



Monitoring intra-fractional motion using a novel range telescope in a mixed He/C beam

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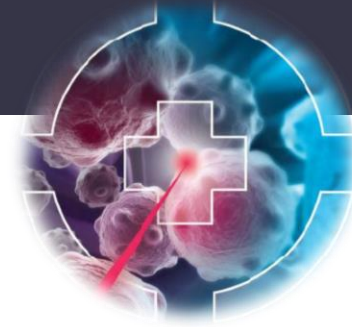
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Outline

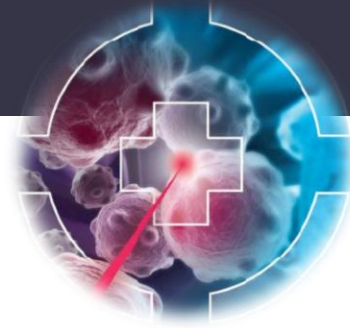


- Carbon therapy
- He/C beam mixing
- Range telescope
- Measurements¹
 - PMMA phantoms
 - Anthropomorphic phantoms²
- Discussion: He/C in clinics

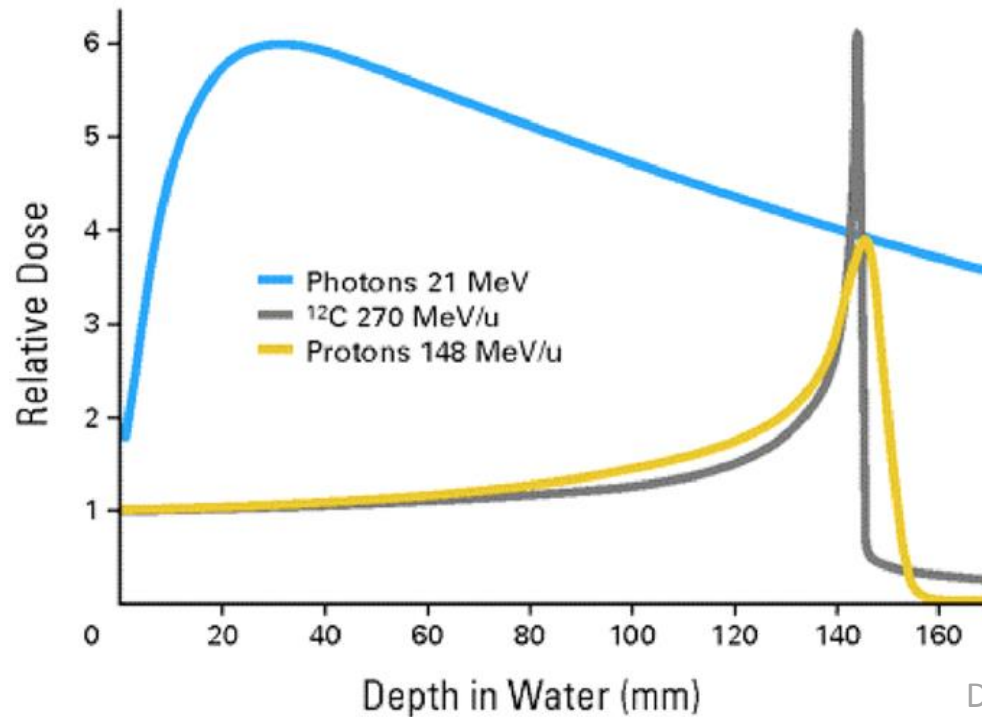
¹ at Heidelberg Ionenstrahl-Therapiezentrum (HIT)

² by DKFZ phantom workshop

Carbon beam therapy

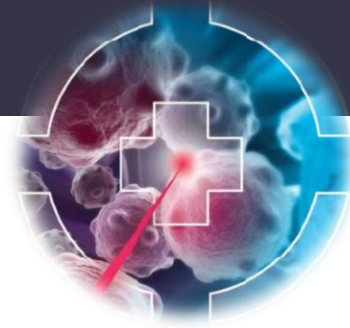


- More conformal dose distributions
- High RBE
- Low OER



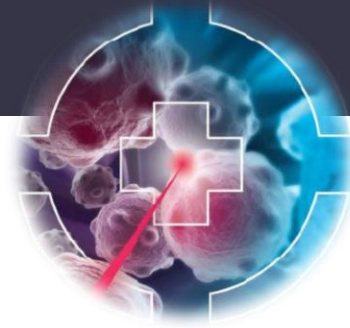
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Anatomical changes

