Exploring Nucleon structure with Timelike Compton Scattering

KAYLEIGH GATES, UNIVERSITY OF GLASGOW

Intro

Theory

The Timelike Compton Scattering (TCS) process

QCD and GPDs

Observables accessible with TCS

Obtaining each unknown

Jefferson Lab and The CLAS12 Detector

RGC Longitudinally Polarized Target and Experimental Procedure

Preliminary Results

Simulation Studies

Nuclear Background

Kinematic Comparisons

Conclusions

Timelike Compton Scattering (TCS)

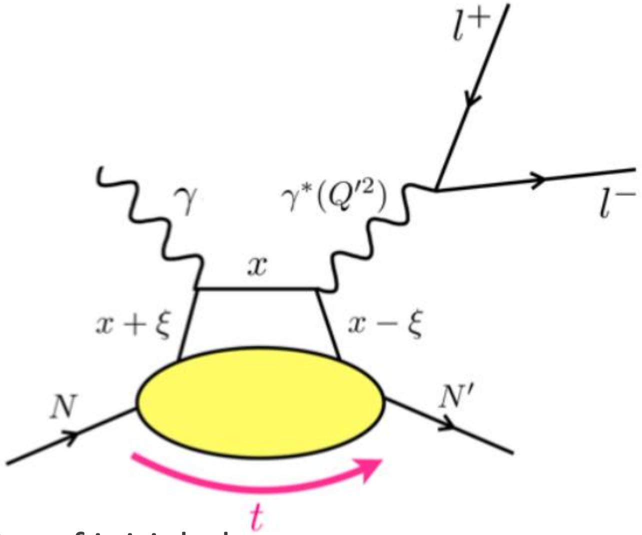
- A quasi real photon interacts with the target nucleon, causing release of virtual photon.

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

- A QED process with identical final state, Bethe-Heitler (BH), interferes with TCS at the amplitude level

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

[1]



Q^2 = virtuality of initial photon

$Q'^2 = q'^2 = (l^+ + l^-)^2$ virtuality of final state photon

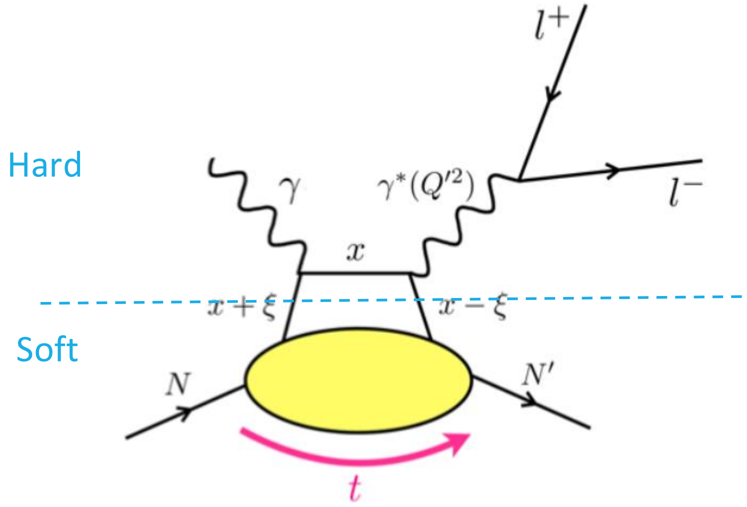
$t = (p'(N') - p(N))^2 = (q - q')^2$ four momentum transfer to struck quark

x = longitudinal momentum fraction of struck quark

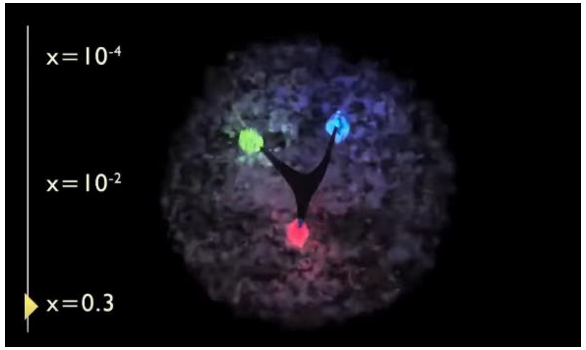
2ξ = longitudinal momentum fraction gained/lost by struck quark

Generalised Parton Distributions

- At high timelike photon virtuality, TCS scattering amplitude can be factorized.
- 'Hard' part → QED and perturbative QCD.
- 'Soft' part → non-perturbative QCD, described by four leading twist 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.



[2]

