Nuclear effects in pA

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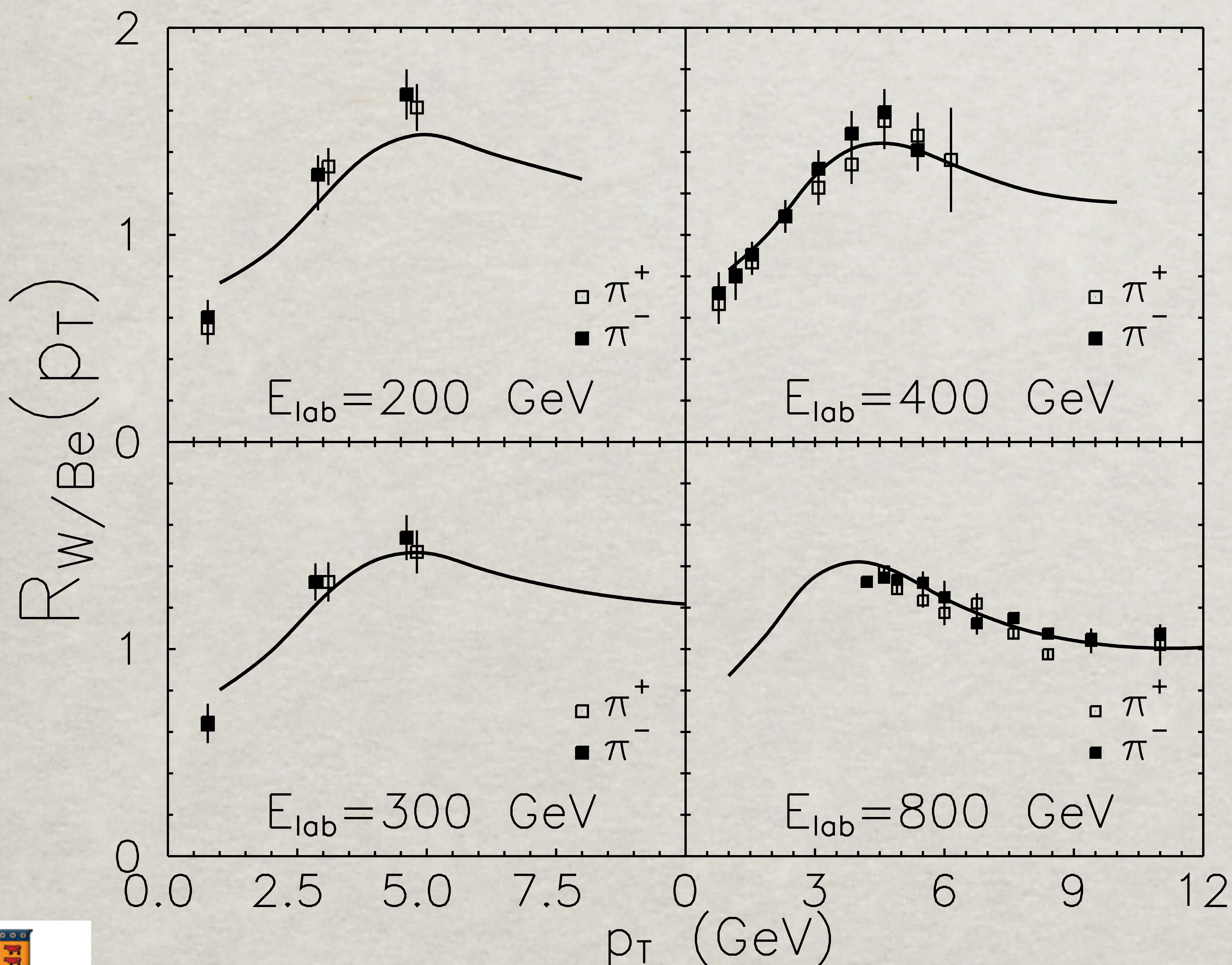
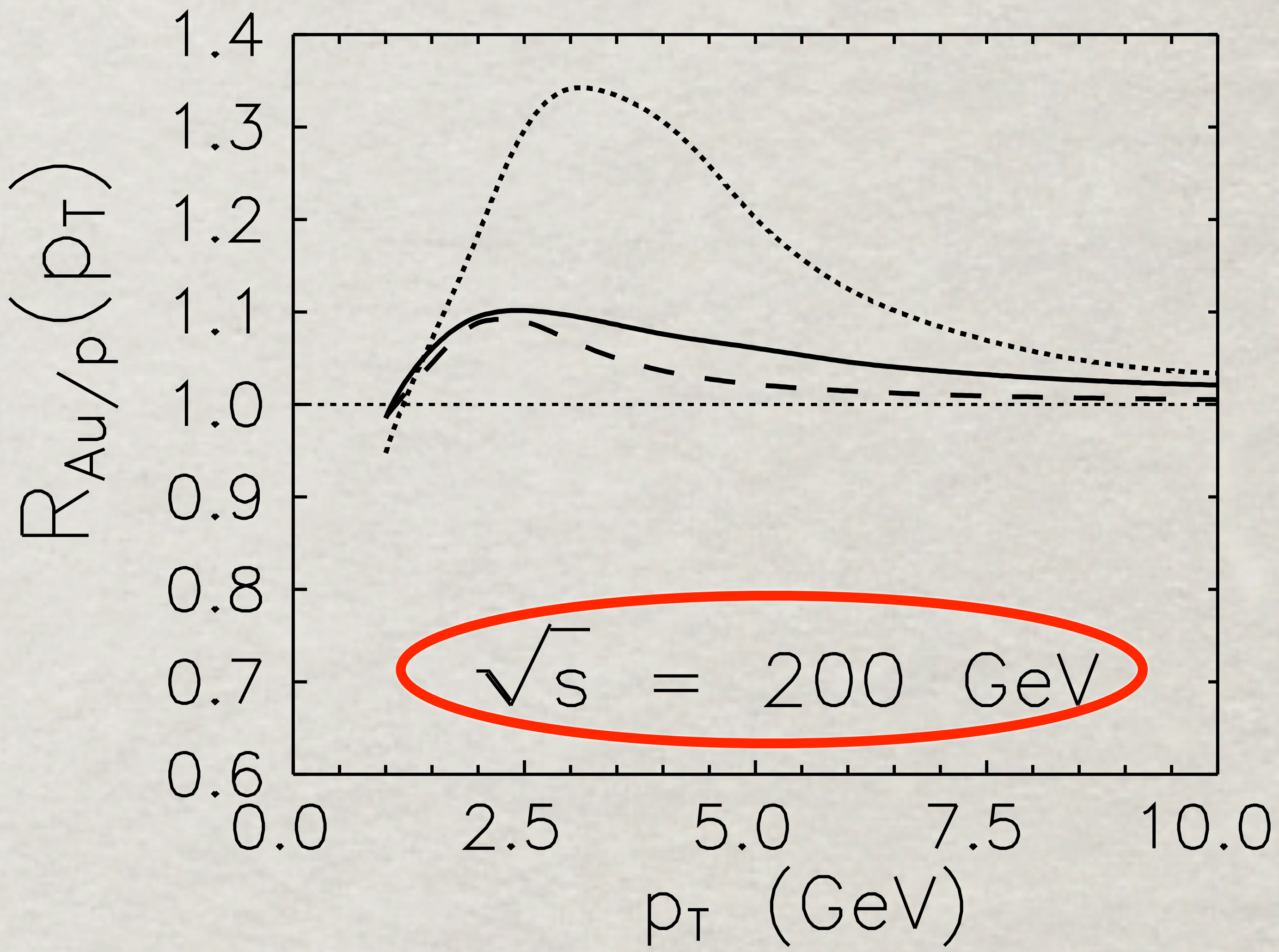
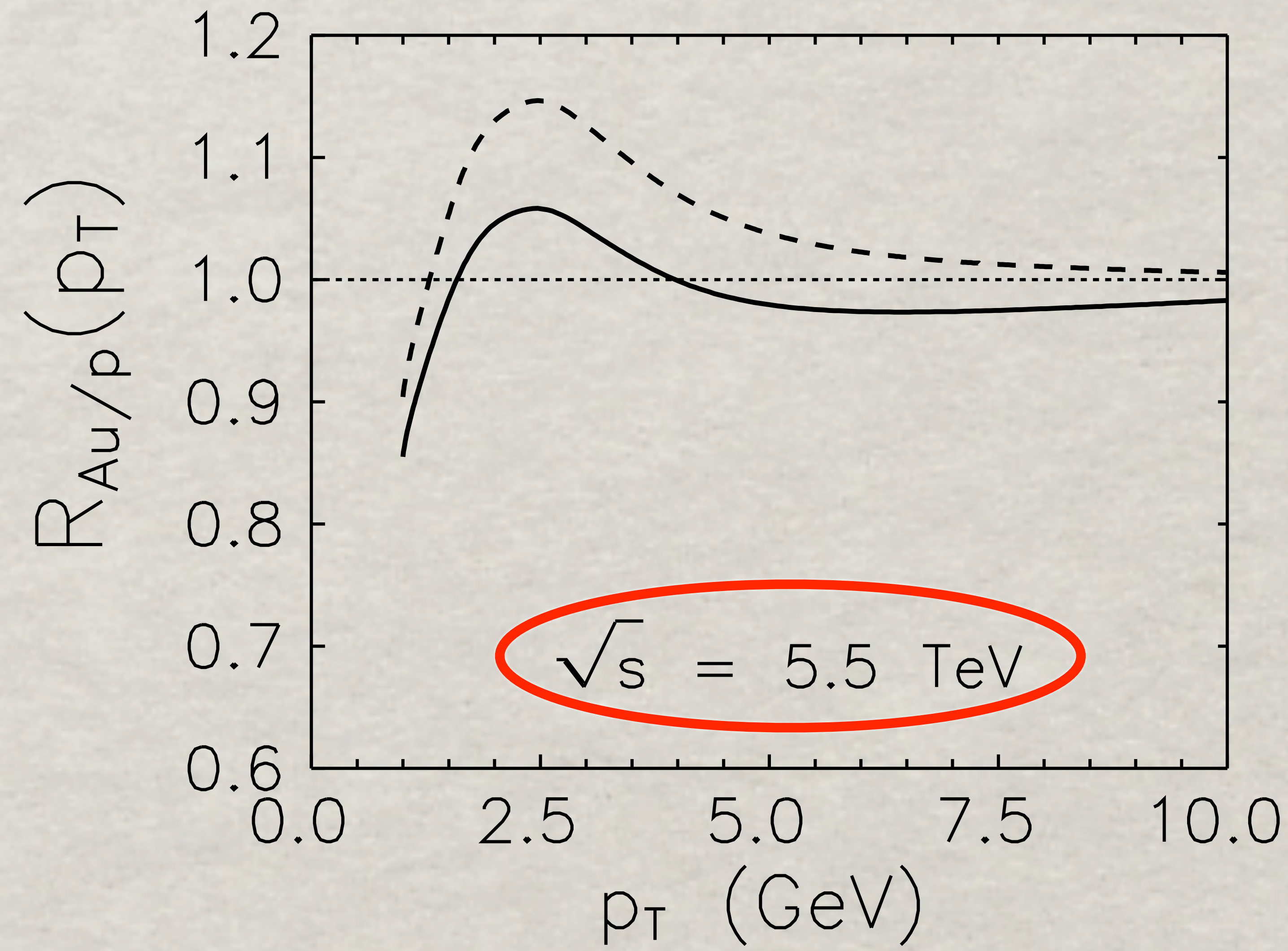
Cronin effect

High-pT hadrons can be produced coherently from multiple interactions in nuclei at very high energies (LHC), but not at low energies of fixed target experiments. Correspondingly, the mechanisms for the Cronin enhancement are different.



