Distinguishing partonic FSI from hadronic FSI using transverse momentum broadening

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Will Brooks
Universidad Técnica Federico Santa María

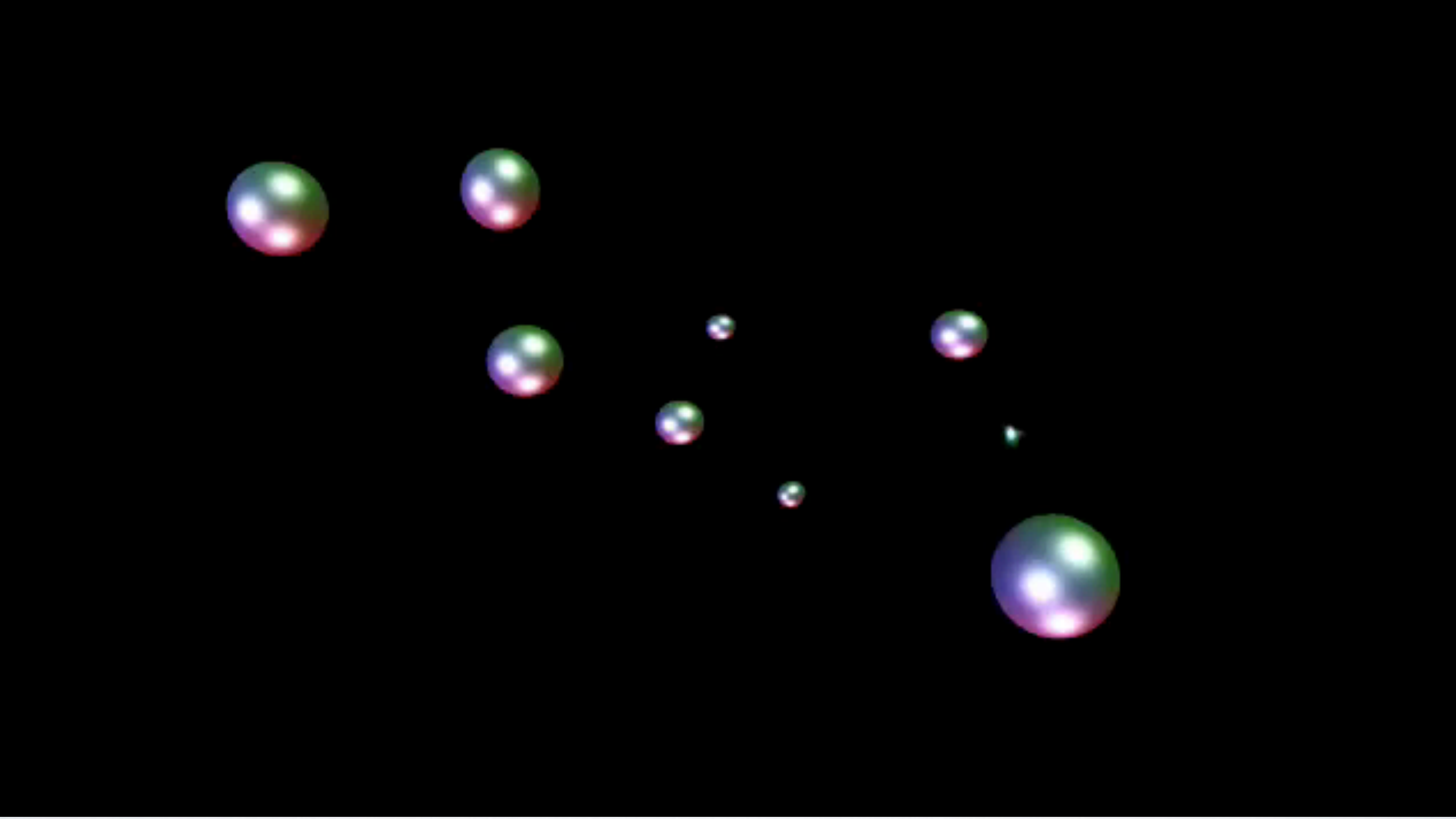
SYNOPSIS

We explore color propagation, neutralization, and fluctuations by using deep inelastic scattering on *nuclei*

The struck quark interacts with the partons in the nucleus, becoming a secondary *probe*

The modifications of the properties of the final-state hadrons reveal the details of how the *struck quark interacted*, and how the final-state hadrons were formed

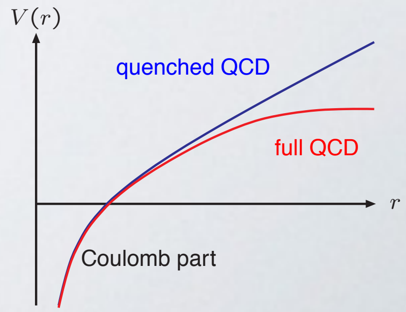
https://indico.bnl.gov/event/EICAC



Creating QCD color from pure energy - dynamic confinement

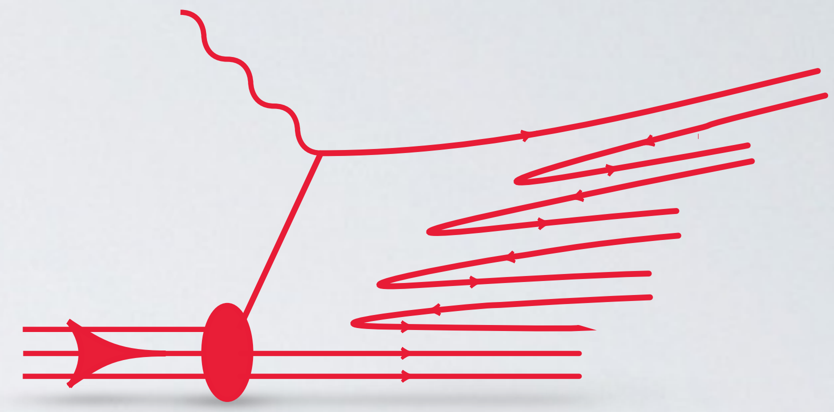
Partonic energy loss in-medium - jet quenching

