Exercises for Advanced Particle Physics - Winter term 2013/14
Exercise sheet No. VIII

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The solutions have to be returned to mail box no. 1
in the foyer of the Gustav-Mie-House before **Monday, January 13th, 12:00h**.

Phenomenology and experimental aspects of the top quark

Exercise No. 1: Phenomenology (2+1 points)

This exercise aim to recall a few charateristics of the top quark and the basics of its phenomenology at hadron colliders.

1. What is the main charateristic that makes the top quark special ? Given the diagram of the top quark decay, explain why its decay width is proportionnal to G_{F}, the Fermi constant.
   - By dimensional arguments only, give the order of magnitude of the decay width Γ_t as a function of m_t.
   - A leading order computation provides an additional dimensionless factor of $(\sqrt{2}\ 8\pi)^{-1}$ to this expression.
   - Compute the numerical value of Γ_t and explain *why* the top quark is the only quark that decays (by a *weak* process) before hadronisation (*hard* interaction).
2. What are the four diagrams that are involved in the $t\bar{t}$ production in pp collisions? What are the possible final states of a $t\bar{t}$ pair? Compute the branching ratio of each final state.
3. *Bonus.* Is it possible to produce single top quarks at hadron colliders? If yes, how?

Exercise No. 2: Reconstruction of a top quark pair (7 points)

In this exercise, we consider the reconstruction of a top quark pair produced in pp collisions. We consider the semi-leptonic decay of the $t\bar{t}$ system (*i.e.* with only one lepton in the final state). The root file

`http://rmadar.web.cern.ch/rmadar/Teaching/Pyhtia/ttbar/ttbarSemiLep_noSmear.root`

contains such events at the parton level (quarks don't hadronise). The electric charge of quarks are not accessible, since we want to get closer to the experimental conditions.

In a first step, we assume that the 4-momentum of the neutrino is experimentally accessible. A more realistic case is described in questions 4-7.

1. Write down the top quark mass m_t as a function of the 4-momenta of the decay products (Hint: we want to avoid as much as possible to use quarks, since their energy resolution is worse than for leptons). Do you see an ambiguity to apply this formula event by event?
2. For each event, compute the two possible reconstructed top quark masses m_1 and m_2 and plot their distribution. Comment on the obtained result and propose a solution to suppress the ambiguity. Check that this solution works and check that top quark width is compatible with the value obtained in exercise 1.

3. In reality, the energy of quarks measured by the experiment fluctuates around the true value. In the root file `ttbarSemiLep_ttbarSemiLep_Smear10.root`, the energy of the quarks are smeared to simulate the detector effects. Repeat the previous question and comment on the result.

Since neutrinos only interact via the weak force, they cannot be measured directly in a collider. This represents an additional challenge with respect to the b-quark combinatorics described earlier.

4. How we can indirectly measure the sum of the neutrino momenta. Why is the longitudinal component of the initial momentum not known? Deduce the experimental observable associated to the neutrino kinematics. What happens if there are several neutrinos in the final state?

5. Using the file containing the detector resolution, plot the distribution of the two possible masses (cf. question 2) using the true transverse momentum of the neutrino. What is the effect of neglecting the longitudinal component?

6. For each event, compute the reconstructed transverse momentum of the neutrino, as described in question 4. Compare with the distribution of the true transverse momentum of the neutrino and comment.

7. Considering the known W mass and the $W \to \ell + \nu$ decay involed in the top quark decay chain, explain how to measure the longitudinal component of the neutrino. Plot the reconstructed top quark mass distribution before and after this treatment.