SoLID GPD Program Development Summary

University of Regina

Garth Huber

SoLID Collaboration Meeting
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The SoLID GPD Program

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- **Following the 2015 Director's Review recommendation *"The SoLID Collaboration should investigate the feasibility of carrying out a competitive GPD program. Such a program would seem particularly well suited to their open geometry and high luminosity"*, there are several GPD experiments in different stages of study/approval:**
  - **Deep Exclusive π^- Production using Transversely Polarized ^{3}He Target**
    - *G.M. Huber, Z. Ahmed, Z. Ye*
    - *Approved as run group with Transverse Pol. ^{3}He SIDIS (E12-10-006B)*
  - **Timelike Compton Scattering (TCS)** with circularly polarized beam and unpolarized LH_2 target
    - *Z.W. Zhao, P. Nadel-Turonski, J. Zhang*
    - *Approved as run group with J/ψ (E12-12-006A)*
  - **Double Deeply Virtual Compton Scattering (DDVCS)** in di–lepton channel on unpolarized LH_2 target
    - *E. Voutier, M. Boer, A. Camsonne, K. Gnanvo, N. Sparveri, Z. Zhao*
    - *LOI12-12-005 reviewed by PAC43*
  - **DVCS on polarized ^{3}He**
    - *Z. Ye (under study)*

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Leading Twist GPD Parameterization

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- **GPDs are universal quantities and reflect nucleon structure independently of the probing reaction.**
  - At leading twist–2, four quark chirality conserving GPDs for each quark, gluon type.
  - Because quark helicity is conserved in the hard scattering regime, the produced meson acts as a helicity filter.

$H^{q,g}(x,\xi,t)$ spin avg no hel. flip	$E^{q,g}(x,\xi,t)$ spin avg helicity flip
$\tilde{H}^{q,g}(x,\xi,t)$ spin diff no hel. flip	$\tilde{E}^{q,g}(x,\xi,t)$ spin diff helicity flip

- **Need a variety of Hard Exclusive Measurements to disentangle the different GPDs.**

Deeply Virtual Compton Scattering:

- Sensitive to all four GPDs.

Deep Exclusive Meson Production:

- Vector mesons sensitive to spin–average H, E.
- Pseudoscalar sensitive to spin–difference $\tilde{H}$,$\tilde{E}$.

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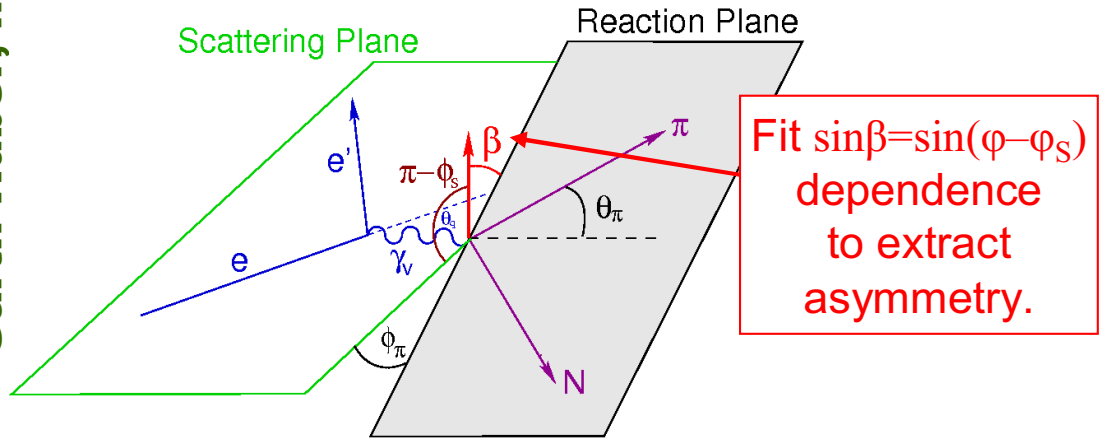
Exclusive π^- from Transversely Polarized Neutron

- Probe GPD $\tilde{E}$ with DEMP

$$\sum_q e_q \int_{-1}^{+1} dx\ \tilde{E}^q(x,\xi,t) = G_P(t)$$

  - *GPD $\tilde{E}$ is not related to any already known parton distribution.*
  - *$G_P(t)$ is highly uncertain because it is negligible at the momentum transfer of β–decay.*
  - *Experimental measurements can provide new nucleon structure information unlikely to be available from any other source.*

The most sensitive observable to probe $\tilde{E}$ is the transverse single–spin asymmetry in exclusive π production:



Fit sinβ=sin(φ–φS) dependence to extract asymmetry.

$$A_L^{\perp} = \frac{\left(\int_0^{\pi} d\beta \frac{d\sigma_L^{\pi}}{d\beta} - \int_{\pi}^{2\pi} d\beta \frac{d\sigma_L^{\pi}}{d\beta}\right)}{\left(\int_0^{2\pi} d\beta \frac{d\sigma_L^{\pi}}{d\beta}\right)}$$

$$= \frac{\sqrt{-t'}}{2m_p} \frac{\pi\xi\sqrt{1-\xi^2}\,\mathrm{Im}(\tilde{E}^*\tilde{H})}{(1-\xi^2)\tilde{H}^2 - \frac{t\xi^2}{4m_p}\tilde{E}^2 - 2\xi^2\,\mathrm{Re}(\tilde{E}^*\tilde{H})}$$

Theoretical calculations suggest higher twist corrections, which may be significant at low Q^2 for σ_L, likely cancel in $A_\perp$.