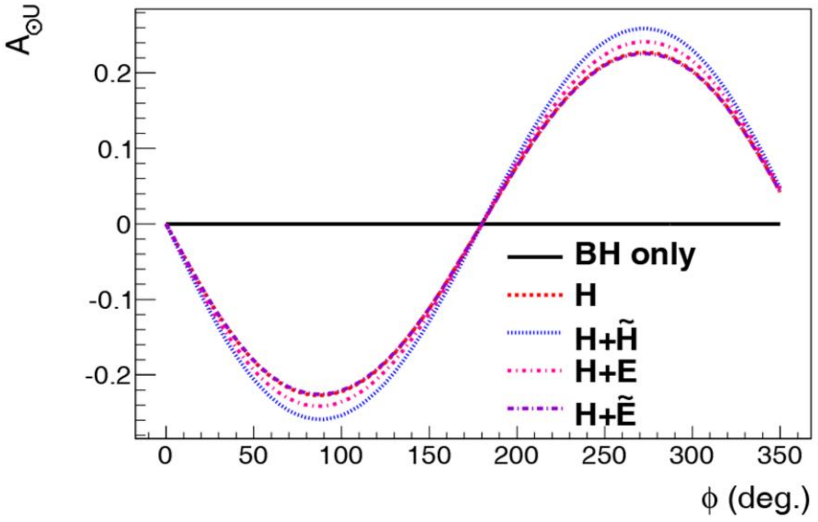


Observable Predictions

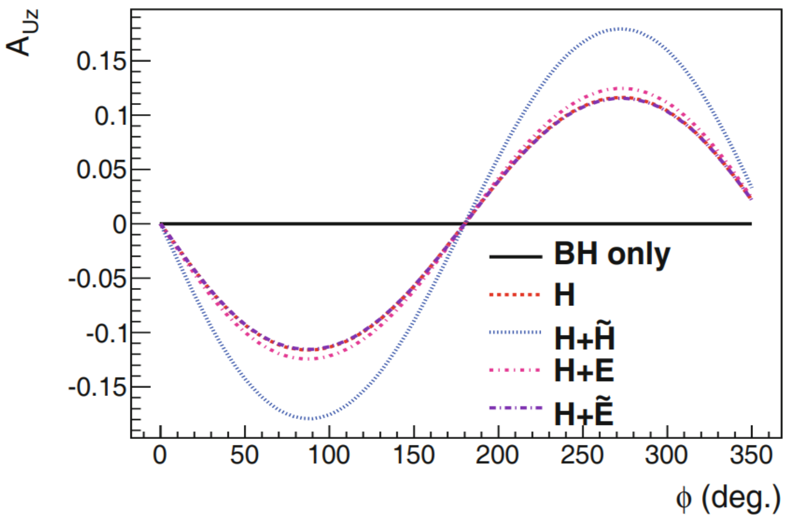
- Beam Spin Asymmetry – H dominates, first ever measurement of TCS in 2021[3], continuation of this effort on a polarized target.
- Target spin asymmetry – Access to H and $\widetilde{H}$
- Measurements accessing H allow investigation into GPD universality, $\widetilde{H}$ is less known, both Deeply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

[4]

BSA



TSA

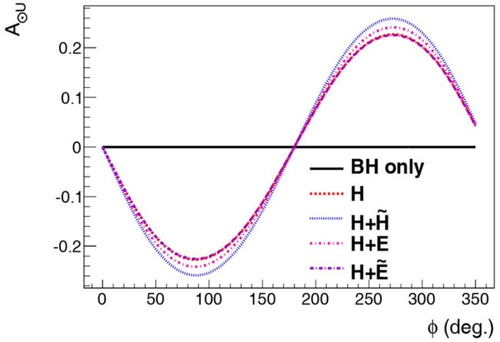


BSA and TSA – calculation procedure

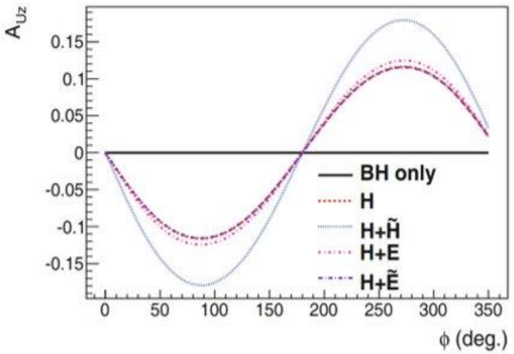
$$A_{LU} = \frac{P_t^-(N^{++}-N^{-+})+P_t^+(N^{+-}-N^{--})}{Pb\times(P_t^-(N^{++}+N^{-+})+P_t^+(N^{+-}+N^{--}))}$$

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

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 ~ 12% based on sPlot Signal to Background split

Obtaining each unknown

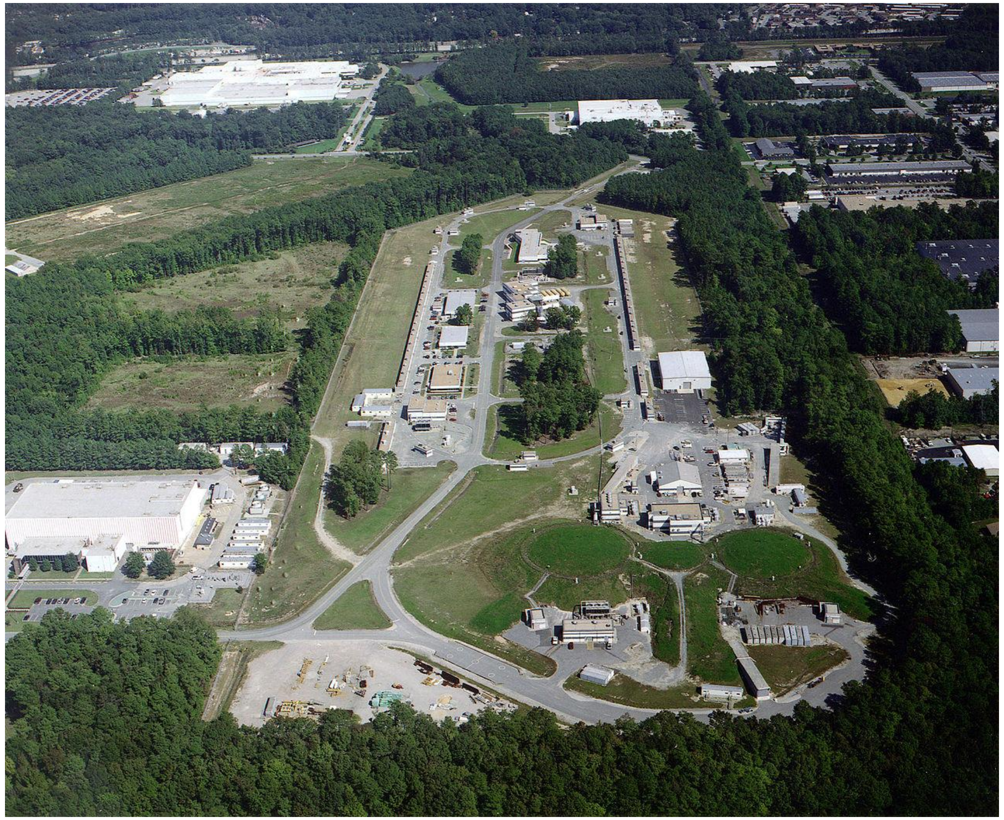
Jefferson Lab

- 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.

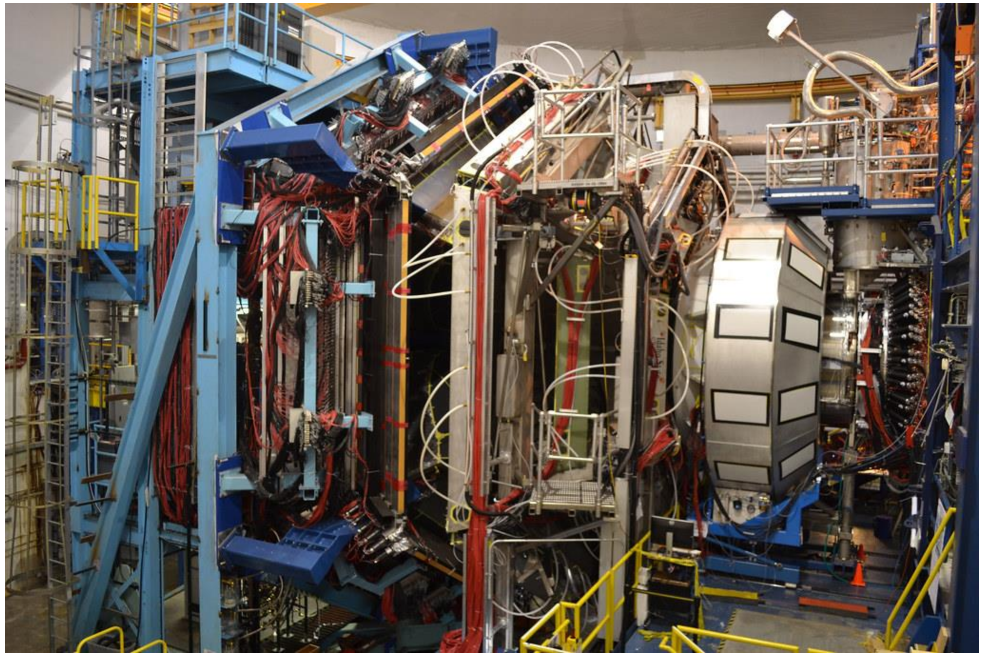
  - Hall D - - home of the GlueX (the Gluonic Excitation Experiment), and has a dedicated photon beamline.



