Programy finansowane
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FNP

Entropy production in hadron hadron collisions

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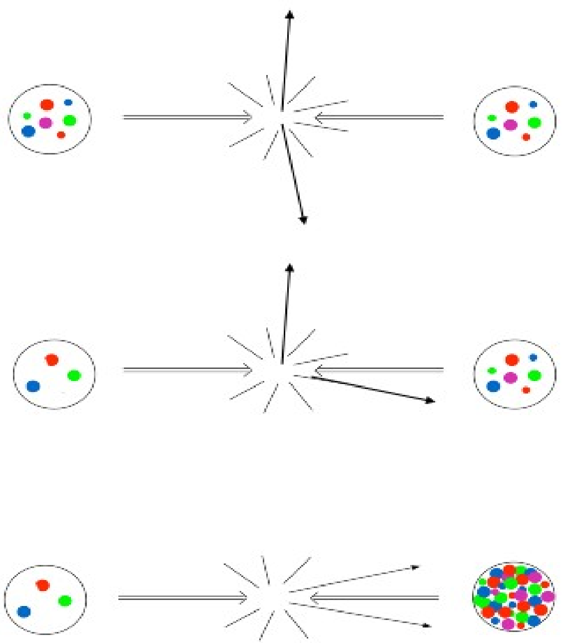
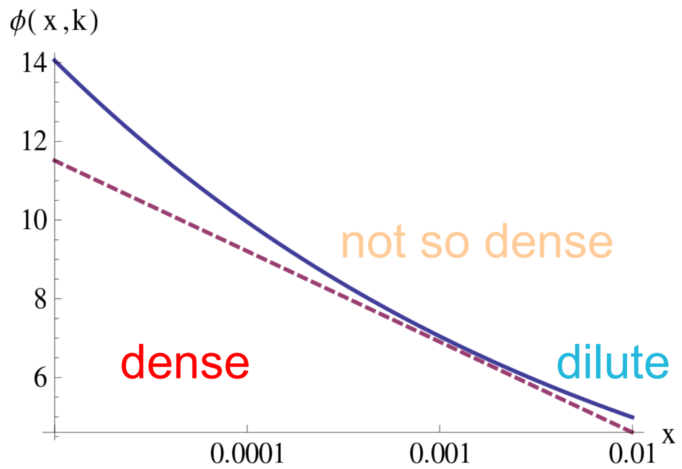
LHC as a scaner of gluon



central-central i.e.
not so dense-not so dense

forward-central i.e.
dilute – not so dense

forward-forward i.e.
dilute -dense



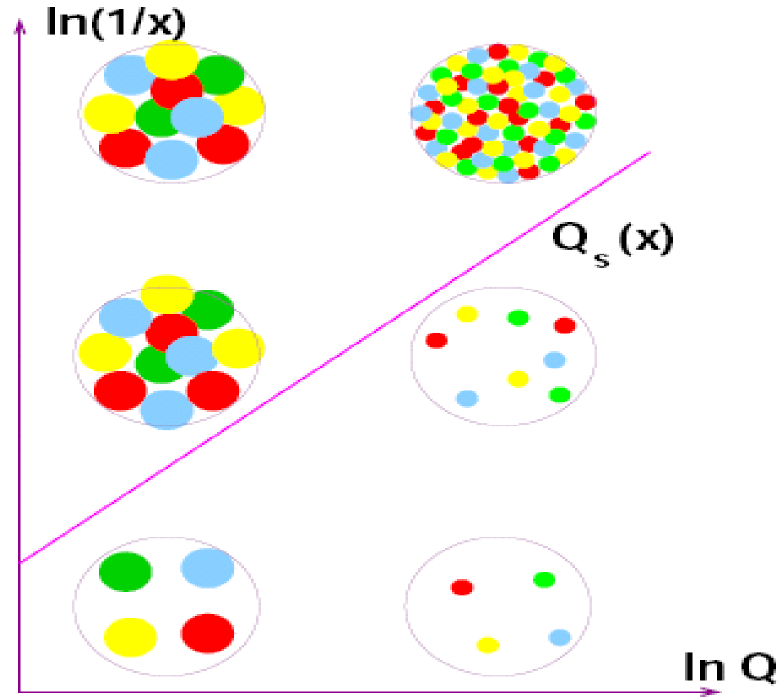
From C. Marquet

High energy factorization and saturation

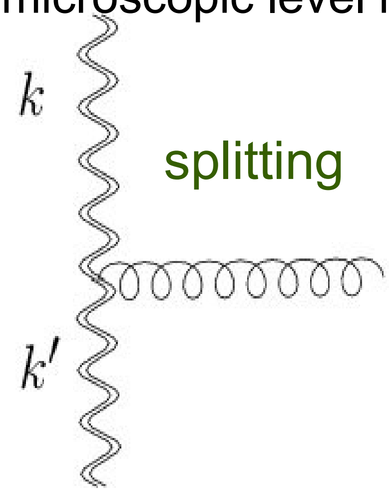
Saturation – state where number of gluons stops growing due to high ocupation number

Cross sections change their behaviour from power like to logarithmic like.

