Target Single Spin Asymmetry Measurements in the Inclusive Deep-Inelastic $\vec{N}(e, e')$ Reaction on Transversely Polarized Proton and Neutron (^{3}He) Targets using the SoLID Spectrometer

Hall A Collaboration Meeting

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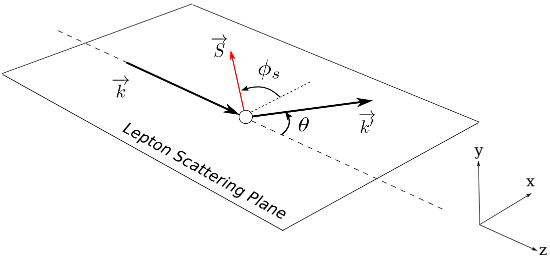
Dec., 2014

Overview

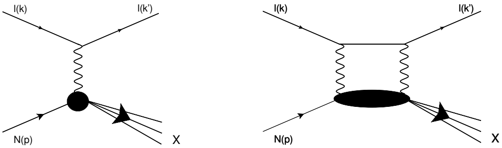
- Final DIS results from A_y at 6 GeV
- Two new experiments, proton (NH_3) and neutron (^3He) using SoLID
- Other Target SSA recent results

Kinematics



- Deep Inelastic Scattering, $N(e, e')$, unpolarized beam, transversely polarized NH_3 and ^{3}He.
- Measure target single-spin asymmetry (SSA).
- $A_{UT} = \frac{\sigma^{\uparrow} - \sigma^{\downarrow}}{\sigma^{\uparrow} + \sigma^{\downarrow}} = A_y \sin\phi_S$

Physical Motivation



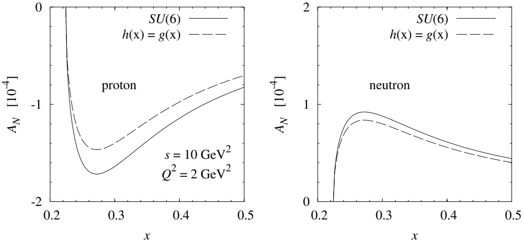
- Two-photon exchange studies–Renewed interest motivated by discrepancy between Rosenbluth/Polarization Transfer measurement of G_E/G_M; many calculations now exist for the two-photon exchange reaction. e.g. Test GPD models through two-photon intermediate state.
- $A_y = \frac{\sigma^\uparrow - \sigma^\downarrow}{\sigma^\uparrow + \sigma^\downarrow} \frac{1}{\sin\phi_S} = \frac{d\sigma_{UT}}{d\sigma_{UU}}$
- $d\sigma_{UU} \propto \mathrm{Re}(M_{1\gamma} M_{1\gamma}^*)$ and $d\sigma_{UT} \propto \mathrm{Im}(M_{1\gamma} M_{1\gamma}^*) = 0$ at Born level–time-reversal invariance
- $d\sigma_{UT} \propto \mathrm{Im}(M_{1\gamma} M_{2\gamma}^*) \neq 0$ with one- and two-photon interference

Physical Motivation (con't)

- Evaluation of 2γ box diagram involves *full* nucleon response.
- In DIS, can use parton models. e.g. two-photons scattering from single quark (Afanasev *et al.*); two photons scattering from two different quarks (Metz *et al.*, Schlegel *et al.*)
- An analysis of A_{UT} in DIS has to be performed at sub-leading twist accuracy requiring correlations of the transverse nucleon spin and the transverse partonic motion, as well as multipartonic correlations.–M. Schlegel, 2013
- A_y provides a unique new tool to directly study non-perturbative nucleon structure.

Theoretical Predictions

- A. Afanasev *et al.* assumes the scattering is dominated by two-photon exchange with a single quark. They predict $A_y^n \sim 10^{-4}$ and $A_y^p \sim -2 \times 10^{-4}$ at $x \sim 0.3$ and $Q^2 = 2.0\ \mathrm{GeV}^2$.



