The SoLID GPD Program

Garth Huber University of Regina

On behalf of the SoLID Collaboration

SoLID SOLENOIDAL LARGE INTENSITY DEVICE

Supported by: NSERC CRSNG SAPIN-2021-00026

Towards Improved Hadron Femtography with Hard Exclusive Reactions
ECT* Workshop, Trento, Italy
August 8, 2024

SoLID @ 12 GeV JLab: the QCD Intensity Frontier

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SoLID will ***maximize*** the science return of the 12-GeV CEBAF upgrade by **combining...**

High Luminosity
$10^{37\text{-}39}$ /cm^2/s
[>100x CLAS12][>1000x EIC]

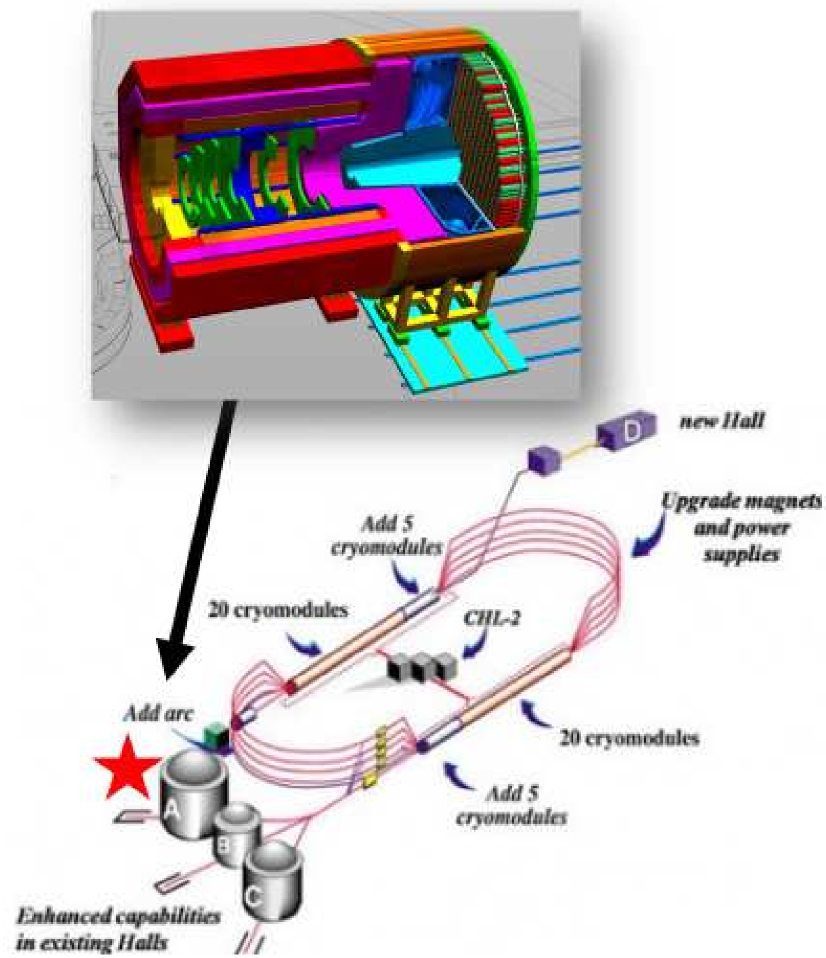
+

Large Acceptance
Full azimuthal ϕ coverage

Research at **SoLID** will have the ***unique*** capability to **explore** the QCD landscape while **complementing** the research of other key facilities

- **Precision lepto-quark couplings** at unique mass and sensitivity scales
- 3D momentum imaging of a relativistic strongly interacting confined system (nucleon spin)
- Superior sensitivity to the differential electro- and photo-production cross section of J/ψ near threshold (proton mass)

Synergizing with the pillars of EIC science (proton spin and mass) through high-luminosity valence quark tomography and precision J/ψ production near threshold

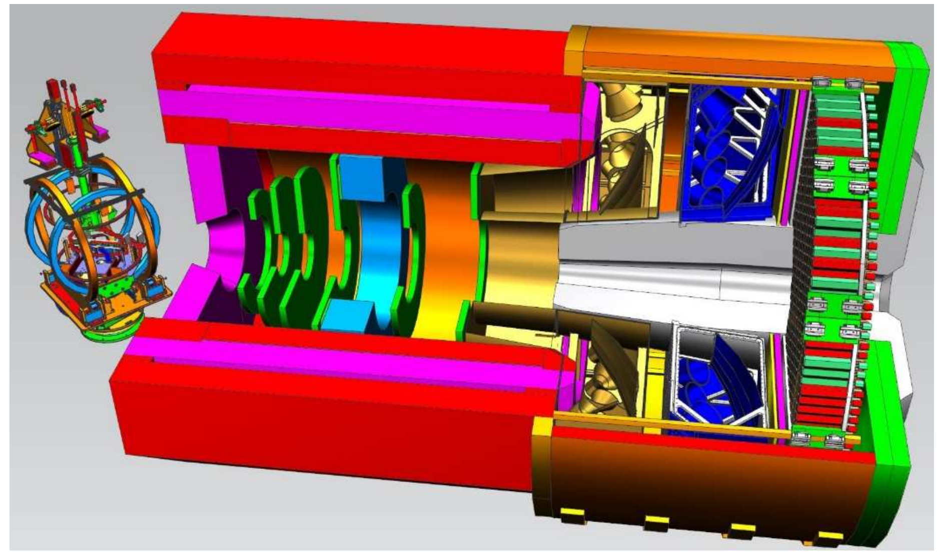


SoLID Apparatus

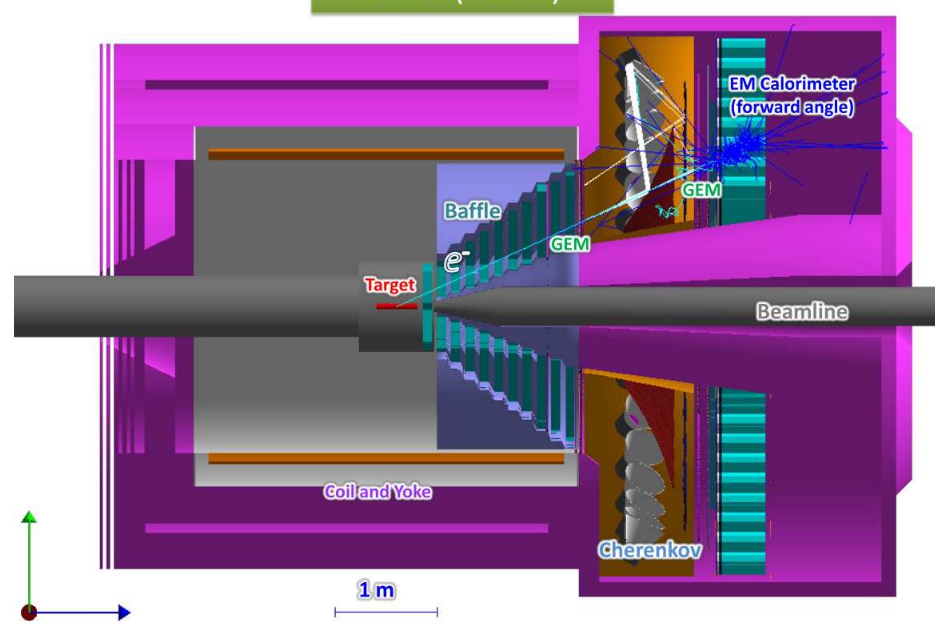
Requirements are Challenging

- High Luminosity (10^{37}-10^{39}/cm²/s)
- High data rate
- High background
- Low systematics
- High Radiation Tolerance
- Large scale detectors
- Modern Technologies
    - GEM's
    - Shashlik ECal
    - Pipeline DAQ
    - Rapidly Advancing Computational Capabilities
- High Performance Cherenkovs
- Baffles (for PVDIS)

Polarized ^{3}He ("neutron") @ SoLID



SoLID (PVDIS)



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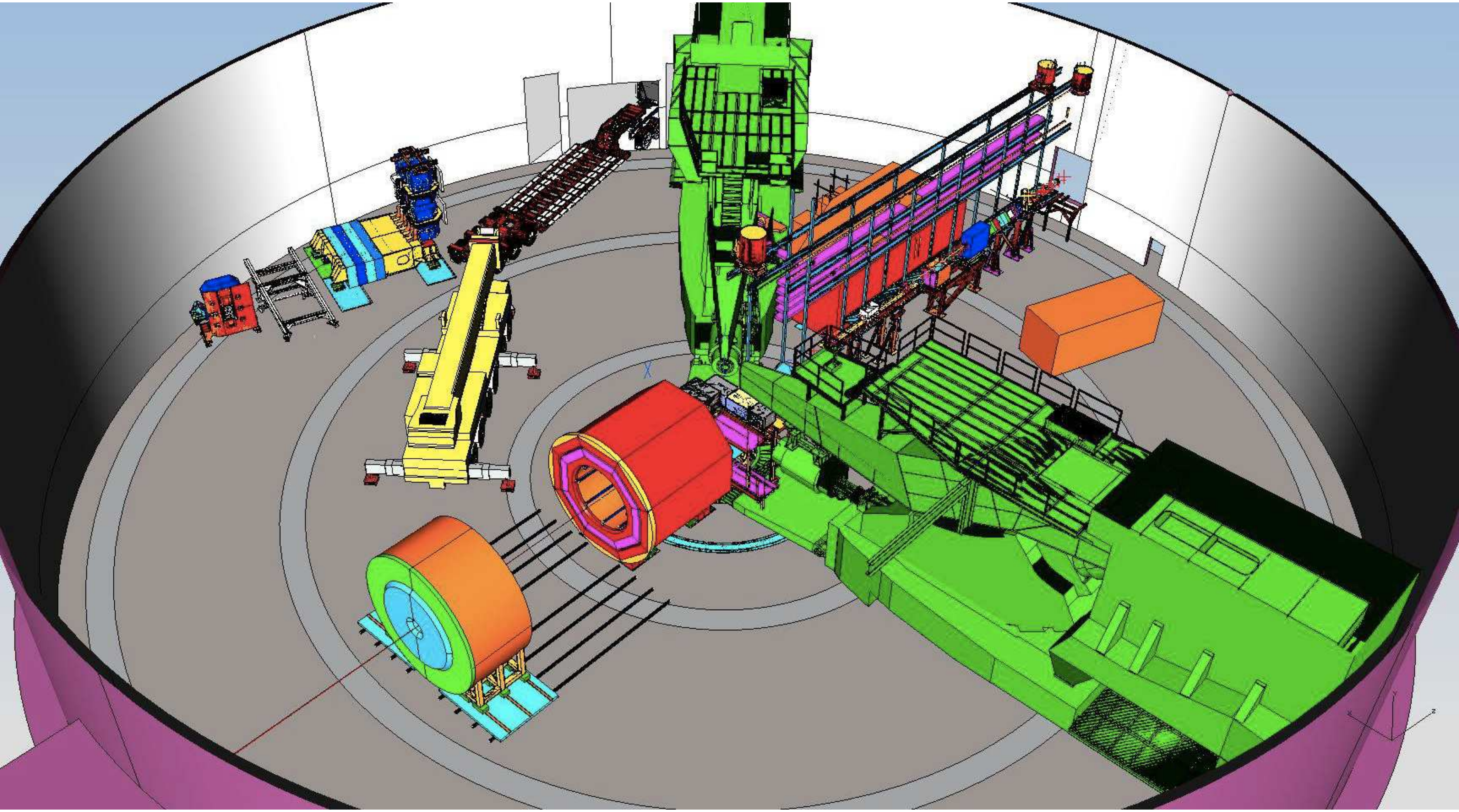
SoLID in Jefferson Lab Hall A



Plan for installing SoLID in JLab Hall A with other equipment moved out of the way

The SoLID GPD Program

- **2015 SoLID 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"

- **A broad array of GPD experiments are now planned:**
  - **DVCS on polarized ^{3}He**
    - *Z. Ye (under study)*
  - **Timelike Compton Scattering (TCS)** with circularly polarized beam and unpolarized LH_2 target
    - *Z.W. Zhao, M. Boer, 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*
    - *LOI12-23-012 reviewed by PAC51, full proposal encouraged*
  - **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)*

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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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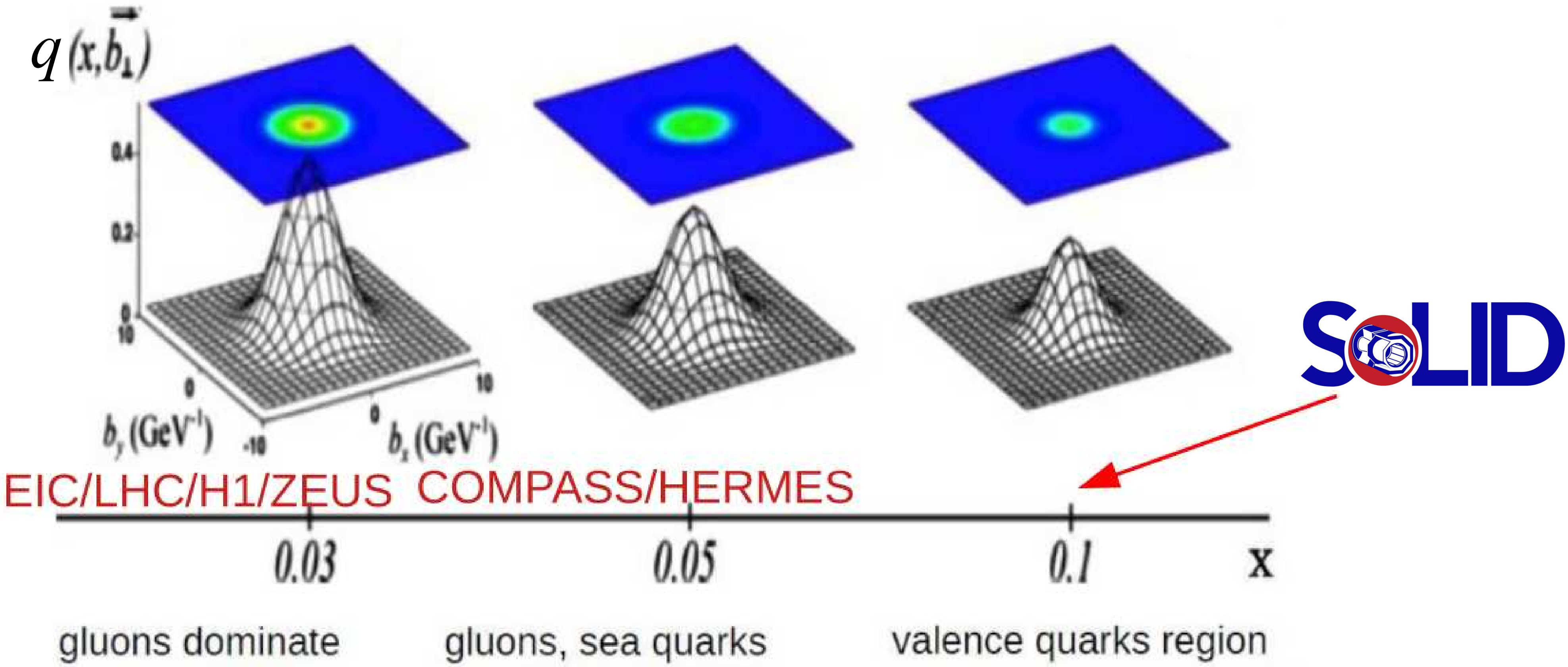
Accessible GPD Regions

- One of the interpretations of GPDS: tomographic imaging of the nucleon
- Other: spin, angular momenta correlation, “pressure”, etc

Momentum dependent impact parameter distributions
Quarks and gluons transverse position versus their longitudinal momentum



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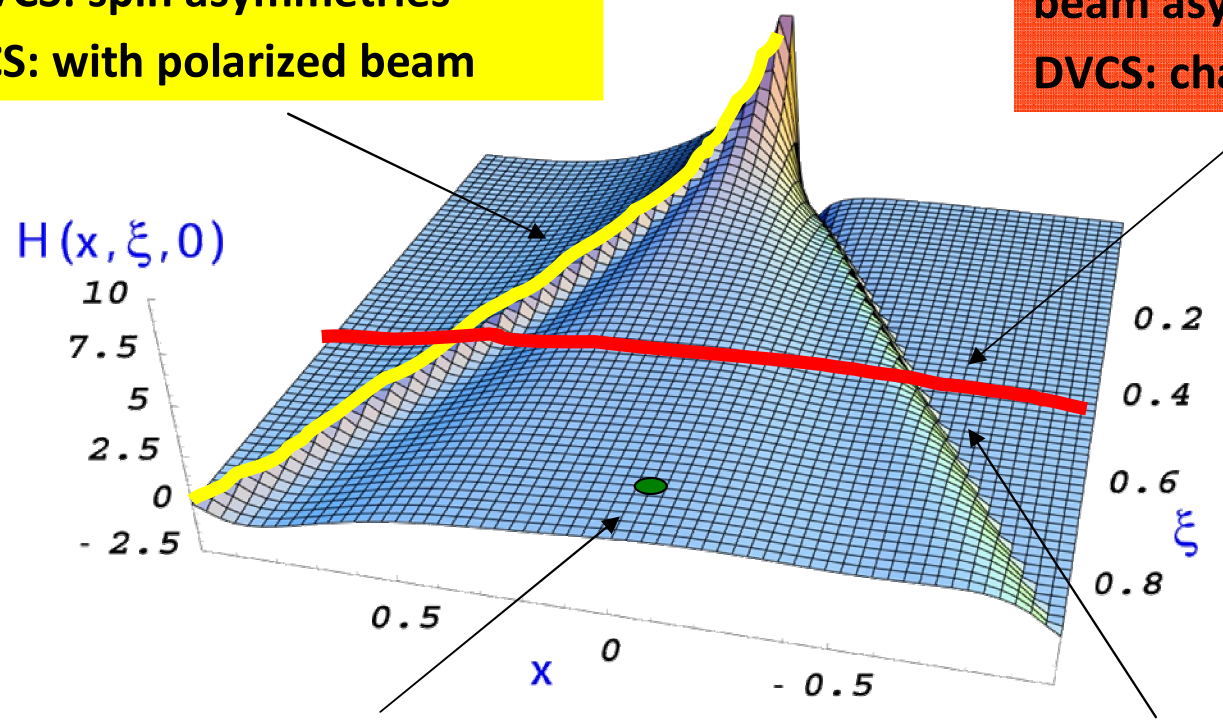
Marie Boer, Va Tech

Compton Processes Accessing GPDs

(Im, x=ξ)
DVCS: spin asymmetries
TCS: with polarized beam

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



(Im, x ≠ ξ, x < |ξ|)
Double DVCS

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

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SoLID DVCS Study

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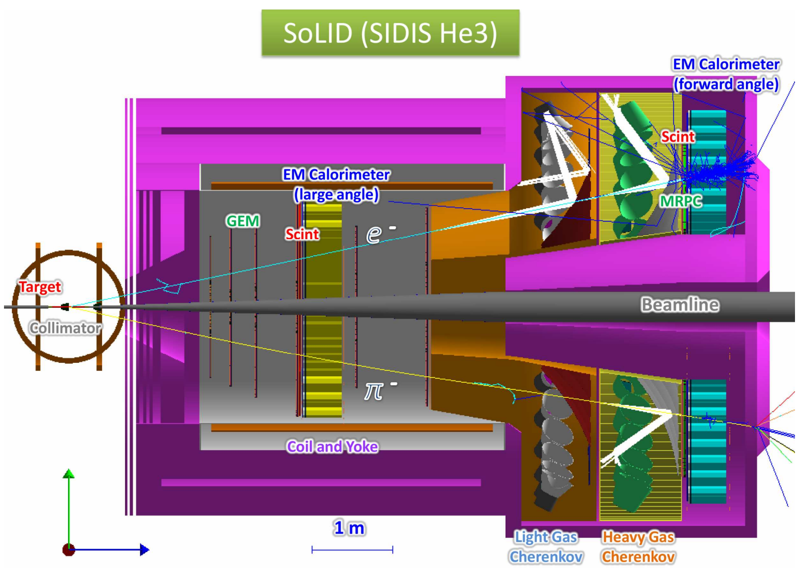
➢ DVCS with polarized electron beam and targets:

- 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 (DNO), TSA,BSA

▪ 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)

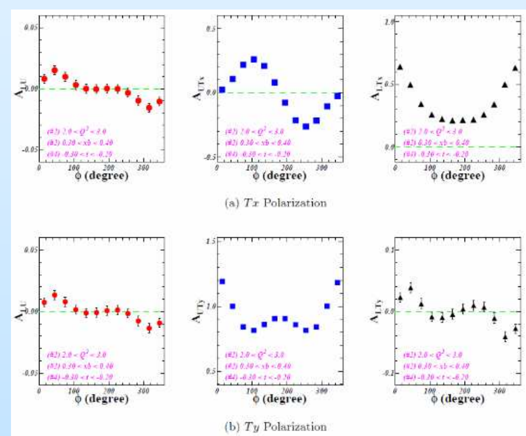
Polarization	Asymmetries	CFFs
Longitudinal Beam	A_{LU}	$Im\{\mathcal{H}_p, \widetilde{\mathcal{H}}_p, \mathcal{E}_p\}$ $Im\{\mathcal{H}_n, \widetilde{\mathcal{H}}_n, \mathcal{E}_n\}$
Longitudinal Target	A_{UL}	$Im\{\mathcal{H}_p, \widetilde{\mathcal{H}}_p, \}$ $Im\{\mathcal{H}_n, \mathcal{E}_n, \widetilde{\mathcal{E}}_n\}$
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}	$Re\{\mathcal{H}_p, \mathcal{E}_p\}$ $Re\{\mathcal{H}_n\}$



▪ **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)

SoLID DVCS Study

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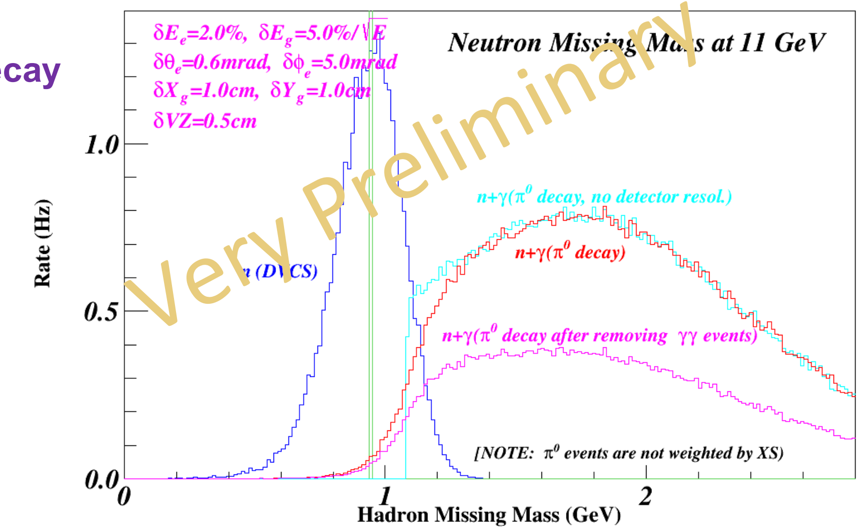
- Exclusivity and Backgrounds:

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

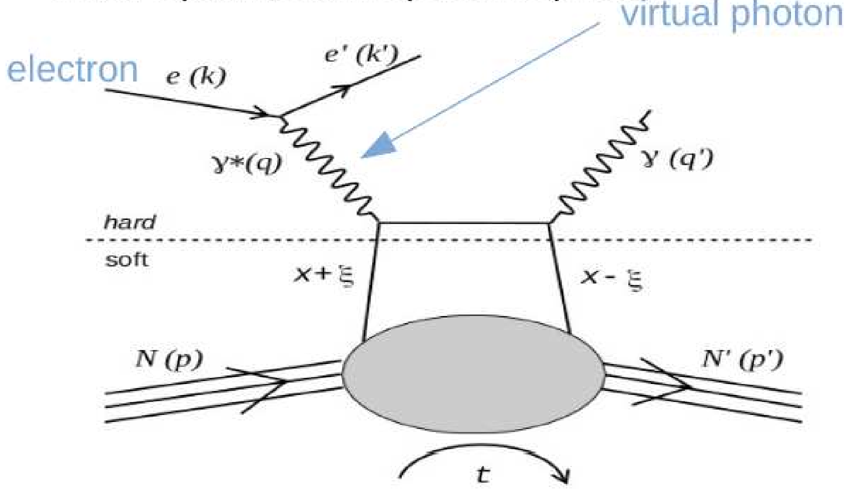
$N_{\pi^0}^{MC-Total}$ ($N_{\pi^0}^{MC-Accept}$) → All π^0 events in the entire from simulation

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.

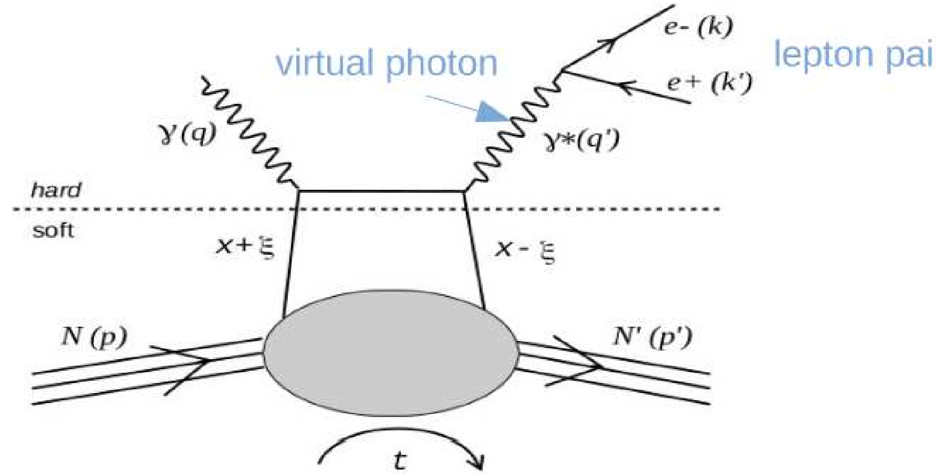
Complementarity of DVCS and TCS

Initial lepton beam / spacelike photon



Deeply Virtual Compton Scattering (DVCS)

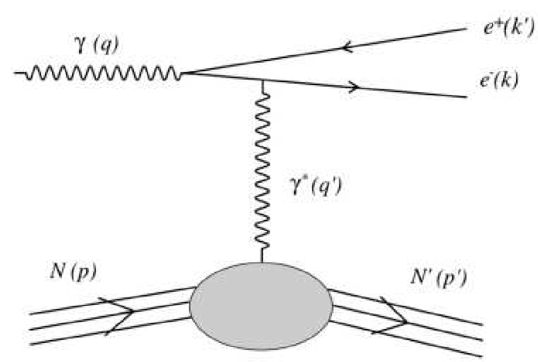
Final lepton pair / timelike photon



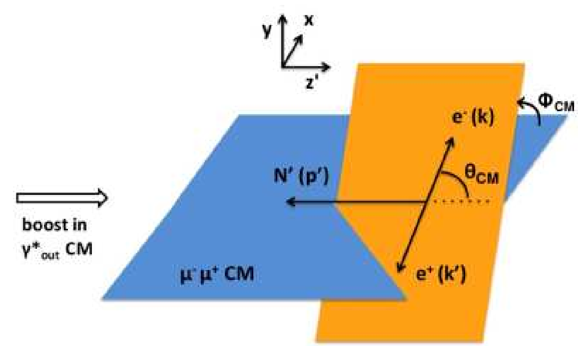
Timelike Compton Scattering (TCS)

Interference with “BH”
Harmonics in φ (φ_S)

Measuring cross section, beam/target spin asymmetries...



