Chiral Dynamics in External Magnetic Fields

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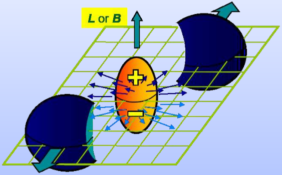
Motivation

In off-central heavy-ion collisions strong magnetic fields are created.



(STAR collaboration)

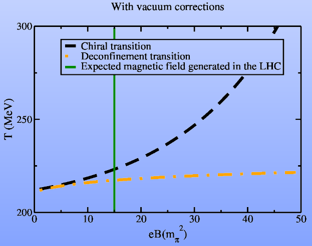
(Kharzeev et al, Nucl. Phys. A **803**, 227 (2008))
(Skokov et al, Int. J. Mod. Phys. A **24**, 5925 (2009))
...

How does the magnetic field influence strongly interacting matter?

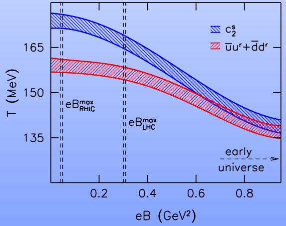
Motivation

Chiral critical temperature depending on B.

magnetic catalysis



inverse magnetic catalysis



(Mizher et al, Phys. Rev. D **82**, 105016 (2010))
(Gatto and Ruggieri, Phys. Rev. D **82**, 054027 (2010))
(Fraga et al, Phys. Lett. B **731**, 154 (2014))
(Fukushima and Pawlowski, Phys. Rev. D **86**, 076013 (2012))
(Kamikado and Kanazawa, JHEP **1403**, 009 (2014))
(Andersen and Tranberg, JHEP **1208**, 002 (2012))
(Andersen et al, JHEP **1404**, 187 (2014))
...

(see e.g. Bali et al, JHEP **1202**, 044 (2012))

main tool: Wetterich equation (C. Wetterich, Phys. Lett. B **301**, 90 (1993))

$$\partial_t \Gamma_k = \frac{1}{2} \mathrm{Tr} \left[\frac{\partial_t \mathcal{R}_k}{\Gamma_k^{(2)} + \mathcal{R}_k} \right]$$

truncation:

$$\Gamma_k = \int \mathrm{d}^4 x \left\{ \frac{1}{4} F^i_{\mu\nu} F^i_{\mu\nu} + \bar{\psi}\, \imath \not{D} \psi - \frac{1}{2\xi} A^i_\mu \partial_\mu \partial_\nu A^i_\nu + \frac{\bar{\lambda}_\sigma}{2} \left[\left(\bar{\psi}\psi\right)^2 - \left(\bar{\psi}\tau_\chi \gamma_5 \psi\right)^2 \right] \right\}$$

specific choices:

- Litim's regulator (D. F. Litim, Phys. Lett. B **486**, 92 (2000), Phys. Rev. D **64**, 105007 (2001))
- Feynman gauge ($\xi = 1$)
- $N_\mathrm{f} = 2$ flavours and $N_\mathrm{c} = 3$ colors
- $\lambda_\sigma^{\mathrm{UV}} = 0$

main tool: Wetterich equation (C. Wetterich, Phys. Lett. B **301**, 90 (1993))

$$\partial_t \Gamma_k = \frac{1}{2}\mathrm{Tr}\left[\frac{\partial_t \mathcal{R}_k}{\Gamma_k^{(2)} + \mathcal{R}_k}\right]$$

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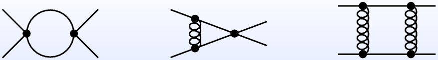
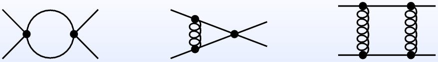
$$\left. + \frac{\bar{\lambda}_\sigma}{2}\left[\left(\bar{\psi}\psi\right)^2 - \left(\bar{\psi}\tau_\chi \gamma_5 \psi\right)^2 \right] \right\}$$

chiral symmetry breaking:

- criterion for χSB: $k^2 \bar{\lambda}_\sigma = \lambda_\sigma \to \infty$ for $k \to k_{\mathrm{crit}}$
- k_{crit} sets the scale for IR observables
  e.g. the chiral condensate $\langle \bar{\psi}\psi \rangle$

