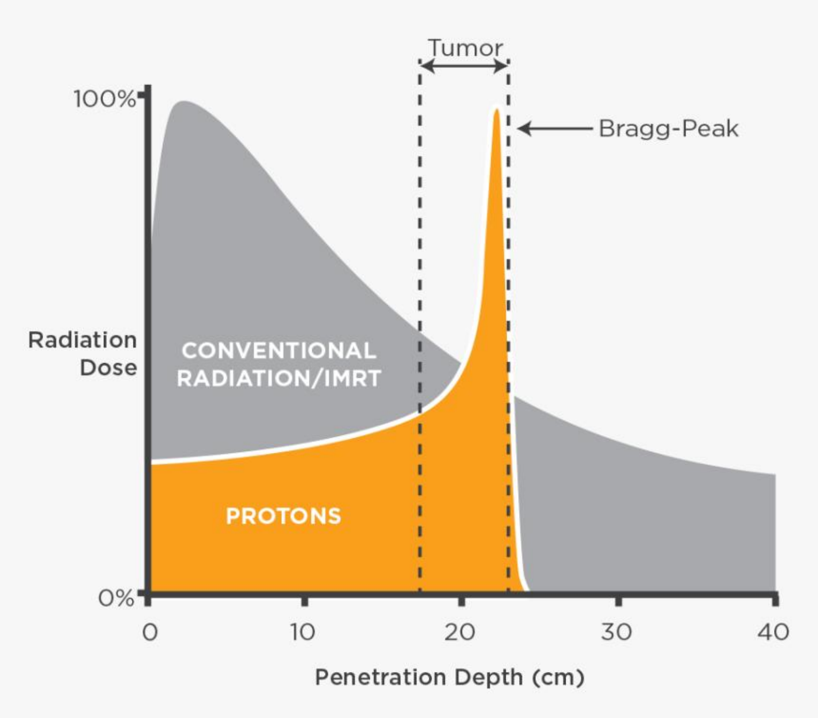
# 111 - Performance of microdosimetric detectors using Monte-Carlo

Filipe Ficalho and Juan Jose Gomez

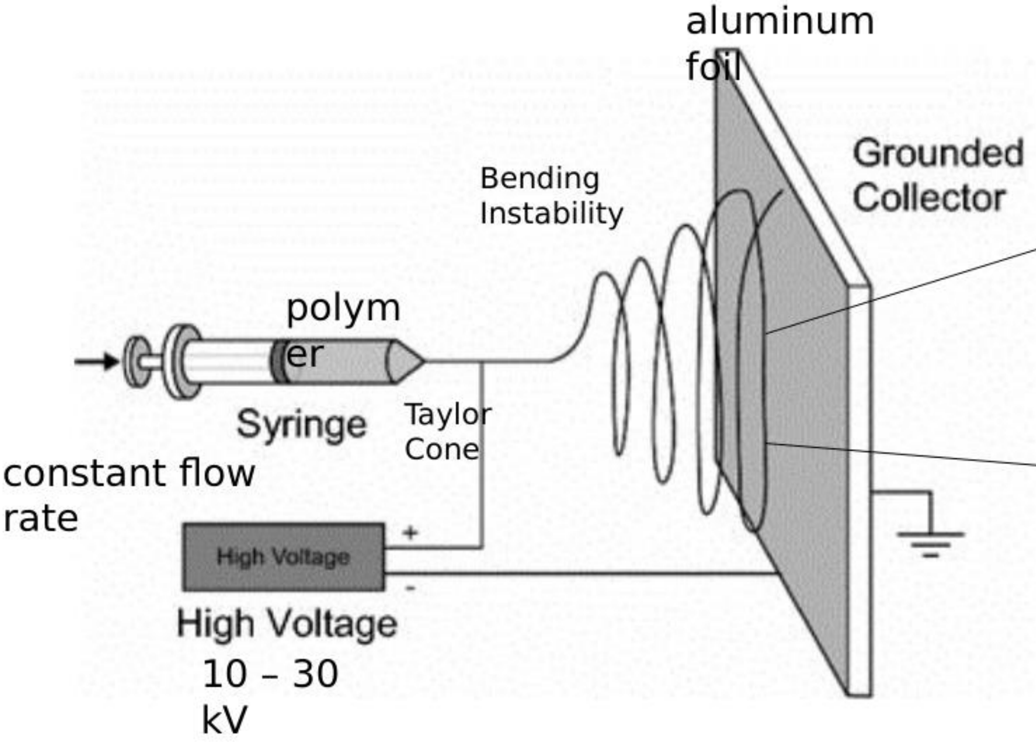
# Why do we need this kind of detectors?

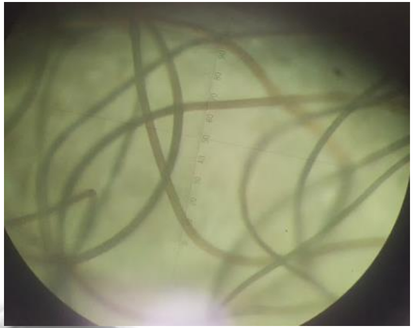
## Proton Therapy

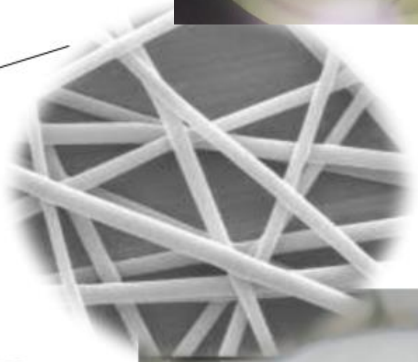
Proton therapy is a great treatment for certain types of cancer due to the Bragg peak, which maximizes the radiation dose in the area that needs it while reducing the dose in areas that don't. This peak's penetration depth can be changed by changing the proton's energy, making this treatment highly versatile



# Fiber Production in Our Labs





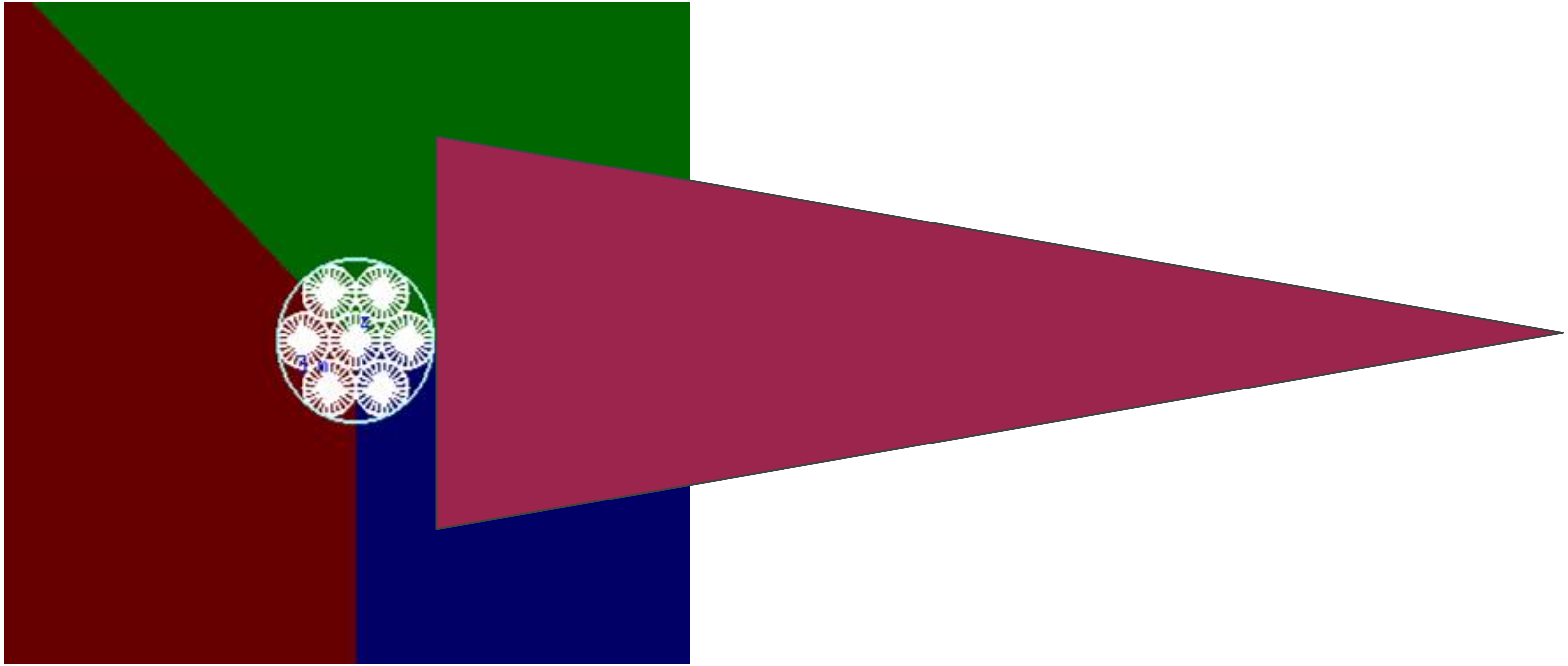
# The investigation process

Every fiber is made of polystyrene, has a diameter of 25 μm and a length of 5 cm. We then group this in different ways creating different geometries and compare their efficiencies.

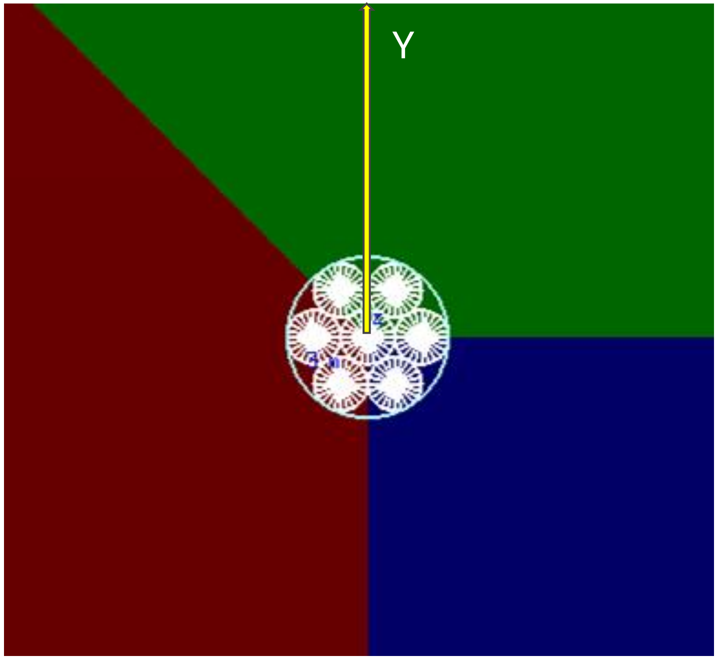
Those fibers will be hit by a proton beam from 15 mm away to the central fiber, whose protons have an energy of 150 MeV each. The beam has a circular spread of 2.5 mm radius, spreading the protons in a gaussian.

