STUDYING THE QUARK GAP EQUATION AT FINITE TEMPERATURE, MAGNETIC FIELD, AND DIFFERENT FLAVOR AND COLOR NUMBERS

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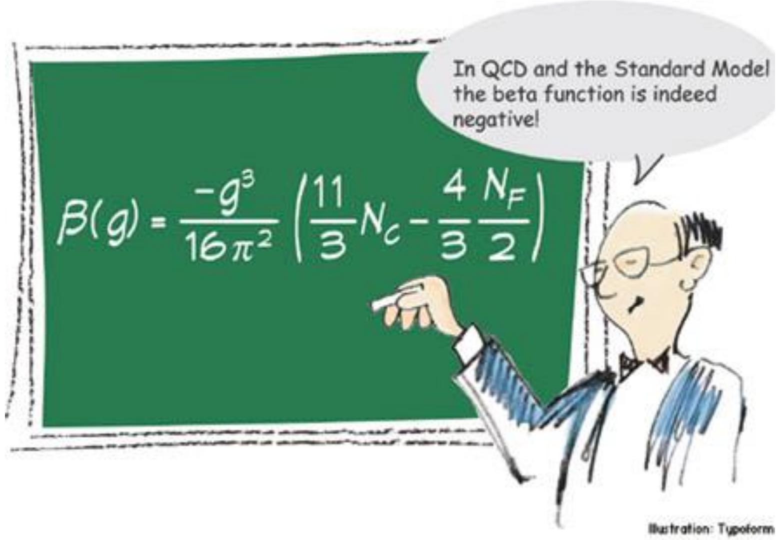
MOTIVATION

What can we say about the infrared and ultraviolet behavior of QCD?

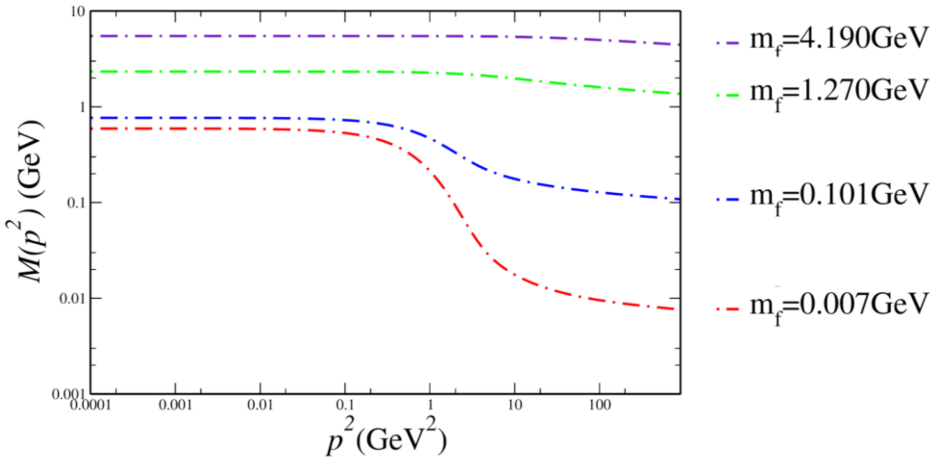
Asymptotic Freedom and dynamic Mass

The "-" sign on the beta function for N_c=3 makes possible asymptotic freedom.



The coupling becomes smaller and it is possible to use perturbation theory.

In the infrared region, QCD exhibits confinement and dynamical chiral symmetry breaking.



The coupling increases so is not posible to use perturbation theory.

It will be possible to change N_c and N_f in such a way that we have an Universe without asymptotic freedom and restore chiral symmetry?

A. Ahmad, A. Bashir, M.A. Bedolla and J.J.Cobos-Martínez,

Color, Flavor, Temperature and Magnetic Field Dependence of QCD Phase Diagram: Magnetic Catalysis and its Inverse.

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CHANGING FLAVOR AND COLOR NUMBERS

How this affect to dynamical mass generation an confinement?

