- Quark propagation and hadronization
- Parton Energy loss
- Transverse momentum broadening

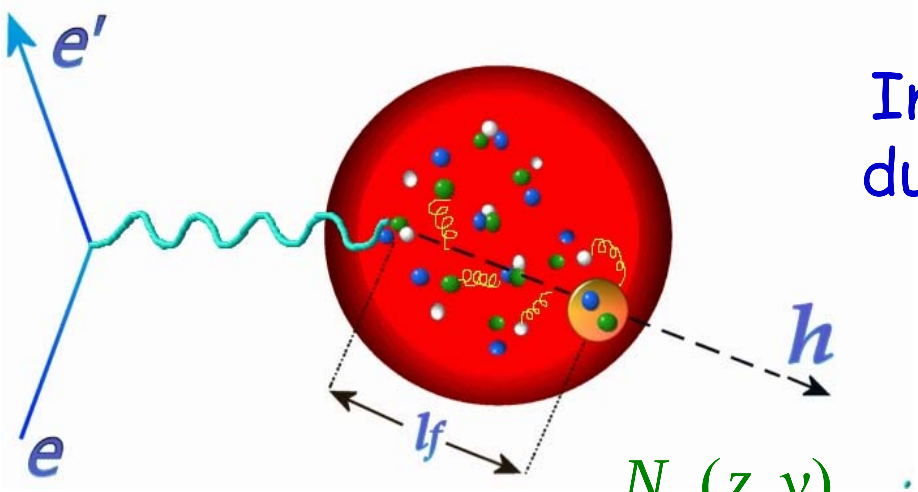
- Present status
- Jlab measurements at 12 GeV

- Talks: Brooks, Ciofi degli Atti, Kopeliovich, Mosel, Muccifora, Peng

SIDIS and hadronization distance scales

Determine the scale of hadronization using nuclei

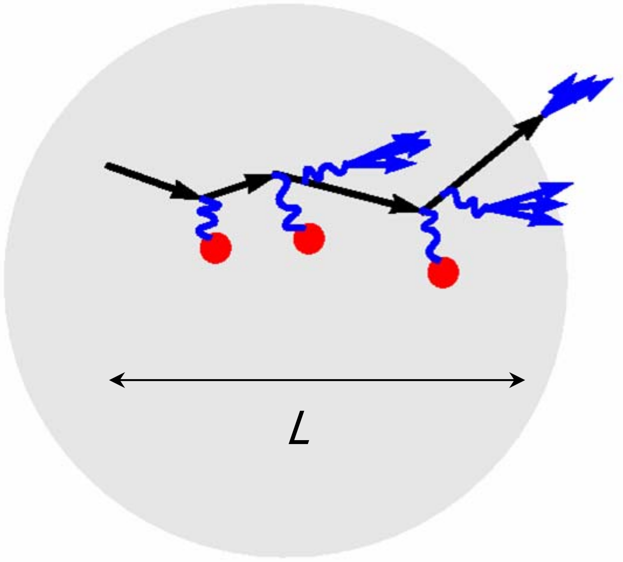
Nucleus acts as an ensemble of targets: reduction of multiplicity of fast hadrons due to both *hard partonic* and *soft hadron interaction.*

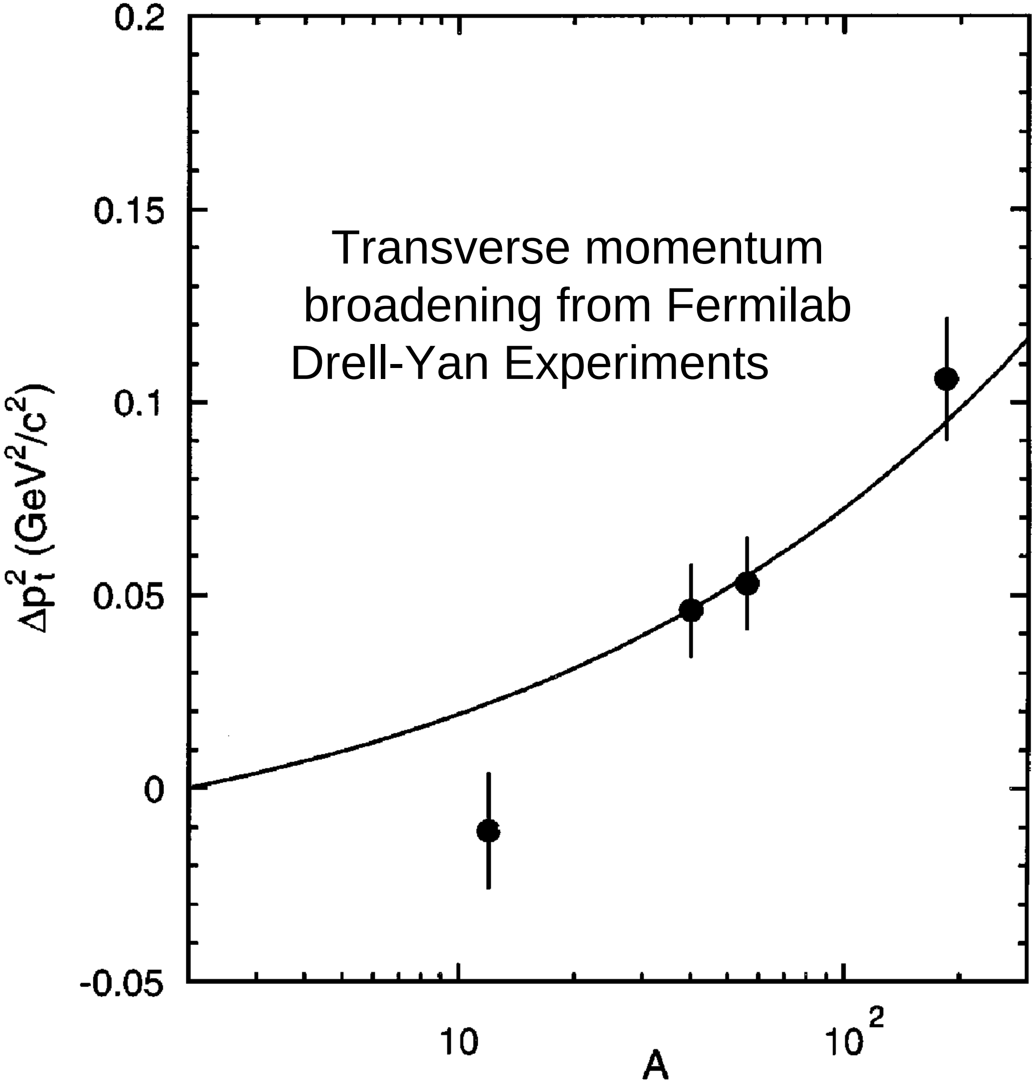


Interactions with the medium during l_f → space-time picture of hadronization

$$R_M(z,\upsilon)=\frac{\dfrac{N_h(z,\nu)}{N_{DIS}}}{\dfrac{N_h(z,\nu)}{N_{DIS}}}=\frac{\left.\dfrac{1}{\sigma_{DIS}}\dfrac{d^2\sigma_h}{dz d\nu}\right|_A}{\left.\dfrac{1}{\sigma_{DIS}}\dfrac{d^2\sigma_h}{dz d\nu}\right|_D}=\frac{\left.\dfrac{\Sigma e_f^2 q_f(x) D_f^h(z)}{\Sigma e_f^2 q_f(x)}\right|_A}{\left.\dfrac{\Sigma e_f^2 q_f(x) D_f^h(z)}{\Sigma e_f^2 q_f(x)}\right|_D}$$

Quark-Gluon Dynamics





Transverse momentum broadening from Fermilab Drell-Yan Experiments

Figure 15 $\Delta\langle p_t^2\rangle \equiv \langle p_t^2\rangle(A) - \langle p_t^2\rangle(^2H)$ versus A for the DY process from E772 (123; PL McGaughey, JM Moss, JC Peng, unpublished data). Solid curve corresponds to $0.027((A/2)^{1/3} - 1)$.

as L^2 (!) – QCD LPM effect

nected to transverse

rvable):

L

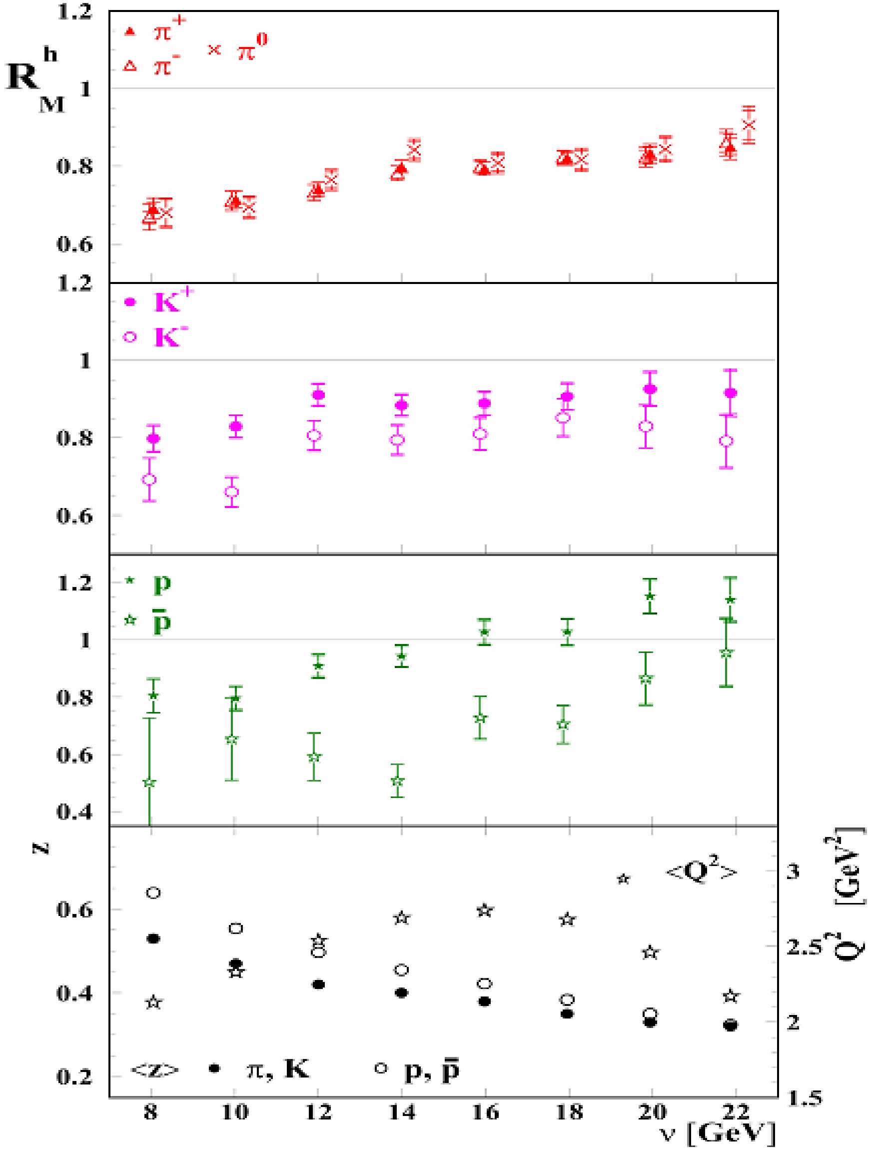
lx may be of measurable

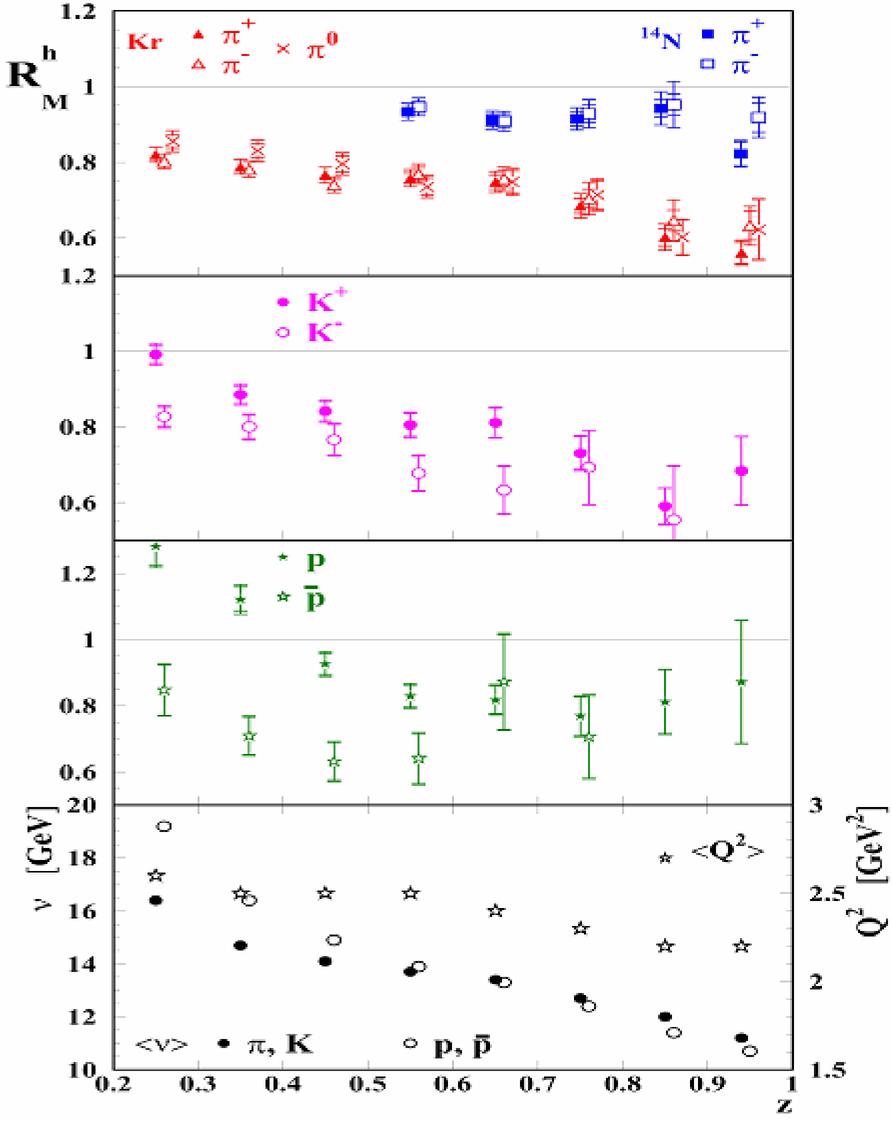
function (Guo and Qiu,

of the medium

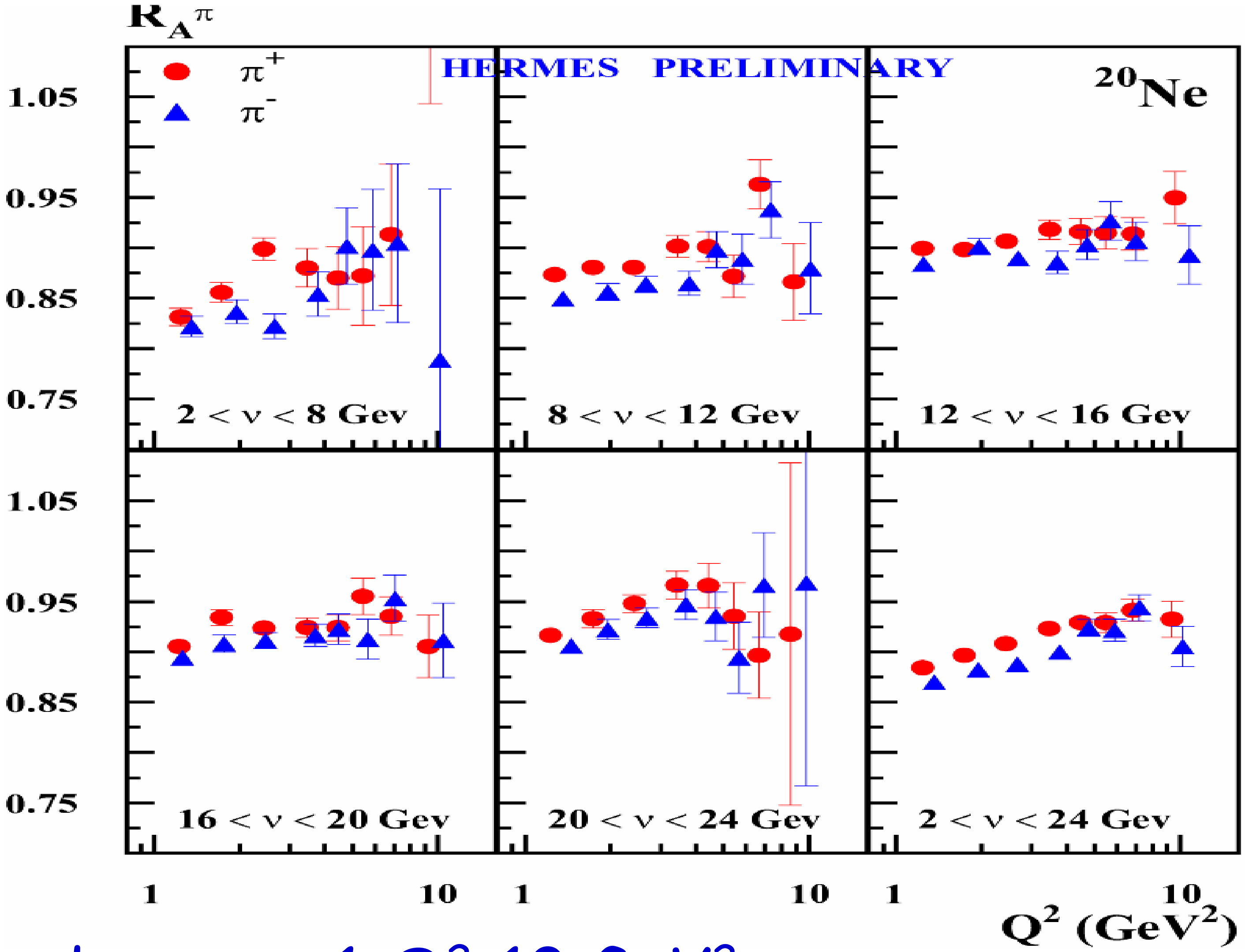
Multiplicity ratio for identified hadrons vs ν, z

