Flavour physics problems.

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Problems to accompany the flavour physics lecture in the virtual Terascale Summer School 2020.
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1. Basics

a. What does FCNC stand for?

b. What is the formula for q^2?

c. What is the mass of the B^0 meson? Where should you go to find this information? [Hint you will need the second part of the answer for many other questions, so ask someone if you can't find it! Wikipedia is the wrong place.]

d. What is the mass of the $\Upsilon(4S)$?

e. What is the quark content of the $\Upsilon(4S)$?

f. An electron at Belle II has $7\,\mathrm{GeV}$ of energy and collides with a positron of $4\,\mathrm{GeV}$ energy. What is the centre-of-mass energy of the collision?

g. A proton at the LHC collides with another proton both have $6.5\,\mathrm{TeV}$ of energy. What is the centre-of-mass energy of the collision?

h. What is the lifetime of the B meson?

i. I (hopefully) said something like "B mesons fly an observable length" in my lecture. But their lifetime is small. How can we reconcile this? A B meson in LHCb flies for something on the order of millimetres.

j. Why is vertex reconstruction important in B-physics experiments?

2. Branching fractions and observables

a. What is the measured branching fraction for $B^+ \to J/\psi K^+$ decays?

b. What is the measured branching fraction for $J/\psi \to \mu^+\mu^-$ decays?

c. We observe 700 000 $B^+ \to J/\psi K^+$ events where the J/ψ decayed to 2 muons. We observe 5000 $B^+ \to K^+\mu^+\mu^-$ events. What is our measurement of branching fraction of $B^+ \to K^+\mu^+\mu^-$? You can assume the efficiencies to measure both decays are equal.

d. A famous observable in b-physics is labelled R_{D^*}. Which of the following formulae is R_{D^*} and why?

$$w = \frac{\Gamma[\bar{B}^0 \to K^{*0}\mu^+\mu^-] - \Gamma[B^+ \to K^{*+}\mu^+\mu^-]}{\Gamma[\bar{B}^0 \to K^{*0}\mu^+\mu^-] + \Gamma[B^+ \to K^{*+}\mu^+\mu^-]}$$
$$x = \frac{\Gamma[\bar{B}^0 \to K^-\pi^+] - \Gamma[B^0 \to K^+\pi^-]}{\Gamma[\bar{B}^0 \to K^-\pi^+] + \Gamma[B^0 \to K^+\pi^-]}$$
$$y = \frac{\mathcal{B}[B^0 \to K^{*0}\mu^+\mu^-]}{\mathcal{B}[B^0 \to K^{*0}e^+e^-]}$$
$$z = \frac{\mathcal{B}[B^+ \to D^*\tau^+\nu_\tau]}{\mathcal{B}[B^+ \to D^*\mu^+\nu_\mu]}$$

e. *Just for fun.* Based on the rules I mentioned on page 35, what would you call the others? (Let's see how close you get.)

3. Rare decays and modern b-physics

a. Draw a Standard-Model Feynman diagram for the process $B_s^0 \to \mu^+\mu^-$.

b. On page 42 of the lecture, I showed you a Standard-Model Feynman diagram for $B^0 \to K^{*0}\mu^+\mu^-$. There is another one! Draw it.

4. Advanced

Obtain a copy of

Phys.Rev.Lett.**110**, 221601.

You do **not** have to pay to access this paper. [Hint: if you have trouble try googling for “inspire hep” and search there. If you really really have trouble email me!] Read the introduction, conclusions, and look at Figure 1. Try to understand the gist of the paper (you can read the whole thing if you like, or just look up things in the main body of the text as questions come up). To test your understanding:

a. What are they trying to measure?

b. What is the formula for the thing they are trying to measure?

c. What effect can you see in the plot?

d. Can you put this into wider context? Is this weird?

5. To finish: a difficult one

Think about the answer to part c of the previous question. Compare with page 53 of the lecture.

The two histograms of $m(K\mu\mu)$ and $m(Kee)$ have very different y-axis scales. And yet the ratio is only 0.8. By eye, it looks like the ratio should be something very roughly $350/100 = 3.5$!!

How can we reconcile this?