University of Glasgow

Science & Technology Facilities Council

Timelike Compton Scattering on a polarized target with CLAS12, at Jefferson Lab

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Intro

Theory

The Timelike Compton Scattering (TCS) process

Generalised Parton Distributions (GPDs)

Observables accessible with TCS

Experimental Setup

Jefferson Lab and the Continuous Electron Beam Facility (CEBAF)

Hall B and The CEBAF Large Acceptance Spectrometer at 12 GeV (CLAS12)

Experimental Procedure

Preliminary Results

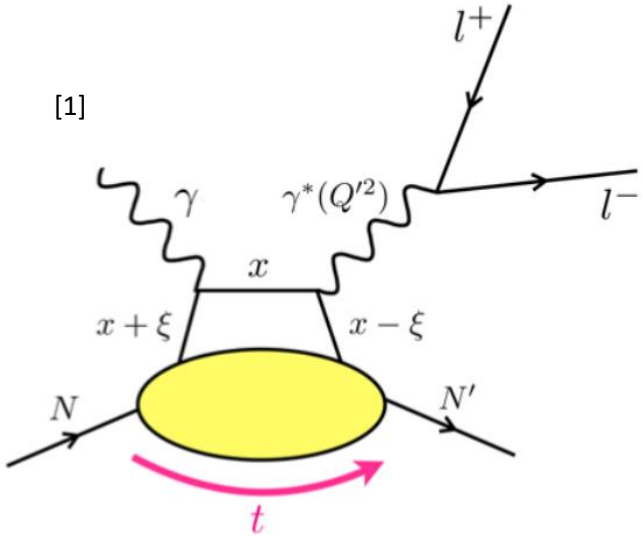
Timelike Compton Scattering (TCS)

- High energy, exclusive scattering process.
- A real photon interacts with the target nucleon, causing release of virtual photon which decays into a lepton pair.

$$ep \rightarrow e'p'\gamma^*$$
$$\gamma^* \rightarrow \mu^+\mu^- \; or \; e^+e^-$$

- TCS gives access to Generalised Parton Distributions via cross section and polarization asymmetry measurements.

[1]



Q^2 = virtuality of initial photon

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

$t = (p'(N') - p(N))^2 = (q - q')^2$

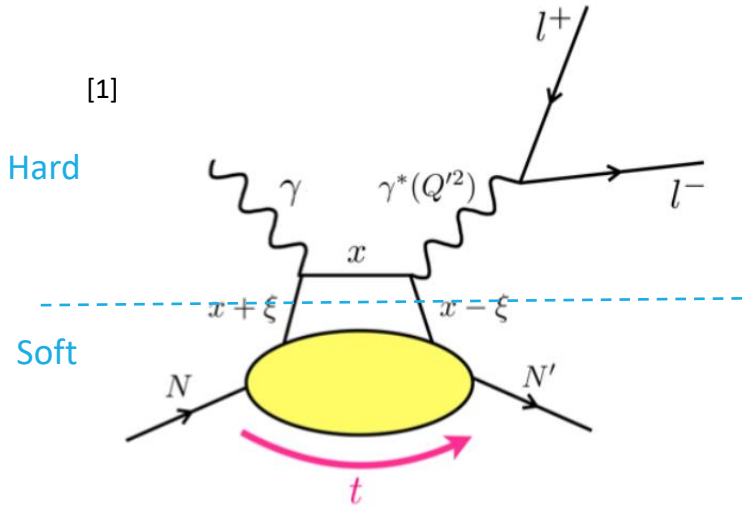
x = longitudinal momentum fraction of struck quark

ξ = longitudinal momentum fraction gained/lost by struck quark

Generalised Parton Distributions

- At high photon virtuality, TCS scattering amplitude can be factorized.
- ‘Hard’ part → QED and perturbative QCD.
- ‘Soft’ part → non-perturbative QCD, described by four Generalized Parton Distributions (GPDs) $H, \widetilde{H}, E, \& \, \tilde{E}$.
- H and E are insensitive to quark helicity, $\widetilde{H}$ and $\tilde{E}$ are helicity dependent.
- GPDs relate the transverse positions of quarks and gluons to their longitudinal momentum.
- This relation helps to provide a tomographic mapping of nucleon structure.

[1]



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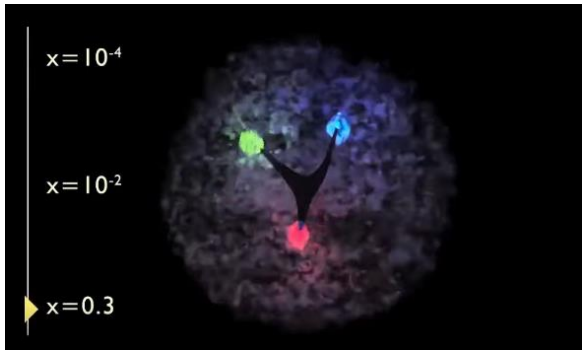
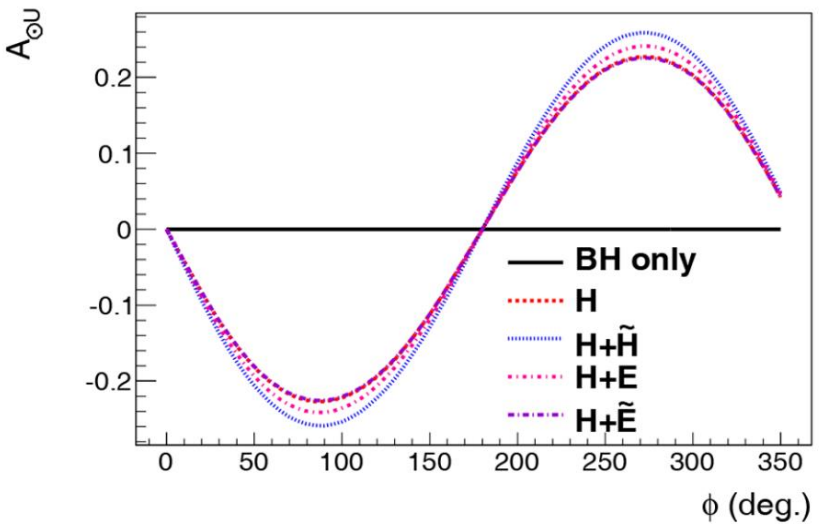


