PROTON THERAPY
Particle Interaction and Detection

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1 Introduction

1.1 Proton Therapy

Proton therapy is an advanced and highly precise radiation treatment for tumors. Compared to other methods, it focuses more energy on the tumor itself with less radiation to surrounding healthy tissue.

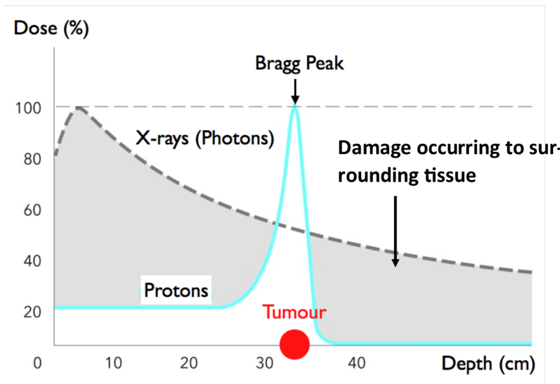


Figura 1: Proton ...

In regular radiation therapy, the beam of energy goes into the body, through the tumor, and out the other side. This "exit dose" of radiation might affect healthy tissue beyond the tumor. Protons, in contrast, are larger particles than those used in regular radiation. They release more of their energy within the tumor itself. This burst of energy can appear on a graph as what is called the Bragg peak.

After delivering the energy to the tumor, the protons stop. not exiting the tumor and harming healthy tissue on the other side.

In this way, proton therapy reduces radiation exposure and potential damage to healthy tissue, especially in sensitive areas such as the brain, eyes, spinal cord, heart, major blood vessels and nerves.

1.2 Bragg Peak

When a fast charged particle moves through matter, it ionizes atoms of the material and deposits a dose along its path. A peak occurs because the interaction cross section increases as the charged particle's energy decreases.

Energy lost by charged particles is inversely proportional to the square of their velocity, which explains the peak occurring just before the particle comes to a complete stop.

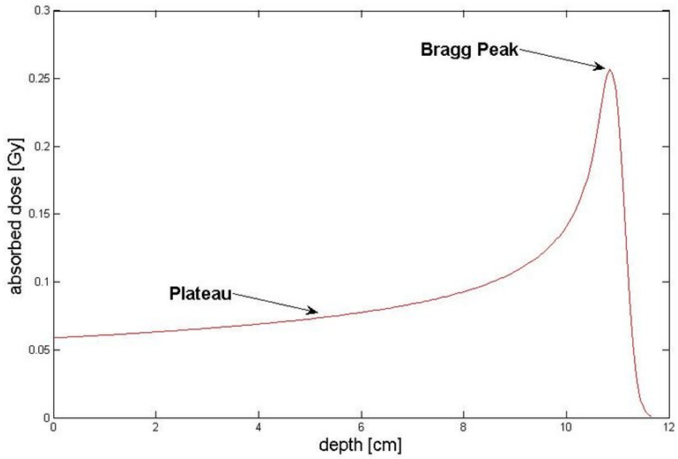


Figura 2: Characteristic Bragg curve of a mono energetic proton beam

1.3 Box-Muller Method - Gaussian Generator

The Gaussian function $G(\mu, \sigma)$ is written in the form:

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(x-\mu)^2}{2\sigma^2}}$$

The Box-Muller method transforms a two-dimensional continuous uniform distribution to a two-dimensional bi-variate normal distribution, a good and often used approximation:

$$Z = (-2\ln(r_1))^{1/2} \cos(2\pi r_2) \tag{1}$$

- Use 2 random numbers from a uniform distribution (r_1, r_2).
- Z will follow a Gaussian distribution with $\mu = 0$ and $\sigma = 1$.
- Use $x = \mu + Z\sigma$ to get a specific distribution $G(\mu, \sigma)$.

