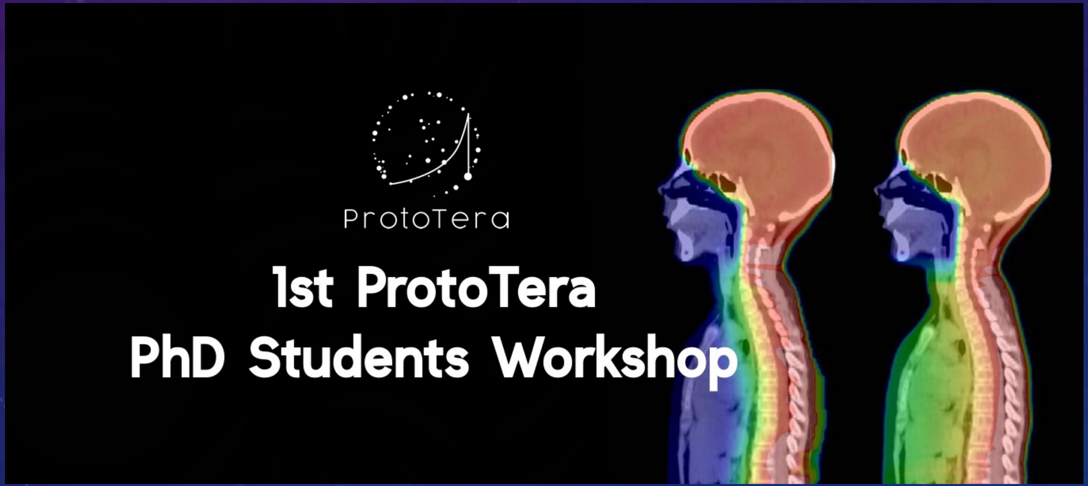
PROMPT-GAMMA DETECTION AND INSTRUMENTATION FOR BRAGG PEAK MONITORING



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LABORATÓRIO DE INSTRUMENTAÇÃO E FÍSICA EXPERIMENTAL DE PARTÍCULAS
partículas e tecnologia

IDPASC

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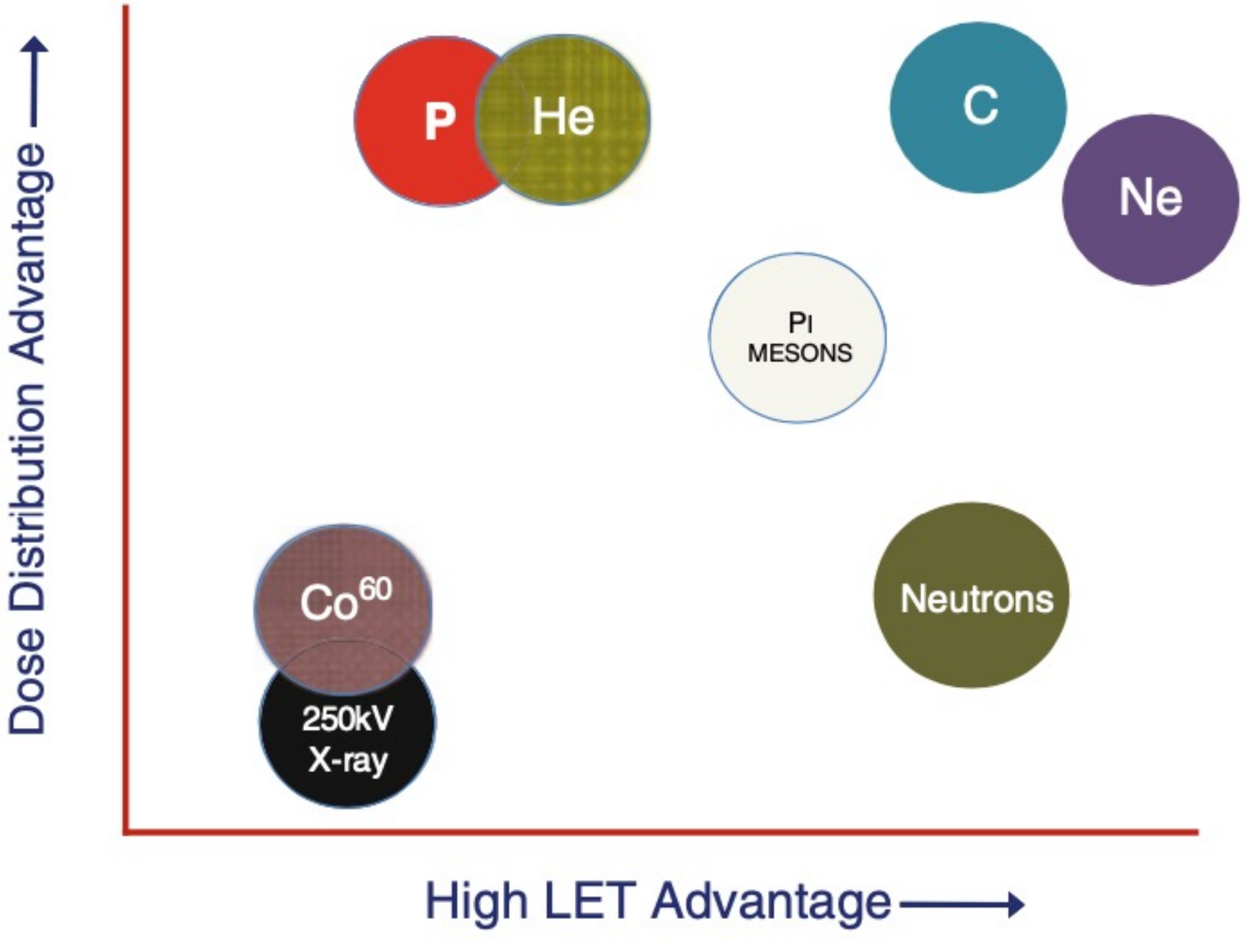
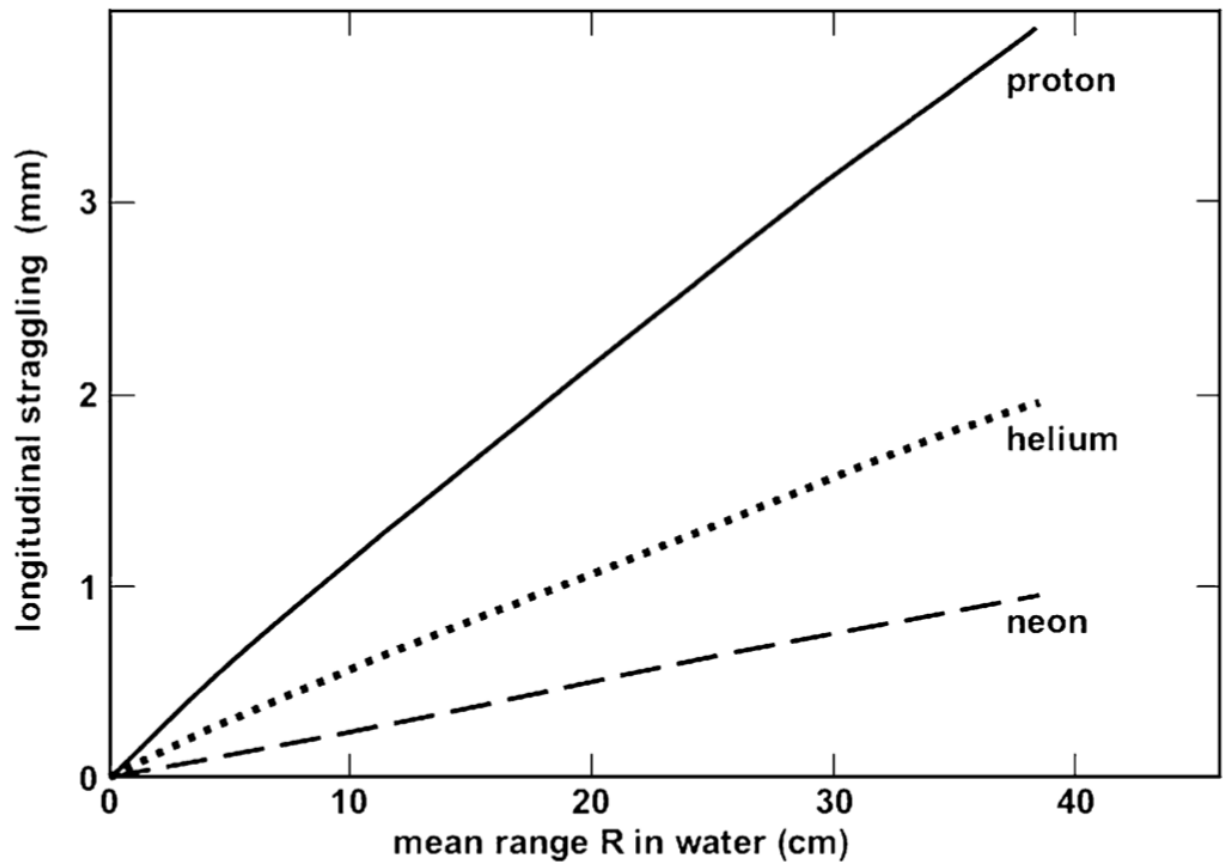
Particle Radiotherapy
or Ion Beam Therapy

