

PARTON PROPAGATION AND HADRON FORMATION: PRESENT STATUS, FUTURE PROSPECTS

Will Brooks
Santa Maria University
Valparaiso, Chile

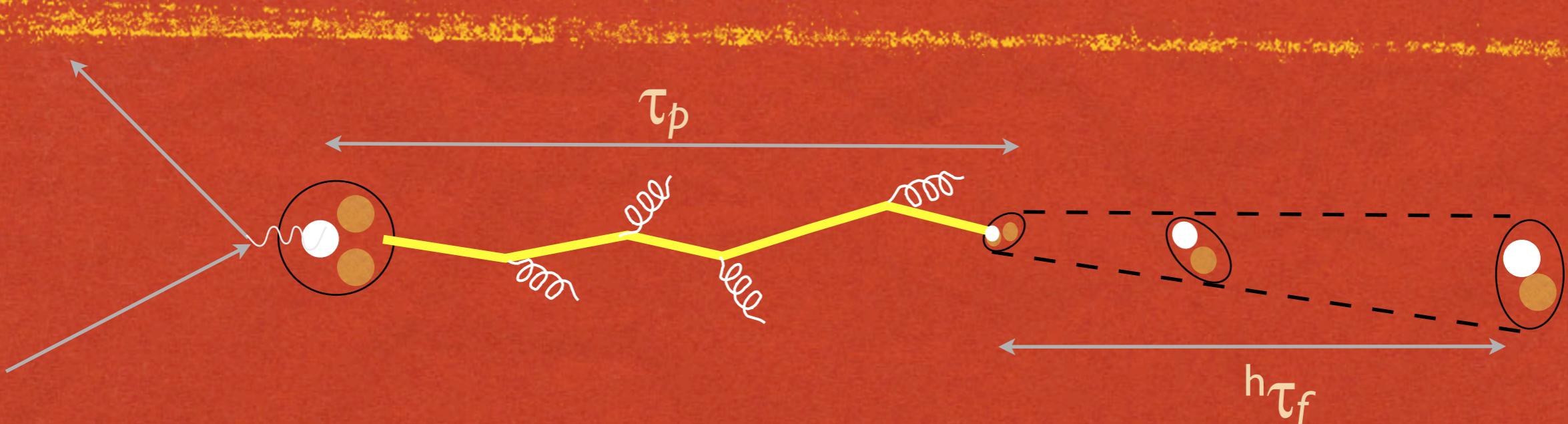
OUTLINE

- Physical picture
- Assumptions
- p_T broadening
- Hadron attenuation
- Future

Physical Picture



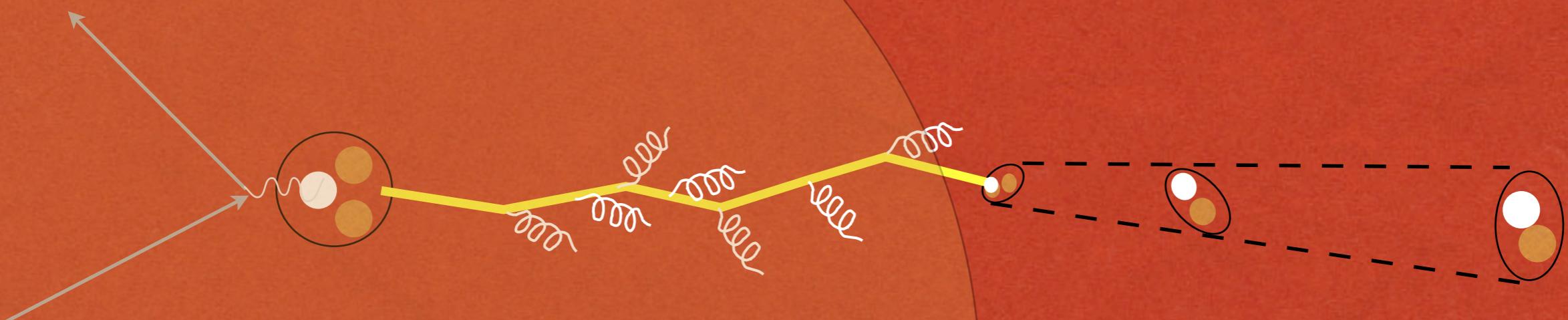
PHYSICAL PICTURE - VACUUM



- ***production time*** τ_p is time required to form color singlet pre-hadron; ‘lifetime of deconfined quark’; universal(?)
- ***formation time*** ${}^h\tau_f$ is time required to form full-sized hadron

MEDIUM - DIS

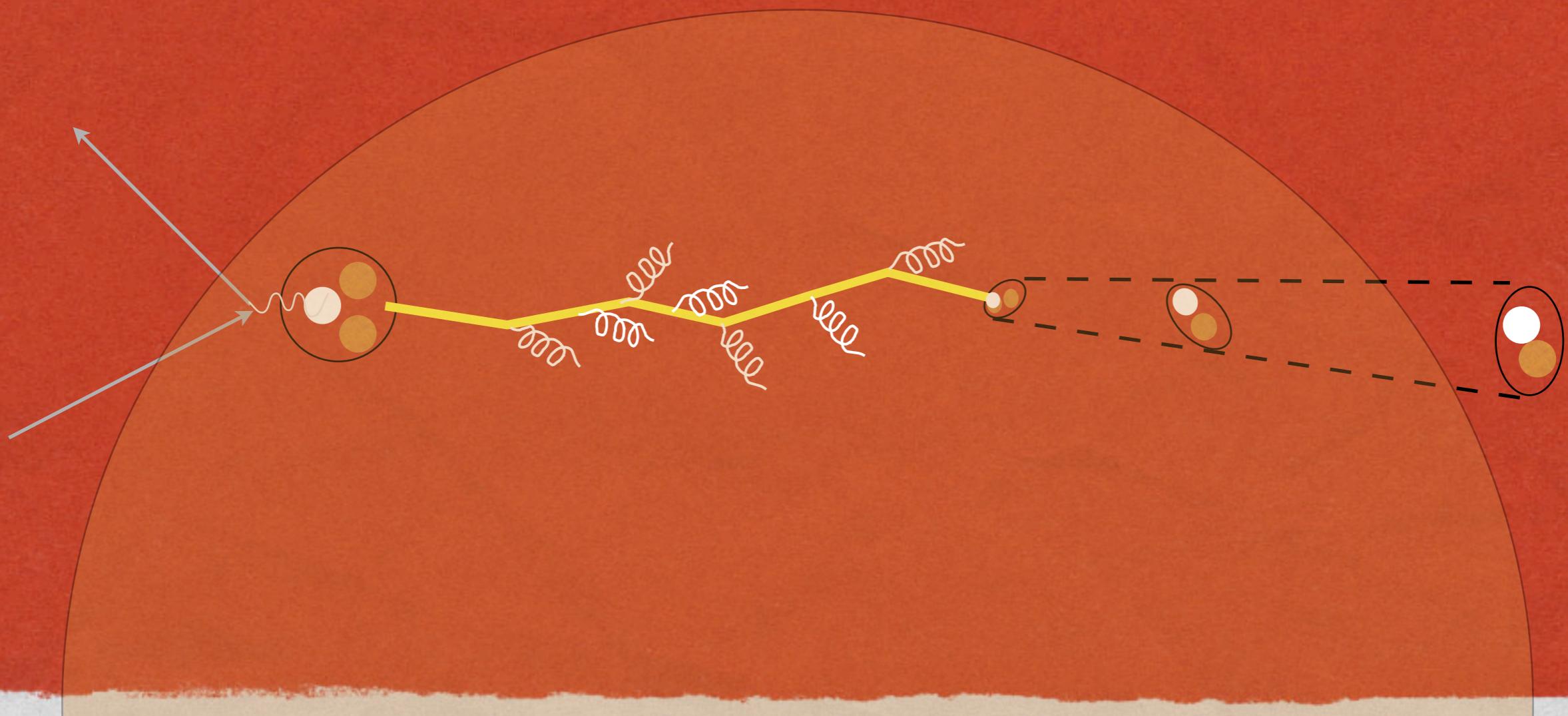
Partonic multiple scattering:
medium-stimulated
gluon emission,
broadened p_T



Hadronization occurs
outside the medium; or...

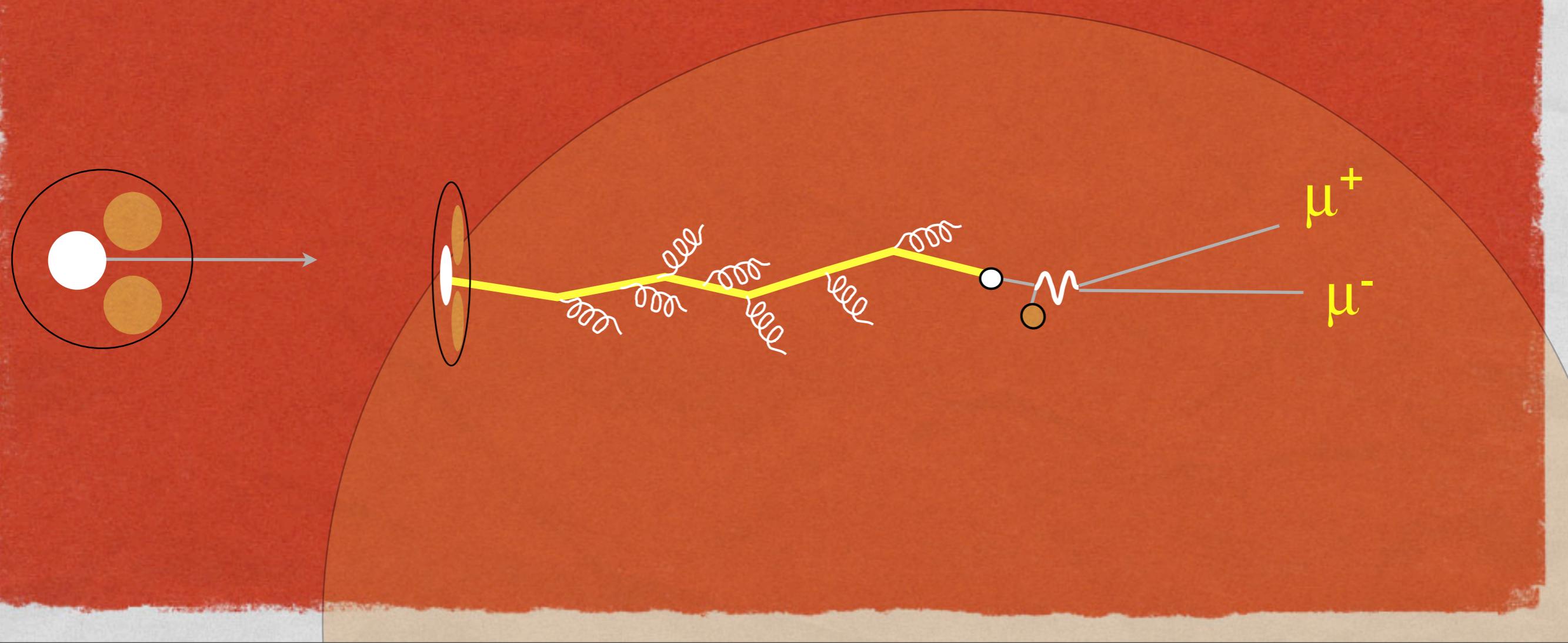
MEDIUM - DIS

Hadronization occurs
inside the medium; then also have
prehadron/hadron interaction