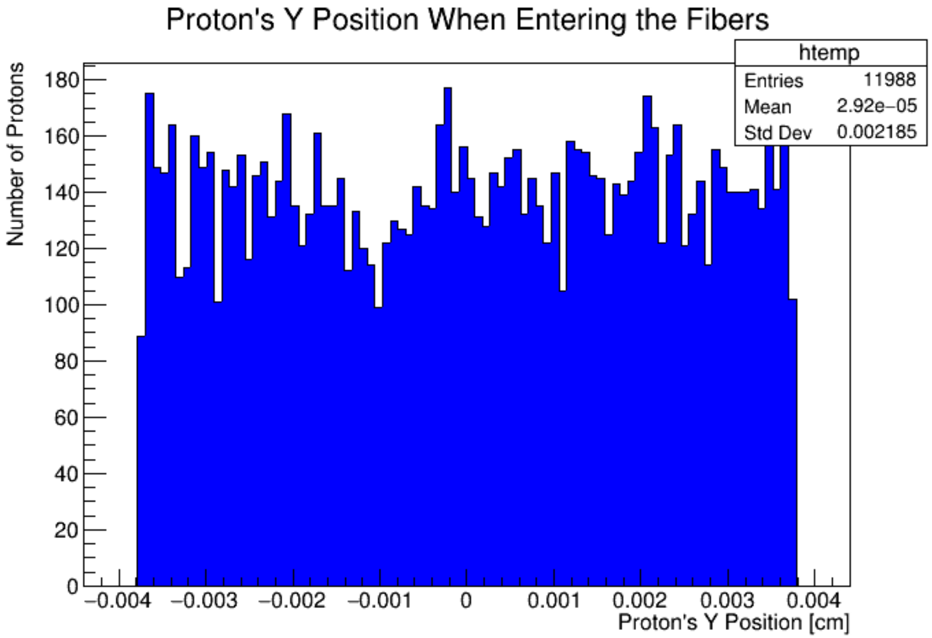
- Single Fiber
- Small Agglomerate of Fibers Close Together
- Small Agglomerate of Fibers Separated by Air
- Small Agglomerate of Fibers Separated by PMMA

