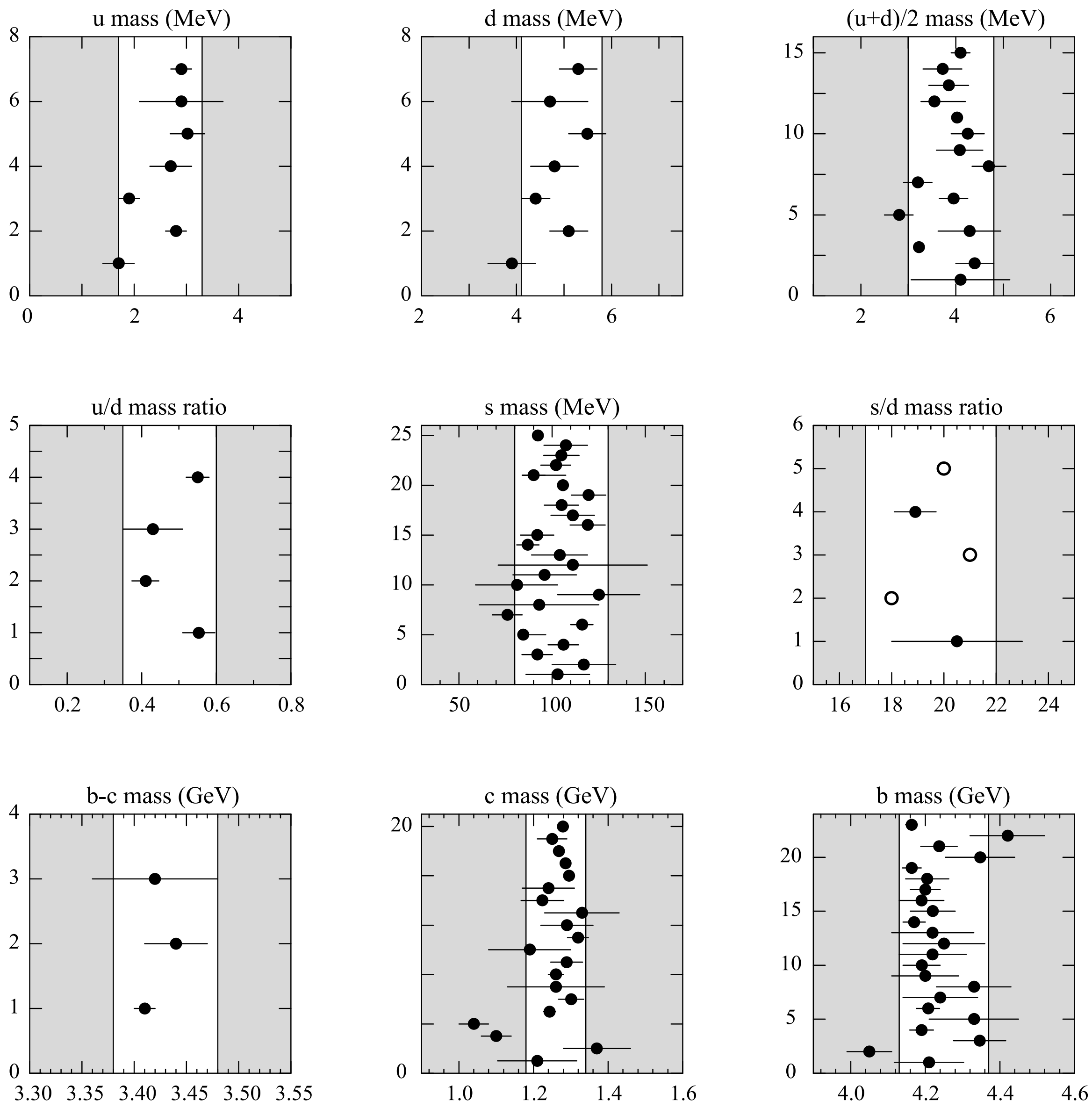
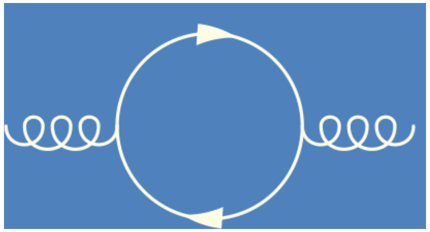
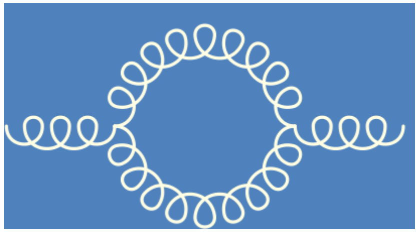
Quark masses



PDG, 2010

Vacuum polarization in QCD





The left diagram is shared by QED and QCD which renders the interaction stronger at shorter distance (screening). The second diagram arising from the nonlinear interaction between gluons in QCD has the antiscreening effect, which makes the coupling weaker at short distance.

