Feasibility study of a system for computerized tomography with a proton beam

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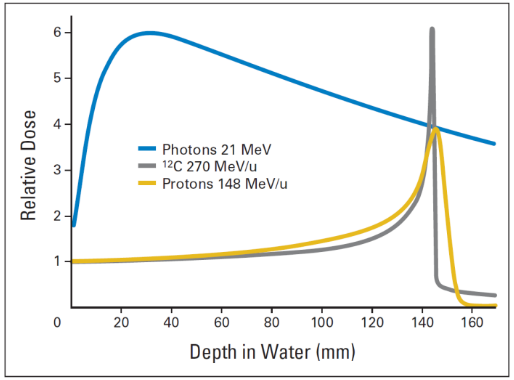
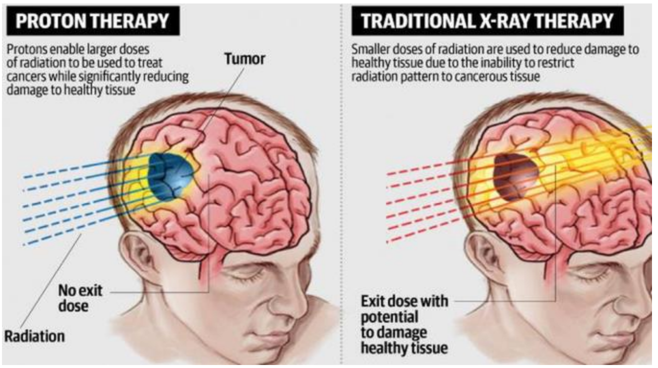
System for computerized tomography with a proton beam.



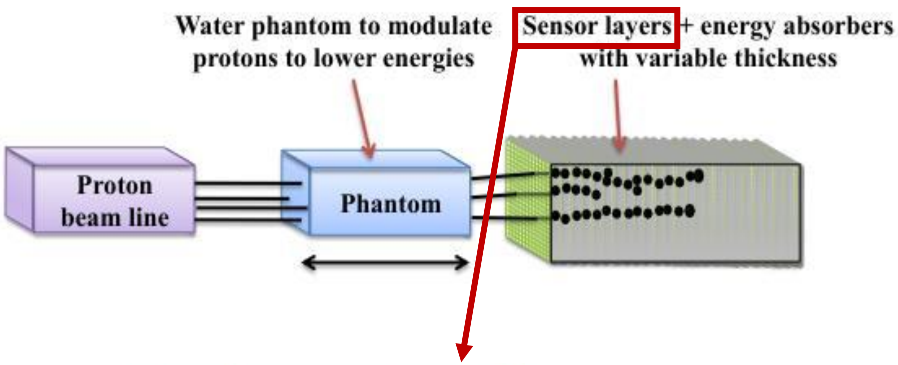
- Protons experience a continuous slow down as they cross matter, until they stop and release a large fraction of their initial energy, originating the Bragg pick at the end of their path.
- From measuring the energy loss of the protons in the tissues, a pCT can be performed.
- Dose delivered to the patient with a pCT (few mGy).

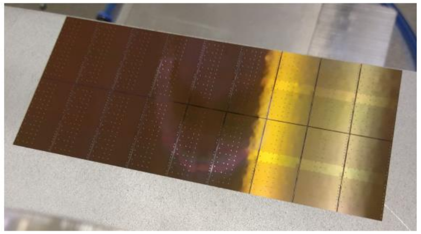
At least an order of magnitude lower than traditional X-ray CT (10–100 mGy).



Hybrid calorimeter with layers of pixelated silicon sensors.

- Single technology for both tracking and residual energy measurement would simplify the system assembly and guarantee stable operation in a clinical environment.
- Needs to fulfill the requirements to handle pencil beams with therapeutic characteristics:
  - High particle rate and localized dose depositions.
  - Readout speed fast enough to handle many tracks at the same time.
  - Accurate determination of the ranges of individual protons.





Prototype of a silicon pixel detector with area of 138 × 60.1 mm^2 and thickness of 40 µm.

