Equation of state of multicomponent hadron gas with finite size corrections and phase transition to quark-gluon plasma

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Plan

1. Introduction
2. Models of equation of state fro phases
3. Results

Reseacrh

- There are a lot of theoretical and experimental works in the area of high energy physics and heavy ion collisiions.
- In such collisions can be formed state of quark-gluon plasma.
- For purpose of calculating dynamic and thermal properties of such expanding systems one need equation of state for all phases: HP and QGP.

Hadron gas Phase

- The most studied in this phases is phase of hadron resonance gas.
- As seen from works statistical thermal models well described properties of this phase
- Some applications: SHARE, THERMUS.
- In central collisions of (Au, Pb) were produced large number of hadrons.
- This fact gives opportunity to consider this phase from positions of grand-canonical ensemble.

$$v \sim (0.5-3) fm^3 \qquad \ln Z^{GC}(T,V,\{\mu_i\}) = \sum_i \frac{g_i V}{(2\pi)^3} \int d^3p \, ln(1 \pm e^{-\frac{(E_i-\mu_i)}{T}})^{\pm 1}$$

$$N_i^{GC} = T \frac{\partial \ln Z^{GC}}{\partial \mu_i} \qquad S^{GC} = \frac{\partial (T \ln Z^{GC})}{\partial T} \qquad P^{GC} = T \frac{\partial \ln Z^{GC}}{\partial V}$$

$$V' = V - \sum_i v_i N_i \qquad v_i = \frac{16}{3} \pi r_h{}^3 \qquad V \to V'$$

$$P = \sum_i P_i(\mu_i^{\sim}, T) \qquad \mu_i^{\sim} = \mu_i - v_i P \qquad \mu_i = B_i \mu + S_i \mu_s$$

$$P = P(\mu, \mu_s, T) \qquad dP = s dT + n d\mu + n_s d\mu_s$$

Andronic A., Braun-Munzinger P., Stachel J. Phys. Lett. B. 2009. V.,673. n.,2. p.,142-145.
Satarov L.,M., Dmitriev M.,N., Mishustin I.,N. Phys. Atom. Nucl. 2009. v.,72. n.,8. P.,1390-1415.

Thermodynamic quantities

$$s = \frac{\partial P}{\partial T} = r \sum_i s_i^{\sim} (\mu_i^{\sim}, T) \qquad n = \frac{\partial P}{\partial \mu} = r \sum_i B_i n_i^{\sim} (\mu_i^{\sim}, T) \qquad n_S = \frac{\partial P}{\partial \mu_S} = r \sum_i S_i n_i^{\sim} (\mu_i^{\sim}, T)$$

$$s_i^{\sim} = \frac{\partial P_i}{\partial T} \qquad n_i^{\sim} = \frac{\partial P_i}{\partial \mu_i^{\sim}}$$

Energy ,entropy and baryon densities so can be calculate

$$n_i = \frac{\partial P}{\partial \mu_i} = r n_i^{\sim} \qquad r = \left(1 + \sum_i n_i^{\sim} v_i\right)^{-1}$$

$$\epsilon = -P + Ts + \mu n + n_S \mu_S$$

$$\epsilon = r \sum_i \epsilon_i^{\sim} (\mu_i^{\sim}, T)$$

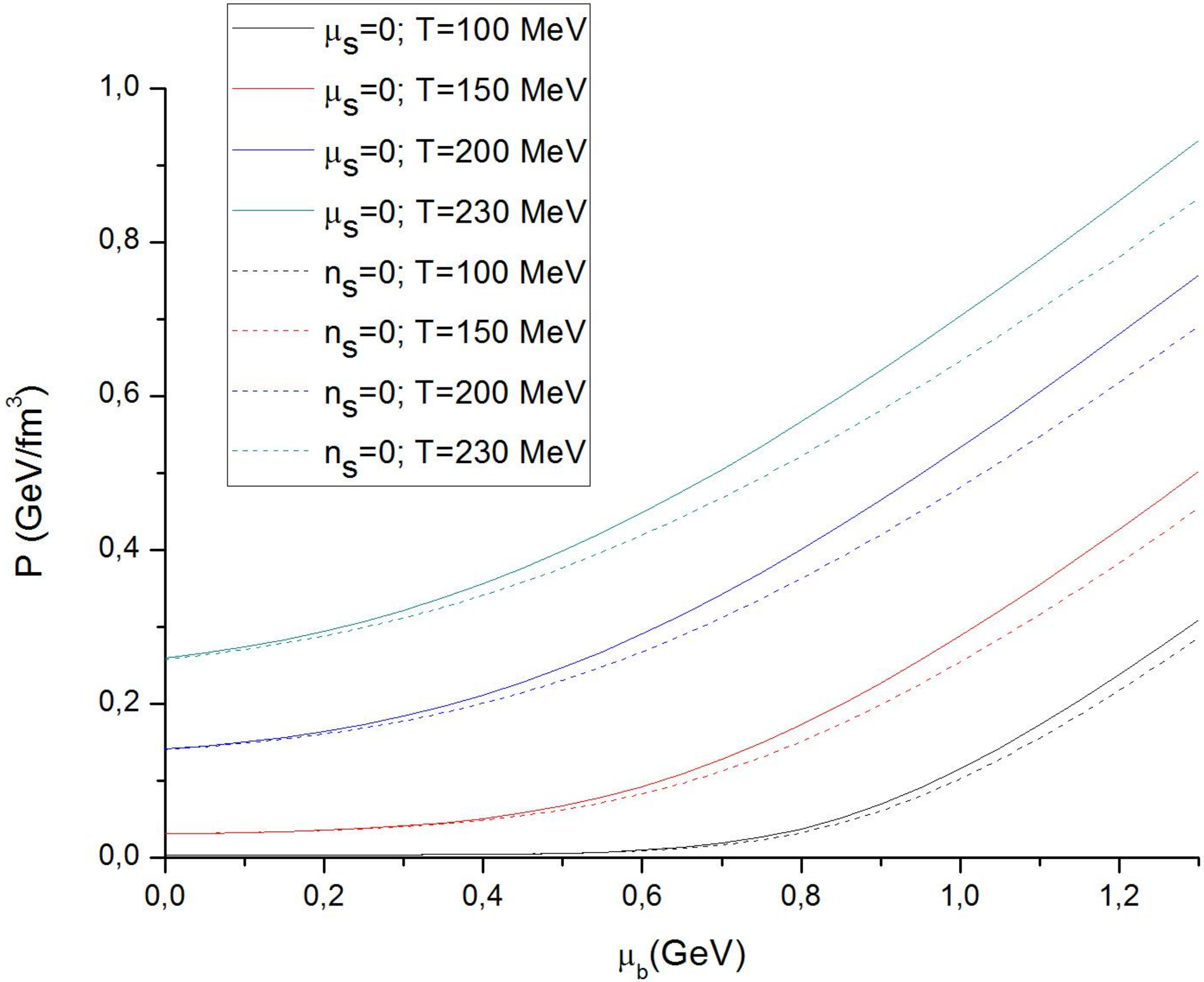
$$\begin{matrix} \epsilon_i^{\sim} \\ P_i \\ n_i^{\sim} \end{matrix} = \frac{1}{(hc)^3} \frac{g_i}{2\pi^2} \int_{m_i}^{\infty} d\epsilon \frac{\sqrt{(\epsilon^2 - m_i{}^2)}}{\exp\left(\frac{\epsilon - \mu_i^{\sim}}{T}\right) \pm 1} \begin{matrix} \epsilon^2 \\ \frac{1}{3}(\epsilon^2 - m_i{}^2) \\ \epsilon \end{matrix}$$