HERMES, PLB 577 (2003) 37



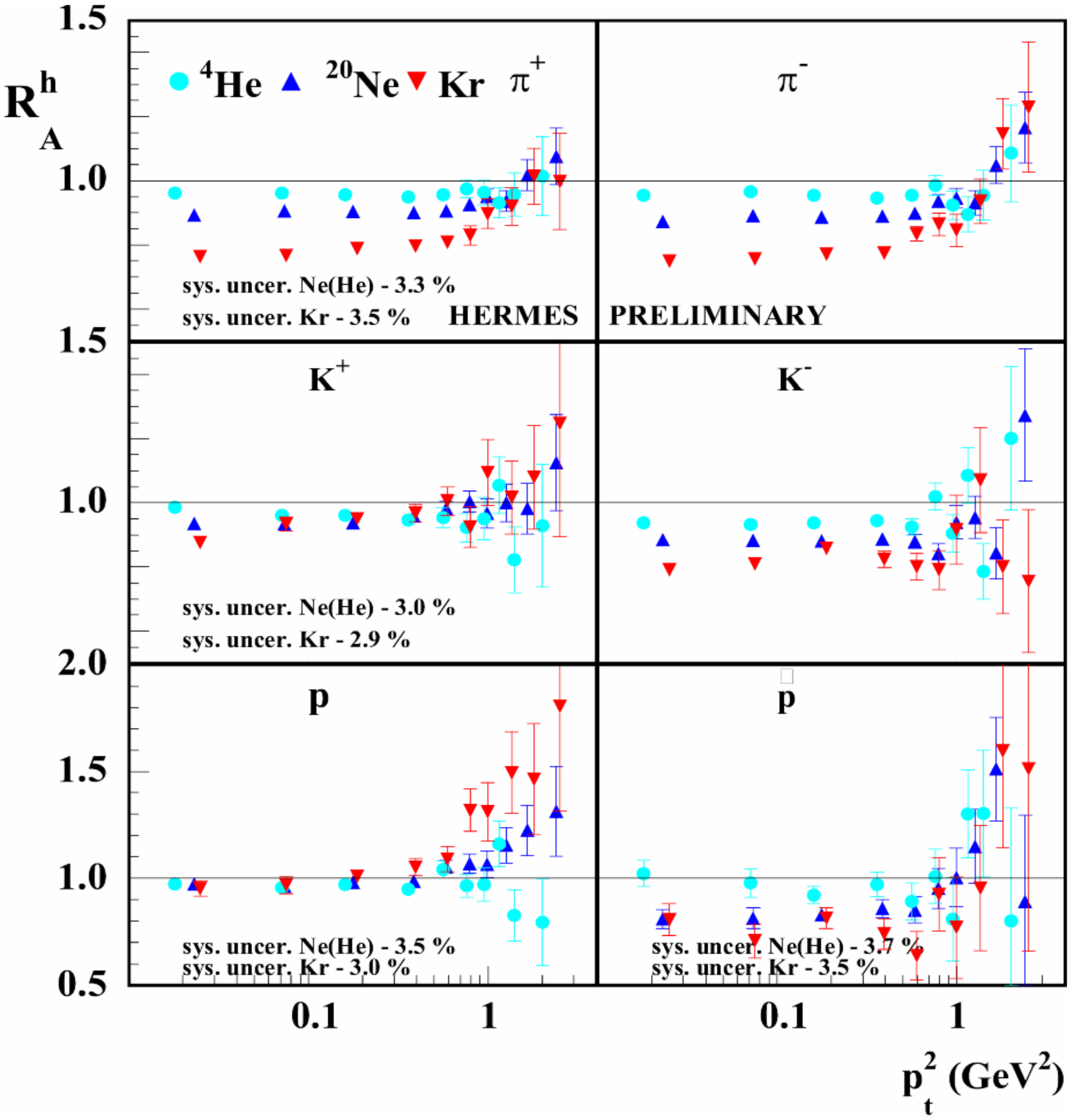


Multiplicity ratio vs Q^2

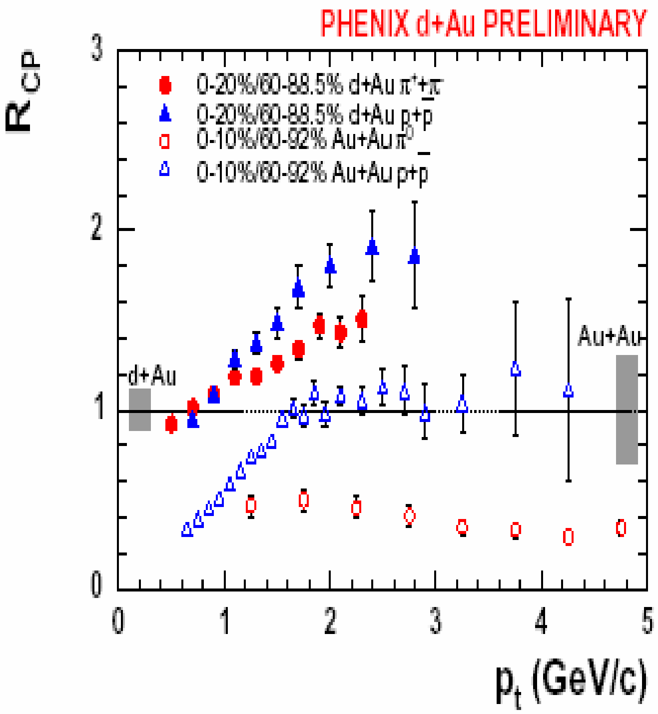


Dependence on $1<Q^2<10$ GeV^2:
stronger at small ν, weaker at high ν

P_t dependence for identified hadrons



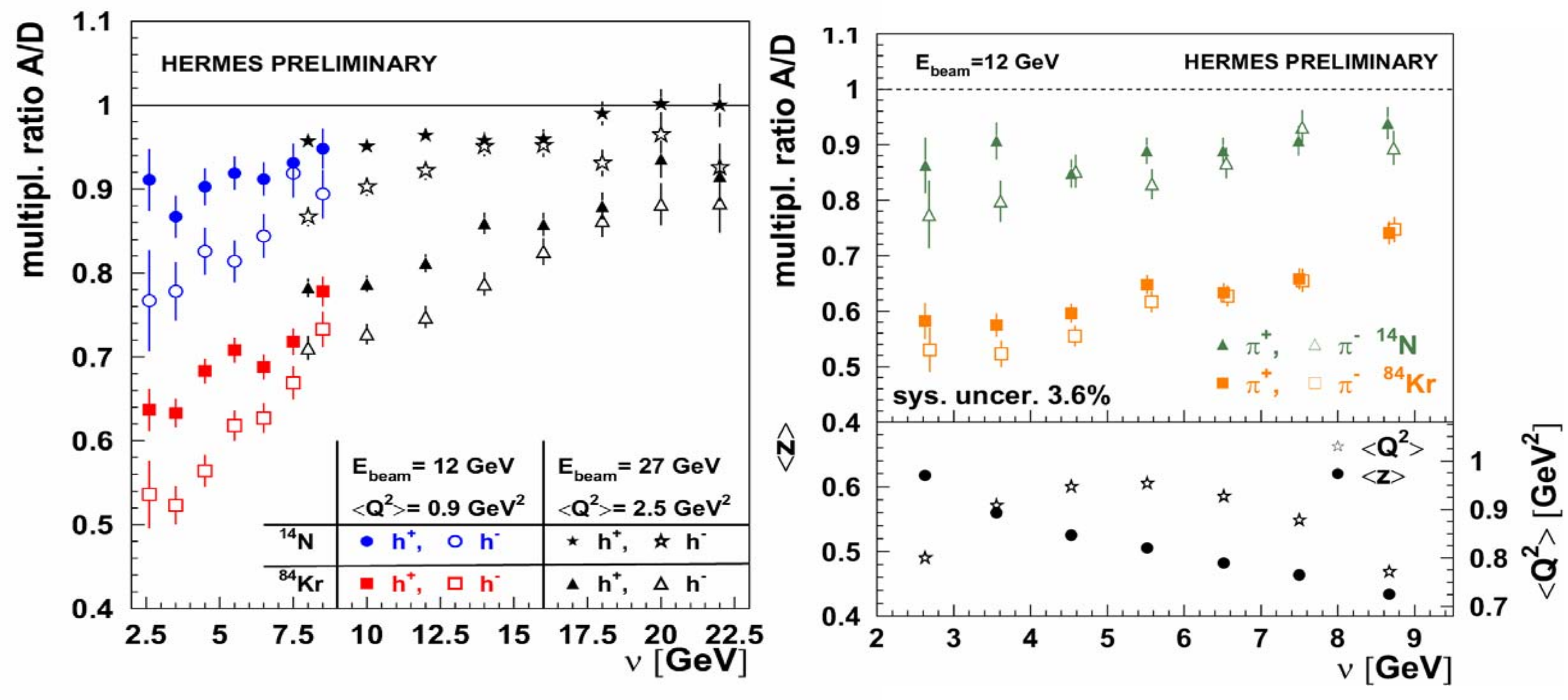
Nucl-ex/0403029



Dependence of the Cronin effect on the hadron species.
Cronin effect for protons larger than for pions.

Hadrons and Pions @ E_{beam}=12 & 27 GeV

Extension of the ν range down to 2 GeV



- Measurements are in progress at HERMES

2<ν<23 GeV Q^2<10 GeV^2

He, N, Ne, Kr, Xe

Jefferson Lab Experiments: Next 7 Years

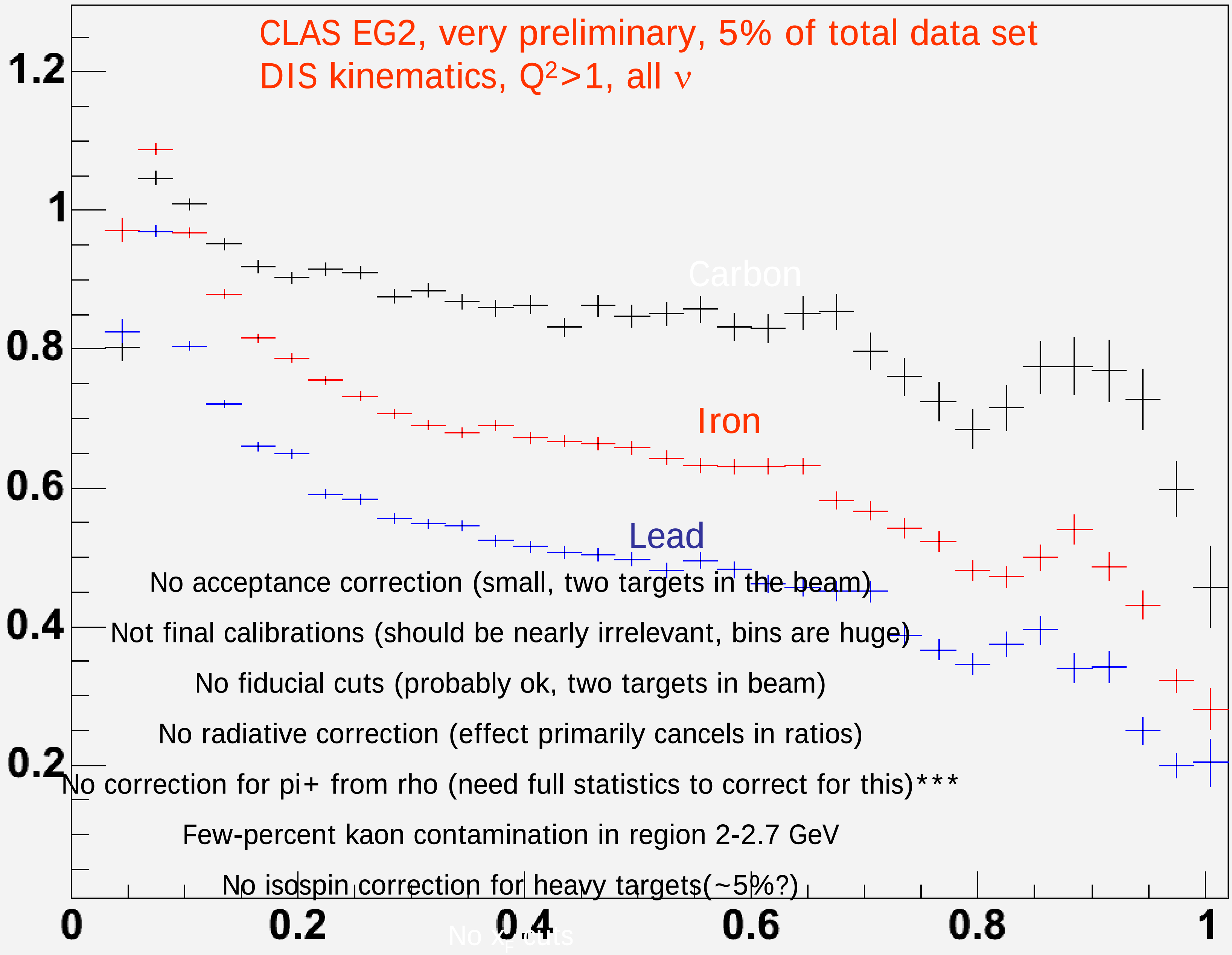
- E02-104 (Brooks, CLAS EG2) in Hall B
  - Took part of data in January-February this year
  - Hadronization, transverse momentum broadening surveyed over a wide kinematic range

- E04-002 (Chen, Norum, Wang) in Hall A
  - Hadronization in narrow kinematic bins with good particle ID for charged K and π
  - Waiting to get on the schedule

- Interest in Hall C (Ent, Gaskell, Keppel, Kinney)
  - Transverse momentum broadening in narrow kinematic bins with good particle ID for charged K and π
  - Proposal under discussion

Multiplicity ratio for pion+:

Hayk Hakobyan, Yerevan State U.



CLAS EG2, very preliminary, 5% of total data set

DIS kinematics, $Q^2>1$, all ν

No acceptance correction (small, two targets in the beam)

Not final calibrations (should be nearly irrelevant, bins are huge)

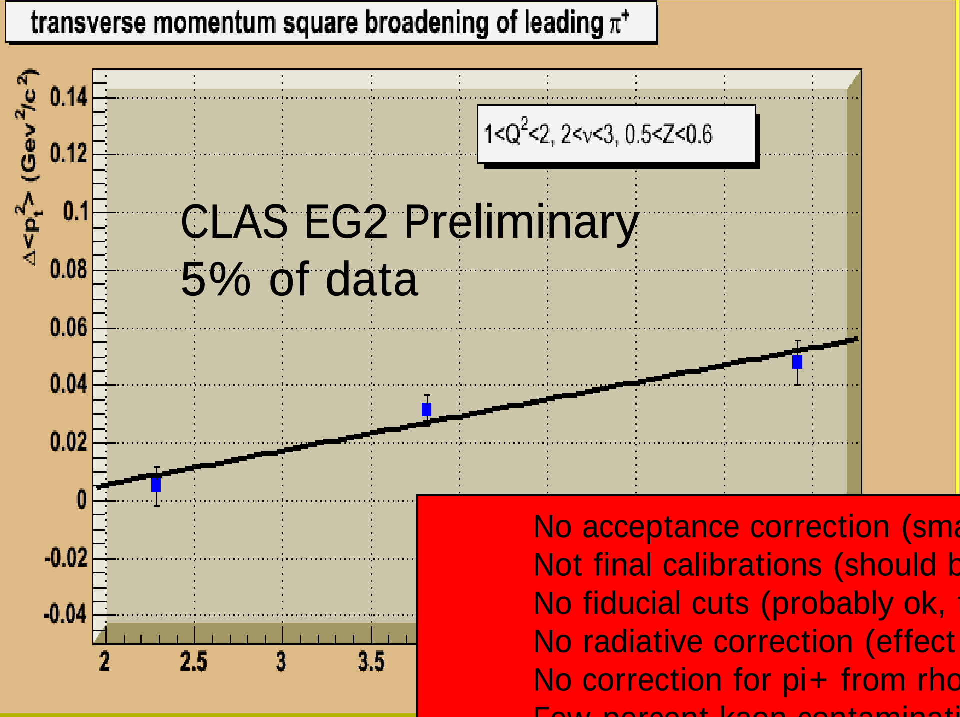
No fiducial cuts (probably ok, two targets in beam)

No radiative correction (effect primarily cancels in ratios)

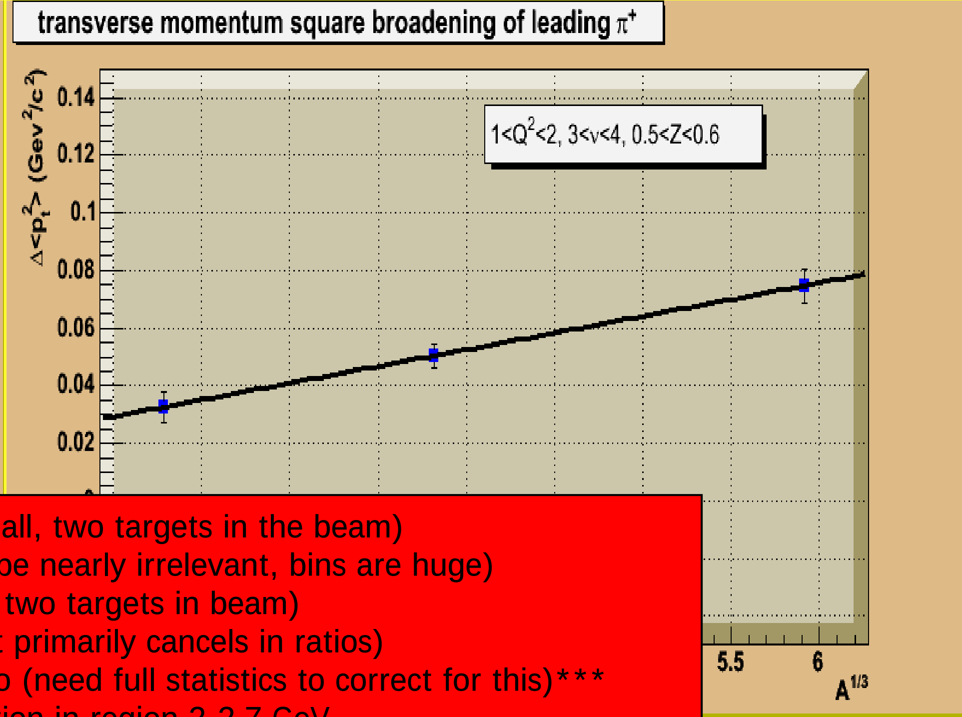
No correction for pi+ from rho (need full statistics to correct for this)***

Few-percent kaon contamination in region 2-2.7 GeV

No isospin correction for heavy targets(~5%?)


