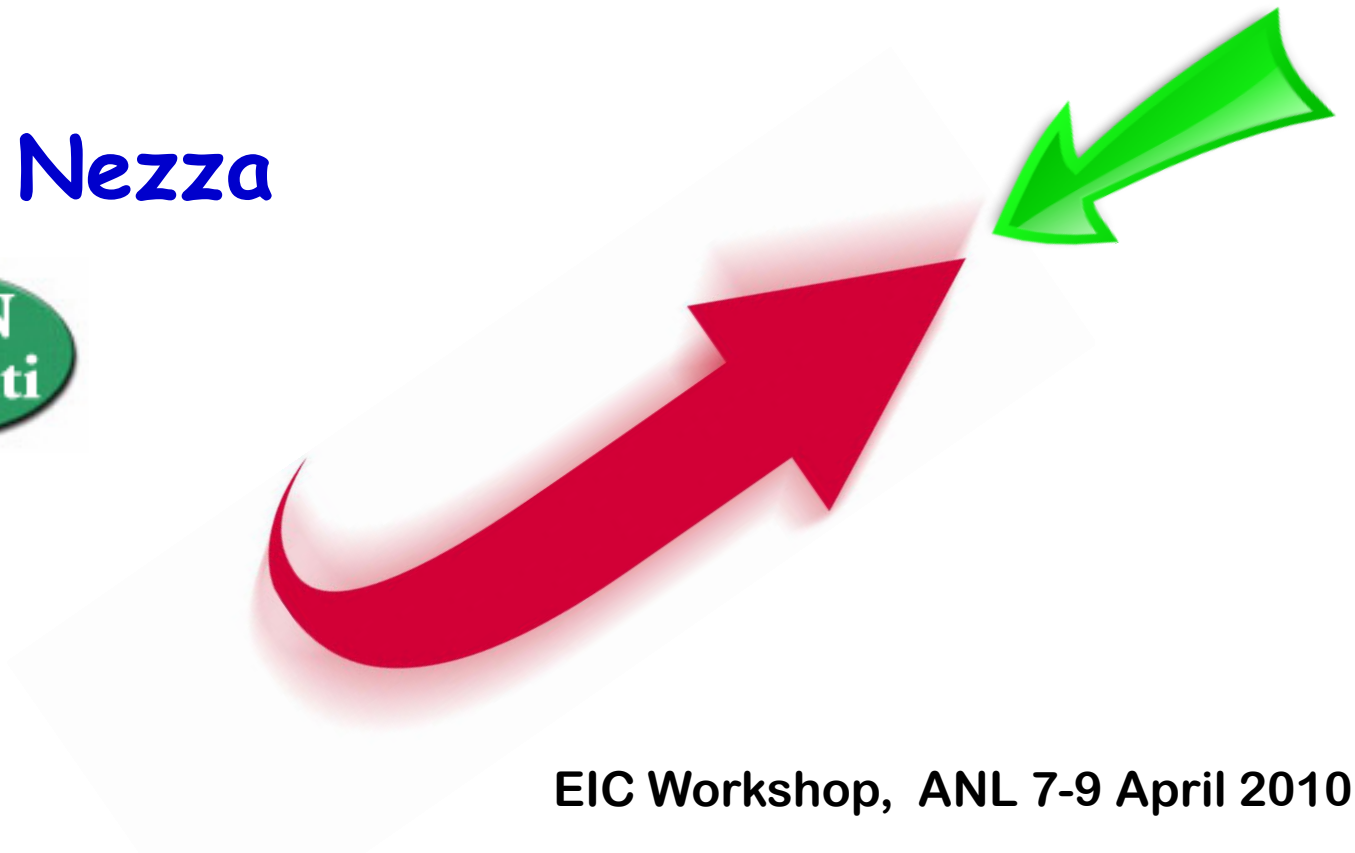
Hadron propagation in nuclei: HERMES overview

Pasquale Di Nezza

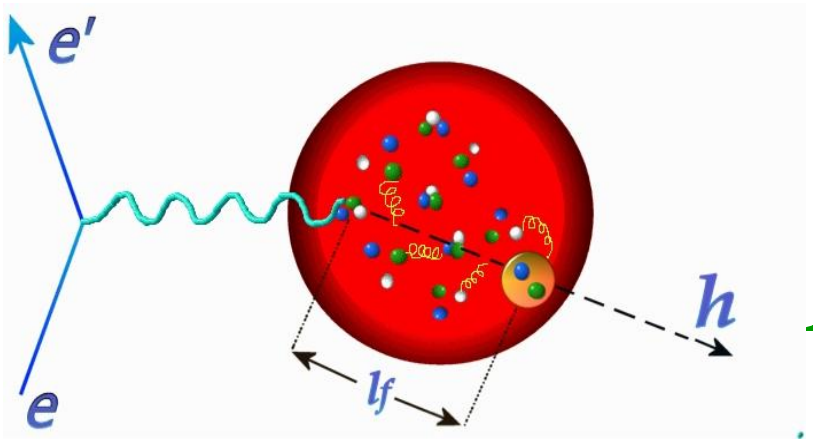
INFN Frascati



EIC Workshop, ANL 7-9 April 2010

The birth of a hadron in DIS

Observations: reduction of multiplicity of fast hadrons due to both *hard partonic* and *soft hadron interaction*, correlation for double-h production, p_t-broadening



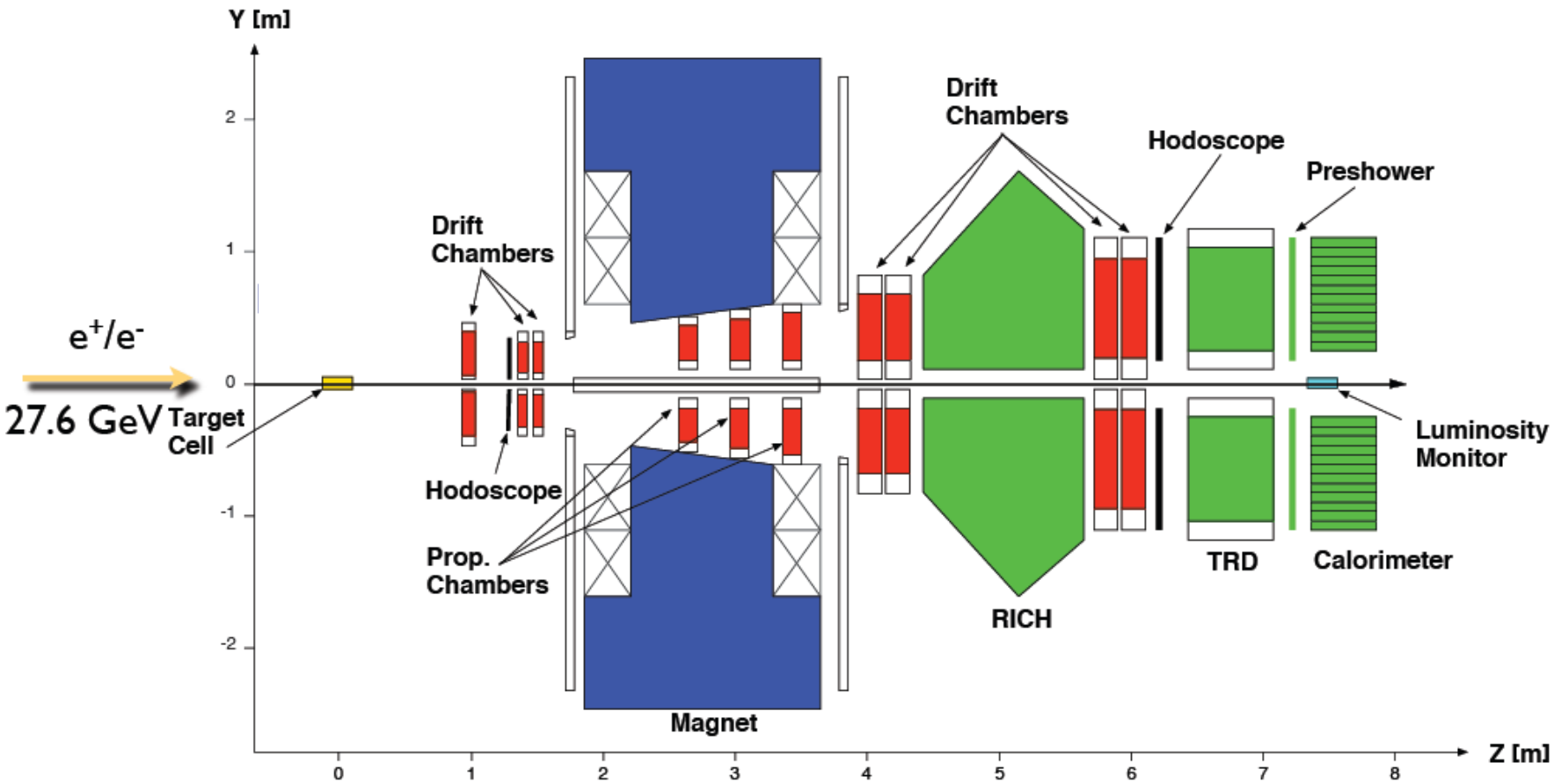
All nuclear effects in Semi-Inclusive DIS are FSI

Keywords:

- Underlying effects → are well tested, static and known density of the system
- Partonic distribution functions → access to their modification (EMC eff., shadowing, gluon saturation at low x, ...)
- Partonic fragmentation functions → access to their modification (parton energy loss, scattering, pre-hadronic formation and interaction, hadron formation time)