Particle set includes 151 hadron:
70 mesons,
81 baryons and anti-baryons.
$m_i < 2{,}5$ GeV.
System of equations for solving according to conservation laws:

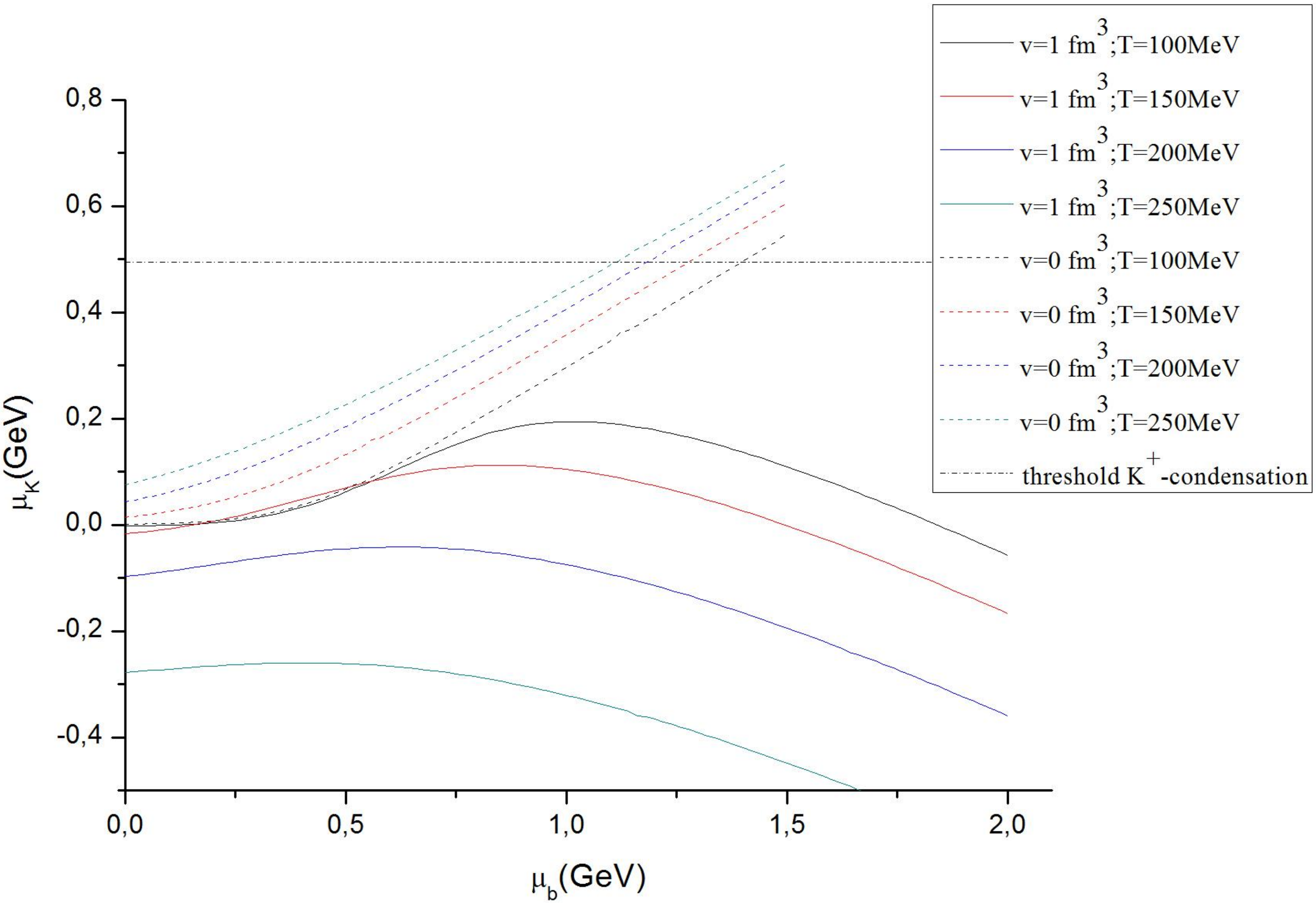
$$\begin{cases} P = \sum_i P_i\left(\mu B_i + \mu_S S_i - vP, T\right) \\ \sum_i S_i n_i\left(\mu B_i + \mu_S S_i - vP, T\right) = 0 \end{cases}$$

$$\begin{cases} P = \sum_i P_i\left(\mu B_i + \mu_S S_i + \mu_Q Q_i - Pv, T\right) \\ \sum_i S_i n_i\left(\mu B_i + \mu_S S_i + \mu_Q Q_i - Pv, T\right) = 0 \\ \dfrac{\sum_i Q_i n_i\left(\mu B_i + \mu_S S_i + \mu_Q Q_i - Pv, T\right)}{\sum_i B_i n_i\left(\mu B_i + \mu_S S_i + \mu_Q Q_i - Pv, T\right)} = \dfrac{Z}{A} \end{cases}$$

