Nucleon reverse engineering: Structuring the nucleon with quarks and gluons

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Description

Our present understanding of the strong interaction is summarized in a quantum field theory named *Quantum Chromo Dynamics* (QCD). Its fundamental degrees of freedom, *quarks* and *gluons*, are generically called *partons*. By exchanging a *color* charge, they form bound states, *hadrons*, which are the observed degrees of freedom of the strong interaction. Even if QCD is defined by a restricted number of parameters and principles, its phenomenology is exceptionally wealthy : structure of hadrons, spectrum of baryonic resonances, phase diagram, nuclear physics, ... However usual perturbative technics fail in describing its large distance regime. In spite of important recent theoretical and experimental progress, actual physical mechanims to confine color charges, or to create hadrons from quarks and gluons, have still to be clarified.

The central theme of this course is the charge, spin and energy - momentum structure of the nucleon in terms of quarks and gluons. This partonic description is obtained through the study of several non-perturbative objects : *form factors*, *parton distributions* and *generalized parton distributions*. These functions are theoretically well defined, and can be experimentally accessed through different deep processes, among which : elastic and inelastic lepton - nucleon scattering, or nucleon leptoproduction of a real photon or a meson.

This course will motivate the theoretical definition of form factors, parton distributions or generalized parton distributions, describe the procedures to extract them from measurements, and detail the corresponding knowledge of the nucleon structure. This empirical information will be systematically compared to first principles QCD computations (lattice QCD) and to model expectations, mapping out some effective degrees of freedom and the effective forces between them.

The role and impact of present and future experimental facilities will be discussed, in particular the physics opportunities of an electron - ion collider. If time allows, spectroscopy will be introduced as an approach complementary to deep processes studies, with, for example, the current *Excited Baryon Analysis Center* (EBAC) initiative to determine all nucleon resonances and map out their quark-gluon structure.

Desirable previous knowledge

It is necessary to have some basic knowledge of quantum field theory (in particular computation of Feynman diagrams at tree level in QED and QCD) corresponding roughly to the first part of Peskin & Schroeder's textbook. Familiarity with renormalization and renormalization group equations would be very helpful.

Introductory reading

- S.D. Bass, *How does the proton spin ?*, `Science 315 (2007) 1672`.
- F. Wilczek, *Origins of mass*, `Central Eur. J. Phys.` **10** `(2012) 1021 [arXiv:1206.7114 [hep-ph]]`.

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- J.F. Donoghue, E. Golowich and B.R. Holstein, *Dynamics of the Standard Model*, Cambridge University Press 1992.
- M. E. Peskin and D. V. Schroeder, *An Introduction to quantum field theory*, Addison-Wesley 1995.
- T. Muta, *Foundations of Quantum Chromodynamics : an introduction to perturbative methods in gauge theories*, World Scientific Publishing 2009.
- M. Diehl, *Generalized parton distributions*, `Phys. Rept.` **388** `(2003) 41 [hep-ph/0307382]`.
- A. V. Belitsky and A. V. Radyushkin, *Unraveling hadron structure with generalized parton distributions*, `Phys. Rept.` **418** `(2005) 1 [hep-ph/0504030]`.
- E. Klempt and J.-M. Richard, *Baryon spectroscopy*, `Rev. Mod. Phys.` **82** `(2010) 1095 [arXiv:0901.2055 [hep-ph]]`.
- Ph. .Hagler, *Hadron structure from lattice quantum chromodynamics*, `Phys. Rept.` **490** `(2010) 49 [arXiv:0912.5483 [hep-lat]]`.
- J. Blumlein, *The Theory of Deeply Inelastic Scattering*, `Prog. Part. Nucl. Phys.` **69** `(2013) 28 [arXiv:1208.6087 [hep-ph]]`.