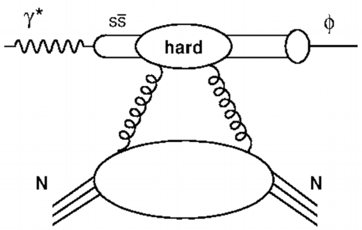
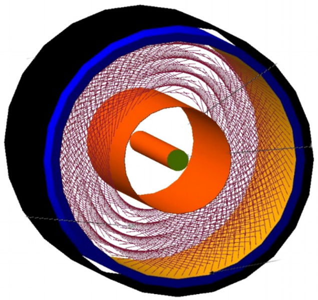
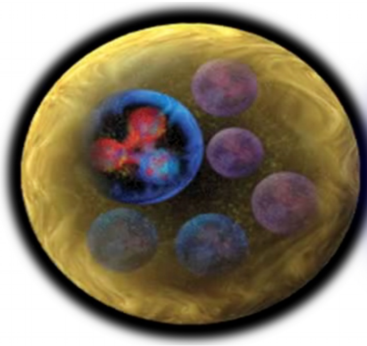
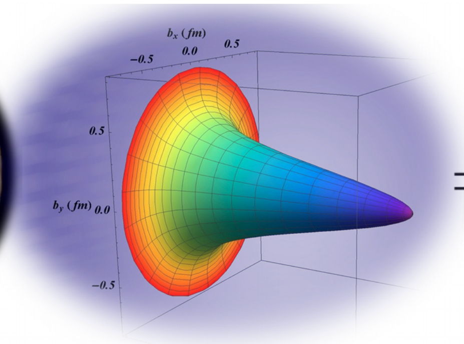
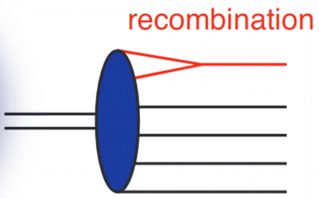
Novel Quark and Gluon Effects in Nuclei











How to understand the nucleus in terms of quarks and gluons ?

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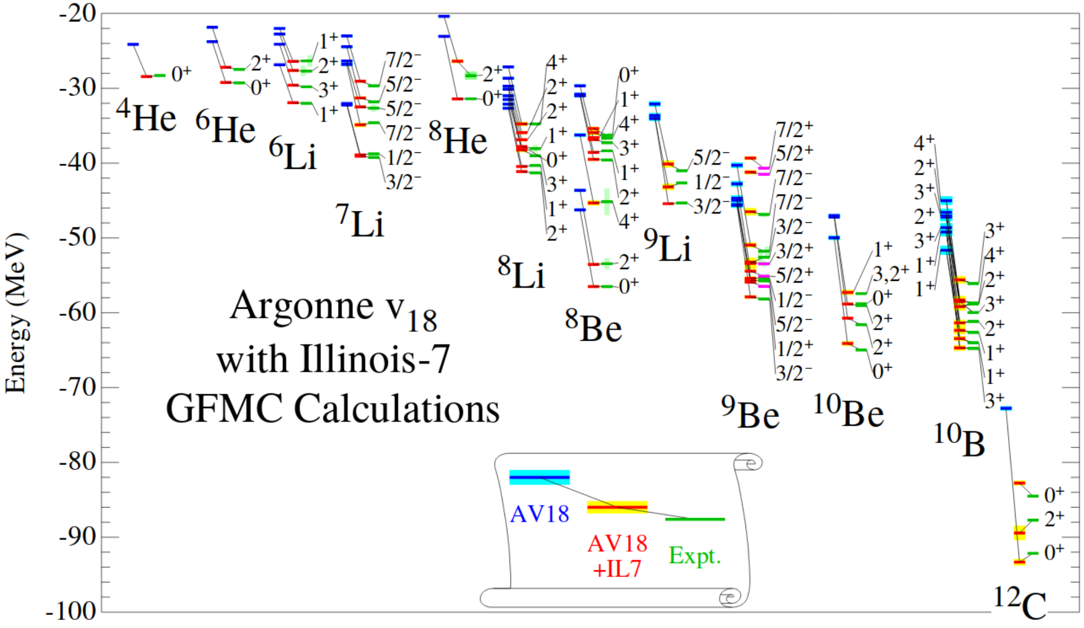
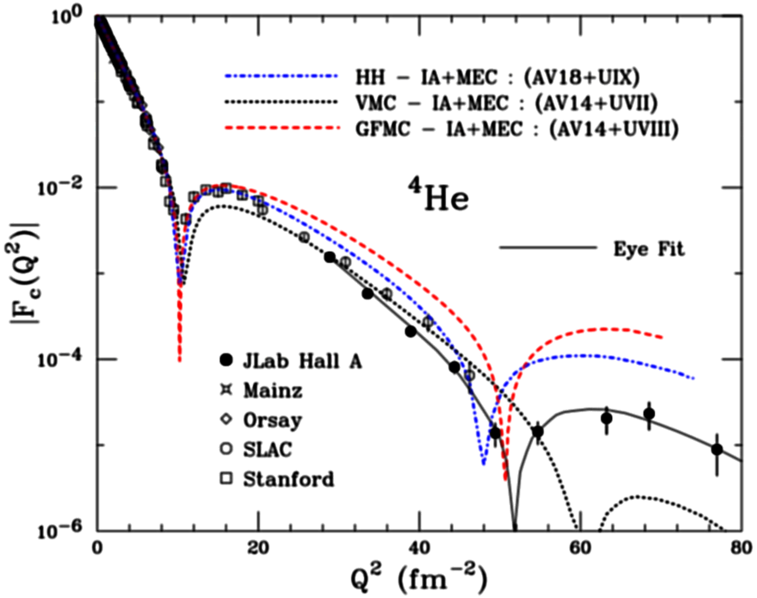
The Classic Nuclei





