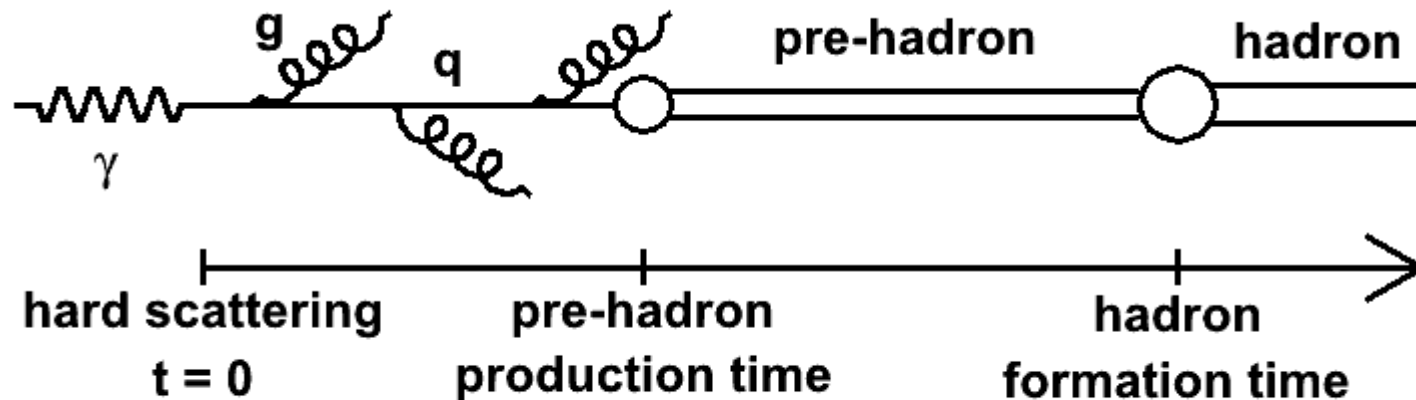


Study of Hadronization Dynamic with Nuclei

Raphaël Dupré

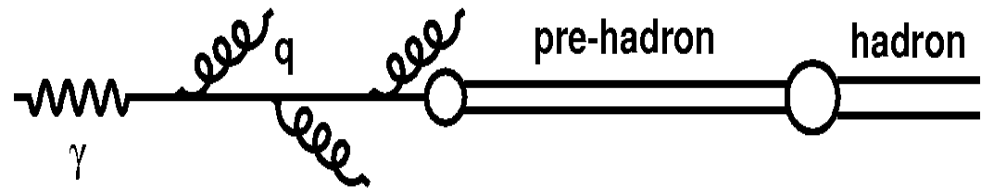
*Service de Physique Nucléaire
CEA/IRFU*

Hadronization



- Non perturbative process
 - cannot be exactly calculated
- Can be characterized by two times
 - Color neutralization at **production time**
 - At **formation time** hadronic properties are definitive

Motivations



- Understanding Hadronization Process
 - Measuring characteristic times
 - Being able to calculate parton energy loss
 - Understand the pre-hadron and the color transparency effects
- Characterization of cold nuclear matter
- Characterization of hot nuclear matter
- Reduce systematic effects in various experiments (such as νA and eA)

