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

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Towards a “3D” View of the Nucleon

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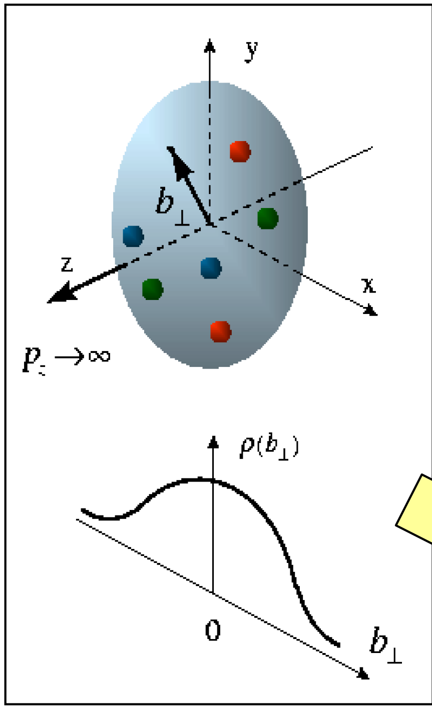
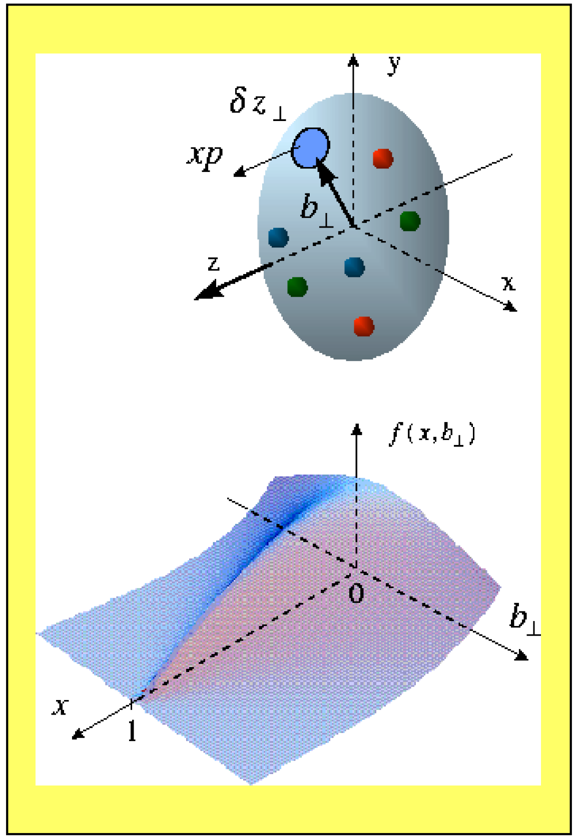
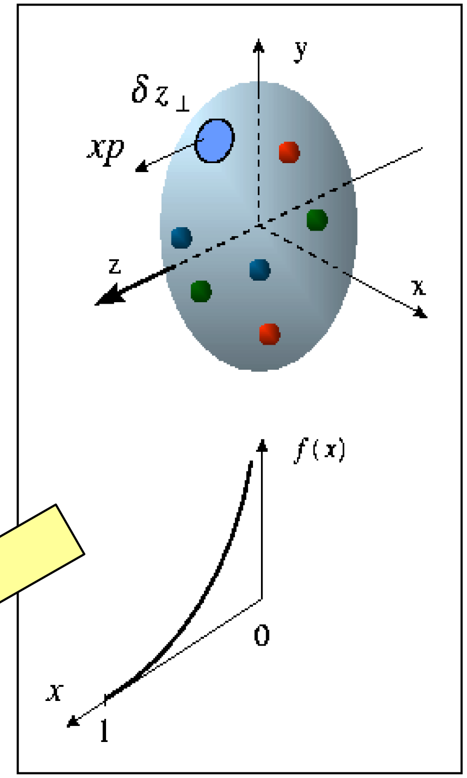


ELASTIC SCATTERING:
Proton form factors, transverse charge & current densities



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



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

Generalized Parton Distributions (GPDs)

- **GPDs interrelate the longitudinal and transverse momentum 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 $\rightarrow \tilde{H}\ \tilde{E}$
  - Vector mesons $\rightarrow H\ E$.

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

- At twist-3, 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.

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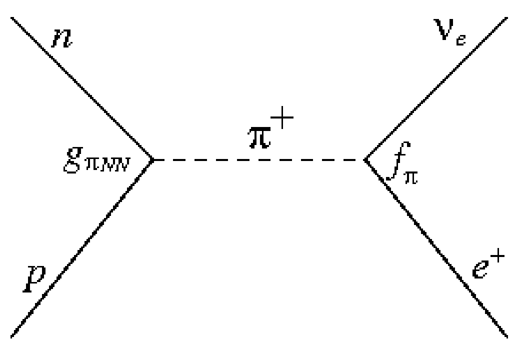
Spin-Flip GPD $\tilde{E}$

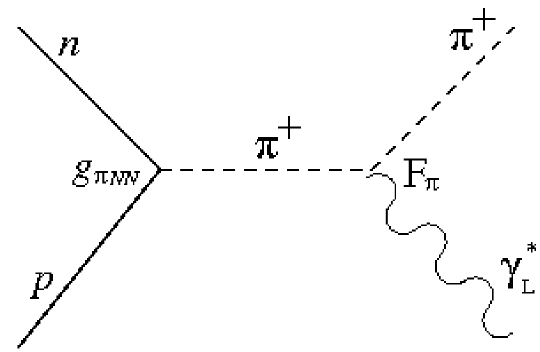
$$\sum_q e_q \int_{-1}^{+1} dx\, \tilde{E}^q(x,\xi,t) = G_P(t)$$

- **$\tilde{E}$ is not related to any already known parton distribution.**
- *$G_P(t)$ is highly uncertain because it is negligible at the momentum transfer of β-decay.*
  - *Due to PCAC, $G_P(t)$ receives contributions from $J^{PG}=0^{--}$ states.*
  - *$\tilde{E}$ is expected to contain an important pion pole contribution.*

Pion pole contribution to $G_P(t)$



Pion pole contribution to meson electroproduction at low –t.



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.

