Nuclear TMD analysis with SIDIS in RG-D Experiment at Jefferson Lab

Partonic Structure of Nuclei at the *"Jlab/EIC"* group in **IJCLab**

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DANIEL MATAMOROS

SUPERVISOR: RAPHAËL DUPRÉ

Motivations: Nuclear TMDs with CLAS12

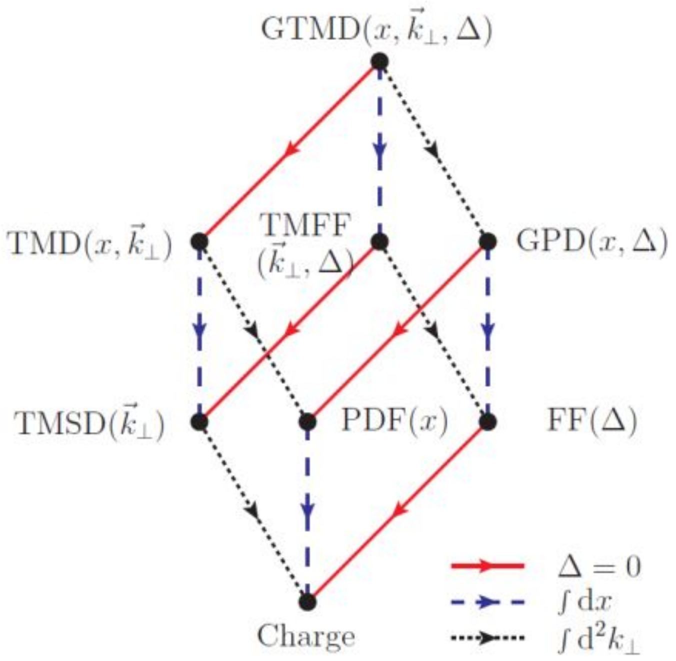
Understand the structure of nuclei in terms of quarks and gluons through 3D momentum space distribution of partons -> Transverse Momentum Distribution Functions (TMDs).

Decipher the effect of in-medium modifications TMDs in nuclei.

This work: Nuclear TMDs

- Study of the modification of final state interactions
- Cross section components can be linked to parton level effect

Transverse Momentum Dependent (TMD) functions. From PDFs to TMDs



PDF: Describes the probability of finding a parton carrying a fraction of the nucleon's **longitudinal** momentum (**1D**)

TMD: Incorporate **transverse** momentum of partons allowing to study the partons' motion and interactions in greater detail (**3D**)

This work: Nuclear TMDs

- Study of the modification of final state interactions
- Cross section components can be linked to parton level effect

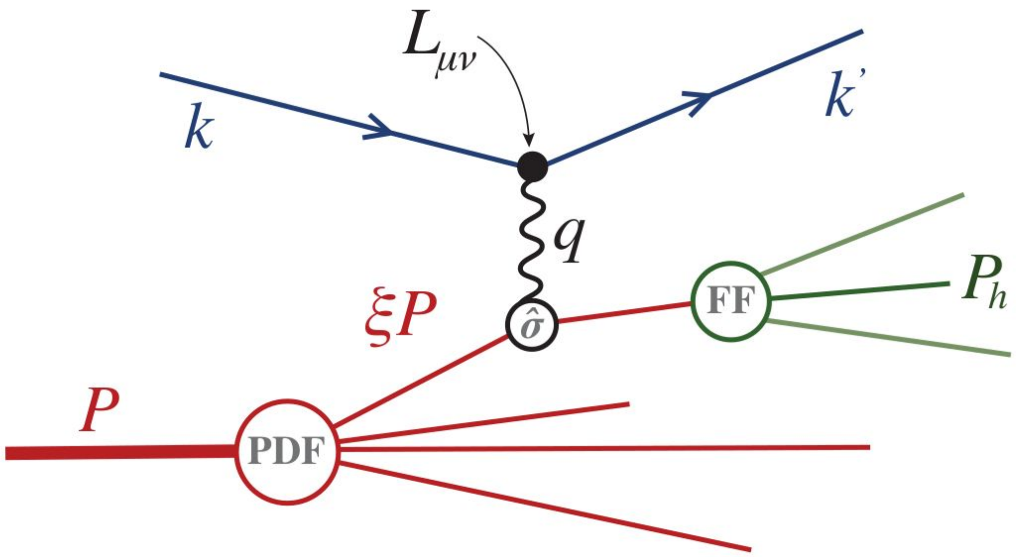
N/q	U	L	T
U	f_1		$h_1^\perp$
L		g_1	h_{1T}^{L}
T	$f_{1T}^\perp$	$g_{1T}^\perp$	h_1 $h_{1T}^\perp$

Semi Inclusive Deep Inelastic Scattering (SIDIS)

