THE EMC EFFECT IN HEAVY ION COLLISIONS

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O U T L I N E

Motivation

– We are testing small-x physics in heavy-ion collisions
– Can we test the high-x region in heavy-ion collisions?
– Is the R_{dA} 'boring'='flat' at high-p_T?

I. The EMC effect

– The EMC effect in pQCD improved parton model
– Signatures for EMC effect in dAu at RHIC

II. Results, uncertainties, and errors

– Results and the uncertainties of the theoretical model
– Slope comparison to existing dAu and $AuAu$ data

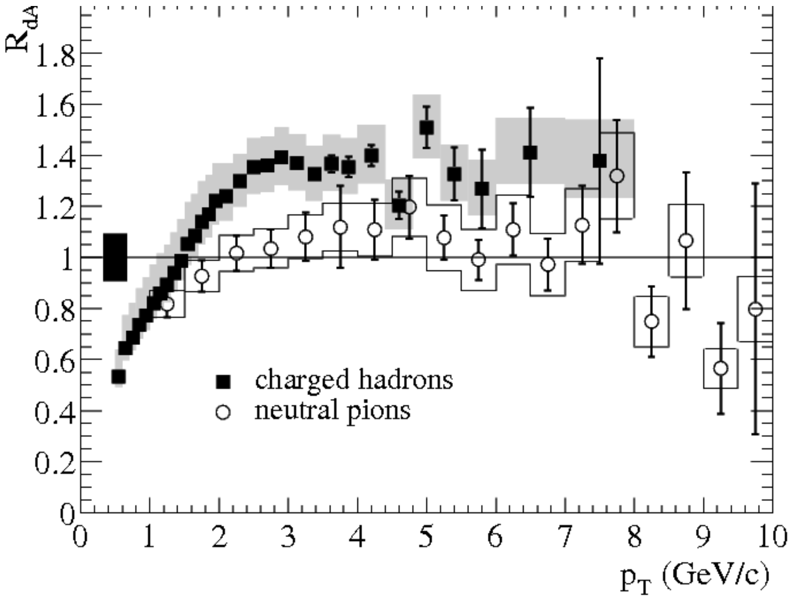
M O T I V A T I O N – π^0

PHENIX π^0 data $p_T \leq 10$ GeV/c

– PRL 91 (2003) 072303

– $R_{dAu} \approx 1$ at highest p_Ts

– Is there 'life' above the Cronin region, $p_T \gtrsim 6-7$ GeV/c?

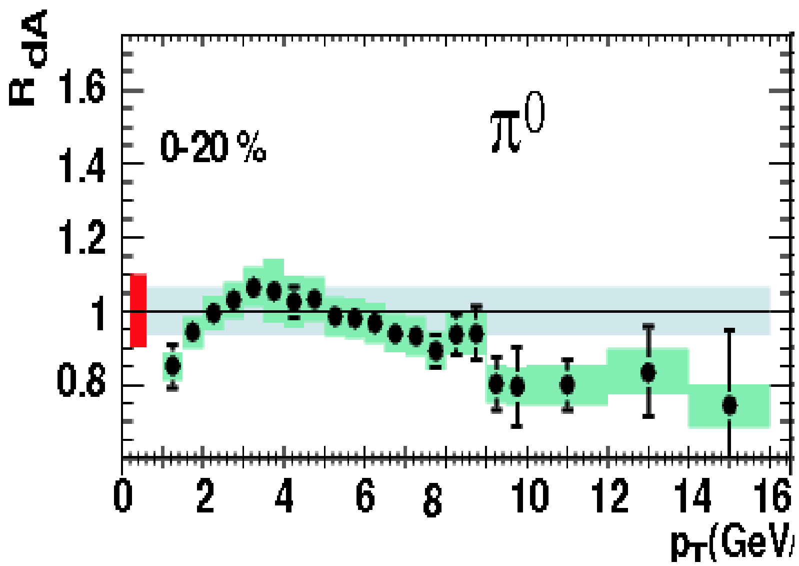


PHENIX has more precise data

– PRL 98 (2007) 172302

– Only huge errors at high p_T?

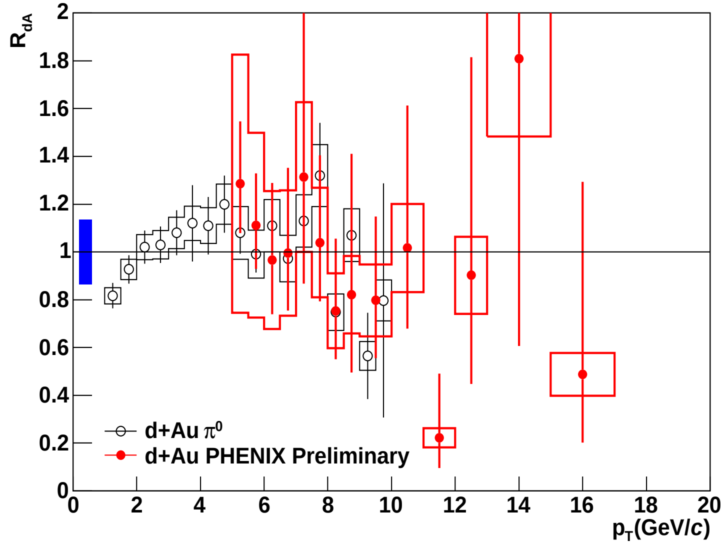
– 20 – 25% suppression and slope structure at high p_T?



MOTIVATION – γ

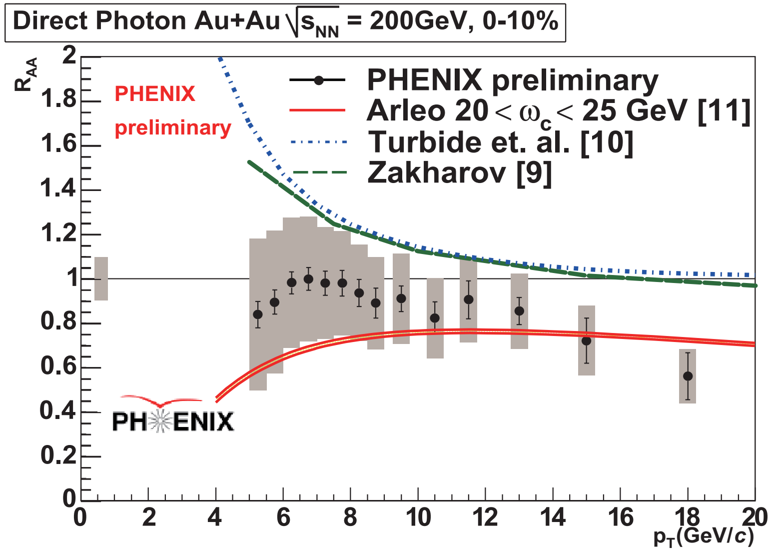
PHENIX prelim. γ data in dAu

- D. Peressounko, hep-ex/0609037
- Weak but, $R^{\gamma}_{dAu} \lesssim 1$, so negative slope at high p_T.

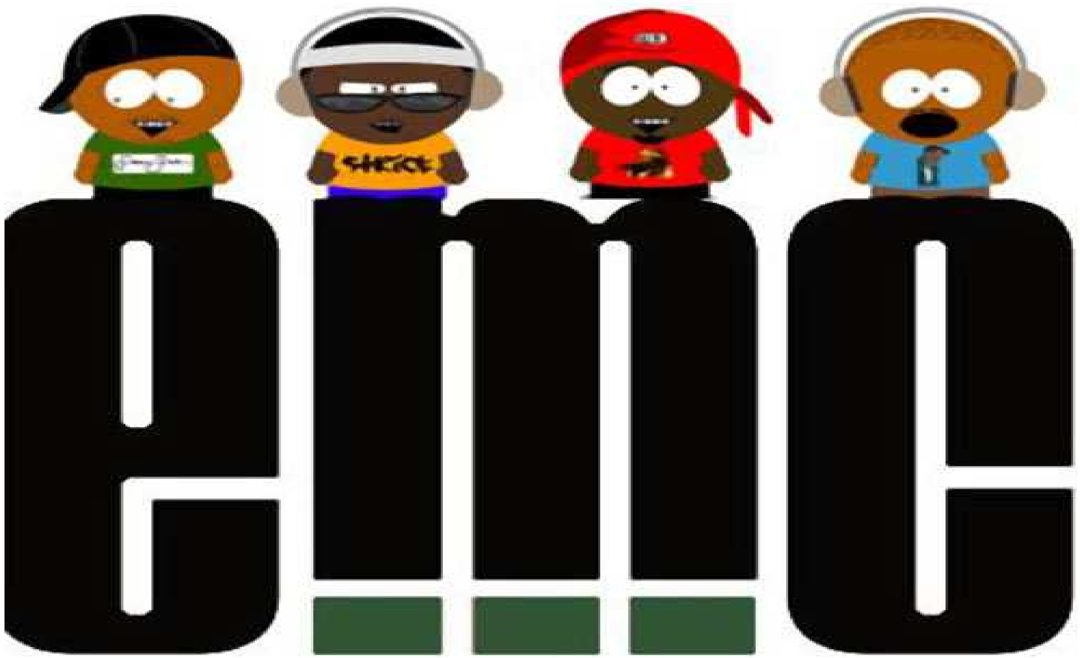


PHENIX prelim. γ data in $AuAu$

- T. Isobe, nucl-ex/0701040
- This is a 20 – 40% effect
- What effect is responsible for these slopes at high p_T?



THE



EFFECT

First Measured by European Muon Collaboration

– EMC, BCDMS, SLAC E139
  measured the ratio of σ_{Fe}/σ_D
  J.J. Aubert *et al.*: PL 123B 275 (1983)
  Benvenuti *et al.*: PL B189 483 (1987)
  J. Gomez *et al.*: PR D49 4348 (1994)

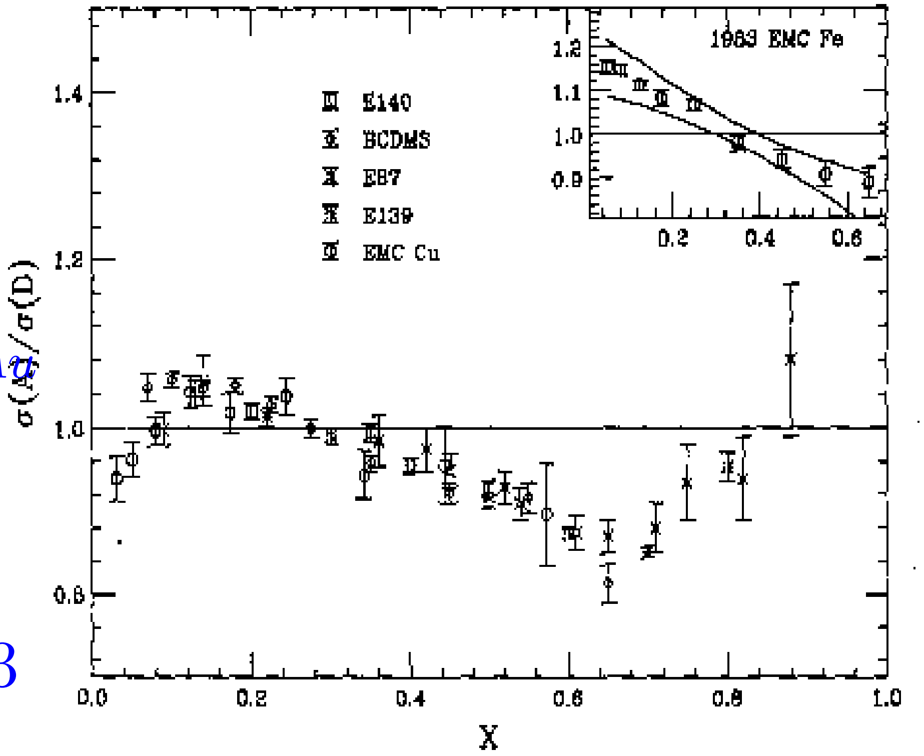
– Various nuclei were measured:
  $^4He, ^9Be, ^{12}C, ^{27}Al, ^{40}Ca, ^{56}Fe, ^{108}Ag, ^{197}Au$

