São Paulo, May 12, 2014

The role of Asymptotic Freedom for the Pseudocritical Temperature in Magnetized Quark Matter

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II Workshop on Perspectives in Nonperturbative QCD

Conselho Nacional de Desenvolvimento Científico e Tecnológico

Universidade Federal de Santa Maria
SEDES SAPIENTIÆ
1960

Outline

- Motivation
- Magnetic Fields and chiral symmetry breaking - magnetic catalysis
- Lattice Results - disagreements between lattice results and model calculations regarding T_{PC} X B
- Including asymptotic freedom in NJL model
- Results and perspectives

Motivation

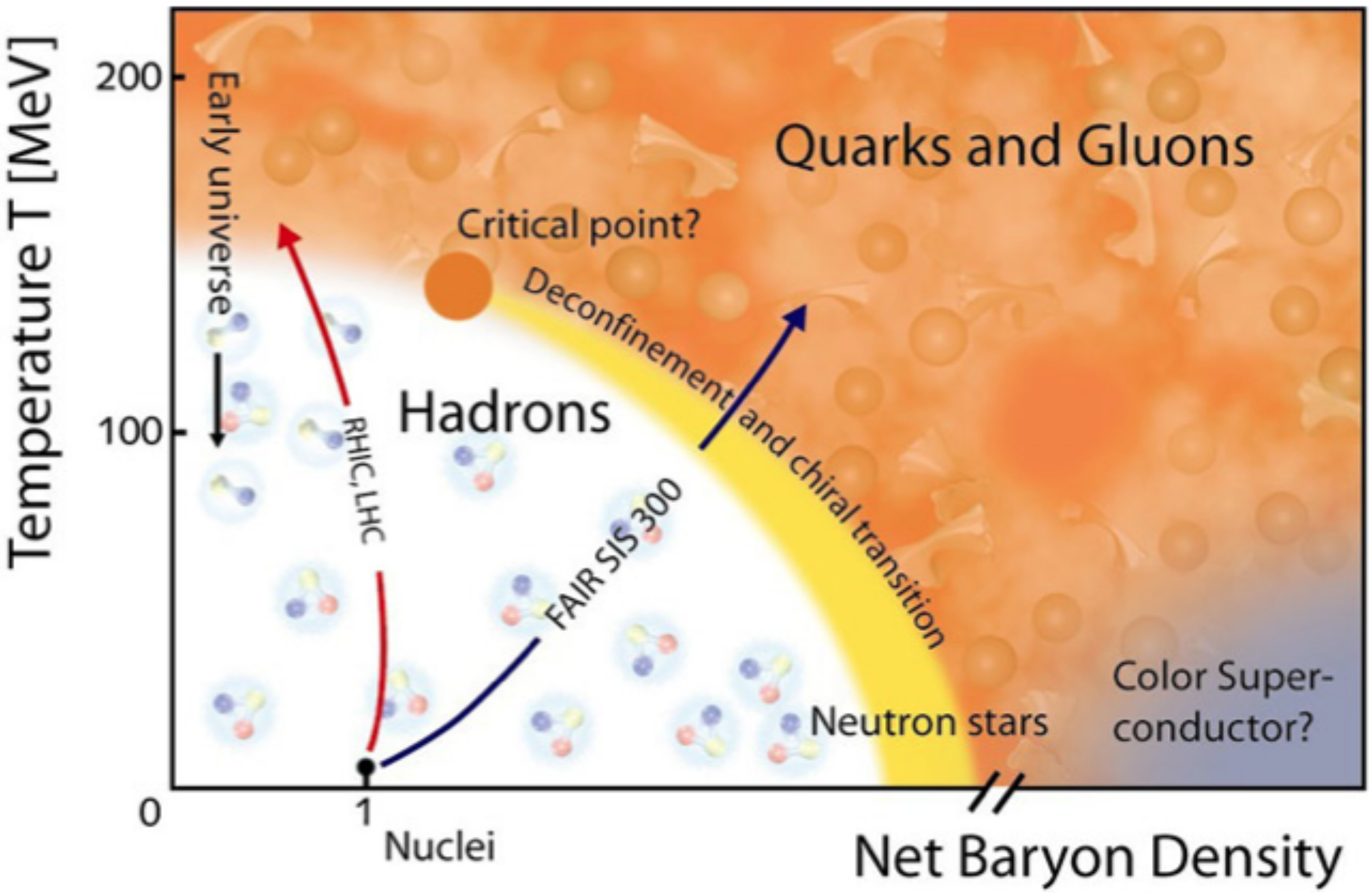
- Why magnetic fields are interesting for QCD matter?

Motivation

- Signatures of QGP in Heavy-ion collisions (large T and low μ)?
- Compact Stars: quark stars? neutron stars? or hybrid stars (large μ (400 MeV) and low T)?

<u>In this regimes LARGE magnetic fields are present!!!</u>

Cartoon of QCD phase diagram



B effects on:

- position of CP
- confinement trans.
- chiral transition
- stars
- 2SC and CFL
- QGP
- Early Universe

credits: GSI Darmstadt

Motivation

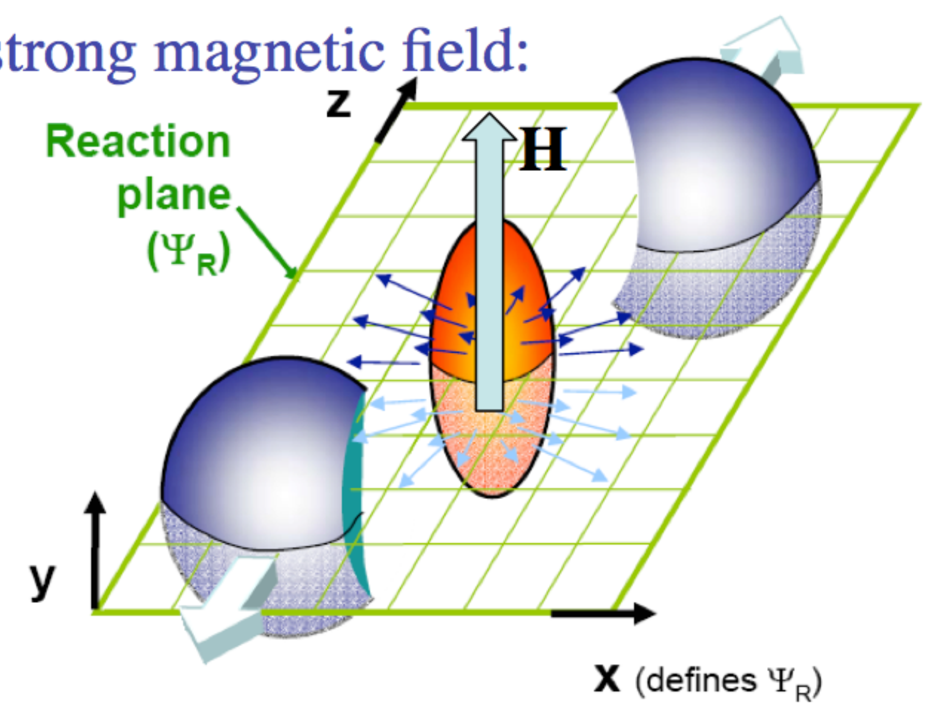
- Strong magnetic fields may be produced in non central heavy ion collisions: K. Fukushima, D. E. Kharzeev, and H. J. Warringa, Phys. Rev. D 78, 074033 (2008). D. E. Kharzeev and H. J. Warringa, Phys. Rev. D 80, 0304028 (2009). D. E. Kharzeev, Nucl. Phys. A 830, 543c (2009).

heavy-ion collisions:

temporarily $B \lesssim 10^{19}\,\mathrm{G}$

Skokov, Illarionov, Toneev,
Int. J. Mod. Phys. A 24, 5925 (2009)

Relativistic ions create
a strong magnetic field:



Motivation

- Strong magnetic fields are also present in magnetars: C. Kouveliotou et al., Nature 393, 235 (1998).

magnetars:

at surface $B \lesssim 10^{15}\,\mathrm{G}$

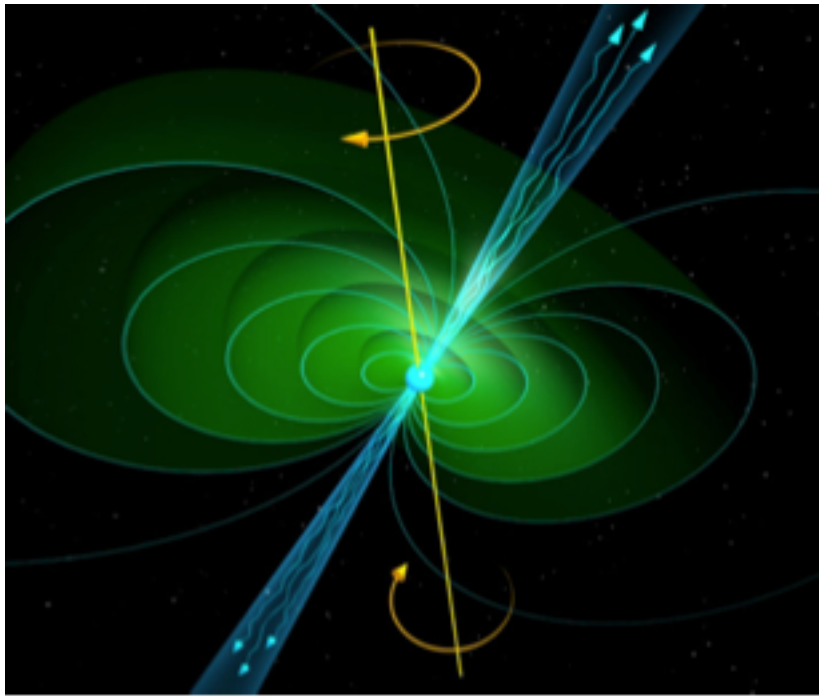
Duncan, Thompson, Astrophys.J. 392, L9 (1992)

larger in the interior,

$B \sim 10^{18-20}\,\mathrm{G}$?

Lai, Shapiro, Astrophys.J. 383, 745 (1991)

E. J. Ferrer *et al.*, PRC 82, 065802 (2010)



A. K. Harding, D. Lai, Rept. Prog. Phys. 69, 2631 (2006)

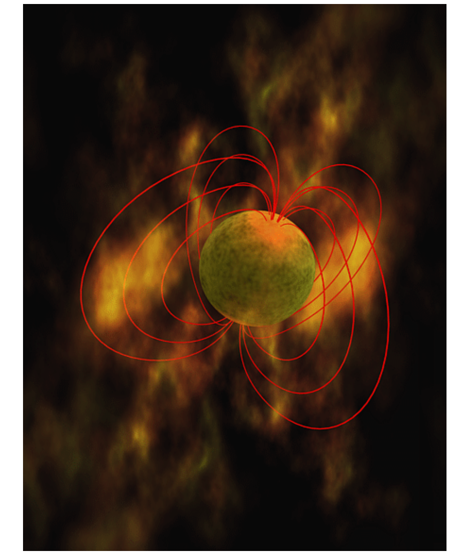
- and might have played an important role in the physics of the early universe. T. Vaschapati, Phys. Lett. B 265, 258 (1991).

Motivation

- We need to understand quark confinement and chiral symm. breaking
- Moreover deconfinement and chiral symmetry restoration at finite temperature and/or density - (NEW PHASES)
- In heavy ion colliders: two beams of charged particles in opposite direction
- Ext. magnetic field: short-time, large magnitude, QCD out of equilibrium?
- ...
- magnetic field as another axis of the QCD phase diagram!

Amplitudes of magnetic fields

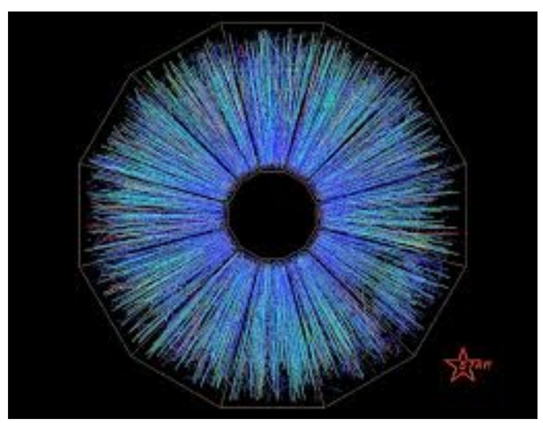
earth - 0.6 Gauss



magnet - 100 Gauss

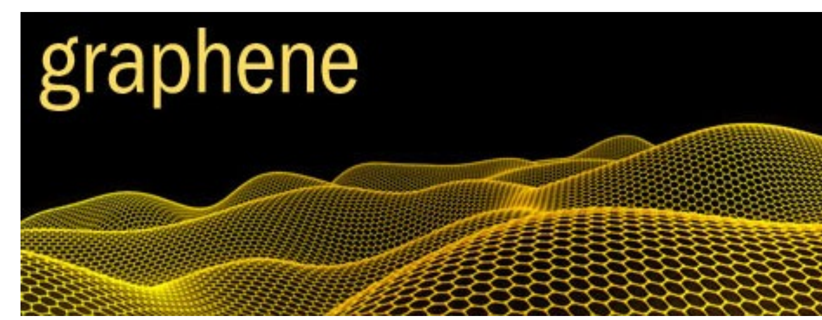
neutron stars (surface of magnetars)

- 10^{13} .. 10^{15} G => $eB^{1/2}$ ~1 MeV



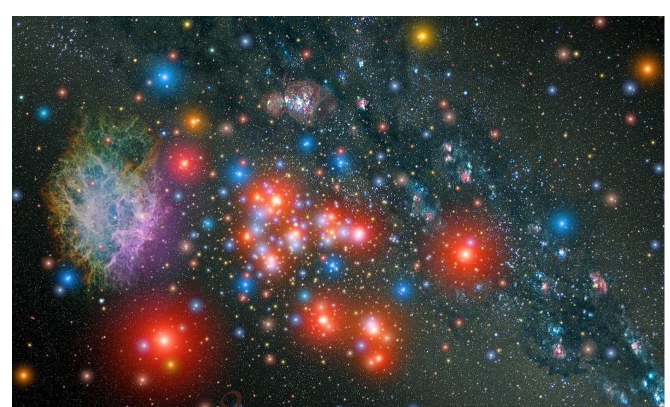
RHIC/LHC - $eB^{1/2}$

= 0.1 .. 0.5 GeV. The strongest magnetic field ever achieved in the lab. (10^{17} G)



~ 10^5 G

early universe - eB^1/2 ~ 2GeV



Motivation

- The behavior of QCD under extreme conditions: temperature, density, external magnetic fields
- Problem: QCD is nonperturbative in relavant scales
- Lattice: Signal problem!!!

To make progress

- We use Quantum Field Theory (in medium)
- Experiments - most expensive!!!
- Effective models (just a few degrees of freedom)
- Lattice (limitations...)

