Effects of saturation in high-multiplicity pp collisions

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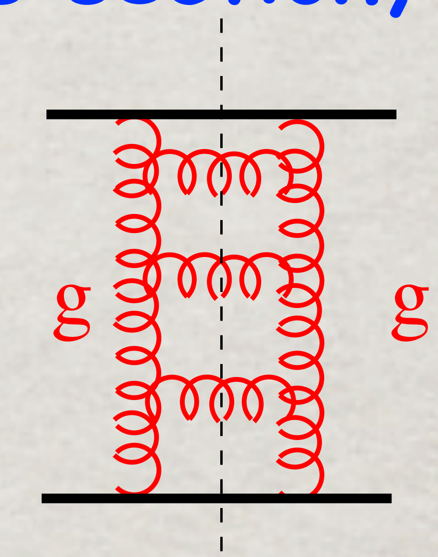
J/ψ in high multiplicity environment

Mechanisms of multi-particle production in pp, pA and AA collisions are poorly understood and based on models involving numerous ad-hoc assumptions.

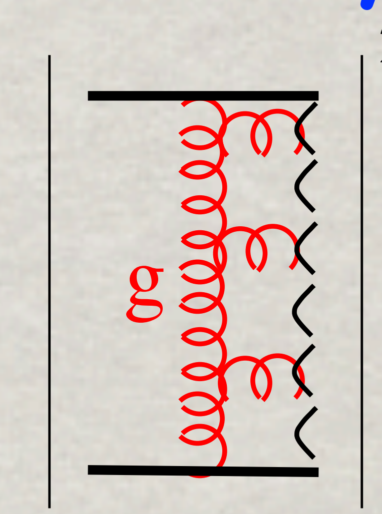
The popular eikonal or Glauber models provide information only about the elastic amplitude, which is related by unitarity with the total inelastic cross section, and do not say anything about the multiplicity distribution.

Example: unitarity cut of the Pomeron

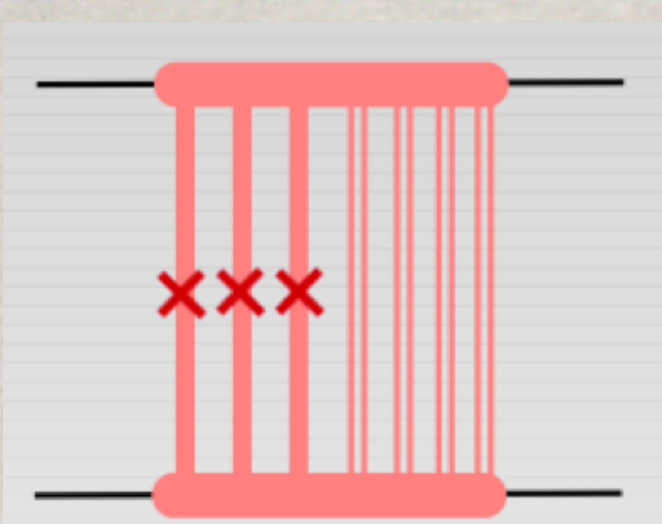
$2\,\mathrm{Im}\, f_{el} =$



$=$



The ambitious problem of relation between different terms in the elastic amplitude and inelastic processes was solved by Abramovsky, Gribov and Kancheli (AGK cutting rules). The main assumption is invariance of the multi-Pomeron vertex relative to different unitarity cuts.



The number of cut Pomerons, called number of collisions $\mathbf{N_{coll}}$ controls the hadron multiplicity

$$\langle \mathbf{n_h} \rangle \propto \mathbf{N_{coll}}$$

Uncut Pomerons play role of absorptive corrections, i.e. shadowing

AGK cancellation

The inelastic cross section is subject to shadowing. It does not need the AGK rules, but is derived directly from the eikonal (Glauber) model.

AGK cancellation:

Inclusive cross section is not affected by shadowing.

$$\sigma_{\mathbf{incl}} \propto \mathrm{N}_{\mathbf{coll}}$$

AGK rules confront data

With notations for the normalized multiplicities of light hadrons and J/ψ

$$\mathbf{R_h \equiv \frac{dN_h/dy}{\langle dN_h/dy\rangle}} \qquad \mathbf{R_{J/\Psi} \equiv \frac{dN_{J/\Psi}/dy}{\langle dN_{J/\Psi}/dy\rangle}}$$

Naively, one would expect $\mathbf{R_{J/\Psi} = R_h = N_{coll}}$, however

$\mathbf{R_h^{pA} = 1 + \beta_h(N_{coll} - 1)}$ with $\beta_\mathbf{h} \approx \mathbf{0.55}$, nearly independent of energy.

Similar, although smaller effect of suppression is observed for J/ψ production in pA,

$$\mathbf{R_{J/\Psi}^{pA} = 1 + \beta_{J/\psi}(N_{coll} - 1)}$$

usually parametrized as $\mathbf{R_{J/\Psi}^{pA} = N_{coll} A^{\alpha-1}}$, with α=0.95-0.98.

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

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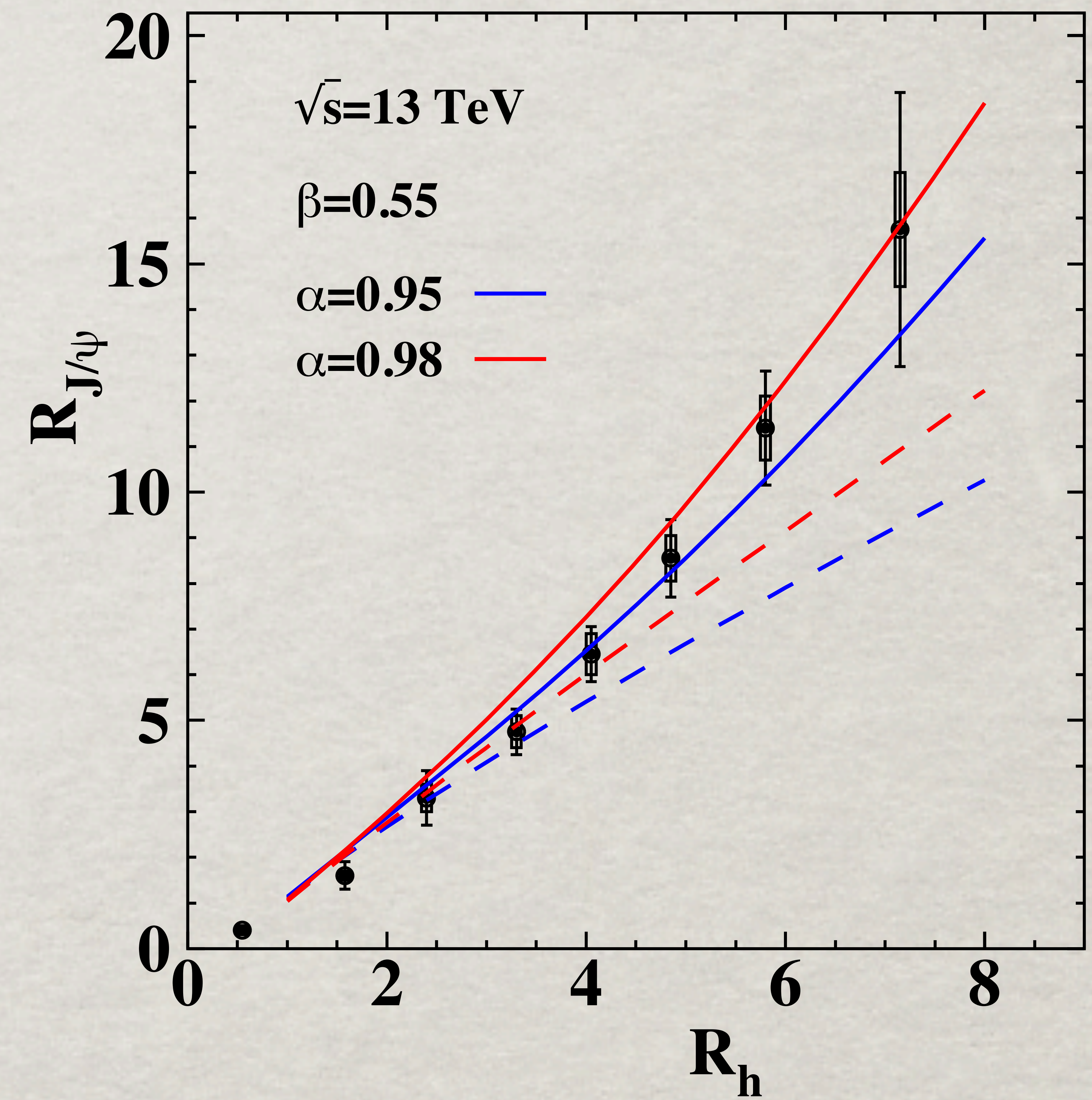
J/ψ vs pions

