Generalized Parton Distributions programs at SoLID

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*speaker
OUTLINE

• GPD physics
  - reactions
  - fits of Compton Form Factors

• GPD projects for SoLID
  - DVCS
  - TCS
  - DDVCS

• Technical requirements for these programs
Generalized Parton Distributions of the nucleon

**Goal:** A 2+1 dimensional picture of the nucleon
GPD contain the correlation between transverse distribution of partons in nucleon and their longitudinal momenta → momentum dependent transverse distributions in position, spin...

Momentum dependent impact parameter distribution:

- transverse momentum distributions from momentum transfer^2 t-dependence → form factors = first momenta of GPDs
- longitudinal momentum fraction x-dependent parton densities → pdf = limits of GPDs at t=0

How could SoLID be involved in the measurement of the GPD?
Exclusive Deeply Virtual Compton processes

Different exclusive processes involving photons, same GPDs:

- outgoing photon is real: **DVCS** (spacelike) Deeply Virtual Compton Scattering: \( e \, N \rightarrow e' \, \gamma \, N' \)

- incoming photon is real: **TCS** Timelike Compton Scattering: \( \gamma \, N \rightarrow l^+l^- \, N' \)

- both photons are virtual: **DDVCS** Double Deeply Virtual Compton Scattering: \( e \, N \rightarrow e' \, l^+l^- \, N' \)

(l stands for any lepton, beam could also be another lepton)

Access 4 chiral even nucleon's quark GPD (scattering off a nucleon): \( H, E, \tilde{H}, \tilde{E} \)

→ unpolarized and polarized distributions of quarks \( u \) and \( d \) in the nucleon

→ flavor separation by comparison of proton and neutron GPD

\[
H^p = \frac{4}{9} H^u + \frac{1}{9} H^d \\
H^n = \frac{1}{9} H^u + \frac{4}{9} H^d
\]
Compton processes + Bethe-Heitler

DVCS + BH
\[ eN \rightarrow e'\gamma N' = \]

TCS + BH
\[ \gamma N \rightarrow e^+ e^- N = \]

DDVCS + BH
\[ e N \rightarrow e' l^+ l^- N' = \]
Other processes: Deeply Virtual Meson Production

Selection of different combinations of GPD depending on meson spin-parity and flavor content
→ flavor separation, gluons
→ easier access to some GPDs compared to virtual Compton processes

- but additional non perturbative part, interpretation (scaling...), need phenomenological models to fit data...

*only Compton processes in the following of this talk
Exclusive pion production at SoLID: talk GM Huber, SoLID meeting May 2015
Extraction of GPDs and Compton Form Factors

- **Case of DVCS and TCS:**

  \[ T^{DVCS} \sim \int_{-1}^{+1} \frac{H(x, \xi, t)}{x \pm \xi + i\epsilon} \, dx + \ldots \]

  \[ P \int_{-1}^{+1} \frac{H(x, \xi, t)}{x \pm \xi} \, dx - i\pi H(\pm \xi, \xi, t) + \ldots \]

  cross sections, double spin asymmetries, charge asymmetries (dvcs)

  \[ \xi, t = \text{measurable} \; ; \; x = \text{loop} \]

- **Case of DDVCS and exclusive meson production:**

  pole at \( x = \pm \xi \left( 1 - \frac{Q'^2}{Q^2} \right) \left( 1 + \frac{Q'^2}{Q^2} \right) \)

  lever arm in \( Q'^2/Q^2 \) to access the "out of diagonal" part of \( H(x, \xi, 0) \)

  unique way to access at GPD\((x \neq \xi)\), needed for deconvolution of these 2 variables and for "3D" imaging at \( \xi = 0 \).
Phase Space for these reactions (11 GeV electron)

[no acceptance considerations]

DVCS: already measured at 6 GeV, extension of the phase space

TCS: out of vector mesons resonance region → only at high \( Q^2 \), need high luminosity

Common region: maybe used for comparison of measured Compton Form Factors and for combined CFFs fits of DVCS+TCS (same CFF at first order)

