Studies of Time-Like Compton Scattering at the EIC with the EPIC Detector and with CLAS12 at Jefferson Lab

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Introduction

Time-like Compton Scattering (TCS) is a high energy, deep inelastic scattering process, wherein a real photon scatters from a nucleon, producing a virtual photon in the final state, which subsequently decays into a lepton pair.

$$ep\gamma \rightarrow e'p'\gamma^* \quad (\gamma^* \rightarrow l^+l^-) \text{ (Fig 1)}$$

TCS gives access to Generalized Parton Distributions (GPDs), which are functions that relate the transverse positions of quarks to their longitudinal momentum, providing a tomographic mapping of nucleon structure. GPDs are also sensitive to mechanical properties of the nucleon, such as pressure distributions, and to the composition of nucleon spin [1,2,3].

TCS is currently being studied at Jefferson Laboratory (JLab) in Virginia, USA, and is planned for the upcoming Electron Ion Collider (EIC), to be built at Brookhaven National Lab, USA.

To this end, I present a feasibility study for measuring TCS on the proton at the EIC, via a full Geant4 simulation of the Detector-1 reference design. Data is also currently being taken at JLab by Run Group C using the CLAS12 detector and a longitudinally polarised proton target.

Fig 1 [4]

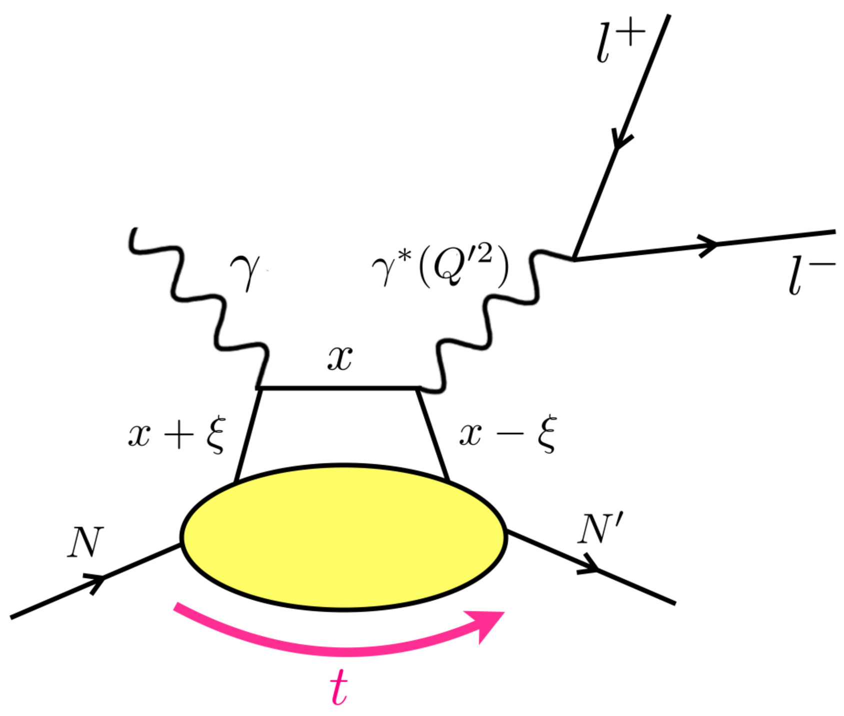


Fig 1) Handbag diagram of the TCS process, where $t = (p'-p)^2 = (q-q')^2$

Simulating Time-like Compton Scattering - EpIC

- MC event generator using GPD models from the PARTONS (PARTonic Tomography Of Nucleon Software) framework[5] to generate deep exclusive processes[6].
- Takes in an input .xml file, where kinematics/energy etc are defined and generates the four vectors of all the particles as the output.
- EpIC has the capability to consistently overcome singularities in production amplitudes.
- Fig 2a and 2b show the distribution of generated events across Q'^2 versus x_B where x_B is defined slightly differently for the photoproduction process as:

$$x_B = \frac{Q'^2}{(s - M_p^2)}$$

with $Q'^2 = (l^+ + l^-)^2$

Fig 2a

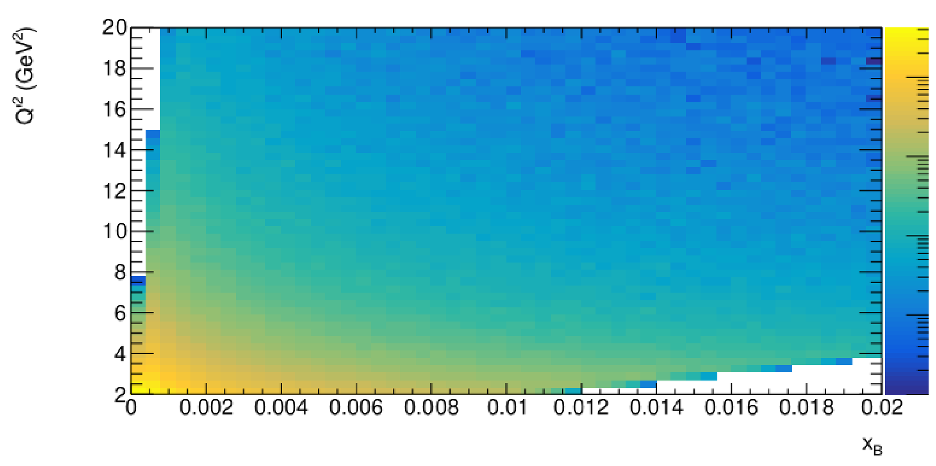


Fig 2b

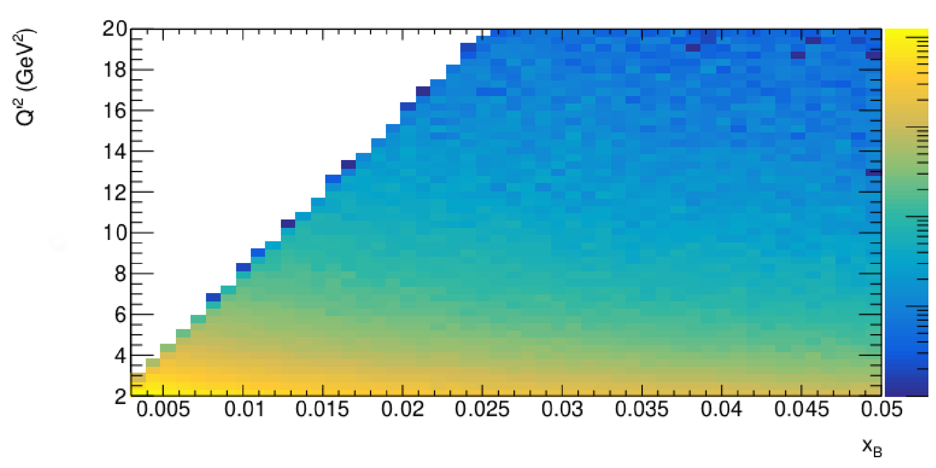
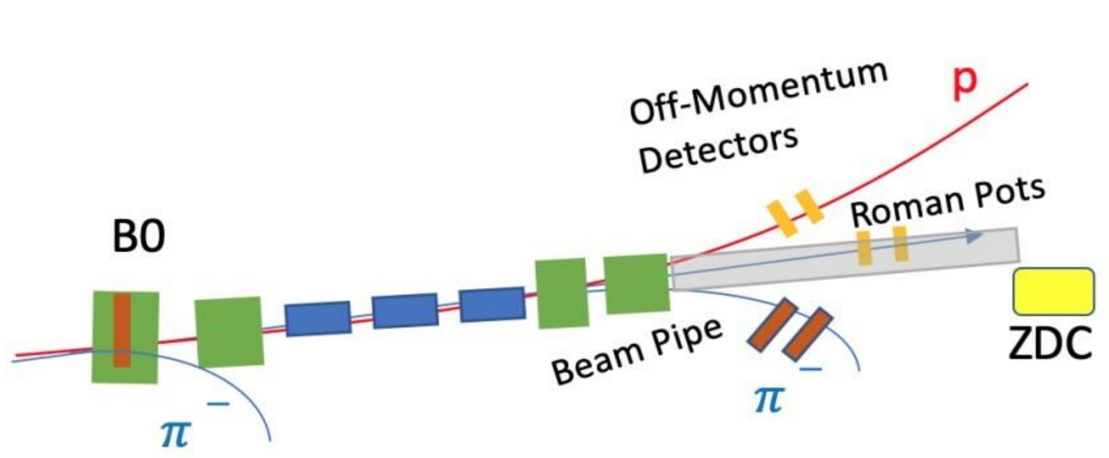


