Deep Exclusive π^- Production using a Transversely Polarized ^3He Target and the SoLID Spectrometer

Garth Huber

University of Regina

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Leading Twist GPD Parameterization

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- **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.**

- 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 helicity filter.
  - Pseudoscalar mesons → $\tilde{H}$ $\tilde{E}$
  - Vector mesons → H E.

$H^{q,g}(x,\xi,t)$ 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

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

Garth Huber, huberg@uregina.ca

How to determine $\tilde{E}$

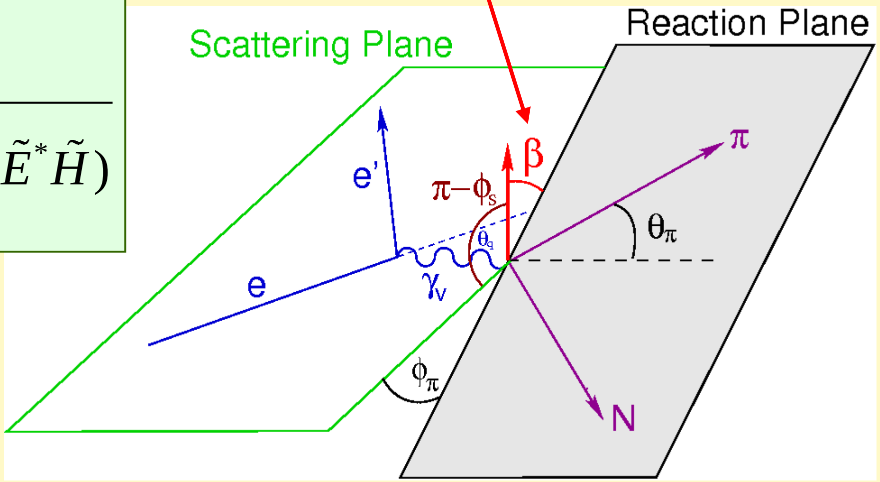
- **GPD $\tilde{E}$ not related to an already known parton distribution.**
- Experimental information on $\tilde{E}$ can provide new nucleon structure info unlikely to be available from any other source.
- The most sensitive observable to probe $\tilde{E}$ is the transverse single-spin asymmetry in exclusive π production:

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

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

$d\sigma_{\pi}^{L}$ = exclusive π cross section for longitudinal γ^*

β =angle between transversely polarized target vector and the reaction plane.



Refs: A.V. Belitsky, D. Mueller, PL**B513** (2001) 349
L.L. Frankfurt, et al., PRD **60**(1999) 014101

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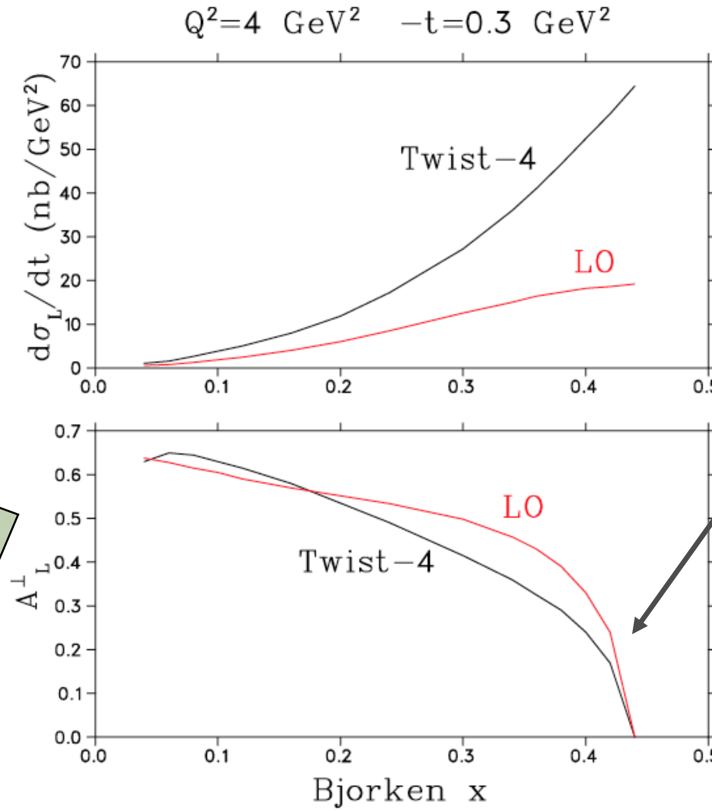
GPD information in $A_L^{\perp}$ may be particularly clean

- **$A_L^{\perp}$ 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 $\varphi - \varphi_s$ 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.

