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(Inverse) Magnetic Catalysis from the Properties of the QCD Coupling in a Magnetic Field.

Luis A. Hernandez

International workshop
QCD challenges at the LHC: from pp to AA.
Taxco, January 21 2016.

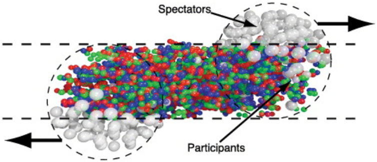
Outline

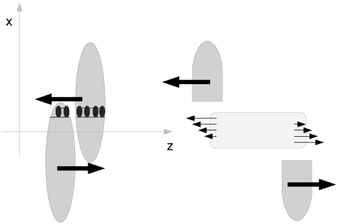
- Motivation.
- Magnetic fields ⇔ QCD phase transition.
- Magnetic fields ⇔ Vacuum and finite temperature systems.
- Magnetic fields ⇔ Coupling constants.
- Conclusions.

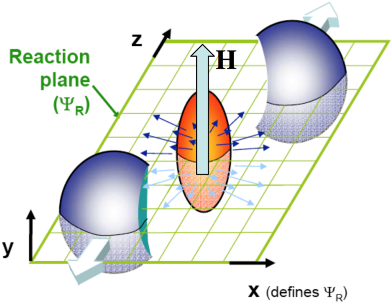
Nature in the presence of Magnetic fields

- The earth's magnetic field → 0.6 Gauss.
- A common hand-held magnet → 100 Gauss.
- The strongest steady magnetic fields achieved so far in the laboratory → 4.5×10^5 Gauss.
- Surface field of magnetars → 10^{15} Gauss.
- Heavy Ion Collisions, the strongest magnetic field ever achieved in the laboratory → 10^{18} Gauss $\approx m_\pi^2$ ($m_\pi = 135\ MeV$).

Magnetic fields generated in HIC.

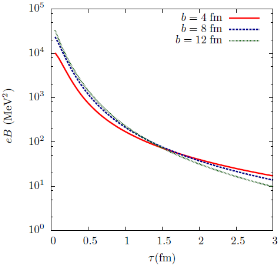




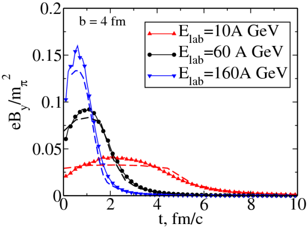


D. E. Kharzeev, Prog.Part.Nucl.Phys. 75 (2014).

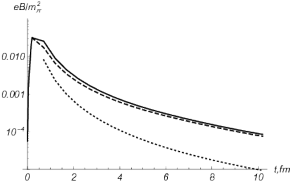
Estimation of magnetic fields strengh



D. Kharzeev *et. al*, Nucl.Phys. A803 (2008) 227-253.

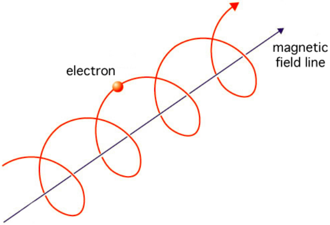


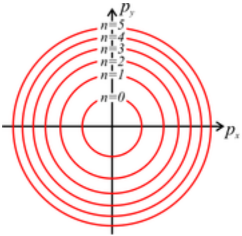
V. Skokov *et al.*, Int.J.Mod.Phys. A24 (2009) 5925-5932.



K. Tuchin, arXiv:1508.06925

Charged particles in presence of magnetic fields.



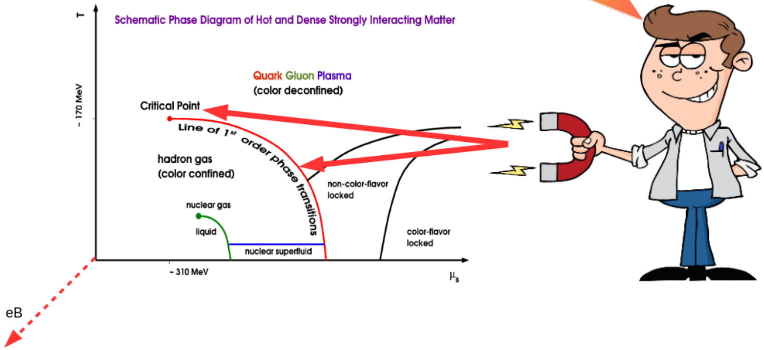


- The physical system looses isotropy.
- Reduction from 3D to 2D.

