Effects of saturation in high-multiplicity pp collisions

Ivan Schmidt
UTFSM, Valparaiso
Chile

In collaboration with:

Boris Kopeliovich
Irina Potashnikova
Hans-Jürgen Pirner
Klaus Reygers

Main point

High multiplicity events pp ← AA

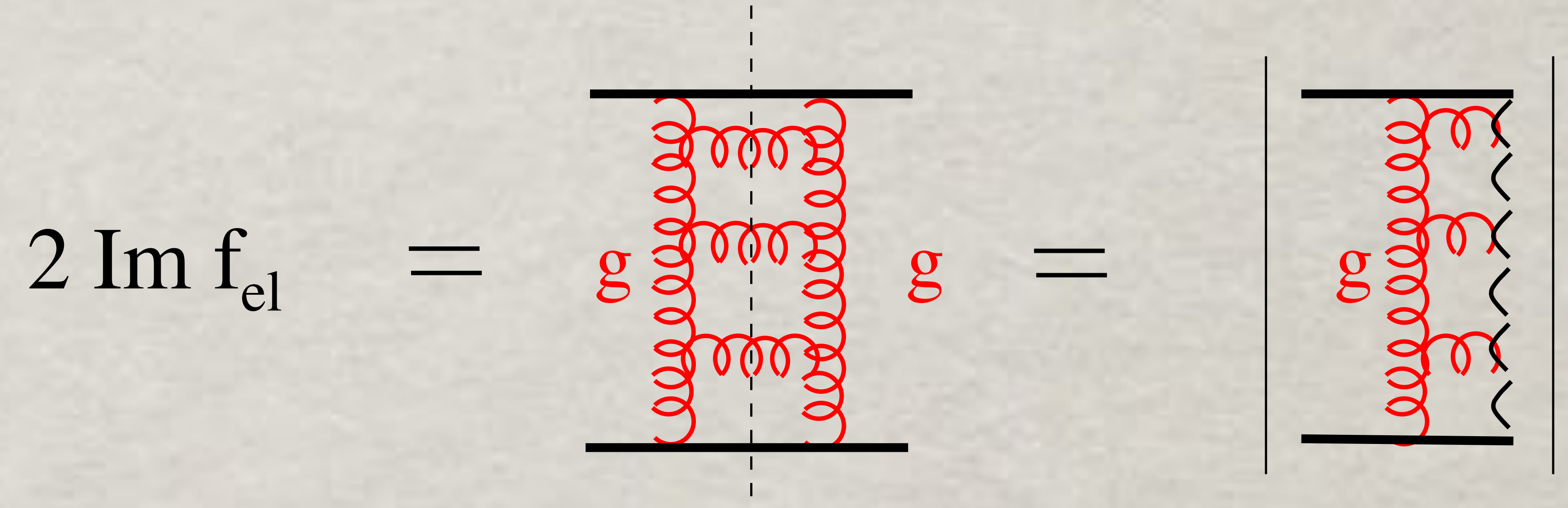
Gluon Saturation

1) J/ψ in high multiplicity environment

Multi-particle production in pp, pA and AA: poorly understood
models with many assumptions

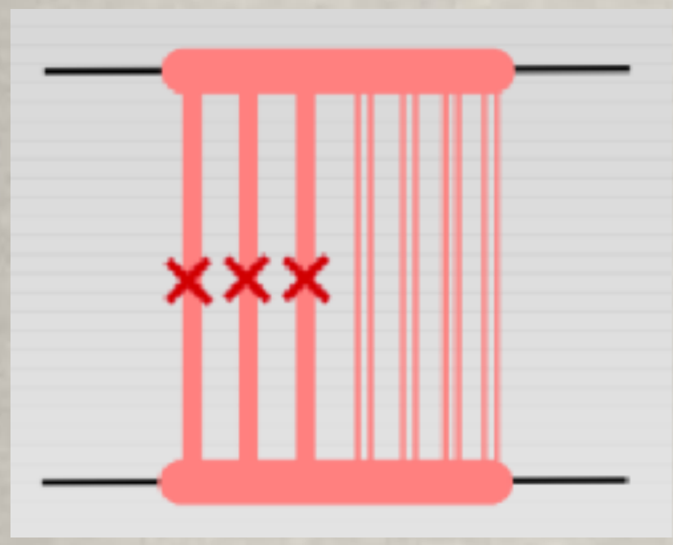
Eikonal or Glauber: information about the elastic amplitude, related to total inelastic CS
do not say anything about the multiplicity distribution.

Example: unitarity cut of the Pomeron



Relation between elastic amplitude and inelastic processes: Abramovsky, Gribov and Kancheli (AGK cutting rules).

Assumption: invariance of the multi-Pomeron vertex relative to different unitarity cuts.



- Number of cut Pomerons (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

2) AGK rules confront data

Normalized multiplicities of light hadrons and J/ψ

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

lack of shadowing should lead to a simple relation $\mathbf{R_{J/\Psi} = R_h = N_{coll}}$

strongly contradicting data

Consider nuclear data

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

Similar, although smaller effect of suppression is observed for J/ψ production in pA, usually parametrized as $\mathbf{R^{pA}_{J/\Psi} = N_{coll} A^{\alpha-1}}$, with α=0.95-0.98.

