UNIVERSITÀ DEGLI STUDI DI CATANIA
INFN-LNS

Quasiparticle approach to hot QGP and Polyakov loop dynamics

S. Plumari, M. Ruggieri, F. Scardina, V. Greco

- **Quasi particle model: EoS and susceptibilities.**
- **Chemical composition of QGP:**
  - **Quasi particle model, inelastic σ_{22} with massive partons.**
- **Quasi particle model + Polyakov loop : SU(3) Yang-Mills theory.**
- **Conclusions**

QP-model: fitting lQCD

U. Heinz and P. Levai, Phys. Rev. C 57, 1879 (1998).

P. Bozek, et al. Phys.Rev. C 57 3263 (1998).

$$\begin{cases} p(T) = \sum_{i=g,q,\bar{q}} \frac{D_i}{(2\pi)^3} \int_0^\infty d^3k \frac{k^2}{3E_i(k)} f_i(k) - B(T) \\ \epsilon(T) = \sum_{i=g,q,\bar{q}} \frac{D_i}{(2\pi)^3} \int_0^\infty d^3k \, E_i(k) f_i(k) + B(T) \end{cases}$$

Thermodynamic consistency →

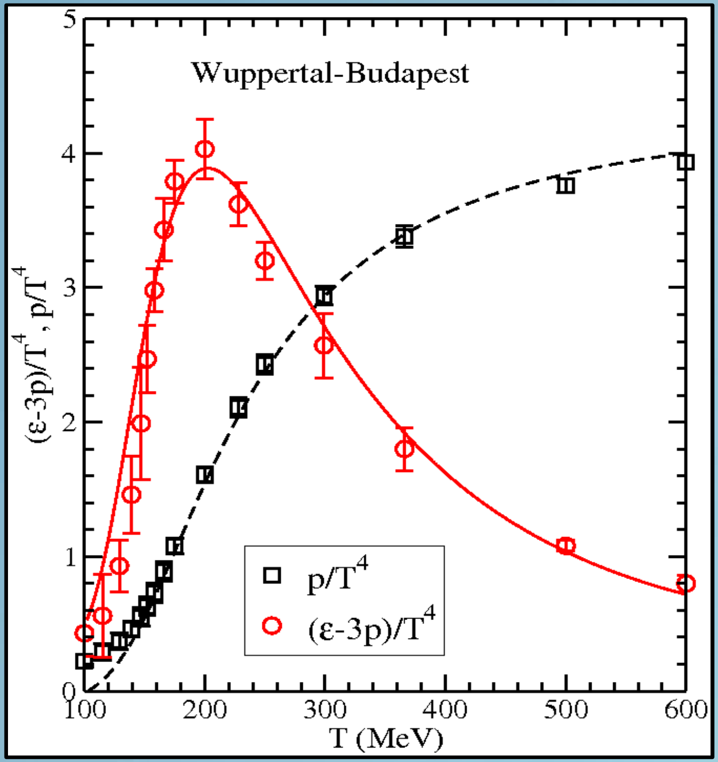
$$\left(\frac{\partial p}{\partial M_i}\right)_{T,\mu} = 0, \quad i = u, d, \ldots$$

$$\frac{\partial B(T)}{\partial M_i} + D_i \int \frac{d^3k}{(2\pi)^3} \frac{M_i}{E_i} f_i(k_i) = 0$$

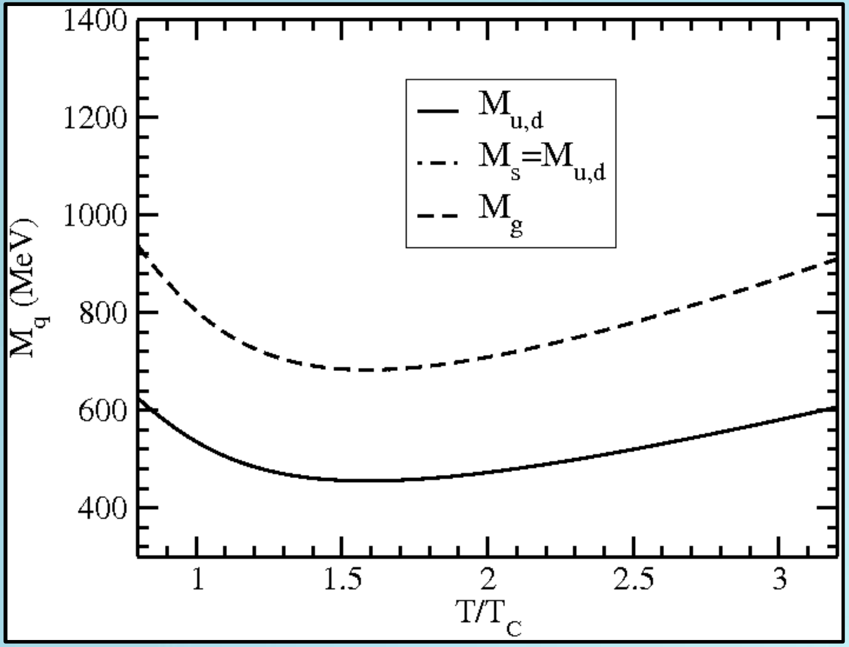
$$\begin{cases} E_i(k) = \sqrt{k^2 + M_i(T)^2} \\ M_i(T)^2 = \alpha_i \, g(T)^2 T^2 \\ g(T)^2 = \frac{48\pi^2}{(11N_c - 2N_f)\log(\lambda(T-w))^2} \end{cases}$$

M(T) and B(T) are fitted to reproduce lQCD data on ε.

Data taken from S. Borsanyi et al., J. High Energy Phys. 11 (2010) 077.



S.Plumari, et al. Phys.Rev. D84 (2011) 094004.



Using the QP-model: susceptibilities

U. Heinz and P. Levai, Phys. Rev. C 57, 1879 (1998).

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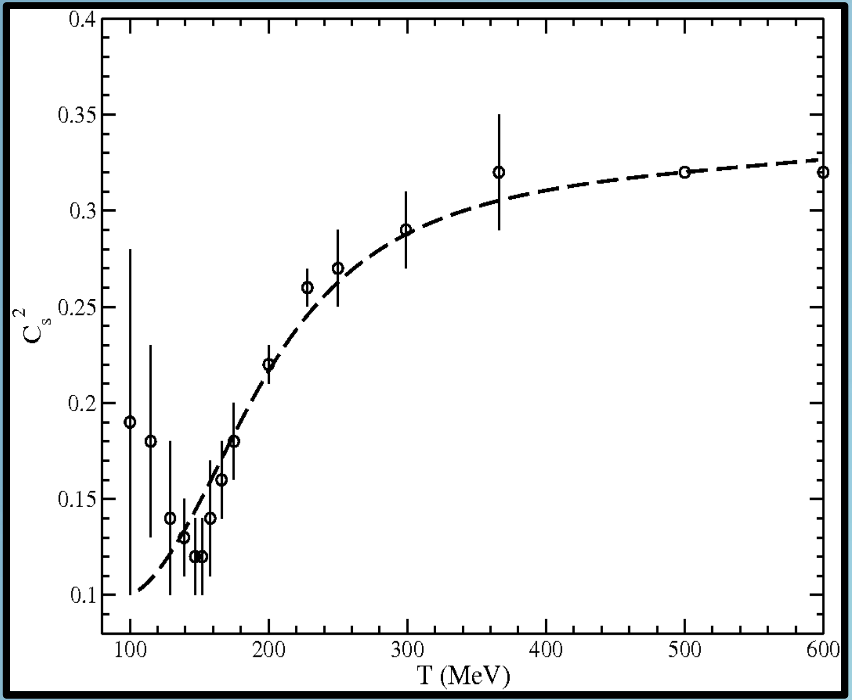
$$\begin{cases} p(T) = \sum_{i=g,q,\bar{q}} \frac{D_i}{(2\pi)^3} \int_0^\infty d^3k \frac{k^2}{3E_i(k)} f_i(k) - B(T) \\ \epsilon(T) = \sum_{i=g,q,\bar{q}} \frac{D_i}{(2\pi)^3} \int_0^\infty d^3k \, E_i(k) f_i(k) + B(T) \end{cases}$$

$$c_2^{uu} = \frac{T}{V}\left[\frac{\partial^2 \ln Z}{\partial \mu_u^2}\right]_{\mu=0} \qquad X_2^s = \frac{T}{V}\left[\frac{\partial^2 \ln Z}{\partial \mu_s^2}\right]_{\mu=0}$$

The susceptibilities obtained using the qusi particle model understimate the lQCD data.