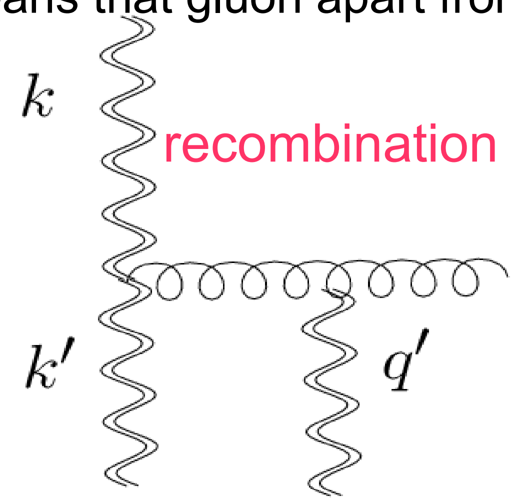
Gribov, Levin, Ryskin '83



On microscopic level it means that gluon apart from



Collinear and anticollinear



Main contribution from anticollinear pole

Nonlinear evolution equation BK

Balitsky, Kovchegov

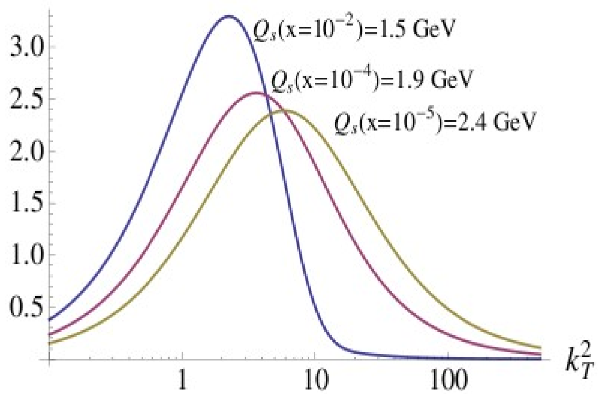
In the saturation regime the anticollinear pole gets substracted and emissions get ordered both in 1/x and kt

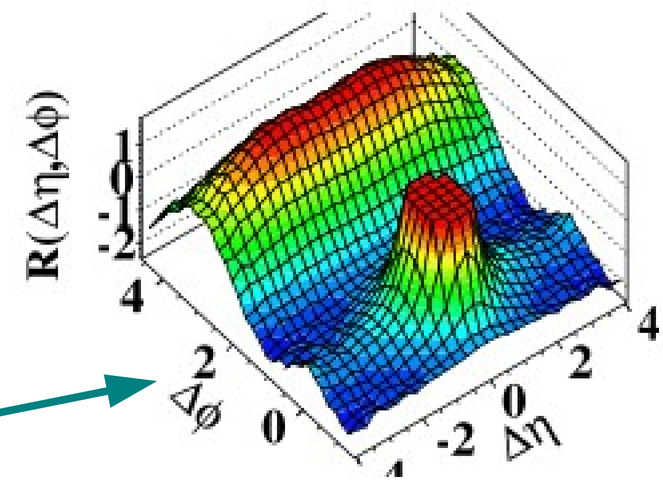
Unintegrated gluon density in saturated region

Possible determination of shape of gluon?
Finally with LHC we can probe gluon

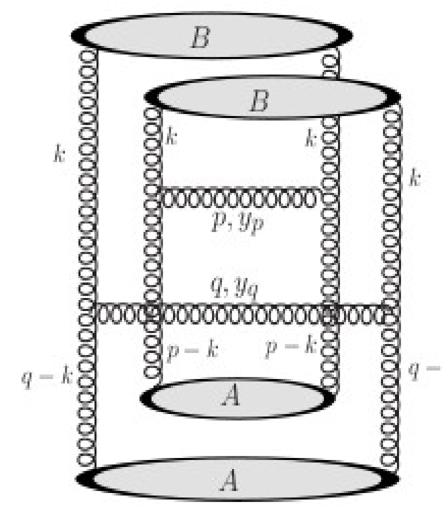
Ridge observed at CMS in 2010

Dumitru, Venugopalan, Gellis McLerran, Lapp '10i





The maximum of glue essential for



$$\varphi(k,x,b) = \frac{C_F}{\alpha_s(k)\,(2\pi)^3} \int d^2\mathbf{r}\; e^{-i\mathbf{k}\cdot\mathbf{r}}\, \nabla^2_{\mathbf{r}} \mathcal{N}_G(r, Y = \ln(x_0/x), b)$$