Nuclei described as a sum of protons and neutrons

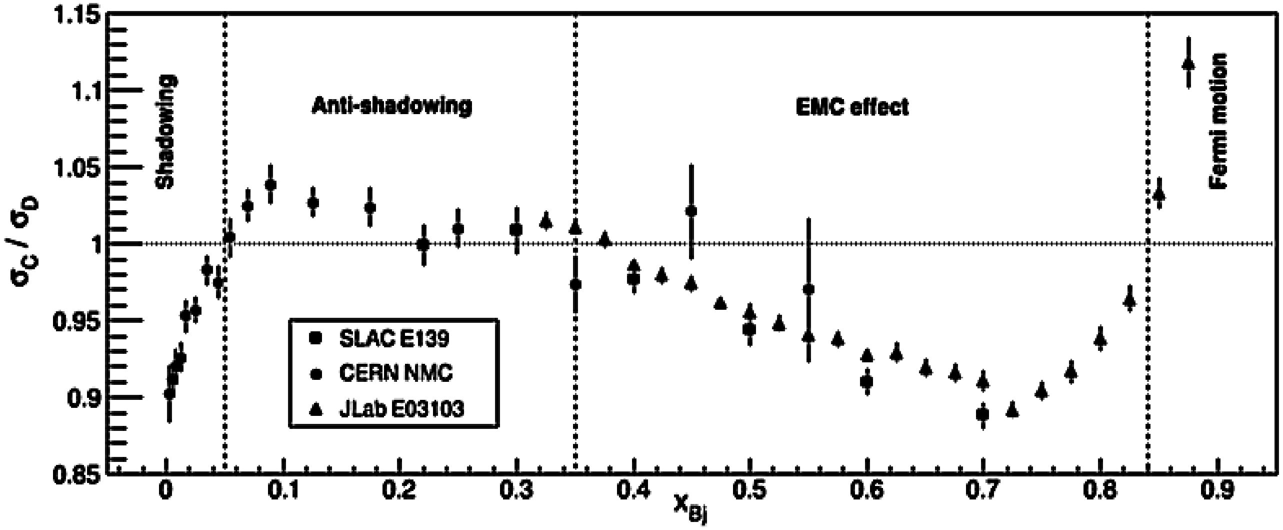
- Bound together by two and three body forces
- Can explain exactly the light nuclei spectrum

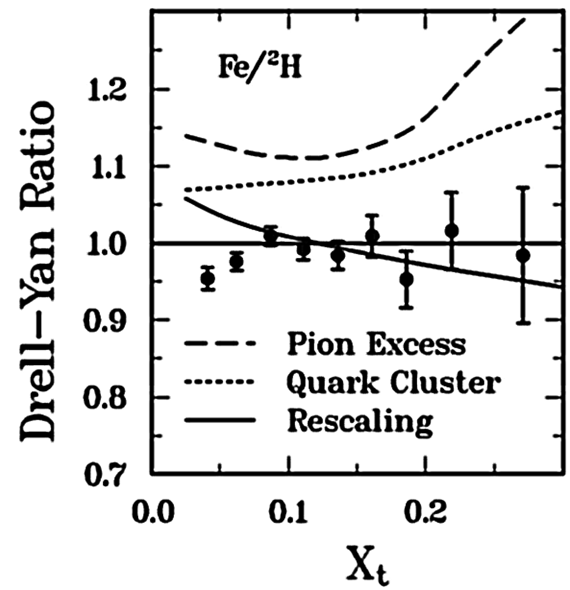
Can be related to electron scattering measurements

- Elastic form factors and quasi-elastic scattering
- Nucleon momentum spectrum matches

All seems well and working, until…

The Nuclear Effects





We discovered nuclear effects at the quark level

- Shadowing, anti-shadowing and EMC effect

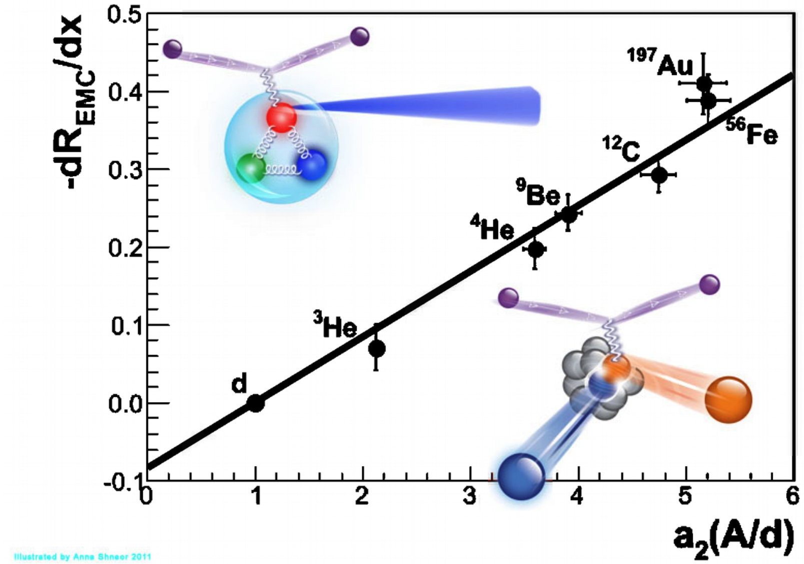
The EMC effect remains a mystery to this day

- **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**

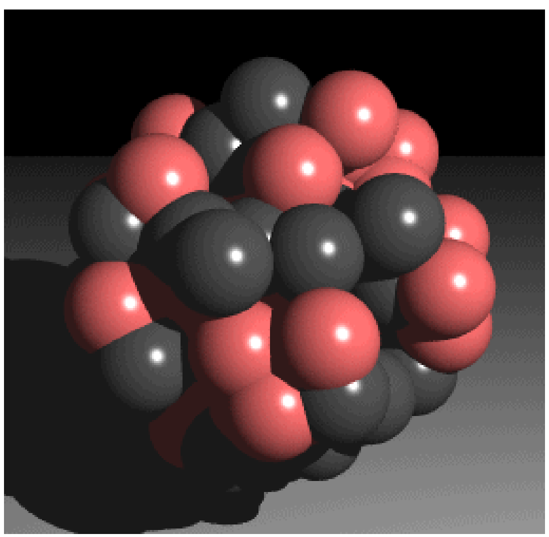
Reconciling Two Points of View

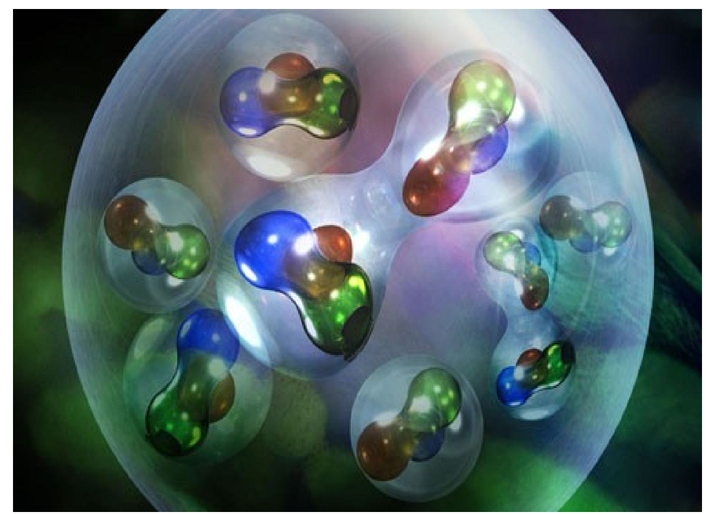
So where do we stand?