M(T) and B(T) are fitted to reproduce lQCD data on ε.

Data taken from S. Borsanyi et al., J. High Energy Phys. 11 (2010) 077.



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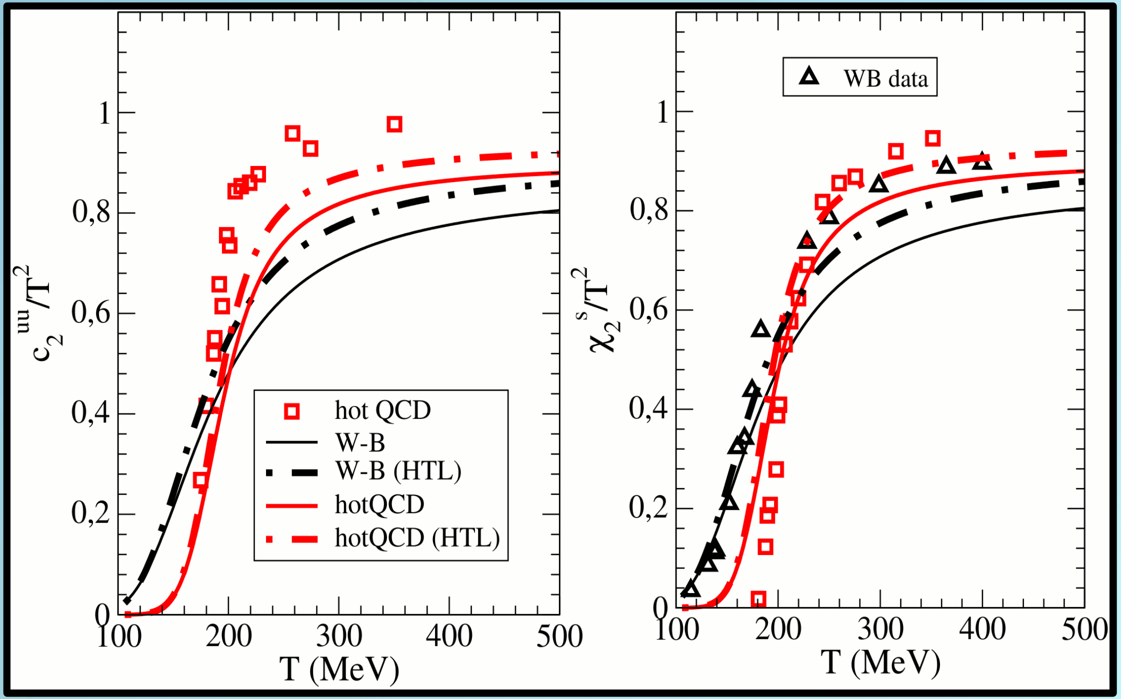

Using the QP-model: q/g ratio

U. Heinz and P. Levai, Phys. Rev. C 57, 1879 (1998).

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$$\begin{cases} p(T) = \sum_{i=g,q,\bar{q}} \frac{D_i}{(2\pi)^3} \int_0^\infty d^3k \frac{k^2}{3E_i(k)} f_i(k) - B(T) \\ \epsilon(T) = \sum_{i=g,q,\bar{q}} \frac{D_i}{(2\pi)^3} \int_0^\infty d^3k \, E_i(k) f_i(k) + B(T) \end{cases}$$

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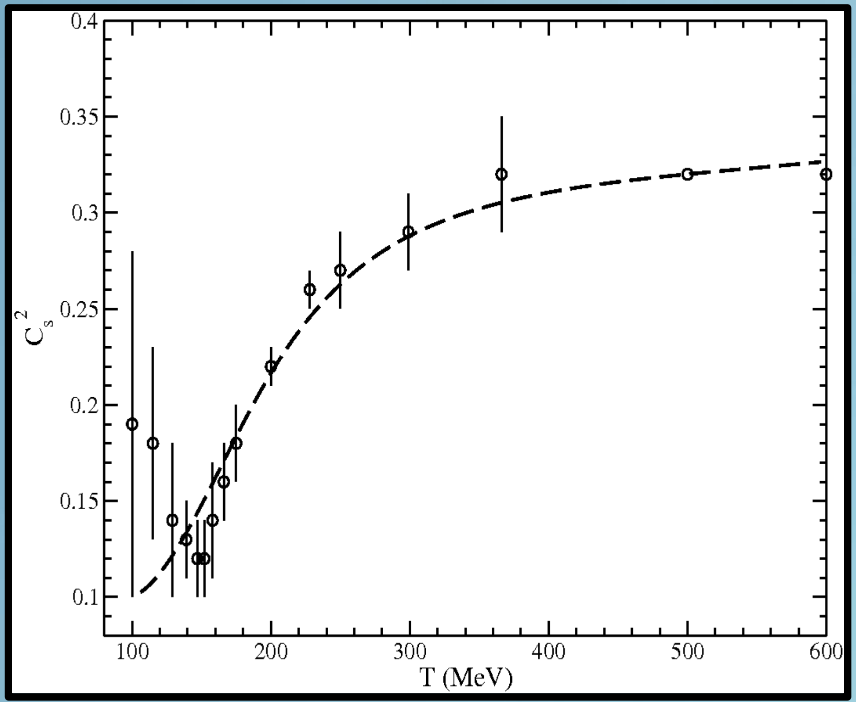
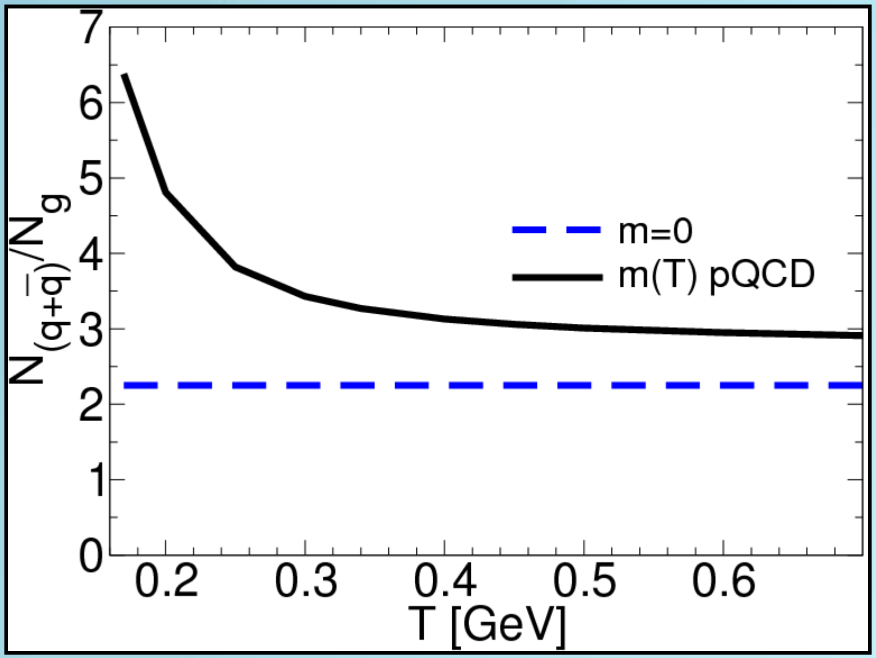


The descrption in terms of quasi particle has a strong effect on the chemical ratio N_q/N_g.