Lattice Results

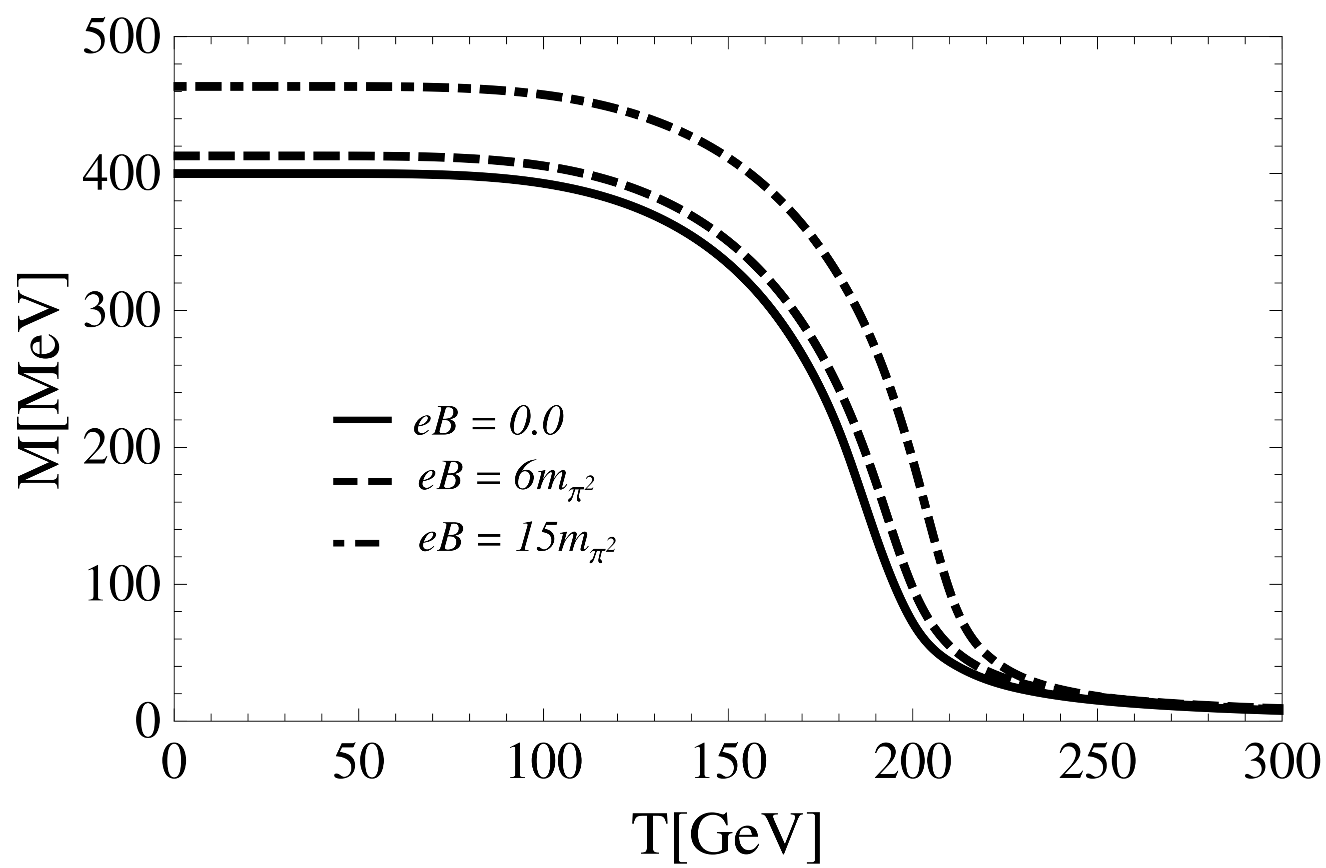
At vanishing baryon density and magnetic field, lattice QCD simulations predict that there is a crossover transition at a pseudo critical temperature T_{pc}.

- Y. Aoki, G. Endrodi, Z. Fodor, S. D. Katz, and K. K. Szabo, Nature 443, 675 (2006).
- Y. Aoki, Z. Fodor, S. D. Katz, and K. K. Szabo, Phys. Lett. B 643, 46 (2006).

First Lattice Results

- M. D'Elia, S. Mukherjee, and F. Sanfilippo, Phys. Rev.D 82, 051501 R (2010).
- M. D'Elia and F. Negro, Phys. Rev. D 83, 114028(2011).

- indications that chiral T_{PC} is increasing as a function of B.



M X T for SU(2) NJL model with G_0

Results in agreement with effective models: NJL,PNJL,QMM...

However:

- They use the bare quark masses used correspond to a pion mass in the range m_π = 200– 480 MeV, i. e. a very heavy pion.

- These results have been confirmed by:

G. S. Bali, F. Bruckmann, G. Endodi, Z. Fodor, S.D. Katz, S. Krieg, A. Schafer, and K. K. Szabo, JHEP1202, 044 (2012).
G. S. Bali, F. Bruckmann, G. Endrodi, Z. Fodor, S.D.Katz, and A. Schafer, Phys. Rev. D 86, 071502 (2012).

- For light quark masses that correspond to the physical pion mass of m_π = 140 MeV, their simulations show a T_{PC} which is a decreasing function of the magnetic field B.

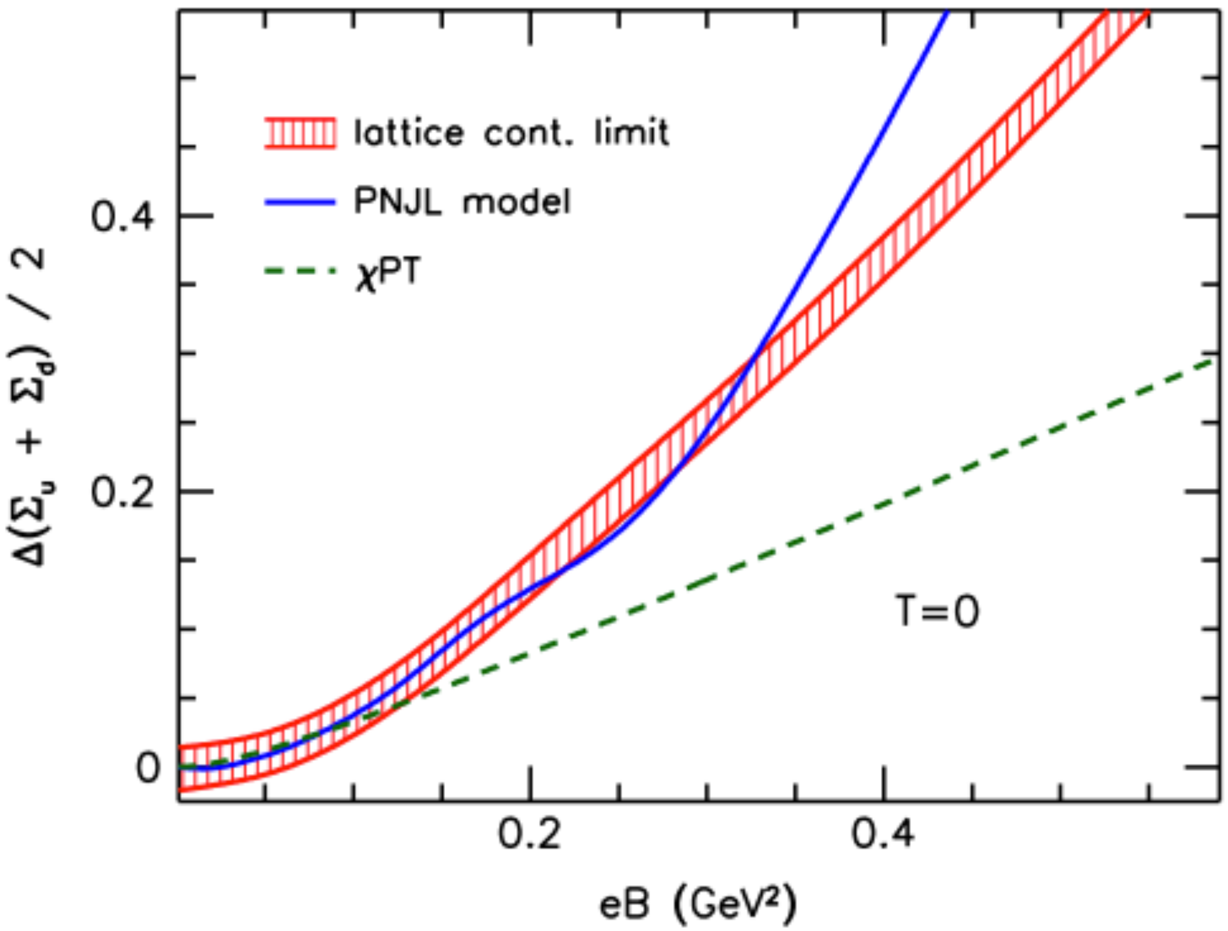
- The basic mechanism seems to be that the MC at T = 0 turns into IMC for T around Tc.
- The results suggest that the T_{PC} is a nontrivial function of the quark masses.

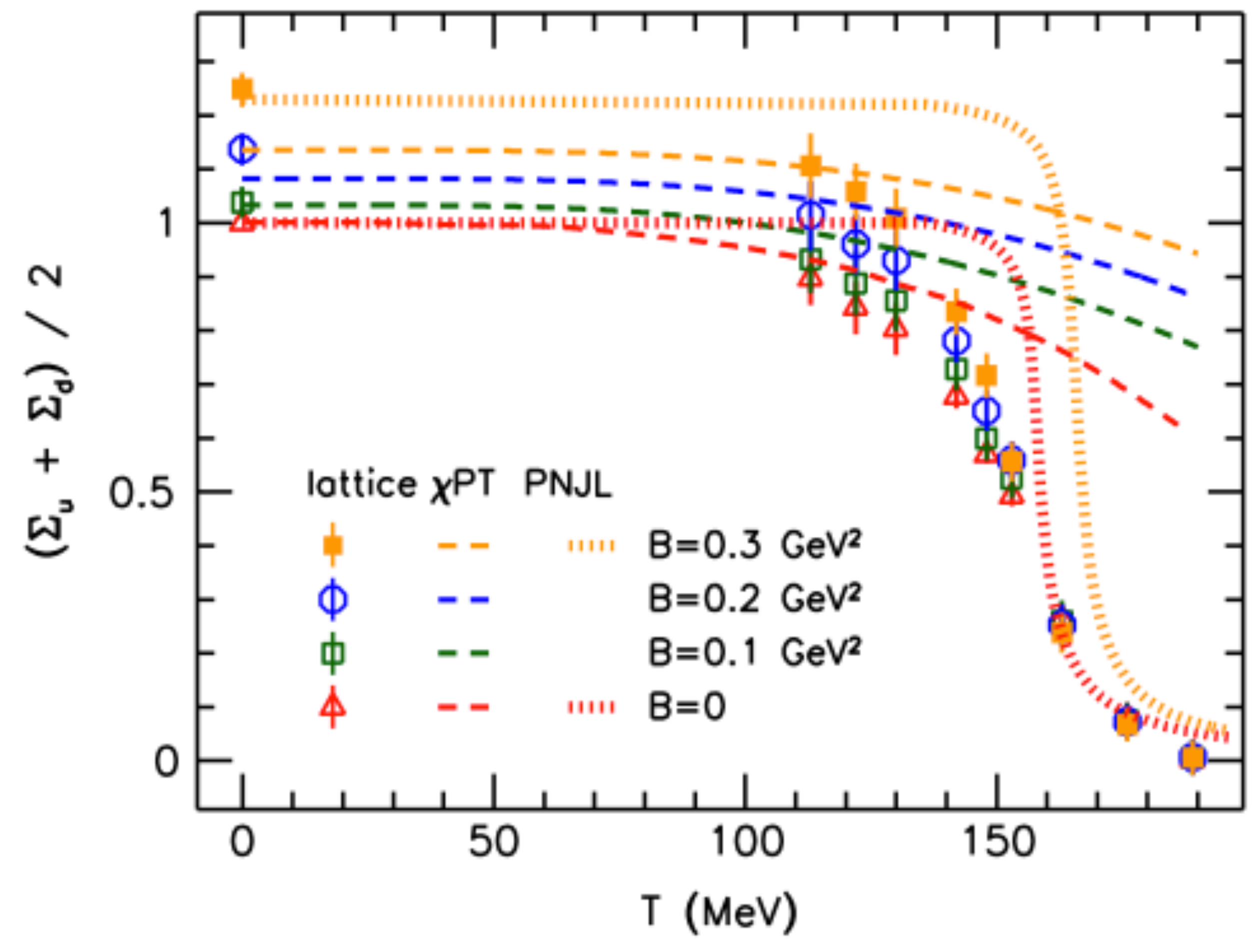
Recent Lattice Results X Effect. models

lattice definitions:

$$\Sigma_f(B,T) = \frac{2m_f}{m_\pi^2 f_\pi^2}\left[\langle\bar{\psi}_f\psi_f\rangle - \langle\bar{\psi}_f\psi_f\rangle_0\right] + 1$$

$$\Delta\Sigma_{u,d}(B,T) = \Sigma_{u,d}(B,T) - \Sigma_{u,d}(0,T).$$

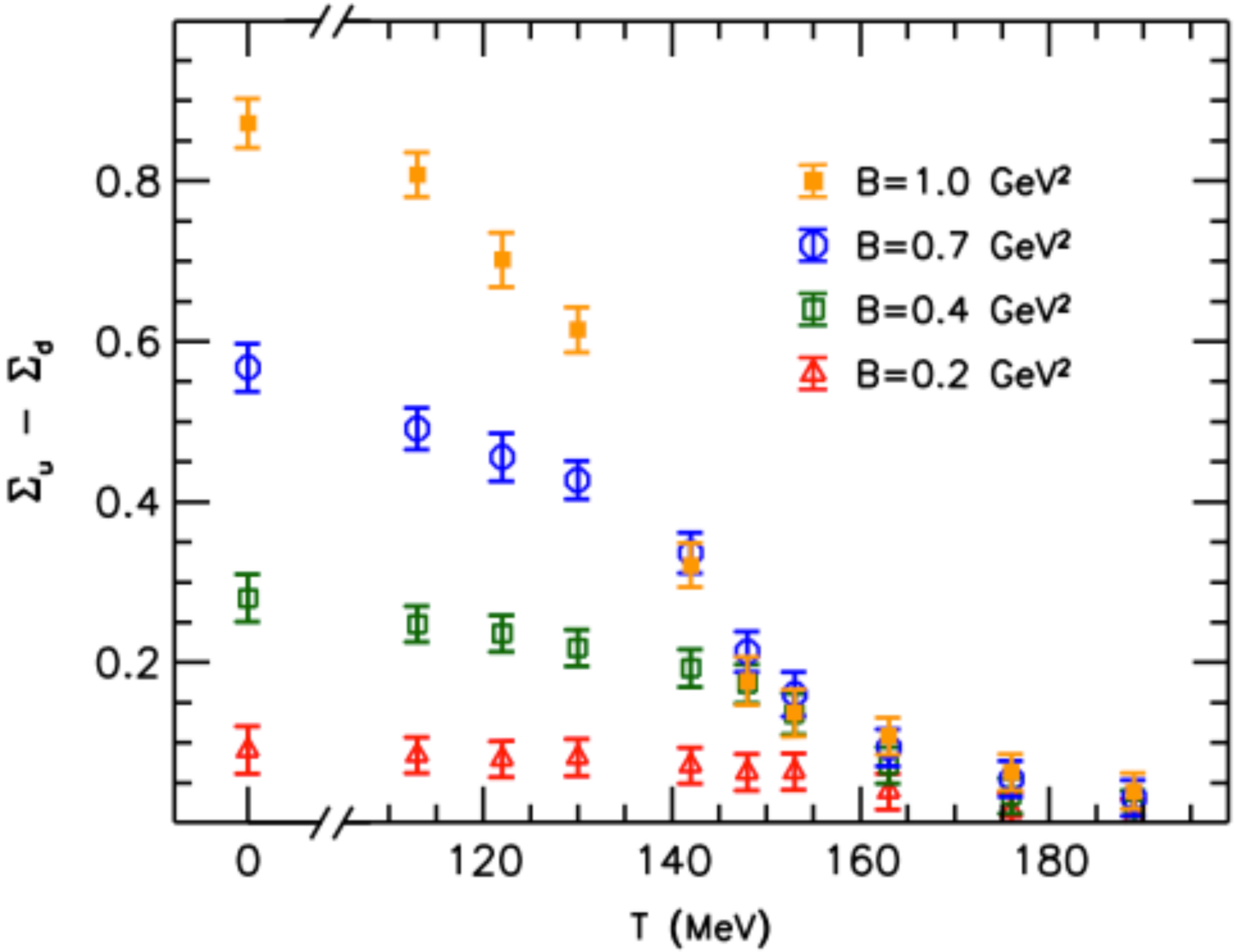




Phys. Rev. D 86, 071502(R) (2012)

