129A HW # 6 (due Oct 17)

When a pair of particles $q + \bar{q}$ is produced from $e^- e^+$ annihilation, it proceeds as follows. First, e^- and e^+ annihilates into a photon as a quantum intermediate state. Then the photon converts into a pair of particles. Therefore, the quantum mechanical amplitude is given by the second order perturbation theory,

$$\mathcal{A} = \langle q, \bar{q}|V|\gamma\rangle \frac{1}{E_i - E_\gamma} \langle \gamma|V|e^+e^-\rangle. \tag{1}$$

V is the interaction Hamiltonian between the photon and charged particles. Since the coupling of the photon to charged particles is proportional to the electric charge, we find

$$\langle q, \bar{q}|V|\gamma\rangle = ceQ_q \tag{2}$$

where Q_q is the electric charge of the particle q in the unit of proton charge e. We compare the production of quark-pairs and muon-pairs. We assume that quarks have spin 1/2, and all particles are highly relativistic that their masses (and hence their differences) can be neglected. Then the proportionality constant c is common for quarks and muons.

1. What is the ratio of probabilities to produce a pair of up-quarks and a pair of muons? (Forget the "color" for the moment.)

2. What is the ratio of probabilities R to produce three kinds of quarks (u, d, s) which are not distinguished from each other and to produce a pair of muons?

3. What is the same ratio for the case of u, d, s, c all together?

4. Download a research paper from WWW `http://xxx.lanl.gov/abs/hep-ph/9502298` by S. Eidelman and F. Jegerlehner, which compiled the data for e^+e^- annihilation to hadrons. One of their plots show the data for the region 2.20 GeV $< E_{CM} <$ 3.10 GeV (below the threshold to produce a pair of charm quark). Make a rough average of the ratio R. Discuss how it compares to the prediction based on the quark model.

5. The paper has another figure for the region 5.00 GeV $< E_{CM} <$ 9.50 GeV (below $b\bar{b}$ but well above $c\bar{c}$ threshold). Make a rough average of the R, *without* the Mark-I data which people do not believe now. Discuss how it compares to the prediction based on the quark model.

Note The data appear somewhat higher than the quark model prediction even after including the color factor. The excess is understood as a higher order perturbative corrections due to the production of $q\bar{q}g$ where g is the gluon.