Fig 2a) Distribution of generated Q'^2 vs x_B for 5x41 GeV
Fig 2b) Distribution of generated Q'^2 vs x_B for 18x275 GeV

Simulating Time-like Compton Scattering - Fun4All

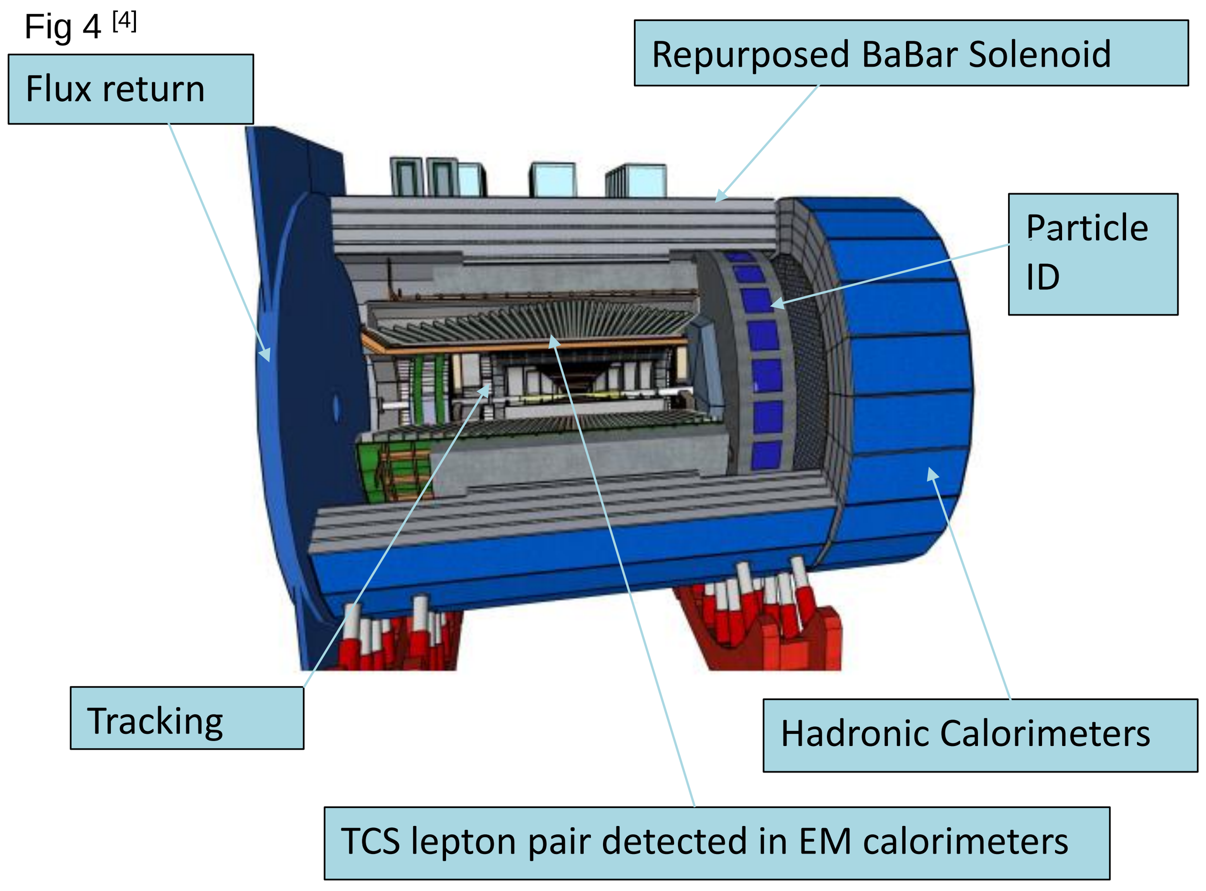
- 500k events at 5x41GeV
- 500k events at 18x275GeV
- TCS + Bethe Heitler (BH) + TCS/BH interference simulated
- Final state scattered proton detected in Fun4All[7] Roman Pots (RP) and B0

