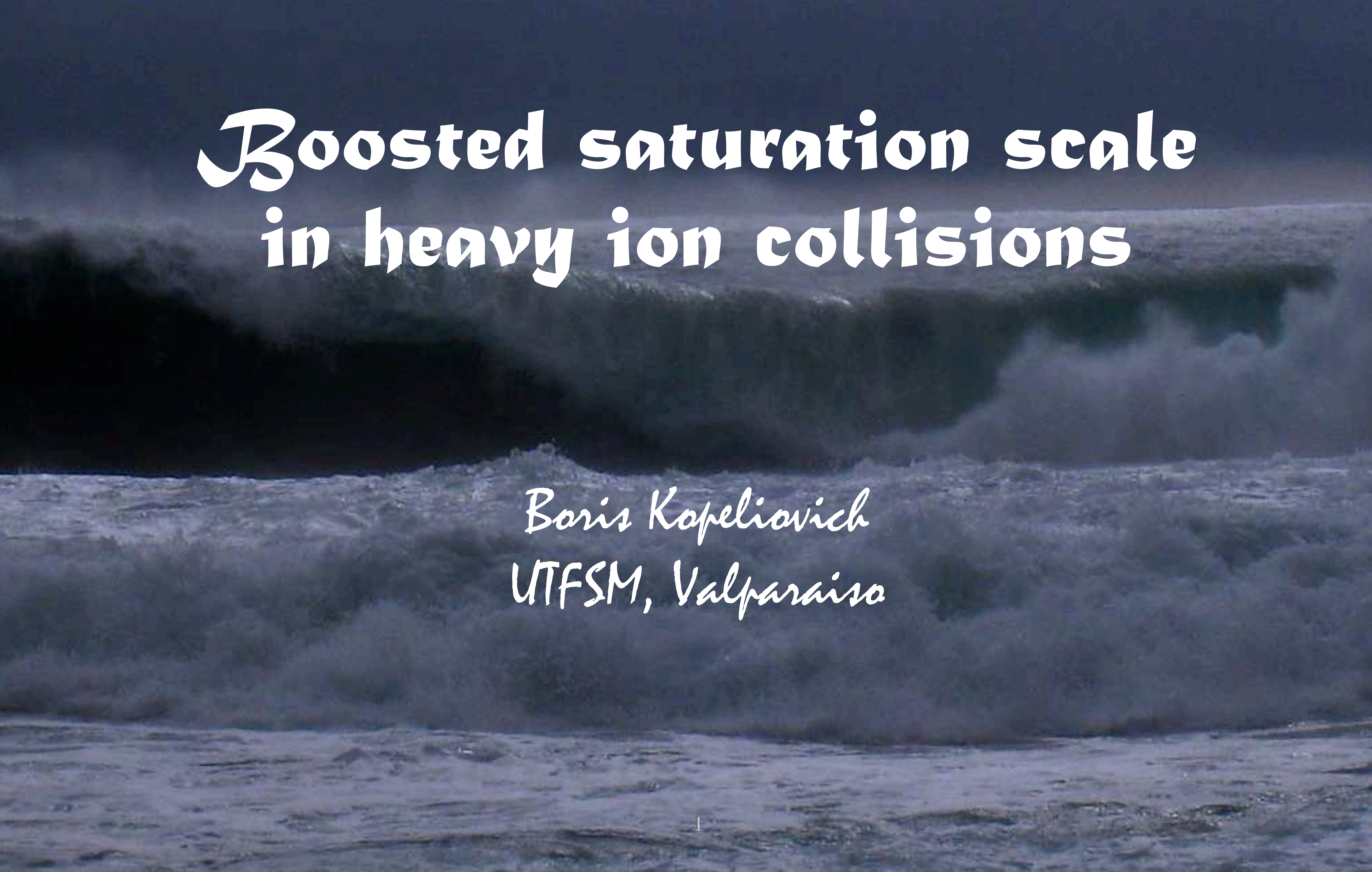

Boosted saturation scale in heavy ion collisions

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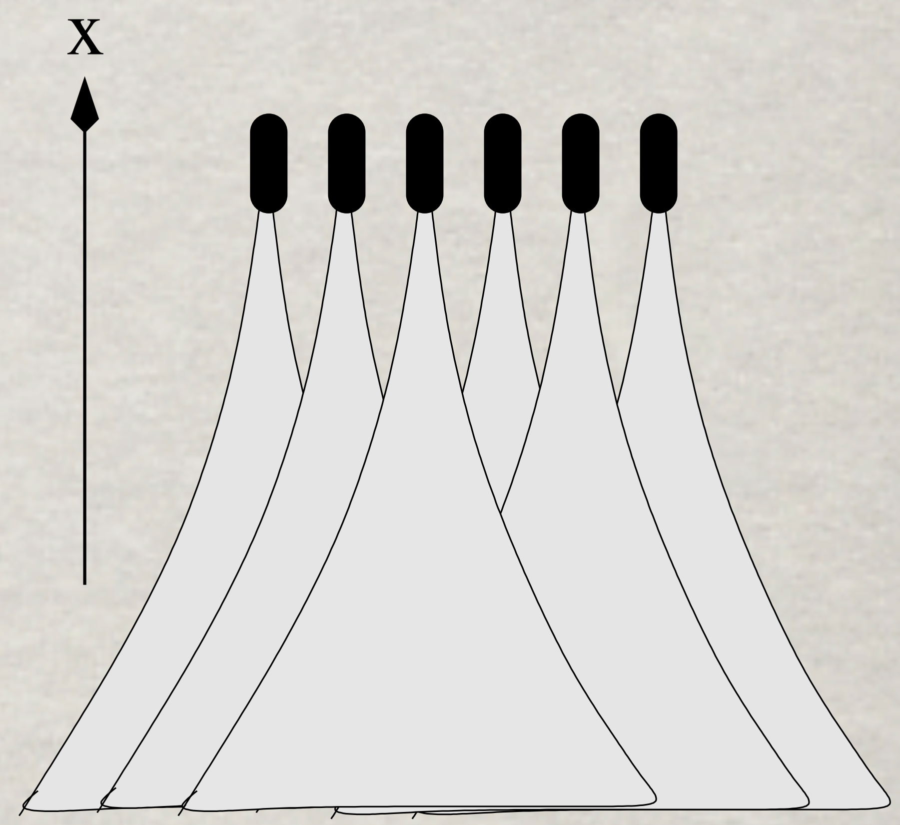
Reference dependent parton model

Parton model description of high-energy hadronic interaction is not Lorentz invariant. It varies from frame to frame, while measurable observables must remain unchanged, i.e. are Lorentz invariant.

Example: nuclear shadowing, which looks like optical analogy in the nuclear rest frame, is interpreted as fusion of overlapping parton clouds in the light-front frame.