Observable Predictions

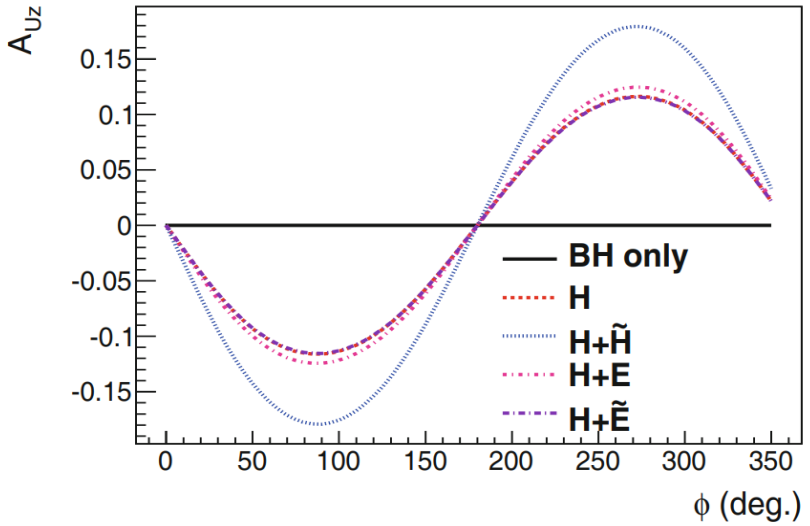
- Beam Spin Asymmetry – H dominates, first ever measurement of TCS in 2021[3], continuation of this effort on a polarized target.
- Target spin asymmetry – Access to H and $\widetilde{H}$
- Measurements accessing H allow investigation into GPD universality, $\widetilde{H}$ is less known, both Deeply Virtual Compton Scattering (DVCS) and TCS provide complementary access.

[4]

BSA

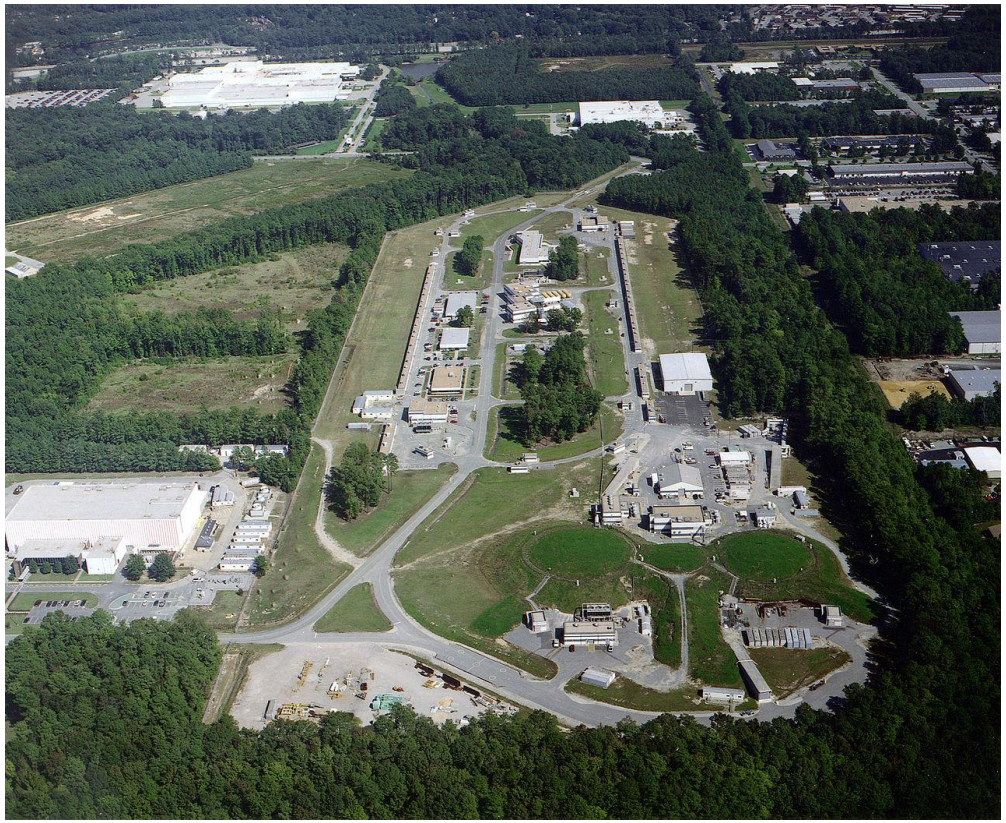


TSA



Jefferson Lab

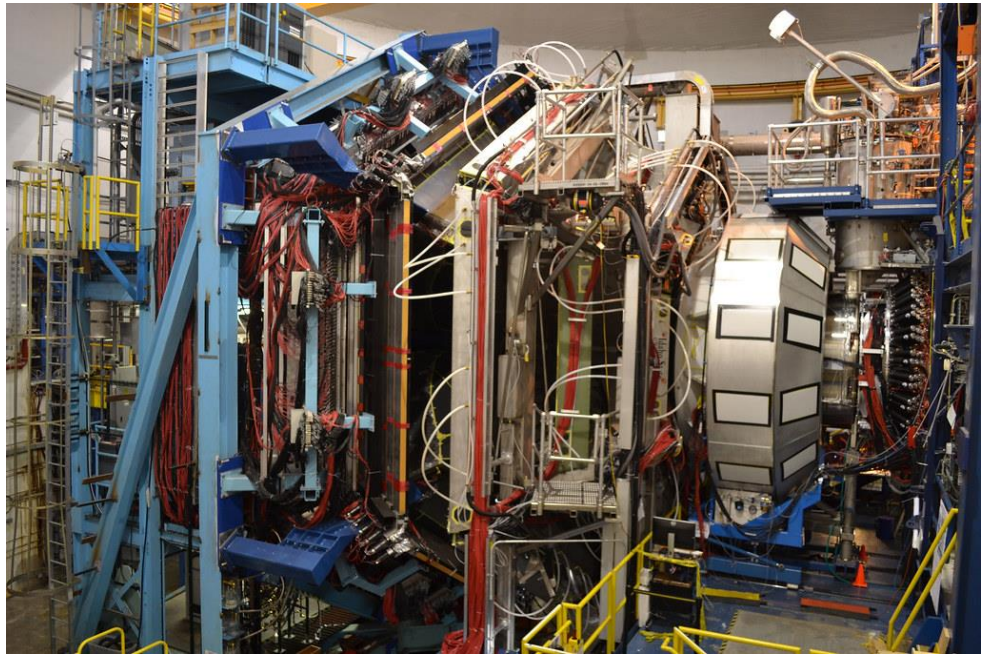
- CEBAF (the Continuous Electron Beam Accelerator Facility) provides an electron beam to four experimental halls housing fixed target experiments;
  - Hall A and C - high resolution, narrow acceptance spectrometers, able to handle large luminosities.
  - Hall B - houses the CEBAF Large Acceptance Spectrometer (CLAS12), where the data in this talk was taken.
  - Hall D - home of the GlueX (the Gluonic Excitation Experiment), and has a dedicated photon beamline.



