UNIVERSITY OF LIVERPOOL

Simulation and measurement of proton and carbon ion beams for radiotherapy

Fajer Alqahtani

Supervisors:
Jon Taylor, Carlos Chavez, Gianluigi Casse

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Particle therapy

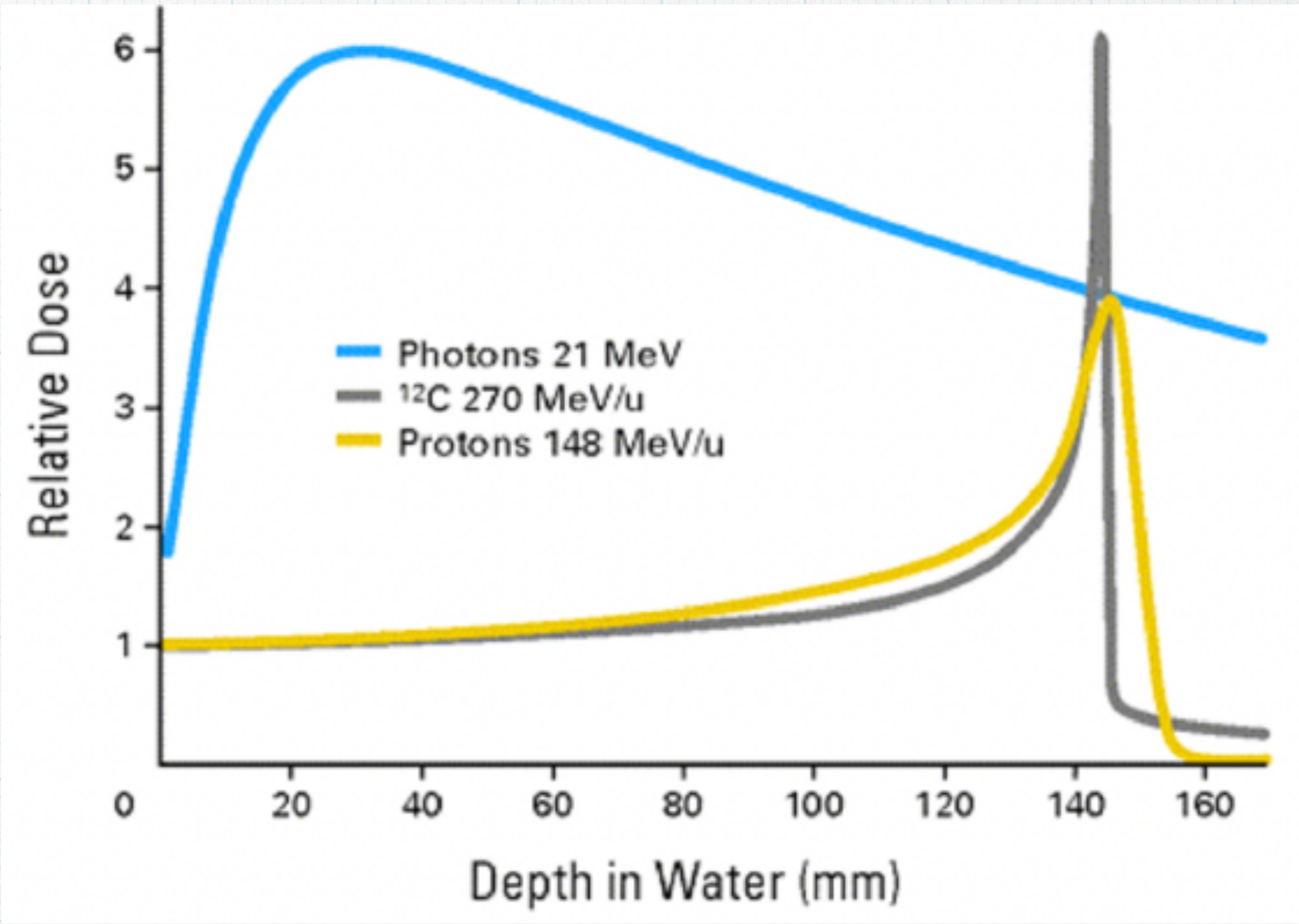
Aims to: treat cancers and reduce the dose received by healthy tissues.

Why protons and carbon ions:

- Their slow-down process is described by the Bethe-Bloch formula:

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

- Carbon ions heavier than protons: the straggling for protons > for carbon
- After the Bragg peak: protons deliver zero energy, while carbon ions deposit a little energy "tail".