- **May allow access to GPDs at Q^2~4 GeV^2 while Q^2>10 GeV^2 needed for σ_L.**

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SoLID – Polarized ^{3}He SIDIS Configuration

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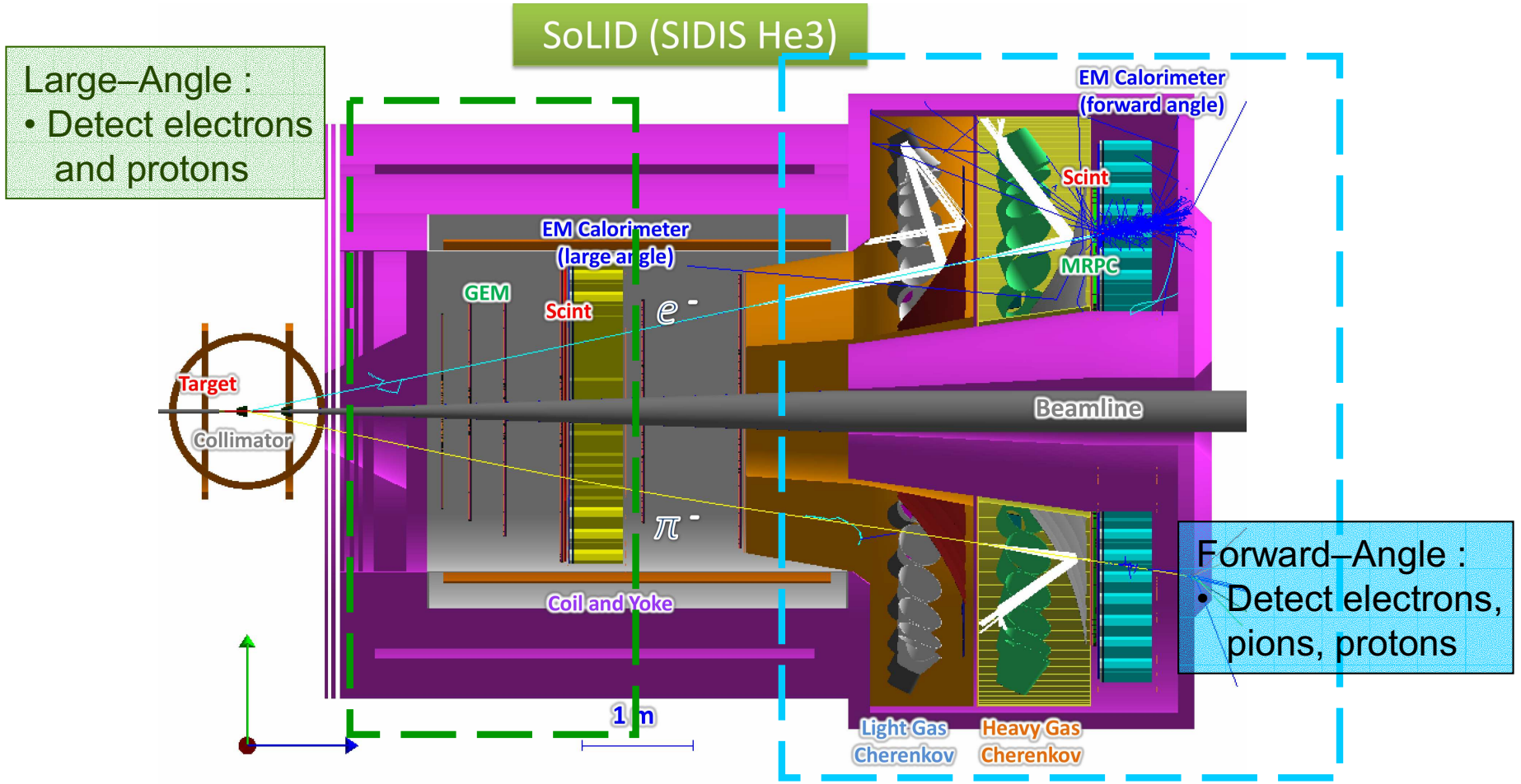
Run in parallel with E12–10–006: E_0 = 11.0 GeV (48 days)
Online Coincidence Trigger: Electron Trigger + Hadron Trigger (pions)
Offline Analysis: Identify (tag) protons and form triple–coincidence
No effect on SIDIS experiment as long as triple coincidence events are not vetoed in data acquisition.



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E12–10–006B Kinematic Coverage

