The Longitudinal Photon, Transverse Nucleon, Single-Spin Asymmetry in Exclusive Pion Production

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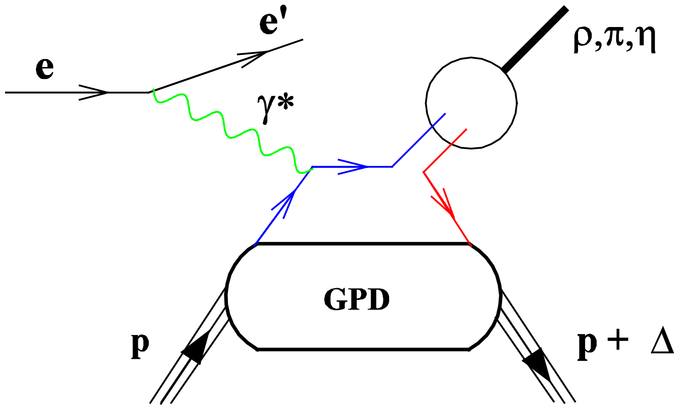
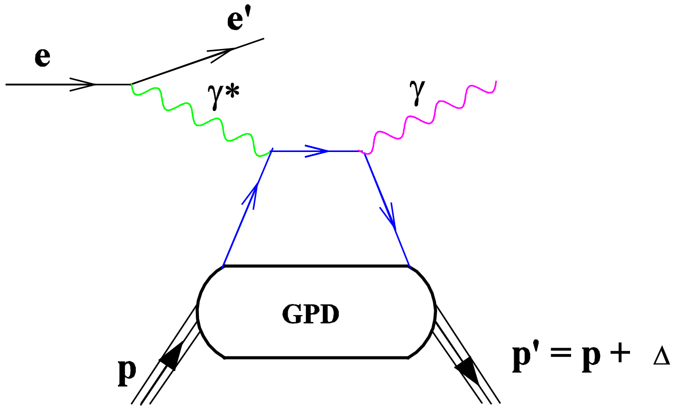
Complementarity of Different Reactions

Deep Exclusive Meson Production:

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





Deeply Virtual Compton Scattering:

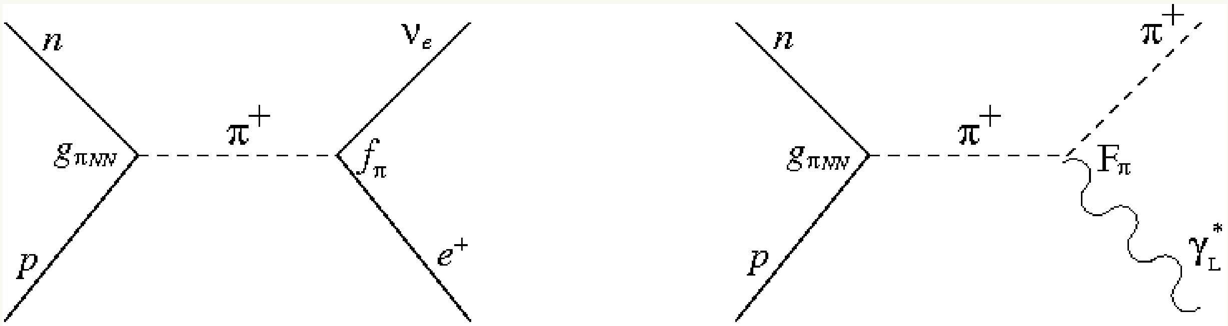
- Sensitive to all four GPDs.

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

Spin-flip GPD $\tilde{E}$

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

- $G_P(t)$ is highly uncertain because it is negligible at the momentum transfer of β-decay.
- **Because of PCAC, $G_P(t)$ alone receives contributions from $J^{PG}=0^{--}$ states.**
  - **These are the quantum numbers of the pion, so $\tilde{E}$ contains an important pion pole contribution.**



Pion pole contribution to $G_P(t)$

Pion pole contribution to meson electroproduction at low –t.

