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Gribov-80 Memorial Workshop on Quantum Chromodynamics and Beyond'

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Evolution Equations, Saturation and the High Energy Limit

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GRIBOV-80
MEMORIAL WORKSHOP ON QUANTUM CHROMODYNAMICS AND BEYOND

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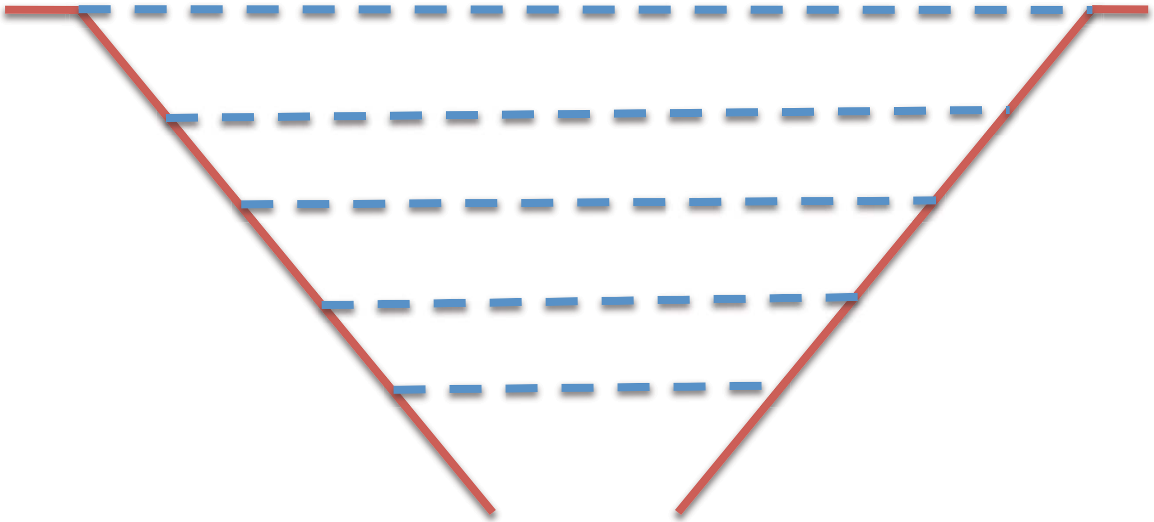
Gluon Evolution and Saturation



Gribov and the Gatchina School

Dokshitzer

Dokshitzer, Diakonov and Troian

Gribov and Lipatov

Kuraev, Lipatov and Fadin

Balitsky and Lipatov

→

$$ln(t) \sim ln(d) \sim ln(1/x) \sim y$$

$$\Delta y \sim 1/\alpha_S$$

Evolution in either of $\alpha_S \, ln(Q^2)$ or $\alpha_S \, ln(1/x)$

Evolution in Q can be shown to follow from conventional renormalization group analysis

At high Q, the coupling is weak and analysis is well defined.

The number of partons increases weakly as one increases Q: If we take a density of partons as

