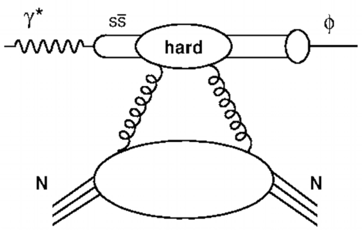
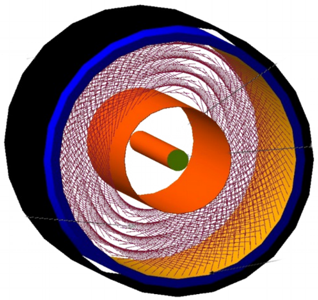
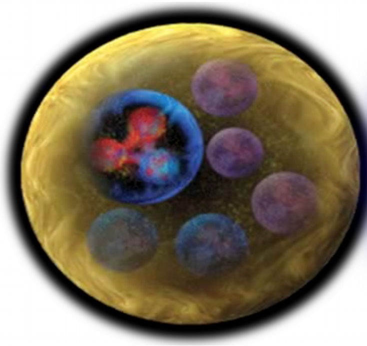
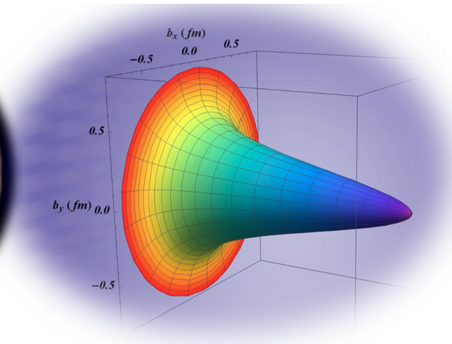
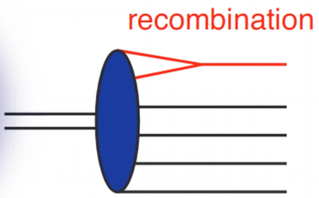
Nuclear TMDs with CLAS12











Proposition for a RG-D
Run Group Proposal

Raphaël Dupré

IPN INSTITUT DE PHYSIQUE NUCLÉAIRE ORSAY

université PARIS-SACLAY

European Research Council
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Nuclear TMDs in CLAS12

W. Armstrong, S. Joosten, Z.-E. Meziani

Physics Division, Argonne National Laboratory, Argonne, IL 60439, USA

H. Szumila-Vance

Jefferson Lab, Newport News, VA 23606, USA

R. Dupré

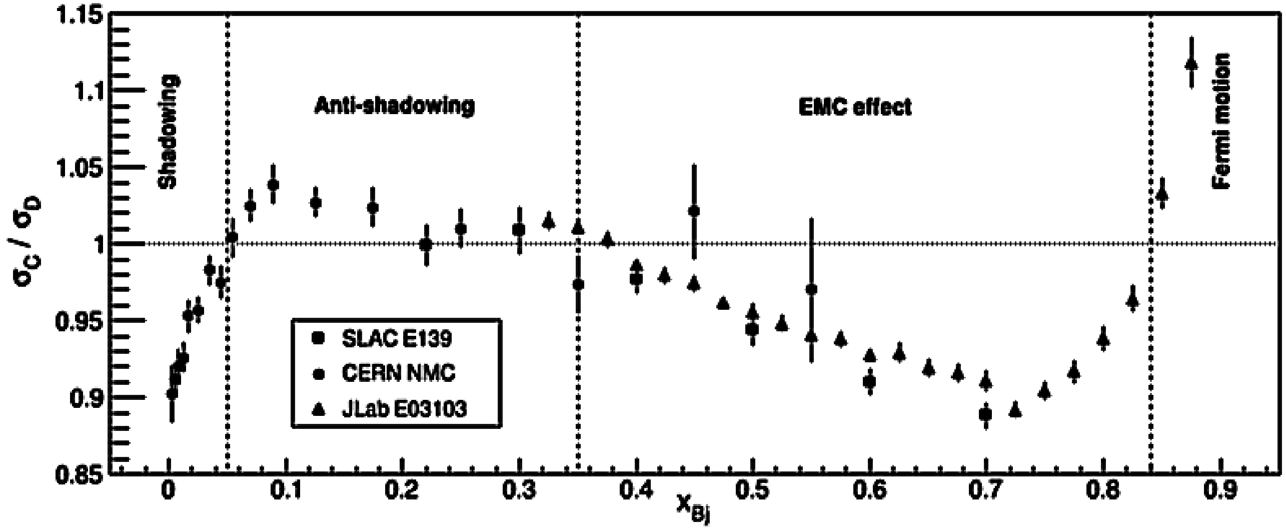
Institut de Physique Nucléaire, CNRS-IN2P3, Univ. Paris-Sud, Université Paris-Saclay, 91406 Orsay Cedex, France

