PARTICLE PRODUCTION AT HIGH ENERGY AND LARGE P$_T$.

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FORWARD PARTICLE PRODUCTION AT HIGH P_T

STRONG SUPPRESSION AT RHIC AT $\eta > 3$

FORWARD REGION IN d-Au COLLISIONS (DIRECTION OF d) IS A GOOD PLACE TO LOOK. (SATURATION SPEAKING)

PRODUCTION AT $x_F = \frac{k}{\sqrt{s}} e^{\eta}$

IS DOMINATED BY THE x VALUES: $x_1 \sim x_F$ IN DEUTERON

AND $x_2 = x_1 e^{-2\eta}$ IN GOLD

AT LOW x THE SATURATION IN THE GOLD NUCLEUS SHOULD MANIFEST ITSELF

NAIVE EXPECTATION FROM SATURATION: PARTICLE PRODUCTION SHOULD BE SUPPRESSED AT FORWARD RAPIDITIES.

AND INDEED A STRONG SUPPRESSION HAS BEEN OBSERVED AT RHIC.

DATA IS FIT REASONABLY WELL BY THE CALCULATION BASED ON CGC.

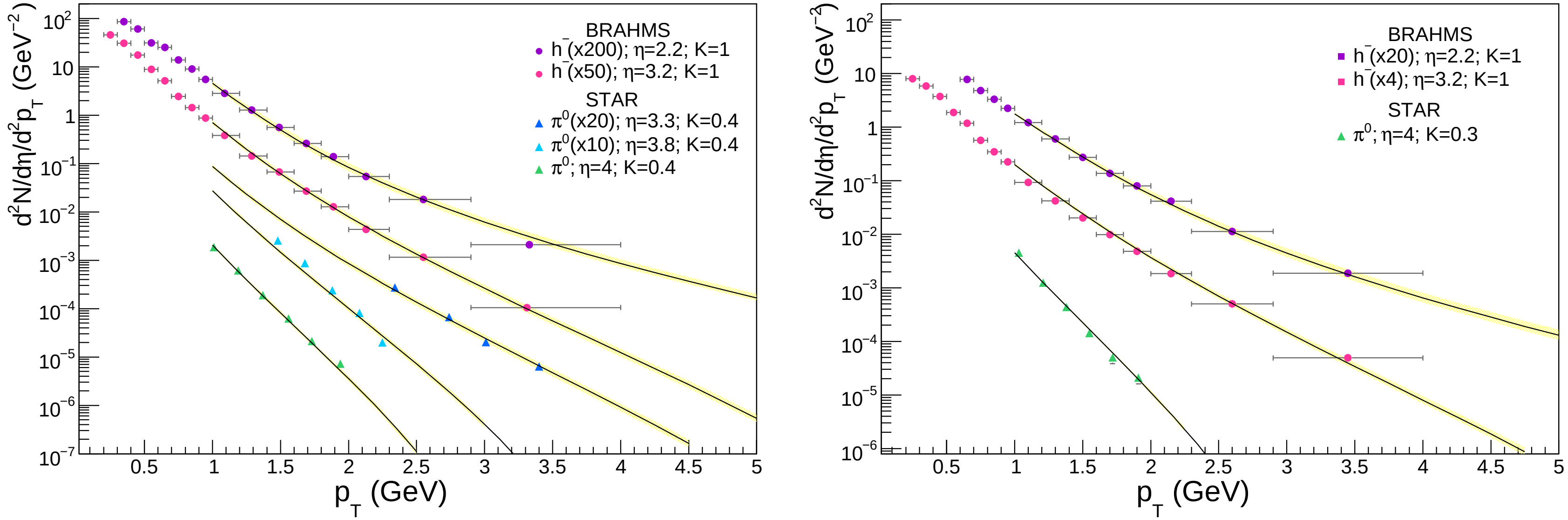


Figure 1: Negatively charged hadron and π^0 yields in proton-proton (at pseudo-rapidities (2.2, 3.2) and (3.3, 3.8 and 4)) and deuteron-gold (at pseudo-rapidities (2.2, 3.2) and 4) collisions at $\sqrt{s_{NN}} = 200$ GeV. Data by the BRAHMS and STAR collaborations. (From Albacete and Marquet)

PERTURBATIVE SATURATION IS NOT THE ONLY MECHANISM ON THE MARKET- GOTTA UNDERSTAND WHO IS RIGHT!

