Simulation and measurement of proton and carbon ion beams for radiotherapy

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Particle therapy

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

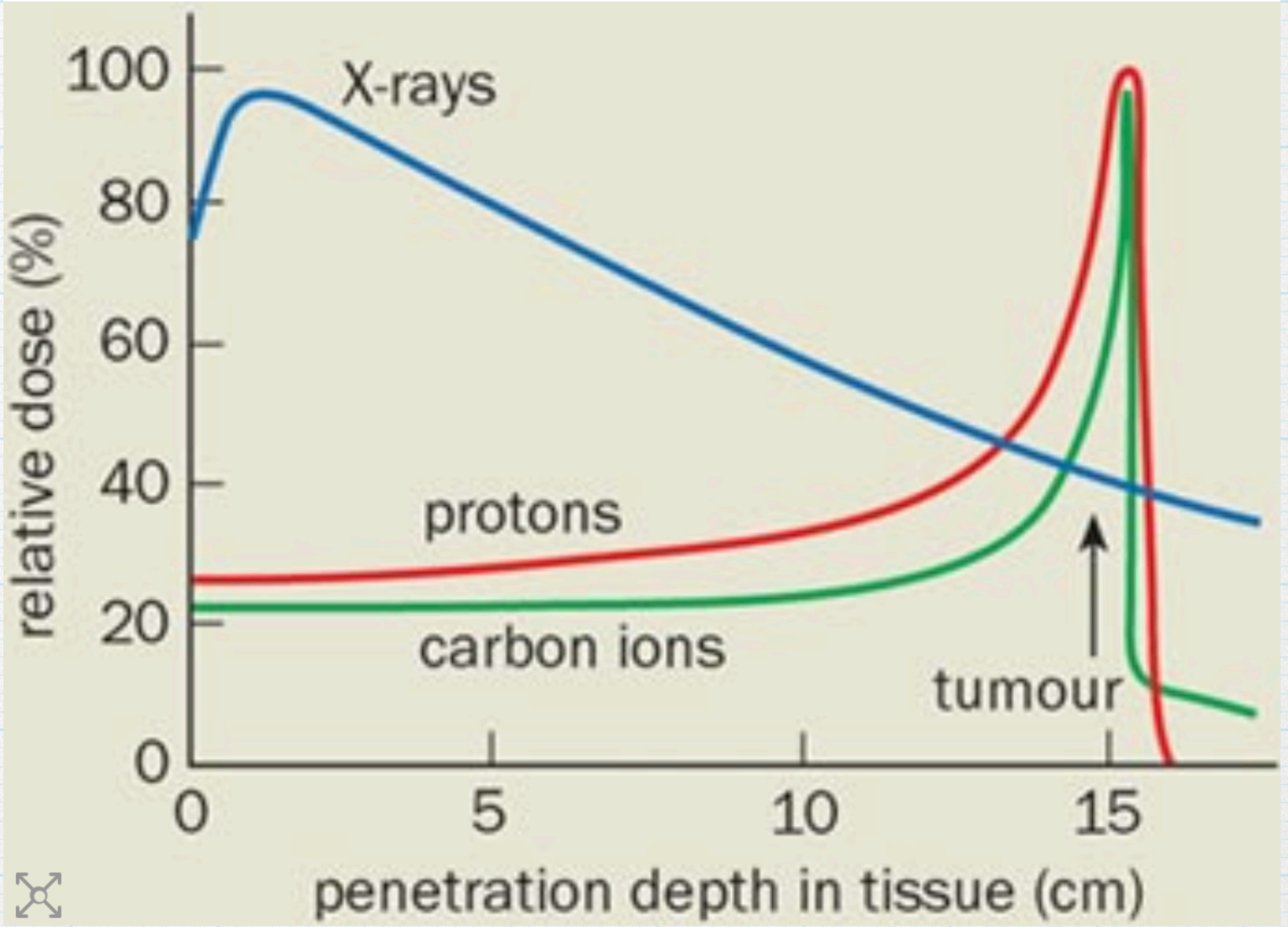
Why protons and carbon ions:

- 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".