– Strong dependence on targets:
  $\sigma_A/\sigma_D = C(x)A^{\alpha(x)}$ or
  $\sigma_A/\sigma_D = D(x)[1+\beta(x)\rho(A)]$

– Suppression were found at $x > 0.3$

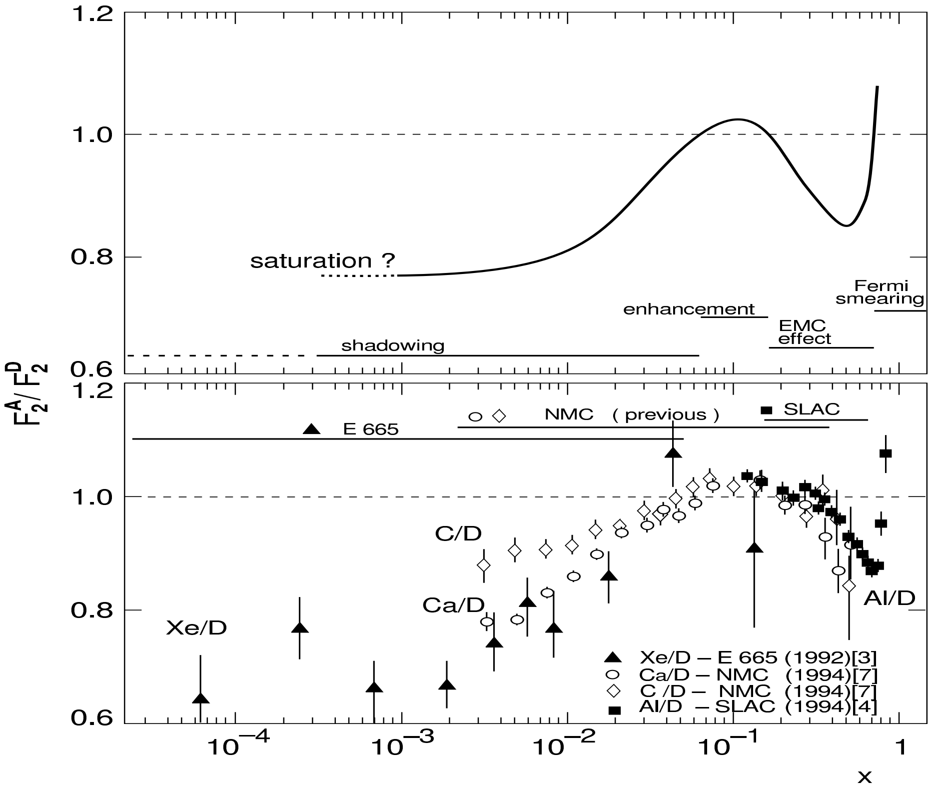
– No significant Q^2 dependence

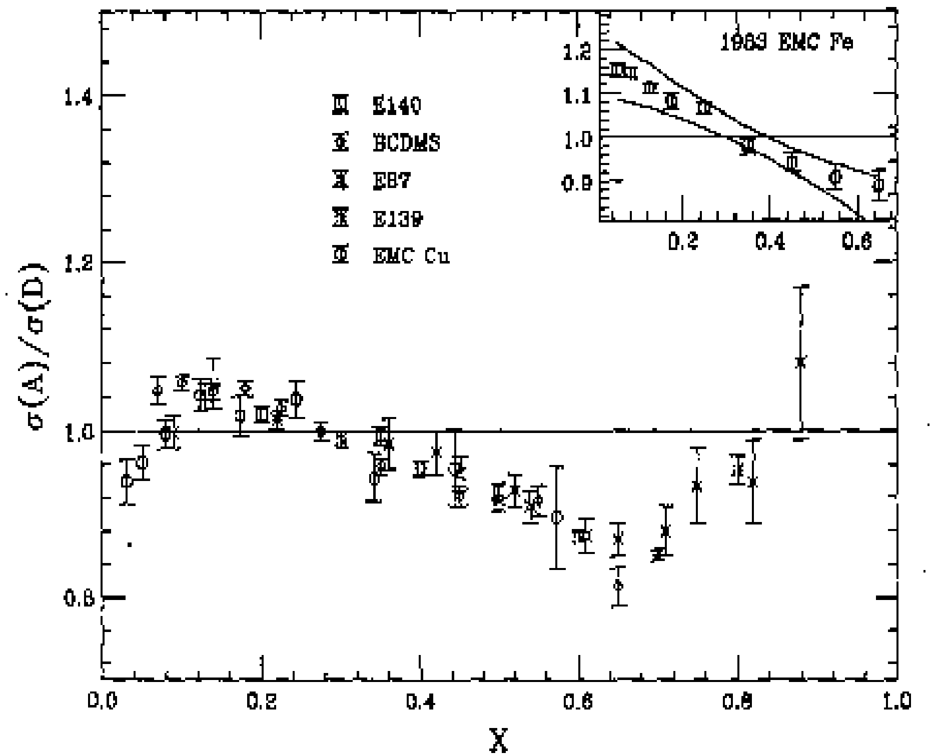
– Measured Q^2 bins:



$$Q^2 = 2 \text{ and } 5\ (\text{GeV/c})^2 \quad \text{for } x < 0.3;$$
$$Q^2 = 2,\ 5, \text{ and } 10\ (\text{GeV/c})^2 \quad \text{for } 0.3 \le x \le 0.5;$$
$$Q^2 = 5 \text{ and } 10\ (\text{GeV/c})^2 \quad \text{for } x > 0.5$$

Nominate Nuclear Modifications





EMC were measured by many experimental collaborations

– Strict def.: EMC effect is in $[0.3; 0.8] \ni x$, where $F_2^A/F_2^D \lesssim 1$

– Non-strict: Where the slope is negative: $[0.1; 0.7] \ni x$

– at RHIC these are $[30; 80]$ and $[10; 70]$ GeV/c $\ni p_T$ respectively

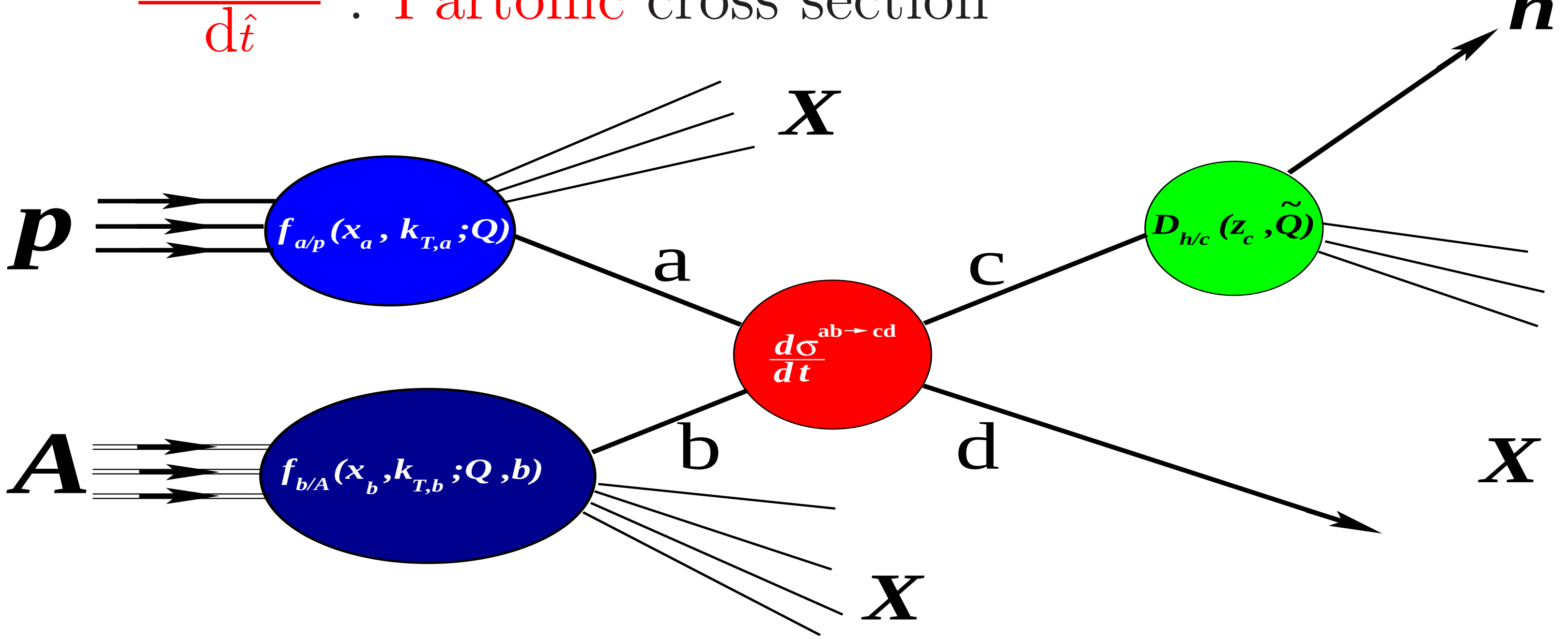
The pQCD Improved Parton Model for pA Collisions

$$E_\pi \frac{\mathrm{d}\sigma_\pi^{pA}}{\mathrm{d}^3 p_\pi} \sim f_{a/p}(x_a, Q^2; k_T) \otimes f_{b/A}(x_b, Q^2; k_T, b) \otimes \frac{\mathrm{d}\sigma^{ab\to cd}}{\mathrm{d}\hat{t}} \otimes \frac{D_{\pi/c}(z_c, \widehat{Q}^2)}{\pi z_c^2}.$$

$f_{b/A}(x_a, Q^2; k_T, b)$: Parton Dist. Function (PDF), at scale Q^2

$D_{\pi/c}(z_c, \widehat{Q}^2)$: Fragmentation Function for π (FF), at scale $\widehat{Q}^2$