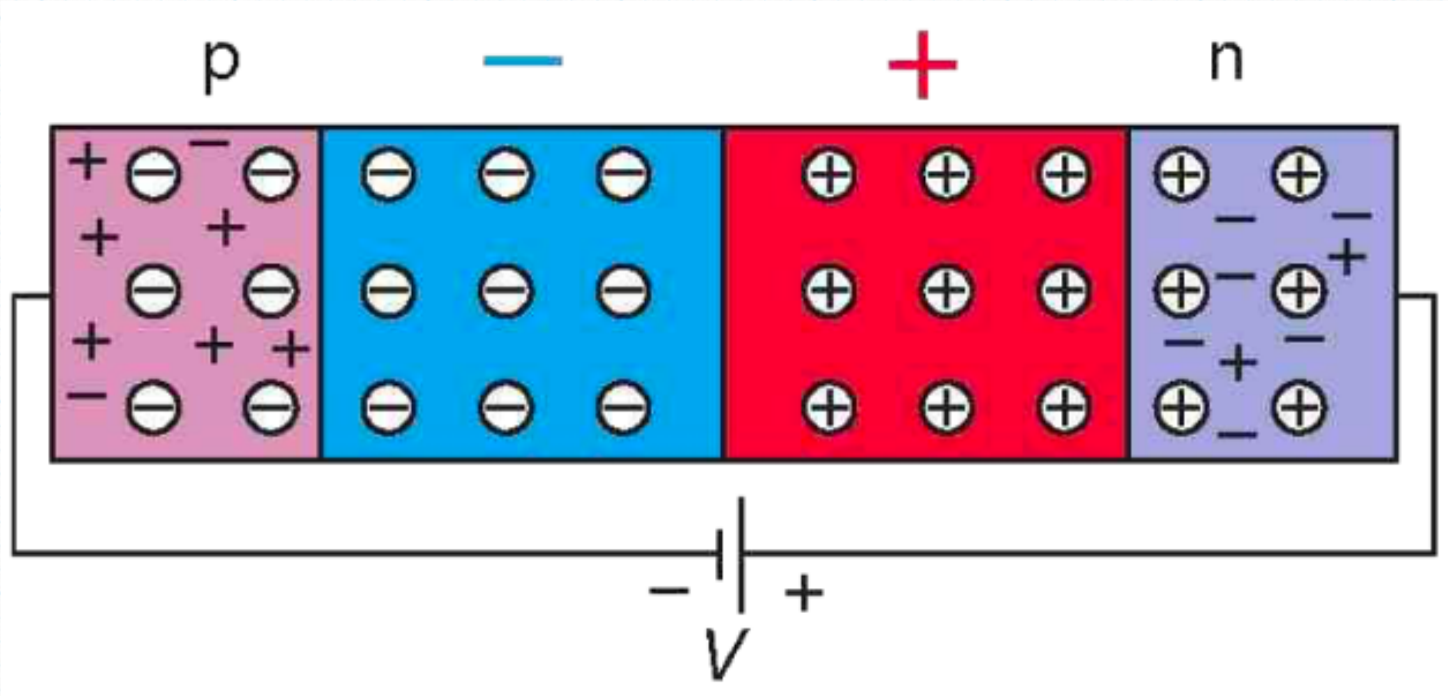


Depth-dose profiles of proton, carbon ion and photon beams; taken from (1)

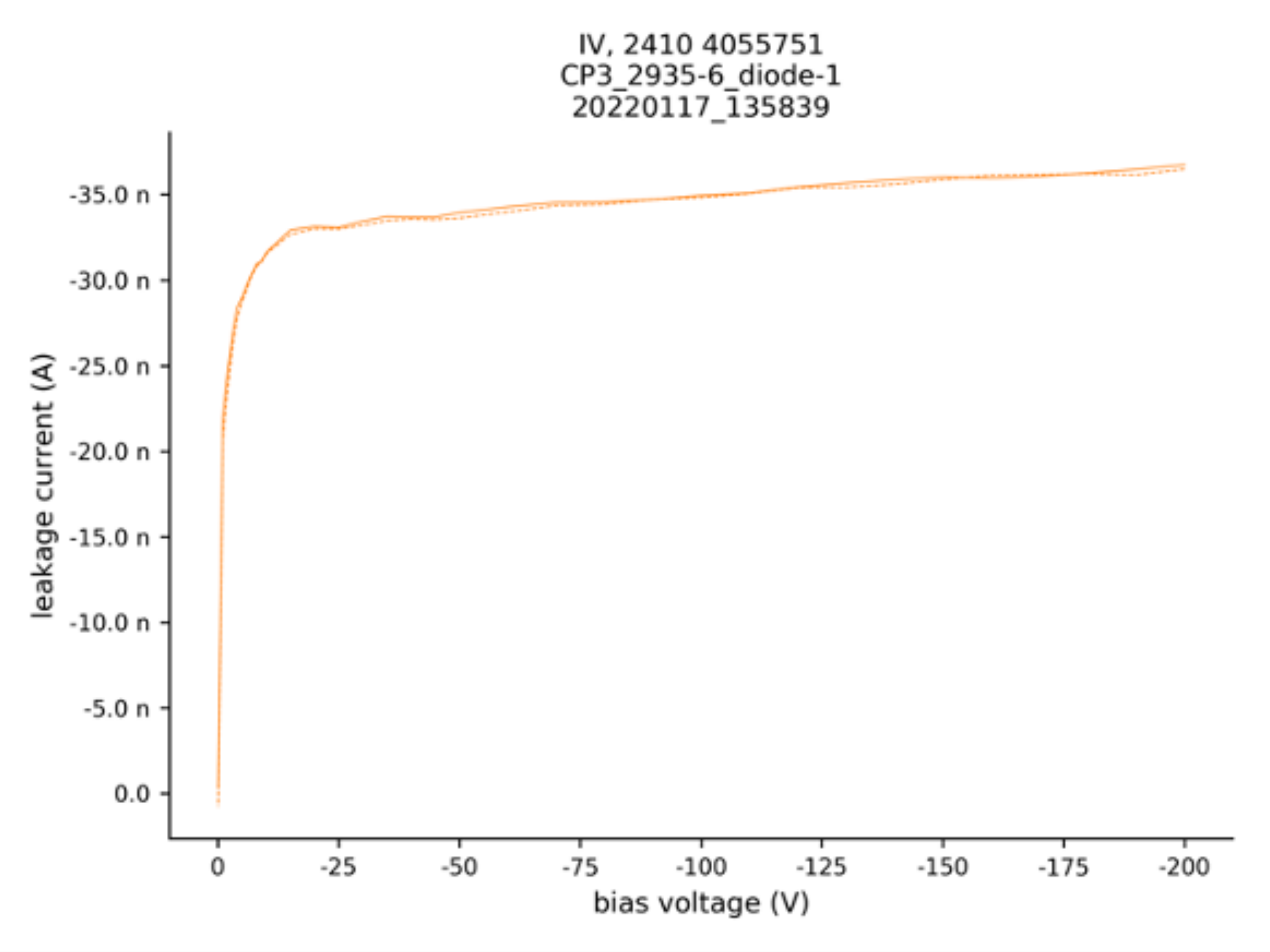
1. Dilmanian, F. A., Eley, J. G., Rusek, A., & Krishnan, S. (2015). Charged particle therapy with mini-segmented beams. *Frontiers in oncology*, *5*, 269.