Deep Inelastic Scattering

- Momentum transfer

$$Q^2 = -q^2$$

- Photon energy

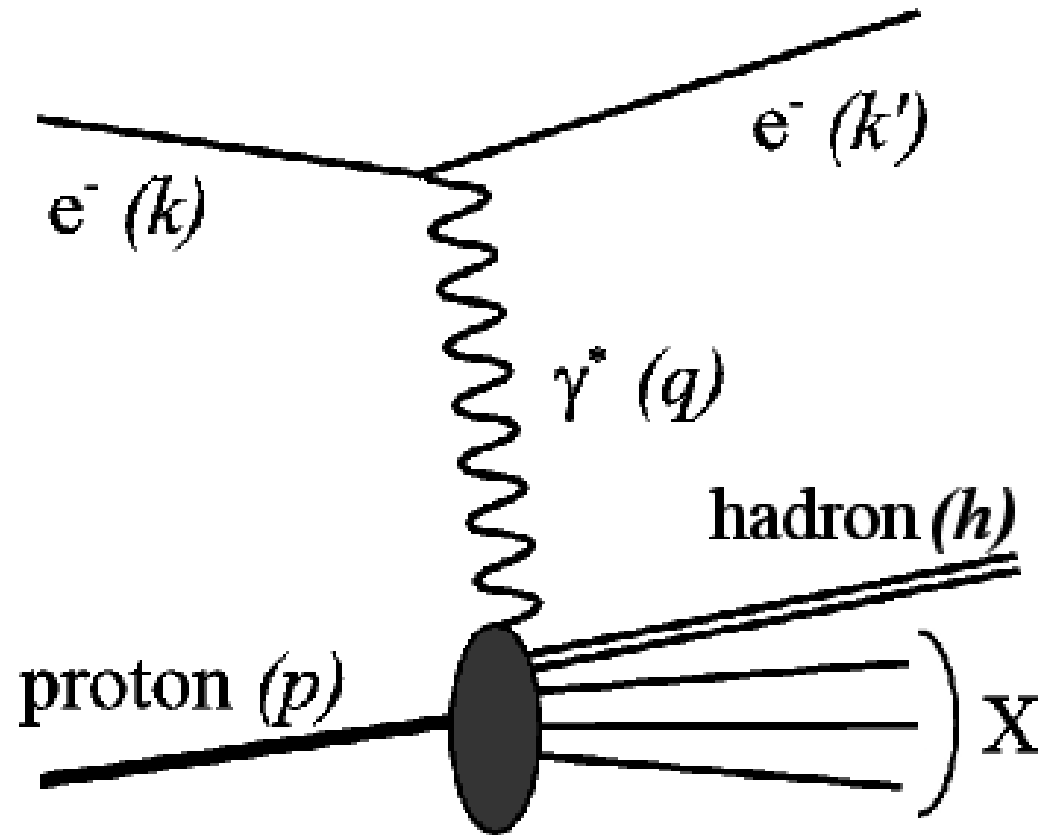
$$\nu = E_\gamma$$

- Fraction of the energy carried by the hadron

$$z = \frac{k \cdot p}{q \cdot p} = E_h / \nu$$

- Transverse momentum

$$\vec{P}_t = \vec{P}_h - \frac{\vec{P}_h \cdot \vec{q}}{\|\vec{q}\|} \vec{q}$$



Observables in Nuclear DIS

- Transverse momentum broadening

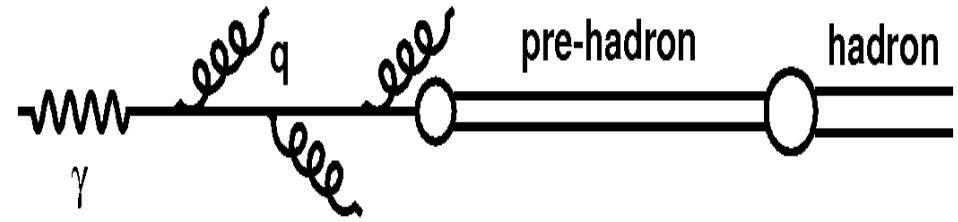
$$\Delta P_T^2 = \langle P_T^2 \rangle_A - \langle P_T^2 \rangle_D$$

- Multiplicity ratio

$$R_A^h(Q^2, x_{Bj}, z, P_T) = \frac{N_A^h(Q^2, x_{Bj}, z, P_T) / N_A^e(Q^2, x_{Bj})}{N_D^h(Q^2, x_{Bj}, z, P_T) / N_D^e(Q^2, x_{Bj})}$$

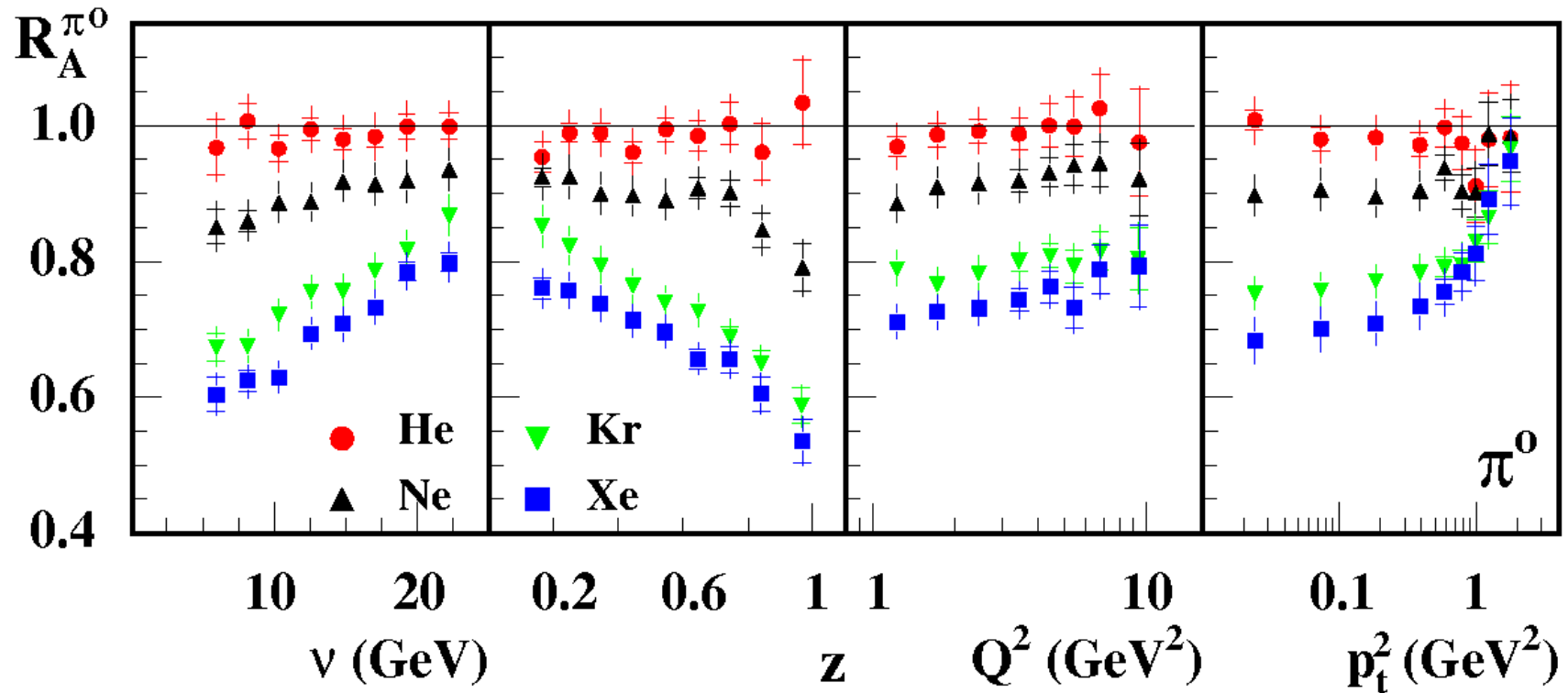
The attenuation is $1-R$

Theoretical Scenarios



- Parton energy loss
- (Pre-)Hadron absorption
- Medium modified fragmentation functions
- Models are either pure or combinations of several effects

The General Picture



- Increase with ν
- Decrease with z
- Slight increase with Q^2
- Strong increase with P_T

Conclusions From HERMES

- Pions have similar behavior
- Demonstrated the raise with v
- Provides interesting baryon measurement