$\frac{\mathrm{d}\sigma^{ab\to cd}}{\mathrm{d}\hat{t}}$: Partonic cross section



The Origin of the EMC – Shadowing inside the Nucleus

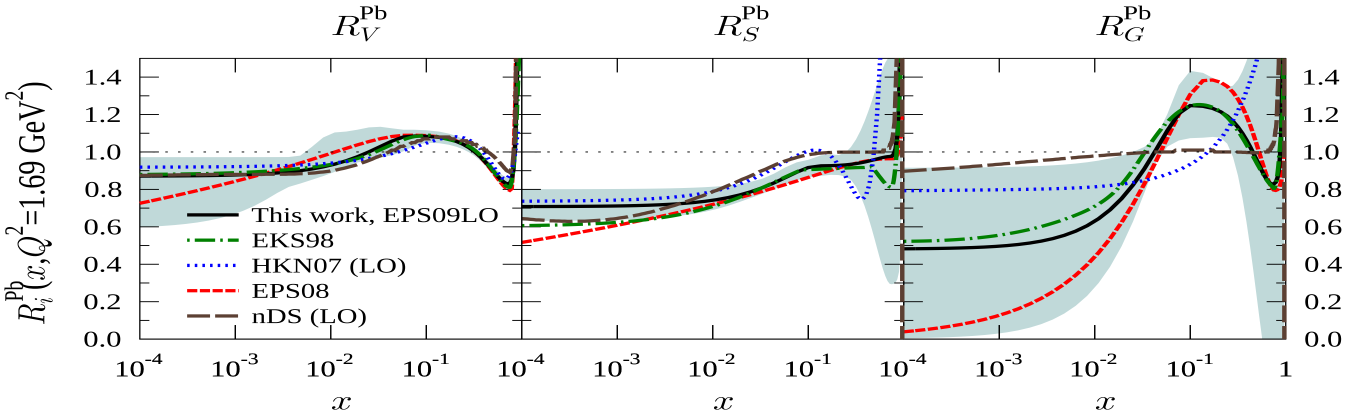
Shadowing – PDFs are modified inside the nucleus:

– PDF based: general, but model dependent (HIJING)

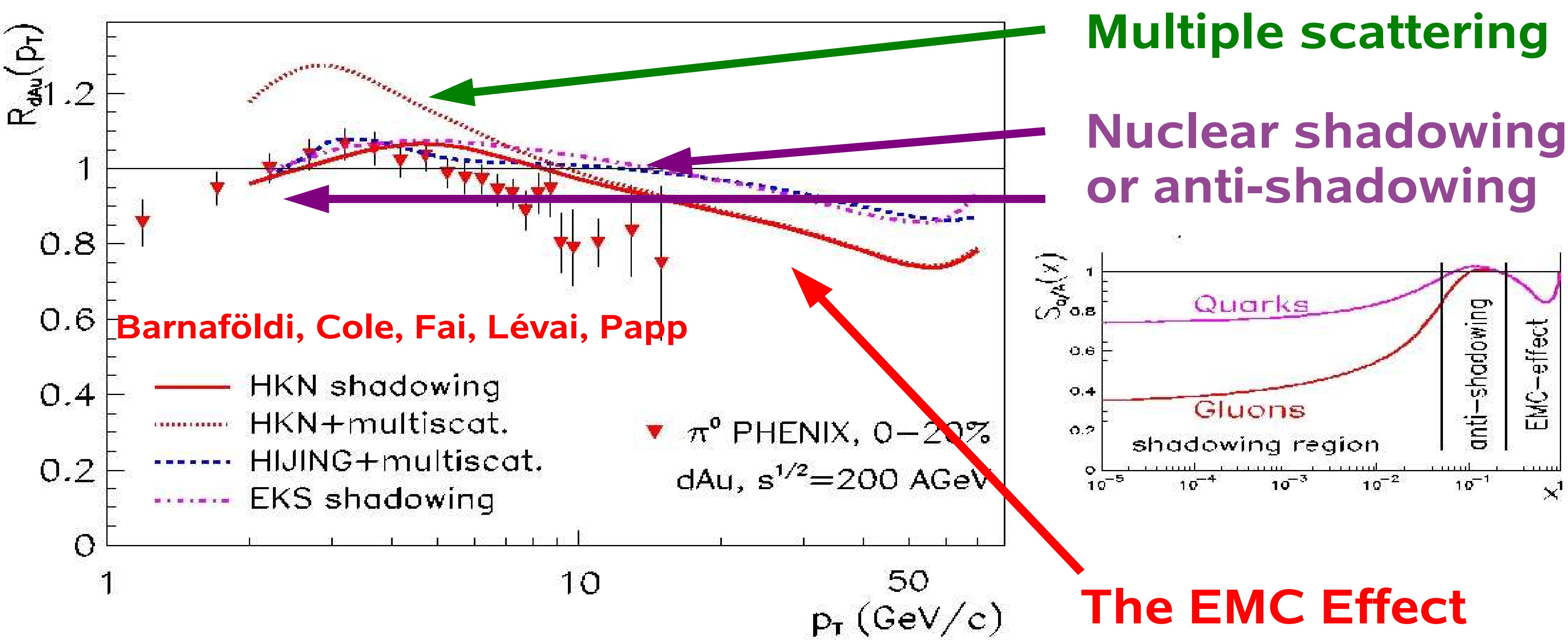
– True NPDFs: only for special nuclei, more precise (HKN)

$$f_{a/A}\left(x,Q^2\right) = S_{a/A}(x,b)\left[\frac{Z}{A}f_{a/p}\left(x,Q^2\right) + \left(1-\frac{Z}{A}\right)f_{a/n}\left(x,Q^2\right)\right]$$

$S_{a/A}(x,b)$: Shadowing function (e.g.: HIJING);
A atomic- and Z the proton number



Nuclear effects at very high-p_T in central dAu collision



MULTIPLE SCATTERING: $2\ \mathrm{GeV/c} \leq p_T \leq 7\ \mathrm{GeV/c}$

(GLUON) SHADOWING: $p_T \leq 1 - 5\ \mathrm{GeV/c}$

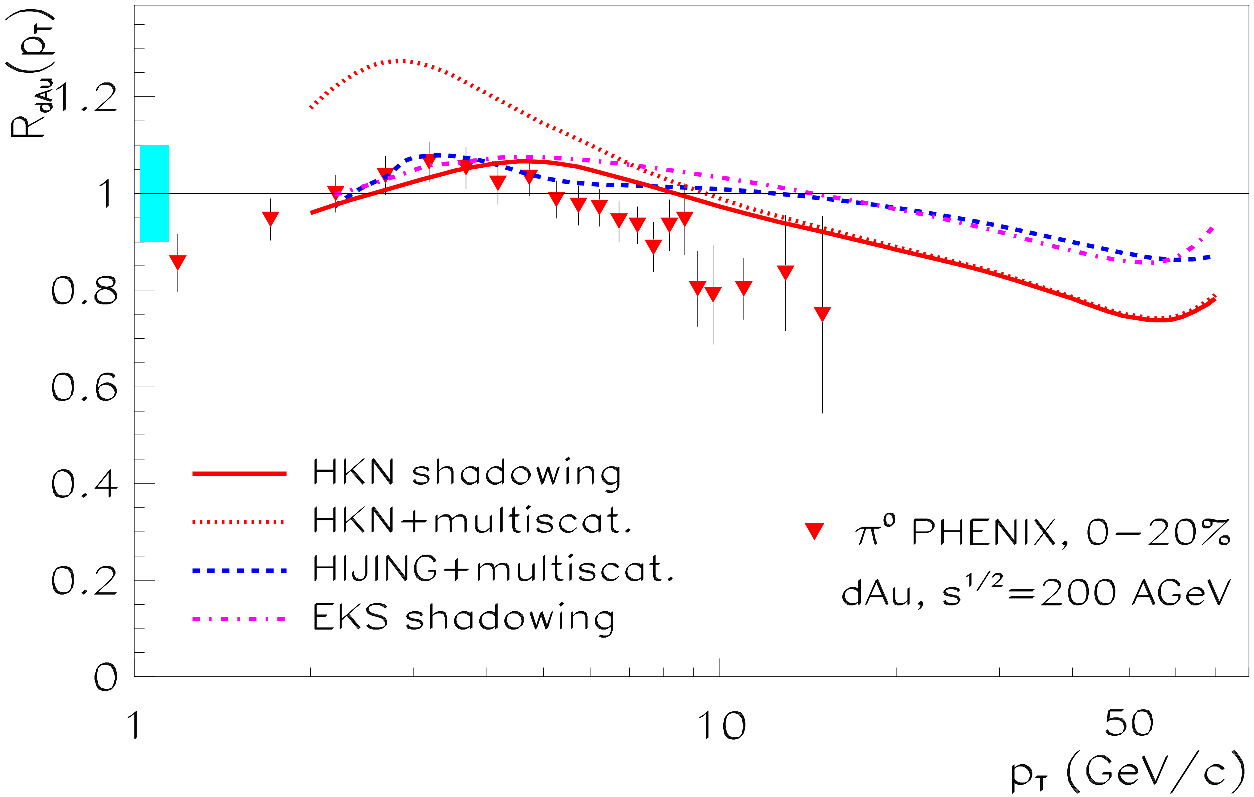
THE EMC REGION: $p_T \geq 10 - 20\ \mathrm{GeV/c}$