This can be also presented as

$$\mathbf{R^{pA}_{J/\Psi} = 1 + \beta_{J/\psi} (N_{coll} - 1)}$$ with $\beta_{J/\psi} \approx \mathbf{1 - (1 - \alpha) \ln A}$

Breakdown of AGK happens for several reasons, higher twist quark shadowing, analogous to shadowing in DIS on nuclei; coherence (gluon shadowing, Landau-Pomeranchuk effect)

Nuclei

Gluons overlap in log. direction
→ Single source of gluons

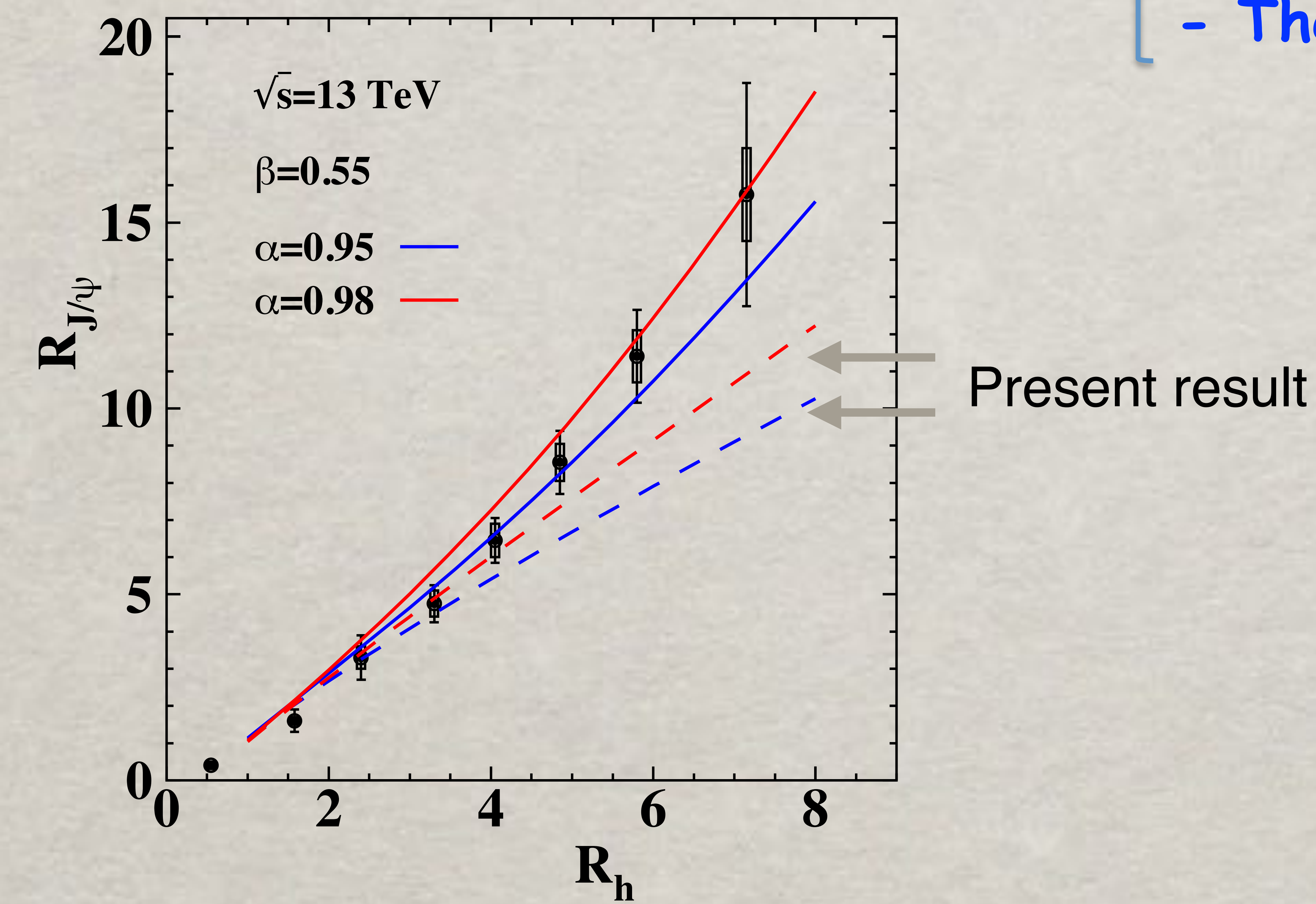
Nucleon

Higher Fock states
→ High multiplicity inelastic collisions
→ Increase heavy flavor production

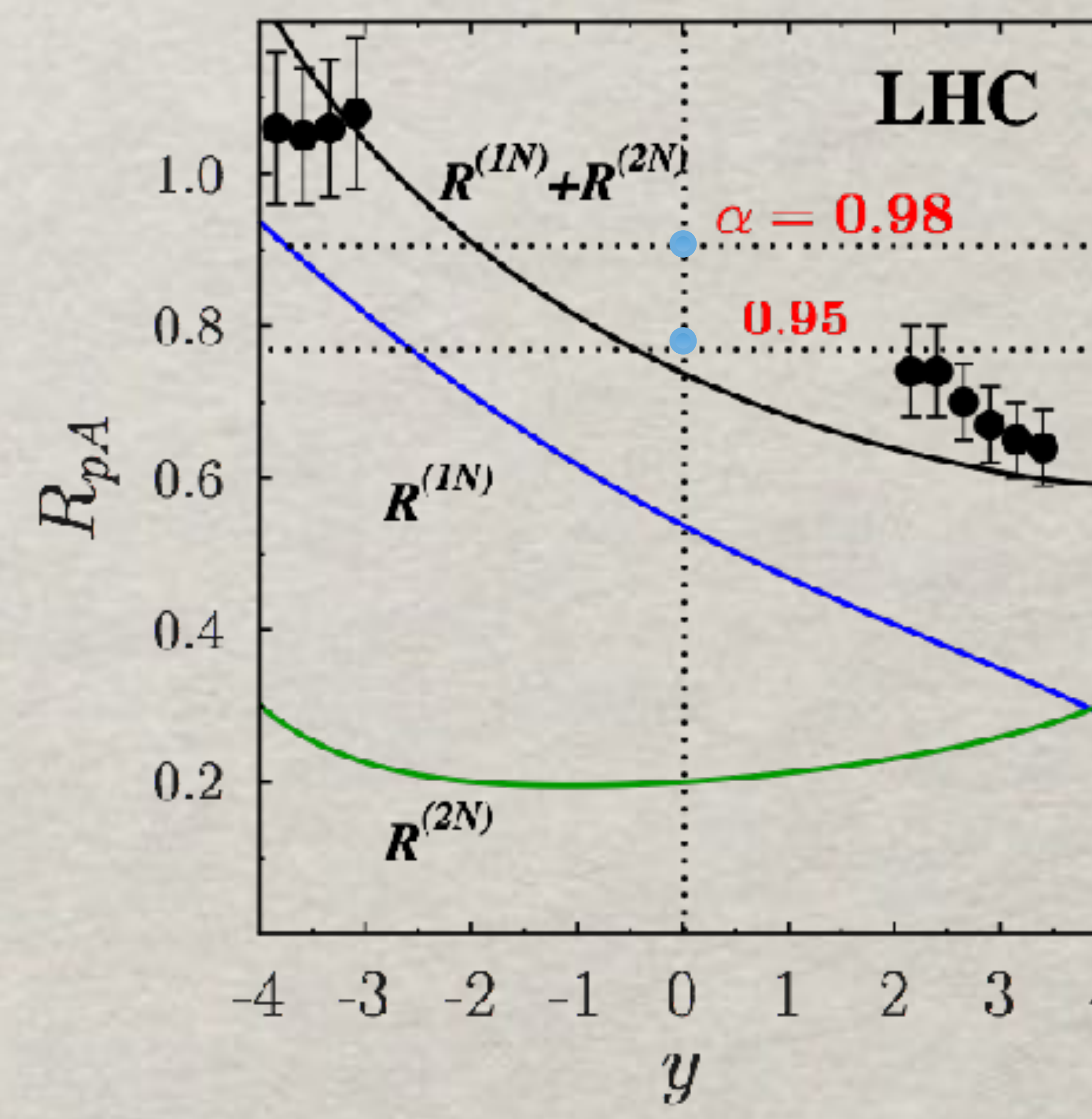
$$\frac{R^{pA}_{J/\Psi} - 1}{R^{pA}_{h} - 1} = \frac{\beta_{J/\psi}}{\beta_{h}}$$

