Hadron Multiplicities in SIDIS off Nucleons and Nuclei at HERMES

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•Inclusive Deep Inelastic Scattering (DIS) of leptons is a powerful tool to study the structure of the nucleon:

○ DIS on nucleons : unpolarized (F_1, F_2) or polarized (g_1, g_2) structure functions
○ DIS on nuclei : medium modification of structure function (shadowing, saturation, EMC effect, ..)

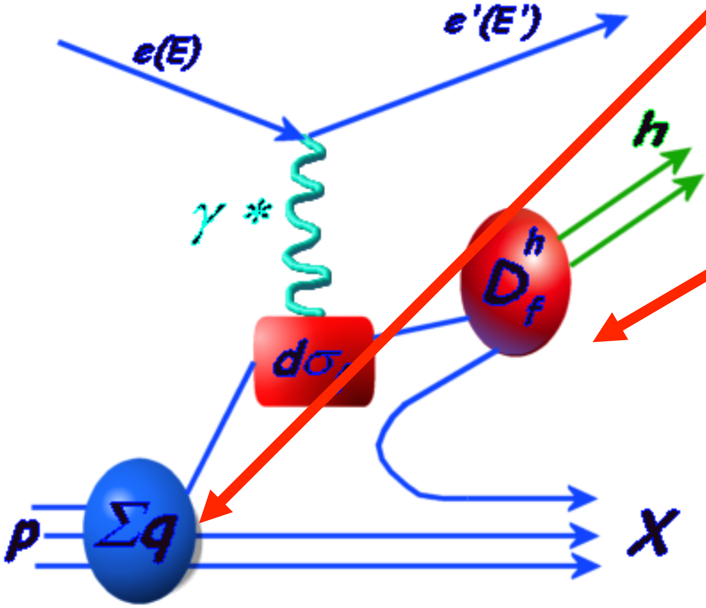
•**Semi-Inclusive Deep Inelastic Scattering (SIDIS)** of leptons is a much more powerful tool to study a huge variety of partonic distributions and partonic fragmentations:

○ SIDIS on nucleons : flavour decomposition of longitudinal unpolarised and polarised distributions (hadron tagging technique), transverse momentum dependent distribution,...

○ **SIDIS on nucleons : parton fragmentation in the vacuum**
○ **SIDIS on nuclei : medium modification of partonic propagation in the medium, hadronization effects, ..**

SIDIS on nucleon

$$d\sigma^{h}(z) \propto \sum q_f(x) \otimes d\sigma_f \otimes D_f^h(z)$$



Under the QPM and (LO) assumption:

DF FF

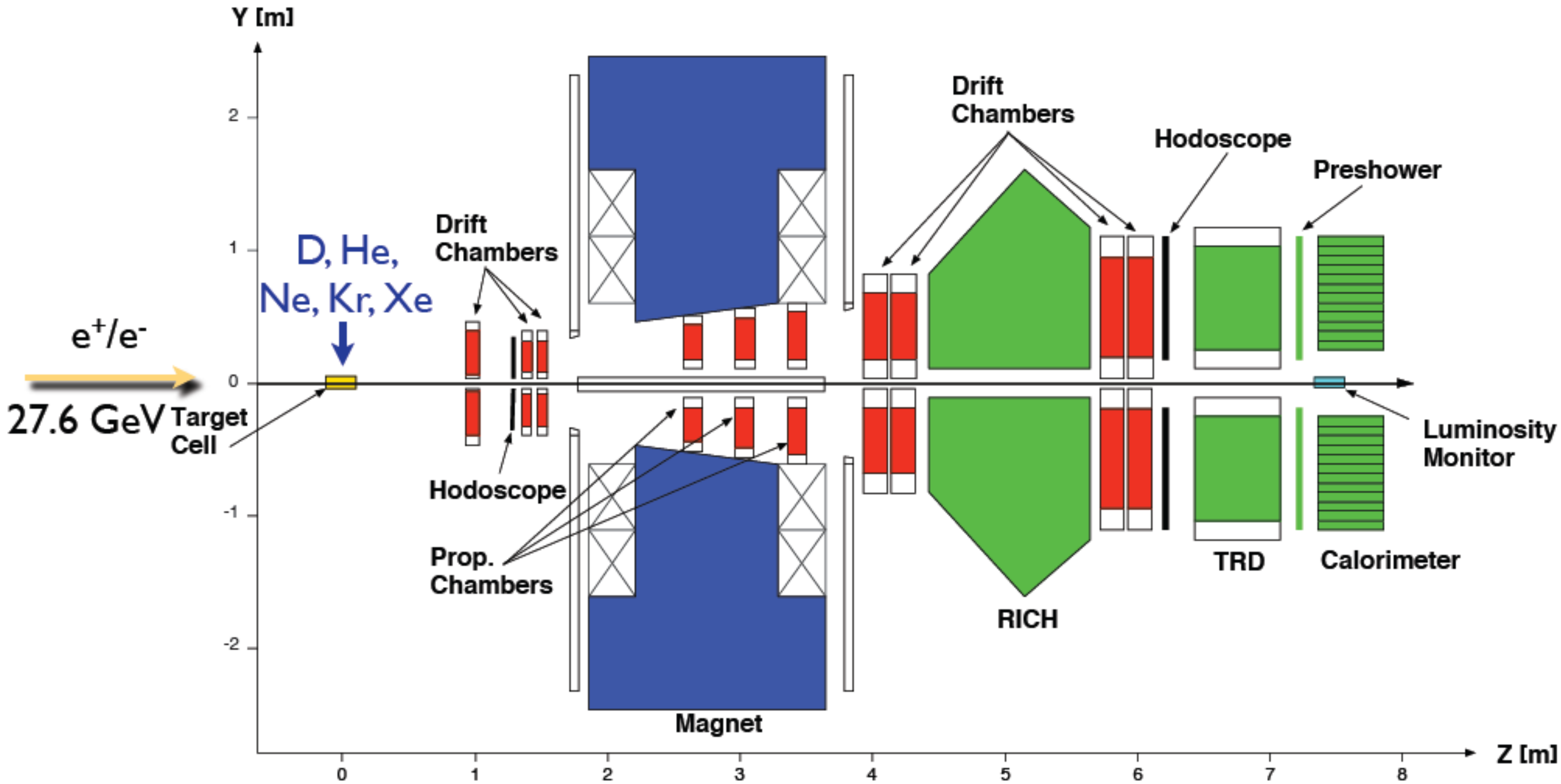
$$\frac{1}{N_e}\frac{d^2N_h(x,z)}{dxdz} = \frac{\sum_q e_q^2 q_f(x) D_f^h(z)}{\sum_q e_q^2 q_f(x)}$$

SIDIS hadron multiplicity open access to parton Fragmentation Function

FFs are measured with precision in e+e-
(+ recent p-p inclusive hadron RHIC data)
FFs follow pQCD Q^2-evolution like DFs
FFs scale with $z=E_h/\nu$ like DFs with x
FFs probabilistic interpretation like DFs

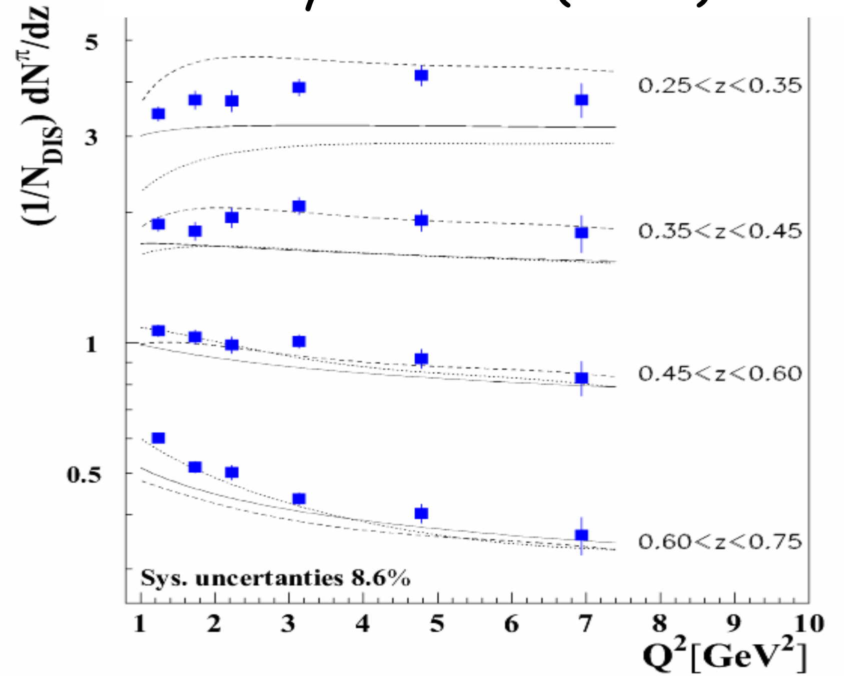
The HERMES experiment

- 27.6 GeV HERA e+/e- beam (data taking ended in 2007)
- pure gas p, D, He, N, Ne, Kr, Xe targets
- forward spectometer with clean e,γ,π,K,p separation
- $Q^2 > 1$ GeV^2, $W^2 > 10$ GeV^2, $0.023 < x < 0.6$, almost full range in z



SIDIS multiplicities : new results

Eur. Phys. J. C21 (2001) 599



First HERMES results: SIDIS pion multiplicities on hydrogen target agreed with NLO FF extrapolation at low-Q^2 from LEP data (BKK, KKP)

New (preliminary) HERMES results:

- full collected statistics
- 3D analysis in x,z,p_T ($Q^2,z,\ p_T$)
- identification and charge separation of π and K

