Nuclear effects in dAu collisions from the final RHIC data

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(Budapest – Columbia – Kent Collaboration)

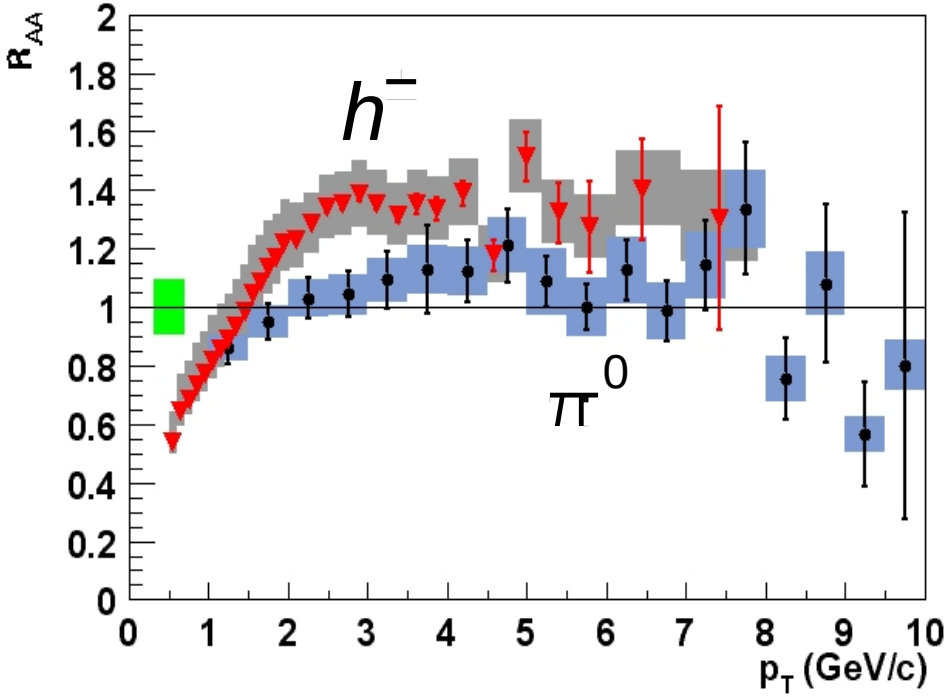
Hard Probes 2006, Asilomar
10 June 2006

Beautiful results from RHIC in dAu at 200 AGeV -- R_{dAu}

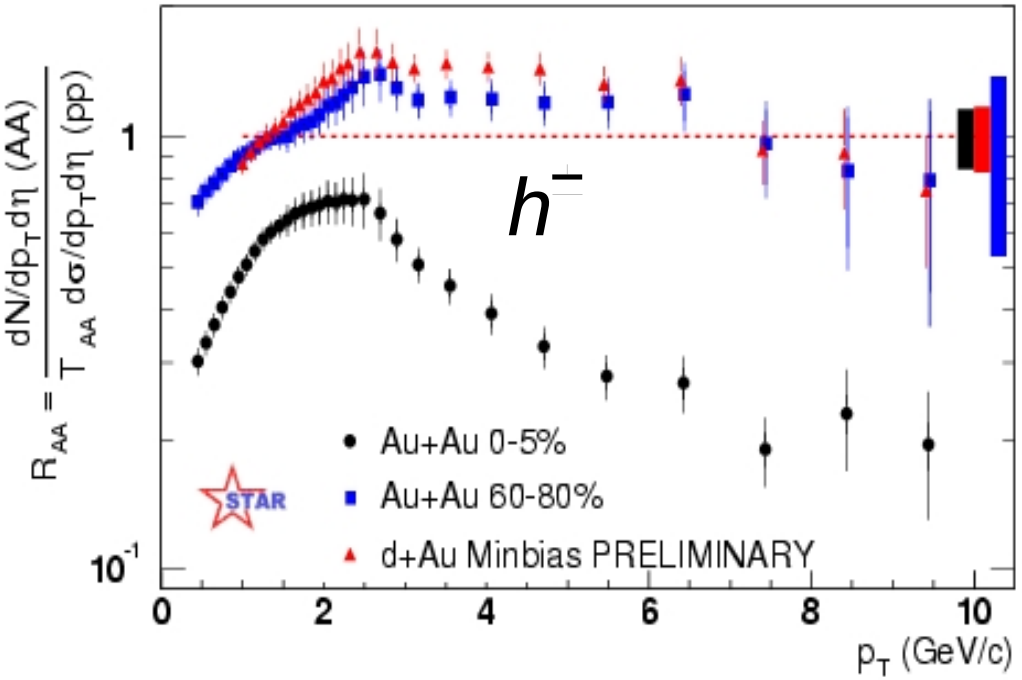
Nuclear modification factor :

$$R_{dAu} = \frac{E_{\pi} d\sigma_{\pi}^{dAu}/d^3p}{N_{bin} * E_{\pi} d\sigma_{\pi}^{pp}/d^3p} = \frac{E_{\pi} d\sigma_{\pi}^{dAu}(\textbf{YES nuclear effect})/d^3p}{E_{\pi} d\sigma_{\pi}^{dAu}(\textbf{NO nuclear effects})/d^3p}$$

PHENIX data at 200 GeV



STAR data at 200 GeV

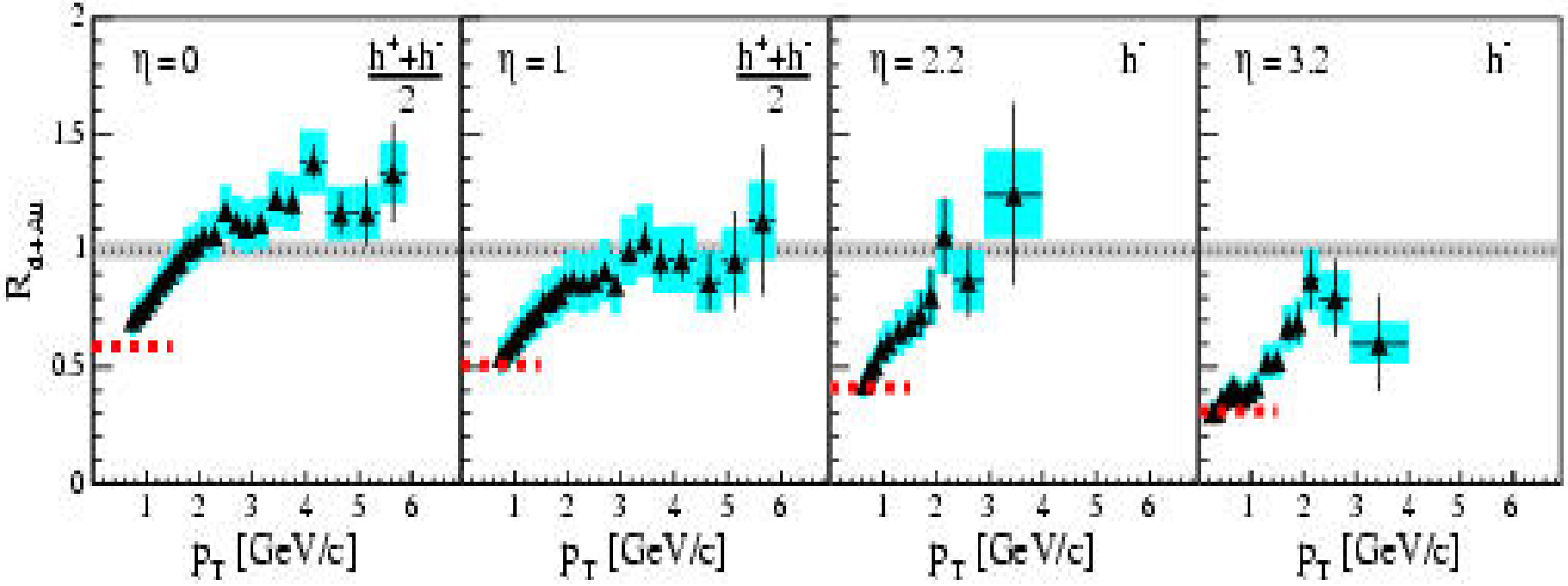


Beautiful results from RHIC in dAu at 200 AGeV -- R_{dAu}

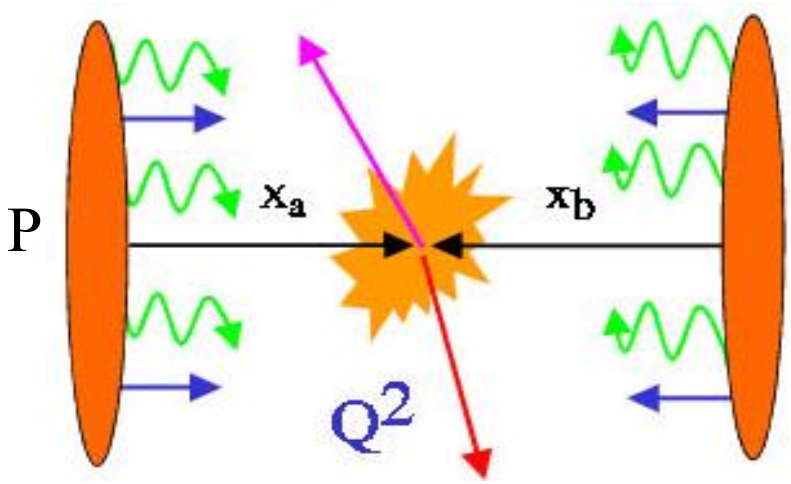
Nuclear modification factor at high pseudorapidities: $\eta > 0$

$$R_{dAu} = \frac{E_n d\sigma_n^{dAu}/d^3p}{N_{bin} * E_n d\sigma_n^{pp}/d^3p} = \frac{E_n d\sigma_n^{dAu}\{\textbf{YES nuclear effect}\}/d^3p}{E_n d\sigma_n^{dAu}\{\textbf{NO nuclear effects}\}/d^3p}$$

BRAHMS data on charged particles at 200 GeV: $\eta = 0, 1, 2.2 3.2$



Jets (high p_T probes) in pp and in pA collisions:



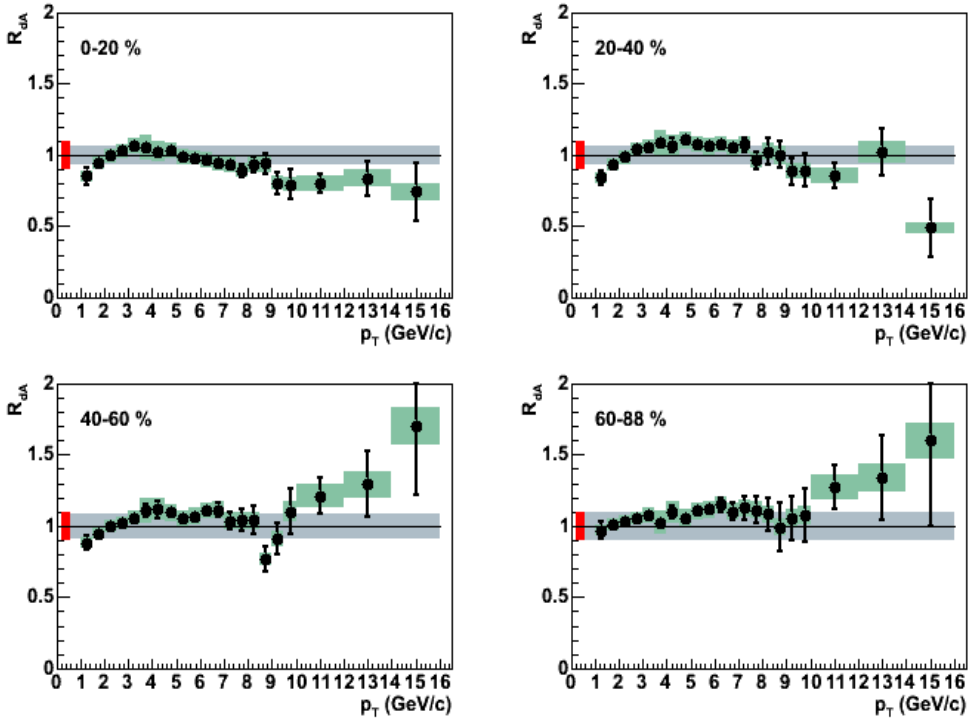
Jet production in pp collision ("in vacuum"):
→ pQCD description

Jet production in pA collision (" in cold dilute matter")
→ modified PQCD description:
--- SHADOWING inside A
--- MULTISCATTERING/BROADENING penetrating A and the "cold matter"
--- ENERGY LOSS penetrating the "cold dilute matter"

Can we separate these mechanisms?
Can we determine them separately during theoretical data analysis ?
What can we learn from high precision RHIC data on dAu collisions ?