For this reason, a pion pole-dominated ansatz is typically assumed:

$$\tilde{E}^{u,d}(x,\xi,t) = F_\pi(t)\frac{\theta(\xi > |x|)}{2\xi}\phi_\pi\left(\frac{x+\xi}{2\xi}\right)$$

where F_π is the pion FF and φ_π the pion PDF.

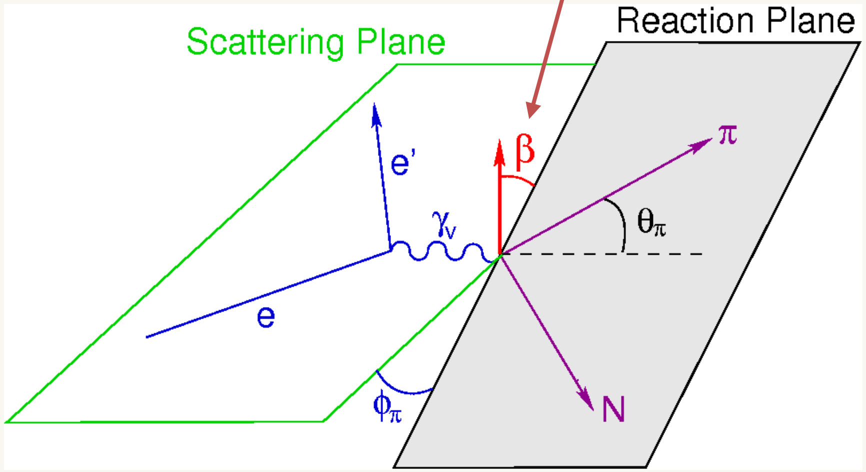
How to determine $\tilde{E}$

- **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:**

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

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

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



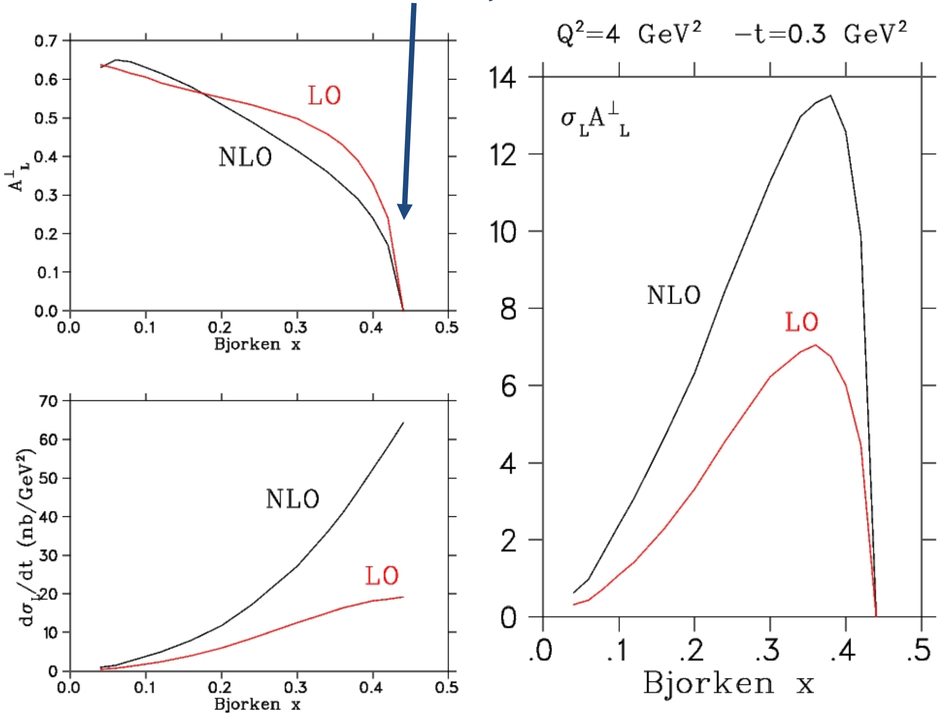
Single Spin Asymmetry in Exclusive π Production