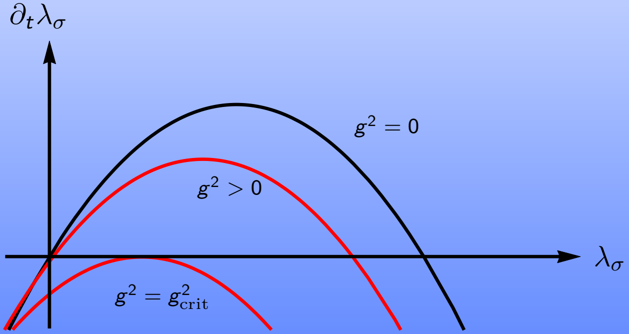


$$\partial_t \lambda_\sigma = 2\lambda_\sigma - a\left(\tfrac{T}{k}, \tfrac{B}{k^2}\right) \lambda_\sigma^2 - b\left(\tfrac{T}{k}, \tfrac{B}{k^2}\right) g^2 \lambda_\sigma - c\left(\tfrac{T}{k}, \tfrac{B}{k^2}\right) g^4$$



$$\partial_t \lambda_\sigma = 2\lambda_\sigma - a(0,0)\,\lambda_\sigma^2 - b(0,0)\,g^2\lambda_\sigma - c(0,0)\,g^4$$

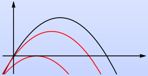
(H. Gies, J. Jaeckel and C. Wetterich, Phys. Rev. D **69**, 105008 (2004))
(H. Gies and J. Jaeckel, Eur. Phys. J. C **46**, 433 (2006))



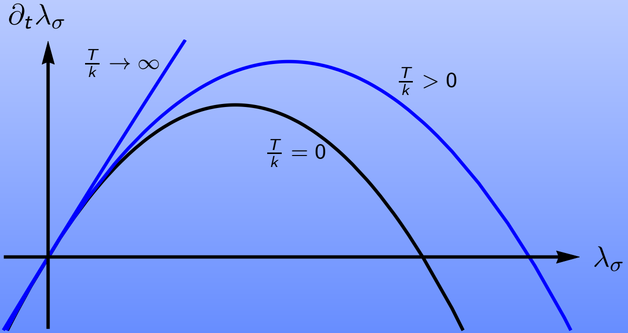
$$g^2 > g^2_{\mathrm{crit}} \quad \Rightarrow \quad \lambda_\sigma \to \infty \quad \Rightarrow \quad \chi\mathrm{SB}$$

$$\partial_t \lambda_\sigma = 2\lambda_\sigma - a(\tfrac{T}{k},0)\,\lambda_\sigma^2 - b(\tfrac{T}{k},0)\,g^2\lambda_\sigma - c(\tfrac{T}{k},0)\,g^4$$

$g^2 > 0$:



$g^2 = 0$:



(J. Braun and H. Gies, Phys. Lett. B **645**, 53 (2007), JHEP **0606**, 024 (2006))

$T \Rightarrow$ SYM

$$\partial_t \lambda_\sigma = 2\lambda_\sigma - a(0, \tfrac{B}{k^2})\,\lambda_\sigma^2 - b(0, \tfrac{B}{k^2})\,g^2\lambda_\sigma - c(0, \tfrac{B}{k^2})\,g^4$$

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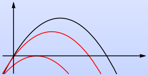
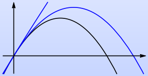


$\frac{T}{k} > 0$:



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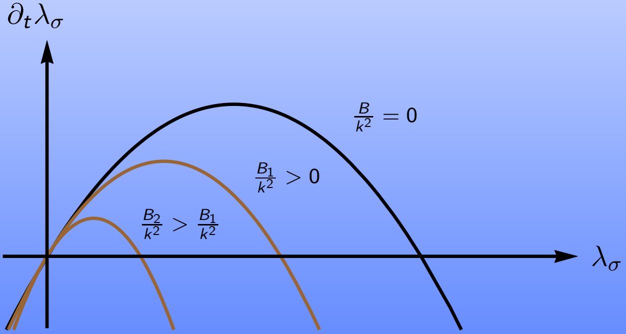

$B \Rightarrow \chi$SB

(K. Fukushima and J. M. Pawlowski, Phys. Rev. D **86**, 076013 (2012))
(D. D. Scherer and H. Gies, Phys. Rev. B **85**, 195417 (2012))
(J. Braun, W. A. Mian and S. Rechenberger, in preparation)

$$\partial_t \lambda_\sigma = 2\lambda_\sigma - a\left(\frac{T}{k}, \frac{B}{k^2}\right) \lambda_\sigma^2 - b\left(\frac{T}{k}, \frac{B}{k^2}\right) g^2 \lambda_\sigma - c\left(\frac{T}{k}, \frac{B}{k^2}\right) g^4$$

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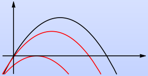
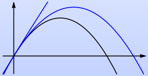
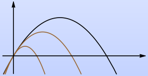