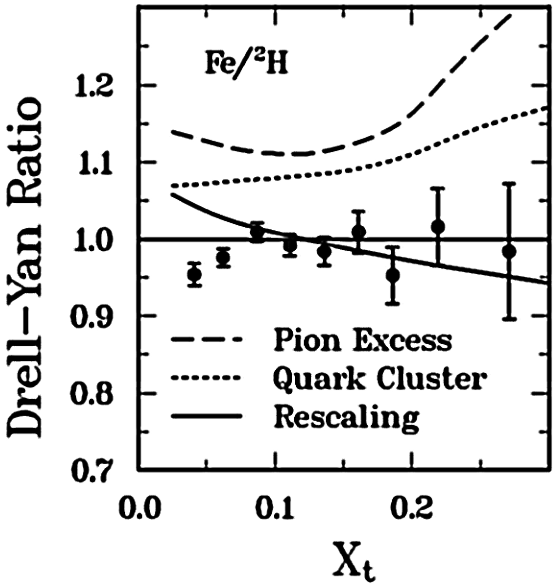
T. Chetry, L. El Fassi and S. Nanda

Mississippi State University, P. O. Box 5167, Mississippi State, Mississippi 39762, USA

a CLAS Collaboration Proposal

The Nuclear Effects





We discovered nuclear effects at the quark level

- Shadowing, anti-shadowing and EMC effect

The EMC effect remains a mystery to this day

- Meson content induced by NN interaction
- 6, 9, 12-quark clusters
  - *Both are excluded by Drell-Yan measurements*
- Nucleon size might change → bound FF
  - *Difficult to prove due to FSI effects*
- Q^2- or x-rescaling with widely different physical meaning

Resolving the EMC Effect Mystery

Higher precision

- Performed in JLab Hall-C already
- Tough to compete with CLAS12 on this front

New processes

- Tagging/SRC (ALERT, BAND, Bonus)
- Nuclear DVCS (ALERT)
- Nuclear TMDs (This talk !)

Large program

- Missing piece is nuclear TMDs
  - *It also involves in-medium hadronization*
- Could be easily performed with RG-D and RG-E data

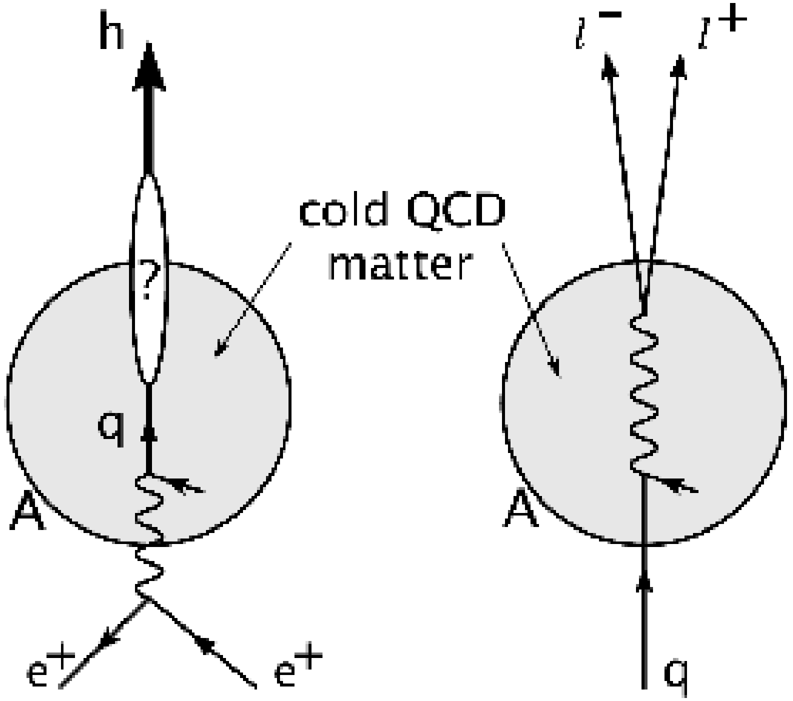
Semi-Inclusive DIS on Nuclei

Understand the hadronization process

- Measuring the characteristic times
- Measuring parton energy loss in QCD medium
- Understanding the pre-hadron structure

