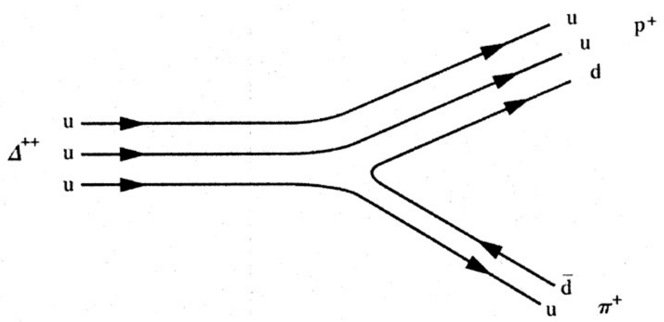

Figure D.1. The decay $\Delta^{++} \to p + \pi^+$ represented within the constituent quark model framework.

D Homework exercises II

This set of exercises should be completed and submitted via **Brightspace** by **Wednesday 24th of January 2018** before 17h.

1) Consider that we have detected photons and neutrinos, both with an energy of 1 MeV, coming from a supernova explosion which is at a distance of 10^5 light years from us. We measure that the arrival time on Earth of these photons and neutrinos differ by less than 10 seconds. Given that photons are massless, derive from this observation an upper bound on the neutrino mass.

2) Construct the four-momentum vector $(E/c, \vec{p})$ for the following particles. Verify explicitly in all cases that the mass-shell condition holds.
a) A proton at rest.
b) A neutron with a total energy of 1500 MeV, moving the z direction.
c) An electron with kinetic energy of 500 keV, moving in the z direction.
d) A proton moving in the z direction with speed $\beta = 0.9$.
e) A photon with wavelength $\lambda = 10^{-15}$ m, moving in the z direction.

3) Consider the Φ meson, see Table 3.2. In the framework of the quark model, can you give a possible quark content of this meson? Is this choice unique? This Φ meson has a width (a fundamental uncertainty in its rest mass) of around 4.3 MeV/c^2. What can we say about its expected lifetime?

4) Consider the following decay modes of the tau leptons, where X represents one or more unknown particles. Indicate which of these decay modes are actually possible, and if they are not possible why is so. For the allowed decays, indicate what particle(s) X stands for.

a) $\tau^- \to e^- + X$
b) $\tau^- \to \mu^- + X$
c) $\tau^+ \to \pi^+ + X$
d) $\tau^+ \to p + X$
e) $\tau^+ \to \nu_\mu + X$

5) The decay $\Delta^{++} \to p + \pi^+$ can be interpreted in terms of the constituent quark model as indicated in Fig. E.1.

Based on the example of Fig. E.1, draw the corresponding diagrams, taking into account the quark composition of the initial and final-state hadrons, for the following processes:

a) $\pi^0 + p \to n + \pi^+$
b) $\Phi \to K^+ + K^-$
c) $\pi^- + p \to \Lambda^0 + K^0$
d) $\Lambda^0 \to p + \pi^-$

In all cases describe any assumption that you might have used. Note that the first three processes are mediated by the strong interaction, and therefore the only allowed lines are those connecting the same quark in the initial and in the final state, and those connecting a quark and an antiquark of the same flavor in either the initial or the final state. Discuss why the last reaction is different and cannot be mediated by the strong interaction.