Silicon detectors

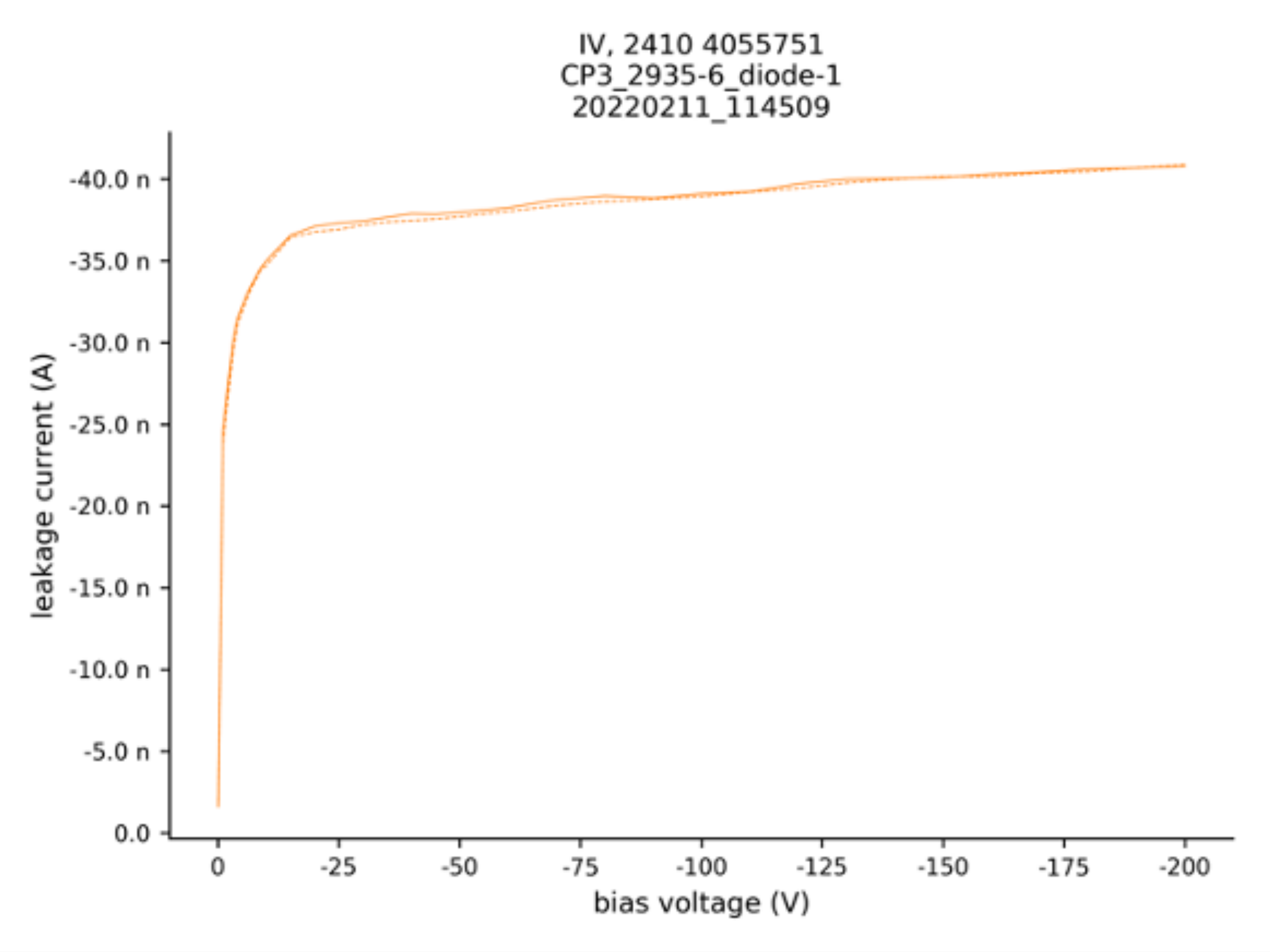
- Small bandgap
- High specific density
- High carrier mobility
- Depend on leakage current



leakage current measurements for CERN Pixel 3 diodes after storing diodes in air and dry storage:



After storing diodes in air

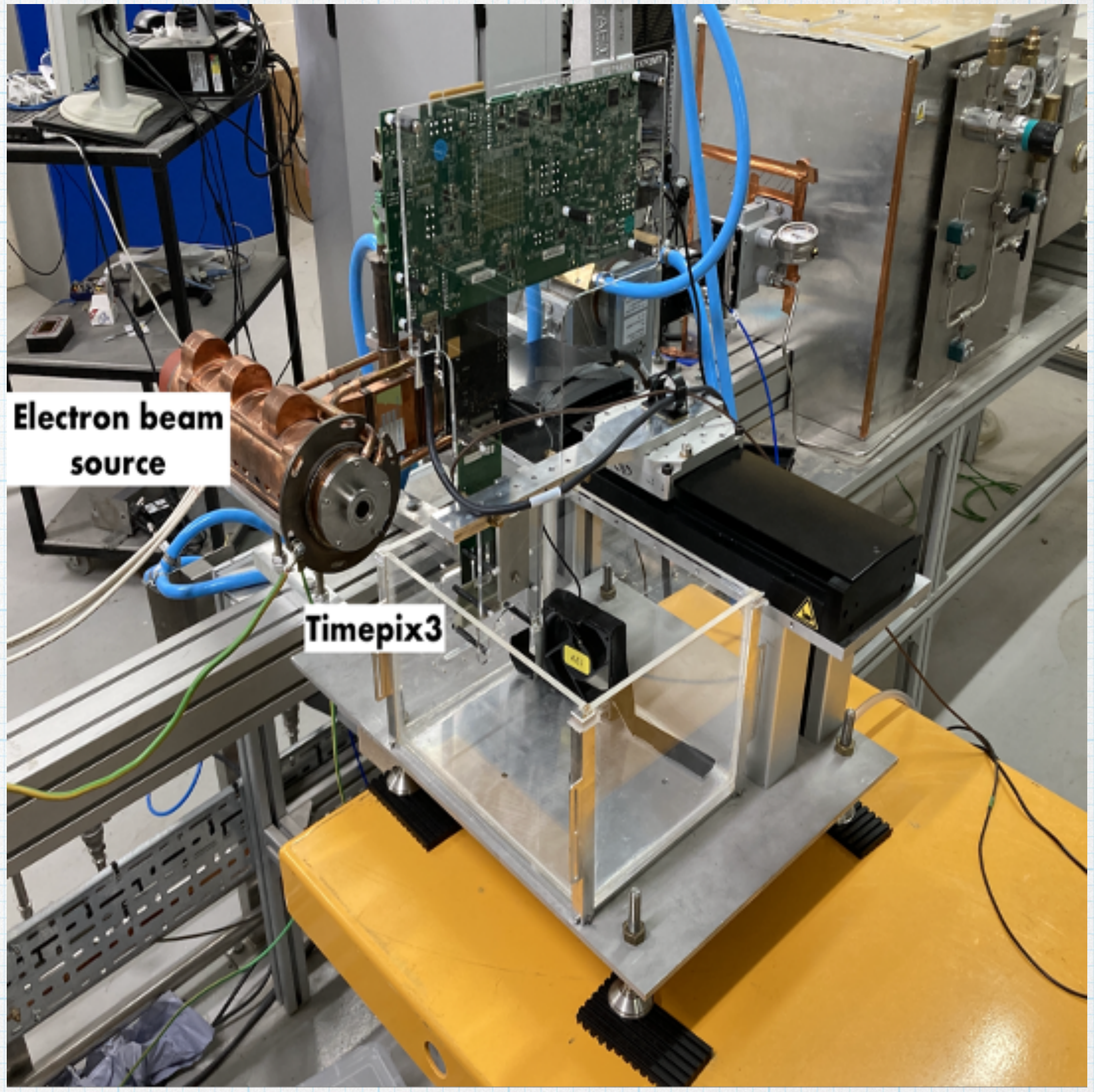


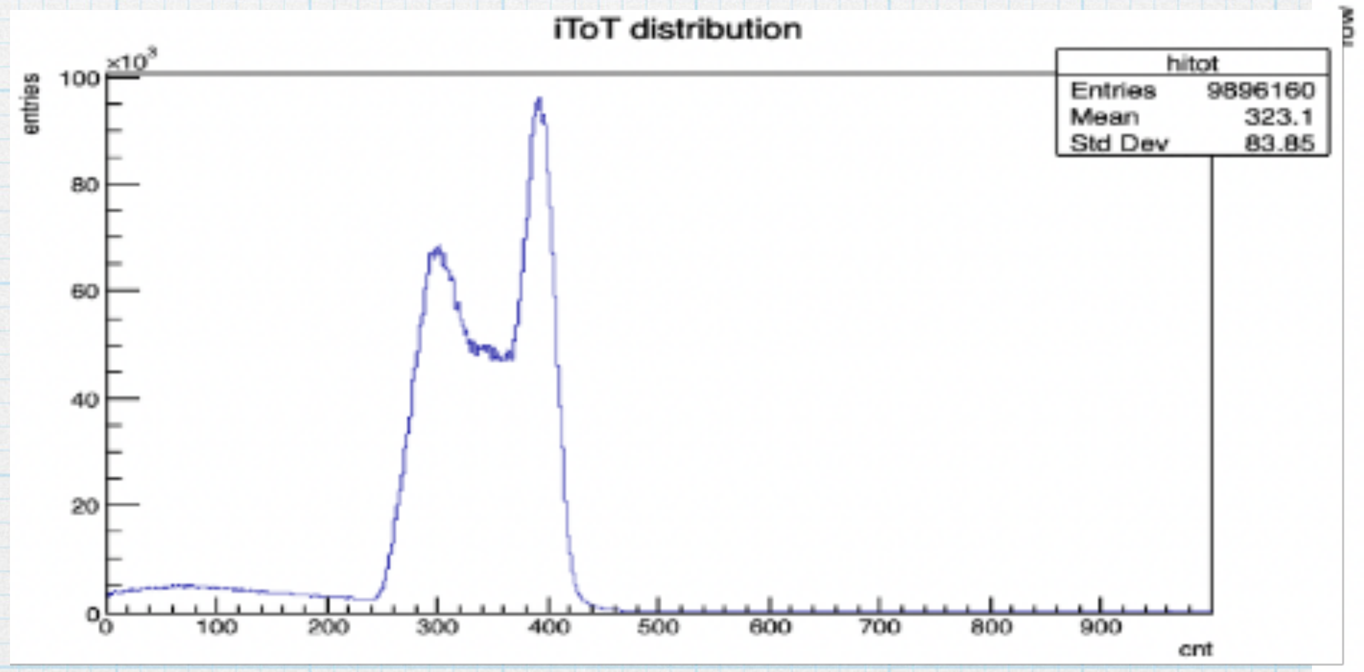
After storing diodes in dry storage

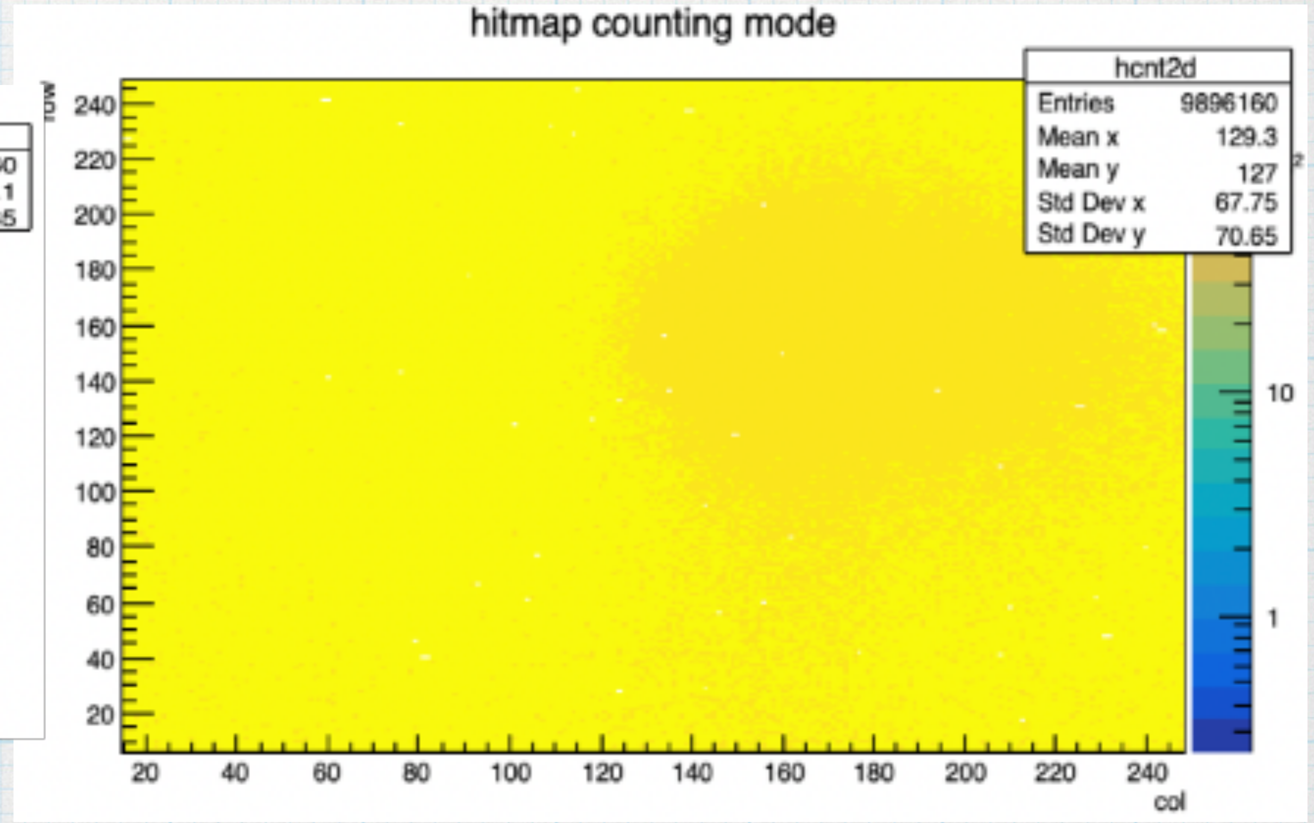
Timepix3 water phantom

- Timepix3 triplet with readout recycled from LHCb
- Detector coating in parylene C as a water barrier
- Mechanical stage moves detector through water to allow profile of the beam with depth

- Each chip has:
    - 65536 hybrid pixels
    - 256 columns by 256 rows
    - Pixel pitch 55 µm by 55 µm
- Measurements have recently been taken for electron beam at 6 MeV in Daresbury, analysis ongoing







Timepix3 in the front of the electron beam source, and a sample of data taken at Daresbury.