HERMES: 27.6 GeV e^{+-}-beam on p, D, He, N, Ne, Kr, Xe

EPJ C20 (2001) 479	Single hadron attenuation
PLB 577 (2003) 37	Single hadron attenuation (hadron PiD)
PRL 96 (2006) 162301	Double hadron (correlation) attenuation
NPB 780 (2007) 1	Hadron attenuation data summary paper
PLB 684 (2010) 114	Direct p_t-broadening measurement



Hadron multiplicity ratio

$$R_M(z,\nu,Q^2,p_t^2) = \frac{\left.\dfrac{N_h(z,\nu,Q^2,p_t^2)}{N_{DIS}}\right|_A}{\left.\dfrac{N_h(z,\nu,Q^2,p_t^2)}{N_{DIS}}\right|_D} \propto \frac{\left.\dfrac{\Sigma e_f^2 q_f(x,Q^2,p_T^2) D_f^h(z,Q^2,k_T^2)}{\Sigma e_f^2 q_f(x,Q^2,p_T^2)}\right|_A}{\left.\dfrac{\Sigma e_f^2 q_f(x,Q^2,p_T^2) D_f^h(z,Q^2,k_T^2)}{\Sigma e_f^2 q_f(x,Q^2,p_T^2)}\right|_D}$$

Leptonic variables : ν (or x) and Q^2

Hadronic variables : z and p_t^2

Different nuclei : size and density

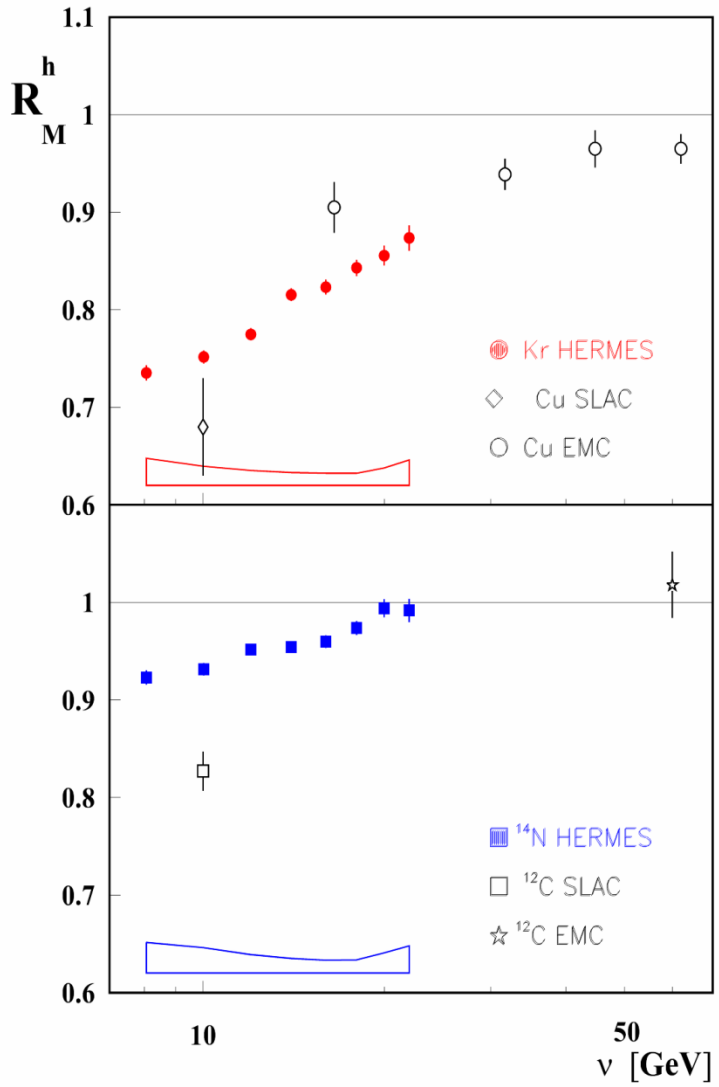
Different hadrons : flavors and mixing of FFs

