# First look at nTMD observables with RG-D data

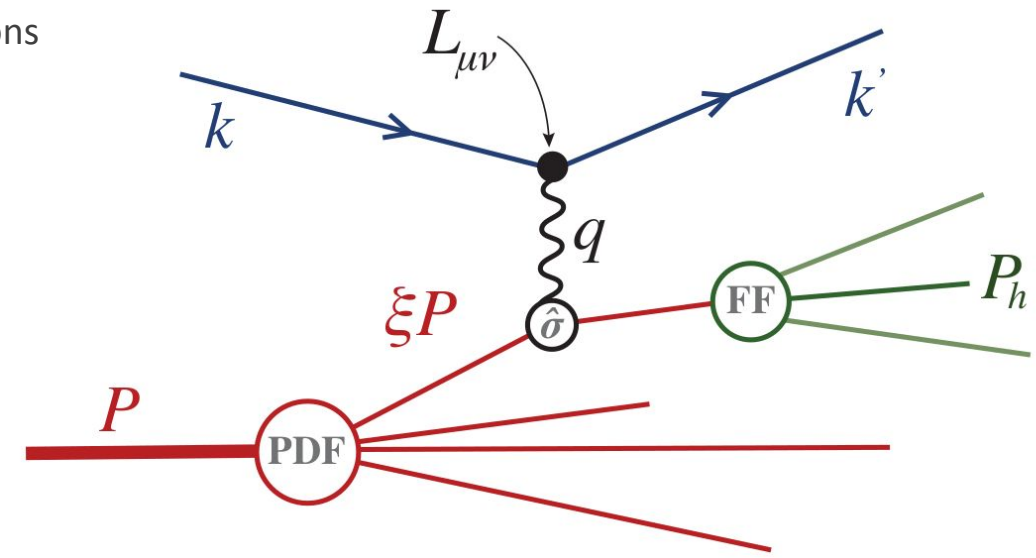
**Jun 26th 2024**

DANIEL MATAMOROS

# nTMD studies through SIDIS in RG-D

**Goal:** Study of nTMDs: Understand the structure of nuclei in terms of quarks and gluons through 3D momentum space distribution of hadrons. through SIDIS processes.

- Hadron production through $\gamma$ *
  - ➢ **e(k) + N(p) -> e(k') + X(p') + h(P_h)**
  - ➢ detection of one of the produced hadrons
  - ➢ cross section -> convolution of TMD parton distributions and TMD fragmentation functions
- Experimental Observables: Cross section, Beam Spin Asymmetry
- Studied observables: $\cos\phi_h$, $\sin\phi_h$, $\cos 2\phi_h$



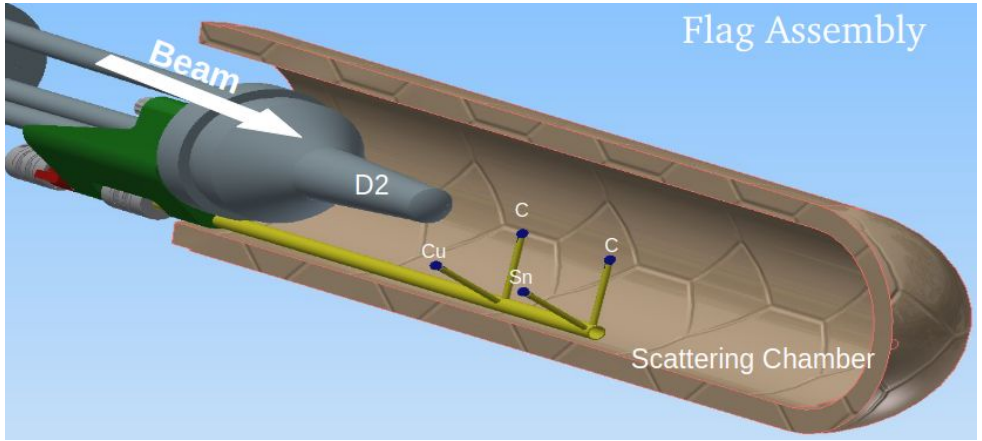

**This Work:** Use of unpolarized nuclear targets where only the cos φ, cos 2φ and sin φ components will contribute in this cross section. Study of TMDs, using nuclear targets. On going study of experimental observables such as multiplicity Ratio R, $Pt^2$ broadening , and cosϕ ratio, using a deuterium target for reference.

