Non-perturbative aspects of gauge theories

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Wednesday 11 c.t., Phil 19 SR

Prerequisites: Theoretical Physics I-IV, QFT, basic knowledge of renormalisation & gravity

- Content
- Literature
- Exercises & bonus material

Non-perturbative aspects of gauge theories

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Content of lecture series

In the lecture course modern Renormalisation Group techniques are applied to strongly-correlated physics in QCD and Quantum Gravity The lecture course provides an introduction to the stronly-correlated physics of QCD and Quantum Gravity. The related physics problems are treated within the Functional Renormalisation Group (FRG), and a survey of alternative approaches is provided.

Outline

- The Functional RG
  - Derivation
  - Truncation schemes, optimisation & numerics
  - Fixed points in the Functional RG
- QCD
  - Introduction
  - Confinement & chiral symmetry breaking
  - Confinement-deconfinement phase transition at finite T
  - A glimpse at the QCD phase diagram
- Quantum Gravity
  - Introduction
  - RG approach to quantum gravity
  - Fixed point structure of quantum gravity
  - Cosmological applications

Literature

- ***Introductory reviews on FRG***

Aoki	Introduction to the Non-perturbative RG	Int.J.Mod.Phys.B14:1249-1326,2000
Berges, Tetradis, Wetterich	Non-Perturbative Renormalization Flow in Quantum Field Theory and Statistical Physics	Phys.Rept.363:223-386,2002
Polonyi	Lectures on the functional renormalization group method	Central Eur.J.Phys.1:1-71,2003

- ***Reviews on FRG in gauge theories & gravity***

Litim, Pawlowski	On gauge invariant Wilsonian flows	Proceedings 'The ERG', Word Scientific '99
Pawlowski	On Wilsonian flows in gauge theories	Habilitation thesis, Erlangen '02
Pawlowski	Aspects of the FRG	Annals Phys.322:2831-2915,2007
Gies	Introduction to the FRG and applications to gauge theories	Lecture notes
Reuter, Saueressig	FRG Equations, Asymptotic Safety, and Quantum Einstein Gravity	Lecture notes
Niedermaier, Reuter	The Asymptotic Safety Scenario in Quantum Gravity	Living review

FRG-reviews on various topics are listed as refs. [15]-[27] in 'Aspects of the FRG' .

- ***Reviews on DSEs in QCD***

Alkofer, von Smekal	The Infrared Behavior of QCD Green's Functions	Phys.Rept.353:281,2001
Fischer	Infrared Properties of QCD from Dyson-Schwinger equations	J.Phys.G32:R253-R291,2006

Literature, basics

- ***Textbooks on the renormalisation group and critical phenomena***

Amit	Field Theory, the Renormalization Group, and Critical Phenomena	World Scientific
Binney, Dowrick, Fisher, Newman	The Theory of Critical Phenomena, an Introduction to the Renormalization Group	Clarendon Press, Oxford
Cardy	Scaling and Renormalization in Statistical Physics	Cambridge University Press
Collins	Renormalization	Springer
Parisi	Statistical Field Theory	Addison-Wesley
Zinn-Justin	Quantum Field Theory and Critical Phenomena	Claredon Press, Oxford

- ***Quantum field theory, basics***

Haag	Local Quantum Physics	Springer, 1996
Itzykson, Zuber	Quantum Field Theory	McGraw-Hill
Peskin, Schroeder	An Introduction to Quantum Field Theory	Addison Wesley
Siegel	Fields	hep-th/9912205
Weinberg	The Quantum Theory of Fields, Vol. 1-2	Cambridge University Press

- ***Quantum field theory, applications***

Kugo	Eichtheorie	Springer, 1997
Miransky	Dynamical Symmetry Breaking in Quantum Field Theories	World Scientific, 1993
Muta	Foundations of Quantum Chromodynamics	World Scientific, 1987
Pokorski	Gauge Field Theories	Cambridge, 1987
Wu-Ki Tung	Group Theory in Physics	World Scientific, 1985
Zinn-Justin	Quantum Field Theory and Critical Phenomena	Oxford, 1993

- ***General relativity***

Carroll	Spacetime and Geometry	Addison Wesley
Göckeler & Schücker	Differential Geometry, gauge theories, and gravity	Cambridge University Press
Misner, Torne, Wheeler	Graviation	Freeman

Introduction

Two of the most pressing questions of present elementary particle/cosmology physics:

(1) The phase diagram of QCD

(a) confinement 1a

- mechanism, signatures/order par.
- spectrum, string tension

(b) chiral symmetry breaking 1b

- mechanism, order parameter
- spectrum (hadronisation)
- relation to confinement

(c) finite Temperature

- confinement - deconfinement phase tr.
  critical temp., spectrum
- chiral symmetry breaking
  critical temp., spectrum
- quark gluon plasma