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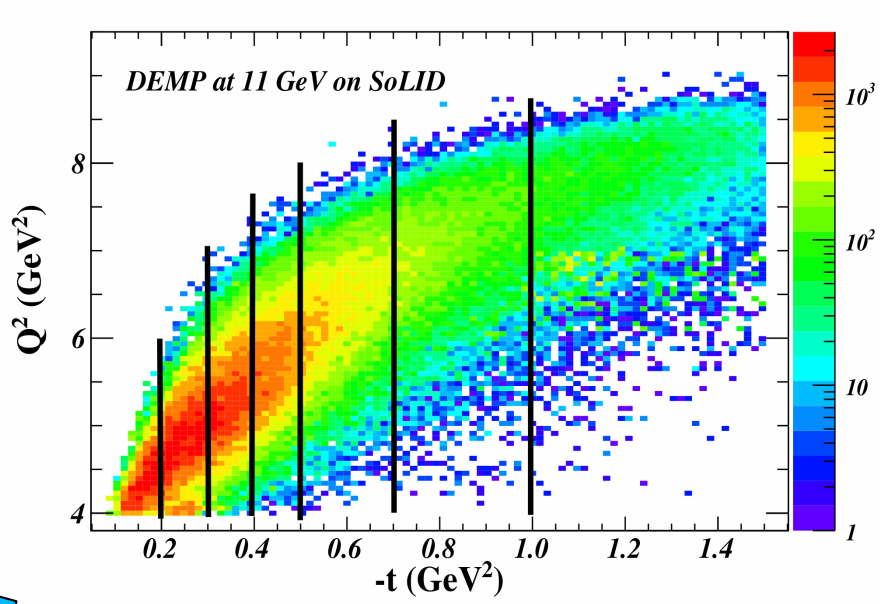
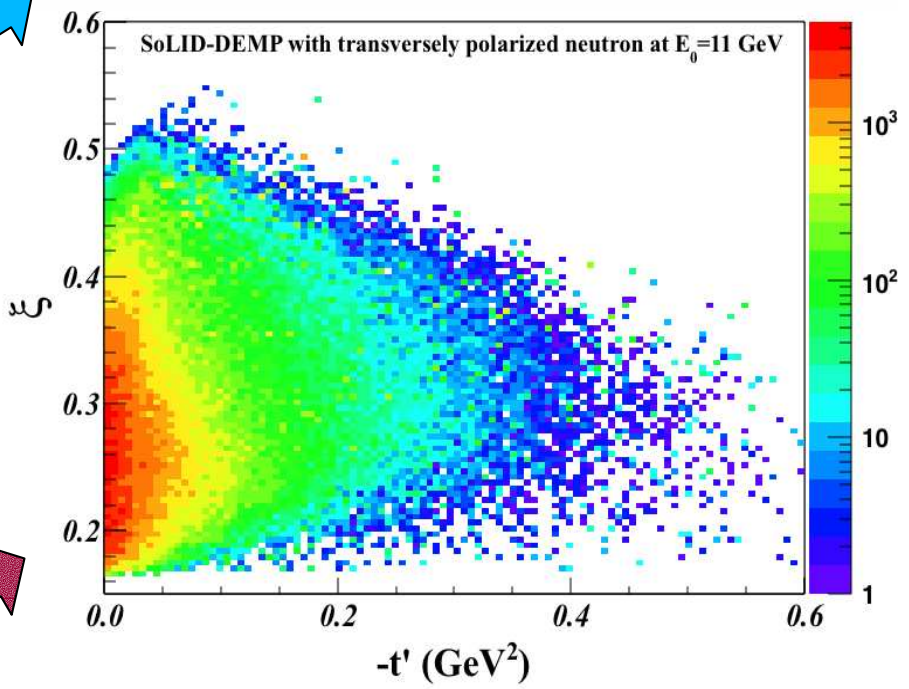
Q^2>1 GeV^2 W>2 GeV	Q^2>4 GeV^2 W>2 GeV
DEMP: $n(e,e'\pi^-p)$ Triple Coin (Hz)	
4.95	0.40
SIDIS: $n(e,e'\pi^-)X$ Double Coin (Hz)	
1425	35.8

- Event generator based on data from HERMES, Halls B,C with VR Regge+DIS model used as constraint in unmeasured regions.
- Data divided in 7 *t*–bins concentrating on the Q^2>4 GeV^2 region of greatest physics interest.
- Pioneering HERMES data at: $\langle Q^2\rangle$=2.38 GeV^2, $\langle x_B\rangle$=0.13, $\langle -t\rangle$=0.46 GeV^2, small skewness ξ<0.1.
- **With SoLID, we can measure the skewness dependence of the relevant GPDs over a fairly large range of ξ.**





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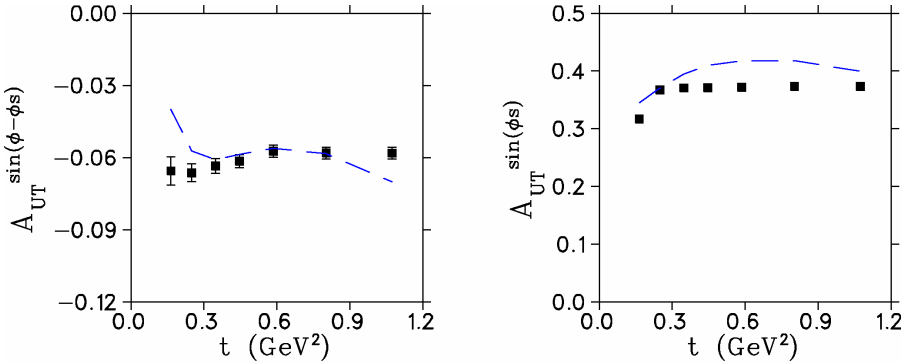
Exclusive π^- from Transversely Polarized Neutron

- **A wide –*t* coverage is needed to obtain a good understanding of the transverse single spin asymmetry, and the high luminosity capabilities of SoLID make it well–suited for this measurement.**

- Since an L–T separation is not possible with SoLID, the observed $A_{UT}^{\sin(\varphi-\varphi S)}$ asymmetry will be diluted by the ratio of the longitudinal cross section to the unseparated cross section.
- This was also true for the pioneering HERMES measurements, which provided a valuable constraint to models for the $\tilde{E}$ GPD.
- $A_{UT}^{\sin(\varphi S)}$ asymmetry can be extracted from the same data, providing powerful additional GPD model constraints.

Projected Uncertainties.
Includes all scattering, energy loss, resolution effects. Corresponds to when proton resolution is good enough to correct for Fermi momentum effects.



Projected "parasitic" E12–10–006 data.
→ analyze 2–track (e' π^-) data offline for recoil proton track.

