From the Glasma to a Quark Plasma

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Outline

- Transport Code
- Quasi particle model
- N_q N_g at equilibrium
- $\sigma_{2->2}$ inelastic with non zero partons masses
- Results for RHIC and LHC
- Conclusion and future developments

Transport approach

$$p^{\mu}\partial_{\mu}f(x,p) = C_{22} + C_{23} + \ldots$$

$$C_{22} = \frac{1}{2E_1}\int \frac{d^3p_2}{(2\pi)^3 2E_2}\frac{1}{\upsilon}\int \frac{d^3p_1'}{(2\pi)^3 2E_1'}\frac{d^3p_2'}{(2\pi)^3 2E_2'} f_1' f_2' \times$$
$$\left|M_{1'2'\to 12}\right|^2 (2\pi)^4 \delta^{(4)}\left(p_1' + p_2' - p_1 - p_2\right)$$

Elastic + Inelastic (Inelastic massive according to quasi-particle model fitted to lQCD data)

Collision integral is solved with a local stochastic sampling

[Z. Xhu, C. Greiner, PRC71(04)]
[G. Ferini et al Phys.Lett.B670:325-329,2009]

$$P_{22} = \frac{\Delta N_{coll}^{2\to 2}}{\Delta N_1 \Delta N_2} = v_{rel}\sigma_{22}\frac{\Delta t}{\Delta^3 x}$$

Quasiparticle model

We have included in our model the effect of a mean field using the **quasi particle model** of Heinz Levai

The quasi particles behave like a free-gas of massive constituents

$$P(T) = \sum_{i=g,q,\bar{q}} d_i \int \frac{d^3p}{(2\pi)^3} \frac{p^2}{3E_i} f_i(p) - B(T)$$

$$\varepsilon_{qp} = \sum_i d_i \int \frac{d^3p}{(2\pi)^3} E_i f_i(E_i) + B(m_i(T)) + W(T)$$

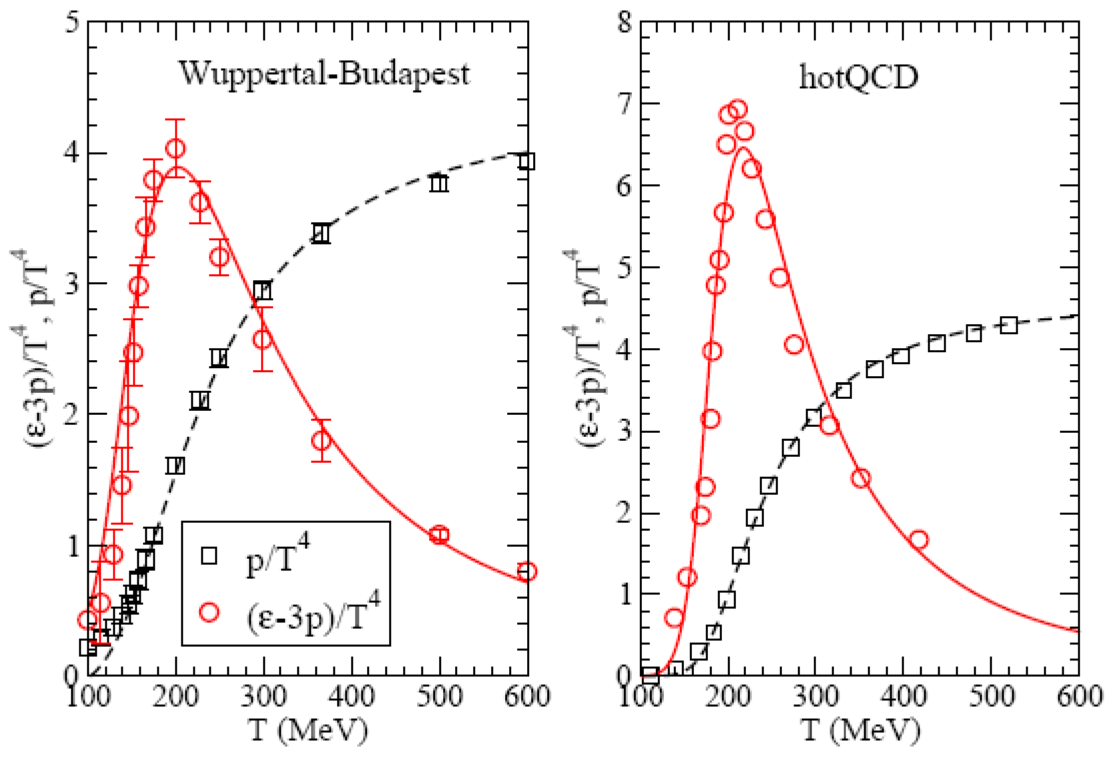
Imposing thermodynamic consistency we obtain the relation between B(T) and M(T)

