nTMDs in SIDIS analysis with RG-D

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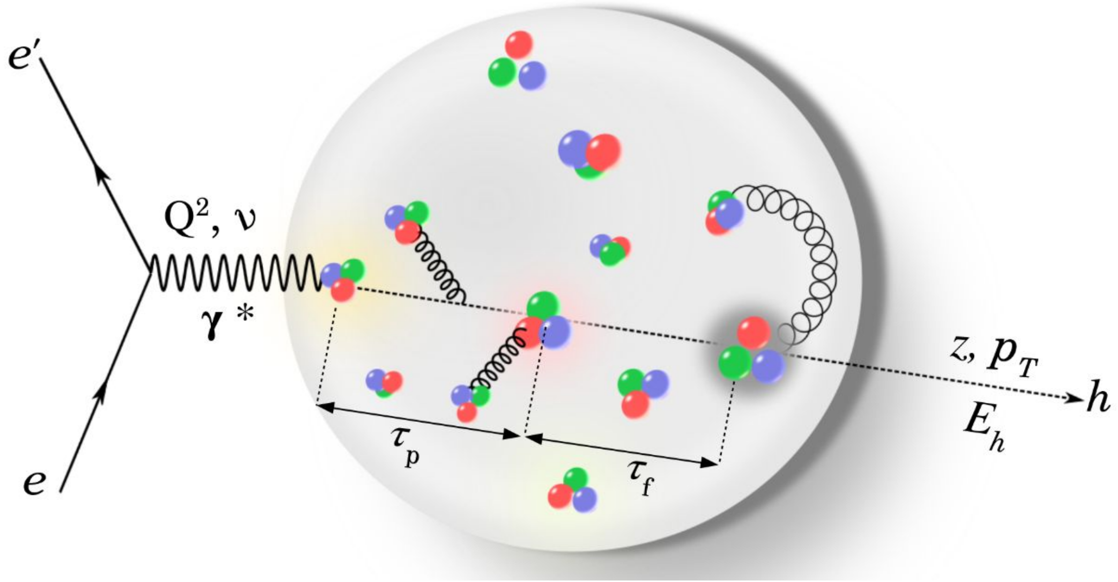
nTMD studies through SIDIS in RG-D

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

Semi-Inclusive Deep Inelastic Scattering (**SIDIS**):

- Electron scattering off a target nucleus producing hadrons through virtual photon exchange.
- In SIDIS, different components of the cross-section can be directly linked to parton-level dynamics.



Transverse-momentum-dependent parton distribution functions (**TMDs**):

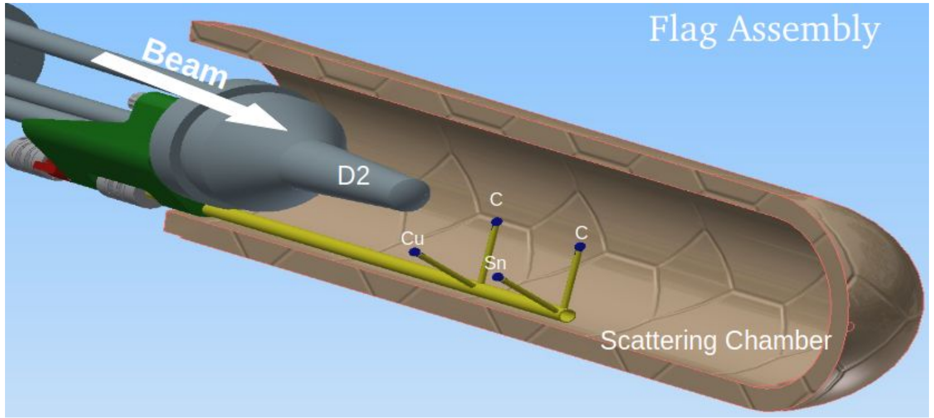
- Accessing TMD Structure and TMD Fragmentation functions.
- Nuclear effects such as EMC effect and hadronization modifications influence SIDIS in nuclear targets.
- Using the TMD framework will allow to separate initial and final state effects.

This Work: $R_A^h = \frac{(N_h/N_e)_A}{(N_h/N_e)_D}$ $\quad \Delta < p_t^2 >=< p_t^2 >_A - < p_t^2 >_N$ $\quad \frac{< cos2\phi_h >_A}{< cos2\phi_h >_N}$

RG-D Experimental configuration

10.5 GeV electron beam on nuclear targets

- Unpolarized targets: nuclear solid foils Cu, C and Sn. And LD2 cryogenic cell
- Currently developing analysis tools to monitor the reconstructed particles such as e-, π, etc

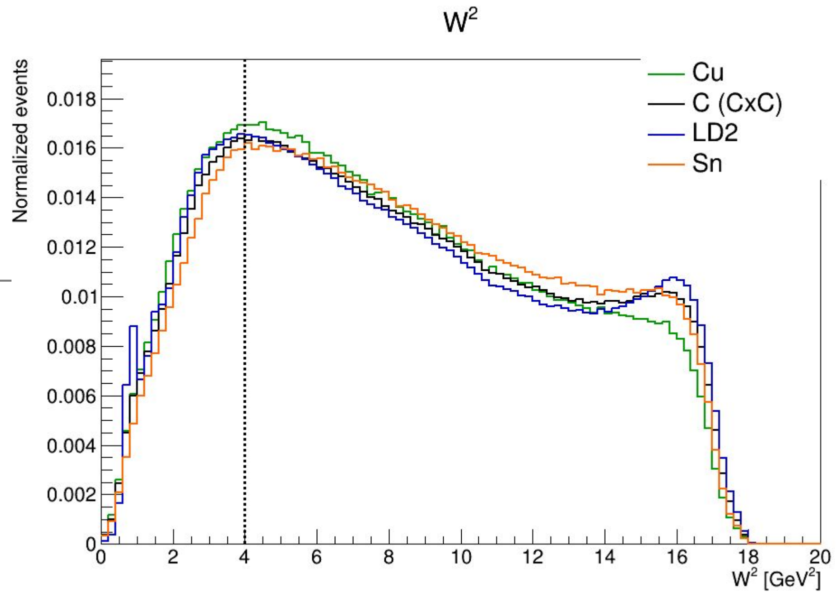


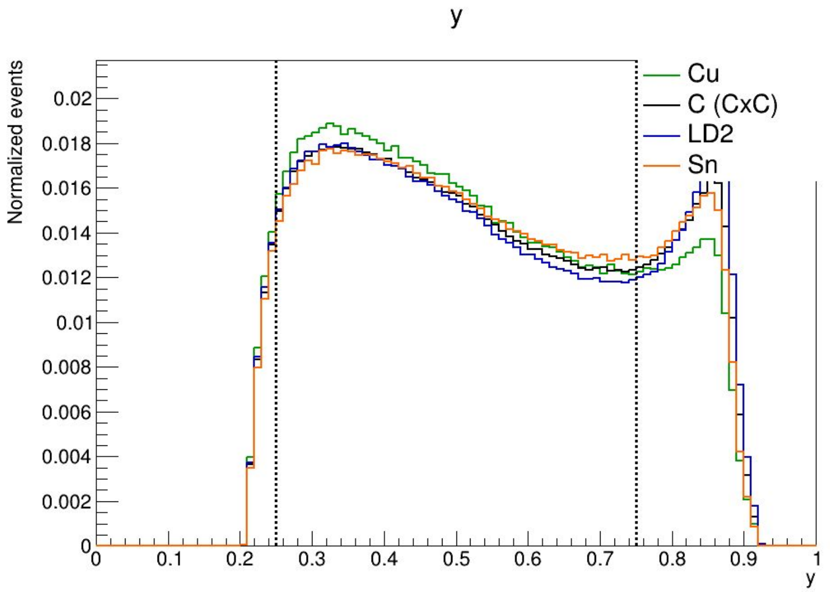
This work: Successful completion of data taking (Oct. 04, 2023 - Dec. 15, 2023).

