Investigating the impact of secondaries neutrons on Compton camera for medical imaging

JULY 12–16 2020 VIRTUAL
JOINT AAPM | COMP MEETING
EASTERN TIME [GMT-4]

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INTRODUCTION

Prompt Gamma Imaging: The production of prompt gammas during a proton therapy treatment provides a mechanism for indirectly evaluating proton dose delivery. Prompt gamma imaging (PGI) aims to use the detection and reconstruction of the prompt gamma distribution to produce an in-vivo dose verification technique for proton therapy[1].

Compton Camera: The basic function of a Compton camera is to track an incident gamma as it undergoes multiple Compton scatters, recording the energy deposited (ΔE) and the position of each interaction. From two or three consecutive scatters it is possible to limit the source location of the incident gamma to the surface of a cone-of-origin. The addition of further events generates a picture of the gamma source[2] or, hopefully, in our case, a correlation to the delivered proton dose distribution.

AIM

To better understand the impact of neutrons and their secondaries on the performance of a pre-clinical prompt gamma (PG) Compton camera (CC).

METHOD

Geometry: A Monte Carlo (MC) model of the POLARIS Compton camera (CC) imaging system[3] (consisting of two detection stages containing a total of 64 Cadmium Zinc Telluride (CZT) crystals) based at the Maryland Proton Treatment Center was constructed using Geant4 (v10.p03). With the MC model, simulations of a 175 MeV proton pencil beam incident on a 30 x 10 x 10 cm high-density poly-ethylene phantom were performed. Detectors were located 10 cm from phantom.

Data Processing: The MC model tracked all secondary particles interacting with the CZT crystals, specifically any particle with an energy loss greater than zero. For each interaction in the CC, the particle type, position, energy deposition, time stamp was stored in a ROOT output file. The reaction history of each interacting particle was also stored in order to determine whether it was produced by a neutron interaction. The resulting interactions were split into non-neutron secondaries (NNS) and neutron secondaries (NS), and their impact on the energy deposition, timing and PG scatters recorded by the CC were investigated.

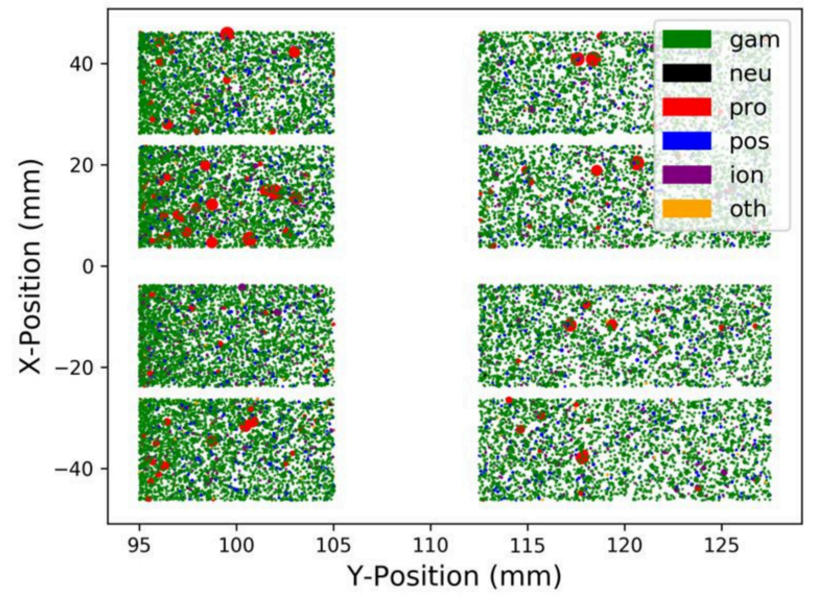
Reconstructions: A simple back projection algorithm was used to reconstruct the data using a 300 x 100 x 100 mm^3 reconstruction volume with 4 mm^3 resolution.

RESULTS

Table 1 demonstrates the large number of secondaries produced by neutron interactions, including 27% of the detected gammas. Figures 1 & 2 highlight the energy deposited by particles other than gammas. In both figures, we can see that gammas dominate, but the red dots (Figure 1) and flat orange line (Figure 2) demonstrate that a relatively few (0.5%) high-energy protons can have a big impact. Figure 3 demonstrates the difference in time stamps for the non-neutron secondaries and the neutron secondaries. Lastly, Figure 4 shows how the non-neutron secondaries create noise in the reconstructed back-projection images.