- **Frankfurt et al. have shown $A_L^{\perp}$ vanishes if $\tilde{E}$ is zero** [PRD 60(1999)014010].
  - **If $\tilde{E} \neq 0$, the asymmetry will display a *sinβ* dependence.**
- They also argue that precocious factorization of the π production amplitude into three blocks is likely:
  1. overlap integral between γ, π wave functions.
  2. the hard interaction.
  3. the GPD.
  - **Higher order corrections, which may be significant at low Q^2 for σ_L, likely cancel in $A_L^{\perp}$.**
- **$A_L^{\perp}$ expected to display precocious factorization at moderate Q^2~2-4 GeV^2.**

Cancellation of Higher Twist Corrections in $A_L^{\perp}$

- **Belitsky and Müller GPD based calc. reinforces this expectation:**
  - At Q^2=10 GeV^2, NLO effects can be large, but cancel in $A_L^{\perp}$ (PL **B513**(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 P_y 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.

Implications for Pion Form Factor Experiments

- **The study of $A_L^{\perp}$ is also important for the reliable extraction of F_π from $p(e,e'\pi^+)n$ data at high Q^2** [Frankfurt, Polyakov, Strikman, Vanderhaeghen PRL **84**(2000)2589].
  - Non-pion pole contributions need to be accounted for in some manner in order to reliably extract F_π from σ_L data at low $-t$.
  - "A-rated" 12 GeV Pion Form Factor experiment restricted to $Q^2=6$ GeV^2 by need to keep non-pole contributions to an acceptable level ($-t_{min}<0.2$ GeV^2).
  - Hall C instrumentation and beam will allow $Q^2=8.3$ GeV^2 F_π measurements if higher $-t$ region is better understood.

- **$A_L^{\perp}$ is an interference between pseudoscalar and pseudovector contributions.**
  - **Help constrain the non-pole contribution to $p(e,e'\pi^+)n$.**
  - **Assist the more reliable extraction of the pion form factor.**
  - **Possibly extend the kinematic region for F_π measurements.**

Measurement of $A_L^{\perp}$

$$A_L^{\perp} = \frac{1}{P_{\perp}} \frac{2}{\pi} \frac{2\sigma_L^y}{\sigma_L}$$

- At very high Q^2, σ_T suppressed by $1/Q^2$ compared to σ_L.
- At JLab energies, can't ignore contributions from transverse photons.
  - Require two Rosenbluth separations and ratio of longitudinal cross sections:

$$\sigma_A = \sigma_T^{\perp} + \varepsilon \sigma_L^{\perp}$$

$$\sigma_U = \sigma_T + \varepsilon \sigma_L$$

where $\sigma(\varepsilon) = \sigma_U + \sigma_A \sin\beta + \ldots$

To cleanly extract $A_{\perp}$, we need:

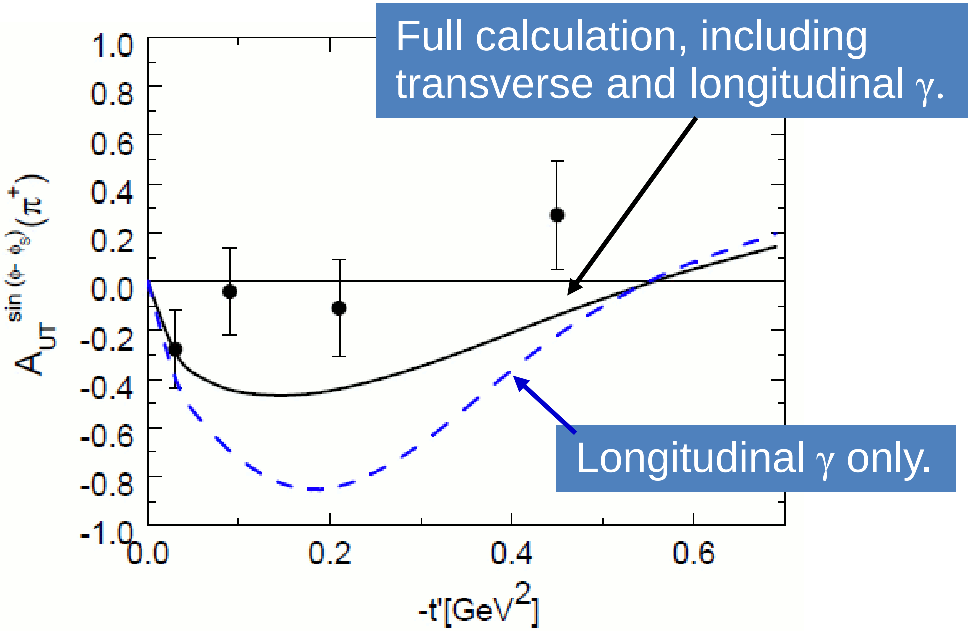
- Target polarized transverse to γ^* direction.
- Large acceptance in π azimuthal angle (i.e. φ, β).
- Measurements at multiple beam energies and electron scattering angles.