- Developed analysis: π+ selection
- Implemented RGD target geometry and vertex distribution in simulation framework

Data Selection (DIS)

- DIS Kinematic selection considered:
  - $Q^2 > 1$ GeV² - DIS region
  - $W^2 > 2$ GeV - suppress resonances
  - $0.25 < y < 0.85$ - avoid low energy region





Data Selection (SIDIS)

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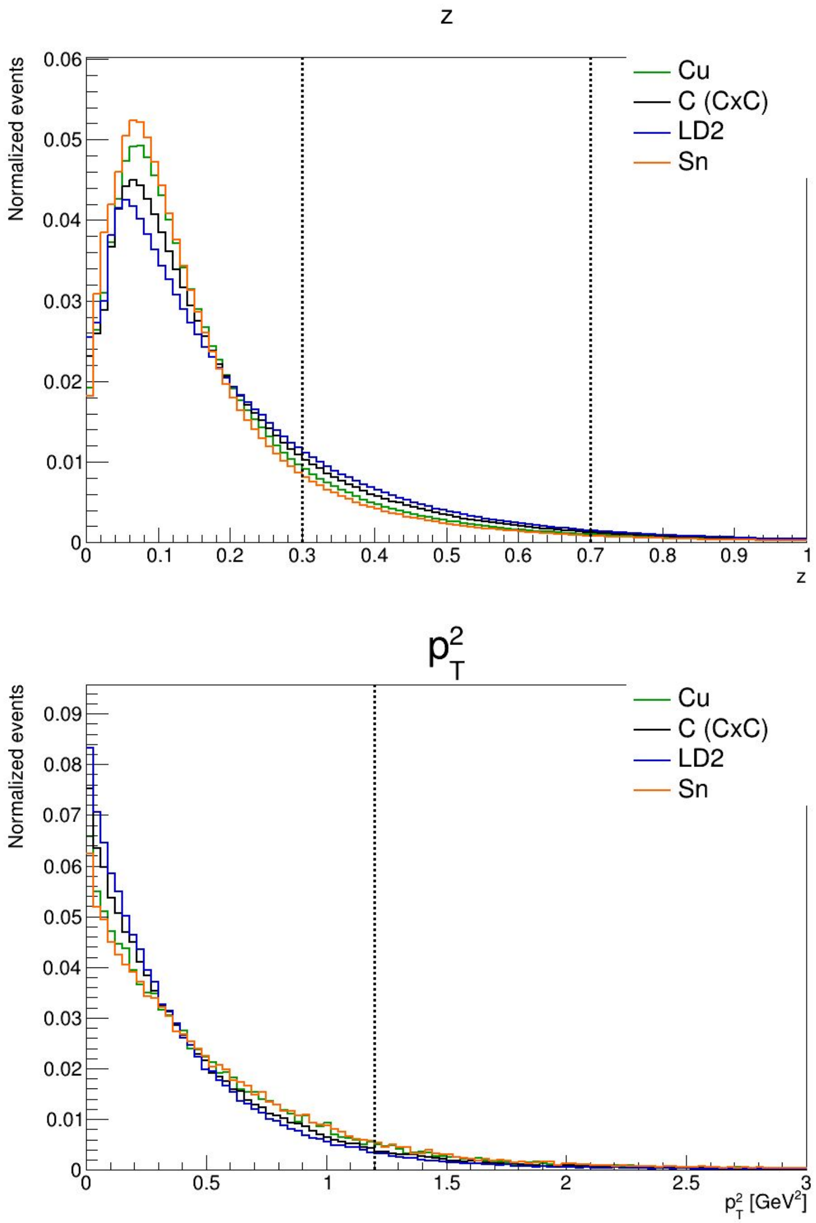
- Events considered with **$\pi+$** production in coincidence with electron
- Kinematic cuts for SIDIS **hadron** selection:
  - **z** = Fraction of the virtual photon energy carried by the hadron.
  - 0.3 < **z** < 0.7
  - **pt^2** = transverse momentum of hadrons
  - **pt^2** < 1.2 GeV^2 - avoids regions with low statistics



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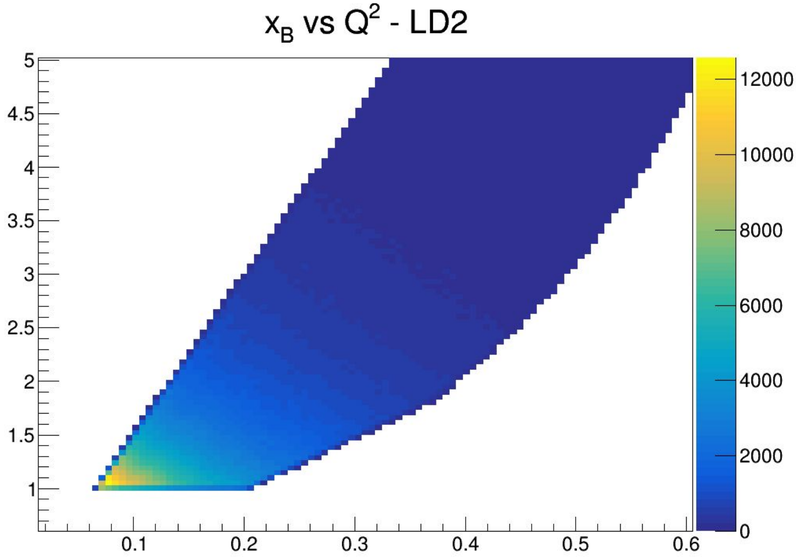
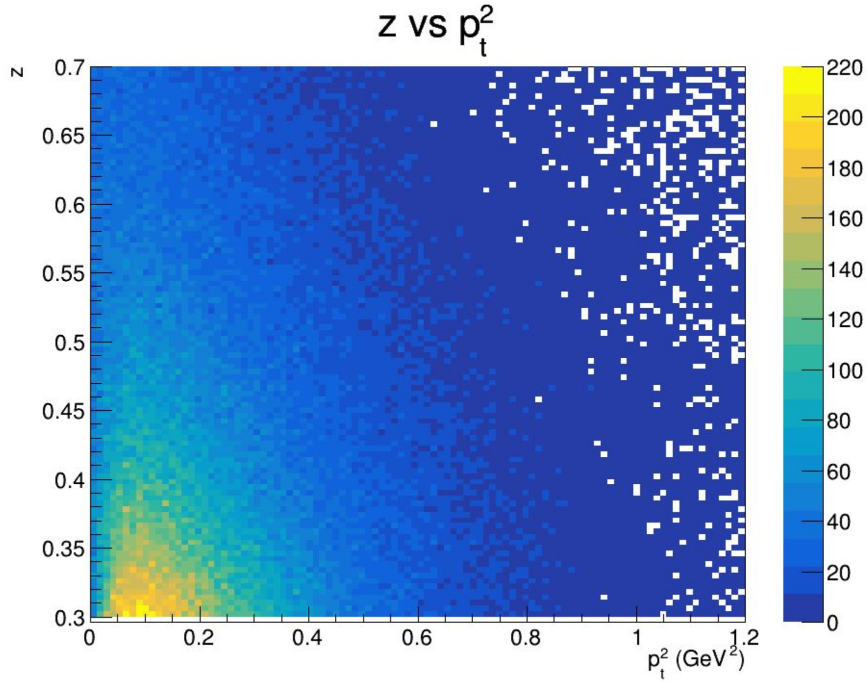
- Resulting distribution after DIS+SIDIS selection
  - Sufficient statistics for binning across kinematic ranges (xB, Q², pt², z)