transverse momentum square broadening of leading π^+

CLAS EG2 Preliminary
5% of data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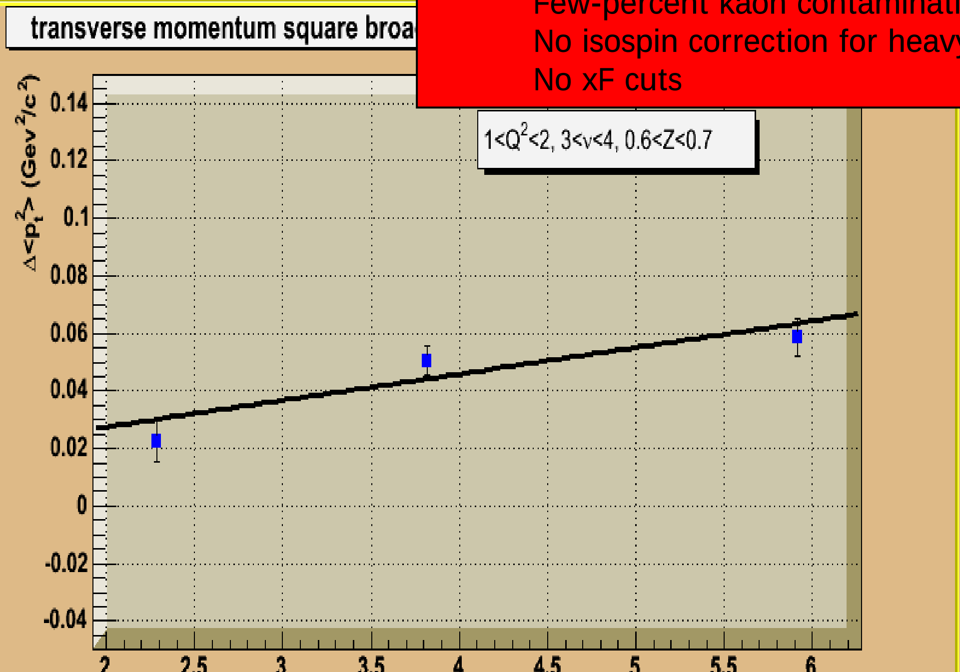
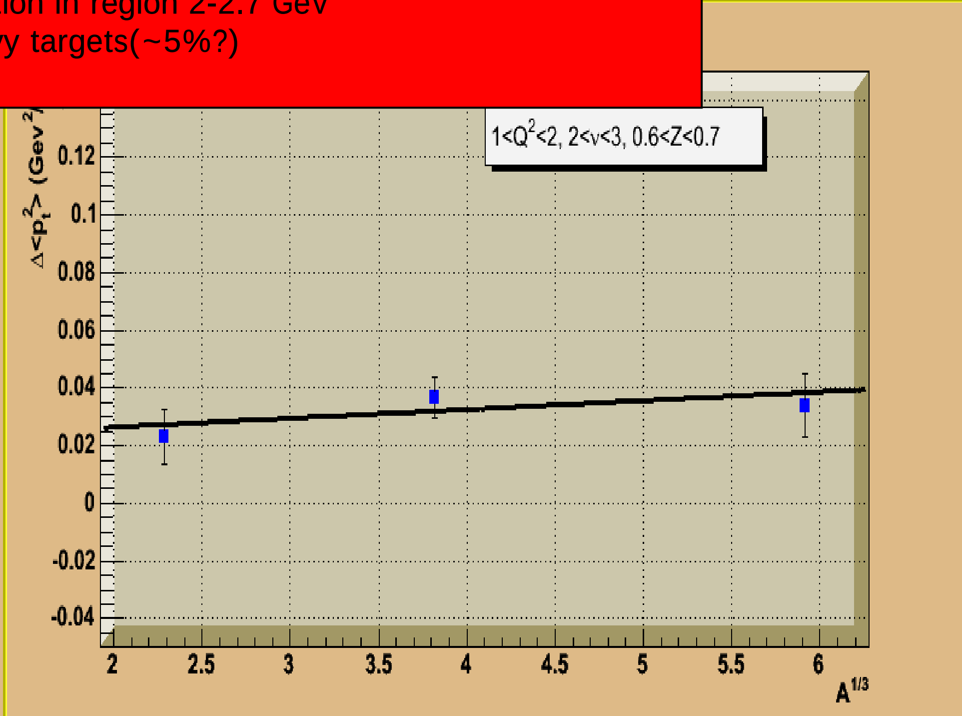
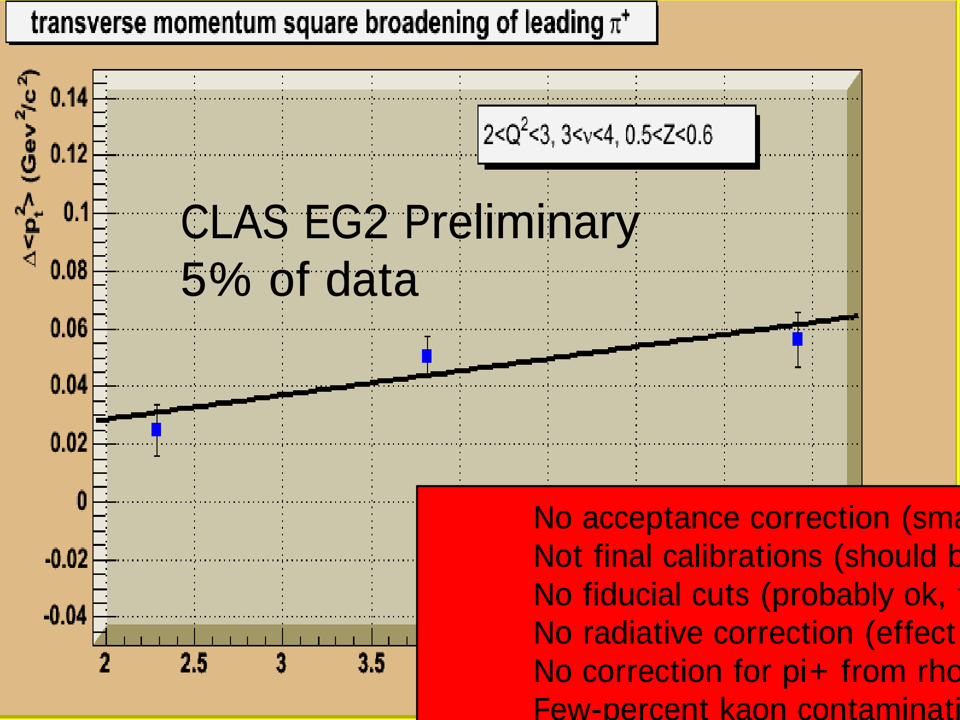
No xF cuts

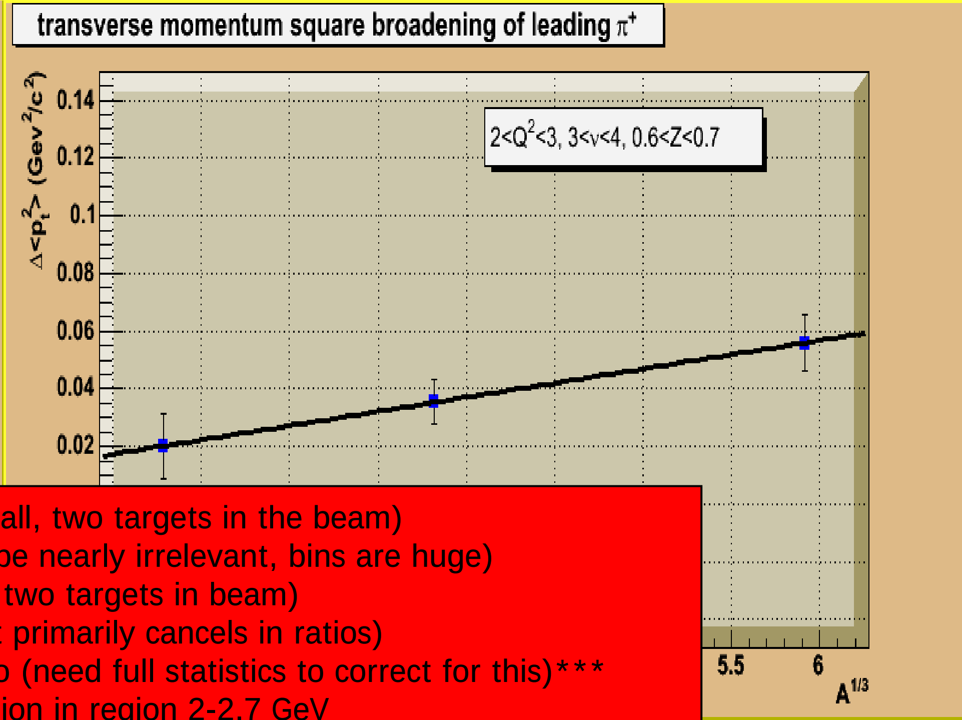

transverse momentum square broa



Catherine Silvestre (Nantes)



CLAS EG2 Preliminary
5% of data



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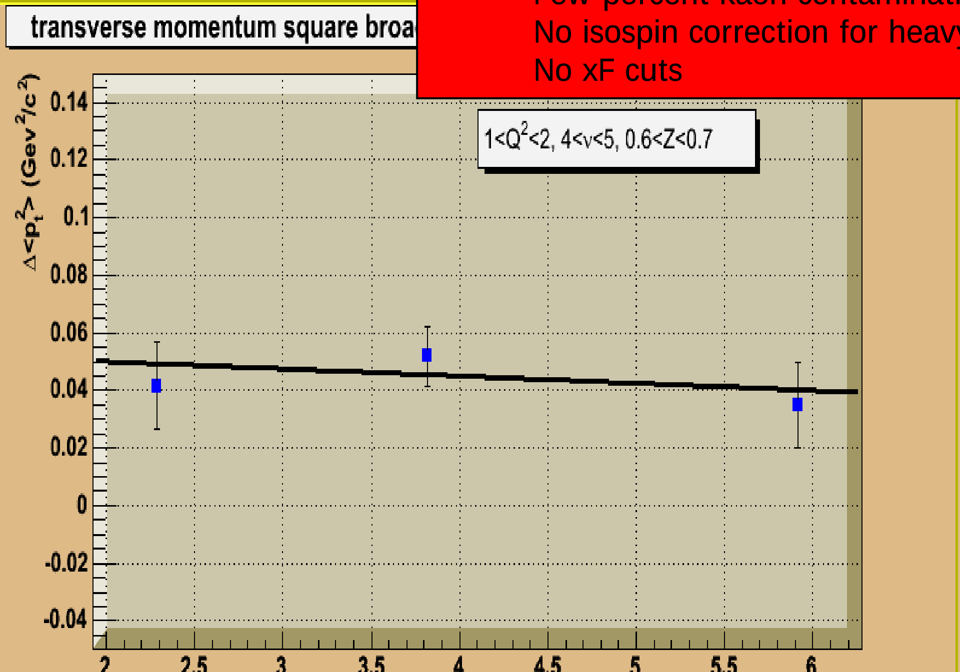
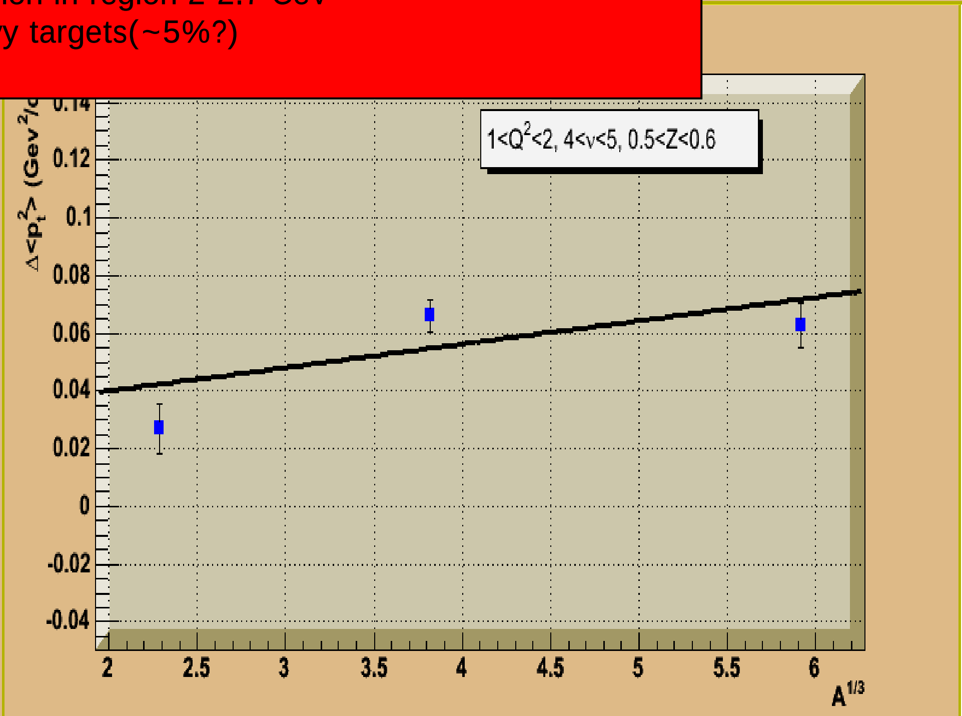
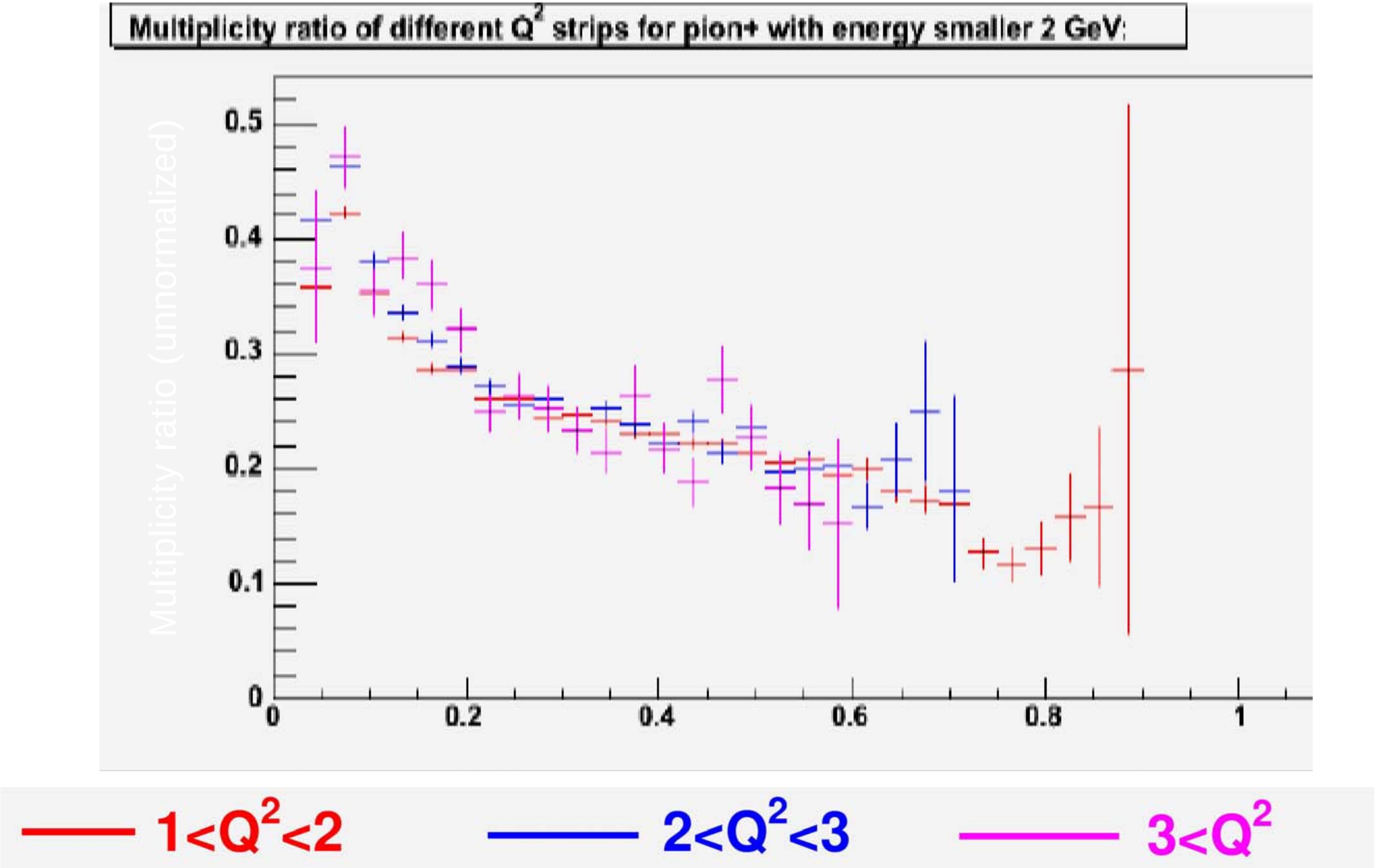




Catherine Silvestre (Nantes)

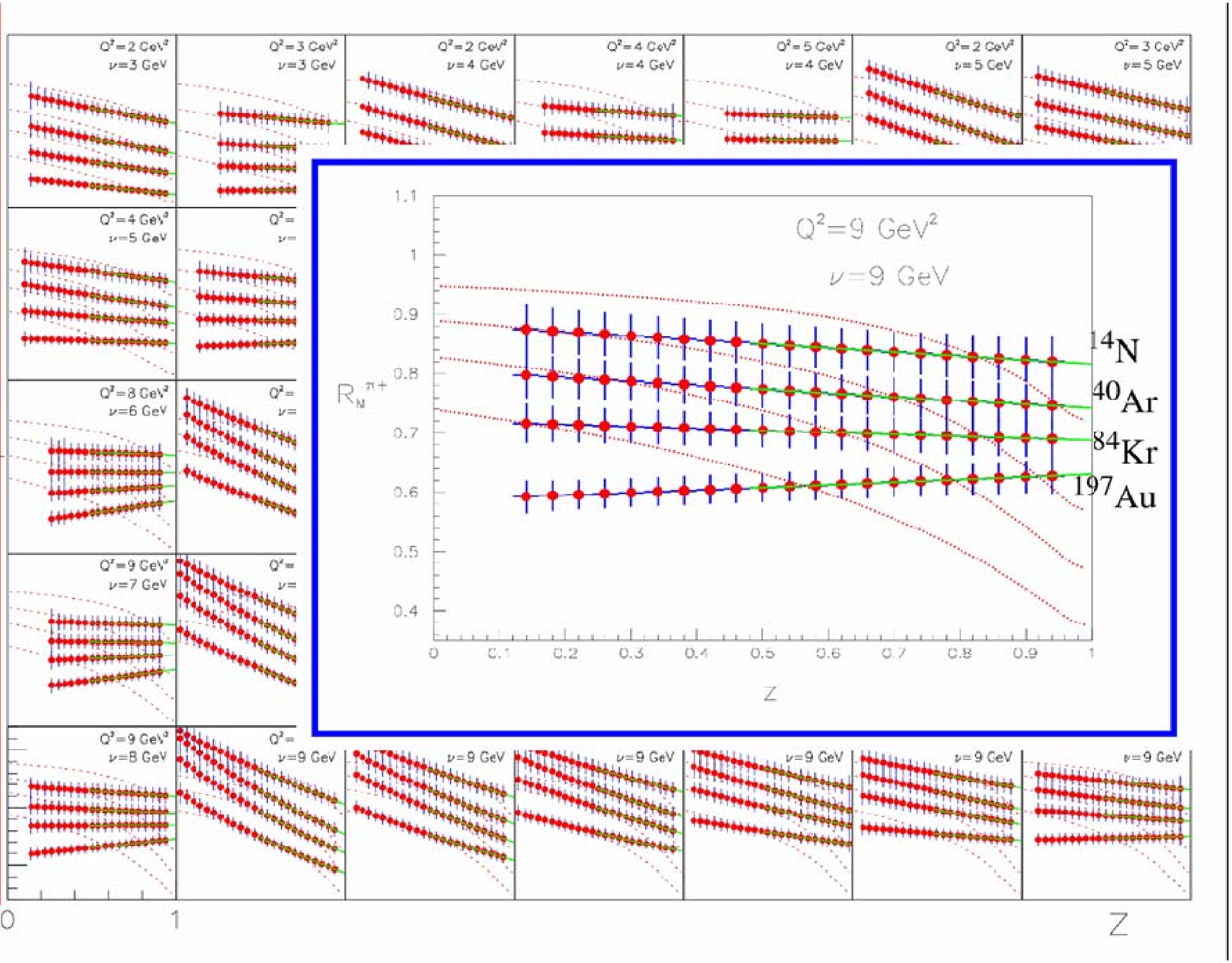
No clear Q^2 dependence seen



- 6 GeV beam : $Q^2 < 4$ GeV^2, $\nu < 5$ GeV.