	Total	Gamma	Ion	Positron	Proton	Neutron
All	2904620 (100%)	2366974 (81.5%)	359582 (12.4%)	135128 (4.7%)	13791 (0.47%)	14257 (0.49%)
Non-Neutron Secondaries (NNS)	1837130 (63.25%)	1723065 (93.8%)	1309 (0.07%)	98011 (5.34%)	3174 (0.17%)	0 (0.0%)
Neutron Secondaries (NS)	1067490 (36.75%)	643909 (60.3%)	358372 (33.6%)	37117 (3.48%)	10617 (0.99%)	14257 (1.34%)

Table 1. Breakdown of particles interacting with the detector. Total number of starting particles: 1 x 10^8 protons.



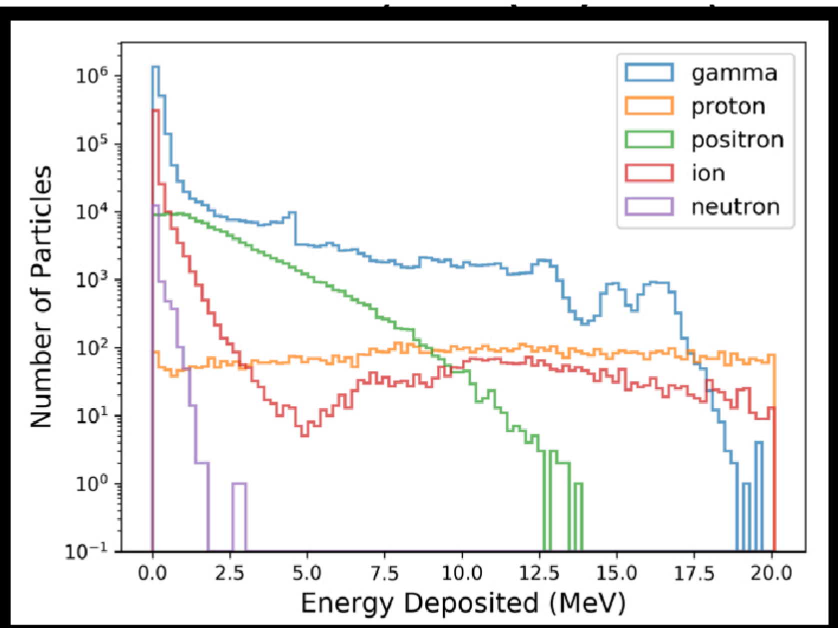
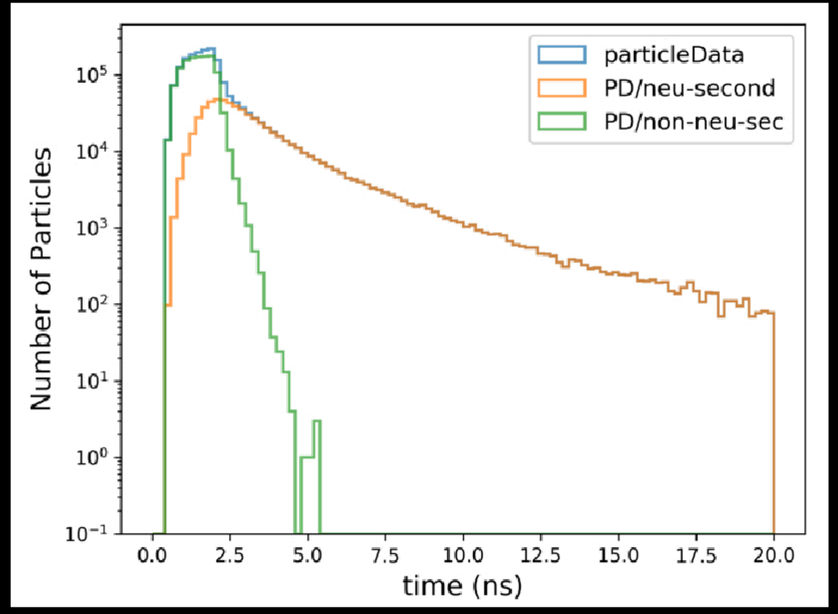


Figure 1. (Above) 2D position plot of particle interaction, showing the type of particle (marker color) and the amount of deposited energy (marker size).