Modeling a hybrid calorimeter

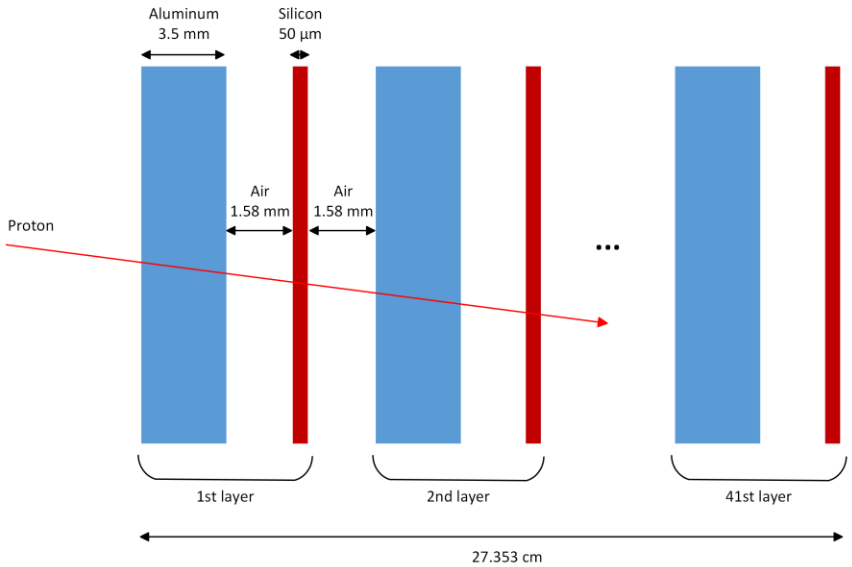
GEANT4 based simulation:

- Accurate representation of the calorimeter sandwich structure.
- **Calibration of protons stopping range after traversing phantoms with different volumes and materials.**

Irradiation: single particle beam of 230 MeV protons perpendicular to the front surface of the calorimeter layers.

Setup layout:
41 layers 1.58 mm spaced.
Each layer:
3.5 mm thick aluminum plate.
50 µm thick silicon detector.
1.58 mm air gap.
Total volume: $280 \times 94.2 \times 273.53$ mm^3.

Distance between beam origin and first layer: 20 cm



5 phantom types:

Tissue	Density (g/cm^3)
Lung	0.2958
Adipose	0.93
Soft	0.9869
Glandular	1.04
Skeleton	1.4862

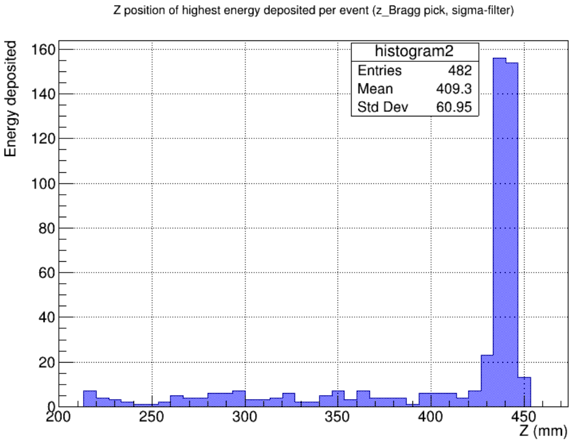
x – y dimensions: 10×10 cm^2.

Material depth (varied in steps of 2):
6 - 10 cm (lung)
2 - 10 cm (rest of materials)

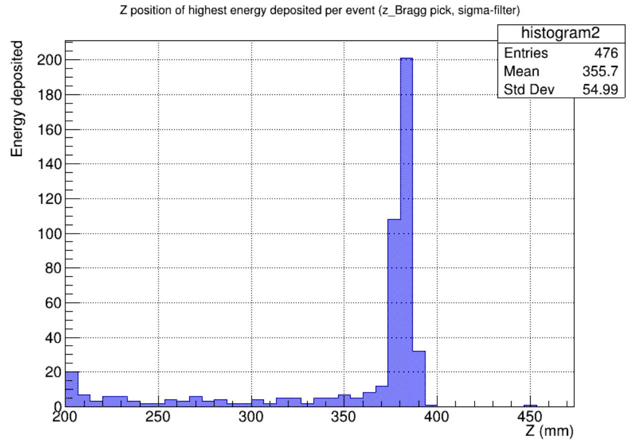
23 phantoms in total.