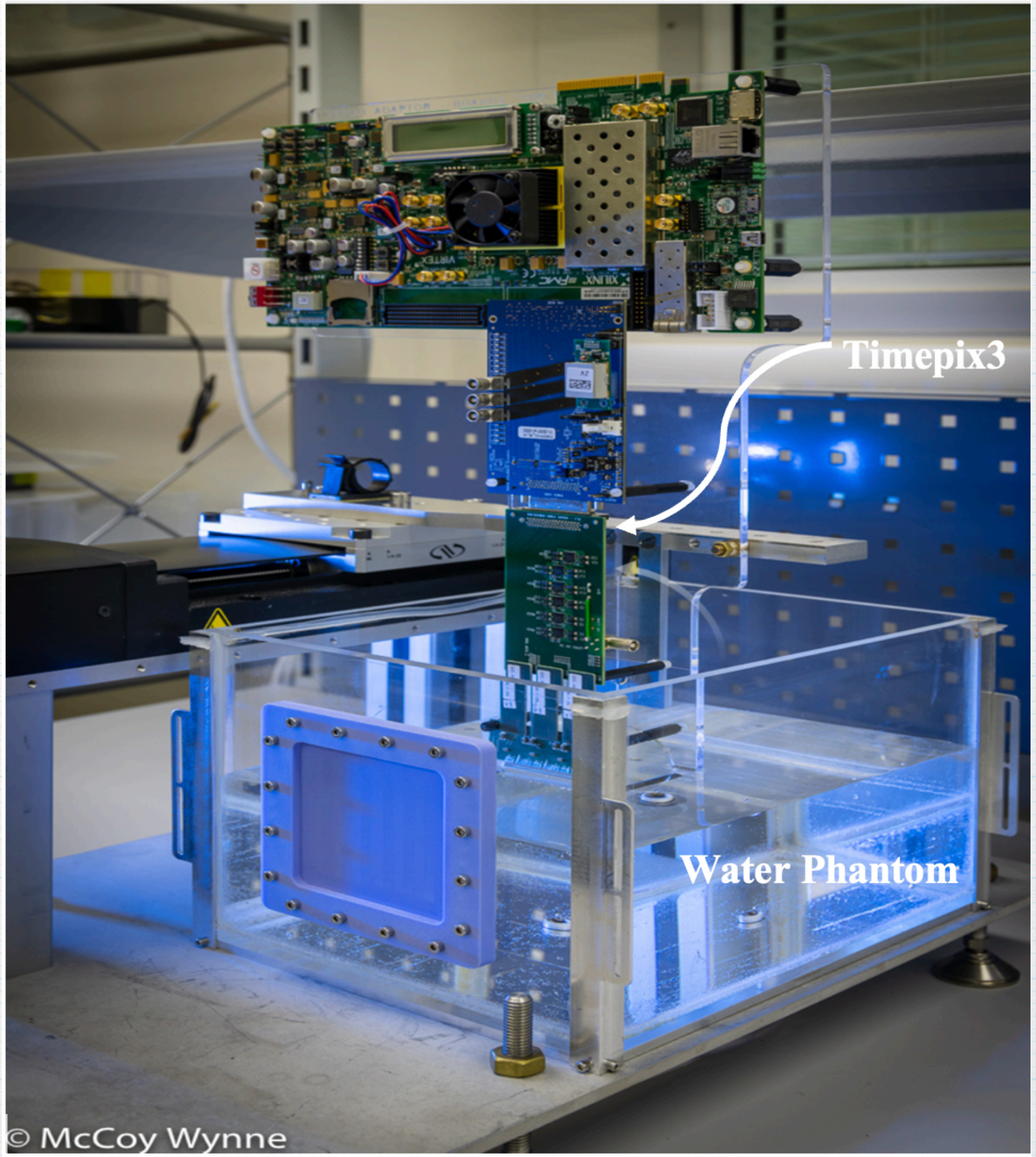


https://physicsworld.com/a/how-particles-can-be-therapeutic/

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



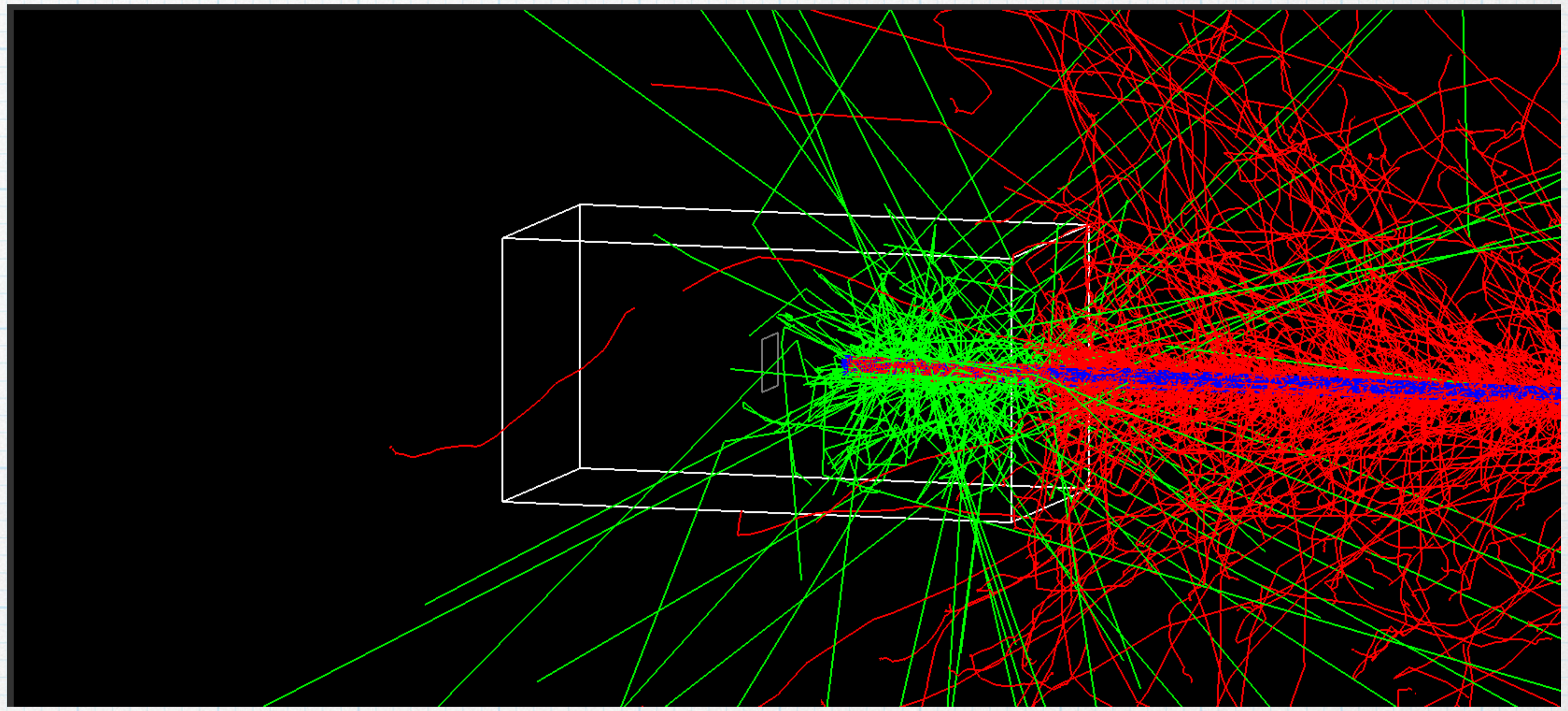
TOPAS
Monte Carlo toolkit

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: Protons/Carbon ions.
- Distribution: Gaussian.
- Energy: 3.0 GeV
- Physics list: Default.



