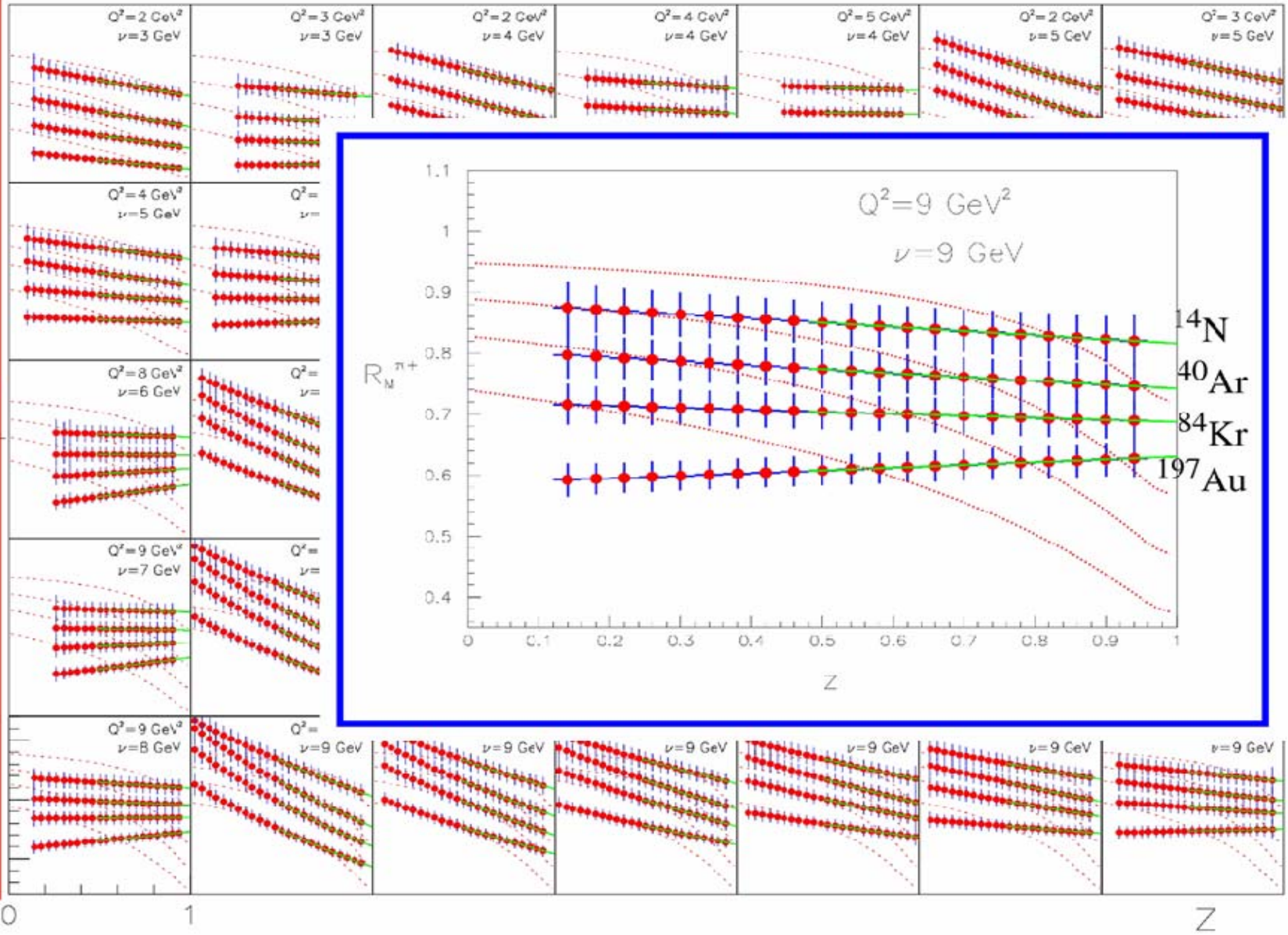
# Introduction to experimental results on the in medium hadronization and quark energy loss