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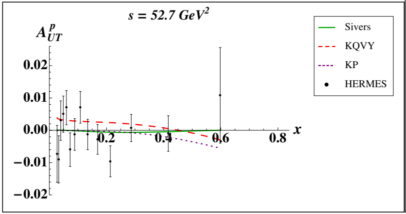
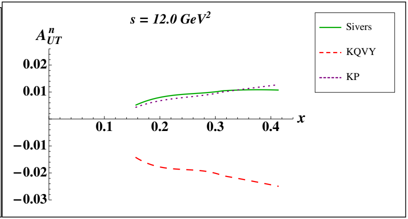
Theoretical Predictions (con't)

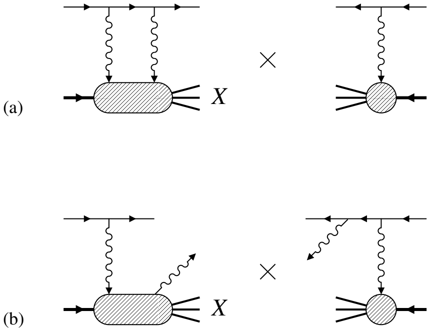
- A. Metz *et al.* argue that the DIS asymmetry is dominated by the process in which one of the photons couples to an active quark and the other couples to one of the quarks in the spectator di-quark system.
- They predict a proton asymmetry with magnitude $A_y^p < 10^{-2}$ that crosses zero in the mid-x range.
- Neutron A_y^n is predicted to be $\sim \pm 10^{-2}$ depending on the quark-gluon-quark correlators T_F^f for quarks of flavor f. $\Longrightarrow$ important puzzle in nucleon structure studies.





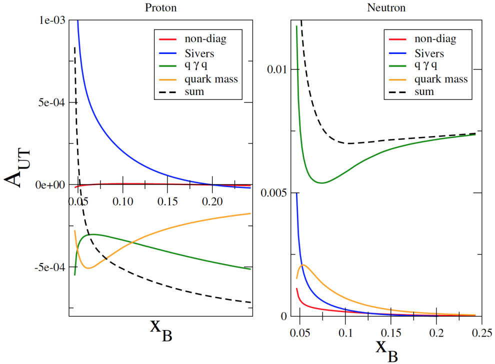
Theoretical Predictions (con't)

- An additional contribution to $d\sigma_{UT}$ at $\mathscr{O}(\alpha_{em}^3)$ may arise from interference between real photon emission (bremsstrahlung) by the electron and the hadronic system.
- Recent work by M. Schlegel calculated all of this together in a parton model.



Parton Model calculation from M. Schlegel

- **Model includes:**
- • Single quark coupling: $m_q h_1^q$ (quark mass, transversity), qgq correlations (non-diag., twist-3), moment of k_T (Sivers)
- • Two-quark coupling: $q\gamma q$ correlation, can be related to Sivers.
- NOTE: Sign of $q\gamma q$ term depends on Sivers input (SIDIS vs. h-h). Unresolved puzzle.
- NOTE: $A_y^n \sim 10 \times A_y^p$



HERMES Proton DIS Data

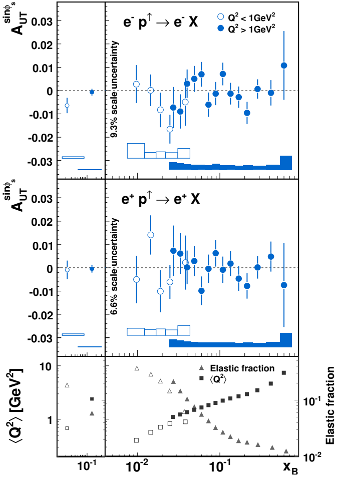


Figure: $Q^2 > 1$ GeV^2 data consistent with zero at $\sim 10^{-3}$ level.

Neutron DIS Data-JLab E07-013

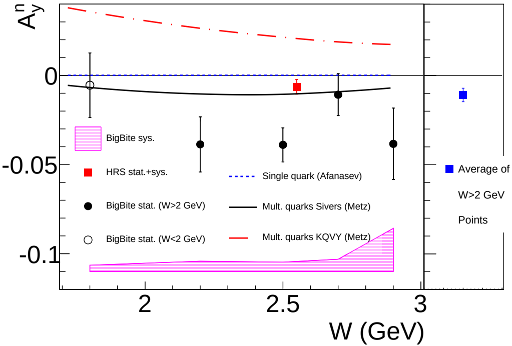
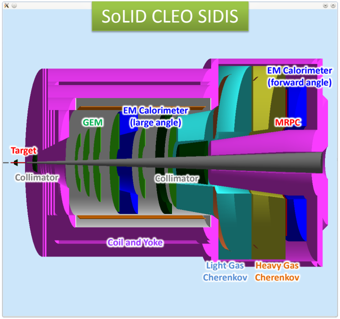


Figure: First-ever non-zero measurement of A_y ($\sim 3\sigma$). Consistent with Metz *et al.* using Sivers input. Phys. Rev. Lett. 113 (2014) 022502.