How N_c and N_f affect the dynamic Mass?

We modify the coupling in the contact interaction model in order to have a flavor number dependence.

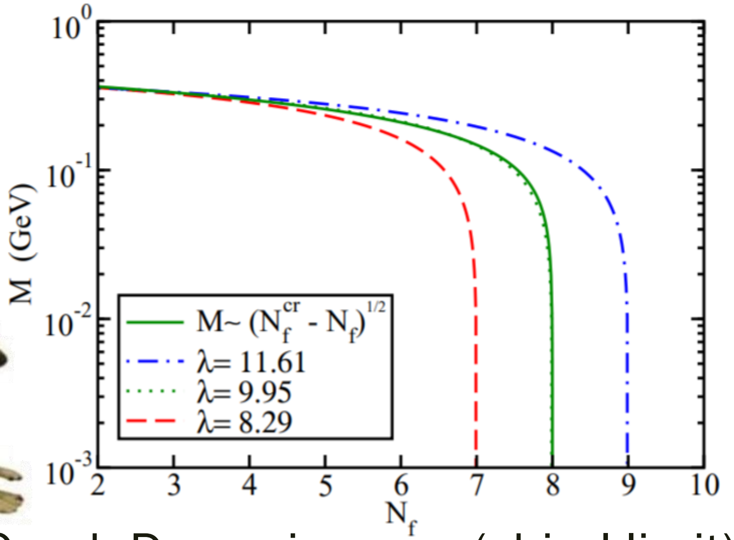
$$\alpha_{\text{eff}}^{N_c}(N_f) = \alpha_{\text{eff}}^{N_c}\sqrt{1 - \frac{(N_f - 2)}{\lambda}}.$$

Motivaded by A. Bashir, A. Raya and J. Rodriguez-Quintero, Phys. Rev. D 88, 054003 (2013) doi:10.1103/PhysRevD.88.054003, where they presented a dynamical mass model as follows $m_{\text{dyn}} \sim \sqrt{1 - N_f/N_f^c}$

Lattices studies show that chiral symmetry is restored for N_f between 8 and 12.

M. Hayakawa, K.-I. Ishikawa, Y. Osaki, S. Takeda, S. Uno and N. Yamada, Phys. Rev. D 83, 074509 (2011) doi:10.1103/PhysRevD.83.074509

Chiral symmetry is restored at N_f>6 for different critical values of lambda.



Quark Dynamic mass (chiral limit) as a function of flavors N_f for N_c=3

Continuum QCD studies demonstrate thar for N_c=3, chiral symmetry restoration happens at N_f between 7 and 12.

T. Appelquist, J. Terning and L. C. R. Wijewardhana, Phys. Rev. Lett. 77, 1214 (1996) doi:10.1103/PhysRevLett.77.1214

For a review on the contact interaction M.A. Bedolla, et. al Phys. Rev. D 92, 054031 (2015).

How N_c and N_f affect confinement?

We introduce a flavor-dependent infrared cutoff:

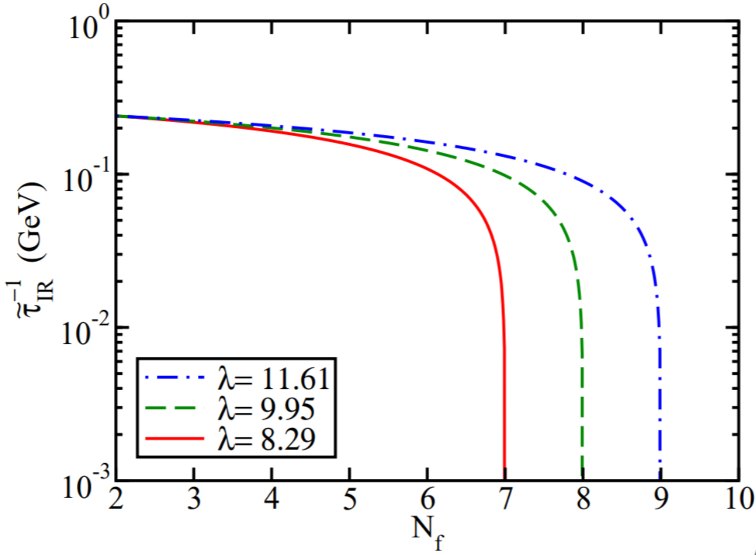
$$\widetilde{\tau}_{\mathrm{IR}} = \tau_{\mathrm{IR}} \frac{M(2)}{M(N_f)}$$

