QUARK-HADRON TRANSITION AND HADRONIZATION STUDIES AT THE EIC

POETIC VI Conference

Ecole Polytechnique

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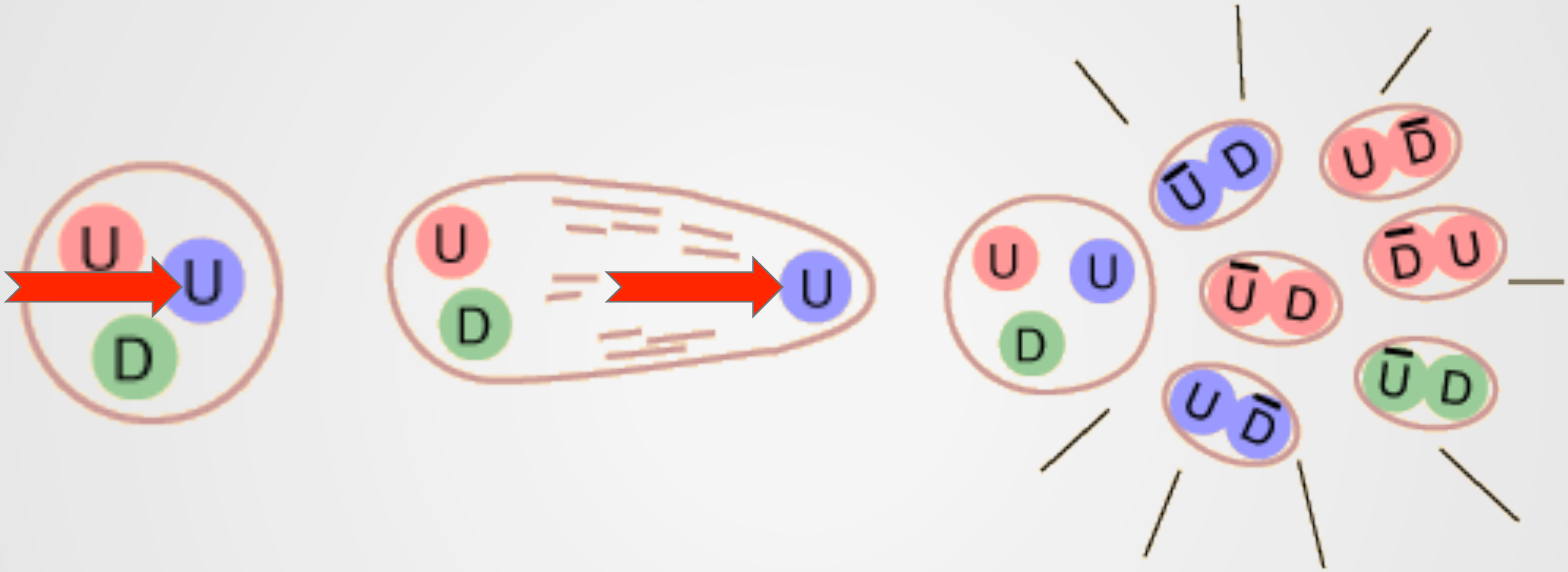
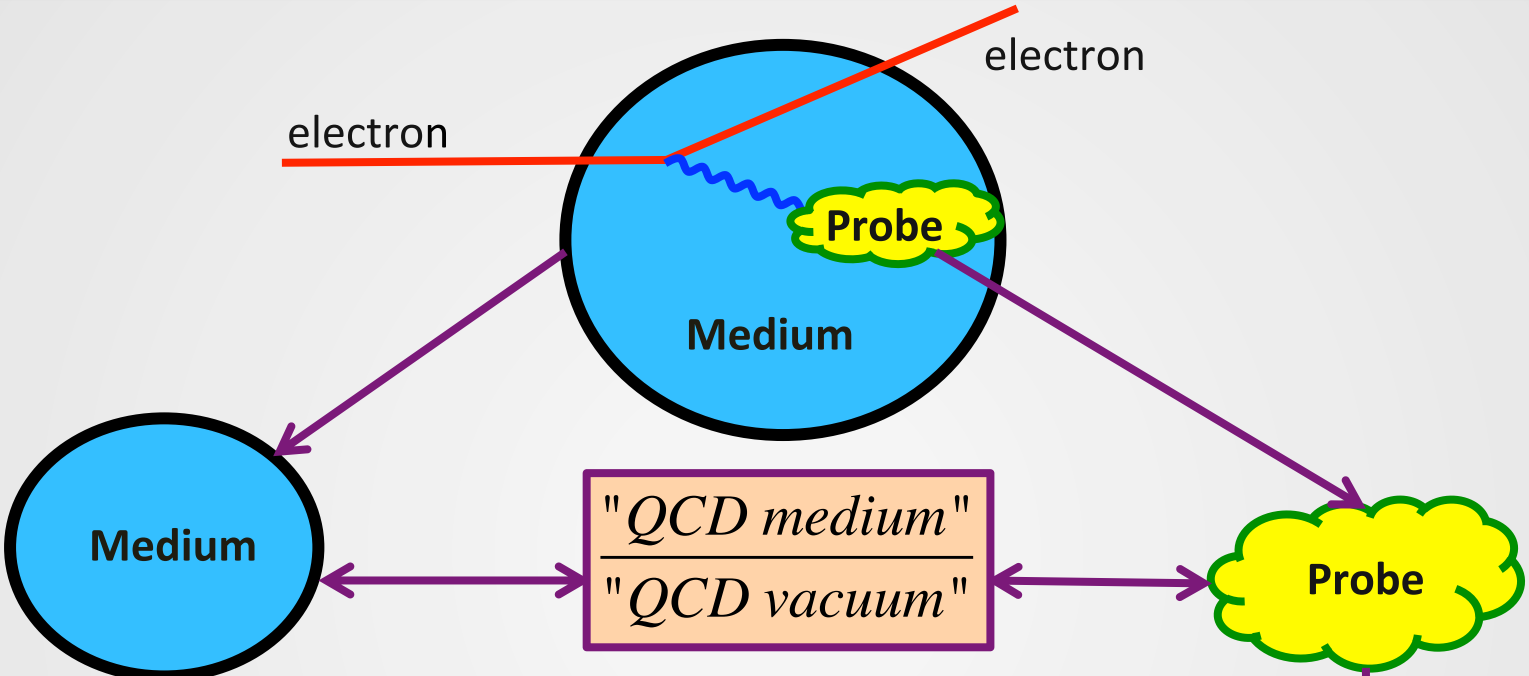
HADRONIZATION IS A DIRECT MANIFESTATION OF CONFINEMENT



How do energetic quarks transform into hadrons ?