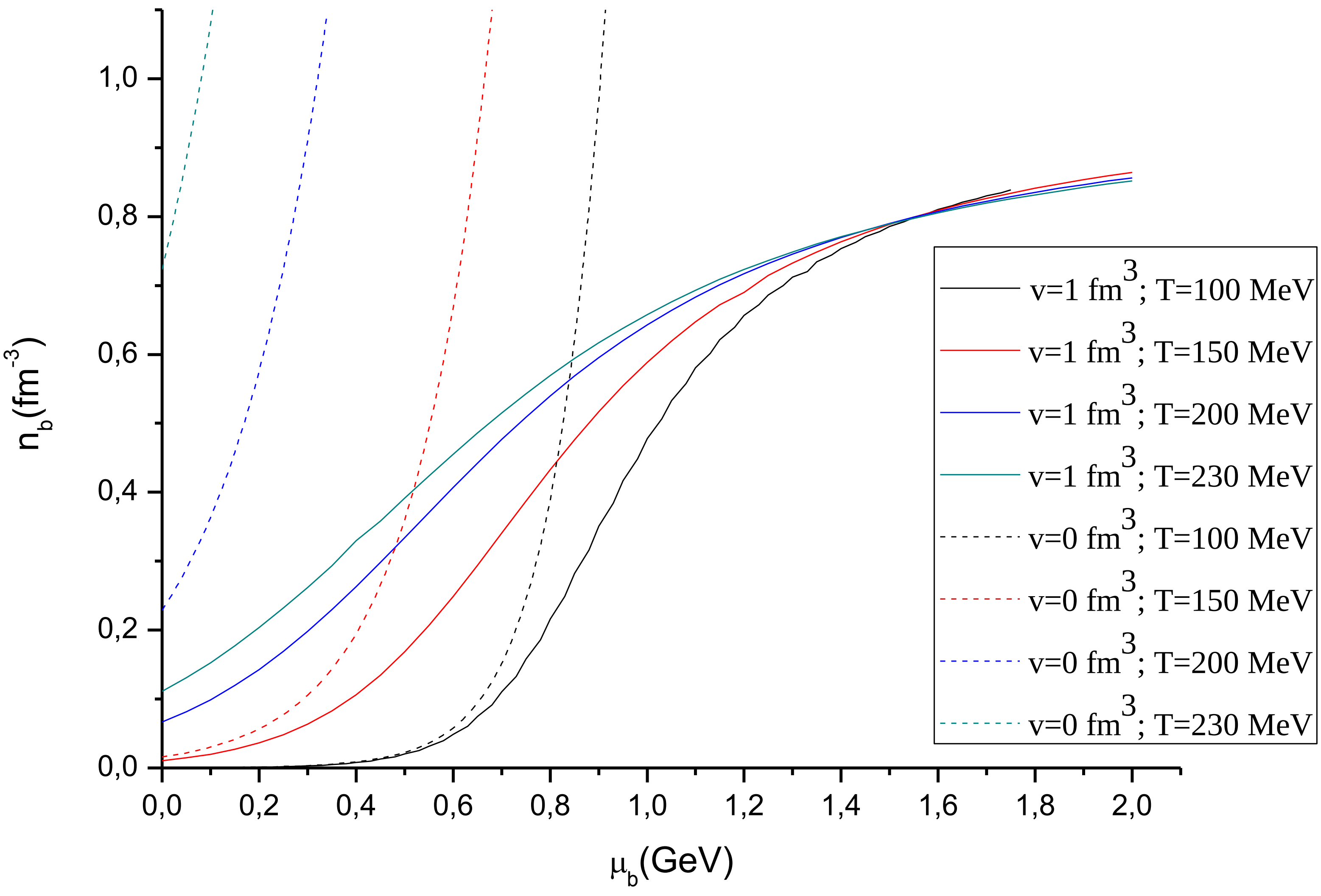
Importance of strangeness constraint



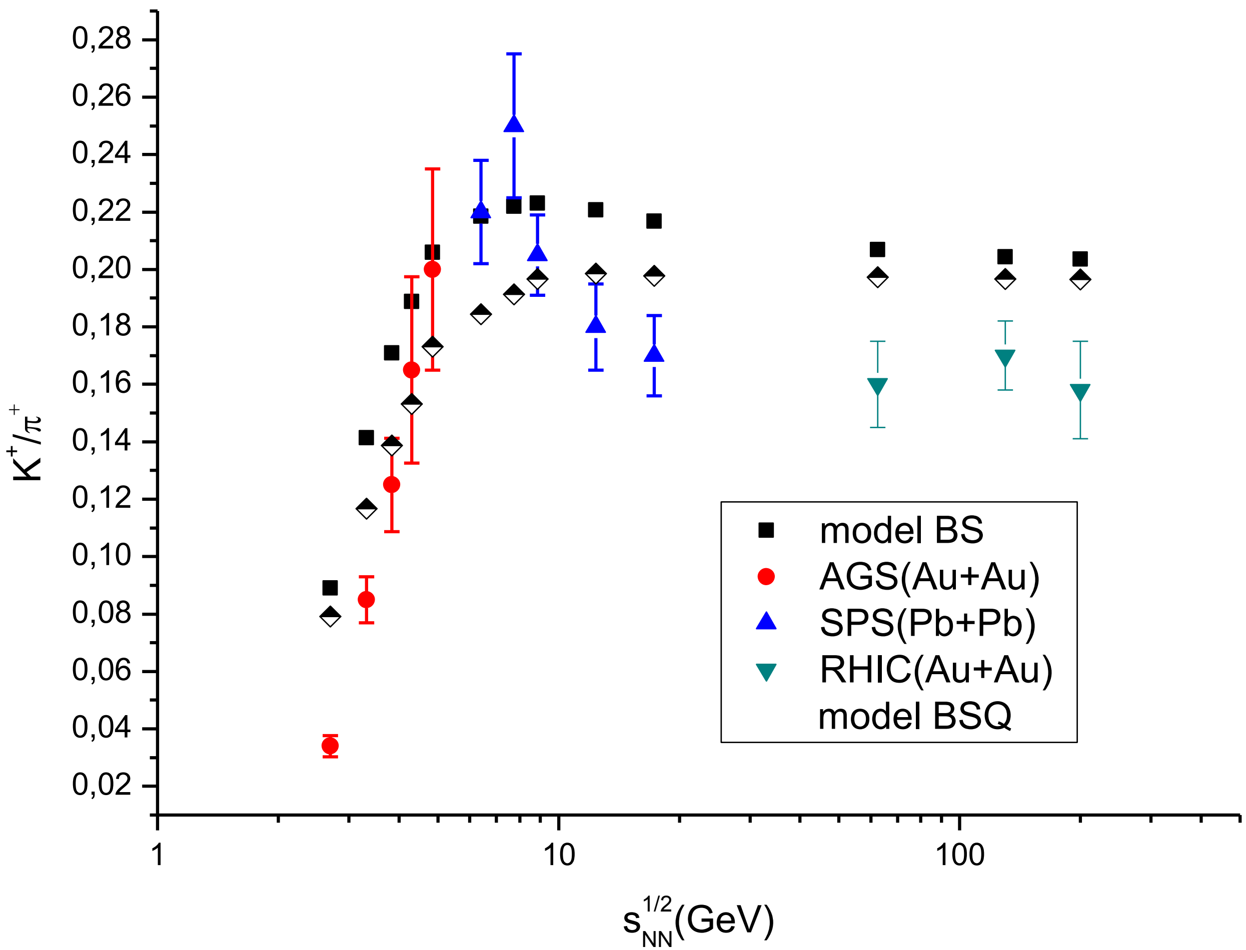
Kaons condensation



Baryon density



Results for hadron multiplicity ratio of K+/pi+ $\frac{K^+}{\pi^+}$



Quark-gluon phase

MIT Bag model:

$$\mu_g = 0;\ \mu_q = -\mu_{q^\sim} = \frac{\mu}{3};\ \mu_s = -\mu_{s^\sim} = \frac{\mu}{3} - \mu_S.$$

$$P = \left(N_g + \frac{21}{2}N_f\right)\frac{\pi^2 T^4}{90} + N_f\left(\frac{\mu^2 T^2}{18} + \frac{\mu^4}{324\pi^2}\right) - B$$
$$+ \frac{(1-\varepsilon)}{\pi^2}\int_{m_s.}^{\infty} d\epsilon(\epsilon^2 - m_s{}^2)^{3/2}\{\frac{1}{1+\exp\left(\frac{\epsilon-\mu_s}{T}\right)} + \frac{1}{1+\exp\left(\frac{\epsilon+\mu_s}{T}\right)}\}$$

$N_g = 16(1-0.8\varepsilon)$

$N_f = 2(1-\varepsilon)$

– effective number of quarks and gluons

$n_s = -n_s + n_{s^\sim} = \frac{\partial p}{\partial \mu_S} = 0$ with $\mu_s = -\mu_{s^\sim} = \frac{\mu}{3} - \mu_S = 0.$

Model parameters:

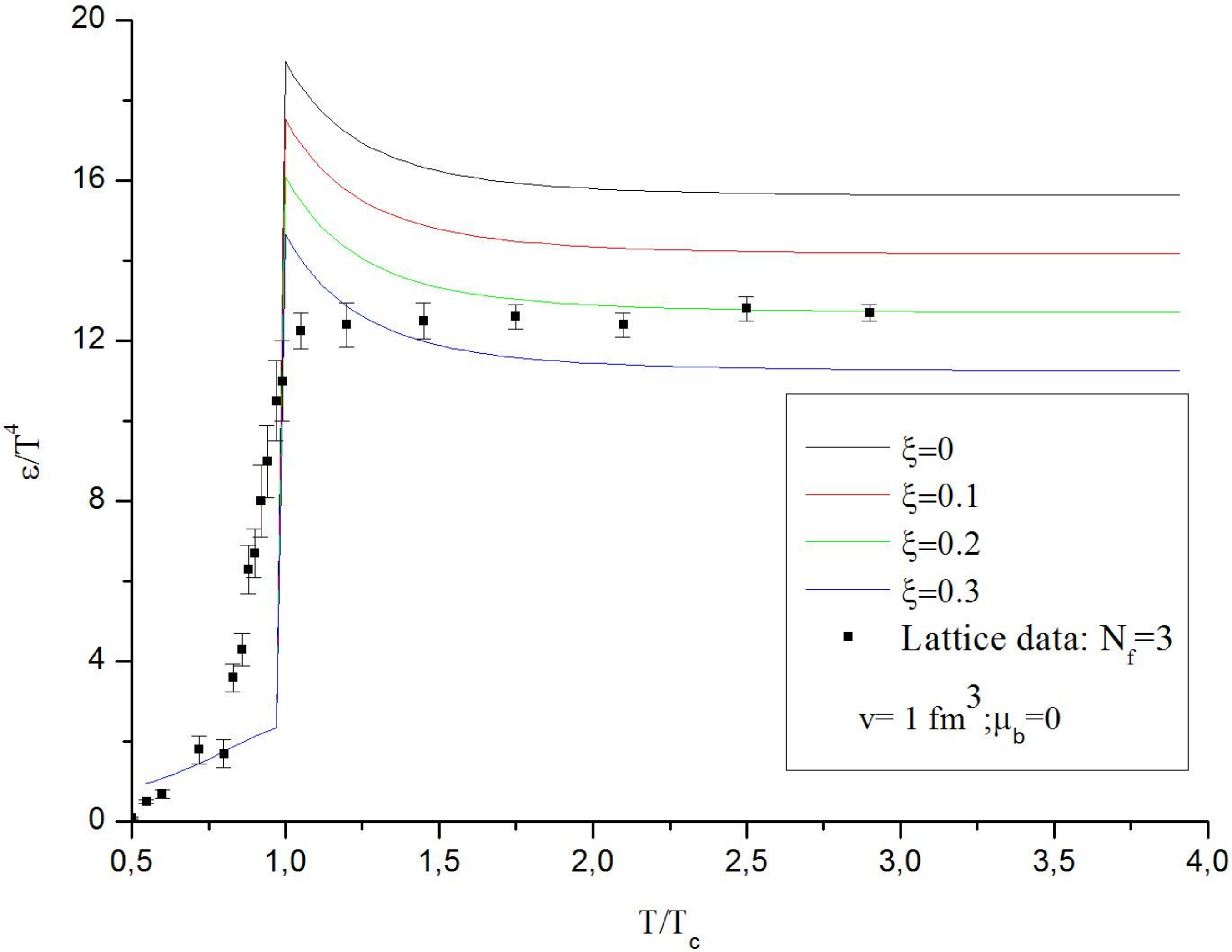
$B = 344\ MeV/fm^3$

$m_s = 150\ MeV$

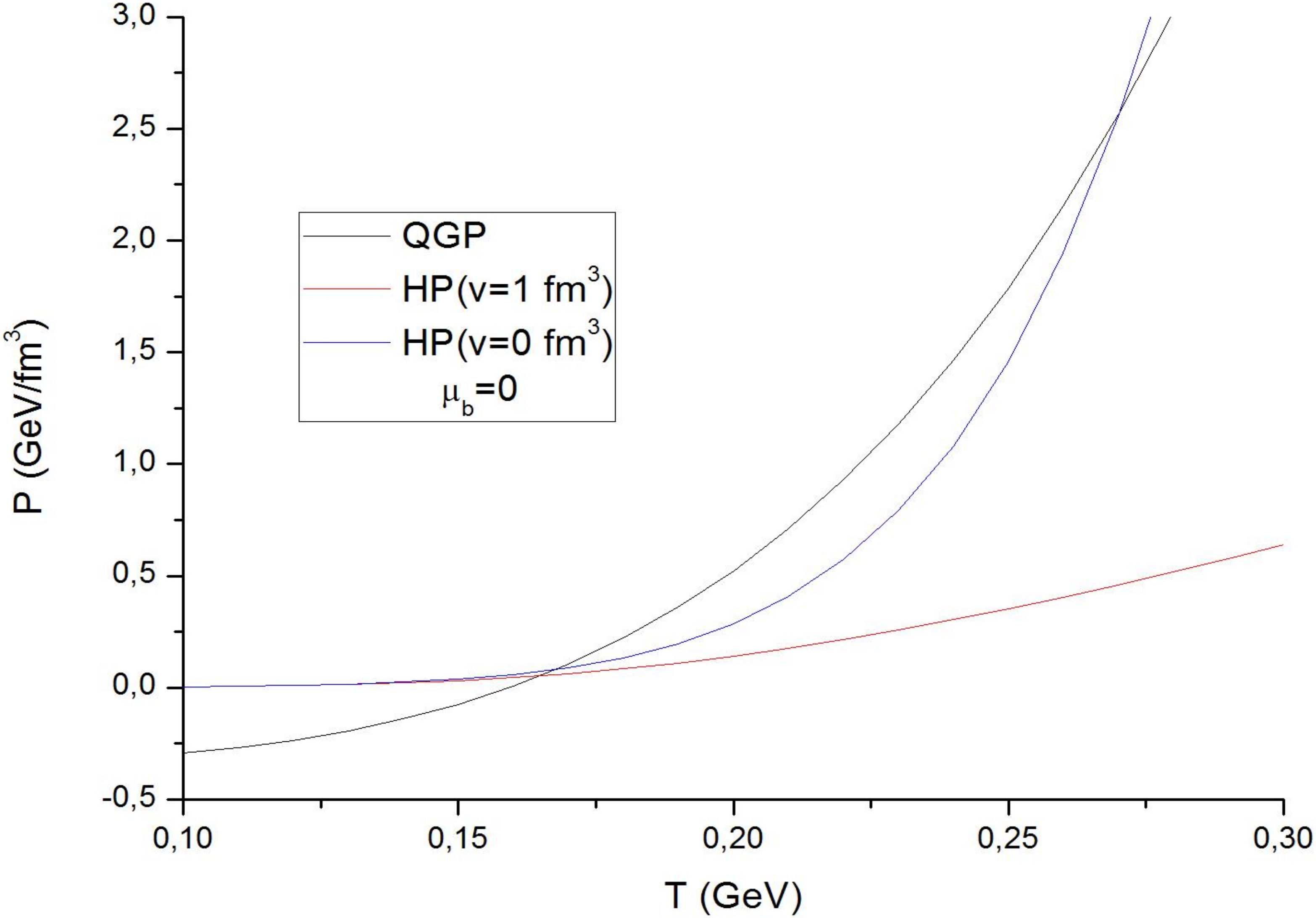
$\varepsilon = 0.2$

Satarov L.,M., Mishustin I.,N., Merdeev A.,V., Stocker H. Phys. Rev. C. 2007. V.,75. P.,024903.