Garth Huber, huberg@uregina.ca

Transverse Target Single Spin Asymmetry in DEMP

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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

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

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

Note: Trento convention used for rest of talk

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HERMES sin(φ–φ$_S$) Asymmetry Moment

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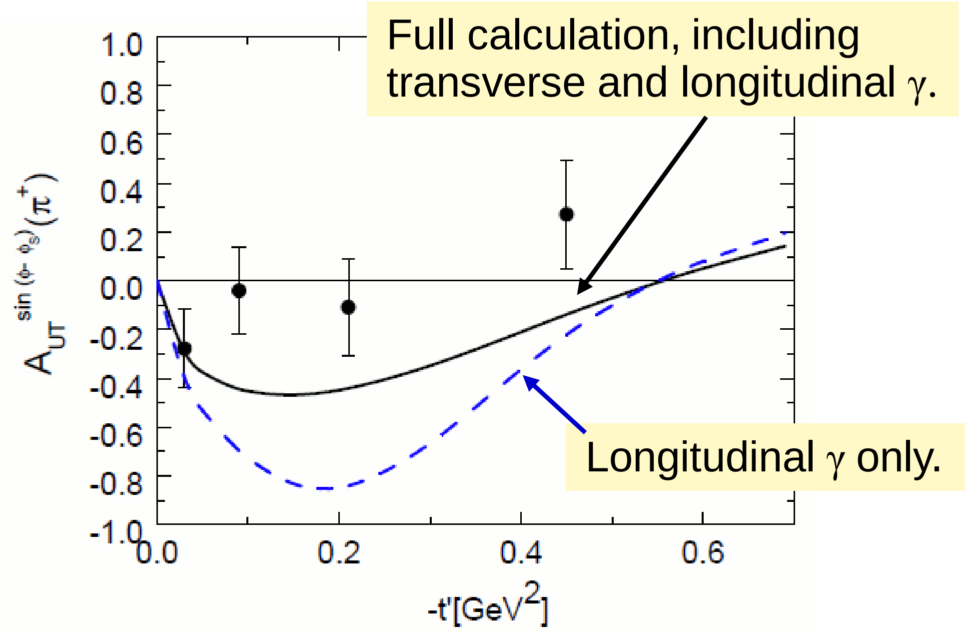
- Exclusive π^+ production by scattering 27.6 GeV positrons or electrons from transverse polarized ^{1}H [PL **B682**(2010)345].
- Analyzed in terms of 6 Fourier amplitudes for φ_π,φ_S.
- $\langle x_B\rangle=0.13$, $\langle Q^2\rangle=2.38$ GeV^2, $\langle -t\rangle=0.46$ GeV^2.