PROBE VS. MEDIUM

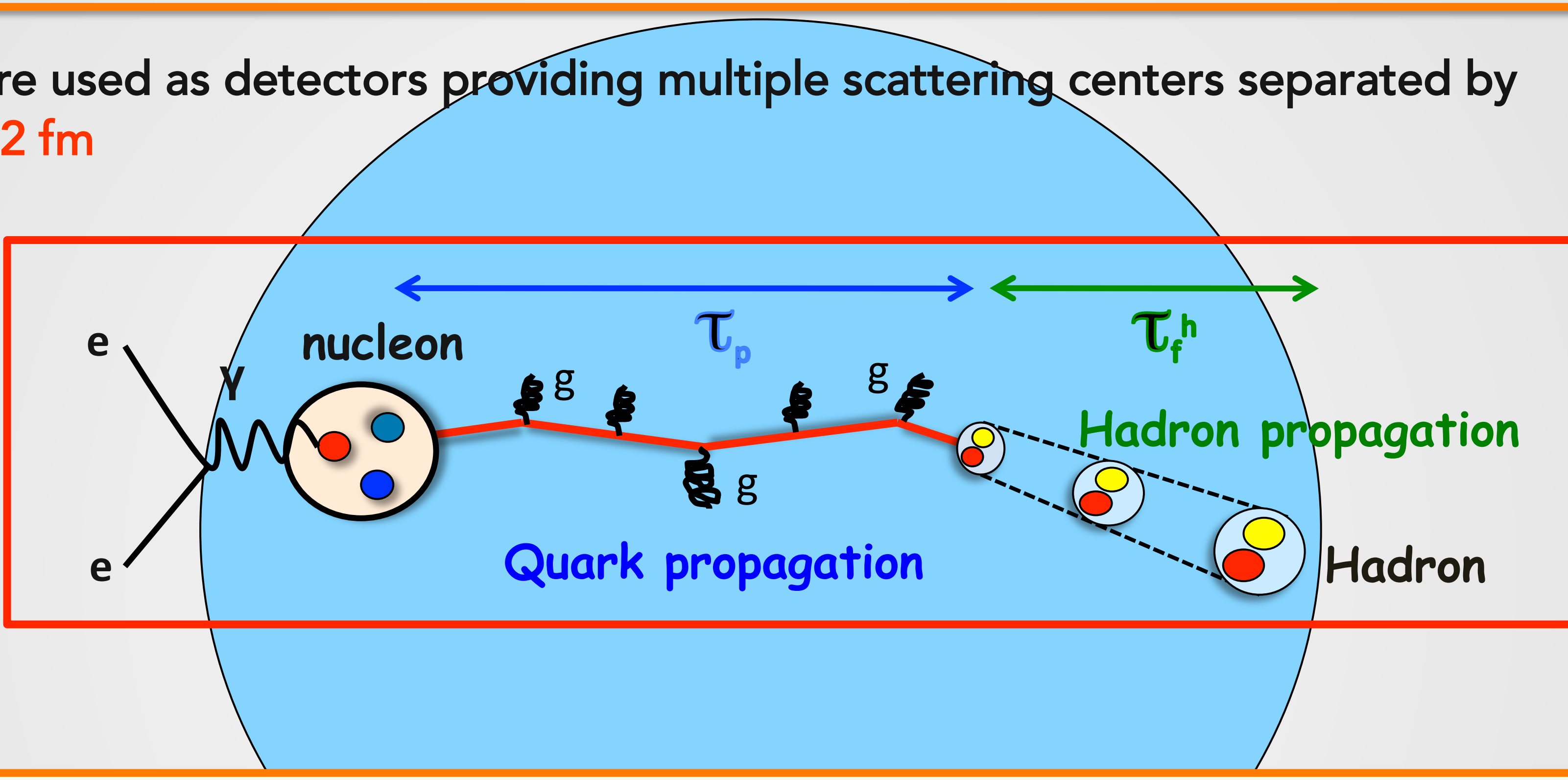


- Medium modification of quark distributions – EMC
- Short range structure – SRC
- 3D mapping – Nuclear GPDs and TMDs

- Color confinement dynamics – Hadronization
- Creation and evolution of small size hadrons – Color Transparency

PROBE: HOW DO QUARKS HADRONIZE INTO HADRONS?

Nuclei are used as detectors providing multiple scattering centers separated by only 1 – 2 fm

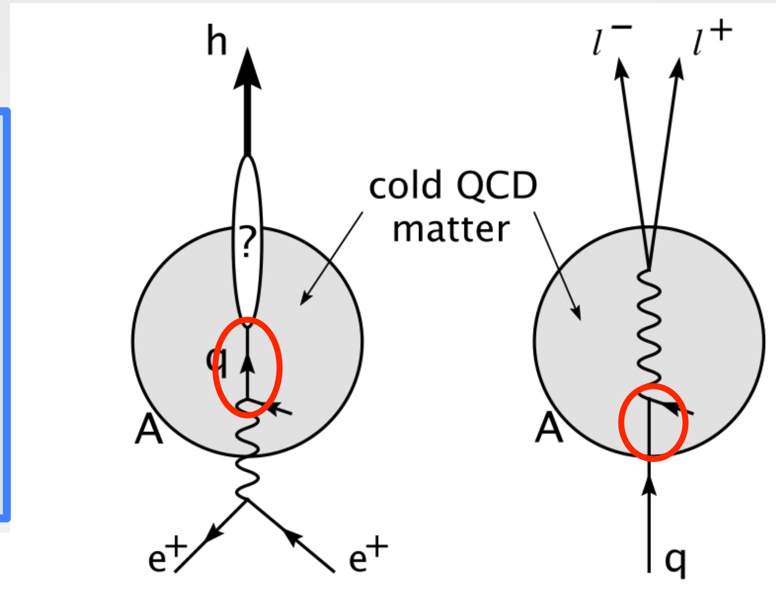


- What is the interaction and the lifetime τ_p of the struck quark before it neutralizes its color ? – partonic energy loss
- How long does it take to form the color field of a hadron τ_f and which kind of interaction is in play ?

COMPLEMENTARY PROCESSES TO STUDY HADRONIZATION

Deep Inelastic scattering

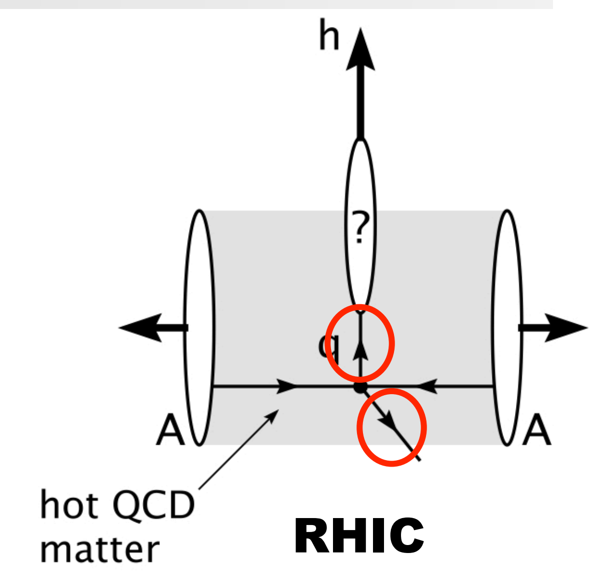
- ✧ Quark propagation
- ✧ Hadron formation
- ✧ Final state effects



DIS **DY**

Drell-Yan

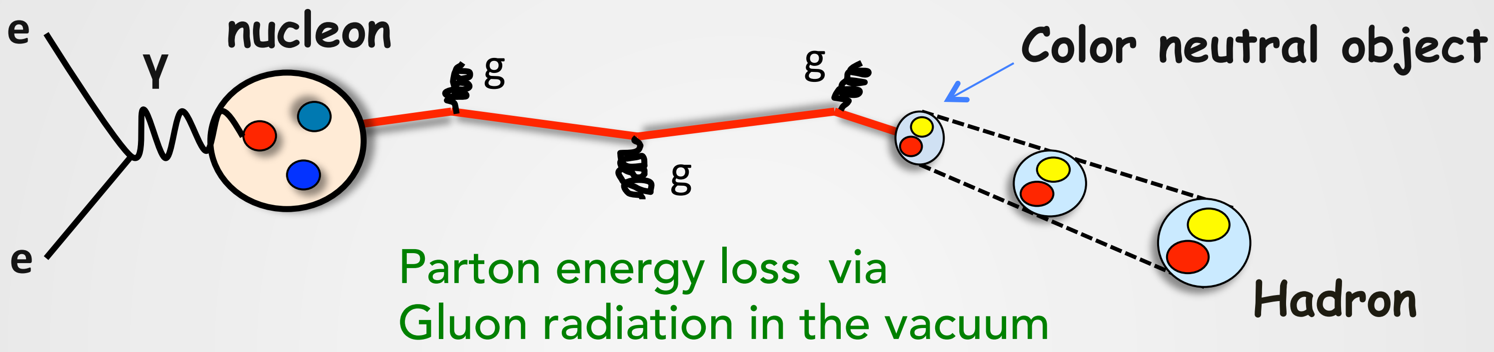
- ✧ Quark propagation
- ✧ Initial state effects