$$\frac{\partial B}{\partial m_i} + d_i \int \frac{d^3p}{(2\pi)^3} \frac{m_i}{E_i} f_i(E_i) = 0$$

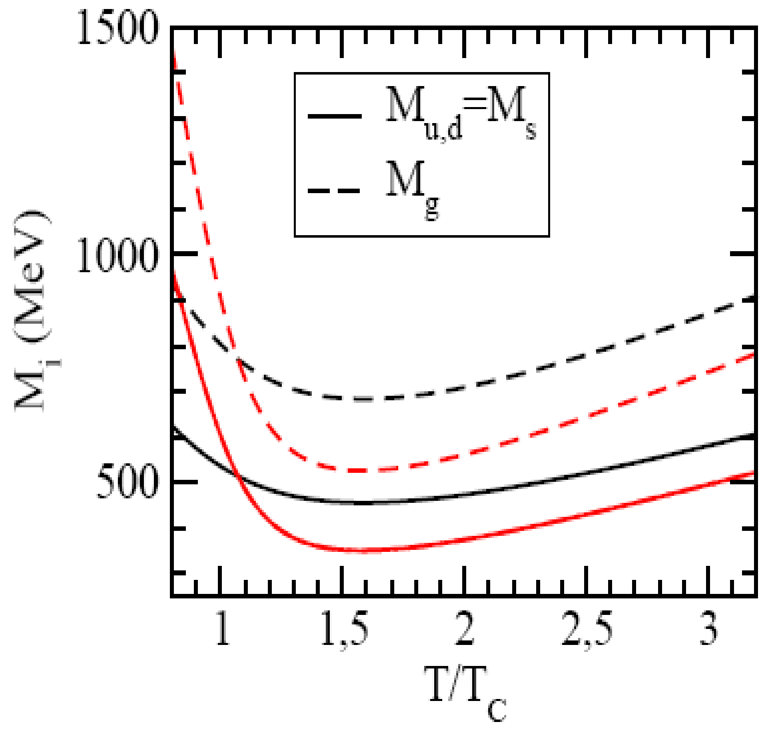
Imposing the condition $\varepsilon_{qp}(T) = \varepsilon_{lattice}(T)$ we derive B(T)

How it works with some lQCD data

Lattice data for the pressure and trace anomaly compared with the quasi-particle model



Quark and gluon quasi-particle masses



[S.Plumari, W. Alberico, C. Ratti, V. Greco arXiv:1103.5611]