$$R_A^h = \frac{(N_h/N_e)_A}{(N_h/N_e)_D} \qquad \Delta < p_t^2 >=< p_t^2 >_A - < p_t^2 >_N \qquad \frac{< cos\phi_h >_A}{< cos\phi_h >_N}$$

# Experimental configuration

10.5 GeV electron beam on nuclear targets

- Targets: nuclear solid foils **LD2**, Cu, C and Sn.
- Currently developing analysis tools to monitor the reconstructed particles such as e-, $\pi$, $k$, etc




**This work:** Successful completion of data taking (Oct. 04, 2023 - Dec. 15, 2023). Data Calibration ongoing.

- Analysis Implemented: $\pi+$ selection
- Currently Implementing this target configuration in simulations.

# Simulation Procedure

- Using a Leading Order event generator, Pythia based, used to simulate SIDIS processes with added nuclear effects to simulate processes on nuclear targets.

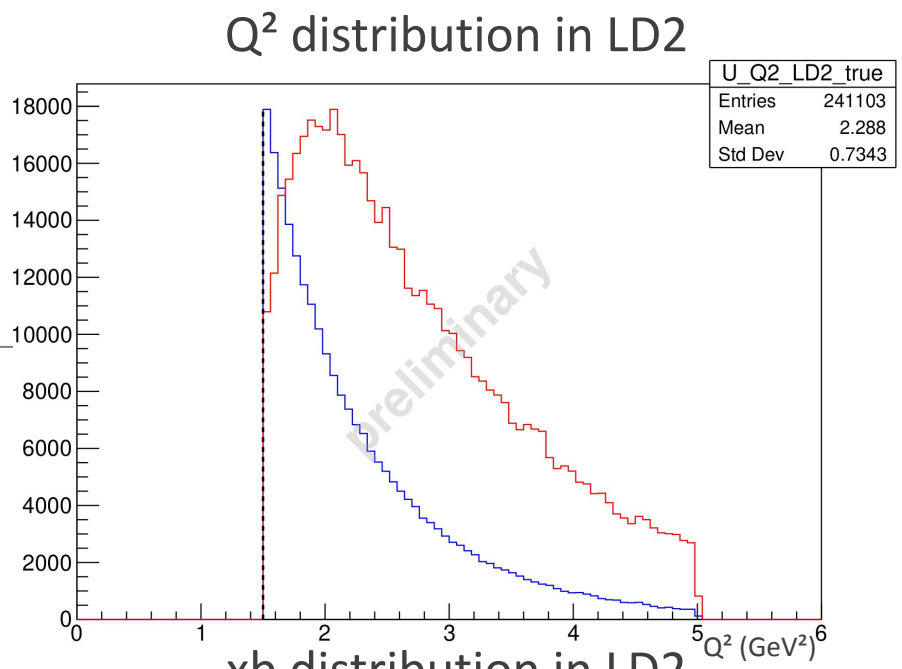
- Using an official version of RG-D gcard for GEMC, that considers the target assembly and vertex z positions. Most recent configurations on RG-D cryo-target and flag assembly can be found in https://github.com/gemc/detectors/pull/233 .

