Time-like Compton Scattering in Hall C

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For the Hall C TCS collaboration

NPS Collaboration Meeting, 07/17/2024
Outline

TCS with **polarized** target
- Physics case and motivation
- Experimental setup
- Simulations
- Status

TCS with **un-polarized** target
- Physics case and motivation
- Experimental setup
- Simulations
- Status
Physics goals

\[ \gamma P \to e^+e^- P' = \text{TCS} \]

\[ \begin{align*}
\gamma (q) & \rightarrow e^- (k) \\
\gamma (q') & \rightarrow e^+ (k') \\
N (p) & \rightarrow GPD (x, \xi, t) \\
N' (p') & \rightarrow \text{FF (t)}
\end{align*} \]

\[ \sin(\varphi) \text{ moment of transverse spin asymmetry vs } \varphi_s \]

Dependence in GPD E and \( J^{ud} \) (VGG model)

TSA as a function of \( \varphi \) and \( \varphi_s \)
- Sensitive to \( \text{Im} \text{(interference)} \), BH cancels
- Strong dependence in angular momenta, Sensitivity to GPD E (also to H, Ht)

\[ \text{Courtesy M.Boer} \]
Kinematic region out of pion resonance production
TCS w/ polarized target: Extraction of CFFs from TCS versus DVCS

Example estimates of accuracies on the model extraction of CFFs. TCS with trans. pol. Target:

- Allows for extraction of $\text{Im}(E)$ (unique to this proposal)
- Allows for extraction of $\text{Im}(H)$ to good accuracy (universality tests)
\[ \gamma + p \rightarrow \gamma^* (e^+ + e^-) + p' \]

- Detect $e^+$, $e^-$, recoil $p$ in coincidence
- CPS bremsstrahlung photon beam
- Jlab-UVA NH$_3$ target, transversely polarized
- Detectors arranged in 4 quarters, oriented to target
- Multiple GEMs for $e^+$, $e^-$, $p$ tracking
- Hodoscopes for recoil proton detection/PID
- PbWO$_4$ calorimeters for $e^+$, $e^-$, $p$ detection/PID
Compact Photon Source (CPS):
• Combines polarized photon source, collimator and beam dump;
• High intensity photon beam (\(1.5 \times 10^{12} \, \gamma/s\) in [5.5 GeV, 11 GeV] range from 2.5 µA primary e- beam on 10% X\(_0\) Cu radiator, ~1 mm spot size at 2 m from radiator).

Target:
• Material: \(^{15}\text{NH}_3\) in LHe at 1°K, packing fraction 0.6.
• Polarization: 5 T transverse magnetic field; DNP by 140 GHz, 20 W RF field; NMR monitored.
• Acceptance: ±25° horizontally, ±23° vertically.

GEM trackers:
• Coordinate reconstruction accuracy \(\sim 80 \, \mu m\)
• Background rate tolerance up to \(10^6\, \text{Hz/mm}^2\)
• Minimum material thickness along particle pass, big size manufacturing
• Use at Jlab: SBS, SoLID DDVCS, Prad

Calorimeters, clones of the NPS calorimeter:
• 2x2x20 cm\(^2\) PBWO\(_4\) scin. crystals, arranged in carbon fiber/µ-metal mesh
• Expected energy resolution 2.5%/\(\sqrt{E}\) + 1%
• Expected coordinate resolution \(\sim 3\, \text{mm}\) at 1 GeV
• Modules arranged in 4 assemblies of 23x23 matrix
• Total number of modules 2116.
- Trigger based on e+ and e- coincident signals from calorimeters in opposite quarters
- Establish thresholds on $E_{\text{DEP}}(e^+)$, $E_{\text{DEP}}(e^-)$, $E_{\text{DEP}}(e^+)+E_{\text{DEP}}(e^-)$ to control background
- Exclude high background region close to beam pipe

Accidental background rate ($E(e^\pm)_{\text{CL}} > 2.5$ GeV, $\Delta(T)$) = 50 ns

 Beam background rate and TCS triple coin. detection efficiency vs cut on polar angle $\Theta$.
TCS w/ polarized target: Reconstructed versus True Quantities

Note: physical and beam backgrounds are not taken into account in the reconstruction.
The proposal C-12-18-005 was conditionally approved by PAC 46 and PAC48 with C2 rating, was deferred by PAC 50:

**Summary**: The PAC acknowledges that the physics case of the proposal is strong and nicely complements the extensive program of GPD-related measurements at JLab. However, given the difficulty of the measurement, the PAC feels that a deeper review of the experimental issues raised above is required, and that the collaboration needs to increase their workforce focusing on the challenging technical issues of this proposal. Given the extent of the additional work needed, the PAC recommends a deferral of this proposal, to enable sufficient time for addressing the technical issues.