Distribution of maximum energy deposited by protons in the calorimeter layers after traversing 10 cm thick phantoms

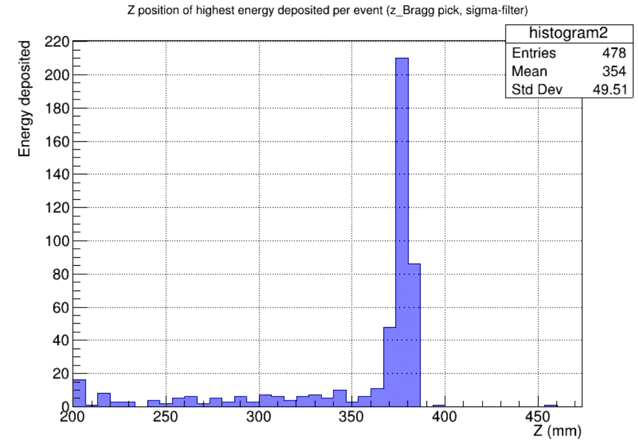
Lung



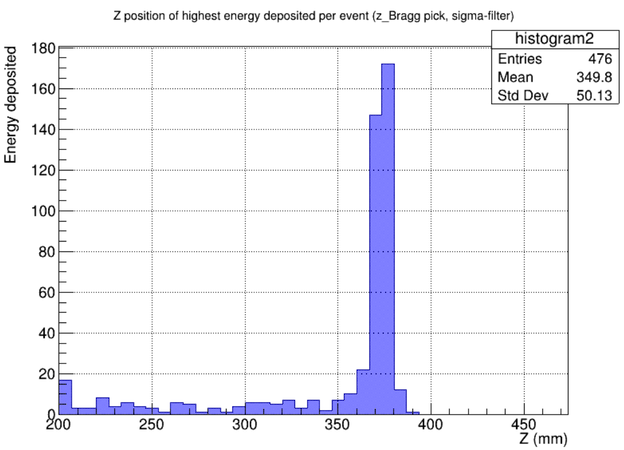
Adipose



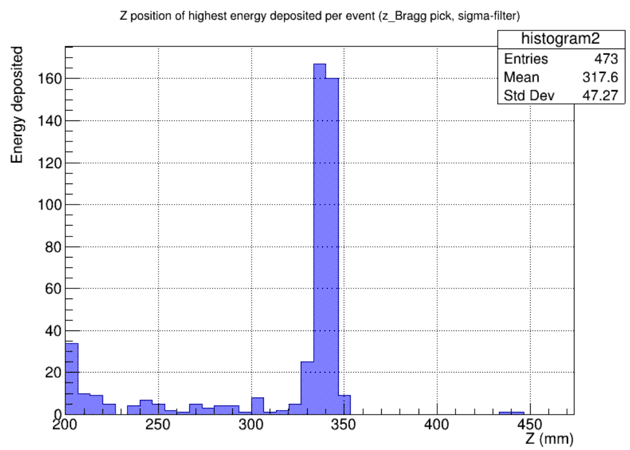
Soft



Glandular



Skeleton

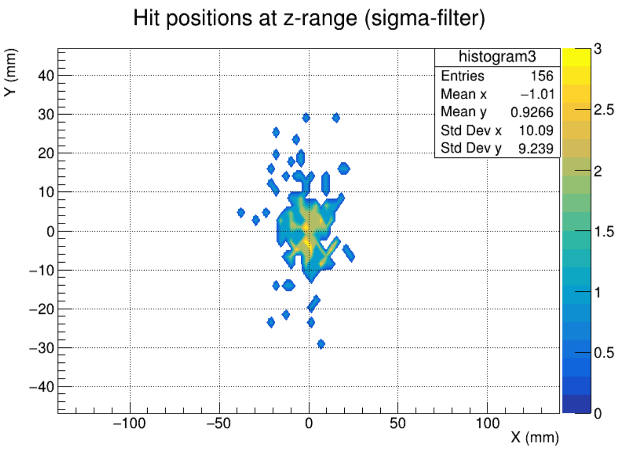


Dependency of the Bragg pick position and material density.