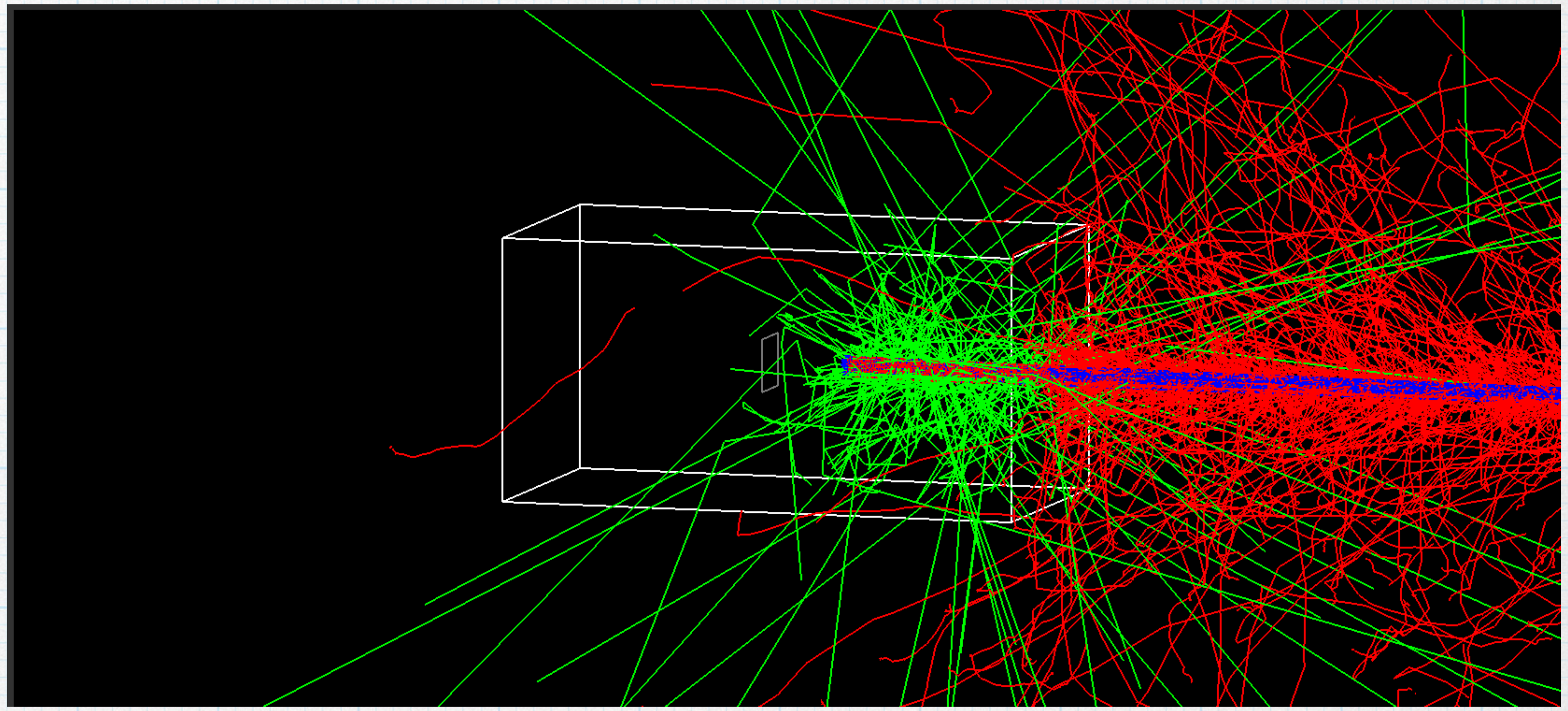
TOPAS
Monte Carlo toolkit

Designed to:

- assist clinical physicists and researchers to use Monte Carlo simulation easily.
- using Geant4 toolkit radiation physics libraries easily and supports visualization.
- modelling fundamental particles, complicated imaging devices and therapy.
- simulate the ionizing radiation passage via any complicated geometry.

Components configuration

- Water phantom: 200mm x 200mm x 400mm.
- Silicon detector: 50um thick.
- Particle source: Proton/Carbon ion beams.
- Distribution: Gaussian.
- Physics list: Default.



