Two-particle correlations in gluon emission from high energy QCD.

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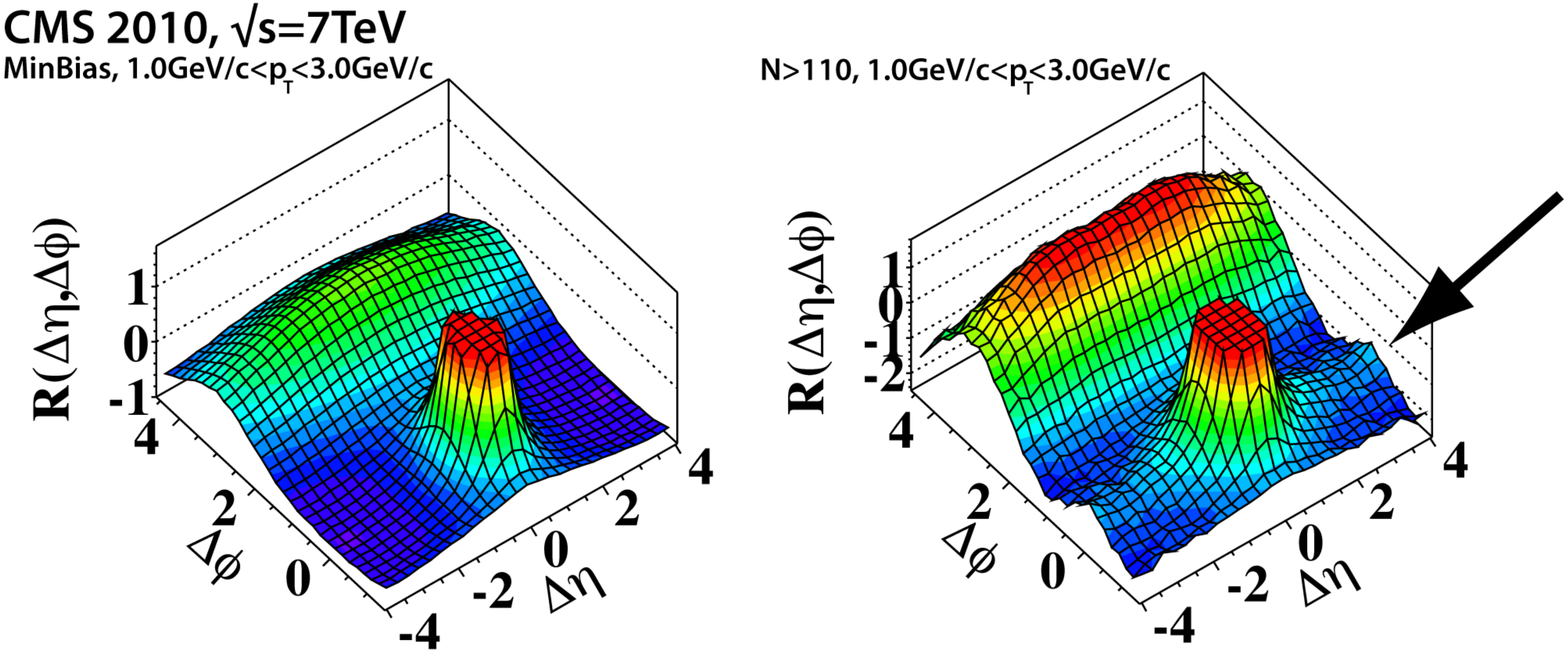
with Alex Kovner; arXiv:1012.3398 [hep-ph] , arXiv:1109.0347 [hep-ph]

"RIDGE" - ANGULAR CORRELATIONS

Two particle correlations in $p-p$: long range in rapidity, near-side angular correlations



"High multiplicity" collisions with over a hundred charged particles produced

Forward pick. Backward ridge at the angle π – back-to-back correlation.

