EFFECT OF MAGNETIC FIELD ON QGP EQUATION OF STATE

YOGESH KUMAR

Department of Physics
Deshbandhu College, University of Delhi
Delhi, India

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OUTLINE

INTRODUCTION

MOTIVATION

RESULTS

CONCLUSION

Two unusual properties of quarks

Asymptotic Freedom:

Its essence is that: At small ranges ($< 10^{-16}$ m) the quark-quark forces are negligible. In accordance with uncertainty principle this means that quarks behave as free particles at relativistic momenta.

Confinement:

Its essence is that: The potential energy of quark-quark interaction rises infinitely with distance, such an increase being so rapid that two quarks cannot be separated beyond the radius of a hadron.

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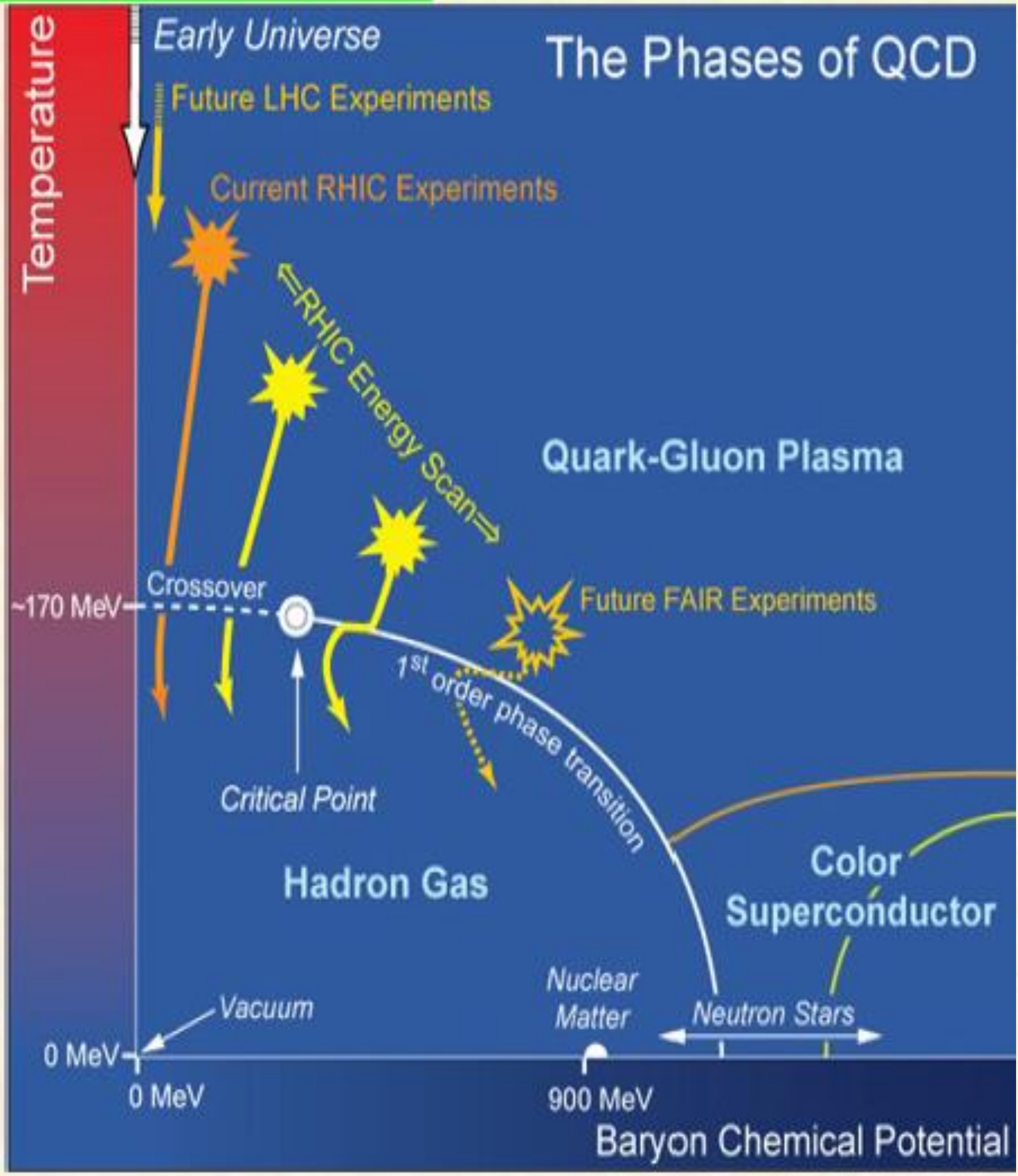
Phase Diagram of QCD

A new phase of matter called the Quark Gluon Plasma (QGP)

QGP $\equiv$ ***a (locally) thermally equilibrated state of matter in which quarks and gluons are deconfined from hadrons, so that color degrees of freedom become manifest over nuclear, rather than merely nucleonic, volumes.***



MOTIVATION AND WORK

- At present a rigorous QCD treatment of the QGP is almost impossible, given the complexity of the physical system involved.

- However, the existence of a QGP can be theoretically inferred through lattice gauge simulations of QCD, which provide the only rigorous method to compute the QCD equation of state. These simulations predict a phase transition of confined hadronic matter to a deconfined state of hadrons.

- In the meanwhile, a number of papers using some phenomenological models have appeared over the past decade investigating the phase transition between hadronic and QGP phases.

