UNIVERSITY OF LIVERPOOL

Simulation and measurement of carbon ion beams

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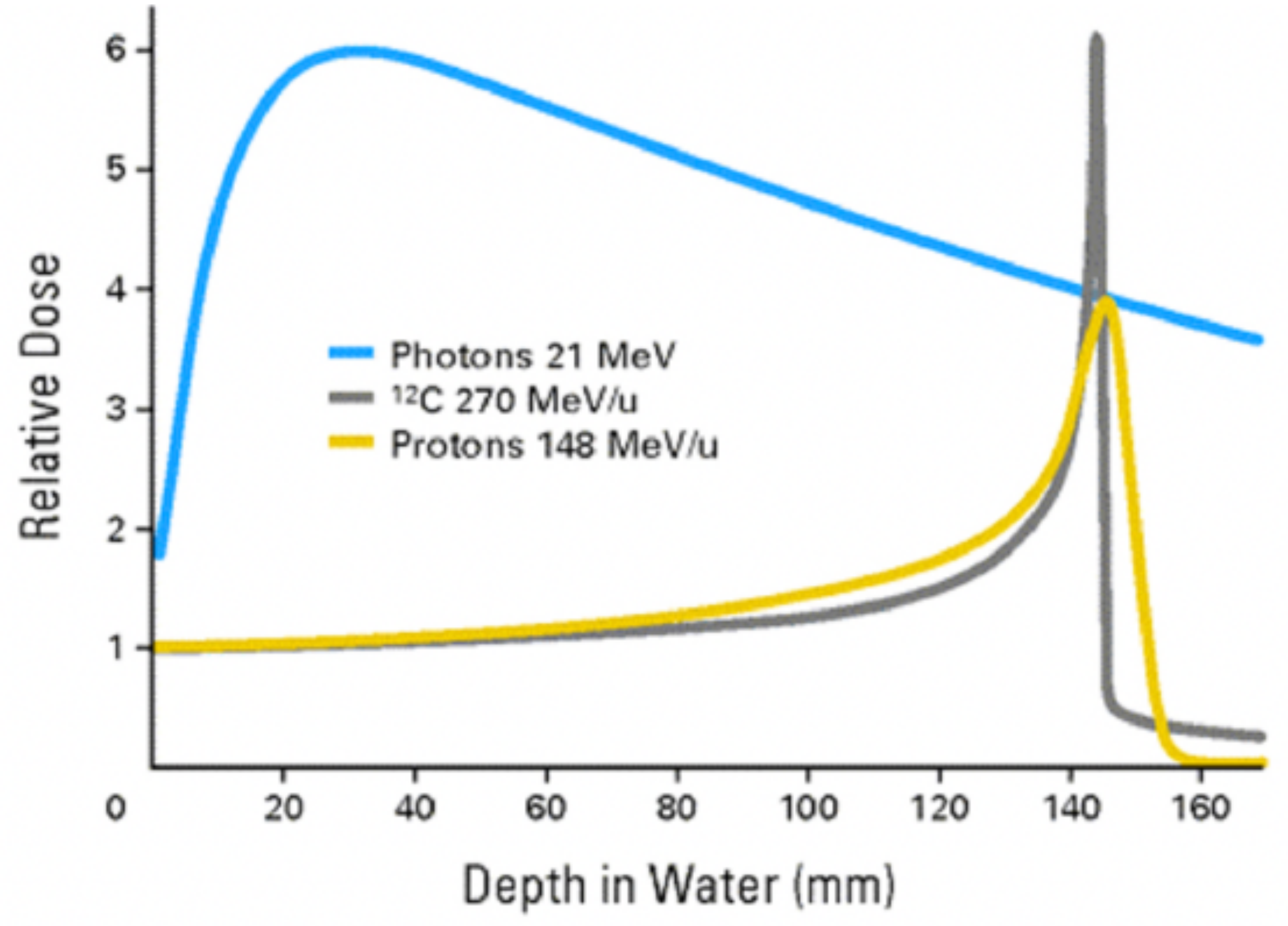
Particle therapy

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 damage 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)
- Monitor the secondary particles produced during beam interactions within the water phantom to infer the primary beam Bragg peak

2- Measurements using silicon detectors (pixels: HVTrack & strips: DAMPE) to compare with the simulation's results

