Deep Exclusive Meson Production at Jefferson Lab Hall C

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CAP Congress, Université de Montréal, May 27, 2013.

Fundamental questions in hadron physics

1950-1960: Does the proton have finite size and structure?

- Elastic electron-proton scattering
  - ⇨ the proton is not a point-like particle but has finite size
    - ▪ charge and current distribution in the proton, G_E/G_M

Nobel prize 1961- R. Hofstadter

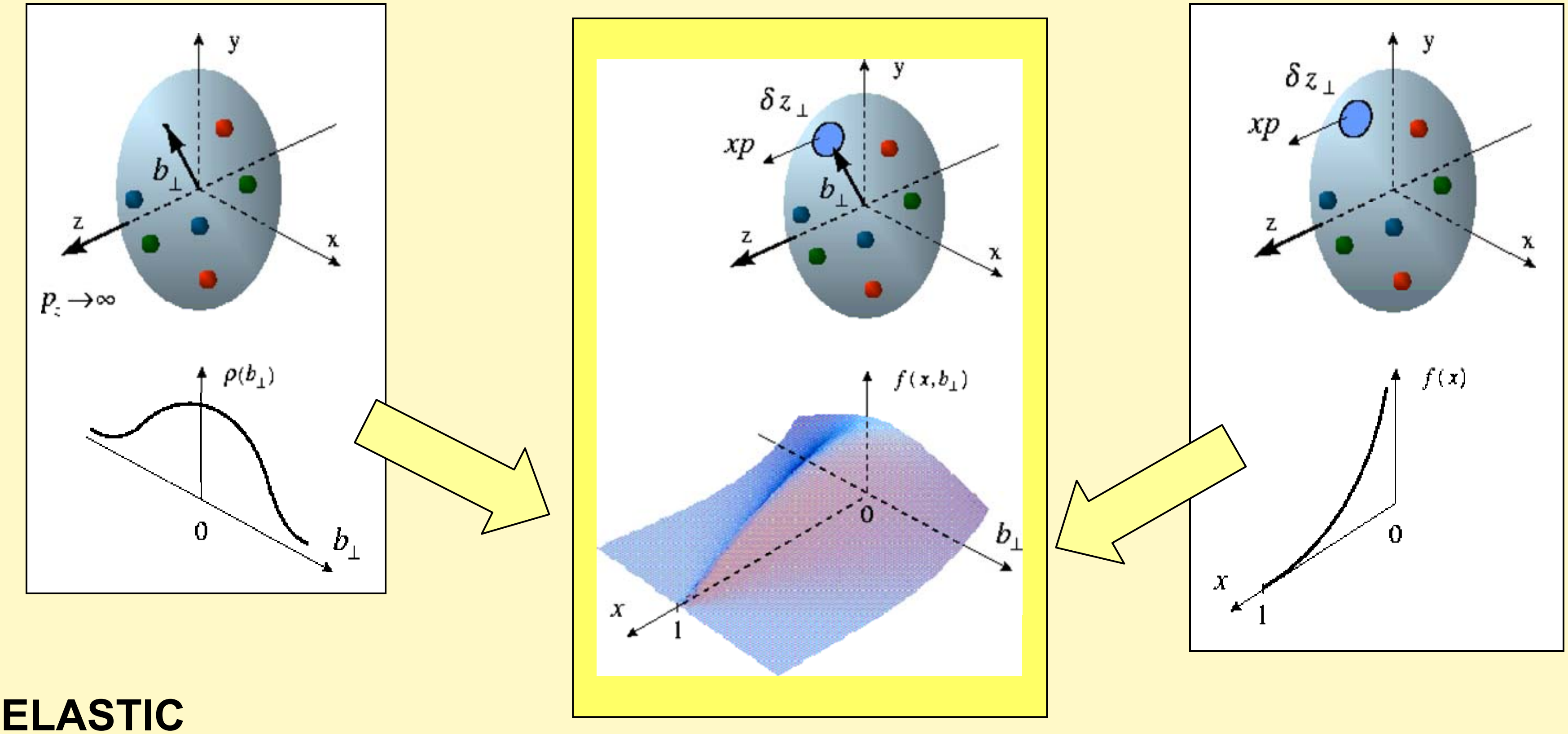
1960-1990: What are the internal constituents of the nucleon?

- Deep inelastic scattering
  - ⇨ discover quarks in ‘scaling’ of structure function and measure their momentum and spin distributions

Nobel prize 1990 - J. Friedman, H. Kendall, R. Taylor

Today: How are the nucleon’s charge & current distributions related to the quark momentum & spin distributions?

Beyond form factors and quark distributions – Generalized Parton Distributions (GPDs)



ELASTIC SCATTERING:
Proton form factors, transverse charge & current densities

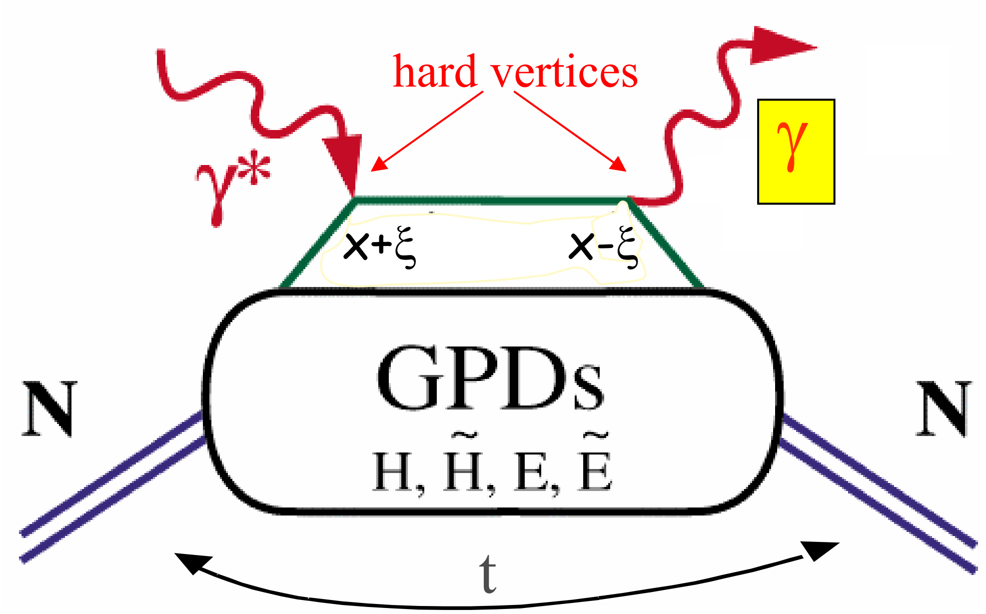
DEEP EXCLUSIVE SCATTERING:
Correlated quark momentum and helicity distributions in transverse space - GPDs

DEEP INELASTIC SCATTERING:
Structure functions, quark longitudinal momentum & helicity distributions

Explore GPDs via Deep Exclusive Processes

Reaction must proceed via “handbag” mechanism.

Deeply Virtual Compton Scattering (DVCS)



x – longitudinal quark momentum fraction

2ξ – longitudinal momentum transfer

$\sqrt{-t}$ – Fourier conjugate to transverse impact parameter

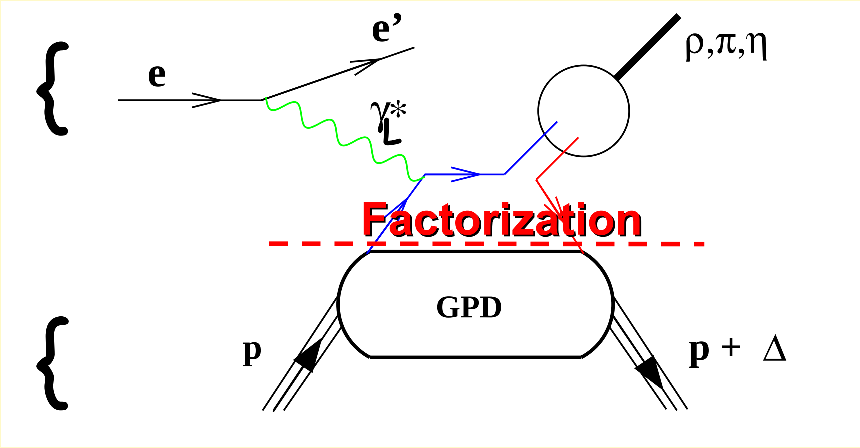
$H(x,\xi,t), E(x,\xi,t), \ldots$

$$\xi = \frac{x_B}{2-x_B}$$

GPD Studies require Hard Exclusive Reactions

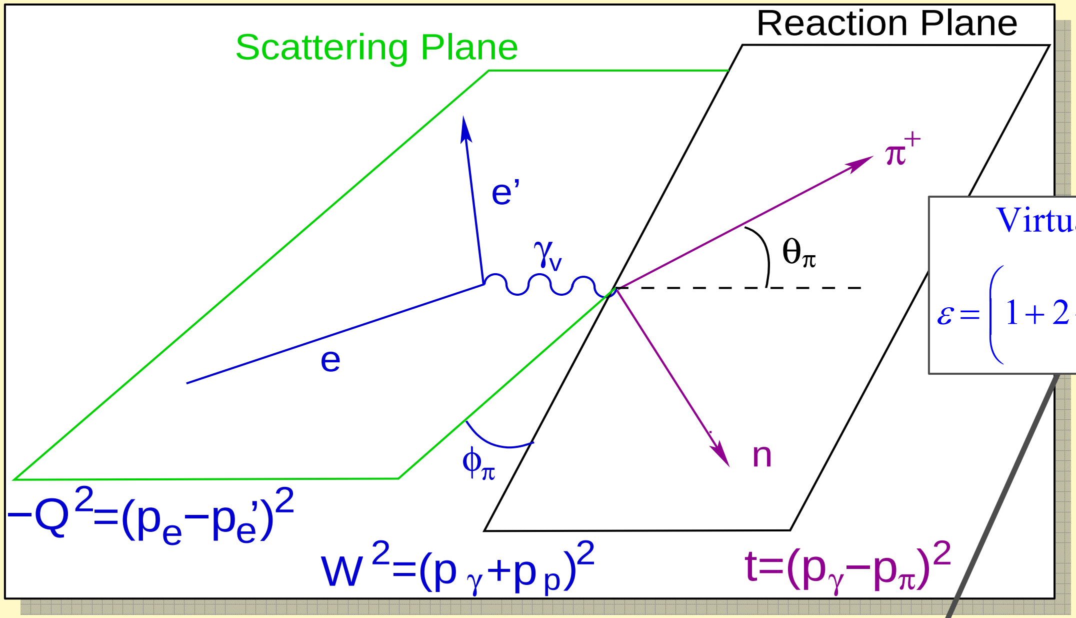
- In order to access the physics contained in GPDs, one is restricted to the hard scattering regime.
  - No single criterion for the applicability, but tests of necessary conditions can provide evidence that the Q^2 scaling regime has been reached.

- **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).



GPD Studies require Longitudinal Virtual Photons

- 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*.**

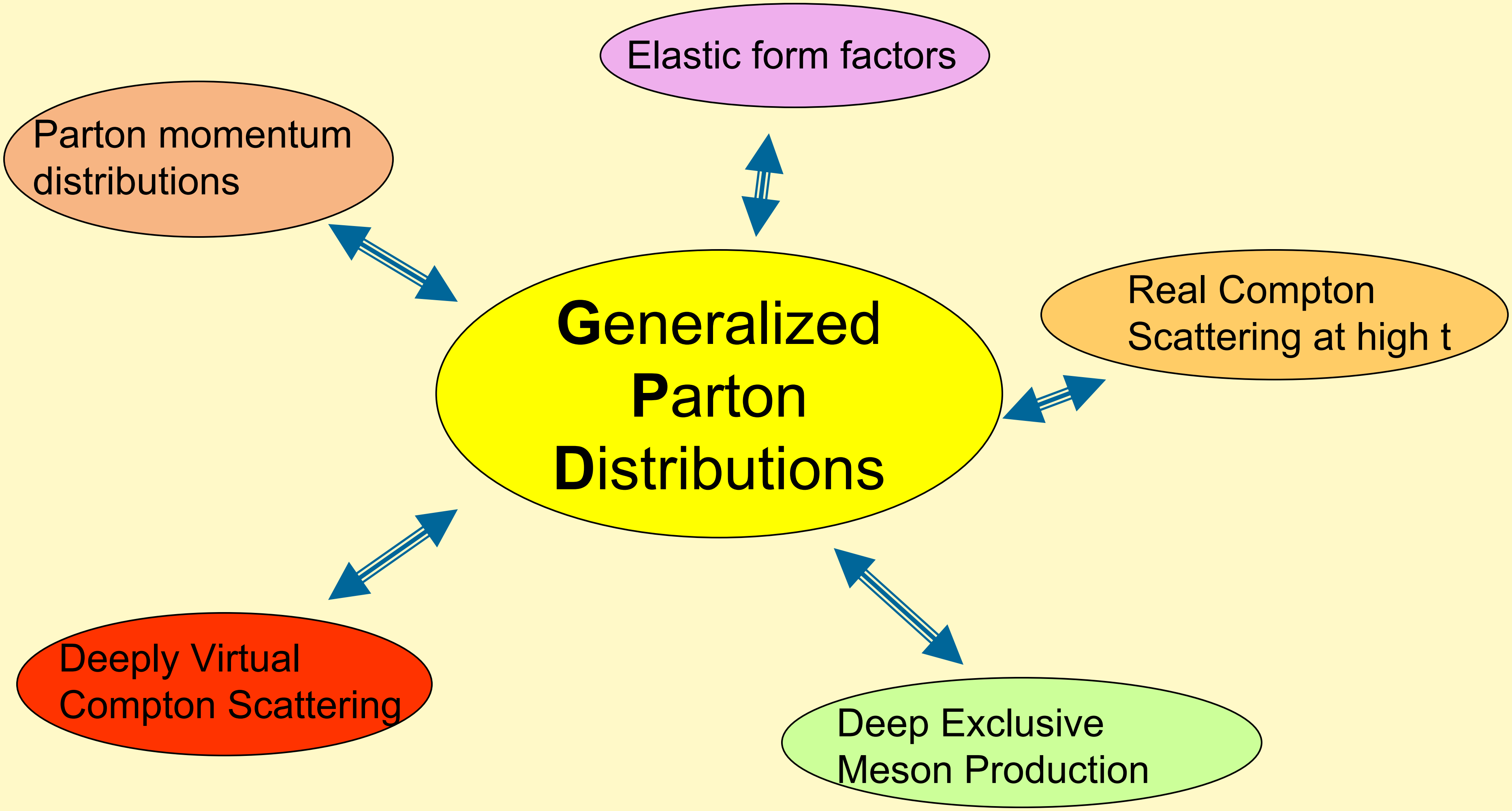


Virtual-photon polarization:

$$\varepsilon=\left(1+2\frac{(E_e-E_{e'})^2+Q^2}{Q^2}\tan^2\frac{\theta_{e'}}{2}\right)^{-1}$$