J/ψ vs pions

- α not well measured at y=0.
- Theoretical evaluation not totally reliable



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



B.Kopeliovich, I.K.Potashnikova, M.Siddikov, I.S., PRC 95(2017)065203

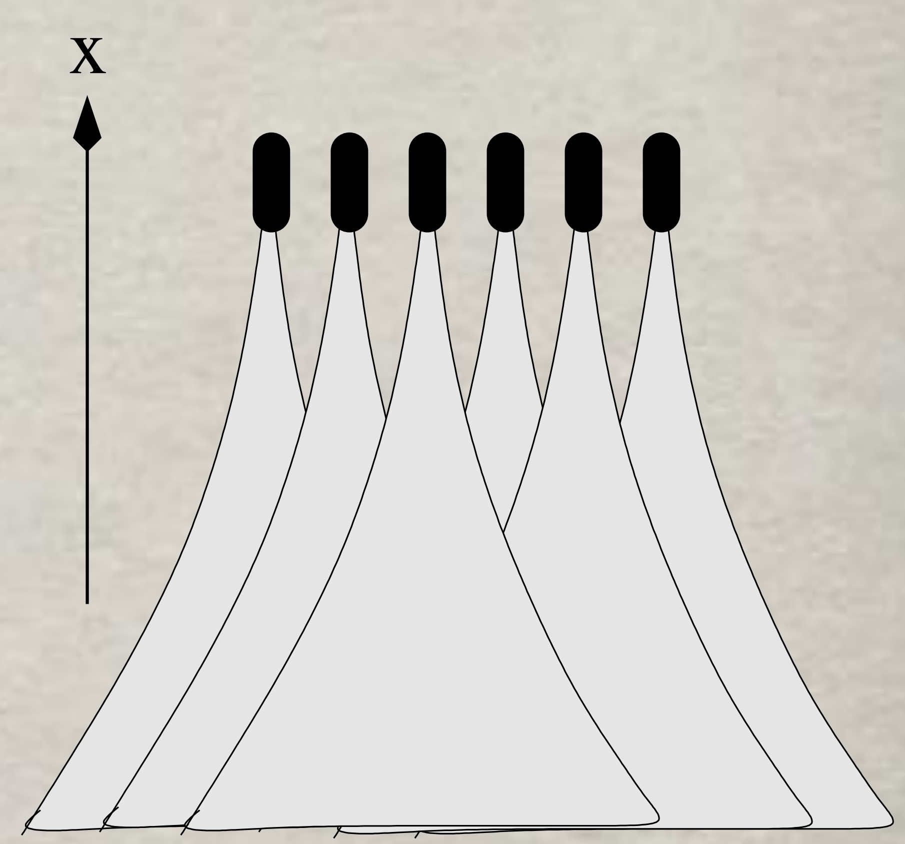
UNIVERSIDAD TECNICA FEDERICO SANTA MARIA

Other source of AGK breakdown: **3) Saturation effects** (Increase R_ψ)

Frame dependent parton model

Parton model description of high-energy hadronic interaction is not Lorentz invariant. Measurable observables are Lorentz invariant.

Example: DIS absorption of virtual photon in Bjorken frame,
photon splitting to q-qbar in nuclear rest frame.



Another example: nuclear shadowing
optical analogy in the nuclear rest frame
fusion of overlapping parton clouds in infinite momentum frame.

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

Effects of parton saturation

Multiple coherent interactions in pp or nuclear collisions lead to broadening of transverse momenta calculated in a parameter free way within the dipole approach

$$\Delta p_T^2 = \frac{9\,C(E)}{2\,\sigma_{in}^{pp}}\,(N_{coll}-1) \qquad \text{with}$$

$$C(E) = \frac{1}{2}\,\tilde{\nabla}_{r_1}\cdot\,\tilde{\nabla}_{r_2}\,\sigma_{\bar{q}q}(\tilde{r}_1-\tilde{r}_2,E)\Big|_{\tilde{r}_1=\tilde{r}_2}.$$