Same-side ridge is a new "correlation" effect PYTHIA and friends fail

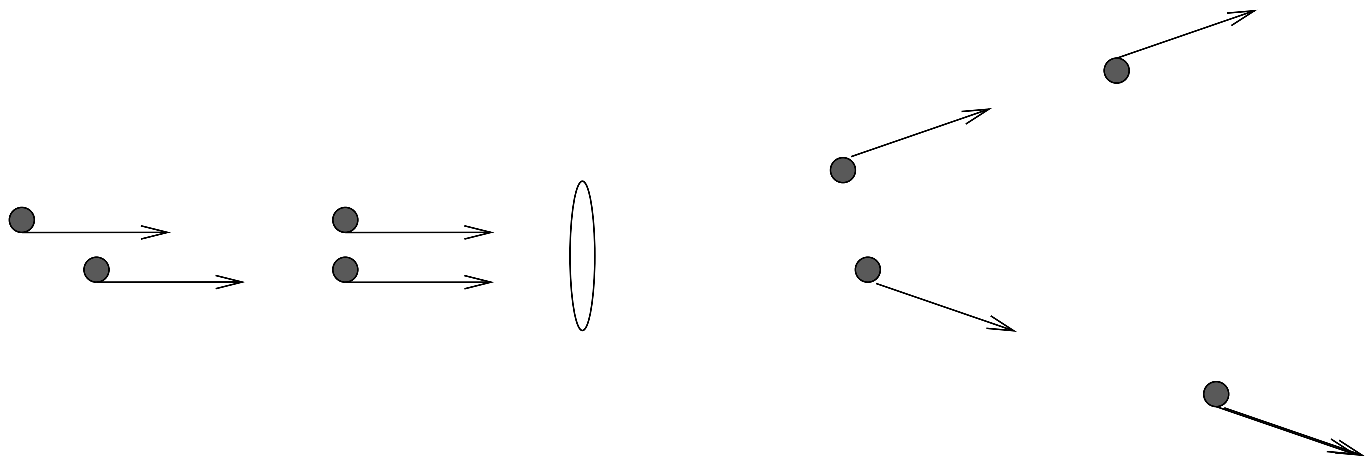
a very similar phenomenon in heavy ion collisions at RHIC

NAIVE PICTURE OF EIKONAL GLUON PRODUCTION

Long range rapidity correlations come for free with boost invariance

Incoming $|P\rangle$ is boost invariant: exactly the same gluon distribution at Y_1 and Y_2.
What happens at Y_1, happens also at Y_2: If it is probable to produce a gluon at Y_1, it is also probable to produce a gluon at Y_2.

But exactly by the same logic there must be angular correlations:
Gluons scatter on exactly the same target
If the first gluon is most likely to be scattered to the right, the second gluon at the same impact parameter will be also scattered to the right

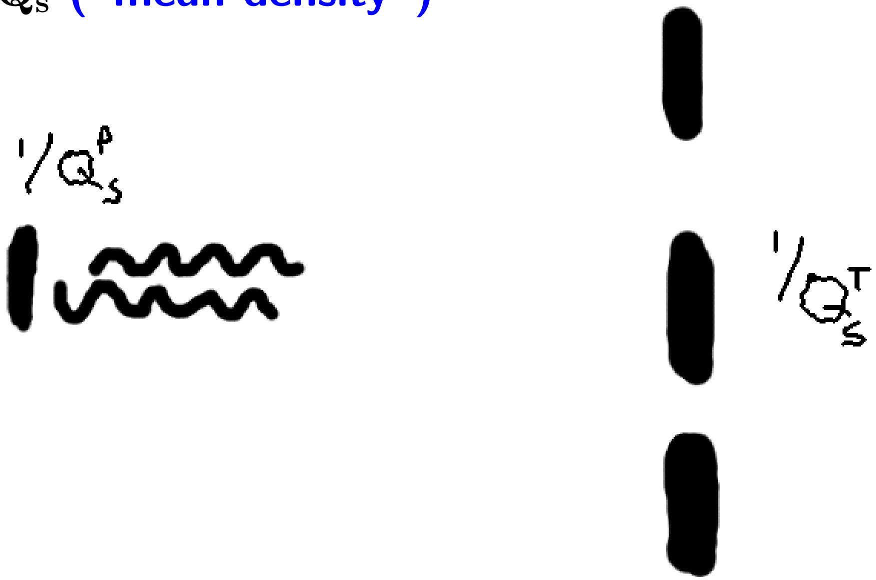


To be correlated two gluons have to be in the same incoming color state and have to scatter of the same target field

Transverse correlation length in the hadron $\mathbf{L = 1/Q_s}$ ("mean density")

