# Investigating the nuclear dependence of $R = \frac{\sigma_L}{\sigma_T}$ in Semi-Inclusive Deep Inelastic Scattering

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## Background

Semi-Inclusive Deep Inelastic Scattering (SIDIS), detects a final-state hadron in coincidence with the scattered electron providing access to study the flavor and transverse momentum dependence of the nucleon.

So far, analyses in SIDIS have assumed that the relative contribution of longitudinal and transversely polarized polarized virtual photon cross-section ($R = \frac{\sigma_L}{\sigma_T}$) is the same as the one measured in inclusive DIS, but this assumption hasn't been rigorously tested.

Moreover, no measurements of a possible nuclear dependence of $R$ have been performed in SIDIS, where the struck quark and subsequently formed hadron can undergo additional interactions with the surrounding medium, modifying the hadronization process.

The presented work utilizes data from experiments **E12-06-104** and **E12-24-001** in Hall C to perform precise measurements of $R$ in hydrogen, deuterium, carbon and copper.

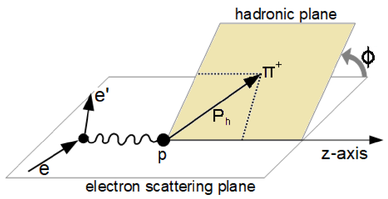


Figure 1. Schematic diagram of a SIDIS process

## Research Questions

- Is $R$ in SIDIS the same as previous measurements in inclusive DIS?
- How is $R$ in SIDIS modified by the nuclear environment?

## Experimental Setup

Standard Hall C equipment has been used to detect the final state hadrons and scattered electrons:

- High Momentum Spectrometer (HMS): used to detect the scattered electrons. A combination of heavy-gas Cerenkov detector and calorimeter were used to select electrons and discriminate pions
- Super High Momentum Spectrometer (SHMS): used to detected tagged final-state hadron (pions). A combination of heavy-gas ($C_4F_8O$) and aerogel Cerenkov detectors were use to select pions and discriminate kaons/protons.

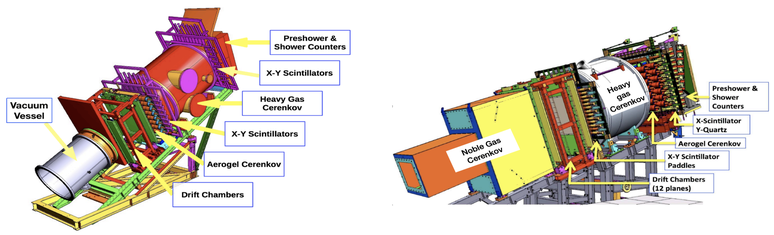


Figure 2. CAD representation of the HMS (left) and SHMS (right) detector layers.

## Rosenbluth Separation

Inclusive DIS cross section can be expressed in terms of longitudinally and transversely polarized contributions:

$$\frac{d^2\sigma}{d\Omega dE'} = \Gamma \left[ \sigma_T(x, Q^2) + \epsilon\sigma_L(x, Q^2) \right]$$

One can obtain $\sigma_T, \sigma_L$ by plotting measured cross section at fixed $(x, Q^2)$ and plot as a function of $\epsilon$.

SIDIS cross section contains interference terms:

$$\frac{d\sigma}{dE_e d\Omega_e dP_\pi d\Omega_\pi} = \Gamma \left[ \sigma_T + \epsilon\sigma_L + \sqrt{2\epsilon(1+\epsilon)}\sigma_{LT}\cos\phi_{pq} + \epsilon\sigma_{TT}\cos 2\phi_{pq} \right]$$

Now each contribution $\sigma_T, \sigma_L, \sigma_{LT}, \sigma_{TT}$ depend on $(x, Q^2, z, p_T)$.

So now we need to integrate over $\phi_{pq}$ at each $\epsilon$ value in order to perform Rosenbluth separation.

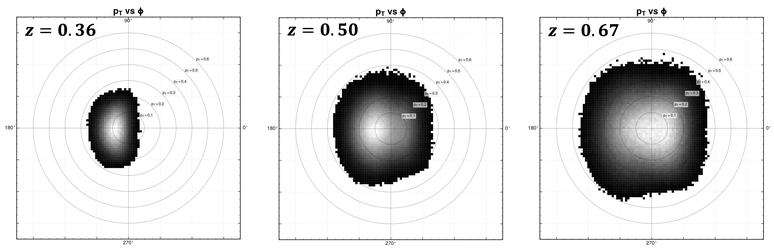


Figure 3. $p_T$ vs $\phi_{pq}$ coverage for different $z$ settings ($\epsilon = 0.59$)

