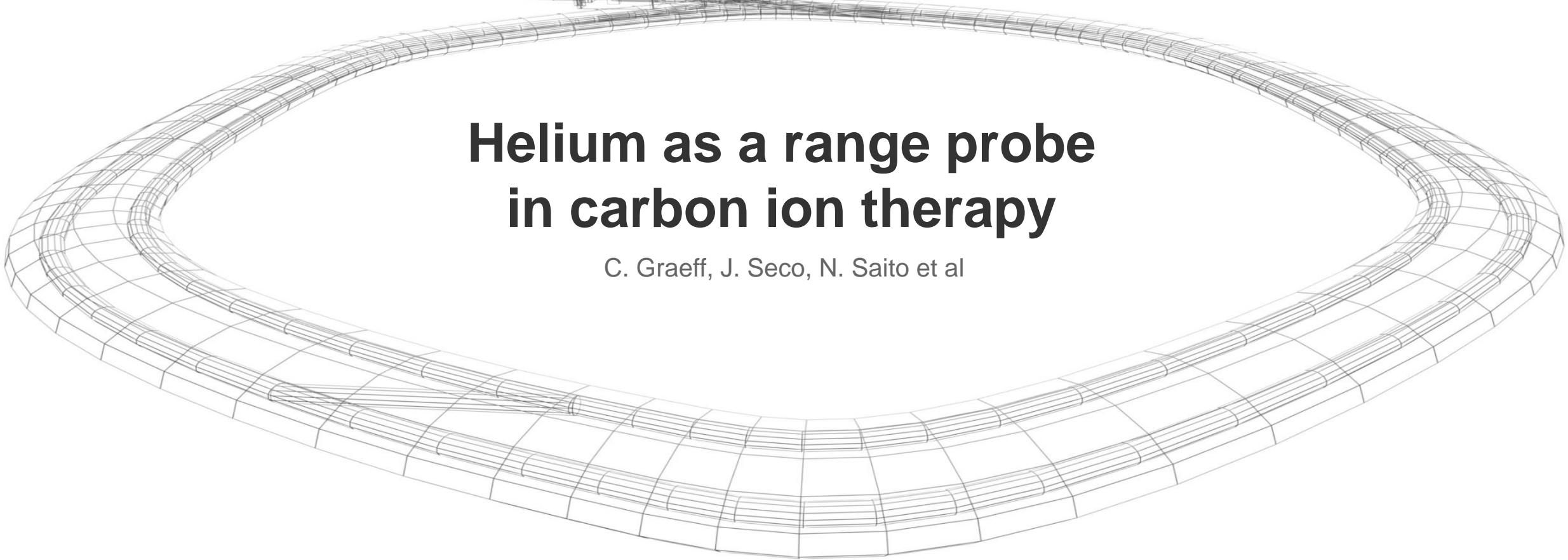
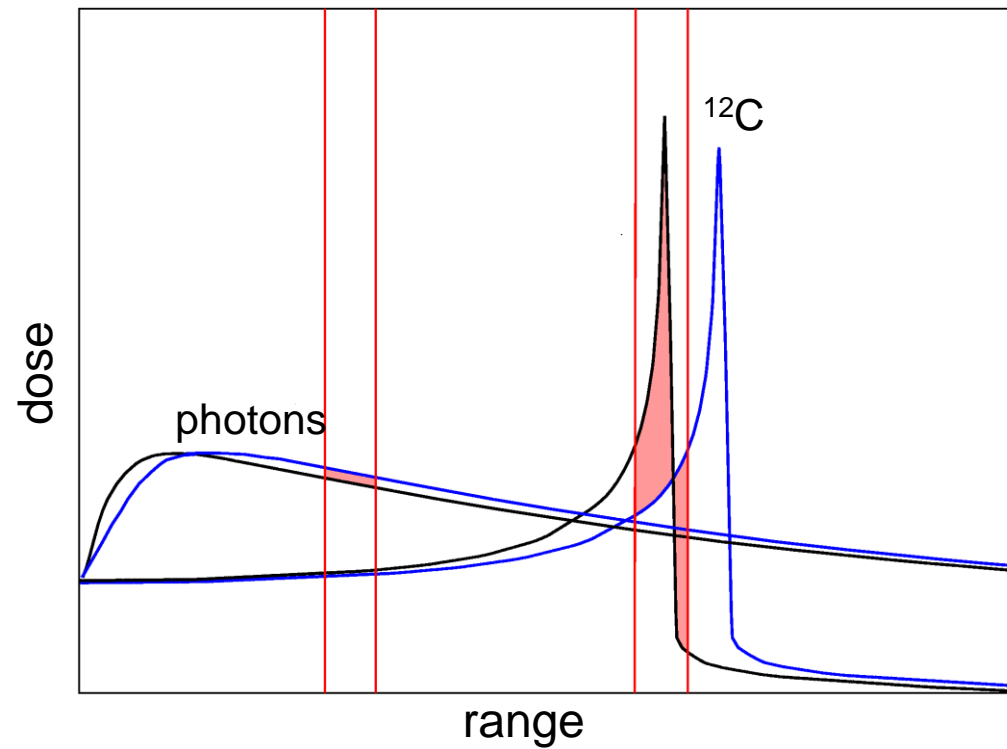