Additional studies planned to study Fermi momentum and other reconstruction effects, with goal to "sharpen the physics case"

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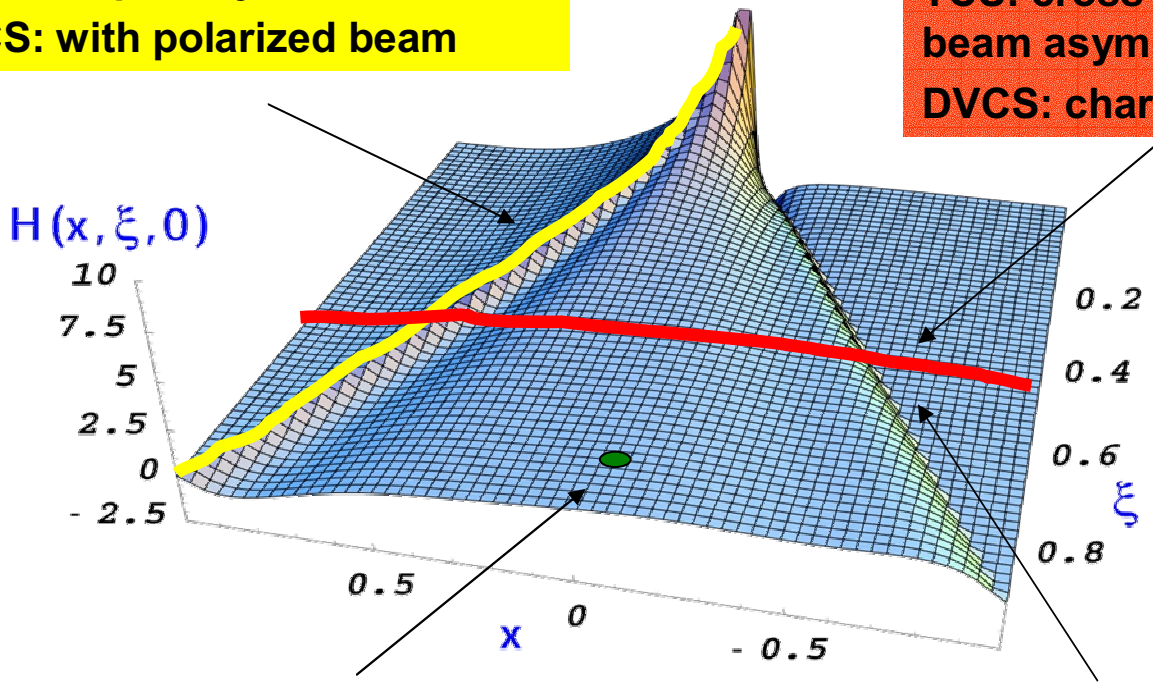
General Compton Processes Accessing GPDs

(Im, $x=\xi$)
DVCS: spin asymmetries
TCS: with polarized beam

(Re)
TCS: cross section, linear beam asymmetry
DVCS: charge asymmetry



(Im, $x \neq \xi$, $x < |\xi|$)
Double DVCS

($|Im|^2+|Re|^2$)
DVCS: cross section

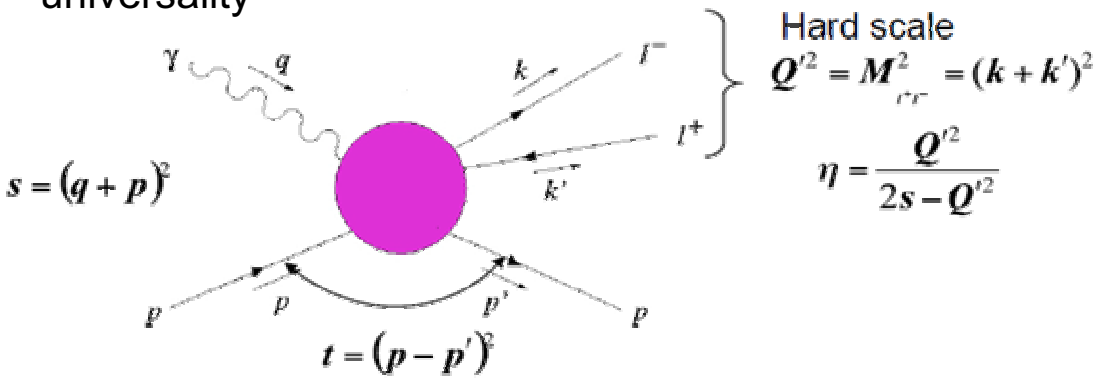
Zhiwen Zhao, Duke

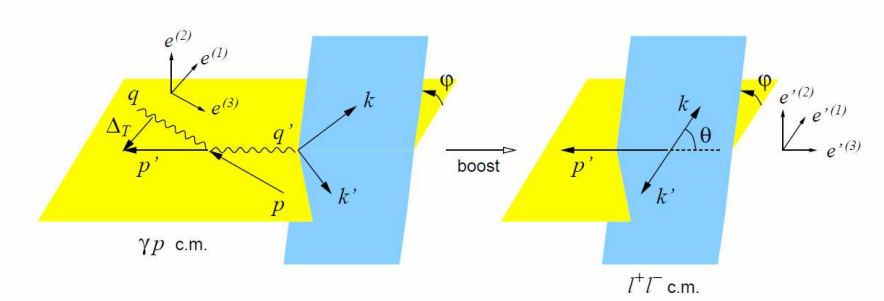
SoLID TCS (E12–12–006A)

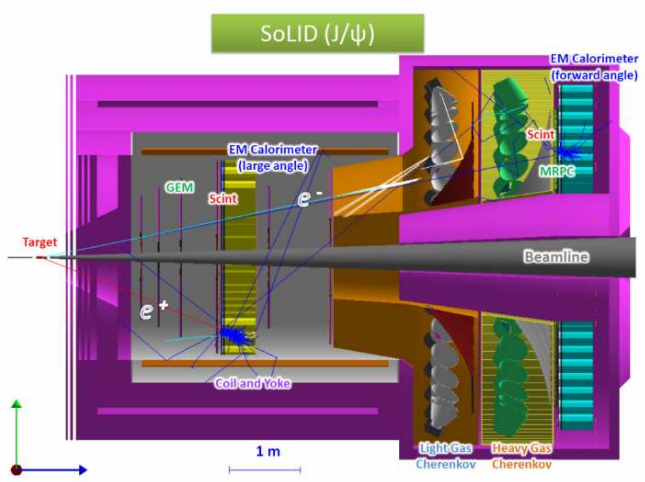
approved as run group with SoLID J/ψ(E12–12–006)

