# PROTON ENERGY ESTIMATION BY USING LEAST SQUARE METHOD (A STUDY OF GEANT4 MONTE CARLO SIMULATION)

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## 1. Introduction

Proton energy determines the proton range, the penetration distance of the proton. The higher the proton energy, the deeper the proton range. Proton has a uniqe physical characteristic called as Bragg peak, in which proton deposit almost all of its energy at the region at the end of the range [1]. This physical characteristic of proton provides more benefit in clinical use, especially for cancer treatment by using proton beam [2].

Proton therapy offers a lower dose to healthy tissue surround the cancer, while maximizing the dose for the cancer compare to the conventional photon therapy technique. The current proton energy which is used for therapy has an energy lower limit around 70 MeV which can only be used for superficial tumors and ocular tumors [3]. The proton energies lower than 70 MeV have a very short range and a very sharp Bragg peak, which means a high resolution of detector will be needed to get the information of the proton range.

This study related to the range finder part of the experiment for proton multiple scattering study (Figure 1a). This experiment measures the multiple scattering angle and the remaining kinetic energy of a particle one by one at each time, which includes two Multi Wire Drift Chamber (MWDC) as the proton tracking before and after the target. The stack of water equivalent material which is called as range finder is located behind the second MWDC to measure the remaining energy of proton.

## 2. Purpose

The main purpose of this study is to find out whether the Least Square method can provide a good result to estimate a relatively low incoming proton energy ( <100 MeV) with finite number of measurements. This implies that the Least Square method has a possibility to improve the performance of current detector in measuring proton energy.

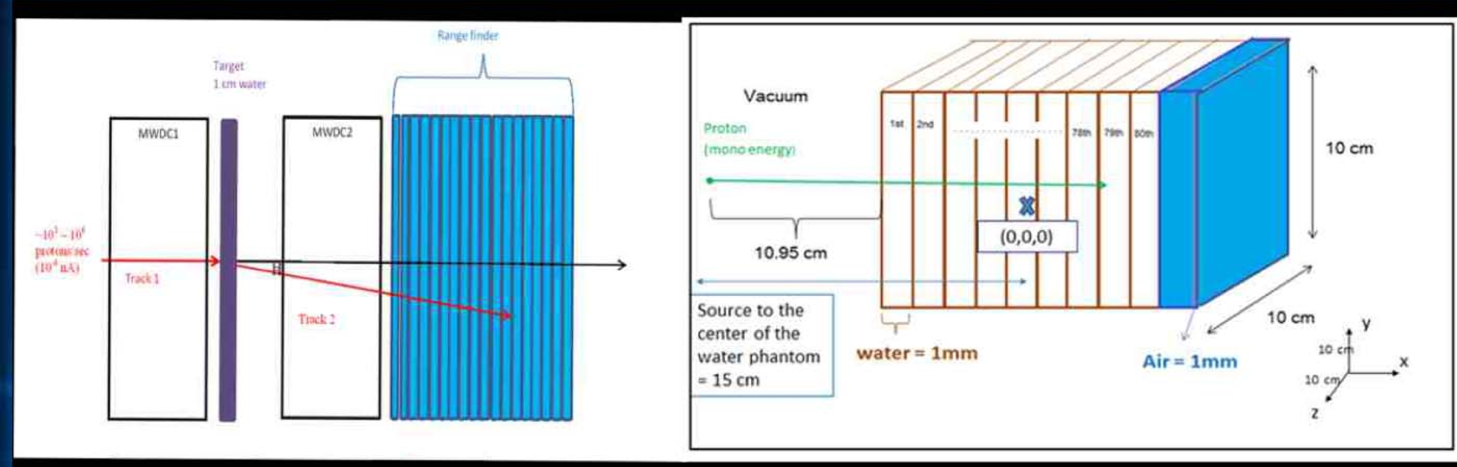
## 3. Method

This study only concern about the range finder in multiple scattering experiment (Figure 1a) and will only estimate the energy of a proton one by one by using Least Square method. The simulation geometry for this study is shown in Figure 1b.