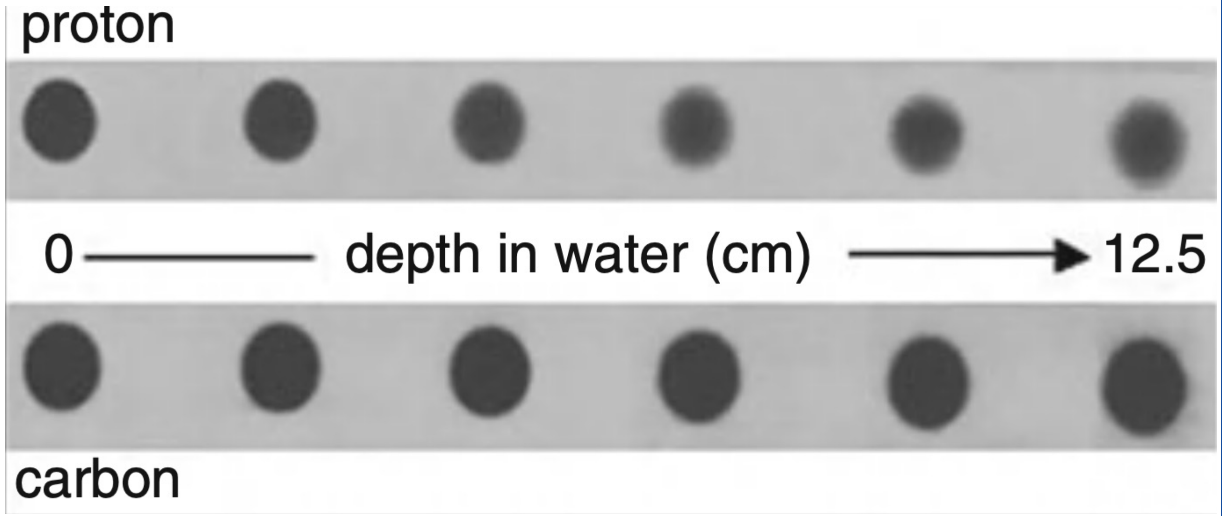
- Since the beginning of Clinical Radiotherapy, it has been the goal of radiation oncologists to restrict the deposited dose to the target volume;
- From all alternatives of Radiotherapy, ion beams are the closest to accomplish the objective;
- Protons and other accelerated ions can irradiate a tumour at any depth of the body with minimum dose given to the surrounding healthy tissues;
- Adjustments to penetration depth of ions to precisely “coincide” with the location of the tumour.



Proton, He and Carbon nuclei in Particle Radiotherapy

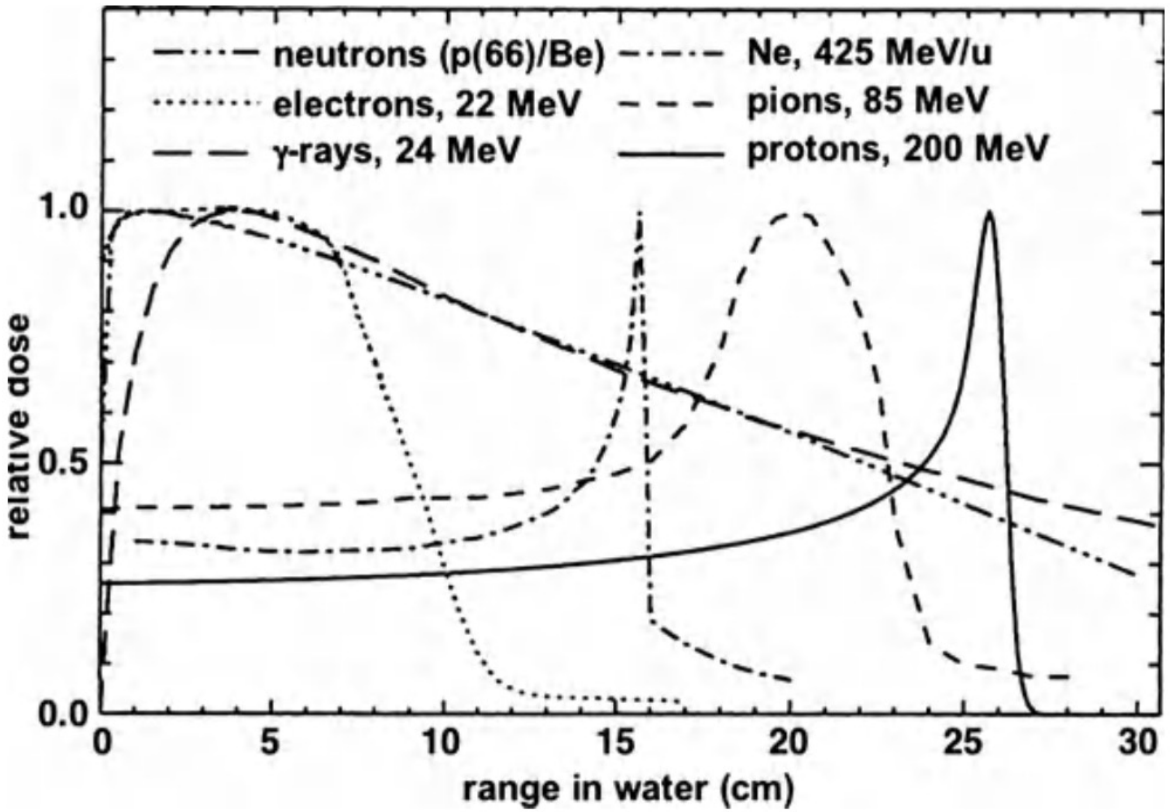
- Protons and heavier ions have a better depth-dose distribution when compared to photons;
- Ion beam therapy particles suffer straggling;
- Lateral spreading due to electron collision occurrence;
- Ions heavier than Helium will have higher stopping power which creates higher biological damages.