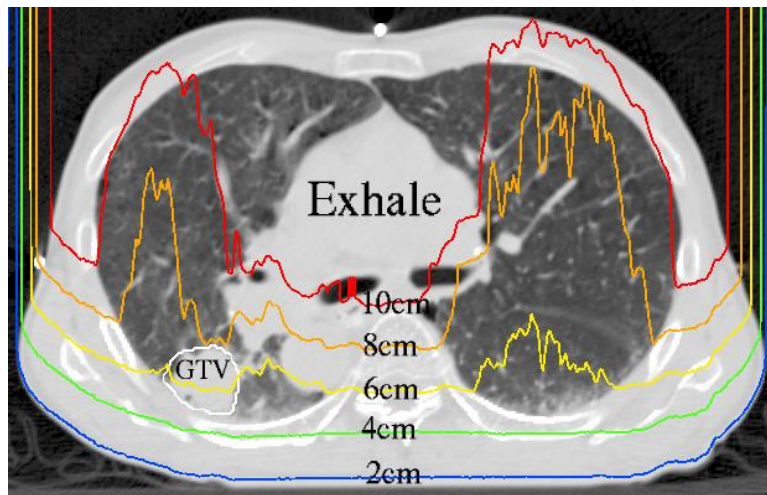
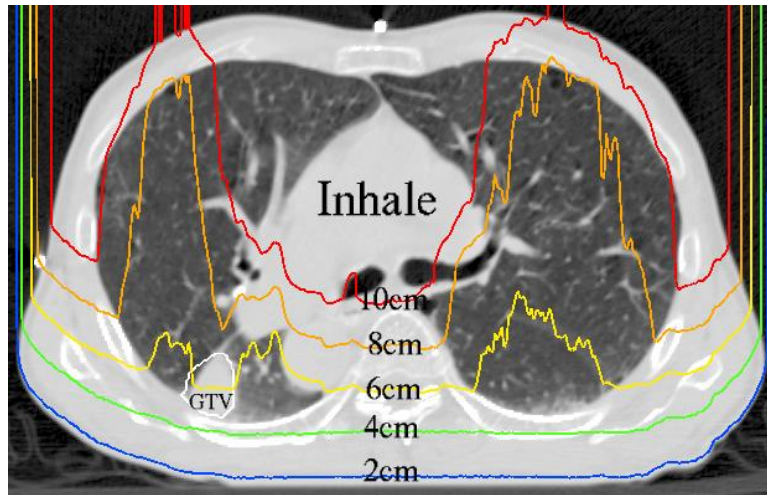


