



**HAL**  
open science

## Understanding image artifacts for a prototype proton computed tomography scanner via Monte Carlo simulations

Jannis Dickmann, Philipp Wesp, Simon Rit, Mark Pankuch, Robert Johnson,  
Vladimir Bashkirov, Reinhard Schulte, Katia Parodi, Guillaume Landry,  
George Dedes

### ► To cite this version:

Jannis Dickmann, Philipp Wesp, Simon Rit, Mark Pankuch, Robert Johnson, et al.. Understanding image artifacts for a prototype proton computed tomography scanner via Monte Carlo simulations. International Conference on the Use of Computers in Radiation Therapy (ICCR), Jun 2019, Montreal, Canada. hal-02283822

**HAL Id: hal-02283822**

**<https://hal.science/hal-02283822v1>**

Submitted on 31 Jan 2025

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

# Understanding image artifacts for a prototype proton computed tomography scanner via Monte Carlo simulations

J. Dickmann<sup>1</sup>, P. Wesp<sup>1</sup>, S. Rit<sup>2</sup>, M. Pankuch<sup>3</sup>, R. Johnson<sup>4</sup>, V. Bashkirov<sup>5</sup>, R. Schulte<sup>5</sup>, K. Parodi<sup>1</sup>, G. Landry<sup>1,6</sup>, G. Dedes<sup>1,†</sup>

<sup>1</sup>*Department of Medical Physics, Fakultät für Physik, Ludwig-Maximilians-Universität München (LMU Munich), Garching bei München, Germany;* <sup>2</sup>*CREATIS, Université de Lyon, France;*

<sup>3</sup>*Northwestern Medicine Chicago Proton Center, Warrenville, USA;* <sup>4</sup>*Department of Physics, U.C. Santa Cruz, USA;* <sup>5</sup>*Division of Biomedical Engineering Sciences, Loma Linda University, USA;*

<sup>6</sup>*Department of Radiation Oncology, University Hospital, LMU Munich, Munich, Germany*

## Introduction

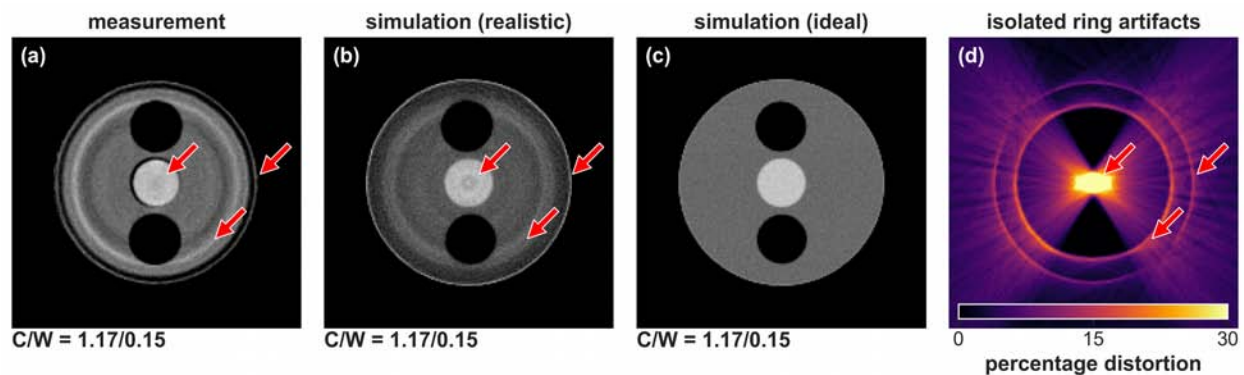
In proton therapy, accurate determination of a relative stopping power (RSP) map of the patient is required for treatment planning and treatment plan adaptation. Proton computed tomography (pCT) could achieve low dose and high accuracy RSP images at the treatment site. Previous studies on pCT accuracy [1] indicate the potential of imaging with protons and heavier ions. The phase II prototype pCT scanner of the Loma Linda University and the University of California Santa Cruz consists of two tracker modules, one before and one after the scanned object and a five-stage scintillator acting as energy detector. The scanner operates in single particle tracking mode at 1 MHz counting rate and registers positions, directions and the residual energy of every proton. An important tool for understanding the potential and limitations of the prototype scanner is its detailed simulation. To reproduce and understand artifacts present in reconstructed images, we extended a simulation platform, which was initially presented in [1]. The digitization procedure was emulated to obtain simulation output that can be processed with the standard reconstruction chain used for experimental data. Furthermore, the simulation was amended in order to reproduce non-linearities and subtle geometrical detector effects.