Precise "final" results from dAu collisions (theory-killers):

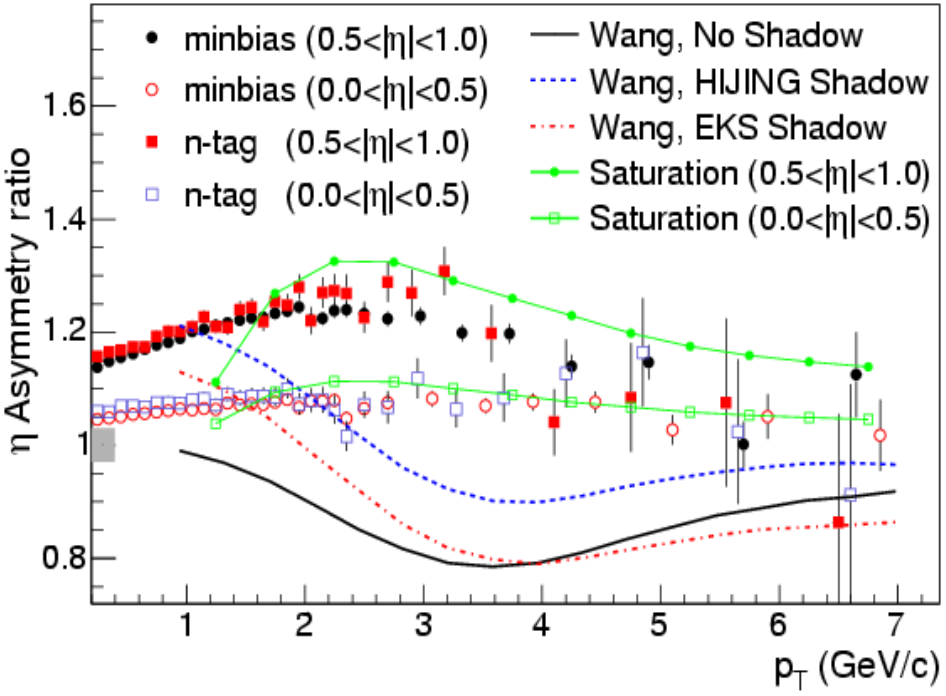
R_{dAu} (π^0) at different centralities



PHENIX

H. Buesching, HQ06

Asymmetry ratio (y<0 / y>0) (charged particles)

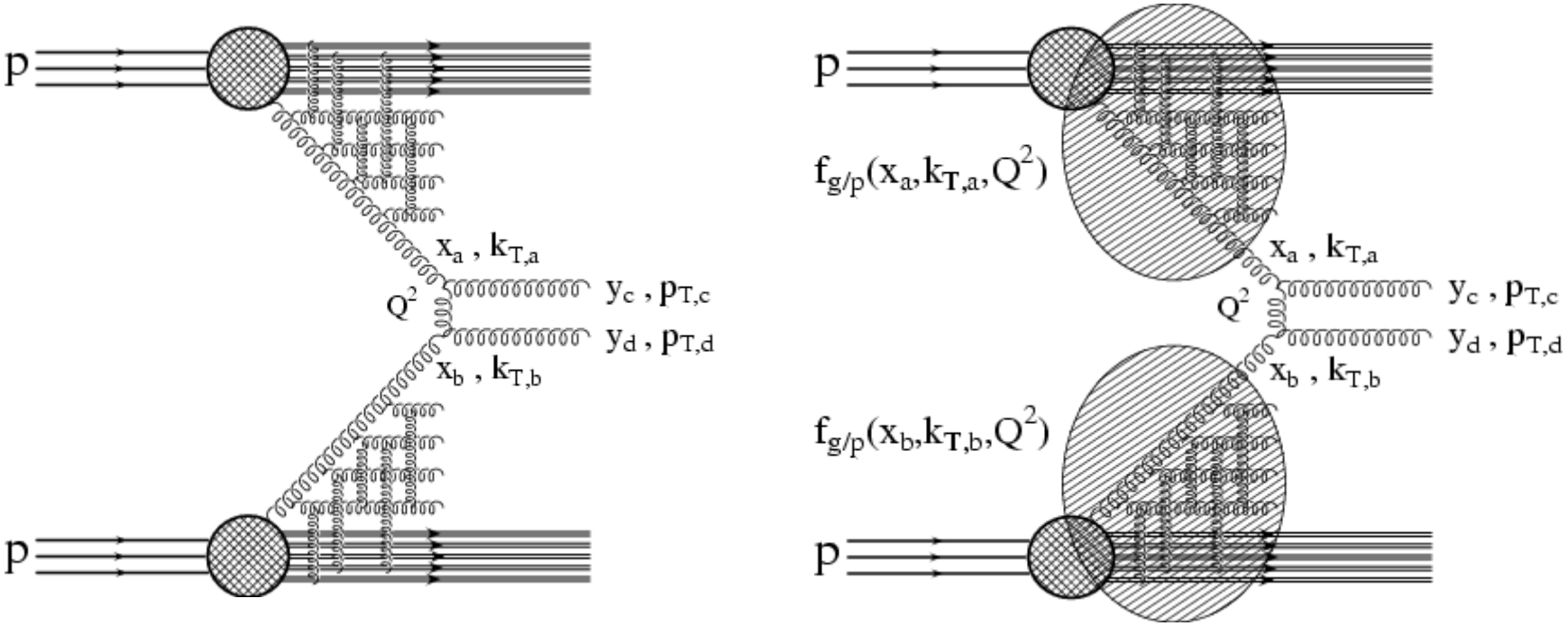


STAR

J. Adams et al. PRC70,064907,2004

Parton model with pQCD: collinear approximation in LO

p + p collisions at CERN SPS, FERMILAB, RHIC, LHC energies

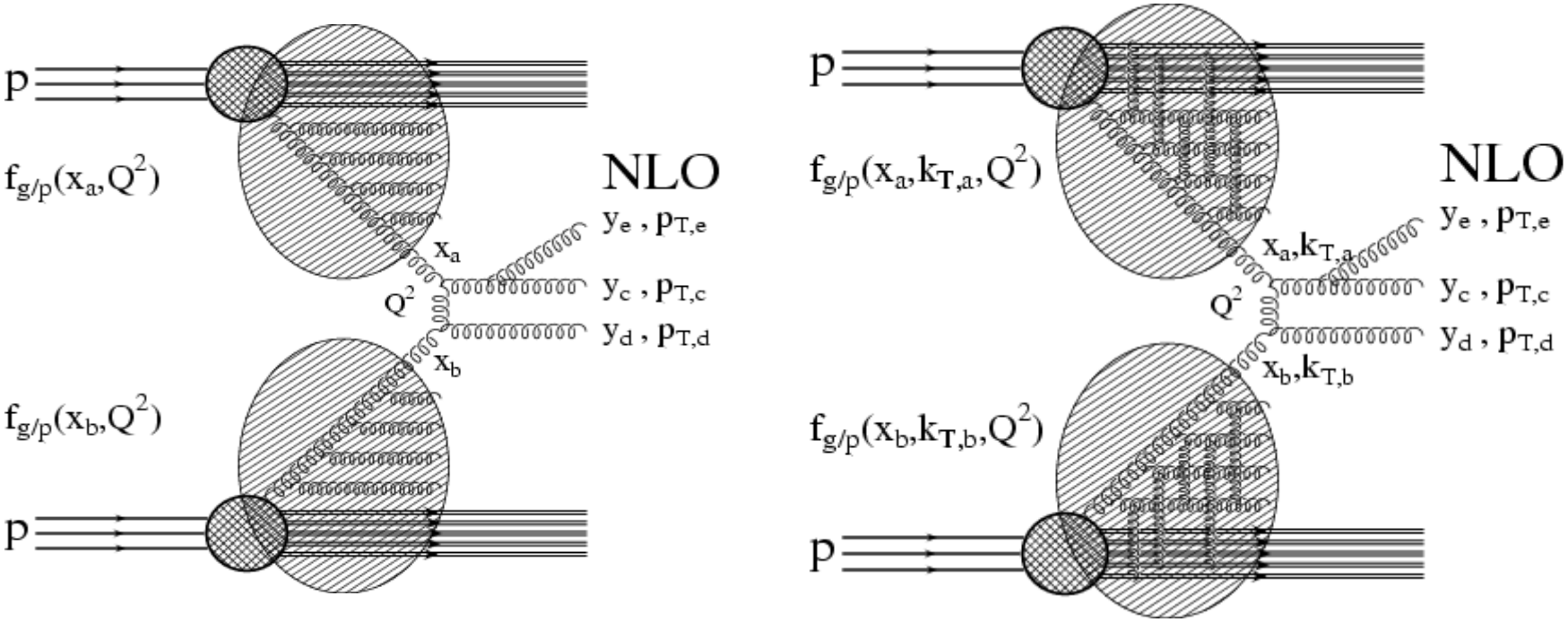


Collinear approximation + pQCD cross sections

+ interaction among the initial partons → "intrinsic k_T"
(resummation at lower-pT) k_T broadening

Parton model with pQCD: collinear approximation in NLO

p + p collisions at CERN SPS, FERMILAB, RHIC, LHC energies



Collinear approximation + pQCD cross sections (NLO)

+ interaction among the initial partons → "intrinsic k_T"
(resummation at lower-pT) k_T broadening

Hard physics: pion production in pp collision at high- p_T

Perturbative QCD calculations in NLO for p+p → π + X process with finite - k_T

NLO : M. Aversa et al. NPB327,105; P. Chiappetta et al. NPB412,3; P. Aurenche et al. NPB399,34; ...)

+ intrinsic kT: G. Papp, P. Levai, G.G. Barnaföldi, G. Fai, hep-ph/0212249, EPJC33(2004)609

$$E_\pi \frac{d\sigma^{pp}}{d^3 p_\pi} = \frac{1}{S} \sum_{abc} \int_{VW/z_c}^{1-(1-V)/z_c} \frac{dv}{v(1-v)} \int_{VW/vz_c}^{1} \frac{dw}{w} \int^{1} dz_c$$

$$\int d^2\boldsymbol{k}_{Ta} \int d^2\boldsymbol{k}_{Tb}\; f_{a/p}(x_a, \boldsymbol{k}_{Ta}, Q^2)\; f_{b/p}(x_b, \boldsymbol{k}_{Tb}, Q^2)$$

$$\left[\frac{d\sigma^{BORN}}{dv}\delta(1-w) + \frac{\alpha_s(Q_R)}{\pi} K_{ab,c}(s, v, w, Q, Q_R, Q_F)\right] \frac{D_c^\pi(z_c)}{\pi z_c^2}$$

An approximation for the unintegrated parton distribution functions (PDFs) :

$$f_{a/p}(x_a, \boldsymbol{k}_{Ta}, Q^2) = f_{a/p}(x_a, Q^2)\; g(\boldsymbol{k}_{Ta})$$

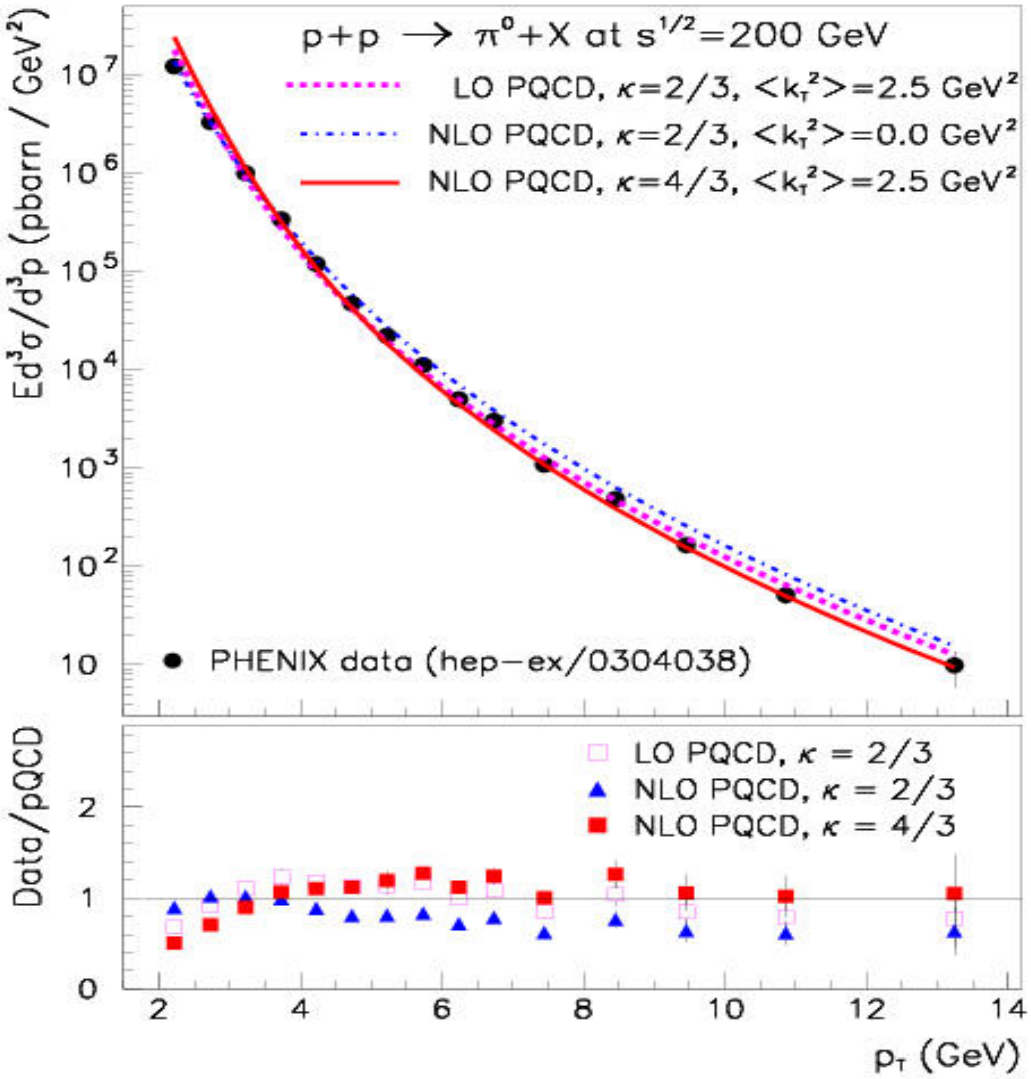
Where we use gaussian

$$g(\boldsymbol{k}_{Ta}) = \frac{1}{\pi \langle k_T^2 \rangle} e^{-k_T^2/\langle k_T^2 \rangle}$$

The width of the gaussian distribution for intrinsic-kT

Hard physics: pion production in pp collision at high- p_T

Perturbative QCD calculations in LO and NLO for pp --- including intrinsic- kT



LO:

$$Q=\kappa\, p_T/z_c,\ \ Q_F=\kappa\, p_T$$

NLO:

$$Q=Q_R=\kappa\, p_T/z_c,\ \ Q_F=\kappa\, p_T$$

All descriptions are approx.
good enough at 2 GeV < pT < 5 GeV.

