Introduction

Elementary Particle Physics
Strong Interaction Fenomenology

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Course Outline

- Introduction
- The Standard Model
- Running coupling constants
- Grand unification
- Introduction to QCD and hadron physics
- Charmonium spectroscopy
- Electromagnetic form factors
- Structure functions

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Theoretical Framework

Quantum Field Theory

Interaction ⟺ Exchange of quanta

Lagrangian ⟹ Calculation of σ, Γ, ...

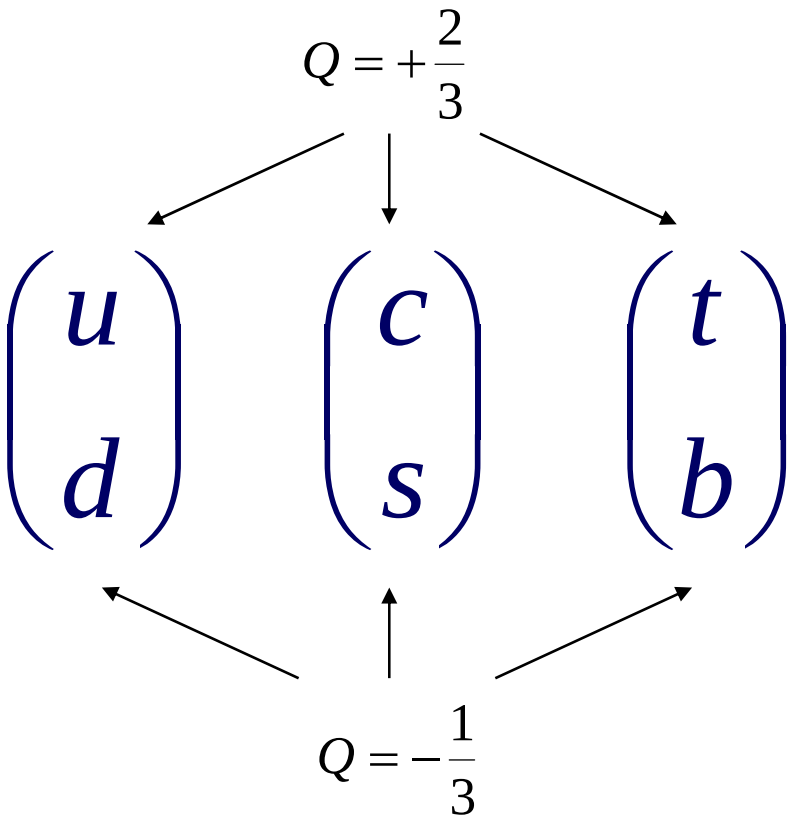
Symmetry ⟹ Interaction

⟹ **Gauge Theories**

Interactions

Force	Theory
Gravity	Classical
Weak	Grand
Electromagnetic	Unification
Strong	?

Particles I
Quarks



	«free» quark	Constituent quark
d	15 MeV/c^2	330 MeV/c^2
u	7 MeV/c^2	330 MeV/c^2
s	200 MeV/c^2	500 MeV/c^2
c	1.3 GeV/c^2	1.5 GeV/c^2
b	4.8 GeV/c^2	5 GeV/c^2
t	180 GeV/c^2	180 GeV/c^2

$B = \frac{1}{3}$

3 colors

Particles II
Leptons

$$\begin{pmatrix} \nu_e \\ e \end{pmatrix} \quad \begin{pmatrix} \nu_\mu \\ \mu \end{pmatrix} \quad \begin{pmatrix} \nu_\tau \\ \tau \end{pmatrix}$$

ν_e	< 3 eV/c^2
ν_μ	< 0.19 MeV/c^2
ν_τ	< 18.2 MeV/c^2
e	0.511 MeV/c^2
μ	105.66 MeV/c^2
τ	1777 MeV/c^2

Lepton number
Neutrino masses
Neutrino oscillations

Particles III
Bosons

Gauge bosons

boson	interaction	J^P	Mass (GeV/c^2)
graviton	gravitational	2^+	0
$W^{\pm}$ Z^0	weak	1^- 1^+	80.425 ± 0.038 91.1876 ± 0.0021
photon, γ	electromagnetic	1^-	0
gluon, G	strong	1^-	0

Higgs Bosons

Our universe consists of particles from the first family.
Particles of the second and third family are produced in particle accelerators and very high-energy cosmic rays.

