Argonne NATIONAL LABORATORY

E12-10-006B:
Deep Exclusive π^- Production with transversely polarized He3 using SoLID

A run-group proposal with E12-10-006

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proposal: https://userweb.jlab.org/~yez/Work/solid/solid_neutron_DEMP.pdf

Office of Nuclear Physics — Exploring Nuclear Matter - Quarks to Stars

U.S. DEPARTMENT OF ENERGY

Outline

- Physics Motivation
- Experimental Setup
- Projected Results
- Missing Mass
- Systematic Uncertainties
- Answers to Theory and TAC Comments
- Summary

Physics Motivation

▪ Generalized Parton Distribution:

- GPDs give the 3D spatial distributions of quarks and gluons in a nucleon

GPDs interrelate the longitudinal and transverse momentum structure of partons within a fast moving hadron.

- At leading twist-2, four quark chirality conserving GPDs $(H, E, \widetilde{H}, \tilde{E})$, 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 heli. flip	$E^{q,g}(x, \xi, t)$ spin avg. helicity flip
$\widetilde{H}^{q,g}(x, \xi, t)$ spin diff. no heli. flip	$\tilde{E}^{q,g}(x, \xi, t)$ spin diff. helicity flip

- Chiral-odd GPDs $(H_T, E_T, \widetilde{H}_T, \tilde{E}_T)$ at twist-3 offer a new way to access the transversity dependent quark content of nucleon

Physics Motivation

- **Generalized Parton Distribution:**

➢ Integral of transverse components reduces GPDs into one-dimensional PDF
➢ Access to Angular Momenta of quarks & gluons.

➢ 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.

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

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

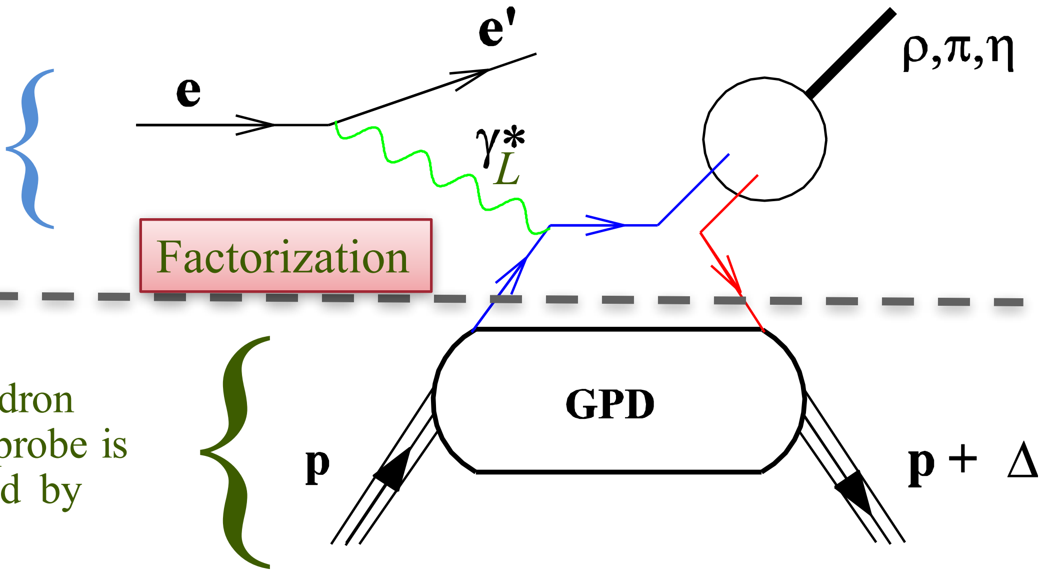
$$\sum_q e_q \int_{-1}^{+1} dx \widetilde{E}^q(x,\xi,t) = G_p(t)$$

Pseudoscalar form factor. Very poorly known.

Physics Motivation

- Factorization of Hard Reactions:

➢ Hard probe creates a small size $q\bar{q}$ or gluon configuration
(or a real photon in DVCS);
(described by pQCD)



➢ Non-perturbative part describes how hadron reacts to this configuration, or how the probe is transformed into hadrons; (parameterized by GPDs).

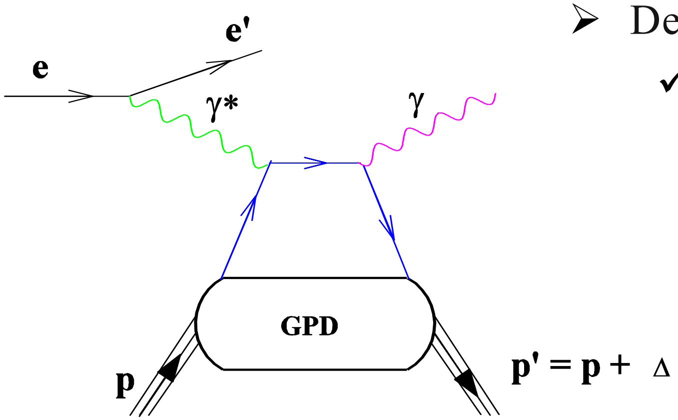
✓ Hard exclusive meson electroproduction first shown to be factorizable by Collins, Frankfurt & Strikman [PRD 56(1997)2982].

✓ Factorization applies when the γ^* is longitudinally polarized.

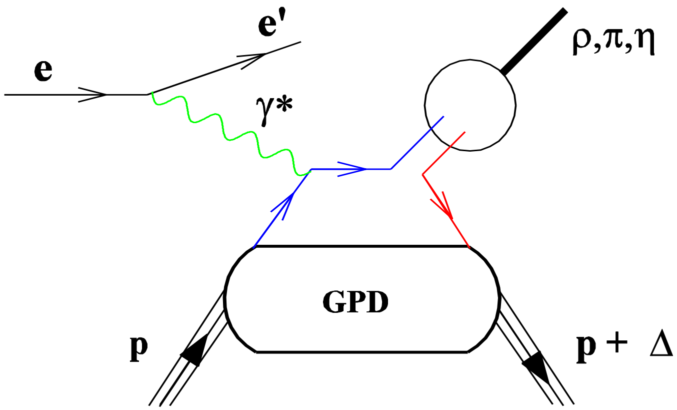
  ✓ corresponds to small size configuration compared to transversely polarized γ^*.

Physics Motivation

- Exclusive Hard Processes to probe GPDs:



- ➢ Deeply Virtual Compton Scattering (DVCS):
  - ✓ Sensitive to all four twist-2 GPDs (H, E, $\tilde{H}$ and $\tilde{E}$).



Virtual ***(DVMP)***

- ➢ Deep Exclusive Meson Production (DEMP): *at leading twist*
  - ✓ Vector mesons sensitive to spin-average H, E.
  - ✓ Pseudoscalar mesons sensitive to spin-difference , $\tilde{H}$ and $\tilde{E}$.
  - ✓ neutron+pseudoscalar DEMP is uniquely sensitive to $\tilde{E}$
  - ✓ DEMP is also sensitive to chiral-odd GPDs (H_T, E_T, $\tilde{H}_T$, $\tilde{E}_T$)

- ➢ Time-Like Compton Scattering (TCS), Double Deeply Virtual Compton Scattering (D-DVCS), etc.

Need a variety of Hard Exclusive Measurements to disentangle different GPDs

Physics Motivation

- Probe GPD-$\tilde{E}$ with DEMP:

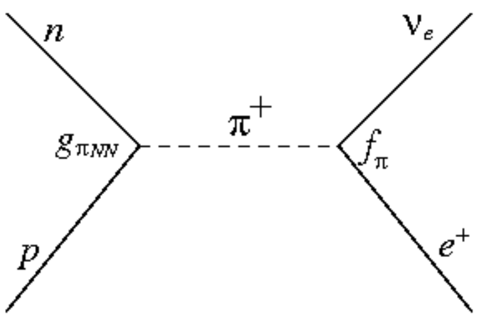
$$\sum_q e_q \int_{-1}^{+1} dx \tilde{E}^q(x,\xi,t) = G_p(t)$$

✓ GPD-$\tilde{E}$ is not related to an already known parton distribution.

