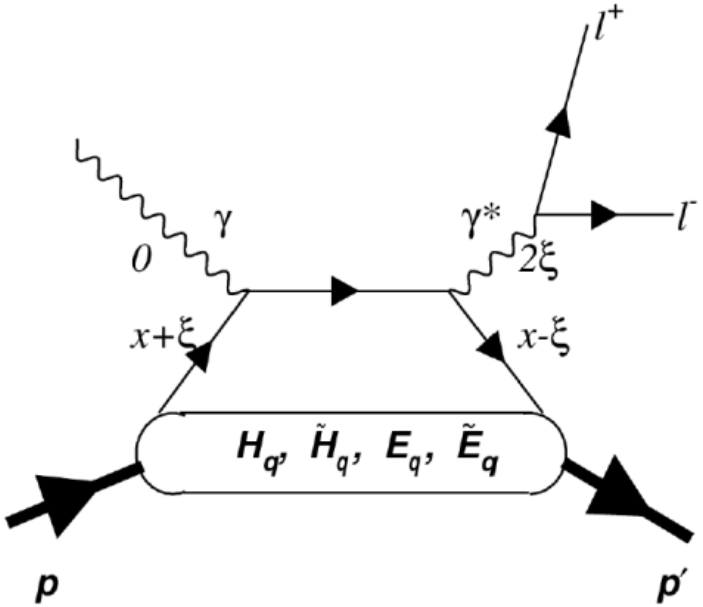
Timelike Compton Scattering



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3-D Structure of the Nucleon

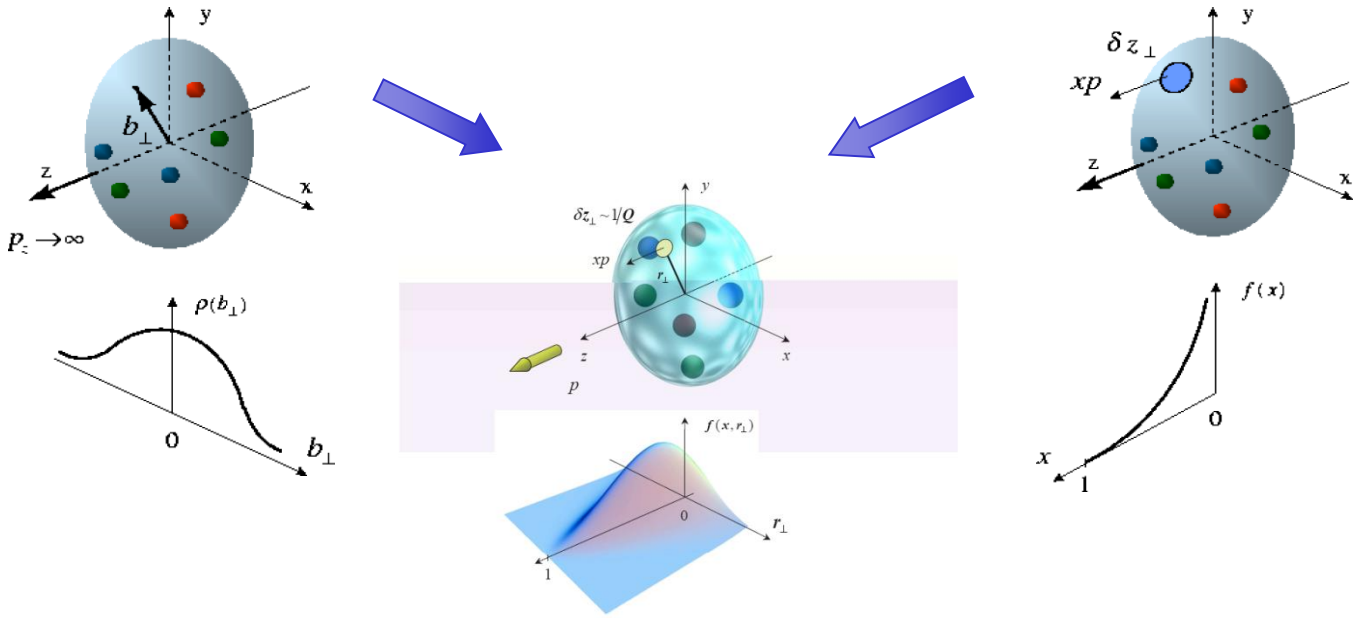
Form Factors

transverse charge and magnetization distributions

(GPD integrated over x)