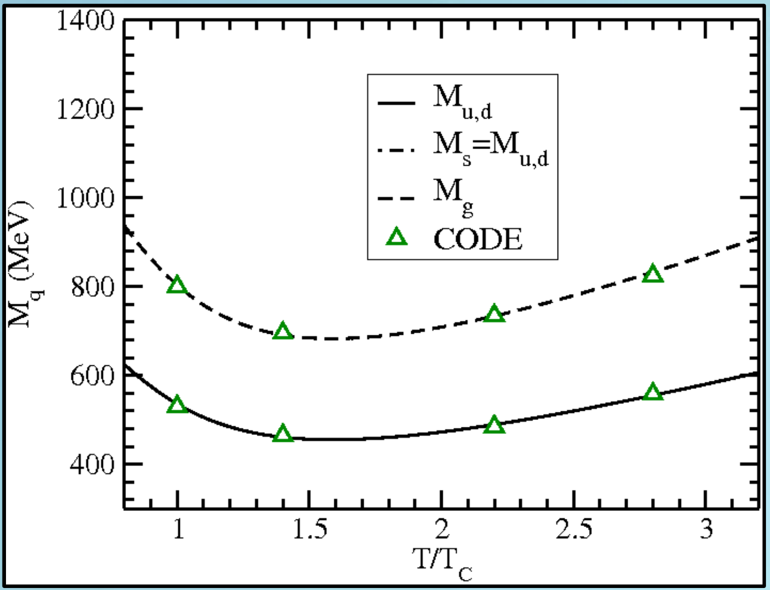
$$\frac{N_q}{N_g} = \frac{d_q}{d_g} \frac{m_q^2(T) K_2(m_q/T)}{m_g^2(T) K_2(m_g/T)}$$

S.Plumari, et al. Phys.Rev. D84 (2011) 094004.



Using the QP-model: equilibrium

Passed several numerical test on the box.
We reproduce the lQCD EoS .



$$\begin{cases} p^\mu \partial_\mu f(x,p) + m_i(x)\partial_\mu m_i(x)\partial_p^\mu f(x,p) = C_{22} \\ \dfrac{\partial B}{\partial m_i} + d_i \displaystyle\int \frac{d^3p}{(2\pi)^3}\frac{m_i(x)}{E_i(x)} f(x,p) = 0, \quad \text{i=g,u,d,s} \end{cases}$$

Inelastic cross section with massive partons: $\sigma_{gg \to qq}$

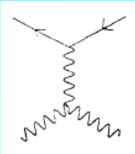
$$|M_t|^2 = \alpha_s^2\pi^2 \frac{8}{3}\frac{(m_q^2+m_g^2-t)(m_q^2+m_g^2-u)-2m_q^2(m_q^2+t)-m_g^2 s-4m_q^2m_g^2}{(t-m^2)^2}$$

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

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

→

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



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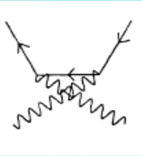
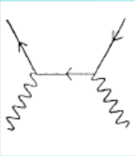
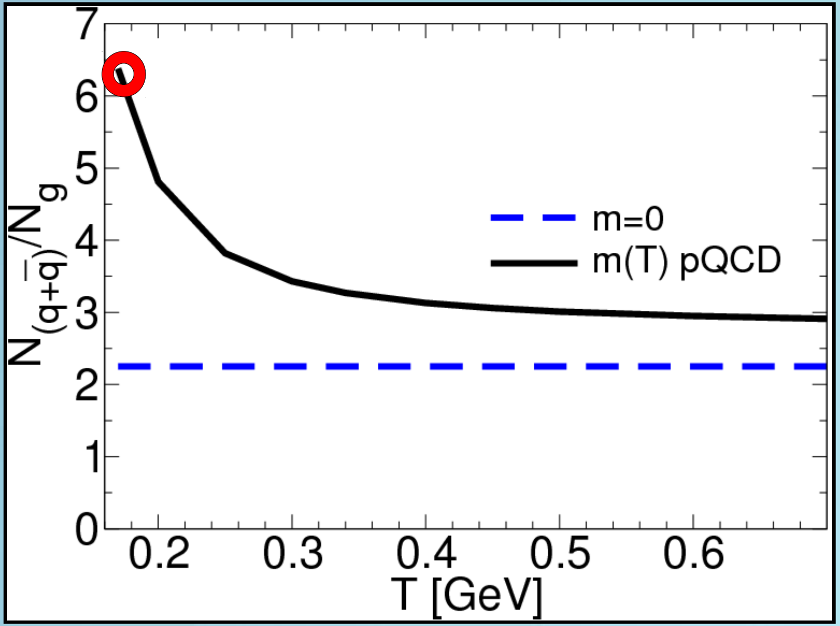


