Quantum Chromodynamics (QCD)

Thu 12.15 - 13.45 → 12.30 - 14.00 ?
Fri 10.15 - 11.45

45, E6-118, 6221, yorke2 ... 

www.physik.uni-bielefeld.de/~yorke/qcdM

prerequisites: QFT (maybe G. Akemann's QFT SS11?)
Elementary Particle Physics (useful for context)

literature: → see webpage, Semester Apparat

topics: → 

credits: 6 = 3 + 3

oral exam after end of semester
L attending lecture + signup sheet

exercises: will be occasionally offered in the lecture
1. Introduction

Nature is extremely strange - but also very beautiful. We have built a system of understanding (her):

- QM + Special Rel = QFT
- Objects: space-filling fields;
  Excitations: particles
- "Standard Model" ≈ 3 basic conceptual structures
  → gauge system: \( SU(3) \times SU(2) \times U(1) \)
    ~ 3 parameters \( g_i \)
  → gravity system: Einstein-Hilbert action
    + minimal matter coupling
    → 2 parameters \( G_N, \Lambda \)
  → Higgs system: no deep principle
    ~ many parameters
    Provisional concept?

- (extremely) accurately tested/confirmed
  by many experiments

1.1. QCD Appetizer

"Zoom" into part of gauge system: QCD
theory of strong interactions
3 models you know from particle physics (quarks, color, photons)
+ mathematical structure you know from QFT
  (non-Abelian gauge theory, [Yang, Mills 1954])
In analogy to QED: specify QCD via Feynman rules

**Vertices:**

- gluon
- quark
- quark

Some qualitative remarks:

- Gluon couples to color change
  - color of quark typically changes at $gqg$-vertex
  - e.g., $\langle b \bar{c} q \rangle$; gluon carries the difference

  (the fact that quarks carry 3 (e.g., red/green/blue) color charges has been determined experimentally, more lab)

- Gluons therefore interact also among themselves
  - in contrast to the electrically neutral photon

- QCD has very few parameters
  - "gauge invariance" requires $\gamma \sim g$, $X \sim g^2$

- Define $\alpha_s = \frac{g^2}{4\pi}$ (cf. $\alpha_{EM} = \frac{e^2}{4\pi} \approx \frac{1}{127}$)

  Now, $\alpha_s \approx \frac{1}{10}$ is "large"

  → perturbation theory is not "as perfect" as in QED

  → QCD is "more interesting", has a very rich structure, features surprising effects (more later; material of this course)

  → Theoretical calculations typically have errors $> 1\%$

→ One important method to "solve" QCD

- (Numerical) **Lattice QCD**
Some highlights:

- Central feature: asymptotic freedom
  QCD shows different forces at long and short distances
  
  **Long distance**
  low energy
  confinement
  
  **Short distance**
  high energy
  asymptotic freedom
  hard scattering
  cross sections
  perturbative methods

- Rough qualitative picture of asymptotic freedom:
  (more later → "renormalization")
  value of $\alpha_s$ depends on distance (i.e. energy)

\[ \begin{align*}
  \frac{1}{3} + \frac{1}{3} + \frac{1}{3} & \\
  & \quad \text{screening of the charge}\n  & \quad \text{like in QED} \\
  & \quad \text{anti-screening} \quad \text{non-abelian}
\end{align*} \]

\[ \alpha_s(r) \propto \frac{1}{r} \]

who wins? \[ \alpha_s(q^2) \propto \frac{4\pi}{\left(-\frac{2}{3}N_f + 11\right) \ln \left(\frac{q^2}{\Lambda^2}\right)} \]

\[ \alpha_s(\Lambda) \]

Nobel 2004:
Gross/Politzer/Wilczek

plot online
[PDG; LEP EWG]