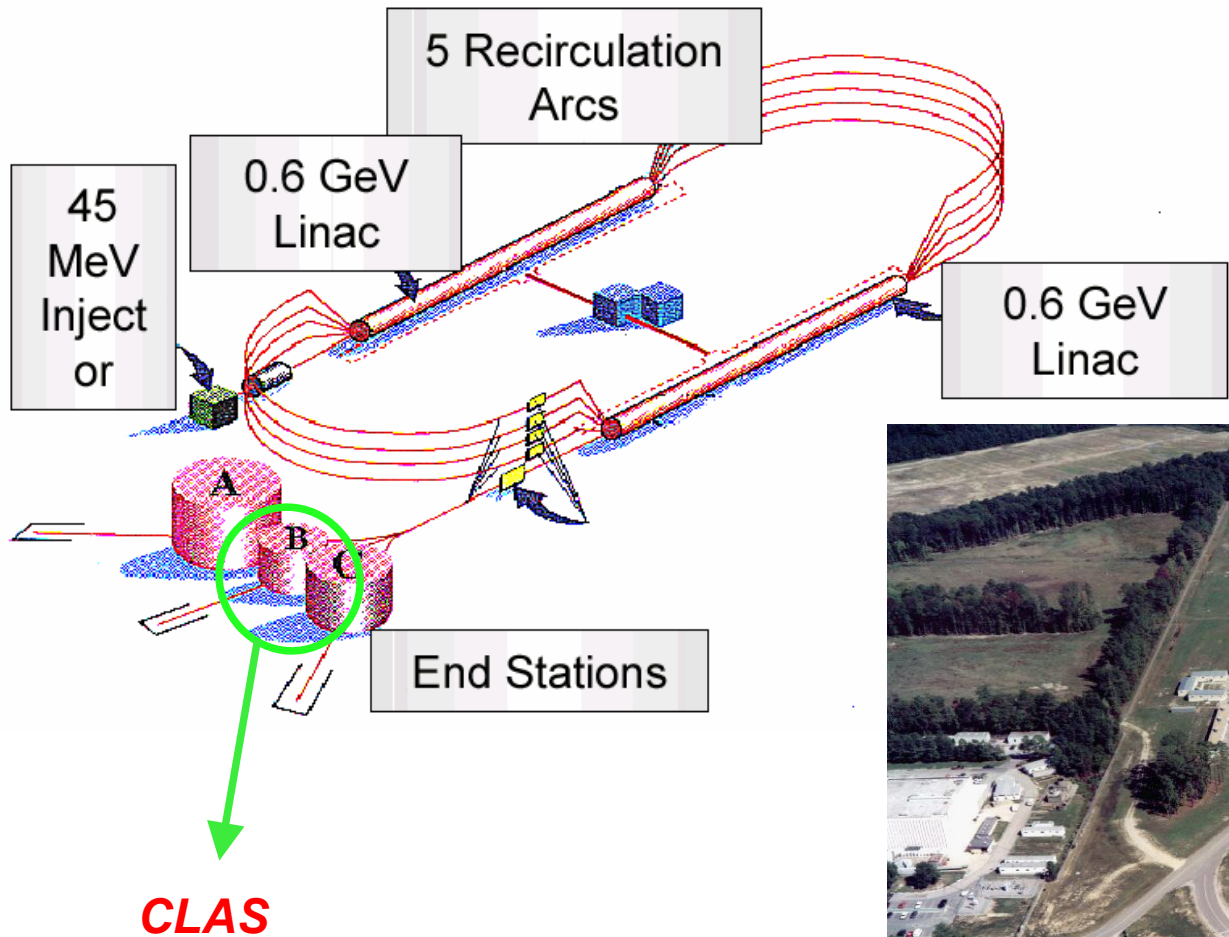
However

- Target fragmentation might be an issue
- All model types remain

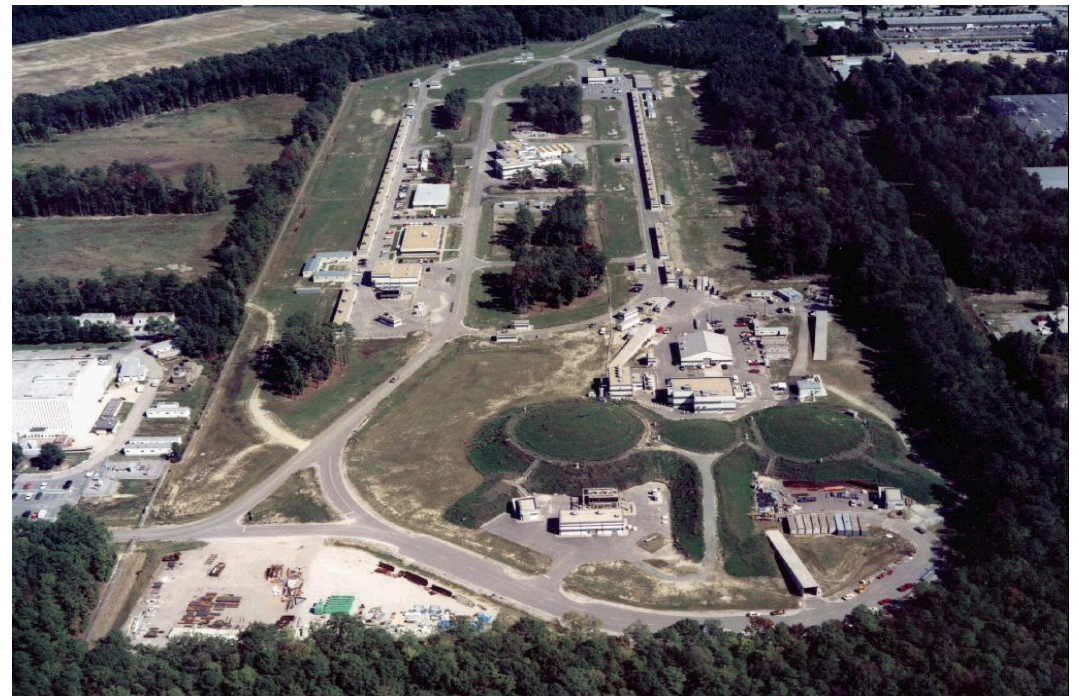
Still to be done

- Some multidimensional results are not confronted to models yet
- Interesting hints for a Q^2 and flavor effects need to be confirmed

Jefferson Laboratory (JLab)



$E_{\text{max}} \sim 6 \text{ GeV}$
 $I_{\text{max}} \sim 200 \mu\text{A}$
Duty Factor $\sim 100\%$