Fundamental QCD processes

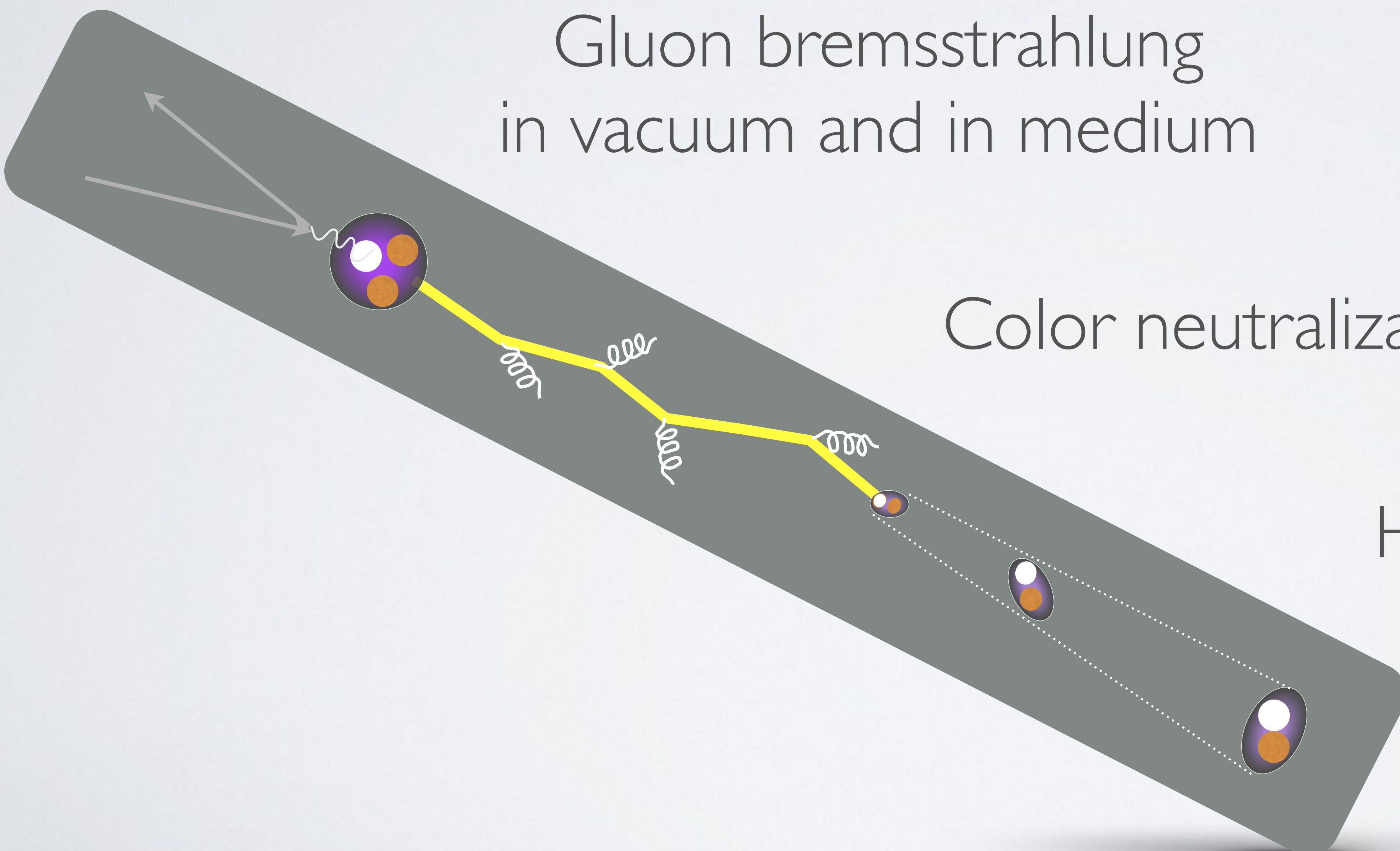


FUNDAMENTAL QCD PROCESSES

Partonic elastic scattering
in medium



Gluon bremsstrahlung
in vacuum and in medium

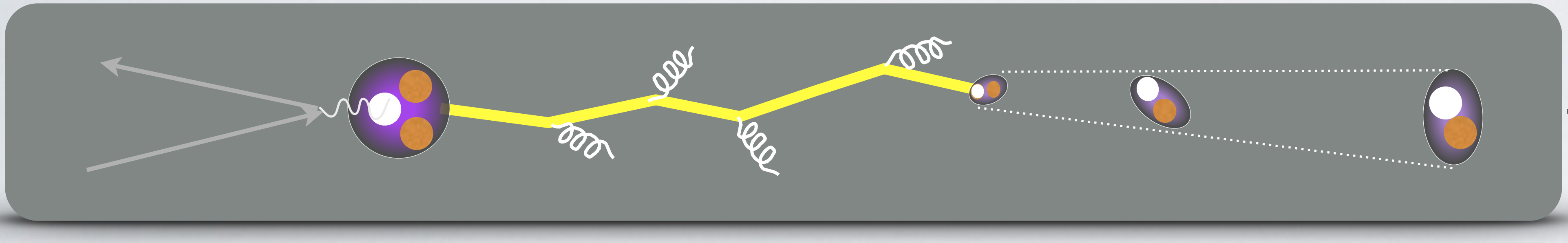


Color neutralization

Hadron formation

Virtual light quark lifetime from the Lund String model:

$$l_p = z \frac{(ln(\frac{1}{z^2}) - 1 + z^2)}{1 - z^2}$$



→ 0 for z=0 and z=1

Hadron formation time?

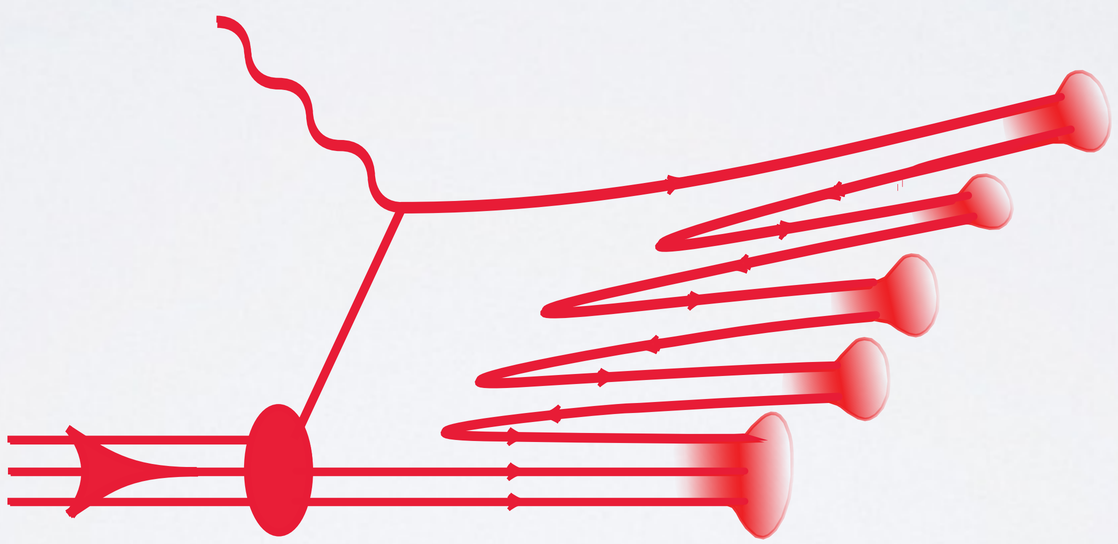
Back of envelope: $\approx \nu R^2_{hadron}$

E.g., 10 fm for ν = 3 GeV

…but this assumes a very simple mechanism….

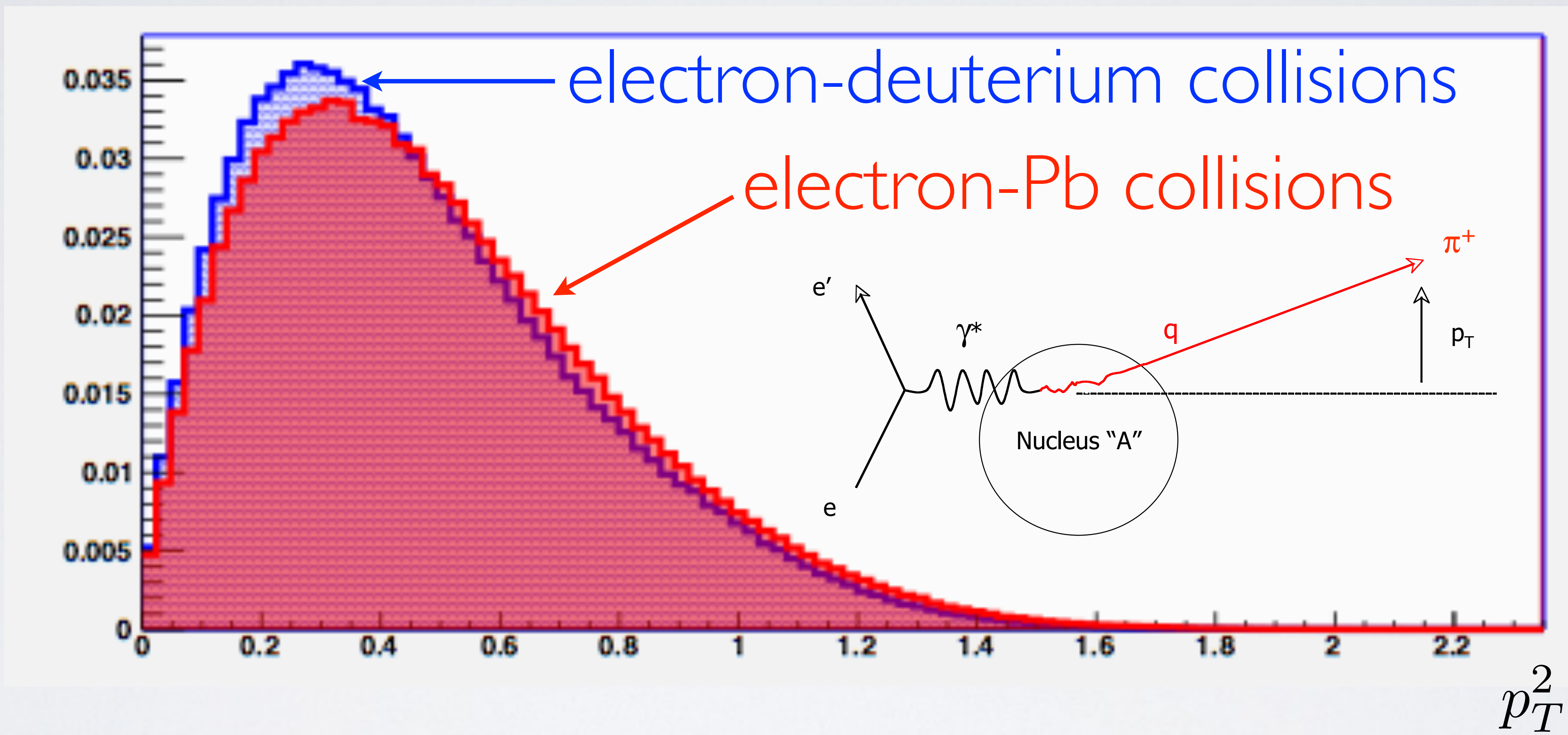
$$z_\pi \equiv \frac{E_\pi}{\nu}$$

Hadronization mechanisms:
how do the hadrons form?



