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

M. Ruggieri1, A. Puglisi1,2, L. Oliva1,2, S. Plumari1,2, F. Scardina1,2 and V. Greco1,2
1Department of Physics and Astronomy, Catania University via S. Sofia 64, I-95125, Catania (Italy)
2INFN-Laboratori Nazionali del Sud via S. Sofia 64, I-95125, Catania (Italy)

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, namely, a configuration of longitudinal color–electric and color–magnetic flux tubes.

The qualitative picture

Longitudinal view of a single expanding flux tube

Schwinger effect

$r = 0$: Strong color-electric field

$r = 0.2 - 1$ fm/c: Color-electric field

Particle quanta: quarks and gluons (QGP)

The model

Focus on a single flux tube:

1. neglect color–magnetic fields;
2. assume color–electric fields evolve as classical abelian fields;
3. initial field is longitudinal;
4. assume Schwinger effect takes place.

Color–electric field decays into quark–antiquark as well as gluon pairs

Relativistic kinetic equation

Governs evolution of Parton distribution function

The quantitative picture

$p_0 \partial^\mu \{ Q_{j\nu} F^\mu^\nu + p_0 \partial^\mu F_{j\nu} \} f_{j\nu} = \frac{\partial}{\partial t} \frac{dN_{j\nu}}{d^3x d^3p} + C[f]

Longitudinal view

Transverse plane view

Initial out-of-equilibrium state:

- Glasma:
  - Small $\eta/s$:
    - Monotonic decrease
    - Field relevant for late time evolution
  - Large $\eta/s$:
    - Plasma oscillations
    - Field important for late time evolution
  - Particle production within 1 fm/c:
    - Fast QGP production regardless of $\eta/s$

Field decay and QGP production

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:
- Isotropization and thermalization
- Chemical equilibration
- QGP time formation

Selected results

Thermalization and Isotropization

- Particle spectrum becomes thermal within 1 fm/c.
- Longitudinal pressure becomes positive because of particle production.
- Small $\eta/s$:
  - Almost perfect isorotopization is achieved within 1 fm/c.
  - Plasma oscillations imply oscillations of $P_j$.
- Large $\eta/s$:
  - Isotropization is not achieved.
- Temperature dependent $\eta/s$.
  - Few bumps of $P_j$, but late time isorotopization unaffected.

References

M. Ruggieri et al., arXiv:1505.08081