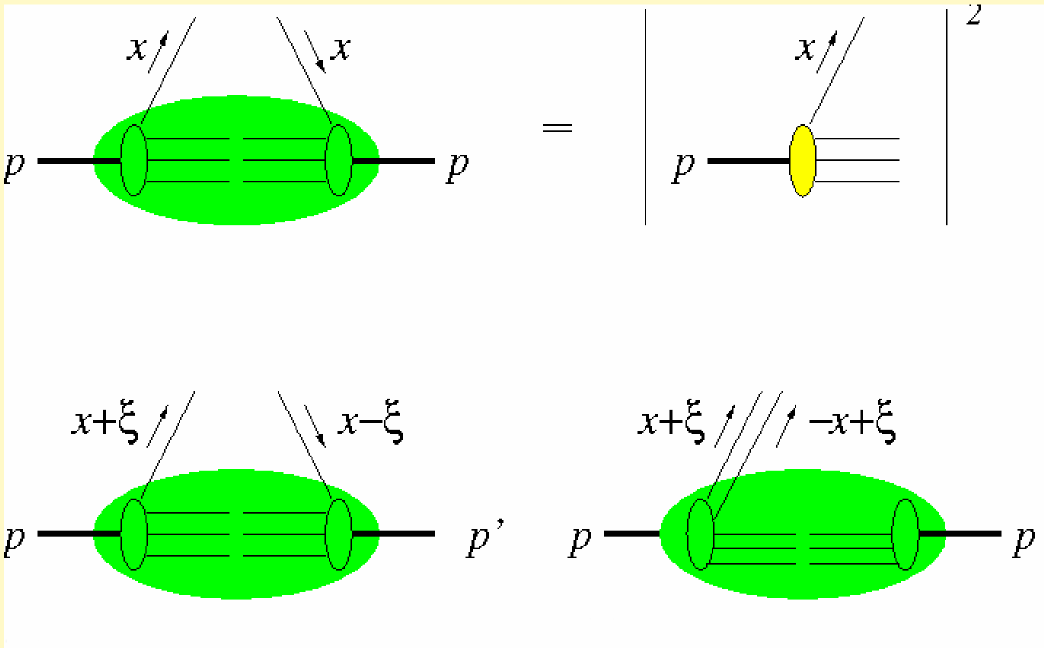
Transverse Target Asymmetry in Exclusive Charged Pion Production at 11 GeV

Garth Huber, *University of Regina*
Dipangkar Dutta, *Mississippi State*
Dave Gaskell, *Jefferson Lab*

Hall C Summer Workshop, Jefferson Lab, August 27, 2010.

Generalized Parton Distributions

Over the last decade, tremendous progress has been made on the theory of generalized parton distributions (GPD).

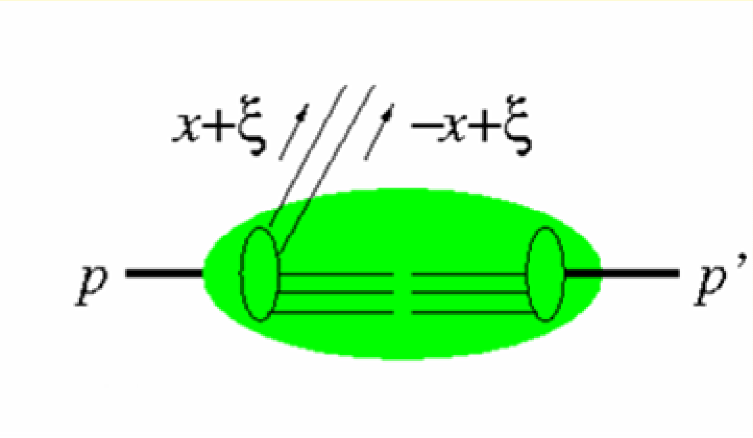


PDFs : **Squared hadronic wavefunctions = probability of finding a parton with specified longitudinal momentum fraction and polarization in fast moving hadron.**

GPDs : **interference between wavefns of parton with momentum fraction x+ξ and parton with momentum fraction x-ξ.**

- In addition to x and ξ, GPDs depend also on $t=-(p-p')^2$.
  - t is independent of x, ξ since p, p' may differ in either their longitudinal or transverse components.
- **GPDs interrelate the longitudinal and transverse momentum structure of partons within a fast moving hadron.**