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

GPDs - A Unified Description of Hadron Structure



Elastic form factors

Parton momentum distributions

Generalized **P**arton **D**istributions

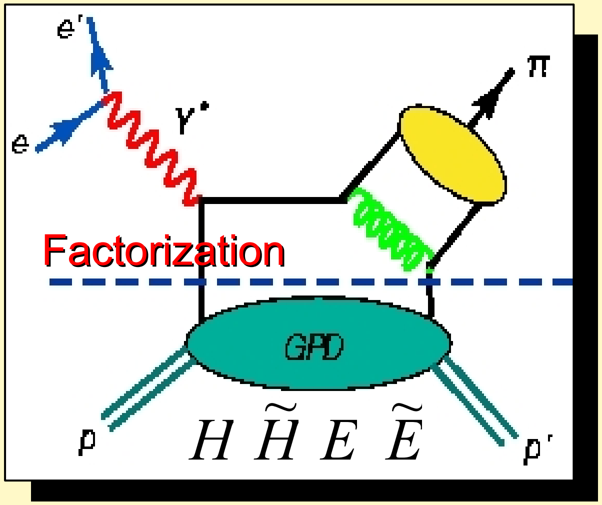
Real Compton Scattering at high t

Deeply Virtual Compton Scattering

Deep Exclusive Meson Production

Applicability of the GPD Mechanism

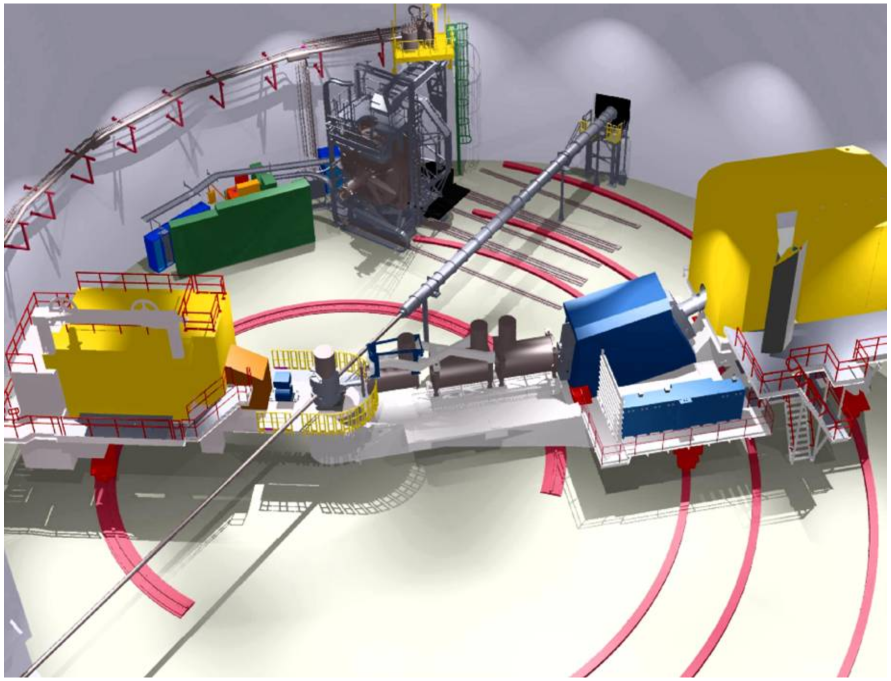
- **Determining the bounds of the kinematic regime where the GPD mechanism may apply is a high priority for JLab 12 GeV.**
  - **GPDs can only be extracted from hard exclusive data where hard-soft factorization applies.**
- One of the most stringent tests of factorization is the Q^2 dependence of the π^+ or K^+ electroproduction cross section
  - σ_L scales to leading order as $1/Q^6$.
  - σ_T scales as $1/Q^8$.
  - As Q^2 becomes large: $\sigma_L >> \sigma_T$.



- **Contribution of σ_T unknown at higher energies.**
- **Need to <u>experimentally demonstrate</u> σ_L>>σ_T at higher Q^2**
  → not just assume it.
- **If transverse contributions are larger than anticipated, the accessible phase space for GPD studies may be limited.**

Upgrades to Experimental Hall C

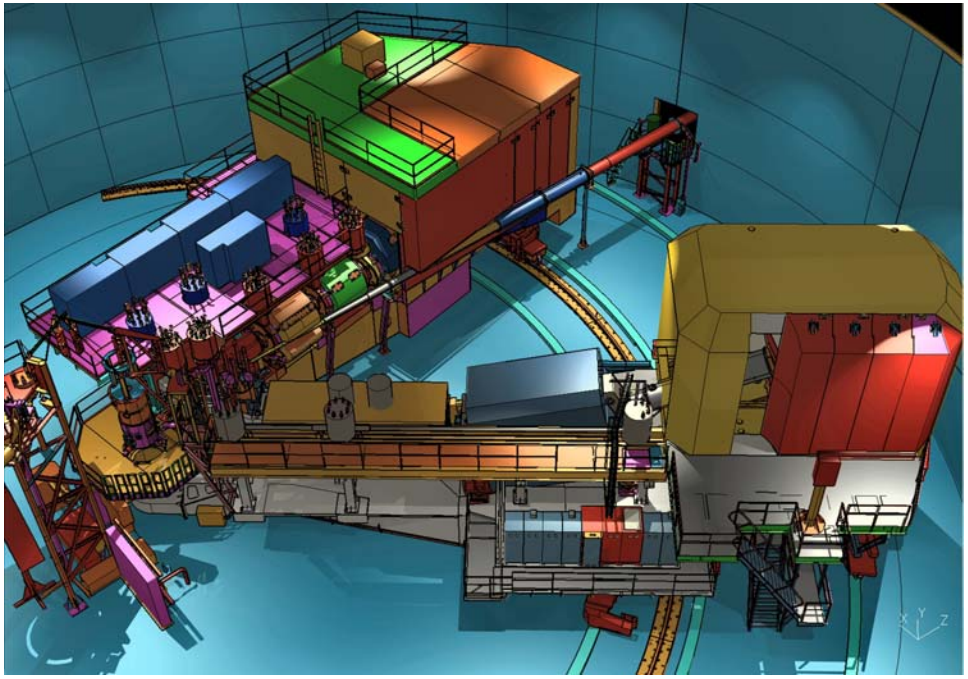
Standard 6 GeV Operation



Hall C's High Momentum Spectrometer, Short Orbit Spectrometer and specialized equipment for studying:

- The strange quark content of the proton.
- Form factors of simple quark systems.
- The transition from hadrons to quarks.
- Nuclei with a strange quark embedded.

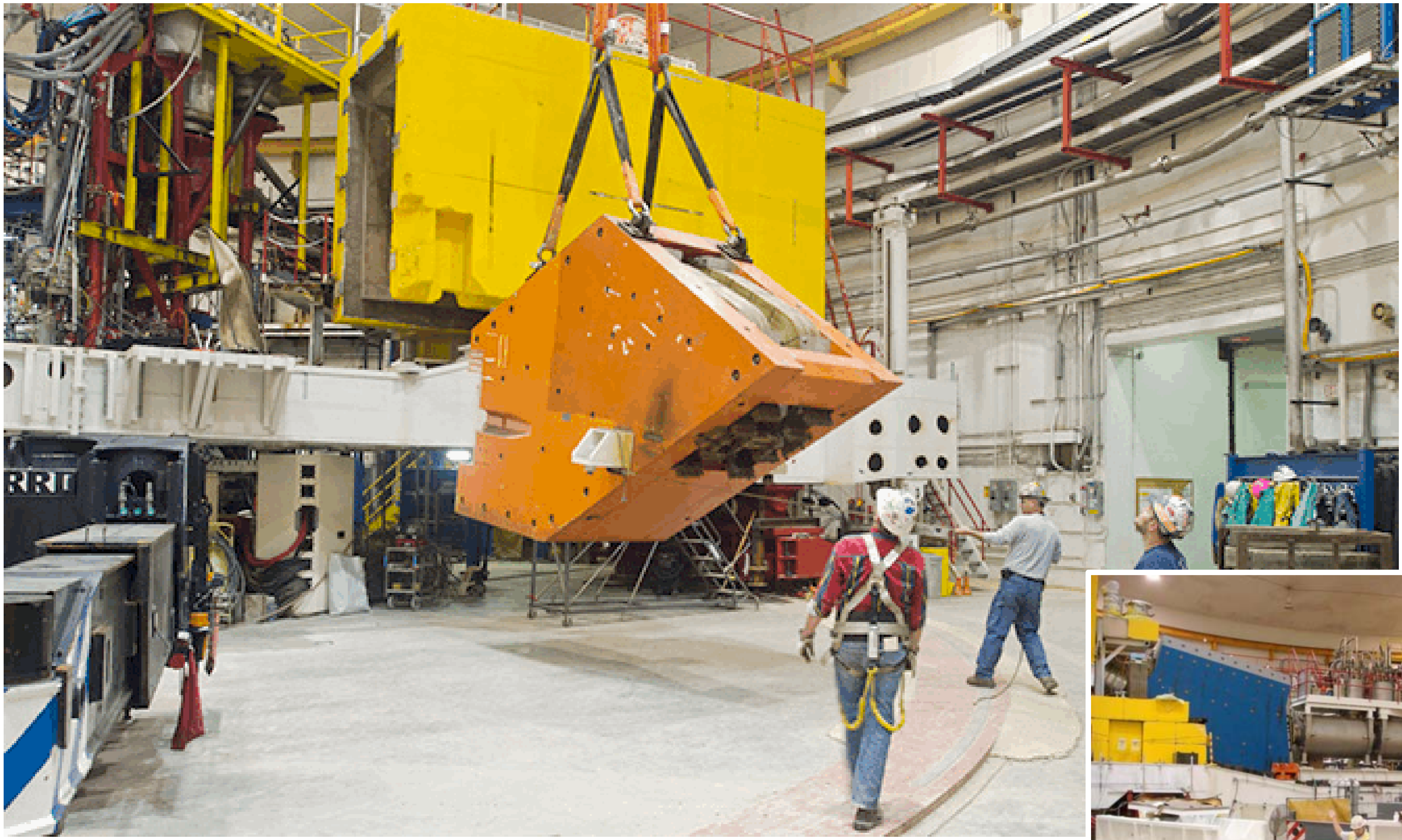
Future 12 GeV Operation



Add a Super- High Momentum (11 GeV) Spectrometer for studying:

- Super-fast (high x_B) quarks.
- Form factors of simple quark systems.
- The transformation of quarks into hadrons.
- Quark-quark correlations.