Breakdown of AGK happens for several reasons, higher twist quark shadowing; enhanced Pomeron graphs; coherence (gluon shadowing, Landau-Pomeranchuk effect). Difficult to evaluate, better rely on data.

$$\frac{\mathbf{R}^{\mathbf{pA}}_{\mathbf{J/\Psi}} - \mathbf{1}}{\mathbf{R}^{\mathbf{pA}}_{\mathbf{h}} - \mathbf{1}} = \frac{\beta_{\mathbf{J/\psi}}}{\beta_{\mathbf{h}}}$$



BK, I.Potashnikova, H.J.Pirner & K.Reygers, PRD 88(2013)116002

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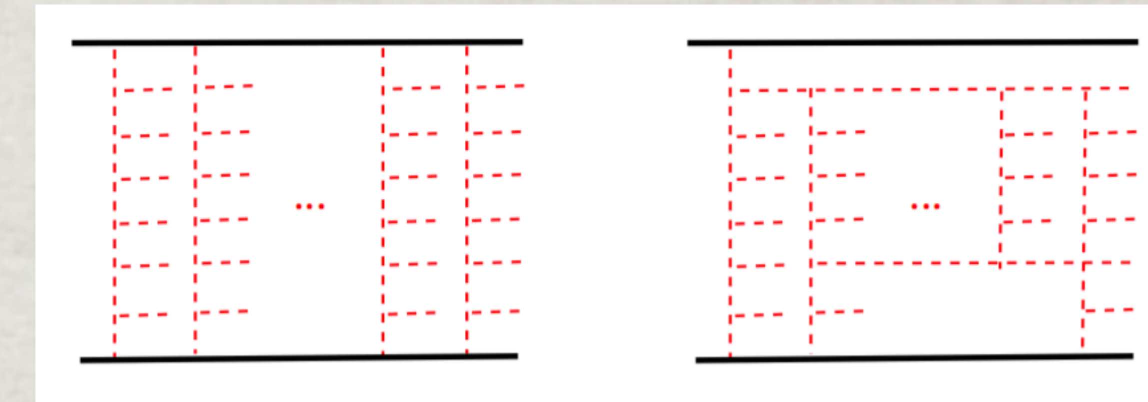
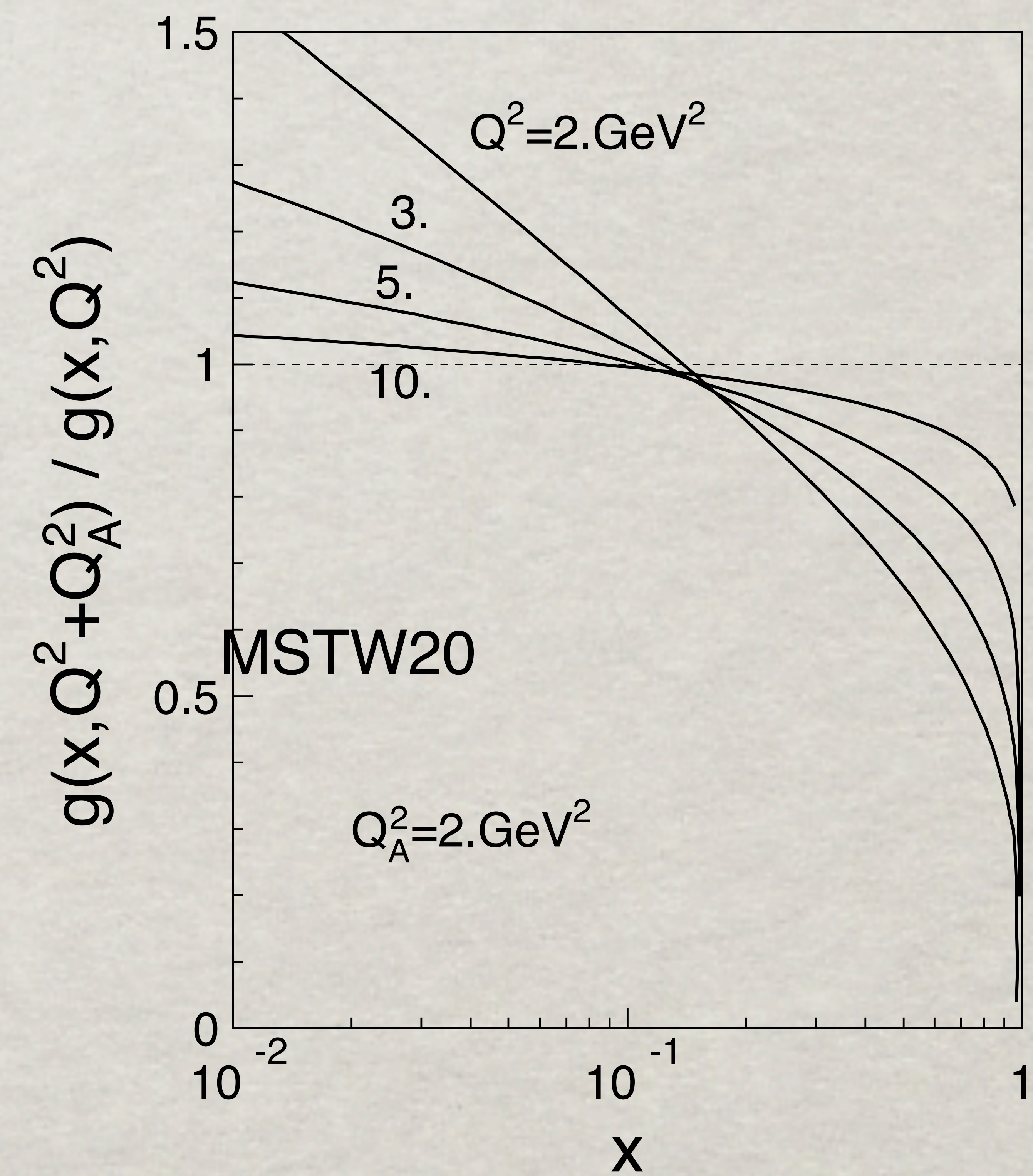
Effects of parton saturation