- Hadron production through γ *

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

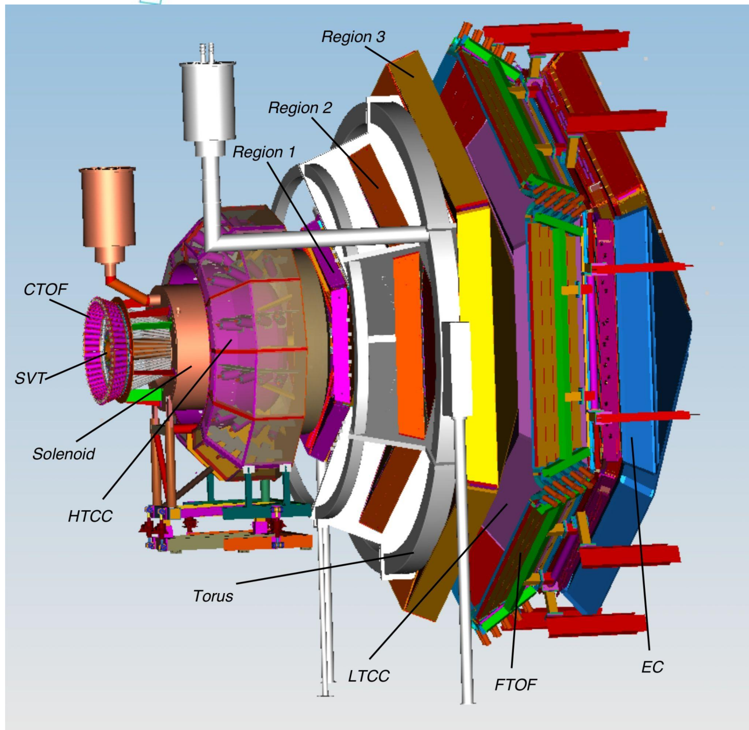


TMD study with JLab’s CLAS12

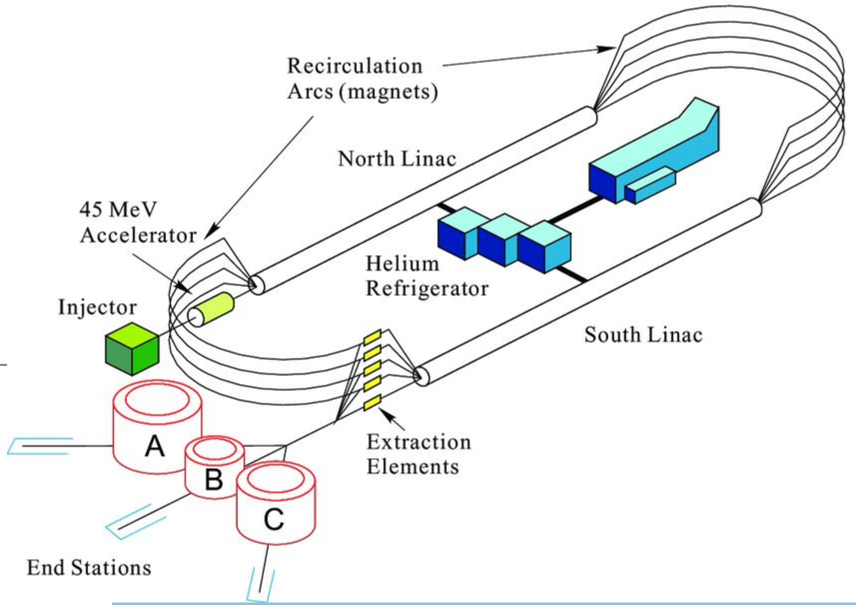
- Located at Jefferson Lab in Newport News (VA), USA
- Use of the 12 GeV electron beam at JeffersonLab
- Use of the CLAS12 spectrometer in Hall B.

Using the CLAS12 spectrometer @ JeffersonLab provides several advantages for SIDIS study

- Use of multiple targets, and possibility of beam polarization.
- Large Acceptance allowing the detection of scattered leptons and produced hadrons over a wide range of angles
- Precise measurements of various kinematic variables, including momentum, angle, and transverse momentum



TMD study with JLab's CLAS12



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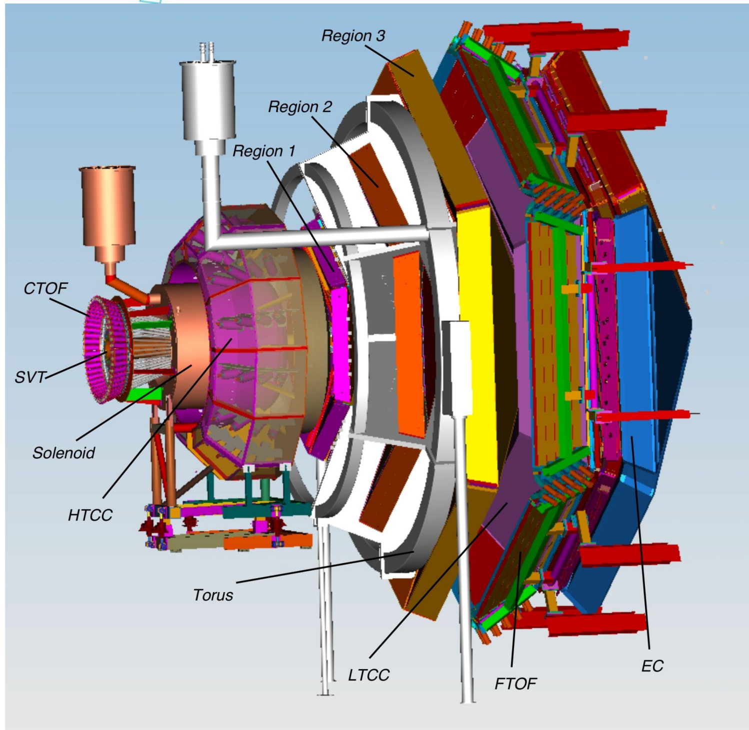
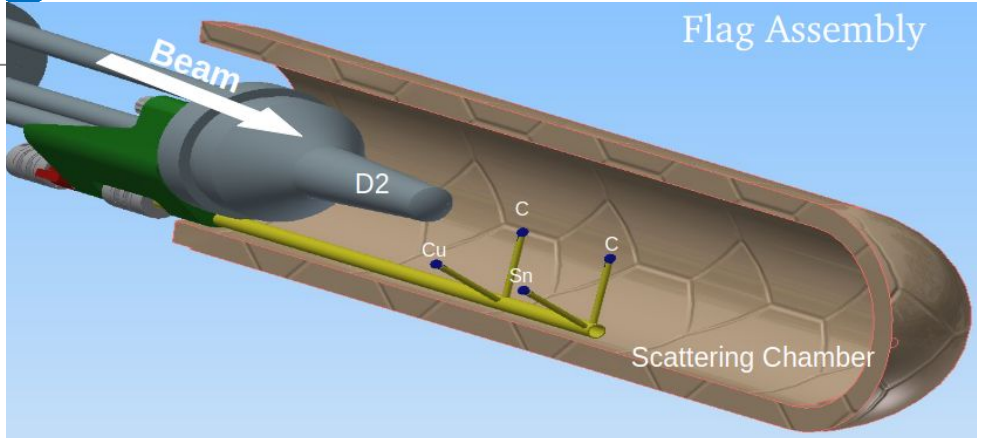
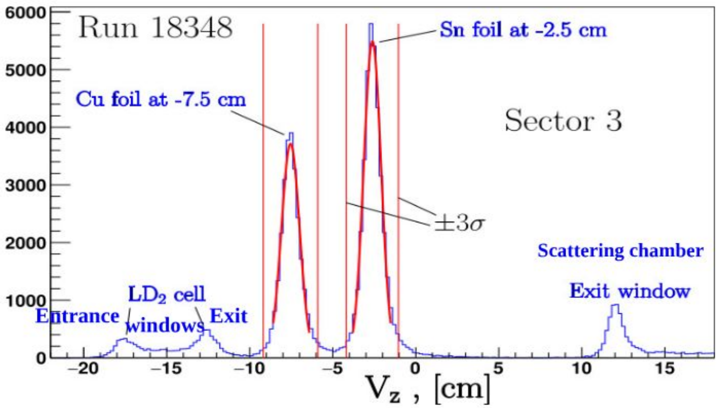