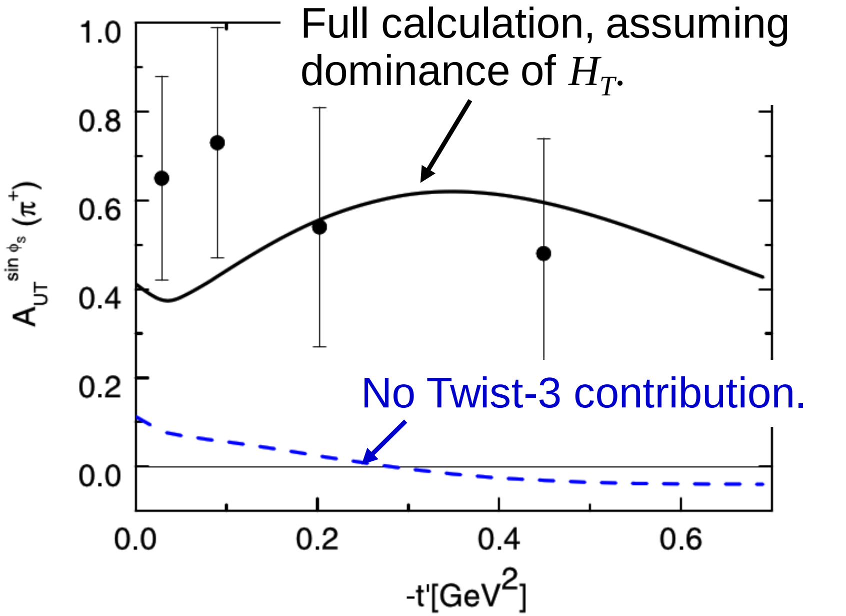


- **Since there is no L/T separation, $A_{UT}^{\sin(\varphi-\varphi_S)}$ is diluted by the ratio of the longitudinal cross section to the unseparated cross section.**
- Goloskokov and Kroll indicate the HERMES results have significant contributions from transverse photons, as well as from L and T interferences [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.

Garth Huber, huberg@uregina.ca

HERMES sin(φ_s) Asymmetry Moment

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



- In contrast to the sin(φ-φ_s) modulation, which has contributions from LL and TT interferences, the sin(φ_S) modulation measures only the LT interference.
- **The HERMES sin(φ_S) modulation is large and nonzero at $-t'$=0, giving the 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 the transversity GPD H_T dominates and that the other three can be neglected.**