CLEAR PATHOLOGY: CURIOUSLY SLOW APPROACH TO PERTURBATIVE REGIME (OR RATHER THE LACK THEREOF)

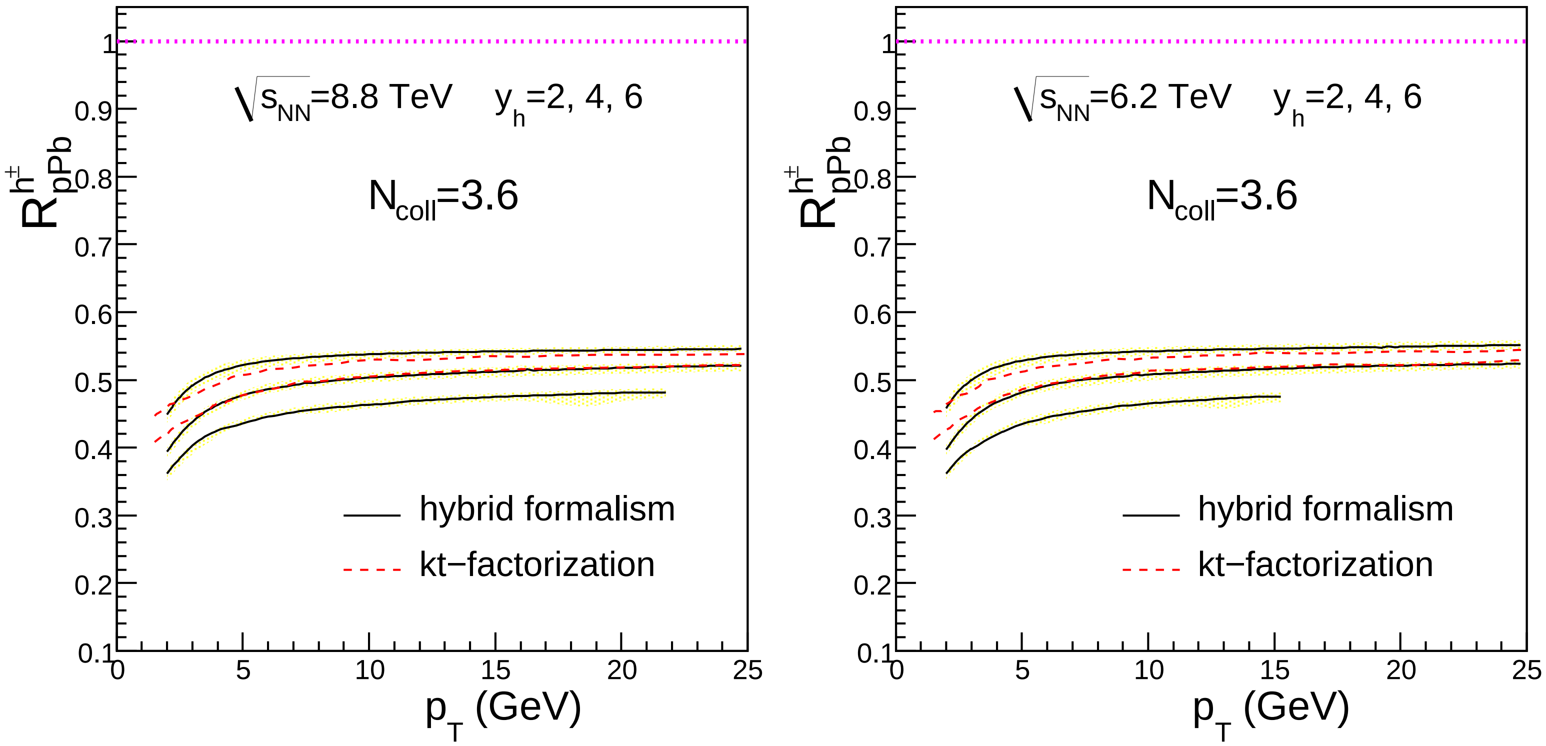


Figure 2: Nuclear modification factors for $h^\pm$ production in p+Pb collisions, $R^{h^\pm}_{pPb}$, for collision energies $\sqrt{s_{NN}} = 8.8$ (left) and 6.2 TeV (right) and for rapidities $y_h = 2$, 4, and 6. For comparison, the red dashed line corresponds to the same quantity calculated in the k_t-factorization scheme. (From Albacete and Marquet)

WHAT GOES INTO THIS CALCULATION?