Hierarchy of structures.
The QCD force between colored quarks binds them into colorless hadrons.
The residual color force outside hadrons is the nuclear force, that binds stable hadrons into nuclei.
Nuclei (positive charge) and electrons (negative charge) are bound into (electrically neutral) atoms by the electromagnetic force.
The residual electromagnetic force outside atoms binds them into molecules.

Particle $\rightarrow$ Antiparticle

Elementarity: are the quarks and leptons structureless or are they composite particles with internal structures ?

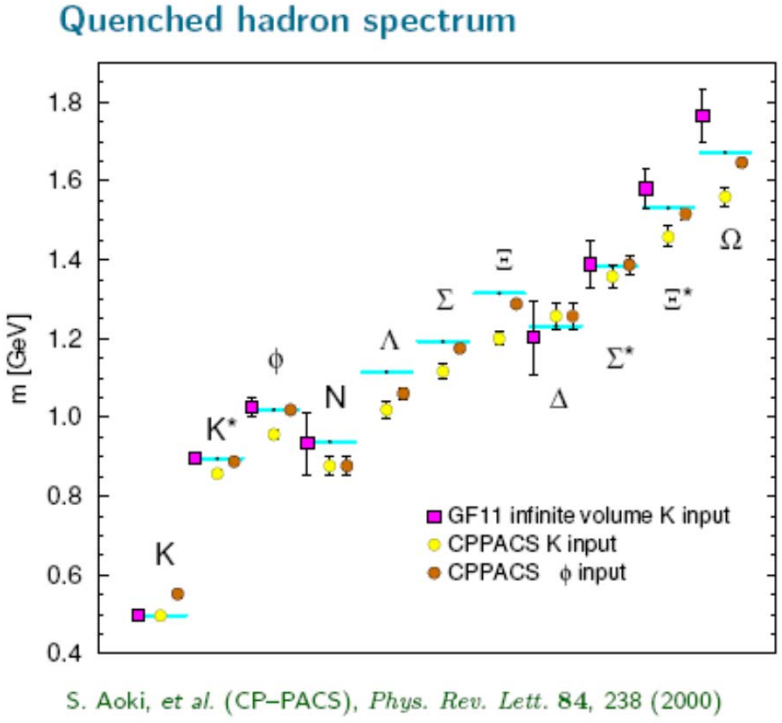
Symmetry: symmetries prescribe interactions.

Unity: do all interactions we encounter have a common origin (and a common strength) at suitably high energy ?.

Identity: understand the physics that sets quark masses and “mixing”.

Sources of Mass

- Masses of atoms “understood” in terms of the masses of the atomic nuclei, the mass of the electron and QED.
- Masses of nuclei “understood” in terms of the p and n mass and our knowledge of nuclear forces.
- Masses of proton and neutron: according to QCD the dominant contribution to the light-hadron masses is the energy stored in confining quarks in a tiny volume: still to be demonstrated !



S. Aoki, *et al.* (CP–PACS), *Phys. Rev. Lett.* **84**, 238 (2000)

Masses in the Standard Model

$$M_W^2 = \frac{g^2 v^2}{2} = \frac{\pi\alpha}{G_F \sqrt{2} \sin^2 \theta_W}$$

$$M_Z^2 = \frac{M_W^2}{\cos^2 \theta_W}$$

$$v = \sqrt{\frac{1}{G_F \sqrt{2}}} = 246\ \text{GeV}$$

g = gauge coupling
θ_W = weak mixing parameter

Fermion masses are derived from new, so far incalculable Yukawa couplings (interaction with the Higgs field), non calcolabili, whose origin in unkwown.

$$\mathcal{L}_{Yu} = -\zeta_e \left[\bar{R} \left(\varphi^+ L \right) + \left(\bar{L} \varphi \right) R \right]$$

$$L = \begin{pmatrix} \nu_e \\ e \end{pmatrix}_L \qquad R = e_R$$

$$m_f = \frac{\zeta_f v}{\sqrt{2}}$$

$$\zeta_e \approx 3 \times 10^{-6}$$

$$\zeta_t \approx 1$$