Snapshot of simulating 100 events of carbon ions.

main interactions addressed by the default physics list:

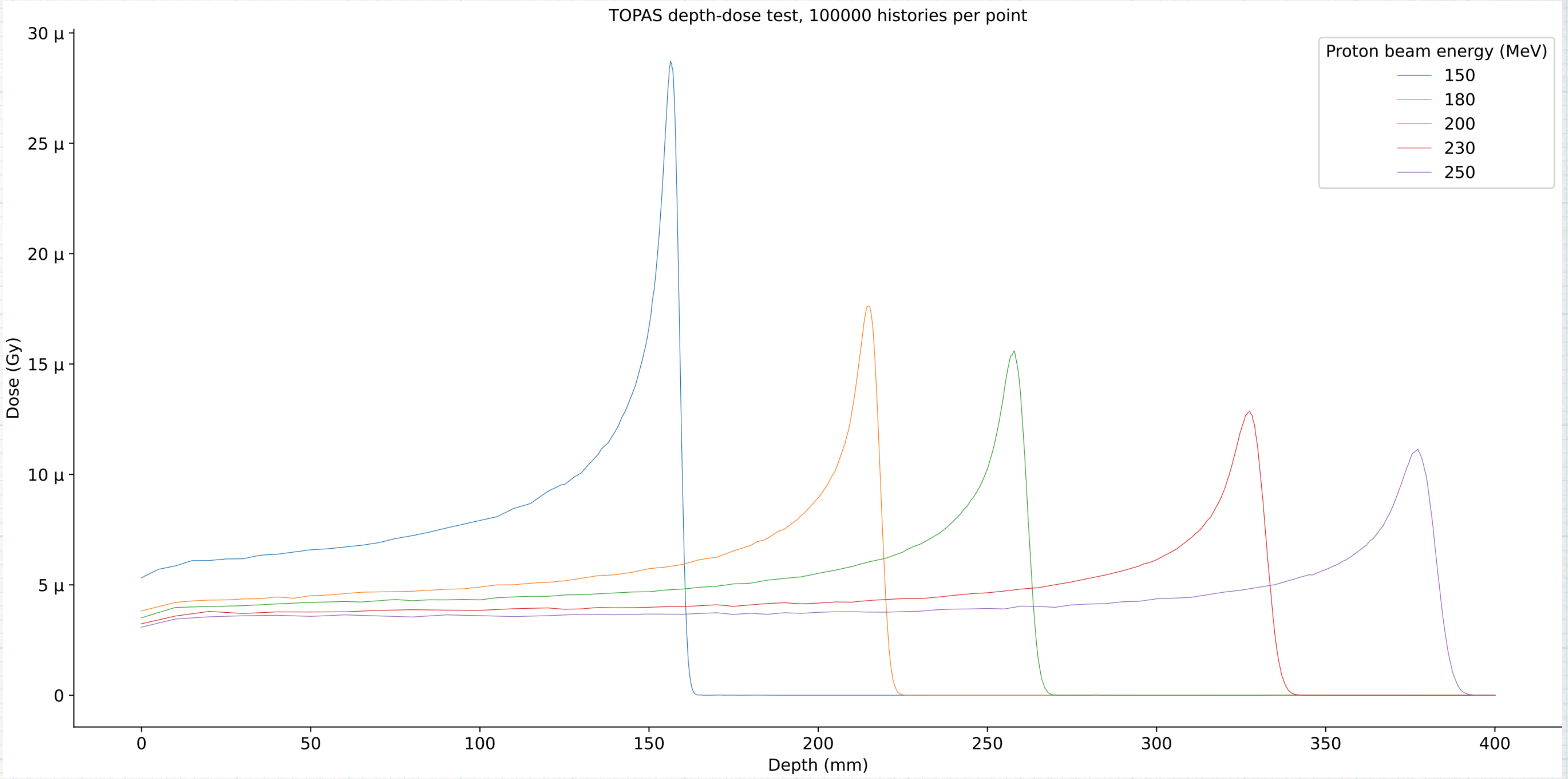
- Electromagnetic process
- Inelastic scattering of (heavier ions, neutrons and protons).
- Elastic scattering