- New models still coming up
- Use nucleon short range correlations
- Apply the nuclear mean field at quark level



How do we resolve this?





Selection of Topics

Many experiments are planned to resolve the issue of the EMC effect

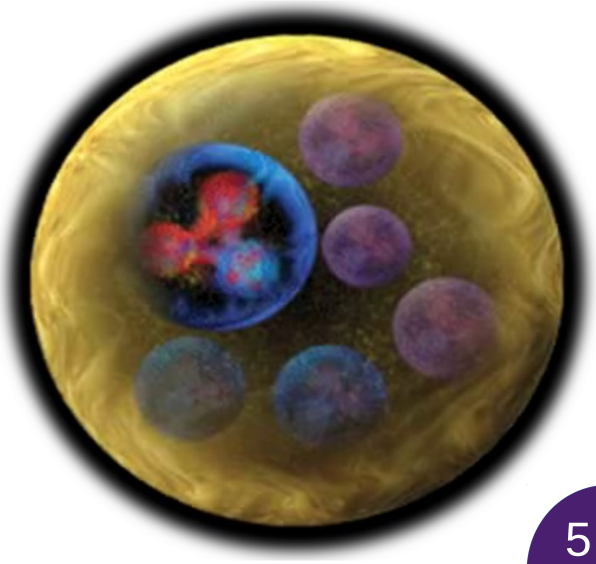
- My preference goes to the ones using new observables

My selection of topics for this talk

- Generalized parton distributions of nuclei
- Tagged processes
- Transverse momentum dependent nuclear PDFs

There are many more

- Exclusive vector meson production
- Parity violating measurements
- Spin dependent measurements
- Drell-Yan measurements
- ...



GPDs & Nuclei

Generalizing the parton distributions

- Three dimensions: x, ξ and t
- Spin-0 → 1 GPD // Spin-1/2 → 4 GPDs

Deep virtual Compton scattering

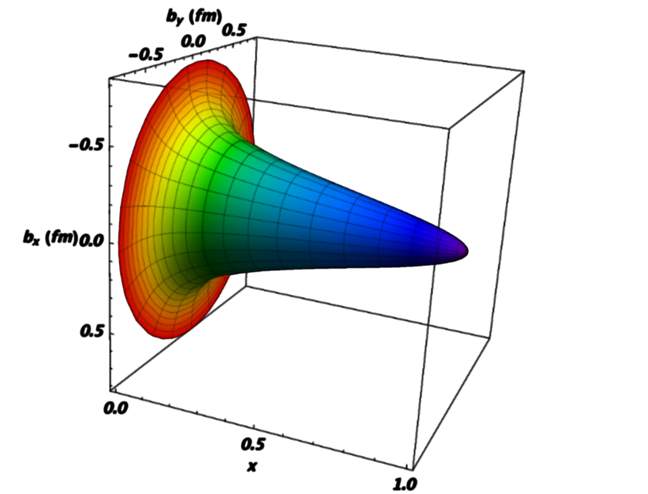
- The simplest access to GPDs
- Allow a tomography of the proton

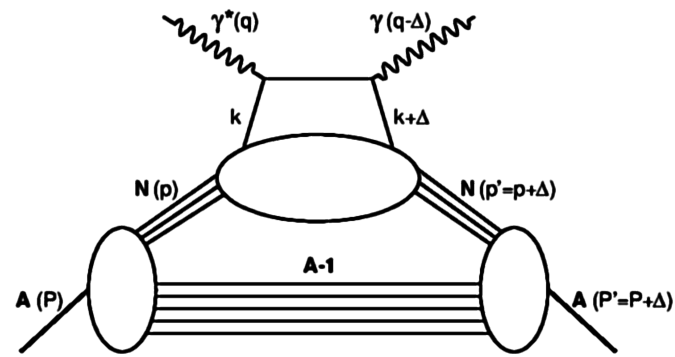
In the nucleus

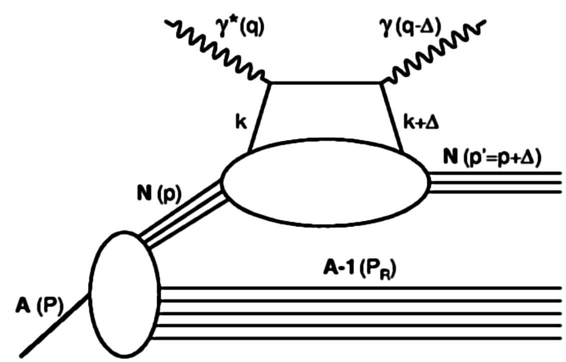
- Coherent and incoherent channels
  - *Similar to elastic and quasi-elastic*