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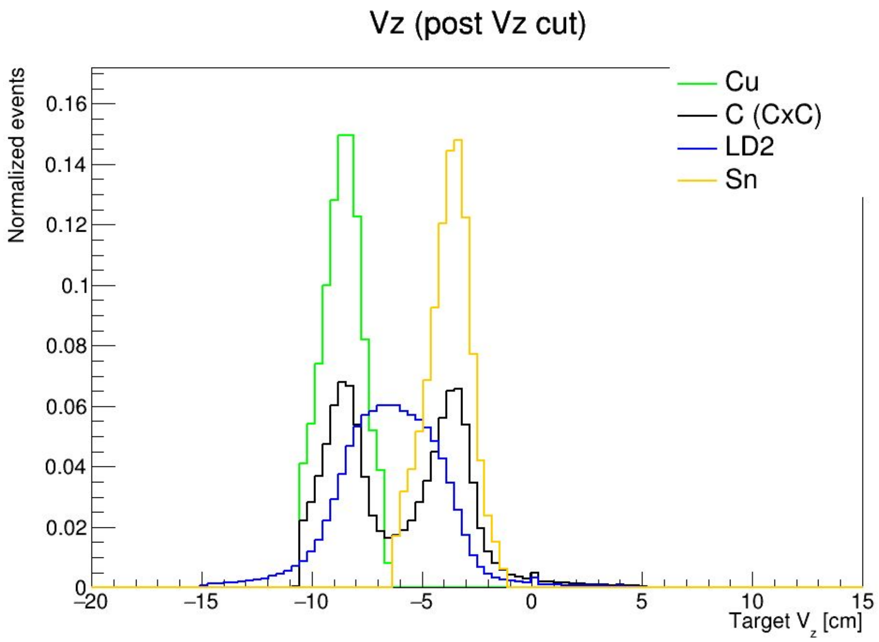
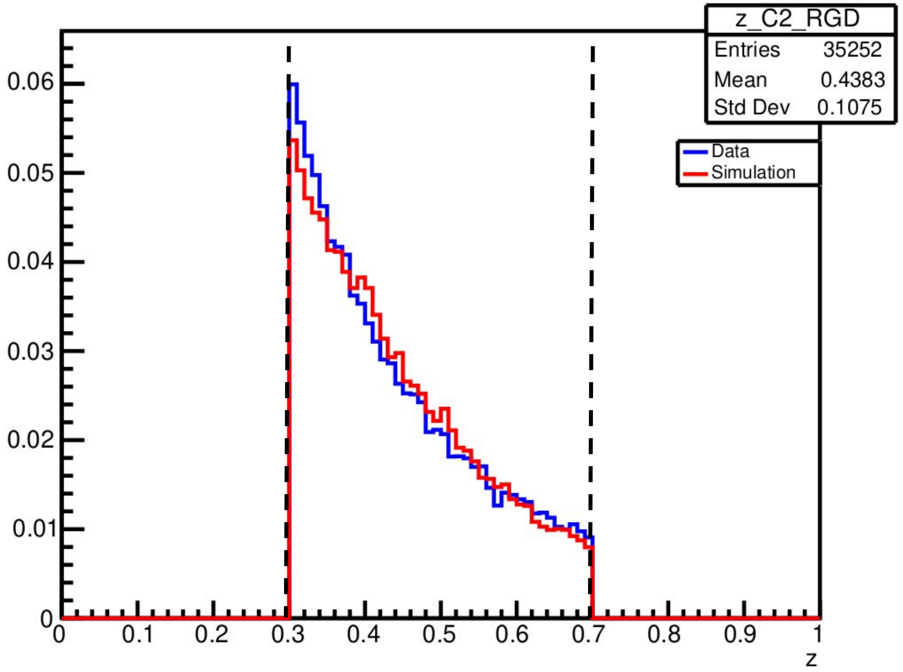
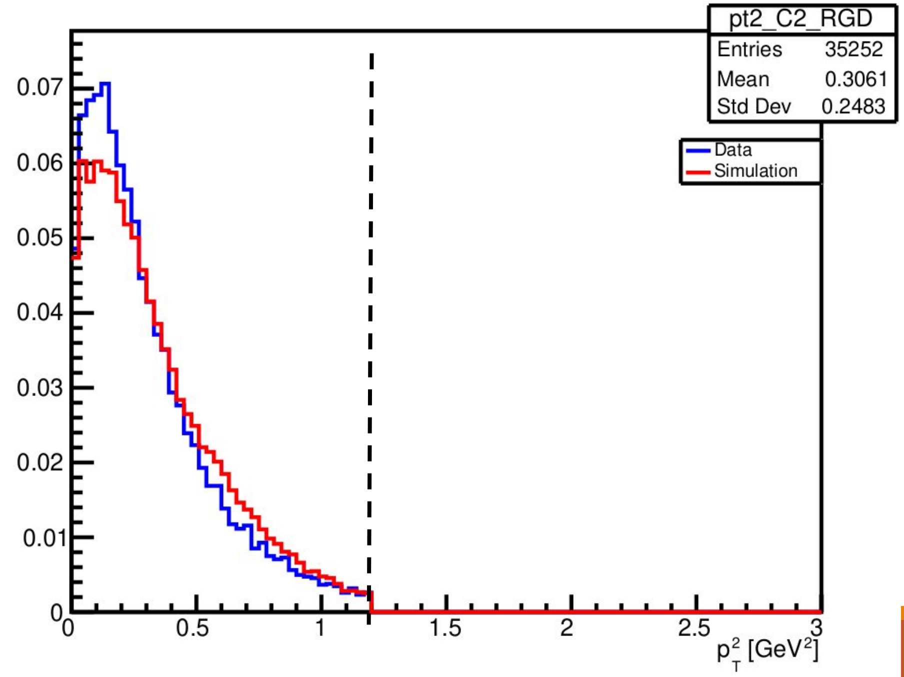
- Vertex z cuts need to be considered according to target positions
  - Specific Target Vz Cuts provided by M. Ouillon.



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. RG-D target configurations were included.
- Using an official version of RG-D gcard for GEMC, that considers the target assembly and vertex z positions.
- Simulation data was initially used for monitoring the behavior of initially available RGD data.
- Goal is to use simulation data to apply create Respo,de matrices for unfolding corrections on RGD data.