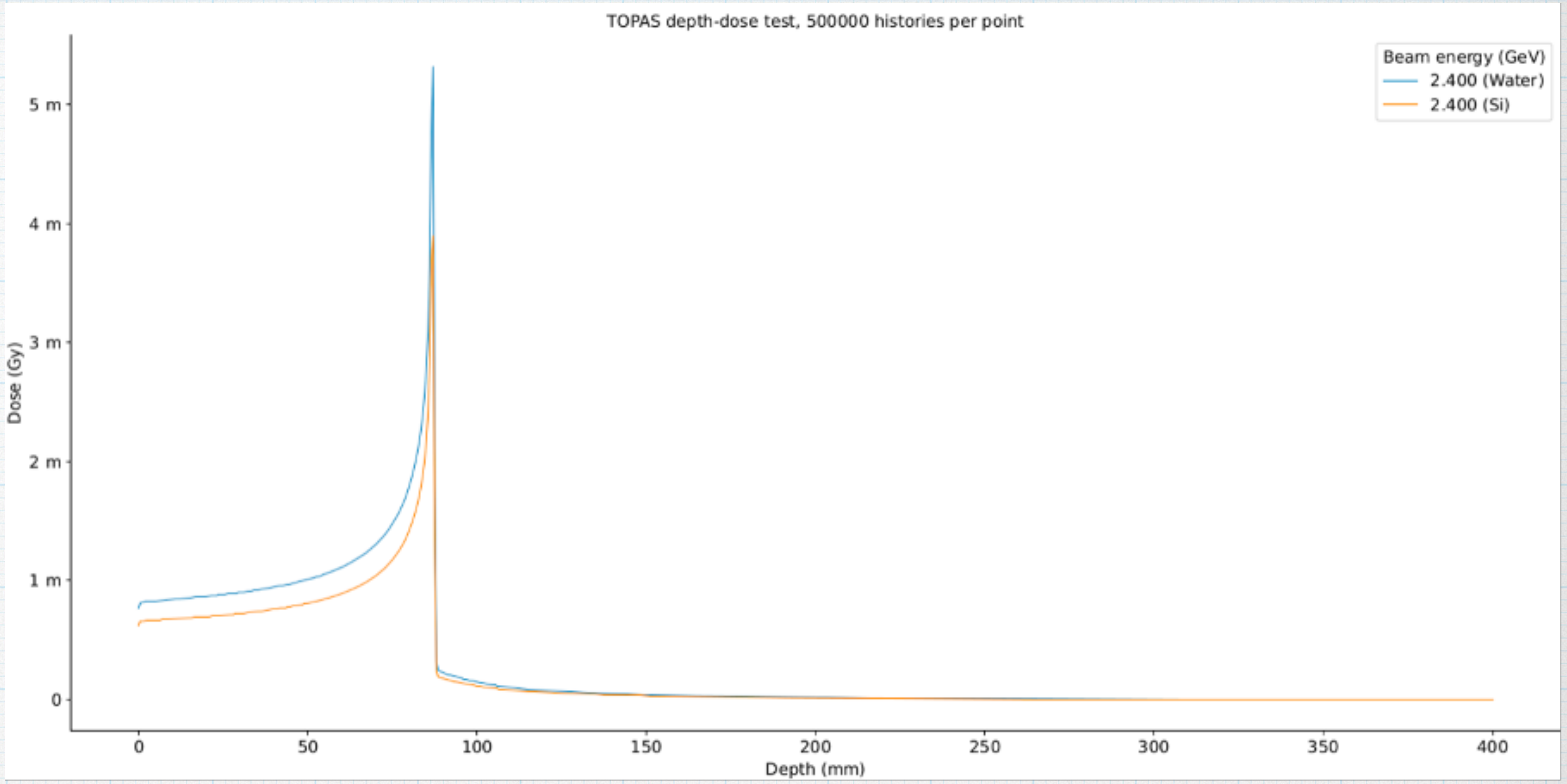
Snapshot of simulating 100 events of carbon ions.

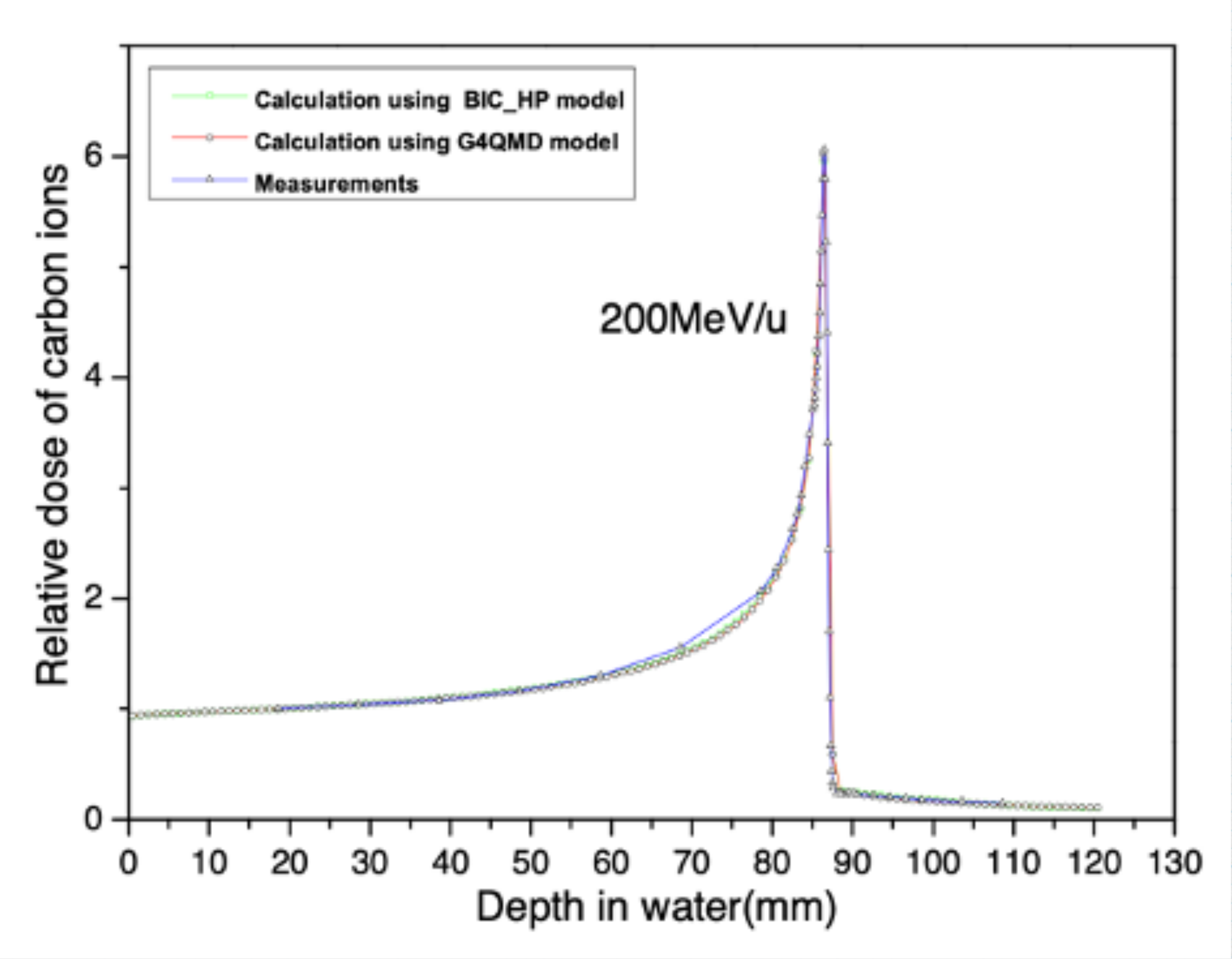
main interactions addressed by the default physics list:

- Electromagnetic process
- Inelastic scattering of (heavier ions, neutrons and protons).
- Elastic scattering

Carbon ion Beam

- Dose distribution including Bragg peak for carbon ion beam for water and silicon detector.
- Energy: 2.4 GeV
- Distribution: Gaussian
- Events number: 500K
- Physics list: Default.
- The difference in stopping power → the absorbed dose of water > silicon
- The ratio of Bragg peak to plateau = 6.75





The ratio of Bragg peak to plateau = 6.78

A snapshot taken from a paper published by (Liu, H., et al 2017) (2).