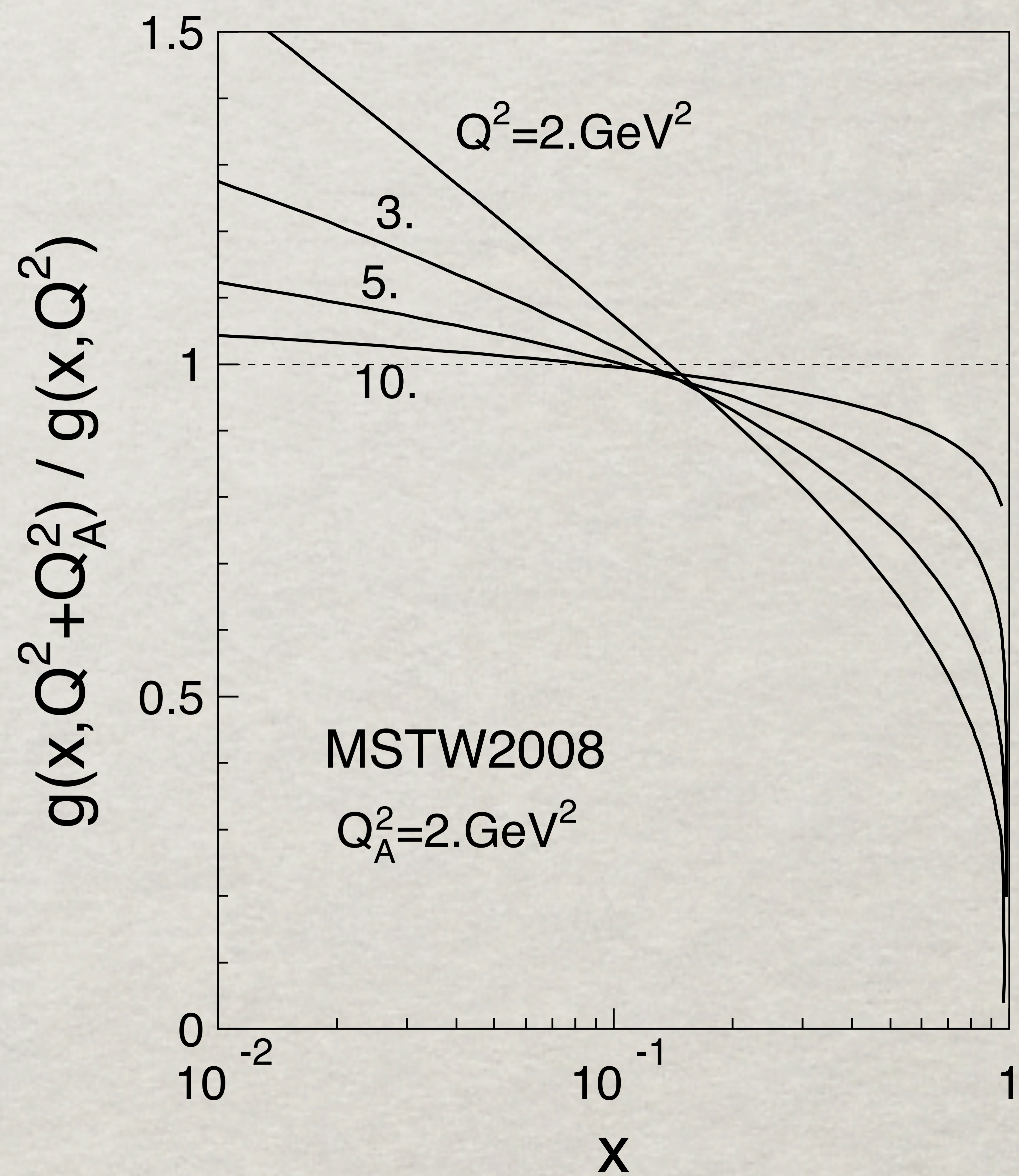


Color-glass condensate (saturation): increase of the mean transverse momenta of nuclear partons in the light-front frame, looks like pT-broadening of a parton propagating through the nucleus in its rest frame.

This all is about initial-state interaction (ISI)

Proton PDF modification in pA collisions

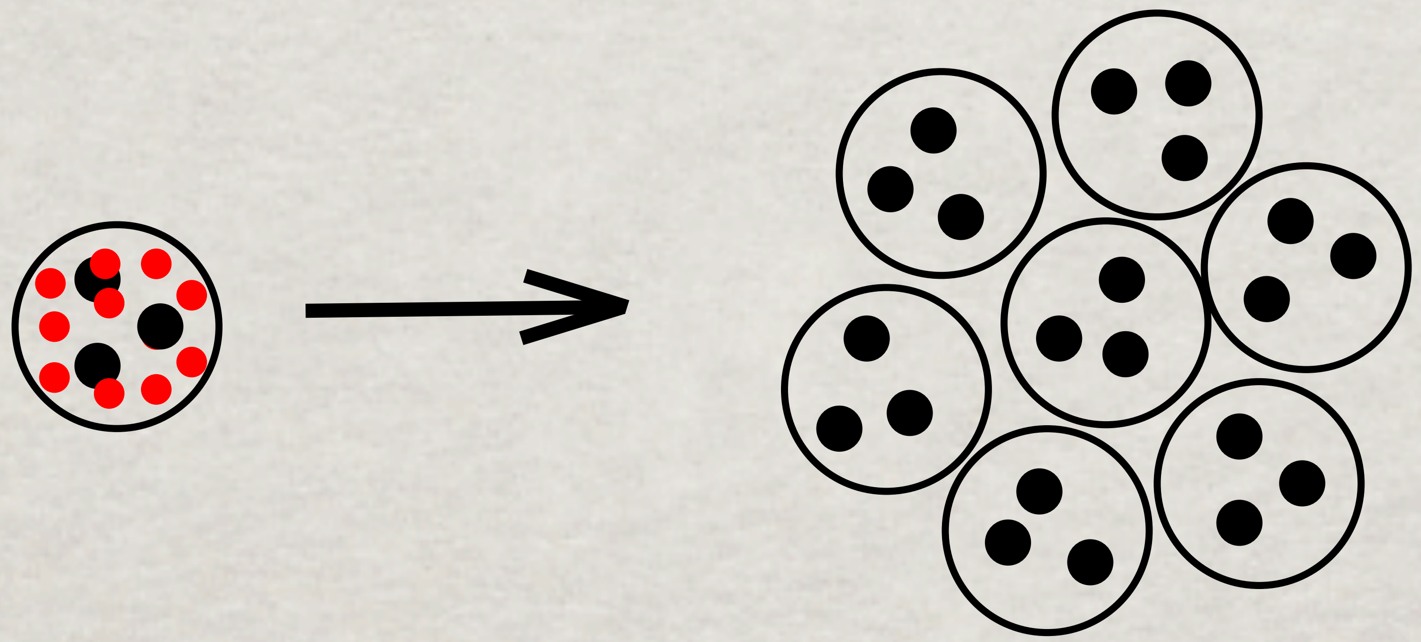
Due to broadening, the nuclear target probes the parton distribution in the beam hadron with a higher resolution, so in a hard reaction the effective scale Q^2 for the beam PDF drifts to a higher value $Q^2 + Q_A^2$.