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- **It is fine to use the MIT bag model to describe the hadrons as bags of quarks, anti quarks and gluons, but to extend the idea to represent the phase boundary between the QGP droplet and the bulk hadronic medium makes one a bit uneasy.**

- **It is to remedy this rather unnatural assumption, i.e. the confining bag of the hadrons has the same property as the interface separating the two phases, we propose an alternative model to represent the same physical situation.**

- **Another drawback of the MIT bag model is its disagreement with "numerical experiments" using lattice gauge pure SU(3) simulation. As pointed out by Peshier et al., the simulation "data" is satisfied only by a bag pressure** $p = ae - 4B/3$ **,with** $a = 0.297$ **(not** 1/3 **as for MIT bag Model), where 'e' is the energy density and** $B^{1/4} = 205 MeV$ **for the bag constant.**

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- **Simple statistical model for analysis of QGP droplet (fireball) formation and EoS of QGP (PRC 70, 027903(2004), PJP 68,757 (2007))**

- **In our present work we use the statistical tools to extract some knowledge about the formation and evolution of the quark gluon plasma. Here we basically used the statistical model developed by Ramanathan and Kumar et al.**

- **Since the model depends crucially on the nature of the effective semi-phenomenological QCD oriented potential (mean field potential) between quarks that we extract from the large momentum approximation to the "thermal mass" introduced by Peshier et al. (PLB 337, 235 (1994)) and adopt their phenomenological parametrization in our scheme.**

- **The model has its merits in its simplicity and robustness to give a qualitative and quantitative idea about QGP.**

we construct the density of states using methods analogous to the Thomas–Fermi model (ZFP 48, 73 (1928)) for the atoms and the Bethe model (RMP 9, 691937) for the nucleons as

$$\rho_{q,g}(k)=\left(\frac{\upsilon}{\pi^2}\right)\left\{\left(-V_{eff}(k)\right)^2\left(\frac{-dV_{eff}}{dk}\right)\right\}_{q,g}$$

where effective potential $\left(V_{eff}(k)\right)$ is considered as:

,

$$V_{eff}(k)=\left(\frac{1}{2k}\right)\gamma_{q,g}\,g^2(k)T^2$$

Known as mean field effective potential among the quarks-gluons.

The above potential is a result of the use of a thermal Hamiltonian for the Quark-Gluon system.

we have used $\gamma_q = \frac{1}{6}$ and $\gamma_g = 6\gamma_q$ or $\gamma_g = 8\gamma_q$. The choice of these parameters motivates from the fact that they exhibit the formation of most stable QGP droplet.

In the effective thermal potential, g(k) is the first order running coupling constant given as,

$$g^2(k) = \left(\frac{4}{3}\right)\left(\frac{12\pi}{27}\right)\left[\frac{1}{\ln\left(1+\frac{k^2}{\Lambda^2}\right)}\right]$$

So in this statistical model we have an advantage that it has a natural low momentum cut-off leading to finite results hence avoiding any infra-red divergence,

$$k_{\min} = \left(\frac{\gamma N^{1/3} T^2 \Lambda^2}{2}\right)^{\frac{1}{4}}$$

Here $\Lambda = 150\, MeV$ is the QCD parameter and N is $\left(\frac{4}{3}\right)\left(\frac{12\pi}{27}\right)$

where γ is introduced to take care the plasma (hydro-dynamical) nature of the droplet and it is chosen as:

$$\gamma = \sqrt{2} \times \sqrt{\left(\frac{1}{\gamma_q}\right)^2 + \left(\frac{1}{\gamma_g}\right)^2}$$

It is the inverse rms value of the flow parameter of the quarks and gluons.

The Weyl density of states is:

$$\rho_{Weyl}(k) = \left(\frac{4\pi R^2}{16\pi} \right) k^2$$

Where R is the radius of the droplet of QGP.

The basic idea here is to treat the QGP as composed of u,d,s quarks and gluons, confined in a volume 'v', outside the volume (which is assumed having spherical symmetry) pions are present. Our aim is to calculate the free energy of this whole system which can be used to calculate various thermodynamic quantities.

We compute the free energies in which we used the usual continuum expression for the system of non-interacting Fermions and Bosons:

$$F_i = \mp g_i T \int dk \rho_i(k) \ln\left[1 \pm e^{\frac{-\sqrt{m_i^2+k^2}}{T}}\right]$$

where for fermions we used upper sign and for bosons lower sign.

The interface is no longer assumed a MIT bag, and yet it has a contribution to free energy on account of the surface energy which is assumed to be scalar Weyl surface. Hence the interface free energy is taken as:

$$F_{\mathrm{int}\,erface} = \gamma T \int dk \rho_{weyl}(k) \delta(k-T)$$

$$F_{\mathrm{int}erface} = \frac{R^2 T^3 \gamma}{4}$$

Pion free energy is :

$$F_{\pi} = -\left(\frac{3T}{2\pi^2}\right)\upsilon\int_0^{\infty} k^2 dk \ln\left(1 - e^{\frac{-\sqrt{m_{\pi}^2 + k^2}}{T}}\right)$$

The total free energy (F) is given as:

$$F = F_i + F_{interface} + F_{\pi}$$

Here i stands for u,d,s (quarks) and gluon.