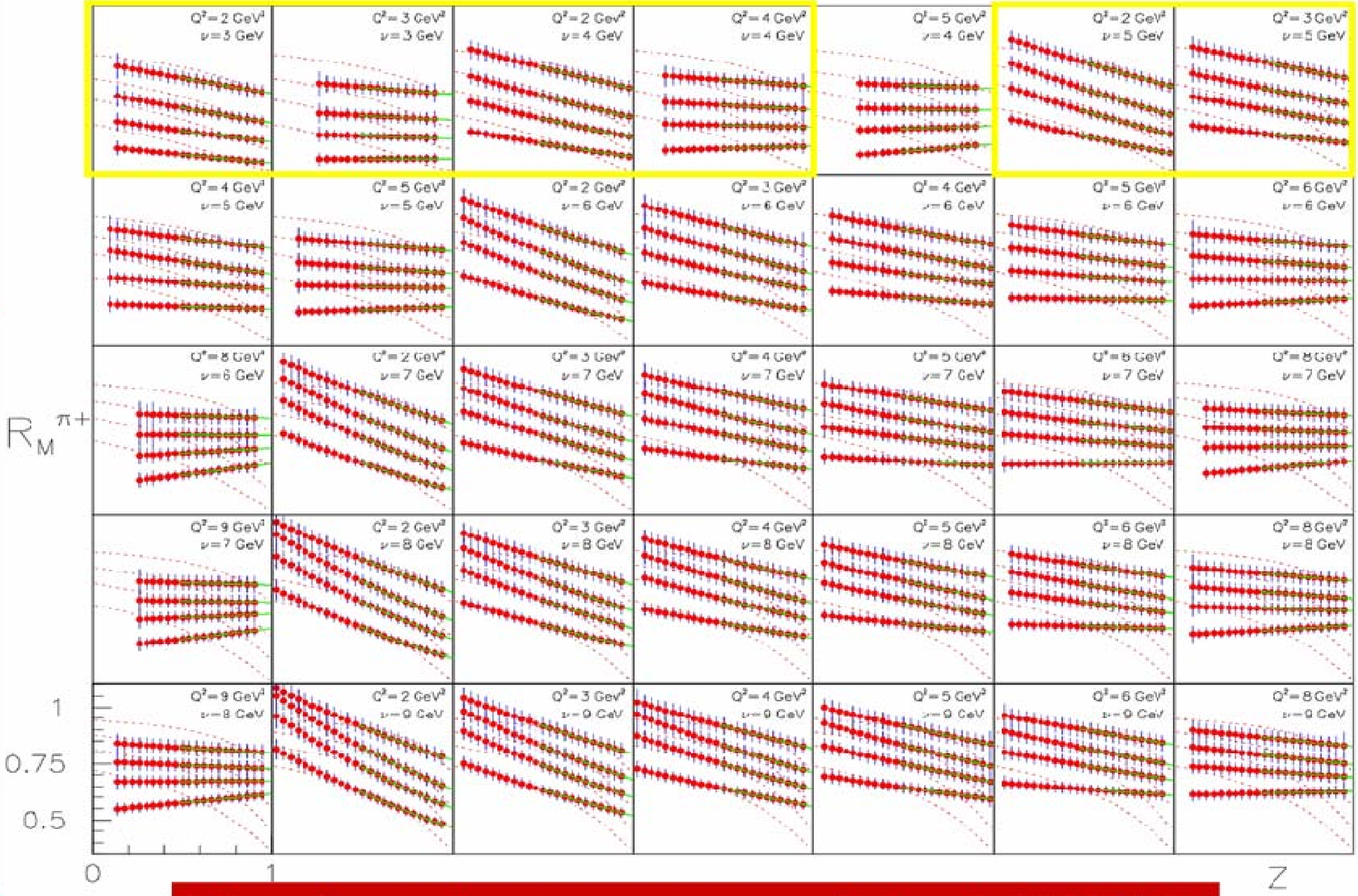
12 GeV beam : $Q^2 < 9$ GeV^2, $\nu < 9$ GeV.

12 GeV Anticipated Data



12 GeV Anticipated Data

Examples of Experimental Data and Theoretical Predictions



Bins in yellow are accessible at 6 GeV

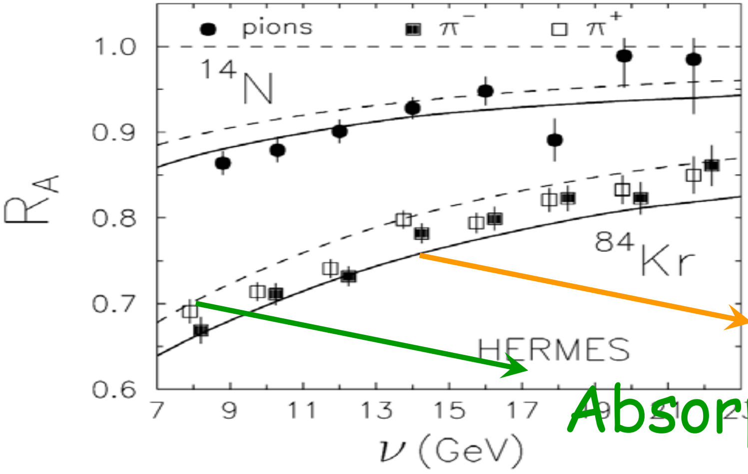
Accessible Hadrons (12 GeV)

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
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	ud	direct	1100
$\bar{p}$	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

The essential reaction mechanism has not been isolated: Hadron forms *inside* nucleus or *outside*? or *both*?

Gluon bremsstrahlung (Kopeliovich)

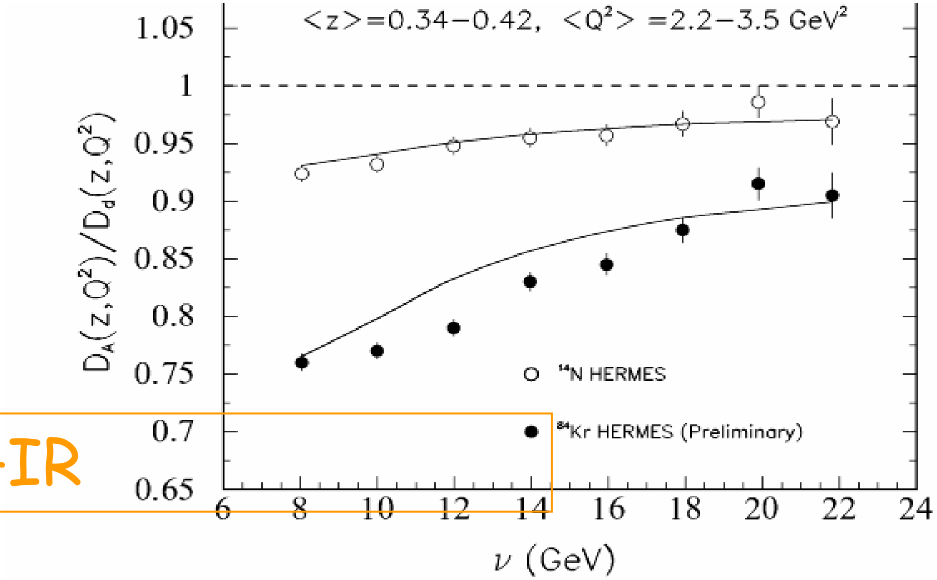
- Gluon radiation of colored quark
- Formation of color singlet pre-hadron
- Color transparency modulates pre-hadron (color dipole) attenuation
- Hadron attenuates in medium



Absorption

Twist-4 pQCD model (Wang)

- Medium-induced gluon radiation modifies F. F
- *No* hadronization
- Non-abelian LPM effect predicted
- Can extrapolate to predict jet quenching in RHIC collisions



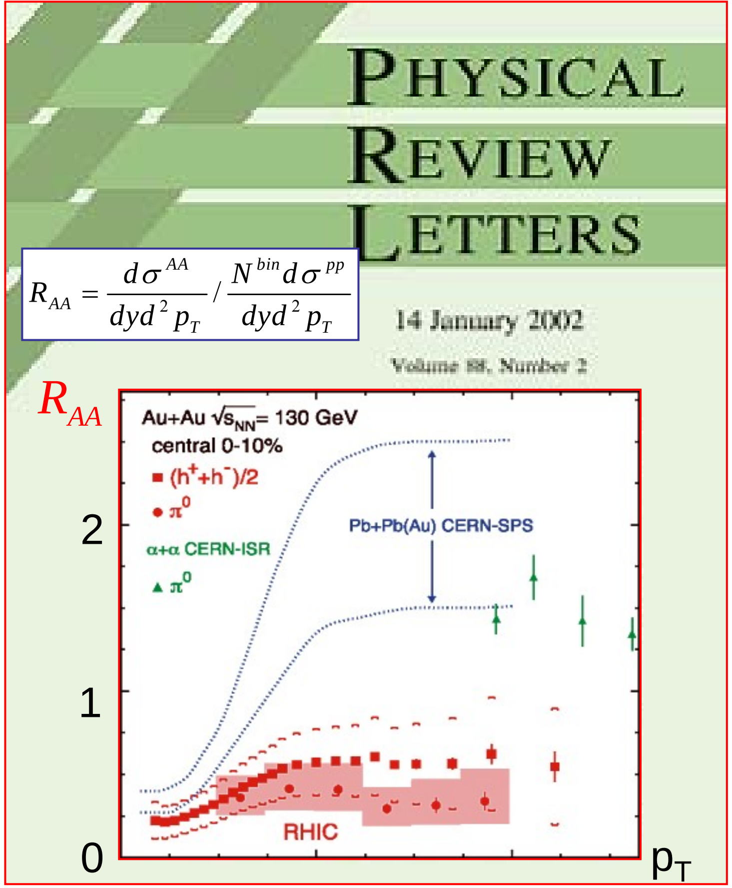
Ab+IR

<dE/dL>≈0.5 GeV/fm

Connections to Relativistic Heavy Ions

Nuclear SIDIS is related to parton progation in AA collisions

- P_T (A-A) ≈ $E_h = z\nu$(DIS) → the relevant energies are few - few tens of GeV.
- Jet quenching (suppression of high P_T hadrons) and depletion of the Cronin effect at RHIC:



$$R_{AA} = \frac{d\sigma^{AA}}{dyd^2 p_T} / \frac{N^{bin} d\sigma^{pp}}{dyd^2 p_T}$$

Jet quenching, ascribed to radiative energy loss, would be an indication of high partonic density, e.g. QGP.

(Pre-)hadron interaction in the nuclear medium might give alternative explanation.

W.Cassing, K.Gallmeister, C. Greiner NPA 735, 277 (2004).

Summary

- A unified picture is starting to emerge from the study of quark energy loss in Drell-Yan, SIDIS, and hadron production in d+Au collision. The 12 GeV upgrade provides an opportunity to further study the SIDIS.
- Future Drell-Yan, SIDIS, and p-A data will provide quantitative information on the propagation and hadronization of quarks in cold and hot nuclear medium.

Perturbative hadronization

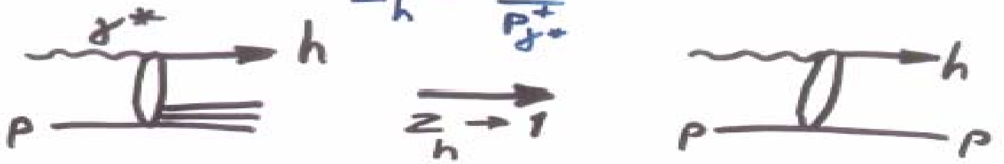
Although hadronization is usually considered as a manifestation of confinement, it also may be a perturbative process.

Positronium production

Of course, formation of the wave function is always nonperturbative.

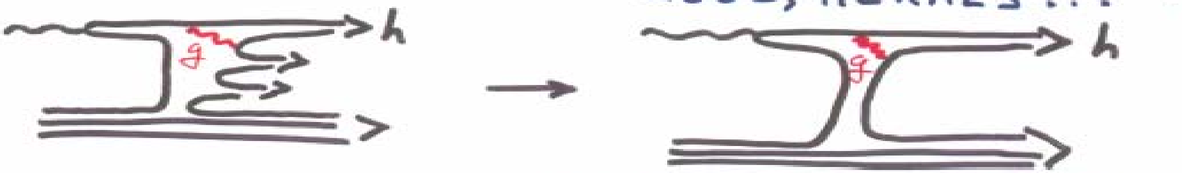
Inclusive production of leading hadrons has a limiting case of exclusive process.

$z_h = \frac{P_h^+}{P_{\gamma^*}^+}$



Subject to Color Transparency

E665, HERMES ...



Instantaneous production

Slower $q\bar{q}$ pairs are produced earlier.

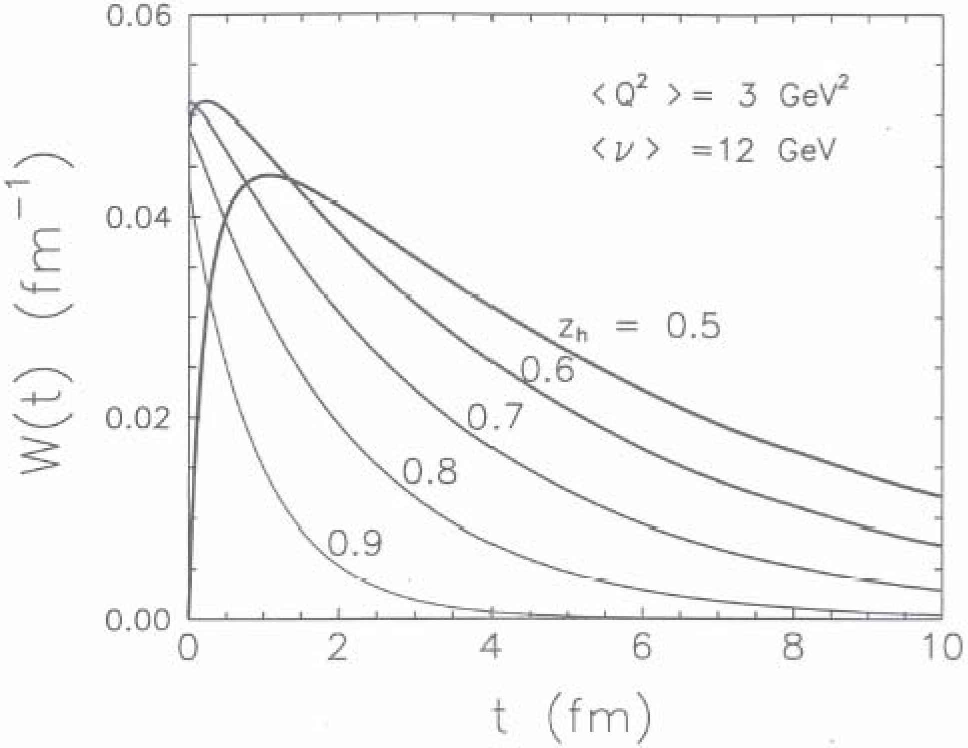
The less z_h is, the more $q\bar{q}$ pairs is produced, the longer it takes.

The pre-hadron (a $q\bar{q}$ dipole) is produced perturbatively with a size $\bar{r}(Q^2, z_h)$ controlled by Q^2 and z_h.

In the limit $z_h \to 1$ $\quad \bar{r} \sim \frac{1}{Q}$

! The string model contradicts data on

- CT at large z_h.



The production time distribution function

$t_p = \langle t \rangle$ shrinks at $z_h \to 1$

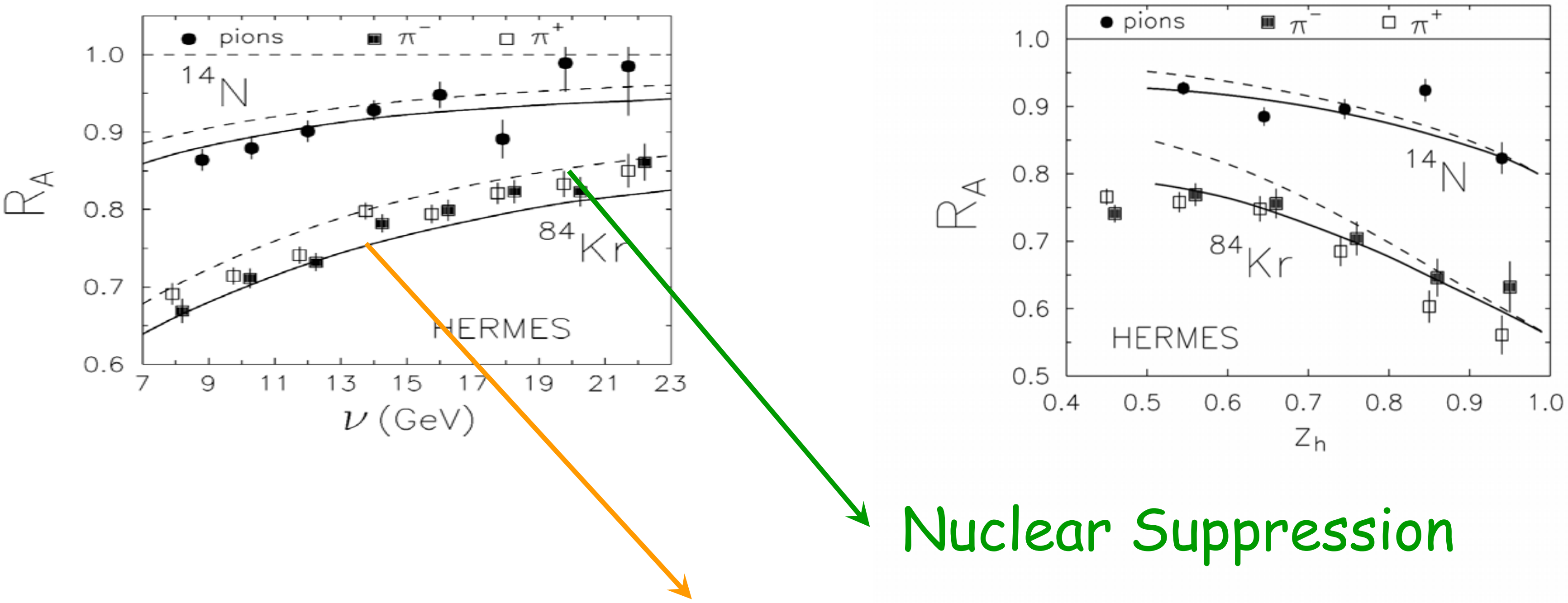
Gluon Bremsstrahlung

B.Kopeliovich et al.,
hep-ph/9511214
NPA 740, 211 (2004)

FF modification: Nuclear Suppression + Induced Radiation

Nuclear suppression: interaction of the $q\bar{q}$ in the medium.