[5]

CLAS12 – Jefferson Lab

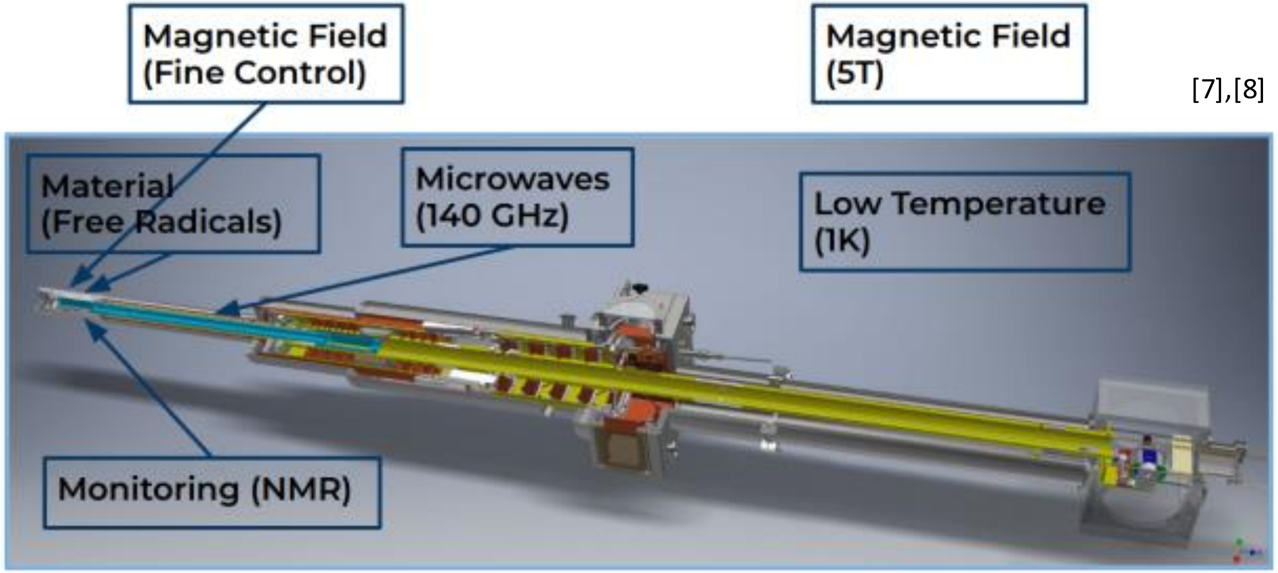
- Close to full azimuthal angular coverage
- Polar angle θ range $35^\circ - 125^\circ$ covered by the central solenoid magnet and detector
- Forward polar angle range $< 35^\circ$ covered by the superconducting torus magnet and forward detector, including a forward tagger (FT) .
- Allows for efficient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



[6]

Longitudinally Polarised Target

- Paramagnetic target material dynamically polarised 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 localised depolarisation

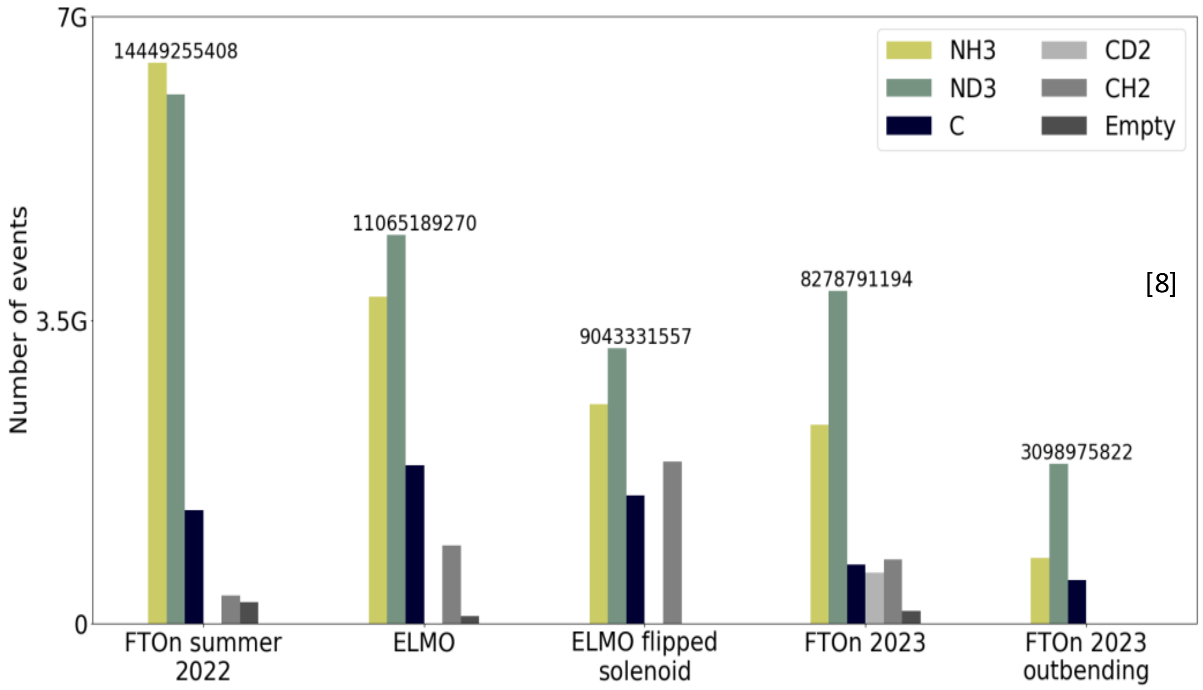


[7],[8]