GPDs in Deep Exclusive Meson Production

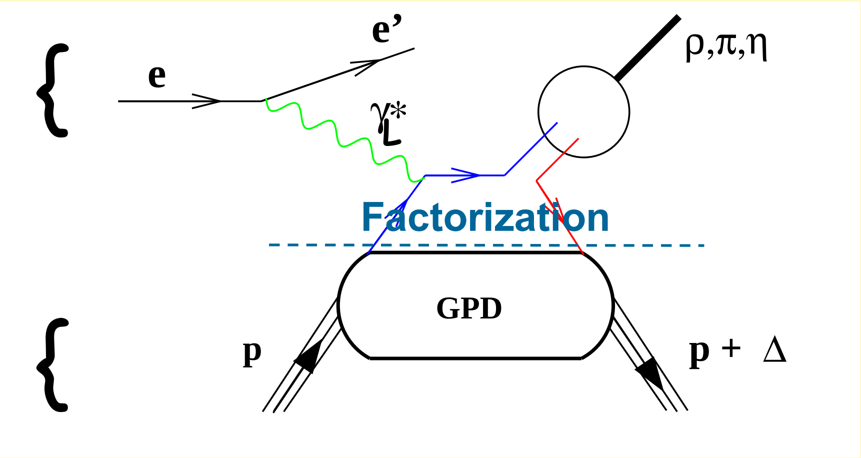


- A special kinematic regime is probed in deep exclusive meson production, where initial hadron emits a $q\bar{q}$ or gg pair.
- This has no counterpart in usual PDFs.
- Since GPDs correlate different parton configurations in the hadron at the quantum mechanical level,
  - GPDs determined in this regime carry information about $q\bar{q}$ and gg-components in the hadron wavefunction.

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^*.

Leading Twist GPD Parameterization

- **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

Leading order QCD predicts:

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

Links to other nucleon structure quantities

- First moments of GPDs are related to nucleon elastic form factors through model-independent sum rules:

$$\sum_q e_q \int_{-1}^{+1} dx\, H^q(x,\xi,t) = F_1(t)$$

$$\sum_q e_q \int_{-1}^{+1} dx\, E^q(x,\xi,t) = F_2(t)$$

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

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

Isovector axial form factor. *t* –dep. poorly known.

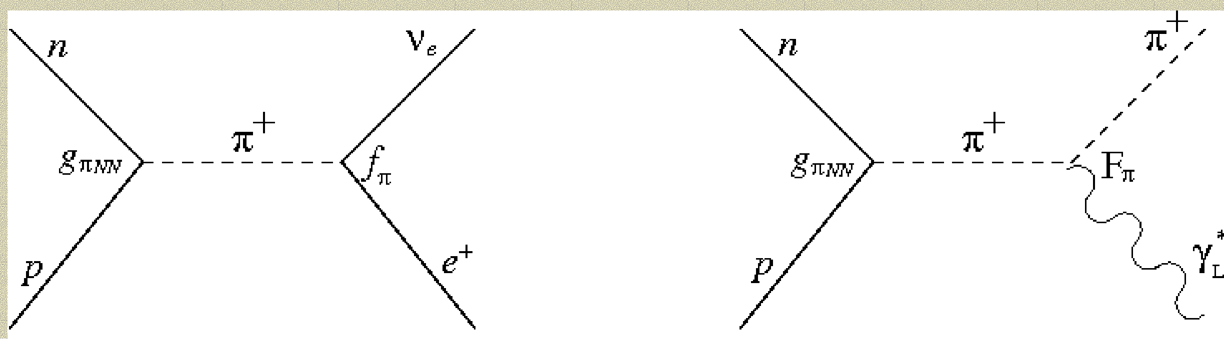
$$\sum_q e_q \int_{-1}^{+1} dx\, \tilde{E}^q(x,\xi,t) = G_P(t)$$

Pseudoscalar form factor. Very poorly known.

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.