Double-ratio: no need for acceptance corrections

Systematic uncertainties are minimize in the double-ratio

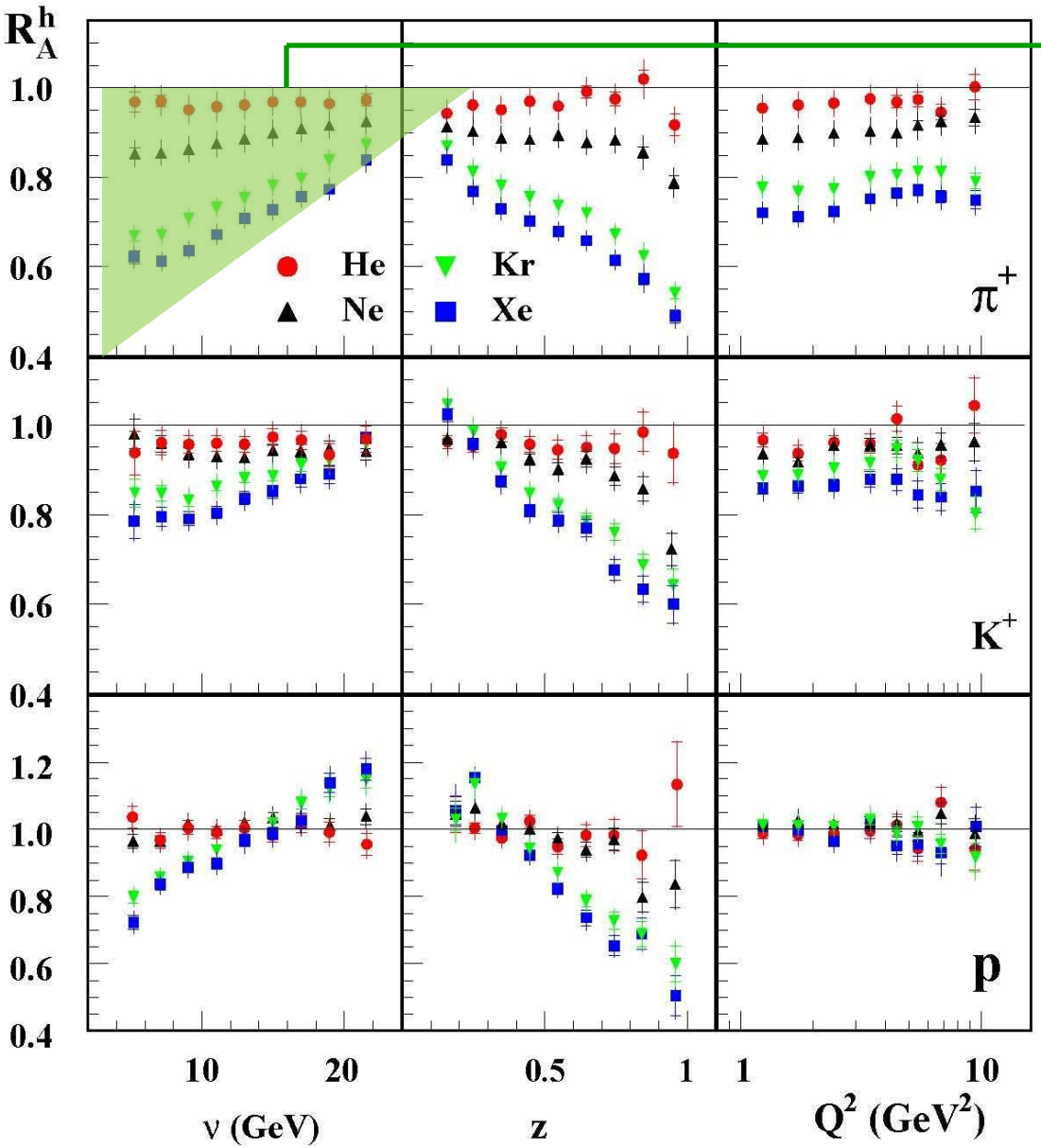
HERMES vs SLAC/EMC

HERMES PLB 577 (2003) 37
EMC Z.Phys. C52 (1991) 1
SLAC PRL 40 (1978) 1624



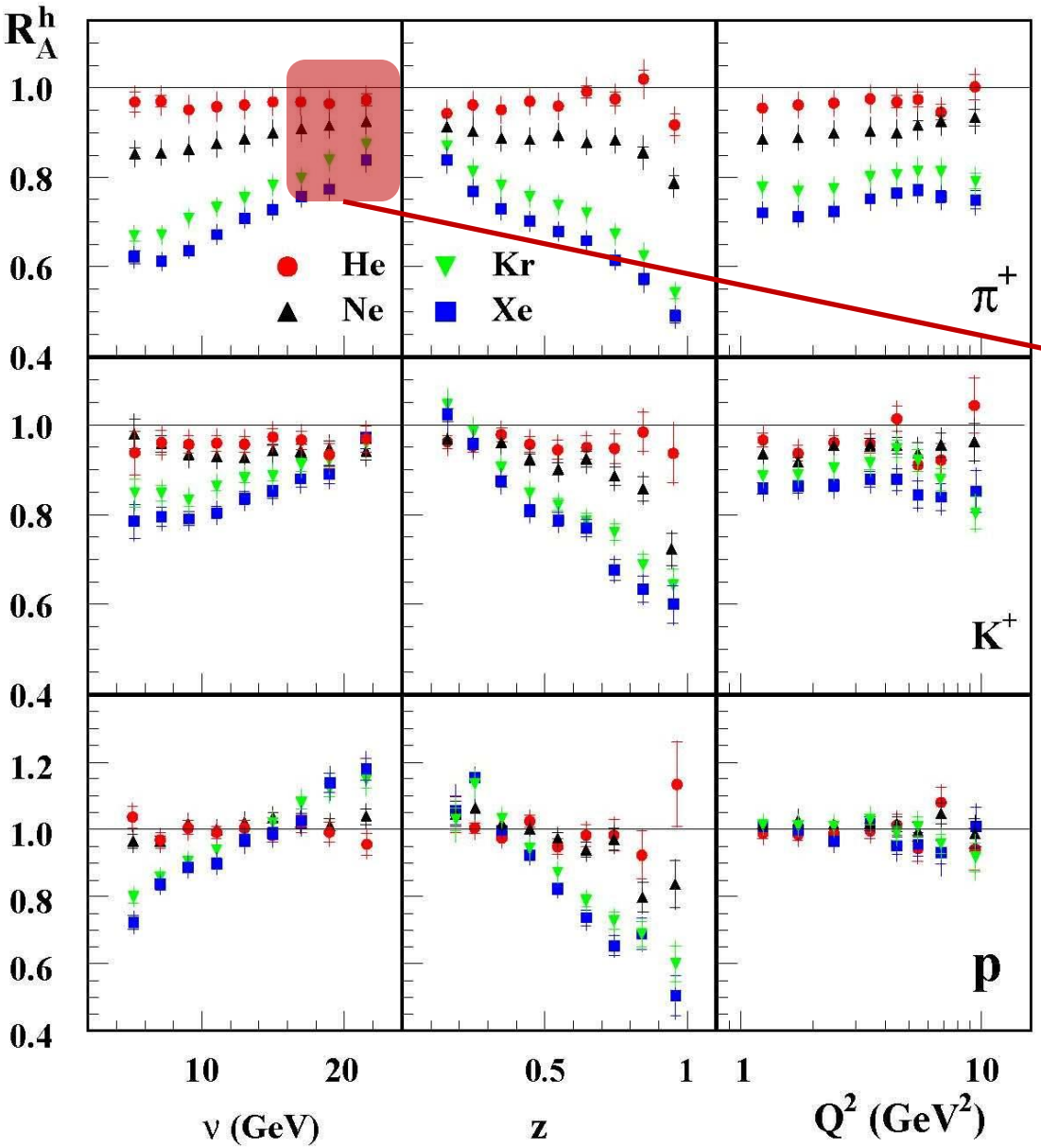
- Clear nuclear attenuation effect for charged hadrons
- Increase with ν consistent with EMC data at higher energy
- Discrepancy with SLAC due to the *EMC effect*, not taken into account at that time
- HERMES kinematics is well suited to study quark propagation and hadronization

Multiplicity ratio: hadron types



Strong A mass effect

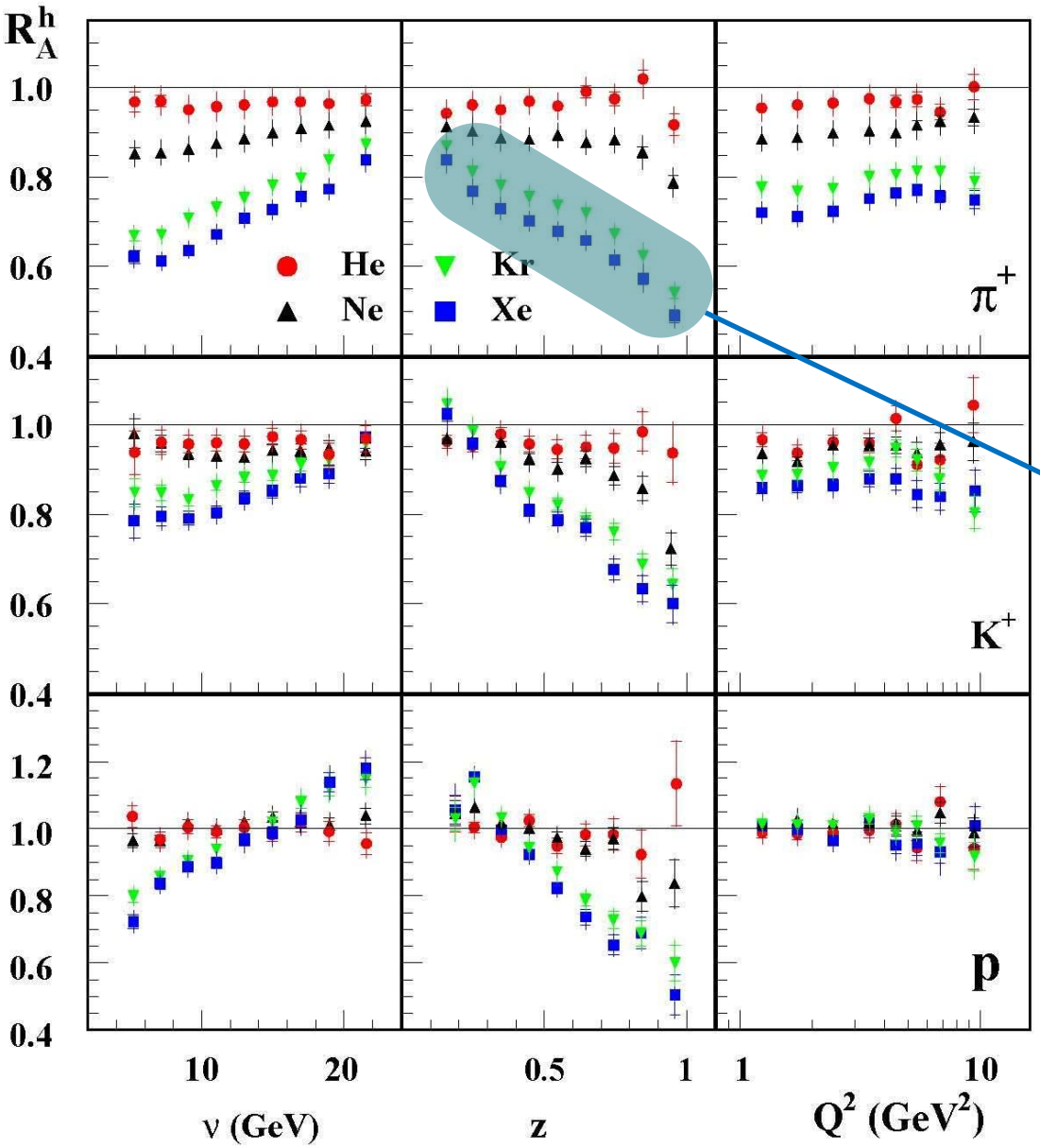
Multiplicity ratio: hadron types



Strong A mass effect

Smaller effect at high ν
→Lorentz boost

Multiplicity ratio: hadron types

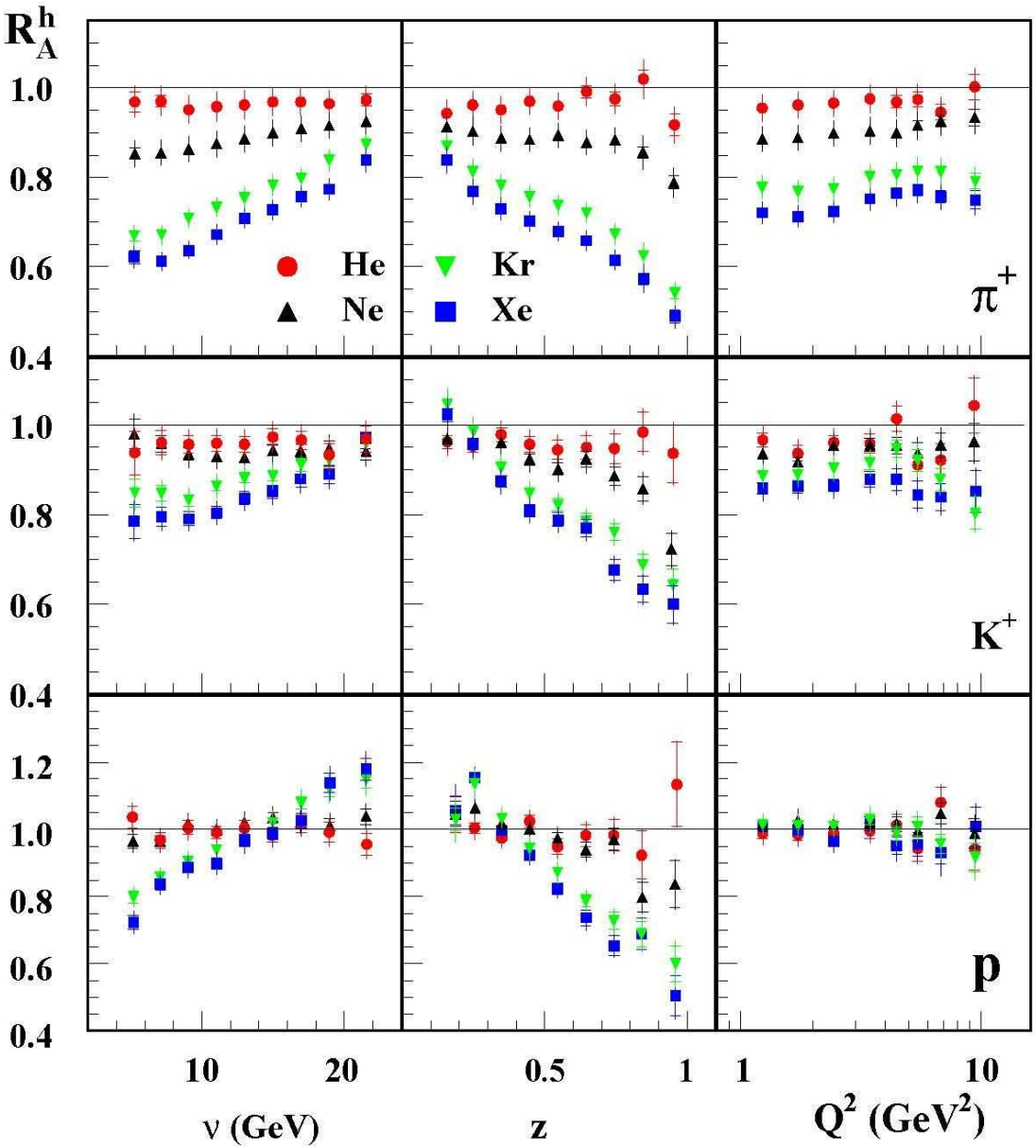


Strong A mass effect

Smaller effect at high ν
→Lorentz boost

z behaviours
Partonic: energy loss +
FF modification
Hadronic: h formation length
+ absorption

