Introduction to Particle Physics

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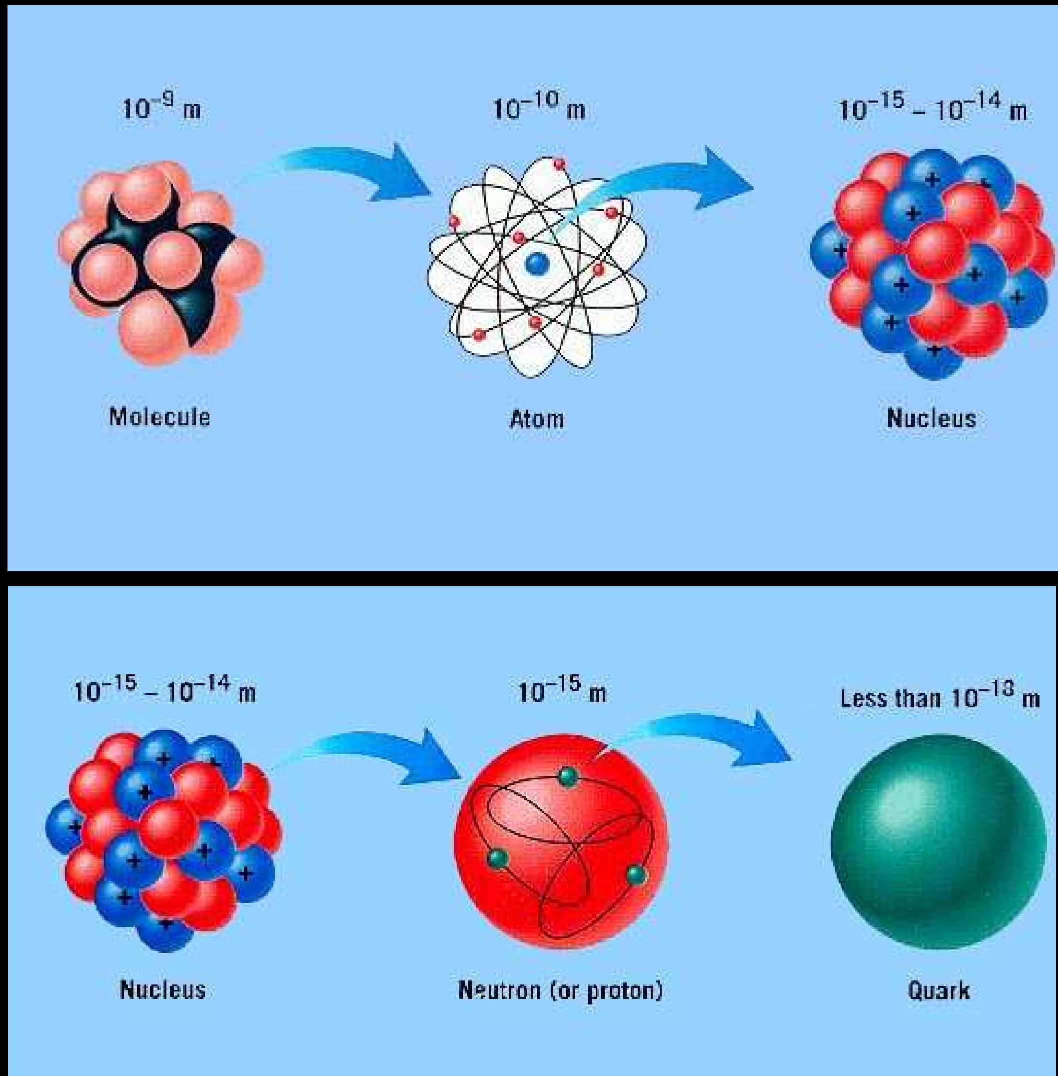
Hierarchy of scales



Particles of the Standard Model

Leptons

spin $\frac{1}{2}$

$q_\nu = 0,\ q_e = -1$

$$\begin{pmatrix} \nu_e \\ e \end{pmatrix}_L, \quad e_R, \quad \nu_{eR}$$

$$\begin{pmatrix} \nu_\mu \\ \mu \end{pmatrix}_L, \quad \mu_R, \quad \nu_{\mu R}$$

$$\begin{pmatrix} \nu_\tau \\ \tau \end{pmatrix}_L, \quad \tau_R, \quad \nu_{\tau R}$$

Quarks

spin $\frac{1}{2}$, 3 colors

$q_u = 2/3,\ q_d = -1/3$

$$\begin{pmatrix} u \\ d \end{pmatrix}_L, \quad u_R, \quad d_R$$

$$\begin{pmatrix} c \\ s \end{pmatrix}_L, \quad c_R, \quad s_R$$

$$\begin{pmatrix} t \\ b \end{pmatrix}_L, \quad t_R, \quad b_R$$

Particles of the Standard Model

Gauge bosons (spin 1):