$$N_G(x,b,r) = 2N(x,b,r) - N^2(x,b,r)$$

$$N_Q(x,b,r) = 1 - e^{-f(x,r,b)} \qquad N_G(x,b,r) = 1 - e^{-2f(x,r,b)}$$

$$\alpha_s(Q^2_{s\,g}) \qquad \alpha_s(Q^2_{s\,q})$$

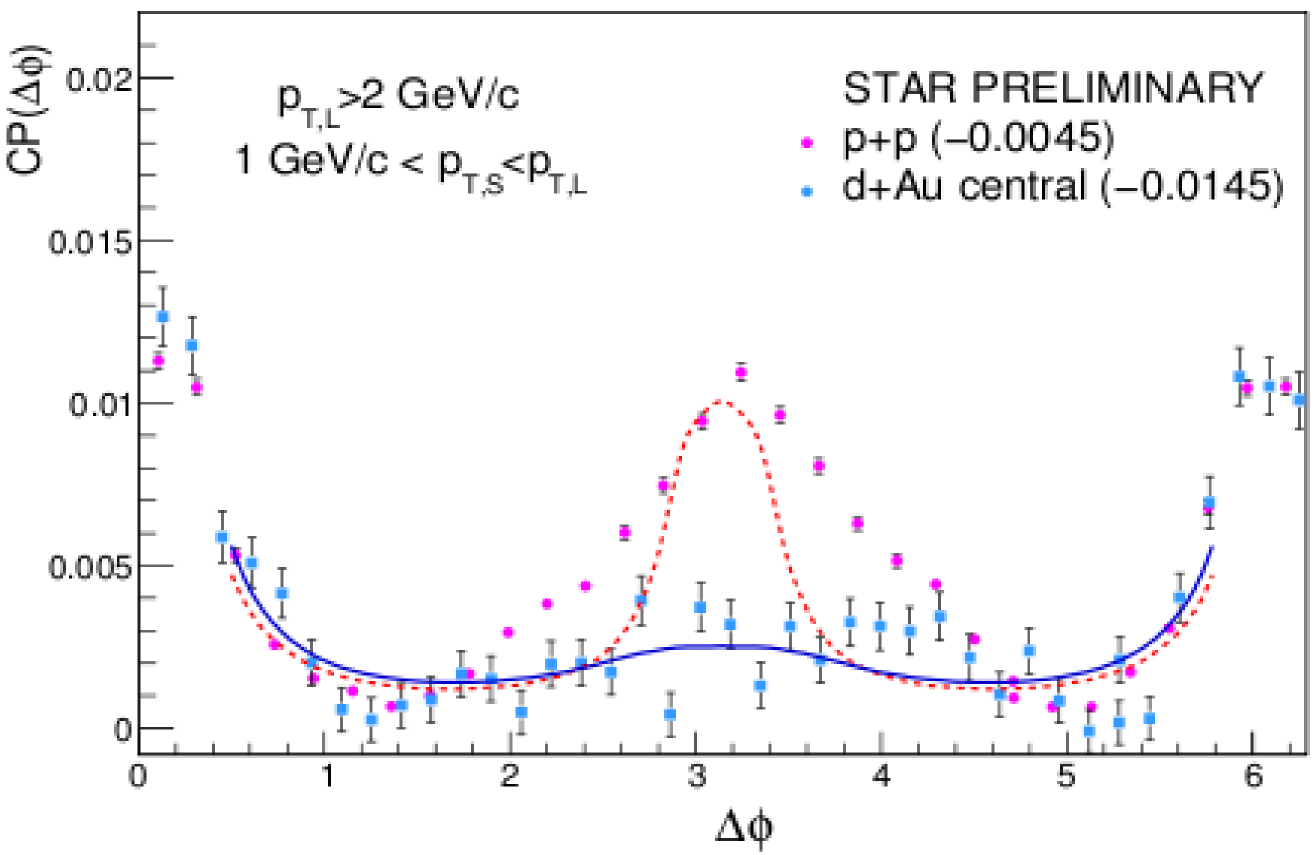
$$|\mathbf{p}_\perp - \mathbf{k}_\perp| \sim Q_s$$

$$|\mathbf{q}_\perp - \mathbf{k}_\perp| \sim Q_s$$

But at least 10 more possible
explanations: Levin, Razaian; Pierog,..