BH interferes with TCS



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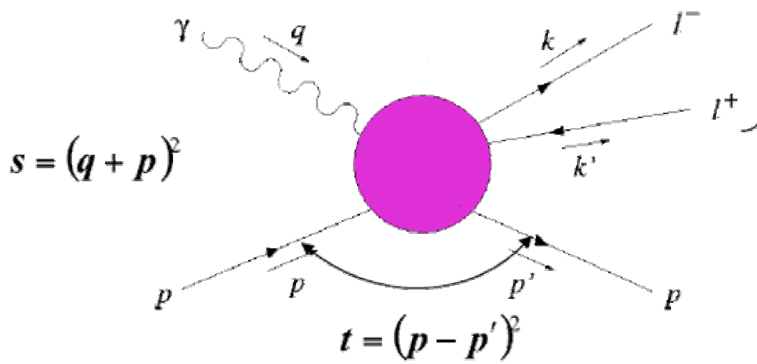
SoLID TCS (E12–12–006A)

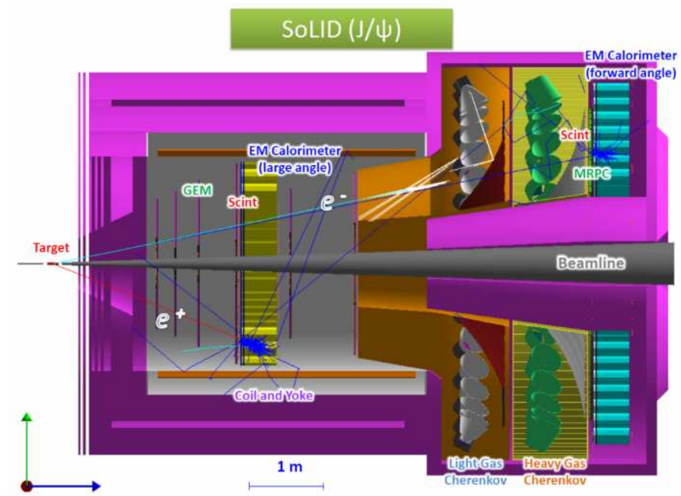
- Unpolarized data access to real part of CFFs, sensitive to D-term in GPD parametrization with observables cross section ratio (R) and forward backward asymmetry (A_{FB})
- Circularly polarized data access to imaginary part of CFFs with BSA (similar to DVCS) to study GPD universality

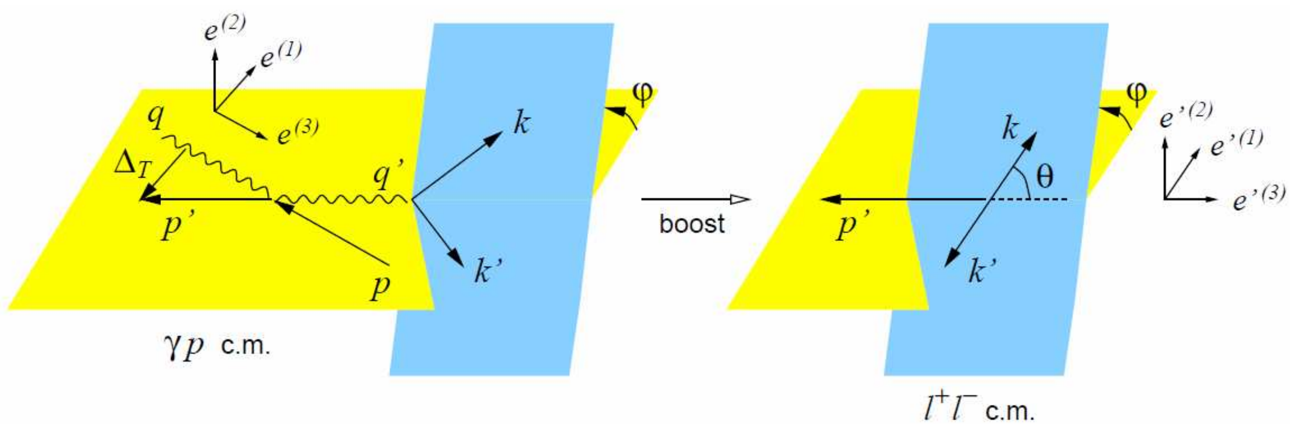


Hard scale

$$Q'^2 = M^2_{l^+l^-} = (k+k')^2$$

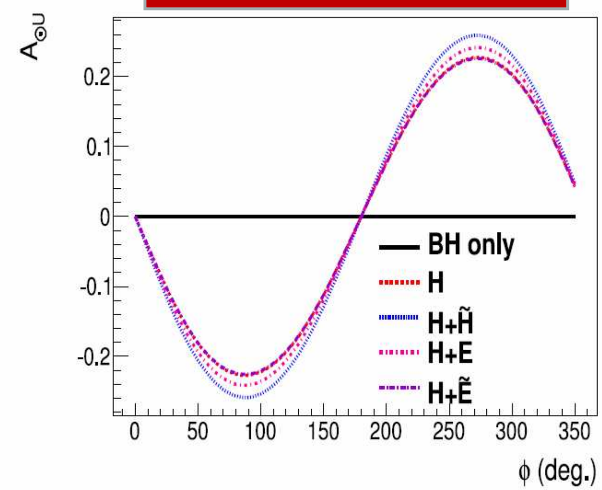
$$\eta = \frac{Q'^2}{2s - Q'^2}$$





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

BSA calculation



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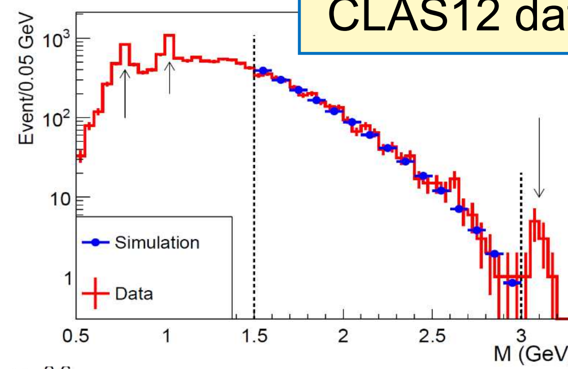
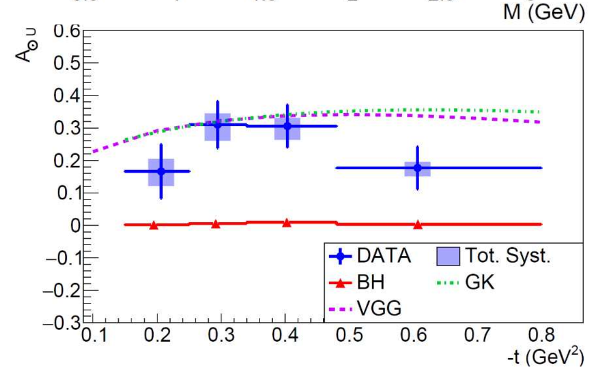
SoLID TCS Impact

15cm LH2 target, 3μA current, 1.2x10^{37}/cm^2/s luminosity for 50+10 days

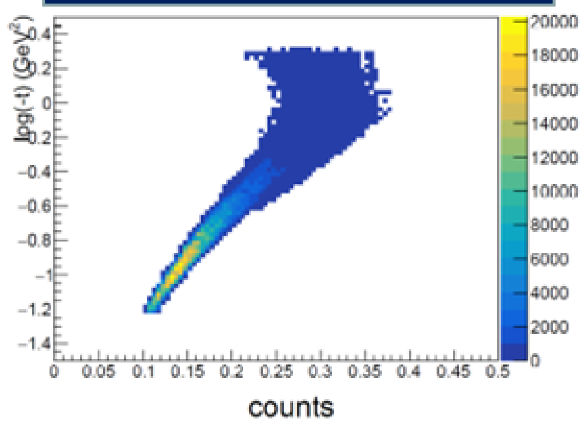
- SoLID TCS will have at least 1 order of magnitude larger statistics than CLAS12 and usher TCS study into precision era with multi–dimensional binning
  - 250x more integrated luminosity, but ¼ CLAS12 acceptance
  - Full azimuthal coverage ideal for forward–backward asymmetry
- SoLID TCS could lead to study of NLO correction

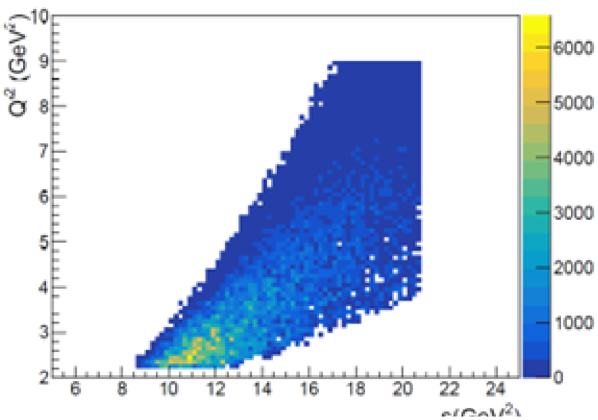
CLAS12 data





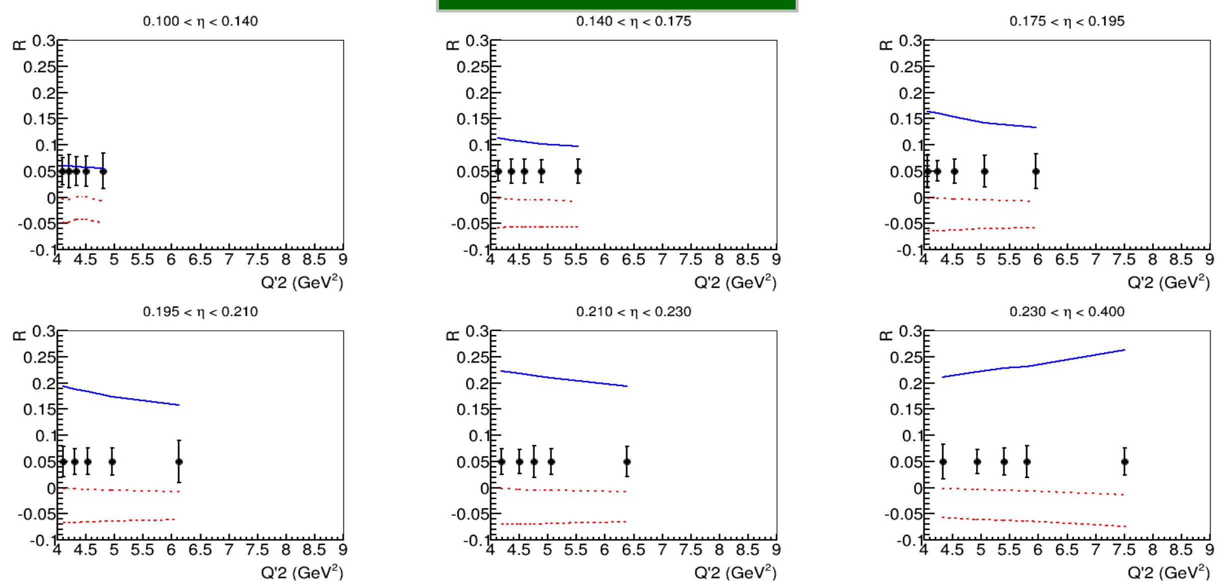
Kinematic coverage





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

R projection



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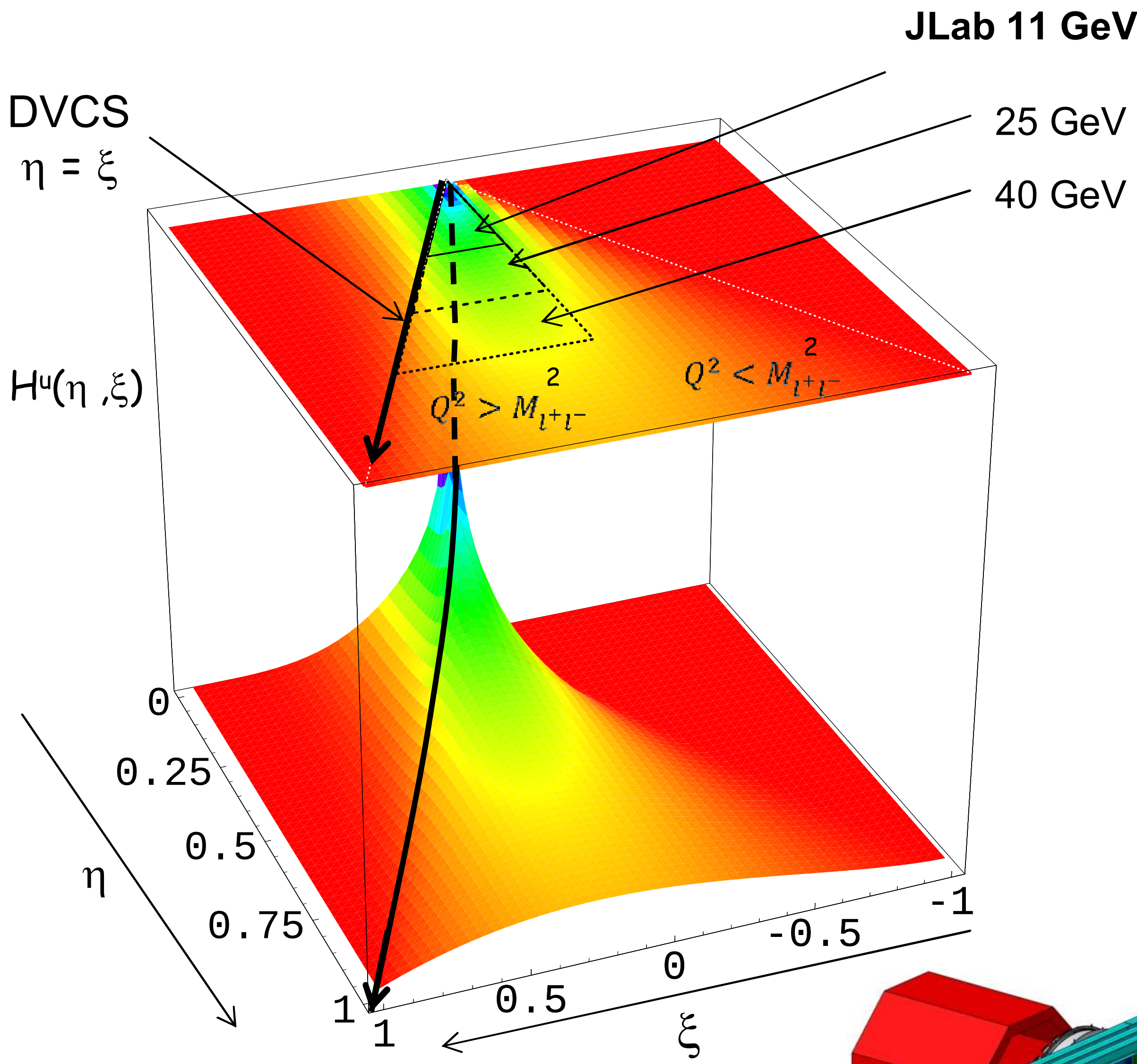
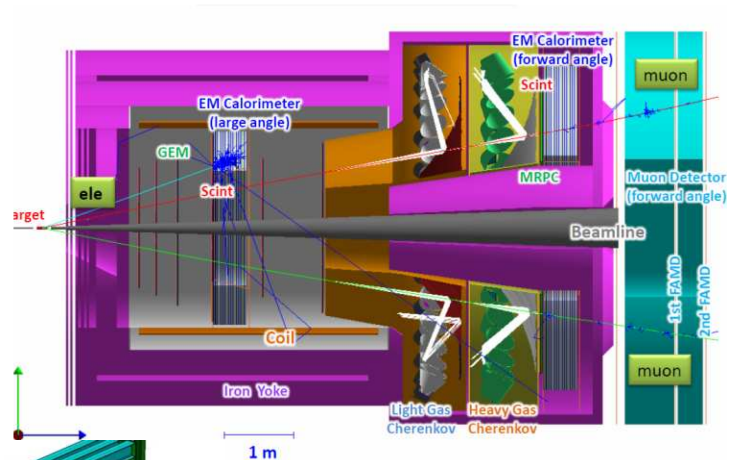
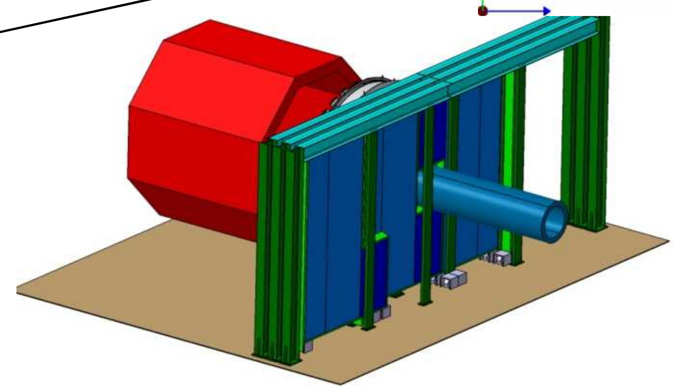
Double DVCS with SoLID



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





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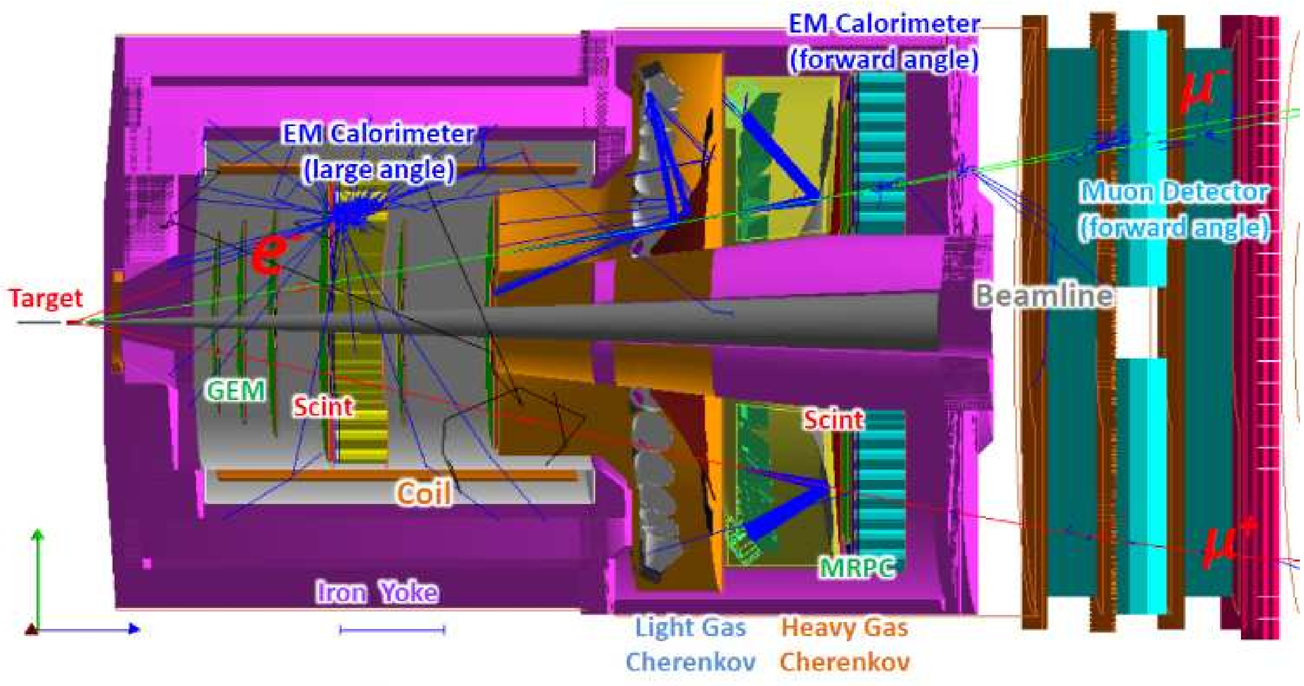
SoLID Double DVCS Setup

SoLID DDVCS



- Solenoidal configuration ideal for high luminosity
- Based on J/ψ and TCS setup with forward muon detector added
- 2023 LOI

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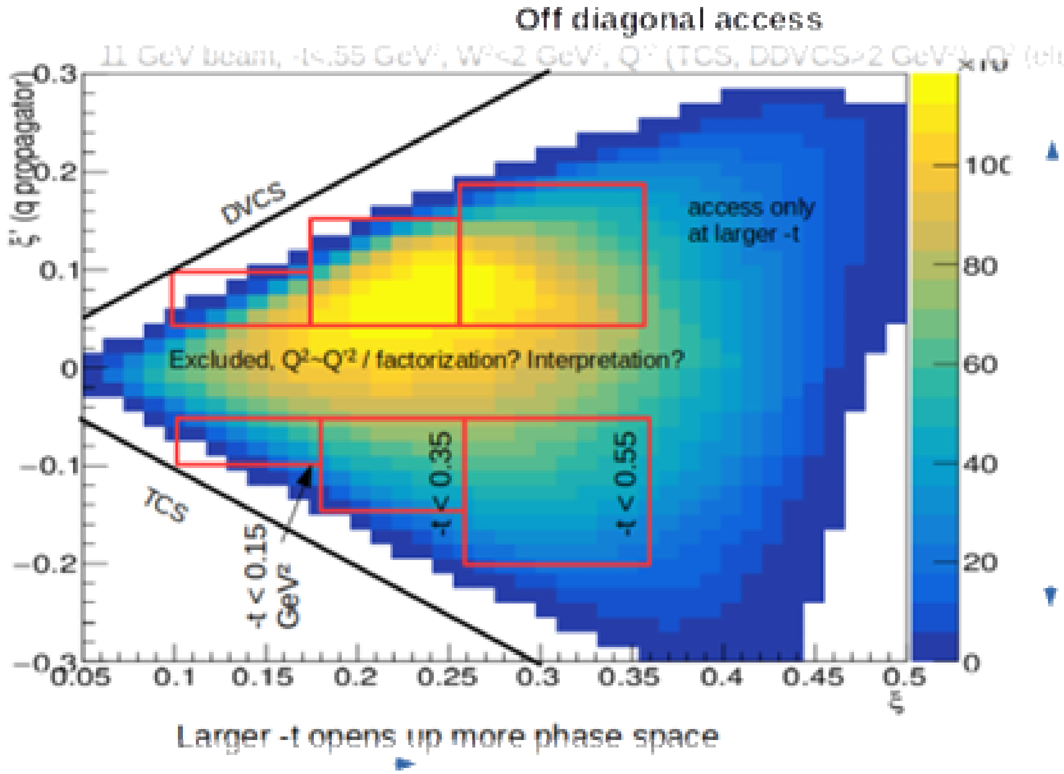
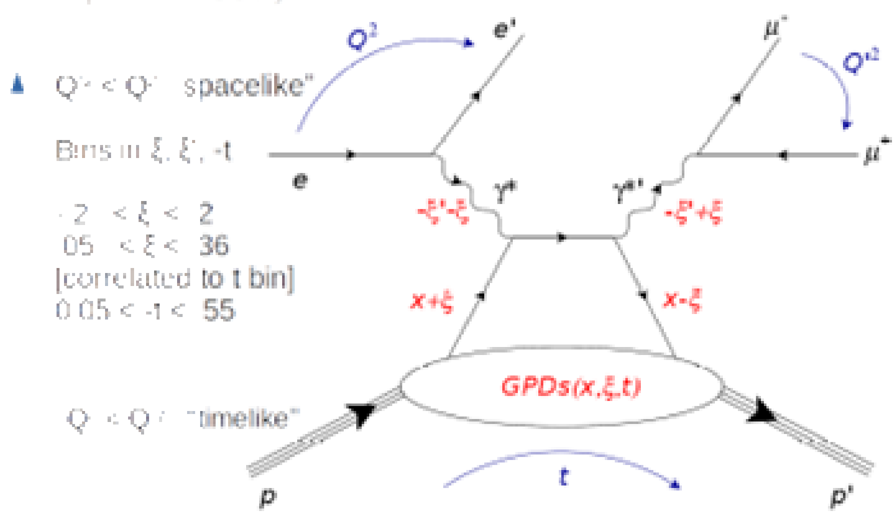
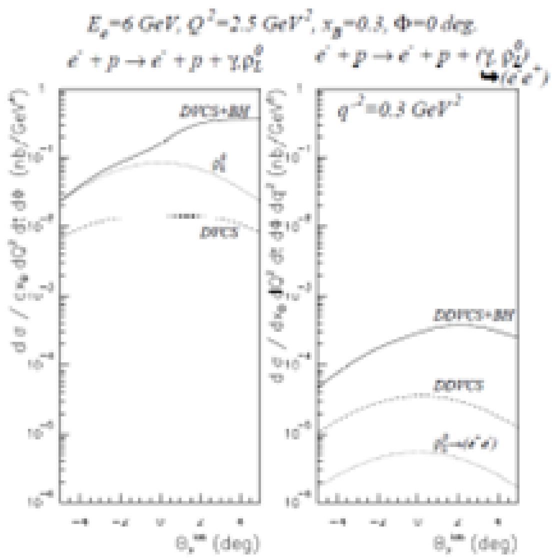
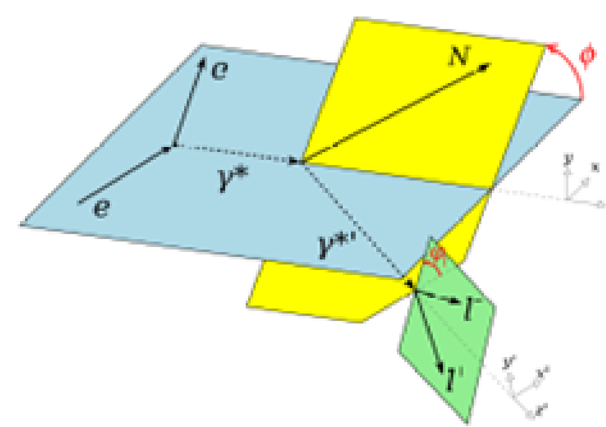
DDVCS with Circularly Polarized Beam









