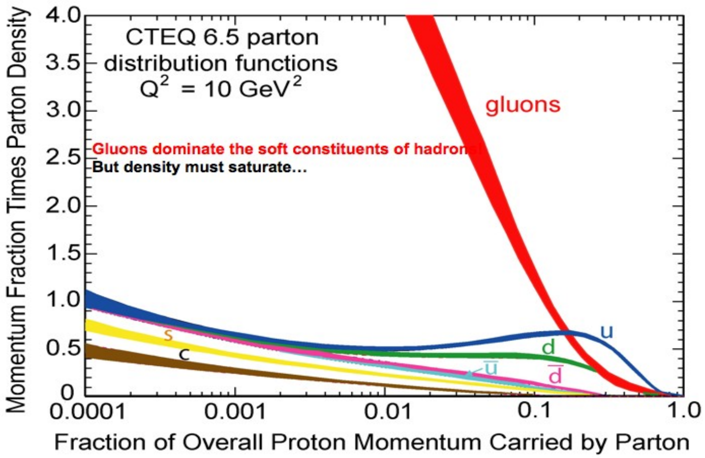
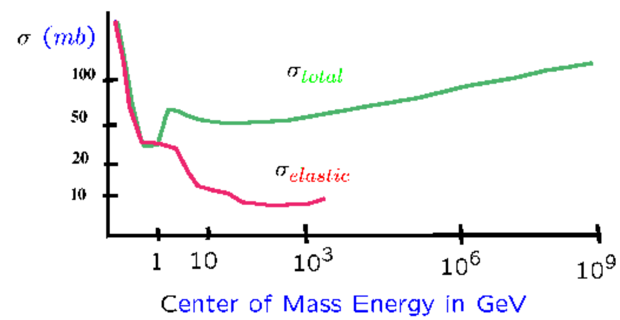
The Topological Glasma

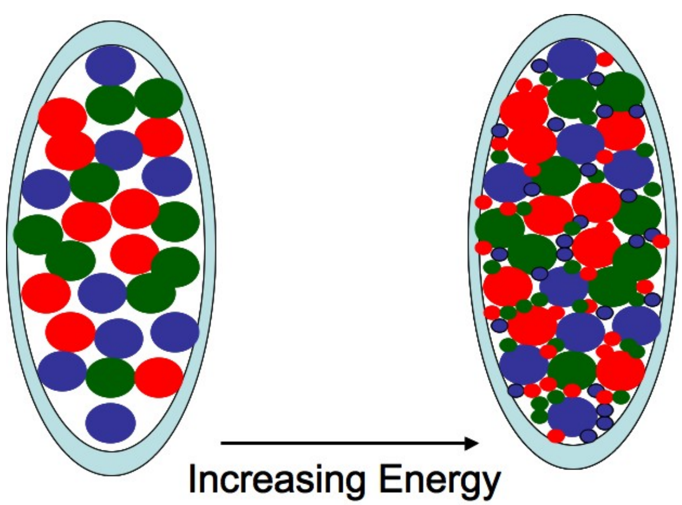
As one evolves the gluon density, the density of gluons becomes large:



The total hadronic cross section:



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



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

Leads to name for the saturated gluon media of Color Glass Condensate:

Color: Gluon Color

Glass: V. Gribov's space time picture of hadron collisions

Condensate: Coherence due to phase space density

$$\frac{dN}{dyd^2p_Td^2r_T} \sim \frac{1}{\alpha_S(Q_{sat})}$$

Derivation JIMWLK evolution equations that for correlators is BK equation

The theoretical description overlaps:

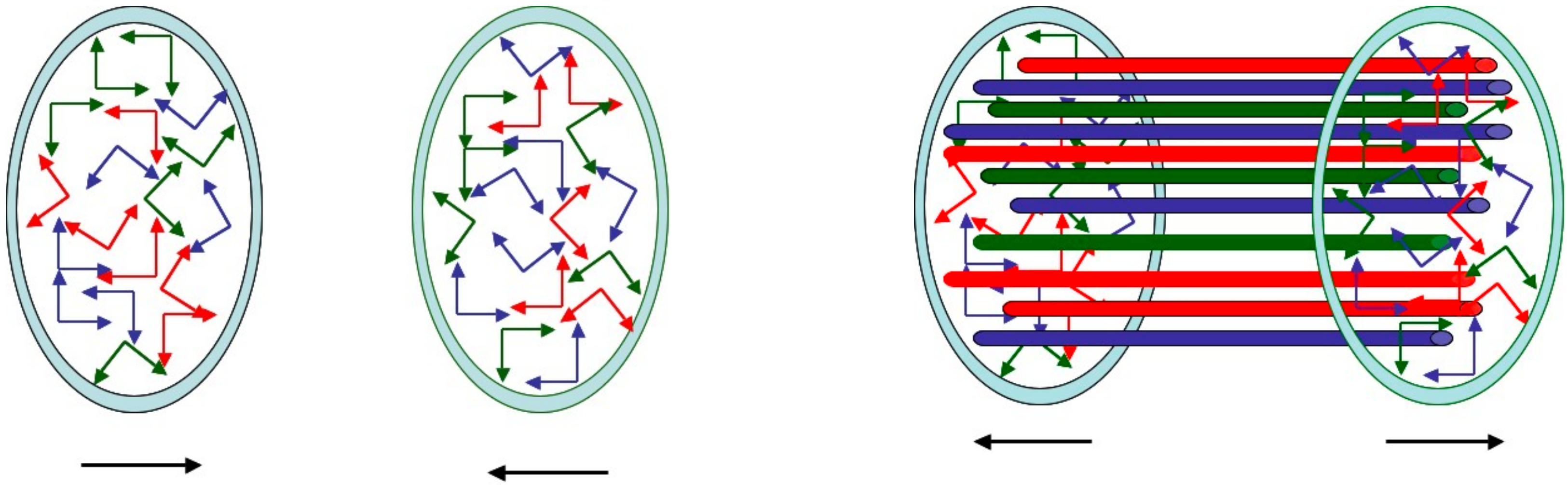
Perturbative QCD at large momenta (low density)

Includes the Pomeron and Multi-Reggeon configurations of Lipatov

In various approximations, "Pomeron loop" effects can be included.

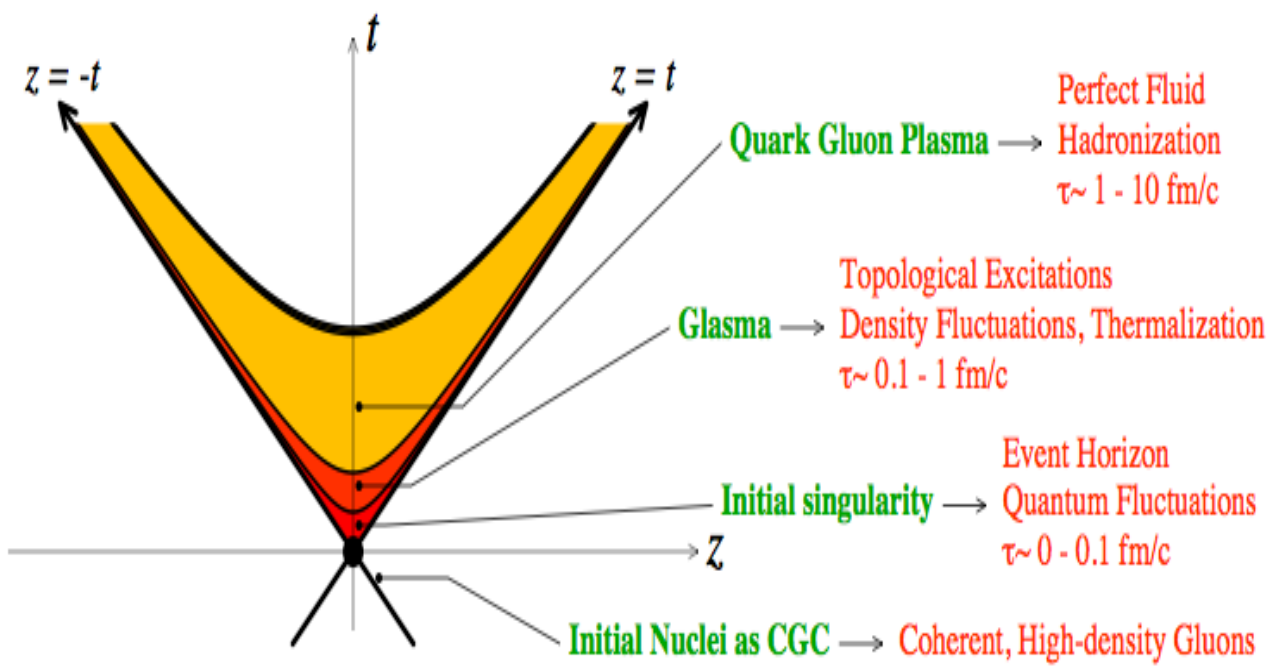
Theoretical issue is more when the approximations used are valid, not whether framework is valid

