Proposition for a RG-D
Run Group Proposal

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Nuclear TMDs with CLAS12
Nuclear TMDs in CLAS12

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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

\[ \hat{q}_F(\xi_N) = \frac{2\pi^2 \alpha_s}{N_c} \rho_N^A(\xi_N) [x f_g^N(x)]_{x \rightarrow 0} \]
The HERMES data

The graph shows data for $R_A^{\pi^0}$ as a function of $v$ (GeV), $z$, $Q^2$ (GeV$^2$), and $p_t^2$ (GeV$^2$) for different elements: He, Kr, Ne, and Xe. The data points are indicated by various markers and error bars.
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!

\[
\frac{d\sigma}{dx_B \, dy \, d\phi_s \, dz \, d\phi_h \, dP_{h \perp}^2} = \frac{\alpha^2}{x_B y Q^2} \frac{y^2}{2(1-\epsilon)} \times \left\{ F_{UU,T} + \epsilon F_{UU,L} + \sqrt{2 \epsilon(1+\epsilon)} \cos \phi_h F_{UU}^{\cos \phi_h} \\
+ \epsilon \cos(2\phi_h) F_{UU}^{\cos 2\phi_h} + \lambda_e \sqrt{2 \epsilon(1-\epsilon)} \sin \phi_h F_{LU}^{\sin \phi_h} \\
+ S_{\parallel} \left[ \sqrt{2 \epsilon(1+\epsilon)} \sin \phi_h F_{UL}^{\sin \phi_h} + \epsilon \sin(2\phi_h) F_{UL}^{\sin 2\phi_h} \right] \\
+ S_{\parallel} \lambda_e \left[ \sqrt{1-\epsilon^2} F_{LL} + \sqrt{2 \epsilon(1-\epsilon)} \cos \phi_h F_{LL}^{\cos \phi_h} \right] \\
+ |S_{\perp}| \sin(\phi_h - \phi_S) \left( F_{UT,T}^{\sin(\phi_h - \phi_S)} + \epsilon F_{UT,L}^{\sin(\phi_h - \phi_S)} \right) \\
+ \epsilon \sin(\phi_h + \phi_S) F_{UT}^{\sin(\phi_h + \phi_S)} + \epsilon \sin(3\phi_h - \phi_S) F_{UT}^{\sin(3\phi_h - \phi_S)} \\
+ \sqrt{2 \epsilon(1+\epsilon)} \sin \phi_S F_{UT}^{\sin \phi_S} + \sqrt{2 \epsilon(1+\epsilon)} \sin(2\phi_h - \phi_S) F_{UT}^{\sin(2\phi_h - \phi_S)} \right] \\
+ |S_{\perp}| \lambda_e \left[ \sqrt{1-\epsilon^2} \cos(\phi_h - \phi_S) F_{LT}^{\cos(\phi_h - \phi_S)} + \sqrt{2 \epsilon(1-\epsilon)} \cos \phi_S F_{LT}^{\cos \phi_S} \\
+ \sqrt{2 \epsilon(1-\epsilon)} \cos(2\phi_h - \phi_S) F_{LT}^{\cos(2\phi_h - \phi_S)} \right].
\]
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

\[
\Delta_{2F} = \int d\xi_N \hat{q}_F(\xi_N)
\]

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

\[ \hat{q}_F(\xi_N) = \frac{2\pi^2\alpha_s}{N_c} \rho^A_N(\xi_N)[x f^N_g(x)]_{x \to 0} \]

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
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!