SOS Dipole Leaves Hall-C…

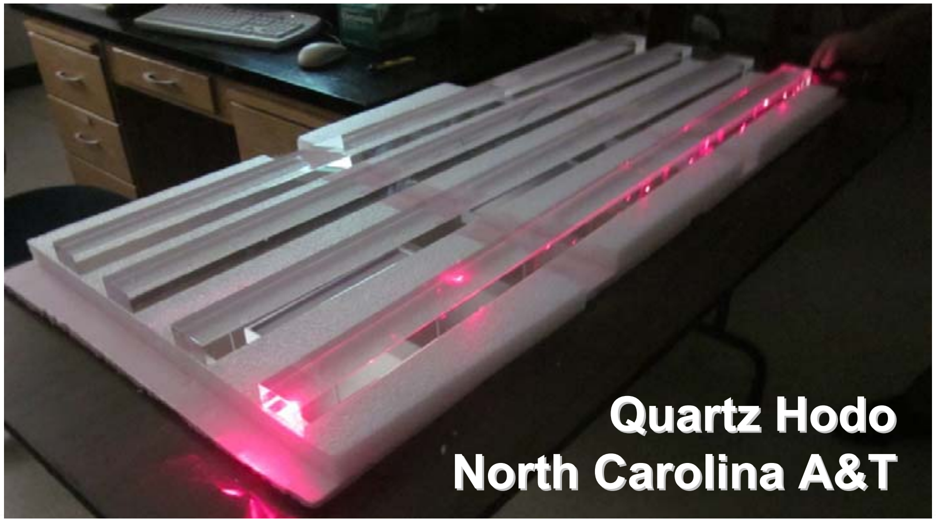


…and SHMS Wheels Arrive

SHMS Focal Plane Detectors


Drift Chambers
Hampton U.


Lead Glass Pre-Shower
Yerevan Phys. Inst.


Quartz Hodo
North Carolina A&T


Heavy Gas Cherenkov
U. Regina

SHMS+HMS Scaling Experiment Goals

- **Measure the Q^2 dependence of the $p(e,e'\pi^+)n$, $p(e,e'K^+)\Lambda$, $p(e,e'K^+)\Sigma$ cross sections at fixed x_B and –t to search for evidence of hard-soft factorization**
  - Separate the cross section components: L, T, LT, TT
  - Highest Q^2 for any L/T separation in π,K^+ electroproduction

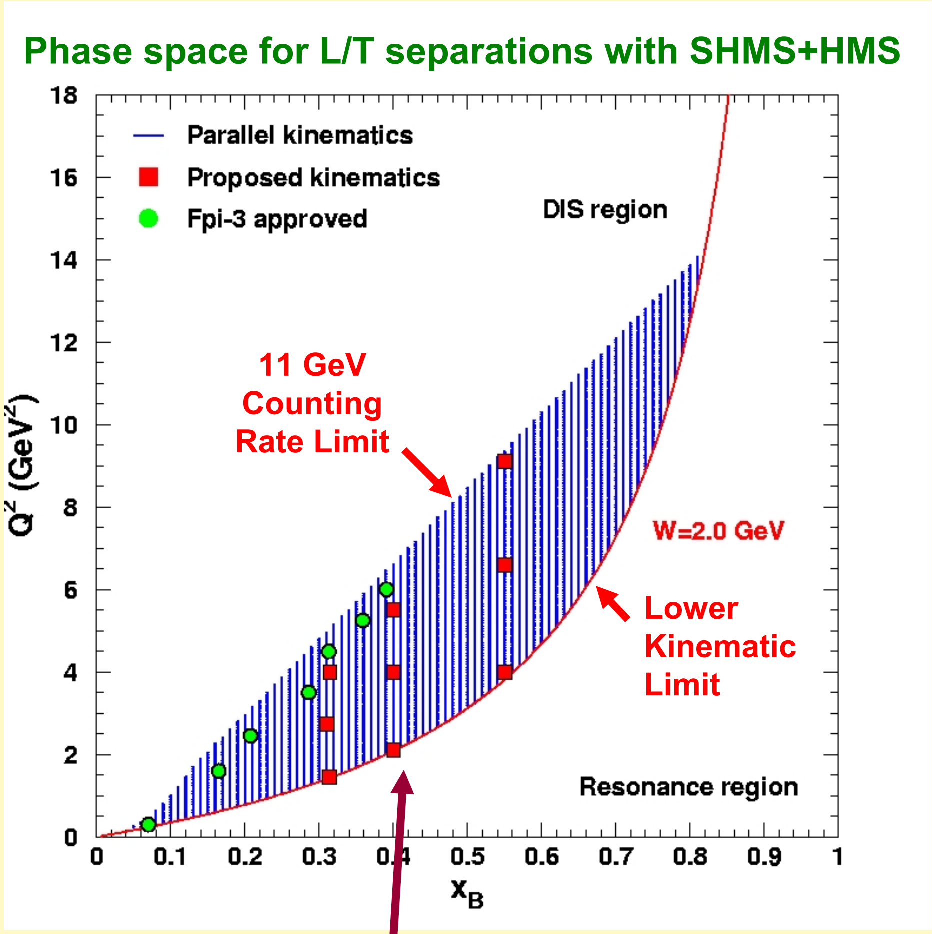
Our theoretical understanding of hard exclusive reactions will benefit from L/T separated pion and kaon data over a large kinematic range

- Quasi model-independent comparison of pion and kaon data would allow a better understanding of the onset of factorization
- Constraints for QCD model building using both pion and kaon data (flavor degrees of freedom)
- Understanding of basic coupling constants (Σ°/Λ ratio)

SHMS+HMS Scaling Experiment Overview

- Measure separated cross sections for the $p(e,e'\pi^+)n$, $p(e,e'K^+)\Lambda$, $p(e,e'K^+)\Sigma$ reactions at three values of x_B.
- **Q^2 coverage is a factor of 3-4 larger compared to 6 GeV.**
  - **Facilitates tests of the Q^2 dependence even if L/T is less favorable than predicted.**

x	Q^2 $(GeV/c)^2$	W (GeV)	-t $(GeV/c)^2$
0.31	1.5-4.0	2.0-3.1	0.1
0.40	2.1-5.5	2.0-3.0	0.2
0.55	4.0-9.1	2.0-2.9	0.5


Phase space for L/T separations with SHMS+HMS

Kinematics for π measurements

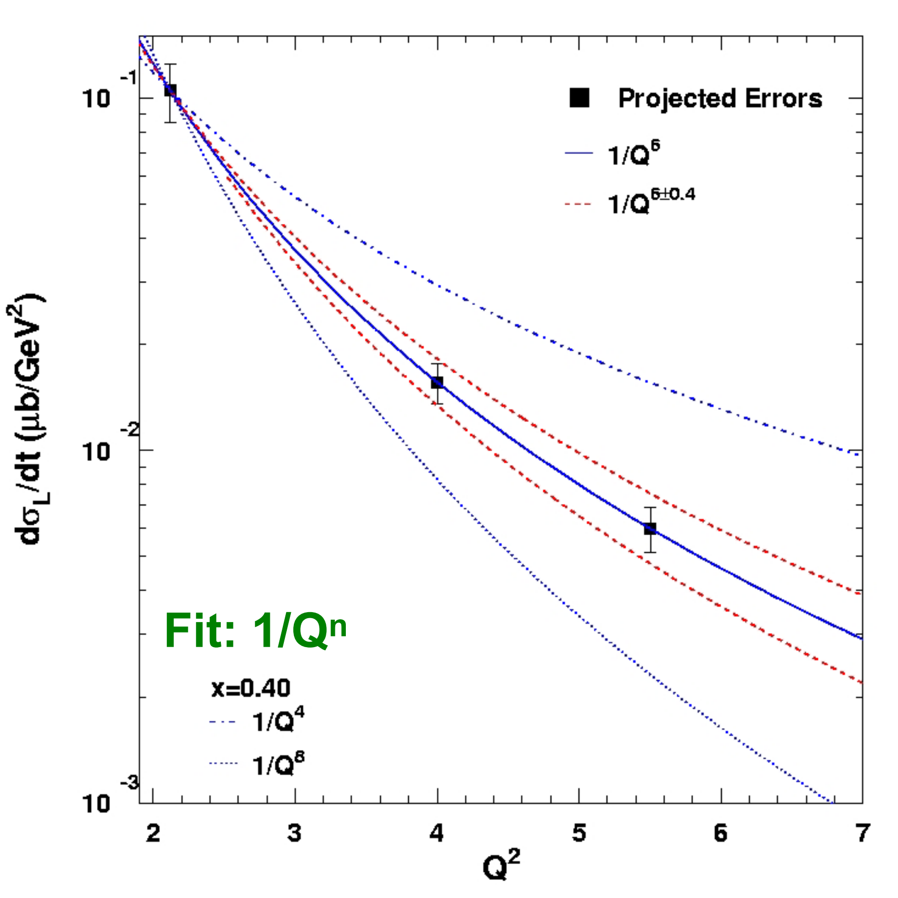
Projected $p(e,e'\pi^+)n$ Uncertainties for $1/Q^n$ Scaling

QCD scaling predicts:

$\sigma_L \sim 1/Q^6$

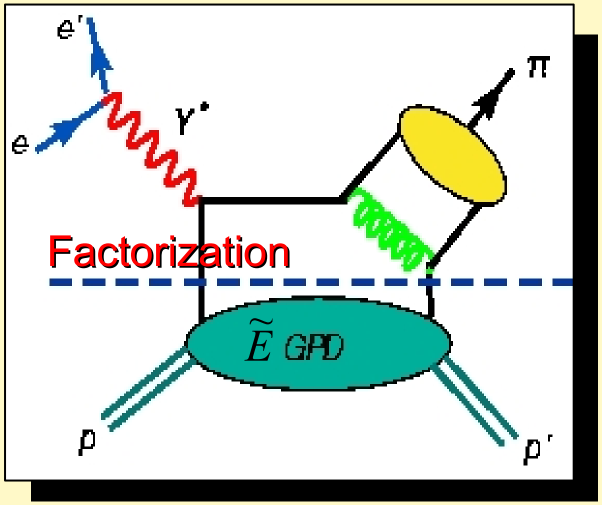
$\sigma_T \sim 1/Q^8$

x_B	dn^L	dn^T	dn^{LT}	dn^{TT}
0.31	0.3	0.2	0.5	0.6
0.40	0.4	0.3	0.7	0.8
0.55	2.5	1.0	-	-



$p(e,e'K^+)\Lambda,\Sigma$ measurement scheduled as one of the SHMS+HMS commissioning experiments, to run in 2016-17.
→ First L/T separation involving both spectrometers.

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.

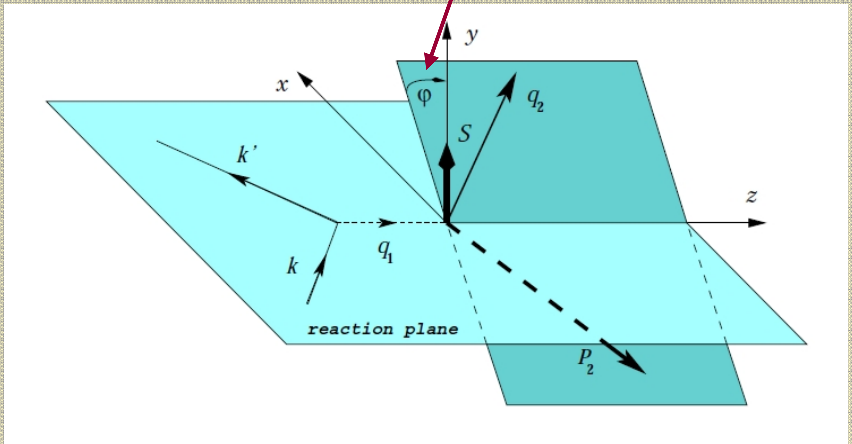
Polarized GPD $\tilde{E}$

- 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.



Requires both an L/T separation and a transversely polarized target.
→ Very challenging measurement!

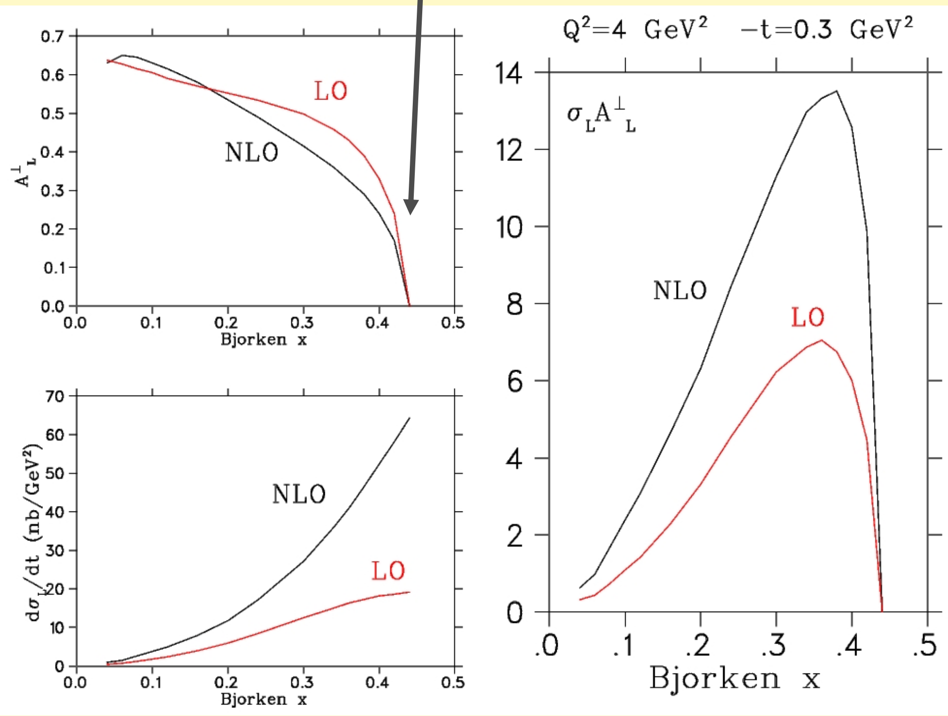
GPD information in $A_L^\perp$ may be particularly clean

- GPD formalism is restricted to regime where hard & soft contributions factorize.
- $A_L^\perp$ is especially interesting because it is expected to display **precocious factorization** at only Q^2~2-4 GeV^2.
- Argument by Frankfurt et al. [PRD **60**(1999)014010]
  - 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:**
  - 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 to $A_L^{\perp}$

- In hard meson electroproduction, factorization can only be applied to **longitudinal photons**.