Observable: p_T broadening

$$\Delta p_T^2 \equiv \langle p_T^2 \rangle_A - \langle p_T^2 \rangle_D$$



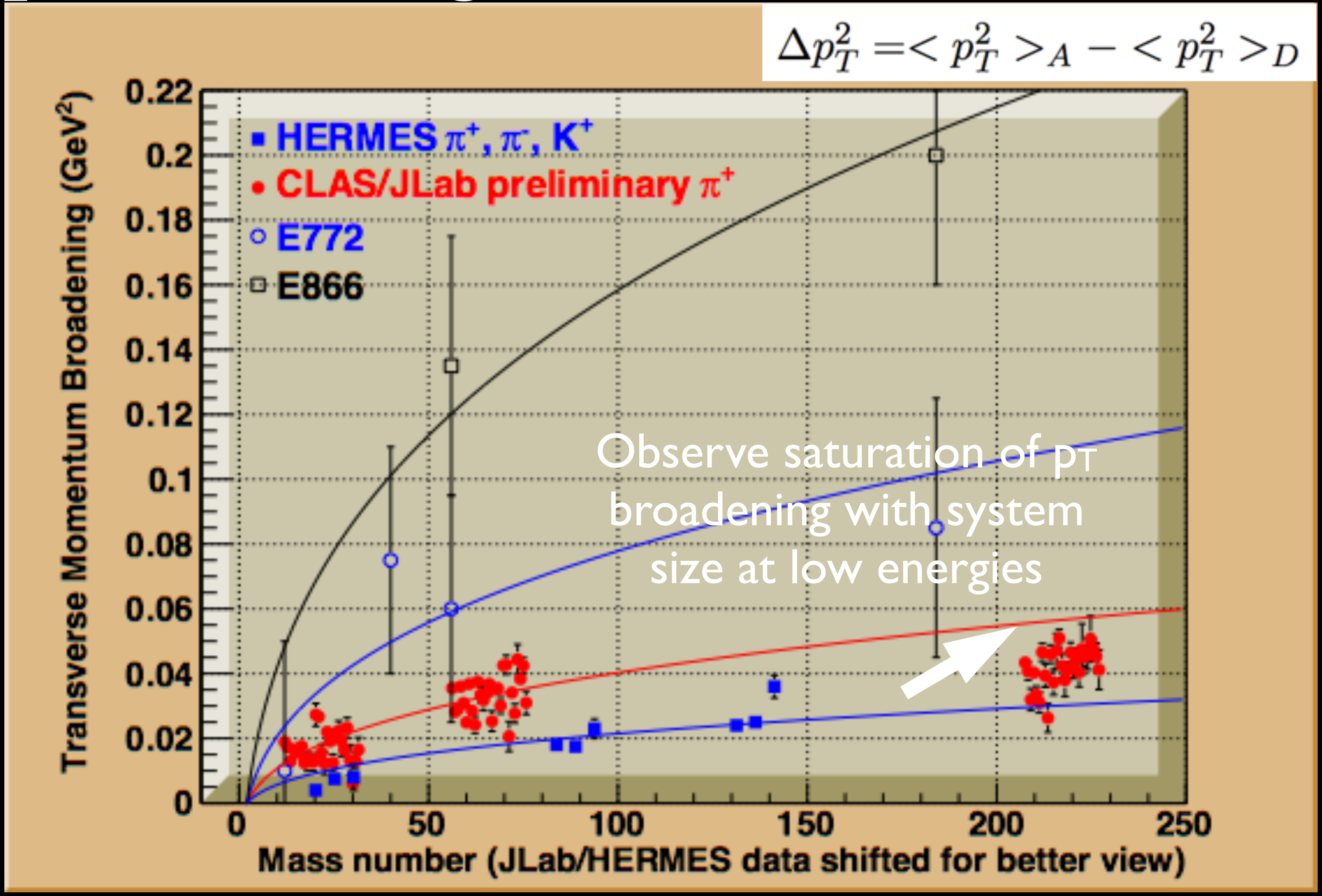
p_T broadening is a tool: sample the gluon field using a colored probe:

$$\Delta p_T^2 \propto G(x, Q^2)\rho L$$

and radiative energy loss:

$$-\frac{dE}{dx} = \frac{\alpha_s N_c}{4}\Delta p_T^2$$

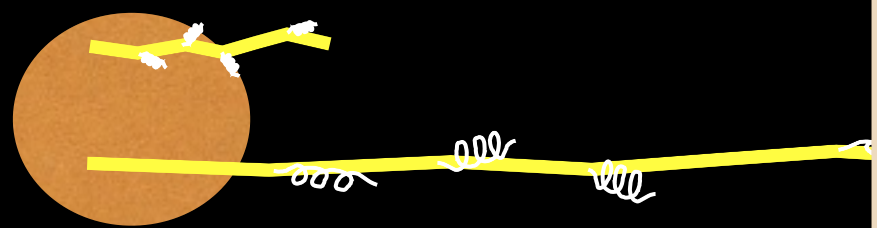
p_T broadening data - Drell-Yan and DIS

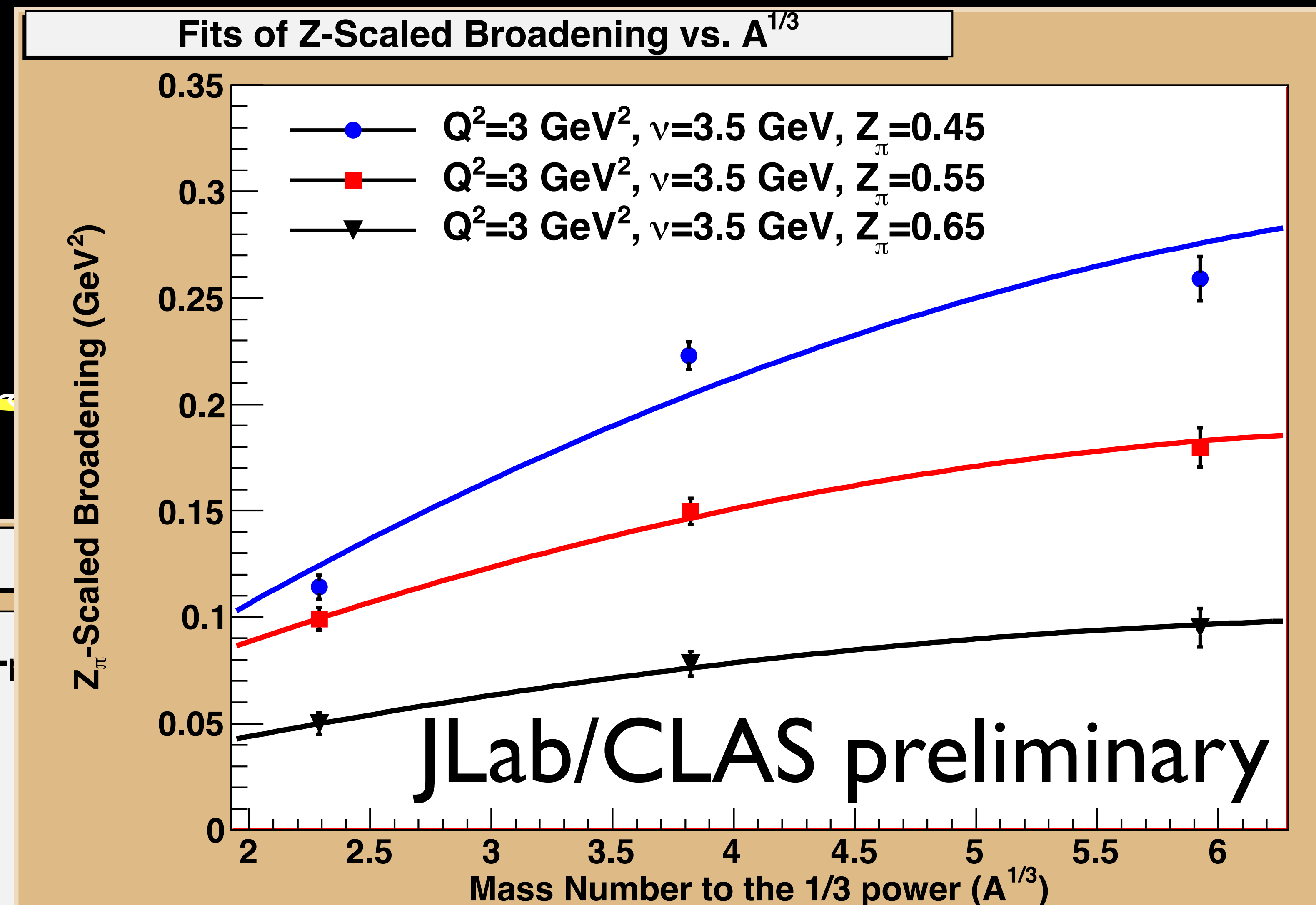


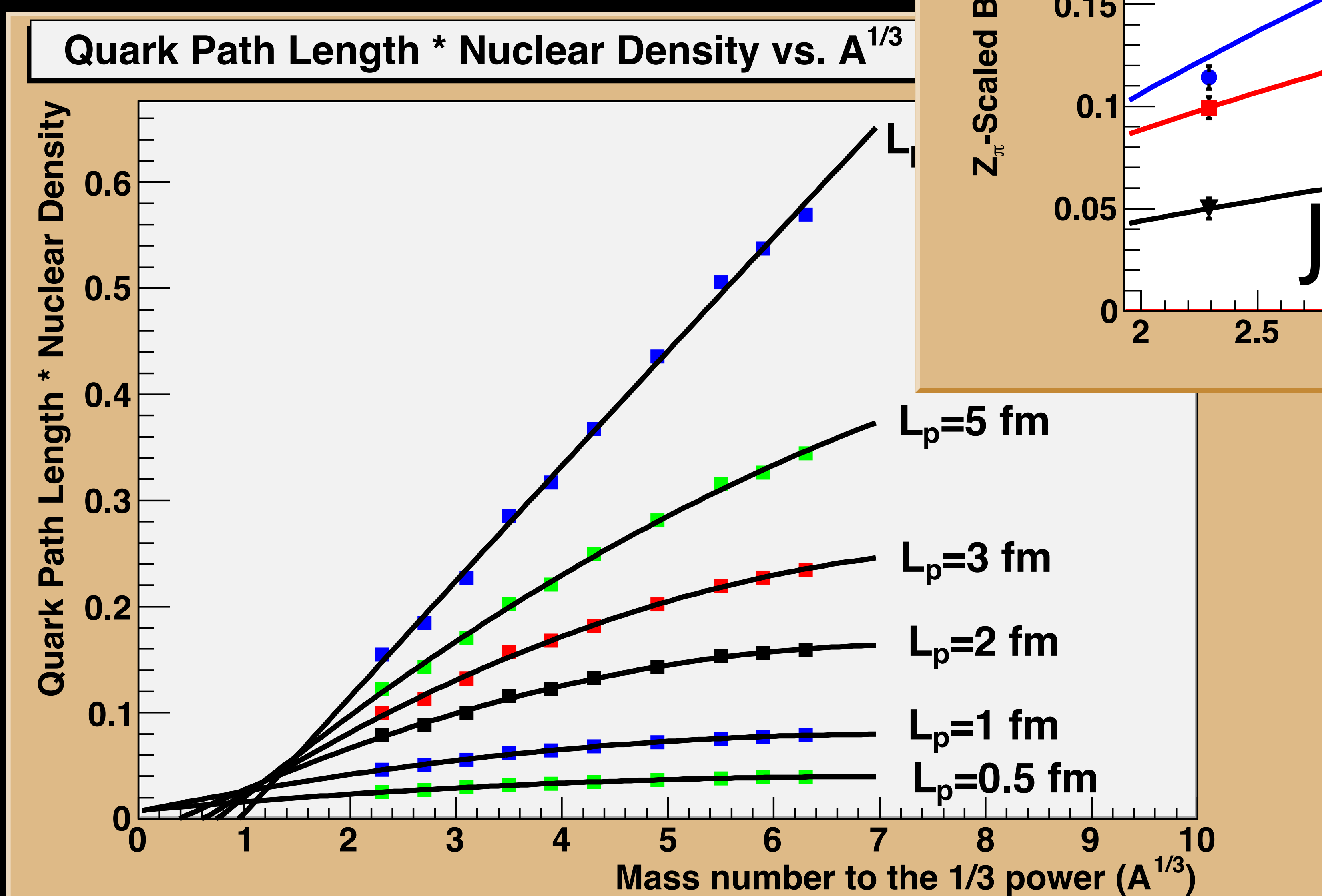
- New, precision data with identified hadrons!
- CLAS π^+: 81 four-dimensional bins in Q^2, ν, z_h, and A
- Intriguing *saturation*: production length or something else?

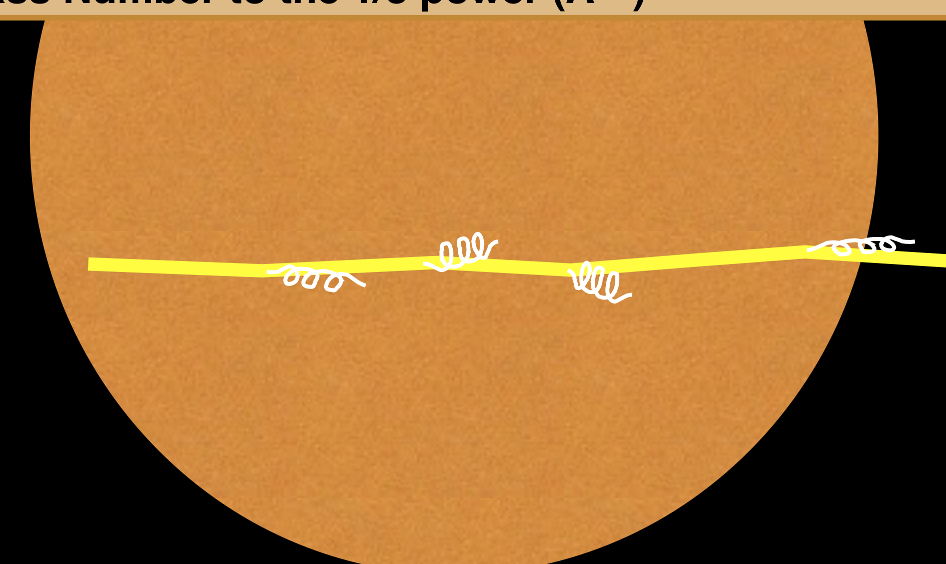
Production Time Extraction: Geometrical Interpretation

1) Assume saturation is due to shorter production length ℓ : then can *measure* ℓ

