Dark Matter (WS 2018/19) - Problem sheet 8

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Deadline for this sheet: 19.12.2018

Gamma-ray background

There are three main processes, that lead to attenuation of photons as they propagate through matter. The photoelectric effect, Compton scattering and e^+e^- pair production. Each of these processes is dominant for photons of a given energy range. The gamma ray attenuation length of xenon at different photon energies is shown in Figure 1.

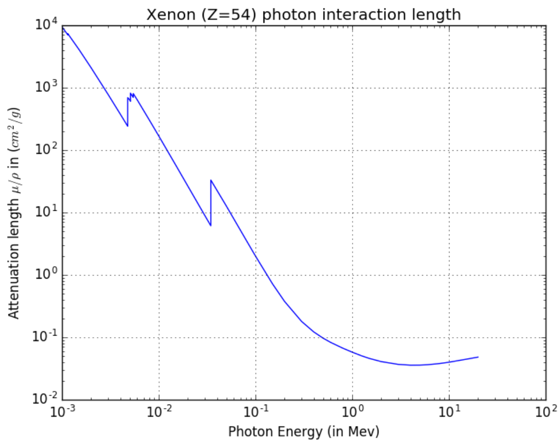


Figure 1: Photon attenuation length in xenon for different energies [1].

8.1 Self shielding of the detector *6.5 Points*

The intensity $I(x)$ of gamma rays after traversing a certain distance x within a medium can be computed using the following expression.

$$I(x) = I_0 \cdot e^{-x\mu} \tag{1}$$

Where I_0 is the initial intensity of the gamma radiation and μ is the absorption coefficient of the material.

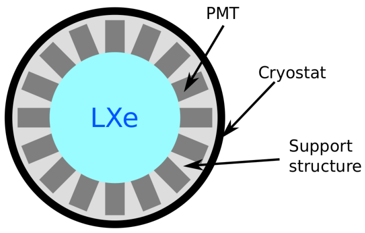
a) Some radioactive isotopes, which are commonly found in detector materials, are listed in the below table. Look up the energy of their (dominant) gamma emission line and estimate the corresponding attenuation length μ using Figure 1. Assume that these gamma quanta propagate in liquid xenon ($\rho_{Xe} \approx 3\,\mathrm{g/cm^3}$).
(*Hint: One commonly used database with nuclear decay data can be found here* `http://nucleardata.nuclear.lu.se/toi/`)

[1]Data available at (`https://physics.nist.gov/PhysRefData/XrayMassCoef/ElemTab/z54.html`)

Isotope	^{137}Cs	^{208}Tl	^{40}K	^{214}Pb	^{60}Co$^{*)}$	^{60}Co$^{*)}$
Energy [MeV]						
$\mu\,[cm^{-1}]$						

$^{*)}$ Find both characteristic lines

b) You want to operate a liquid xenon detector with an active mass of 2 tons. For simplicity we assume a spherical detector, with a central liquid xenon (LXe) target and photo sensors (PMTs) which are fixed around it using a support structure.



Now consider that all detector materials except of the liquid xenon contain trace amounts of the above listed isotopes. To simplify further, assume that the photon emission is always directed towards the center and that they do not loose any energy before they reach the xenon volume.

In order to reduce the background from this gamma radiation for the dark matter search, we can "fiducialize" the data (discard events that happen in the outermost LXe layer). Assume that we need to reduce the gamma induced background by one order of magnitude; Evaluate for each of the isotopes the fraction of the active LXe mass that remains, after applying the fiducialization.

c) With this in mind, discuss why it is usually beneficial to operate one large detector instead of several small ones.

8.2 Material screening using germanium detectors *3.5 Points*

During your lab tour at the MPIK, you have seen several of our germanium detectors, that are used for gamma-ray screening. Figure 2 shows background spectra collected with three different germanium spectrometers operated at different locations.

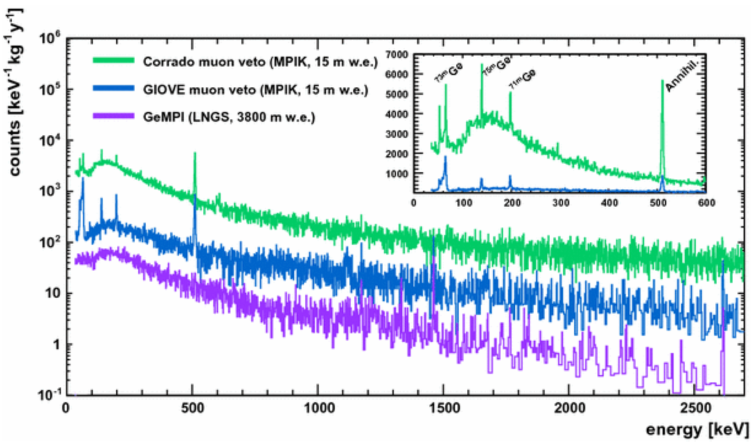


Figure 2: Background gamma spectra of differen germanium detectors (*arXiv:1507.03319*).

a) What is the origin of the line located slightly above $500\,\mathrm{keV}$? What could be the reason that this line is not visible in the background spectrum of the GeMPI detector?

b) What is the minimum energy that a photon needs to have in order to produce a $e^+ + e^-$ pair? Why is this process impossible in vacuum?