Multiplicity ratio: hadron types

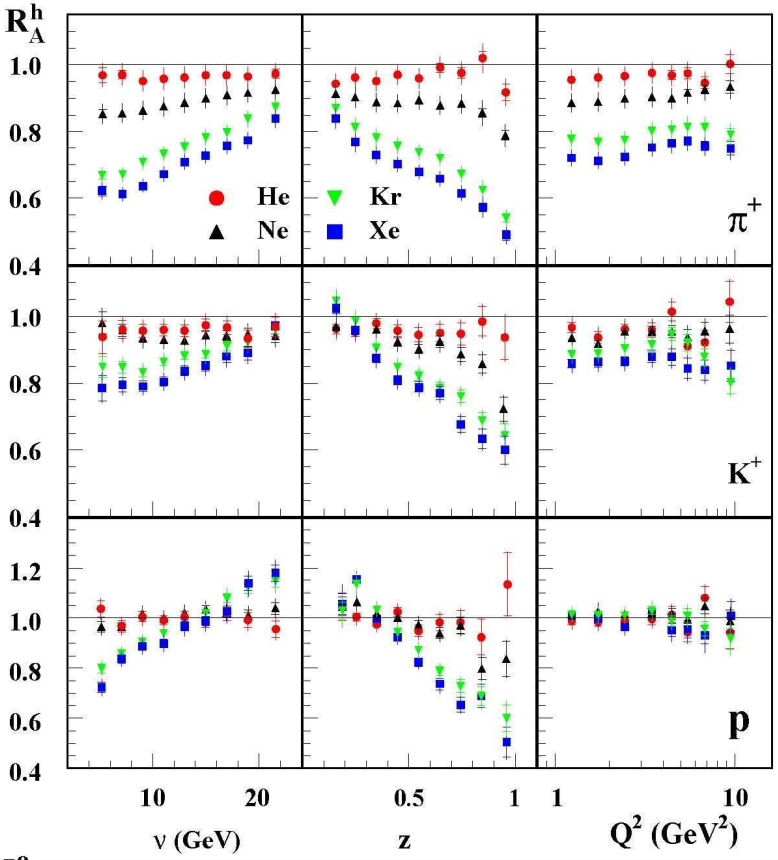


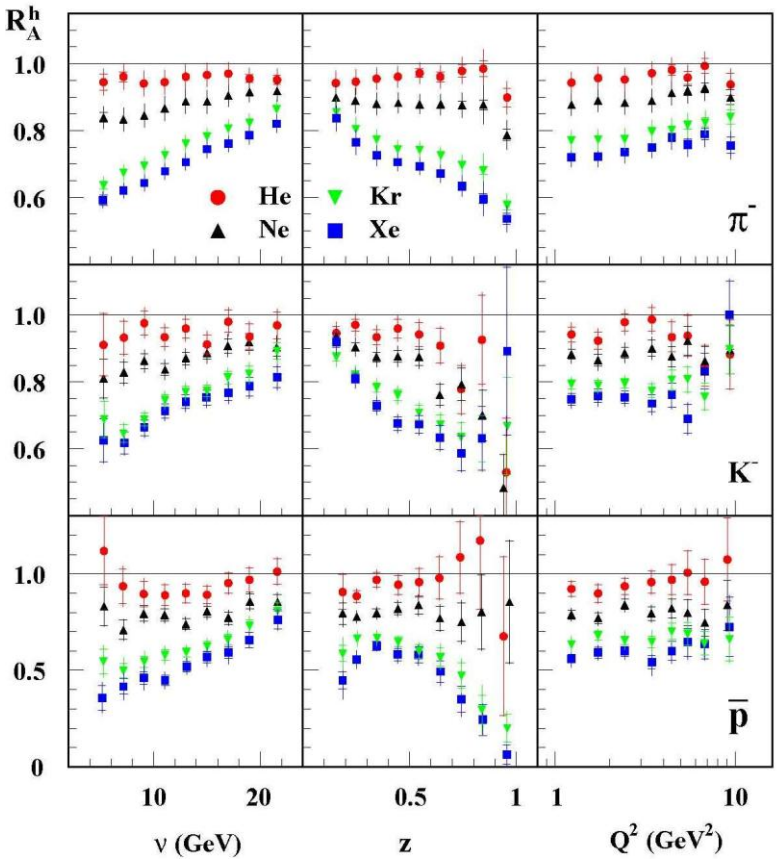
Strong A mass effect

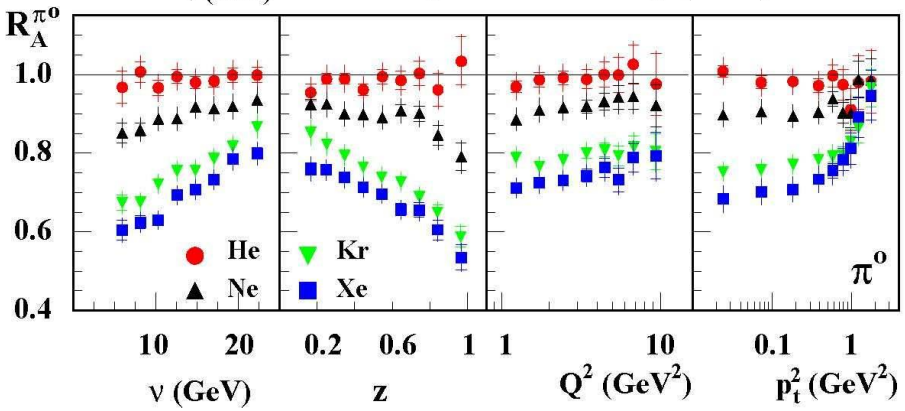
Smaller effect at high ν
→Lorentz boost

z behaviours
Partonic: energy loss +
FF modification
Hadronic: h formation length
+ absorption

Multiplicity ratio: hadron types





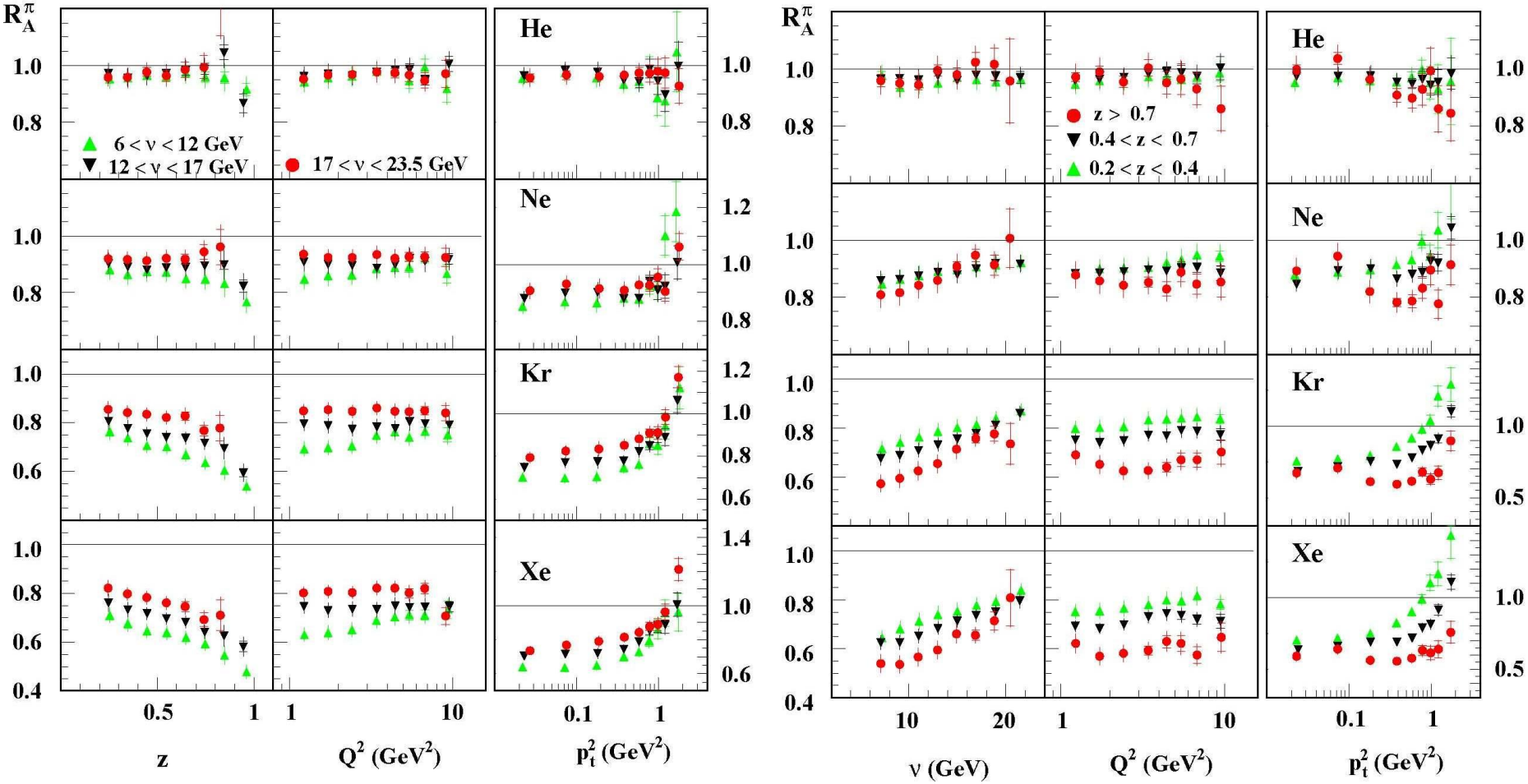


$\pi^+ = \pi^- = \pi^0 \sim K^-$

$K^+ < K^-$

$p < \bar{p}$, $p < \pi$, $p < K$

Multiplicity ratio 2D:
service for fit/model "builders"

