Probing the QCD phase diagram with the chemical potentials

A D P, P. Katsas
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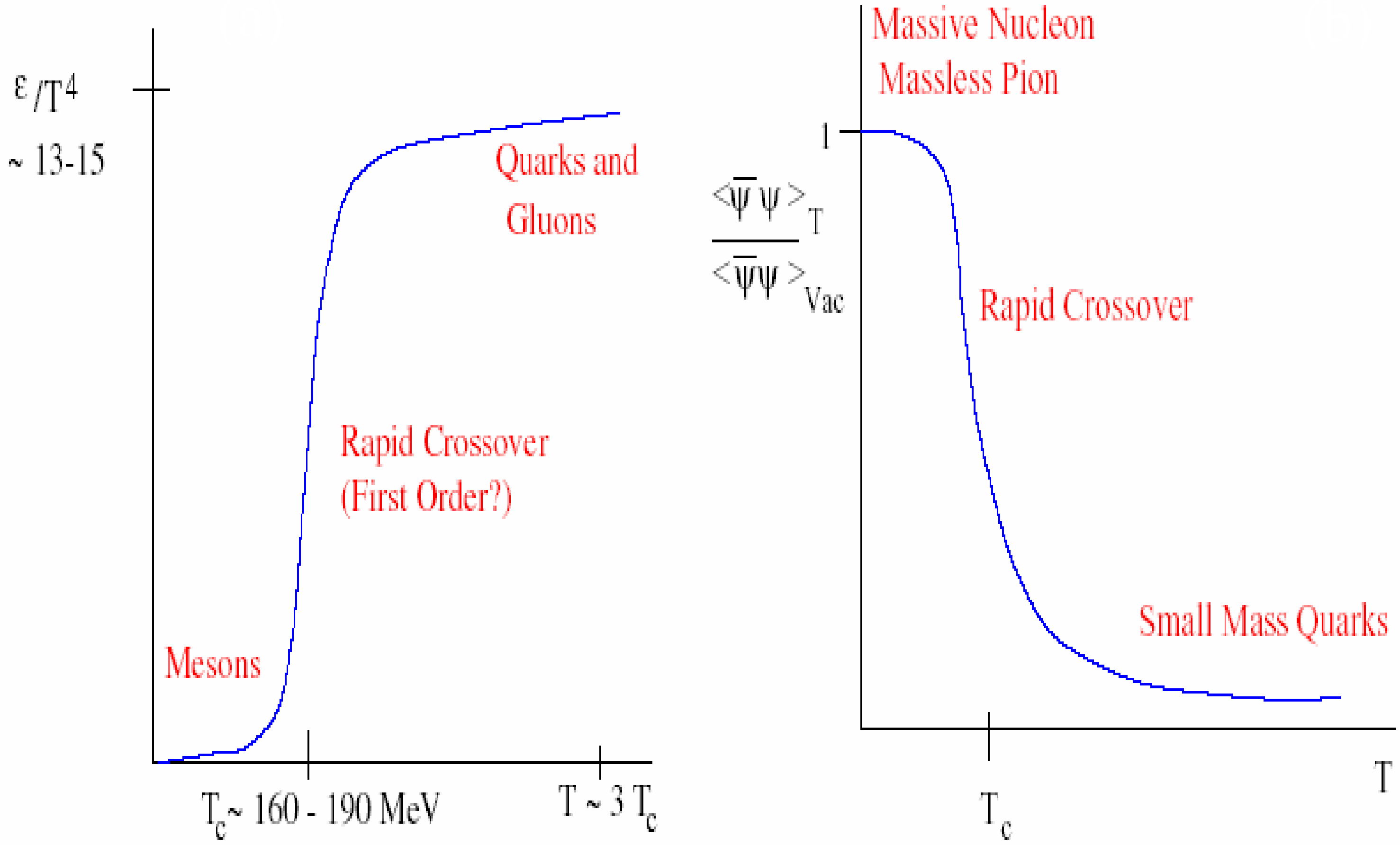
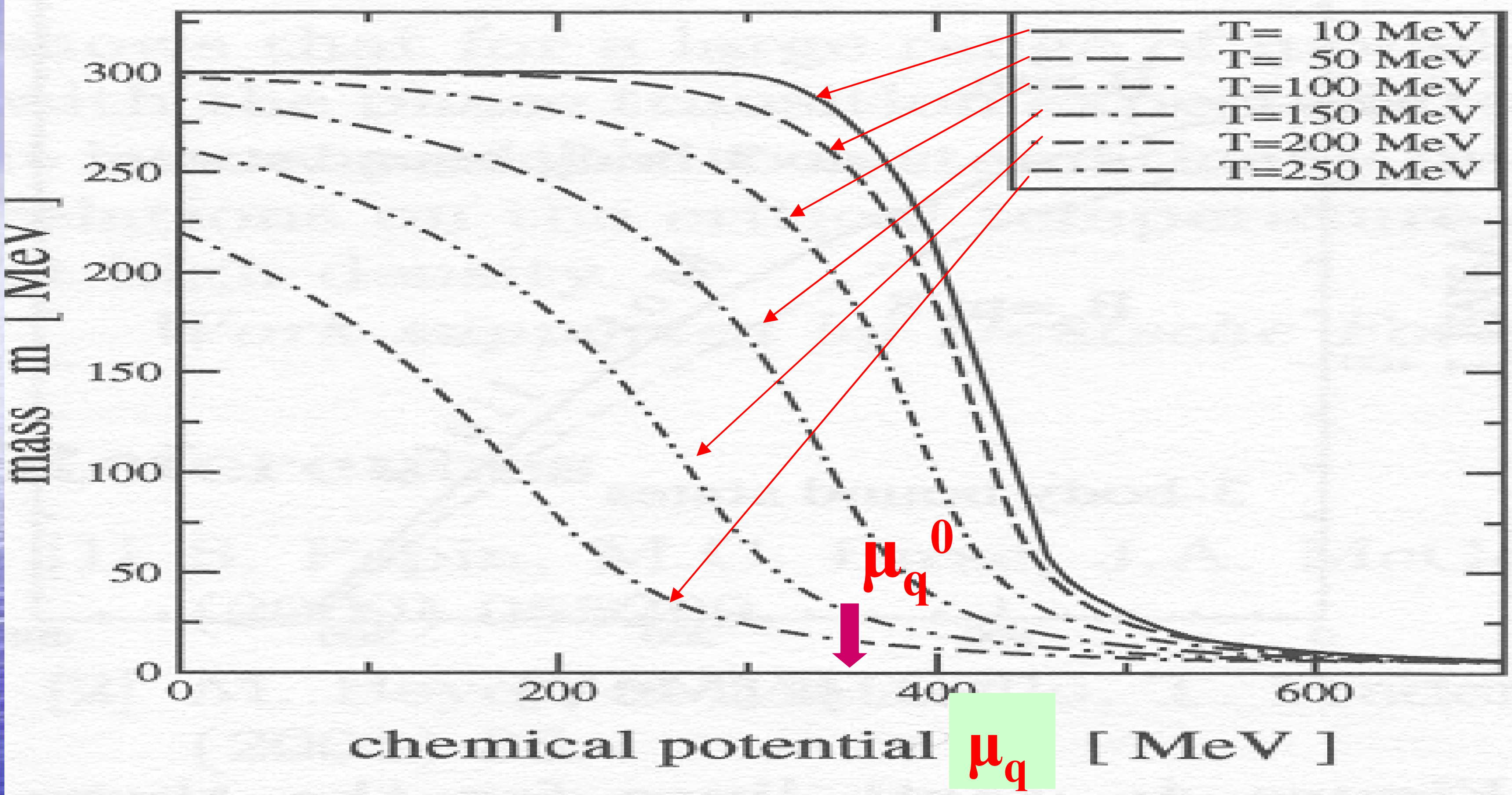