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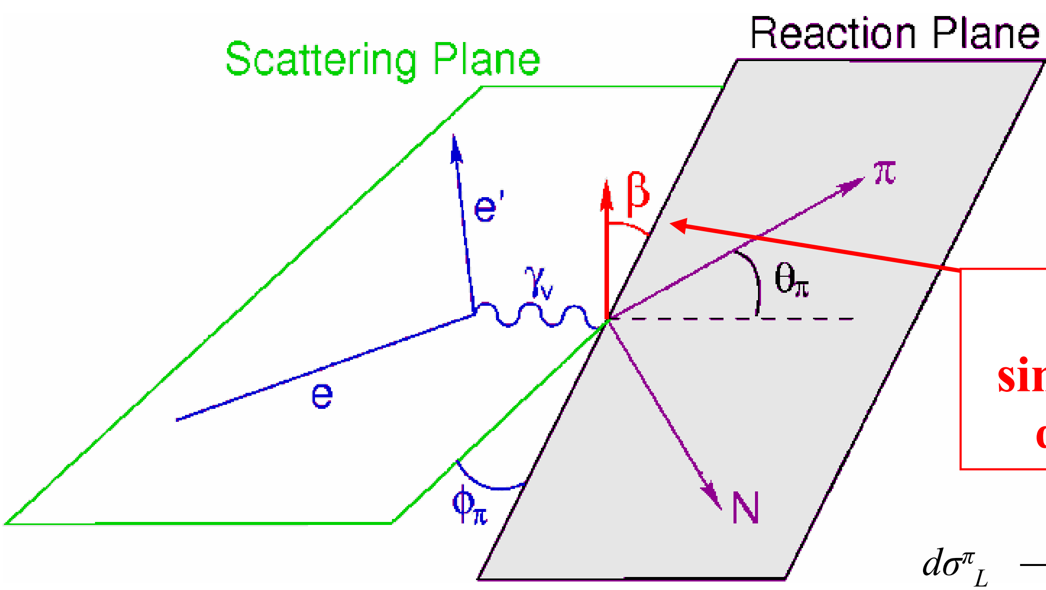
Exclusive π^- from Transversely Polarized Neutron

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

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

- **These experimental measurements can provide new nucleon structure information unlikely to be available from any other source.**



Fit
sinβ=sin(φ-φ$_S$)
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

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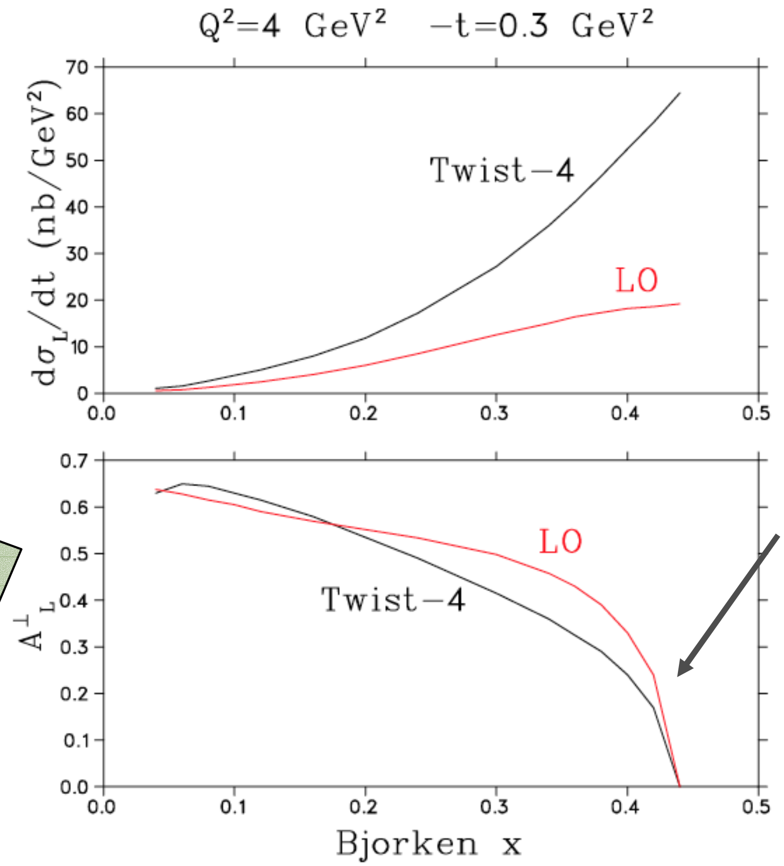
GPD information in $A_L^{\perp}$ may be particularly clean

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

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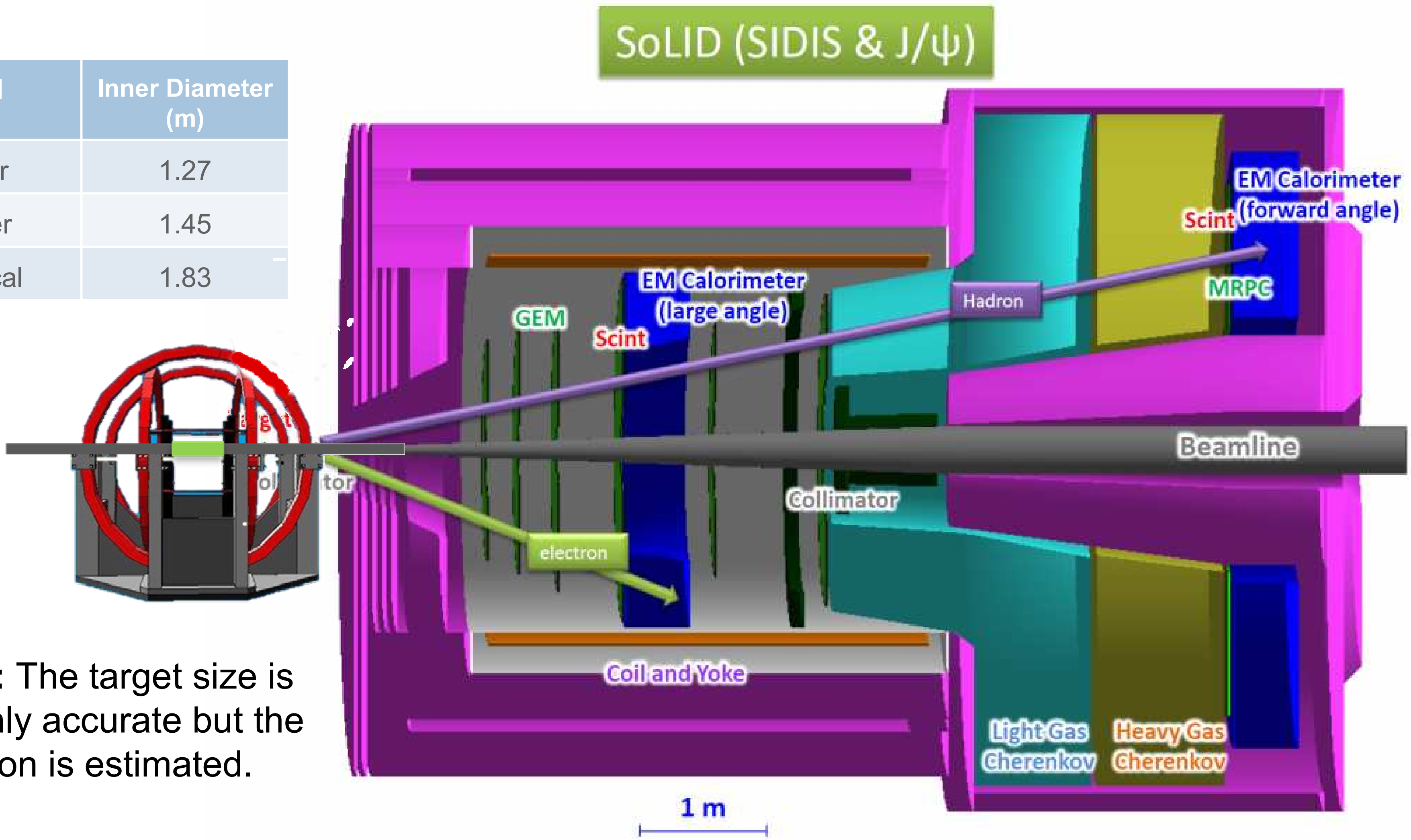
Measure DEMP with SoLID - Polarized ^{3}He

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

Coil	Inner Diameter (m)
Inner	1.27
Outer	1.45
Vertical	1.83



Note: The target size is roughly accurate but the location is estimated.