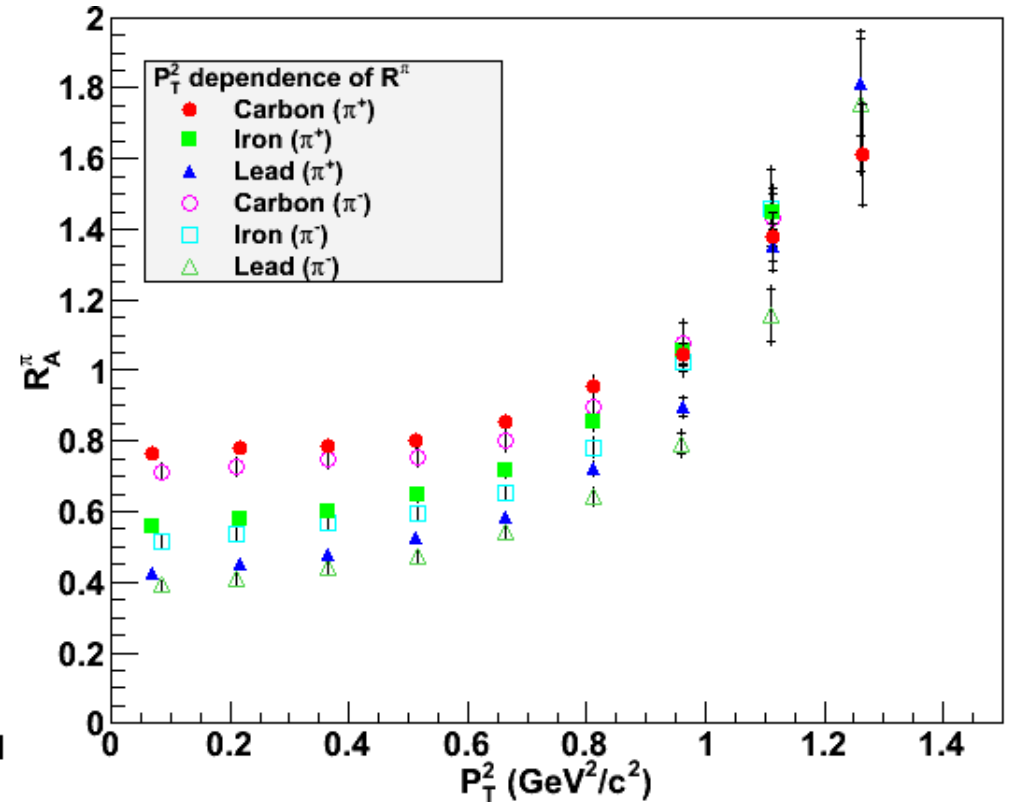
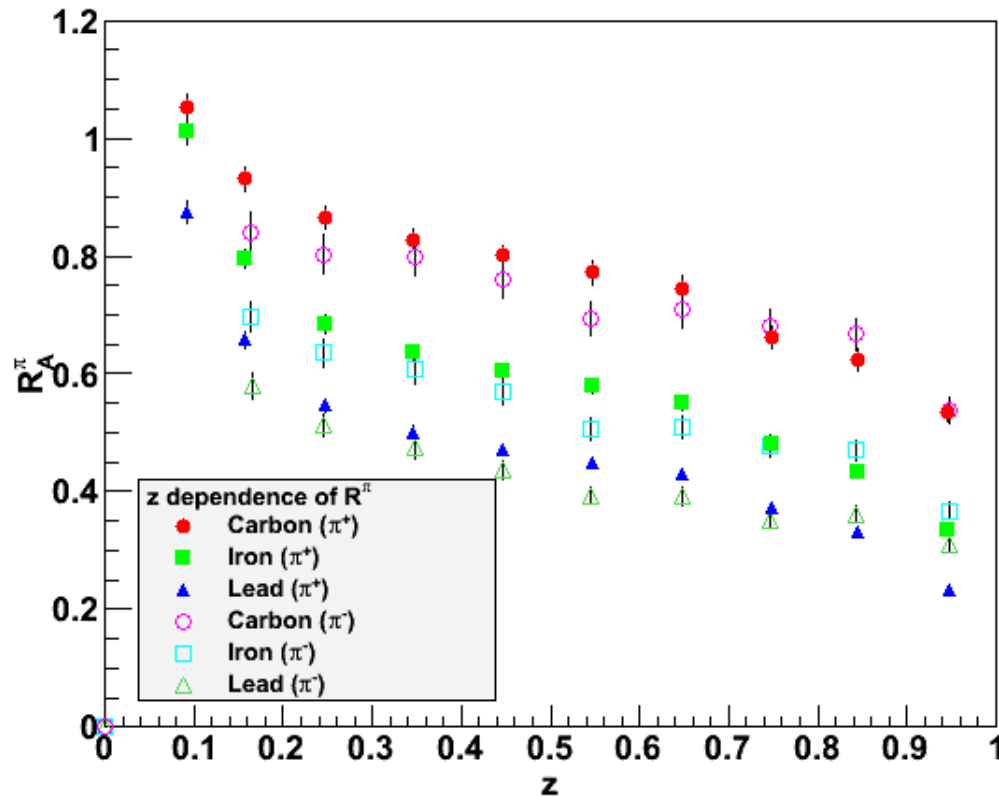


The eg2 run

- Proposed by W. Brooks et al. in “Quark Propagation Through Cold QCD Matter”
- Running 50 days in Hall B of JLab (CLAS Collaboration)
- 5 GeV electron beam
- Main goal is to obtain statistic for a multi-dimensional study
- Use 5 targets (C, Al, Fe, Sn, Pb)