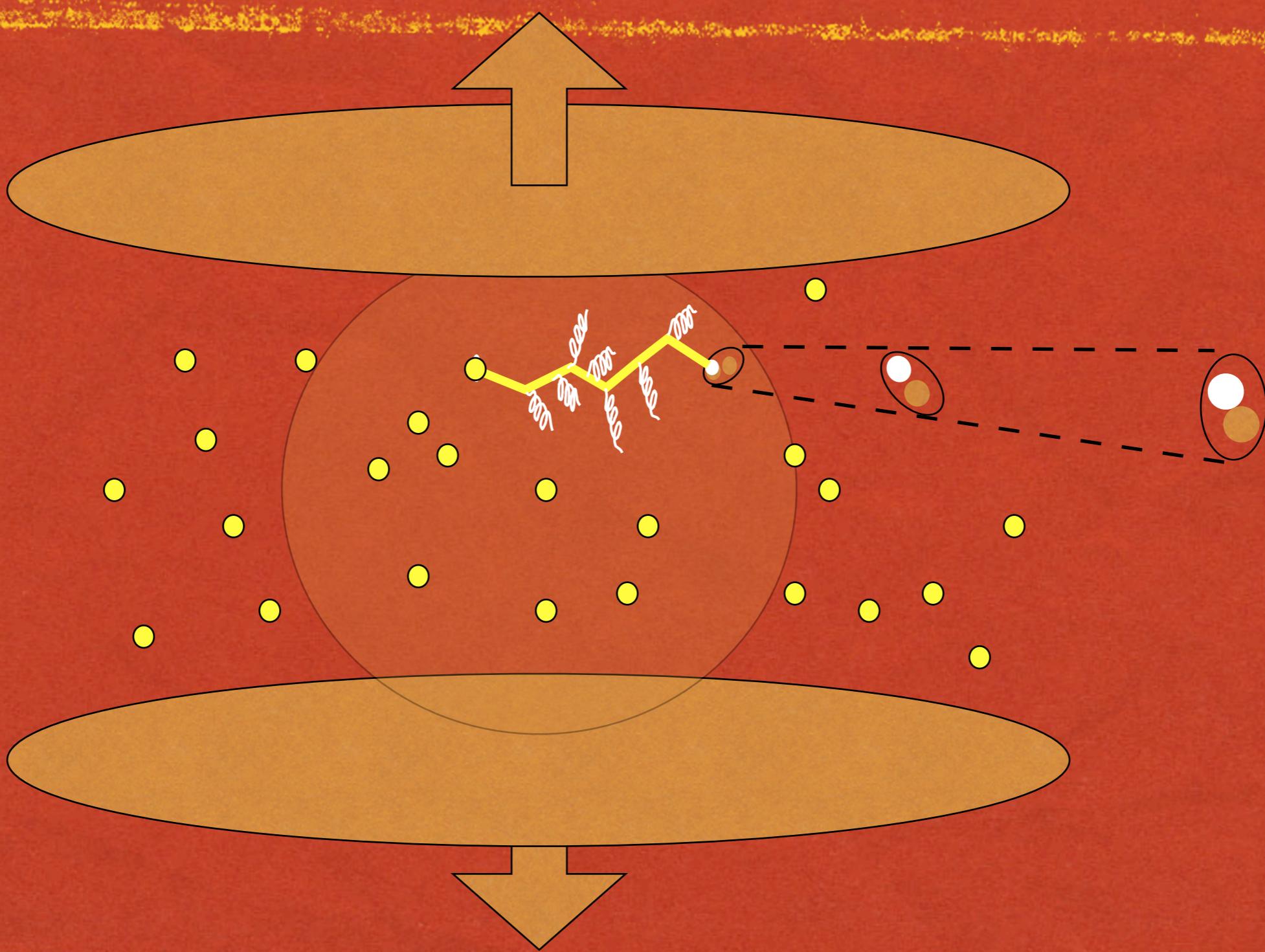


MEDIUM - DRELL-YAN

e.g., 800 GeV protons - no in-medium hadronization -
have p_T broadening



MEDIUM - RHIC/LHC





ASSUMPTIONS

ASSUMPTIONS - DIS

- $x_{Bj} > 0.1$ to avoid quark pair production
- $z_h > \sim 0.5$, struck quark most likely in hadron
- factorization at nucleon level not manifestly broken
- contamination (rho, baryon resonance decays) limited
- adequate Q^2, W, W' to define DIS conditions

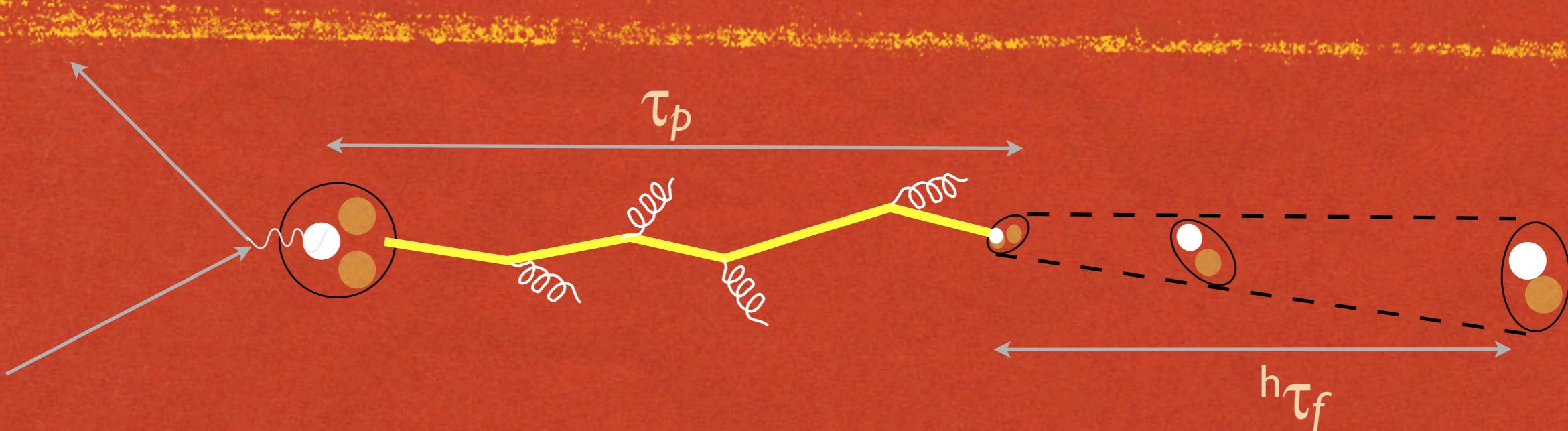
NUCLEAR DIS

- Simple view, ca. 2005: ‘hadron attenuation,’ e.g. in HERMES data is primarily due to either gluon radiation or prehadron/hadron interaction - which one is right?
- Reality: both are involved; both are statistical processes averaged over nuclear volume
- What are the relative contributions of the two mechanisms?

The background image shows a coastal scene with a rocky shoreline in the foreground. In the middle ground, there's a large, steep hill covered in dense green trees. A thick layer of white fog or low-hanging clouds rests on the hillside and extends towards the horizon. The water is a vibrant blue, with small waves crashing against the rocks. The overall atmosphere is serene and somewhat mysterious due to the fog.