(a)The energy density vs temperature. (b) The chiral condensate vs T. Both plots are at zero baryon number density.

McLerran, hep-ph/0202025

Variation of Quark mass with μ_q (N-J-L)



Dependence of the q mass on the (quark) chemical potential and temperature.

Beyer, Mattiello, Frederico, Weber (2000)

♦ Existence of an intermediate region of deconfined, interacting and massive quarks, the Decofined Quark Matter "DQM" region.

Hadronic Matter	⟷	DQM	⟷	Ideal QGP
m_q, $a_s(T) \sim 1$		$m_q^*(T)$, $1 > a_s(T) > 0$		m_q^0, $a_s(T_\chi) \rightarrow 0$
		$T_d < T < T_\chi$		

The ONLY assumption is that m_q scales with temperature in the DQM region.

Actually, m_q is a function of T, μ_q not only in the DQM region, but also in very dense nuclear matter

(G.E. Brown, M. Rho)

Effective Masses in DQM Region

- "Effective quark" mass:

$$m_q^*(T) = R_\chi(T)(m_q - m_q^o) + m_q^o,$$

where $\underline{R_\chi(T) = 1 \rightarrow 0}$, as $T = T_d \rightarrow T_x$ $[R_\chi(T) \sim \alpha_s(T)]$

$m_q(m_q^o)$ is the constituent(current) quark mass, respectively

Approximate using mass-scaled partition function: **$\ln Z_{QGP}^*$**

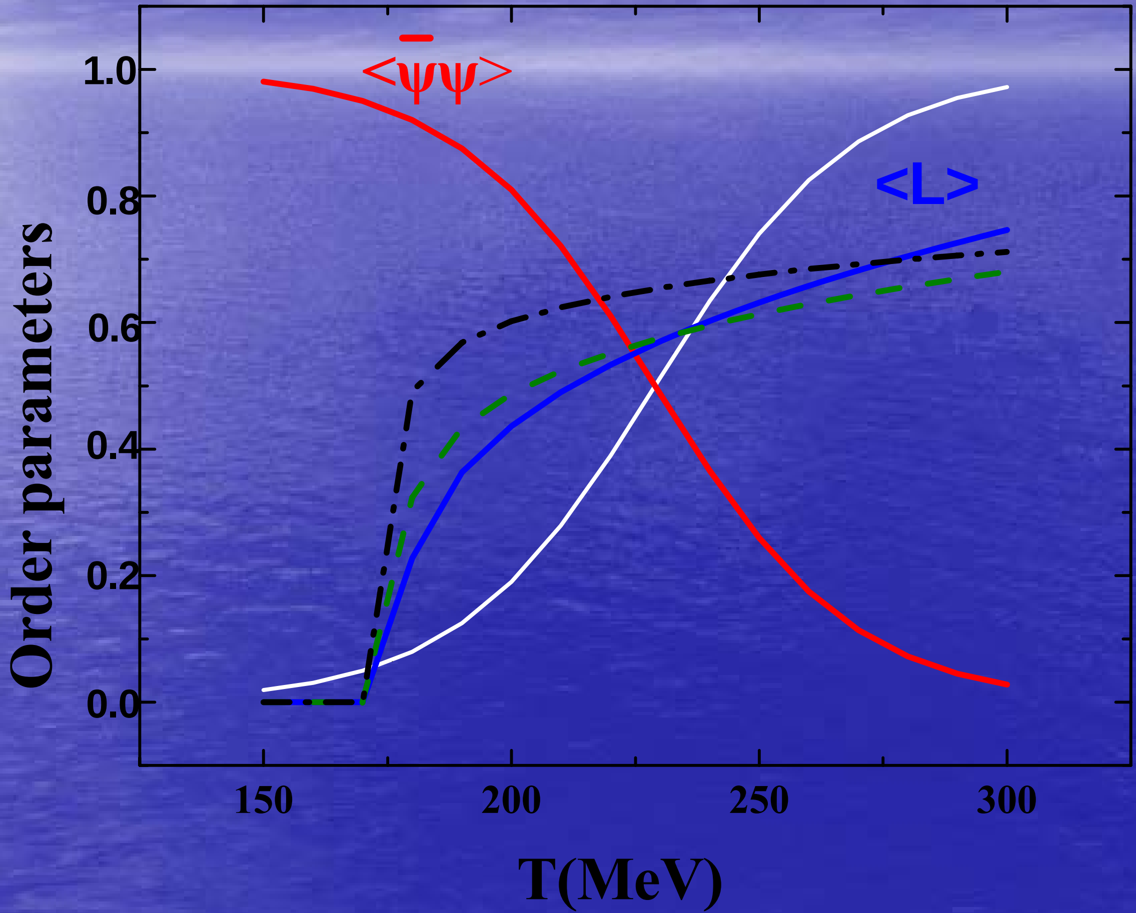
- "Effective hadron" mass:

$$m_j^*(T) = R_\chi(T)(m_j - m_j^o) + m_j^o,$$

m_j^o is equal to the sum of hadron's current-mass quarks.

Approximate using mass-scaled partition function: **$\ln Z_{HG}^*$**

Approximated Order Parameters



Empirical EoS of DQM region

$$\ln Z_{DQM}(V,T,\lambda) \sim R_\chi(T,\mu_q)\, \ln Z_{HG}^{*}(V,T,\lambda) + [1-R_\chi(T,\mu_q)]\, \ln Z_{QGP}^{*}(V,T,\lambda)$$

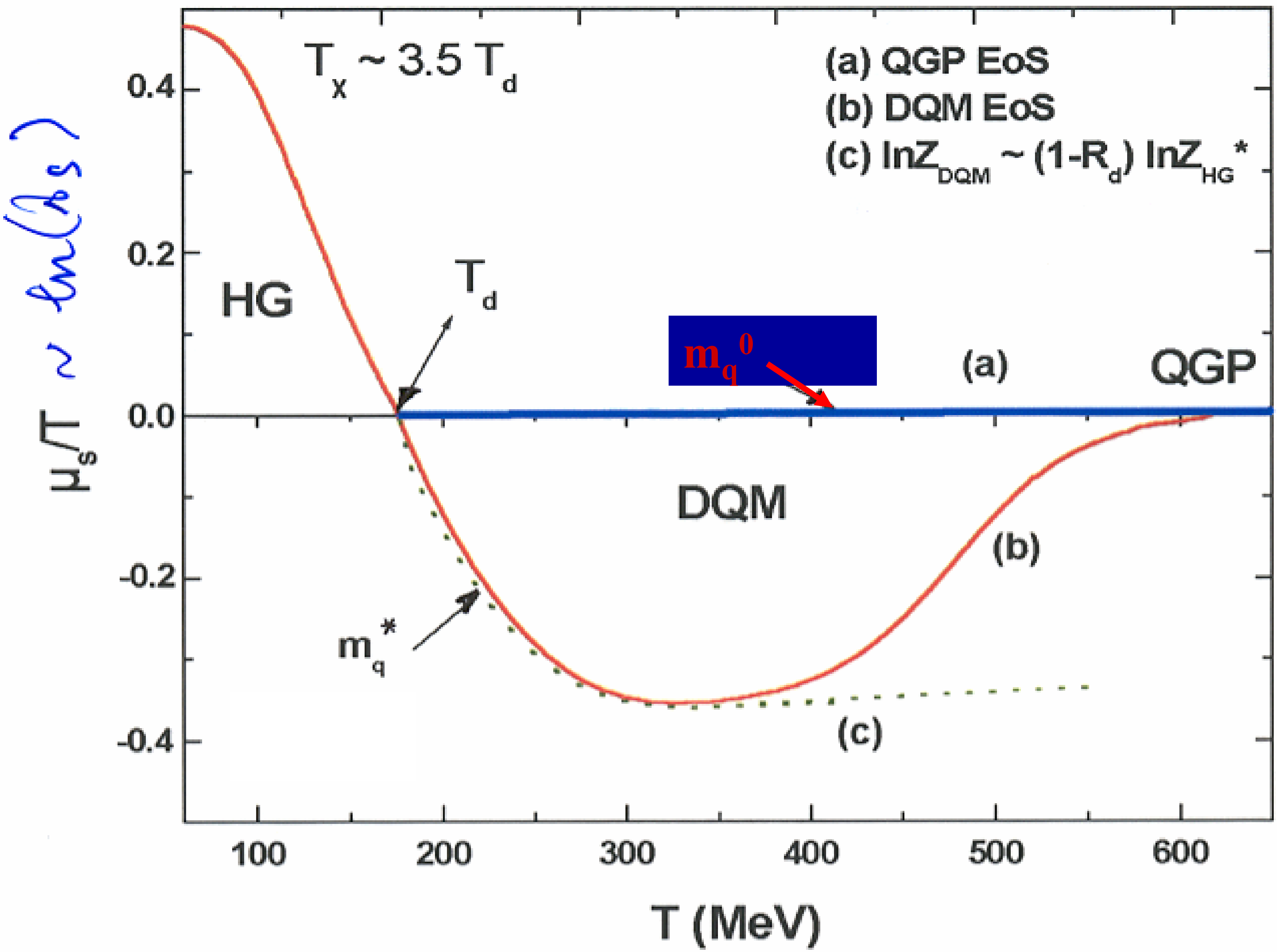
Includes T-dependent factor R_χ and mass-scaled EoS in HG and QGP phases. Has desired asymptotic behaviour at HG & ideal QGP regions.