✓ Experimental information can provide new nucleon structure info unlikely to be available from any other source.

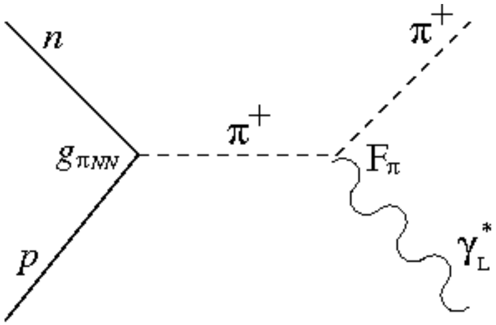
✓ $G_P(t)$, which is highly uncertain, contains an important pion pole contribution.

Pion pole contribution to $G_P(t)$



a)

Pion pole contribution to meson electroproduction at low –t.



b)

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

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

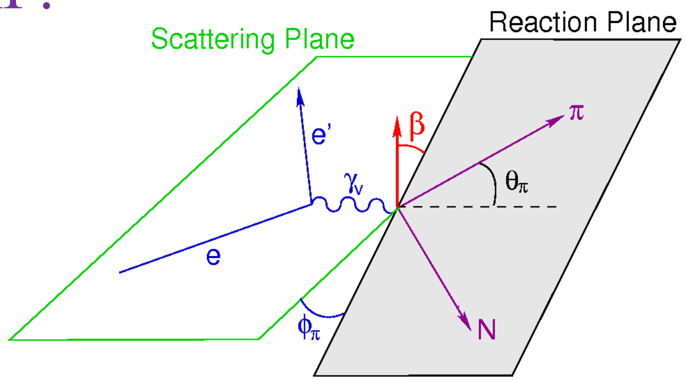
where F_π is the pion FF and ϕ_π the pion PDF.

Physics Motivation

- Target Single Spin Asymmetry in DEMP:

➢ Asymmetry with transversely polarized target and longitudinally polarized virtual photon

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



➢ Unpolarized Cross section

L/T Separation

$$2\pi\frac{d^2\sigma}{dtd\phi} = \epsilon\frac{d\sigma_{\mathrm{L}}}{dt} + \frac{d\sigma_{\mathrm{T}}}{dt} + \sqrt{2\epsilon(\epsilon+1)}\frac{d\sigma_{\mathrm{LT}}}{dt}\cos\phi + \epsilon\frac{d\sigma_{\mathrm{TT}}}{dt}\cos 2\phi$$

$\beta = \phi - \phi_S$

➢ Transversely polarized cross section:

$$A_L^{\perp} = A_{LT}^{\sin\beta} = -\frac{1}{P_\perp}\frac{2}{\pi}\frac{2\sigma_L^y}{\sigma_L}$$

$$\sigma_t = -P_\perp \sin\beta\,[\sigma_{TT}^y + 2\epsilon\,\sigma_L^y]$$
$$- P_\perp \sin\beta\,[\epsilon(\cos 2\phi_s \cos 2\beta + \sin 2\phi_s \sin 2\beta)\,\sigma_{TT'}^y]$$
$$- P_\perp \sin\beta\left[\sqrt{2\epsilon(1+\epsilon)}(\cos\phi_s\cos\beta + \sin\phi_s\sin\beta)\,\sigma_{LT}^y\right]$$
$$- P_\perp \cos\beta\left[\sqrt{2\epsilon(1+\epsilon)}(\sin\phi_s\sin\beta - \cos\phi_s\cos\beta)\,\sigma_{LT}^x\right]$$
$$- P_\perp \cos\beta\,[\epsilon(\sin 2\phi_s \sin 2\beta - \cos 2\phi_s \cos 2\beta)\,\sigma_{TT}^x]$$

sin β module

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

$\beta = \phi - \phi_S$ angle between transversely polarized target vector and the reaction plane.

Physics Motivation

- Target Single Spin Asymmetry in DEMP:

➢ Frankfurt et al. have shown $A_L^{\perp}$ vanishes if $\tilde{E}$ is zero [PRD 60(1999)014010].

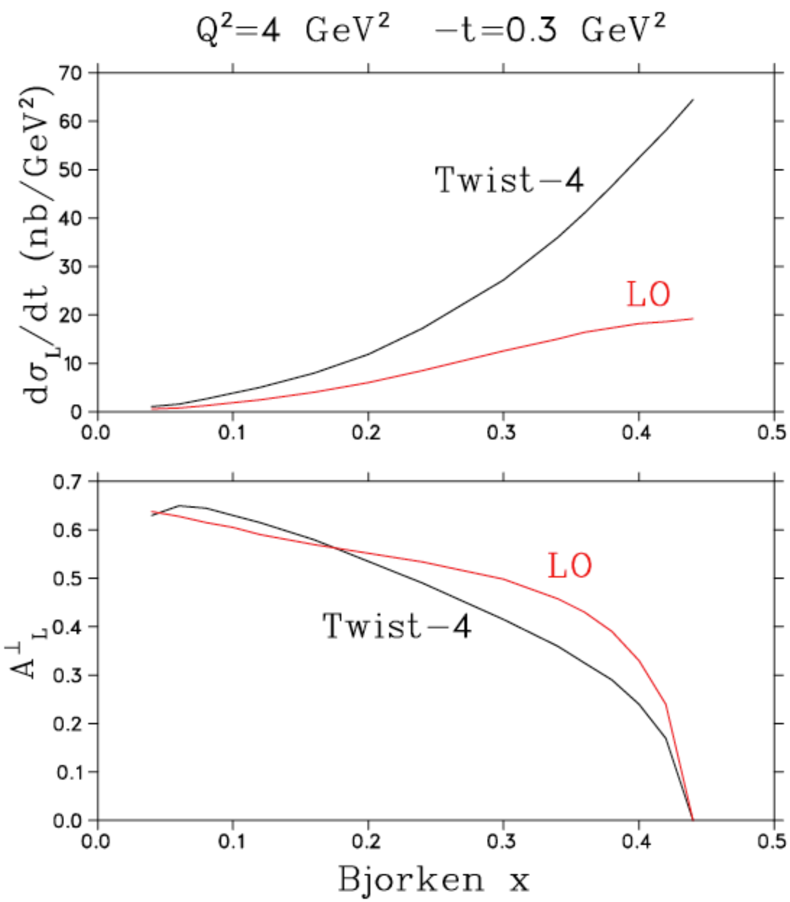
- If $\tilde{E} \neq 0$, the asymmetry will display a sinβ dependence.
- Higher order corrections, which may be significant at low Q^2 for σ_L, likely cancel in $A_L^{\perp}$.

➢ Belitsky and Müller calculations:

✓ At Q^2=10 GeV^2, Twist-4 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).

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.