Characterization of the QCD medium

- Using parton energy loss (q hat)
  - *BDMPS & Kopeliovich et al.*
- Characterize both cold and hot nuclear matter
- Understand QCD evolution in medium

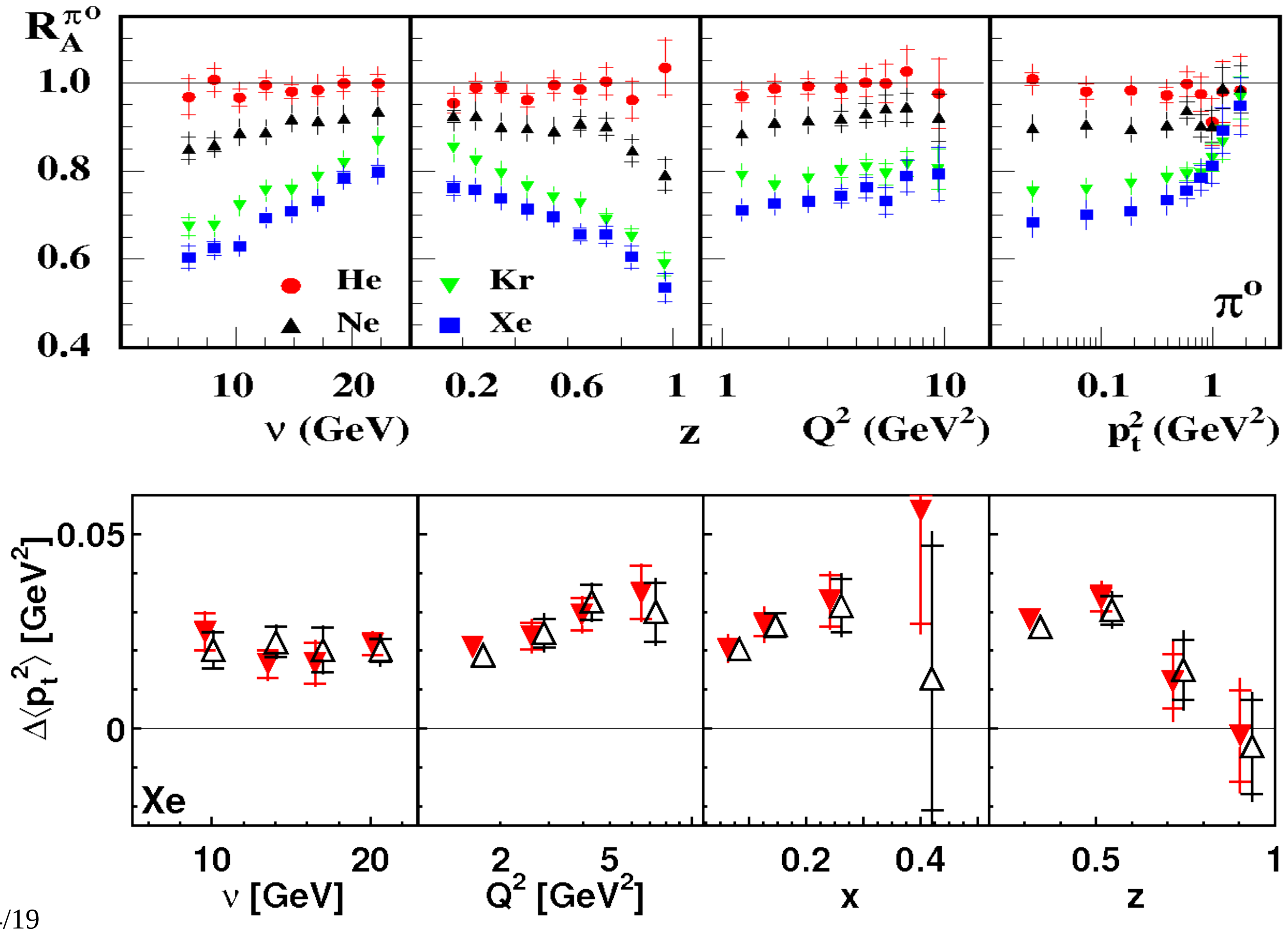


Reduce systematic effects on measurements where attenuation needs to be corrected

- Lepton scattering is a unique process for its control over the initial state
- Neutrino experiments
- Nucleon structure in nuclei

$$\hat{q}_F(\xi_N) = \frac{2\pi^2\alpha_s}{N_c}\rho_N^A(\xi_N)[xf_g^N(x)]_{x\to 0}$$