Strangeness conservation:

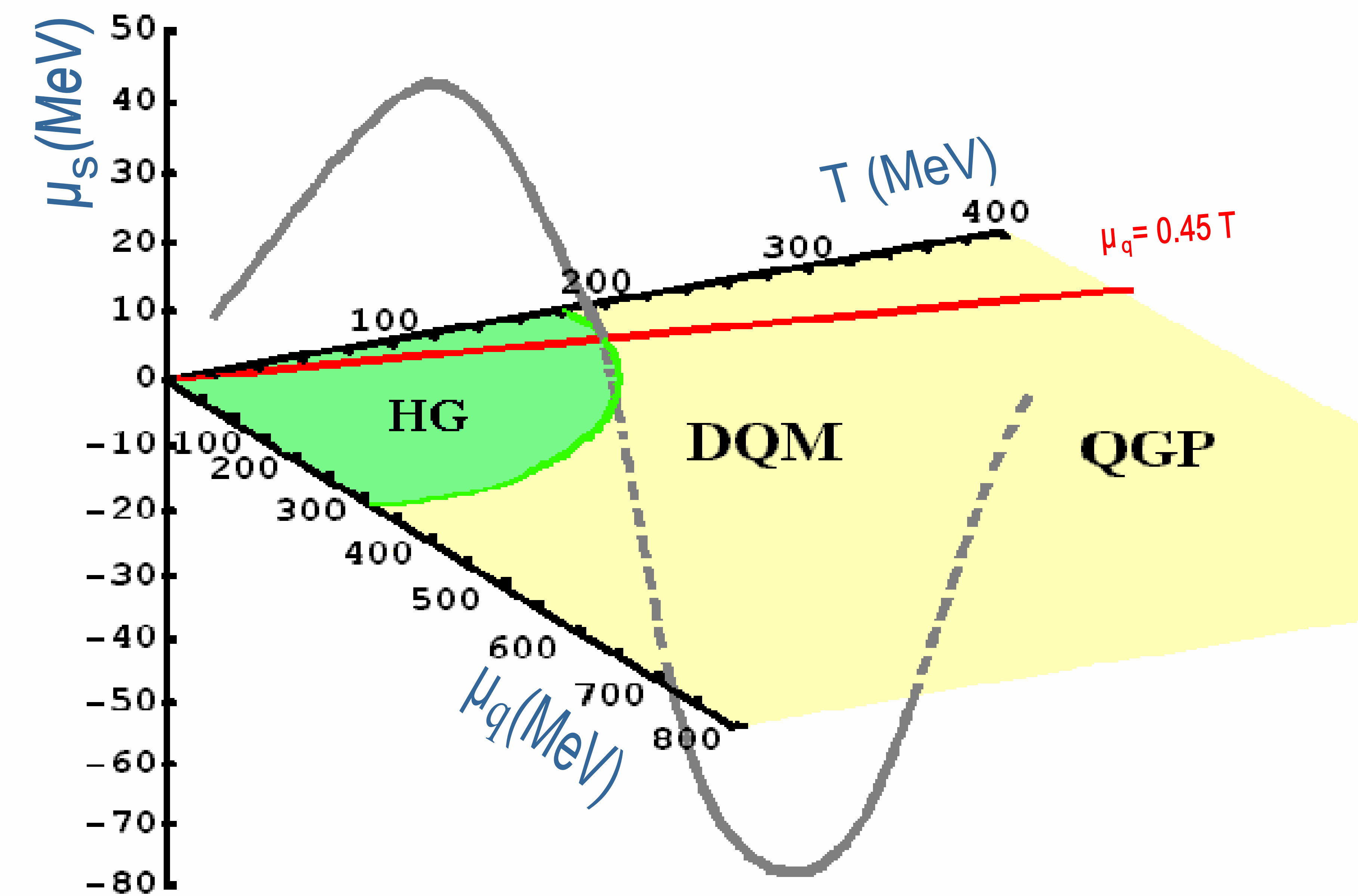
$$R_\chi(T,\mu_q)[Z_K^{*}(\lambda_s \lambda_q^{-1} - \lambda_s^{-1} \lambda_q) + Z_Y^{*}(\lambda_s \lambda_q^{2} - \lambda_s^{-1} \lambda_q^{-2})$$

$$+ 2Z_\Xi^{*}(\lambda_s^{2} \lambda_q - \lambda_s^{-2} \lambda_q^{-1}) + 3Z_\Omega^{*}(\lambda_s^{3} - \lambda_s^{-3})]$$