Energy loss: induced gluon radiation by multiple parton scattering in the medium

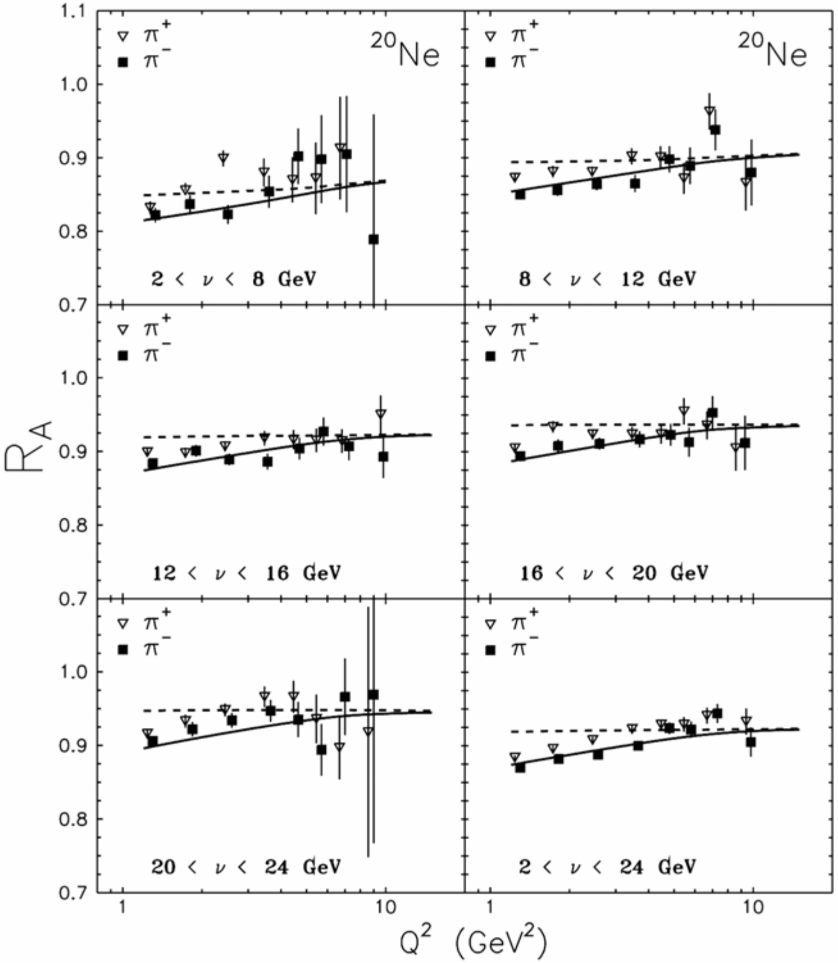


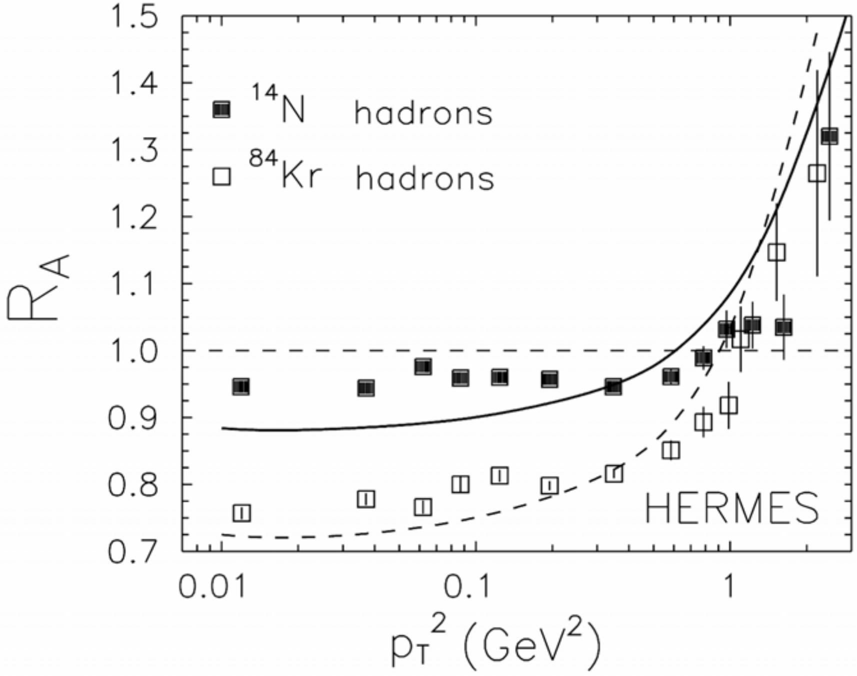
Nuclear Suppression

Nuclear Suppression + Induced Radiation

Gluon Bremsstrahlung

B.Kopeliovich et al.,
NPA 740, 211 (2004)





Q^2-dependence: mainly due to Induced Radiation.

Good description of ν, z, Q^2 and P_t -dependence .

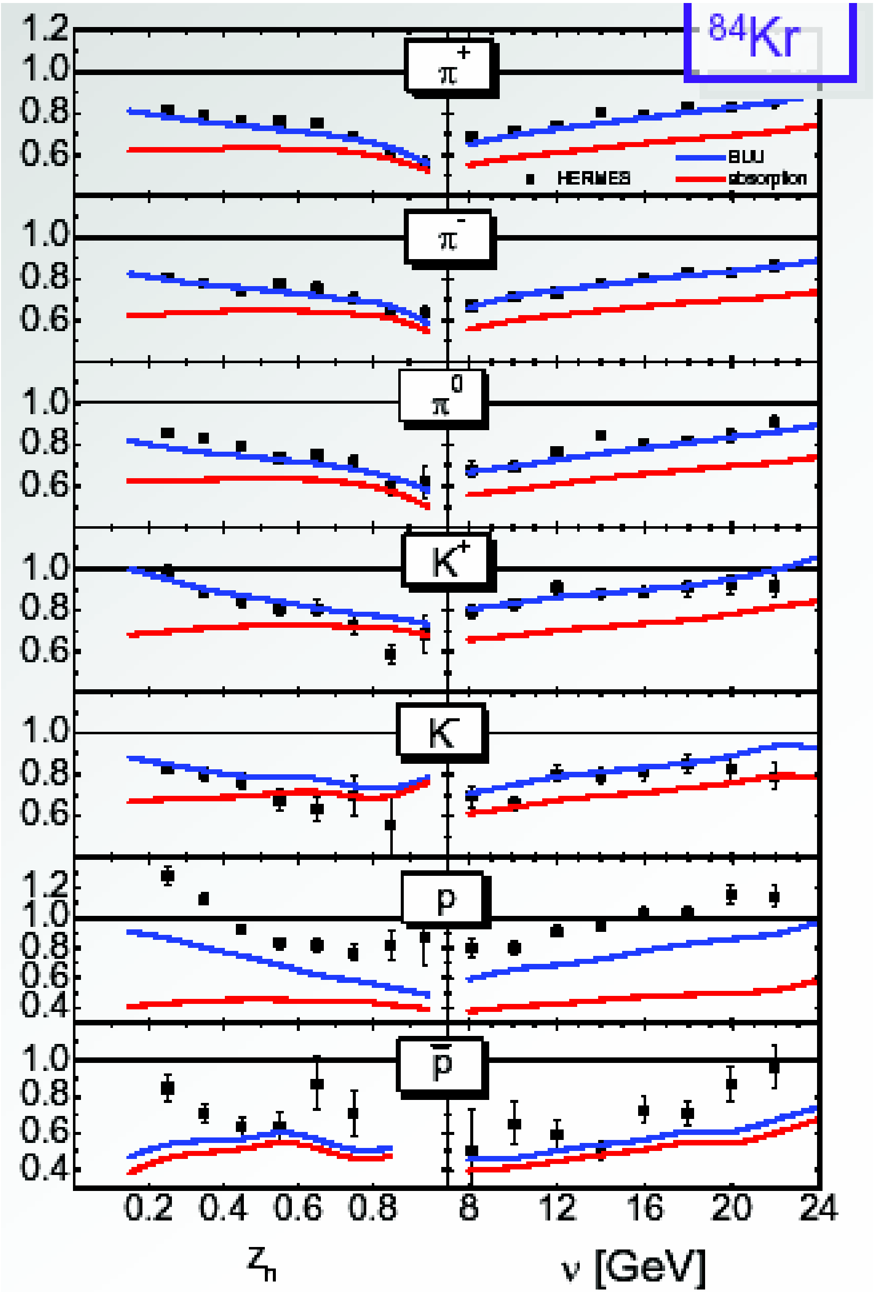
FSI in BUU Transport model

T.Falter, U. Mosel et al.,
nucl-th/0406023

γ-A eA reaction splitted in 2 parts:

-γ*N → X using PYTHIA & FRITIOF

-propagation of final state X within BUU transport model.



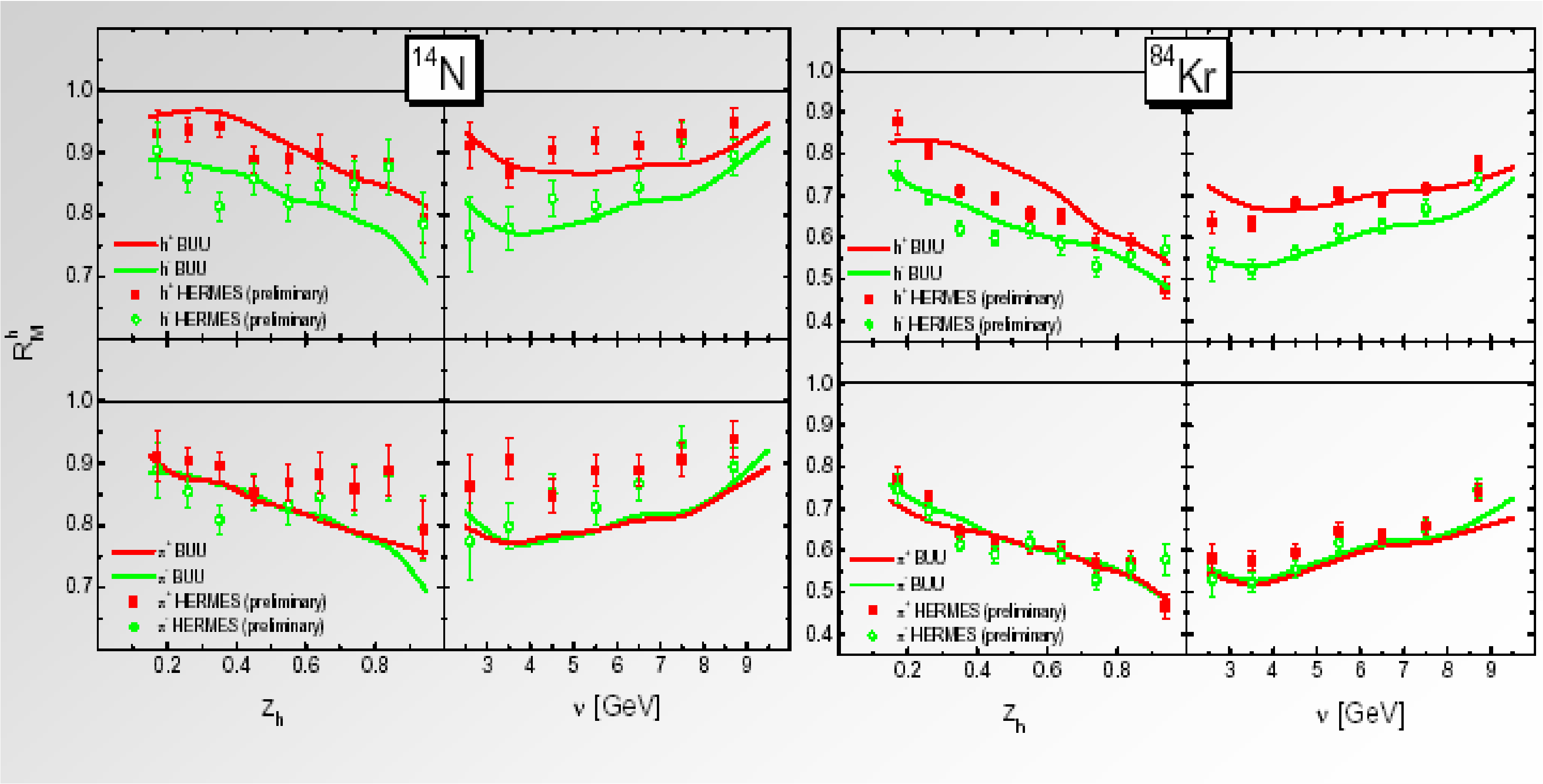
•___ pre-hadron τ_F=0.5 fm, σ^* by costituent quark model: $\sigma^*_{meson}=\#q_{orig}/2\ \sigma_{meson}$

•___ purely absorbitive FSI

FSI in BUU Transport model

T.Falter, U. Mosel et al.,
nucl-th/0406023

HERMES @ 12 GeV (τ_f=0.5 fm/c)

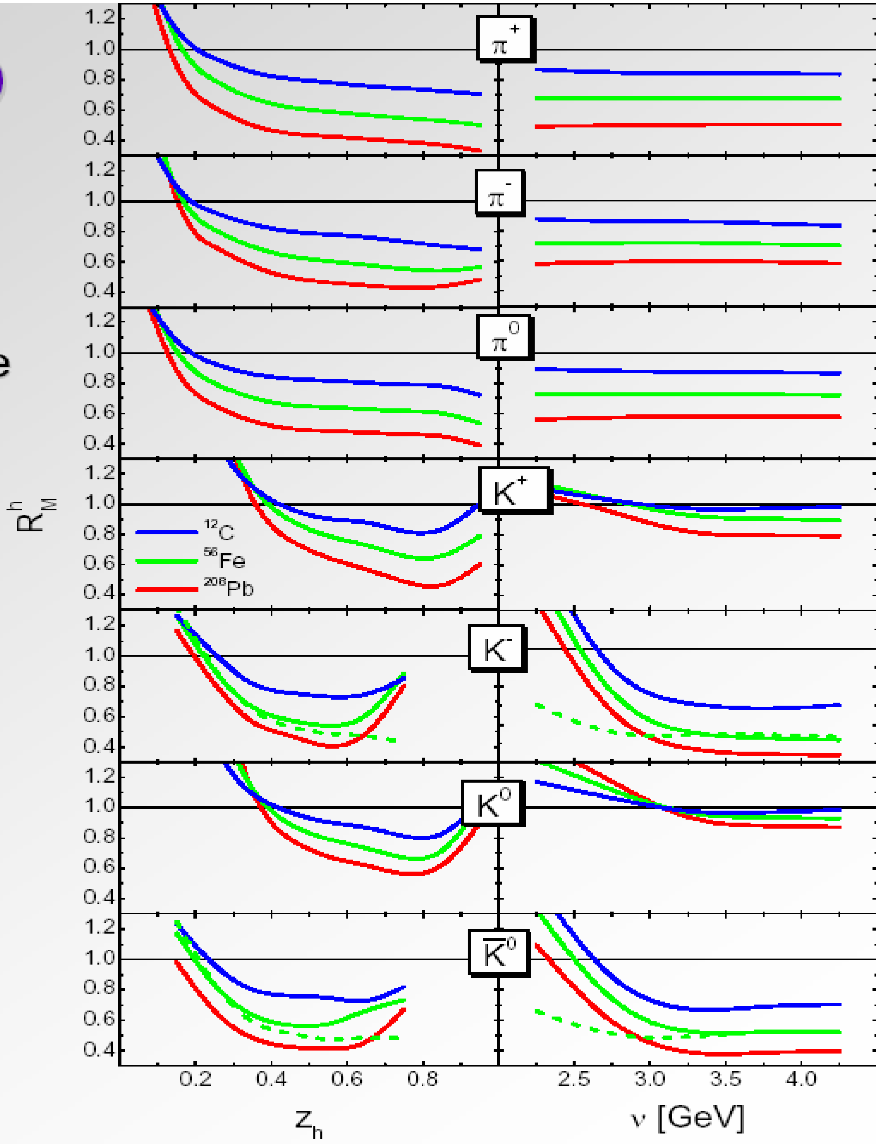


Model seems to work also at lower energy

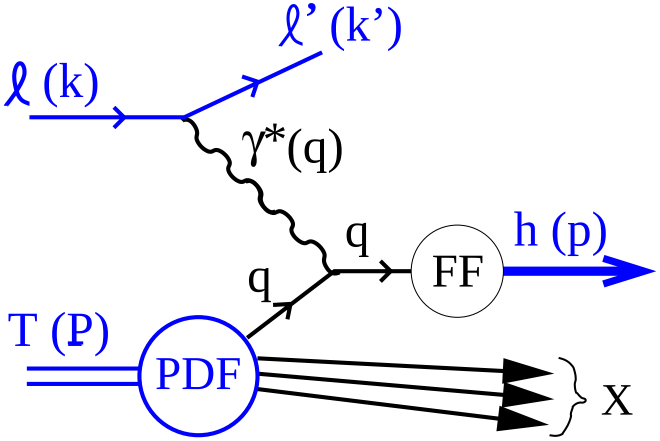
FSI in BUU Transport model

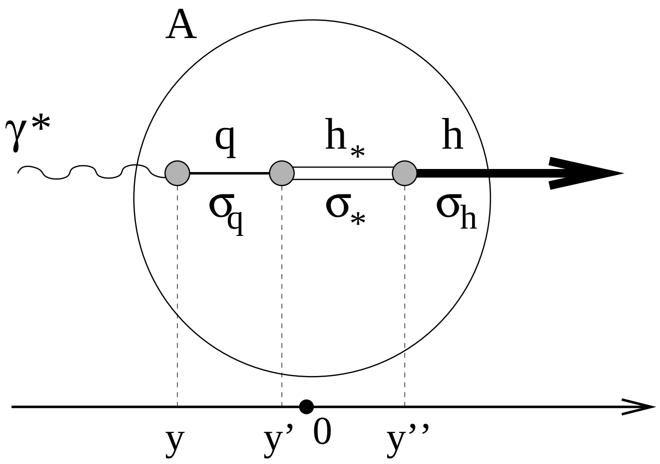
T.Falter, U.Mosel et al.,
nucl-th/0406023

- Jefferson Lab ($\tau_f = 0.5$ fm/c)
  - CLAS detector
    larger geometrical acceptance
    - detects more secondary particles from FSI
  - CEBAF
    lower energy
    - strong effect of Fermi-motion



Quark energy loss from semi-inclusive DIS

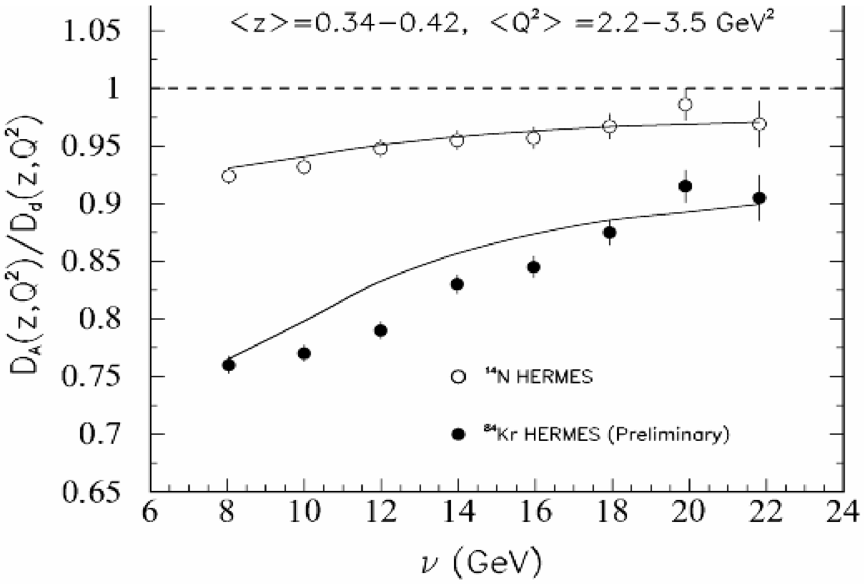


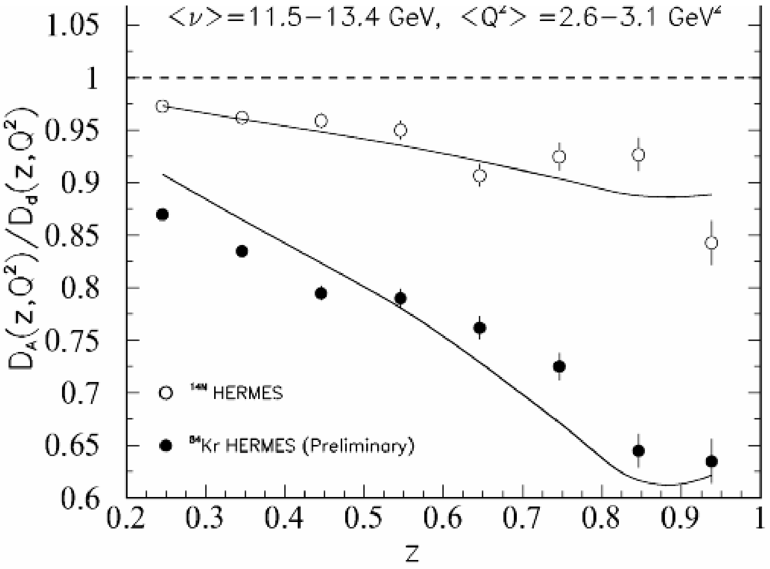


- No initial-state interation
- Energy loss of quarks and hadrons in nuclei
- Need to avoid the target fragmentation region
- Complementary to Drell-Yan

Energy loss from DIS

due to multiple parton scattering and induced parton energy loss
(without hadron rescattering)
pQCD approach: LPM interference effect →$A^{2/3}$ dependence





- 1 free parameter C≡quark-gluon correlation strength in nuclei.
- From ^{14}N data C=0.0060 GeV^2: $\Delta E = n < \Delta z_g > \propto C \alpha_s^2 m_N R_A^2$

<dE/dL>≈0.5 GeV/fm .