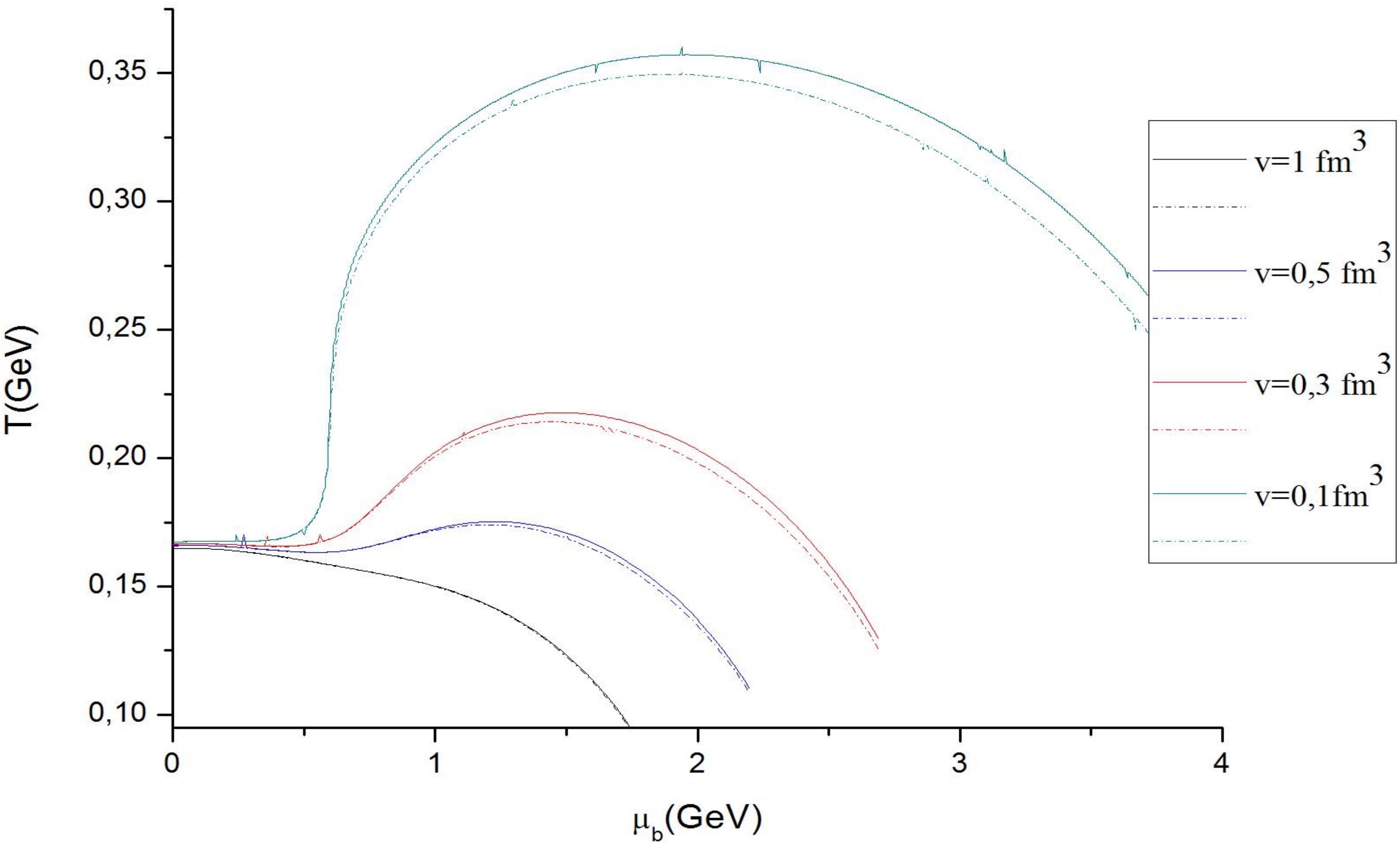
Defining model parameters according to lattice results