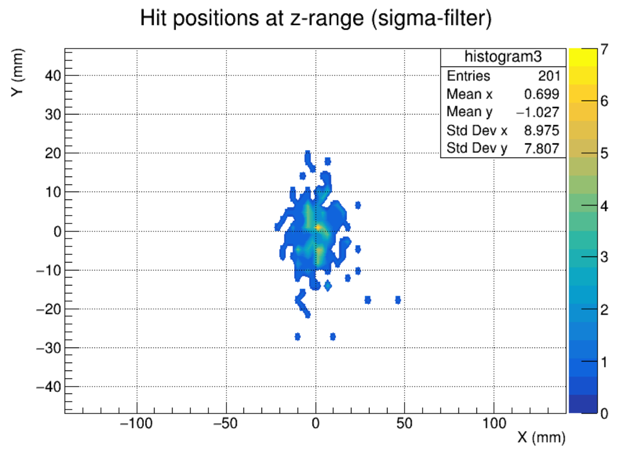
The higher energy deposit occurs at lower z as protons traverse denser tissues.

Hit maps of detector layers where the Bragg pick occurs for protons after traversing 10 cm thick phantoms

Lung



Adipose



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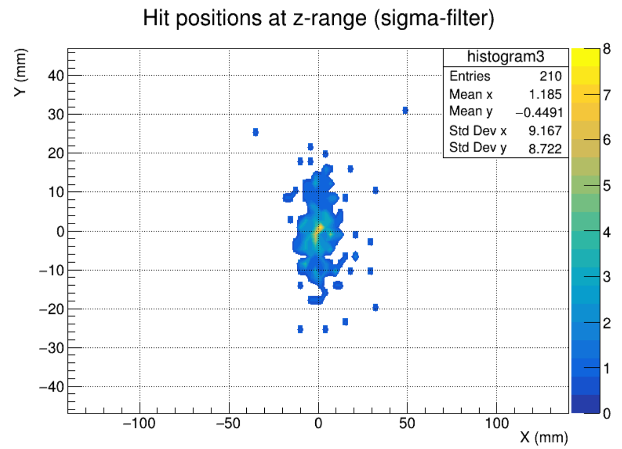
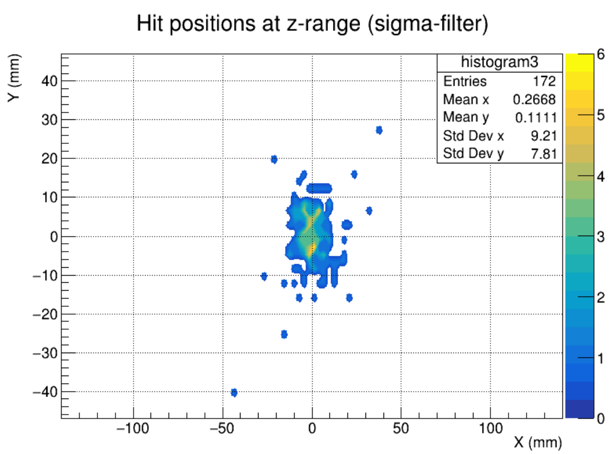
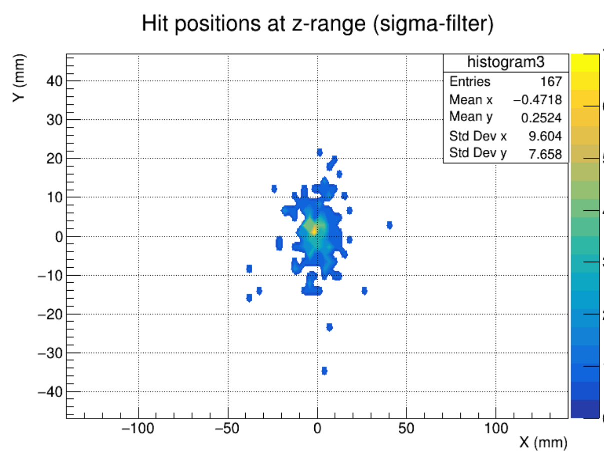