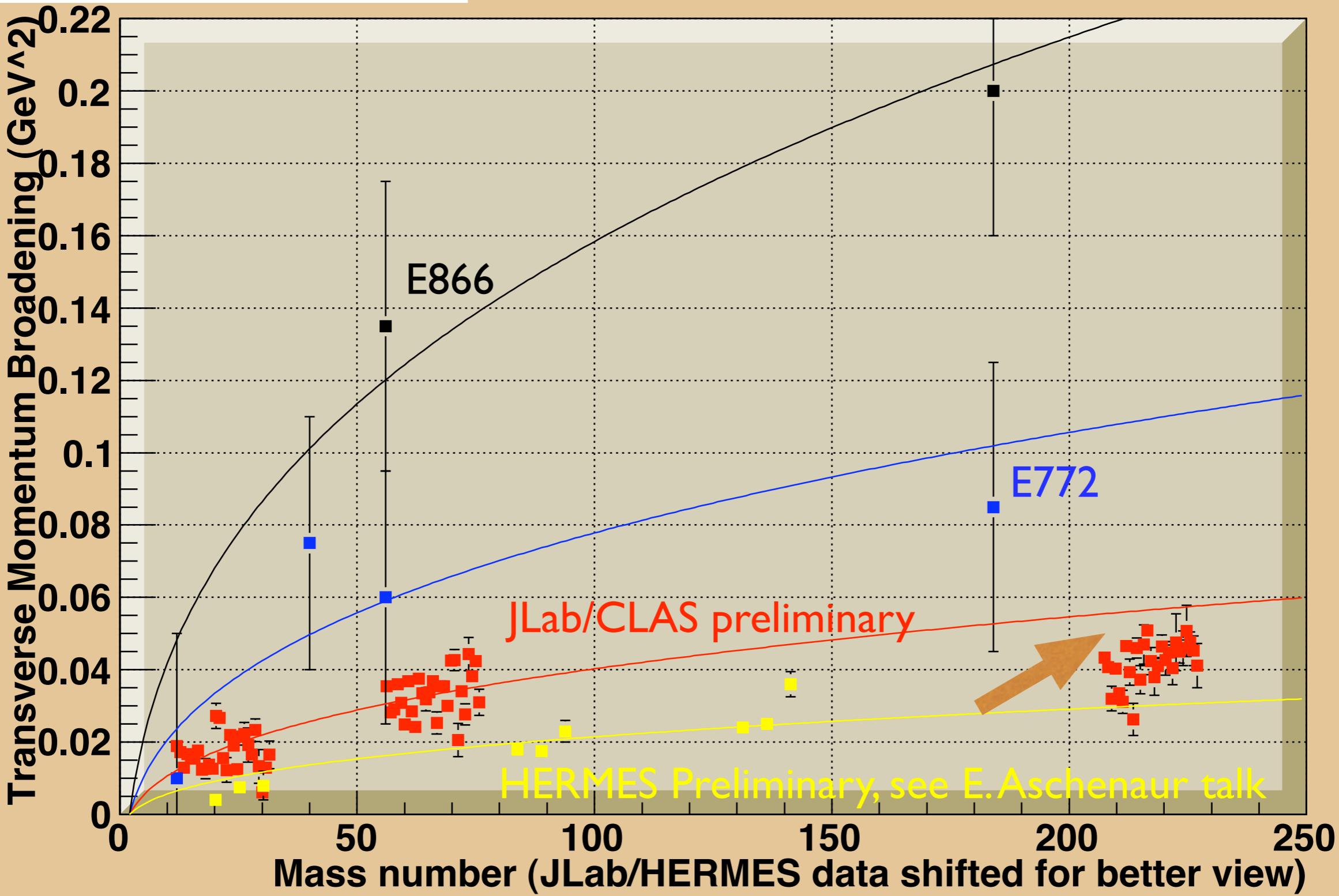
pT broadening in cold nuclear matter

PRODUCTION TIME EXTRACTION



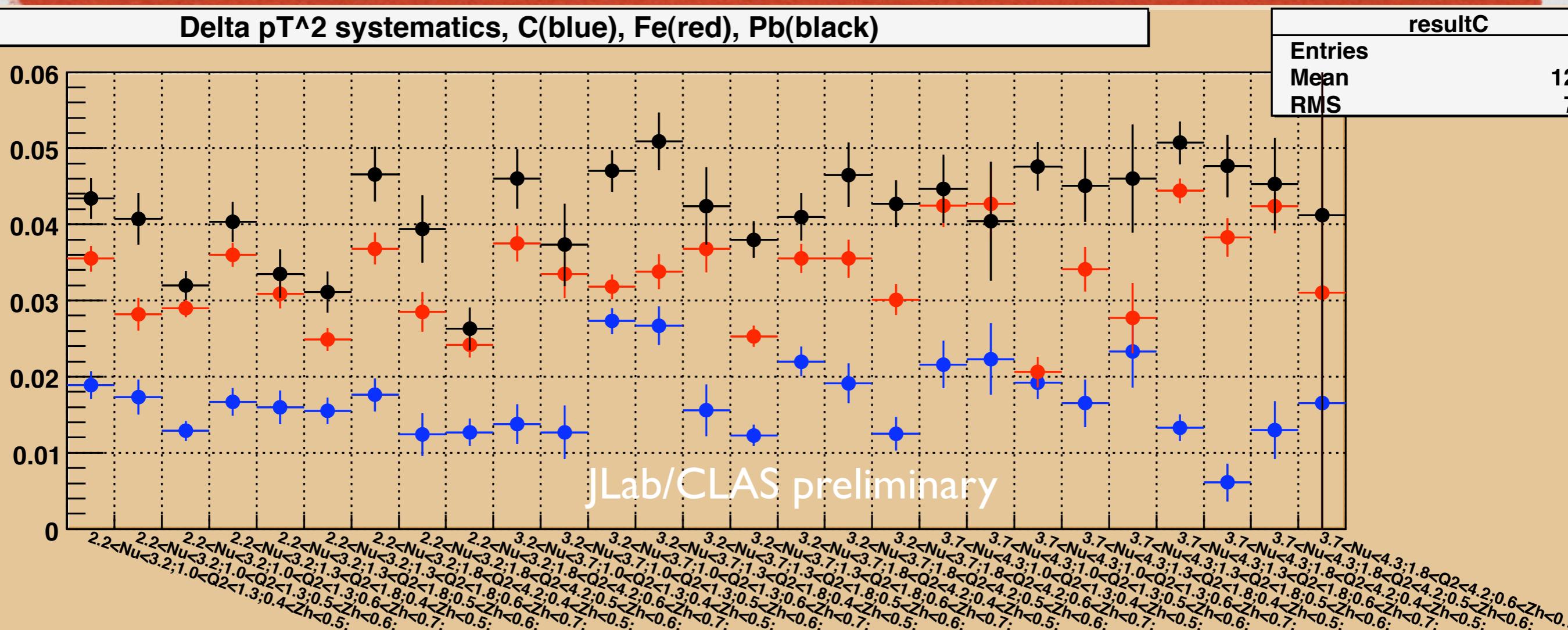
- **production time** τ_p is time required to form color singlet pre-hadron;
‘lifetime of deconfined quark’
- **Postulate:**
 - pT broadening (δp^2_T) only accumulates during production time phase
 - **Saturation of δp^2_T vs. A signals end of production time phase - enables extraction of τ_p**

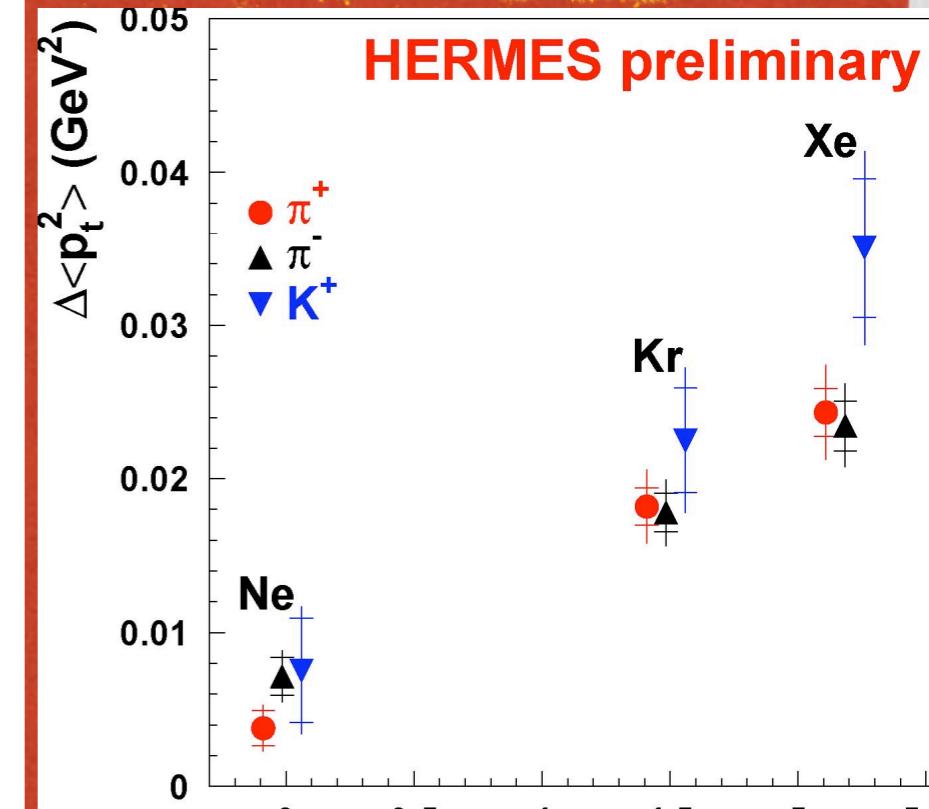
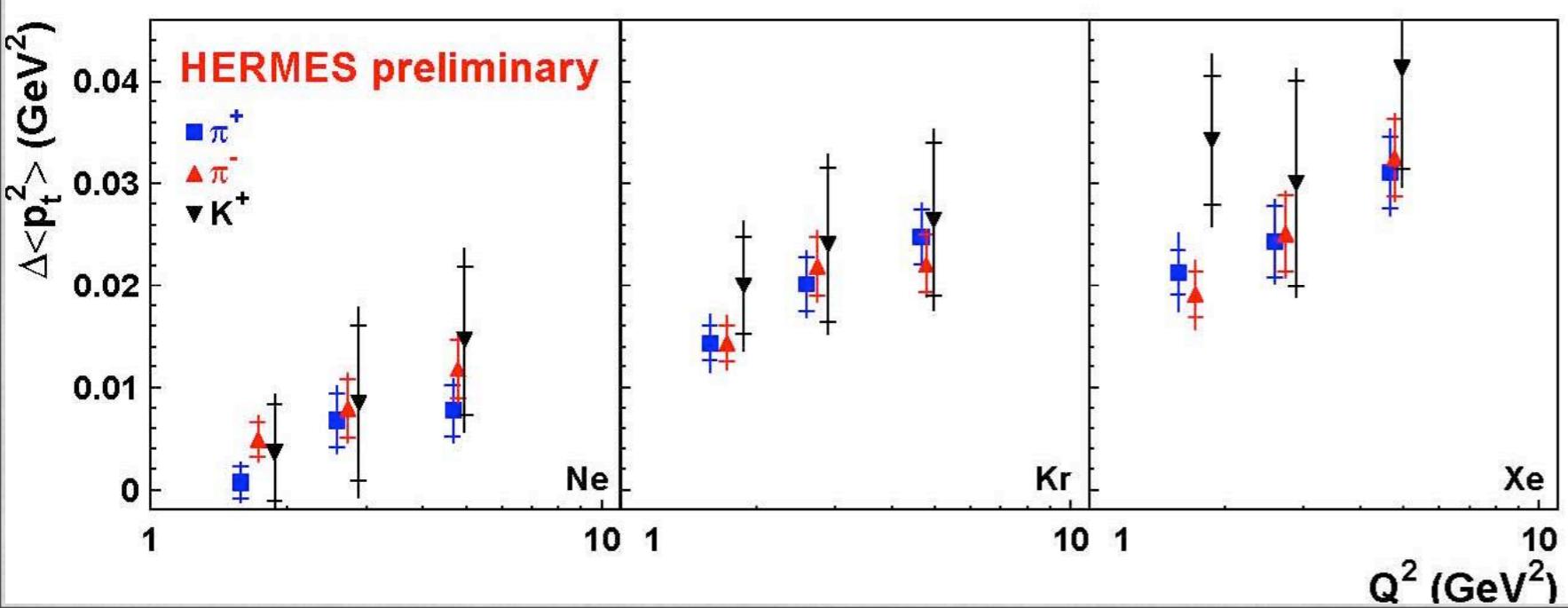
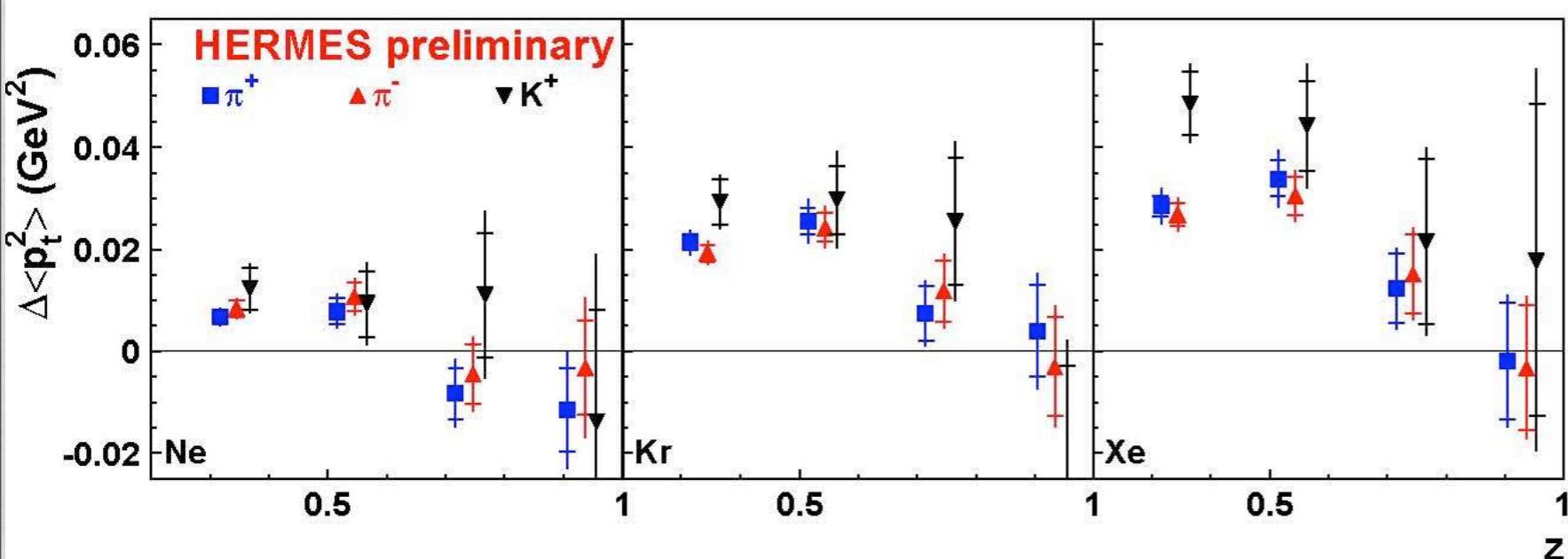
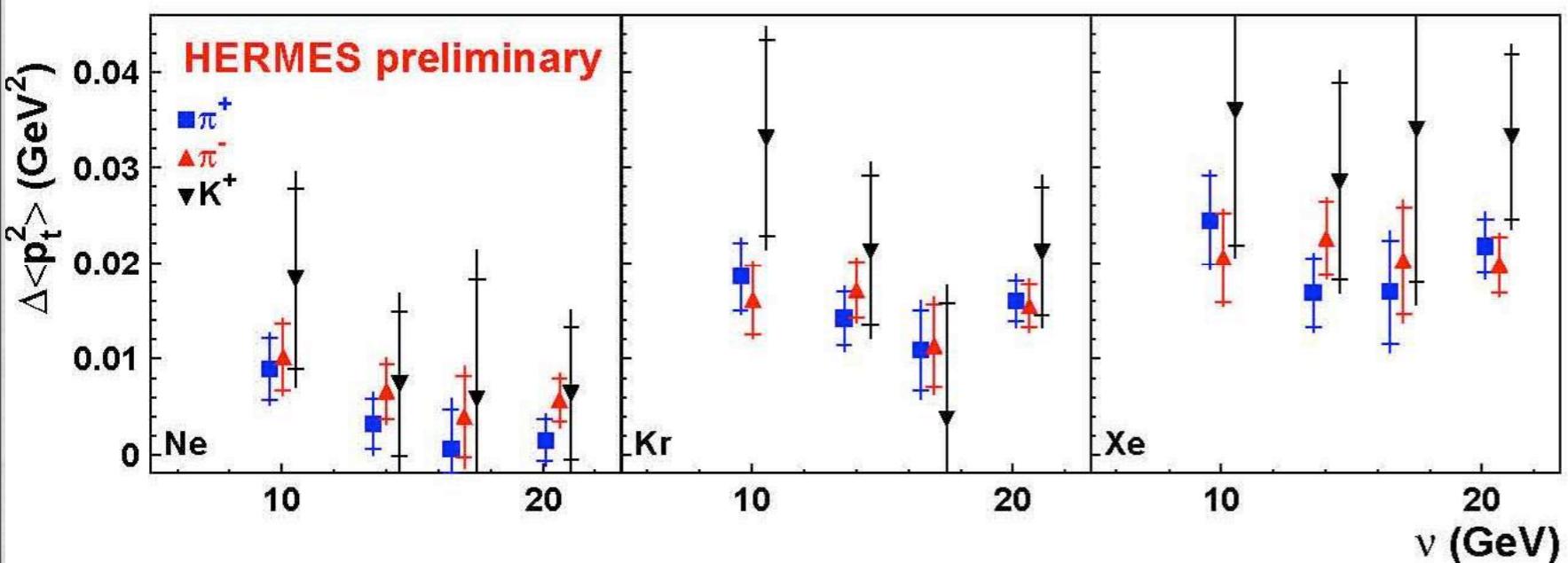
$$\Delta \langle p_T^2 \rangle = D \left[(A/2)^{1/3} - 1 \right]$$