Experimental configuration



10-11 GeV electron beam on nuclear targets

- Targets: nuclear solid foils; **Deuterium**, Copper; Carbon and Tin.
- we will develop analysis tools to monitor the reconstructed particles yields such as e-, π, k, etc



calibration cooking V_z vertex reconstruction

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

Analysis Implemented: π+ selection

Experimental Observables

Comparison study of data with a nucleon target N and a nuclear target A

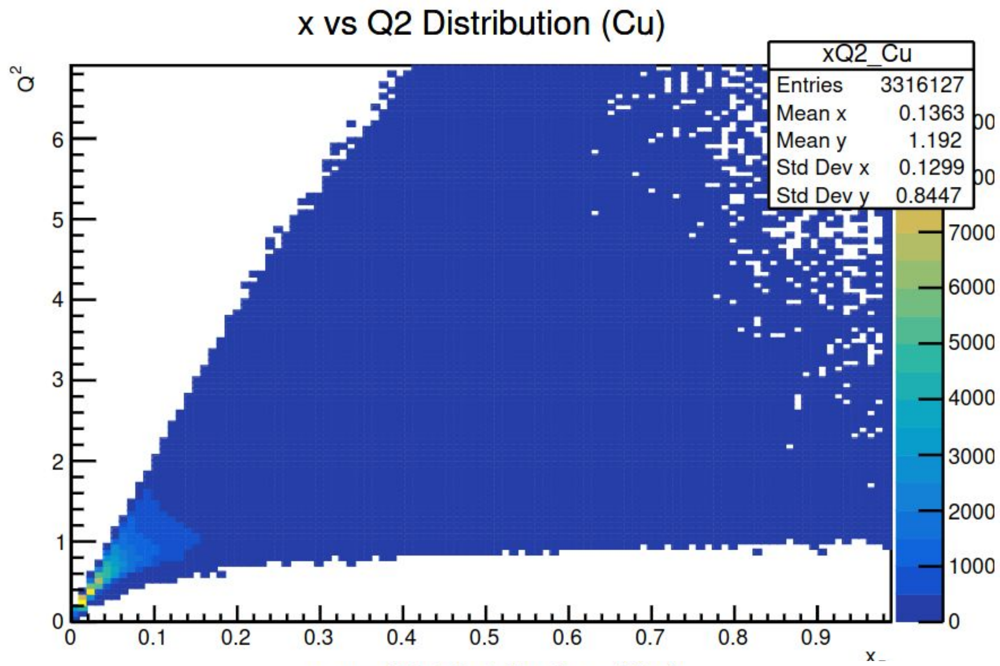
- Multiplicity Ratio R: $$R_A^h = \frac{(N_h/N_e)_A}{(N_h/N_e)_D}$$

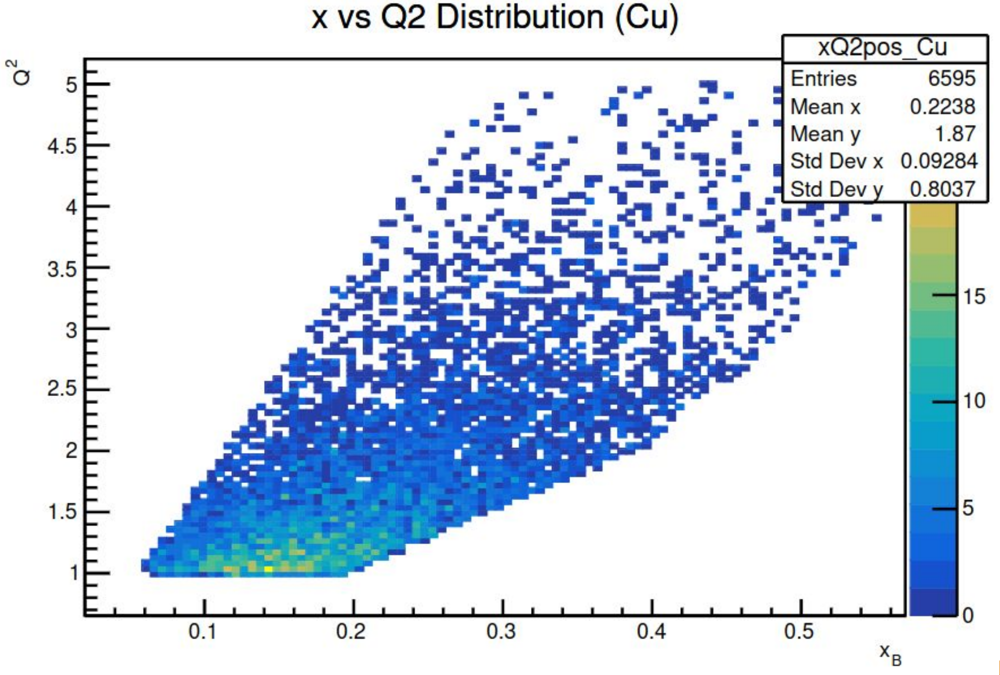
- Pt^2 difference: $$\Delta < p_t^2 >=< p_t^2 >_A - < p_t^2 >_N$$

Both Observables can be studied as a function of different kinematic variables.

