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Characterisation of Secondary Neutrons Produced During Beam Therapy Using TOPAS MC Simulations

Fajer Alqahtani 1,2 , Jon Taylor 1 , Carlos Chavez-Barajas1 , Gianluigi Casse1, Alan Taylor 1 , Tony Smith 1, Nicola Massari 3, and Luca Parmesan3

1 University of Liverpool, Department of Physics, Oliver Lodge, Oxford Street, Liverpool L69 7ZE, U.K.
2 University of Bisha, Department of Physics, College of Sciences, P.O. Box 344, Bisha 61922, Saudi Arabia.
3 Fondazione Bruno Kessler (FBK), Sensors & Devices Center (S&D), via Sommarive 18, 38123 Trento, Italy

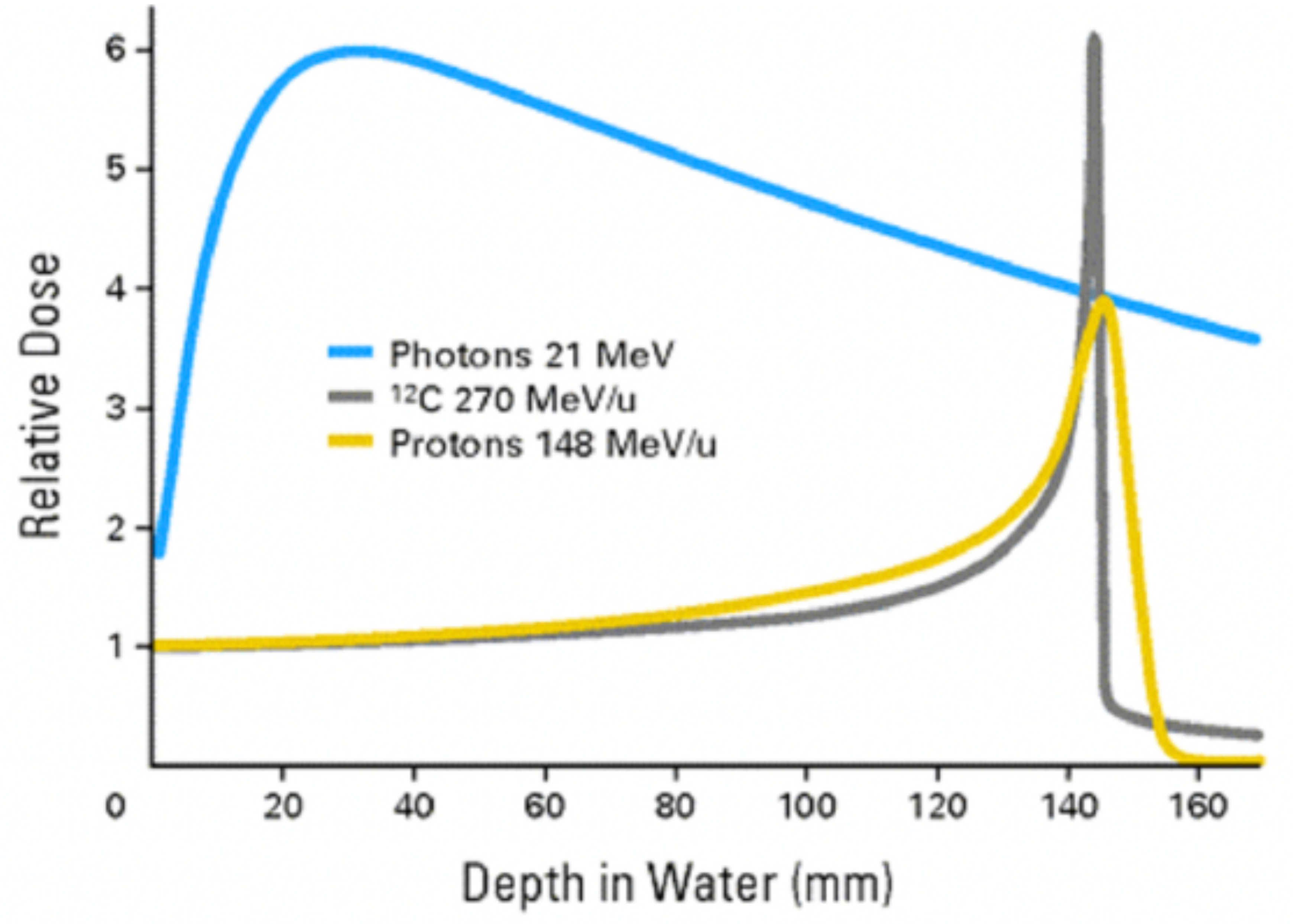
Particle therapy

Aims to: treat cancers and reduce the dose received by healthy tissues

- A beam of particles is generated by an accelerator
- Carbon ions and protons deposit most of their energies at the Bragg Peak (Bethe-Bloch)

$$-\frac{dE}{dx} = \frac{4\pi z^2 e^4}{m_0 v^2} nZ \left[\ln\left(\frac{2m_0 v^2}{I}\right) - \ln\left(1 - \frac{v^2}{c^2}\right) - \frac{v^2}{c^2}\right]$$

- Interactions with human tissue (or water) lead to coulomb scattering and fragmentation reactions which affects surrounding tissues
- Carbon ions have a 'sharper' Bragg peak than protons but also have an exit dose (fragmentation 'tail') after the Bragg peak due to fragmentation of the carbon ions



Depth-dose profiles of proton, carbon ion and photon beams; taken from (1)

1. Dilmanian, F. A., Eley, J. G., Rusek, A., & Krishnan, S. (2015). Charged particle therapy with mini-segmented beams. *Frontiers in oncology*, *5*, 269.

Particle therapy monitoring

Aims to: ensure that the correct dose is directed to the target within acceptable tolerances

In this work:

1- TOPAS Monte Carlo used to:

- Monitor the primary beam in a water phantom (representing human tissue) using a pixelated silicon detector
- Monitor the secondary neutrons produced during beam interactions within the water phantom to infer the primary beam Bragg peak using strips (DAMPE) silicon detector

2- Measurements using strips (DAMPE) silicon detector to compare with the simulation’s results