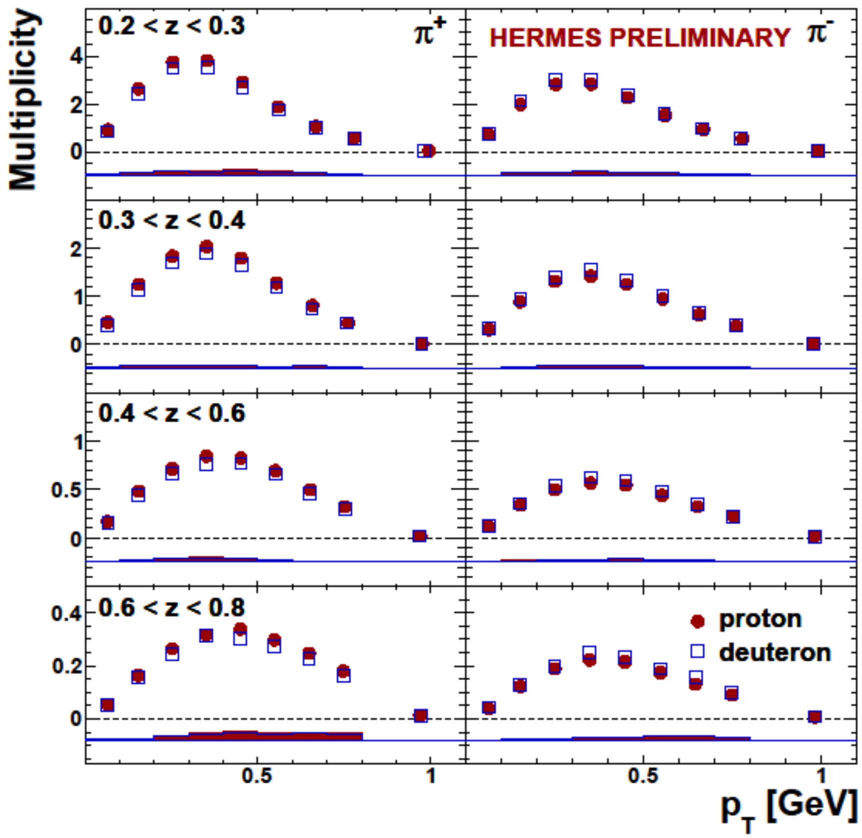
○ Corrections for detector efficiencies

○ 3D unfolding for smearing and acceptance effects

○ In-depth systematic analysis

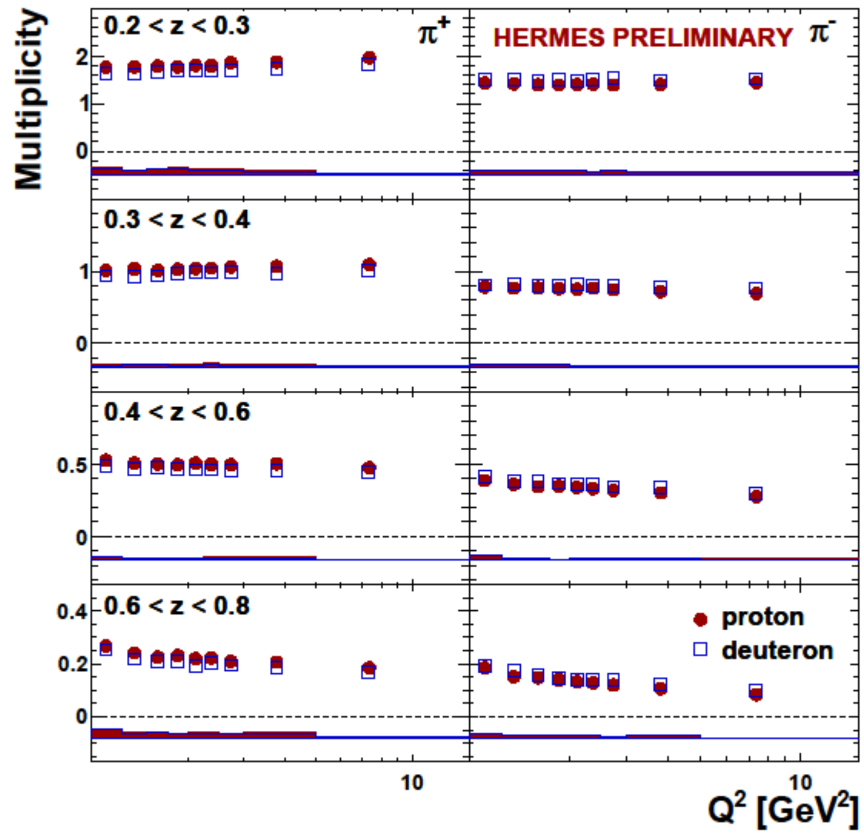
Projection vs p_T or Q^2

Access to :
the transverse intrisinc quark p_T
and fragmentation k_T



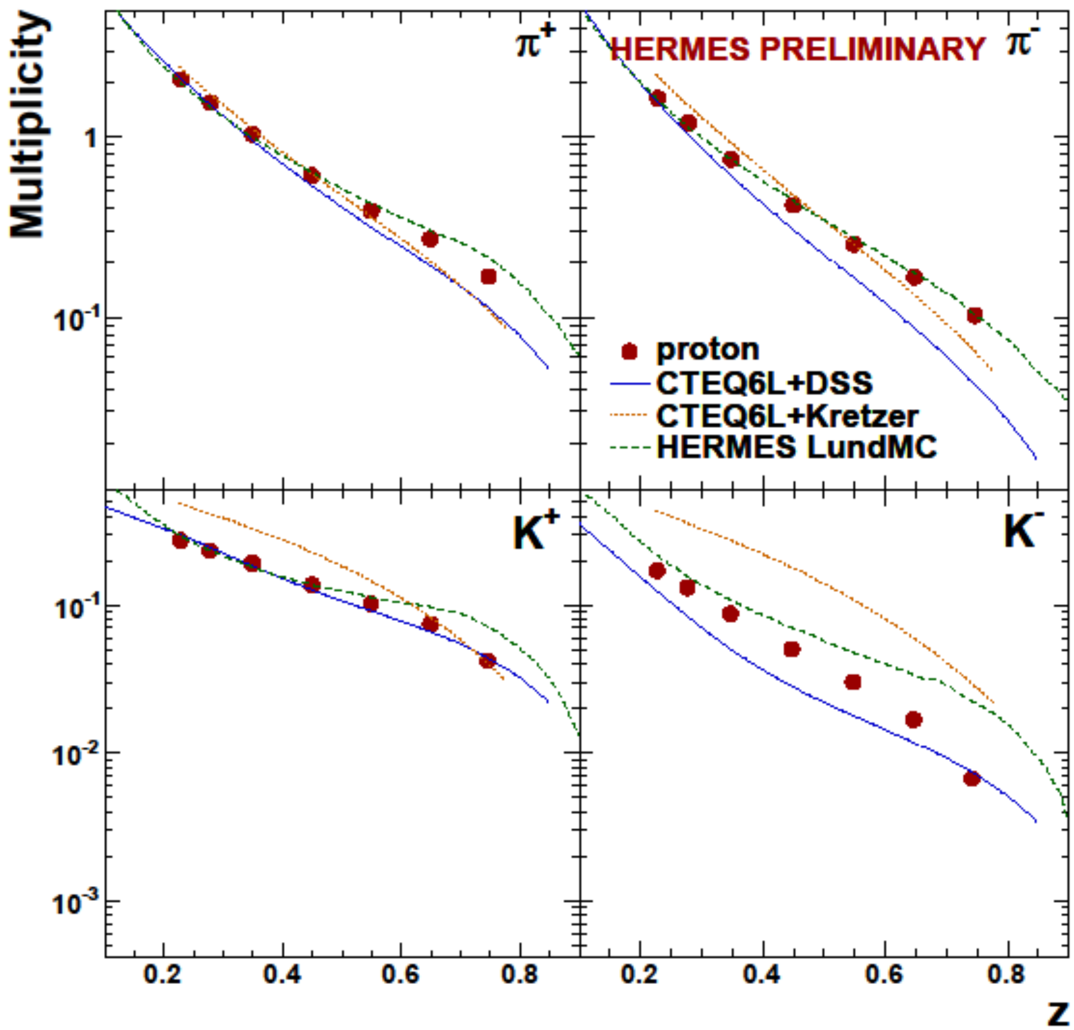
More strings breaks in LUND for unfav FF (broader p_T for negative hadrons)

Access to:
QCD evolution of FF at low Q^2



Q^2 dependence at large z
x-independence (factorization)

Projection (proton) vs z



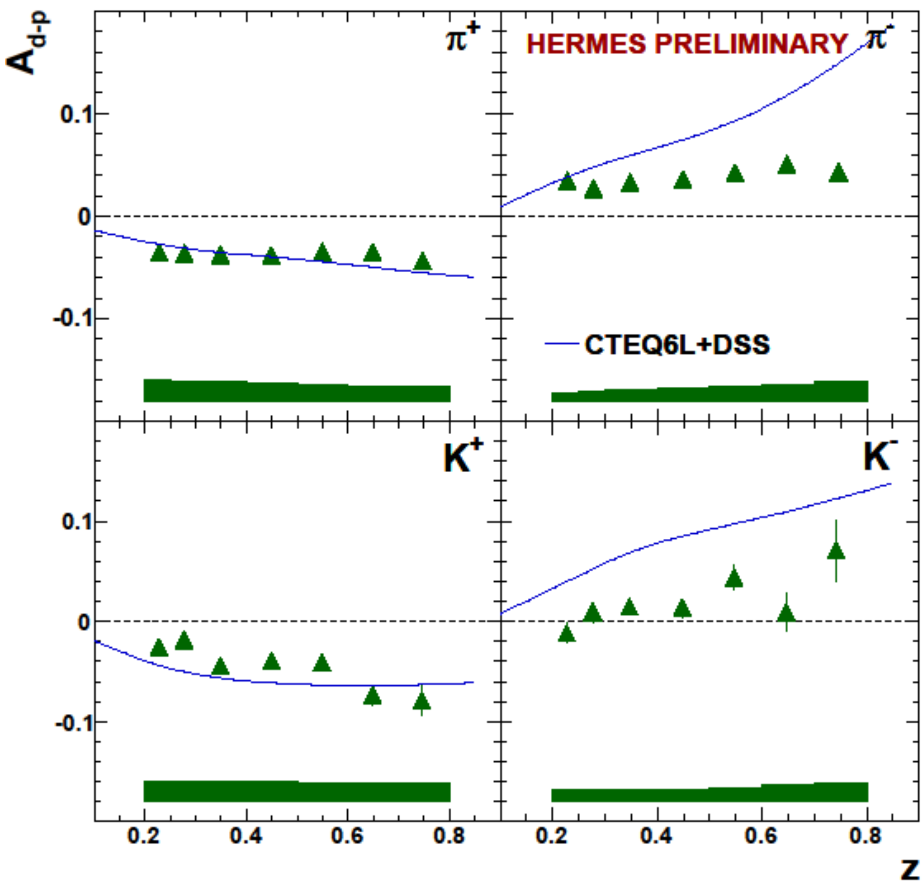
LO interpretation

- OK with CTEQ6 pdfs + DSS FF for π^+ and K^+
- OK with CTEQ6 pdfs + Kretzer FF for π^+ and π^-
- poor agreement for K^-