The correlated production $\propto 1/(Q_s^{max})^2$,

while the total multiplicity $\propto S_A^{min}$



$$\left[\frac{d^2N}{d^2p\, d\eta\, d^2k\, d\xi} - \frac{dN}{d^2k\, d\xi}\frac{dN}{d^2p\, d\eta}\right] \Big/ \frac{dN}{d^2k\, d\xi}\frac{dN}{d^2p\, d\eta} \propto \frac{1}{(Q_s^{max})^2\, S_A^{min}}\,.$$

TWO GLUON INCLUSIVE PRODUCTION

Using dilute projectile formulae, but thinking of it as being dense

$$\frac{\mathbf{dN}}{\mathbf{d^2pd^2kd\eta d\xi}} = \langle \mathbf{A^{ab}(k,p)A^{*ab}(k,p)} \rangle_{\mathbf{P,T}} = \langle \sigma^4 \rangle_{\mathbf{P,T}} + \text{ terms subleading in } \rho$$

$$\sigma^4 = \int_{\mathbf{z,\bar{z},u,\bar{u},x_1,\bar{x}_1,x_2\bar{x}_2}} \mathbf{e^{ik(z-\bar{z})+ip(u-\bar{u})}\vec{f}(\bar{z}-\bar{x}_1)\cdot\vec{f}(x_1-z)\,\vec{f}(\bar{u}-\bar{x}_2)\cdot\vec{f}(x_2-u)}$$

$$\times \left\{\rho(x_1)[S^\dagger(x_1) - S^\dagger(z)][S(\bar{x}_1) - S(z)]\rho(\bar{x}_1)\right\}\left\{\rho(x_2)[S^\dagger(u) - S^\dagger(x_2)][S(\bar{u}) - S(\bar{x}_2)\rho(\bar{x}_2)\right\}$$

Here

$$f_i(x-y) = \frac{(x-y)_i}{(x-y)^2}$$

$$\sigma^4 \;=\; \sigma_1(\mathbf{k})\;\sigma_1(\mathbf{p})$$

Configuration by configuration
(for fixed configuration of projectile charges ρ and fixed target fields S)

$$\sigma_1(\mathbf{k}) = \int_{\mathbf{z},\bar{\mathbf{z}},\mathbf{x_1},\bar{\mathbf{x}}_1} \mathrm{e}^{\mathrm{i}\mathbf{k}(\mathbf{z}-\bar{\mathbf{z}})}\vec{\mathbf{f}}(\bar{\mathbf{z}}-\bar{\mathbf{x}}_1)\cdot\vec{\mathbf{f}}(\mathbf{x}_1-\mathbf{z})\;\Big\{\rho(\mathbf{x}_1)[\mathbf{S}^\dagger(\mathbf{x}_1)\;-\;\mathbf{S}^\dagger(\mathbf{z})][\mathbf{S}(\bar{\mathbf{x}}_1)\;-\;\mathbf{S}(\mathbf{z})]\rho(\bar{\mathbf{x}}_1)\Big\}$$

$\sigma_1(k)$ is a nontrivial real function of k, which has a maximum at some value $k = q_0$. Clearly then the two gluon production probability configuration by configuration has a maximum at

$$\mathbf{k}\;=\;\mathbf{p}\;=\;\mathbf{q_0}$$

The value of q_0 depends on configuration, but the fact that $\mathbf{k}\;\simeq\;\mathbf{p}$ does not.

We expect $\mathrm{q}_0\;\simeq\;\mathrm{Q}_s$

This is the near side correlation!

Target correlations $\langle tr[S^\dagger S]\, tr[S^\dagger S]\rangle_T$ from the BK equation

BKe for imaginary part of the dipole scattering amplitude $\mathbf{N(\vec{r}) = 1 - tr[S^\dagger_x S_y]/N_c}$

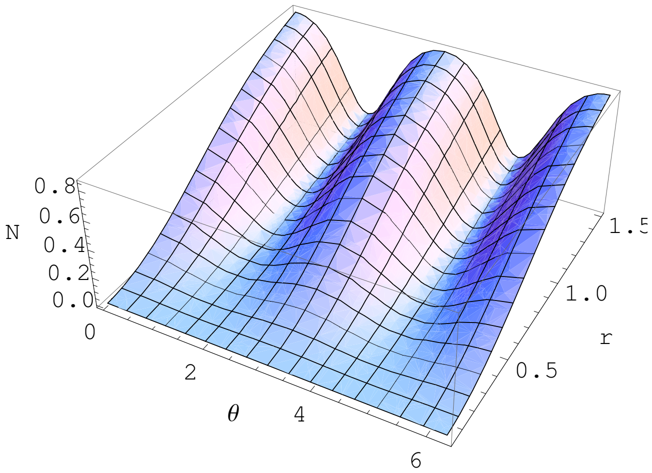
$$\partial_Y \mathbf{N(\vec{r})} = \frac{\mathbf{C_F}\,\alpha_s}{\mathbf{2}\,\pi} \int \mathbf{d^2\vec{r}'} \frac{\mathbf{\vec{r}^2}}{\mathbf{\vec{r}'^2\,(\vec{r}-\vec{r}')^2}} \left[\mathbf{N(\vec{r}') + N(\vec{r}-\vec{r}') - N(\vec{r}) - N(\vec{r}')\,N(\vec{r}-\vec{r}')}\right]$$