## Current Status

- ✓ The first run period of data collecting for R-SIDIS finished in September 2025, while the second period is schedule to start in **June 12th, 2026**

| $x$ | $Q^2$, (GeV/$c$)$^2$ | $E_e$, GeV | $\epsilon$ | $z$ | $\theta_{pq}$, deg | $A > 1$ |
|---|---|---|---|---|---|---|
| 0.16 | 1.6 | 6.5, 8.6 | 0.32, 0.65 | 0.5 | 2.0 | No |
| 0.22 | 2.2 | 6.5, 8.6 | 0.31, 0.64 | 0.5 | 2.0 | No |
| 0.25 | 3.3 | 8.6, 10.7 | 0.32, 0.59 | 0.36, 0.5, 0.67 | 2.0 | $\pi^+$ (all), $\pi^-$ |
| | | | | 0.5 | 5.2, 8.5 | $\pi^+$ only |
| | | 10.7 | 0.59 | 0.5, 0.67 | -0.8 | Yes |
| 0.31 | 3.1 | 6.5, 8.6, 10.7 | 0.30, 0.63, 0.78 | 0.5 | $-1$, 2 | $\pi^+$ only |
| 0.44 | 4.4 | 6.5, 8.6, 10.7 | 0.28, 0.62, 0.77 | 0.52 | 2.0 | Yes |
| | | | | 0.4, 0.67 | | No |
| | | 10.7 | 0.77 | 0.52 | -2.0 ,0 | Yes |
| | | | | 0.4, 0.67 | | No |

Table 1. Requested kinematics for R-SIDIS. Gray section corresponds to kinematics covered in the first run period

- ✓ Reconstruction pass 0 of data has been successfully completed
- ✓ Performed luminosity studies on liquid targets to determine density corrections due to target boiling
- ✓ Worked on determination of a correction factor to account for instability in the fan frequency of the LH2 target

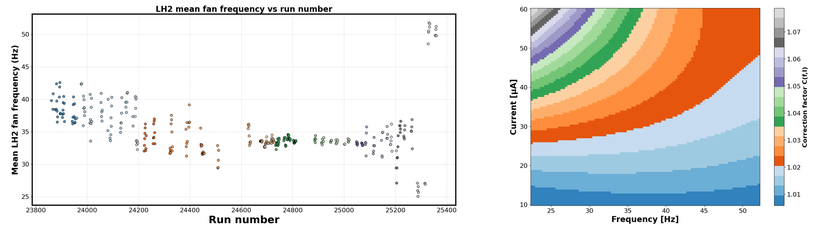


Figure 4. Instability of the average fan frequency of $LH2$ target (left). Extracted correction factor $C(I, f)$ (right)

- ✓ Considerable progress on kinematic offset determination has resulted in corrections to nominal HMS angle and momentum and proposed kinematics for future studies in the upcoming run

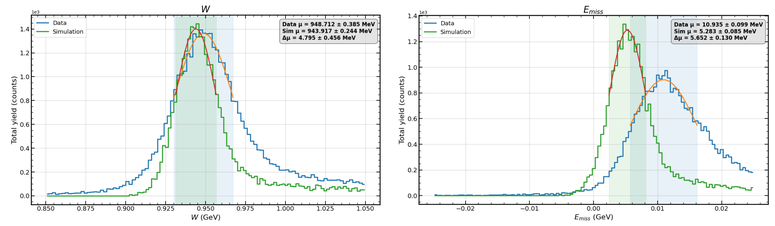


Figure 5. Measured kinematic quantities: final-state invariant mass $W$ and missing energy $E_{miss}$ compared to the simulation prediction

## Preliminary Results

### Pion multiplicities extraction

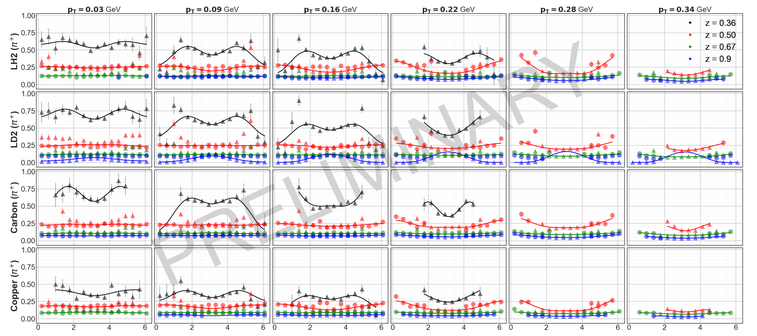


Figure 6. $\phi_{pq}$ dependence of $\pi^+$ multiplicities for LH2, LD2, Carbon and Copper

## Conclusions

- Extraordinary efforts from the $R$-SIDIS collaboration have allowed early access to physics results in both inclusive and semi-inclusive DIS regimes.
- Pass0 reconstruction data has been fully replayed and significant progress towards pass1 is being produced
- Second run period of data taking will provide access to the required kinematics to complete DIS and SIDIS Rosenbluth separations

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