Parton Distributions Functions (PDFs)

longitudinal momentum (DIS)



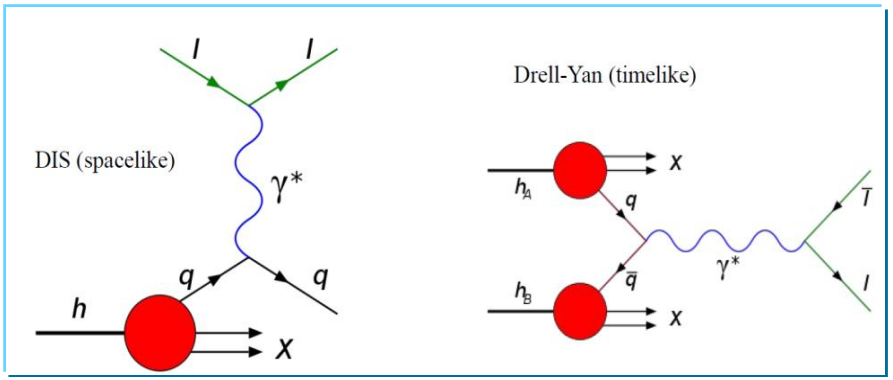
Generalized Parton Distributions (GPDs)

Transverse spatial distribution of quarks with longitudinal momentum fraction x

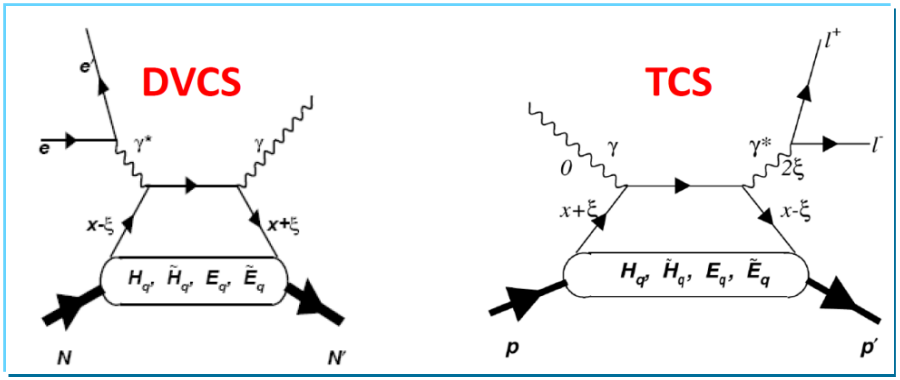
GPDs “unify” form factors and parton distributions

Timelike-spacelike Correspondence and Universality

- Spacelike DIS and timelike Drell-Yan processes both factorize into partonic cross section and a Parton Distribution Function (PDF)
  - Measurement of both demonstrated the universality of PDFs



- In Deeply Virtual Compton Scattering (DVCS) there is a similar factorization at the amplitude level into a perturbative coefficient function and a Generalized Parton Distribution (GPD)



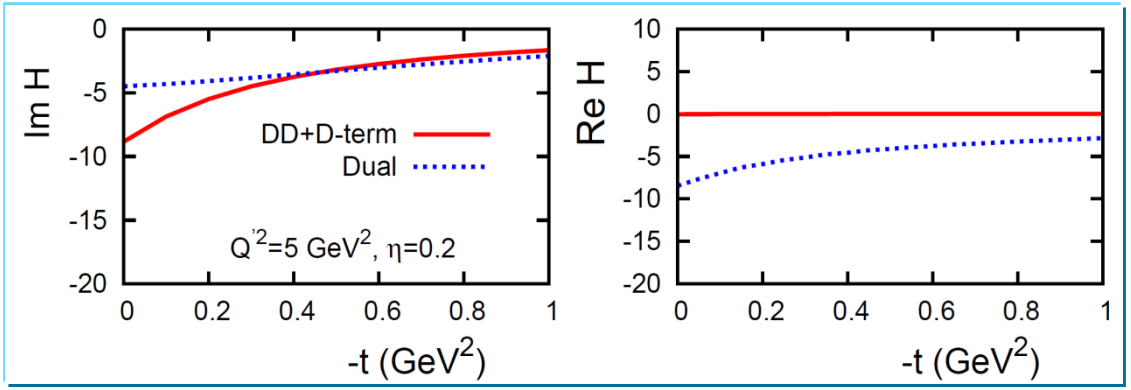
- In TCS the real part of the scattering amplitude can be accessed through the azimuthal angular asymmetry of lepton pair (unpolarized beam and target) or through the spin asymmetries (polarized beam and/or polarized target).