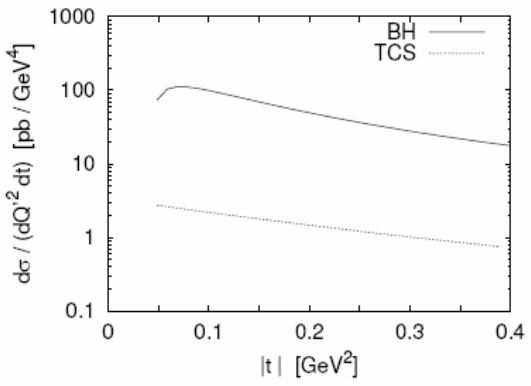
As a key reaction for studying GPD, SoLID TCS will have

- Unpolarized data access to the real part of CFFs, sensitive to the D-term in GPD parametrization with observables cross section ratio (R) and forward backward asymmetry (A_{FB})
- Circularly polarized data access to imaginary part of CFFs with BSA (similar to DVCS) to study universality









$$R=\frac{2\int_0^{2\pi} d\phi\cos\phi\,\frac{dS}{dQ^2\,dt\,d\phi}}{\int_0^{2\pi} d\phi\,\frac{dS}{dQ^2\,dt\,d\phi}}$$

$$A_{FB}(\theta,\phi)=\frac{d\sigma(\theta,\phi)-d\sigma(180^\circ-\theta,180^\circ+\phi)}{d\sigma(\theta,\phi)+d\sigma(180^\circ-\theta,180^\circ+\phi)}$$

E. Berger *et al.*, Eur. Phys. J. C23, 675 (2002)

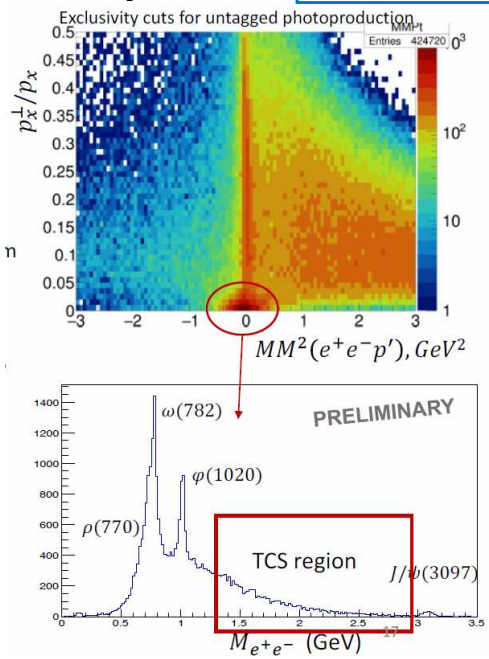
SoLID TCS Impact

Zhiwen Zhao, Duke

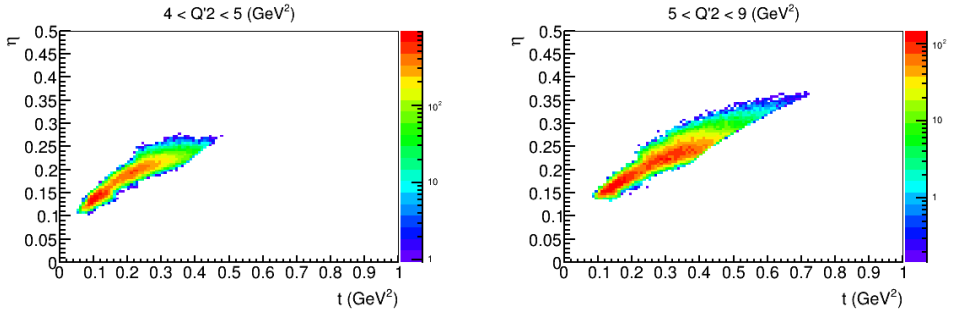
15cm LH2 target, 3μA current, $1.2\times10^{37}/cm^2/s$ luminosity for 50+10 days

- CLAS12 TCS data shows promising results
- SoLID TCS with different acceptance and higher statistics will expand the study into multidimensional binning as input for global GPD fitting
- SoLID TCD is also complementary to Hall C TCS with transversely polarized target (C2)