Here, M(2) is the Dynamic mass for N_f=2 y N_c=3. And at the limit M(Nf)--->0, the cutoff is infinite.

In the fundamental representation $SU(N_c)$, Gell-Mann matrices satisfy:

$$\sum_{a=1}^{8} \lambda^a \lambda^a = 2\,(N_c - 1/N_c)$$

The quark is deconfined when the critical point N_f is reached.

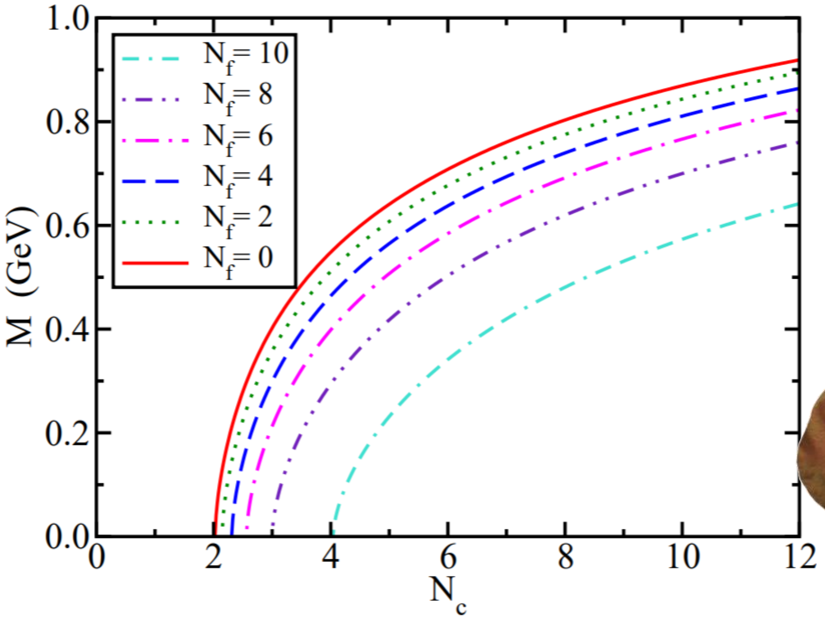


Confinement scale as a function of flavor number.

Thus, we obtain dynamical chiral symmetry breaking and confinement simultaneously.

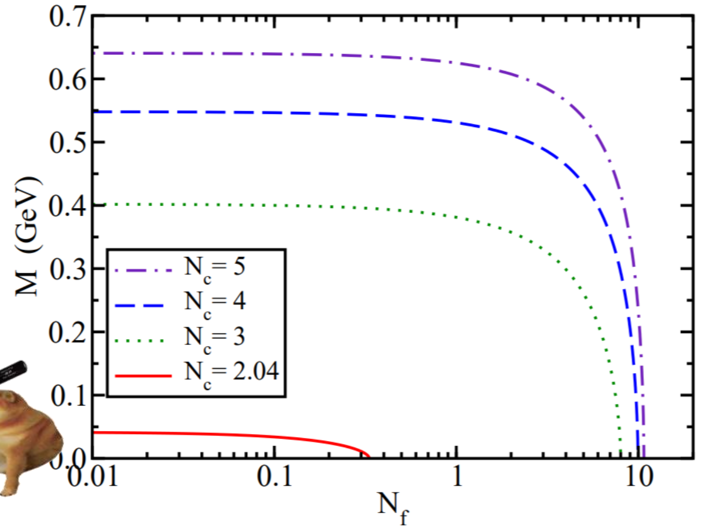
How N_c and N_f affect confinement?