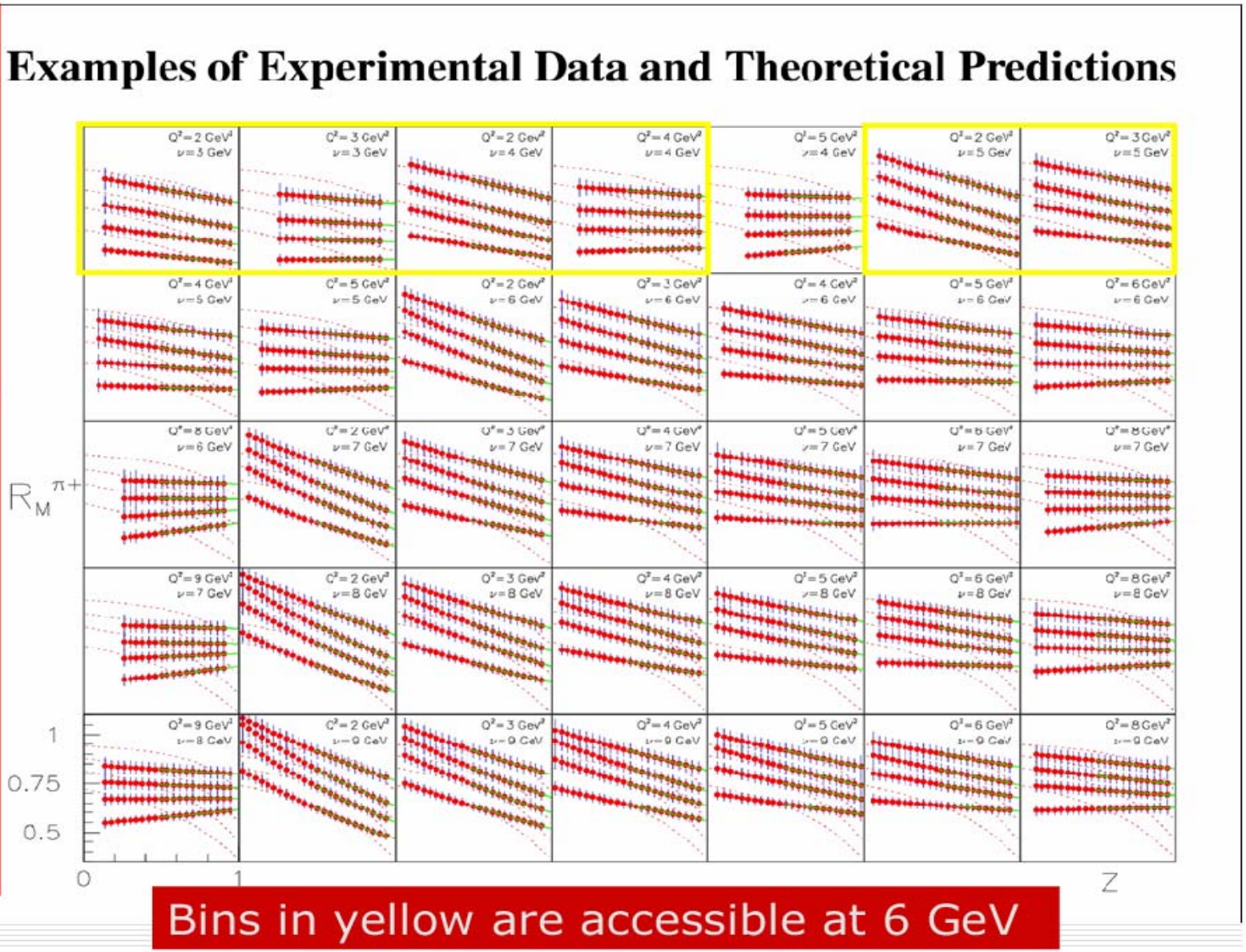
Valeria Muccifora

- The role of nuclear DIS in the hadron production.
- Connections to heavy ions collisions.
- Similarities in Drell-Yan reactions.

# 12 GeV Anticipated Data



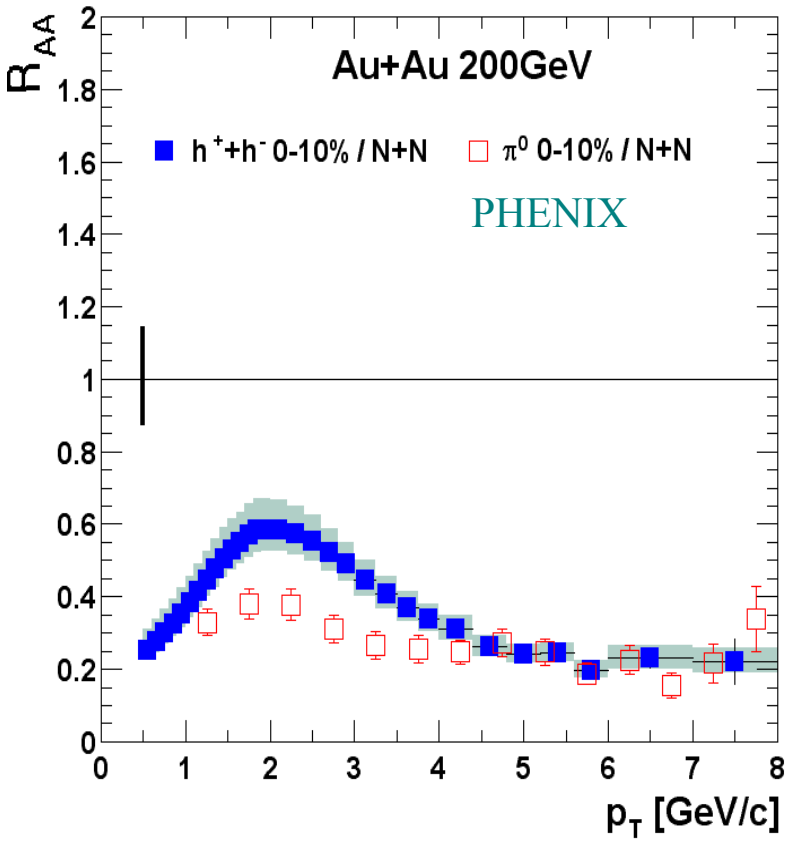
12 GeV Anticipated Data



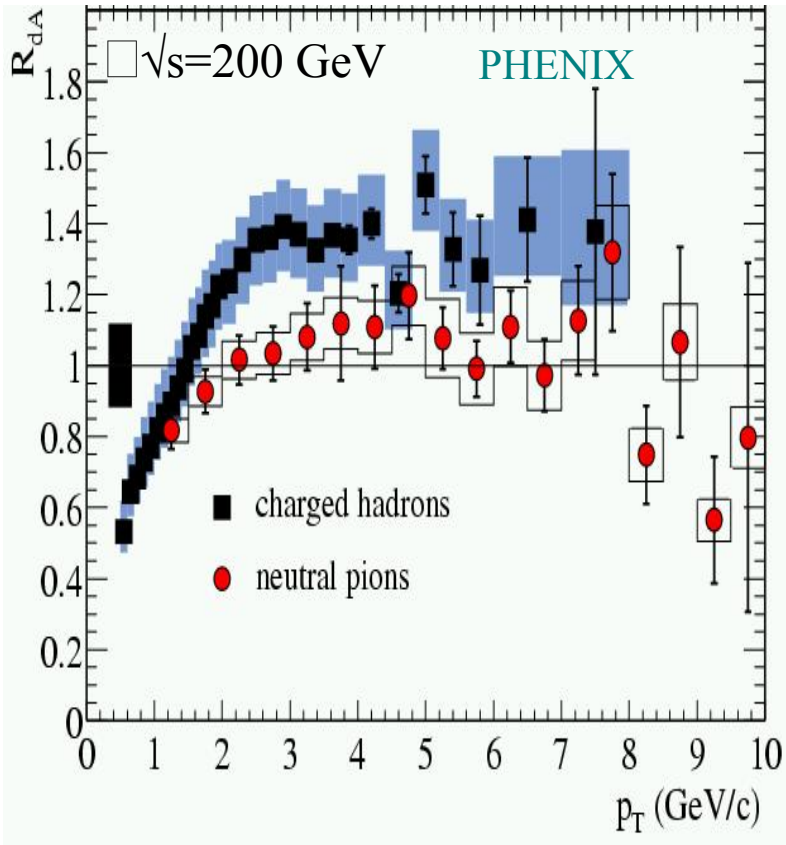

- W. Brooks "DIS on nuclei with CLAS at JLab: present and future"