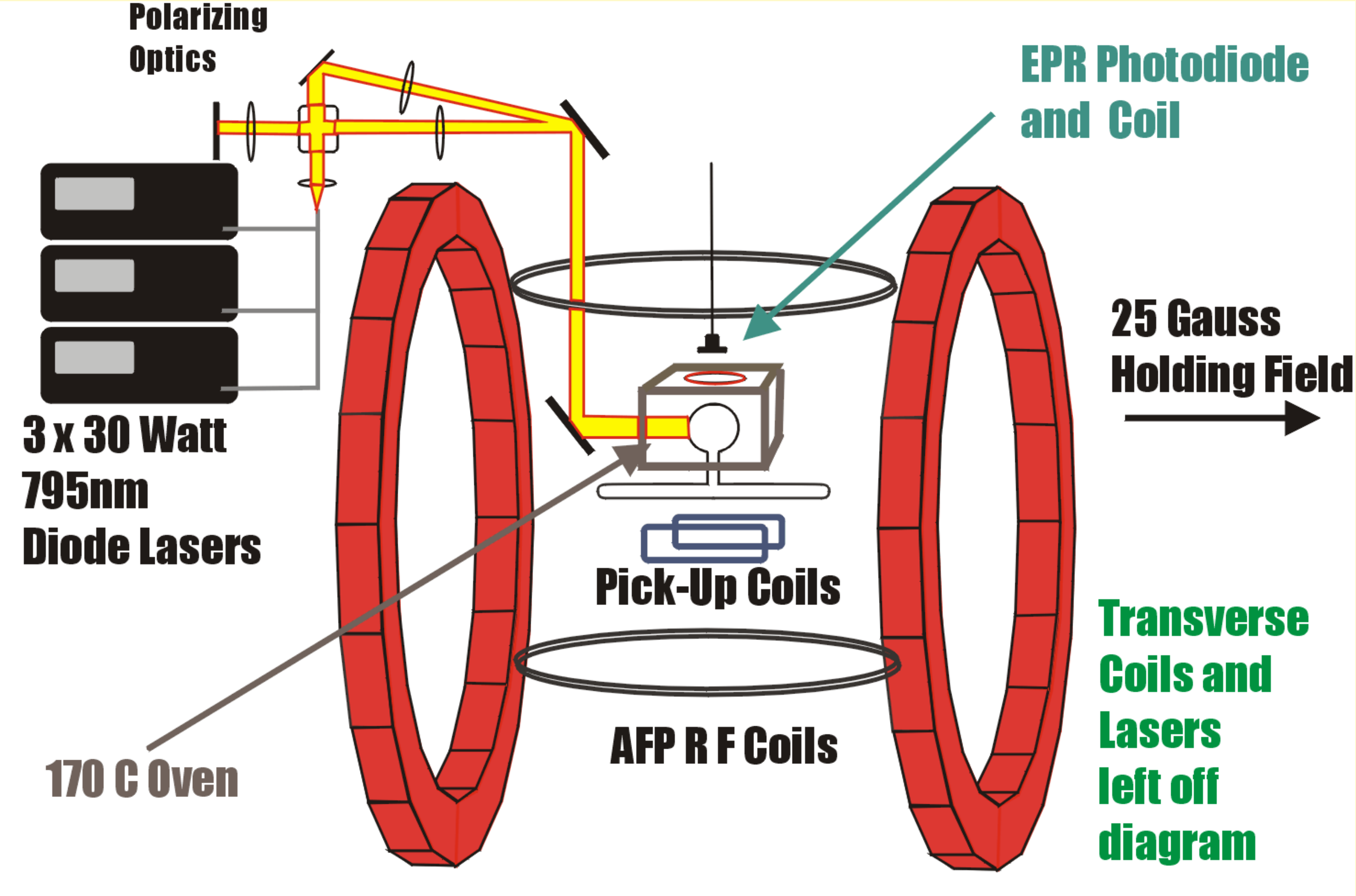
- **Unlike other ongoing or proposed experiments, where dominance of longitudinal contribution is simply assumed, JLab's unique contribution to this field is in:**
  - **ability to take measurements at multiple beam energies.**
  - **unambiguous isolation of $A_L^{\perp}$ using Rosenbluth separation.**

- A JLab $A_L^{\perp}$ measurement could thus establish the applicability of the GPD formalism, and precocious scaling expectations, for other $A^{\perp}$ experiments.

High Luminosity Essential to $A_L^{\perp}$

- **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.
- The measurement has long been considered to be impossible 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.**

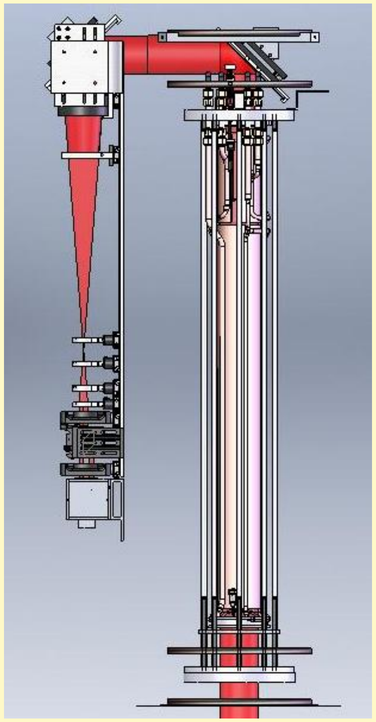
Hall A Polarized ^{3}He Target: FOM(P^2L)=0.22E+36



UNH/Xemed Target Loop Concept: $P^2L=0.55E+38$

- Compress polarized ^{3}He and deliver to aluminum target cell
- Non-ferrous diaphragm compressor achieves 3000 psi (~200 bar)
- Returns through a pressure-reducing orifice

External polarizer



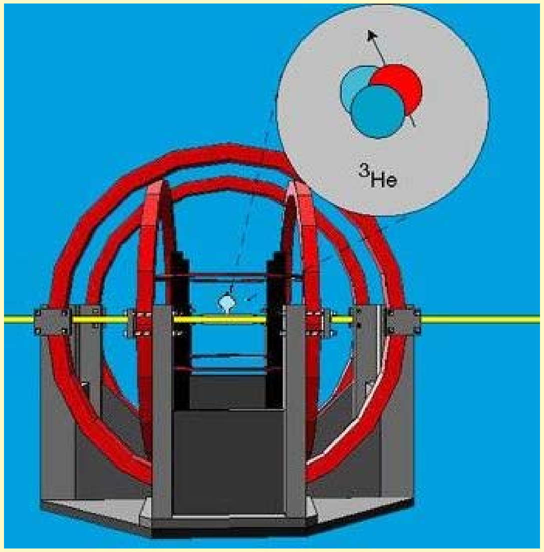
Requires two ports,
entrance and exit

20 Bar

Non-ferrous diaphragm compressor

200 Bar

Nuclear physics target



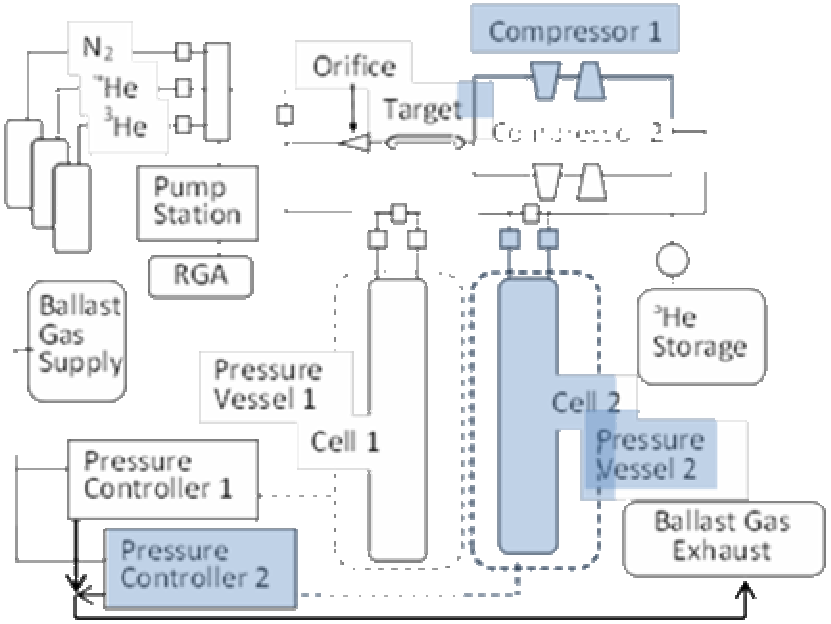
9 cm aluminum target cell
Cooled with LN_2 to 77K
Thickness of 0.5 g/cm^2

Expansion through an orifice

Recirculates at 25 SLPM

^{3}He Polarized Target Rationale

- By providing optical pumping repolarization rates that keep ahead of beam depolarization rates, we propose development of a scalable polarized ^{3}He target system that:
  - provides a ^{3}He target thickness as high as 0.5 g/cm^{2} in 10 cm
  - accepts the full 80μA polarized beam current at Jefferson Laboratory, and
  - maintains 65% polarization at luminosity of 10^{38} e-nucleons/cm^{2}.



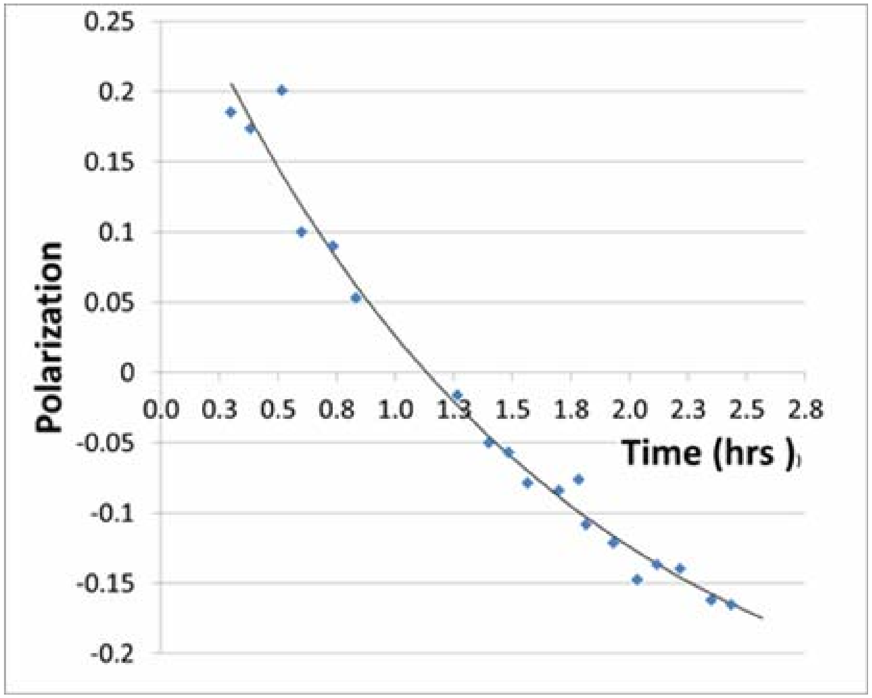
- By relocating critical components of the polarizer system in a loop outside the beam enclosure, we can incorporate redundancy and eliminate single points-of-failure.

Working Large-Scale ^{3}He Polarizer Prototype

Assembled, Operating ^{3}He Polarizer

- 8.5L aluminosilicate glass cell.
- Pressure-vessel enclosure.
- Operation up to 20 atm.
- Hybrid pumping with K:Rb.
- Spectrally narrowed 2.5kW laser.

- Spin-up curve measured by laser-polarization-inversion.
- Spin-up rate ~15%/hr.



High Luminosity Polarized ^{3}He Target Status

Many of the hardest technological hurdles have been demonstrated through working prototypes.

1. Large-scale ^{3}He polarizer can operate at temperatures, pressures and laser-beam intensities that replace spins (much) faster than they will be destroyed by the beam at $\mathcal{L}$=5x10^{37} cm^{-2}s^{-1}.
2. Capability to develop and produce industrial-quality compressor pumps from non-ferrous materials.

Next phase of development:

1. Need to demonstrate high polarization (inadvertent contamination has limited asymptotic polarization <50%).
2. Need to make a cell with inlet and exit ports.
3. Need to measure ^{3}He depolarization in a loop that includes pump and orifice.

JLab PAC39 Comments, June 2012

PR12-12-005: *"The Longitudinal Photon, Transverse Nucleon, Single-Spin Asymmetry in Exclusive Pion Electroproduction"*, D.J. Gaskell, F.W. Hersman, G.M. Huber, D. Dutta, Spokespersons

- "The scientific case is really worthwhile. However, in view of many technical issues for this very challenging high luminosity polarized ^{3}He target, the proposed experiment cannot be part of the top half of the priority list of experiments to be established for the first 5 years of 12 GeV operations.