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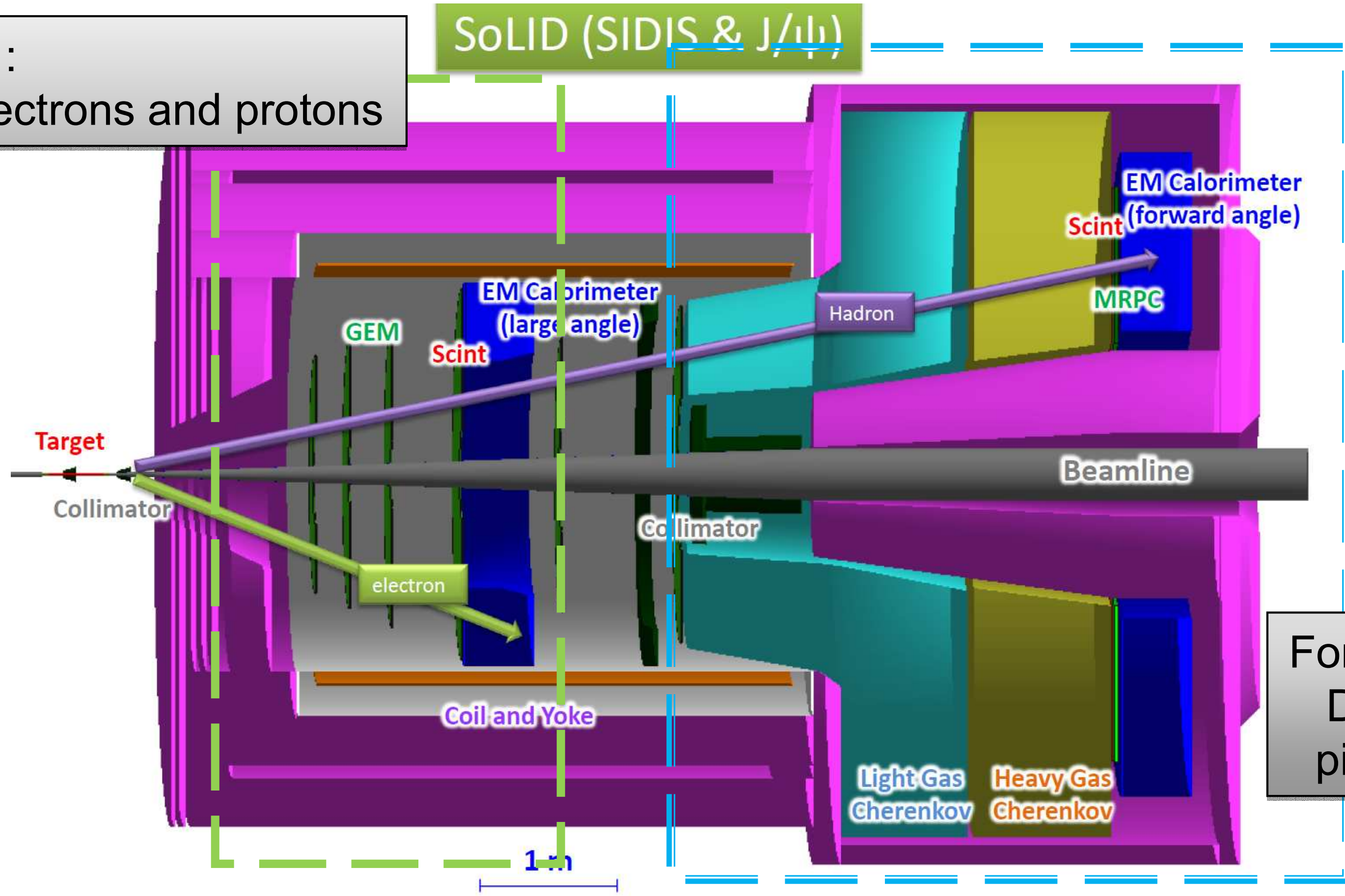
SoLID-SIDIS Detector Configuration

Large-Angle :
Detect electrons and protons



Forward-Angle :
Detect electrons
pions & protons

e/$\pi^{\pm}$ Coverage: →Forward Acceptance: ϕ: 2π, θ: 8°-14.8°, P: 1.0 – 7.0 GeV/c, for e/$\pi^{\pm}$
→Large Acceptance: ϕ : 2π, θ: 16°-24°, P: 3.5 – 7.0 GeV/c, for e only

Proton Coverage : →same to e/pi at FA and LA, except the momentum-range can be much lower

