Opportunities provided by polarization observables to study GPDs

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GPD Study w/ Polarization Observables

Some Facts:

- All leading-twist GPD entangle together in nearly all observables.

  Before we can talk high-twist GPD, high-order effects, etc

- One single measurement cannot isolate individual GPDs

  Need DVCS, TCS, DVMP, DDVCS …

- Both proton and neutron data are needed

  Not just for flavor decomposition

- Different exclusive channels have different sensitivities to different GPDs

- Absolute X-Section measurements are essential to study GPDs

- Experimentally measuring asymmetries are easier than measuring absolute X-Sections.

  Many systematic uncertiantites could be cancelled in the asymmetries

- During the 12GeV era, we will expect to have more hard-exclusive data released in terms of asymmetries (from CLAS12 and SoLID) wider kinematic coverages, high statistics

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Some remarks:

- Beam polarization and/or target polarization observables may have some unique feature to isolate certain GPDs, such as helicity flip GPDs with polarized targets
- Some high-twist and high-order effects could be possibly cancelled in the asymmetries
- Further isolation of different GPDs and/or different effects by analyzing different angular moments.

For Example, for DVMP with polarized target:

$$A_L^{\perp} = \left(\int_0^{\pi} d\beta \frac{d\sigma_L^{\pi}}{d\beta} - \int_{\pi}^{2\pi} d\beta \frac{d\sigma_L^{\pi}}{d\beta}\right)\left(\int_0^{2\pi} d\beta \frac{d\sigma_L^{\pi}}{d\beta}\right)^{-1} = \frac{\sqrt{-t'}}{m_p} \frac{\xi\sqrt{1-\xi^2}\,\mathrm{Im}(\tilde{E}^*\tilde{H})}{(1-\xi^2)\tilde{H}^2 - \frac{t\xi^2}{4m_p}\tilde{E}^2 - 2\xi^2\mathrm{Re}(\tilde{E}^*\tilde{H})}$$

Asymmetry Moments:

$$A(\phi,\phi_s) = \frac{d^3\sigma_{UT}(\phi,\phi_s)}{d^2\sigma_{UU}(\phi)} = -\sum_k A_{UT}^{\sin(\mu\phi+\lambda\phi_s)_k} \sin(\mu\phi+\lambda\phi_s)_k$$

Unseparated sinβ=sin(φ-φ$_s$) Asymmetry Moment

$$A_{UT}^{\sin(\phi-\phi_s)} \sim \frac{d\sigma_{00}^{+-}}{d\sigma_L\binom{++}{00}} \sim \frac{\mathrm{Im}(\tilde{E}^*\tilde{H})}{|\tilde{E}|^2} \text{ where } \tilde{E} \gg \tilde{H}$$

sin(φ$_s$) Asymmetry Moment

$$A_{UT}^{\sin(\phi_S)} \sim \mathrm{Im}[M_{0+++}^* M_{0-0+} - M_{0-++}^* M_{0+0+}],$$

helicities: [pion, neutron, photon, proton]

$$\mathcal{M}_{0-,++} = e_0\sqrt{1-\xi^2}\int \mathrm{d}x \mathcal{H}_{0-,++} H_T,$$

$$\mathcal{M}_{0+,\pm+} = -e_0 \frac{\sqrt{t_{\min}-t}}{4m}\int \mathrm{d}x \mathcal{H}_{0-,++} \bar{E}_T.$$

