

PHYS6011 Experimental Particle Physics - Problem Set 3 Questions - 2015

1. 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 barn =  $10^{-24} \text{ cm}^2$ ):

- (a)  $pp \rightarrow b\bar{b} : \sigma \sim 10 \mu\text{b}$
- (b)  $pp \rightarrow W : \sigma \sim 10 \text{ nb}$
- (c)  $pp \rightarrow t\bar{t} : \sigma \sim 10 \text{ pb}$

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.

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

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

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:

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

- (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  $X \rightarrow j_1 j_2$  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  $B^0 \bar{B}^0$  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  $X$ ?