INITIAL STUDIES on PROTON COMPUTED TOMOGRAPHY USING a SILICON STRIP DETECTOR TELESCOPE

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Abstract

We report initial results from a feasibility study of proton computed tomography (pCT) for applications in proton therapy treatment planning. The aim of the study is to explore experimentally if pCT, which is based on the specific energy loss of protons traversing tissues of different density, could be preferred to conventional computed tomography (CT), which relies on differential absorption of x-rays and is presently used for proton radiation treatment planning.

We present data from proton transmission studies through simple phantoms, taken with a telescope of silicon detectors with very high spatial and good energy resolution. In addition, we report the results of simulations of proton transport through the same phantoms, done with GEANT4, which show good agreement with experimental results. We will evaluate key parameters for pCT-based treatment planning: the spatial and stopping power resolution as a function of the dose deposited in the patient.

We also present our first results on reconstruction of density distribution in a phantom.

Summary

Proton radiation therapy is a highly precise form of cancer therapy, which requires accurate knowledge of the dose delivered to the patient and verification of the correct patient position with respect to the proton beam to avoid damage to critical normal tissues and geographical tumor misses. In existing proton treatment centers dose calculations are performed based on x-ray computed tomography (CT) and the patient is positioned with x-ray radiographs. The use of x-ray CT images for proton treatment planning ignores fundamental differences in physical interaction processes between photons and protons and is therefore inherently inaccurate. Further, x-ray radiographs depict only the skeletal structures of the patients but do not show the tumor itself. Ideally, one would image the patient directly with proton CT by measuring the energy loss of high-energy protons that traverse the patient [1,2]. This method has the potential to significantly improve the accuracy of proton radiation therapy treatment planning and the alignment of the target volume with the proton beam.

Our approach to pCT is to use state-of-the-art silicon detectors, which measure the energy and position of individual protons before and after they traversed the image object. This system, described in [3], permits precision measurements of the position (~50um) and good determination of the energy of protons in the 20-300MeV range, which is accomplished by measuring their specific energy deposition using the time over threshold (TOT) signal (Fig. 1a). This method of determining the energy has best accuracy at low proton energies, where the differential energy loss (linear energy transfer, LET) is largest.. Figure 1 shows the measured energy loss, and the resolution of the energy loss and the inferred energy, which is of the order of 15%.

Figure 2 shows one of our first proton transmission radiographs, a picture of a hollow Al cylinder of 5cm length, 3cm OD, and 0.6cm ID taken with 250MeV protons from the Loma Linda University Medical Center synchrotron. Assuming rotational symmetry, the image allows

reconstruction of a cross-sectional view orthogonal to the cylindrical axis.

We will use measurement and simulations with the Monte-Carlo code GEANT4 as a tool to study the influence of a variety of physical factors on the performance of pCT in general and our experimental setup in particular. The GEANT4 code has proven ability to simulate the interaction of protons down to low energies faithfullly. The code can also be used to estimate the number of proton events which will be rejected due to large-angle scattering as a function of initial proton energy. Figure 3 shows the results of an intial trial simulation of a 250 MeV proton beam impinging on a slab of 10 cm water and an iron plate of varying thickness. This demonstrates that the energy loss and straggling are as expected.
Using theoretical calculations and our measurements, we will present preliminary answers to the following questions:

1. What is the dependence of spatial and density resolution on incident proton energy?
2. What spatial and density resolution can be reached with pCT for a reasonable data acquisition time?
3. How much would additional measurement of entry and exit angles of the protons improve the spatial resolution of pCT?
4. What would be the typical dose to a patient undergoing a pCT?

References

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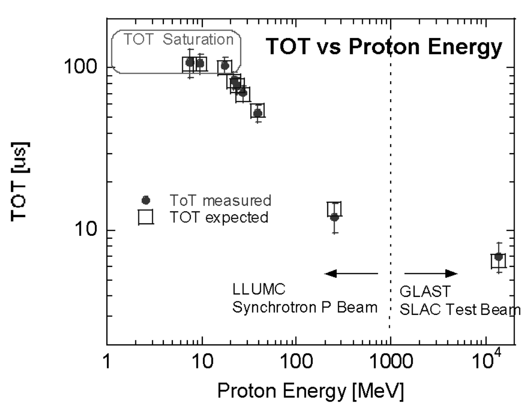

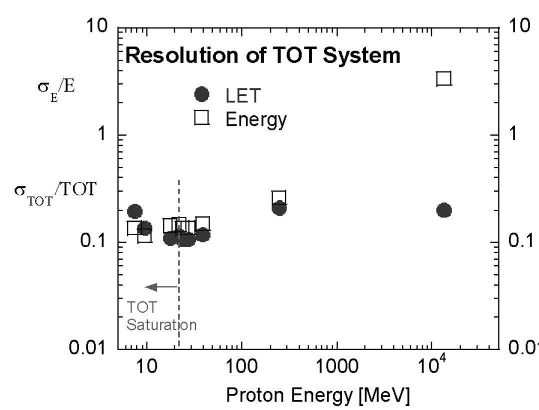

Fig. 1. a. Measured and predicted mean time-over-threshold (TOT) signal as a function of the proton energy. The proton energy can be measured uniquely at energies above 20 MeV (and below 3 MeV, where the signal of stopping protons is not saturating the TOT). The error bars shown are the RMS width of the TOT spectra .
b. Relative width of the measured TOT spectra σ_{TOT}/TOT, and derived energy resolution σ_E/E. The TOT resolution is of the order 10-20% and represents the LET resolution of a single plane. The energy resolution

is about 20% below 250MeV. At energies above 250 MeV, the dE/dx curve is relatively flat, which leads to a relatively low energy resolution.