The basic idea of Least Square method is to minimize the weighted sum of squares of deviation (equation 1) between the energy deposition of the references and the unknown incoming proton energy at five consecutive measurement points which are corresponding to certain thickness (depth) of water equivalent material.

Least Square method is used to estimate a proton energy by using primary proton energy deposition data obtained from Geant4 Monte Carlo simulation. A set of data base consists of average energy deposition from 1,000,000 protons with energy of 65, 70, 75, and 80 MeV was generated as reference to estimate the unknown proton energy.

Another 1,000 monoenergetic protons with energy of 73.5 MeV was generated as the unknown proton energy and later will be estimated by using Least Square method. In order to compare different energies data, the energy deposition was normalized at the first measurement point. Every single "unknown" proton is tested by Least Square method.




(a) (b)

Figure 1. (a) Multiple scattering experimental setup. Scattering angle measurement of each proton by using multi wire drift chamber and single proton remaining kinetic energy measurement by using range finder. (b) Simulation geometry to estimate the incoming proton energy. The geometry consists of 80 layers of water phantom and 1 layer of air at the end of $80^{th}$ water layer.

In this study, sum of square of deviations ($\chi^2$) of an unknown proton energy from the rerefence proton energies were evaluated, then least square fitting was performed to estimate the unknown proton energy (Figure 3).

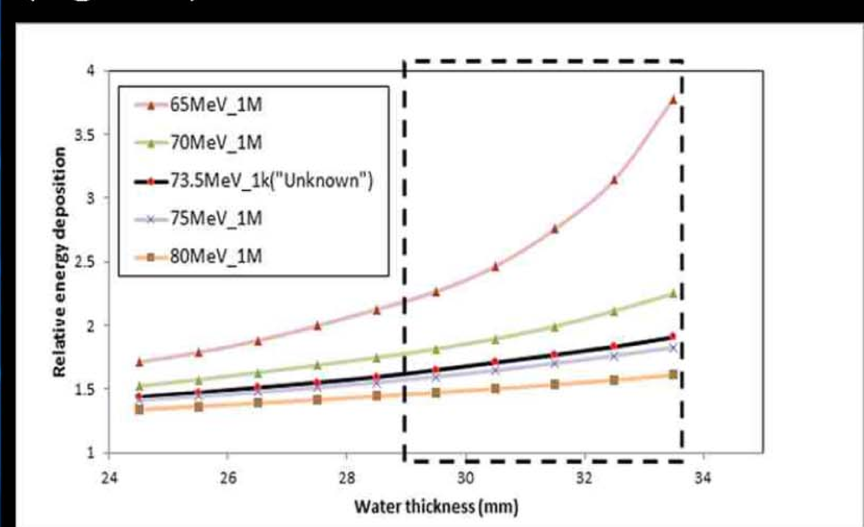



Figure 2. A proton's energy deposition and average energy deposition of different reference proton energies

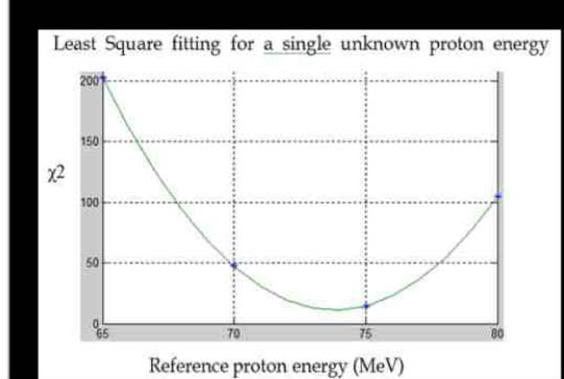



Figure 3. Least Square fitting to estimate an unknown proton energy

The sum of square of deviations were calculated according to the formula given by equation 1,