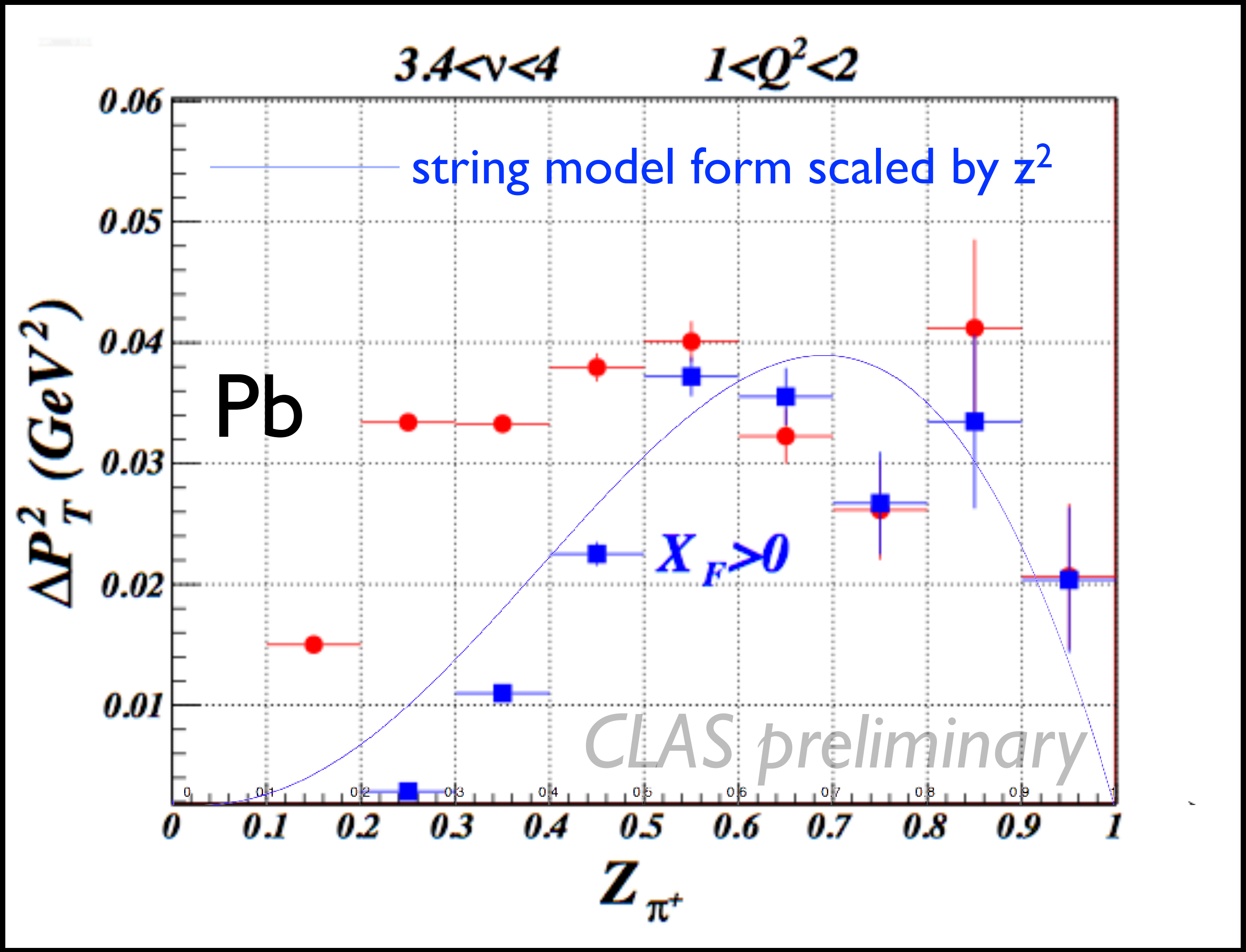


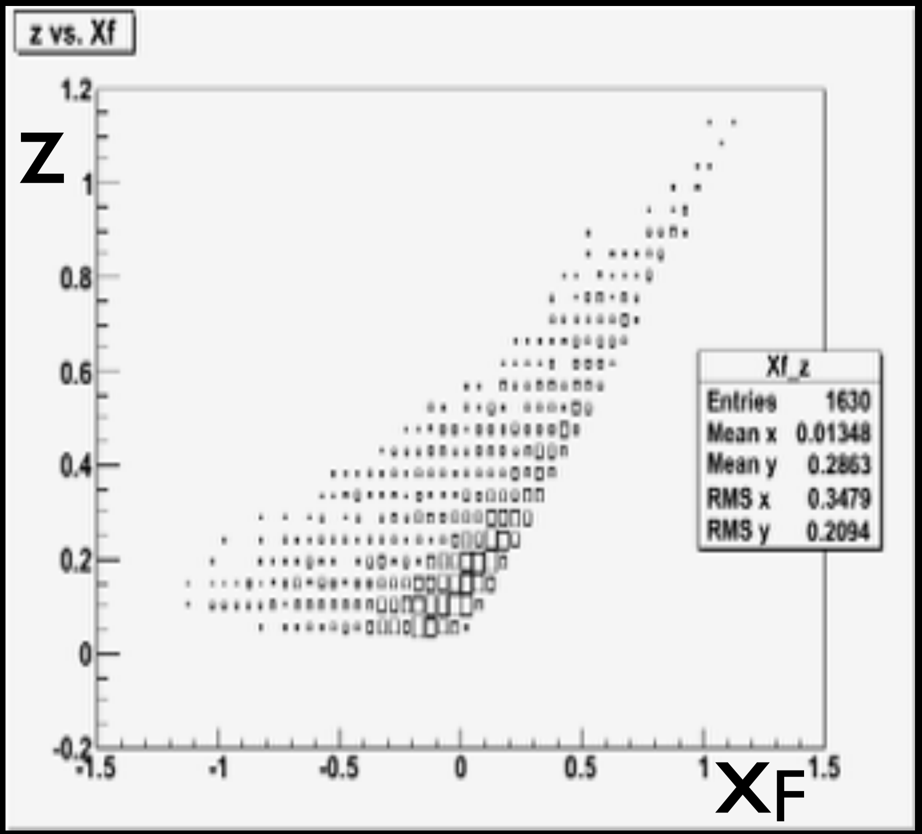






Dependence of p_T broadening on Feynman x

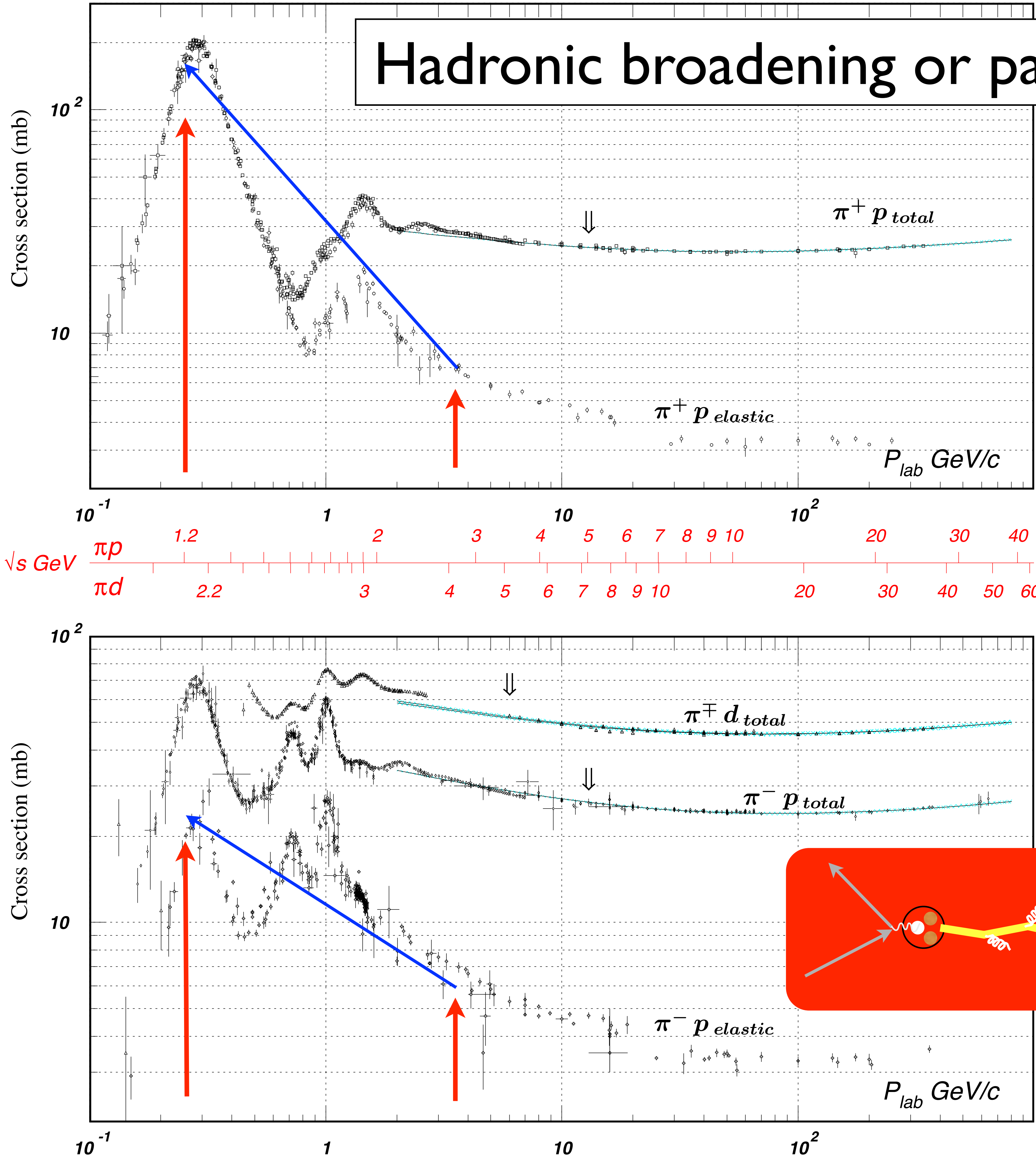


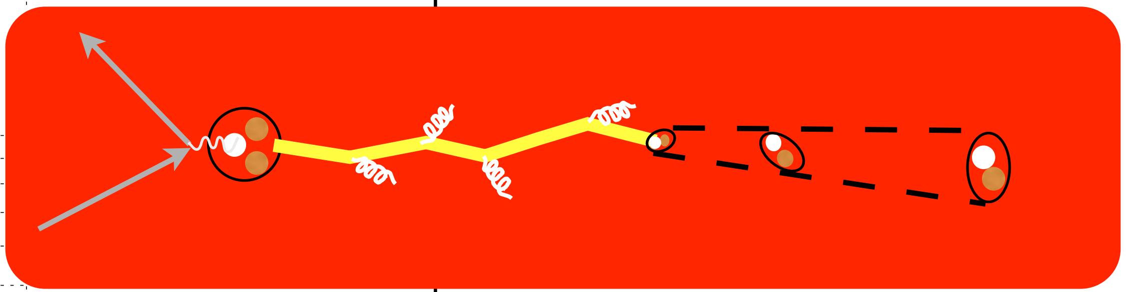


- x_F and z_h are partially correlated

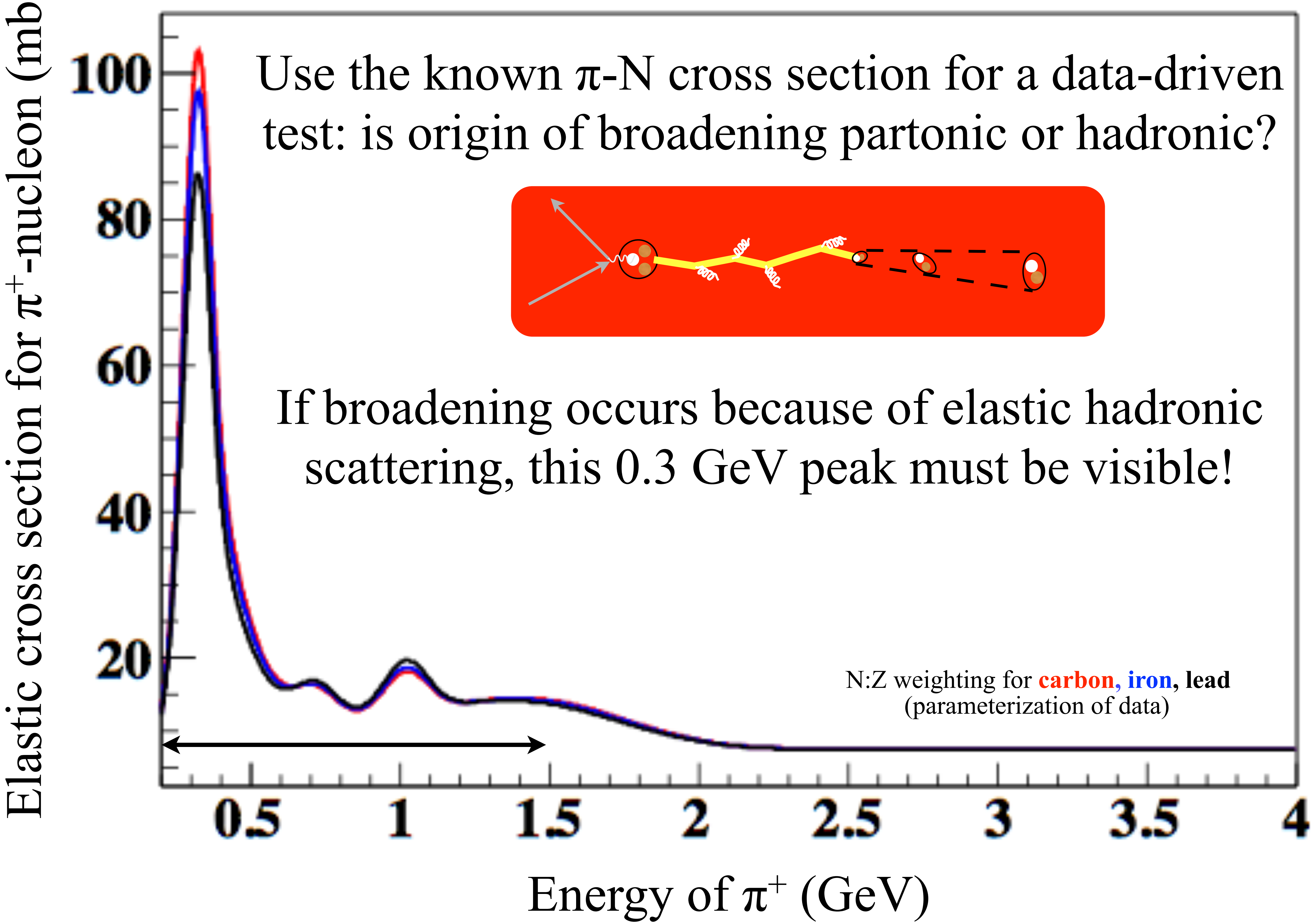
- Feynman x is the fraction ${}^{\pi}p_L/\max\{{}^{\pi}p_L\}$ in the γ^*-N CM system
- Emphasizes current ($x_F>0$) vs. target ($x_F<0$) fragmentation
- First observation that *p_T broadening originates in both regimes*

Hadronic broadening or partonic broadening?