Color number anti screens the interaction:



When N_f increases, higher values of N_c are needed to generate Dynamic mass.

For N_f=0, the minimum N_c to generate dynamic mass is close to 2.



For a given N_c, we can increase N_f to a critical value in order to generate mass.

The interaction of N_f y N_c are in constant competition, the first screens the interaction (deconfines) and the second, anti screens (confines).

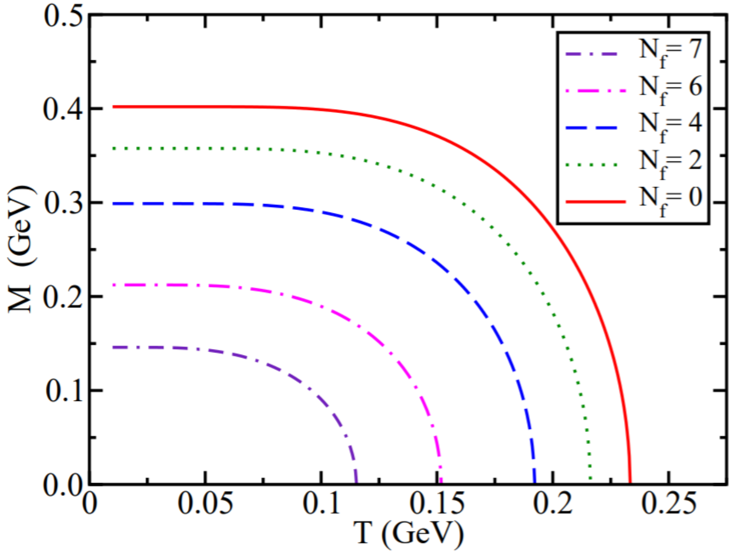
NOW WE PUT THE QUARK IN A THERMAL BATH AND MAGNETIC FIELD

How this affect the dynamical
mass generation and the critical values?

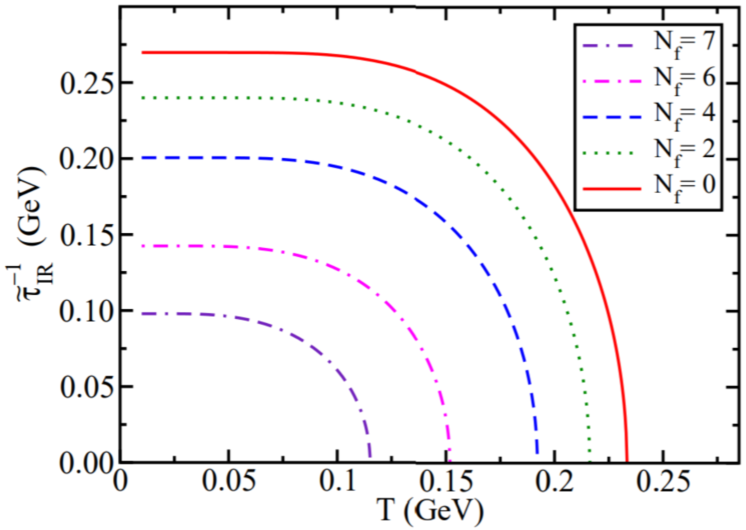
How temperature T influences on M?

At low temperatures, the quark is confined. At high temperature, the interaction diminishes.

Increasing temperature restores chiral symmetry.



Dynamical mass for different flavor numbers.