Relativistic Heavy ion collisions

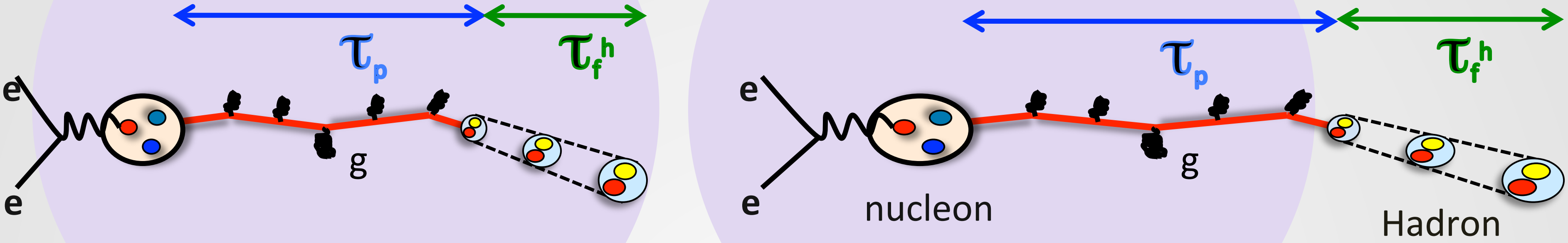
- ✧ Quark propagation in strongly interacting matter
- ✧ Hadron formation
- ✧ Initial and final state effects

SEMI-INCLUSIVE DIS (SIDIS) IN THE VACUUM (NUCLEONS) – FLAVOR TAGGING TECHNIQUES



- Flavor decomposition of longitudinal unpolarized and polarized distributions
- Transverse momentum dependent distribution (TMDs)
- Parton fragmentation in the vacuum

SIDIS IN THE MEDIUM



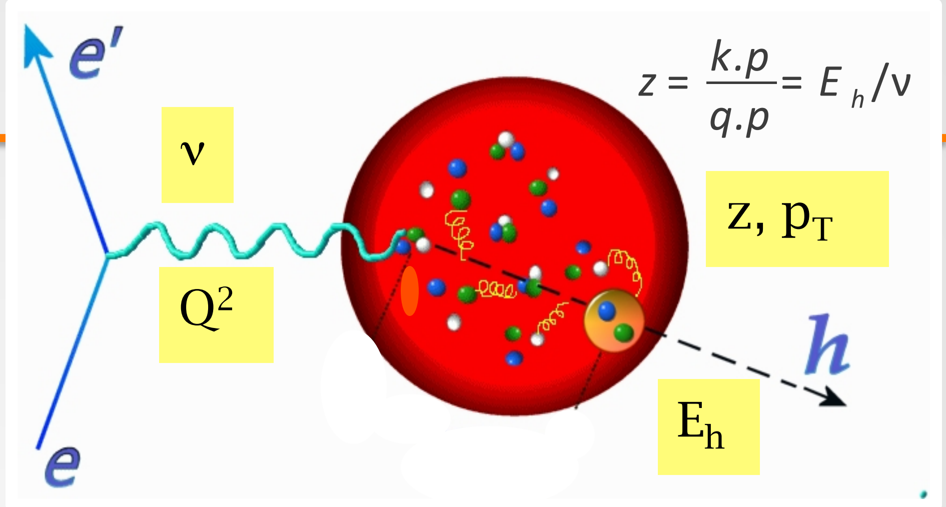
Hadron forms inside the medium
Accessible at low energies

Hadron forms outside the medium
dominant at high energies

- Parton energy loss in the medium: Medium induced gluon emission
- Modification of the fragmentation functions in the medium
- Hadron/pre-hadron formation and interaction with the medium
- Low/Medium energy DIS offers a unique kinematic window with hadronization time scales comparable to the nuclei sizes

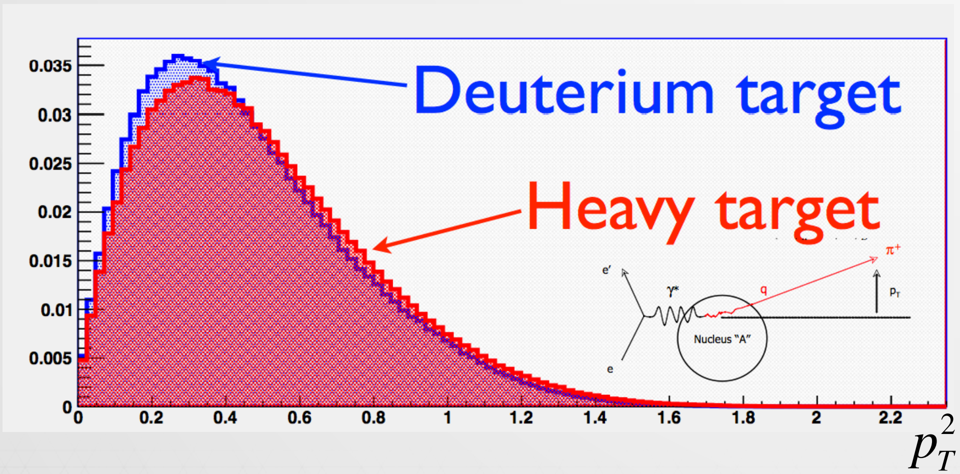
SIDIS OBSERVABLES

Leptonic variables: ν (or x), Q^2
Hadronic variables: z and p_T
Different nuclei: size and density
Different hadrons: quark's flavor