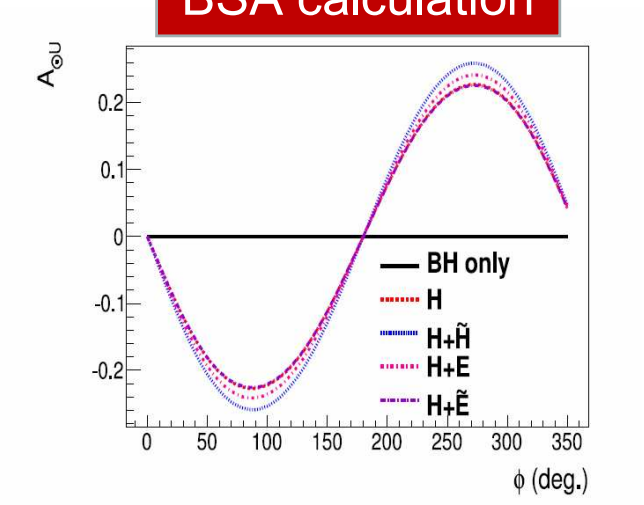
CLAS12 data



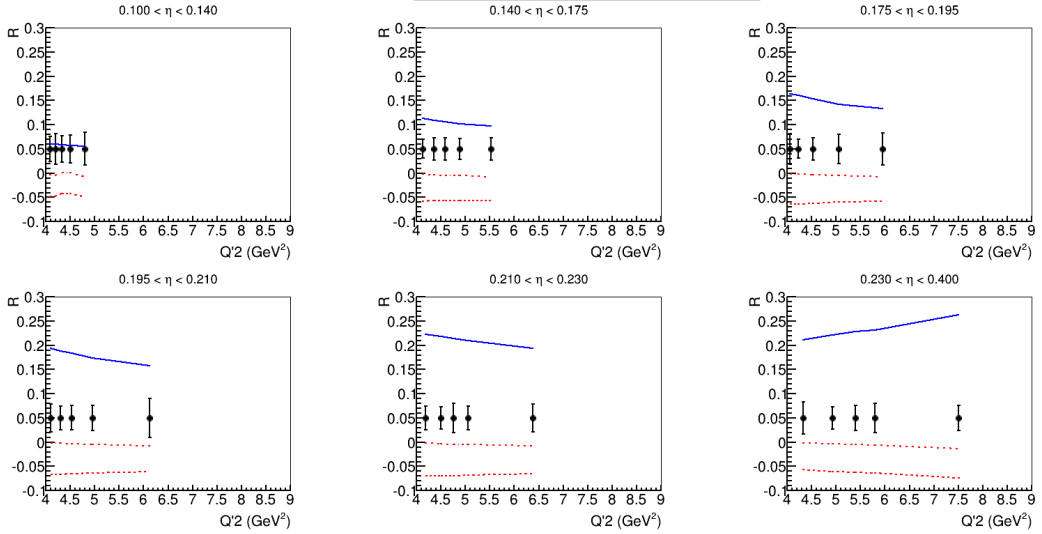
Kinematic coverage



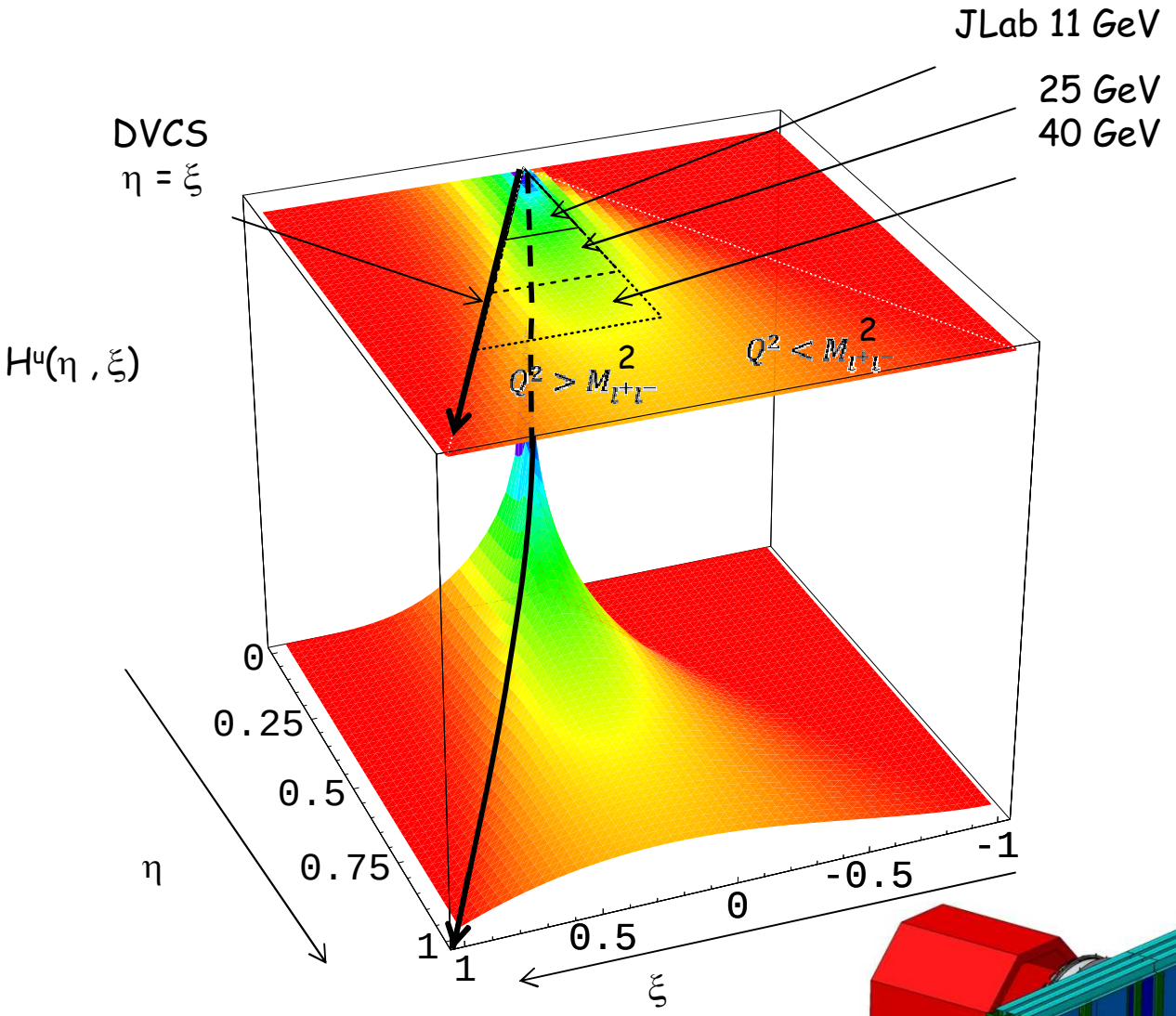
BSA calculation



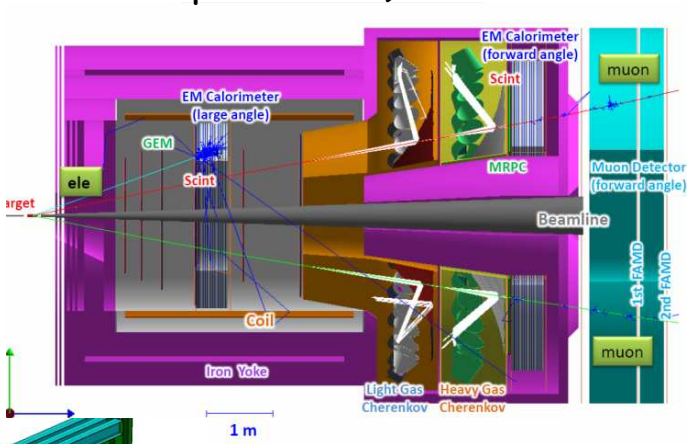
R projection

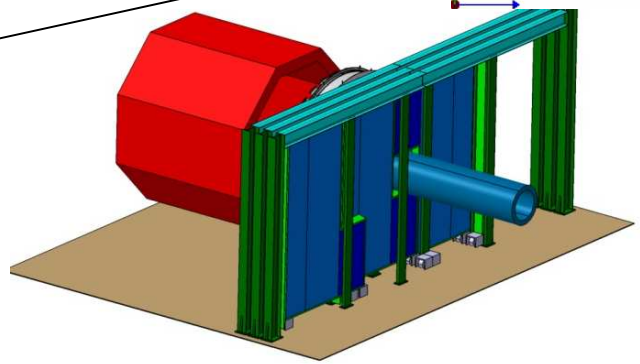


Double DVCS with SoLID



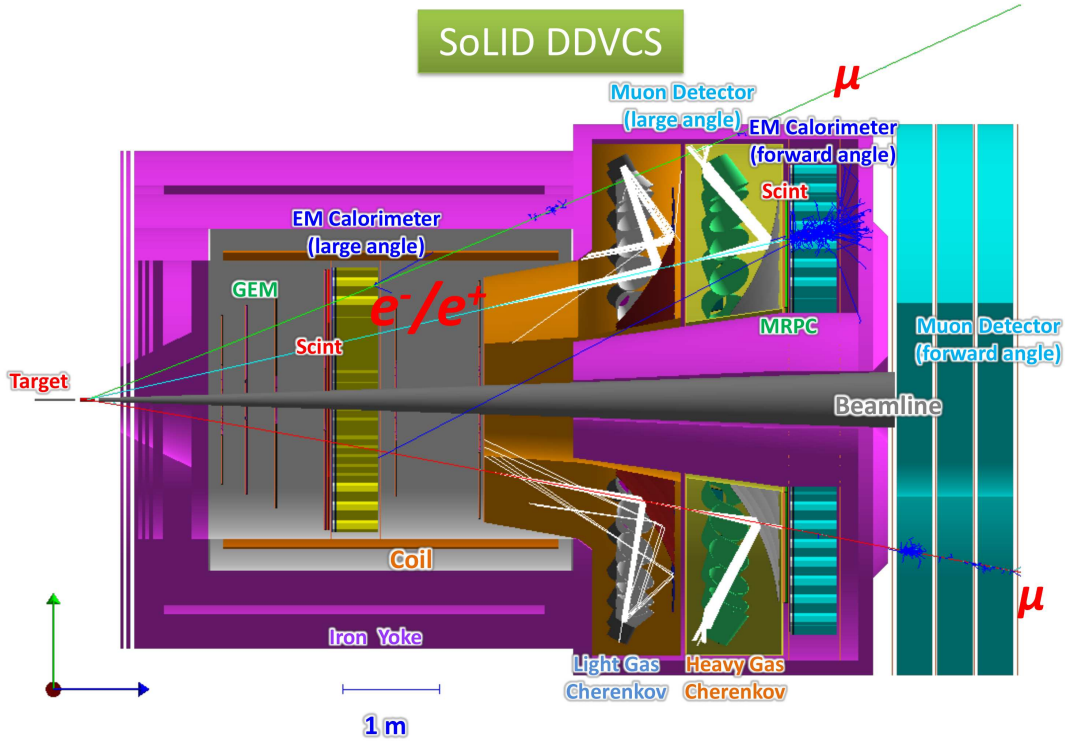
- DVCS only probes $\eta = \xi$ line
- Example with model of GPD H for up quark
- JLab : $Q^2>0$
- Kinematical range increases with beam energy (larger dilepton mass)





Double DVCS with SoLID

- SoLID run at $10^{37}cm^{-2}s^{-1}$ J/ψ experiment
- Solenoidal configuration ideal for high luminosity
- Might be able to run at $10^{38}\ cm^{-2}s^{-1}$ with dedicated setup



- Plan
  - –Fully parasitic rungroup proposal for e^+e^- channel