Overview

- **TECHNICAL ASPECTS:** Run concurrent with SoLiD-SIDIS and request no beam time.
- This experiment will test parton-models for protons and neutrons in DIS.
- The goal is to determine A_y for both proton and neutron with a statistical precision of $10^{-4} - 10^{-3}$ (kinematic dependent) over a broad range of x and $1.5 < Q^2 < 7.5$ GeV^2 ($0.05 < x < 0.65$, $W > 2$ GeV) by measuring the ϕ_S-dependence of A_{UT}.
- Systematic uncertainties will be kept to the $\sim 10^{-4}$-level.
- The polarized NH_3 (100 nA, 3 cm) and ^{3}He targets (15 μA, 40 cm) with 8.8 and 11 GeV beam.
- Expect maximum DAQ trigger rate is 100 kHz. 68 kHz coincidence, 32 kHz singles.



Trigger

- These numbers are from the pCDR:
- Maximum trigger rate is $\approx$ 100 kHz, limited by GEM readout
- Transversity expects 68 kHz coincidence triggers; 90% are randoms
- A_y will take 32 kHz of singles triggers and use randoms from coincidence trigger to get 90+ kHz of “singles" electrons.
- Dedicated singles trigger will allow study of possible bias in singles/randoms in coincidence trigger.
- All projected statistical uncertainties assume 80 kHz of singles data.

Kinematic Coverage

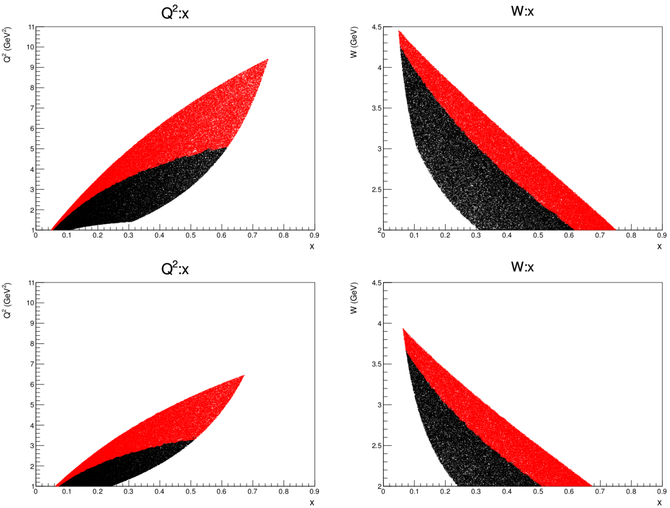


Figure: Kinematic coverage with polarized NH_3 target. The upper plots are for 11 GeV. The lower plots are for 8.8 GeV. Black (red) is for forward (large) angle.

Typical Projected Results (NH_3 11 GeV)

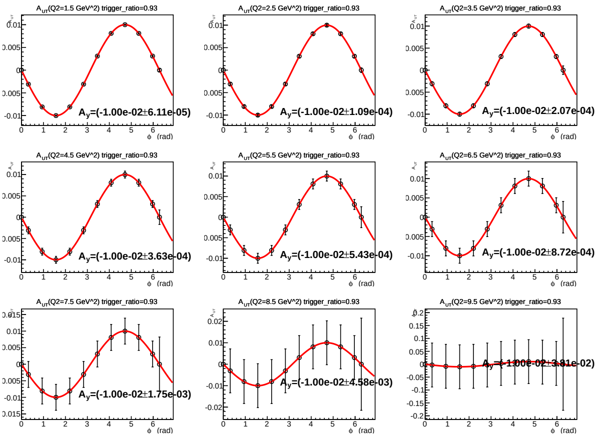


Figure: Expected statistical uncertainties in A_{UT} vs. ϕ_S at different Q^2 for the NH_3 target. Figures are for 11 GeV from $1.5 \leq Q^2 \leq 9.5$ (GeV^2). Arbitrarily choose $A_y = -0.01$.