  The PAC encourages the group to purse all these technical efforts to provide a new generation of high luminosity polarized ^{3}He target from which several other experiments can benefit."

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.**

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

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:

$$\left.\begin{array}{l} \sum_q e_q \int_{-1}^{+1} dx\, H^q(x,\xi,t) = F_1(t) \\[2em] \sum_q e_q \int_{-1}^{+1} dx\, E^q(x,\xi,t) = F_2(t) \end{array}\right\}$$

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.

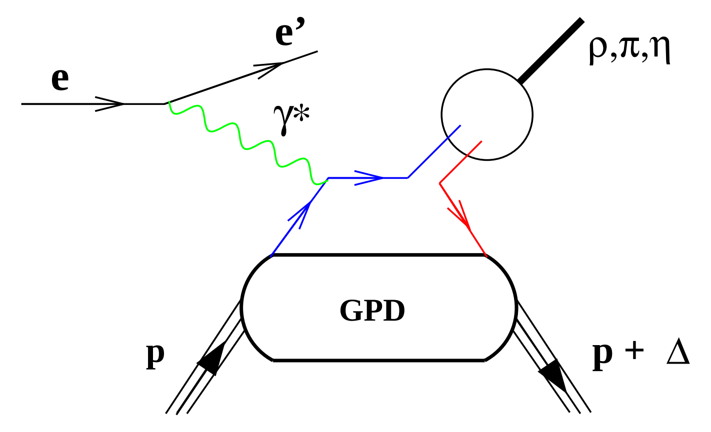
$$\sum_q e_q \int_{-1}^{+1} dx\, \tilde{E}^q(x,\xi,t) = G_P(t)$$

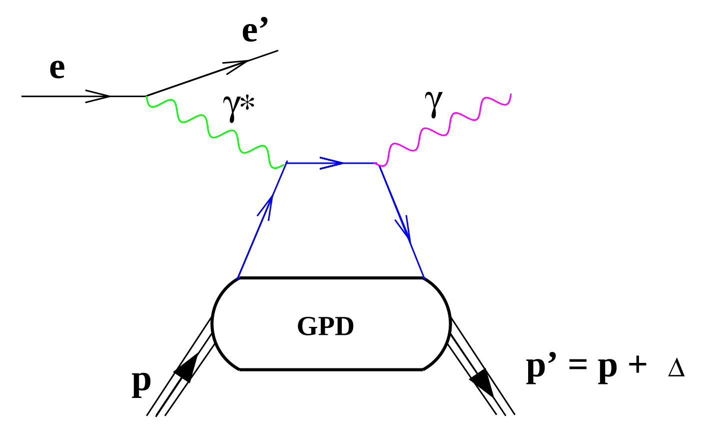
Pseudoscalar form factor. Very poorly known.

Complementarity of Different Reactions

Deep Exclusive Meson Production:

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





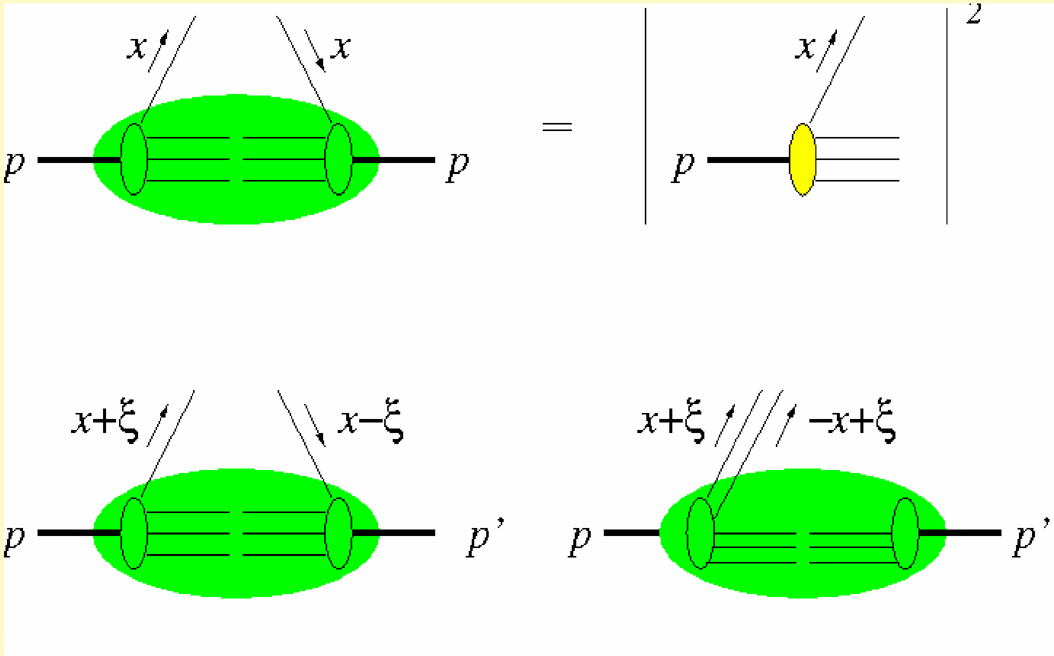
Deeply Virtual Compton Scattering:

- Sensitive to all four GPDs.

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

Generalized Parton Distributions

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

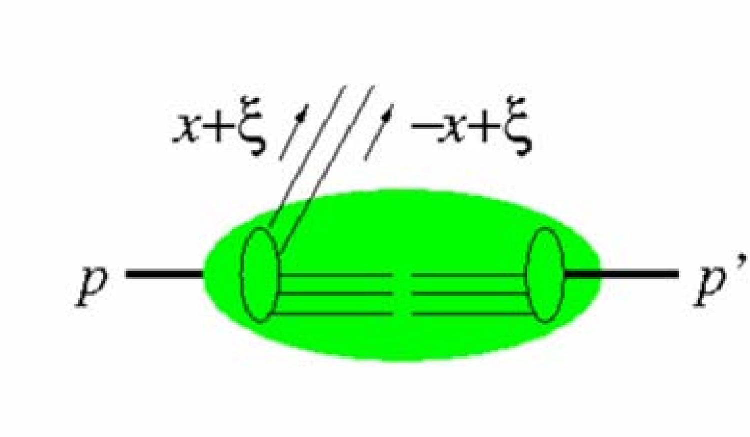


PDFs : **Squared hadronic wavefunctions = probability of finding a parton with specified longitudinal momentum fraction and polarization in fast moving hadron.**

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

- 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

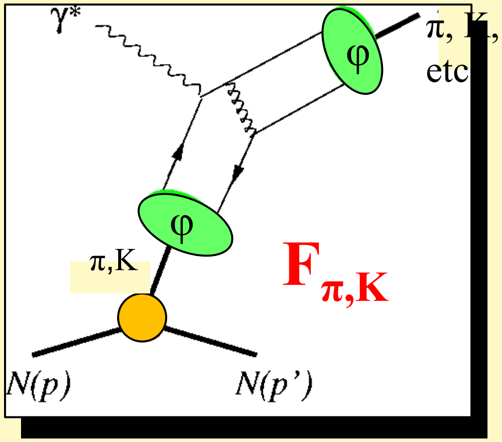


- A special kinematic regime is probed in deep exclusive meson production, where initial hadron emits a $q\bar{q}$ or gg pair.
- This has no counterpart in usual PDFs.
- Since GPDs correlate different parton configurations in the hadron at the quantum mechanical level,
  - GPDs determined in this regime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

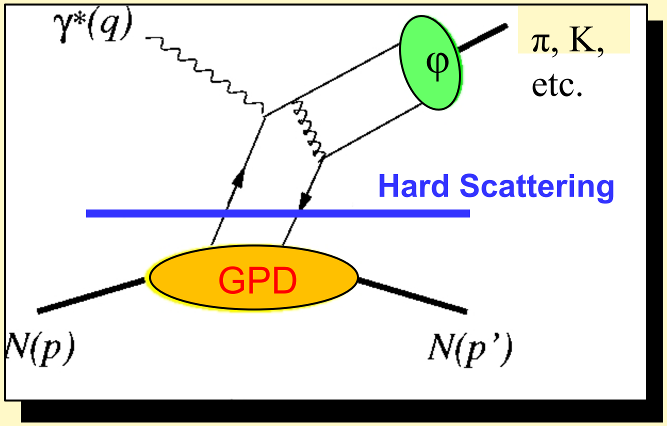
Form Factors and GPDs

- Form factors and GPDs are essential to understand the structure of nucleons, which make up nucleons and mesons (q-$\bar{q}$ systems)

- But measurements of form factors and GPDs have certain prerequisites:
    - *Before we can start looking at form factors*, we must make sure that σ_L is dominated by the meson pole term at low -t
    - *Before we can learn about GPDs*, we must demonstrate that factorization applies



- A *comparison of pion and kaon* production data may shed further light on the reaction mechanism, and intriguing 6 GeV pion results