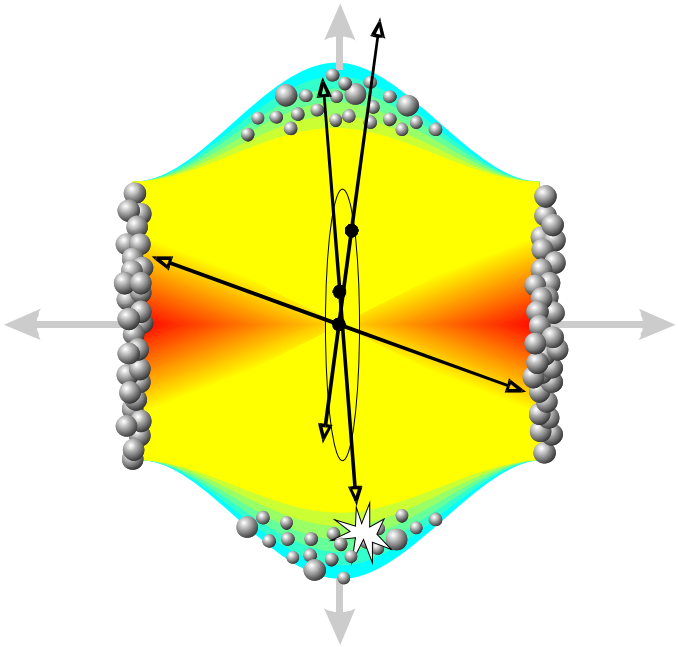


Reduced correlations among z, ν, p_t

Dependence of the Cronin suppressed at high z

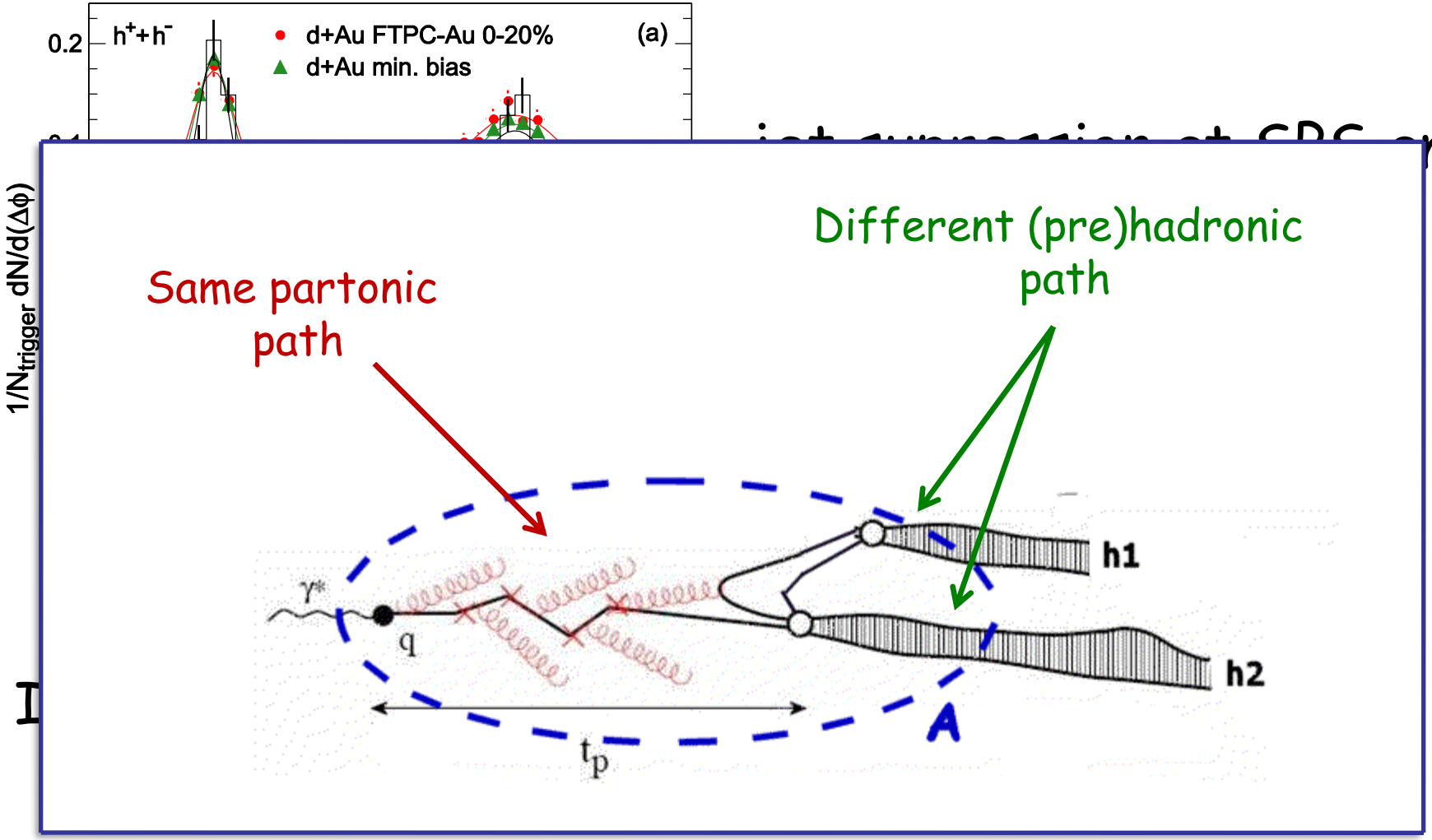
Cronin effect for baryons larger than for mesons

Hadronic or partonic effect (?)



jet supression at SPS and RHIC (partly due) to hadronic FSI ?

Hadronic or partonic effect (?)



- If partonic effects dominate: prod. of double-hadron is correlated
- If absorption dominates: prod. of double-hadron is UNcorrelated

Hadronic or partonic effect (?)

$$R_{2h}(z_2) = \frac{\left(\frac{d^2N(z_1,z_2)}{dN(z_1)}\right)_A}{\left(\frac{d^2N(z_1,z_2)}{dN(z_1)}\right)_D}$$

Number of events with at least 2 hadrons ($z_{leading}=z_1>0.5$)

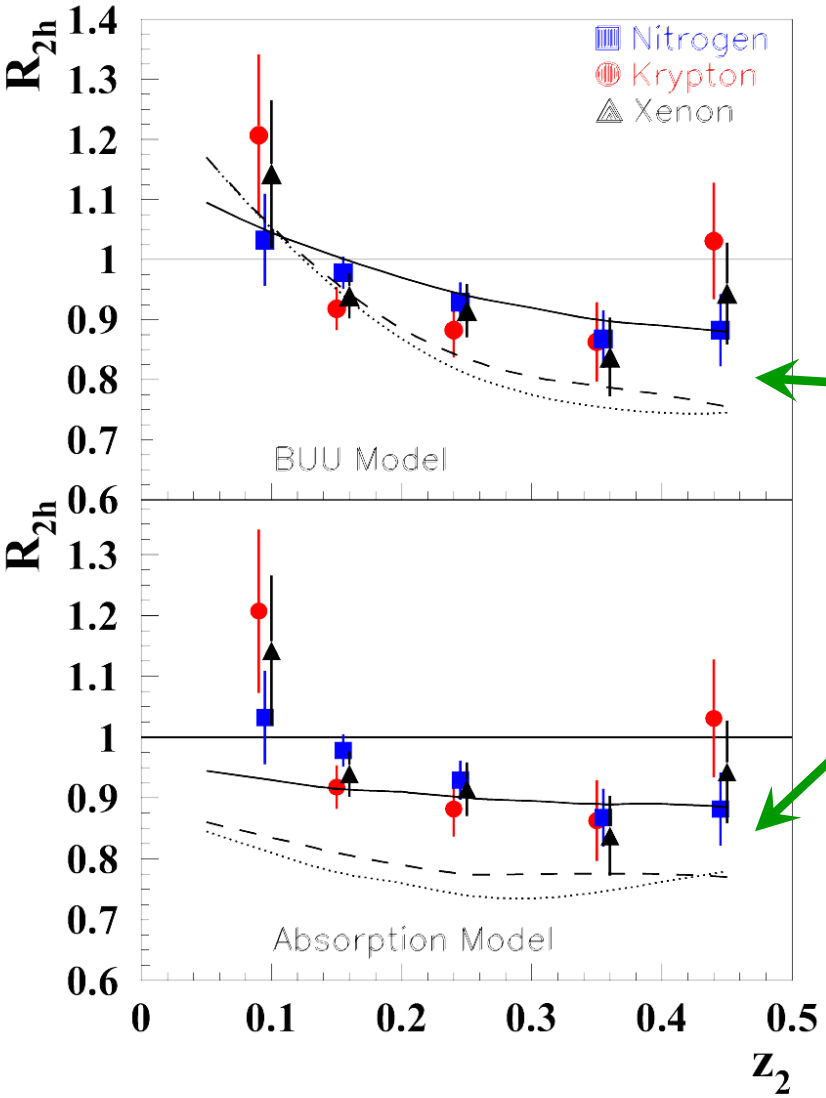
Number of events with at least 1 hadron ($z_1>0.5$)

If mainly <u>partonic effects</u> (correlated): double-hadron over single hadron ratio in nucleus and deuterium is expected to be only slightly A-dependent.