- Small DDVCS crosssection demands high luminosity and large acceptance
- Interference with Beth-Heitler helps construct observable

$$\xi' = \frac{Q^2 - Q'^2 + t/2}{2Q^2/x_B - Q^2 - Q'^2 + t}$$

$$\xi = \frac{Q^2 + Q'^2}{2Q^2/x_B - Q^2 - Q'^2 + t}$$

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SoLID DDVCS Projections

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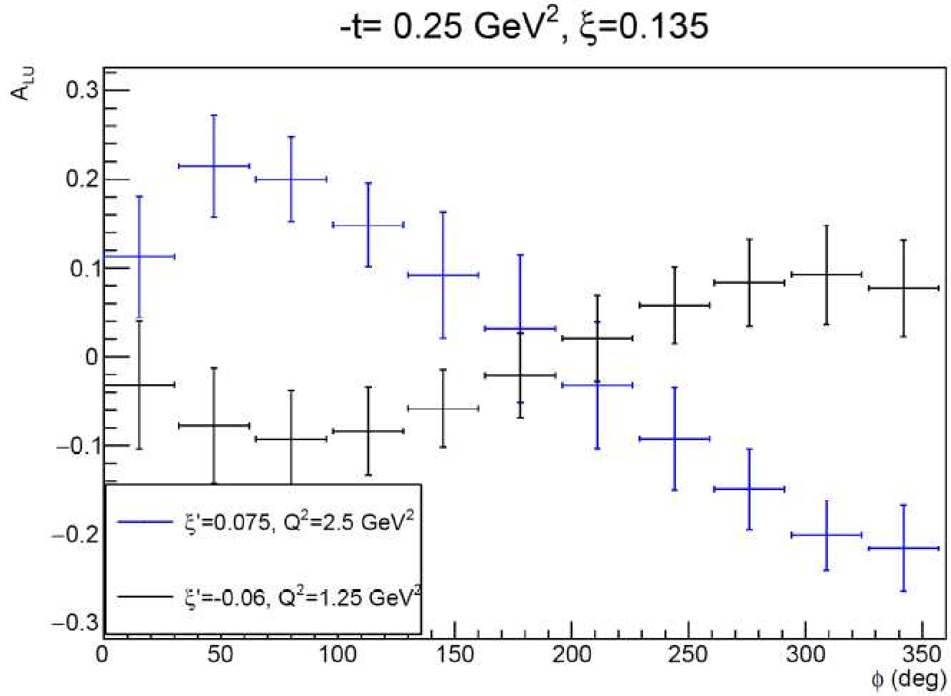
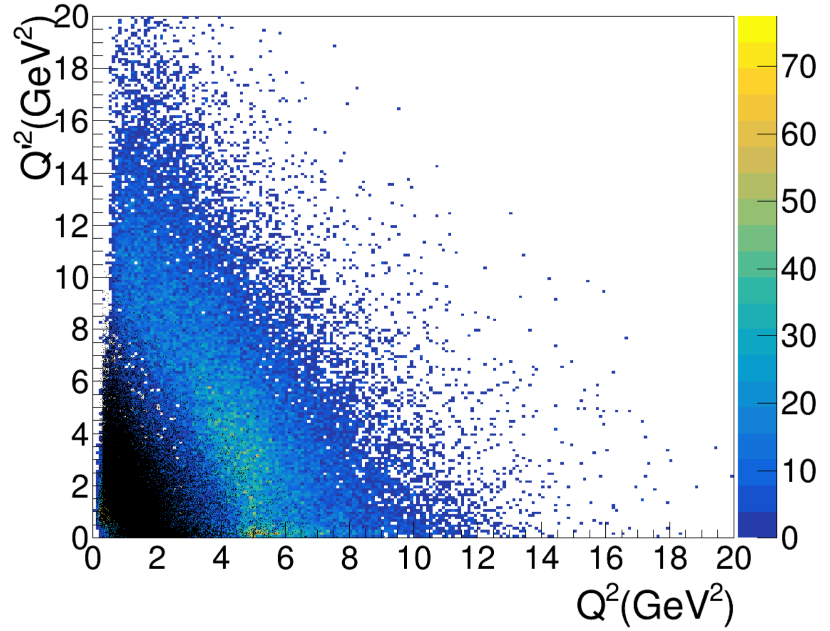
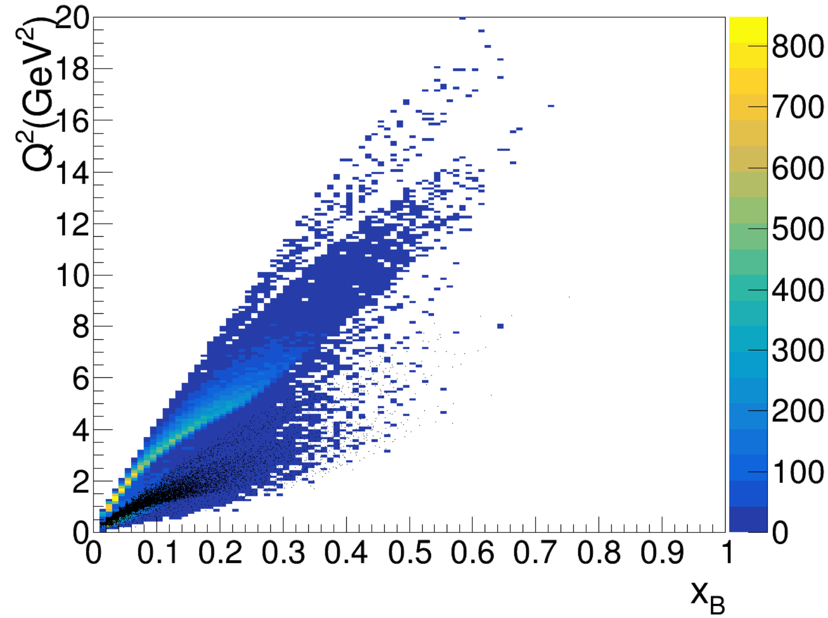
11 GeV Beam Asymmetry Projection



$$A^{\pm}_{LU}(\phi) = \frac{1}{\lambda^{\pm}} \frac{d^5\sigma^{\pm}_{+} - d^5\sigma^{\pm}_{-}}{d^5\sigma^{\pm}_{+} + d^5\sigma^{\pm}_{-}} \qquad (15)$$

$$= \frac{d^5\tilde{\sigma}_{DDVCS} \mp d^5\tilde{\sigma}^{\mathrm{INT1}}}{d^5\sigma_{BH_1} + d^5\sigma_{BH_2} + d^5\sigma_{DDVCS} \mp d^5\sigma_{INT_1}}$$





22 GeV (colored) has ~10% event rate of 11 GeV (black) but much larger kinematic coverage

Marie Boer, Alexandre Camsonne, Eric Voutier, Zhiwen Zhao

Exclusive π^- from Transversely Polarized Neutron

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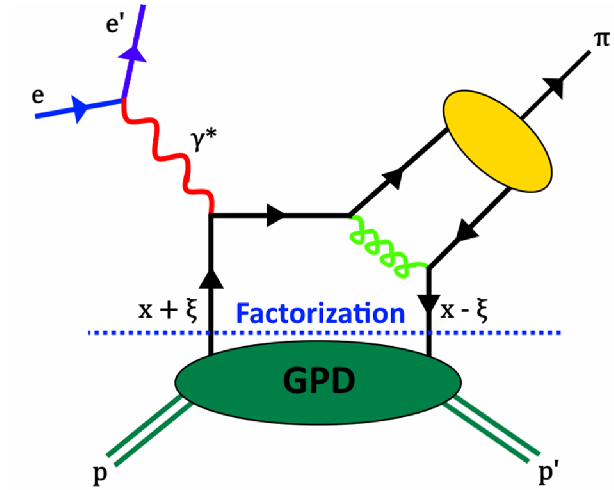
Polarized GPD $\tilde{E}$ via Deep Exclusive π Production

- *GPD $\tilde{E}$ involves a helicity flip*

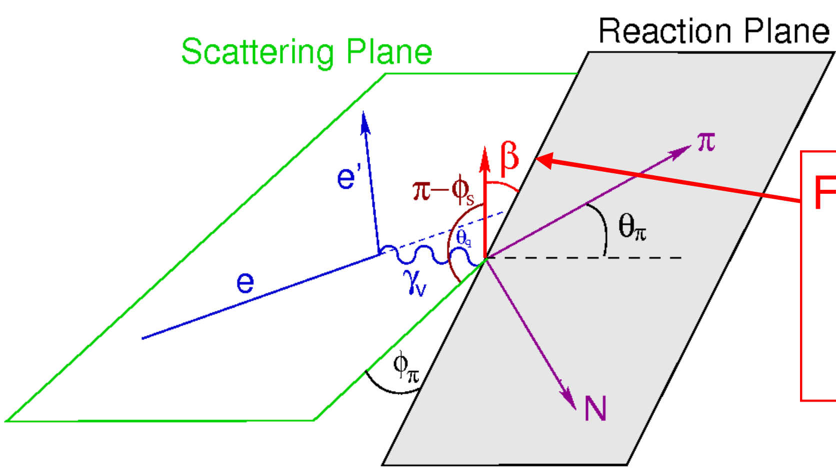
$$\sum_q e_q \int_{-1}^{+1} dx\, \tilde{E}^q(x,\xi,t) = G_P(t)$$

- *$G_P(t)$ is highly uncertain because it is negligible at momentum transfer of β–decay*
- *GPD $\tilde{E}$ not related to an already known parton distribution → Essentially unknown*
- *Experimental data 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:

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



Fit sinβ=sin(φ−φ$_S$) dependence to extract asymmetry.

$$A_\perp = \frac{\int_0^\pi d\beta \frac{d\sigma_L^{\pi^-}}{d\beta} - \int_\pi^{2\pi} d\beta \frac{d\sigma_L^{\pi^-}}{d\beta}}{\int_0^{2\pi} d\beta \frac{d\sigma_L^{\pi^-}}{d\beta}}$$

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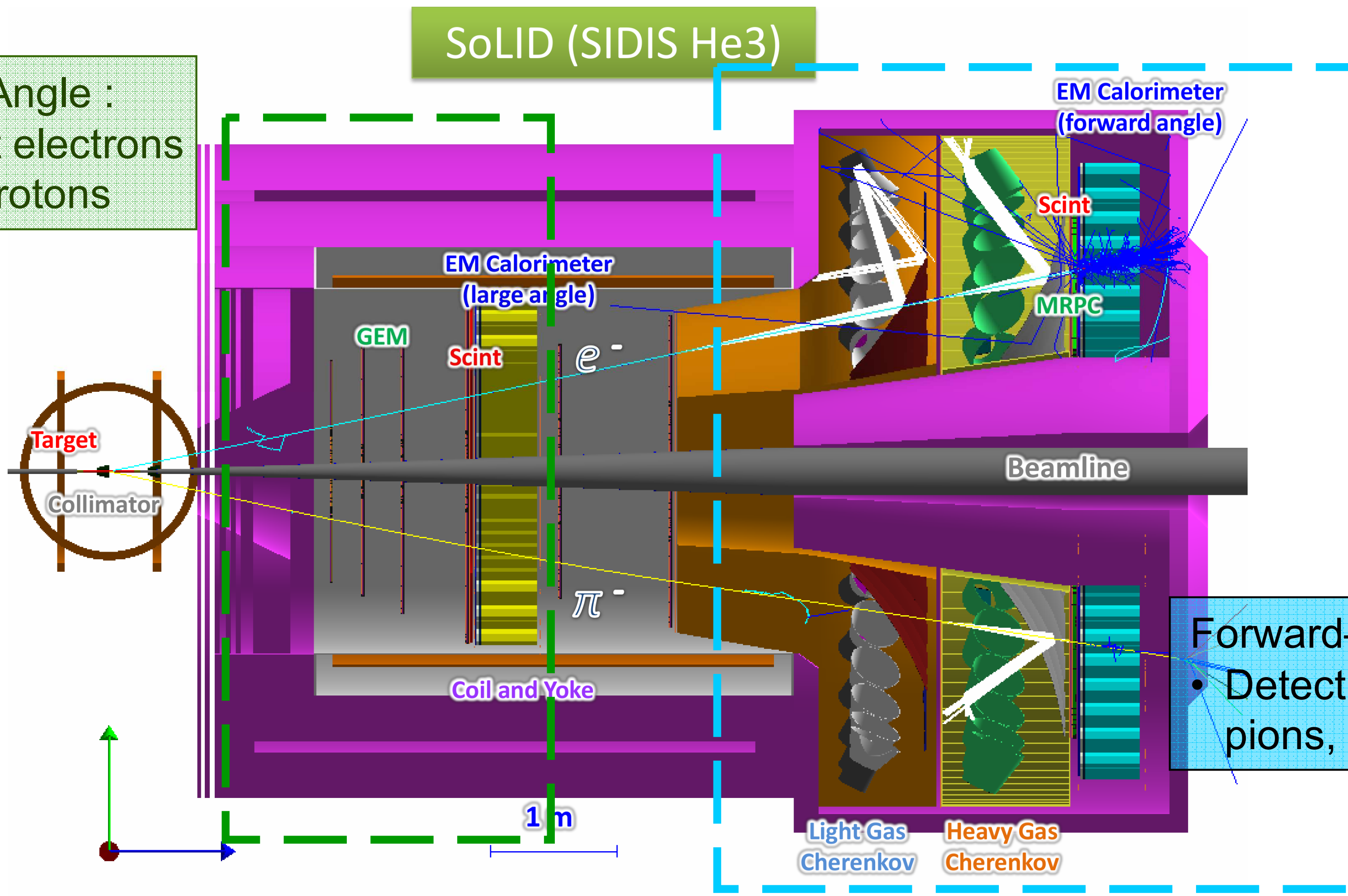
SoLID – Polarized ^{3}He SIDIS Configuration

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
SoLID's Large Acceptance, Full Azimuthal Coverage,
High Luminosity Capability are Essential for this Measurement!

Large–Angle :
- Detect electrons and protons



Forward–Angle :
- Detect electrons, pions, protons

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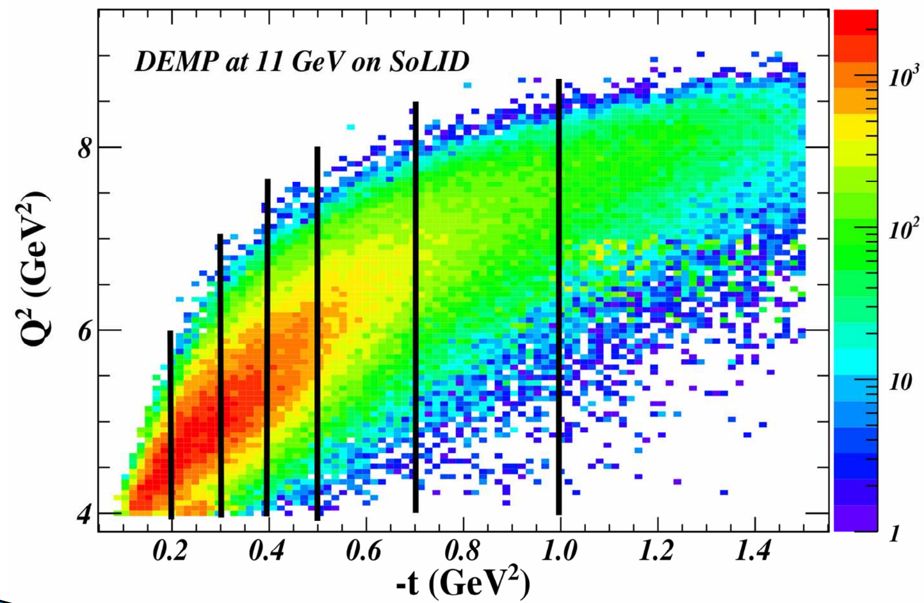
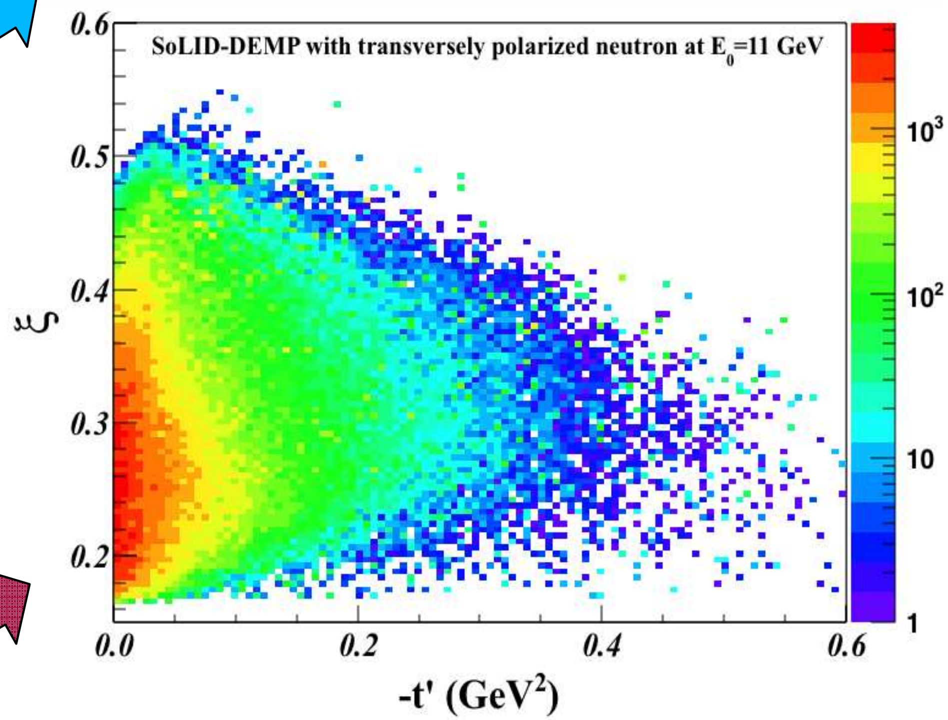
E12–10–006B Kinematic Coverage

$Q^2>1$ 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 $\xi<0.1$.
- **With SoLID, we can measure skewness dependence of the relevant GPDs over a fairly large range of ξ.**





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Example Cuts to Reduce Inclusive Background

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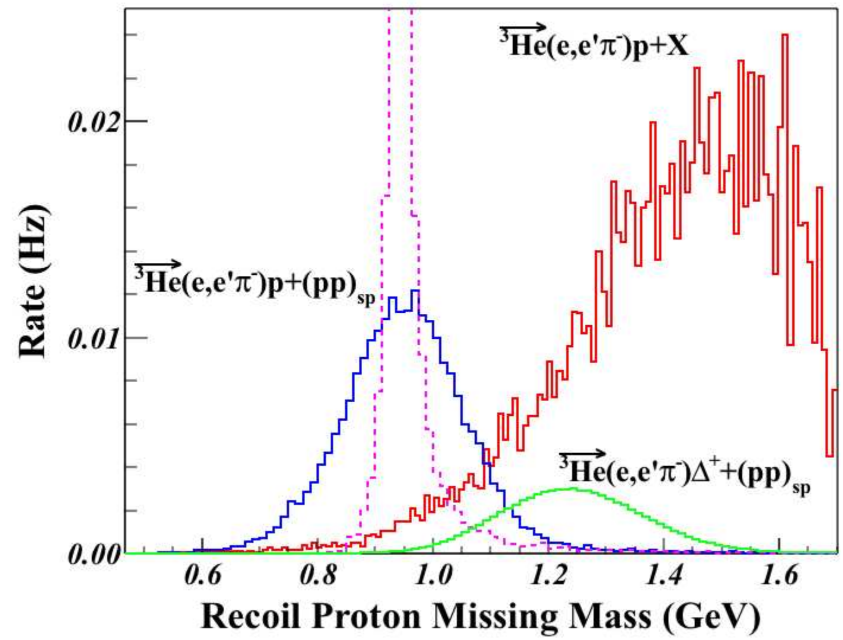
Two different background channels were simulated:

- SoLID–SIDIS generator $p(e,e'\pi^-)X$ and $n(e,e'\pi^-)X$, where we assume all X fragments contain a proton (over-estimate).
- $en \rightarrow \pi^- \Delta^+ \rightarrow \pi^- \pi^0 p$ where the Δ^+ (polarized) decays with l=1, m=0 angular distribution (more realistic).

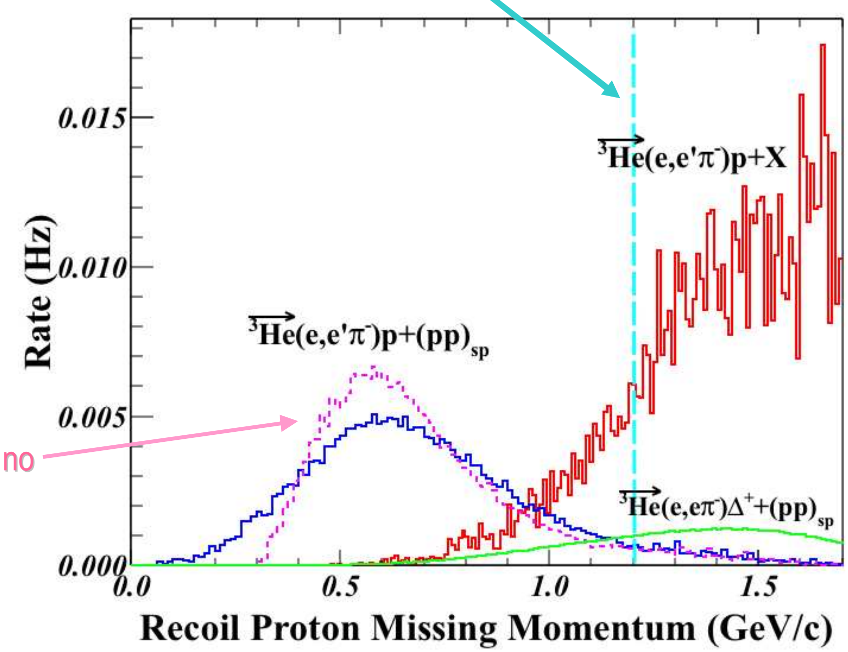


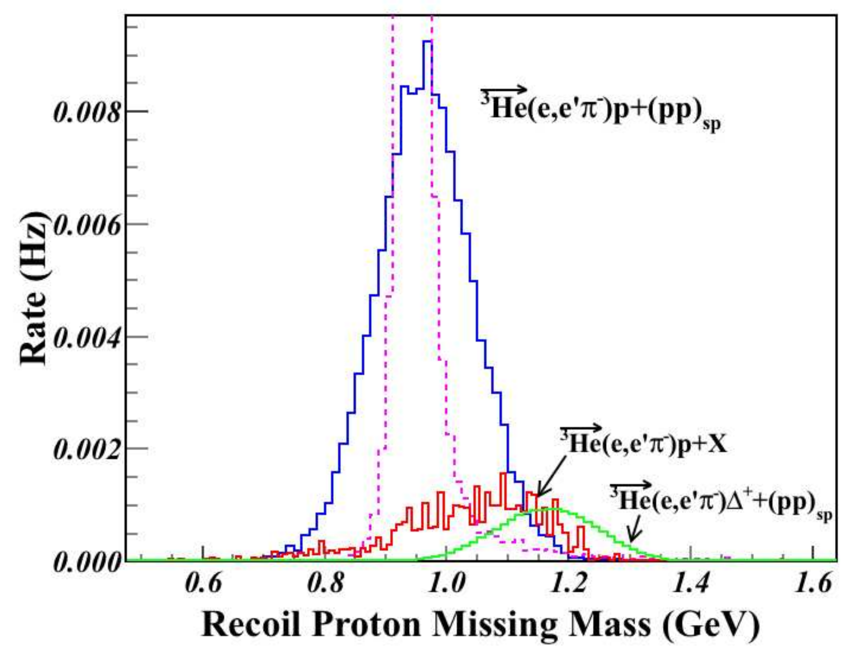
Apply P_{miss}>1.2 GeV/c cut

$$p_{miss} = \left| \vec{p}_e - \vec{p}_{e'} - \vec{p}_{\pi^-} \right|$$

Background remaining after P_{miss} cut

Scattering & radiation but no resolution smearing





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Unbinned Maximum Likelihood (UML)

- **Same method used by HERMES in their DEMP analysis** [PLB **682**(2010)345].
- Instead of dividing the data into (φ,φ_s) bins to extract the asymmetry moments, UML takes advantage of full statistics of the data, obtains much better results when statistics are limited.

1. Construct probability density function

$$f_{\uparrow\downarrow}(\phi,\phi_s;A_k)=\frac{1}{C_{\uparrow\downarrow}}\left(\begin{array}{c}1\pm\dfrac{|P_T|}{\sqrt{1-\sin^2(\theta_q)\sin^2(\phi_s)}}\\ \times\sum_{k=1}^{5}A_k\sin(\mu\phi+\lambda\phi_s)\end{array}\right)$$

where A_k are the asymmetries that can minimize the likelihood function.

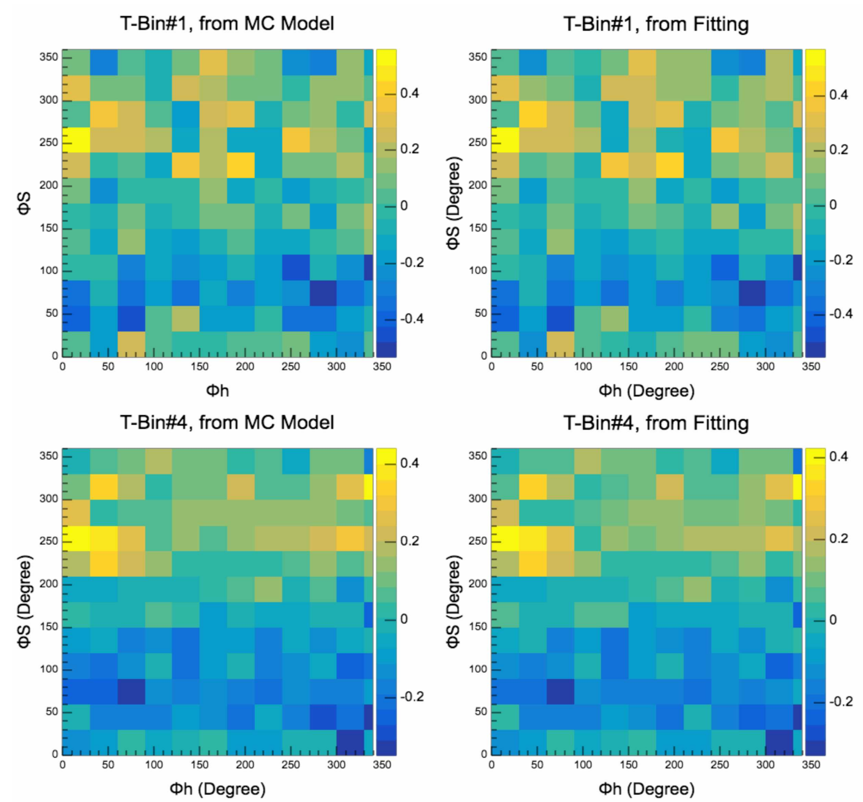
2. Minimize negative log-likelihood function:

$$-\ln L(A_k)=-\ln L_\uparrow(A_k)-\ln L_\downarrow(A_k)$$

$$=\sum_{l=1}^{N_{MC}^{\uparrow}}\left[w_l^{\uparrow}\cdot\ln f_\uparrow(\phi_l,\phi_{s,l};A_k)\right]-\sum_{m=1}^{N_{MC}^{\downarrow}}\left[w_m^{\downarrow}\cdot f_\downarrow(\phi_m,\phi_{s,m};A_k)\right]$$

where w_l, w_m are MC event weights based on cross section & acceptance.