CGC Gives Initial Conditions for QGP in Heavy Ion Collisions

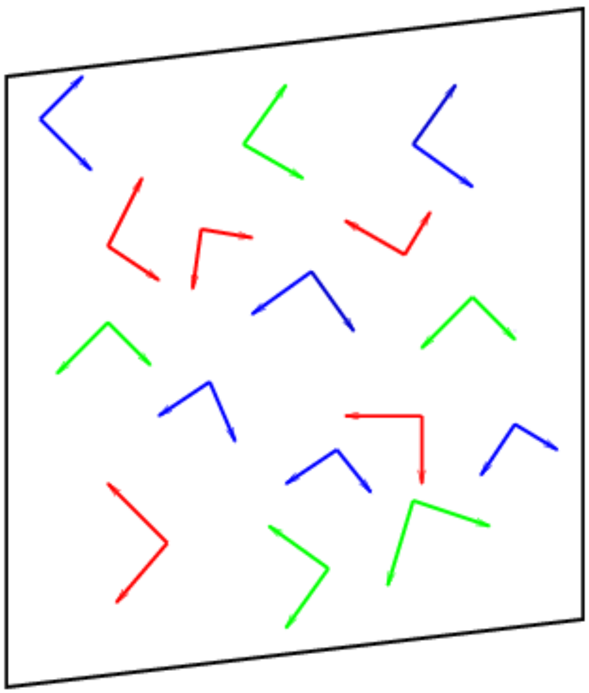


Longitudinal electric and magnetic fields are set up in a very short time

$$t \sim \frac{1}{Q_{sat}}\, e^{-\kappa/\alpha_S} << \frac{1}{Q_{sat}}$$



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} 0(1)