  → ε dependence (L/T separation).

  → controlled systematic uncertainties (L/T separation).

HERMES Transverse Spin Asymmetry

- Exclusive π+ production by scattering 27.6 GeV positrons or electrons from transverse polarized ^{1}H **without L/T separation.**
  [PLB **682**(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.



- 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 simply interpreted in terms of GPDs.**
- Without L/T separation, at JLab the asymmetry dilution is expected to be a similar percentage.

Possible roles of SoLID and SHMS+HMS Expts

SHMS+HMS:

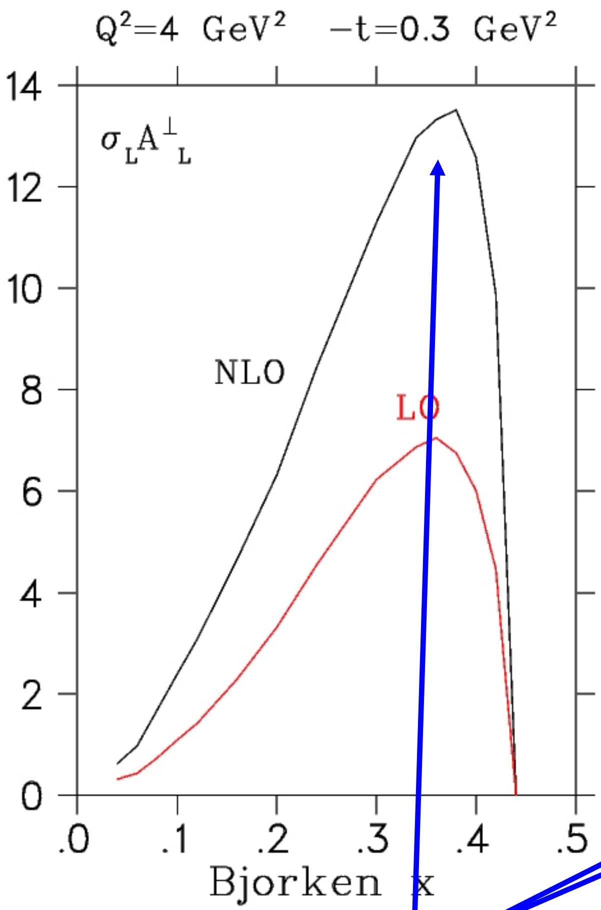
- HMS detects scattered e'.

  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^{o} 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.**

SoLID:

- Complete azimuthal coverage (for π) up to θ=24^{o}.
- High luminosity, particle ID and vertex resolution capabilities well matched to the experiment.
- Need to better understand:
  - Expected missing mass resolution.
  - Expected systematic uncertainties in L/T separation.
- **If L/T separation possible**, this is a likely `A' rated experiment.
- **If L/T separation not possible**, measurement still valuable to obtain $A^{\perp}$ over a wide kinematic range, complementary to Hall C.

