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Synchrotron Radiation — Exercises 1

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1 Future Circular Collider

Particle physicists are evaluating the potential of building a future circular collider, which aims at colliding two proton beams with 500 mA current each and 100 TeV particle energy (FCC-hh). The protons would be circulating in a storage ring with 100 km circumference, guided by superconducting magnets. The dipoles aim at a field of 16 T. Calculate

- The Lorentz factor γ
- The critical energy of the synchrotron radiation
- The total power emitted by both beams through synchrotron radiation

2 Muon Storage Rings

Muons are considered as an alternative to electrons for a future circular lepton collider. Argue

- why they might be preferable to electrons, and
- what could be possible disadvantages.

3 Undulator Radiation

Assume an undulator of 15 mm period and 5 m length. The pole tip field is B_t = 1.5 T, and the gap can be varied between 8 and 16 mm.
This undulator is placed in a storage ring, with an electron beam energy of E = 3.2 GeV, and a beam current of 500 mA. The beam is focused to a waist of $\sigma_x = \sigma_y$ = 20 µm inside the undulator.

- What range can be reached with the fundamental photon energy?
- What brilliance can be reached at the fundamental photon energy?
- Is there a significant flux higher harmonics?

4 Preparation for an Upgrade

Petra-III is a 2.3 km circumference light source at 6 GeV and 1 nm horizontal emittance, located at DESY in Hamburg. An upgrade based on multi-bend achromats will decrease the emittance to 10 pm. Before the upgrade, the DESY team wants to test instrumentation for the new ring at low emittance.
Suggest a way to lower the emittance at the existing machine in order to test the instrumentation. What are some issues with your suggestion?

5 New Storage Ring

You have been nominated as director for the new Mexican Light Source. The aim of this synchrotron is protein crystallography. What are your considerations? Give at least one advantage and one disadvantage for each of the two following aspects:

- Higher beam energy
- Large circumference

6 Cosmic Electron

A cosmic electron with an energy of 1 GeV enters an interstellar region with a magnetic field of 1 nT. Calculate

- The radius of curvature
- The critical energy of the emitted synchrotron radiation
- The energy emitted in one turn

How would you measure this radiation?

7 Superconducting Undulators

What is the advantage of using undulators made with superconducting coils, in comparison to permanent-magnet arrays? What are drawbacks?

8 Emittance and Energy Spread

The equilibrium emittance of an electron bunch in a storage ring occurs when factors increasing ε are compensated by those reducing ε.

- Which effect increases the horizontal emittance ε_x?
- Which effect decreases the horizontal emittance ε_x?
- Which effect increases the vertical emittance ε_y?
- Which effect decreases the vertical emittance ε_y?

9 Fundamental Limits

The ESRF-EBF (European Synchrotron Radiation Facility – Extremely Brilliant Source) has a circumference of 843.977 m. Electrons with an energy of 6 GeV circulate around the ring. The horizontal and vertical emittances are 110 pm and 5 pm, respectively. How far is this away from the de Broglie emittance, i.e. the minimum emittance given by the uncertainty principle?