Homework set 6, FYTN04, Autumn 2018

Due: Friday 21 December 2018, 10.15

1. Show that the state of two π^0's has even CP. Which of the K_L and K_S could decay to $\pi^0\pi^0$?

2. Try to enumerate all potential two-particle decay modes of the proton. Note that the X and Y bosons could mix flavours between generations, similarly to the W.

3. a) Draw a few diagrams that can lead to gluino production at a hadron collider.
b) Estimate the partonic cross section for gluino production from a $q\overline{q} \to \tilde{g}\tilde{g}$ diagram, i.e the subprocess cross section before convolution with parton distribution functions (PDFs).
Hint: the diagrams can be constructed using Standard Model vertices and replacing pairs of particles by their supersymmetric partners. That way you should be able to get "within a factor of two" for the partonic process.
c) The convolution with PDFs gives expressions that require numerical integration. Do a rough estimation for a $m_{\tilde{g}} = 1$ TeV at the LHC pp collider running at 13 TeV, as follows:
(i) Simplify the cross section by replacing the square-root expression for the three-momentum absolute value in the phase space by its asymptotic value $\sqrt{\hat{s}}/2$ once above the threshold $\sqrt{\hat{s}} = 2m_{\tilde{g}}$. Thereby we overestimate the cross section.
(ii) Simplify the integration over PDFs by replacing the coupled integral over the region $x_1x_2 > 4m_{\tilde{g}}^2/s$ by separated integrals over $x_i > 2m_{\tilde{g}}/\sqrt{s}$, $i = 1$ or 2. Thereby we underestimate the cross section, (over- or under-)compensating the effect of *(i)*.
(iii) For the relevant Q^2 scale and in the relevant range of x values you can approximate
$xu(x) = 2\,xd(x) = 0.7\,(1-2x)$ for $x < 1/2$ and else $= 0$,
$x\overline{u}(s) = x\overline{d}(s) = 0.1\,(1-3x)$ for $x < 1/3$ and else $= 0$,
and neglect other quarks.

d) How many events would be produced assuming an integrated LHC luminosity of 5 fb^{-1}? (This is the number for 2015; next year higher numbers are expected.) Hint: 1 fb $= 10^{-15}$ b $= 10^{-15} \cdot 10^{-28}$ m^2 $= 10^{-13}$ fm^2, where 1 fm $= 10^{-15}$ m? Also recall that $\hbar c = 1 \approx 0.197$ GeV·fm.
e) The gluino can decay in different ways, or not at all, depending on the mass ordering in the supersymmetric sector. Study a few possibilities and what might be interesting experimental signatures in these respective cases.

4. The MINOS experiment studies oscillations by shooting neutrinos of energy roughly 10 GeV from Fermilab to the 730 km distant Soudan detector. In order to calibrate the produced neutrino flux, a near detector is located at about 1 km from the production region. Calculate for which neutrino mass differences Δm^2 one might miss a signal because the amount of oscillation coincides in the two detectors. Especially explain why the problem simplifies in the interesting region $\Delta m^2 < 10^{-2}$ eV^2. Also suggest a strategy that might circumvent problems in the complementary mass region.

5. The supernova SN1987A was detected as a pulse of neutrinos of about 5–10 MeV arriving within a 10 s window, from a distance of about 170 000 light years. The pulse length is consistent with the expectations in supernova models, but could alternatively be used to set limits on the ν_e mass. Roughly what would those limits be?