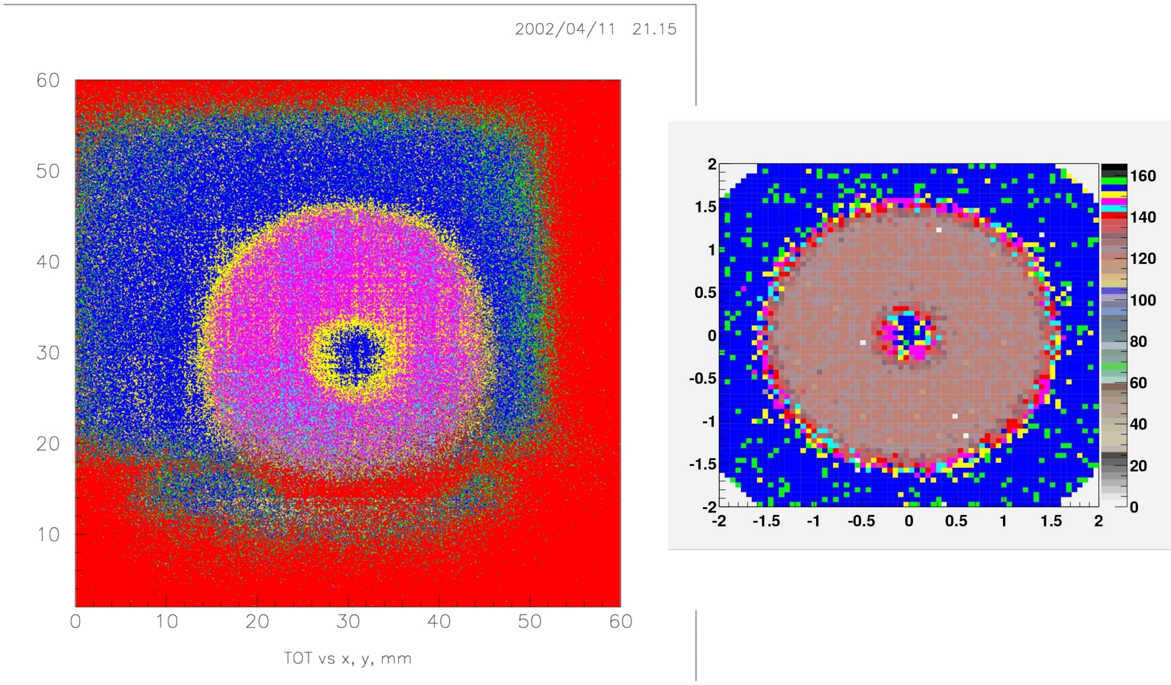

Fig. 2 Date (left) and simulation (right) of Proton transmission data taken with a beam of about 1million 250MeV protons impinging on 25.4cm wax and a 5cm long Al pipe of 3cm OD and 0.6cm ID. The data color code from largest to least energy loss is: red (i.e. the holder), purple, violet, yellow, blue (i.e. the hole and the surrounding). The effect of multiple scattering diffusing the edges is well seen.

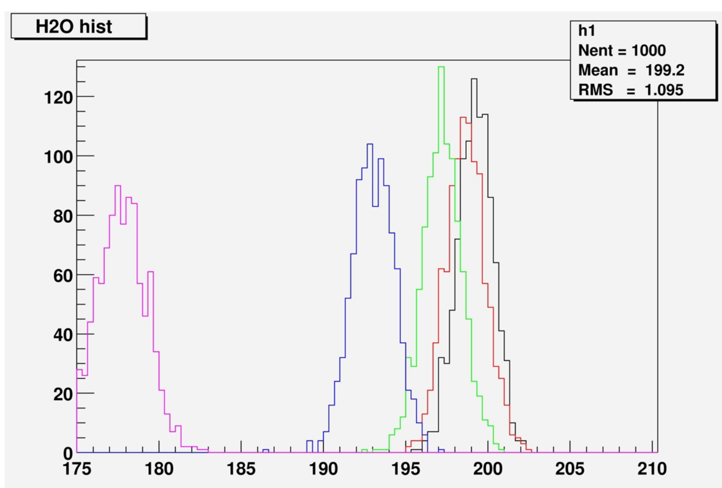

Fig. 3 Simulated energy spectra of 250MeV protons after traversal of 10cm of water and iron plates of varying thickness. Color code of the plate thickness: black =0mm, red = 0.3mm, green =1mm , blue = 3mm, purple = 10mm. The mean energies of the different distributions agree well with the prediction of the NIST tables [4].