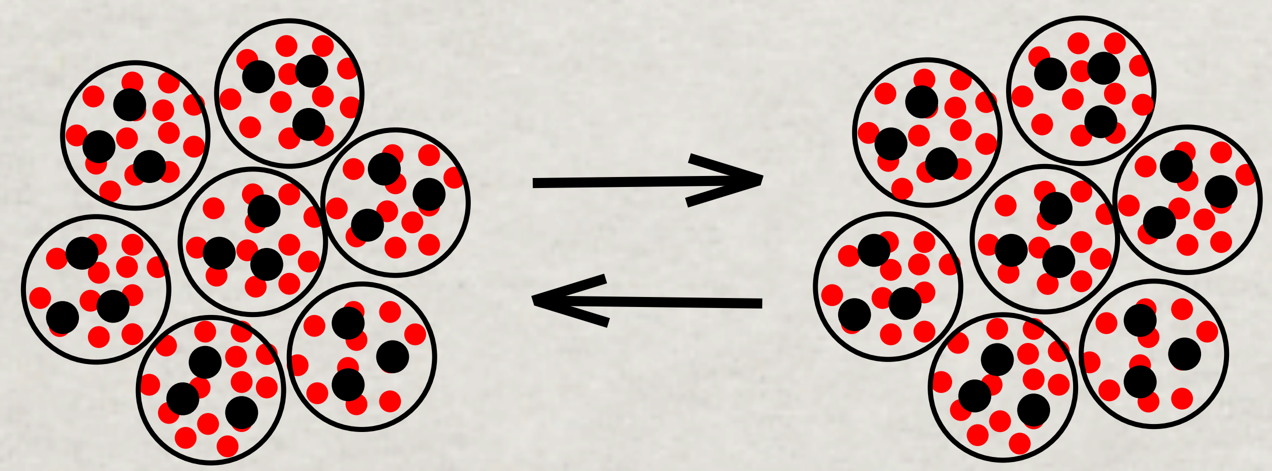
Due to broadening the nuclear target probes the parton distribution in the beam hadron with a higher resolution, so in a hard reaction the effective scale Q^2 for the beam PDF drifts to a higher value $Q^2 + Q_A^2$. More gluons at small x.



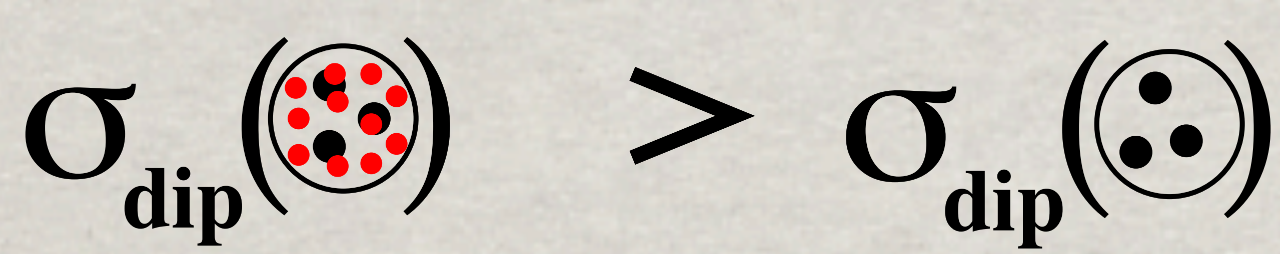
The production rate of J/ψ is increased by saturation.