Transverse momentum broadening

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

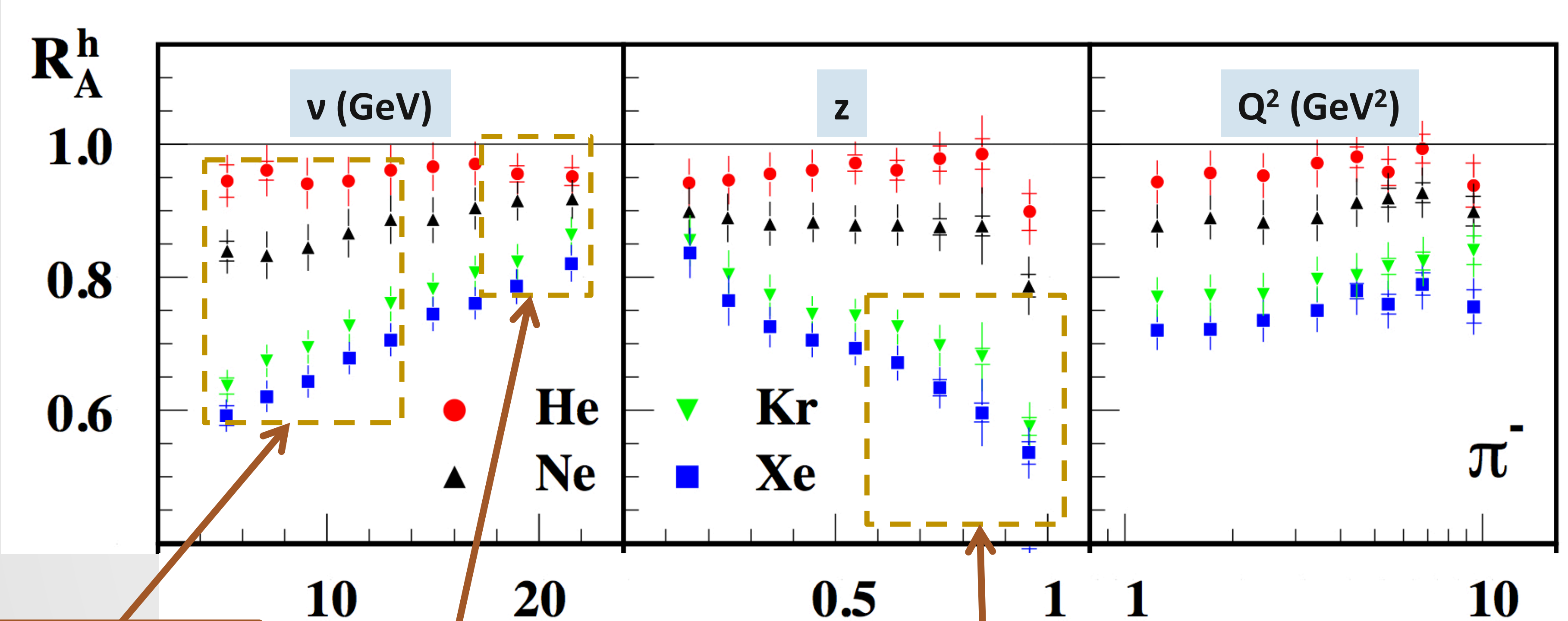


Multiplicity ratio

$$R_M(z,\nu,Q^2,p_t^2) = \frac{\left.\frac{N_h(z,\nu,Q^2,p_t^2)}{N_{DIS}}\right|_A}{\left.\frac{N_h(z,\nu,Q^2,p_t^2)}{N_{DIS}}\right|_D}$$

GENERAL FEATURES OF MULTIPLICITY RATIOS

HERMES NPB 780 (2007)

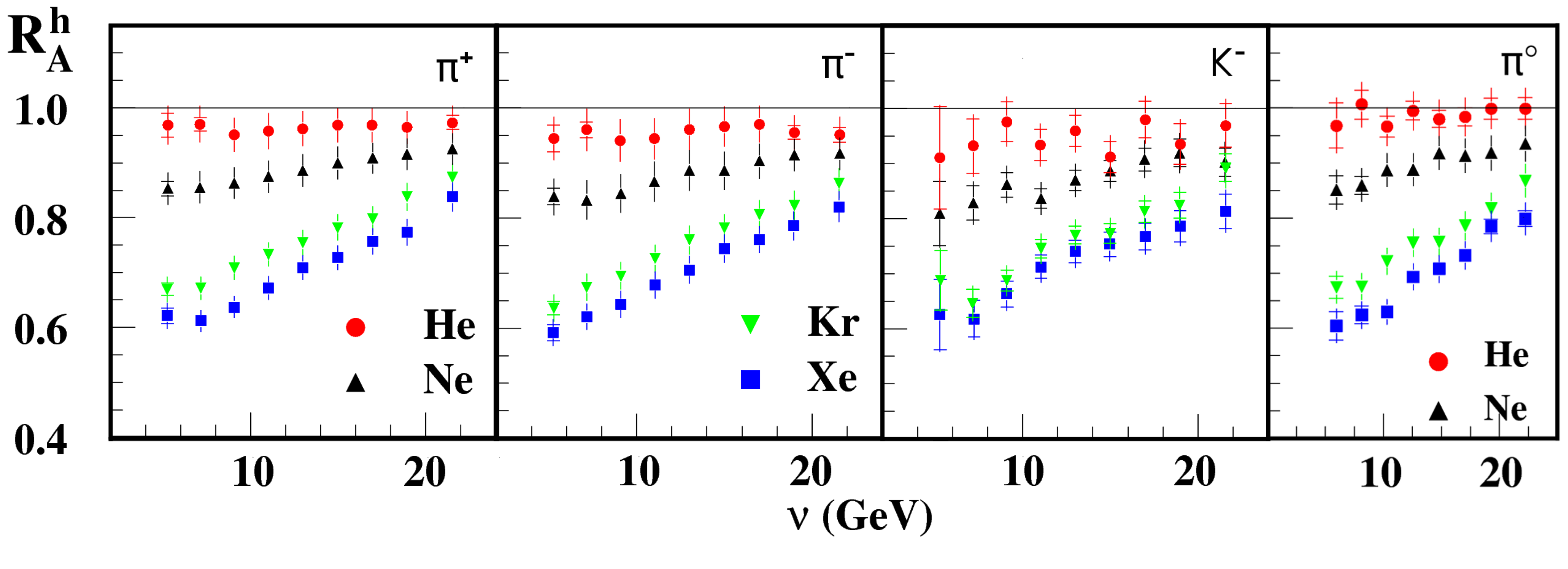


Mass effect

Lorentz boost effect

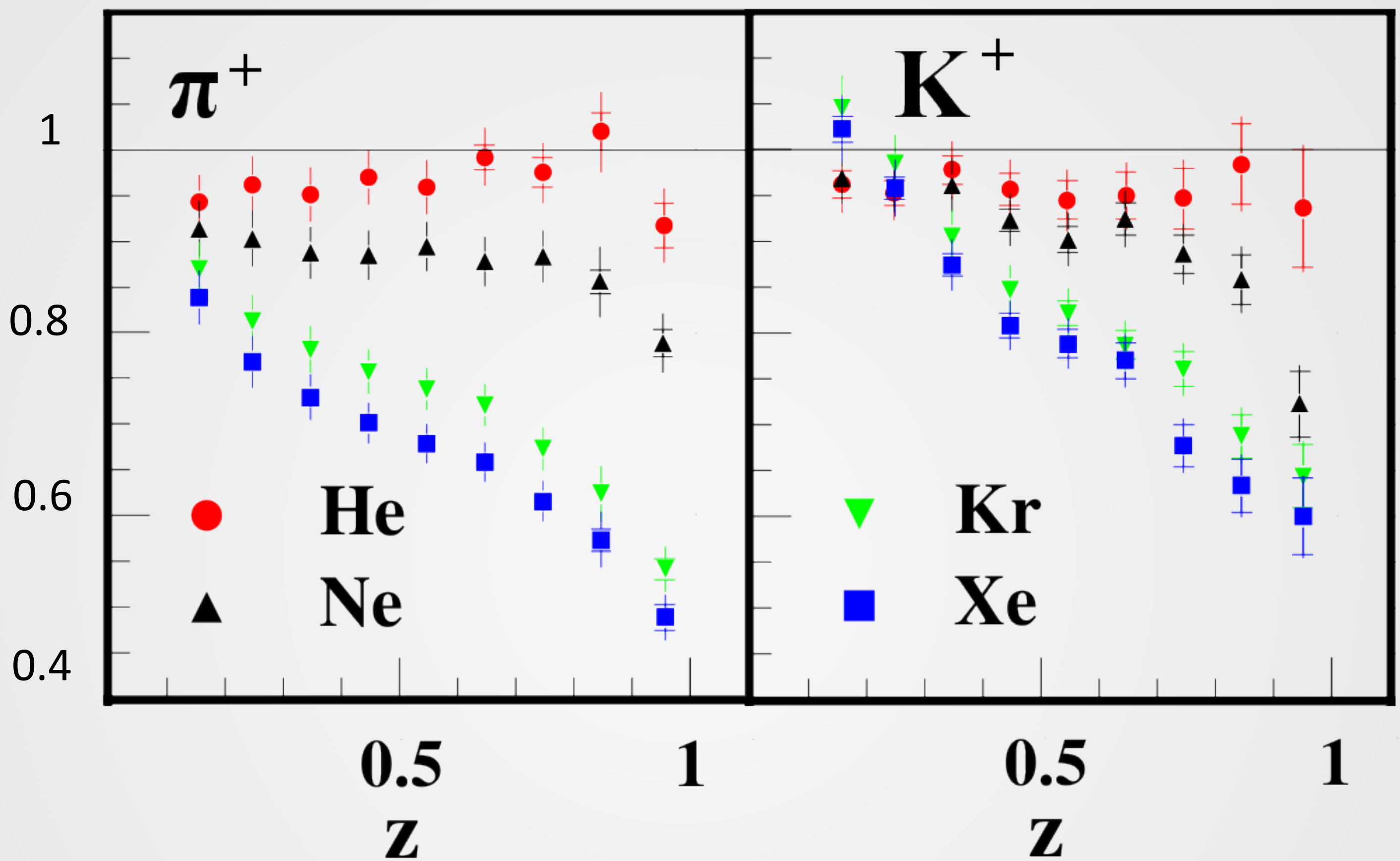
- Partonic: energy loss and modified fragmentation functions
- Hadronic: Hadron formation length and absorption