Lienard-Wiechart potentials

Random Color

Density of gluons per unit area

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

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 Λ

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

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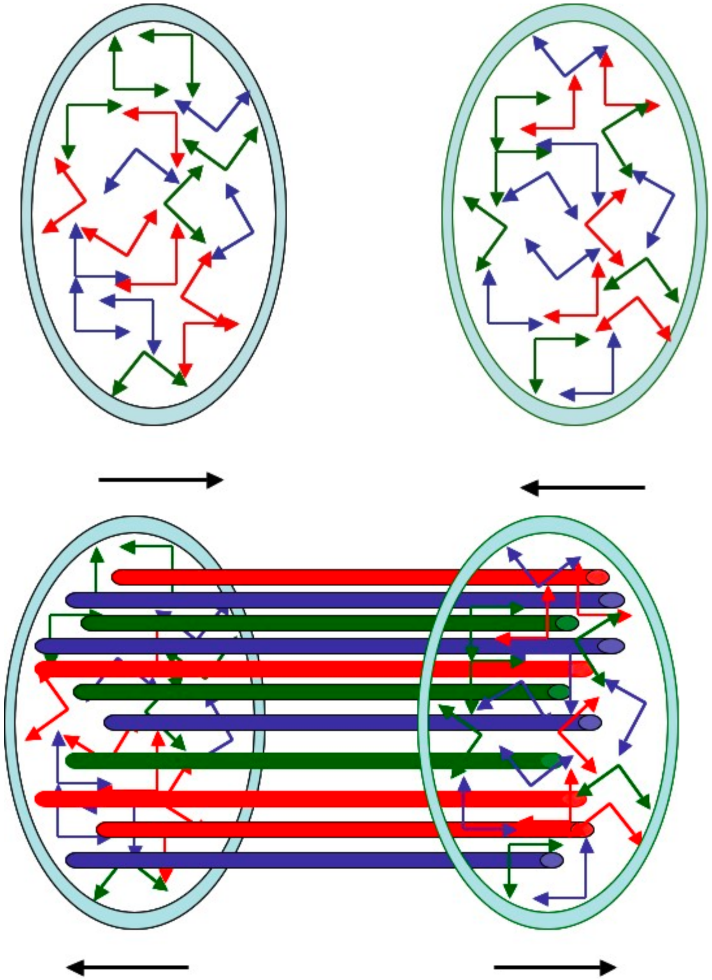
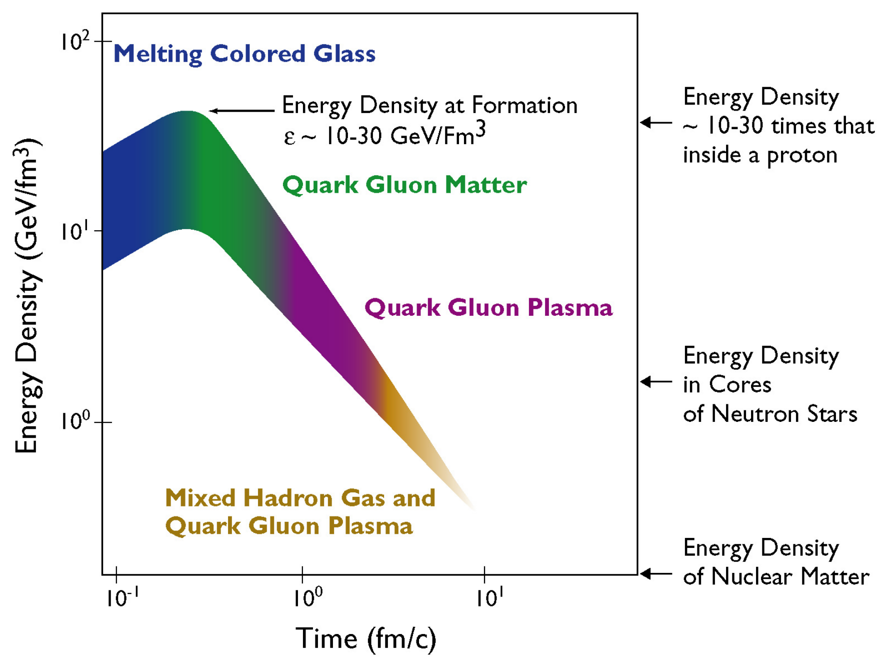


Two sheets of colored glass collide

Glass melts into gluons and thermalize

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

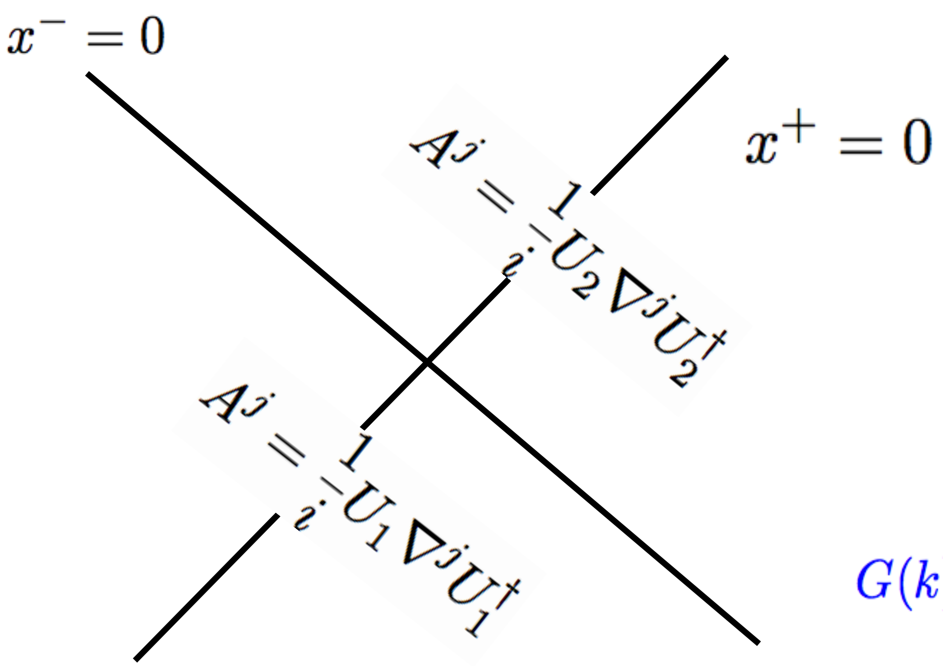
"Instantaneously" develop longitudinal color E and B fields