Saturation and production of forward dijets in d-Au at RHIC

Going to more dense system the disribution flattens. More saturation?...



Albacete, Marquet '10; Tuchin '10

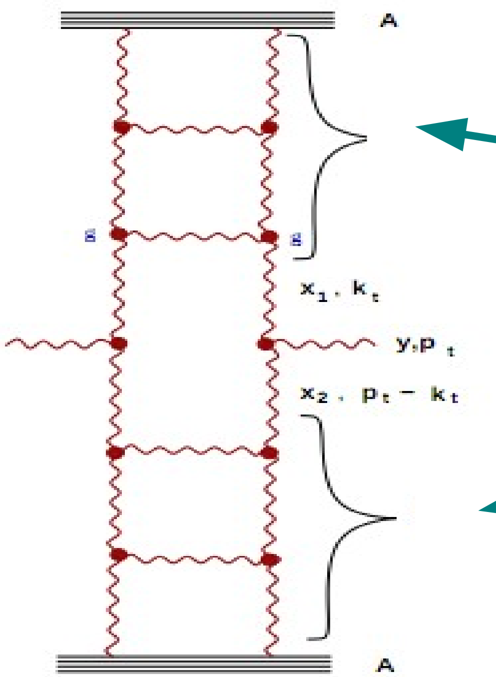
$$CP(\Delta\phi) = \frac{N_{pair}(\Delta\phi)}{N_{trig}}$$

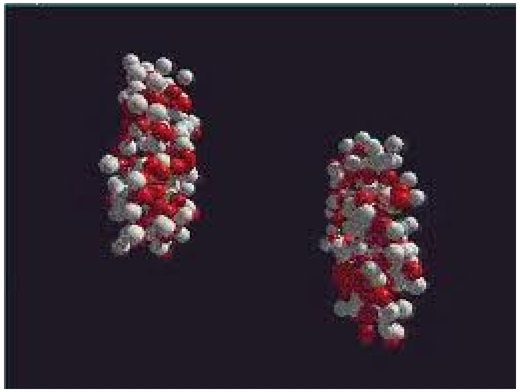
$$N_{pair}(\Delta\phi) = \int_{y_i, |p_{i\perp}|} \frac{dN^{pA\to h_1 h_2 X}}{d^3p_1 d^3p_2}$$

$$N_{trig} = \int_{y,\ p_\perp} \frac{dN^{pA\to hX}}{d^3p}$$

Production of gluons

Kovchegov; Levin, Razaian; Praszłowicz,.....





$$\frac{d\sigma}{d^2p_t\,dy} = \frac{2\,\alpha_s}{C_F}\,\frac{1}{{p_t}^2}\int d^2k\,\phi(k, x_1)\,\phi(k - p_t, x_2)$$