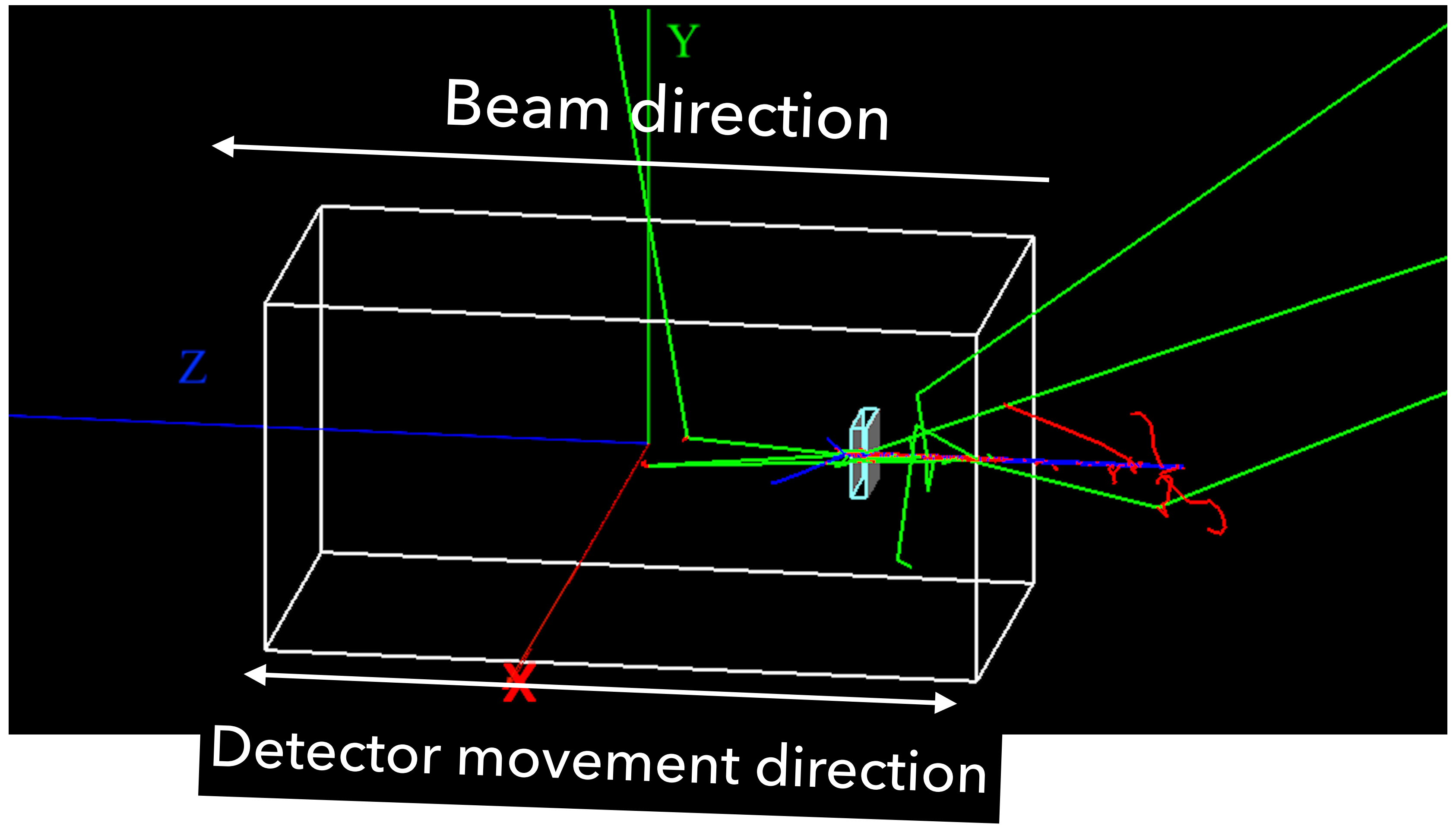
TOPAS Monte Carlo toolkit

New MC toolkit Designed to:

- assist clinical physicists and researchers to use Monte Carlo simulation easily
- using Geant4 toolkit radiation physics libraries easily and supports visualization
- TOPAS MC is typically less memory-intensive and faster than Geant4
- provide a high level of accuracy and be easy to use
- generate realistic images of the distribution of dose in the patient
- simulate the transport of particles through complex geometries

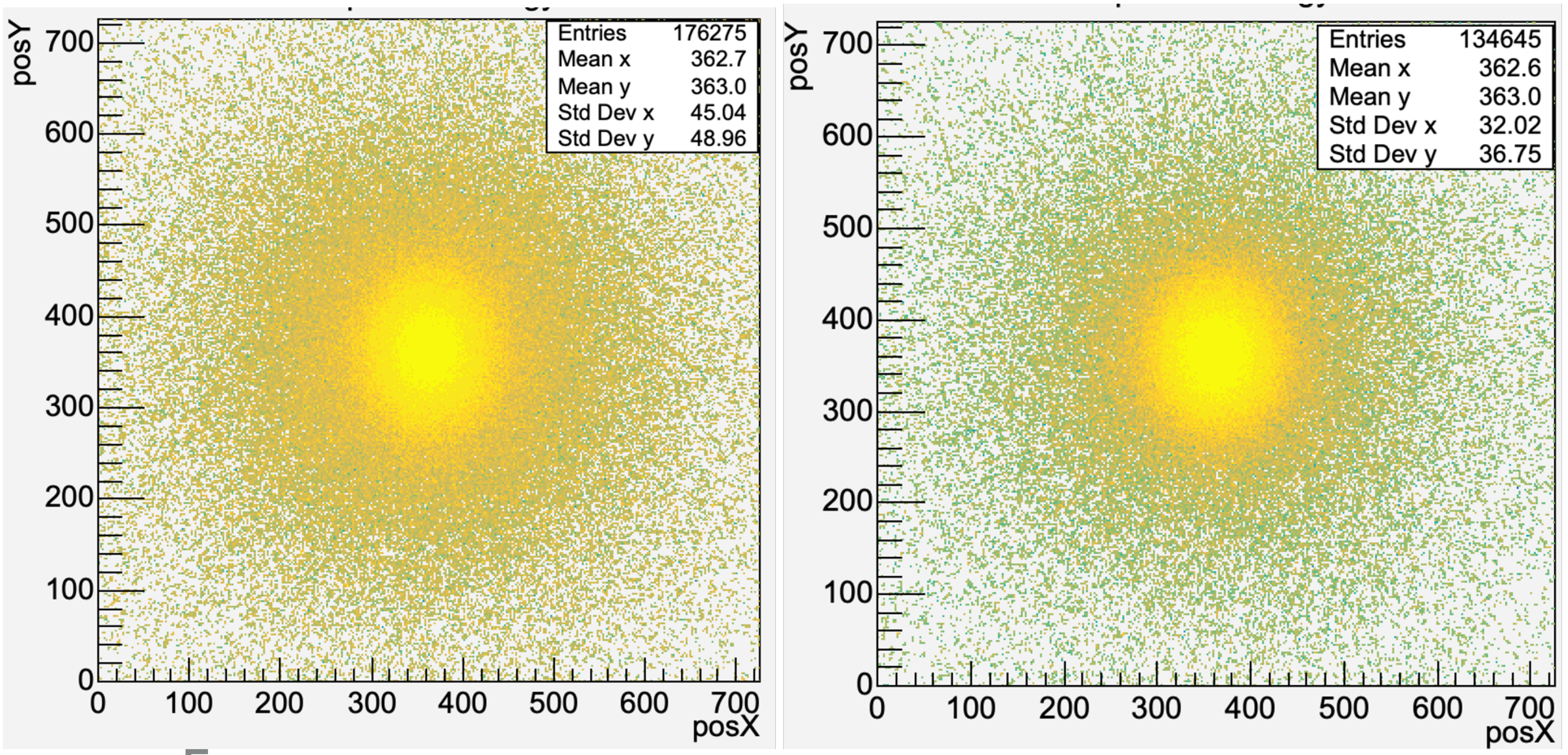
TOPAS MC configuration

- Water phantom: 200mm x 200mm x 400mm
- Silicon detectors: 150um thick
- Particle source: Carbon ion beams
- Distribution: Gaussian
- Physics list: Default
- Pixel size: 80*80 μm^2
- Each detector consists of 500*500 pixels