$$\rho = N/\pi R^2$$

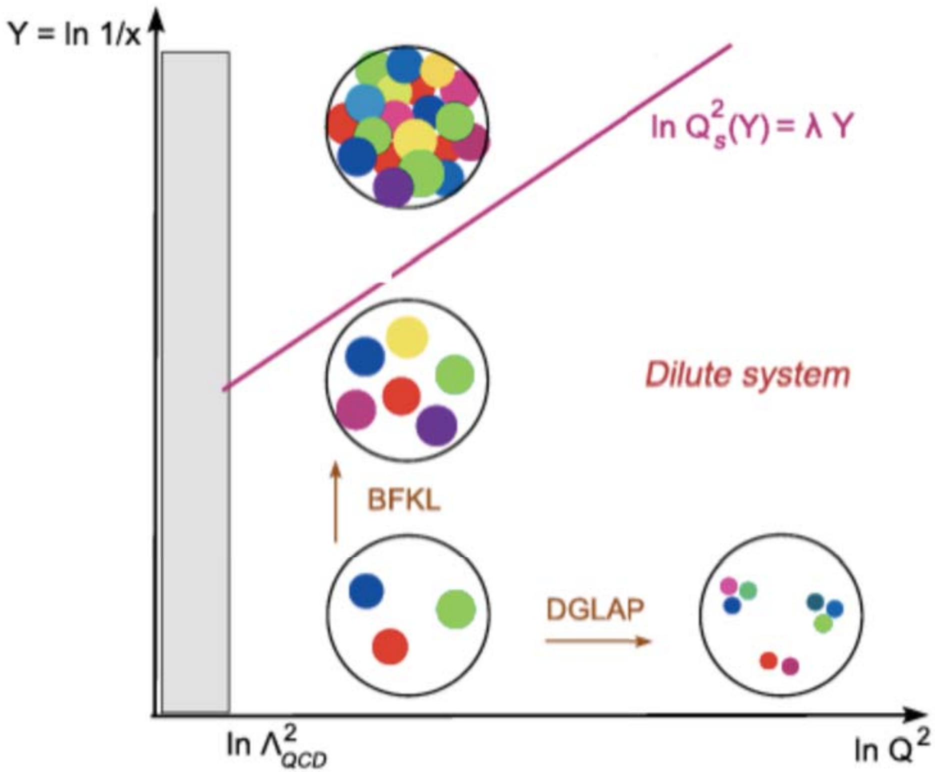
The fractional area of the partons divided by the area of the hadron scattered from shrinks to zero

$$\rho/Q^2 \rightarrow 0$$

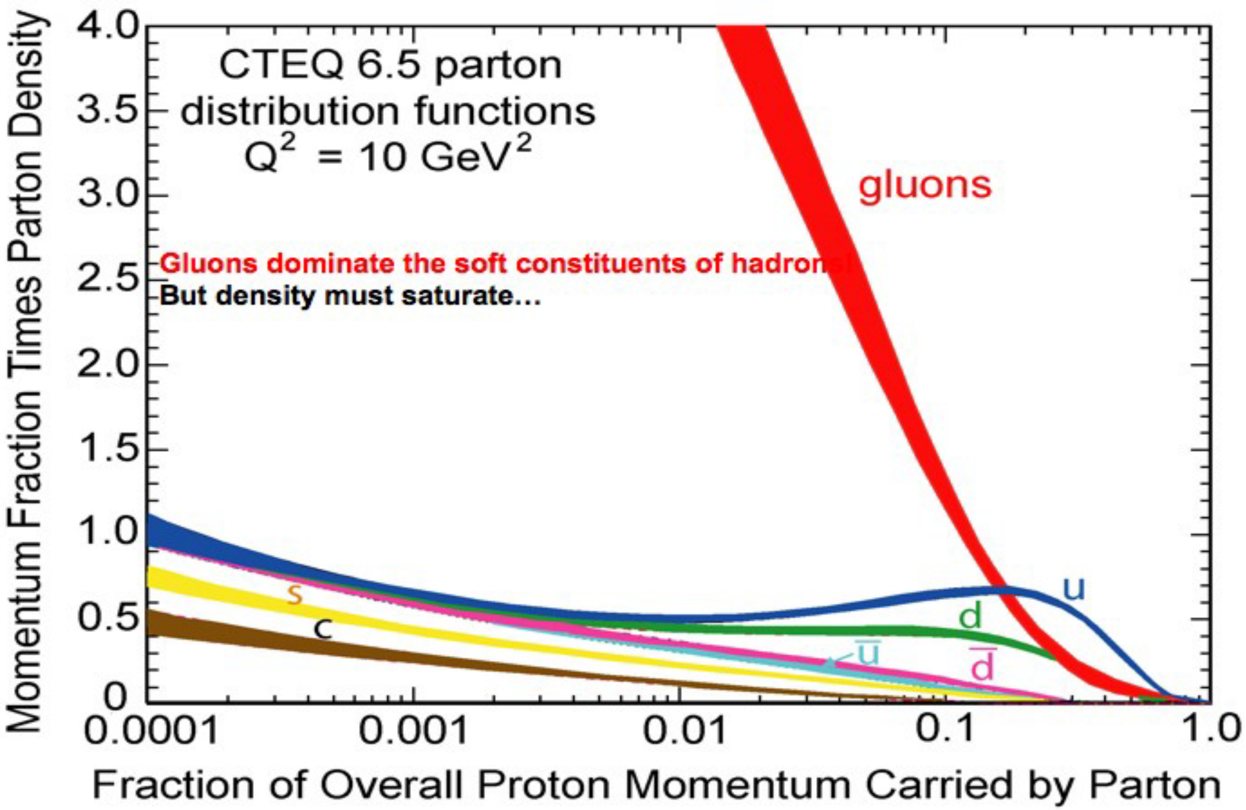
Evolution in Q takes one into a short distance, low density limit

