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Introduction to Biophysics
Winter Semester 2024/25, Exercise Sheet 4

Problem P4.1 Compact Light Source

a) What is the principle of the Munich Compact Light Source? How is it possible to shrink a synchrotron source from several hundreds to few meters? Please explain it in both - the wave and the particle picture.

Solution:
Wave picture: The same physics as for an undulator. The difference is the wavelength of the magnetic field (electro-magnetic field of a laser) - the period is approximately 1 micrometer (conventional undulator has a period in the range of centimeters). The electron energies of a compact light source are in the MeV range (conventional synchrotron rings reach 1-6 GeV). In a compact light source a laser undulator produces x-ray photons from electrons in the MeV range.
Particle picture: The principle of a compact light source can be explained with the inverse Compton effect. A laser photon collides with a highly-accelerated electron. The electron transfers a part of its energy to the laser photon and shifts it into the x-ray regime.

b) How would you increase the X-ray energy of a Compact Light Source?

Solution:
There are two ways: 1) Increasing the energy of the electrons - not feasible without increasing the size of the source (see the large acceleration rings of synchrotron sources; 2) Decreasing the wavelength of the laser (using a green laser instead of a red one) - this is exactly, what is planned at the MuCLS;

Problem P4.2 Radiation Therapy

a) What is the primary target for radiation effects in living cells?

Solution:
The primary target is the DNA of the tumor cells. The radiation causes double-strand breaks, which cannot be repaired correctly and lead to cell death.

b) Annotate the following depth dose curves by their correct particle type and explain your choice.

Choose from: electrons, heavy ions, neutrinos, photons, protons

Solution:
The depth dose curves of photons reach the maximum at lower depths and exponentially decay with depth. Protons and heavy ions look very similar showing a distinct peak in a certain depth depending on the energy of the ions. The depth curves differ in the small tail at higher depths, which are generated by small fragments of carbon (i.e. heavy ion) particles.

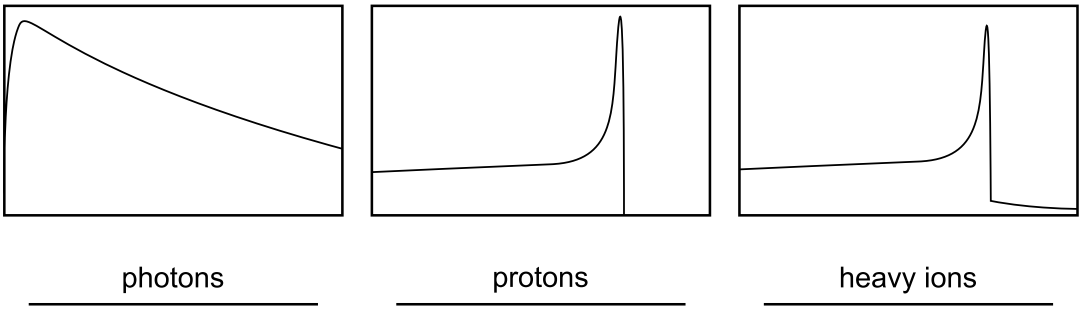

FIGURE 1

c) Order the following radiation types / beam energies with respect to their range in water (highest to lowest) and briefly explain your decision:

A) 100 MeV protons
B) 200 MeV protons
C) 50 MeV/u carbon ions
D) 100 MeV/u carbon ions

Solution:
B) 200 MeV p+_> _A) 100 MeV p+_>_D) 100 MeV/u C6+_>_C) 50 MeV/u C6+ _

The relation for the depths of different charged particles can be estimated with the following equation:

$\frac{R_1}{R_2} = \frac{M_1}{M_2} \cdot \frac{z_2^2}{z_1^2}$, with M_1 and M_2 being the masses of the ions and z_1 and z_2 the charges.

This explains that the range in water of 100 MeV protons is larger than of 100 MeV C6+ particles.