3. As an illustration, reconstruct azimuthal modulations & compare:



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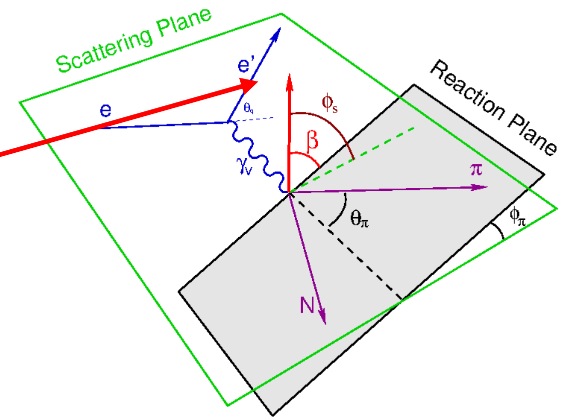
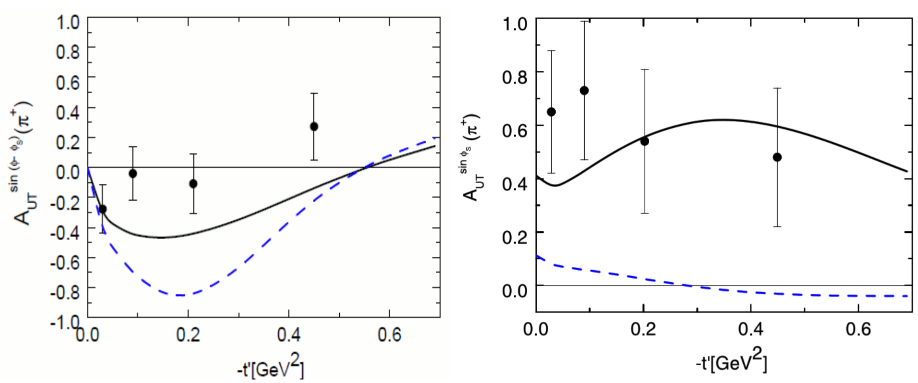
E12–10–006B Projected Data

- **Azimuthal modulations of Transverse Single Spin Asymmetry allow access to different GPDs:**
  - $\sin(\beta=\varphi-\varphi_s)$ moment sensitive to helicity-flip GPD $\tilde{E}$
  - $\sin(\varphi_s)$ moment sensitive to transversity GPDs



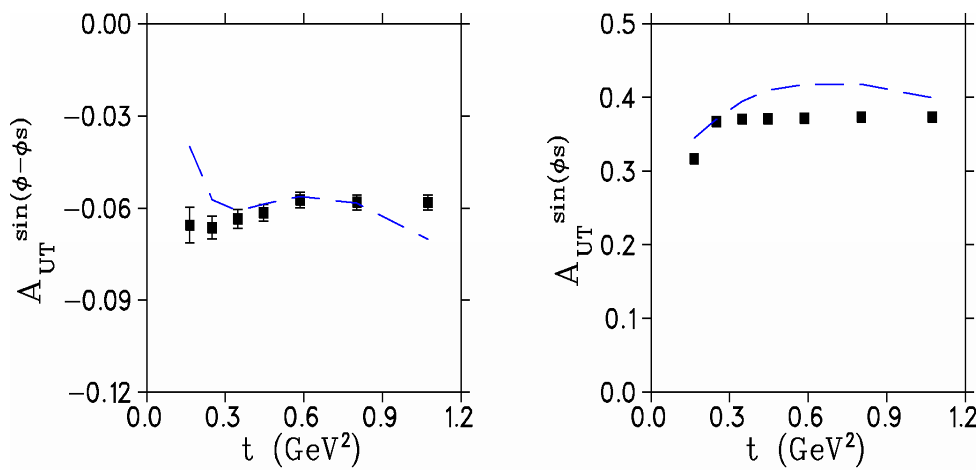
World Data: HERMES

Pioneering measurement [PLB **682**(2010)345]



SoLID Projected Uncertainties

Proton is tagged to isolate exclusive π^- events



SoLID's large acceptance and high luminosity essential to this measurement

- **Dramatically better statistics, at higher Q^2 and x_B, with broader –*t* coverage than pioneering HERMES measurement**
- **World unique, cannot be done anywhere else!**

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Summary

- SoLID's Large Acceptance and High Luminosity capabilities are key to measuring GPDs using deep exclusive processes
- Multi–dimension binning with high statistics
- SoLID has a broad exclusive physics program for GPD measurements:
  - DVCS on polarized ^{3}He — under study
  - TCS — approved, *J/ψ* run group *(E12-12-006A)*
  - DDVCS — LOI12-23-012 reviewed by PAC51, full proposal planned for next PAC
  - DEMP — approved, SIDIS run group *(E12-10-006B)*
  - More ideas under study (e.g. deuterium and other nuclear targets)
- ***Collaborators welcome!***

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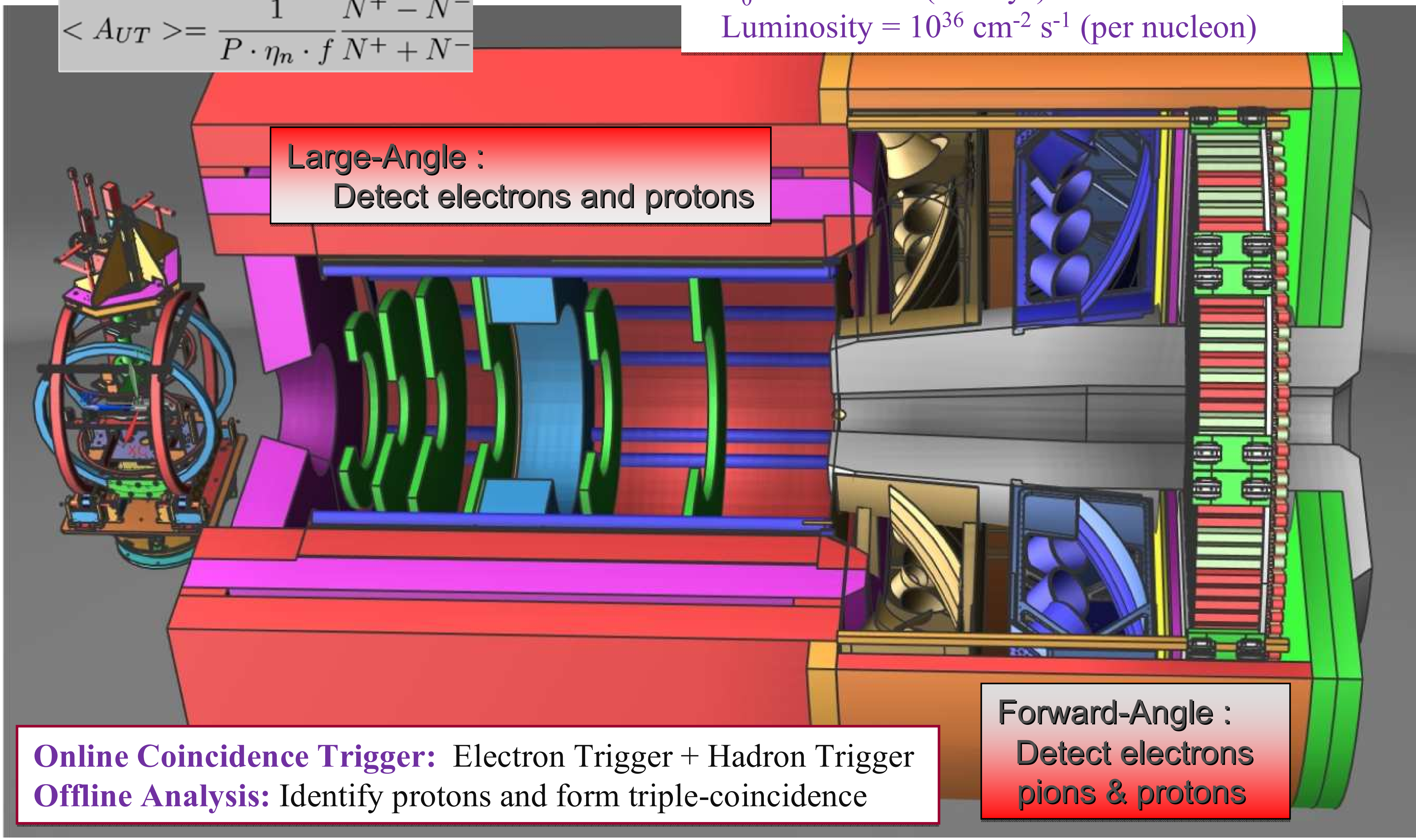
Measure DEMP with SoLID – Polarized ^{3}He

University of Regina

$\vec{n}(e,e'\pi^-)p$: with transversely polarized ^{3}He

$$< A_{UT} >= \frac{1}{P \cdot \eta_n \cdot f} \frac{N^+ - N^-}{N^+ + N^-}$$

Run in parallel with E12-10-006:
- E_0 = 11.0 GeV (48 days)
- Luminosity = 10^{36} cm^{-2} s^{-1} (per nucleon)



Online Coincidence Trigger: Electron Trigger + Hadron Trigger
Offline Analysis: Identify protons and form triple-coincidence

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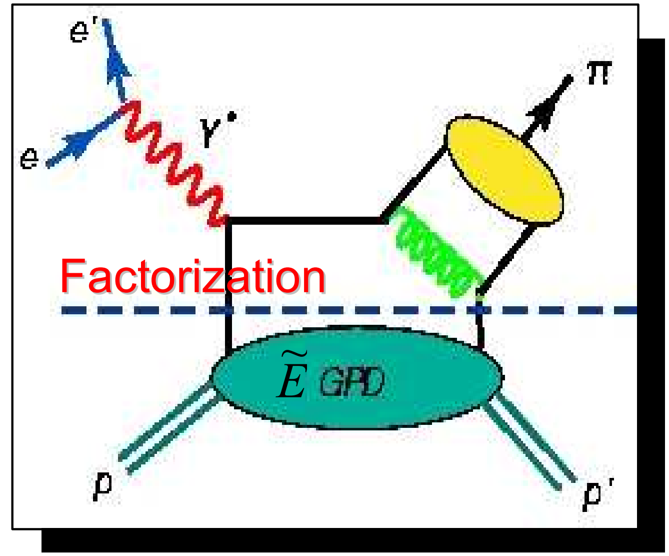
Next Generation Study: Polarized GPD $\tilde{E}$

- $\tilde{E}$ **involves a helicity flip:**
  - Depends on the spin difference between initial and final quarks.



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

$G_P(t)$ is highly uncertain because it is negligible at the momentum transfer of β-decay.

- $\tilde{E}$ **not related to an already known parton distribution → essentially unknown.**
- Experimental information can provide new nucleon structure information unlikely to be available from any other source.

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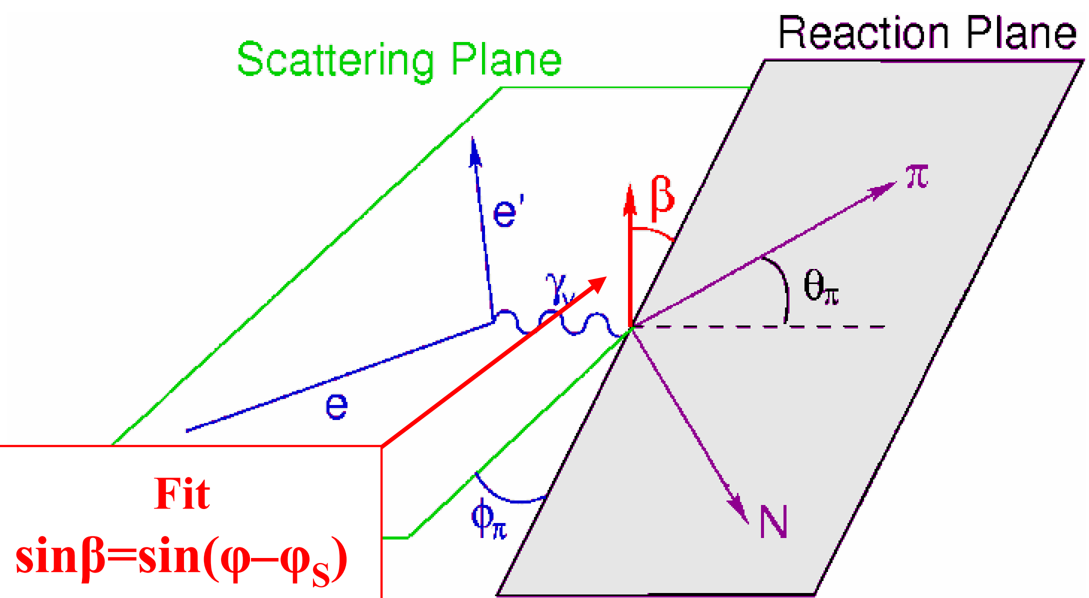
Exclusive π^- from Transversely Polarized Neutron

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

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



Fit $\sin\beta = \sin(\varphi - \varphi_S)$ dependence.

$$A_{\perp} = \frac{\int_0^{\pi} d\beta \frac{d\sigma_L^{\pi^-}}{d\beta} - \int_{\pi}^{2\pi} d\beta \frac{d\sigma_L^{\pi^-}}{d\beta}}{\int_0^{2\pi} d\beta \frac{d\sigma_L^{\pi^-}}{d\beta}}$$

$d\sigma^{\pi}_L$ → exclusive cross section for longitudinal γ^*

$\beta = \varphi - \varphi_S$ → angle between polarized target and reaction plane

The asymmetry vanishes if $\tilde{E}$ is zero. If $\tilde{E}$ is non–zero, the asymmetry will display a $\sin(\varphi - \varphi_s)$ dependence.

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GPD information in $A_L^{\perp}$ may be particularly clean

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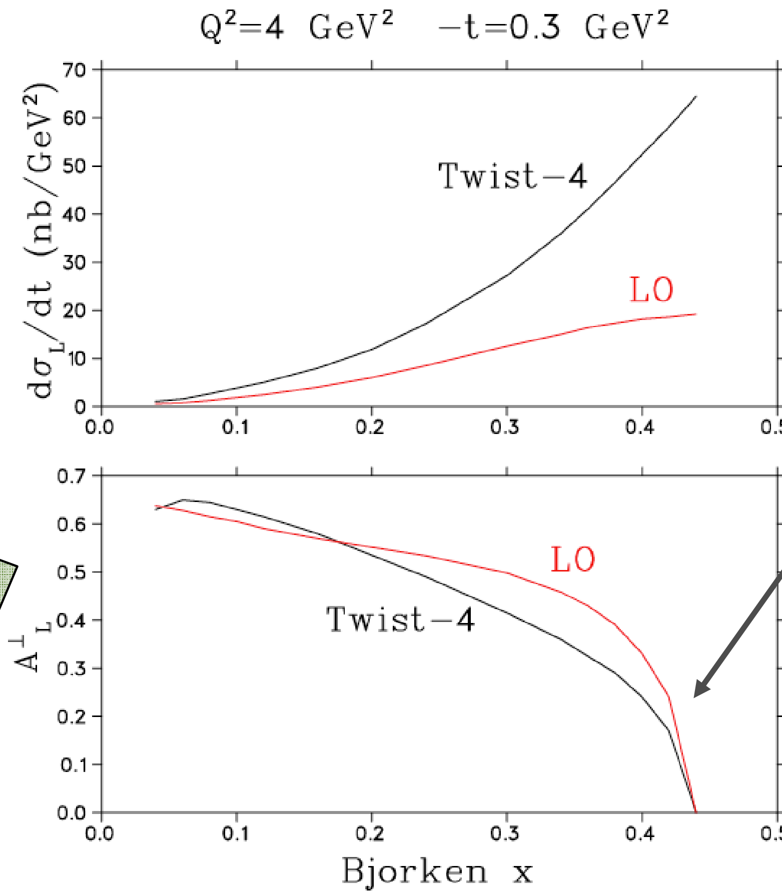
- **$A_L^{\perp}$ is expected to display precocious factorization at only Q^2~2–4 GeV^2:**
  - At Q^2=10 GeV^2, Twist–4 effects can be large, but cancel in $A_L^{\perp}$ (Belitsky & Műller PLB 513(2001)349).
  - At Q^2=4 GeV^2, higher twist effects even larger in σ_L, but still cancel in the asymmetry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



$A_L^{\perp}$=0 at parallel kinematic limit, where φ–φ_s is not well defined.

This relatively low value of Q^2 for the expected onset of precocious scaling is important, because it is experimentally accessible at JLab 12 GeV.

Transverse Target Single Spin Asymmetry in DEMP

University of Regina

Unpolarized Cross section

$$2\pi\frac{d^2\sigma_{UU}}{dt\,d\phi}=\varepsilon\frac{d\sigma_L}{dt}+\frac{d\sigma_T}{dt}+\sqrt{2\varepsilon(\varepsilon+1)}\frac{d\sigma_{LT}}{dt}\cos\phi+\varepsilon\frac{d\sigma_{TT}}{dt}\cos 2\phi$$

Transversely polarized cross section has additional components

$$\frac{d^3\sigma_{UT}}{dt\,d\phi\,d\phi_s}=-\frac{P_\perp\cos\theta_q}{\sqrt{1-\sin^2\theta_q\sin^2\phi_s}}\left(\begin{array}{l}\sin\beta\,\mathrm{Im}(d\sigma_{++}^{+-}+\varepsilon d\sigma_{00}^{+-})\\+\sin\phi\sqrt{\varepsilon(1+\varepsilon)}\,\mathrm{Im}(d\sigma_{+0}^{+-})\\+\sin(\phi+\phi_s)\frac{\varepsilon}{2}\mathrm{Im}(d\sigma_{+-}^{+-})\\+\sin(2\phi-\phi_s)\sqrt{\varepsilon(1+\varepsilon)}\,\mathrm{Im}(d\sigma_{+0}^{-+})\\+\sin(3\phi-\phi_s)\frac{\varepsilon}{2}\mathrm{Im}(d\sigma_{+-}^{-+})\end{array}\right)$$

$\sigma_{mn}^{ij}\rightarrow$ nucleon polarizations $ij=(+1/2,-1/2)$

photon polarizations $mn=(-1,0,+1)$

Gives rise to 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

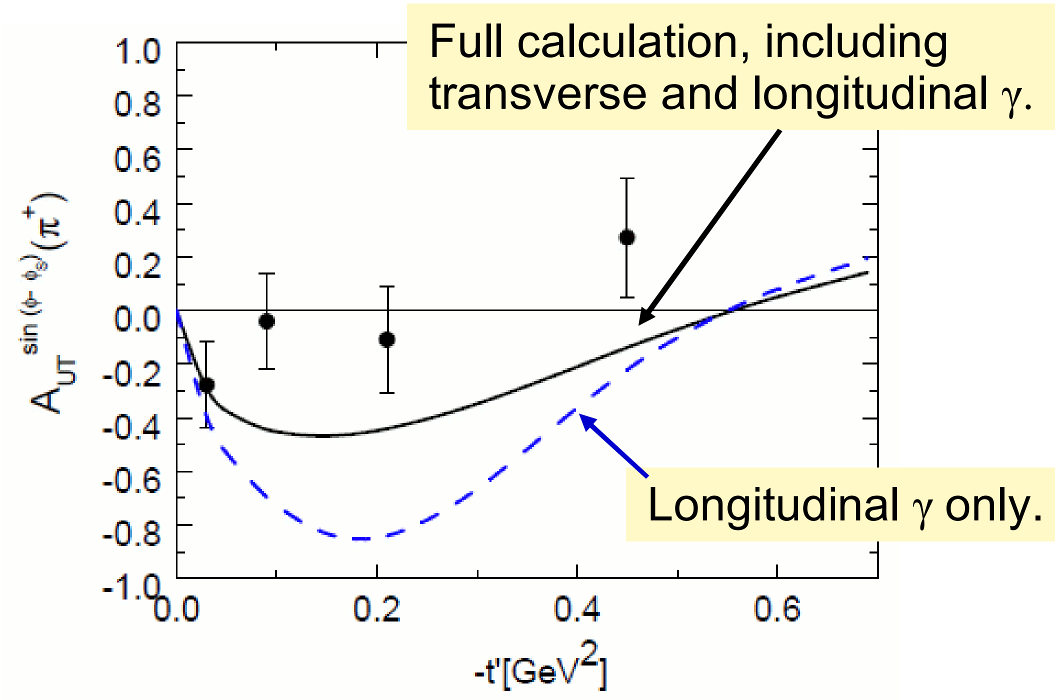
$$A_{UT}^{\sin(\phi-\phi_s)}\sim\frac{d\sigma_{00}^{+-}}{d\sigma_L\binom{++}{00}}\sim\frac{\mathrm{Im}(\tilde{E}^*\tilde{H})}{\left|\tilde{E}\right|^2}\text{ where }\tilde{E}\gg\tilde{H}$$

Ref: M. Diehl, S. Sapeta, Eur.Phys.J. C**41**(2005)515.

Note: Trento convention used for rest of talk

HERMES $\sin(\varphi - \varphi_S)$ Asymmetry Moment

- Exclusive π^+ production by scattering 27.6 GeV positrons or electrons from transverse polarized ^1H [PL **B682**(2010)345].
- Analyzed in terms of 6 Fourier amplitudes for φ_π, φ_s.
- $\langle x_B \rangle = 0.13$, $\langle Q^2 \rangle = 2.38$ GeV^2, $\langle -t \rangle = 0.46$ GeV^2.

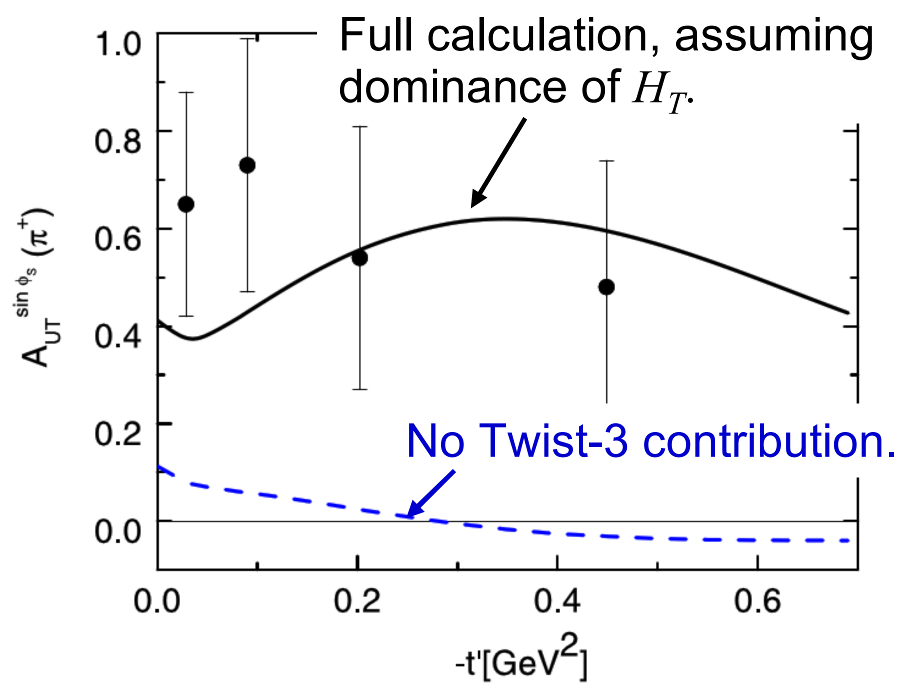


- **Since there is no L/T separation, $A_{UT}^{\sin(\varphi-\varphi s)}$ is diluted by the ratio of the longitudinal cross section to the unseparated cross section.**
- Goloskokov and Kroll indicate the HERMES results have significant contributions from transverse photons, as well as from L and T interferences [Eur Phys.J. **C65**(2010)137].
- Because no factorization theorems exist for exclusive π production by transverse photons, these data cannot be trivially interpreted in terms of GPDs.

HERMES sin(φ_s) Asymmetry Moment

- **Additional chiral–odd GPDs (H_T E_T $\tilde{H}_T$ $\tilde{E}_T$) offer a new way to access transversity–dependent quark–content of nucleon**

- While most theoretical interest and the primary motivation of our experiment is sin(φ–φ_s) asymmetry moment, there is growing interest in sin(φ_s) moment, which may be interpretable in terms of transversity GPDs



- **HERMES sin(φ_S) modulation large and nonzero at –*t'*=0, giving first clear signal for strong contributions from transversely polarized photons at rather large values of *W* and Q^2**
- Goloskokov and Kroll calculation [Eur.Phys.J. **C65**(2010)137] assumes H_T dominates and the other three can be neglected

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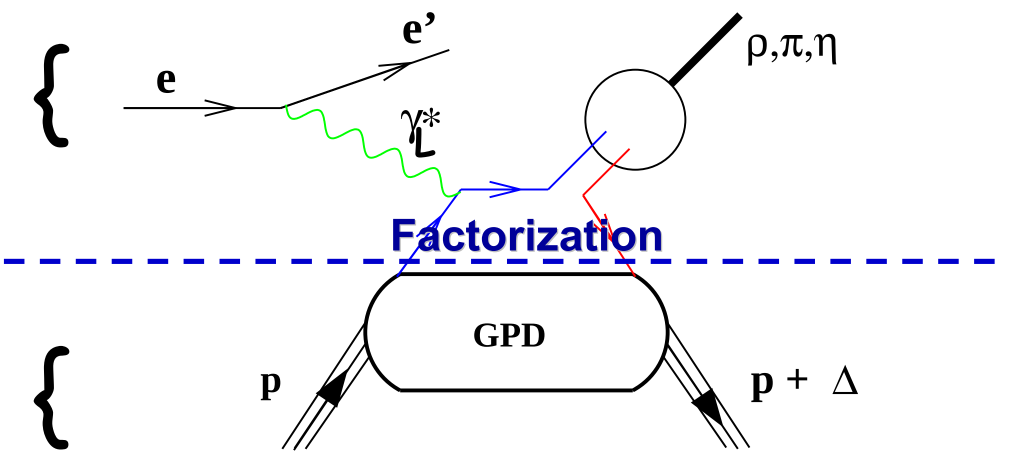
GPDs require Hard Exclusive Reactions

- **In order to access the physics contained in GPDs, one is restricted to the hard scattering regime.**
- **Factorization property of hard reactions:**
  - **Hard probe creates a small size $q\bar{q}$ and gluon configuration,**
    - **interactions can be described by pQCD.**
  - **Non-perturbative part describes how hadron reacts to this configuration, or how the probe is transformed into hadrons (parameterized by GPDs).**



- Hard Exclusive Meson Electroproduction first shown to be factorizable by Collins, Frankfurt & Strikman [PRD **56**(1997)2982].
- Factorization applies when the γ^* is longitudinally polarized.
  - corresponds to small size configuration compared to transversely polarized γ^*.

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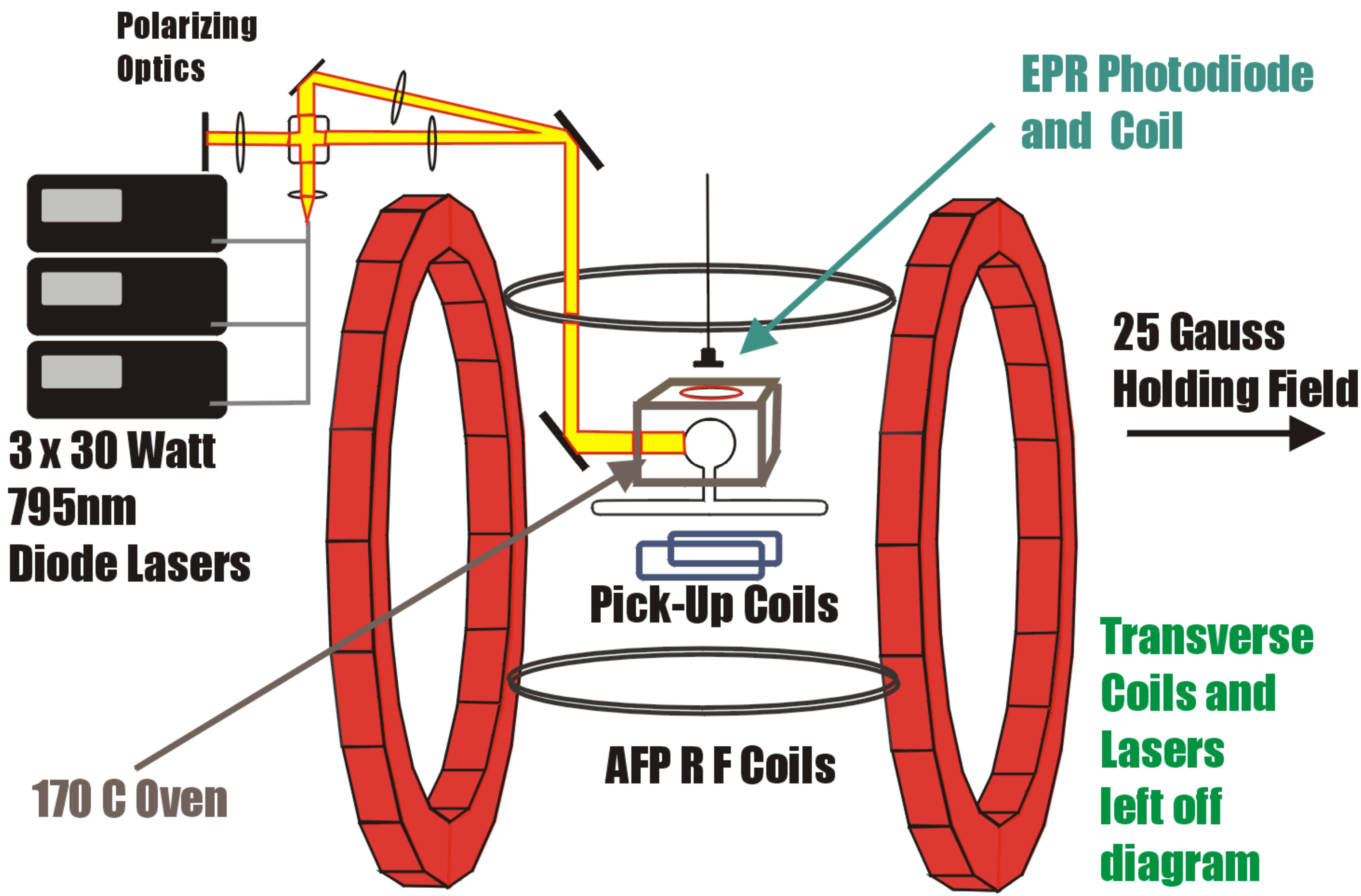
Hall A Polarized ^{3}He Target: FOM(P^2L)=0.22E+36



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L–T Separated versus Unseparated Expts

- **Our reaction of interest is $\vec{n}(e,e'\pi^-)p$ from the neutron in transversely polarized ^{3}He.**
- **It has not yet been possible to perform an experiment to measure $A_L^{\perp}$.**
  - Conflicting experimental requirements of transversely polarized target, high luminosity, L–T separation and closely controlled systematic uncertainties make this an exceptionally challenging observable to measure.
- **The most closely related measurement, of the transverse single-spin asymmetry in $\vec{p}(e,e'\pi^+)n$, without an L–T separation, was published by HERMES in 2010.**
  - Significant GPD information was obtained.
  - Our proposed SoLID measurements will be a significant advance over the HERMES data in terms of kinematic coverage and statistical precision.