Helium as a range probe in carbon ion therapy

C. Graeff, J. Seco, N. Saito et al

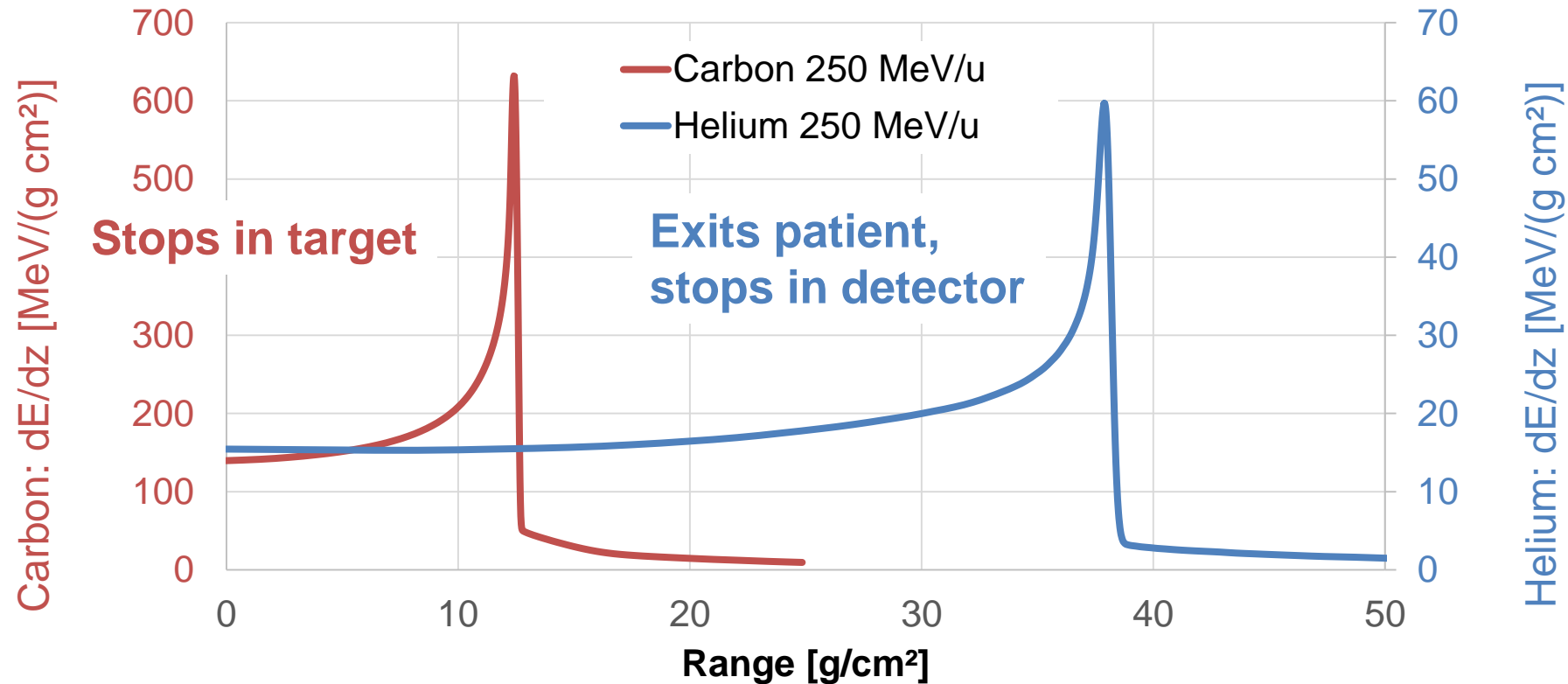


Range uncertainty - a major issue



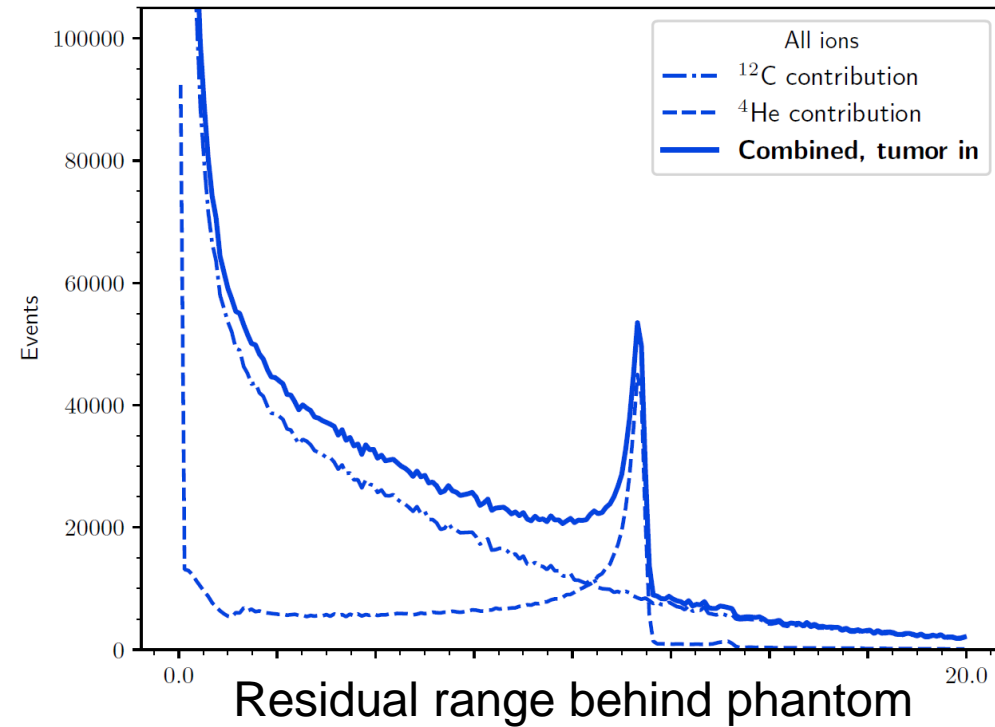
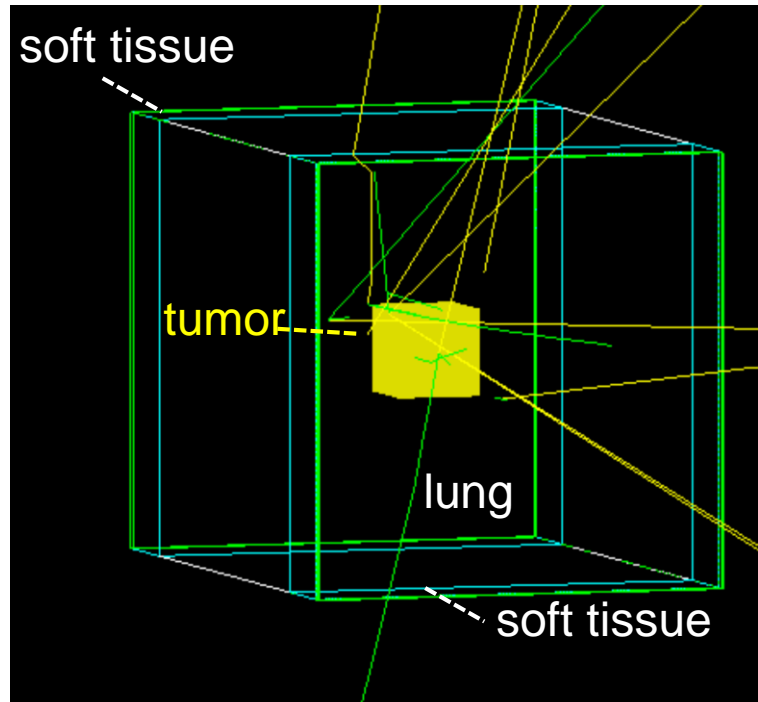
A mixed He-C beam

- Fully ionized Helium and Carbon – (nearly) same mass:charge ratio
- Can be accelerated to same velocity - range of ${}^4\text{He}^{2+} \approx 3 \times$ range of ${}^{12}\text{C}^{6+}$



Monte Carlo: Carbon fragments vs. primary Helium

- Simple test setup: parallel plates of soft tissue, lung, and tumor
- Residual range of all particles exiting distal phantom plane recorded



