PROCEEDINGS OF SCIENCE

Reducing the risk of proton therapy with prompt-gamma

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Radiotherapy, one of the techniques used to treat cancer, can be divided into conventional (gamma and electrons) and heavy charged particles radiotherapy. The latter, realized mainly with proton or carbon nuclei, has been highly anticipated due to its dose deposition profile characterized by a high deposition region at a particular depth - the Bragg Peak. Dose deposition profile affects the risk to the surrounding healthy tissues and the existence of a Bragg Peak allows to increase the dose in the target region, whilst minimizing the dose to surrounding healthy tissues, reducing the risk of the technique. The control and monitoring of the Bragg Peak location can further increase the precision of the treatment. One way to perform this monitoring is to measure the prompt-gamma detected perpendicular to the incident proton beam. For that purpose, a detector with a GSO scintillator crystal connected to a SiPM is being studied. A set of blades in front of the sensor will act as a collimator to ensure that only perpendicular photons to the sensor are detected. Currently SiPM coupled to GSO crystals time and amplitude response are being studied to design a DAQ for the full prototype with a number of sensors in the order of magnitude of 100.

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1. Introduction

Cancer nowadays can be treated with several different types of therapies. We have surgical therapy, chemotherapy, radiotherapy and immunotherapy.

In surgical therapy the tumour volume is surgically removed from the body.

Chemotherapy uses medication to kill tumour cells.

Radiotherapy uses ionizing radiation to kill malignant cells or cancer.

Another therapy recently added to this list is immunotherapy. This therapy uses the immune system of the human body to fight cancer.

1.1 Types of Radiotherapy

Radiotherapy can be divided in two main groups: Conventional Radiotherapy and Particle Radiotherapy[1]. Conventional Radiotherapy uses photons (X-rays and γ-rays) or electrons as the beam particle whereas Particle Radiotherapy typically uses protons or carbon nuclei.

Conventional Radiotherapy uses broad dose deposition profile coupled with multiple beam exposure and the pile-up at the target region increases the ratio of dose exposure in cancer cells. However, healthy cells are also exposed to a significant amount of dose.

In Particle Radiotherapy, thin beams are used and the depth deposition profile is explored. The dose profile peaks at the Bragg Peak with low dose deposition before the Bragg Peak and minimal dose deposition after the Bragg Peak. This feature spares the surrounding healthy cells from exposure to higher amount of dose as it happens in conventional radiotherapy, as we can see in Figure 1.

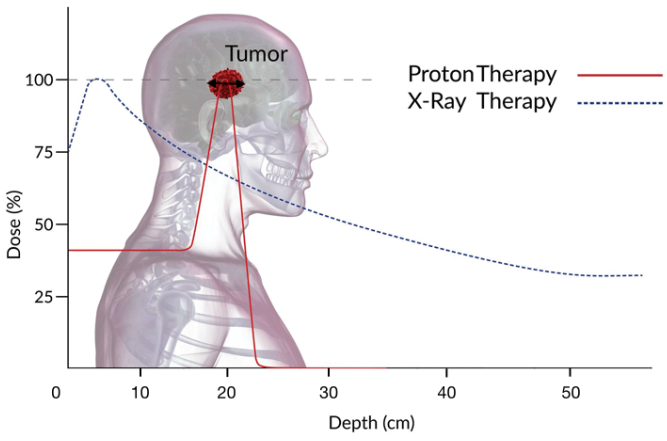


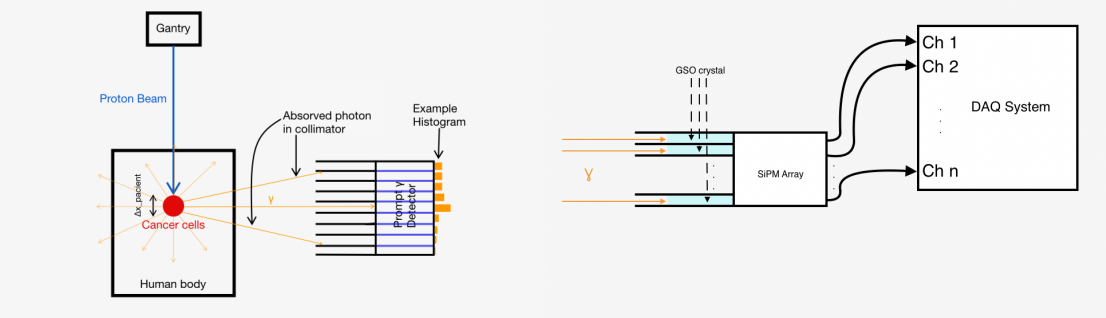
Figure 1: Proton therapy versus conventional radiotherapy radiation dose as a function of tissue depth.