Fig 3



EPIC Detector design

Fig 4 [4]



EPIC Detector Performance

η acceptance for the scattered proton

Fig 5a

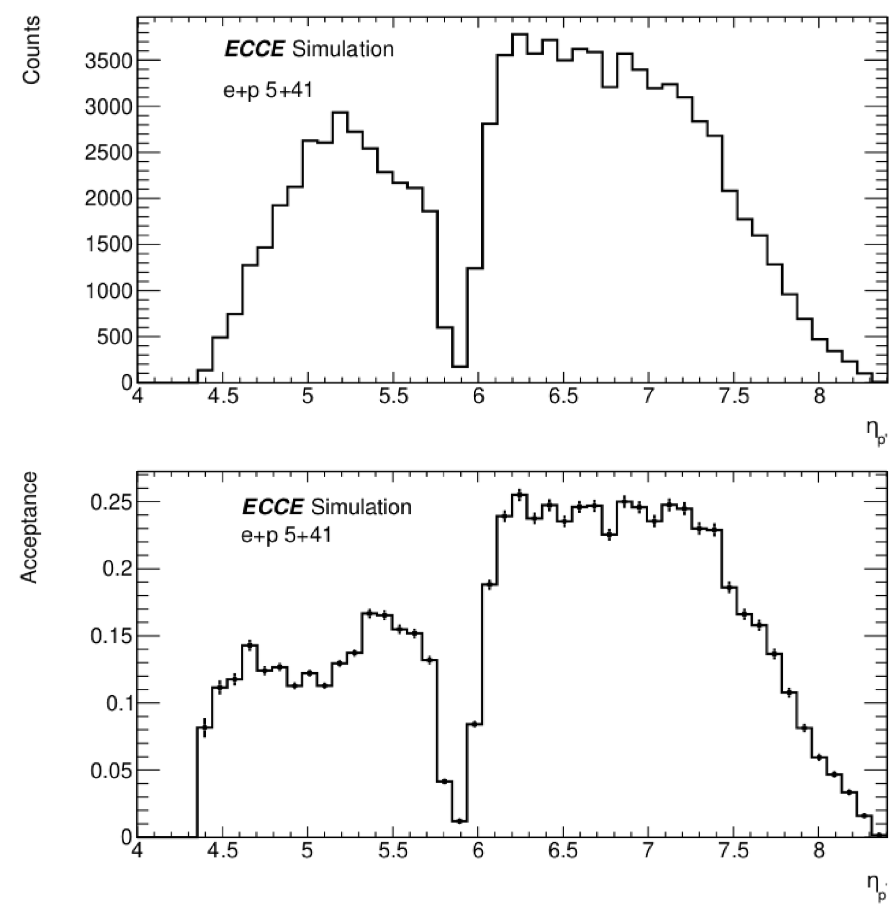


Fig 5a) 5x41GeV $\eta_{p'}$ distributions counts (top) and acceptance (bottom)