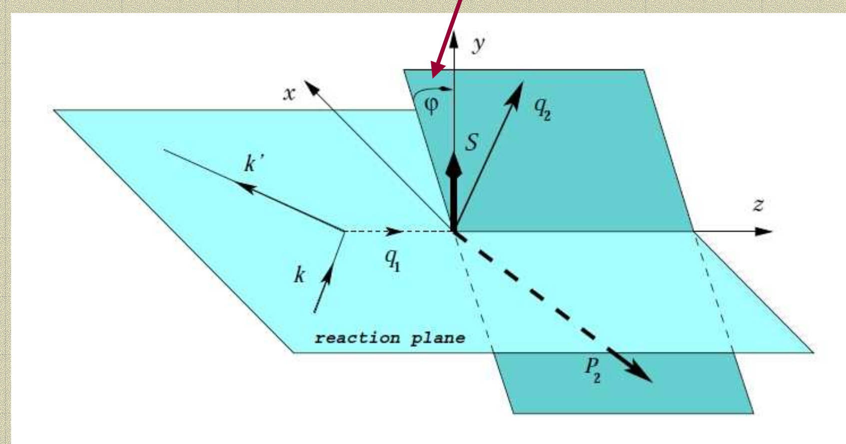
How to determine $\tilde{E}$

- **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

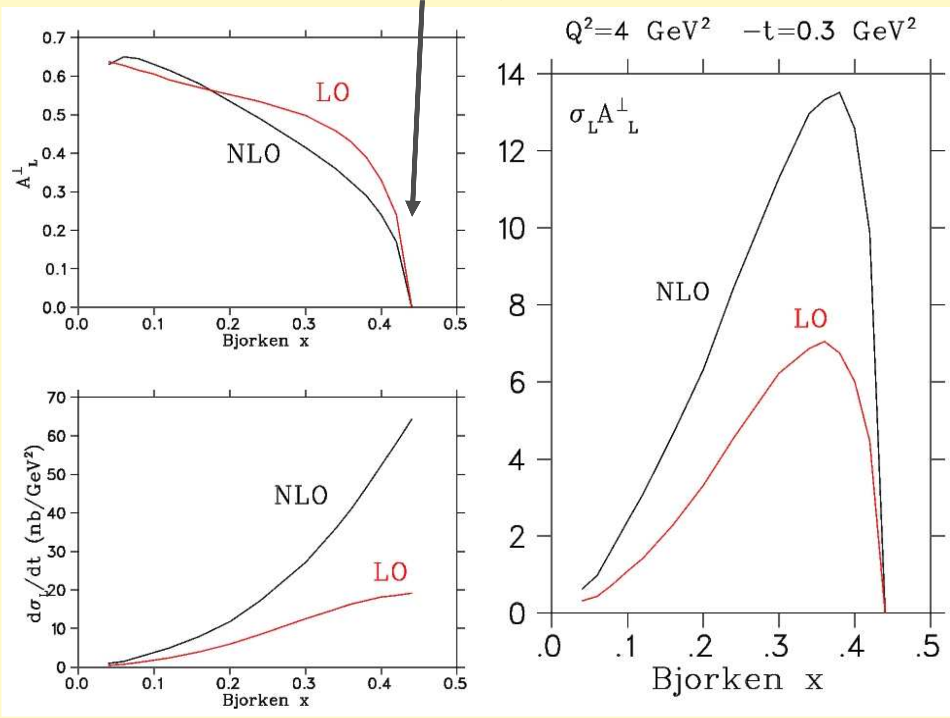
- Frankfurt et al. [PRD **60**(1999)014010] have shown the $A_L^{\perp}$ asymmetry vanishes if $\tilde{E}$ is zero.
  - If $\tilde{E} \neq 0$, the asymmetry will display a *sinβ* dependence.

- $A_L^{\perp}$ is also expected to display precocious factorization at moderate Q^2~2-4 GeV^2.
  - 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, likely cancel in the asymmetry ratio.**

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

- Belitsky and Müller GPD based calc. reinforces this expectation:
  - Even at Q^2=10 GeV^2, NLO effects can be large, but cancel in the asymmetry, $A_L^{\perp}$ (PL **B513**(2001)349).
  - At Q^2=4 GeV^2, higher twist effects even larger in σ_L, but still cancel in 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.