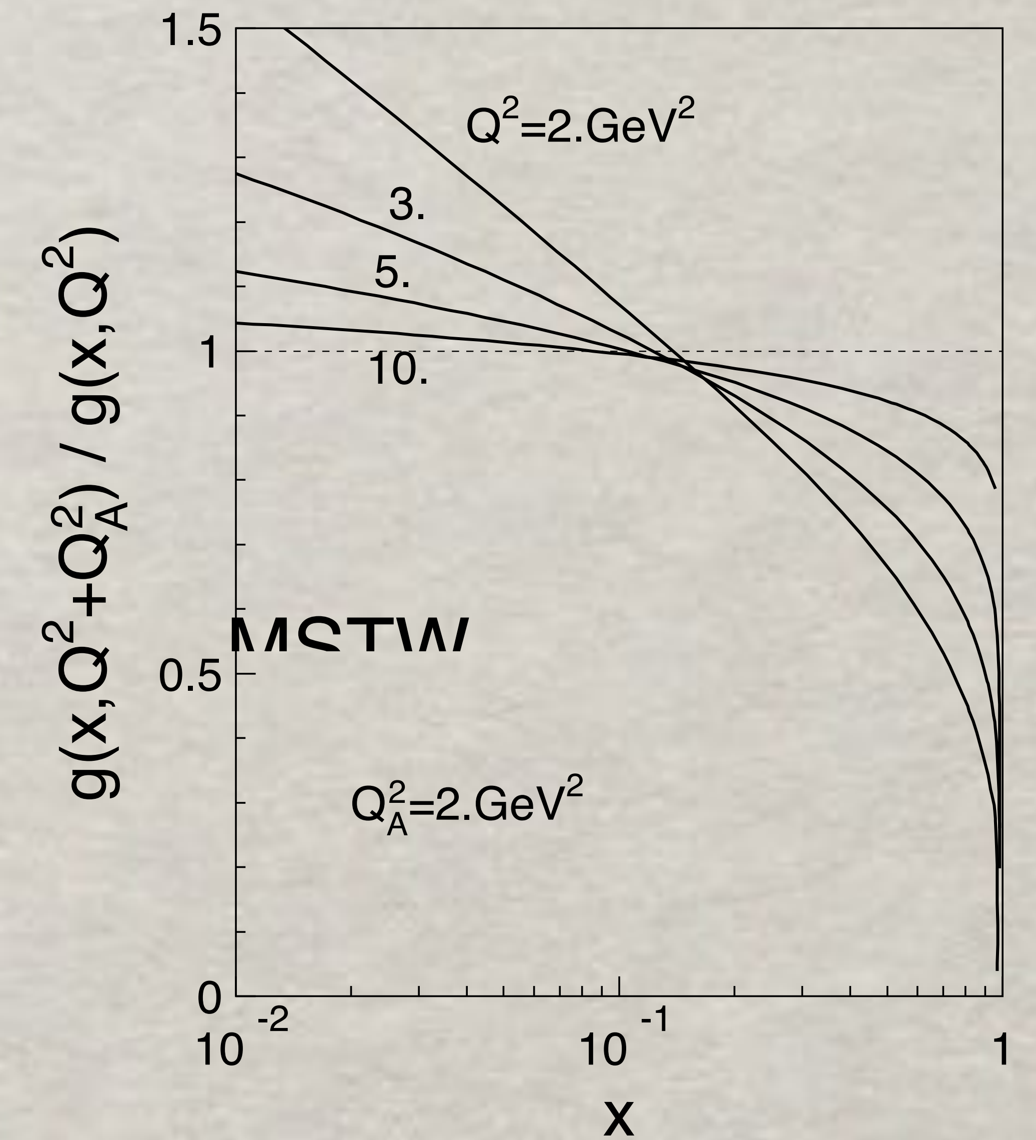
M.Johnson, B.K., A.Tarasov PRC638(2001)0352203

The dipole cross section $\sigma_{\bar{q}q}(r,x)$ is fitted to DIS data from HERA.

Broadening: nuclear target probes beam partons with higher resolution

effective scale Q^2 for the beam PDF drifts to a higher value $Q^2+Q_A^2$

more gluons at small x.

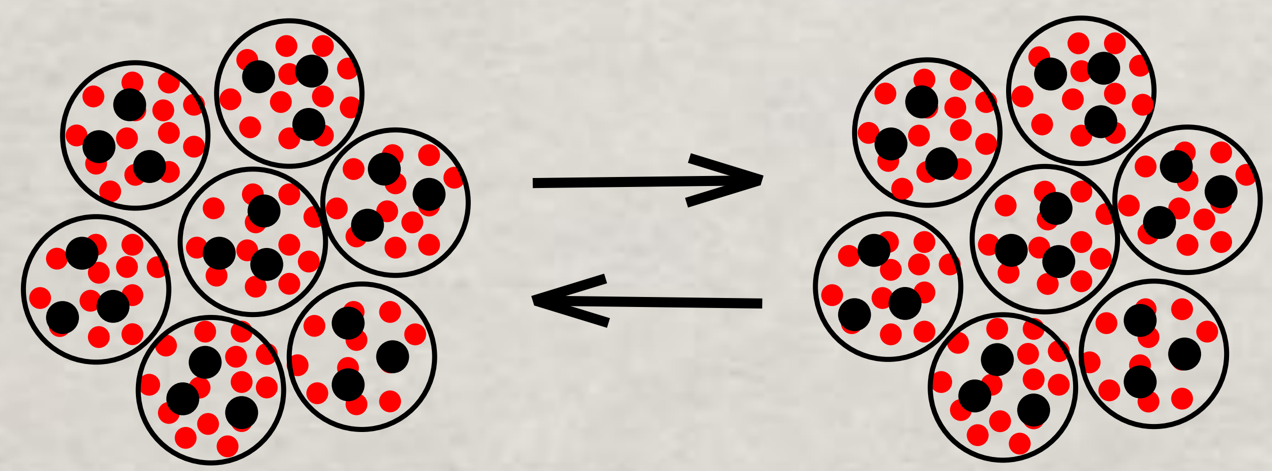


→ Rate of J/ψ is increased by saturation.