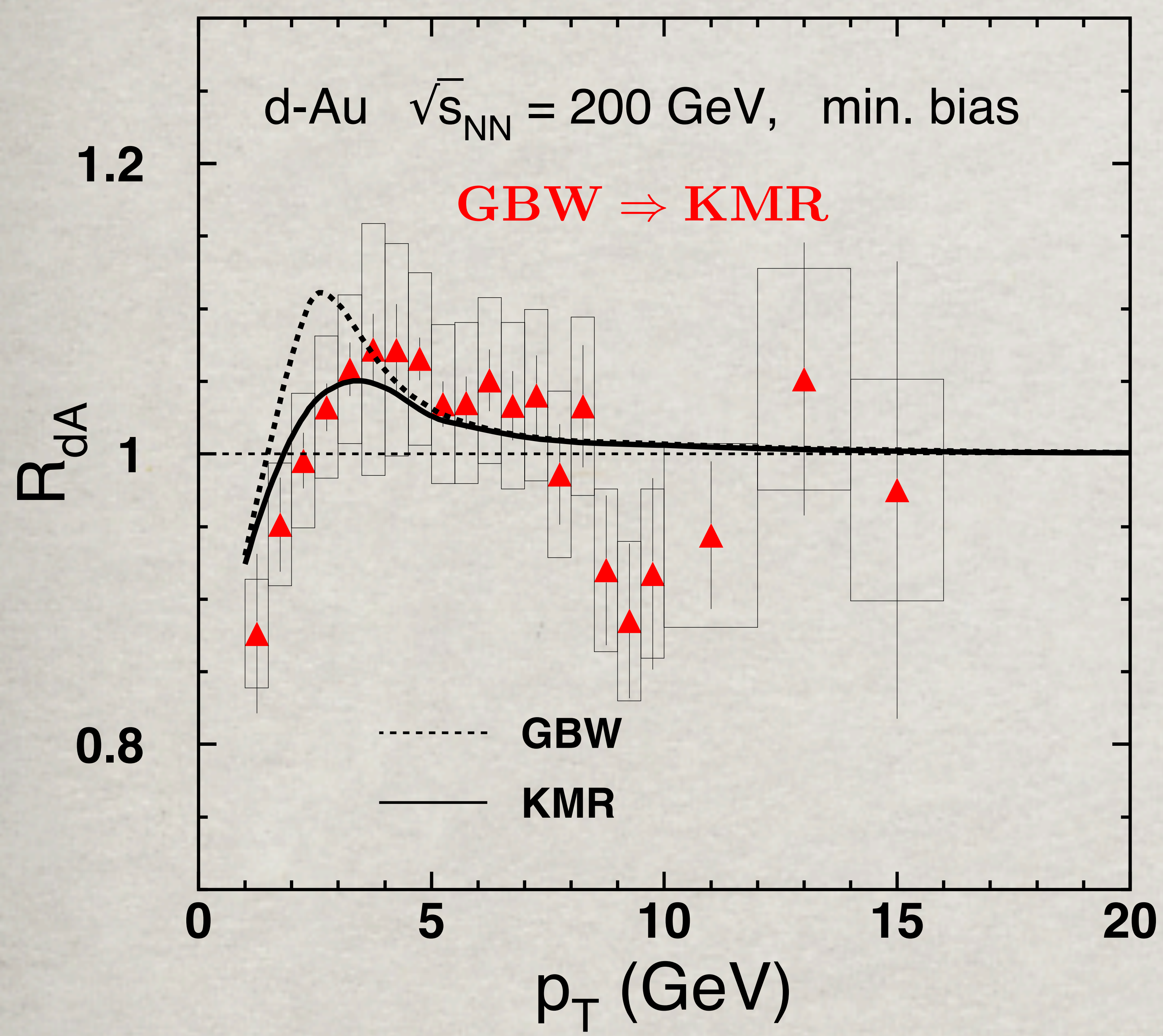
B.K., J.Nemchik, A.Schafer, A.Tarasov, PRL 88(2002)232303





Cronin effect at RHIC: predicted and observed

The predicted magnitude was OK, but the shape was not. The employed unintegrated gluon density of K.J.Golec-Biernat & M.Wustoff, 1999 (GBW) peakes at too small pT.

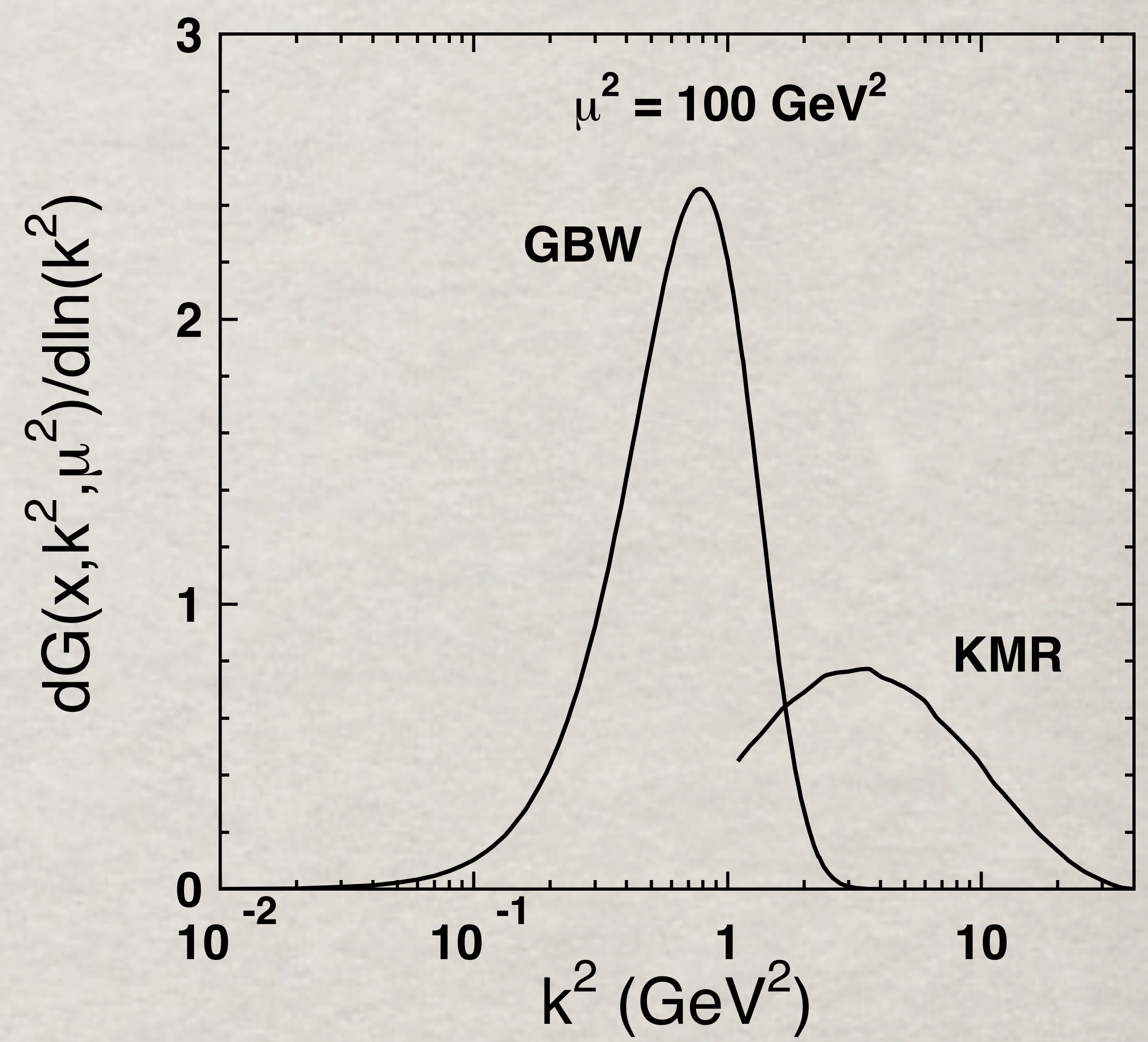


More realistic parametrization for the unintegrated gluon distribution proposed later,

M.Kimber, A.Martin & M.Ryskin, 2001 (KMR)

A.Martin, M.Ryskin & G.Watt, 2010

improves the shape (with no other modifications in the computing code).

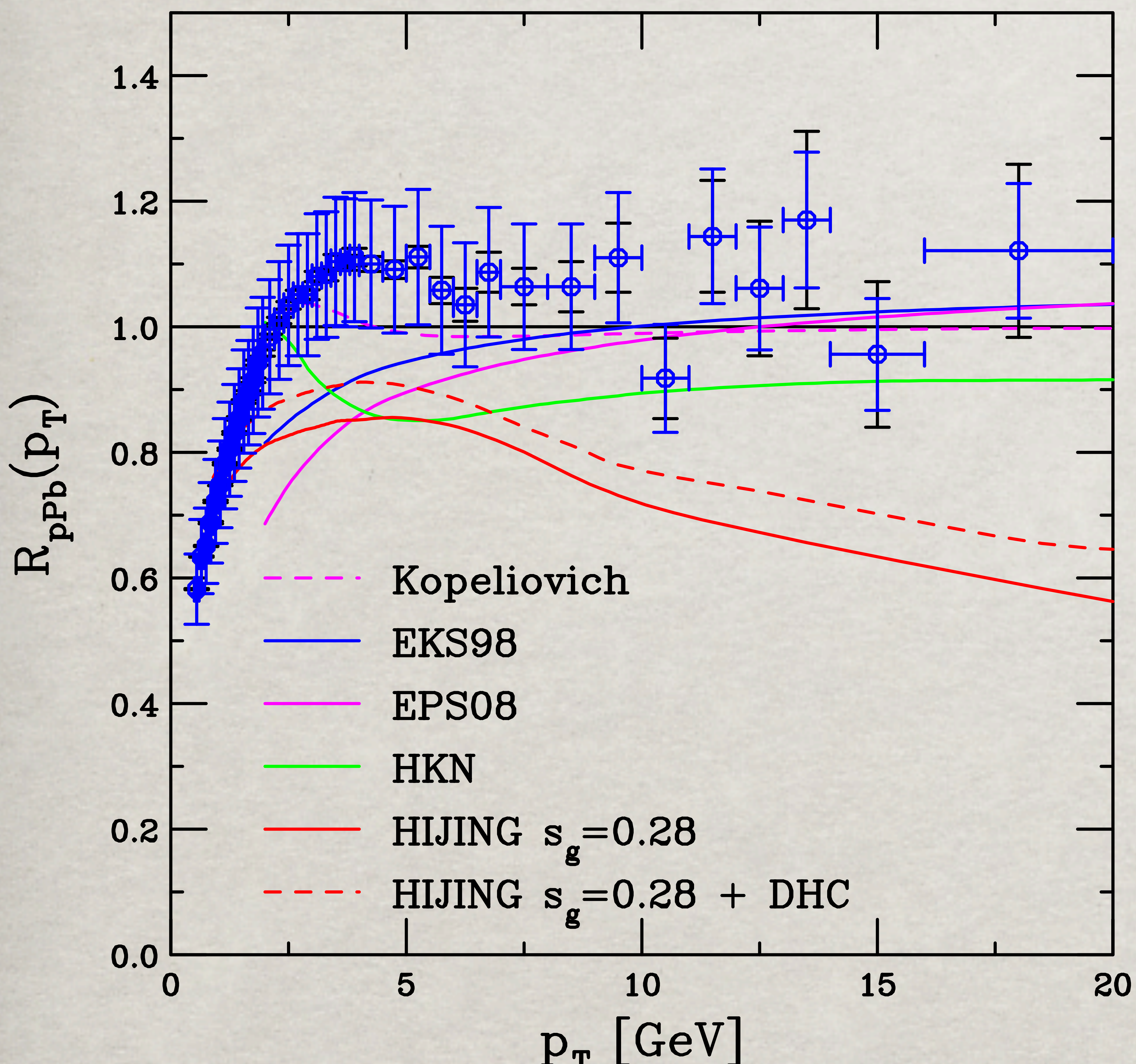


D.Kharzeev, E.Levin,L.McLerran, PL B561(2003)93:

Color Glass Condensate models exaggerated the magnitude of the coherence effects predicting a sizable suppression $R_{dA} = 0.75$

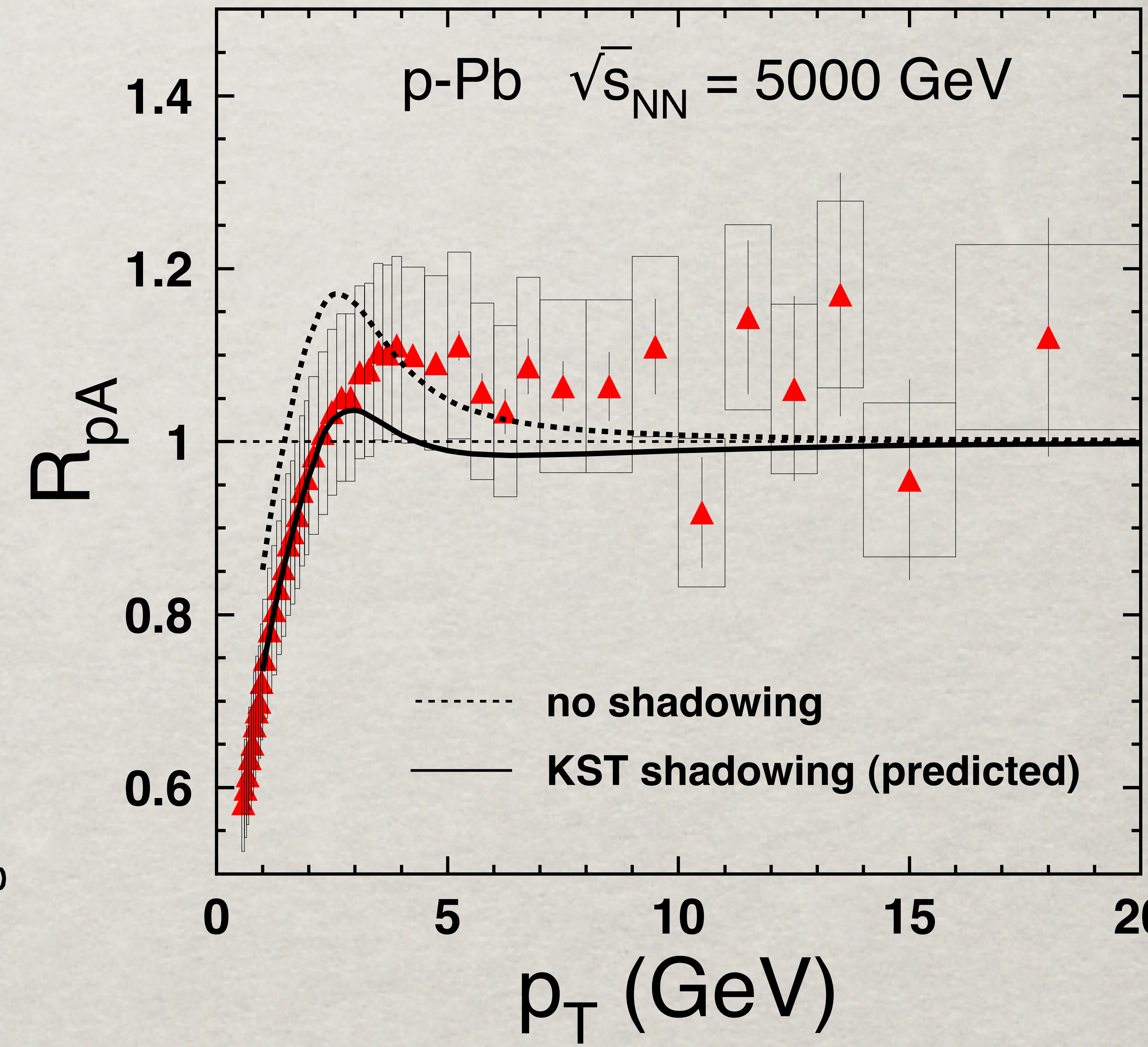
Cronin effect at LHC: predicted and observed