Project Results (NH_3) (con't)

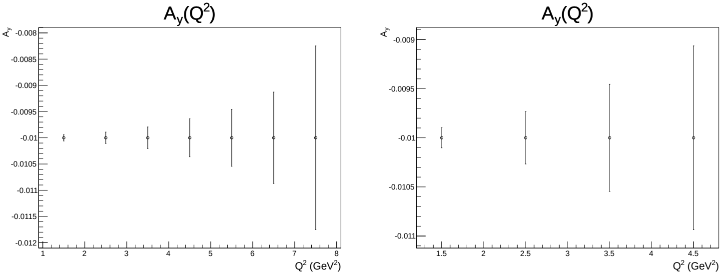


Figure: Expected statistical uncertainties in A_y vs. Q^2 for the NH_3 target. Left one is for 11 GeV. Right one is for 8.8 GeV.

Arbitrarily choose $A_y = -0.01$.
Expected statistical uncertainty: $\delta A_y \sim 10^{-4} - 10^{-3}$.

Updated Systematic Uncertainties (NH_3)

Sources	Type	δA_y^{raw}	δA_y^{phys}
False Asymmetries	absolute	$\sim 10^{-5}$	$\sim 10^{-4}$
Background Subtraction	absolute	$\sim 10^{-5}$	$\sim 10^{-4}$
Target Polarization	relative	3%	3%
Dilution Factor	relative	5%	5%
Radiative Correction	relative	2%	2%

Table: Systematic uncertainties on the proton asymmetries for the proposed NH_3 experiment.

- Expected statistical uncertainties: $\delta A_y^{raw} \approx 10^{-5}$, $\delta A_y^{phys} \approx 10^{-4}$

A_y in the Quasi-elastic Region

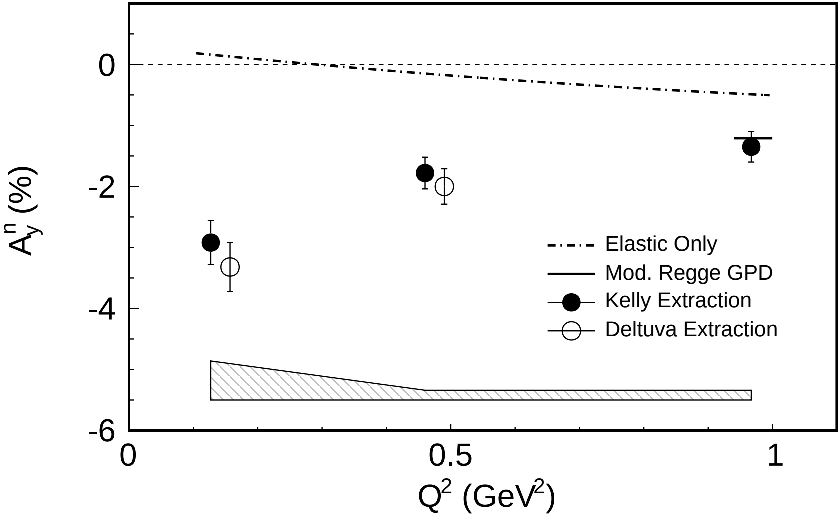


Figure: Final (neutron) results for the target-normal single spin asymmetry in

Summary

- Measurements of $A_{UT}(\phi_S)$ and A_y in a large number of x and Q^2 bins ($1.5 < Q^2 < 7.5$ GeV^2, $0.05 < x < 0.65$, $W > 2$ GeV) for both proton and neutron.
- The statistical uncertainties of $10^{-4} - 10^{-3}$ (kinematic dependent) with systematic uncertainties of $\sim 10^{-4}$ will provide information on the transverse target single spin asymmetry at a level never before achieved.
- This precision will discriminate between parton model predictions/contributions.
- Will the measured proton and neutron asymmetries differ by an order of magnitude?
- Provide an answer to the important sign mis-match in the neutron predictions using either the Sivers or KQVY input for quark-gluon correlations.
- A new opportunity to directly access the dynamics of the nucleon beyond the naïve parton model without the significant contribution from Born scattering.

Rate Estimation

- Most recent acceptance.
- NH_3 (100 nA, 3 cm) and ^{3}He targets (15 μA, 40 cm) with 8.8 and 11 GeV beam.
- “line of flame" cut on NH_3 target.
- FAEC trigger: $E_f \geq 4$ GeV at $\theta \leq 8^\circ$, $E_f \geq 1$ GeV for $\theta > 12^\circ$
- GC coincidence with FAEC
- LAEC trigger: $E_l > 3$ GeV
- Impose a maximum rate of 80 kHz on the singles trigger.