$$x_1 \sim \frac{e^{y}}{\sqrt{s}} \qquad x_2 \sim \frac{e^{-y}}{\sqrt{s}}$$

$$Q_{s1} < p_t < Q_{s2}$$

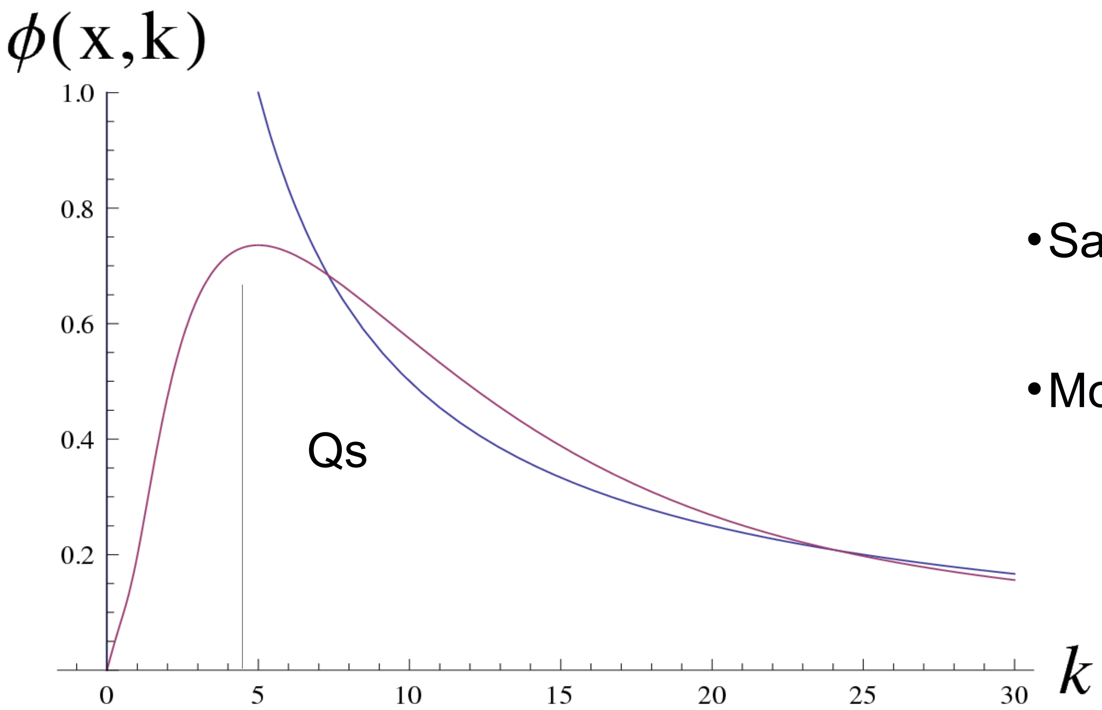
Kutak '11

Dumitru, McLerran,Blaizot,...

$$\frac{d\sigma}{dy} = \frac{2A_\perp^2 C_F Q_{s1}^2 Q_{s2}^2 e^{-\frac{p_{t\,min}^2}{Q_{s1}^2+Q_{s2}^2}}\left(p_{t\,min}^2 Q_{s1}^2 Q_{s2}^2 + Q_{s1}^6 + Q_{s2}^6\right)}{\pi^2\alpha_s(Q_{s1}^2+Q_{s2}^2)^4} + \frac{4A_\perp^2 C_F Q_{s1}^4 Q_{s2}^4 \Gamma\left(0, \frac{p_{t\,min}^2}{(Q_{s1}^2+Q_{s2}^2)}\right)}{\pi^2\alpha_s(Q_{s1}^2+Q_{s2}^2)^3}$$

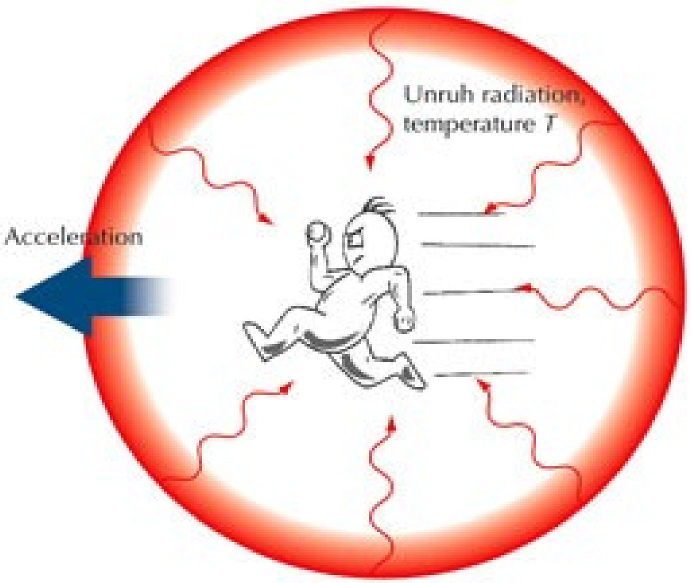
$$\frac{d\sigma}{dy} = \frac{2A_\perp^2 C_F Q_{s1}^2}{\pi^2\alpha_s} - \frac{2A_\perp^2 C_F Q_{s1}^4}{\pi^2\alpha_s Q_{s2}^2}\left(2\log\left(\frac{Q_{s1}^2}{Q_{s2}^2}\right) + 5 + 2\gamma_E\right) + O\left((Q_{s1}^2/Q_{s2}^2)^3\right)$$

The gluon density - fetures



- Saturation scale regulates the divergence
- Most of gluons have momentum of the order of Qs

Hint for relation of saturation scale Q_s to temperature T: Unruh effect



Observer in its rest frame feels thermal
Radiation or Bose-Einstein distribution

$$T = \frac{|a|}{2\pi}$$

$$\hat{n}_M \xrightarrow{\text{Bogoliubov transformation}} \hat{n}_R$$

$$\langle 0_M | \hat{n}_R | 0_M \rangle = \frac{1}{e^{\frac{2\pi\omega}{a}} - 1}$$