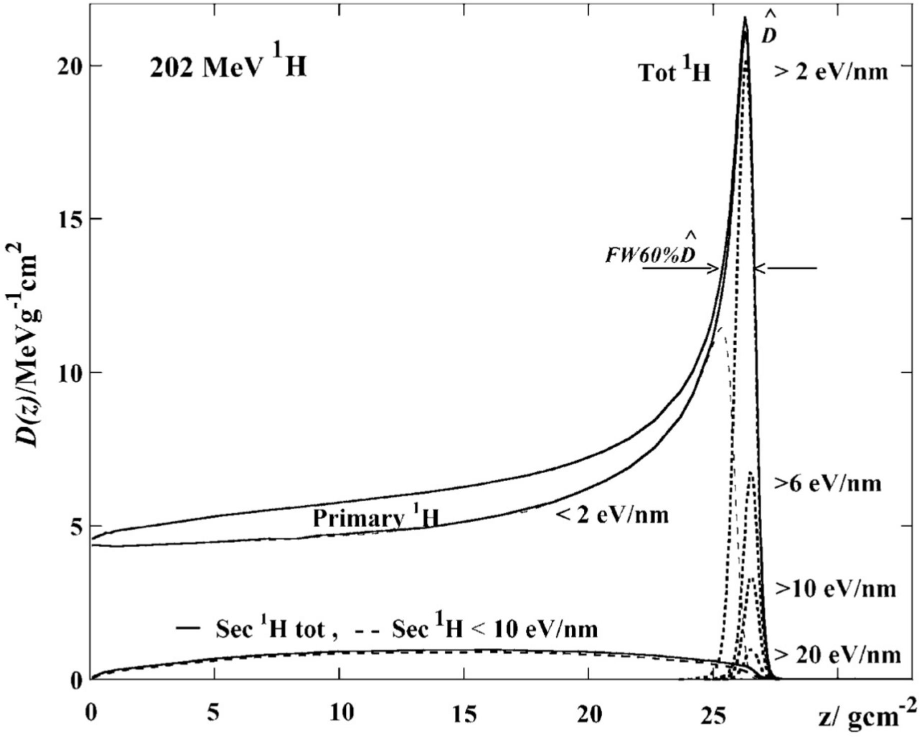


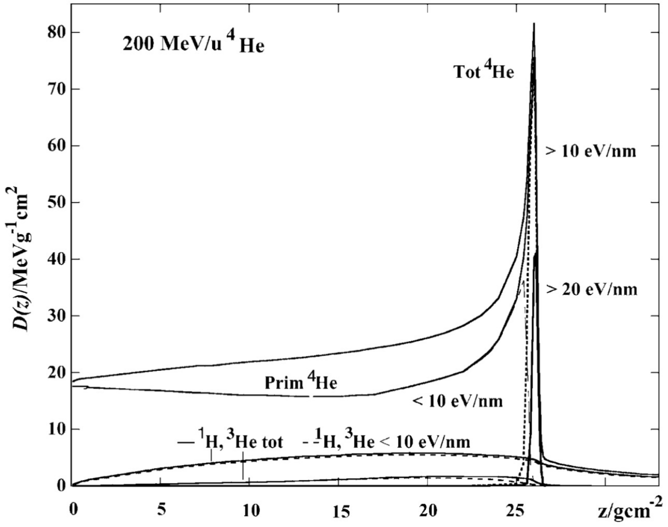
Proton vs carbon and He nuclei

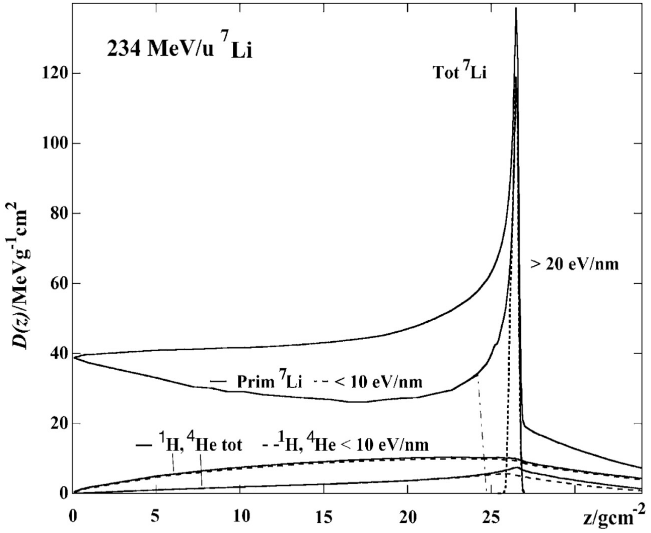
- Advantages of Carbon and He are offset by Fragmentation;
- Nuclear interactions cause a tailing after the Bragg Peak;
- Study made by Kempe confirmed dose distribution dependency on the number of nucleons N(1/√N);
- As such, clinical revival of ions with Z > 6 is unlikely;
- He, Li and Be are interesting alternatives to carbon ions;
- Proton is the most affordable of possible ions for Ion Beam Therapy.

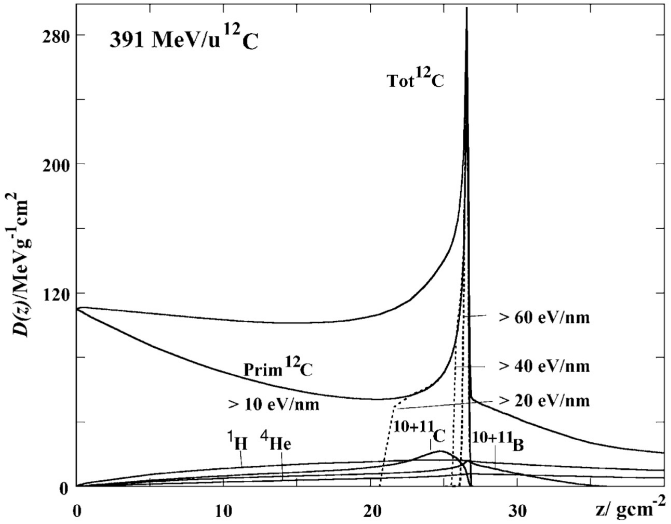


Kempe – depth absorbed dose distributional for Protons, Helium, Lithium and Carbon