Which κ should be used ?

Hard physics: pion production in dAu collision at high- p_T

Perturbative QCD calculations in LO and NLO for pp + CRONIN + SHADOWING:

CRONIN (nuclear multiscattering):

$$E_\pi \frac{d\sigma^{dAu}}{d^3p_\pi} = \int d^2\boldsymbol{b}\; d^2\boldsymbol{r}\; t_d(\boldsymbol{r})\, t_{Au}(|\boldsymbol{b}-\boldsymbol{r}|)\; E_\pi \frac{d\sigma^{pp}(\langle k_T^2\rangle_{pAu}, \langle k_T^2\rangle_{pd})}{d^3p_\pi}$$

Where the k_T broadening in dAu :

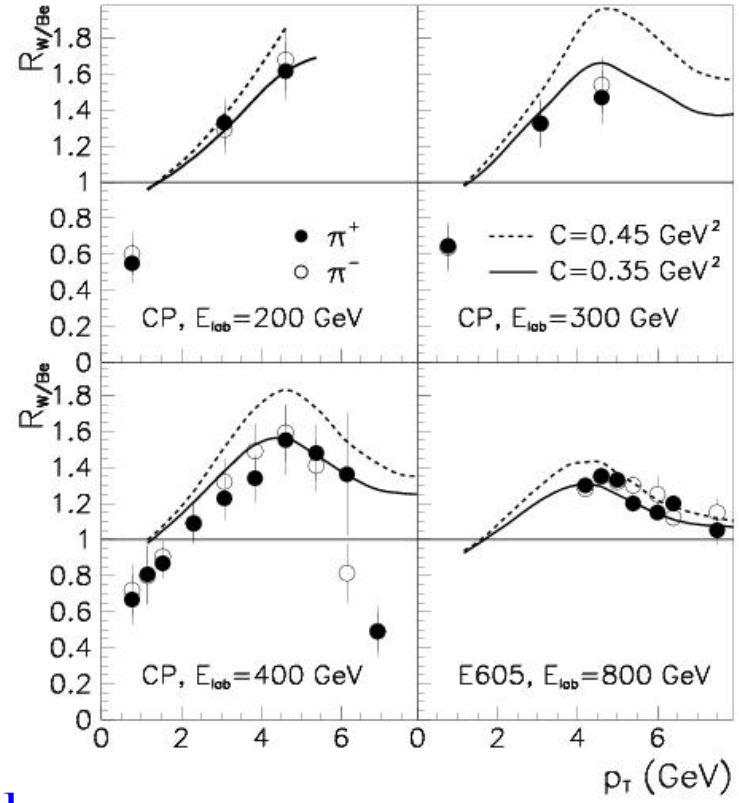
$$\langle k_T^2\rangle_{pAu} = \langle k_T^2\rangle_{pp} + C\; h_{pAu}(b)$$

- with the effective broading per collision

$$C = 0.4 \pm 0.05\, GeV^2$$

$$\langle k_T^2\rangle_{pp} = 2.2 - 2.4\, GeV^2$$

Fixed on FERMILAB data
[Antresyan et al, PRD19,764 (1979)]



LO: Zhang, Fai, Papp, Barnafoldi, Levai, PRC65, 034903 (2002)

Hard physics: pion production in dAu collision at high- p_T

Perturbative QCD calculations in LO and NLO for pp + CRONIN + SHADOWING:

SHADOWING : New-Hijing parametrization, **Li & Wang, PLB527 (2002) 85.**

$$f_{a/A}(x_a,Q^2) = A\ S_a^A(x_a,Q^2)\ f_{a/N}(x_a,Q^2)$$

Shadowing function for quarks:

$$S_q^A = 1.0 + 1.19\log^{1/6}A(x^3 - 1.12x^2 + 0.21x) -$$
$$-s_q(A^{1/3}-1)^{0.6}(1-3.5\sqrt{x})\exp(-x^2/0.01)$$

Shadowing function for gluons:

$$S_g^A = 1.0 + 1.19\log^{1/6}A(x^3 - 1.2x^2 + 0.21x) -$$
$$-s_g(A^{1/3}-1)^{0.6}(1-1.5x^{0.35})\exp(-x^2/0.004)$$

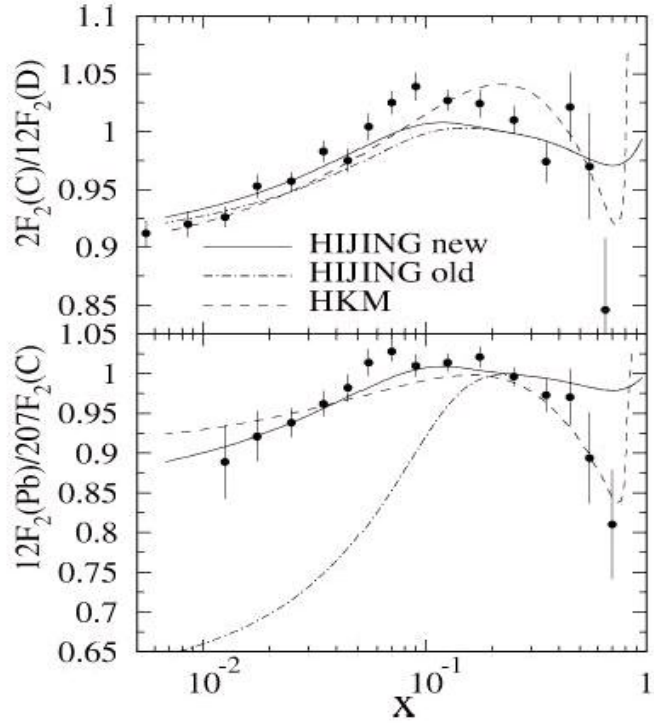
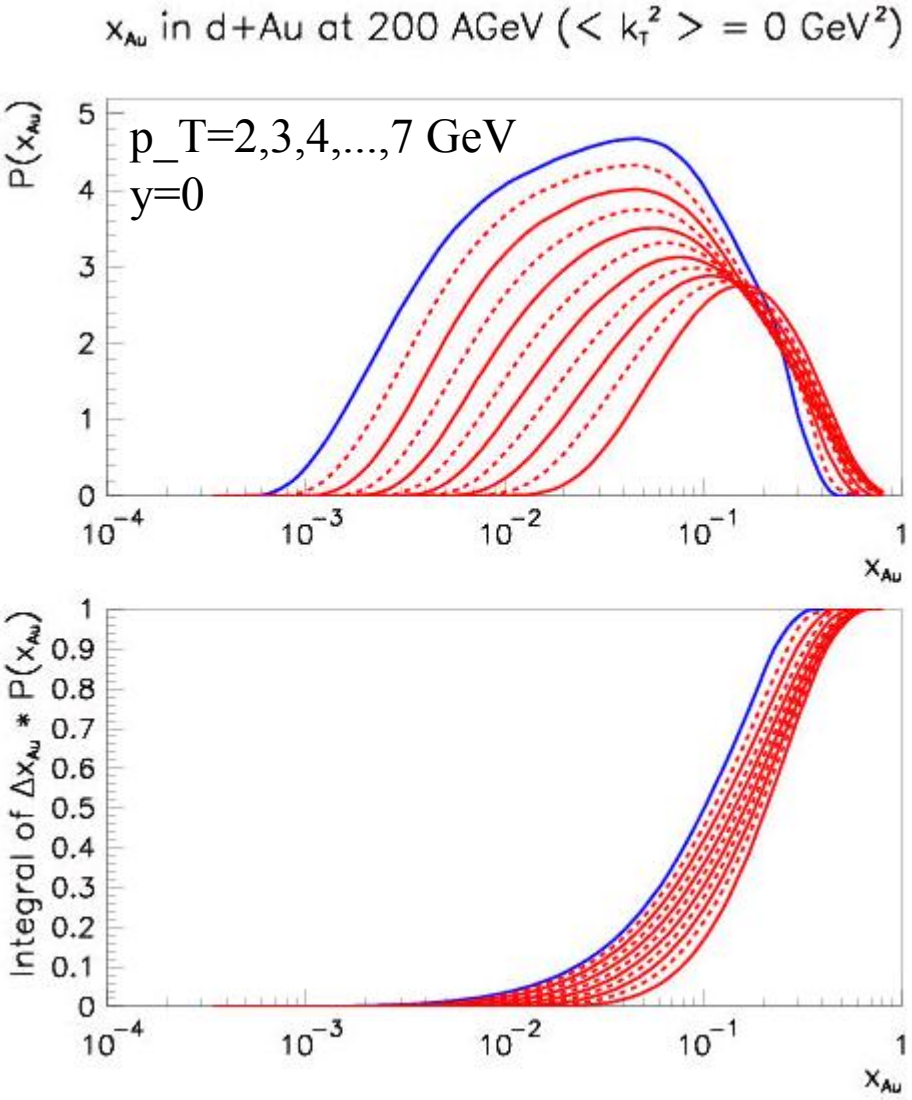


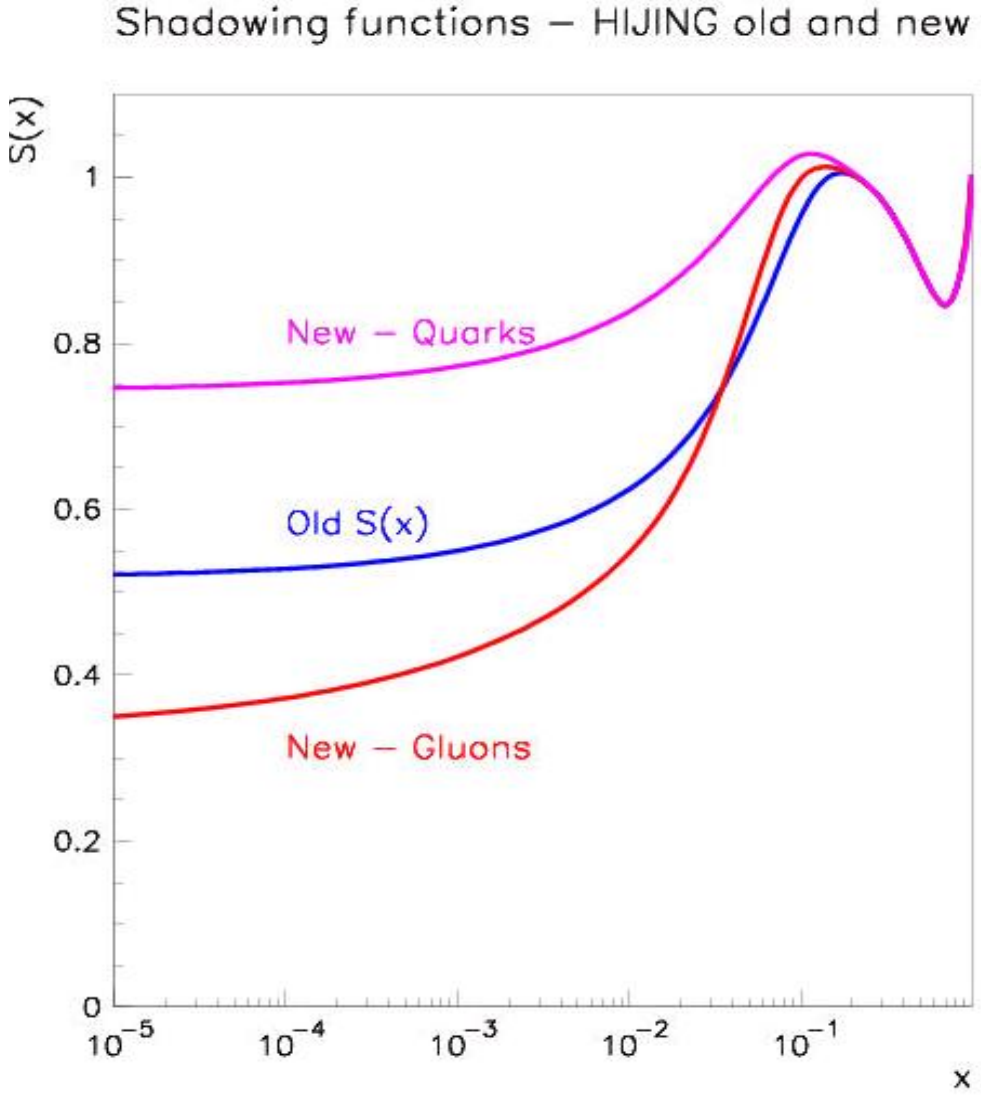
Fig. 2. Ratio of nuclear structure functions as measured in DIS. Solid lines are the new HIJING parameterization (Eq. (8)), dashed lines are the HKM parameterization [32] and dot-dashed lines are the old HIJING parameterization [16]. The data are from Ref. [30].