Right Panel: CM and IMC

Recent Lattice Results



Phys. Rev. D 86, 071502(R) (2012)

CM(T=0) and IMC(high T)

SU(2) NJL model

The standard two flavor NJL model is defined by a fermionic Lagrangian density

$$\mathcal{L}_{\rm NJL} = \bar{\psi}\,(i\partial\!\!\!/ - m)\,\psi + G\left[(\bar{\psi}\psi)^2 - (\bar{\psi}\gamma_5\vec{\tau}\psi)^2\right]$$

In mean field approximation (MFA):

$$\mathcal{F}^{\rm NJL} = \frac{(M-m)^2}{4G} + \frac{i}{2}{\rm tr}\int \frac{d^4p}{(2\pi)^4}\,\ln[-p^2+M^2]$$

NJL at finite T, μ and B

To study the effect of B in the chiral transition at finite T and μ a dimensional reduction is induced:

$$p_0 \to i(\omega_\nu - i\mu)$$
$$p^2 \to p_z^2 + (2n+1-s)|q_f|B$$
$$s = \pm 1$$
$$n = 0, 1, 2...$$

$$\int_{-\infty}^{+\infty} \frac{d^4p}{(2\pi)^4} \to i\frac{T|q_f|B}{2\pi} \sum_{\nu=-\infty}^{\infty} \sum_{n=0}^{\infty} \int_{-\infty}^{+\infty} \frac{dp_z}{2\pi}$$

$$\mathcal{F}^{\rm NJL} = \frac{(M-m)^2}{4G} + \mathcal{F}^{\rm NJL}_{\rm vac} + \mathcal{F}^{\rm NJL}_{\rm mag} + \mathcal{F}^{\rm NJL}_{\rm med}$$

NJL at finite T, μ and B

$$\mathcal{F}_{\rm vac}^{\rm NJL} = -2N_c N_f \int \frac{d^3\mathbf{p}}{(2\pi)^3}(\mathbf{p}^2 + M^2)^{1/2}$$

$$\mathcal{F}_{\rm vac}^{\rm NJL} = \frac{N_c N_f}{8\pi^2}\left\{M^4 \ln\left[\frac{(\Lambda+\epsilon_\Lambda)}{M}\right] - \epsilon_\Lambda\,\Lambda\left[\Lambda^2+\epsilon_\Lambda^2\right]\right\}$$

$$\epsilon_\Lambda = \sqrt{\Lambda^2+M^2}$$

$$\mathcal{F}_{\rm mag}^{\rm NJL} = -\frac{N_c}{2\pi^2}\sum_{f=u}^{d}(|q_f|B)^2\left\{\zeta^{(1,0)}(-1,x_f) - \frac{1}{2}[x_f^2 - x_f]\ln(x_f) + \frac{x_f^2}{4}\right\}$$

$$\mathcal{F}_{\rm med}^{\rm NJL} = -\frac{N_c}{2\pi}\sum_{f=u}^{d}\sum_{k=0}^{\infty}\alpha_k|q_f|B\int_{-\infty}^{+\infty}\frac{dp_z}{2\pi}\left\{T\ln[1+e^{-[E_{p,\,k}(B)+\mu]/T}] + \mu\to-\mu\right\}$$

Numerical Implementation: difficulties

- $T = 0$ OK!
- $T \neq 0$ We need to numerically perform the sums over the Landau levels, or find suitable approximations...
- Job becomes easier in the high magnetic field regime: $\sqrt{eB} \gg T$
- But this is not so in the low magnetic field regime, with $\sqrt{eB} \lesssim T$, and $\Omega/T \lesssim 1$ (requires to sum up to very large Landau levels)
- Any numerical computation to become quickly expensively ($+$ integrations involved no high T)

Here we discuss a more natural alternative for dealing with the cases of low magnetic fields!!!

PHYSICAL REVIEW D 84, 083525 (2011) D. C. Duarte, R. L. S. Farias, and R. O. Ramos

Euler-Maclaurin formula

$$\sum_{k=a}^{b} f(k) = \int_a^b f(x)\,dx + \frac{1}{2}[f(a)+f(b)] + \sum_{i=1}^{n} \frac{b_{2i}}{(2i)!}\left[f^{(2i-1)}(b) - f^{(2i-1)}(a)\right]$$
$$+ \int_a^b \frac{B_{2n+1}(\{x\})}{(2n+1)!} f^{(2n+1)}(x)\,dx$$

b_i are the Bernoulli numbers, defined by the generating function

$$\frac{x}{\exp(x)-1} = \sum_{n=0}^{\infty} b_n \frac{x^n}{n!}$$

$B_n(x)$ are the Bernoulli polynomials, with generating function

$$\frac{z\exp(zx)}{\exp(z)-1} = \sum_{n=0}^{\infty} B_n(x)\frac{z^n}{n!}$$

Reliability of the use of the EM formula

$$L\tilde{Y} = \sum_{k=0}^{\infty} \int_{-\infty}^{+\infty} \frac{dz}{2\pi} \ln\left[1 - e^{-E(z,\Omega,T,B,k)}\right]$$

where

$$E(z,\Omega,T,B,k) = \sqrt{z^2 + \frac{\Omega^2}{T^2} + (2k+1)\frac{eB}{T^2}}$$

$$L\tilde{X} = \sum_{k=0}^{\infty} \int_{-\infty}^{+\infty} \frac{dz}{2\pi} \frac{1}{E(z,\Omega,T,B,k)} \frac{1}{e^{E(z,\Omega,T,B,k)} - 1}$$

eB/T^2	order	$L\hat{Y}$ EM approx.	Landau sum	error (%)	$L\hat{X}$ EM approx.	Landau Sum	error (%)
	0	-688.7717		0.04	508.2575		1.67
	1	-689.0258		1.00×10^{-4}	515.7328		0.22
0.001	2	-689.0271	-689.0264	1.00×10^{-4}	517.0372	516.8633	0.03
	3	-689.0270		1.00×10^{-4}	516.7096		0.03
	4	-689.0271		1.00×10^{-4}	517.2016		0.07
	0	-68.6567		0.35	47.7384		5.00
	1	-68.8954		5.10×10^{-3}	49.8997		0.70
0.01	2	-68.8990	-68.8989	1.00×10^{-4}	50.3031	50.2488	0.11
	3	-68.8988		1.00×10^{-4}	50.2007		0.10
	4	-68.8990		1.00×10^{-4}	50.3549		0.21
	0	-6.6735		2.99	3.9418		14.07
	1	-6.8706		0.13	4.4852		2.22
0.1	2	-6.8797	-6.8793	5.80×10^{-3}	4.6037	4.5873	0.36
	3	-6.8791		2.90×10^{-3}	4.5725		0.30
	4	-6.8796		4.40×10^{-3}	4.6199		0.70
	0	-0.5400		18.70	0.2195		34.89
	1	-0.6497		2.18	0.3128		7.21
1	2	-0.6652	-0.6642	0.15	0.3416	0.3371	1.34
	3	-0.6637		0.07	0.3329		1.25
	4	-0.6651		0.14	0.3465		2.79
	0	-0.0159		59.54	0.0034		66.99
	1	-0.0328		16.54	0.0081		21.36
10	2	-0.0407	-0.0393	3.56	0.0112	0.0103	8.74
	3	-0.0383		2.55	0.0095		7.77
	4	-0.0413		5.09	0.0124		20.39
	0	-6.8468×10^{-6}		88.48	5.9362×10^{-7}		89.52
	1	-3.6528×10^{-5}		38.52	3.4235×10^{-6}		39.54
100	2	-8.3692×10^{-5}	-5.9413×10^{-5}	40.87	8.3706×10^{-6}	5.6626×10^{-6}	47.82
	3	-1.1413×10^{-5}		80.80	3.6803×10^{-6}		35.00
	4	-3.8726×10^{-4}		551.81	5.6924×10^{-5}		905.27

NJL at finite T, μ and B

$$E_{p,\,k}(B) = \sqrt{p_z^2 + 2k|q_f|B + M^2}$$

where M is the effective self consistent quark mass

$$M = m + \frac{N_c N_f M G}{\pi^2}\left\{\Lambda\sqrt{\Lambda^2 + M^2} - \frac{M^2}{2}\ln\left[\frac{(\Lambda + \sqrt{\Lambda^2 + M^2})^2}{M^2}\right]\right\}$$
$$+ \frac{N_c M G}{\pi^2}\sum_{f=u}^{d}|q_f|B\left\{\ln[\Gamma(x_f)] - \frac{1}{2}\ln(2\pi) + x_f - \frac{1}{2}(2x_f - 1)\ln(x_f)\right\}$$
$$- \frac{N_c M G}{2\pi^2}\sum_{f=u}^{d}\sum_{k=0}^{\infty}\alpha_k|q_f|B\int_{-\infty}^{\infty}\frac{dp_z}{E_{p,k}(B)}\left\{\frac{1}{e^{[E_{p,k}(B)+\mu]/T}+1} + \frac{1}{e^{[E_{p,k}(B)-\mu]/T}+1}\right\}$$

Quark Condensate

$$\langle\bar{\psi}_f\psi_f\rangle = -\frac{N_c M}{2\pi^2}\left\{\Lambda\sqrt{\Lambda^2+M^2} - \frac{M^2}{2}\ln\left[\frac{(\Lambda+\sqrt{\Lambda^2+M^2})^2}{M^2}\right]\right\}$$
$$-\frac{N_c M}{2\pi^2}|q_f|B\left\{\ln[\Gamma(x_f)] - \frac{1}{2}\ln(2\pi) + x_f - \frac{1}{2}(2x_f-1)\ln(x_f)\right\}$$
$$+\frac{N_c M}{4\pi^2}\sum_{k=0}^{\infty}\alpha_k|q_f|B\int_{-\infty}^{\infty}\frac{dp_z}{E_{p,k}(B)}\left\{\frac{1}{e^{[E_{p,k}(B)+\mu]/T}+1} + \frac{1}{e^{[E_{p,k}(B)-\mu]/T}+1}\right\}$$

Where: $E_{p,\,k}(B) = \sqrt{p_z^2 + 2k|q_f|B + M_f^2}$

$$x_f = M_f^2/(2|q_f|B)$$
$$\alpha_k = 2 - \delta_{0k}$$

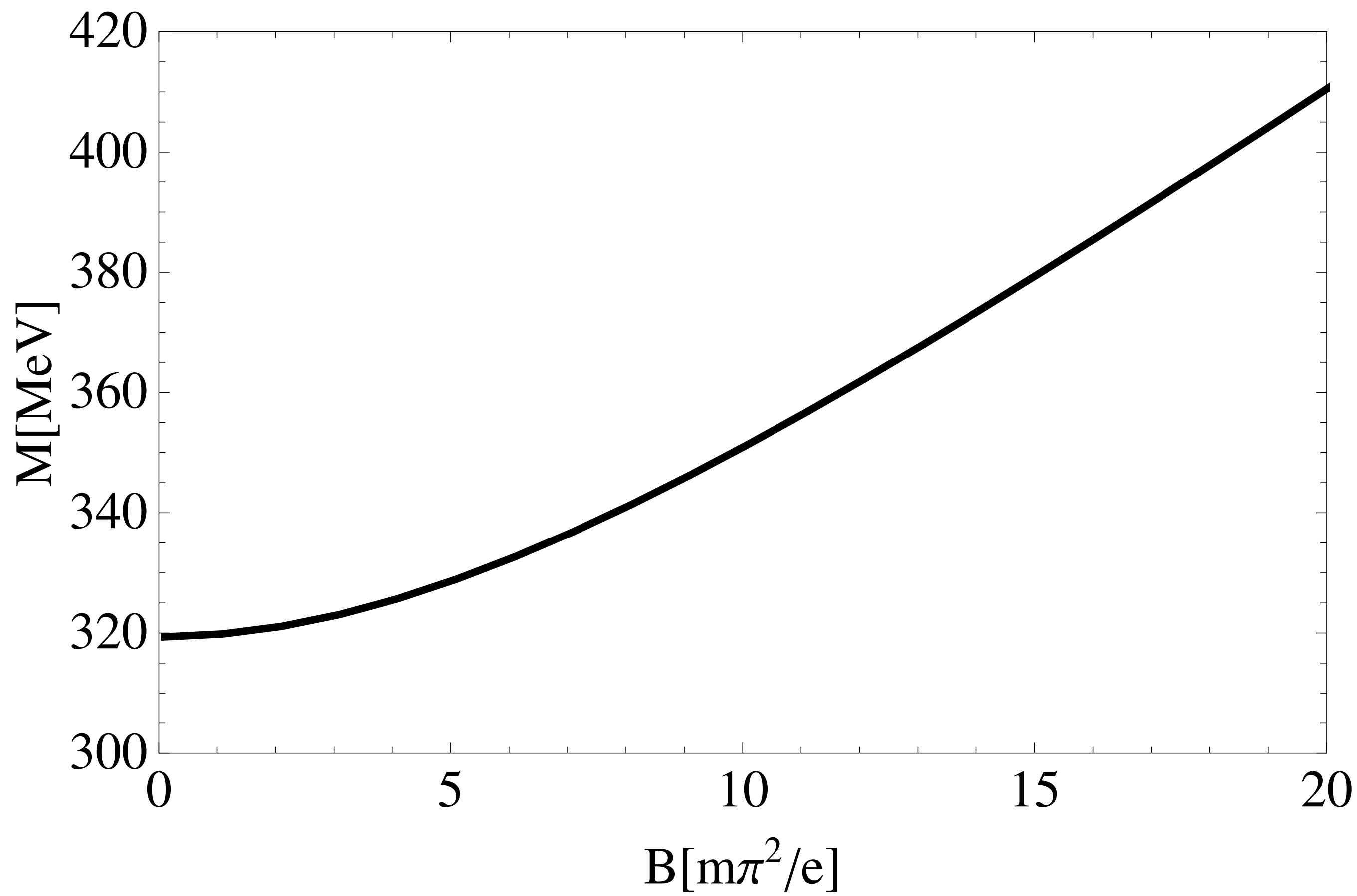
$$|q_u| = 2e/3\,, |q_d| = e/3$$

We use Gaussian natural units $\rightarrow$ $1\,\mathrm{GeV}^2 = 1.44\times10^{19}\ G$