2 Code setup

Creating a Gaussian energy distribution following a Gauss curve with a sigma of 2%, with expression (1).
For this we created a method **Muller**.

```
#ifndef BoxMullerGenerator_h
#define BoxMullerGenerator_h 1


class Muller {

// -> where the normal distribution is centered
// s-> Standard deviation
```

```
public:
float box_muller(int m, float s) {
float x1, x2, w, y1;
static float y2;
static int use_last = 0;

if (use_last) {
    y1 = y2;
    use_last = 0;
}
else {
    do {
        x1 = 2.0 * ((double)rand() / (RAND_MAX)) - 1.0;
        x2 = 2.0 * ((double)rand() / (RAND_MAX)) - 1.0;
        w = x1 * x1 + x2 * x2;
    } while (w >= 1.0);

    w = sqrt((-2.0 * log(w)) / w);
    y1 = x1 * w;
    y2 = x2 * w;
    use_last = 1;
}

return(m + y1 * s);
}


}mulls;
```

Creating a Beam of protons with initial energy of 100MeV, and gaussian destribution.
Where we atribute the initial energy to a proton, and can be read $number.box\_muller(150, 0.02)$, means that the normal distribution is centered in the a value E_0 with a error of 2%. The iniital momenta of particles is in the direction of the x axis.

```
PrimaryGeneratorAction::PrimaryGeneratorAction(
                                    DetectorConstruction* myDC)
:myDetector(myDC)
{
  G4int n_particle = 1;
  particleGun = new G4ParticleGun(n_particle);

// default particle

  G4ParticleTable* particleTable = G4ParticleTable::GetParticleTable();
  G4ParticleDefinition* particle = particleTable->FindParticle("proton");

  particleGun->SetParticleDefinition(particle);
  particleGun->SetParticleMomentumDirection(G4ThreeVector(1.,0.,0.));
  Muller number;
  particleGun->SetParticleEnergy((number.box_muller(150,0.02*150.0))*MeV);
  // energia 100mev * valor do muller box
  particleGun->SetParticlePosition(G4ThreeVector(-25.*cm,0.*cm,0.*cm));
}
```

Creating a Soft Tissue material with density $\approx 1gm/cm^3$. In the NIST DataBase can be found many different tissue like material, but we choose the one with the asked specifications.(NIST BioMaterials)

```
#include "G4NistManager.hh"
#include "G4Material.hh"

//tissue
G4Material* Tissue = man->FindOrBuildMaterial("G4_TISSUE_SOFT_ICRP")
```

Creating the Target, thusly we created the Target environment, with 14 cm thickness, located in the origin of axis.

```
  G4double targetThickness = 0.5*14.0*cm;

G4Box* solidTarget =
new G4Box("Target",targetThickness,HalfWorldLength,HalfWorldLength);

G4LogicalVolume* logicTarget =
new G4LogicalVolume(solidTarget,Tissue,"Target",0,0,0);

G4ThreeVector pos = G4ThreeVector(0,0,0);

G4VPhysicalVolume* physiTarget =
new G4PVPlacement(0, pos,logicTarget,"Target", logicWorld,false,0);
```

3 Simulation

Studying the position of the Bragg peak as a function of the initial energy of the proton beam, starting from 50 to 150 MeV, in steps of 10 MeV). It's possible to obtain the next figure (more figures in **Apendix A**):

