# Development of Proton Computed Tomography (pCT) Detector for Cancer Therapy

Kavita Lalwani for the pCT collaboration (Northern Illinois University, Fermilab and Delhi University).*
**Department of Physics and Astrophysics, University of Delhi, 110007, INDIA*

## Introduction

Proton radiation therapy is an external beam radiation therapy in which dose is delivered by protons. It is much more effective than traditional X-ray therapy because X-rays deposit energy in small packets along their path through tissue, whereas protons deposit much of their energy at the end of their path (called the Bragg Peak) and deposit less energy along the way, therefore protons do less harm to normal tissue. The energy deposition profiles of X-rays and protons are shown in Figure 1.

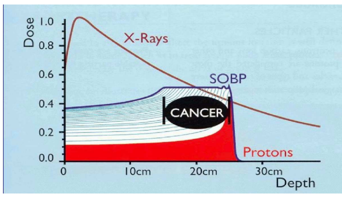


FIG. 1: Curve for energy deposition.

Proton Beam Therapy was first proposed by Robert Wilson in 1946.There are currently about 28 proton therapy centers around the world treating thousands of patients every year. Unfortunately, there is not a single proton therapy facility in India. Proton therapy is a rapidly expanding form of cancer treatment. Because protons have a finite range in matter, this treatment modality allows for a greater degree of conformality than conventional external beam X-ray therapy. To maximize the inherent advantages of proton therapy, the range of protons inside the patient must be able to be predicted with millimetre resolution. In current clinical practice, proton therapy treatment plans are made with pre-treatment X-ray CT scans of the patient. To convert the X-ray CT Hounsfield units to proton relative stopping powers, which are required by the treatment planning software, an empirically derived calibration function is used, which is specific to each X-ray CT machine. However, because of the different dependencies on Z and the Z/A ratio of X-ray attenuation and proton energy loss, the relationship between Hounsfield units and relative stopping powers is not unique. This conversion process leads to range uncertainties of about 3.5 % at treatment time. The uncertainty in relative linear stopping power (RLSP) from XCT data can exceed 5% as shown in Figure 2. Further, X-ray radiographs

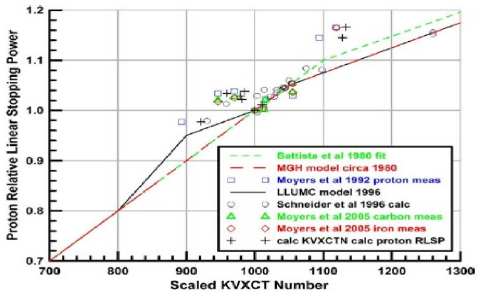


FIG. 2: Uncertainty in Relative Linear Stopping Power from XCT data.

depict only skeletal structures, they do not show the tumor itself. Therefore we would like to image the patient directly with proton CT by measuring the energy loss of high-energy protons that traverse the patient. The development of proton CT is the goal of our project. The advantages and goal of Proton Computed Tomography are listed below:

*Electronic address: `pankavi@gmail.com`

- Lower dose ( factor 5) to patient relative to X-ray CT
- Decrease the range error from 3% to 1% (better electron density map for proton treatment planning → better dose accuracy to target volume)
- Reduce or eliminate CT artifacts due to metal/dental implants with high Z materials
- pCT imaging could replace Cone Beam CT for patient alignment verification before each treatment

How proton CT works, is illustrated in Figure 3. Protons with known entry energy E are

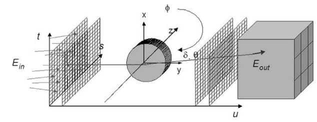

FIG. 3: Illustration of working method used in proton CT.

recorded one by one in the detector reference system (s, t, u) as they traverse the image object from many different projection angles. The recorded data include entry and exit positions and entry and exit angles as well as exit energy E in the energy detector.

Reconstruction of the proton path inside head is shown in Figure 4. We can see that when only the entry position and direction of the incoming proton are known, the best approximation of the proton path within the object is straight line L (Figure 4 (a)). Taking into account both entry and exit position one approximates the proton trajectory by straight line L connecting entry and exit point (Figure 4 (b).

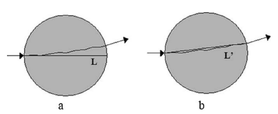


FIG. 4: Reconstructing proton path inside the Head.

A schematic of the pCT device is shown in Figure 5. A proton beam of about 200 MeV traveling from left to right traverses two fiber tracker planes, the phantom head, and the two exit fiber tracker planes. A calorimeter, made

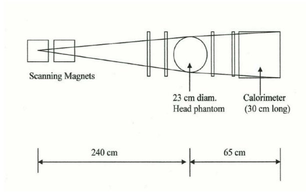


FIG. 5: Schematic of our pCT.

up of 100 layers of scintillators, is used to measure the energy of out going proton from phantom. As seen in Figure 6, the full pCT detector has been simulated in Geant-4.

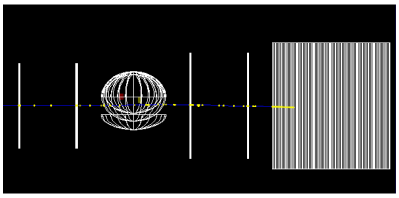

FIG. 6: Visualization of Proton Computed Tomography Detector in Geant4 simulation.

## Status and Outlook

- Simulation work for detector optimization is nearly done and was centered at Delhi.
- Much of the hardware is in procurement.
- Prototypes have been tested with beam, and the full detector will be commissioned in a test beam.
- Final goal is to build a clinical system after development of technology.

## Acknowledgments

I am thankful for the pCT collaboration for giving me the opportunity to work with them for the benefit of mankind.