If mainly <u>hadronic effects</u> (uncorrelated): double-hadron over single hadron ratio is expected to decrease with A.

Two-hadron production

No +- and -+ → no rank 2, only 1,3



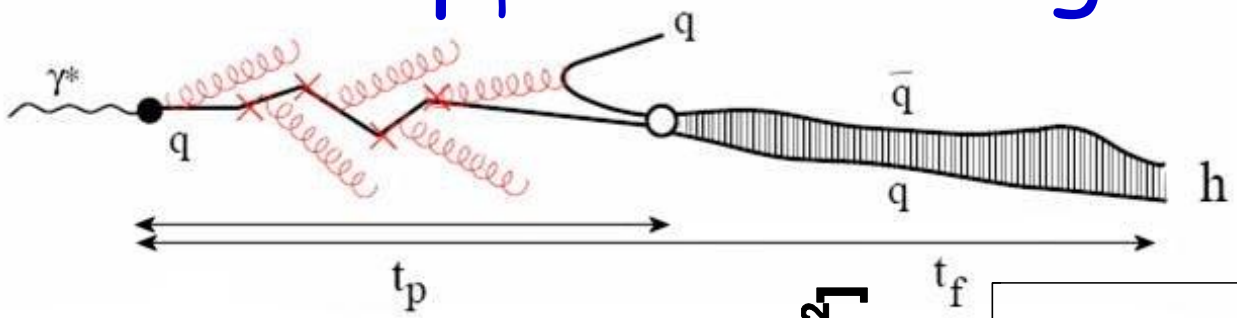
- Small effect in R_{2h} compared to single hadron multiplicity
- Small A-dependence

Pre-hadronic FSI described by a trasport code

Purely absorptive treatment of hadronic FSI

Data do not support naïve expectations for pure absorptive hadronic FSI

p_t-broadening vs A

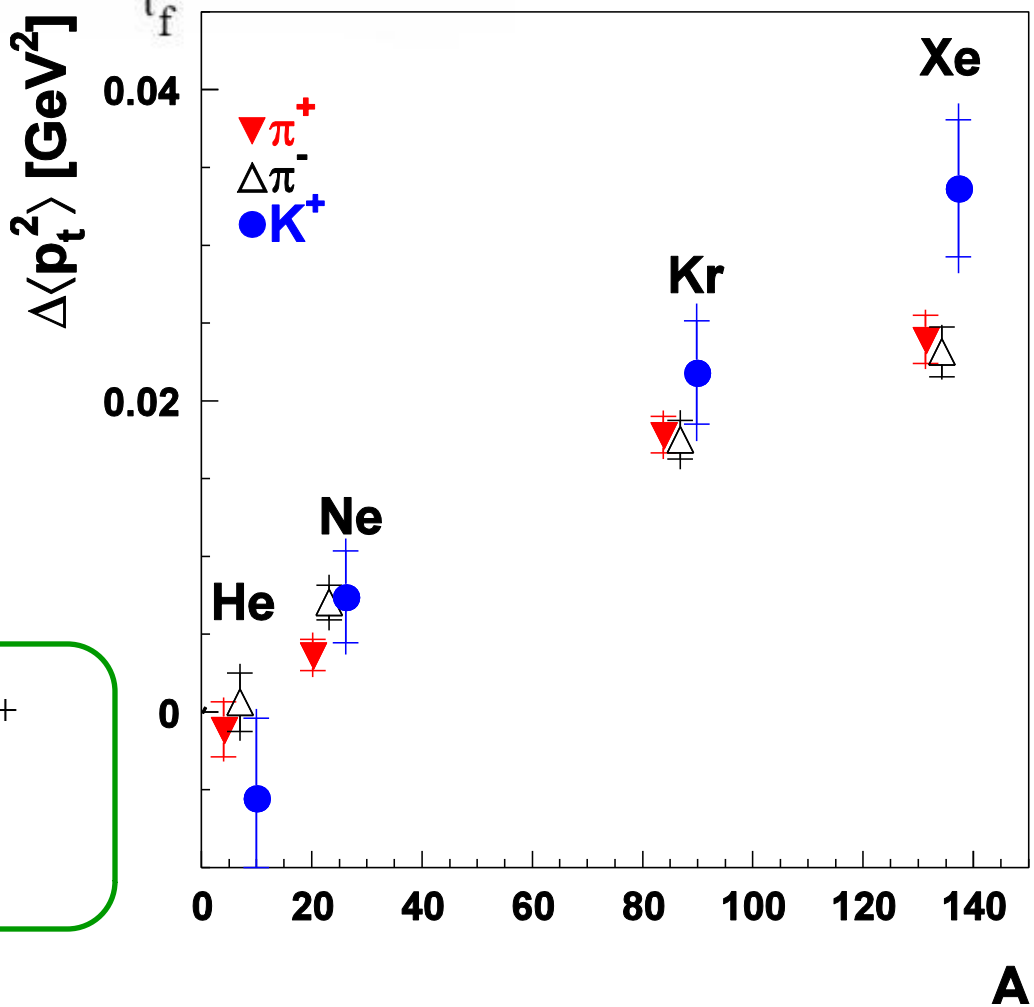


First measurement of p_t-broadening in DIS

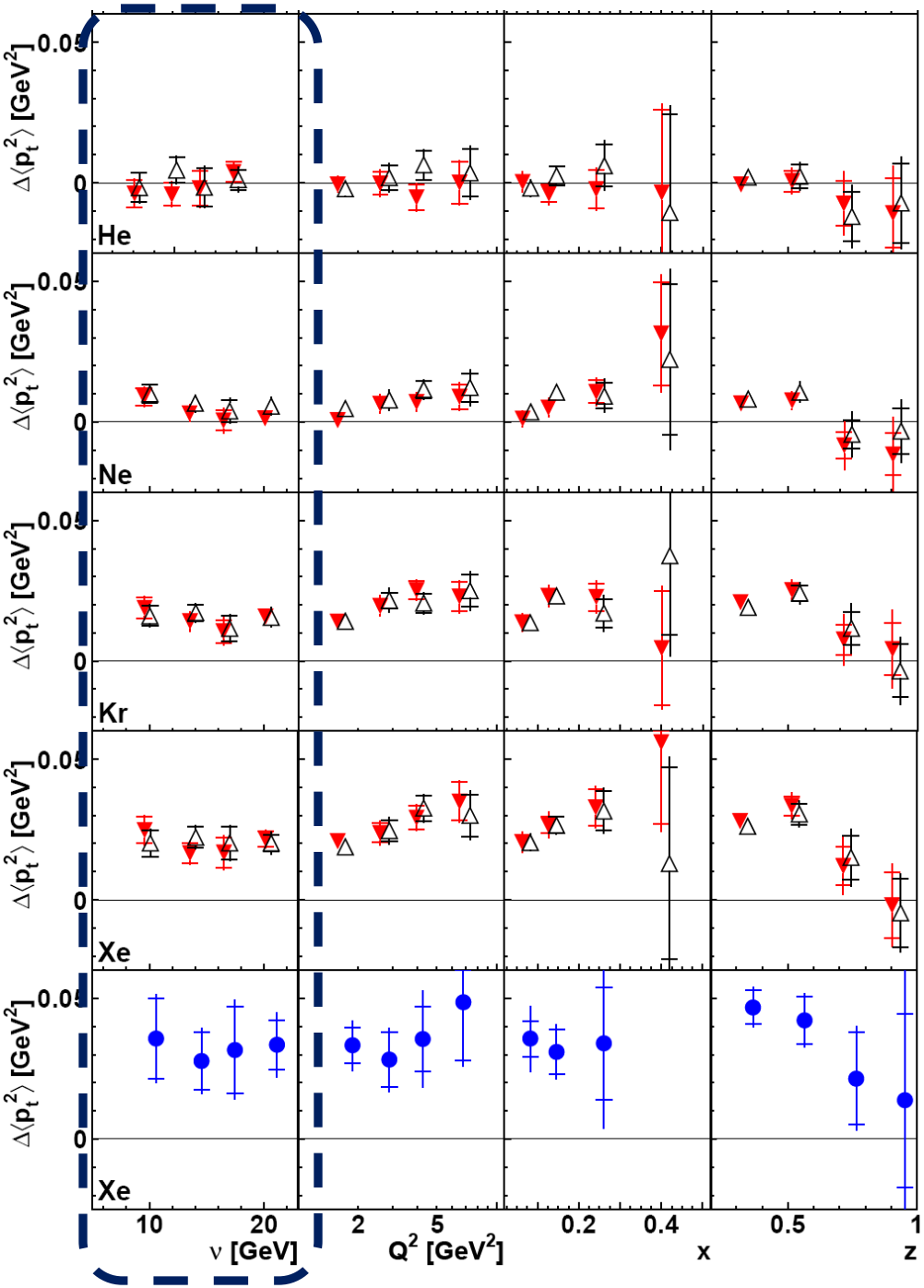
$$\Delta\langle p_t^2\rangle = \langle p_t^2\rangle_A - \langle p_t^2\rangle_D$$

By B.K. model :