Figure 2. (Top Right) Energy deposited within the detector, broken down by particle type. Gamma is the dominant depositor of energy below 12 MeV but proton and ions become dominant above 18 MeV.

Figure 3. (Right) Time stamps for NNS and NS particles. Notice the lack of time stamps for NNS particles above 4 ns.



CONCLUSION

Secondaries produced from neutron interactions in the target have a substantial impact on the function of a CdZnTe Compton camera during a proton irradiation, negatively affecting both data and image quality.

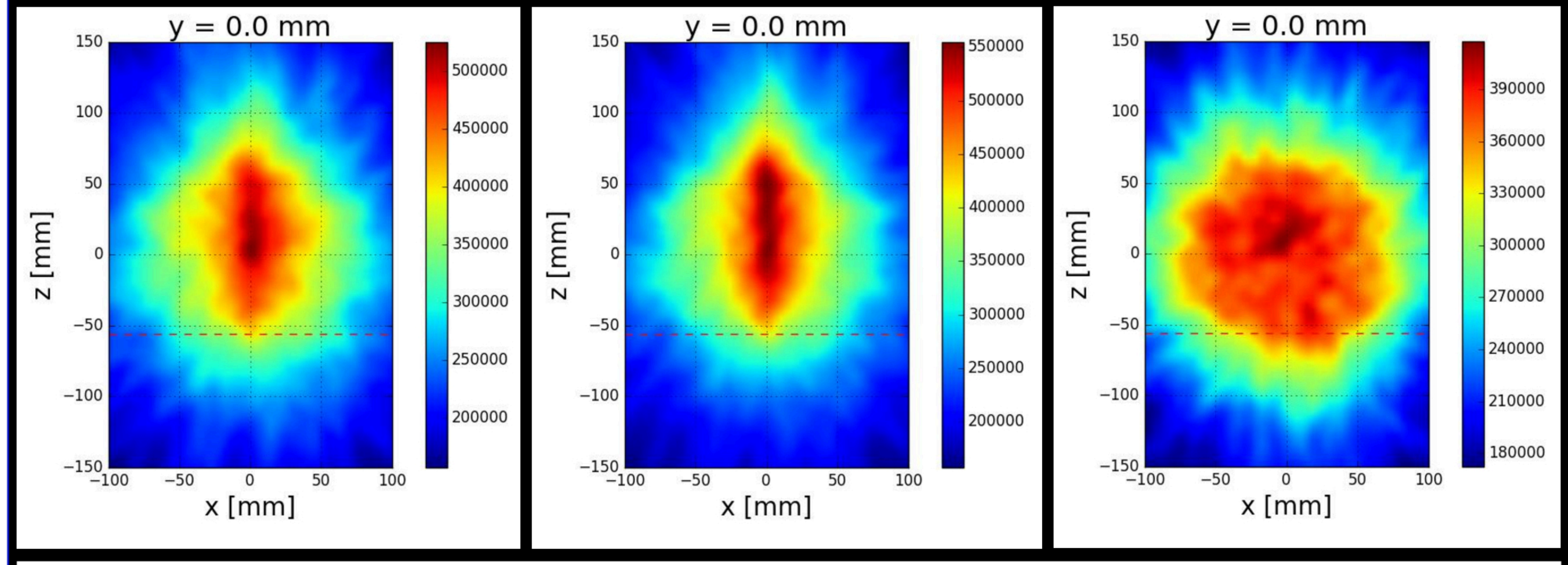


Figure 4. 2D Backprojection slices thru center of beam for all gammas (left), only non-neutron secondary gammas (middle) and only neutron secondary gammas (right). The dashed line represents the end of range for the 175 MeV protons.

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ACKNOWLEDGEMENTS

H3D Inc. from Ann Arbor, MI USA for supporting their Polaris J detectors.

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