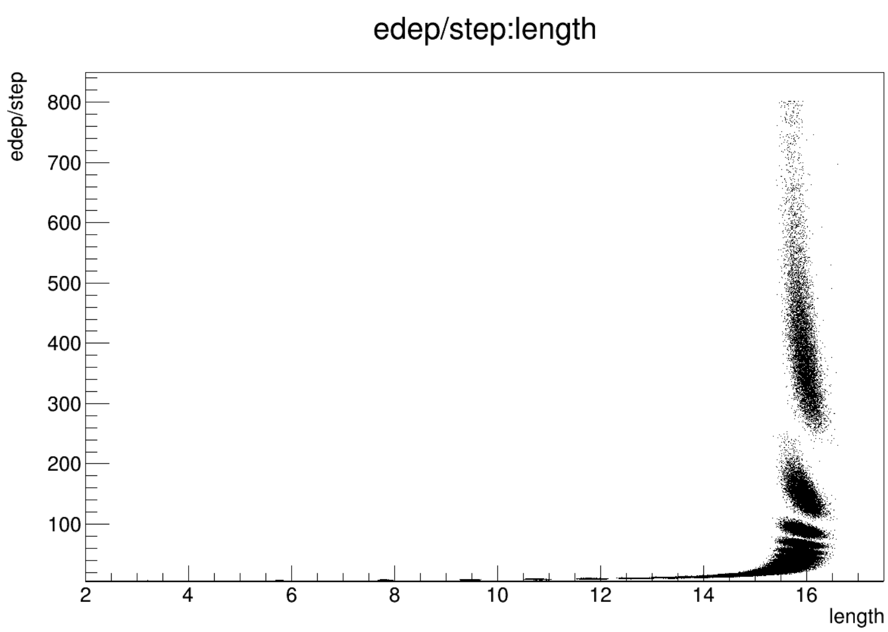


Figura 3: 150 MeV

To estimate the range where the particle has its energy fully deposited in the skin, we make a histogram of the range of particles:

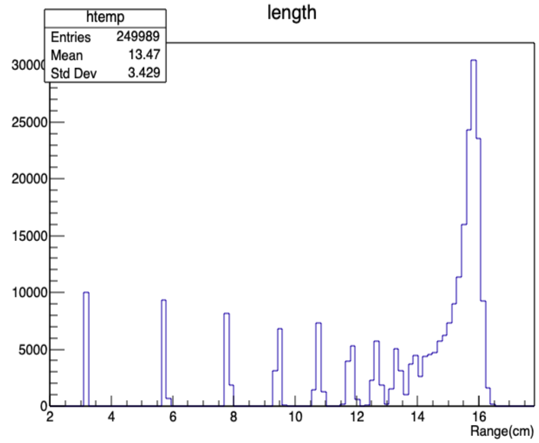


Figura 4: Histogram for protons with 150 MeV

and using the energy deposited vs range plots, we verified the best energy to use as a cut in order to obtain a histogram with the shape of a Gaussian.

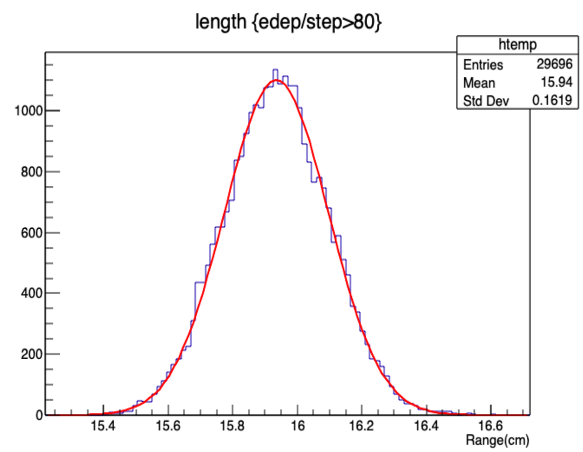


Figura 5: Gaussian for proton with 150 MeV

Using root to fit the histogram in order to obtain the values of the Gaussian parameters, it was possible to obtain the mean value and the standard deviation. Repeat this process for all given energies, we are able to plot the Range versus Initial energy in order to find the relationship between these two quantities:

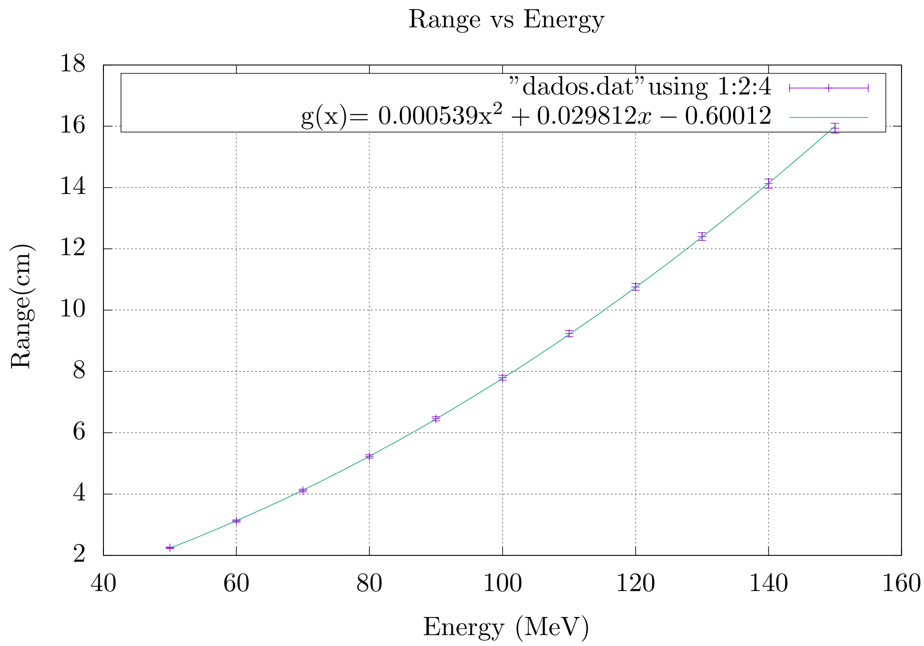


Figura 6: Range versus Initial Energy.

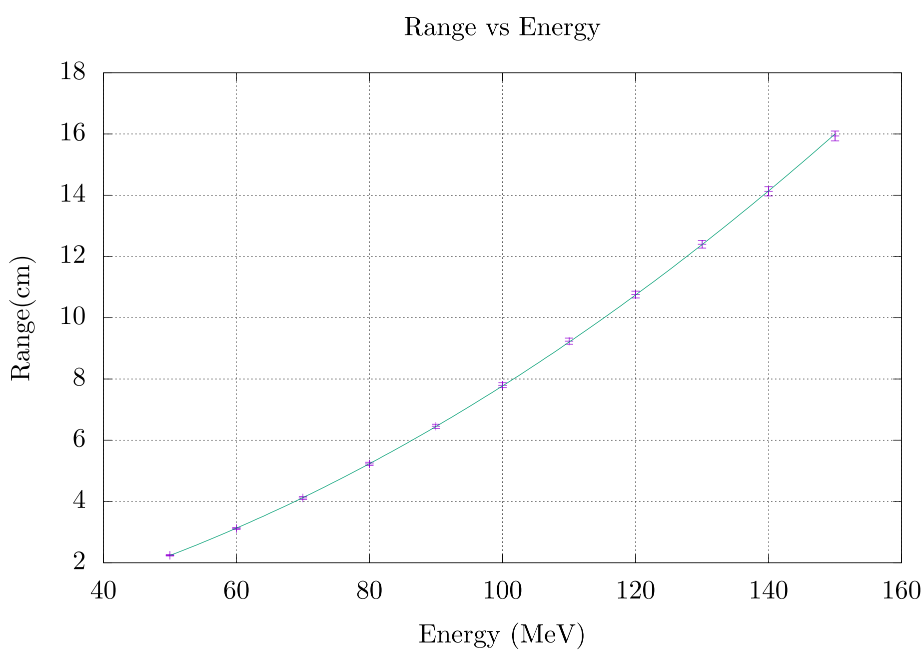


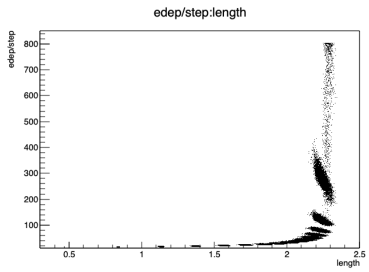
Figura 7: Range versus Initial Energy.