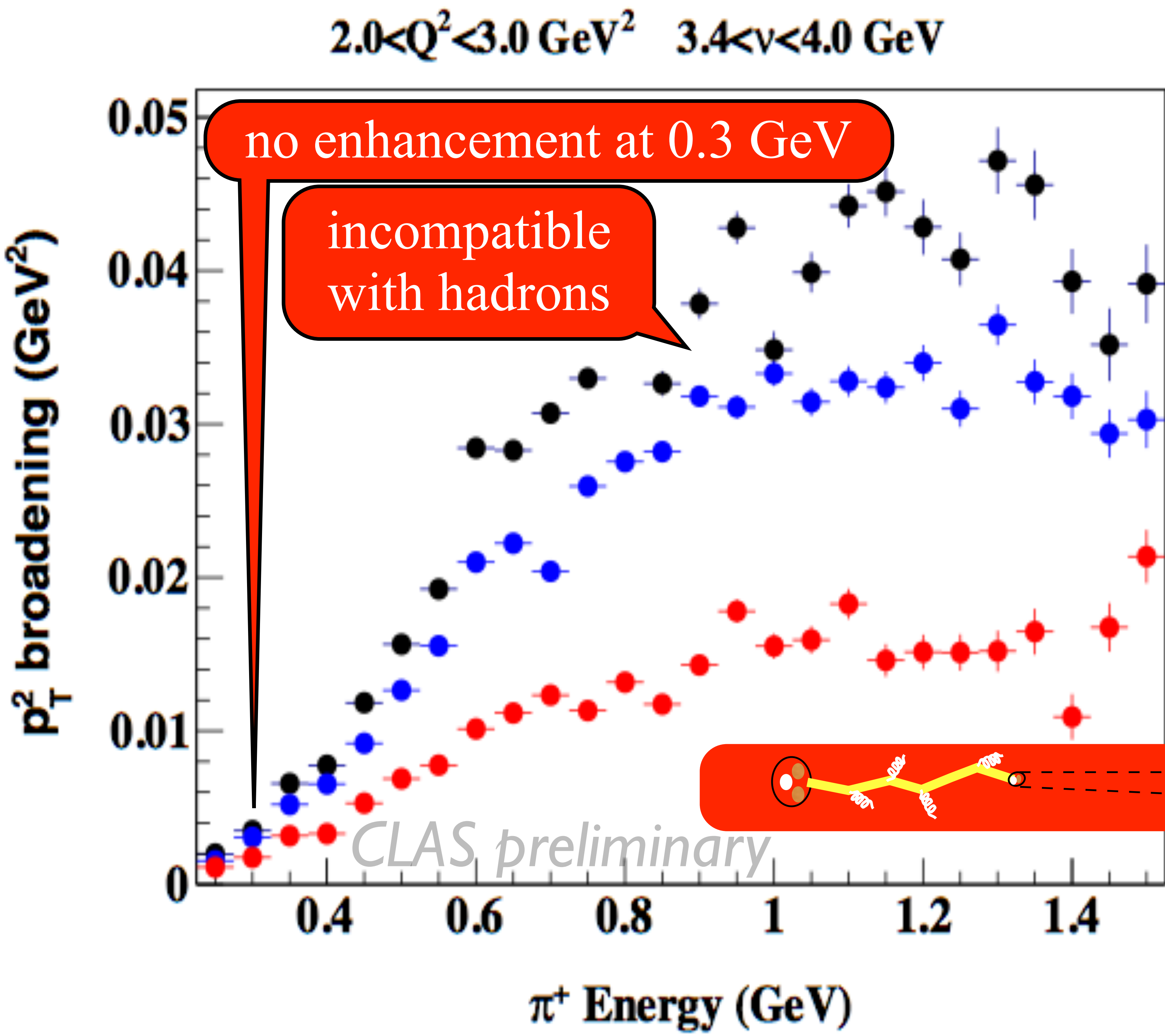


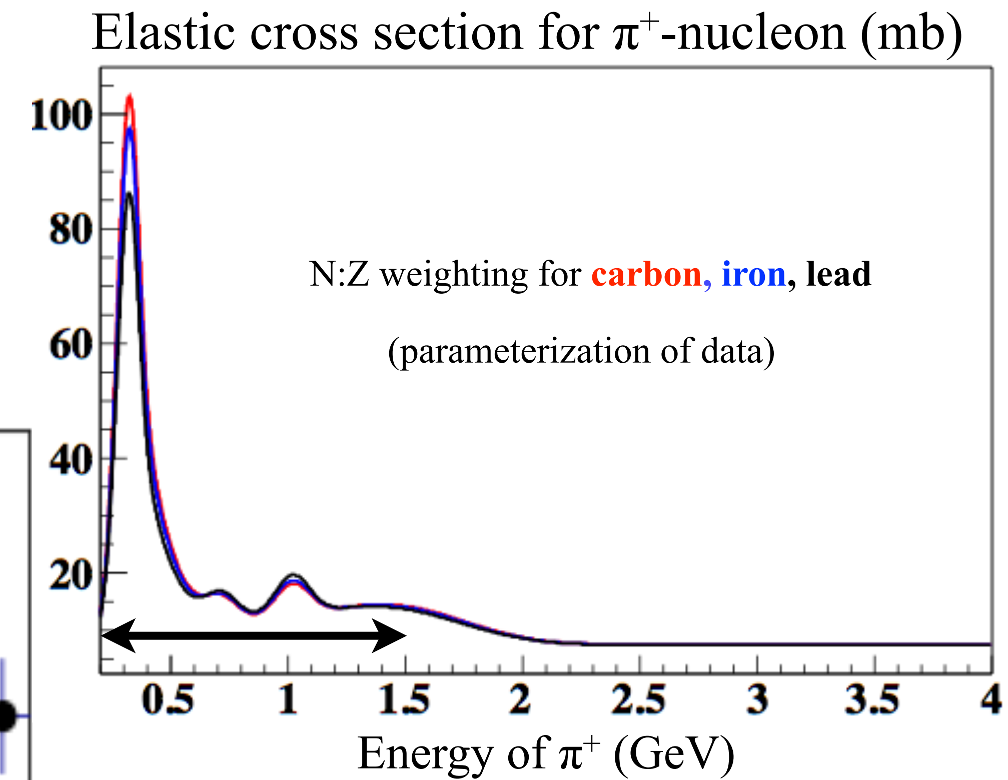


Elastic cross section for π^+-nucleon



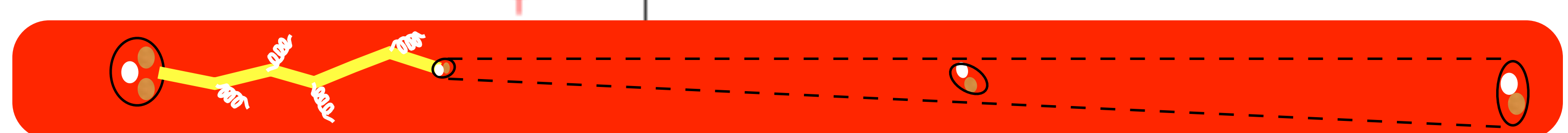
p_T^2 Broadening vs. Hadron Energy





No visible evidence of hadronic elastic scattering? Suggests:

1) formation length is very long



2) broadening is purely partonic

CONCLUSIONS

- Transverse momentum broadening, in conjunction with the known hadronic cross sections, can distinguish partonic FSI from hadronic FSI

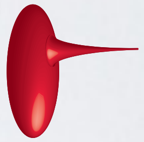
- In JLab kinematics, no evidence for hadronic FSI - formation length is long, broadening is partonic

- Need a real theory calculation! can constrain hadronic formation length for pion

Additional slides

ADDITIONAL IMPORTANT STUDIES

- Jets (see backup slides from Alberto Accardi)
- Di-hadron attenuation (hadronization mechanisms)
- Photon-hadron correlations
- Bose-Einstein correlations
- Correlated low-energy particles
- Target fragmentation, and target-current correlations