The projectile gluon distribution is suppressed at large $x \to 1$, but enhanced at small x. This looks like a breakdown of k_T-factorization, but is a higher twist effect

Proton PDF modification in pA collisions

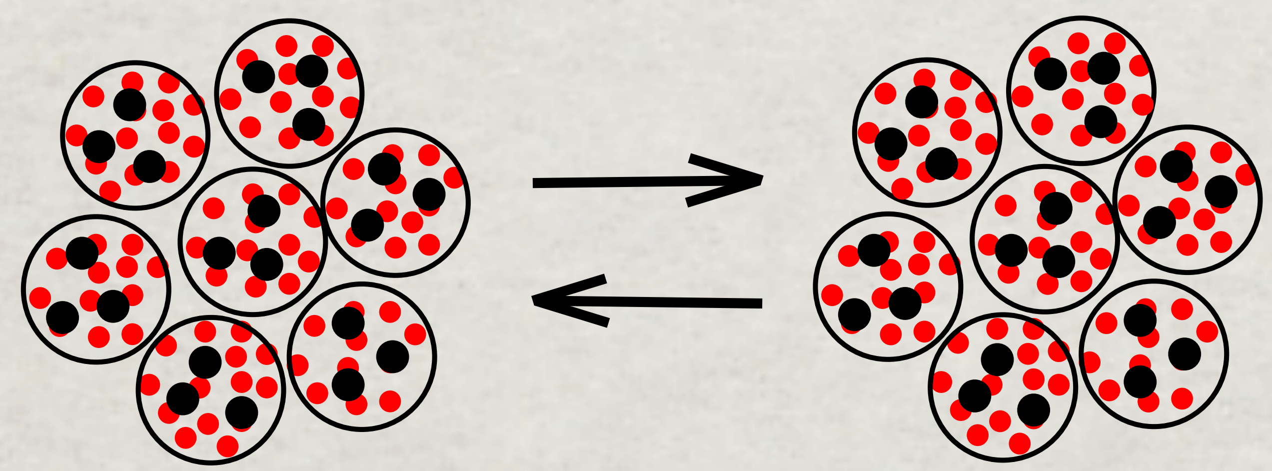
The PDF is averaged over different Fock states.
At higher scale a probe resolves more partons at small **x**.
A nucleus provides a harder scale, i.e. a better resolution than a proton target (Cronin effect)



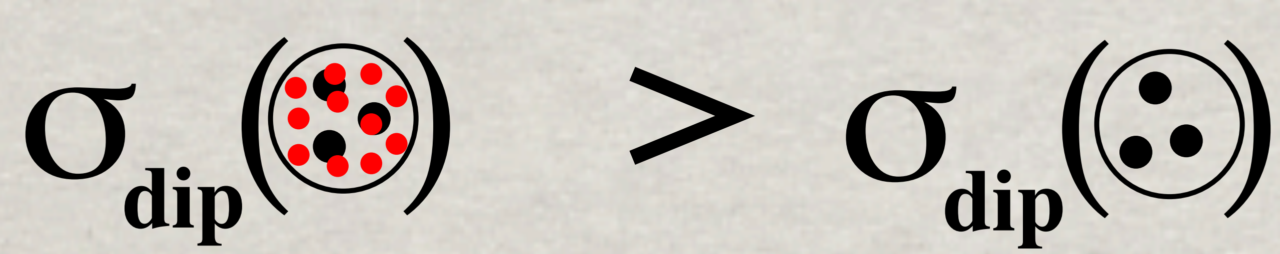
There is an asymmetry in the nucleon PDFs of the colliding **pA**:
The PDF of the beam proton, which undergoes multiple interactions, has more partons at small **x** compared with the bound nucleons, which can interact only once.

Mutual broadening in AA

In nuclear collisions the PDFs of bound nucleons in both nuclei are drifting towards higher scales.



This in turn enhances broadening compared to **pA**, since the properties of the target nucleons change.



Therefore, broadening, i.e. the saturation momentum, increases

Reciprocity of saturation scales

As far as the properties of bound nucleons in nuclear collisions are modified compared to N N collision, the saturations scales in the colliding nuclei should be revised. The usual relations for the gluon saturation scales Q^2_{sA} (Q^2_{sB}) in pA(pB) collisions, in the case of collision of two nuclei A and B are replaced by the system of reciprocity equations,

$$\tilde{Q}^2_{sB}(x_B) = \frac{3\pi^2}{2}\,\alpha_s(\tilde{Q}^2_{sA} + Q^2_0)\,x_B g_N(x_B, \tilde{Q}^2_{sA} + Q^2_0)\,T_B$$

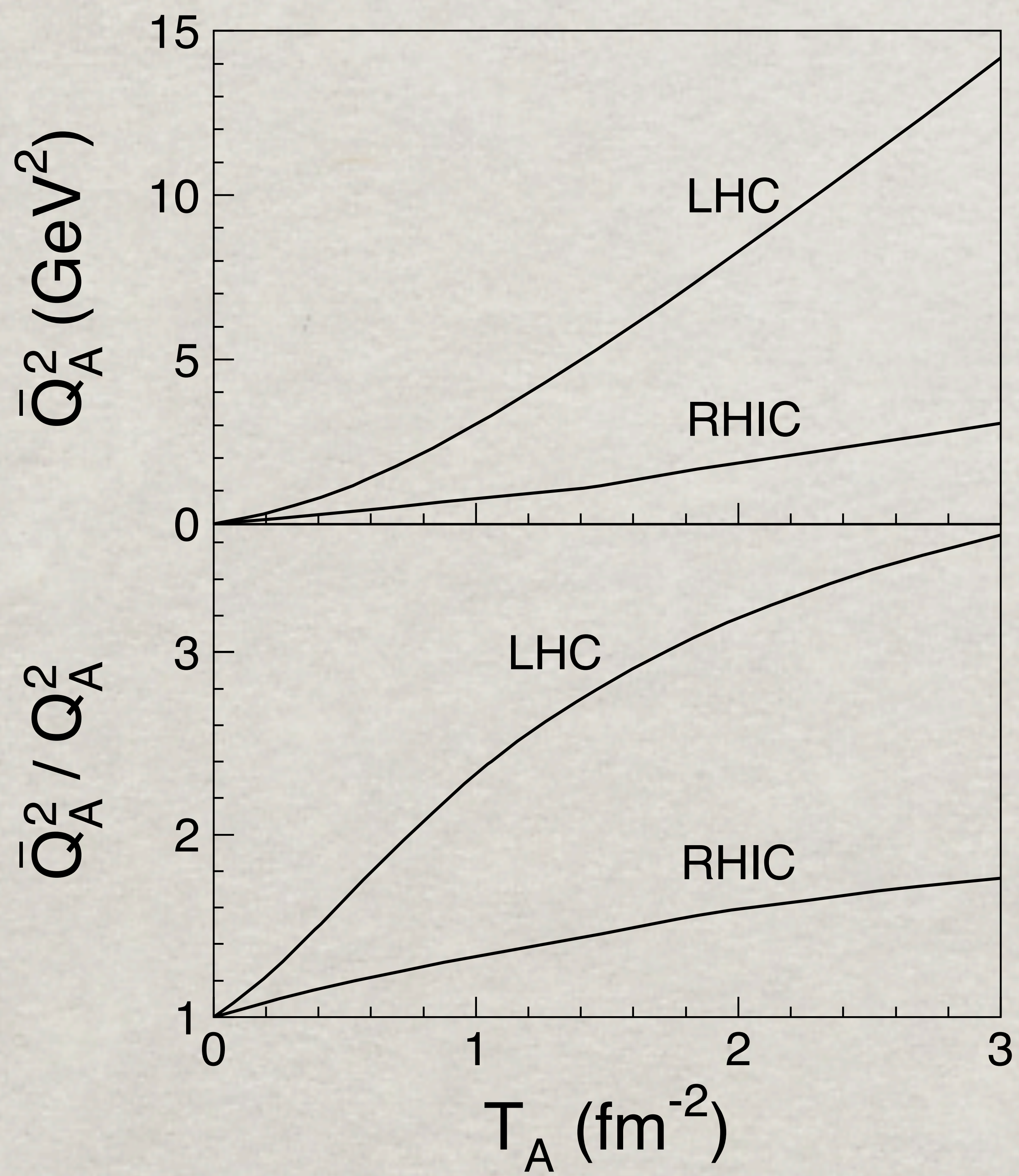
$$\tilde{Q}^2_{sA}(x_A) = \frac{3\pi^2}{2}\,\alpha_s(\tilde{Q}^2_{sB} + Q^2_0)\,x_A g_N(x_A, \tilde{Q}^2_{sB} + Q^2_0)\,T_A$$

where $x_{A,B}$ are the fractional light-cone momenta of the radiated gluon relative to the colliding nuclei, $x_A x_B = k_T^2/s$

Q^2_0 = 1.7 GeV^2 is chosen to get the right infra-red behavior.

