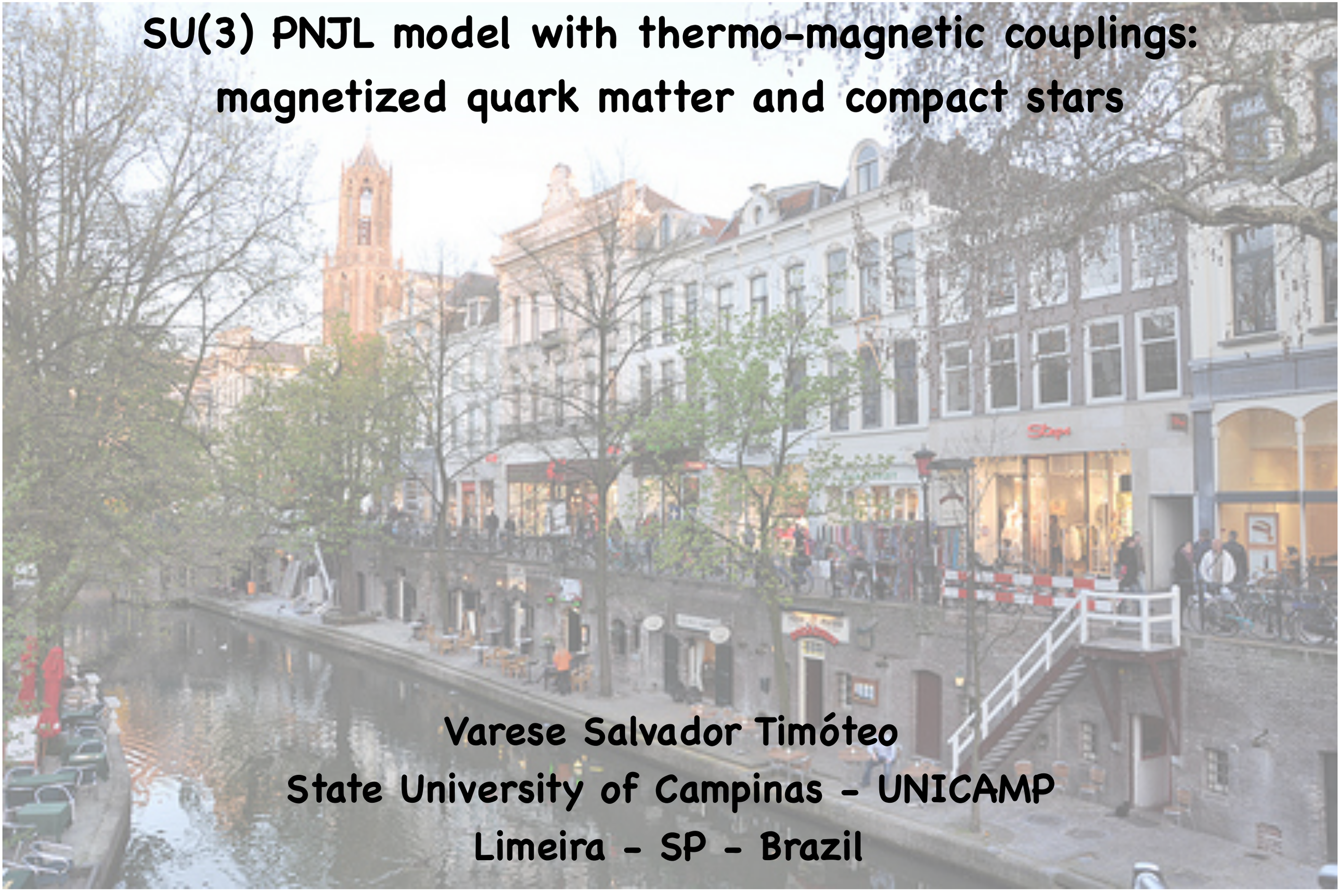
SU(3) PNJL model with thermo-magnetic couplings: magnetized quark matter and compact stars



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Collaborators

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G. Krein W. Tavares

Acknowledgements

Outline

* Introduction / Motivation

* Thermo-magnetic NJL coupling - SU(2) prototype

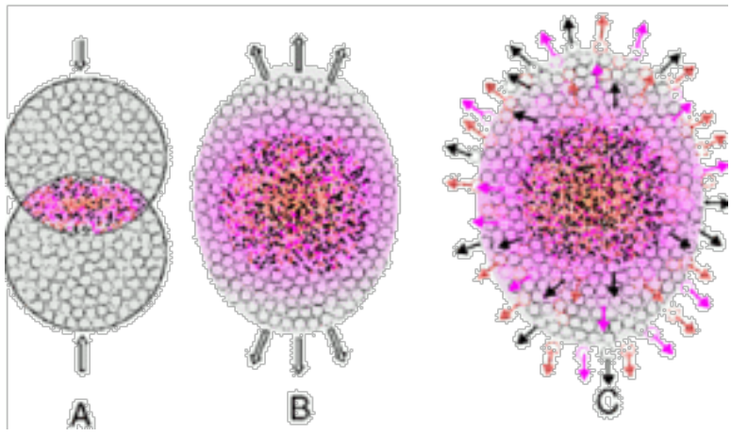
* Thermo-magnetic PNJL couplings - SU(3) - strangeness

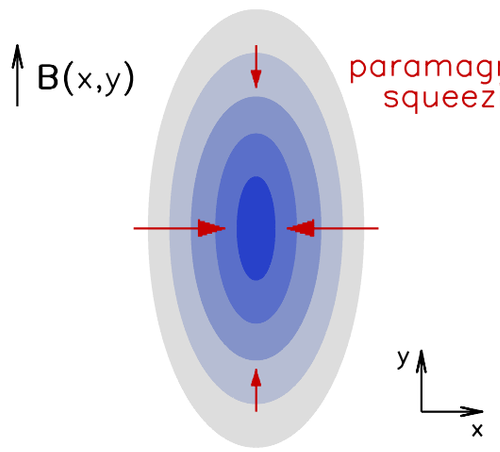
* Thermodynamics and EOS

* Compact stars

Introduction / Motivation

LHC / RHIC





"This anisotropy will then contribute to the elliptic flow observed in such collisions"

Phys. Rev. Lett. 112 (2014) 042301

Magnetars

neutron stars

hadronic matter

Related works

Eduardo Fraga, Letícia Palhares RJ

Jorge Noronha, Bruno Mintz RJ

Ricardo Farias, Gastão Krein RS

Débora Menezes, Sidney Avancini, Marcus Benghi SC

Odilon Lourenço, Tobias Frederico SP

Constância Providência PT

Norberto Scoccola AR

Models

Klevansky, Weise, Buballa, Ratti, ...

SU(2)

$$\mathcal{L}_{\mathrm{NJL}} = -\frac{1}{4} F^{\mu\nu} F_{\mu\nu} + \bar{\psi} \left(\not{D} - m \right) \psi + G \left[(\bar{\psi}\psi)^2 + (\bar{\psi} i \gamma_5 \tau \psi)^2 \right]$$

SU(3)

$$\mathcal{L} = \bar{q} \left[i \gamma_\mu D^\mu - \hat{m}_c \right] q \; + \; \mathcal{L}_{sym} \; + \; \mathcal{L}_{det}$$

$$+ \mathcal{U} \left(\Phi, \bar{\Phi}; T \right) - \frac{1}{4} F_{\mu\nu} F^{\mu\nu}$$

$$\mathcal{L}_{sym} = \frac{G_s}{2} \sum_{a=0}^{8} \left[(\bar{q} \lambda_a q)^2 + (\bar{q} i \gamma_5 \lambda_a q)^2 \right]$$

$$\mathcal{L}_{det} = -K \left\{ \det \left[\bar{q} (1 + \gamma_5) q \right] + \det \left[\bar{q} (1 - \gamma_5) q \right] \right\}$$

Mean Field Approximation

$$\Omega = -\,T\;ln\;\mathcal{Z} \qquad\qquad \mathcal{Z} = Tr\;e^{-\beta(H-\mu N)}$$

$$\Omega(T,\mu) = G_s \sum_{f=u,d,s} \left\langle \bar{q}_f q_f \right\rangle^2 + 4K \left\langle \bar{q}_u q_u \right\rangle \left\langle \bar{q}_d q_d \right\rangle \left\langle \bar{q}_s q_s \right\rangle$$

$$+\mathcal{U}(\Phi,\bar{\Phi},T) + \sum_{f=u,d,s} \left(\Omega^f_{\rm vac} + \Omega^f_{\rm med} + \Omega^f_{\rm mag}\right)$$

$$\Omega^f_{\rm vac} = -6 \int_\Lambda \frac{d^3p}{(2\pi)^3} \sqrt{p^2 + M_f^2}$$

$$\Omega^f_{\rm med} = -T \frac{|q_f B|}{2\pi} \sum_{k=0} \alpha_k \int_{-\infty}^{+\infty} \frac{dp_z}{2\pi} \left(Z^+_\Phi(E_f) + Z^-_\Phi(E_f) \right)$$

$$\Omega^f_{\rm mag} = -\frac{3(|q_f|B)^2}{2\pi^2} \left[\zeta^{'}(-1,x_f) - \frac{1}{2}(x_f^2 - x_f)\ln x_f + \frac{x_f^2}{4} \right]$$