○ Role of unfavored FF
○ Role of NLO term for negative particles

Deuteron-proton multiplicity asymmetry

$$(M^h_d - M^h_p)/(M^h_d + M^h_p)$$



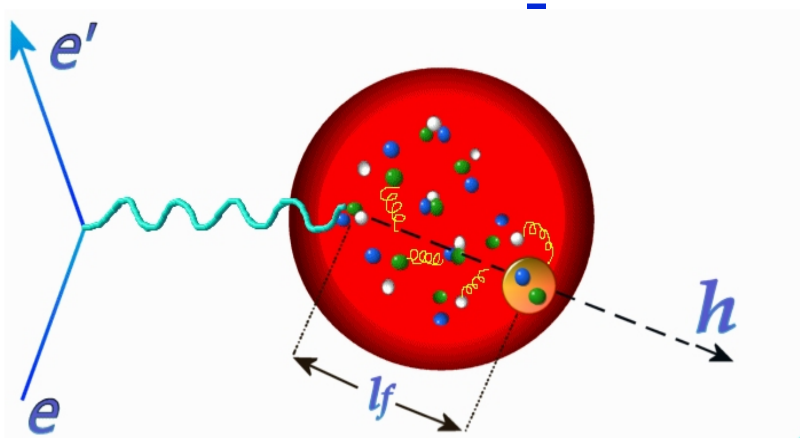
- Reflects different valence quark content
- Improve precision by syst. error cancellation

- Good agreement with LO (CTEQ6L + DSS FF) for positive hadrons

- Larger discrepancy for negative hadrons

What happens in a nuclear medium?

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 fragmentation functions → access to their modification (parton energy loss, scattering, pre-hadronic formation and interaction, hadron formation time)

Interpretation review → A.Accardi,F.Arleo,W.K.Brooks,D.D'Enterria,V.Muccifora Riv. Nuovo Cimento 32, 439 (2010)

Hadron multiplicity ratio

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

Leptonic variables : ν (or x) and Q^2

Hadronic variables : z and p_t^2

Different nuclei : size and density

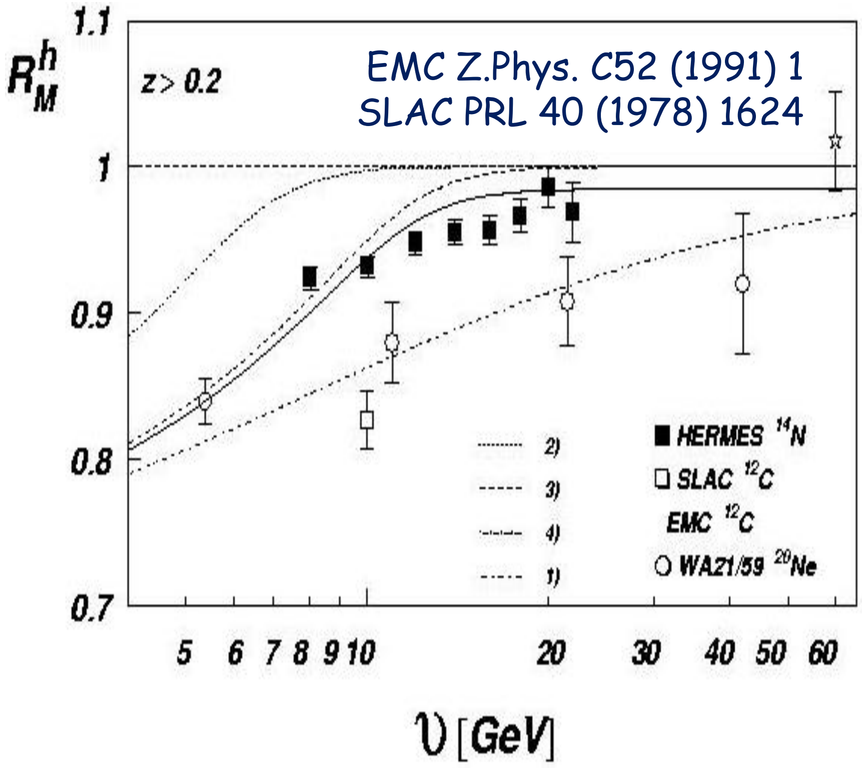
Different hadrons : flavors and mixing of FFs

Double-ratio: no need for acceptance corrections

Systematic uncertainties are minimize in the double-ratio

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

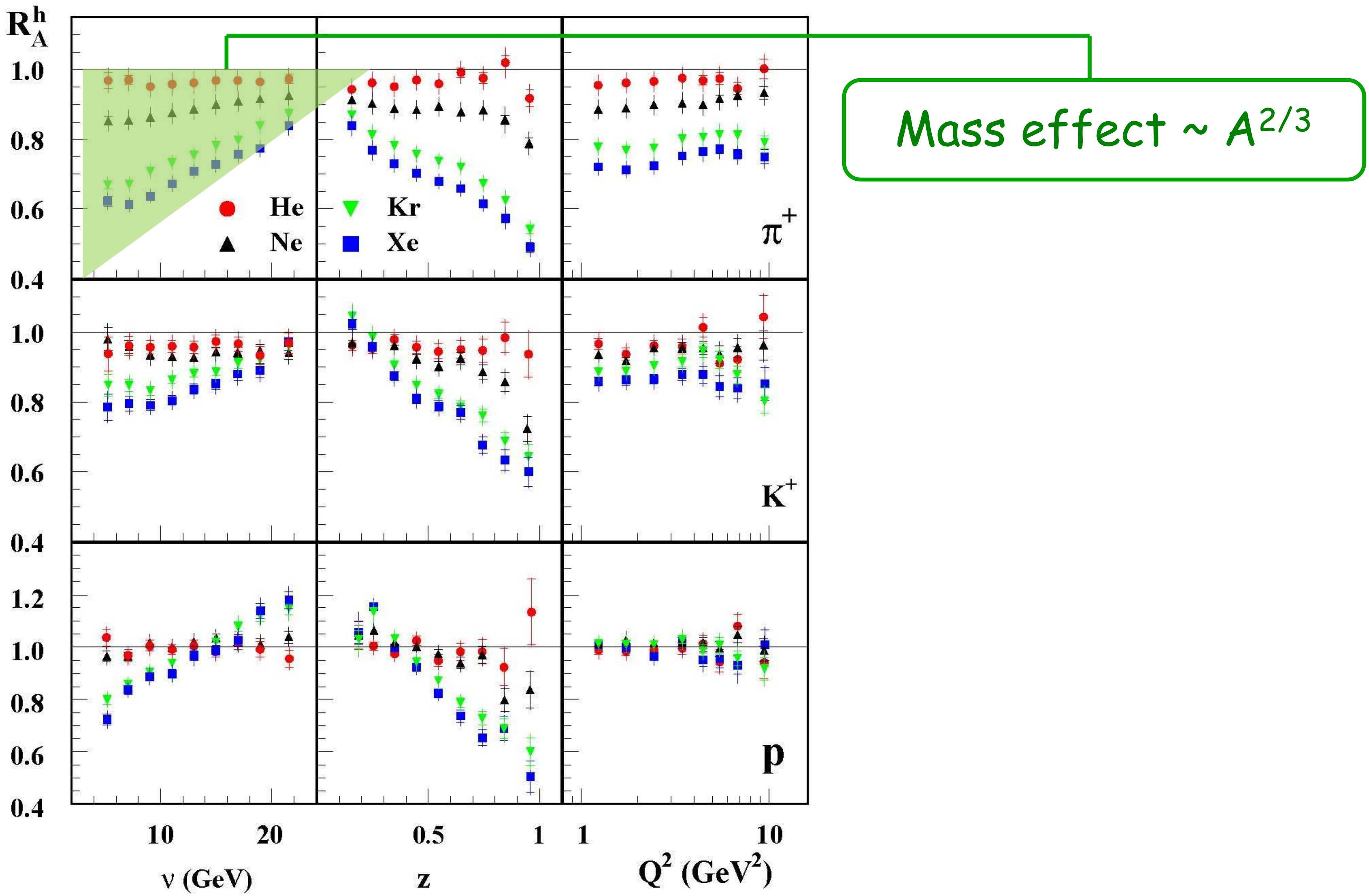
HERMES Coll: EPJ C20 (2001) 479 Single hadron attenuation



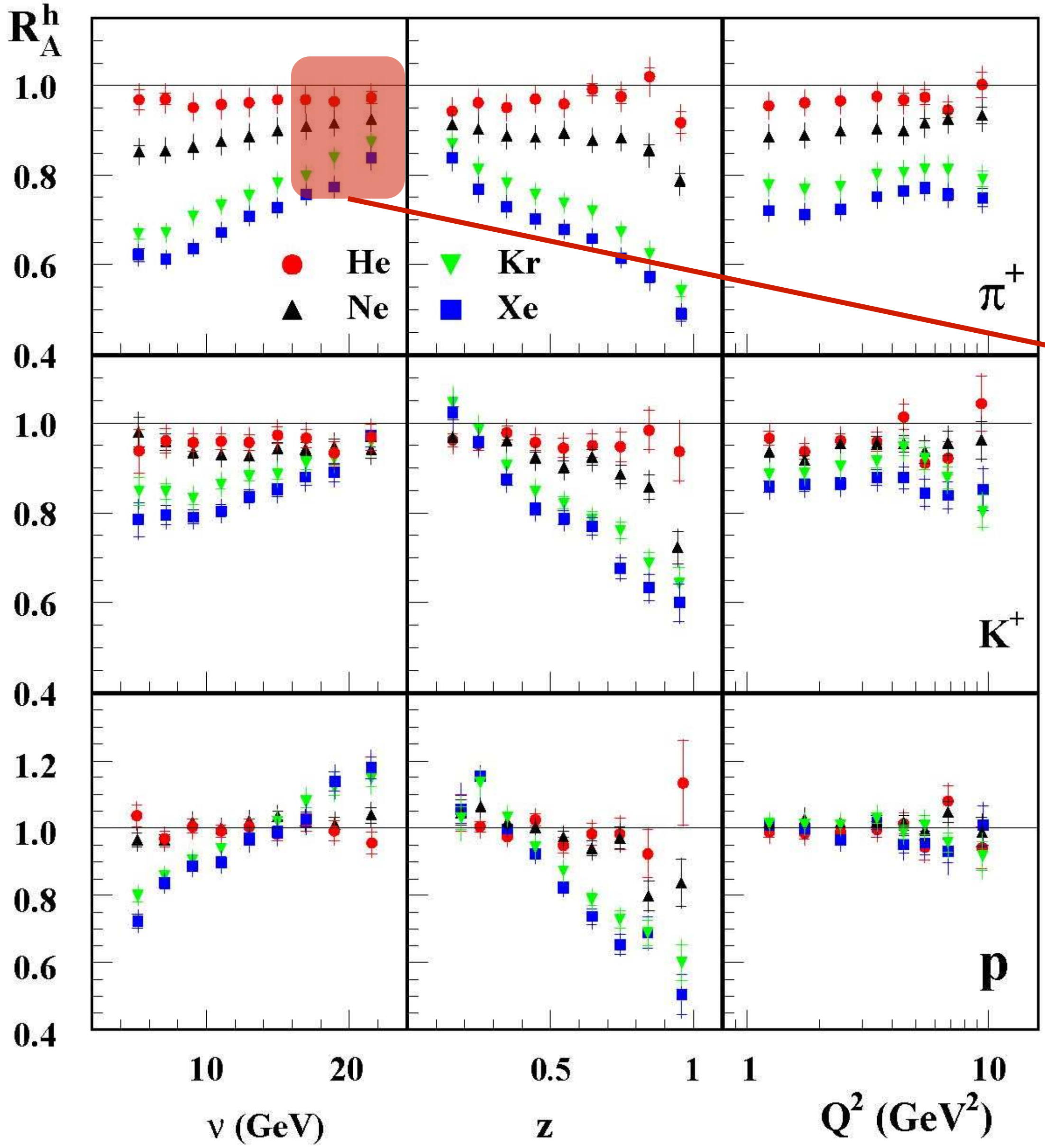
- Approach unity with ν consistent with EMC data at higher energy
- Discrepancy with SLAC due to the *EMC effect*, not taken into account at that time
- HERMES kinematics is well suited to study quark propagation and hadronization