$\Delta\langle p_t^2\rangle \sim t_p$

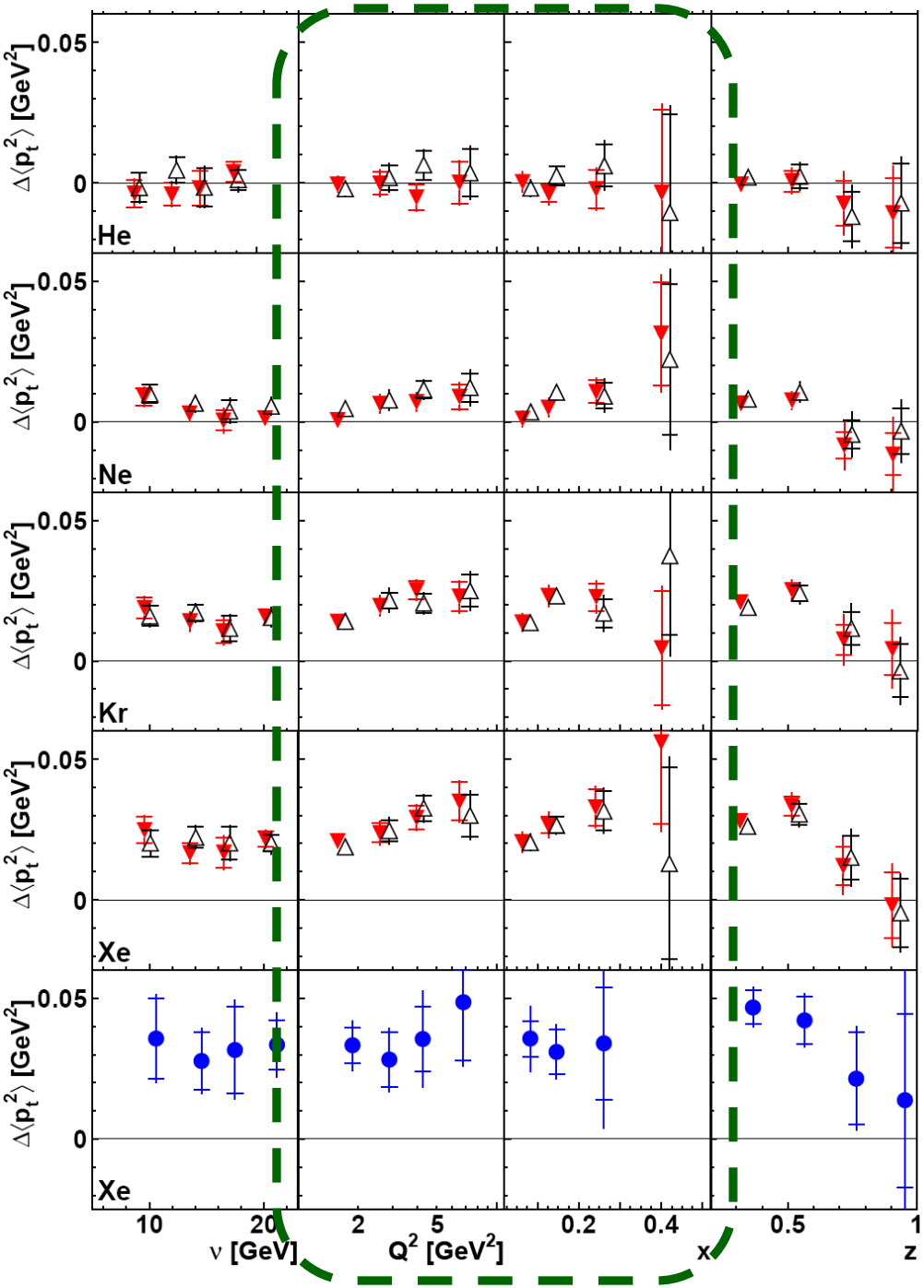


- Clear increase with A $\pi^+=\pi^- \leq K^+$
- No saturation observed (?)
- No clear functional form



No ν dep :

color neutralization formed mainly at the surface (outside) of the nucleus (<z>~0.4)



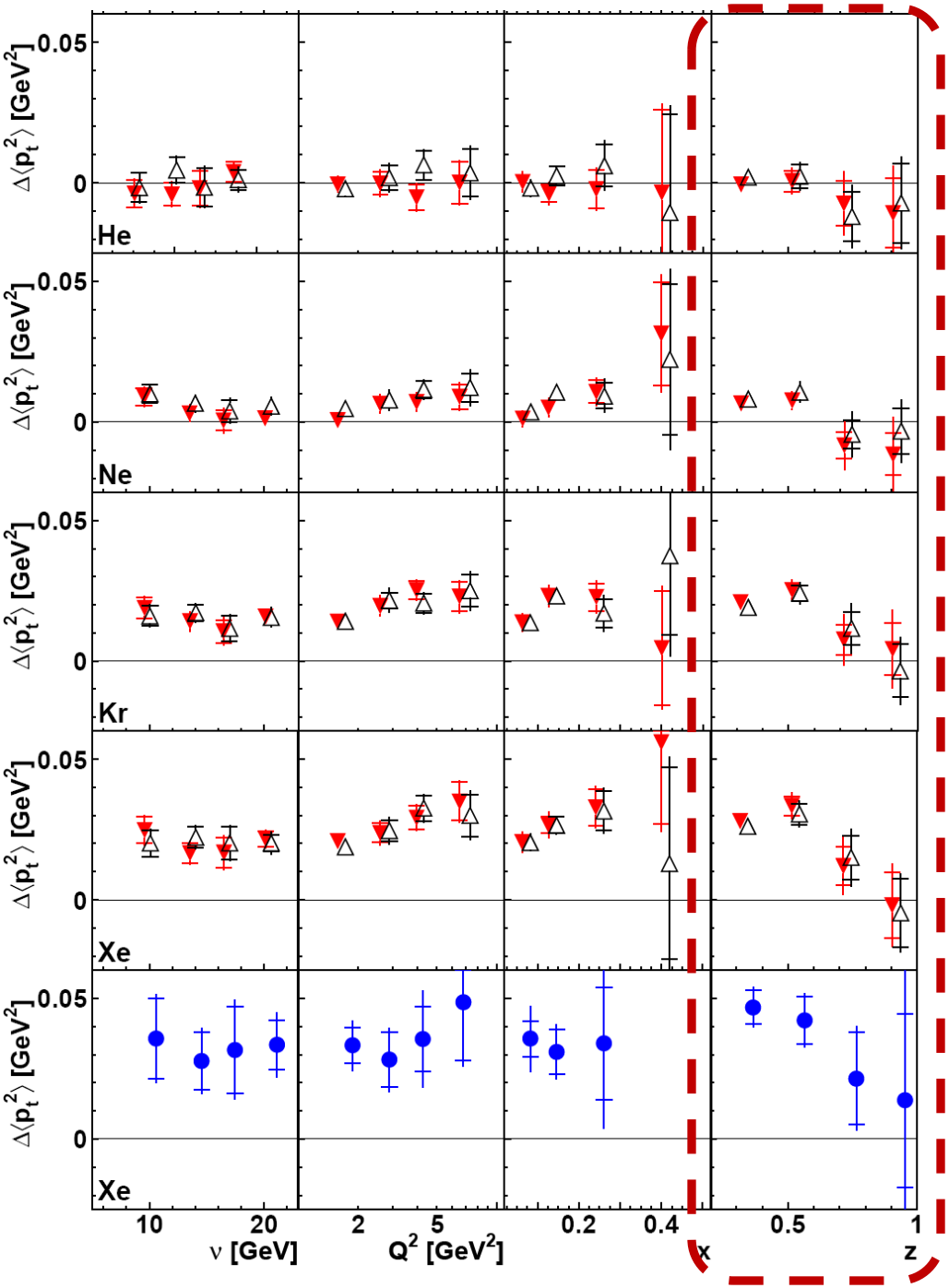
No ν dep :

color neutralization formed mainly at the surface (outside) of the nucleus (<z>~0.4)

Similar x-Q^2 behavior, strong correlation:

-slight increase?

-direct interpretation difficult: gluon radiation, decrease of t_p with Q^2?



No ν dep :

color neutralization formed mainly at the surface (outside) of the nucleus (<z>~0.4)

Similar x-Q^2 behaviour, strong correlation:

-slight increase?

-direct interpretation difficult: gluon radiation, decrease of t_p with Q^2?