At first sight, evolution in rapidity is problematic $y = ln(1/x)$

Evolution is at fixed parton size 1/Q, and as one evolves in y, the number of partons increases. Eventually, even if Q is taken large enough at fixed y, the density of partons will become large. The partons become tightly packed together and cannot act incoherently



Such an increase in the density of gluons is seen experimentally:



If saturation occurs at sufficiently large Q, it should be treatable by weak coupling methods. If the saturation momentum is large enough at fixed y, then saturation itself can be consistently computed.

When the gluon density begins to grow, but is sufficiently small that it may be treated as a perturbation:

$$\frac{\partial^2 \, xG(x,Q^2)}{\partial \ln(1/x)\, \partial \ln Q^2} = \frac{3\alpha_s}{\pi} xG(x,Q^2) - \frac{3\alpha_s^2}{\pi^2 R^2} \frac{[xG(x,Q^2)]}{Q^2}$$

[Gribov, Levin, Ryskin,83'- Mueller, Qiu, 86']

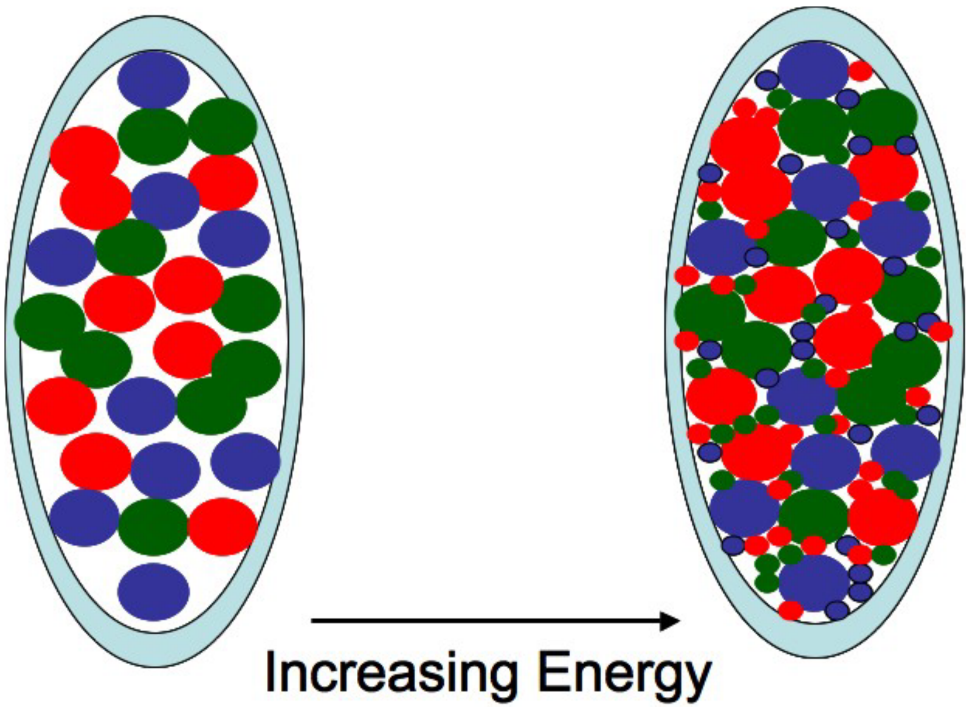
Extrapolating to the density where the gluons become large:

$$\frac{xG(x,Q_S^2)}{\pi R^2 Q_s^2} \sim \frac{1}{\alpha_S}$$

$$\frac{dN}{dy d^2x_T d^2q_T} \sim \frac{1}{\alpha_S}$$

Is a phase space density. When large, quantum mechanical occupation of states is big.

Suggests that the gluons may be treated as classical fields.



Gluons are described by a stochastic ensemble of classical fields, and will argue there is a renormalization group description

Mueller and Qiu, Nucl. Phys. B268, 427 (1986)

L. Gribov, Levin and Ryskin, Phys. Rept. 100, 1 (1983)

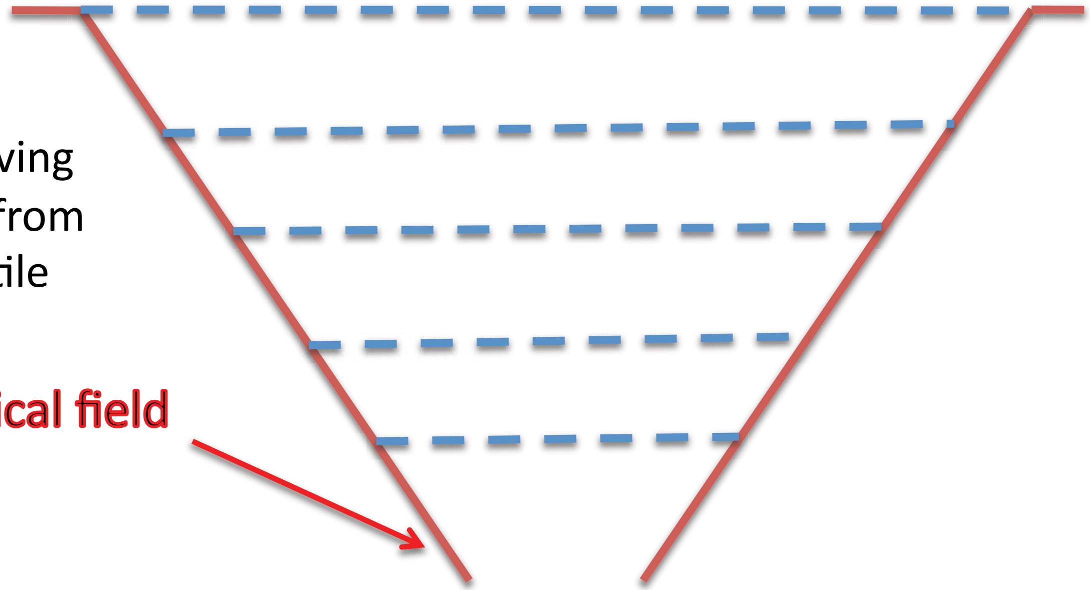
McLerran & Venugopalan, Phys. Rev. D49, 2233 (1994); 3352 (1994)

In target rest frame: Fast moving particle sees classical fields from various longitudinal positions as coherently summed

In infinite momentum frame, these fields are Lorentz contracted to sit atop one another and act coherently

Density per unit rapidity is large

Essential Ingredient is Glassy Nature of Matter: Gribov's space-time picture of hadronic interactions



