1. LHC particle accelerator at CERN has two beams of protons circulating around the accelerator to opposite directions. The protons collide with energy 7 TeV/proton; i.e. 14 TeV/collision.

   a) How high could you lift one pencil of mass 10 g from tabletop with this energy?

   b) What is the velocity of the protons in the lab frame?

   c) One beam has around 3×10^{14} protons circulating at a time. What is the rest mass of the beam in kg? What is the kinetic energy of the beam (note: at this v, kinetic energy = total energy to a very good approximation)?

   d) At what speed should a car of mass 1000 kg move in order to have the same kinetic energy as the beam in c)?

2. Which of the following decays are *not* possible and why?

   $n \to pe^-\bar{\nu}_e$ $\quad n \to \bar{p}e^+\nu_e$ $\quad n \to p\pi^0$ $\quad n \to \pi^+\pi^-\gamma$ $\quad \pi^0 \to \gamma\gamma$

   $\pi^- \to \mu^-\bar{\nu}_e$ $\quad \pi^- \to \mu^-\bar{\nu}_\mu$ $\quad \pi^- \to \tau^-\bar{\nu}_\tau$ $\quad \mu^- \to e^-\gamma$

3. Draw the leading order Feynman diagrams for the decays of

   a) π^+ $(u\bar{d})$,

   b) π^0 $(\sim u\bar{u} - d\bar{d})$,

   c) $\rho^+ \to \pi^+\pi^0$. In this case $m_\rho \sim 770\text{MeV} > m_{\pi^+} + m_{\pi^0}$, thus this decay is possible. Quark content of ρ^+ is $u\bar{d}$, but it is a spin-1 state as opposed to π^+ which is spin-0.

   What is the ordering of the lifetimes of the 3 decaying particles, and why? Find the lifetimes in the Particle Data Book(let) (or in the table given in lecture notes).

4. Which of the following states could be possible, and if not, why not?

   u, uu, uuu, $u\bar{u}$, $u\bar{s}$, uds, $\bar{u}\bar{d}\bar{s}$, $ud\bar{s}\bar{c}$, $uudd\bar{s}$, $u\bar{d}e^-$

5. Which of the following processes are forbidden and why (for hadronic structure, consult the table in the lecture notes)?

   $\Sigma^+ \to \mu^+\nu_\mu$

   $p\bar{p} \to \Lambda\bar{\Lambda}$

   $p\bar{p} \to K^+K^0\pi^-$

   $e^+\mu^- \to \bar{\nu}_e\nu_\mu$