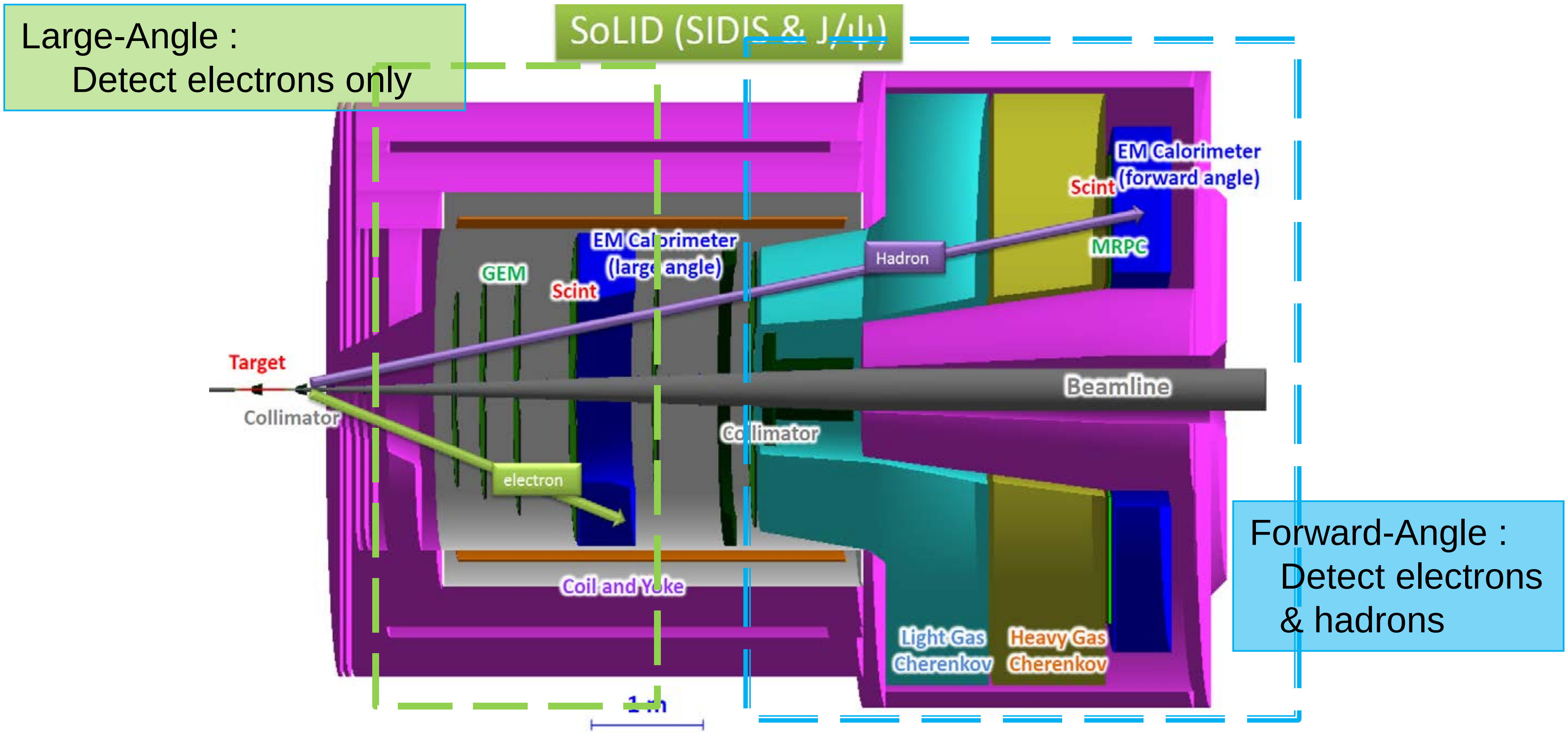
SHMS+HMS PR12-12-005 Kinematics



Near peak of
Figure of Merit in
Belitsky's calculation

n(e,e'π-)p Kinematics						
E_{beam}	$E_{e'}$	$\theta_{e'}$	ε	θ_q	p_π	$\Theta_{\pi q}$
MAIN Q^2=4.0 W=2.6 x=0.40 $-t_{min}$=0.22						
6.60	1.34	39.2	0.33	-8.7	5.14	0, +2.5
10.92	5.66	14.6	0.79	-14.7	5.14	0, ±2.5
SCALING Q^2=3.0 W=2.3 x=0.40 $-t_{min}$=0.22						
6.60	2.66	23.9	0.64	-14.5	3.82	0, ±2.5
10.92	6.98	11.4	0.89	-18.7	3.82	0, ±2.5
NON-POLE Q^2=4.0 W=2.25 x=0.50 $-t_{min}$=0.39						
6.60	2.66	29.3	0.57	-14.3	4.03	0, ±2.5
10.9	6.69	13.4	0.87	-19.4	4.03	0, ±2.5