R.Vogt et al, arXiv: 1301.3395



The first successful prediction

B.K., J.Nemchik, A.Schafer, A.Tarasov (2002)



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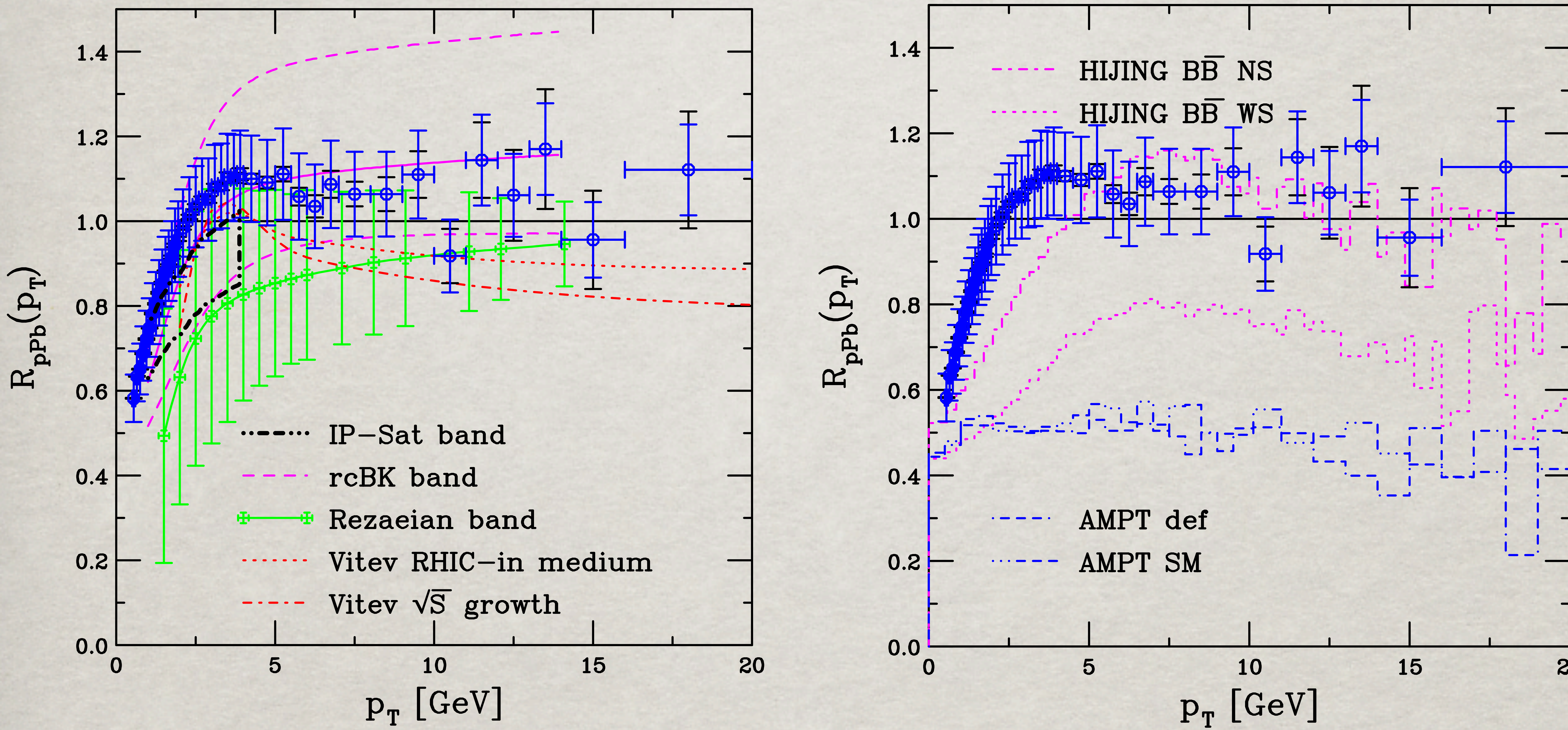
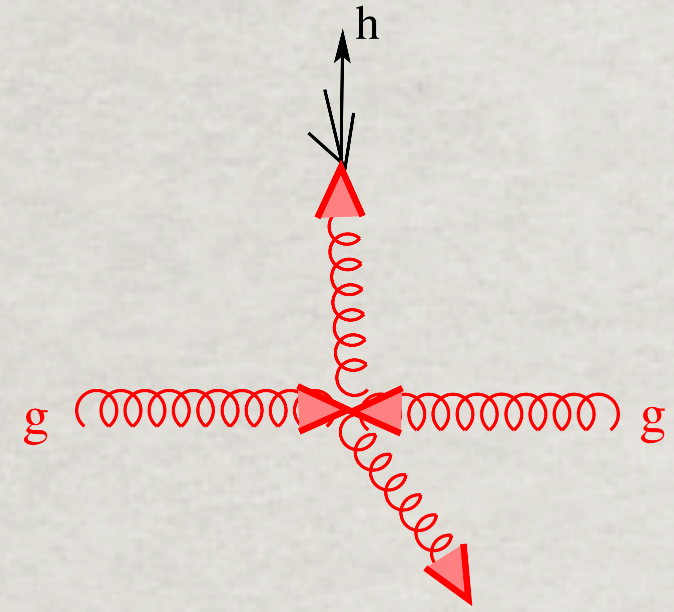
Predicted vs measured

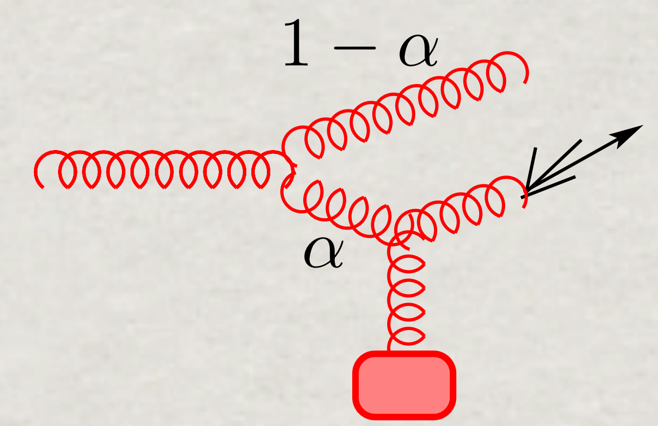


Not successful either

Details

parton model





dipole description

$$\frac{\mathbf{d}\sigma^{\mathbf{N(A)}}_{\mathbf{g\to 2g}}(\alpha,\mathbf{x_2})}{\mathbf{d^2k_T\,dy}} = \int \mathbf{d^2r d^2r'}\, \mathbf{e^{ik_T(r-r')}} \left\langle \mathbf{\Psi^\dagger_{gg}(r,\alpha)\Psi_{gg}(r',\alpha)} \right\rangle \mathbf{\Sigma^{N(A)}_{3g}(r,r',\alpha,x_2)}$$

$$\Sigma^{N(A)}_{3g}(\vec{r},\vec{r}\,',\alpha,x_2) = \begin{cases} \sigma^N_{3g}(r,\alpha)+\sigma^N_{3g}(r',\alpha)-\sigma^N_{3g}(\vec{r}-\vec{r}\,',\alpha); & \textbf{(pp)} \\ 2\int d^2b\left[1-e^{-\frac{1}{2}\sigma^N_{3g}(r,\alpha)T_A(b)}e^{-\frac{1}{2}\sigma^N_{3g}(r',\alpha)T_A(b)}+e^{-\frac{1}{2}\sigma^N_{3g}(\vec{r}-\vec{r}\,',\alpha)T_A(b)}\right] & \textbf{(pA)} \end{cases}$$

$$\sigma^N_{3g}(r,\alpha) = \frac{9}{8}\Big\{\sigma_{\bar{q}q}(r)+\sigma_{\bar{q}q}(\alpha r)+\sigma_{\bar{q}q}[(1-\alpha)r]\Big\}$$

$$\Psi_{gg}(\vec{r},\alpha) = \frac{\sqrt{8\alpha_s}}{\pi\, r^2}\exp\left[-\frac{r^2}{2\,r_0^2}\right]\left[\alpha(\vec{e}_1^{\,*}\cdot\vec{e})(\vec{e}_2^{\,*}\cdot\vec{r})(1-\alpha)(\vec{e}_2^{\,*}\cdot\vec{e})(\vec{e}_1^{\,*}\cdot\vec{r})-\alpha(1-\alpha)(\vec{e}_1^{\,*}\cdot\vec{e}_2^{\,*})(\vec{e}\cdot\vec{r})\right]$$

$\mathbf{r_0 \approx 0.3fm}$

$$\left\langle \Psi^\dagger_{gg}(\vec{r})\Psi_{gg}(\vec{r}\,') \right\rangle = \frac{4\alpha_s}{\pi^2}\,\frac{\vec{r}\cdot\vec{r}\,'}{r^2\, r'^2}\,\exp\left[-\frac{r^2+r'^2}{2\,r_0^2}\right]\left[1+\alpha^4+(1-\alpha)^4\right]$$

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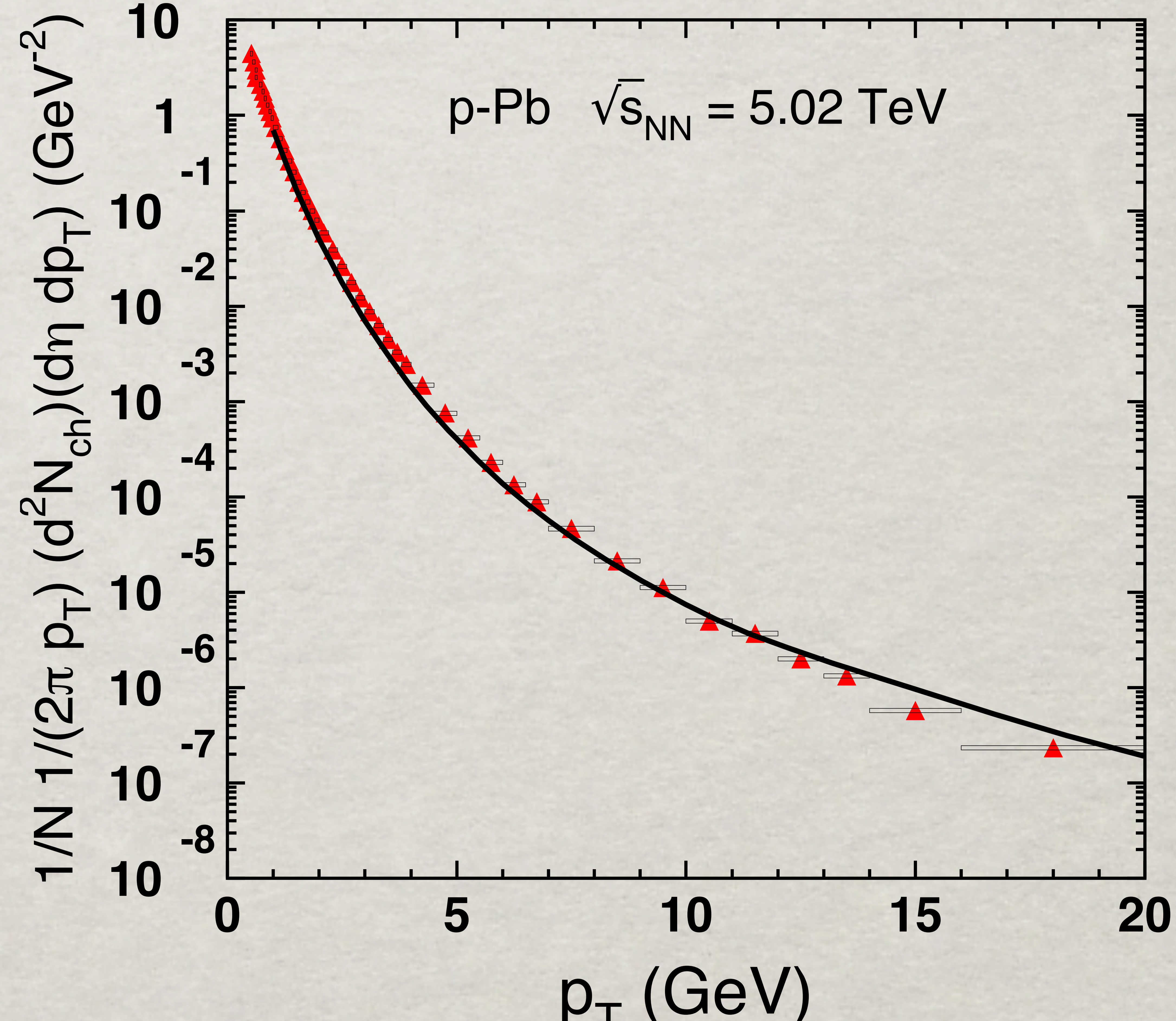
$$\frac{d^2\sigma(pN(A)\to hX)}{d^2p_T\,dy} = \int\limits_{z_{min}}^{1} \frac{dz}{z^2}\, D_{h/g}(z,k_T^2) \int\limits_{x_{min}}^{1} dx_1\, g(x_1,k_T^2) \frac{d^2\sigma^{N(A)}_{g\to 2g}(\alpha,x_2)}{d^2k_T\,dy}$$