$$|M_s|^2 = \alpha_s^2\pi^2 12\frac{u\cdot t}{s^2}$$

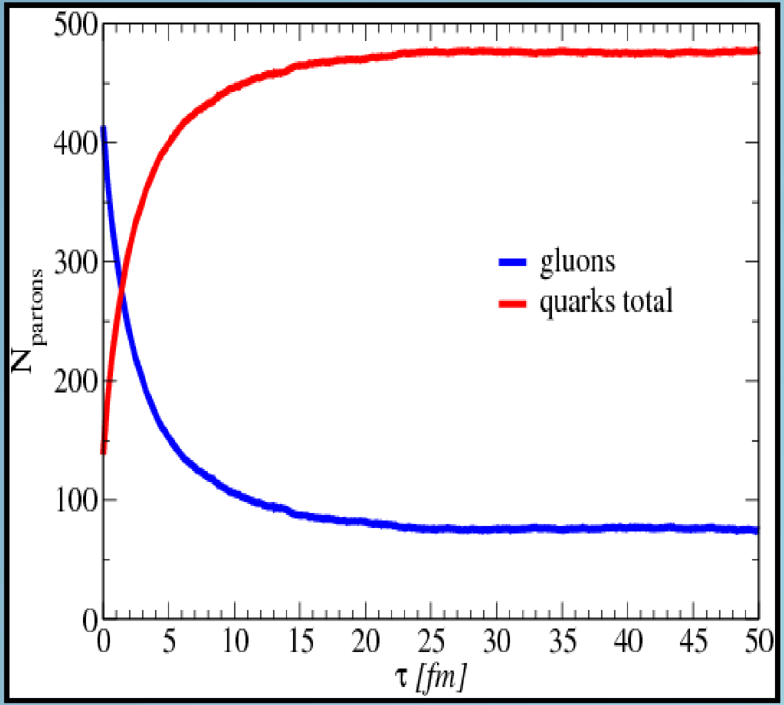


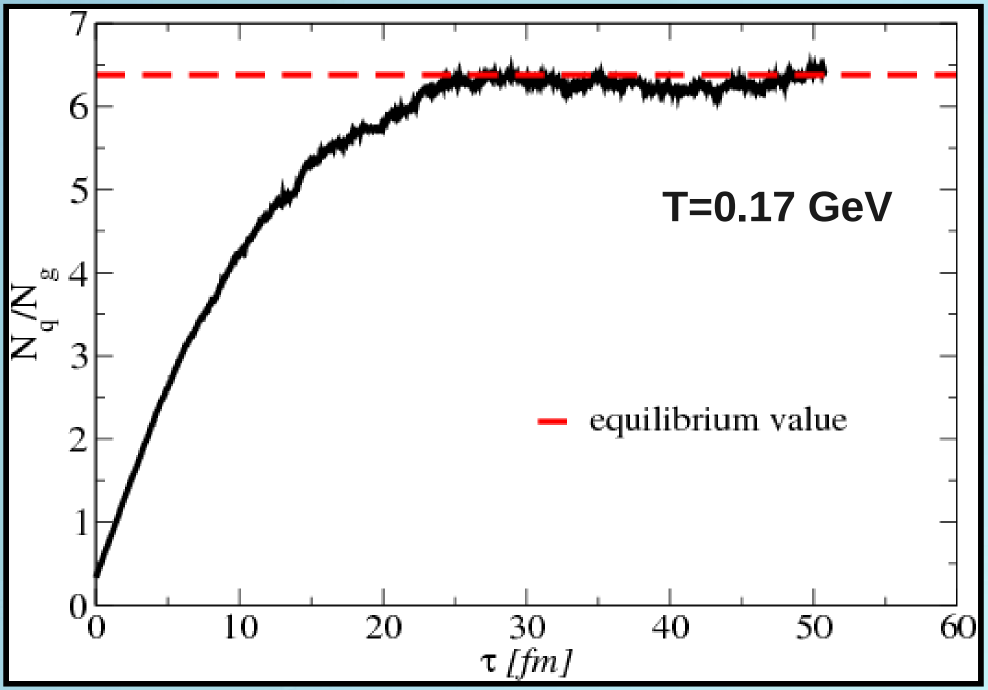
Using the QP-model: towards equilibrium

$$\begin{cases} p^{\mu}\partial_{\mu} f(x,p) + m_i(x)\partial_{\mu} m_i(x)\partial_p^{\mu} f(x,p) = C_{22} \\ \dfrac{\partial B}{\partial m_i} + d_i \displaystyle\int \frac{d^3p}{(2\pi)^3}\frac{m_i(x)}{E_i(x)} f(x,p) = 0, \ \text{i=g,u,d,s} \end{cases}$$



F. Scardina et al.,arXiv:1202.2262 [nucl-th].





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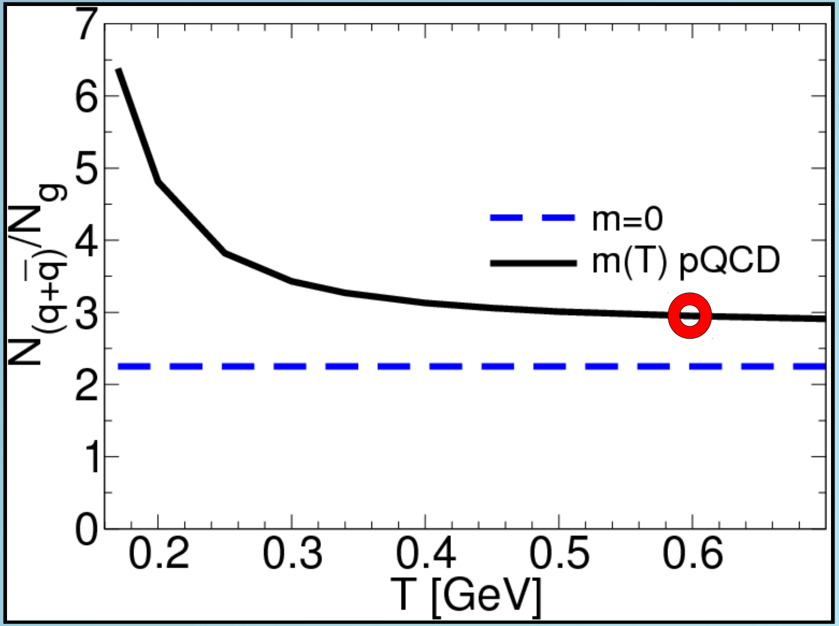

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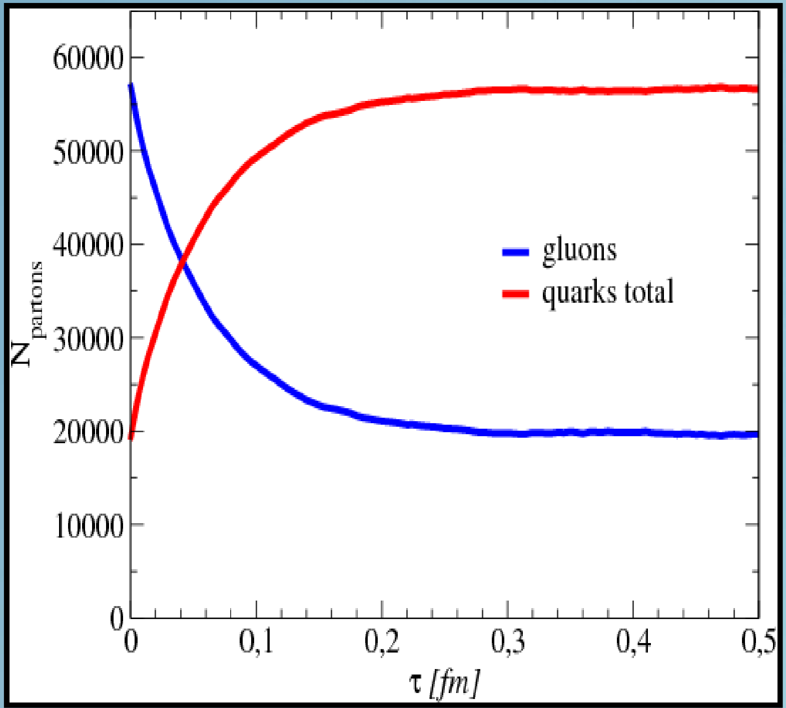
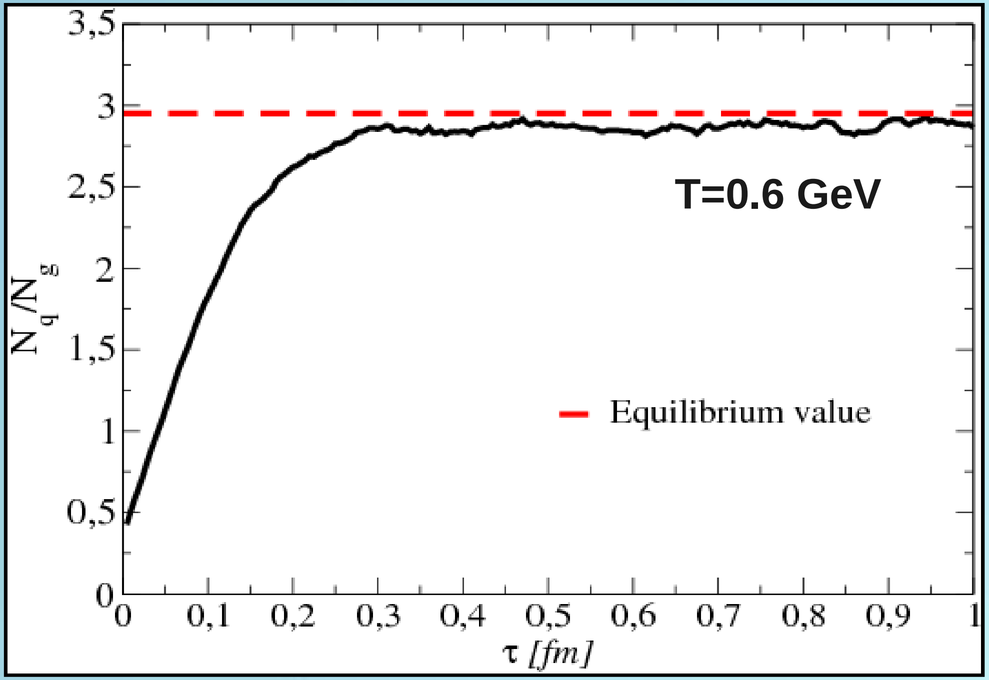
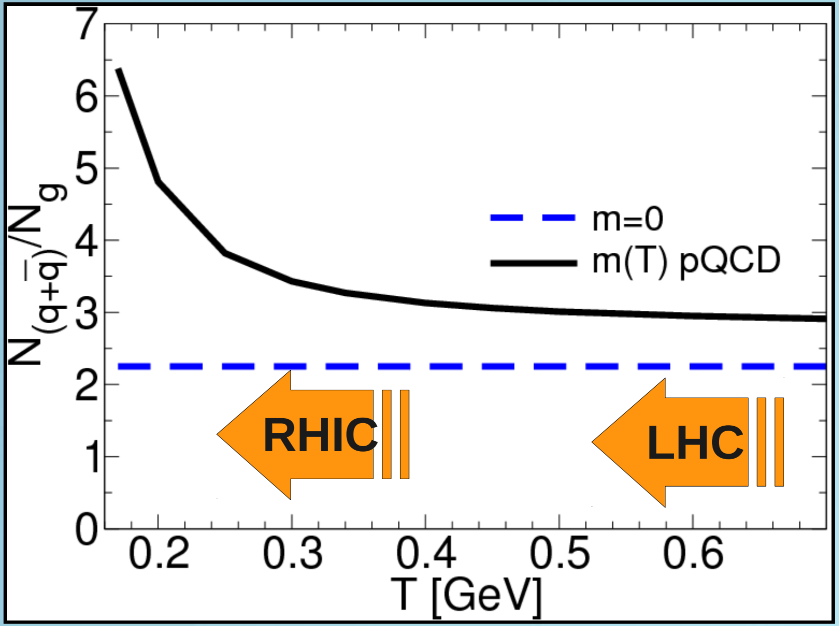