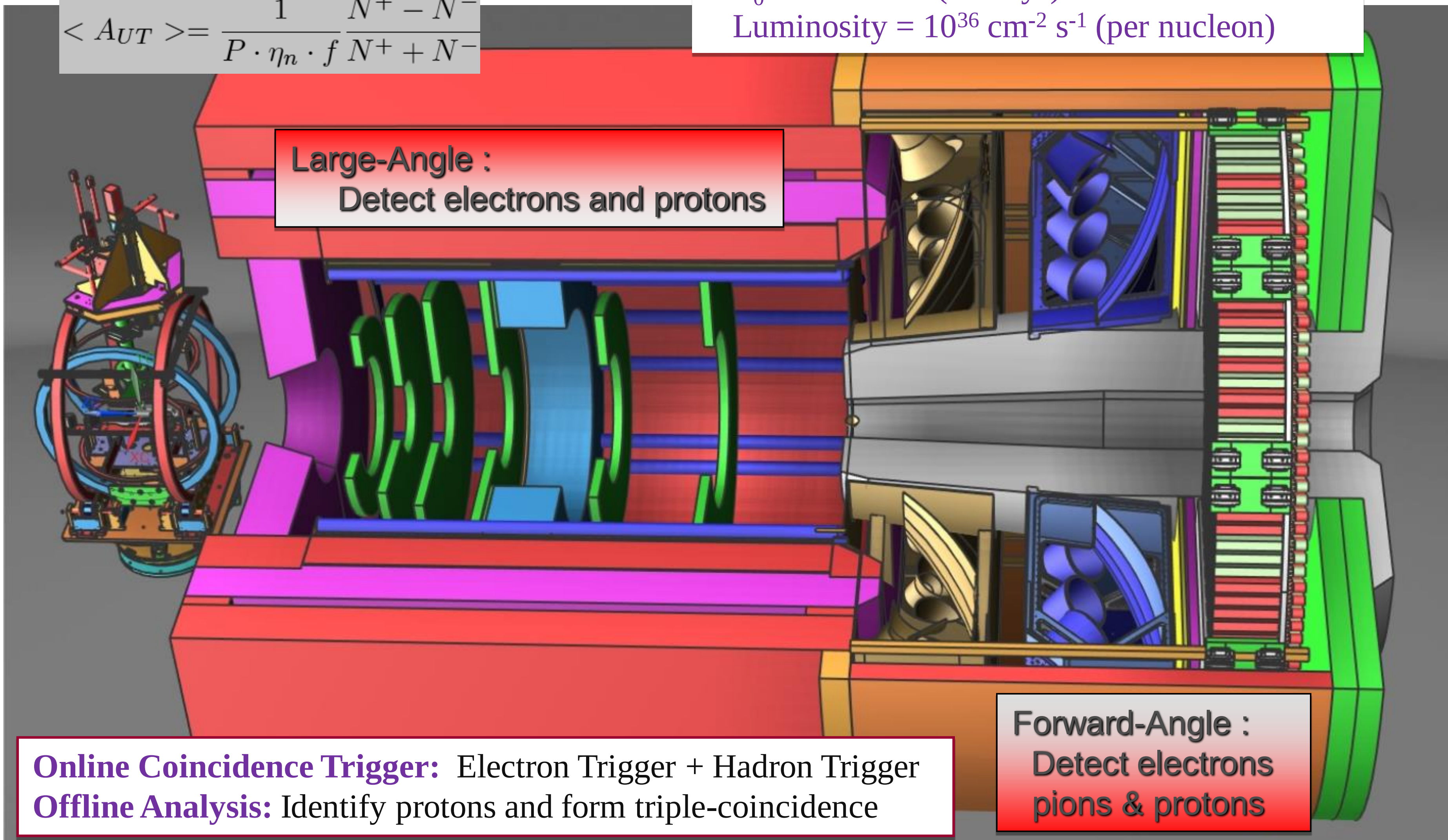
Garth Huber, huberg@uregina.ca

Measure DEMP with SoLID – Polarized ^{3}He

$\vec{n}(e,e'\pi^-)p$: 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)



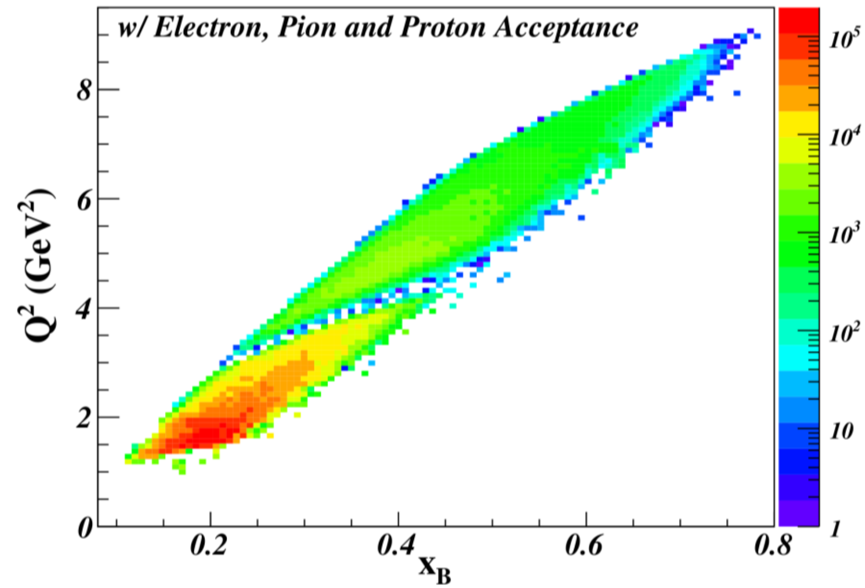
Online Coincidence Trigger: Electron Trigger + Hadron Trigger
Offline Analysis: Identify protons and form triple-coincidence