# Baryon anomaly

## in A+A

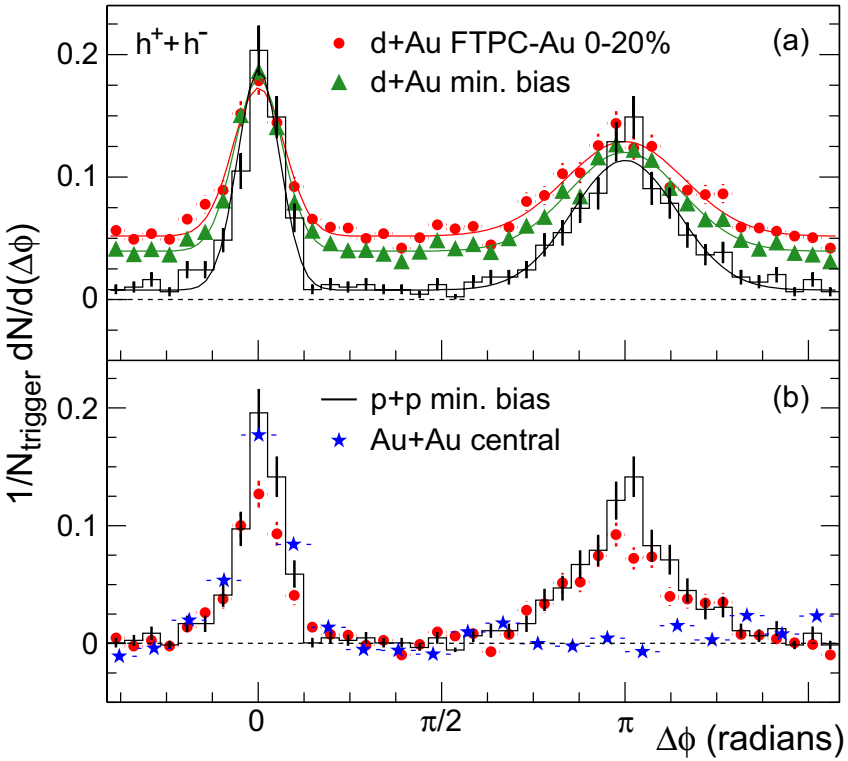



## in h+A




Different effect for baryons and mesons vs. $p_T$

# Disentangling hadronic and partonic effects




In central Au-Au the opposite-side pair are suppressed due to FSI, while the same-side pairs exhibit jet-like correlations similar to p+p and p+d collisions.

X.N.Wang, Phys. Lett. B579 (2004) 299 : If hadron interaction is responsible for the hadron suppression, it would destroy the jet structure i.e. the correlation between leading and subleading hadrons.

In cold nuclear matter ⇒ double- hadron correlation

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

# Interpretation of DIS results

## Models based on (pre-)hadronic absorption

B. Kopeliovich, J.Nemchik, E.Predazzi, A.Hayashigaki: NPA 740, 211 (2004). hep-ph/9511214.

T. Falter, W. Cassing, K.Gallmeister, U.Mosel.,: PRC 70 (2004) 054609

A. Accardi, D.Grunewald, V.Muccifora, H.J.Pirner,: hep-ph/0502072 and NPA in print, and NPA 720, 131 (2003).

## Models based on partonic energy loss

E.Wang, X.N. Wang: PRL 89, 162301 (2002) $\langle -dE/dL \rangle_{cold} \approx 0.5\, GeV/\, fm$

F. Arleo: EPJ C 30, 213 (2003) $\langle -dE/dL \rangle_{cold} \approx 0.6\, GeV/\, fm$

# Models summary.

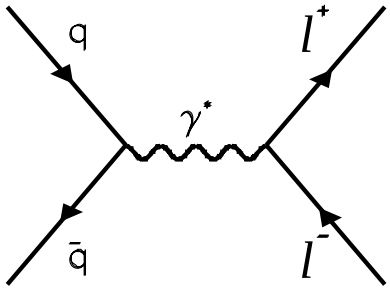
Absorption Models:

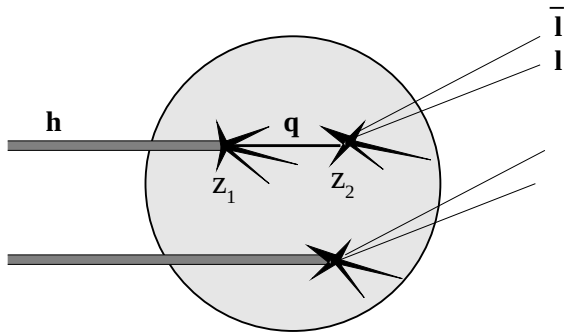
Important role of the pre-hadron formation and interaction.
Hadron formation mainly outside the nucleus.
Induced radiation smaller contribution compared to absorption.
$\Rightarrow$ Strong dependence on the pre-hadron interaction cross section.

Energy loss models:

Energy loss mechanism mainly,
competing processes play a modest role.
$\Rightarrow$ Strong dependence on the gluon transport coefficient that reflects the medium gluon density