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
EPJ A47 (2011) 113	Multidimensional hadron attenuation

Multiplicity ratio: hadron types



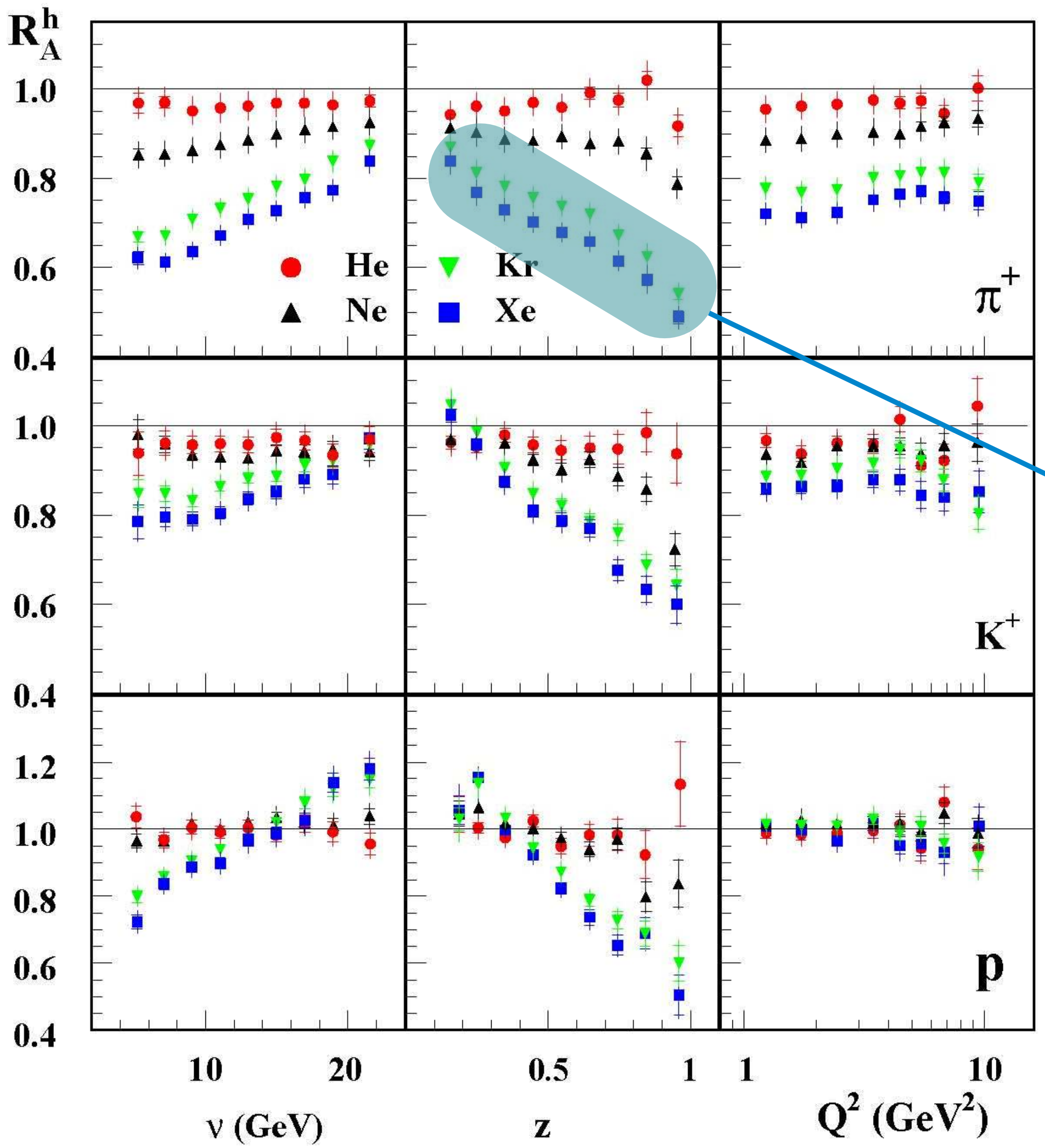
Multiplicity ratio: hadron types



Mass effect ~ $A^{2/3}$

Smaller effect at high ν
→Lorentz boost

Multiplicity ratio: hadron types

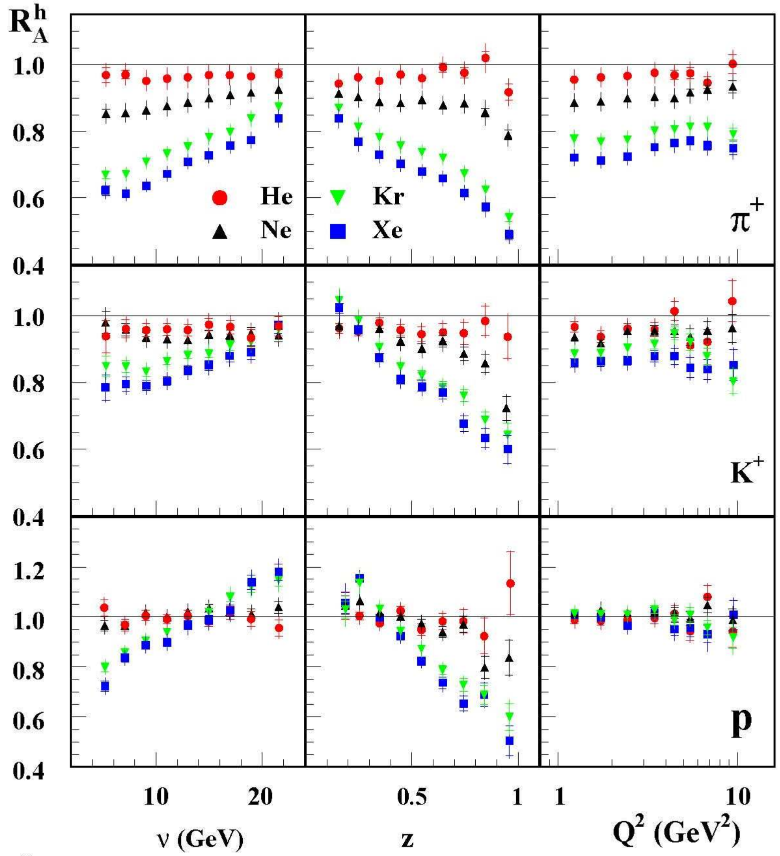


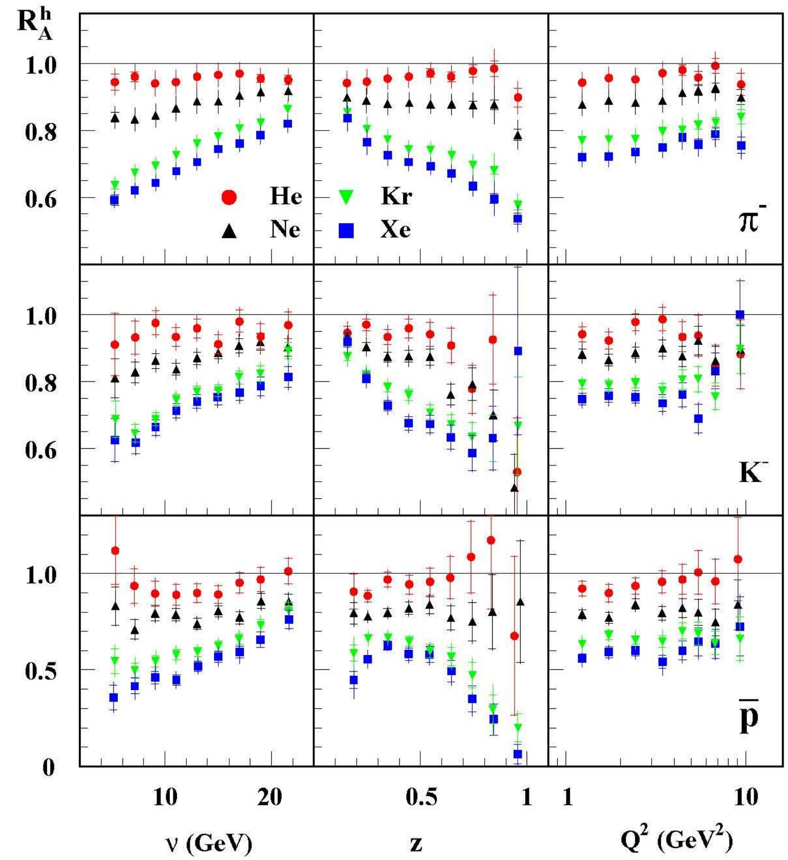
Mass effect ~ $A^{2/3}$

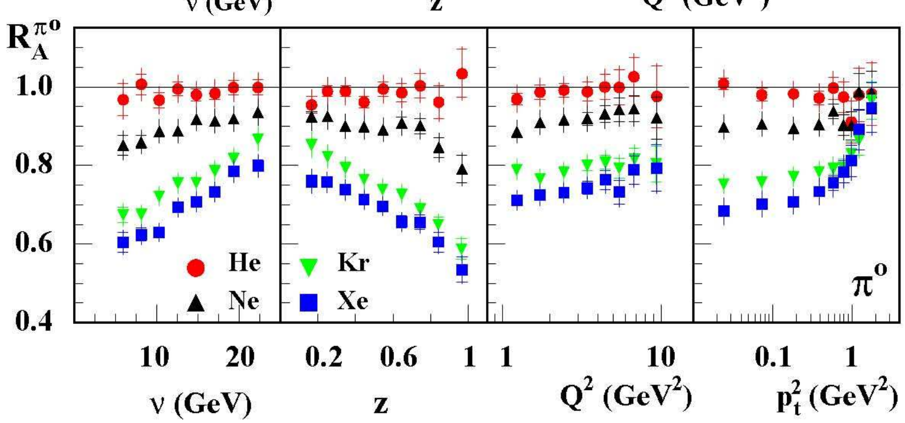
Smaller effect at high ν
→Lorentz boost

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