Experimental Procedure

- Quasi-real photoproduction data taken using electron beam at 10.6 GeV
- Data taking finished on March 23rd
- There were 6 target configurations – NH_3 is the subject of my analysis
- Total NH_3 accumulated charge = 13.06mC

- Current status of data = 157 runs processed for analysis, 4.2mC $\approx$ 32% of total dataset, equally split between P_t^+ and P_t^-



[8]

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

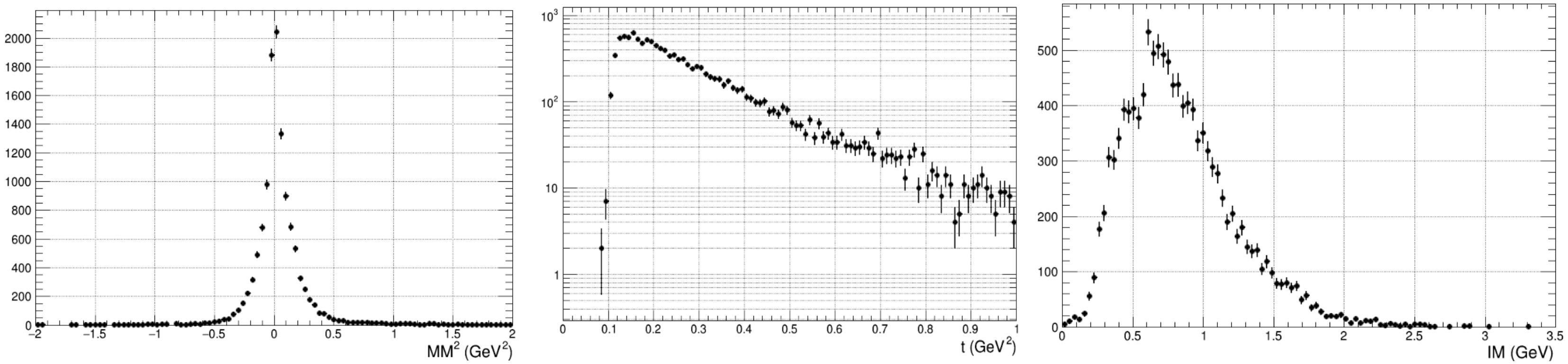
Simulation Studies

GRAPE and TCSGen

GRAPE [9]

- Unweighted
- Conditions – 10.6GeV electron beam, elastic dilepton production, full invariant mass range
- Simulates Bethe Heitler and QED Feynmann diagrams
- 2.2M events generated

GRAPE

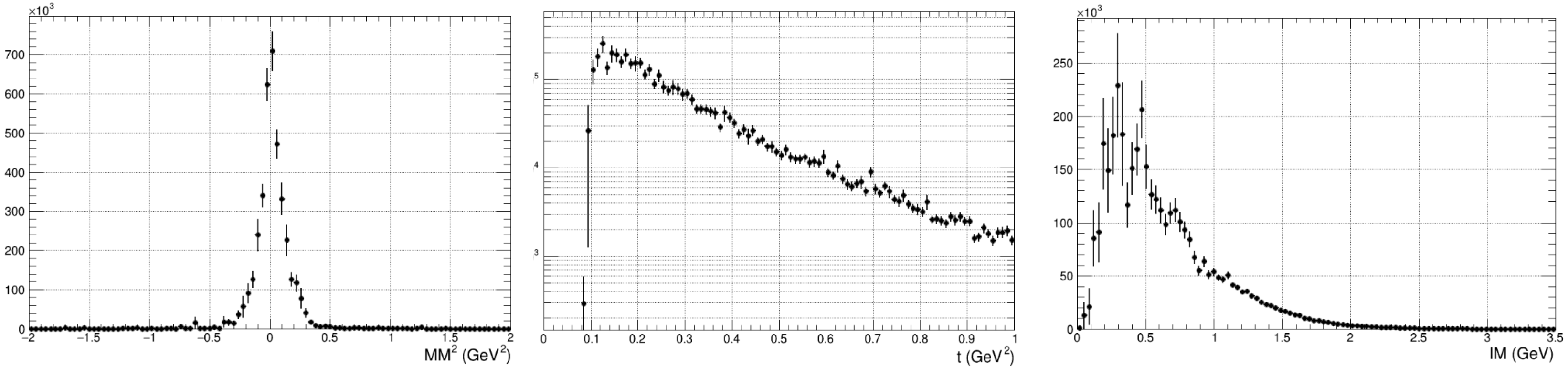


TCSGen[10]

- Weighted
- Conditions – full invariant mass range
- Simulates BH and TCS + BH interference
- 1M events generated

Both simulations passed through OSG with RGC Summer FTON configuration, no background merging.