DDVCS: very narrow phase space (not all the cuts are represented)
→ only at high \( Q'^2 \) (like TCS)
→ need very high luminosity due to the multiple kinematical cuts and both high \( Q^2 \) and \( Q'^2 \)
Complementarity on fits: what could we achieve with DVCS + TCS?

exercise with simulation: doesn't represent any realistic case / just comparative (relative statistics...) [in progress]

DVCS: observables already measured at JLab@6 GeV, TCS: proposed measurements

- Complementarity: DVCS+TCS observables for fits, assuming same CFF for DVCS and TCS (LO/twist)
- Comparison of GPD H with DVCS or TCS (high precision required): check universality => for SoLID.
- Equivalent results with transversally polarized target DVCS... this example is not exclusive
Comparison: fits of proton and neutron CFF with DVCS and TCS

Exercise with simulation: doesn't represent any realistic case / just comparative (relative statistics...) [in progress]

DVCS: observables already measured at JLab@6 GeV, TCS: proposed measurements

- Both proton and neutron are needed to separate u and d quark GPD
- Similar results for DVCS p compared to n and TCS p compared to n

- Re(H) poorly constrained with neutron compared to proton
- “n” more sensitive to GPD E than “p”, “p” more sensitive to GPD H compared to “n”
**Goal:** measurement of DVCS off (polarized) proton or neutron with polarized $e^-$

- measurement of all combinations of beam and/or target spin asymmetries, polarized cross-sections
- other experiment in Hall A, B, C have already published results or accepted proposals, no DVCS@SoLID yet
- transversally polarized neutron would be new if proposed for SoLID => GPD E, spin...
- high luminosity and large acceptance of SoLID are a plus for this purpose / systematics are to be studied
- work in progress (Z. Ye...):
  
  need background simulations, clarify what are the resolutions especially for the neutron detection, studies on what are the needs for the experimental setup: recoil detector?... manpower welcome!

> DVCS with polarized electron beam and targets:  Z. Ye, May 2015

<table>
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<tr>
<th>Polarization</th>
<th>Asymmetries</th>
<th>CFFs</th>
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<td>Longitudinal Beam</td>
<td>$A_{LU}$</td>
<td>$\text{Im}{H_p, H_n, T_p}$</td>
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<td>Longitudinal Target</td>
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<td>Long. Beam + Trans. Target</td>
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<td>$\text{Re}{H_n, T_n}$</td>
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NH3: Transversely polarized (proton)
He3: Transversely & Longitudinally polarized (neutron)

\[\text{Suppressed at } t \to 0 \text{ where } F_1^n \to 0 \text{ but should be sensitive at large } t\]
**TCS @ SoLID**

\[ e \ P \rightarrow (e') \ y \ P \rightarrow (e') \ P' \ e^+e^- \]

[quasi-real photon beam, circularly polarized 50% → 85%]

run group proposal E12-12-006A (2015)

**cross section**

- highly dominated by BH (at any kinematic): high precision required to distinguish TCS signal sensitive to Real and Im. part of amplitudes

**beam spin asymmetry [circular]**

- comes from interference term sensitive to Im. part of TCS amplitude distinction between different GPD's parametrizations

- High luminosity and resolution of SoLID, large acceptance is a plus for this measurement.
  Hall B: same observables but lower luminosity ; Hall C: transversally polarized target.
- Could also be measured in muon pair [cf DDVCS].
DDVCS @ SoLID

e P → e' P' µ⁺ µ⁻

Interest: GPD extracted at x ≠ ξ
How: lever arm with Q^2/Q'^2 ratio


cross section and beam spin asymmetry for 2 kinematics vs phi (DVCS-like angle)

- BH only

- highly dominated by BH

- BSA signal comes from interference

- phenomenological efforts ongoing for interpretations and to lead the proposal

- plan to turn LOI of 2015 into a run group proposal in 2016 (with E12-12-006)

SoLID: first DDVCS LOI (Hall B LOI also in progress), very high luminosity and acceptance needed

Goal: run "parasitic" with another experiment to show feasibility, then dedicated experiment if possible
Muon detector for “parasitic” SoLID DDVCS (with J/ψ exp.)