Resolution: $\delta P/P \sim 2\%$, $\theta \sim 0.6$mrad, $\phi \sim 5$mrad

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

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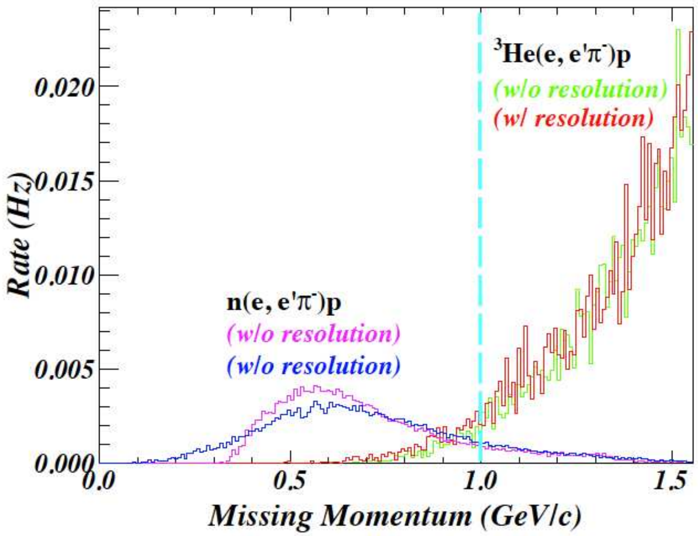
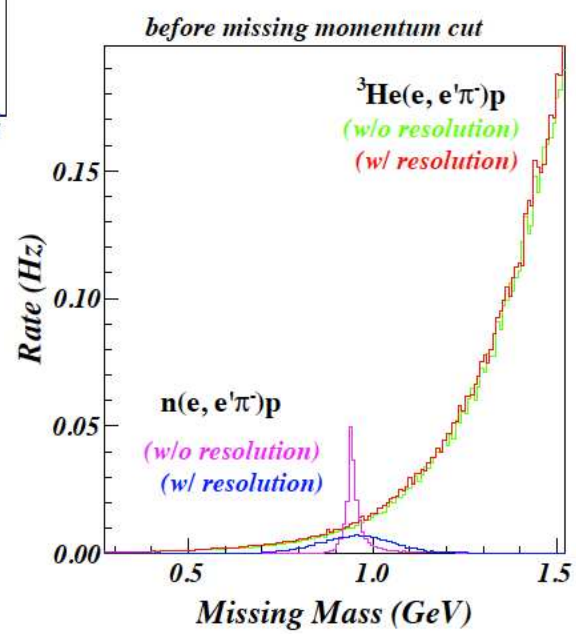
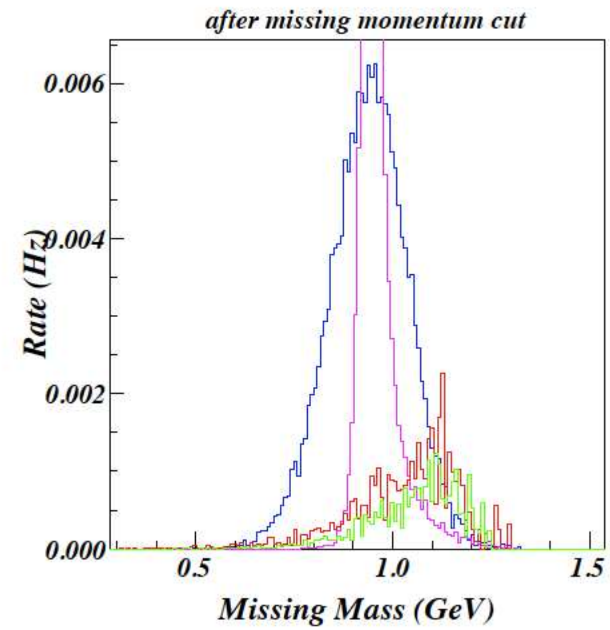
Projected Missing Mass Resolution

- **Analyze 3-track e π^- p events to isolate exclusive DEMP.**



- Missing Momenta are well separated for SIDIS and DEMP.
- Cutting P_{miss}<1.0 GeV/c, reject most of SIDIS background
- Background is expected to be even smaller, since SIDIS rate are overestimated





- Other backgrounds will be more uniform in the MM, asymmetries of which can be evaluated and corrected.
- Rest of random background will largely suppressed in the asymmetry.

SIDIS rate is overestimated since we assume all “X” in SIDIS contain a proton

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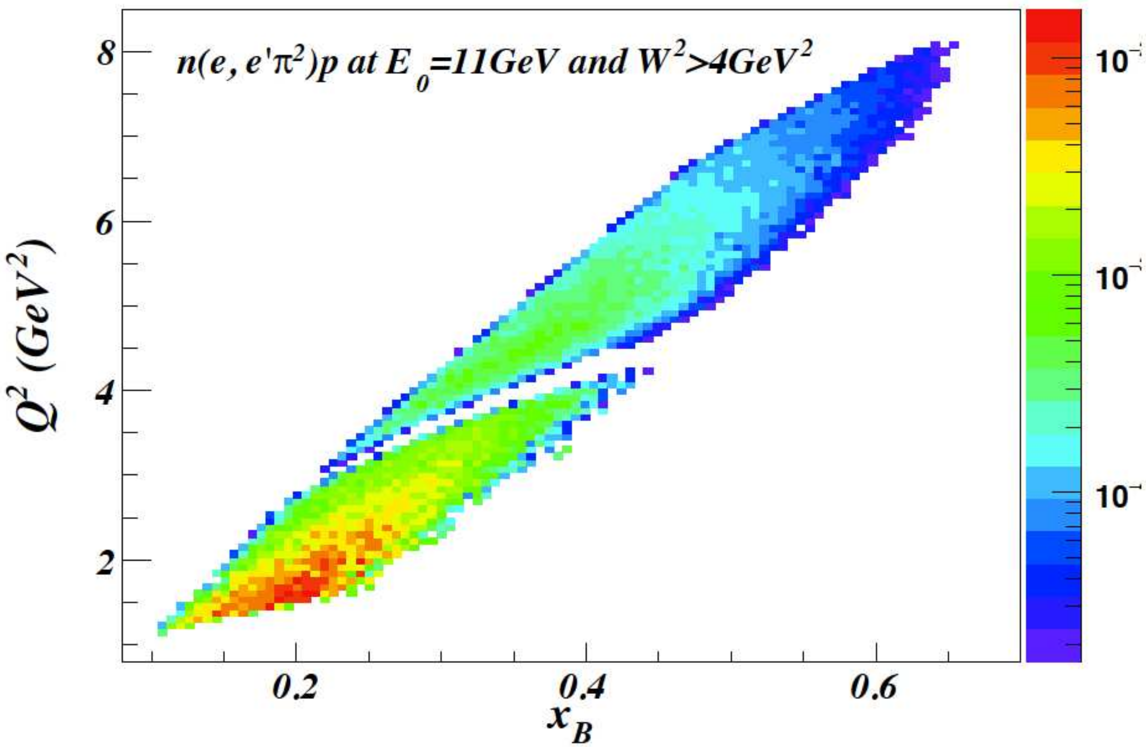
Projected Kinematic Coverage & Rates



Q^2 >1 GeV^2	Q^2 >4 GeV^2
DEMP: $\vec{n}(e, e'\pi^- p)$ Triple-Coincidence (Hz)	
4.22	0.20
SIDIS: $\vec{n}(e, e'\pi^-)X$ Double-Coincidence (Hz)	
1424.62	35.77

- Rates were estimated with an empirical model developed in Regina.
- Fermi-Motion and Energy-Loss are implemented in the generator.
- Good physics rates are at Q^2>4GeV^2:
- Dominant background is SIDIS events.