Shadowing effect in dAu collisions:

Effective <x> inside Au



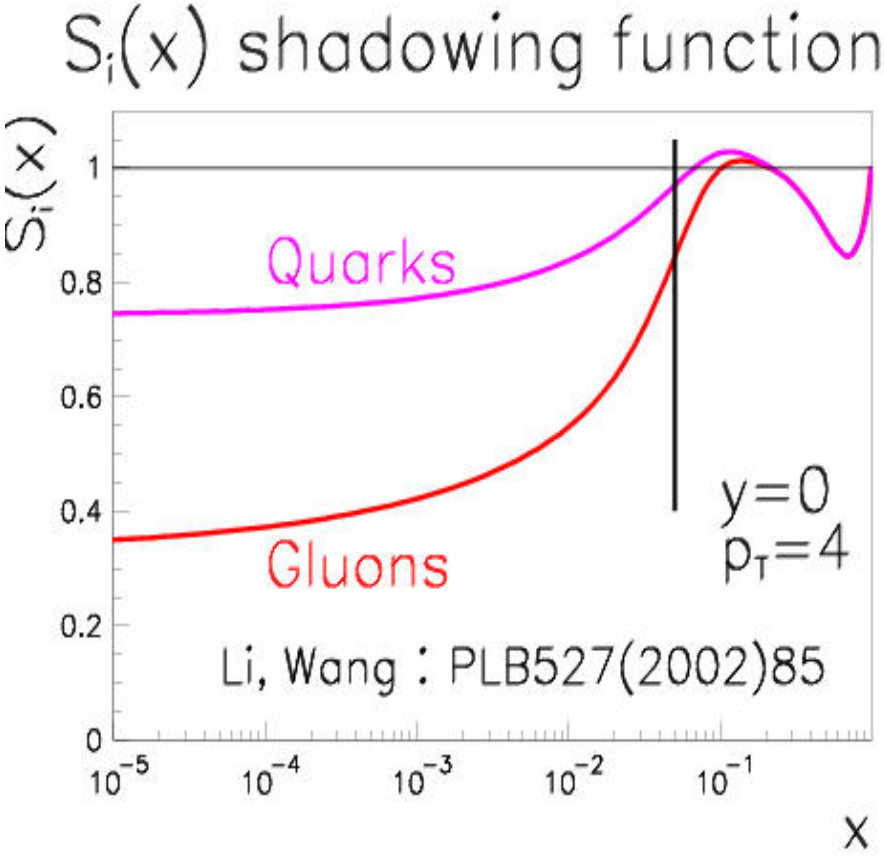
S(x): shadowing function



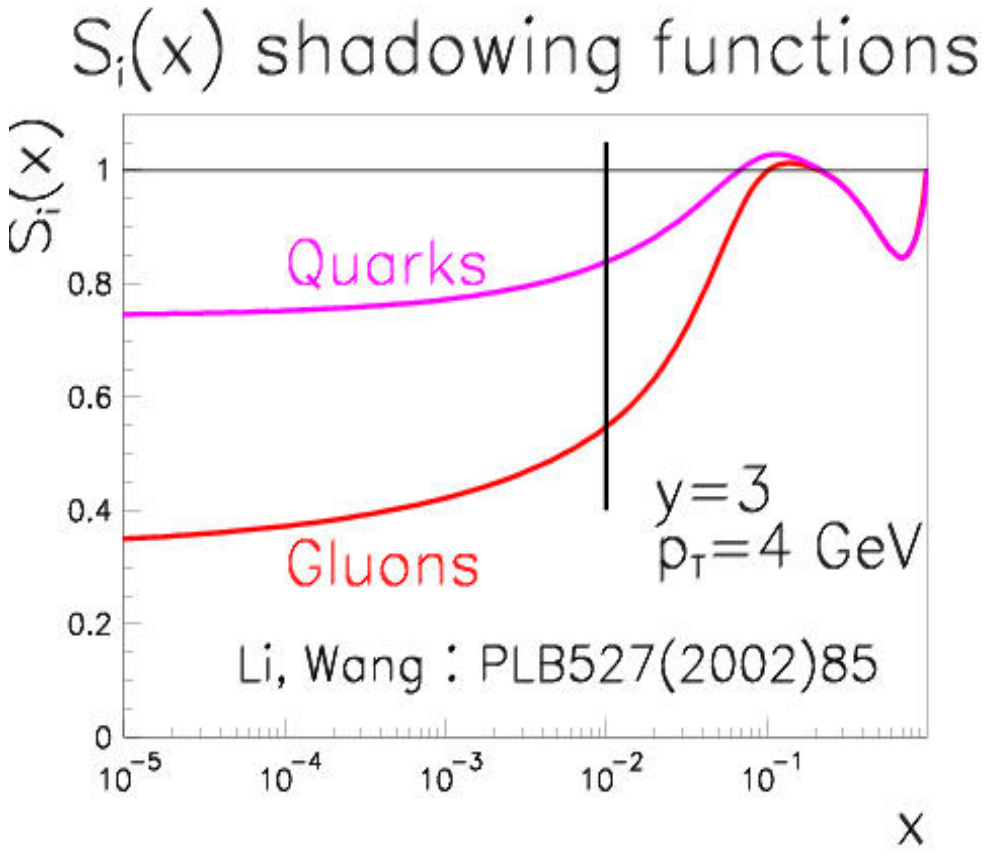
$X \rightarrow 0$: S(x) is small

Shadowing in dAu collisions:

S(x) at y=0 & p_T = 4 GeV

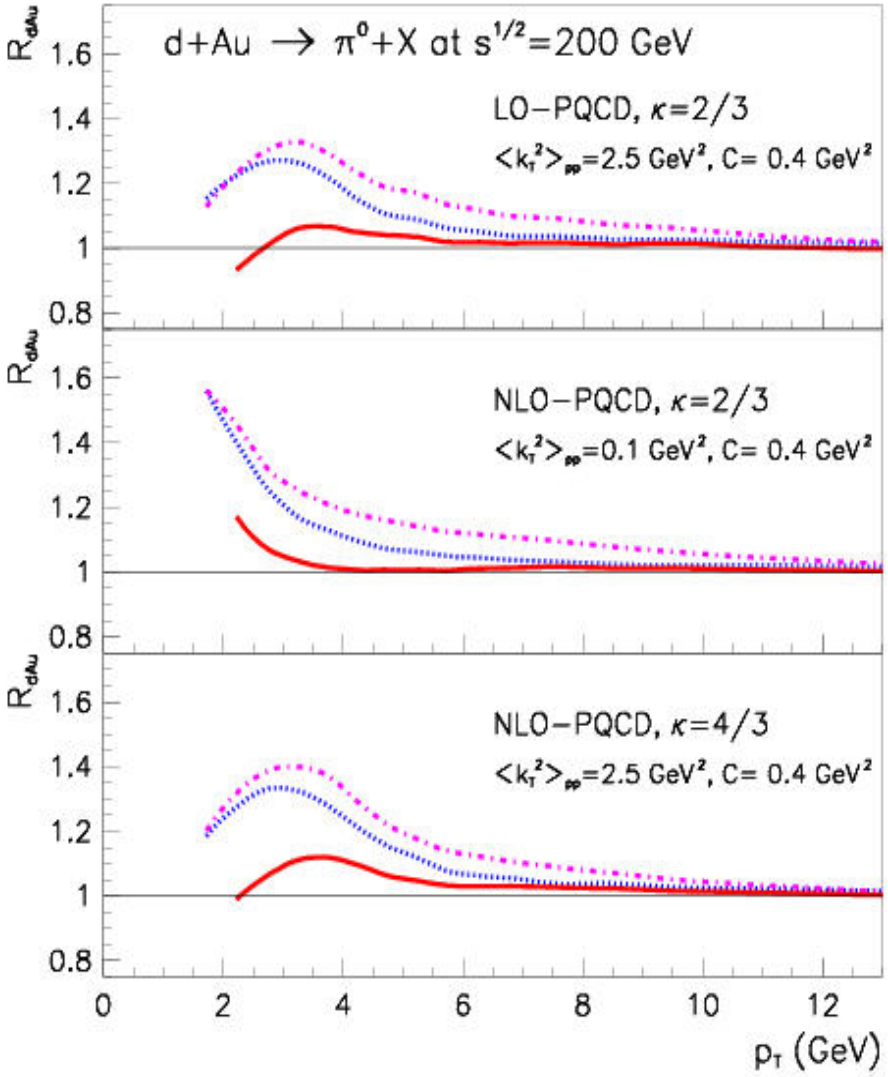


y=3 & p_T=4 GeV

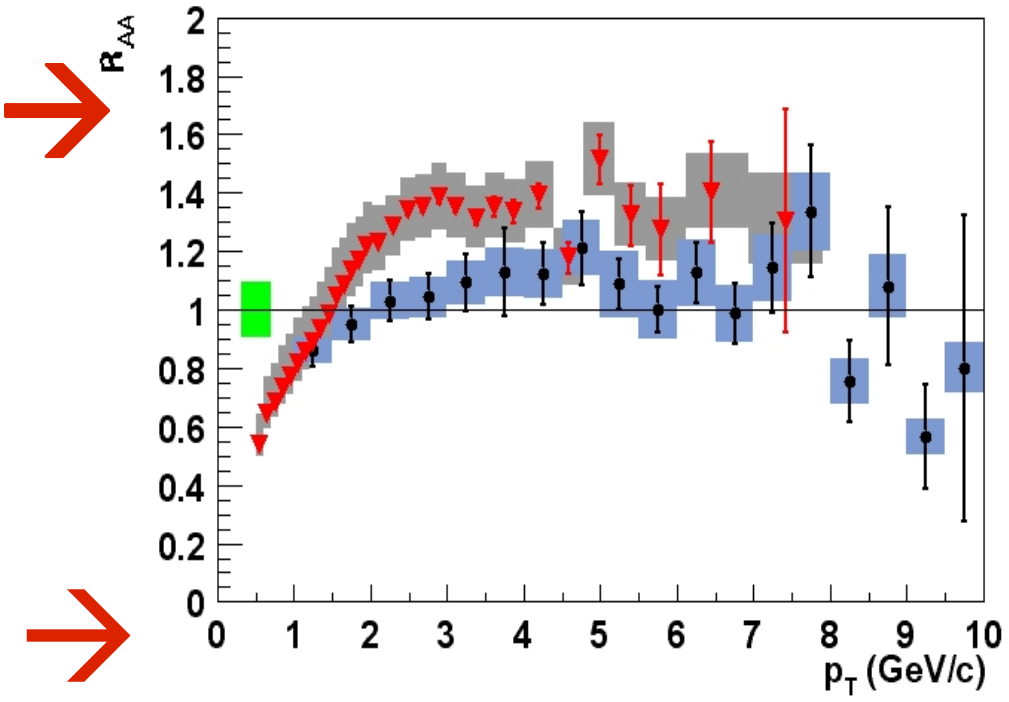


Hard physics: pion production in dAu collision at high- p_T

Perturbative QCD calculations in NLO for pp + CRONIN + SHADOWING (LI & XNW): + SHADOWING (EKS)



Data: PHENIX Coll., at AGS User Meeting'03

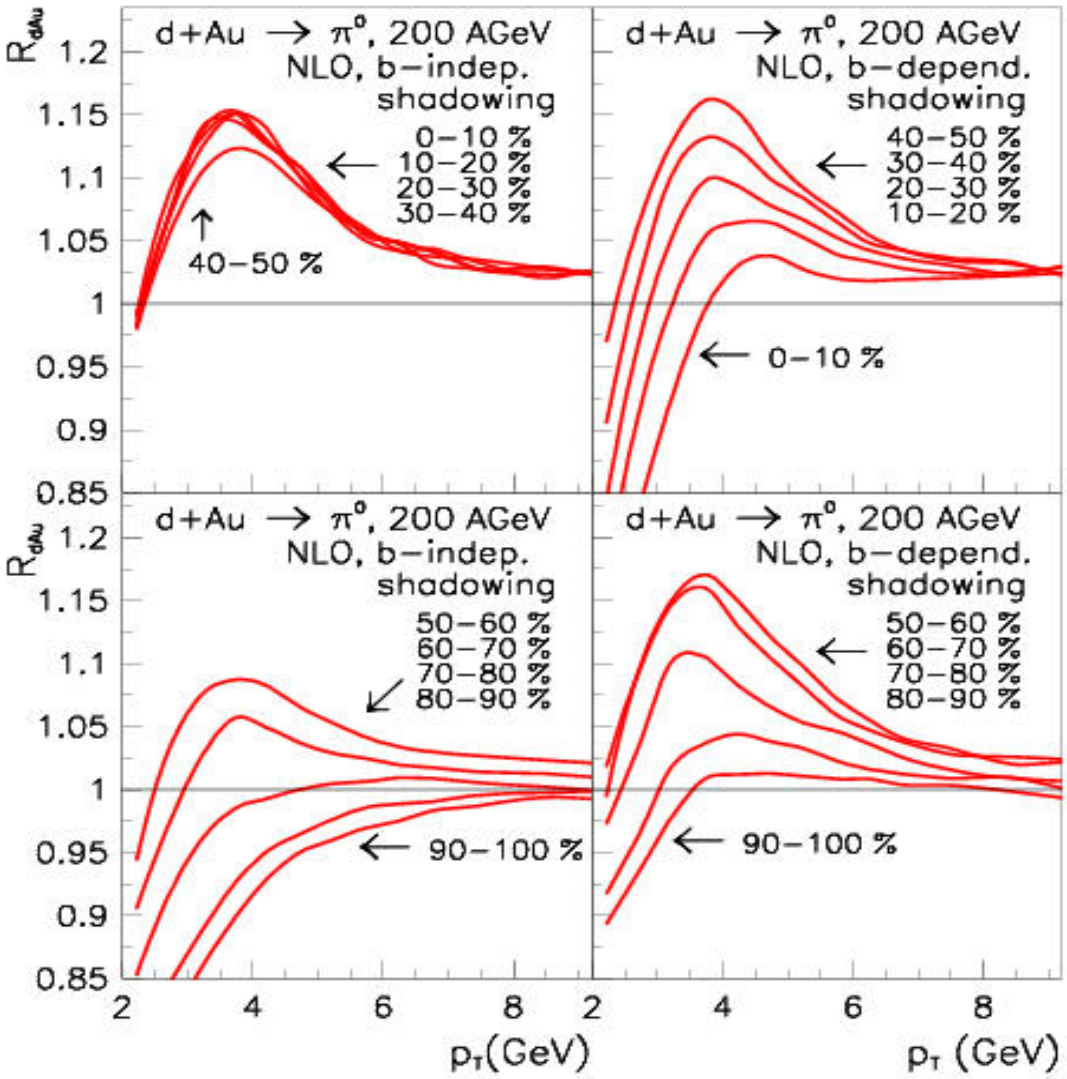


d+Au results can decide between good p+p parametrizations !!!!