Physics Motivation

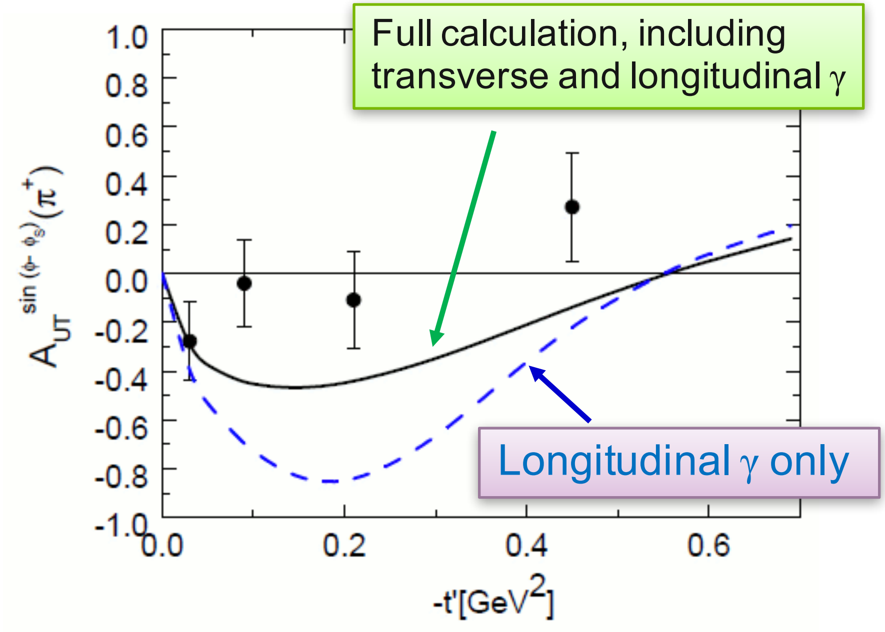
- Target Single Spin Asymmetry in DEMP:

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

HERMES Data:

➢Exclusive π^+ production by scattering 27.6 GeV positrons or electrons from transverse polarized ^1H without L/T separation. [PLB 682(2010)345]

➢$\langle x_B \rangle$=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]
- ✓ Asymmetries are "diluted" w/o LT separation
- ✓ Because no factorization theorems exist for exclusive π production by transverse photons, these data cannot be simply interpreted in terms of GPDs.

Physics Motivation

- Target Single Spin Asymmetry in DEMP:

➢ $A_{UT}^{\sin(\phi_S)}$ may access contribution of transversity GPDs (e.g. H_T) at small –t *(P. Koll)*

helicities: [pion, neutron, photon, proton]

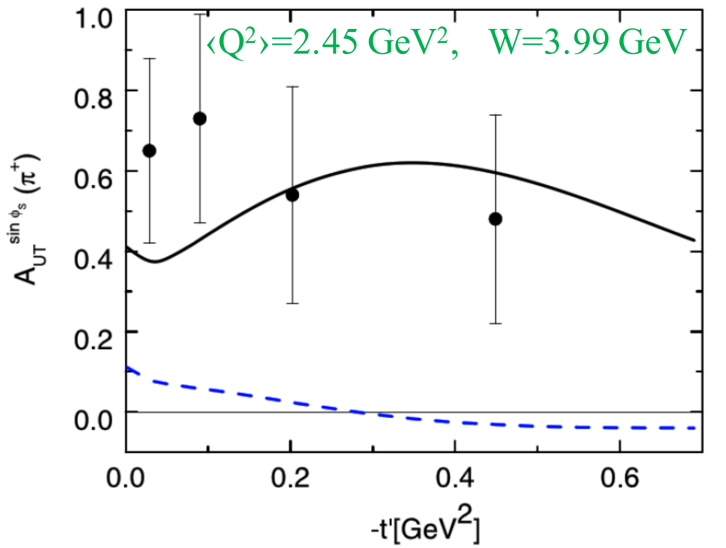
$$A_{UT}^{sin(\phi_S)} \sim \text{Im}[M^*_{0+++} M_{0-0+} - M^*_{0-++} M_{0+0+}],$$

$$\gamma^*_T \rightarrow M_L$$

$$\mathcal{M}_{0-,++} = e_0 \sqrt{1-\xi^2} \int dx \mathcal{H}_{0-,++} H_T,$$

$$\mathcal{M}_{0+,\pm+} = -e_0 \frac{\sqrt{t_{\min} - t}}{4m} \int dx \mathcal{H}_{0-,++} \bar{E}_T.$$

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



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

✓ 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.

✓ Can be easily be accessed in the unseparated SoLID experiment.

Physics Motivation

- Complementarity of SoLID and SHMS+HMS Experiments

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° 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, polar angle θ= 8° up to 24° for e and π
- 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.

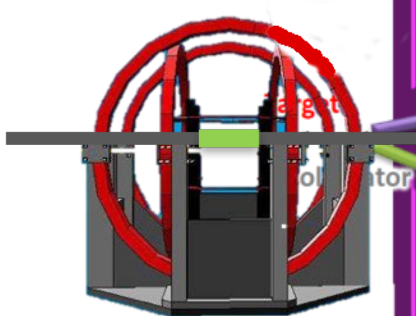
Experimental Setup

$\vec{n}(e, e'\pi^-)p$:with transversely polarized He3

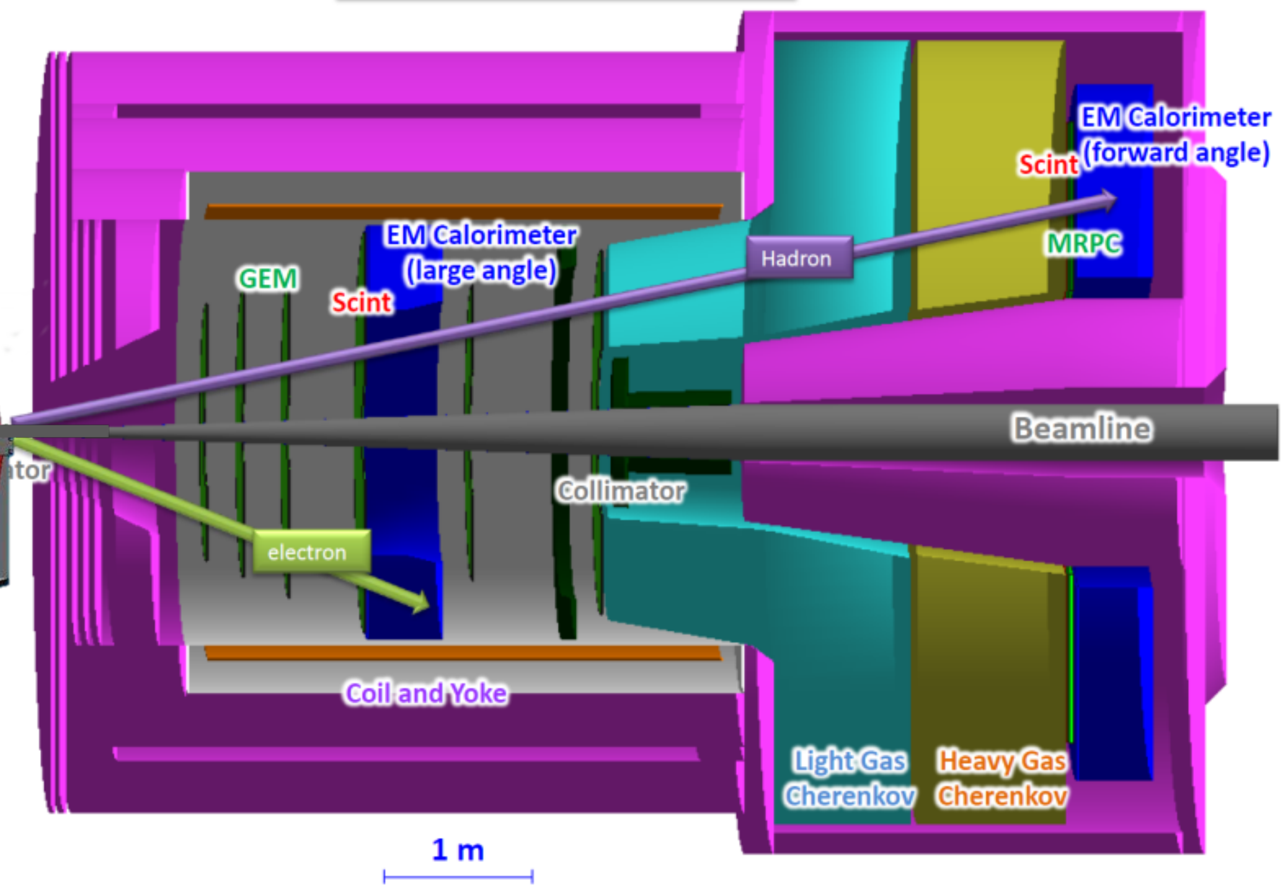
$$< A_{UT} >= \frac{1}{P \cdot \eta_n \cdot f} \frac{N^+ - N^-}{N^+ + N^-}$$