[1]Also referred as Heavy Charged Particle Radiotherapy or Hadron Radiotherapy.

2. Work Description

This project requires an exact monitoring of the dose profile. This monitoring is done by accurately measuring the Bragg Peak position, since its position affects the location of the delivered dose. Simulations show the possibility to achieve resolutions in the order of the millimeter [1]. The aim is to monitor the Bragg Peak position in vivo conditions and provide better and live adjustments in the treatment plan in response to the feedback from its position.

This monitoring is done by analysing the prompt-gamma originated from the interaction between a proton from the beam and the nucleus of the cells, more precisely between the interaction between a proton and DNA which leads to its break. The placement of the detector that maximizes the detection efficiency of the prompt-gamma is such that the detector is orthogonal to the proton beam path, as shown in Figure 2a. A collimator singles out photons perpendicular to the detector and by construction, perpendicular to the primary beam. The pixelization and collimators allow the detector to have spatial resolution of the beam direction. Each pixel is composed by a crystal coupled to a light sensor and the collimator is a series of high density material blades isolating each crystal, as shown in Figure 2b.



(a) **(b)**

Figure 2: Figure 2a is a schematic of proton therapy - proton beam and γ ejection and a possible histogram example observed in the detector. Figure 2b is a schematic of the GSO crystal, SiPM and DAQ system.

The instrumentation solution to be used has to be capable of handling a large quantity of sensors and it is expected to have a large volume of scintillators and a number of sensors in the order of magnitude of 100. The baseline scintillator is BGO or GSO crystals. The light sensor selected for this setup is SiPM and techniques to reduce noise and enhance dynamic range are being pursued.

3. Work Development

A temporary instrumentation setup solution was developed based around an oscilloscope (R&S RTH1004, for more information see [2]) to study the requirements of the system and possible simplifications to be done, see Figure 3.

A data acquisition setup was developed for this temporary solution which transfers the data shown in the oscilloscope to a computer by using a script developed in Python. Further analysis begins by using data processing in ROOT or Python to verify the data shown in the oscilloscope and acquired in the previous step. This dataset may allow the distinction between the activation

of a microcell from the SiPM and the electronic noise coming from the circuit board, since the contribution from each cell in a SiPM is in the same range as the electronic noise.

The experimental data used in this part was acquired by having the circuit board of the SiPM in a dark box to reduce the surrounding environmental light.

Studies, so far, where mostly done with dark counts.

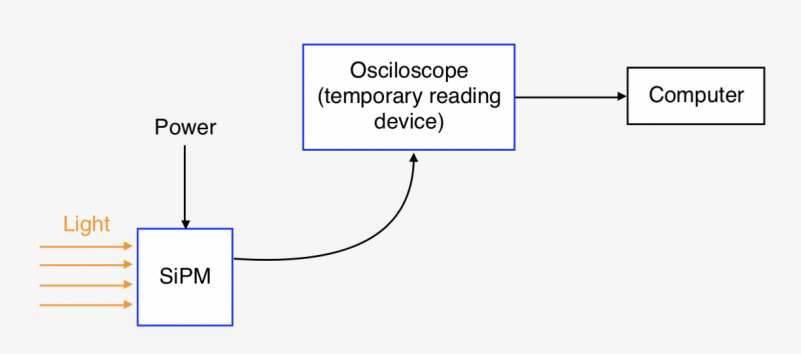


Figure 3: Schematic of preliminary system composed by the SiPM, oscilloscope and computer.

4. Conclusion and Future Endeavours

This project is still in its early stages but nonetheless the first experimental setup was developed and tested for verifying the contribution of each micro-cell from the SiPM sensor array.

After the successful identification of the contribution of a single micro-cell activation of the SiPM to the final output value obtained in the instrumentation setup, the next step is to couple the scintillator crystal to the SiPM. After enclosing the system SiPM-scintillator crystal in a dark box, we will expose the system to a radioactive source and study its behaviour.

Afterwards a comparison between this system and a simple prototype system with the possibility for scalability for large number of channels will be compared. This prototype system will likely be based in the ROC ASIC chips from the OMEGA group with which LIP institute has great experience.

References

[1] Paulo Crespo, Patricia Cambraia Lopes, Hugo Simões, Rui Ferreira Marques, Katia Parodic and Dennis R Schaart, *Simulation of proton range monitoring in an anthropomorphic phantom T using multi-slat collimators and time-of-flight detection of prompt-gamma quanta* Physica Medica, volume 54 - pages 1-14, October 2018

[2] *User Manual for the R&S rth1004 oscilloscope* R&S RTH1004 user manual