JLab data saturate, allows extraction of production time $\tau_p!!$

JLAB/CLAS 3-DIMENSIONAL VARIABLE DEPENDENCES - δp_T^2





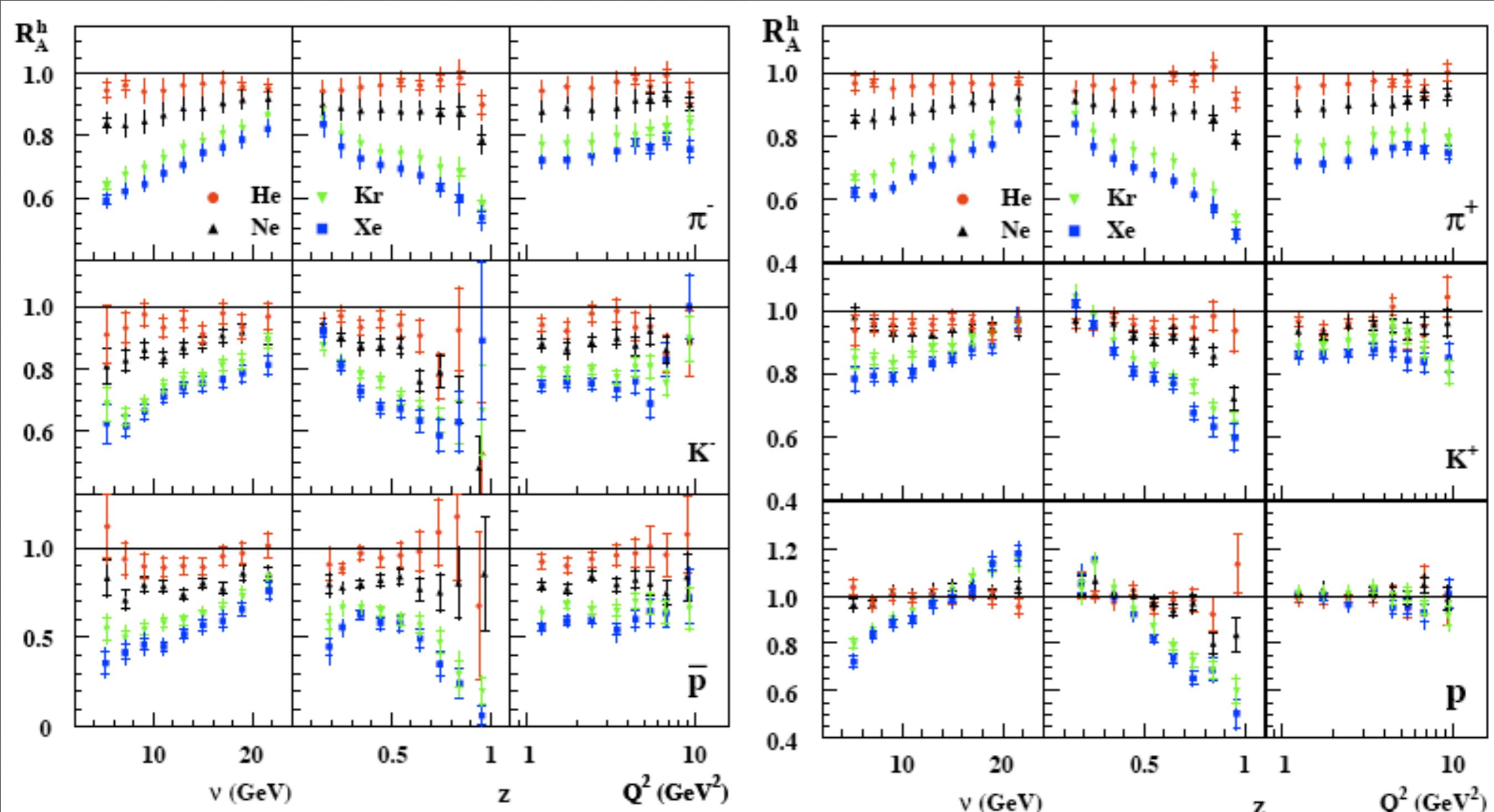
See Elke
Aschenaur's
talk

PT BROADENING CONCLUSIONS

- Broad agreement of data from different experiments in functional form: broadening proportional to medium thickness, some energy dependence.
- JLab data saturation may enable production time extraction
- Broadening dependence on kinematic variables seems to exist but is mild

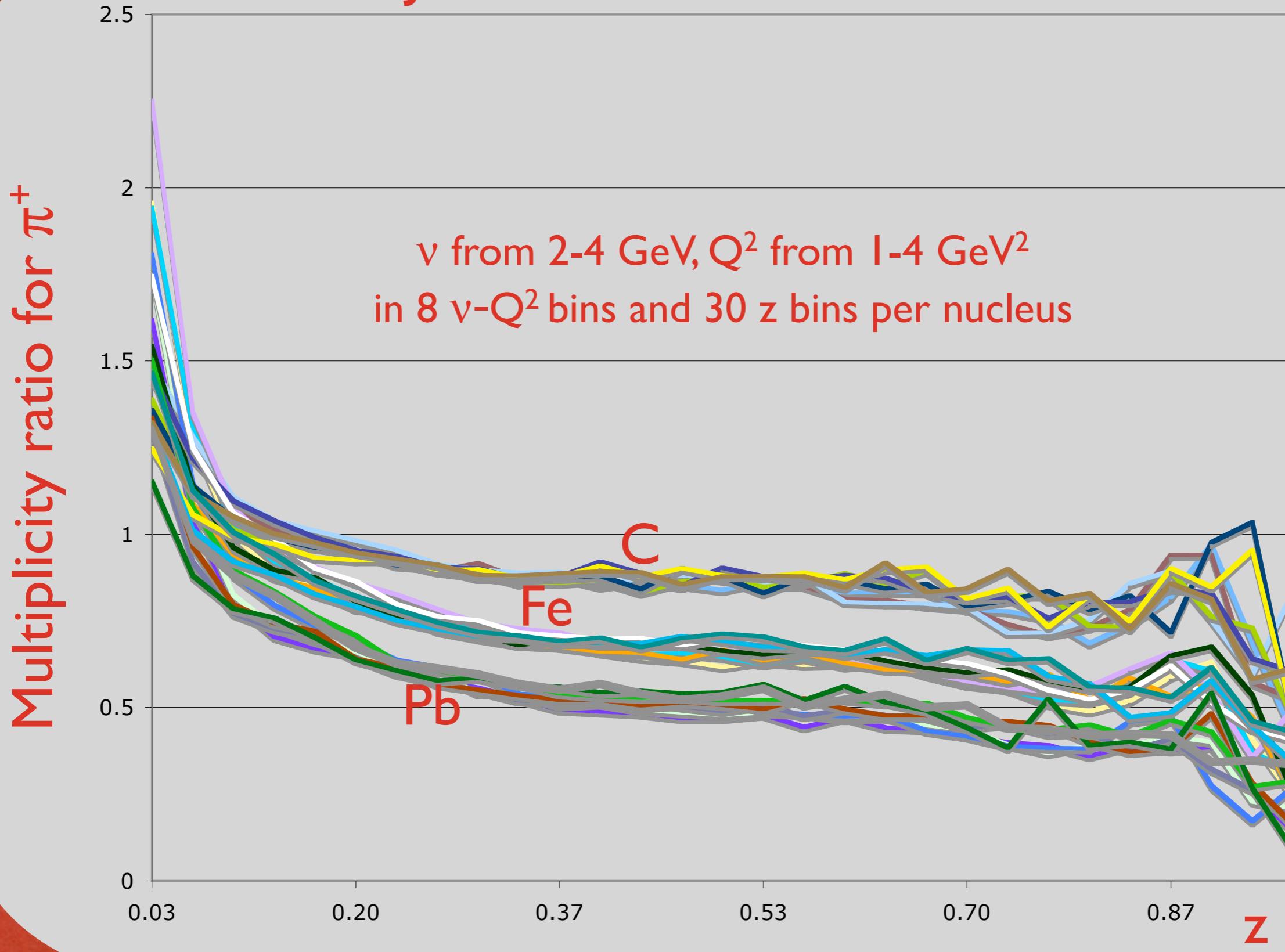
A vibrant field of flowers, likely Crocosmia, with a mix of red, orange, and white blooms. The flowers are densely packed along tall green stems. In the background, there are more flowers and some purple ones further back.