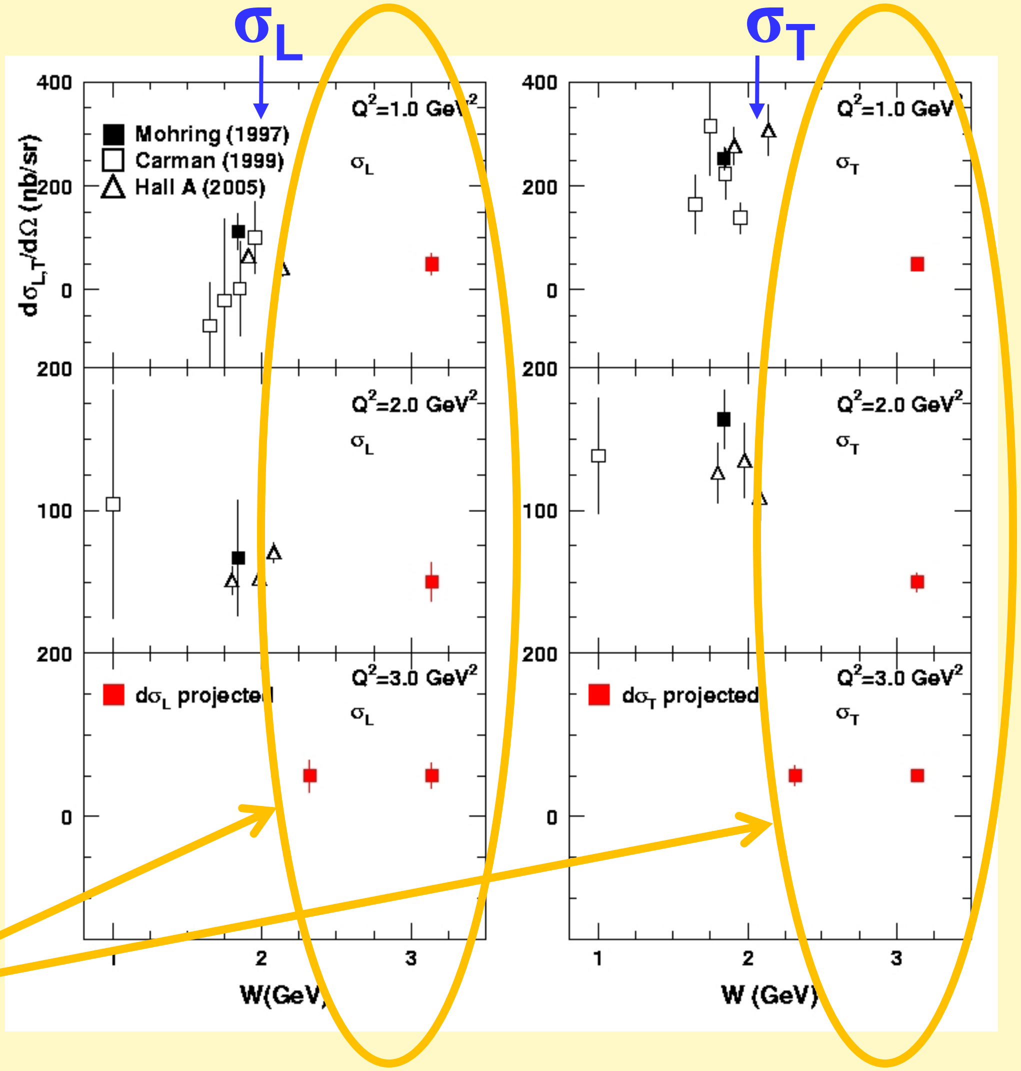


Projected Uncertainties for σ_L and σ_T

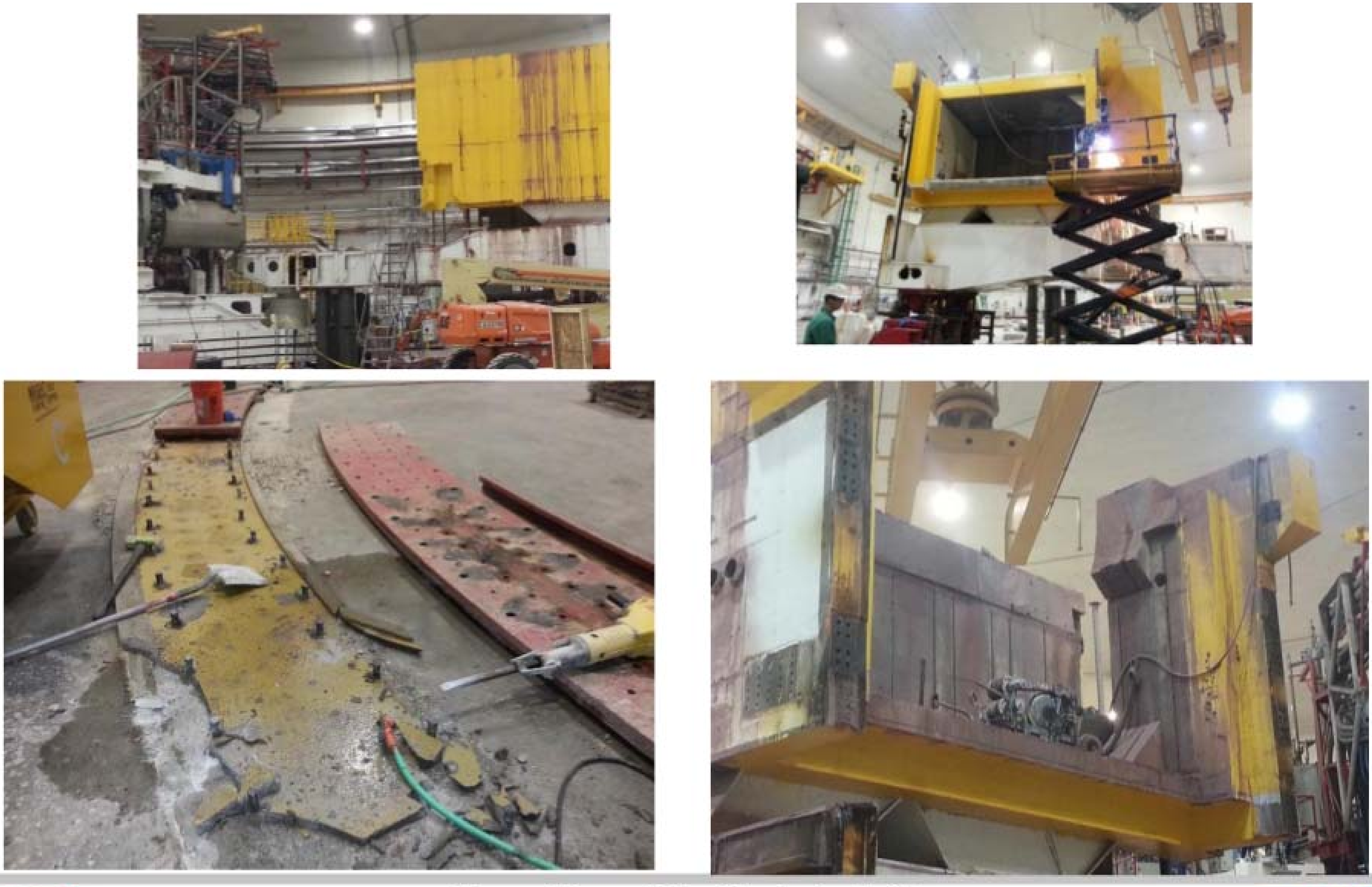
- High quality kaon L/T separation above the resonance region

- Projected uncertainties for σ_L and σ_T use the L/T ratio from Hall C parameterization

PR12-09-011:
Precision data
for W > 2.5 GeV



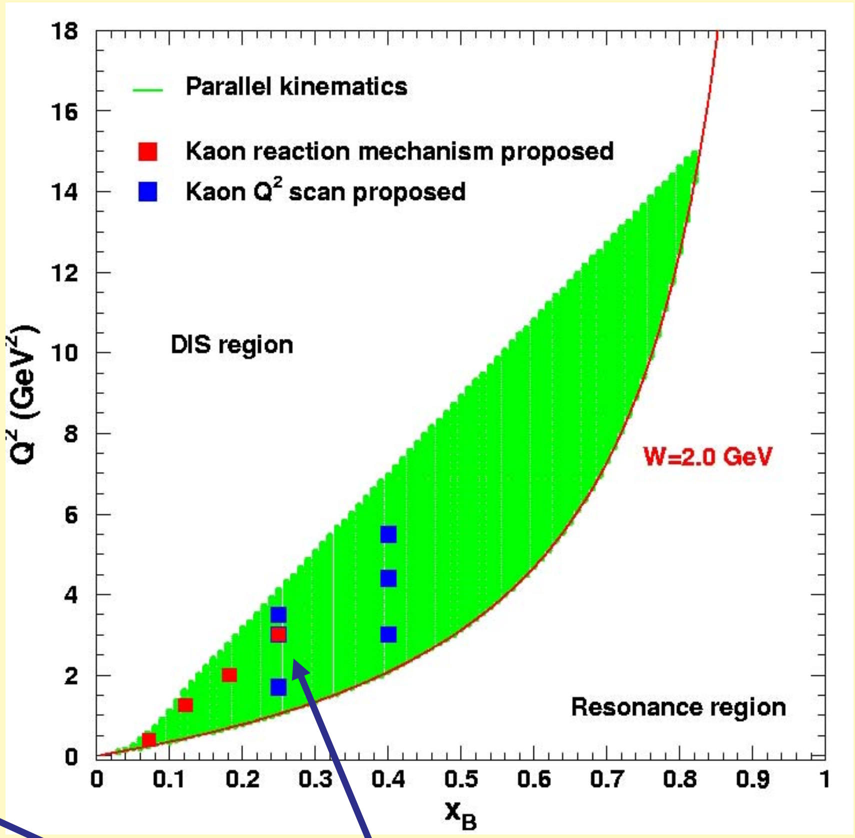
SOS Removal now Completed



SHMS Support Structure installation

Experiment Overview

- Measure the separated cross sections at varying –t and x_B
  - If K^+ pole dominates σ_L allows for extraction of the kaon ff (W>2.5 GeV)
- Measure separated cross sections for the $p(e,e'K^+)\Lambda(\Sigma^\circ)$ reaction at two fixed values of –t and x_B
  - Q^2 coverage is a factor of 2-3 larger compared to 6 GeV at much smaller –t
  - Facilitates tests of Q^2 dependence even if L/T ratio less favorable than predicted



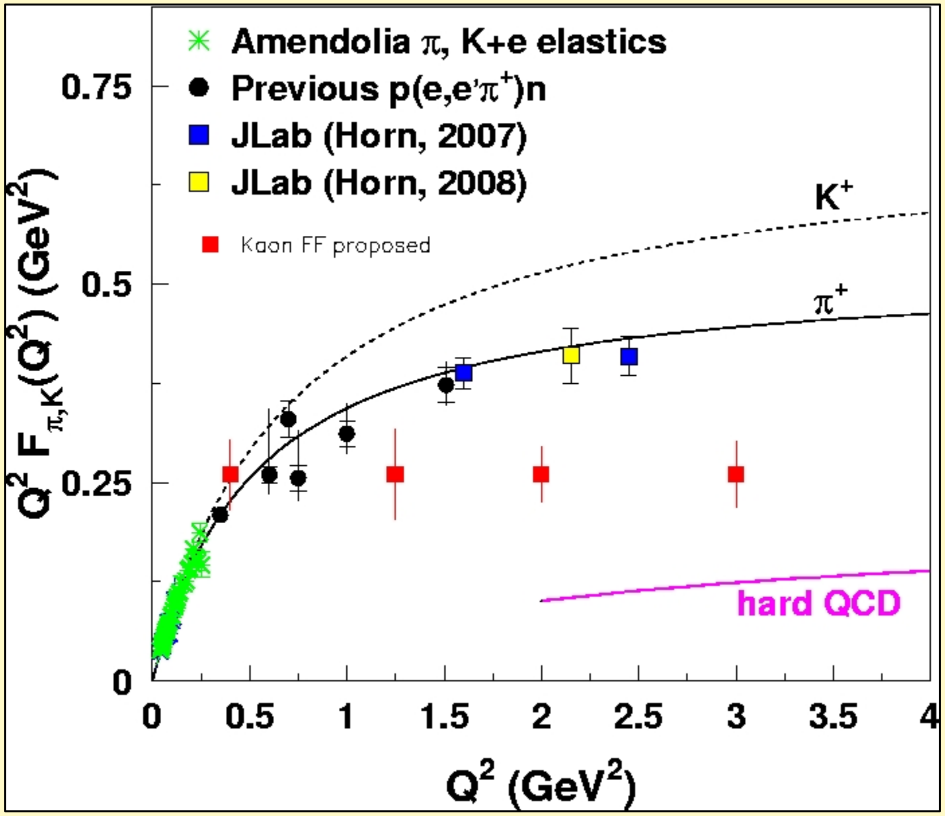
x	Q^2 (GeV^2)	W (GeV)	-t $(GeV/c)^2$
0.1-0.2	0.4-3.0	2.5-3.1	0.06-0.2
0.25	1.7-3.5	2.5-3.4	0.2
0.40	3.0-5.5	2.3-3.0	0.5

Q^2=3.0 GeV^2 was optimized to be used for both t-channel and Q^{-n} scaling tests

Projected Uncertainties for the Kaon FF

- If the K^+ pole dominates low -t σ_L, we would for the first time extract F_K above the resonance region (W>2.5 GeV)

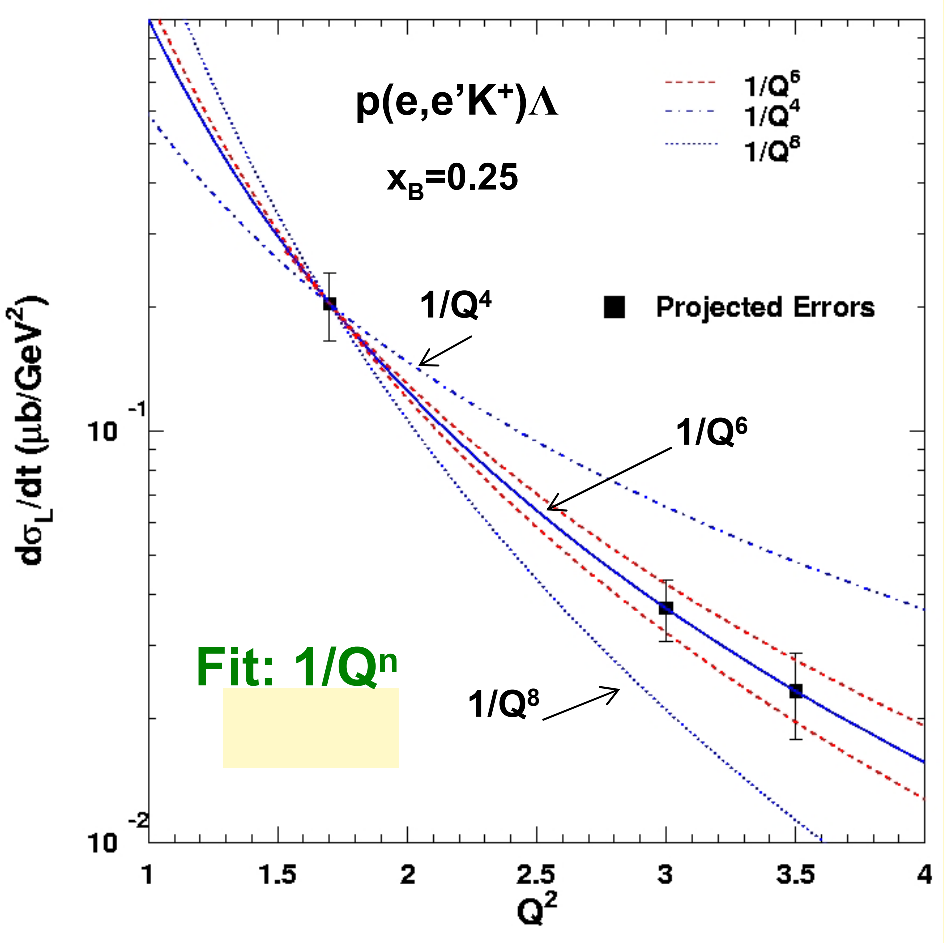
- Projected uncertainties for σ_L use the L/T ratio from Hall C parameterization



Projected Uncertainties for Q^{-n} scaling

- QCD scaling predicts $\sigma_L \sim Q^{-6}$ and $\sigma_T \sim Q^{-8}$
- Projected uncertainties use R from the Hall C parameterization