FLAVOR DEPENDENCE OF MULTIPLICITY RATIOS (1)



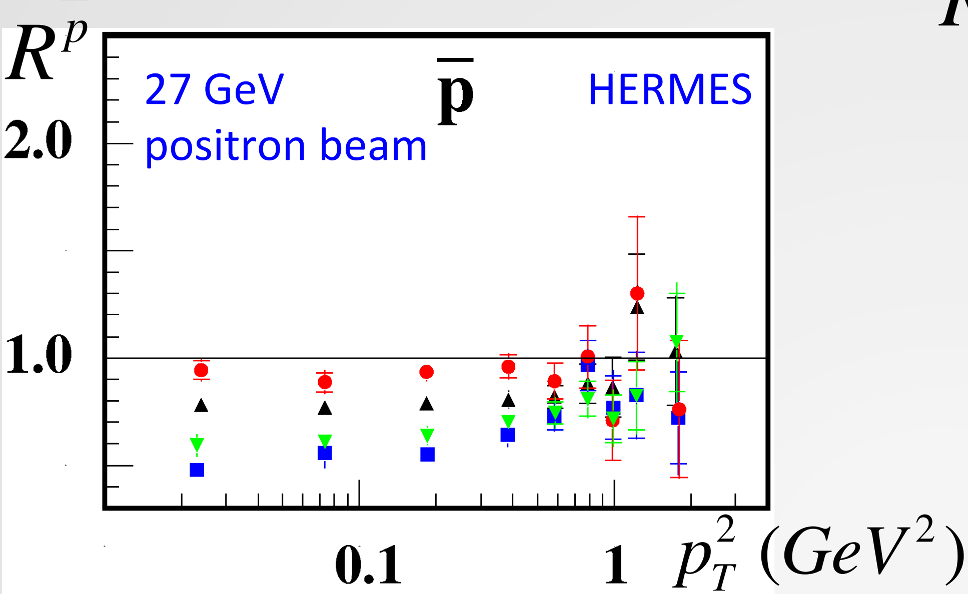
HERMES: All three pions and K- undergo similar attenuation

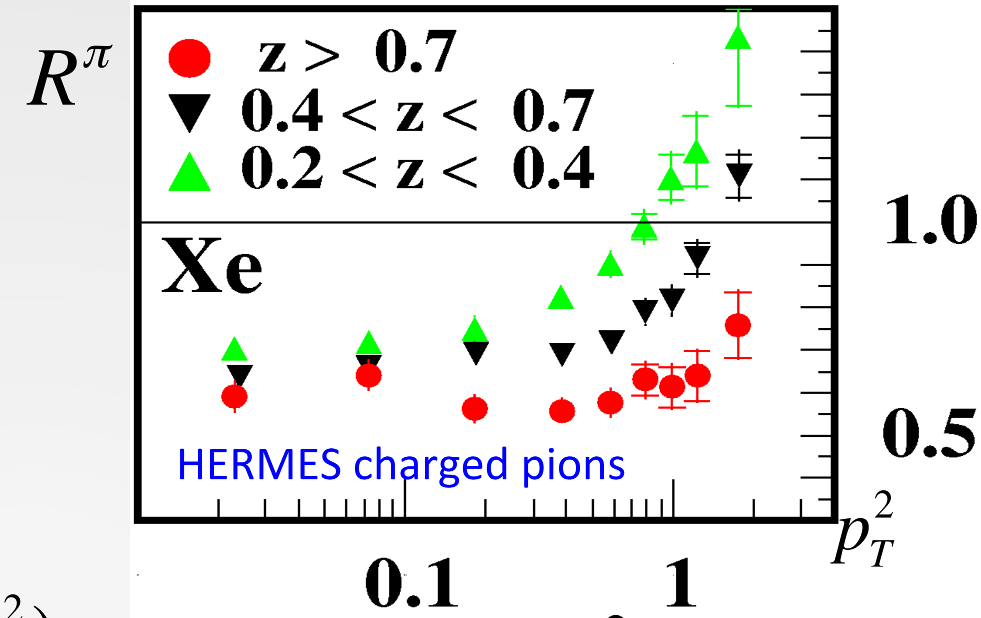
FLAVOR DEPENDENCE OF MULTIPLICITY RATIOS (2)