The HERMES data



Extracting Signal of the TMDs

TMD extraction is simple, in principle

- Each function has a different modulation
- Experimentally, it is a bit more complicated
  - *In particular due to the convolution with fragmentation functions*

Experimental needs

- Polarized targets
  - *Probably not anytime soon for nuclear targets*
- High acceptance
  - *CLAS12 !*

$$
\begin{aligned}
\frac{d\sigma}{dx_B\,dy\,d\phi_S\,dz\,d\phi_h\,dP_{h\perp}^2} &= \frac{\alpha^2}{x_B y Q^2}\,\frac{y^2}{2(1-\varepsilon)} \\
&\times \Big\{ F_{UU,T} + \varepsilon F_{UU,L} + \sqrt{2\varepsilon(1+\varepsilon)}\,\cos\phi_h\,F_{UU}^{\cos\phi_h} \\
&+ \varepsilon\cos(2\phi_h)\,F_{UU}^{\cos 2\phi_h} + \lambda_e\,\sqrt{2\varepsilon(1-\varepsilon)}\,\sin\phi_h\,F_{LU}^{\sin\phi_h} \\
&+ S_\parallel\Big[\sqrt{2\varepsilon(1+\varepsilon)}\,\sin\phi_h\,F_{UL}^{\sin\phi_h} + \varepsilon\sin(2\phi_h)\,F_{UL}^{\sin 2\phi_h}\Big] \\
&+ S_\parallel\lambda_e\Big[\sqrt{1-\varepsilon^2}\,F_{LL} + \sqrt{2\varepsilon(1-\varepsilon)}\,\cos\phi_h\,F_{LL}^{\cos\phi_h}\Big] \\
&+ |\boldsymbol{S}_\perp|\Big[\sin(\phi_h-\phi_S)\Big(F_{UT,T}^{\sin(\phi_h-\phi_S)} + \varepsilon\,F_{UT,L}^{\sin(\phi_h-\phi_S)}\Big) \\
&\quad + \varepsilon\,\sin(\phi_h+\phi_S)\,F_{UT}^{\sin(\phi_h+\phi_S)} + \varepsilon\,\sin(3\phi_h-\phi_S)\,F_{UT}^{\sin(3\phi_h-\phi_S)} \\
&\quad + \sqrt{2\varepsilon(1+\varepsilon)}\,\sin\phi_S\,F_{UT}^{\sin\phi_S} + \sqrt{2\varepsilon(1+\varepsilon)}\,\sin(2\phi_h-\phi_S)\,F_{UT}^{\sin(2\phi_h-\phi_S)}\Big] \\
&+ |\boldsymbol{S}_\perp|\lambda_e\Big[\sqrt{1-\varepsilon^2}\,\cos(\phi_h-\phi_S)\,F_{LT}^{\cos(\phi_h-\phi_S)} + \sqrt{2\varepsilon(1-\varepsilon)}\,\cos\phi_S\,F_{LT}^{\cos\phi_S} \\
&\quad + \sqrt{2\varepsilon(1-\varepsilon)}\,\cos(2\phi_h-\phi_S)\,F_{LT}^{\cos(2\phi_h-\phi_S)}\Big]\Big\}.
\end{aligned}
$$