Run in parallel with E12-10-006:
E0 = 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

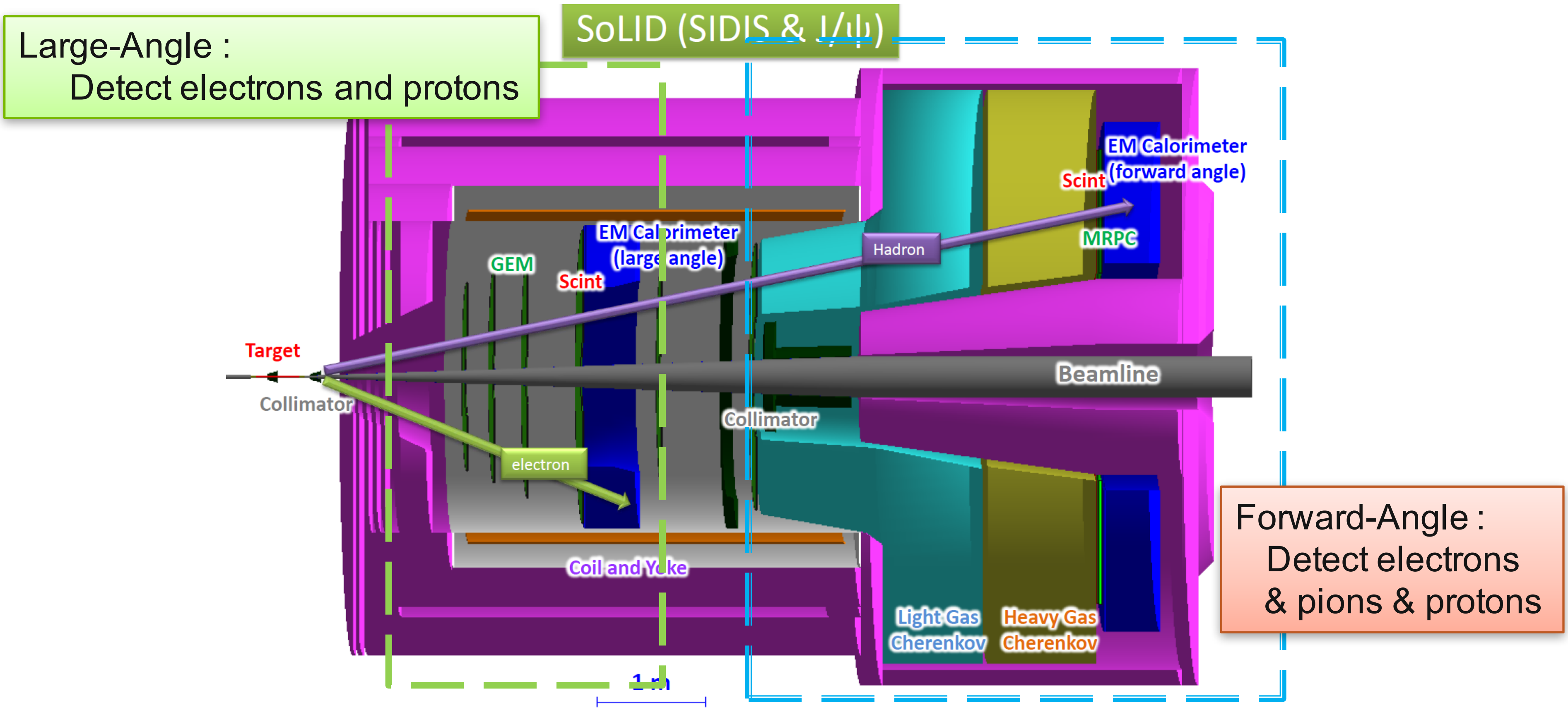


SoLID (SIDIS & J/ψ)



Note: The target size is roughly close to real but the location is estimated.

Experimental Setup



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

→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

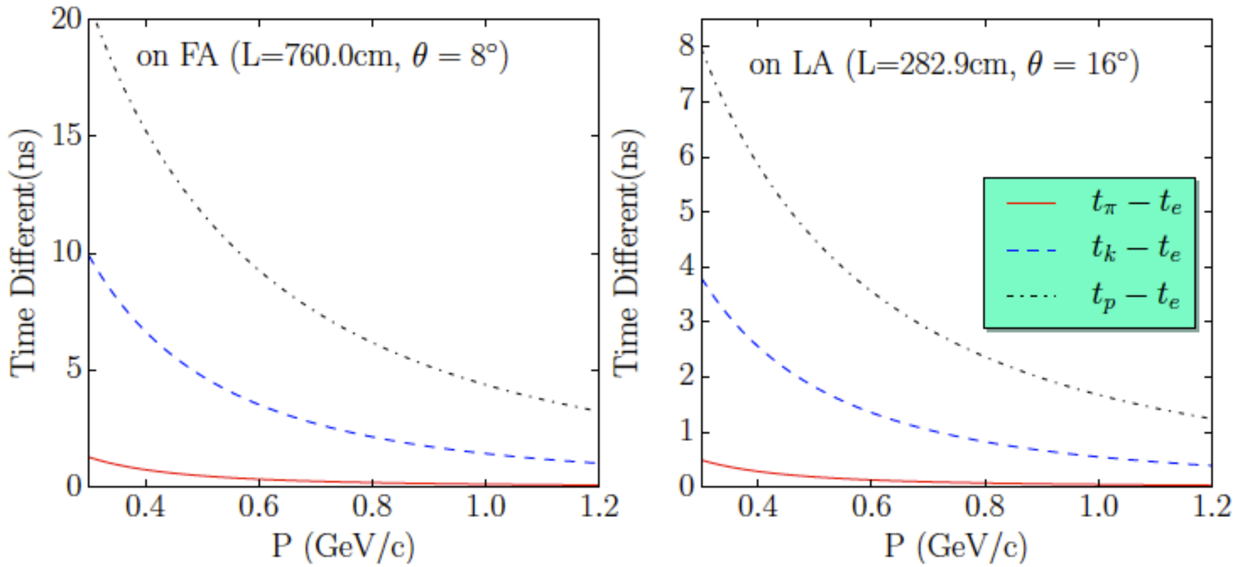
Resolution: δP/P ~ 2%, θ ~ 0.6mrad, ϕ ~ 5mrad

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

Experimental Setup

- Proton Detection: ***Time-Of-Flight***

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

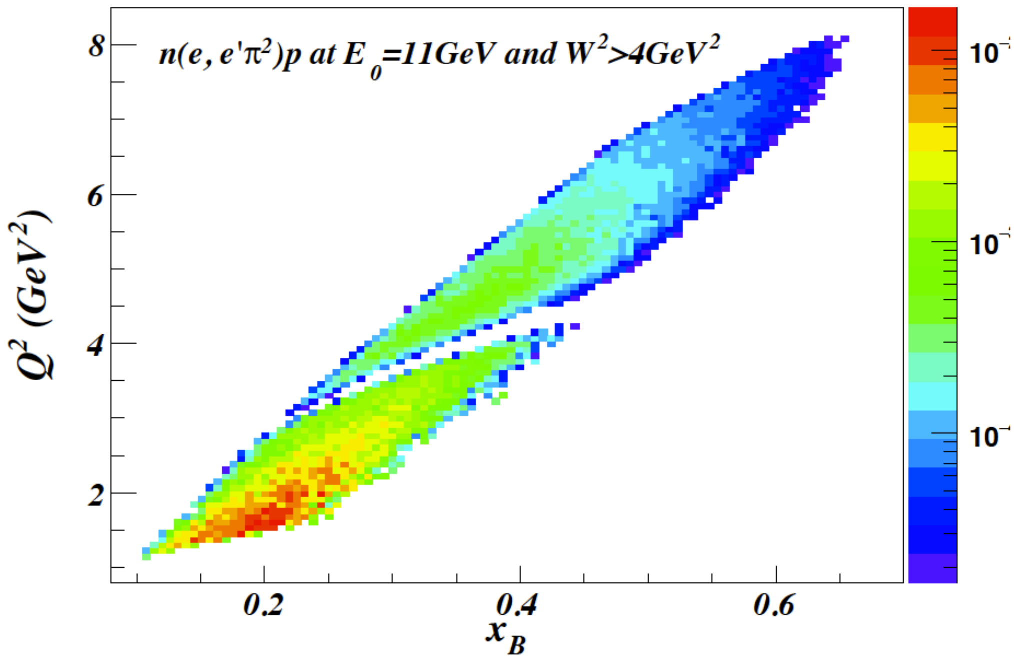


- Existing SoLID Timing Detectors:
  - ✓ MRPC & FASPD at Forward-Angle: cover $8^0 \sim 14.8^0$; > 3ns separation
  - ✓ LASPD at Large-Angle: cover $14^0 \sim 24^0$; > 1ns separation