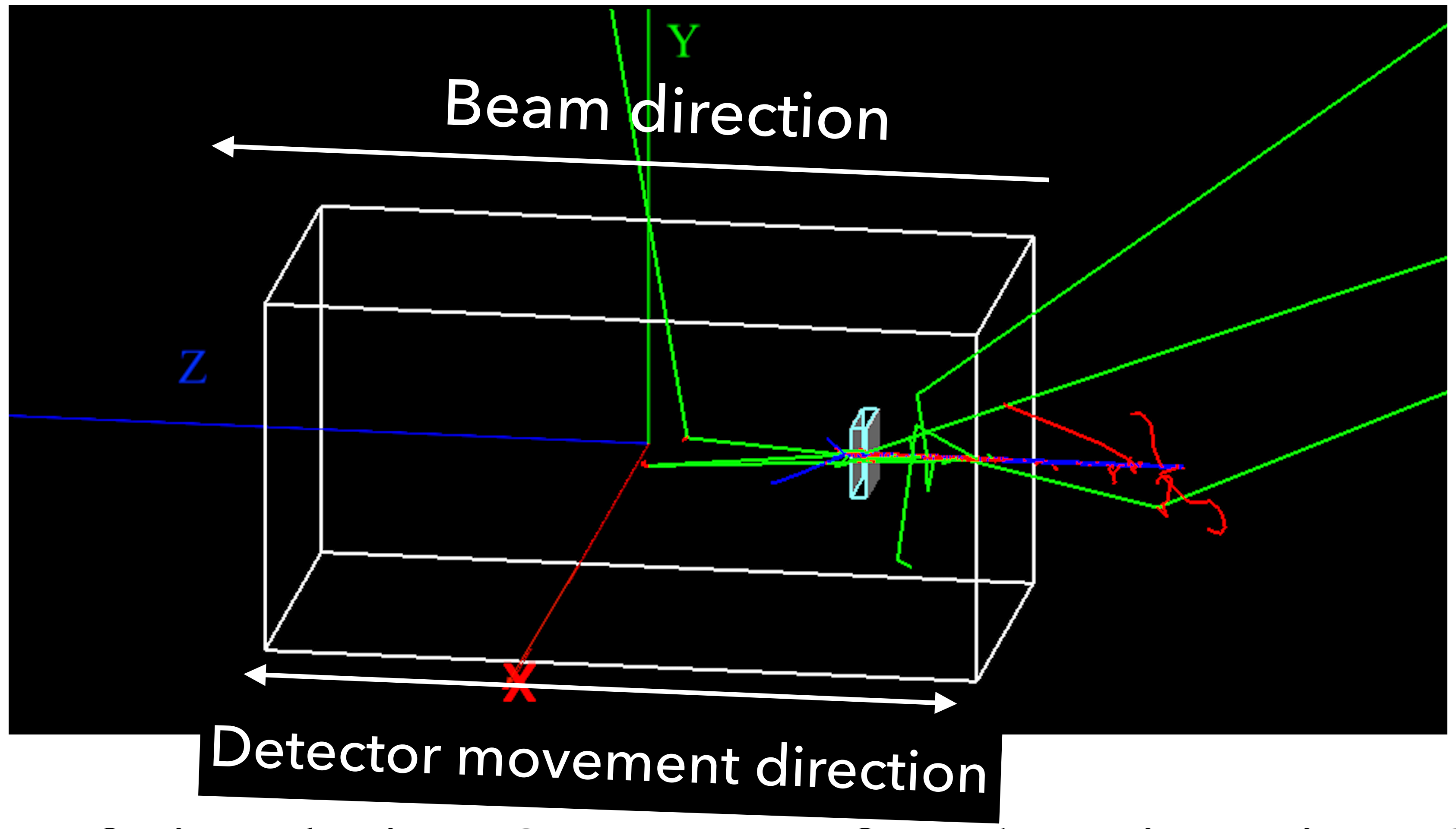
TOPAS Monte Carlo toolkit

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

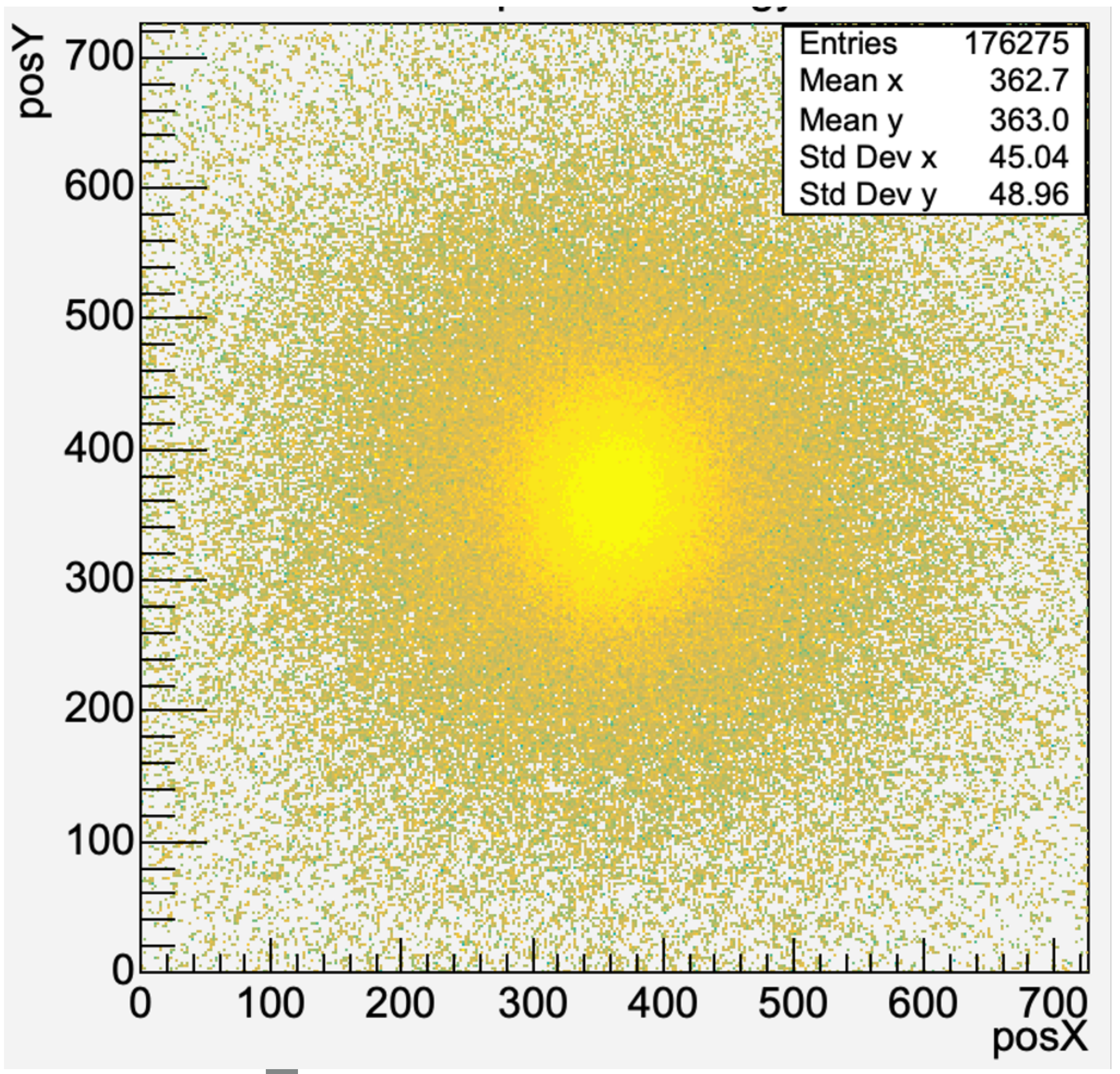