## Materials & Methods

The simulation platform is based on Geant4 (release 10.02.p01). We developed a beam model based on position and direction measurements of a prior pCT scan. To model the non-linear response of the scintillating detector due to quenching, we obtained parameters of Birk's law [2] based on experimental data. This quenching model was then incorporated into the simulation. The detector response and the calibration results from the simulations were compared to that of measurements. To obtain the water-equivalent path length (WEPL) needed for reconstruction, a look-up table is created based on data of an initial calibration run. Inaccuracies in the look-up table manifest themselves in the reconstructed image as artifacts, affecting RSP accuracy. To understand these artifacts, the platform is capable of simulating pCT scans in three levels of realism: ideal scans (i.e. no detector effects), fully realistic scans taking into account inhomogeneities in the detector response and non-linearities in the energy detector, and finally semi-realistic scans as combinations of ideal and realistic detector information. We quantified the mean RSP accuracy of the realistic simulation and compared it to measurements. We used the semi-realistic simulation to identify causes of artifacts by gradually increasing the level of realism. Experimental and simulated scans of a water phantom and several cylindrical phantoms with plastic tissue equivalent inserts were investigated. We identified distorted WEPL intervals and verified that these correspond to the artifacts in the image by reconstructing the distorted WEPL fraction of every voxel in the volume.

## Results

In fig. 1 (a), an experimentally acquired reconstruction of a cylindrical phantom with inserts and in fig. 1 (b) the corresponding realistic simulations incorporating all detector effects are shown. Both display ring-shaped artifacts as indicated by arrows. In the idealized simulation shown in fig. 1 (c), these artifacts are not present and thus they are caused by detector effects. Artifacts occurred at WEPL intervals around multiples of about 50 mm. These may be caused by protons stopping near the stage boundaries of the 5-stage energy detector (48.7 mm, 101.4 mm and 154.1 mm) or due to the calibration phantom geometry (repeated blocks with WEPL of 52.3 mm). In fig. 1 (d), the voxel-wise percentage fraction of WEPLs in these intervals is shown. Regions with a high fraction correspond to regions in the image with low RSP accuracy. Mean RSP accuracy was 0.9% both in measured and realistic simulated scans.



**Figure 1:** RSP reconstructions of (a) experimental data, (b) realistic simulated data and (c) idealized simulated data. In (d) the voxel-wise fraction of WEPLs originating from distinct distorted intervals are shown and correspond to ring artifacts in (a) and (b). Arrows indicate location of image artifacts.

## Discussion & Conclusions

In this study we present a detailed simulation of the phase II pCT prototype scanner. The extended simulation platform creates realistic raw detector data which agree with experimental data. The RSP accuracy of experimental scans can be reproduced and detector related image artifacts could be identified. Further improvements of RSP fidelity may even allow for a reduction of image artifacts in measurements.

## References

- [1] Giacometti, V. et al. (2017). Software platform for simulation of a prototype proton CT scanner. *Med. Phys.*, 44(3), 1002–1016. <https://doi.org/10.1002/mp.12107>
- [2] Birks, J. B. (1951). Scintillations from Organic Crystals: Specific Fluorescence and Relative Response to Different Radiations. *Proc. Phys. Soc. A*, 64(10), 874. <https://doi.org/10.1088/0370-1298/64/10/303>

## Acknowledgements

German Research Foundation project #388731804 and Munich-Centre for Advanced Photonics. Bavaria-California Technology Center and Franco-Bavarian university cooperation center.

†Corresponding Author: [G.Dedes@lmu.de](mailto:G.Dedes@lmu.de)