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

Projected Results

- Kinematic & Rates:



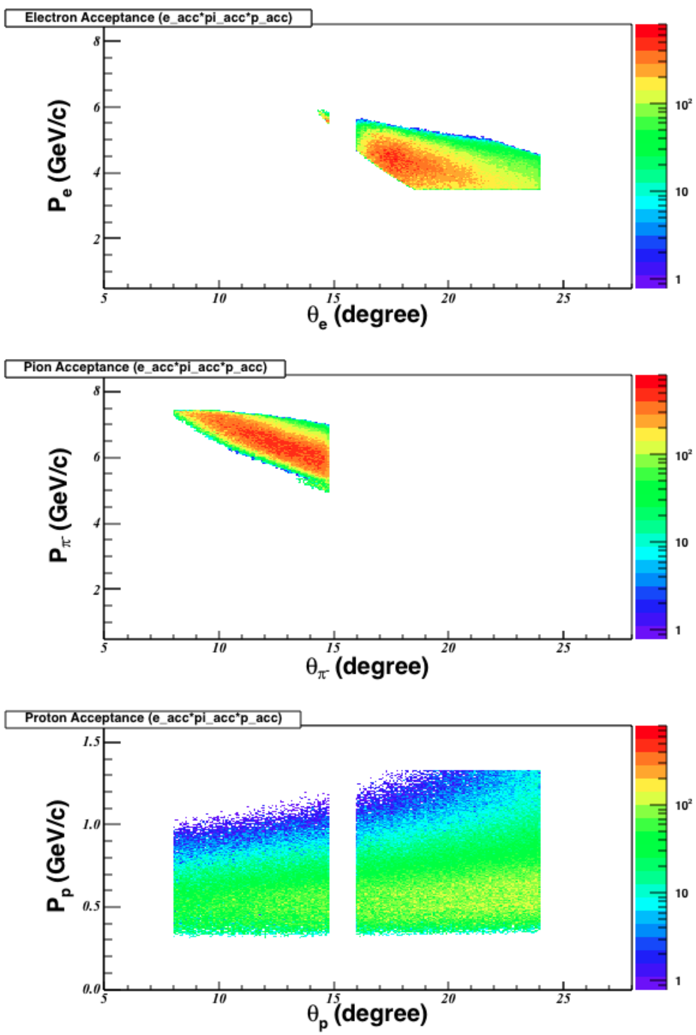
Q^2 >1 GeV^2	Q^2 >4 GeV^2
DEMP: $\vec{n}(e, e'\pi^- p)$ Triple-Coincidence (Hz)	
4.22	0.20
SIDIS: $\vec{n}(e, e'\pi^-)X$ Double-Coincidence (Hz)	
1424.62	35.77

- Rates were estimated with a model developed by Garth & Zafar.
- Fermi-Motion and Energy-Loss are implemented in the generator.
- Good physics rates are at Q^2>4GeV^2:
- Dominated background are SIDIS events

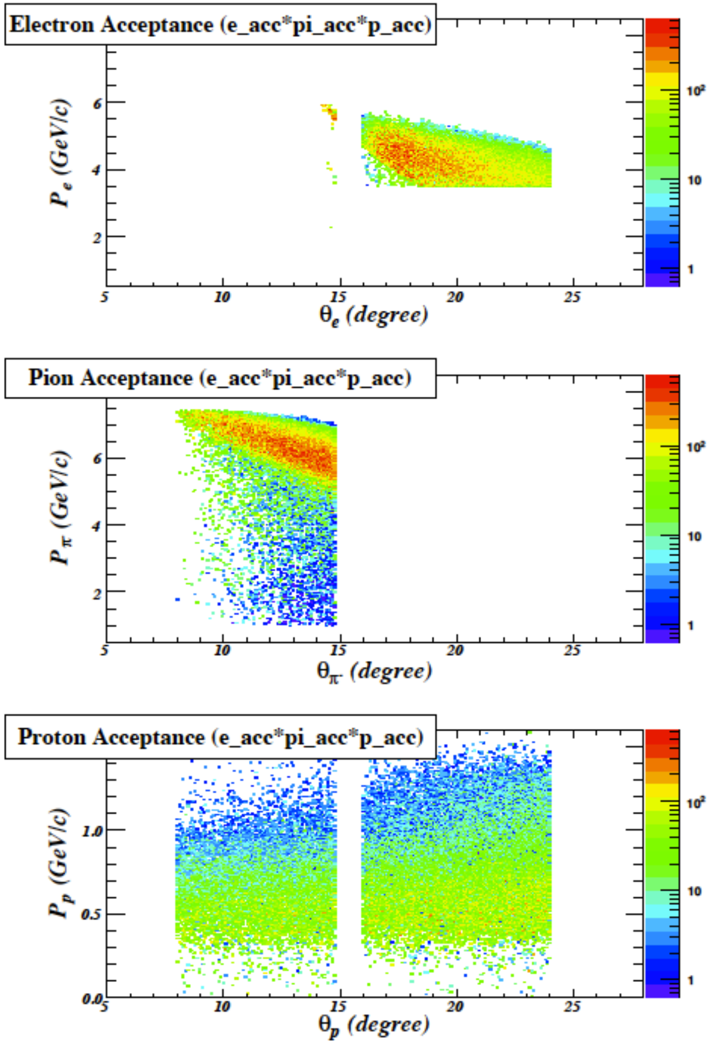
Projected Results

- Acceptance: (Cuts on Q2>4 GeV^2 and W>2 GeV)

without Fermi-Motion & Energy Loss



with Fermi-Motion & Energy Loss



Projected Results

- Asymmetry Binning:

➢ 2D binning on –t and Q^2

➢ Asymmetries are diluted due to not doing L/T separation:

from expected data:

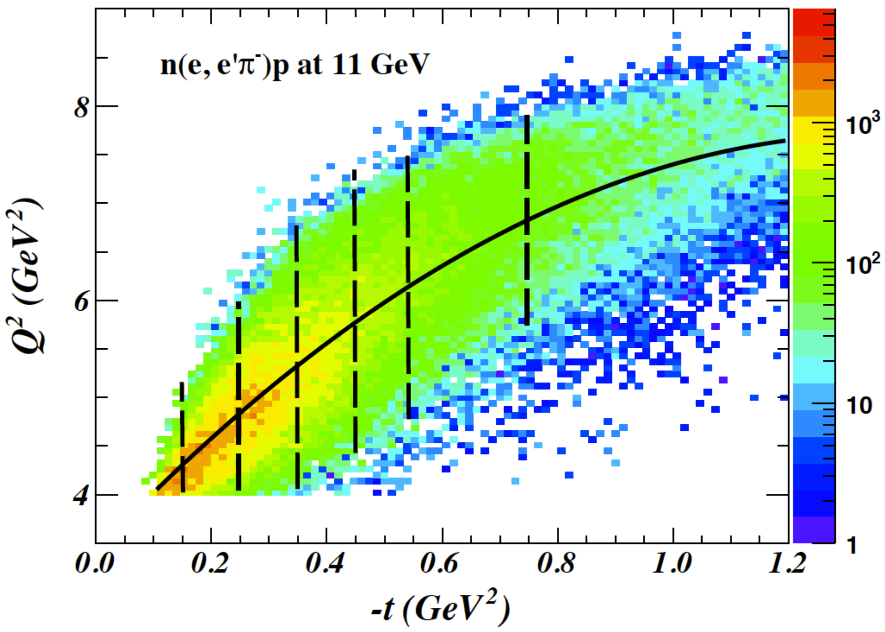
$$< A_{UT} >= \frac{1}{P \cdot \eta_n \cdot f} \frac{N^+ - N^-}{N^+ + N^-}.$$