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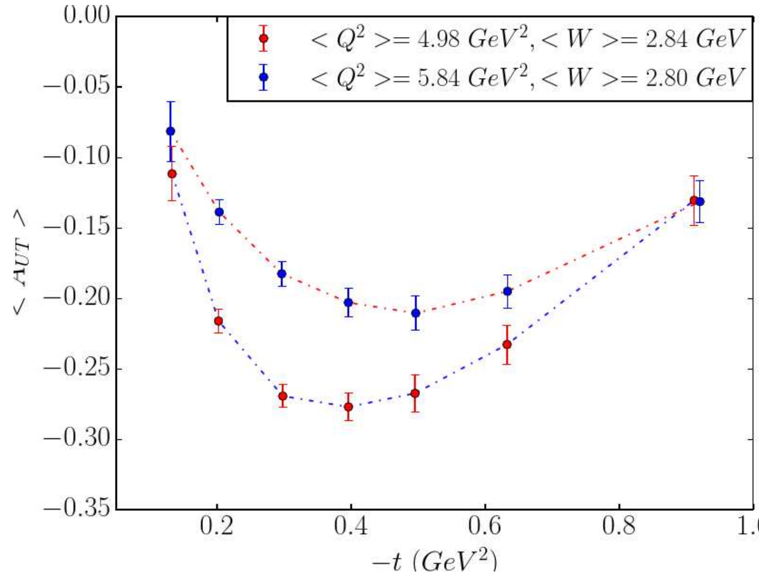
Exclusive π^- from Transversely Polarized Neutron

- Since an L/T separation is not possible with SoLID, the observed $A_{UT}^{sin(\varphi-\varphi S)}$ asymmetry will be diluted by the ratio of the longitudinal cross section to the unseparated cross section.
- This was also true for the pioneering HERMES measurements, which provided a valuable constraint to models for the $\tilde{E}$ GPD.
- $A_{UT}^{sin(\varphi S)}$ asymmetry can be extracted from the same data, providing powerful additional GPD model constraints.



Projected E12-10-006B data
→ analyze 2-track (e' π^-) data offline for recoil proton track.
→ Error bars are statistical only.

A wide *-t* coverage is needed to obtain a good understanding of the transverse single spin asymmetry, and the high luminosity capabilities of SoLID make it well-suited for this measurement.

E12-10-006B Run Group Proposal

(G.M. Huber, Z. Ahmed, Z. Ye, spokespersons)

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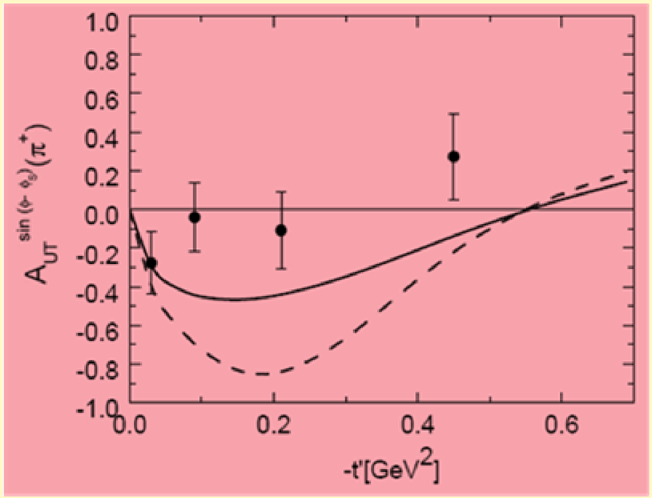
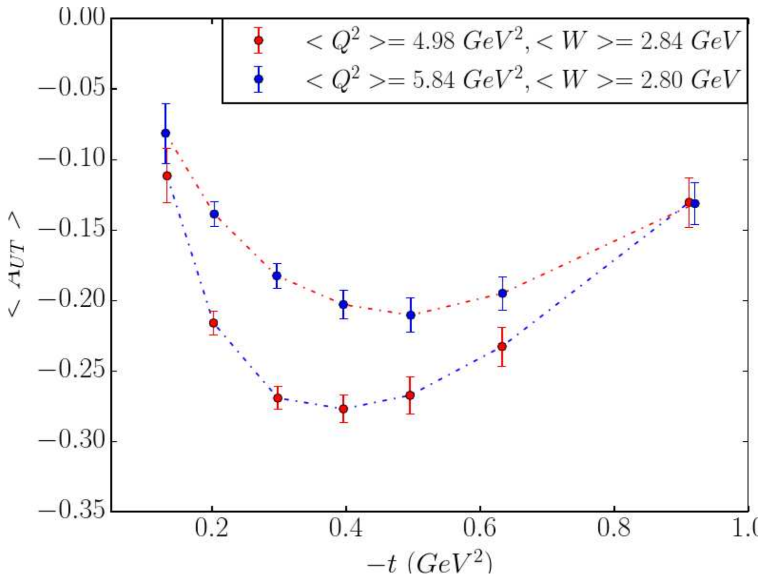
Exclusive π^- from Transversely Polarized Neutron

Compare with HERMES' p(e,e'π+)n results



A. Airapetian, et al., PLB 682(2010)345.



Projected E12-10-006B data
→ analyze 2-track (e' π^-) data offline for recoil proton track.
→ Error bars are statistical only.

SoLID Collaboration Review (July/16):

- "This proposal includes a number of key features that would likely make it successful with high impact"
- "the committee feels that the physics is exciting, and looks forward to an updated proposal"

A revised proposal incorporating more detailed simulations is in progress.

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SoLID HGC Prototyping

- We have recently received two equipment grants totaling C$99,960 (~US$77,300) for HGC prototyping.

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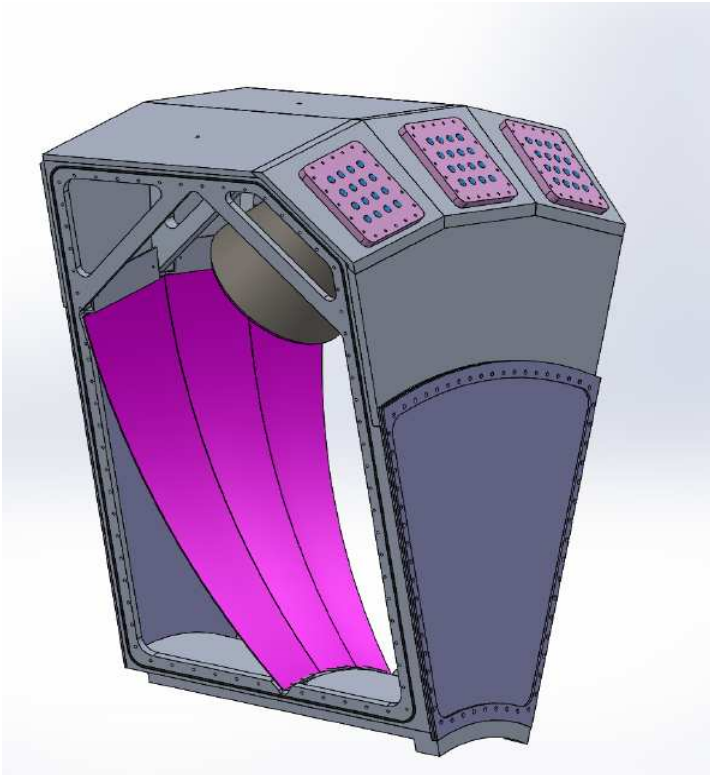
- The grants rely on an international partnership with our Duke University partners (MOU in progress).