[5]

CLAS12 – Jefferson Lab

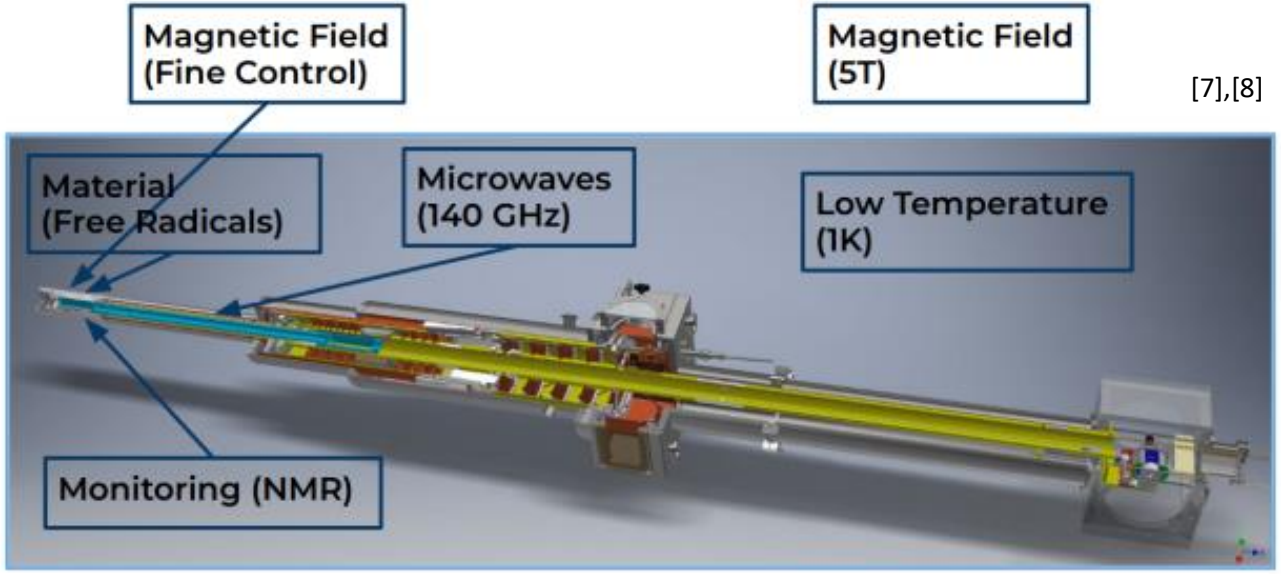
- Close to full azimuthal angular coverage
- Polar angle θ range 35◦ – 125◦ covered by the central solenoid magnet and detector
- Forward polar angle range < 35◦ covered by the superconducting torus magnet and forward detector, including a forward tagger (FT) .
- Allows for efficient detection of both charged and neutral particles.



[6]

Longitudinally Polarized Target

- Paramagnetic target material dynamically polarized using microwaves
- Target material kept under conditions of low temperature and high magnetic field
- Target polarisation monitored using NMR
- Beam moved uniformly across surface of target material to prevent localized depolarization

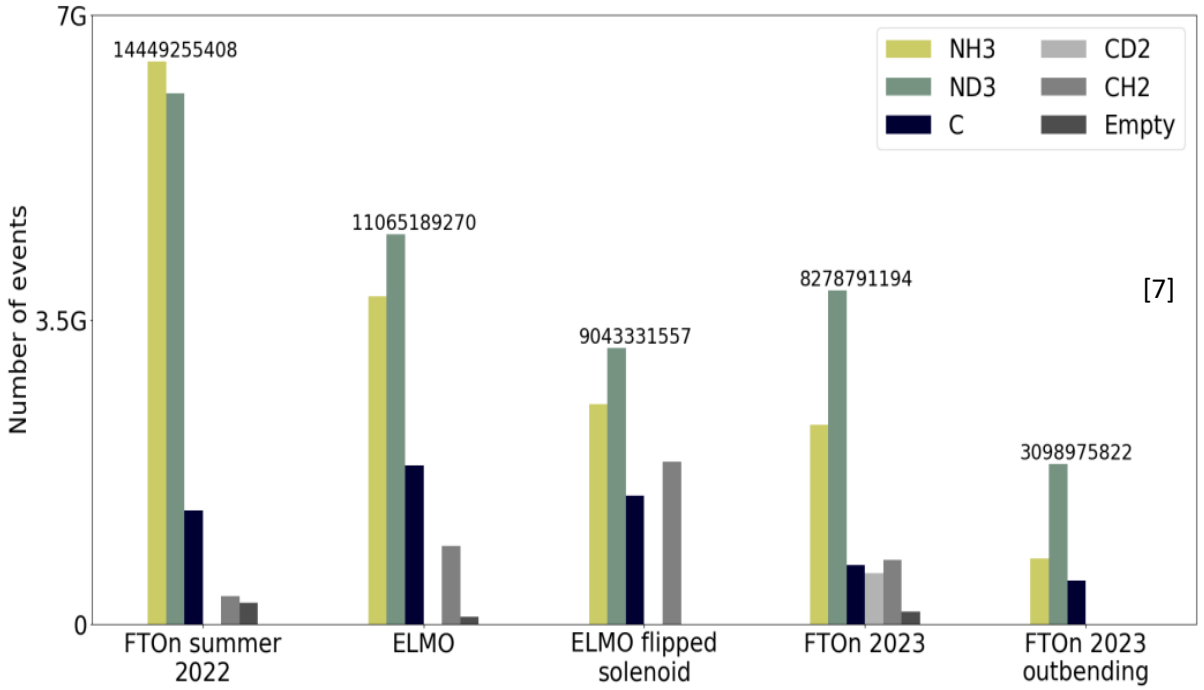


[7],[8]