# Quark energy loss in cold nuclei from the Drell-Yan process



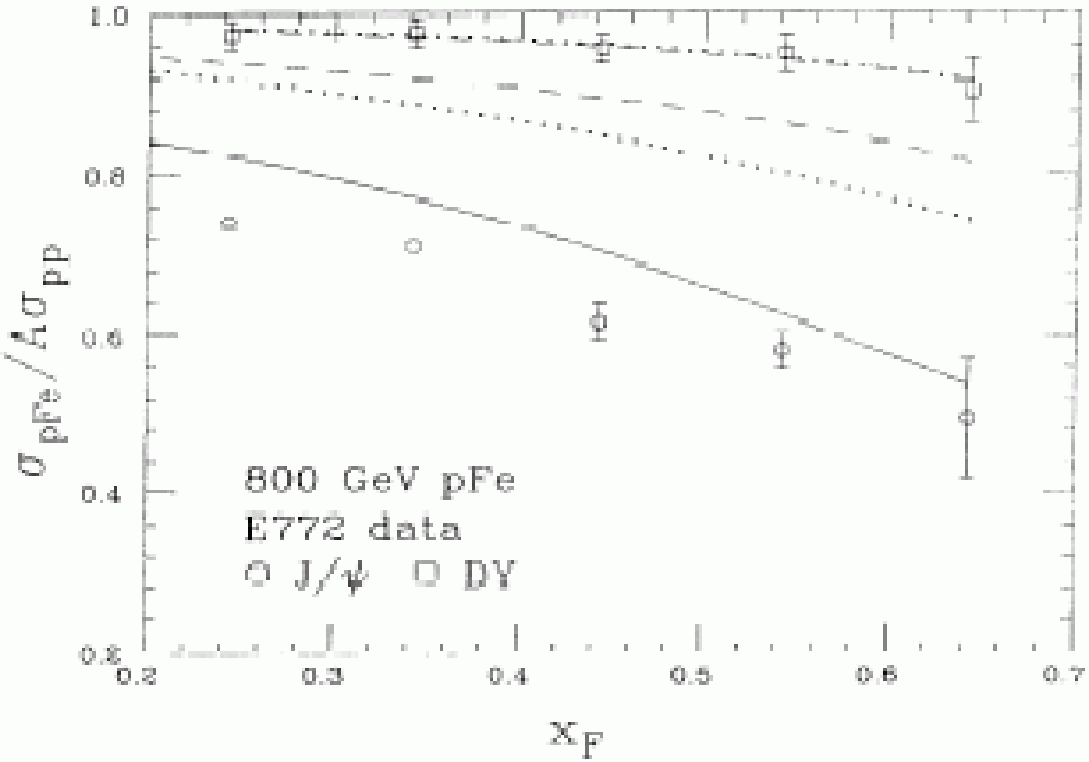




- Quark energy loss is reflected in the increased transverse momentum of the lepton pair.

→quark energy loss by varying the quark path-length, i.e., by varying the nuclear size, A.

- Advantage of D-Y is that lepton-pairs do not have final-state interactions.
- Difficult to isolate the quark energy loss effect from other nuclear effects (shadowing, EMC effects, etc.)

# Quark energy loss deduced from D-Y




- $x_F = x_1 - x_2$
- $x_1$ and $x_2$ momentum fraction carried by projectile and target partons

Gavin and Milana, PRL 68 (1992) 1834

**dE / dZ ~ 1.5 GeV/fm**

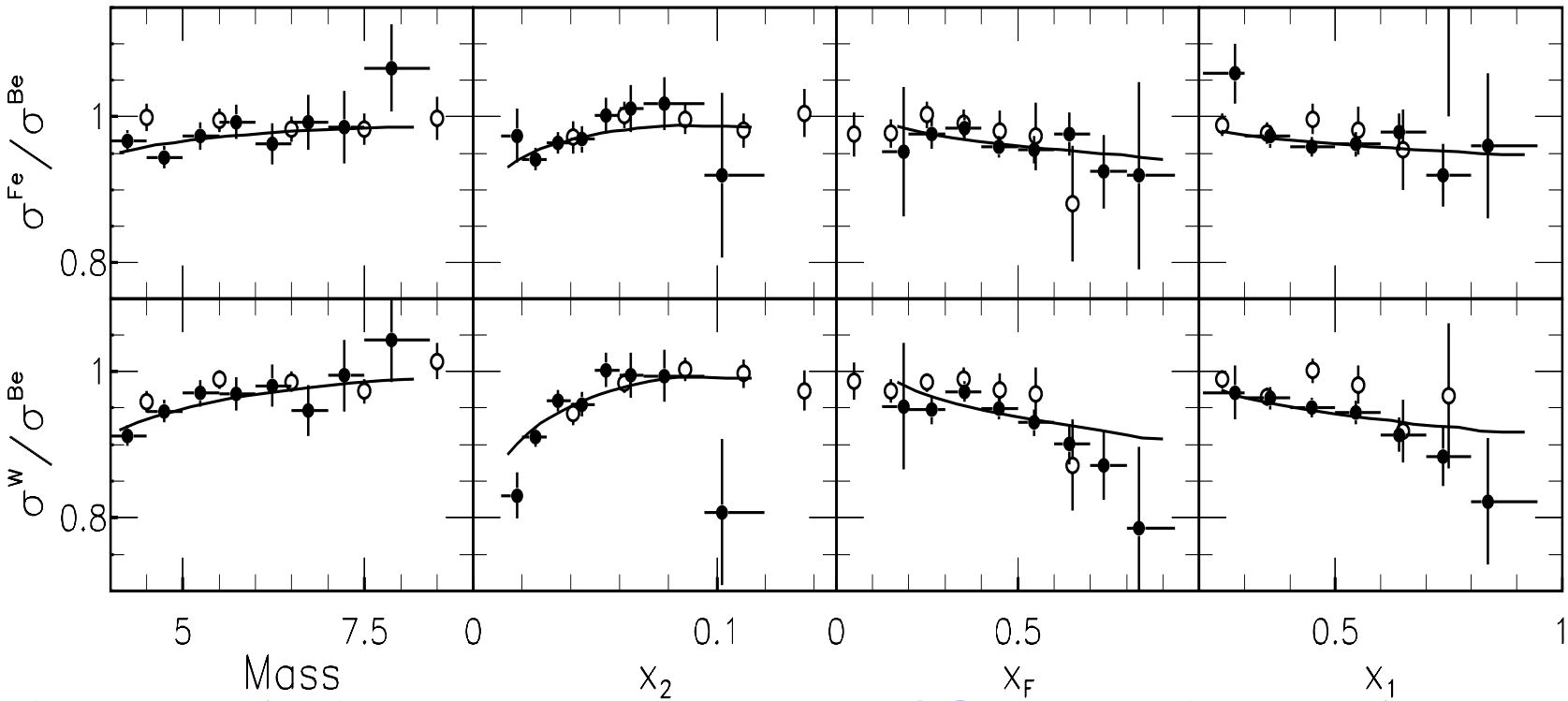
Large $x_F$ corresponds to large $x_1$ and small $x_2$.

The depletion at large $x_F$ can be ascribed to nuclear shadowing at small $x_2$.

# A-dependence D-Y data from E866

(PRL 83 (1999) 2304)

D-Y for p+W, p+Fe, and p+Be, at smaller $x_2$ (0.01-0.12) and larger $x_1$(0.21-0.95) than E772→increases sensitivity to shadowing and energy loss.