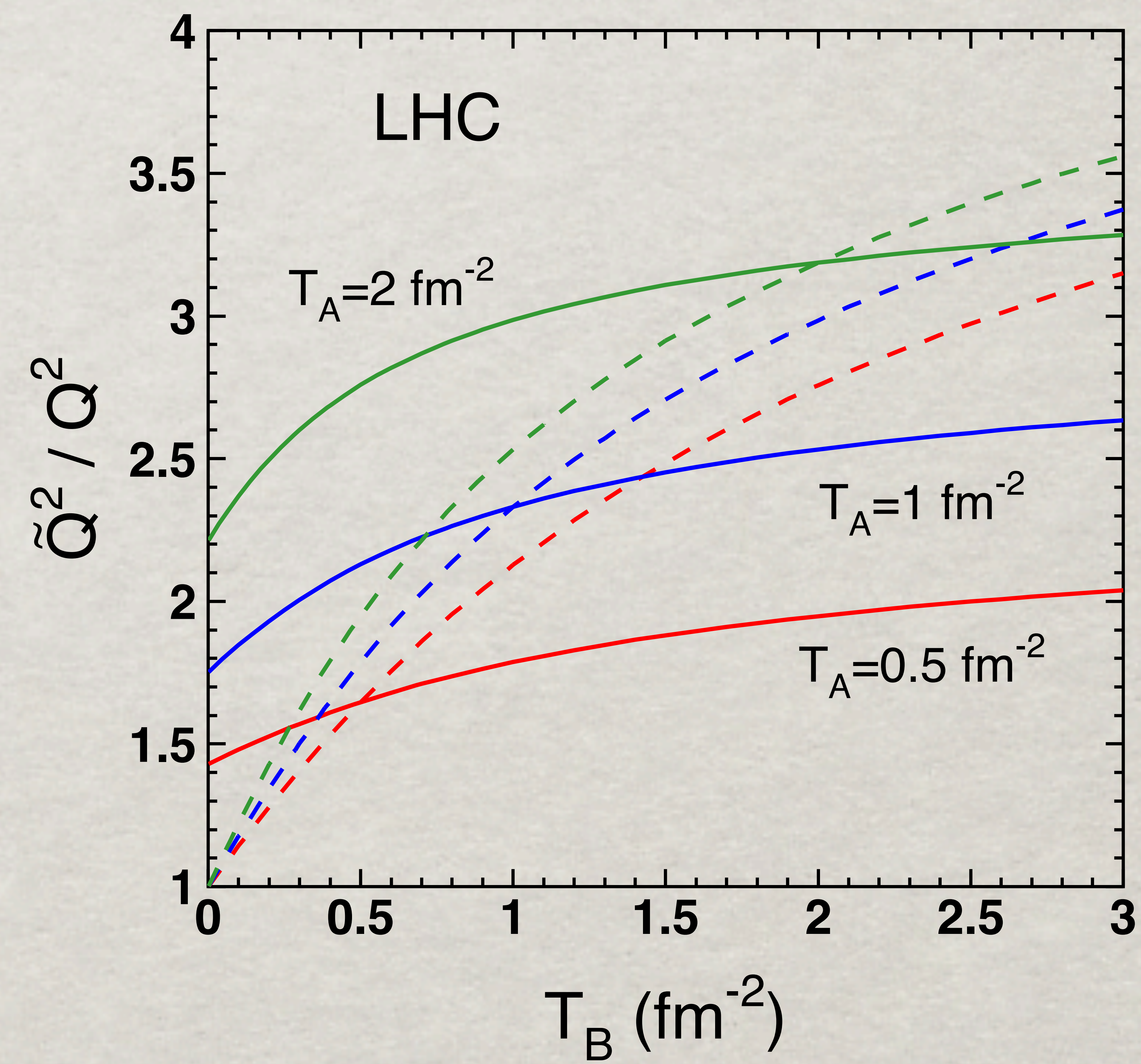
Saturation scale in AA vs pA

For central collisions TA = TB
the equations are easy to solve:



For non-central collisions TA ≠ TB

---- Q^2_B —— Q^2_A



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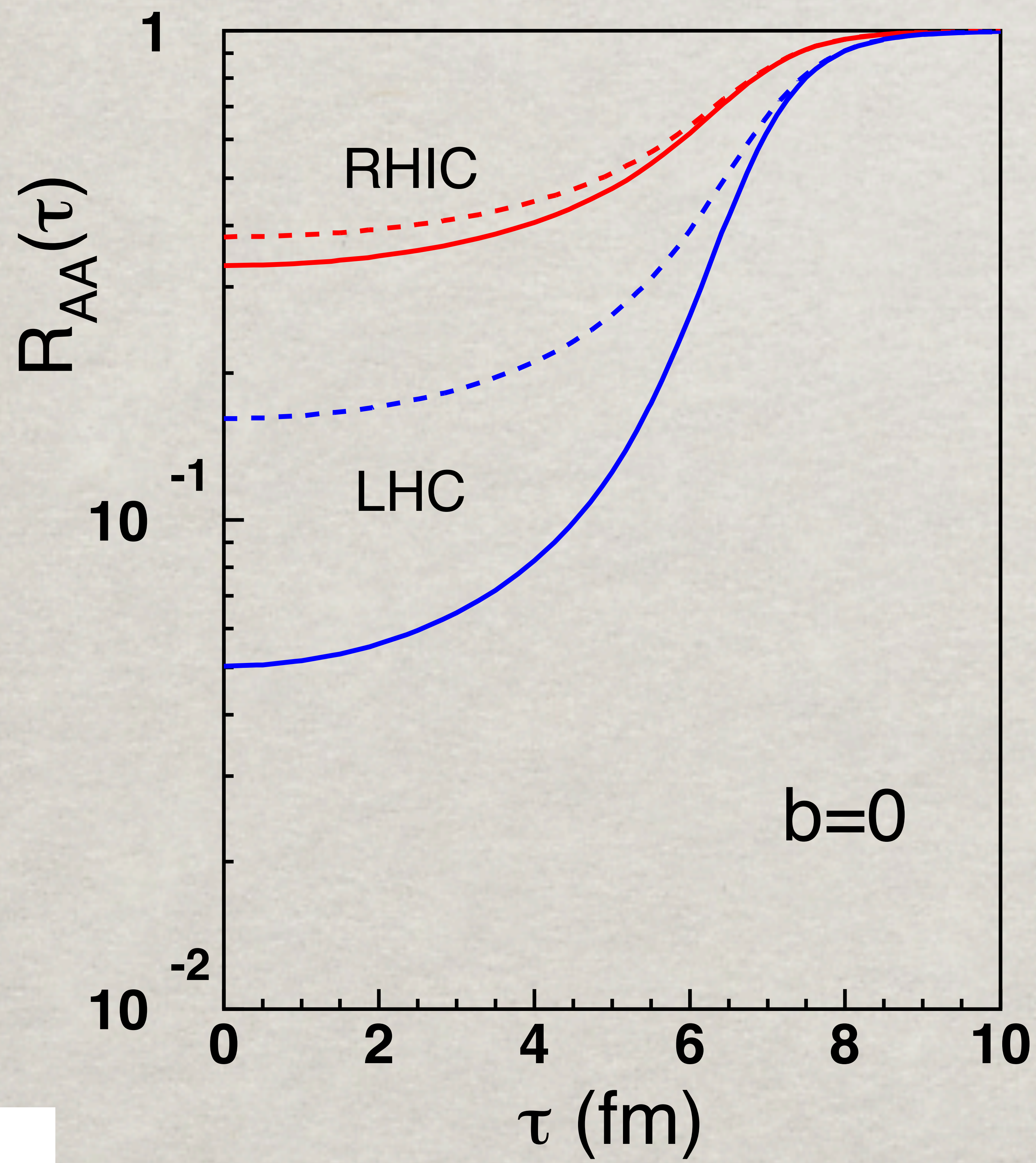
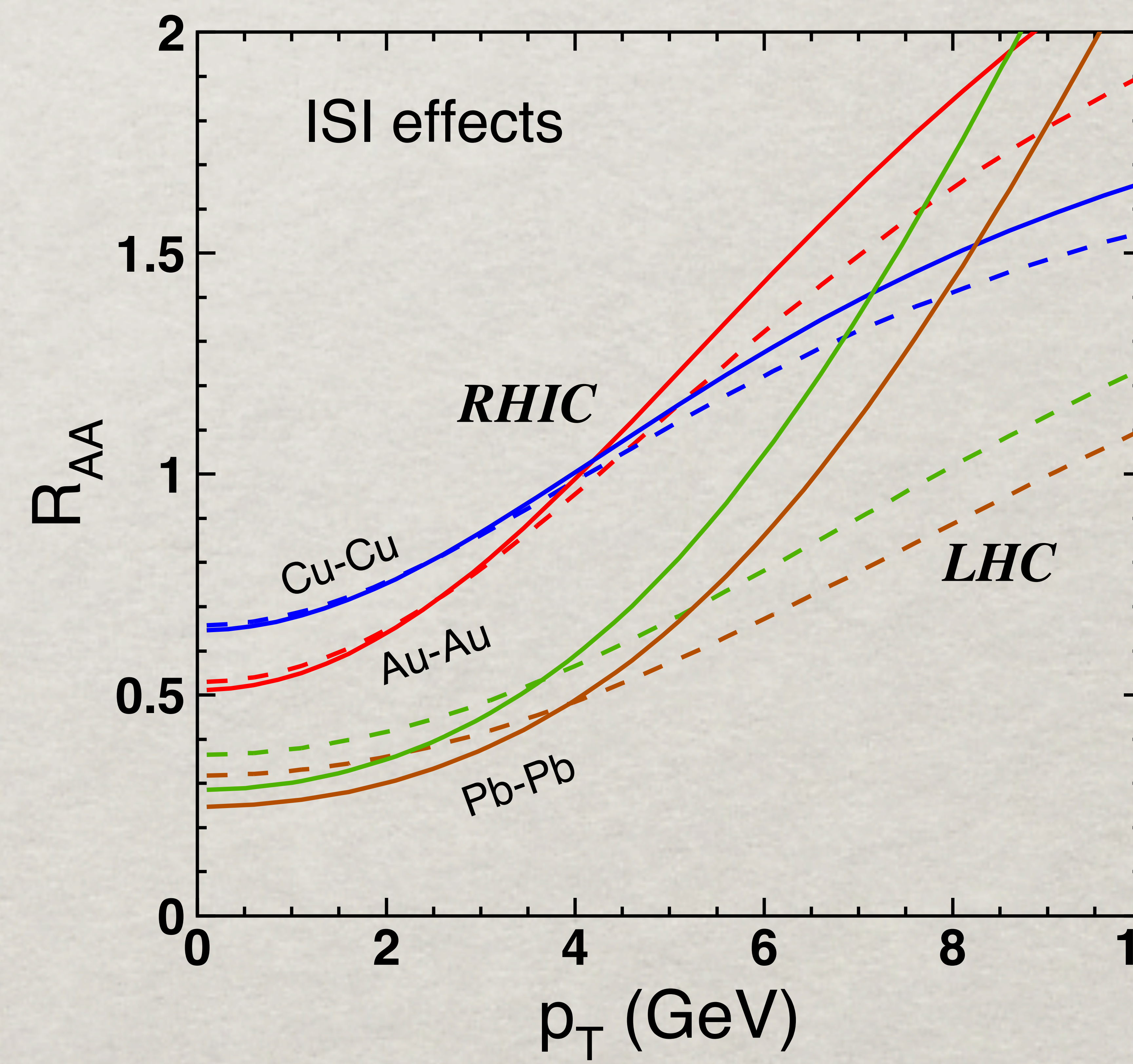
Boosted gluons in J/Ψ production

The boosted gluon density at small x in the colliding nuclei make the nuclear matter more opaques for color dipoles.



The shift of Q^2_s, i.e. of the mean transverse momentum, enhances the Cronin effect for J/Ψ.



B. Kopeliovich, Santiago 2017

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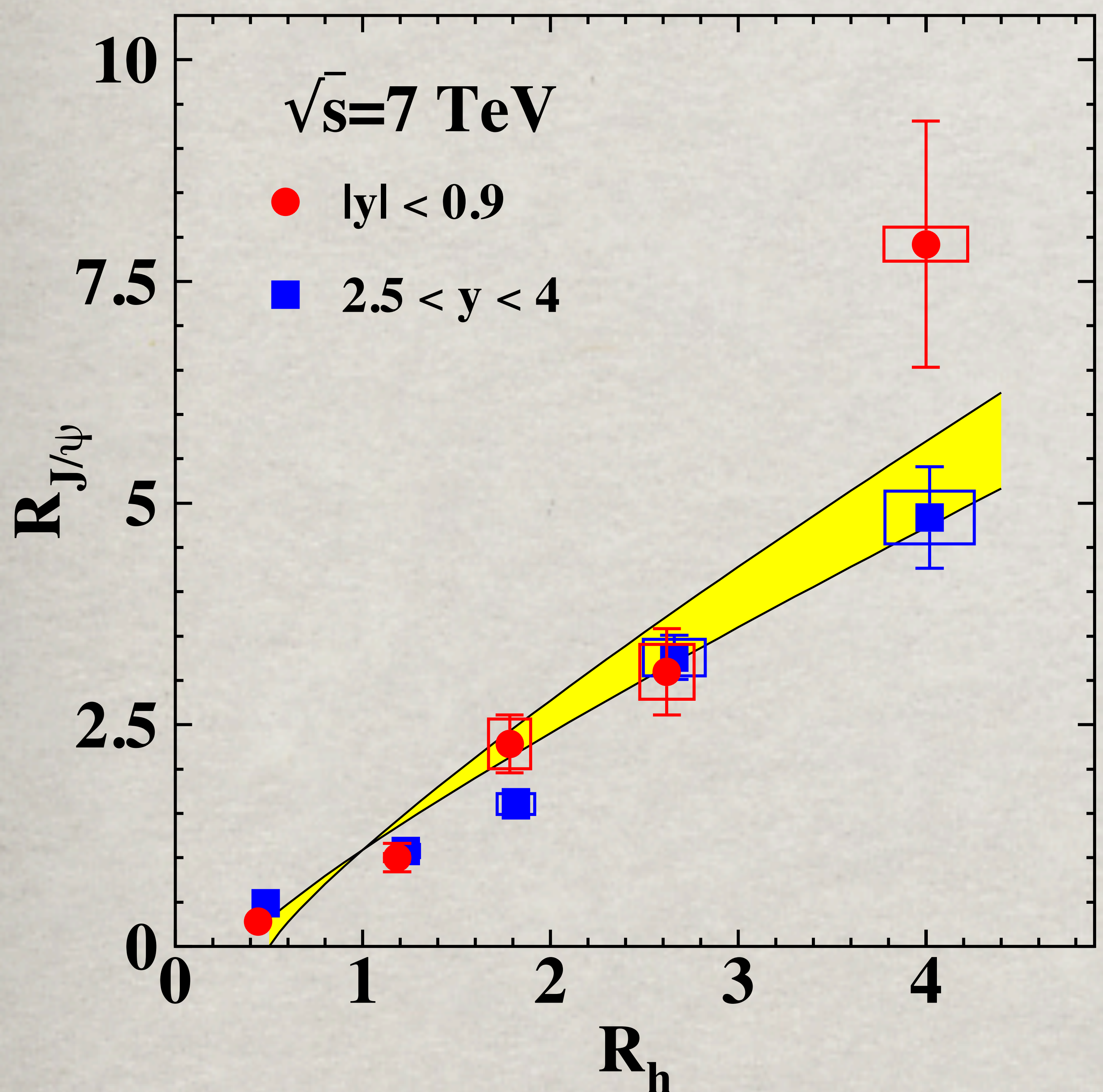
High multiplicity events in pp collisions