Experimental Procedure

- Data taking finished on March 23rd
- There were 6 target configurations – NH3 is the subject of my analysis
- Total accumulated charge = 13.06mC

- Current status of data = 28 runs processed for analysis $\approx 6\%$ of total dataset, equally split between P_t^+ and P_t^-

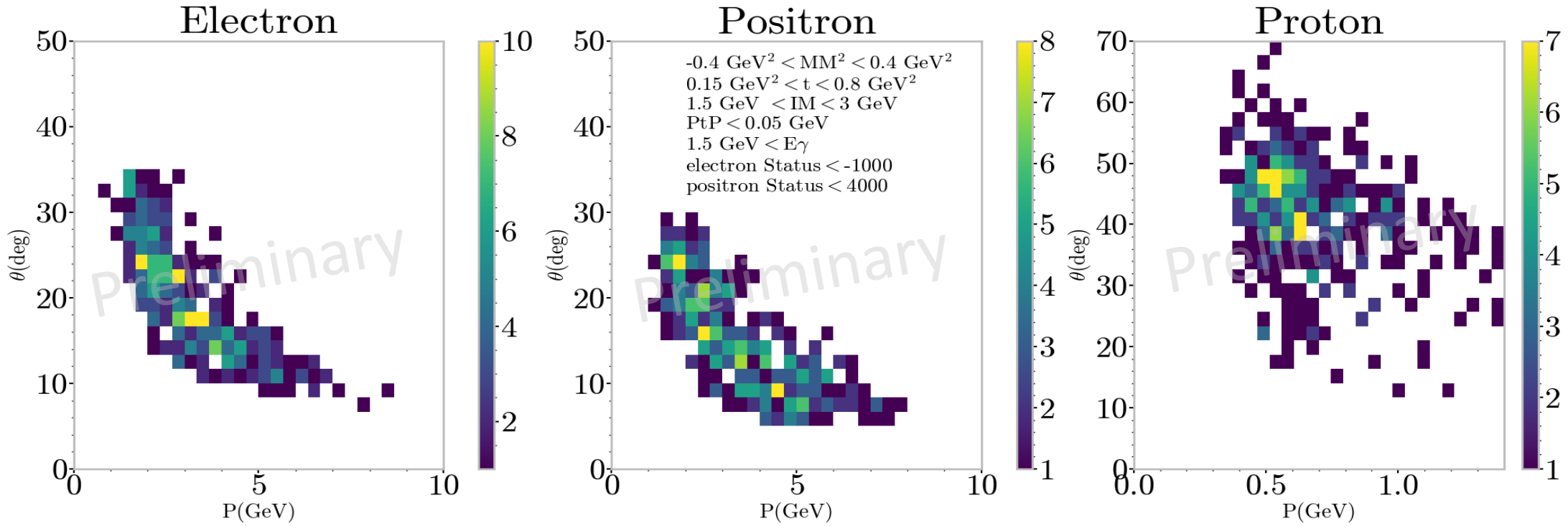


[7]