Fast moving partons from projectile

Classical field

Classical field is static (during collision time)

$$ln(t) \sim ln(d) \sim ln(1/x) \sim y$$

$$\Delta y \sim 1/\alpha_S$$

Target Rest Frame

The CGC Path Integral:

$$Z = \int_\Lambda [dA][d\rho] exp\{iS[A,\rho] - F[\rho]\}$$

The current source:

$$J^\mu = \delta^{\mu +} \rho(x_T, y)$$

Rapidity:

$$y = ln(x_0^-/x^-) \sim ln(1/x) \sim \frac{1}{2} ln(p^+/p^-)$$

The separation scale is in rapidity or longitudinal momentum

$$\Lambda$$

The Renormalization Group Equation:

$$Z_0 = e^{-F[\rho]}$$

$$\frac{d}{dy}\; Z_0 = -H[d/d\rho, \rho] Z_0$$

For strong and intermediate strength fields: H is second order in

$$d/d\rho$$

It has no potential, and a non-linear kinetic energy term

Like diffusion

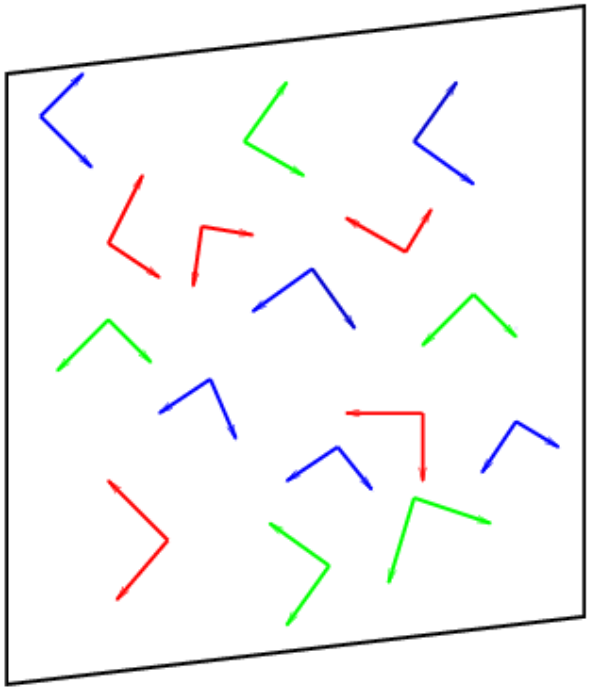
$$d/dt \;\psi = -p^2/2 \;\psi$$

$$\psi \sim e^{-x^2/2t}$$

Wavefunction spreads for all time, and has universal limit:

Universality at high energy

What does a sheet of Colored Glass look like?