Multiplicity ratio: different charges





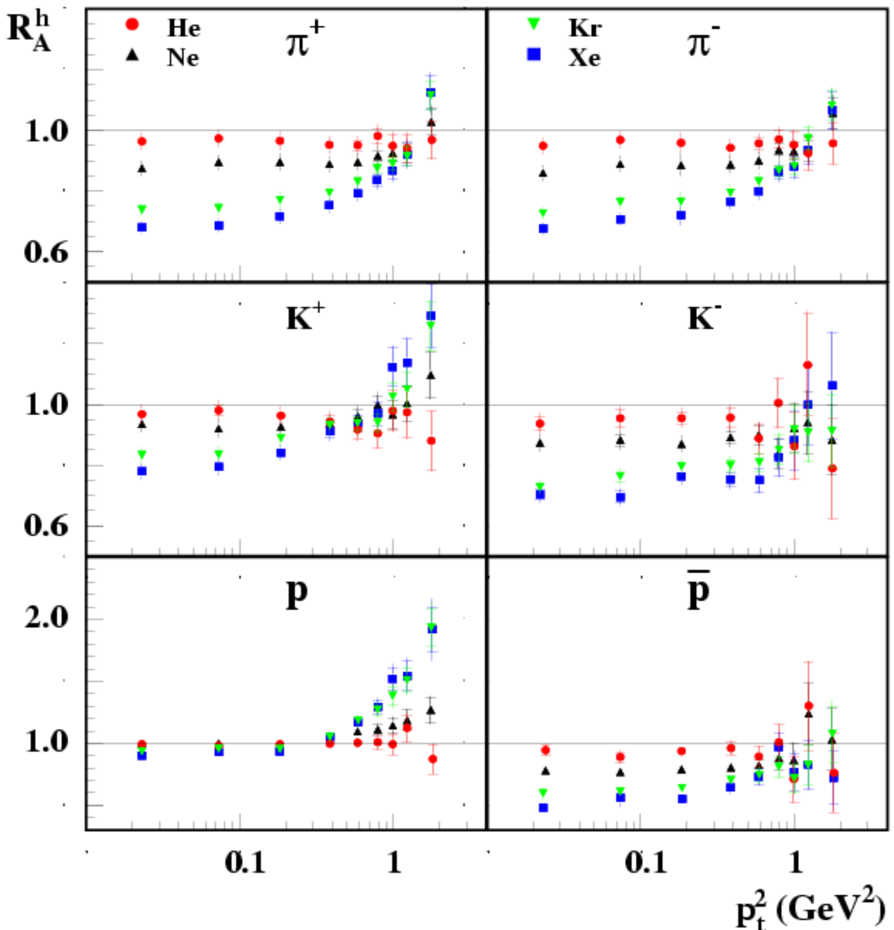


$\pi^+ = \pi^- = \pi^0 \sim K^-$

$K^+ < K^-$

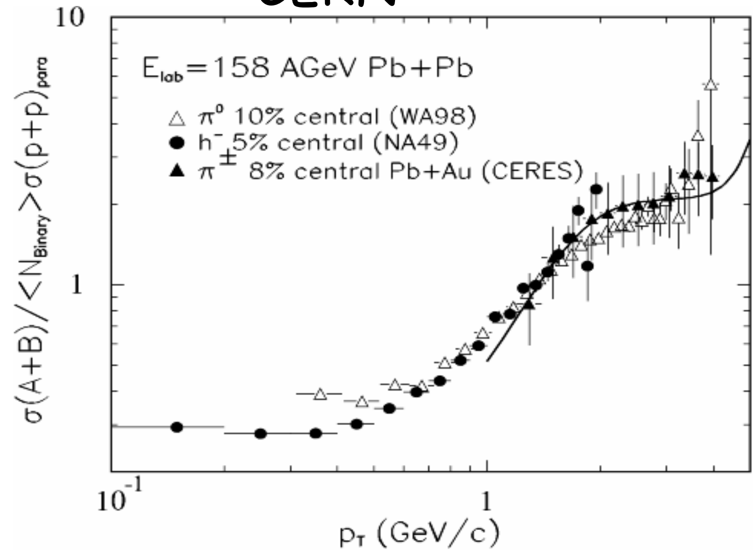
$p < \bar{p}$, $p < \pi$, $p < K$

p_t dependence for identified hadrons

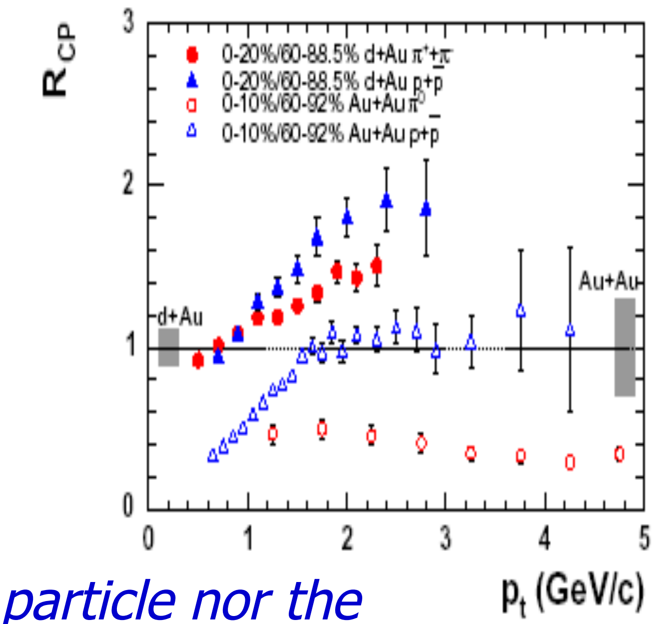


Cronin effect larger for protons

CERN

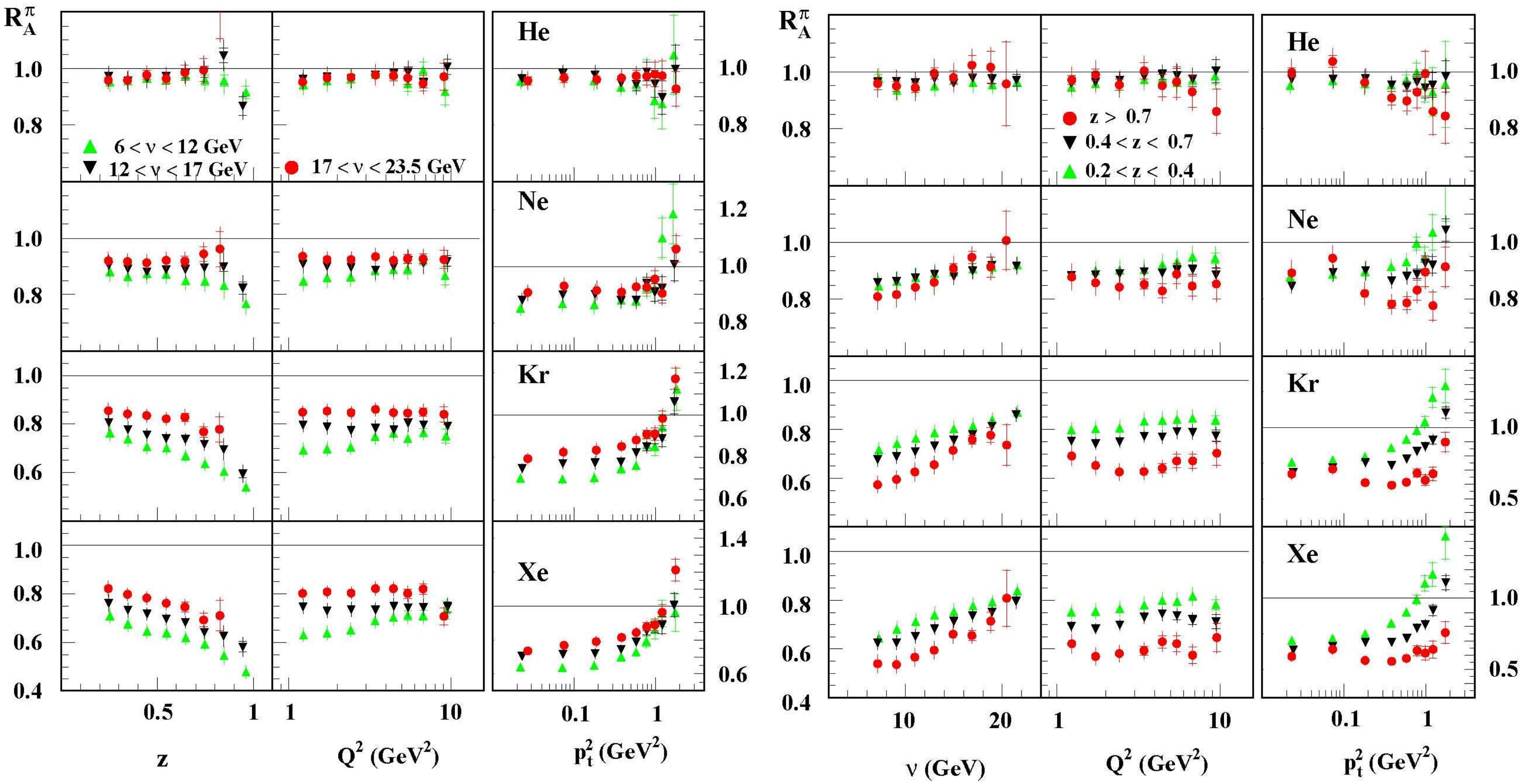


Phenix data



In DIS neither multiple scattering of the incident particle nor the interactions of its constituents are present → FSI contribution to the Cronin