# What happens in the simulations?

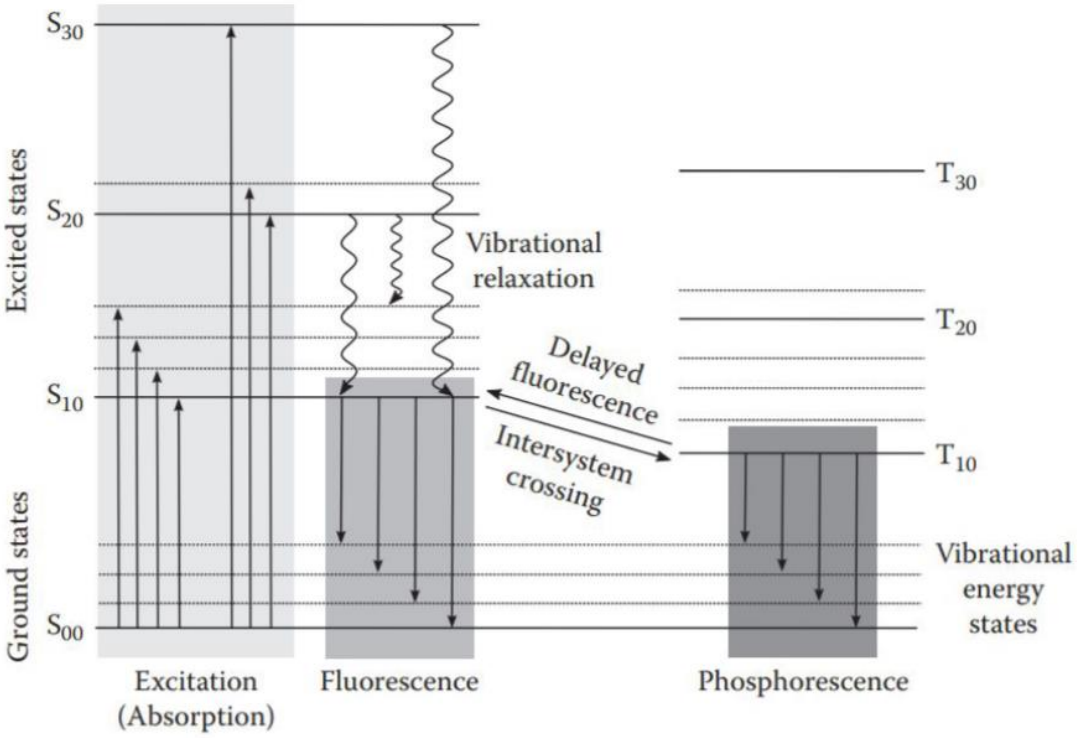


# What happens in the simulations?

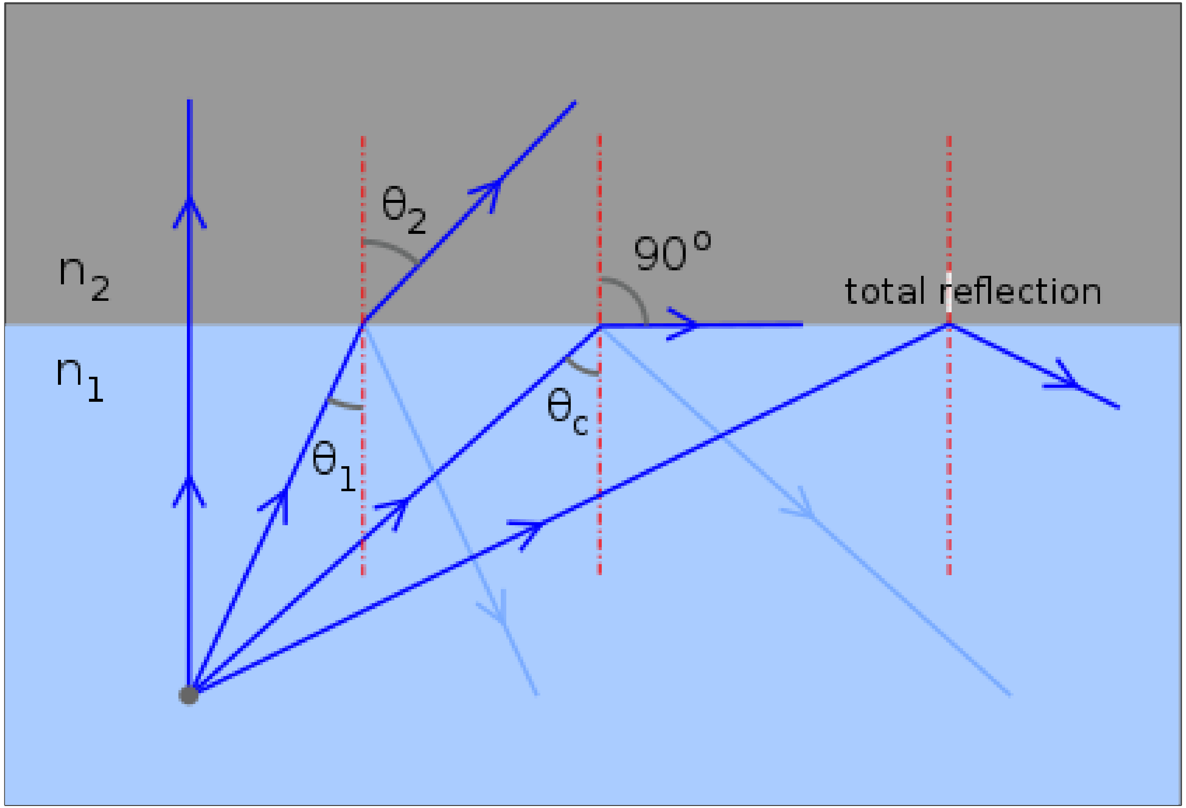


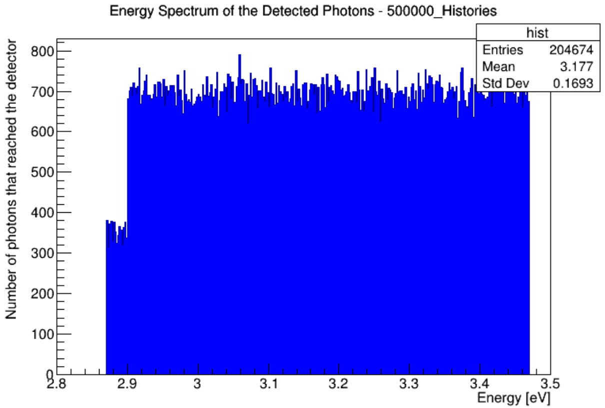



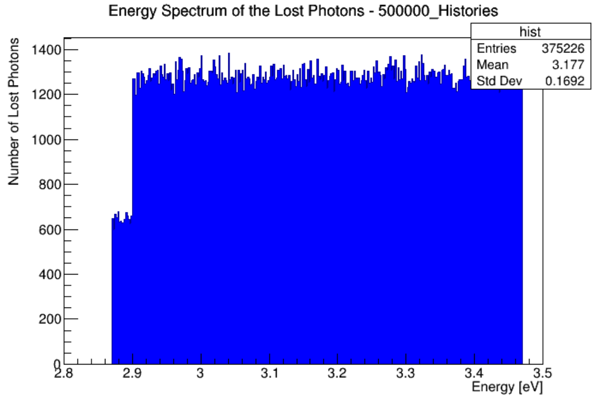
# A brief description of Scintillation



# Produced Photons’ Spectrum

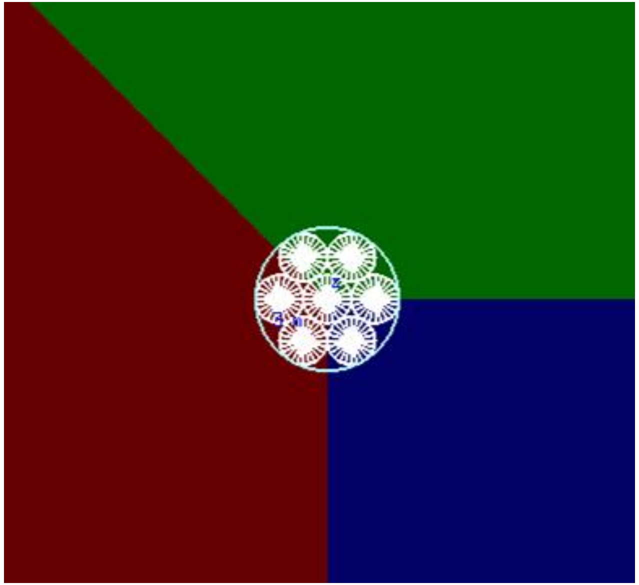


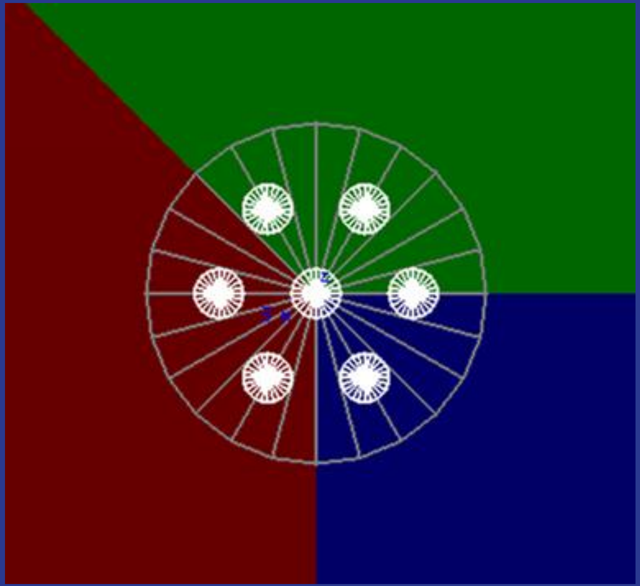



# Let’s Compare Different Geometry Layouts

# Fibers Close Together



# Fibers Separated by Air



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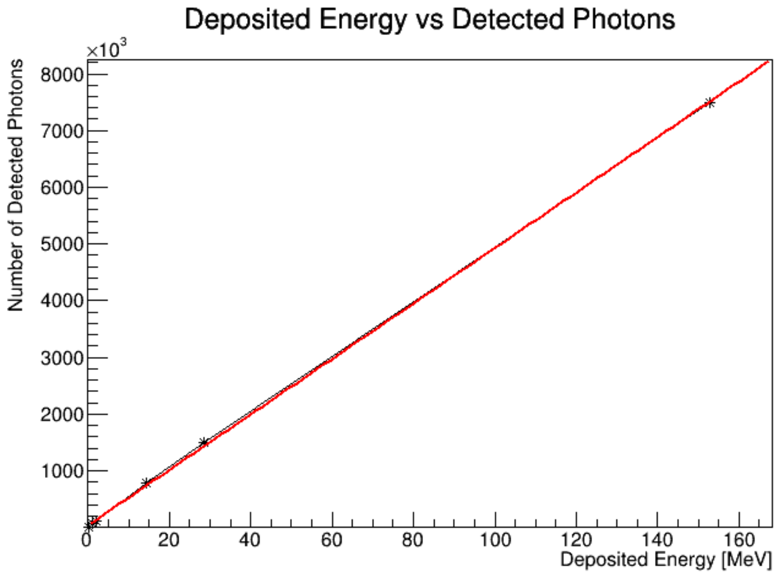
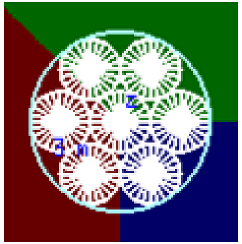
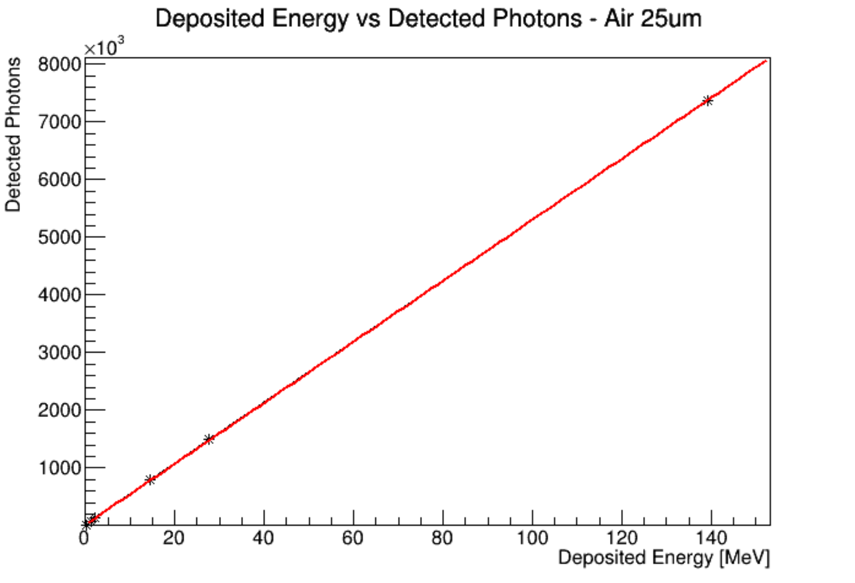


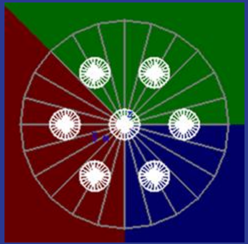



$N = m \cdot E + b$

$m = 48893 \pm 4382.124$
$b = 42316.3 \pm 24359.9$
Correlation = 0.999878

# Fibers Separated by Air

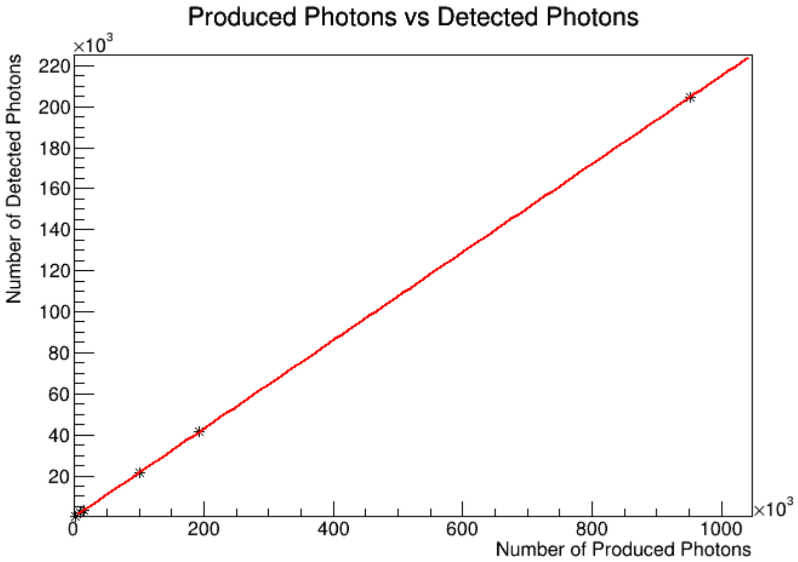


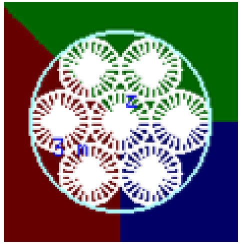



$N = m \cdot E + b$

$m = 52890.8 \pm 124.024$
$b = 16264.2 \pm 7223.88$
Correlation = 0.999989

# Fibers Close Together

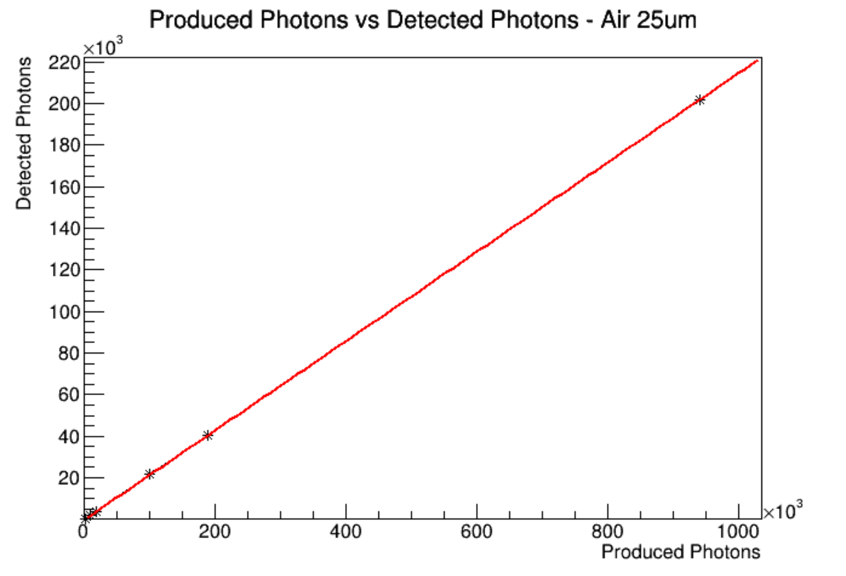


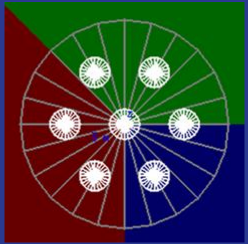



$$N_{Det.} = m \cdot N_{Prod.} + b$$

$m = 0.214877 \pm 8.69245e\text{-}05$
$b = 106.763 \pm 34.6613$
Correlation ≈ 1

# Fibers Separated by Air



$$N_{Det.} = m \cdot N_{Prod.} + b$$

$m = 0.214714 \pm 9.19411e\text{-}05$
$b = -53.0323 \pm 36.2084$
Correlation ≈ 1

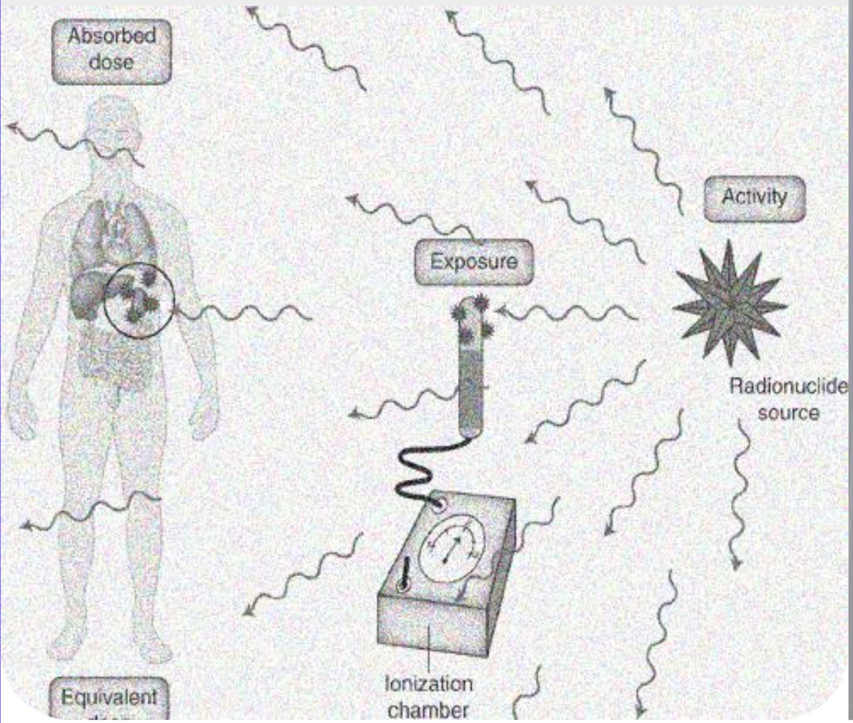
# Summary

We are still in the very beginning of this research topic!

All we can say for now is:

- There are no preferential energies to get caught in the fibers or escape them
- We observe a linear relation between the energy deposited in the fibers and the photons detected
- The efficiency of our fibers doesn't seem to change if we separate them small distances

# OSL Dosimetry $Al_2O_3:C/Mg$



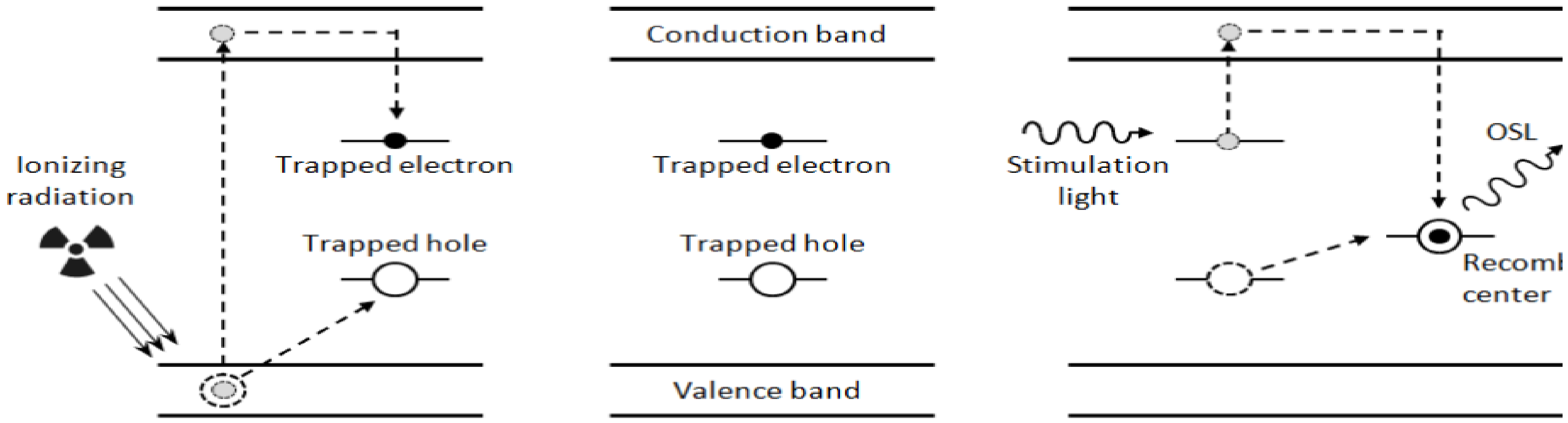


# Outline

- Brief comments on the OSL dosimetry
- Geometry, source and material of the crystal.
- Results for both crystals and soft tissue
- Conclusions
- Bibliography