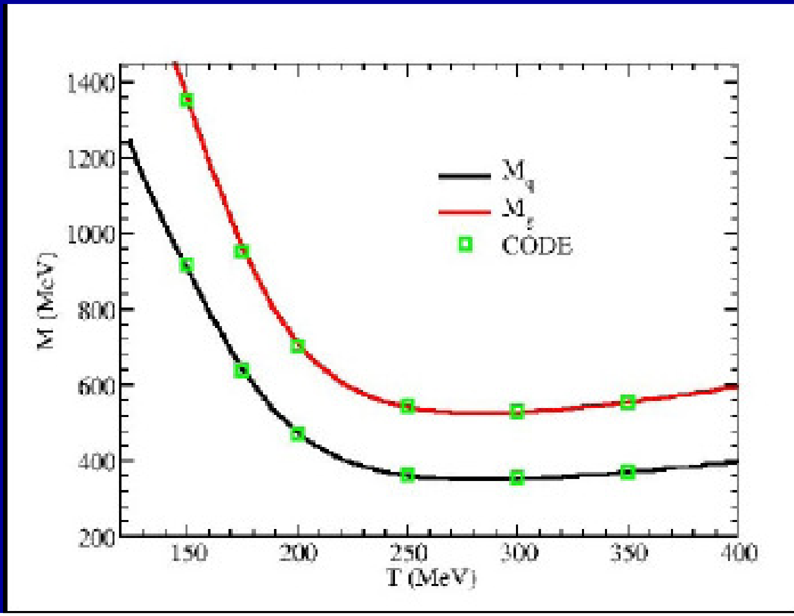
Transport with local finite masses

$$p^{\mu}\partial_{\mu}f(x,p)+M(X)\partial_{\mu}M(X)\partial_{p}^{\mu}f(X,p)=C_{22}$$

$$\frac{\partial B}{\partial m_i}+d_i\int\frac{d^3p}{(2\pi)^3}\frac{m_i}{E_i}f_i(x,p)=0$$ Gap equation

Like the NJL gap equation [A. Abada and J. Aichelin, Phys.Rev.Lett. 74 (1995) 3130]; [S.Plumari PLB (2010)].

Test in a Box at equilibrium



Chemical equilibrium

Massless case

$$\rho_{eq} = \nu \frac{T^3}{\pi^2}$$

$$\frac{\rho_{eq}^{quark}}{\rho_{eq}^{gluon}} = \frac{\nu_{quark}}{\nu_{gluon}} = \frac{2*2*3*Nfl}{2*8} = 2.25$$

(Nfl=3)

Massive case

$$\rho_{eq} = \nu_q \frac{e^{\mu/T}}{(2\pi\hbar)^3}(4\pi)T^3 \int_{m/T}^{\infty} d\tau\, \tau \sqrt{\tau^2 - \left(\frac{m}{T}\right)^2}\, e^{-\tau} \longrightarrow \frac{\rho_{eq}^{quark}}{\rho_{eq}^{gluon}}$$

