Master 2 internship and PhD proposal
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Laboratory: Laboratoire de Physique Subatomique et de Cosmologie (L.P.S.C.)

Group : Theory Group

Supervisors: Mariane Mangin-Brinet(*)/ Savvas Zafeiropoulos(**)

Address, phone, e-mail: (*)53, avenue des Martyrs – 38026 Grenoble
Tel : 04 76 28 40 46
mariane@lpsc.in2p3.fr
(**)Institut de Physique Théorique
Université de Heidelberg
Philosophenweg 12, 69120
Heidelberg, Allemagne
zafeiropoulos@thphys.uni-heidelberg.de

Title: Non-perturbative renormalization and fundamental parameters of Quantum Chromodynamics

General motivation and summary of the project:

Quantum Chromodynamics (QCD) is the theory of strong interaction, whose ambition is to explain nuclei cohesion as well as neutron and proton structure, i.e. most of the visible matter in the Universe. Its application domain is even wider, since QCD controls the structure and interactions of all hadrons: proton, neutron, hyperons, pions, kaons,...It is one of the most elegant theory of Science History (with General Relativity). It has only seven parameters (one for each of the six quarks and a coupling constant) and allows to give a physical interpretation to a very broad range of phenomena using a well-defined and very compact formalism.

However, this theory is far from been solved and the understanding of many phenomena has long remained – and for some of them still remains – a challenge. This is in particular the case for *ab initio* computation of the fundamental parameters of QCD, that is the quark masses and the strong coupling constant.

The only systematic and rigorous method to solve QCD at low energy (i.e. in the domain where it is non-perturbative) is Lattice QCD (LQCD). LQCD aims at providing solutions of this fundamental theory of matter, without uncontrolled hypothesis, and with accuracies which rival that of experimental data. LQCD procedure -- whose principle is inspired by Statistical Physics -- consists in discretizing space-time on a 4-dimensional grid and use Feynman path integral formalism.

In most cases, the observables computed on the lattice are not directly those measured by experiments, but they require a renormalization. To reach the required accuracy, the renormalization must be done non perturbatively.

During the Master 2 internship, a first step will consist in gaining knowledge in and understanding the main issues of non-perturbative renormalization. The internship project will then consist in computing renormalization constants for a selected set of quark bilinear operators, using Ward-Takahashi identity and gauge configurations with four dynamical quarks, generated by the ETM Collaboration. Renormalized quark masses will then be deduced.

A solid knowledge of the basis of quantum field theory is required. Even if no particular expertise in programming is required, a certain ease in using computing means is needed. The languages used are C, C++, Fortran90 and MPI (parallelism).

PhD subject:

The work started during the Master 2 internship will naturally continue towards a PhD thesis whose main subject will be the determination of fundamental parameters of QCD, using Lattice QCD. Although there exists already several computations of quarks masses and strong coupling constant, a determination including four dynamical quarks (u, d, s, c) at the physical mass with twisted mass fermions has never been done. The PhD work will consist in getting familiar with subtleties of lattice QCD and in developing strategies to compute quarks masses and strong coupling constant. A large part of the project will be in particular devoted to the non-perturbative renormalization, fundamental ingredient of most lattice computations.

Several techniques of non-perturbative renormalization exist and a major part of this work will consist in implementing and comparing some of these procedures.

In addition to the determination of fundamental parameters of QCD Lagrangian, and once non-perturbative renormalization will be mastered, this PhD subject can also extend to the computation of other crucial quantities of strong interaction physics, such as $\langle x \rangle$ (the average momentum carried by quarks and gluons in the proton) or g_A.

This work will be done in the framework of the "European Twisted Mass Collaboration" (ETMC, http://www-zeuthen.desy.de/~kjansen/etmc). This collaboration gathers nine European countries (Germany, Italy, UK, Netherlands, Switzerland, France, Cyprus, Poland and Spain) and uses a special discretization of QCD action called "twisted mass QCD", which presents several interesting advantages. Two other French laboratories are also members of ETMC (LPT Orsay and LPC Clermont) and several meetings are organized yearly in France and in Europe.

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