Thermodynamics

$$\Omega = -\ T\ ln\ \mathcal{Z} \qquad\qquad \mathcal{Z} = Tr\ e^{-\beta(H-\mu N)}$$

$$\epsilon = \Omega + T\ s + \mu\ \rho$$

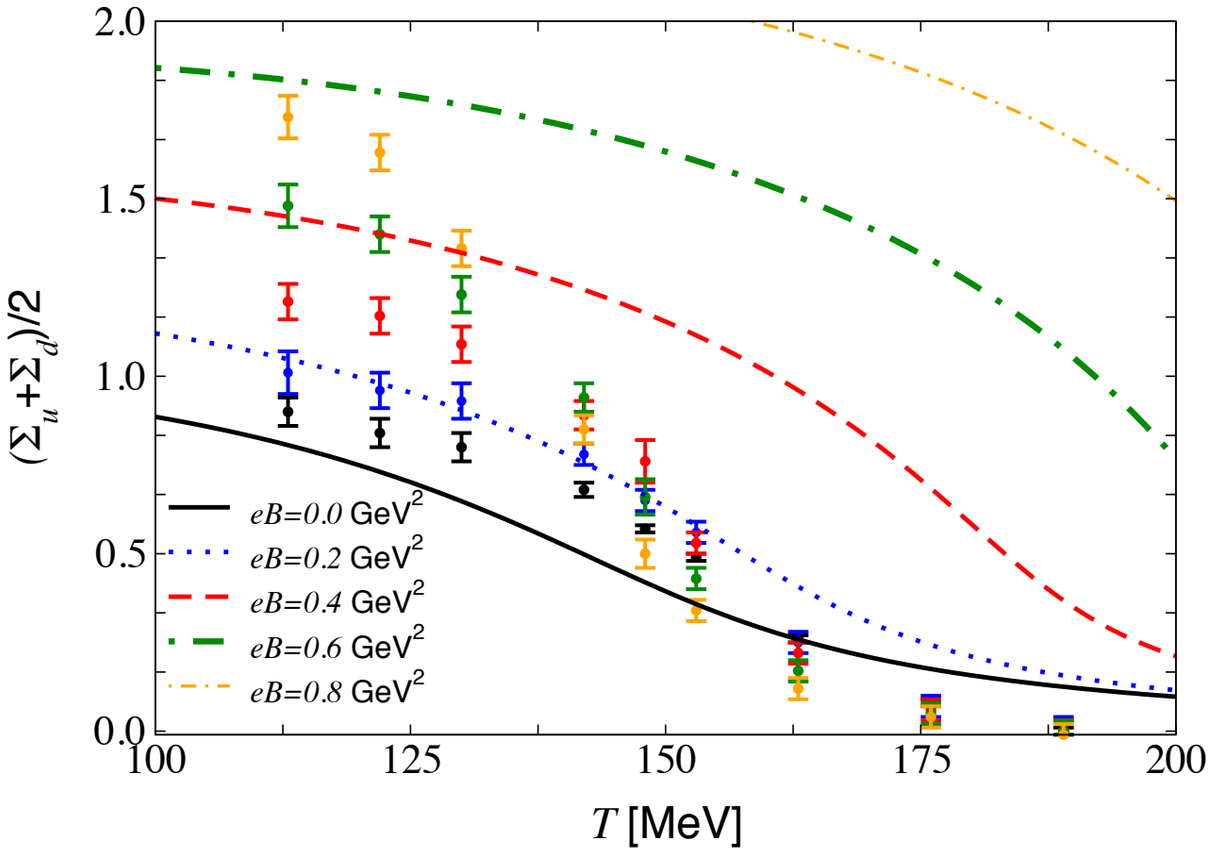
$$p = -\Omega \qquad\qquad s = -\frac{\partial \Omega}{\partial T} \qquad\qquad c_v = T\frac{dS}{dT}$$

$$\Delta = \epsilon - 3\ p \qquad\qquad v_s^2 = \frac{dp}{d\epsilon} \qquad\qquad \mathcal{M} = \frac{dp}{dB}$$

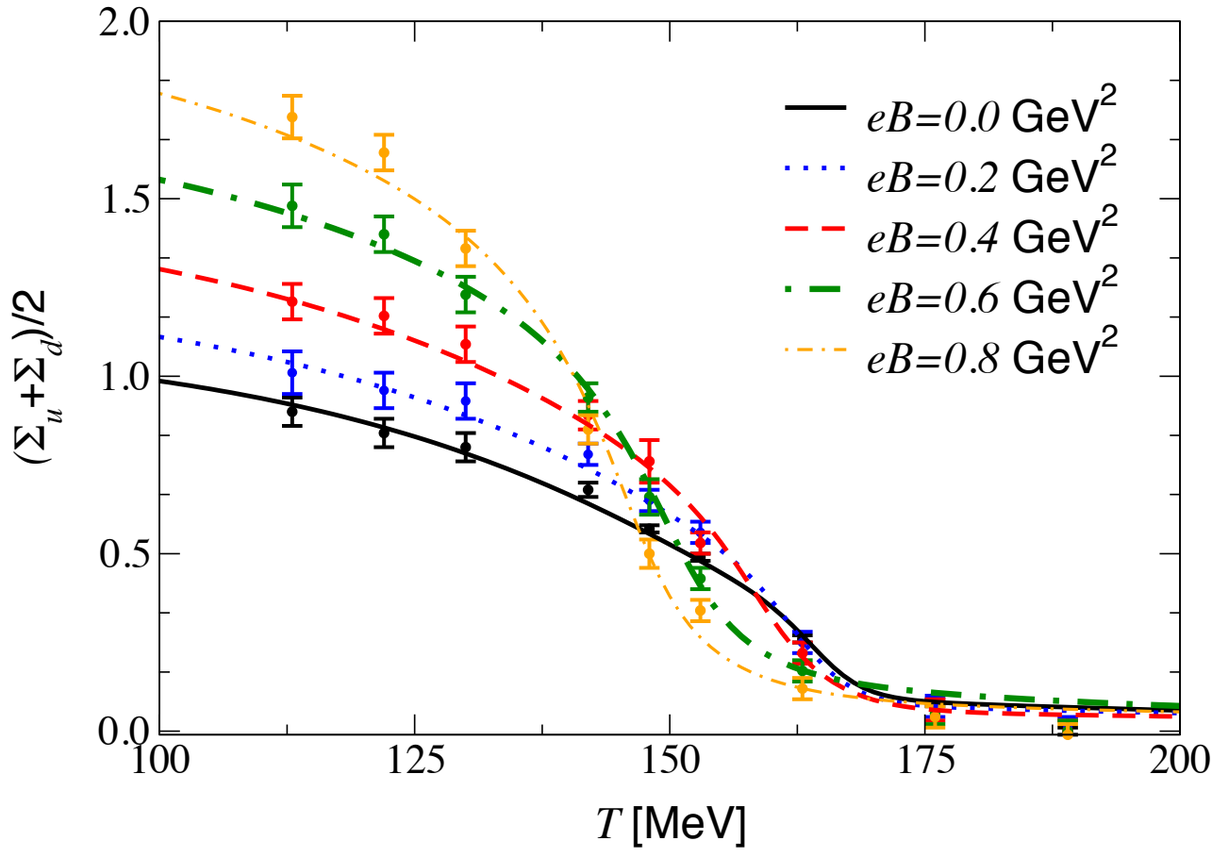
Thermo-magnetic dependent coupling prototype:

SU(2) NJL model

G



G(eB,T)



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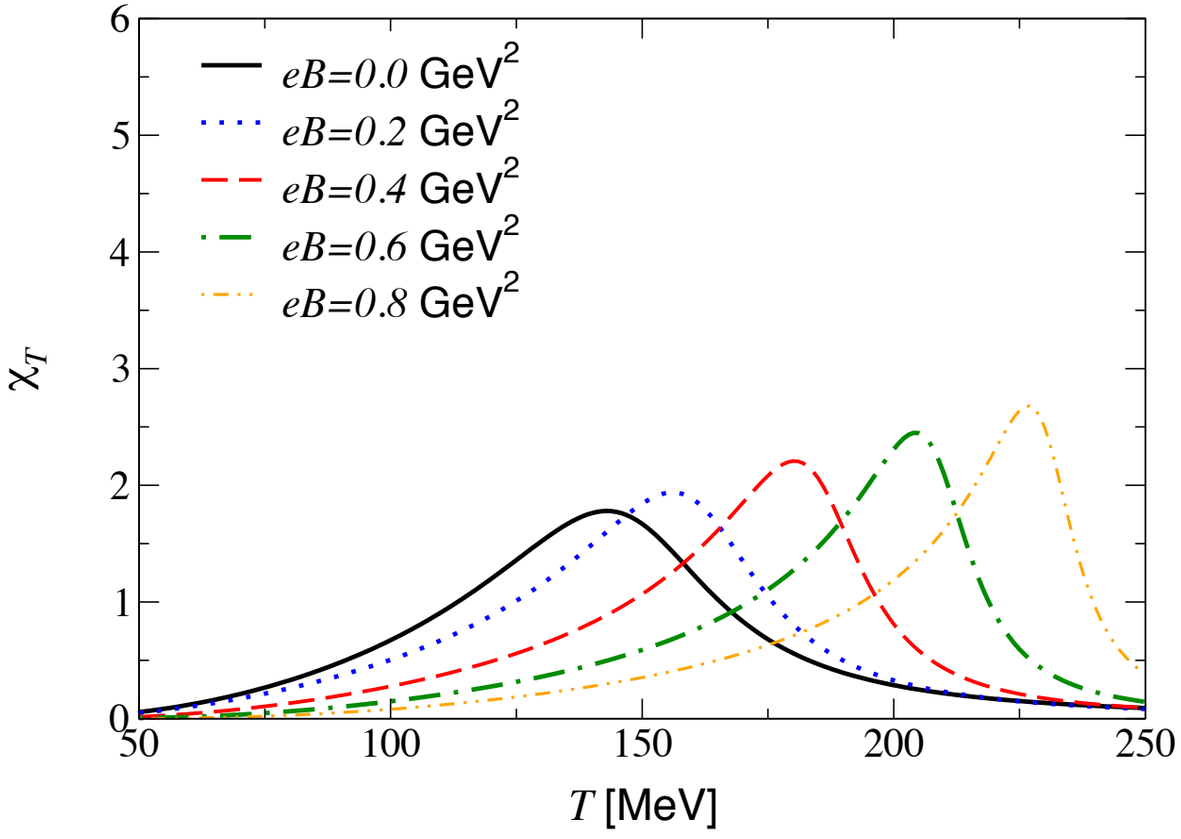
Thermal Susceptibilities

SU(2)

G



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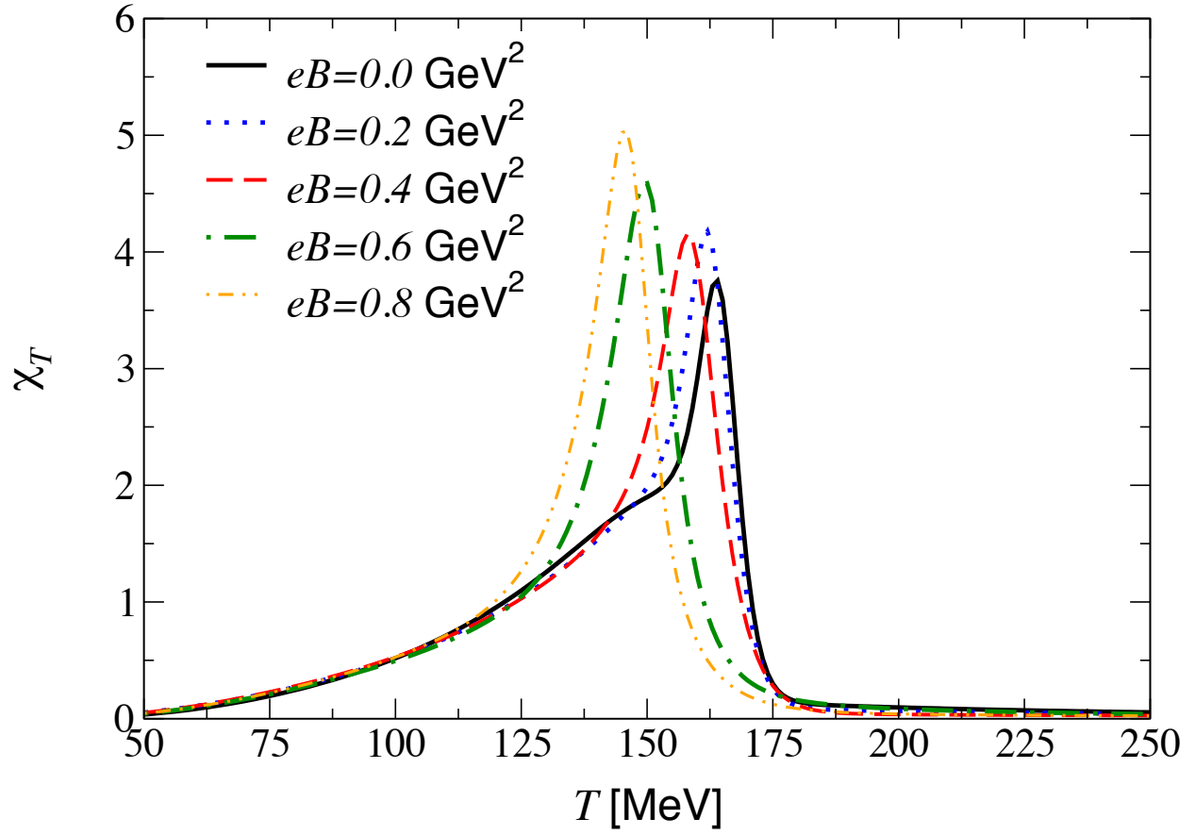