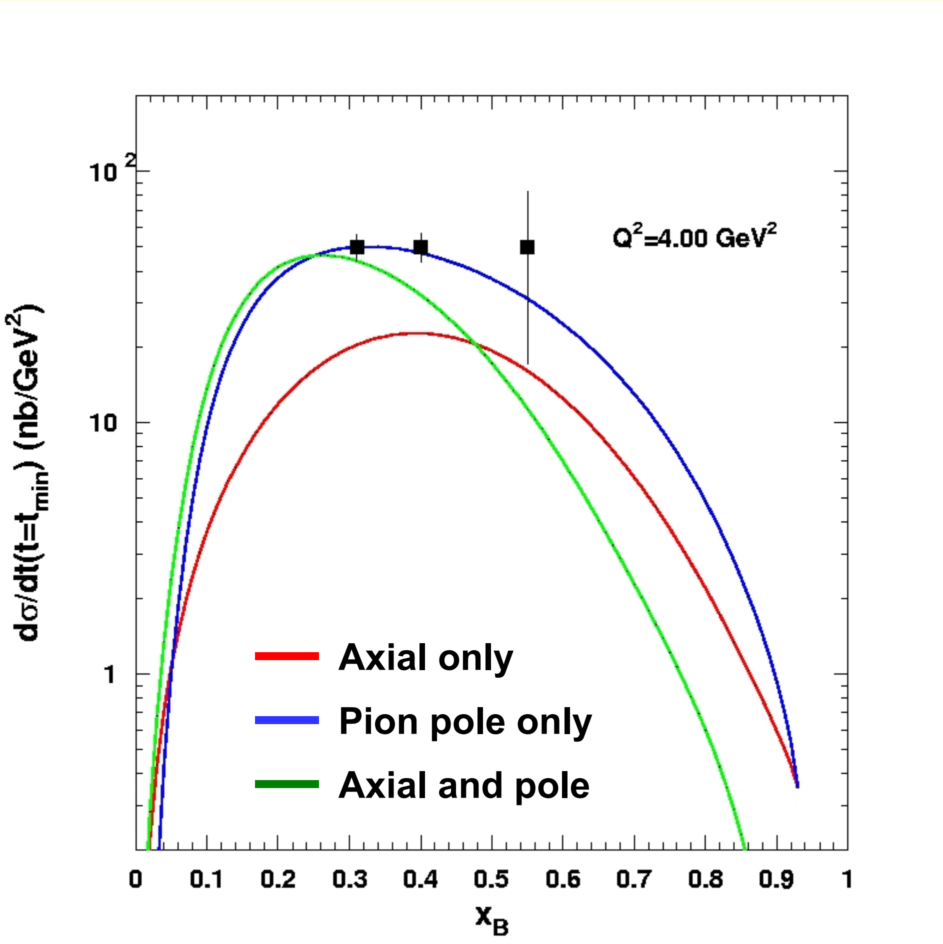
x	Q^2 (GeV^2)	W (GeV)	-t $(GeV/c)^2$
0.25	**1.7-3.5**	**2.5-3.4**	**0.2**
0.40	**3.0-5.5**	**2.3-3.0**	**0.5**



Is onset of scaling different for kaon than pion?
Kaons and pions together provide quasi model-independent study

Projected Uncertainties for σ_L at constant Q^2

- x_B scan at Q^2=4 GeV^2
- Can easily distinguish between pole and axial contributions within the framework of GPD calculations
  - Provides information about non-pole contributions
- May constrain longitudinal backgrounds in the extraction of F_π

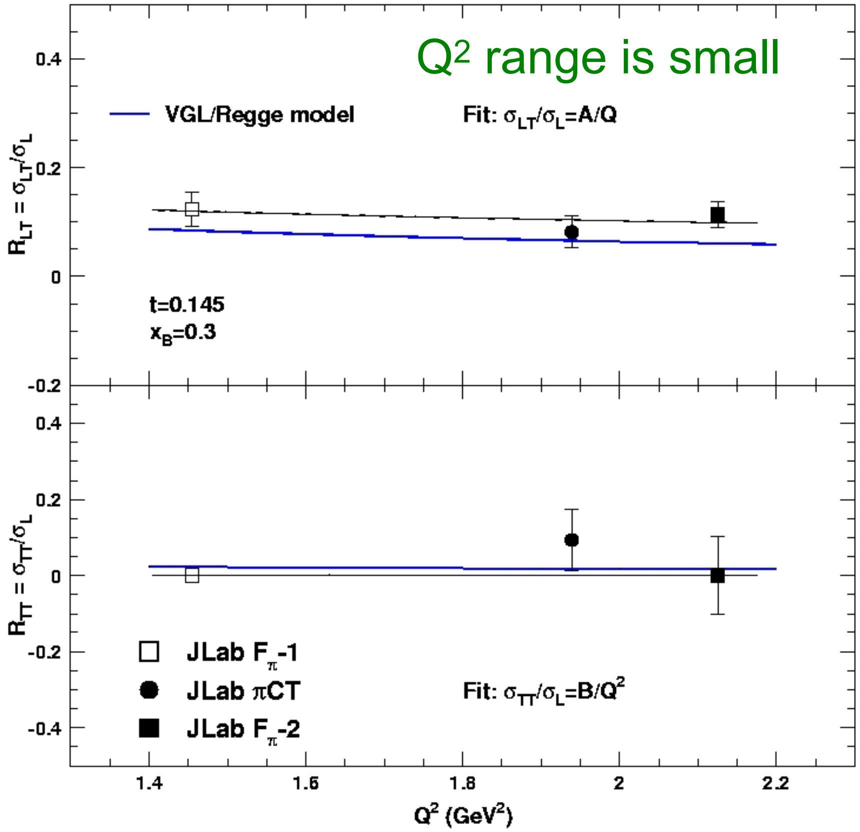


Dr. Garth Huber, Dept. of Physics, Univ. of Regina, Regina, SK S4S0A2, Canada.

Q^2 Scaling of the Interference Terms

- Scaling prediction based on transverse content to the amplitude
  - $\sigma_{LT} \sim Q^{-7}$
  - $\sigma_{TT} \sim Q^{-8}$
- Limited Q^2 coverage complicates the interpretation
  - Interference terms decrease in magnitude as Q^2 increases

Preliminary from Fpi1, Fpi2

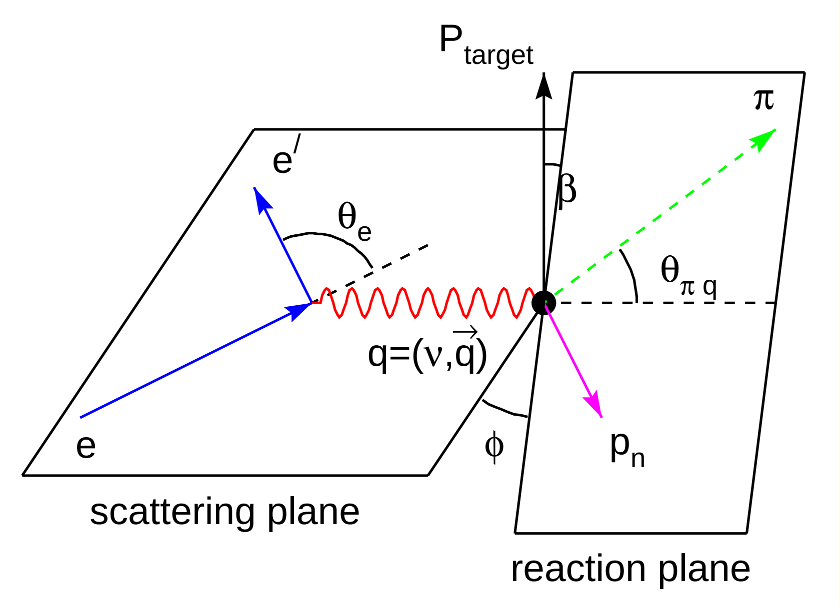


Q^2 range is small

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

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

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

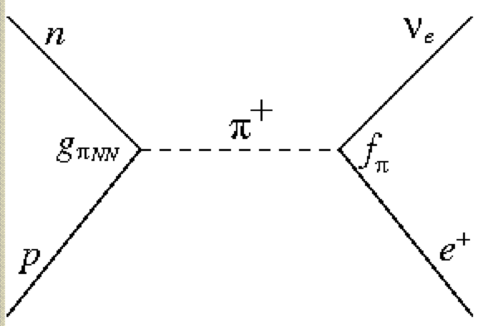
$$\begin{aligned}\sigma_t = P_x & \left[-\sqrt{2\epsilon(1+\epsilon)}\sin\phi\,\sigma_{LT}^x - \epsilon\sin 2\phi\,\sigma_{TT}^x\right] \\ - P_y & \left[\sigma_{TT}^y + \epsilon\cos 2\phi\,\sigma_{TT'}^y + 2\epsilon\,\sigma_L^y + \sqrt{2\epsilon(1+\epsilon)}\cos\phi\,\sigma_{LT}^y\right] \\ & + P_z\left[\epsilon\sin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

Spin-flip GPD $\tilde{E}$

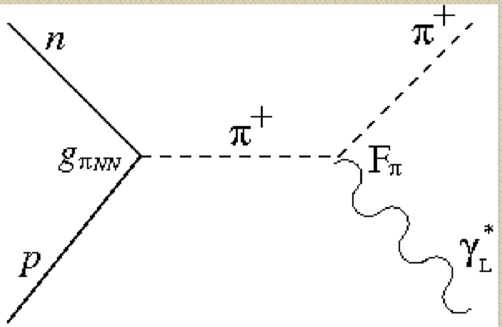
$$\sum_q e_q \int_{-1}^{+1} dx\, \tilde{E}^q(x,\xi,t) = G_P(t)$$

- $G_P(t)$ 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.

Implications for Pion Form Factor Experiments

- Vanderhaeghen et al. [PRL **84**(2000)2589] point out that the study of $A_L^{\perp}$ is important for the reliable extraction of F_π from $p(e,e'\pi^+)n$ data.
  - At $Q^2=10\mathrm{GeV}^2$, $x=0.3$, $t=t_{min}$, Mankiewicz, Piller & Radyushkin [EPJ **C10**(1999)307] find that the pion pole contributes about 80% of σ_L.
  - The non-pole contributions need to be accounted for in some manner in order to reliably extract F_π from σ_L data at low -t.
- **Since $A_L^{\perp}$ is an interference between pseudoscalar and pseudovector contributions, its measurement would help constrain the non-pole contribution to $p(e,e'\pi^+)n$, and so assist the more reliable extraction of the pion form factor from the data.**

Measurement of $A_\perp^L$

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

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

$\sigma_A=\sigma_T^\perp + \varepsilon\sigma_L^\perp$ where $\sigma(\varepsilon)=\sigma_U + \sigma_A \sin\beta + \ldots$

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

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)

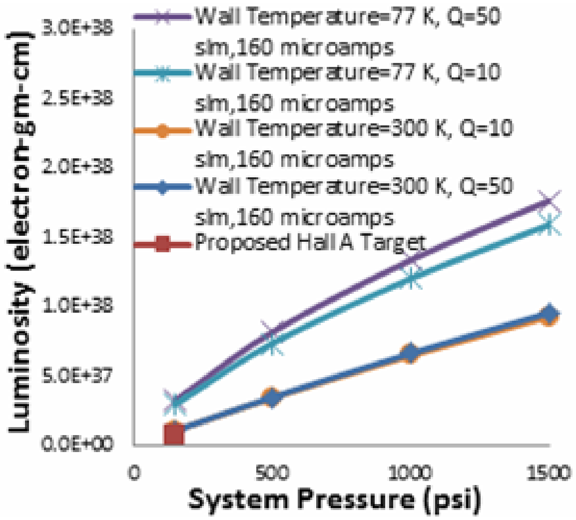
(advantage of focusing spectrometers in Hall C)

- **Need $\Delta\varepsilon$ as large as possible.**

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 **($P^2 \mathscr{L}$)**	0.22E+36	0.55E+38

Target Performance Goals

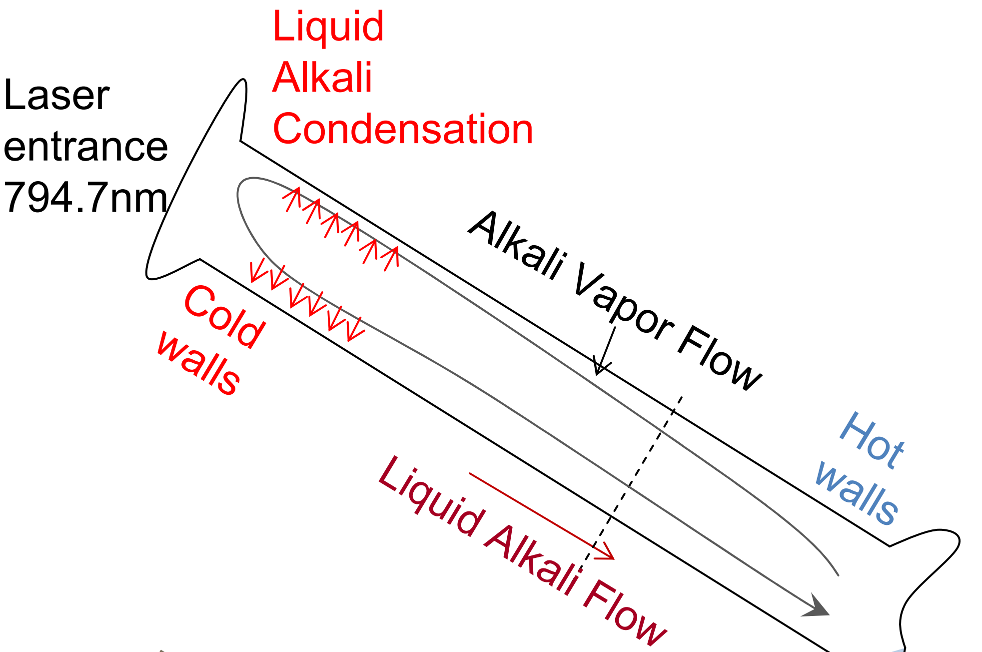
- Spin-up rate of one mole per hour (25% per hour with four moles of ^{3}He gas)
- Beam depolarization constant 10^{-39} per e-nucleon/cm^2 per hour per atom
  - for rate, multiply times luminosity divide by dilution