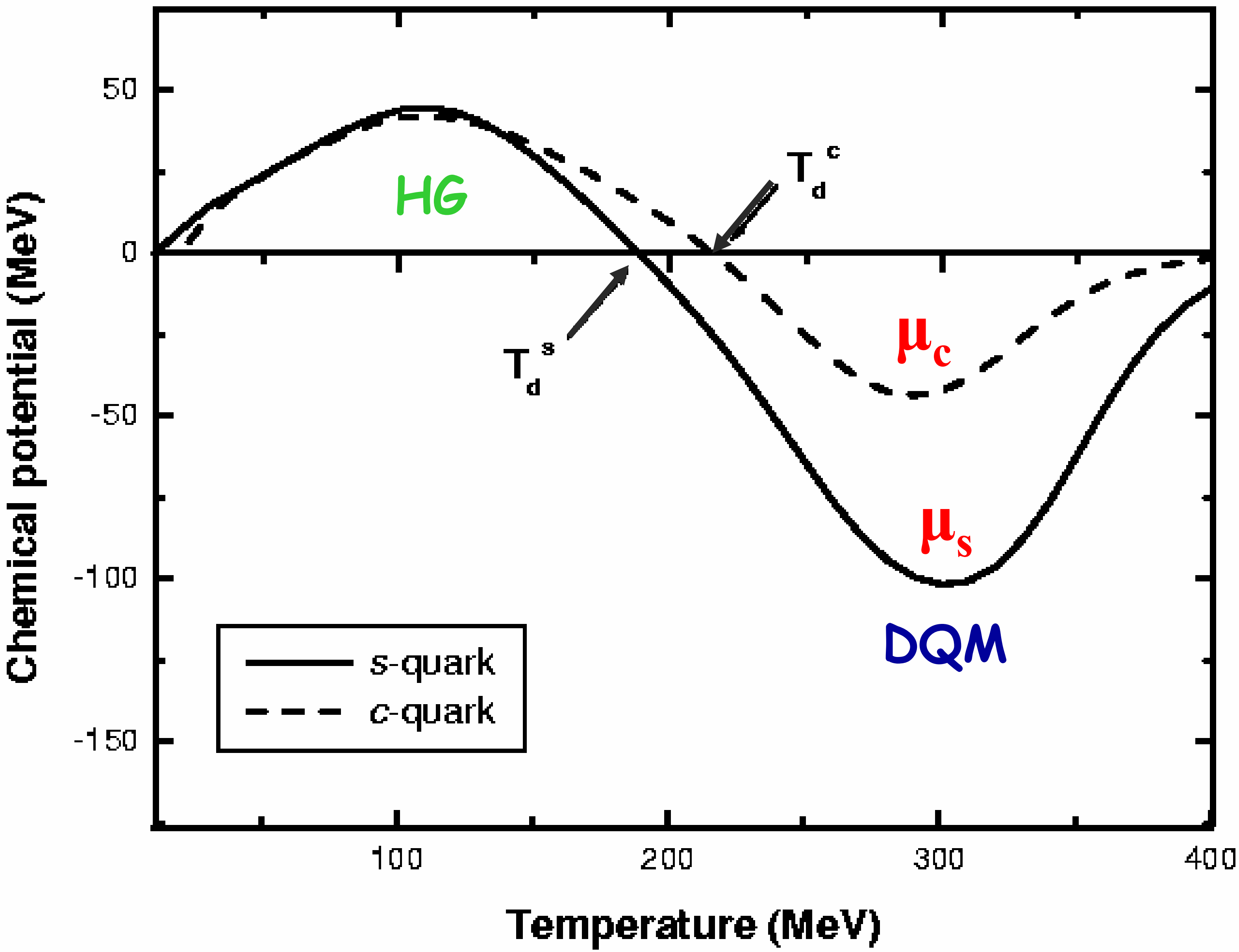
$$+ [1-R_\chi(T,\mu_q)]\, g_s\, m_s^{*2} K_2(m_s^{*}/T)(\lambda_s - \lambda_s^{-1}) = 0$$

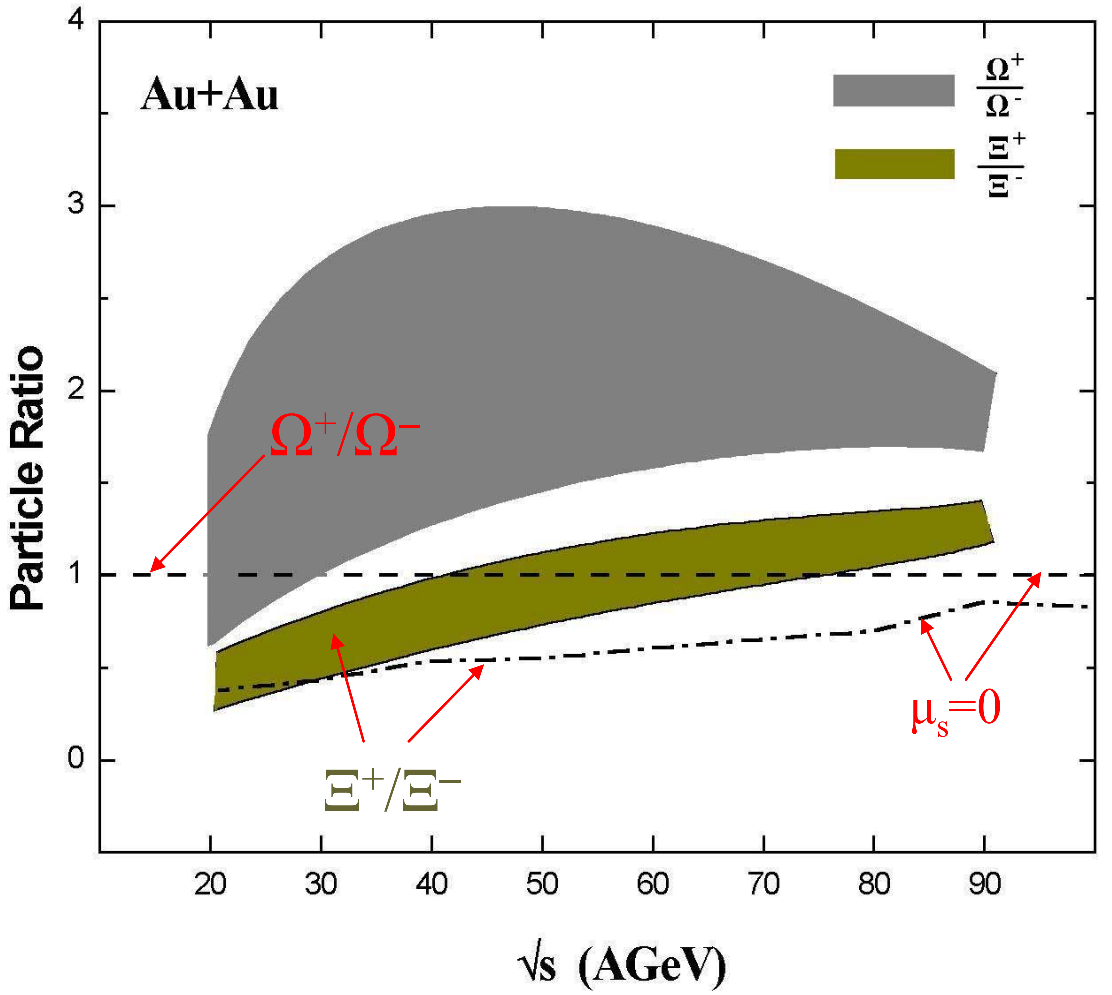


Tχ ~ 3.5 Td
(a) QGP EoS
(b) DQM EoS
(c) lnZDQM ~ (1-Rd) lnZHG*
HG
Td
mq0
(a)
QGP
DQM
(b)
mq*
(c)
μs/T ~ ln(λs)
0.4
0.2
0.0
-0.2
-0.4
100
200
300
400
500
600
T (MeV)