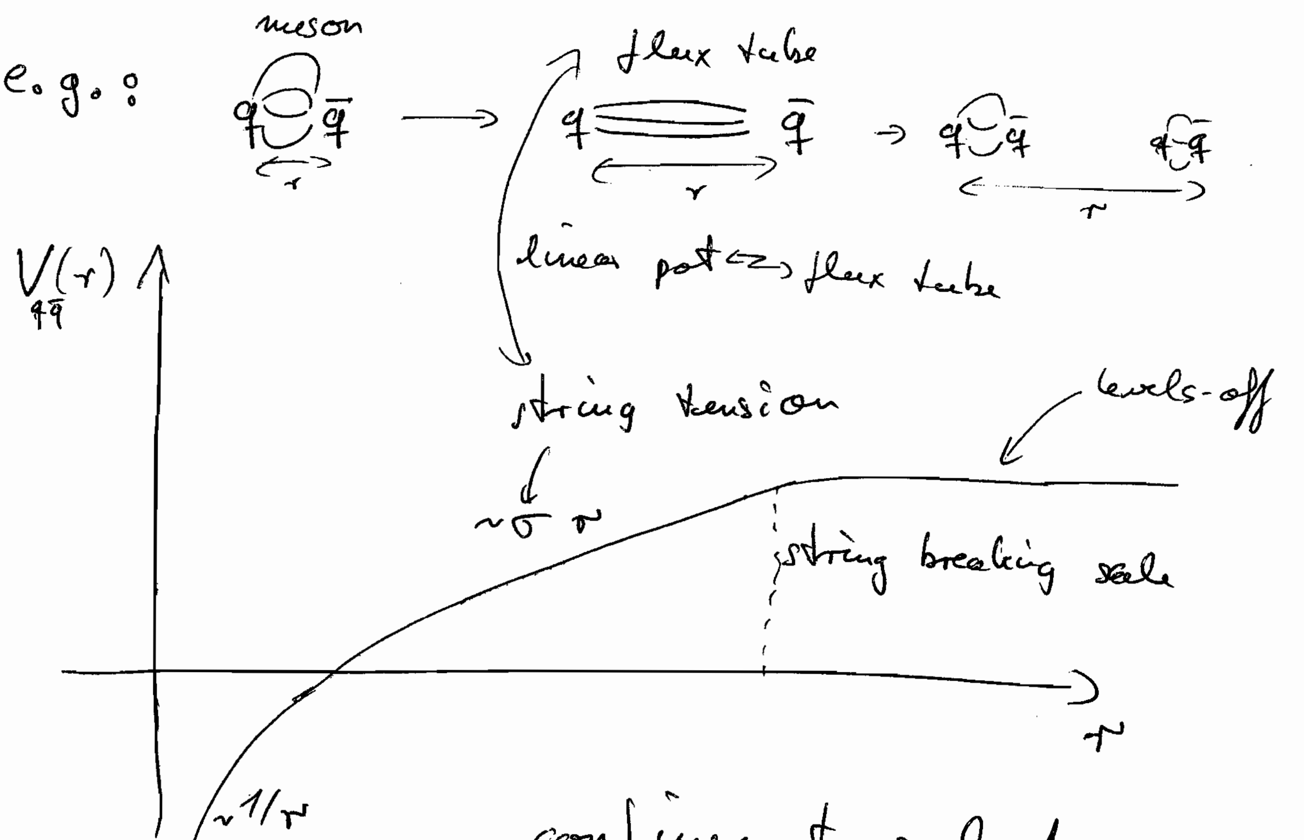
Confinement:

- a la Jaffe, Witten: 1 Mio \$

  Yang-Mills existence and mass gap (lowest 1particle states is massive) glueballs

- all physical states are colour-neutral

e.g.:



confinement scale $\Lambda_{QCD} \sim 3\text{-}400$ MeV

- dual Meissner effect (no stable colourmag. monopoles
- vortex percolation (no stable vortices)
- instanton-induced confinement (& with chiral sym.)
  finite T: calorons have monopole constituents

chiral symmetry breaking:

quark masses:

u	d	s	c	b	t	[MeV]
1.5 - 3	3 - 7	95	1250	4200	$170 \cdot 10^3$	

scale of spontaneous chiral sym. breaking ~ 400 MeV

- $\Delta m \sim 400$ MeV flavour-blind
- relevant for u,d light quarks
  s heavy quarks
- correction for c, b, t
- π is Goldstone boson of chiral symmetry breaking