$QCD\ phase\ transition\ \&\ eB \neq 0.$

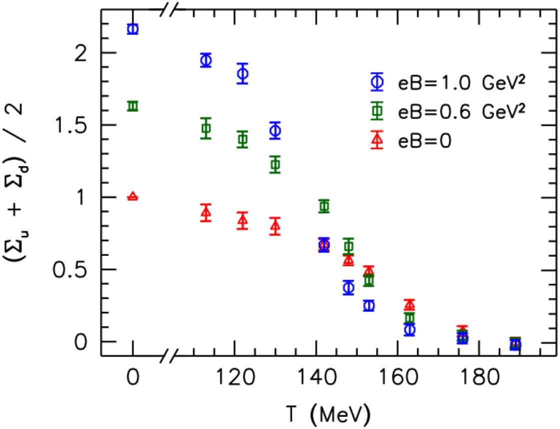
Is the Tc modified by strong magnetic fields?
Does the CEP move due to the strength of the magnetic field?

PoS HIGH-PTLHC08 (2008) 027 by T. Csorgo.



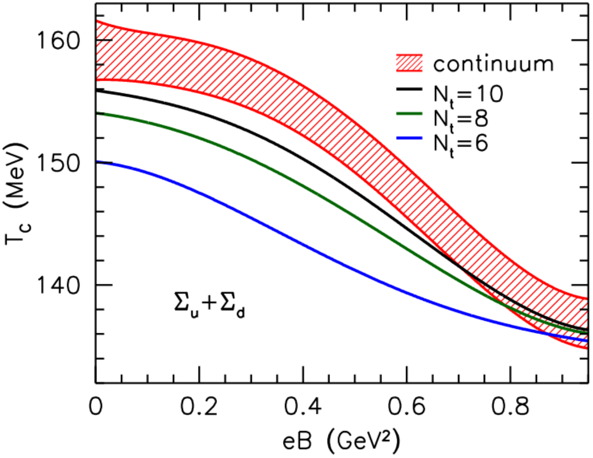
The Magnetized QCD Phase Diagram

Magnetic catalysis & Inverse Magnetic catalysis



G. S. Bali *et al.*, PoS ConfinementX (2012) 197

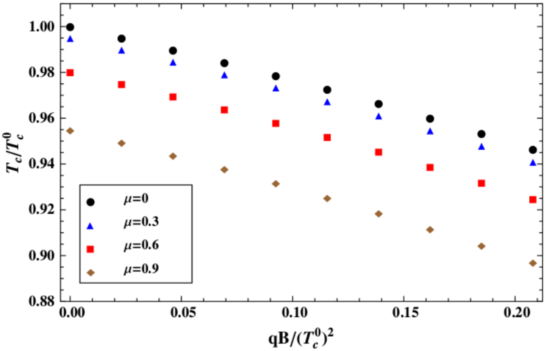
Magnetic catalysis & Inverse Magnetic catalysis



G. S. Bali *et al.*, PoS ConfinementX (2012) 197

Some theoretical models.

Linear Sigma Model Coupled to quarks.



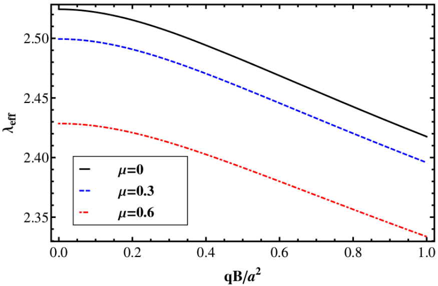
A. Ayala *et al.*, Phys.Rev. D92 (2015) 9, 096011

Beyond mean field approximation.

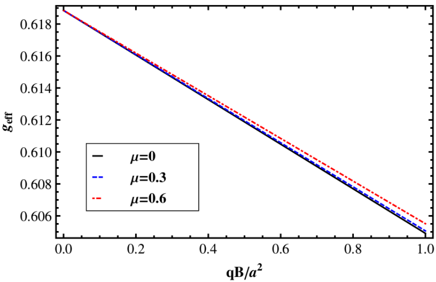
- More than one-loop correction.
- First correction to coupling constants.

Some theoretical models.

First order correction to coupling constants.