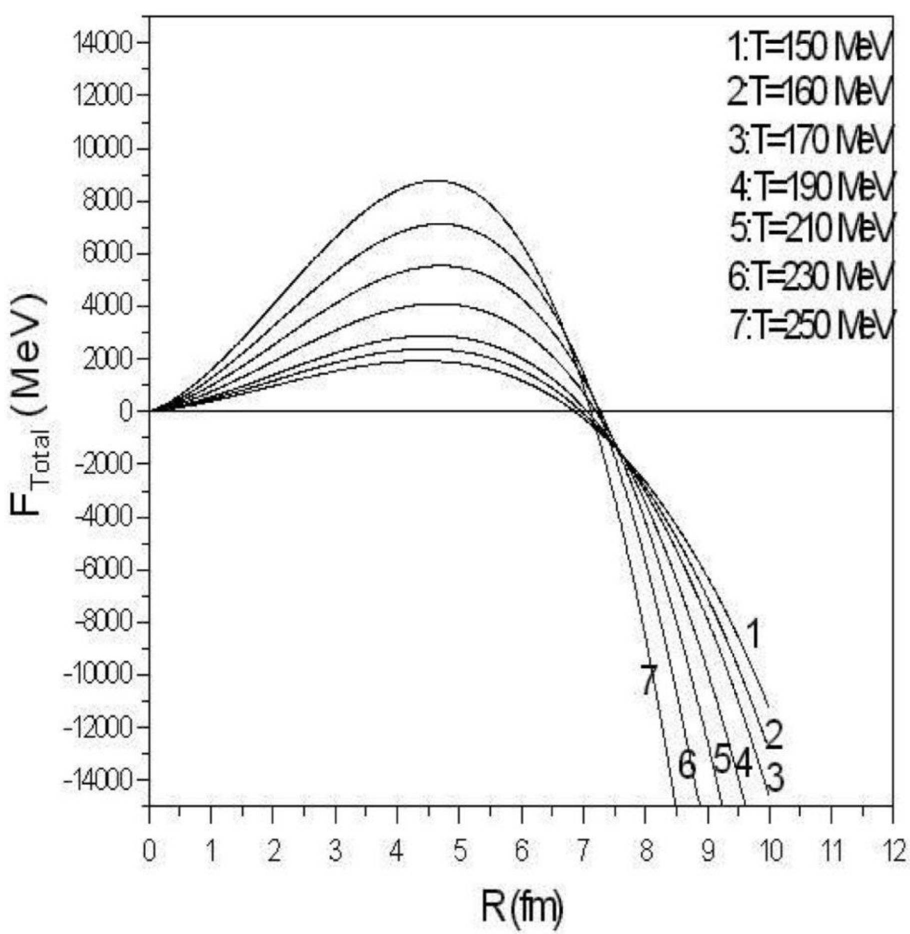
It explains the creation of the plasma formation with the size of the droplets and also indicate the nature of QGP fireball.

Various thermodynamic quantities can be calculated using total free energy (F) :-

$$P = -\left(\frac{dF_{total}}{d\upsilon}\right) \quad ; \quad \varepsilon = T\frac{dP}{dT} - P \quad ; \quad S = \frac{dP}{dT} \quad ; \quad C_v = -\left(\frac{\partial^2 F}{\partial T^2}\right)_v \quad ; \quad C_S^2 = \frac{dP}{d\varepsilon}$$

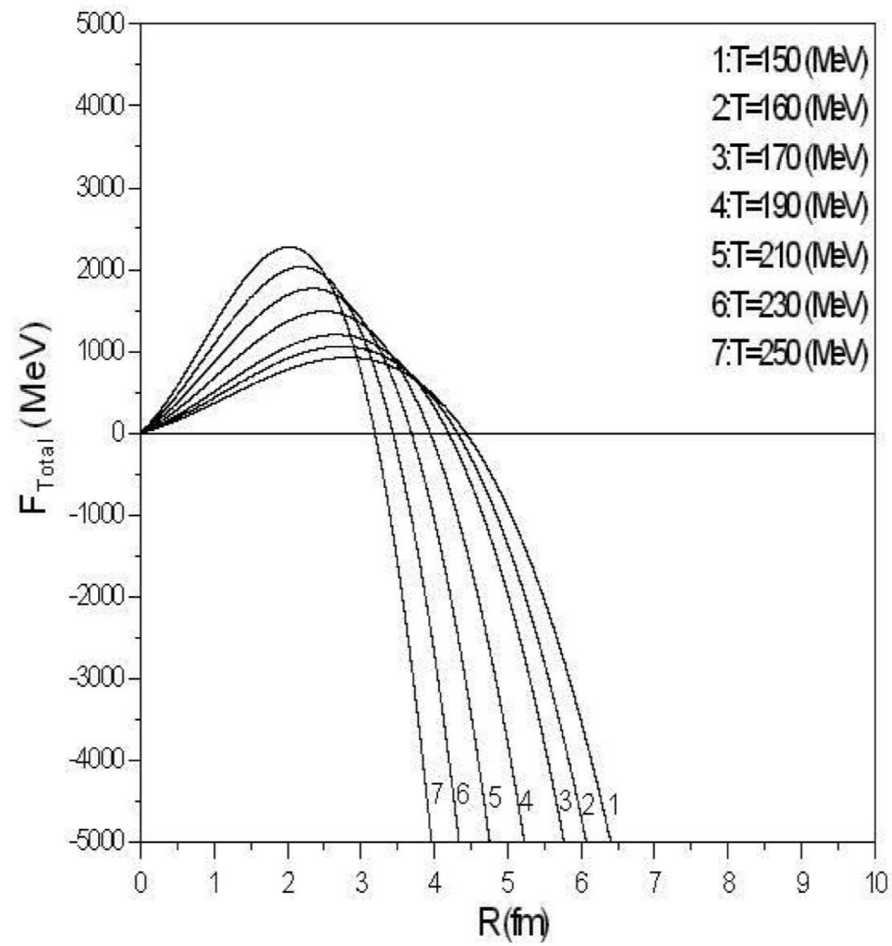
RESULTS

Variation of free energy with size of QGP droplets :