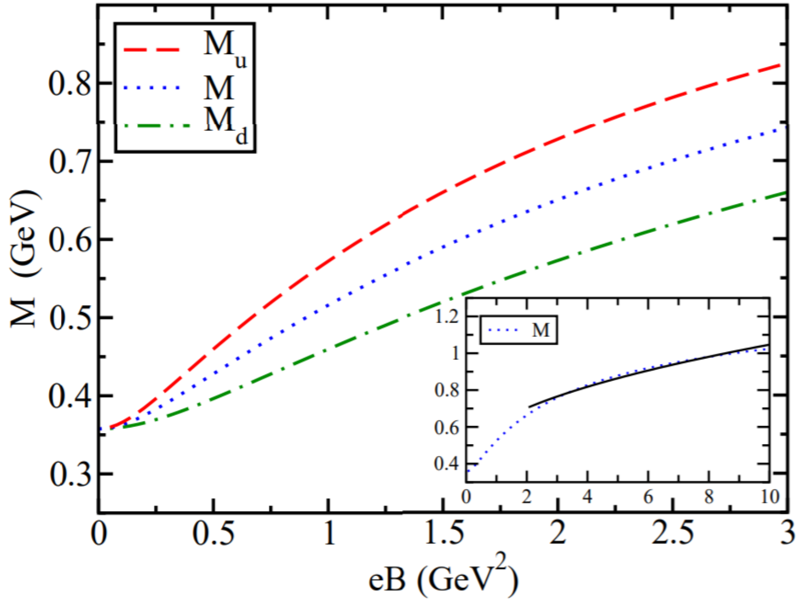
$$\widetilde{\tau}_{\rm IR} = \tau_{\rm IR}\frac{M(0,2)}{M(T,N_f)}$$

Confinement scale as a function of T for different N_f.

Both T and N_f contribute to chiral symmetry restoration an deconfinement.

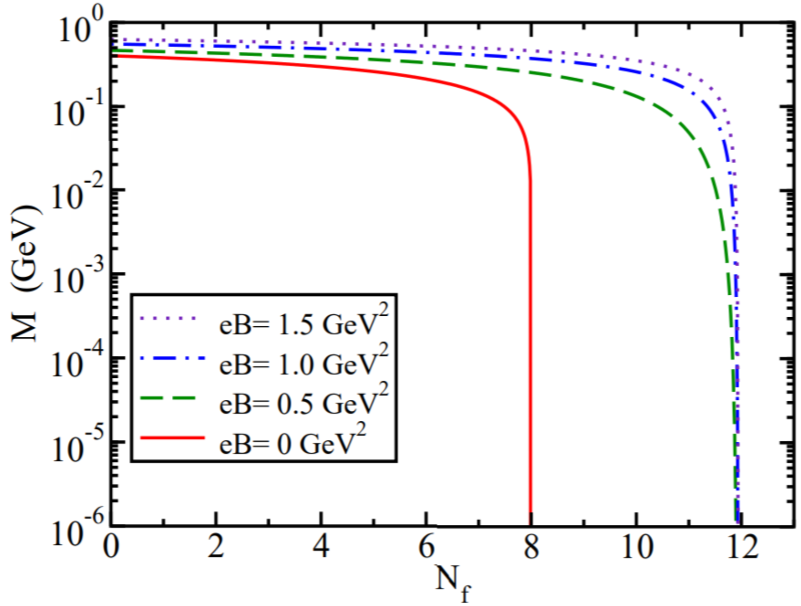
How a magnetic field *B* influences on *M*?

Lets consider a homogeneous magnetic field, transverse to quark momentum.



Dynamic mass of quarks *u and d*. N_f=2 and N_c=3.