Kinematic Variables

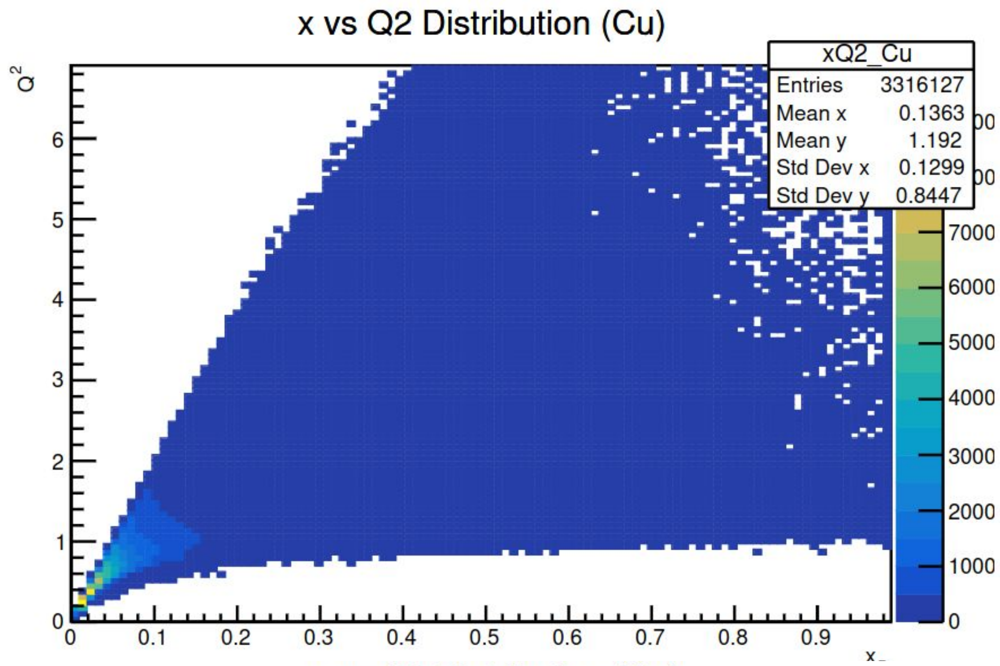
- Considering first coincidences on e- and π+
- different kinematic variables can be considered we will focus here on the following variables from the **scattered electron**.
  - $Q^2 = -\gamma^{*2}$
  - v= E_e−E_e’
  - xb = Q²/(2.M.v)

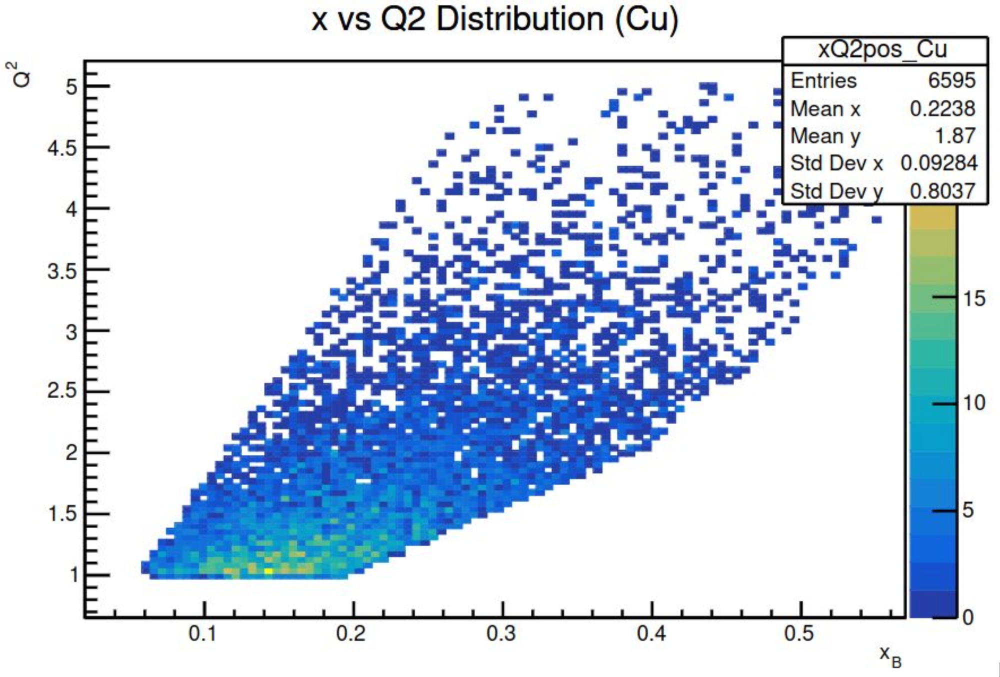




Data Selection

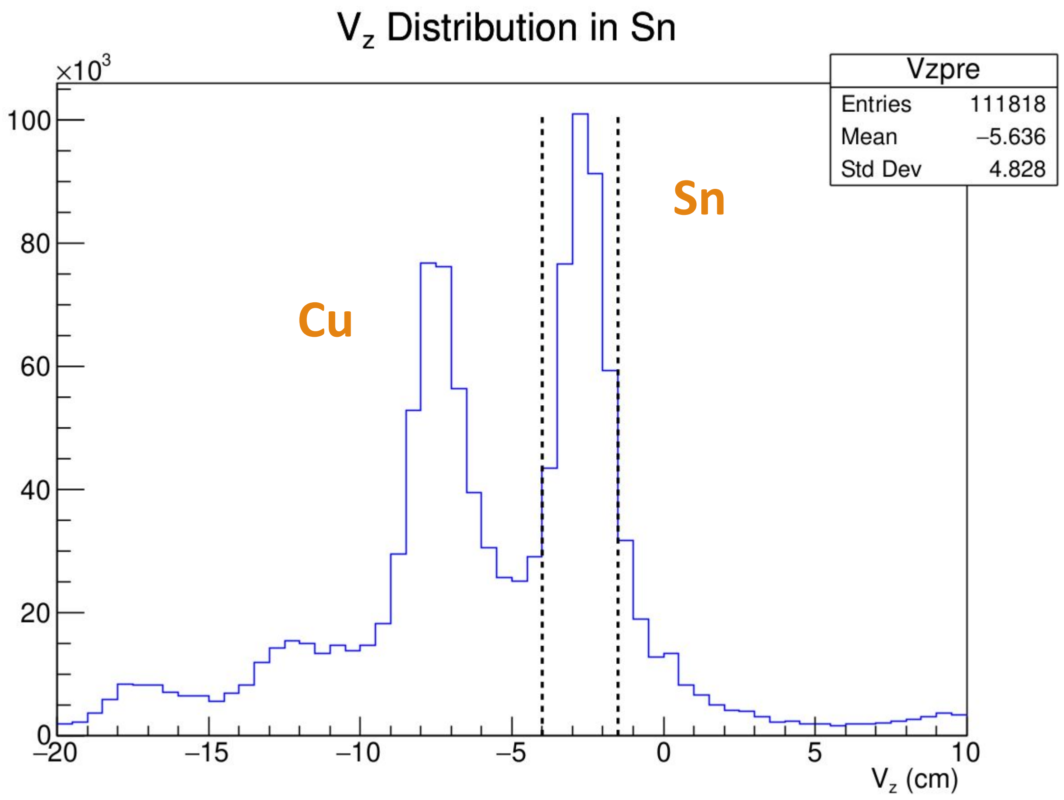
- Considering first coincidences on e- and π+
- Kinematic variables considered and cuts for example:
    - $Q^2 > 1\ GeV^2$
    - Setting a missing mass threshold
    - Specific detector cuts