UNIVERSIDAD TECNICA FEDERICO SANTA MARIA

Mutual broadening in AA

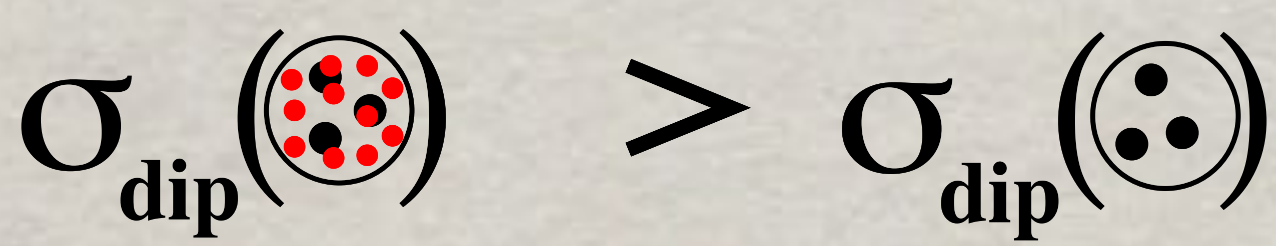
Nuclear collisions: PDFs of bound nucleons in nuclei are drifted towards higher scales.



Broadening enhanced compared to **pA**, since the properties of the target nucleons change.

CS of small dipole with proton

~ small-x gluon density



→ Broadening (the saturation momentum) increases

Mutual boosting of the saturation scale

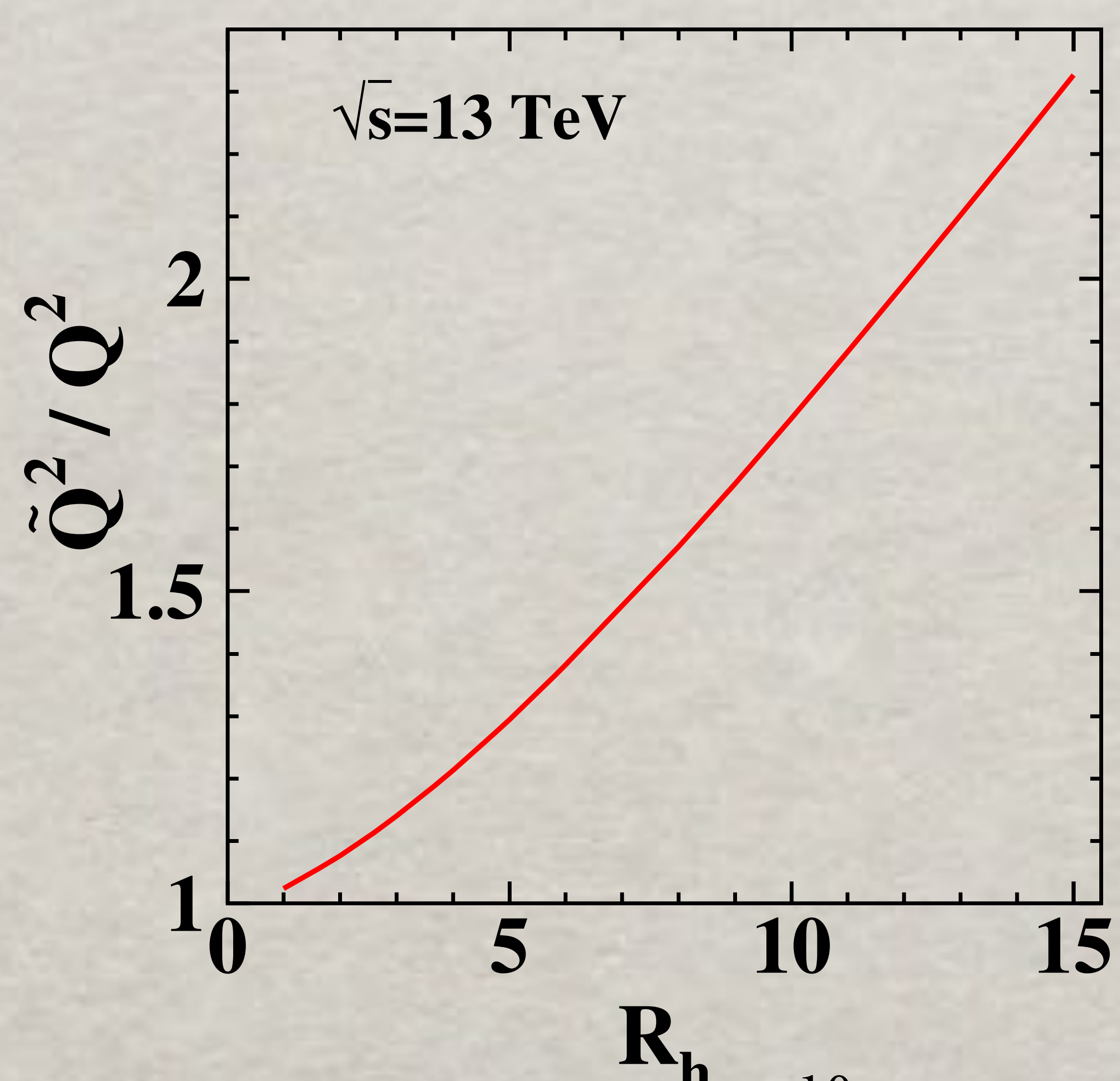
pA collisions: only the projectile proton undergoes multiple interactions (modify its PDF)
PDFs of bound nucleons remain unchanged.