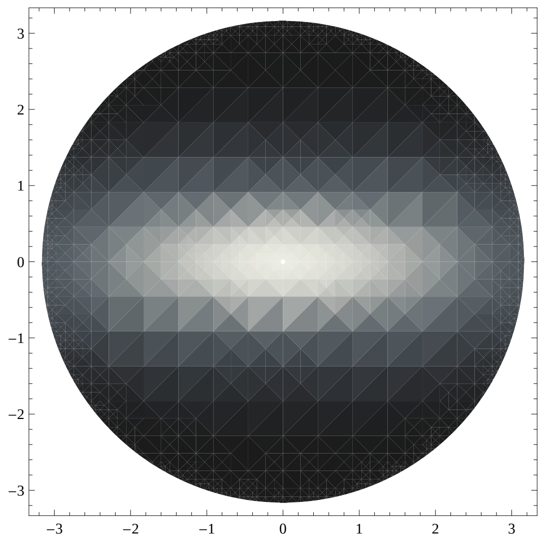
$\mathbf{\vec{r} = \vec{x} - \vec{y}}$ is a vector of the dipole moment.

Anisotropic initial conditions at some initial rapidity $Y_0 = \ln 10^2$.

$$\mathbf{N(Y_0, \vec{r}) = 1 - Exp[-a\,r^2\,xg^{LOCTEQ6}(x_0, 4/r^2)\,F(\theta)];} \qquad \mathbf{a} = \frac{\alpha_s(\mathbf{r^2})\,\pi}{\mathbf{2\,N_c\,R^2}}$$

$$\mathbf{F(\theta)} = \frac{\mathbf{1}}{\mathbf{4}} + \frac{\mathbf{3}}{\mathbf{2}}\mathbf{\cos^2(\theta)}$$



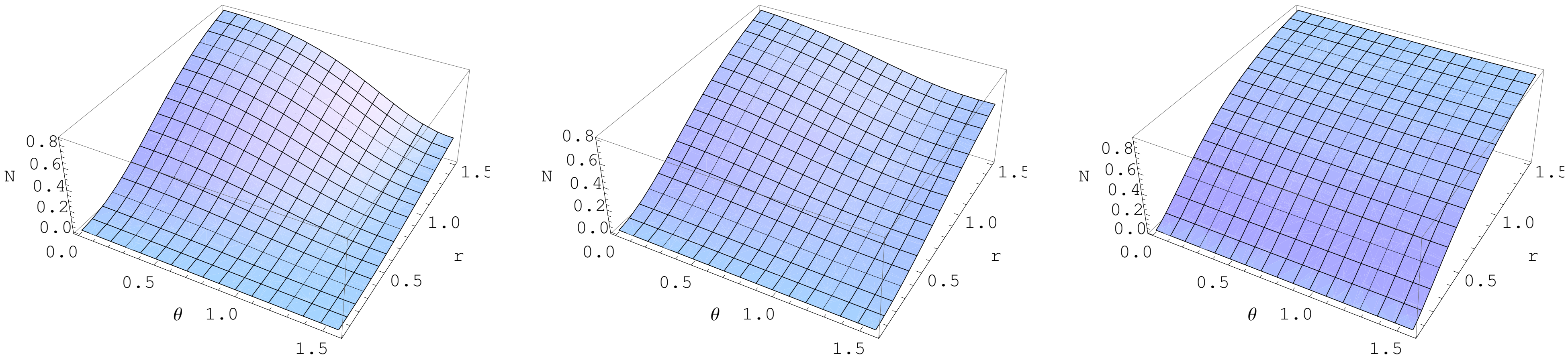


$\mathbf{W}[\delta] = \mathbf{1/2}\pi$, **constant for any δ ranging from 0 to 2π.**