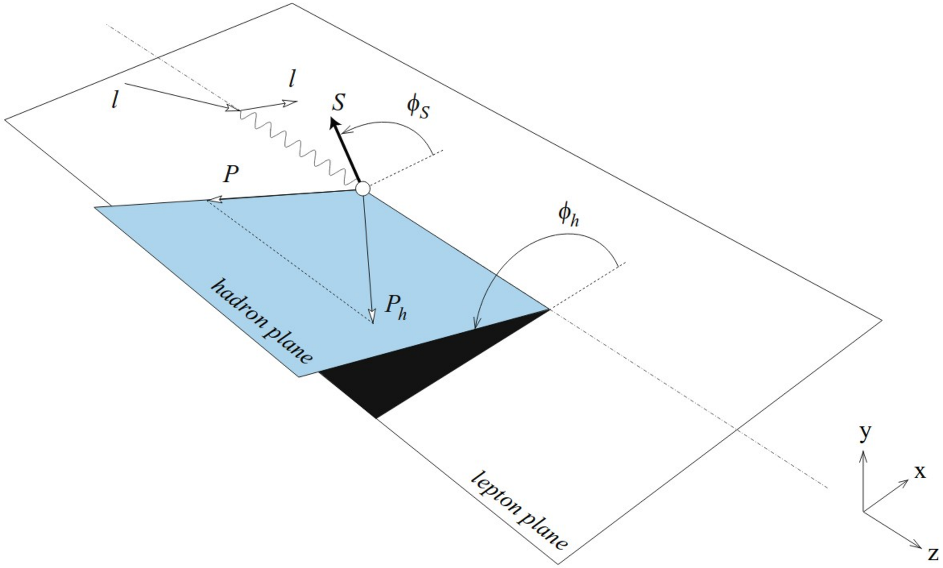
Nuclear TMD

Theory only, no experimental data

- Similarly to GPDs can offer an insight in nucleon modifications in medium
- Offers a view into the transport coefficient of the nuclear matter
  - *A controversial question with variations of an order of magnitude between theoretical extractions from data*

Asymmetries generated at the partonic level

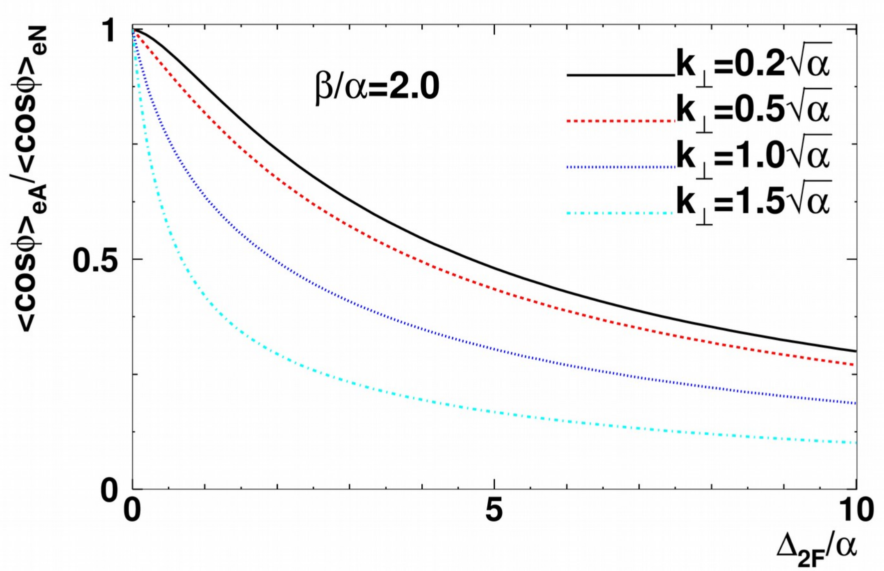
- Independent of final state effects

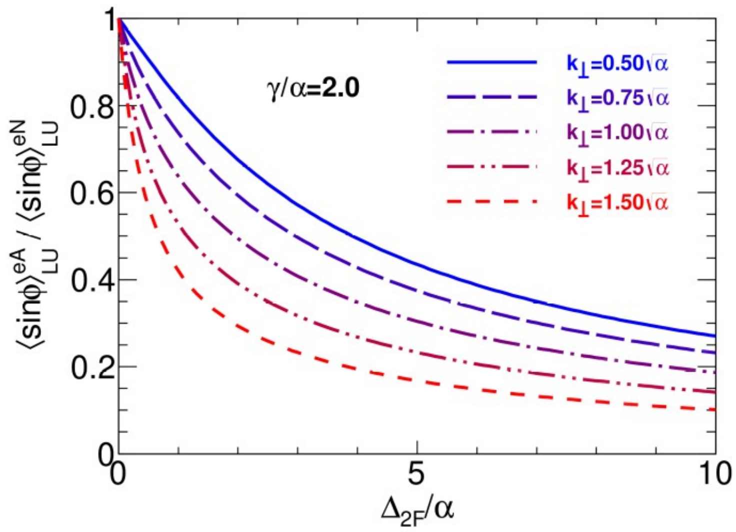


$$\Delta_{2F} = \int d\xi_N^- \hat{q}_F(\xi_N)$$

$$\hat{q}_F(\xi_N) = \frac{2\pi^2\alpha_s}{N_c}\rho_N^A(\xi_N)[xf_g^N(x)]_{x\to 0}$$