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.
  - **pt²** = transverse momentum of hadrons
- Vertex z cuts need to be considered according to target positions
  - Preliminary Arbitrary Cuts on Vz for all targets



Using determined variables to determine multiplicity Ratio as follows:

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

Multiplicity Ratio

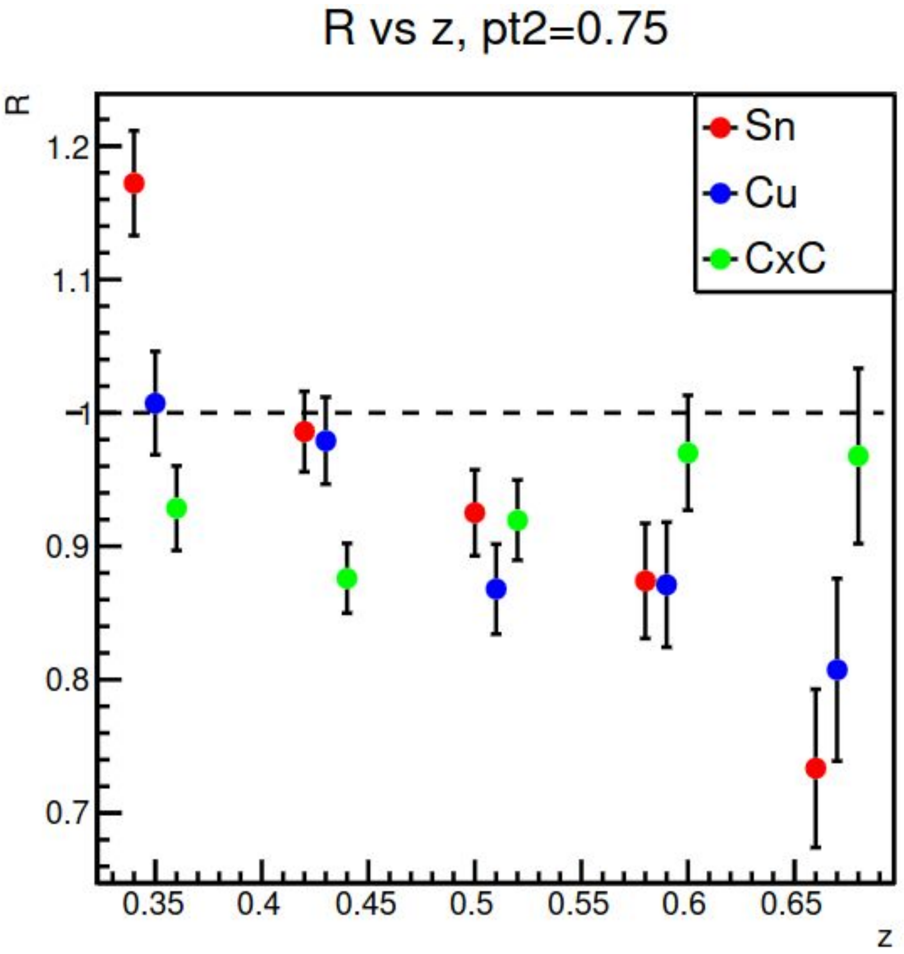
$$R_A^{\pi}(\nu, z, p_t^2) = \frac{N_{\pi}^{Sn}(\nu, z, p_t^2)/N_e^{Sn}(\nu)}{N_{\pi}^{D}(\nu, z, p_t^2)/N_e^{D}(\nu)}$$

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

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

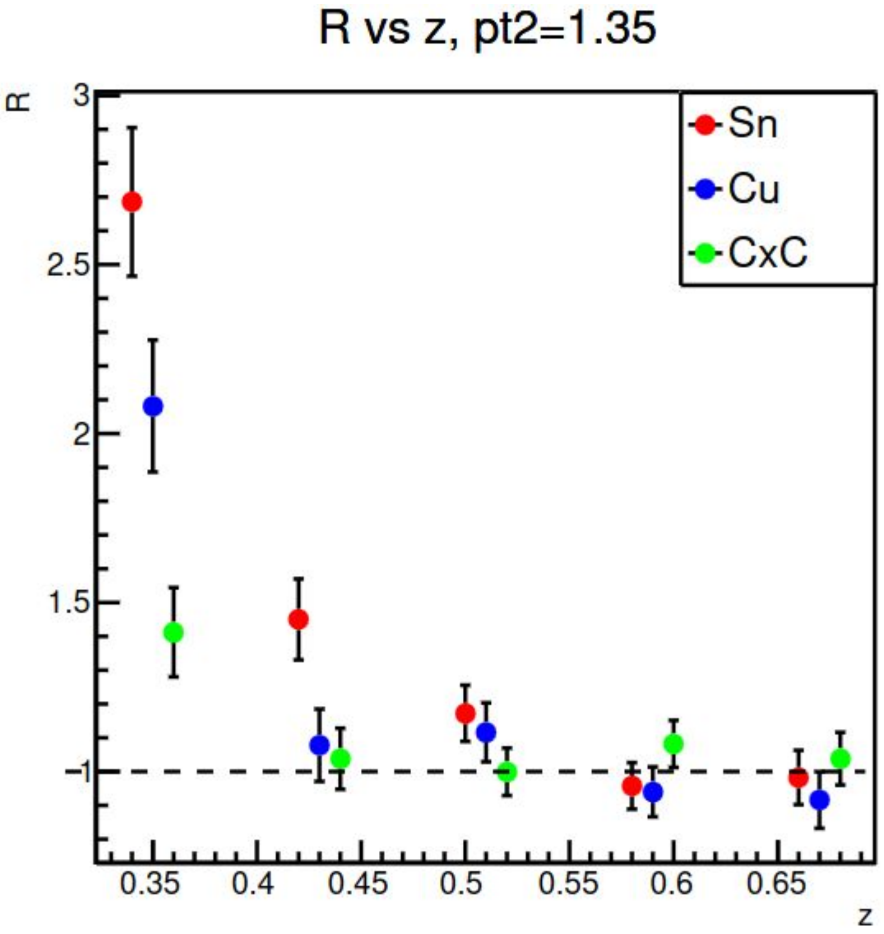
Multi dimensional analysis can be implemented in order to consider cross-variable correlations.