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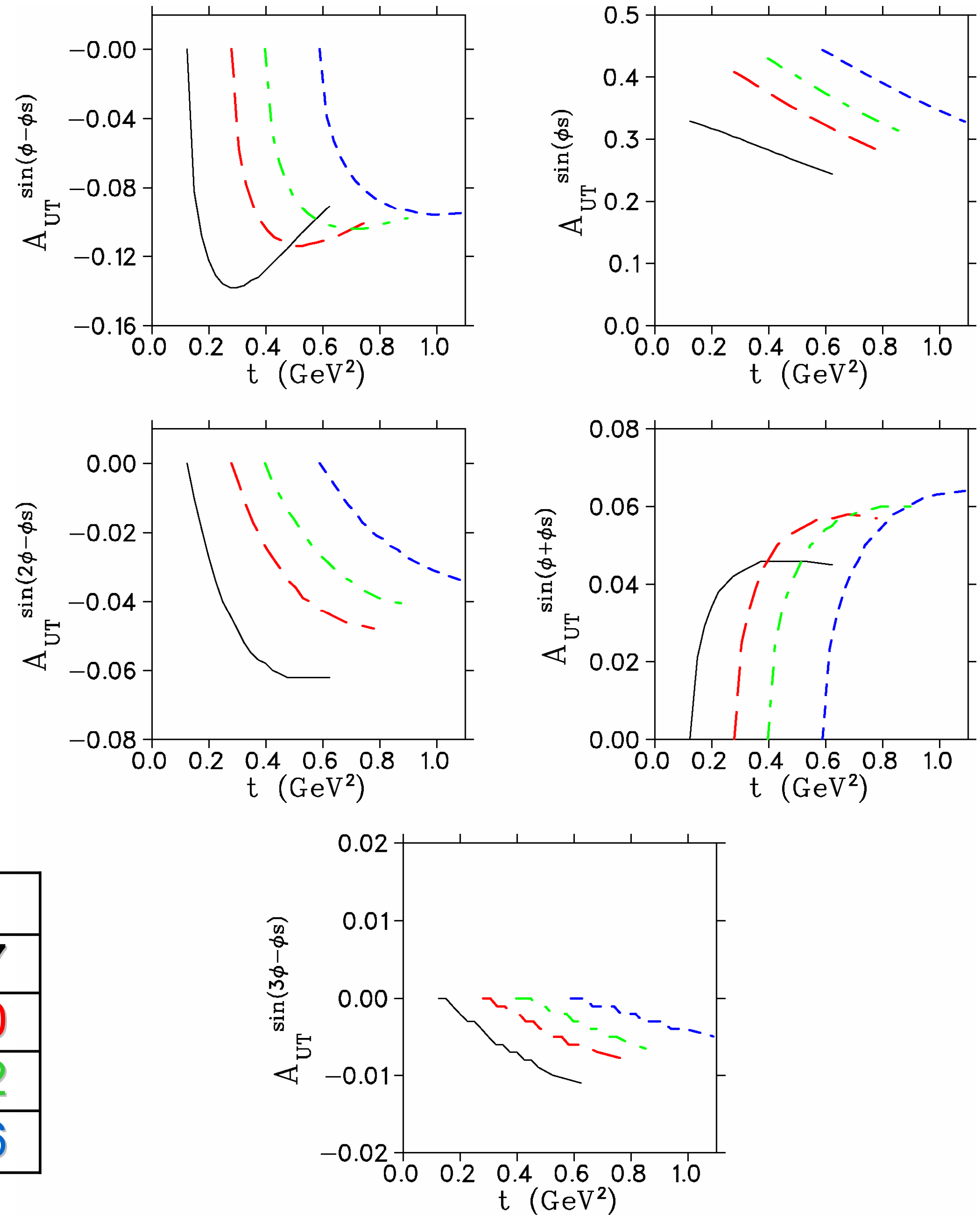
Asymmetry Moment Modeling

University of Regina

- **Event generator incorporates A_{UT} moments calculated by Goloskokov and Kroll for kinematics of this experiment.**
- GK handbag approach for π^- from neutron:
  - Eur.Phys.J. C**65**(2010)137.
  - Eur.Phys.J. A**47**(2011)112.
- **Simulated data for target polarization up and down are subjected to same *Q*²>4 GeV², *W*>2 GeV, 0.55<ε<0.75 cuts.**

Q^2	W
4.11	3.17
5.14	2.80
6.05	2.72
6.89	2.56



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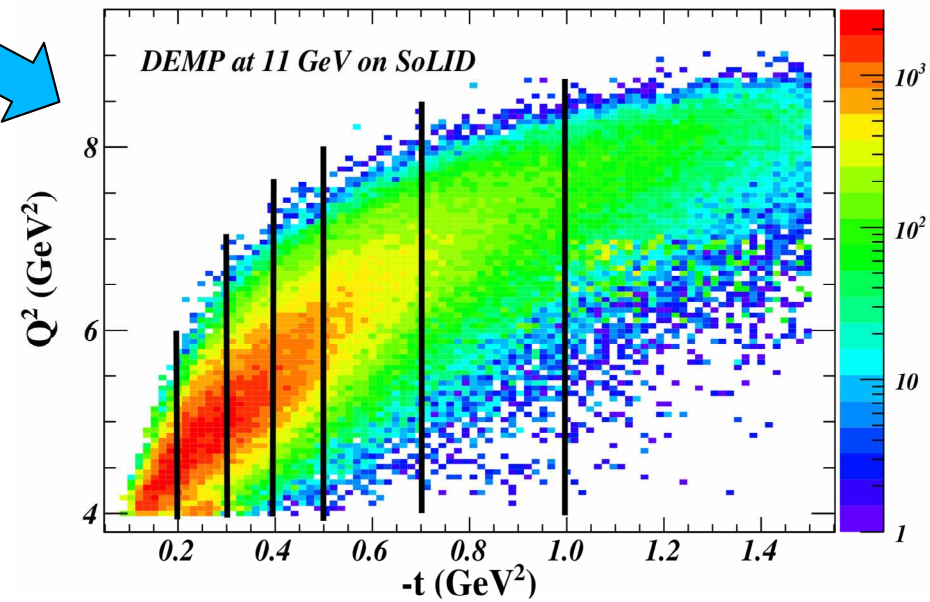
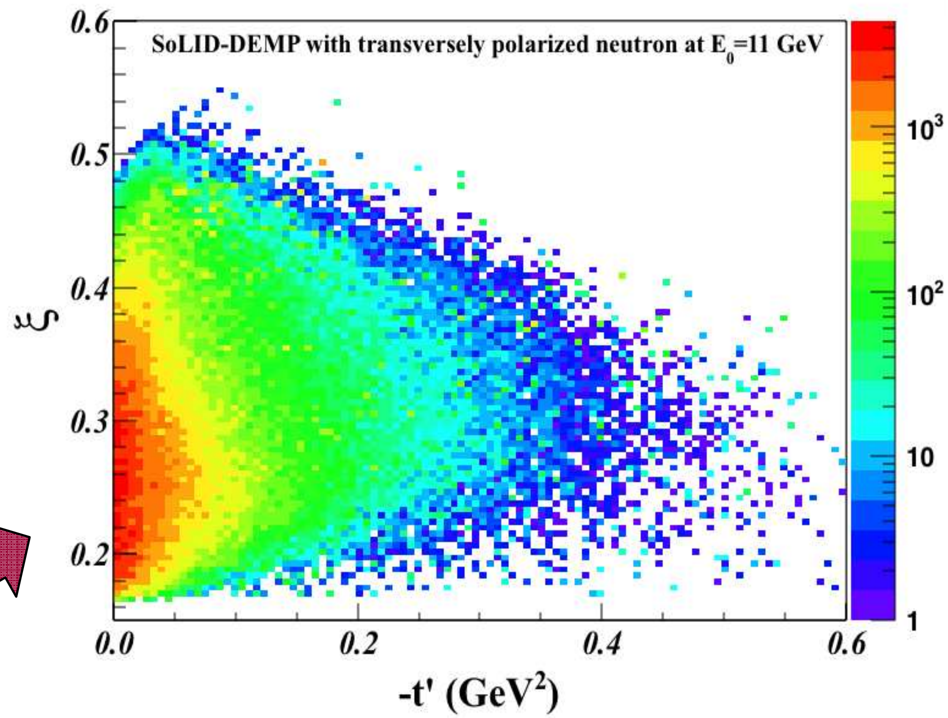
Kinematic Coverage and Binning

- We binned the simulated data in 7 *t*–bins.
- **In actual data analysis, we will consider alternate binning.**
- All JLab data cover a range of Q^2, x_{Bj} values.
  - x_{Bj} fixes the skewness (ξ).
  - Q^2 and x_{Bj} are correlated. In fact, we have an almost linear dependence of Q^2 on x_{Bj}.
- HERMES and COMPASS experiments are restricted kinematically to very 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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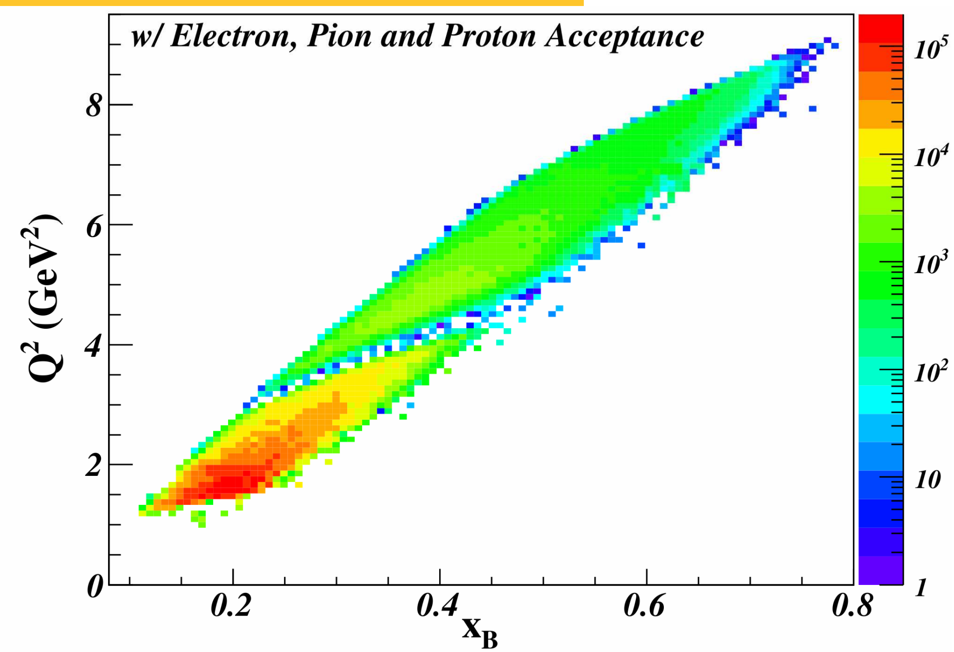
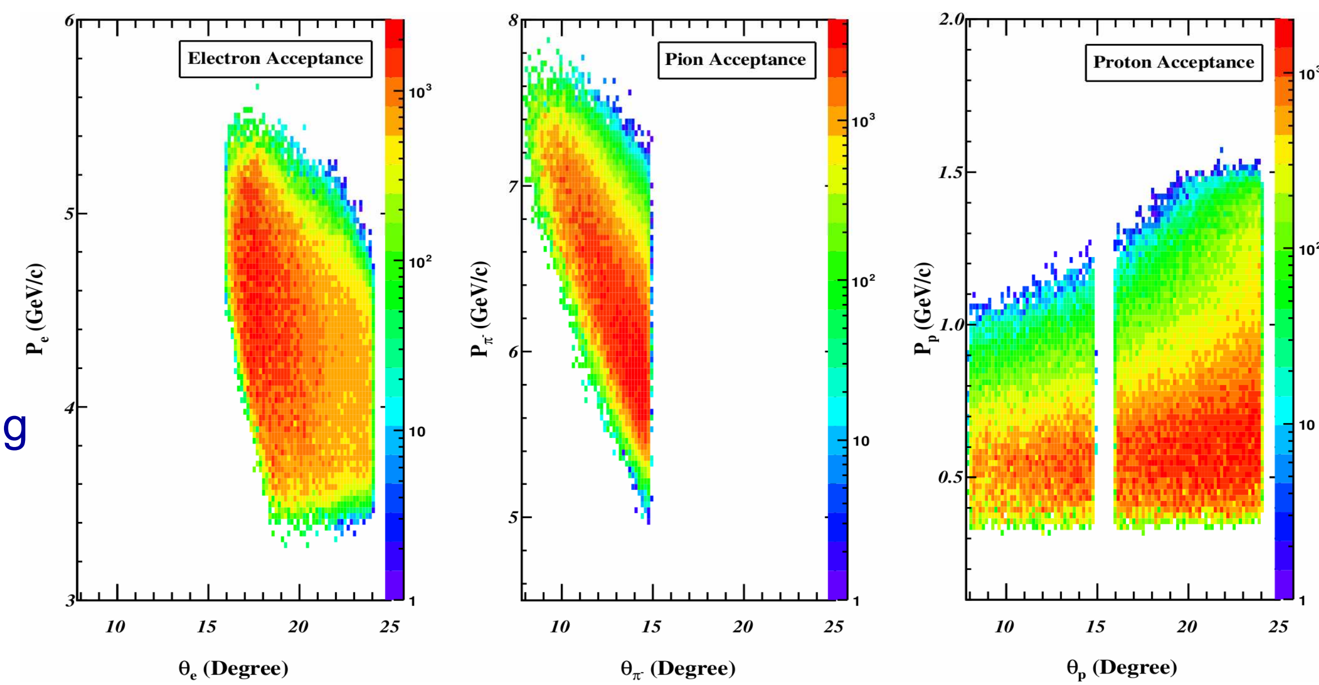
SoLID Acceptance and Projected Rates

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 is based on data from HERMES, Halls B,C with VR Regge+DIS model used as a constraint in unmeasured regions.
- Generator includes electron radiation, multiple scattering and ionization energy loss.
- Every detected particle is smeared in (P,θ,φ) with resolution from SoLID tracking studies, and acceptance profiles from SoLID-SIDIS GEMC study applied.



Q^2>4 GeV^2, W>2 GeV, 0.55<ε<0.75 cuts applied.



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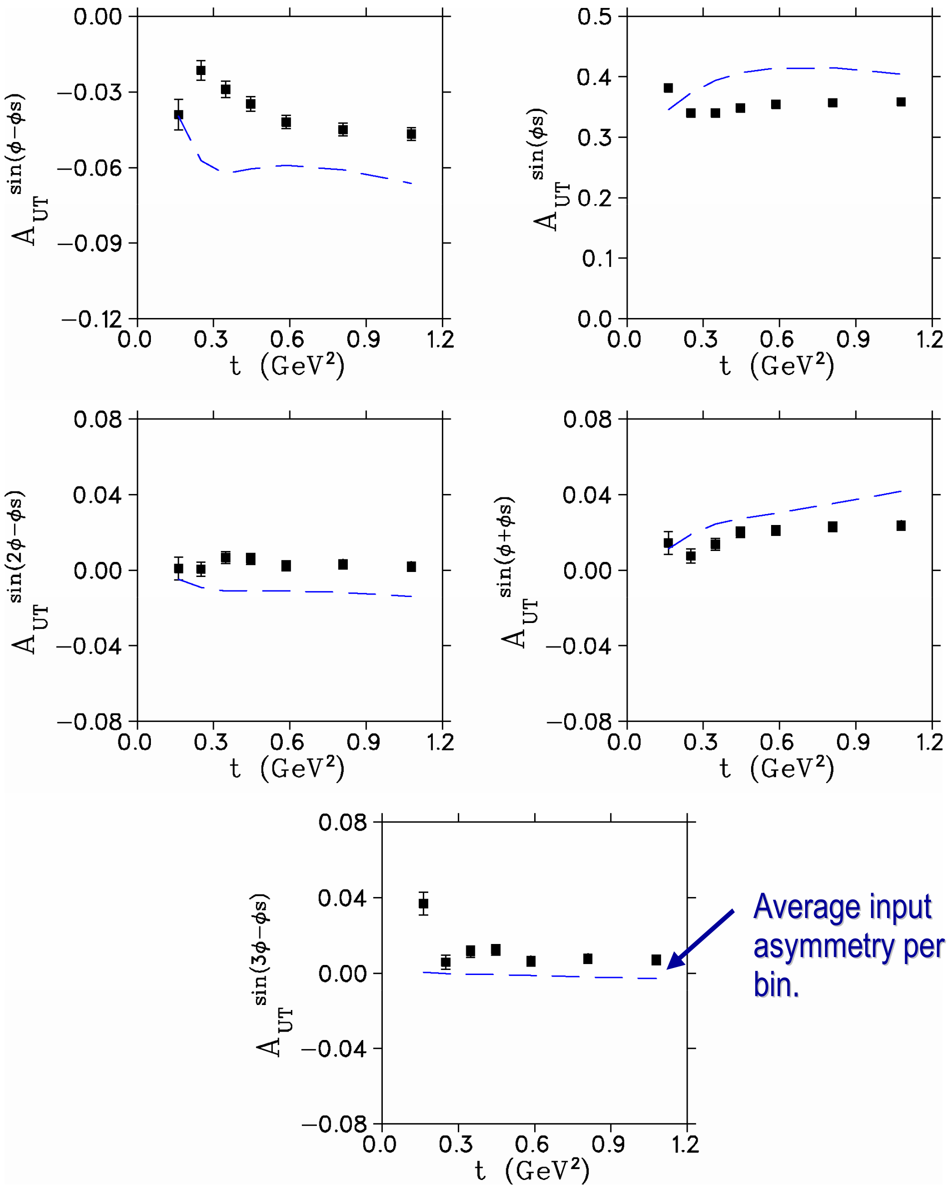
E12–10–006B Projected Uncertainties

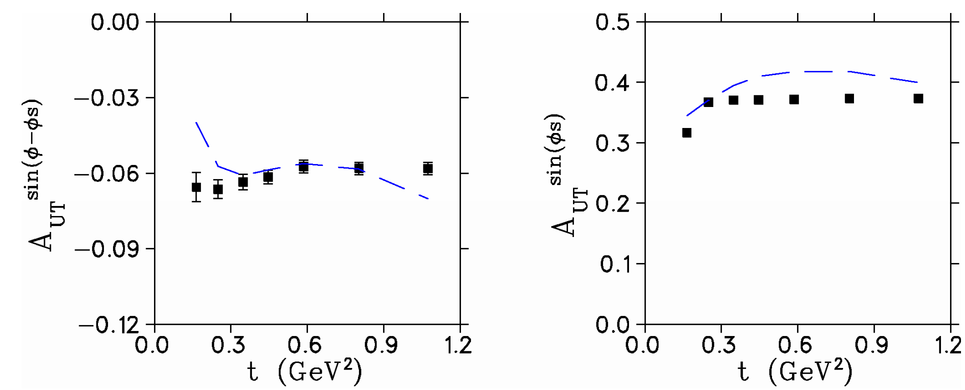
All effects on.

Includes all scattering, energy loss, resolution and Fermi momentum effects.



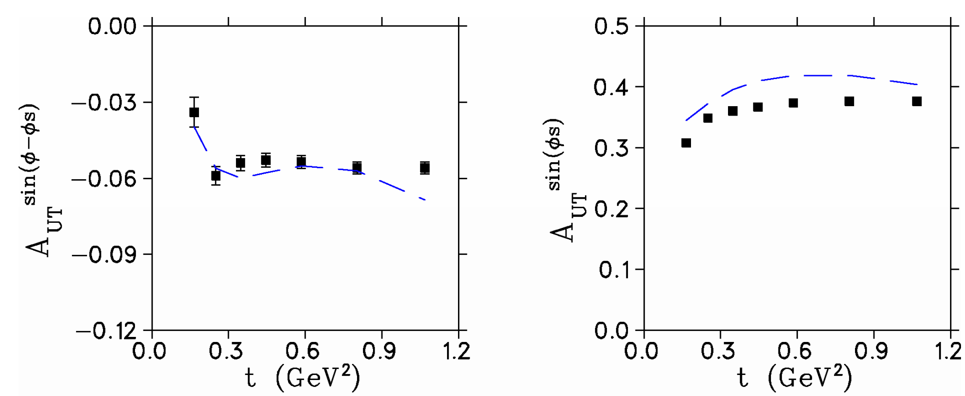
Only Fermi momentum off.

Includes all scattering, energy loss, resolution effects. Similar to where proton resolution is good enough to correct for Fermi momentum effects.



All effects off.

- Agreement between input and output fit values is very good. Validates the Unbinned Maximum Likelihood analysis procedure.



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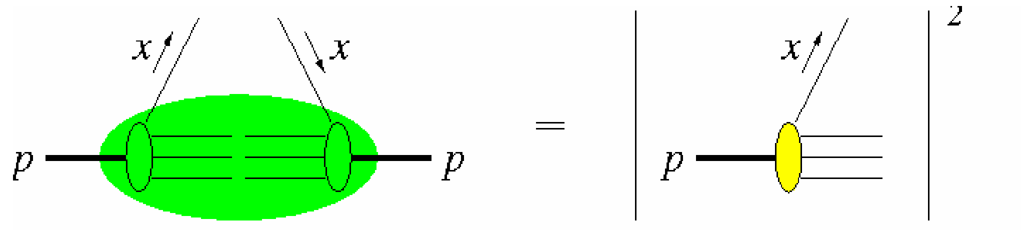
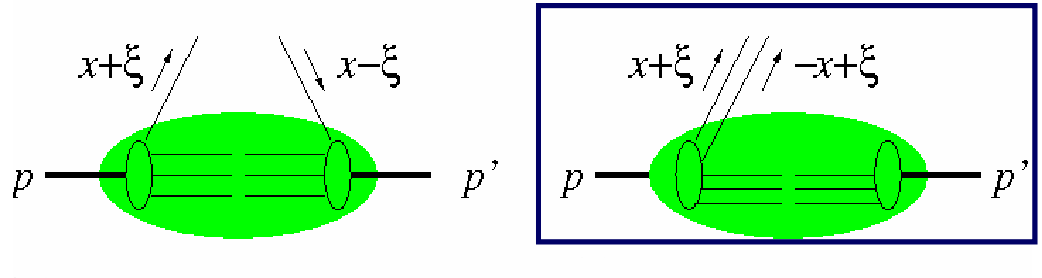
GPDs in Deep Exclusive Meson Production

PDFs : **probability of finding a parton with longitudinal momentum fraction x and specified polarization in fast moving hadron.**



GPDs : **interference between partons with $x+\xi$ and $x-\xi$, interrelating longitudinal momentum & transverse spatial structure of partons within fast moving hadron.**



A special kinematic regime is probed in Deep Exclusive Meson Production, where the initial hadron emits $q\bar{q}$ or gg pair.

- No counterpart in usual PDFs.
- Since GPDs correlate different parton configurations in the hadron at quantum mechanical level,
  - GPDs determined in this regime carry information about $q\bar{q}$ and gg-components in the hadron wavefunction.

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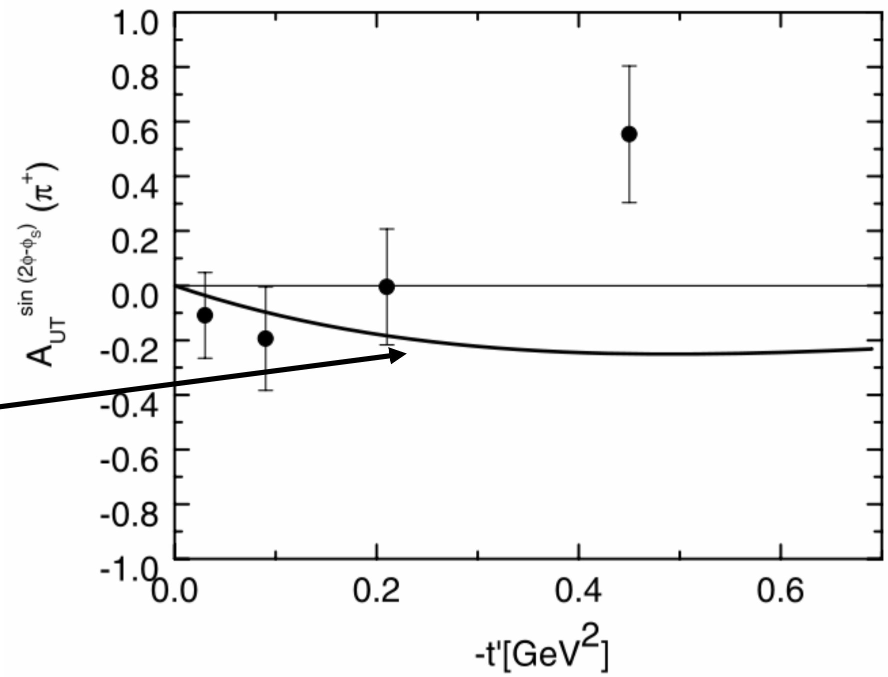
HERMES $\sin(2\varphi-\varphi_s)$ Asymmetry Moment

- $\langle Q^2\rangle=2.38$ GeV^2, $\langle W\rangle=3.99$ GeV.
- Experimental values and model calculation are both small.

Handbag approach calculation by Goloskokov & Kroll [Eur.Phys.J. **C65**(2010)137] .



- **$\sin(2\varphi-\varphi_S)$ modulation has additional LT interference amplitudes contributing that are not present in $\sin(\varphi_s)$.**
  - Improvement to calculation to reproduce sign change would require a more detailed modeling of these smaller amplitudes.
  - This would also improve description of other amplitude moments. **In this sense, different moments provide complementary amplitude term information.**
- **The remaining $\sin(\varphi+\varphi_s)$, $\sin(2\varphi+\varphi_s)$, $\sin(3\varphi-\varphi_s)$ moments are only fed by TT interference and are even smaller.**

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Missing Mass and Missing Momentum

Separating Exclusive Events from Inclusive Background:

- Although we will detect the recoil proton to separate the exclusive channel events, here, we do not assume that the proton momentum resolution is sufficiently good to provide an additional constraint.
- Thus, we compute the missing mass and momentum as if the proton were not detected:

$$M_{miss} = \sqrt{(E_e + m_n - E_{e'} - E_{\pi^-})^2 - (\vec{p}_e - \vec{p}_{e'} - \vec{p}_{\pi^-})^2}$$

$$p_{miss} = \left| \vec{p}_e - \vec{p}_{e'} - \vec{p}_{\pi^-} \right|$$

- **Of course, in the actual analysis, we will try to reconstruct the proton momentum as accurately as possible.**
- If the resolution is sufficiently good, this would allow additional background discrimination, as well as the effect of Fermi momentum to be removed from the asymmetry moments on an event-by-event basis.

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Complementarity of Hall C and SoLID Expts

SHMS+HMS:

- HMS detects scattered e'.

  SHMS detects forward, high momentum π.
- **Expected small systematic uncertainties to give reliable L/T separations.**
- Good missing mass resolution to isolate exclusive final state.
- Multiple SHMS angle settings to obtain complete azimuthal coverage up to 4° from q-vector.
- **It is not possible to have complete azimuthal coverage at larger –*t*, where $A_L^{\perp}$ is largest.**
- **PR12-12-005 by GH, D. Dutta, D. Gaskell, W. Hersman** based on next generation polarized ^{3}He target (e.g. UNH).