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

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

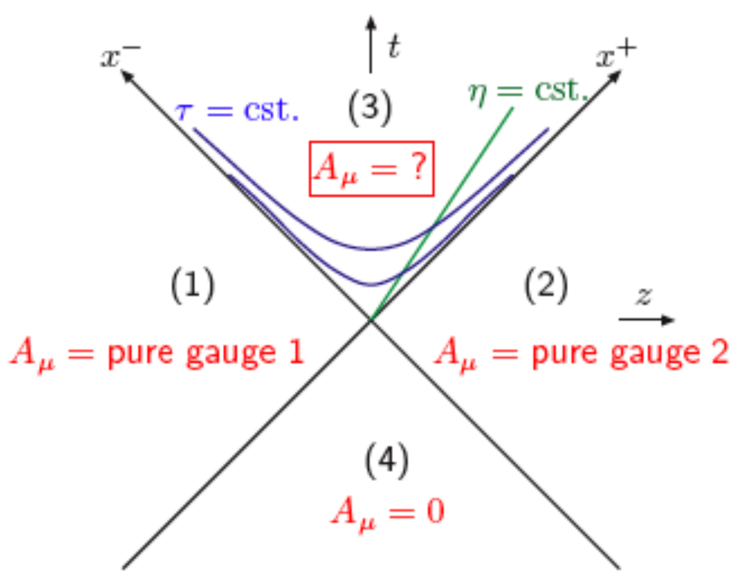
$$G(k) = < a^\dagger(k) a(k) > \sim < A(k) A(-k) >$$

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!

$$\partial^\mu J^5_\mu = \kappa\ E \cdot B + O(m_{quark})$$

Different signs

Generate different chiralities and vorticity in the fluid.

Violates P and CP on an event by event basis

Integral vanishes initially

Topological charge density is maximal:

Anomalous mass generation

In cosmology:

Anomalous Baryogenesis

Classical equations do not generate net topological charge.

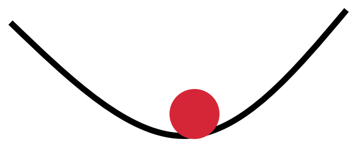
Instabilities in these solutions will generate such charge, and might thermalize the system

At late times field decays into particles classically:

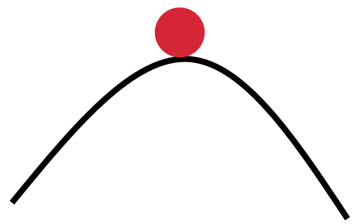
$$D^0 \vec{E} = \vec{D} \times \vec{B}$$

Because both E and B are nonzero

Longitudinal fields decay into purely transverse radiation fields



Before collision, stability



After collisions, unstable

Quantum fluctuations can become as big as the classical field

Quantum fluctuations analogous to Hawking Radiation

Growth of instability generates turbulence => Kolmogorov spectrum

Analogous to Zeldovich spectrum of density fluctuations in cosmology

Topological mass generation

Interactions of evaporated gluons with classical field is g x 1/g ~ 1 is strong

Thermalization?

$$W[p, X] = \int dz e^{-ipz} \psi^*(X + z/2) \psi(X - z/2)$$

Wigner distribution of initial wavefunction gives seeds of fluctuations.

These seeds grow when inserted into classical equations