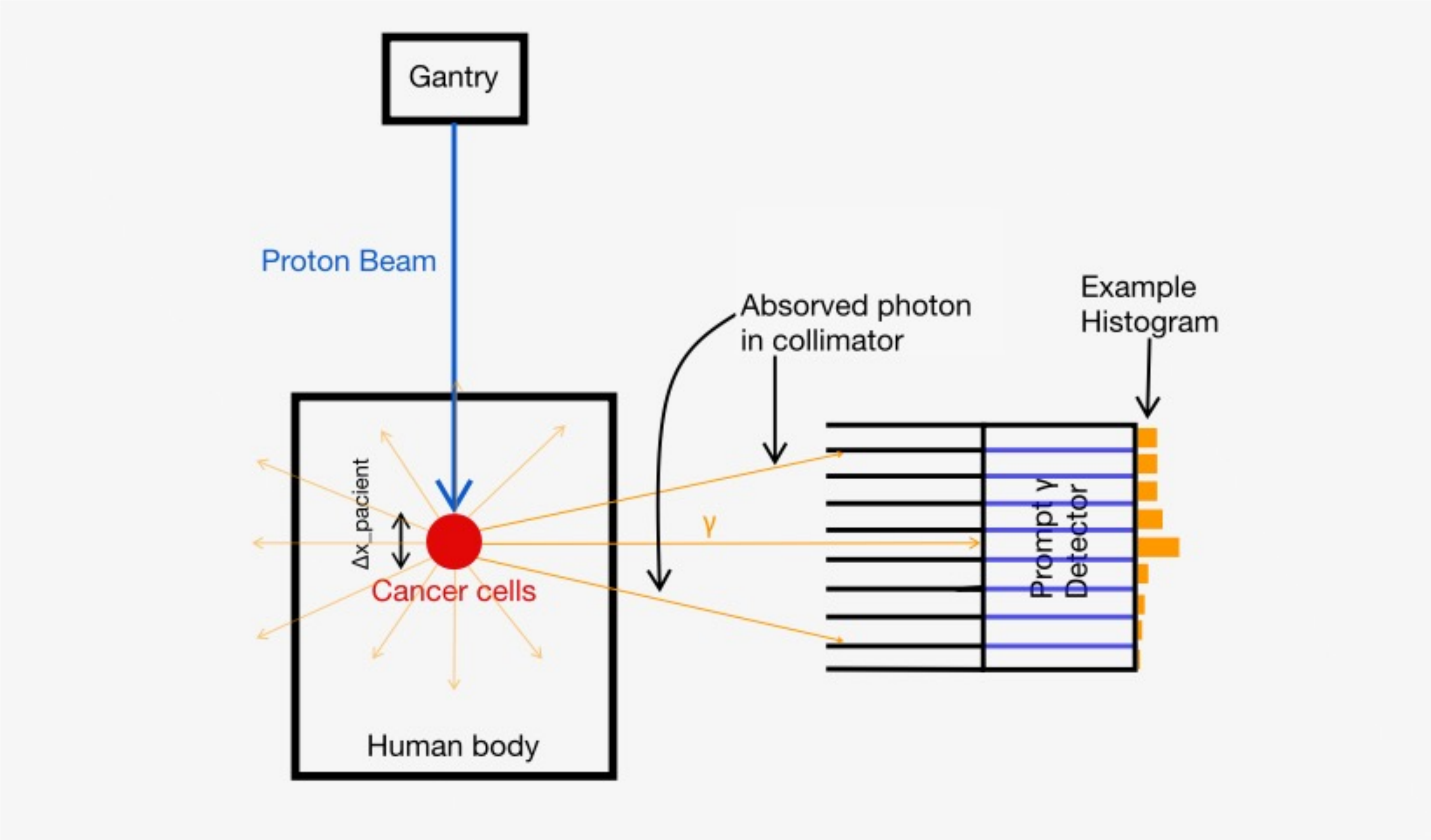








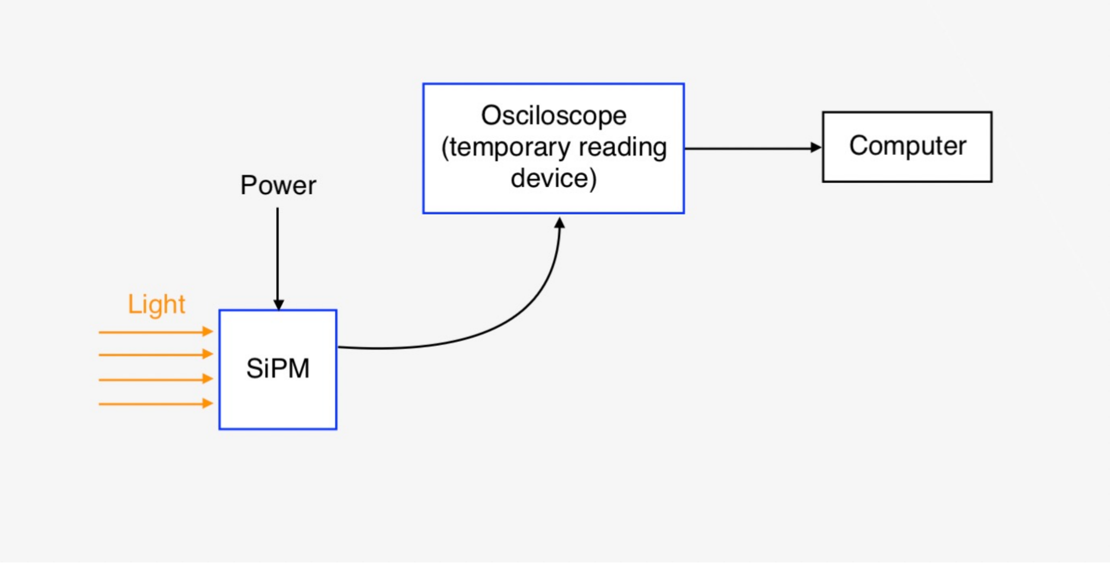
Instrumentation

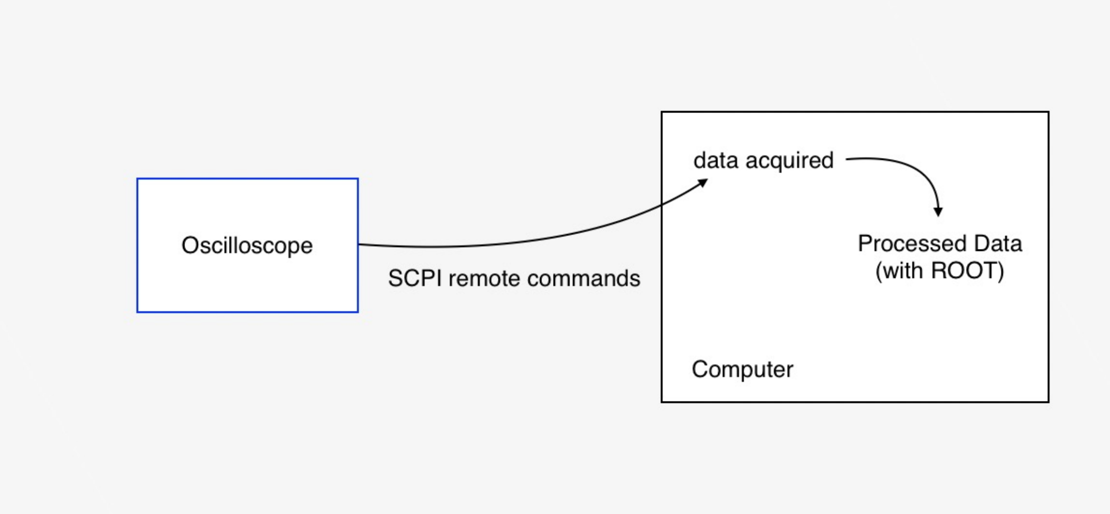


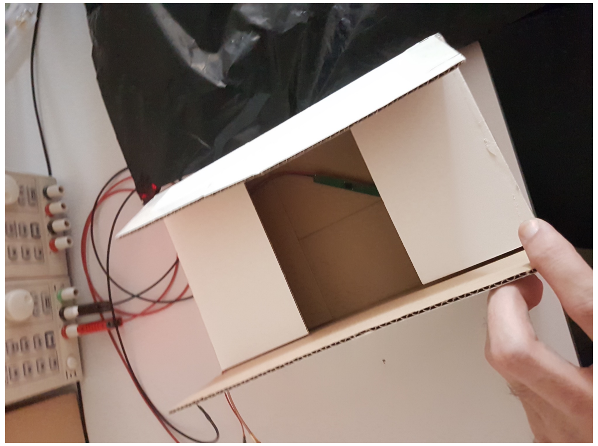
Experimental Setup
System Requirements

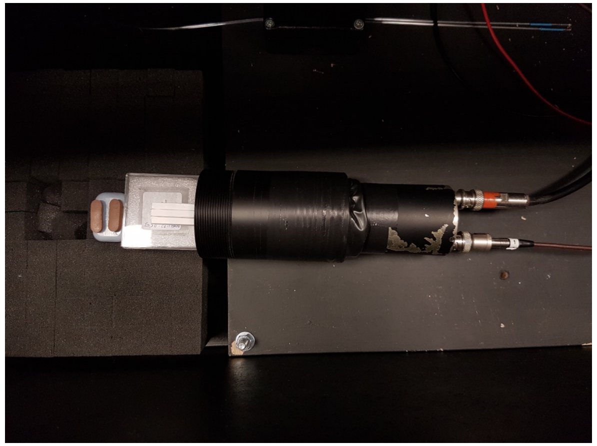
Work Developed

- First setup based in an oscilloscope;
- Experimental setup using a SiPM with 6x6 mm area;
- Baseline setup with a PMT in a dark box.