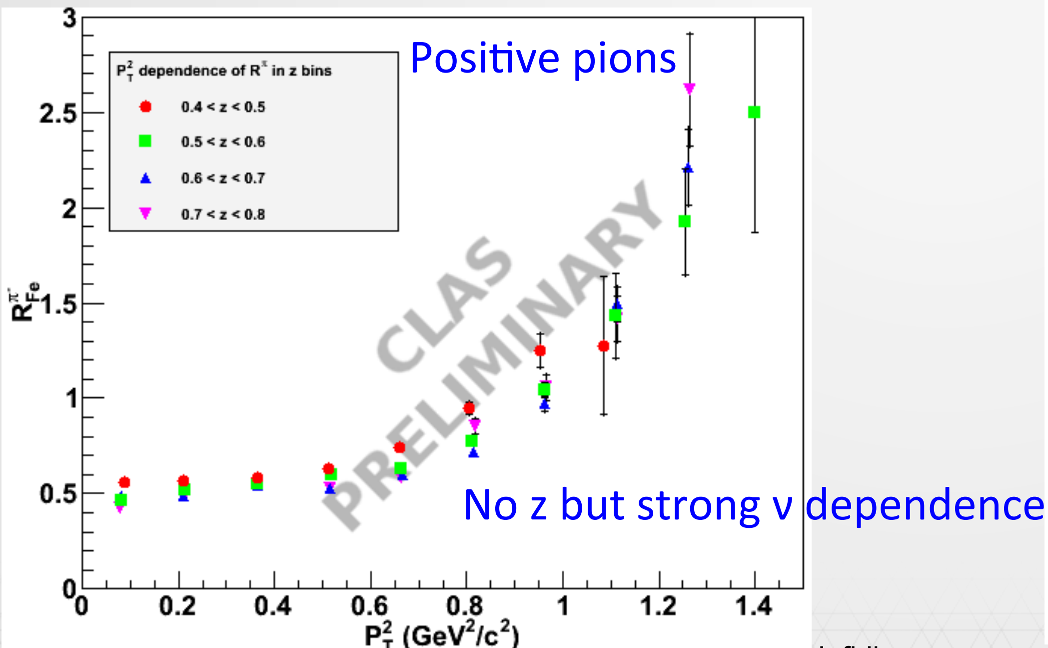


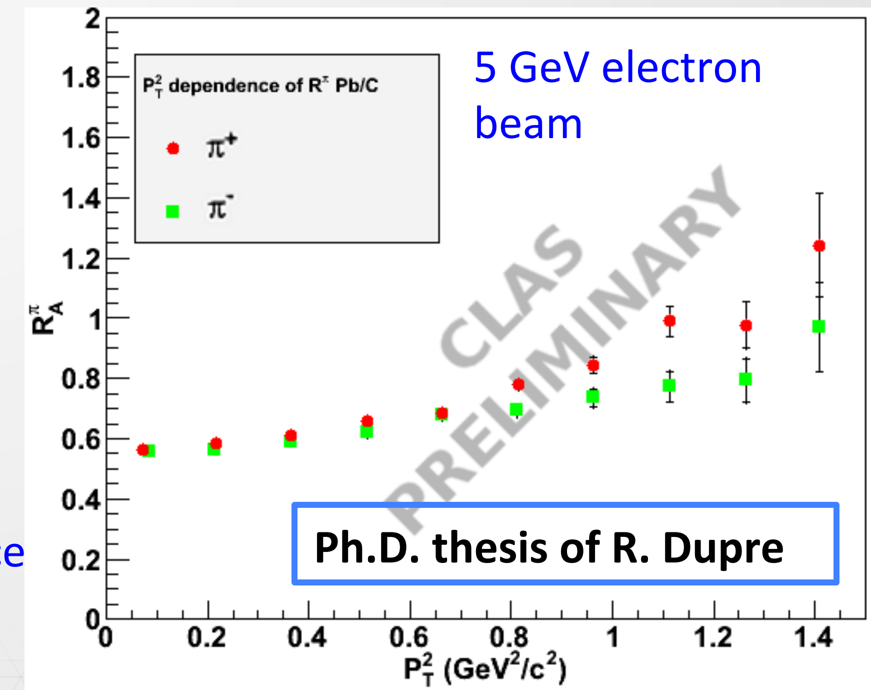
HERMES: K^+ is less attenuated most likely due to contamination from π + p -> Λ + K (B. Kopeliovich et al.)

CRONIN EFFECT

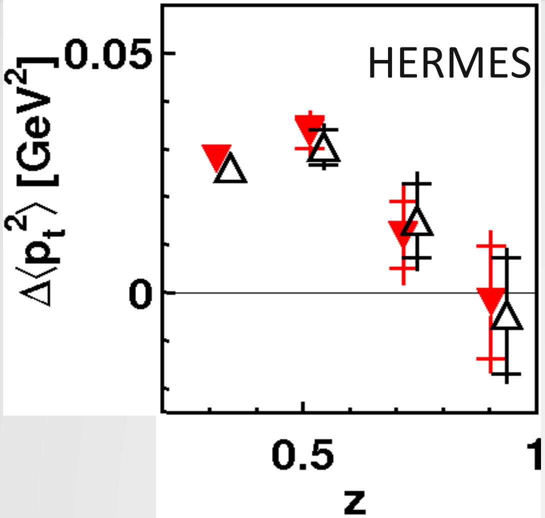




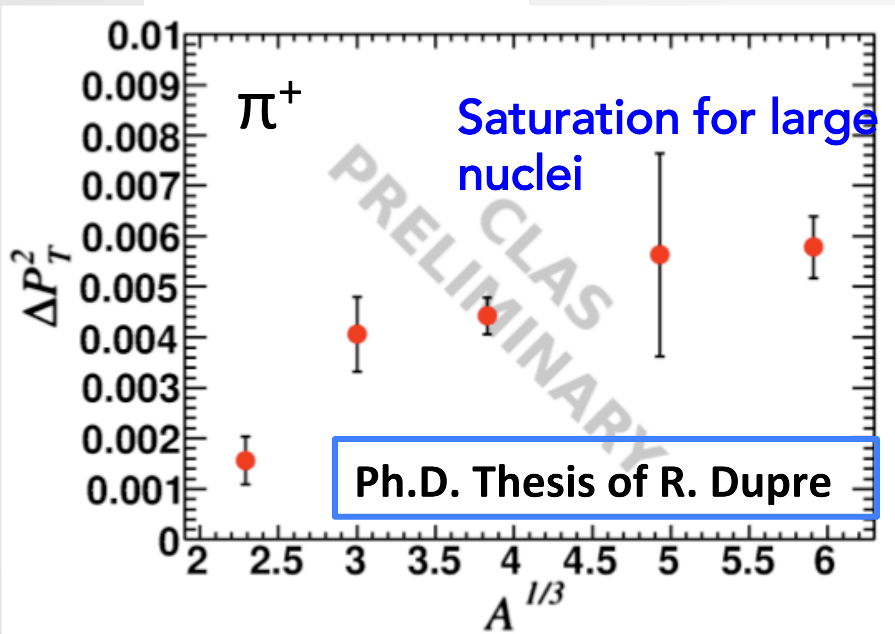


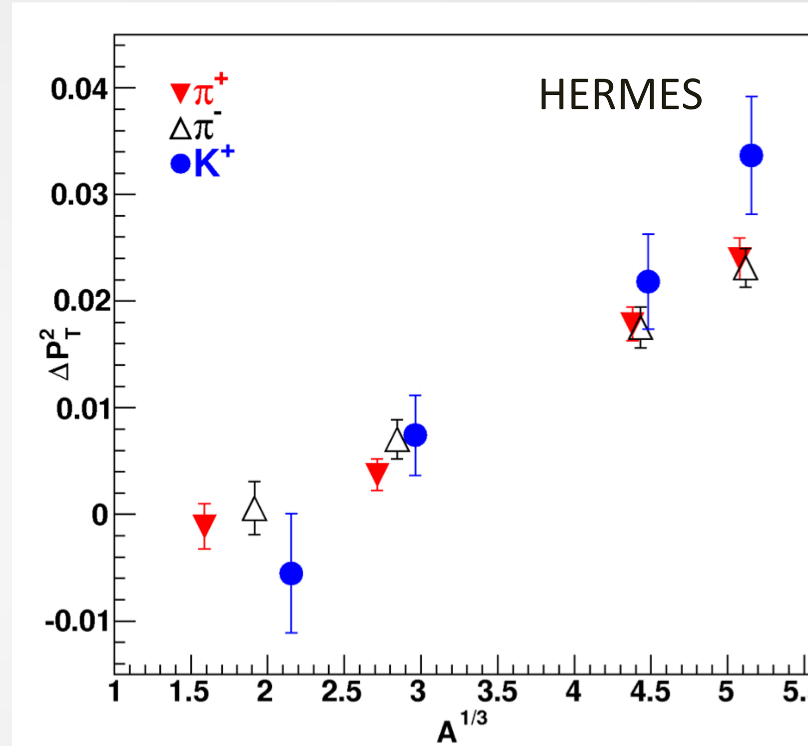


TRANSVERSE MOMENTUM BROADENING



- No broadening at high z
→ Effect at the partonic level





- Dependence in A not conclusive
→ Compatible with $A^{1/3}$ and $A^{2/3}$
- Flavor dependence?