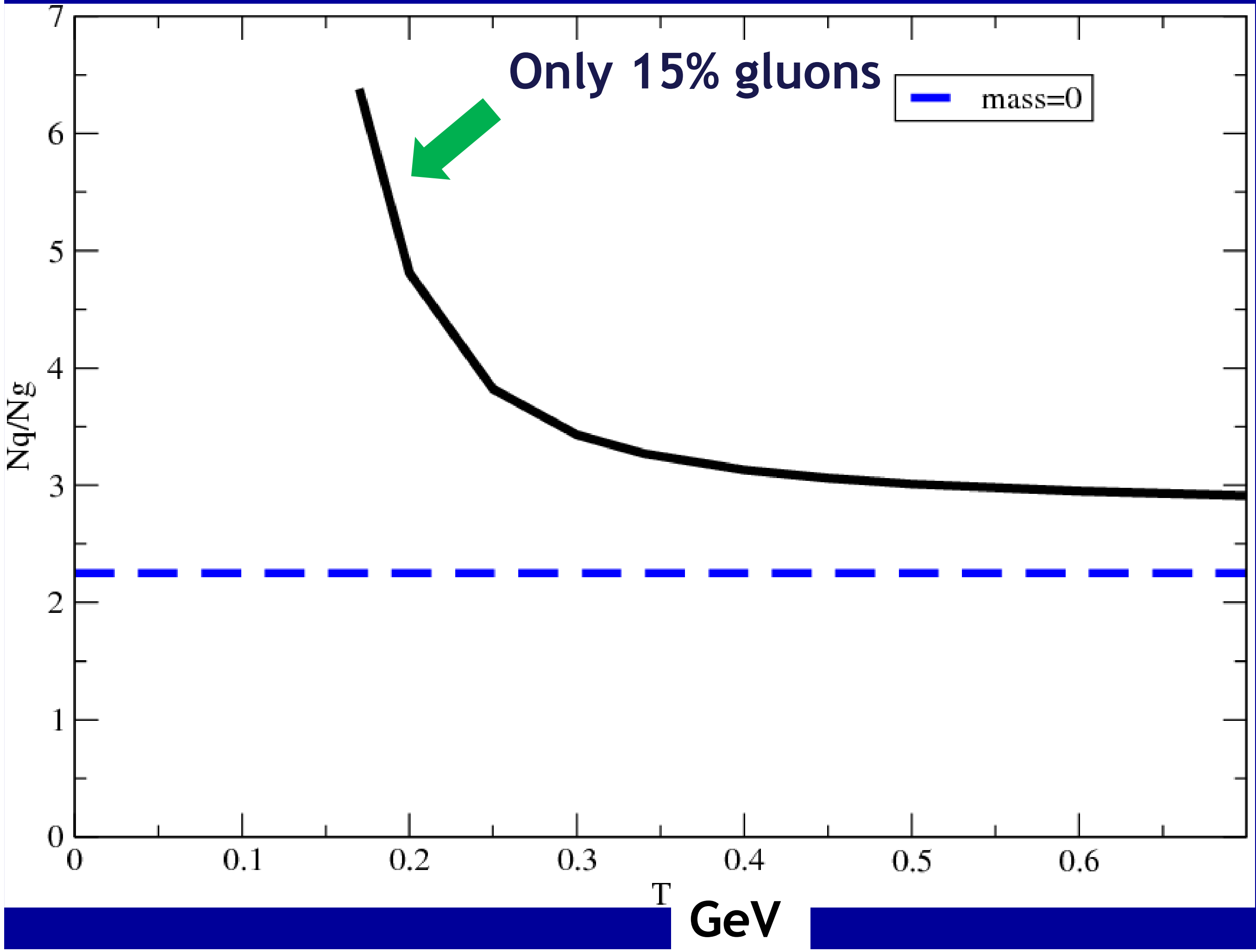
$$\tau = \frac{1}{T}\sqrt{m^2 + p^2}$$

Depends from degree of freedom but also from the masses

The higher is the ratio m_g/m_q the higher is $\frac{\rho_{eq}^{quark}}{\rho_{eq}^{gluon}}$

Chemical equilibrium

For a fixed m_g and m_q the effect of the masses increases when the temperature decreases

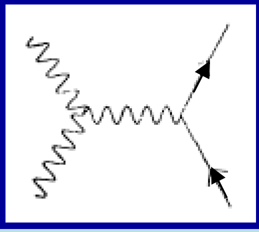


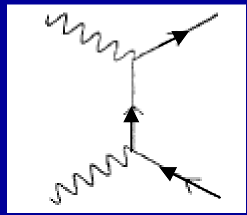
For T=Tc plasma at equilibrium is composed mostly by quarks

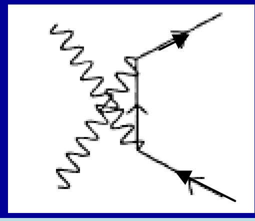
During the fireball evolution in HIC do the q/g equilibrate and up to what P_T?

$\sigma_{2->2}$ inelastic with massive partons

$$\sigma_{gg\to q\bar{q}}$$







massless case

$$|M_s|^2 = \alpha_s^2\pi^2 12\frac{u\cdot t}{s^2}$$

$$|M_u|^2 = \alpha_s^2\pi^2 \frac{8}{3}\frac{u}{t}$$

$$|M_t|^2 = \alpha_s^2\pi^2 \frac{8}{3}\frac{t}{u}$$

Plus interference terms

massive case

$$|M_s|^2 = \alpha_s^2\pi^2 12\frac{\left(m_q^2+m_g^2-t\right)\left(m_q^2+m_g^2-u\right)-3m_g^2 s+2m_q^2 m_g^2}{\left(s-m_g{}^2\right)^2}$$

[For m_g= 0 and $m_q \neq 0$ are equal to those calculated B. L. Combridge Nulc.Phys. B 151 (1979)]

$$|M_t|^2 = \alpha_s^2\pi^2 \frac{8}{3}\frac{\left(m_q^2+m_g^2-t\right)\left(m_q^2+m_g^2-u\right)-2m_q^2\left(m_q^2+t\right)-m_g^2 s-4m_q^2 m_g^2}{\left(t-m^2\right)^2}$$