➤ Helium can be separated from Carbon fragment tail

Feasibility test: a patient simulation

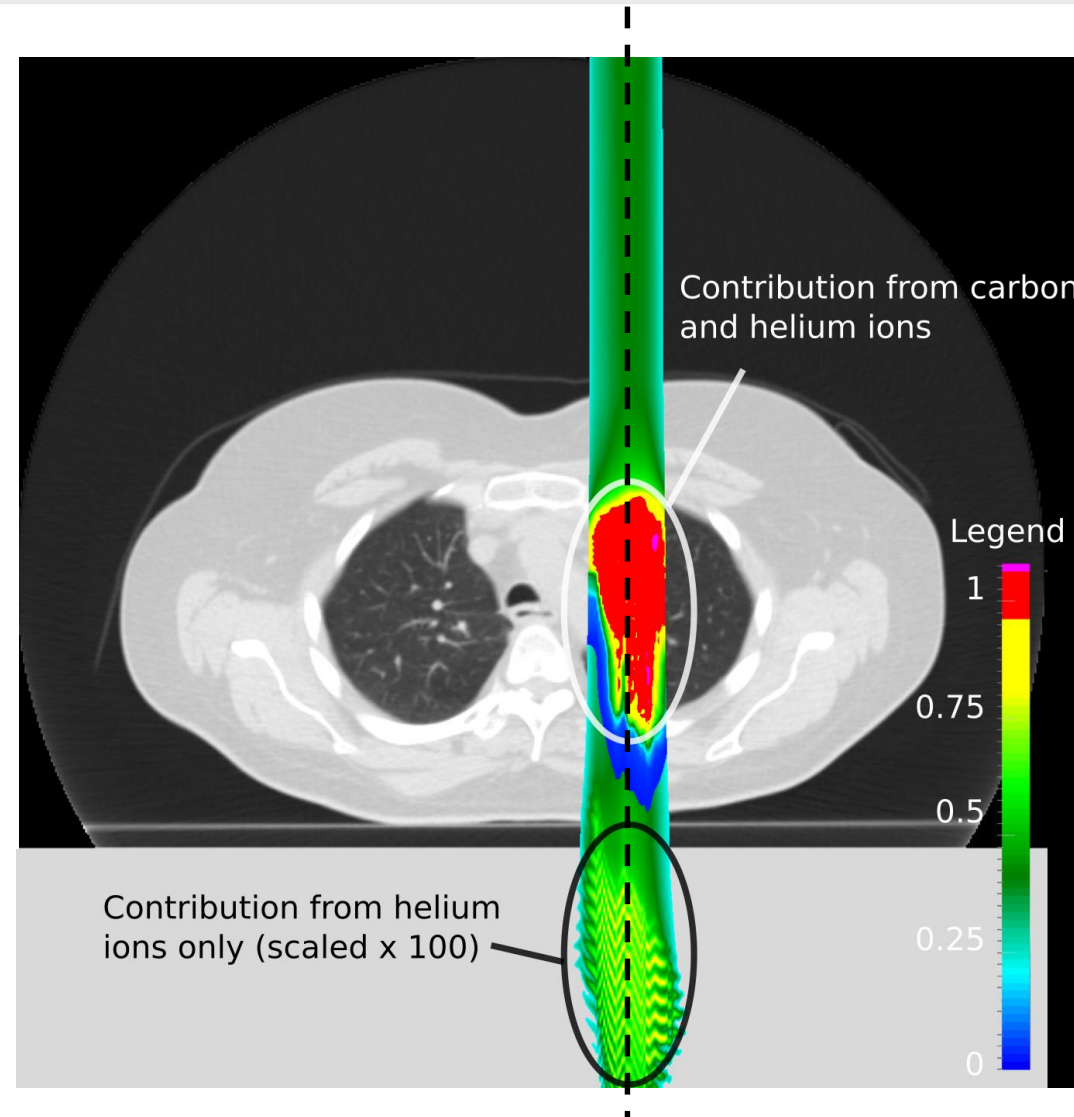
- RBE-weighted doses & optimization of mixed beam using LEM IV
- Plan setup & optimization steered by carbon therapy
 - Helium dose considered
 - ... but assigned fixed portion of spot weight N in each iteration i