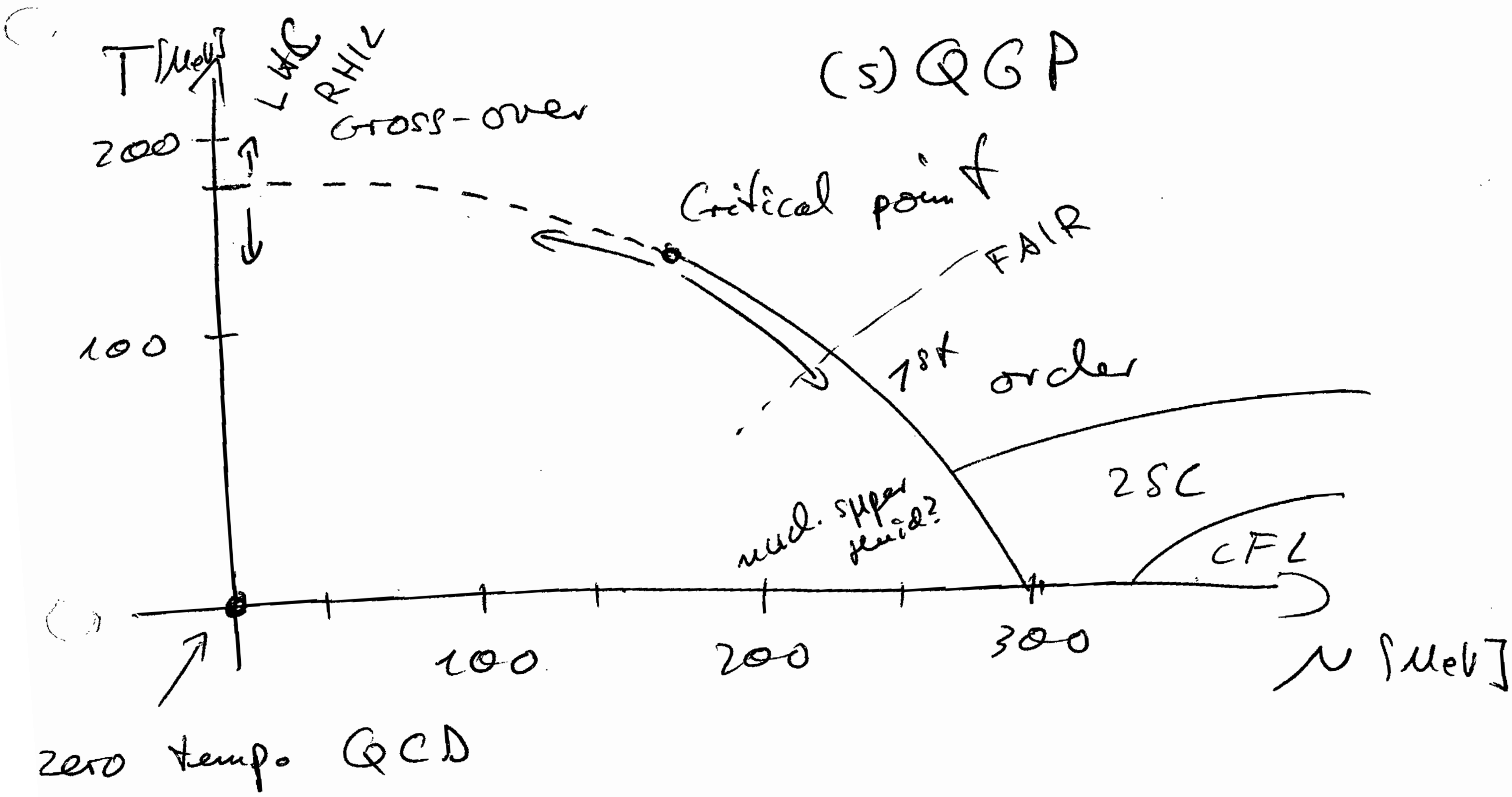
Relation between confinement and chiral symmetry breaking

[at $\mu, T = 0$: 't Hooft anomaly matching: $n_f > 2$]

(d) finite density

- phase diagram
- thermodynamics
- quark gluon plasma

Phase diagram (for 2+1 flavours)
(2 = light u,d ~1.5-3-7 MeV; 1 = heavy s ~95 MeV)



In this lecture

- confinement - deconfinement $T=0$, $T\neq 0$
- chiral symmetry breaking
- a glimpse at finite μ

(2) Quantum gravity

(a) Existence (perturbatively non-renormalisable

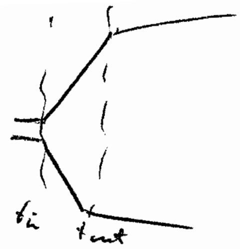
- general relativity low-energy limit of UV-gravity: string theory
- canonical quantisation: Loop quantum gravity
- asymptotic safety (Weinberg):
  - 'Non-Gaußian UV fixed-point
    - dynamical triangulations 'lattice gravity'
    - RG-gravity (this lecture)