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:

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

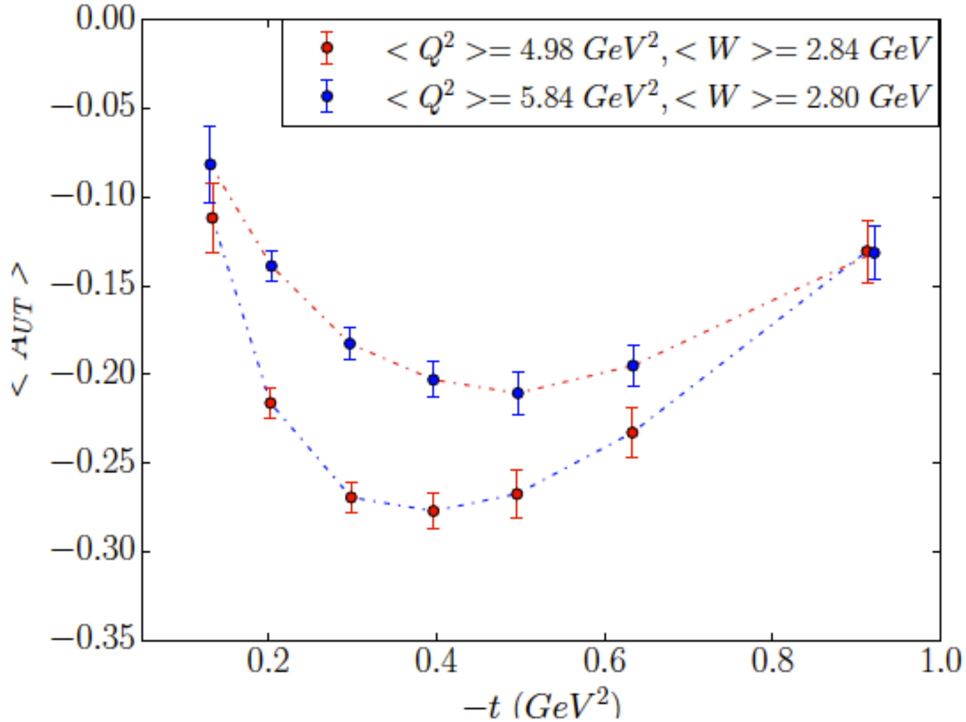
P → He3 polarization 60%

η_n → Effective neutron 0.865

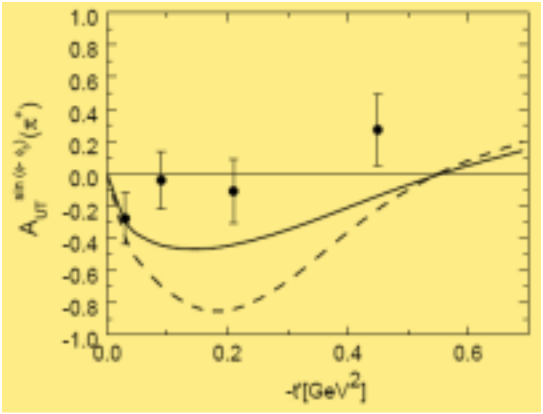
f → Dilution from protons (0.9 estimated)

Projected Results

- Projected Asymmetries:



Compared with HERMES' results



➢ Error bars only include statistical uncertainties
Systematic uncertainties are expected to be similar to SIDIS

Missing Mass

- Exclusivity of DEMP Events

  - With Proton detection, most of background events can be suppressed
  - Major background would be SIDIS events

    from (a) Protons in "X",

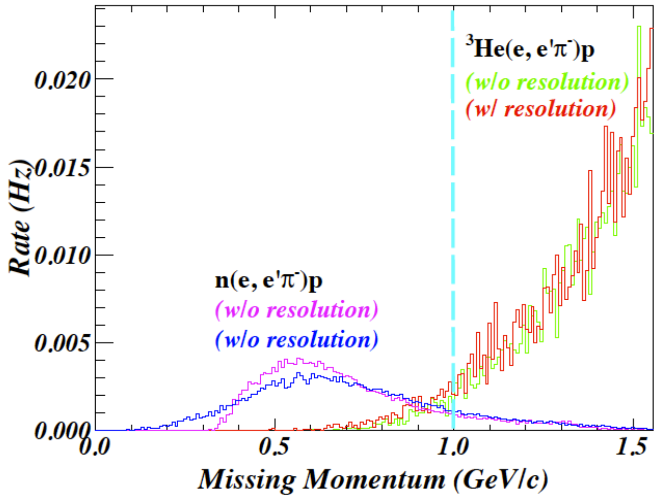
    (b) Accidental coincidence of SIDIS events with protons in all background sources

  - Reconstructing Missing Momentum and Missing Mass to further suppress background during offline analysis.

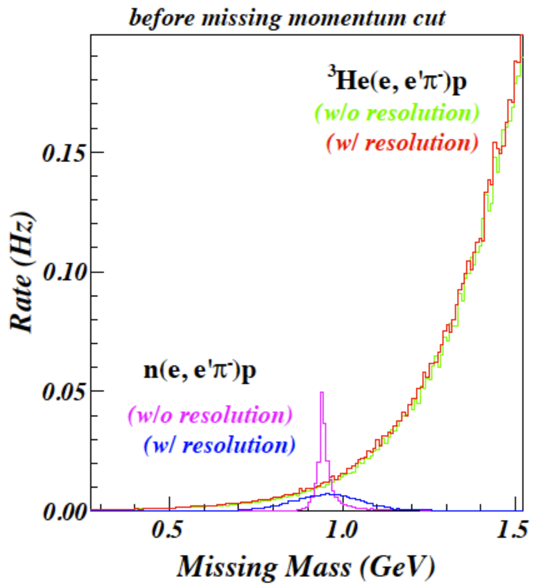
- ✓ Assuming all "X" in SIDIS contain protons (hard to estimate the real branching-ratio)
- ✓ Fold in detector resolutions: $\frac{\delta P}{P} = \frac{2\%}{\sqrt{E}}, \delta\theta = 0.6\ mrad, \delta\phi = 5\ mrad$
- ✓ Fermi Motion and Radiative Effect have been taken into account

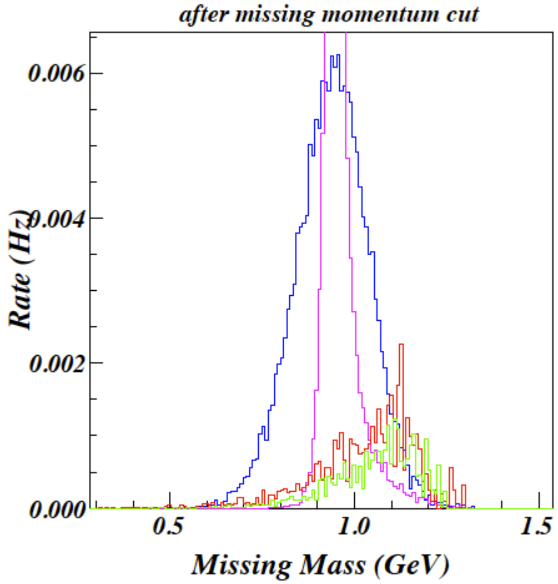
Missing Mass

- Exclusivity of DEMP Events



- ✓ 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 still overestimated since we assume all "X" in SIDIS contain a proton

Systematic Uncertainties

- Detector-wide, DEMP measurement shares the same systematic uncertainties with SIDIS experiments:

Sources	Relative Value
Beam Polarization	2%
Target Polarization	3%
Dilution Factor	1%
Nuclear Effect	$< 4\%$
Acceptance	3%
Radiation Correction	2%
Background Contamination	$< 5\%$

Table 5: Expected systematic errors.

