Quantum Chromodynamics (QCD)

Tue 8.30 - 10
Thu 12.30 - 14

45, E6-118, 6221, yorks @ physik....

www.physik.uni-bielefeld.de/~yorks/qcd13

→ language? Ger / En

prerequisites : QFT (or Laermann's QFT SS13)
Elementary Particle Physics (for context)

literature : → see webpage, Semesterapparat

topics : → ./.

credits : 5 = 3 + 2
(2: oral exam; 3: attending lecture ⇝ signup sheet)

exercises : mini-reviews @ start of each lecture

1. Introduction

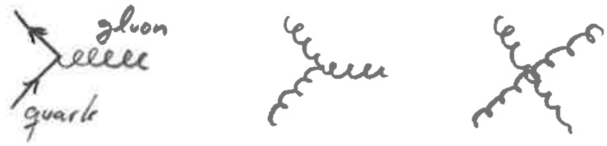
Nature is extremely strange – but also very beautiful.
We have built a system of understanding (her):

- QM + Special Rel ⇒ QFT
- objects: space-filling fields;
  excitations: particles
- "Standard Model" ≙ 3 basic conceptual structures
  → gauge system: $SU(3)_c \times SU(2)_L \times U(1)_Y$
  ~ 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

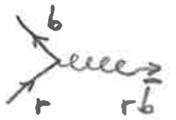
1.1. QCD Appetizer

"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: 

some qualitative remarks:

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

  , gluon carries the difference

  ((the fact that quarks carry 3 (e.g. 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:

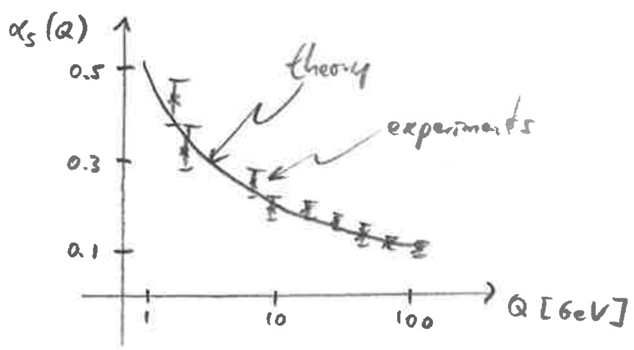
  (more later → "renormalization")

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

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

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

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



Nobel 2004: Gross / Politzer / Wilczek

← plot online [PDG; LEP EWWG]