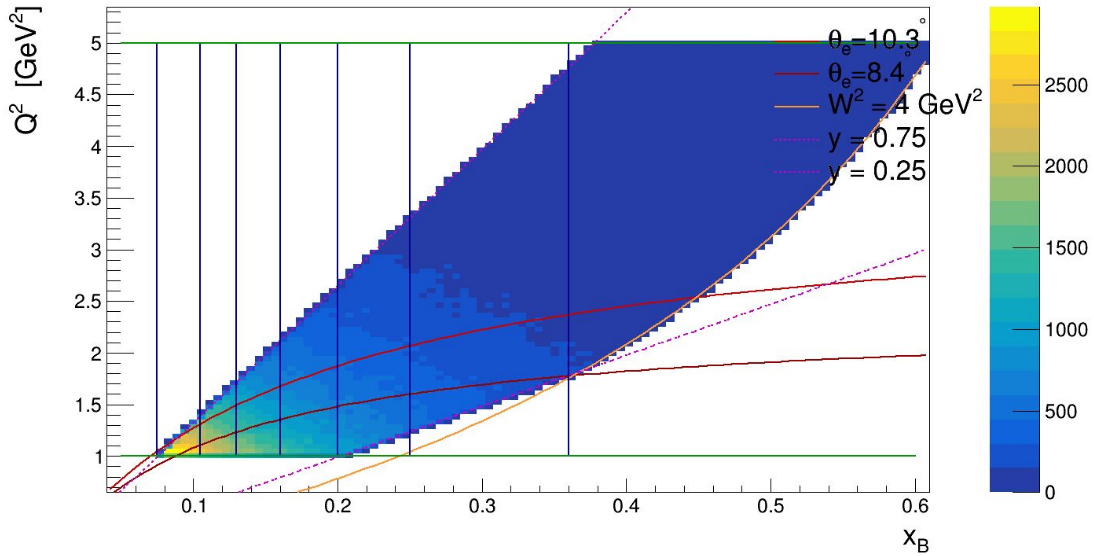




Unfolding

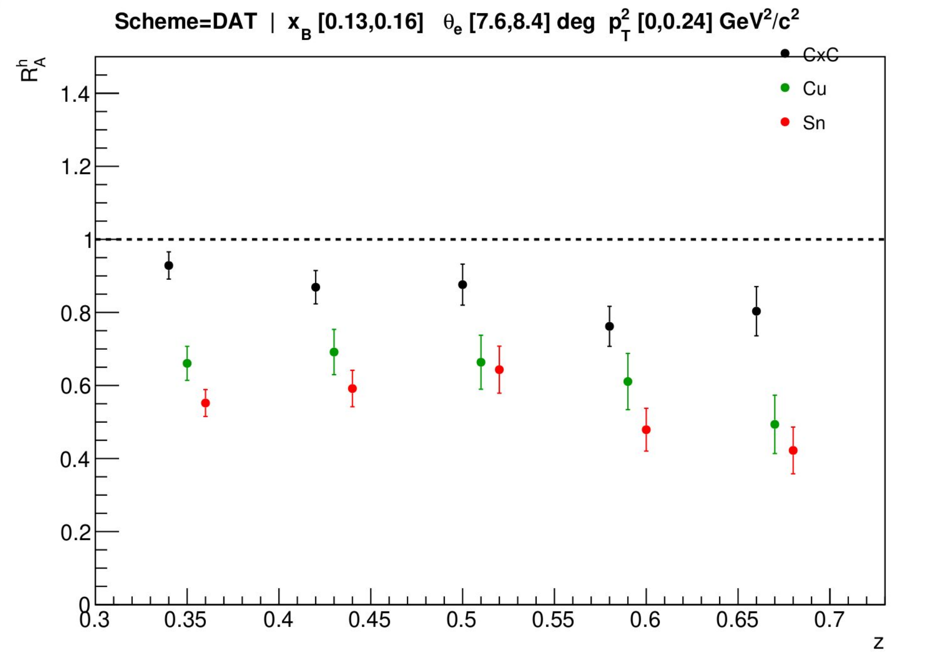
- Use Unfolding to correct detector level effects, and migration between bins
- Using **Roounfold** framework
- Building response matrix through electron kinematics (xB, Q^2)
- Using a custom θe assisted binning for true (MC) and reconstructed (REC) distributions
- Estimating a an approximately close amount of events per bin in each distribution.

- Full unfolding implementation in progress.



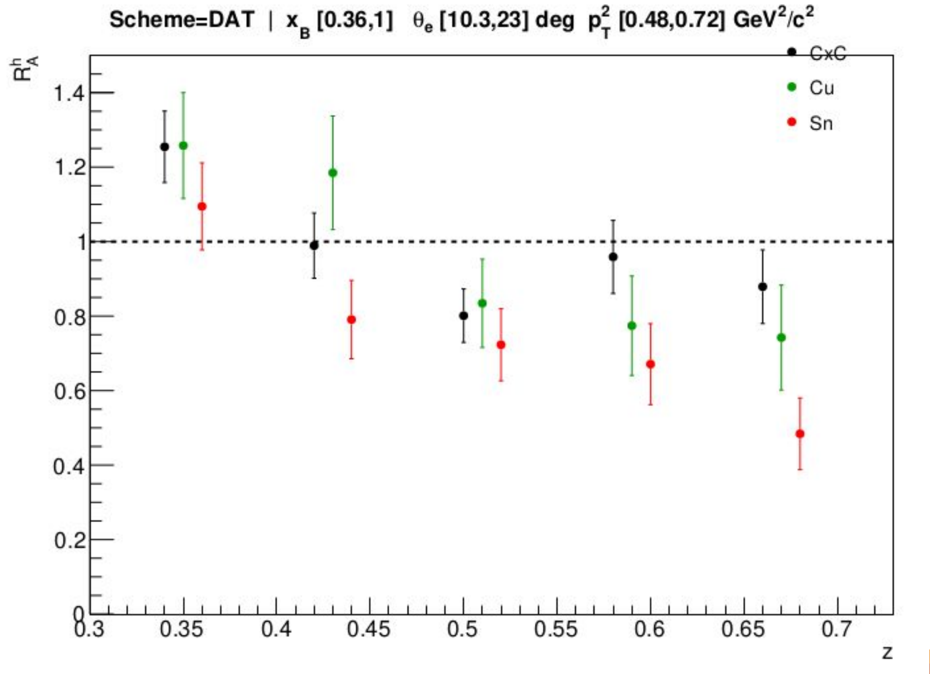
Multiplicity Ratio

$$R_A^{\pi}(Q^2, x_B, z, p_t^2) = \frac{N_\pi^A(Q^2, x_B, z, p_t^2)/N_e^A(Q^2, x_B)}{N_\pi^D(Q^2, x_B, z, p_t^2)/N_e^D(Q^2, x_B)}$$



Triple target comparison of Pass1 four-dimensional results: R across a (xB, Q², pt²)-coverage, as a function of z.

Noticeable suppression as R<1 for all targets. R increases with pt² due to nuclear attenuation.
Target order: heavier nuclei (Sn) show stronger suppression than lighter ones due to important absorption in heavier nuclei.