Fig 5b

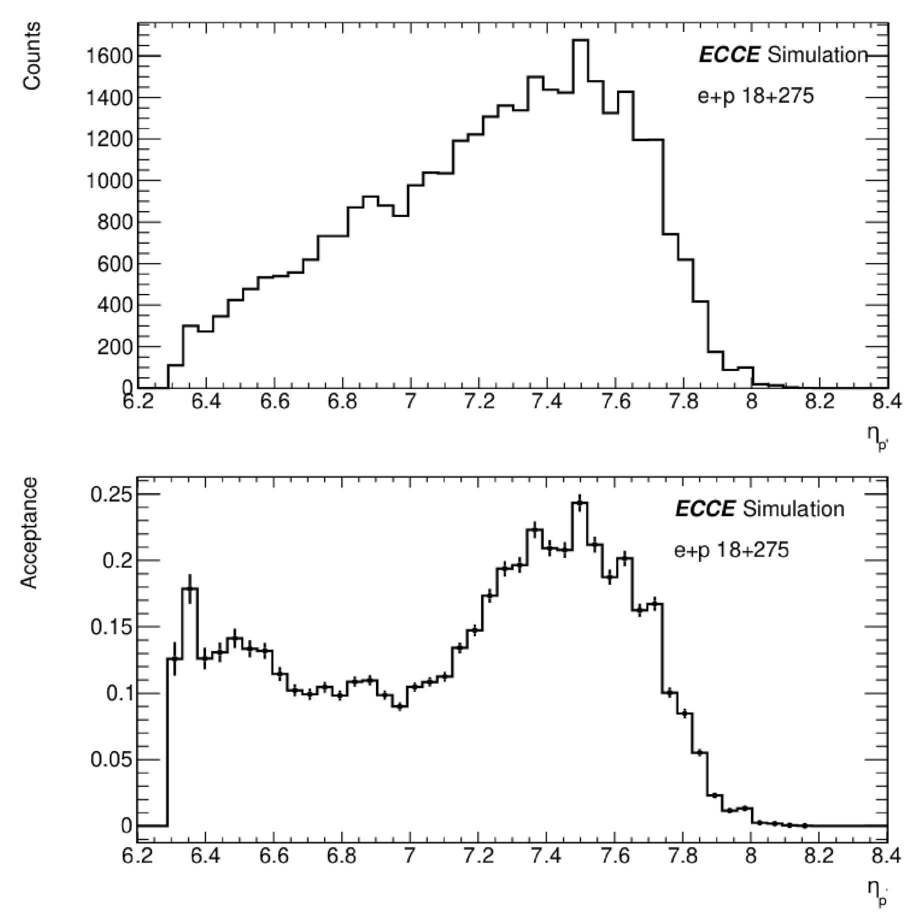


Fig 5b) 18x275GeV $\eta_{p'}$ distributions counts (top) and acceptance (bottom).

Figures 5a and 5b show the pseudorapidity (η) of the scattered proton, where;

$$\eta = -\ln\left[\tan\left(\frac{\theta}{2}\right)\right]$$

where θ is the scattering angle.

- At 5x41GeV, a significant fraction of protons are detected for 4.2 < η < 6, indicative of the B0 instrumentation region.
- For 18x275 GeV, we see no counts in this region, but all of the counts are in the range 6.2 < η < 8.2, indicative of the Roman Pots instrumentation. These plots respectfully show the requirement for both far forward detection systems in ensuring the scattered proton is detected.

