1. Given an average luminosity $1.1 \times 10^{34}\,\text{cm}^{-2}s^{-1}$, estimate how often the following inclusive processes occur at the ATLAS detector (1 barn = $10^{-24}\,\text{cm}^2$):

   (a) $pp \to b\bar{b}\ : \sigma \sim 10\,\mu\text{b}$

   (b) $pp \to W\ : \sigma \sim 10\,\text{nb}$

   (c) $pp \to t\bar{t}\ : \sigma \sim 10\,\text{pb}$

2. The width of the top quark (i.e. the quantum uncertainty in its mass) is expected to be about $1.5\,\text{GeV}/c^2$. What is its lifetime? Explain why there are no top-flavoured hadrons given $\Lambda_{QCD} \approx 200\,\text{MeV}$.

3. What fraction of top pair production events will have a "di-lepton" final state i.e.

$$pp \to t\bar{t} \to l_1 l_2 \nu_1 \nu_2 b\bar{b} \tag{1}$$

   where l_1 and l_2 can be either 2 electrons, two muons or one of each.

4. In a semi-leptonic top pair candidate event there is a muon, a transverse momentum imbalance, two b-tagged jets (b_1, b_2) and 2 non-tagged jets (j_1, j_2). The measured jet energies and directions in spherical coordinates ($\theta = 0$ is the beam directions, the x axis is horizontal and all angles are in radians) are as follows:

   - $b_1 : E = 145\,\text{GeV}\ \ \theta = 0.3\ \ \phi = -1.6$
   - $b_2 : E = 90\,\text{GeV}\ \ \theta = 1.3\ \ \phi = -0.2$
   - $j_1 : E = 125\,\text{GeV}\ \ \theta = 0.9\ \ \phi = 2.1$
   - $j_2 : E = 15\,\text{GeV}\ \ \theta = 1.7\ \ \phi = -1.7$

   (a) The momenta of the jets approximates the momenta of the original partons. Write down the 4-momenta of the four final state quarks (assume j_1 and j_2 come from massless partons). Hint: to convert from spherical coordinates to rectangular coordinates $(p_x, p_y, p_z) = (p \sin\theta \cos\phi, p \sin\theta \sin\phi, p \cos\theta)$

   (b) Show that the light quark jets are consistent with being the decay products of a W. (Hint: assume they come from the decay $X \to j_1 j_2$ and calculate the mass of X).

   (c) Which of the two b jets probably came from the same top quark as this hadronically decaying W boson?

5. A search for the supersymmetric particle of the top quark, the *stop* or $\tilde{t}$, using $200\,\text{pb}^{-1}$ has an expected background of 17 events with a total systematic error of 5 events. The data shows 30 selected events:

   (a) How significant is this excess?

   (b) Assuming that the excess is really due to a signal, approximately how much more data will need to be collected before a discovery can be claimed (significance S> 5)? Assume the systematic error remains constant.

6. The fraction of $B^0\overline{B}^0$ particles (created by colliding e^+e^-) decaying to a K^{*+} and a K^{*-} ($B^0\overline{B}^0 \to K^{*+}K^{*-}$) compared to total number of decays ($B^0\overline{B}^0 \to X$) has been measured to be $(0.6 \pm 0.4) \times 10^{-6}$. This is called the Branching Fraction.

(a) What is the probability that the number of decays is in fact zero or less?

(b) As the result is not significant, we need to quote an upper limit on the Branching Fraction in our paper. What Branching Fraction X should we quote that ensures that there is a 95% chance that the true Branching Fraction is less than X?