$$k_T = p_T/z$$

$$z_{min} = \frac{p_T}{\sqrt{s}}\, e^y\,; \qquad x_{min} = z_{min}/z\,;$$

$$\alpha = \frac{p_T\, e^y}{x_1 z\sqrt{s}}$$

$$x_2 = \frac{p_T^2}{x_1 z^2\, \alpha(1-\alpha)s}$$



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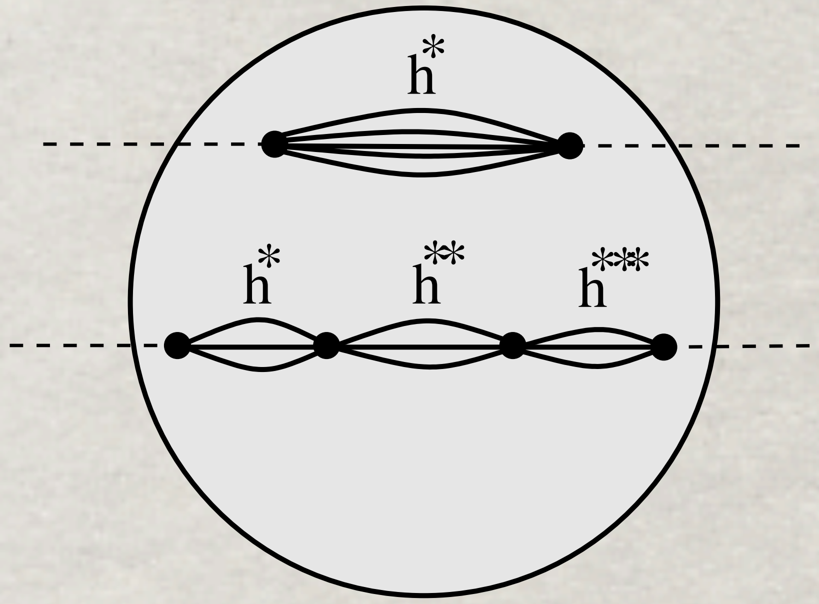
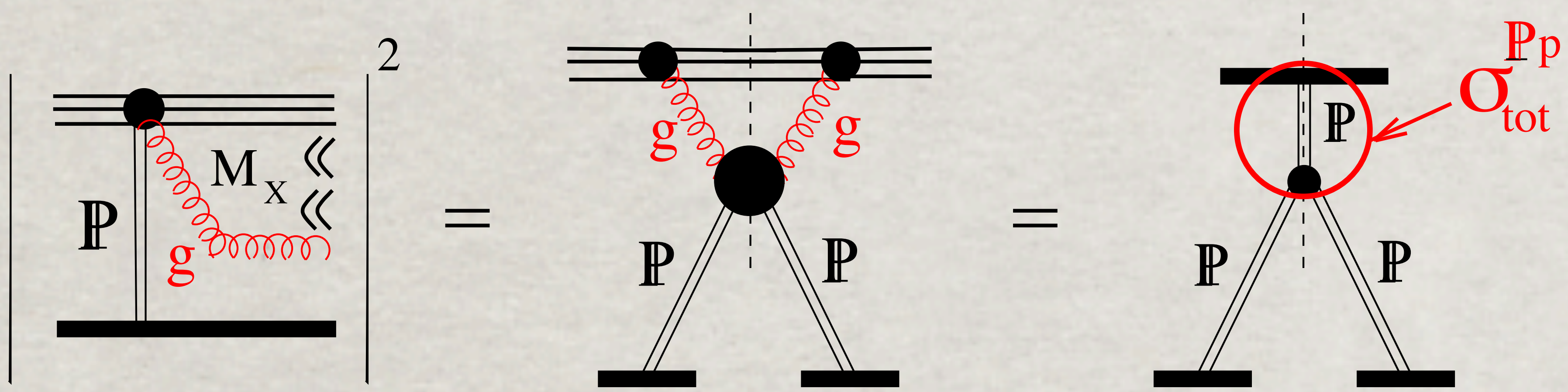
Weakness of gluon shadowing



Gluon shadowing is a part of the Gribov inelastic corrections related to the triple-Pomeron term in diffraction.



expected: $\sigma_{\mathbf{tot}}^{\mathbf{Pp}} \sim 50\,\mathrm{mb}$

measured: $\sigma_{\mathbf{tot}}^{\mathbf{Pp}} \lesssim 2\,\mathrm{mb}$!!!

Smallness of the diffractive cross section means weakness of gluon shadowing.

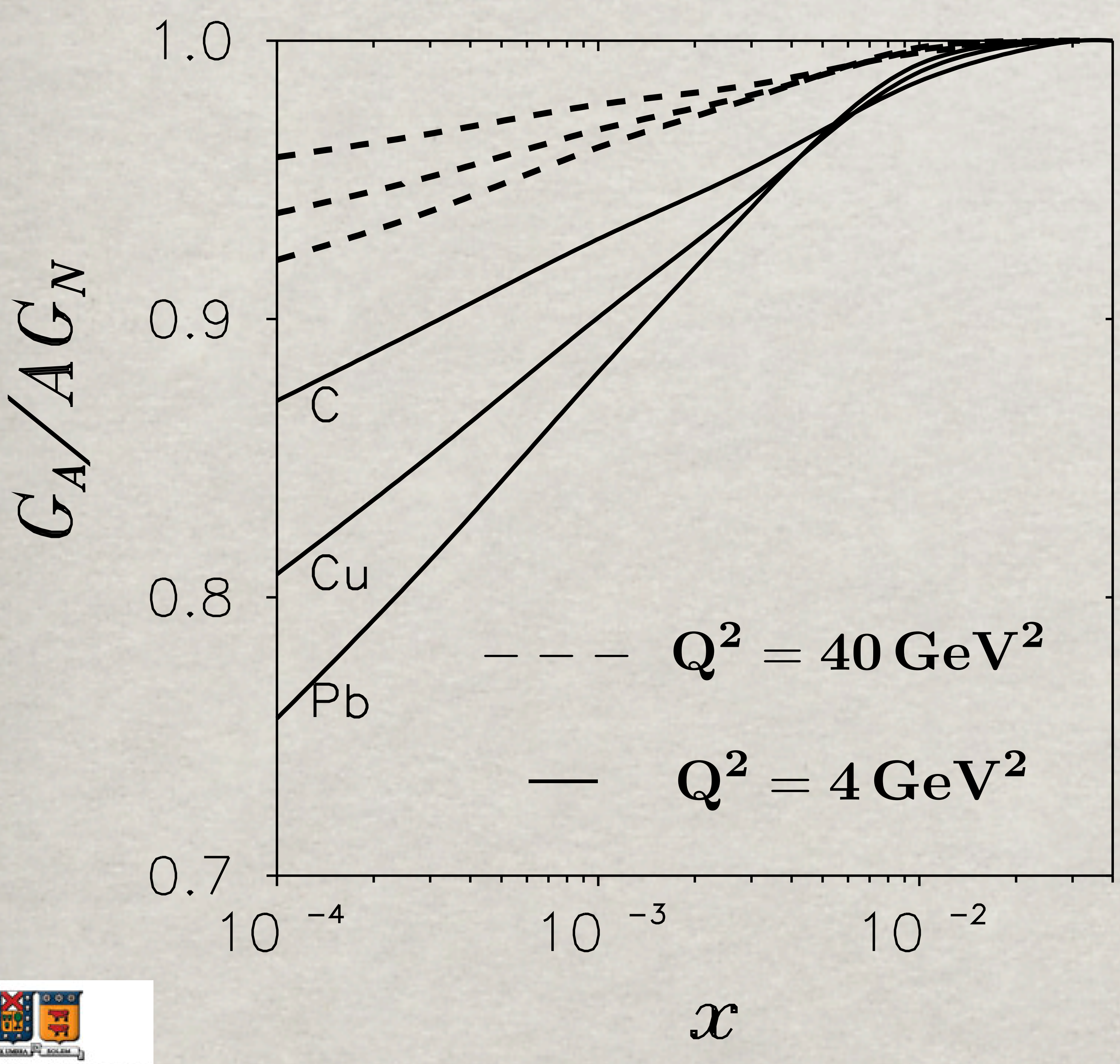
In terms of pQCD this shows a suppression of diffractive gluon radiation, which can only be related to smallness of gluonic dipoles.

Gluon shadowing from DIS

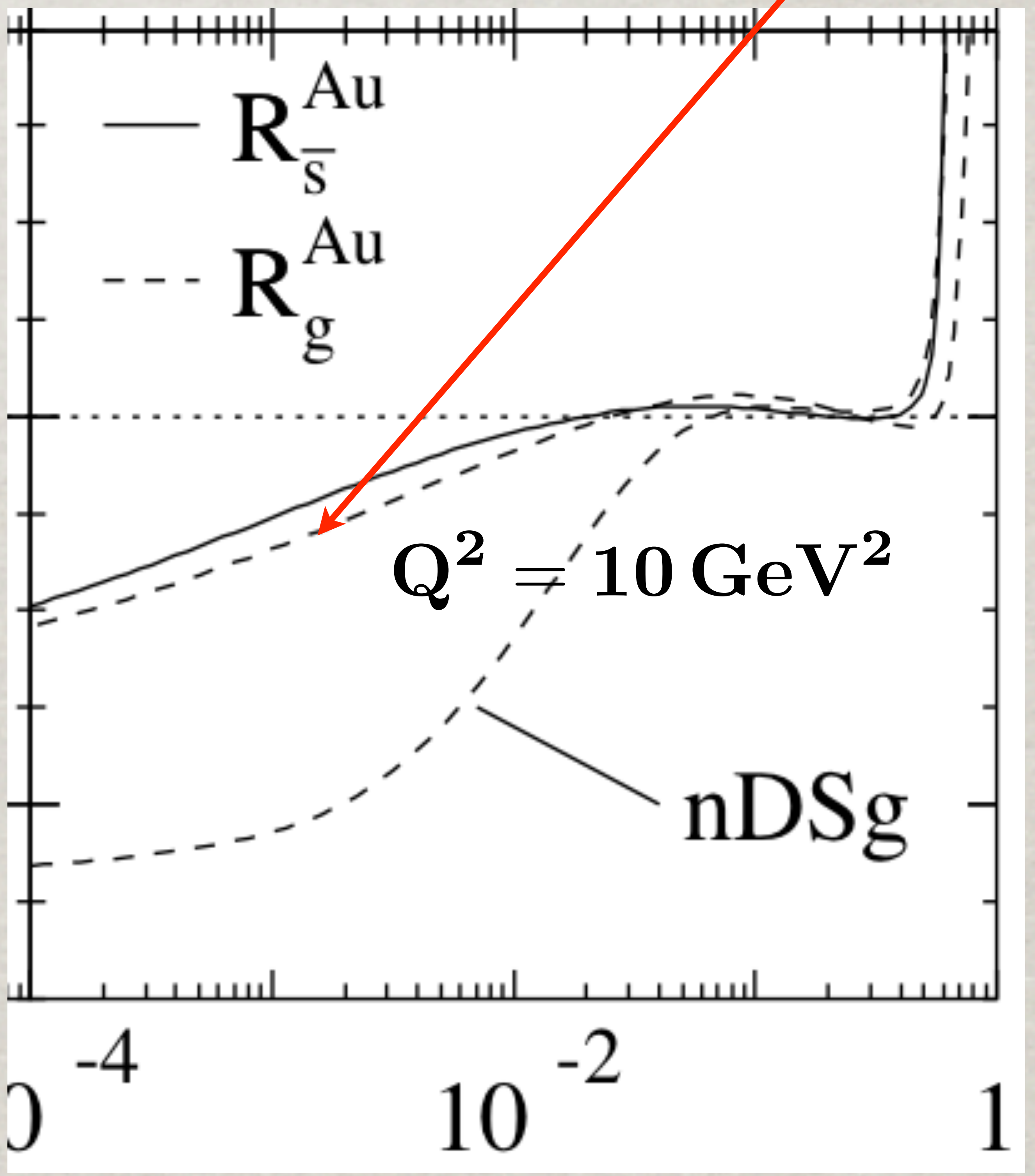
Gluon shadowing in DIS correspond to inclusion of the higher Fock components of the photon, $\gamma^* \to \bar{\mathbf{q}}\mathbf{q} + \mathbf{g}$, B.K., A.Schaefer, A.Tarasov,1999 .