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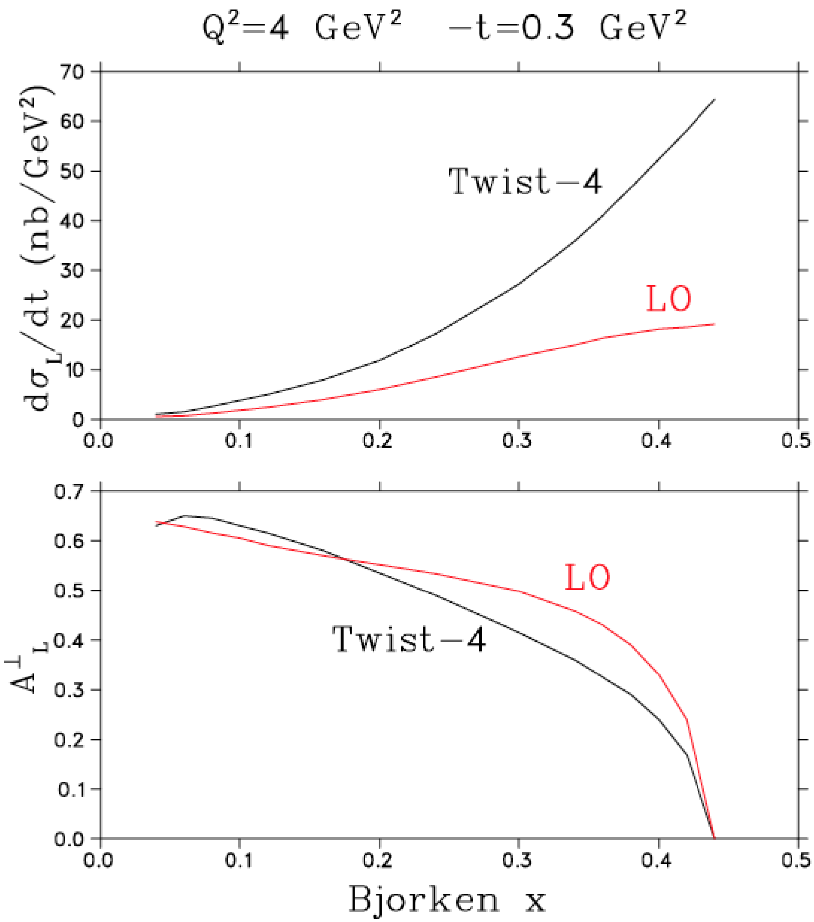
➢ Cancellation Effects in DVMP Asymmetries:

- Frankfurt et al. have shown $A_L^{\perp}$ vanishes if $\tilde{E}$ is zero. If $\tilde{E} \neq 0$, the asymmetry will produce a $\sin\beta$ dependence.

  (PRD 60(1999)014010)

- $A_L^{\perp}$ is expected to display precocious factorization even at only Q^2~2-4 GeV^2:
  - ✓ At Q^2=10 GeV^2, Twist–4 effects can be large, but cancel in $A_L^{\perp}$ *(Belitsky & Műller PLB 513(2001)349).*
  - ✓ At Q^2=4 GeV^2, higher twist effects even larger in σ_L, but still cancel in the asymmetry *(CIPANP 2003).*



GPD Study w/ Polarization Observables

- DVCS with polarized electron beam and targets:

Polarization	Asymmetries	CFFs
Longitudinal Beam	A_{LU}	$Im\{\mathcal{H}_p, \tilde{\mathcal{H}}_p, \mathcal{E}_p\}$ $Im\{\mathcal{H}_n, \tilde{\mathcal{H}}_p, \mathcal{E}_n\}$
Longitudinal Target	A_{UL}	$Im\{\mathcal{H}_p, \tilde{\mathcal{H}}_p\}$ $Im\{\mathcal{H}_n, \mathcal{E}_n, \tilde{\mathcal{E}}_n\}$
Long. Beam + Long. Target	A_{LL}	$Re\{\mathcal{H}_p, \tilde{\mathcal{H}}_p\}$ $Re\{\mathcal{H}_n, \mathcal{E}_n, \tilde{\mathcal{E}}_n\}$
Transverse Target	A_{UT}	$Im\{\mathcal{H}_p, \mathcal{E}_p\}$ $Im\{\mathcal{H}_n, \mathcal{E}_n\}$
Long. Beam +Trans.Targt	A_{LT}	$Re\{\mathcal{H}_p, \mathcal{E}_p\}$ $Re\{\mathcal{H}_n, \mathcal{E}_n\}$

NH3: Transversely polarized (proton)
He3: Transversely & Longitudinally polarized (neutron)