- Electromagnetic interactions:

  photon γ

- Weak interactions:

  $W^{\pm}$ and Z^0

- Strong interactions

  8 gluons g

Higgs boson (spin 0)

Hadrons: baryons

fully symmetric in quark type and spin,
fully antisymmetric in color ("white", R+G+B)

- baryons spin 1/2 ($\uparrow\uparrow\downarrow$)
  - p, n (uud, udd)
  - Λ (uds)
  - Σ (uus, uds, dds)
  - Ξ (uss, dss)
- baryons spin 3/2 ($\uparrow\uparrow\uparrow$)
  - Δ (uuu, uud, udd, ddd)
  - Σ^* (uus, uds, dds)
  - Ξ^* (uss, dss)
  - Ω (sss)

Hadrons: mesons

“white” – color+anticolor

- mesons spin 0 ($\uparrow\downarrow$)
  - π ($u\bar{d}$, $u\bar{u} - d\bar{d}$, $d\bar{u}$)
  - K ($u\bar{s}$, $d\bar{s}$, $s\bar{d}$, $s\bar{u}$)
  - η, η' ($s\bar{s}$, $u\bar{u} + d\bar{d}$)
- mesons spin 1 ($\uparrow\uparrow$)
  - ρ
  - K^*
  - ω, φ

Masses and interactions

particle	mass	interaction
photons	0	EM
gluons	0	S
$W^{\pm}$	80.40 GeV	W, EM
Z^0	91.19 GeV	W
Higgs	???	W + Yukawa