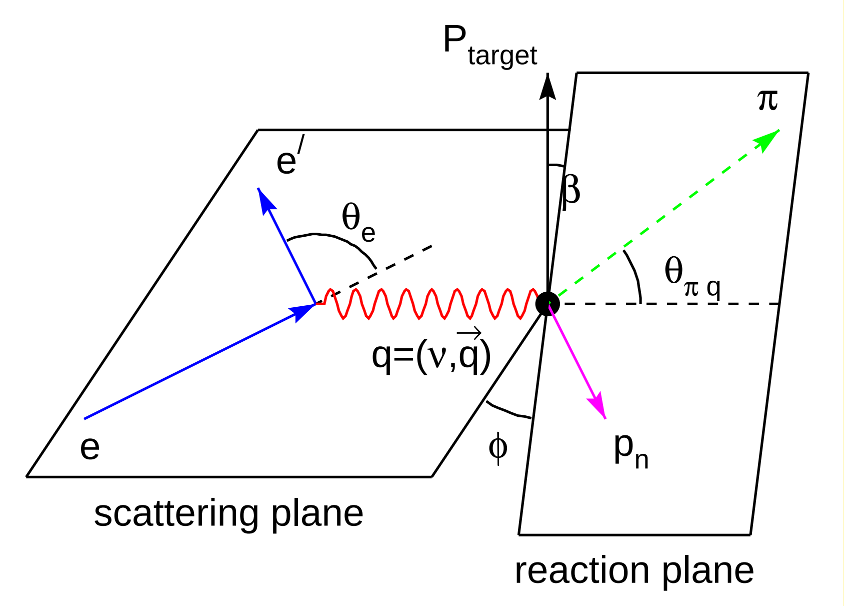
L/T Separations Essential

- In hard meson electroproduction, factorization can only be applied to **longitudinal photons**.
- Unlike other ongoing or proposed experiments, where dominance of longitudinal contribution is simply assumed, JLab's unique contribution to this field is in:
  - ability to take measurements at multiple beam energies.
  - unambiguous isolation of $A_L^{\perp}$ using Rosenbluth separation.
- **A JLab $A_L^{\perp}$ measurement could thus establish the applicability of the GPD formalism, and precocious scaling expectations, for other $A^{\perp}$ experiments.**

Require Target Polarization Parallel to $\hat{q} \times \hat{p}_\pi$

- **Target polarization components (P_x, P_y) are defined relative to reaction plane.**
- **β = azimuthal angle between (transverse) target polarization and reaction plane**

  $P_x = P_\perp \cos\beta$ and $P_y = P_\perp \sin\beta$
- $P_y \parallel \hat{q} \times \hat{p}_\pi$ **uniquely defined only in non-parallel kinematics.**



Unpolarized Cross section

$$\frac{d\sigma}{d\Omega} = \sigma_T + \epsilon\sigma_L + \sqrt{\frac{1}{2}\epsilon(\epsilon+1)}\sigma_{LT}\cos\phi + \epsilon\sigma_{TT}\cos 2\phi$$

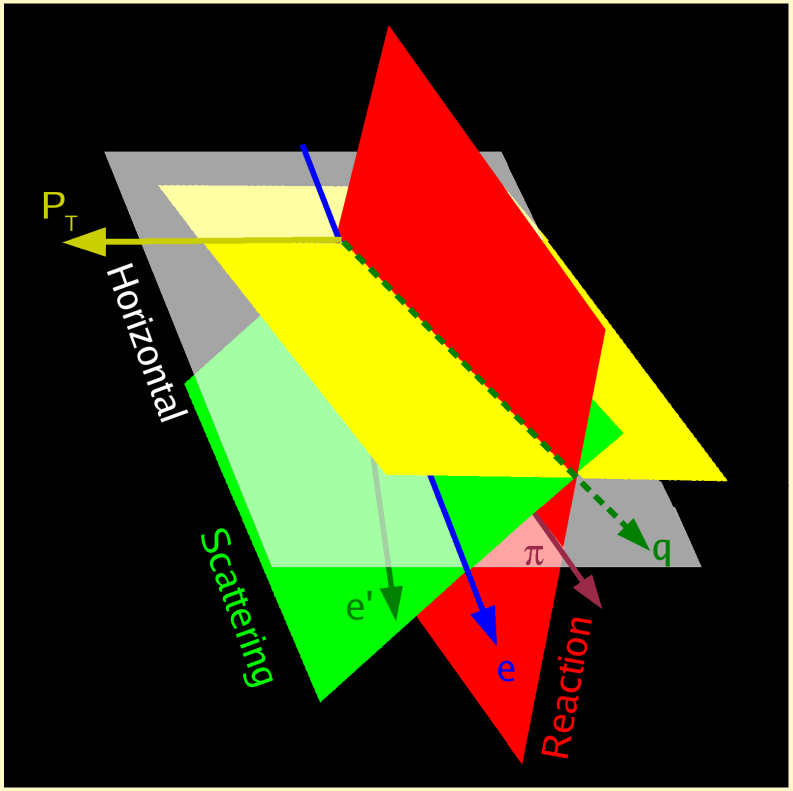
$$A_\perp = \frac{1}{P_\perp}\frac{2}{\pi}\frac{2\sigma_L^y}{\sigma_L}$$

$$\sigma_t = P_x\left[-\sqrt{2\epsilon(1+\epsilon)}\sin\phi\,\sigma_{LT}^x - \epsilon\sin 2\phi\,\sigma_{TT}^x\right]$$
$$-P_y\left[\sigma_{TT}^y + \epsilon\cos 2\phi\,\sigma_{TT'}^y + 2\epsilon\,\sigma_L^y + \sqrt{2\epsilon(1+\epsilon)}\cos\phi\,\sigma_{LT}^y\right]$$
$$+P_z\left[\epsilon\sin 2\phi\,\sigma_{TT}^z + \sqrt{2\epsilon(1+\epsilon)}\sin\phi\,\sigma_{LT}^z\right]$$