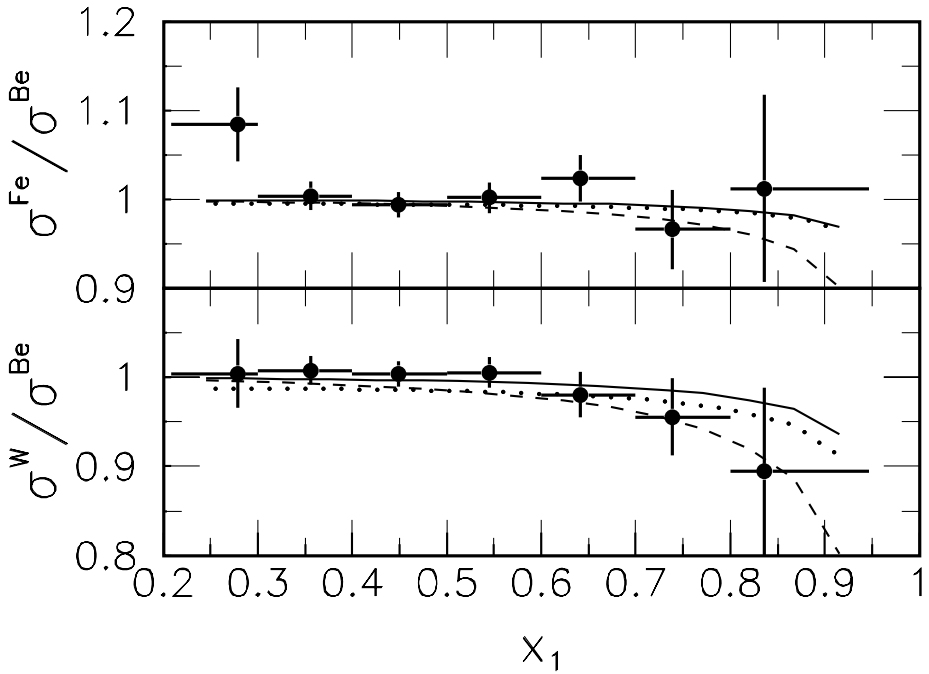



Solid curves: shadowing parametrization of EKS98 and no quark energy loss

Dependence vs $x_F$ and $x_1$ seems explained by shadowing at small $x_2$.

# A-dependence D-Y data from E866

(PRL 83 (1999) 2304)




$$\Delta x_1 = -K_1 x_1 A^{1/3}$$

$$\Delta x_1 = -\frac{K_2}{s} A^{1/3}$$

$$\Delta x_1 = -\frac{K_3}{s} A^{2/3}$$

Fitting data by these energy loss expressions, very small K are found, and an upper limit of dE/dz < 0.44 GeV/fm is found

How reliable is the shadowing parametrization used ?

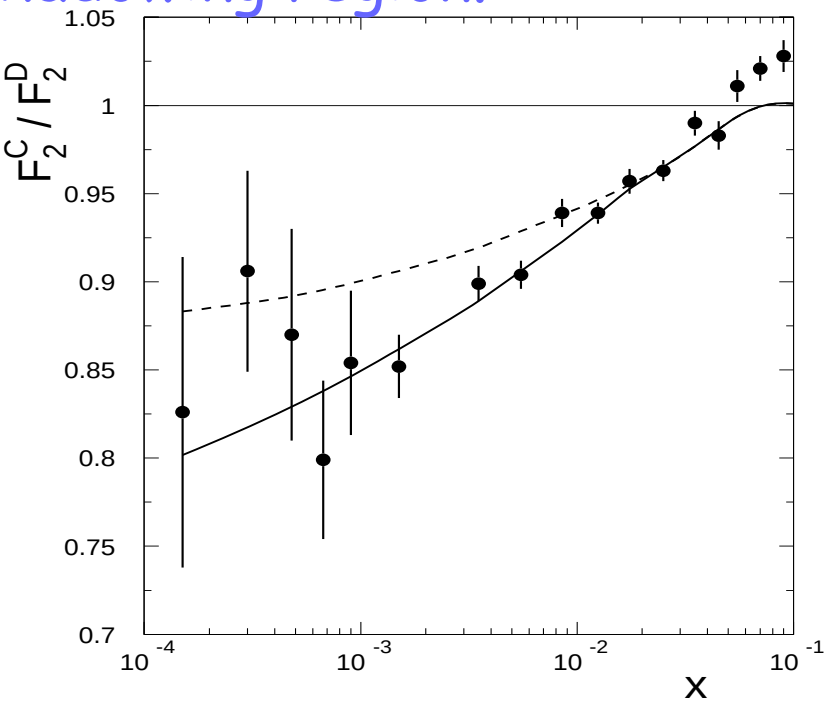
# Nuclear Shadowing in D-Y and DIS

Kopeliovich et al.: quantitative description of the shadowing

PRC 65 (2002) 025203

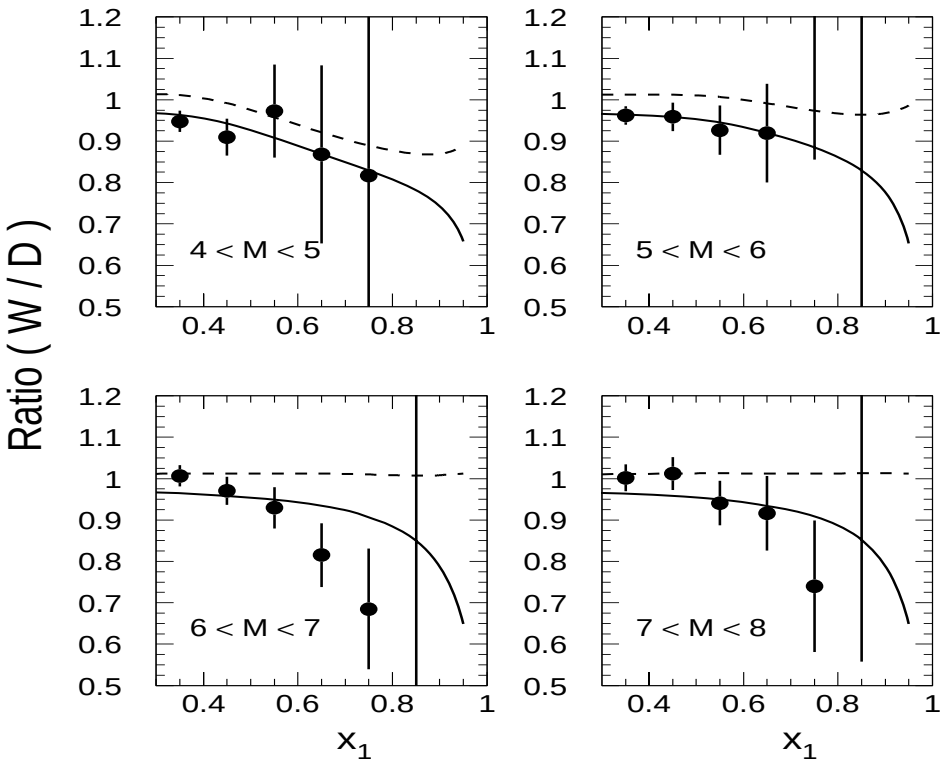
Phenomenological treatment of the dipole cross section by fitting it to DIS data.