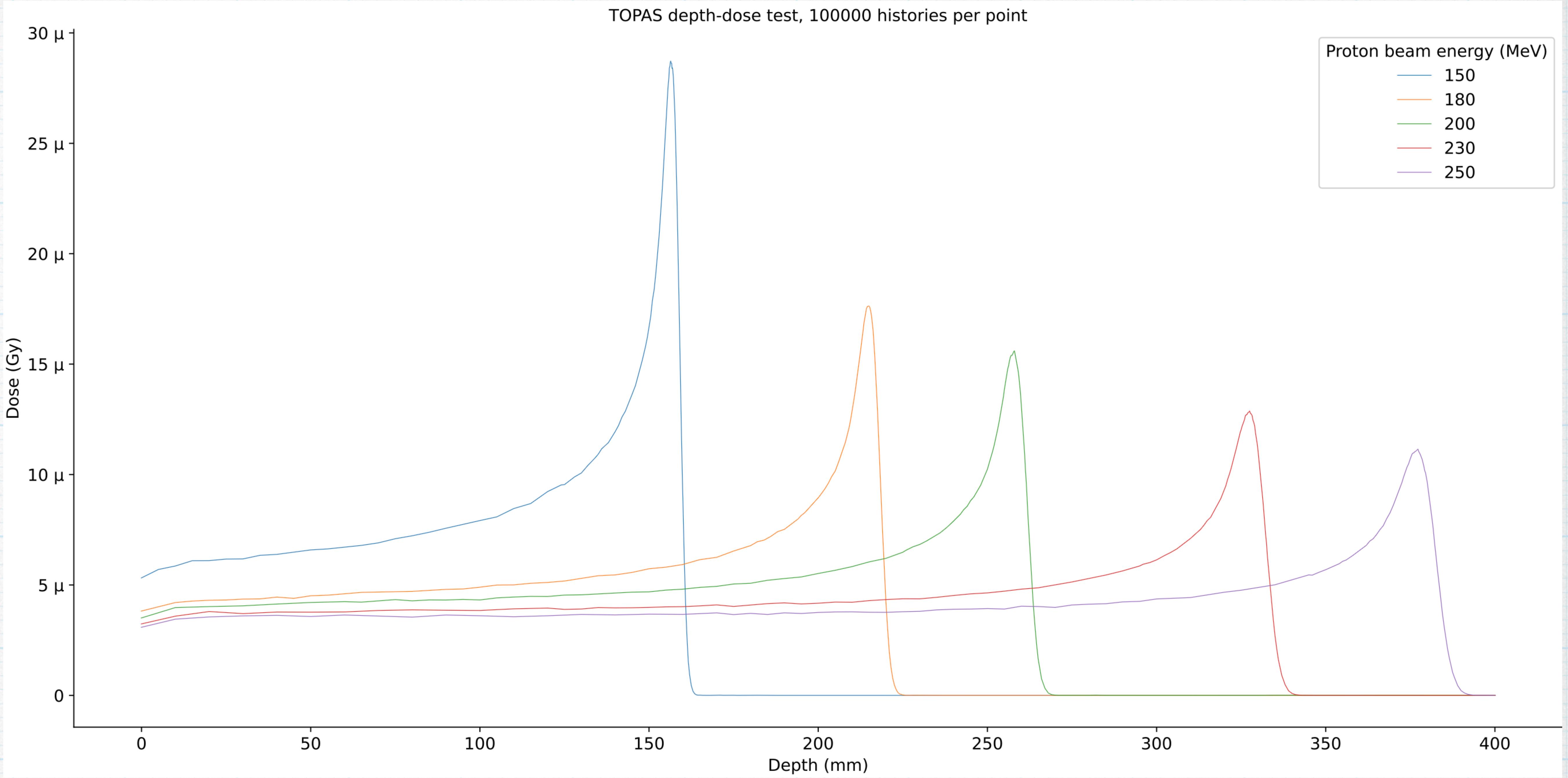
(2) Liu, H., Zhang, L., Chen, Z., Liu, X., Dai, Z., Li, Q., & Xu, X. G. (2017). A preliminary Monte Carlo study for the treatment head of a carbon-ion radiotherapy facility using TOPAS. In *EPJ Web of Conferences* (Vol. 153, p. 04018). EDP Sciences.