Gluon PDFs in DIS are probed via the DGLAP evolution from the $\mathbf{Q^2}$ dependence of $\mathbf{F_2(x, Q^2)}$
So far only the NMC experiment managed to detect a variation of the nuclear PDF with $\mathbf{Q^2}$

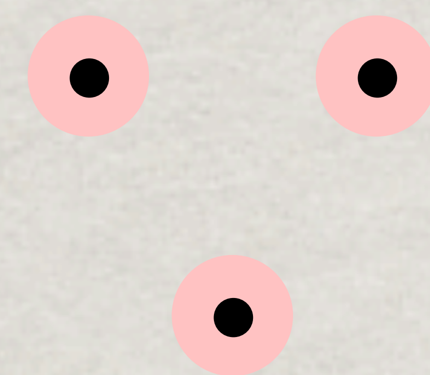
B.K., A.Schaefer, A.Tarasov,1999 (KST)

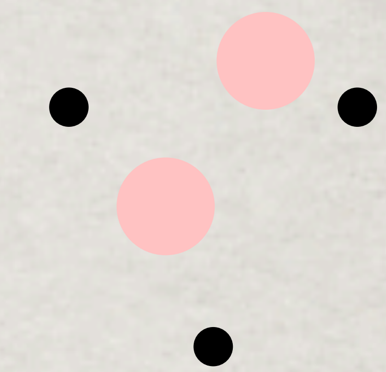


D.de Florian, R.Sassot, 2004 (DS)



Two-scale hadronic structure





B.K., A.Schafer, A.Tarasov(1999):
the valence quarks carry small size gluon clouds, $r_0 \approx 0.3\mathrm{fm}$

Shuryak & Zakhed (2004):
gluonic spots of small size, $r_0 \approx 0.3\mathrm{fm}$ are floating in the proton.

Small gluonic spots ==> weak gluon shadowing:

$$\left.\frac{G_A(x)}{AG_N(x)}\right|_{x\ll 1} = \frac{2}{\langle\sigma_{GG}(r)\rangle}\int d^2b\left[1-\left\langle e^{-\frac{1}{2}\sigma_{GG}(r)T_A(b)}\right\rangle\right] = 1-\frac{3C}{8}\,r_0^2\,\rho_A R_A + \ldots \approx 0.8$$

Even if small-x gluons overlap in the longitudinal direction, they can miss each other in transverse plane, if they are located within small spots. Indeed, for a heavy nucleus (lead) the mean number of gluonic spots overlapping with a given one is,

$$\langle n\rangle = \frac{3\pi}{4}\,r_0^2\,\langle T_A\rangle = \pi\,r_0^2\,\rho_A\,R_A = 0.3$$

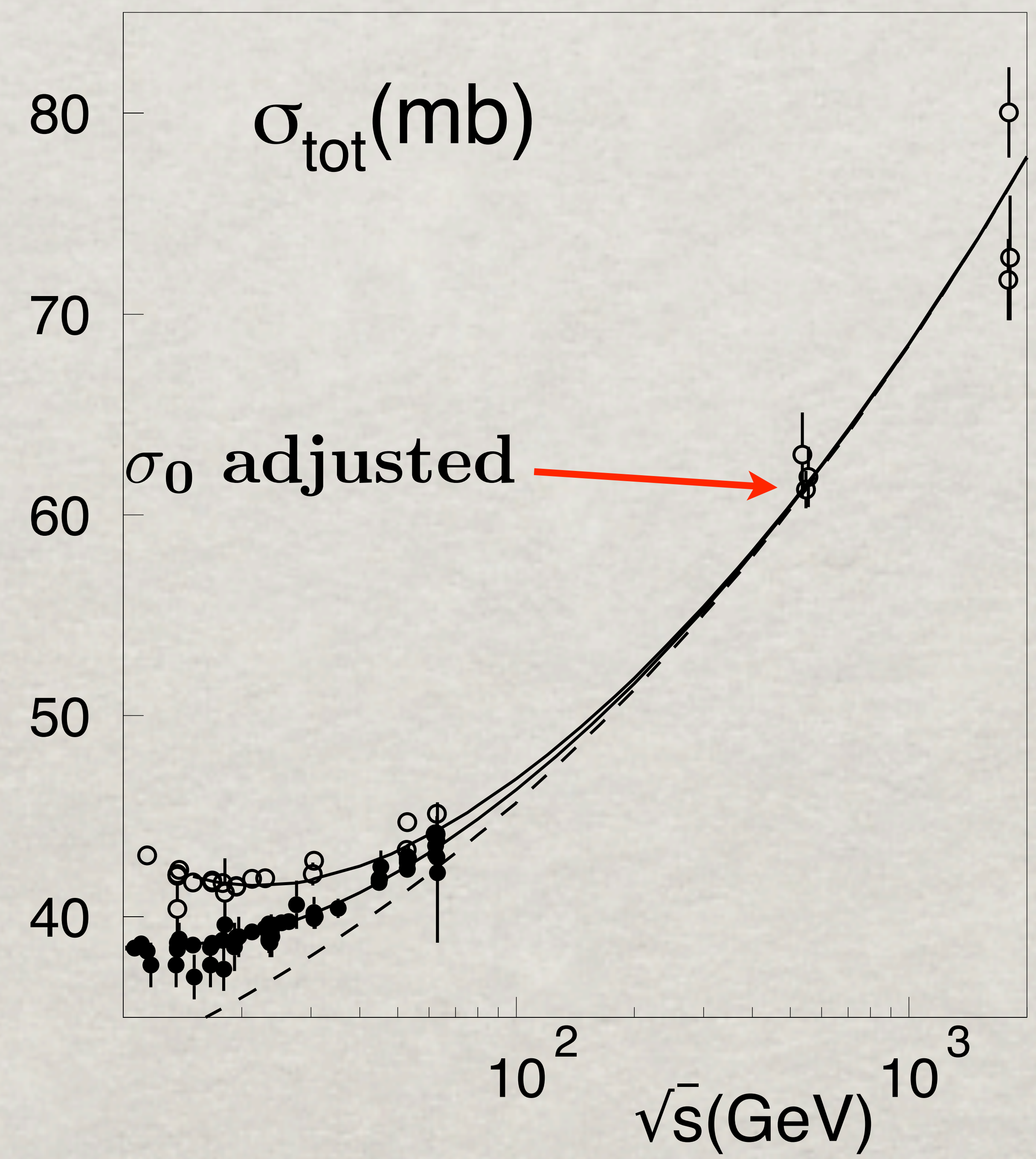
Evidences for two-scales

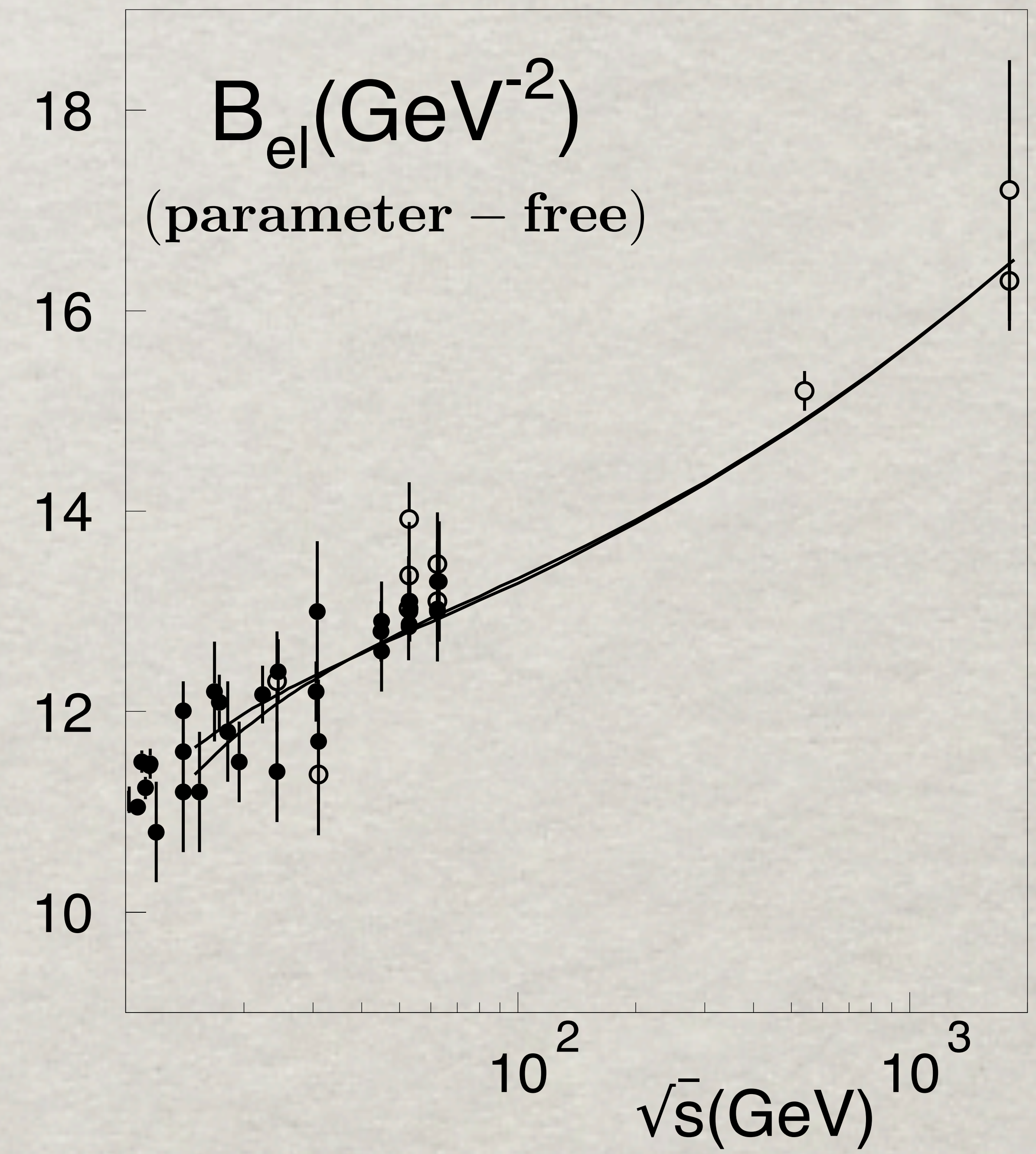
As far as gluon radiation is suppressed, hadronic cross sections should rise slowly with energy. Indeed, the observed energy dependence of the total pp cross section is well described [B.K., I.Potashnikova, E.Predazzi, B.Povh, PRL 85(2000)507]