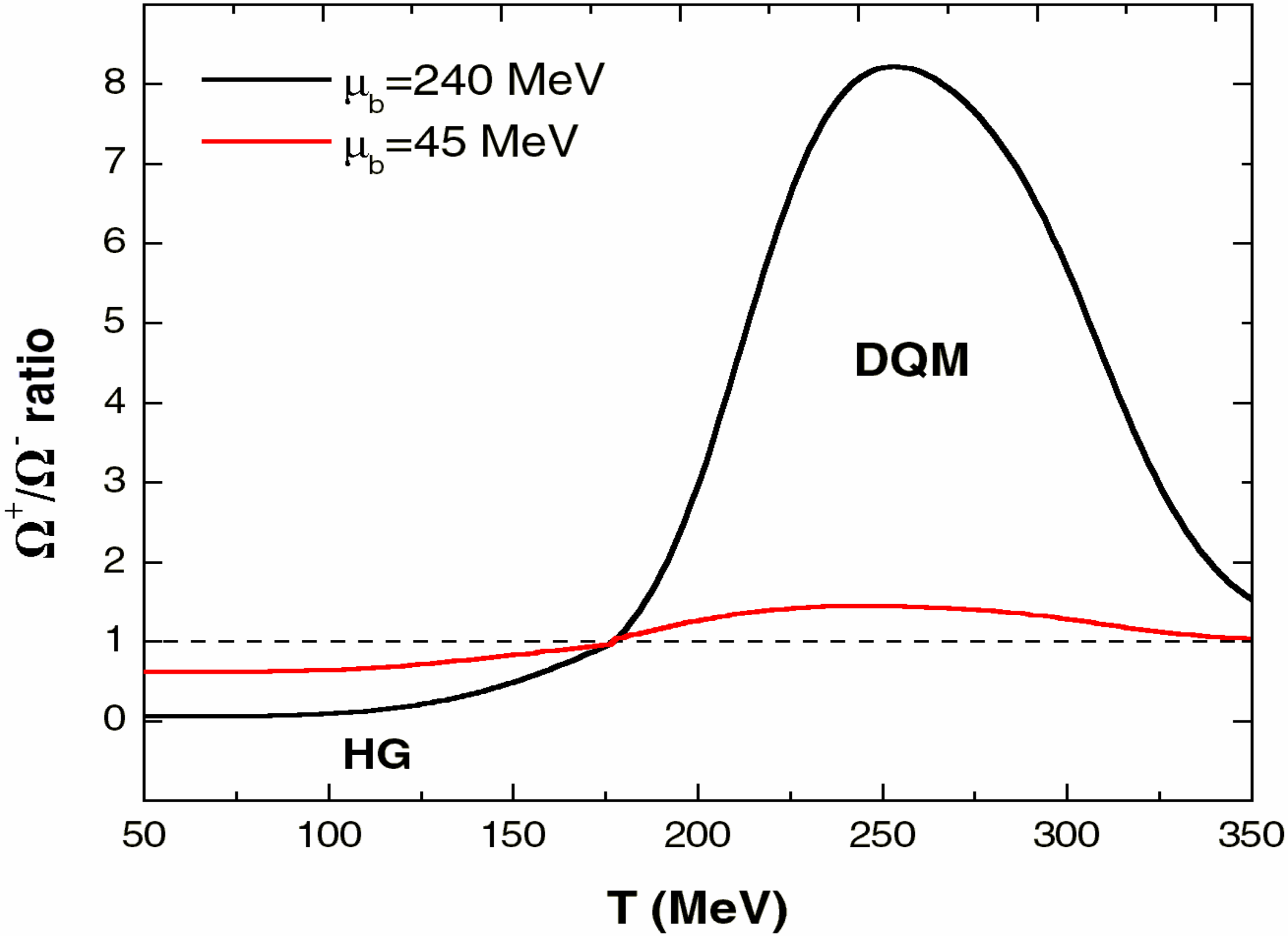

μS(MeV)
50
40
30
20
10
0
−10
−20
−30
−40
−50
−60
−70
−80
T (MeV)
100
200
300
400
μq= 0.45 T
HG
DQM
QGP
μq(MeV)
100
200
300
400
500
600
700
800