- Other sources of uncertainties are still under estimation.

Theory Comments

This proposal is meant to complement proposal PR12-12-005, that envisaged a Rosenbluth-type separation of the $A_L^{\perp} \propto \tilde{E}$ contribution to the $A_{UT}^{\sin(\phi-\phi_s)}$ asymmetry. Achieving the desired statistics for a precise enough separation requires, however, the development of a new generation polarized Helium target (currently being developed at New Hampshire U.) to provide the required high luminosity levels. Since this is a completely new technology, no timeline has been established for that experiment. This proposal aims, instead, at providing shorter term results than PR12-12-005, with an unseparated measurement, that builds on pioneering HERMES results in exclusive π^+ production on proton targets and does not need additional beam time compared to E12-10-006. It is thus an interesting measurement, worth pursuing.

- Answer to the PAC Theory Comments:

1) Q: The authors may want, however, to expand on possible contamination arising from Δ^{++} production on bound protons, and subsequent decay into π^+ and p.

We applied very strict cuts, W>2 GeV, which will largely suppress contributions from all resonances, including Δ^0, Δ^{++} *etc*

Theory Comments

- Answer to the PAC Theory Comments:

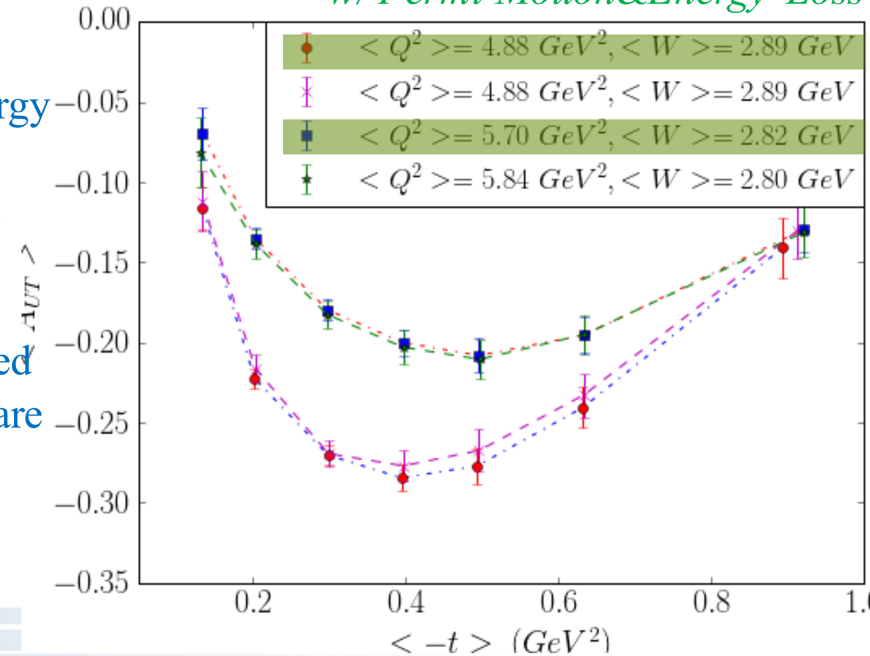
2) Q:

how large and in which kinematics they see a difference. Having evidence of non-negligible nuclear effects at an early stage would encourage theorists to extend now their calculations from inclusive to exclusive measurements for a timely and correct utilization of the data the authors propose to take. It would also be helpful to elaborate on the possible corrections in addition to Fermi motion, such as from binding and nucleon off-shell effects, as well as corrections beyond the impulse approximation from rescattering or final state interactions of the detected proton.

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



TAC Comments

This is a run group proposal with experiment E12-10-006 using the SoLID spectrometer. It does not require any modifications or additions to the equipment planned for E12-10-006. It does not require any change to the trigger for that experiment, as long as the DAQ is not configured to reject tracks not participating in the trigger.

- Answer to the TAC:

1. The simulations for this measurement may benefit from tracking DEMP events through the full SoLID Geant4 simulation, particularly for kinematics with the lowest momentum protons (300 MeV/c).

- A full Geant4 simulation can be done with other proposals in the near future
- We just need to identify proton events but do not require high resolution detection (e.g., momenta and angles)

Summary

- GPDs provide new information of the 3D spatial distributions of quarks and gluons; connect 1D-PDF, Form-Factors and so on.

  Four chiral-even GPDs for each quark flavor or gluon: H, E, $\tilde{H}$ *and* $\tilde{E}$. Also four chiral-odd GPDs

- DEMP with Pseudoscalar meson production can measure $\tilde{H}$ and $\tilde{E}$; nDEMP is an unique process to probe $\tilde{E}$, which gets access to pion form factors; DEMP is uniquely to chiral-odd GPDs
- Target Single-Spin Asymmetry, of DEMP has relatively low requirement on the Q^2

  (Higher order effects are largely cancelled even at Q^2~4 GeV^2).

- DEMP using transversely polarized He3 on SoLID will run in-parallel with approved SIDIS experiments; (No new beam time; No configuration change)
- Expect to have very low statistical uncertainties over a wide –t coverage and with two Q^2 bins.
- Proton Detection will help us to maintain the Exclusivity. Missing Momentum and Missing Mass cuts can further reject most background.
- First of many new DEMP measurements on SoLID; Great preparatory work for future extensive measurements on EIC

Backup Slides

DEMP TSSA Connection to GPDs

L. Frankfurt *et. al.* , PRD 60 014010 (1999):

- Charge Pion Production:

$$\mathcal{A} = \frac{1}{|S_\perp|} \frac{\int_0^\pi d\beta |\mathcal{M}(\beta)|^2 - \int_\pi^{2\pi} d\beta |\mathcal{M}(\beta)|^2}{\int_0^{2\pi} d\beta |\mathcal{M}(\beta)|^2} = \frac{2\sigma_1}{\pi\sigma_0}$$

$$\sigma = \sigma_0 + \sigma_1([\vec{p}_\perp{}', \vec{S}_\perp] \cdot \vec{e}_z)/|\vec{p}_\perp{}'| = \sigma_0 + \sigma_1 |\vec{S}_\perp| \sin\beta,$$

$$\mathcal{A}_{+,0} = \frac{|\Delta_\perp|}{\pi M_N} \frac{\xi \, \mathrm{Im}(A_{+,0} B^*_{+,0})}{|A_{+,0}|^2 \left(1 - \frac{\xi^2}{4}\right) - |B_{+,0}|^2 \frac{t\xi^2}{16 M_N^2} - \frac{\xi^2}{2} \mathrm{Re}(A_{+,0} B^*_{+,0})}$$

$$A_+ = \int_{-1}^{1} d\tau \tilde{H}^{(3)}(\tau,\xi,t)(3\alpha^-(\tau) - \alpha^+(\tau))$$

$$B_+ = \int_{-1}^{1} d\tau \tilde{E}^{(3)}(\tau,\xi,t)(3\alpha^-(\tau) - \alpha^+(\tau)),$$

$$\tilde{H}^{(3)}(\tau,\xi,t) = \tilde{H}_u(\tau,\xi,t) - \tilde{H}_d(\tau,\xi,t),$$

$$\tilde{E}^{(3)}(\tau,\xi,t) = \tilde{E}_u(\tau,\xi,t) - \tilde{E}_d(\tau,\xi,t),$$

$$\alpha^\pm(\tau) = \frac{1}{\tau + \frac{\xi}{2} - i0} \pm \frac{1}{\tau - \frac{\xi}{2} + i0},$$

Physics Motivation

▪ Target Single Spin Asymmetry in DEMP:

- 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 order to reliably extract F_π from σ_L data at low -t.
  - 12 GeV Pion Form Factor experiment restricted to Q^2=6 GeV^2 to keep non-pole contributions to an acceptable level ($-t_{min}$<0.2 GeV^2).