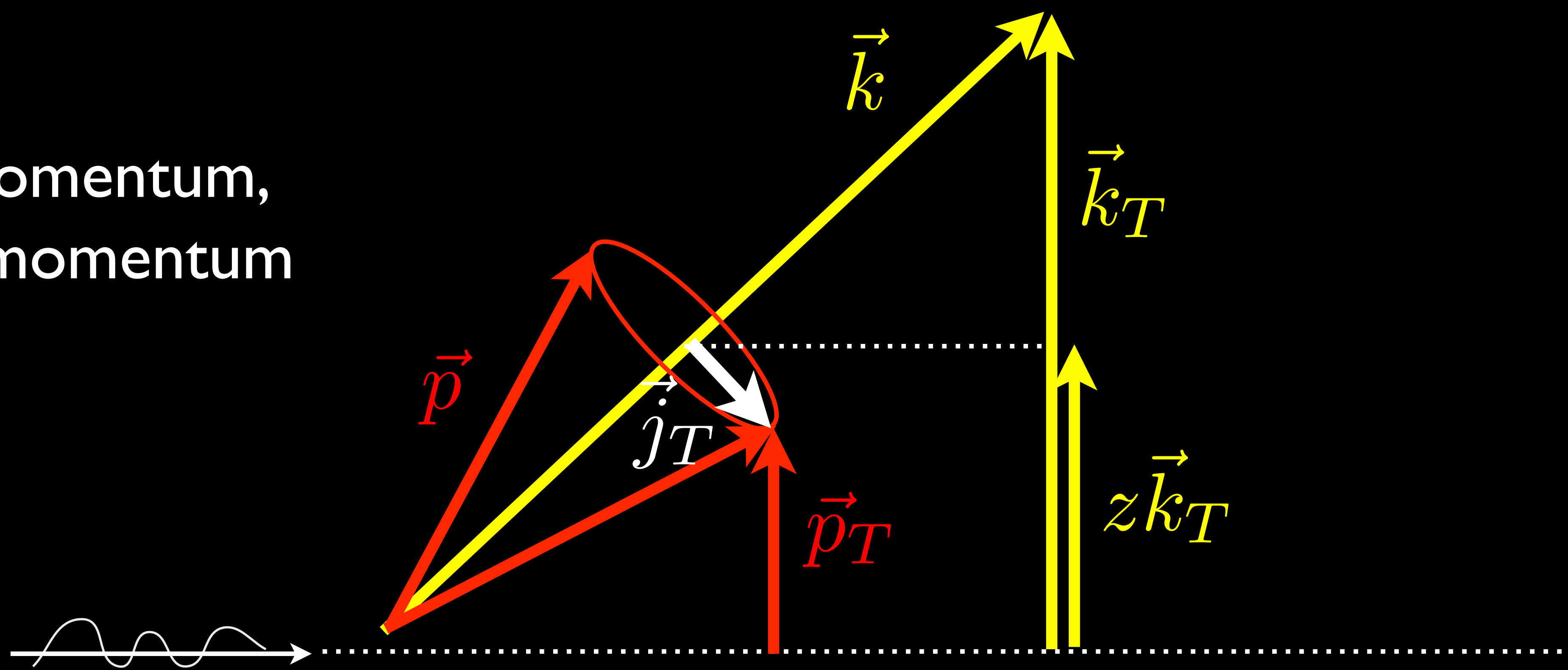
Proton minus one quark

- Single and double spin asymmetries in meson production from nuclei
- Color transparency
- Baryon multiplicity

Quark k_T broadening vs. *hadron* p_T broadening

The k_T broadening experienced by a quark is "*diluted*" in the fragmention process

k is the ***quark*** momentum,
p is the ***hadron*** momentum



$$\vec{p}_T = z\vec{k}_T + \vec{j}_T$$

$$\langle p_T^2 \rangle = \langle z^2 k_T^2 \rangle + \langle j_T^2 \rangle$$

$$\Delta\langle p_T^2 \rangle = \Delta\langle z^2 k_T^2 \rangle + \Delta\langle j_T^2 \rangle$$

~0

$$\Delta\langle p_T^2 \rangle \approx z^2 \Delta\langle k_T^2 \rangle$$

Verified for pions to 5-10% accuracy for vacuum case, z=0.4-0.7, by Monte Carlo studies

Basic questions at low energies:

Partonic processes dominate, or hadronic? in which kinematic regime? classical or quantum?

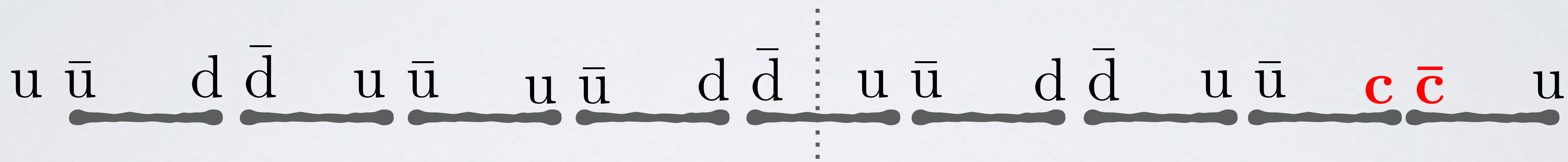
Can identify dominant hadronization mechanisms, uniquely? what are the roles of flavor and mass?

What can we infer about fundamental QCD processes by observing the interaction with the nucleus?

If p_T broadening uniquely signals the partonic stage, can use this as one tool to answer these questions

HADRONIZATION MECHANISMS

- Can we learn more about hadronization mechanisms using nuclear targets?
- Lund string model: expect ~correlation between rapidity and string position



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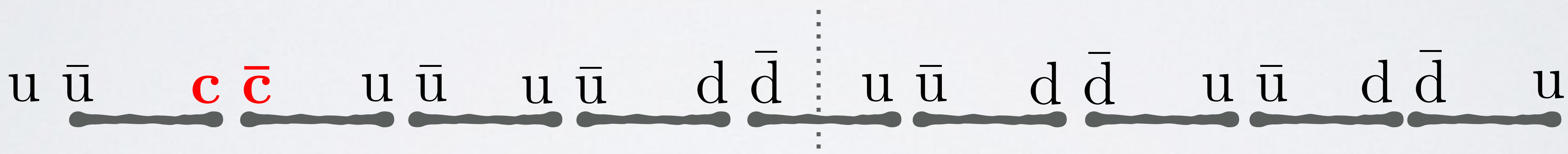
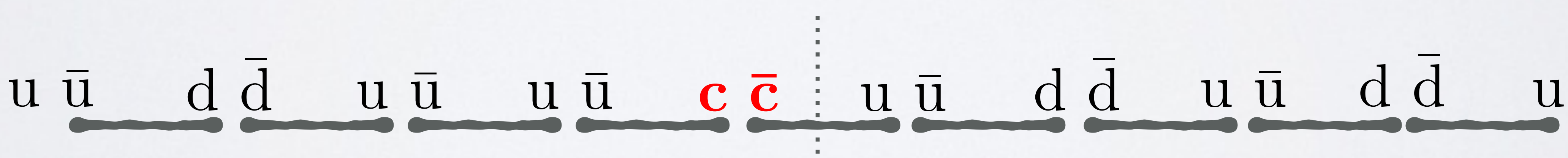