The grants will permit us to construct one SoLID HGC module for testing.

Questions to be addressed:

- Enclosure deformation at 1.5 atm operating pressure (investigate design and metal alloy options).
- Performance of the O-ring seals against adjacent units.
- Performance of thin entrance window in terms of light and gas tightness (test several options).
- Optical performance.



Conceptual design by Gary Swift, Duke U.

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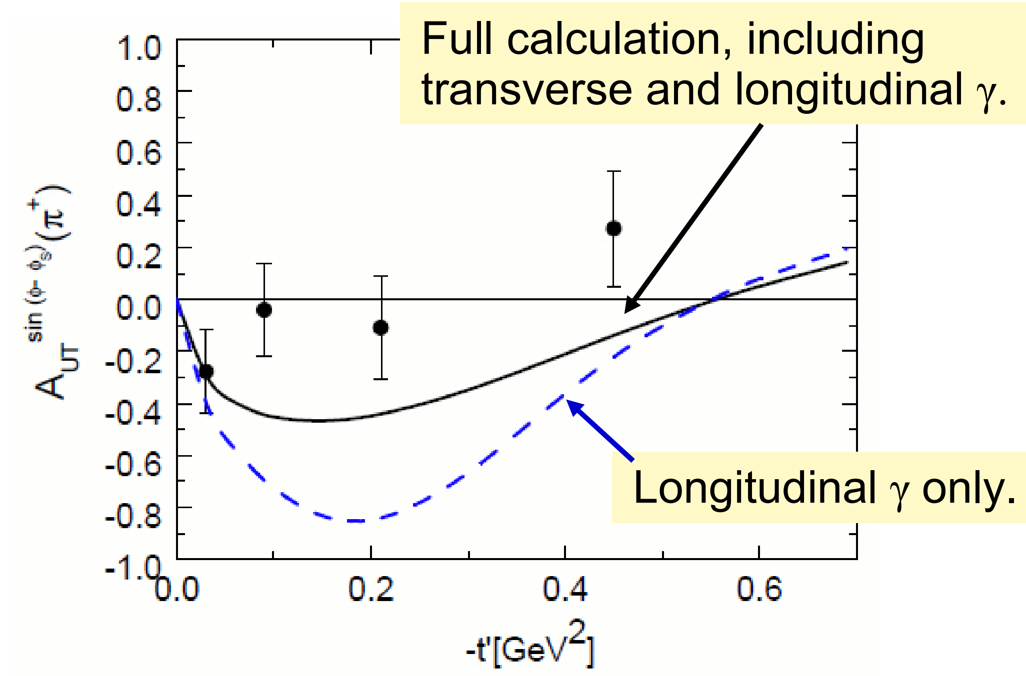
HERMES $\sin(\varphi-\varphi_S)$ Asymmetry

- 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.**
- For SoLID, the asymmetry dilution is expected to be less due to more favorable $0.55<\varepsilon<0.75$, vs HERMES $\varepsilon\approx0.35$.

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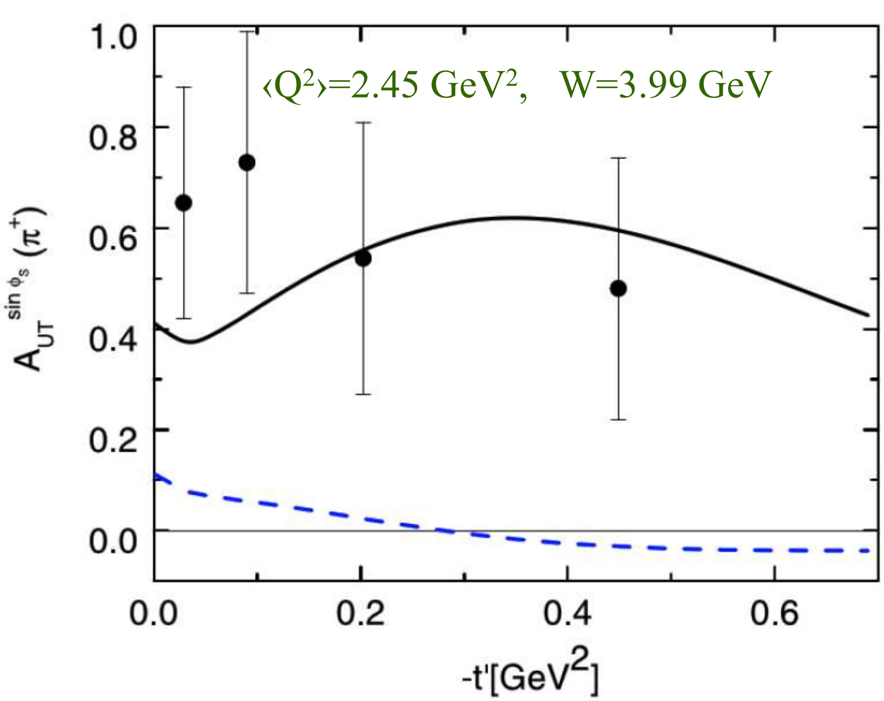
HERMES sinφ_S Asymmetry

- **May access contribution of transversity GPDs at small –t** *(P. Kroll)*

$$A_{UT}^{sin(\phi_S)} \sim \mathrm{Im}[M^*_{0+++} M_{0-0+} - M^*_{0-++} M_{0+0+}],$$

helicities: [pion, neutron, photon, proton]



S. Goloskokov et. al. [PLB 682(2010)345]

✓ $A_{UT}^{\sin(\phi_S)}$ only measures the LT interference, while $A_{UT}^{\sin(\phi-\phi_S)}$ has contributions from both LT and TT.

✓ $A_{UT}^{\sin(\phi_S)}$ provides additional GPD model constraints to aid in the interpretation of the unseparated asymmetry data. Any DEMP pion model needs to describe both $A_{UT}^{\sin(\phi_S)}$ and $A_{UT}^{\sin(\phi-\phi_S)}$ simultaneously.

✓ HERMES data shows large asymmetries which do not vanish at -t=0, indicating strong contribution from transversely polarized photons at rather large W and Q^2.

✓ Due to its transverse contributions, $A_{UT}^{\sin(\phi_S)}$ can easily be accessed in the unseparated SoLID experiment.

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Complementarity 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 $\theta=24^o$.
- High luminosity, particle ID and vertex resolution capabilities well matched to the experiment.
- **L/T separation is not possible**, the asymmetry is "diluted" by T, 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.
- Complementary to Hall C measurement.