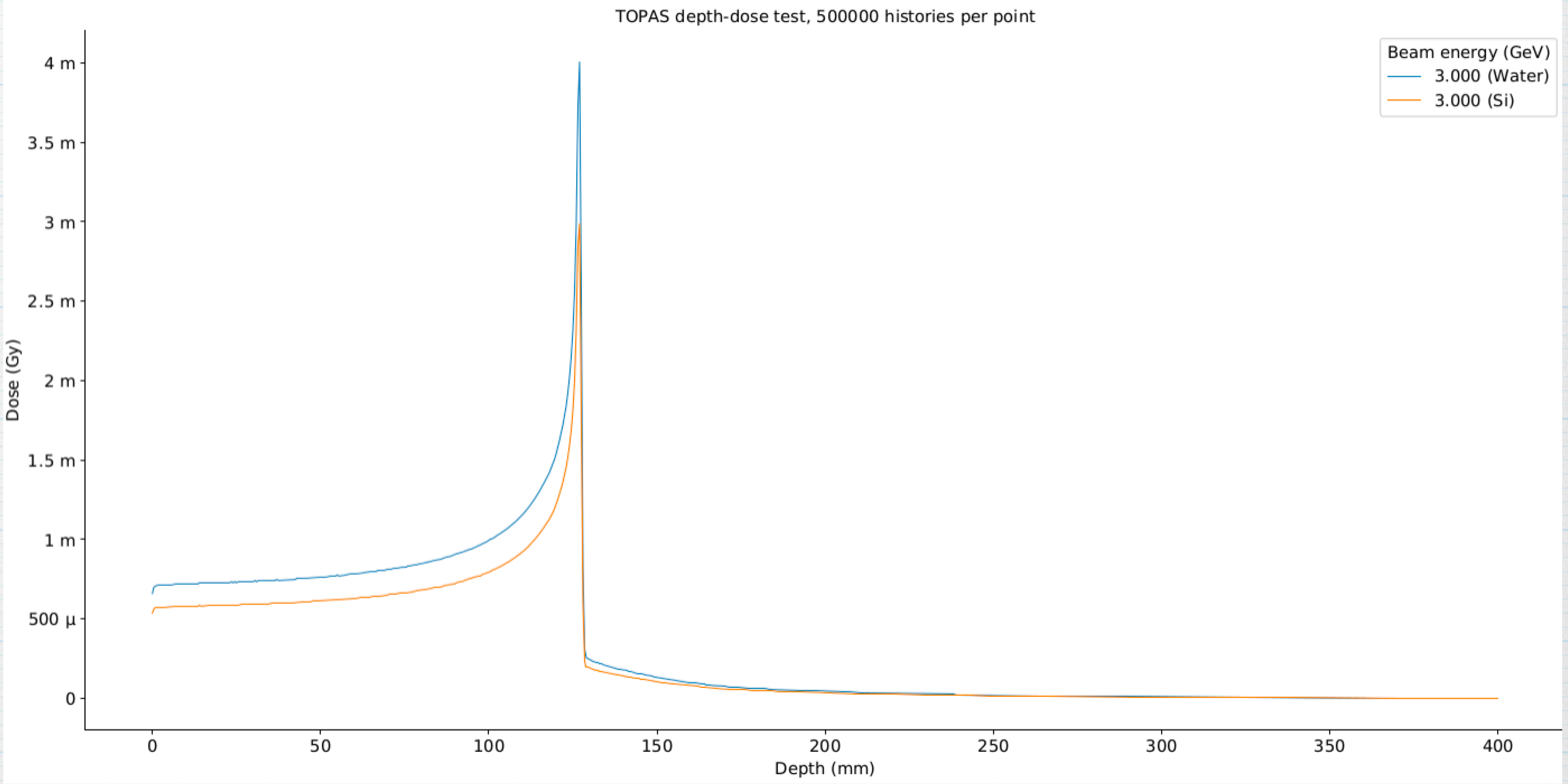
Proton and Carbon ion Beams

- 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

- Dose distribution including Bragg peak for carbon ion beam for water and silicon detector.
- Energy: 3.0 GeV
- Distribution: Gaussian
- Events number: 500K
- Physics list: Default.
- The difference in stopping power → the absorbed dose of water > silicon





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.