- FTOn = Forward Tracker on
- ELMO = Extra Large Möller Shield

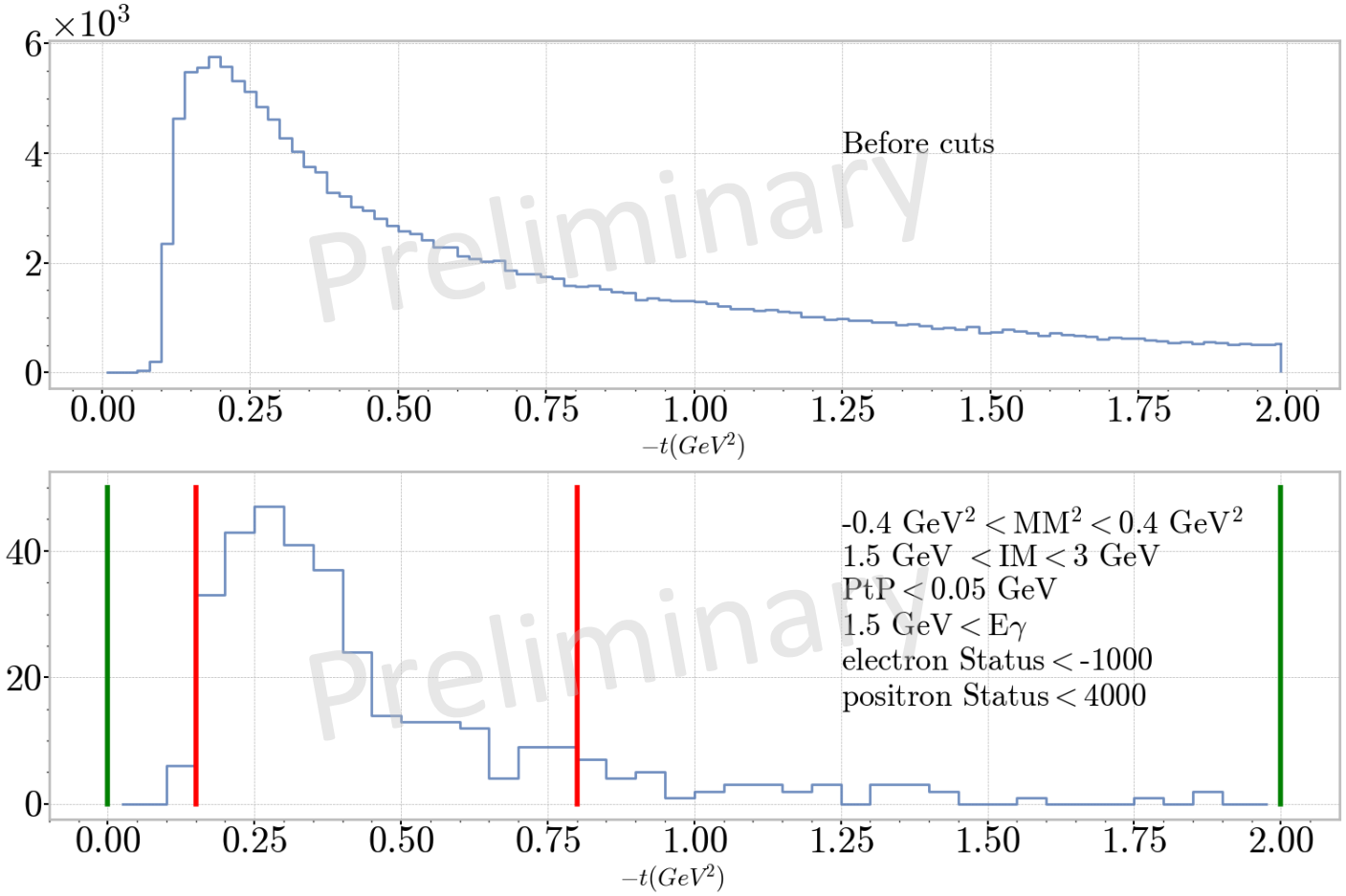
Final state particles

- Three final state particle momentum vs theta full exclusivity (tight t cut $0.15\ GeV^2 < t < 0.8\ GeV^2$)
- Follows shapes seen with first published TCS result on proton data[3]



Preliminary Results: $-t$

- $-t = (p' - p)^2 = (q - q')^2$ invaluable for accessing GPDs
- For statistics purposes require $0\text{GeV}^2 < -t < 2GeV^2$
- Tight cut proposed at $0.15\text{GeV}^2 < -t < 0.8GeV^2$



Preliminary Results: $MM_{e^-}^2$

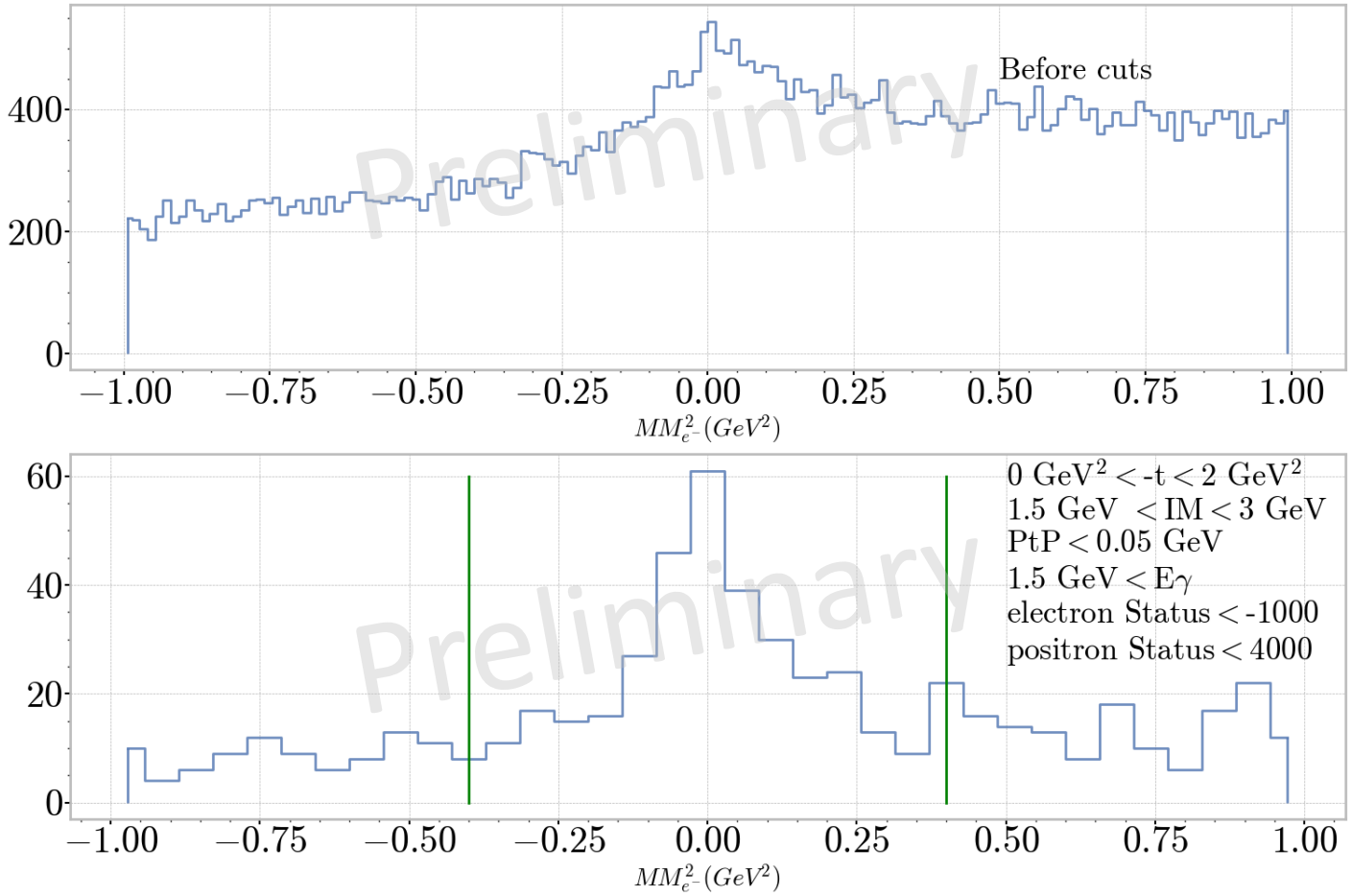
- MM^2 of scattered electron;