Suppressed at t→0 where F_1^n→0 but should be sensitive at large t

GPD Study w/ Polarization Observables

- DVCS with polarized electron beam and targets:
  - Beam-Spin Asymmetr (A_{LU}):

    $$\Delta\sigma_{LU} \propto \sin\varphi \, Im\{F_1\mathcal{H} + \xi(F_1 + F_2)\widetilde{\mathcal{H}} + kF_2\mathcal{E}\}d\varphi$$

    $Im\{\boldsymbol{\mathcal{H}}_{\boldsymbol{p}}, \widetilde{\mathcal{H}}_p, \mathcal{E}_p\}$
    $Im\{\boldsymbol{\mathcal{H}}_{\boldsymbol{n}}, \widetilde{\mathcal{H}}_n, \mathcal{E}_n\}$

  - Longitudinal Target-Spin Asymmetry (A_{UL}):

    $$\Delta\sigma_{UL} \propto \sin\varphi \, Im\{F_1\widetilde{\mathcal{H}} + \xi(F_1 + F_2)\mathcal{H} + kF_2\mathcal{E}\}d\varphi$$

    $Im\{\boldsymbol{\mathcal{H}}_{\boldsymbol{p}}, \widetilde{\boldsymbol{\mathcal{H}}}_{\boldsymbol{p}}, \}$
    $Im\{\boldsymbol{\mathcal{H}}_{\boldsymbol{n}}, \mathcal{E}_n, \tilde{\mathcal{E}}_n\}$

  - Longitudinal Double-Spin Asymmetry (A_{LL}):

    $$\Delta\sigma_{LL} \propto (A + B\cos\varphi) \, Re\left\{F_1\widetilde{\mathcal{H}} + \xi(F_1 + F_2)\left(\mathcal{H} + \frac{x_B}{2}\mathcal{E}\right)\right\}d\varphi$$

    $Re\{\boldsymbol{\mathcal{H}}_{\boldsymbol{p}}, \widetilde{\boldsymbol{\mathcal{H}}}_{\boldsymbol{p}}, \}$
    $Re\{\boldsymbol{\mathcal{H}}_{\boldsymbol{n}}, \mathcal{E}_n, \widetilde{\boldsymbol{\mathcal{E}}}_n\}$

  - Transverse Target-Spin Asymmetry (A_{UT}):

    $$\Delta\sigma_{UT} \propto \sin\varphi \, Im\{k(F_2\mathcal{H} - F_1\mathcal{E}) + \ldots\}d\varphi$$

    $Im\{\boldsymbol{\mathcal{H}}_{\boldsymbol{p}}, \boldsymbol{\mathcal{E}}_{\boldsymbol{p}}\}$
    $Im\{\boldsymbol{\mathcal{H}}_{\boldsymbol{n}}\}$

  - Transverse Double-Spin Asymmetry (A_{LT}):

    $Re\{\boldsymbol{\mathcal{H}}_{\boldsymbol{p}}, \boldsymbol{\mathcal{E}}_{\boldsymbol{p}}\}$
    $Re\{\boldsymbol{\mathcal{H}}_{\boldsymbol{n}}\}$

Suppression by the kinematic factors in proton and neutron can help us to isolate certain GPDs.

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To summarize:

To disentangle different GPDs, we need all kinds of observables. To study different kinds of effects, we need precision measurements on wide kinematic phase space. The best observables are the absolute X-Section with both unpolarized and polarized proton and neutron during all exclusive reaction. However, experimentally it is very difficult to get these info

The questions yet to be answered are:

1) If obtaining high precision X-Sections are not feasible, what are the next important observables, such as asymmetries, are essential to study GPDs?

2) What observables are more unequally sensitive to certain GPDs?

3) What observables can provide good cancellation of higher twist and higher order effects, when extracting leading twist GPD, or saying, are "cleaner"?

4) What observables can help us to better understand certain higher-twist or higher-order effects?

Ultimately, we hope there is a complete description (or mapping) of what observables (including DVCS and others channels) are more sensitive to what GPDs in what kinematic limits. It will provide important guidance to the experimental designs.