Minkowski vacum

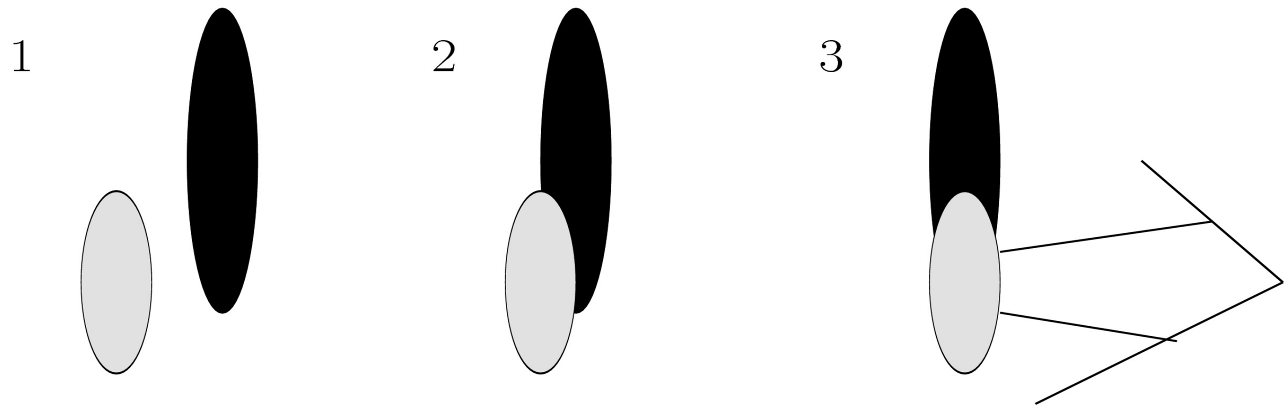
Rindler number operator

Result independent of particulars
of field theory i.e. the same
for QED, QCD

Colliding hadrons and Unruh effect

Stages of collision

Kharzeev, Tuchin '05



$$P(M \leftarrow m) = 2\pi |\mathcal{T}(M \leftarrow m)|^2 \, \rho(M),$$

$$\int dM \, P(M \leftarrow m)$$

Probability for transition to final state

should be finite

density of states determined by typical momentum. Qs emerges

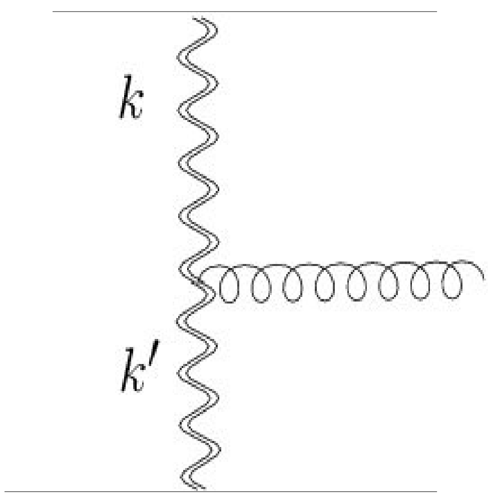
$$|\mathcal{T}(M \leftarrow m)|^2 \sim \exp(-2\pi M/a)$$

$$\frac{a}{2\pi} \equiv T \leq \frac{\sqrt{6}}{4\pi} \, \frac{1}{\sqrt{b}} \equiv T_{Hag}$$

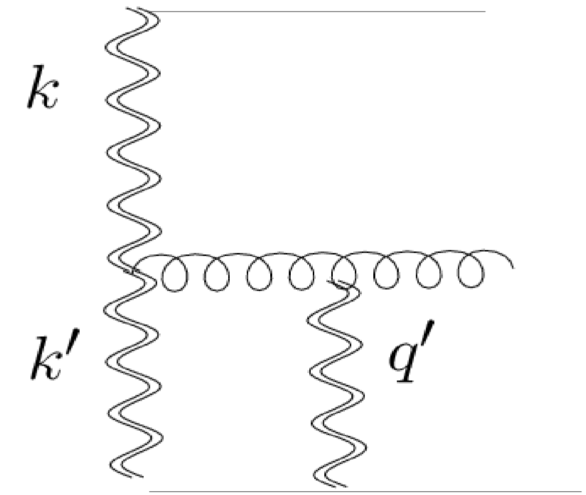
$$T = \frac{Q_s(x)}{2\pi}$$

Saturation nonlinearities and fluctuations

BFKL



BK



The thermal fluctuations are vacum fluctuations experienced by accerelated apparatures.
In the linear QCD equations as BFKL no fluctuation on a level or Reggeized gluon since they collapse to linear equation. BK equation brings nonlinearities and loops...

During deceleration the horizon forms so there are regions of the global spacetime which will never be observer by us, so there should be a certain entropy.