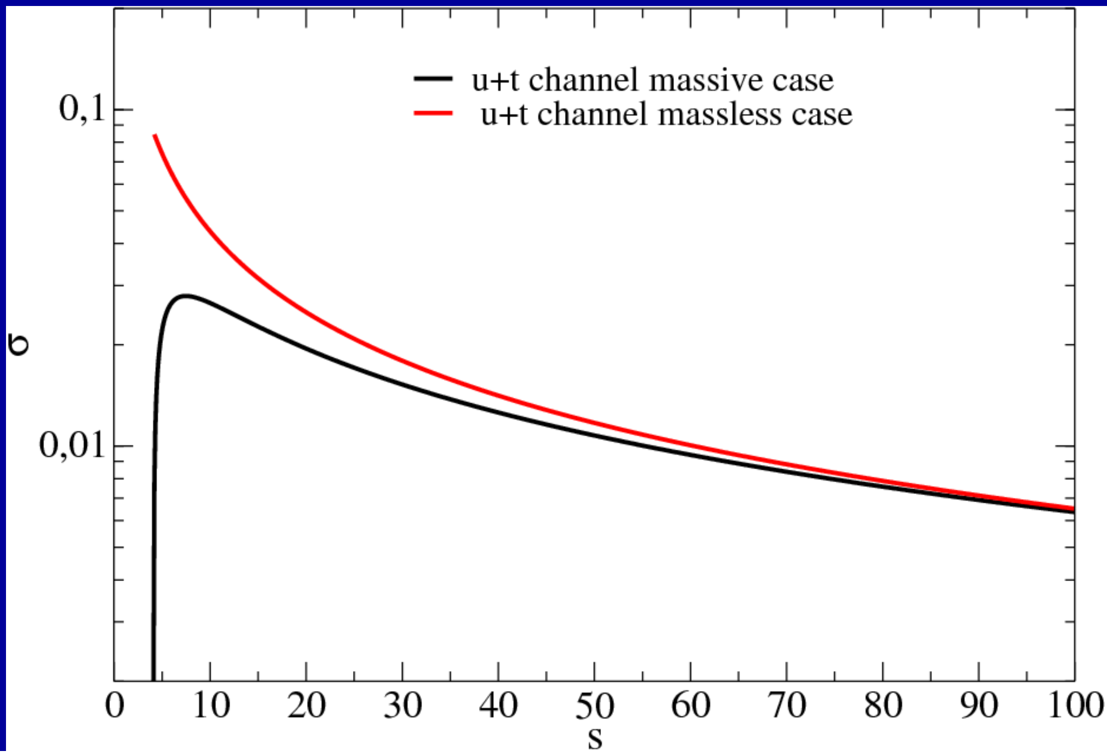
$$|M_u|^2 = \alpha_s^2\pi^2 \frac{8}{3}\frac{\left(m_q^2+m_g^2-t\right)\left(m_q^2+m_g^2-u\right)-2m_q^2\left(m_q^2+u\right)-m_g^2 s-4m_q^2 m_g^2}{\left(u-m^2\right)^2}$$

t and u channel are dominant, so we consider only these two

Total cross section

$$\sigma_{gg\to q\bar{q}}(s) = \frac{1}{16\pi s\left(s-4m_g^2\right)}\int_{t_-}^{t_+} dt\left(\left|M_t\right|^2 + \left|M_u\right|^2\right)$$

$$t_{\pm} = m_q^2 + m_g^2 \mp \frac{s}{2}\left(1-\sqrt{1-4m_q^2/s-1-4m_g^2/s+16m_q^2m_g^2/s^2}\right)$$



$\sigma_{q\bar{q}\to gg}$

$$\sigma_{gg\to q\bar{q}}(s) = \frac{1}{16\pi s\left(s-4m_g^2\right)}\int_{t_-}^{t_+} dt\left(\left|M_t\right|^2+\left|M_u\right|^2\right)$$

The cross section $\sigma_{q\bar{q}\to gg}$ is obtained from $\sigma_{gg\to q\bar{q}}$ just taking into account the different color averaging of the initial state
i.e. multiply $\sigma_{gg\to q\bar{q}}$ by a factor **64/9**

$$\sigma_{q\bar{q}\to gg}(s) = \frac{64}{9}\frac{1}{16\pi s\left(s-4m_q^2\right)}\int_{t_-}^{t_+} dt\left(\left|M_t\right|^2+\left|M_u\right|^2\right)$$