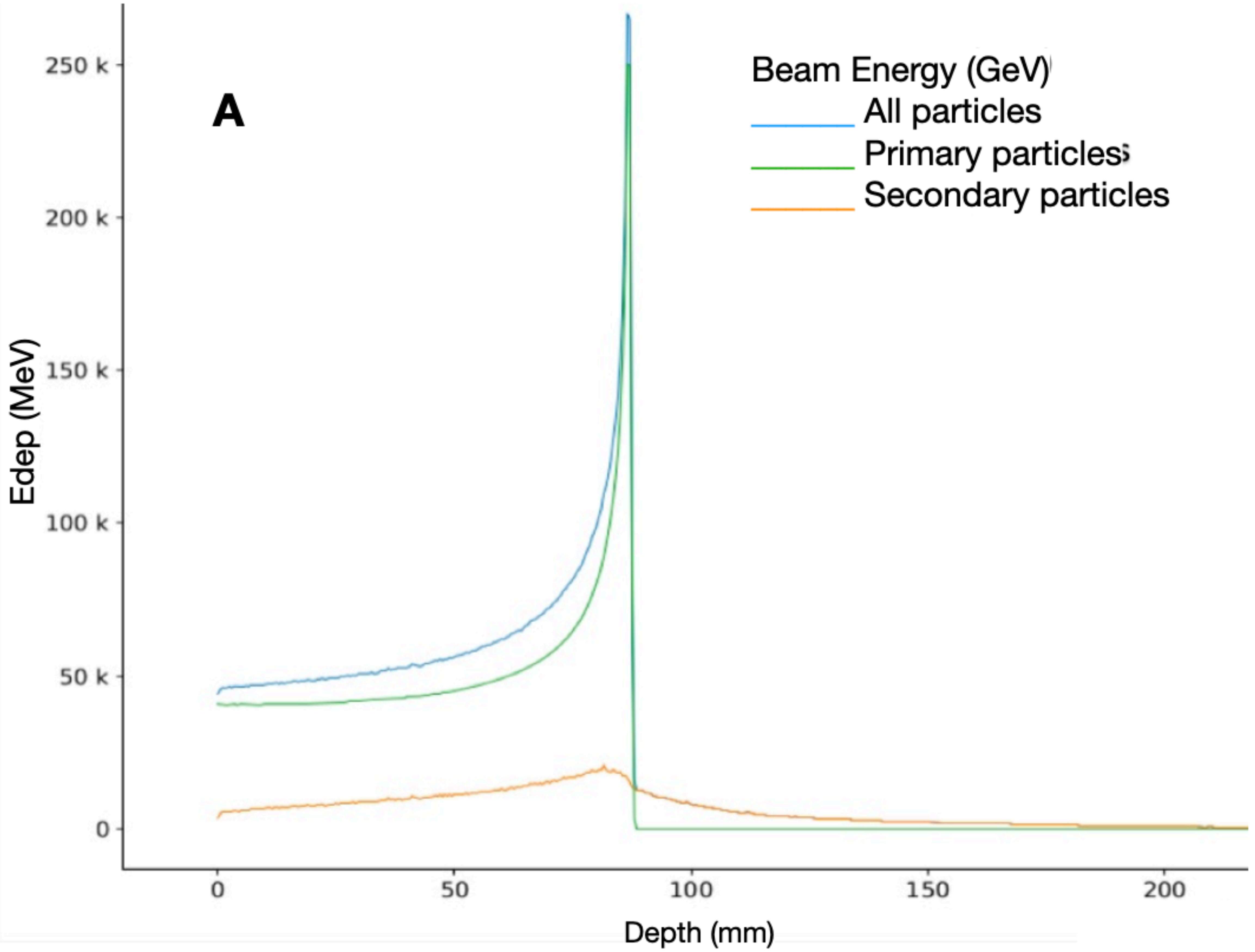


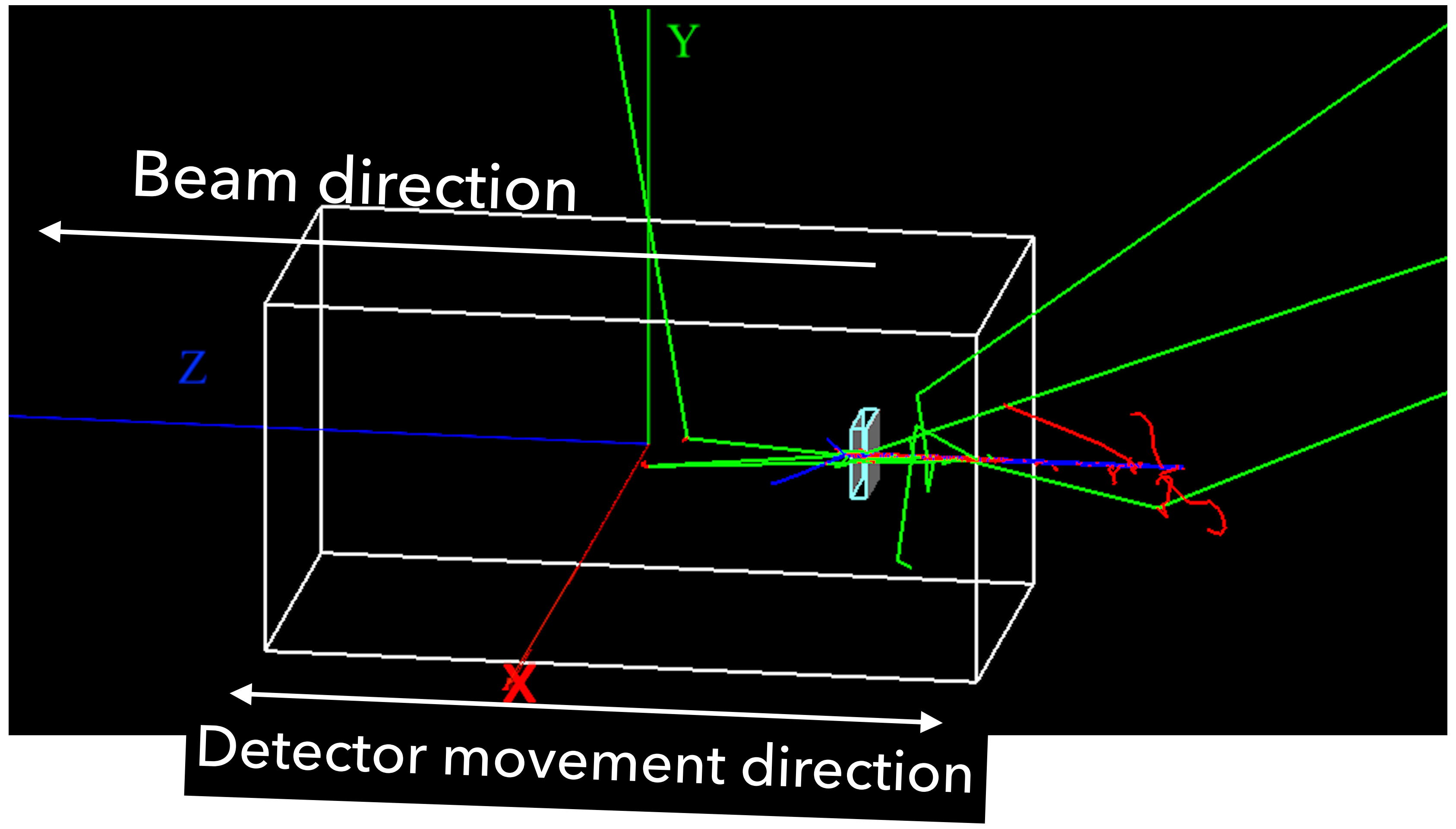
Snapshot of simulating 2 events of carbon ions in TOPAS.