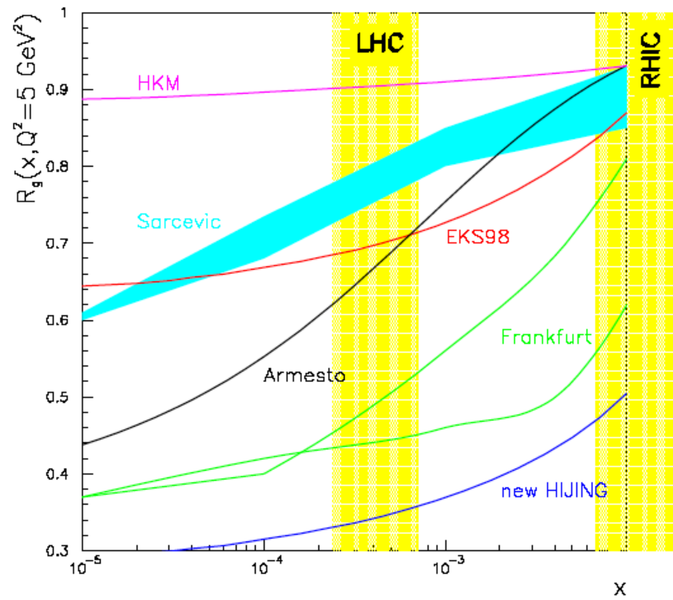
THEORETICAL RESULTS WITH

THEORETICAL RESULTS WITH

ERRORS AND UNCERTAINTIES

Results: different shadowing parameterizations in dAu



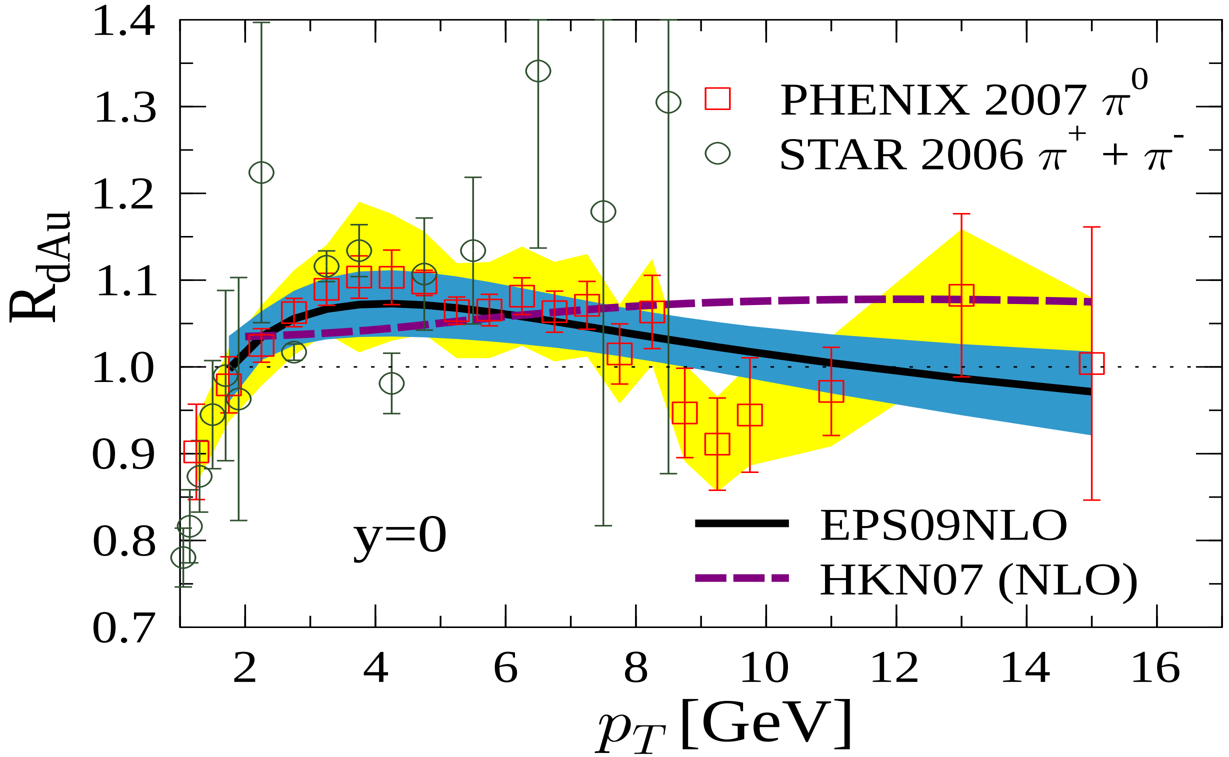


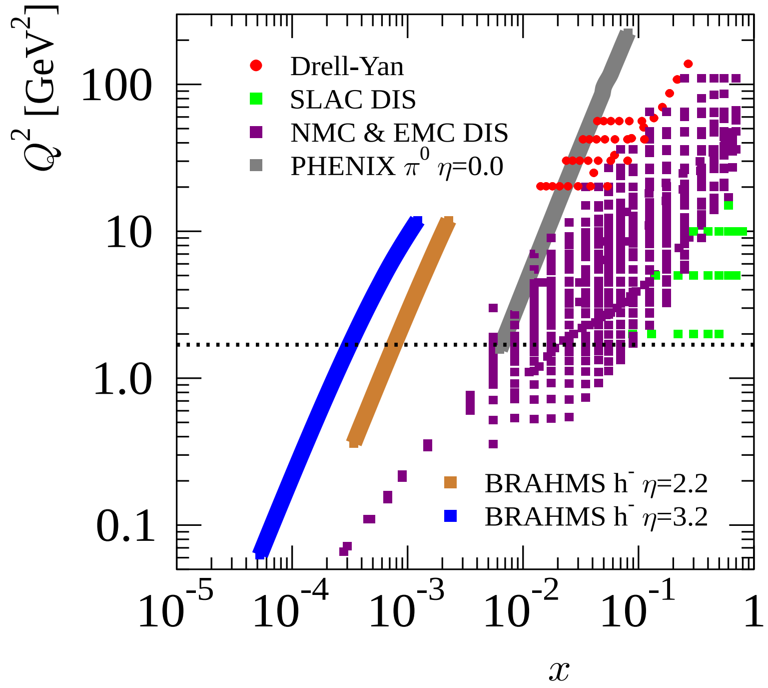
HKN: Hirai *et al.*, Phys.Rev. **C76** 065207 (2007)

HIJING: Wang and Gyulassy, Phys. Rev **D44**, 3501 (1991)

EKRS: Eskola *et al.*, Eur. Phys. Jour. **C9**, 61 (1998)

Good agreement with fitted EPS09 shadowing in dAu





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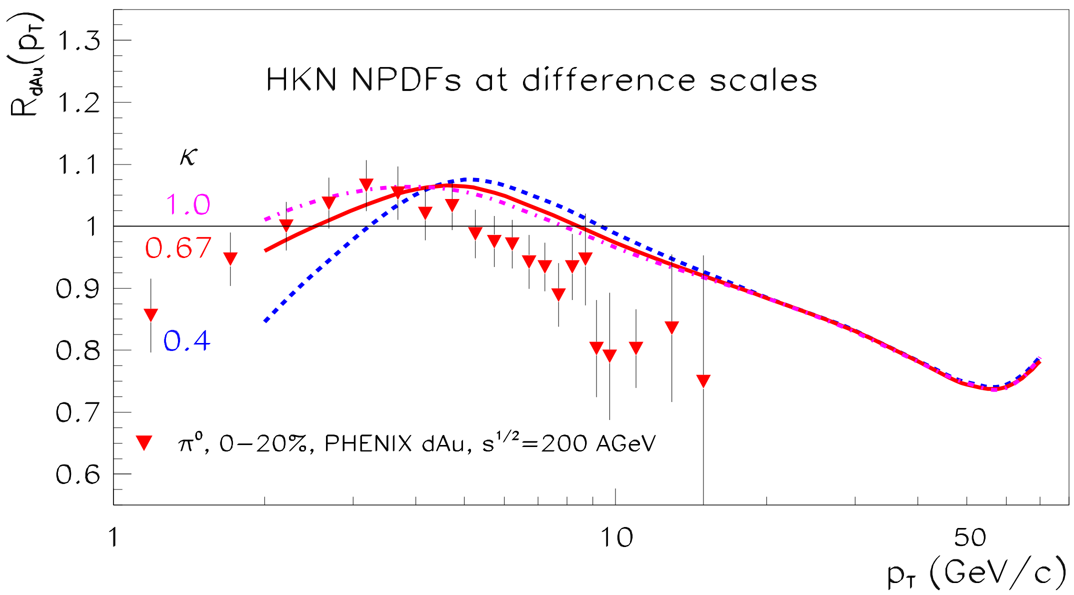
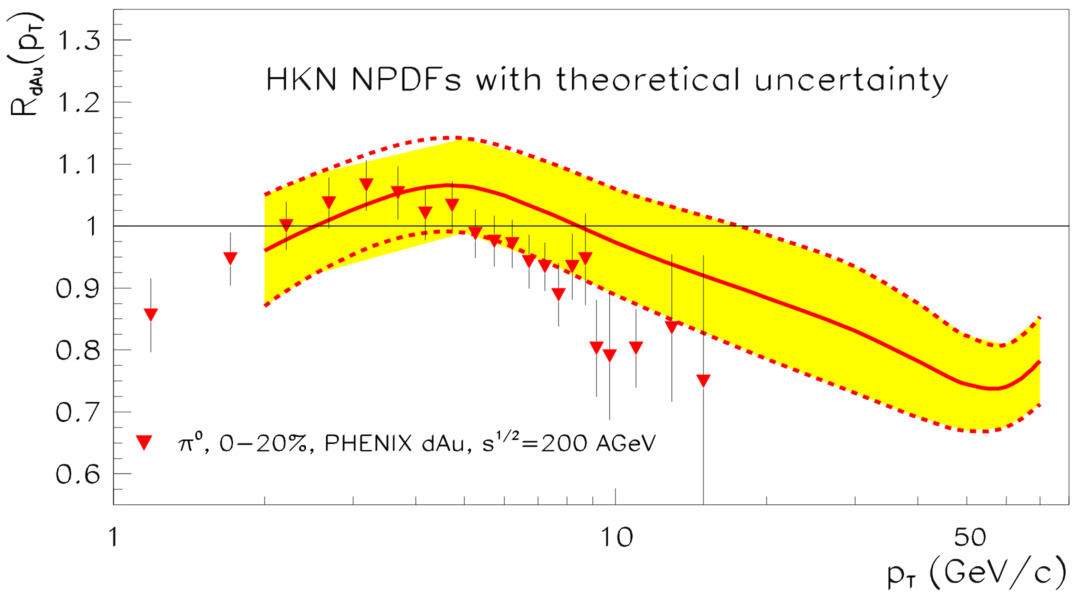
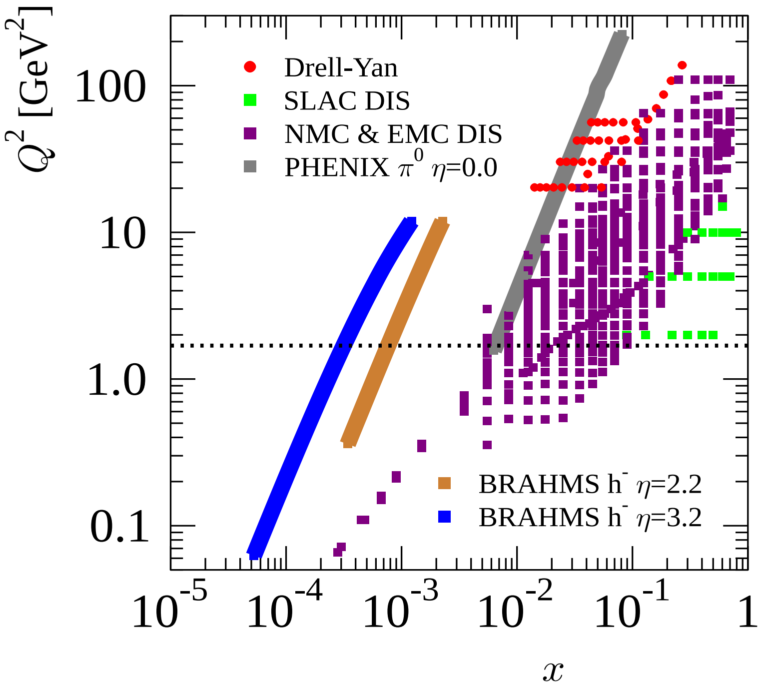
EPS09: Eskola *et al.*, JHEP04 065 (2009)

Uncertainties of HKN parameterizations in $R_{dA}(p_T)$







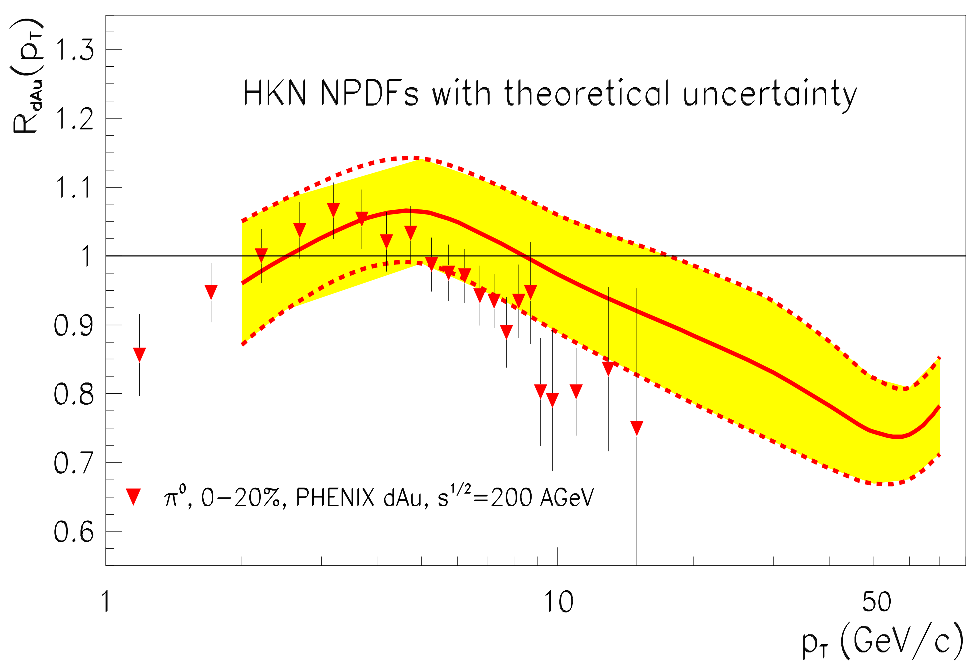
JHEP04 065 (2009)