$$R_h^{pp} \equiv \frac{dN_h^{pp}/dy}{\langle dN_h^{pp}/dy \rangle} \qquad R_{J/\Psi}^{pp} \equiv \frac{dN_{J/\Psi}^{pp}/dy}{\left\langle dN_{J/\Psi}^{pp}/dy \right\rangle}$$



B.K., H.J.Pirner, I.K.Potashnikova, K.Reygers, I.Schmidt, PRD 88(2013)116002

Naive eikonal multi-Pomeron model, supplemented with the AGK cutting rules, leads to $R_{J/\Psi} = R_h$, contradicting data.

$$R = 1 + \beta(N_{coll} - 1)$$

Fit to pA data gives

$$\beta_h \approx 0.55$$

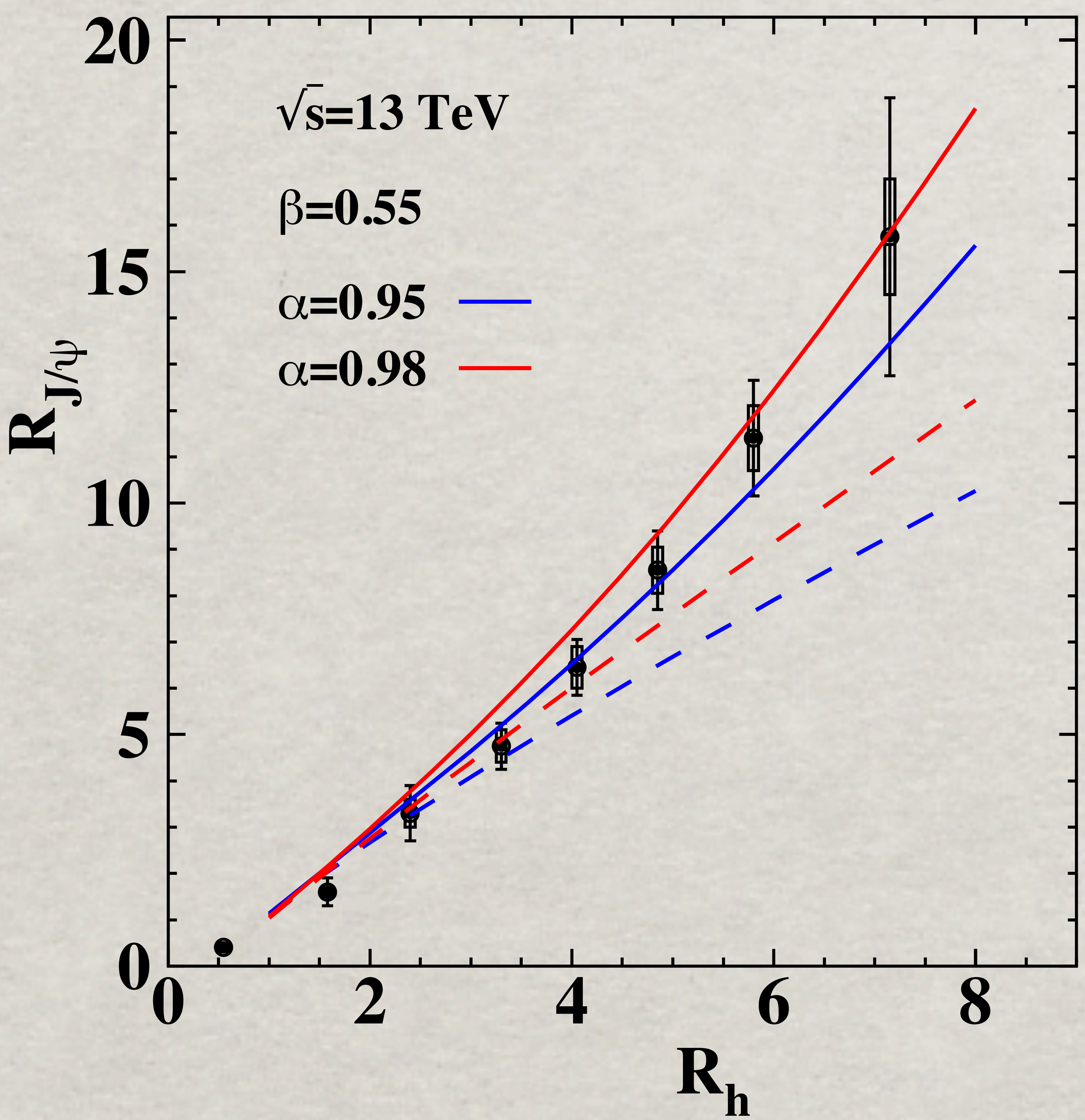
$$\beta_{J/\psi} \approx 1 - (1-\alpha)\ \ln A.$$

