HW #1 (129A), due Sep 13, 4pm

So-called B-factory experiments are looking for subtle difference between properties of matter and anti-matter, hopefully getting insight into the question why there exists only matter but no anti-matter in our Universe. There are two of them running, one called BABAR (`http://www.slac.stanford.edu/BFROOT/`) at Stanford Linear Accelerator Center (SLAC) and the other called Belle (`http://belle.kek.jp/`) at KEK Laboratory in Japan. Both of them collide beams of electrons and positrons (anti-particle of electron) of different energies and produce a particle called $\Upsilon(4S)$, a bound state of a bottom quark and an anti-bottom quark in $4S$ state with total spin 1, of mass 10.580 GeV/c^2. In this process, there is no other particle produced. Answer the following questions.

1. SLAC experiment collides an electron of energy 9.0 GeV, while the KEK experiment uses 8.0 GeV electron. What is the energy of positron in each experiment?

2. $\Upsilon(4S)$ quickly decays into a pair of B-mesons, of mass 5279 MeV/c^2. In the rest frame of $\Upsilon(4S)$, what are their energies and momenta?

3. B-mesons live 1.54×10^{-12} sec on average. How far do they go on average in the rest frame of $\Upsilon(4S)$ before they decay?

4. When a $\Upsilon(4S)$ decays, it produces B-meson (and also anti-B-meson) at different angles each time. Using the angle θ defined relative to the beam axis in the rest frame of $\Upsilon(4S)$, give the analytic expression of four-momentum of the B-meson in the laboratory frame (not numbers!).

5. Using the probability distribution

$$\frac{dP}{d\cos\theta} = \frac{3}{8}(1+\cos^2\theta), \tag{1}$$

work out the average distance a B-meson can go in the laboratory frame for each experiment (a number for each).

Note These experiments collide electrons and positrons of different energies so that B-mesons go over longer distance. They determine the points of their decays for detailed studies of their properties.