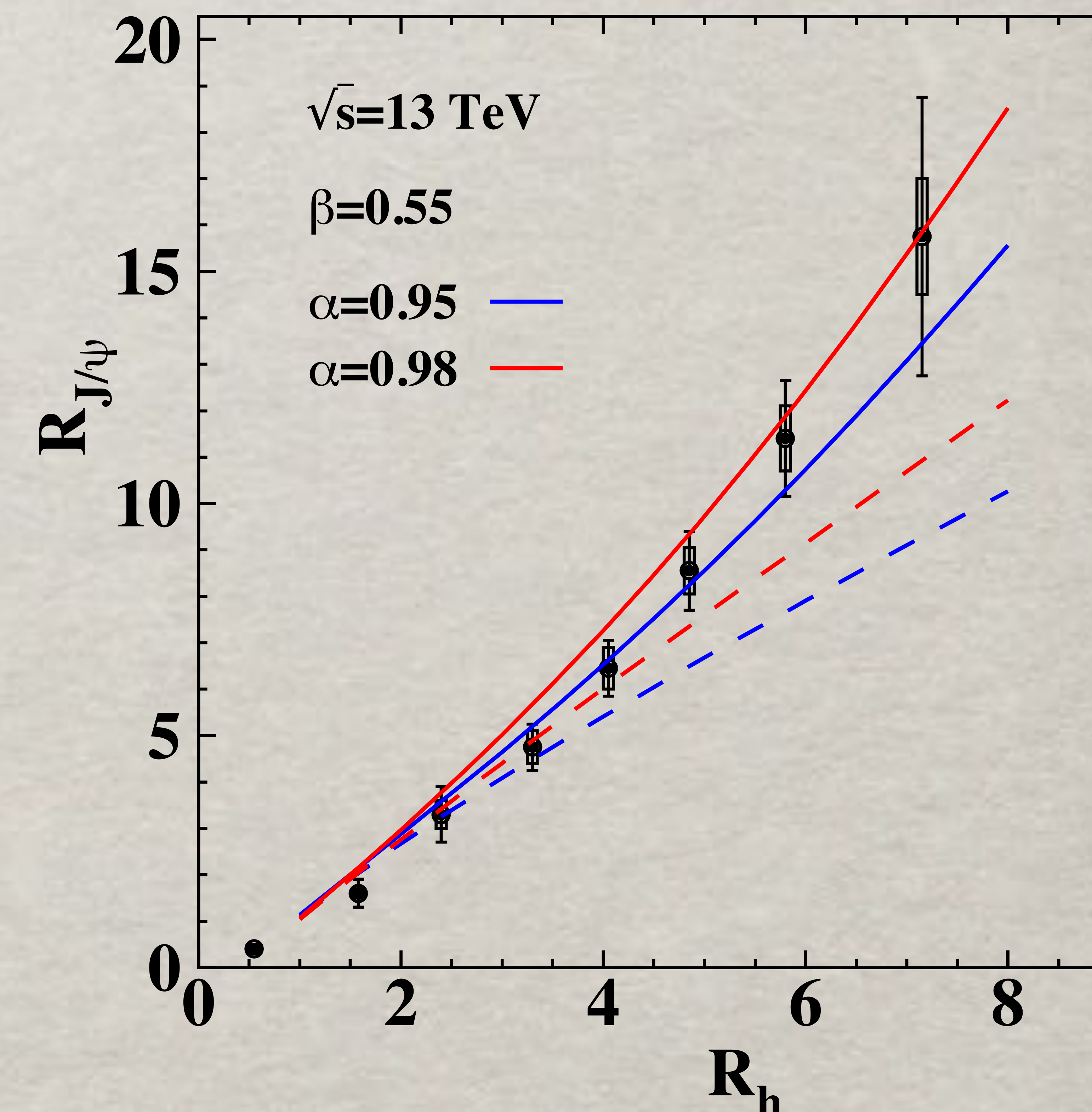
AA
high multiplicity pp
- interaction becomes symmetric
- assembles of colliding constituents are subject to multiple interactions,
- increased partonic content at small x.

$$\tilde{Q}^2_{sA}(x) = \frac{3\pi^2}{2}\,\alpha_s(\tilde{Q}^2_{sA}+Q_0^2)\,xg_N(x,\tilde{Q}^2_{sA}+Q_0^2)\,\frac{N_{coll}}{\sigma^{pp}_{tot}}$$

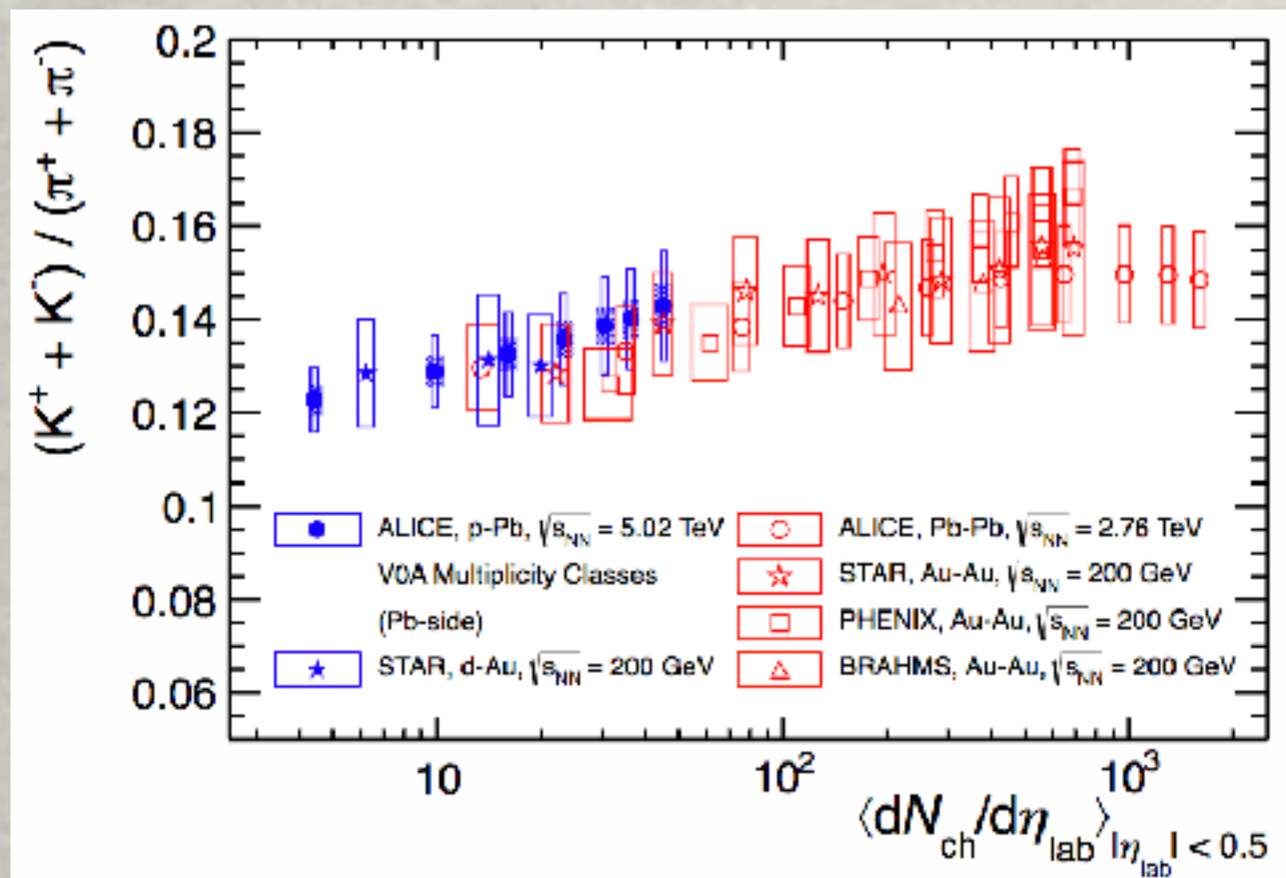
$$\frac{3\pi^2}{2}\,\alpha_s(Q_0^2)\,xg(x,Q_0^2) = C(E),$$