Small data sample (~5%) of available data. Full RGD statistics coverage ongoing

Multiplicity Ratio (Carbon on Carbon)

$$R^{\pi}_{C\times C}(Q^2, x_B, p_t^2, z) = \frac{N_\pi^{C1}(Q^2, x_B, p_t^2, z)/N_e^{C1}(Q^2, x_B)}{N_\pi^{C2}(Q^2, x_B, p_t^2, z)/N_e^{C2}(Q^2, x_B)}$$

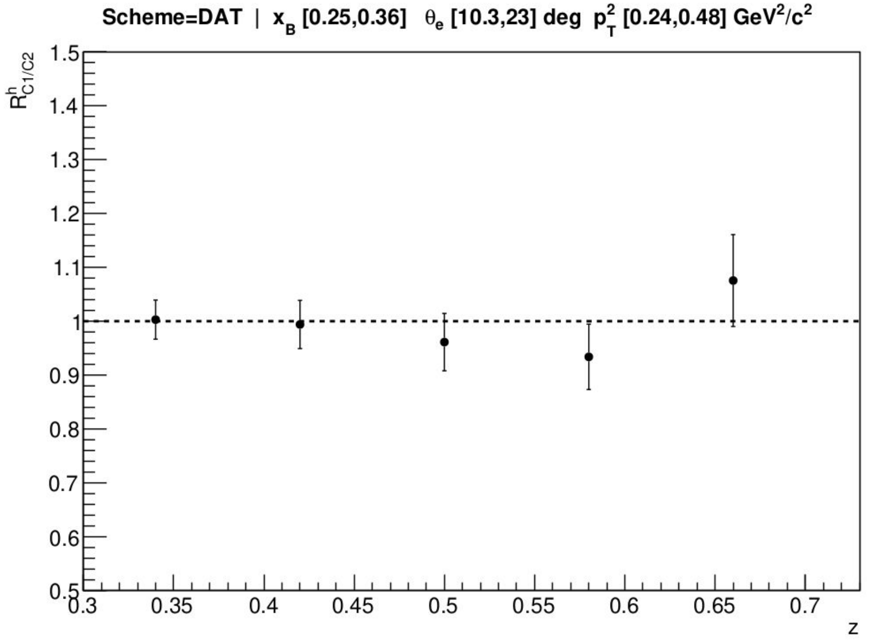
Using carbon target separation in Pass1 four-dimensional results: R across a (xB, Q², pt²)-coverage, as a function of z.

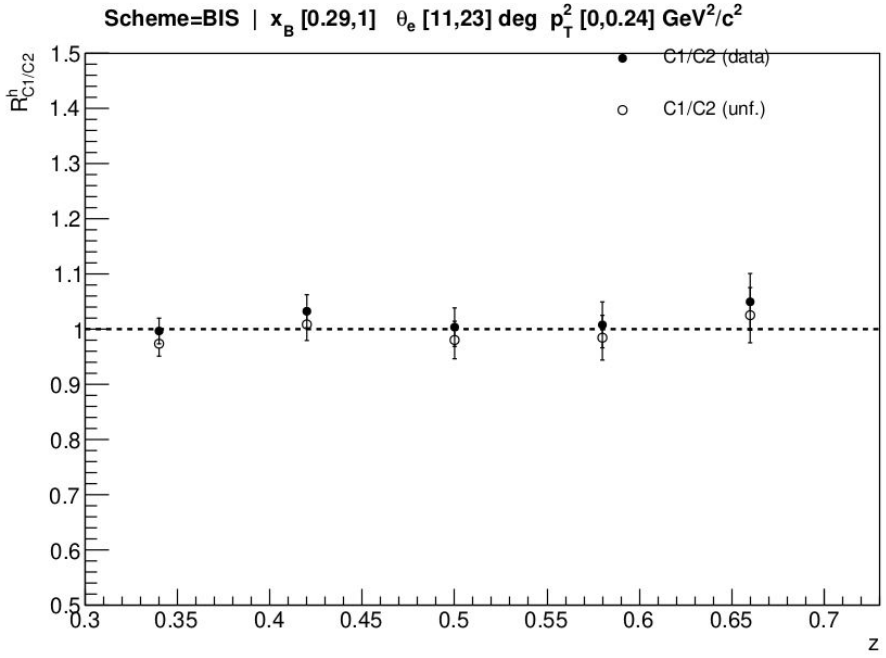
Using the carbon on carbon multiplicity ratio to monitor the ration determination as well as a proper behavior of data.

Consistency on R≈1 across various kinematic ranges indicate low acceptance effects.

carbon on carbon ratio can also be used to monitor the proper application of the unfolding correction. ongoing.

Small data sample (~5%) of available data. Full RGD statistics coverage ongoing





Pt² broadening

$$\Delta < p_t^2 > = < p_t^2(x_B, Q^2, z) >_A - < p_t^2(x_B, Q^2, z) >_{LD_2}$$

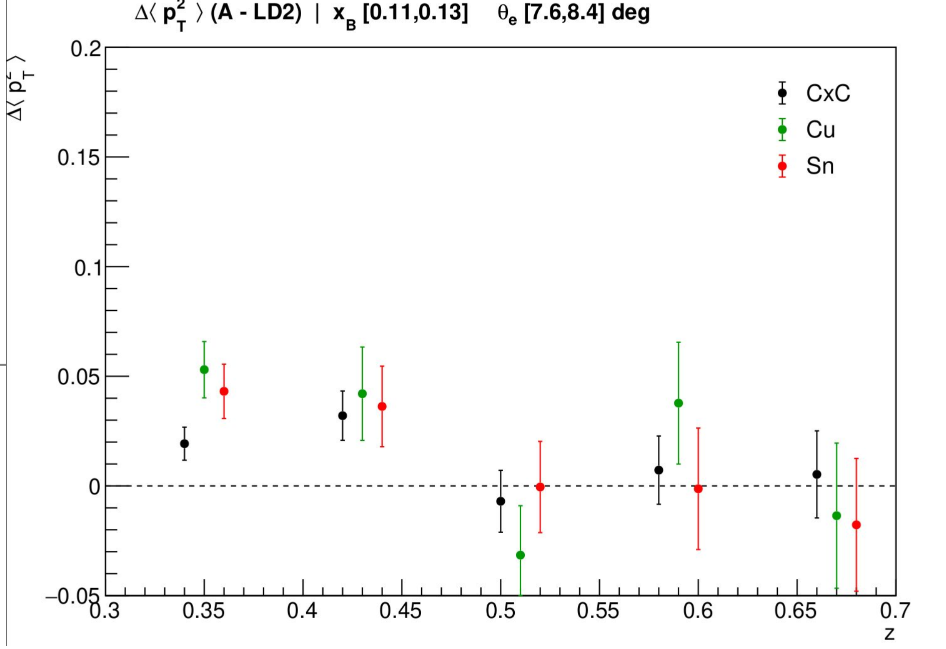
Triple target comparison of Pass1 three-dimensional results: across a (xB, Q²)-coverage, as a function of z.