Using the QP-model: HIC

- **In the massless case the system reaches the equilibrium value R=2. in less than 1 fm/c.**

- **In the massive case M(T) the equilibrium value is strogly T dependent (close T_c). The fireball reaches a value close to the equilibrium value with the ~80% of total partons composed of quarks and anti-quarks.**



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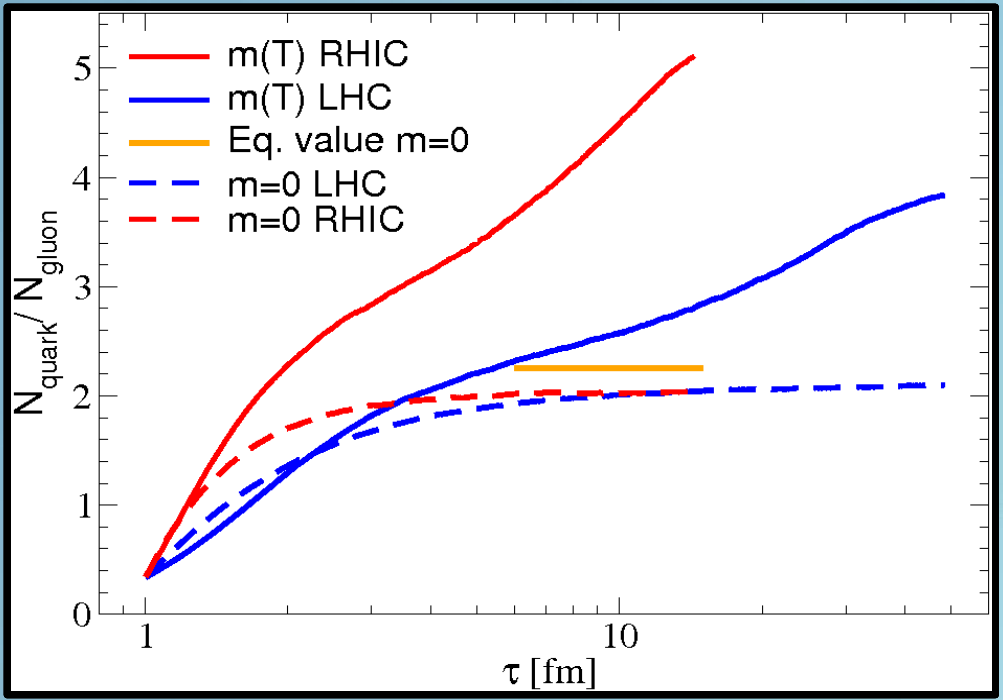


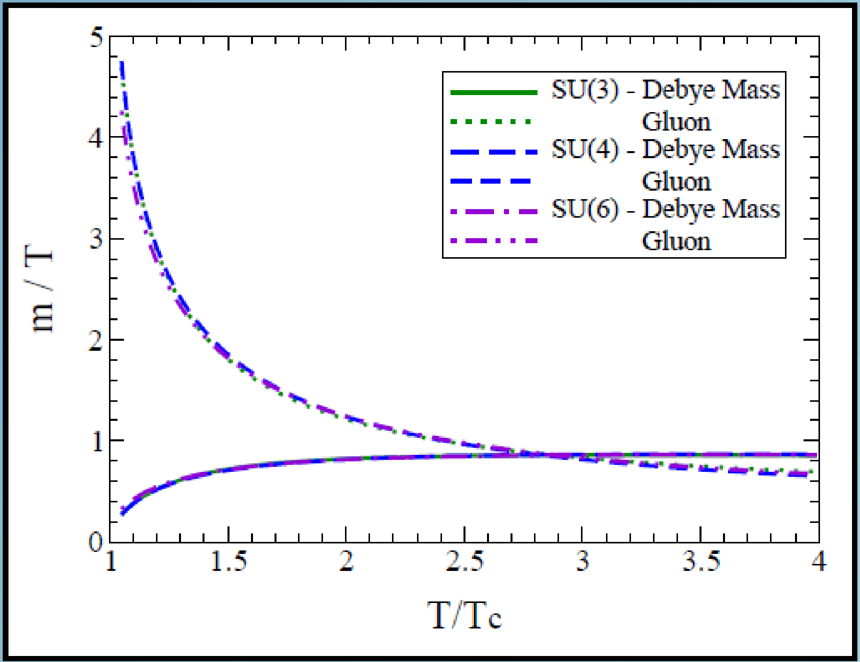
Next step – to study the Lattice data in terms of gluon quasiparticles propagating in a background of Polyakov loop