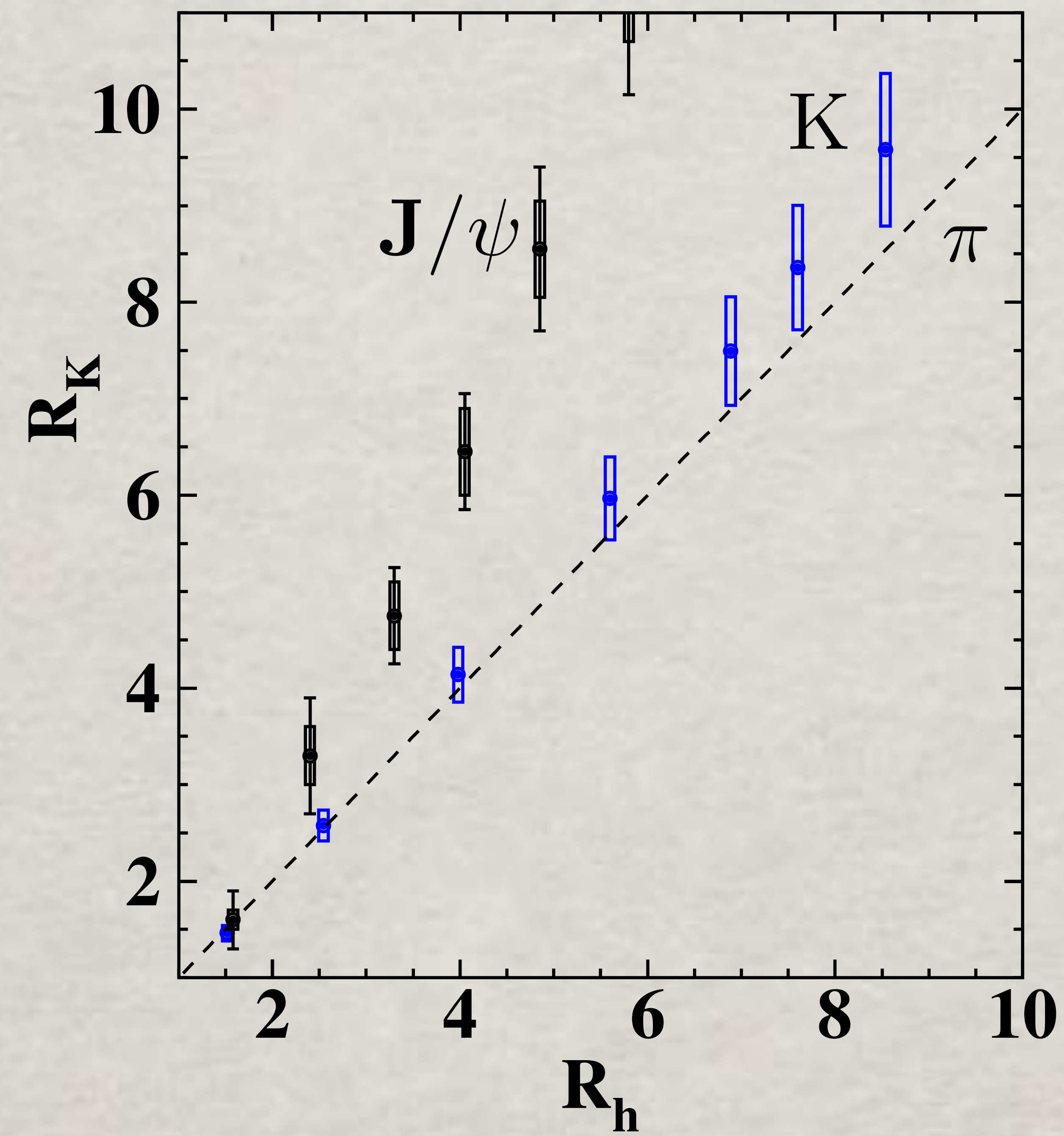
B.Kopeliovich, I.Potashnikova, H.J.Pirner & I.S., PLB697(2011)333