Garth Huber, huberg@uregina.ca

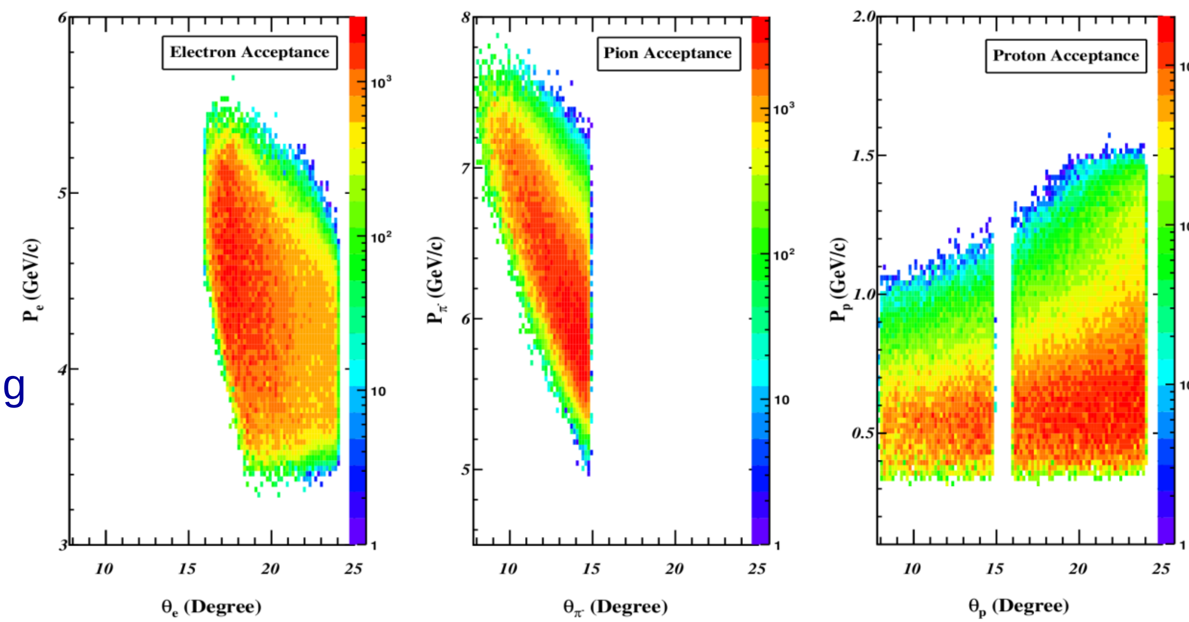
SoLID Acceptance and Projected Rates

*Q*²>1 GeV², *W*>2 GeV	*Q*²>4 GeV², *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 GeV², *W*>2 GeV, 0.55<ε<0.75 cuts applied.