Hit maps for Carbon ions beam and associated secondary particles at 2.4GeV, to two silicon detectors placed within a water phantom at Bragg Peak region



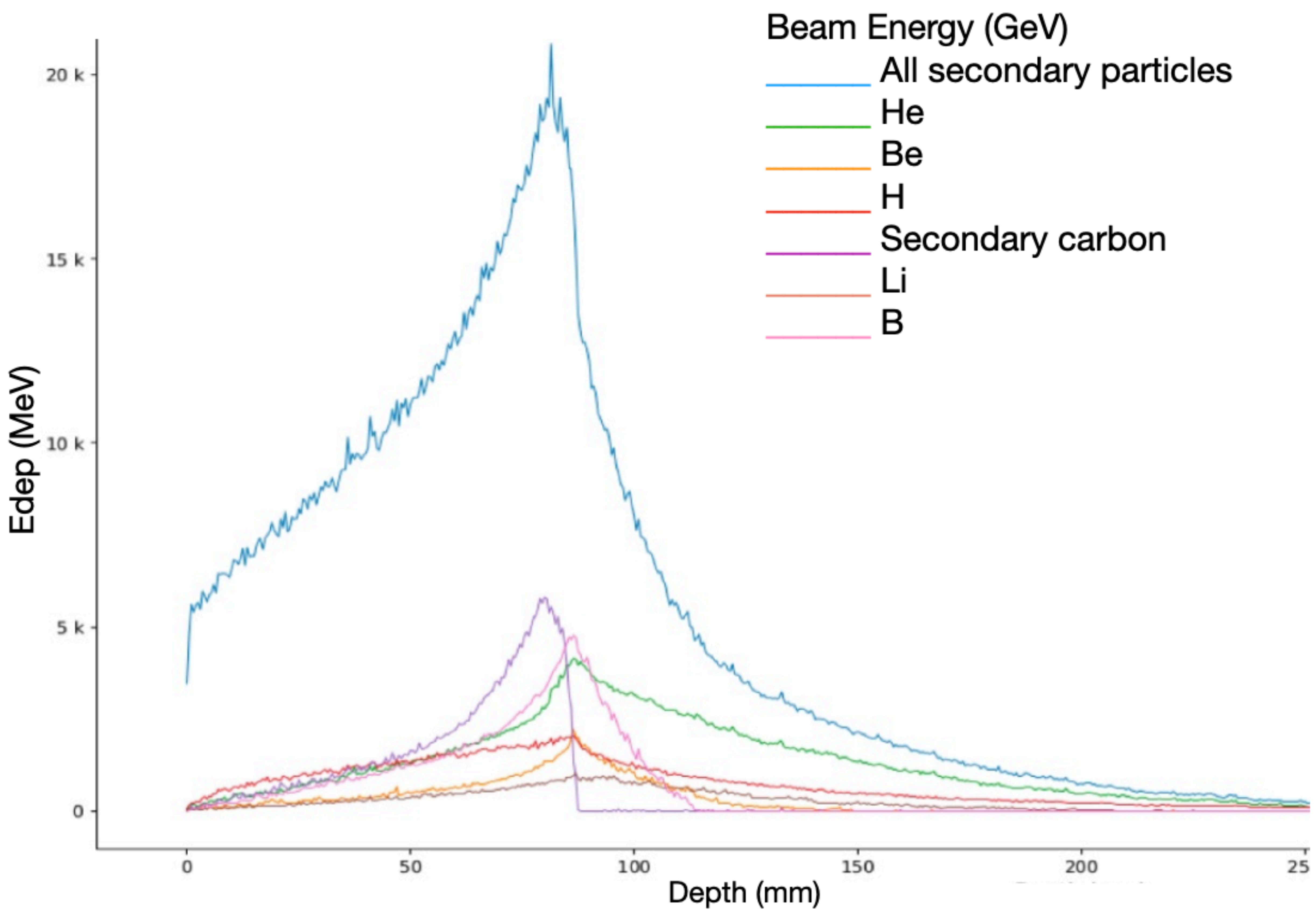
Energy deposited of primary beam and secondary particles