Enhancement of strangeness

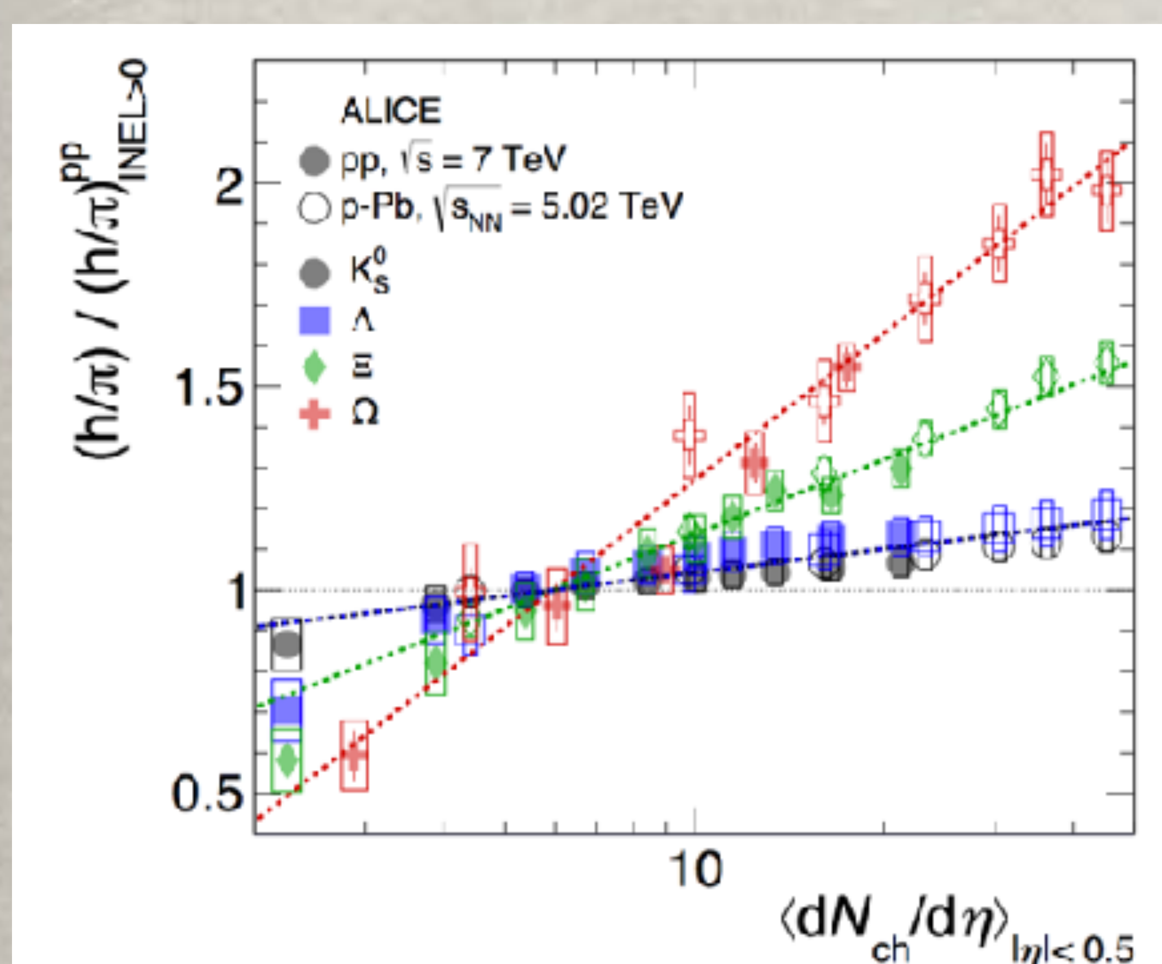




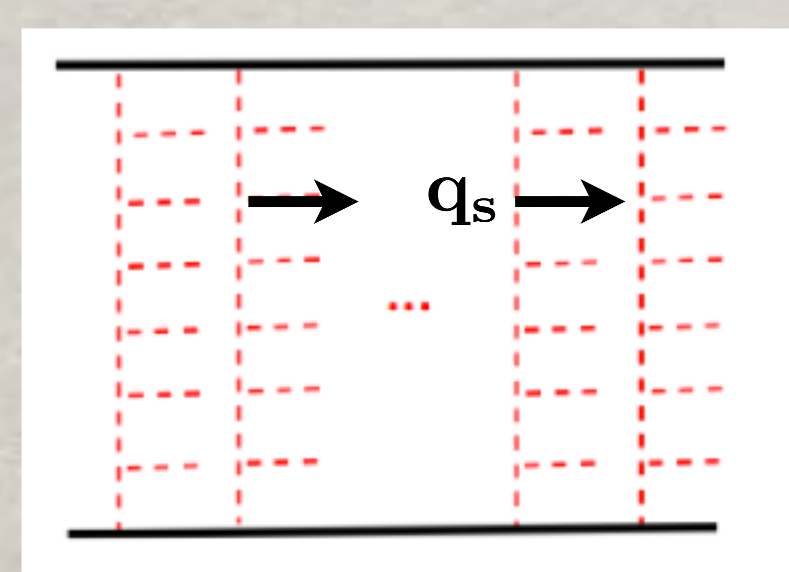
Shadowing for kaons is weaker than for pions, so AGK are less broken.

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

$$R_\psi > R_K > R_\pi\,.$$



Multi-strange hyperons are enhanced more due to simultaneous production from several parton chains



enhanced by $\mathbf{N_{coll}(N_{coll}-1)/2}$

or by $\mathbf{N_{coll}(N_{coll}-1)(N_{coll}-2)/3}$

$$\mathbf{N_{coll} = 1 + (R_h - 1)/\beta_h}$$

4) Summary

- Multiplicity distribution in pp and pA collisions are described based 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.

Shadowing at high multiplicities

$$\frac{d\sigma_{in}}{d^2b} = e^{-N_{coll}} \sum_{k=1}^{\infty} \frac{[N_{coll}]^k}{k!} = 1 - e^{-N_{coll}}$$

Inelastic cross section: subject to shadowing.
Derived from the eikonal (Glauber)
Does not need AGK
(Applies to different inelastic channels)

$\sim A^{2/3}$

$$\frac{d\sigma_{incl}}{d^2b} = e^{-N_{coll}} \sum_{k=1}^{\infty} \frac{[N_{coll}]^k}{k!} k = N_{coll}$$

Mueller-Kancheli theorem:
Inclusive cross section is not affected by shadowing.

Inclusive cross sections
Mean multiplicities of different particles
} proportional to N_{coll}

No shadowing

$\sim A$

Independence of the hadron multi-Pomeron vertex on N_{coll}
(Glauber vertex in elastic amplitude)

based on AGK
not proven in QCD

UNIVERSIDAD TECNICA FEDERICO SANTA MARIA