SoLID:

- Complete azimuthal coverage (for π) up to θ=24°.
- **High luminosity, particle ID and vertex resolution capabilities well matched to the experiment.**
- L/T separation is not possible, the $\sin(\varphi-\varphi_s)$ asymmetry moment is "diluted" by LL, TT contributions.
- **The measurement is valuable as it is the only practical way to obtain $A_{UT}^{\sin(\varphi-\varphi_s)}$ over a wide kinematic range.**
- We will also measure $A_{UT}^{\sin(\varphi_s)}$ and its companion moments, as was done by HERMES.
- **Provides vital GPD information not easily available in any other experiment prior to EIC.**

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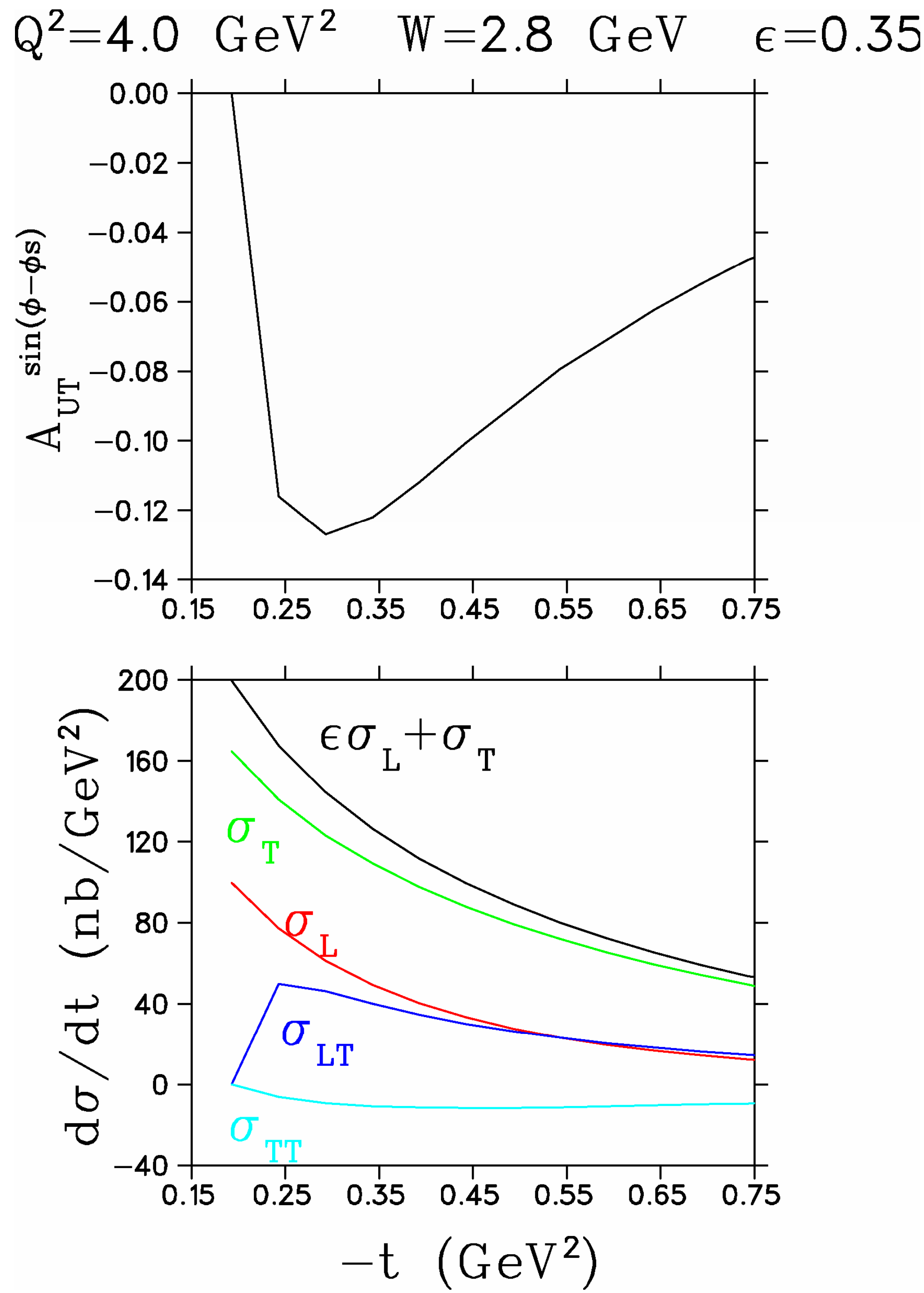
Asymmetry Dilution with SoLID

- **Calculation of cross section components and sin($\beta=\varphi-\varphi_s$) asymmetry moment in handbag approach by Goloskokov & Kroll for our kinematics.**
  - Although their calculation tends to underestimate σ_L values measured by JLab Fπ–2, their model is in reasonable agreement with unseparated dσ/dt.
- Similar level of $A_{UT}^{\sin(\varphi-\varphi s)}$ asymmetry dilution as observed by HERMES is expected in SoLID measurement.
- **SoLID measurement at higher *Q*² than HERMES, will cover a wide range of –*t* (and ξ) with good statistical precision.**



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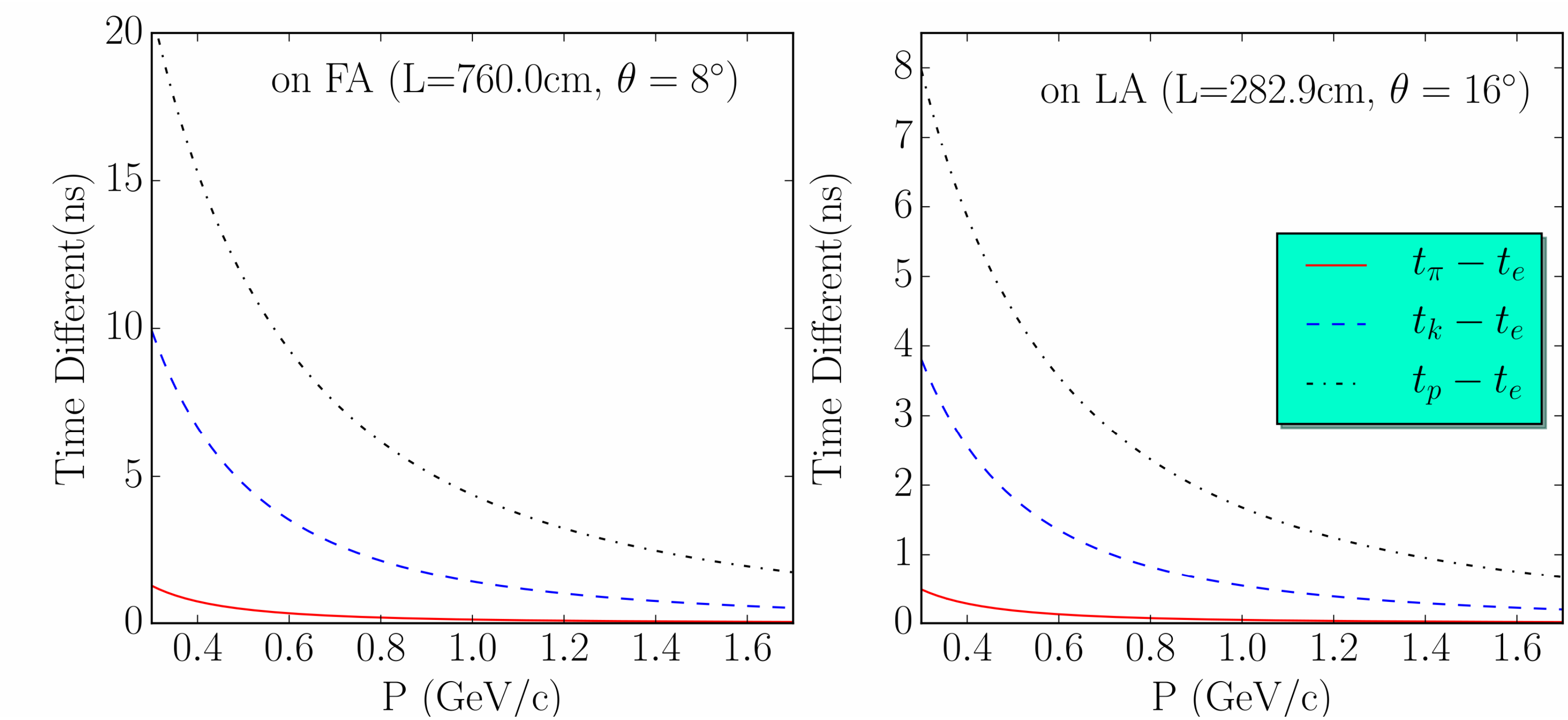
Recoil Particle Detection: Time of Flight

$$^{3}He(e,e'\pi^{-}p)pp_{sp}$$

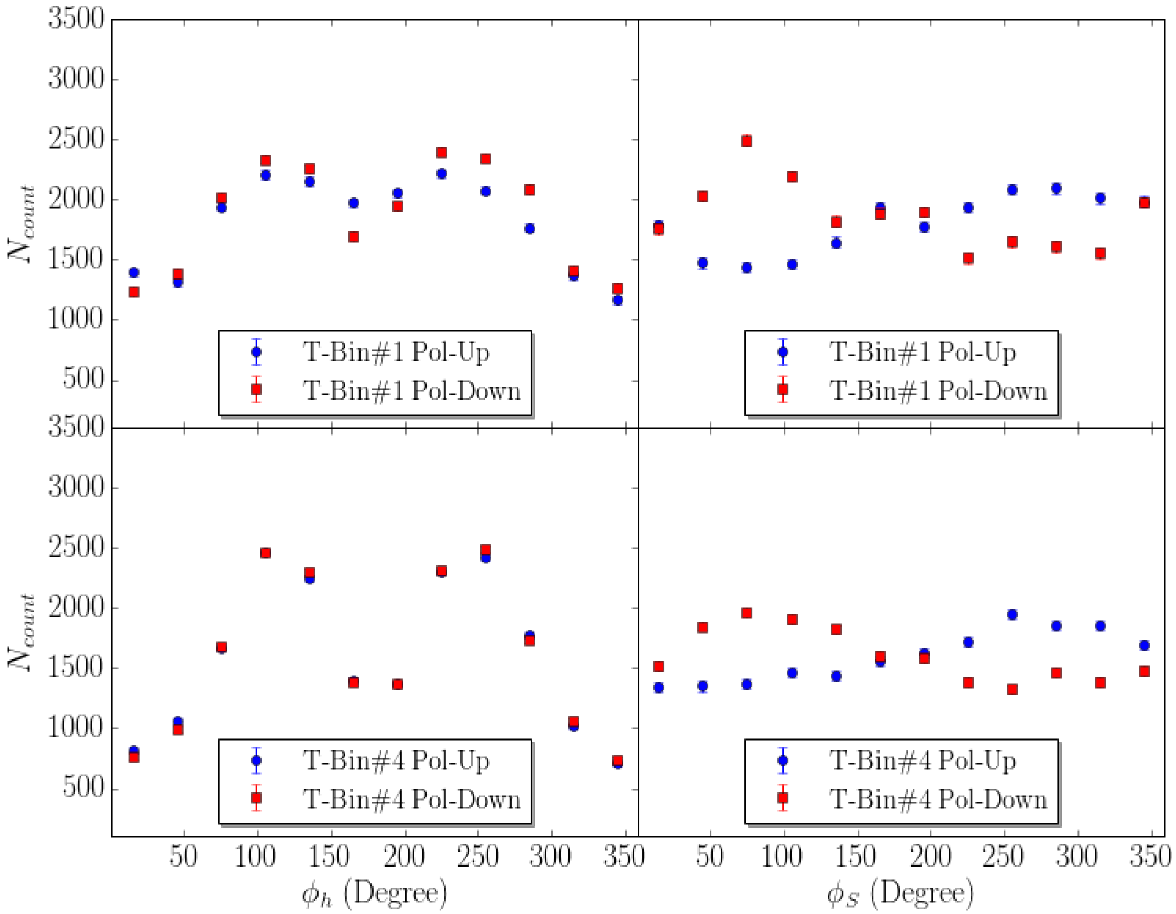
- Need >5σ timing resolution to identify protons from other charged particles



- **Exisiting SoLID Timing Detectors:**
  - MRPC & FASPC at Forward-Angle: cover 8º~14.8º, >3 ns separation.
  - LASPD at Large-Angle: cover 14º~24º, >1 ns separation.
- The currently designed timing resolution is sufficient for proton identification using TOF.

Acceptance Effects vs. (φ, φ_s)

- Expected yield as function of φ, φ_s for *t*–bins:
  - #1 (0.05–0.20)
  - #4 (0.40–0.50)
- Acceptance fairly uniform in φ_s.
- Some drop off on edges of φ distribution, since *q* is not aligned with the solenoid axis.
  - Critical feature is that φ drop off is same for target pol. up, down.



- **UML analysis shows that sufficient statistics are obtained over full (φ,φ_s) plane to extract asymmetry moments with small errors.**

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Systematic Uncertainties

- Detector–wide, DEMP measurement shares the same systematic uncertainties with SIDIS experiments

Sources	Relative Value
Beam Polarization	2%
Target Polarization	3%
Acceptance	3%
Other Contamination	$< 5\%$
Radiation Correction	1%

- Other sources of uncertainties are still under estimation.

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Fermi Momentum Effects

- **If the recoil proton momentum resolution is sufficiently good, it will be possible to correct for Fermi momentum on an event–by–event basis.**
- For the purposes of the proposal, we take the more conservative view that the resolution is not good enough, even though the removal of the Fermi momentum effect would simplify the physics interpretation of our data.
- To estimate the impact of Fermi momentum, we ran the generator in a variety of configurations and repeated our analysis:
  - Multiple scattering, energy loss, radiation effects ON/OFF.
  - Fermi momentum ON/OFF.
- The effect of Fermi momentum is about –0.02 on the $\sin(\varphi - \varphi_s)$ moment, and about –0.04 on the $\sin(\varphi_s)$ moment.
- We hope this estimate of Fermi momentum effects at an early stage will encourage theorists to calculate them for a timely and correct utilization of our proposed data, as suggested in last year's Theory review.
- 2017 Theory review appeared to be satisfied with this response.

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Final State Interaction (FSI) Effects

- To estimate FSI effects, we used an empirical (phase–shift) parameterization of $\pi^- N$ differential cross sections.
- Based on this model, and the fact that there are only two proton spectators in the final state to interact with, we anticipate about 1% of events will suffer FSI interactions. The FSI fraction is weakly dependent on Q^2, rising to about 1.2% for Q^2>5 GeV^2 events. Of these, a large fraction of FSI events are scattered outside the triple-coincidence acceptance, reducing the FSI fraction to ~0.4%. This will be further reduced by analysis cuts such as P_{miss}<1.2 GeV/c.
- Over the longer term, we will consult with theoretical groups for a more definitive FSI effect study.
  - e.g. Del Dotto, Kaptari, Pace, Salme and Scopetta recent study of FSI effects in SIDIS from a transversely polarized ^{3}He target [arXiv:1704.06182] showed that extracted Sivers and Collins asymmetries are basically independent of FSI. A similar calculation for DEMP, after this proposal is accepted, would be a natural extension of their work.

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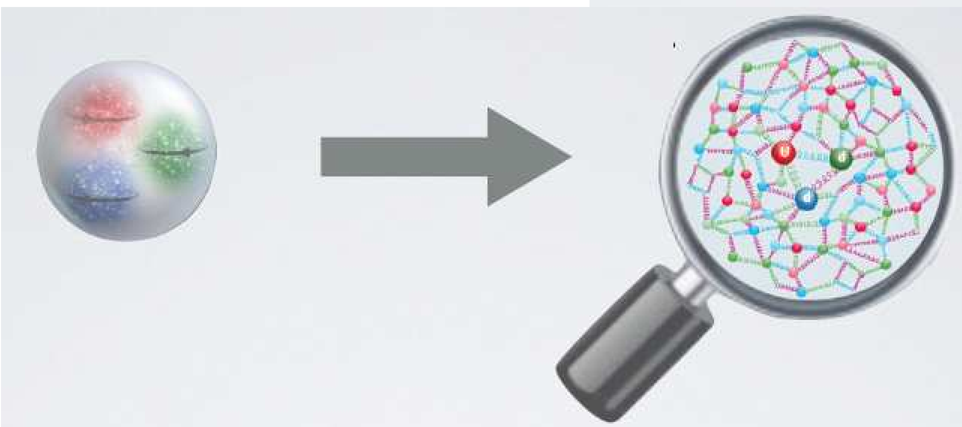
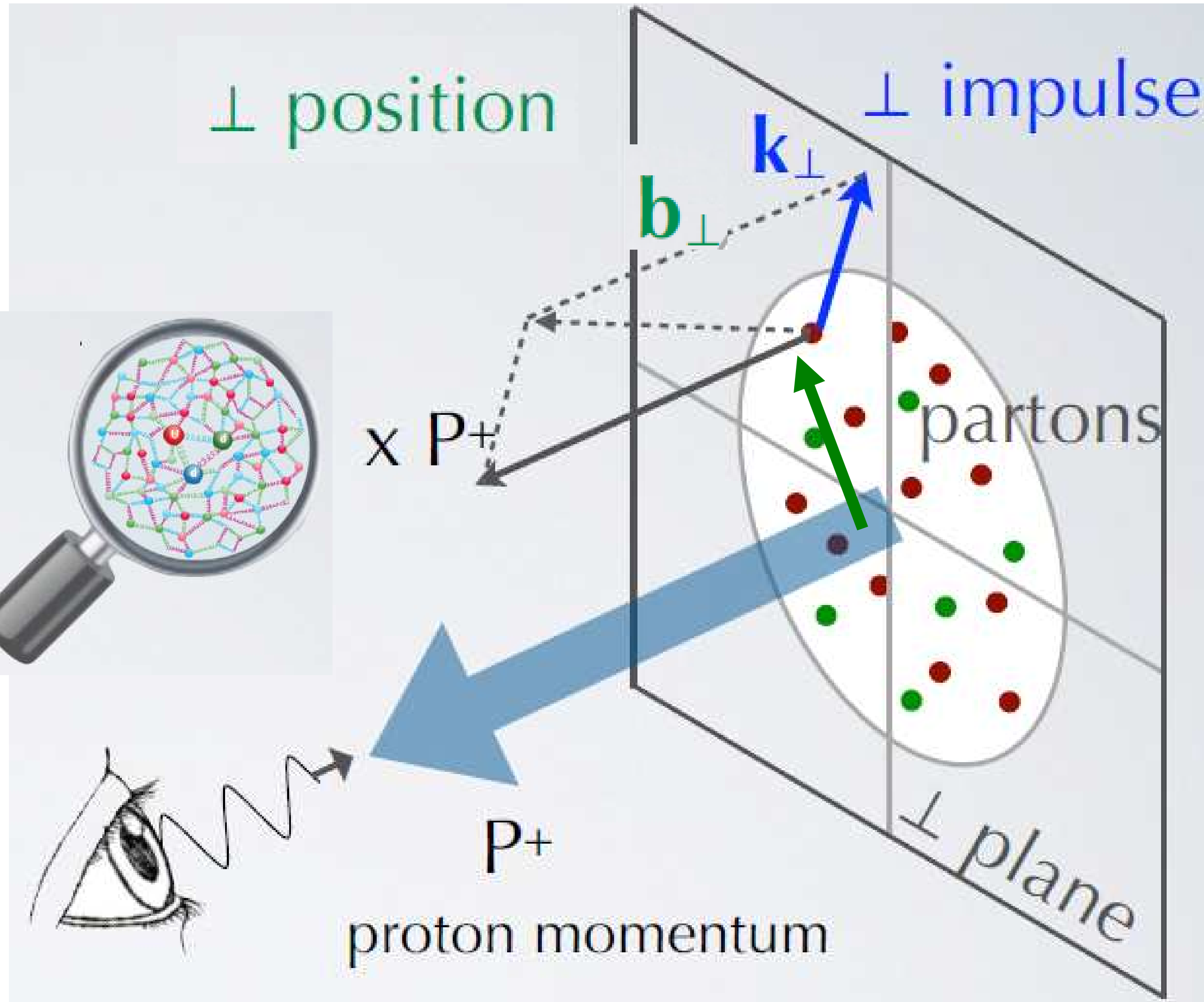
Towards 3D Imaging of the Nucleon

Motivation: in other sciences, imaging the physical systems under study has been key to gaining new understanding.





Structure mapped in terms of
$\mathbf{b}_T$ = transverse position
$\mathbf{k}_T$ = transverse momentum

Taken from a talk by Rolf Ent, Jefferson Lab

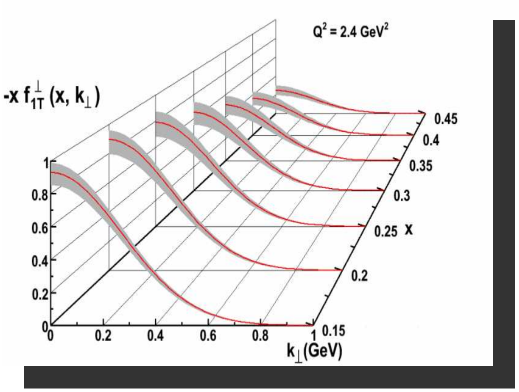
3D Imaging of the Nucleon

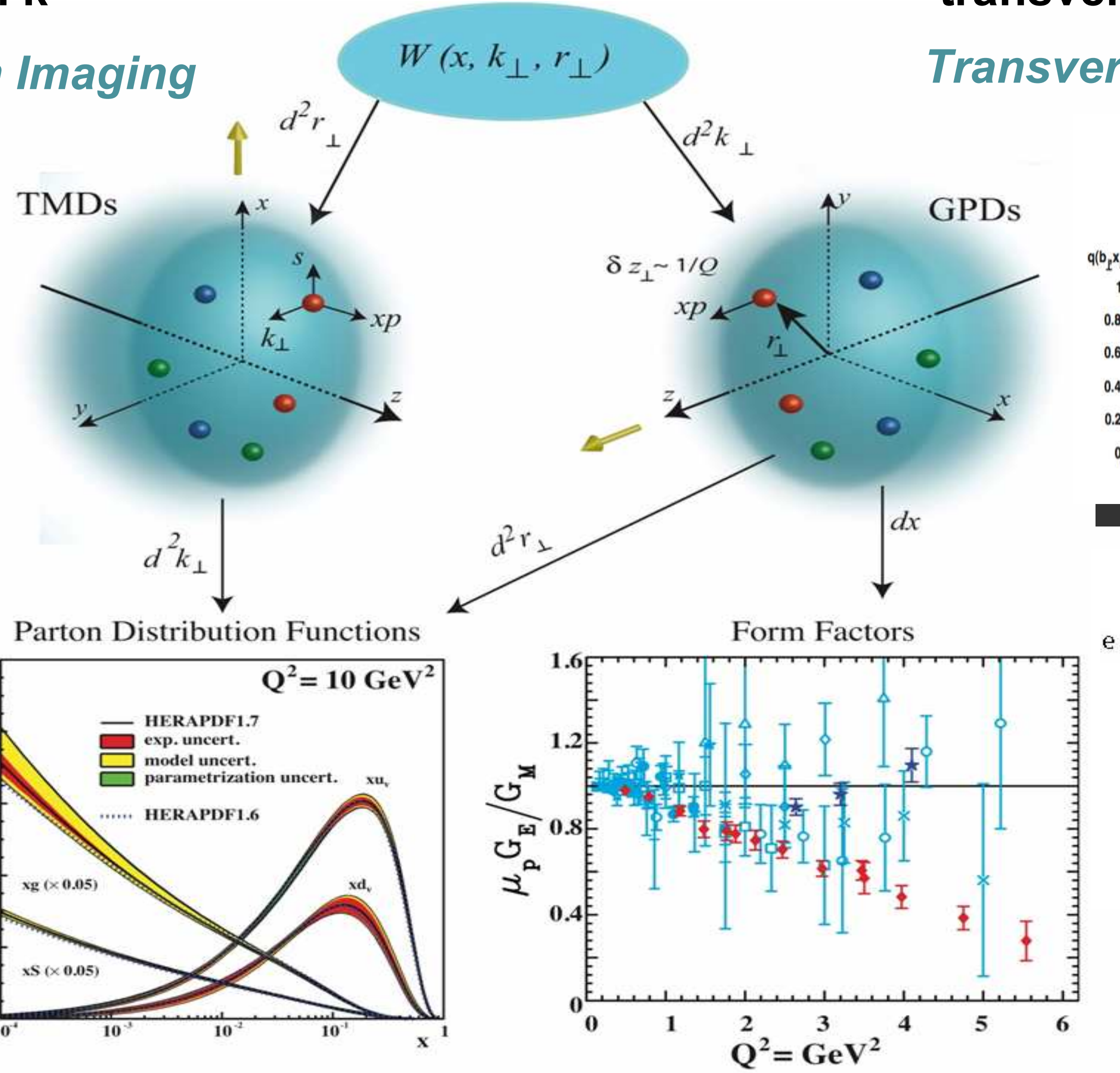
TMDs: Longitudinal momentum fraction x and transverse momentum k

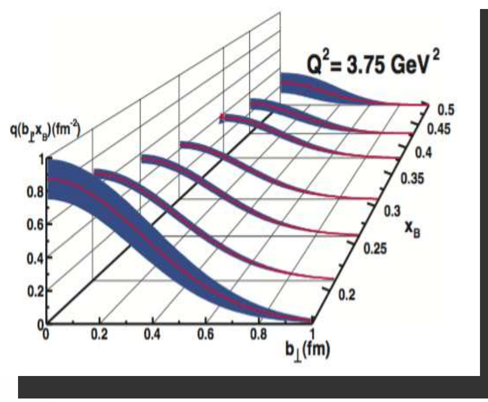
Transverse Momentum Imaging

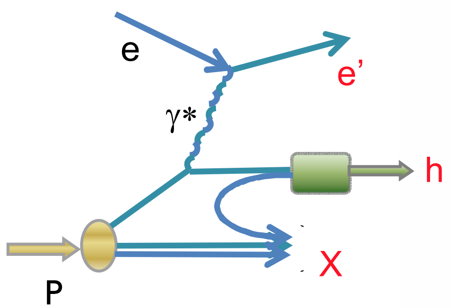
GPDs: Longitudinal momentum fraction x at transverse location b

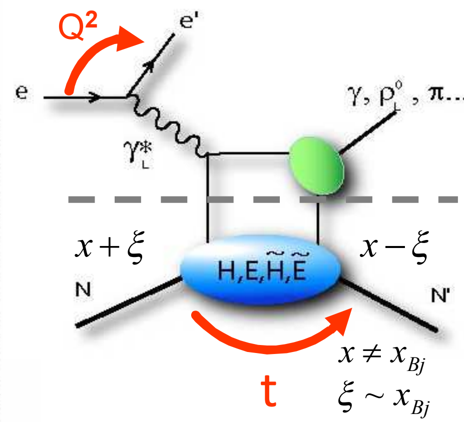
Transverse Spatial Imaging





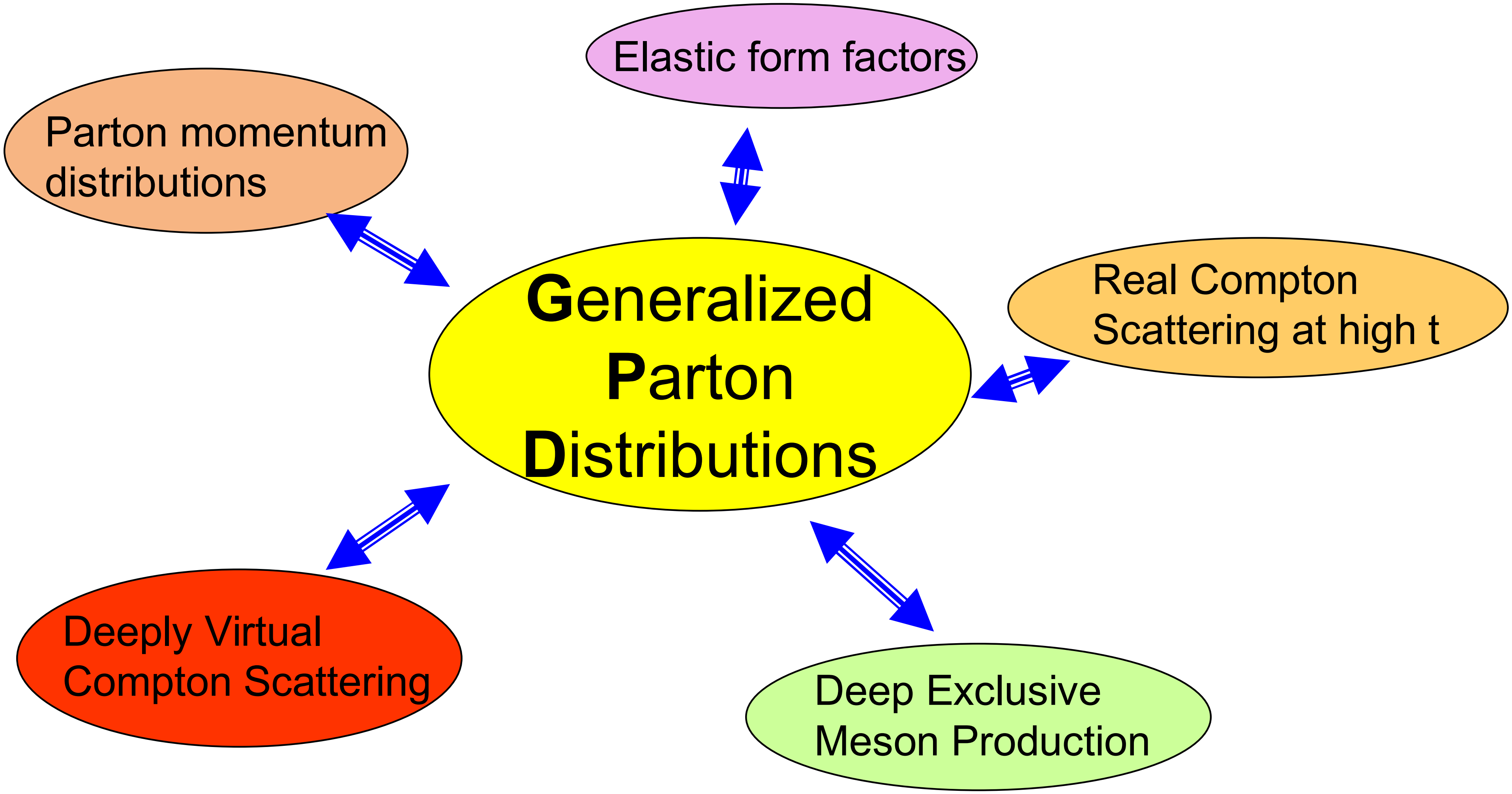






Taken from a talk by Rolf Ent, Jefferson Lab

GPDs – A Unified Description of Hadron Structure



- GPDs interrelate the longitudinal momentum and transverse spatial structure of partons within a fast moving hadron.
- GPDs are universal quantities and reflect nucleon structure independently of the probing reaction.