p_t-broadening vanishes at $z \rightarrow 1$

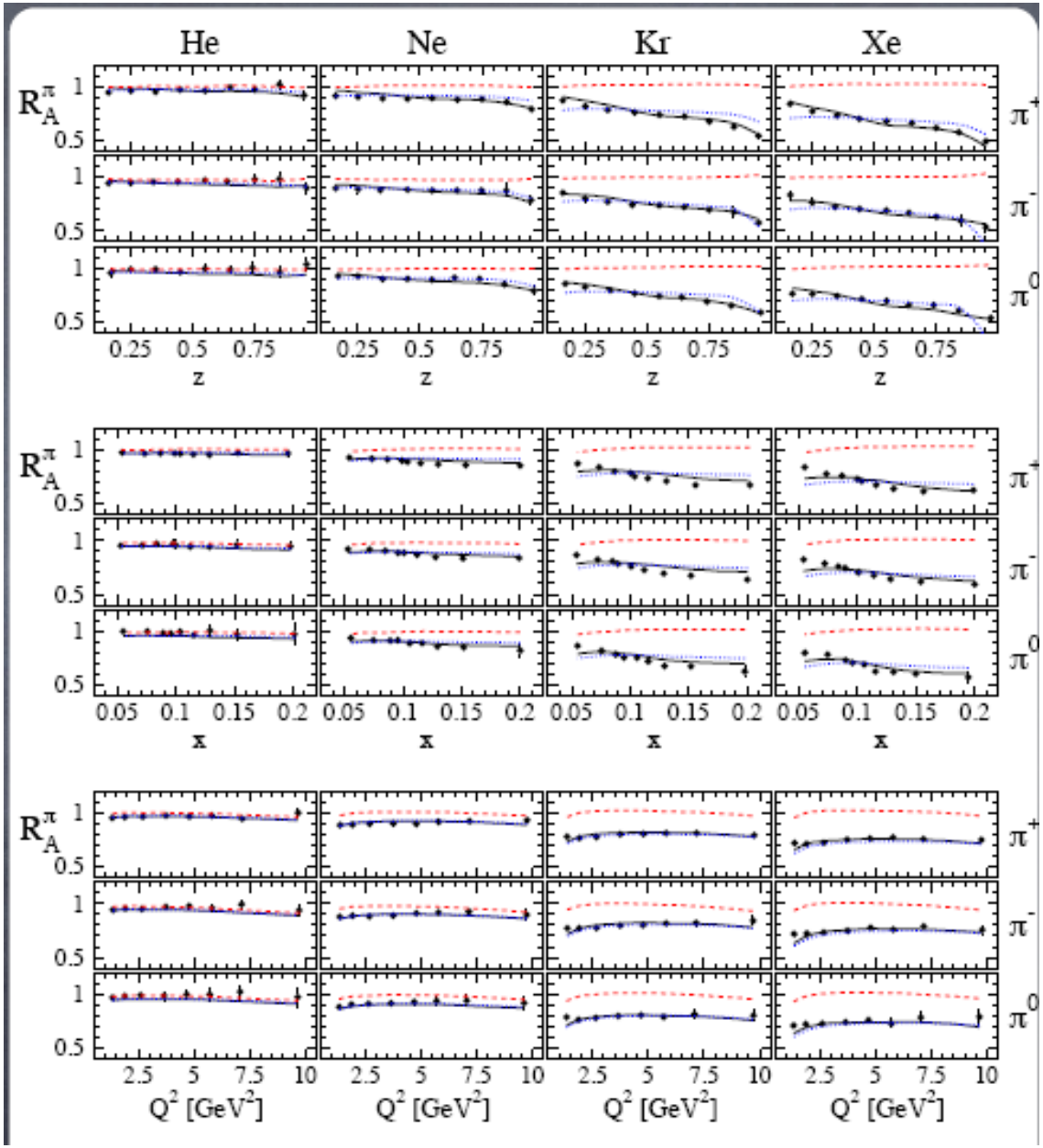
no energy loss at z=1

possible k_t modification? It is not evident by these data

nFF from HERMES + RHIC

R.Sassot, M.Stratmann, P.Zurita

PRL D81, 054001 (2010)



$$d\sigma^h(z) \propto \sum_f nPDF_f(x) \otimes d\sigma_f \otimes nFF_f^h(z)$$

Simultaneous fit to HERMES and RHIC data

$\chi^2 = 396.0$

381 data points

14 parameters

$\chi^2/d.o.f = 1.08$

nFF from HERMES + RHIC

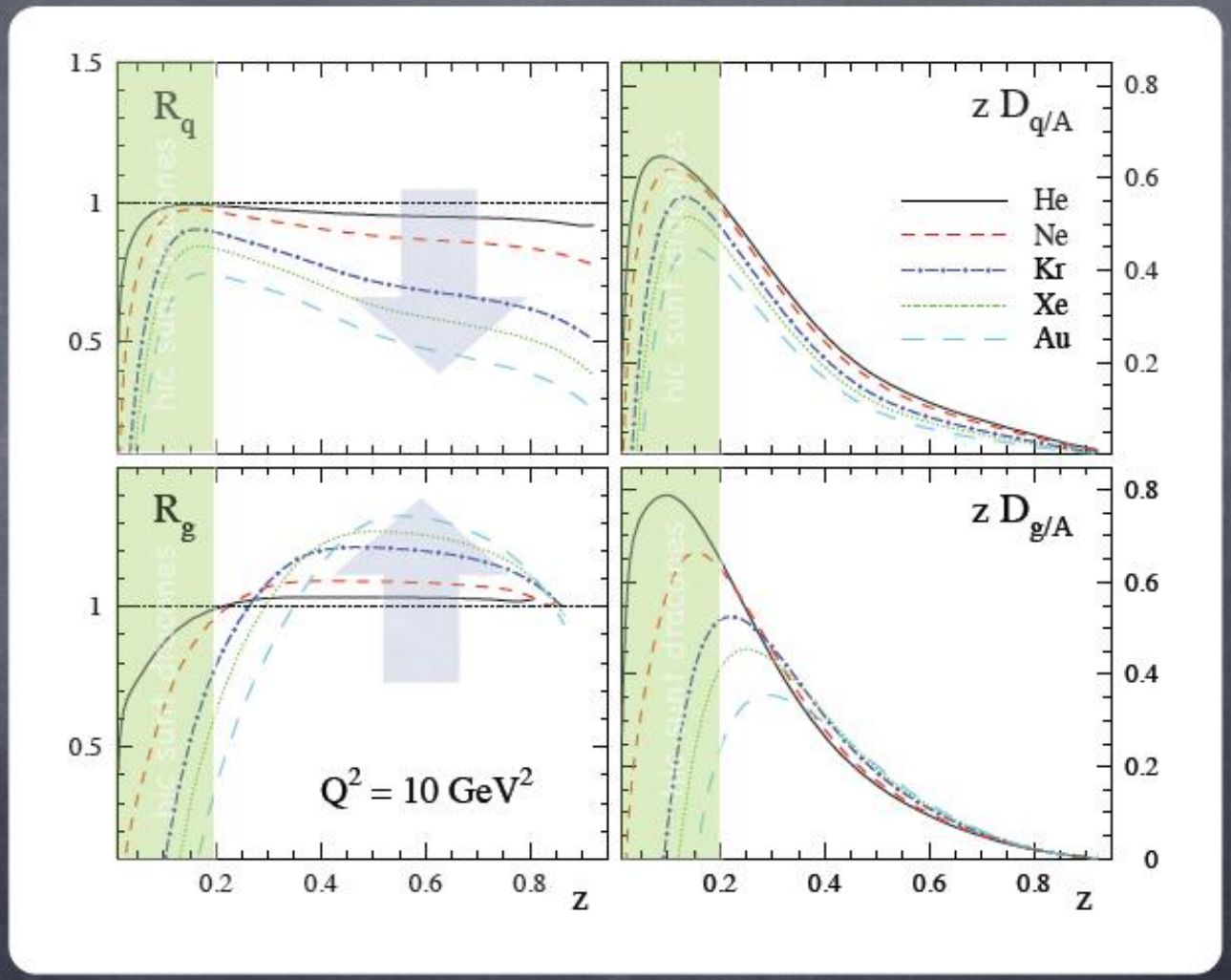
R.Sassot, M.Stratmann, P.Zurita

PRL D81, 054001 (2010)

$$R_q = \frac{D_{q/A}(z, Q^2)}{D_{q/p}(z, Q^2)}$$

quarks mimic SIDIS

gluons do the opposite



low z behavior not supported by data: artifact?

Nuclear data "helping" TMDs

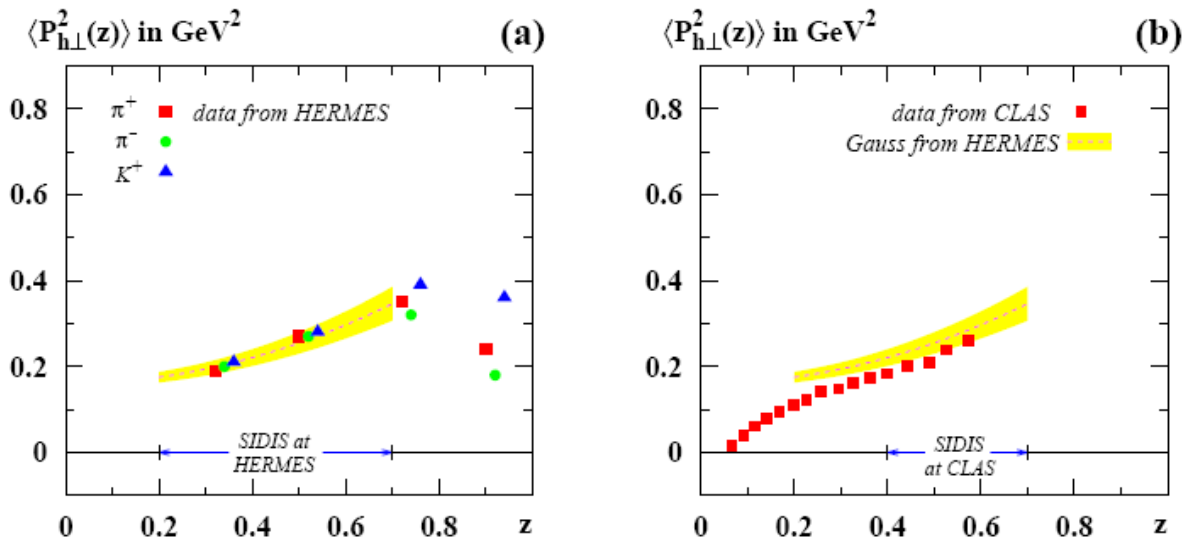
P.Schweitzer, T.Teckentrup, A.Metz

aiXiv:1003.2190

$$f_1^a(x, p_T) = f_1^a(x) \frac{\exp(-p_T^2/\langle p_T^2 \rangle)}{\pi \langle p_T^2 \rangle}$$

$$D_1^a(z, K_T) = D_1^a(z) \frac{\exp(-K_T^2/\langle K_T^2 \rangle)}{\pi \langle K_T^2 \rangle}$$

Unintegrated PDFs assume a gaussian distribution for intrinsic Kt



By nuclear data: Gaussian ansatze works very well in this kinematical domain
→ Model independent

Summary

Lepto-production in nuclei provides precious information to understand the space-time evolution of the hadronization process

- HERMES (& friends) with the largest data set for the nuclear effect on cold nuclear matter can be considered a reference for many other physics researches
- The definitive step will happen with EIC covering a much wider kinematic range and huge statistics
- EIC will have the possibility to formulate consistent pictures of nuclear effects in cold and hot nuclear matter