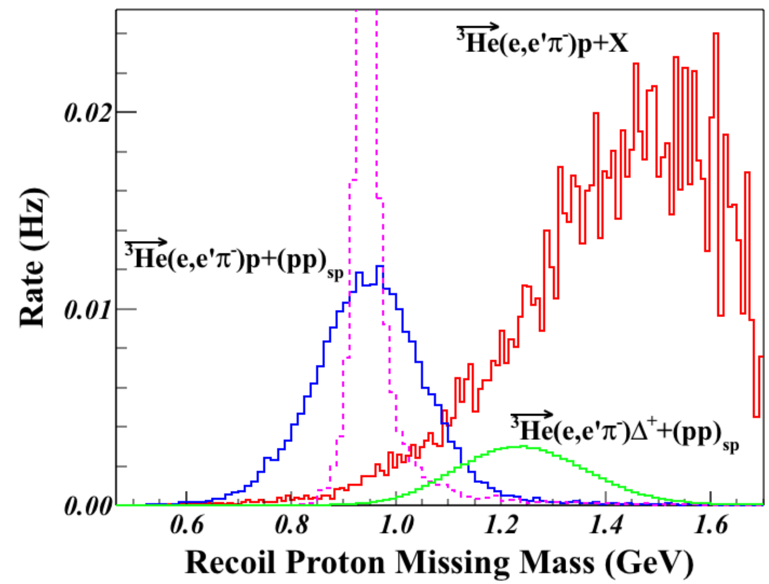


Garth Huber, huberg@uregina.ca

Example Cuts to Reduce Background

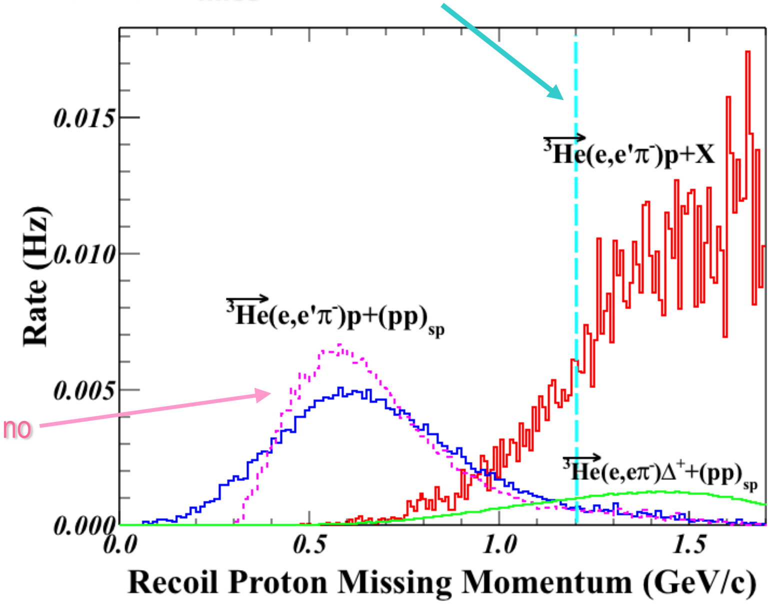
Two different background channels were simulated:

- 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).