"HYBRID FORMALISM" OF DUMITRU, HAYASHIGAKI, JALILIAN-MARIAN

$$\frac{dN}{d^2k\,d\eta} = \frac{1}{(2\pi)^2}\int_{x_F}^{1}\frac{dz}{z^2}$$

$$\left[x_1 f_g(x_1, Q^2) N_A(x_2, \frac{k}{z}) D_{h/g}(z, Q) + \Sigma_q x_1 f_q(x_1, Q^2) N_F(x_2, \frac{k}{z}) D_{h/q}(z, Q)\right]$$

WITH

$$x_F = \frac{k}{\sqrt{s}} e^{\eta}; \qquad x_1 = \frac{x_F}{z}; \qquad x_2 = x_1 e^{-2\eta}$$

$$N_F(x, x_T) = \frac{1}{N_C} tr[1 - S_F^{\dagger}(0) S_F(x_T)]$$

VERY SIMPLE - INCOMING PROJECTILE SCATTERS EIKONALLY ON THE CLASSICAL FIELD OF THE TARGET. PARTONS OF THE PROJECTILE HAVE VERY LITTLE TRANSVERSE MOMENTUM - ALL THE MOMENTUM IN THE FINAL STATE IS ACQUIRED THROUGH HARD SCATTERING WITH THE TARGET.

BUT DOES IT TAKE INTO ACCOUNT ALL RELEVANT PHYSICS?

IN PARTICULAR ARE ALL LEADING TWIST CONTRIBUTIONS IMPORTANT AT HIGH k_T INCLUDED?

FIRST OFF - CLEAR TENSION WITH THE SOFT LIMIT.

IN THE SOFT LIMIT (K_T FACTORIZATION) THE SINGLE GLUON SPECTRUM:

$$\frac{dN}{d^2b\,d^2k\,d\eta} = \frac{\alpha_s N_c}{N_c^2-1}\frac{1}{k^2}\int_l \phi_T(l+k, Y-\eta)\phi_P(l,\eta)$$

$$= \frac{\alpha_s N_c}{N_c^2-1}\int_l \left[\frac{1}{(l+k)^2} + \frac{1}{(l+k)^2}\frac{l^2}{k^2} + 2\frac{1}{(l+k)^2}\frac{l\cdot k}{k^2}\right]\phi_T(l+k)\phi_P(l)$$

HERE $\phi_P(k)$ AND $\phi_T(k)$ ARE UNINTEGRATED GLUON DISTRIBUTIONS OF THE PROTON AND THE TARGET.

DHJ MODEL CORRESPONDS TO THE FIRST TERM ONLY.

BUT THE OTHER TWO TERMS ARE NO LESS IMPORTANT IN GENERAL.

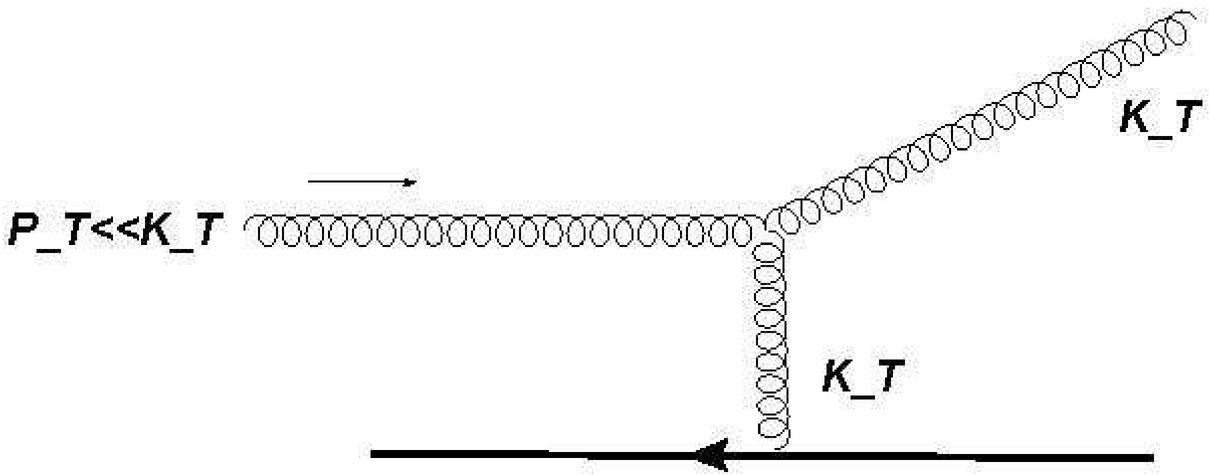
LET'S SAY THE TARGET IS CHARACTERIZED BY SOME SATURATION MOMENTUM $Q_S > \Lambda_{QCD}$

