Particules Élémentaires, Gravitation et Cosmologie
Année 2005-2006
Interactions fortes et chromodynamique quantique
II: aspects non-perturbatifs

Cours Ib: 7 fevrier 2006

QCD non perturbative: problèmes et outils

- Non-perturbative problems
- Non-perturbative tools
- Which tools for which problems?
- Outline of upcoming lectures/seminars

The problems

1. Colour Confinement
2. Symmetry breaking
3. The hadronic spectrum:
   3.1 Masses
   3.2 Couplings, widths, cross sections
4. OPE matrix elements (structure functions)
5. Weak matrix elements
6. Strong-CP problem
7. The string behind QCD

1. Colour Confinement

- No doubt the biggest challenge facing QCD, a theory defined in terms of fundamental quark and gluon d.o.f. (both carrying colour charges)
- In nature (at least at low temperature) we only observe hadrons, i.e. colour singlets
- However, some observable quantities are computed at the «partonic» level (almost paradoxical..)
- The challenge is to show that the only finite-energy states in QCD are colour singlets. This is not what we see in perturbation theory

2. (Chiral) Symmetry breaking

- As we shall see QCD has more symmetry than what we observe. How come?
- We know of two ways of breaking a symmetry: explicit and spontaneous, both turn out to be needed phenomenologically
- The challenge is to prove that both kinds of breakings do occur in QCD

3. The hadronic spectrum:
3.1 Masses

- Besides proving colour confinement we would like to compute the masses of (at least the lightest) hadrons and to compare them with a vast amount of precise experimental data
- In principle, all masses should be calculable in QCD in terms of very few parameters, some even in absolute terms once we know Λ_{QCD}

3. The hadronic spectrum:

3.2 Couplings, widths, cross sections

- We would then like to compute couplings among hadrons (=> input to Nuclear Physics!) Again, no new parameter is in principle needed, just a matter of computational power..
- Couplings will give (S.I.) lifetimes, (S.I.) scattering amplitudes, cross-sections (e.g. the pp total cross section at E=10 GeV)

4. OPE matrix elements
(structure and fragmentation functions)

- We saw last year that PQCD allows to compute the way structure (and fragmentation) functions evolve as a function of the hardness of the process, Q.
- PQCD is unable (with very few exceptions, cf. sum rules) to compute structure functions at some given scale
- These are related to matrix elements of certain local operators in the nucleon state, clearly a non-perturbative quantity

5. Weak matrix elements

- Similarly, if we wish to compute a quantity related to a weak-interaction hadronic process (e.g. K decay), this can be reduced to the matrix element of some operator (provided by the EW theory) between two hadronic states, once more a non-perturbative quantity

6. Strong-CP problem

- As we shall see, QCD has a built-in mechanism for inducing possibly large violations of the CP (charge conjugation times parity) symmetry
- Experimentally, there are strong upper bounds on such violations (electric dipole moment of the neutron, for instance)
- Understanding exactly the nature of CP violation in QCD calls for non-perturbative considerations

7. The string behind QCD

- Colour Confinement should imply a string-like structure of the hadrons whith the string providing the confining force through its « tension »
- In fact string theory was born in the late sixties from an attempt to understand the strong interactions before the advent of QCD
- It is clear, however, that the old string, or its later improvement, the superstring, do not correspond to the one describing hadrons in QCD
- The right string is still being hunted for..

The (not so many) available tools

1. Symmetry/effective Lagrangian considerations
2. Large-N techniques
3. Lattice QCD:
4. String inspired techniques (so far mostly for supersymmetric extensions)

This year we will limit our attention to the first three

Matching tools to problems

Tool	Problem	Lecture /Seminar
● Symmetry & effective Lagrangian considerations	1,2,7	2, 3
● Large-N techniques	2,6,7	4, 5
● Lattice QCD: ❑ Quenched ❑ Unquenched	1,2,3,4, 5,6,7	6,7,8,9
● Supersymmetry and String inspired techniques	1,2,8	Next year?

Breakdown of upcoming lectures/seminars

• 14/2-21/2 Symmetry techniques	• K. Konishi (Pise)
• 28/2-7/3 Large-N techniques	• P. Di Vecchia (Copenhagen)
• 14/3-21/3 Lattice techniques (anal.)	• E. Rabinovici (Jerusalem)
• 28/3-4/4 Lattice techniques (num.)	• L. Giusti (CERN)