The physics program is solid, issues with experimental setup and feasibility of measurements.

Discussed PAC identified issues and pass forward with E.Aschenauer:

- Prioritized tasks (Physics background calculations first)
- Identified pitfalls (Rad. Damage of hodo-s, SiPM sensitivity to neutrons...)
- Discussed possible modifications of detector package (GEM based TRD)
- Identified experts to contact

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**TCS Program**

<table>
<thead>
<tr>
<th>Observables</th>
<th>GPD</th>
<th>Target</th>
<th>Beam</th>
<th>Experiments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unpol. cross sections vs $\phi$</td>
<td>$\Re(H)$, $\Im(H)$</td>
<td>Unpolarized (Lh2)</td>
<td>unpolarized</td>
<td>CIAS12, SoLID (future), Unpol. TCS in Hall C</td>
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<td>Circularly polarized</td>
<td>CIAS12, SoLID (future), Unpol. TCS in Hall C</td>
</tr>
<tr>
<td>Cross sections vs $\phi$ &amp; $\psi$</td>
<td>$\Re(H)$, $D$ – term</td>
<td>Unpolarized (Lh2)</td>
<td>Linearly polarized</td>
<td>Possible with GlueX</td>
</tr>
<tr>
<td>Cross sections vs $\phi$</td>
<td>$\Im(\tilde{H})$</td>
<td>Longitudinally polarized target</td>
<td>unpolarized</td>
<td>Possible with CLAS12</td>
</tr>
<tr>
<td>Cross section vs $\phi$ &amp; $\phi_S$</td>
<td>$\Im(E)$, $\Im(\tilde{H})$</td>
<td>Transversely polarized target</td>
<td>unpolarized</td>
<td>Pol. TCS in Hall C Work in progress</td>
</tr>
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From D.Biswa’s presentation on 2024 Winter Hal A/C meeting.

With unpol. circularly pol. $\gamma$ incident, TCS unpolarized is sensitive to $\Re(H)$ and $\Im(H)$ GPD-s.
TCS w/ un-polarized target: Experimental apparatus

\[ \gamma + p \rightarrow \gamma^* (e^+ + e^-) + p' \]

- Detect e^+, e^-, recoil p in coincidence
- **Circularly polarized** CPS brem. photon beam
- Jlab 15 cm LH2 cryogenic target
- Analyzing ~2Tm SBS magnet (31”x48” bore)
- Detectors arranged in 4 quarters
- Multiple GEMs for e^+, e^-, p tracking
- Hodoscopes for recoil proton detection/PID
- PbWO_4 calorimeters for e^+, e^-, p detection/PID
Key differences between polarized and unpolarized setups:

- 15 cm LN2 target versus 3cm NH$_3$ polarized target, no polarizing magnetic field.

- Analyzing magnet:
  - ~2 Tm field integral
  - 31” wide, 48” high, 48” deep bore
  - Allows separation of e-, e+ tracks at detectors
  - Momenta from tracking useful for PID with calorimeters and hodoscopes
  - Allows vertex reconstruction at target
A setup from Geant4 simulations used for acceptance and optimization studies.
Distributions of TCS e- (left) and recoil proton (right) track coordinates at the face of plane calorimeter. The rectangle encompasses tracks within aperture of the SBS magnet. The SBS magnet is not exited.
TCS w/ un-polarized target: Status

Done:
- A Geant 4 code is developed to simulate setup
- TCS events are sampled by the DEEPGen generator
- Responses of detectors to the TCS events are simulated
- Rates of e+e- coincidence and triple coincidence events are estimated for a configuration of setup

To be done:
- Optimize the setup for max. triple coincidence triple rate (magnets’ field and position, detector coverage and positions)
- Estimate TCS trigger rates and triple coincidences
- Generate events of principal physics backgrounds and estimate their rates in the setup
- Estimate background rates from beam interaction with matter
...
Thank you for your attention!
Backup slides
Compact Photon Source under development in Hall C at JLab:

- Combines polarized photon source, collimator and beam dump;
- High intensity directed brem. photon beam ($1.5 \times 10^{12} \text{ y/s in [5.5 GeV, 11 GeV]}$ range from $2.5 \text{ \mu A}$ primary e- beam on $10\% X_0$ Cu radiator, $\sim 1 \text{ mm spot size}$ at 2 m from radiator);
- 3.2 T warm magnet to bend incoming electrons to local beam dump;
- Highly shielded design (W/Cu alloy) to minimize prompt and residual radiation.