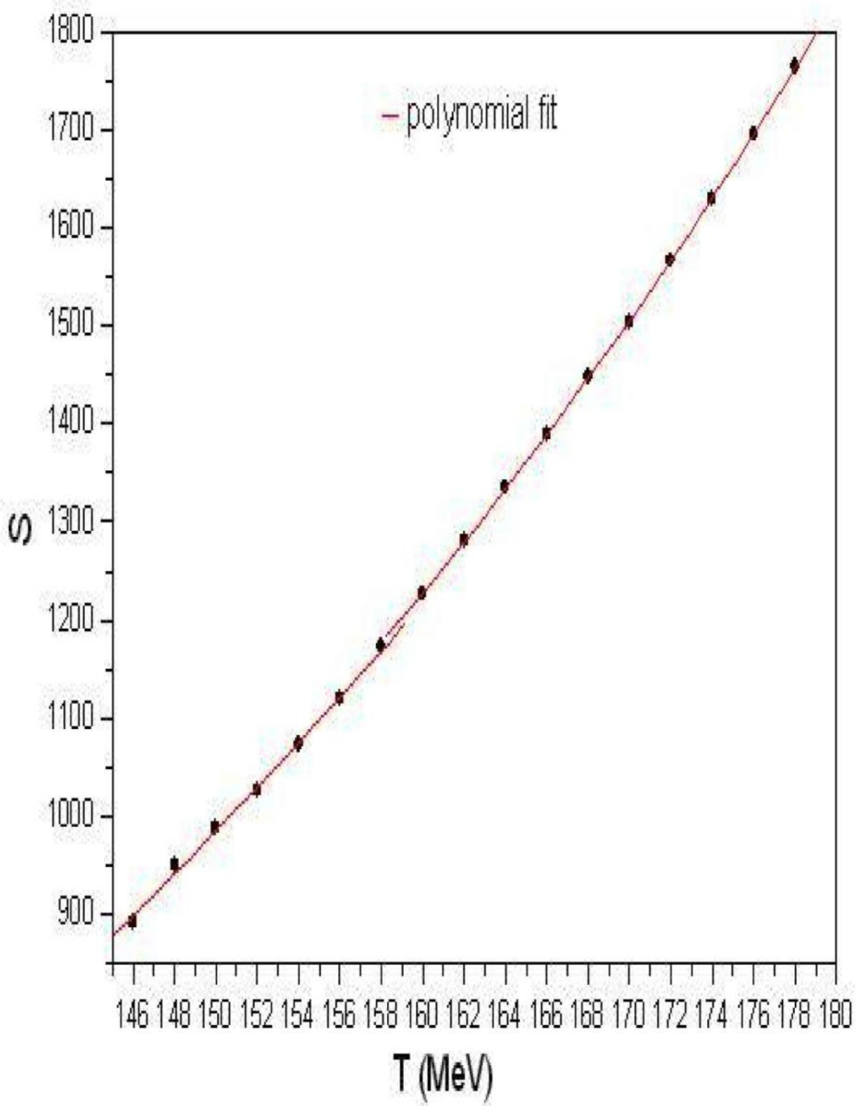
Modified F_{total} at $\gamma_g = 6\gamma_q$, $\gamma_q = \frac{1}{6}$

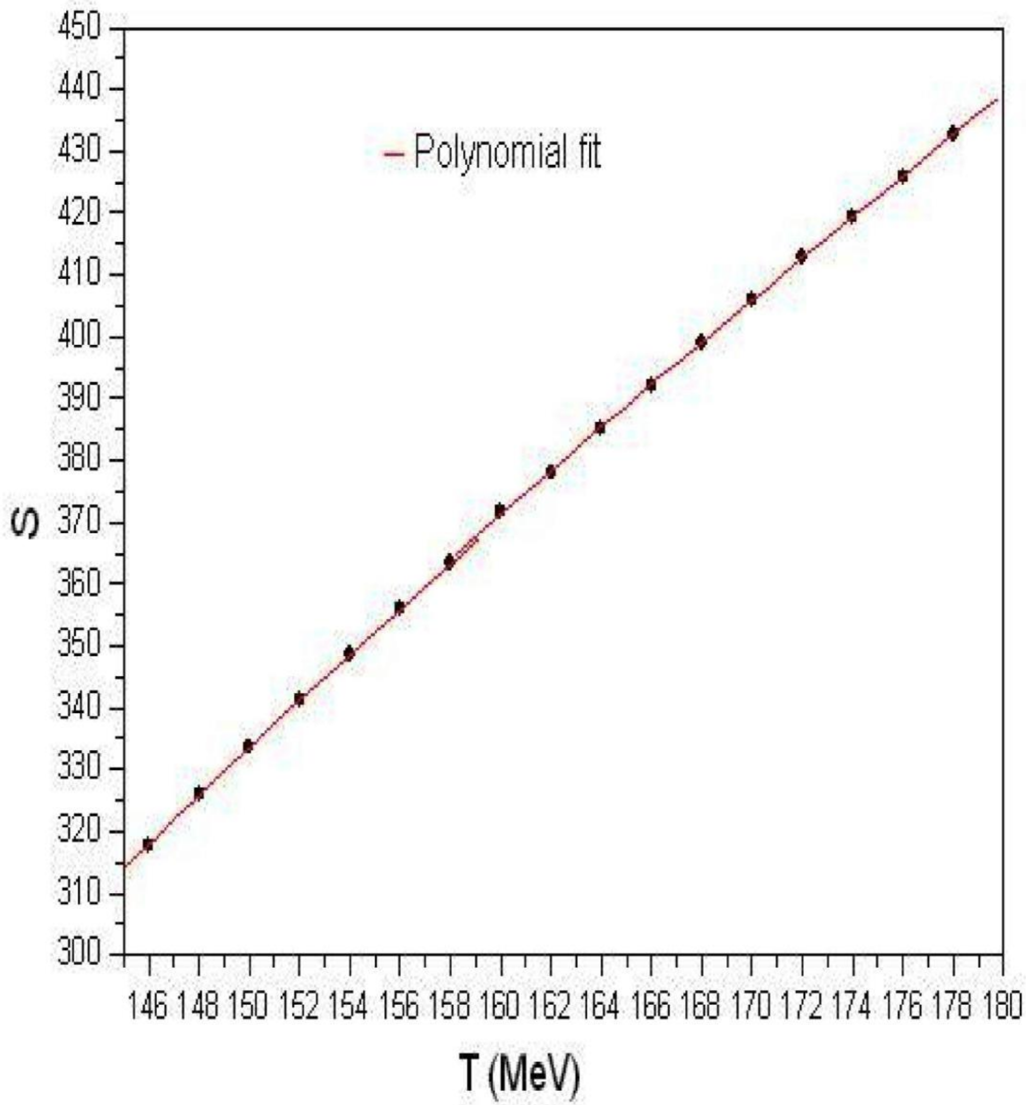
for various temperatures



Modified F_{total} at $\gamma_g = 8\gamma_q$, $\gamma_q = \frac{1}{6}$

for various temperatures.