Verify the theory by comparing to DIS scattering data on nuclei in the shadowing region.



# Energy loss and shadowing in D-Y

Kopeliovich et al.: PRC 65 (2002) 025203

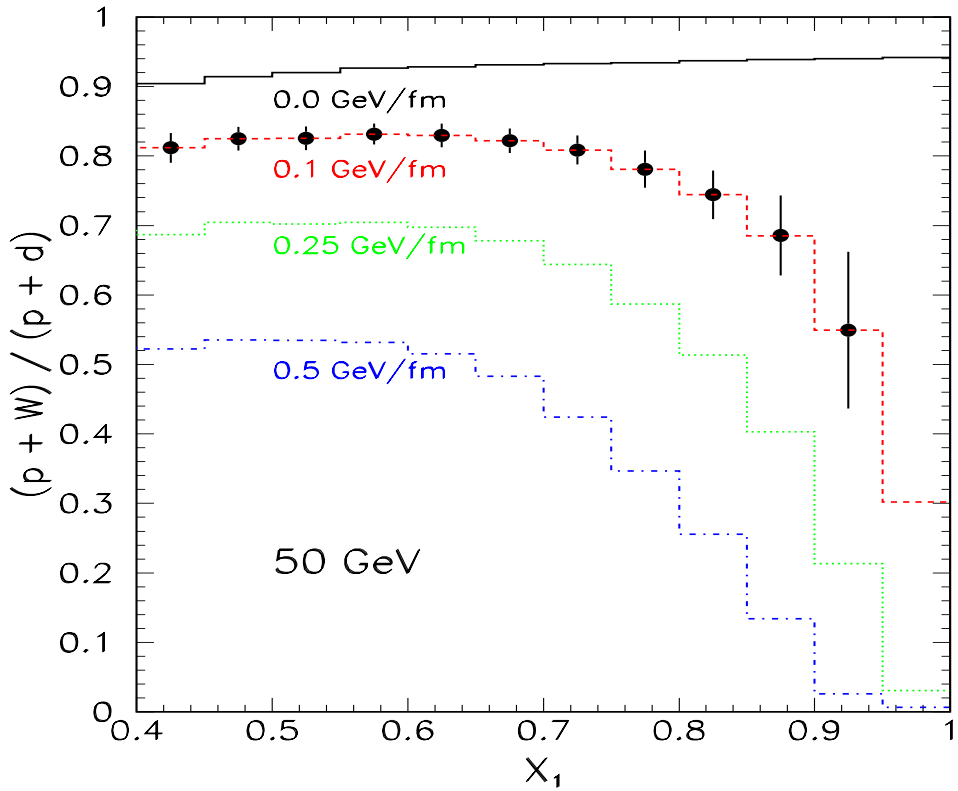



- Shadowing alone can not explain the DY data
- Quark energy loss is required dE/dz = 2.73 ± 0.7GeV/fm

# Quark Energy Loss with D-Y at Lower Energies

Garvey and Peng, PRL 90 (2003) 092302

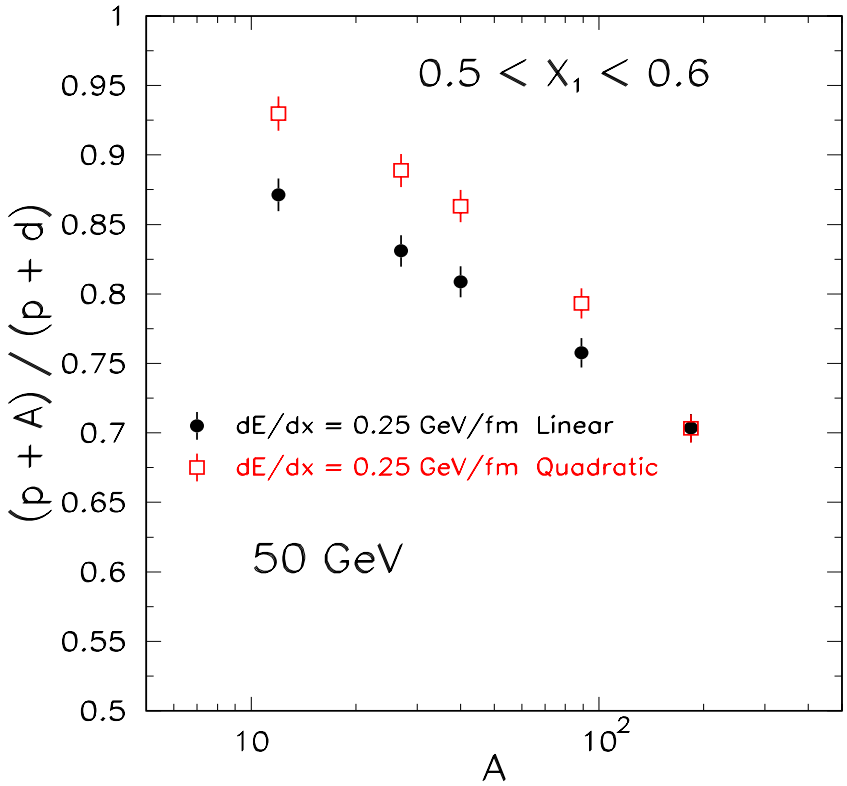
The lower proton energy enhances the energy loss, access larger $x_2$ where shadowing is smaller.