*D.Day et al., NIMA 957 (2020) 163429*
Experimental apparatus: Polarized target

- Target material: $^{15}\text{NH}_3$, in LHe at $1^\circ\text{K}$.
- Packing fraction 0.6.
- Magnetic field generated by superconducting Helmhotz coils.
- DNP polarization by 140 GHz, 20 W RF field.
- Polarization monitored via NMR.
- Depolarization mitigated by combined rotation (~1 Hz) around horizontal axis and vertical up/down movement (~10 mm).

New polarizing magnet arrived in September 2021!
- Drop-in replacement for old Jlab-UVA target
- 5 T magnetic field, 100 ppm uniformity
- $\pm 25^\circ$ horizontal opening angle in transverse filed configuration
  (increase from $\pm 18^\circ$ --> increase of TCS acceptance, help with background rates.)
Experimental apparatus: trackers, hodoscopes

GEM trackers:
- Coordinate reconstruction accuracy $\sim 80 \, \mu m$
- Background rate tolerance up to $10^6 \, \text{Hz/mm}^2$
- Minimum material thickness along particle pass
- Big size manufacturing

Use at Jlab: SBS, SoLID DDVCS, Prad

Hodoscopes:
- To provide $dE/dX$ signal from low momentum recoil protons
- 2x2x5 cm$^3$ scintillators arranged in “Fly’s eye” hodoscopic construction

Calorimeters, clones of the NPS calorimeter:
- 2x2x20 cm$^2$ PBWO$_4$ scin. crystals, optically isolated
- Modules arranged in a mesh of carbon fiber/µ-metal
- Expected energy resolution $2.5\%/\sqrt{E} + 1\%$
- Expected coordinate resolution $\sim 3 \, \text{mm at 1 GeV}$
- Modules arranged in 4 “fly’s eye” assemblies of 23x23 matrix

Total number of modules needed 2116.
Recoil proton ID

Low energy protons, $E_{\text{kin}}$ from $\sim 30$ MeV to 450 MeV

Cuts to select good protons:

- $E_{\text{HODO}} > 15$ MeV
- $90$ MeV < $E_{\text{HODO}} + E_{\text{CALO}}$ < 450 MeV
- $2800$ MeV$^2$ < $E_X < 4200$ MeV$^2$, where $E_X = (E_{\text{HODO}} + E_{\text{CALO}} - 12) \times (E_{\text{HODO}} - 7)$
5T target field localized at target cell

Field behind scattering chamber too weak to distinguish pos. and neg. tracks.

Alternative: use reconstructed incident photon mass:
• Reconstruct recoil proton;
• Reconstruct leptons twice, by assigning (+,-) and (-,+) charges;
• Combine with reconstructed proton to get 2 masses, choose smaller one.

Random lepton charge assignment

Lepton charges according selection criteria

Messing e+, e- 3%!
Anticipated results: target asymmetries

- Shows strong dependence on angular momenta
- 8 bins: fit of 2x2 orthogonal bins (4 independent ones) for CFFs global fits

with GPDs (VGG model):
- t=0.25 GeV²
- ξ = 0.18
- Q²=5 GeV²
- 30°<θ<150°
Feasibility of recoil proton detection

400 MeV/c ($E_{KIN} = 81$ MeV) proton passed from target to 1-st layer GEM.

Tracks with $\theta_Y = 15^\circ$ at vertex:
- Hit spot size $\sigma \sim 1.5 \text{ cm}$
- Fraction of hits within $R < 4.5 \text{ cm} -- 94.5\%$
Cuts to select good protons:

- $E_{HODO} > 15$ MeV
- $90$ MeV $< E_{HODO} + E_{CALO} < 450$ MeV
- $2800$ MeV$^2 < ExE < 4200$ MeV$^2$,

$ExE = (E_{HODO} + E_{CALO} - 12) \times (E_{HODO} - 7)$
Assuming 0.2ns rms can be achieved, these resolutions would be
1) Competitive with best-case total absorption measurements in the hodo+calorimeter, but
2) Would not suffer from the large fraction of events with corrupted KE information due to nuclear reactions in the many g/cm² needed to stop the protons in the hodo+calorimeter.

Courtesy D.Mack
Residuals of reconstructed quantities

$h_{dq2}$
Entries 36662
Mean -0.01305
RMS 0.1435

$h_{dt}$
Entries 36662
Mean 0.02614
RMS 0.0766

$h_{ds}$
Entries 36662
Mean 0.2147
RMS 0.575

$h_{dx}$
Entries 36662
Mean -0.003618
RMS 0.009814

$h_{dthetaCM}$
Entries 36662
Mean 4.376e-05
RMS 0.02338

$h_{dphiCM}$
Entries 36662
Mean -0.0009064
RMS 0.1164

Resolutions acceptable for analysis.