Physics 2405 Problem Set #2
Due 18 March 2013

1. The predicted rate of top quark production is effected by the top quark mass.

   a. Typically, theorists have provided an ad hoc parametrization of the Next to Leading Order (NLO) cross section as a function of mass. A recent example is:

   $$\sigma_{t\bar{t}}\,[\text{pb}] = a + bx + cx^2 + dx^3 + ex^4, \tag{2}$$

   where $x = (m_t\,[\text{GeV}] - 171)$. The central values for $\sqrt{s} = 10$ TeV are

   $a = 419.062, \quad b = -11.9351, \quad c = 0.199035, \quad d = -0.269327 \times 10^{-2}, \quad e = 3.09784 \times 10^{-5}.$

   For $\sqrt{s} = 14$ TeV the central values are

   $a = 920.475, \quad b = -24.9757, \quad c = 0.400681, \quad d = -0.523783 \times 10^{-2}, \quad e = 5.85946 \times 10^{-5}.$

   Plot this relationship as a function of top quark mass for both energies, within the range defined by about six standard deviations of the current world average.

   b. Using the predicted relationship between the top quark pair production cross section and m_t, what is the necessary accuracy of a cross section measurement in order to constrain the top quark mass to 0.5% uncertainty? Do this for both 10 and 14 TeV centre of mass energies and assume $m_t = 171$ GeV/c^2.

   c. Why does the required accuracy change with increasing centre of mass energy?

   d. Is this level of accuracy possible in an LHC experiment? What are the limiting factors?

2. We're designing a silicon strip tracker, with a cylindrical geometry similar to what the CDF II detector used. Assume that one has available 200 micron thick silicon wafers, and that we're only interested in particles produced at 90 degrees to the beam.

   a. What is the multiple scattering uncertainty on the position of a particle with momentum p on the n+1 layer arising from layer n? Take the radii, R_n, to be given by the formula $R_n = R_0 + \Delta_r$, where $R_0 = 2.5$ cm and $\Delta_r = 2$ cm. Calculate this for $p = 0.1$, 1 and 10 GeV/c. Estimate the overall position uncertainty

   b. If the silicon strip tracker has strips separated by 50 microns, and assuming that the charge deposited by a single particle is observed on a single strip, at what radial separation will the multiple scattering uncertainty be equal to the intrinsic uncertainty of the silicon detector?

   c. How much energy is lost by a pion with $p = 0.1$ GeV/c traversing a silicon layer at normal incidence? How much by a proton of the same momentum? What happens to a proton produced at almost normal incidence if the silicon tracker has 6 layers.

   d. The occupancy of a silicon layer has to be limited to less than 1% in order to ensure good pattern recognition capabilities. If we are designing for 1000 charged particles per collision, what is the minimum radius for the first layer?

3. Here are a few calculations on a straw drift chamber, like the ATLAS one. You can refer to the paper on their construction. Most of the values of the parameters of the straws are "made up" to simplify the calculations.

Assume that the straws are 4 mm in diameter, have a field of 2 kV/cm applied to them, and work at 600 mbar over pressure from atmospheric pressure. Let's assume that they use Argon (they don't–they use mainly Xenon to detect the transition radiation photons), which has a drift velocity of 8.5 cm/microsecond and an electron diffusion coefficient of 10 microns-squared per nanosecond. It takes 26 eV to create one ion pair, and dE/dx (minimum) is 2.4 keV/cm. The anode wires are 31 micron tungsten, and a straw has a capacitance of 10 pf.

a. For tracks half-way between the tube wall and the inner wire, estimate the mean number of ion pairs produced.
b. For the situation in a) estimate the ratio of the voltages induced electrons and the positive ions from the gas amplification cascade.
c. Estimate the drift time to the wire. How does this compare to the beam crossing time at the LHC? Have you any comment on the relative size of these numbers?
d. Make a rough plot of the rise time of the voltage on the anode wire, and again comment on how this compares to the LHC beam crossing time of 25ns. What values would you use in a simple shaper using an RC differentiator?
e. Calculate the spread in arrival time due to diffusion. What limitation does this give on the spatial accuracy obtainable? How does this compare with the actual spatial accuracy of a typical drift chamber?
f. If the magnetic field in the central region of ATLAS is 2 Tesla, calculate the Lorentz angle.
g. Does this have any effect on the straw chamber operation?