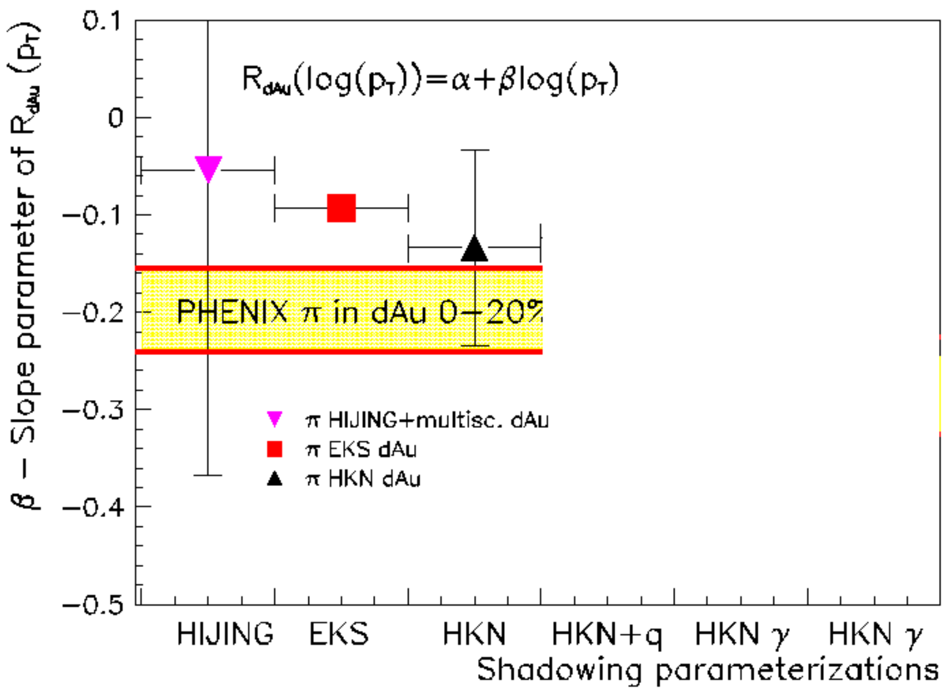
Scale uncertainty at low-p_T

Errors of HKN $\Longrightarrow \pm 10\%$

Phys. Rev. **C76** 065207 (2007)

Extracting the slope of R_{dAu} in dAu collision at PHENIX



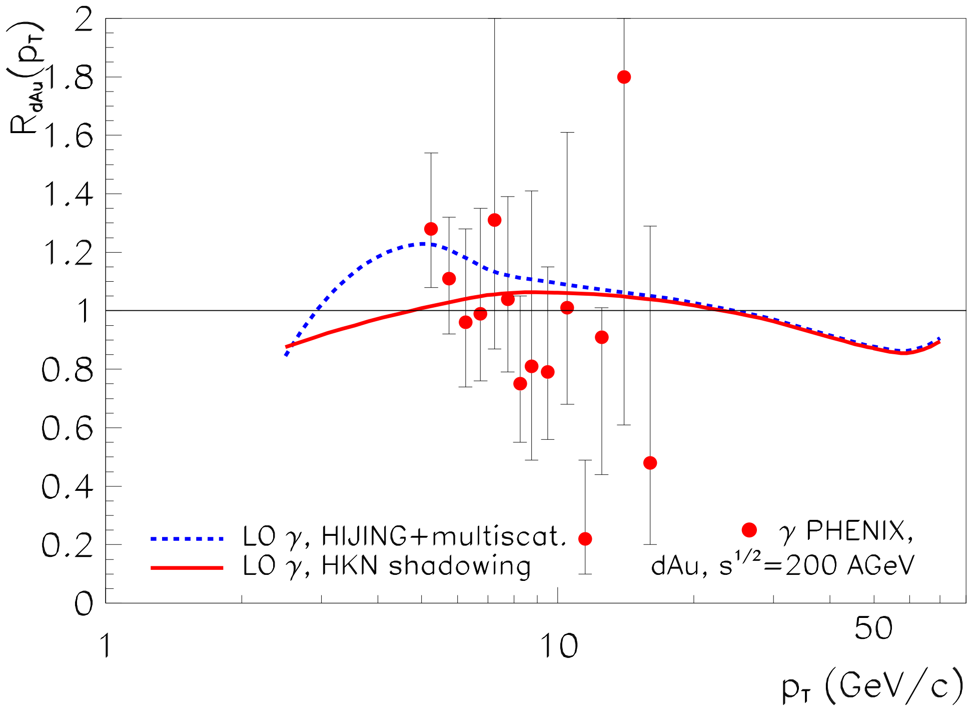


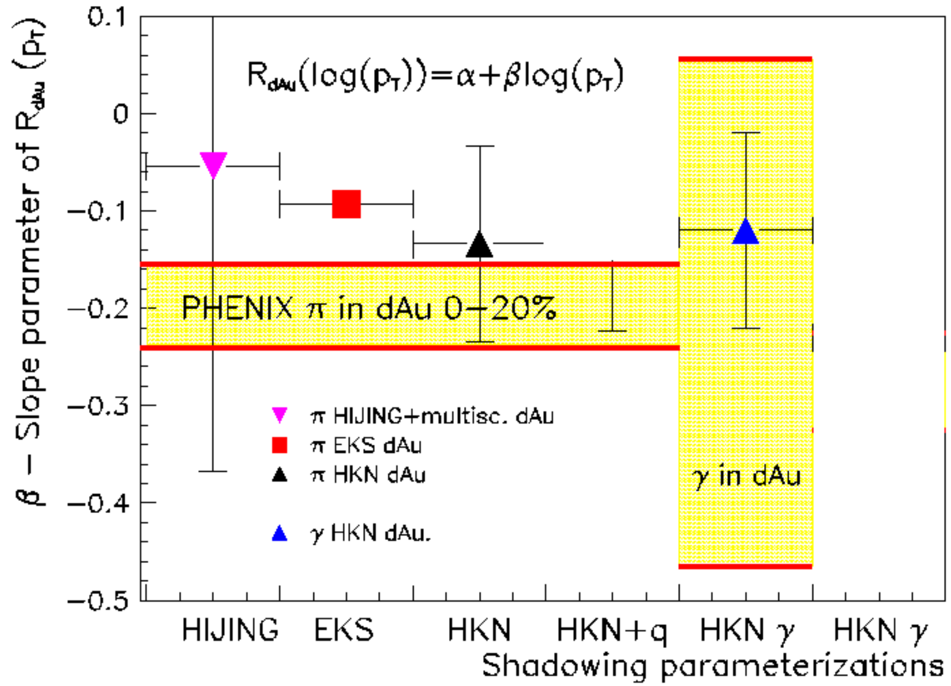
Comparing different shadowing parameterizations

Fit linear for the $\sim \log(p_T)$ in the $8 < p_T < 30$ GeV/c range

What is missing in the EMC region for π^0?

Extracting the slope of R_{dAu} in dAu collision at PHENIX



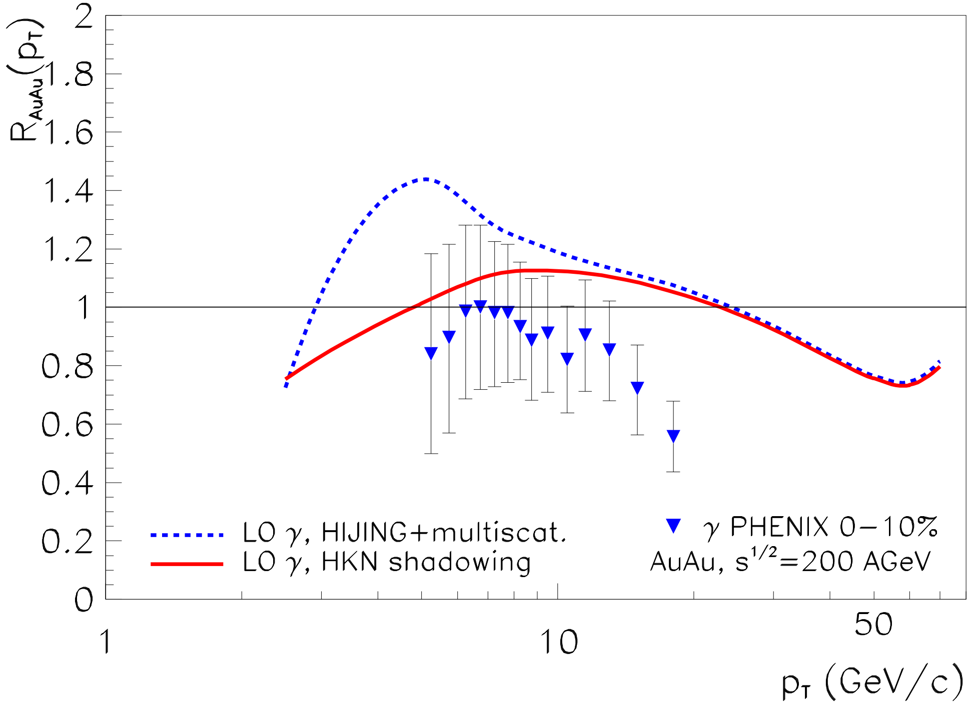


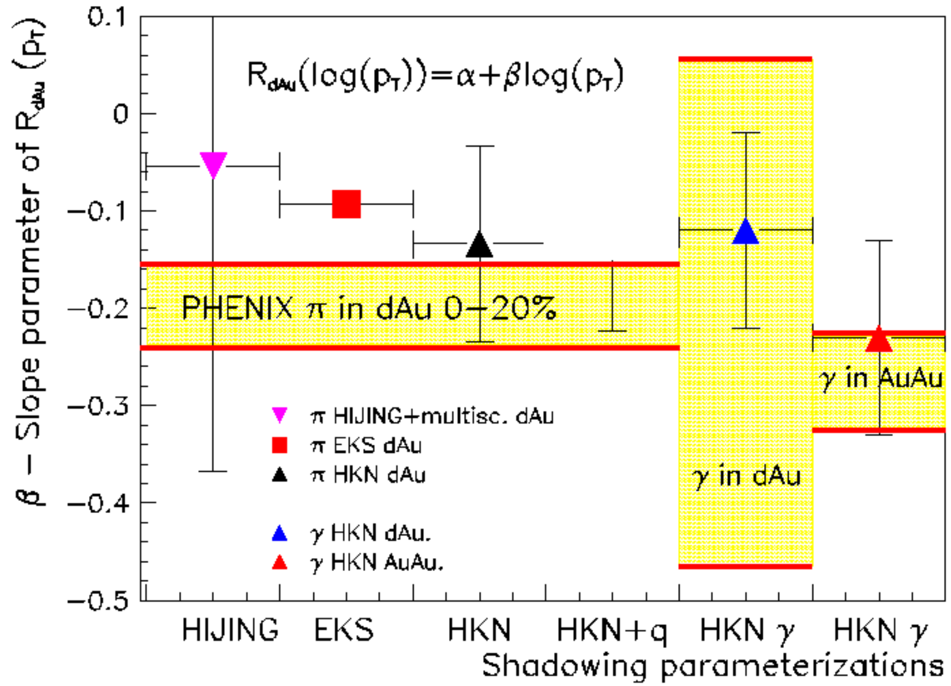
Further test on preliminary $dAu \rightarrow \gamma$ PEHNIX data

LO direct photon calculations, without FSI (suppression)

Negative slope is hopefully seen . . .