$$ep \rightarrow e'p'e^+e^-$$

$$ep \rightarrow Xp'e^+e^-$$

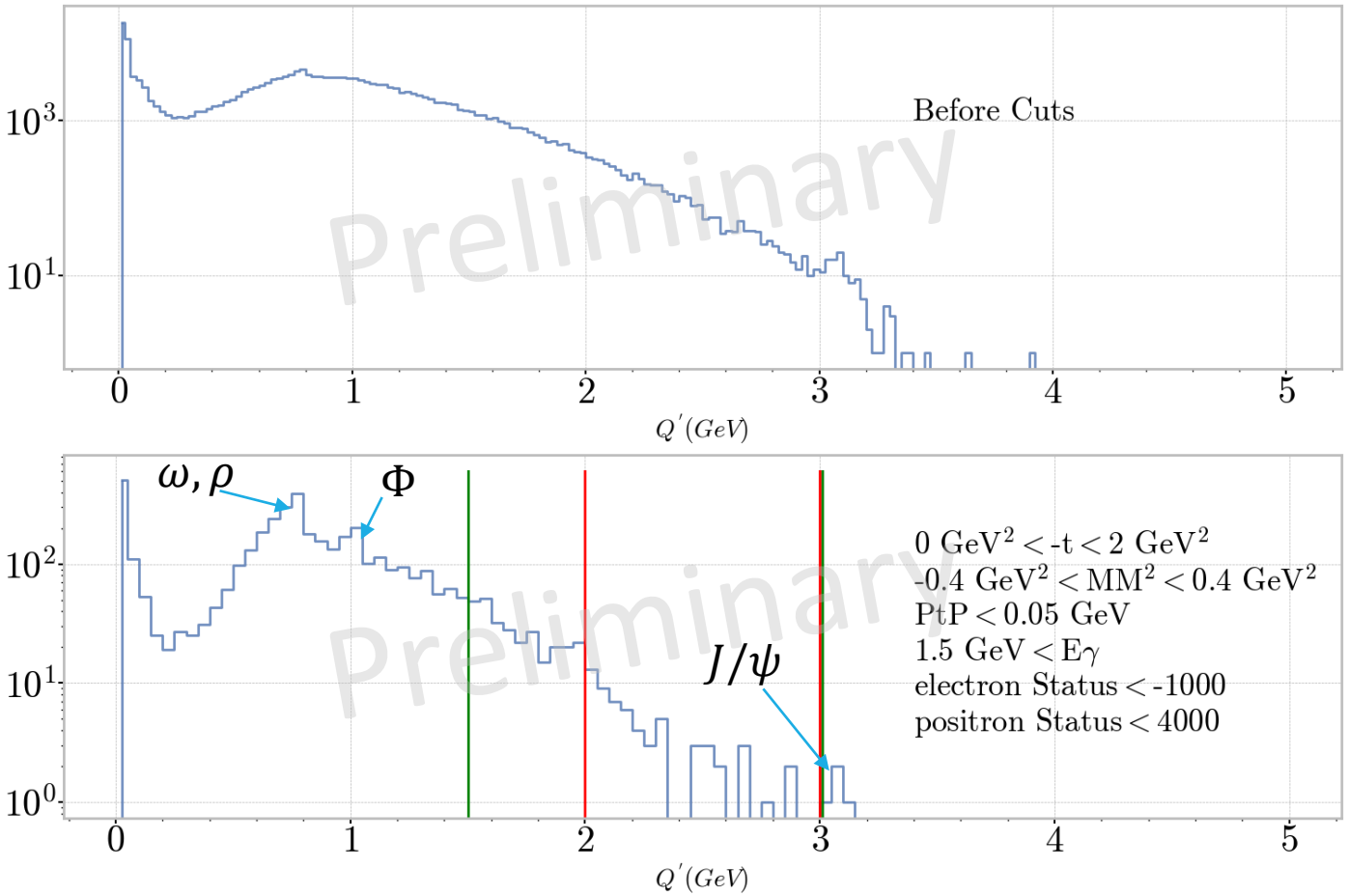
$$\Rightarrow e + p - p' - e^+ - e^- = X$$

- Large source of background after cuts attributed to NH_3 target
- Cut proposed at $\pm 0.4\ GeV^2$



Preliminary Results: Q'

- Q' = Invariant Mass of decay lepton pair ($Q' = e^+ + e^-$)
- Begin to see known meson peaks after cuts
- Loose cut proposed at
  $1.5\ GeV < Q' < 3\ GeV$
- Tight cut proposed at
  $2\ GeV < Q' < 3\ GeV$

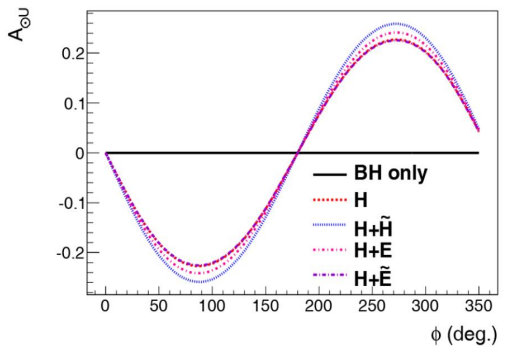


BSA and TSA – calculation procedure

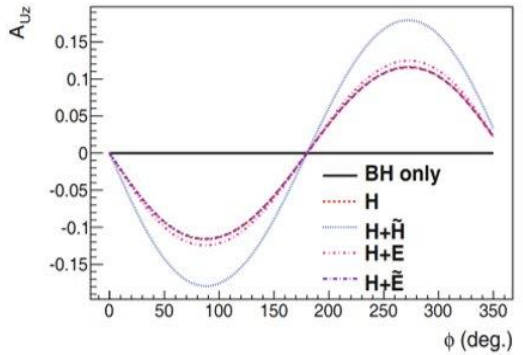
$$A_{LU} = \frac{P_t^-(N^{++} - N^{-+}) + P_t^+(N^{+-} - N^{--})}{Pb \times (P_t^-(N^{++} + N^{-+}) + P_t^+(N^{+-} + N^{--}))}$$

$$A_{UL} = \frac{N^{++} + N^{-+} - N^{+-} - N^{--}}{Df \times (P_t^-(N^{++} + N^{-+}) + P_t^+(N^{+-} + N^{--}))}$$

BSA



TSA



$N^{\{ij\}}$ = number of counts in ϕ histogram with beam helicity i and target polarization j

Pt^+/Pt^- = Value of positive/negative target polarisation, calculated using elastic analysis (N.Pilleux)

P_b = beam polarization – taken to be 83% after averaging across Möller run measurements

D_f = Dilution factor $\approx 1 - \frac{C}{NH3}$

Conclusions/Next Steps

- Can see trends comparable to published TCS result at this stage, can pick out expected features in preliminary kinematic distributions.
- New improvement in reconstruction included in most recent software mean that the next round of data processing is predicted to show improvements in many areas, notably reconstruction of the scattered proton.
- Calibrations for this run period still in progress – these are progressing on schedule, some resolutions will be expected to improve when these are complete.
- Simulation studies are the next step, before extraction of BSA and TSA observables on complete dataset.