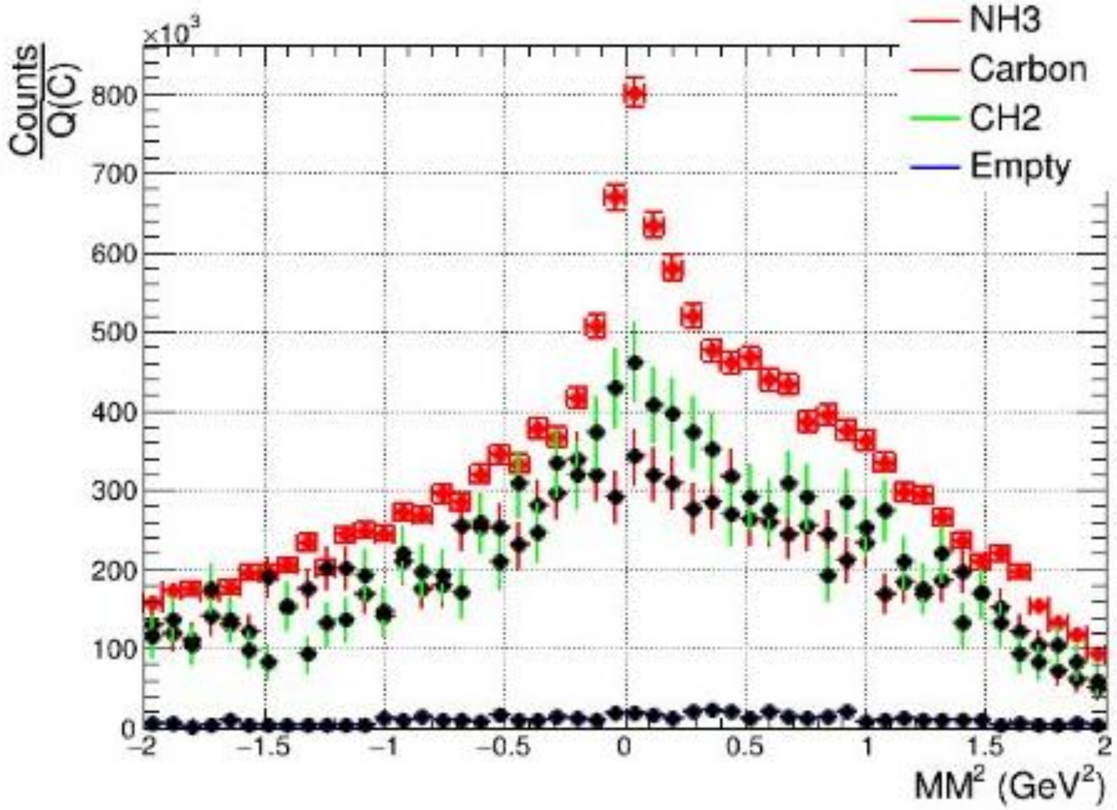
TCSGen



Accounting for Nuclear Background

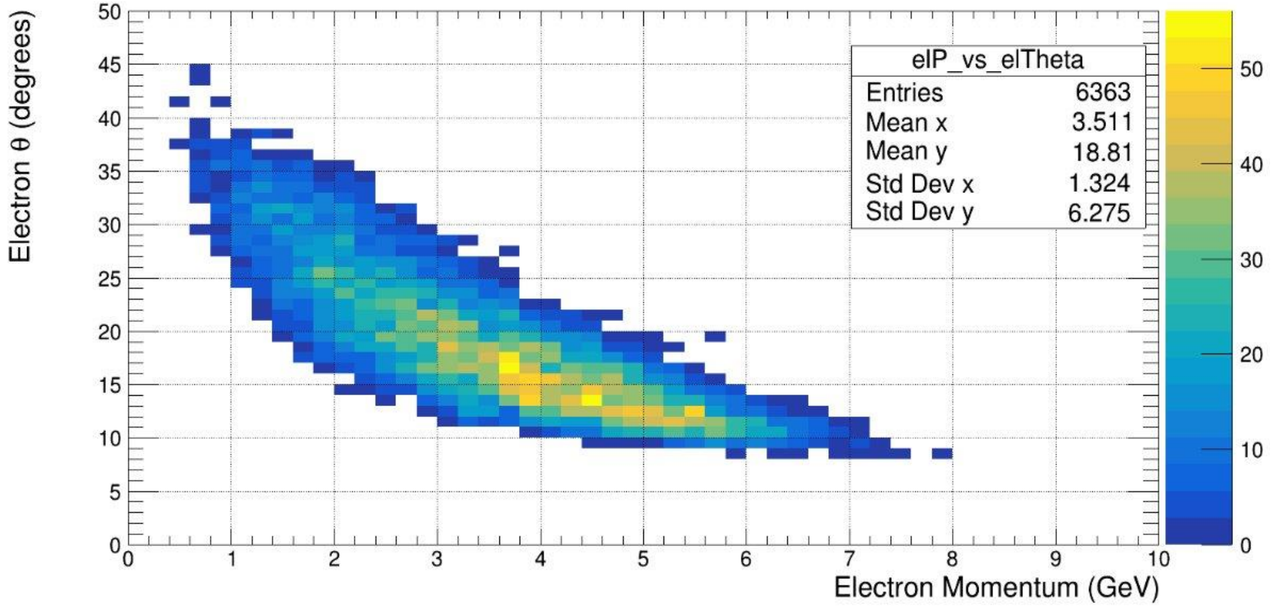
Dilution factor

- Proportion of events that are attributed to signal with respect to those from nuclear background contributions
- Have Carbon target to model background effects from Nitrogen
- Have CH2 target to model the carbon + two hydrogen atoms that form background
- Have Empty target which models refrigerator foils, Liquid helium and target cell contributions
- Approximately 18% -20% for TCS

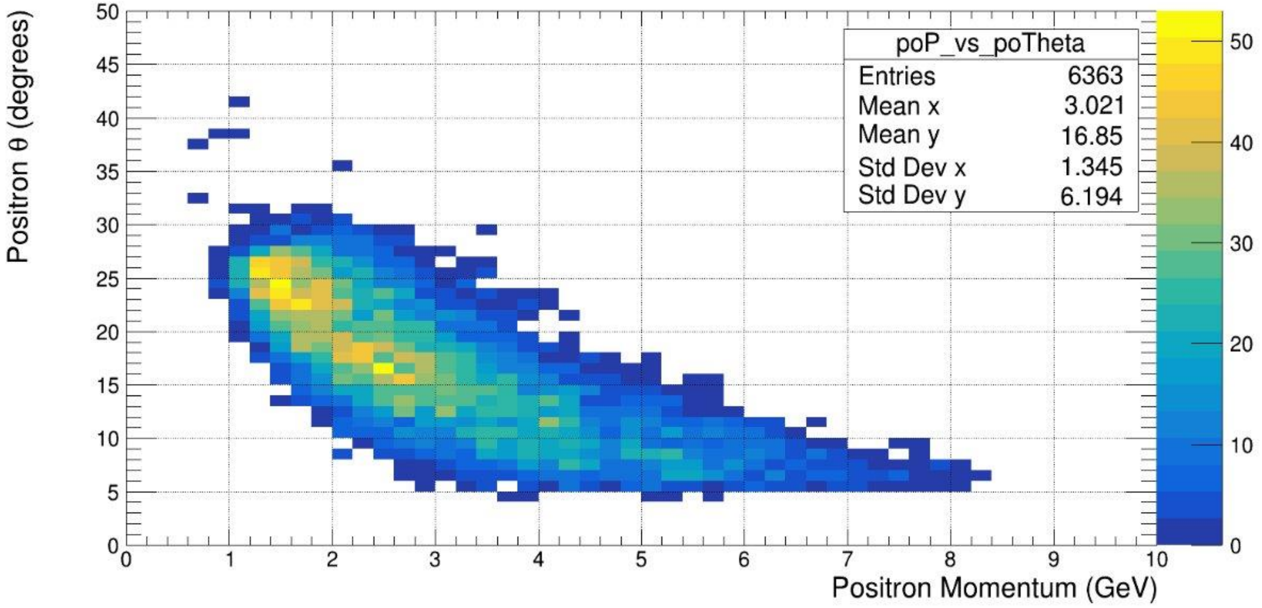


$$DF = \frac{9(n_A - n_{MT})\rho_A(l_C L(-n_{CH} + n_{MT})\rho_C + l_C l_{CH}(n_F - n_{MT})(\rho_C - \rho_{CH}) + l_{CH} L(n_C - n_{MT})\rho_{CH})}{n_A(9 l_C L(-n_{CH} + n_{MT})\rho_A\rho_C + 2 l_{CH} L(n_C - n_{MT})\rho_A\rho_{CH} + l_C l_{CH}(n_F - n_{MT})(9\rho_A\rho_C - 2(\rho_A + 3\rho_C)\rho_{CH}))}$$