SHMS+HMS Kinematic Considerations

SHMS and HMS have their largest acceptances in vertical direction.

- Scattered e^- detected at some vertical angle in the HMS.
  - Forces scattering plane and q-vector to be non-horizontal.
- π^- is detected in SHMS.
  - Either above or below q-vector, depending if scattered e^- is detected above or below horizontal plane.
- Target polarization is horizontal, parallel to $\hat{q} \times \hat{p}_\pi$.
  - Nearly transverse to $\vec{q}$ for all angles between the scattering and reaction planes.



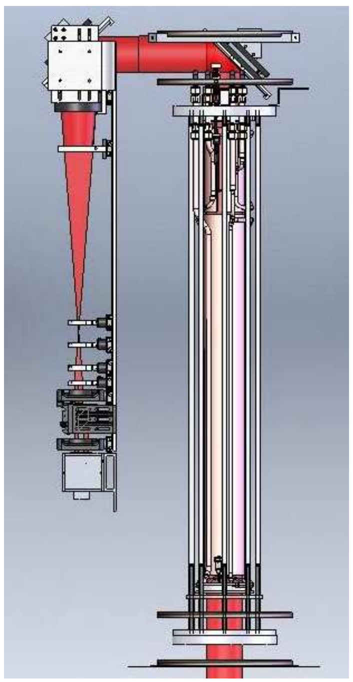
Dr. Garth Huber, Dept. of Physics, Univ. of Regina, Regina, SK S4S0A2, Canada.

High Luminosity Essential

- **Physics case for a measurement of $A_L^{\perp}$ is compelling.**
- High luminosity required:
  - σ_L is largest in parallel kinematics, where $A_L^{\perp}=0$.
  - σ_L is small where $A_L^{\perp}$ is maximal.
- We have performed numerous studies, but the measurement has not been feasible to date because of the lack of a polarized target that can handle the required high luminosity.
- Recent advancements in polarized ^3He target technology may allow the measurement to proceed via the $n(e,e'\pi^-)p$ reaction.

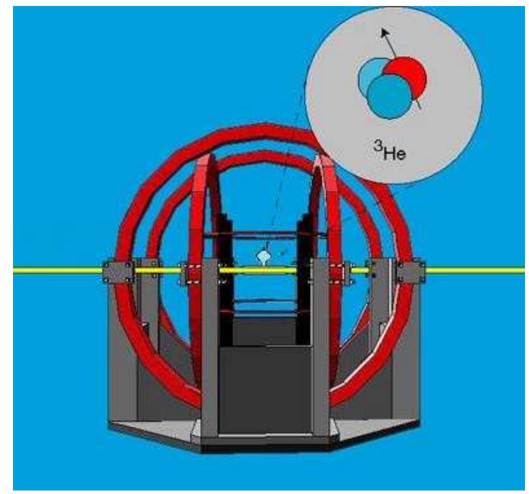
XeMed/UNH Target Loop Concept

- Compress polarized ^{3}He and deliver to 40cm long titanium target cell
- Commercial compressors achieve >3500 psi (238 bar)
- Requires compression ratio ~16, immersion in magnetic field, rubidium-free gas leaving polarizer, entrance and exit, <3% polarization loss



14 atm

200 atm



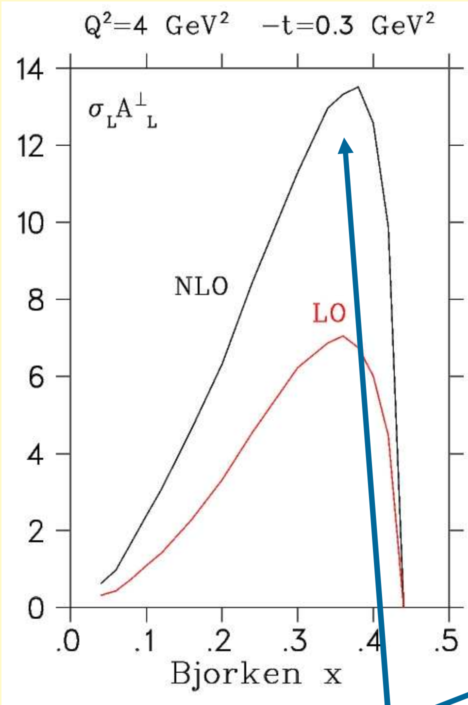
Requires two ports, entrance and exit

Recirculating at 1.0 scfm

1 cm x 40 cm titanium target cell
Getter purifier? RGA?