Projected DY ratios at 50 GeV proton beam and calculations for different rates of energy loss

# Quark Energy Loss with D-Y at Lower Energies

Garvey and Peng, PRL 90 (2003) 092302




Possible to test the LPM effect from the A-dependence:

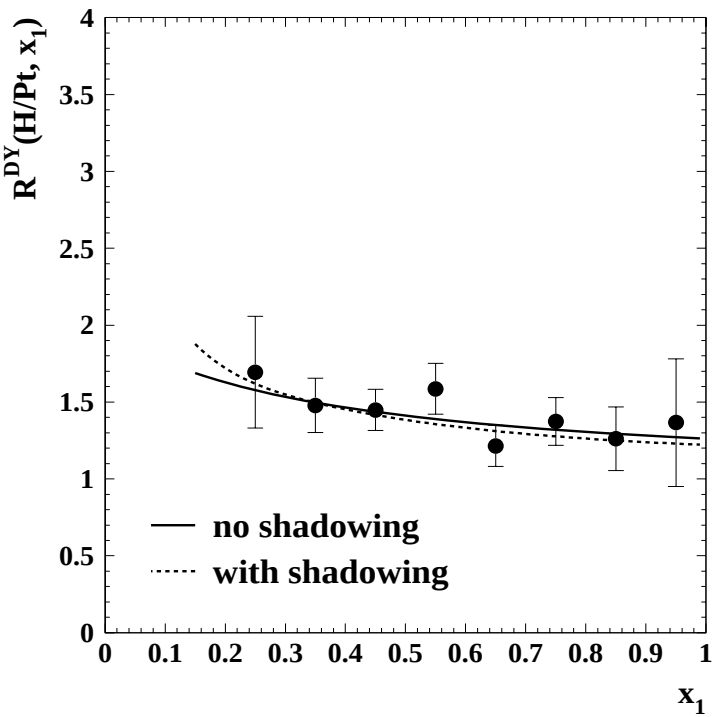
A-dependence is linear or quadratic with the path length?

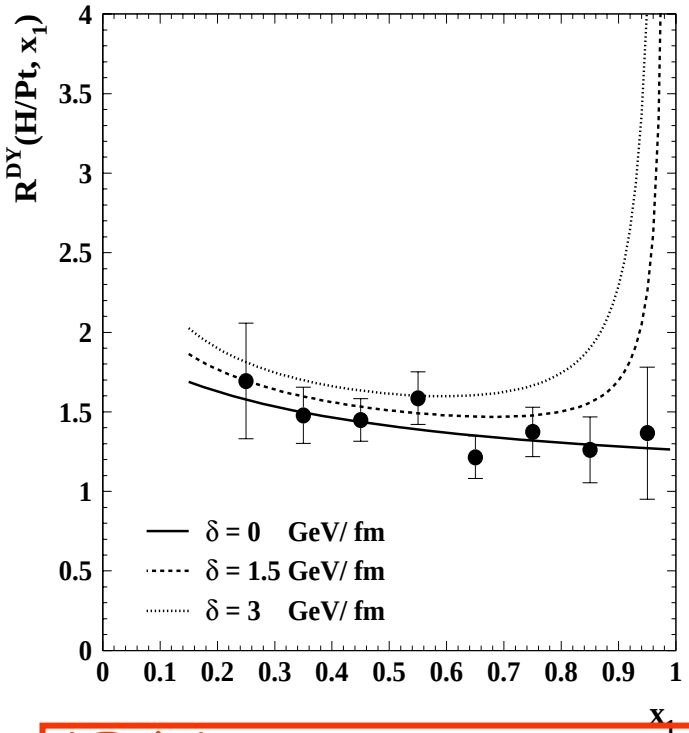
It's possible to distinguish between the L and $L^2$ dependence of energy loss already at 0.25 GeV/fm.

# Pion-induced Drell-Yan experiments

NA3 data: small shadowing in pion-induced D-Y at SPS ($x_2$>0.06)

$$\sigma_{DY}(\pi^- + p)/\sigma_{DY}(\pi^- + Pt) \quad \text{at 150 GeV}$$



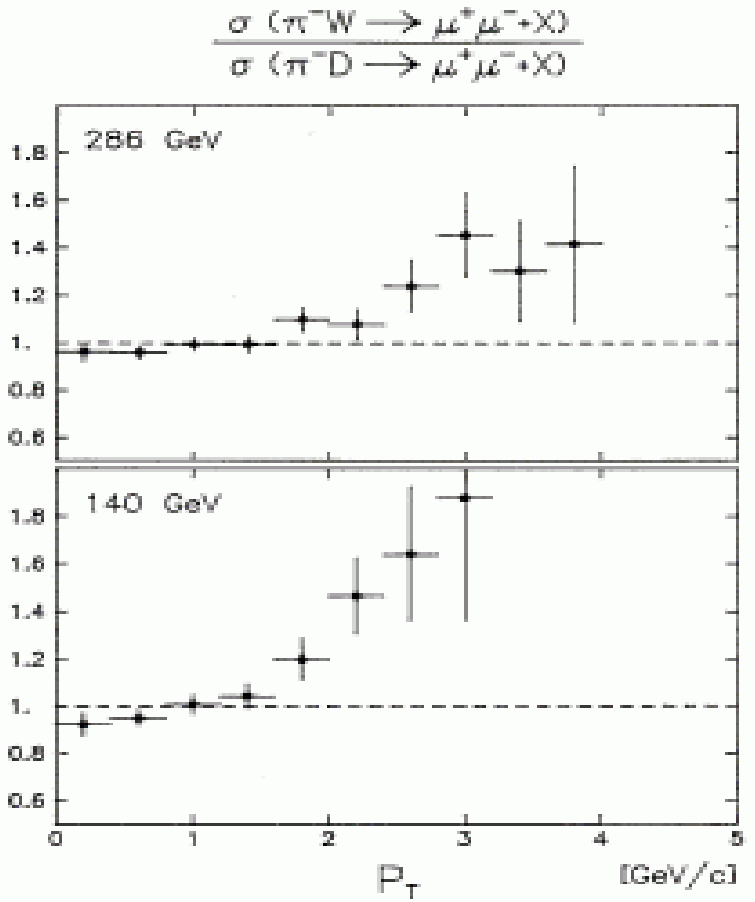

Arleo, Phys. Lett. B532 (2002) 231

dE/dz = 0.2 ± 0.15GeV/fm

- Relatively poor statistics (535 π + p DY events)