TOPAS MC configuration

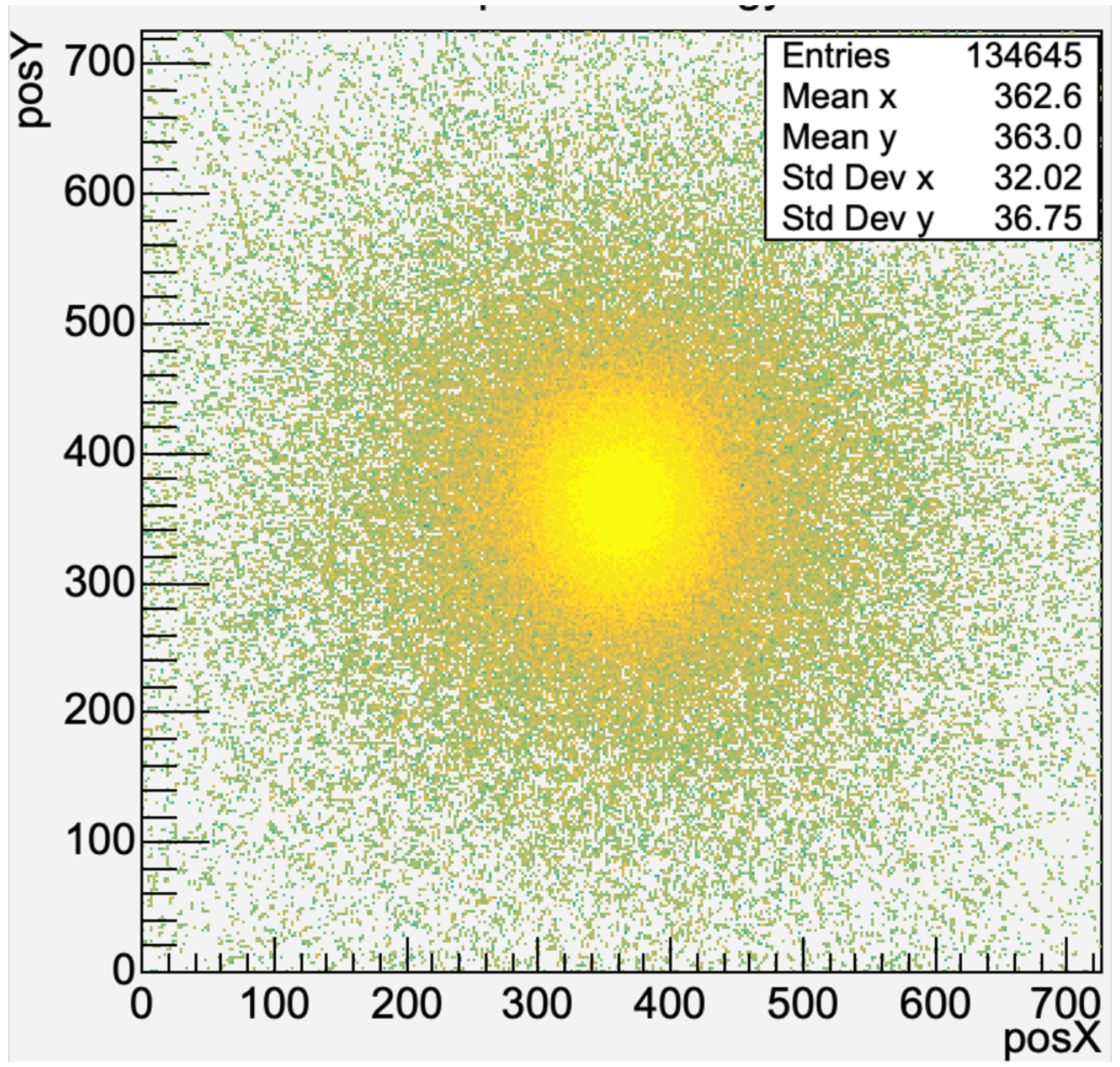
- Water phantom: 200mm x 200mm x 400mm
- Silicon detectors: 150um thick
- Particle source: Carbon ion beams
- Distribution: Gaussian
- Physics list: Default
- Pixel size: 80*80 μm^2
- Each detector consists of 500*500 pixels



