Problem 1 – CT, SPECT and PET characteristics

Several imaging methods using x-ray detection are currently used: CT, SPECT and PET. In order to understand what are their differences and similitudes describe for each of them:

- which data collection method they use.
- what image reconstruction method is required.
- what produces the x-rays detected.
- what is their spatial resolution and what defines it.
- how the signal is attenuated and how to correct for it.

Problem 2 – Coincidence Detection

At a nuclear physics department a coincidence setup has been built. It consists of two detectors equipped with cylindrical NaI(Tl) crystals with a 5 cm diameter and a 5 cm length. The distance between the detectors is 40 cm, and they are positioned exactly opposite to one another ($\varphi = 180°$; see Figure 2). The detectors have been set up so they can be rotated so that other values of ϕ can also be chosen. They have also been connected to a coincidence circuit which creates a pulse if both its connections give pulses that are less than τ=10 ns apart. Here it does not matter which of the two connections pulses first. Exactly in the middle of the two detectors a pure positron emitter is placed. This source has a strength A of 10 MBq. Decay can be neglected.

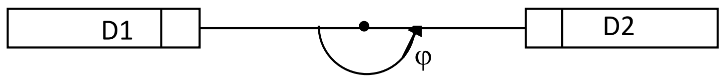
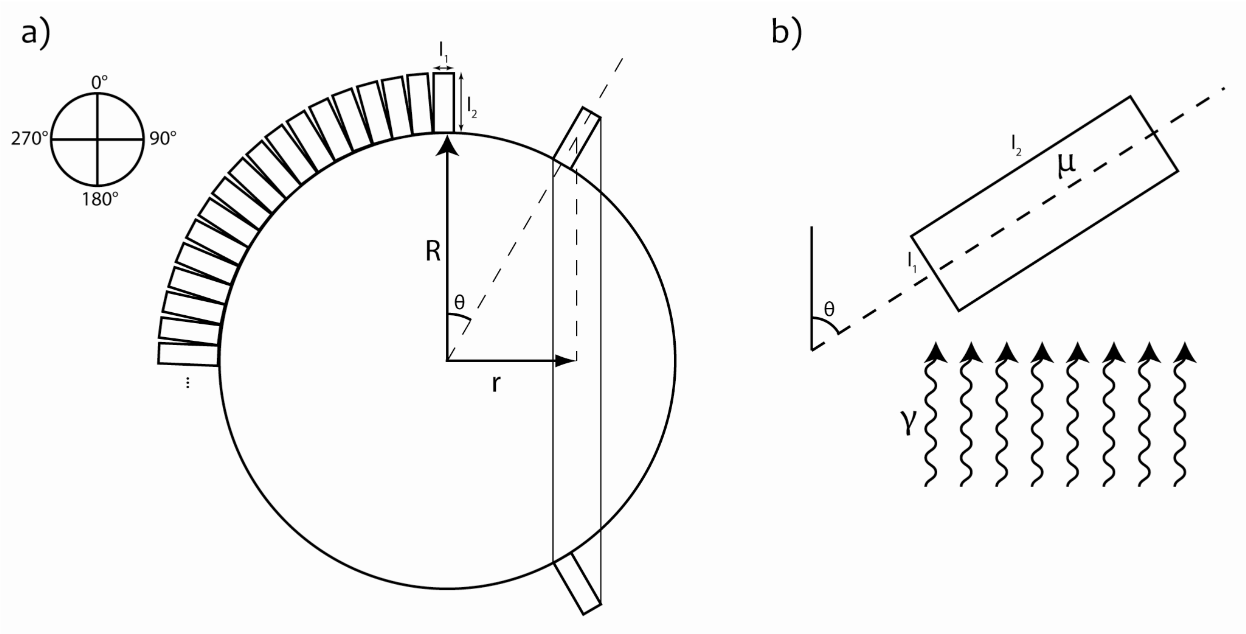


Figure 2

a) Calculate the geometric efficiency ε_{geom} of the detection of a 511 keV photon for a detector in the described setup. This should correctly be calculated by using the solid angle $\Omega = \frac{S}{R^2}$, with S the surface of the sphere around the source that intersects the detector and R radius of that sphere (a lengthy calculation). However, it can be approximated by dividing the surface of the detector by the surface of the sphere.
b) About 70% of the photons that reach the detector will cause a pulse. The pulses are filtered according to their energy and only pulses corresponding to 511 keV ('photopeak pulses') are accepted. Due to this selection half of the offered pulses are neglected. Calculate the 'singles count rate' per detector.
c) Calculate the counting speed for real coincidences. Assume that two 511 keV photons coming from the same annihilation create pulses in the detector that are less than 10 ns apart.
d) Calculate the counting speed of random coincidences.
e) One wants to measure the random coincidence counting speed. Assuming there is no scattering of photons at the source or surroundings, how can the mentioned counting speed be simply measured without using the 'delayed window' technique?

Problem 3 – PET radial resolution variations

The geometry of the detection in a PET scanner has usually a cylindrical symmetry. It is build in order to obtain the best detection characteristics in the middle of the ring of detectors. However, the resolution and sensitivity might depend significantly from the distance to the center of the scanner.
Let's consider one of these detection rings of radius R with rectangular detectors of size l_1*l_2, ($l_1 << R$) and linear absorption coefficient μ. A point source is placed in the ring (no scatter or random events).



a) We consider a vertical projection (0° projection in the sinogram) and are interested in the radial evolution of the PET resolution. Find an analytical expression of the uncertainty *Δr* on the measured position *r* of a point source on this projection. For the sake of argument, we consider the continuous case in which there is for each value of *r* a couple of detectors perfectly centered on *r* (see figure).
b) Which experimental parameter would you change and how would you modify them to improve the resolution out of the scanner center? Explain for which reason these modifications are not possible in practice without compromise.