Property	Hall A	UNH
Polarization (%)	55	60
Beam Current (μA)	15	100
Pressure (atm)	10	200
Cell type	Glass/sealed	Ti/continuous flow
"Spin UP" time (h)	7	4
Beam Relaxation (h^{-1})	41	0.1
Laser Power (W)	150	1500-2500
Thickness (cm^{-2})	1.07E+22	1E+24
FOM **(*P^2L*)**	0.22E+36	0.55E+38

SHMS+HMS Kinematics



Near peak of Figure of Merit in Belitsky's calculation

n(e,e'π-)p Kinematics at Q^2=4.0GeV^2, W=2.8 GeV							
$E_{e'}$ (GeV)	$\theta_{e'}$ (deg)	p_π (GeV/c)	θ_π (deg)	$\Theta_{\pi q}$ (deg)	-t (GeV^2)	x	z
High ε=0.745 Setting, E_{beam}=11.00 GeV							
5.160	15.25	5.744	-12.70	0	0.175	0.365	0.984
		5.666		±3	0.322	0.365	0.970
		5.531		±5	0.576	0.365	0.947
Low ε=0.200 Setting, E_{beam}=6.60 GeV							
0.860	49.23	5.744	-6.06	0	0.175	0.365	0.984
		5.666		±3	0.322	0.365	0.970
		5.531		±5	0.576	0.365	0.947

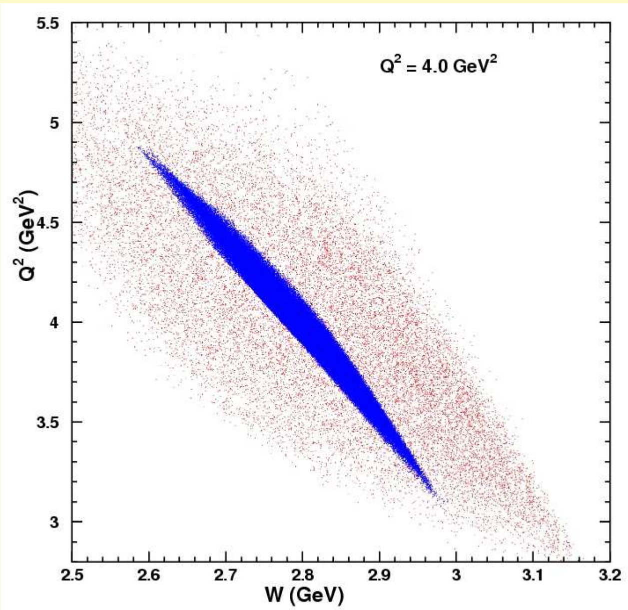
- Scattered electron in HMS, π^- in SHMS.
- $\Theta_{\pi q}$ is π^- lab angle wrt $\vec{q}$, mostly above or below scattering plane.
- For Q^2=4 GeV^2, x=0.365 → $-t_{max} \approx 1-(M^2x^2/Q^2)$=0.97 GeV^2.

Dr. Garth Huber, Dept. of Physics, Univ. of Regina, Regina, SK S4S0A2, Canada.