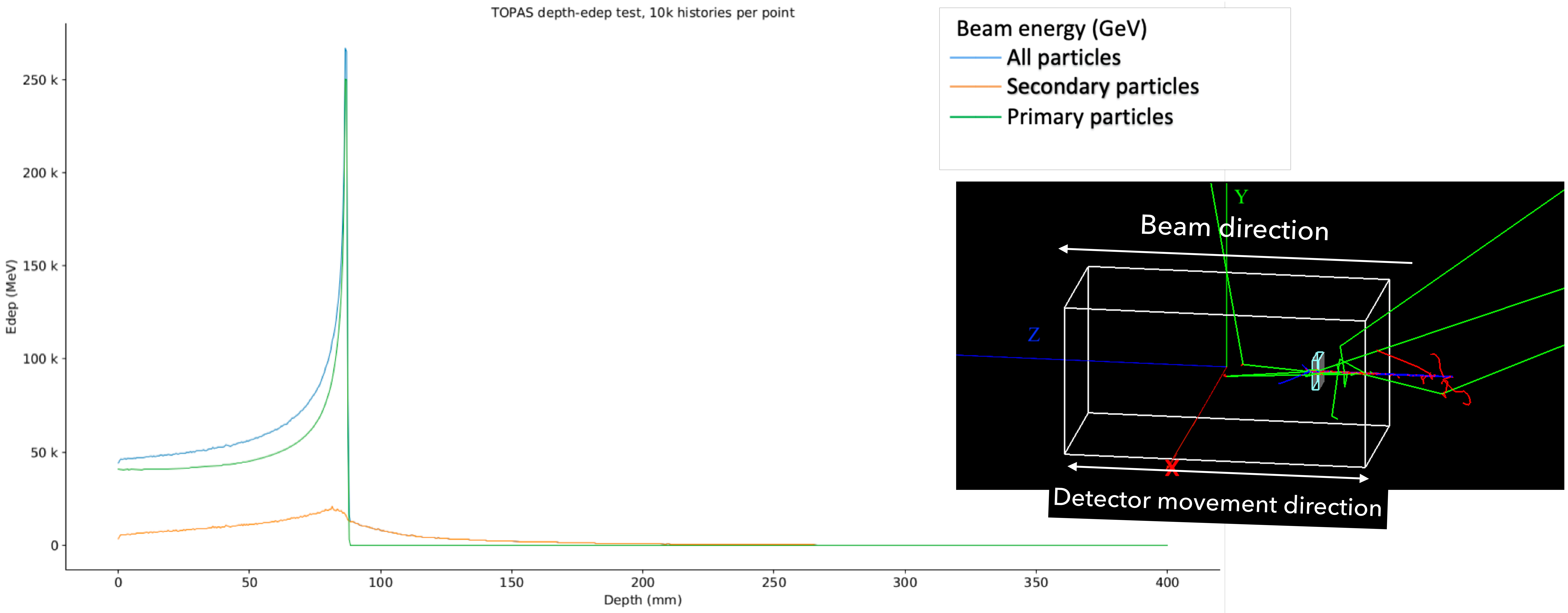
Snapshot of simulating 2 events of carbon ions in TOPAS.

