# Modelling early stages of relativistic heavy ion collisions: relativistic transport theory and color-electric flux tubes


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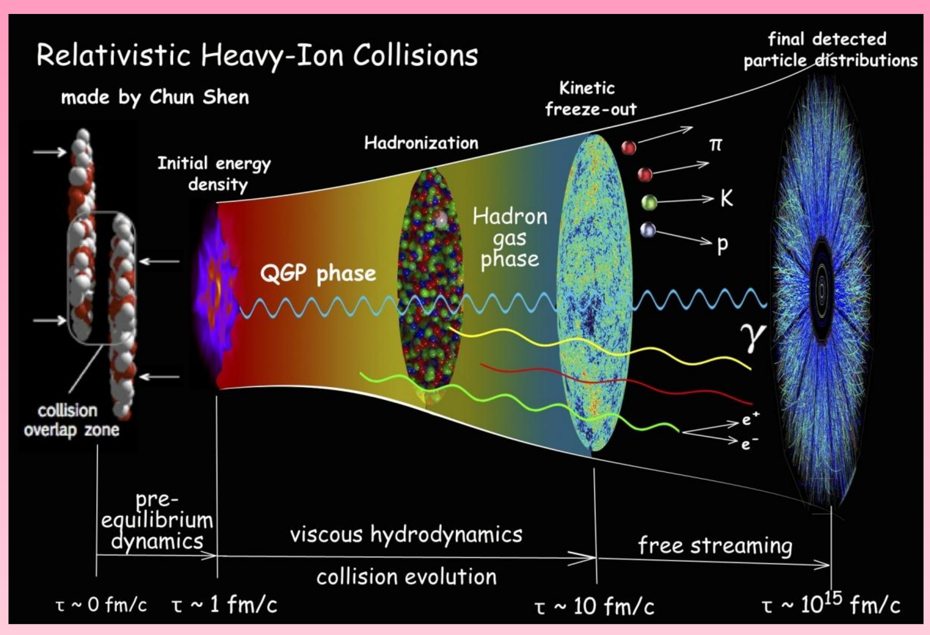
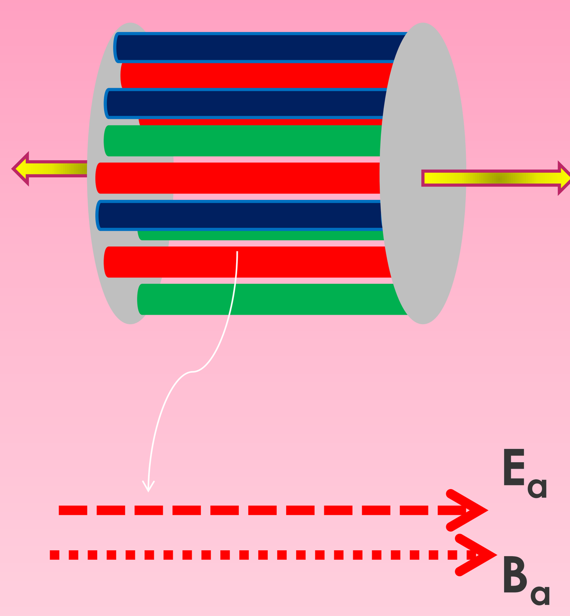
In this study we model early times dynamics of relativistic heavy ion collisions by an initial color electric field which then decays to a plasma by the Schwinger mechanism. We couple the dynamical evolution of the classical field to that of the many particles system produced by the decay. The latter is described by relativistic kinetic theory; the backreaction on the color field is taken into account by solving self-consistently the kinetic and the field equations. Within a single self-consistent calculation scheme we address the problems of isotropization and thermalization of QGP as well as the QGP formation time and its chemical equilibration.
We find that regardless of the viscosity of the produced plasma, the initial color electric field decays within 1 fm/c. In case of small $\eta/s$ ($\eta/s$ <0.3) we find isotropization occurs within 0.8 fm/c and thermalization within 1 fm/c. Moreover QGP production occurs in about 1 fm/c, and almost perfect chemical equilibration takes place within 1 fm/c. Hence our work supports the common assumptions of hydrodynamics about thermalization, isotropization and equilibration of quark-gluon plasma.