Magnetic Catalysis - NJL T=0

K. G. Klimenko, Theor. Math. Phys. 89, 1161-1168 (1992)

V. P. Gusynin, V. A. Miransky, I. A. Shovkovy, PLB 349, 477-483 (1995)



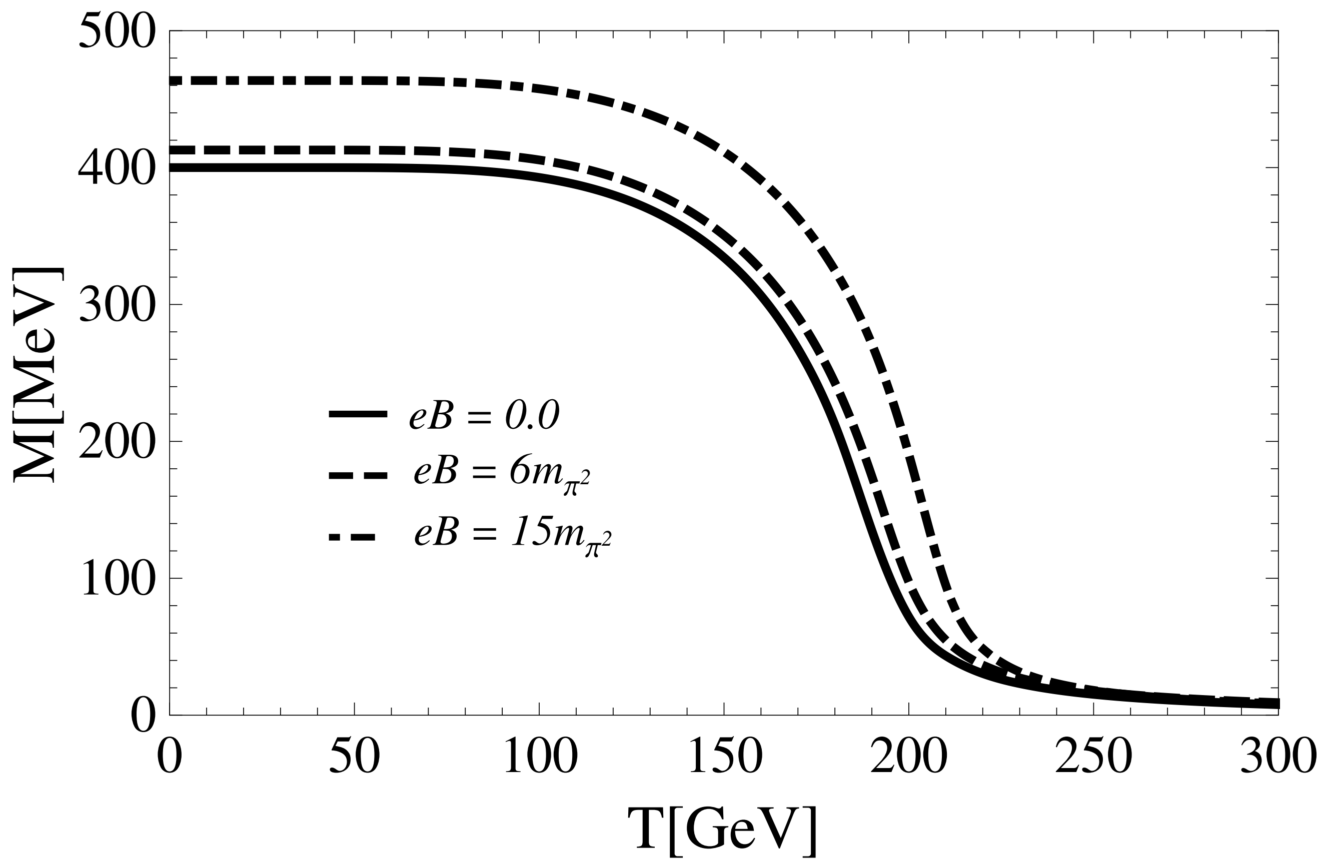
At

$T = \mu = 0$

The phenomenological values of quantities such as the pion mass m_π, the pion decay constant f_π, and the quark condensate $\langle\bar{\psi}_f\psi_f\rangle$ are used to fix G, Λ, and m. Here, we choose the set $\Lambda = 650\,\mathrm{MeV}$ and $G = 5.022\,\mathrm{GeV}^{-2}$ with $m = 5.5\,\mathrm{MeV}$ in order to reproduce $f_\pi = 93\,\mathrm{MeV}$, $m_\pi = 140\,\mathrm{MeV}$, and $\langle\bar{\psi}_f\psi_f\rangle^{1/3} = -250\,\mathrm{MeV}$ in the vacuum.

NJL results at finite T and B

- Gap equation $M_f = m_f - 2G \sum_f \langle \bar{\psi}_f \psi_f \rangle$
- where $\langle \bar{\psi}_f \psi_f \rangle$ is the quark condensate of flavor f



these evaluations have been considered at more sophisticated levels:

- Polyakov Loop (PNJL, EPNJL)
- Chiral PT (Andresen)
- including strangeness
- beyond MFA (FRG) (Fukushima)

- despite those refinements in model calculations, no qualitative changes in TPC X B.

Exceptions?

1) Bag model calculation (First order PT) - E. S. Fraga and L. F. Palhares, Phys. Rev. D 86, 016008 (2012)

2) Polyakov extended QMM - A. J. Mizher, M. N. Chernodub, and E. S. Fraga, Phys. Rev. D 82, 105016 (2010).

3) Large Nc Calculation - E. S. Fraga, J. Noronha, and L. F. Palhares, Phys. Rev. D 87, 114014 (2013).

- All predict a decreasing T_{PC} with B

- In 1 and 2 it is probably related to their treatment of vacuum fluctuations and related renormalization issues…

Exceptions?

K. Fukushima and Y. Hidaka, Phys. Rev. Lett. 110,031601 (2013) - Magnetic Inhibition

F. Bruckmann, G. Endrodi and T. G. Kovacs, JHEP 1304, 112 (2013) - IMC is the result of the back-reaction of the gluons due to the coupling of the magnetic field to the sea quarks.

T. Kojo and N. Su, Phys. Lett. B 720, 192 (2013)
- consider an effective interaction with infrared enhancement and ultraviolet suppression.

Be careful with the approximations!

The chiral phase transition and the role of vacuum fluctuations
Jens O. Andersen, Rashid Khan, Lars T. Kyllingstad (Norwegian U. Sci. Tech.).
Feb 2011. 12 pp. e-Print: arXiv:1102.2779 [hep-ph]

e.g., QM model, chiral symmetry breaking takes place in the meson sector, and as a consequence, the vacuum contribution to the free energy from the fermions is sometimes omitted.

In the NJL model, on the other hand, this term is responsible for the chiral symmetry breaking, and so it cannot be neglected.

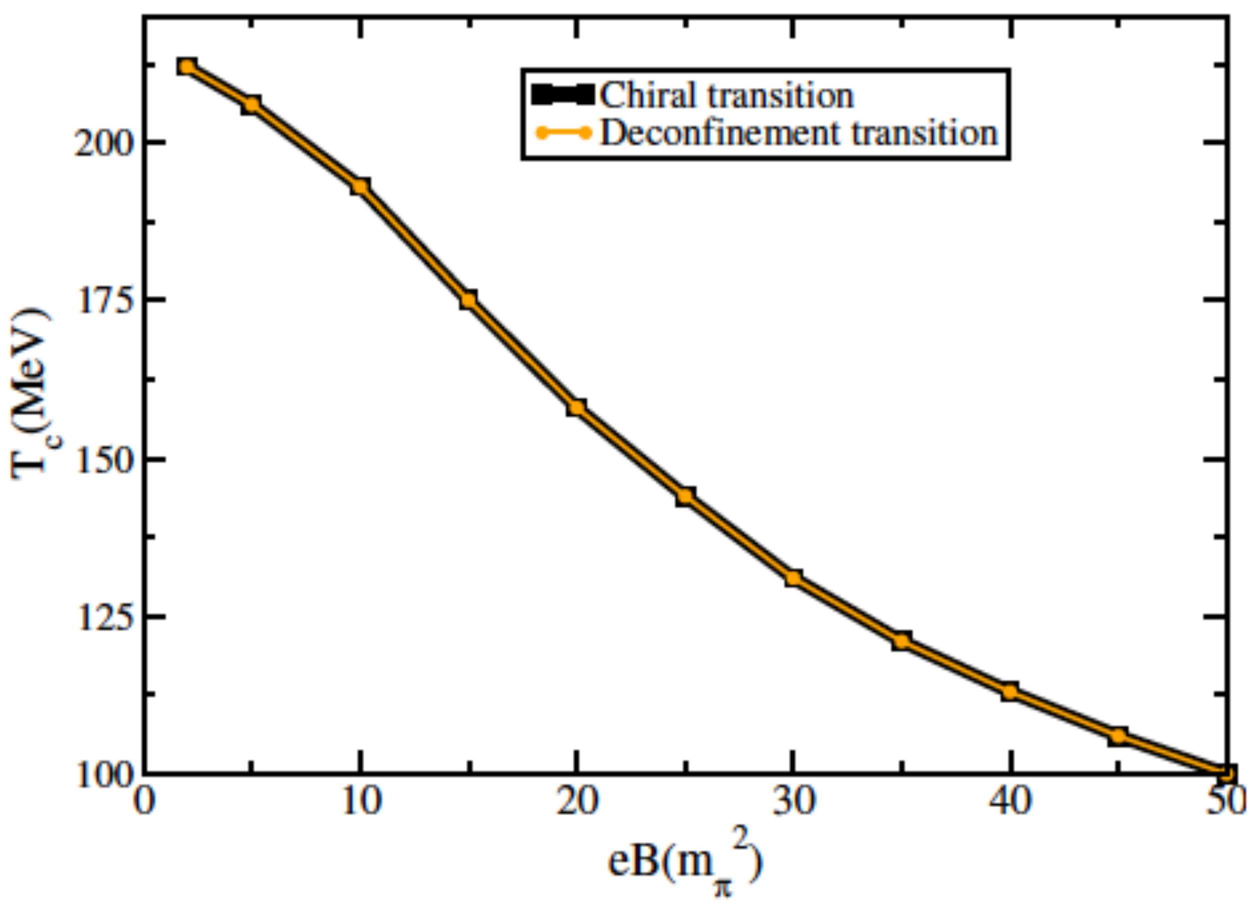
When making such simplifications, however, it is important to know exactly what one is discarding, in order not to "throw the baby out with the bath water"

V. Skokov, B. Friman, E. Nakano, K. Redlich, and B.-J. Schaefer, Phys. Rev. D 82 (2010), 034029

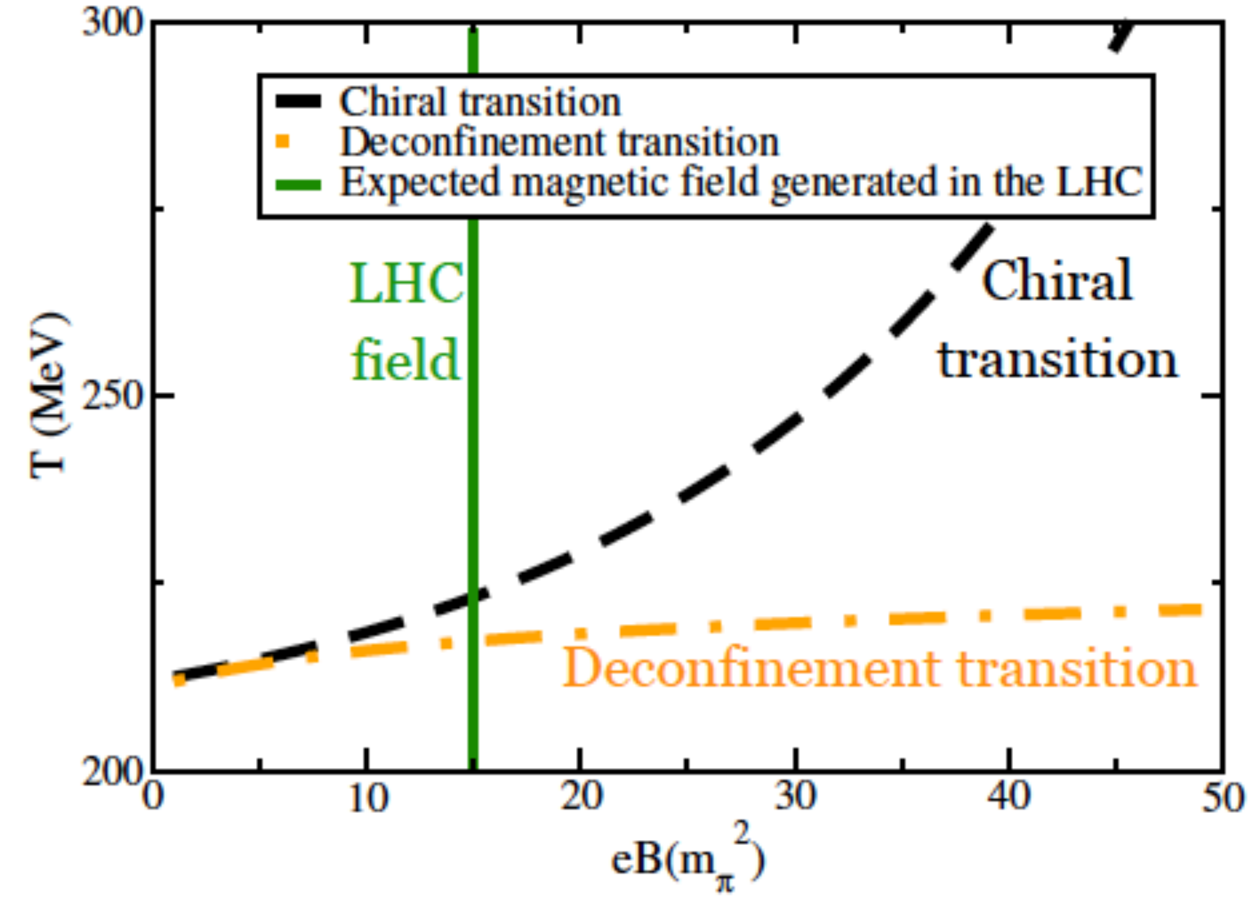
It was recently shown that neglecting the fermion vacuum contribution to the QM free energy changes the order of the phase transition!