$$D_{RBE} = (D_{absorbed}^{He} + D_{absorbed}^C) \cdot RBE_{He,C}$$

$$N_{i+1,He} = \rho \cdot N_{i,C}$$

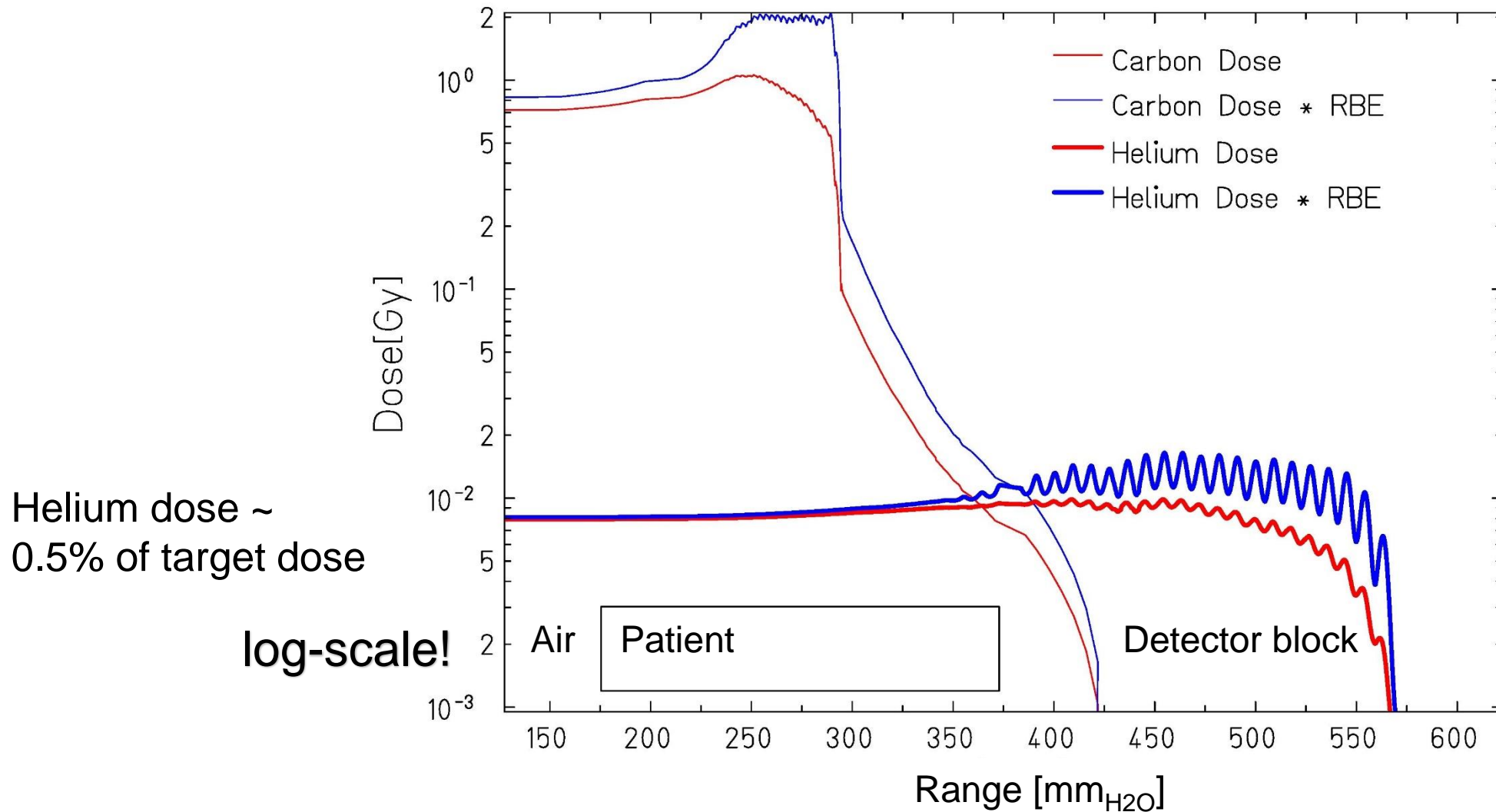
- Single AP field: 2 Gy(RBE), no OARs considered, $\rho = 10\%$

Image-guided particle therapy



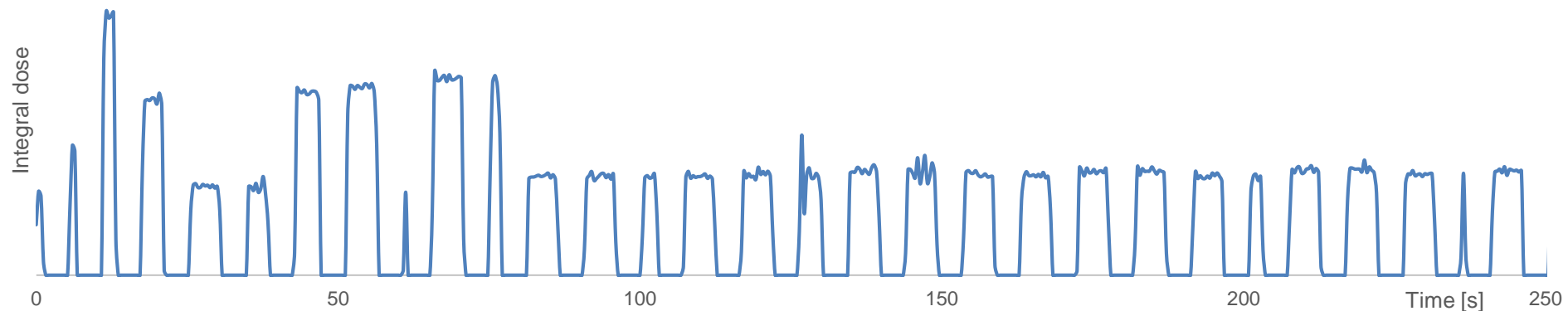
Beam' eye view
dose profile
(next slide)