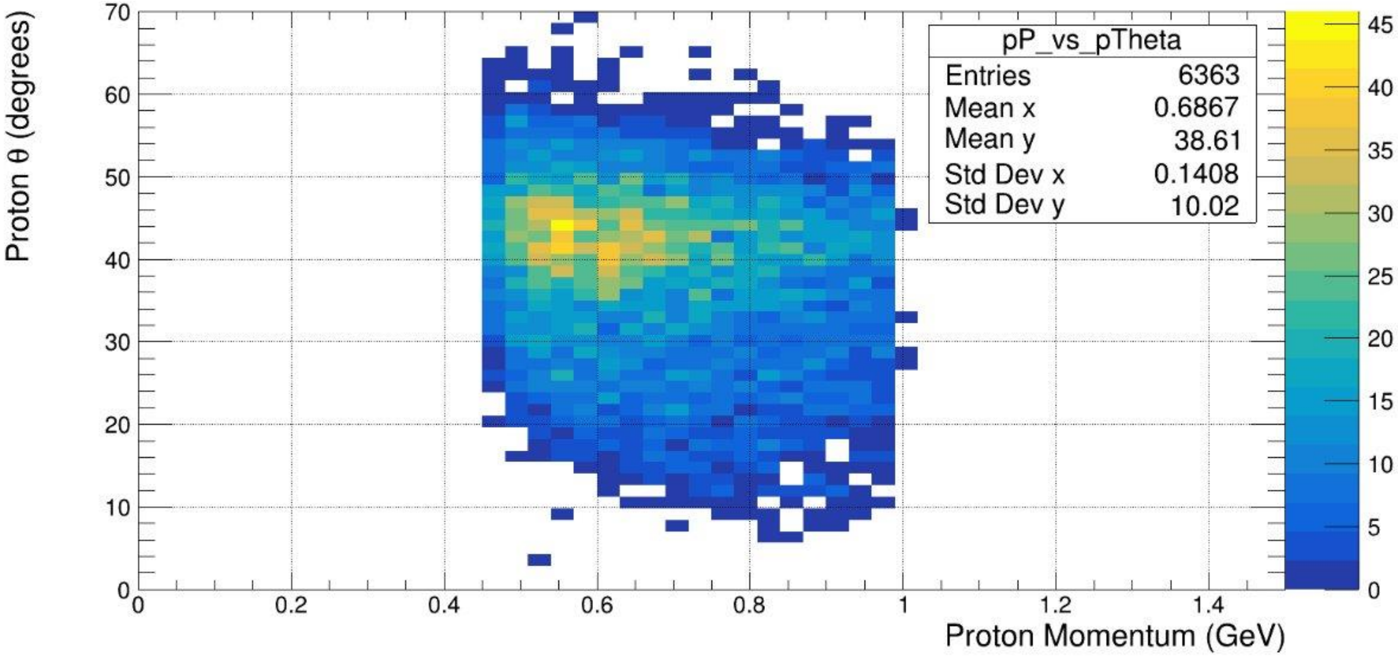
Final State Kinematics



elP_vs_elTheta
Entries 6363
Mean x 3.511
Mean y 18.81
Std Dev x 1.324
Std Dev y 6.275
Electron θ (degrees)
Electron Momentum (GeV)