Using TMDs for Hadronization





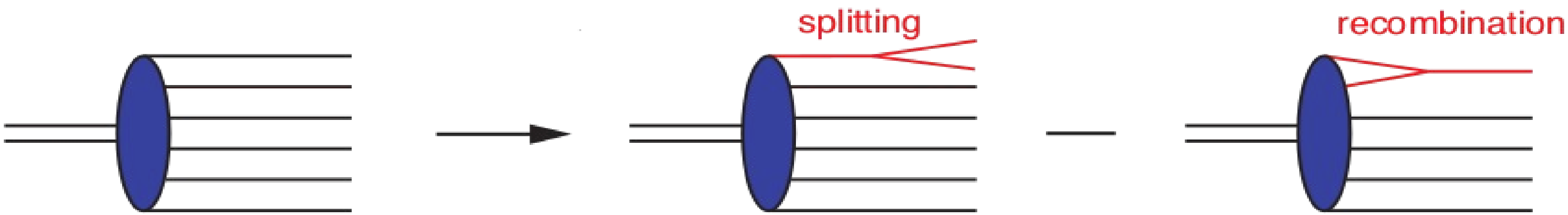
Usual hadronization measurements use outdated methods

- We should use the TMD framework to study semi-inclusive DIS on nuclei
- The sin and cos moments give direct parton level sensitivity to the transport coefficient

Two independent transport coefficient measurements

- To be compared with the absorption and the transverse momentum broadening

From Hadronization to Saturation



Saturation is one of the key topics of EIC

- We want to look at the saturation scale in nuclei
- Transport coefficient and gluon saturation scale are the same
  - *They inform on the highest density of gluons in the nuclei*

$$\hat{q}_F(\xi_N) = \frac{2\pi^2\alpha_s}{N_c}\rho_N^A(\xi_N)[xf_g^N(x)]_{x\to 0}$$

The hadronization studies will provide an independent result for this

- RG-D will measure it for several nuclei
- Possibility to test the A dependence of the saturation scale

Projections

We made some simulations

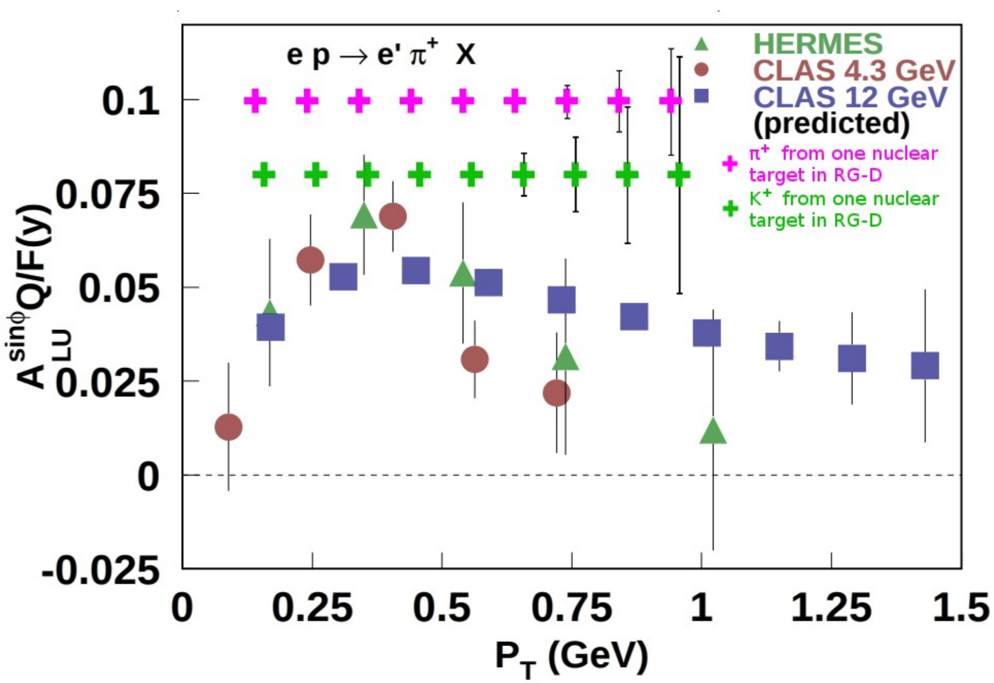
- Using GEMC + Full CLAS12 reconstruction

Results for sin moment

- Similar to proton target with slightly less coverage

Maximum of distribution available

- We assumed the same for the cos observables



Summary

We have studied nuclear hadronization and EMC

- Both are messy and not well understood

The TMD framework will help

- Different asymmetries are generated at the partonic and fragmentation level
- Different asymmetries allow to cross check the results from the same data set with different observables

This is a modernization of the hadronization studies

- It comes for free in the nuclear data
- Well almost, we would like polarization

So… we will be back next year at the PAC!