Measurement of *both* spacelike DVCS and Timelike Compton Scattering (TCS) can test the universality of GPDs

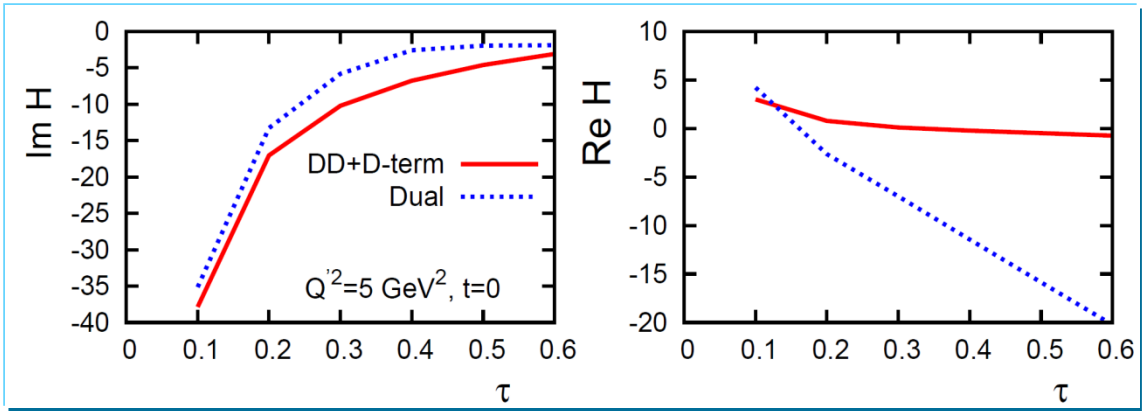
GPD models sensitive to real part at large x

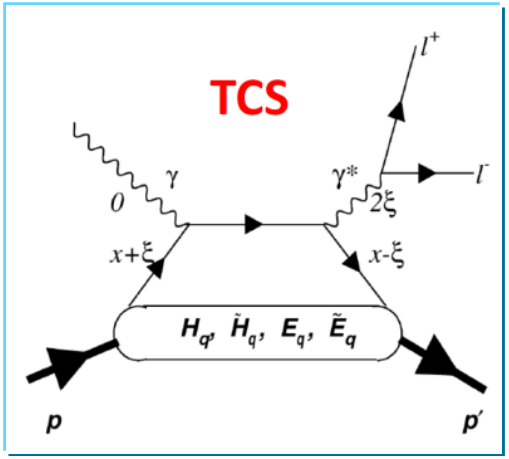
Model predictions similar for Im H, but large differences for Re H

[Calculation by V. Guzey, 2010]



TCS provides straightforward access to the real part through azimuthal asymmetry of the lepton pair