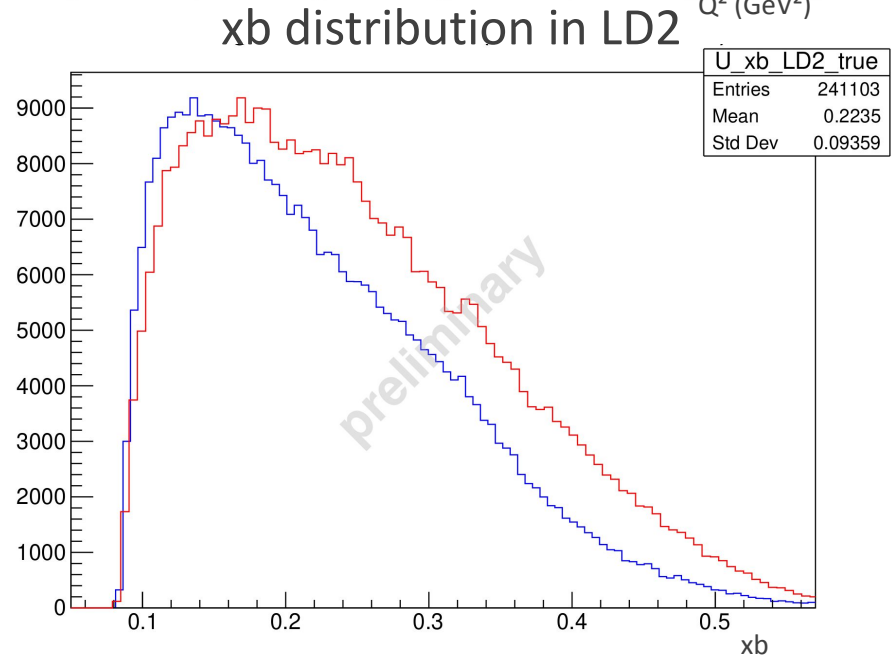
- Currently using simulation for monitoring and comparison on preliminary results.

# Data Selection

- Considering first coincidences on e- and $\pi$+
- Standard kinematic variables considered and cuts for example:
  - $Q^2 > 1$ GeV$^2$
  - $0.25 < y < 0.85$
  - $W > 2$ GeV

- Detector cuts from RG-A analysis note.
- Simulation not fully optimized yet. On going.