Perfect probe into the EMC effect

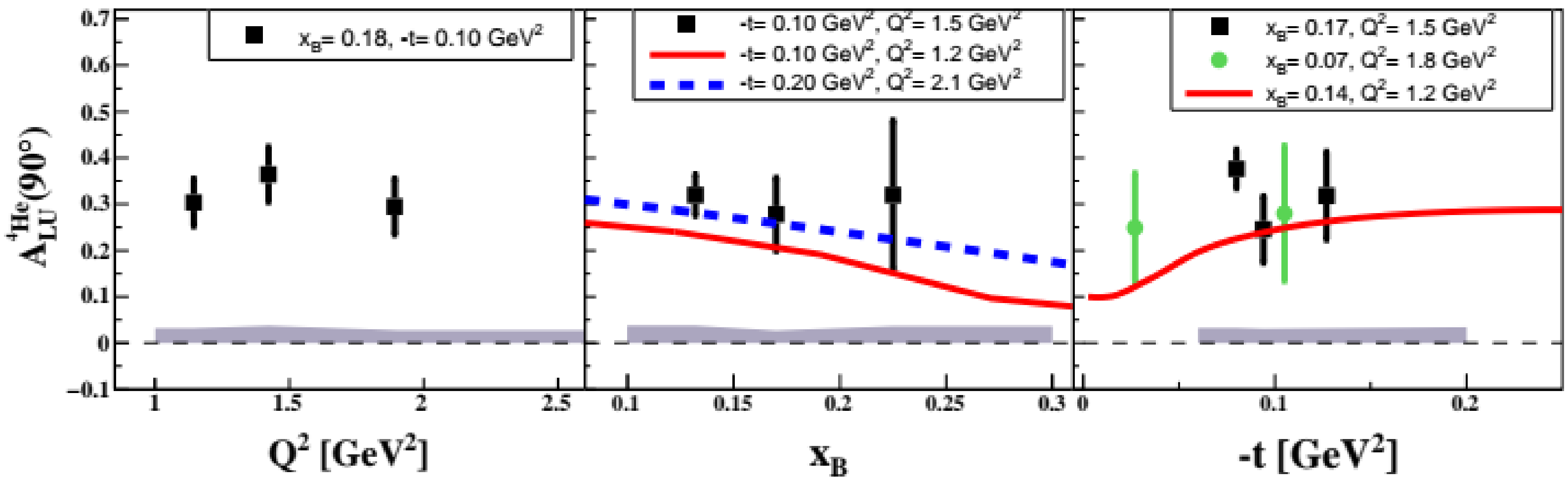
- Offer localization with the t dependence
- Coherent DVCS gives access to non-nucleonic degrees of freedom
- Incoherent DVCS gives access to the modifications of the nucleon in the nuclear medium

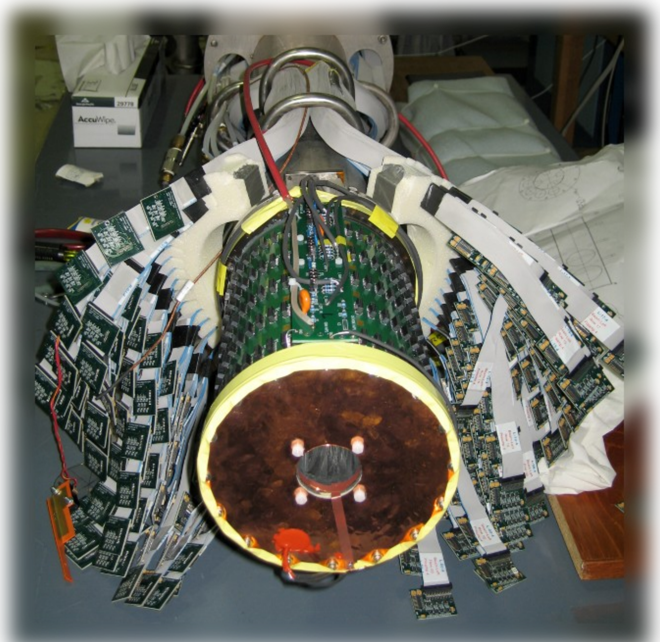






CLAS Coherent DVCS





Coherent DVCS on helium

- **Measured at CLAS**
  - *Use recoil detector to ensure exclusivity*
- **Shows very strong beam spin asymmetry**

Interpretation

- **Very strong signal proves that we have the nuclei as a whole**

Easy direct GPD extraction

- **Helium has a single GPD**

CLAS Incoherent DVCS

Measurement of CLAS

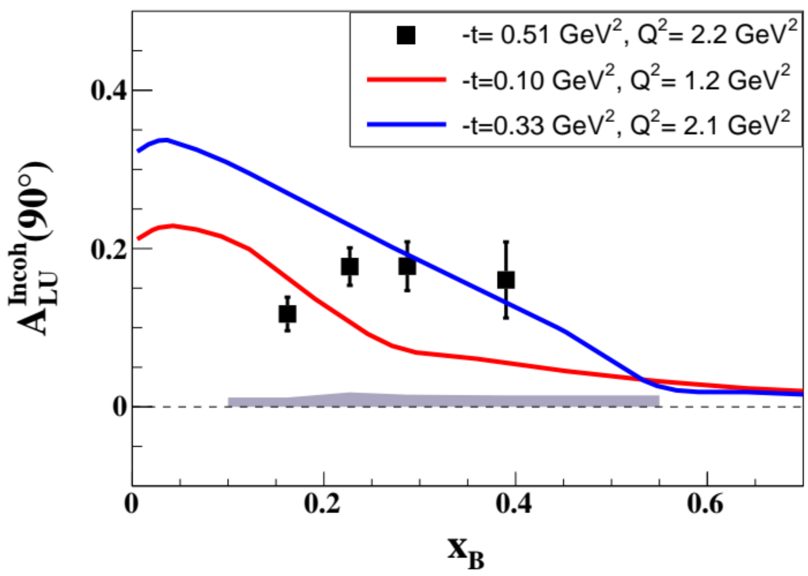
- Proton bound in helium target

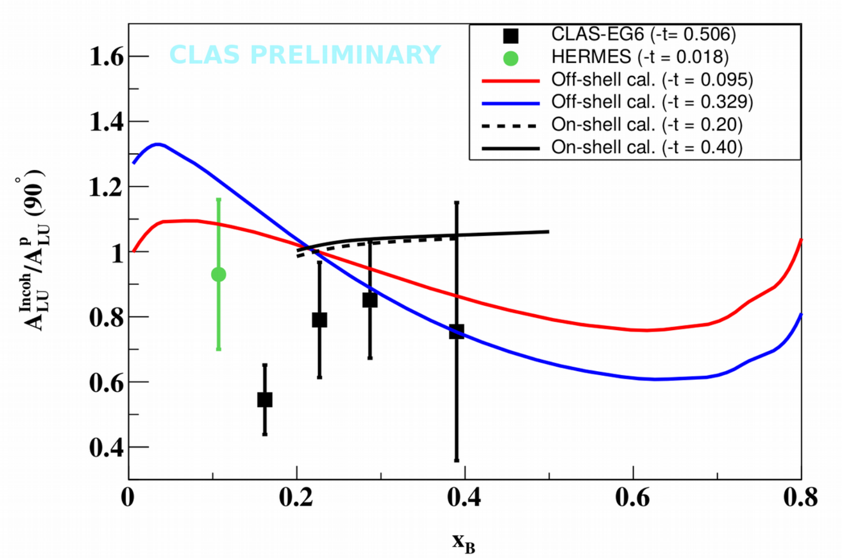
Gives a generalized EMC

- Strongly suppressed in particular in the anti-shadowing region
- Strange behavior compared to the models

A New kind of EMC effect?