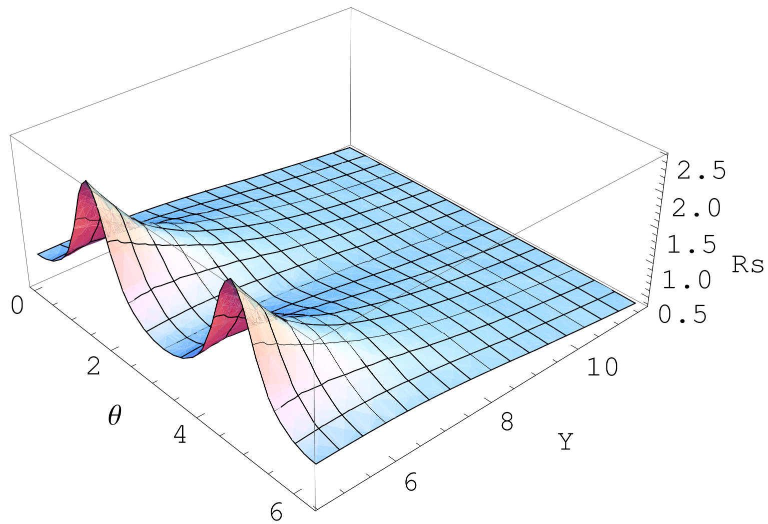
$$\langle \mathbf{F} \rangle_\delta = \int_0^{2\pi} \mathbf{d}\delta\, \mathbf{F}(\theta + \delta)\, \mathbf{W}[\delta] = \mathbf{1}$$

We are interested in the two-dipole correlator $\langle \mathbf{N}(\mathbf{Y}, \mathbf{r_1}, \theta_1, \delta)\, \mathbf{N}(\mathbf{Y}, \mathbf{r_2}, \theta_2, \delta) \rangle_\delta$.