## The physical context



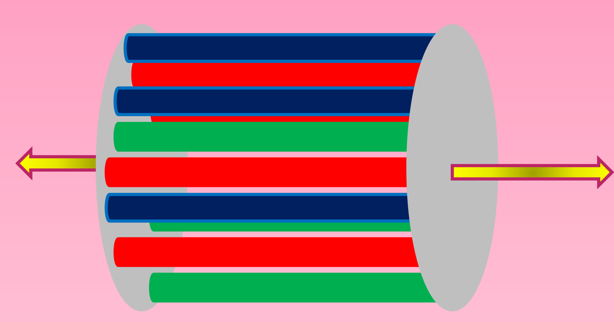

Glasma: Longitudinal view



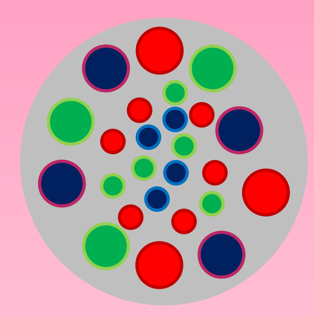

Initial out-of-equilibrium state:
***Glasma***, namely, a configuration of ***longitudinal color–electric and color-magnetic flux tubes.***

## The model

Longitudinal view



Transverse plane view

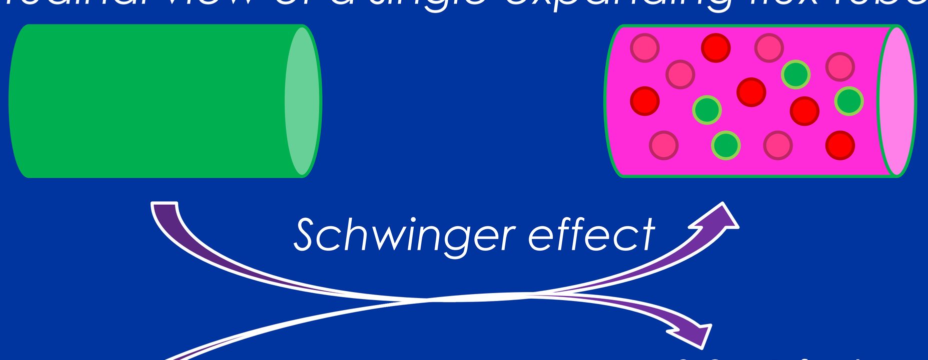


Focus on a *single flux tube*:
(.) neglect color-magnetic fields;
(.) assume ***color-electric fields*** evolve as ***classical abelian fields***;
(.) initial field is ***longitudinal;***
(.) assume ***Schwinger effect*** takes place:
*Color-eletric color field decays into quark-antiquark as well as gluon pairs*

***Abelian Flux Tube Model***

## The qualitative picture

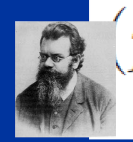
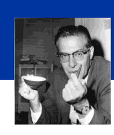
*Longitudinal view of a single expanding flux tube*




*$\tau$ =0⁺*
*Strong color-electric field*

*$\tau$ =0.2 – 1 fm/c*
*Color-electric field*
*+*
*Particle quanta:*
*quarks and gluons (QGP)*

## The quantitative picture

$$(p_\mu \partial^\mu + gQ_{jc}F^{\mu\nu}p_\mu\partial^p_\nu)\, f_{jc} = p_0\frac{\partial}{\partial t}\frac{dN_{jc}}{d^3x\,d^3p} + \mathcal{C}[f]$$

**Field interaction** — **Invariant source term**

***Relativistic kinetic equation***
Governs evolution of Parton distribution function

*Invariant source term:* change of **f** due to *particle creation* by Schwinger effect in the volume at ***(x,p).***