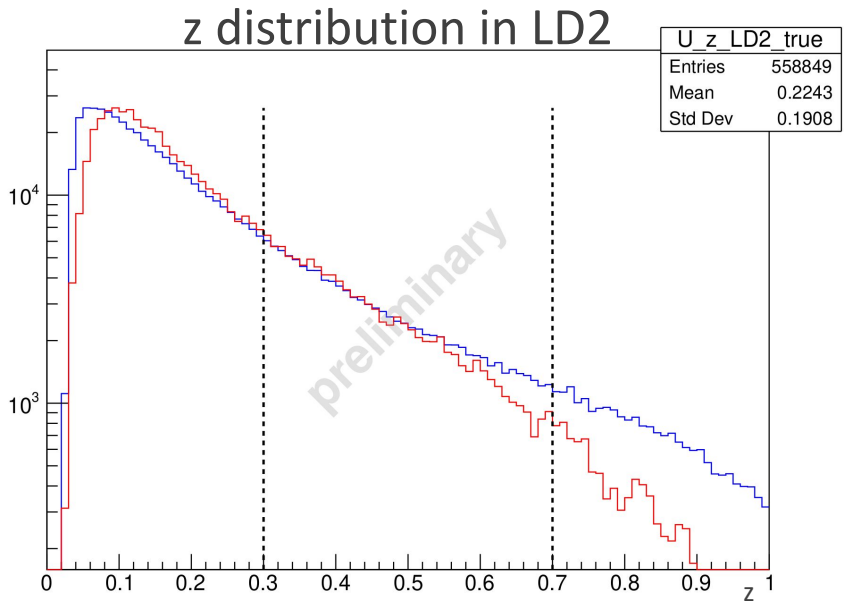


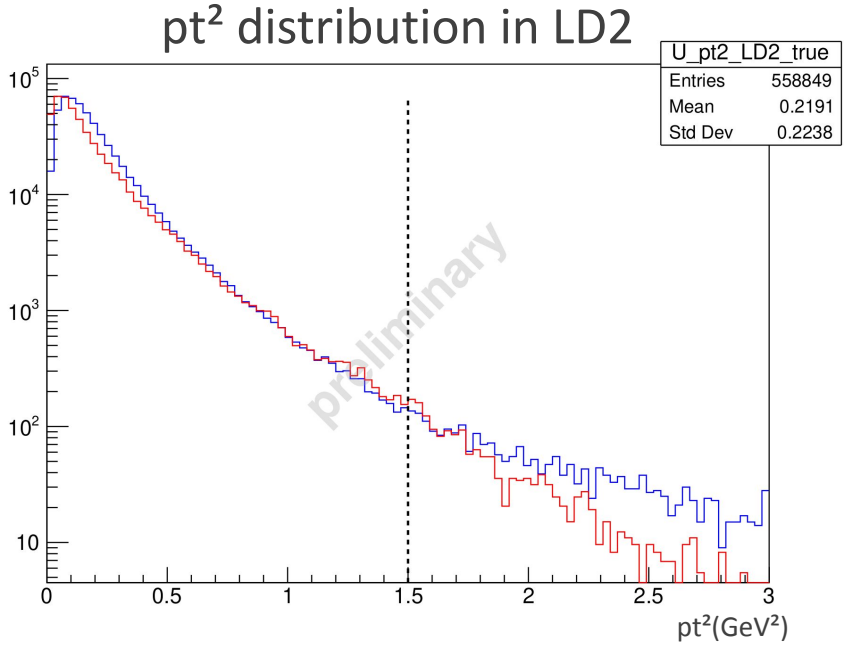




**red** is simulated data
**blue** is RG-D data

# specific preliminary analysis

- Monitoring data from available data
- Events considered with **π+** production
- Kinematic Variables specific to the **hadron** for TMDs:
  - **z** = Fraction of the virtual photon energy carried by the hadron.
  - 0.3 < **z** < 0.7
  - **pt²** = transverse momentum of hadrons
  - **pt²** < 1.5 GeV²