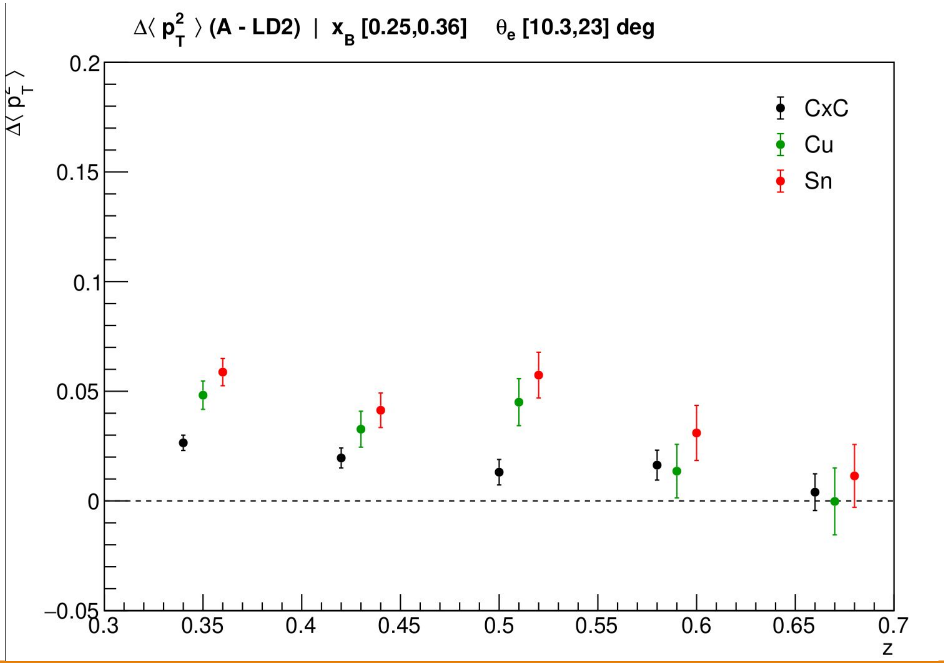
Broadening increases with nuclear mass: Sn>Cu>CxC

Larger broadening for heavier nuclei.

Broadening decreases with z as hadronization happens outside of the nuclei

Small data sample (~5%) of available data





Azimuthal Modulation Ratio

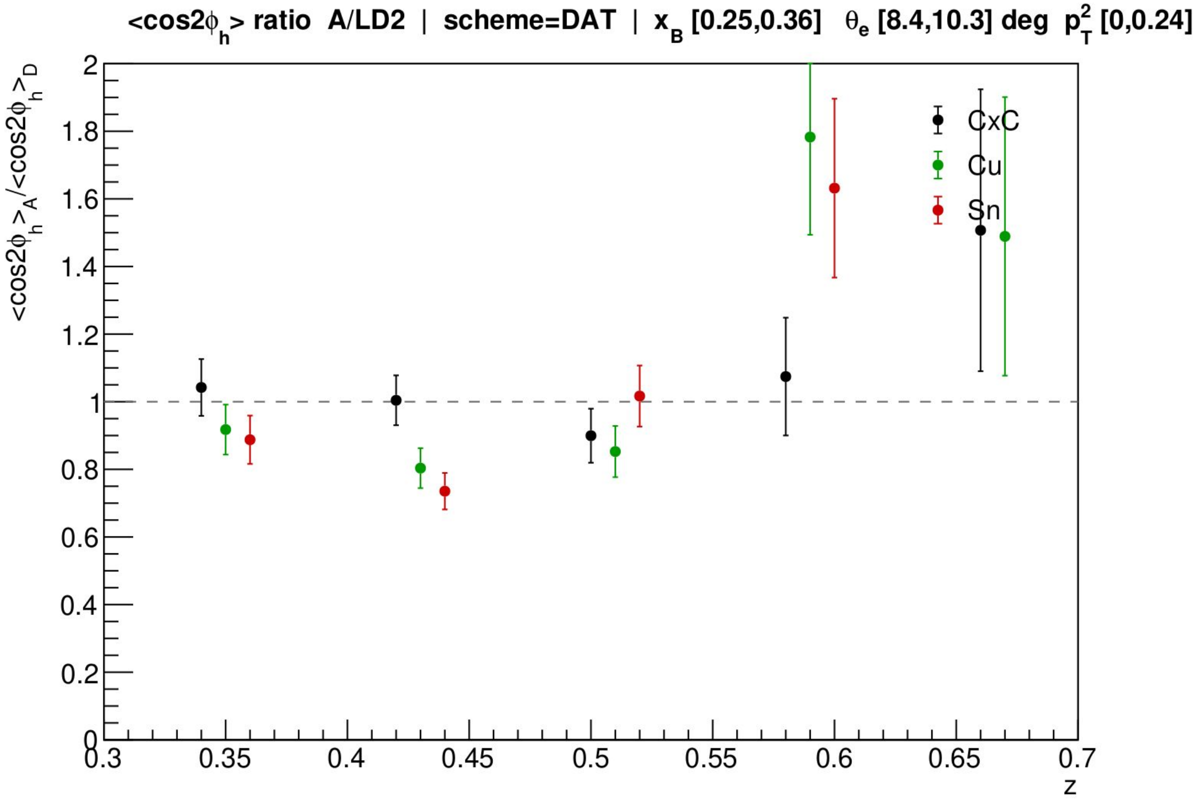
$$\frac{< cos2\phi_h(x_B, Q^2, p_t^2, z) >_A}{< cos2\phi_h(x_B, Q^2, p_t^2, z) >_{LD_2}}$$

Triple target comparison of Pass1 four-dimensional results: across a (xB, Q², pt²)-coverage, as a function of z.

⟨cos 2φ□⟩ ratio is expected to stay close to or slightly below 1, with a stronger reduction for heavier nuclei as observed.

Small suppression at intermediate z follows the expected ordering (C×C > Cu > Sn), compatible with a reduced modulation in larger nuclei.

Small data sample (~5%) of available data



Summary

Implemented work

- Current state of analysis for a study of TMDs on SIDIS with pass1 available RGD data.
- Coherent results on available data with analysis. Study can be conducted in larger samples.
- Adaptation of a SIDIS simulation to replicate RG-D conditions.

Study of the simulation and Results

- Simulation used to monitor available RG-D data.
- Adaptation of a SIDIS generator to replicate RG-D experimental conditions.
- Using a the simulation for an initial application of corrections, ongoing.
- Determination of observables.