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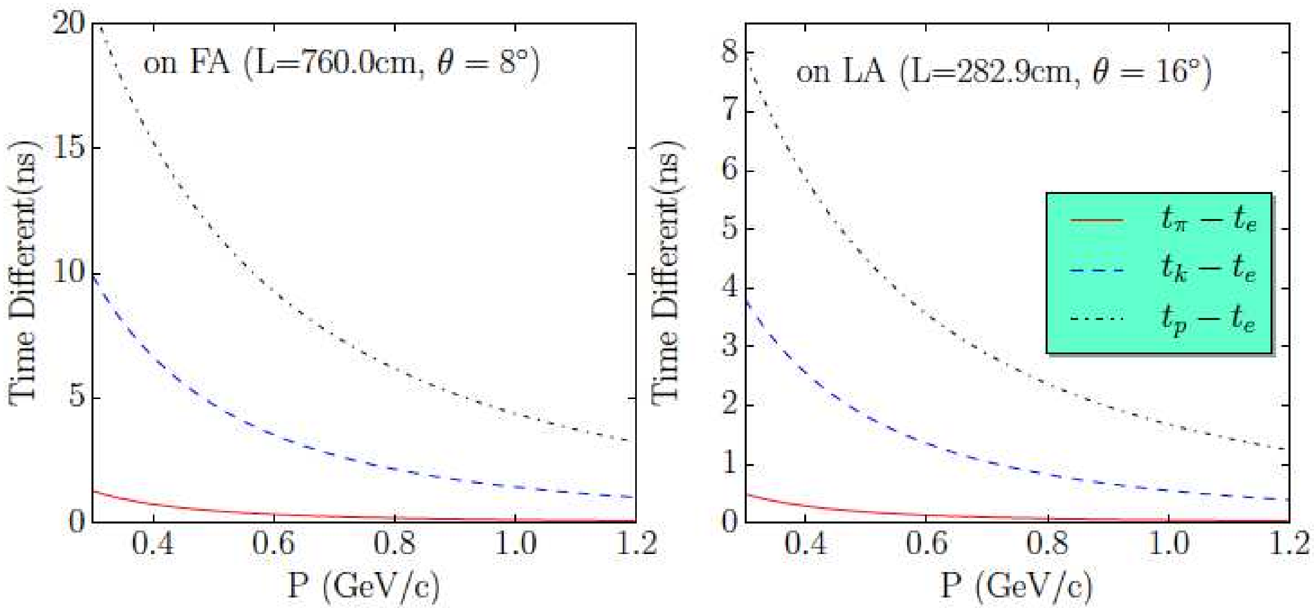
Proton Detection

- Use Time-Of-Flight as Proton-PID:

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



➢ Existing SoLID Timing Detectors:

✓ MRPC & FASPD at Forward-Angle: cover $8^0 \sim 14.8^0$; > 3ns separation

✓ LASPD at Large-Angle: cover $14^0 \sim 24^0$; > 1ns separation

➢ The current designed timing resolution is sufficient for proton identification using TOF

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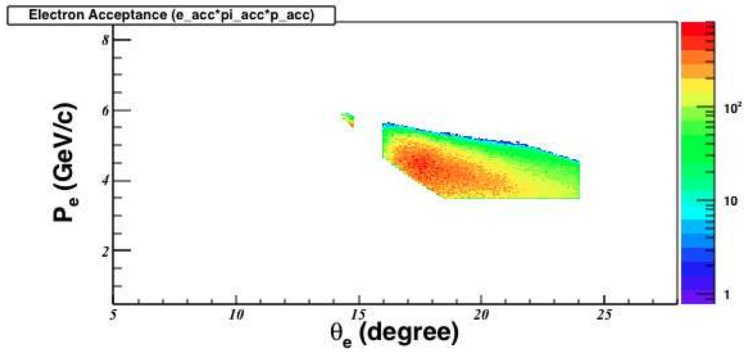
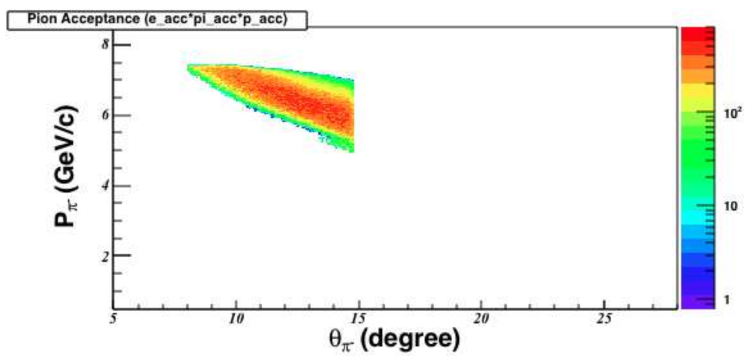
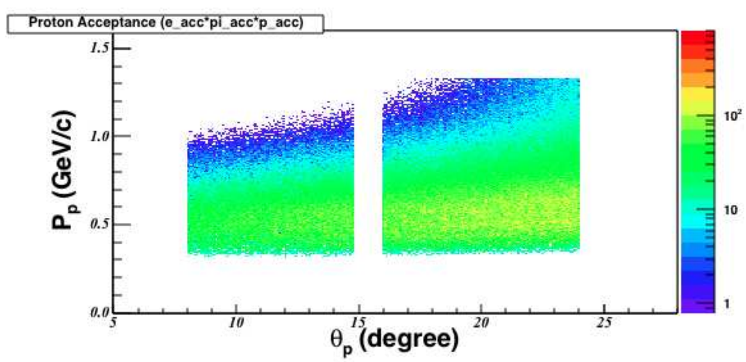
Projected Kinematic Coverage

(Cuts on Q^2>4 GeV^2 and W>2 GeV)