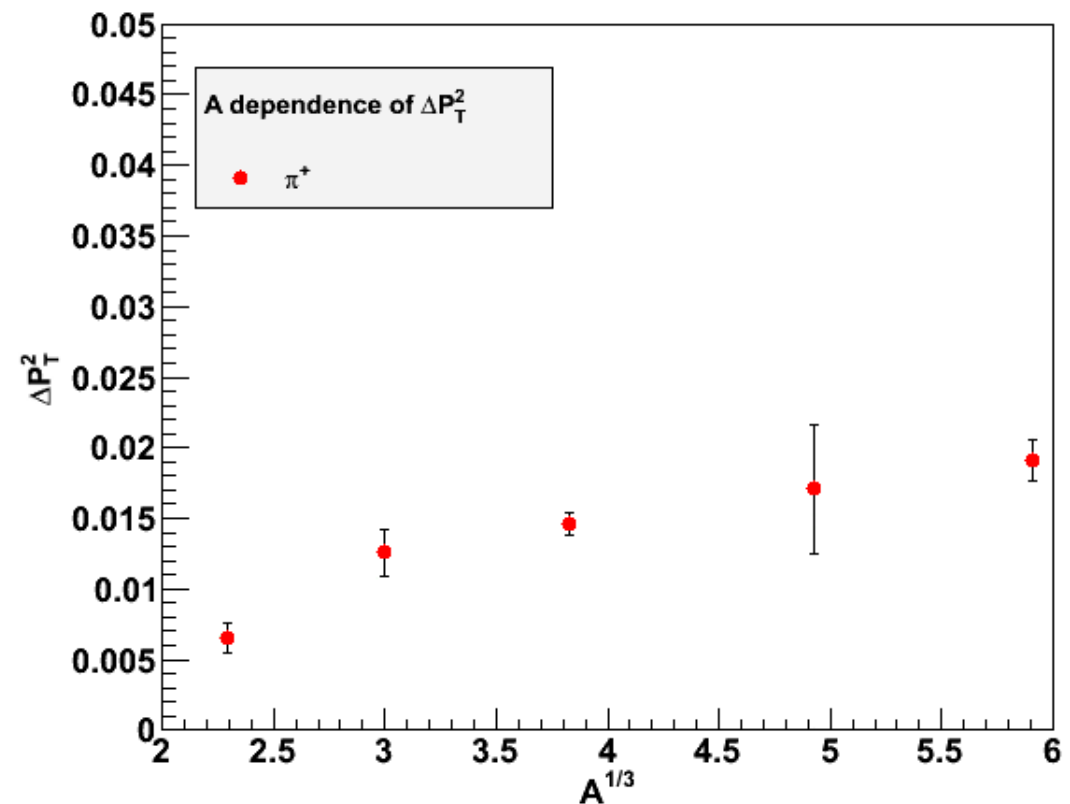
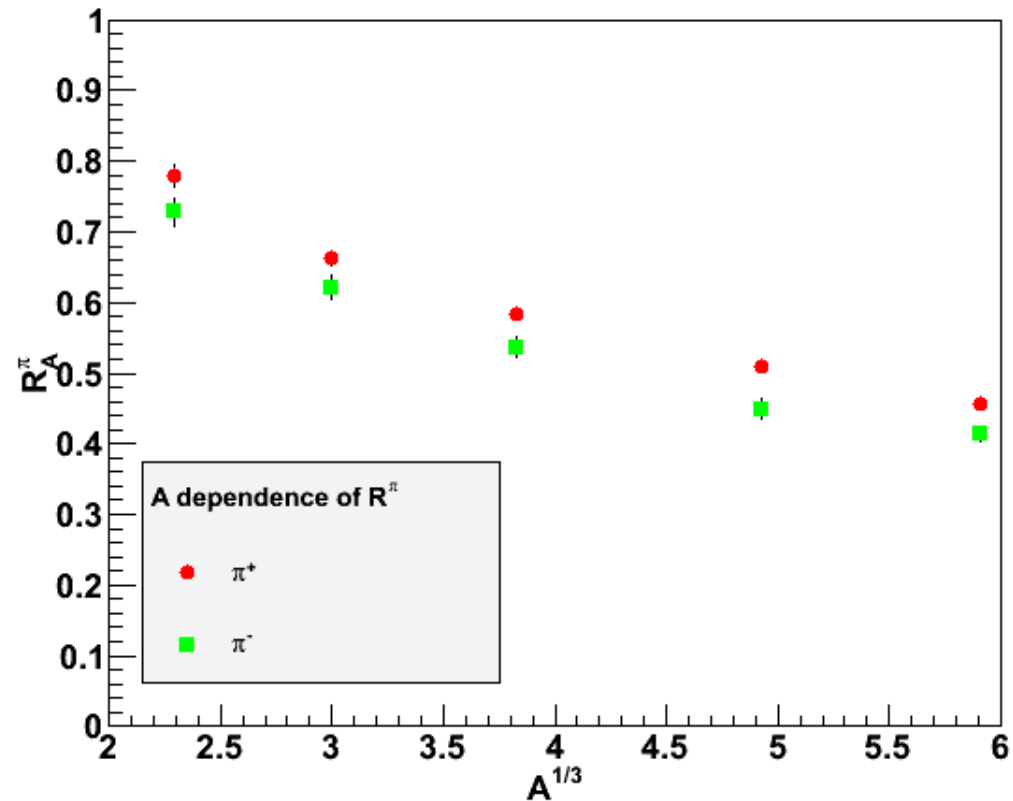