- It could be a nuclear effect
- Or it could be due to final state interactions
  - *Can be very complicated in DVCS*

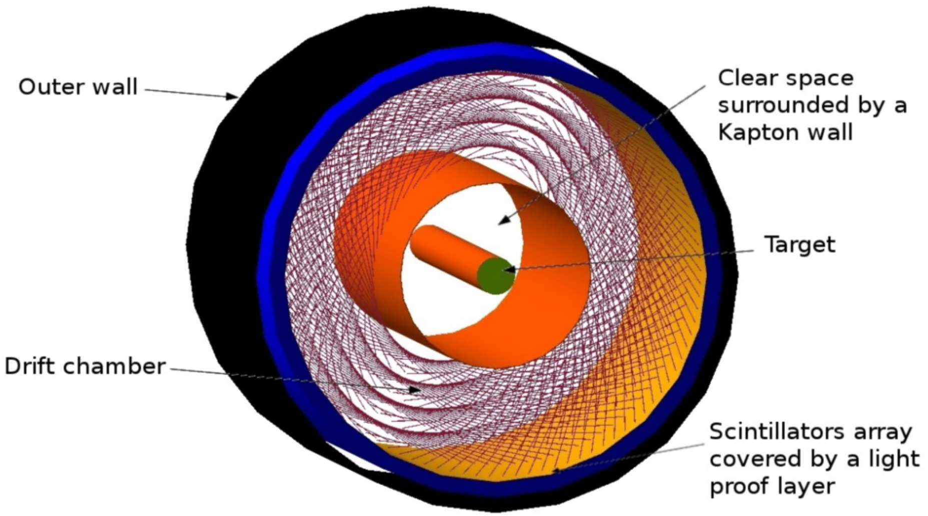




Future of Nuclear GPDs

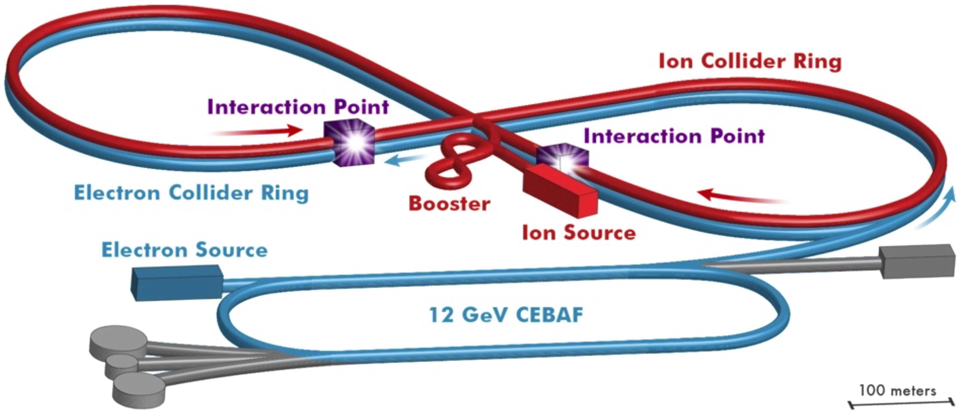
Short term @ JLab

- The ALERT run group
  - *A Low Energy Recoil Tracker*
- Measure nuclear DVCS
  - *Coherent and tagged incoherent*
- Allows tagging
  - *Will help control FSI*



Long term @ EIC

- Collider kinematics
  - *Simplify low angle detection*
  - *Increase the phase space available*
- Polarized light nuclei
  - *Gives access to new observables*



Tagging Nuclear Reactions

Tagged processes

- When we detect nuclear fragments in coincidence
- Mix classic nuclear physics with quark level observables

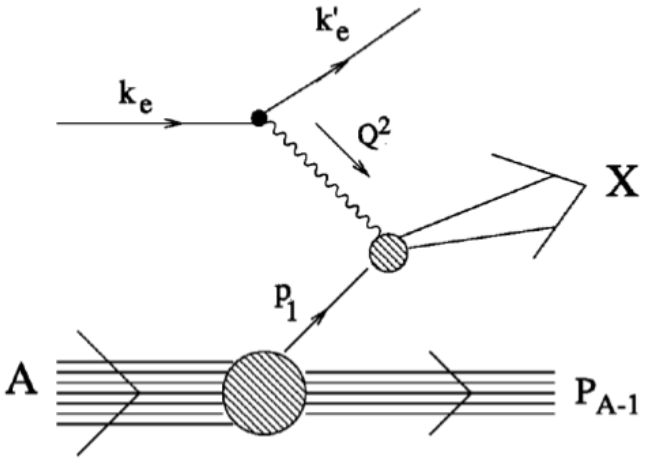
Why tagging?

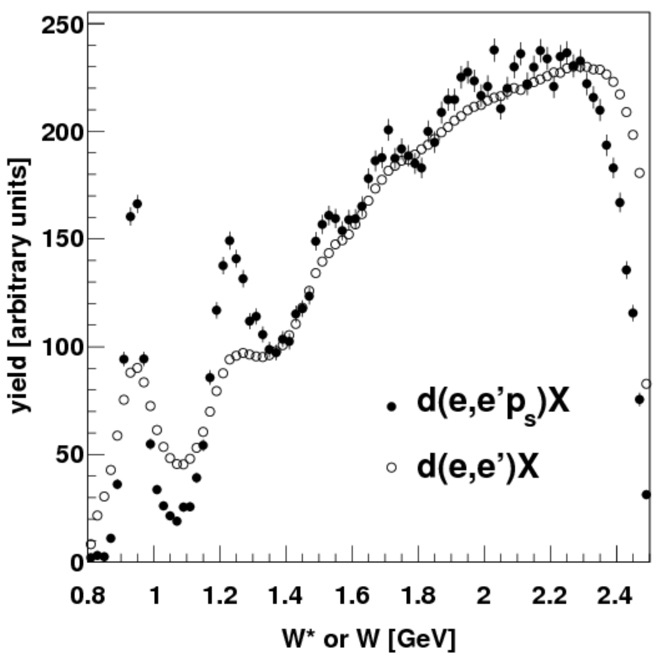
- To control final state interaction
- To control the initial state

How to tag?