Dose profile along central beam axis



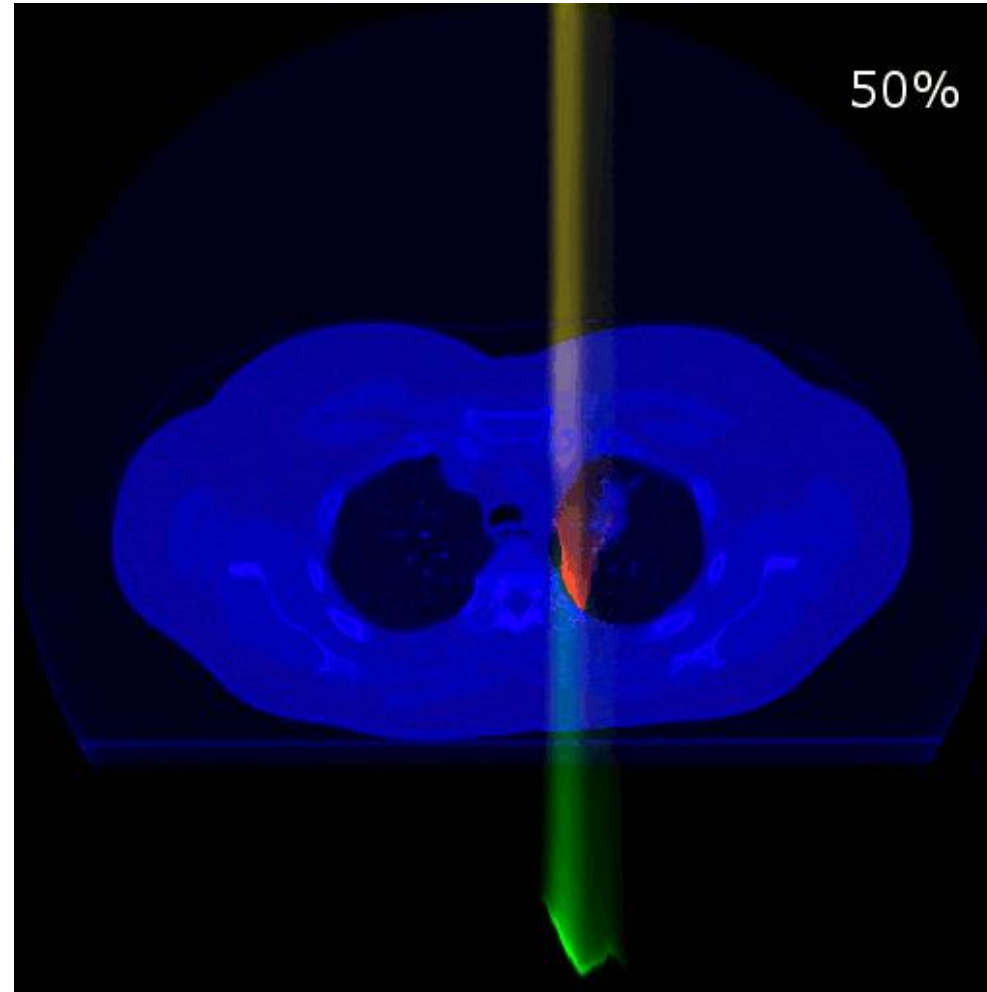
Preliminary: Range detection under motion

- Time-resolved simulation of same plan as for static test
- Dose calculated for each motion phase of 400 ms
 - Plan simulated for GSI Cave M: 26 IES in 56 spills
 - single breathing trajectory with 4 sec period
 - Dose calculated for each consecutive motion phase
- Mimicking an IC / scintillator stack:
Dose integrated on each CT plane perpendicular to the beam
- Quantification of range ongoing –
qualitative impression for consecutive motion phases, single energy