Be careful with the approximations!

no vacuum corrections



with vacuum corrections



Phase Diagram of Strong Interactions in an External Magnetic Field
Ana Julia Mizher (Rio de Janeiro, CBPF), Eduardo S. Fraga (Rio de Janeiro Federal U.), M.N. Chernodub (Tours U., CNRS & Gent U.). Mar 2011.
Published in PoS FACESQCD (2010) 020

Recently...

Deconfinement and chiral restoration within the SU(3) Polyakov--Nambu--Jona-Lasinio and entangled Polyakov--Nambu--Jona-Lasinio models in an external magnetic field

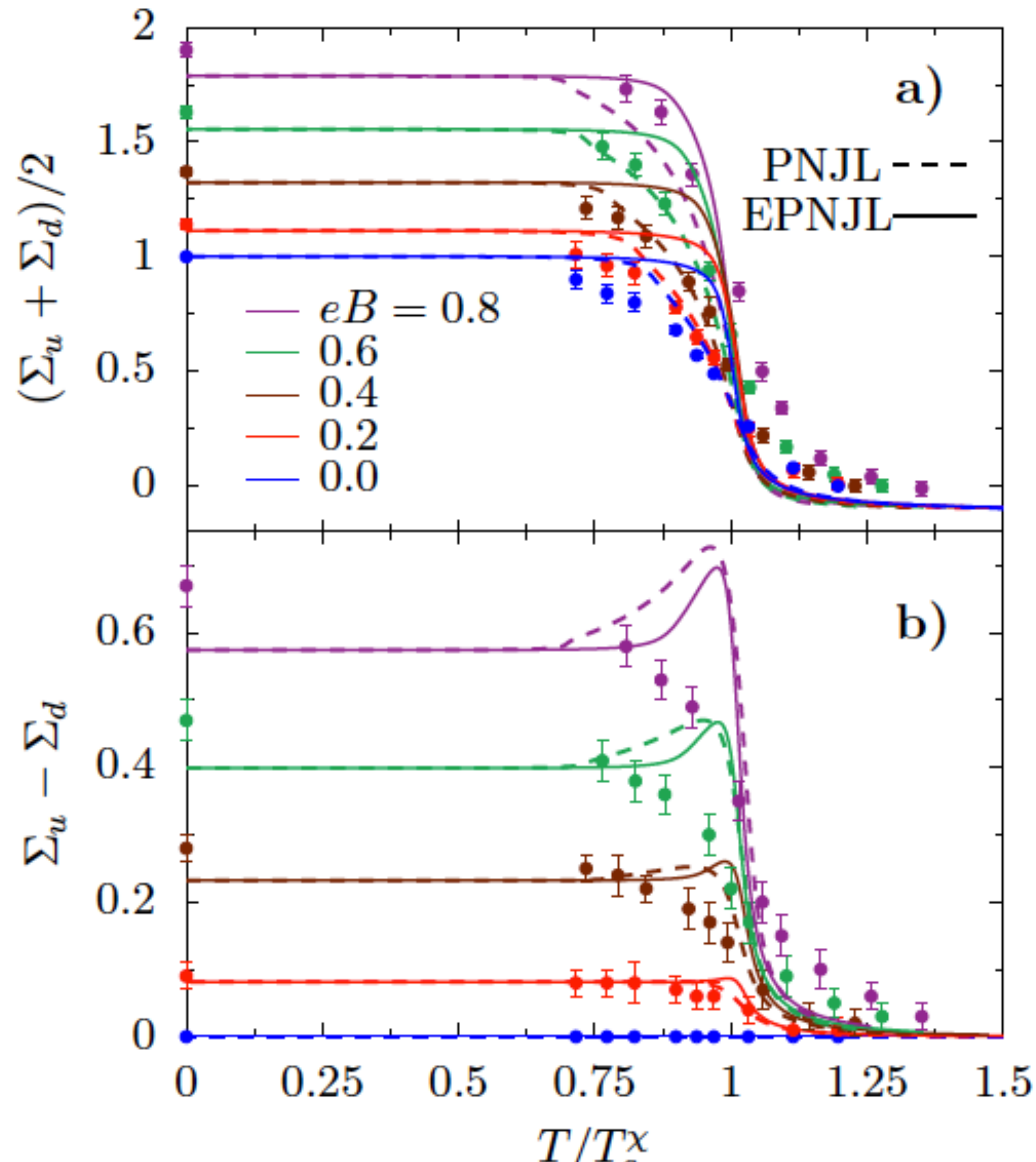
Márcio Ferreira, Pedro Costa (Coimbra U.), Débora P. Menezes (Santa Catarina U.), Constança Providência (Coimbra U.), Norberto Scoccola (Favaloro U. & CNEA, Buenos Aires). May 21, 2013. 6 pp.

Published in Phys.Rev. D89 (2014) 016002

DOI: 10.1103/PhysRevD.89.016002

IMC with critical temperature for the deconfinement phase transition in pure gauge $T_0 = T_0(B)$

EPNJL + TO=TO(B)



a)
b)
PNJL
EPNJL
$eB = 0.8$
0.6
0.4
0.2
0.0
$(\Sigma_u + \Sigma_d)/2$
$\Sigma_u - \Sigma_d$
T/T_c^χ
0
0.25
0.5
0.75
1
1.25
1.5
0.2
0.4
0.6
0.5
1.5
2

Recently...

A search for inverse magnetic catalysis in thermal quark-meson models

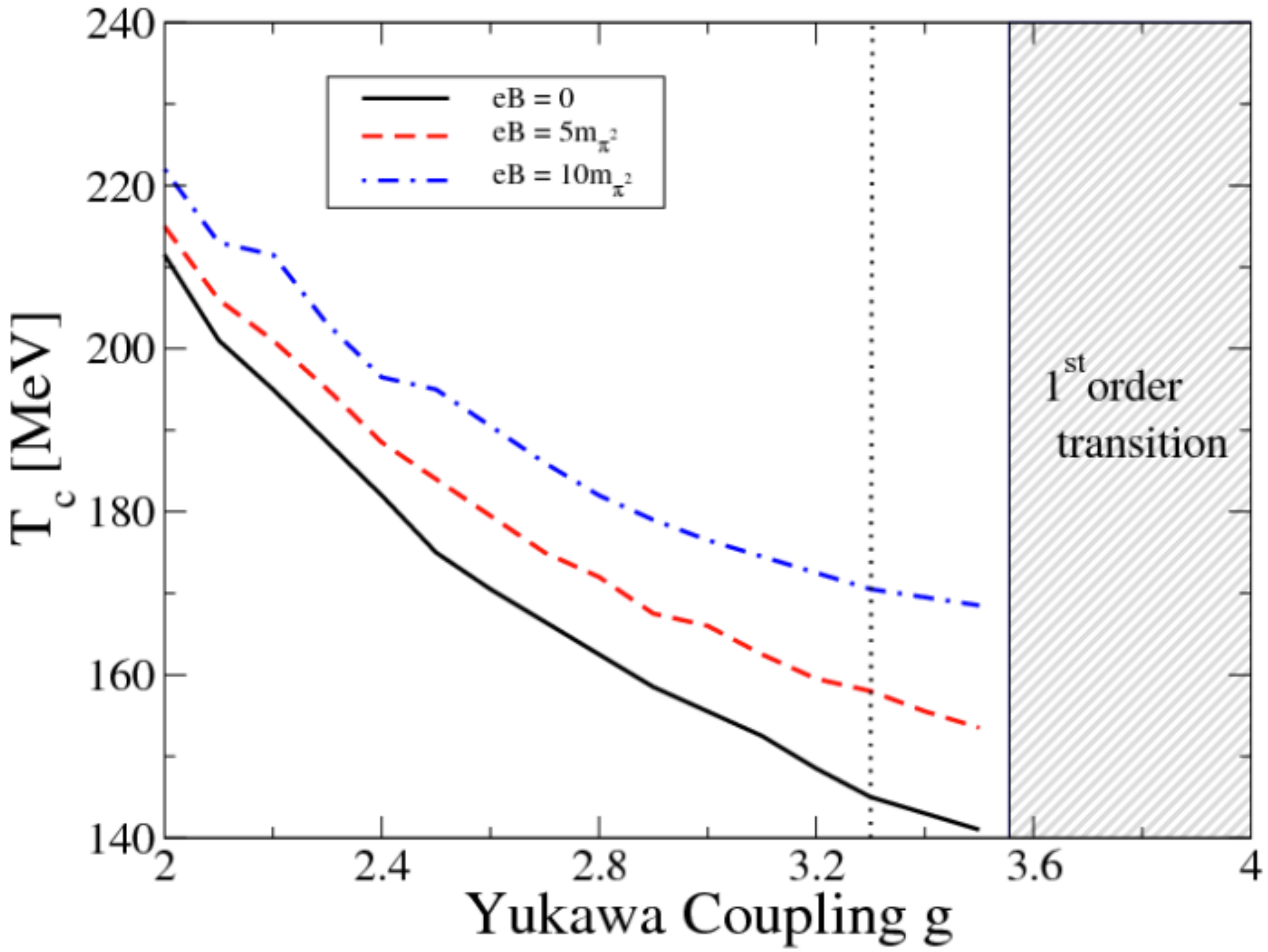
E. S. Fraga, B. W. Mintz, J. Schaffner-Bielich

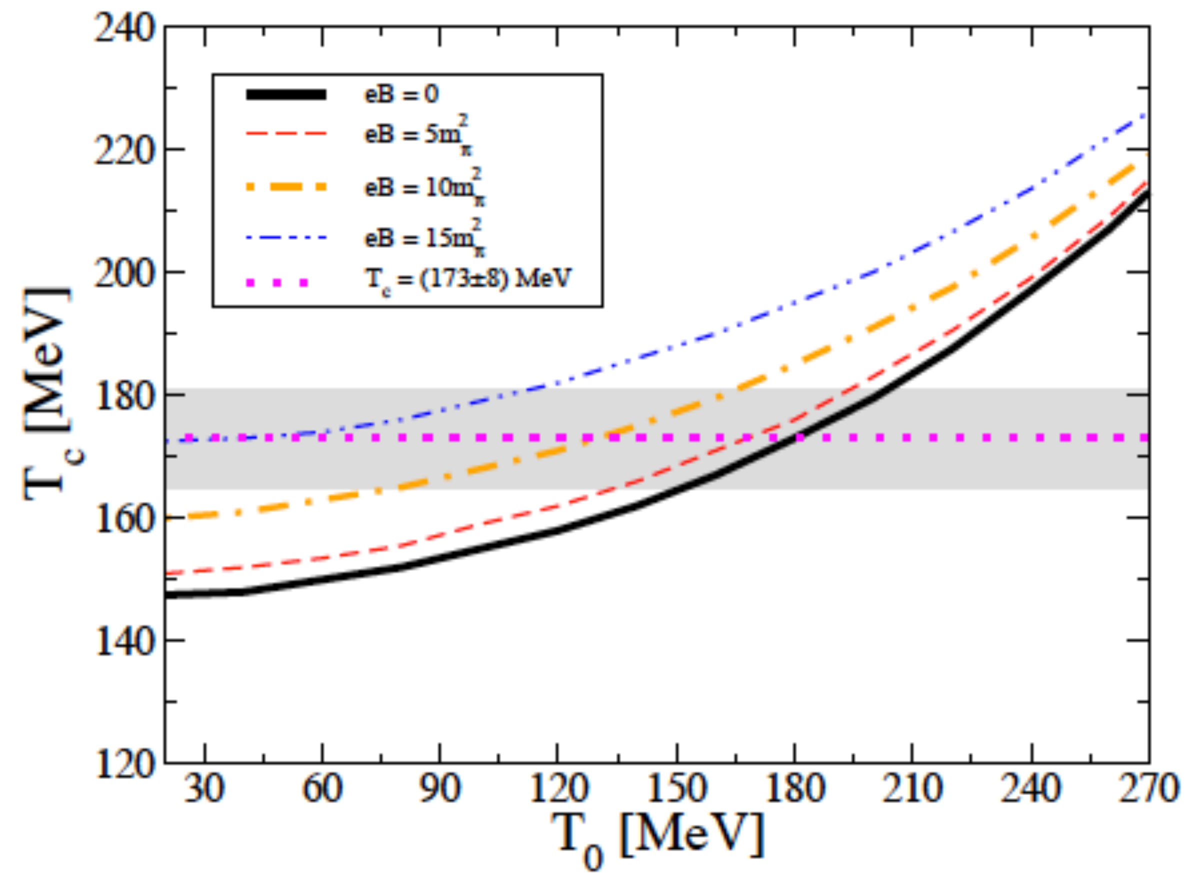
(Submitted on 15 Nov 2013)

We explore the parameter space of the two-flavor thermal quark-meson model and its Polyakov loop-extended version under the influence of a constant external magnetic field B. We investigate the behavior of the pseudo critical temperature for chiral symmetry breaking taking into account the likely dependence of two parameters on the magnetic field: the Yukawa quark-meson coupling and the parameter T0 of the Polyakov loop potential. Under the constraints that magnetic catalysis is realized at zero temperature and the chiral transition at B=0 is a crossover, we find that the quark-meson model leads to thermal magnetic catalysis for the whole allowed parameter space, in contrast to the present picture stemming from lattice QCD.

Published in Phys.Lett. B731 (2014) 154-158

in this paper...





"If one takes the usual parameter fixing in the vacuum, $g(0) \approx 3.3$, there is no continuous function $g(B)$ that could lead to inverse magnetic catalysis in the QM model at finite temperature and zero quark chemical potential, unless the chiral transition is of first order"

Our Purpose

The Nobel Prize in Physics 2004
David J. Gross, H. David Politzer, Frank Wilczek

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The Nobel Prize in Physics 2004

David J. Gross
Prize share: 1/3

H. David Politzer
Prize share: 1/3

Frank Wilczek
Prize share: 1/3

The Nobel Prize in Physics 2004 was awarded jointly to David J. Gross, H. David Politzer and Frank Wilczek *"for the discovery of asymptotic freedom in the theory of the strong interaction"*.