- Done only for deuterium
  - *Bonus measurement from CLAS*
- Need a recoil detector

  → ALERT





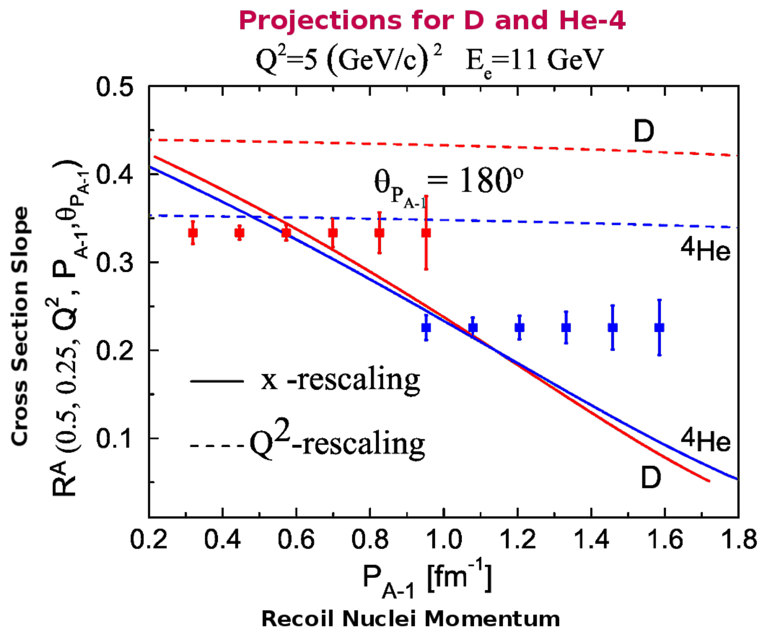
Tagging at Jefferson Lab 12 GeV

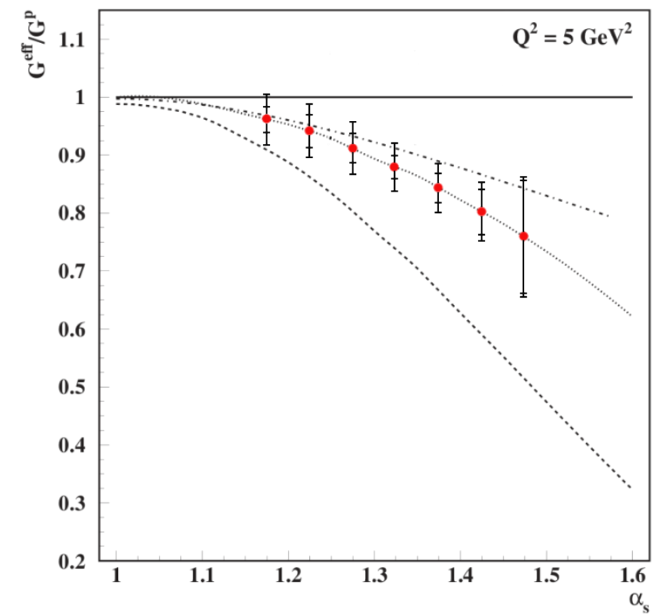
The ALERT run group

- Measure charged recoils
- Tagged DIS to understand the EMC effect
- Tagged DVCS to understand the generalized EMC

The BAND detector

- Will measure high energy backward neutrons
- Investigate short range nucleon correlations in deuterium





Tagging at the EIC

Kinematics of colliders makes it much simpler

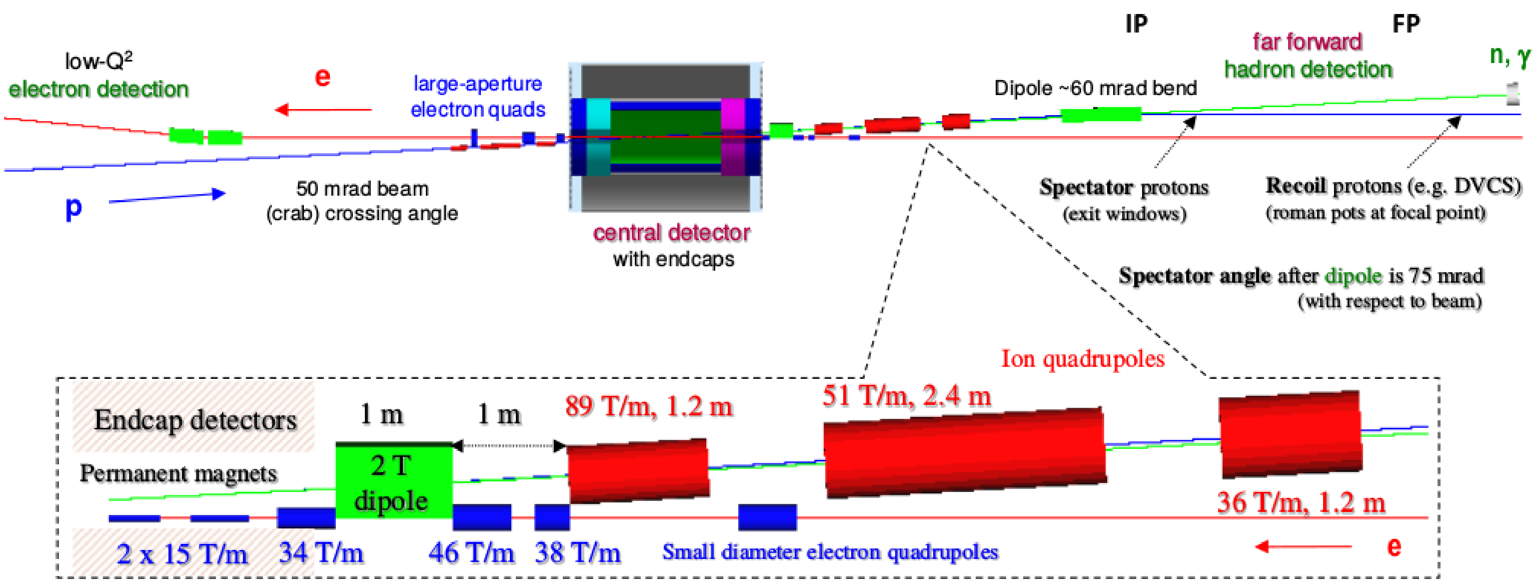
- Allows detection of both proton and neutrons
- As any nucleus with a magnetic rigidity different from the beam