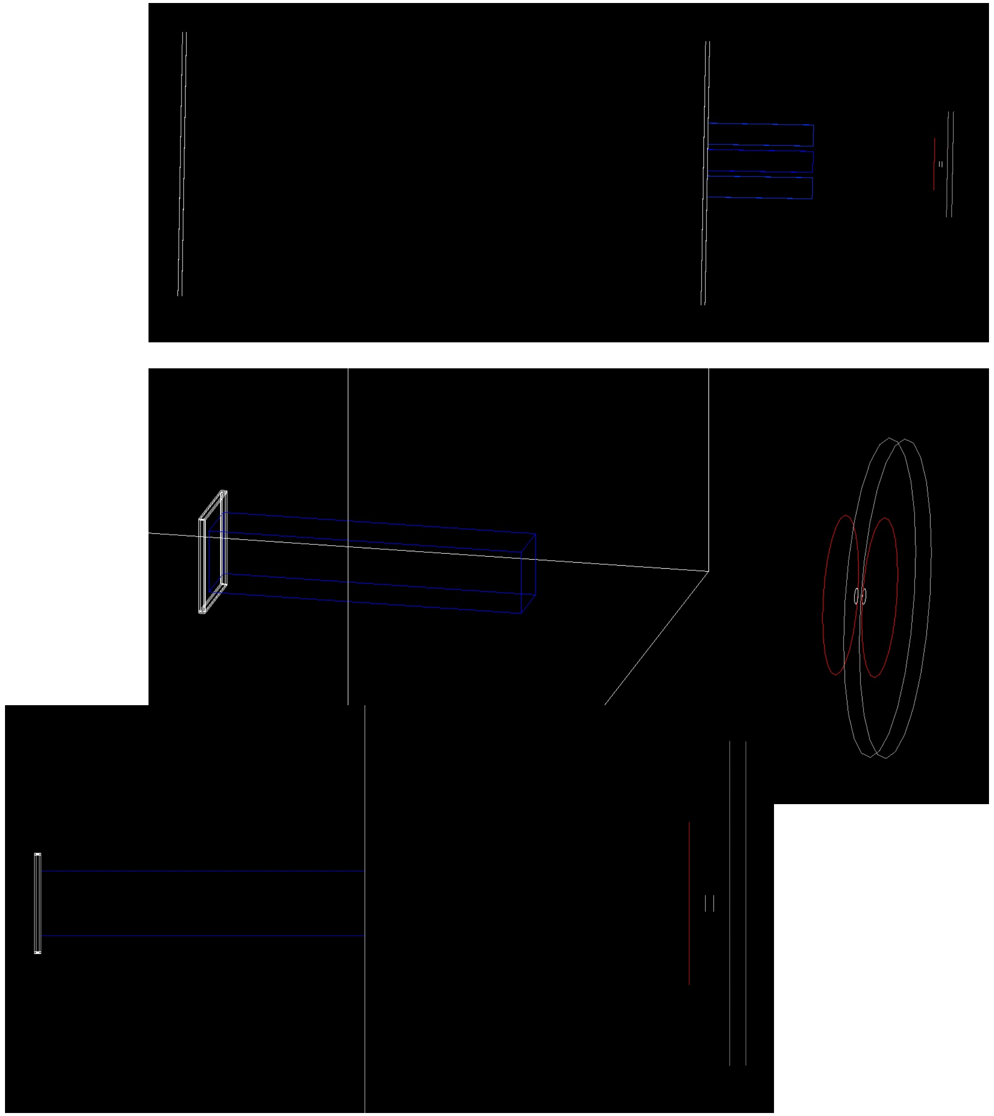






Simulations using Geant4

- Simulation toolkit for particles interaction with matter in its path;
- Some areas of application include:
  1. Medical and Space science;
  2. High Energy;
  3. Nuclear and accelerator physics.
- Simulation script was configured for Multithreading usage;
- Simulations to verify and validate the experimental data acquired.



Conclusions and Future Endeavours

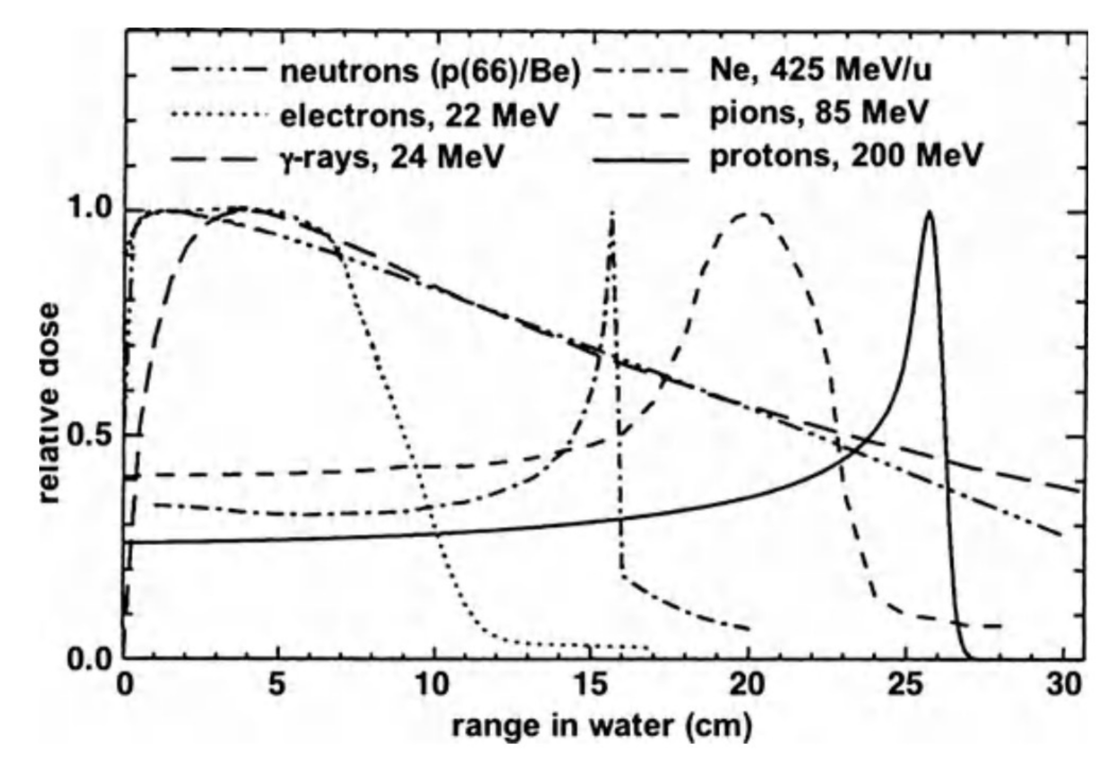
- Update the requirements for the prototype to develop;
- Verify response of a system setup and best suitable type of acquisition setup in Geant4 simulations;
- Comparing the behaviour and performance of the system to a simpler system scalable to a large number of channels when exposed to radioactive sources;
- Simpler system probably based in the ROC ASIC chips from the OMEGA group with which LIP has experience.

THANK YOU FOR YOUR TIME AND I HOPE YOU ENJOYED!

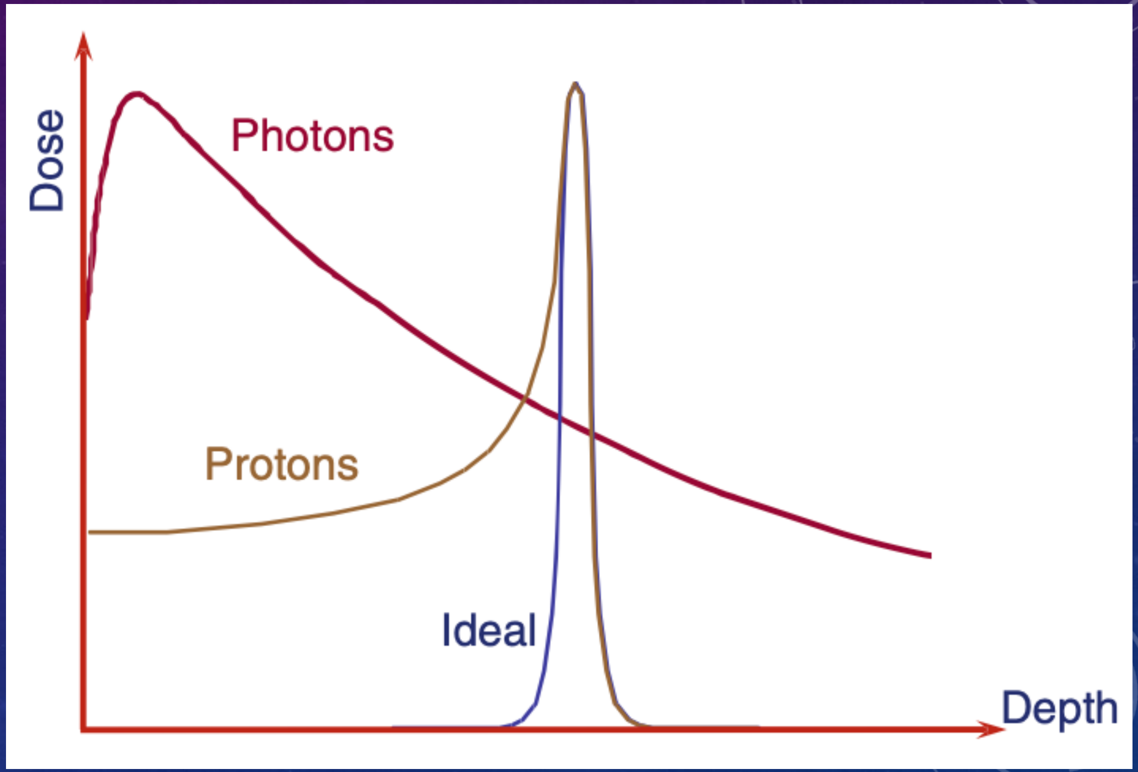
And I am also open for your questions now!