IN THE LARGE PRODUCED MOMENTUM LIMIT $k \gg Q_s, \Lambda_{QCD}$ THIS IS DOMINATED BY TWO INTEGRATION REGIONS:

A. $l \ll k$: $N_E = \frac{\alpha_S N_c}{N_c^2-1}\frac{1}{k^2}\phi_T(k)\int_{l<Q\sim k}\phi_P(l)$

THIS IS THE DHJ TERM

THIS IS "'ELASTIC"' SCATTERING OF A LOW p_t GLUON FROM THE PROJECTILE WAVE FUNCTION WITH LARGE MOMENTUM TRANSFER.

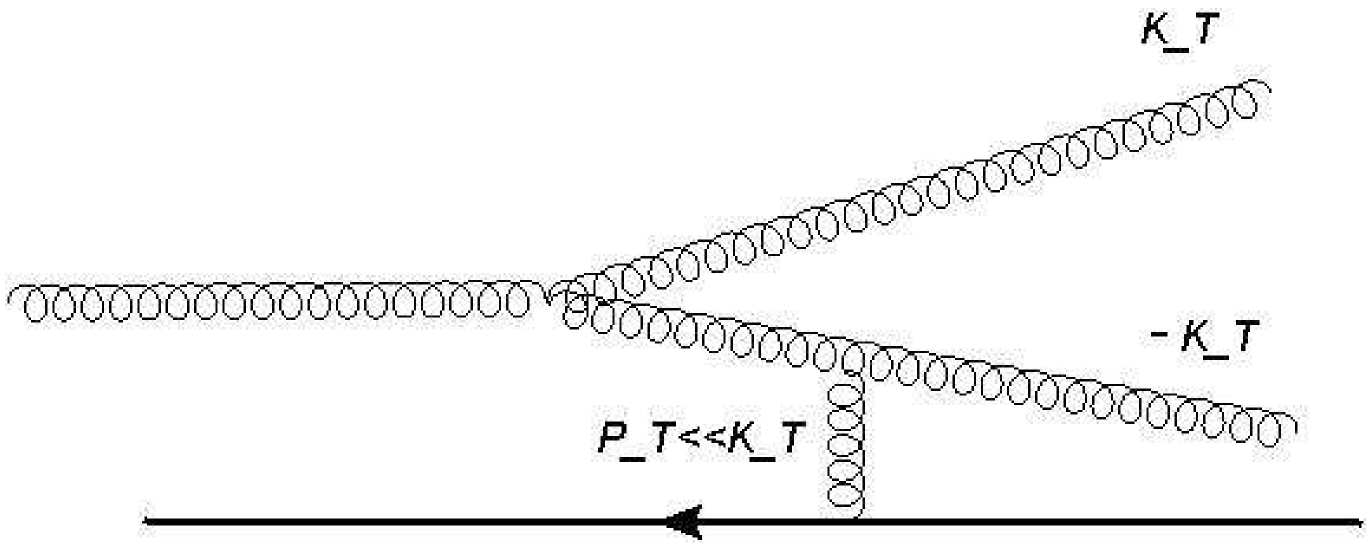


B. $l \ll k$: $N_I = \frac{\alpha_s N_c}{N_c^2-1}\frac{1}{k^2}\phi_P(k)\int_{q<Q\sim k}\phi_T(q)$

THIS IS THE MIRROR TERM - THE GLUONS THAT ARE MEASURED IN THE FINAL STATE ARE KICKED OUT OF THE TARGET WAVE FUNCTION BY HARD SCATTERING FROM THE PROTON.