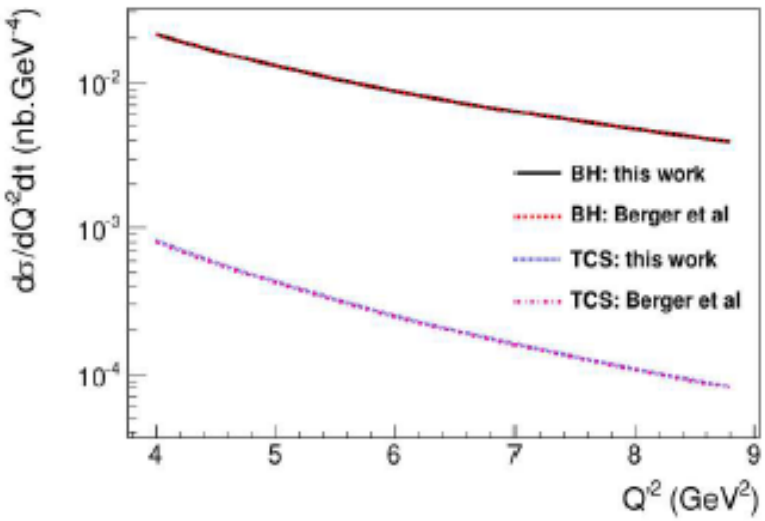


$$\tau = \frac{Q'^2}{s - M_p^2}$$ is the equivalent of Bjorken *x*

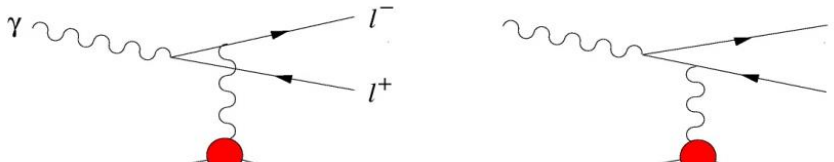
$$Q'^2 = M^2_{e^+e^-}$$ is the virtuality of the outgoing photon, which gives the hard scale

Photoproduction of Lepton Pairs

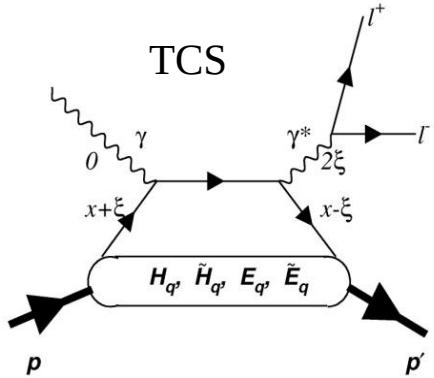
•Interference with B-H allows one to isolate TCS in measurements of asymmetries (*Cosφ* moment in unpolarized experiment, and spin asymmetries in polarized experiments).



Bethe-Heitler (BH)



TCS



- Both TCS and BH processes contribute
  - TCS cross section is smaller than BH
- TCS-BH interference term is enhanced by BH and easy to isolate
  - Under lepton charge conjugation observables that change sign *project out only the interference term*

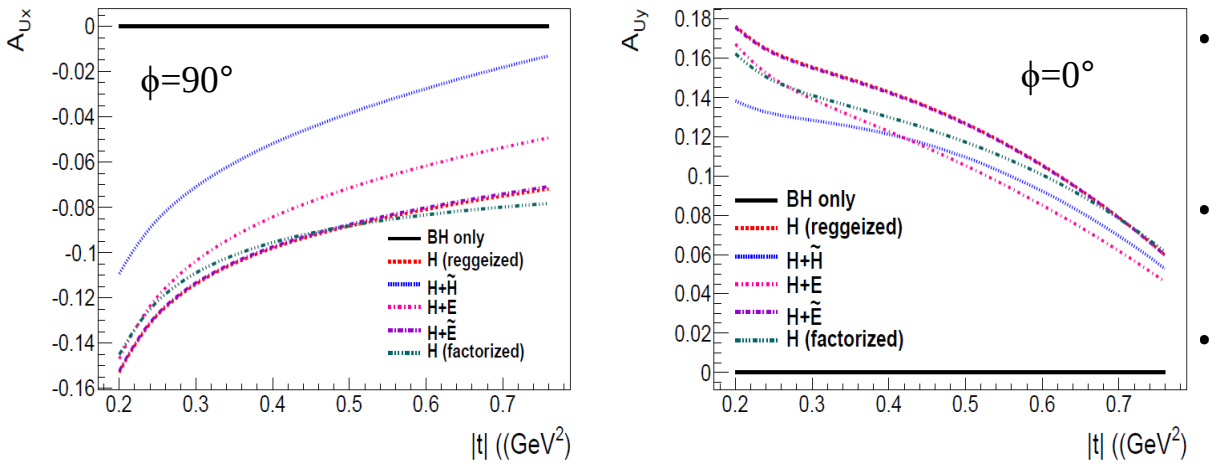
TCS measurements at JLab 12 GeV

- With polarized beam and unpolarized target (CLAS 12 /E12-12-001 & SOLID)

  With polarized photons will measure TCS differential cross section and weighed cross section (R) as a function of –t. and Q'^2 in wider kinematic ranges, which is essential for understanding factorization.