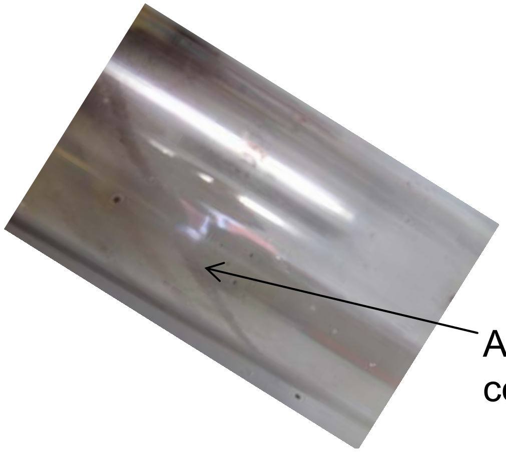
Calculated for 160uA beam current on 40cm target

- Assuming beam depolarization dominates losses, peak figure-of-merit occurs at luminosity 10^{39} with half polarization, ~35%
- Maintains ~65% polarization at luminosity 10^{38} e-nucleons/cm^2

Polarizer Schematic



Alkali puddle
(with heater)

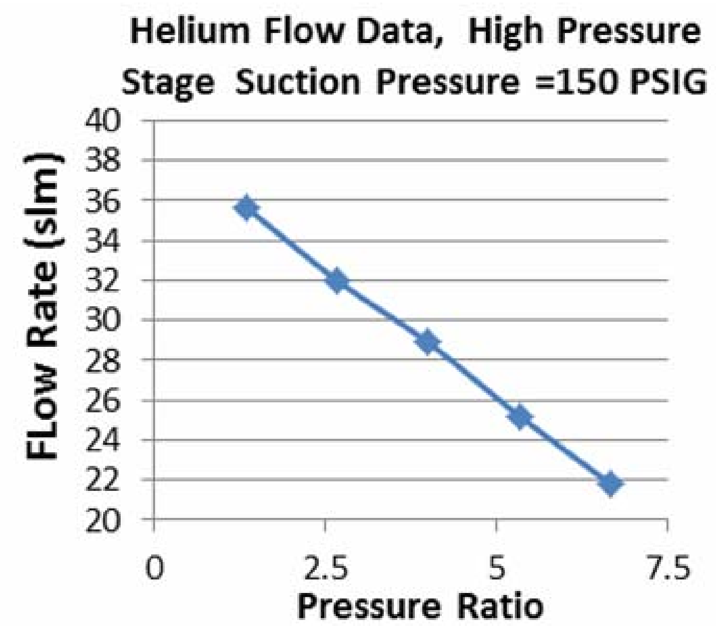


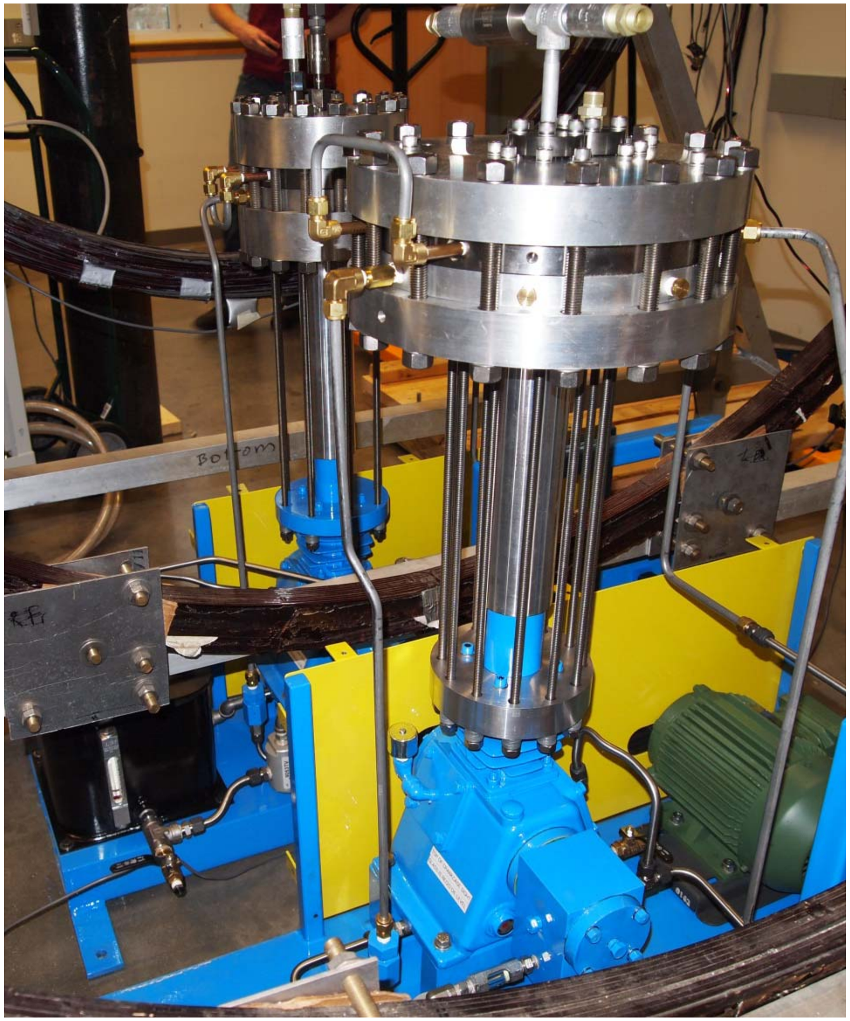
Alkali droplet flow from
cold back to hot section

- K-He spin exchange less "lossy" than Rb-He, requiring fewer replacement photons.
- Can reach higher efficiencies by using high alkali densities at higher temperatures, reducing "spin-up time" to just a few hours.
- 8.5L cylindrical glass vessel with thin optical window at top.
- Enclosed in pressure vessel to neutralize pressure differential across glassware.
- Lower part of cell maintained at 250^{o}C, to achieve desired alkali density for hybrid SEOP.

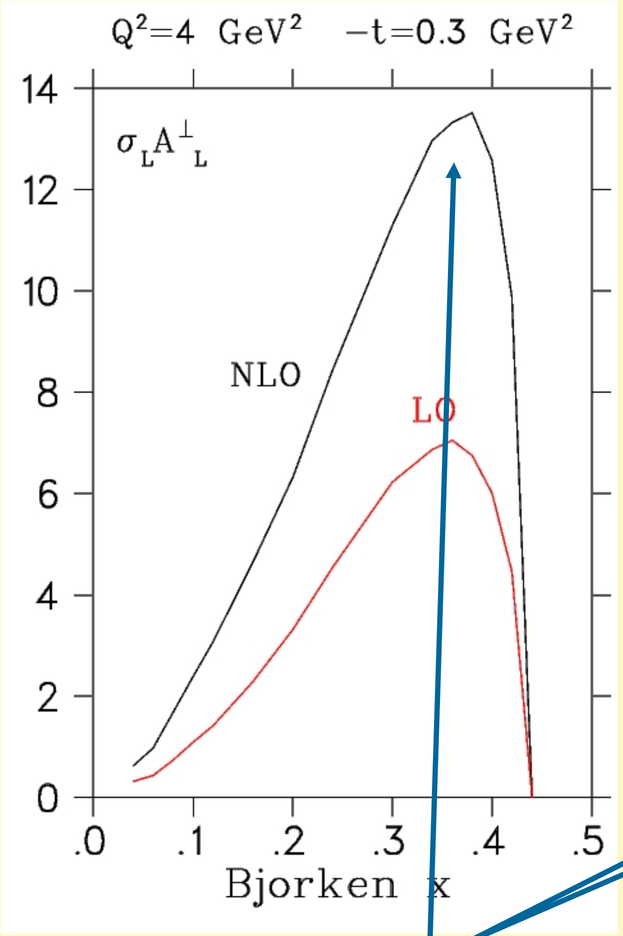
Working Non-ferrous Diaphragm Compressor

- Titanium diaphragm head.
- Phosphor-bronze diaphragm.
- PEEK valves.
- Prototype designed for 1000 psi output pressure.
- Flow of 22 SLPM achieved (^{4}He).
- Incorporated into flow test facility for tests of ^{3}He depolarization.





SHMS+HMS Kinematics

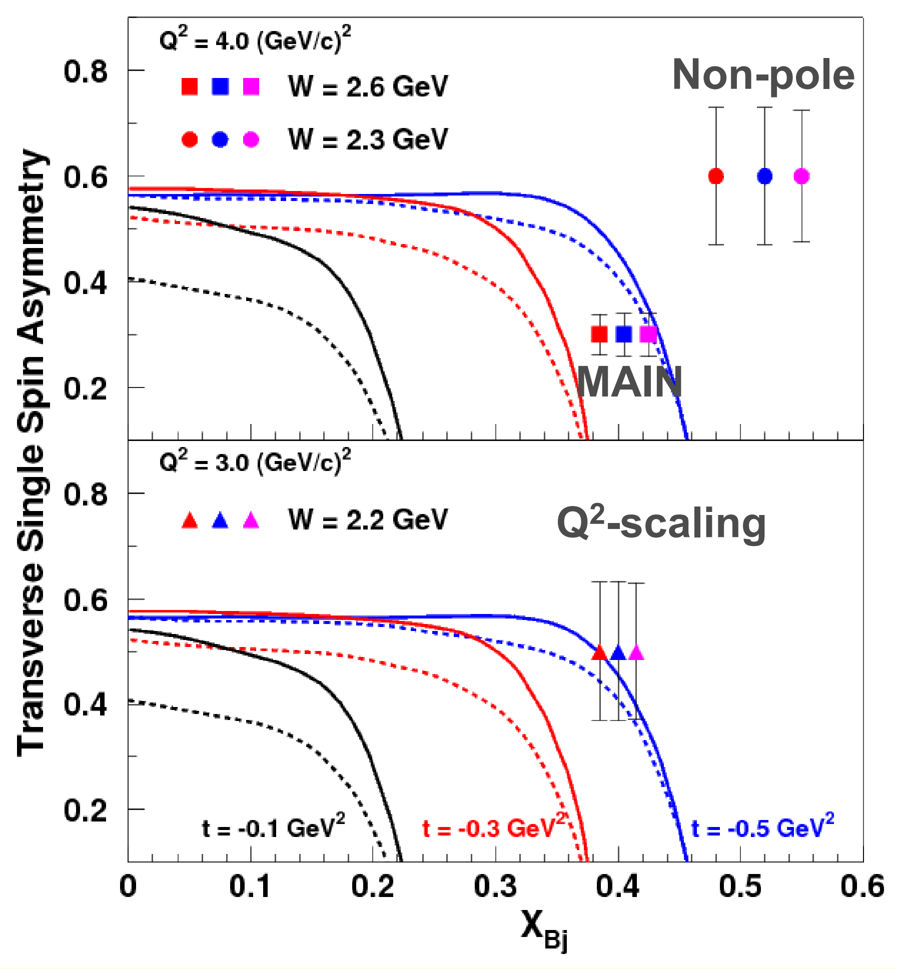


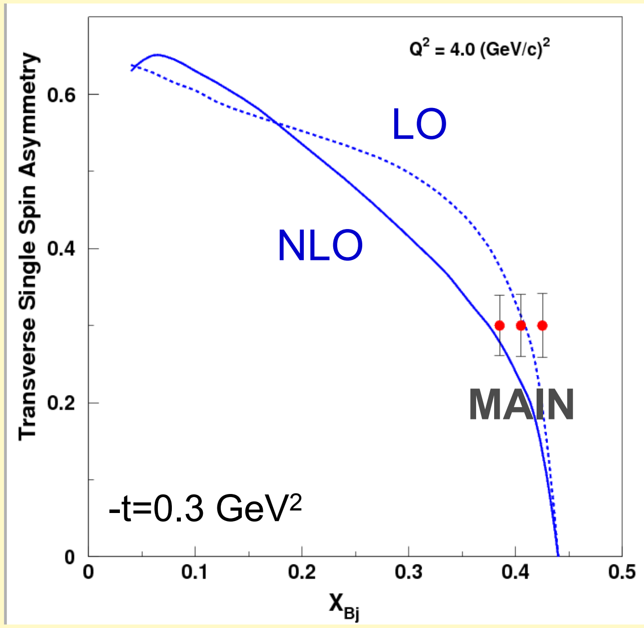
n(e,e'π-)p Kinematics

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

Near peak of
Figure of Merit in
Belitsky's calculation

Projected $A_L^{\perp}$ Uncertainties





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

- **Example t-binning only.** Finer binning will depend on actual experimental factors.
- Errors include statistical and uncorrelated systematic uncertainties (including partial cancellation of uncorrelated systematic errors when forming the ratio).
- Assumes σ_L/σ_T=1 and ^{3}He target polarization of 65%.