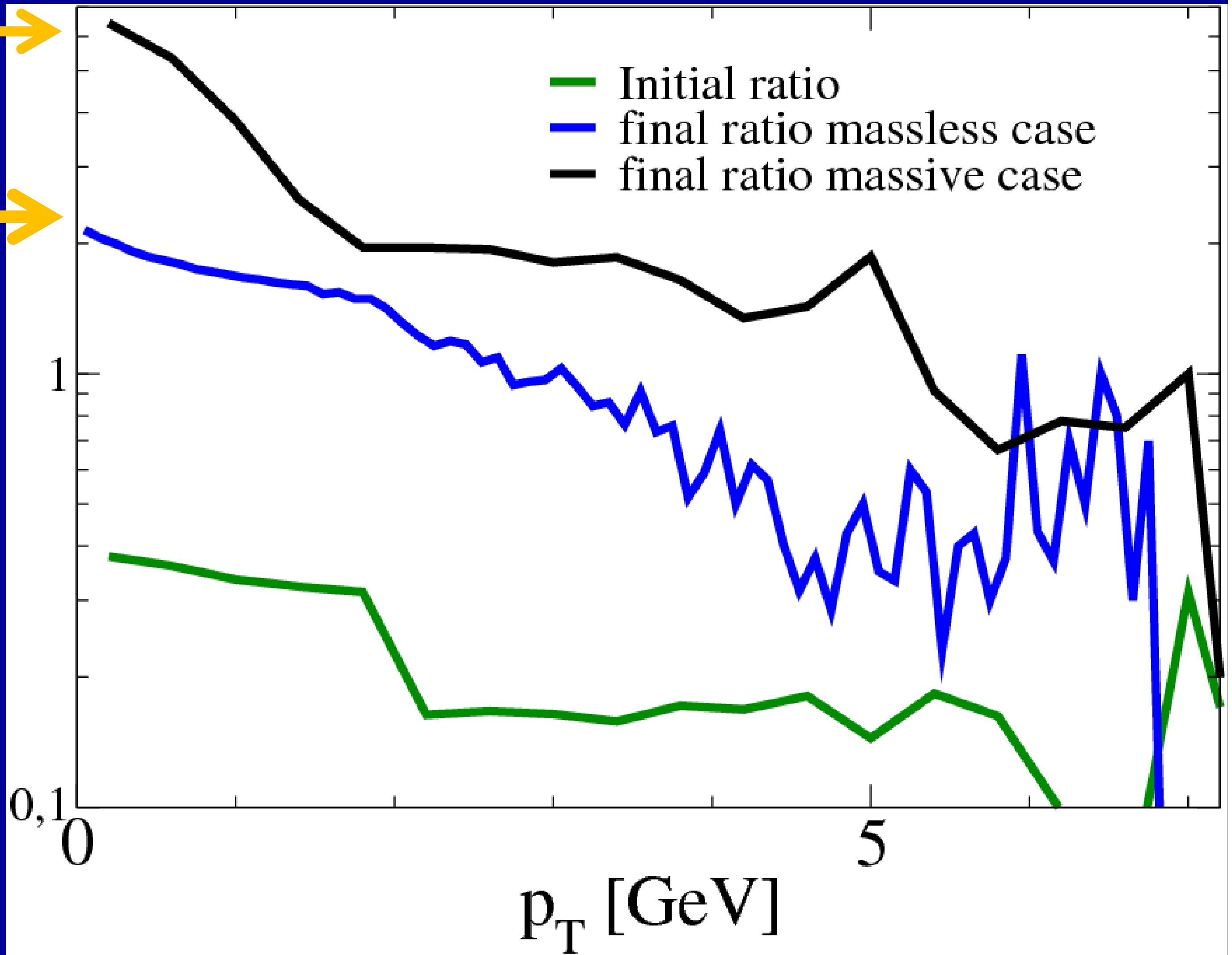
In the massive case there is another difference between the two case due to the difference between m_q and m_g

the cross sections are multiplied by factor K= 4 in order to take into account non perturbative effects