Allows tagging and polarized target at the same time

- Access to effective target of polarized neutrons

Gives access to many body tagging

- For large nuclei, the A-1 contribution becomes small
- Other information can be gathered



Tagging in Many Body Systems

Centrality measurements are now standard in A-A

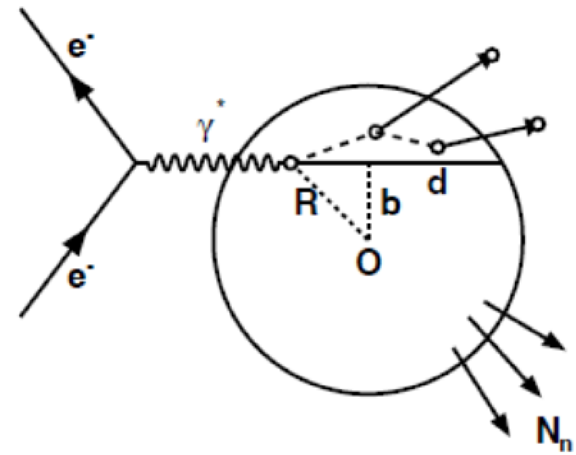
- They get more and more evolved
- Also applied in p-A
  - *With some caveats*

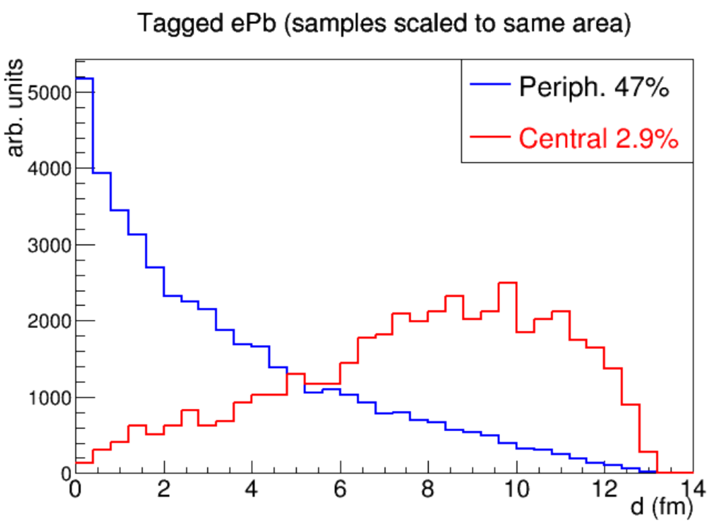
We will need similar measurements at EIC

- Else we are dominated by surface events
- Effort to create proper Monte-Carlo tools with Beagle
- Plans to use E665 data from Fermi Lab to calibrate

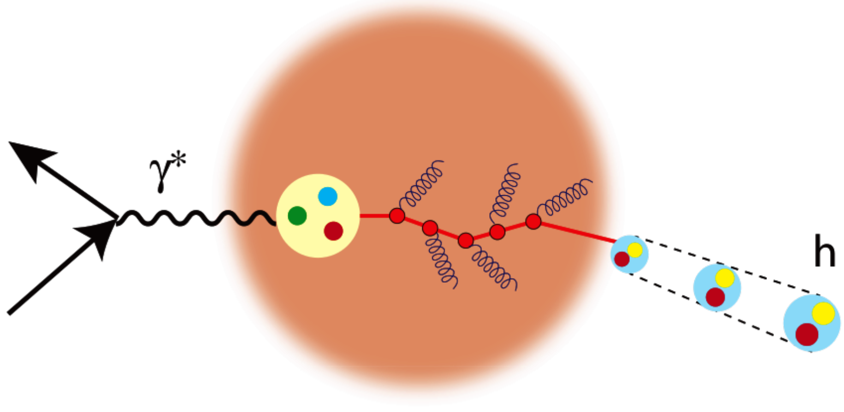
Impacts the beam line design

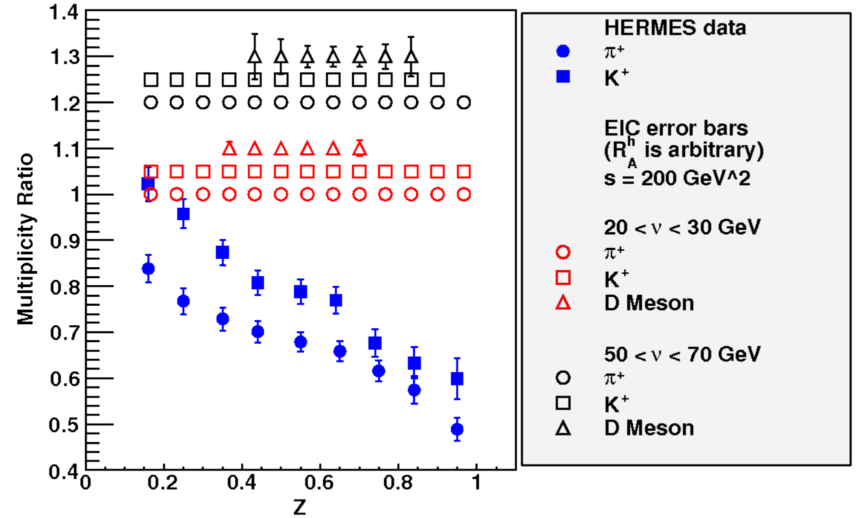
- This is a good time to worry about this