Effective quark theories as the NJL model can be motivated by -> QCD integrating out gluonic degrees of freedom.

Although some features of confinement can be enforced by means of extending the model with the Polyakov loop…

the running with energy scales of the effective coupling, as e.g. due to asymptotic freedom, is lost.

we have examined the effect of introducing a running coupling G

motivated by asymptotic freedom.

Our Purpose

Let us recall the important result by Miransky and Shovkovy (for $eB \gg \Lambda^2_{QCD}$)

V. A. Miransky and I. A. Shovkovy, Phys. Rev. D 66, 045006 (2002)

The leading order running of the QCD coupling constant α_s is given by

$$\frac{1}{\alpha_s} \sim b \ln \frac{eB}{\Lambda^2_{QCD}}$$ with $b = (11N_c - 2N_f)/12\pi$

As $[\alpha_s] = [G\Lambda^2]$ we propose for the NJL coupling, at $T = 0$, the interpolating formula

$$G(B) = \frac{G_0}{1 + \alpha \ln\left(1 + \beta\, \frac{eB}{\Lambda^2_{QCD}}\right)}$$

Our Purpose

$$G(B) = \frac{G_0}{1 + \alpha \ln\left(1 + \beta \frac{eB}{\Lambda_{QCD}^2}\right)}$$

with $G_0 = 5.022\ \mathrm{GeV}^{-2}$, which is the value of the coupling at B=0.

α and β are fixed to obtain a reasonable description of the lattice average $\frac{(\Sigma_u + \Sigma_d)}{2}$ for T=0

At high temperatures, α_s also runs as the inverse of

$$\ln\left(\frac{T}{\Lambda_{QCD}}\right)$$

Our Purpose

However, the values of T used in the lattice simulations

$$T \leq \Lambda_{QCD}$$

are not high enough to justify the use of such a running for G.

Moreover, the exact dependence of the coupling with B AND T is not known presently.

$$G(B) \simeq G_0 \left(1 - \alpha\beta eB/\Lambda_{QCD}^2\right)$$

We use the T dependence for G similar used in

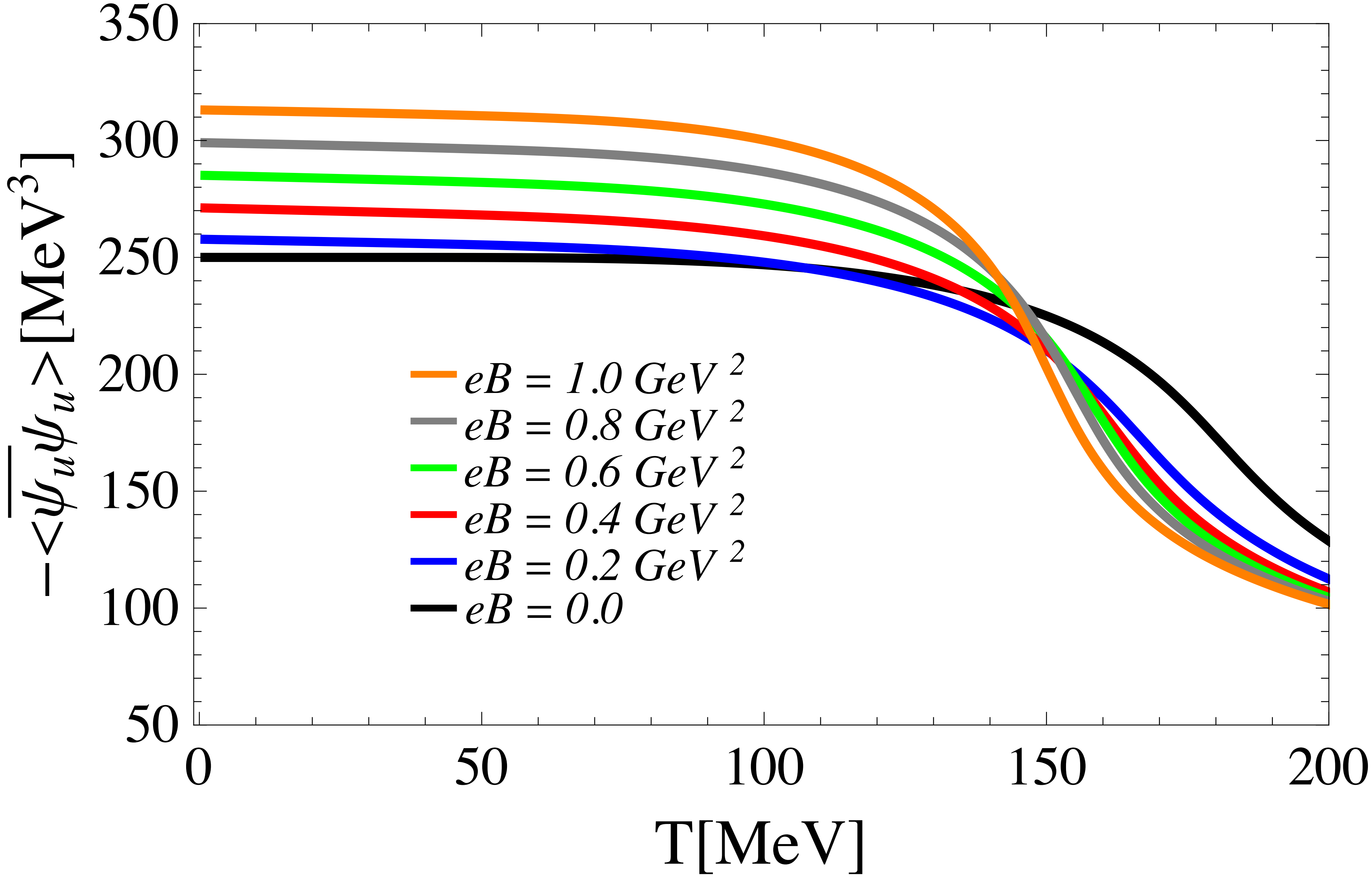
V. Bernard, U.-G. Meissner, and I. Zahed, Phys. Rev. D 36, 819 (1987).

Our Ansatz:

$$G(B,T) = G(B)\left(1 - \gamma\,\frac{|eB|}{\Lambda_{QCD}^2}\,\frac{T}{\Lambda_{QCD}}\right)$$

γ for reasonable lattice $\frac{(\Sigma_u + \Sigma_d)}{2}$ at high T.