- With polarized beam and transversely polarized target in Hall C – LOI PAC43 (2015)

"transverse"

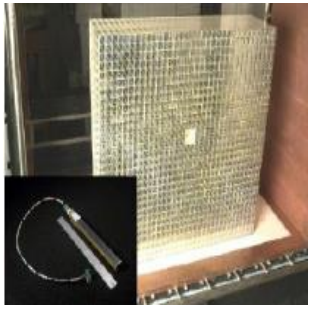


- Theoretical calculations for TCS on polarized target (Boer & Guidal) show that Transverse asymmetries are very sensitive to GPDs
- Predictions for asymmetries with different assumption of GPDs vary up to 20% (experimentally measurable).
- Asymmetries for the B.-H. which is main background for TCS is zero !

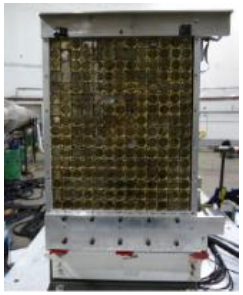
Theoretical predictions for TCS on polarized target (M. Boer, M. Guidal, arXiv:1412.2036, Dec 2014)

Transversely polarized target opens interesting opportunities to probe GPD E-amplitude

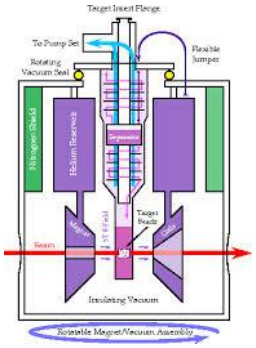
TCS events detection in Hall C



$PbWO_4$

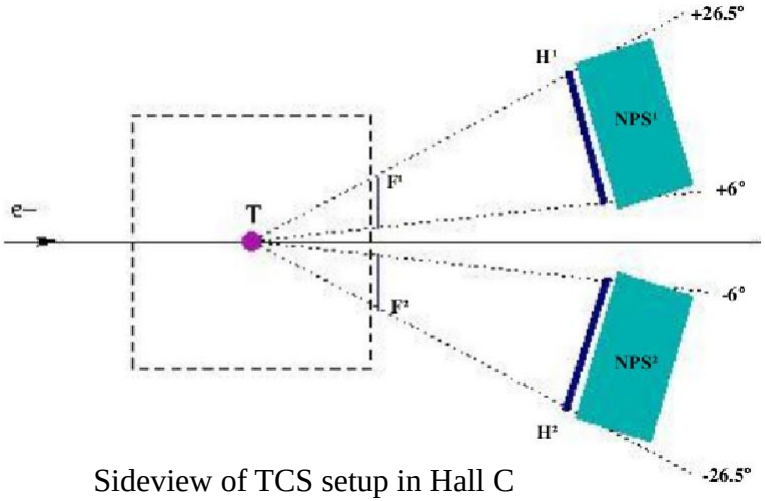


PbF_2



NH_3 Target

Possible versions for the NPS

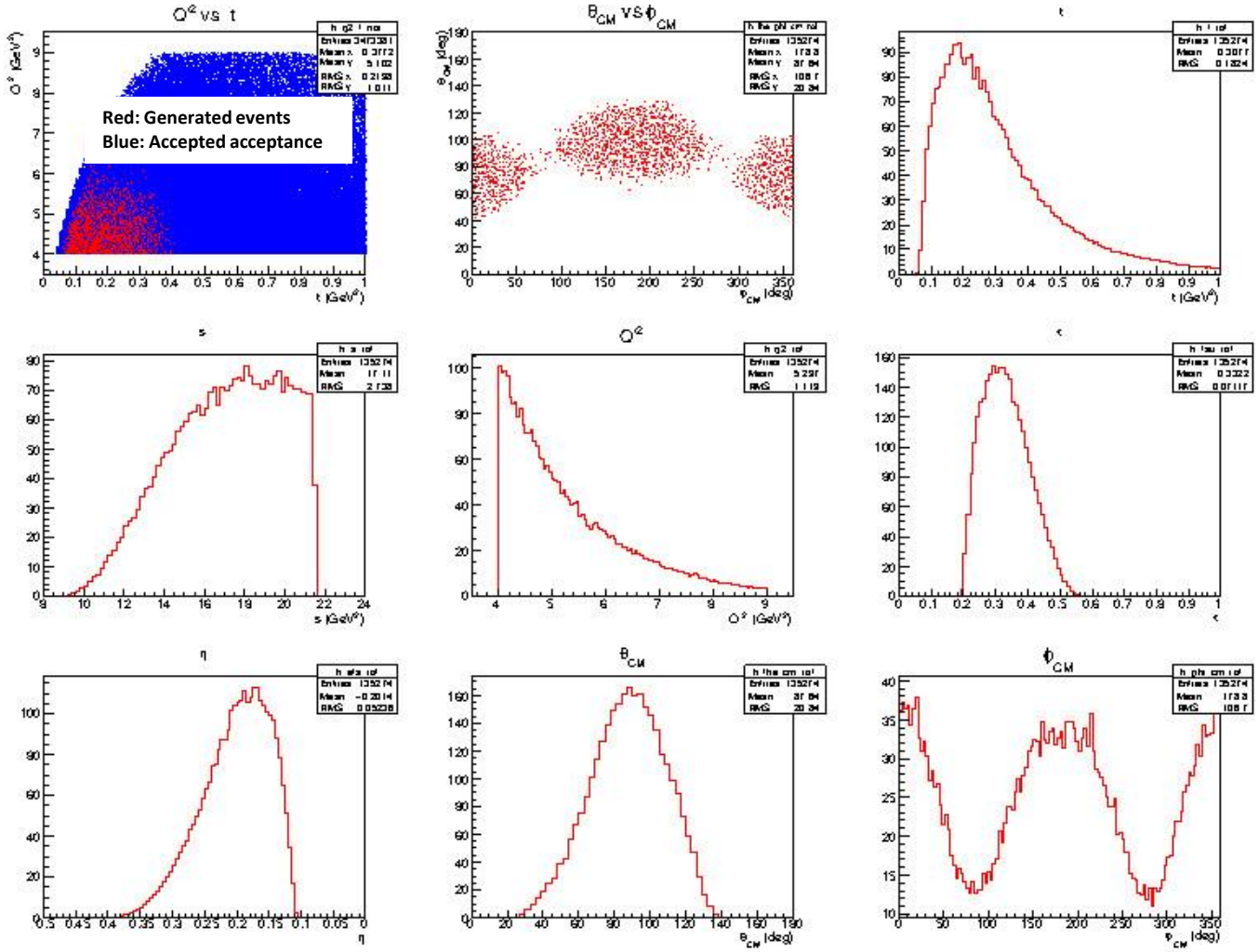


Sideview of TCS setup in Hall C

- Will use area between beam line and HMS and SHMS magnetic spectrometers.
- Lepton pair from reaction $\gamma + p \rightarrow e^- + e^+ + p'$ (e') will be detected by pair of NPS. Note, we changed NPS from horizontal arrangement to the vertical.
- Recoil protons will be detected by combination of Tracker and Hodoscope
- Tracker, ~3 mm diameter scintillation fibers at minimal distance from the target
- Polarized NH_3 target can handle electron beam intensity ~200 nA (~10^{12} e/sec).
- Selection of TCS events from background required recoil proton θ_p and φ_p angular resolutions to be better than ~1°, and missing mass square resolution ~0.05 GeV^2
- To suppress background from pions, the trigger has to contain the two leptons energy cut on the level of E>300 MeV

TCS kinematic variables for 11 GeV energy electrons

Distributions are obtained with target field map and detector acceptances taken into account



- The angular acceptance is limited by magnet poles and the scattering chamber window: ±17° horizontally and ±26.5° vertically.
- The downstrem beam pipe poses small angle limit ±6°.

Comments from the PAC43

PAC43 Recommendation: The Collaboration should present the novel aspects of their measurements more convincingly, in comparison with the other approved experiments, they should carefully address the points raised by the TAC report and fully describe the procedure for the extraction of the GPDs.