Single configuration solution



the saturation scale $N(Y, R_S, \theta) = 1/2$

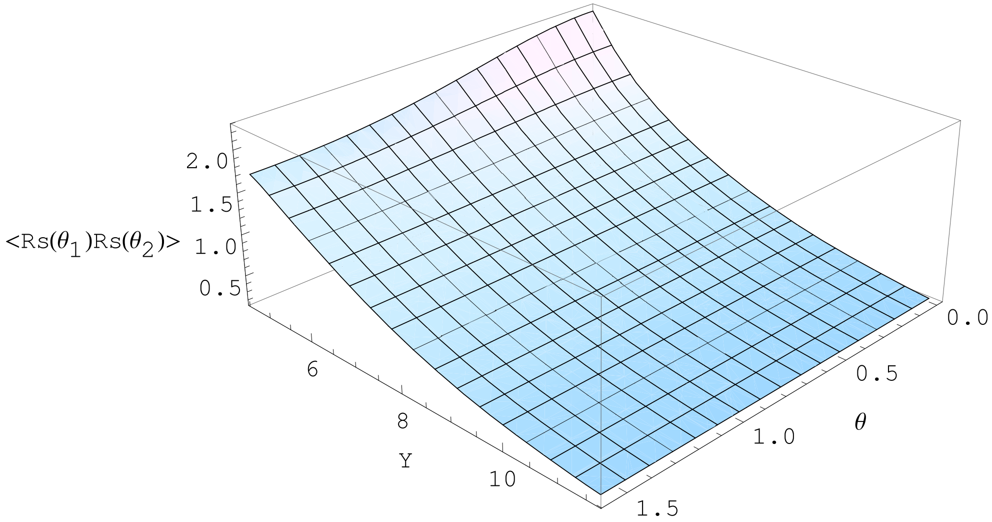


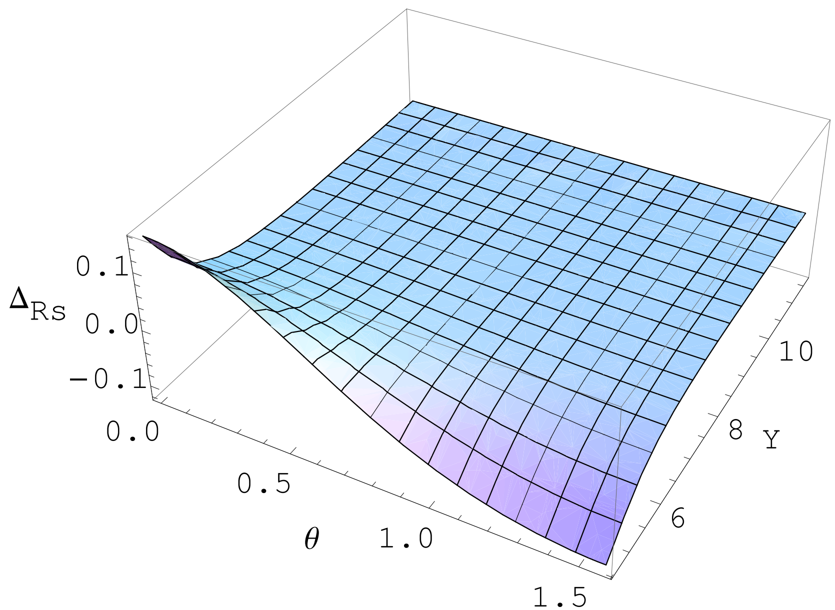
Very fast isotropization!

Angular correlations of the saturation radius

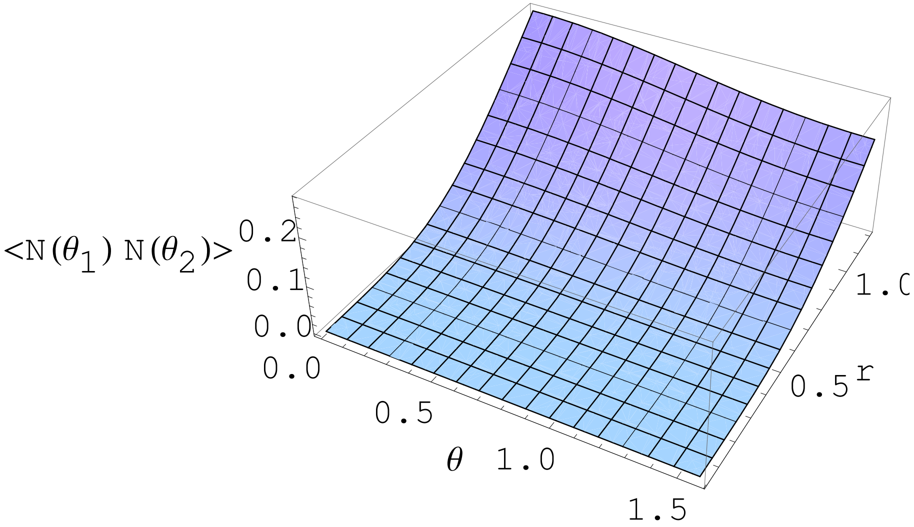
Two quantities of interest: correlator of two saturation scales $\langle \mathbf{R_s}(\theta_1)\mathbf{R_s}(\theta_2)\rangle_\delta$ **and**

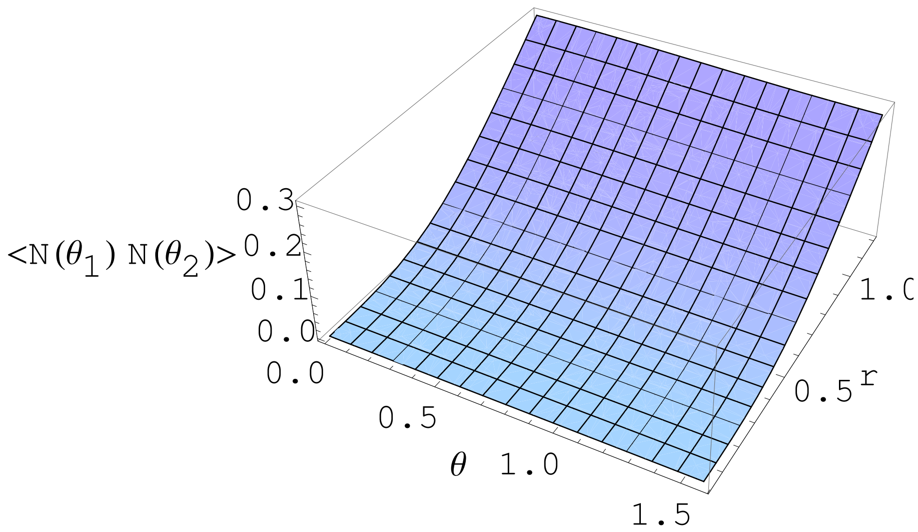
$$\mathbf{\Delta_{R_s}}(\mathbf{Y},\mathbf{r},\theta) \equiv \frac{\langle \mathbf{R_s}(\mathbf{Y},\theta_1,\delta)\,\mathbf{R_s}(\mathbf{Y},\theta_2,\delta)\rangle_\delta - \langle \mathbf{R_s}(\mathbf{Y},\theta_1,\delta)\rangle_\delta\,\langle \mathbf{R_s}(\mathbf{Y},\theta_2,\delta)\rangle_\delta}{\langle \mathbf{R_s}(\mathbf{Y},\theta_1,\delta)\rangle_\delta^2}, \qquad \theta = \theta_1 - \theta_2$$