Hadron Attenuation



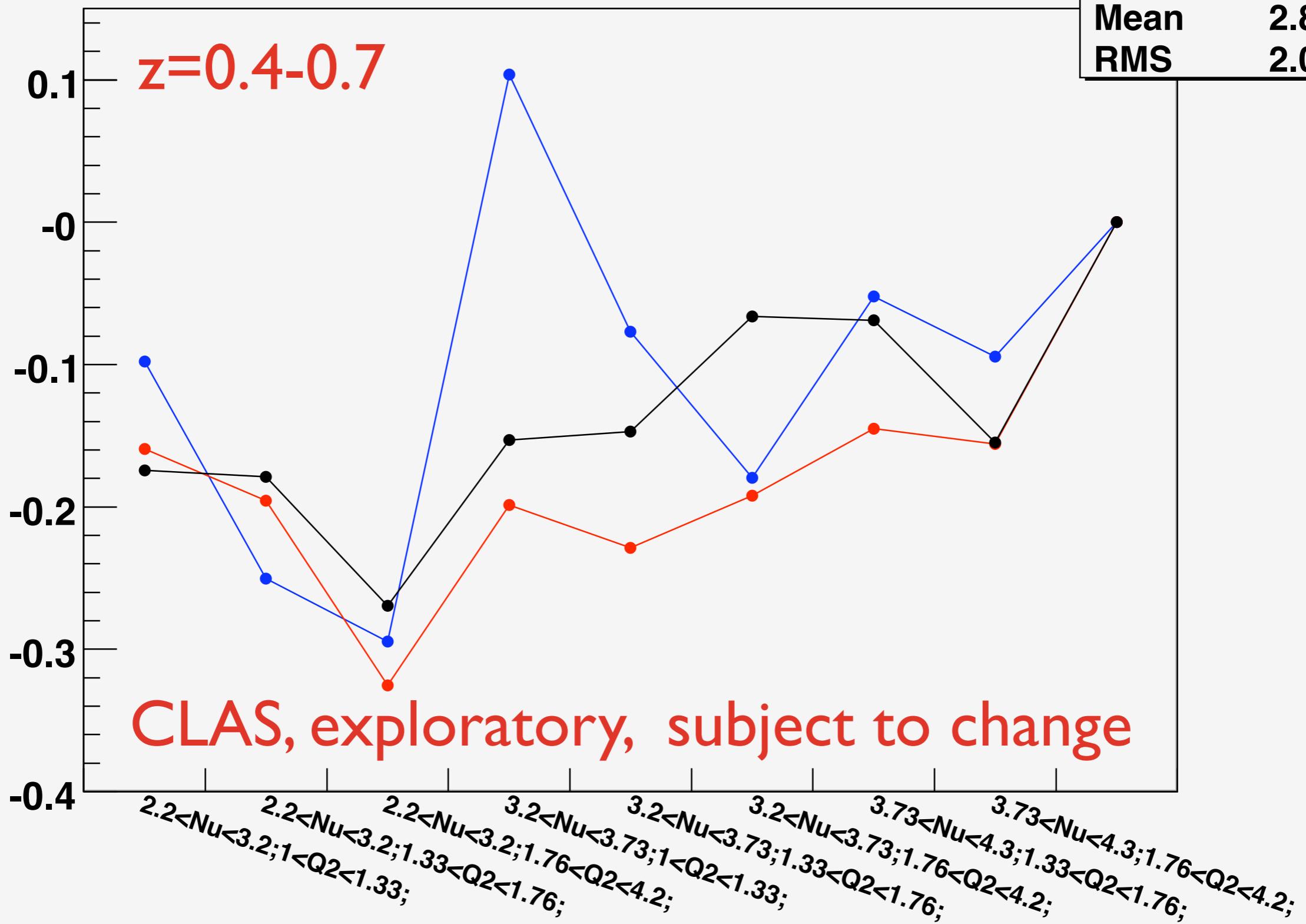
HERMES data for He, Ne, Kr, Xe: π^{+-} , K^{+-} , p , antiproton

JLab/CLAS data for C, Fe, Pb

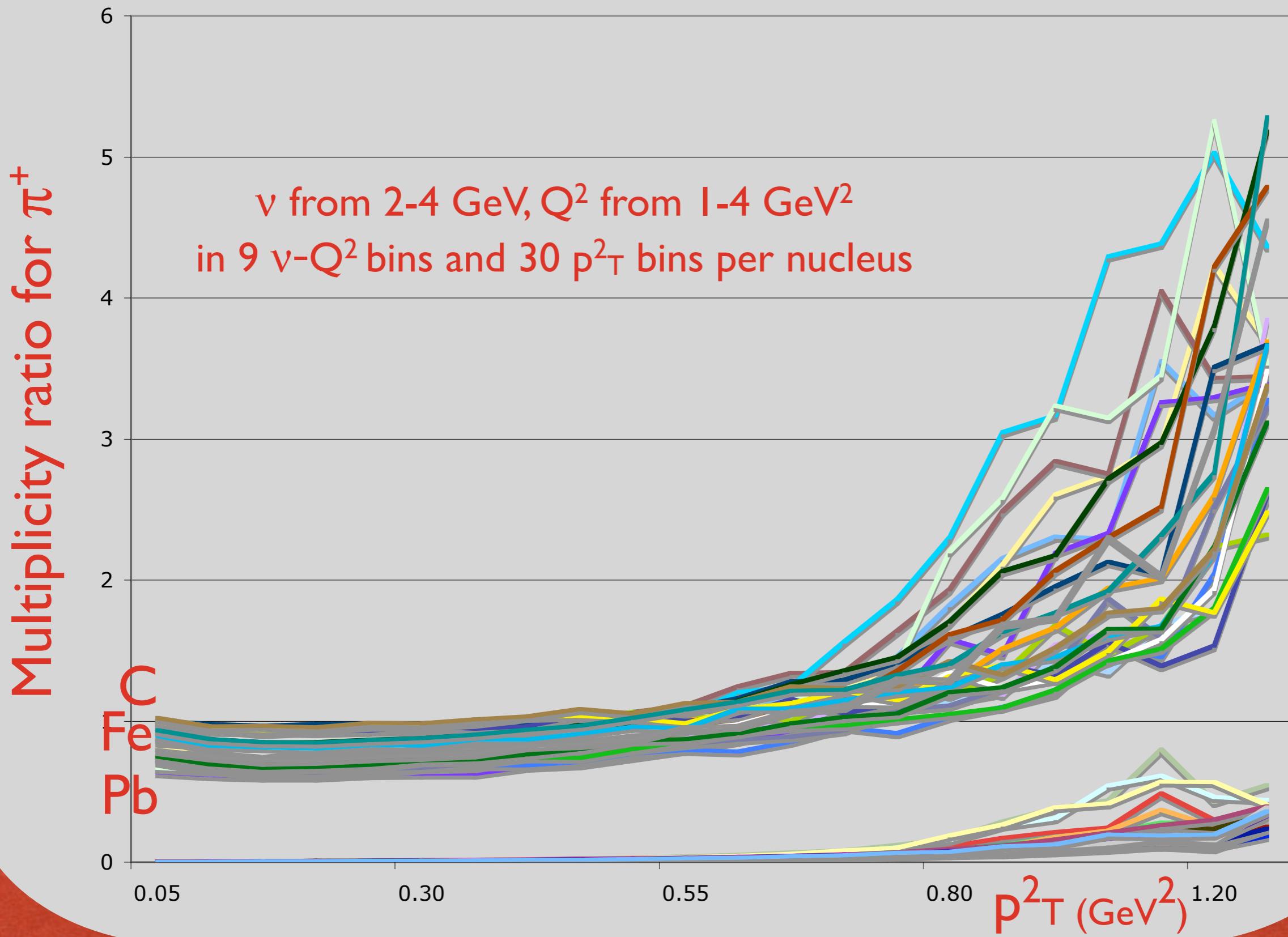


slope of z distribution, C(blue), Fe(red), Pb(black)