TAC Comments:

1. The D-term in the theory section is not defined in the LOI but is in a reference. It is unclear from the LOI if this term has any significance to the proposed measurements.
2. The description of the DNP-UVA target seems to account for the magnet used during SANE09 in Hall C. This magnet quenched more than a dozen times after it was repaired for 6 weeks during SANE cutting the amount of data acquired by SANE significantly. It is unclear whether the collaboration still wants to use this magnet or a replacement. All acceptance calculations seem to have been done for this magnet's geometry.
3. These measurements require a transversely polarized DNP target. During SANE09 the UVA target had stability problems with the target polarization at 80° to the beam axis. Some of these problems were attributed to the surrounding magnets in Hall C from HMS and SOS. The collaboration should investigate if the baseline spectrometers in Hall C (and A) would affect the target's stability while transversely polarized.
4. As all detectors and sweeping magnet(s) are new equipment, the collaboration should investigate interferences and installation issues between their equipment and the baseline equipment in the Halls A and C (they are not settled on a single hall, they claim that these measurements could be done in either A or C).
5. The estimate for beam time request seems to account for production data only, it is unclear if time for calibrations and target maintenance is included or not.

The way to develop the LOI into a full proposal

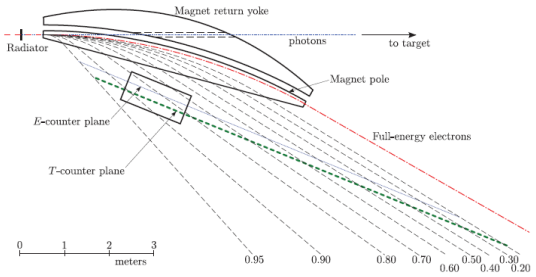
The collaboration is determined to address the PAC43 recommendations and TAC comments and develop the LOI in to a full proposal.

- Theoretical studies are underway to quantify the impact on GPD/CFF fits from this measurement, the TCS alone and together with DVCS data. (see Marie's talk in the sequel).
- The principles of future data analysis procedure are being developed in the theory studies with inclusion of key experimental conditions, such as direction of the target polarization and setup's finite acceptances.
- Development of a Geant4 simulation code is underway to estimate and optimize background conditions for the experimental setup (thanks G.Niculescu for an example code).
- Though the UVA target's magnet got much stable since SANE experiment (J.Zhang, private communication), additional in situ studies may be needed to ensue its proper performance.
- Potential vendors of lead tungstate crystals for the calorimeters are identified by the NPS collaboration. The collaboration develops set of test measurements to ensure proper quality of delivered crystals.