$\frac{T}{k} > 0$:



$\frac{B}{k^2} > 0$:



$$g^2_{\mathrm{crit}} = \frac{1}{b + \sqrt{ac}}$$

$$\partial_t \lambda_\sigma = 2\lambda_\sigma - a(\tfrac{T}{k},0)\,\lambda_\sigma^2 - b(\tfrac{T}{k},0)\,g^2\lambda_\sigma - c(\tfrac{T}{k},0)\,g^4$$

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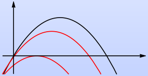
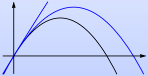


$\frac{T}{k} > 0$:



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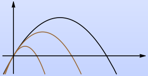
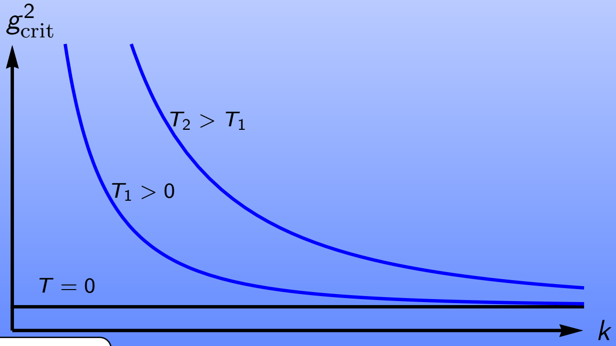
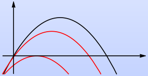


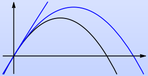


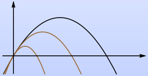
T increases g^2_{crit}

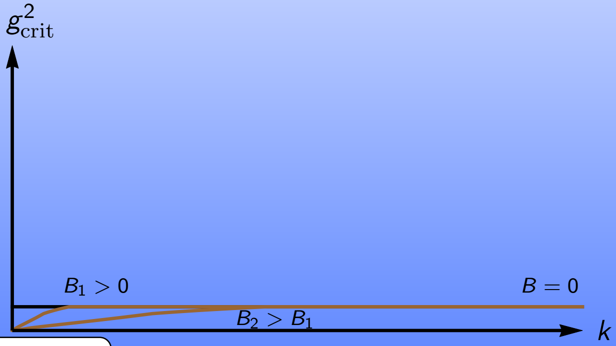
(J. Braun and H. Gies, Phys. Lett. B **645**, 53 (2007), JHEP **0606**, 024 (2006))

$$\partial_t \lambda_\sigma = 2\lambda_\sigma - a(0, \tfrac{B}{k^2})\, \lambda_\sigma^2 - b(0, \tfrac{B}{k^2})\, g^2 \lambda_\sigma - c(0, \tfrac{B}{k^2})\, g^4$$

$g^2 > 0$: 

$\frac{T}{k} > 0$: 

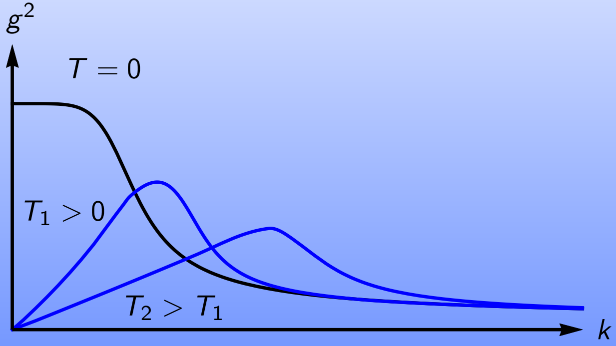
$\frac{B}{k^2} > 0$: 



B decreases g^2_{crit}

(J. Braun, W. A. Mian and S. Rechenberger, in preparation)

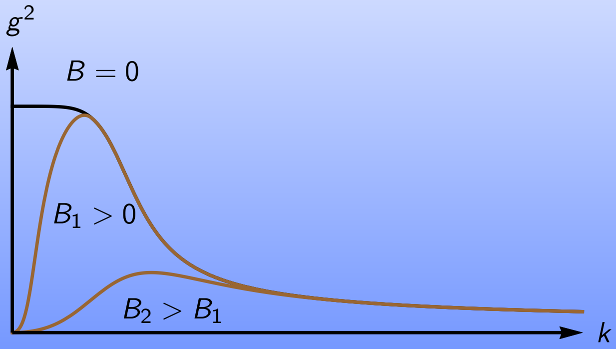
running gauge coupling



T decreases g^2

(J. Braun and H. Gies, Phys. Lett. B **645**, 53 (2007), JHEP **0606**, 024 (2006))