Variation of S with at Temperature T at $\gamma_g = 6\gamma_q$, $\gamma_q = \frac{1}{6}$.

Variation of S with Temperature T at $\gamma_g = 8\gamma_q$, $\gamma_q = \frac{1}{6}$.

Effective quark mass in the presence of Magnetic field :

The effective quark mass created in heavy-ion collisions is considered as linear function of square of current mass, coupling of thermal and current mass and square of thermal mass which is again suitably modified with the help of magnetic field : Phys. Rev. D 82, 014023 (2010)

$$M_{eff}^2 = m_c^2 + \sqrt{2}\,m_c m_q + m_q^2$$

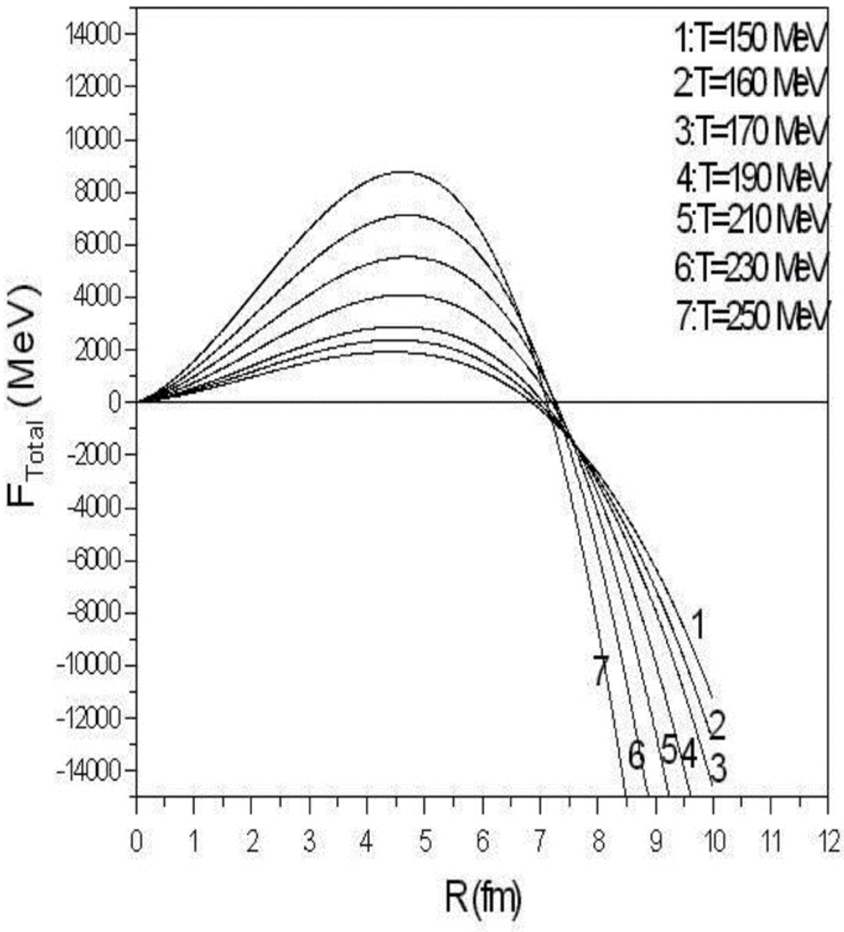
where mc is the current quark mass and mq is the thermal quark mass :

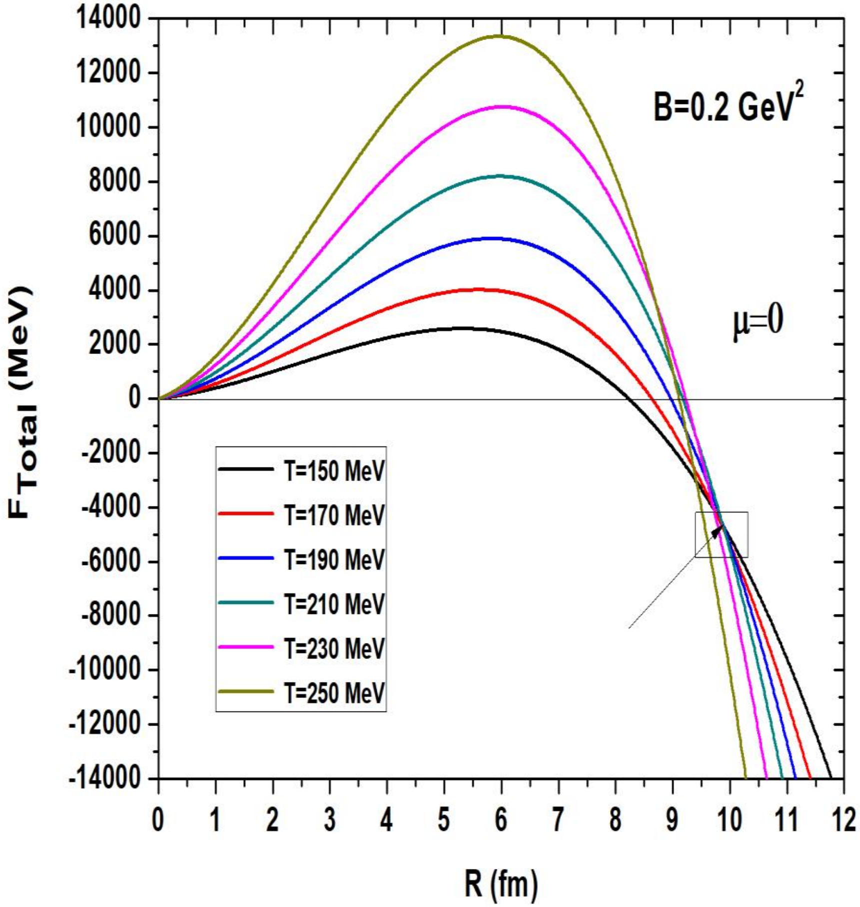
$$m_q^2(T,\mu) = \gamma_q^{'} \left(\frac{N}{\ln\left(1+\frac{k^2}{\Lambda^2}\right)} \right) T^2 \quad \textbf{and} \quad \gamma_q^{'} = \gamma_q \left(1 + \frac{\mu^2}{\pi^2 T^2} \right)$$