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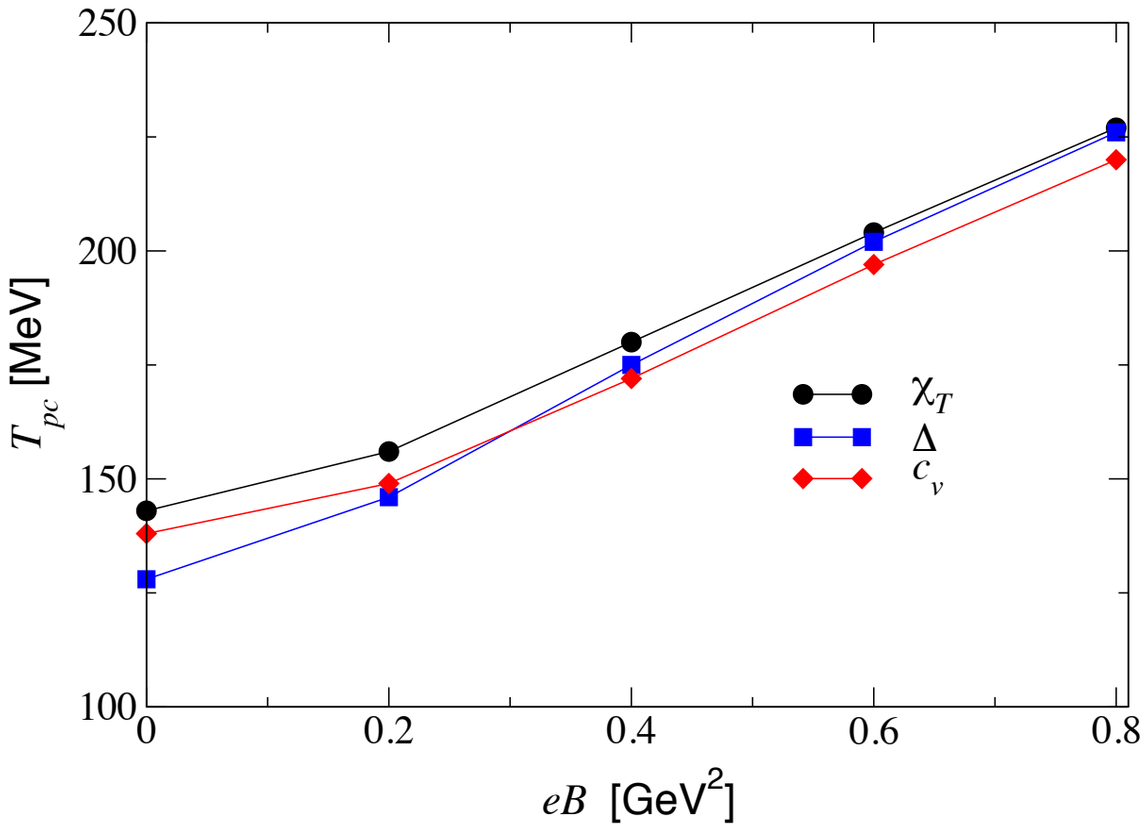
Pseudo-critical temperature

SU(2)

G



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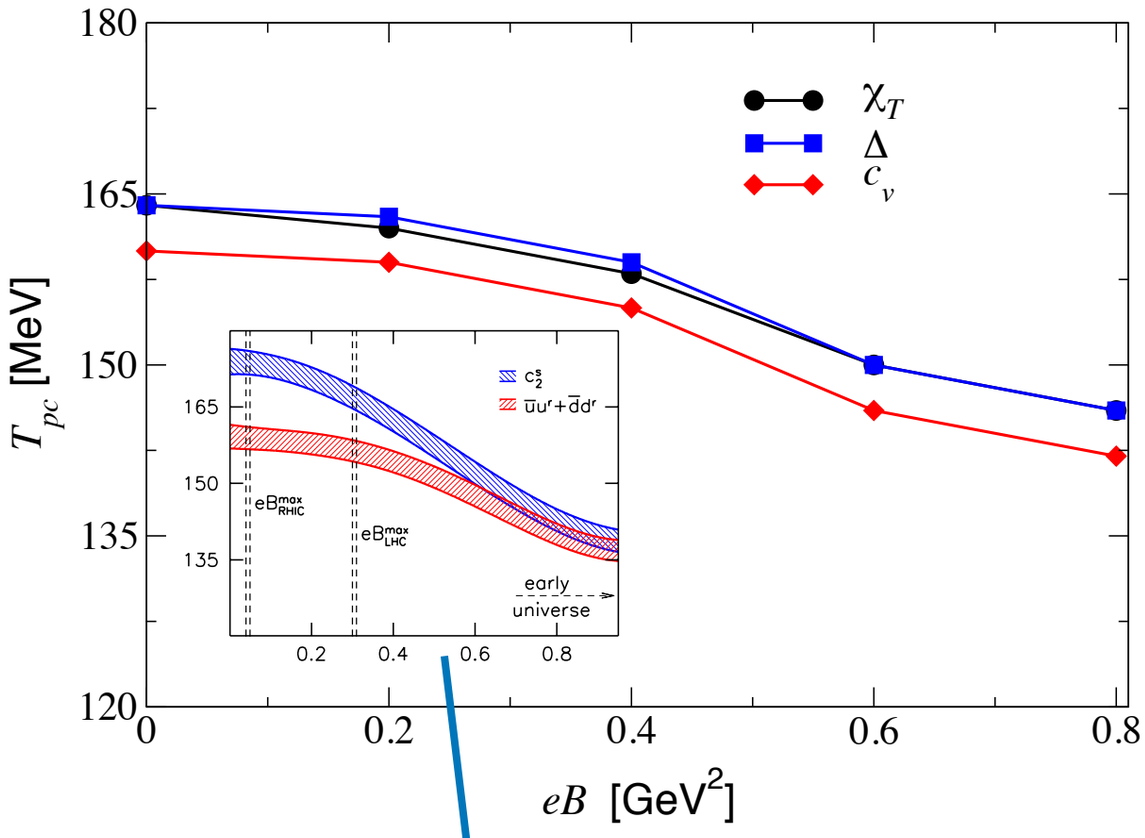

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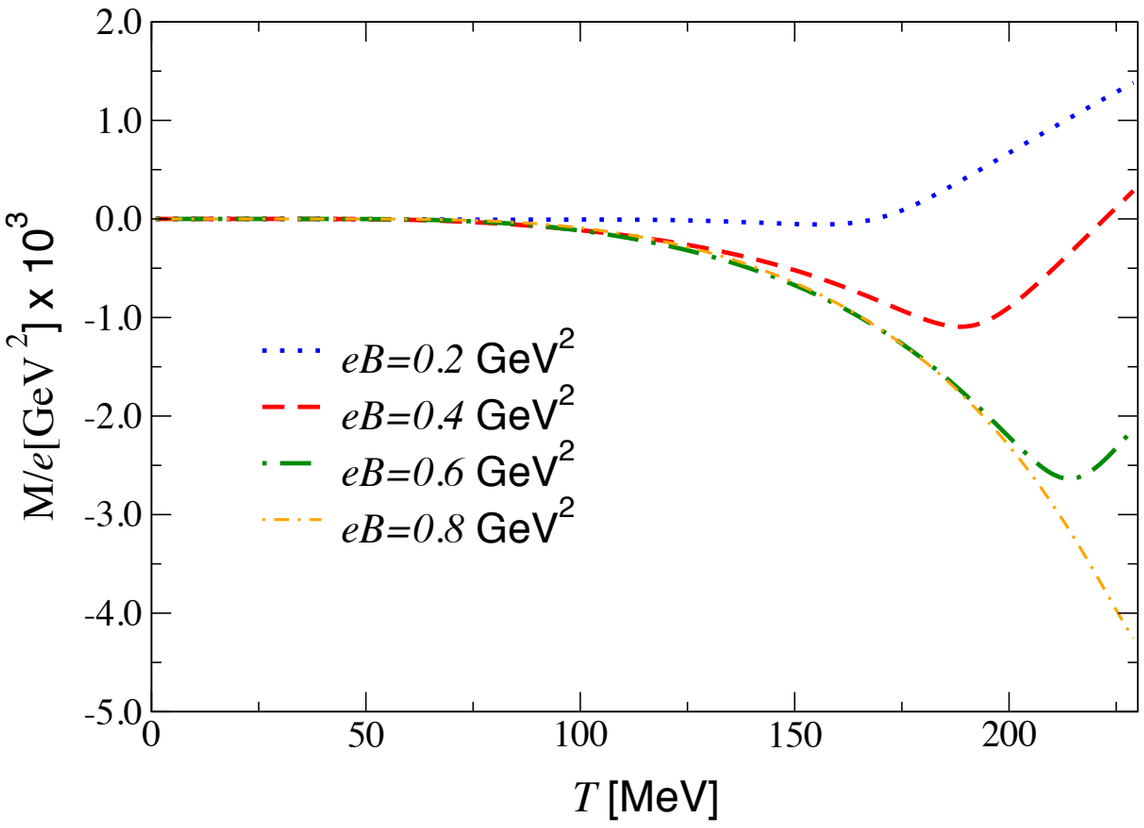
JHEP 02 (2012) 044