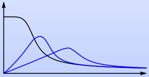
running gauge coupling

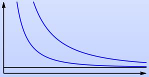


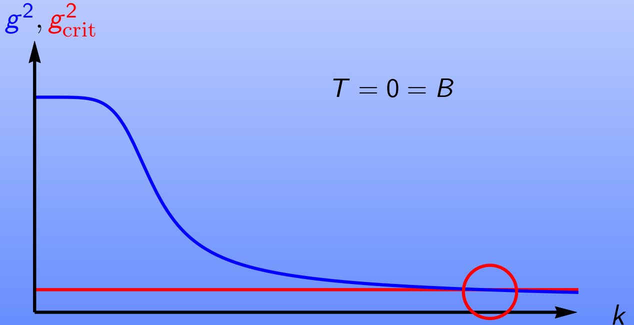
B decreases g^2 **as well**

(J. Braun, W. A. Mian and S. Rechenberger, in preparation)

running g^2 vs. g^2_{crit}

$g^2(k)$: 

$g^2_{\mathrm{crit}}(k)$: 

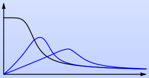


χSB for $T = 0$

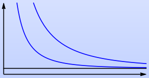
(H. Gies and J. Jaeckel, Eur. Phys. J. C **46**, 433 (2006))

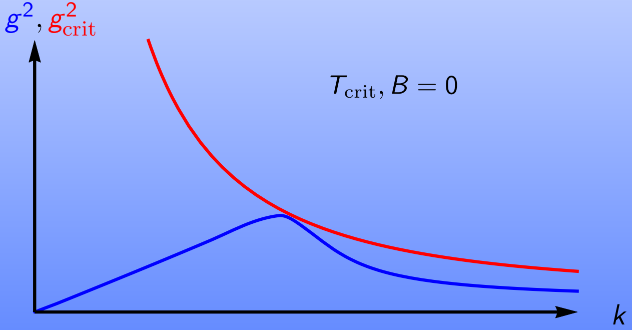
running g^2 vs. g^2_{crit}

$g^2(k)$:



$g^2_{\mathrm{crit}}(k)$:



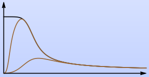


SYM for $T > T_{\mathrm{crit}}$

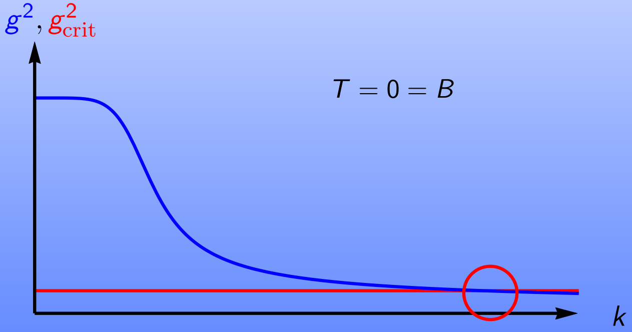
(J. Braun and H. Gies, Phys. Lett. B **645**, 53 (2007), JHEP **0606**, 024 (2006))

running g^2 vs. g^2_{crit}

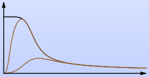
$g^2(k)$:



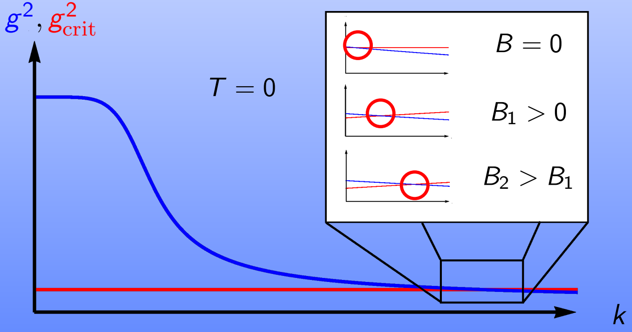
$g^2_{\mathrm{crit}}(k)$:



running g^2 vs. g^2_{crit}

$g^2(k)$: 

$g^2_{\mathrm{crit}}(k)$: 

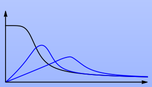


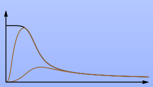
k_{crit} grows with B

(J. Braun, W. A. Mian and S. Rechenberger, in preparation)

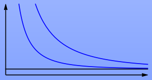
Conclusion and Outlook

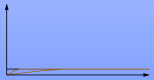
- critical scale ($\Rightarrow \langle\bar{\psi}\psi\rangle$) grows with B
- T and B act similar on g^2





- T and B act opposite on g^2_{crit}





- competing effects of T and B might enable inverse catalysis