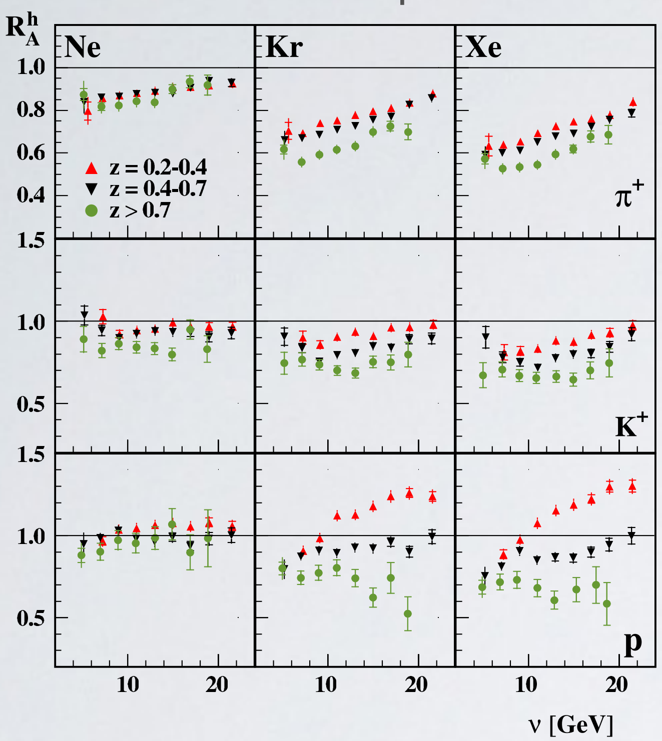
versus

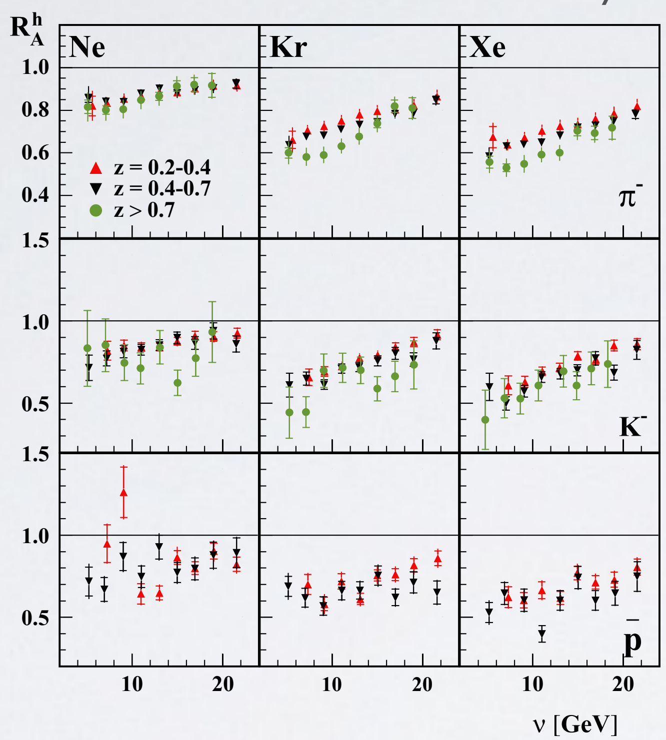


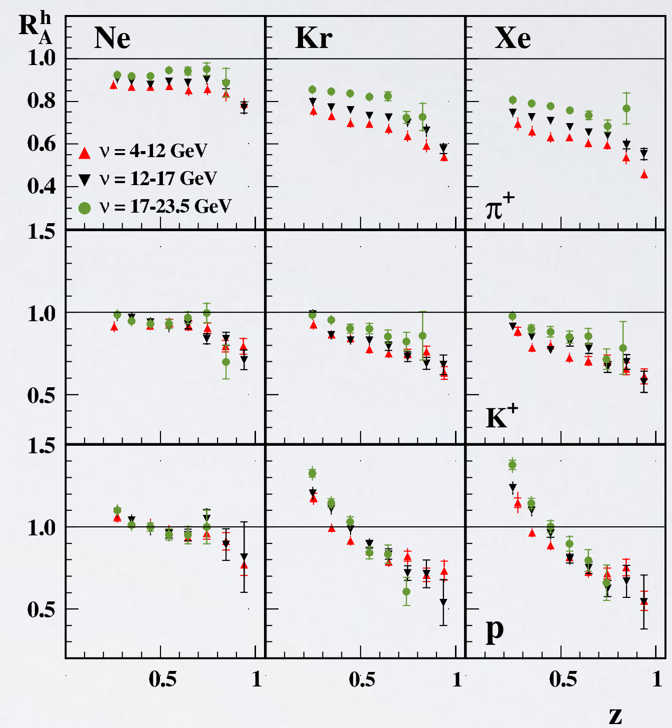
Hadrons near mid-string sample more medium path length. Look for greater attenuation and broadening in mid-rapidity?

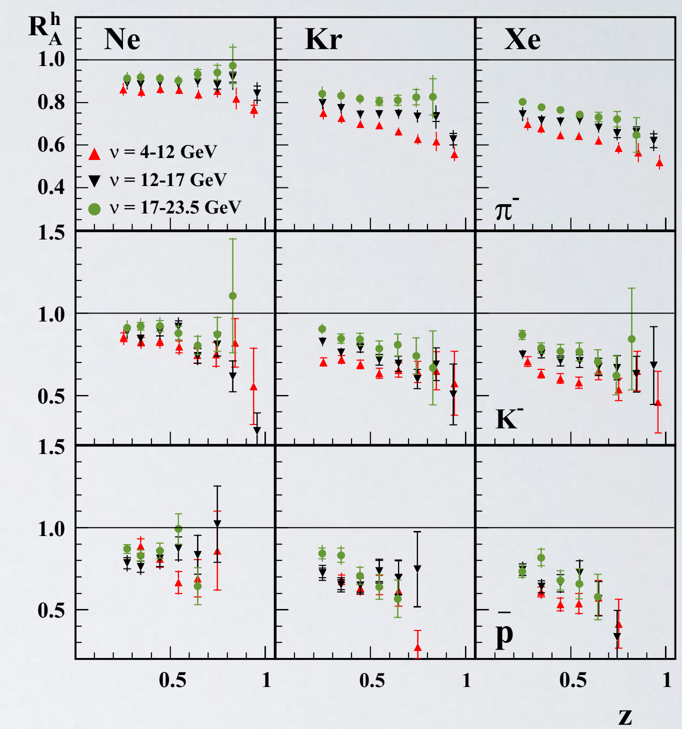
HADRONIZATION MECHANISMS FROM INTERCOMPARING DIFFERENT HADRONS

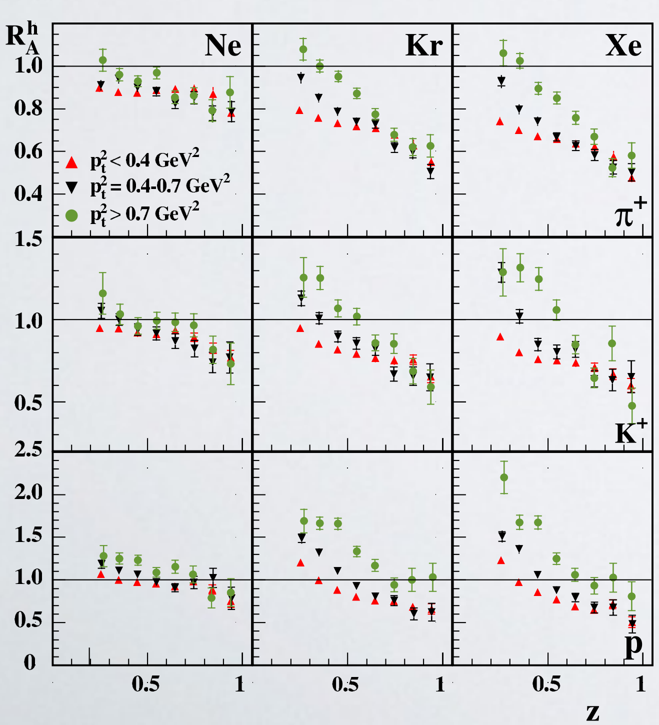
HERMES demonstrated that simple expectations about hadron flavor independence are naïve - Eur. Phys. J. A (2011) 47: 113.

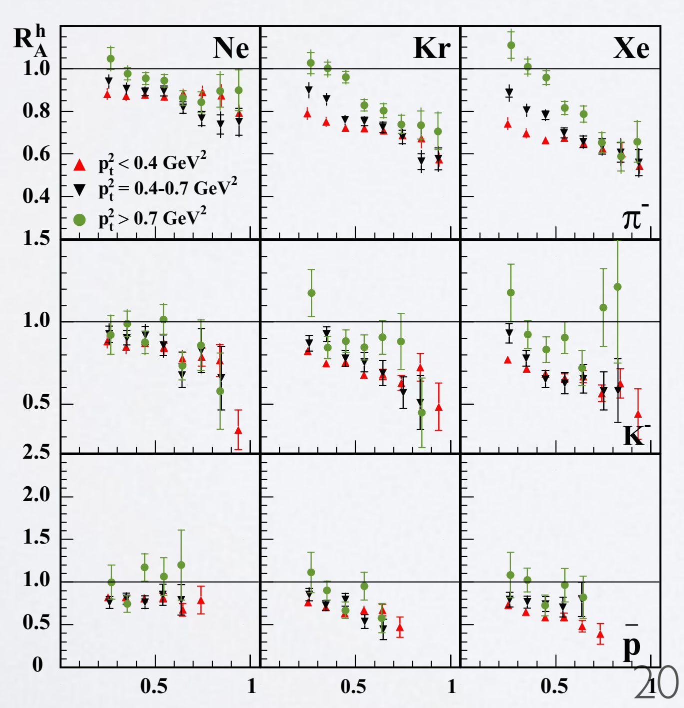


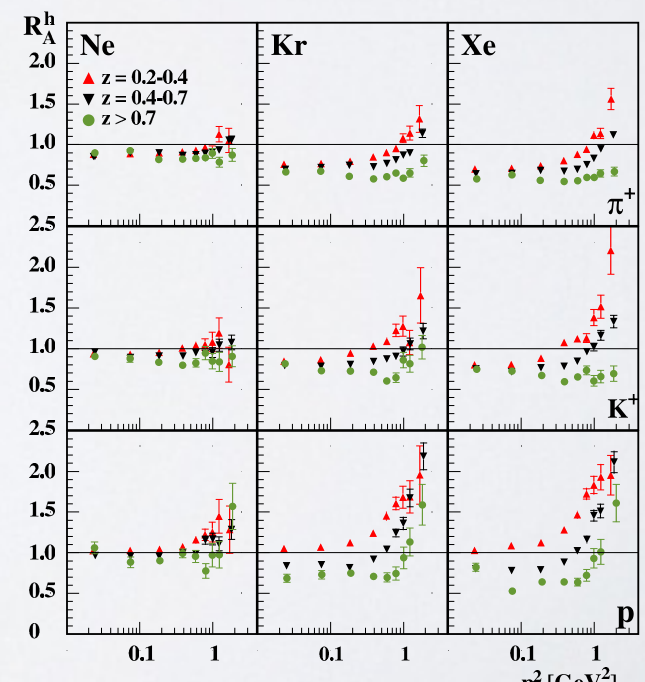












DIS channels: *stable* hadrons, accessible with 11 GeV JLab experiment PR12-06-117

Actively underway with existing 5 GeV data

meson	cτ	mass	flavor content
π	25 nm	0.13	ud
π	7.8 m	0.14	ud
η	170 pm	0.55	uds
ω	23 fm	0.78	uds
η’	0.98 pm	0.96	uds
φ	44 fm	1	uds
f1	8 fm	1.3	uds
K	27 mm	0.5	ds
K	3.7 m	0.49	us

baryon	cτ	mass	flavor content
p	stable	0.94	ud
$\bar{p}$	stable	0.94	ud
Λ	79 mm	1.1	uds
Λ(1520)	13 fm	1.5	uds
Σ	24 mm	1.2	us
Σ	44 mm	1.2	ds
Σ	22 pm	1.2	uds
Ξ	87 mm	1.3	us
Ξ	49 mm	1.3	ds