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

Analysis with no corrections implemented (on going)

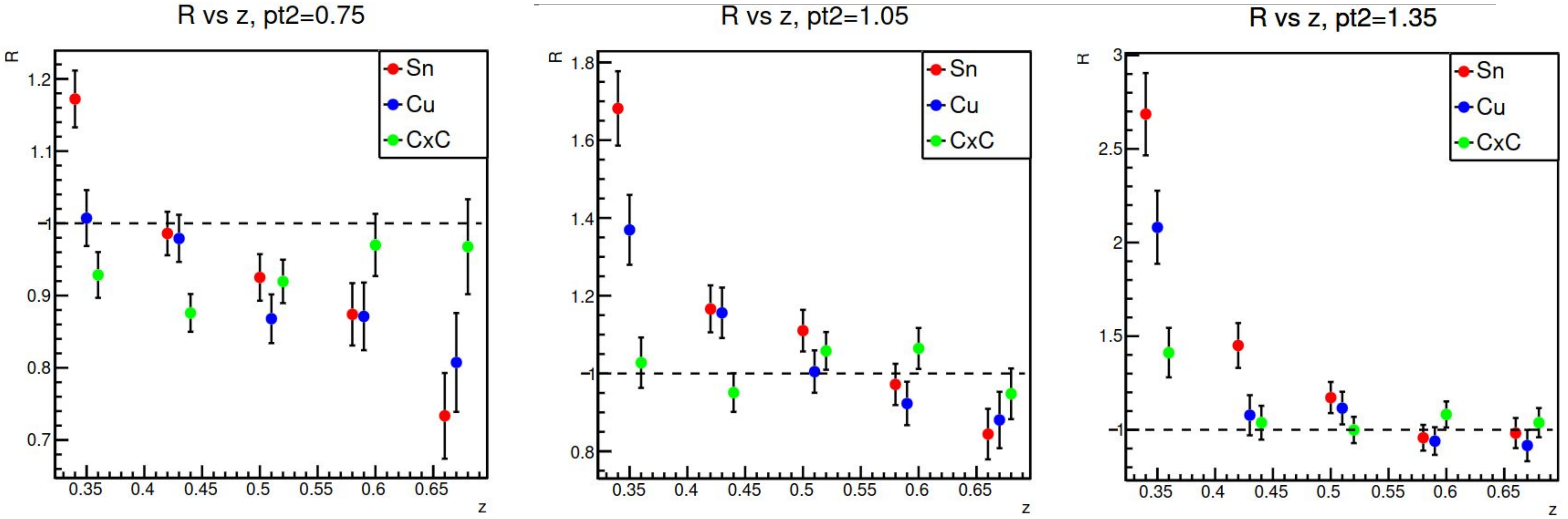
Here, plot of multiplicity Ratio for different nuclei targets compared to reference Deuterium for ν=4.5 ; pt^2 = **1.35** as a function of z.

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

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



Preliminary Studies show coherent behaviour between targets.
Potentially large amount of results with small uncertainties.

Summary

Implemented work

- Preliminary Data analysis for a study of TMDs on SIDIS with most recent available data.
- Coherent/expected results on available data with initial analysis.