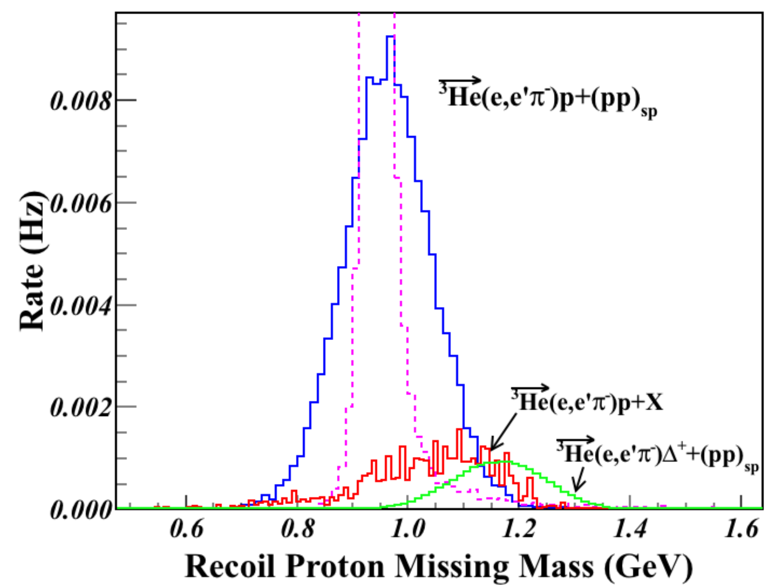


Apply P_{miss}>1.2 GeV/c cut

Background remaining after P_{miss} cut



Scattering & radiation but no resolution smearing



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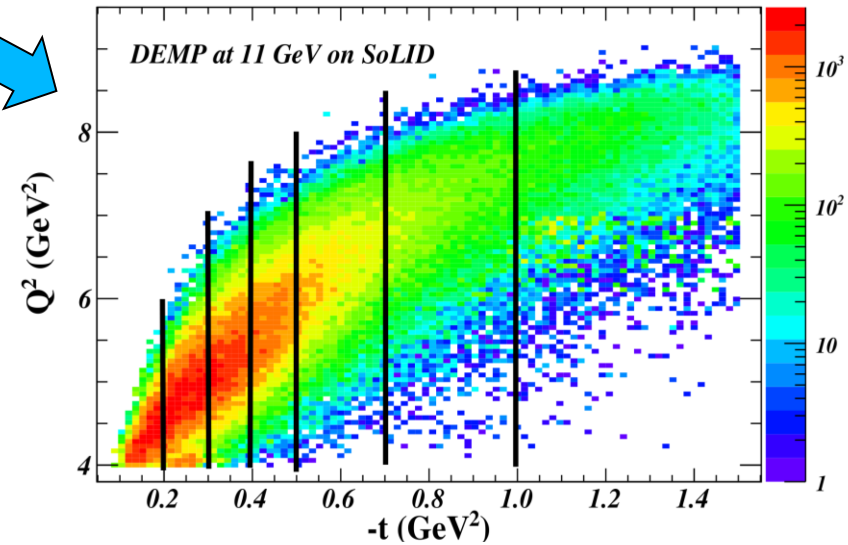
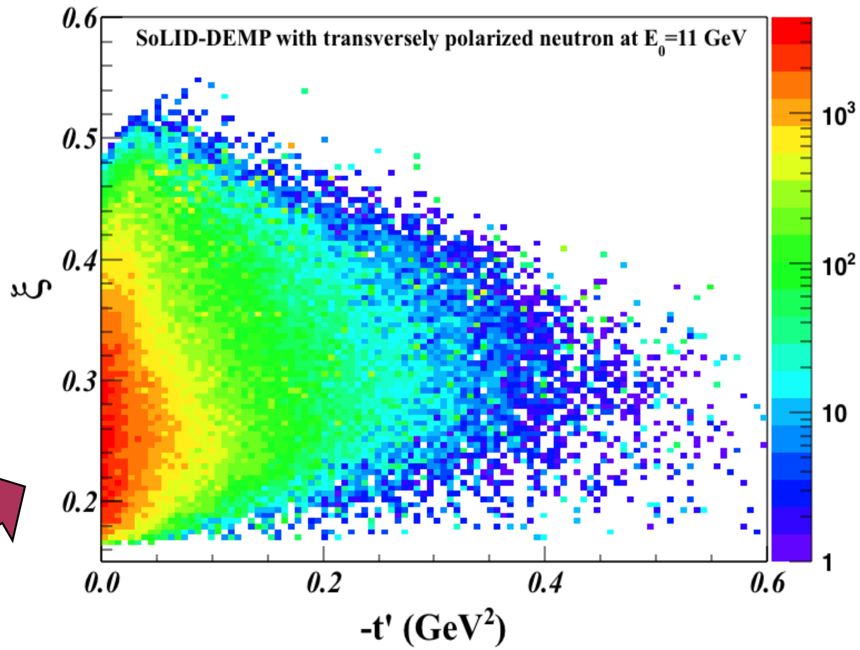
Kinematic Coverage and Binning

- **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.**





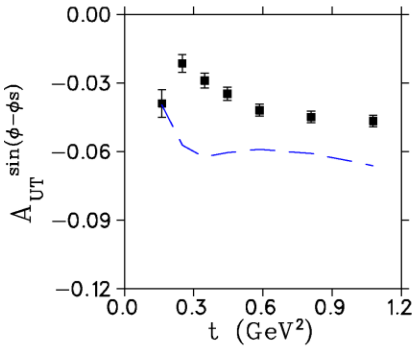
Garth Huber, huberg@uregina.ca

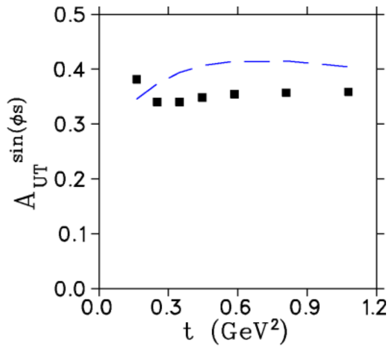
E12–10–006B Projected Uncertainties

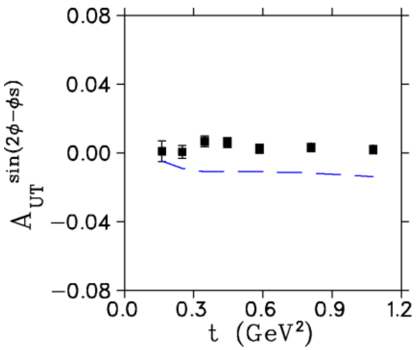
Garth Huber, huberg@uregina.ca

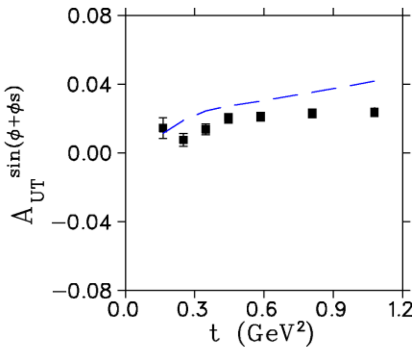
All effects on.