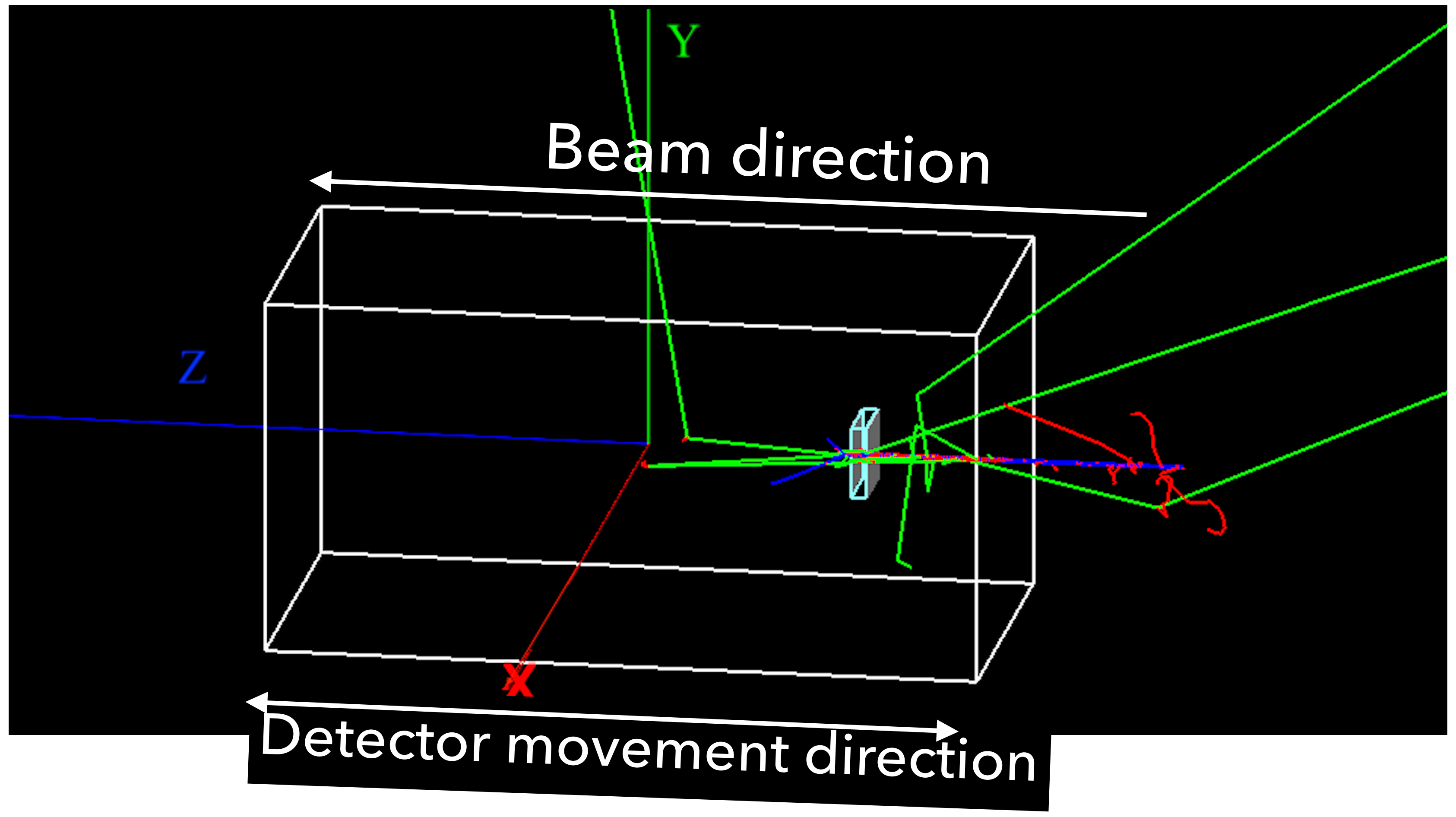




- Energy deposited for 2.4 GeV carbon ions and secondary particles irradiating a silicon detector positioned along the beam axis within a water phantom.
- The deposited energy after the Bragg peak is from the fragmentations of carbon ions

Energy contributions for secondary particles associated with carbon ion beam





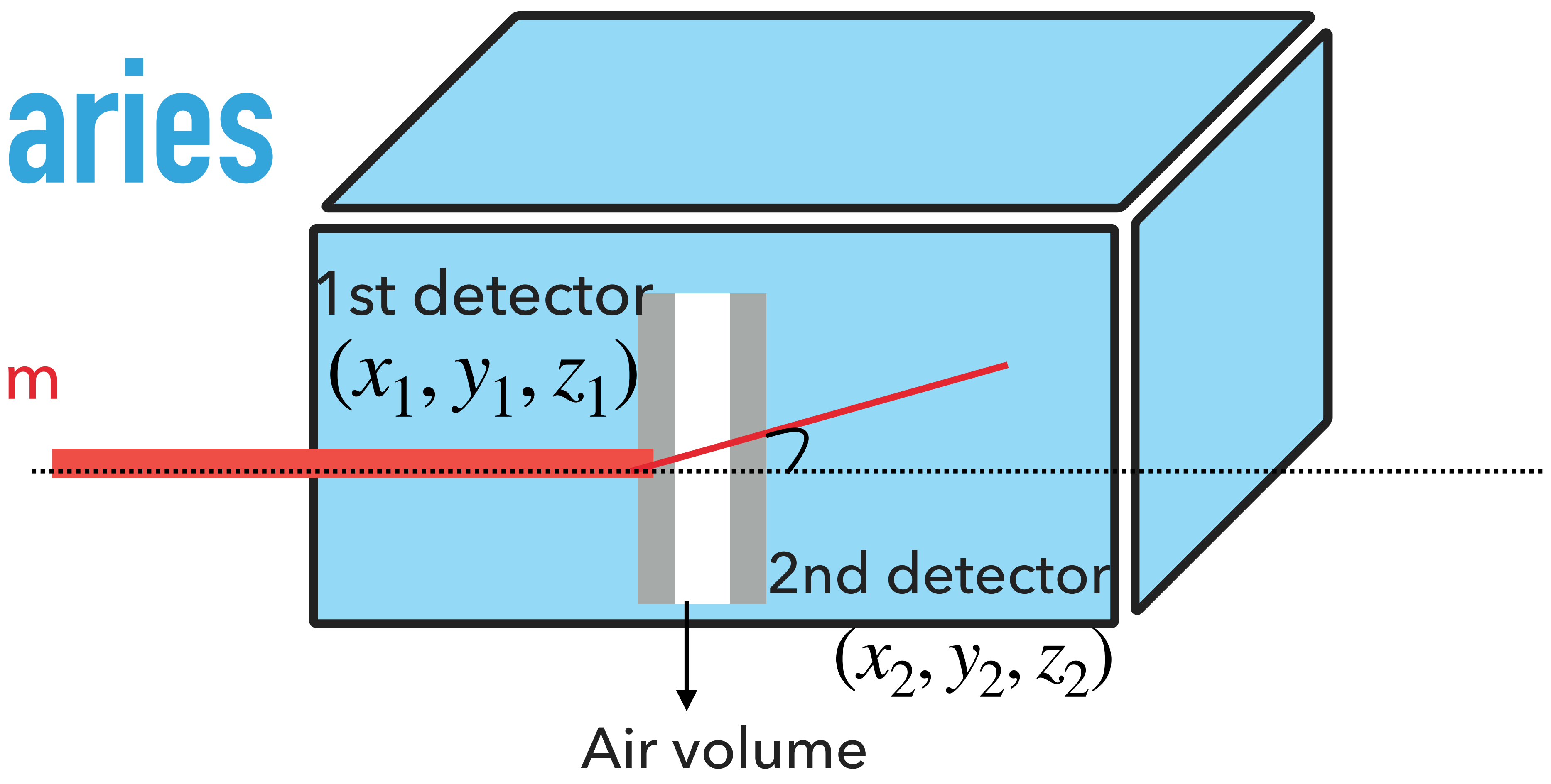
- Because of their extended ranges, He and H fragments greatly influence the long energy deposition tail.
- The energy deposition peak of the secondary carbon and B ions is larger than the other fragments.
- Fragments with a lower atomic number (He, H, Li), carry a significant amount of the projectile's momentum. Results showed good agreement with literatures