FUTURE SIDIS HADRONIZATION MEASUREMENTS @ JLAB

Examples of Experimental Data and Theoretical Predictions

CLAS12 experiment E12-06-117

- ✓ Improved particle identification
- ✓ Access to higher masses
- ✓ Much larger kinematical range

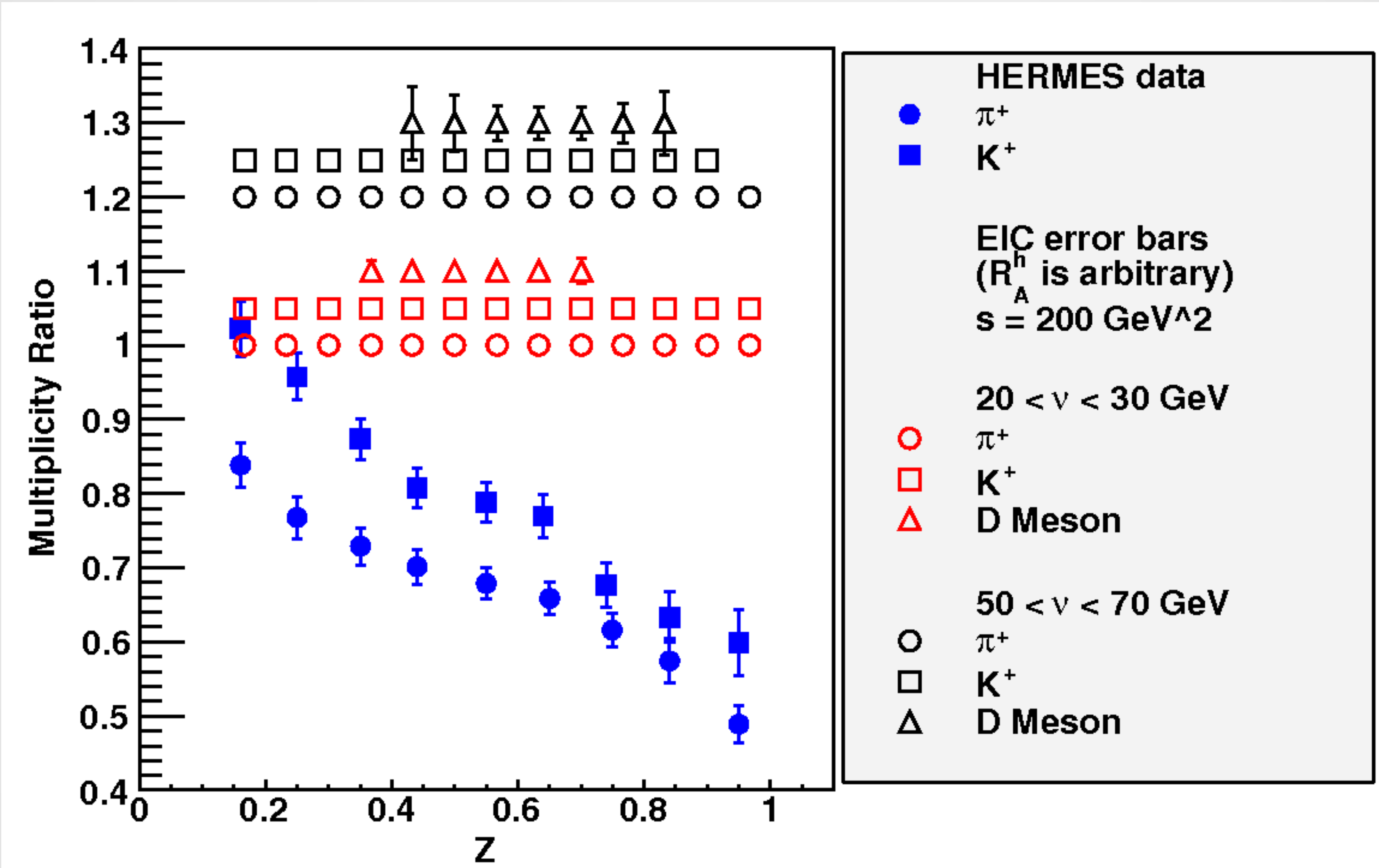
- ✓ CLAS12 has 10 times more luminosity than CLAS and 1000 times more than HERMES

FUTURE HADRONIZATION MEASUREMENTS AT THE EIC – SIMULATIONS BY RAPHAEL DUPRE

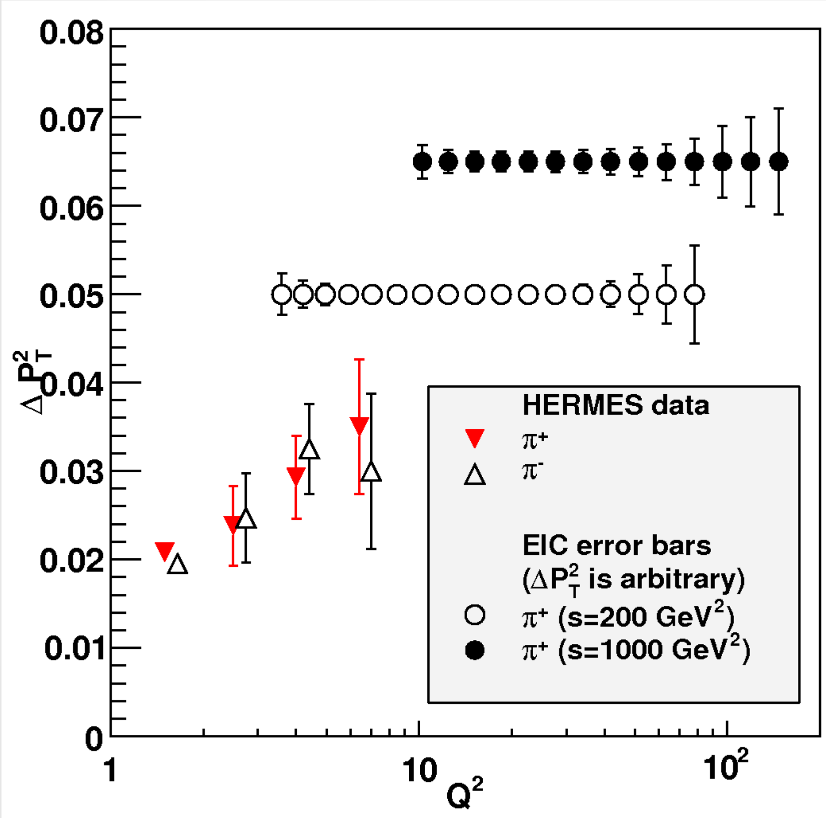
Simulation parameters:

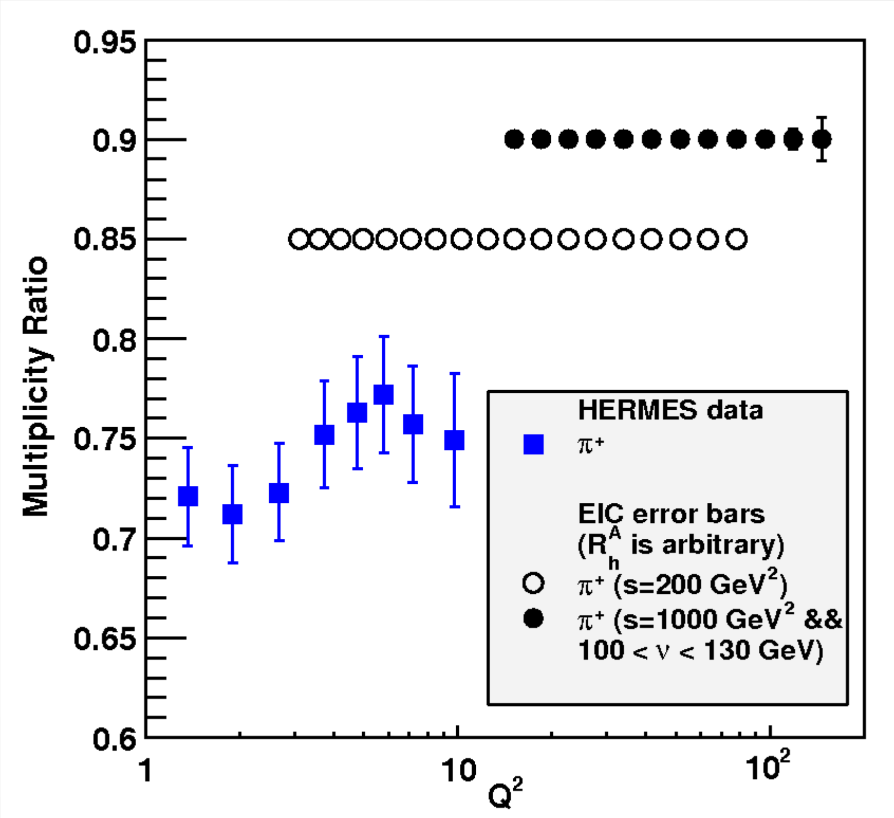
- Usual DIS cuts: $Q^2 > 1$ GeV^2 and $W > 4$ GeV
- $x_b > 0.1$ to suppress di-quark production
- $z_h > 0.4$ to select the leading hadron
- $0.1 < y < 0.85$
- Assume kaon, pion and eta acceptance ~ 50% and 2% for D and B mesons
- Measure at $s = 200$ GeV^2 and 1000 GeV^2
- Integrated luminosity of 200 fb^{-1} per target

HEAVY FLAVOR MULTIPLICITY RATIO



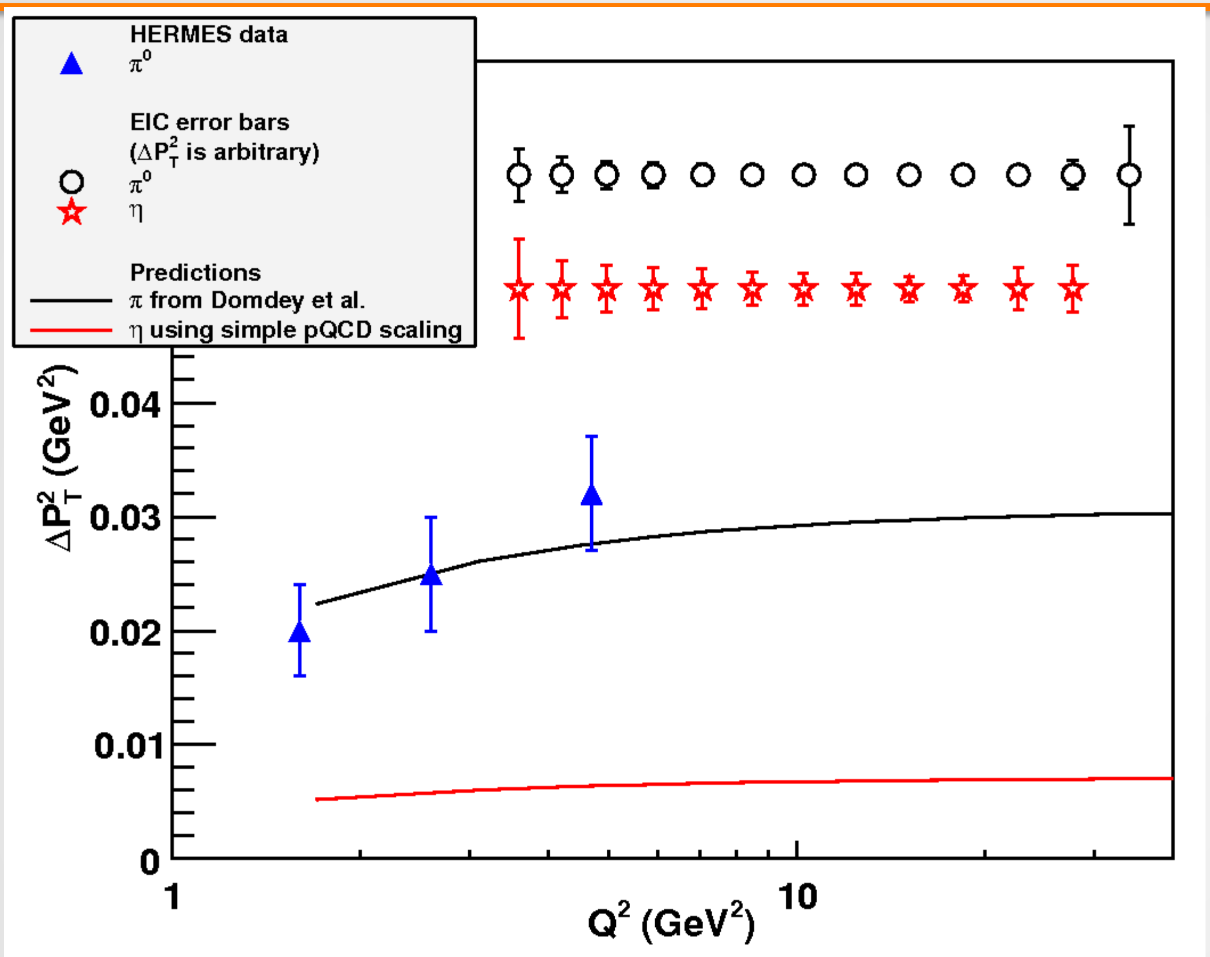
Q^2 EVOLUTION





- ❑ **Q^2 dependence allows to measure any modification of the DGLAP evolution in medium**
- ❑ **It is a very important tool to constrain energy loss calculations**

FLAVOR SCALING OF P_T BROADENING



20 GeV < ν < 30 GeV

Pions – Domdey et al. 2009

Eta – Accardi et al. 2009

The Q^2 dependence of p_T broadening can be used to check the simple pQCD scaling of in-medium energy loss as a function of quark flavors

SUMMARY AND OUTLOOK

- Hadronization Provides complementary way of studying confinement
- It allows testing and calibrating theoretical tools used to determine the properties of strongly coupled Quark-Gluon Plasma
- It allows probing nuclear media, either cold or hot
- Good progress has been made by both HERMES and CLAS collaborations
- CLAS12 will provide the multi-dimensional data needed to constrain the existing models
- EIC will allow the study of hadronization dynamics of heavy quarks in cold nuclear matter and obtain for the first time its dependence on the mass of the quarks (π, K, and D mesons)