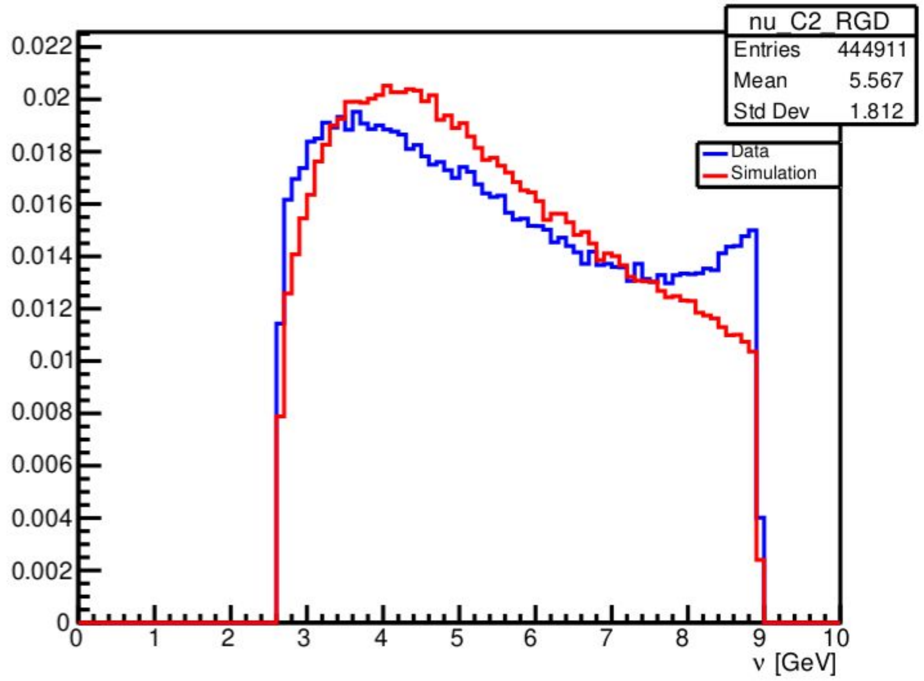
On going work and prospects

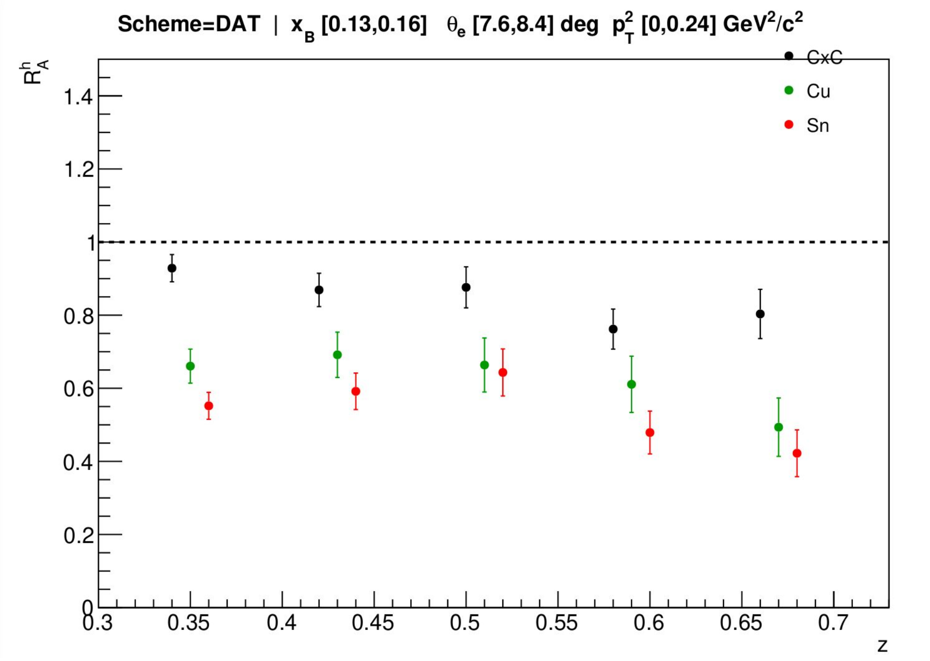
- Studying observables in all available RG-D data.
- Proper implementation of corrections.
- Consider other experimental observables, azimuthal modulations

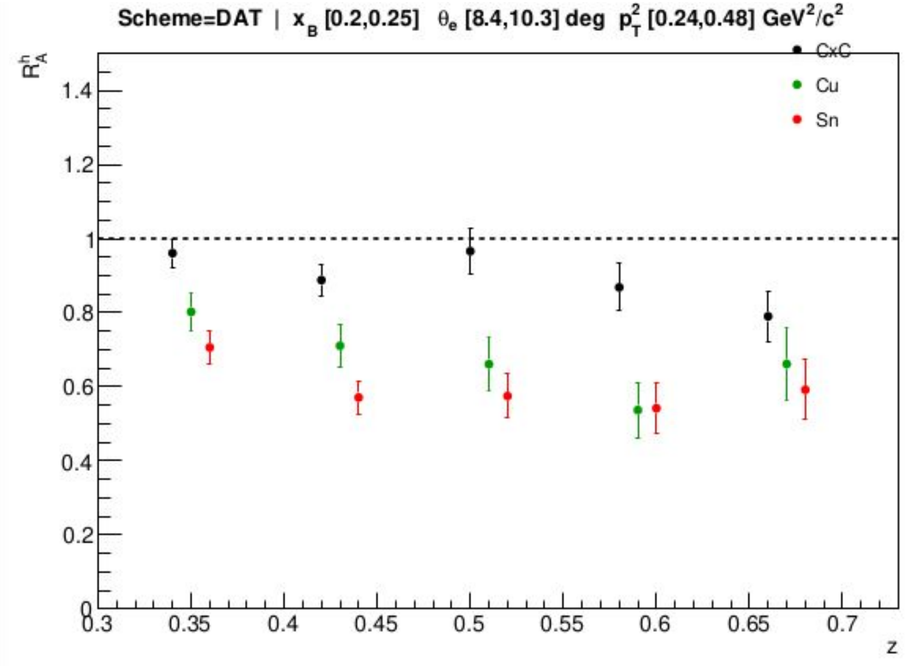
Observations

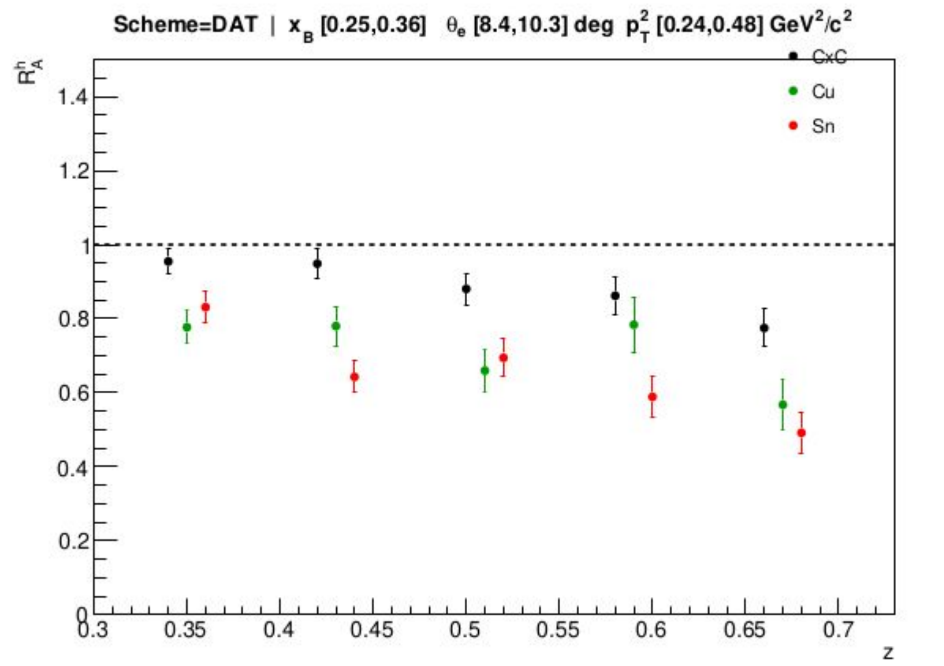
- RGD data calibration is still ongoing.
- Coherent results on multiplicity Ratio for an initial data set can validate progress on this observables to propagate the method to other observables on even larger data sets.
- Ongoing progress with simulations, that could be used to monitor as well observable behavior.