Cross Sections

Fig 6a

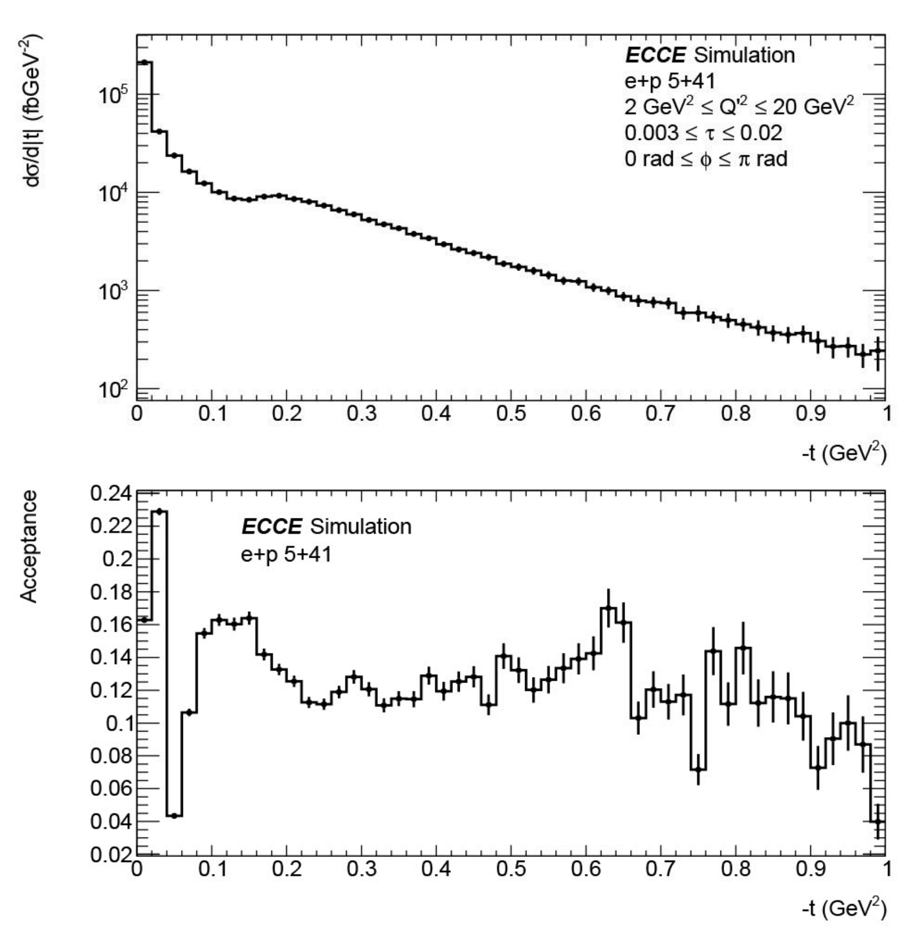


Fig 6a) 5x41 t cross section distributions (top) and acceptance (bottom)

Fig 6b

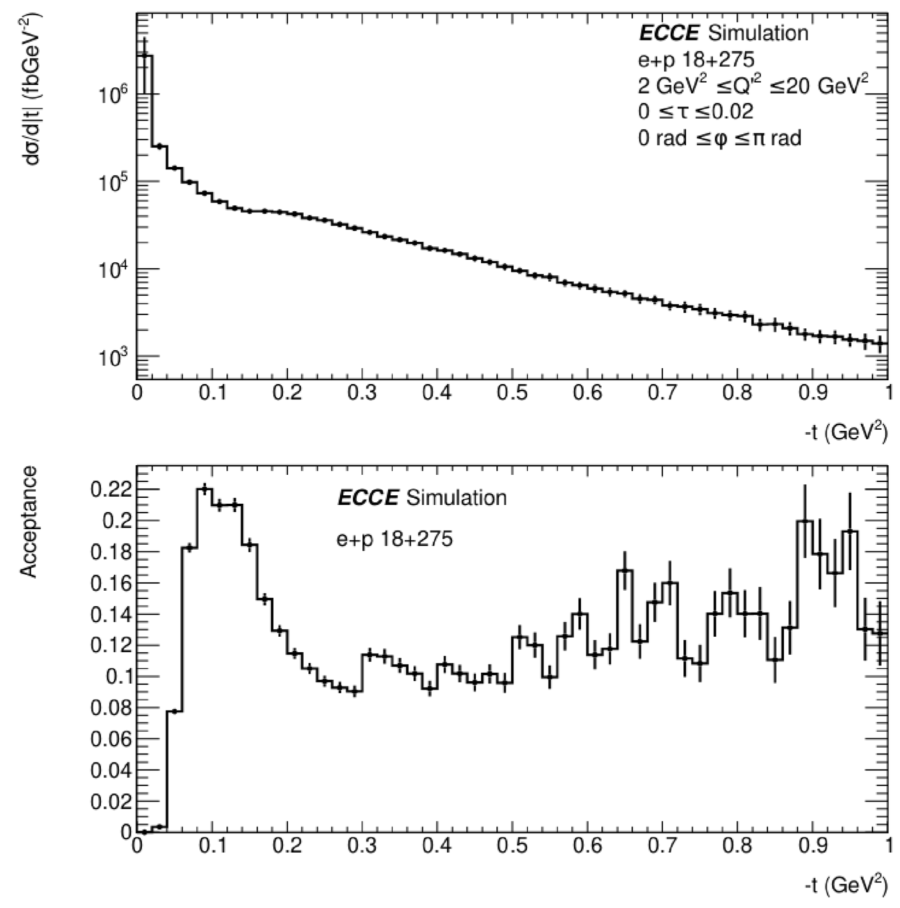


Fig 6b) 18x275 t cross section distributions (top) and acceptance (bottom)