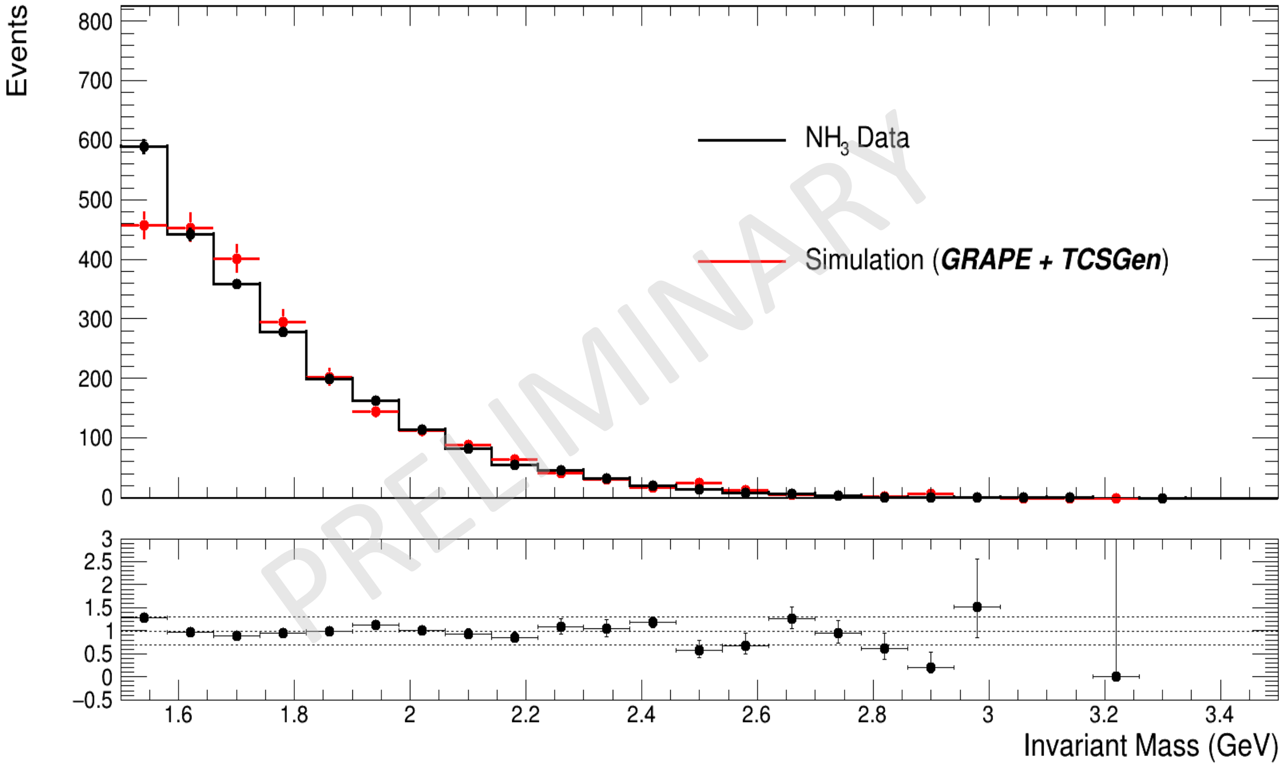


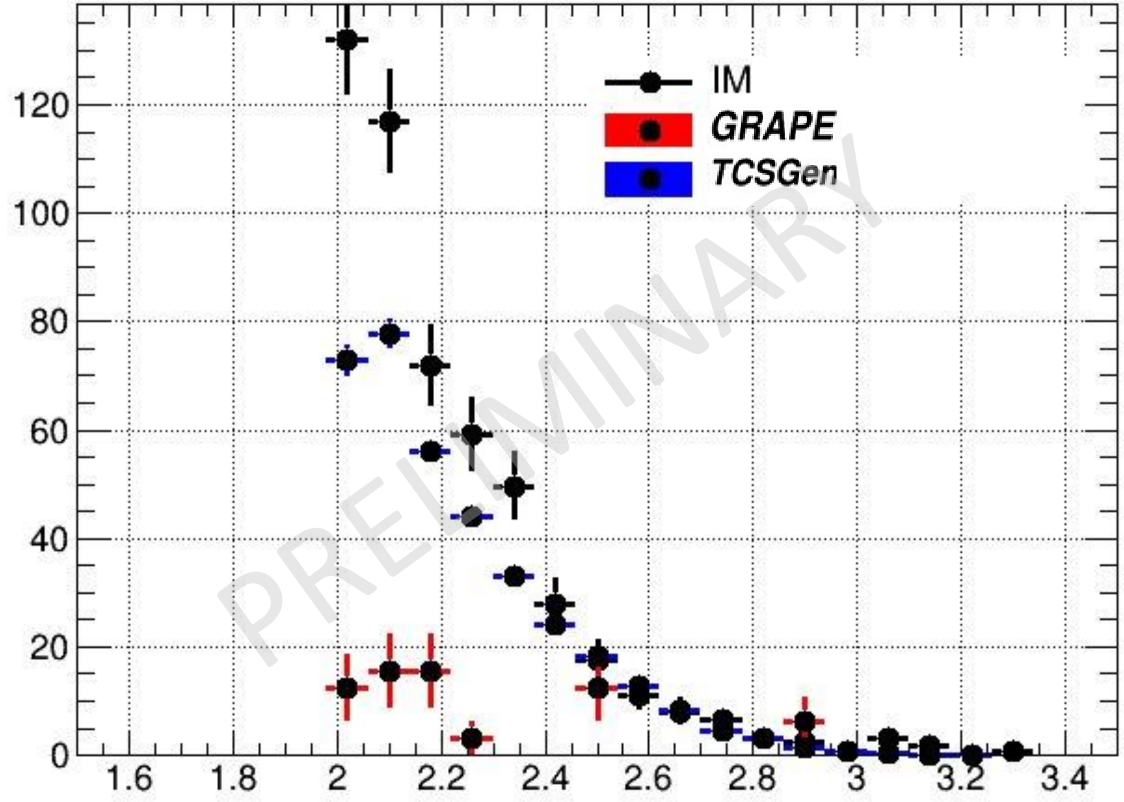
poP_vs_poTheta
Entries 6363
Mean x 3.021
Mean y 16.85
Std Dev x 1.345
Std Dev y 6.194
Positron θ (degrees)
Positron Momentum (GeV)



pP_vs_pTheta
Entries 6363
Mean x 0.6867
Mean y 38.61
Std Dev x 0.1408
Std Dev y 10.02
Proton θ (degrees)
Proton Momentum (GeV)

IM = $M_{\{e^{+}+e^{-}\}}$


Events
NH$_3$ Data
Simulation (***GRAPE + TCSGen***)
PRELIMINARY
Invariant Mass (GeV)


IM
GRAPE
TCSGen
PRELIMINARY

Conclusions/Next Steps

- TCS is a key channel for exploring the universality of GPDs
- Measuring TCS is being explored for the first time on a longitudinally polarised target at Jefferson Lab
- Can see trends comparable to published TCS result at this stage, can pick out expected features in preliminary kinematic distributions.
- Good statistics in final state bodes well for a multidimentional binned asymmetry extraction.

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

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

[9] Abe, T., 2001. GRAPE-Dilepton (Version 1.1): A generator for dilepton production in ep collisions. *Computer physics communications*, *136*(1-2), pp.126-147.

[10] GitHub - JeffersonLab/TCSGen: Generator for Timelike Compton Scattering.

Thank you for your attention

QUESTIONS?

Normalising events to data

- Q = 4.2mC
- l = 5cm
- N_t = 3 (three free protons in NH_3)
- N_A = 6.02×10^{23}
- C = conversion factor from $cm^{-2} \rightarrow pb^{-1}$
- e =electron charge $1.602 \times 10^{-19}\ C$
- M_t = molar mass of NH_3 $17.03\ g/mol$
- ρ = the density of target material $0.817 g.cm^{-3}$ (density of solid NH_3 at $-80\ °C$), multiplied by packing fraction of 60%

$$L_{INT} = N_{beam} \times n_{Target} = \frac{Q}{e} \times \frac{l\ \cdot \rho \cdot N_t \cdot N_A \cdot C}{M_t}$$