$$\chi^2 = \sum_{i=1}^{i=5} \frac{\left(x_i - x_{e_i}\right)^2}{\sigma^2} \qquad \text{.......... (1)}$$

where $x_i$ is proton energy deposition of an unknown incoming proton energy at $i^{th}$ water layer. $x_{e_i}$ is the average energy deposition of 1,000,000 reference protons with certain energy (65, 70, 75, and 80 MeV) at $i^{th}$ water layer which were obtained by Gaussian fitting. Both of the xi and $x_{ei}$ were normalized by the data at the first measurement point which refers to the data at the first water layer. The σ is the standard deviation of reference proton energy deposition at $i^{th}$ water layer. The sum square was chosen within a specific region ( i=1 to i =5 ) to avoid the Bragg peak and the entrance regions where energy deposition variation is dramatic or too close to each other (Figure 2).

## 4. Results

The estimation result from 1,000 single protons with energy of 73.5 MeV is 74.16 ± 0.68 MeV, which has a deviation from the actual energy (73.5 MeV) by (73.5-74.16)/73.5 = 0.66/73 ~ 1%. This means the Least Square estimation method based on Geant4 simulation can provide a good result for proton energy estimation with uncertainty ~ 1% (Figure 4).

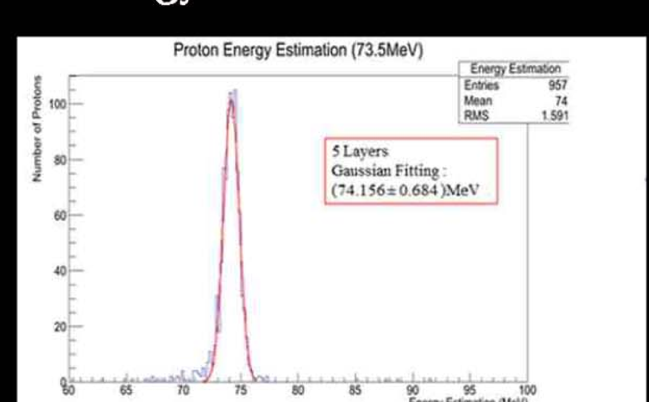



Figure 4. Result of proton energy estimation by using Least Square

The 957 remaining proton number in Figure 4 shows nuclear interaction occured inside the range finder material, this prevented protons in reaching the water layer which was used in Least Square method. According to the result in Figure 4, the range region for Least Square method which was chosen to be used in this study could provide a good result to estimate the proton energy since the remaining proton in this region was still around 95%. The remaining proton number existed in the region of Least Square assured that the Least Square method can be applied for a relatively low proton energy, in which in this case a 73.5 MeV has been estimated by Least Square method with the uncertainty ~ 1%.

## 5. Conclusion and Discussion

The use of least Square method to estimate an unknown proton energy showed a good result since there were two basic conditions [4] faced in this study that the energy deposition inside the material is a Gaussian distribution and the standard deviation in energy deposition at every measurement point is uncorrelated to the other measurement point.

According to the result of Monte Carlo simulation in Figure 4 which provides a result with uncertainty ~ 1%, we can expect that Least Square Monte Carlo method can be used to improve the detector performance, especially for range finder performance in multiple scattering experiment.

## 6. Future work

The Least Square method has a possibility to estimate the proton energy within the therapeutic energy ranges (70 MeV - 230 MeV), especially for proton quality assurance. One of the qualification for monthly proton quality assurance in Chang Gung Memorial Hospital is to measure proton Bragg peak and depth dose distribution by using a detector called as Zebra. This detector is a water equivalent measurement device with resolution ~ 2 mm.

The Bragg peak and depth dose measurement by using Zebra detector can provide a good result, especially for a relatively high energy proton ( > 100 MeV), but the limitation of Zebra resolution may have some difficulties in measuring the Bragg peak of a low energy proton ( < 100 MeV), since a lower the proton energy will have a very narrow Bragg peak spread which means the Bragg peak and proton range determination need a higher detector resolution ( < 2mm).

## References

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