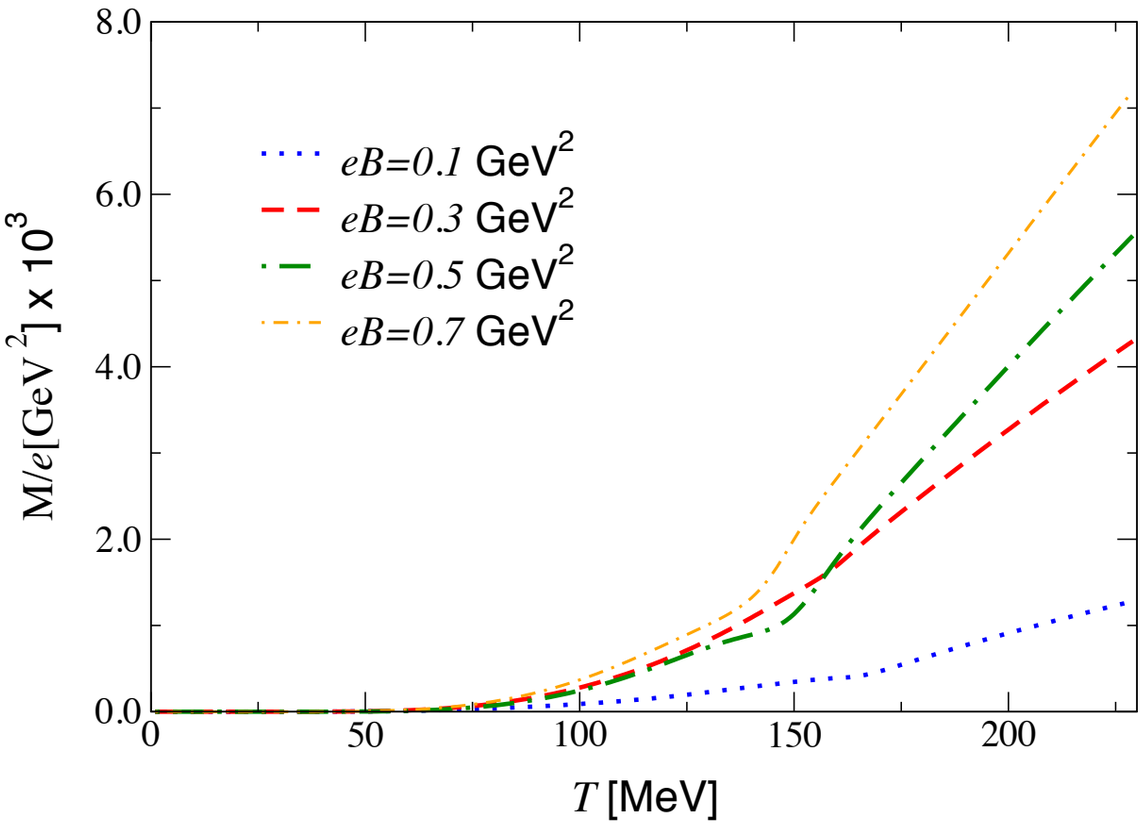
Magnetization

SU(2)

G



G(eB,T)



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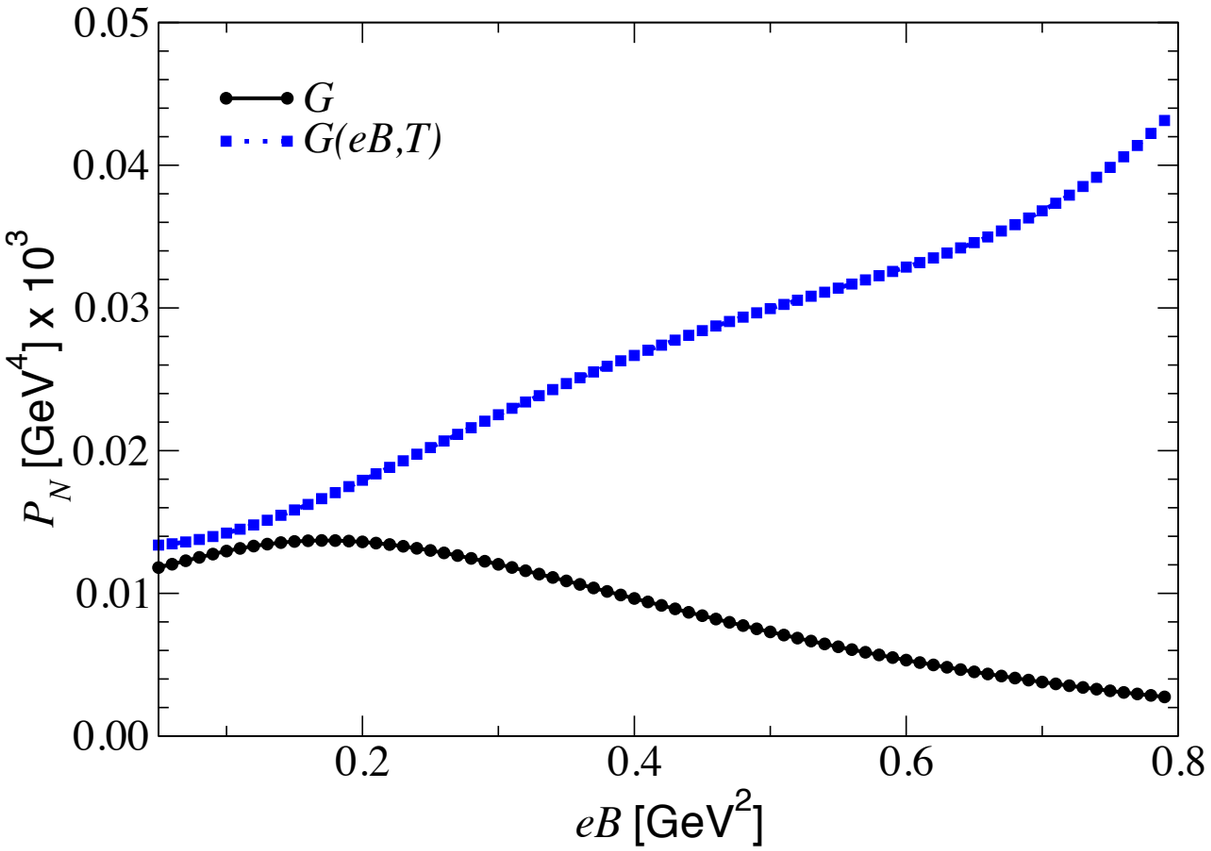
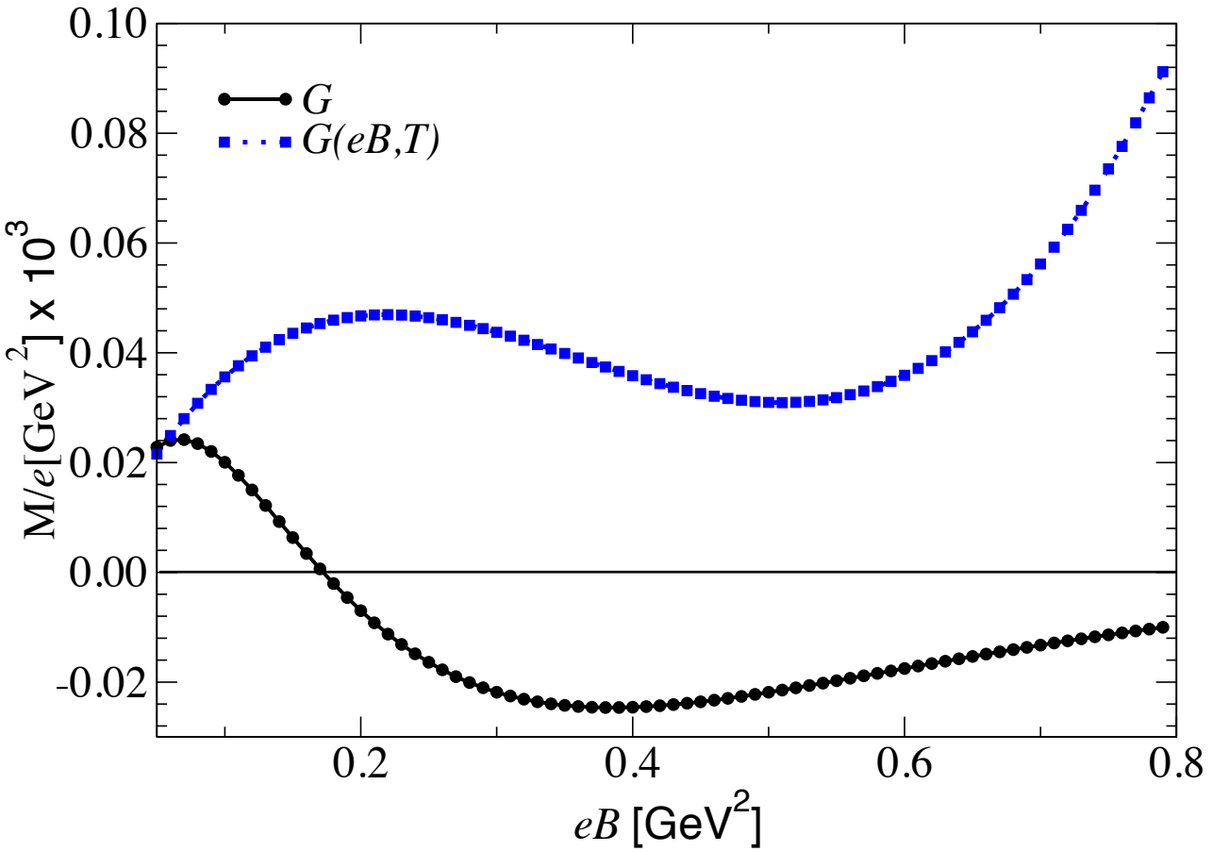
Pressure & Magnetization @ T = 70 MeV

SU(2)





