

Nonperturbative QCD: The promise of a bridge from elementary particle interactions to nuclear forces

Workshop in hadronparticle physics: 1st - 5th October 2012, Matalascañas (Huelva, Spain)

1. Introduction

This meeting aims to bring together experts in Nuclear, Hadron and Particle Physics in order to facilitate communication, and discern and highlight those features of their common foundation which should provide a means of bridging the gap between the fundamental interactions between elementary particles and an explanation of nuclear forces. Namely, to expose the physics hidden in the non-perturbative phenomena of Quantum Chromodynamics (QCD), which is the strong-interaction part of the Standard Model of Particle Physics. Solving QCD presents a fundamental problem that is unique in the history of science. Never before has Science been confronted by a theory whose elementary excitations are not those degrees-of-freedom readily accessible via experiment; i.e., whose elementary excitations are *confined*. Moreover, there are numerous reasons to believe that QCD generates forces which are so strong that less-than 2 % of the visible matter in the Universe can be attributed to the so-called current-quark masses that appear in the theory's formulation; viz., forces capable of generating mass from nothing, a phenomenon known as dynamical chiral symmetry breaking (DCSB).

Our driving goal is to create a collaborative environment that will permit the participants to openly discuss recent progress in theoretical and phenomenological aspects of non-perturbative QCD. This will foster the development of the collaborative research that is necessary if we are to solve the challenges posed by Nature's most demanding physical theory. Moreover, since physics is an experimental science, we will place emphasis on comparison with real-world phenomena, which must ultimately be the measure of a solution to QCD. With this in mind, selected experimentalists will be amongst the participants. They will highlight the capabilities and discovery potential of current and future facilities, whilst the theorists will present their cases for those quantities whose measurement is most critical.

2. Nonperturbative QCD

The manner by which the quarks and gluons of QCD combine to form the known hadrons is as yet unknown. More striking, perhaps, is the failure to comprehend even which hadrons the theory might support. For example, QCD can potentially produce bound-states constituted solely from gluons. The existence of such states would change forever the concept of "matter," eliminating immediately any further distinction between matter and radiation. However, no theoretical tools exist today that can satisfactorily address these problems, which can only be rigorously posed within the context of non-perturbative relativistic quantum field theory. Notwithstanding this, modern experimental facilities are pushing hard at the frontier of hadron physics, seeking to discover states at which theory can now only hint.

This is unacceptable. Hence, the greatest novelty and the greatest challenge within the Standard Model of Particle Physics is to find essentially new ways and means to predict and explain precisely via mathematics the observable content of QCD. This means that the problem of confinement must be tackled and its connection with dynamical chiral symmetry breaking elucidated. In parallel with these fundamentals, there are numerous other problems that must be tackled,

given the experimental programmes that are already in place; e.g., the symmetry-preserving computation of hadron elastic and transition form factors, and the computation and parametrisation of parton distribution functions. These problems provide a unifying cord that joins a diverse array of fields, e.g.: few-body nuclear reaction theory; hadron structure and interactions; relativistic heavy-ion collisions; and the physics of heavy-flavour. This workshop will bring together experts in all these areas.

A variety of theoretical frameworks have been deployed against these problems, amongst them Dyson-Schwinger equations (DSEs), lattice-QCD (LQCD), and a range of models which attempt to exploit one particular feature or another anticipated of QCD. The models produce results quickly but it is difficult to know whether the predictions are truly representative of QCD. The *ab initio* LQCD approach produces results and demonstrates the predictive power needed to guide experiment only very slowly. In this connection the partially *ab initio* DSE approach shows promise as a tool to bridge that gap. Indeed, there are ample opportunities for cross-fertilisation between the DSE and LQCD approaches, with numerous successful examples available in the public record. In addition, standing alone and as a complement to these methods, effective field theories for light- and heavy-hadrons play a valuable role, providing access to observables through a combination of precise computation within perturbation theory and unknown matrix elements that can experimentally be constrained. The strengths and weaknesses of all these approaches will be canvassed at the meeting.

3. Program

The scientific programme will be arranged in connection with these physical and theoretical themes, paying particular attention also to planning for and anticipating results from the new generation of facilities, e.g.: the upgraded Jefferson Lab facility; the Japan Proton Accelerator Research Complex (JPARC); the Facility for Antiproton and Ion Research (FAIR); and experiments at the Large Hadron Collider (LHC).

The workshop must provide participants with an environment that, through a week of presentations and discussions, fosters interaction and cooperation, with the longer-term aim of building new national and international collaborations.

We therefore plan for the workshop to last five days (Tuesday to Saturday), with six invited talks, each of $45 + 15 = 60$ mins duration, on each of the first four days:

- Morning – 09:30 - 13:00 (30min break at 11:30);
- Afternoon – 16:00 - 19:30 (30min break at 18:00);

and a full session on Saturday morning. The long luncheon break will provide opportunities for detailed discussions of those points raised during the 15 min. question periods.

We plan to host the meeting and accommodate the approximately thirty participants at the University of Huelva's CIECEM facility, a venue which specialises in such events.