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



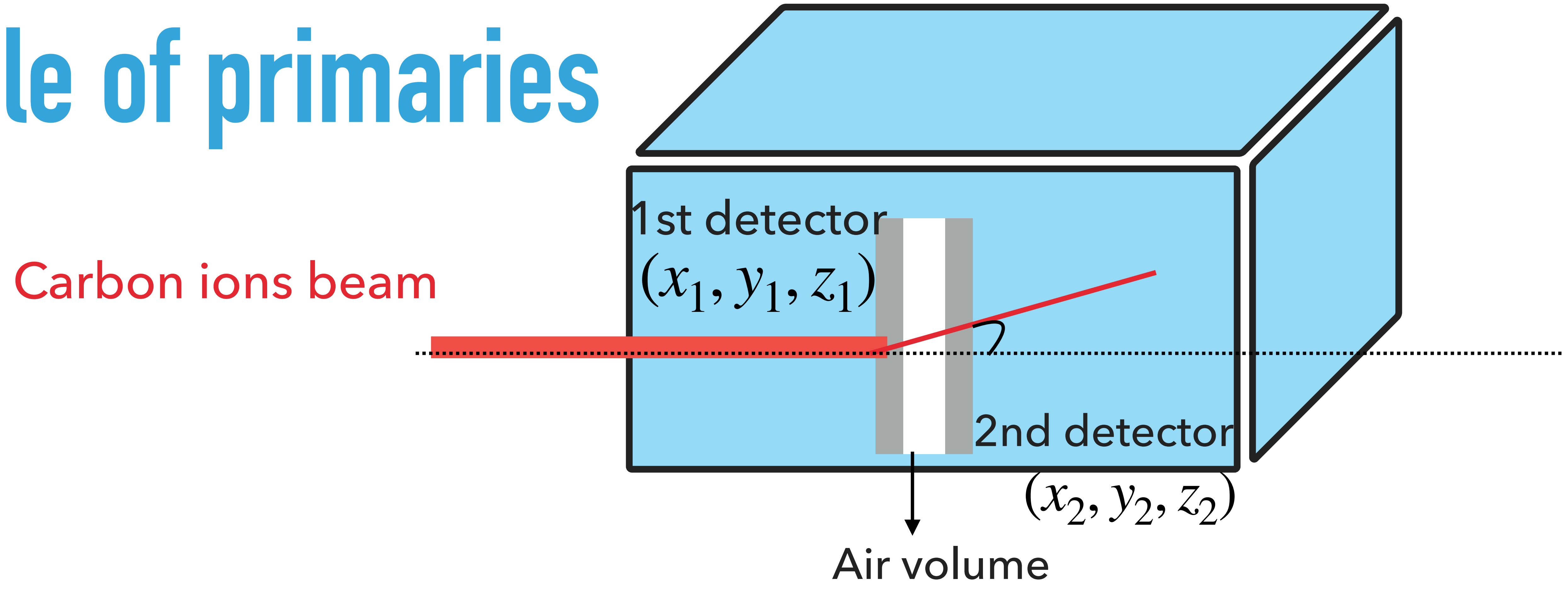


Energy deposited of primary beam and secondary particles

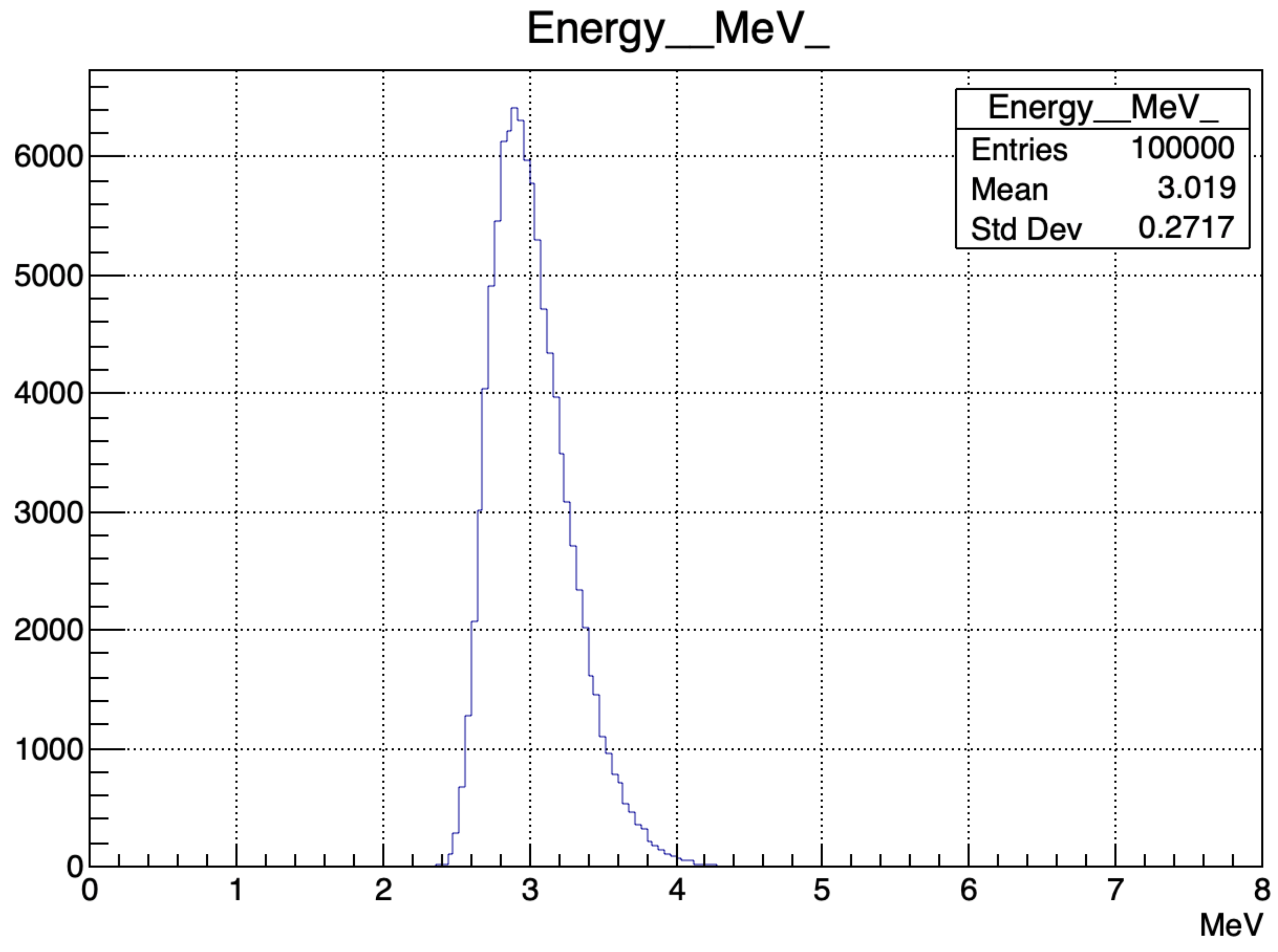


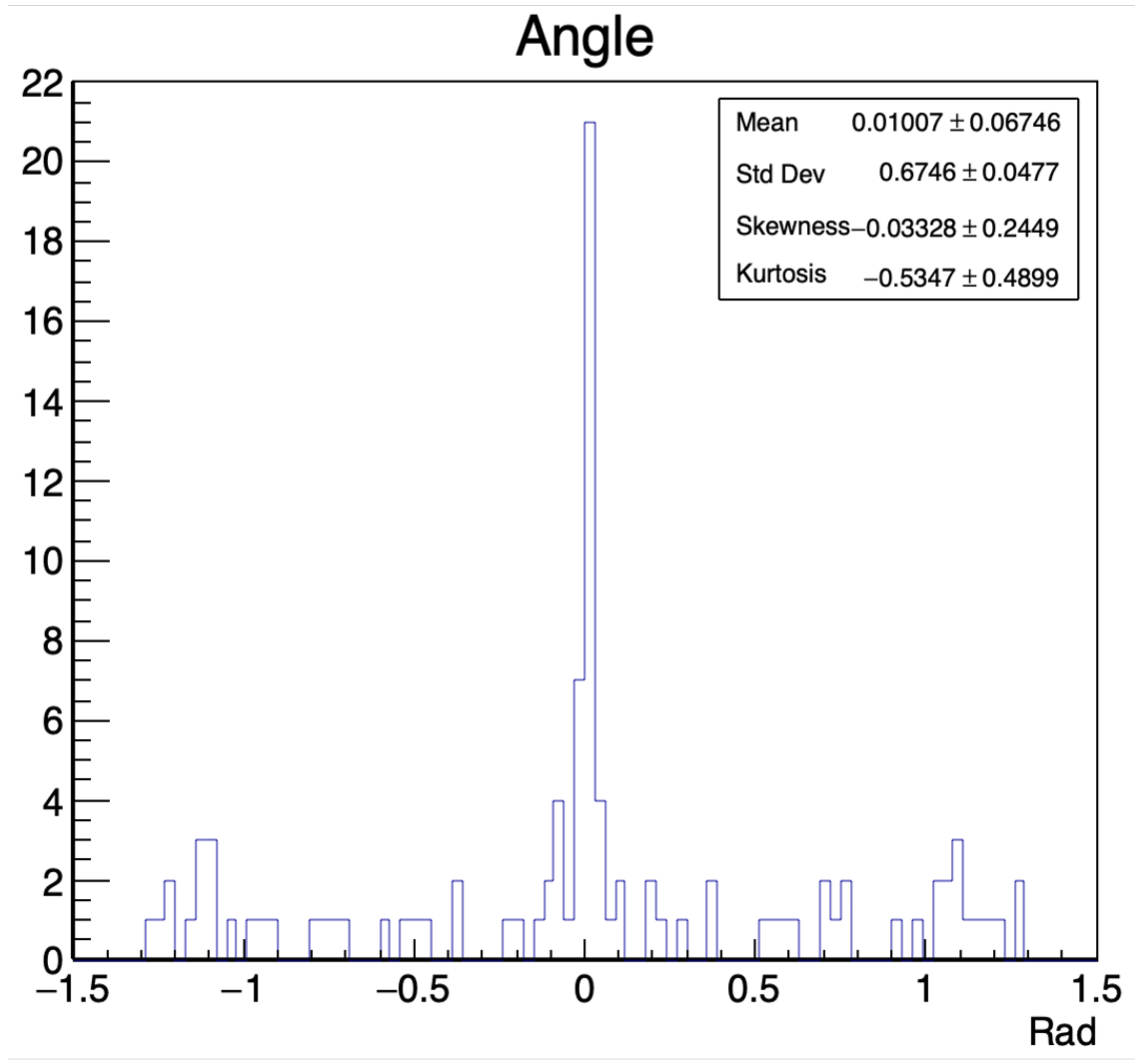
- Energy deposited for 2.4 GeV carbon ions and secondary particles irradiating a silicon detector positioned along the beam axis within a water phantom.
- The deposited energy after the Bragg peak is from the fragmentations of carbon ions