Hadronization





Dominated by parton energy loss at EIC

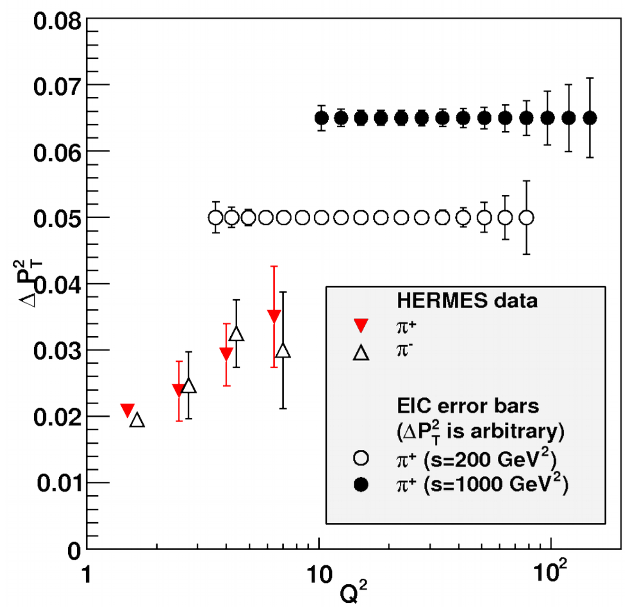
- Describe hadron suppression and transverse momentum broadening in nuclear material
- Gives access to the properties of the medium
  - *In particular gluon density*

Wide variety of calculations are available

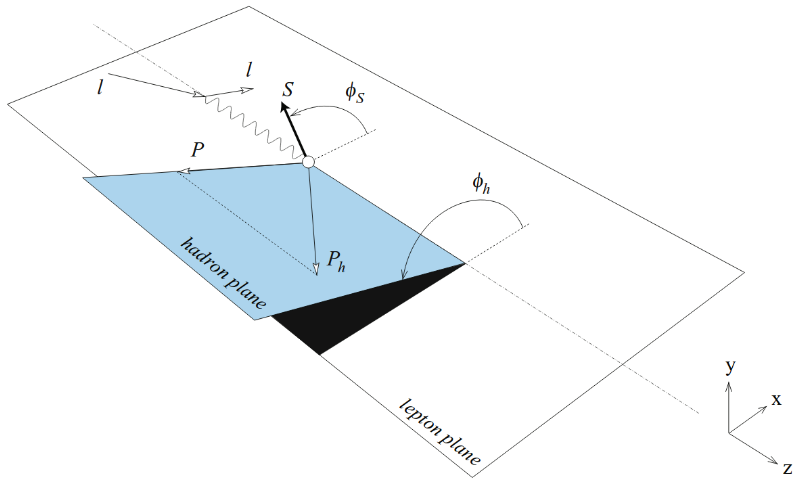
- Predictions are spreading over an order of magnitude
- Cold nuclear matter is a perfect benchmark

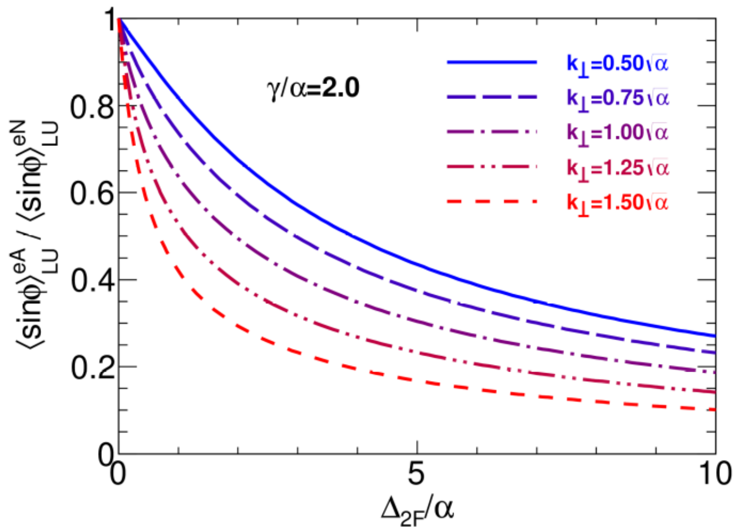
EIC energies comparable to RHIC and LHC

- And access to heavy quarks



Using TMDs for Hadronization





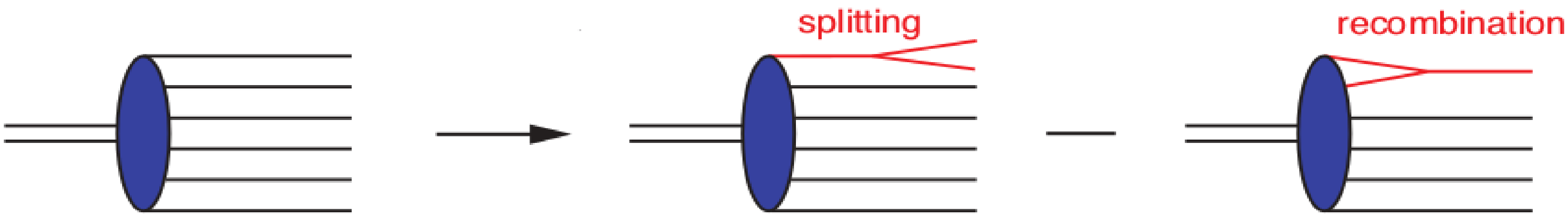
Usual hadronization measurements use outdated methods

- 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 $\hat{q}$

Offers two independent 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
- With BDMPS calculation, one can relate transport coefficient and gluon saturation scale

The hadronization studies will provide an independent result for this

- It can be measured for several nuclei
- Possibility to test the A dependence of the saturation scale

Summary

We have a direct conflict between traditional nuclear physics and hadron physics measurements

- **We need new observables to resolve this**

We have now access to nuclear GPDs

- **We are able to measure nuclear DVCS**
- **EIC will offer the perfect ground for nuclear DVCS**
  - *At high luminosity, moderate energies*

Tagged process offer clean observables

- **To help resolve the EMC effect**
- **To enhance nuclear effects at EIC with a centrality like measurement**

Hadronization will be key at EIC

- **We need to apply the modern TMD framework**
- **Clean measurement of the transport coefficient**
- **Will give in independent access to the saturation scale**