BEAM RANGE MEASUREMENT

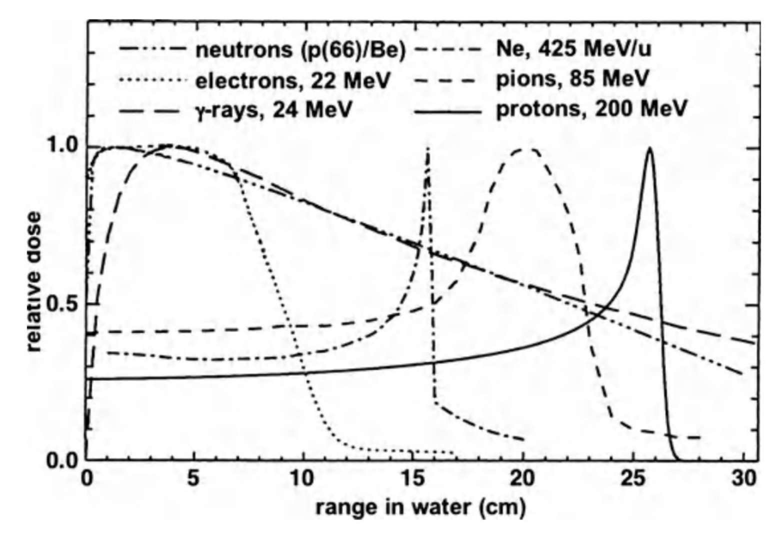
- Different factors influence the range of the beam;
- This project involves the measurement of the Bragg Peak position in vivo conditions;
- Prompt-gamma monitoring;
- Simulations show the possibility to achieve resolutions in the order of the millimetre.



BRAGG PEAK



- A monoenergetic beam of protons will have a peak in the dose deposited spectrum;
- Ion particles used for the Bragg Peak
- Spread-Out Bragg Peak is used to irradiate the tumour volume;



KEMPE - DOSE DISTRIBUTIONAL EFFECTS OF IONS OF THE FIRST 10 ELEMENTS OF THE PERIODIC TABLE

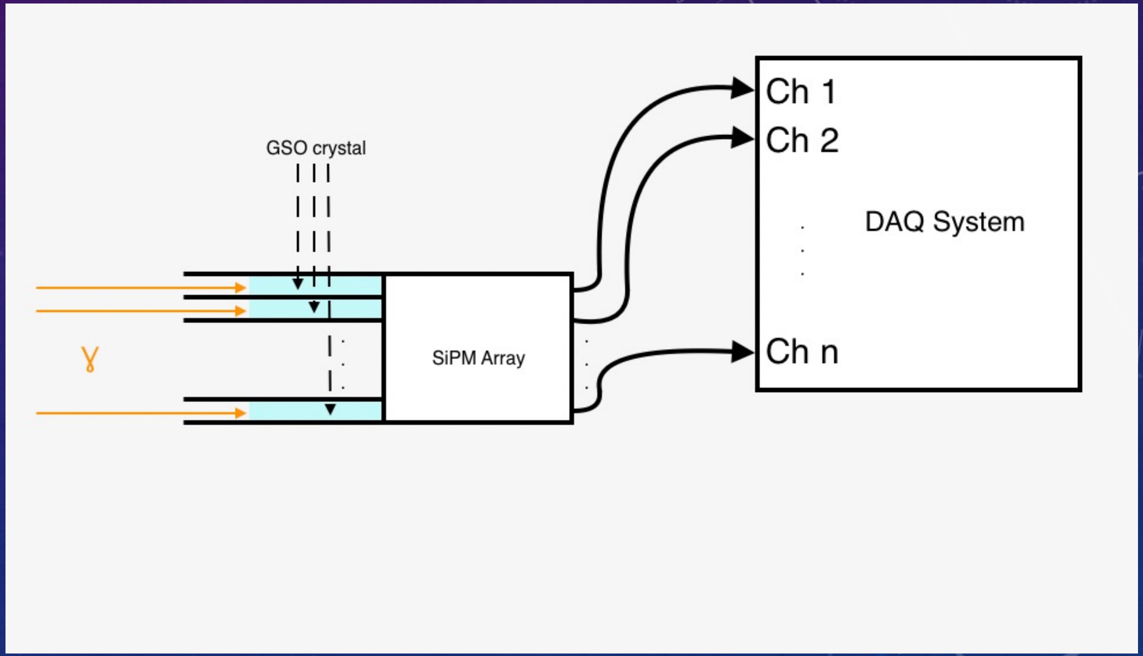
Ion	A	B	C	Total relative cost
Proton	1	1	1	1
Helium	1	1.5	1.4	1.3
Carbon	1	1.9	4.1	2.3
Oxygen	1	2.1	5.8	3.0
Neon	1	2.2	7.6	3.6

Assumptions: normal-conducting synchrotron, fourfold symmetric lattice, vault: 4 m high, 2 m clearance around the edges; 1 transport line: 10 m; 1 treatment room with conventional 45°–45°–90° gantry, 3 m distance to isocenter, ion range: 30 cm; shielding: 1.5 m concrete for protons. Cost components: (A) Fixed costs, (B) Technical components $\sim f$ (magnetic rigidity), (C) Shielding $\sim f$ (beam energy)

INSTRUMENTATION - DETECTION

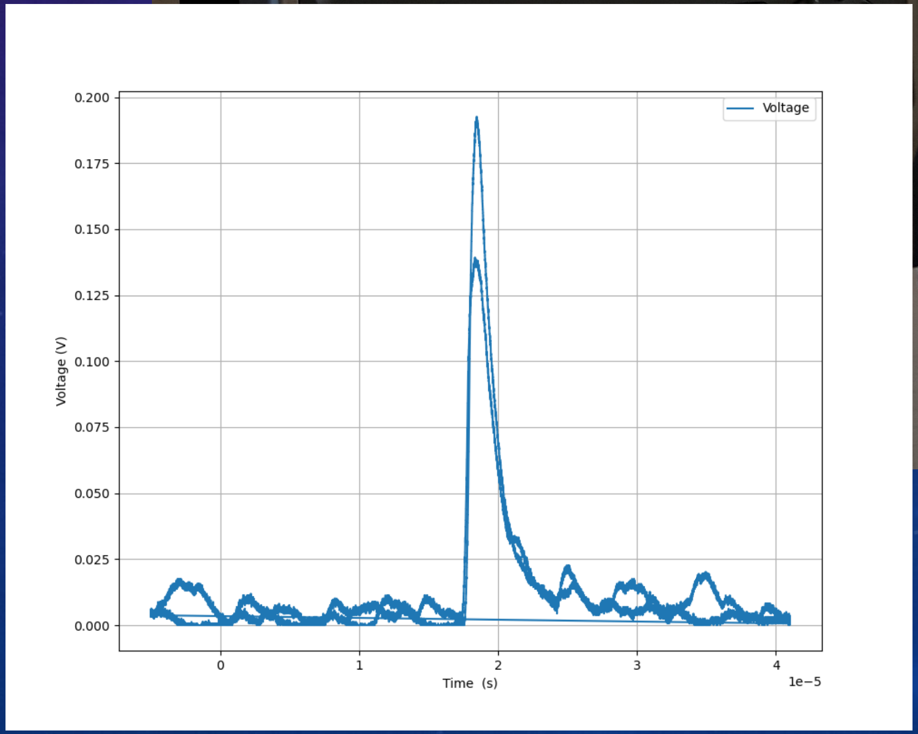
Collimators and pixelization allow spatial resolution in the beam direction:

1. Each pixel is composed by a light sensor coupled with a scintillator crystal;
   - I. The candidate for light output is SiPM;
   - II. The Baseline scintillator will be either BGO or GSO.
2. A collimator is a series of high density material blades isolating each scintillator crystal and only near perpendicular gammas are detected.



