Project 3: Hadron Colliders
Due: March 21, 2008

Collider Physics Homework Project 3: Hadron Colliders

Choose and do ONE of the following. You can turn it in to my mailbox in Tech.

1. Discover the Missing Mass of the Universe at the LHC

Use MadEvent to search for two jets and missing energy at the Large Hadron Collider (proton on proton with a center of mass energy of 14 TeV). What are the Standard Model processes which lead to missing energy in the detector? (You can answer in terms of generic quarks and leptons). Generate them with MadEvent.

Now generate a new process, changing the model from "SM" to "MSSM" (which stands for the "Minimal Supersymmetric extension of the Standard Model". Ask for the process $p\ p \rightarrow u\ u\ n1\ n1$, which is proton proton interacting to form two up quarks (jets) and two "lightest neutralinos" - the lightest of the supersymmetric states. Set MAX QED = 2 to weed out some uninteresting diagrams that don't contribute very much. Compare the distributions for the signal (MSSM) and background (the SM process(es) you generated).

Compute the significance (Number of signal events / square root of the number of background events) assuming you collect 100 fb^{-1} of data. Using the distributions as a guideline, try changing the cuts in run_card.dat (regenerate the signal and the background for the new cuts) to see if you can make the significance higher.

The lightest neutralino is a leading candidate particle to be the dark matter that we observe in the Universe, but the Standard Model itself can't explain. By producing such particles in the laboratory, you would have at least found a candidate particle to be the dark matter of the Universe!

2. Measure the Missing Mass of the Universe

(Read the physics background in problem one, but don't do any of the steps.) Instead:

Generate a process, in the "MSSM"model. Ask for the process $p\,p \rightarrow u\,u\,n1\,n1$, which is proton proton interacting to form two up quarks (jets) and two "lightest neutralinos" - the lightest of the supersymmetric states. Set MAX QED = 2 to weed out some uninteresting diagrams that don't contribute very much. Look at the Feynman diagrams and identify any virtual particles that could become on-shell (this is tricky because you don't know the masses of $n1$ and other new particles like ul, ur, or go, so you will have to be open-minded about what their masses could turn out to be). Explain for which conditions a graph can actually lead to an on-shell virtual particle.

Generate events for pp collisions at 14 TeV. Looking at the distributions for this process, and comparing with the Feynman diagrams, try to figure out as many of those unknown masses as you can, and explain your reasoning.

3. Discover the Higgs Boson at the Tevatron

Generate $pp \rightarrow le\ vle\ b\ \bar{b}$ in the Standard Model (You will need to select the third option on the "sum over leptons" line in the process generation). This contains the Standard Model Higgs boson, being radiated off of a virtual W boson which then decays into an electron or muon and a neutrino. The Higgs decays into $b\bar{b}$. Generate events for the Tevatron ($p\bar{p}$ at center of mass energy 2 TeV). These distributions contain your signal (the Higgs) as well as a lot of non-Higgs related processes.

Generate the same process at the Tevatron, but edit param_card.dat (using the web form) and change the Higgs mass to 1 TeV. These events represent a sample with only non-Higgs physics in it - the Higgs is there, but when it is so heavy it has a negligible effect at the Tevatron energies. The Higgs signal is thus your first run (with the default Higgs mass of 120 GeV) minus the second run (with the huge Higgs mass the Tevatron can never see). Compute the significance for a data set of 10 fb^{-1}. Argue for some cuts that could be helpful and rerun both processes for those cuts (apply them in run_card.dat). How high can you get the significance? - try to get it as high as you can. If you can get it above 5, you have discovered the Higgs!