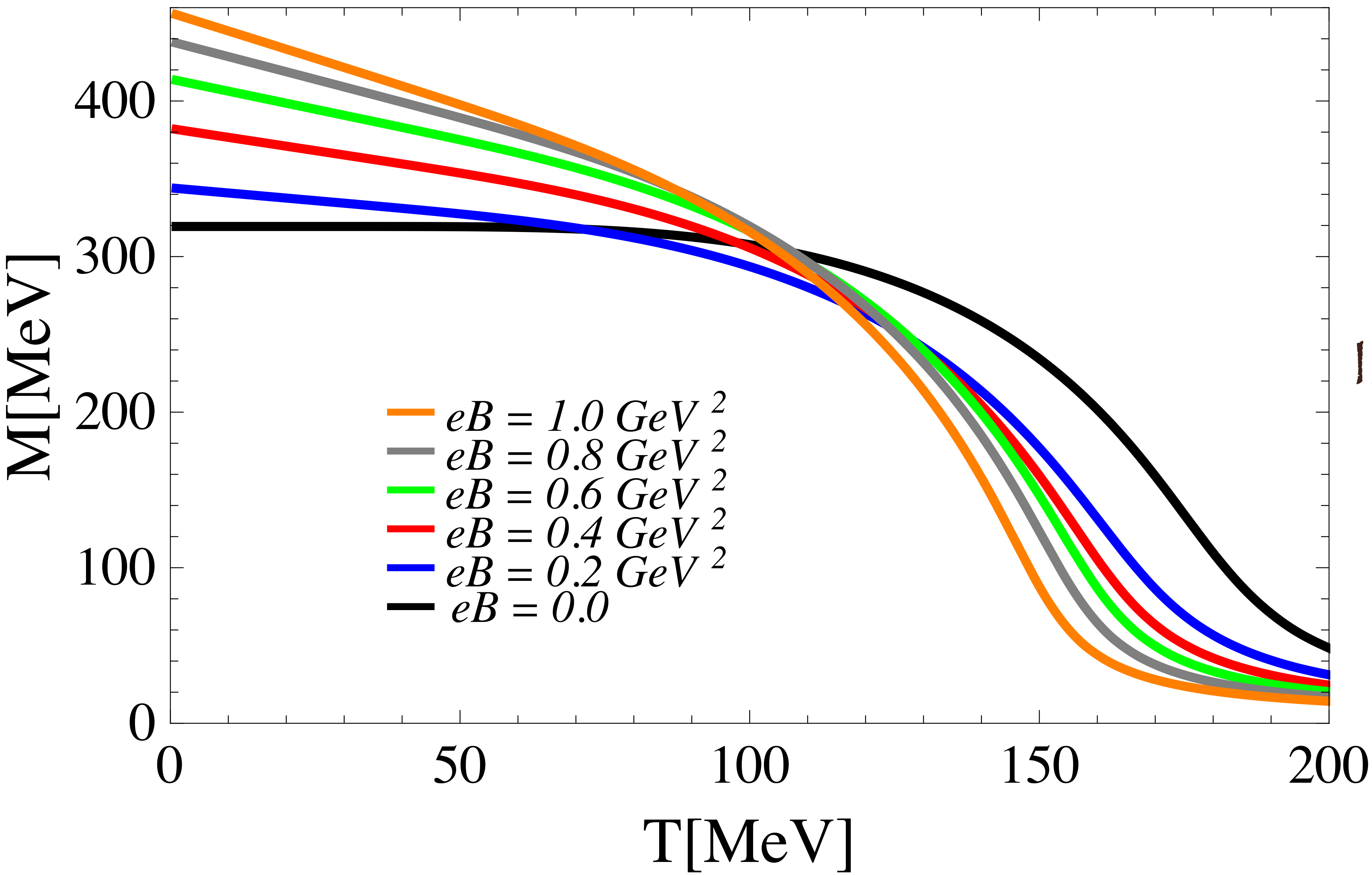
Numerical Results - quark(u) condensate



MC at T=0

IMC at high T

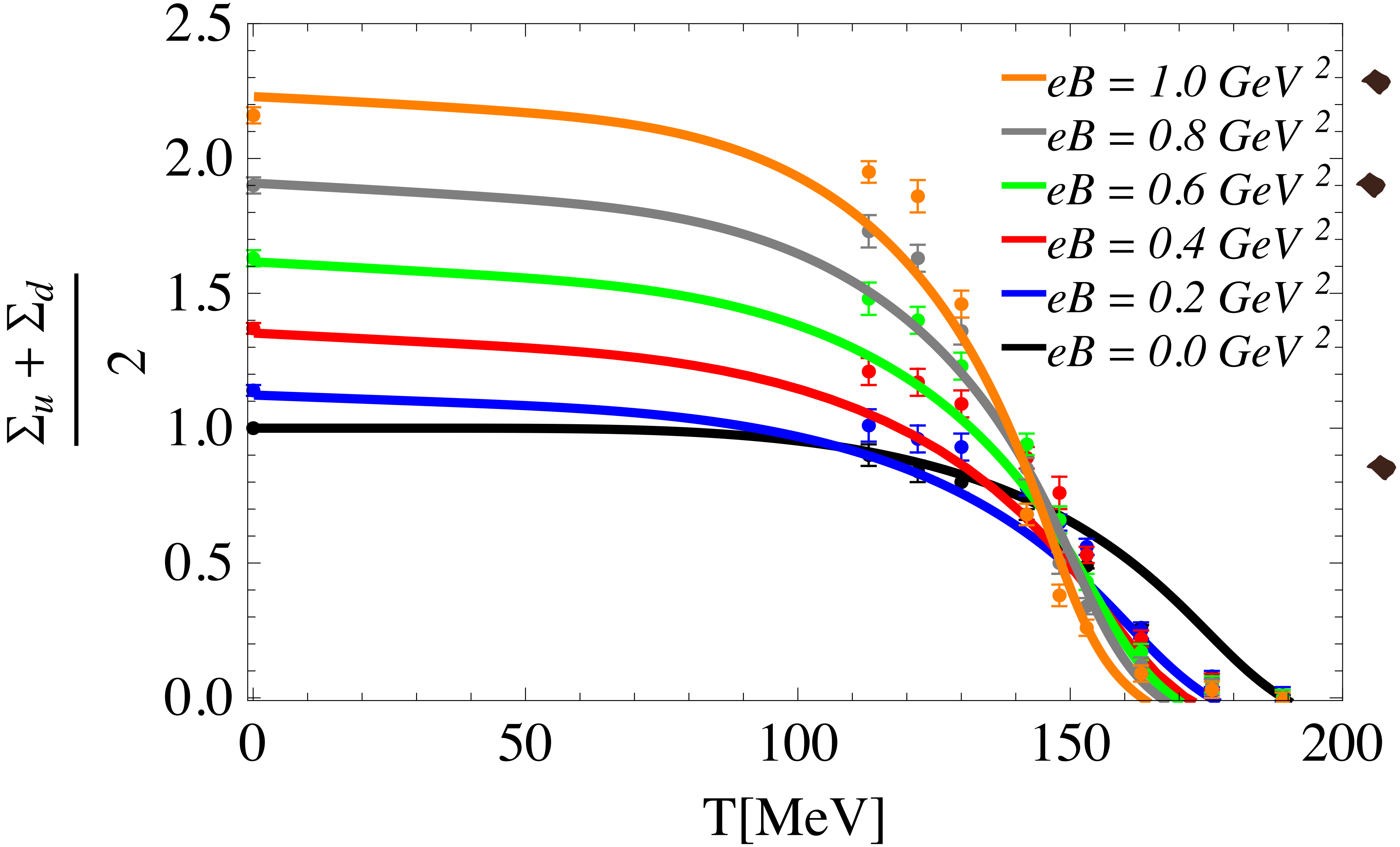
Numerical Results - Thermal Mass



MC at T=0

IMC at high T

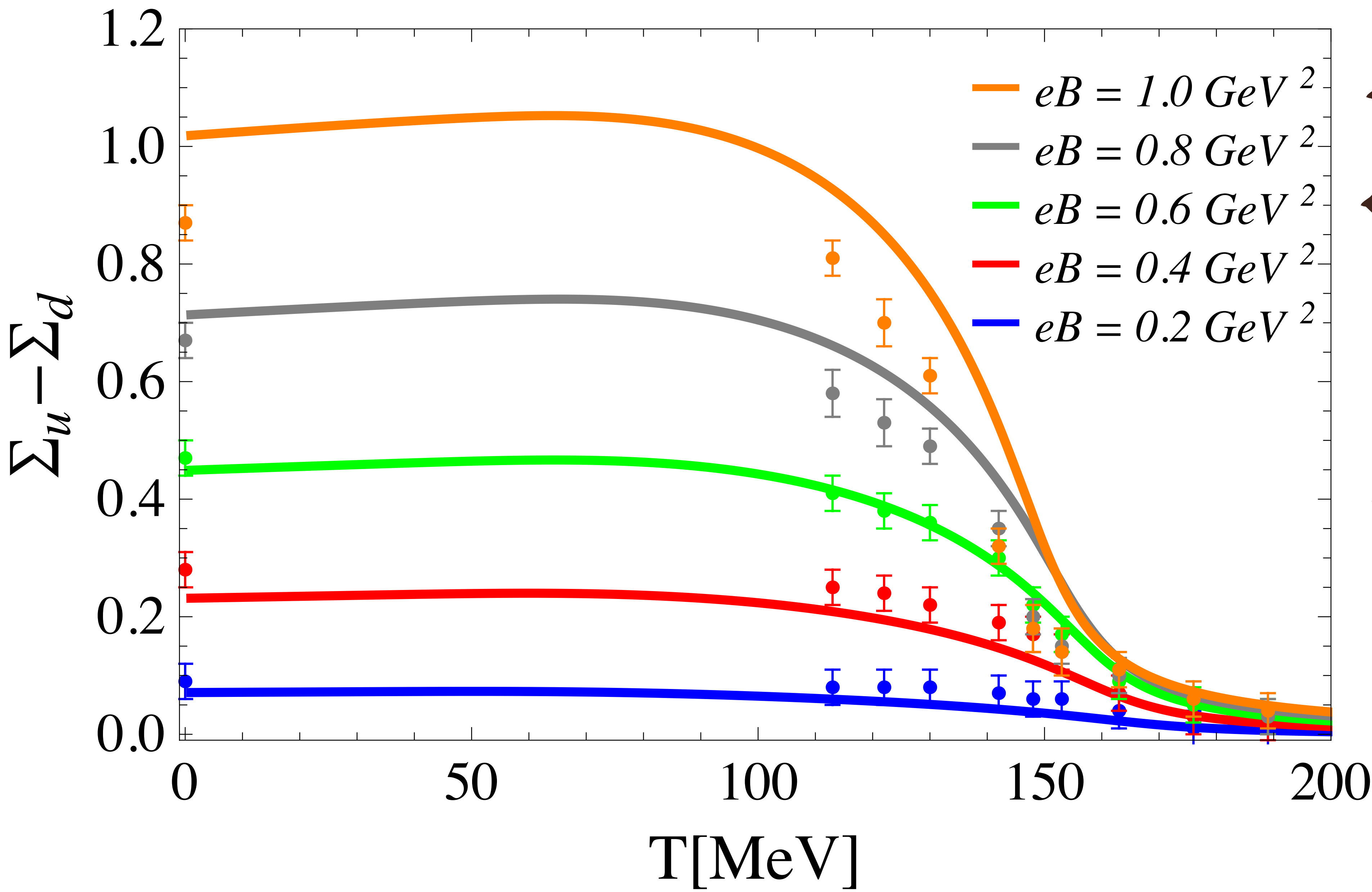
Numerical Results - condensate average



- MC at T=0
- good results at T=0
- IMC at high T

Lattice data points - G. S. Bali, F. Bruckmann, G. Endrodi, Z. Fodor, S. D.Katz,S.Krieg,andA.Schafer,Phys.Rev.D86, 071502(R) (2012).

Numerical Results - condensate difference



- MC at T=0
- good results at T=0
- IMC at high T

Lattice data points - G. S. Bali, F. Bruckmann, G. Endrodi, Z. Fodor, S. D.Katz,S.Krieg,and A.Schafer,Phys.Rev.D86, 071502(R) (2012).

Pseudocritical temperature T_{PC} X B

we consider the physical point with nonzero m

at high temperatures -> crossover

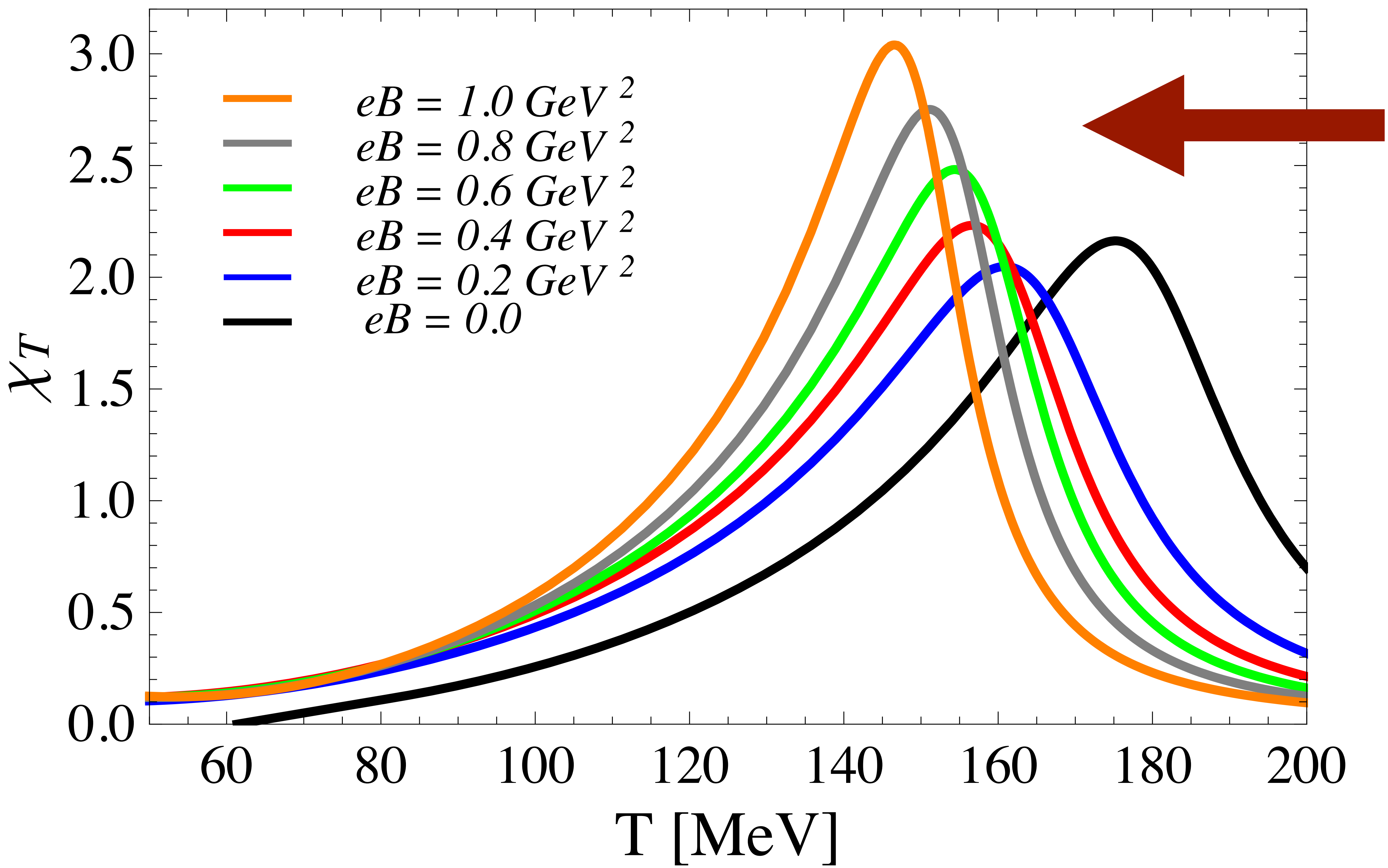
chiral symmetry is partially restored.

One can only establish a pseudocritical temperature T_{PC}

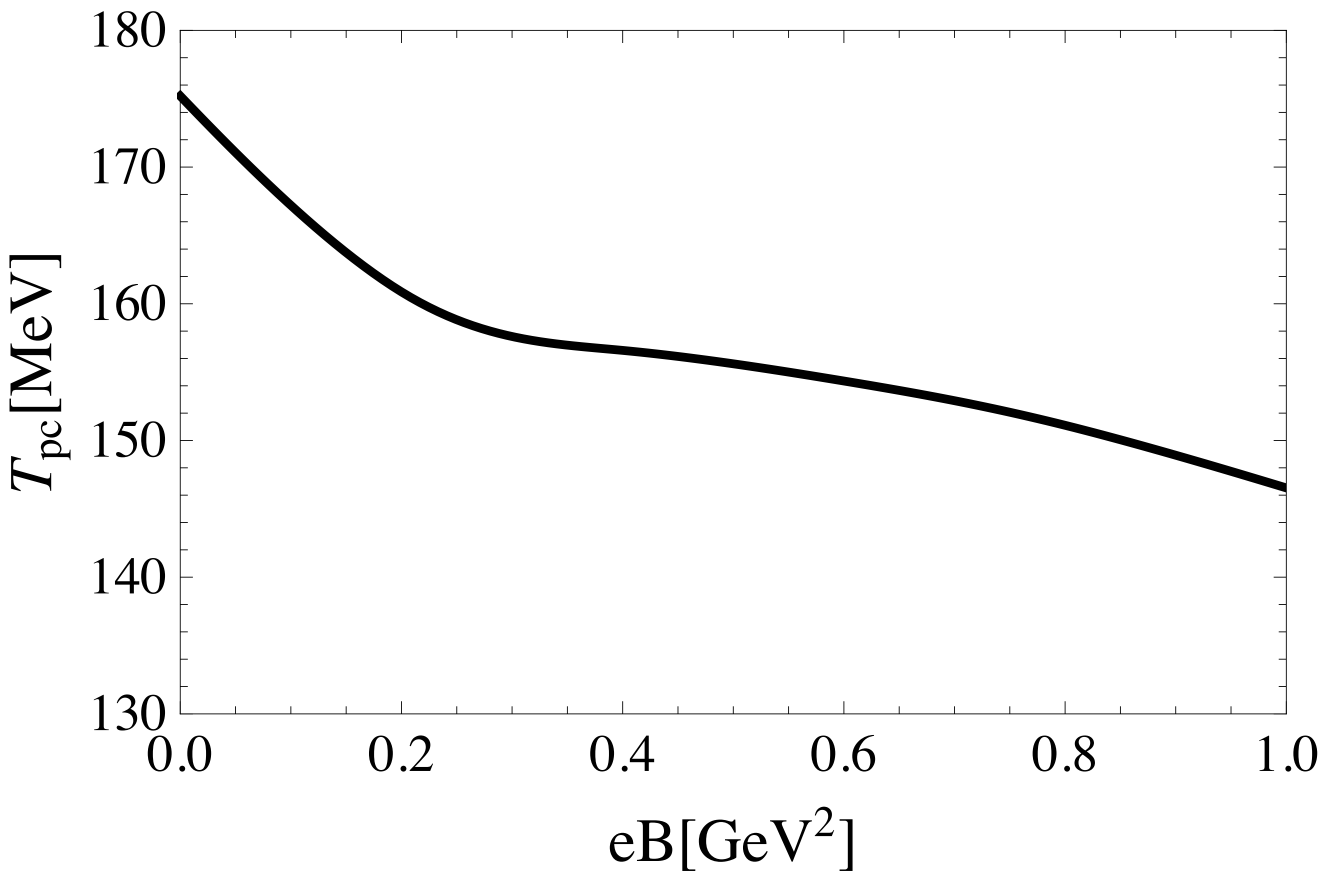
we use the location of the peaks for the vacuum normalized quark condensates, where the thermal susceptibilities are:

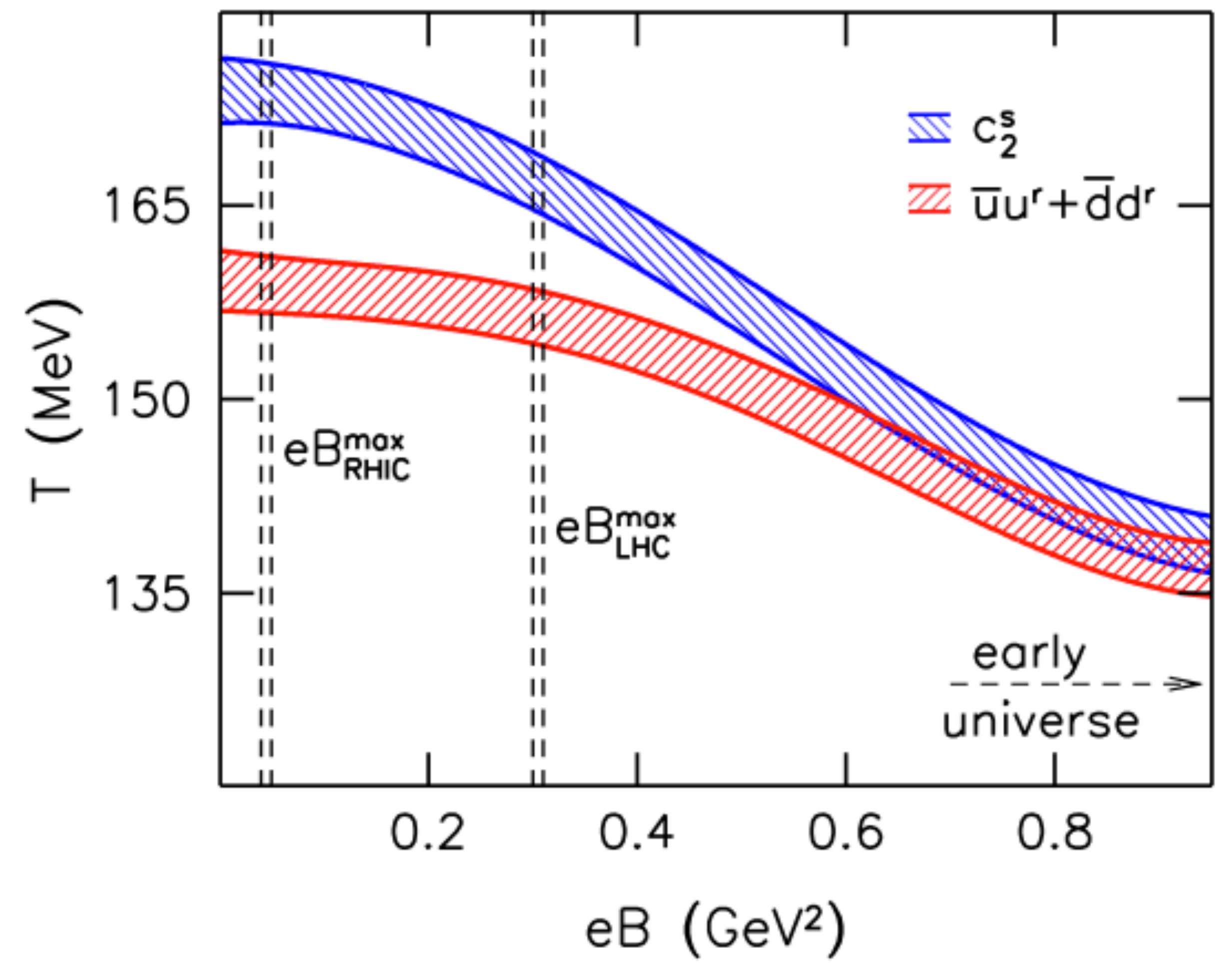
$$\chi_T = -m_\pi \frac{\partial \sigma}{\partial T} \quad \text{where} \quad \sigma = \frac{\langle \bar{\psi}_u \psi_u \rangle (B,T) + \langle \bar{\psi}_d \psi_d \rangle (B,T)}{\langle \bar{\psi}_u \psi_u \rangle (B,0) + \langle \bar{\psi}_d \psi_d \rangle (B,0)}$$