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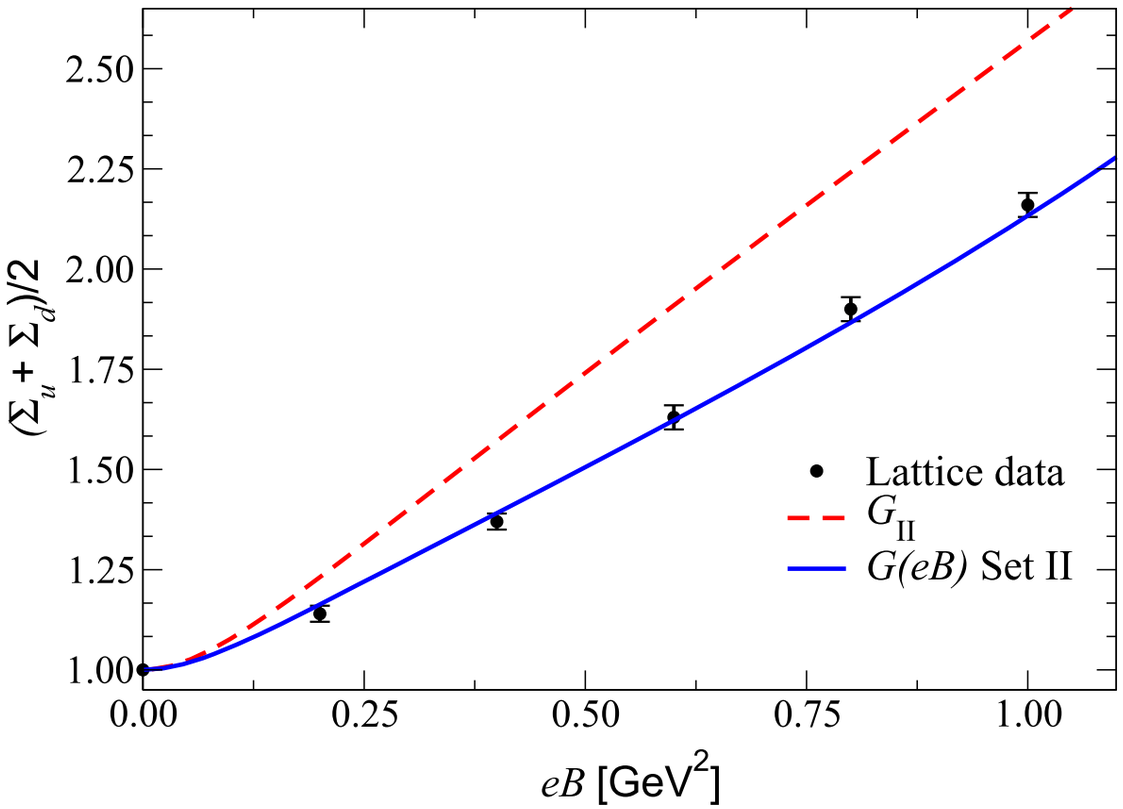
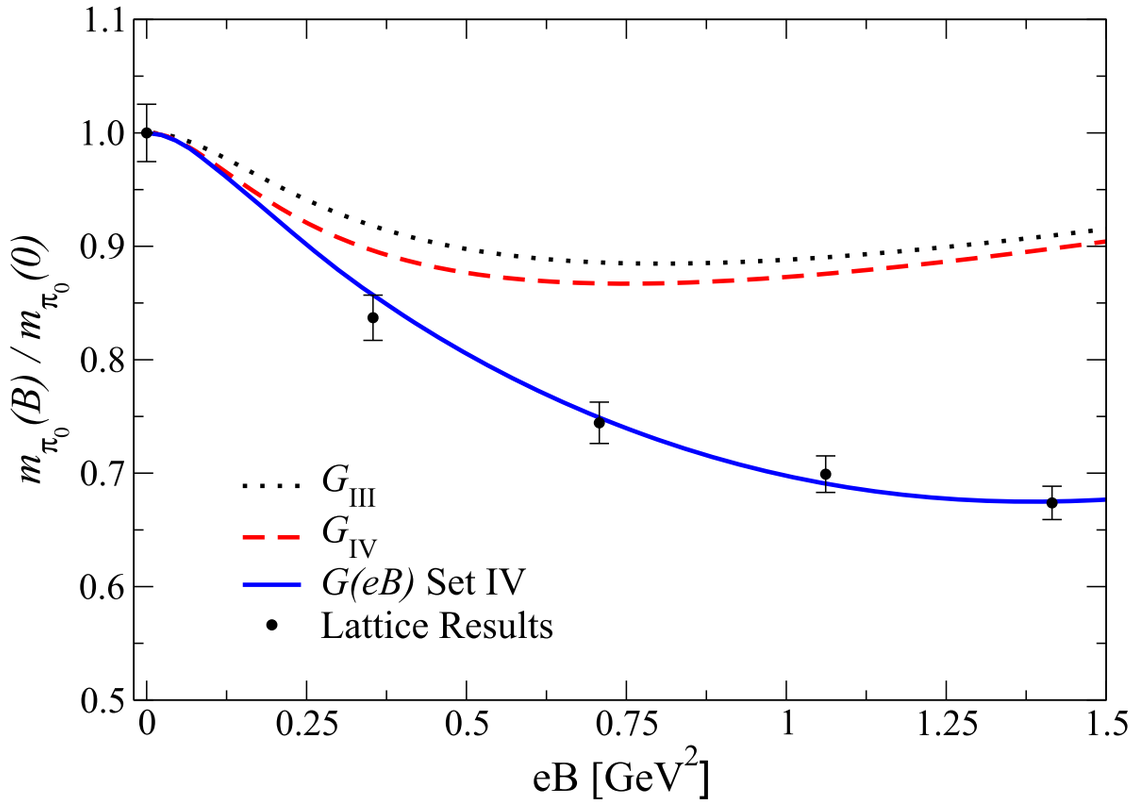
π_0 mass @ T = 0

SU(2)

G



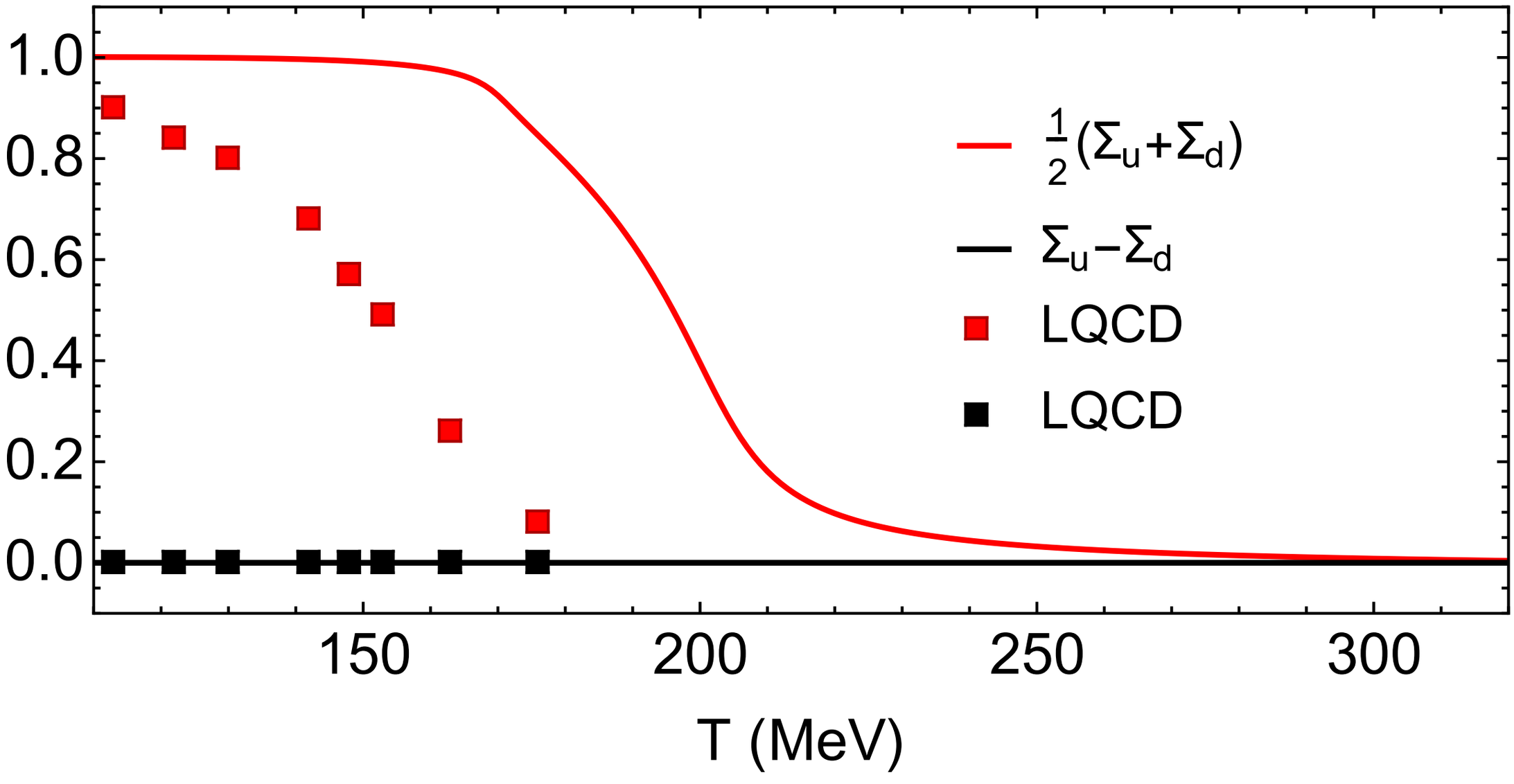
G(eB)



Physics Letters B 767 (2017) 247–252

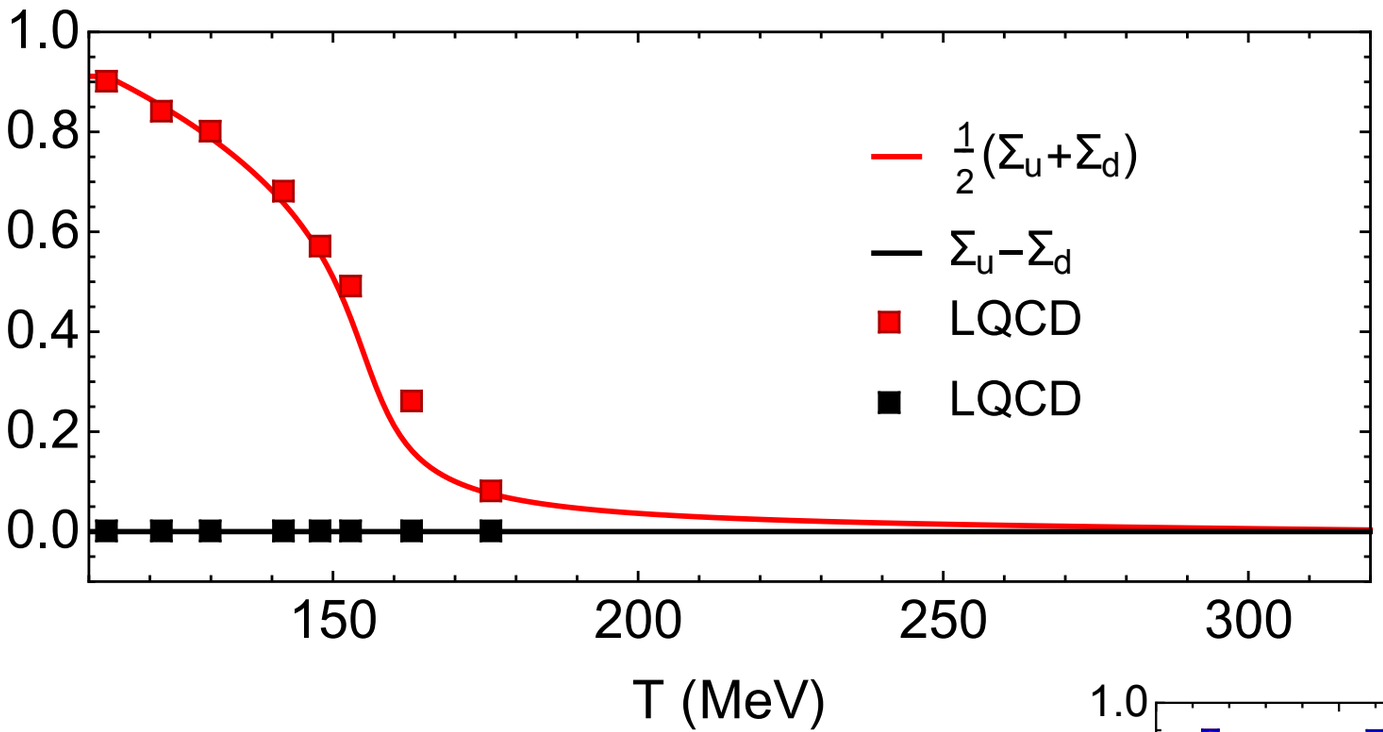
Fixed couplings (B = 0)