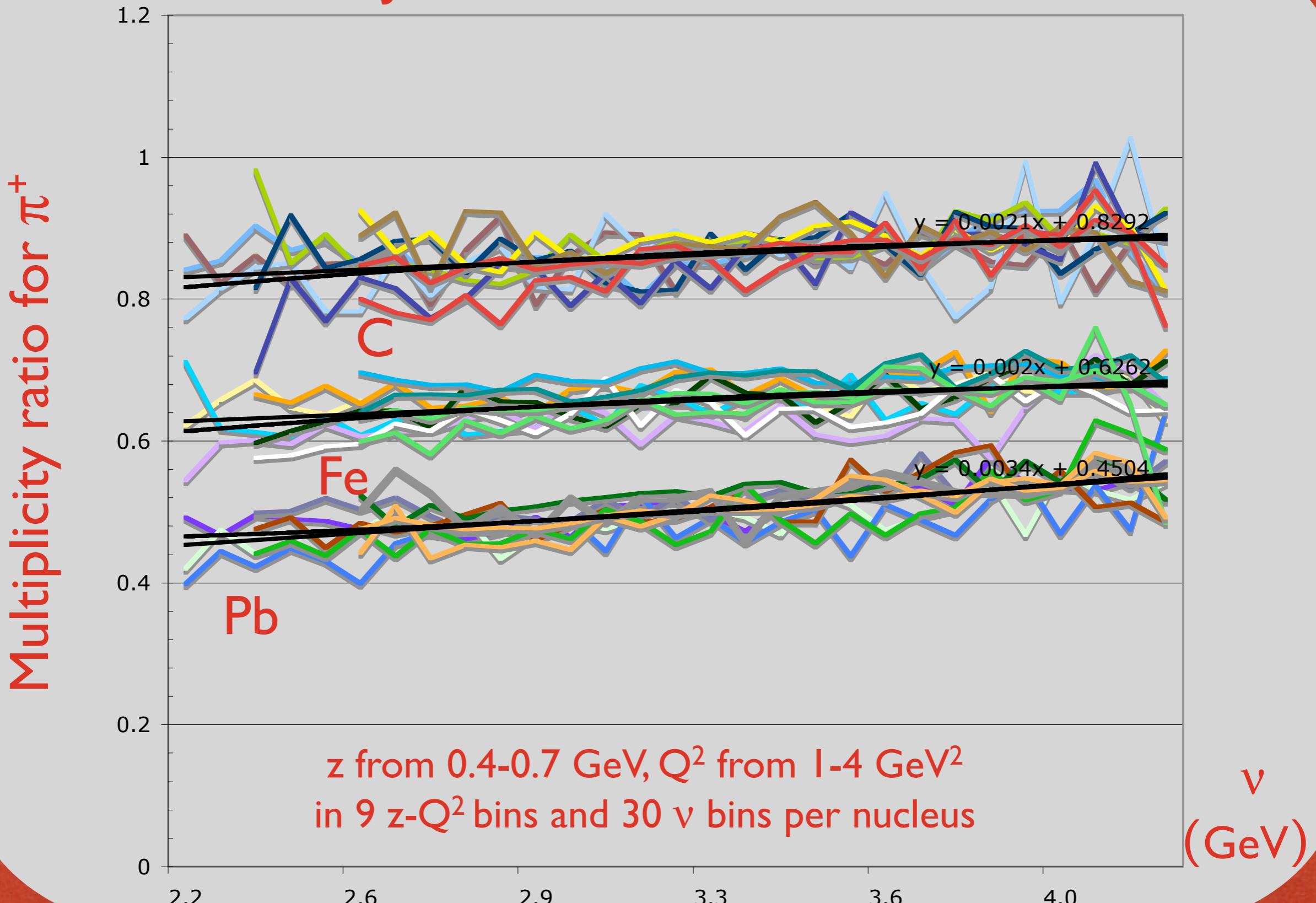
resultC
Entries 8
Mean 2.898
RMS 2.073



JLab/CLAS data for C, Fe, Pb



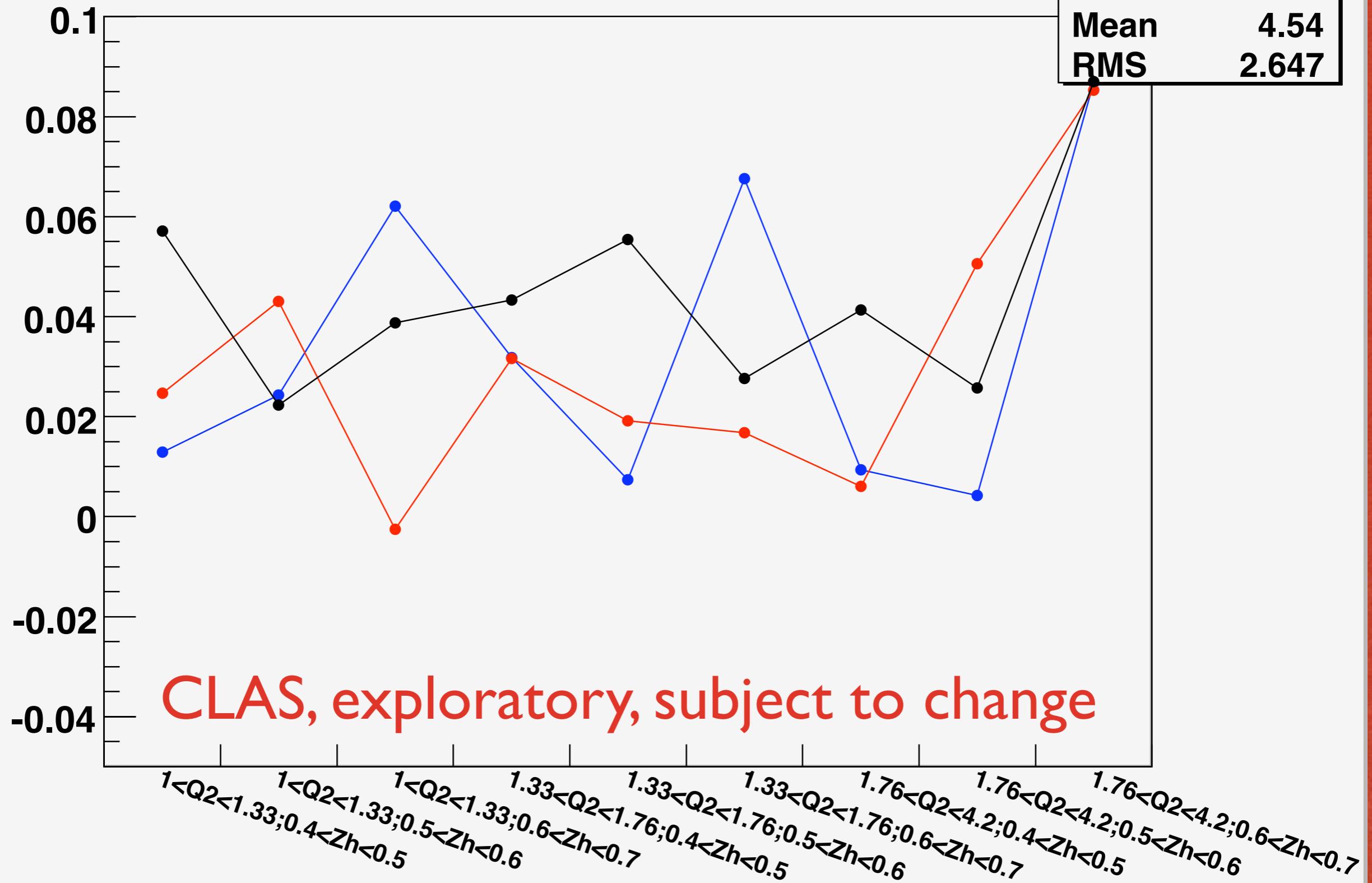
JLab/CLAS data for C, Fe, Pb



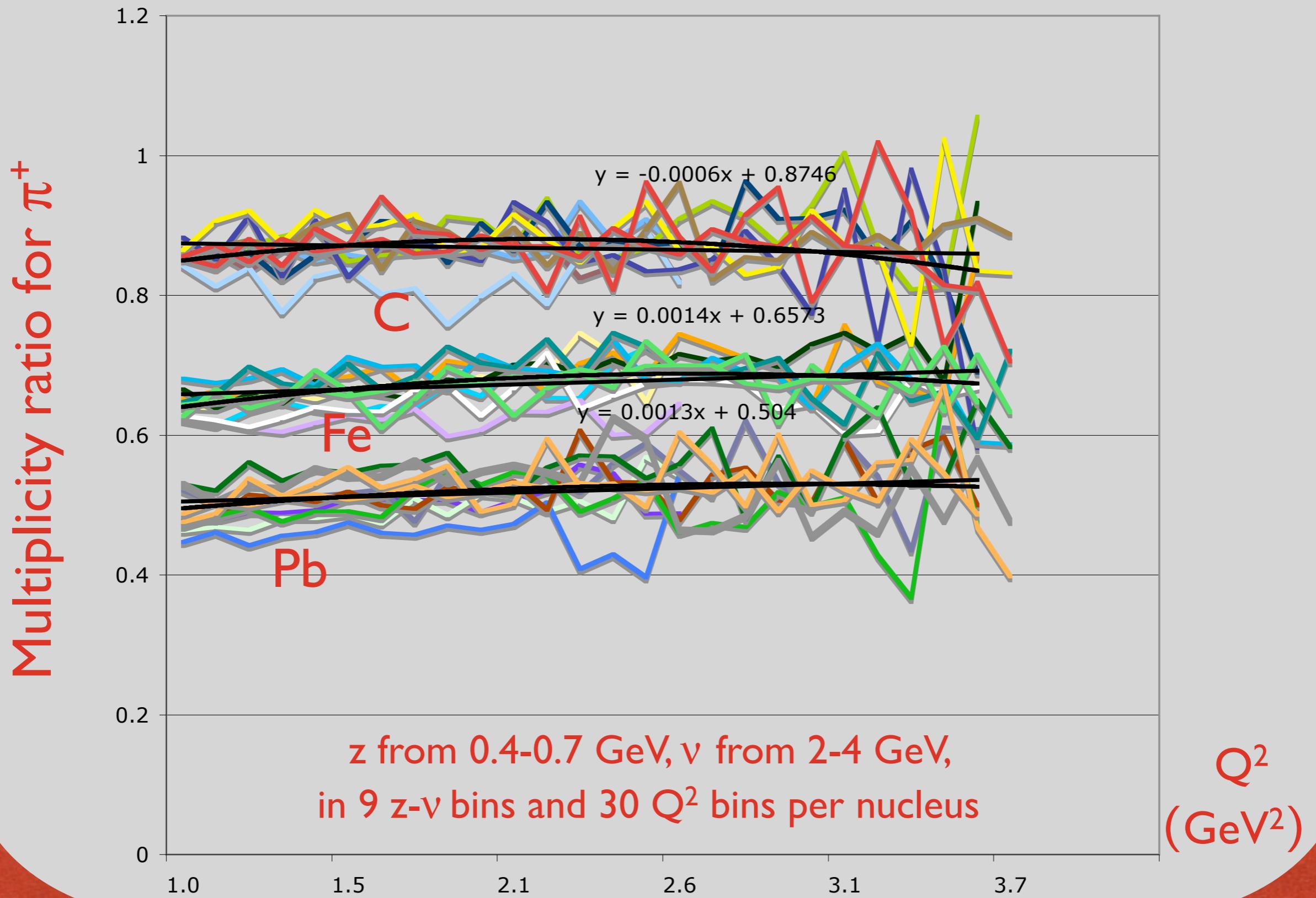
slope of nu distribution, C(blue), Fe(red), Pb(black)

resultC
Entries
Mean
RMS

9
4.54
2.647

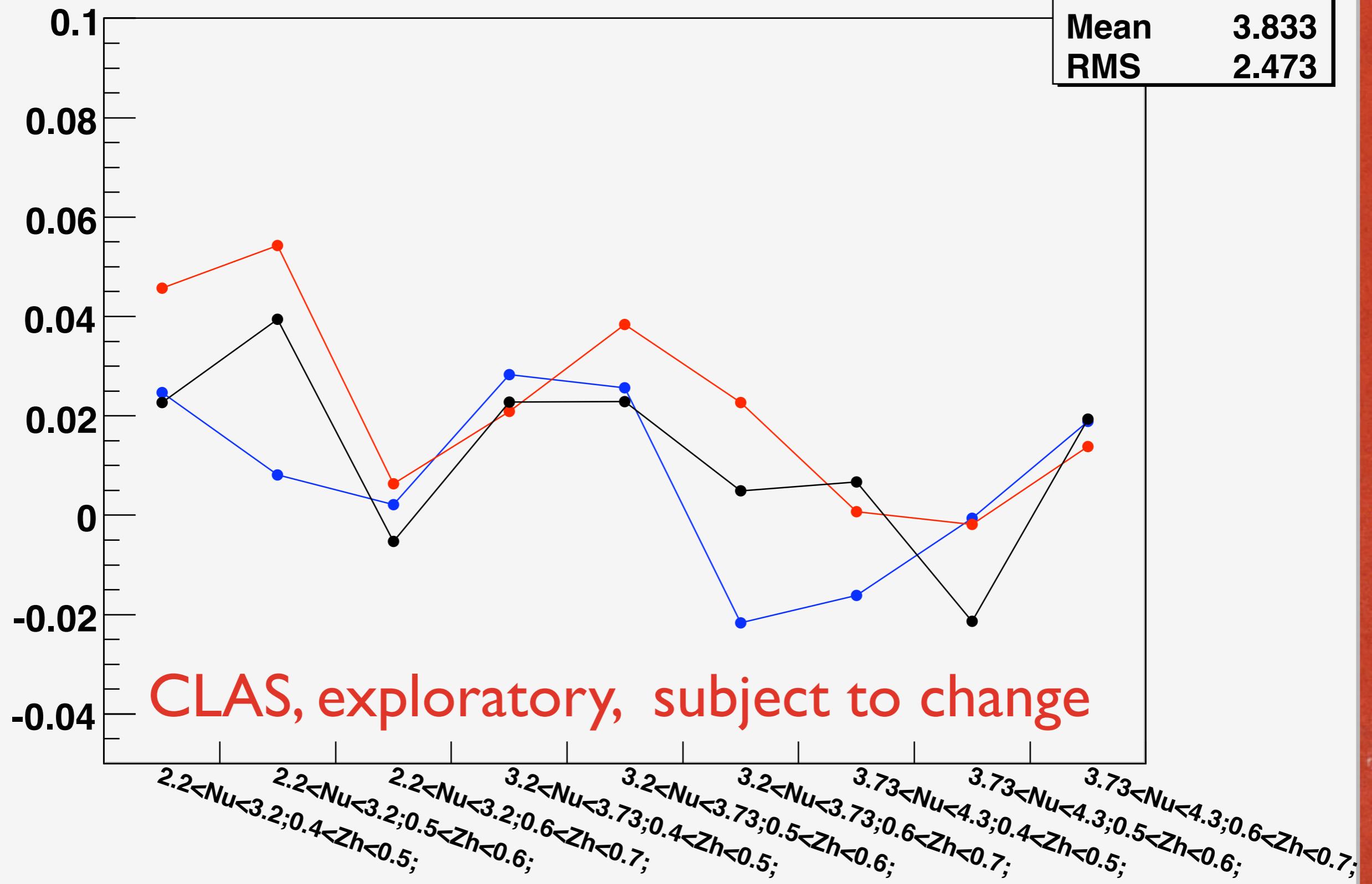


JLab/CLAS data for C, Fe, Pb



slope of Q^2 distribution, C(blue), Fe(red), Pb(black)

resultC
Entries 9
Mean 3.833
RMS 2.473



HADRON ATTENUATION CONCLUSIONS

- Good consistency of data from HERMES and CLAS
- Hermes data: landmark study
- Exploratory 3-variable study performed with JLab/CLAS data, provides quite stringent test for models