Leading Twist GPD Parameterization

Leading order QCD predicts:

- Vector meson production sensitive to unpolarized GPDs, H and E.
- Pseudoscalar mesons sensitive to polarized GPDs, $\tilde{H}$ and $\tilde{E}$.

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

Dirac and Pauli elastic form factors.
t -dependence fairly well known.

$$\left\{ \begin{array}{l} \sum_q e_q \int_{-1}^{+1} dx\, H^q(x,\xi,t) = F_1(t) \\ \sum_q e_q \int_{-1}^{+1} dx\, E^q(x,\xi,t) = F_2(t) \end{array} \right.$$

Isovector axial form factor.
t –dep. poorly known. $\longrightarrow$

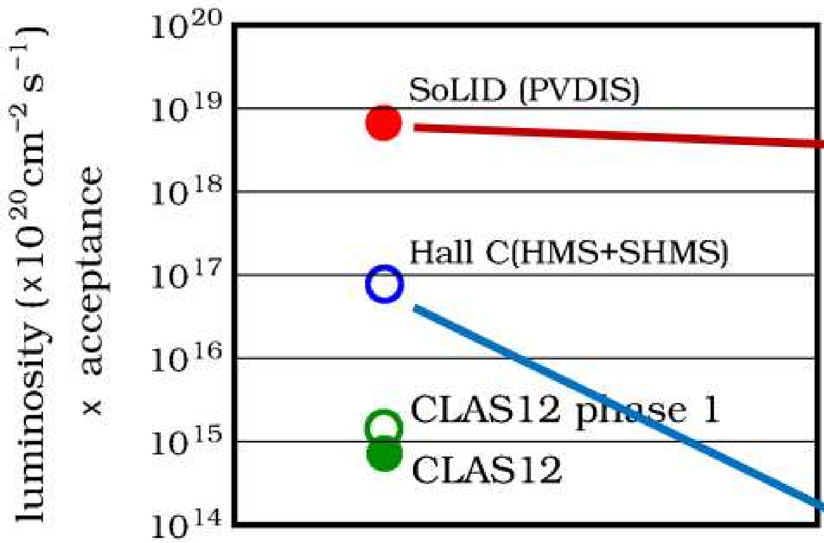
$$\sum_q e_q \int_{-1}^{+1} dx\, \tilde{H}^q(x,\xi,t) = G_A(t)$$

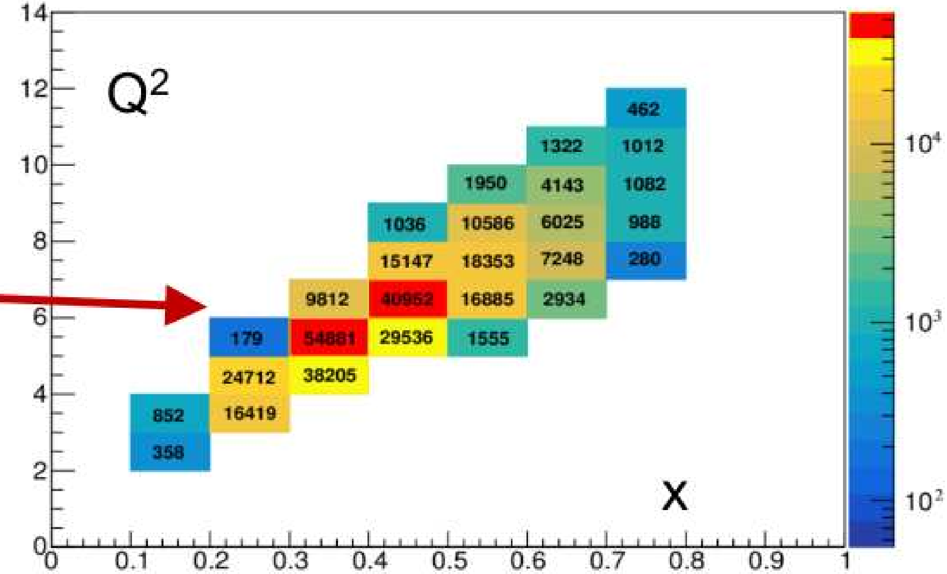
Pseudoscalar form factor.
Very poorly known. $\longrightarrow$

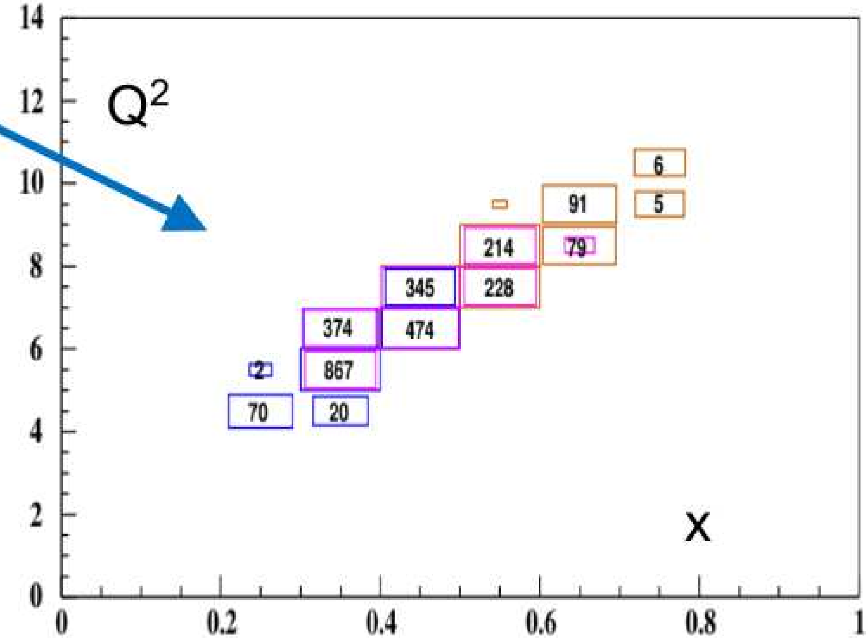
$$\sum_q e_q \int_{-1}^{+1} dx\, \tilde{E}^q(x,\xi,t) = G_P(t)$$

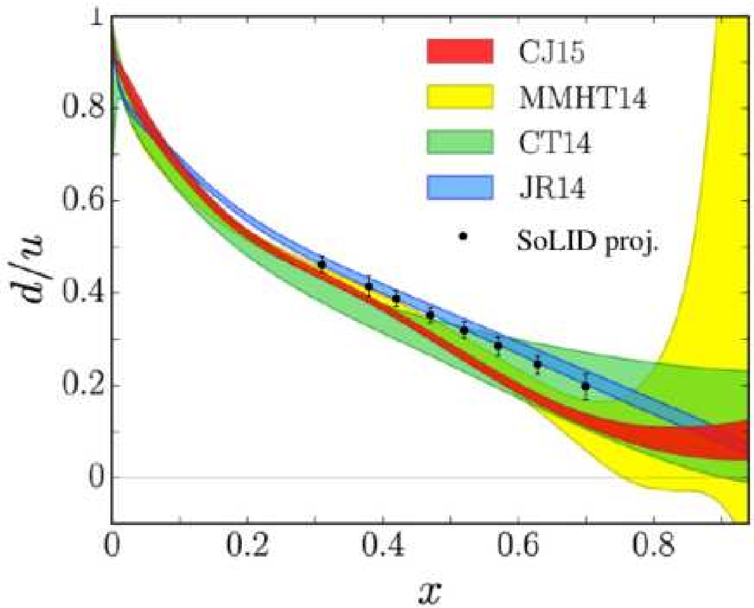
SoLID Optimized for High Luminosity Science

SoLID has >1000 times the rate of CLAS12
and ~100 times the rate of Halls A or C





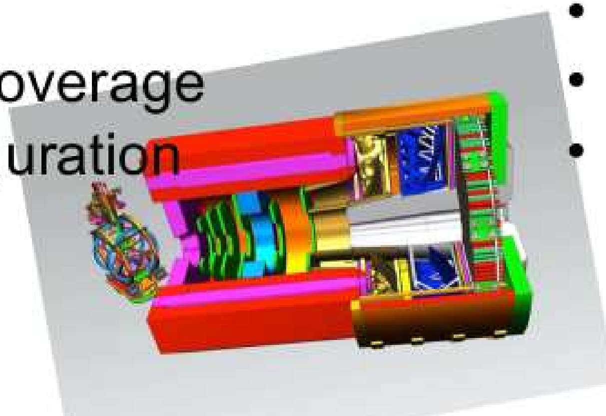




State–of–the–Art Technology

Quantum Leap Science Requirements are Challenging

- High Luminosity (10^{37}-10^{39})
  - beam currents ~100 microA) on ~10 cm liquid targets
  - beam currents of ~50 microA on ~30cm polarized ^{3}He target
- Solenoidal field provides access to azimuthal asymmetry
- High data rate (~100 KHz)
- High background (~ GHz)
- Low systematic uncertainties
- High Radiation
- Broad kinematic coverage
- Flexibility in configuration



SoLID pre-conceptual design began “ground up” with the latest available advanced technologies to ensure every piece of sub-systems can meet the challenging requirements

- GEM tracking
- Shashlik Electron Calorimetry
- High Performance Cerenkovs
- Pipeline DAQ
- Rapidly Advancing Computational Capabilities
- Parity beamline
- Advanced polarimetry
- High power and polarized targets

SoLID Magnet: Requirement and Design

Requirements:

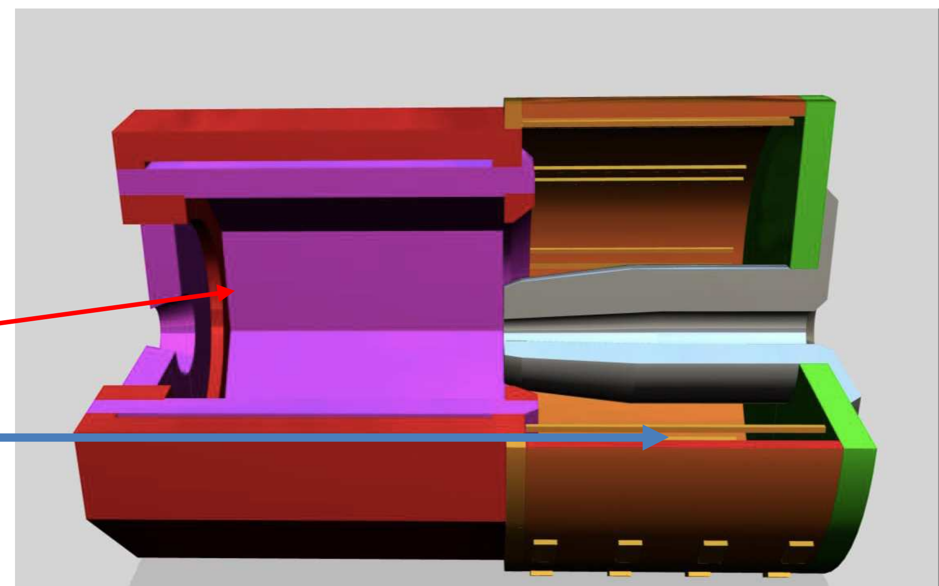
→Acceptance: P: 1.0 – 7.0 GeV/c;
Φ: 2π; θ: 8°-24° (SIDIS), 22°-35° (PVDIS)

→ Resolution: $\delta P/P \sim 2\%$
(requires 0.1 mm tracking resolution)

→ Fringe field at the ^{3}He target < 5 Gauss

CLEO–II coil at JLab

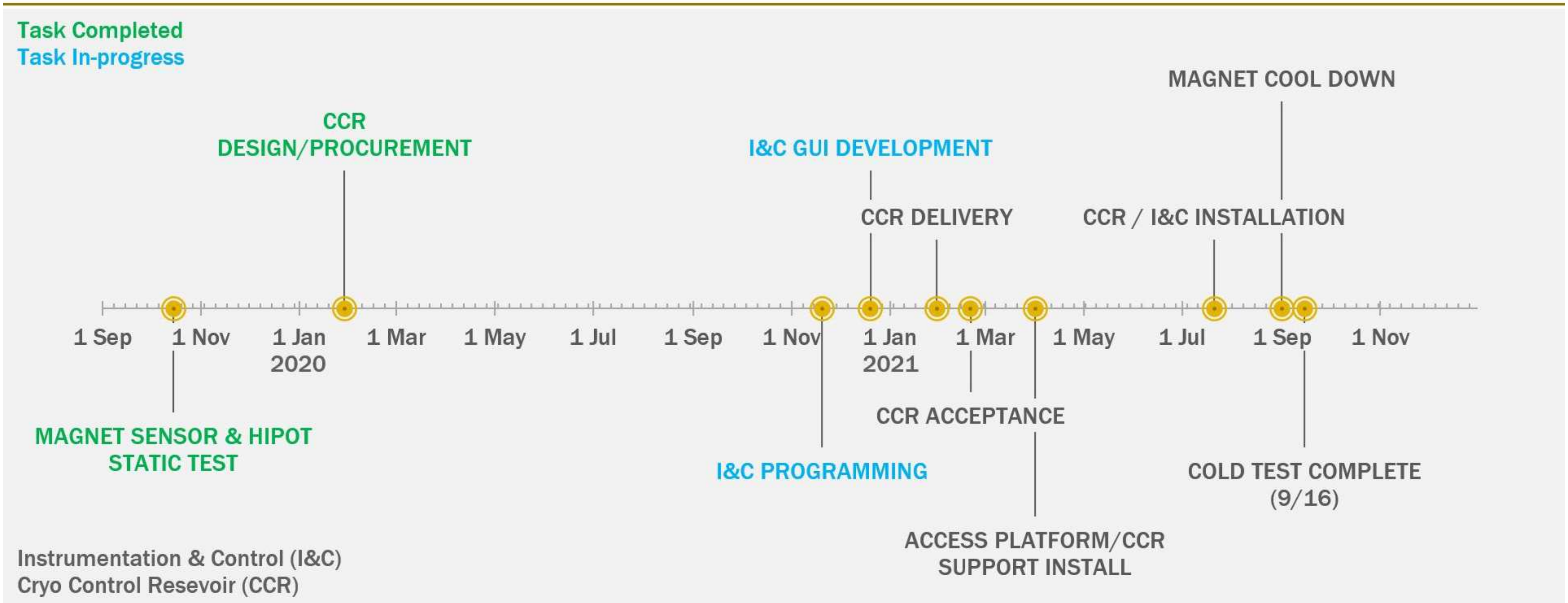
- Use CLEO II magnet with the following modifications
  - Two of three layers of return yoke needed
  - Add thickness to front endcap
  - Add extended endcap

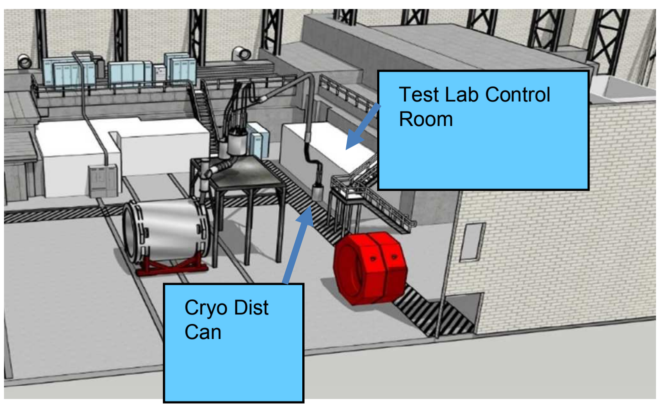


Yoke for SoLID

Cold Test Update – Cold Test Milestones

Phase 1 Solenoid Rehab Milestones

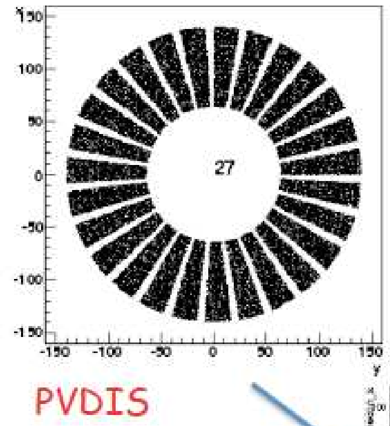


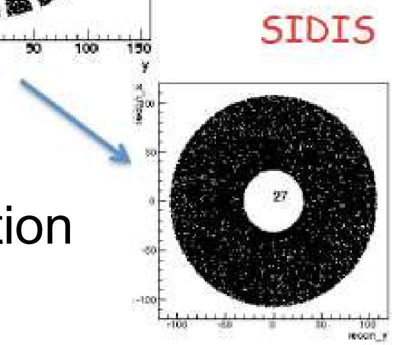


- Solenoid rehab will confirm condition of the magnet
- Provide risk reduction to the project
- Improve magnet cost estimate
- Estimated completion Sept 2021

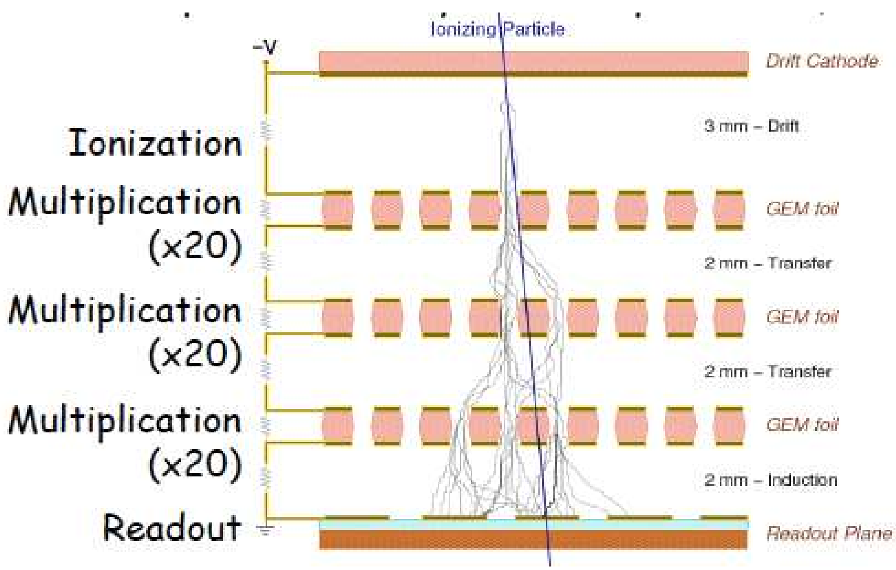
GEM tracking

- Rate capabilities > many MHz/cm^2
- High position resolution
- Cover large areas at reasonable cost
- Low thickness (~0.5 radiation length)
- Used in many experiments (COMPASS, STAR, ALICE, PRad@**JLab**…) and planned for many future experiments SBS@JLab, CMS upgrade, EIC…)





GEM configuration



GEM Technology

EIC Prototype: similar to SoLID design

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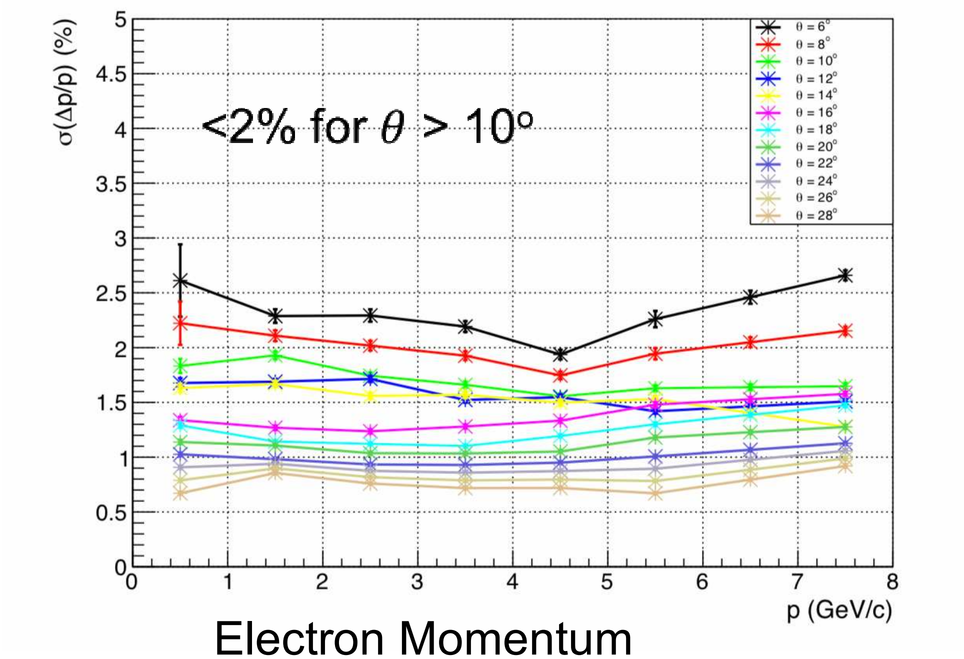
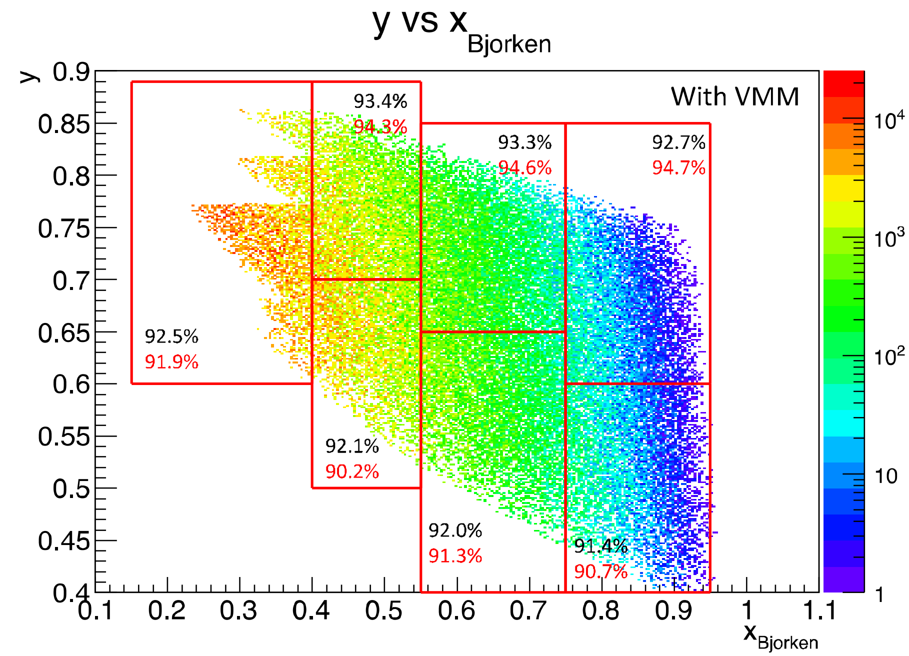
Simulated GEM Performance

