# Fundamental Particles

**Matter:** $s = 1/2$

| LEPTONS | | | |
|---|---|---|---|
| $Q = -1$ | | $Q = 0$ | |
| $e^-$ | $0.511\, MeV/c^2$ | $\nu_e$ | $< 1\, eV/c^2$ |
| $\mu^-$ | $106\, MeV/c^2$ | $\nu_\mu$ | $< 0.19\, MeV/c^2$ |
| $\tau^-$ | $1777\, MeV/c^2$ | $\nu_\tau$ | $< 18.2\, MeV/c^2$ |

| QUARKS | | | |
|---|---|---|---|
| $Q = 2/3$ | | $Q = -1/3$ | |
| $u$ (up) | $0.3\, GeV/c^{2*}$ | $d$ (down) | $0.3\, GeV/c^2$ |
| $c$ (charm) | $1.6\, GeV/c^2$ | $s$ (strange) | $0.5\, GeV/c^2$ |
| $t$ (top) | $174\, GeV/c^2$ | $b$ (bottom) | $4.5\, GeV/c^2$ |

*Since quarks have never been seen in isolation it is not possible to measure their mass directly. The values quoted here are obtained by naively dividing up the masses of the hadrons that are made up of the quarks. Thus $m_u \approx m_d \approx m_p/3$.

**Force particles:** (s=1)

| | | | |
|---|---|---|---|
| Photon $\gamma$ | | $< 2 \times 10^{-16}\, eV/c^2$ | $Q = 0$ |
| Gluons $G$ | | Massless | $Q = 0$ |
| Weak bosons | $W^\pm$ | $80.4\, GeV/c^2$ | $Q = \pm 1$ |
| | $Z^0$ | $91.2\, GeV/c^2$ | $Q = 0$ |

In addition to all of the particles above there is one more boson to add to the list, called the *Higgs boson*, which is expected to have spin $s = 0$ and charge $Q = 0$. It is essential for the internal consistency of our current understanding of particle physics and a particle that appears to have some of the expected properties of the Higgs boson was found only this year, some 48 years after its was first predicted in 1964. In 2012 the Large Hadron Collider (LHC) at CERN (the European particle physics facility near Geneva), running at an energy of 8 $TeV$ discovered the Higgs boson with a mass of 126 $GeV/c^2$. As a consequence the 2013 Nobel prize for physics was awarded to two of the people who did the fundamental theoretical work that predicted its existence: Peter Higgs and Francois Englert.