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

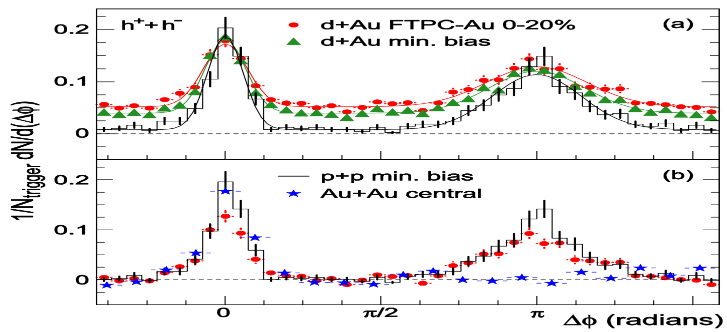


Reduced correlations among z, ν, p_t

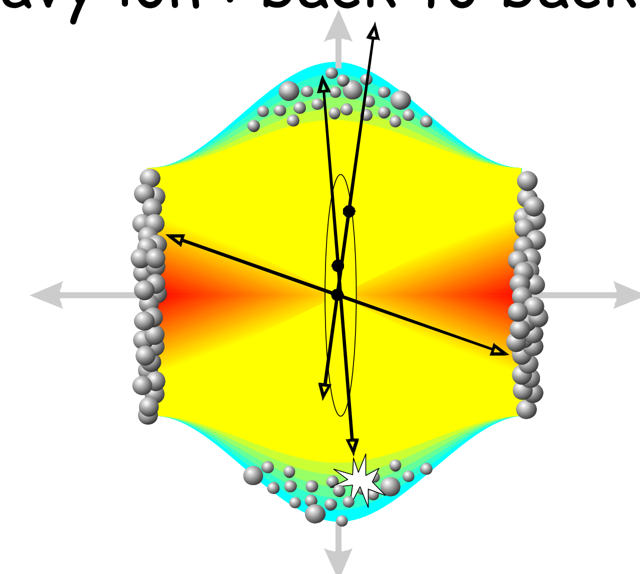
Dependence of the Cronin suppressed at high z

Cronin effect for baryons larger than for mesons (similar to heavy ion data)

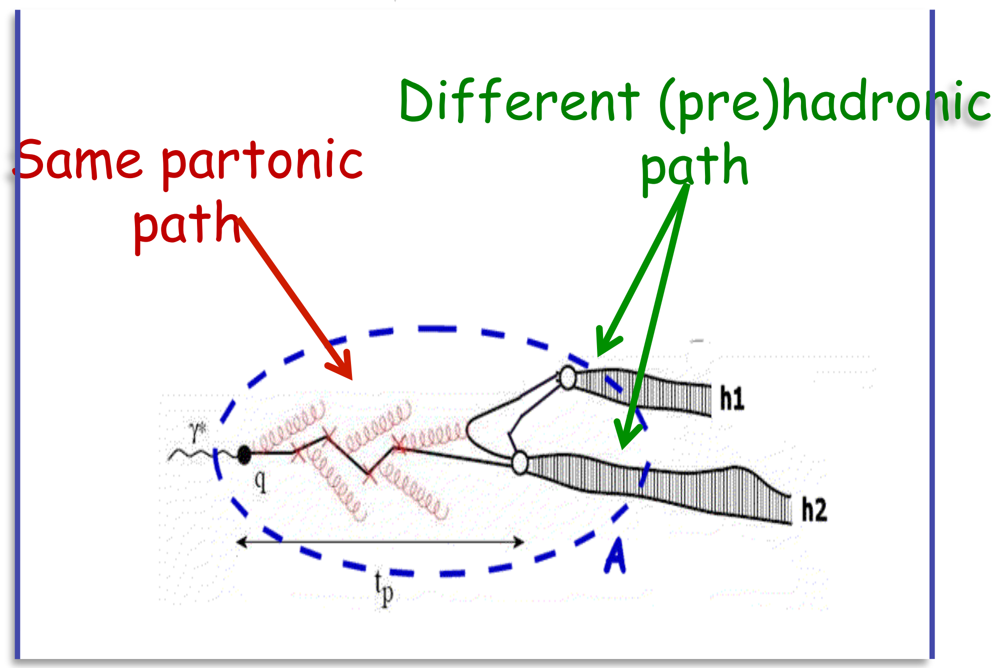
Hadronic or partonic effect (?)



Heavy ion : back to back jets



SIDIS: 2 hadron correlation



•If partonic effects dominate: double-hadron are correlated

•If absorption dominates: double-hadron are 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 ($z_{leading}=z_1>0.5$)

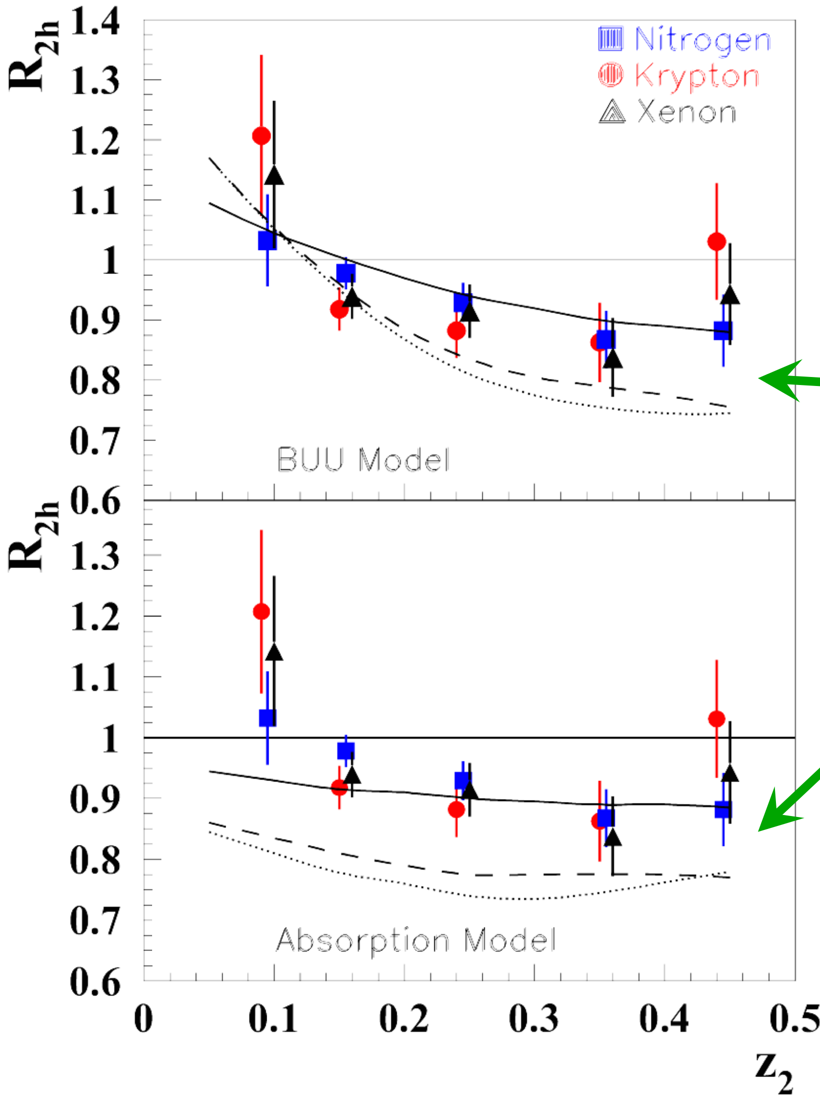
Number of events with at least 1 hadron ($z_1>0.5$)

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



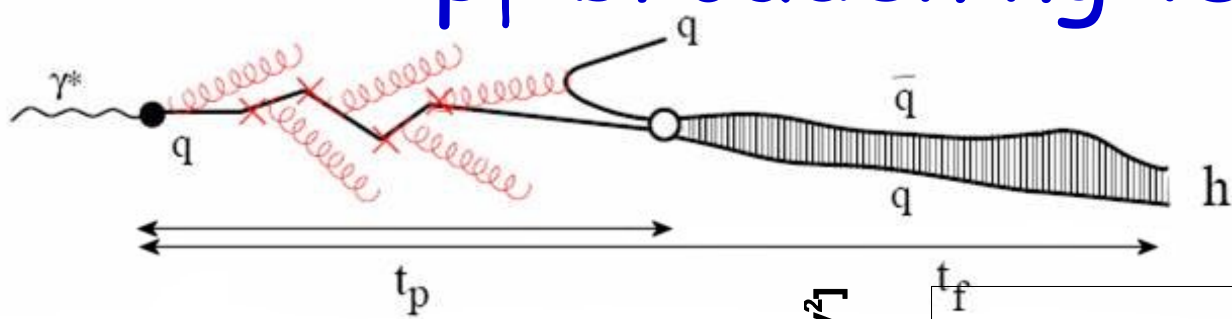
- Small effect in R_{2h} compared to single hadron multiplicity
- Small A-dependence