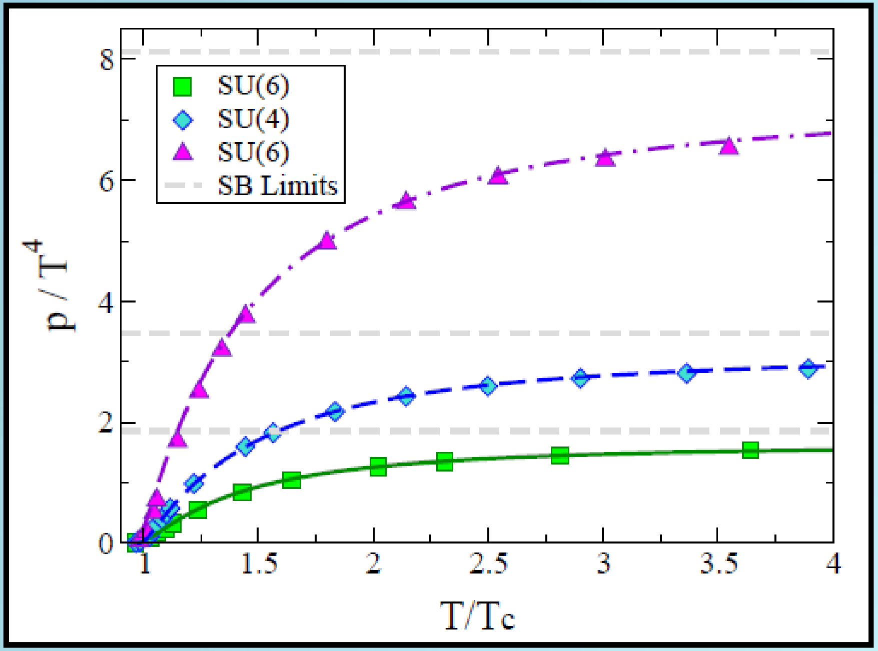
Using the QP-model: pure Yang-Mills

$$\begin{cases} p(T) \propto T \int_0^\infty \frac{d^3k}{(2\pi)^3} \log\left(1-e^{-\beta\omega}\right) \\ \omega = \sqrt{k^2+m^2(T)} \\ m(T) = \frac{A}{(t-\delta)^c} + B\,t, \quad t = \frac{T}{T_c} \end{cases}$$

- **Lattice data well described in terms of transverse quasi-particles.**
- **Rapid increase of m(T) for $T \to T_c$.**

P. Castorina et al., Eur. Phys. J. C71 (2011).





QP-model + Polyakov loop

M. Ruggieri *et al.*, arXiv:1204.5995 [hep-ph].

$$\Omega=\Omega_{PM}(\langle l_f\rangle)+\Omega_{qp}(\langle l_f\rangle, M)$$

$$\begin{cases}\Omega_{PM}=bT\left(-6N_C^2 e^{-a/T}\langle l_f\rangle^2+N_C\alpha\langle l_f\rangle-\log F(\alpha)\right)\\ \Omega_{qp}=2T\int\frac{d^3k}{(2\pi)^3}\left\langle Tr_A\log\left(1-L_A e^{-E(k)/T}\right)\right\rangle\end{cases}$$

$$\log\left\langle det_A\left(1-L_A e^{-E(k)/T}\right)\right\rangle=\underbrace{2\log\left(1-e^{-E(k)/T}\right)+\sum_{i=1}^{3}\log\left(1+e^{-2E(k)/T}-\langle\omega_i\rangle e^{-E(k)/T}\right)}$$

$$\underset{\langle\omega_i\rangle\to 1}{for\ T\to\infty}\longrightarrow 8\log\left(1-e^{-E(k)/T}\right)$$

$$\begin{cases}E(k)=\sqrt{k^2+M(T)^2}\\ M(T)^2=\frac{1}{2}g(T)^2T^2\\ g(T)^2=\frac{48\pi^2}{11N_c\log(\lambda(T-w))^2}\end{cases}$$

H. Abuki and K. Fukushima, Phys.Lett. B676 (2009).
T. Zhang et al., JHEP 1006 (2010) 064.

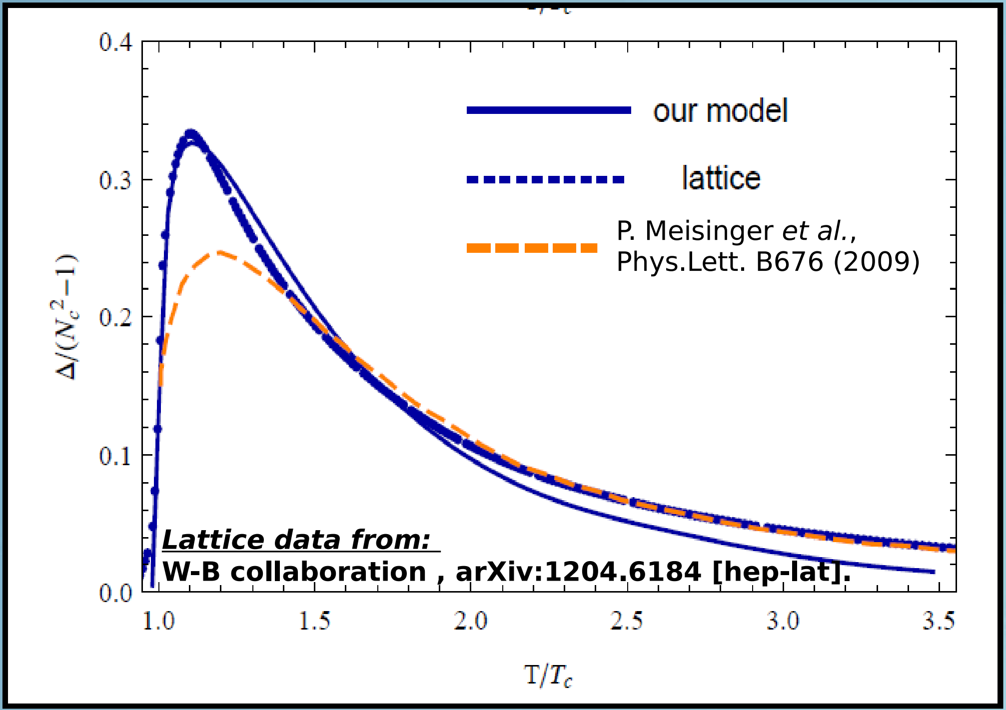
P. Meisinger, M.C. Ogilvie, T.R. Miller, Phys.Lett. B585, 149 (2004).
C. Sasaki and K. Redlich, arXiv:1204.4330[hep-ph].