Heavy Quark Chemical Potential



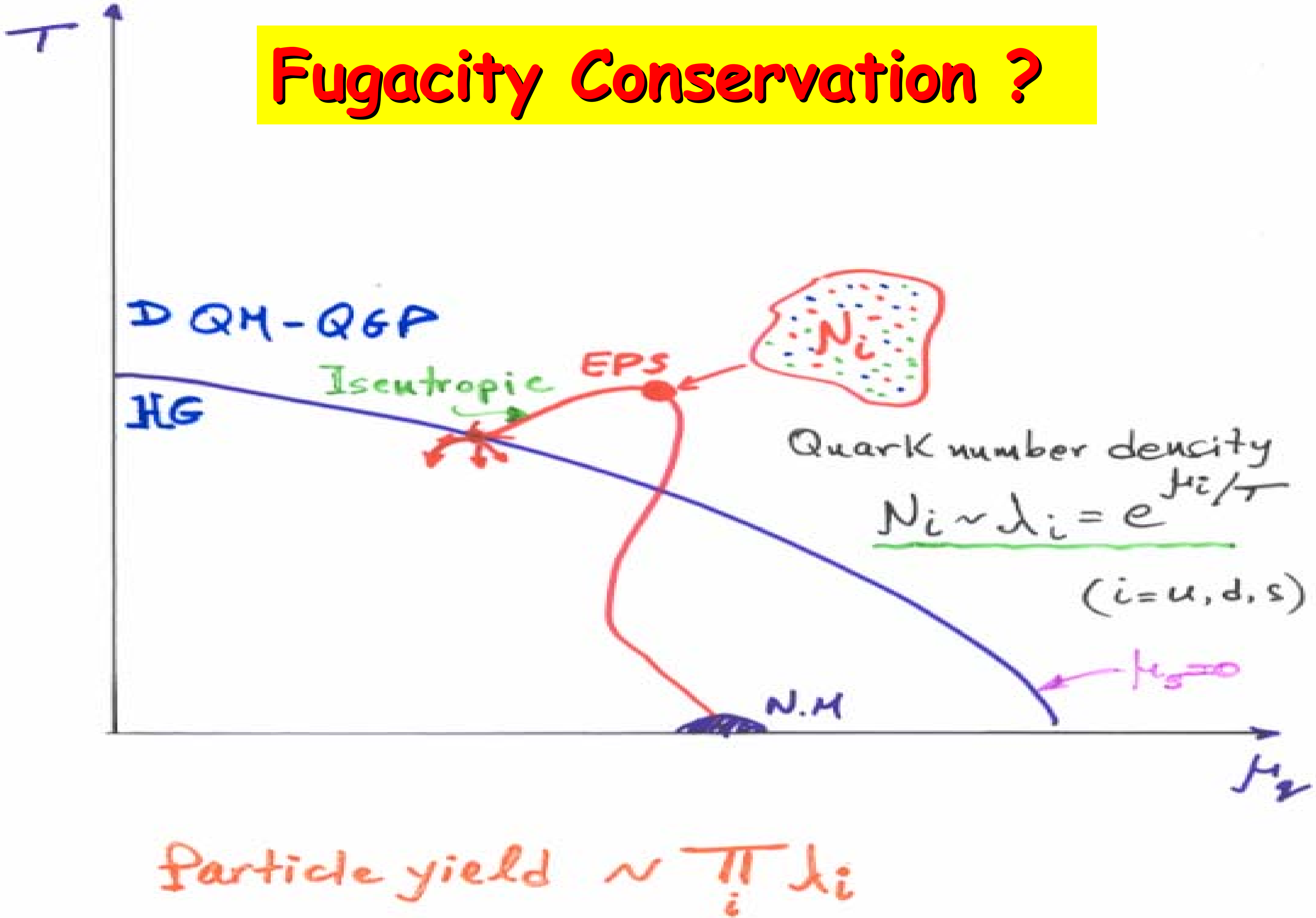


Au+Au
Ω+/Ω-
Ξ+/Ξ-
μs=0
Particle Ratio
4
3
2
1
0
20
30
40
50
60
70
80
90
√s (AGeV)



μ_b=240 MeV
μ_b=45 MeV
DQM
HG
Ω^+/Ω^- ratio
T (MeV)
0
1
2
3
4
5
6
7
8
50
100
150
200
250
300
350

Fugacity Conservation ?



Conclusions

- Strange quark chemical potential is:

Positive in the Hadronic phase & Zero at the end.

Negative in the DQM region.

Zero at the chirally symmetric QGP phase.

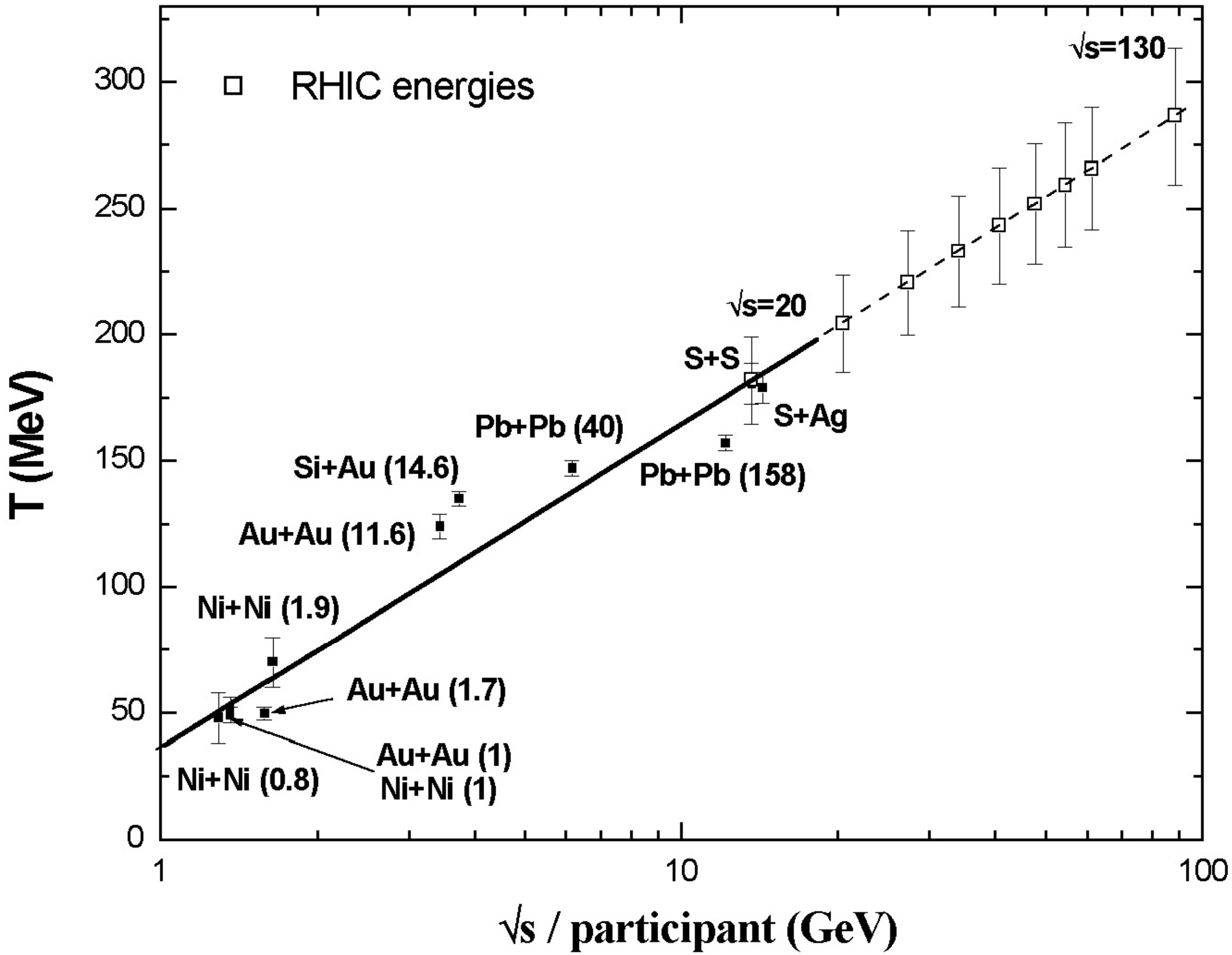
- Proposal:

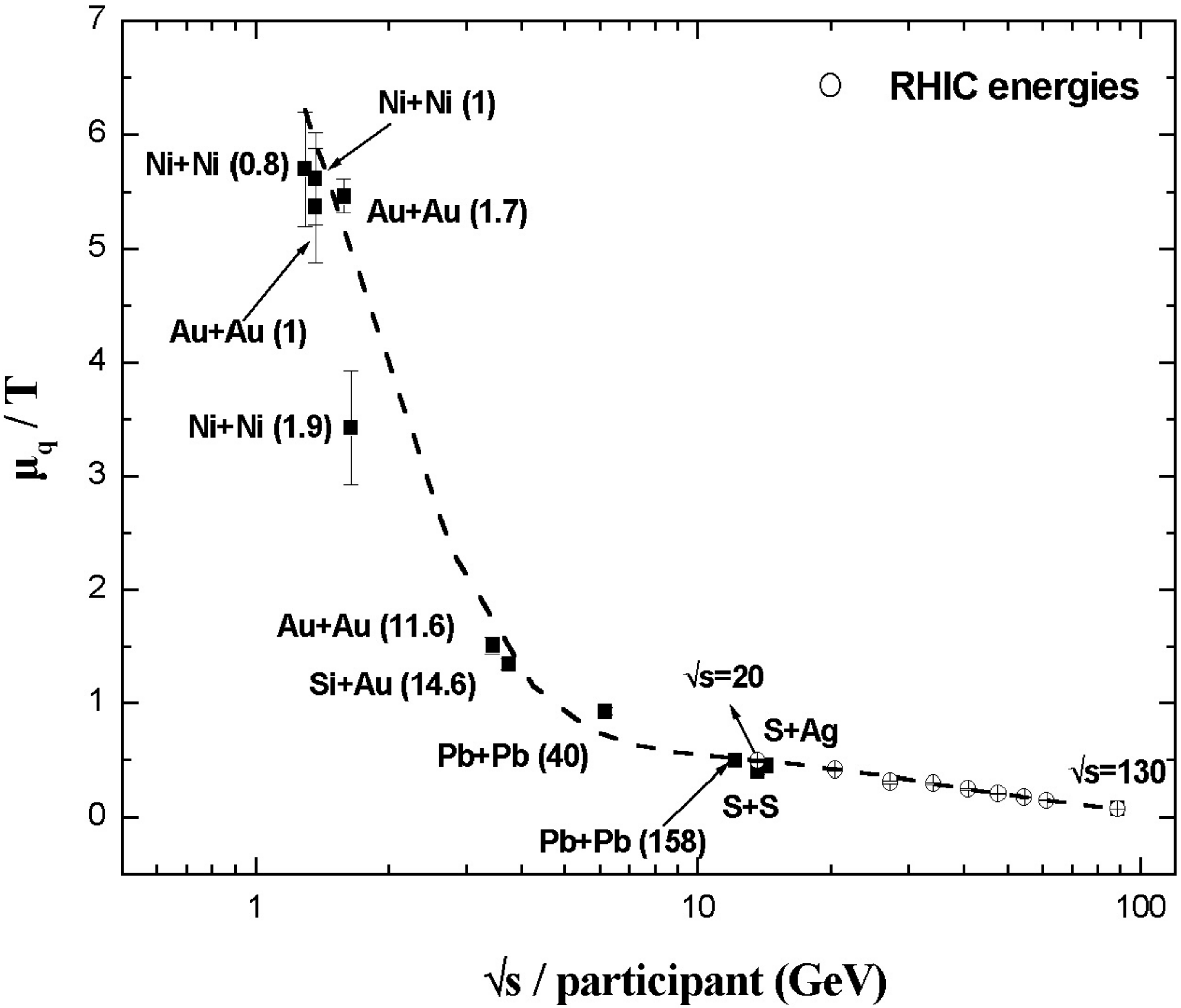
"The change of μ_s is a unique indication of the quark-deconfinement phase transition in nuclear matter".

μ_s is potentially an experimentally accessible parameter, provided that fugacity is conserved, obtainable from particle yield ratios, e.g.

$$\Omega^+/\Omega^- = \exp(-6\mu_s/T)$$

“Fireball” Temperature





RHIC energies
Ni+Ni (1)
Ni+Ni (0.8)
Au+Au (1.7)
Au+Au (1)
Ni+Ni (1.9)
Au+Au (11.6)
Si+Au (14.6)
Pb+Pb (40)
√s=20
S+Ag
√s=130
S+S
Pb+Pb (158)
μq / T
√s / participant (GeV)