# $p_T$ dependence in $\pi$-A D-Y from NA10

Phys Letts. 193 (1987) 373 $\pi$- @ SPS 140 GeV and 286 GeV




- $p_T$-broadening observed on nuclei for muon pair production

This effect is independent of dimuon mass and $P_L$

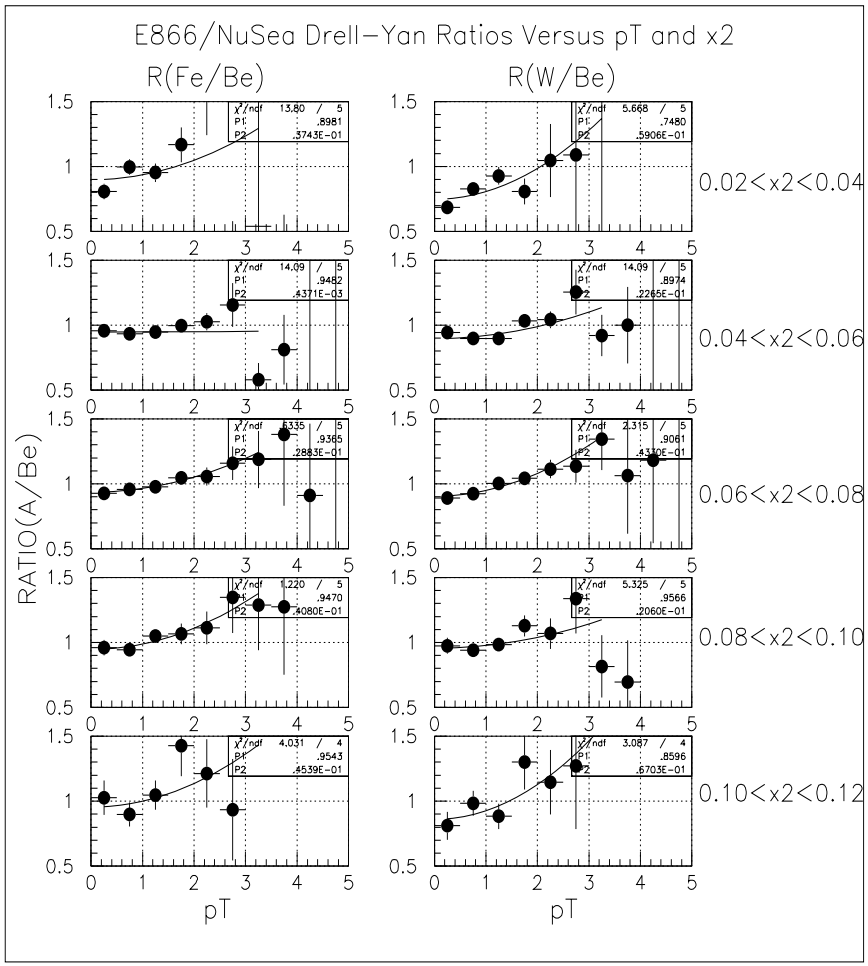
$$< p_T^2 >_W - < p_T^2 >_D = 0.15 \pm 0.04 GeV^2/c^2 \text{ at 286 GeV}$$

$$< p_T^2 >_W - < p_T^2 >_D = 0.16 \pm 0.04 GeV^2/c^2 \text{ at 140 GeV}$$

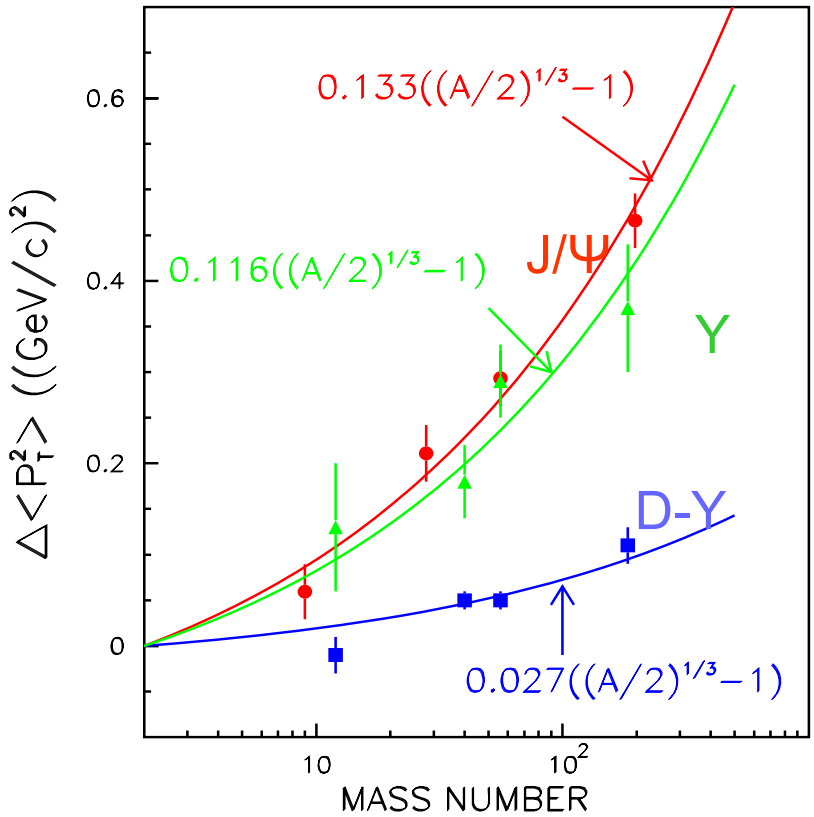
Alternative way to distinguish quark energy loss from shadowing

# $p_T$ – dependence in p+A D-Y

E866




E772 + E866




J-C Peng PN12 Workshop

# Summary and Outlook

- A unified picture is starting to emerge from the measurements in SIDIS, hadron production in d+Au collision and Drell-Yan reactions.

•Future SIDIS, p-A, and D-Y data will provide quantitative information on the propagation and hadronization of quarks in cold and hot nuclear medium.