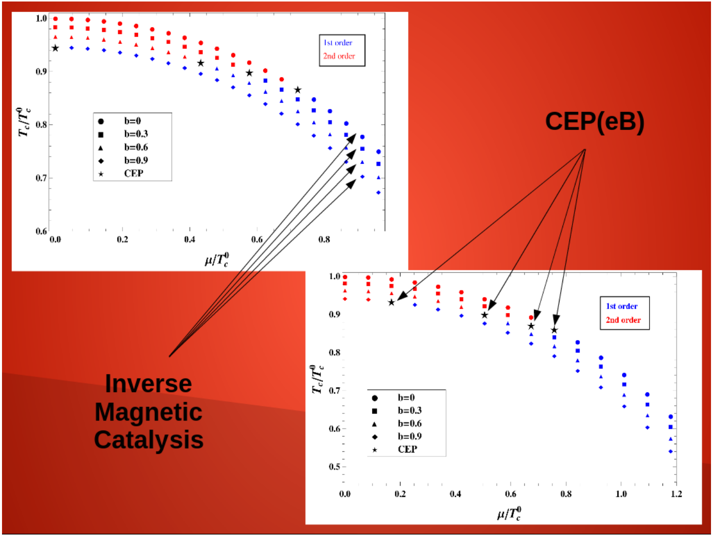


A. Ayala *et al.*, Phys.Rev. D92 (2015) 9, 096011



A. Ayala *et al*, Phys.Rev. D92 (2015) 9, 096011

Magnetized Effective QCD Phase Diagram.



CEP(eB)

Inverse Magnetic Catalysis

A. Ayala *et al*, Phys.Rev. D92 (2015) 9, 096011

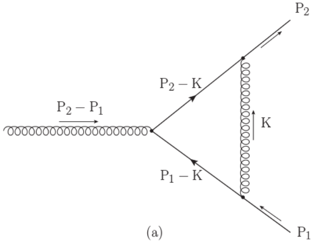
Physics behind (inverse) magnetic catalysis.

Is the coupling constant the key to understand the (inverse) magnetic catalysis?

- Working within QCD.
- In the framework of perturbation theory.
  - High temperature ($T^2 > eB$).
  - High virtuallity ($q^2 > eB$).

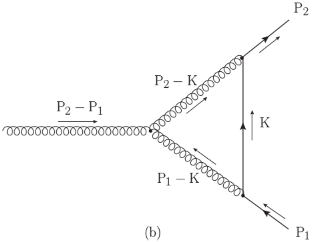
Physics behind (inverse) magnetic catalysis.

The thermo-magnetic correction to the quark-gluon vertex in the presence of a weak magnetic field was computed.



QED-like contribution.

The vacuum one-loop quark-gluon vertex correction at zero temperature in the presence of magnetic field was computed.

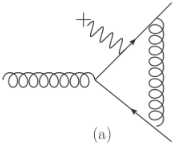


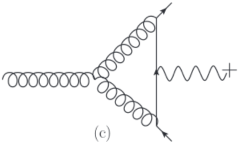
Pure QCD contribution.

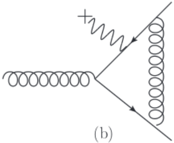
Weak field approximation.

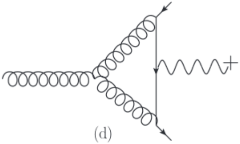
Magnetic fields modify the behaviour of Quarks.

$$
\begin{aligned}
S_B(K, m_f) &= \frac{(m_f - \not{K})}{K^2 + m_f^2} - i\frac{\gamma_1\gamma_2(qB)(m_f - \not{K}_\parallel)}{(K^2 + m_f^2)^2} \\
+ \quad & \frac{2(qB)^2 K_\perp^2}{(K^2 + m_f^2)^4}\left[(m_f - \not{K}_\parallel) + \frac{\not{K}_\perp(m_f^2 + K_\parallel^2)}{K_\perp^2}\right].
\end{aligned}
$$


(a)


(c)


(b)


(d)

$$HTL.$$

thermo-magnetic correction of g.