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

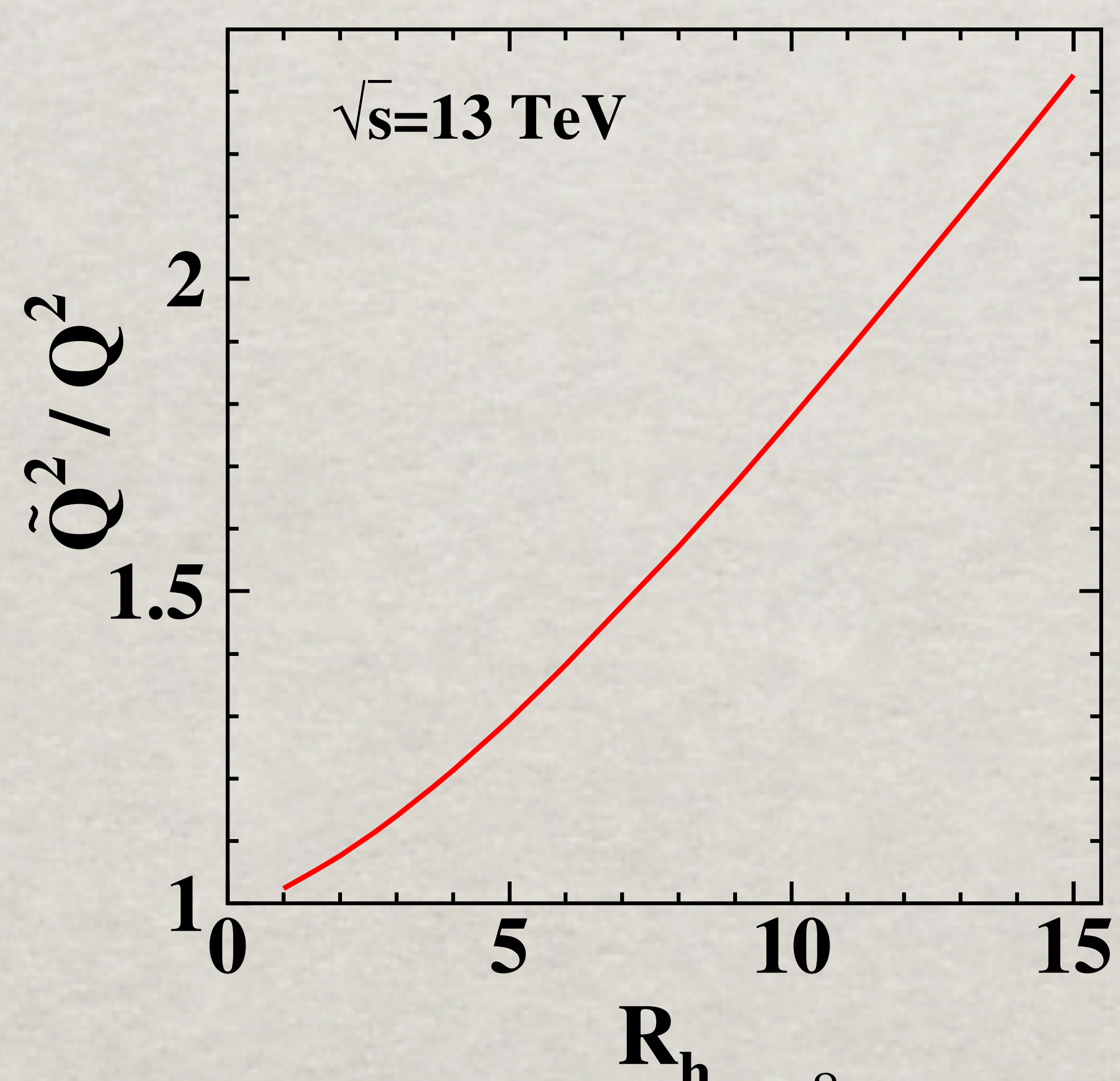
Mutual boosting of the saturation scale

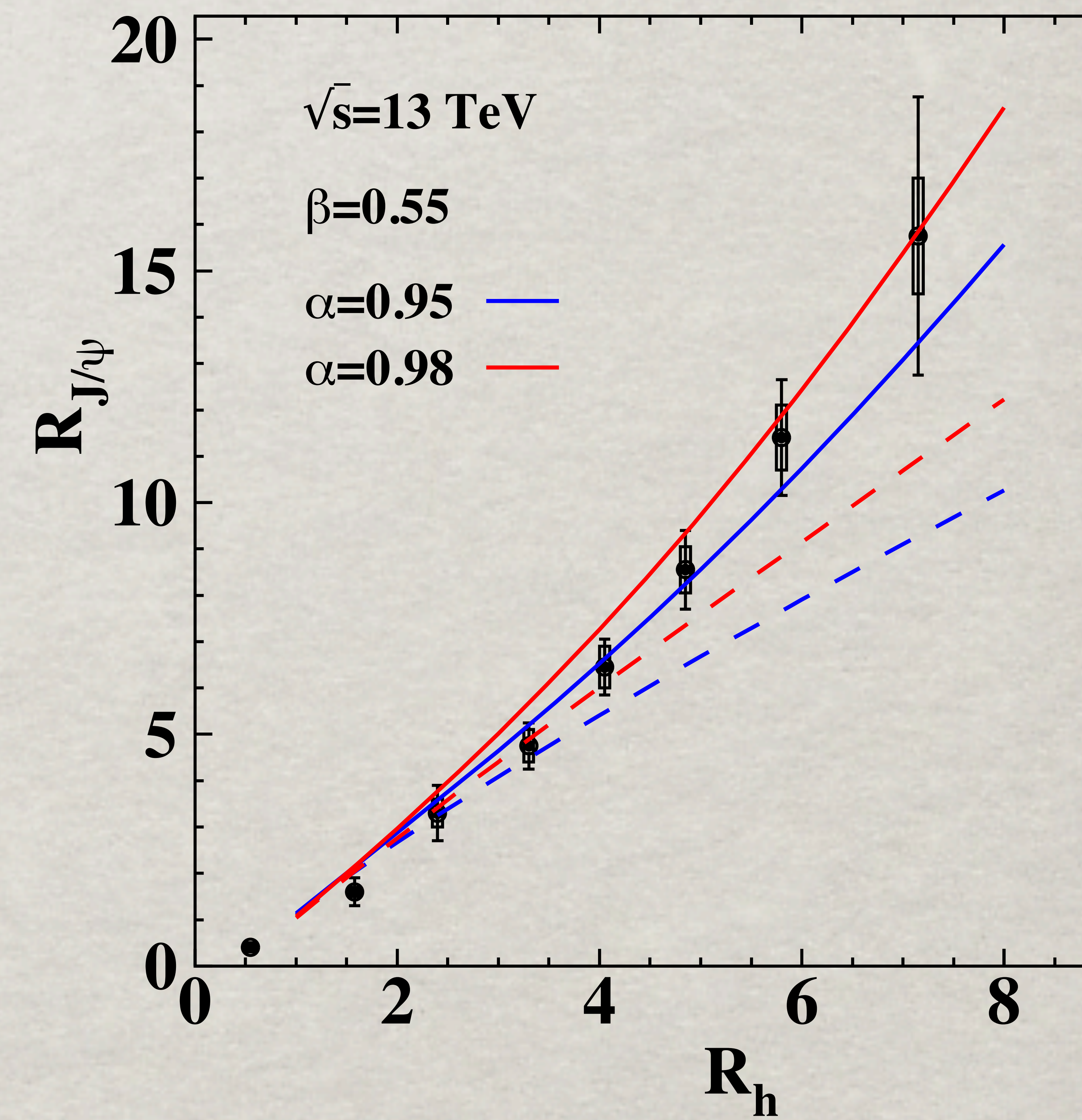
In pA collisions only the projectile proton undergoes multiple interactions, which modify its PDF, while the PDFs of bound nucleons remain unchanged. In the case of AA, or high multiplicity pp collisions, the interaction becomes symmetric, both assembles of colliding constituents are subject to multiple interactions, increasing their partonic content at small x.

$$\tilde{\mathbf{Q}}^2_{\mathbf{sA}}(\mathbf{x}) = \frac{3\pi^2}{2}\,\alpha_s(\tilde{\mathbf{Q}}^2_{\mathbf{sA}}+\mathbf{Q}_0^2)\,\mathbf{x}\mathbf{g}_{\mathbf{N}}(\mathbf{x},\tilde{\mathbf{Q}}^2_{\mathbf{sA}}+\mathbf{Q}_0^2)\,\frac{\mathbf{N}_{\mathbf{coll}}}{\sigma^{\mathbf{pp}}_{\mathbf{tot}}}$$

$$\frac{3\pi^2}{2}\,\alpha_s(\mathbf{Q}_0^2)\,\mathbf{x}\mathbf{g}(\mathbf{x},\mathbf{Q}_0^2)=\mathbf{C}(\mathbf{E}),$$