Ideally, the relationship between these two properties should be linear, however, for our values, a quadratic relationship is more suitable for the points, having obtained the following expression:

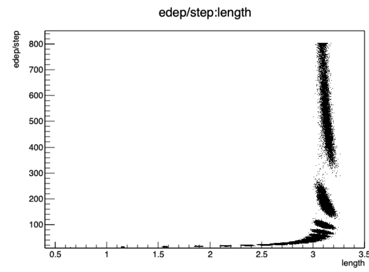
$$g(x) = 0.000539x^2 + 0.0298812x - 0.60012 \tag{2}$$

To find the energy of protons needed to treat a tumor at 7 cm depth To estimate the mean proton energy required for treatment of a tumour at a depth of 7 cm under the skin. Finding the roots for g(x)=7, getting the result of $x = 94.258592 \pm 0.63429$ MeV for the mean energy.

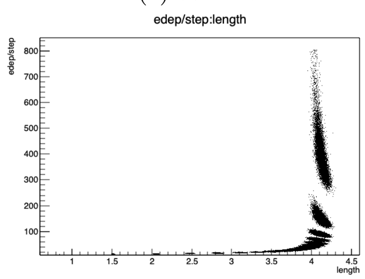
Apendix A



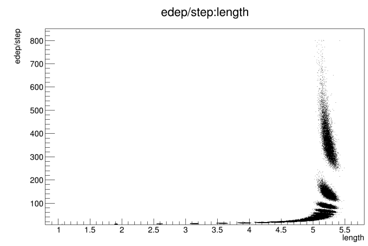
(a) 50 MeV



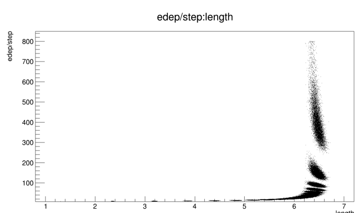
(b) 60 MeV



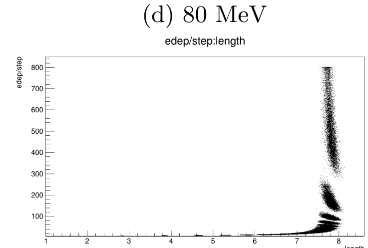
(c) 70 MeV



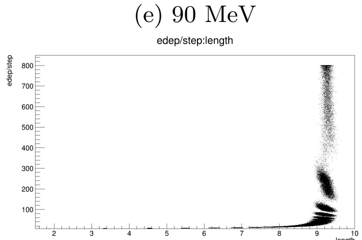
(d) 80 MeV



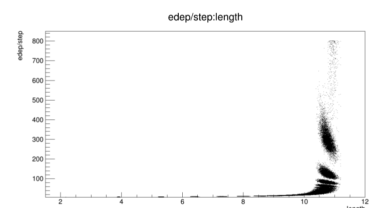
(e) 90 MeV



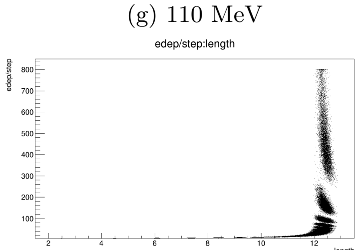
(f) 100 MeV



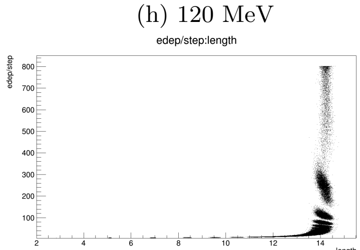
(g) 110 MeV



(h) 120 MeV



(i) 130 MeV



(j) 140 MeV

Referências

[1] https://www.hopkinsmedicine.org/health/treatment-tests-and-therapies/proton-therapy (Proton Therapy Explained)

[2] pdf slides on Proton radiotherapy

(Bragg Peak Explained)

[3] W. Leo “Techniques for Nuclear and Particle Physics Experiments: a how to approach”, Springer, 1994.