Assume the system in the presence of a strong magnetic field background that is constant and homogeneous so the single particle energy eigen value is given by,

$$E = \left[k^2 + M_{eff}^2 + eB(2n+s+1) \right]^{1/2}$$

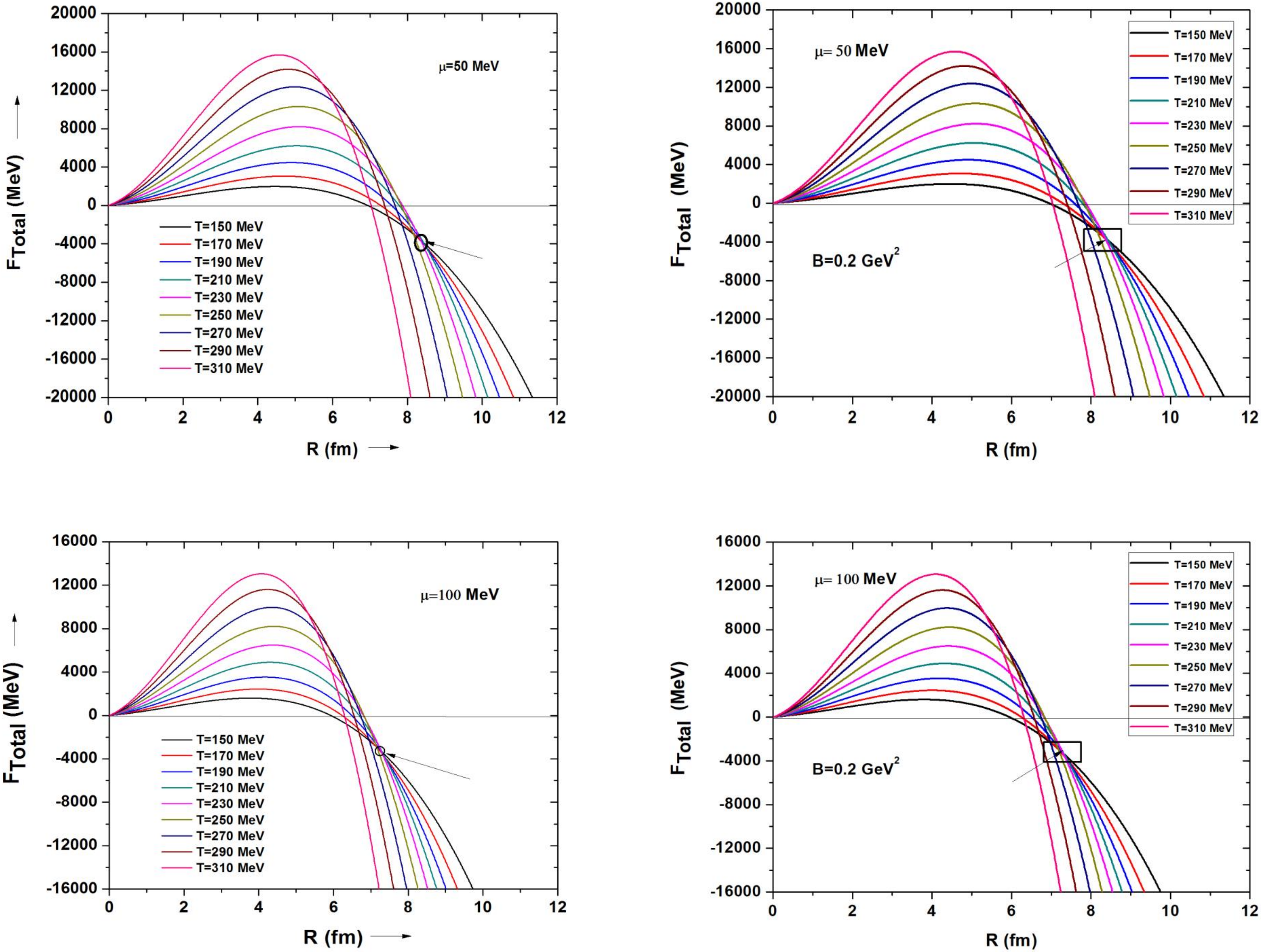
Where, n=0,1,2,….. are the principle quantum numbers for allowed Landau levels , s=plus(minus)1 refers to spin up (+) or down (-) states.

