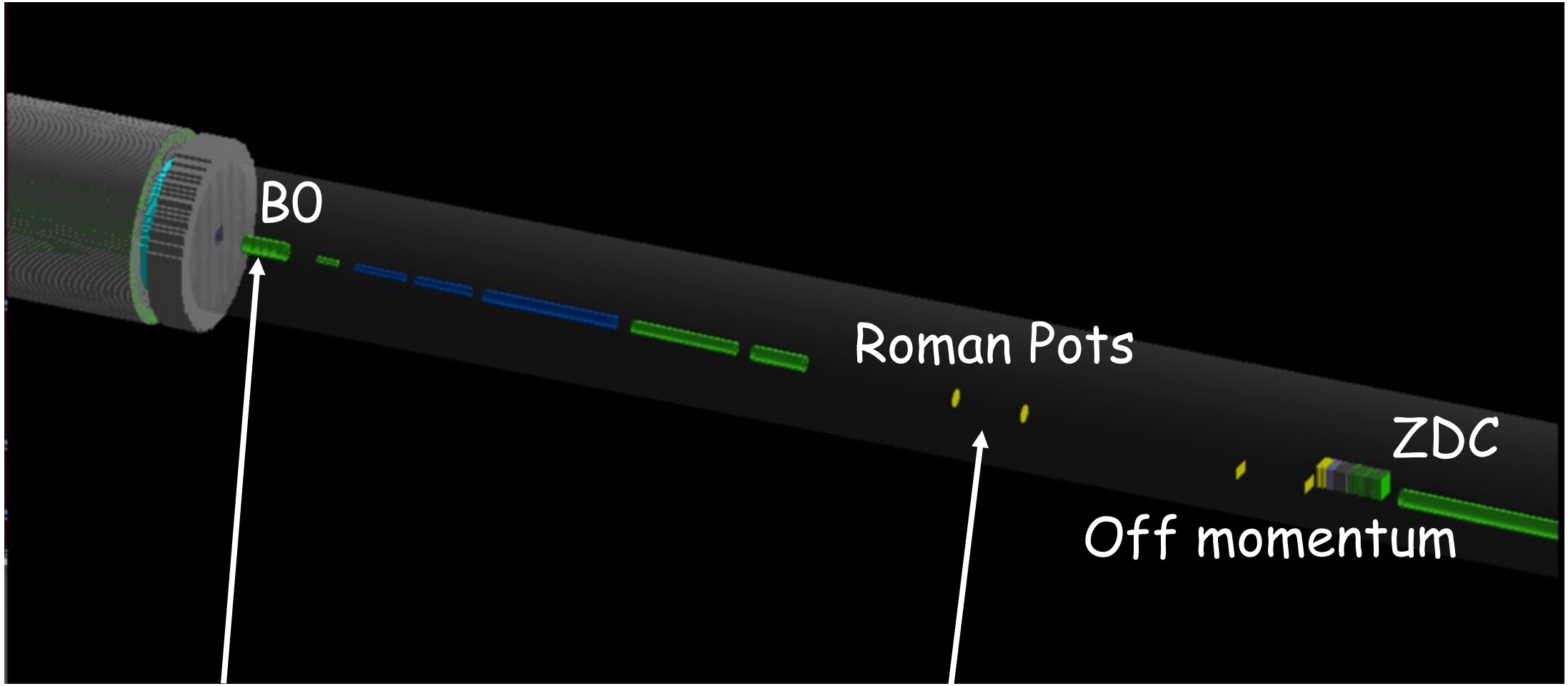


Protons escape through beam pipe opening in the endcaps

Detection of scattered protons in Far Forward region



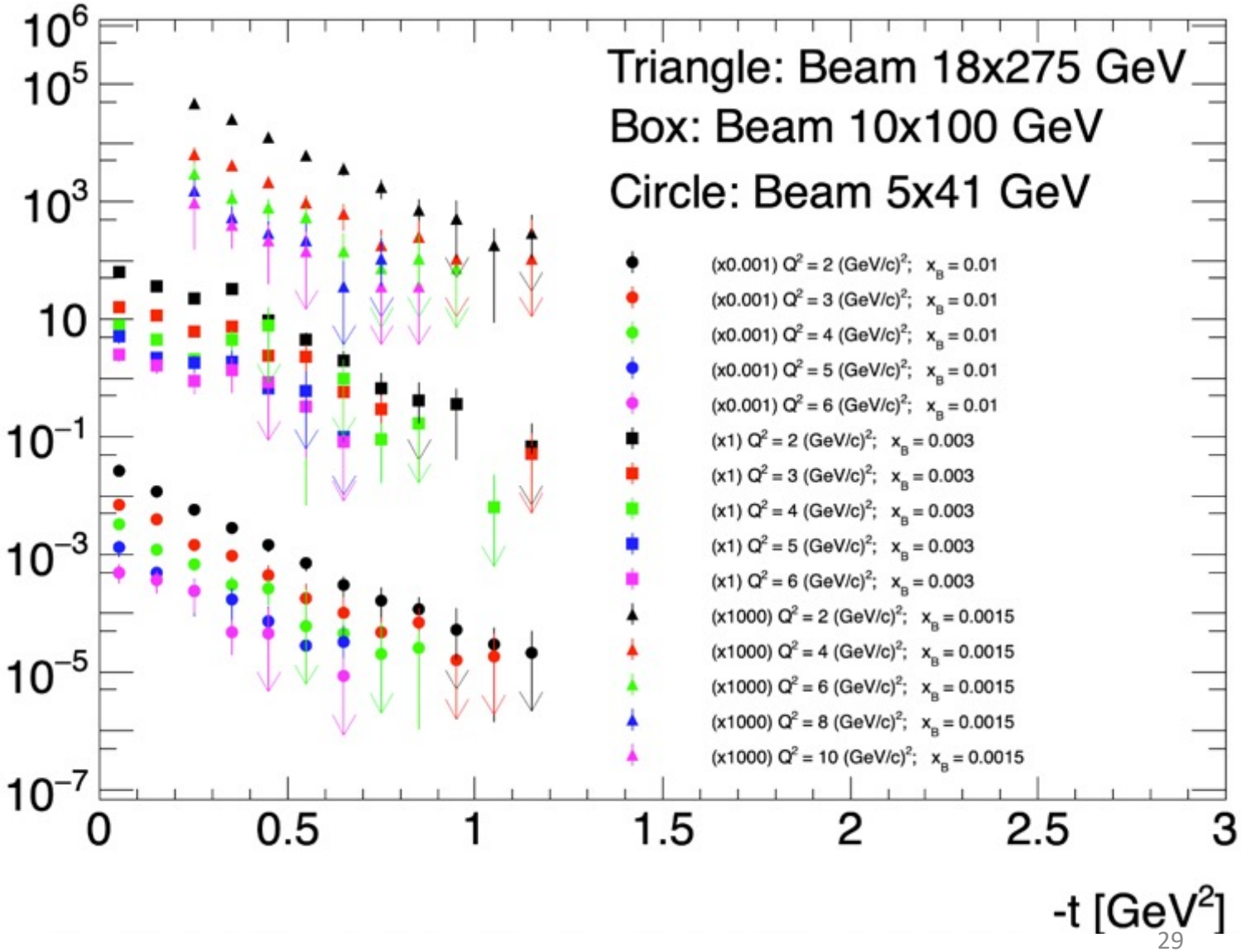
Far-Forward simulation



Cross section

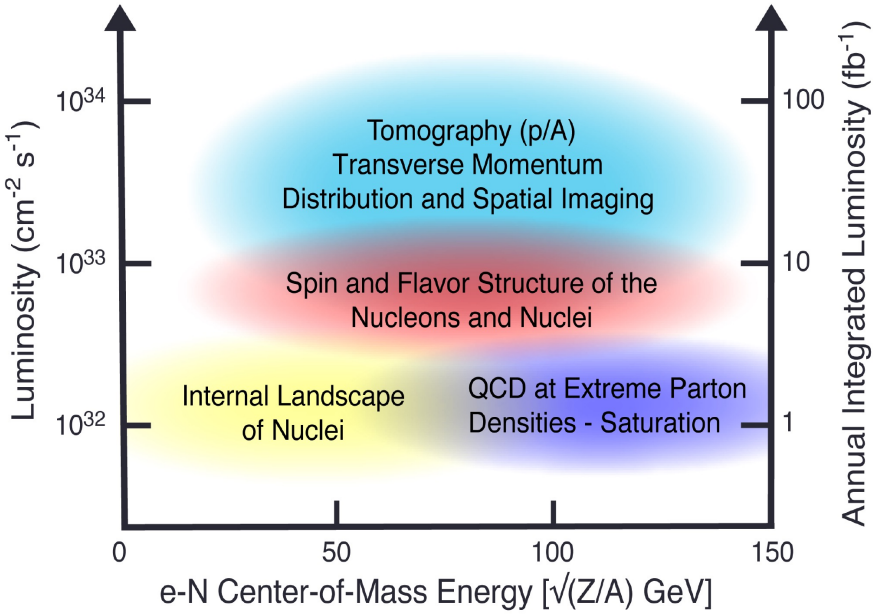
$d\sigma$

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



Summary

Future EIC



DVCS important process to study GPDs

Fully exclusive measurement of DVCS at EIC

GPDs study is very active filed, both experimentally and theoretically

EIC - Study GPDs at low and intermediate x Bjorken region

High luminosity and large acceptance – precision measurements of GPDs

Thank you for your attention