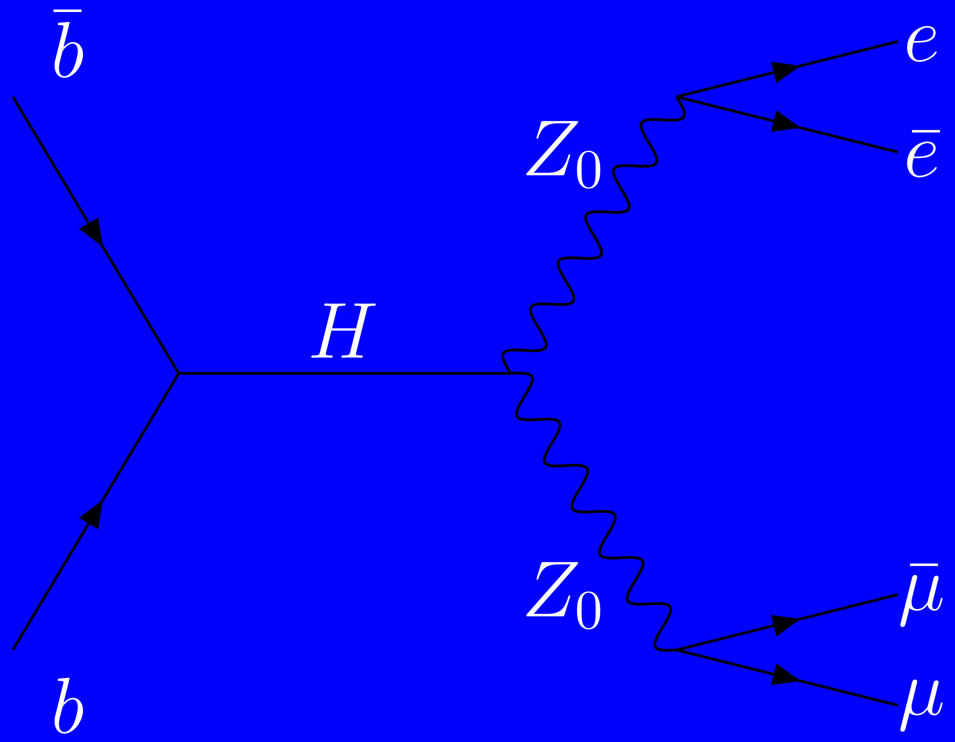
Masses and interactions

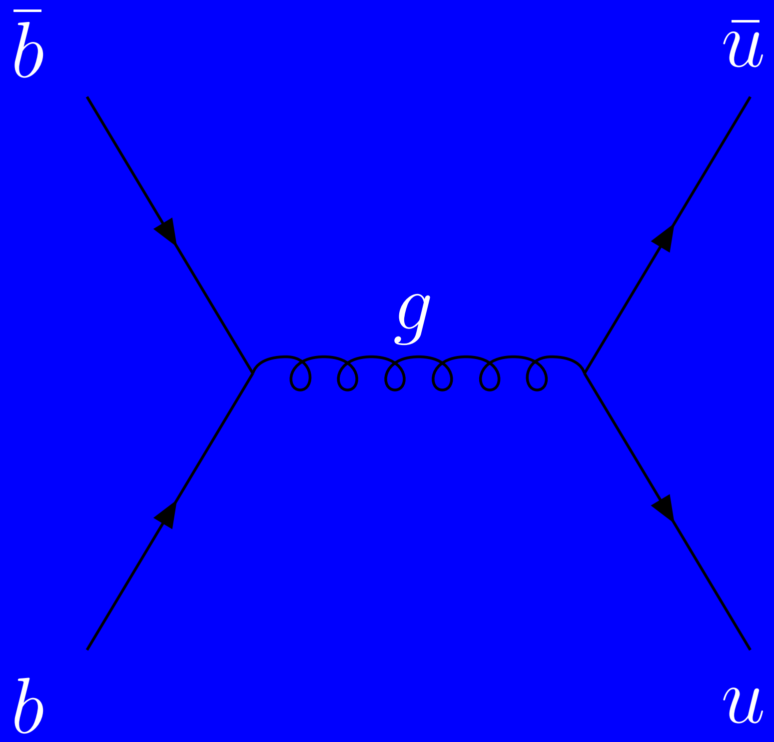
particle	mass	interaction
neutrinos	< 1 eV	W
e	0.000511 GeV	EM, W
μ	0.10566 GeV	EM, W
τ	1.777 GeV	EM, W

Masses and interactions

particle	mass	interaction
u, d	$\sim$ 0.004 GeV	EM, W, S
s	$\sim$ 0.1 GeV	EM, W, S
c	$\sim$ 1.25 GeV	EM, W, S
b	$\sim$ 4.2 GeV	EM, W, S
t	$\sim$ 174 GeV	EM, W, S

Feynman diagrams





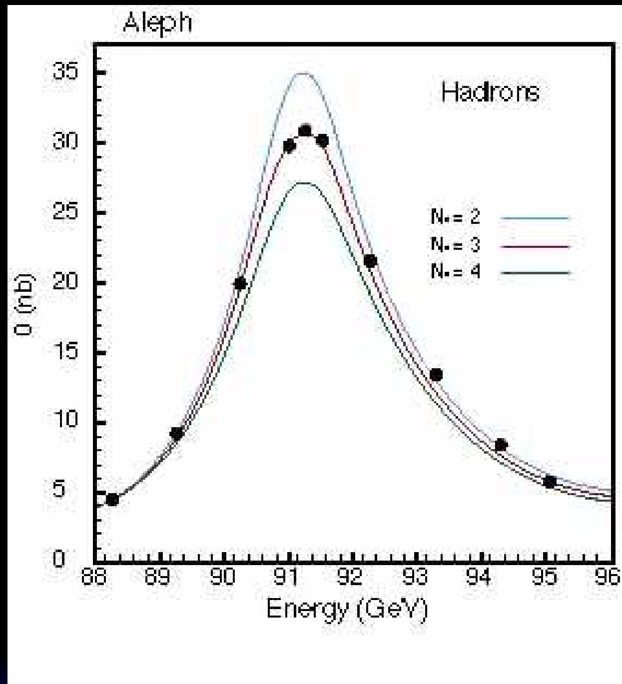
Theoretical predictions

- for each diagram we calculate amplitude $\mathcal{A}$
- $|\mathcal{A}|^2$ gives a probability: “cross section”
- $\mathcal{A} \neq 0$ only if:
  - energy and momentum are conserved
  - initial and final particles exist i.e. $E_i^2 - p_i^2 c^2 = m_i^2 c^4$
  - charge, lepton number, baryon number ... are conserved
- if $m > E \Rightarrow$ particle cannot be produced
- for some diagrams $\mathcal{A} = \infty \rightarrow$ renormalization

Resonances

- if a particle slowly decays (like Z^0) $\tau \gg \frac{\hbar}{m_Z c^2}$
- $(E_1 + E_2)^2 - (\vec{p}_1 + \vec{p}_2)^2 c^2 \neq m_i^2 c^4$

  but $|\mathcal{A}|^2$ has a peak with width $1/\tau$ around m_Z



theory $\longrightarrow$ experiment

- each collision at LHC will produce more than 100 particles
- there will be 40 milion collisions per second
- it would be a total mess if we didn't know $|\mathcal{A}|^2$ from theory to pick out interesting collisions and then to interpret them
- to design and plan any accelerator or detector one has to know possible $|\mathcal{A}|^2$ in advance

Summary

- Particle physics allows us to describe, predict and interpret results of accelerator experiments
- to discover new massive particles we need bigger accelerators
- there are several theoretical ideas predicting new, massive particles (supersymmetry, conformal symmetry, ...)
- LHC will (hopefully) tell...