Extracting the slope of R_{AuAu} in $AuAu$ collision at PHENIX



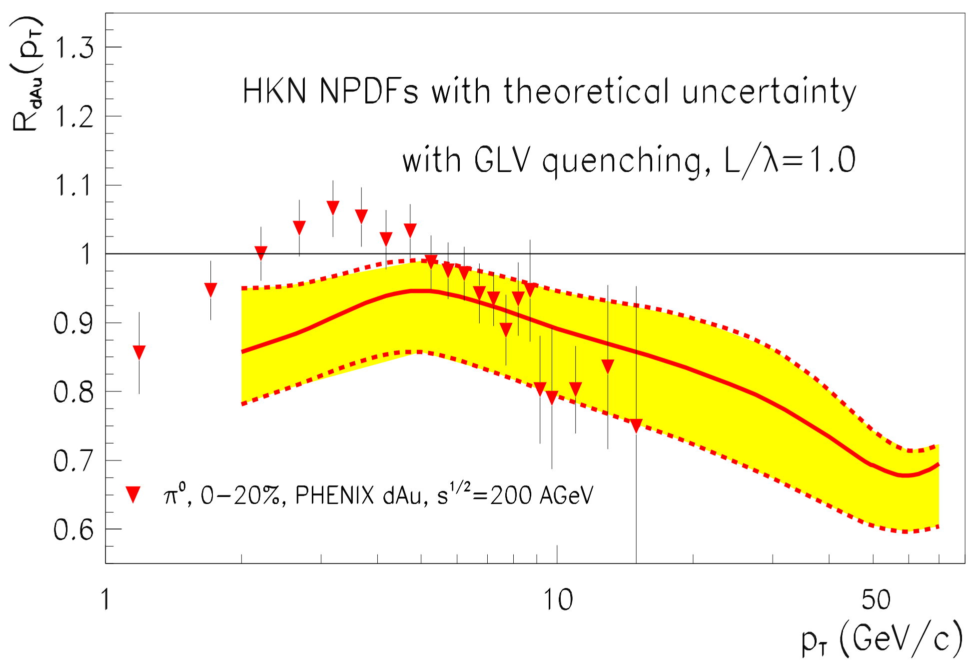


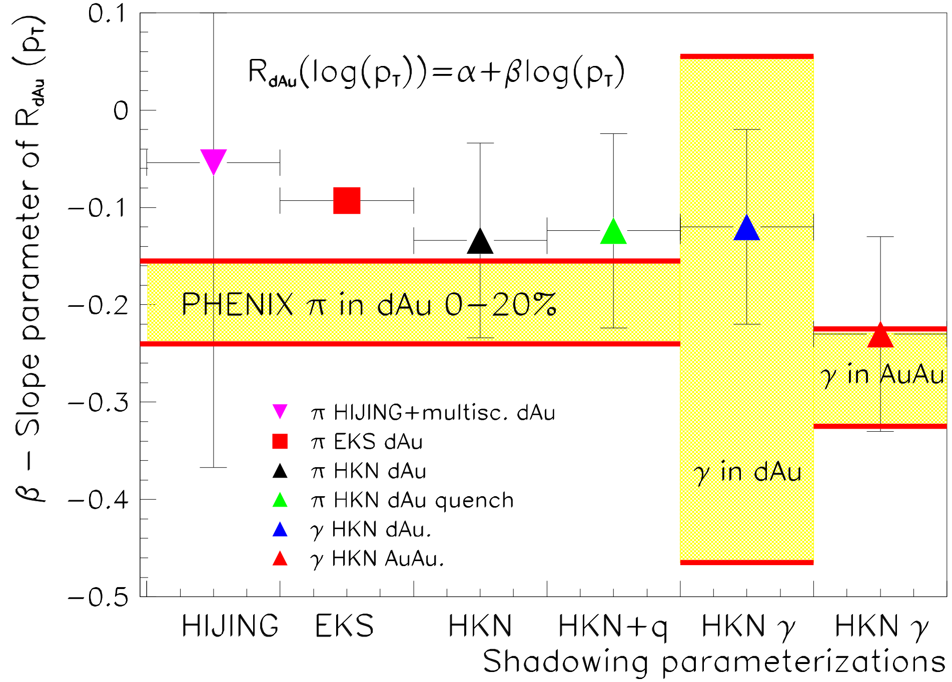
Test on preliminary $AuAu \rightarrow \gamma$ PEHNIX data

LO direct photon calculations, still NO FSI (suppression)

Clear slope, but more than linear power (double effect)

Extracting the slope of R_{AuAu} in $AuAu$ collision at PHENIX





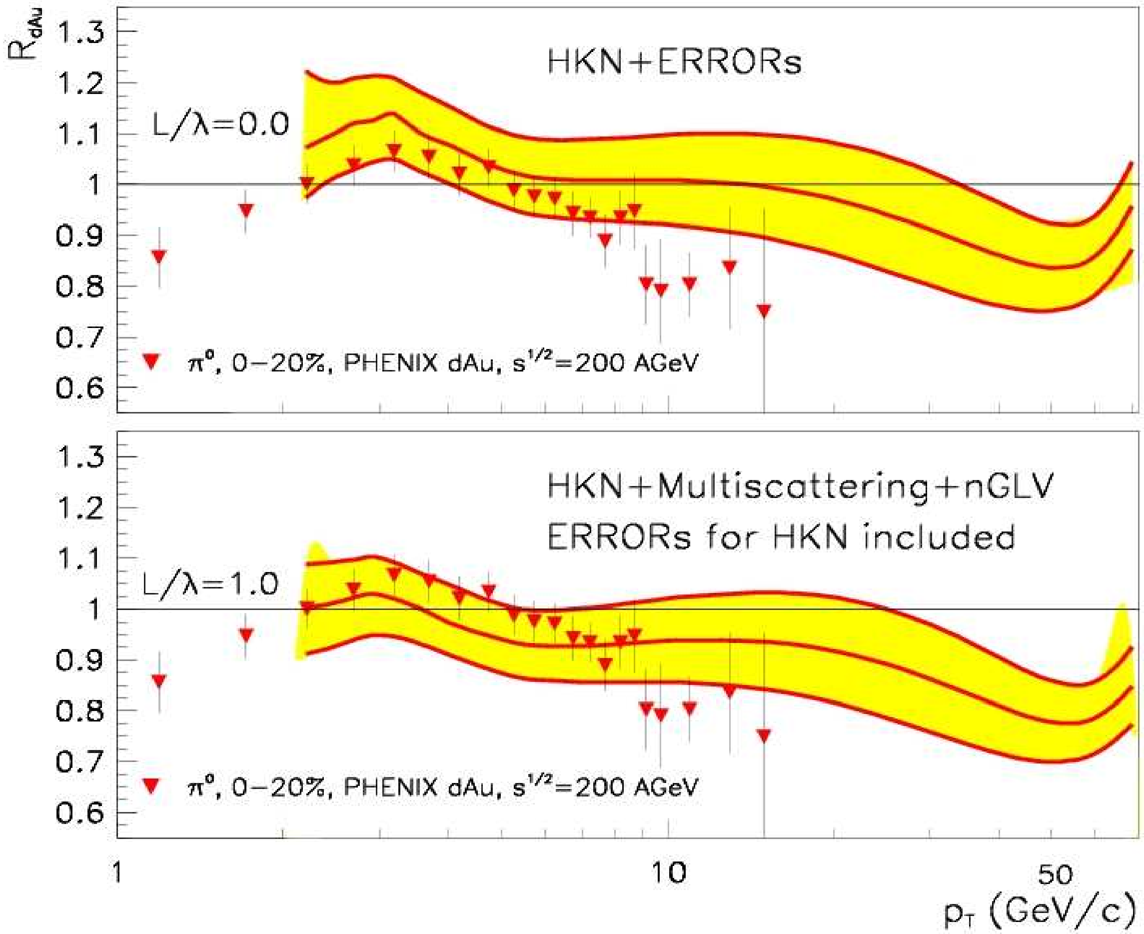
What if we would include FSI for π^0 in dAu at RHIC

GLV-like suppression: shifts down $R_{dAu} \sim 10\%$

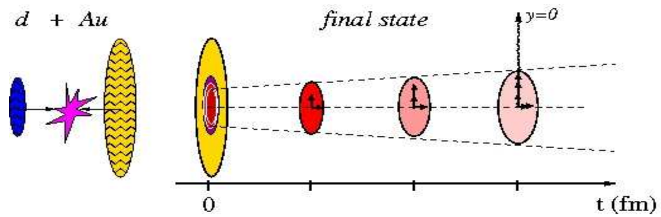
in this simple case no relevant change in the high-p_T slope