The magnetic field produces magnetic catalysis, this compete versus N_f

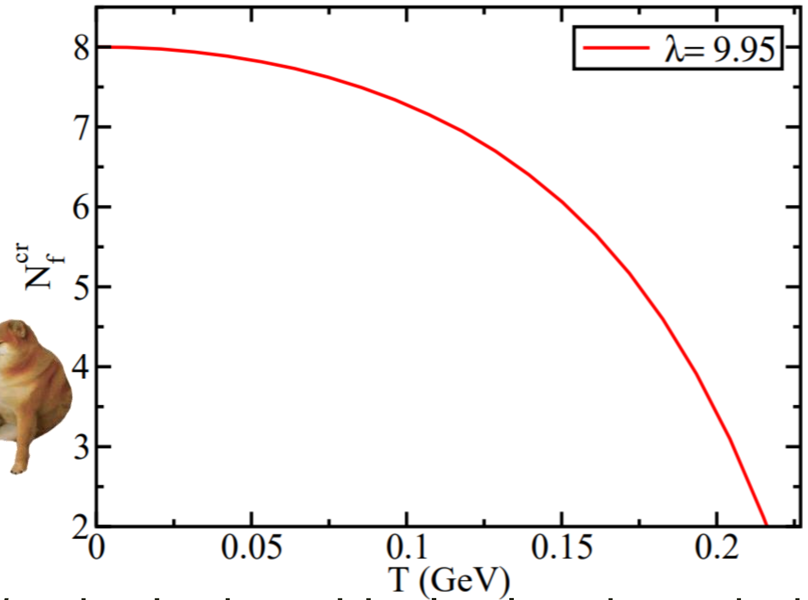


Dynamic Mass *M* as a function of N_f

Increasing *eB* is translated in a larger critical number flavor needed to restore chiral symmetry.

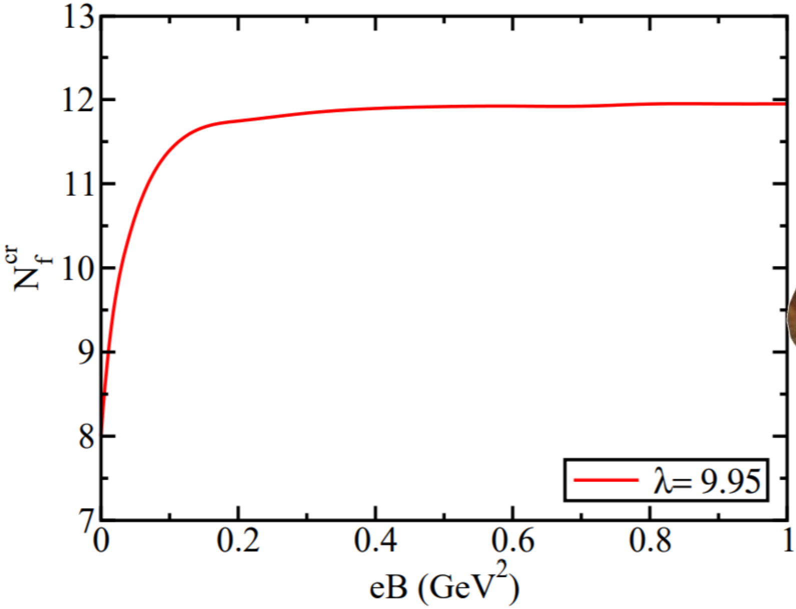
¿Difference between *eB* and *T* on *M*?

The hotter the temperature, the smaller the critical N_f to produce deconfinement.



We obtain the critical value through the mass gradient $\partial_T M$.

A larger magnetic field increases the critical N_f to exhibit confinement .