BK, I.Potashnikova, H.J.Pirner & I.Schmidt, PLB 697(2011)333





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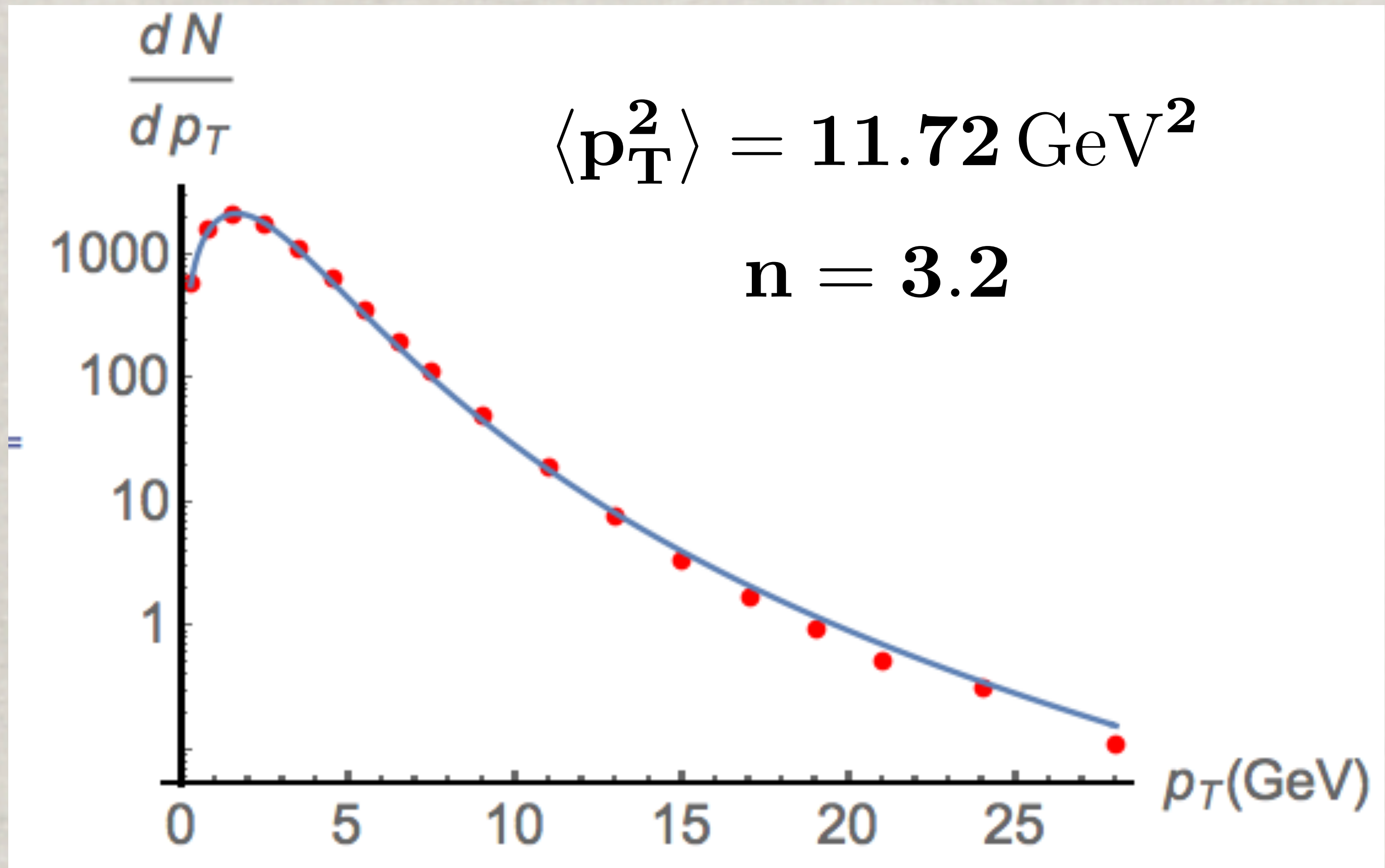
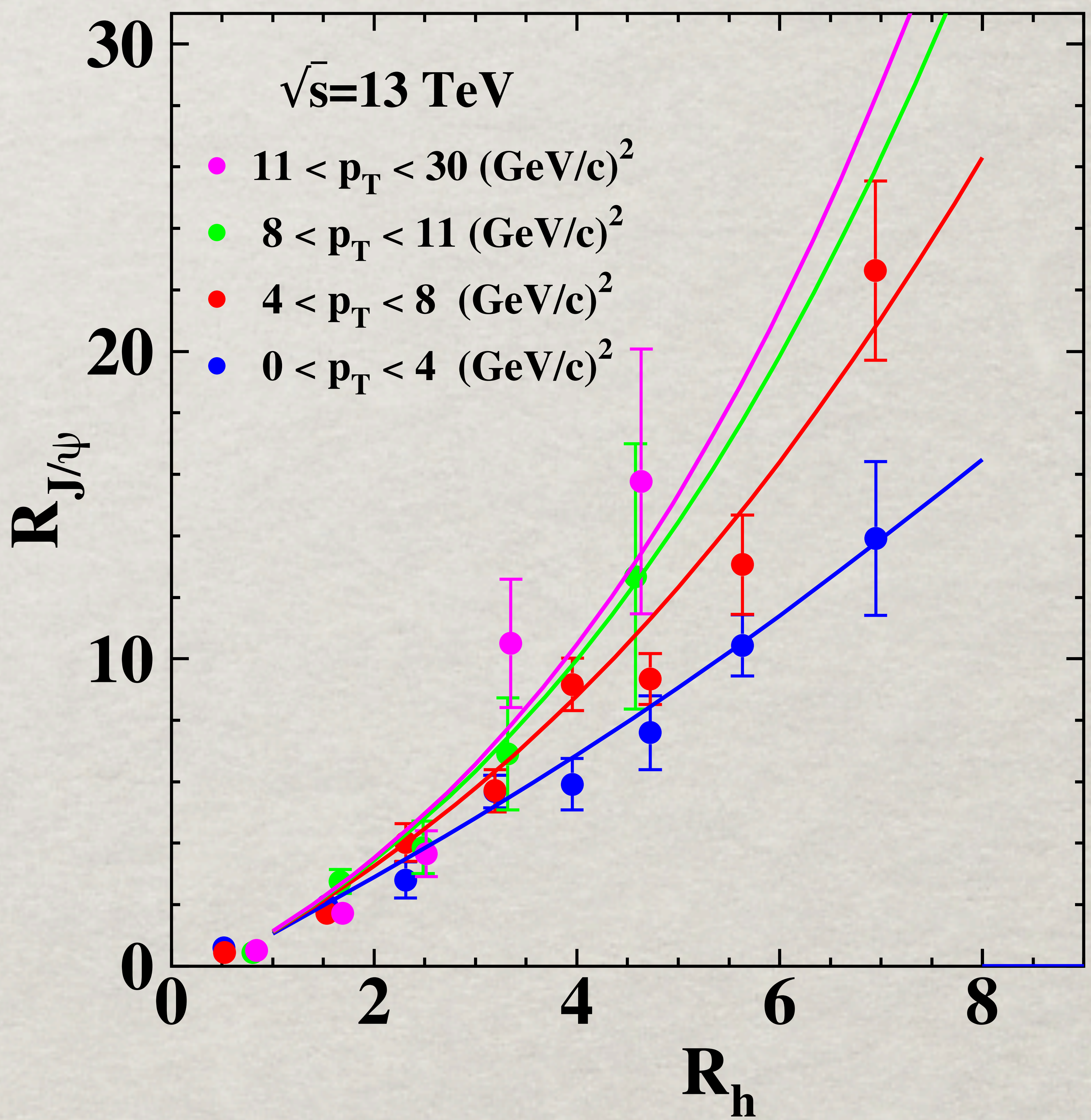
Effects of parton saturation in pT intervals

$$R_{J/\psi}(p_T) = \frac{\int_{p_T^{min}}^{p_T^{max}} dp_T p_T \, dN^{pp}_{J/\psi}(R_h)/dyd^2p_T}{\int_{p_T^{min}}^{p_T^{max}} dp_T p_T \left\langle dN^{pp}_{J/\psi}/dyd^2p_T \right\rangle}$$

$$\frac{dN^{pp}_{J/\psi}}{dyd^2p_T} = \frac{dN^{pp}_{J/\psi}}{dy} \frac{1}{\langle p_T^2 \rangle} \left(1 + \frac{p_T^2}{(n-2)\langle p_T^2 \rangle}\right)^{-n}$$