# OSL Dosimetry

• The OSL dosimetry is a technique to assess some operational and/or **radiation protection** quantity (**absorbed dose, equivalent dose, effective dose**). The basic principle is the **energy storing** of the incident radiation (ionizing and non-ionizing) in terms of electrons/holes trapped in defects that are created in a **crystal using a dopant.** Then, the dose information **"collected"** is obtained by using light stimulation (visible light). That's why is called **Optical Stimulated Luminescence.**




a): Ionization and charge carriers capture

b): Storage

c): Stimulation and OSL emission

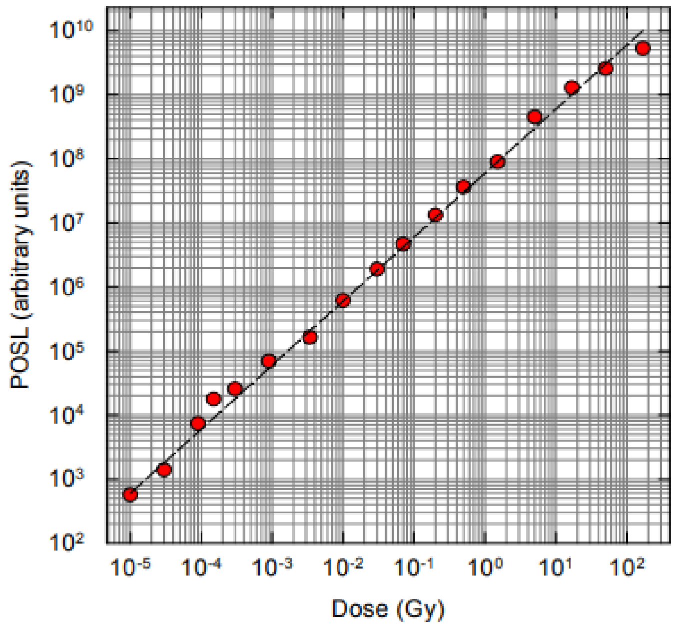
# OSL Dosimetry

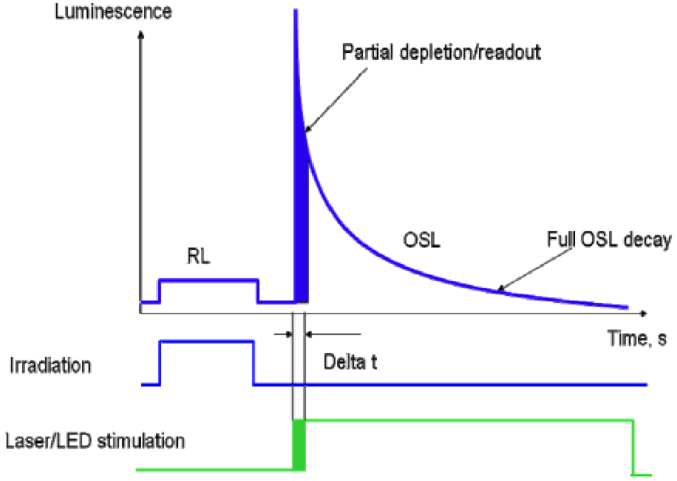
- The typical materials used in OSL Dosimetry are **Al2O3 : C/Mg** and **BeO.** These are typically taken by individuals, and they store the information from weeks up to one year depending on the device.

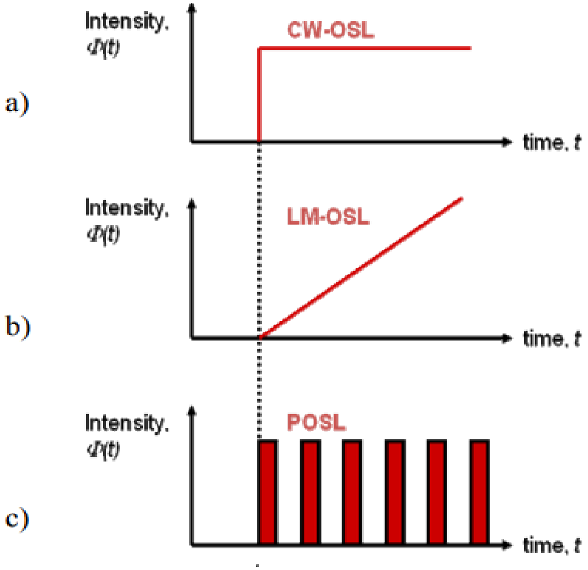
- Ideally, these devices must behave in a similar way to the **soft tissue.** The soft tissue defined by the **ICRP** (International Commission of Radiation Protection) trying to define the composition, effective atomic number and **density of human tissue.**

# OSL Dosimetry

- In a dosimeter, one desires to have a **linear response** between the **dose** and the **output signal**. Currently, this can be achieved between the range of the 10uSv to 10Sv. (The value for a flight between Frankfurt – New York is **40 – 60 uSv** and annual dose of a person is 2-3 mSv).
- The stimulation can be **pulsed POSL, constant, linear.** The readout is done **fractionated.**

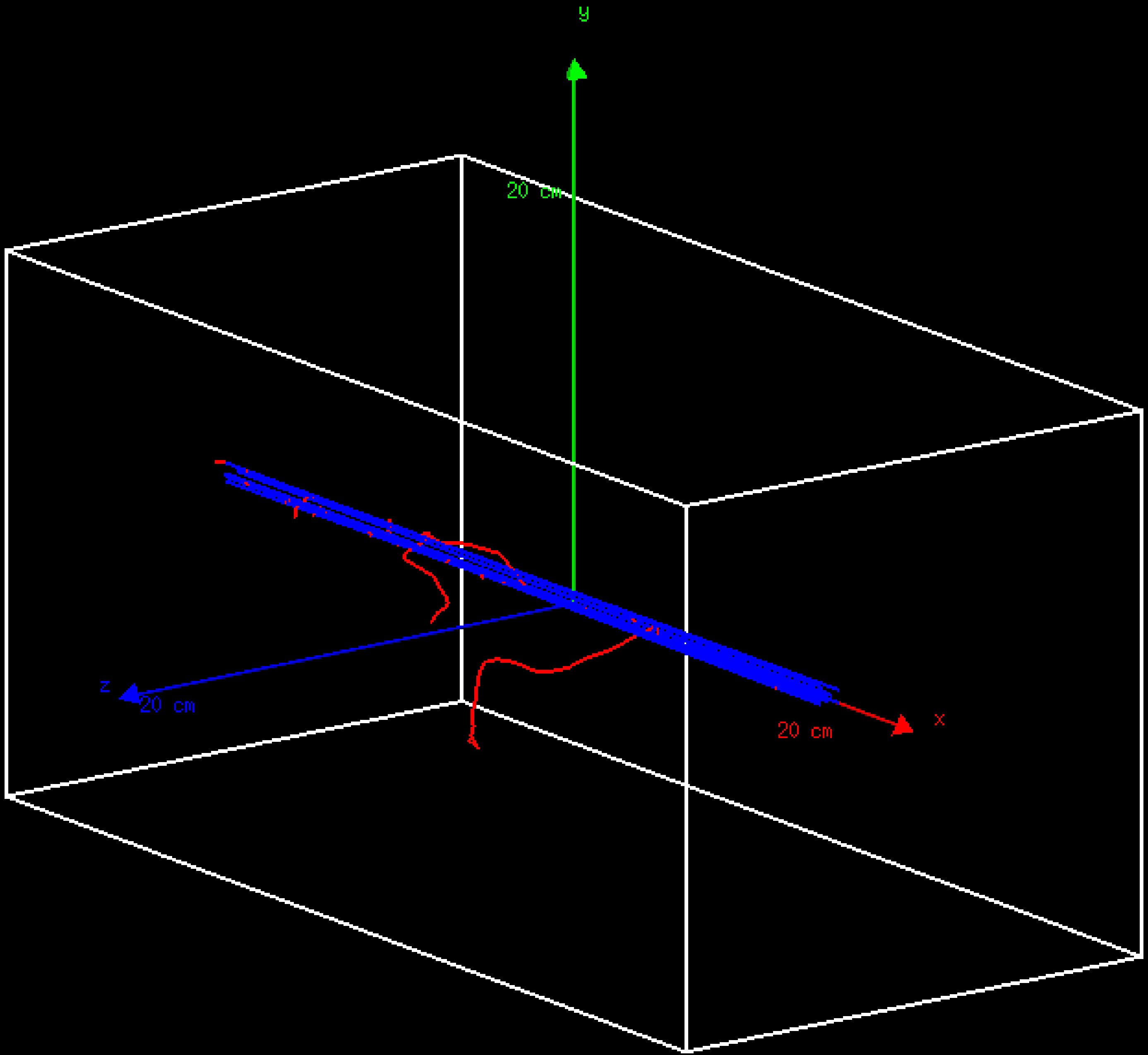


# Geometry, source and material of the crystal

**How is the MC simulation done? Which materials are used? What is the size of the crystal? How is the geometry of the simulation?**



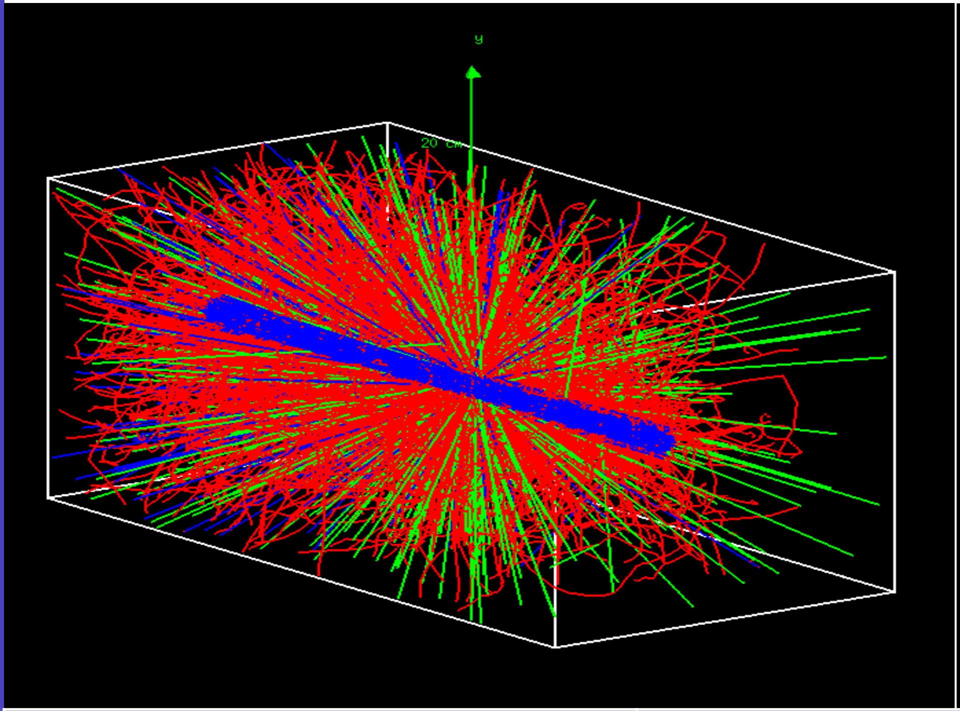
# Geometry, Beam source and crystal composition