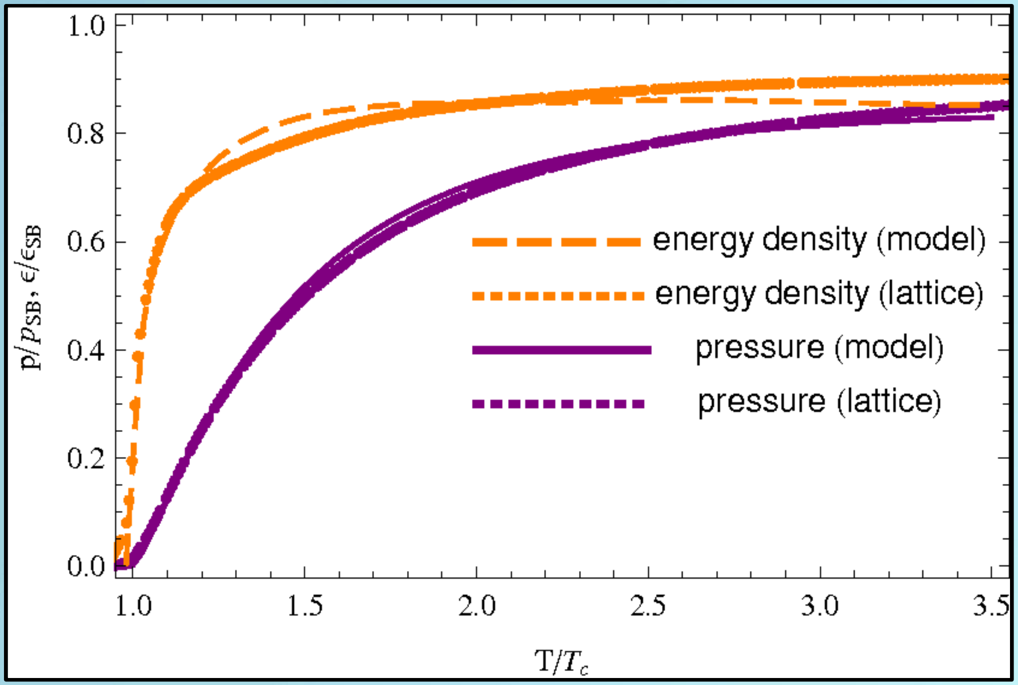
QP-model + Polyakov loop

The parameters are fixed to reproduce:

- **1st order phase transition at T=270 MeV**
- **Mean quadratic deviation for p, ε, Δ of QP-model and lattice are minimized.**

M. Ruggieri et *al.*, arXiv:1204.5995 [hep-ph].



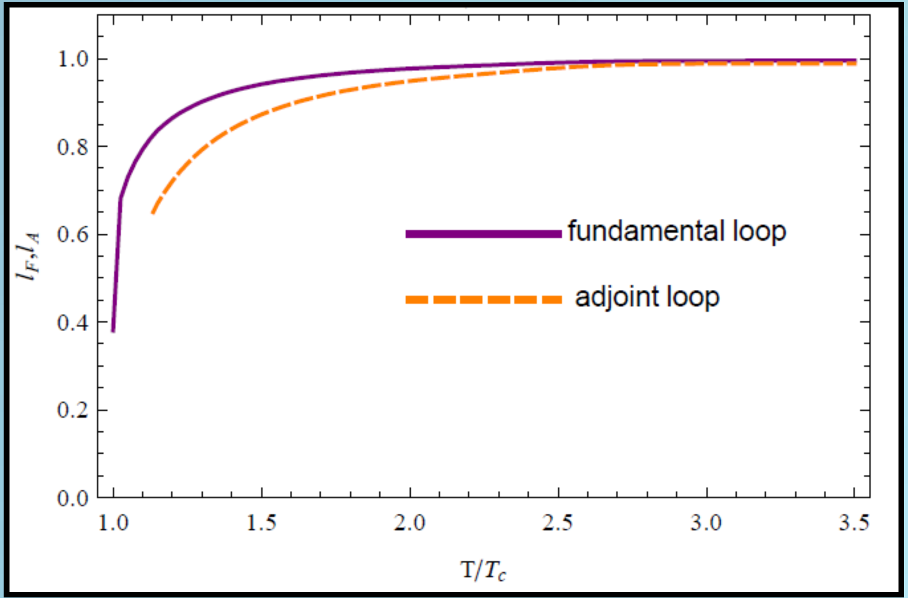


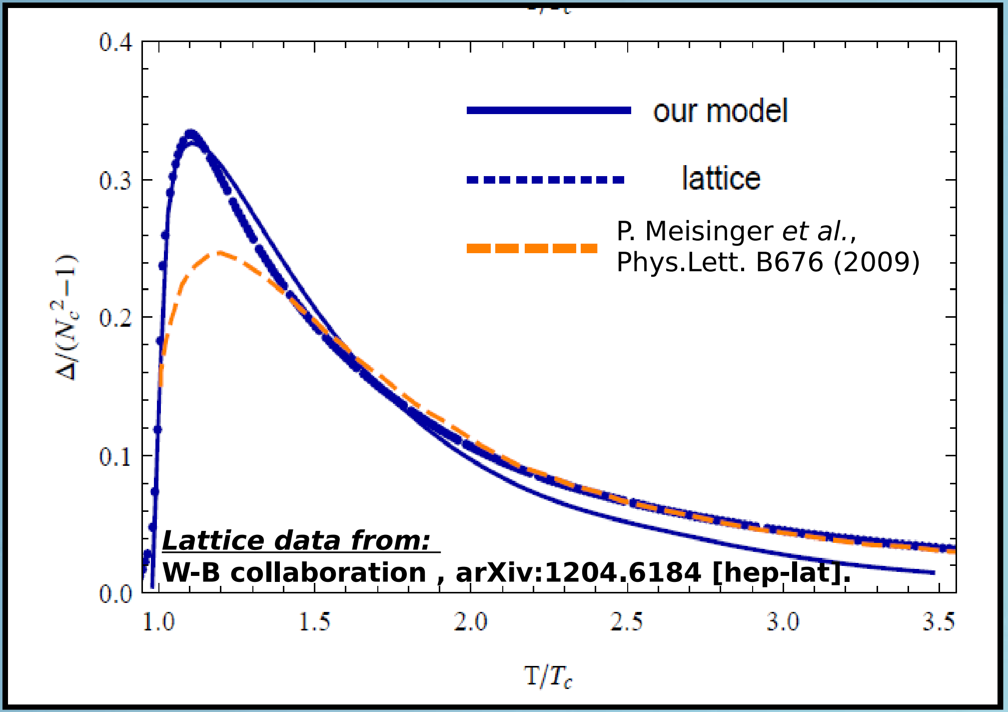
QP-model + Polyakov loop

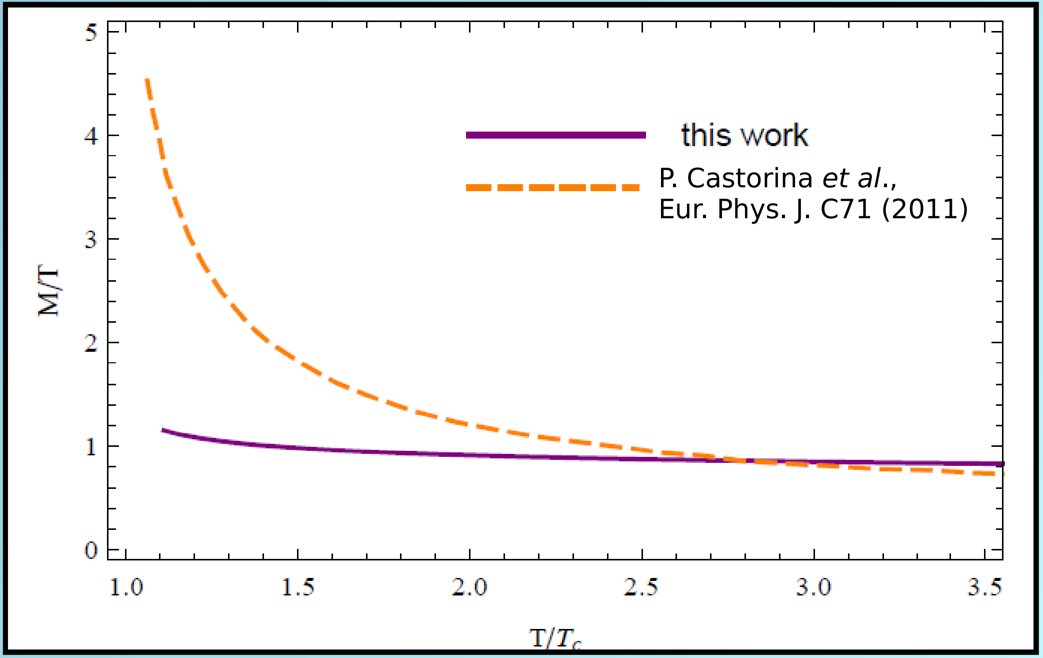
The indigo line corresponds to the mass which offers the *best agreement* with the Lattice data.