Energy distribution and scattering angle of primaries



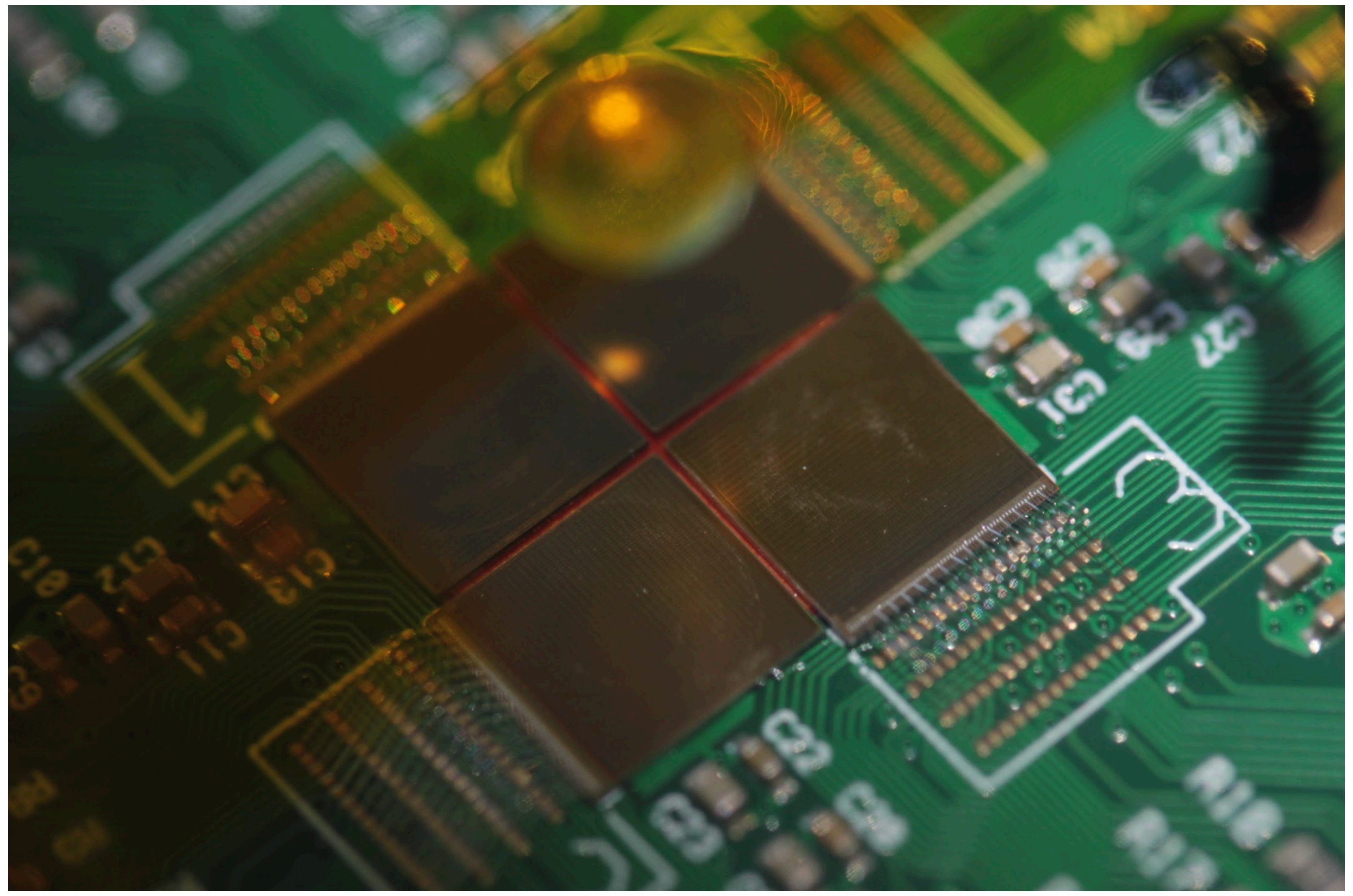
Two silicon detectors separated by a volume of air are used to measure the hit positions in the detectors to evaluate the scattering angle





Pixel detector for measurements of primary carbon beam

- HVTrack is a HV-CMOS detector designed specifically for particle therapy applications
- MPW in 0.13um produced by LFoundry
- 80x80um pixels with an active area of: 1.06cm x1.06cm and a pixel pitch of 80µm x 80µm (>15k pixels/cm2)
- Three modes of operation: particle counting mode, energy mode (dose), tracking mode (time)
- 4 chips tiled together on a PCB designed by Liverpool (T. Smith)
- Firmware for communication and calibration being finished by FBK
- A setup for the LSDC in the coming months MPW in 0.13um produced by LFoundry



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

Thanks for listening!