General Picture



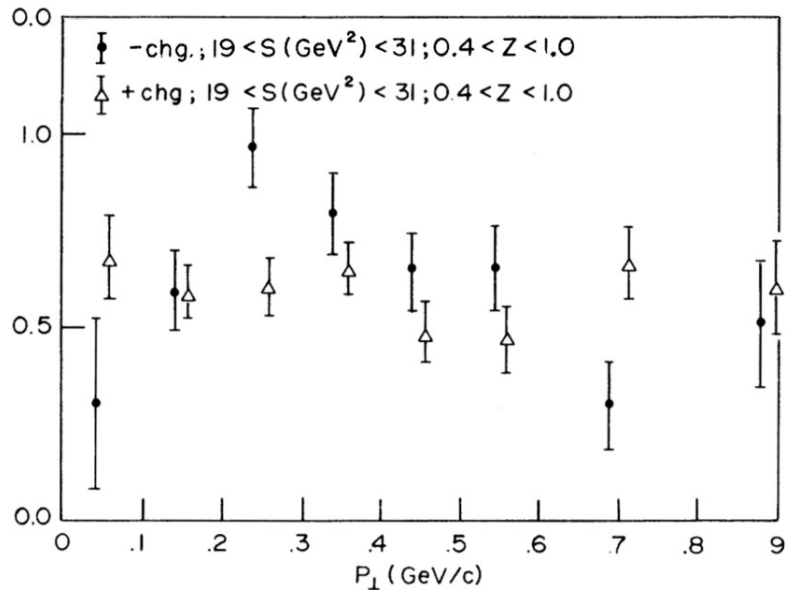
- Similar to HERMES in z and P_T

The A Dependence

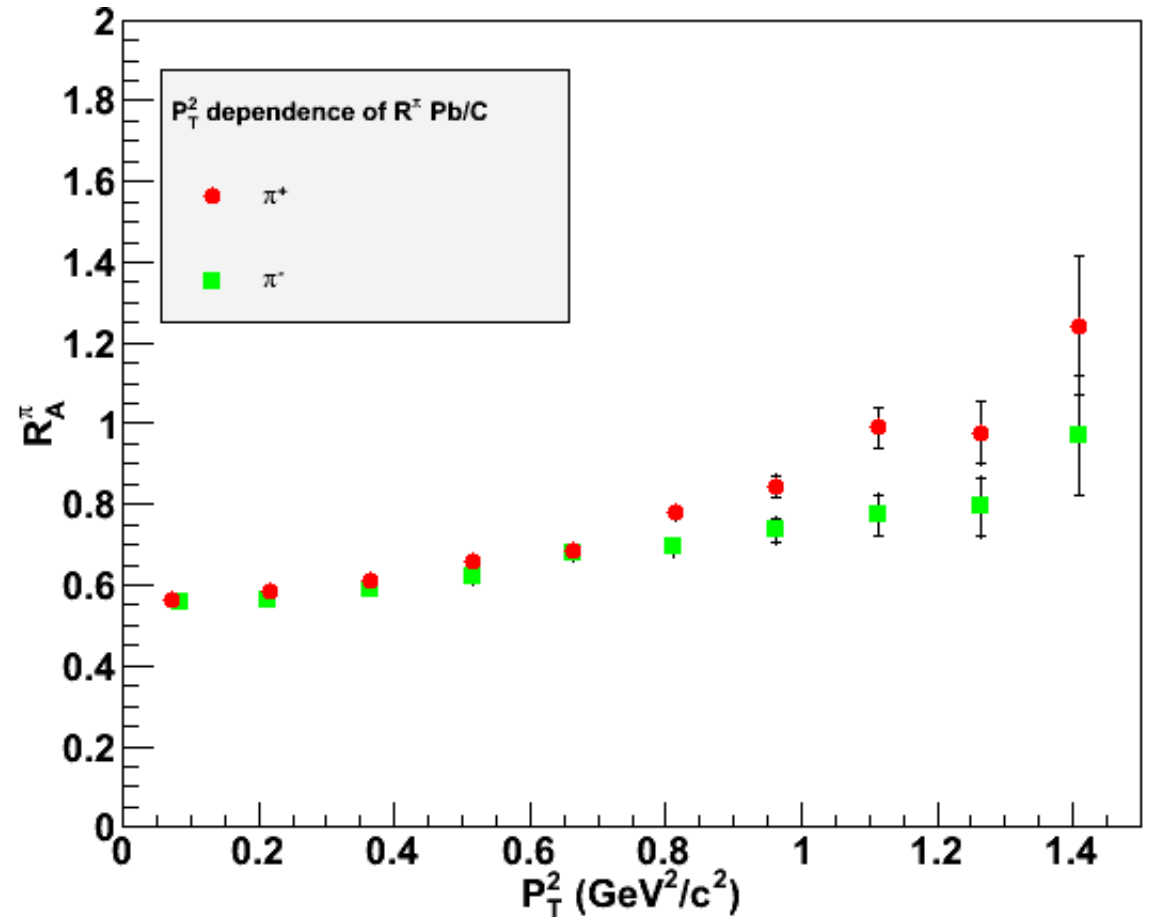


- Non-linear with $A^{1/3}$ neither $A^{2/3}$
- Nuclear effect seem to saturate

P_T Broadening



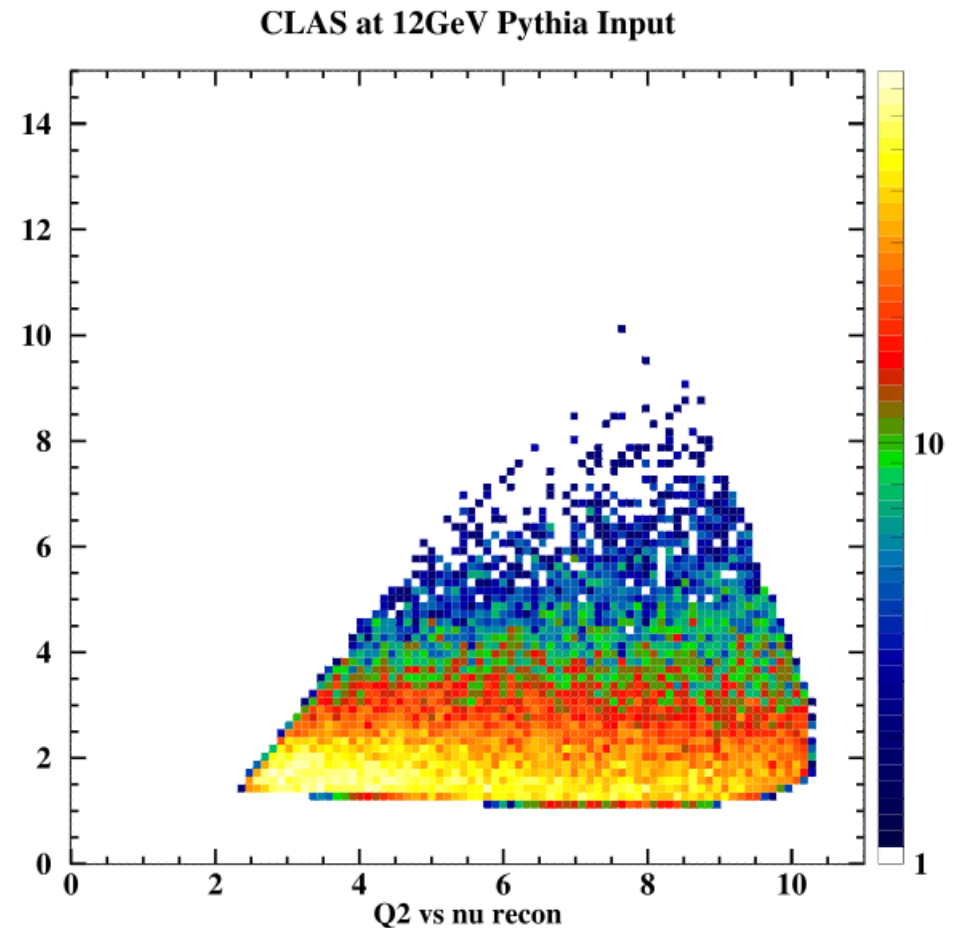
SLAC Osborne et al.
(PRL40 (1978) 1624)