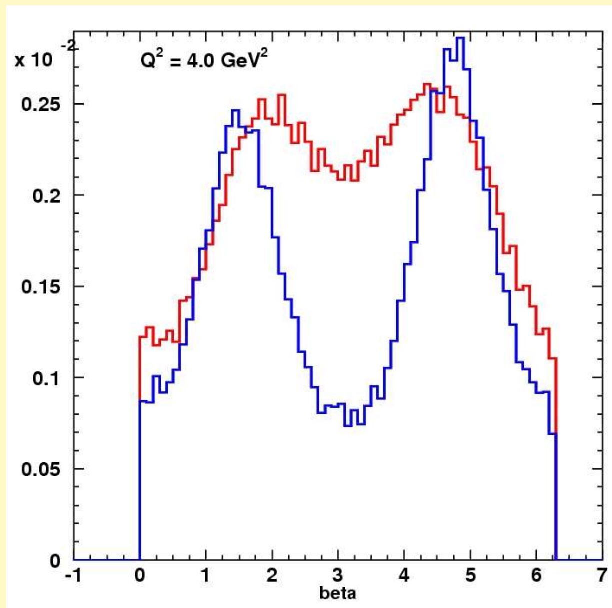
Simulated SHMS+HMS Acceptance

n(e,e’π)p

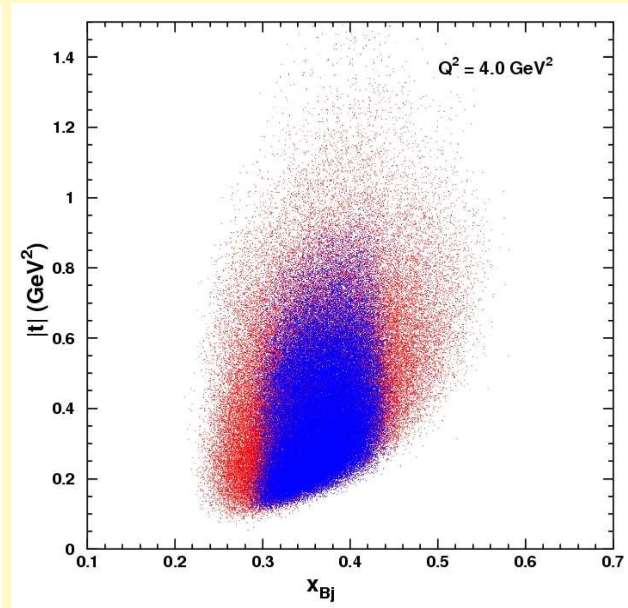
low ε   high ε   Δε = 0.55



Q^2-W acceptance at high and low ε.

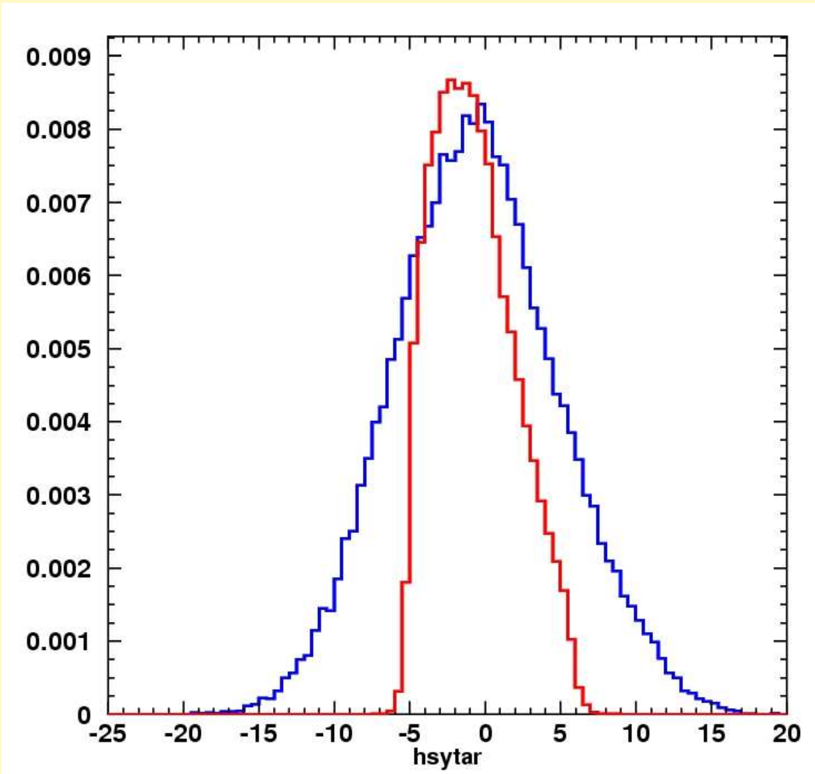


Azimuthal angle of (transversely) polarized target wrt hadron reaction plane.



SHMS+HMS acceptance covers $0.1<-t<0.7$ GeV^2 at nearly fixed x_{Bj}.