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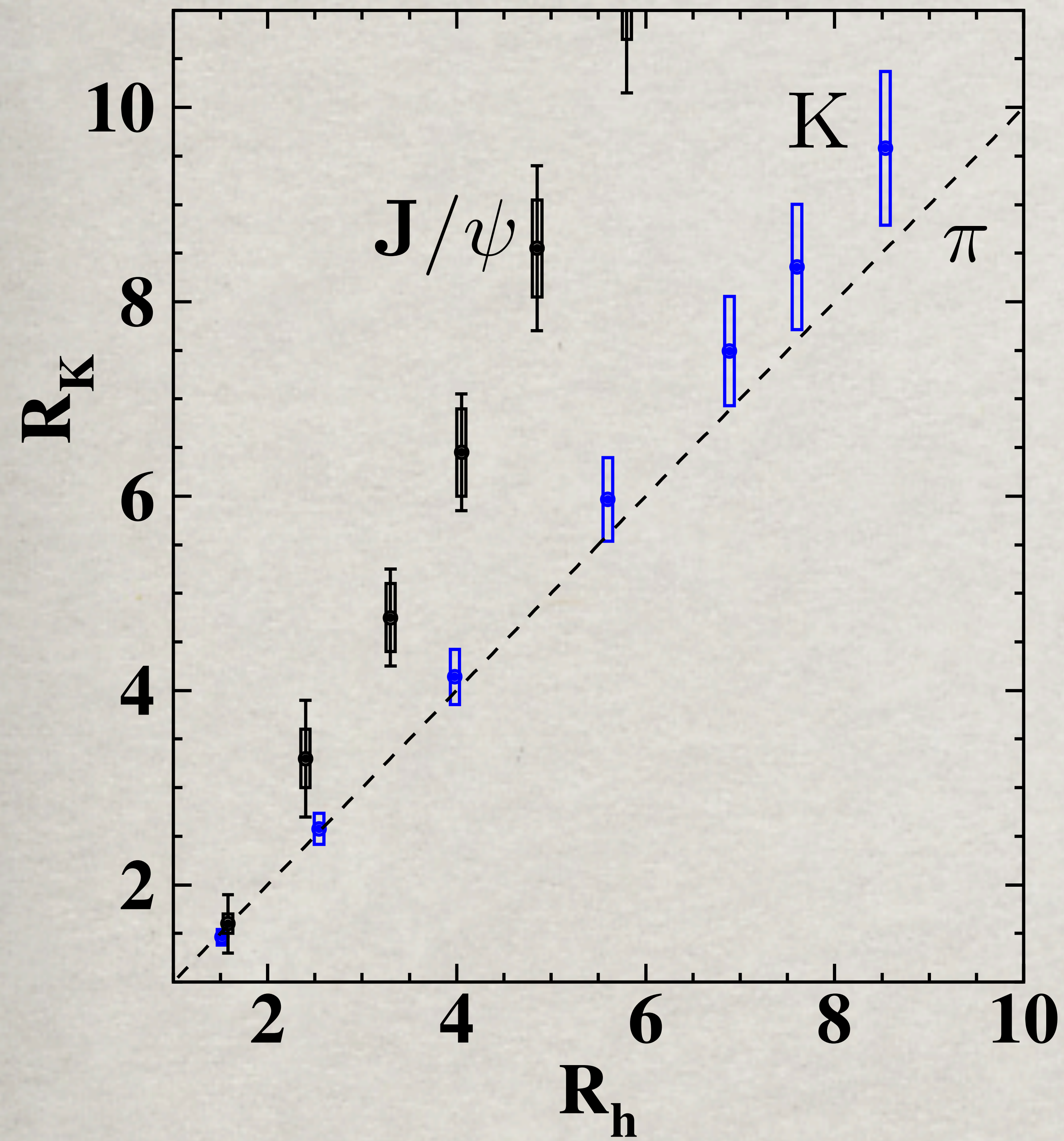
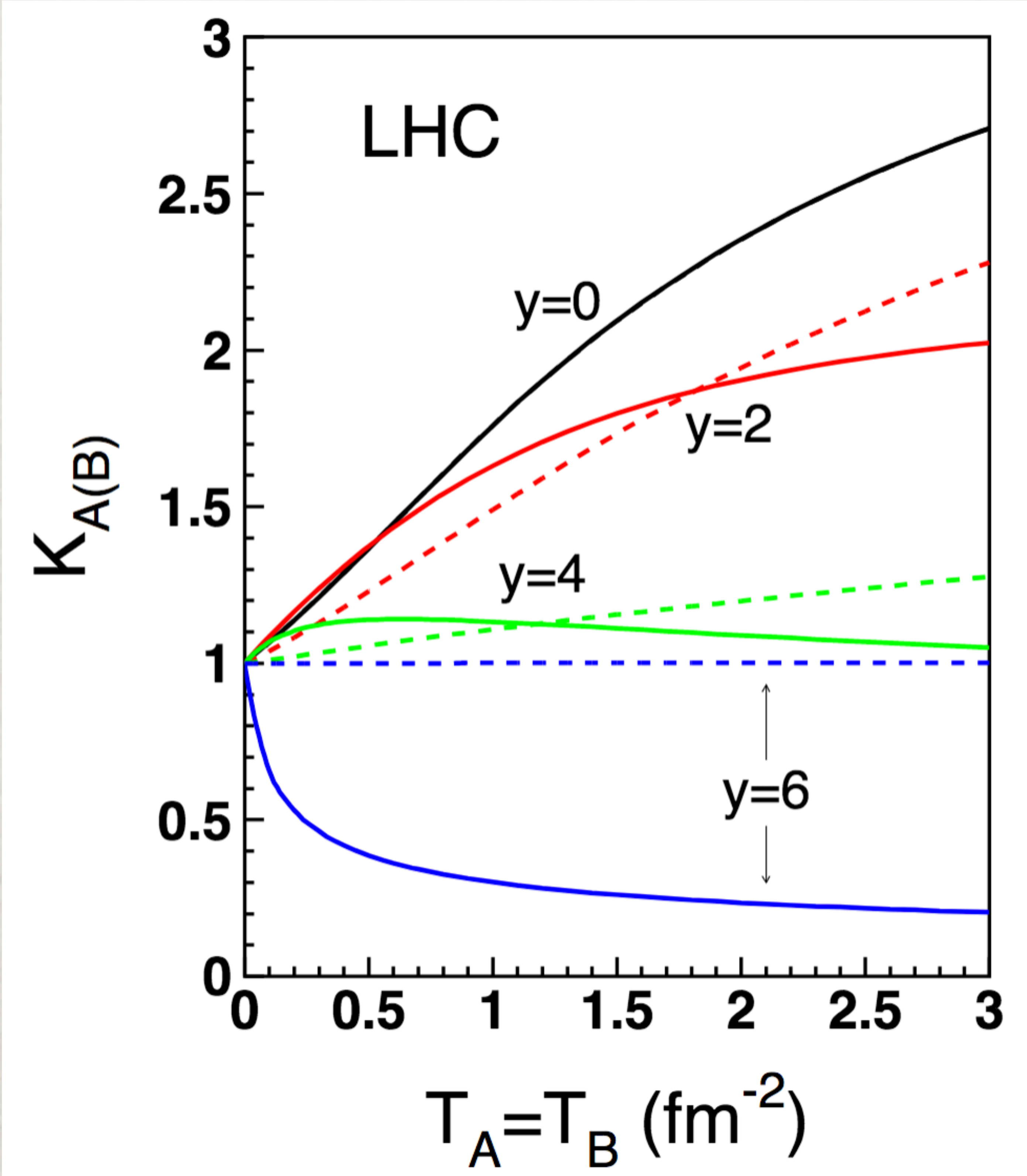
Rapidity dependence