BUT IT CAN ALSO BE INTERPRETED AS " INELASTIC " SCATTERING OF THE PROJECTILE GLUON: HIGH p_t GLUON FROM THE PROJECTILE SCATTERS WITH SMALL MOMENTUM TRANSFER.

INELASTIC - BECAUSE HIGH p_T GLUONS LIVE IN THE WAVEFUNCTION ONLY AS A PART OF THE "UNRESOLVED STRUCTURE" OF THE NAIVE PARTON MODEL PARTONS!



HOW IMPORTANT IS THE INELASTIC CONTRIBUTION?

NAIVELY INELASTIC CONTRIBUTION IS HIGHER ORDER IN α_s

BUT IN FACT BOTH CONTRIBUTIONS ARE THE SAME ORDER !

ELASTIC DENSITY IS $O(1)$, BUT THE SCATTERING PROBABILITY (E- TARGET CHROMOELECTRIC FIELD)

$$P \propto \alpha_s E^2(k) \sim O(\alpha_s^2)$$

INELASTIC DENISTY IS $O(\alpha_s)$, BUT THE SCATTERING IS ON THE SOFT TARGET FIELD, AND SO $P = O(\alpha_s)$

ASSUME PERTURBATIVE BEHAVIOR: $\phi = \frac{\mu^2}{p^2}$. THEN

$$\left[\frac{dN}{d^2k d\eta}\right]_{elastic} = \alpha_s \mu_P^2 \mu_T^2 \ln \frac{p^2}{\Lambda_{QCD}^2}$$

$$\left[\frac{dN}{d^2k d\eta}\right]_{inelastic} = \alpha_s \mu_P^2 \mu_T^2 \ln \frac{p^2}{Q_s^2}$$

AT $p \gg Q_S$ IT IS NOT SUPPRESSED EVEN LOGARITHMICALLY!

WE HAVE CALCULATED THE INELASTIC CORRECTION TO THE DHJ RESULT

CHIRILLI, XIAO AND YUAN - LATER WITH CAREFUL TREATMENT OF FACTORIZATION SCALE.

IN THE HIGH TRANSVERSE MOMENTUM LIMIT $k >> Q_s$**:** NEGLECTING FRAGMENTATION FOR SIMPLICITY

$$\left[\frac{dN_i}{d^2k d\eta}\right]_{inelastic} = \frac{\alpha_s}{2\pi^2}\frac{1}{k^4}\int_{p^2<Q^2}\frac{d^2p}{(2\pi)^2}p^2 N_F(p) x_F \int_{x_F}^1 \frac{d\xi}{\xi}\Sigma_{j=q,\bar{q},g} w_{i/j}(\xi) P_{i/j}(\xi) f_j(\frac{x_F}{\xi}, Q)$$

WITH "INELASTIC WEIGHTS"

$$w_{g/g}(\xi) = 2\frac{N_c^2}{N_c^2-1}(1-\xi+\xi^2)$$

$$w_{g/q}(\xi) = w_{g/\bar{q}}(\xi) = \frac{N_c^2}{N_c^2-1}\left[1+(1-\xi)^2 - \frac{\xi^2}{N_c^2}\right]$$

$$w_{q/q}(\xi) = w_{\bar{q}/\bar{q}}(\xi) = \frac{N_c^2}{N_c^2-1}\left[1+\xi^2 - \frac{(1-\xi)^2}{N_c^2}\right]$$

$$w_{q/g}(\xi) = w_{\bar{q}/g}(\xi) = \frac{1}{2}\left[(1-\xi)^2+\xi^2 - \frac{2\xi(1-\xi)}{N_c^2-1}\right]$$

HOW IMPORTANT IS THE INELASTIC CONTRIBUTION?

