Thermalization and quark production in spatially homogeneous systems of gluons

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Boltzmann Equation in Diffusion Approximation

- In the early stages after a heavy ion collision, a dense system of gluons is produced.
- We use the **Boltzmann Equation in the Diffusion Approximation** (BEDA) in order to study this process in a homogeneous and non-expanding system.

$$\partial_t f^a = C^a_{2\leftrightarrow 2} + C^a_{1\leftrightarrow 2} \quad , \quad a = \{g, q, \bar{q}\}$$

- The distribution functions f^a allows us to compute some characteristic parameters of the system such as the **jet-quenching parameter**, the **Debye mass** and the **effective temperature** and **baryonic chemical potential** of the system.

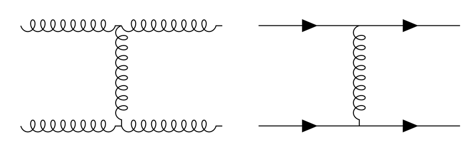
$$\hat{q} = \hat{q}[f] \qquad m_D^2 = m_D^2[f] \qquad T_*(t) = \frac{\hat{q}}{2\alpha_s N_C \ln\frac{\langle p_T^2\rangle}{m_D^2} m_D^2} \qquad \mu_* = \mu_*[f]$$

- The diffusion approximation lies in the assumption of **small angle scattering** dominance.

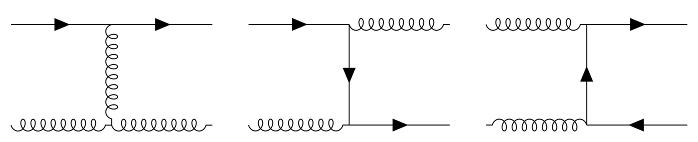
The collision kernels

We distinguish three different terms in the collision kernel:

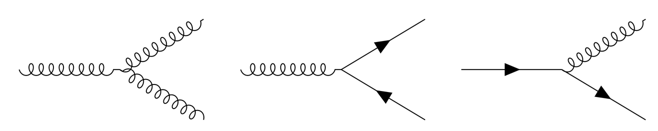
Flux $2 \leftrightarrow 2$. Can be rewritten as a Focker-Planck-like term in diffusion approximation [1], [2].



Source $2 \leftrightarrow 2$. Additional term responsible of quark-gluon interaction [2].



Splitting $1 \leftrightarrow 2$. This kernel is computed in the deep LPM regime [3], [4].



Rapid thermalization in the soft sector

- At early times, the $g \leftrightarrow gg$ and $g \leftrightarrow q\bar{q}$ are the dominant processes in the production of gluons and (anti)quarks, respectively.
- One can see that both **gluons and quarks quickly fill a thermal distribution** up to a characteristic momentum