Rate Estimation (^{3}He)

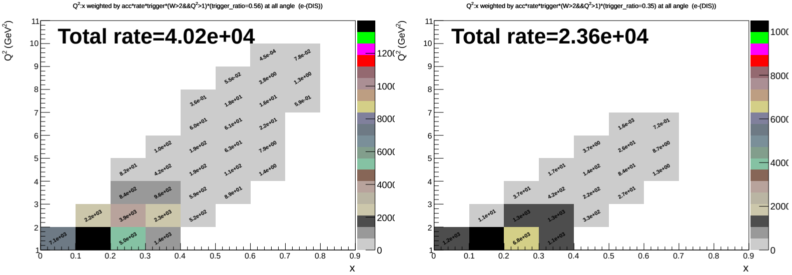


Figure: Good electron rates (after PID and DIS cuts) in each Q^2 vs x bin for the ^{3}He target. Units for rates are Hz. Left one is for 11 GeV. Right one is for 8.8 GeV.

Projected Results

Corrections used to determine the A_{UT}^{phys} from A_{UT}^{raw}.

- Dilution factor 13% for NH_3, 85% for ^3He.
- Target polarization 70% for NH_3, 60% for ^3He.
- Nuclear correction 80% for ^3He.

Projected Results (^{3}He)–8 GeV

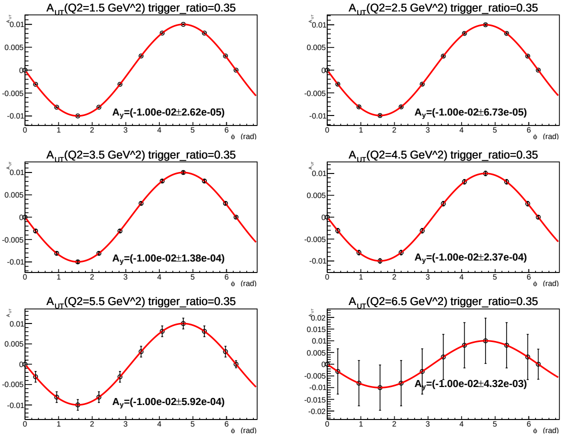


Figure: Expected statistical uncertainties in A_{UT} vs. ϕ_S at different Q^2 for the ^{3}He target for 8.8 GeV from $1.5 \leq Q^2 \leq 6.5$ (GeV^2). Arbitrarily choose $A_y = -0.01$.

Projected Results (^{3}He) (con't)

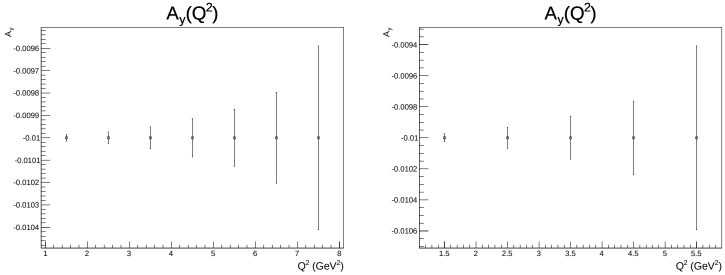


Figure: Expected statistical uncertainties in A_y vs. Q^2 for the ^{3}He target. Left one is for 11 GeV. Right one is for 8.8 GeV.

Arbitrarily choose $A_y = -0.01$.
Expected statistical uncertainty: $\delta A_y \sim 10^{-4}$.

Systematics–Overview and Update

- Predicted (model) asymmetries $10^{-4} - 10^{-2}$.
- Expect to measure with statistical uncertainty in raw asymmetry (lowest Q^2-bins) $\delta A_y^{raw}(\text{stat.}) \approx 10^{-5}$
- $P_b f = 0.1$ for $NH_3 \Longrightarrow \delta A_y^{phys}(\text{stat.}) \approx 10^{-4}$.
- $P_b f \eta = 0.4$ for ^{3}He $\Longrightarrow \delta A_y^{phys}(\text{stat.}) \leq 10^{-4}$.
- Goal: Keep $\delta A^{phys}(\text{sys.}) \approx 10^{-4}$
- Two largest systematics: 1) Time-dependent false asymmetries; 2) Background corrections.
- Fewer target spin-flips for NH_3 compared to ^{3}He
- All other uncertainties 2-5% (rel.)