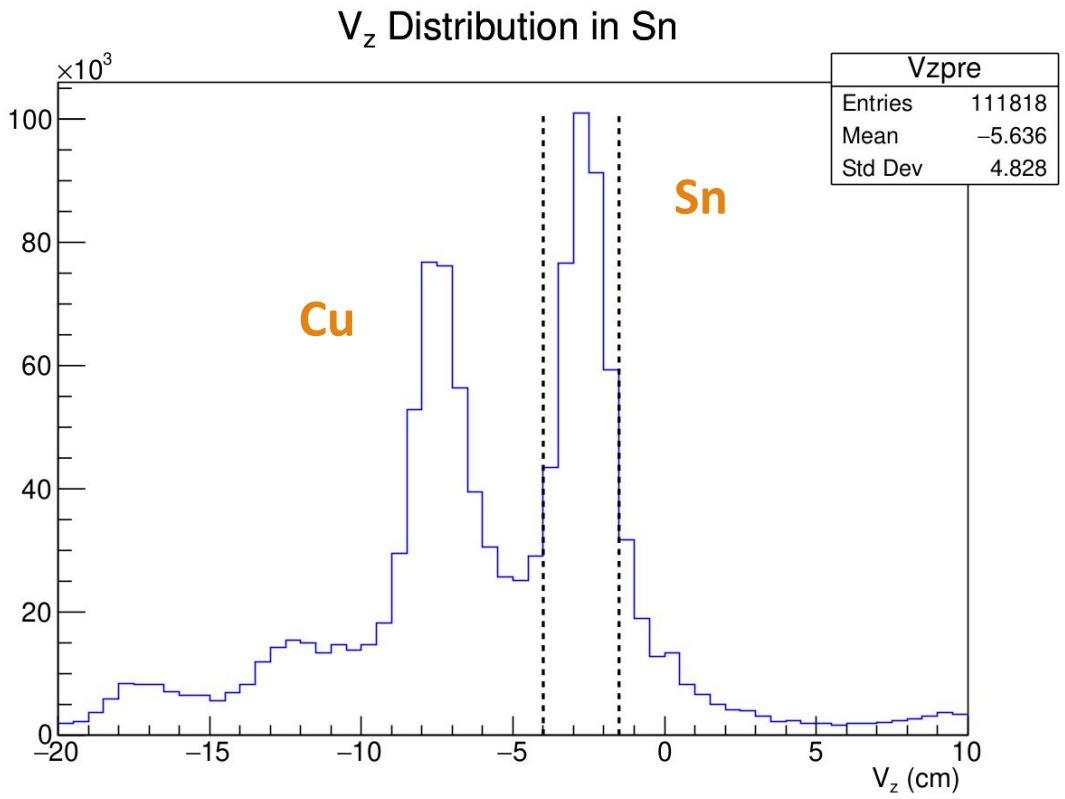



**red** is simulated data
**blue** is RG-D data

# specific preliminary analysis

- Monitoring data from available data
- Events considered with **π+** production
- Kinematic Variables specific to the **hadron** for TMDs:
  - **z** = Fraction of the virtual photon energy carried by the hadron.
  - $0.3 < \mathbf{z} < 0.7$
  - $\mathbf{pt^2}$ = transverse momentum of hadrons
  - $\mathbf{pt^2} < 1.5\ GeV^2$
- Vertex z cuts need to be considered according to target positions
  - Preliminary Arbitrary Cuts on Vz for all targets



# Multiplicity Ratio

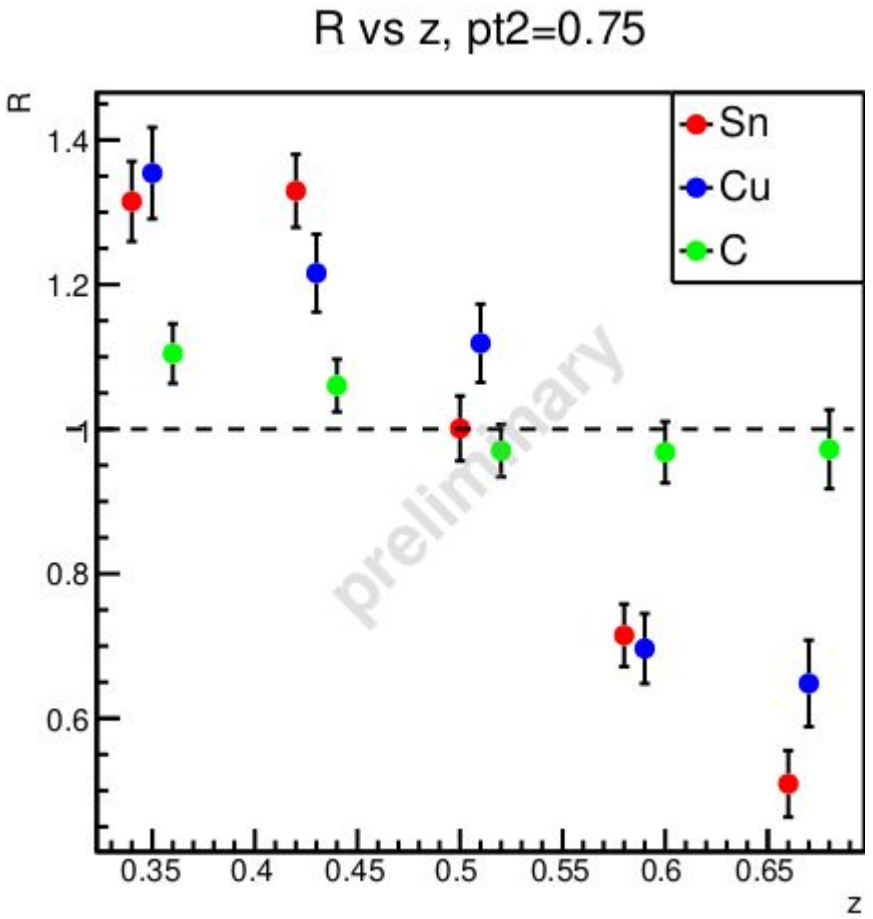
$$R_A^{\pi}(\nu, z, p_t^2) = \frac{N_{\pi}^{Sn}(\nu, z, p_t^2)/N_e^{Sn}(\nu)}{N_{\pi}^{D}(\nu, z, p_t^2)/N_e^{D}(\nu)}$$