$$\sigma_{tot} = \sigma_0 + \sigma_1 \left(\frac{s}{s_0}\right)^{\Delta}$$

$$\Delta = \frac{4\alpha_s}{3\pi} = 0.17$$

$$\sigma_1 = \frac{27}{4} C\, r_0^2$$





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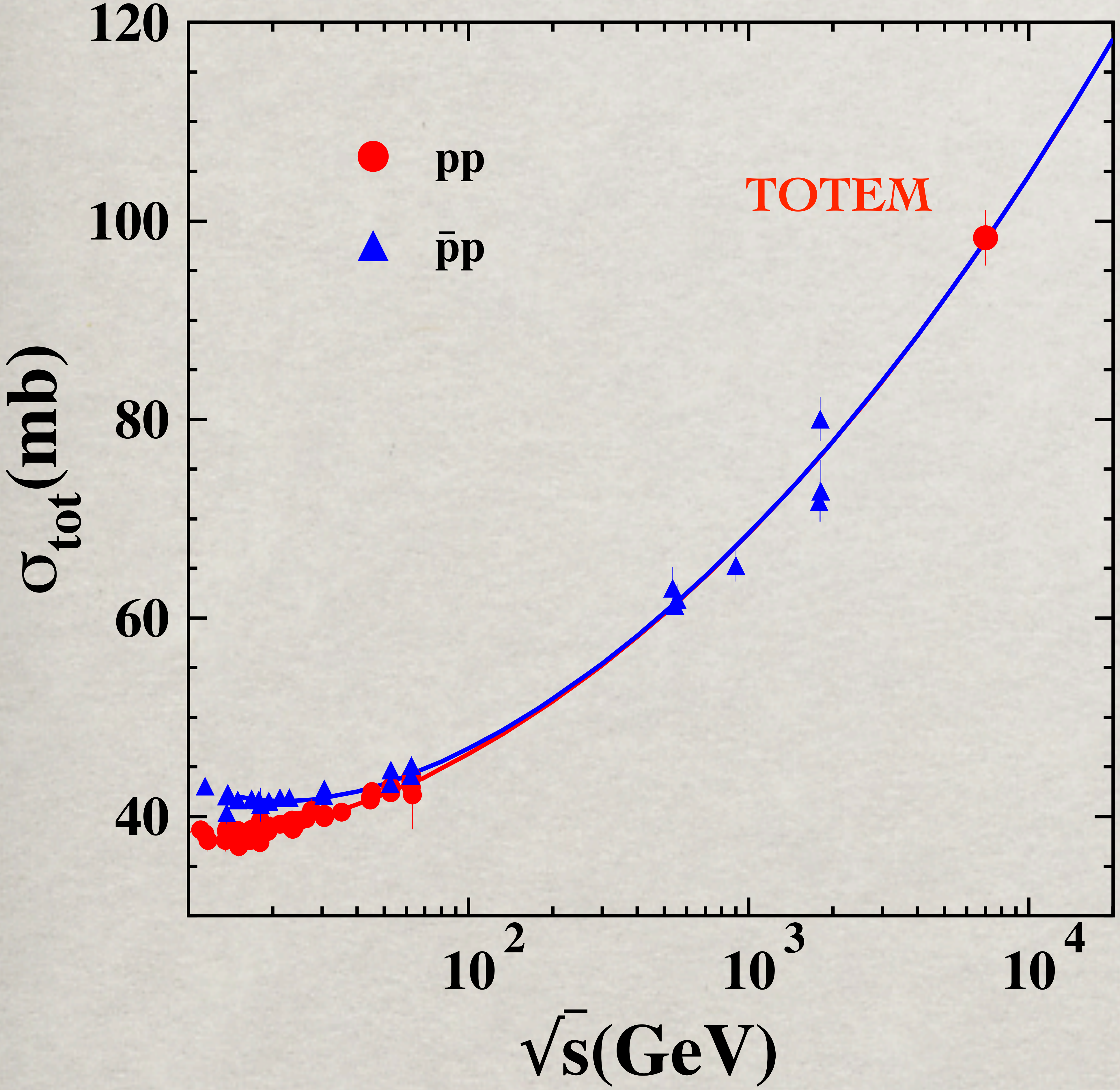
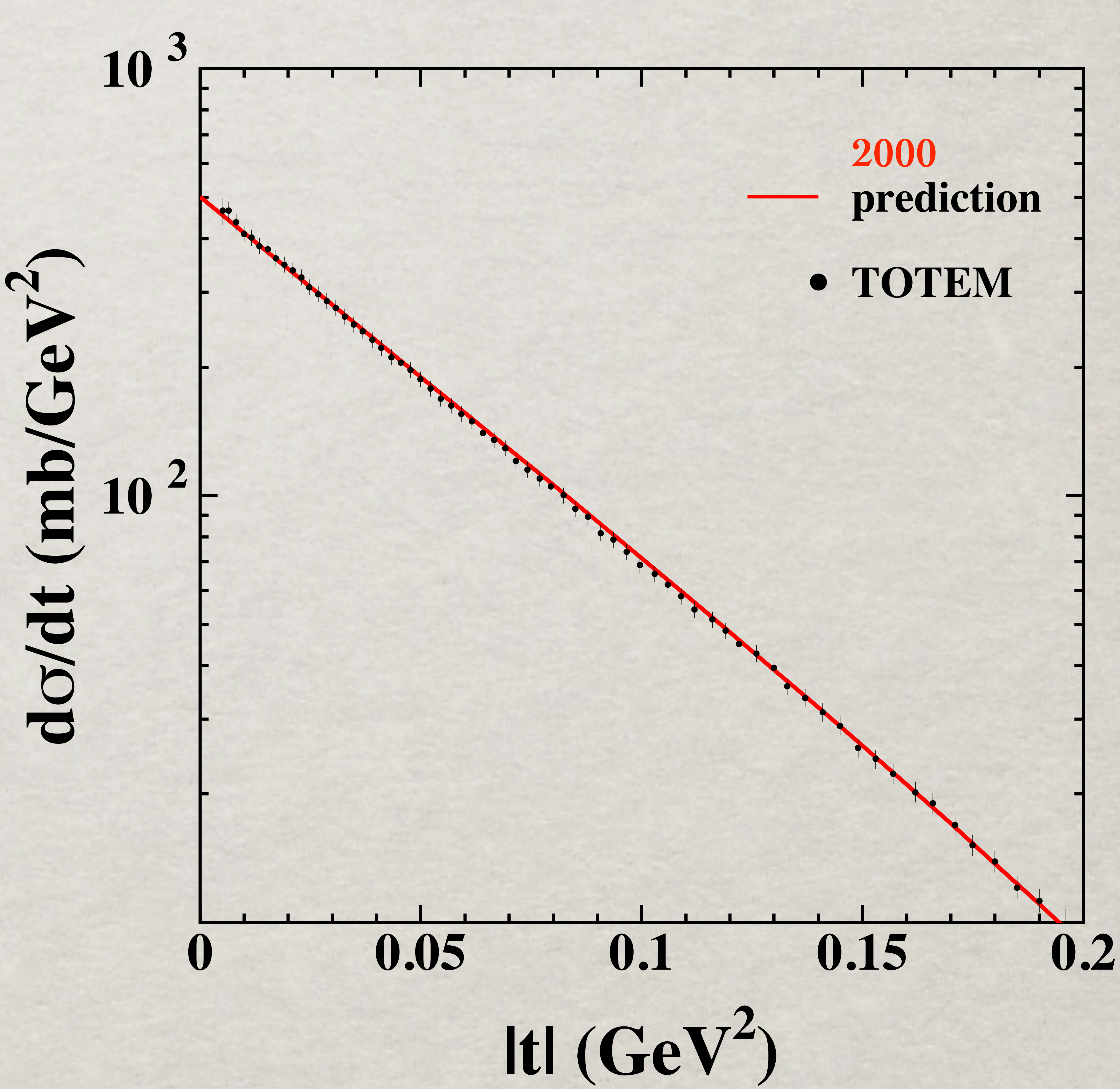
Evidences for two-scales

B.K., I.Potashnikova, B.Povh, E.Predazzi (2000)

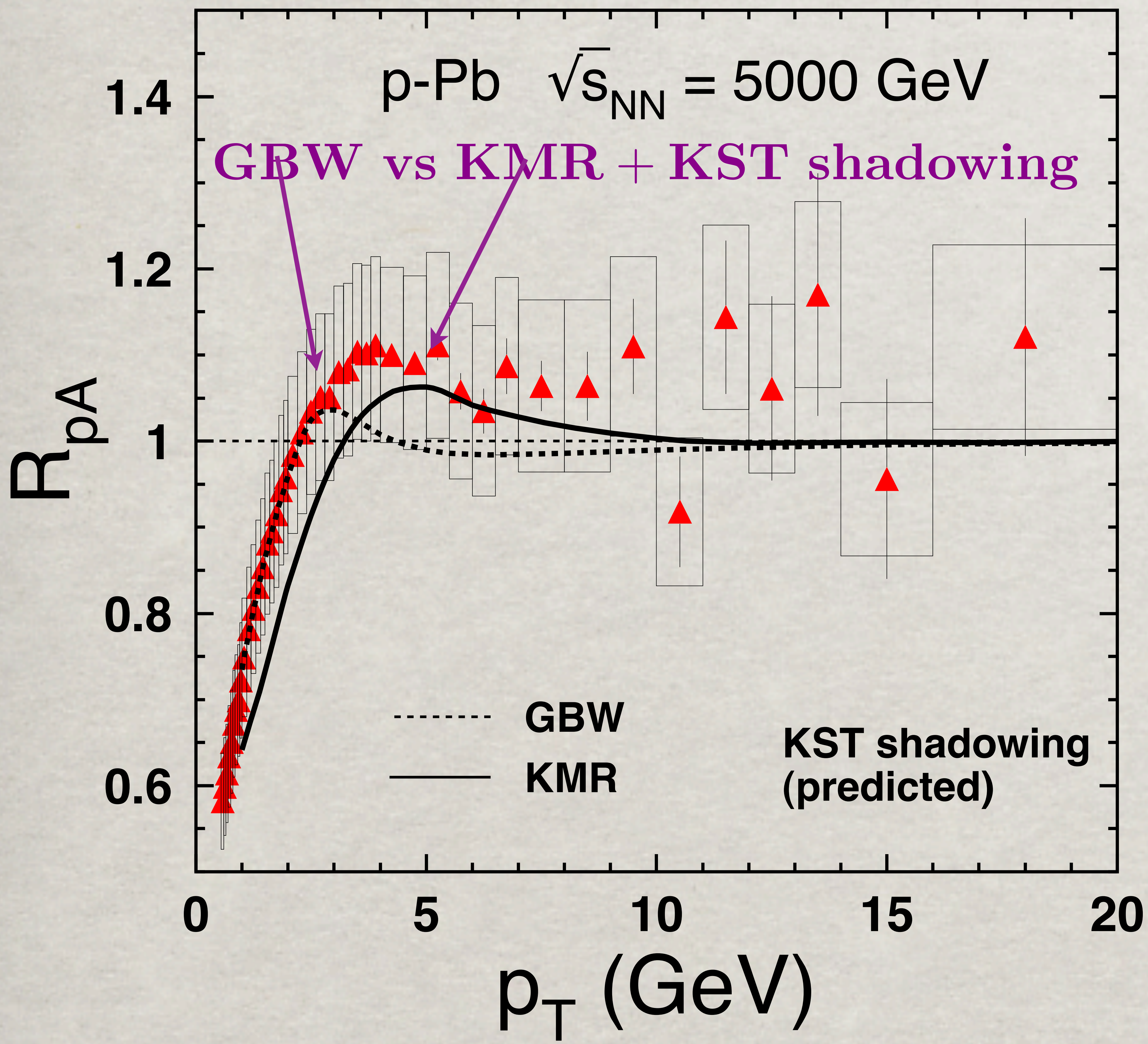


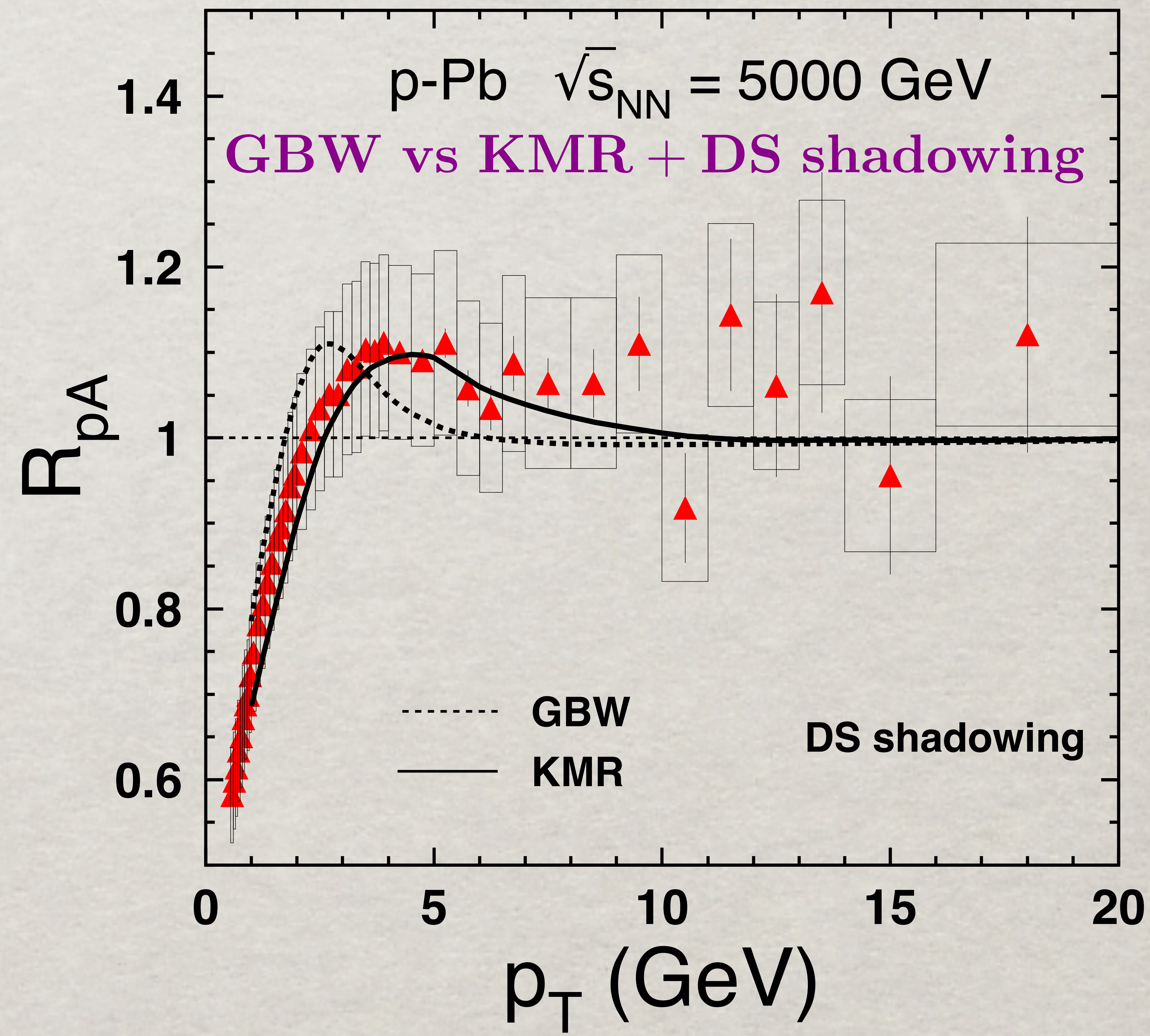


B.K., I.Potashnikova, B.Povh (2012)

Improved predictions

With the same 2002 computer code, but using a contemporary versions of the unintegrated gluon distribution (KMR) one can improve the shape of pT-dependence.