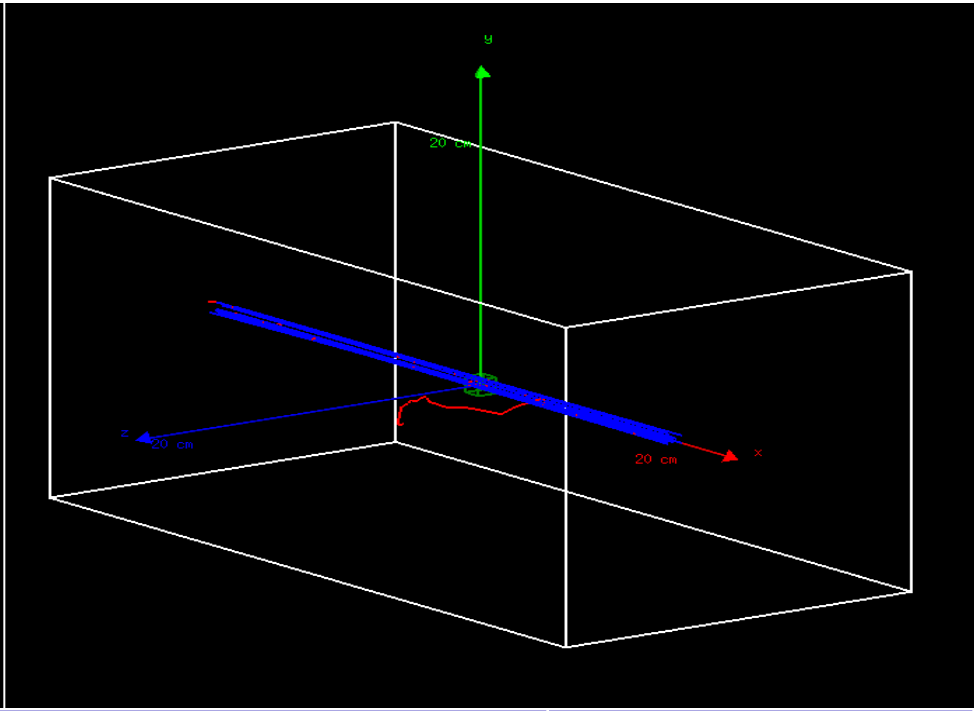
- The simulation is composed by done in TOPAS Code

| | **Material** | **Size and Location** |
|---|---|---|
| The **'world':** A rectangular box. | **Air:** G4_AIR. | X-size : 40cm.<br>Y-size : 20cm.<br>Z-size : 20cm. |
| The **'crystal':** A squared box. | • **Aluminum Dioxide:** G4_ALUMINUM_OXIDE<br>• **Aluminum Dioxide: Carbon doped** (0.01%, 0.1%, 0.5%, 1%, 5%, 10%, 100% Carbon)<br>• **Aluminum Dioxide: Magnesium doped** (0.01%, 0.1%, 0.5%, 1%, 5%, 10%, 100% Magnesium)<br>• **Soft Tissue** | X-size: 1 mm<br>Y-size: 1 mm<br>Z-size: 1 mm<br>Location: Center of the geometry (0,0,0) |
| The **proton source:** | • **150 MeV** monoenergetic beam<br>• Gaussian angular beam distribution<br>• **Number of events: 100000** | Position : 15cm in the positive x-axis.<br>Rotated 90 degrees respect to the y-axis.<br>Parallel to the x-axis. |

# Geometry, Beam source and crystal composition

- The simulation looks like: (Enlarging the crystal x10 to see it)



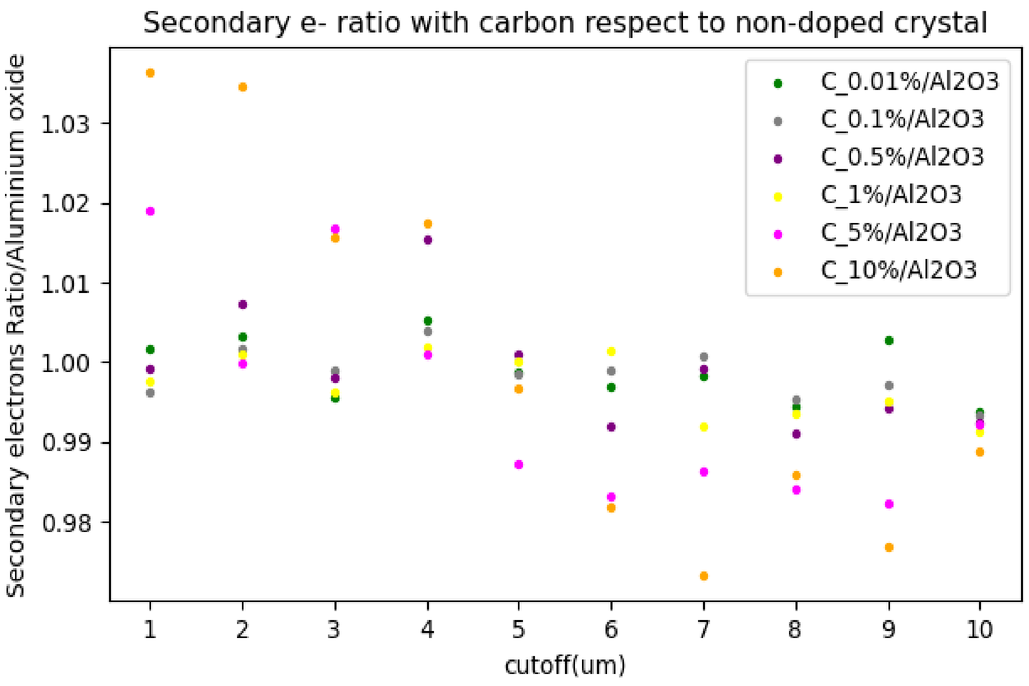



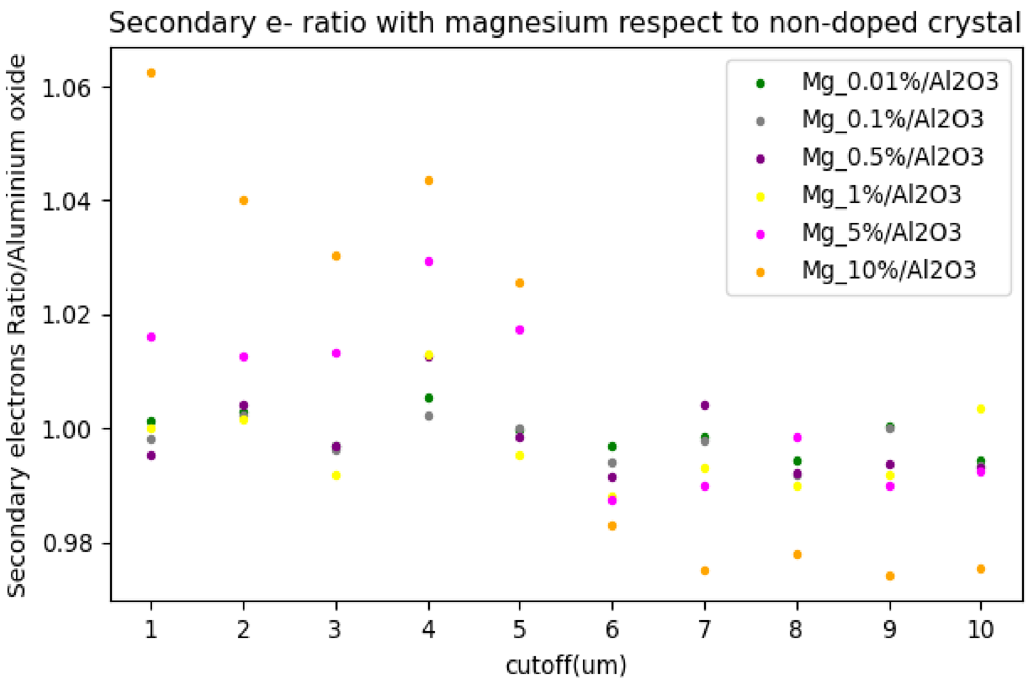

# The simulations procedure

| Simulations | Composition | Cutoff (μm) – Threshold range |
|---|---|---|
| 100000 histories AlO3:C/Mg with **8 compositions** and different densities. | **C or Mg** 0.01%, 0.1%, 0.5%, 1%, 5%, 10%, 100%<br>Various densities. | 1,2,3,4,5,6,7,8,9,10 |
| 100000 histories of **non-doped Al2O3** | 100% **Al2O3**.<br>Density: 3.95 g/cm³ | 1,2,3,4,5,6,7,8,9,10 |
| **Soft Tissue** | **H** 10.5%, **C** 25.6%, **N** 2.7%, **O** 60.2%, **Na** 0.1%, **P** 0.2%, **S** 0.3%, **Cl** 0.2%, **K** 0.2%<br>Density: 1.03 g/cm³ (ICRP) | 1,2,3,4,5,6,7,8,9,10 |

# Results and Data Analysis

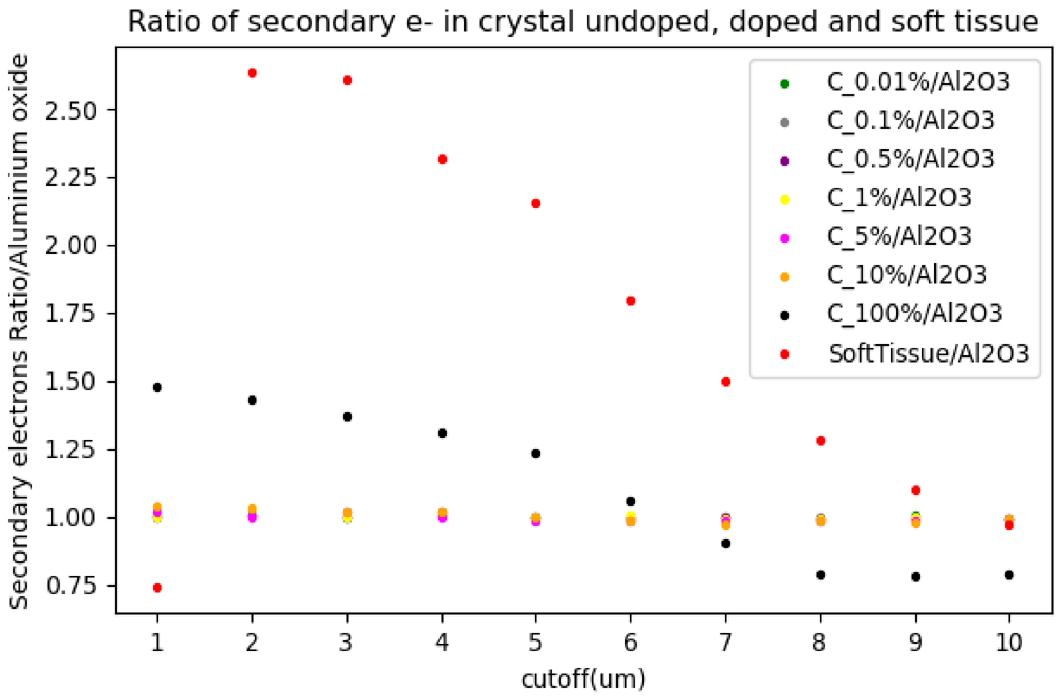
The large number of particles that are produced due to the interactions in the world and in the crystal are **secondary electrons.** Therefore, the secondary electrons that are produced **mainly by ionizations** and are shown in the **undoped crystal** and **carbon doped** crystal. To visualize better the effect of the magnesium and carbon dopants in the crystal, it's plotted **the ratio between the number of the secondary electrons with dopants and without dopant.**