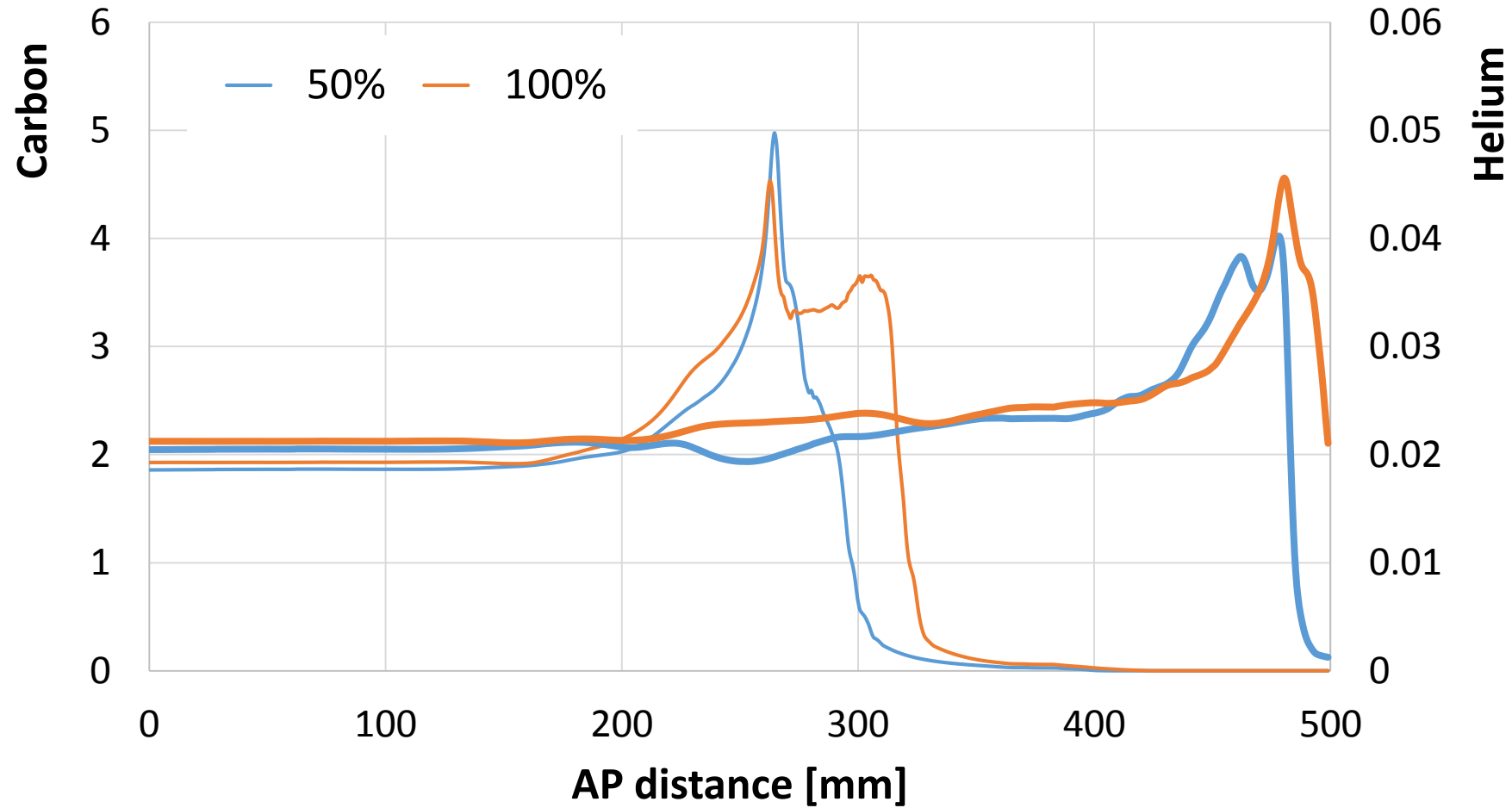
Preliminary: Range detection under motion

Carbon
Helium



Motion phases #555 to #550; $E = 210.83 \text{ MeV/u}$

Integral dose perpendicular to beam



Outlook

- Simulations show feasibility for **online portal imaging and range detection** at low additional dose (<0.5% at 10 % He)
- Clinical relevance: Identify suitable patients
 - Carbon range to tumor sets energy, Helium not always exits patient
- Technical challenges
 - Multiple / mixed ion sources required
 - Mass-charge ratio differs by 0.6 ‰ – challenge in synchrotron
 - Technical feasibility needs to be shown, i.e. stable injection, acceleration and extraction of mixed beam
 - Experimental investigation will start with separate ion beams at GSI this fall