NUMERICAL RESULTS COURTESY JALILIAN MARIAN + REZAEIAN

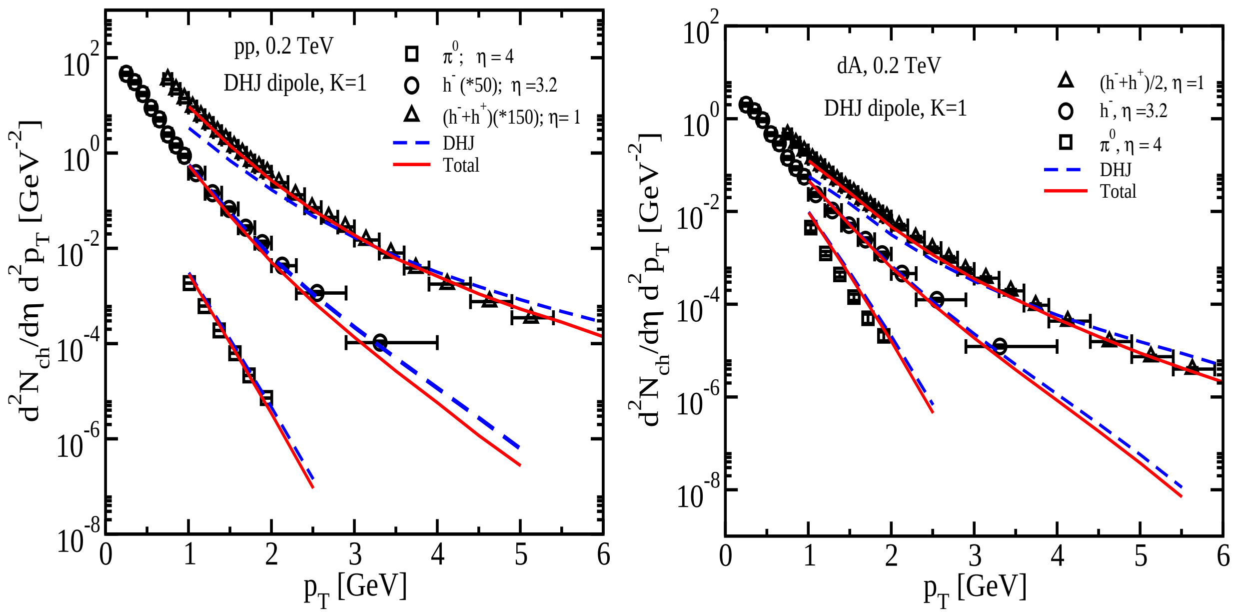
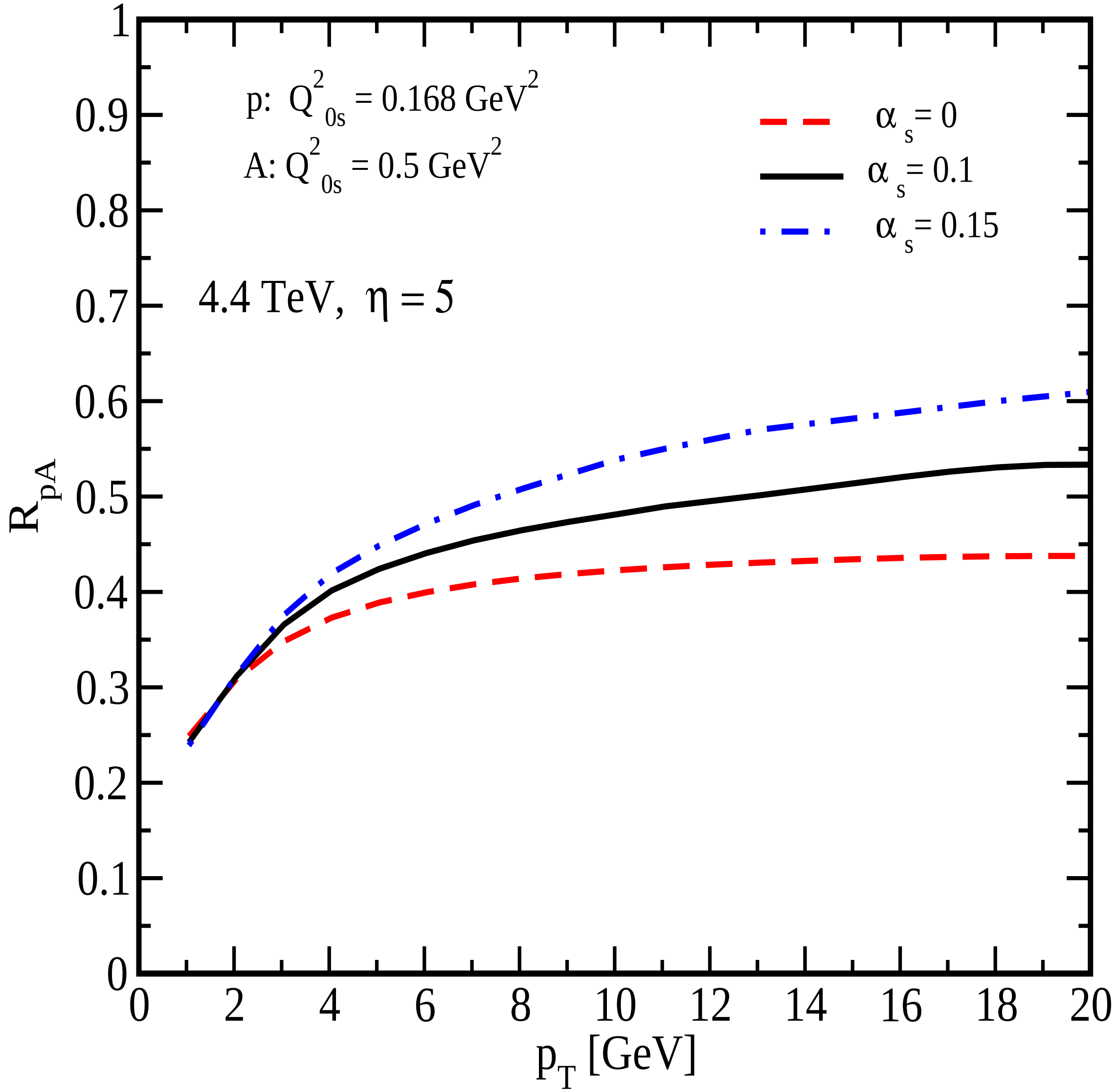