Time-dependent False Asymmetries, NH_3

- **Luminosity Asymmetry:** Flip target spin at 4 hours per pair using AFP gives 495 pairs; Expect average target polarization to drop by 10% (abs.)
- Per pair: $\delta A^{lumi} = 1/\sqrt{100 \text{ kHz } \times 4 \times 3600} = 2.6 \times 10^{-5}$
- Goal: control luminosity asymmetry to $\sim 10^{-4}$
- We will also get luminosity as a function of ϕ (8-bins).
- Could we reverse target (and chicane) field direction once?
- **Detector efficiency:** Rate studies by varying beam current. Efficiency monitoring/studies using scalers on selected detectors (as many as reasonably possible); dedicated HV studies. Online detector gain monitoring–not sure what is planned.

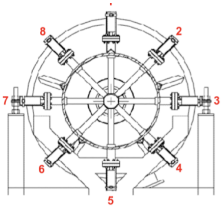


Figure: Hall A 6 GeV luminosity monitors.

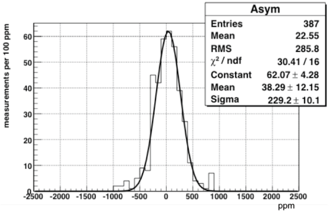


Figure: Measured lumi asymmetry during 6 GeV: $\delta A^{lumi} = 38 \pm 12$ ppm. 387 spin-flip pairs; 40 minutes per flip. Each pair $\delta A^{lumi} \sim 5 \times 10^{-4}$.

Pion Background

- Measured (raw) pion asymmetry from 6 GeV: $A^{\pi} < 0.04 \pm 0.005$.
- SoLID: *Worst Case* pion contamination at $E' = 2$ GeV, $\theta = 24^{\circ}$: $\pi/e = 250$. With PID: $\pi/e = 10^{-2}$.
- Need raw $\delta A^{\pi}(\text{stat}) \approx 10^{-3}$ to achieve $\delta A_y^{phys} \approx 10^{-4}$. Can do. Plenty of statistics, good PID.

π/e^- ratio

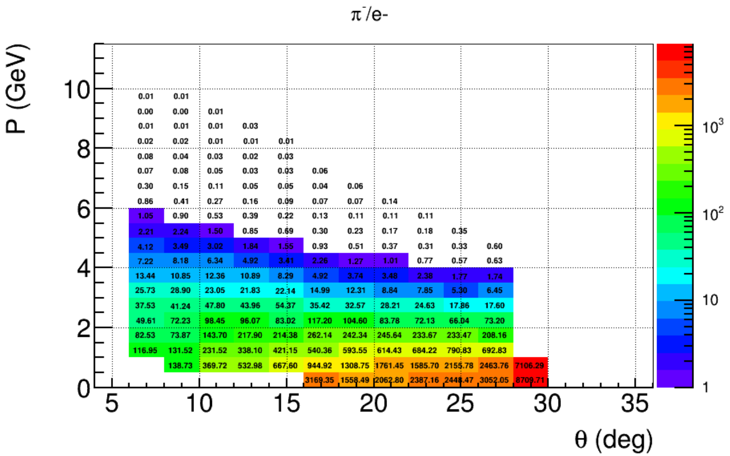


Figure: The π^-/e^- ratio for the SIDIS experiment with a 15 $\mu\mathrm{A}$ beam on a 40 cm $^3\mathrm{He}$ target. The momentum and polar angles are at the vertices in the target where particles are created.

π/e^- ratio (con't)

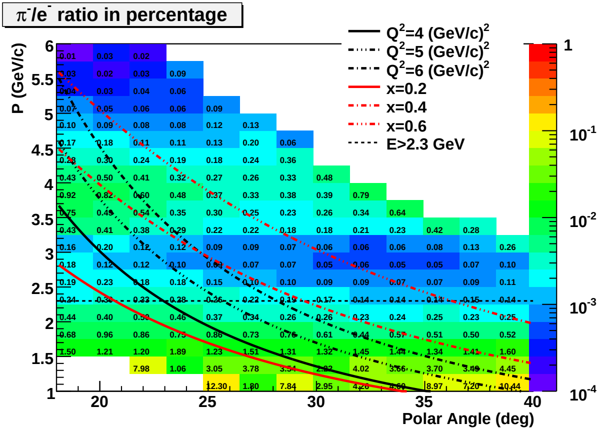


Figure: The π/e^- ratio from combined Cherenkov and Calorimeter detector performance as a function of the scattered momentum P and polar angle θ. The numerical values are the ratios corresponding to that cell in (P,θ). The curves indicate various regions of Q^2, x or scattered energy E.