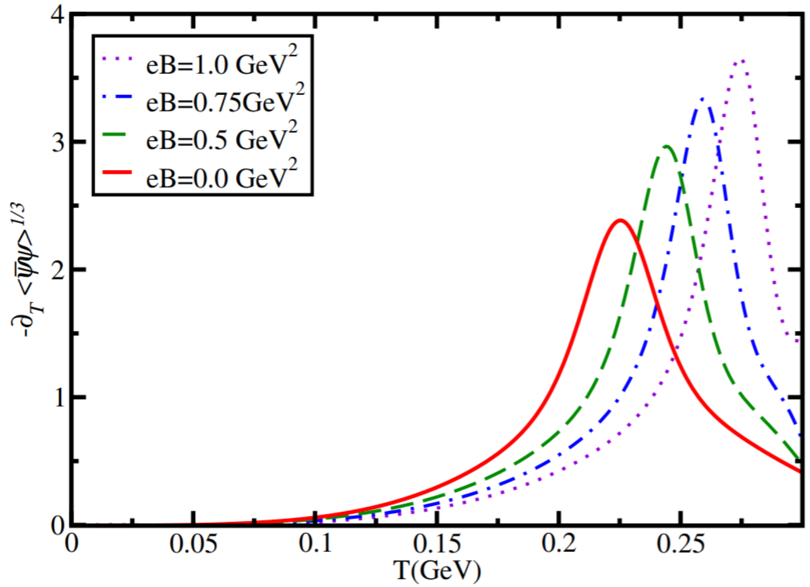


We obtain the critical value through the mass gradient $\partial_{eB} M$.

Temperature and magnetic field have opposite effects on dynamical mass generation.

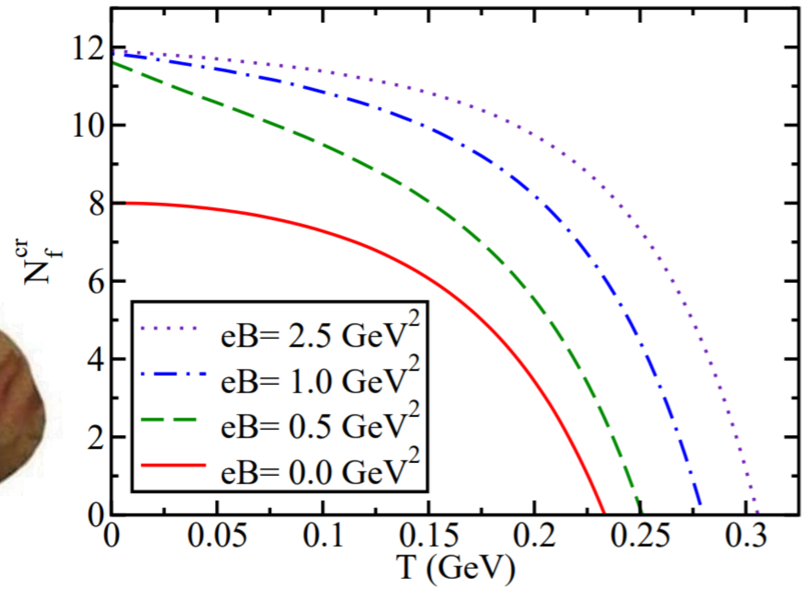
Quark inside a thermal bath and a magnetic field

Now, lets consider a quark with isospin symmetry *m=7MeV eB*-independent coupling.



We obtain the critical value through the condensate gradient. $\partial_T \langle \bar{\psi}\psi \rangle^{1/3} (N_f, eB, T)$

A larger magnetic field requires a larger temperature to exhibit deconfinement: magnetic catalysis.