Models summary.

Absorption Models:

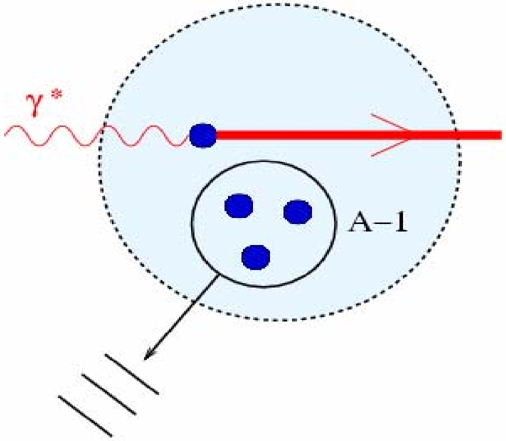
Important role of the pre-hadron formation and interaction.
Hadron formation mainly outside the nucleus.
Induced radiation smaller contribution compared to absorption.
⇒ Strong dependence on the pre-hadron interaction cross section.

Energy loss models:

Energy loss mechanism mainly,
competing processes play a modest role.
⇒ Strong dependence on the gluon transport coefficient that reflects the medium gluon density
→ Observables sensitive to models assumptions

3. THE SEMI-EXCLUSIVE DIS $A(e, e'B)X$ PROCESS

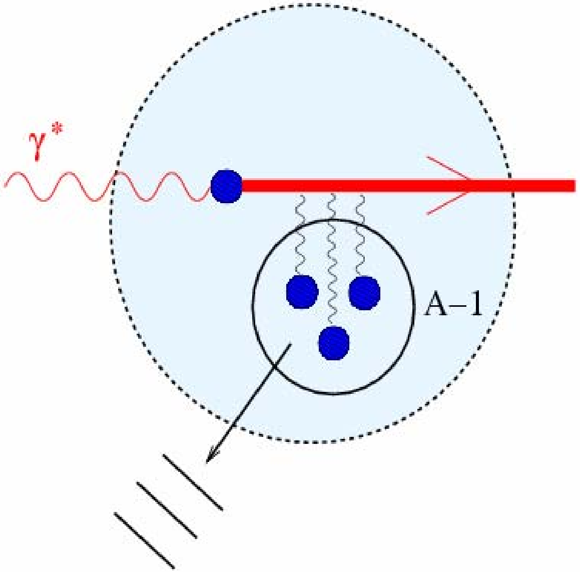
PWIA : The debris propagates through the nucleus freely



Melnitchouk, Sargsian, Strikman,
Z. Phys.A356(97)99
Simula, Phys. Lett. B387(96)245
CdA, Kaptari, Scopetta, EPJA 5(99)181

$$\frac{d\sigma^A}{dx dQ^2 d\vec{P}_{A-1}} = K^A(x, Q^2, y_A, z_1^{(A)}) z_1^{(A)} F_2^{N/A}(x_A, Q^2, p_1^2)\, P^A(E, |\vec{P}_{A-1}|)$$

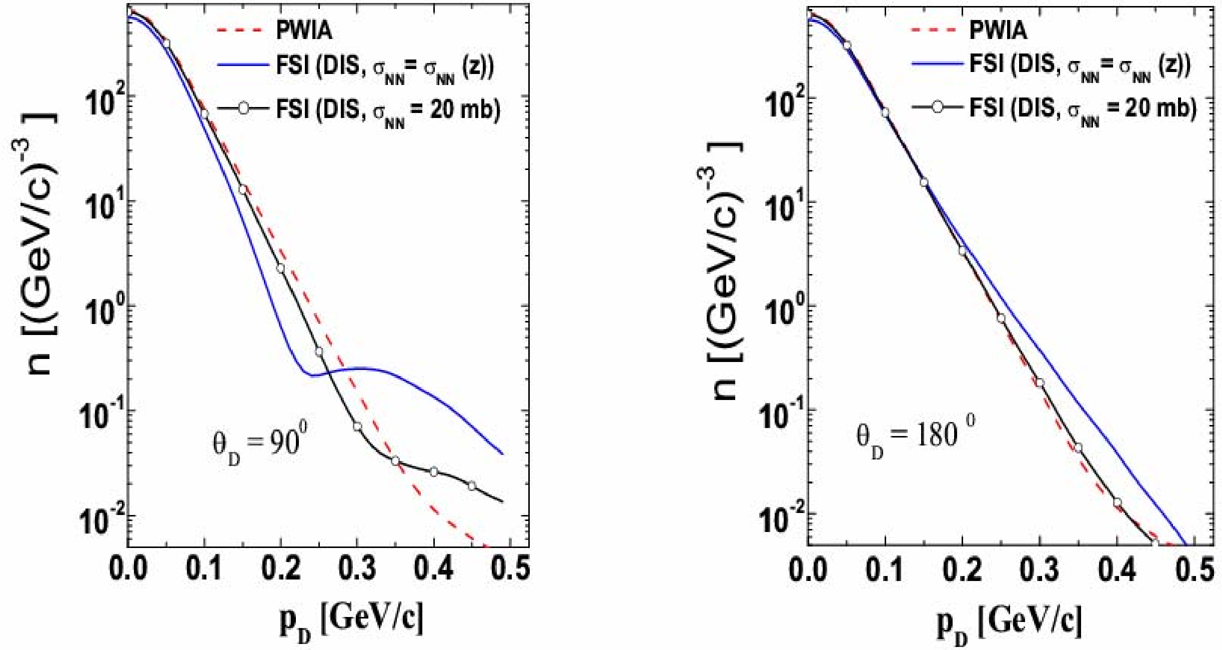
FSI



- The hadronizing quark interacts with the spectator nucleons via $\sigma_{eff}(t)$
- The survival probability of (A-1) is reduced depending on the features of $\sigma_{eff}(t)$.

CdA, Kopeliovich, EPJA17(2003)133

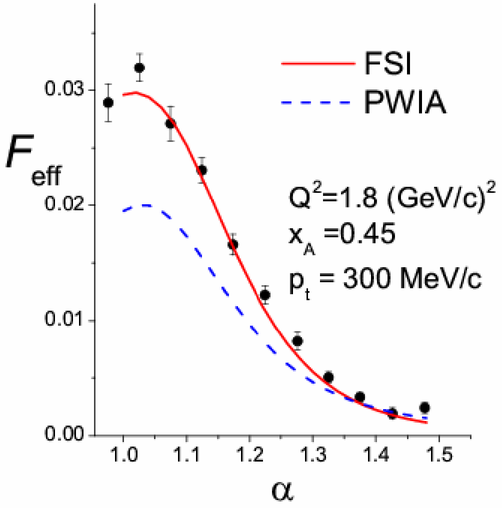
$^3He(e,e'D)X$



$$\theta_D = \widehat{\mathbf{q}\mathbf{p}}_D$$

(After CdA, Kaptari unpublished)

$^2H(e,e'p)X$ theory *vs.* experiment



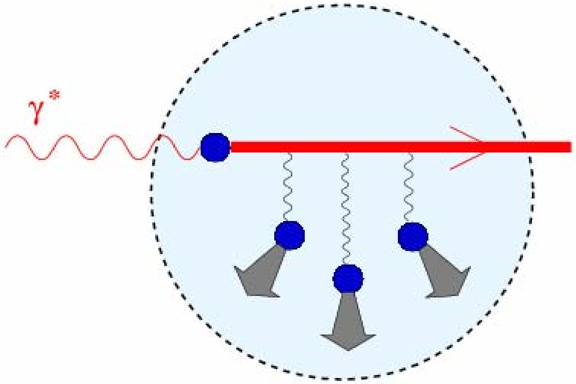
$$F_{eff} \equiv P_A^D(\alpha, \mathbf{p}_T) F_2^{(2/A)}(\frac{x_{Bj}}{2-\alpha}, \mathbf{p}_T, Q^2) \quad \alpha = \frac{E - p_\parallel}{m_N}$$

Experiment(PRELIMINARY):

Jlab 94-102 S. E. Kuhn, K. A. Griffioen , co-spokespersons, *Inelastic electron scattering off a moving nucleon in deuterium*

Theory (After CdA, Kaptari, unpublished)

4. HADRONIZATION MECHANISM AND GREY TRACKS



- **The whole jet inelastically interacts with spectators nucleons, which recoil and form Grey Tracks (GT). GT production covers the main bulk of inelastic events.**

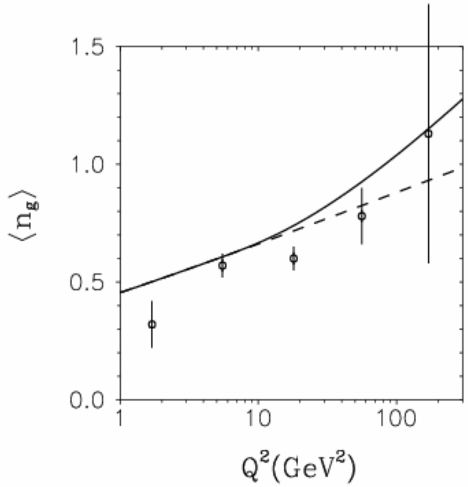
Calculation of GT production (CdA, Kopeliovich, hep-ph/0409077)

- Theory: debris-nucleon cross section;
- Experiment: Fermilab E665($\mu - Xe$ and $\mu - D$ processes at 490 GeV beam energy; GT- protons with momentum $200 - 600\ MeV/c$).
- Empirical relation: between the mean number of collisions, $\langle \nu_c \rangle$, and the mean number of GT $< n_g >$

$$< n_g > = \frac{\langle \nu_c \rangle - (2.08 \pm 0.13)}{(3.72 \pm 0.14)}$$

- The Model: DIS on a bound nucleon at coordinate $(\vec{b}, z)$. The hadronizing quark (The debris) propagates through the nucleus interacting with spectator nucleons via $\sigma_{eff}(z - z')$. The number of collisions, (plus the recoiling nucleon formed in the hard $\gamma * -N$ act) is

$$\langle \nu_c \rangle = \int d^2b \int_{-\infty}^{\infty} dz\, \rho_A(b, z) \int_{z}^{\infty} dz'\, \rho_A(b, z')\, \sigma_{eff}(z - z') + 1\ .$$



The mean number of grey tracks $\langle n_g \rangle$ produced in the μXe DIS *vs* Q^2 in the non-shadowing region ($x_{Bj} = 0.07$) (full). The solid curve includes the $Q^2 - x_{Bj}$ correlation.

- The Debris-Nucleon cross section,**with no readjustment of the parameters** correctly predicts the Q^2 dependence, thanks to the Q^2 and x_{Bj}-dependent gluon radiation mechanism;

- Extend ‘traditional’ EMC effect measurements:
  Improve the data at large x and A-dependence
  EMC effect for separated structure functions
  Flavor dependence

- Structure functions of nuclei at $x>1$:
  Information about the high momentum components
  →SRC’s in nucleus

- Space-time characteristics of hadronization:
  -Multivariate measurements of nuclear multeplicity vs ν, z, Q^2, p_t
  Measurements of the p_t broadening.
  Connections to the fundamental process of gluon emission.
  -Complementary analysis of Grey Tracks

High-density configurations: quark distributions at x>1

The EMC effect compares light nuclei to heavy nuclei in order to see the effect of changing the ***average*** density (0.06-0.15 nucleons/fm^{-3})

Probing the quark structure of SRCs allows us to see the effect of changing ***local*** density. Densities can be several times larger in the region where nucleons overlap

Need the following:

- A way to isolate high density configurations
- Understanding of SRCs in terms of nucleonic degrees of freedom

* DIS (e,e'): Measure *quark* distributions at x>1.

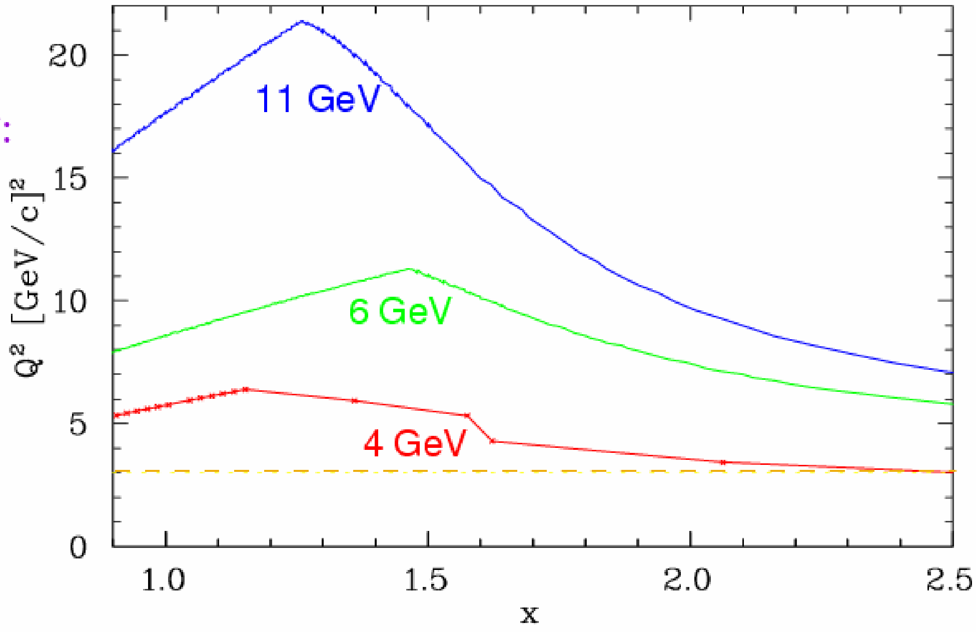
- Structure of SRCs: Superfast quarks
  At x>1, contributions from mean-field momentum distributions are negligible, and we probe the distribution of SRCs
- Look for deviations from simple convolution model

$$q_A(x) = q_{p/n}(x) \otimes n_A(k)$$

10-20% for EMC effect measurements
Possibly much higher when probing high-density configurations

J. Arrington

Summary I: Nuclear Structure



1) A(e,e'): x>1.5, Q^2~ 5-10 GeV^2:

A-dependence of 2N SRCs

Isolate multi-nucleon SRCs

⇨ Map out size of 2N, 3N SRCs in nuclei

2) Exclusive A(e,e'p) and A(e,e'NN) reactions, 'tagged' SRCs

Provide much more detailed information on SRCs, but with reduced kinematic range, larger issues with reaction mechanism (FSIs, MECs,...)

3) x ~ 1.0-1.5, Q^2 > 15 GeV^2:

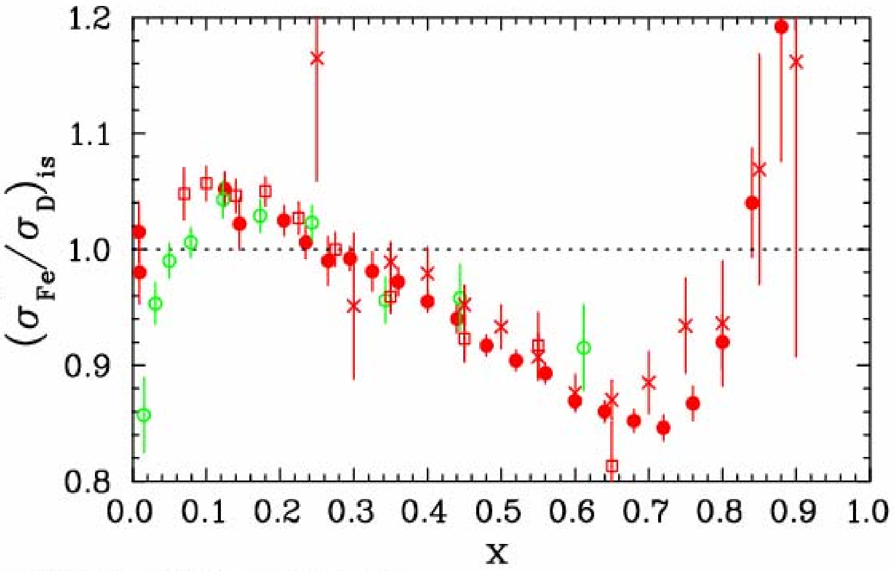
Measure PDFs for x>1

Look for excess superfast quarks - beyond contribution from quarks in ordinary (but high momentum) nucleons