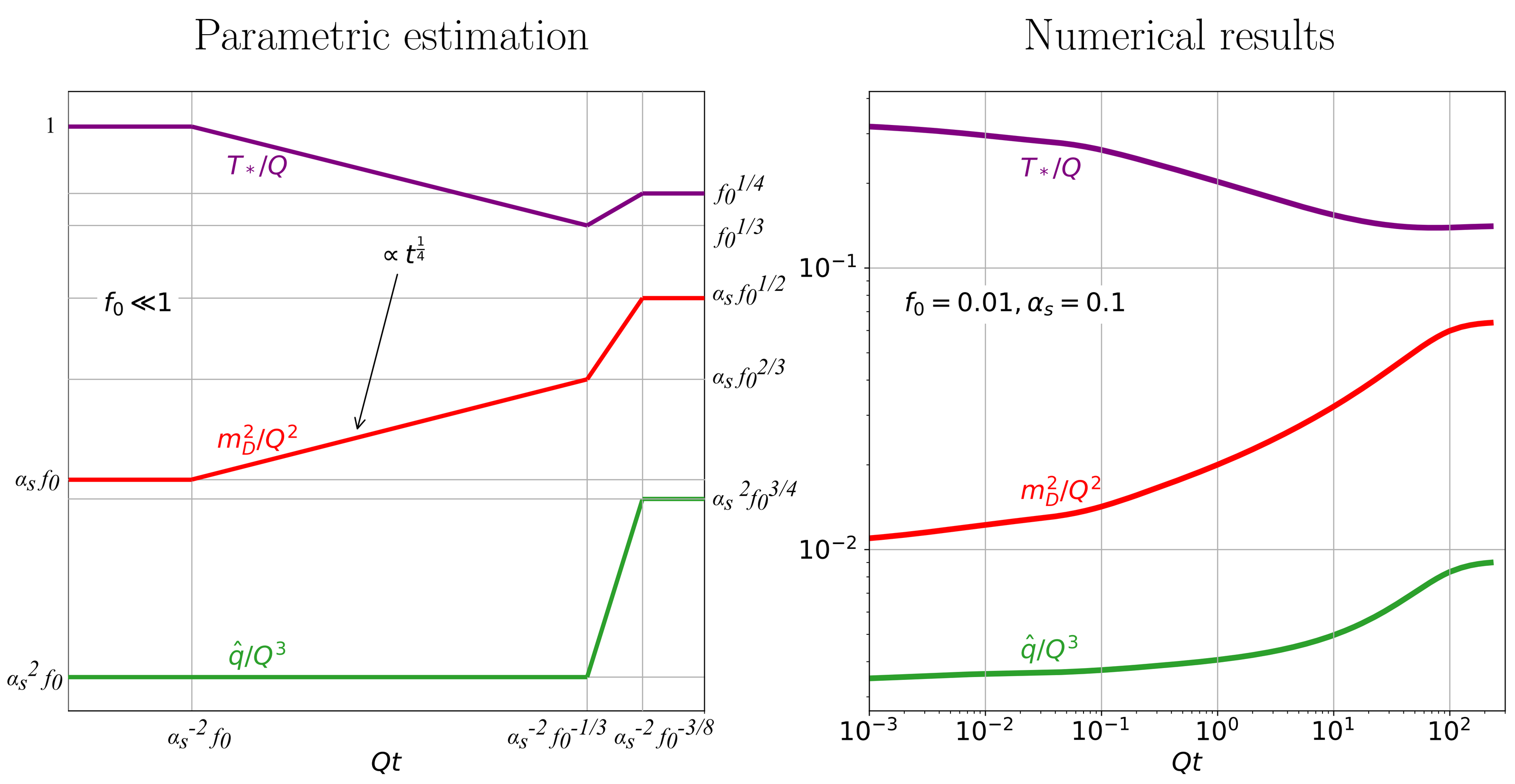
$$p_{A*} \equiv (\hat{q}_A m_D^4 t^2/2)^{\frac{1}{5}} \qquad \mathcal{I}_c = \mathcal{I}_c[f]$$
$$p_{F*} \equiv [\alpha_s C_F \pi(\mathcal{I}_c + \bar{\mathcal{I}}_c)t]^{\frac{2}{5}} \hat{q}_F^{\frac{1}{5}} \qquad \bar{\mathcal{I}}_c = \bar{\mathcal{I}}_c[f]$$

$$p f_p(t) \approx T_*\left[1 - \left(1 - \frac{p f_p(t=0)}{T_*}\right) e^{-\left(\frac{p_{A*}}{p}\right)^{\frac{5}{2}}}\right]$$

$$F_p(t) \approx F_0(T_*, \mu_*) - [F_0(T_*, \mu_*) - F(0)] e^{-\left(\frac{p_{F*}}{p}\right)^{\frac{5}{2}}}$$

where $F_0(T_*, \mu_*) = 1/\left(e^{-\frac{\mu_*}{T_*}} + 1\right)$.

Initially under-populated system of pure gluons



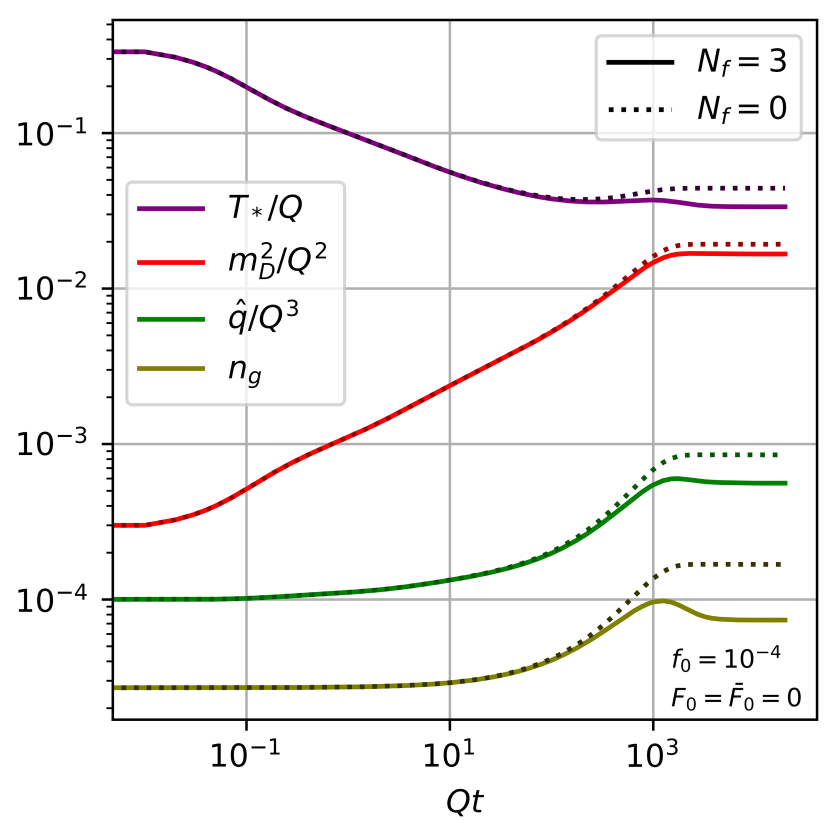
We distinguish **three different stages** [5] in this case just by doing a parametrical study of some characteristic quantities:

1. **Hard gluons radiate soft gluons**, which quickly thermalizes with a momentum scale p_* and a higher temperature than the equilibrium one, T_{eq}.
2. **Soft sector undercools** T_{eq} , and its typical momentum is pushed by elastic scatterings. Debye mass receives dominant contribution from the soft sector.
3. **Reheating of soft gluons** and mini-jet quenching. The Debye mass and the jet quenching parameter are dominated by the soft sector.

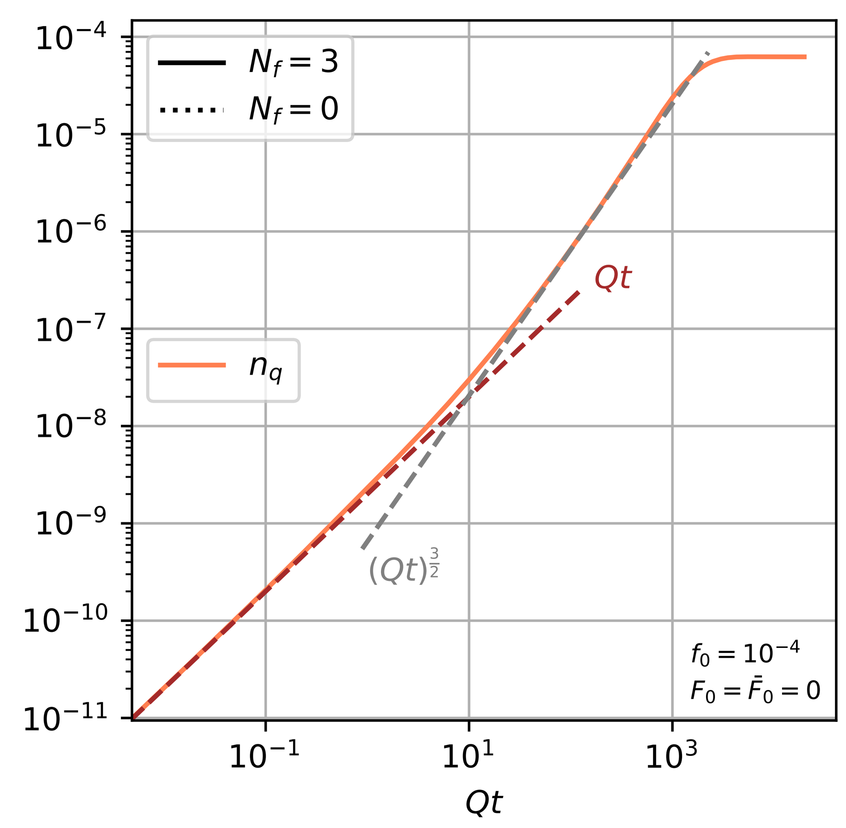
Complete thermalization of under-populated system

Let us study an **initially under-populated system of gluons**, but now quarks are involved in the calculation.

- The behavior of the full system macroscopic parameters is determined at early times by the gluons.
- Only when quark number is comparable with the gluon number the qualitative behavior is modified.
- All quantities acquire a thermal value smaller than the pure gluon scenario.
- **Gluon number** has a maximum after which **decreases** to reach its thermal value.



Quark production



- Initially, the **quark number grows linear with time** due to the $g \to q\bar{q}$ splitting.
- At $Qt \sim \alpha_s^{-2}$, the **quark production is accelerated** ($n_q \sim (Qt)^{\frac{3}{2}}$) due (parametrically) to both $g \to q\bar{q}$ and $gg \to q\bar{q}$ processes.
- Quark production is decelerated when gluon number start to drop.

Summary and Outlook

- We present a full set of BEDA equations which describe the behavior of an spatially homogeneous system of quarks and gluons.
- At early times, both **soft quarks and gluons rapidly acquire a thermal distribution** due to $1 \leftrightarrow 2$ splitting.
- Thermalization of under-populated systems of pure gluons is achieved after three stages.
  - Under-cooling and reheating of the system is identified.
- For a initially under-populated system of gluons, **quarks only play an important role after the second stage**.
- The $gg \to q\bar{q}$ plays an important role in quark production and also in the decrease of gluon number density.
- In the future, **more general geometries will be explored** in order to study physical observables such as **flow**.

References

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