Multi dimensional analysis can be implemented in order to consider cross-variable correlations.

Currently considering a three-Dimensional analysis with ν , z and $pt^2$

Analysis with no corrections implemented (on going)

Here, plot of multiplicity Ratio for different nuclei targets compared to reference Deuterium for ν=4.5 ; $pt^2$ = **0.75** as a function of z.



# Multiplicity Ratio

$$R_A^{\pi}(\nu, z, p_t^2) = \frac{N_{\pi}^{Sn}(\nu, z, p_t^2)/N_e^{Sn}(\nu)}{N_{\pi}^{D}(\nu, z, p_t^2)/N_e^{D}(\nu)}$$

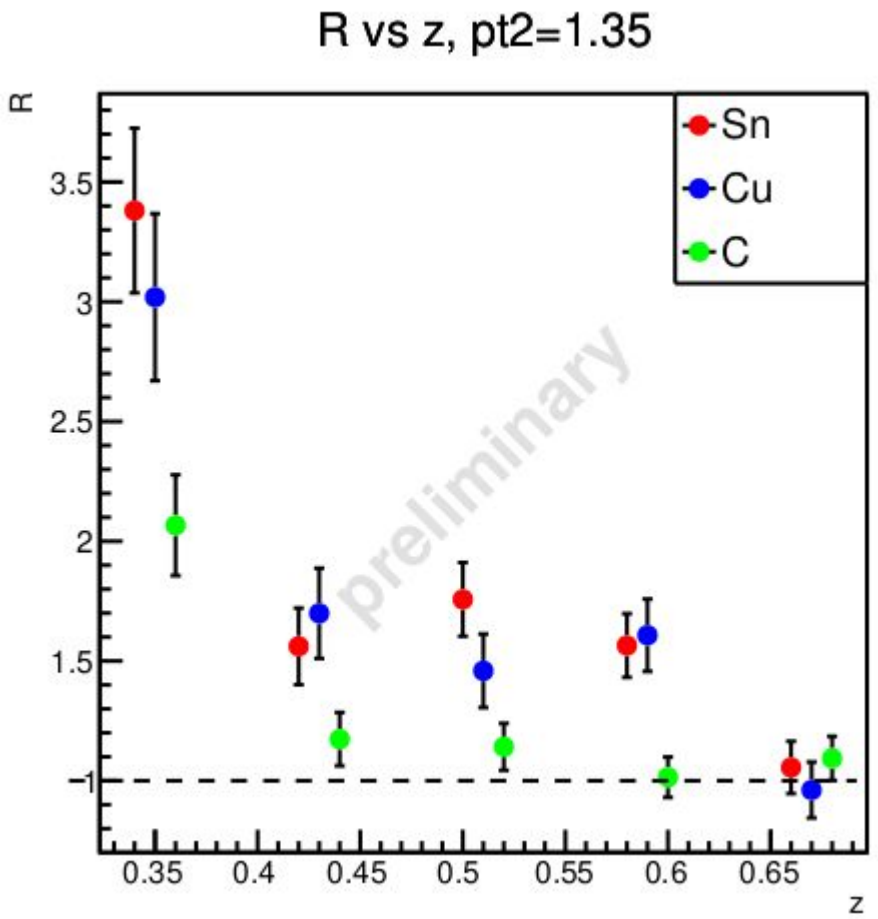
Multi dimensional analysis can be implemented in order to consider cross-variable correlations.