Numerical Results - normalized thermal susceptibility



Numerical Results - T_{PC} X B



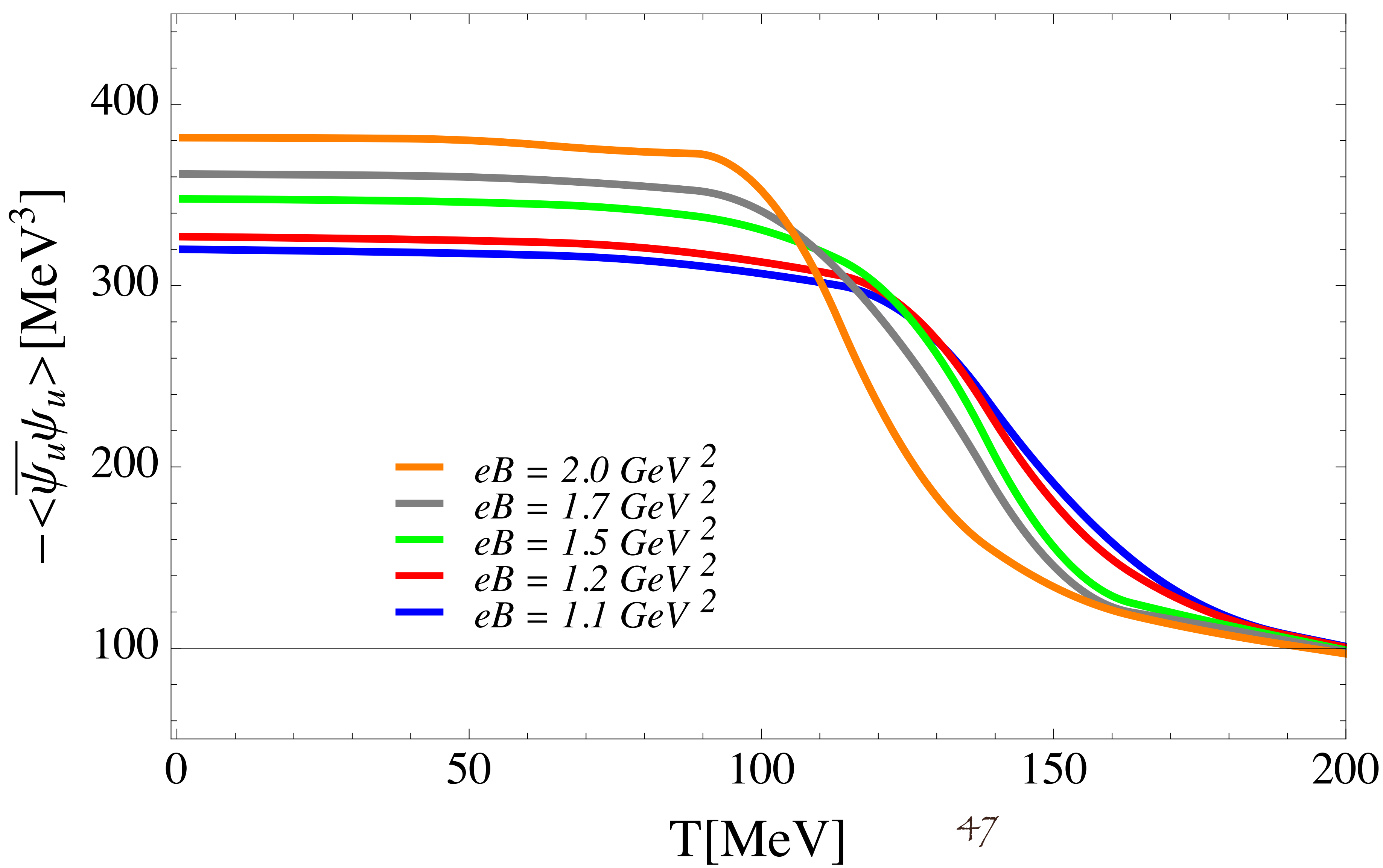


Left panel: our results

Right panel: G. S. Bali, F. Bruckmann,G.Endrodi, Z. Fodor, S. D. Katz, S. Krieg, A. Schafer and K. K. Szabo, JHEP 1202, 044 (2012)

Possible Questions:

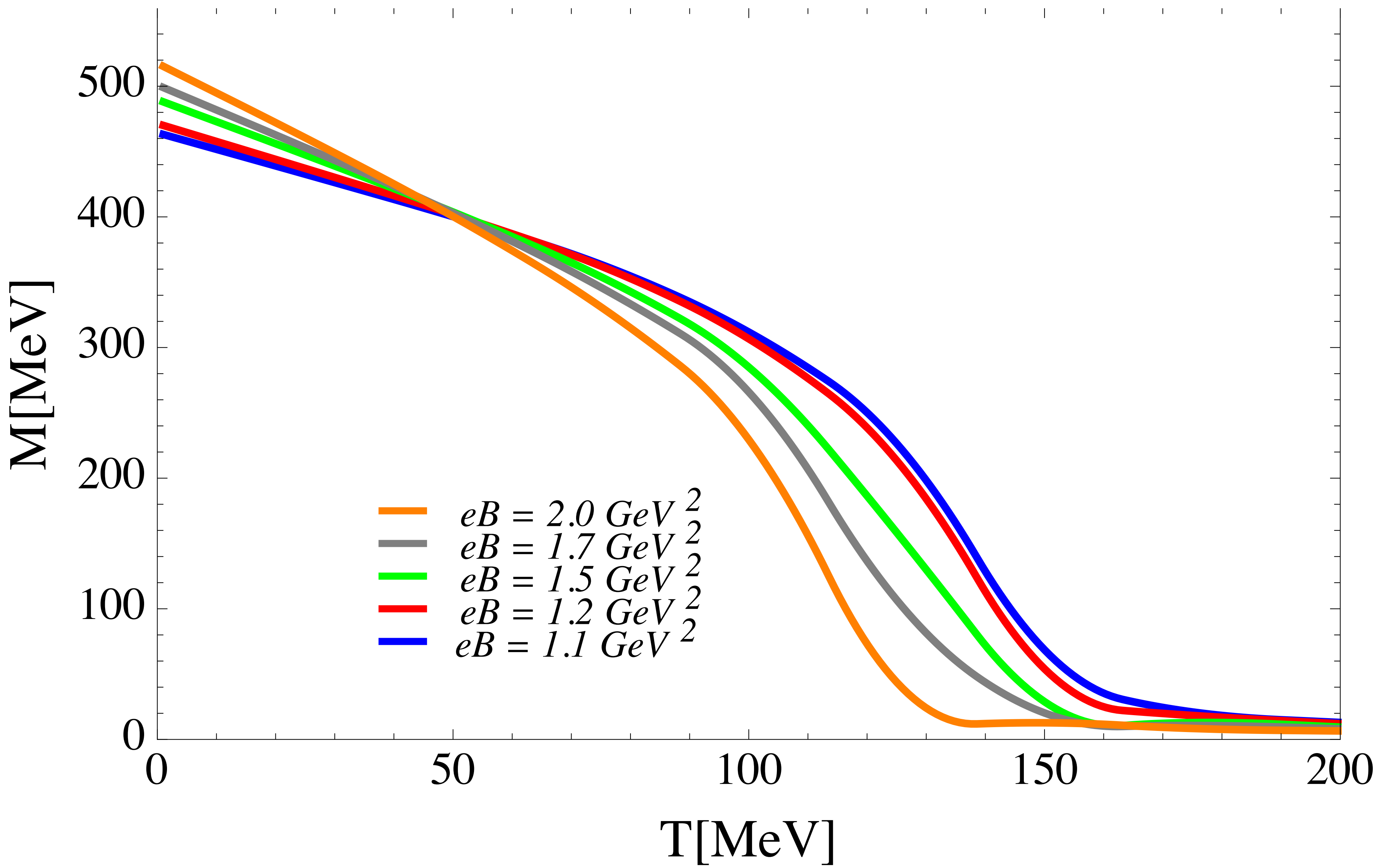
- Similar effect in QMM? in progress...
- If we increase the magnetic field?



MC at T=0

IMC at high T

Possible Questions:



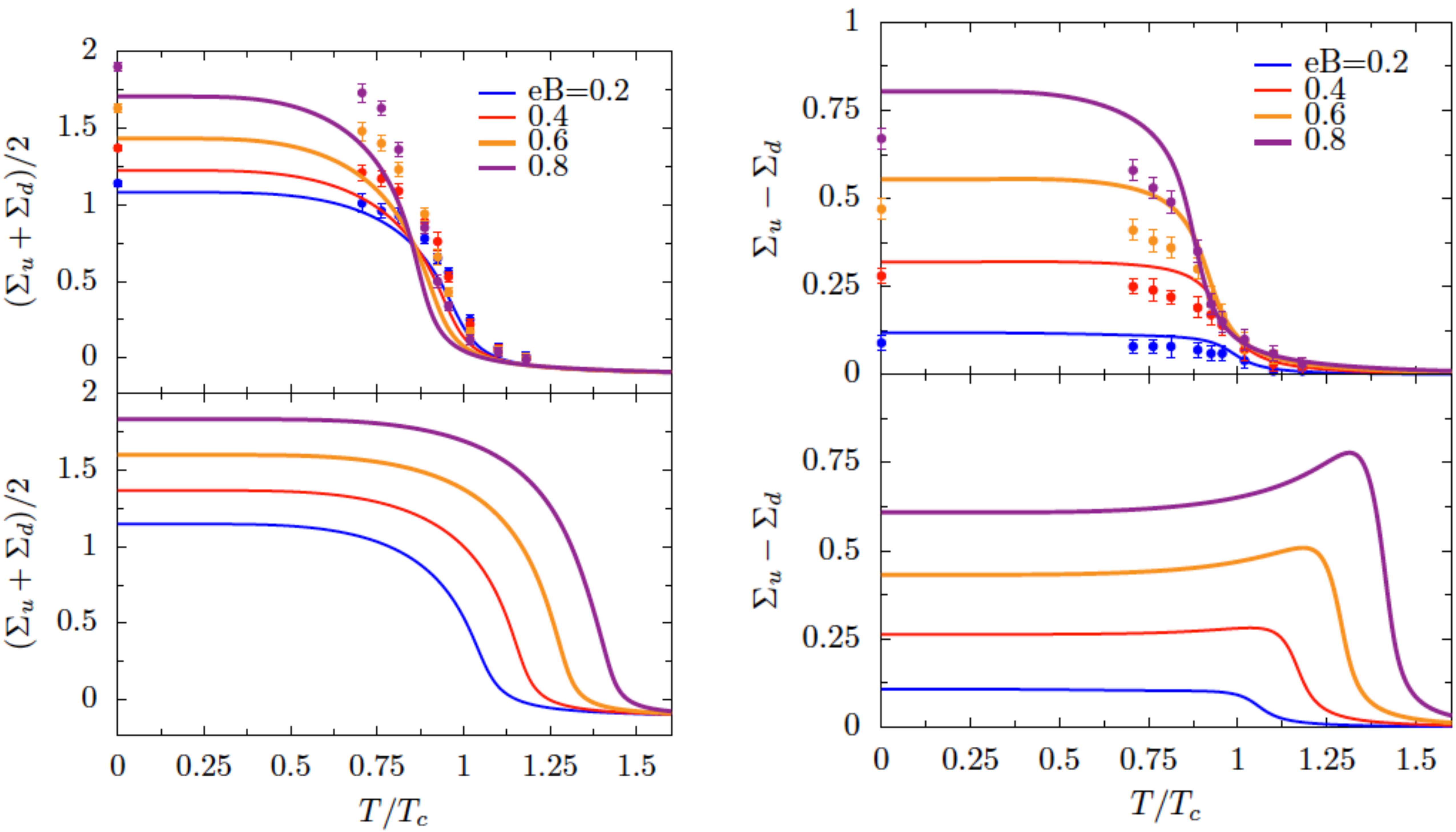
MC at T=0

IMC at high T

Recently...

Magnetic inverse catalysis in the (2+1)-flavor Nambu--Jona-Lasinio and Polyakov--Nambu--Jona-Lasinio models
M. Ferreira, P. Costa, O. Lourenço, T. Frederico,
C. Providência. Apr 22, 2014. 8 pp.
e-Print: arXiv:1404.5577 [hep-ph] | PDF

SU(3) PNJL + G(B) (fitted with the lattice)



Final Remarks

- Our aim -> understanding discrepancies between effective model predictions and recent lattice results . The behavior of T_{PC} as a function of B

- we have examined the effect of introducing a running coupling G motivated by asymptotic freedom.

Final Remarks

- Our assumption of the decrease of G with B and T -> mimicking asymptotic freedom in QCD

- This represents a concrete realization of the back reaction of the sea quarks and confirms its potential importance on explaining the IMC as stressed in the recent literature.

Final Remarks

- But the running of G with T is crucial to obtain results with IMC (lattice results!)

Perspectives

- Asymptotic freedom in QMM (in progress collaboration with G.Krein and M.B. Pinto)
- B effects on BEC BCS crossover in progress (in progress - collaboration with R.O.Ramos)
- B effects on the Langevin Dynamics
- SDE + T + B ???

This talk was based in:

The Importance of Asymptotic Freedom for the Pseudocritical Temperature in Magnetized Quark Matter

R.L.S. Farias, K.P. Gomes, G.I. Krein, M.B. Pinto. Apr 15, 2014. 5 pp.

e-Print: arXiv:1404.3931 [hep-ph]

Thank you for your attention!

Acknowledgments

Fapemig, Capes, Fapesp, Fapesc and Cnpq.