- Muons detector: from CLEO
  - Forward
  - Reuse 2\textsuperscript{nd} and 3\textsuperscript{rd} layer iron
  - Muon chambers between iron

- Move chambers with magnet
- Test one chamber using Ar/Co2 maybe in Temple (N. Sparveri)
### Luminosity requirements and other experiments @12 GeV

**DVCS (only unpolarized target)**
- CLAS12: $10^35 \text{ cm}^{-2}\text{s}^{-1}$
- NPS: $10^37 \text{ cm}^{-2}\text{s}^{-1}$
- SoLID: $10^37 \text{ cm}^{-2}\text{s}^{-1}$ (*)

(*)= feasibility to be demonstrated

**TCS**
- CLAS12: 100+20 days, $10^35 \text{ cm}^{-2}\text{s}^{-1}$ (unpolarized target)
- SoLID: 50 days, $10^37 \text{ cm}^{-2}\text{s}^{-1}$

**DDVCS (unpolarized target)**
- CLAS12: $10^37 \text{ cm}^{-2}\text{s}^{-1}$ (*)
- SoLID: $10^38 \text{ cm}^{-2}\text{s}^{-1}$ (*)

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**Comparison of cross sections for the different processes (at xbj~0.33):**
[remarks for the kinematic shown and for JLab kinematic only]

**DVCS**
- $Q^2=3 \text{ GeV}^2$, $\Phi=90^\circ$, $xbj=0.33$
- $d^2\sigma / dx_b dQ^2 dt d\Phi$
- proton, neutron

**TCS**
- $Q'^2=7 \text{ GeV}^2$, $[\Phi [0,2\pi]$,
- $[\theta [\pi/4,3\pi/4]]$, $\xi=0.2$ (eq. $xbj=0.33$)
- $d\sigma / dQ'^2 dt$
- proton, neutron

**DVCS**
- $d^2\sigma / dx_b dQ^2 dt d\Phi$
- proton, neutron

**DDVCS:** order of fb, very narrow phase space, bh>>ddvcs

- bh>>tcs (always about 2 order of magnitude)
- cross sections order ~ pb

**Very high luminosity required for TCS and DDVCS**
Summary / work ongoing

Thanks to its high luminosity and large acceptance SoLID could provide unique opportunities for GPD physics

- **DVCS: goal = LOI at next PAC**
  - simulations, background
  - experimental requirements: setup - recoil detector?, resolution...
  - counting rates

- **TCS: run group proposal accepted in 2015**
  - still some effort for TCS and background simulations

- **DDVCS: LOI in 2015, goal = run group proposal this year**
  - phenomenological effort: interpretation of the results, interferences with meson production, fits...
  - simulations of DDVCS and background (in progress)
  - experimental setup: muon detector...
  - counting rates

**Need of manpower**

=> join our workshop "ECT dileptons" at Trento, Oct. 24-28, 2016
infos: camsonne@jlab.org
Open questions

- Resolution
  - Exclusivity by missing mass only
    - Electron
    - calorimeter resolution (do we need improvement?)
    - Optimize proton acceptance
- Cross sections measurement: Accuracy possible in SoLID
- Luminosity
  - Can we run more than $10^{37}$ cm$^{-2}$s$^{-1}$ and measure cross sections? (Tracking efficiency in background, PID)
- Evaluation of improved statistics impact on GPDs extraction
- Parallel experiments: trigger requirements
BACKUP SLIDES
Figure 5: TCS $A_{uu}$ on the neutron (top left panel), TCS $A_{uu}$ on the proton (top right panel), DVCS $A_{LU}$ on the neutron (bottom left panel), DVCS $A_{LU}$ on the proton (bottom right panel) as a function of $J^u$ and $J^d$. Calculations are done for $\phi = 90^\circ$, $\xi = 0.2$, $Q^2 = 7 \text{ GeV}^2$, $-t = 0.4 \text{ GeV}^2$ and $\theta$ integrated over $[\pi/4, 3\pi/4]$. 
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