(nucl-th/0306019)

Hard physics: pion production in dAu collision at high- p_T

Perturbative QCD calculations in NLO for pp + CRONIN + SHADOWING (LI & XNW):

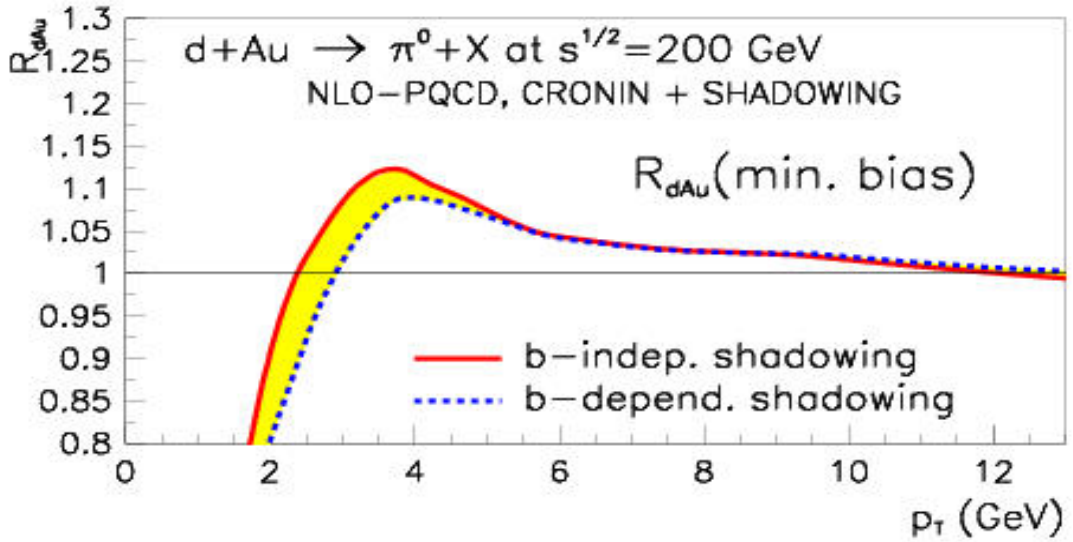


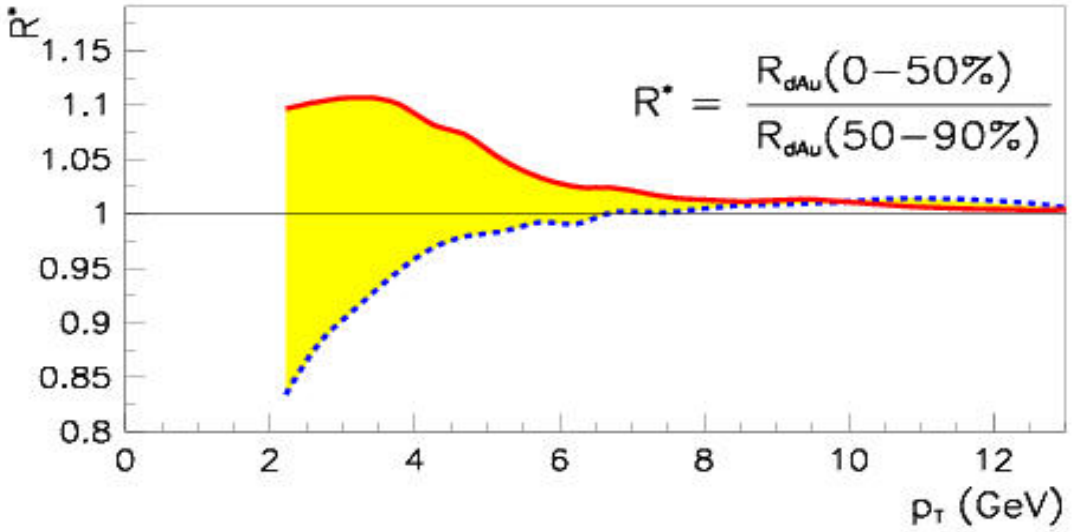
Centrality dependence of R_dAu:

Interplay between multiscattering and shadowing !

Hard physics: pion production in dAu collision at high- p_T

Perturbative QCD calculations in NLO for pp + CRONIN + SHADOWING (LI & XNW):





Min. bias R_{dAu} weakly depends on centrality dependences in S(x).

R* double ratio dependence is increasing at lower pT.

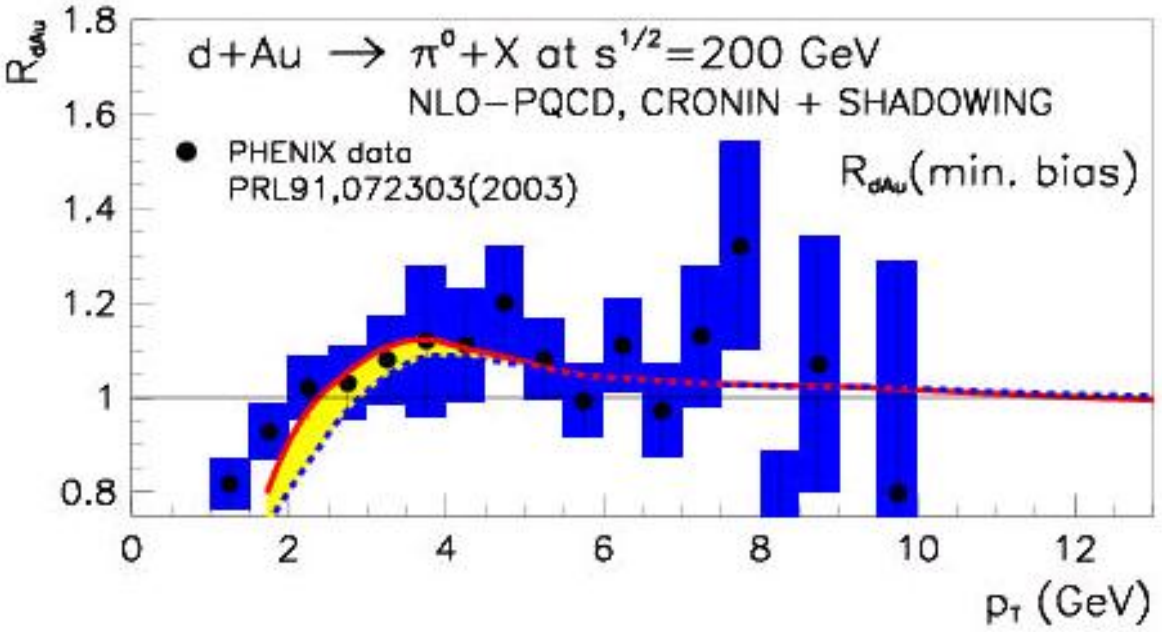
PHENIX data: R* ≈ 1 (± ? %)

Buesching, HQ06

(nucl-th/0306019)

Hard physics: pion production in dAu collision at high- p_T

Perturbative QCD calculations in NLO for pp + CRONIN + SHADOWING (LI & XNW):



- compared to early data from PHENIX on neutral pion

AGS-RHIC User Meeting May 2003

→ 18 June 2003

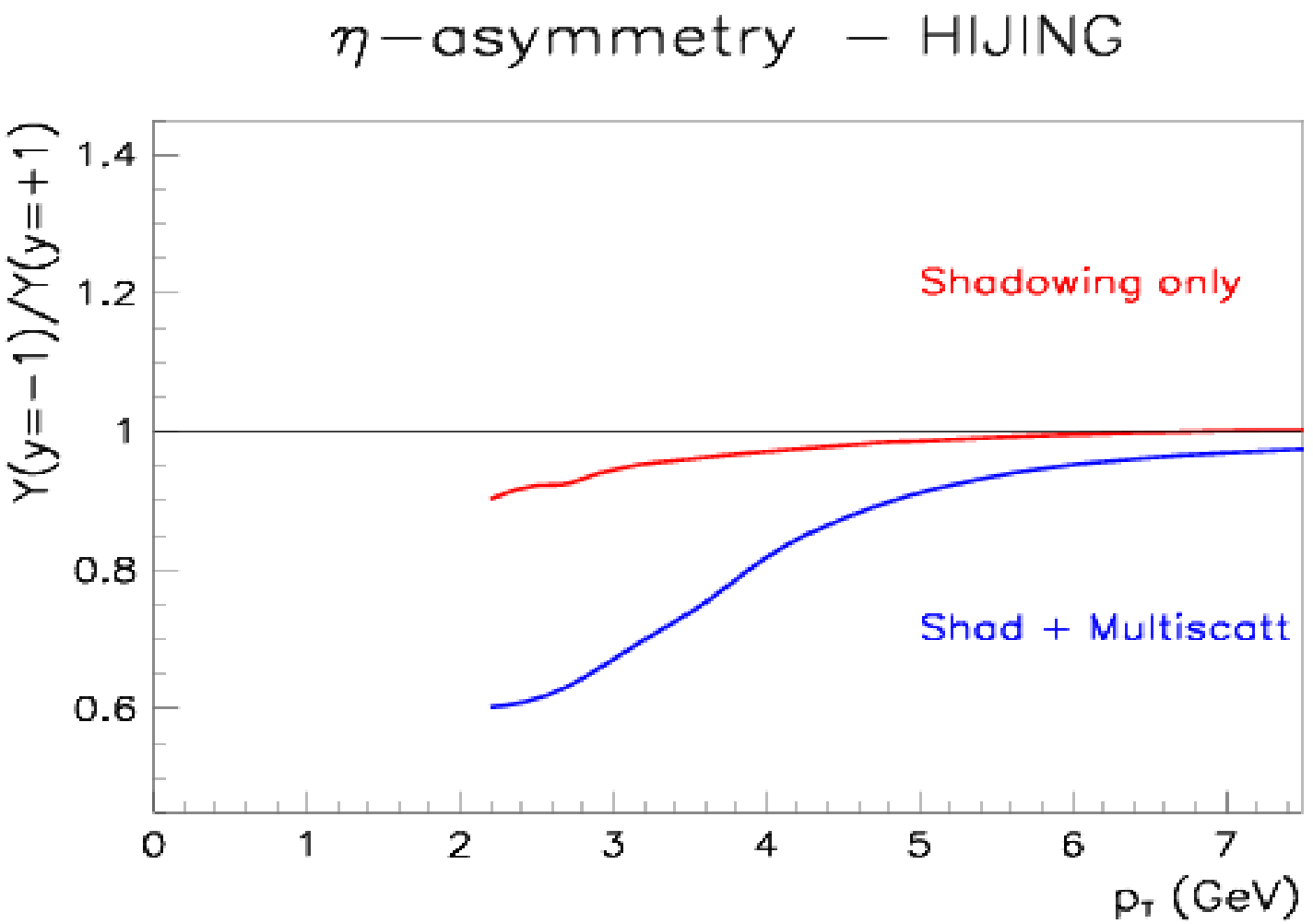
(II. Final data?)

The same multiscattering strength was used as at 27.4 GeV (Antreasyan data)
---- the multiscattering is assumed to be energy independent (C=0.4 GeV^2)

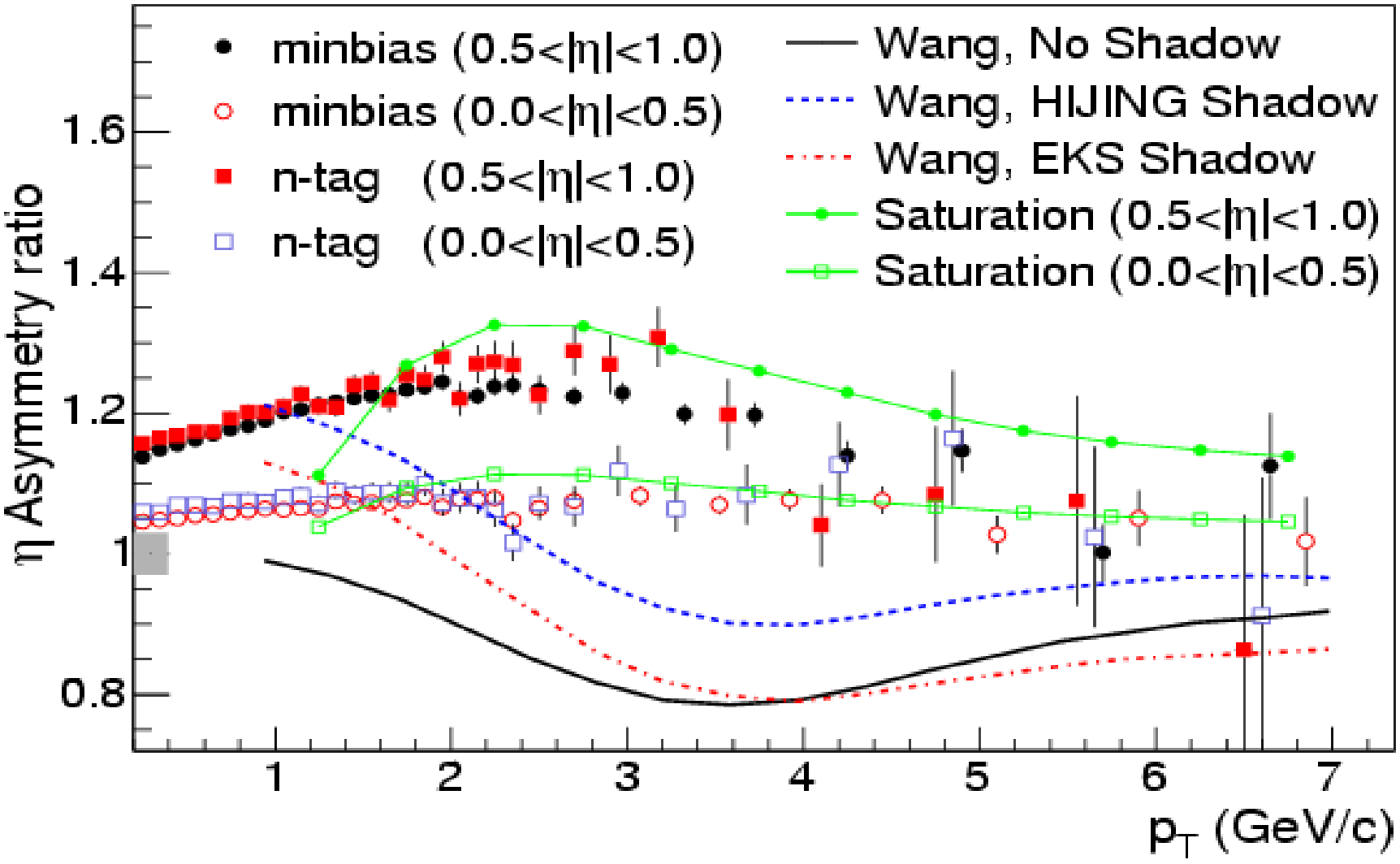
At η=0 there is no room for extra suppression (no CGC) !