$$\delta\Gamma_\mu^{(a)} = ig^2\left(C_F - \frac{C_A}{2}\right)(qB)T\sum_n \int \frac{d^3k}{(2\pi)^3}\gamma_\nu\Big[\gamma_1\gamma_2 \not{K}_\parallel \gamma_\mu \not{K}\tilde{\Delta}(P_2 - K)$$

$$+ \not{K}\gamma_\mu\gamma_1\gamma_2\not{K}_\parallel\tilde{\Delta}(P_1 - K)\Big]\gamma_\nu\Delta(K)\tilde{\Delta}(P_2 - K)\tilde{\Delta}(P_1 - K)$$

$$\delta\Gamma_\mu^{(b)} = 2ig^2\frac{C_A}{2}(qB)T\sum_n \int \frac{d^3k}{(2\pi)^3}\Big[\not{K}\gamma_1\gamma_2\not{K}_\parallel\gamma_\mu - 2\gamma_\nu\gamma_1\gamma_2\not{K}_\parallel\gamma_\nu\not{K}_\mu$$

$$+ \gamma_\mu\gamma_1\gamma_2\not{K}_\parallel\not{K}\Big]\tilde{\Delta}(K)^2\Delta(P_1 - K)\Delta(P_2 - K)\tilde{\Delta}(P_1 - K)$$

with

$$\Delta(K) = \frac{1}{\omega_n^2 + k^2}$$

$$\tilde{\Delta}(K) = \frac{1}{\tilde{\omega}_n^2 + k^2 + m^2}$$

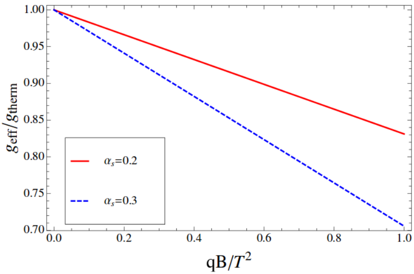
$HTL.$

Result

$$\delta\Gamma_\mu = \delta\Gamma_\mu^{(a)} + \delta\Gamma_\mu^{(b)}$$
$$= g^2 C_F \left(\frac{qB}{6\pi^2 T^2}\right)\left[\log(2) - \frac{\pi T}{2m}\right]\vec{\gamma}_\parallel \Sigma_3$$

Then

$$g_{eff} = g\left[1 - \frac{m^2}{T^2} + \delta\Gamma\right]$$



Vacuum

Magnetic correction of g.

$$\delta\Gamma^{\mu}_{(a)} = g^2(qB)\left(C_F - \frac{C_A}{2}\right)\int \frac{d^4k}{(2\pi)^4}\frac{1}{k^2}$$
$$\times\left[\gamma^{\nu}\frac{\not{p}_2 - \not{k}}{(p_2-k)^2}\gamma^{\mu}\frac{\gamma_1\gamma_2(\not{p}_1 - \not{k})_{\parallel}}{(p_1-k)^4}\gamma_{\nu} + \gamma^{\nu}\frac{\gamma_1\gamma_2(\not{p}_2 - \not{k})_{\parallel}}{(p_2-k)^4}\gamma^{\mu}\frac{\not{p}_1 - \not{k}}{(p_1-k)^2}\gamma_{\nu}\right]$$

$$\delta\Gamma^{\mu}_{(b)} = -2g^2(qB)\frac{C_A}{2}\int \frac{d^4k}{(2\pi)^4}\frac{1}{k^4}\Big[g^{\mu\nu}(2p_2 - p_1 - k)^{\rho}$$
$$+ g^{\nu\rho}(2k - p_2 - p_1)^{\mu} + g^{\rho\mu}(2p_1 - k - p_2)^{\nu}\Big]\gamma_{\rho}\frac{\gamma_1\gamma_2\not{k}_{\parallel}}{(p_2-k)^2(p_1-k)^2}\gamma_{\nu}$$

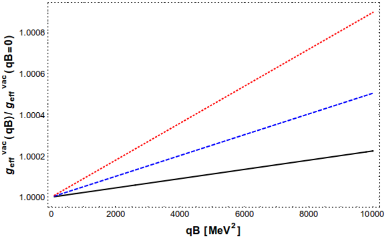
Vacuum

Result

$$\delta\Gamma^{\mu} = \delta\Gamma^{\mu}_{(a)} + \delta\Gamma^{\mu}_{(b)}$$
$$= -g^2 \frac{1}{3\pi^2}\left(\frac{q\overrightarrow{\Sigma}\cdot\overrightarrow{B}}{Q^2}\right)\left[[1-\log(4)]C_F - \frac{[7+3\log(4)]}{10}C_A\right]$$

Then

$$g_{eff} = g\,[1+\delta\Gamma]$$



Conclusions.

- Our results show that the geometrical effect produced by the magnetic field at high temperature, whereby quarks and anti-quarks get closer on average, is accompanied by the decrease of their effective interaction due to the asymptotic freedom.
- In contrast, at $T = 0$ such geometrical effect does not take place. This because the color charge associated to gluons produces a kind of screening of the color charge associated to quarks.

Many Thanks!!!