REFERENCES

[1] *Science Requirements and Detector Concepts for the Electron-Ion Collider: EIC Yellow Report* e-Print: 2103.05419 [physics.ins-det]

[2] R. Milner, R. Ent (Jefferson Lab), C. Boebel, J McMaster (MIT), J. LaPlante: *Visualising the proton.* 2022 https://www.youtube.com/watch?v=e2FrALuacZ4&t=11s

[3] First Measurement of Timelike Compton Scattering. P. Chatagnon et al. (CLAS Collaboration) Phys. Rev. Lett. 127, 262501 – Published 22 December 2021

[4] Boër, M., Guidal, M. & Vanderhaeghen, M. Timelike Compton scattering off the proton and generalized parton distributions. *Eur. Phys. J. A* **51**, 103 (2015). https://doi.org/10.1140/epja/i2015-15103-3

[5] *An aerial view of Jefferson Lab* https://simple.wikipedia.org/wiki/Thomas_Jefferson_National_Accelerator_Facility#/media/File:Jlab_aerial1.jpg Accessed: 25/03/2023

[6] *The CLAS12 Detector* https://physics.uconn.edu/2020/09/16/ Accessed: 22/07/2022

[7] N. Pilleux *RGC end of run report* RG-C end of run and first look at physics (in2p3.fr) *Accessed:* 29/03/2023

[8] J. Brock *Performances of the longitudinally polarized target for CLAS12* International workshop on CLAS12 physics and future perspectives at JLab (21-24 March 2023): Performances of the longitudinally polarized target for CLAS12 · IJCLab Events Directory (Indico) (in2p3.fr) *Accessed:* 29/03/2023

Thank you

Questions?

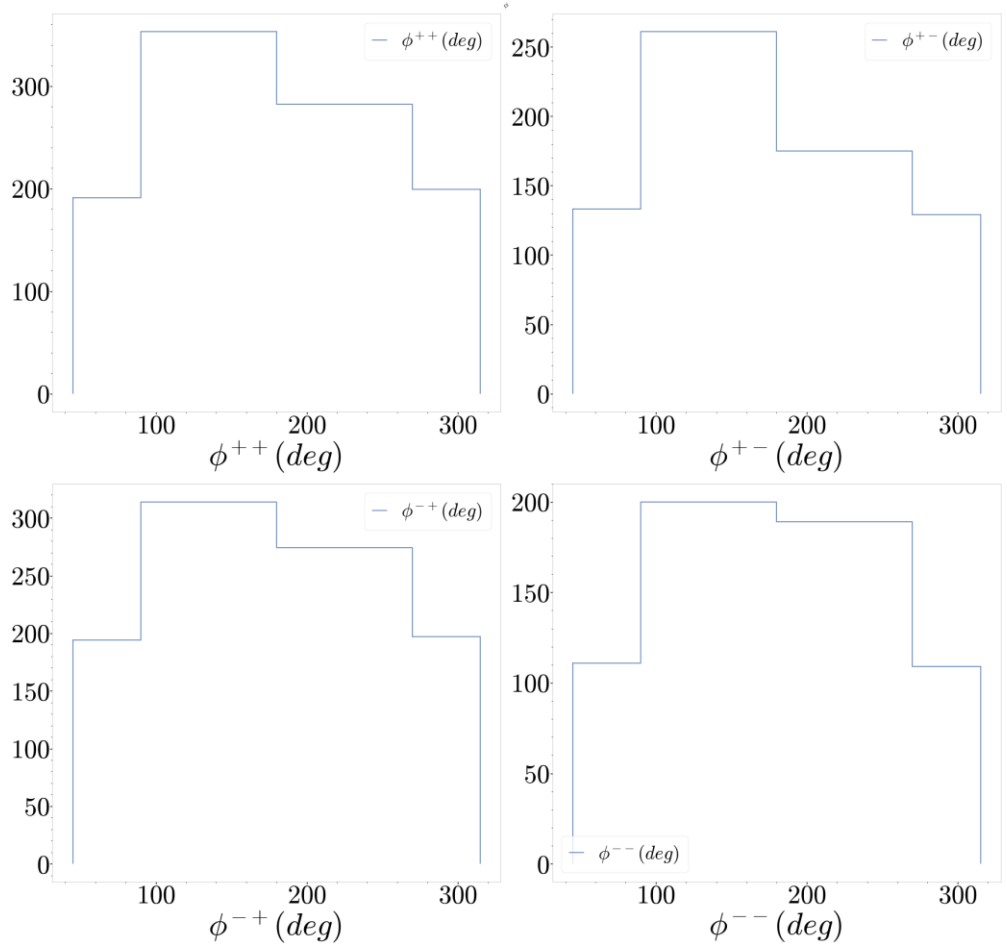
BACKUP

Asymmetries – Phi histograms

- $0.4GeV^2 > MM^2_{e'} > -0.4GeV^2$
- $3GeV > IM_{e^+e^-} > 1.5GeV$
- $10.6\,GeV > E_\gamma > 1.5GeV$
- $0.8GeV^2 > t(p'-p)^2 > 0.15GeV^2$