$\vec{E} \perp \vec{B} \perp \vec{z}$

On the sheet $x^- = t - z$ is small

Independent of $x^+ = t + z$

$F^{i-} = E - B$ small

$F^{i+} = E + B$ big

F^{ij}

Lienard-Wiechart potentials

Random Color

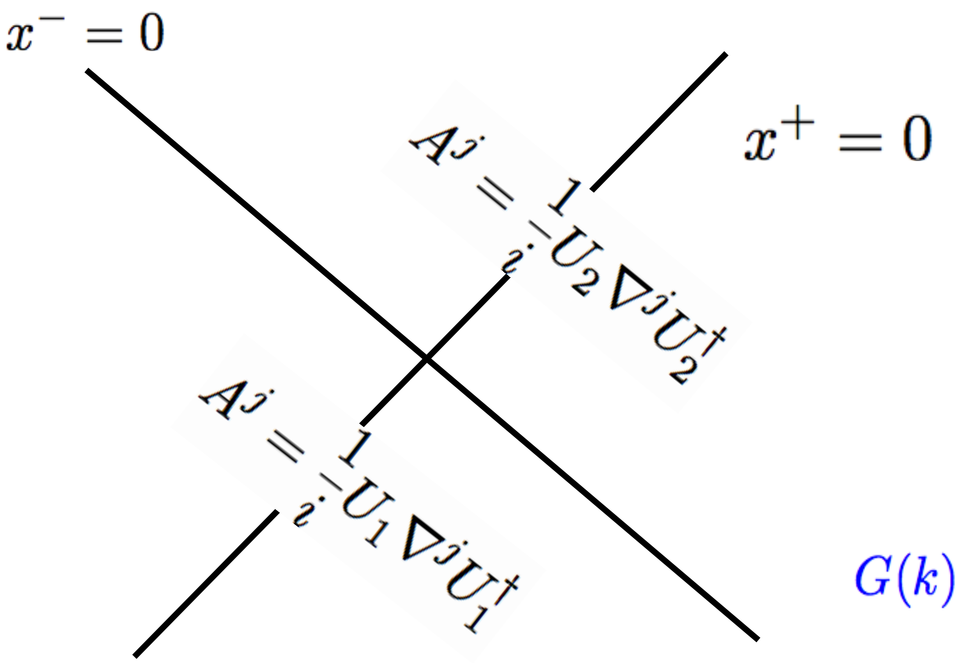
Density of gluons per unit area

$$\frac{1}{\pi R^2}\frac{dN}{dy} \sim \frac{1}{\alpha_{strong}} Q^2_{sat}$$

Fields in longitudinal space:

$$F^{i+}$$

is a delta function on scales less than the inverse longitudinal cutoff



Gluon distribution is at scales larger than the cutoff

$$G(k) \sim 1/p^+$$

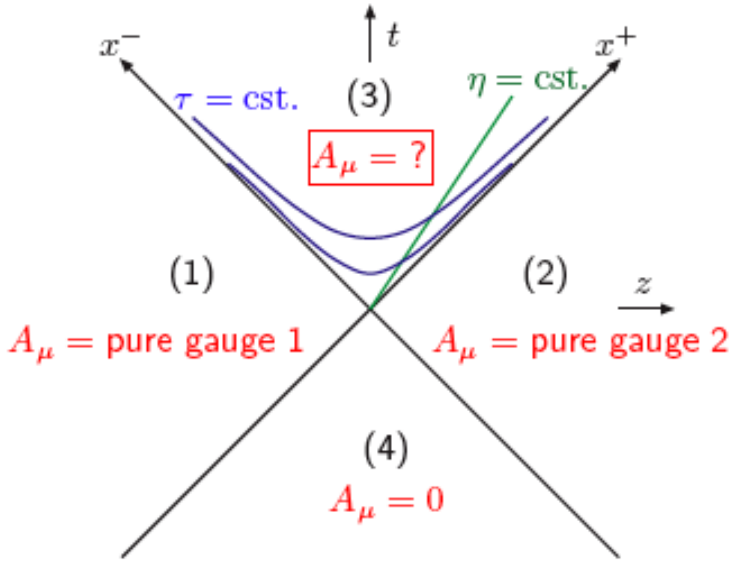
$$G(k) = < a^\dagger(k) a(k) > \sim < A(k) A(-k) >$$

The Glasma:

Before the collision only transverse E and B CGC fields

Color electric and magnetic monopoles

Almost instantaneous phase change to longitudinal E and B



In forward light cone

$$A_1^i + A_2^i$$

generates correct sources on the light cone

$$\nabla \cdot E = A \cdot E$$

$$\nabla \cdot B = A \cdot B$$

$$A_1 \cdot E_2$$

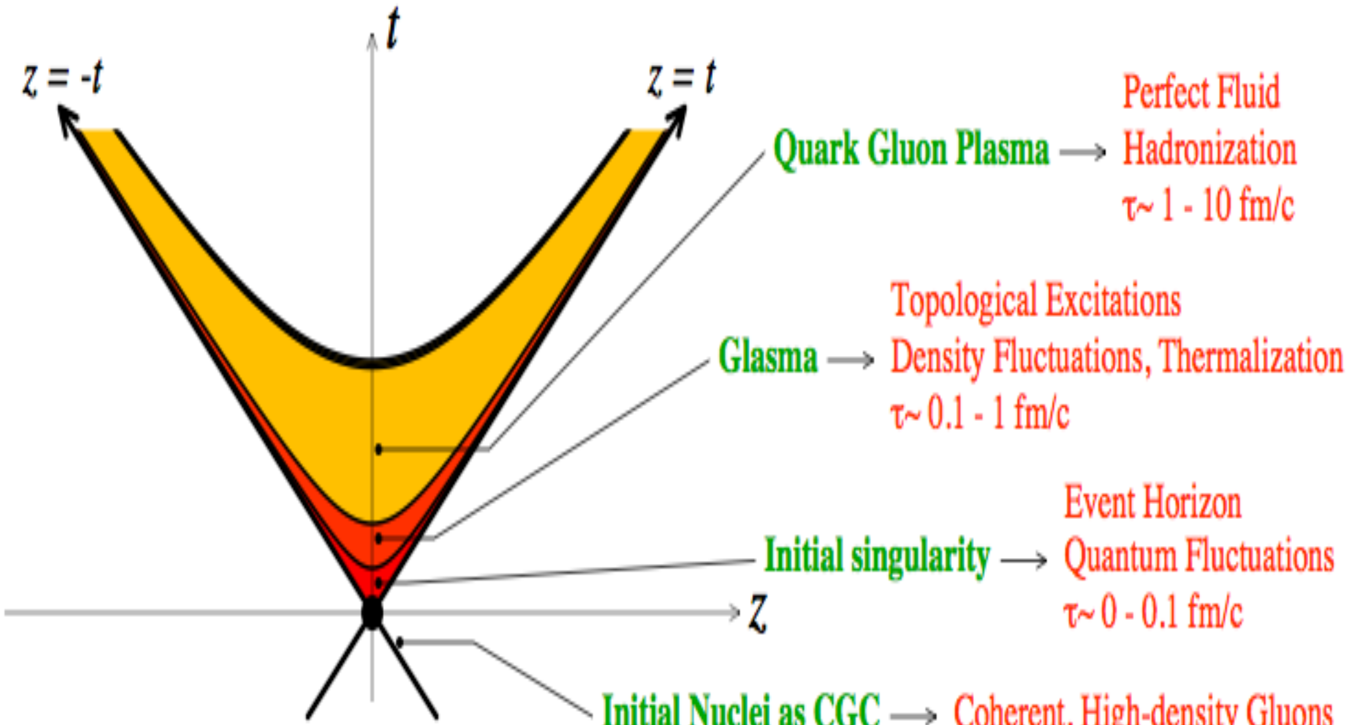
$$A_1 \cdot B_2$$

Equal strength for magnetic and electric charge on average!