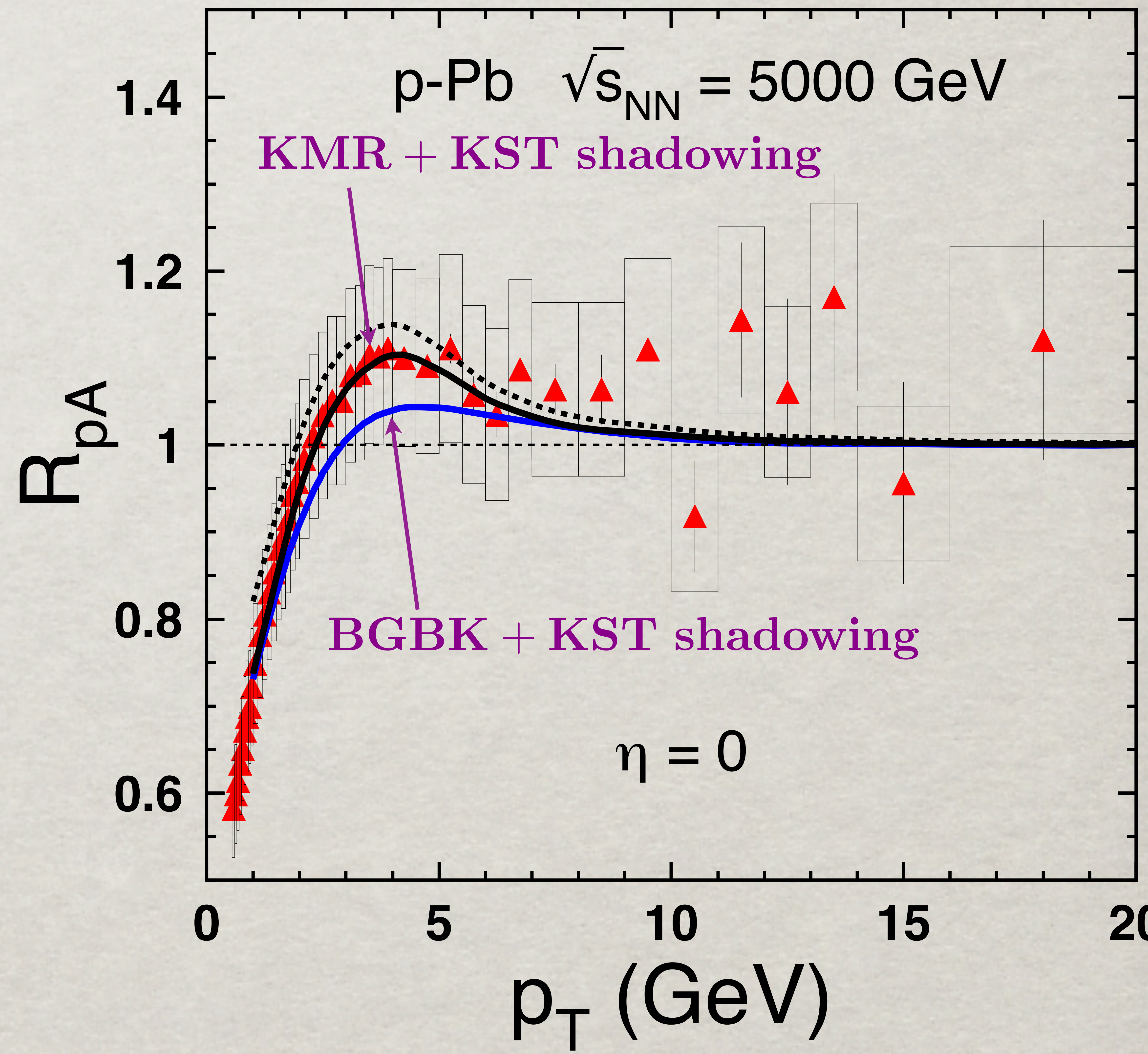
POSTDICTIONS: Further improvements

- A better choice of the scale for gluon shadowung.

$$Q^2 = \frac{4}{xg(x, k_T^2)} \int dq^2 \, \mathcal{F}_g(x, q, k_T^2)$$

- Alternative parametrizations for the dipole cross section:

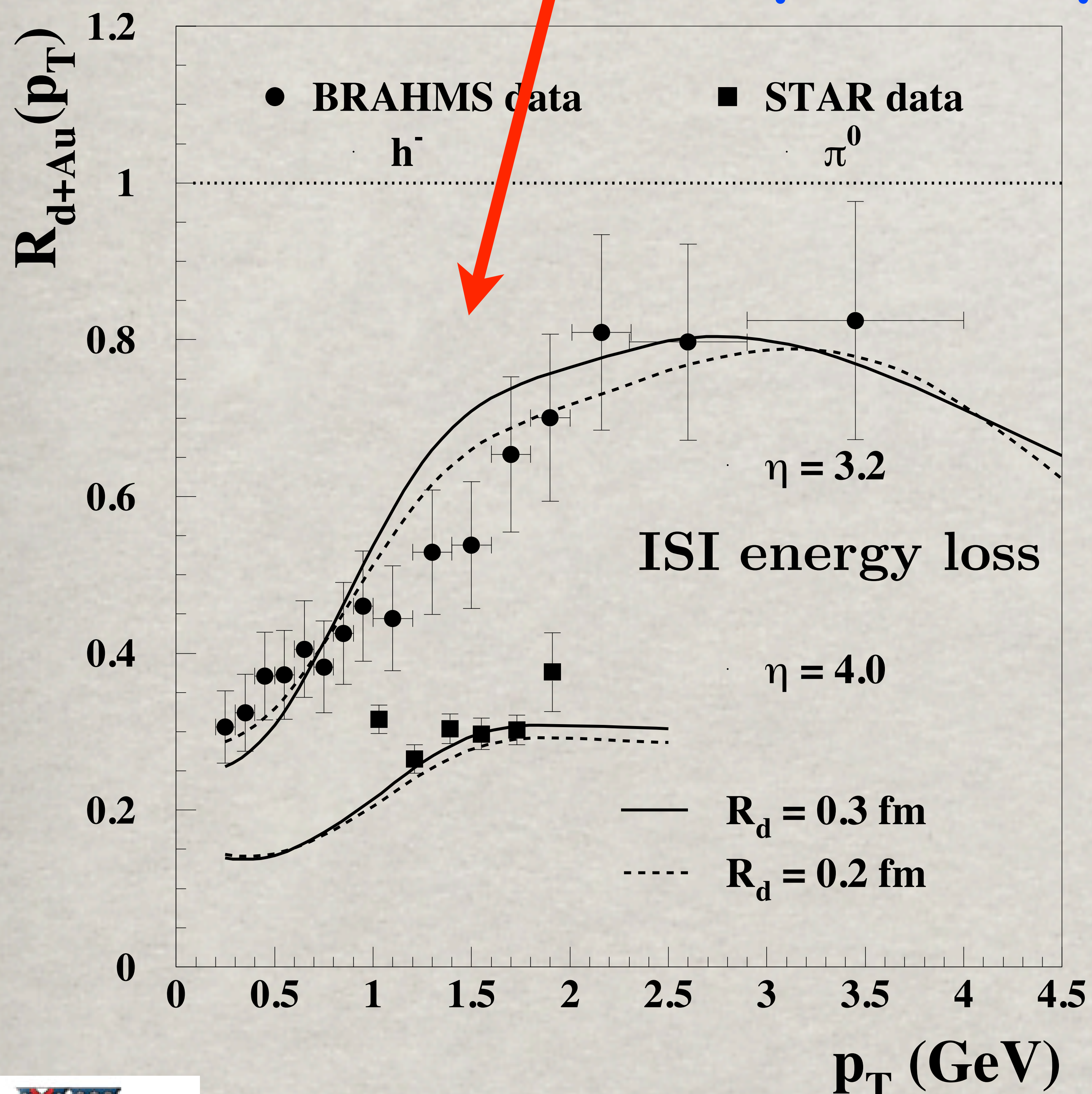
J.Bartels, K.J.Golec-Biernat & H.Kowalsky, 2002 (BGBK)



Toward the kinematic bound

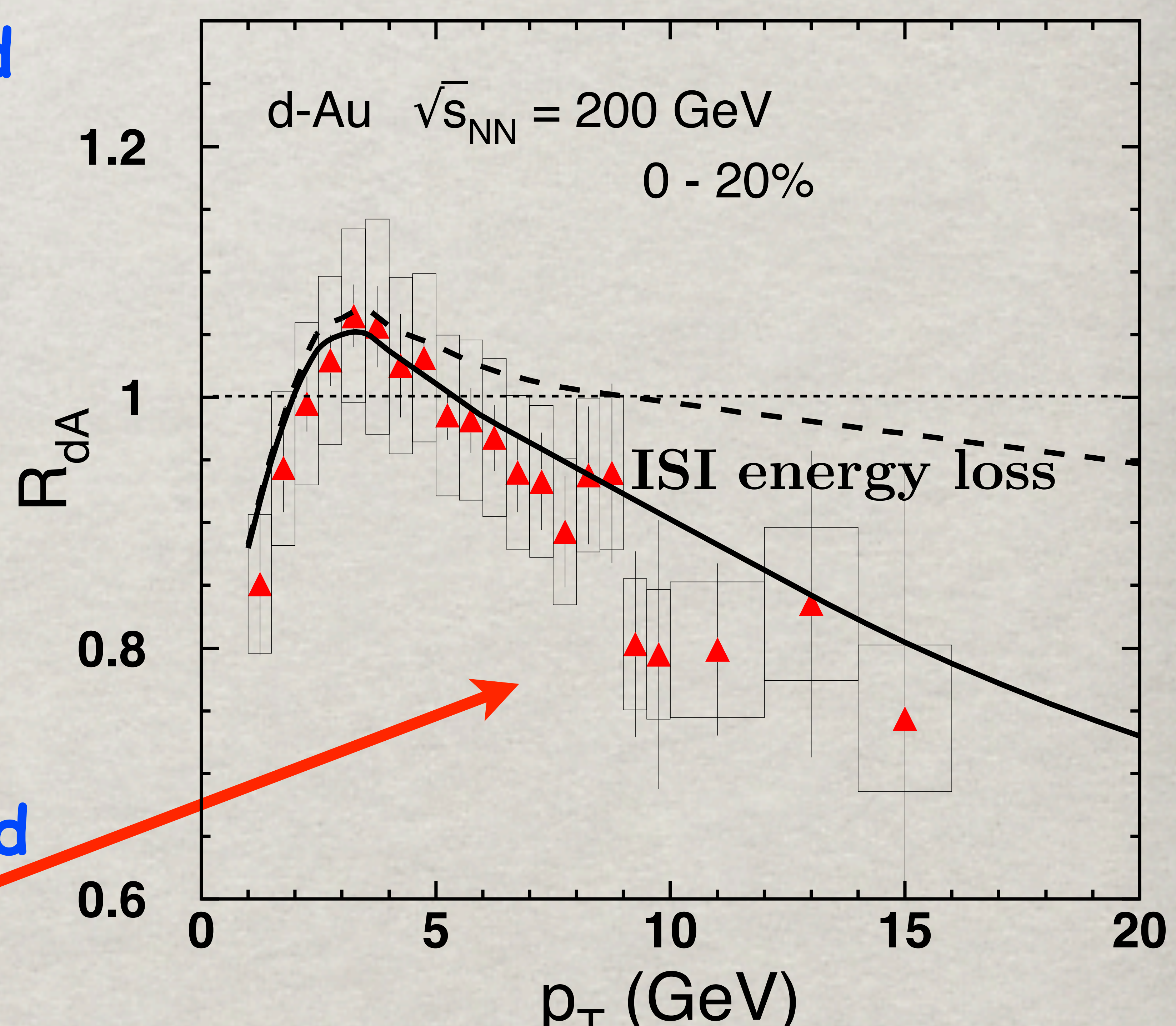
Smallest x2 are reached at forward rapidities. This is why it was tempting to interpret the suppression observed at forward rapidities by BRAHMS and STAR, as a result of coherence, CGC [D.Kharzeev, Yu.Kovchegov, K.Tuchin (2003)]

Initial-state energy loss suppresses particle production toward the kinematic limit x1->1 [B.K., J.Nemchik, I.Potashnikova, I.Schmidt (2005)]



A possibility to settle this controversy would be to go to higher energies and check with the nuclear effects at the same x2, but further away from the kinematic limit (see LHC data below).