Pre-hadronic FSI described by a trasport code

Purely absorptive treatment of hadronic FSI

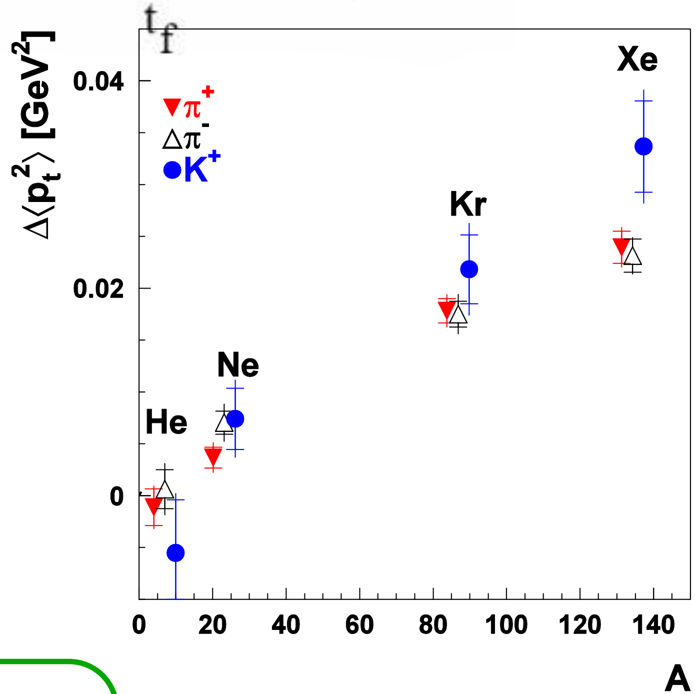
Data do not support naïve expectations for pure absorptive hadronic FSI

p_t-broadening vs A



First measurement of p_t-broadening in DIS

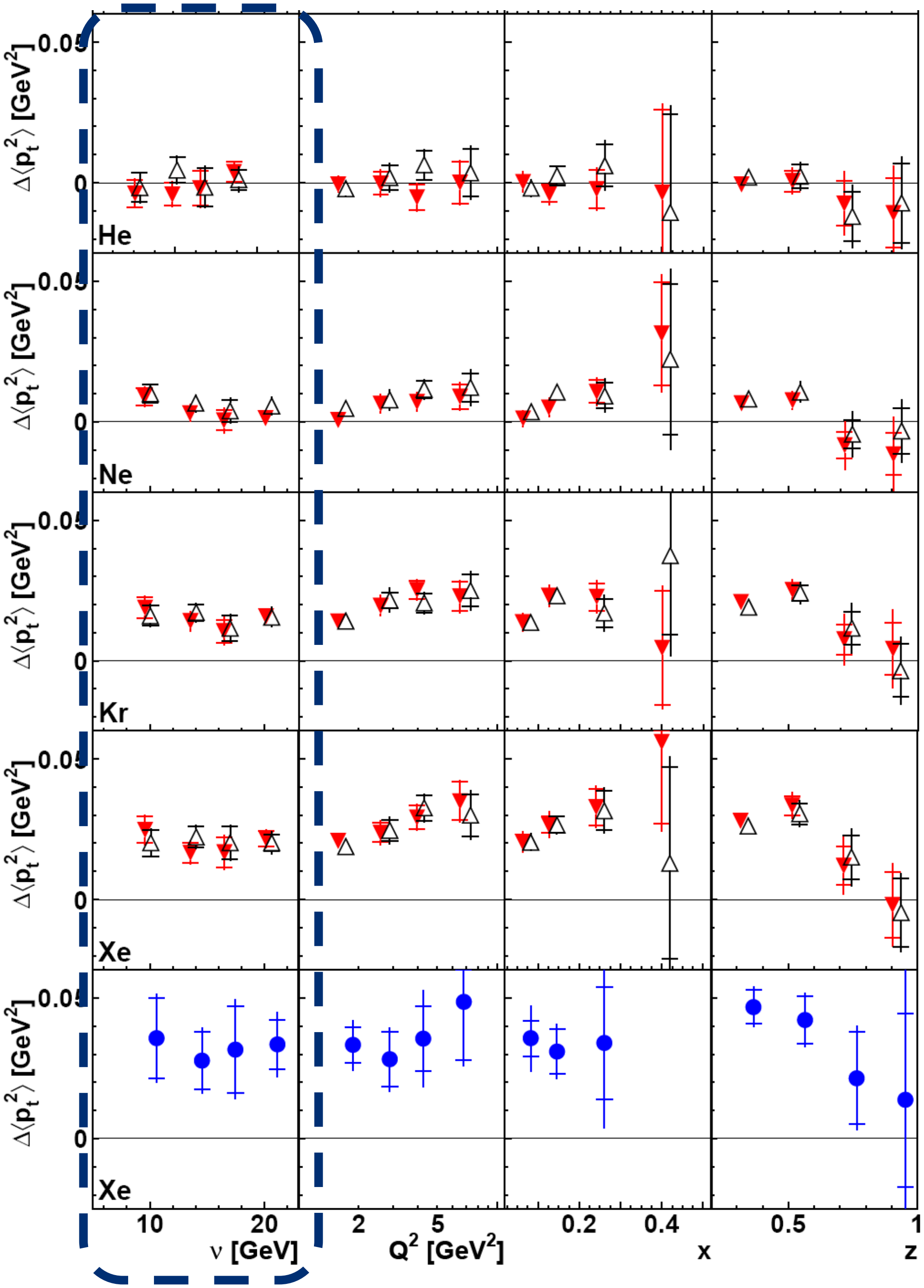
$\Delta\langle p_t^2\rangle = \langle p_t^2\rangle_A - \langle p_t^2\rangle_D$



By B.K. model :

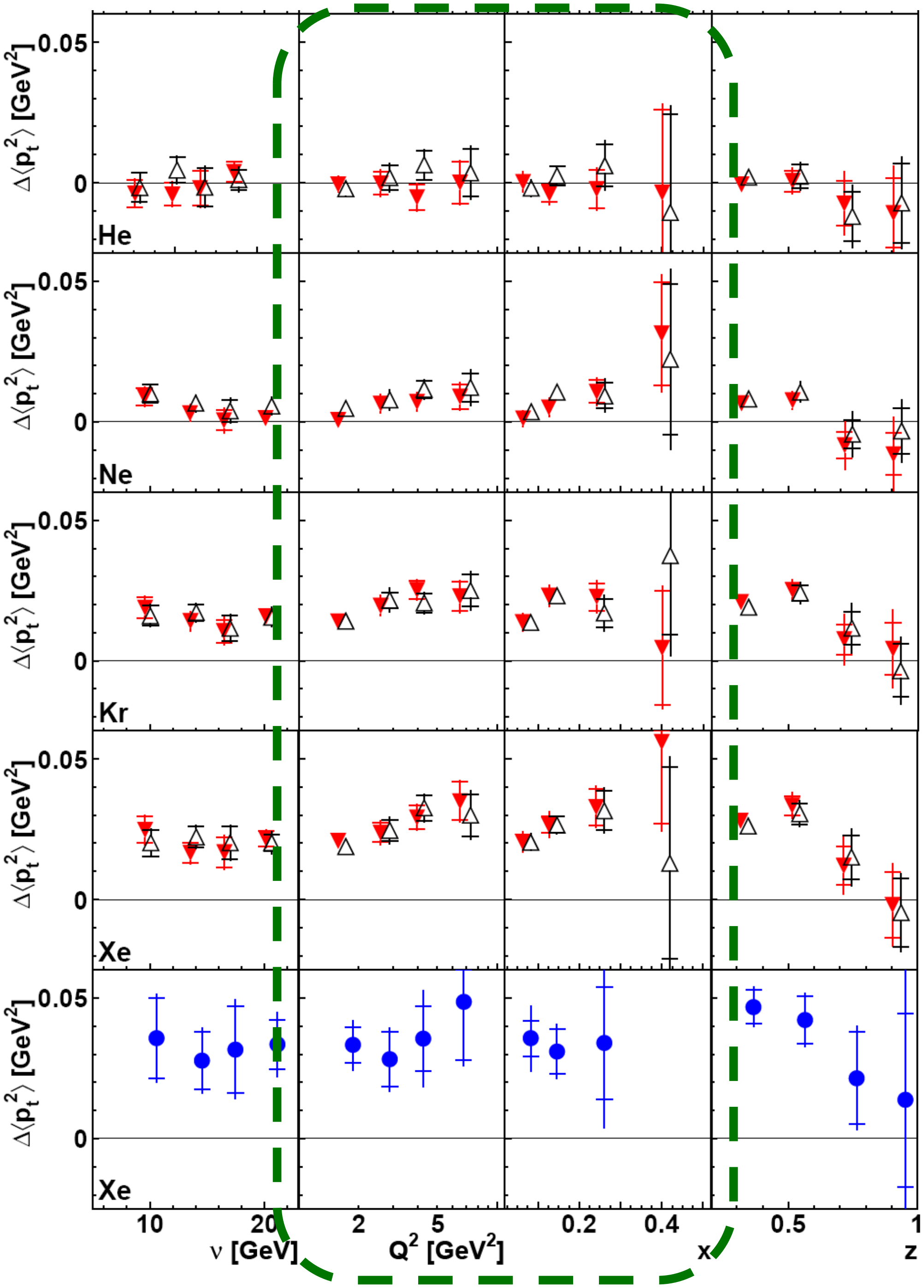
$\Delta\langle p_t^2\rangle \sim t_p$

- 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)



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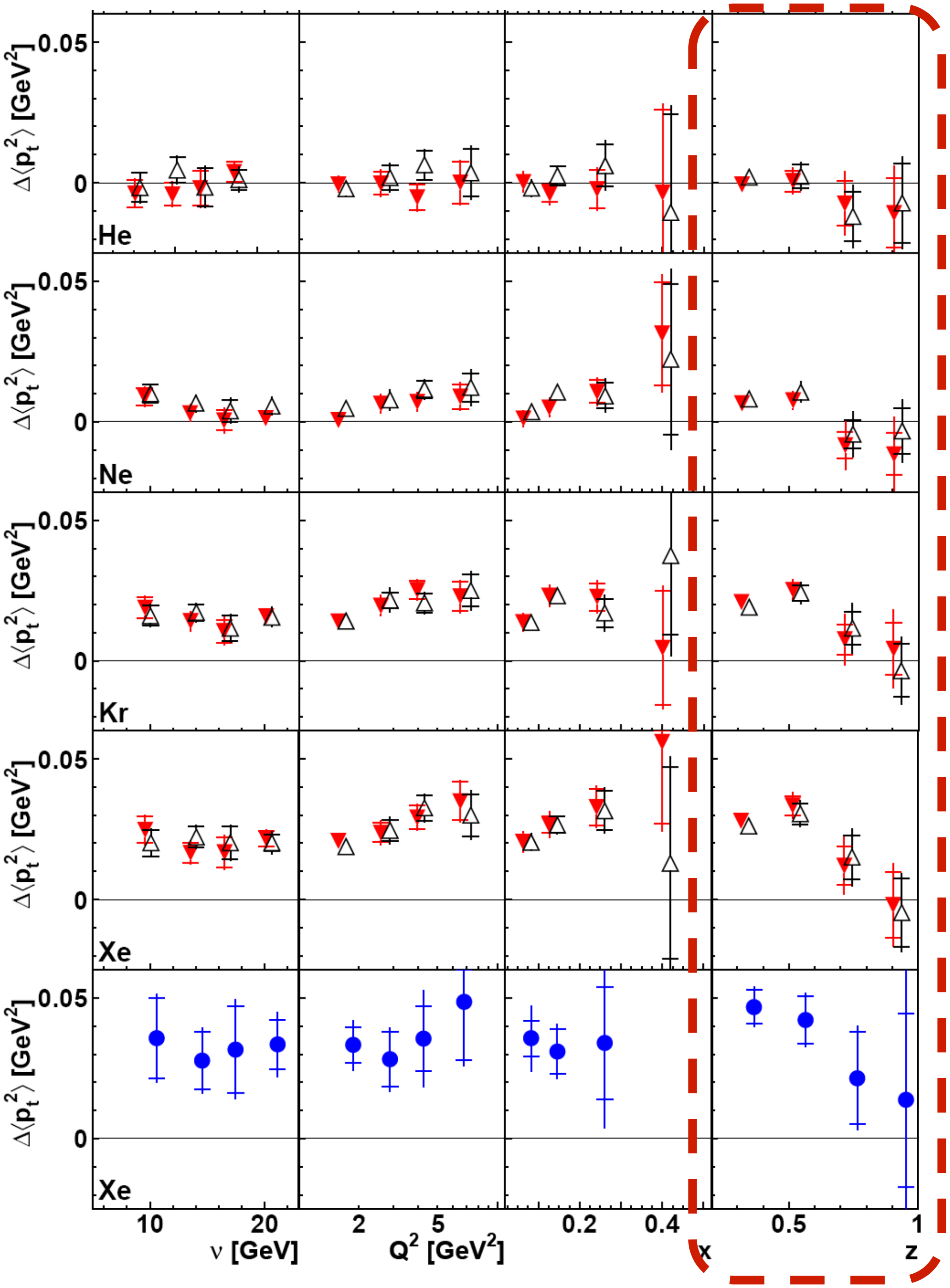
Similar x-Q^2 behavior, strong correlation:

-slight increase with Q^2

- gluon radiation, decrease of t_p with Q^2?



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Similar x-Q^2 behavior, strong correlation:

-slight increase with Q^2

- gluon radiation, decrease of t_p with Q^2?

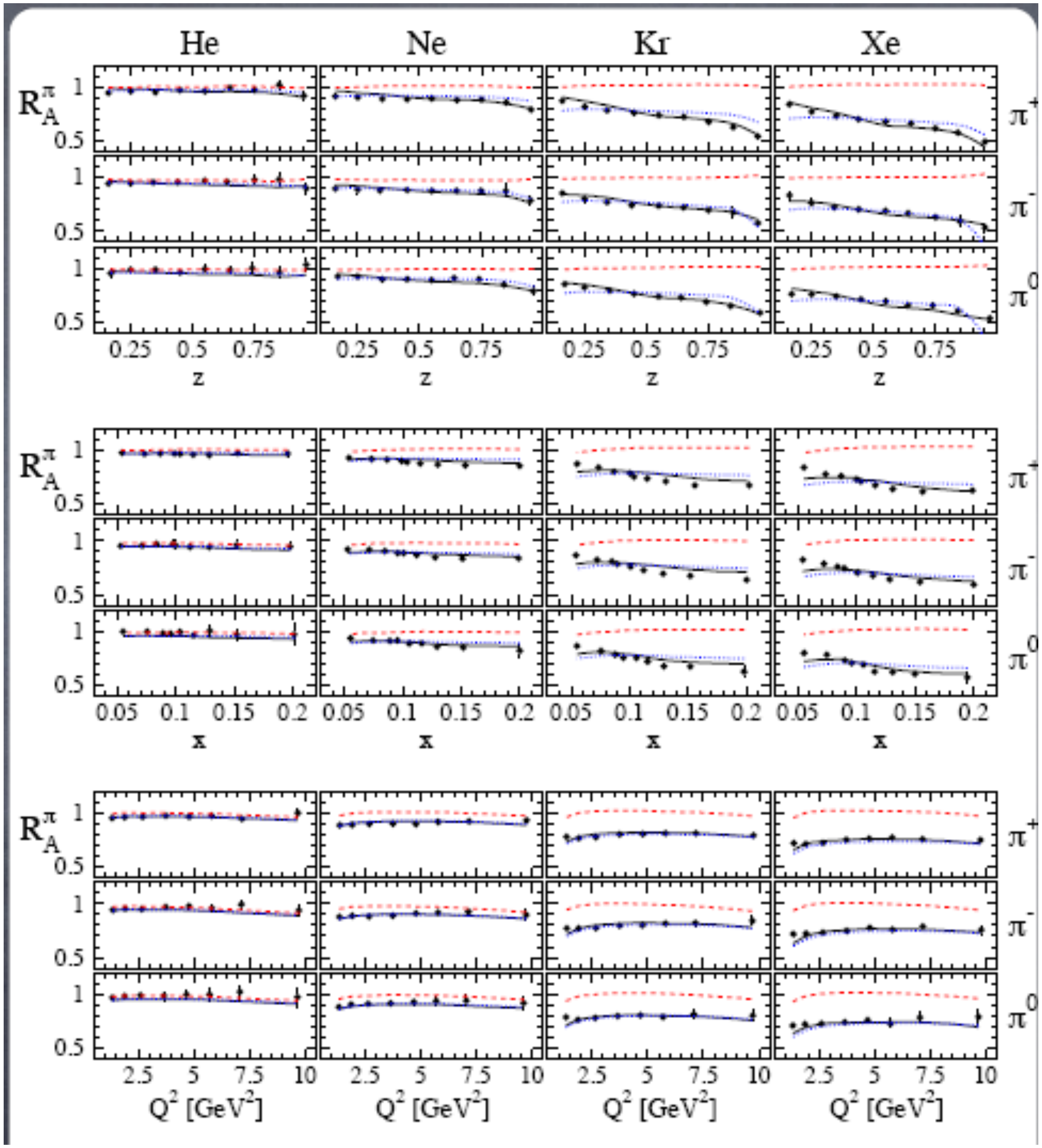
p_t-broadening vanishes at $z \to 1$

no energy loss at z=1

possible k_t modification?

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

e-A HERMES and

d-Au RHIC data

$\chi^2 = 396.0$

381 data points

14 parameters

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

nFF from HERMES + RHIC

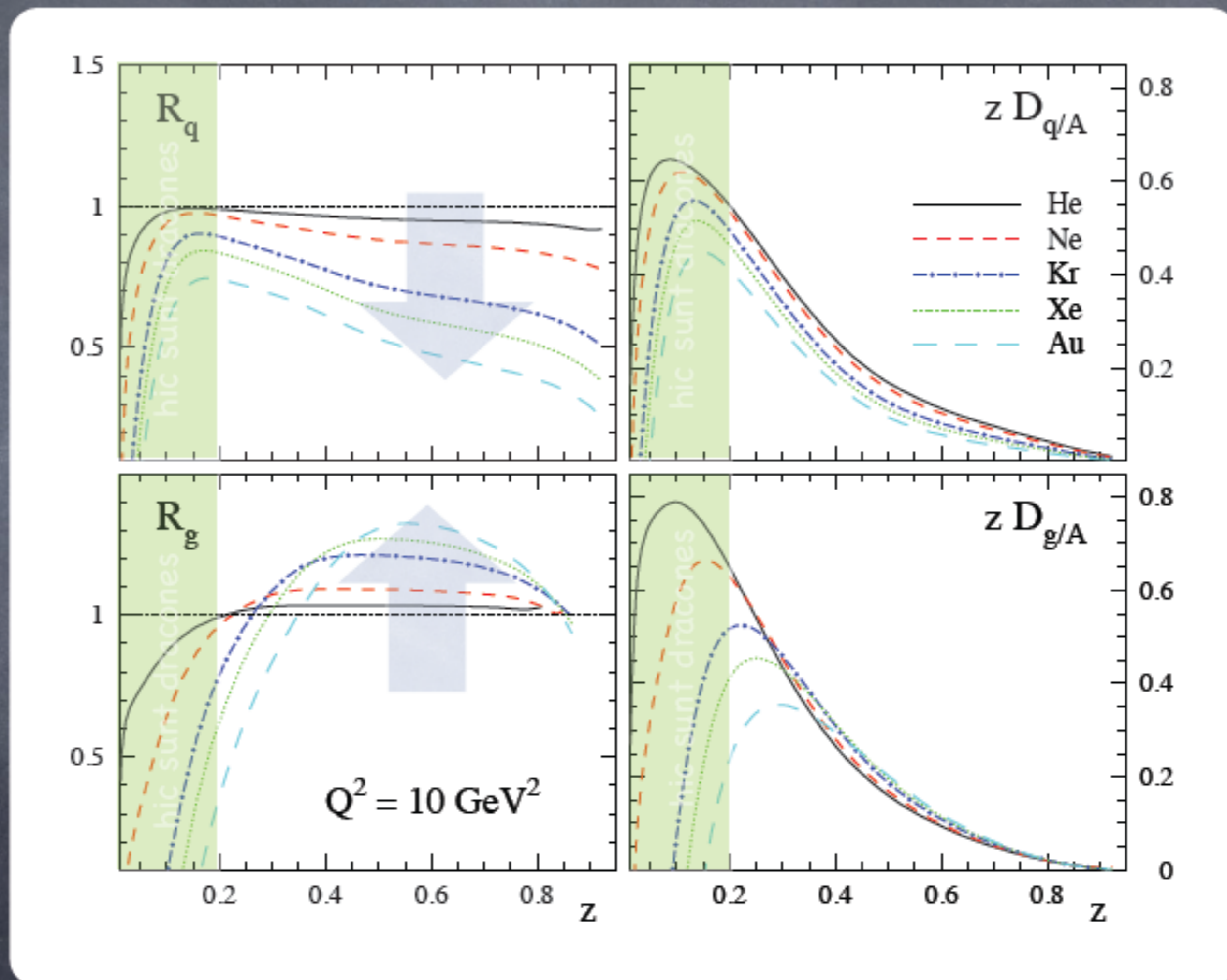
R.Sassot, M.Stratmann, P.Zurita

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?

Summary

SIDIS on nucleons provides precious informations to understand the quark fragmentation process

- HERMES provides high values for QCD fits at low Q^2
- Suggests a new way to disentangle favored and unfavored FF for different hadron types
- Suggests factorization and universality of FF in vacuum

SIDIS on nuclei provides additional informations to understand the space-time evolution of the in-medium fragmentation and hadronization process

- HERMES data set for the cold nuclear matter effect is a reference for many other physics researches
- In particular to better understand hard processes at RHIC and at LHC at higher energies
- Suggest factorization and universality of nFF