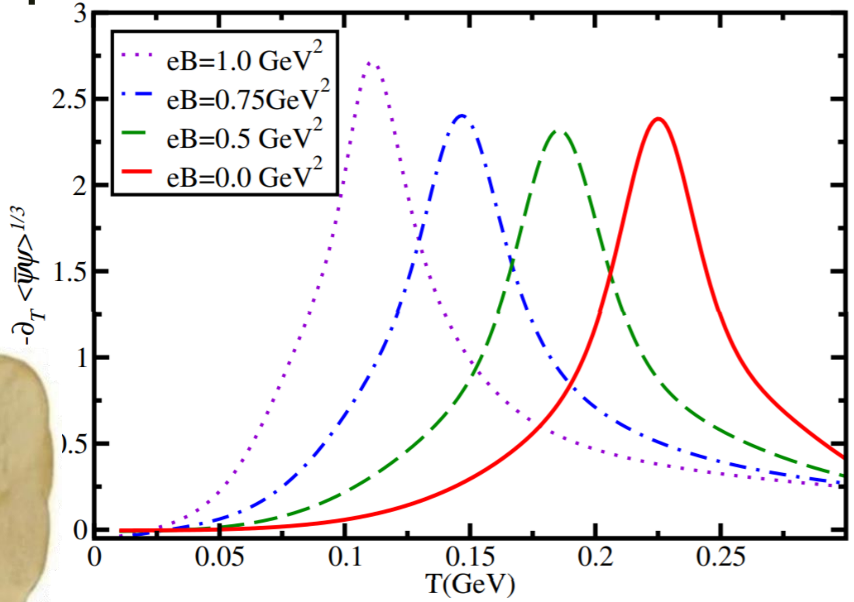


Flavor critical number evolution with temperature for different magnetic fields *eB*.

¿What if we introduce an *eB*-dependent coupling?

Quark inside a thermal bath and a magnetic field

If the coupling decreases with the magnetic field, the inverse magnetic catalysis appears.



We obtain the critical value through the condensate gradient. $\partial_T \langle \bar{\psi}\psi \rangle^{1/3} (N_f, eB, T)$

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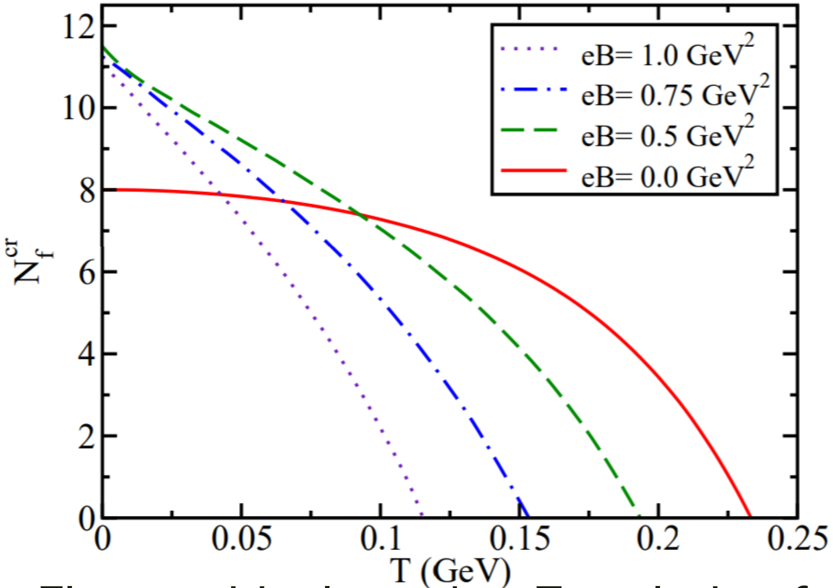
$$\alpha_{\text{eff}}^{N_c}(N_f, x) = \alpha_{\text{eff}}^{N_c}(N_f, 0)\left(\frac{1 + ax^2 + bx^3}{1 + cx^2 + dx^4}\right)$$

Now, a larger magnetic field decreases the *T* required to reach deconfinement .



Flavor critical number T-evolution for different magnetic fields *eB.*

$x = eB/\Lambda_{\text{QCD}}^2$ $\Lambda_{\text{QCD}} = 300$ $a = 0.0108805$

$b = -1.0133 \times 10^{-4}$ $c = 0.02228$

$d = 1.84558 \times 10^{-4}$

M. Ferreira, P. Costa, O. Loureno, T. Frederico and C. Providncia, Phys. Rev. D 89, no.11, 116011 (2014) doi:10.1103/PhysRevD.89.116011

Summary

- Increasing the number of flavors restores the chiral symmetry.
- Increasing the number of colors confines the quark.
- The minimum value of color number to generate Dynamic mass is close to 2.2.
- The temperature also has an effect of restoring the chiral symmetry.
- The magnetic effect produces the magnetic catalysis, and inverse magnetic catalysis with a eB-dependent coupling.
- The flavor critical number decreases with temperature, and increases with the magnetic field.
- For a more detail explanation about the contact interaction model, refer to Gustavo Paredes' talk in Baryon-spectroscopy 4.