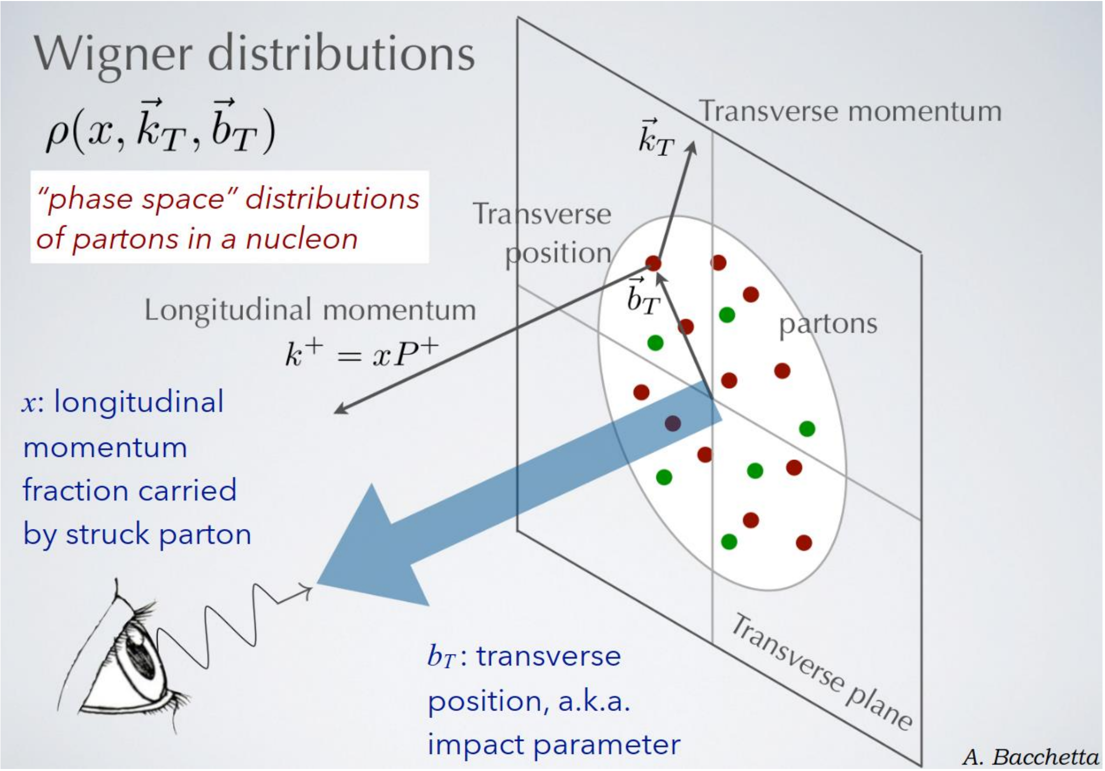
$$L_{INT} = 2163.328\ pb^{-1}$$

$$\omega_{\{GRAPE\}} = L_{INT} \times \frac{\sigma_{GRAPE}}{N_{GEN}} = 2163.328 \times \frac{387.096}{N_{Gen}}$$

$$\omega_{\{TCSGen\}} = L_{INT} \times \frac{p_{beam} \times e_{beam} \times w_{gen}}{N_{GEN}} = 2163.328 \times \frac{W}{N_{Gen}}$$

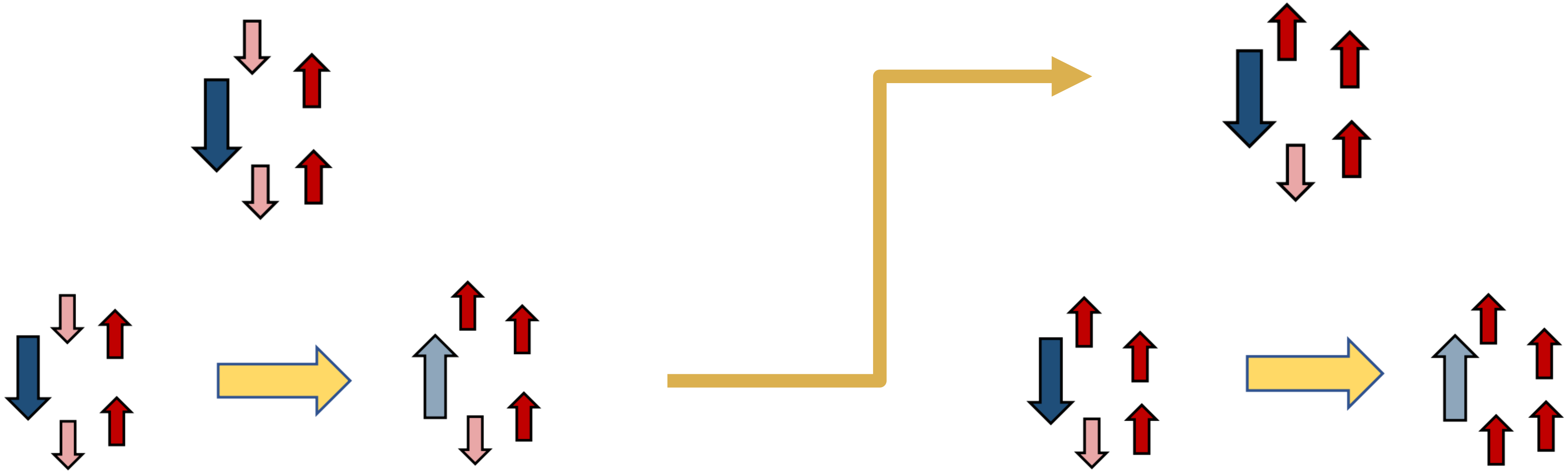
Internal Structure of Nucleons

- 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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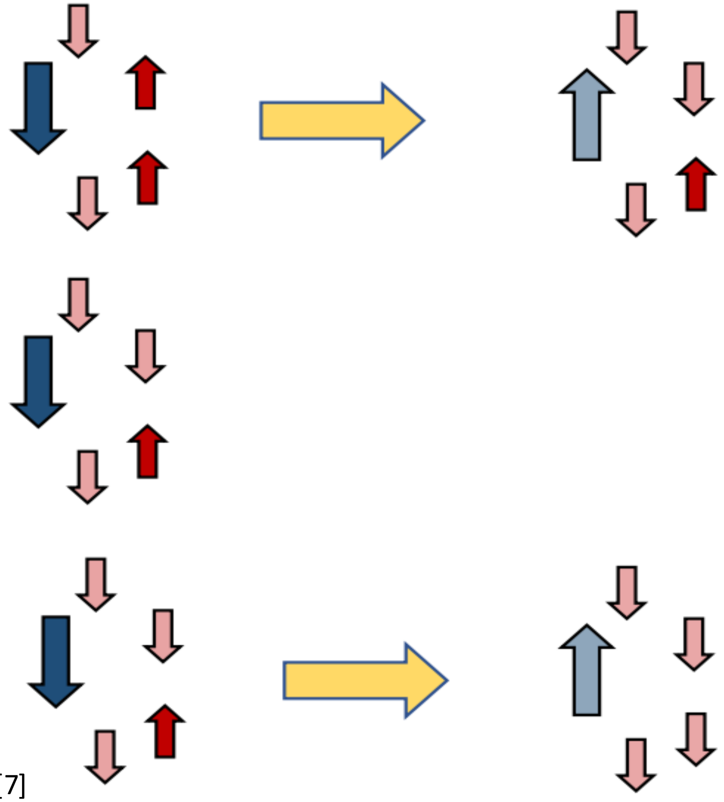

[7]