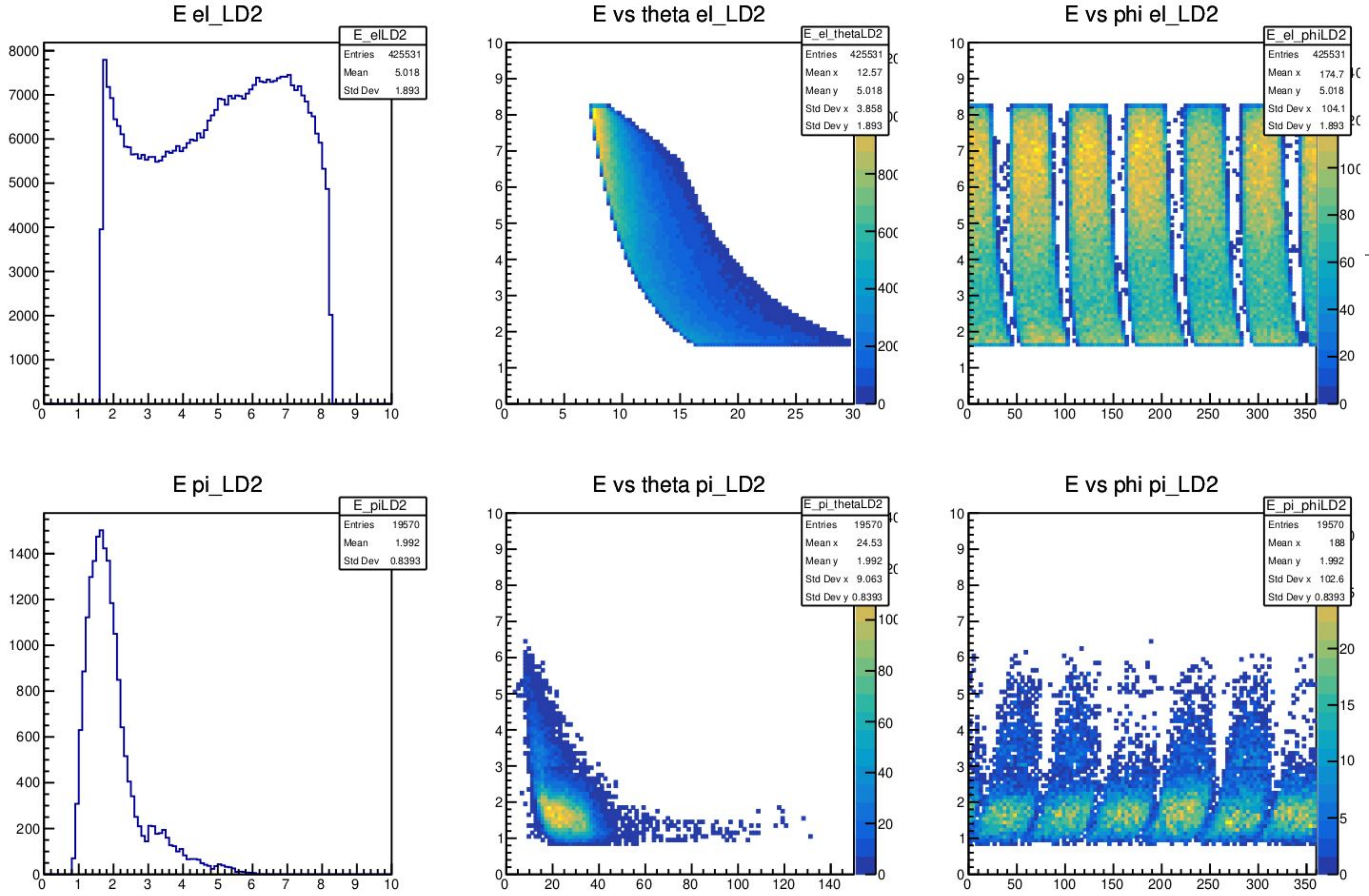
Study of the Simulation

- [In preparation] Very preliminary tests of a simulation non specific for TMD study nuclear effects
- Simulation used to properly compare with available data replicating experimental conditions as possible

On going work

- Calibration on available data remains to be done/perfected.
- Acceptance and Radiative effects need to be considered for corrections.
- Consider other experimental observables