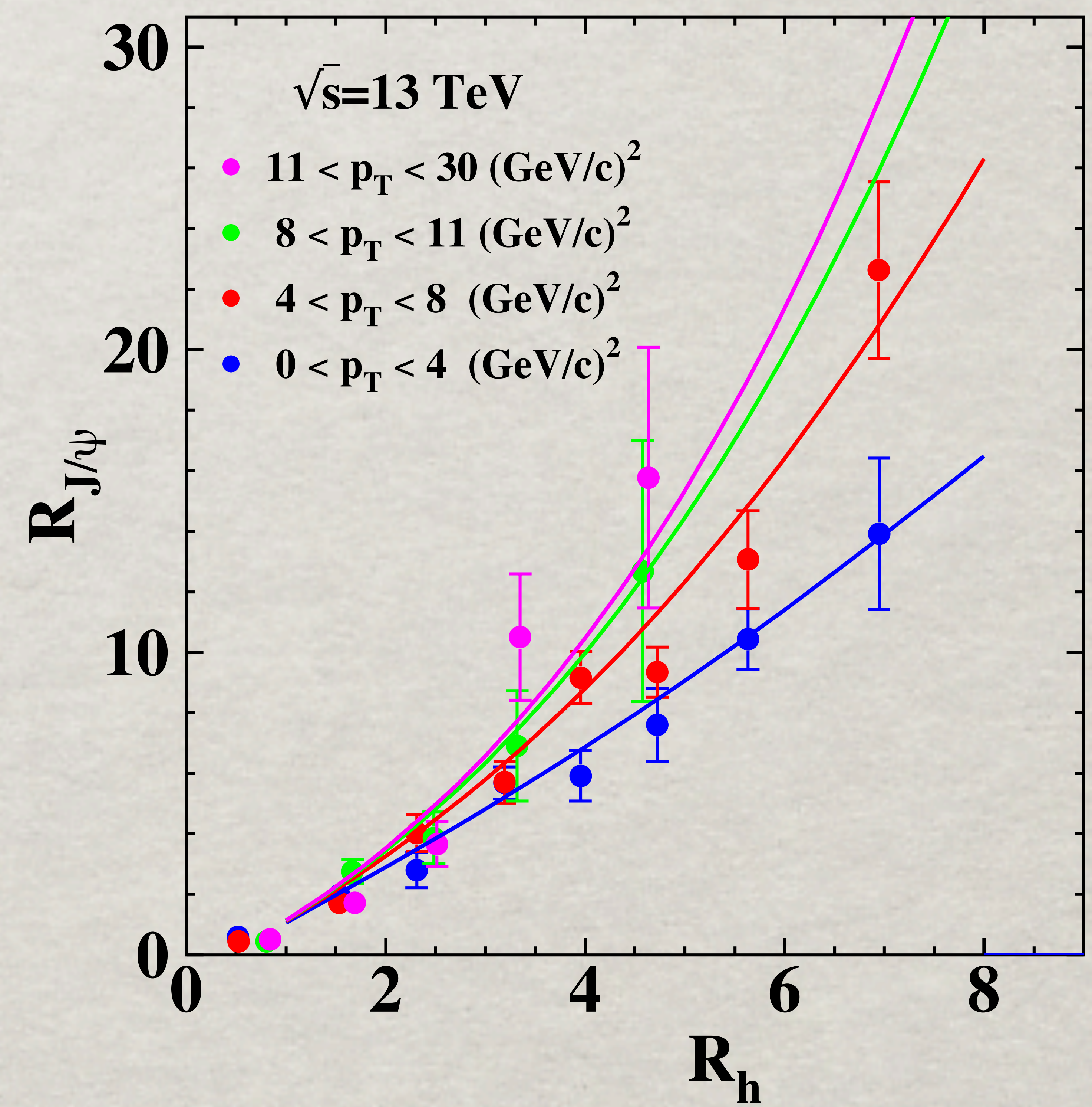
$$\sigma_{J/\psi} \propto A^{\alpha}$$

$$\alpha \approx 0.95 - 0.98$$

High multiplicity events in pp collisions

High multiplicity pp collisionsvare subject to parton saturation, as well as to the mutual boosting effect, which can be evaluated with the same bootstrap equations. As a result, **J/Ψ** is enhanced.