(b) phenomenology

- # relevant parameters
- cosmology, particle physics (extra dim)

  cosmological constant
- matter
- IR gravity

Inflation



between $t_{in} = 10^{-43}s - 10^{-35}s$ to $t_{out} \sim 10^{-30}s$

- explains (1) homogeneity,
  (2) cosmic microwave background
  (3) flatness (fine tuning)
  (4) structure via density fluctuations

- problems
  - fine tuning
  - arbitrariness

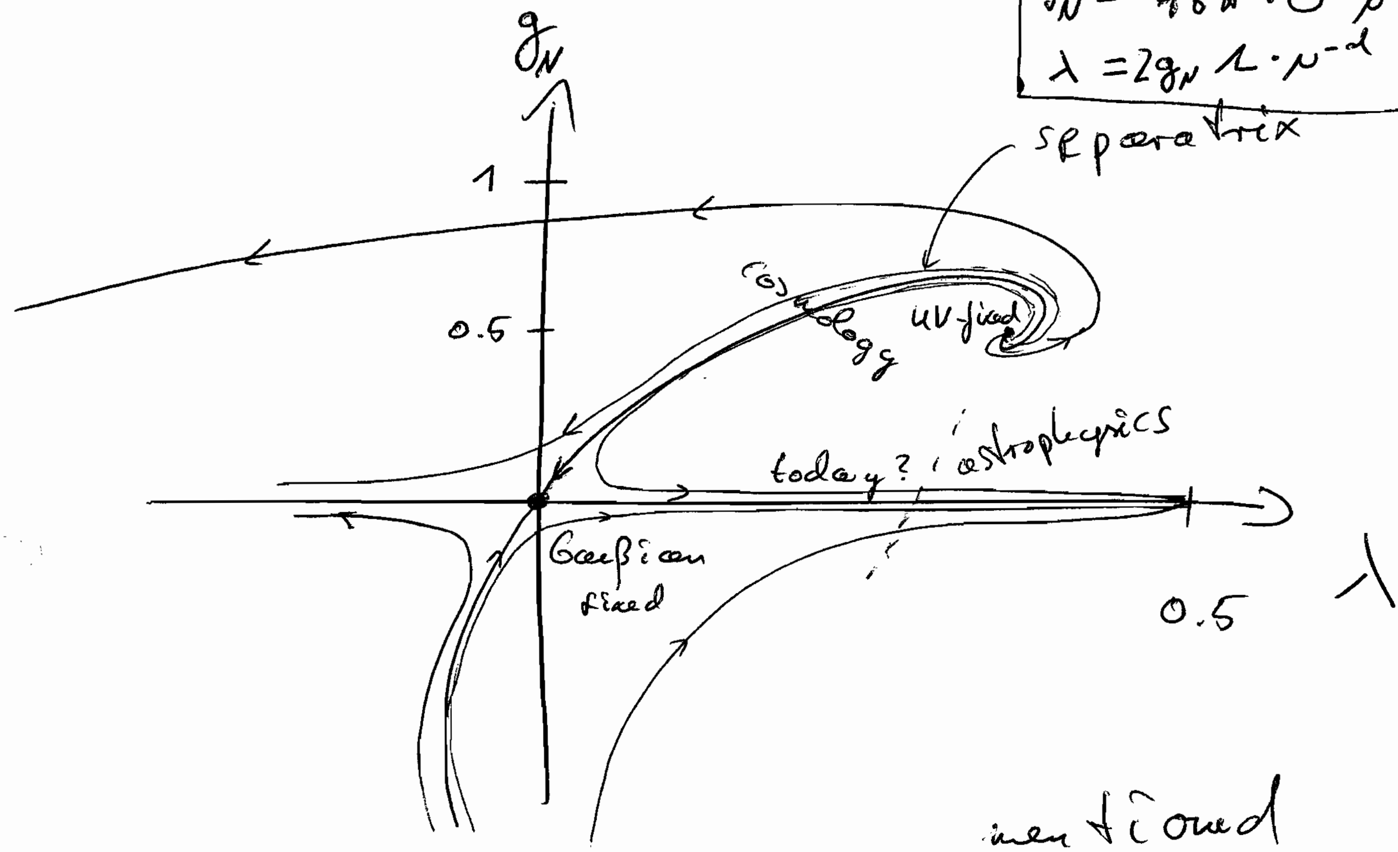
Lepto / Baryo genesis

Rotation curves of galaxies

Phase portrait : $\Gamma[g] = \frac{1}{16\pi G}\int d^4x \sqrt{g}\,(R(g) - \Lambda \cdot G)$

$g_N = 16\pi \cdot G\, \mu^{d-2}$

$\lambda = 2 g_N \Lambda \cdot \mu^{-d}$



mentioned

In this lecture

- phase portrait
  - fixed point(s)
  - relevant directions
- foot prints