Pair-produced (pp) Electron Background

- Measured 6 GeV: raw $A^{e^+} = 0.01 \pm 0.01$
- 6 GeV: BigBite difficult to identify (pp) electrons; Asymmetry not well-measured; Large uncertainty.
- SoLID: 15% of triggers are (pp) electrons.
- Reduce (pp) electron fraction to 10^{-2} by detecting (pp) positrons.
- $\Longrightarrow$ Need raw δA^{e^+}(stat) $\approx 10^{-3}$ to achieve $\delta A_y^{phys} \approx 10^{-4}$. Can do. Plenty of statistics, good PID.

Updated Systematic Uncertainties (^{3}He)

Sources	Type	δA_y^{raw}	δA_y^{phys}
False Asymmetries	absolute	$< 10^{-5}$	$< 10^{-4}$
Background Subtraction	absolute	$\sim 10^{-5}$	$< 10^{-4}$
Target Polarization	relative	3%	3%
Dilution Factor	relative	2%	2%
Radiative Correction	relative	2%	2%
Neutron Extraction	relative	5%	5%

Table: Systematic uncertainties on the neutron asymmetries for the proposed ^{3}He experiment.

- Expected statistical uncertainties: $\delta A_y^{raw} \approx 10^{-5}$, $\delta A_y^{phys} \approx 10^{-4}$

TAC Comments

- **Improve DAQ rate with upgraded GEM readout and L3 farm–**After talking with Jian-ping Chen and Alex Camsonne, it seems that these upgrades are not likely before the first SIDIS experiment without significant additional funding. Also, the improvement in statistics will not likely make a significant improvement in our physics impact.
- **AFP spin flip time for NH_3–**An improvement in the spin flip time interval for NH_3 (while maintaining high polarization) is quite important for understanding time-dependent systematic uncertainties. We will engage the polarized target groups at both UVa (D. Day and D. Crabb) and also at Jefferson Lab (C. Keith) to begin to fully study and optimize the procedure. The current estimate of a 4 hour flip (pair) time is based on data from PSI and needs laboratory studies.

TAC Comments, con't

- **Sensitivity of the ^{3}He target to SoLID field gradients–**There are two mechanisms where field gradients can affect the target polarization. The first is during static optical pumping where we can tolerate transverse gradients up to about 100 mG/cm. The second is longitudinal gradients during AFP which we can tolerate up to about 40 mG/cm. This collaboration has experience running polarized ^{3}He targets near the BigBite spectrometer where the fringe fields are large. We have successfully used iron-plate shielding and external gradient coils to reduce the gradients to the level necessary. We will also be dealing with this problem during the SBS program where TOSCA simulations are underway at UVa (G. Cates group) studying the possibility of active shielding with coils around iron plates placed symmetrically in front and back of the target. We feel confident in our ability and experience dealing with field gradients in the target.

TAC Comments, con't

- **Independent TAC comment: Concerns over the level of understanding of the "line of flame" backgrounds from the NH_3 target**–This was simulated using the BaBar magnet prior to the approval of the NH_3 SIDIS approval at PAC 39. The detectors in the line of flame will be turned off due to high background. The simulation will be repeated for the CLEO magnet to ensure a full understanding of the backgrounds is had (K. Allada). The type of GEM detectors and readout electronics proposed for SoLID have been used previously and are known to be sufficiently radiation resistant (N. Liyanage).
- **Independent TAC comment: Simulation of the synchrotron radiation produced by the upstream chicane needs to be done to understand the impact on the polarized target.** –I have not had time to consider this comment. Are there data or a simulation from g_2^p?

TAC Comments, con't

- **SoLID collaboration comment: What is the precision of the measurement of the target angle achievable for the NH_3 target?**–According to Donal Day, UVa, it was previously measured with a dedicated apparatus to $\pm 0.1^\circ$. Note that the asymmetry is exactly zero for in-plane target orientation. This means that we are relatively insensitive to the target angle. For example, if the target alignment were known to 2° we would expect to have a *relative* uncertainty in our measured asymmetry of $1 - \cos(2^\circ) = 6 \times 10^{-4}$.