# “量子色动力学及其应用”

## 暑期学校

# QCD简介

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15-30 July 2019

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# Introduction to QCD

**Outline:**

I. **History of QCD**

II. **Lagrangian of QCD and its quantization**

III. **Renormalization**

IV. **QCD at hadron colliders**

Useful books and references:
Peskin and Schroeder, “An introduction to QFT”
Ellis, Stirling and Webber, “QCD and collider physics”
Collins, “Foundations of perturbative QCD”

# I. History of QCD

**QCD is the sector of the SM of particle physics that describes the strong interactions of quarks and gluons.**

**It is a basic tool to study the structure of the nucleon and the physics at hadron colliders.**

**QCD is a quantum gauge field theory.**

- **A brief history of QFT**
  - **19th C. Maxwell's equations: a classical field theory for electromagnetism**
  - **1900s: Planck and Einstein: photon as the quantum radiation**
  - **1920s/30s: development of particle quantum mechanics, relativistic version has problems (negative energy)**
  - **1930s/40s: realized that relativity + quantum mechanics => particles are the quanta of a quantized classical field**

- **1940s: formulation of the calculation rules for QED, Feynman diagrams**

- **1950s: the understanding of how to deal with the divergences of loop Feynman diagrams through renormalization**

- **1960s: How can one apply it to weak + strong interactions**

- **1970s: renormalization of non-Abelian gauge theories, the running of its coupling and asymptotic freedom, the formulation of the SM**

- **1980s: string theory, quantum gravity, conformal field theory. All quantum field theories are just effective over some length. Idea of EFT. Factorization of a process at colliders.**

- **1990s: holography, strong/weak duality**

**QCD is the fundamental theory of the strong interactions, which binds protons and neutrons together inside the nucleons, and thus it is important for the formulation of heavy elements and advanced form of structures, e.g., life.**

- **A brief history of QCD**

  - **1932: discovery of neutron by Chadwick. Greek ‘hadros' means bulky**
  - **1935: the first theory of strong interactions constrained by Yukawa, prediction of a meson**
  - **1947: pion mesons were discovered in cosmic rays**
  - **1950s-1970s: the prevailing attitude was that the entire Lagrangian method of field theory should be discarded. Bootstrap, S-matrix (unitarity, causality, spacetime/internal symmetries), Regge theory, string**

**The main job is to build a “Mendeleev Table” of hadrons.**

- **1961: Gell-Mann eight-fold**
- **1964: Gell-Mann’s quark and Zweig’s Ace**
- **1964,65: Nambu, Han, Greeberg, Bogolubov, Struminsky, Tavkhelidze, ‘color’**
- **1969:  e + N -> e + X at SLAC, Feynman, Bjorken and Paschos, parton model**

**Questions: Strong and weak**

# Was field theory died?

- **1954: Yang-Mills theory**
- **1967: Quantization by Faddeev and Popov**
- **1964: Englert-Brout-Higgs-Guralnik-Hagan-Kibble mechanism**
- **1967: Weinberg and Salam constructed the correct gauge theory for weak interactions, based on the model of Galshow in 1961**
- **1971,72: ’t Hooft and Veltman proved the renormalizability and unitarity**
- **1973: three groups (Pati and Salam; Fritzsch, Gell-Mann and Leutwyler; Weinberg) proposed that the strong interaction can be described by Yang-Mills theory. Mediators are gluons. Charge renormalization by Gross, Wilczek and Polizer.**