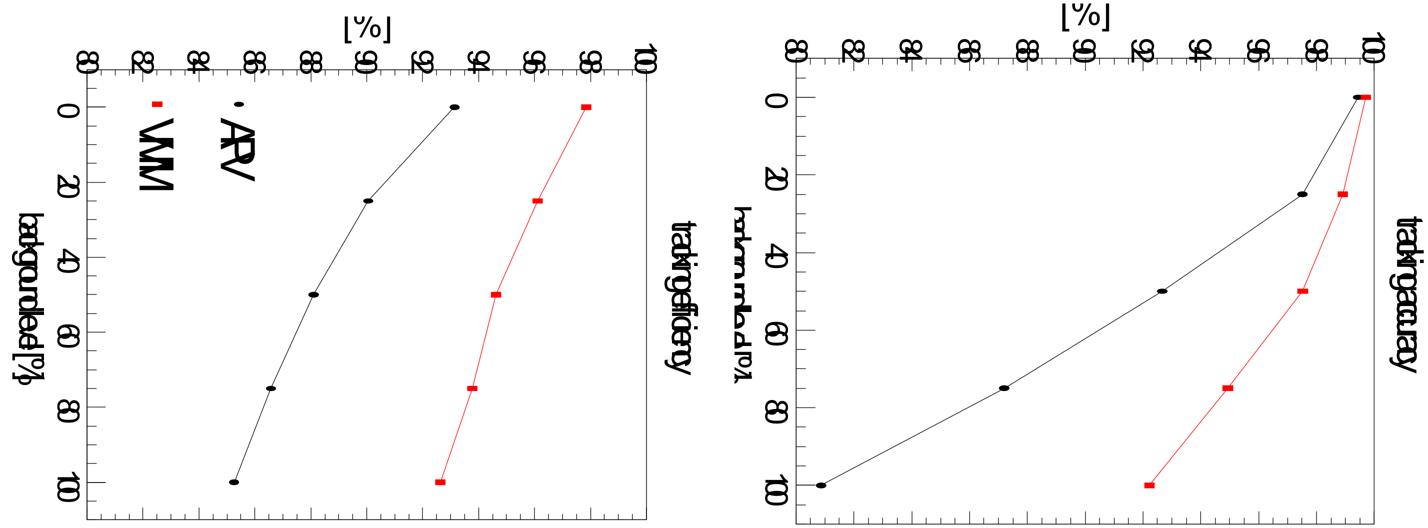


Electron Momentum
Resolution versus angle



Efficiency and accuracy for
PVDIS versus kinematics

Risk:
VMM chips need testing:
addressed in Pre R&D plan

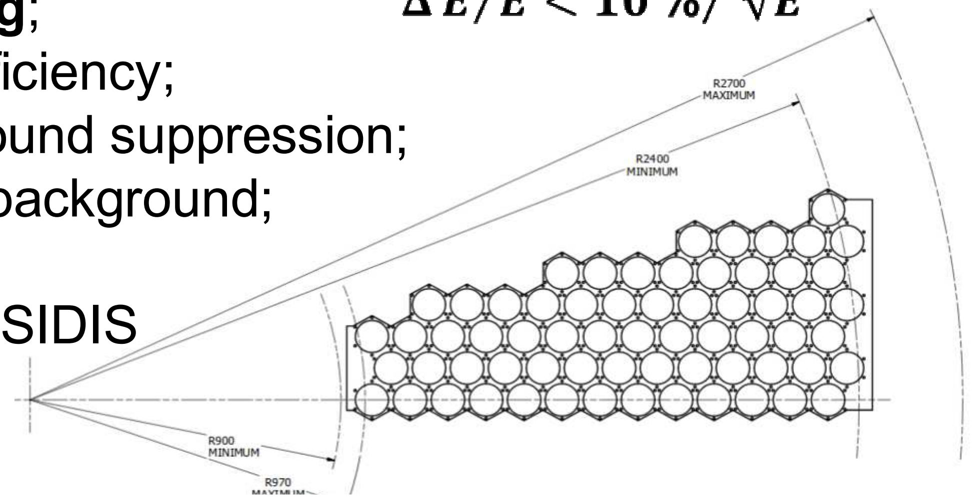


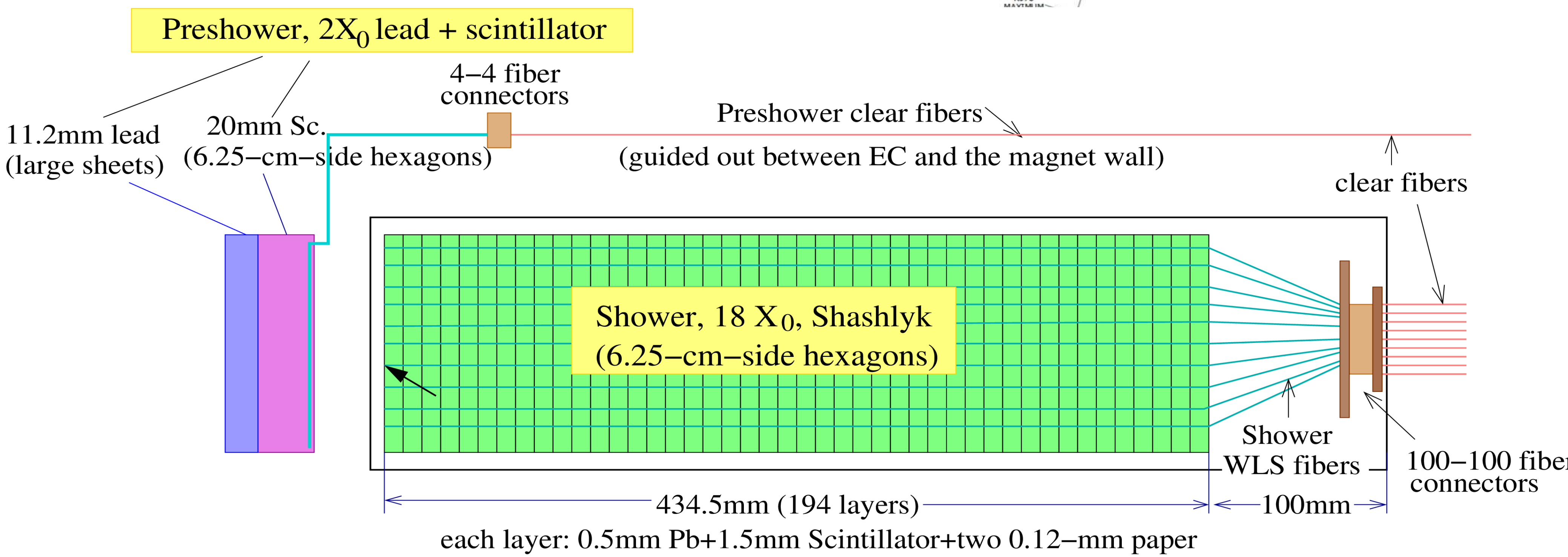
APV versus VMM

ECal Requirement and Design

- Combined with LGC to **provide triggering**;
- **50:1 pion rejection** with 90% electron efficiency;
- provide ~1cm shower position for background suppression;
- **radiation hard**: >500 krad, high neutron background;
- inside 1.5 T field
- modules swappable between PVDIS and SIDIS

$$\Delta E/E < 10\%/\sqrt{E}$$





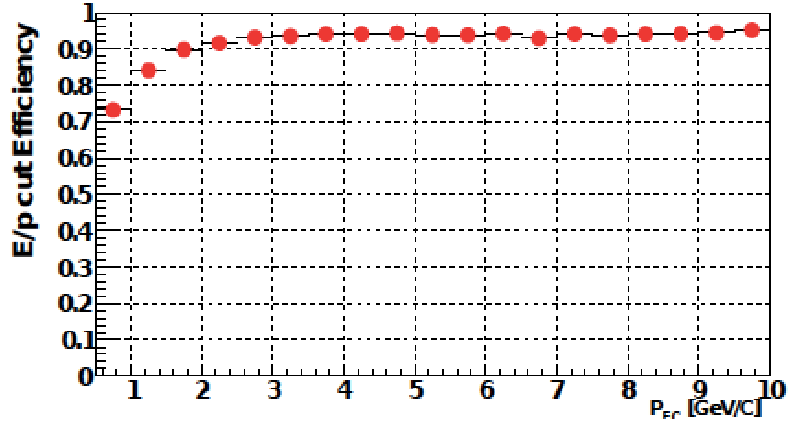
ECAL Performance

Realistic simulation with background and supporting material

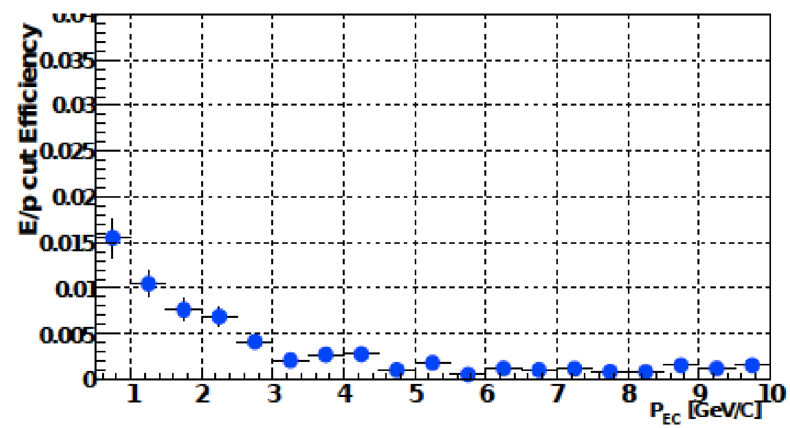
Resolution: for all angles, **reached p0~(5-6)% and p2~(5-6)%**

$$\sqrt{\left(\frac{p0}{\sqrt{E}}\right)^2 + (p1)^2 + \left(\frac{p2}{E}\right)^2}$$

FAEC electron



FAEC pion



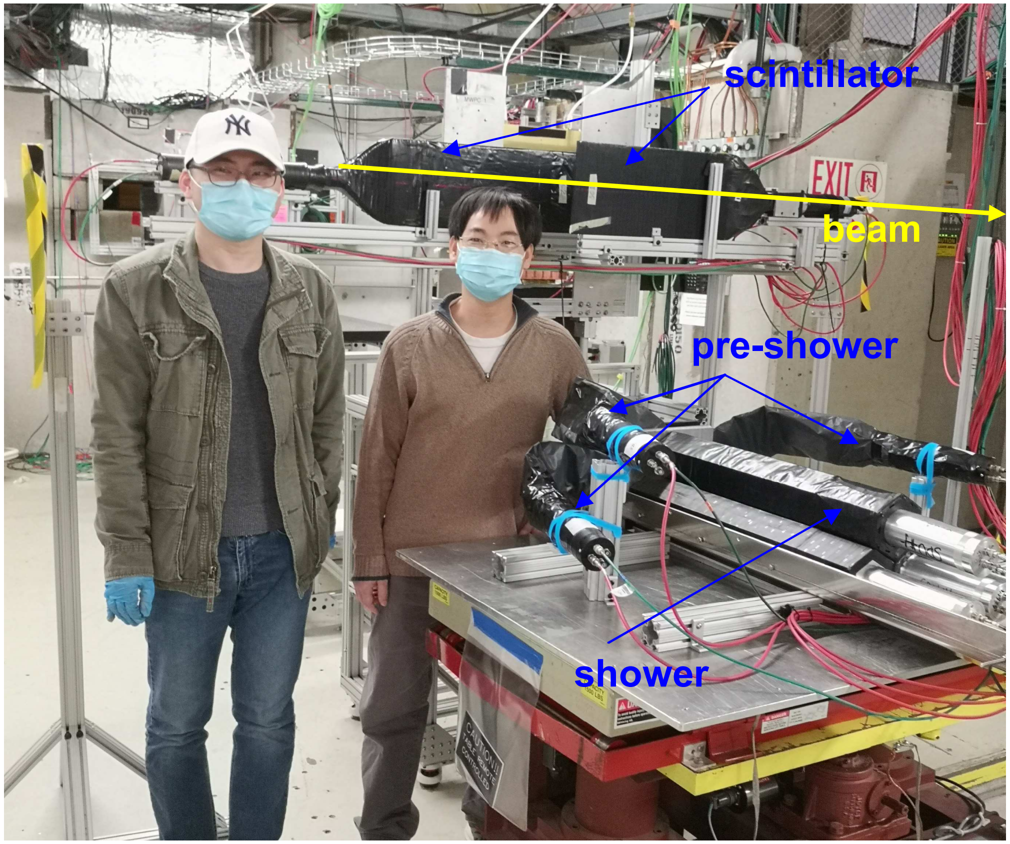
Pion rejection > 50:1

Fermilab Beam Test with Shashlyk Modules

- Goal: Understand the detection resolution and efficiency of the Shashlyk modules
- Beam time: Jan 13-26, 2021
- Setup: $2X_0$ lead, 3 preshower, 2-cm Al support, 3 Shashlyk modules; FTBF's MWPC+Cherenkov

People power: (UVA) Jixie Zhang, Xinzhan Bai; (JLab) Alexandre Camsonne, David Flay; (ANL) Paul Reimer, Junqi Xie, Manoj Jadhav

Beam energy (GeV)	total trigger	total electron trigger (online)
1	3.1M	3.0M
2	2.9M	2.7M
4	4.5M	3.9M
6	2.8M	2.1M
8	5.5M	3.4M
10	6.8M	3.6M
12	3.0M	1.3M
16	7.6M	2.3M



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Scintillator Pad Detector: Requirements and Design

LASPD: photon rejection 5:1;

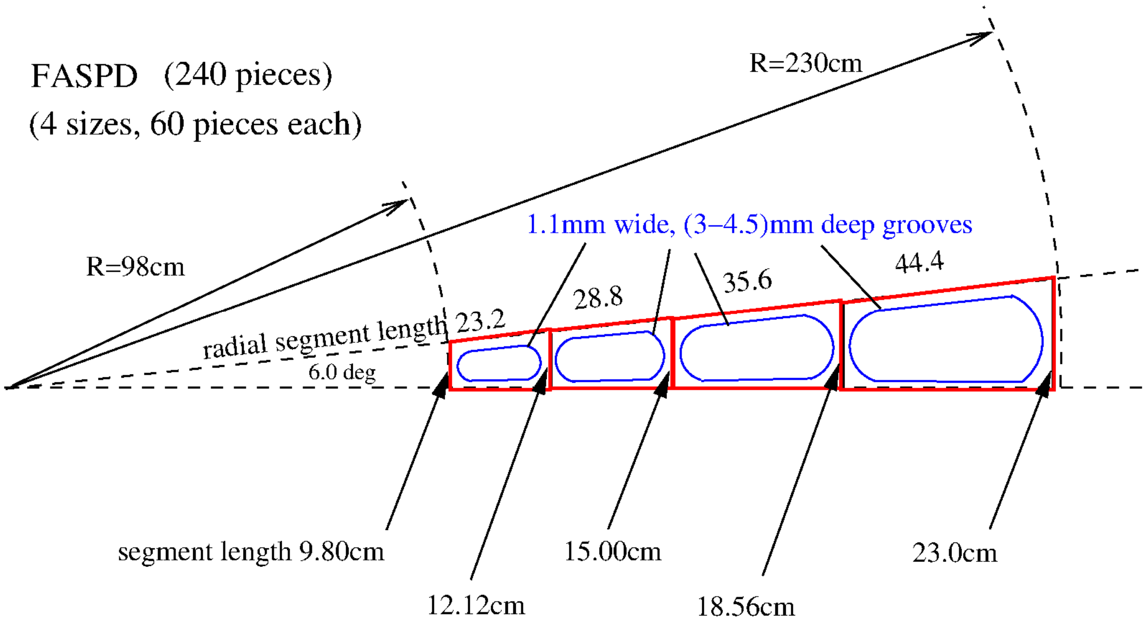
coincidence TOF (150ps)

→ design: 20mm-thick,

60 azimuthal segments,

direct coupling to fine-mesh PMT (for FMPMT study see NIMA 827 (2016) 137-144)

a LASPD prototype equipped with (regular) PMTs



FASPD: **photon rejection 5:1**

→ design: 5-10mm-thick

240 segments (60 X 4)

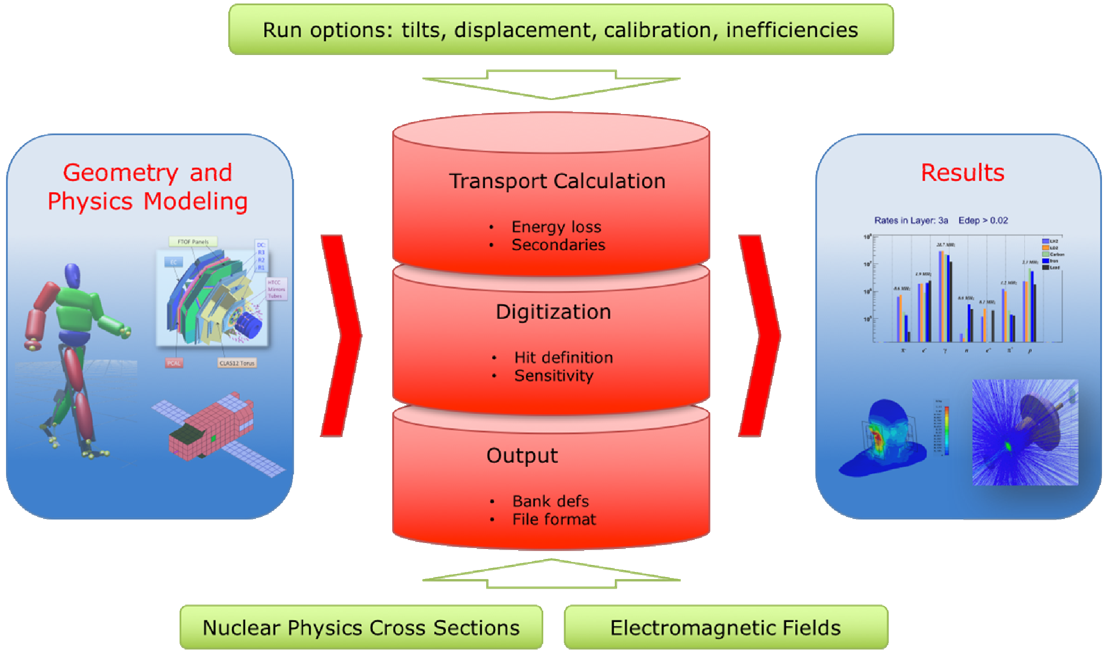
WLS fiber embedding,

MAPMT (outside magnet)

Software and Simulations

Existing simulations: SoLID_GEMC

- GEMC is a Geant4-based simulation package, used by CLAS12.
- Added SoLID detector description and signal digitization, esp. for GEMs.
- Used extensively for SoLID pre-CDR and in current pre-R&D studies.
- Variety of physics generators available.



The architecture of gemc

Long-term goals

- Develop end-to-end simulation and reconstruction chain.
  - Integrated software environment for (almost) all parts of data processing
  - Modern, multi-threaded, grid-enabled framework written in C++
  - Common conditions data and geometry database API
  - Consistent ROOT-based event data file format w/ metadata storage
  - Python or JSON/YAML-based job configuration
- Provide online and offline analysis software, event display, calibration tools etc. as well as complete set of simulation and digitization modules.
- Feasibility studies underway in collaboration with other JLab groups.

SoLID Jefferson Lab

DAQ Requirements and Design

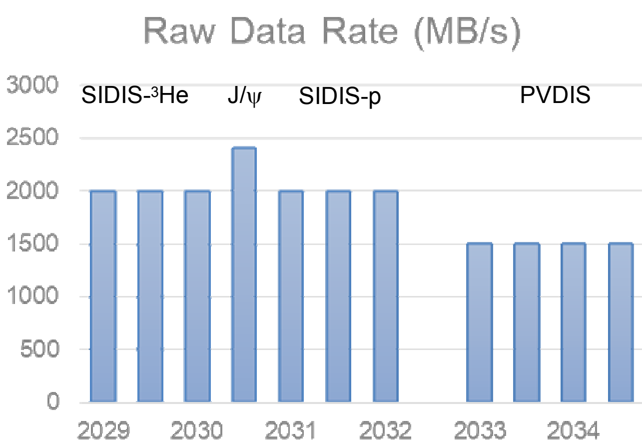
- DAQ based on 12 GeV FADC base pipelined electronics designed for 200 KHz trigger rates,100 kHz rates demonstrated in Hall B and D
- VMM chip based readout for GEMs

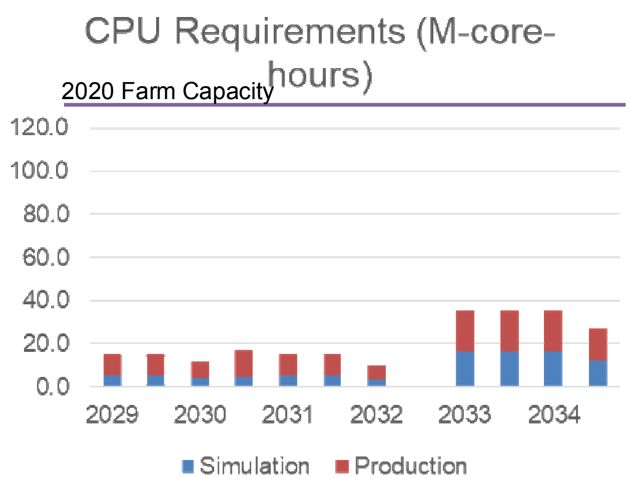
  ATLAS Small Wheel Micromegas readout chip : up to 4 MHz trigger rate per channel, limited by occupancy in detector – designed for 200 KHz

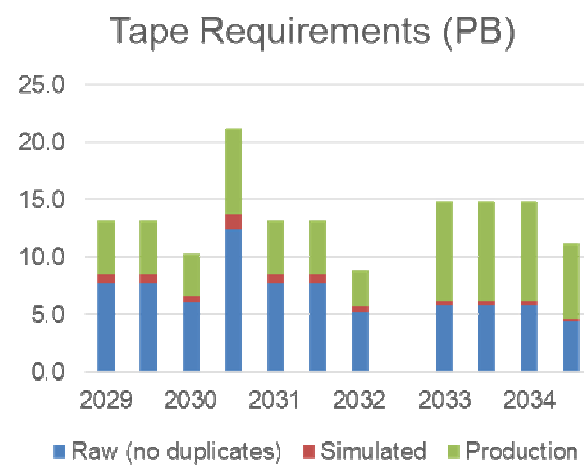
  Older chip APV25 used by SBS as backup option
- Design goal well within hardware capabilities with some safety margin
  - 60 KHz/sector for PVDIS, expect 20 KHz/sector, ~ 2 GB/s, 30 sectors
  - 120 KHz total for SIDIS, expect 100 KHz, ~ 2 GB/s
  - 100 KHz total for J/Psi, expect 60 KHz, ~ 3 GB/s
- Pre-R&D to validate required rates and determine maximum rates achievable
- Existing infrastructure
  - Network : 10 GB/s
  - Silo
    - Current setup: data rate 6 GB/s
    - IBM TS3500 highly scalable: Data rate upgradable up to 69 GB/s
    - Maximum data 250 PB
- Rate limitation mostly from storage cost

Computing Requirements

- Raw data rate comparable to GlueX & CLAS12 (~2 GB/s).
- Estimated CPU requirements already manageable with today's farm resources
- Tape requirements (25–30 PB/yr) significantly higher than current experiments.
- J/ψ has ~50% higher storage requirements due to larger event size.







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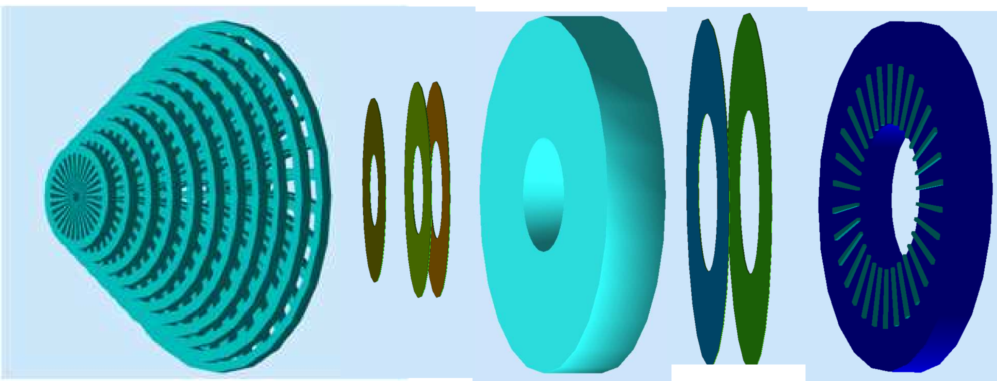
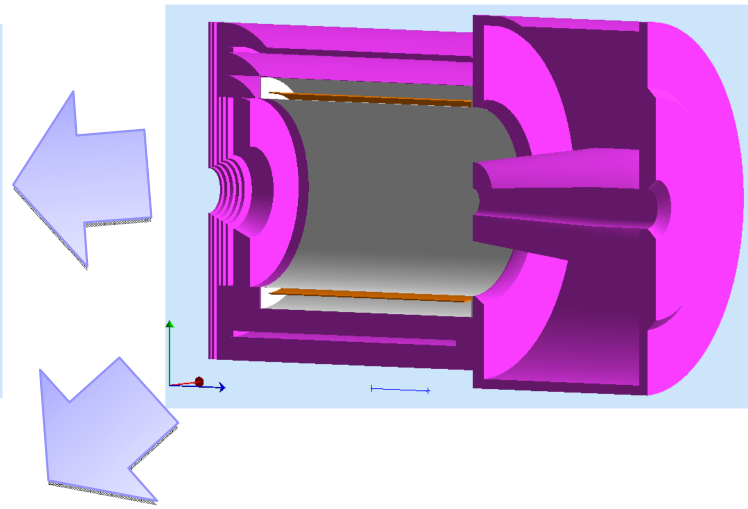
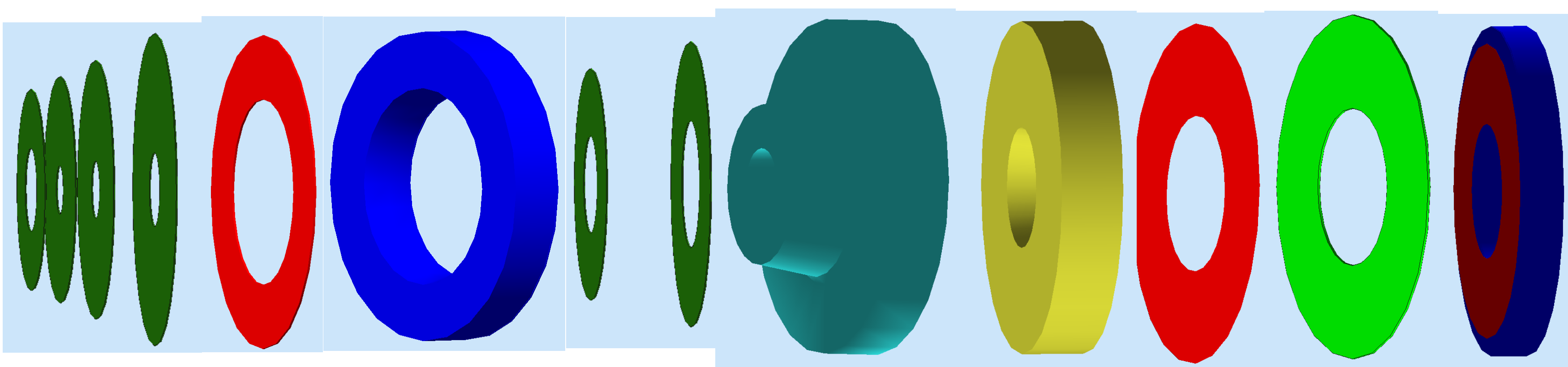
SoLID Detector Technologies

PVDIS: Baffle 3xGEMS LGC 2xGEMs EC





SIDIS&J/y:
4xGEMs LASPD LAEC 2xGEMs LGC HGC FASPD (MRPC) FAEC



Pre-R&D items: LGC, HGC, GEM's, DAQ/Electronics, Magnet

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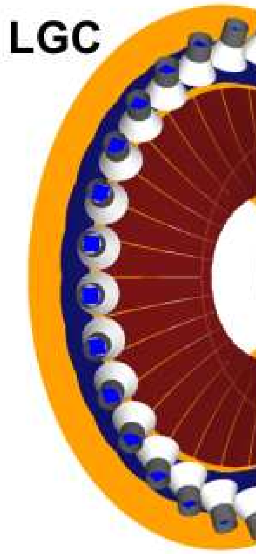
SoLID High Performance Cherenkovs

State of the art design:

- Electron/pion (LGC) and pion/kaon (HGC) separation with good rejection factors while maintaining good detection efficiencies
- Provide input at trigger level in a 2π, high-luminosity, non-negligible magnetic field environment while minimizing complexity and cost
- Exceeds the PID requirements for SoLID science



Pixelized photodetector arrays:

- Allows for flexibility in the trigger design
- Provides data for use in signal pattern recognition
- Efficient photon detection in magnetic fields of ~100 Gauss

High-Rate Test:

- Photodetector arrays and front-end electronics successfully tested in Hall C in 2020
- Analysis confirms the efficacy of SoLID electronics
- Data collected will help with calibration/verification of simulation

SoLID High Performance Cherenkovs

State of the art design:

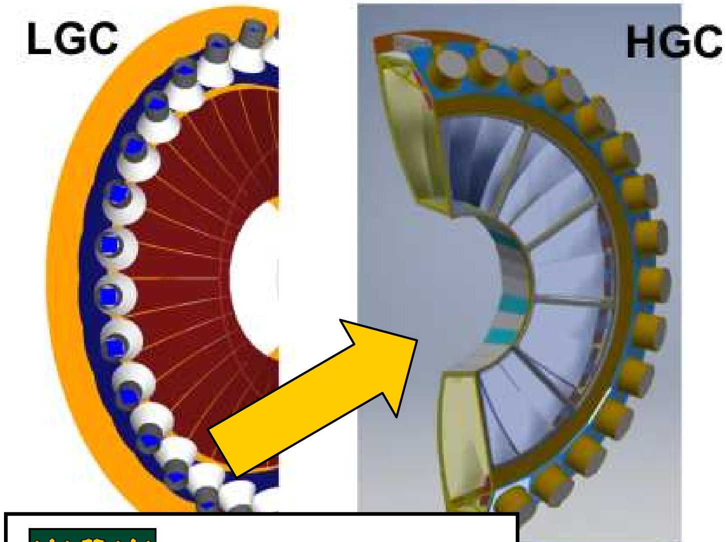
- Electron/pion (LGC) and pion/kaon (HGC) separation with good rejection factors while maintaining good detection efficiencies
- Provide input at trigger level in a 2π, high-luminosity, non-negligible magnetic field environment while minimizing complexity and cost
- Exceeds the PID requirements for SoLID science

Pixelized photodetector arrays:

- Allows for flexibility in the trigger design
- Provides data for use in signal pattern recognition
- Efficient photon detection in magnetic fields of ~100 Gauss

High-Rate Test:

- Photodetector arrays and front-end electronics successfully tested in Hall C in 2020
- Analysis confirms the efficacy of SoLID electronics
- Data collected will help with calibration/verification of simulation



CFI–IF application for HGC vessel & entrance windows