Kaons rise steeper than pions, but less than J/ψs

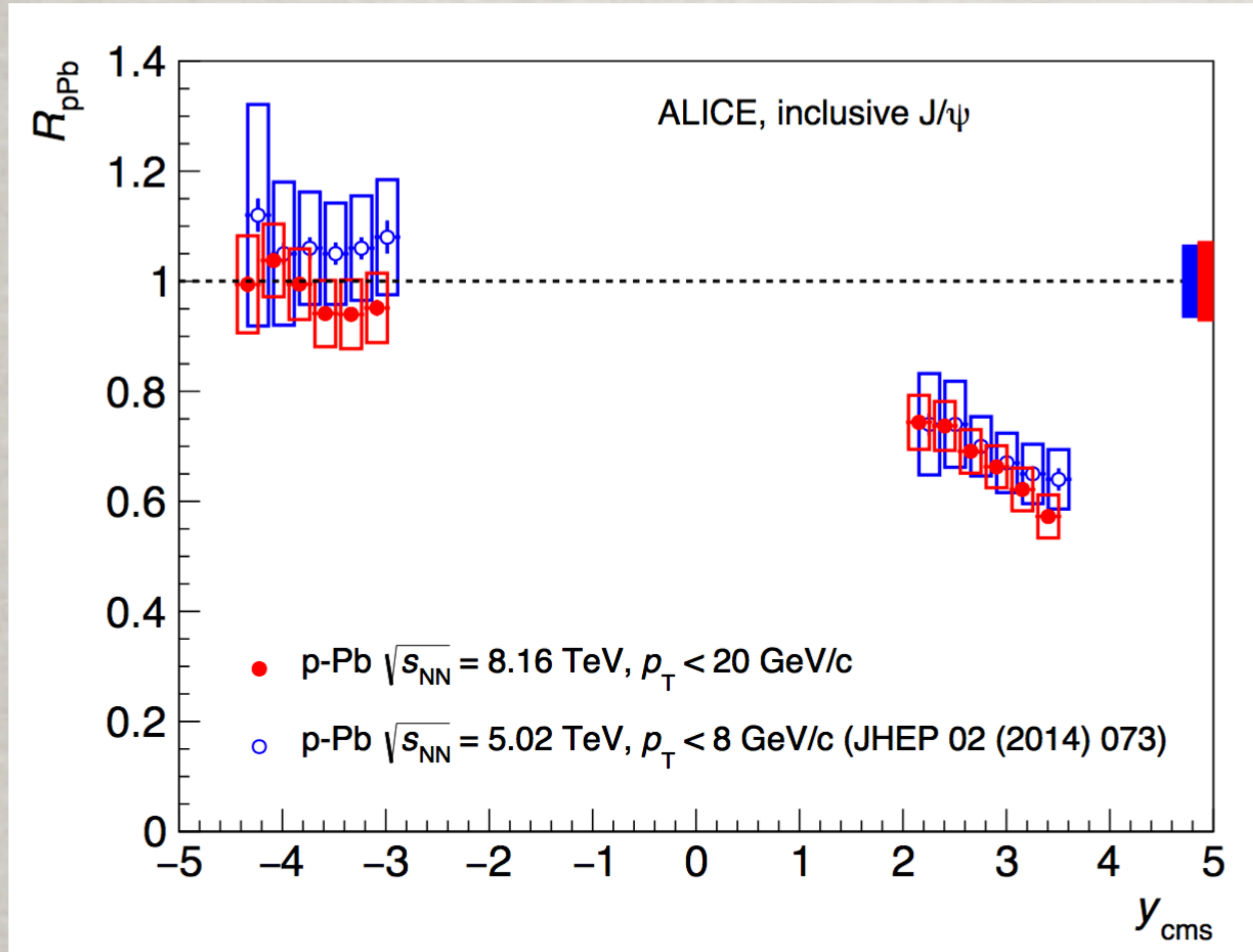
$$K_A = \frac{\tilde{Q}^2_{sA}}{Q^2_{sA}}$$