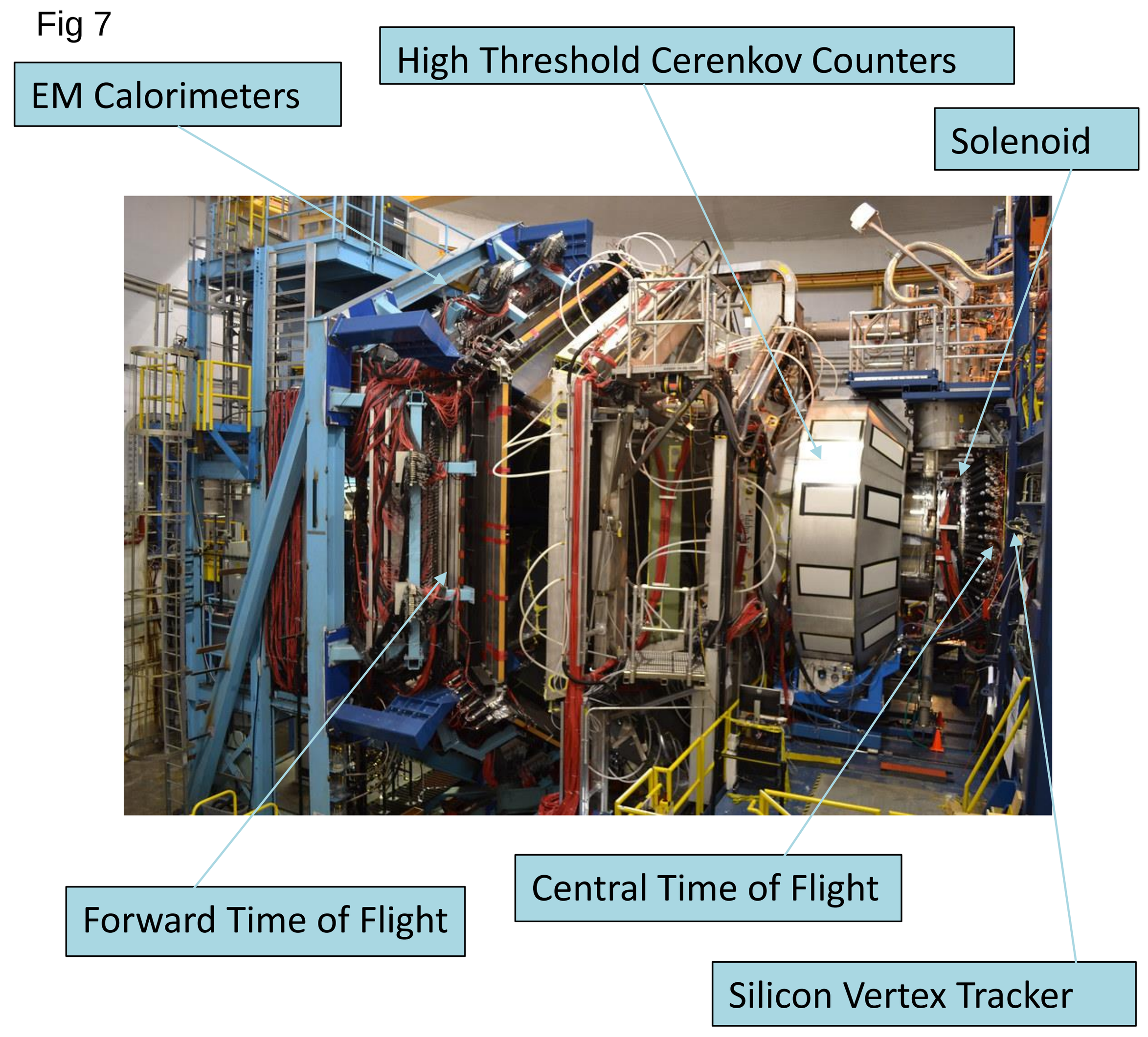
Fourier-transforming GPDs with respect to the squared four momentum transfer to the nucleon gives information on the impact parameter, or in other words transverse position of the parton, thus a good range of accurate t reconstruction is invaluable.

While the cross section for t is low (on the femtobarn scale) across both energies it is nonetheless measurable across a full range in t, with acceptance up to about 20% across the kinematic region of interest. This study also shows it is possible to have a multi dimensional binning of cross section.

TCS with CLAS12

The CLAS12 Detector

Fig 7



TCS on a polarized target

Due to the low cross section of TCS, and the dominance of Bethe Heitler, extracting TCS observables requires looking at the interference term between TCS and BH. This is most easily accessed in an asymmetry measurement, for which the pure Bethe Heitler contribution in the numerator is removed and the interference signal dominates.

