Introduction to Particle Physics Spring 2007 Problem set 1, 24.1.

1. Express in units of GeV

   a) 1 kg

   b) 1 m

   c) 1 s

   d) Newton's gravitational constant $G_N = 6.67 \times 10^{-11}\,\mathrm{m^3 kg^{-1} s^{-2}}$. Planck mass is defined as $m_{\mathrm{Planck}} = 1/\sqrt{G_N}$ (in our "natural units"). How large is it in units of GeV and in kg?

   By dimensional analysis, when the energy in a process is of order m_{Planck}, quantum gravity effects cannot be neglected!

2. In LEP-experiment at CERN beams of electrons and positrons were collided head-on so that the total energy was equal to the Z-boson mass, $m_Z = 91\,\mathrm{GeV}$. How large was the speed of e^- and e^+?

3. Cosmic rays (p) produce pions $\pi^\pm$ in the atmosphere at $\sim 8\,\mathrm{km}$ altitude. Pions move at almost the speed of light, say $v = 0.998$ towards the Earth. Pions decay (in their rest frame) after $\tau = 2.6 \times 10^{-8}\,\mathrm{s}$ into myons, which decay further into electrons after $\tau = 2.2 \times 10^{-6}\,\mathrm{s}$ (again, in their rest frame).

   a) At which altitude should the detector be in order to observe Pions?

   b) What kind of particles reach the Earth surface?

4. Draw the lowest-order Feynman diagram for the process

$$e^+ + e^- \to \mu^+ + \mu^- \,.$$

   Assume that the myons are produced at rest in the center of mass frame. Estimate the distance between the vertices

   a) in the center of mass frame

   b) in the rest frame of e^+.