SU(3)

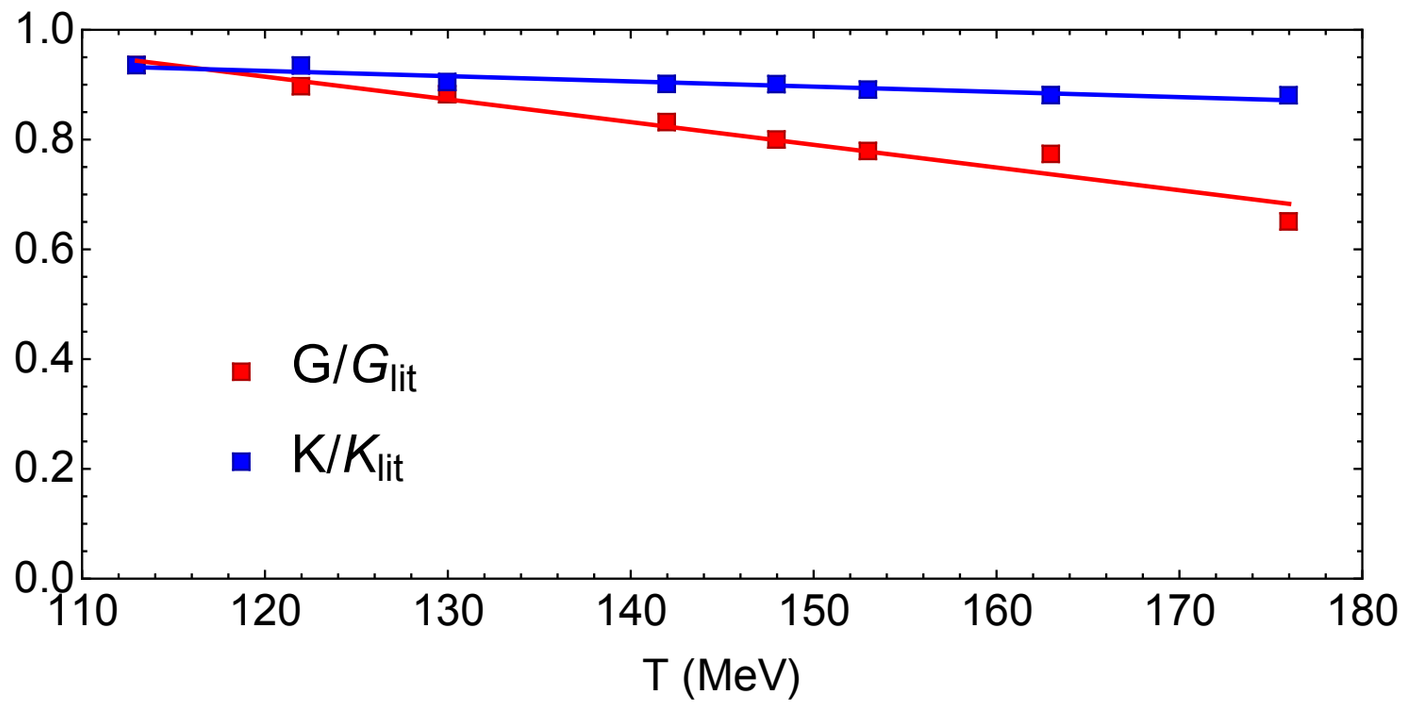


Thermo-magnetic dependent couplings

SU(3)



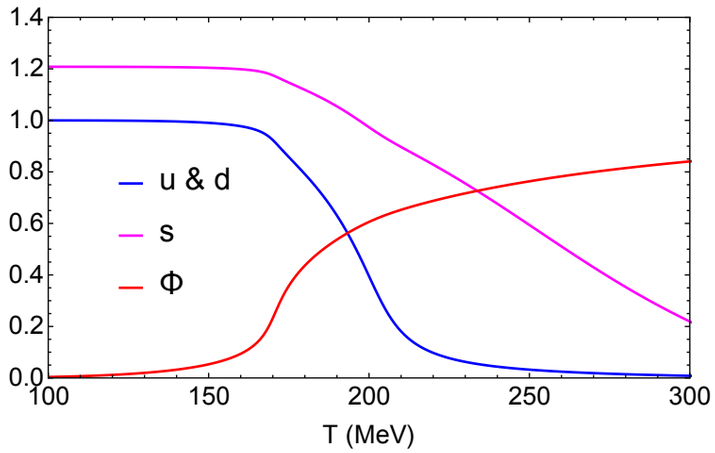
B = 0

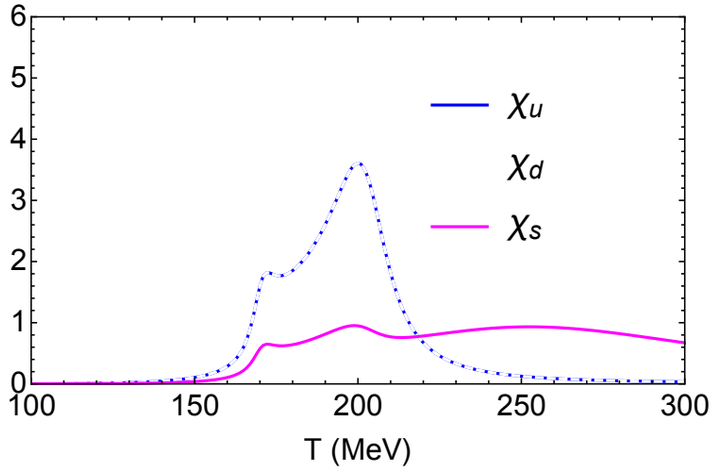


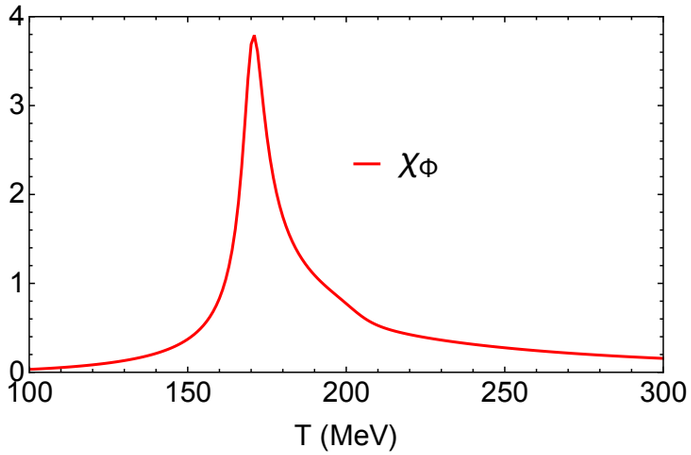
Condensates & Susceptibilities (B = 0)

SU(3)