There have been studies done at Jefferson Lab, most recently by Pierre Chatagnon, who made the first measurement of TCS with data taken by Run Group A[9] using an unpolarized proton target.

I will be conducting research on data taken by Run Group C, which has the advantage of being a dataset with a polarized target, which allows access to different GPD parameters, and will also be a first time measurement of TCS on a longitudinally polarized target.

Fig 8

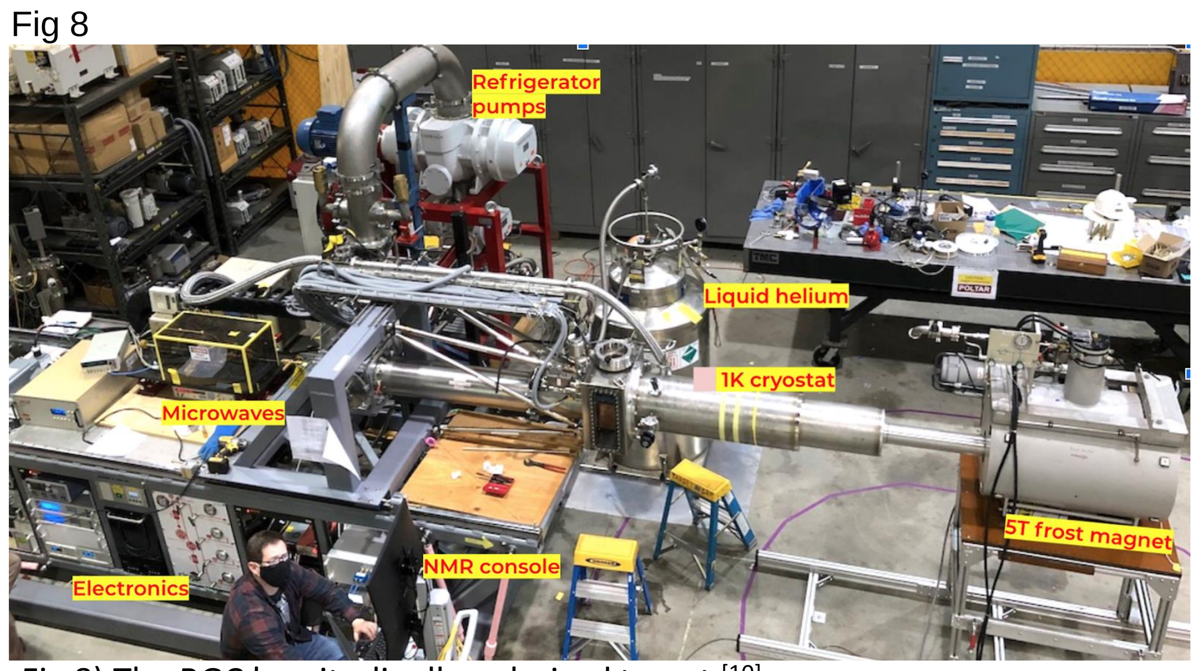


Fig 8) The RGC longitudinally polarized target [10]

Citations

[1] D. Müller et al. Fortschritte der Physik 42, 101 (1994).
[2] A. Radyushkin, Physics Letters B 380, 417 (1996).
[3] X. Ji, Phys. Rev. D 55, 7114 (1997).
[4] EIC Yellow Report: R. e-Print: 2103.05419 [physics.ins-det]
[5] B. Berthou et al., Eur. Phys. J. C78 (2018), 478, DOI: 10.1140/epjc/s10052-018-5948-0
[6] Aschenauer, E.C., Batozskaya, V., Fazio, S., Gates, K., Moutarde, H., Sokhan, D., Spiesberger, H., Sznajder, P. and Tezgin, K.,arXiv preprint arXiv:2205.01762.
[7] C Pinkenburg. Fun4all - the eic software group website URL:https://eic.github.953io/software/fun4all.html FF_region_EIC_target_fragmentation_Sept_2020_v3.pdf (bnl.gov
[8] https://physics.uconn.edu/2020/09/16/ Accessed: 22/07/2022
[9] P. Chatagnon, Thesis: *Nucleon Structure studies with Timelike Compton Scattering.*
[10] P. Panday DNP presentation 2021