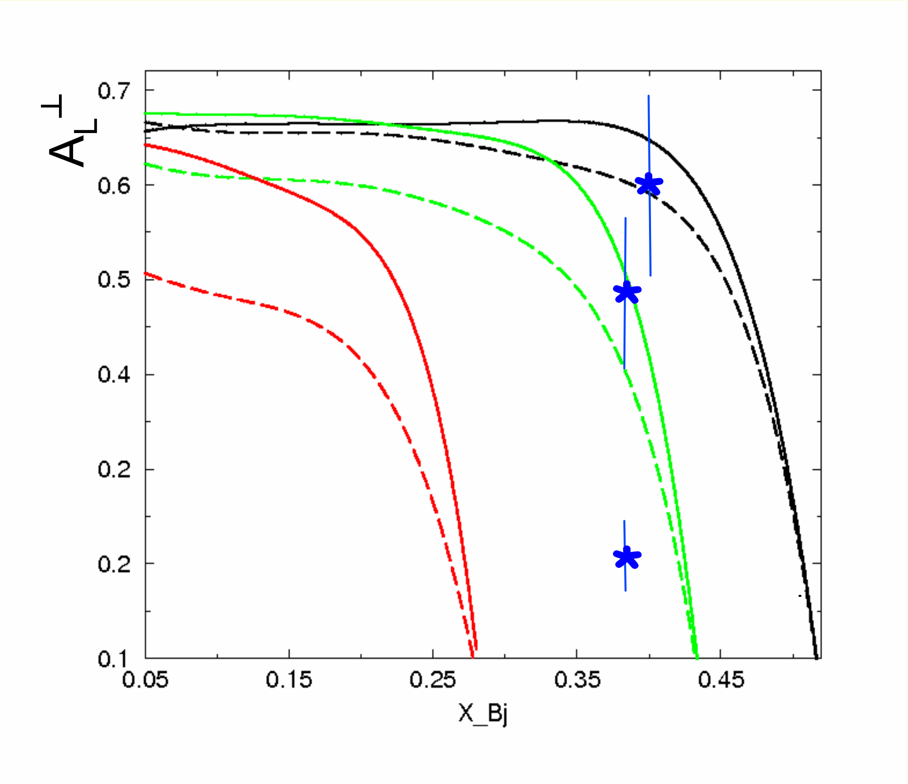
Reliable L/T Separations require shorter ^{3}He cells



low ε   high ε   Δε = 0.55

- For reliable L/T separations, an 8cm ^{3}He cell seems optimal.
- The UNH target is designed for nominal 40cm cells, but Bill Hersman does not believe shorter cells will cause any problem.
- In fact, by cooling the entrance and exit lines of the cell with LN_2 he believes he can reduce the wall thickness by ~x3 or increase the pressure while keeping the wall thickness same.
- These issues need closer investigation to better understand target cell backgrounds for UNH target.

Estimated Rates and Uncertainties



Solid: asymptotic pion distribution amp.
Dashed: CZ pion dist. amp.

t = -0.5 GeV²
t = -0.3 GeV²
t = -0.1 GeV²

- Simulated error bars after 18 days:
  - 12days @low ε, 5k evts in largest –t bin.
  - 6days @high ε, 30k evts in largest –t bin.
- Luminosity=$1.2 \times 10^{37}/cm^2/s$ (8cm tgt).
- P_{targ}=65% → P_n=55.3%.
  - No target dilution since exclusive π^- can be only from neutron.
- 2% random systematic uncertainties
  - slightly larger than assumed for Fpi-12.
- σ_L/σ_T values similar to pionCT ^{1}H data.

Q²=4.0, W=2.8, x=0.365			
-t (GeV^2)	R= σ_L/σ_T	$A_L^\perp$	$\delta A_L^\perp$
0.2	1.0	0.2	0.04
0.4	1.0	0.5	0.08
0.6	1.5	0.6	0.10

Summary

PAC24 Comments on our 2003 6 GeV LOI:

- The experiment is extremely challenging since it requires first the isolation of a Fourier component in the polarized target cross section and then, by Rosenbluth techniques, the separation of the cross section for longitudinally polarized photons.
- The measurement may allow for an extraction of further information on GPDs and is complementary to DVCS. Deep virtual electroproduction of pions is sensitive only to the GPDs $\tilde{H}$ and $\tilde{E}$; H and E do contribute.
- Moreover, since the asymmetry requires proton helicity flip, the experiment may allow the extraction of $\tilde{E}$, one of the two GPDs not constrained by knowledge of ordinary parton distributions. The measurement is therefore very important.
- **The lack of a transversely polarized cryotarget that can handle the required high luminosity has precluded our development of this experiment since 2003.**
- **A transversely polarized ^{3}He target based on the UNH design offers the best hope of measuring this observable.**