

1: (a) Draw lowest-order Feynman diagrams for the reactions

(i) $e^+e^- \rightarrow u\bar{u}$

(ii) $e^+e^- \rightarrow s\bar{s}$

using only the vertices we saw in the lectures, and neglecting diagrams that contain an intermediate Z boson. This would be appropriate, for example, if $E_{\text{cm}} \ll M_Z$. Label all of the particles and indicate the coupling strengths for all vertices. Note that the reactions here are only parts of more complicated reactions, since at some stage the quarks and antiquarks will transform into mesons and/or baryons.

(b) Assuming that the only difference in probabilities for the two reactions above comes from the different coupling strengths, predict the ratio of cross sections

$$\frac{\sigma(e^+e^- \rightarrow u\bar{u})}{\sigma(e^+e^- \rightarrow s\bar{s})}.$$

2: The Intersecting Storage Ring (ISR) accelerator operated throughout most of the 1970s at CERN. Counter-rotating beams of protons were accelerated to energies of $E_{\text{beam}} = 30$ GeV and collided together. Since the two proton beams had to be in separate beam pipes, they could not be brought to a head-on collision, but rather crossed at a 15° angle as shown in Fig. 1. (That is, the angle between the momentum vectors of two colliding protons was $\theta = 165^\circ$.)

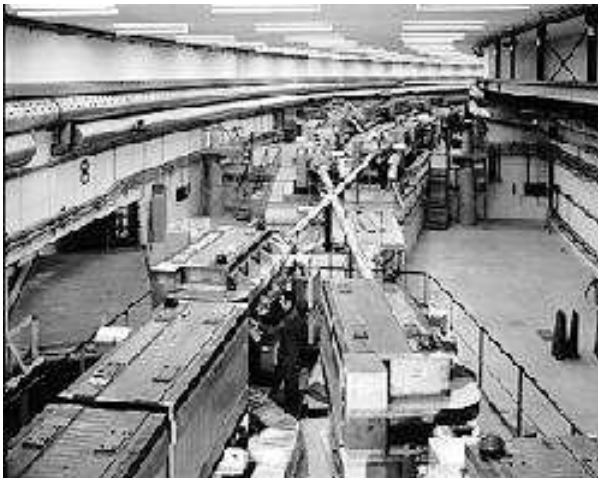


Figure 1: The Intersecting Storage Ring (ISR) accelerator at CERN.

(a) Find the centre-of-mass energy E_{cm} using the beam energy and crossing angle given above. (Recall that this is the invariant mass of the proton–proton system. You may approximate the protons as being highly relativistic, i.e., you may neglect their rest masses in your calculation.)

(b) Suppose one wanted to achieve the same centre-of-mass energy with a proton beam incident on a proton target at rest. What would the beam energy need to be? (If you haven't managed part (a) of this question, make a reasonable guess for E_{cm} and proceed with part (b).)

3: (a) Draw the lowest-order Feynman diagram for beta decay of a neutron at rest, $n \rightarrow p e^- \bar{\nu}_e$, where the neutron and proton are represented by the appropriate collection of quarks. Label all particles and coupling strengths.

(b) Write down the propagator for the intermediate W boson in (a). What is the value of the W's virtual mass squared, q^2 , if the neutrino carries off zero energy? (Recall $m_e = 0.000511$ GeV and use the fact that here q^2 is equal to the invariant mass squared of the electron-neutrino system.)

(c) What is the q^2 if the final state proton remains at rest and the electron and antineutrino fly off back-to-back?

For both (b) and (c) you should find $q^2 \ll M_W^2$, and therefore the the propgator can be approximated by $-1/M_W^2$, regardless of how the neutron's energy is shared between the three final state particles.

(d) What would be the effect on the rate of beta decay if the constants of Nature were suddenly to change such that the weak coupling g increased by a factor of three and the mass of the W boson decreased by a factor of two?

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