Cold Quenching in *dAu* collision at PHENIX

Barnaföldi, Fai, Levai, Papp



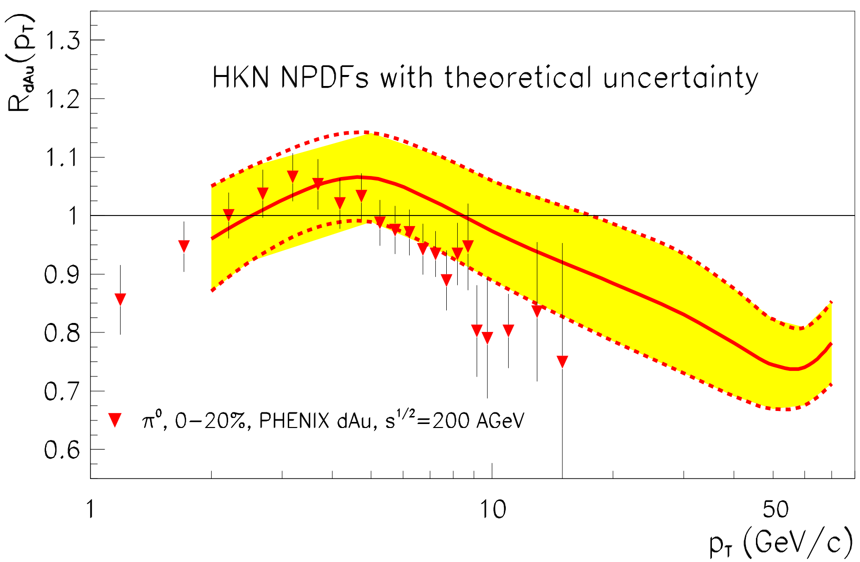
Calculations for dAu with HKN shadowing

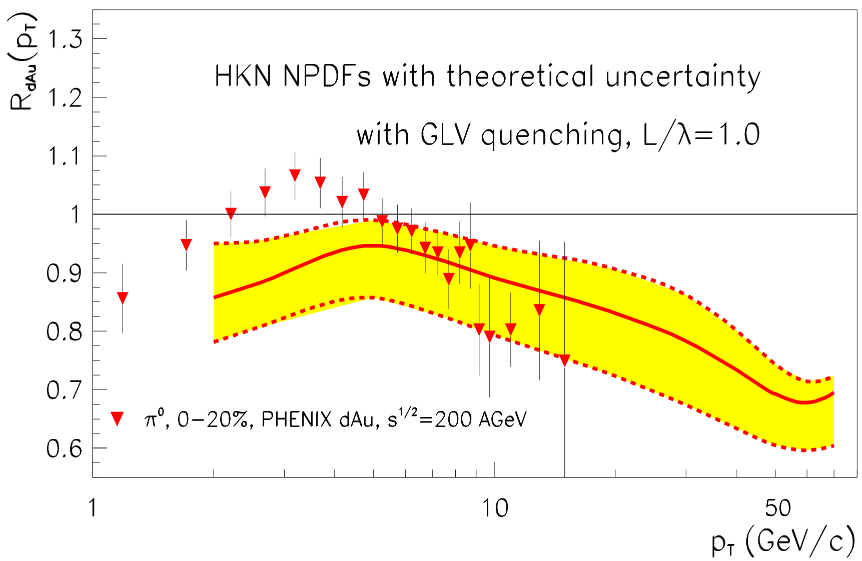


Cold quenching in dAu collision at a small n~1 opacity

better model: (weak color matter) might be seen on slopes at RHIC, but this effect is stronger at LHC energies...

SUMMARY





R_{dAu} and HKN EMC slopes are close to parallel at high p_T

$\Longrightarrow$ ...but, non equal, so room for final state effects

$\Longrightarrow$ π^0 and γ in dAu and $AuAu$ has similar suppression at high p_T

$\Longrightarrow$ Errors and uncertainties are well handled

Summarized in *arXiv: hep-ph/0702101* **and** *0805.3360*

B A C K U P S L I D E S

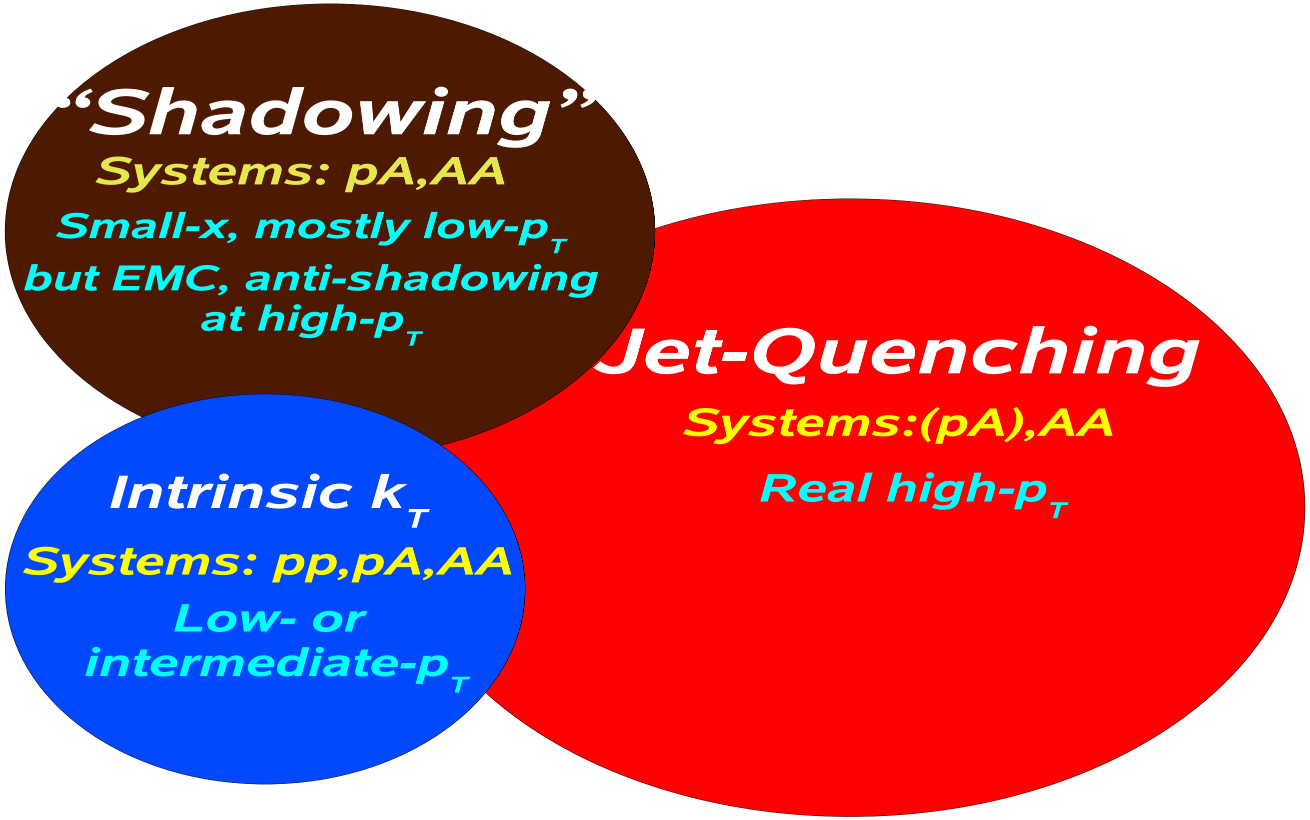
Nuclear effects in our model at:

CERN SPS ENERGIES

Old and new data from Fermilab, WA98, NA49 . . .

Nuclear effects in our model at:

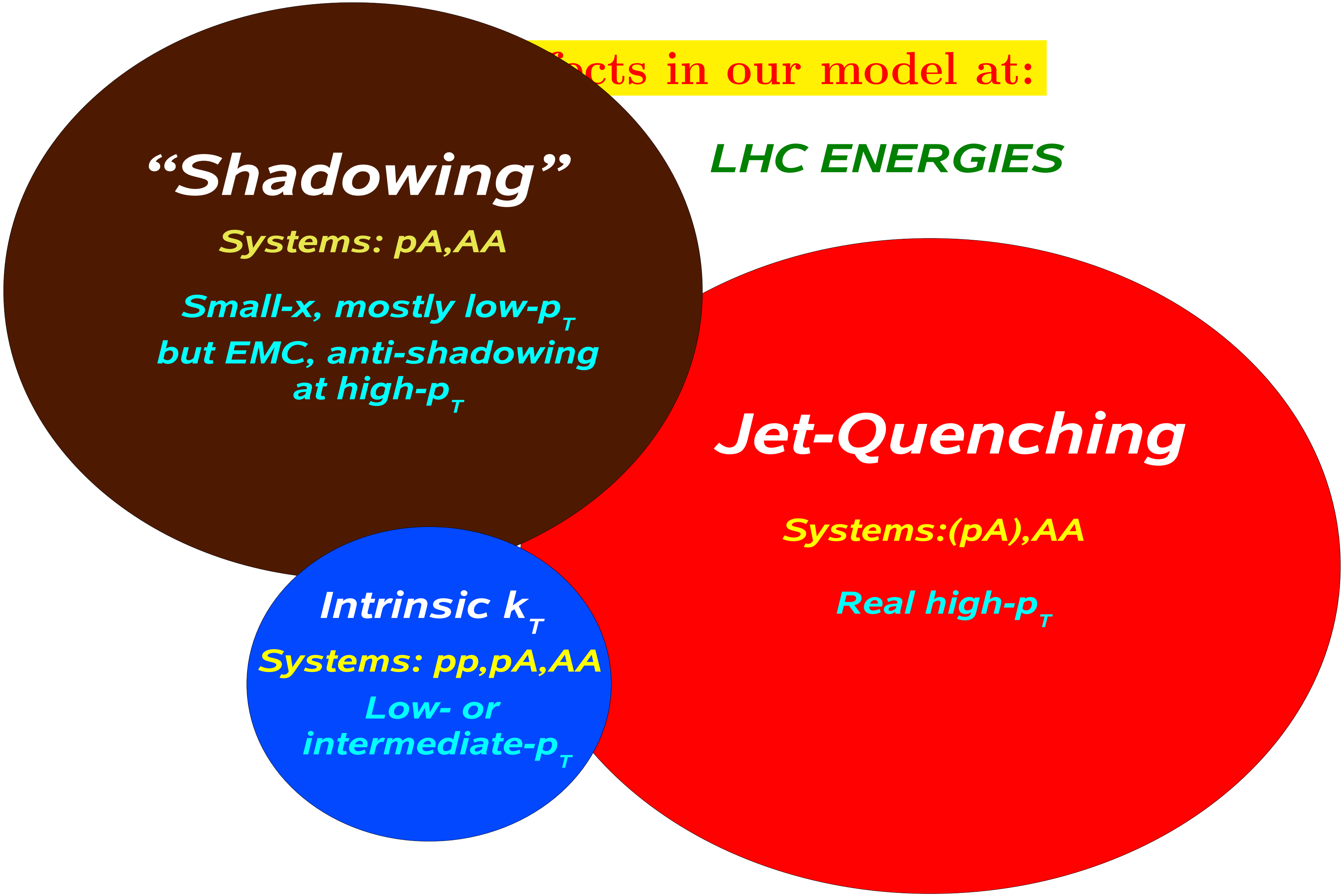
RHIC ENERGIES



. . . high precision data by RHIC experiments . . .

ects in our model at:

LHC ENERGIES



...and predictions for LHC energies!

Suppression or Enhancement at LHC?