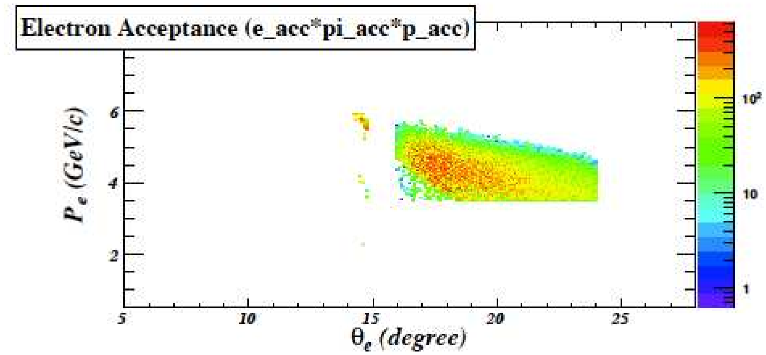
without Fermi-Motion & Energy Loss

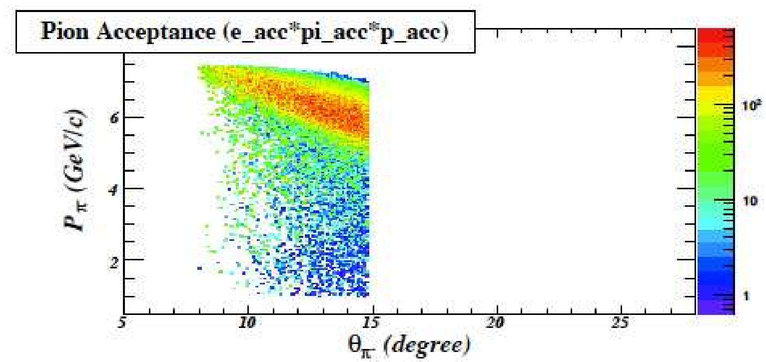


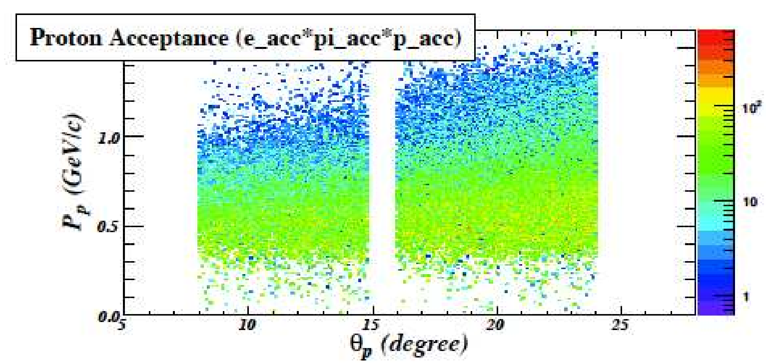




with Fermi-Motion & Energy Loss







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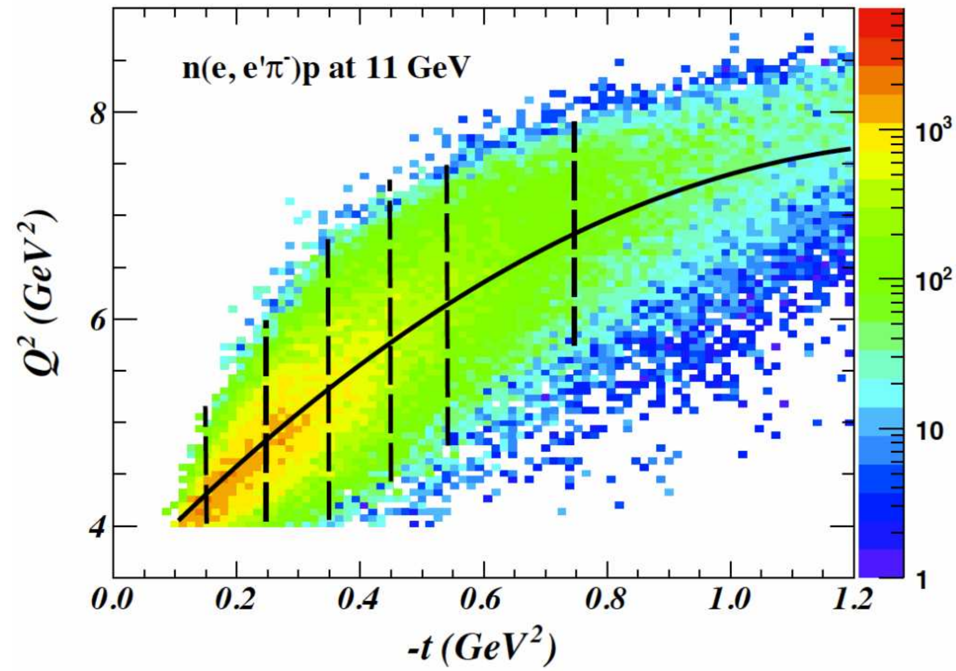
Projected Asymmetry Binning



- 2D binning on –t and Q^2
- Asymmetries are diluted due to not doing L/T separation:

from expected data:

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

from model:

$$A_{UT} = -f_{L/T} \cdot A_L^{\perp, model}$$

$$f_{L/T} = \frac{\epsilon \sigma_L}{\sigma_T + \epsilon \cdot \sigma_L},$$

$$\epsilon = 1/(1 + \frac{2\nu}{Q^2} tan^2(\theta))$$

- Stat. Error is given as:

$$\delta A_{UT} = \frac{1}{P \cdot \eta_n \cdot f} \sqrt{\frac{1 - (P \cdot < A_{UT} >)^2}{N_i^+ + N_i^-}},$$

P → He3 polarization 60%

η_n → Effective neutron 0.865

f → Dilution from protons (0.9 estimated)

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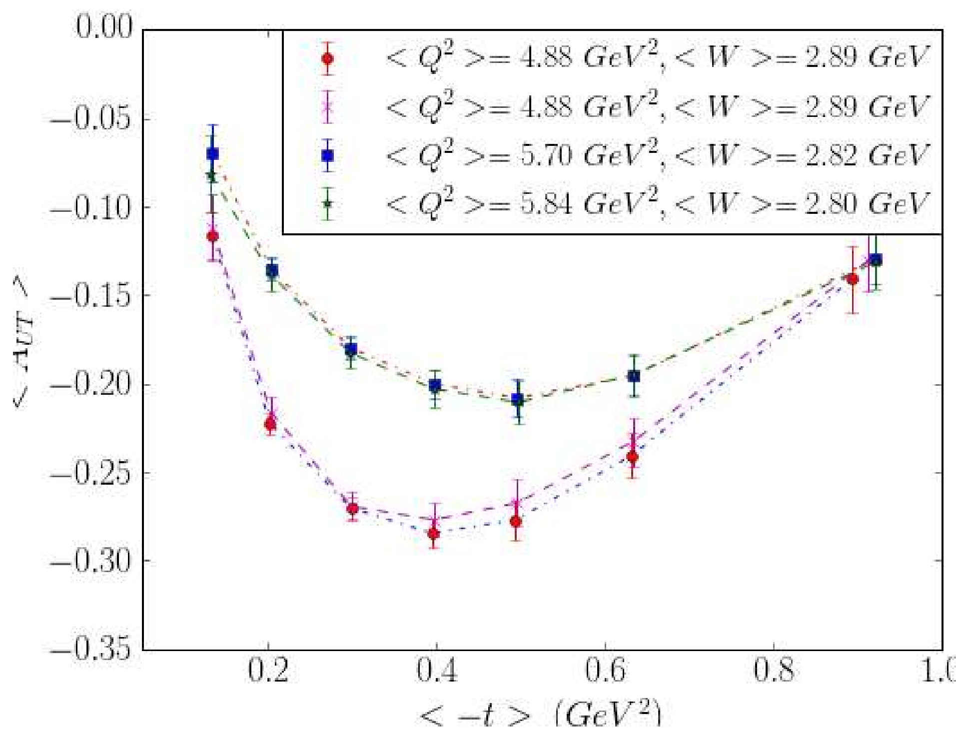
Projected Effect of ^{3}He Fermi Momentum

We turned off the features of Fermi-Motion and Energy Loss due to Bremsshlung Radiation in our generator, extract the projected results, which reveal very small difference compared with one with these effect.

Nucleon binding and off-shell effects can be evaluated later but are expected to be small as well since they are less strong than Fermi-Motion

w/ Fermi-Motion & Energy Loss



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