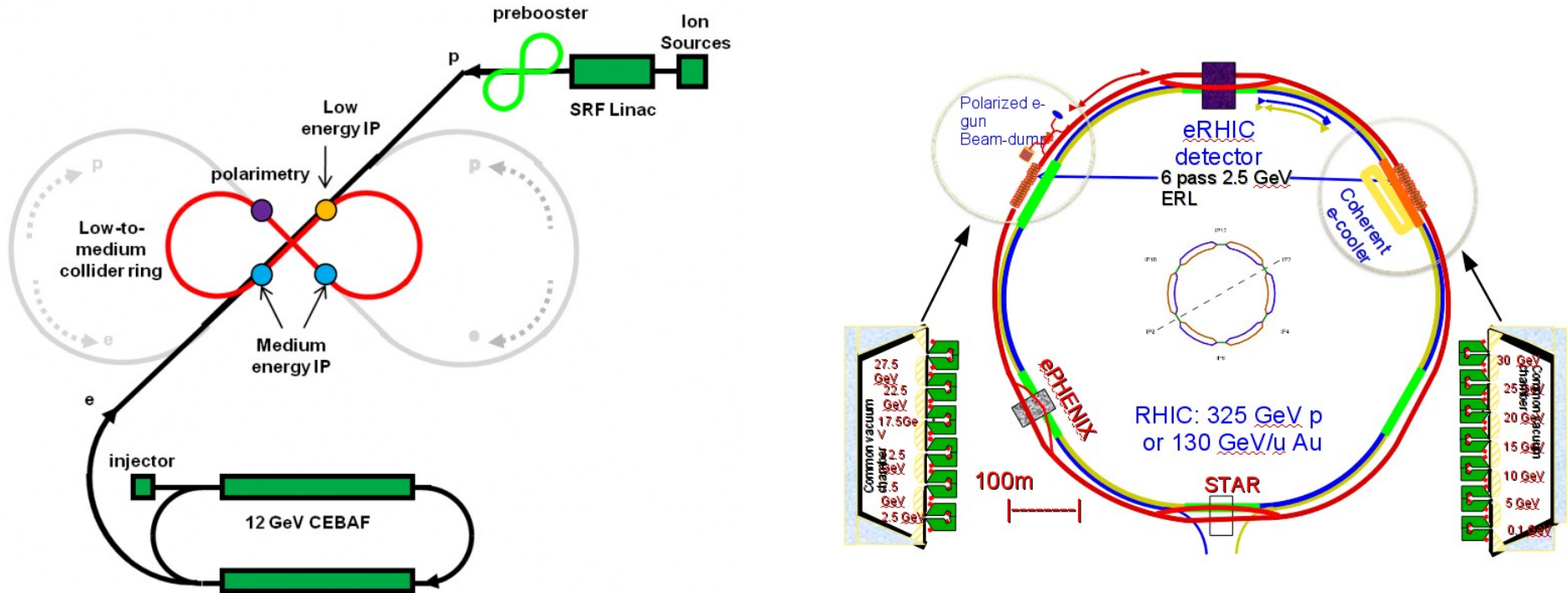
Relative to carbon \rightarrow modest effect
(coherent with results from SLAC)

What's Next?

- Planned experiment at CLAS 12 (11 GeV beam)
 - “Quark Propagation and Hadron Formation” proposal, K. Hafidi et al.
 - To explore both attenuation and ΔP_T^2
 - Many particles available as in HERMES
 - Larger kinematic coverage than CLAS
 - Larger luminosity than CLAS (x10) and HERMES (x1000)