Currently considering a three-Dimensional analysis with ν , z and $pt^2$

Analysis with no corrections implemented (on going)

Here, plot of multiplicity Ratio for different nuclei targets compared to reference Deuterium for ν=4.5 ; $pt^2$ = **1.35** as a function of z.

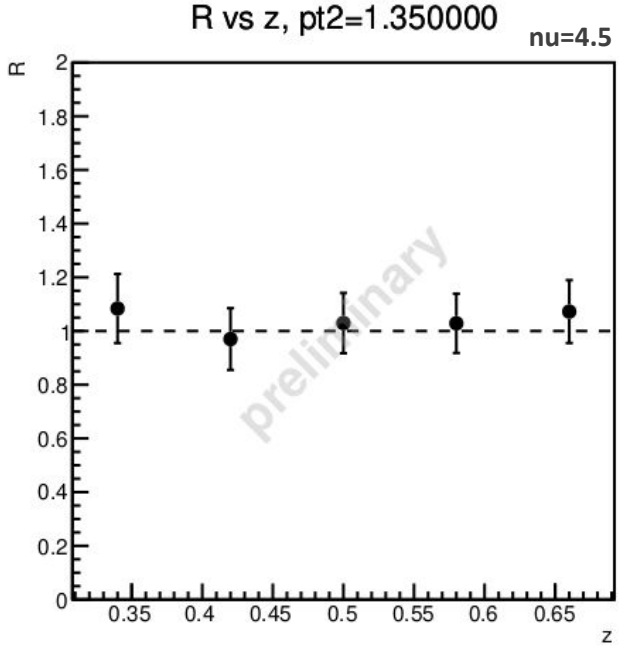
We can observe a deviation for high values of transverse momentum. But non conclusive results yet, calibrations and corrections remain to be implemented

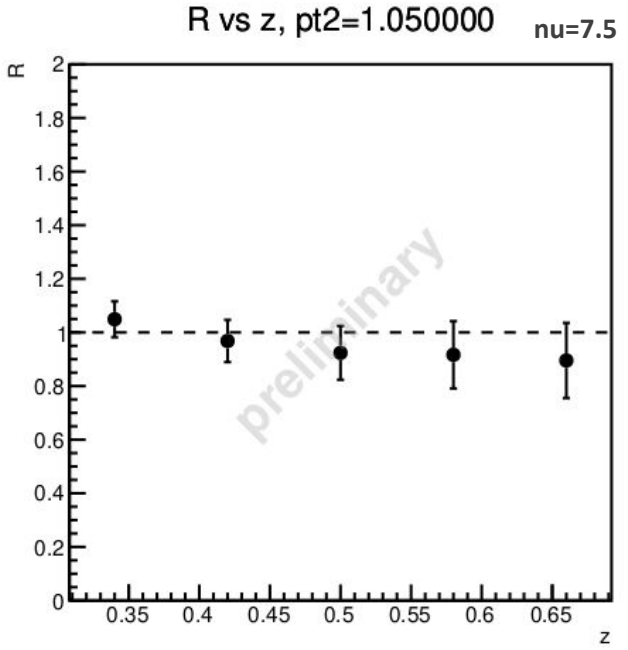


# Multiplicity Ratio on both Carbon targets

$$R^{\pi}_{C\times C}(\nu, z, p_t^2) = \frac{N^{C1}_{\pi}(\nu, z, p_t^2)/N^{C1}_{e}(\nu)}{N^{C2}_{\pi}(\nu, z, p_t^2)/N^{C2}_{e}(\nu)}$$

- Implementing multiplicity ratio with same target (on CxC runs)
- Useful for verification on Multiplicity Ratio
- Showing results for different values of ν and $pt^2$ as generalized example
- All resulting Ratio plots are close to 1 as expected