WHAT ABOUT η-asymmetry ????

η-asymmetry in dAu collision (theory: y=-1 / y=+1):

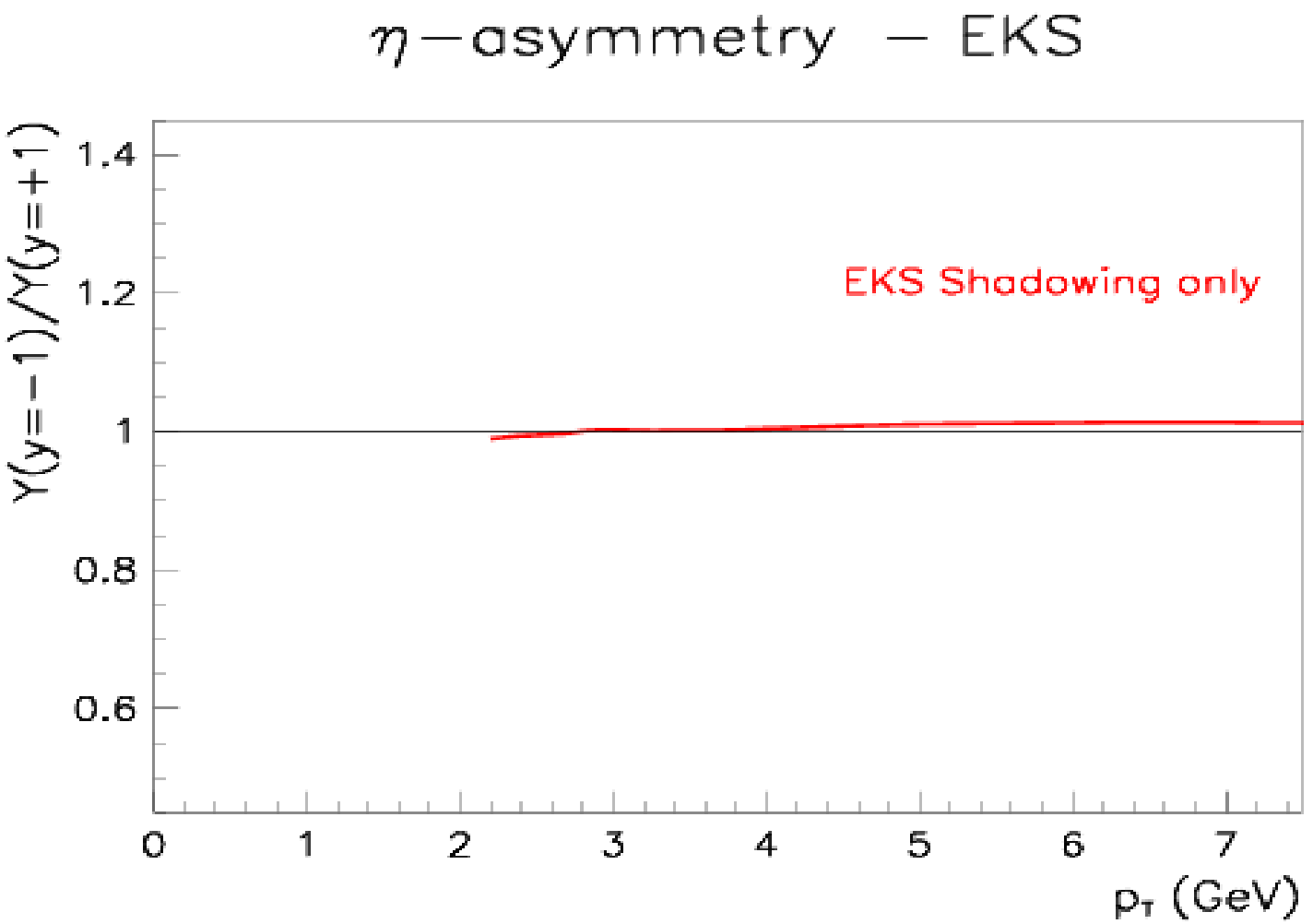


Pion production in dAu collision at high-pT



STAR data on η-asymmetry just show the opposite !
Multiscattering + Shadowing just seems to work
in the opposite way as data shows !

η-asymmetry in dAu collision (theory: y=-1 / y=+1):

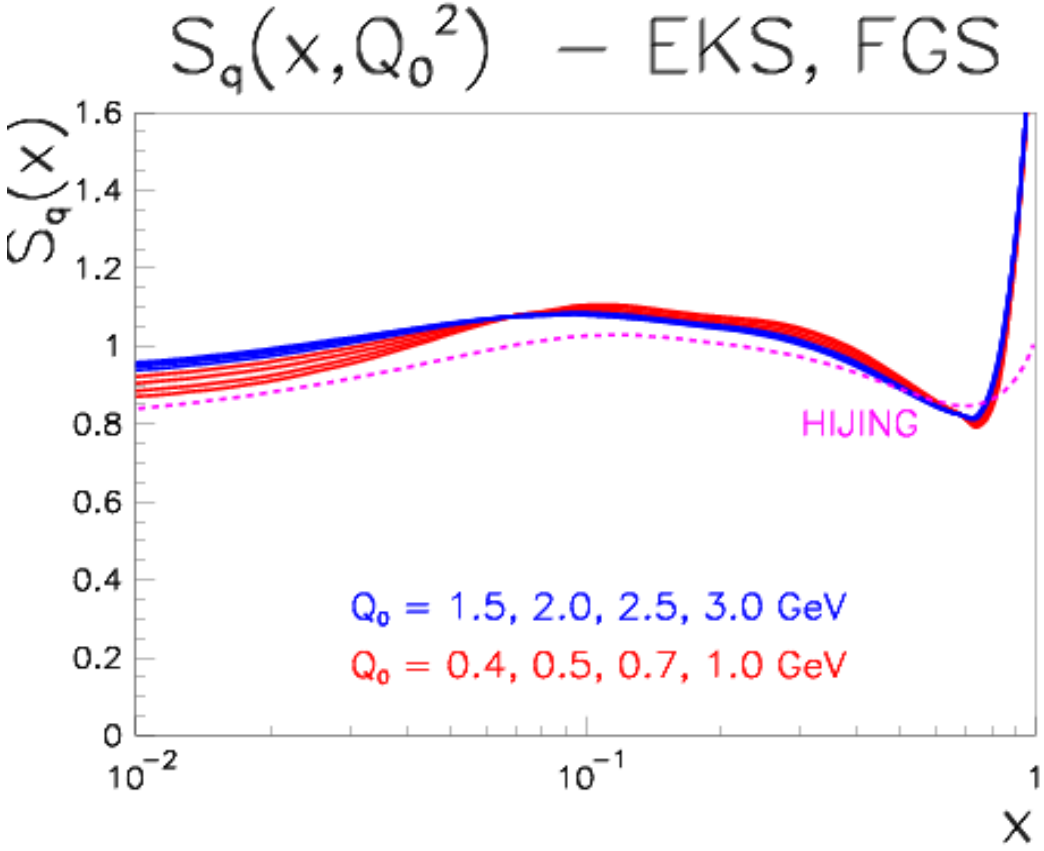


The presence of multiscattering would push the ratio under 1 !!

y< 0 less possibility for multiscattering (Au remnants)

y>0 more multiscattering of the partons from d on Au target

EKS shadowing function with enhanced antishadowing



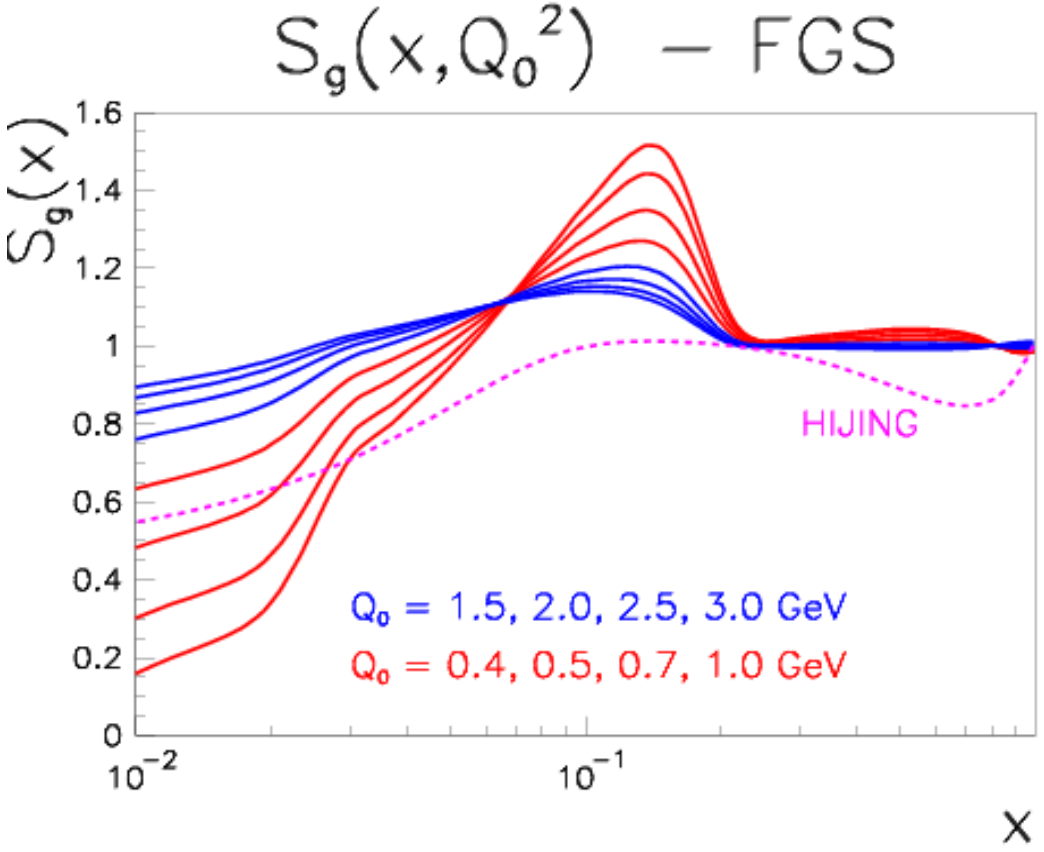
K.J. Eskola,
V.J. Kolhinen,
C.A. Salgado

EPJ C9, 61 (1999)

EKS: antishadowing effect for valence quarks

stronger than HIJING

FGS shadowing function with extra leading twist effect for gluons

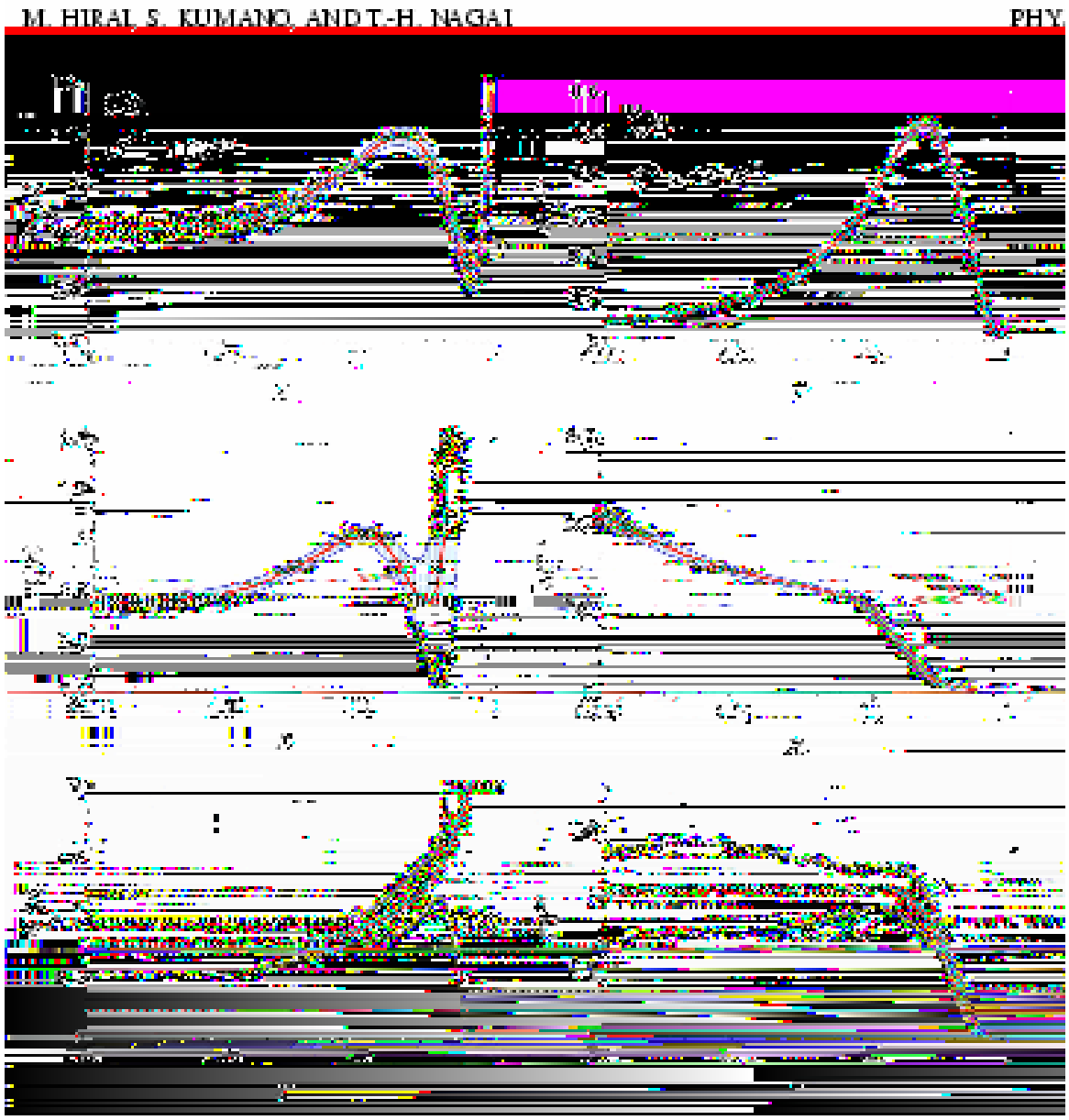


L. Frankfurt,
V. Guzey,
M. Strikman

hep-ph/0303022

EKS antishadowing effect for valence quarks + extra yield for gluons from leading twist ($Q_0^2 > 4$ GeV^2)