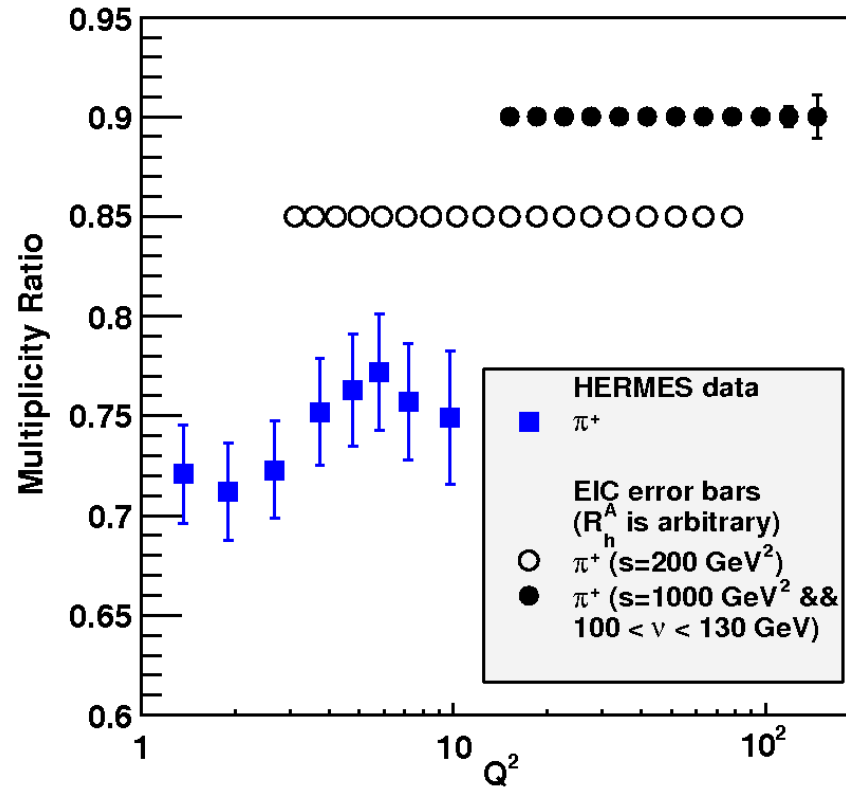


The EIC Projects



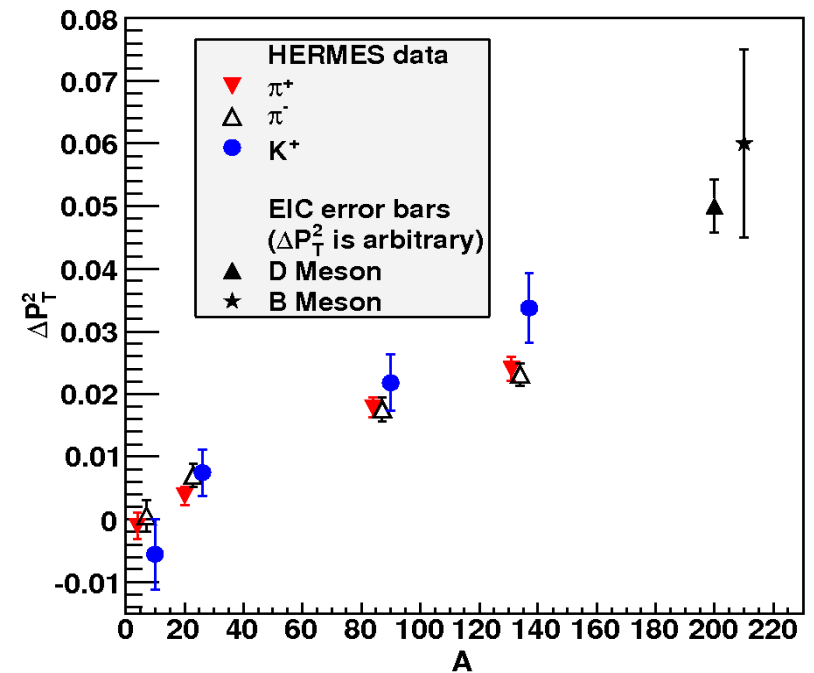
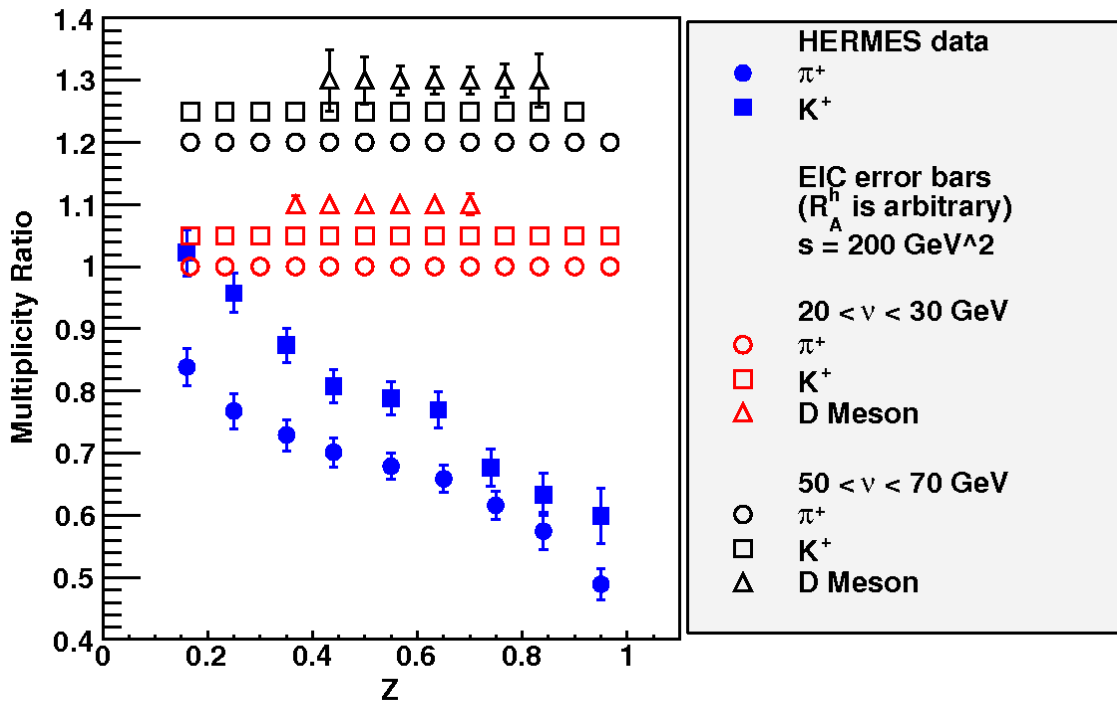
- Project of electron ion collider (EIC)
 - JLab and RHIC projects $\sim 1000 \text{ GeV}^2$ and more
 - Low to no attenuation region \rightarrow centered on ΔP_T^2 measurement
 - Isolate energy loss effects and eventually modification of FF
 - Access to heavy flavor for comparison with Heavy Ion Collisions

Large Q^2 Leverage



Also available for multiplicity ratio
using the medium energy setting

Precise Heavy Flavor Study



- Charm mesons available with high precision with 200 fb^{-1} (115 days per target)
- Bottom also available but need important luminosity or high reconstruction efficiency

Summary

- Great progress achieved by HERMES
 - But issues with target fragmentation
 - They raised new questions
- CLAS helps clarify some of these questions
- CLAS provides new results at low energy to test models
 - Saturation of the nuclear effects at high A
 - Clean measurement of ν , Q^2 , z and P_T
- The Future
 - More results will be extracted from CLAS data
 - CLAS12 to improve the observations of HERMES and CLAS
 - EIC to explore parton energy loss and medium FF