Results for RHIC

6.4 equilibrium value for the massive case

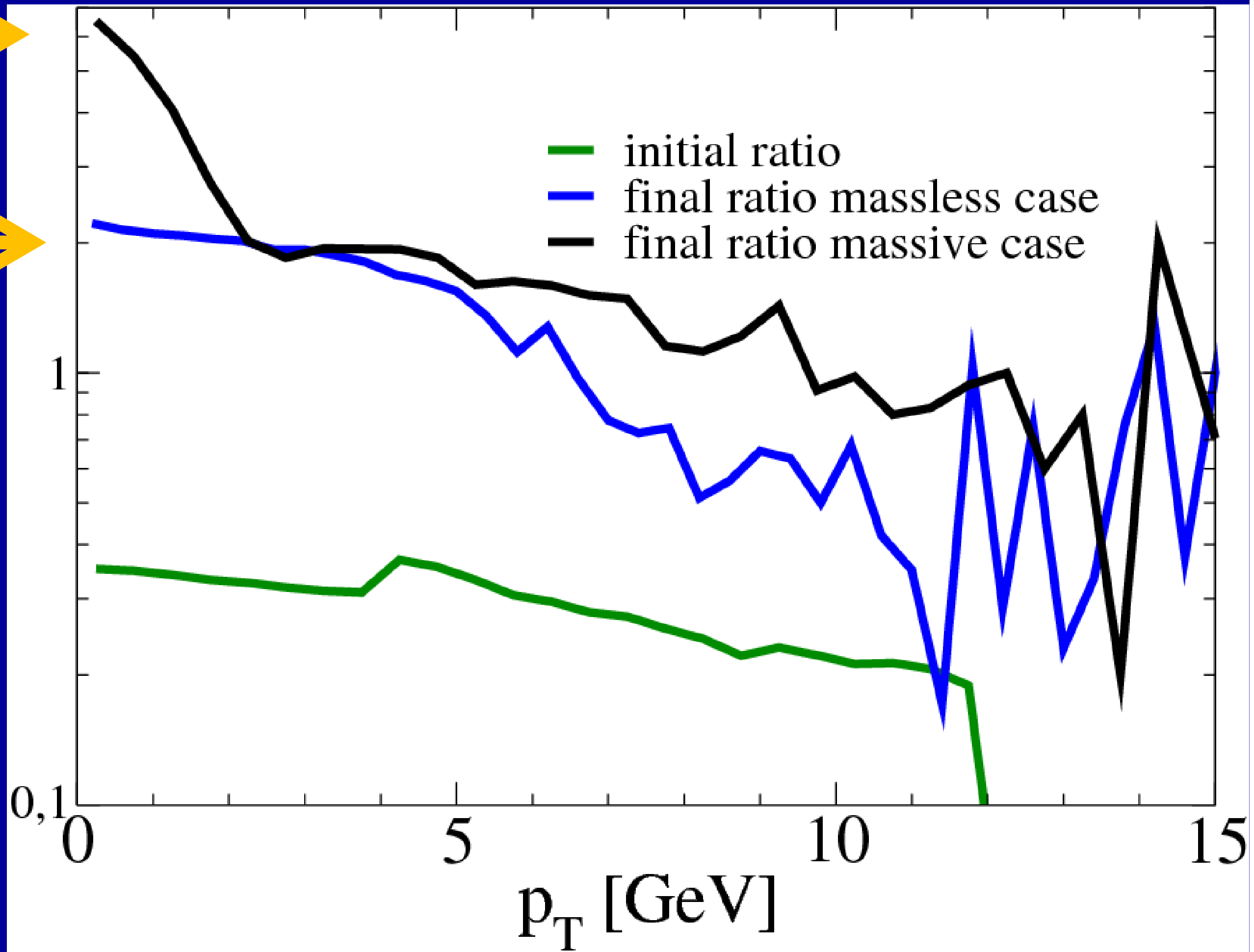
2.25 equilibrium value massless case



Results for LHC

6.4 equilibrium value for the massive case

2.25 equilibrium value massless case



At low p_T the equilibrium value is reached for both massless and massive case

Also at high p_T the ratio N_q/N_g is significantly different from the initial one