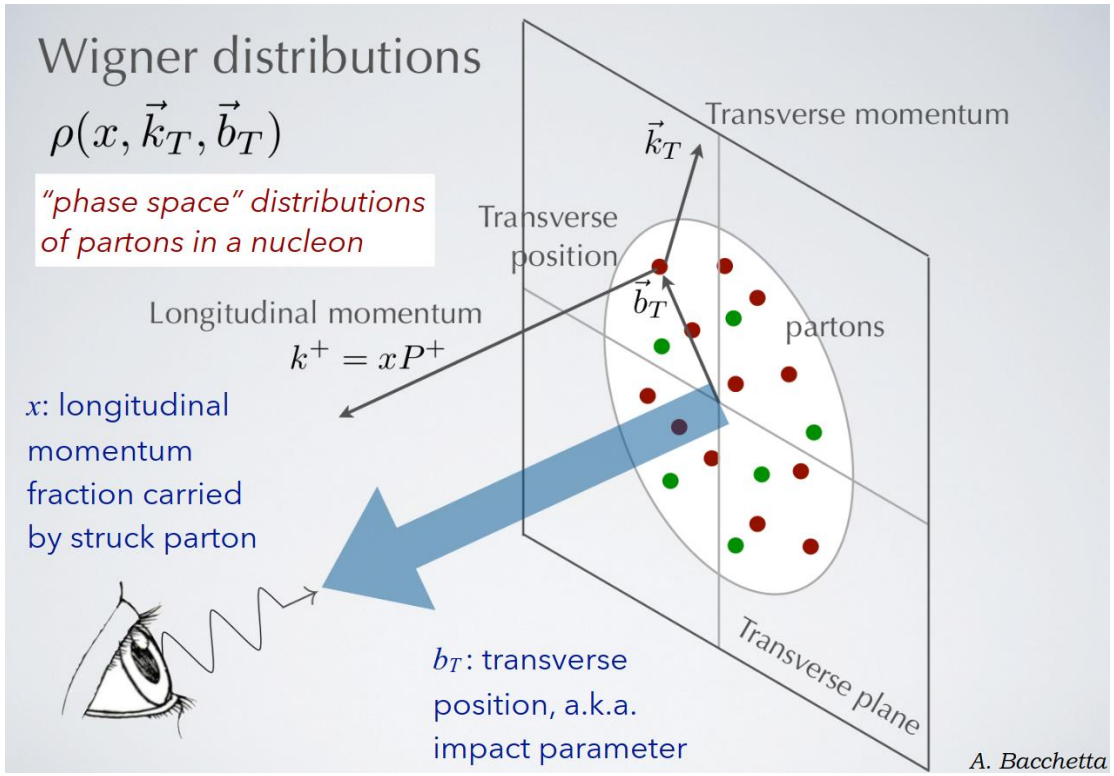
•Decay lepton pair in the FD

•Vertex time difference between decay lepton pair (decay electron Vt – decay positron Vt) < 1ns



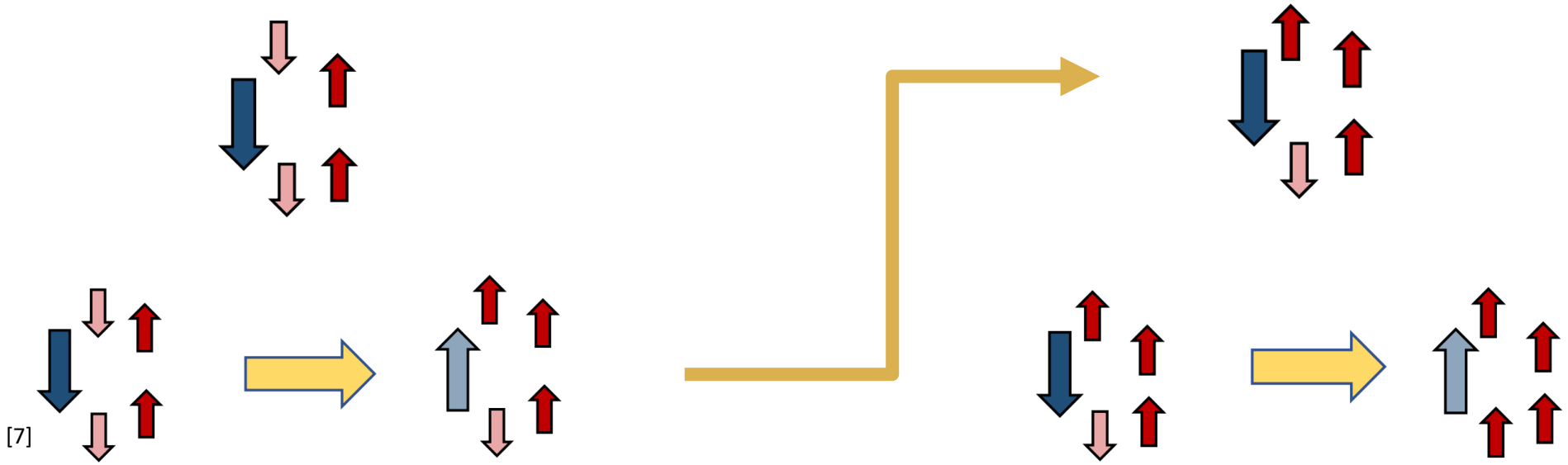
Internal Structure of Nucleons

- The distribution of partons in a nucleon can be represented by three variables;
  - x – describes the longintudinal momentum fraction carried by the struck parton
  - kT – describes transverse momentum of partons
  - bT – describes the impact parameter
- Integrating Wigner functions with respect to transverse momenta k_T(\rightarrow) gives Generalised Parton Distributions
- Information on these variables can be accessed through scattering processes, using electrons as a probe to scatter off of target nucleons.
- One such process is timelike compton scattering (TCS)



RGC Polarised target

- Longitudinally polarized NH3 and ND3 targets give access to observables of interest
- Target polarisation;



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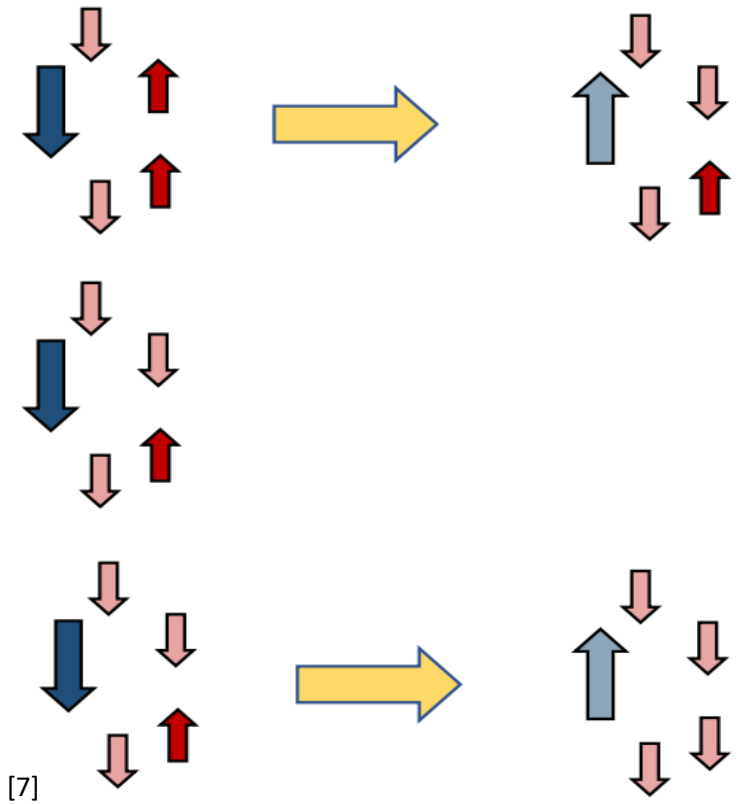

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