Angular correlations $\langle \mathbf{N}(\mathbf{Y},\mathbf{r},\theta_1)\mathbf{N}(\mathbf{Y},\mathbf{r},\theta_2)\rangle_\delta$





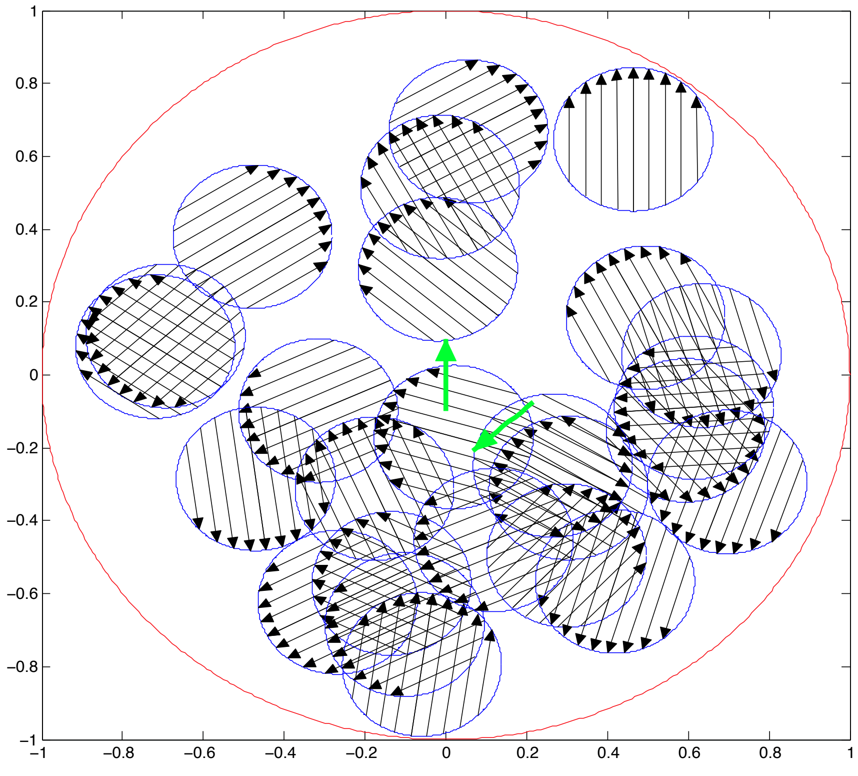
CONCLUSIONS

- **Within the "projectile" dipole model, we find an exponentially fast isotropization with the exponent $\lambda_A \simeq 0.6$.**

- **Observed correlations must arise dynamically. Those we find in the "target" dipole model. Pomeron loops are needed**

Work in progress

with Andrej Kormilitzin



$$\mathbf{N}(\mathbf{Y_0}, \vec{\mathbf{r}}, \vec{\mathbf{b}}) \;=\; \mathbf{1} \;-\; \mathbf{Exp}[\,-\,(\vec{\mathbf{r}}\,\vec{\mathbf{E}}(\vec{\mathbf{b}}))^{\mathbf{2}}]\,;$$

$$\vec{\mathbf{E}}(\vec{\mathbf{b}}) \;=\; \sum \vec{\mathbf{E}}_{\mathbf{0}}(\vec{\mathbf{b}})\,\mathbf{e}^{-\,\mathbf{d}^{\mathbf{2}}\,\mathbf{Q}_{\mathbf{s}}^{\mathbf{2}}}\,; \qquad\qquad \mathbf{E_0} = \mathbf{Q_s}$$