Back Ups



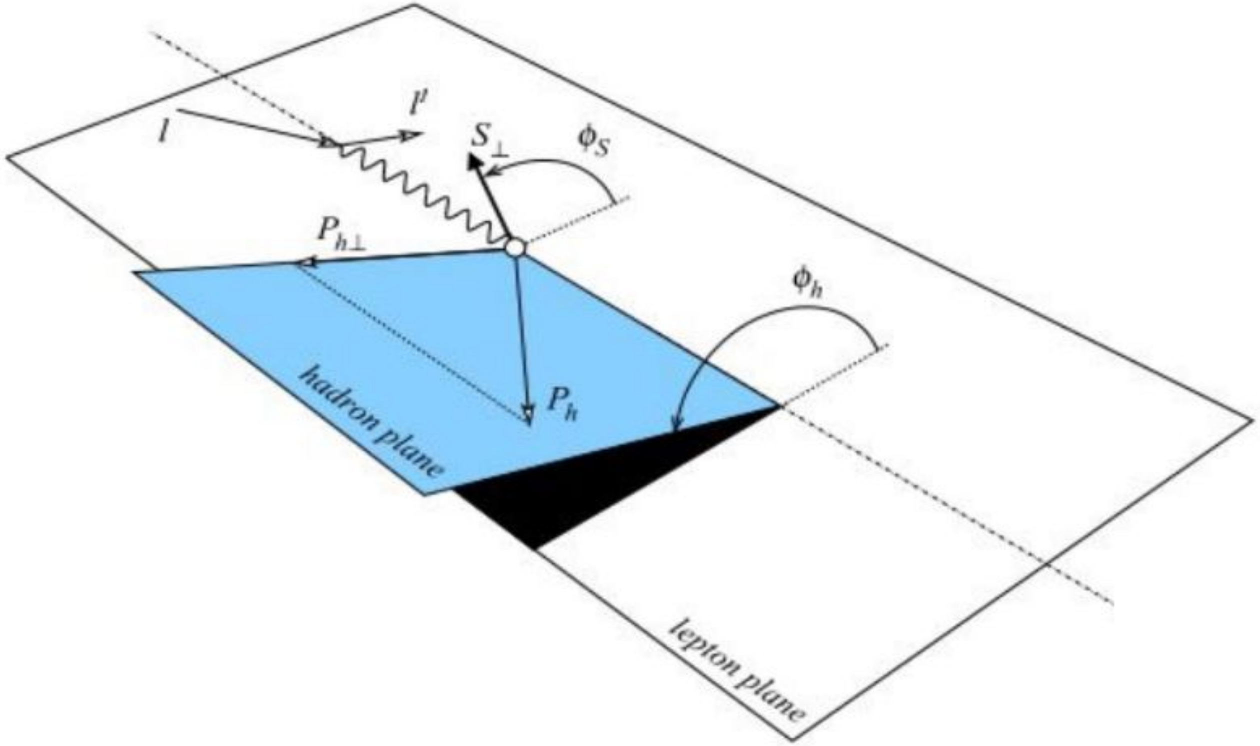
Particle Energies

Electron energy vs azimuthal and polar angle

Pion energy vs azimuthal and polar angle

Observables

- Experimental Observables: Cross section, Beam Spin Asymmetry



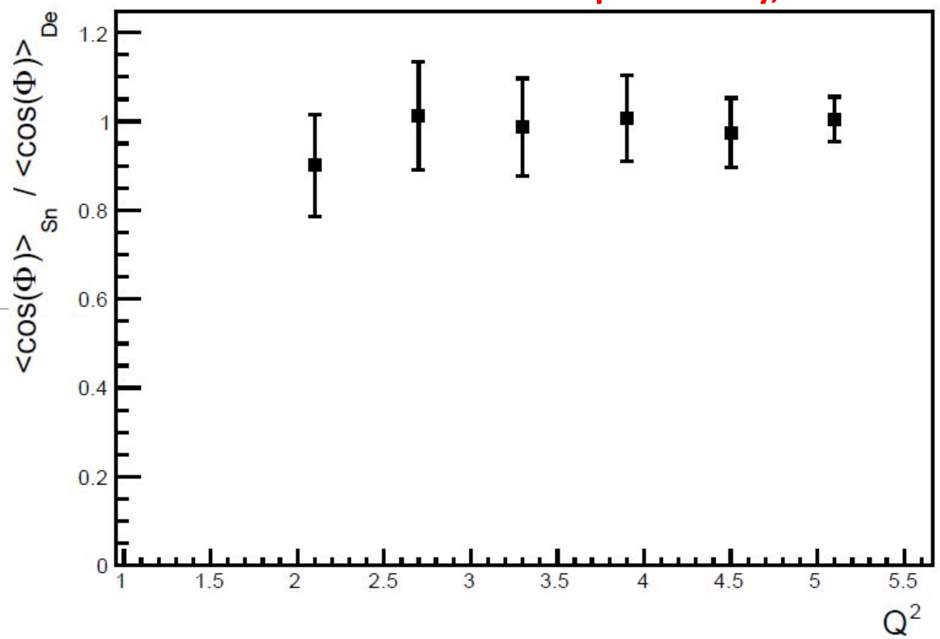
This Work: We use unpolarized nuclear targets where only the cos φ, cos 2φ and sin φ components will contribute in this cross section.

cos Φ ratio

$$\frac{< cos\phi_\pi >_{Sn}}{< cos\phi_\pi >_D}$$

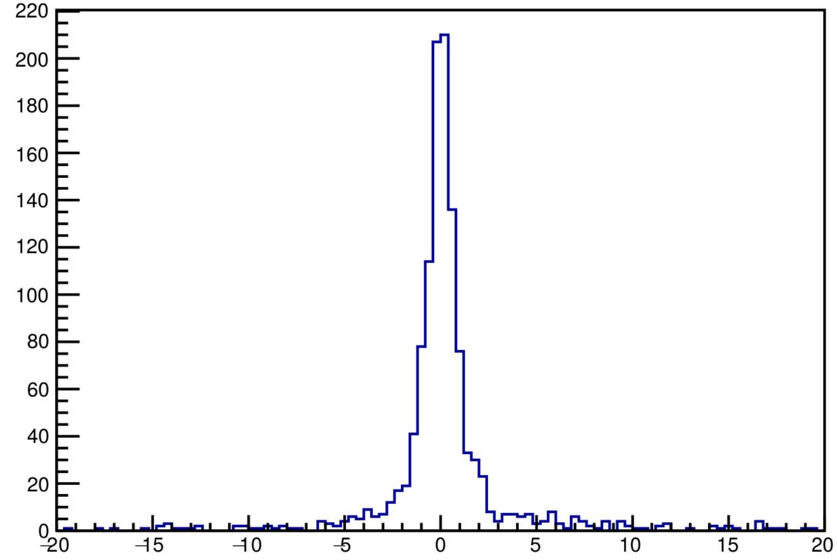
- φ resolution determined by comparison of Simulated and reconstructed φ values
- cos φ and sin φratios remain to be done

preliminary, simulation



- Preliminary result

Δφ (REC - MC) simulation



- Importance of Radiative effects remain to be determined

$$\frac{d\sigma}{dx\,dy\,dz\,d\phi\,d\phi_S\,dP_{h\perp}^2} =$$

$$\frac{\alpha^2}{xyQ^2}\frac{y^2}{2\,(1-\varepsilon)}\left(1+\frac{\gamma^2}{2x}\right)\Bigg\{F_{UU,T}+\varepsilon\,F_{UU,L}+\sqrt{2\,\varepsilon(1+\varepsilon)}\,\cos\phi\,F_{UU}^{\cos\phi}$$

$$+\,\varepsilon\cos(2\phi)\,F_{UU}^{\cos 2\phi}+\lambda_e\,\sqrt{2\,\varepsilon(1-\varepsilon)}\,\sin\phi\,F_{LU}^{\sin\phi}$$

$$+\,S_\parallel\left[\sqrt{2\,\varepsilon(1+\varepsilon)}\,\sin\phi\,F_{UL}^{\sin\phi}+\varepsilon\sin(2\phi)\,F_{UL}^{\sin 2\phi}\right]$$

$$+\,S_\parallel\lambda_e\left[\sqrt{1-\varepsilon^2}\,F_{LL}+\sqrt{2\,\varepsilon(1-\varepsilon)}\,\cos\phi\,F_{LL}^{\cos\phi}\right]$$

$$+\,|\boldsymbol{S}_\perp|\Bigg[\sin(\phi-\phi_S)\left(F_{UT,T}^{\sin(\phi-\phi_S)}+\varepsilon\,F_{UT,L}^{\sin(\phi-\phi_S)}\right)$$

$$+\,\varepsilon\,\sin(\phi+\phi_S)\,F_{UT}^{\sin(\phi+\phi_S)}+\varepsilon\,\sin(3\phi-\phi_S)\,F_{UT}^{\sin(3\phi-\phi_S)}$$

$$+\sqrt{2\,\varepsilon(1+\varepsilon)}\,\sin\phi_S\,F_{UT}^{\sin\phi_S}+\sqrt{2\,\varepsilon(1+\varepsilon)}\,\sin(2\phi-\phi_S)\,F_{UT}^{\sin(2\phi-\phi_S)}\Bigg]$$

$$+\,|\boldsymbol{S}_\perp|\lambda_e\Bigg[\sqrt{1-\varepsilon^2}\,\cos(\phi-\phi_S)\,F_{LT}^{\cos(\phi-\phi_S)}+\sqrt{2\,\varepsilon(1-\varepsilon)}\,\cos\phi_S\,F_{LT}^{\cos\phi_S}$$

$$+\sqrt{2\,\varepsilon(1-\varepsilon)}\,\cos(2\phi-\phi_S)\,F_{LT}^{\cos(2\phi-\phi_S)}\Bigg]\Bigg\},$$