Glandular

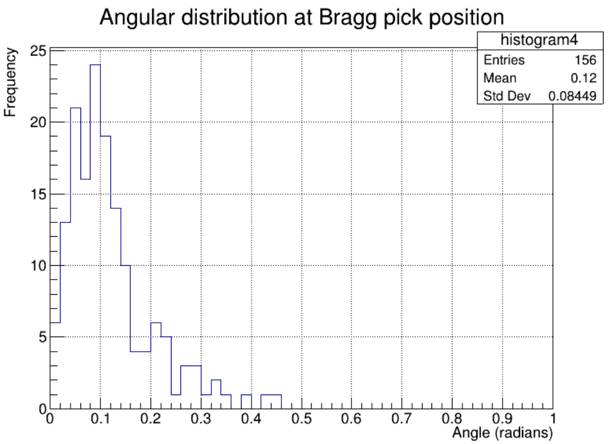


Skeleton

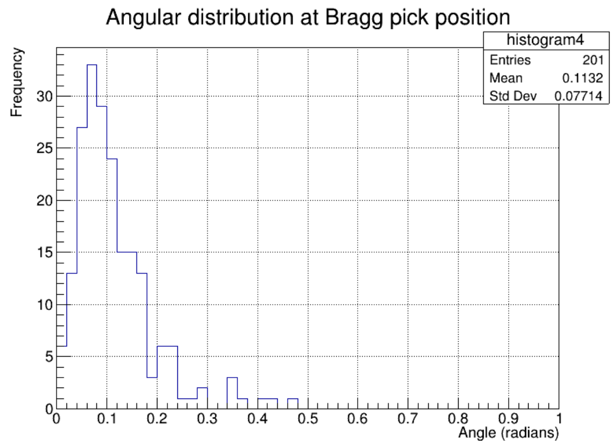


Angular distributions of the hits in the detector layers where the Bragg pick occurs for protons after traversing phantoms with a thickness of 10 cm

