Energy loss of protons in Water

Introduction

The main objective of this TP is the study of protons interaction with matter, and more concretely with a water phantom. As it has been presented during the lectures, the main two effects of the interaction of heavy charged particles with matter are the continuous energy loss, mainly due to the electromagnetic interaction with atomic electrons, and the difussion of the particle from its incident direction, due to elastic electromagnetic scattering with the atomic nucleus.

Both effects can be easily studied if we use a proton beam. We are going to estimate the effect of the scattering measuring the beam broadening after the insertion of a diffusion foil. The energy loss profile will be studied through the Bragg curve of the protons in water. Special interest will be put to compare experimental results with the simulation of the experimental setup with SRIM or GEANT4.

The proton source is the cyclotron CYCLONE-110 at Centre de Recherches du Cyclotron (CRC) at Louvain-la-Neuve. Using the characteristics of the beam, we will profit to study the cyclotron parameters.

Equipment required

- A proton beam. In our case, it's a 65 MeV coming from the CYCLONE 110.
- A Water phantom. The wall is made of plexiglass and it's 1.5 mm thick.
- Measurement diode and its readout "table". Diode cover is equivalent to 0.6 mm of Al.
- Set of motors to move the diode inside the phantom
- A set of degraders (polyethylene): D1=2 mm, D2=4.2 mm, D3=8.2 mm, D4=16 mm.
- A diffusion foil (125 μm of lead)
- A thin window (50 μm of stainless steel)

Setup description

For this experiment we are going to use the experimental setup located in the LIF experimental area at CRC. It's one of the experimental lines available at CRC and is used regularly to test the radiation hardness of electronic components. The experimental setup is sketched in Figure 1

Protons are initially accelerated at 65 MeV, but they loose $\sim$ 3 MeV in the lead sheet, the windows and the air column.

The sensors we are going to use are silicon diodes read in current mode. One of the diodes will be placed in front of the water phantom, in a peripheral side of beam, and will provide a reference current. The other one can be moved in the three directions inside the

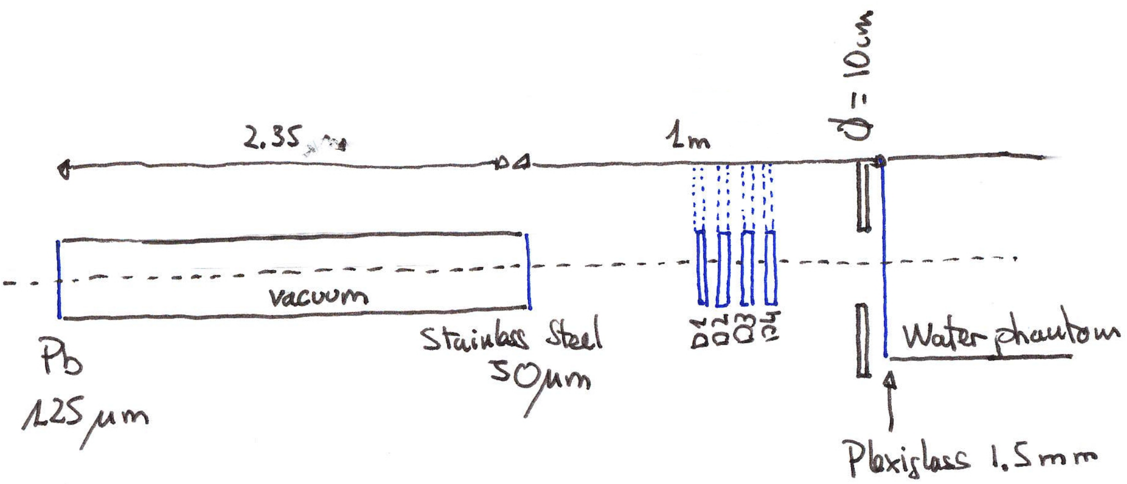

Figure 1: Experimental setup

phantom. The quantity we are interested in is the ratio between the current measured by the moving diode and the reference diode.

Practical details:	Diode voltage:	256 V
	Step motors:	1 step = 1 mm
	Range of 65 MeV protons in water:	∼3 cm

TASK 1: Beam profile measurement

Description

In the setup described in the previous figure, there is a diffusor made of 150 μm of lead located at the entrance of the experimental setup. The main purpose of this element is to scatter the localized beam in such a way that it will produce a relatively uniform irradiation field after the collimator. This diffusor can be removed. We are going to measure the beam size without and with diffusor to see the effect of the scattering by nuclear

Procedure

1. Before to start the beam, and with the "igloo" door open, figure out a way of "calibrate" the step motors in such a way that you can convert steps into distances.

2. Set the beam to 65 MeV

3. With the lead sheet out of the beam. Measure the beam profile close to the phantom window

- Take a measurement every cm, following either a grid of 5x5 cm around the estimated value of the beam center (25 measurements), or horizontal/vertical axis (11 measurements)
- From these measurements localize the beam center

4. Repeat the measurement with the lead sheet in the beam
5. Measure beam size but just following the axes, (~20 measurements more)

Questions

1. With the help of SRIM or GEANT4,
   (a) Calculate the energy of the protons at the entrance of the water phantom for both cases, with and without the diffusor in the beam.
   (b) What's the beam element that produces the larger energy loss
   (c) What's the energy loss in water? You have to take into account the plexiglass wall of the water phantom and the diode cover
   (d) Estimate the beam size measured in the phantom if the original beam size has a gaussian shape with $\sigma_x = \sigma_y = 0.8$cm
2. Represent in a graphic the beam size of both measurements.
   (a) Estimate the beam size (FWHM, σ ,....) for both cases
   (b) Are the results obtained compatible with the SRIM/GEANT4 predictions?

TASK 2: Measurement of the Bragg curve

Description

Protons of few tens of MeV are completely stopped by few cm of water. Energy loss, specially at low energies vary quite quickly, achieving a maximum of energy loss in the end of the trajectory. The plot representing the energy loss wrt track length is known as Bragg curve. We are going to measure the Bragg curve of protons of various energies up to 65 MeV with the help of the water phantom and the diode, being the current measured by the diode proportional to the ionization

Procedure

1. Be sure that the diffusor is in the beam
2. Position the diode, in the center of the beam and as close as possible to the phantom wall
3. Maintaining X and Y fixed, scan in Z, separating from the wall.

4. Start with steps of ∼5 mm, and reduce accordingly the steps once the ionization starts to grow.
5. COntinue doing the measurements until the measured ionization is zero
6. Repeat the previous procedure at various energies between 20 MeV and 65 MeV

Questions

1. With the help of SRIM/GEANT4, compute for all the energies measured experimentally:
   (a) The energy of the proton at the entrance of the water phantom
   (b) The ionization profile inside the water phantom
   (c) The transmission curve (I/I_0) vs the track length in the water
2. Represent graphically the Bragg curves obtained experimentally
   (a) Compare them with the SRIM/GEANT4 estimations. Are they compatible?
   (b) Measure the ratio of the ionization in the peak and at the beginning of the water phantom. Is this value well reproduced by the simulation? If not, do you have an explanation?
   (c) Measure from the experimental Bragg curves the range in the water phantom. Explain how do you measure this range.
   (d) Compare the set of ranges obtained with the values quoted in tables (i.e. pstar) and the values obtained in the simulation. Are they compatible?