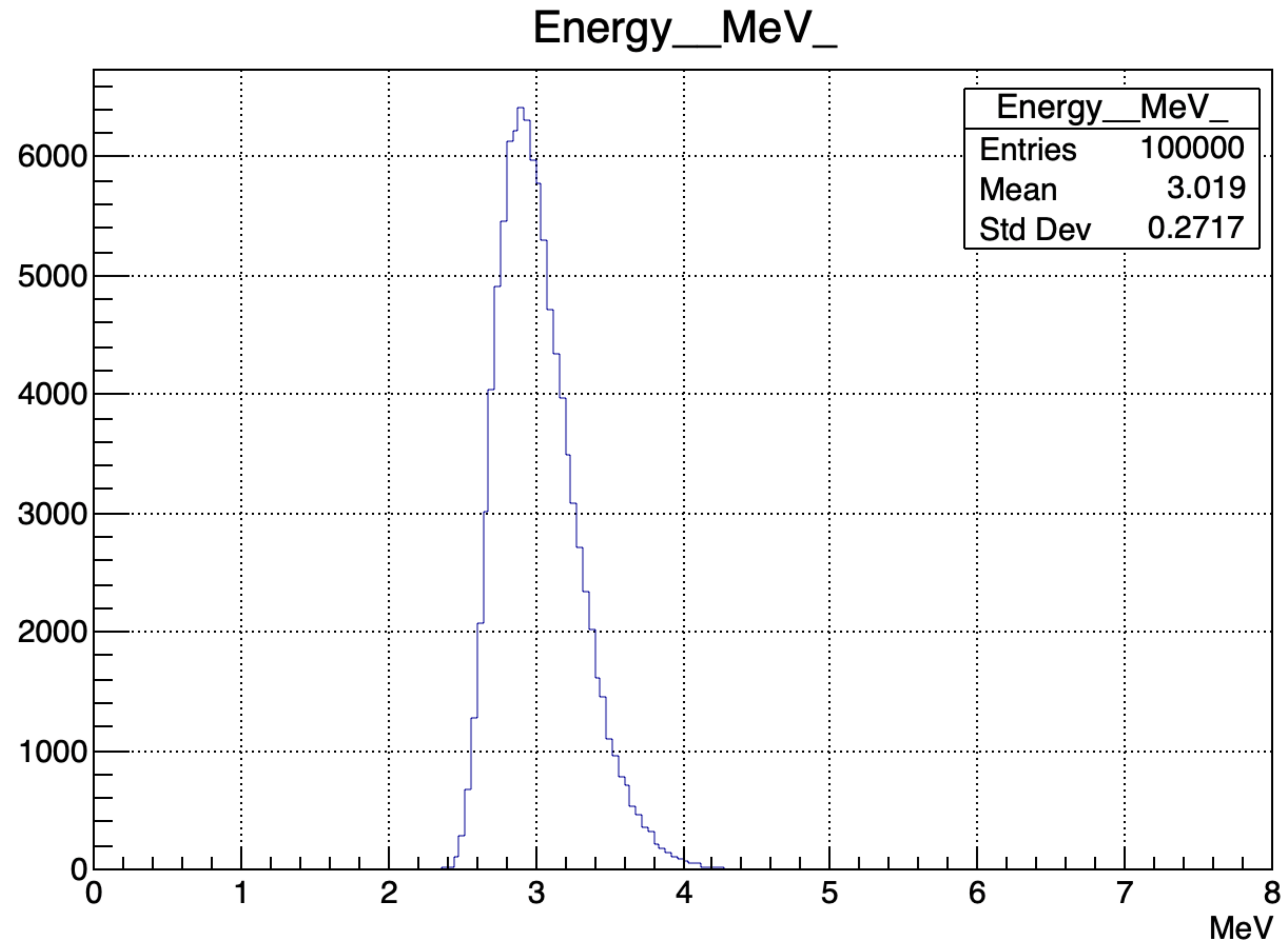
1- Bey, A., Ma, J., Furutani, K.M., Herman, M.G., Johnson, J.E., Foote, R.L., Beltran, C.J., 2022. Nuclear fragmentation imaging for carbon-ion radiation therapy monitoring: an in silico study. International Journal of Particle Therapy 8, 25–36.

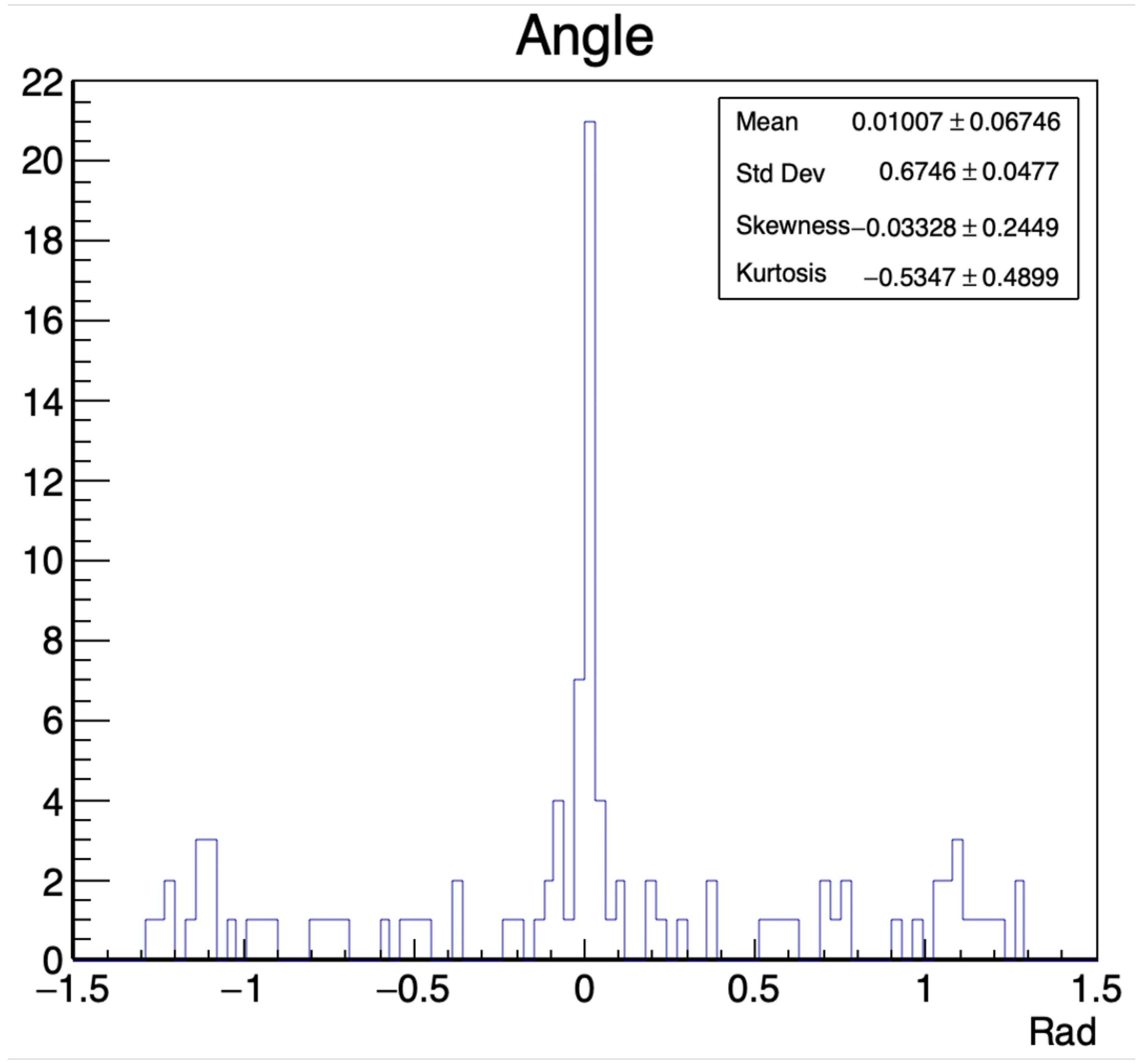
2- Ying, C., Bolst, D., Tran, L.T., Guatelli, S., Rosenfeld, A.B., Kamil, W., 2017. Contributions of secondary fragmentation by carbon ion beams in water phantom: Monte carlo simulation, in: Journal of Physics: Conference Series, IOP Publishing. p. 012033.