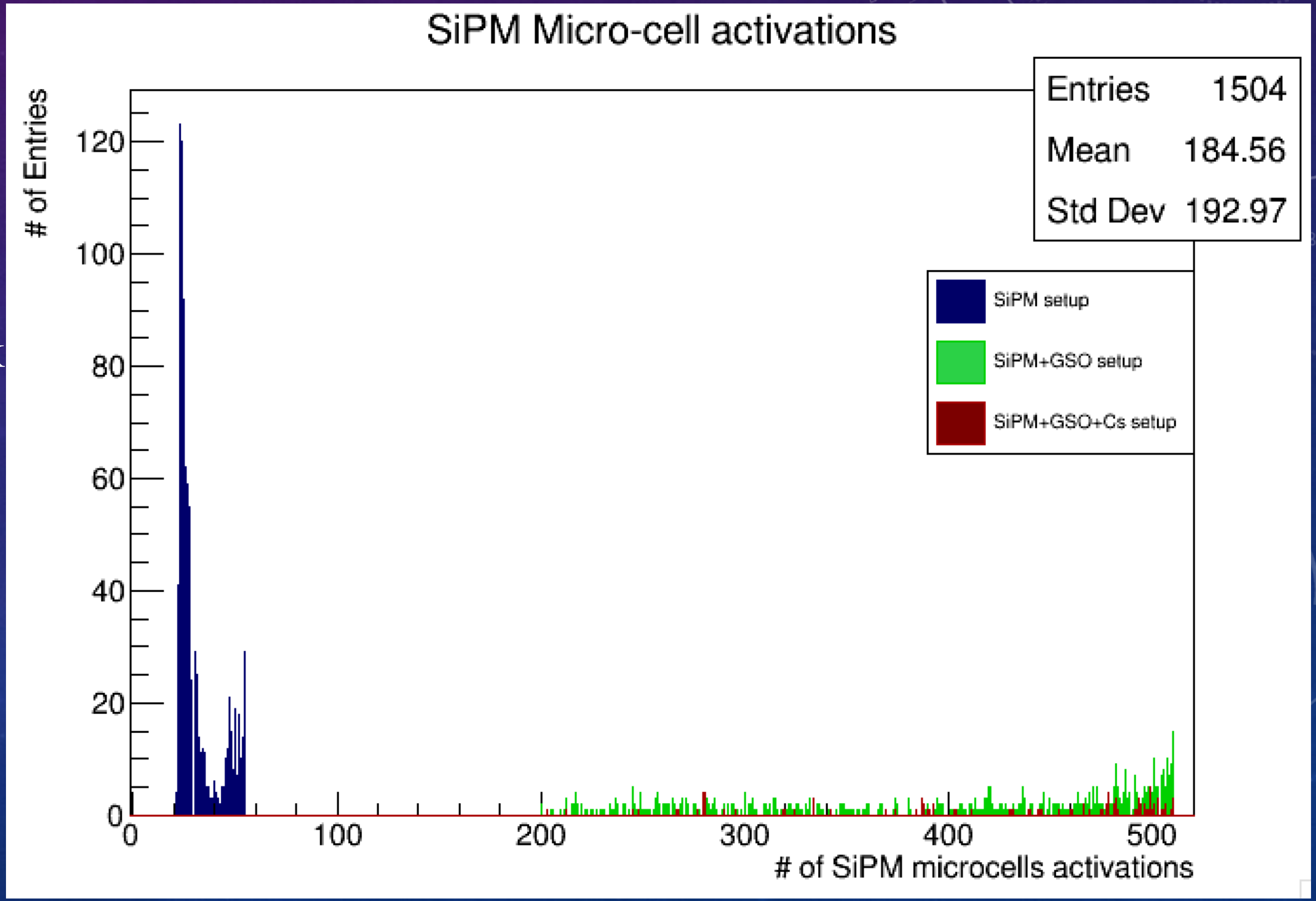
FIRST EXPERIMENTAL TEST SYSTEM REQUIREMENTS

- First tests based with oscilloscope studied system requirements and possible simplifications;
- Data acquired in a dark box to isolate the contribution of an individual micro-cell from SiPM array;
- New setup is being built with SiPM arrays with size 3 and 1 mm.

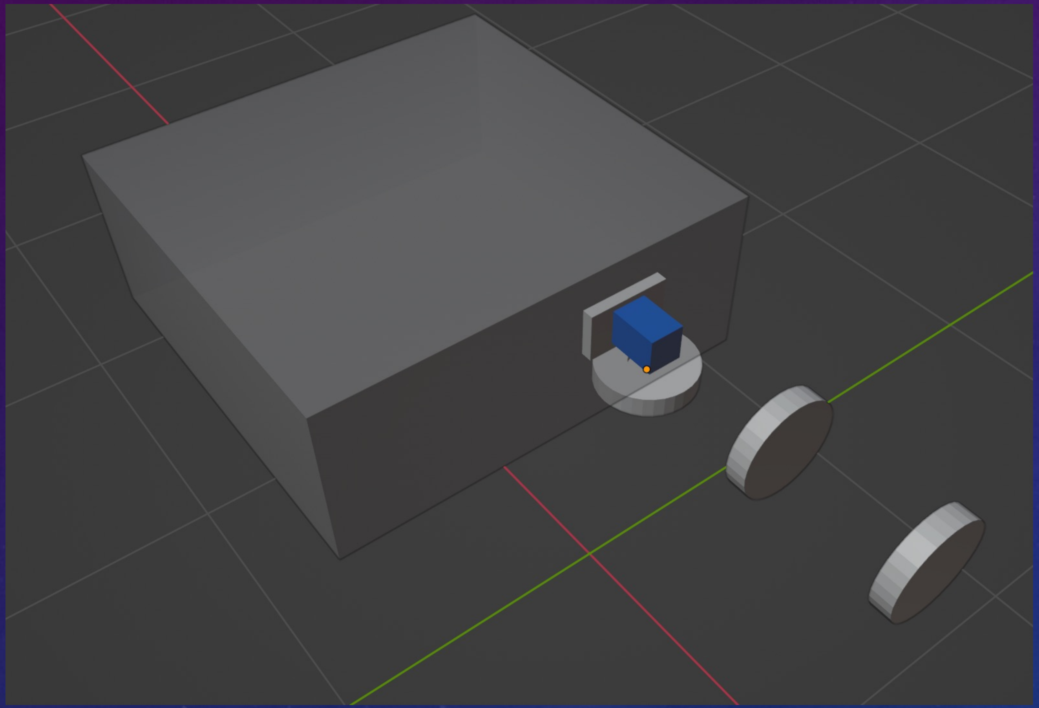


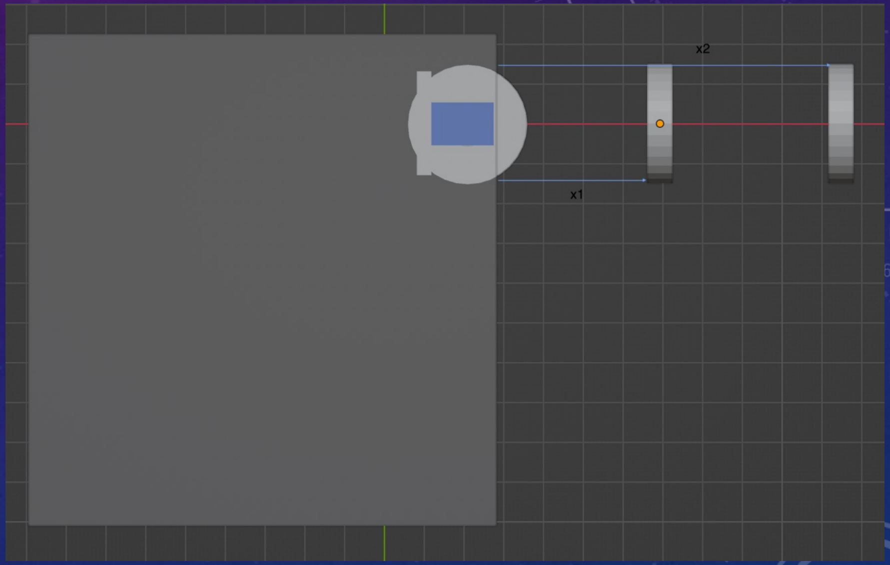
FIRST EXPERIMENTAL TEST
EXPOSURE TO CS-137

- Setup with GSO crystal coupled to SiPM in the dark box;
- Irradiation of detector with Cs-137 source.