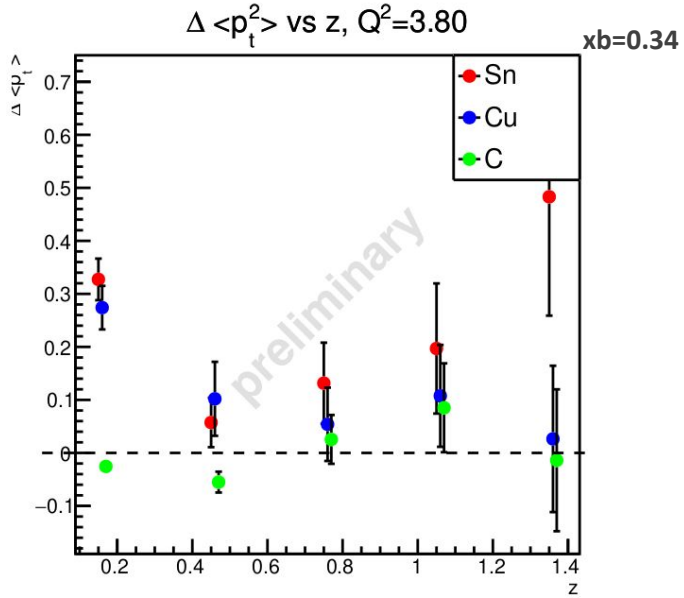



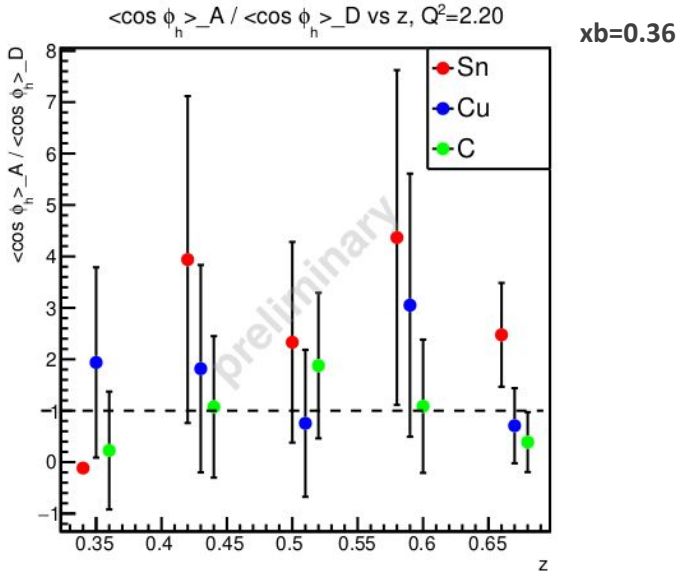
# Other observables in progress

Transverse Momentum Broadening:

$$\Delta < p_t^2 >=< p_t^2(x_b, Q^2, z) >_{Sn} - < p_t^2(x_b, Q^2, z) >_{LD2}$$

cosΦ: $$\frac{< cos\phi_h(x_b, Q^2, z) >_{Sn}}{< cos\phi_h(x_b, Q^2, z) >_{LD2}}$$




Very preliminary plots, work in progress. Results can't be conclusive yet, optimization remains to be done.

Corrections can be implemented. Other variables can be considered.

# Summary

## Implemented work

- Preliminary Data analysis for a study of TMDs on SIDIS with recent available data.
- Coherent/expected results on available data with initial analysis. Progress remains to be done.
- Adaptation of a SIDIS simulation to replicate RG-D conditions. On going

## Update on study of the simulation

- Simulation used to compare  with available data replicating experimental conditions as possible
- Currently implemented RG-D targets on the generator.
- Using official RG-D GEMC configurations for simulation.

## On going work

- Calibration on available data remains ongoing.
- Acceptance and Radiative effects need to be considered for corrections.
- Adapting simulations to experimental configurations & Implementing analysis.
- Consider other experimental observables.