*Invariant source term*
*Field interaction*
} Link *parton distribution function* and *classical color field evolutions*

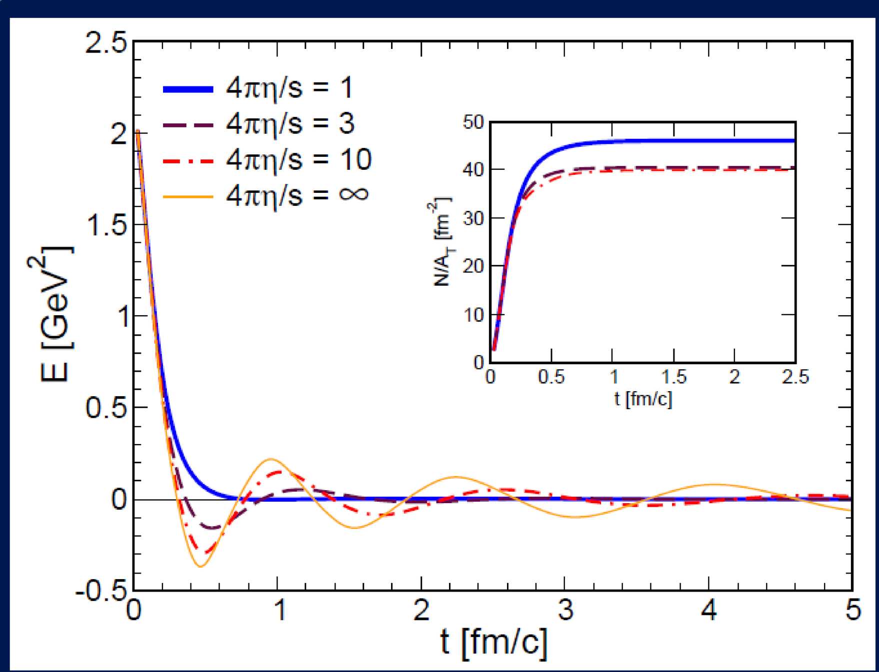
*We solve self-consistently Boltzmann and Maxwell equations*

$$\frac{dE}{dt} = -j_D - j_M$$

$j_D$: displacement current
*Medium polarization due to pair creation*
$j_M$: conduction current
*Ohm law in linear response theory*