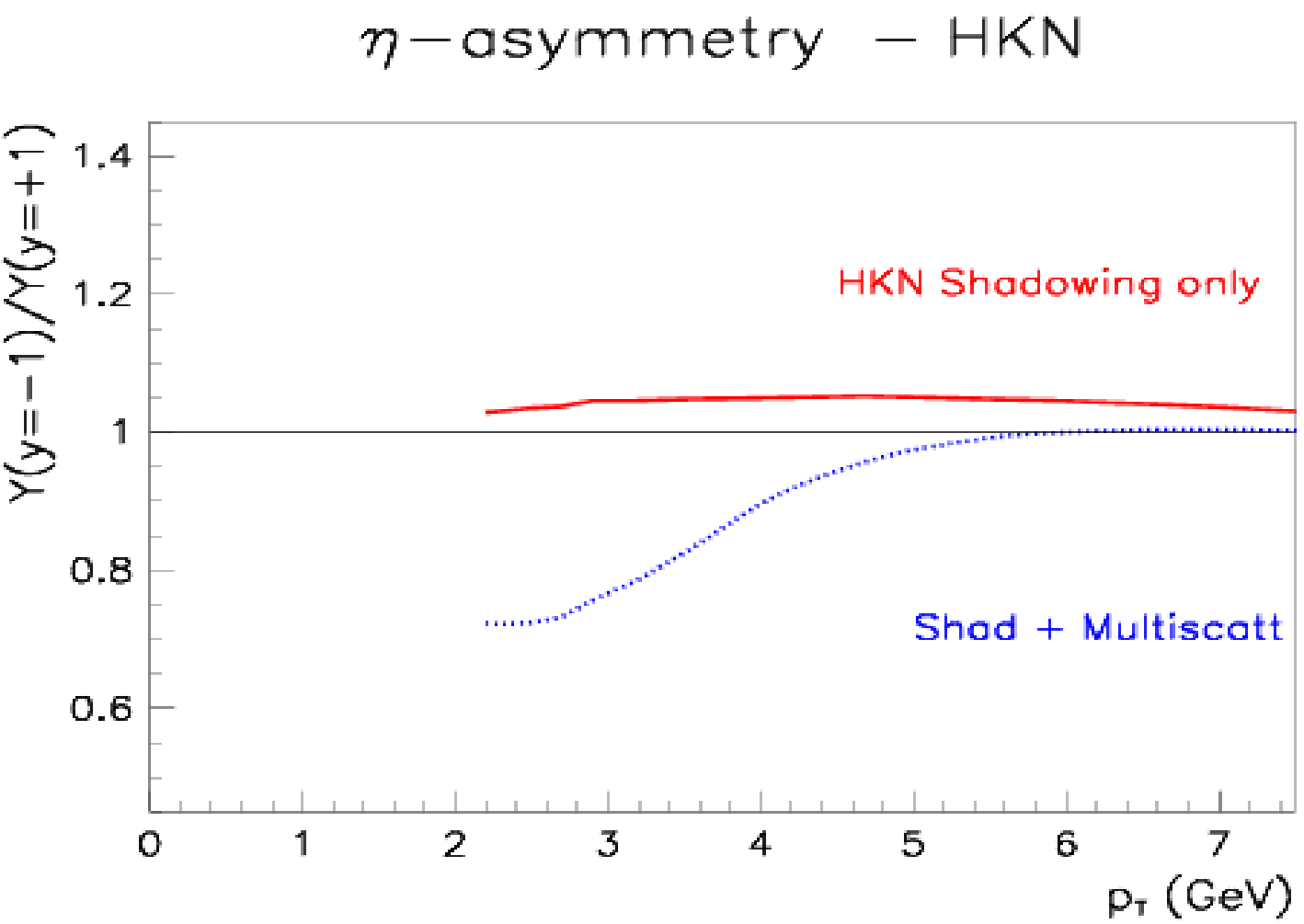
HKN shadowing function with strong antishadowing



Phys. Rev. C70, 044905 (2005)

Antishadowing effect for valence quarks and for gluons

η-asymmetry in dAu collision (theory: y=-1 / y=+1):

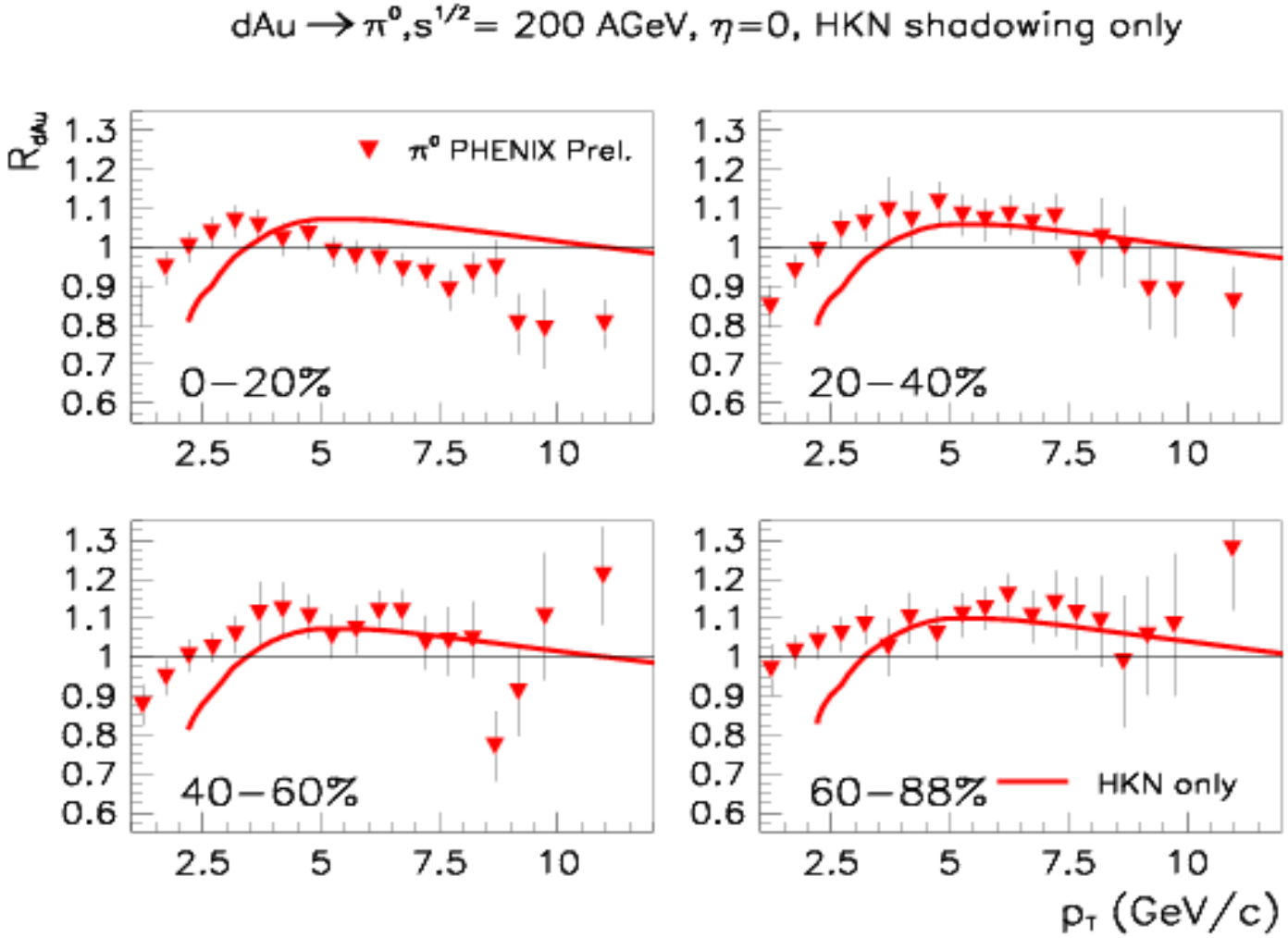


"HKN Shadowing only" works well (+ 5-7 %)

Extra multiscattering would decrease the ratio again !!!!

Even more antishadowing can be accomodated by the STAR data !!

What about the PHENIX data on centrality dependence with HKN?

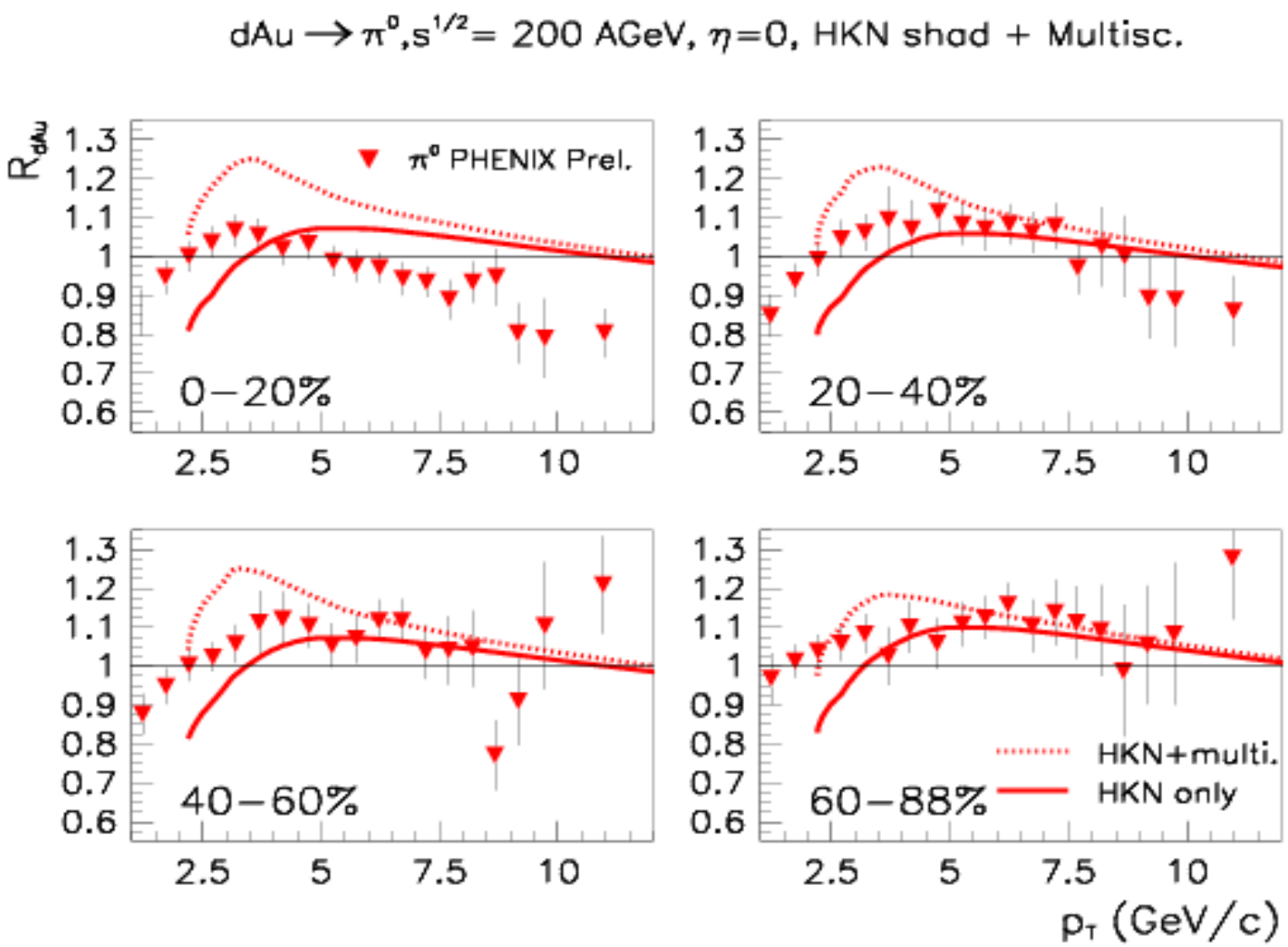


Not bad – but not very good

--- some b-dependence is missing (no multiscatering)

--- what about more antishadowing (mimicking by multiscat.) ?