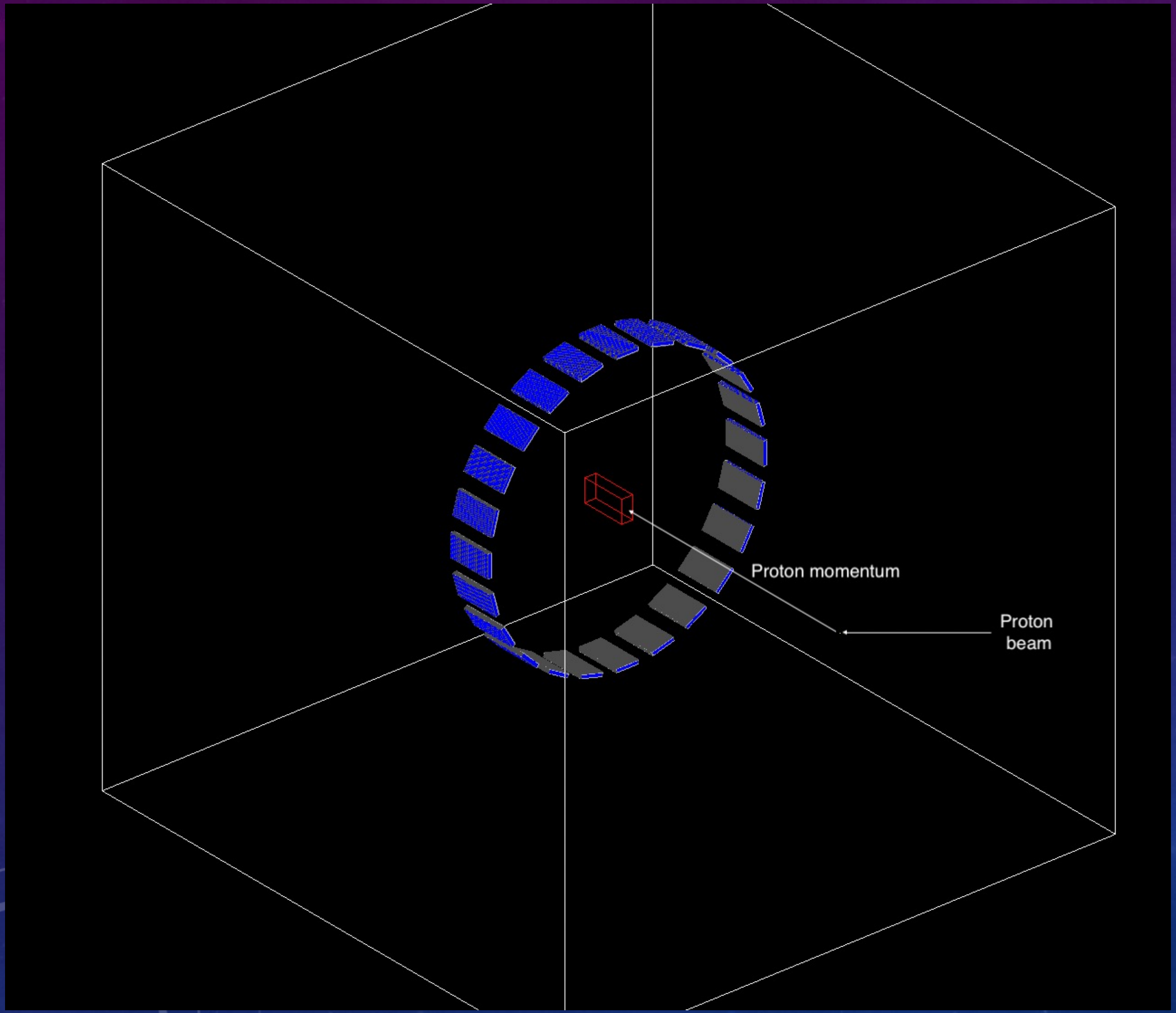


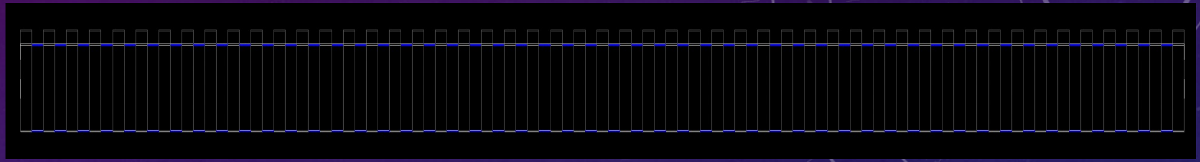
Experimental Setup
Exposure to Cs-137

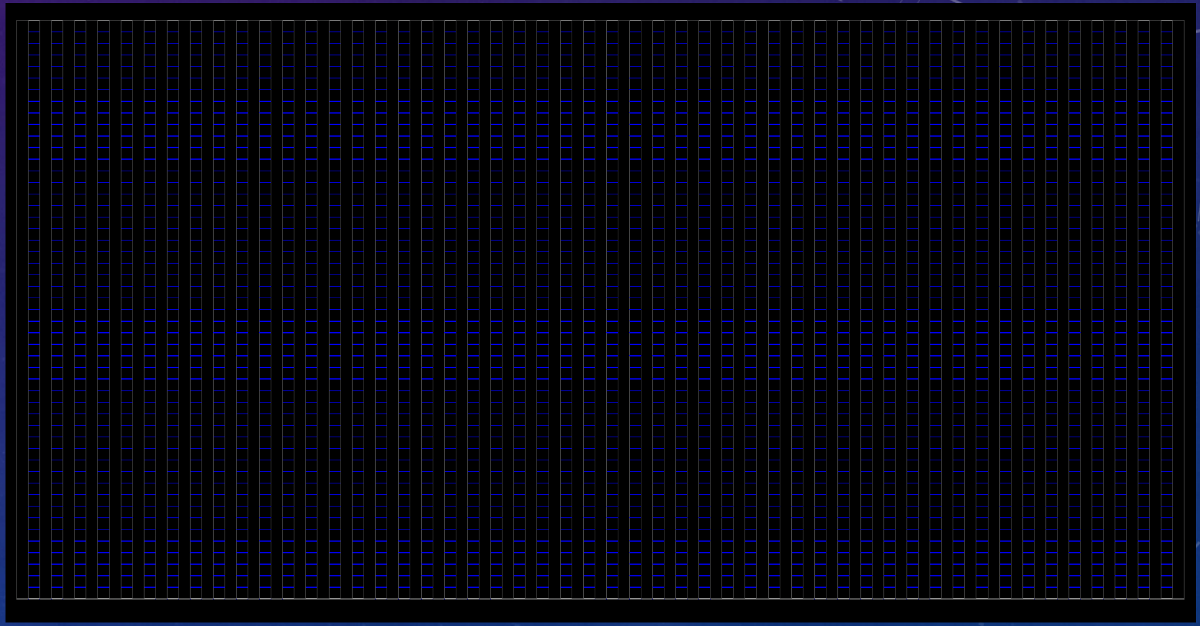




GEANT4 SIMULATION







GEANT4 - RESULTS

- Simulation code validation with 1 MeV gamma;
- Simulated the experimental setup when exposed to a Cs-137 radioactive source.

PROTON INTERACTIONS WITH MATTER

- Linear Stopping Power $\frac{dE}{\rho dx} = \frac{2\pi N_A z_p^2 e^4 Z}{m_e c_0^2 \beta^2 A_r} * [\boldsymbol{ln}\left(\frac{2m_e c_0^2 \beta^2 W}{I_{adj}^2 (1-\beta^2)}\right) - 2\beta^2 - \frac{2}{Z}\sum_i C_i - \Delta + \pi\alpha Z_p \beta + \frac{2 z_p Z \alpha^3 F(\beta,Z)}{\beta^3}]$;
- Relative proton fluence $\phi(x) \approx 1 + 0.0018\,(R_0 - x)^{0.87}$;
- Molière distribution $f(\theta, d) = \frac{1}{4\pi\theta_M^2} * [f^{(0)}(\theta') + \frac{f^{(1)}(\theta')}{B} + \frac{f^{(2)}(\theta')}{B^2} \pm \cdots]$;
- Characteristic multiple scattering angle (θ_M) $\theta_M^2 = \frac{1.56 * d * B * Z^2}{2 * A * (pv)^2}$;
- Pathlength $P_x = \int_{E_f}^{E_0} (\frac{dE}{\rho dx})^{-1}\, dE$;
- Mean range $R_0 = \int_{E_f}^{E_0} \overline{\cos\theta}\, (\frac{dE}{\rho dx})^{-1}\, dE$;
- R_0 for protons in water is $R_0 = \alpha E_0^p$, where $\alpha \approx 0.0022$ and $p \approx 1.77$ and $\alpha \approx \frac{\sqrt{A}}{\rho}$

SCPI COMMANDS FOR DATA ACQUISITION FROM OSCILLOSCOPE R&S-RTH1004

- **Use of python pyvisa library;**
- **connection = pyvisa.ResourceManager();**
- **rth1004=connection.open_resource(ip_address, write_termination='\n', read_termination= '\n', chunk_size= 128, timeout=25000);**
- **screen_data=rth1004.query("CHAN2:DATA:HEAD?") # example of data acquire [-0.0025,0.0025,500000,1]-> [start time, stop time, number of samples, values per sample interval].**

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