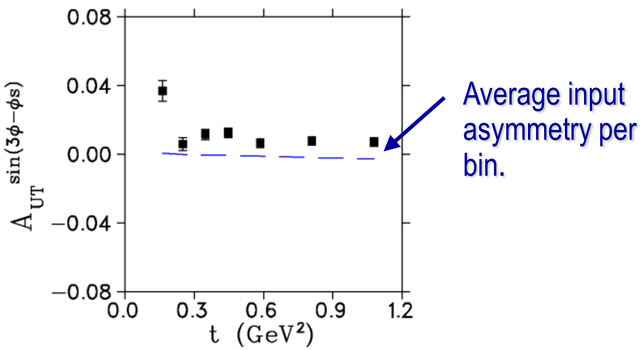
Includes all scattering, energy loss, resolution and Fermi momentum effects.





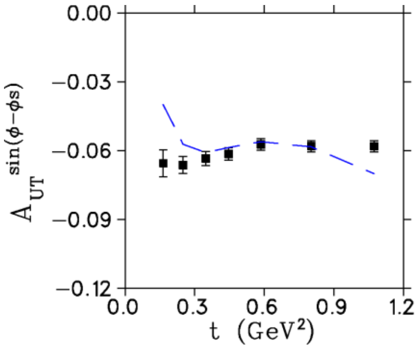


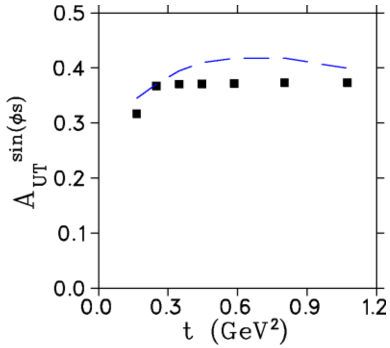




Only Fermi momentum off.

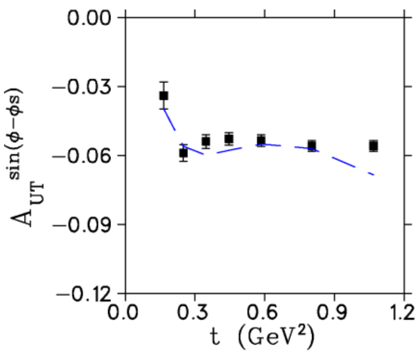
Includes all scattering, energy loss, resolution effects. Similar to where proton resolution is good enough to correct for Fermi momentum effects.

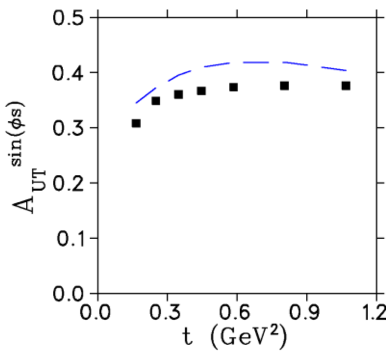




All effects off.

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





Summary

- $A_{UT}^{\sin(\varphi-\varphi_s)}$ transverse single–spin asymmetry in exclusive π production is particularly sensitive to the spin–flip GPD $\tilde{E}$. Factorization studies indicate precocious scaling to set in at moderate Q^2~2-4 GeV^2, while scaling is not expected until Q^2>10 GeV^2 for absolute cross section.
- $A_{UT}^{\sin(\varphi_s)}$ asymmetry can also be extracted from same data, providing powerful additional GPD–model constraints and insight into the role of transverse photon contributions at small $-t$, and over wide range of ξ.
- **High luminosity and good acceptance capabilities of SoLID make it well–suited for this measurement. It is the only feasible manner to access the wide –*t* range needed to fully understand the asymmetries.**
- **SoLID measurement is also important preparatory work for EIC.**

Garth Huber, huberg@uregina.ca