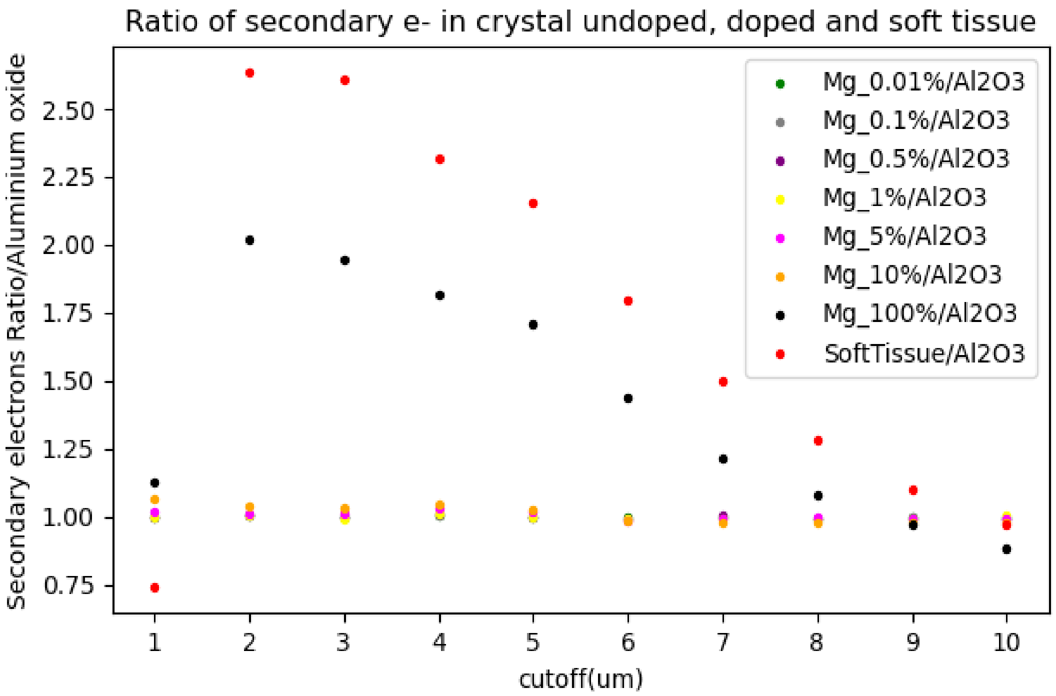


# Results and Data Analysis

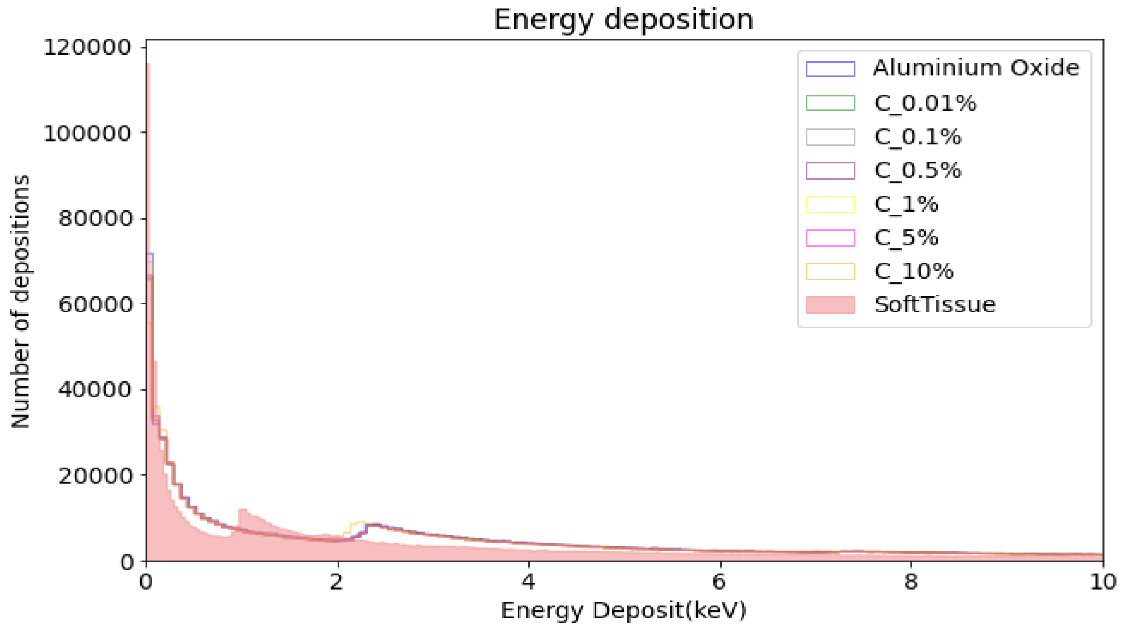
The addition of dopants **increases** the number of secondary electrons produced in the crystal, however, it's important to see if it behaves like the **soft tissue.** The extreme case in which 100% carbon and 100% magnesium is illustrated.

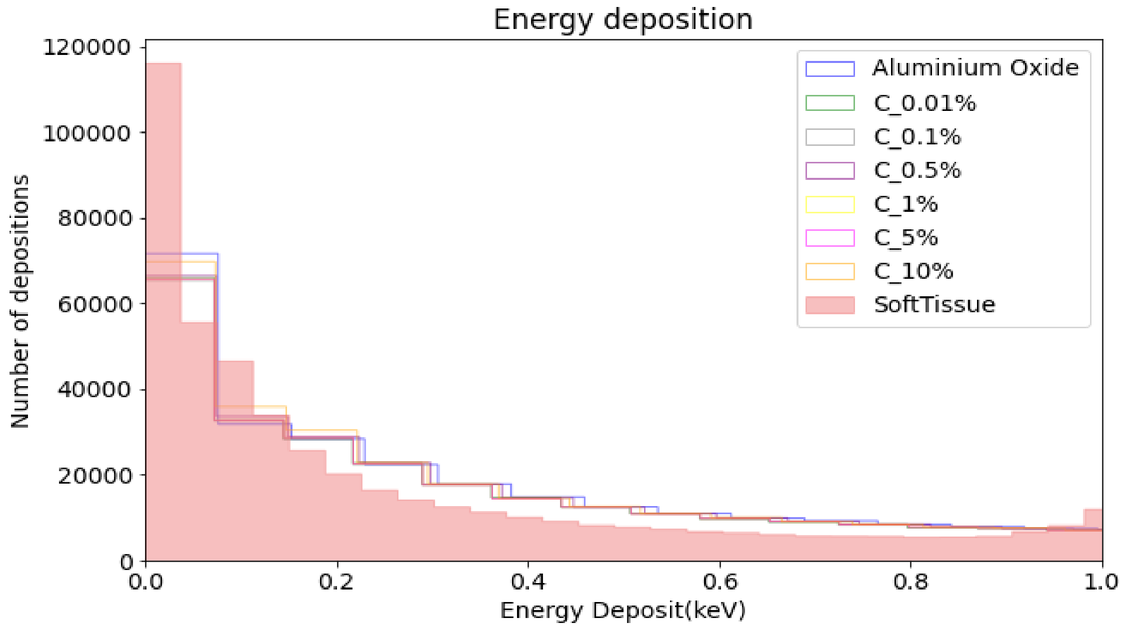


# Results and Data Analysis

- Other features that are important is to analyze the **energy that is deposited for a 150MeV proton beam source** in the crystal due to the proton beam and the further particles and nuclei produced. To see this, the energy deposit is seen for both crystals, it ranges from **0 up to values of 100keV** in few cases.



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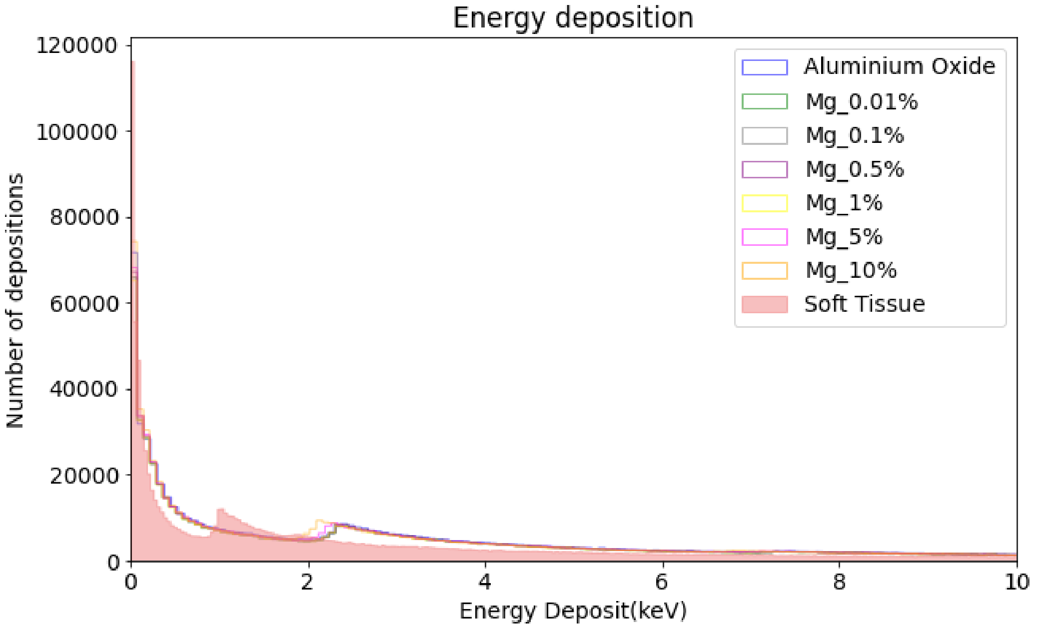


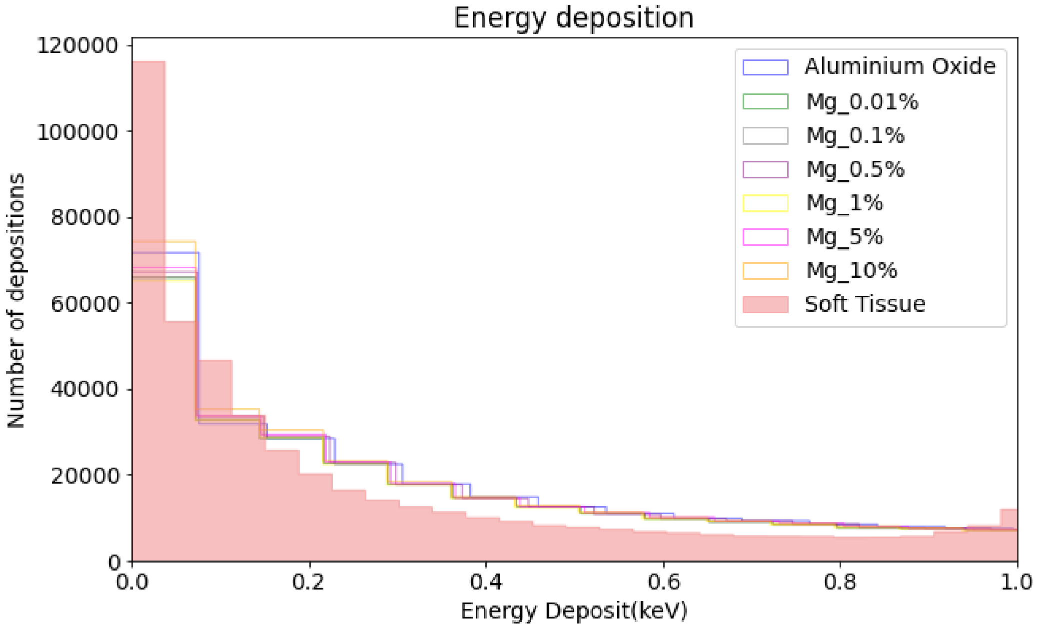

# Results and Data Analysis

For a further assessment of the **dose** that is in principle the main objective, it's required to know which particles are produced and what is the **energy they deposit per unit of distance** in the crystal, the Linear Energy Transfer **LET.**

Consequently, the number of **heavy ions, protons, photons, neutrons and electrons** are computed.