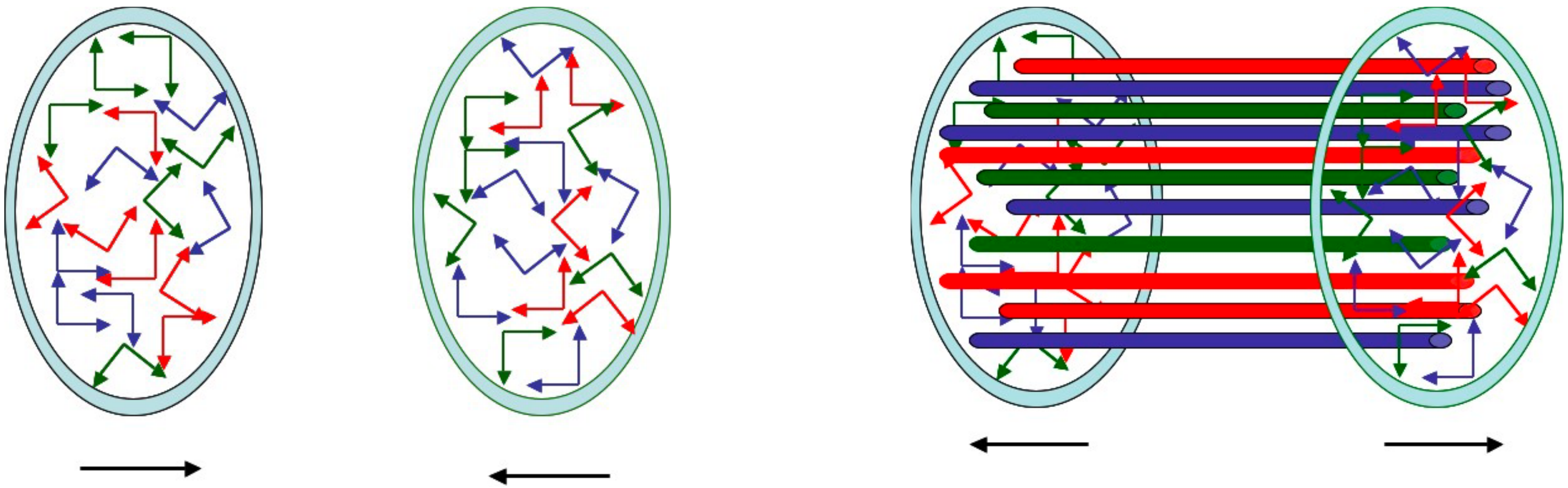
Two sheets of colored glass collide

Glass melts into gluons and thermalize

QGP is made which expands into a mixed phase of QGP and hadrons



Explicit realization of Bjorken space-time picture



"Instantaneously" develop longitudinal color E and B fields

The Wavefunction is the Wavefunction:

It is process independent and universal in the sense of high Q parton distributions.

The wavefunction describes deep inelastic scattering, deep inelastic diffractive scattering and hadron-hadron scattering. There are CGC and Glasma based descriptions of such processes and they provide a broad and robust description of various a wide set of experimental data.

There are a variety of different levels of computation from first principles in a few cases, to computations that involve some modeling, to those that involve much modeling. (See Blaizot's summary talk at www.bnl.gov/riken/glasma)
An example: monojets in dAu collisions at RHIC

Also much work on:
Initial conditions in the low density region, pomeron loops and the Reggeon Caclulus

(Marquet)

Monojets in central d+Au

- in central collisions where Q_s is the biggest

there is a very good agreement of the saturation predictions with STAR data

Albacete and C.M., to appear

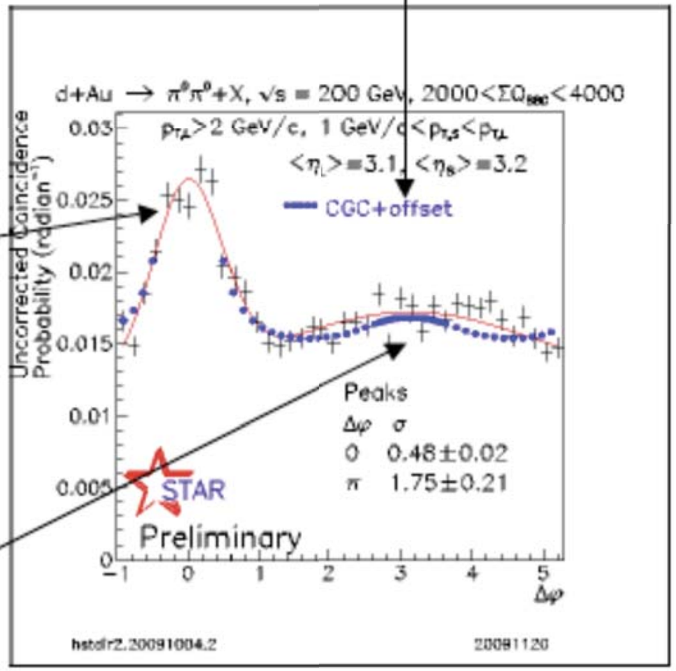
to calculate the near-side peak, one needs di-pion fragmentation functions

- the focus is on the away-side peak

where non-linearities have the biggest effect

suppressed away-side peak

an offset is needed to account for the background



standard (DGLAP-like) QCD calculations cannot reproduce this