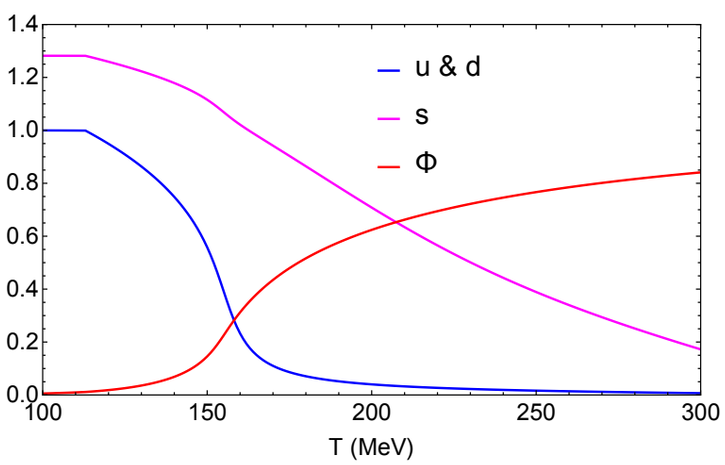
FC

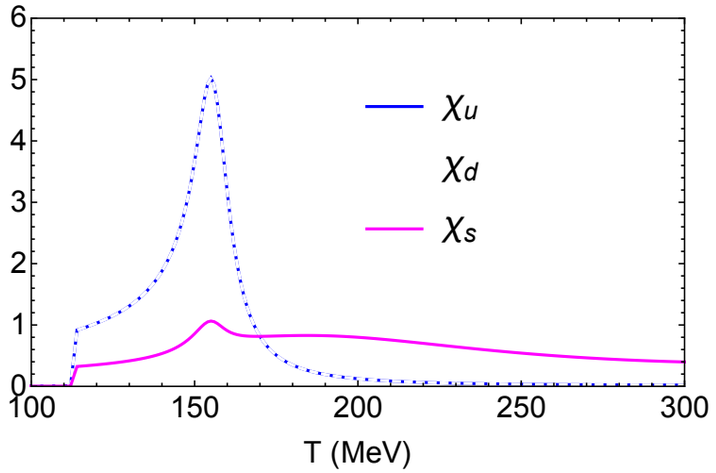


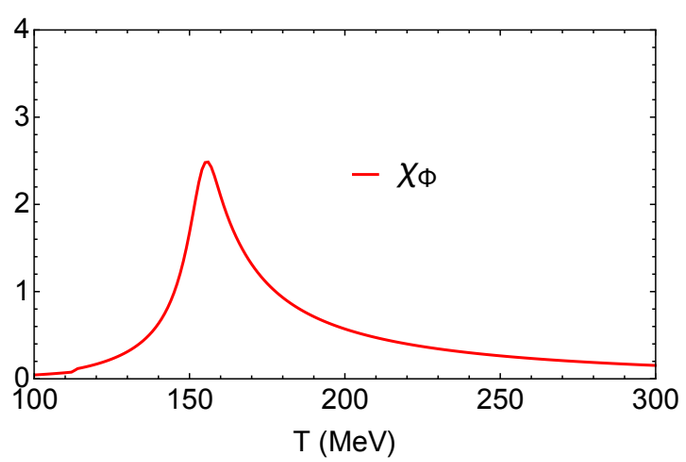




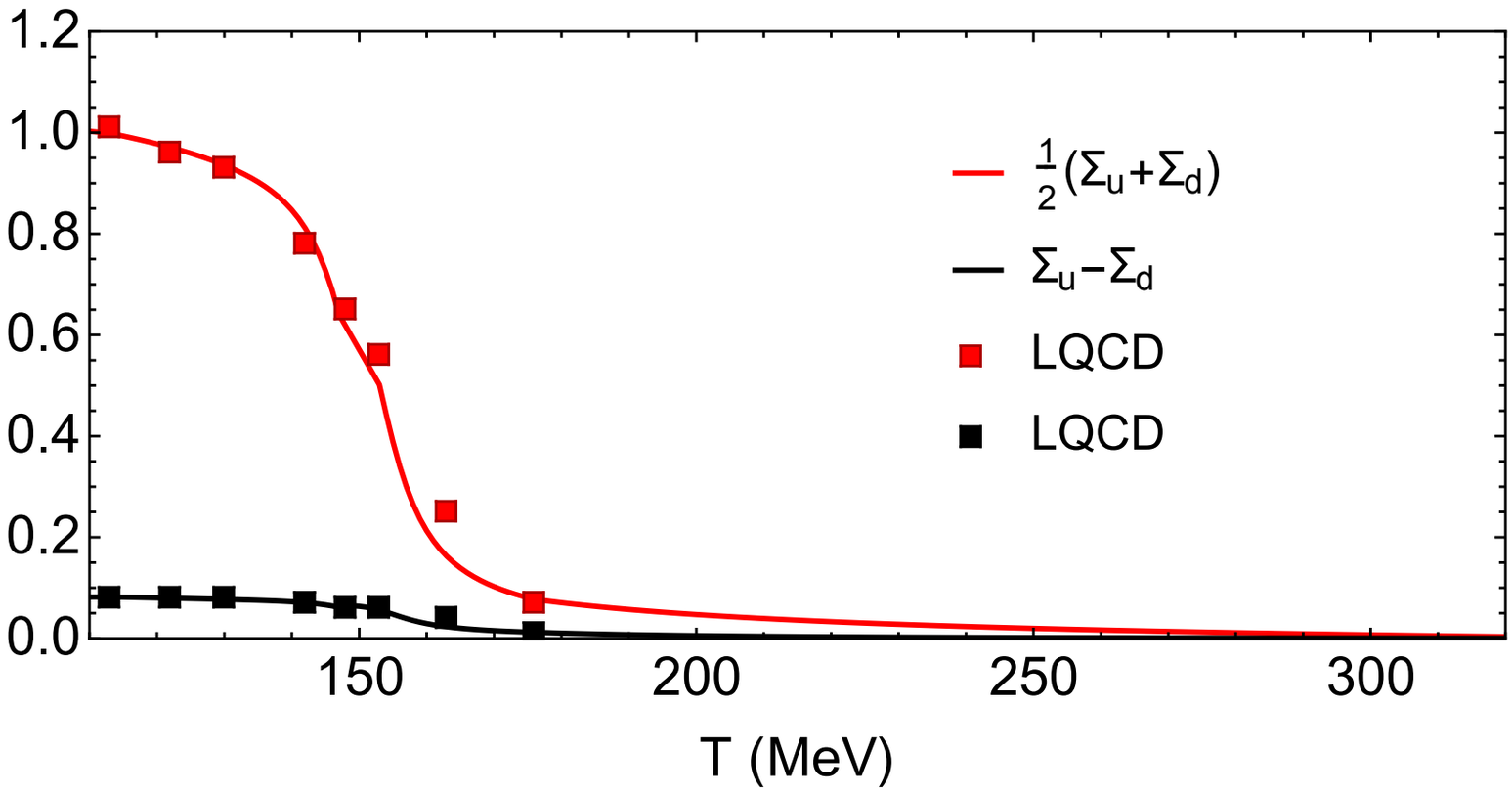
TMC





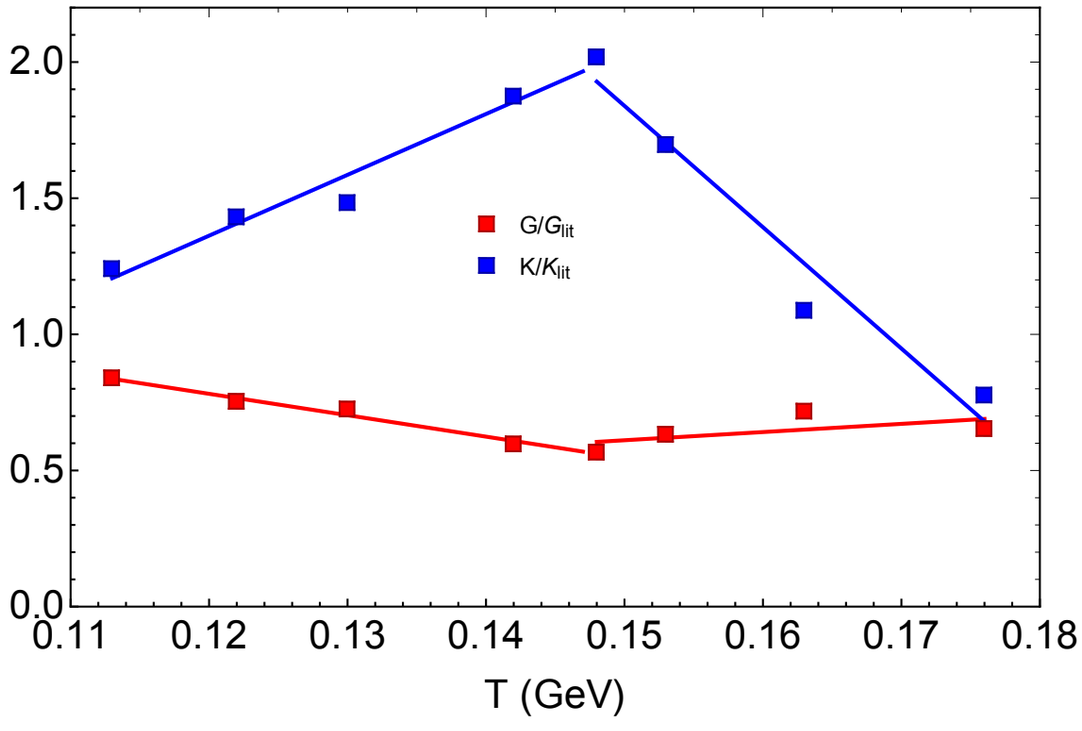


Thermo-magnetic dependent couplings



SU(3)

$eB = 0.2\ GeV^2$

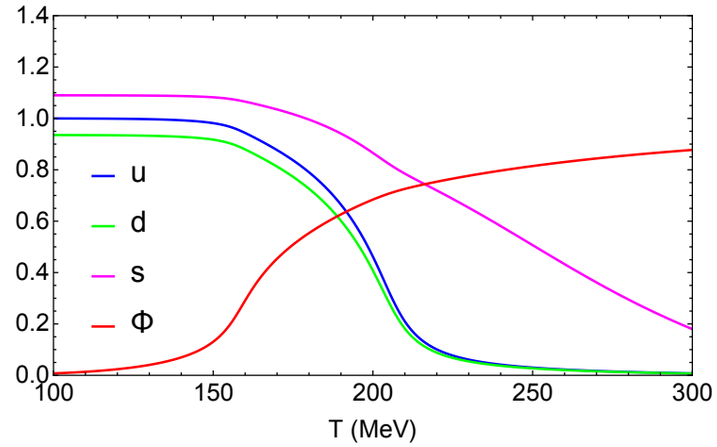


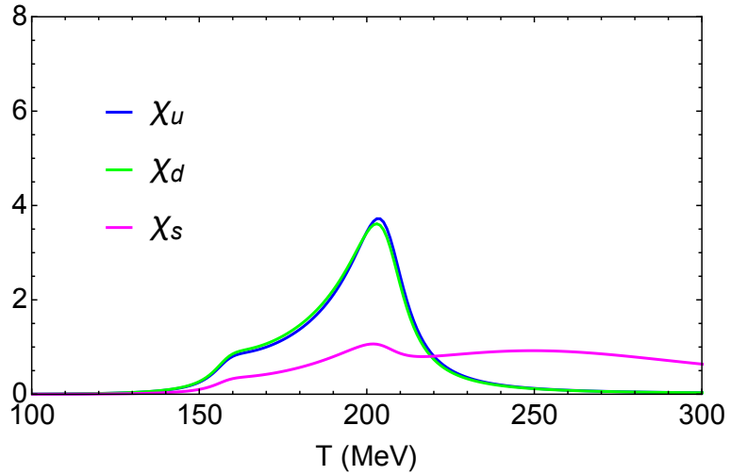
Condensates & Susceptibilities ($eB = 0.2\ GeV^2$)

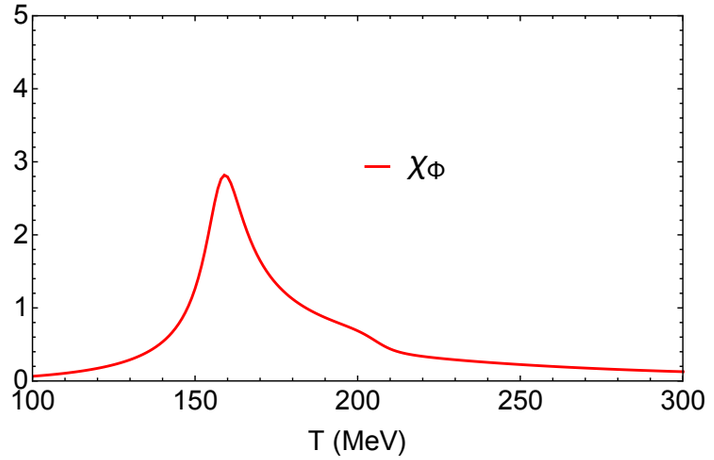
SU(3)