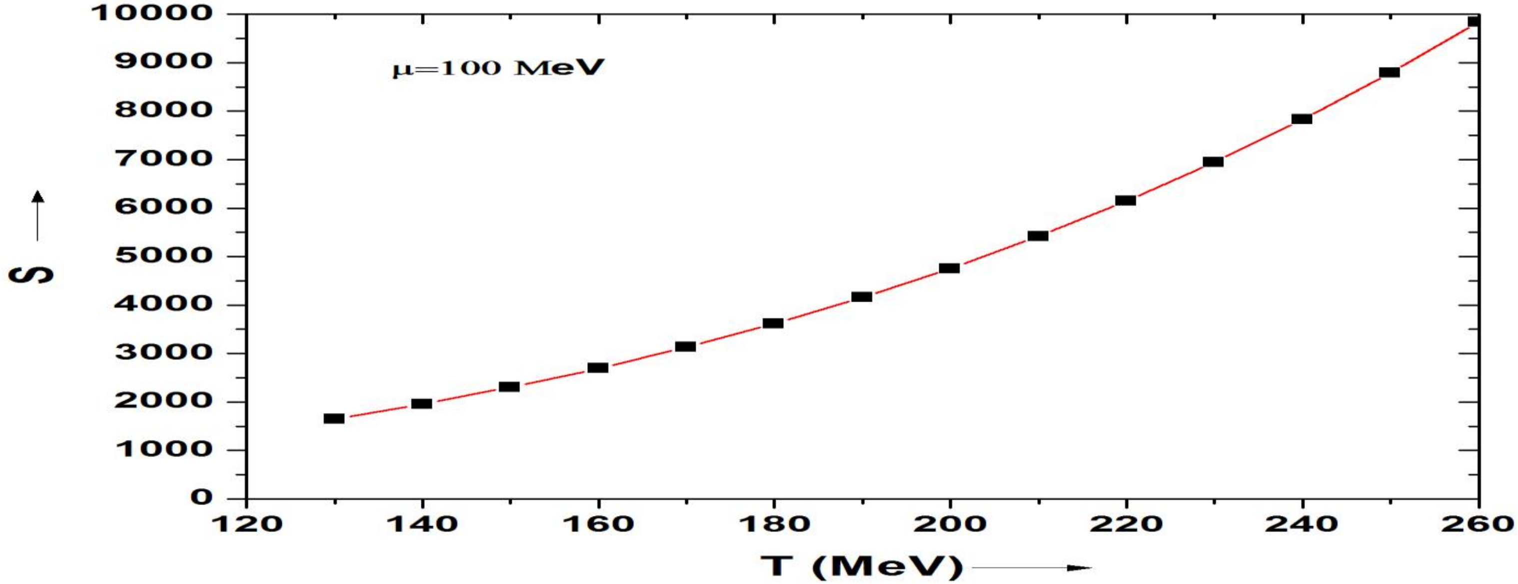


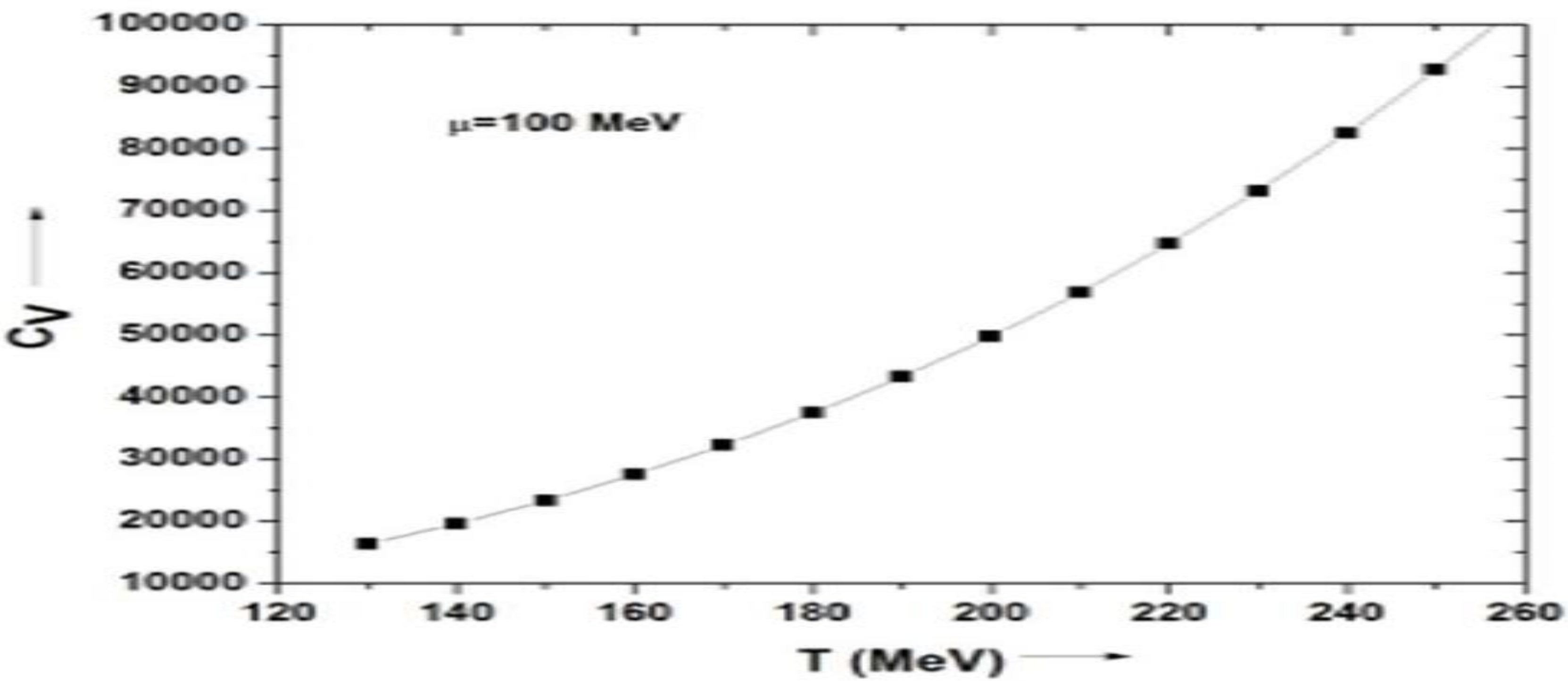


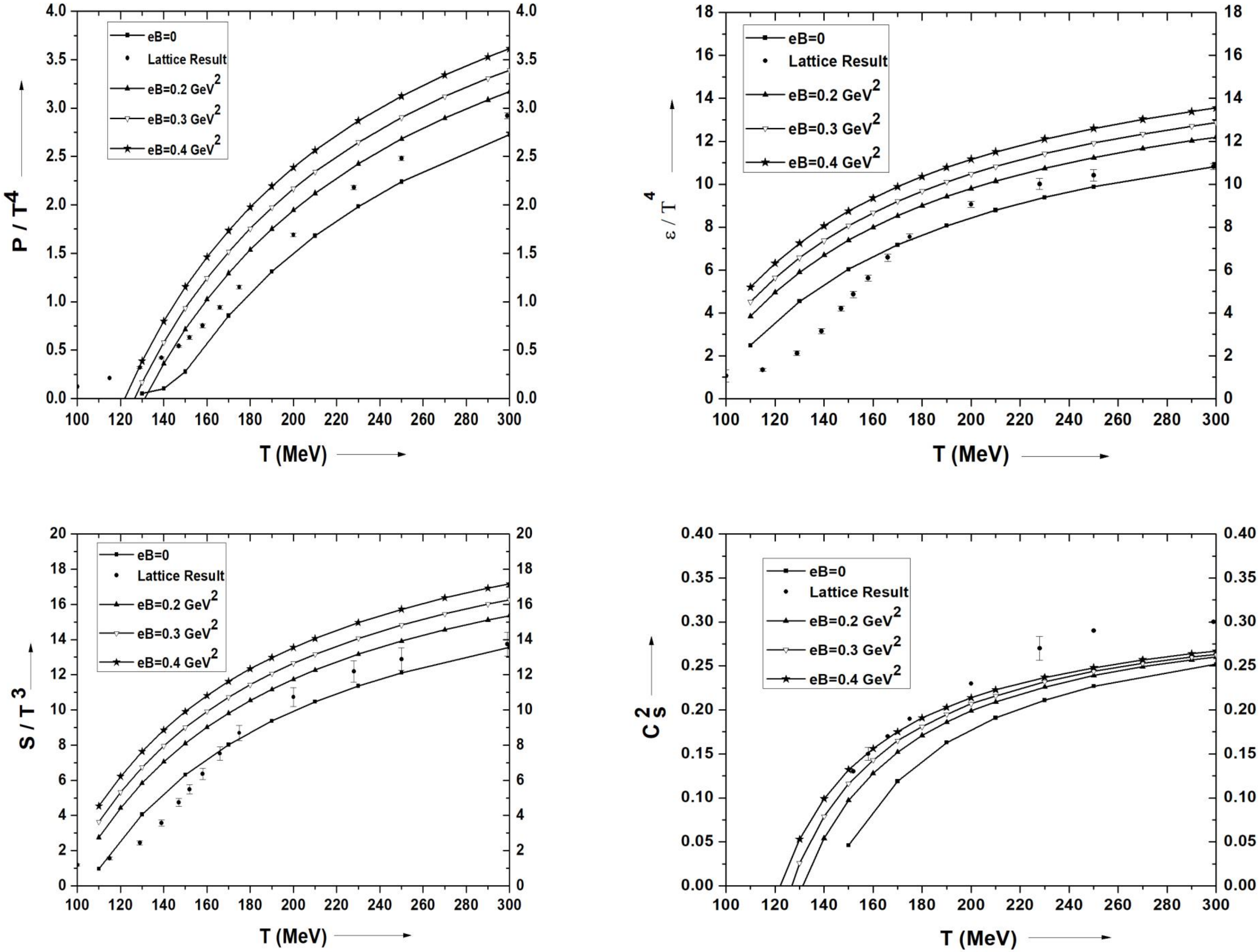
The model result indicate that the use of finite value of quark mass at zero chemical potential in the presence of B enhances the evolution and make more stability in droplet size formation.

The bunching of curves provide more realistic picture for the stability of QGP droplet as shown by arrowhead.


μ=50 MeV
μ= 50 MeV
μ=100 MeV
μ= 100 MeV
B=0.2 GeV²
F_Total (MeV)
R (fm)
T=150 MeV
T=170 MeV
T=190 MeV
T=210 MeV
T=230 MeV
T=250 MeV
T=270 MeV
T=290 MeV
T=310 MeV


μ=100 MeV
S
T (MeV)
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
120
140
160
180
200
220
240
260


μ=100 MeV
Cv
T (MeV)
100000
90000
80000
70000
60000
50000
40000
30000
20000
10000
120
140
160
180
200
220
240
260



P / T4
T (MeV)
ε / T4
S / T3
C2s
eB=0
Lattice Result
eB=0.2 GeV2
eB=0.3 GeV2
eB=0.4 GeV2

CONCLUSION

- The model we have discussed here is not only simple but grasp a lot of physics about the formation and evolution of quark gluon plasma.

- The results with effective quark mass in the presence of magnetic field shows significant improvement in order to enhances the droplet size and make more stability in plasma evolution. The observations could have interesting implications on the expansion dynamics of the medium produced at RHIC and LHC, which may influence the outcomes of various signatures.

- Results are presented for a variety of thermodynamic observables, indicating that the EoS is significantly affected by the magnetic field, even at moderate values of B. Our results are in good agreement with the present lattice QCD simulation.

- Overall all results are folded with a model which explain the evolution through the thermodynamic variables like free energy, entropy, specific heat and also helps us to produce EoS of QGP.

THANK YOU

ありがとうございました

- **Of interest to us here are the work of Mardor and Svetitsky and more recently of Neerguard and Madsen who used the MIT bag model (a famous phenomenological model to probe the phase transition between hadronic and QGP phases) for hadrons and also invoked the idea of zero chemical potential case in the computation of free energy.**

- **The MIT bag model is simplicity itself; it puts all quarks and gluons as free particles inside a bag and makes the impermeable bag as the agent of confinement by ascribing a set of boundary conditions for quarks and gluons.**