*Back-reaction taken into account*

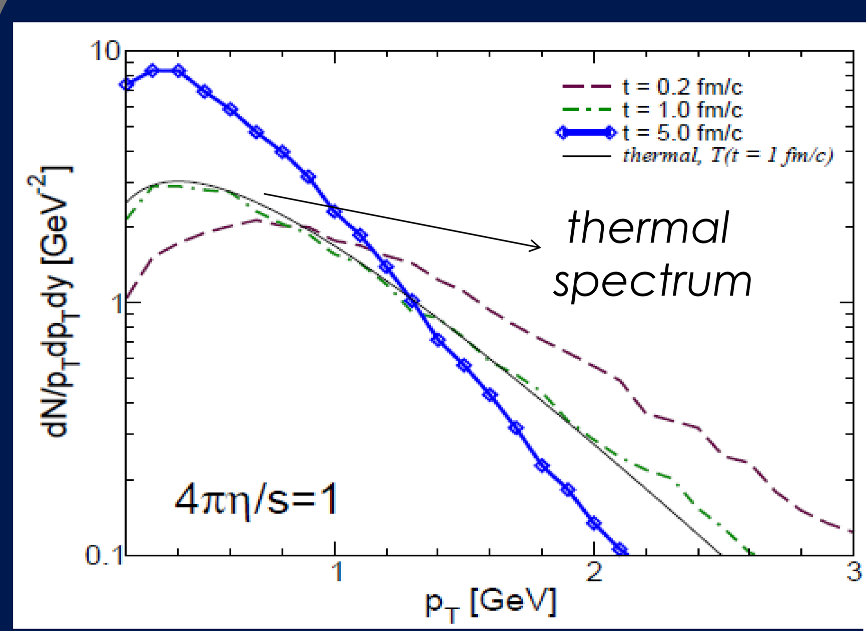
## Selected results

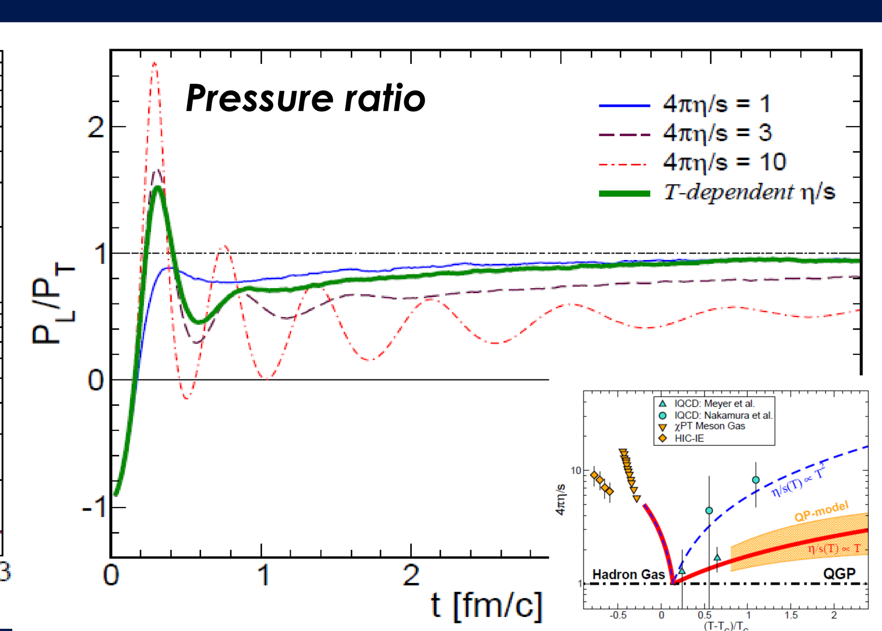



### Field decay and QGP production

.) Color field decays within a fraction of fm/c
.) Small $\eta$/s:
1.) *monotonic decrease*
2.) *field irrelevant for late time evolution*
.) Large $\eta$/s :
1.) *plasma oscillations*
2.) *field important for late time evolution*
.) Particle production within 1 fm/c:
1.) *Fast GQP production regrdless of $\eta$/s*

### Thermalization and Isotropization




.) Particle spectrum becomes thermal within 1 fm/c
.) Longitudinal pressure becomes positive because of particle production
.) Small $\eta$/s:
1.) *almost perfect isotropization is achieved within 1 fm/c*
.) Large $\eta$/s :
1.) *plasma oscillations imply oscillations of $P_L/P_T$*
2.) *isotropization is not achieved*
.) Temperature dependent $\eta$/s:
1.) *few bumps of $P_L/P_T$ but late time isotropization unaffected*

### Conclusions and Outlook

- ***Relativistic Transport Theory, coupled to a decay mechanism for initial color fields, permits to study early times dynamics of heavy ion collisions.***
- ***Schwinger tunneling*** *allows a* ***fast particle production****, typically a small fraction of fm/c.*
- Weakly coupled plasma is characterized by plasma oscillations which are non negligible along the entire evolution of the system.
- ***Strongly coupled plasma*** does not experience important plasma oscillations, rather a ***hydro regime is reached in a very short time***
- Isotropization time is less than 1 fm/c

*The scenario we obtain for the early stages of heavy ion collision is in agreement with, and dynamically justifies, usual assumptions of viscous hydro about*
*-Isotropization and thermalization*
*-Chemical equilibration*
*-QGP time formation*

### References


M. Ruggieri *et al.*, arXiv:1505.08081
M. Ruggieri *et al.*, Nucl. Phys. A941 (2015) 201-211