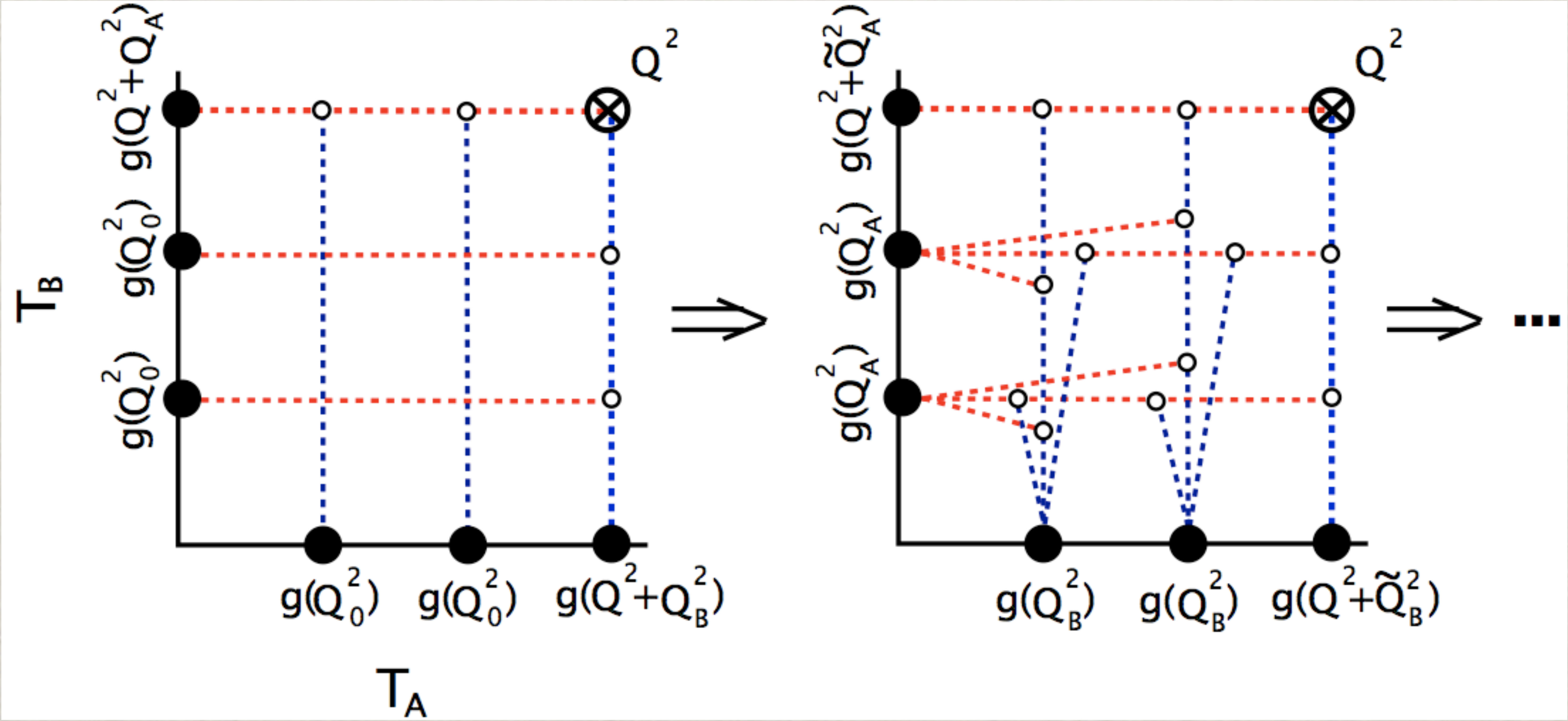


Summary

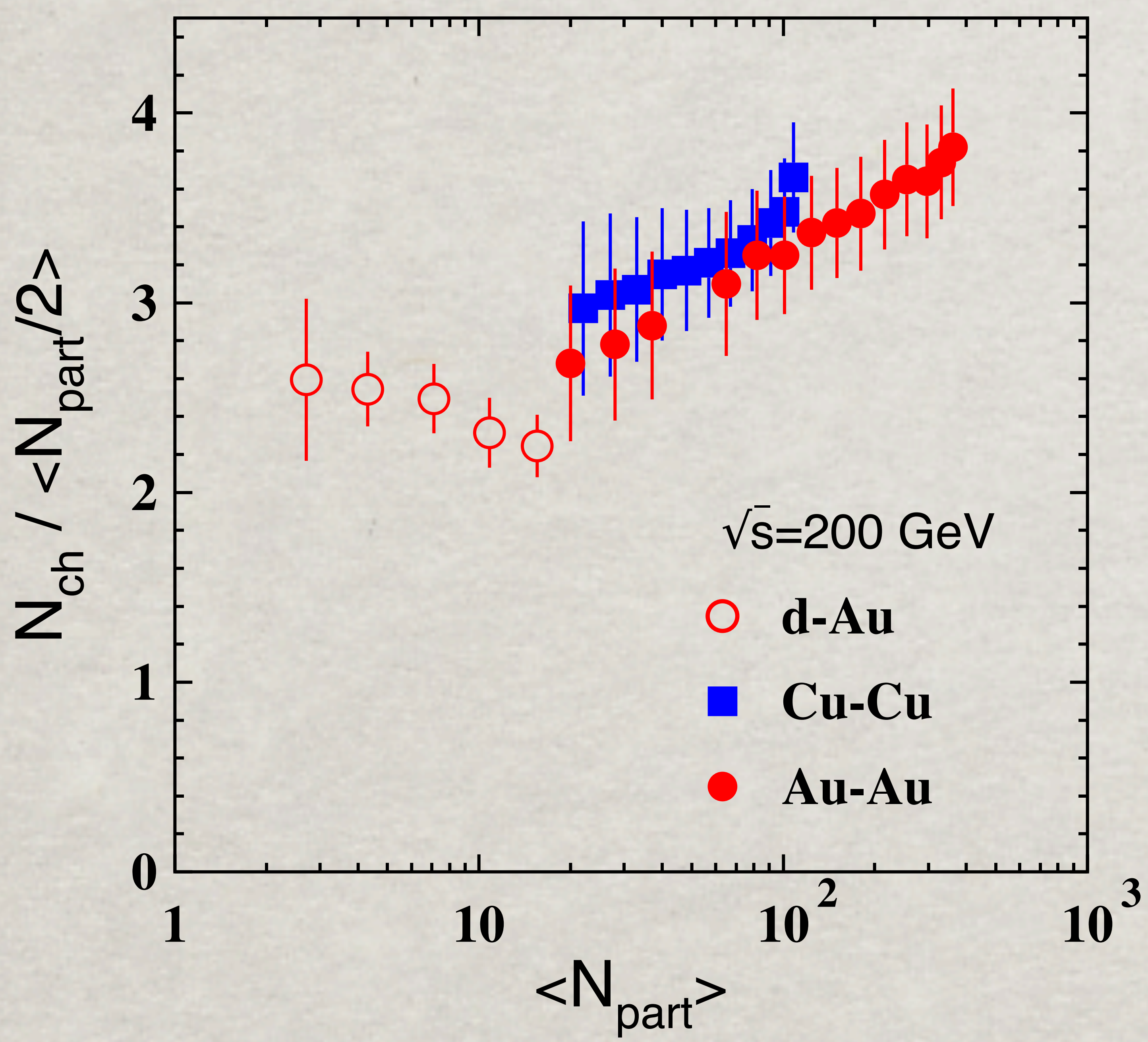
- Multiple interactions in pA collisions significantly modify the gluon PDF in the projectile proton, enhancing small, but suppressing large x. However, the PDFs of the target nucleons remain unchanged.
- The "cold" nuclear medium in AA collisions is not really cold. The PDFs in both nuclei are affected by multiple interactions. Their saturation scales are boosted up to the values significantly higher than in pA collisions.
- The nuclear medium in AA is more opaque for color dipoles (J/Ψ) than in pA collisions. No simple extrapolation from J/Ψ suppression in pA to the ISI effects in AA is possible.
- pp collisions with multiplicity much higher than averaged expose features similar to that in AA collisions, in particula saturation. Boosted saturation scale leads to enhancement of J/Ψ.

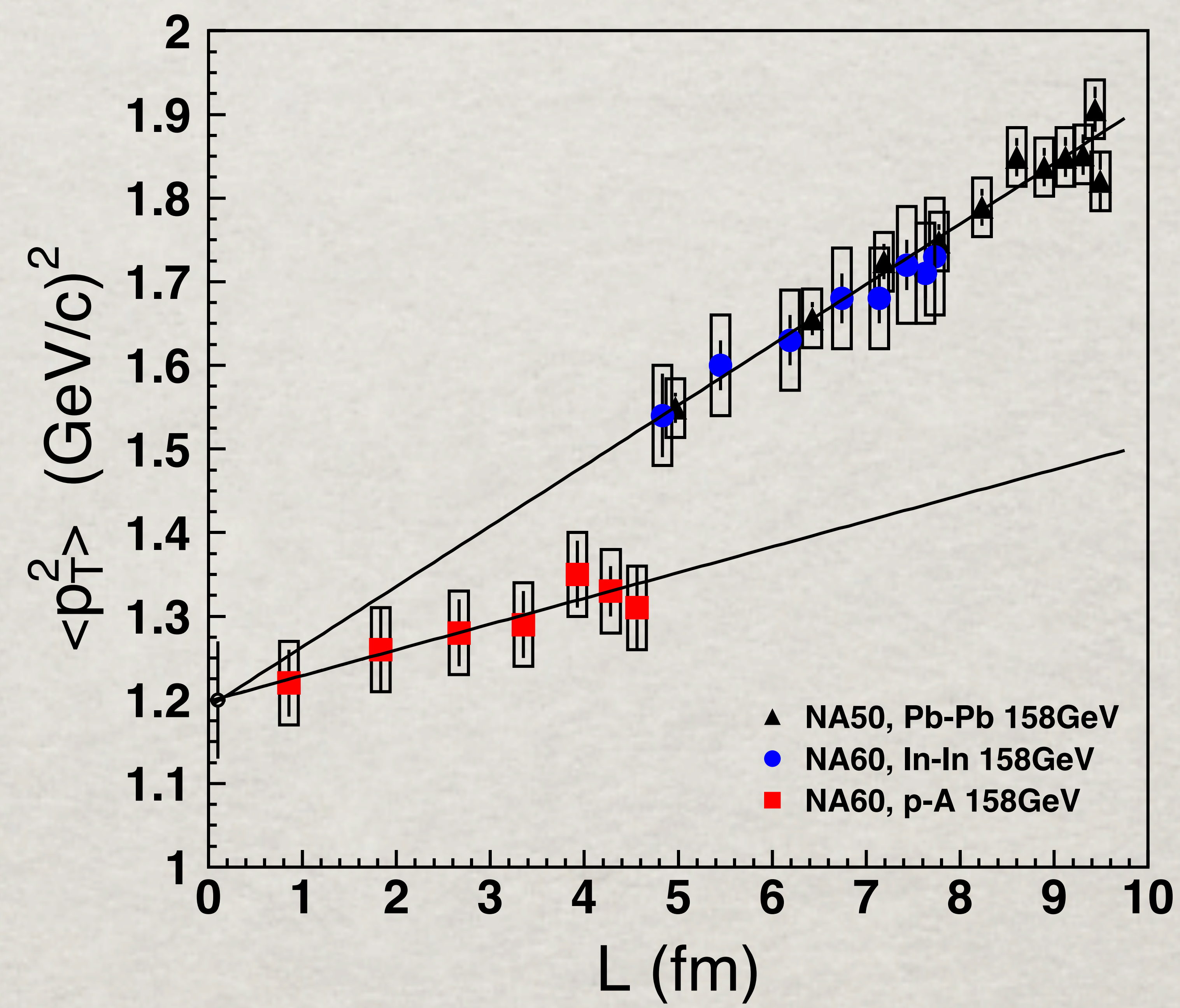
Mutual boosting of saturation scales

t-channel gluons in the rest frame of the nucleus **B**, become s-channel gluons propagating through the nucleus ***A*** in its rest frame. So even gluonic exchanges experience broadening and participate in the boosting of the saturations scales.



Other observables





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