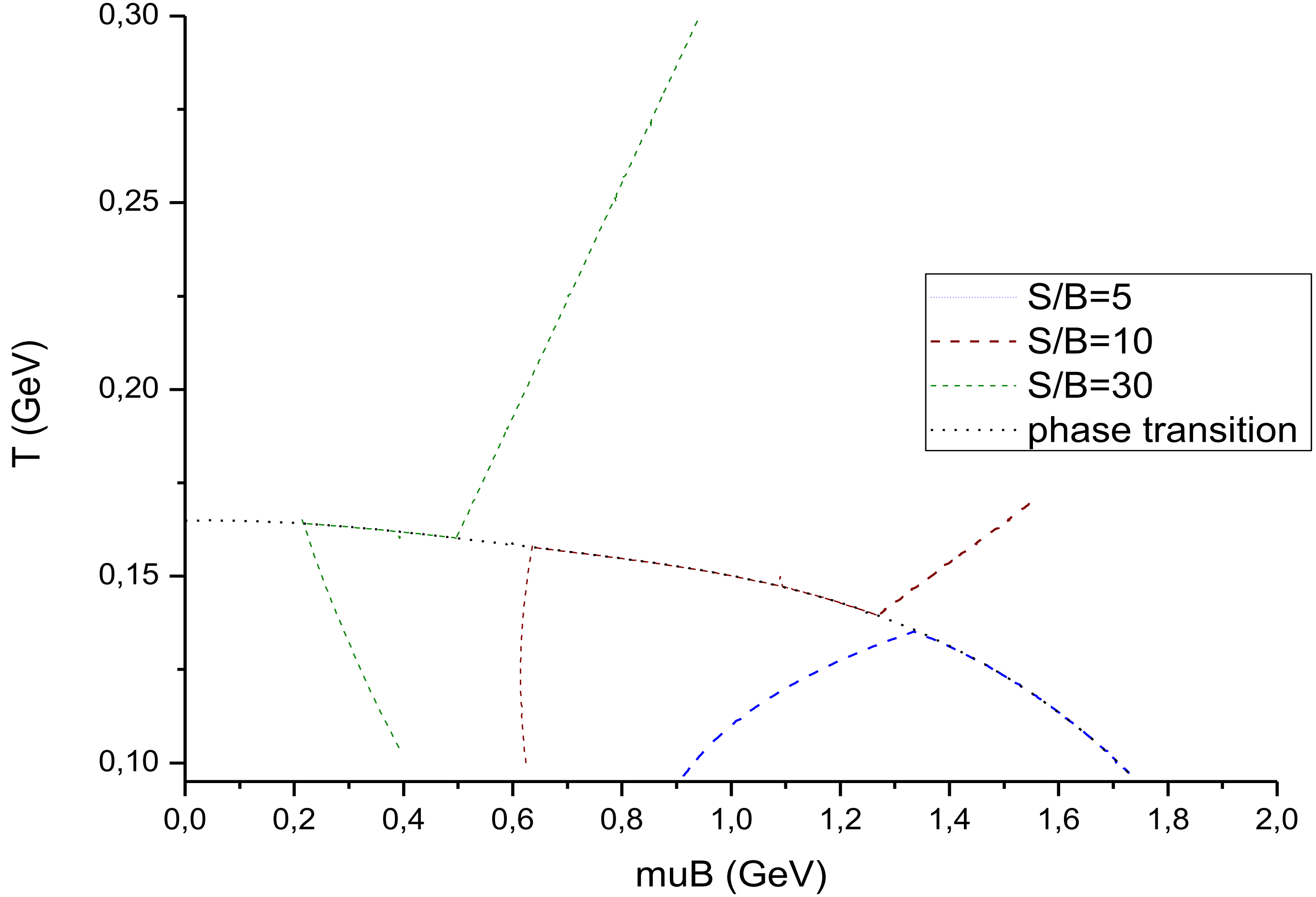
Pressure in different phases



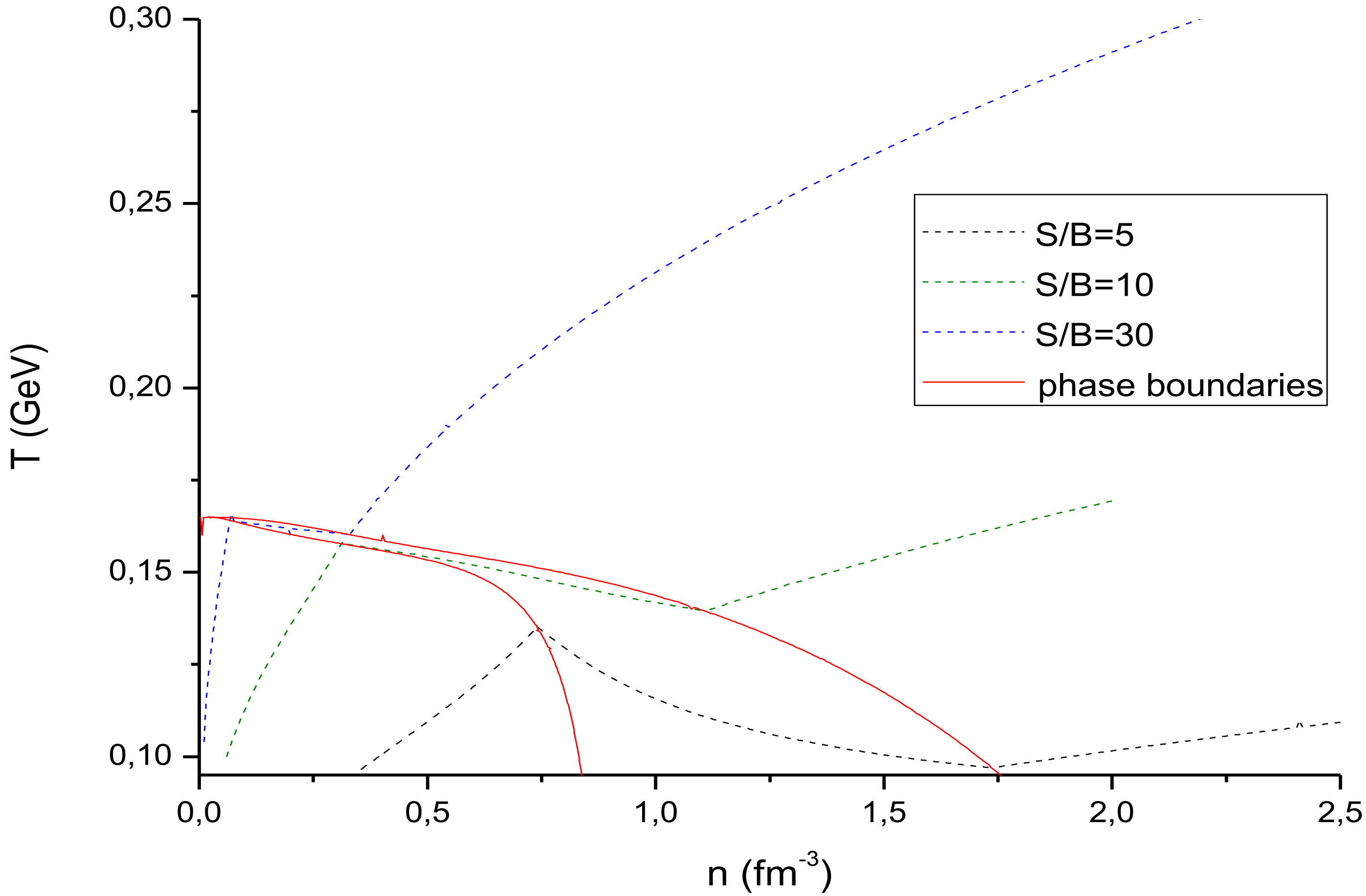
Phase diagram in baryon chemical potential-temperature plane