⇨ Isolate and identify non-hadronic contributions to nuclear structure

J. Arrington

Summary II: EMC effect



Average nuclear densities are quite low - well below expected phase transition

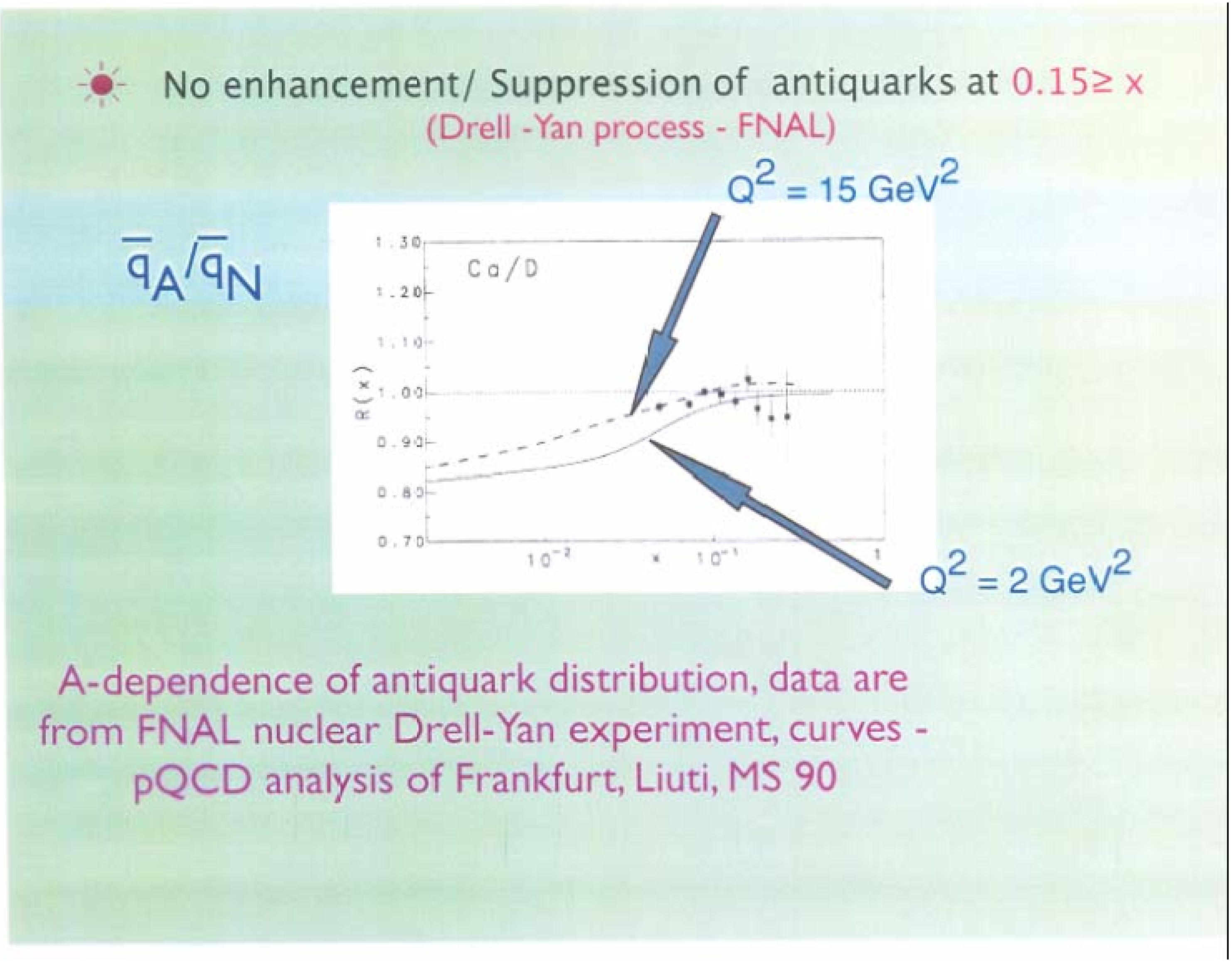
Extend traditional measurements of the EMC effect

- Measure at larger x values
- Separated structure functions
- Flavor dependence
- ^{3}H vs. ^{3}He to separate nuclear effect, neutron excess

Test models that assume non-hadronic explanation more directly

- Modified in-medium nucleon form factors
- Probe SRCs to look for non-hadronic componenets in SRCs
  - *** SRCs provide a small high-density component in nuclei**
  - *** Several times higher than average nuclear densities**
  - *** Tightly packed nucleons could deform, swell, or even merge**
  - *** May be origin of EMC effect, medium modifications**

J. Arrington



No enhancement/ Suppression of antiquarks at 0.15≥ x
(Drell -Yan process - FNAL)

$\bar{q}_A/\bar{q}_N$

$Q^2 = 15\ GeV^2$

$Q^2 = 2\ GeV^2$

A-dependence of antiquark distribution, data are from FNAL nuclear Drell-Yan experiment, curves - pQCD analysis of Frankfurt, Liuti, MS 90

A.Bruell

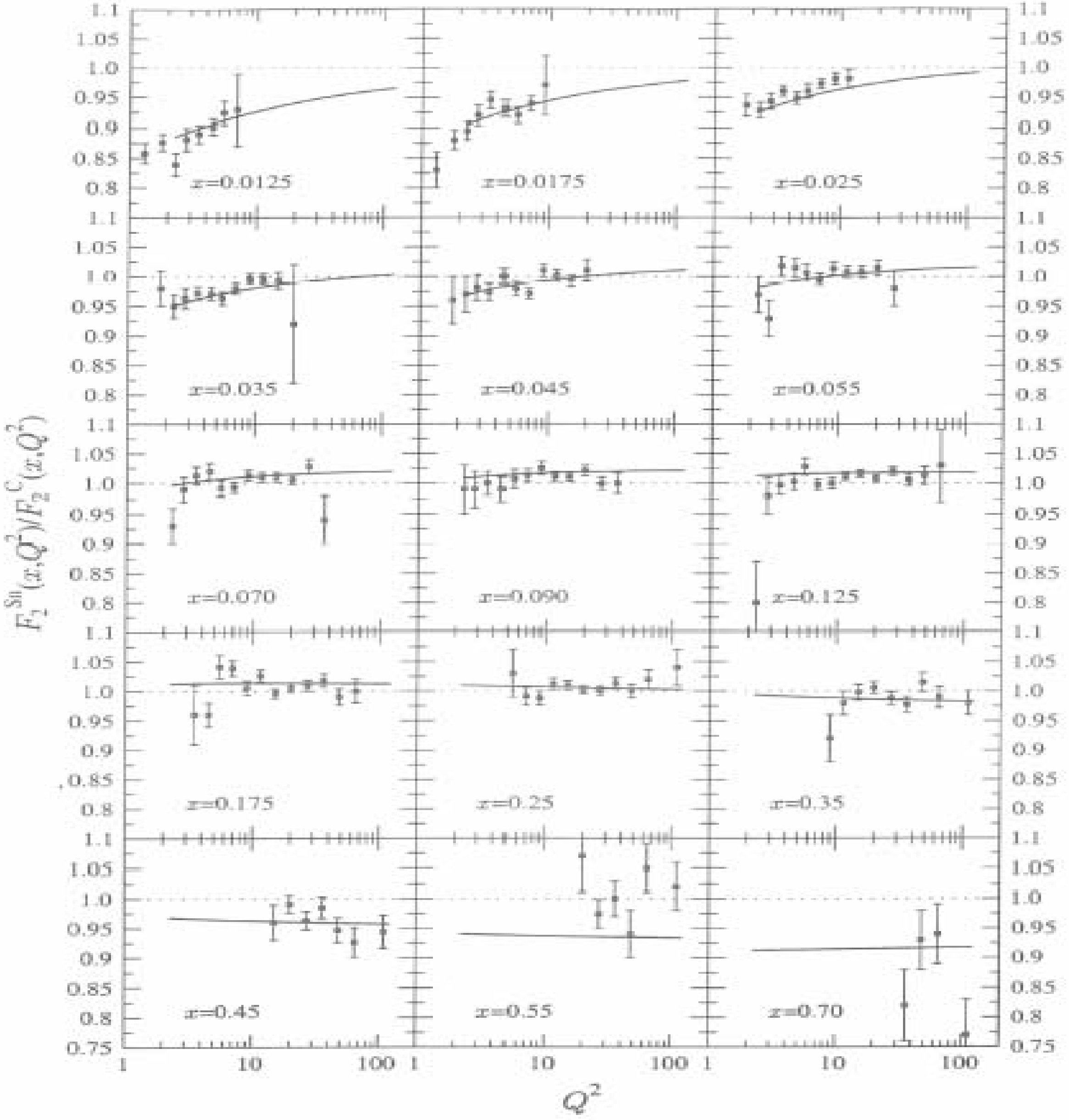
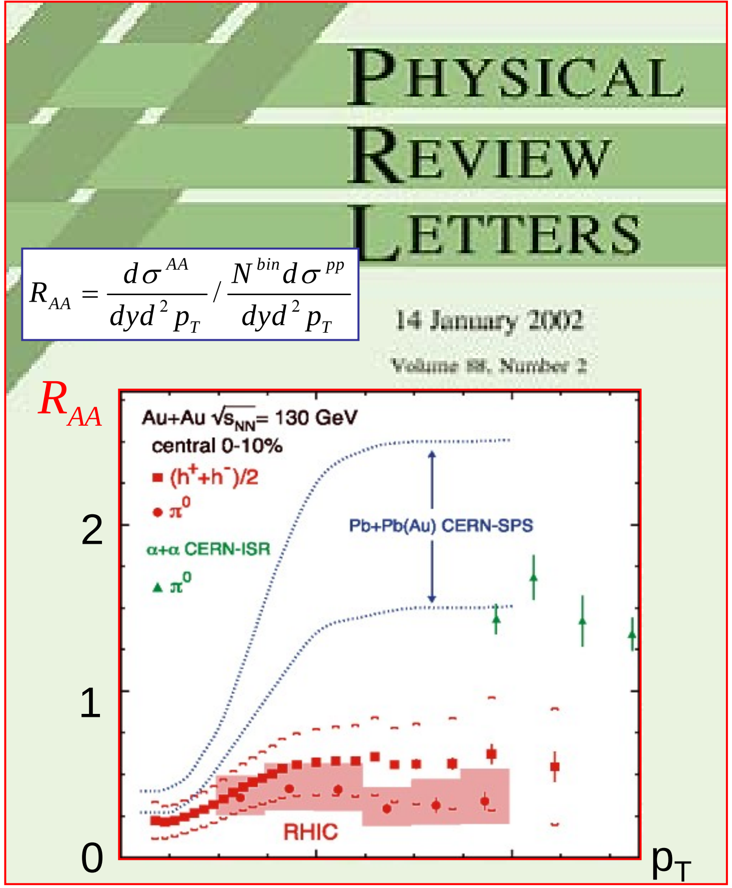


Figure 10: The calculated scale evolution of $F_2^{Sn}(x,Q^2)/F_2^C(x,Q^2)$ compared with the NMC data [3] at different fixed values of x. The data are plotted with statistical errors only.

Connections to Relativistic Heavy Ions

Nuclear SIDIS is related to parton progation in AA collisions

- P_T (A-A) ≈ $E_h = z\nu$(DIS) → the relevant energies are few - few tens of GeV.
- Jet quenching (suppression of high P_T hadrons) and depletion of the Cronin effect at RHIC:



$$R_{AA} = \frac{d\sigma^{AA}}{dyd^2p_T} / \frac{N^{bin}d\sigma^{pp}}{dyd^2p_T}$$

Jet quenching, ascribed to radiative energy loss, would be an indication of high partonic density, e.g. QGP.

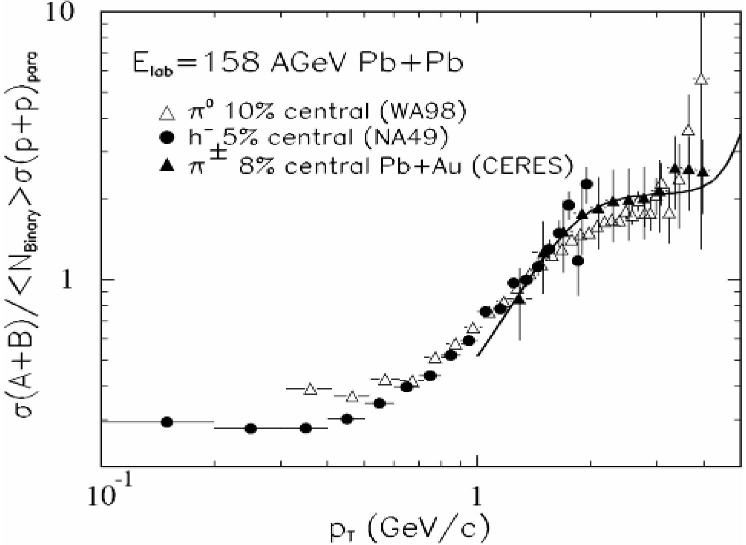
(Pre-)hadron interaction in the nuclear medium might give alternative explanation.

W.Cassing, K.Gallmeister, C. Greiner NPA 735, 277 (2004).

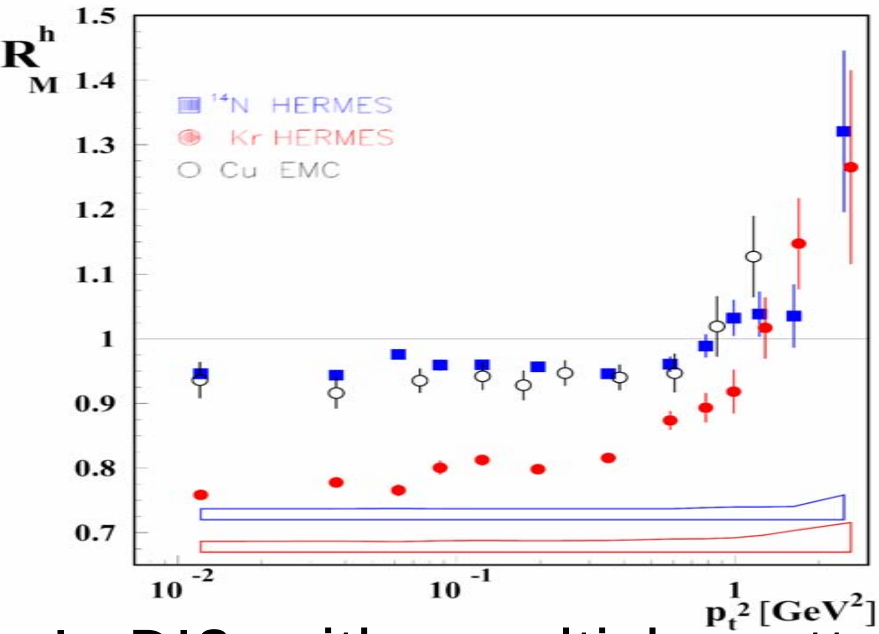
Multiplicity Ratio vs p_t^2

Cronin effect: in pA and AA collisions hadrons gain extra transverse momentum due to the multiple scattering of projectile partons propagating through the nucleus.

CERN



Data show a p_t enhancement similar to that observed in pA scattering at p_t~1-2 GeV.



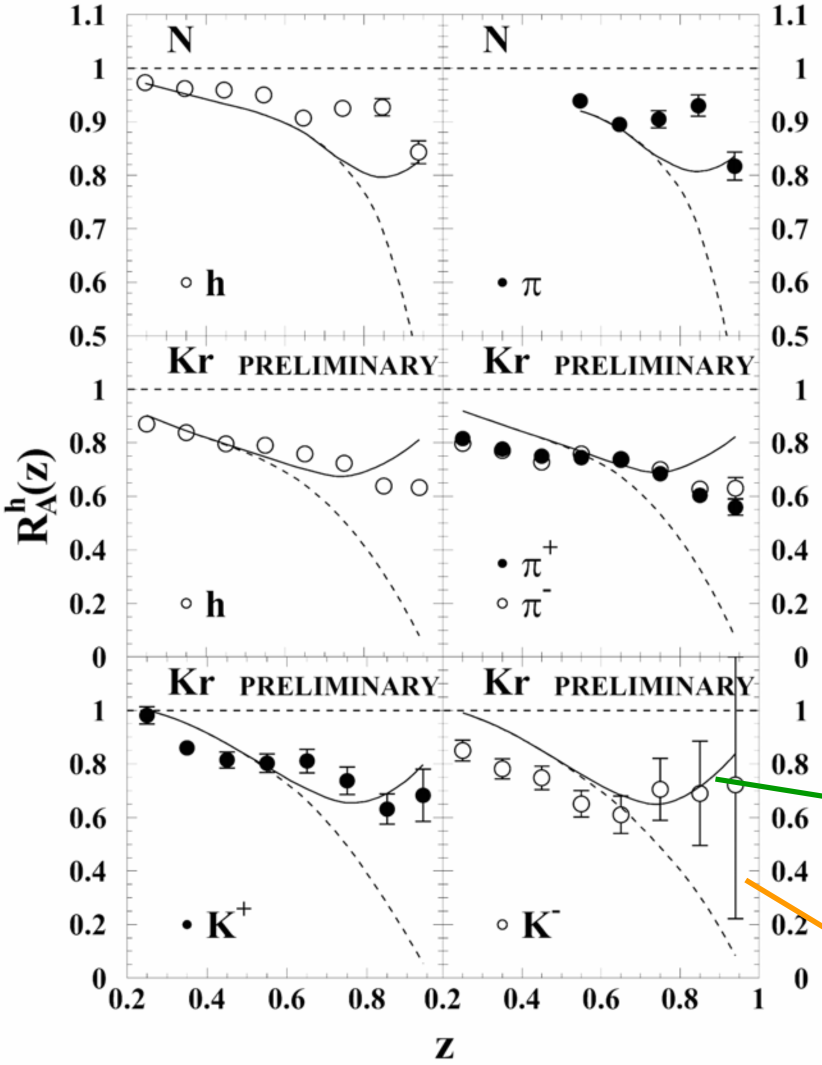
In DIS neither multiple scattering of the incident particle nor interaction of its constituents → FSI contribution to the Cronin .

V. Muccifora

INFN Frascati

FF modification + formation time effect

F.Arleo et al., NPA715(2003)899



- Gluon transport coefficient fixed from Drell-Yan

$$\hat{q} = 0.14\ GeV^2 / fm$$

$$\langle -dE/dL \rangle_{cold}^{final} \approx 0.6\ GeV/fm$$

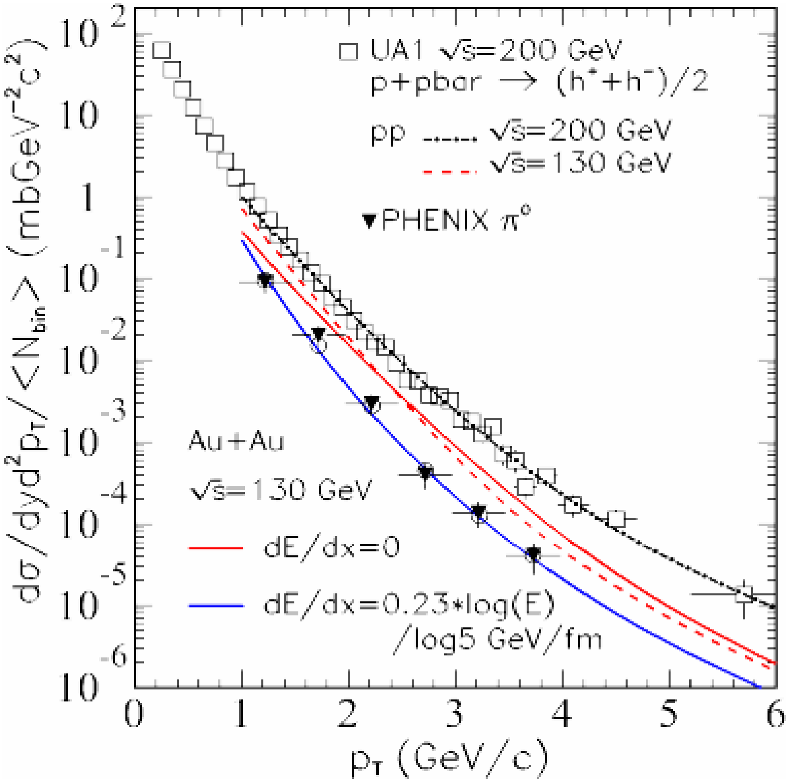
With formation time effect

Without formation time effect

dE/dL and Gluon density at RHIC

E.Wang , X.N. Wang PRL 89 (2002) 162301.