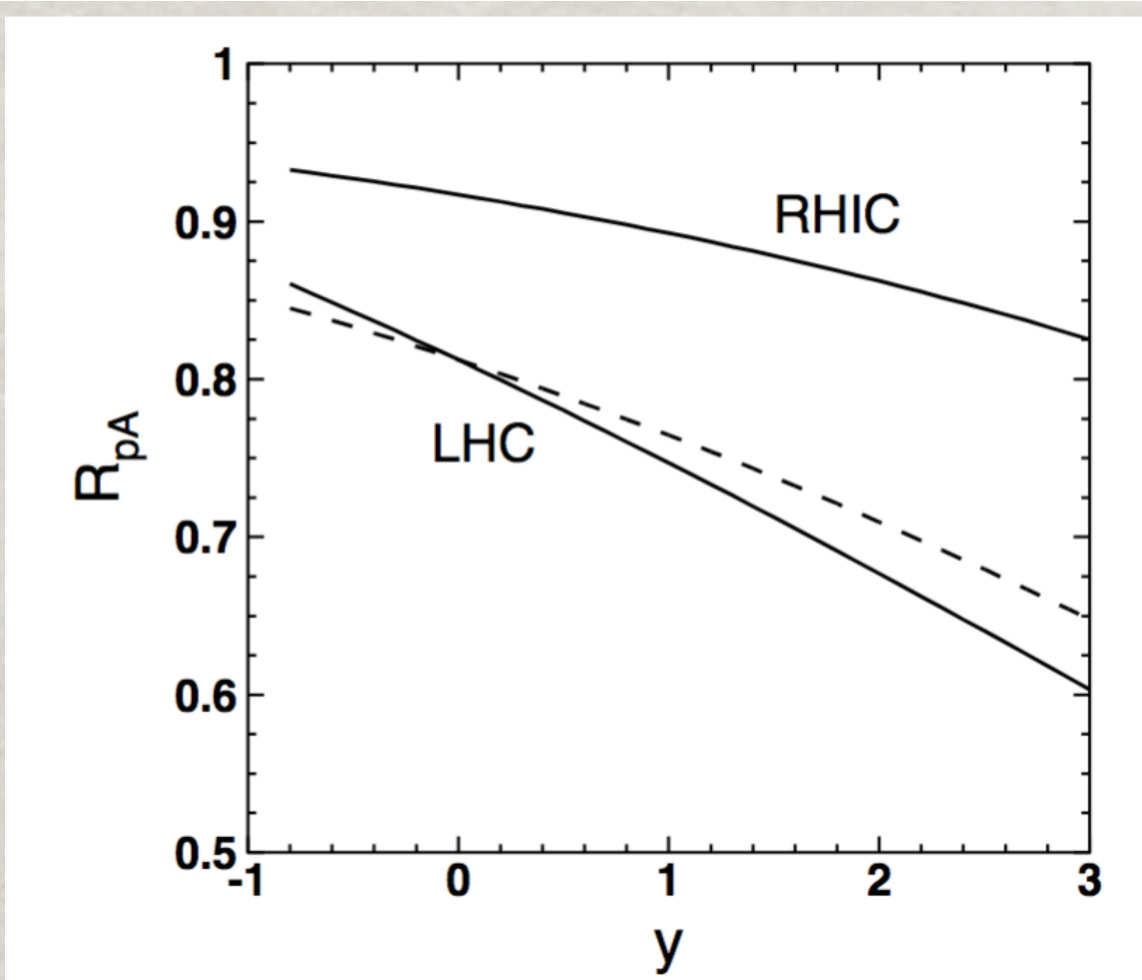
BK, I.Potashnikova, H.J.Pirner & I.Schmidt, PR C83(2011)014912



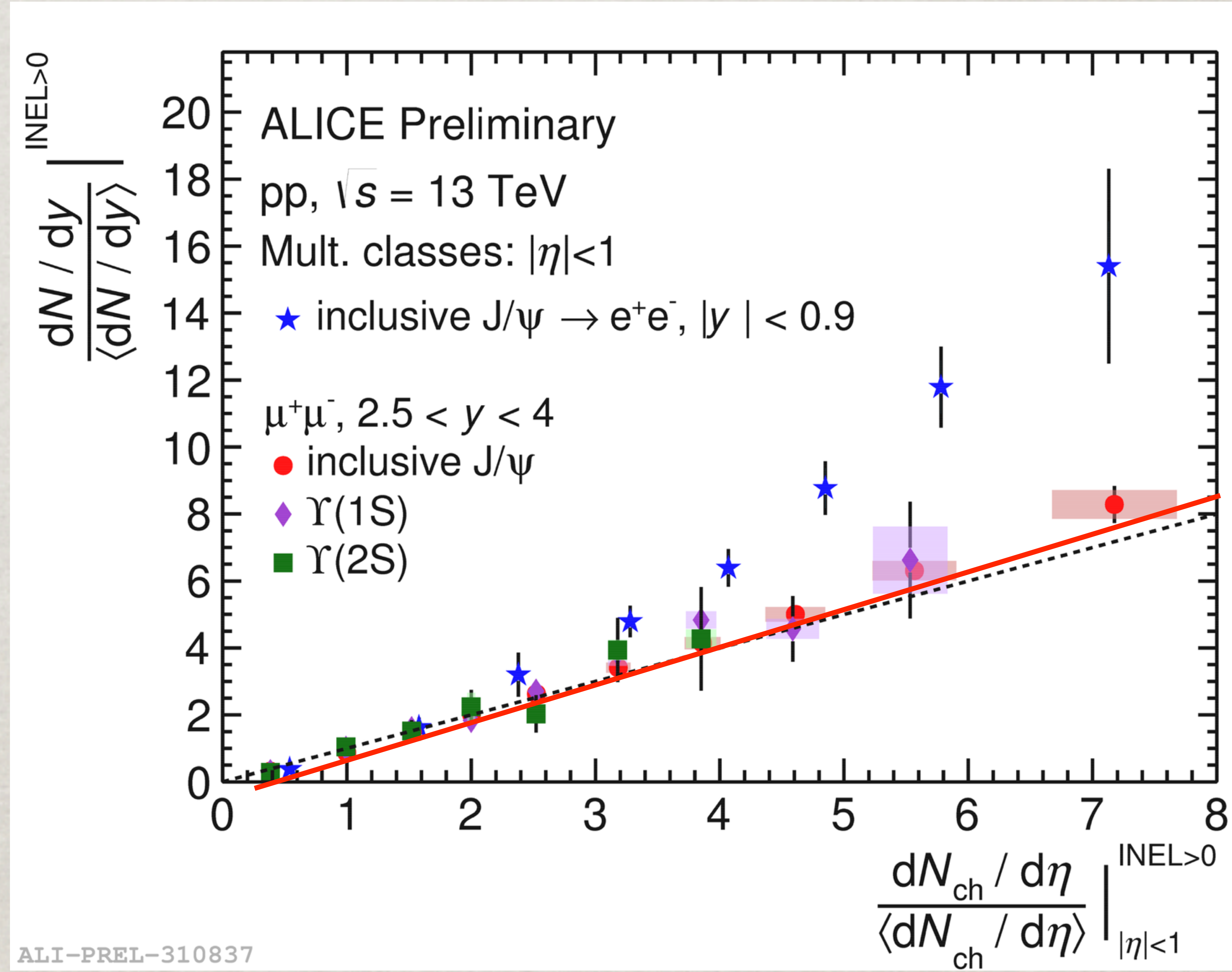
The boosting effect vanishes at forward rapidities.

Rapidity dependence





BK, I.Potashnikova, H.J.Pirner & I.Schmidt, PR C83(2011)014912



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Summary

- Multiplicity distribution in pp and pA collisions are described basing on the AGK cutting rules. The main (poorly proven) idea is equivalence of different unitarity cuts of the multi-Pomeron vertex. It allows to make a bridge to the Glauber/eikonal model.
- AGK rules are broken by the coherence effects and higher-twist quark shadowing, more for light than for heavy quarks. This is why J/Ψs rise with multiplicity faster than kaons. Reliable evaluation of AGK breaking effects is difficult (nonperturbative physics), so we rely on available experimental information.
- Coherence leads to pT broadening in high-multiplicity events, which is equivalent to the effect of parton saturation.Appearance of the saturation scale leads to a DGLAP enhancement of low-x gluons. Mutual enhancement of low-x gluons in the two colliding hadrons (pp, AA) results in a rather strong boost of the saturation scales.
- At forward rapidities the boosting effect of the saturation scale vanishes. Besides, nuclear suppression increases. As a results, the J/Ψ rate vs pions falls down.