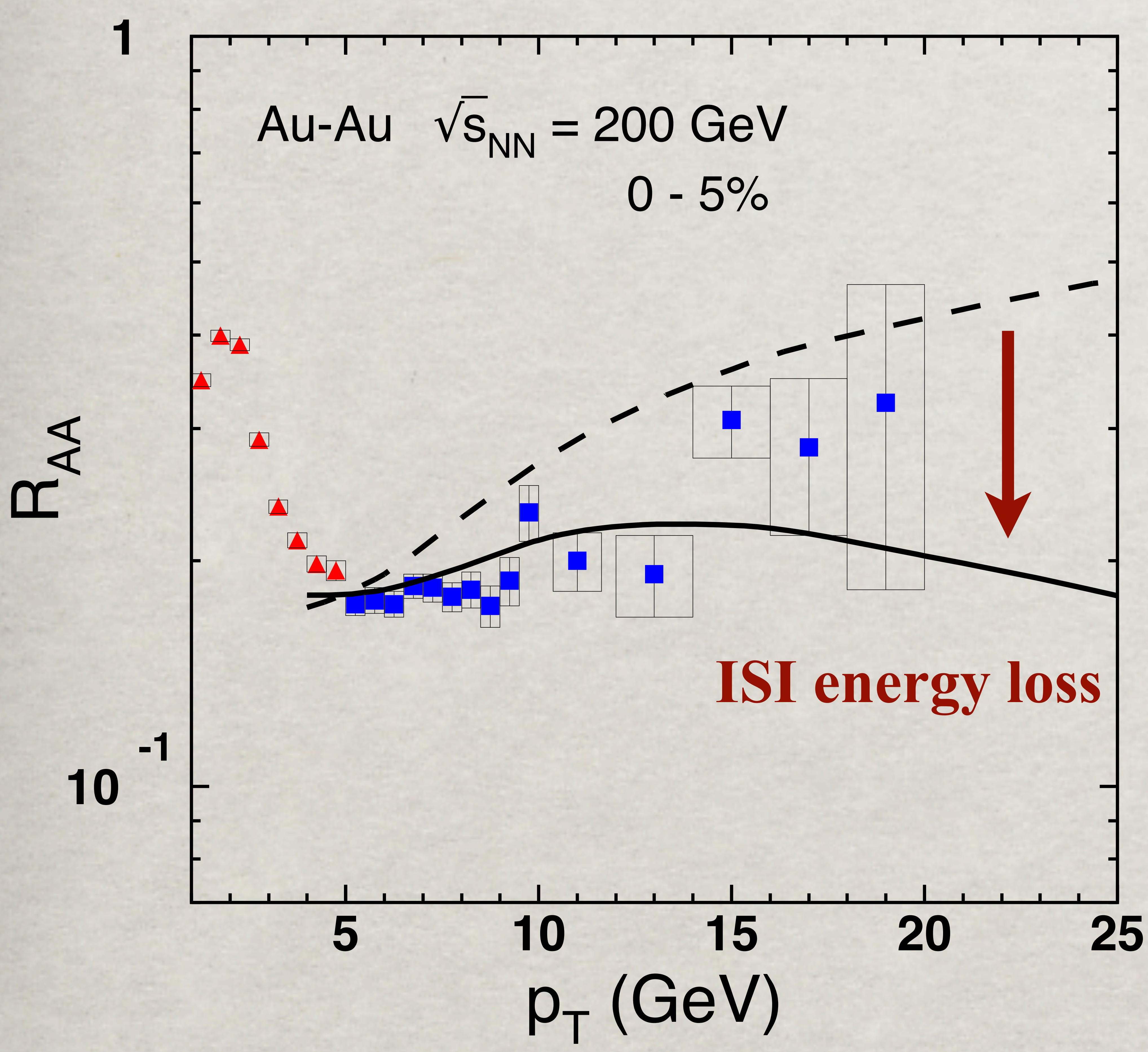
One also approaches the kinematic limit at the mid rapidity, but high pT.

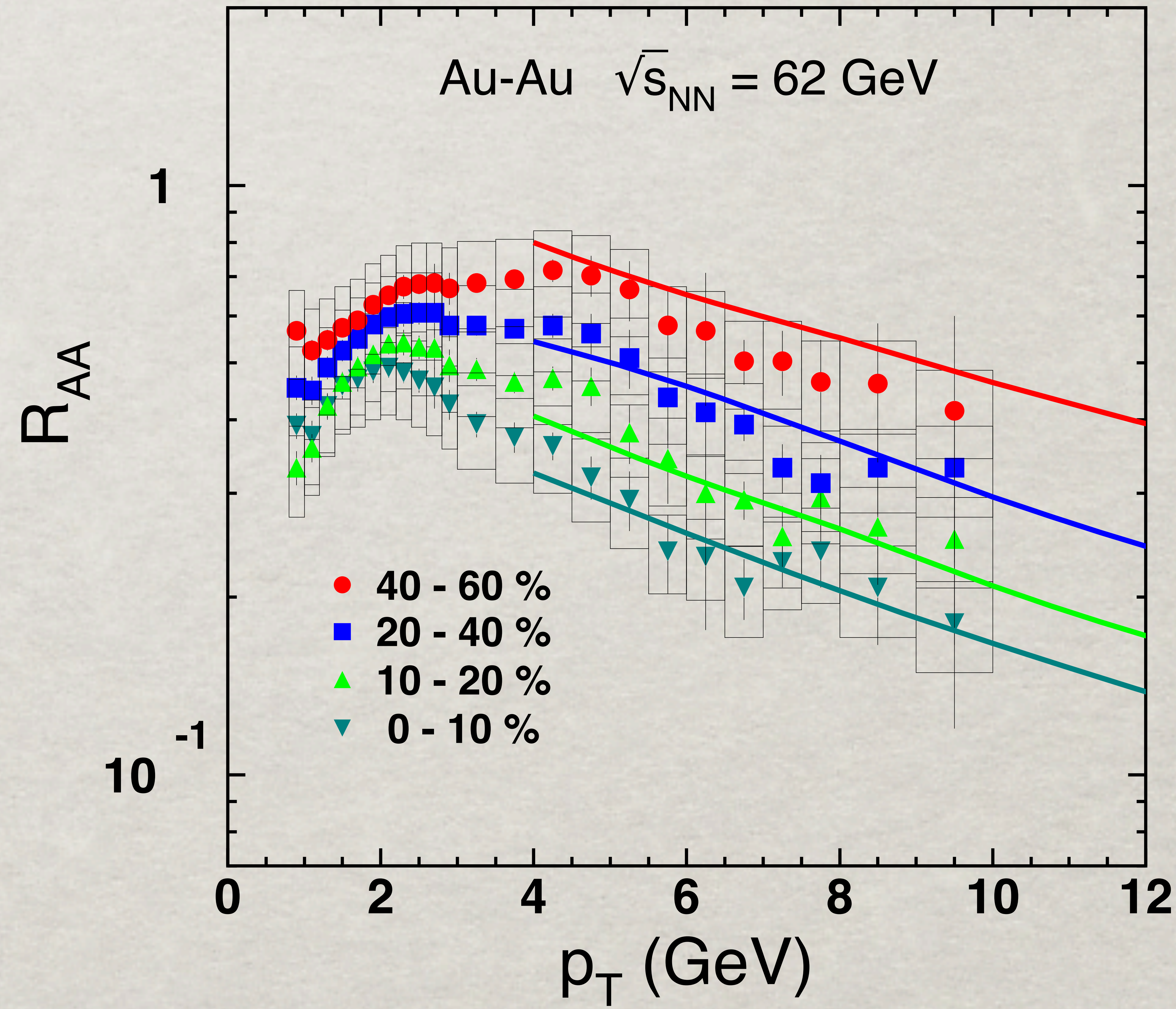


Lower energies - larger xT

Suppression of high-pT hadrons by ISI E-loss in AA collisions at RHIC

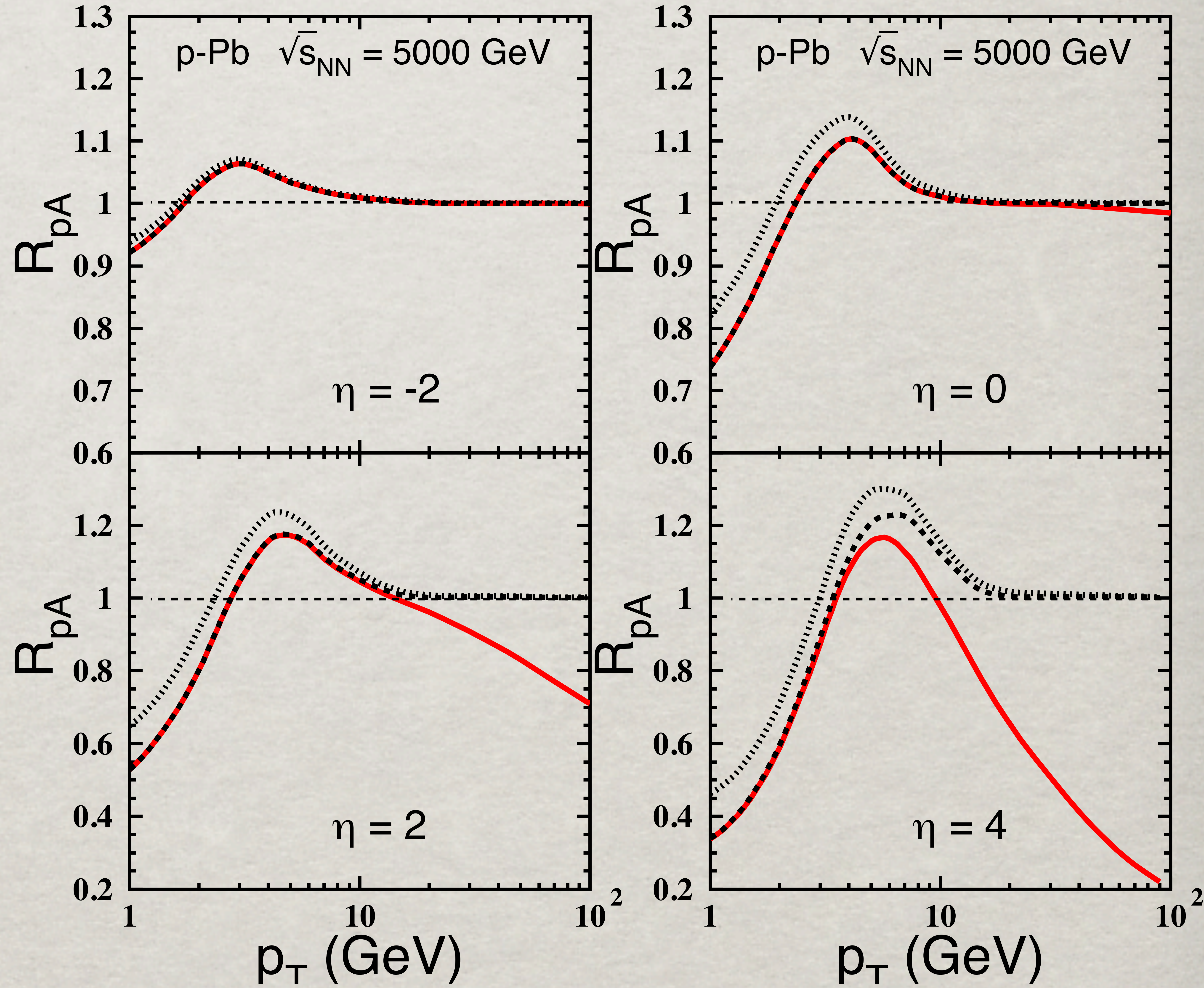
B.K., J.Nemchik, I.Potashnikova, I.Schmidt, PRC86(20012)054904





Cronin effect at forward rapidities

One can enhance the role of ISI energy loss either moving to forward rapidities, or higher pT, or both



······· no shadowing

------ KST shadowing

——— ISI E-loss added

KMR unintegrated gluon density

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Summarizing,

For the first time high-pT hadrons can be produced in pA coherently. Data for the Cronin effect at LHC provide a strong support for the two-scale hadronic structure and weak gluon shadowing. Many popular models are “ruled out”.

The magnitude of the Cronin enhancement predicted in 2002 was correct, while the shape of the pT dependence can be improved applying more realistic up-to-date phenomenology.

Initial state energy loss is expected to suppress significantly inclusive hadron production at large pT and/or at forward rapidities in pA, as well as in AA collisions.

BACKUPS

In order to study the sensitivity of different observables on the amount of shadowing in the nuclear gluon distribution, we have performed an alternative extraction of nPDF from the same data set but constraining the gluon density in heavy nuclei to show a stronger shadowing effect at small x_N. We provide the result in set called nDSg, constrained to satisfy $R_g^{Au} = 0.75$ at $x_N = 0.001$ and $Q^2 = 5$. The χ^2 value of this analysis is around 550, considerably larger than the *unconstrained* fit, and should be considered only as a mean to study variations on, mainly, the gluon nuclear distribution. An example