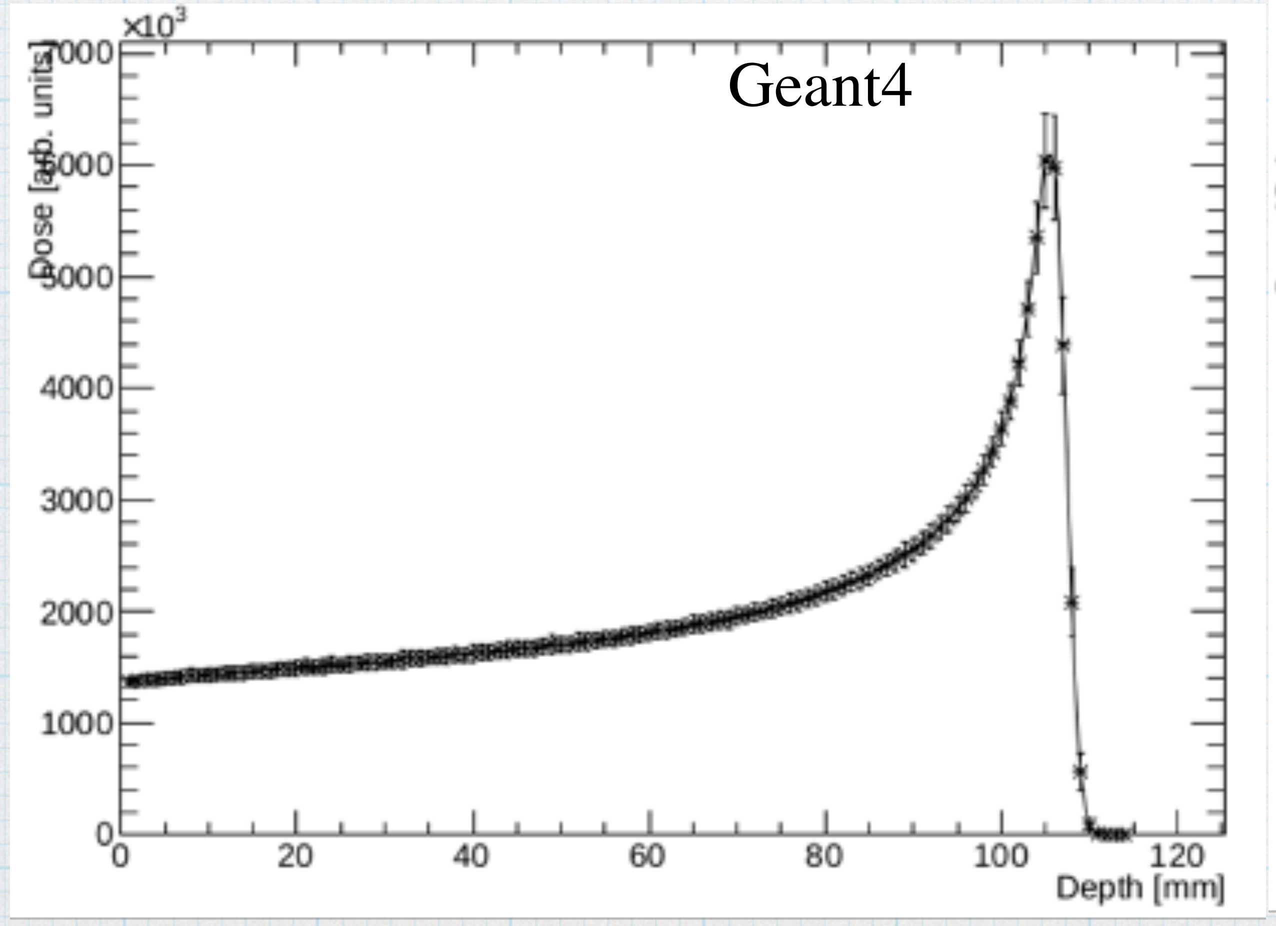
Proton Beam

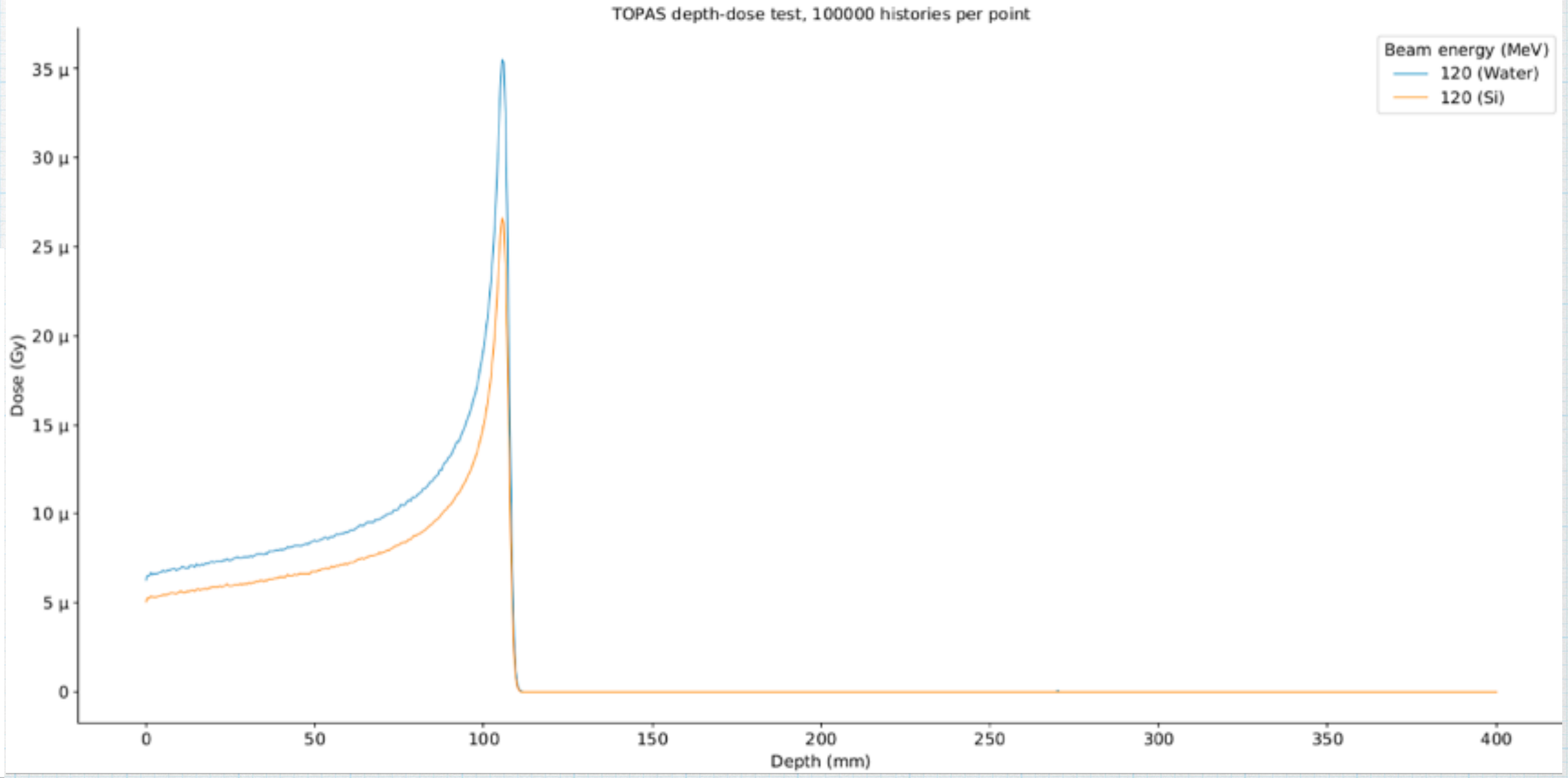
- Dose distribution including Bragg peak for proton beam.
- Energies: 150-250MeV
- Events number: 100K
- Physics list: Default.
- Bragg peak broadens as energy increases
→ energy straggling

The ratio of Bragg peak to plateau (TOPAS) = 5.3

The ratio of Bragg peak to plateau (Geant4) = 5







Future work:

- Taking measurements by Timepix3 and a new HV-CMOS detector in clinical beams of protons and carbon ions
- Use of silicon diodes from Micron for dosimetry measurements in x-ray and electron beams
- Measurement and simulation of detector resolution effects
- Simulation and measurement of secondary particles produced during proton and carbon ion therapy

Thanks for listening.