Figure 3: Single inclusive hadron production in proton-proton and deuteron-gold collisions at different pseudo-rapidities at RHIC . Dashed and full lines refers to the results when $\alpha_s = 0$ (the DHJ term or the elastic contribution) and $\alpha_s = 0.1$ (for the inelastic term), respectively.



R_{pA} for inclusive charged hadron production for various values of the strong coupling constant α_s at the LHC ($\sqrt{s} = 4.4$ TeV and $\eta = 5$) obtained by the rcBK equation.

DISCUSSION.

ELASTIC SCATTERING LEADS TO FINAL STATES WHERE ONLY ONE PARTON (HADRON) GOES FORWARD, WHILE THE BALANCING TRANSVERSE MOMENTUM IS CARRIED ROUGHLY IN THE DIRECTION OF Au.

INELASTIC FINAL STATES ARE PAIRS OF PARTONS (DIHADRONS) WITH LARGE BALANCING TRANSVERSE MOMENTUM WHERE BOTH PARTONS MOVE ROUGHLY FORWARD.

SOME OF THESE STATES WILL HAVE ONE PARTON AT FORWARD RAPIDITY, AND ONE CLOSER TO MID RAPIDITY, WHILE SOME WILL LEAD TO CORRELATED PAIRS AT FORWARD RAPIDITY.

WE DID NOT TAKE INTO ACCOUNT RECOIL FROM THE TARGET, SO THE RAPIDITY DISTRIBUTION FOLLOWS THAT OF THE INITIAL PROJECTILE WAVE FUNCTION

HOW DOES SATURATION EXHIBIT ITSELF?

SATURATION HAS TWO FACES:

DEPENDENCE ON ENERGY, AND DEPENDENCE ON THE ATOMIC NUMBER.

A. AT INITIAL x THE SATURATION MOMENTUM Q_S IS DIFFERENT BETWEEN p AND Au. THIS DIFFERENCES IS AMPLIFIED AT HIGHER ENERGY **EVEN IF THE ENERGY EVOLUTION IS LINEAR** AND DOES NOT INVOLVE "'GLUON FUSION"', OR PERTURBATIVE SATURATION FFECTS.

B. SATURATION EFFECTS IN THE EVOLUTION ARE SIZABLE.

1. ELASTIC CONTRIBUTION **IS NOT SENSITIVE** TO SATURATION IN THE EVOLUTION: IT DEPENDS ONLY ON $N(k)$ AT LARGE MOMENTUM k WHICH IS NOT SENSITIVE TO SATURATION IN THE EVOLUTION AS LONG AS $k > Q_S$.