F

C



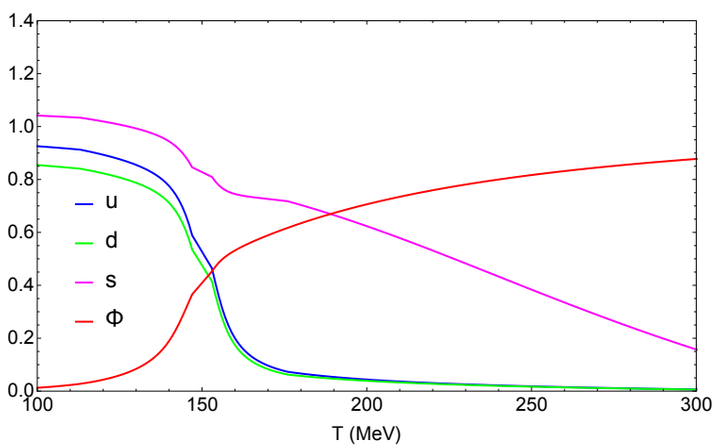


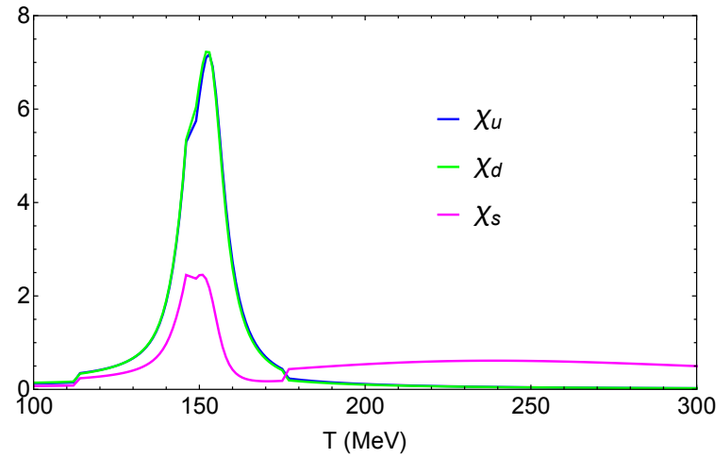


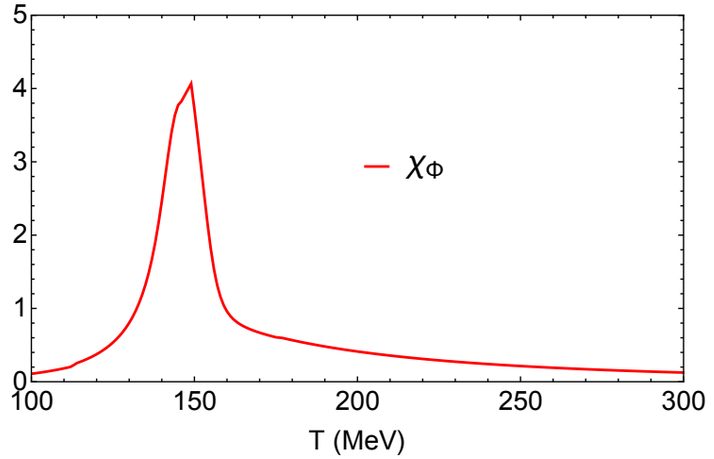
T

M

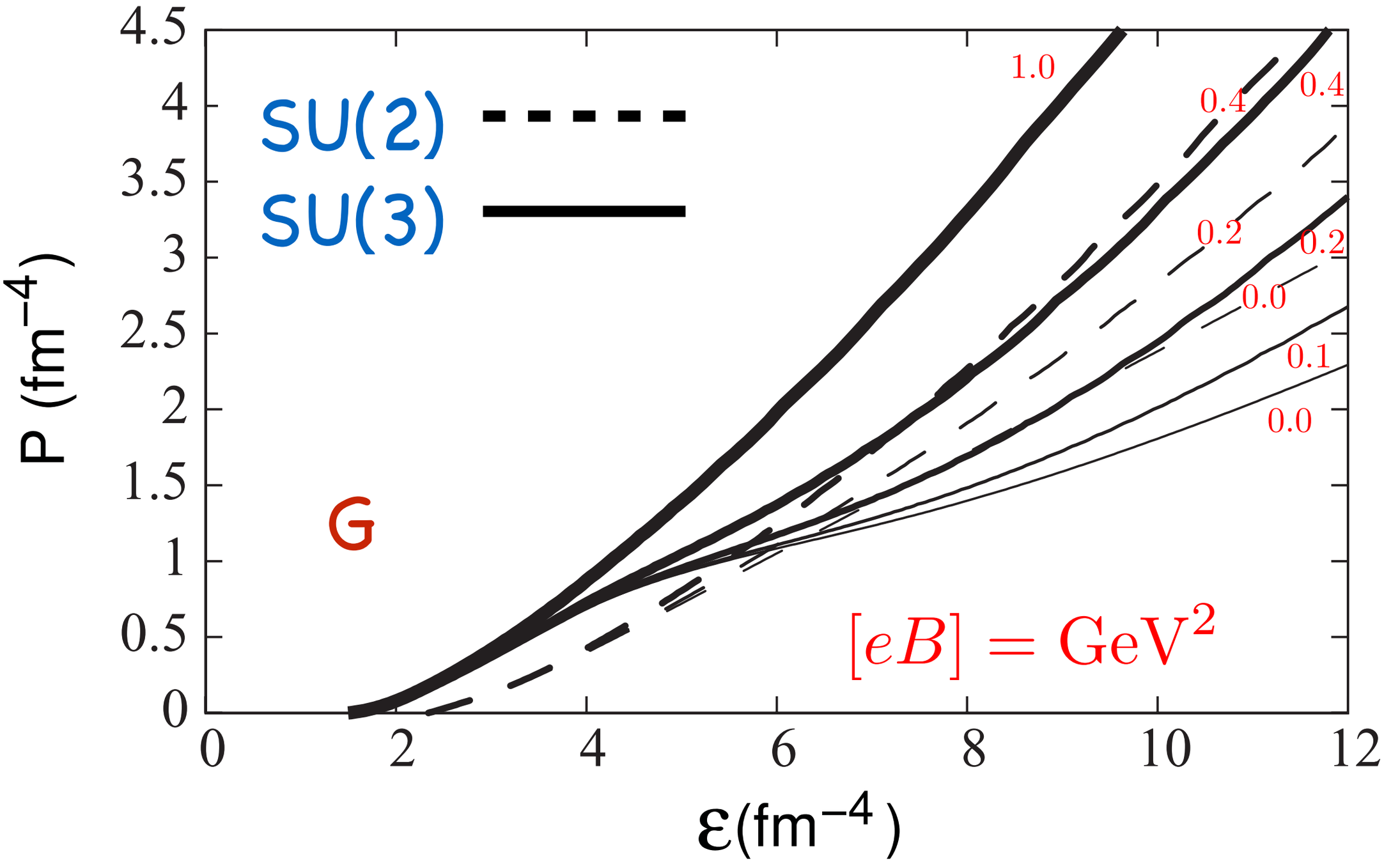
C







Compact Stars: EoS (T=0)

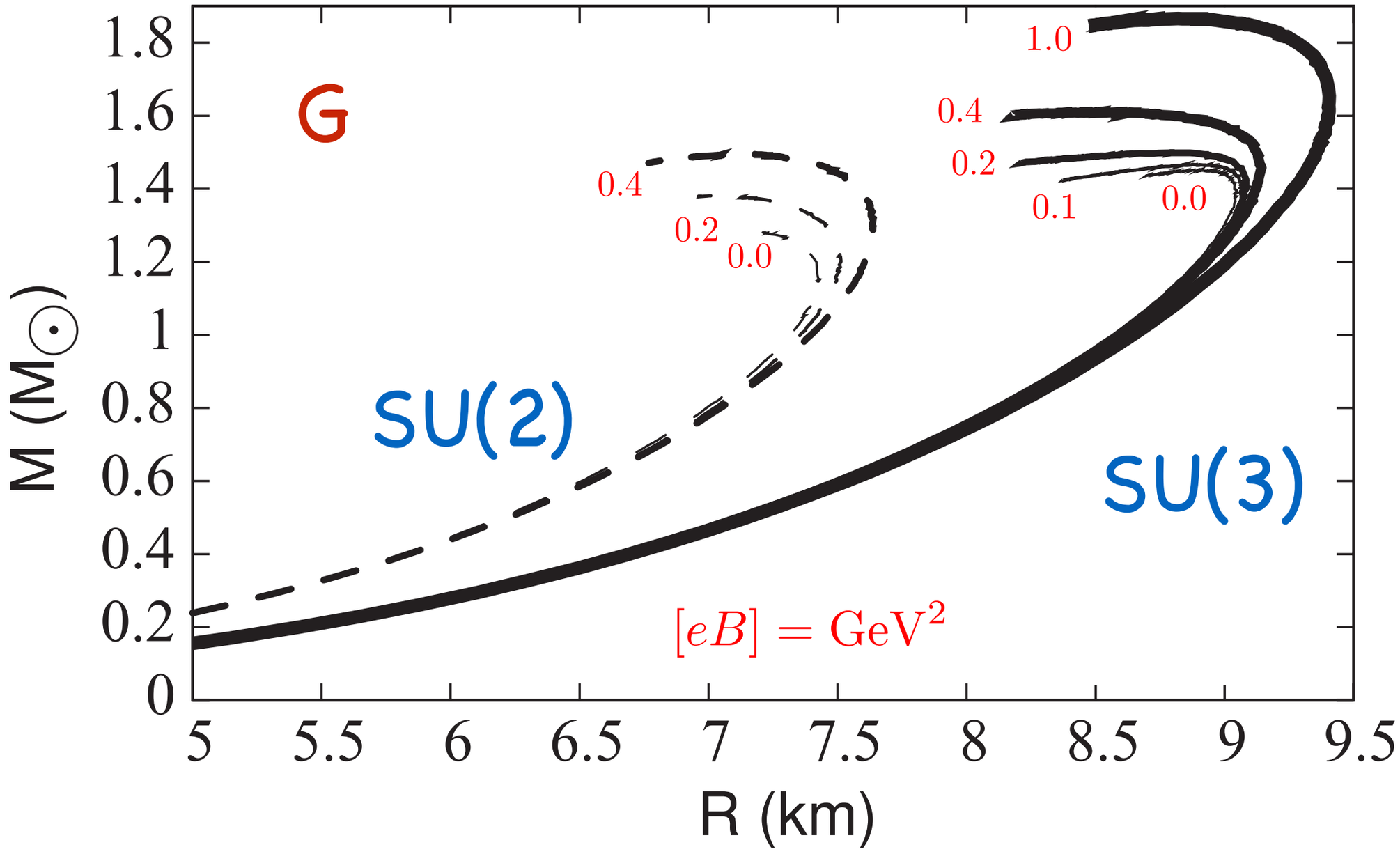


Courtesy of Sidney Avancini

Phys.Rev. C80 (2009) 065805

Phys.Rev. C79 (2009) 035807

Compact Stars: TOV (T=0)



Courtesy of Sidney Avancini

Phys.Rev. C80 (2009) 065805
Phys.Rev. C79 (2009) 035807

Final remarks

* NJL models with fixed coupling fails to describe LQCD simulations

* Thermo-magnetic coupling seems adequate to improve NJL models

* Sign of magnetization also fixed by thermo-magnetic coupling

* Pion mass at T = 0 matches LQCD calculations with G(eB)

* Negative pressure for thermo-magnetic coupling in SU(3) case

Outlook

* Verify mass x radius relation with G(eB,T) & K(eB,T)

* Check what is contributing to the negative pressure

* Compute the magnetization in SU(3) with G(eB,T) & K(eB,T)