  - –Option to add muon detector (need full proposal)
  - –Dedicated setup proposal later

Summary ECT workshop

- **ECT Trento workshop refined physics case Oct 24–28 2016**

- Measurement of zero crossing of asymmetry at various Q^2 model independent information on GPDs
- Access of GPDs outside x=ξ line
- DDVCS gives access to D–term
- Need to evaluate contribution of DDVCS on GPD fitting to make a good physics case

- **Workshop summary paper :**
  https://arxiv.org/abs/1712.04198

Zhihong Ye, ANL

GPD Study with DVCS

DVCS with polarized electron beam and targets:

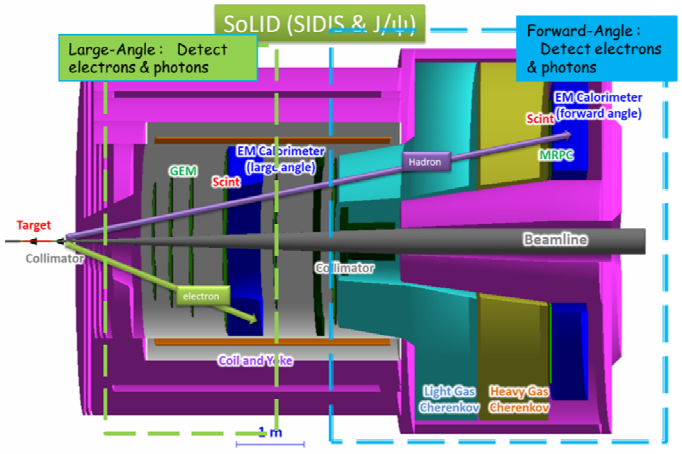
- GPD study needs both proton neutron data (flavor decomposition), and all types of observables (GPD disentangling)
- Approved 12GeV polarized DVCS experiments:

✓ E12-06-119 (Hall-B): longi. pol proton (DNP), BSA, TSA
✓ C12-12-010 (Hall-B): trans. pol. proton (HDice), TSA,BSA

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

- NO polarized neutron-DVCS experiment has been done or proposed at JLab, and SoLID is currently the only place that can do such measurements.
  (only done at HERMES with poor accuracy and limited coverage)

SoLID-SIDIS Configuration for nDVCS

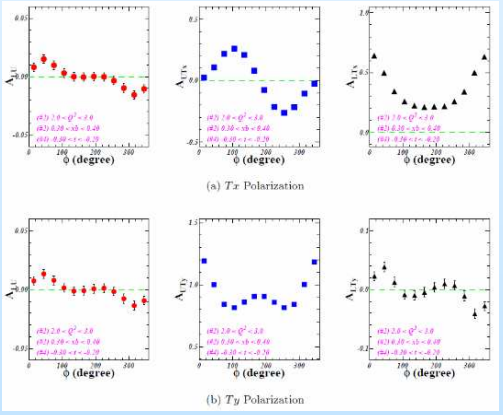


- **SoLID can bring a whole set of polarized DVCS data:**

✓ Transversely & Longitudinally polarized neutron-DVCS
(He3, with E12-10-006&E12-11-007 SIDIS setup)
✓ Transversely & Longitudinally polarized proton-DVCS
(DNP, with E12-11-108 SIDIS setup)

Transversely polarized neutron DVCS:

E_0	8.8 GeV	11 GeV
Single Rates (Hz)		
e- (FAEC)	64.78	36.17
e- (LAEC)	2.57	1.70
γ (FAEC)	45.37	40.54
γ (LAEC)	31.05	28.83
Coincidence Rates (Hz)		
e-(FAEC)+γ(FAEC+LAEC)	36.06	20.50
e-(LAEC)+γ(FAEC+LAEC)	1.46	1.00



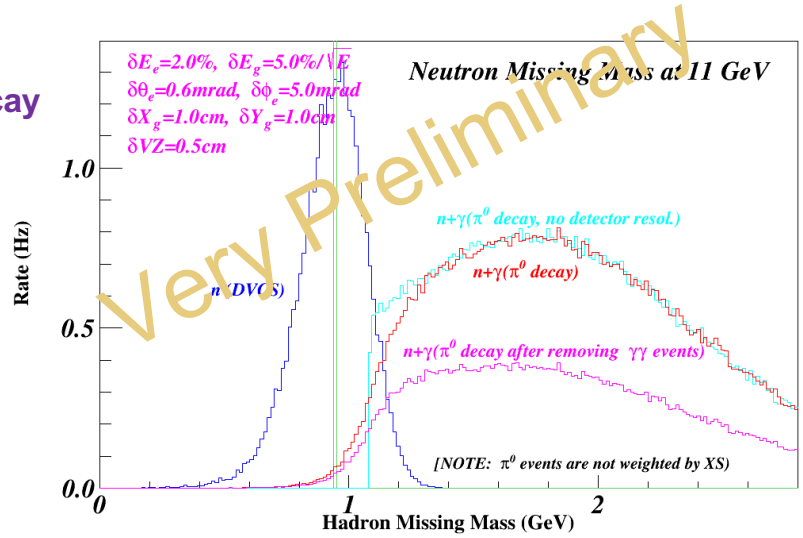
✓ Measurements of BSA, TSA and DSA
✓ Wide kinematic coverage
✓ 4-dimensional binning on Q2, -t, xB and phi (>500 bins)
✓ **To do#1:** Extract CFF distributions with using PARTON fitting toolkit (arXiv:1512.06174)

GPD Study with DVCS

➢Exclusivity and Backgrounds:

Main background if not detecting recoil neutrons: (n+γ) from π^0 decay

- ✓ Missing Mass Reconstruction after detecting electrons and photons (angles, momentum/energy).
- ✓ The spectrum resolution is limited by the EC resolution (~5%)
- ✓ Background Subtraction: ECs can detect partial π^0 decay events by reconstruction two-photons events



$$N_{\pi^0}^{Total} = \frac{N_{\pi^0}^{MC-Total}}{N_{\pi^0}^{MC-Accept}} N_{\pi^0}^{Detect}$$

$N_{\pi^0}^{Total}$ $(N_{\pi^0}^{Detect})$ ←Detected **π^0** events which are mixed into the MM spectrum

$N_{\pi^0}^{MC-Total}$ $(N_{\pi^0}^{MC-Accept})$ ←All **π^0** events in the entire from simulation

To Do #2:

➢Evaluate other background

➢Evaluate systematic uncertainties

➢Study nuclear effects, energy loss (combined with nDEMP works)

To Do #3:

➢Evaluate π^0 background. Current found two generators:

(1) from Prof. Simonetta Liuti

(2) HEPGEN++ provided by Valery Kubarovsky

➢Learn from the new Hall-A 12GeV-DVCS data.

Other Dedicated GPD Options

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- Phase 1 program uses the existing SoLID–SIDIS setup (and beam–time) to initiate the SoLID–GPD program (e.g. DVCS and DEMP) with minimal impact on the approved SoLID program.
- To fully extend the capabilities of the SoLID GPD program, a Phase 2 suite of experiments would likely require:
  - Dedicated configurations (for DDVCS).
  - Increase the EC resolution (to allow exclusive vector meson and π^0 measurements).
  - Recoil detector near the target (based on HERMES experience) such as low momentum proton tagging for DEMP or neutron detection for DVCS.
- These would require further study, clearly beyond the scope of the present proposals.

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