USPAS Graduate Accelerator Physics Homework 6

Due date: Wednesday January 31, 2024

1 LEP electron radiation (Peggs-Satogata 11.3)

Consider 50 GeV electrons in LEP, circulating in a nearly-circular ring with a total circumference of about 27 km. Also consider a 5 TeV electron storage ring that is built around the earth's equator (ρ=6380 km). For each accelerator:

(a) How much energy is radiated per electron per turn?

(b) What is the characteristic damping time τ_0, in turns and in seconds?

(c) What is the bending field?

2 RHIC gold ion radiation (Peggs-Satogata 11.4)

In RHIC, 55 bunches of 10^9 gold ions with $(Z, A) = (79, 197)$ circulate in each ring, at a top energy of $\gamma = 108$. The circumference is 3833 m and the main arc dipole bending radius is $\rho = 243$ m.

(a) How much energy is radiated per gold ion per turn?

(b) What is the characteristic damping time τ_0, in turns and in seconds?

(c) The synchrotron radiation power is a serious cryogenic load if it exceeds about 1 W/m. Is it a problem?

(d) If 360 bunches of 2×10^{11} 10 GeV electrons circulate in a new ring in the existing RHIC tunnel, how much energy is radiated per electron per turn, and what is the characteristic damping time τ_0?

3 FCC wall-plug power (Peggs-Satogata 11.5)

A Future Circular Collider (FCC) might circulate 50 TeV protons in a 100 km circumference tunnel with a main arc dipole bend radius of 11 km.

(a) What is the arc dipole bending field?

(b) What is the critical energy of photons radiated in the dipoles?

(c) What is the total energy lost per turn, per proton?

(d) If each proton beam has a current of 0.5 A, what is the total synchrotron radiation power, per ring?

(e) Assuming that cryogenic refrigerators operate with a Carnot efficiency of 20%, how much "wall-plug" power would be required if the synchrotron radiation were absorbed at a temperature of 4 K?

4 Muon storage ring (Peggs-Satogata 11.6)

Consider muon storage rings, particularly relevant with renewed interest in muon colliders.

(a) What is the total power radiated in an isomagnetic muon storage ring of radius ρ with an average beam current of I?

(b) How much power is emitted in a 30 GeV ring with $\rho = 250\,\text{m}$ that stores 1 A of electrons, or 1 A of muons?

(c) What is the natural beam current lifetime decay for 30 GeV muons?

(d) What is the heat load due to the decay of 1 A of 30 GeV muons?

5 Light source calculations (Peggs-Satogata 12.3)

A light source with a circumference of 176 m contains 8 identical DBA cells, with zero dispersion (and dispersion slope) at one end or the other of all 16 dipoles. Each dipole is 2.7 m long, and the beam energy is 2.5 GeV.

(a) What is the characteristic energy of the photons radiated in the dipoles?

(b) How much energy is radiated per turn, per electron?

(c) What is the momentum compaction factor of the ring?

(d) What are the damping times τ_x, τ_y, and τ_s?

(e) What is the approximate equilibrium horizontal emittance?