C.M. Energy dependence of GLV jet energy loss

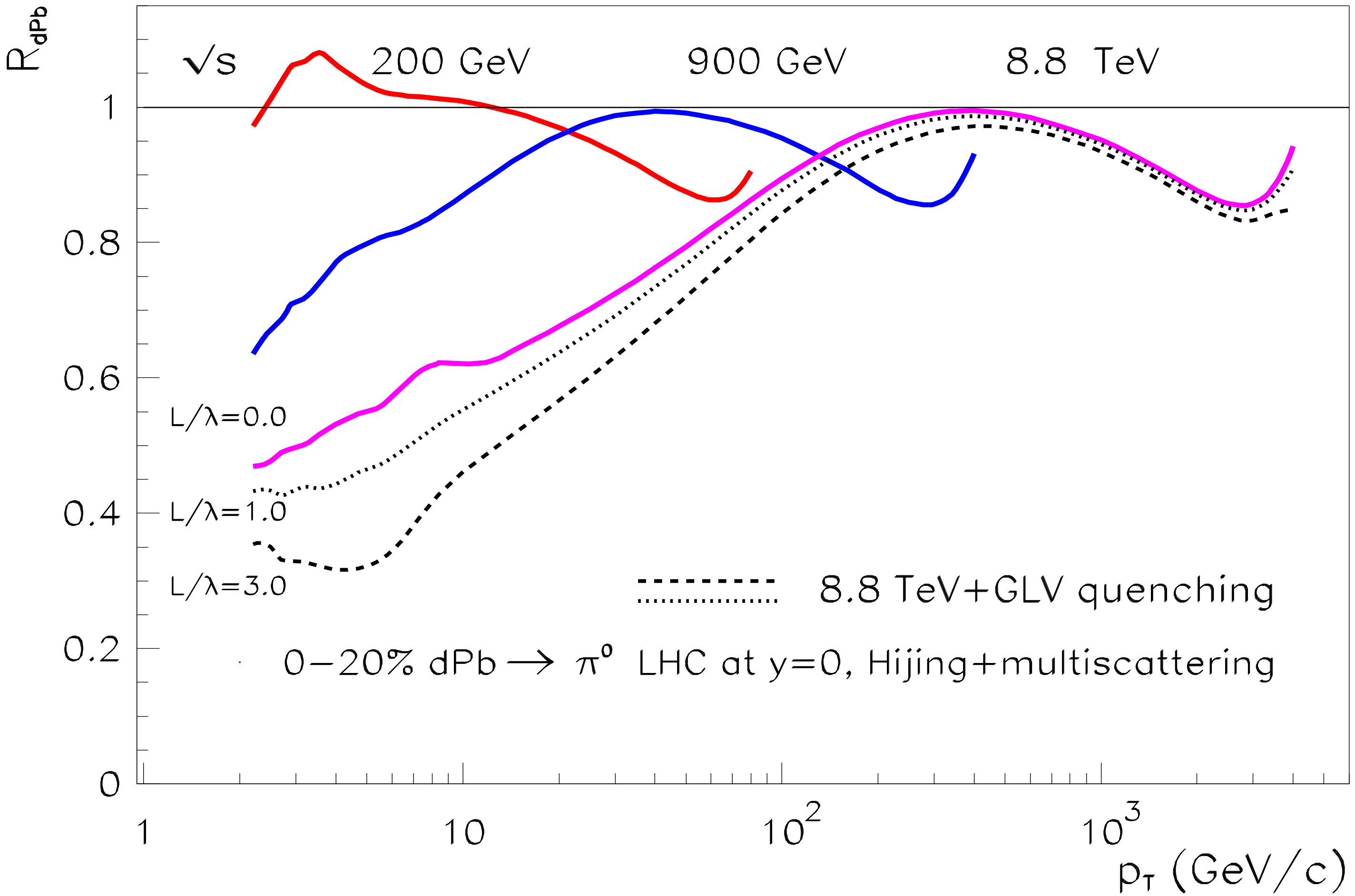
$$\Delta E_{GLV} \approx \frac{C_R \alpha_s}{N(E)} \frac{L^2 \mu^2}{\lambda_g} \log \frac{E}{\mu} = \frac{C_R \alpha_s}{N(E)} \frac{1}{A_\perp} \frac{dN}{dy} \langle L \rangle \log \frac{E}{\langle \mu \rangle}$$

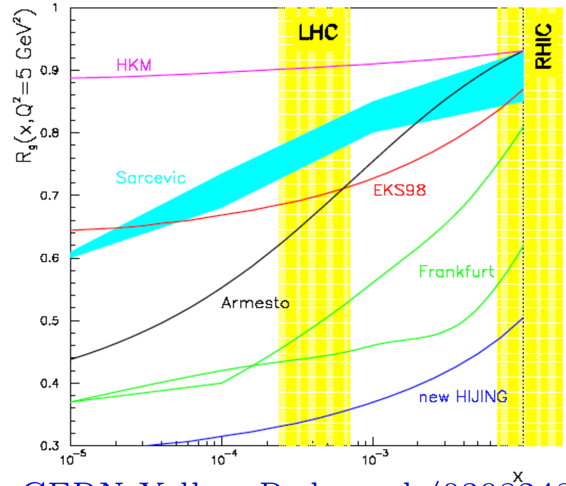
- **For central $AuAu$ collision at RHIC** $\frac{1}{A_\perp}\frac{dN}{dy} \approx \frac{680}{\pi R^2_{AuAu}} = 5.1$

- **For dAu collision at RHIC** $\frac{1}{A_\perp}\frac{dN}{dy} \approx \frac{18}{\pi R^2_{dAu}} = 2.54$

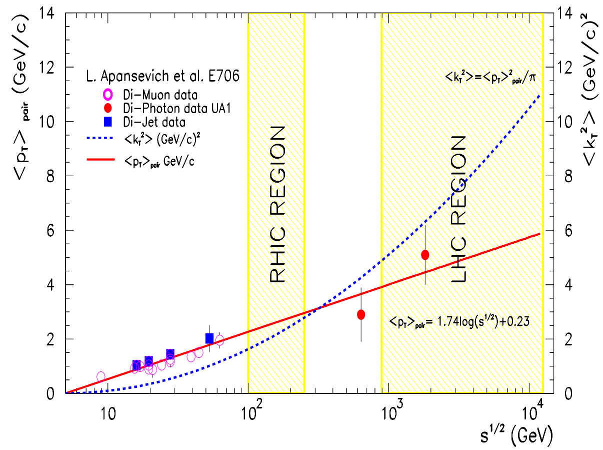
- **Without suppression** $\frac{dN}{dy} \sim \ln \sqrt{s}$
- **At LHC this $\frac{dN}{dy}$ will be** $\sim 1500 - 2000$

R_{dPb} at in dPb Collision at different energies beyond RHIC





CERN Yellow R. hep-ph/0308248

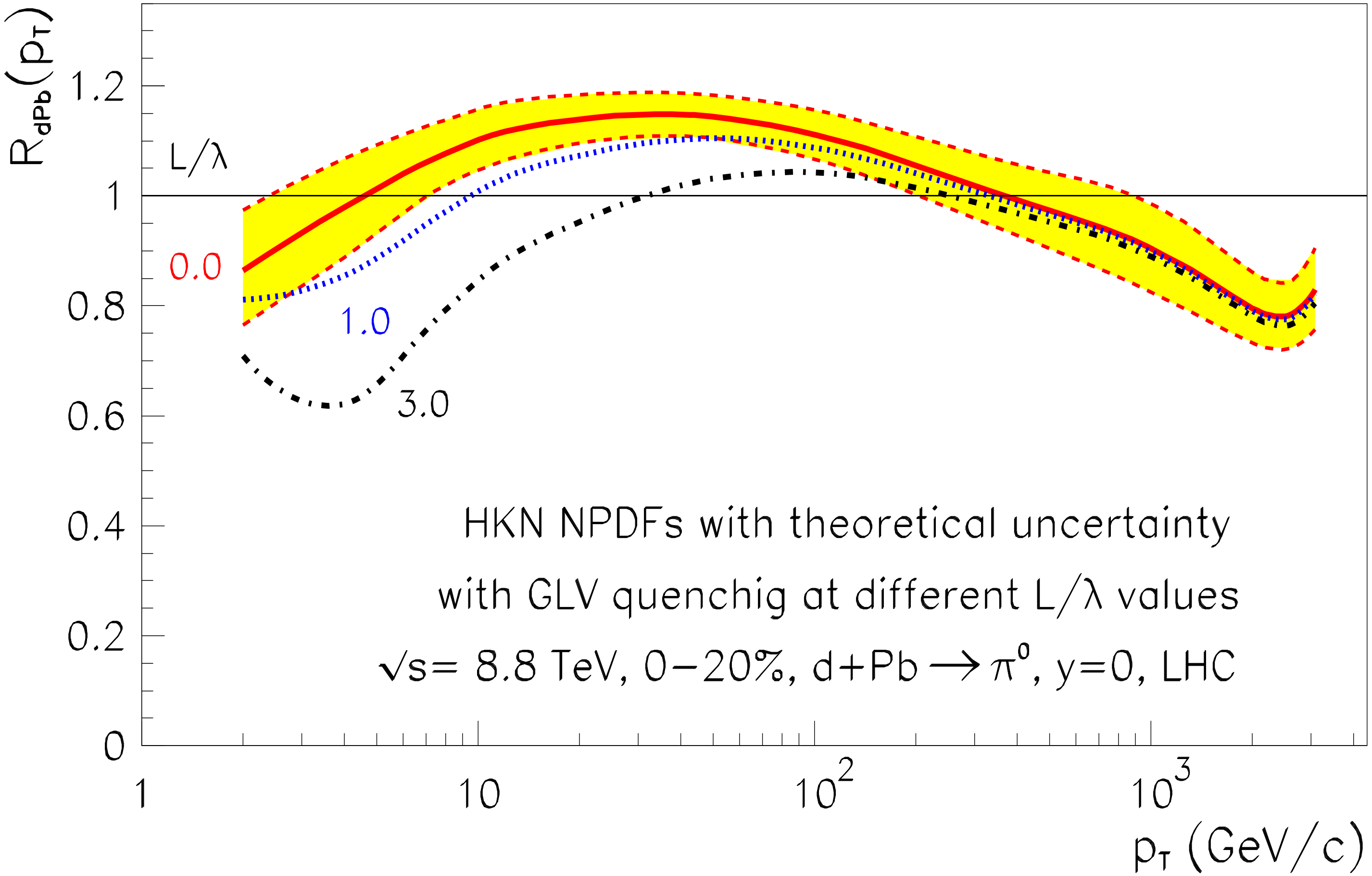


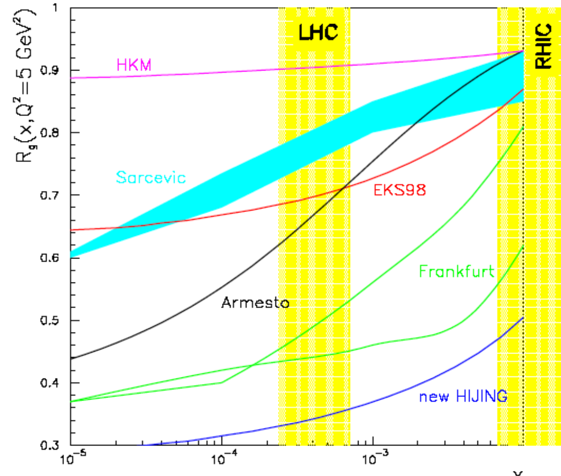
Two main initial state effects:

Suppression can be strong at high-p_T at the LHC energies.

Cronin peak is slightly moving towards higher-p_T values.

R_{dPb} at in dPb collision at different energies beyond RHIC





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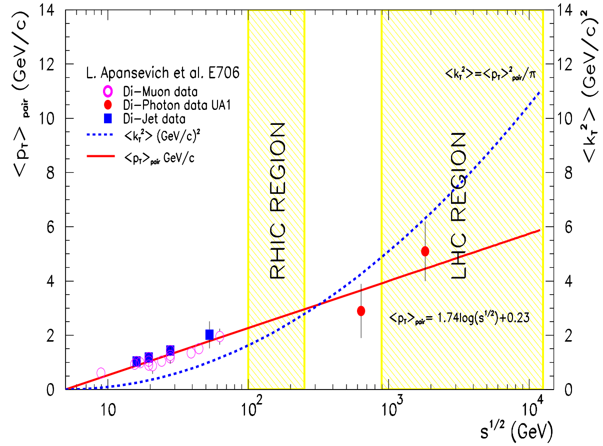

Two main initial state effects:

Suppression is stronger at low-p_T at the LHC energies.

Cronin peak is slightly moving towards higher-p_T values.