$dE/dL_{PHENIX}|_{Au}$ predictions determined by using C=0.0060 GeV^2 from HERMES data.



PHENIX: hot, expanding system.

HERMES: cold, static system.

⇓

- $\Delta E_{sta}\ \alpha\ \rho_0 R_A^2$; ρ_0 gluon density and $R_A \approx 6$ fm
- $\Delta E_{exp} \approx \Delta E_{sta}\,(2\tau_0/R_A)$; τ_0 initial formation time of dense medium

•Gluon density in Au+Au~15 times higher than in cold matter

Observables sensitive to the model assumptions.

- Investigation of the Q^2-dependence of the nuclear effects.

- p_t-broadening and its z-dependence.

B.Z.Kopeliovich et al. NPA 740, 211 (2004).

- Investigation of the Q^2-dependence of "grey tracks" (GT) in SIDIS:

A(e,e'B)X where the recoil nucleus B does not survive, but breaks in fragments (predominantly protons) with few-hundred MeV/c momenta.

C. Ciofi degli Atti and B.Z. Kopeliovich hep-ph/0409077.

- Double/single hadron production

A.Majumder and X.N.Wang hep-ph/0410078.

Models based on (pre-)hadronic absorption

B. Kopeliovich et al.,: hep-ph/9511214 , NPA 740, 211 (2004).

T. Falter et al.,: nucl-th/0406023.

A. Accardi et al.,: NPA 720, 131 (2003).

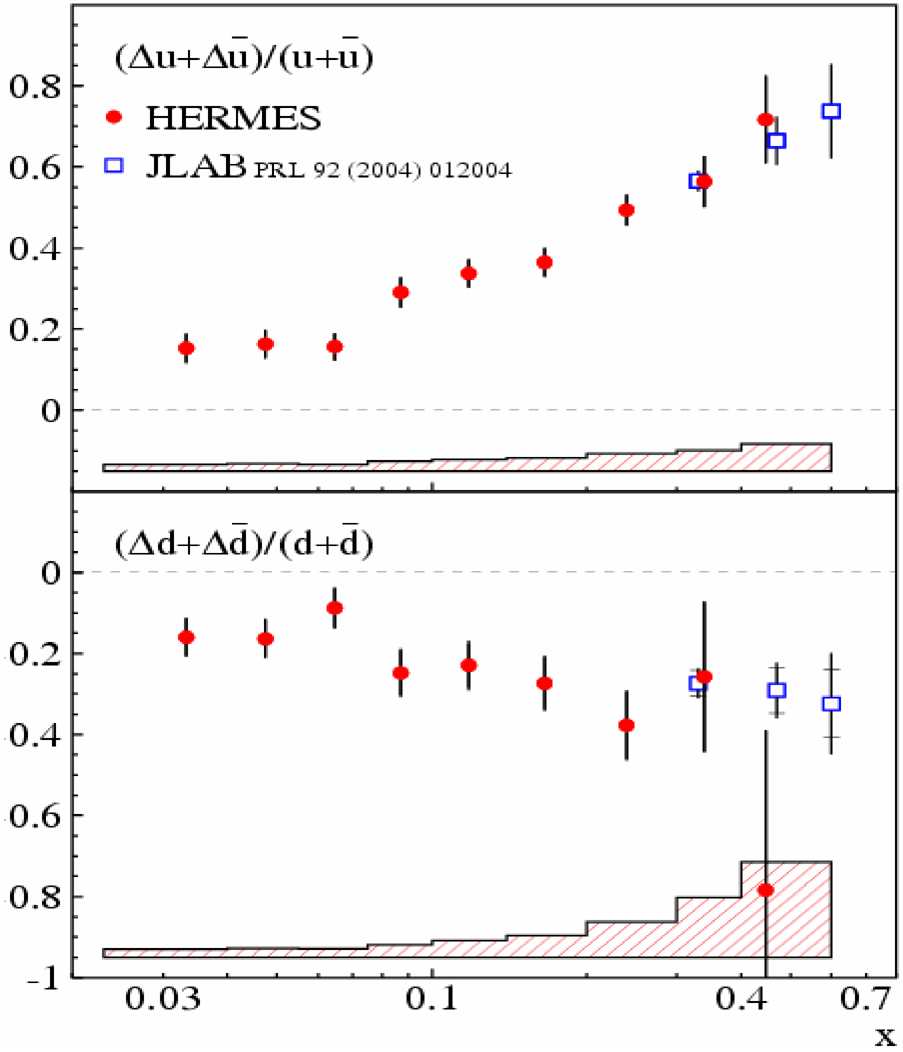
Models based on partonic energy loss

X.N. Wang et al.: PRL 89, 162301 (2002)

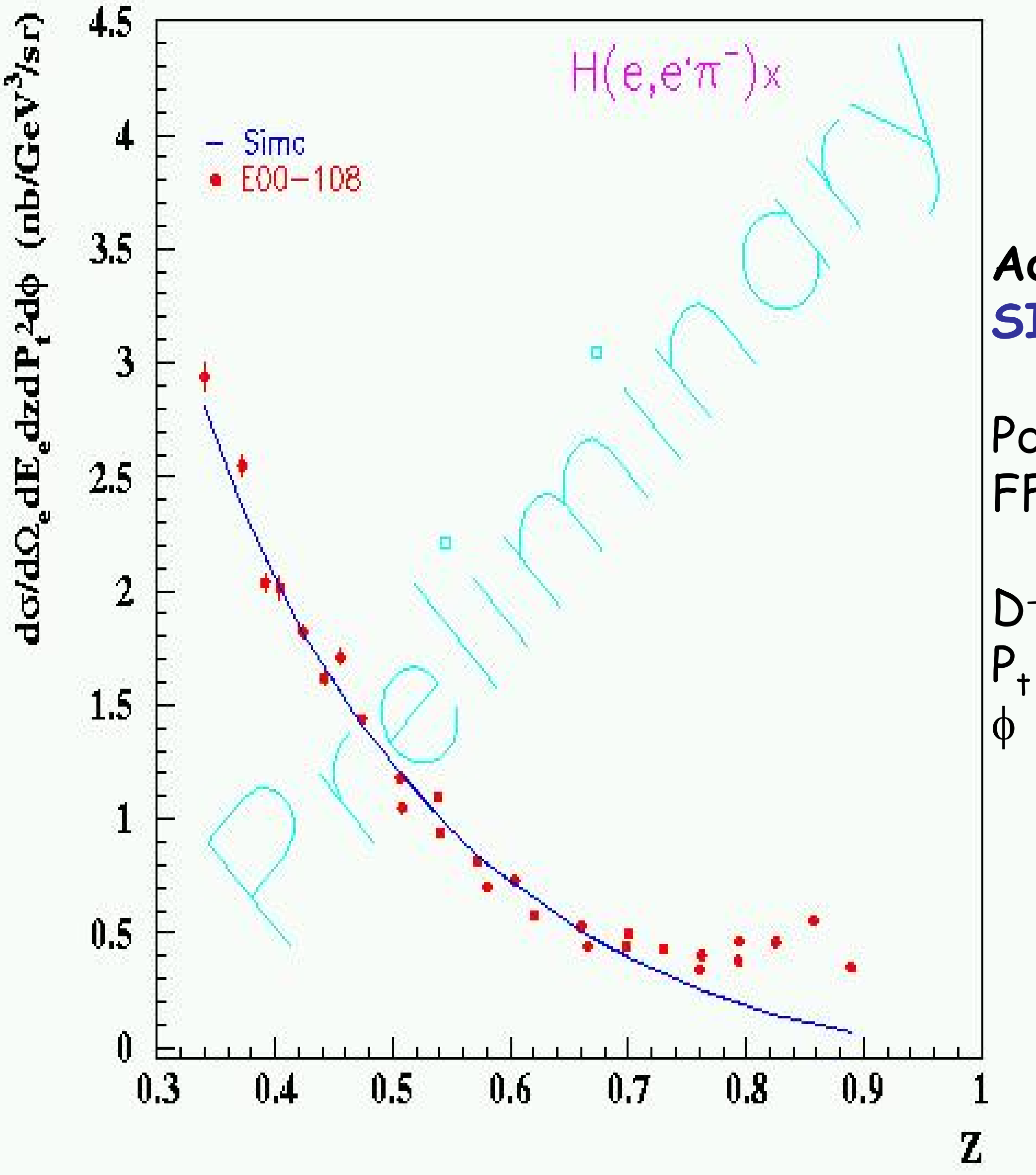
F. Arleo et al.: EPJ C 30, 213 (2003)

→ Observable sensitive to the model assumption

HERMES vs. Jlab data



Using inclusive A1p and A1n Jlab data



E00-108 data
E_0 =5.5 GeV

Add fragmentation process to SIMC

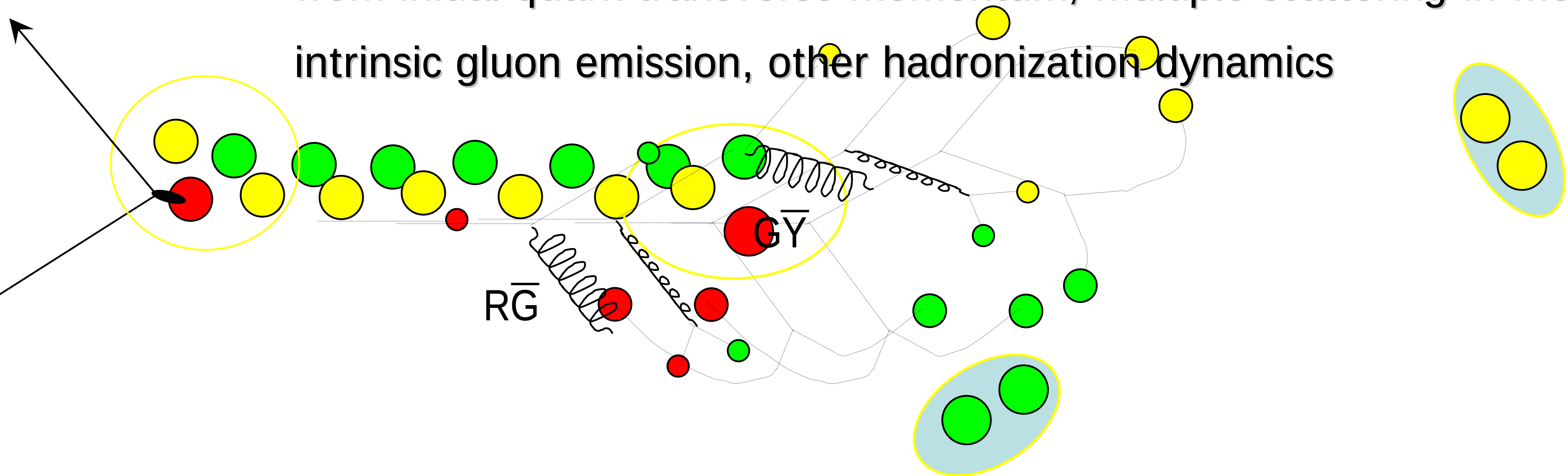
Input parameters:

Pdf's (q_i, q_i) : CTEQ5M
FF's (D_{qi}) : Binnewies et al., given as ($D^+ + D^-$)
D^-/D^+ : from HERMES
P_t (b) : from HERMES
ϕ : assume no ϕ dep.

x ~ 0.3

Fascination with Hadronization

ν	energy transferred by the electron (initial energy of struck quark)
Q^2	four-momentum transferred by the electron (initial size of struck quark)
z_h	$= E_{hadron}/\nu$, fraction of struck quark energy carried by hadron; $0<z_h<1$
p_T	quark/hadron momentum transverse to virtual photon direction; results from initial quark transverse momentum, multiple scattering in-medium, intrinsic gluon emission, other hadronization dynamics



Motivation

- color transparency (CT): phenomenon where hadron produced inside nucleus at large momentum transfer experiences little final state interaction

$\hookrightarrow$ if CT occurs then cross section should should scale $\sim A$

- pert. QCD has been successful in qualitative description of form factors at large $\mathbf{\Delta}_\perp^2$
- pert. QCD also predicts CT at large $\mathbf{\Delta}_\perp^2$
- exp: no clear evidence for CT @Jlab
- Can GPDs shed some light on physics of form factors and CT? (Can CT shed some light on physics of GPDs?)

Summary

- GPDs provide decomposition of form factors w.r.t. the momentum of the active quark

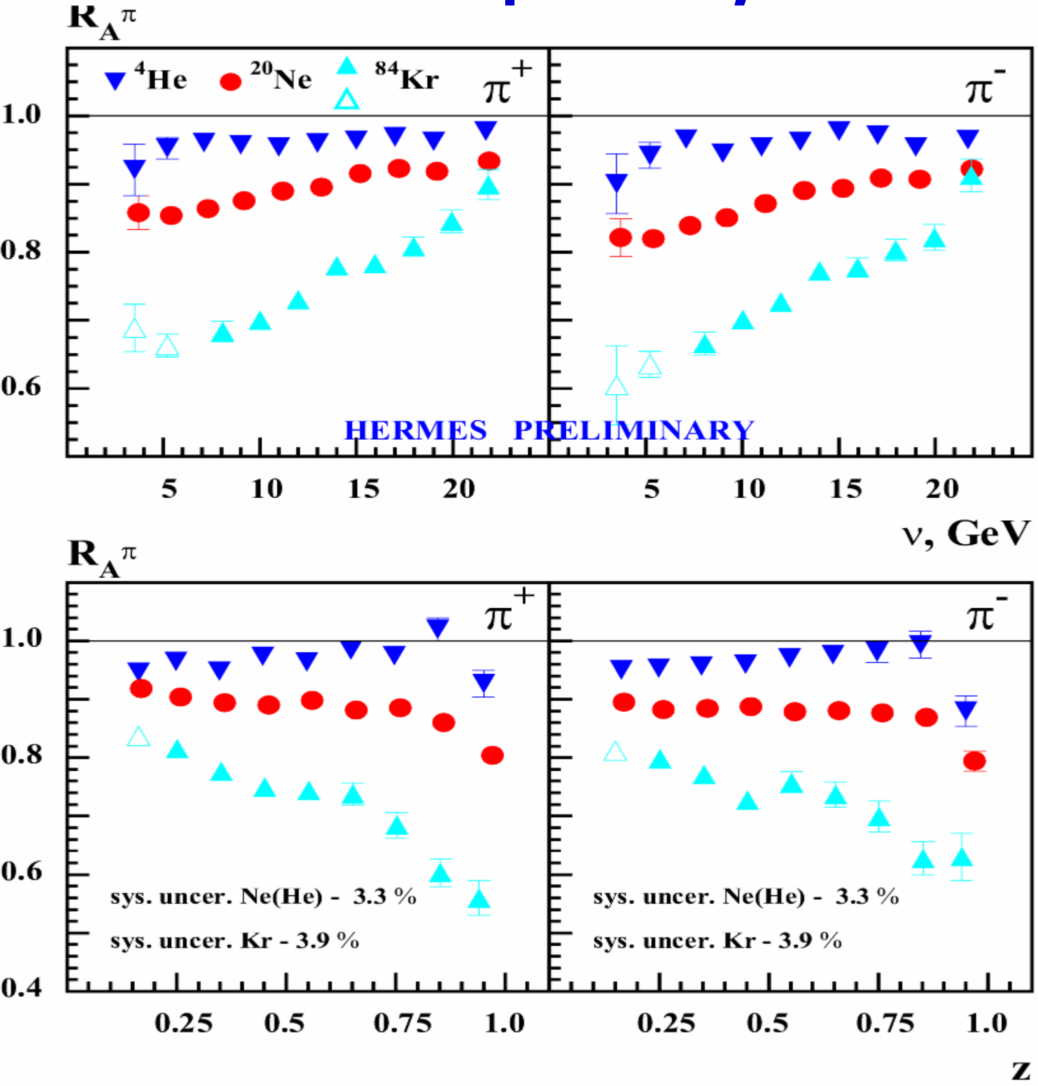
$\hookrightarrow$ GPDs could clarify mechanism for form factor at large $\mathbf{\Delta}_\perp^2$

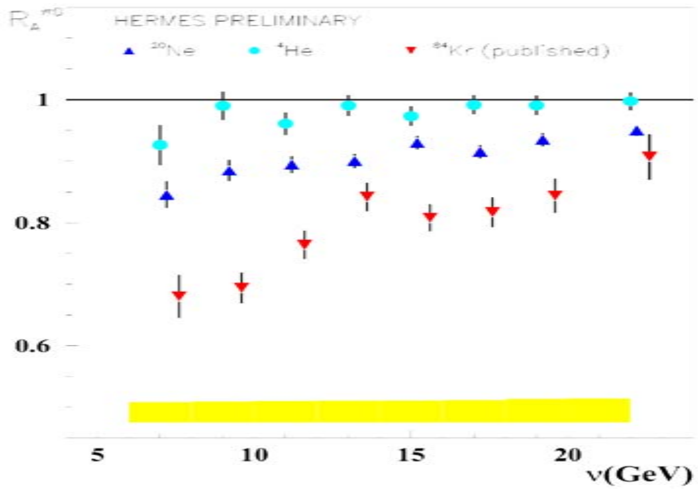
- discussed how hadron confiurations with size $R \sim 1/\Lambda$ can contribute significantly to form factor
- contribution to nucleon form factor can be $\sim \frac{1}{\mathbf{\Delta}_\perp^4}$ until suppression of PDFs due to higher order corrections sets in

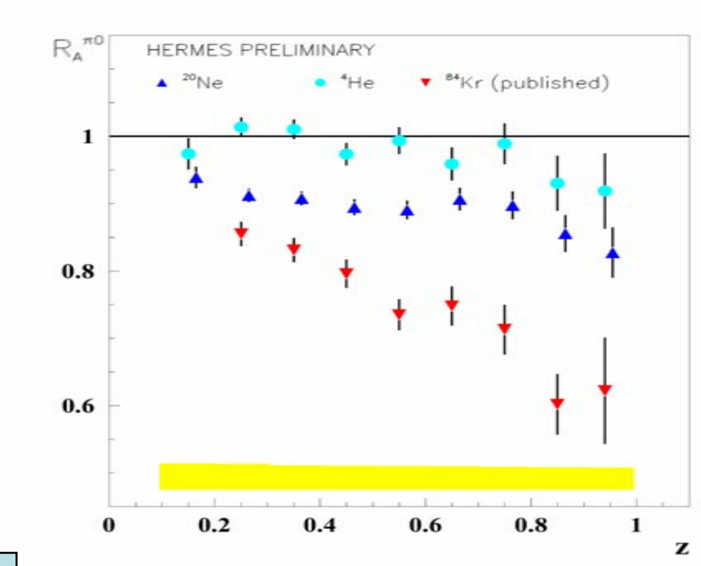
$\hookrightarrow$ could provide additional explanation for lack of CT @JLab

- large x behavior of PDFs & GPDs critical for contribution from large size configurations to form factor
    - how rapidly does $q(x)$ go to zero as $x \to 1$
    - how does $\perp$ size $\mathbf{d}_\perp(x)$ behave for $x \to 1$
- JLab@12GeV could illuminate physics of form factors from three different angles: CT, PDFs@large x, and GPDs.

Multiplicity ratio on He, Ne, Kr







nuclear attenuation: $1-R^h = A^\alpha$

Data suggest $\alpha \sim 2/3$

V. Muccifora