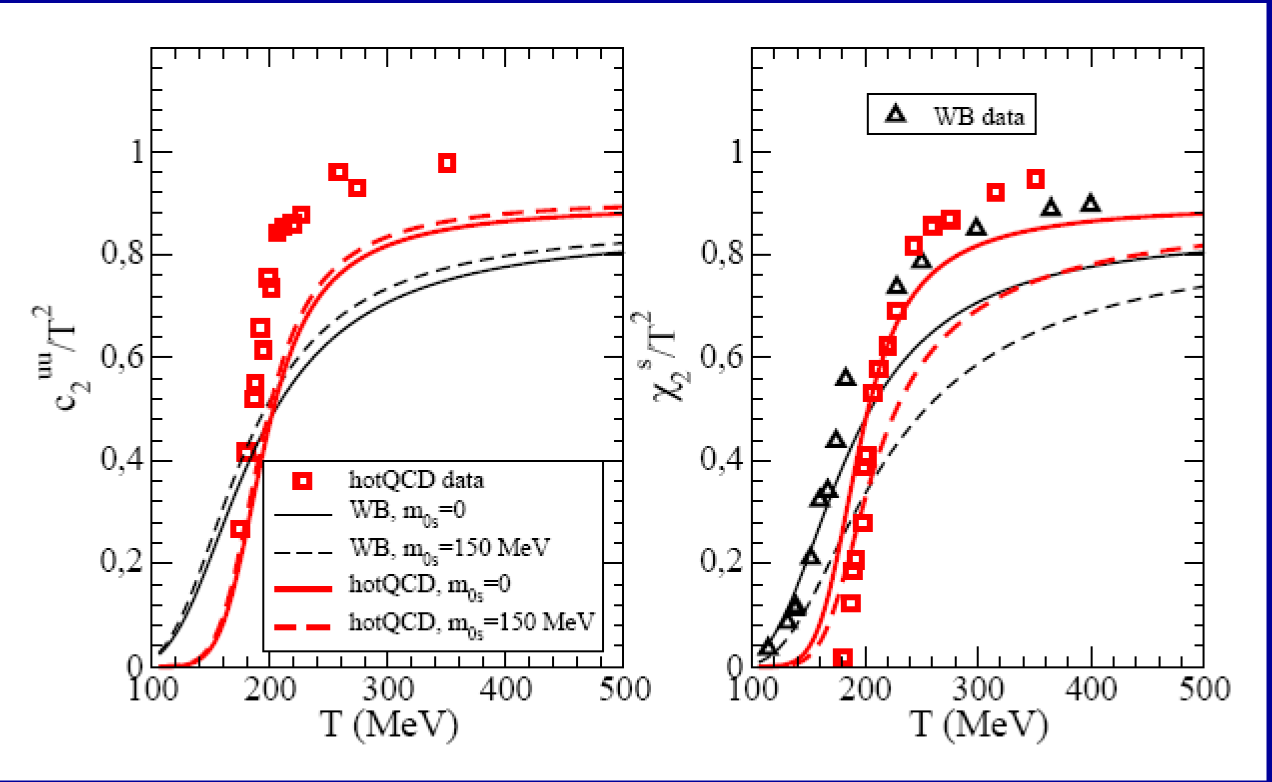
Conclusions and perspective

- ✓ To study chemical equilibration of the plasma is important to consider masses, in fact in the massive case N_q/N_g is almost 3 times greater than N_q/N_g obtained in the massless case

- ✓ The plasma seems to reach the equilibrium value at low p_T but also at high p_T the N_q/N_g is significantly modified

- ✓The bulk seems to be composed mostly by quarks and this should modifies the background for the various energy loss scenarios

- ✓ the abundances of the different species p, π,k… that coming from the fragmentation of partons should be significantly affected by the increasing of the quark number



c_2^{uu}/T^2
T (MeV)
hotQCD data
WB, m_{0s}=0
WB, m_{0s}=150 MeV
hotQCD, m_{0s}=0
hotQCD, m_{0s}=150 MeV
χ_2^s/T^2
WB data