***Main effect of Polyakov loops*:**
QP mass does no longer diverge at the deconfinement temperature.

M. Ruggieri *et al.*, arXiv:1204.5995 [hep-ph].







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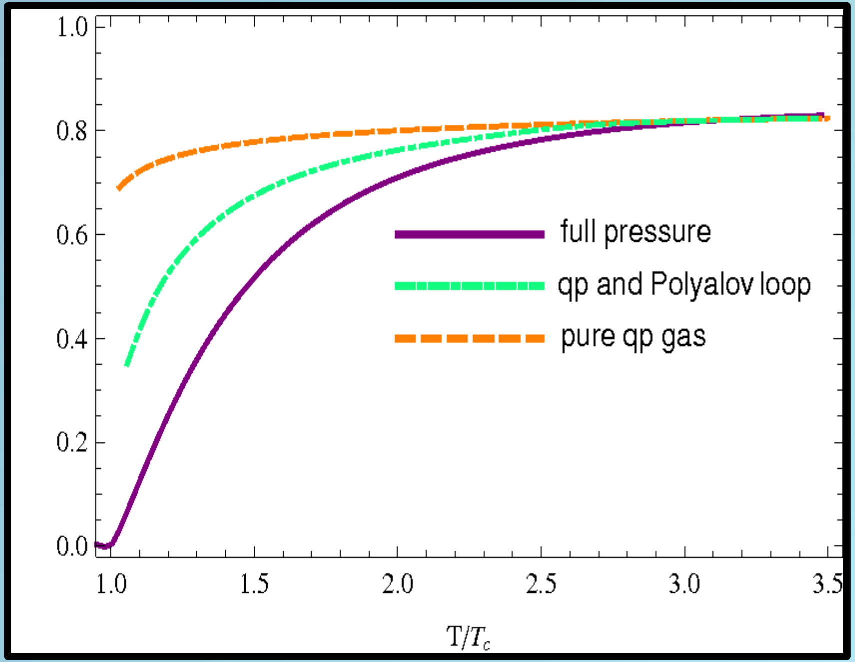

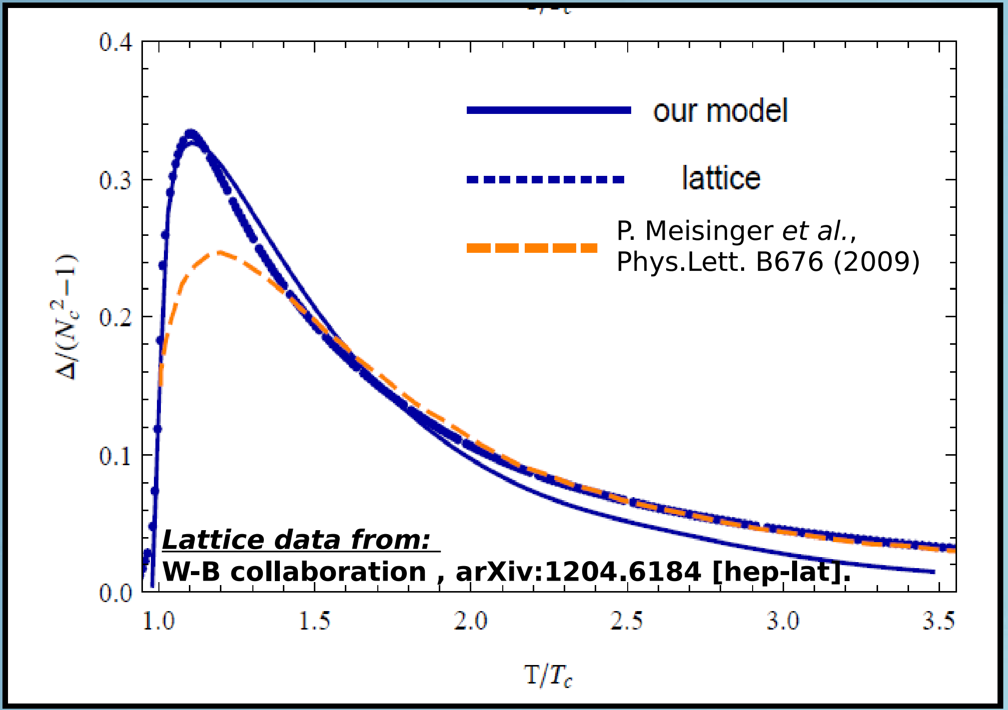

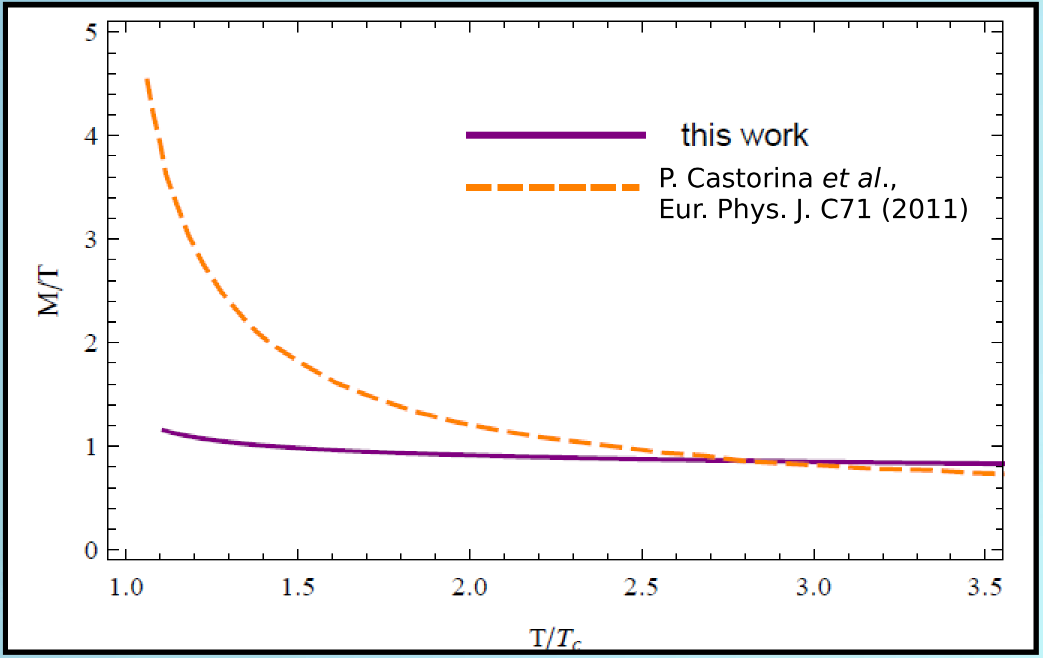

Conclusions and Outlook

- QP model well reproduce lattice data but not able to reproduce the the quark susceptibilities. The susceptibilities suggest lower quark mass.

- QP model implies large q/g ratio that may be reached in HIC.

- Including Polyakov loop dynamics for pure SU(3) theory.
  - Gluon mass of the order of the critical temperature: $m_g \sim 1 - 2\ T_C$.

- Polyakov loop + dynamical quarks.
- Quasi particle + Polyakov loop and transport code.