Towards entropy

The relation $T = \frac{Q_s(x)}{2\pi}$ Can be understood in a generalized sense i.e. that saturation scale defines some temperature.

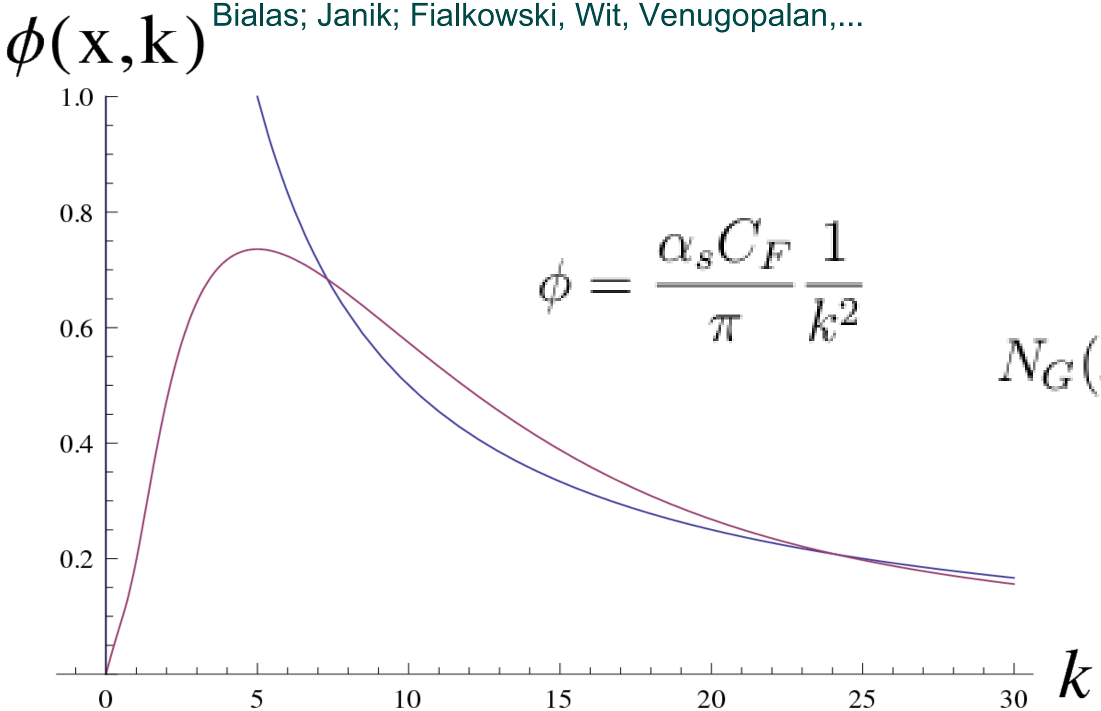
Equilibrium thermodynamics relations $\longrightarrow$ Lower bound on produced entropy

It can be shown that the saturation line has an interpretation of a characteristics i.e. line along which the gluon density has a constant value.

Kutak 2009

Gluon production and entropy

Bialas; Janik; Fialkowski, Wit, Venugopalan,...



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$$M_G(x) = Q_s(x)$$ gluon's mass

$$M(x) = N_G(x) M_G(x)$$ mass of system of gluons

$$N_G(x) \equiv \frac{dN}{dy} = \frac{1}{S_\perp}\frac{d\sigma}{dy}$$ number of gluons

$$dE = TdS$$

$$dM = TdS$$

$$d\left[N_G(x)\,M_G(x)\right] = \frac{Q_s(x)}{2\pi} dS$$

Many-body interactions

Medium generated mass of gluon.
Framework of Hard Thermal Loops.

Entropy due to less dense hadron

$$S = \frac{6 C_F A_\perp}{\pi \alpha_s} Q_s^2(x) + S_0$$

Similarly in QED. Cut on photon`s kt
Is equivalent to introducing mass.