Future Prospects



Examples of Experimental Data and Theoretical Predictions

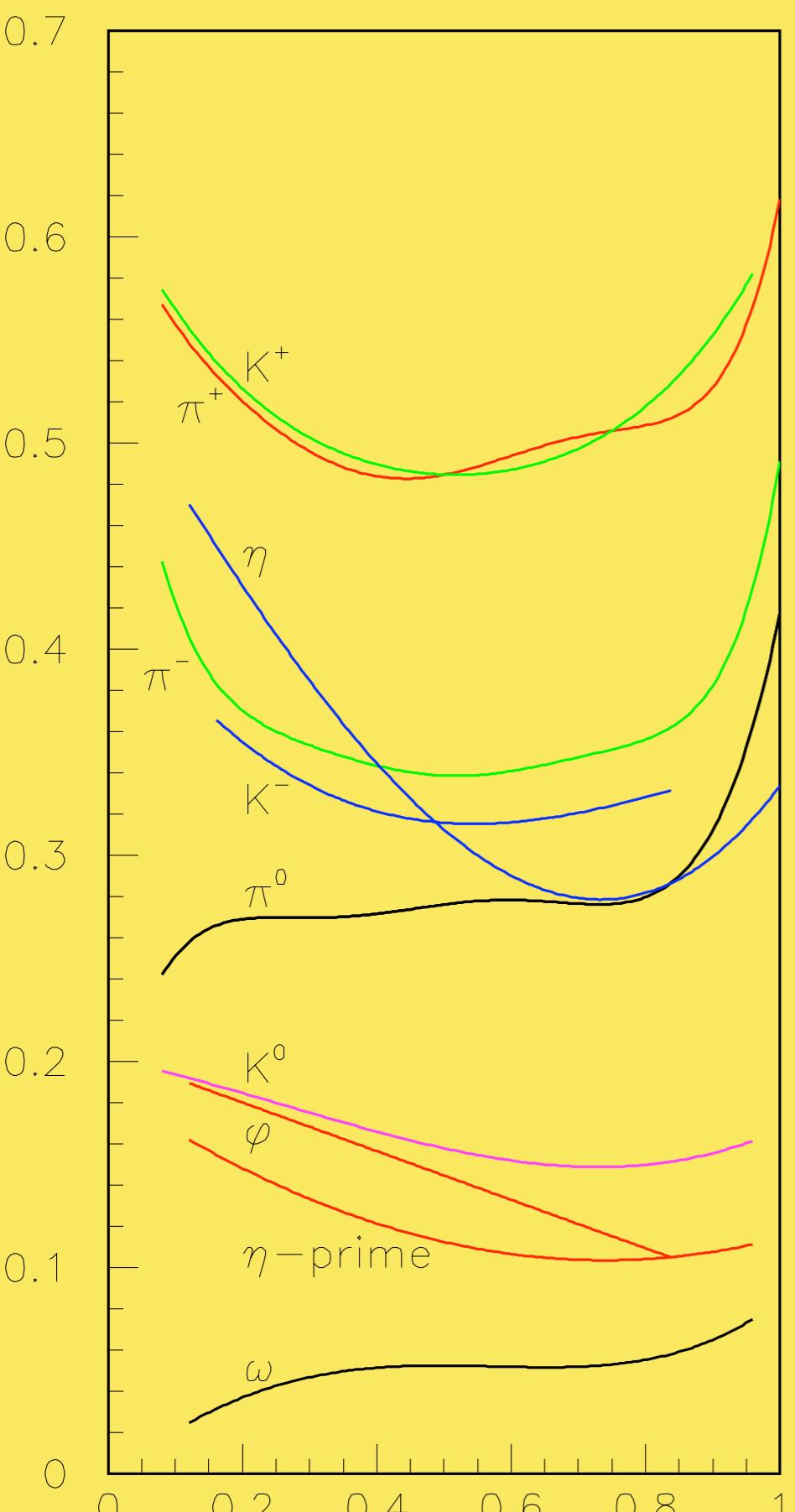


CLAS12 Multiplicity Ratio vs. Z_h, π^+

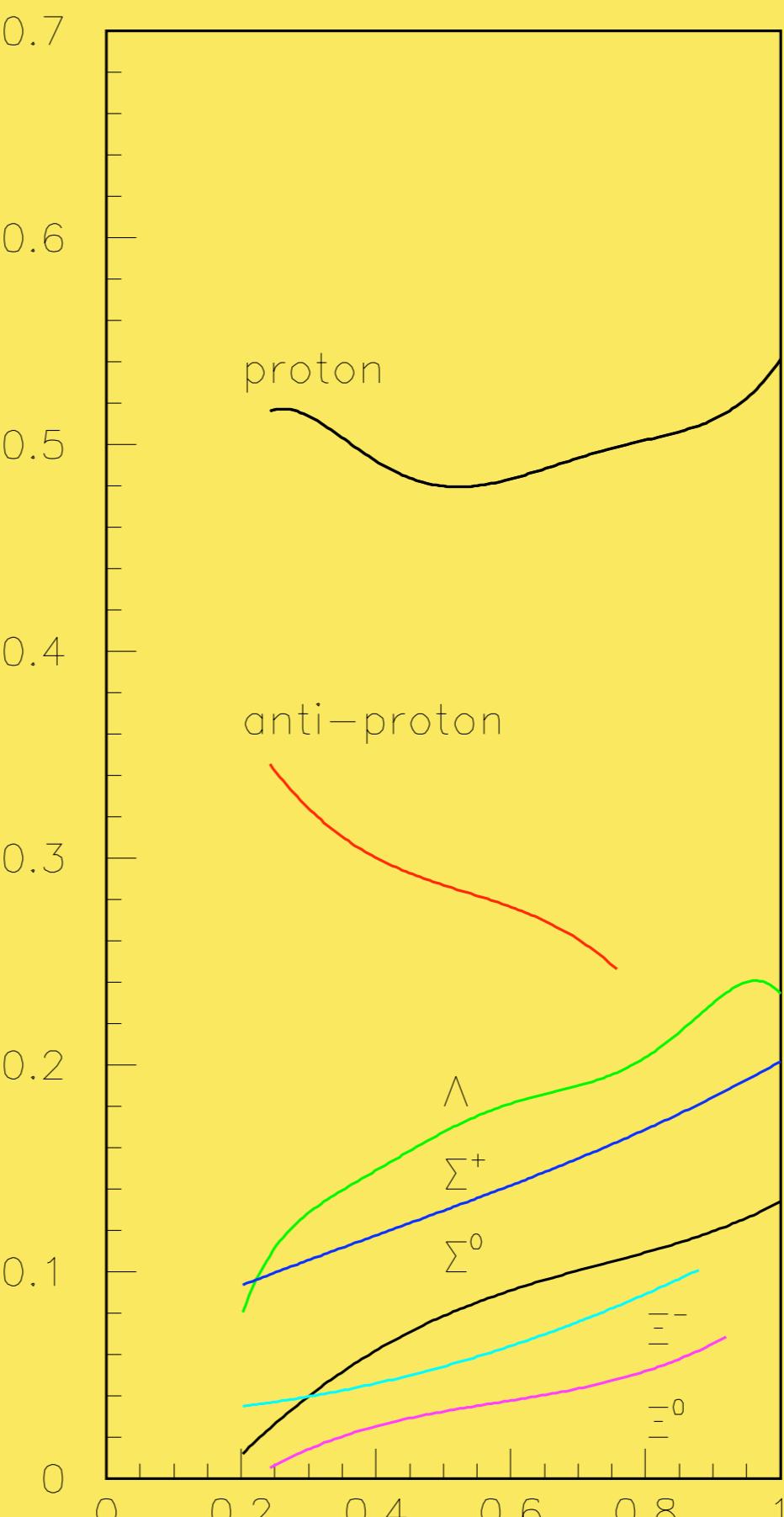
CLAS|2 Hadrons

hadron	$c\tau$	mass (GeV)	flavor content	detection channel	Production rate per 1k DIS events
π^0	25 nm	0.13	$u\bar{u}d\bar{d}$	$\gamma\gamma$	1100
π^+	7.8 m	0.14	$u\bar{d}$	direct	1000
π^-	7.8 m	0.14	$d\bar{u}$	direct	1000
η	0.17 nm	0.55	$u\bar{u}d\bar{d}s\bar{s}$	$\gamma\gamma$	120
ω	23 fm	0.78	$u\bar{u}d\bar{d}s\bar{s}$	$\pi^+\pi^-\pi^0$	170
η'	0.98 pm	0.96	$u\bar{u}d\bar{d}s\bar{s}$	$\pi^+\pi^-\eta$	27
ϕ	44 fm	1.0	$u\bar{u}d\bar{d}s\bar{s}$	K^+K^-	0.8
$f1$	8 fm	1.3	$u\bar{u}d\bar{d}s\bar{s}$	$\pi\pi\pi\pi$	-
K^+	3.7 m	0.49	$u\bar{s}$	direct	75
K^-	3.7 m	0.49	$\bar{u}s$	direct	25
K^0	27 mm	0.50	$d\bar{s}$	$\pi^+\pi^-$	42
p	stable	0.94	$u\bar{d}$	direct	530
\bar{p}	stable	0.94	$\bar{u}\bar{d}$	direct	3
Λ	79 mm	1.1	uds	$p\pi^-$	72
$\Lambda(1520)$	13 fm	1.5	uds	$p\pi^-$	-
Σ^+	24 mm	1.2	us	$p\pi^0$	6
Σ^0	22 pm	1.2	uds	$\Lambda\gamma$	11
Ξ^0	87 mm	1.3	us	$\Lambda\pi^0$	0.6
Ξ^-	49 mm	1.3	ds	$\Lambda\pi^-$	0.9

CLAS12 Geometric Acceptances for Mesons and Baryons



CLAS12 Acceptance for Mesons



CLAS12 Acceptance for Baryons

Conclusions



CONCLUSIONS

- Good consistency among diverse data sets
- 3D analysis of huge JLab data sample
- Controversies remain, wide potential impact
- Need theoretical framework for $\tau_p, {}^h\tau_f$ extraction
- Future: JLab at 12 GeV - CLAS12