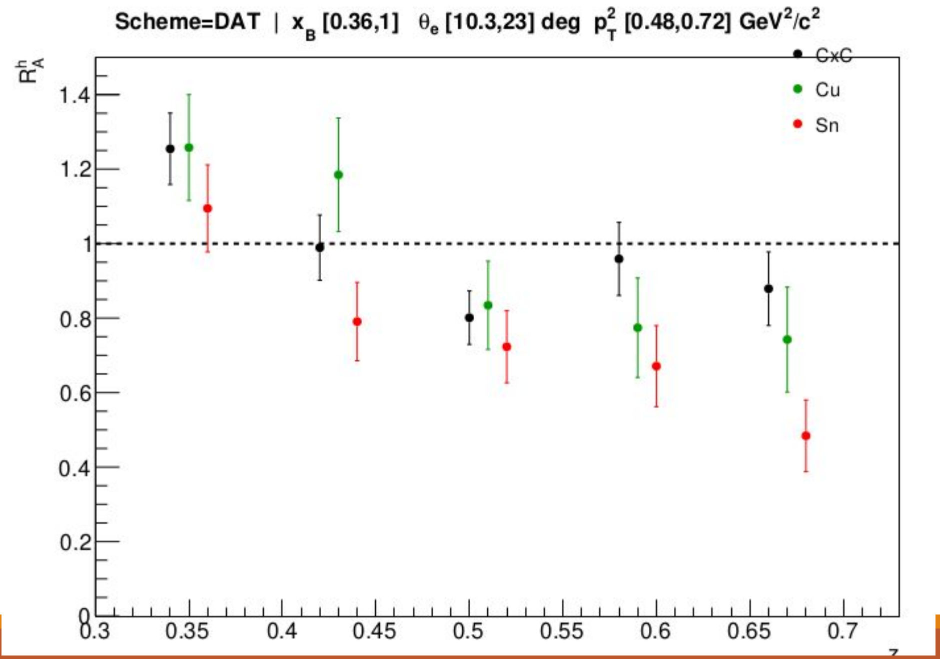
- Corrections remain to be implemented on data with simulations.




Scheme=DAT | x_B [0.13,0.16] θ_e [7.6,8.4] deg p_T^2 [0,0.24] GeV^2/c^2
R_A^h
CxC
Cu
Sn
z


Scheme=DAT | x_B [0.2,0.25] θ_e [8.4,10.3] deg p_T^2 [0.24,0.48] GeV^2/c^2
R_A^h
CxC
Cu
Sn
z


Scheme=DAT | x_B [0.25,0.36] θ_e [8.4,10.3] deg p_T^2 [0.24,0.48] GeV^2/c^2
R_A^h
CxC
Cu
Sn
z


Scheme=DAT | x_B [0.36,1] θ_e [10.3,23] deg p_T^2 [0.48,0.72] GeV^2/c^2
R_A^h
CxC
Cu
Sn

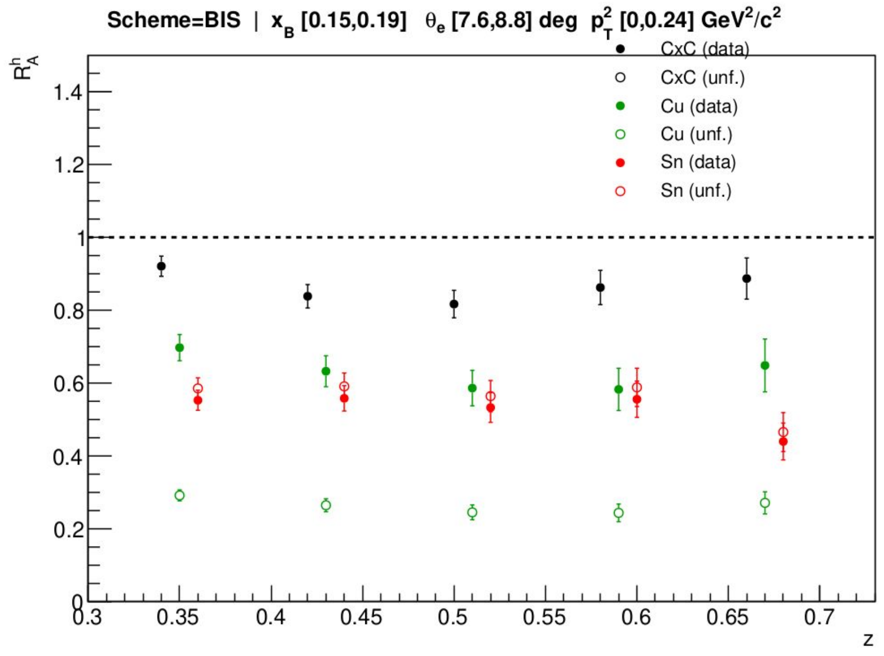
Multiplicity Ratio with Correction

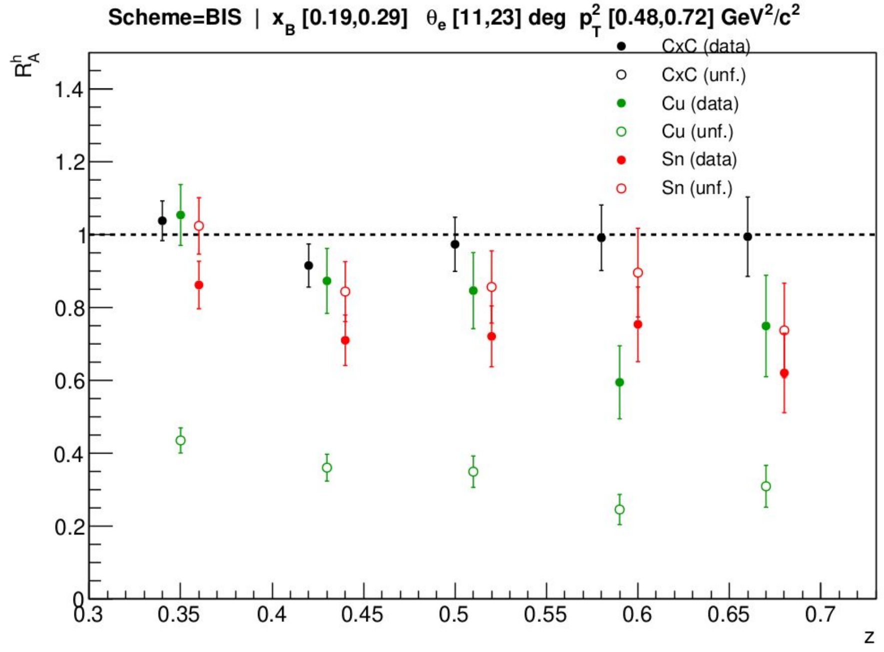
Triple target comparison of Pass1 four-dimensional results: R across a similar (xB, Q^2, pt^2)-coverage, as a function of z.

Noticeable suppression as R<1 for all targets. R increases with pt^2 due to nuclear attenuation.
Target order: heavier nuclei (Sn) show stronger suppression than lighter ones (C).

Correction succeeded, with noticeable improvements for Sn. Failed corrections on Cu and CxC need revisions

Small data sample (~5%) of available data. Full RGD statistics coverage ongoing





Observations

- Corrections remain to be properly implemented on data with simulations.
- higher y cut purpose is too avoid region where acceptance effects may affect the data. As seen in the comparison of Data and simulation.