Quantum Chromodynamics (QCD)

Thu 12.15 - 13.45 → 12.30 - 14.00 ?

Fri 10.15 - 11.45

4S, E6-118, 6221, yorks@ ...

www.physik.uni-bielefeld.de/~yorks/qcd11

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
↳ 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 (here):

- QM + Special Rel ⇒ QFT
- objects: space-filling fields;
  excitations: particles
- "Standard Model" ≙ 3 basic conceptual structures
  - → gauge system: $SU(3)_c \times SU(2)_L \times U(1)_Y$
    ~ 3 parameters g_i
  - → gravity system: Einstein-Hilbert action
    + minimal matter coupling
    → 2 parameters G_N, Λ
  - → 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 ← the $SU(3)_c$ above

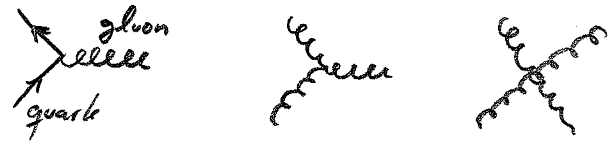
theory of <u>strong</u> interactions

≙ models you know from particle physics (quarks, color; partons)

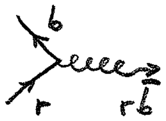
+ mathematical structure you know from QFT

(non-Abelian gauge theory; [Yang, Mills 1954]) in analogy to QED: specify QCD via Feynman rules

Vertices:



<u>Some qualitative remarks:</u>

- gluon couples to <u>color</u> charge
  color of quark typically changes at qqg-vertex
  eg. 

  , gluon carries the difference

  ((the fact that quarks carry 3 (eg. red/green/blue) color charges has been determined experimentally; more later))

- gluons therefore interact also among themselves (in contrast to the electrically neutral photon)

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

- define $\alpha_s \equiv \frac{g_s^2}{4\pi}$ (cf. $\alpha_{EM} = \frac{e^2}{4\pi} \approx \frac{1}{137}$)

  now, $\alpha_s \gtrsim \frac{1}{10}$ 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 semester)
  - ⇒ theoretical calculations typically have errors $\gtrsim 1\%$
  - ⇝ one important method to "solve" QCD is (numerical) <u>Lattice-QCD</u>

Some highlights :

- central feature : asymptotic freedom

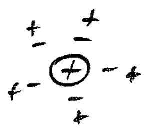
QCD shows different faces at long and short distances

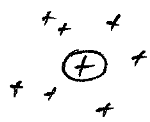
long distance		short distance
low energy		high energy ($Q \sim 1/r$)
confinement	⟵ interplay ⟶	asymptotic freedom
non-perturbative		hard scattering
hadronic structure		cross sections
eg. Lattice QCD		perturbative methods

- rough qualitative picture of asymptotic freedom :
  (more later → "renormalization")

value of α_s depends on distance (i.e. energy)

screening of the charge like in QED | anti-screening non-abelian

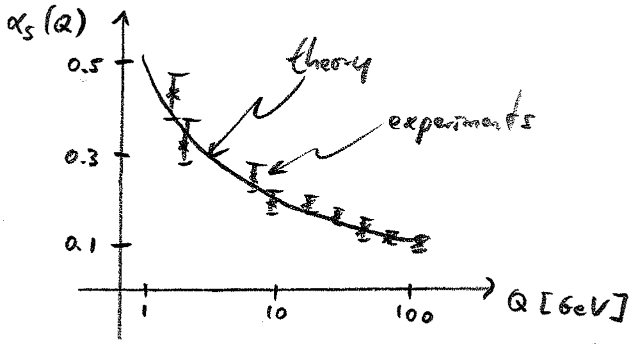




$\alpha_s(r) \nearrow$ if $r \searrow$ | $\alpha_s(r) \searrow$ if $r \searrow$

who wins ?

$$\alpha_s(Q^2) \approx \frac{4\pi}{\left(-\frac{2}{3}N_f + 11\right)\ln\left(\frac{Q^2}{\Lambda^2}\right)}$$



Nobel 2004 : Gross / Politzer / Wilczek

← plot online [PDG ; LEP EWWG]