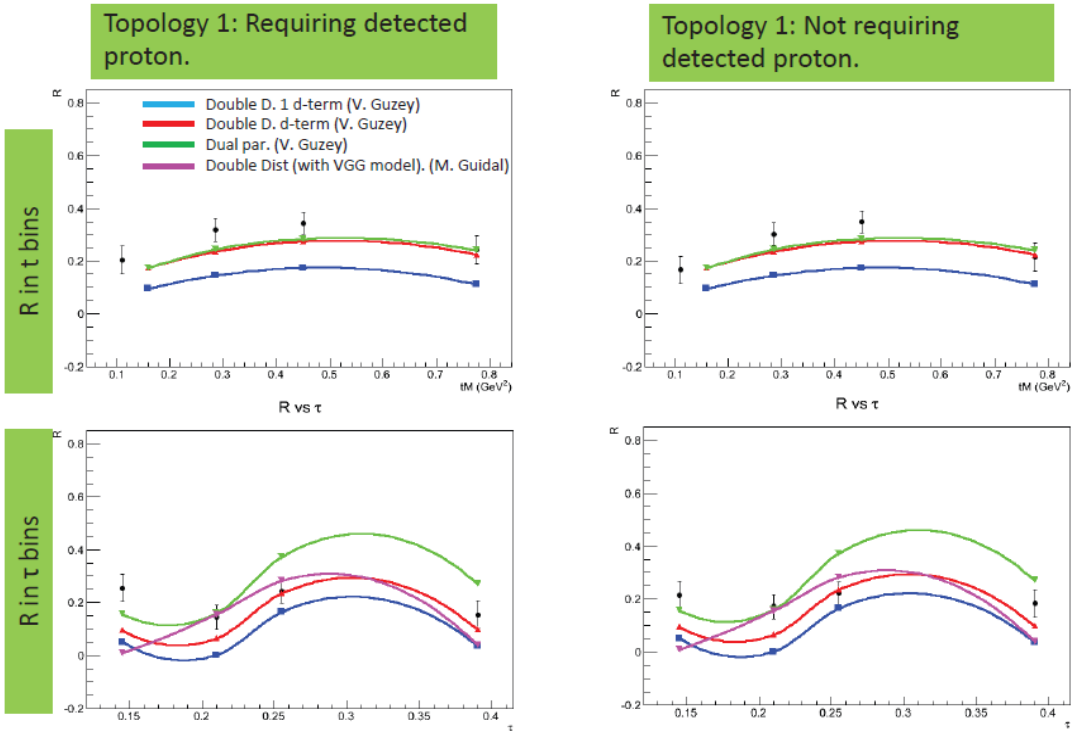
Backup

Measurements with tagged photons at Jlab 6 GeV

- Tagged photon beam:
  - allows for an independent determination of the photon flux
  - Offers an opportunity to explore event topologies with only two out of the three final state particles detected



- Preliminary results for R from Jlab CLAS g12 experiment performed with clean real photon beam.
- Results are shown for both R versus t and R versus τ extracted in two topologies



Initial results from g12. (*Figure from I. Albayrak)*

Error bars are show statistical uncertainties only.

$$t = (p - p')^2 \qquad \tau = \frac{Q'^2}{s - M^2} \sim \frac{Q'^2}{s}$$

- Theoretical calculations are not describing simultaneously t & τ dependence.
- This is the first time study of τ dependence of R which is important, since theoretical GPD calculations can demonstrate significant differences over τ.

This 2 experiments show possibility for future more detailed studies of TCS at higher energy.

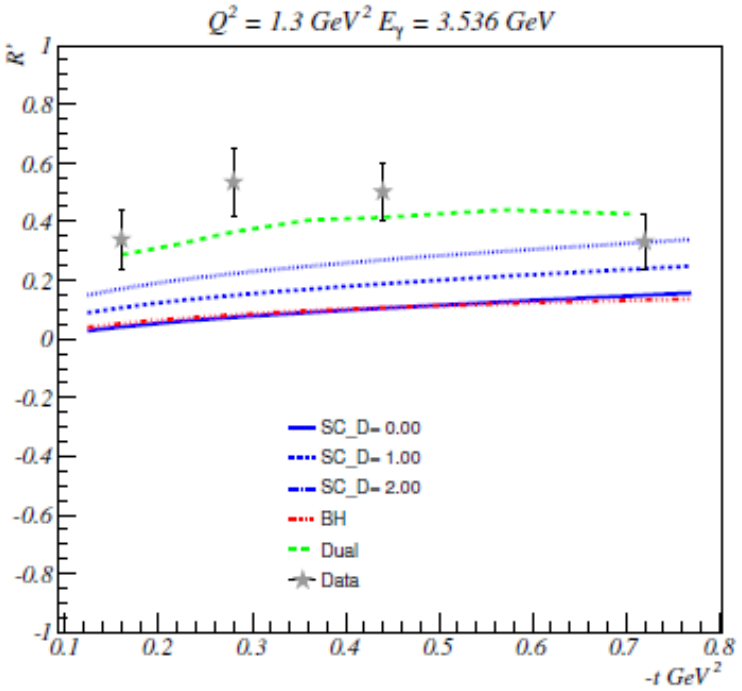
First TCS Measurements at Jlab 6 GeV

- First studies of TCS using real tagged and quasi-real untagged photons were carried out in Hall B at Jlab 6 GeV using the CLAS detector.
  - In these studies, the quantity R was extracted from the data
  - R can be directly compared to the theoretical GPD calculations even with limited statistics.

$R = \frac{\sum_\phi \cos\phi Y_\phi}{\sum_\phi Y_\phi}$ is a cosine moment of the weighted cross section normalized to the total weighted cross section. Y_φ is the acceptance corrected number of events in θ_{cm} & ϕ_{cm} bins, integrated over θ.

- Several 6 GeV Jlab data sets with quasireal photons (e1-6, e1f) have been analyzed and results are compared with theoretical GPD model calculations.

Plot on right compares theoretical models with quasi-real untagged measurements.



(Figure from R. Paremuzyan Ph.D Thesis)