- $A_L^{\perp}$ 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.

- To cleanly extract $A_L^{\perp}$, 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

DEMP Generator

- DEMP cross sections are described by the VR model.
- Parameterization of different XS-terms with the world data:

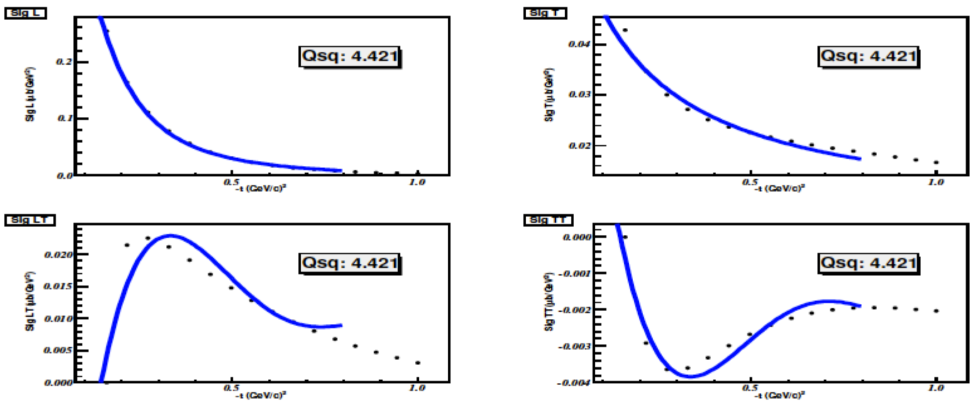
$$\frac{d^5\sigma}{dE' d\Omega_{e'} d\Omega_\pi} = \Gamma_V \frac{d^2\sigma}{d\Omega_\pi} \qquad \frac{d^2\sigma}{d\Omega_\pi} = J \frac{d^2\sigma}{dt d\phi}, \qquad 2\pi \frac{d^2\sigma}{dt d\phi} = \epsilon \frac{d\sigma_{\mathrm{L}}}{dt} + \frac{d\sigma_{\mathrm{T}}}{dt} + \sqrt{2\epsilon(\epsilon+1)} \frac{d\sigma_{\mathrm{LT}}}{dt} \cos\phi + \epsilon \frac{d\sigma_{\mathrm{TT}}}{dt} \cos 2\phi$$

$$\sigma_L = \exp\left(P_1(Q^2) + |t| * P_1'(Q^2)\right) + \exp\left(P_2(Q^2) + |t| * P_2'(Q^2\right.$$

$$\sigma_T = \frac{\exp\left(P_1(Q^2) + |t| * P_1'(Q^2)\right)}{P_1(|t|)}$$

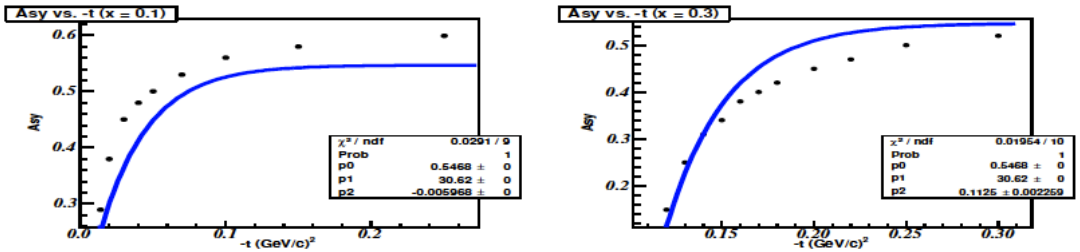
$$\sigma_{LT} = P_5(t(Q^2))$$

$$\sigma_{TT} = P_5(t(Q^2)),$$



- Single-Spin Asymmetry is moded by L. Frankfurt et. al. (PRL 84, 2589, 2000)

$$\mathrm{A_L^{\perp}} = \frac{\int_0^{\pi} \mathrm{d}\beta \frac{\mathrm{d}\sigma_{\mathrm{L}}^{\pi^-}}{\mathrm{d}\beta} - \int_{\pi}^{2\pi} \mathrm{d}\beta \frac{\mathrm{d}\sigma_{\mathrm{L}}^{\pi^-}}{\mathrm{d}\beta}}{\int_0^{2\pi} \mathrm{d}\beta \frac{\mathrm{d}\sigma_{\mathrm{L}}^{\pi^-}}{\mathrm{d}\beta}}$$



- Fermi-Motion is modeled by Argonne potential (R. Schivavilla et. al., Nucl. Phys. A. 449, 219, 1986)
- Energy-Loss includes the ionization and Bremsstralung process.

Proton Recoil Detector

- A Conceptual Design:

✓ Cover angles of 24° to 50°

2π on the azimuthal angle

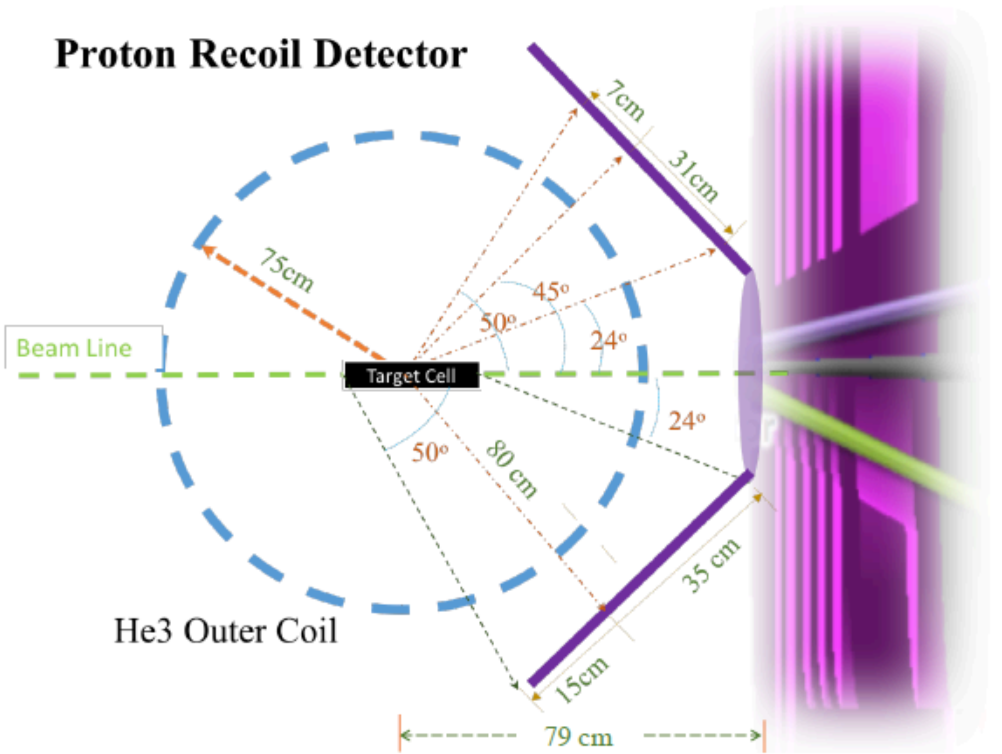
✓ Inner Radius=32 cm

Outer Radis = 67 cm

Detector Length = 50 cm

✓ Distance from Target = 79cm

(far end touches the magnet)



- ➢ Need good timing resolution (<60~ps)
- ➢ Need fine segments due to huge low energy backgrounds

  (An aluminum foil cover can block most of low energy electrons)
- ➢ Need to provide angle information for offline background suppression
- ➢ Photon-Detectors need to work in strong magnetic fields from target & solenoid
- ➢ A good candidate: Scintillating Fiber Tracker
- ➢ Geant4 Simulation is undergoing