Introduction to QCD and collider physics

I. Schienbein
LPSC Grenoble/Univ. Grenoble Alpes

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Abstract

Quantum Chromodynamics (QCD) is widely accepted to be the correct theory of the strong interaction --- the "Tests of QCD" from the 70th and 80th have turned into "Tests of our understanding of QCD". Indeed, it turns out to be quite difficult to extract precise predictions from the fundamental QCD-Lagrangian which can be related to experimental results. Compared to the extremly precisely tested Quantum Electrodynamics (QED) there are several problems: (i) One major obstacle is that the fundamental quark and gluon degrees of freedom of the QCD-Lagrangian cannot be accessed directly since they are confined in hadrons. (ii) Another problem is that due to the rather large strong coupling constant the convergence of the perturbation series is much slower than in QED and higher order calculations are much more complicated in QCD due to its non-Abelian nature. For a wide class of observables at high energy colliders these problems are addressed in the framework of QCD factorization theorems which allow the separation of non-perturbative and perturbative parts in a systematic manner providing a theoretical framework with predictive power.

The goal of this lecture series is to give an introduction to QCD and to discuss its application to processes at high-energy colliders.

General information

- Prerequisites: Knowledge of Standard Model at tree level
- Language of instruction: English or German
- Ca. 32 hours: Lectures + Exercice classes
  - Part I: 13.4. - 24.4.2015
  - Part II: 29.6. - 17.7.2015
- Use of projector and blackboard
- URL: http://lpsc.in2p3.fr/schien/teaching/collider1415/lecture.html
- Contact: ingo.schienbein@lpsc.in2p3.fr

Literature

- Main reference(s) for this lecture:
  - [ESW] R. K. Ellis, W. J. Stirling, B. R. Webber, "QCD and Collider Physics"
- Textbooks:
  - [HM] F. Halzen, A. Martin, "Quarks and Leptons"
  - [Field] R. D. Field, "Applications of Perturbative QCD"
  - [Muta] T. Muta, "Foundations of Quantum Chromodynamics"
  - [CL] T.-P. Cheng, L.-F. Li, "Gauge theory of elementary particles"
  - [DKMT] Yu. L. Dokshitzer, V. A. Khoze, A. H. Mueller, S. I. Troyan, "Basics of Perturbative QCD"
  - [Collins] J. Collins, "Foundations of Perturbative QCD"
  - [CTEQ] CTEQ Handbook of Perturbative QCD
- Other references will be given during the lectures

Outline

I. **Basics of QCD**
[Color SU(3), SU(n), Lagrangian of QCD, Local gauge invariance, Feynman rules, QCD and the SM, Symmetries]

II. **Asymptotic freedom and confinement**
[UV singularities, Regularization, Renormalization, Renormalization group equation, Beta function, Asymptotic freedom, Infrared-slavery, Confinement]

III. **QCD in electron-positron annihilation**
[Total hadronic cross section, Heavy quark production, Jet cross sections, Shape distributions]

IV. **Lepton-Nucleon scattering**
[Elastic scattering and form factors, Deep inelastic scattering and structure functions, Operator Product Expansion, Naive parton model, Parton model and QCD, Factorization, Scaling violations, DGLAP equations, Sum rules]

V. **Parton showers and jets**
[Parton branching, Evolution equations]

VI. **Application of pQCD to hadron-hadron interactions**
[Factorization, Parton-Parton luminosities, Drell-Yan lepton pair production, Production of jets, Production of photons, top-pair production]