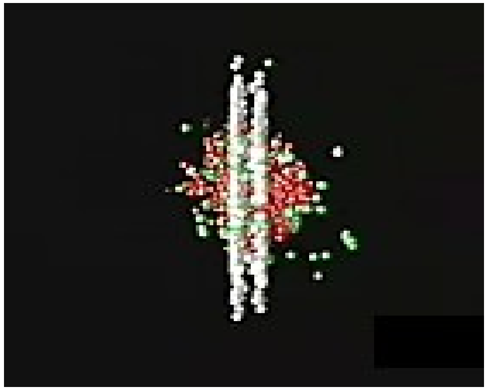
$$S = 3\pi\left[N_G(x) + N_{G0}\right]$$

In presented approach mass is not fixed it is x dependent

Entropy and gluon distribution

Kutak '11

Number of gluons in the updf:



$$n_G(x) \equiv \frac{1}{\pi}\int d^3r\, d^2k\, \Phi(x,k,r) = \frac{1}{\pi}\int d^2k\, \phi(x,k^2)$$

Using GBW gluon we get: $n_G(x) = \dfrac{C_F A_\perp}{2\pi^2 \alpha_s} Q_s^2(x)$

$$d^3r \equiv d^2b\, dl$$
$$r \equiv (l, \mathbf{b})$$

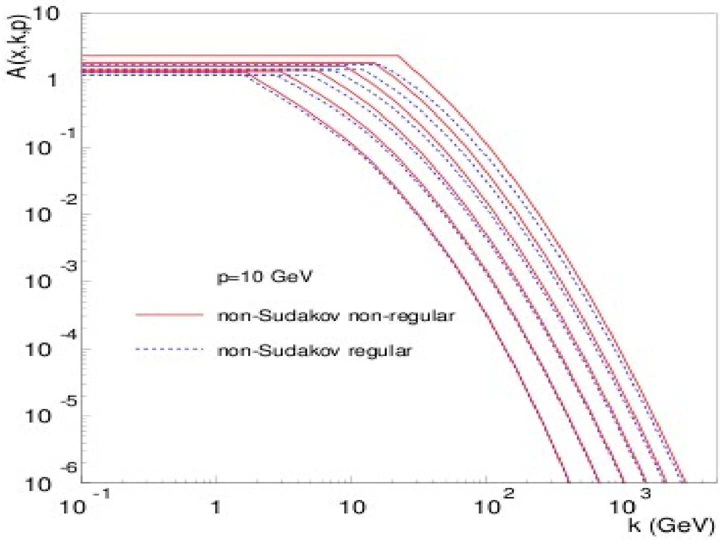
And entropy expressed in terms of number of gluons.

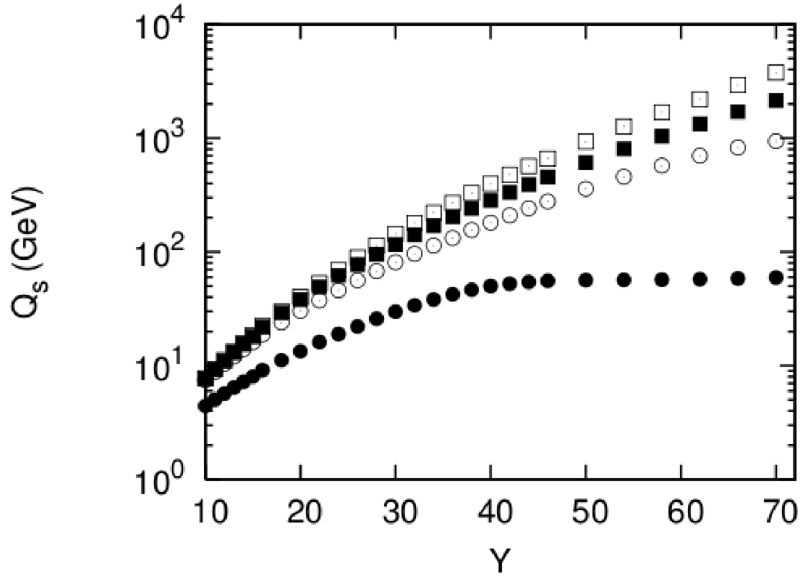
$$S = 12\pi\, n_G(x) + 3\pi\, N_{G\,0}$$

Remark: possible definition of unintegrated entropy in kt

Unitarity corrections via boundary conditions in CCFM

Avsar, Stasto '10





Gluon density supressed in the saturated region. Arbitrary but...

saturation scale saturates itself because of limited phase space due to existence of hard scale

Kutak, Jung '09
Avsar, Iancu '09
Avsar, Stasto 10

From Avsar, Stasto

Consequence: at given hard pt the saturation stops to depend on energy
Therefore there wil be some maximal entropy from saturated region for a given pt

Conclusions and further comments

- Satuartion allows in QCD motivated way to calculate entropy which has intuitive meaning. It behaves like number of produced gluons and scales like the target's size

- Perhaps it offers alternative way of introducing temperature to field theory

- Evidence for Unruh effect?

- Very interesing complementary approach of R. Peschanski.

- Recent paper by E. Kiritsis and A. Tsalios. AdS/CFT calculations of trapped surface with energy cut off on scale factor. The same result for entropy.