['Proton', 'Electron', 'Photon', 'Al26', 'O14', 'Positron', 'eNeut', 'N15', 'Neutron', 'C11', 'Alpha', 'Li7', 'Al25', 'Mg26', 'Mg25', 'Na23', 'O15', 'Mg24m', 'Al27', 'O18', 'O17', 'Na24', 'Na23m', 'eAntineut', 'Mg24', 'Mg23', 'Be7', 'B9', 'Be8', 'Ne20', 'N14m', 'Deuteron', 'O16', 'Na24m', 'Mg26m', 'C10', 'B10m', 'Be9', 'He3', 'Triton', 'F18', 'Na22', 'Ne22', 'Ne21']

| Radiation type and energy range | Radiation weighting factor, $w_R$ |
|---|---|
| Photons, all energies | 1 |
| Electrons and muons, all energies | 1 |
| Neutrons, energy <10 keV | 5 |
| Neutrons, energy 10–100 keV | 10 |
| Neutrons, energy >100 keV–2 MeV | 20 |
| Neutrons, energy >2–20 MeV | 10 |
| Neutrons, energy >20 MeV | 5 |
| Protons, other than recoil protons, energy >2 MeV | 5 |
| Alpha particles, fission fragments, heavy nuclei | 20 |

Source: ICRP, 2003. Relative Biological Effectiveness (RBE), Quality Factor (Q), and Radiation Weighting Factor (wR). ICRP Publication 92. Ann. ICRP 33 (4).

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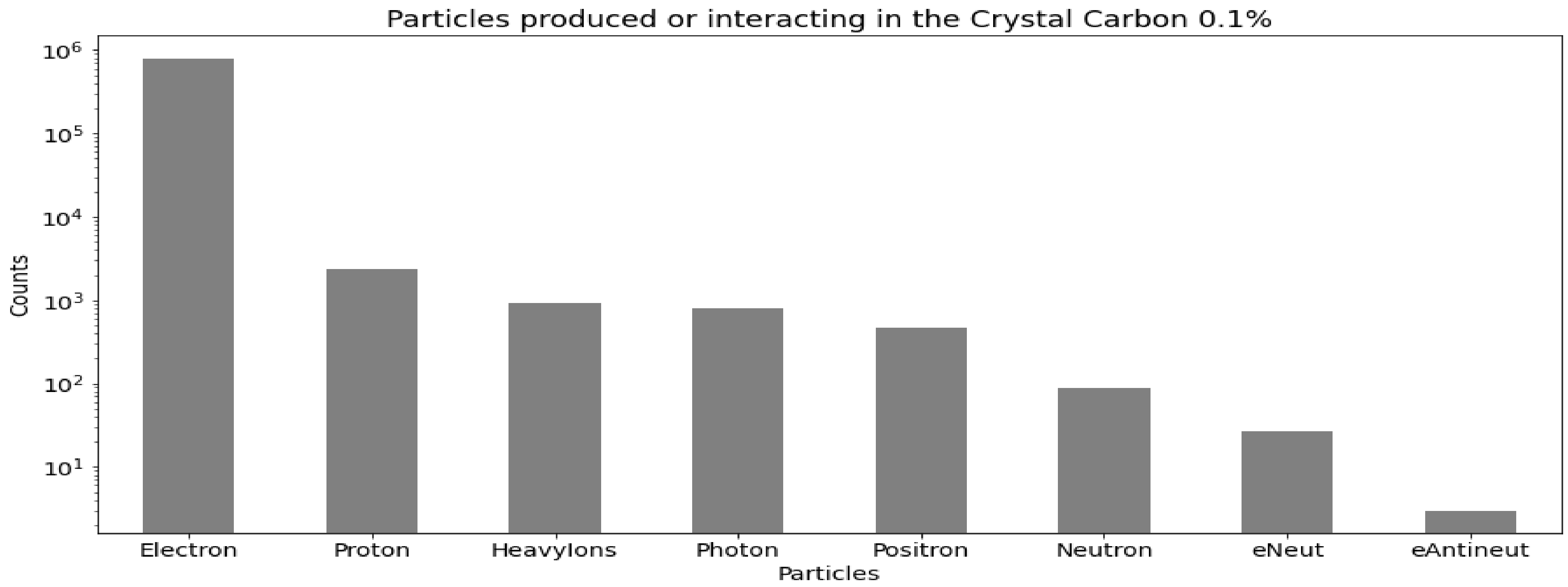

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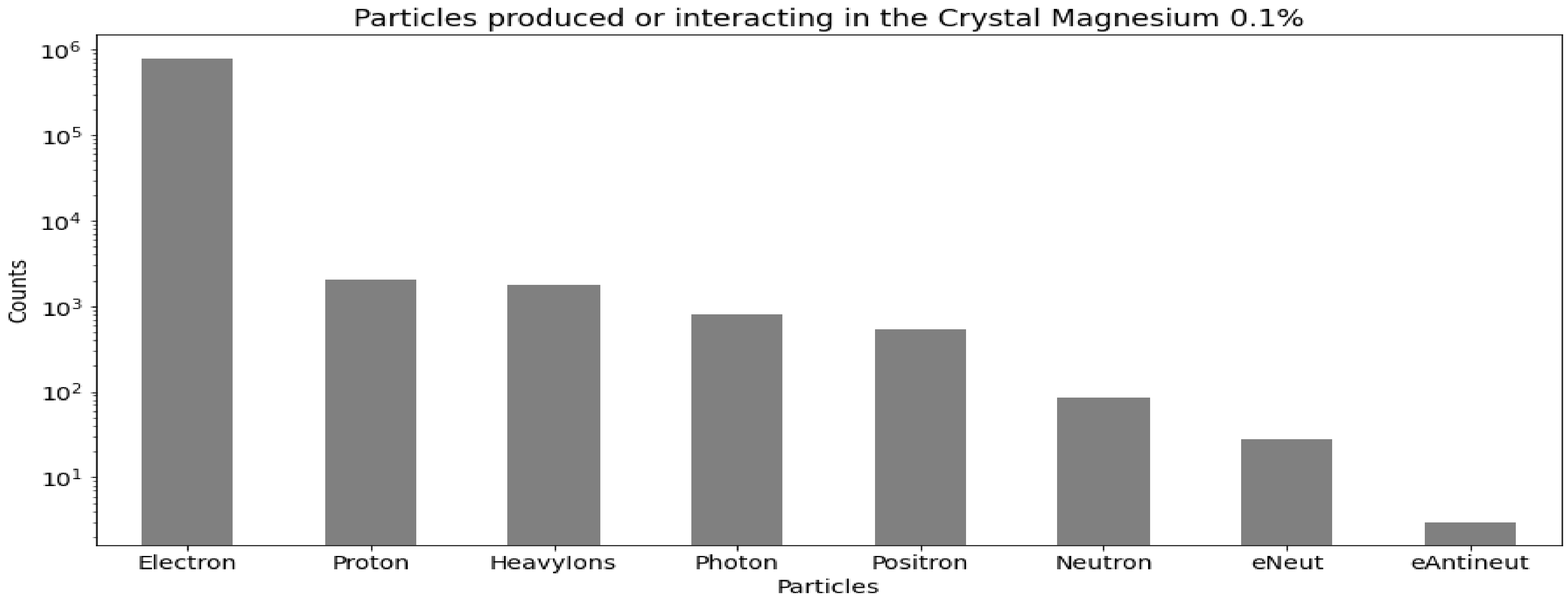
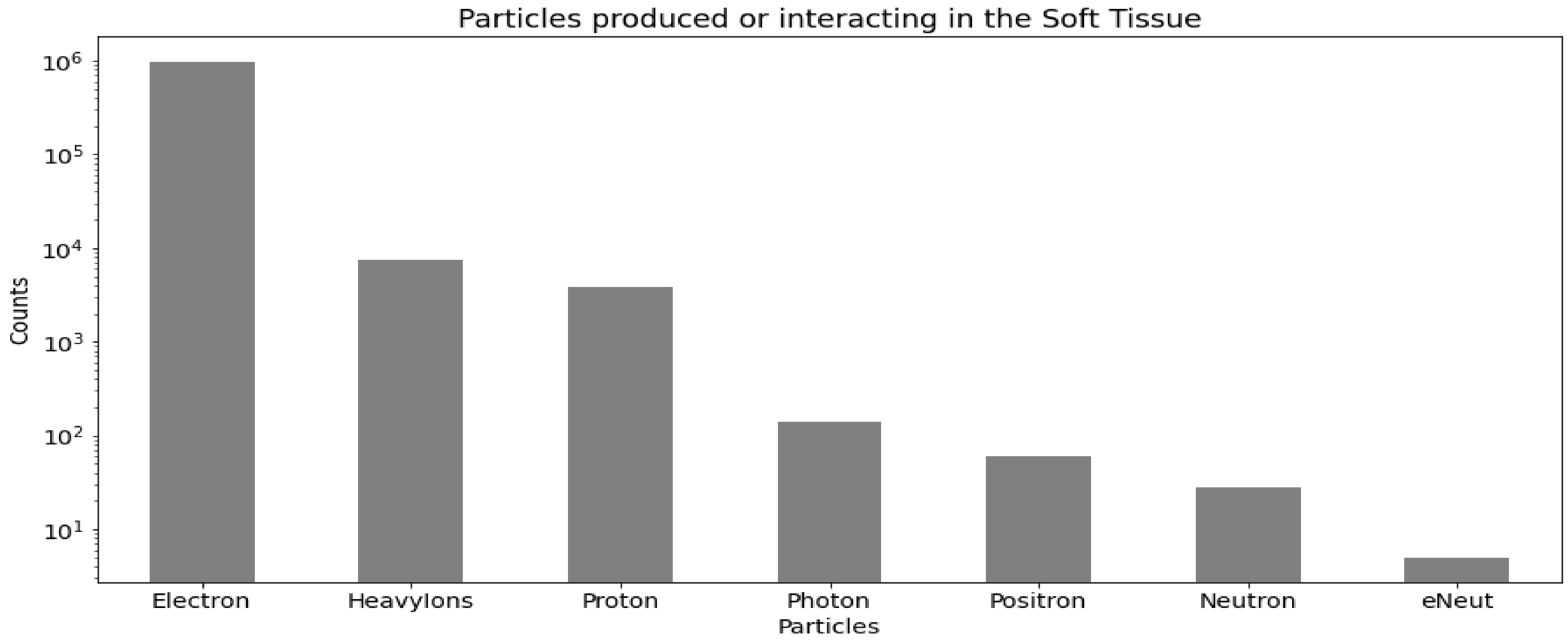


# Results and Data Analysis

For a further assessment of the **dose** that is in principle the main objective, it's required to know which particles are produced and what is the energy they deposit per unit of distance in the crystal, the **LET.**

Consequently, the number of **heavy ions, protons, photons, neutrons and electrons** are computed also for the **soft tissue.**