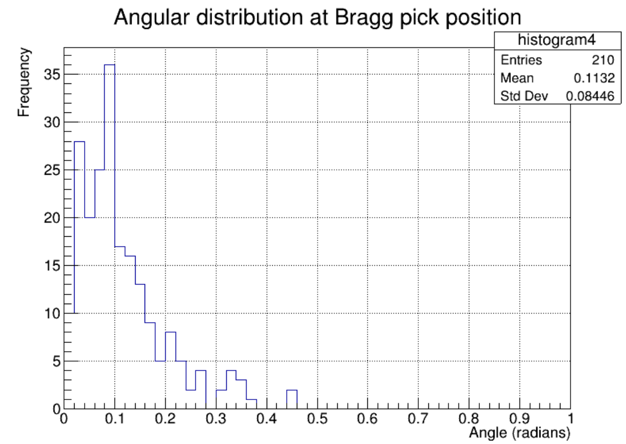
Lung



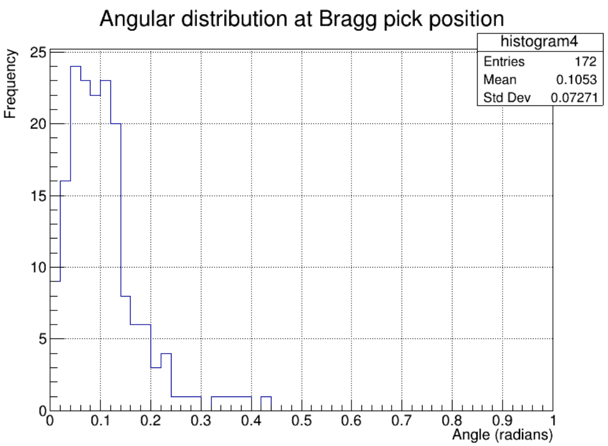
Adipose



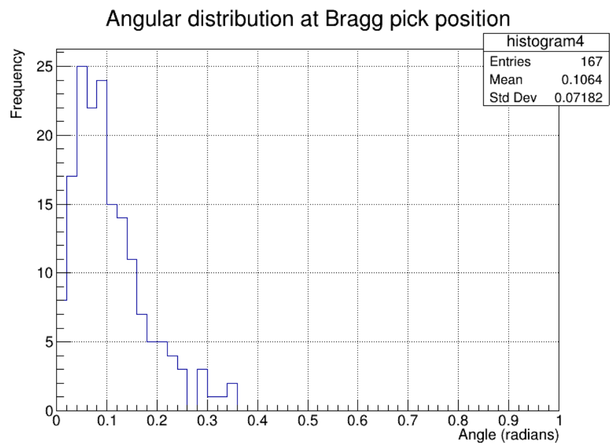
Soft



Glandular

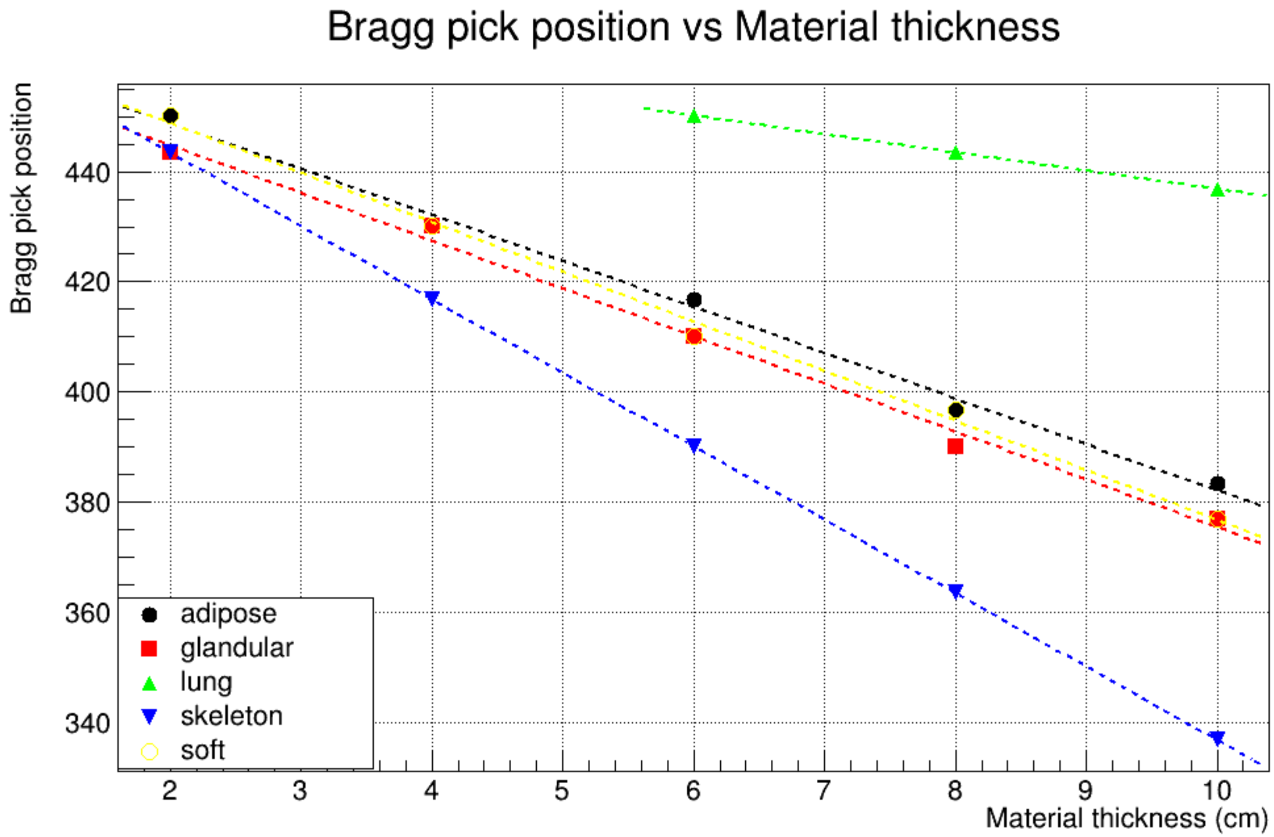


Skeleton



The mean deviation angle decreases by 0.0136 rad from 0.12 rad for lung to 0.1064 rad for skeleton.

Bragg pick position (in mm) for protons after traversing different phantoms.