[STAR data could accommodate it !]



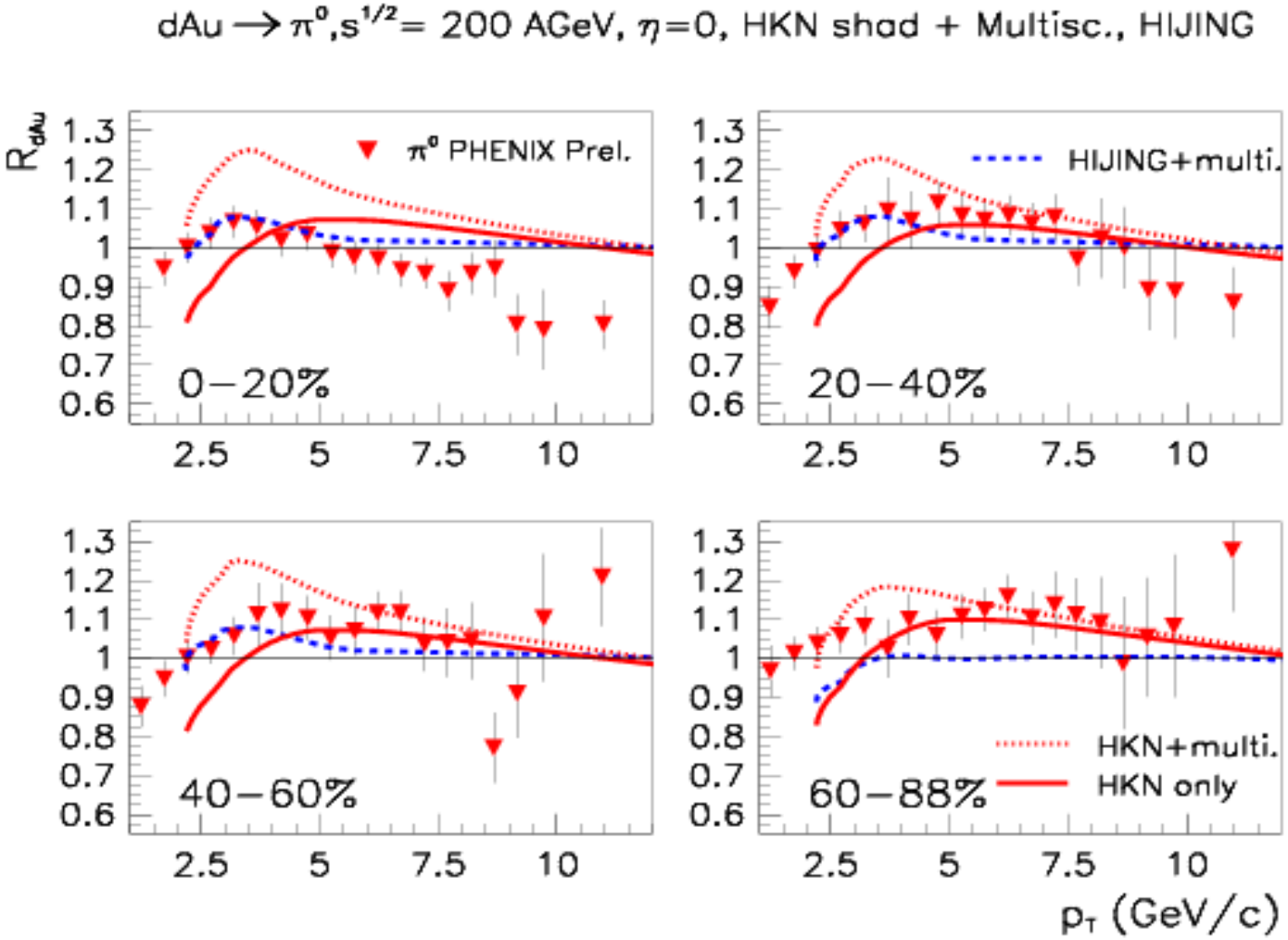
Peripheral cases are good, but with less "antishadowing".

Central collisions: clean overshoot

But slope is remarkably GOOD !

Quenching on cold matter can be included, -15 % !

How cold quenching is working at y=- and at y=+1 ?



What about previous HIJING results?

Clear disagreement in the central collisions at $p_T > 6$ GeV .

in very peripheral case for all p_T .

"No antishadowing + strong multiscattering" does not work !

Recent dAu data at RHIC energies
motivate the modification of our picture

Proton PDF + Binary scaling → Nuclear PDF
Binary collisions → ???
("reaction dependence" ??
very bad news !)

Energy dependence → SPS/FERMILAB energy
low RHIC energies
high RHIC energies

High precision dAu results are needed at 200 AGeV
New (measurable) signatures should be found

What about high rapidities ?
Testing the new description of mid-rapidity data.

Summary:

1. dAu data are excellent (clean) probes to fix

-- pQCD descriptions (scales, ...)

-- nuclear shadowing functions

-- multiscattering mechanisms (if they present at all)

2. Shadowing + multiscattering picture (CRONIN-peak)

-- was working well at SPS and FERMILAB energies;

-- seems to fail at highest RHIC energies.

Is there a transition at an intermediate RHIC energy?

[Au target behaves as a 'sticky' matter beyond a threshold?]

What about η-asymmetry between SPS and RHIC?

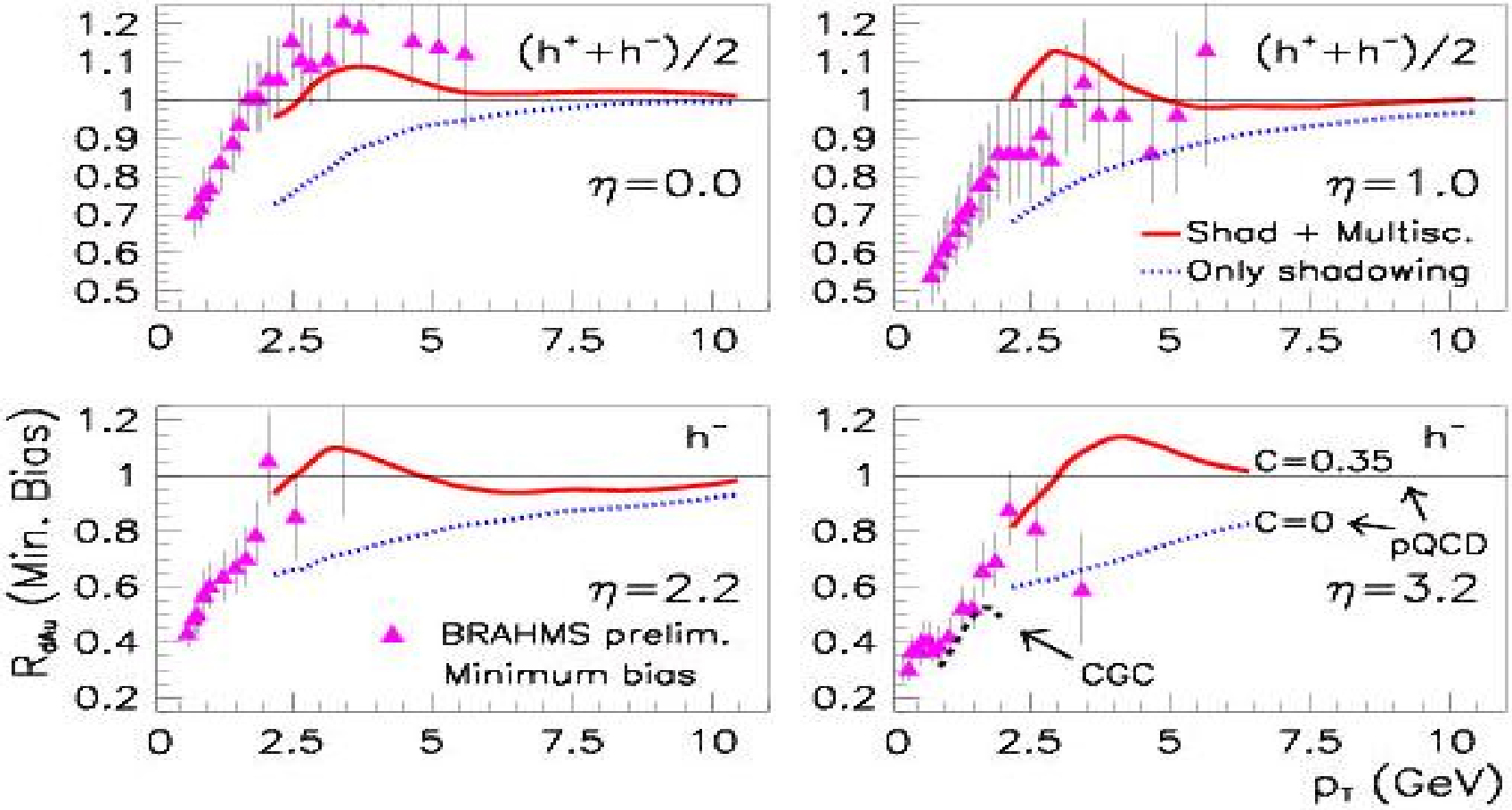
3. Application of Nuclear PDF is needed at RHIC energies.

Baseline (no quenching R_{AA}) may vary !

What about Glauber scaling in this case? $[R_{AA}(\gamma)]$

Hard physics: pion production in dAu collision at high- p_T

Perturbative QCD calculations in NLO for pp + CRONIN + SHADOWING (LI & XNW):

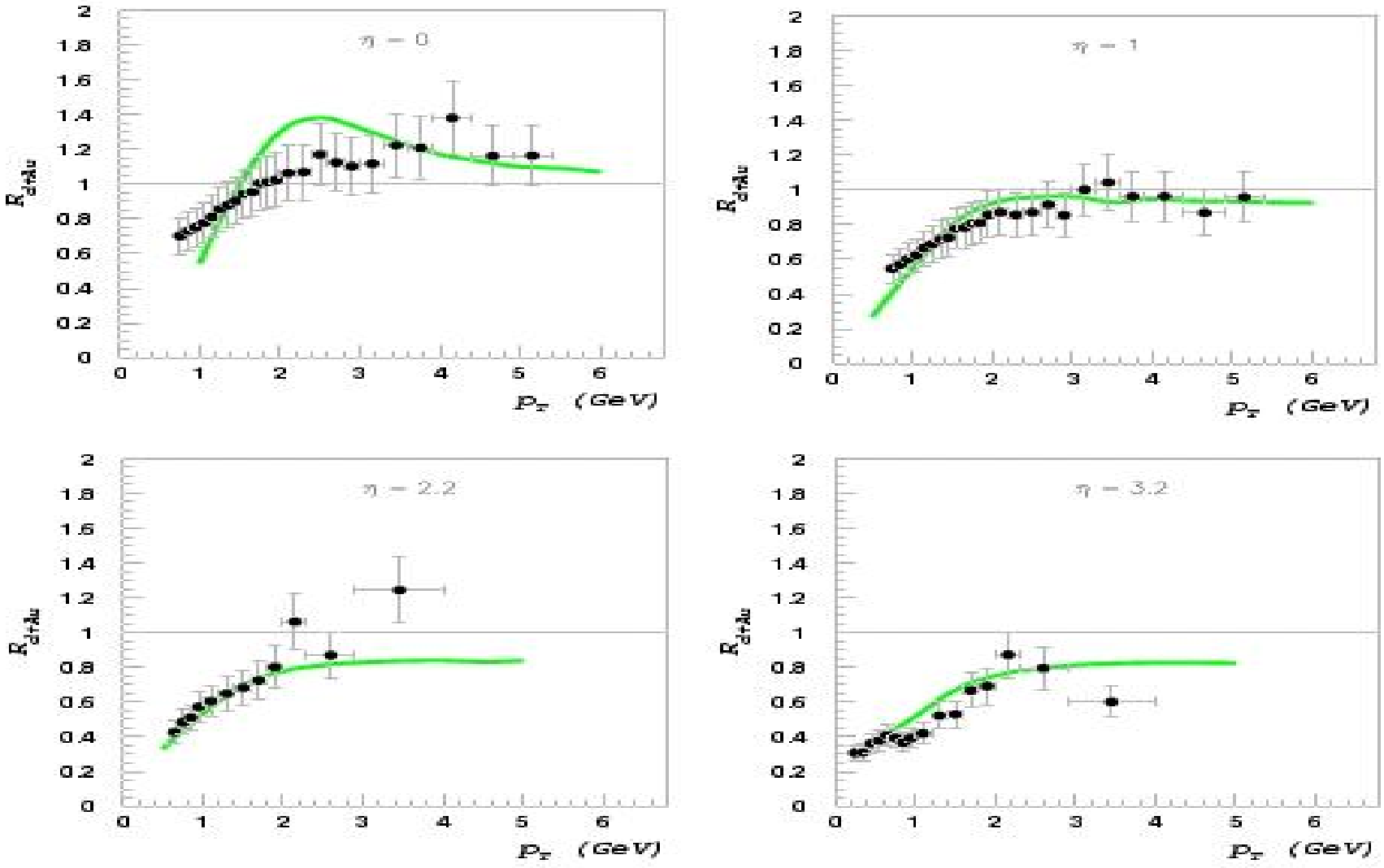


G.G. Barnafoldi, G. Papp, P.L, G. Fai , J. Phys. G. 30 (2004) 1125

At η= 0 - 3 standard pQCD seems to be all right at pT > 2 GeV !

Hard physics: pion production in dAu collision at high- p_T

CGC scenario for dAu collisions:



D. Kharzeev, Yu. Kovchegov, K. Tuchin (PLB599,2004,23)