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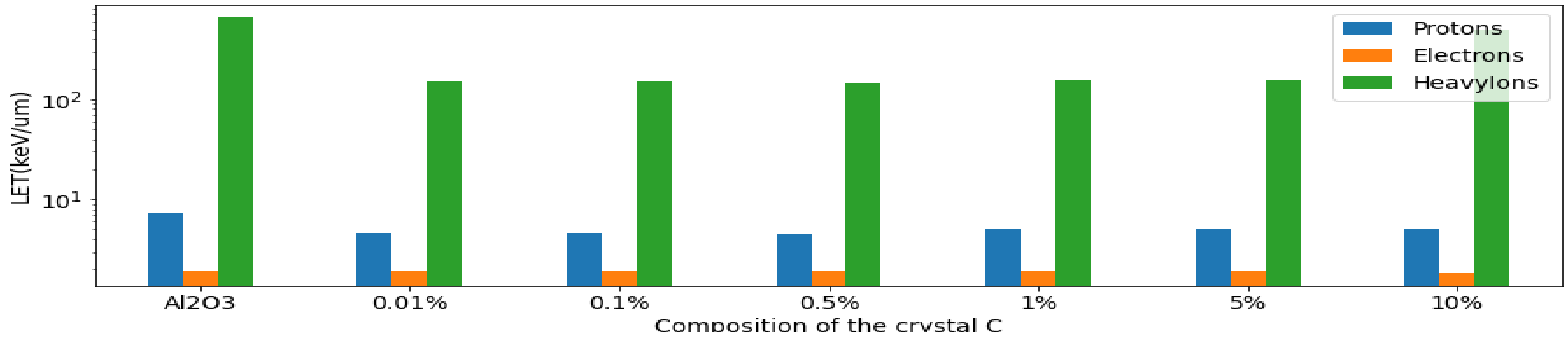


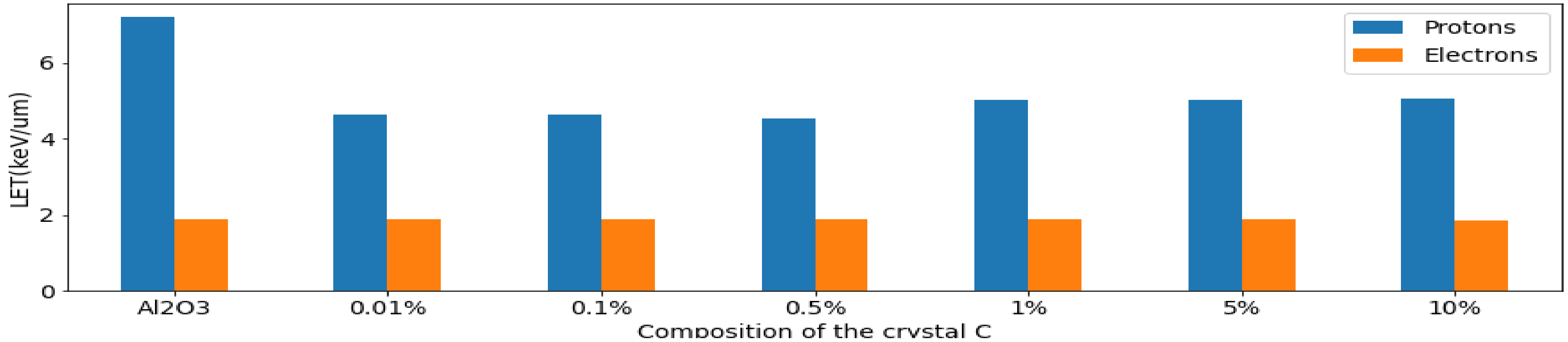

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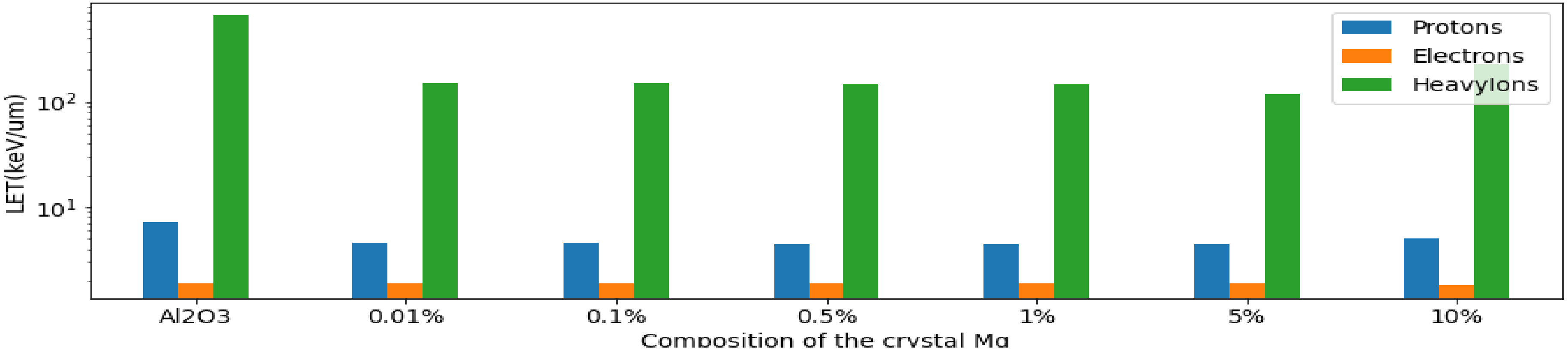


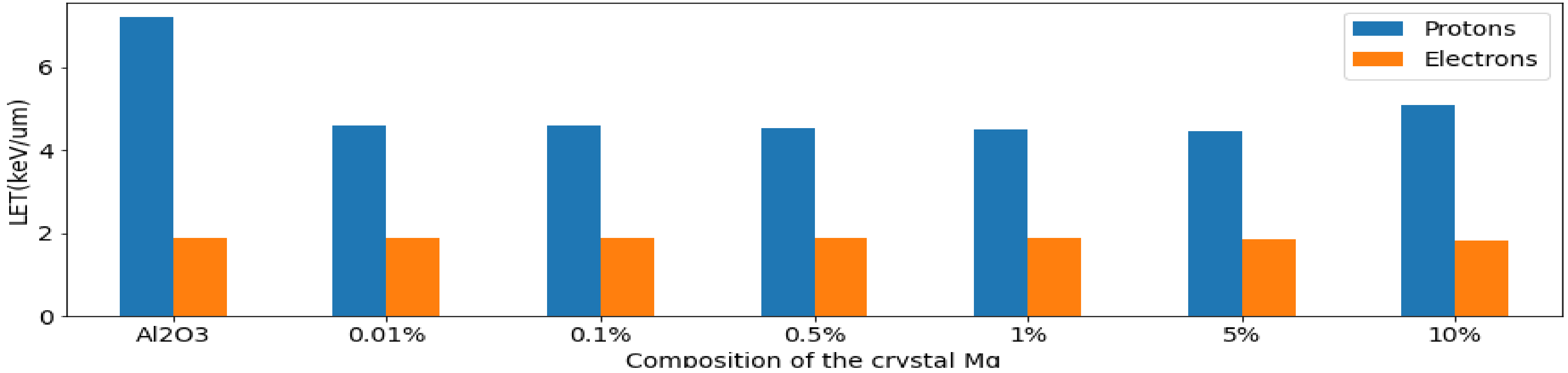

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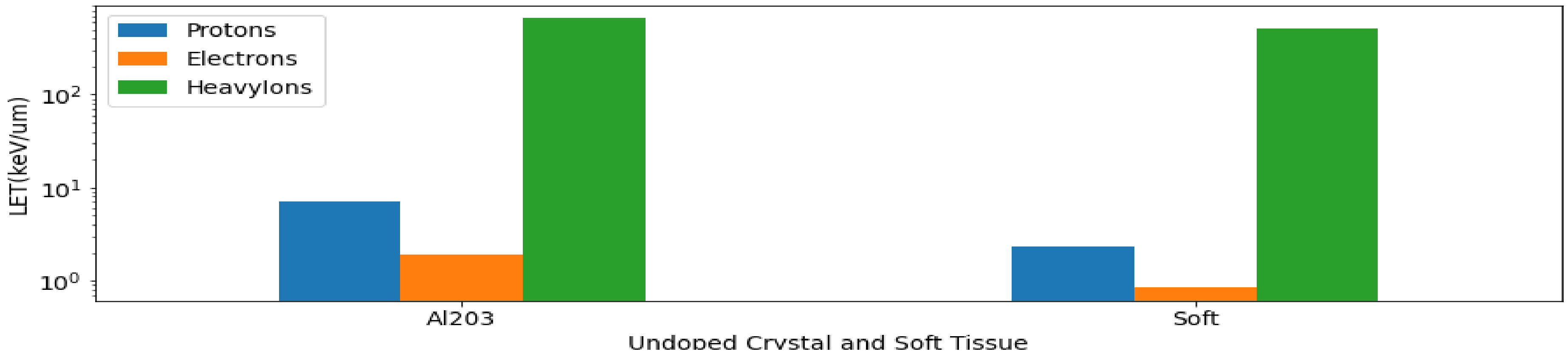


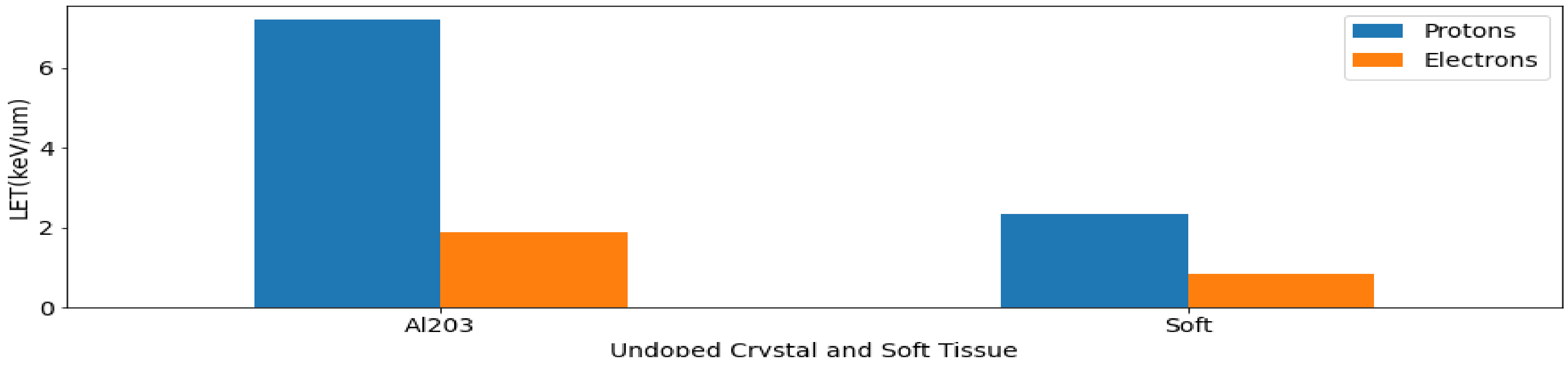

# Summary

- The addition of carbon and magnesium in the **crystal increases the number of secondary electrons** that inevitably increases the **output of the dosimeter** once it gets stimulated.
- The energy deposit is mainly done by secondary electrons inside of the crystal, a small contribution of heavy ions and protons is also seen.
- The **number of secondary electrons respect to heavy ions and other particles in the crystal is larger around two/three magnitudes** order.
- The value found for **the LET in the simulations is typical of the simulations in the field of the proton therapy**. See Suit, H., et al . (2010). Proton vs carbon ion beams in the definitive radiation treatment of cancer patients. *Radiotherapy And Oncology*, *95*(1), 3-22. doi: 10.1016/j.radonc.2010.01.015
- The further step is to **perform simulations with the mixture of magnesium and carbon doping.**

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# Thank you