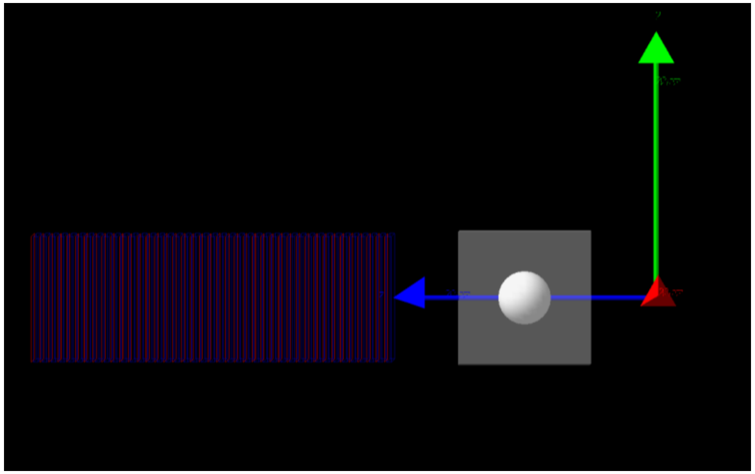


- The Bragg pick position decreases almost linearly as the material thickness increases.
- Faster drop is observed for the skeleton curve, specially with respect to lung.

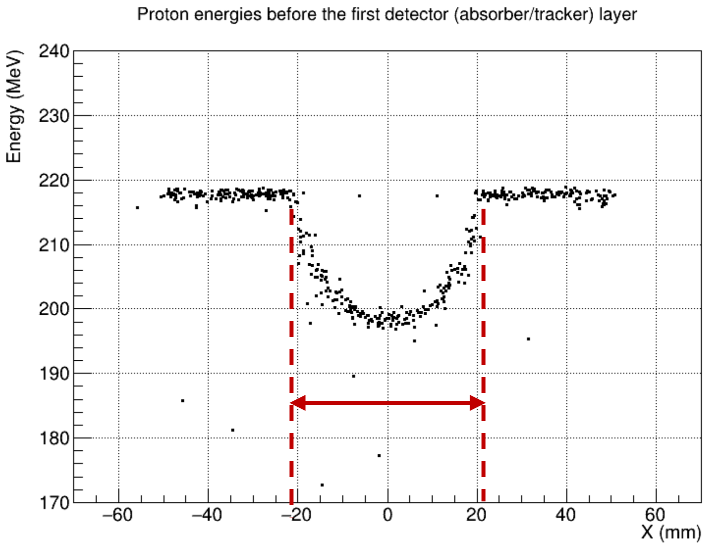
Second setup simulated

Irradiation:
protons generated randomly in a range of x = ±50 cm at y = 0

Phantom:
4 cm diameter skeleton sphere
10 × 10 × 10 cm^3 cubic lung volume

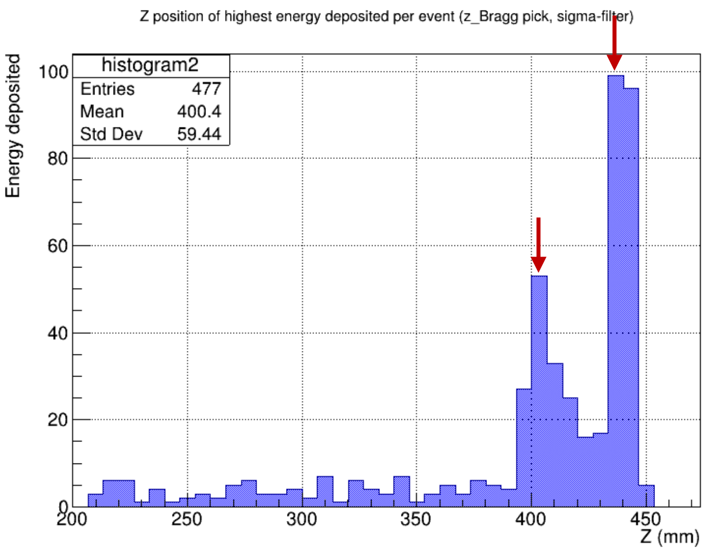


Profile of energy loss in a transversal section of the phantom at y = 0.
Proton energies at the first detector layer as a function of their position in x.



Higher energy loss corresponding to the position and dimensions of the skeleton sphere.

Distribution of maximum energy deposited in the calorimeter layers.



The presence of two peaks indicates different densities of phantom materials

Next steps:

Perform irradiation tests on functional sensors at proton accelerator (LinearBeam S.r.l)