SoLID-SIDIS Configuration



Coverage: →Forward Acceptance: ϕ : 2π, θ: 8°-14.8° , P: 1.0 – 7.0 GeV/c,
→Large Acceptance: ϕ : 2π, θ: 16°-24° , P: 3.5 – 7.0 GeV/c

Resolution: δP/P ~ 2%, θ ~ 0.6mrad, Φ ~ 5mrad

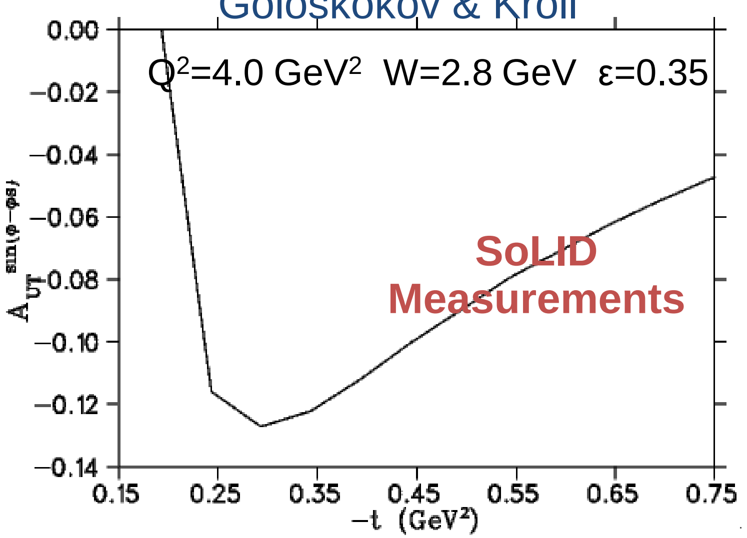
Coincidence Trigger:

Electron Trigger + Hadron Trigger (pions, and maybe kaons)

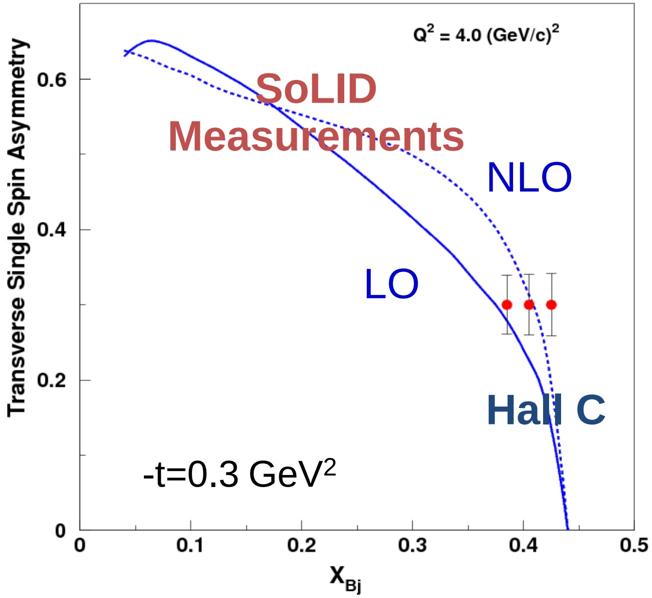
Projected Asymmetries vs $-t$, x_B

- **$A_L^{\perp}$ vanishes in parallel kinematics, grows at larger $\theta_{\pi q}$.**
- SoLID measurements access larger $-t$ at fixed x, or alternately smaller x at fixed $-t$.
- ***-t* dependence from $-t_{min}$ to ~1 GeV^2 is particularly important to constrain non-pion pole background studies for future F_π extraction at higher *-t*.**

Unseparated $A^{\perp}$
Goloskokov & Kroll



Separated $A_L^{\perp}$
Belitsky & Müller



Hall C errors include statistical and uncorrelated systematic uncertainties and assume $\sigma_L/\sigma_T=1$ and ^3He target polarization of 65%.