- Color is anti-screened
- Color builds up away from a source
- Interaction becomes strong at large distances (low momenta)
- Confinement of quarks; quarks are not observed as isolated particles

Strong coupling constant $\alpha_s = \frac{g^2}{4\pi}$

In quantum field theory, the coupling constant is an effective constant, which depends on four-momentum Q^2 transferred. For strong interactions, the Q^2 dependence is very strong (gluons - as the field quanta - carry color and they can couple to other gluons). A first-order perturbative QCD calculation (valid at very large Q^2) gives:

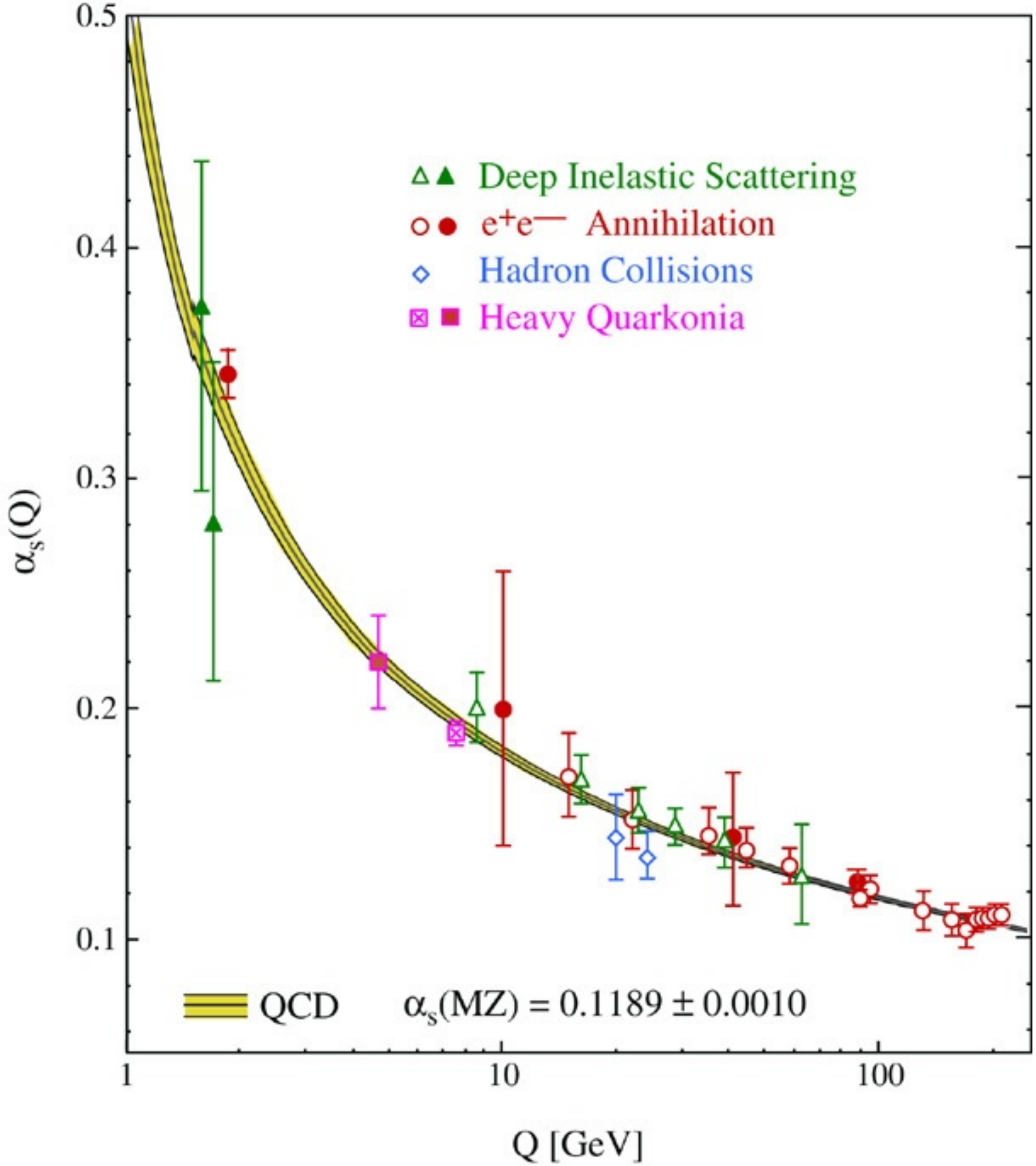
running coupling constant!

$$\alpha_s\left(Q^2\right) = \frac{12\pi}{\left(22 - 2n_f\right)\cdot \ln\left(Q^2 / \Lambda^2_{\mathrm{QCD}}\right)}$$

$n_f = 6$ – number of quark flavors
Λ_{QCD} – a parameter in QCD (~0.22 GeV), an infrared cutoff

The spatial separation between quarks goes as $\lambda = \frac{\hbar}{\sqrt{Q^2}}$

Therefore, for very small distances and high values of Q^2, the inter-quark coupling decreases, vanishing asymptotically. In the limit of very large Q^2, quarks can be considered to be "free" (asymptotic freedom). On the other hand, at large distances, the inter-quark coupling increases so it is impossible to detach individual quarks from hadrons (confinement).
Asymptotic freedom was described in 1973 by Gross, Wilczek, and Politzer (Nobel Prize 2004).



It is customary to quote α_s at the 91 GeV energy scale (the mass of the Z boson)