

- Given an average luminosity $1.1 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$, estimate how often the following inclusive processes occur at the ATLAS detector ($1 \text{ barn} = 10^{-24} \text{ cm}^2$):
 - $pp \rightarrow b\bar{b} : \sigma \sim 10 \mu\text{b}$
 - $pp \rightarrow W : \sigma \sim 10 \text{ nb}$
 - $pp \rightarrow t\bar{t} : \sigma \sim 10 \text{ pb}$

- The top width (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 $\Lambda_{QCD} \approx 200 \text{ MeV}$.
- What fraction of top pair production events will have a “di-lepton” final state i.e.

$$pp \rightarrow t\bar{t} \rightarrow l_1 l_2 \nu_1 \nu_2 b\bar{b} \quad (1)$$

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

- 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:

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

- 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 $(p_x, p_y, p_z) = (p \sin \theta \cos \phi, p \sin \theta \sin \phi, p \cos \theta)$
 - Show that the light quark jets are consistent with being the decay products of a W . (Hint: assume they come from the decay $X \rightarrow j_1 j_2$ and calculate the mass of X).
 - Which of the two b jets probably came from the same top quark as this hadronically decaying W ?
- A search for the supersymmetric particle of the top quark, the $stop$ or \tilde{t} , using 200 pb^{-1} has an expected background of 17 events with a total systematic error of 5 events. The data shows 30 selected events:
 - How significant is this excess?
 - 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.
 - The fraction of $B^0 \bar{B}^0$ particles (created by colliding $e^+ e^-$) decaying to a K^{*+} and a K^{*-} ($B^0 \bar{B}^0 \rightarrow K^{*+} K^{*-}$) compared to total number of decays ($B^0 \bar{B}^0 \rightarrow X$) 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 ?