2. INELASTIC CONTRIBUTION IS PROPORTIONAL TO THE TARGET GLUON DISTRIBUTION BELOW THE MEASURED MOMENTUM

$$\int_{p^2<Q^2} \frac{d^2p}{(2\pi)^2} p^2 N_F(p, x_2) \propto f_{target}(Q, x_2)$$

THIS IS DIRECTLY SUPPRESSED BY THE EVOLUTION AT SMALL x_2 EVEN IF $k > Q_S$!

THIS IS THEN A LITTLE STRANGE: IF ONE NEGLECTS INELASTIC CONTRIBUTION COMPLETELY (AS IN ALBACETE ET.AL. - OLD AND NEW), WHY WOULD ONE SEE ANY R_{pA} DIFFERENT FROM UNITY??.

BECAUSE LINEAR EVOLUTION AFFECTS ELASTIC CONTRIBUTION AS WELL IN A MORE SUBTLE WAY.

e.g. BFKL:

WITHIN BFKL Q_S IS THE SCALE OF THE UNITARITY VIOLATION. BFKL SOLUTION HAS THE "GEOMETRIC SCALING" REGIME: FOR $k \ll Q_S$ THE BFKL SOLUTION HAS THE FORM

$$\phi_{BFKL}(k,Y) \propto [Q_s(Y)/k]^{2-2\gamma}$$

ANOMALOUS DIMENSION γ IS A SLOWLY VARYING FUNCTION OF TRANSVERSE MOMENTUM AND RAPIDITY, AND VARIES BETWEEN $\mathbf{0}$ IN **UV** AND $\mathbf{1/2}$ IN **IR**.

WITHIN BFKL Q_S DEPENDS EXPONENTIALLY ON RAPIDITY:

$$Q_s(Y) = Q_0 \exp\{\lambda Y\}$$

THUS **EVEN EXCLUDING THE SATURATION EFFECTS IN THE EVOLUTION** ONE WOULD GET A NONTRIVIAL R_{dA} SOLELY DUE TO THE BFKL ANOMALOUS DIMENSION

$$R_{pA}(Y) = \frac{1}{N_{coll}} \left[\frac{Q_{sA}(Y)}{Q_{sp}(Y)} \right]^{2-2\gamma(Y,k)} = \left[\frac{Q_{0p}}{Q_{0A}} \right]^{2\gamma(Y,k)} < 1$$

EXCLUDING THE INELASTIC CONTRIBUTION ONE IS PROBING THE EFFECTS OF SATURATION (SHADOWING) AT INTERMEDIATE x AS ITS EFFEECTS PROPAGATE TO HIGHER k VIA **LINEAR** EVOLUTION - E.G. "'BFKL"' ANOMALOUS DIMENSION

INELASTIC CONTRIBUTION IS THE ONE THAT GENUINELY PROBES THE CGC AS THE UNITARIZATION EFFECTS IN THE HIGH ENERGY EVOLUTION!

IN SINGLE INCLUSIVE PRODUCTION THE INELASTIC CONTRIBUTION SHOULD MAKE R_{dA} RISE STEEPER - IT IS SUPPRESSED AT LOW k IN NUCLEI DUE TO EVOLUTION. THIS IS SEEN IN JALILIAN-MARIAN, REZAEIAN CALCULATIONS.

THE INELASTIC CONTRIBUTION DOMINATES CORRELATED DIHADRON PRODUCTION AT FORWARD RAPIDITIES - AND WE EXPECT SUPPRESSION DUE TO EVOLUTION TO BE PRESENT ALSO THERE, ADDITIONALLY TO THE USUAL DECORRELATION DUE TO MOMENTUM BROADENING.

QUALITATIVELY THIS REDUCES THE CORRELATED PEAK ABOVE THE UNCORRELATED BACKGROUND (DUE TO ELASTIC SCATTERING) AND NOT JUST BROADENS THE DISTRIBUTION.

COMBINING SINGLE AND DOUBLE INCLUSIVE FORWARD HADRON PRODUCTION ONE MAY BE ABLE TO DISENTANGLE THE "INITIAL" SHADOWING FORM THE NONLINEAR EFFECTS IN LOW x EVOLUTION.