ADDITIONAL SLIDES

HERMES, CLAS, CLAS12

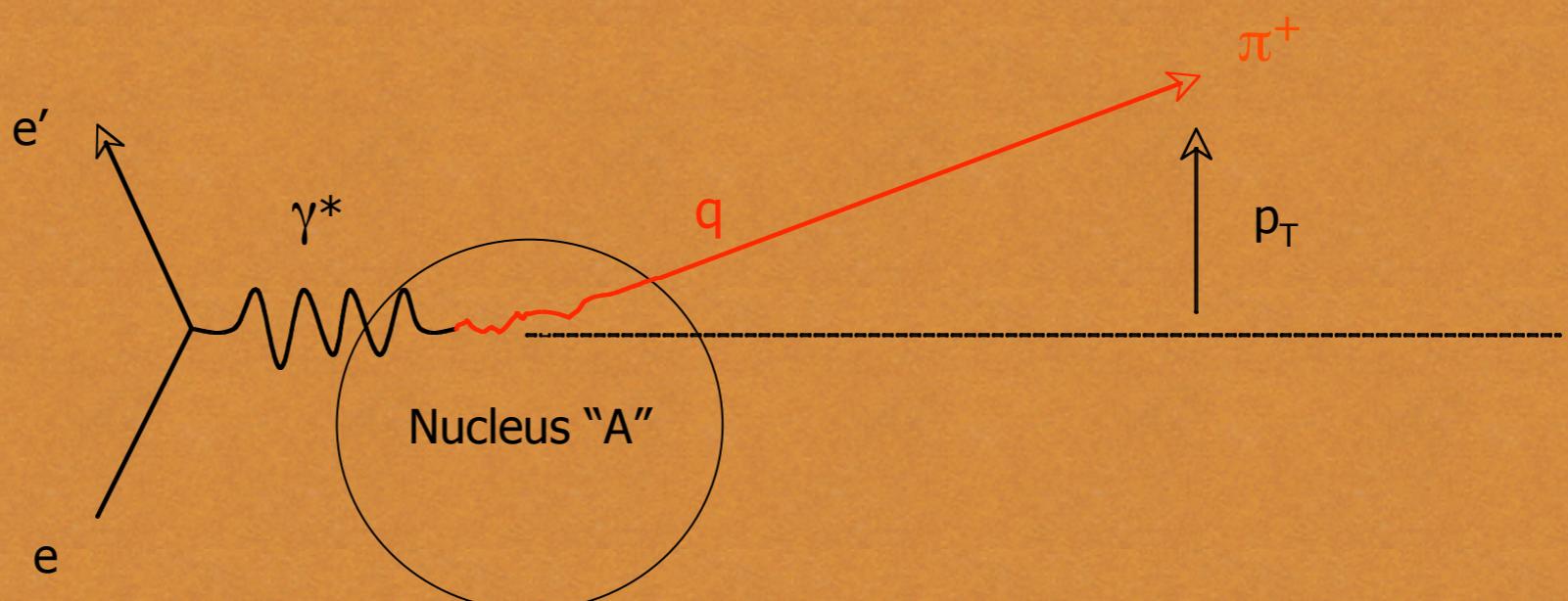
- HERMES took data 1997-2005, 7 nuclear targets, most of data with RICH.
 - 231 pb^{-1} on He+Ne+Kr+Xe at 27 GeV
- CLAS took data 2003, 4 primary nuclear targets
 - $\sim 25,000 \text{ pb}^{-1}$ on C+Fe+Pb, at 5.0 GeV
- CLAS12: approved experiment, $\sim 10x$ CLAS luminosity

REMINDER: EXPERIMENTAL TECHNIQUE

$$R_M^h(z, \nu, p_T^2, Q^2, \phi) = \frac{\left\{ \frac{N_h^{DIS}(z, \nu, p_T^2, Q^2, \phi)}{N_e^{DIS}(\nu, Q^2)} \right\}_A}{\left\{ \frac{N_h^{DIS}(z, \nu, p_T^2, Q^2, \phi)}{N_e^{DIS}(\nu, Q^2)} \right\}_D}$$

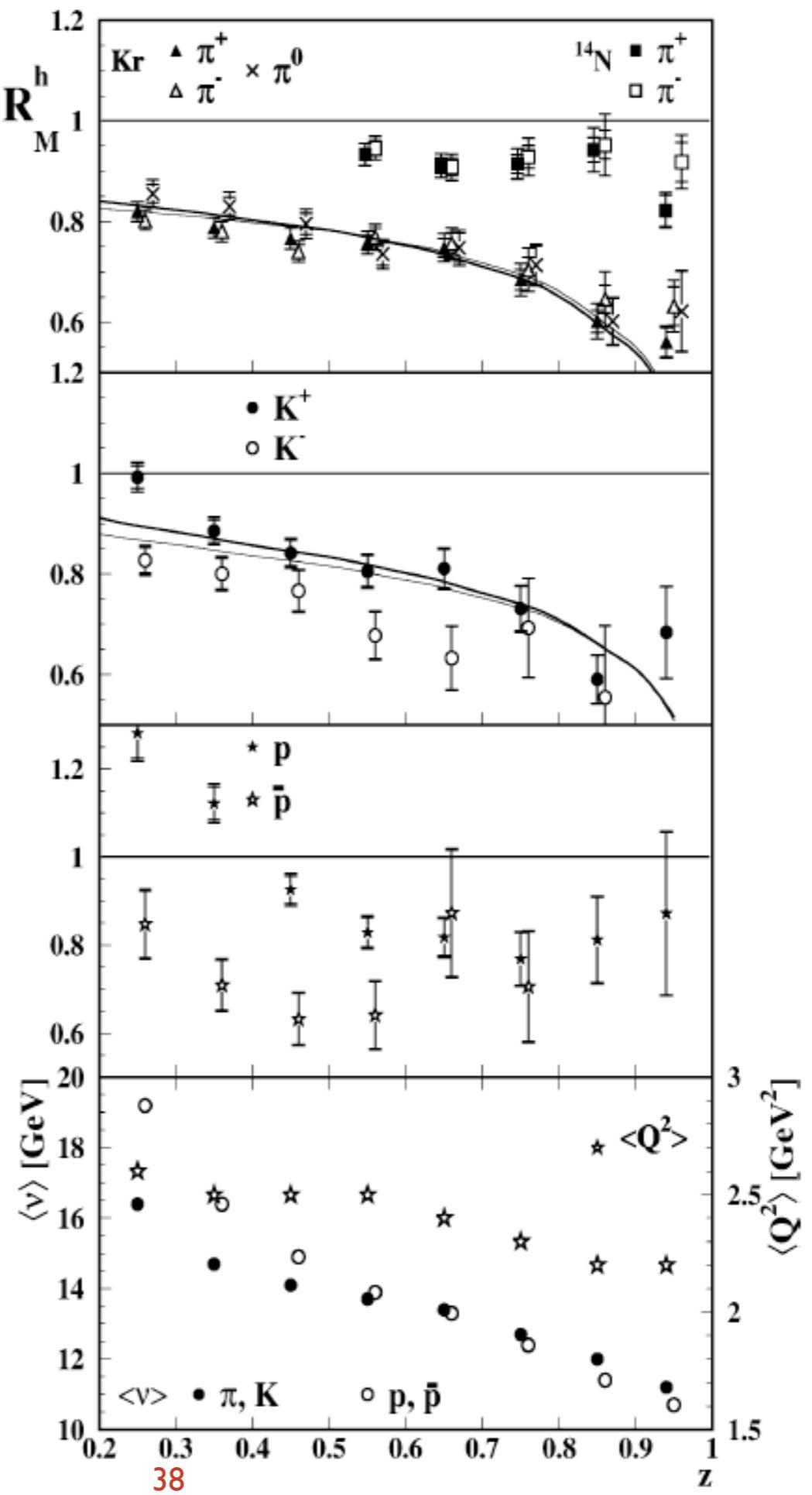
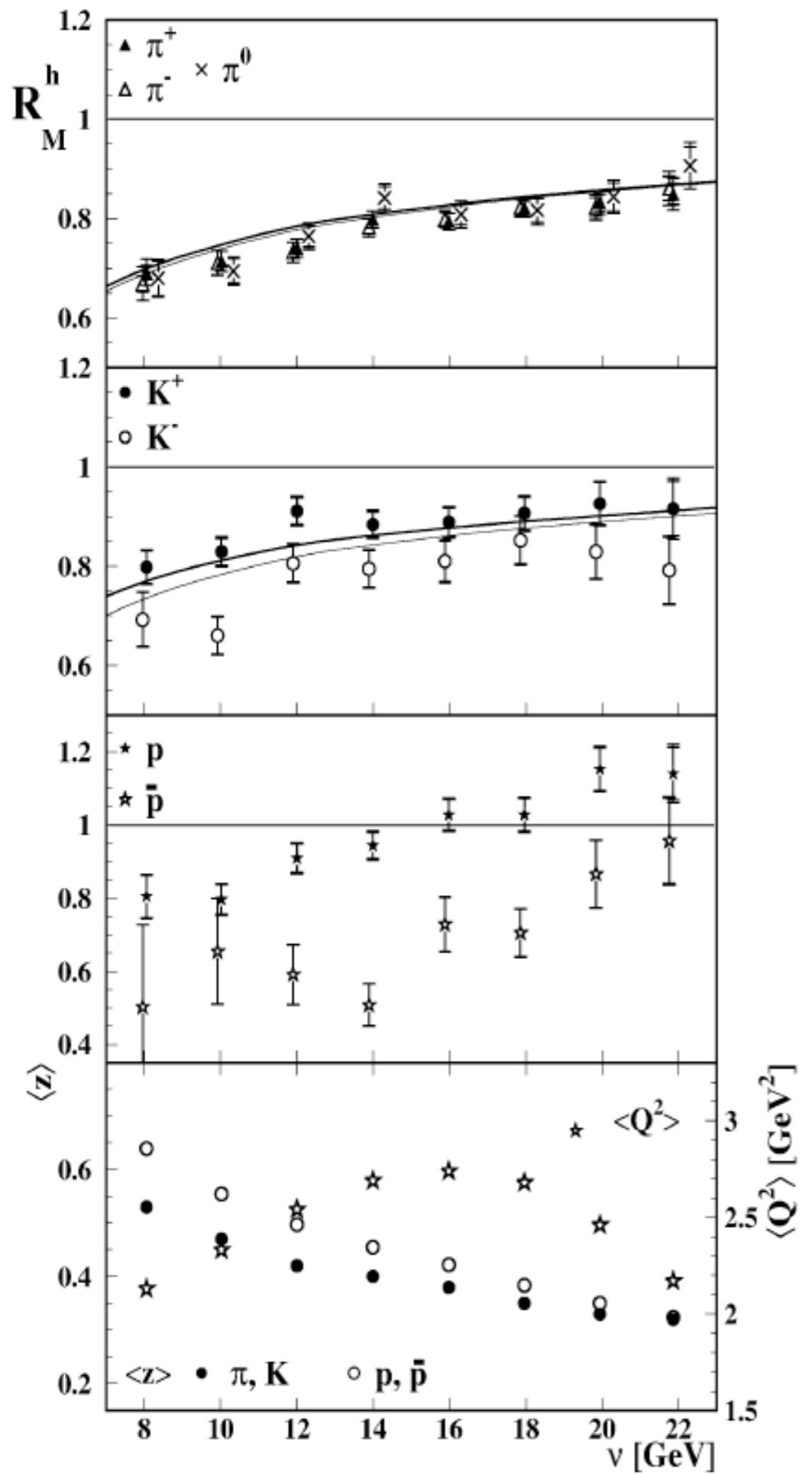
Hadronic multiplicity ratio

$$p_T \text{ broadening: } \Delta p_T^2 = \left\langle p_T^2 \right\rangle_A^{DIS} - \left\langle p_T^2 \right\rangle_D^{DIS}$$



MAJOR IMPACTS OF CLAS RICH

- Continuity with HERMES: π^{+-0} , K^{+-} , baryons
- Compare isospin partners over full multi-dimensional space available with CLAS12
- Test universality of production time τ_p
- Double the constraints on mass/size dependence of ${}^h\tau_f$
- Probe reaction mechanism using known cross sections



HERMES
 Krypton
 Target
 (mostly)