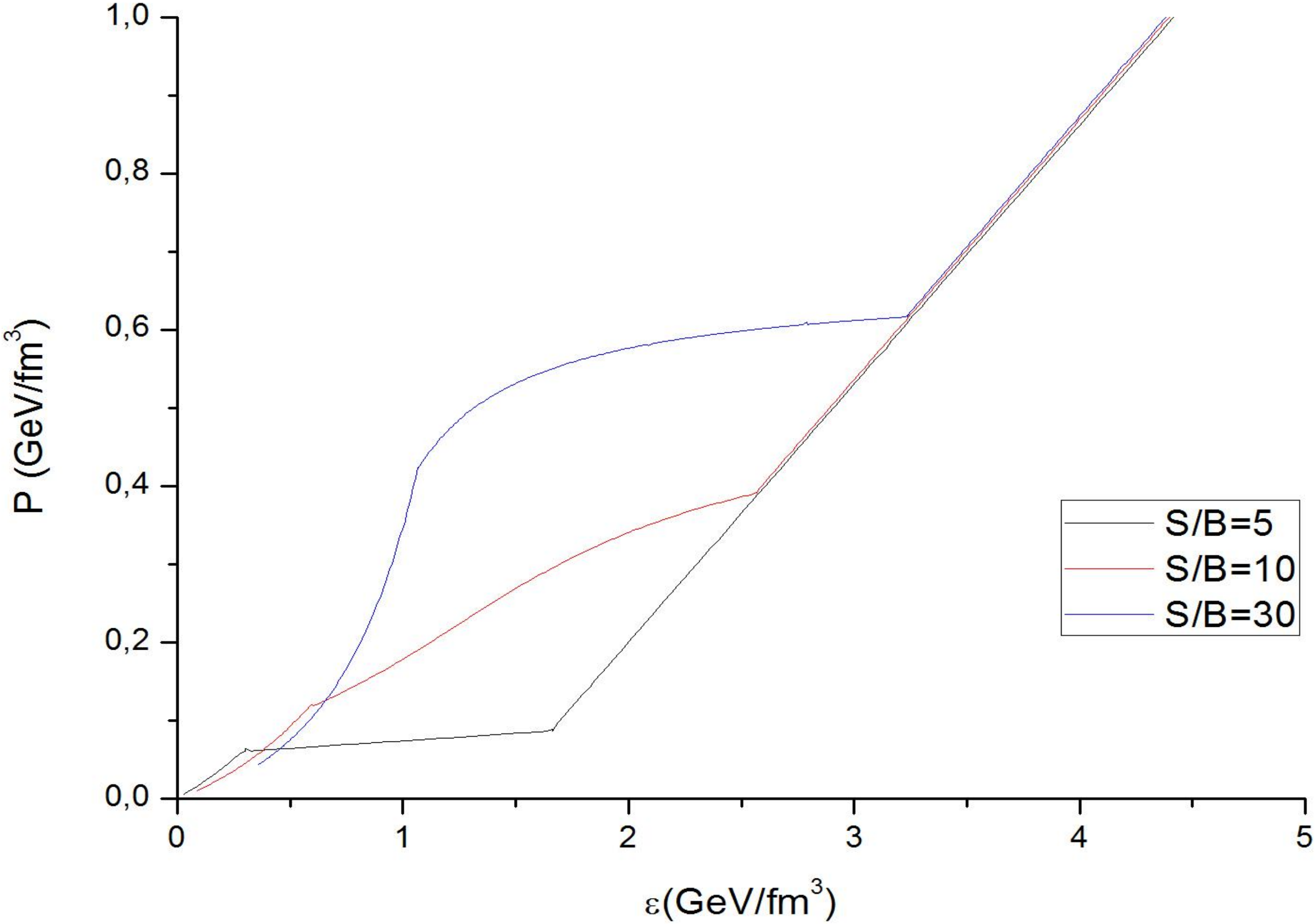
Isoentropes S/B=const



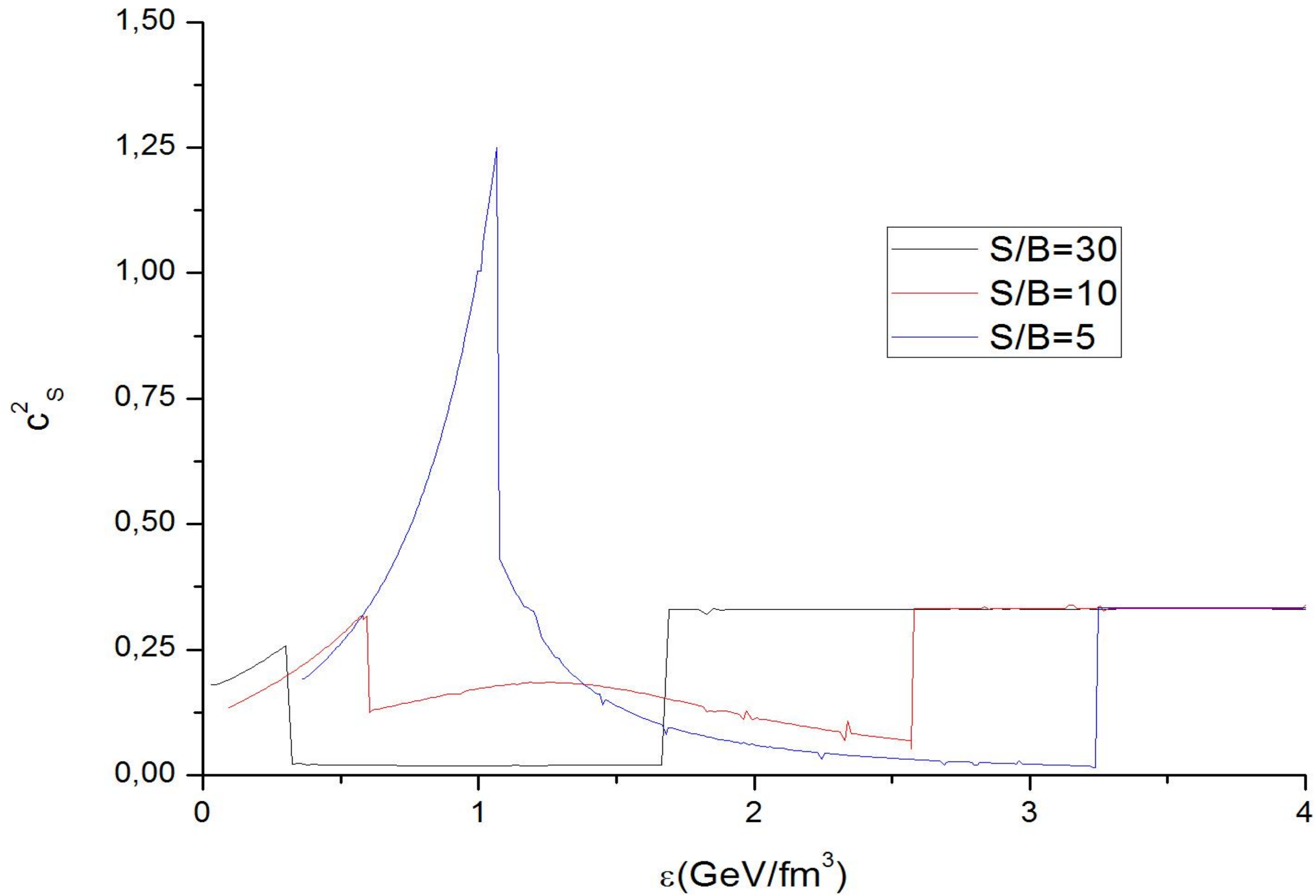
S/B=const in baryon density- temperature plane



Isoentropes S/B=const energy density-pressure plane



Isoentropes S/B=const



Results

- Calculating equation of state for HP(BS,BSQ approach) and QGP phase
- Comparing model results for multiplicity ratio in HP for BS and BSG approach
- Calculating phase diagram