Energy distribution and scattering angle of primaries

- Silicon detectors: 150um thick
- Particle source: Carbon ion beam
- Beam energy: 2.4GeV
- Physics list: Default
- Pixel size: 80*80 μm^2



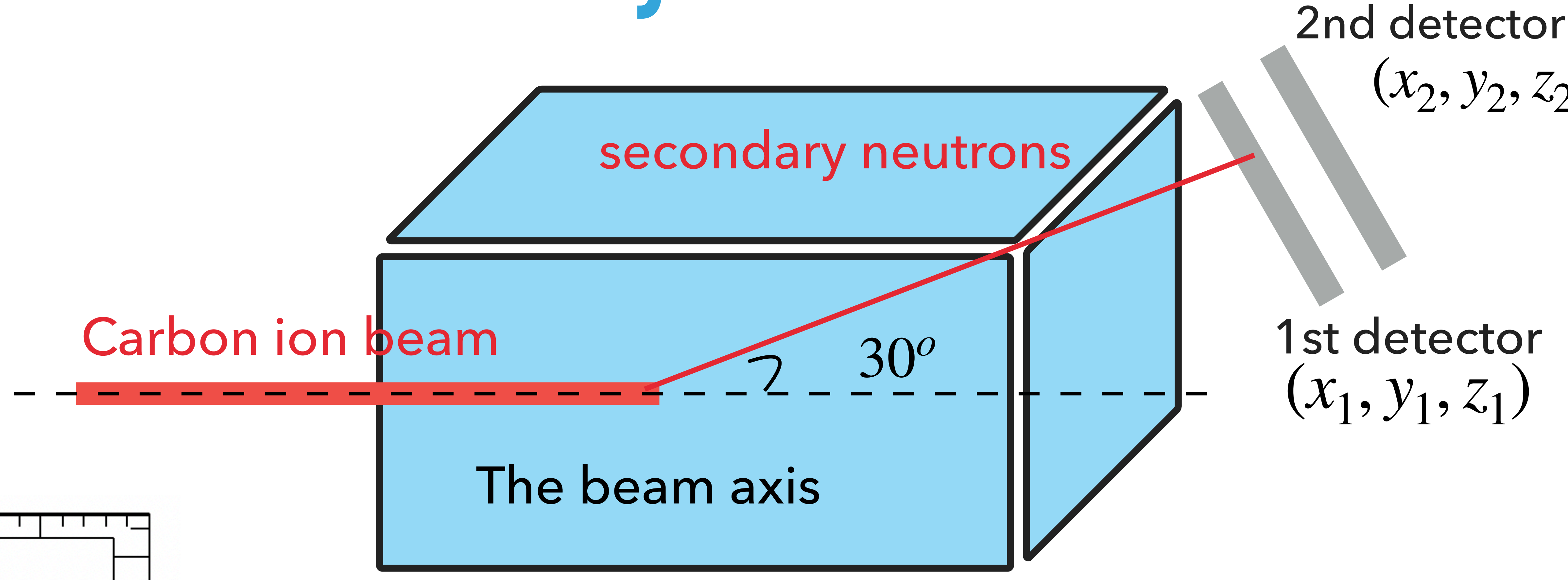


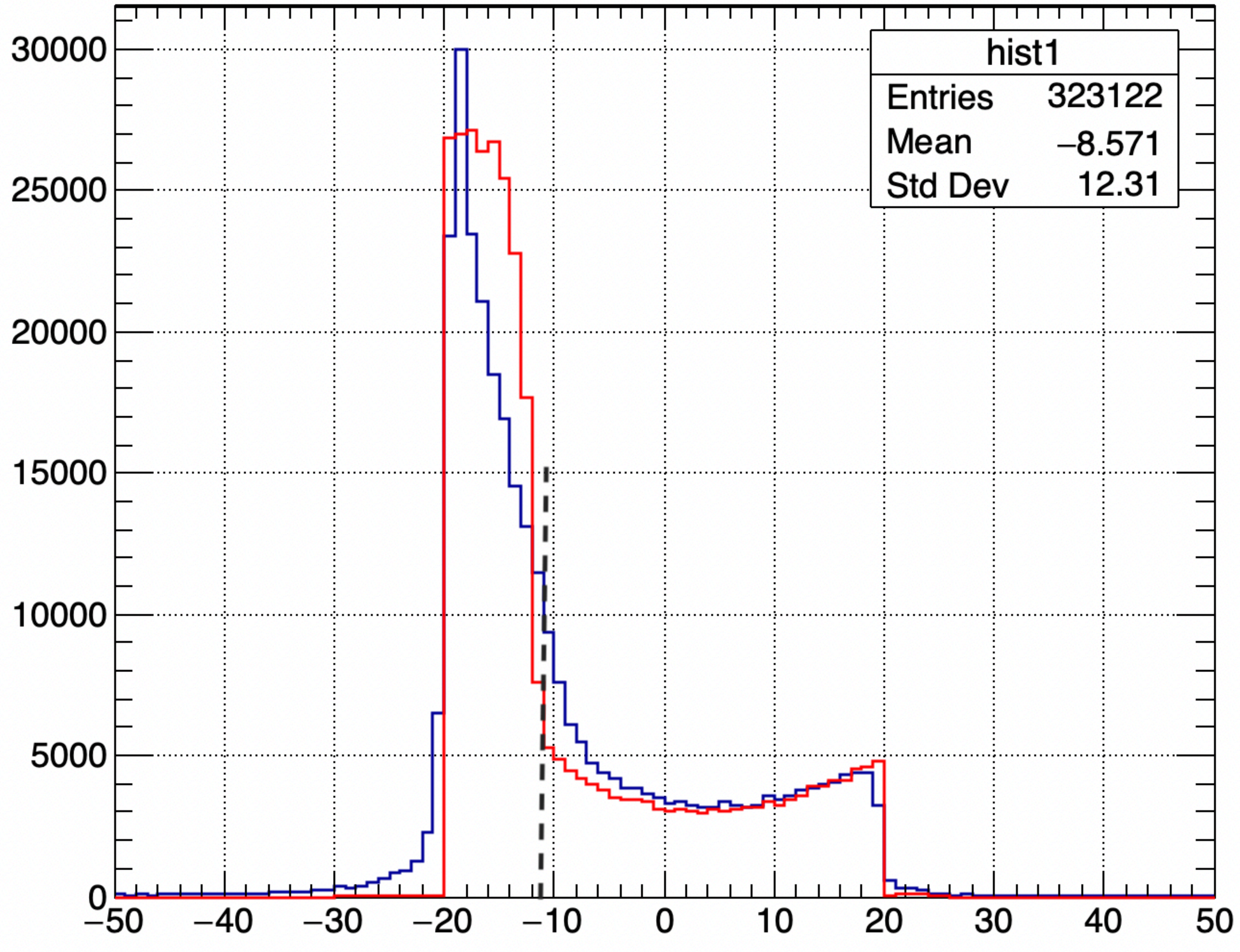


Two silicon detectors separated by a volume of air are used to measure the hit positions in the detectors to evaluate the scattering angle

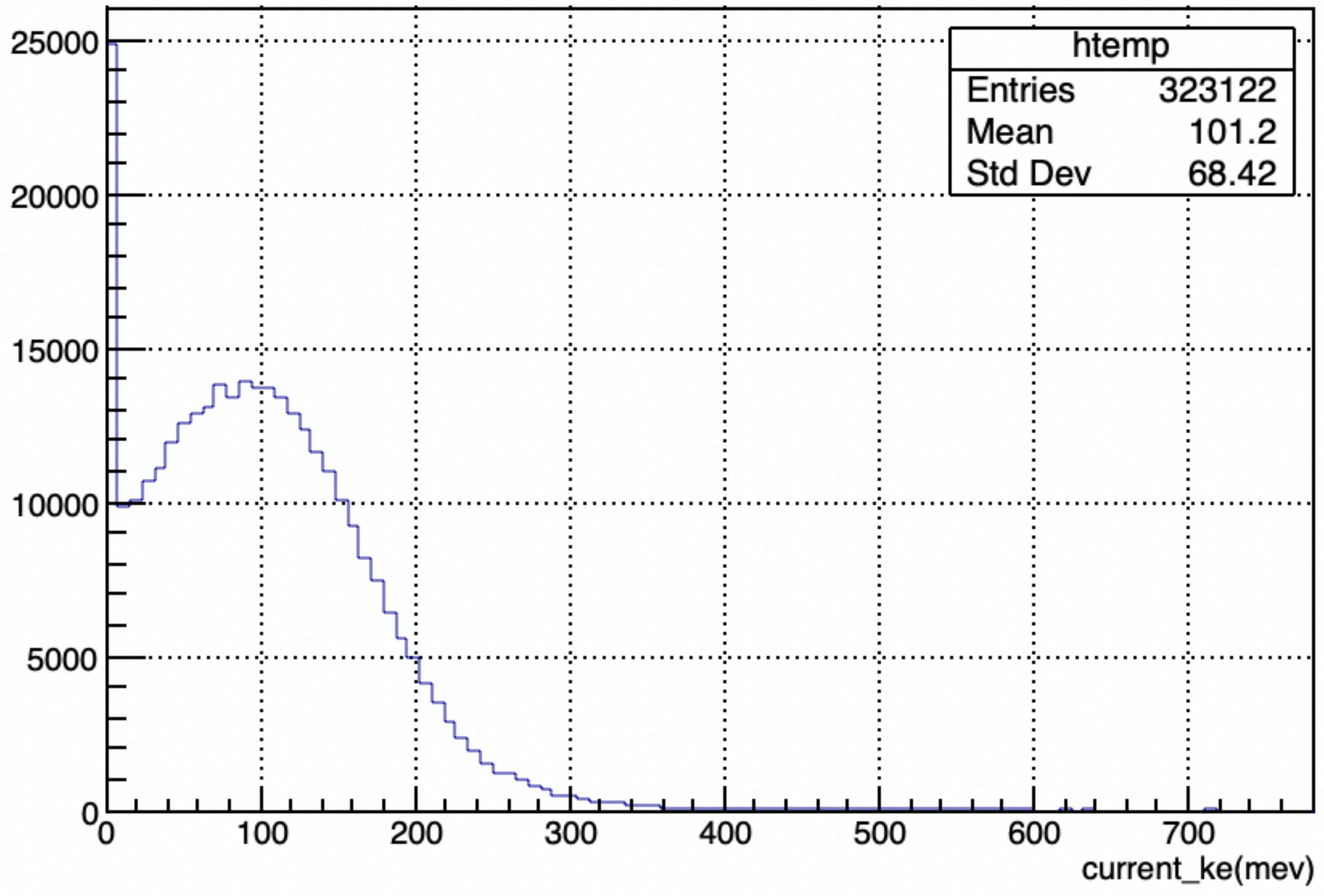
Study the position z and KE and of secondary neutrons

- Particle source: Carbon ion beam
- Beam energy: 2.4GeV
- Physics list: Default
- Medium: Water
- Silicon detectors: 300um thick
- Detector area: 10*10 cm^2
- Strip pitch: 250 μm





Truth Z positions of secondary neutrons
Reconstructed Z positions of secondary neutrons



Strip detector for measurements of carbon beam

- Large area strip detector (10x10cm) developed for the Dark Matter Particle Explorer (DAMPE) experiment
- 300um thick sensors with a strip pitch of 242um readout with VIKING Asic
- Testing starting the LSDC soon
- Can be used for measurements of secondary radiation fields outside of phantom with 6LiF convertor for measuring neutrons

Conclusion:

- Silicon detectors have been successfully simulated using TOPAS MC and the simulation results showed promising results in good agreement with previous studies completed by other MC tools

Future work:

- Taking measurements by silicon detectors in clinical beams of protons and carbon ions

- Measurement and simulation of charge-sharing effects on silicon detectors placed within a water phantom

Thanks for listening!