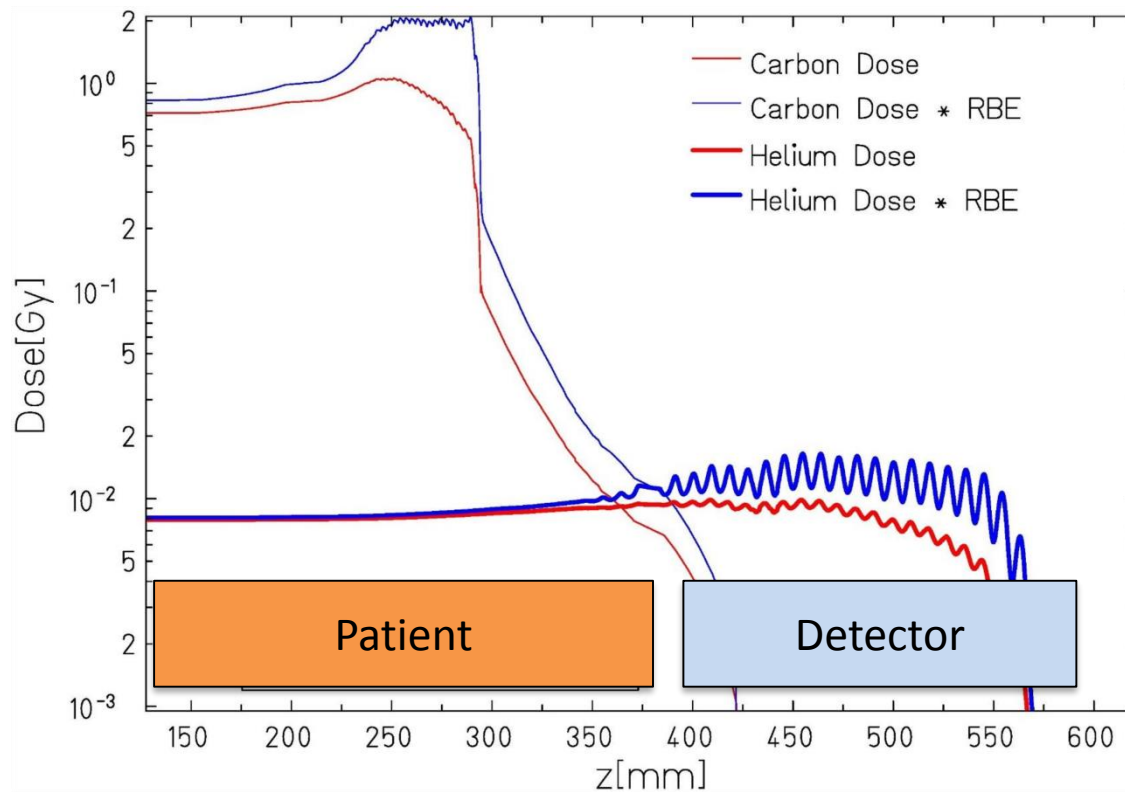


- Inter-fractional movements, e.g.
 - Patient misalignment
 - Tumour shrinking
 - Cavity filling
- Intra-fractional motion, e.g.
 - Breathing
 - Bowel movements
 - Rectal gassing

Helium/Carbon mixing

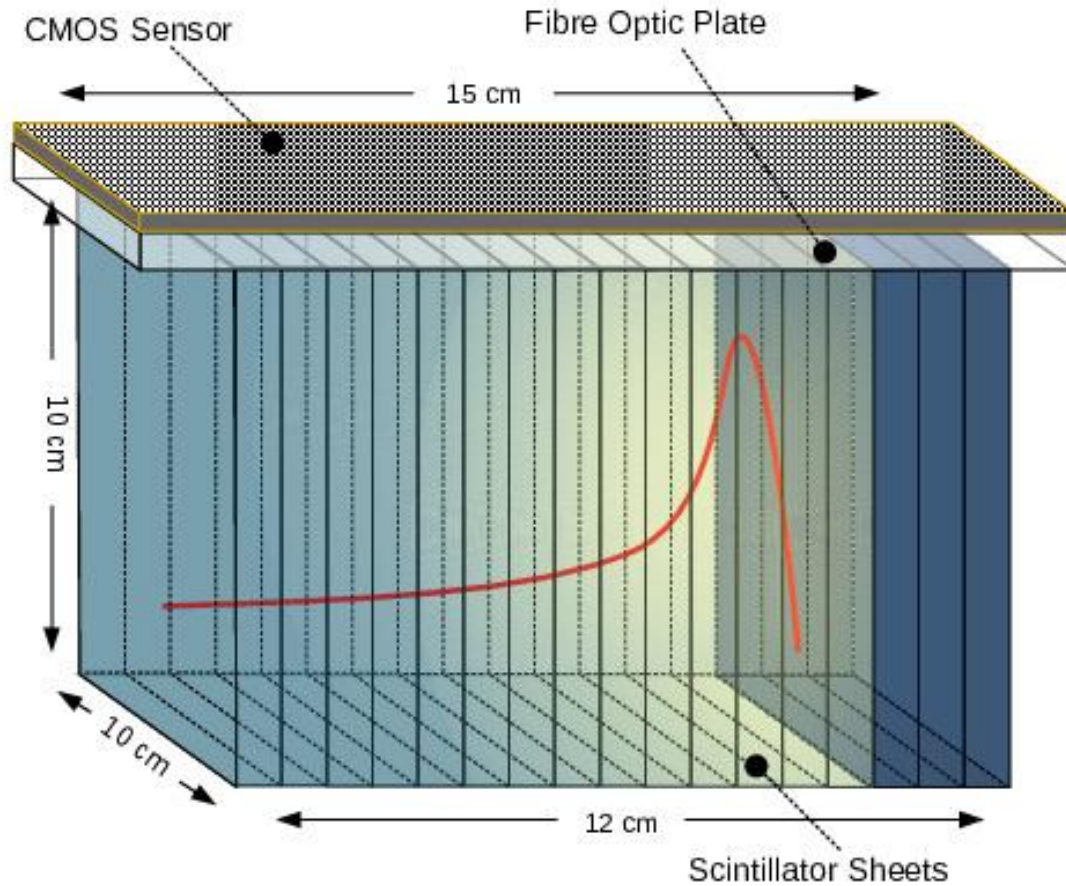
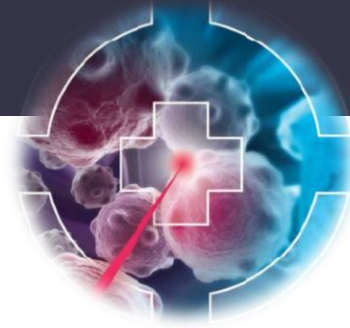


- $A/Q(^4\text{He}^{2+}) = A/Q(^{12}\text{C}^{6+}) = 2 \rightarrow$ Accelerate together
- $R_0(\text{He}) = 3 \times R_0(\text{C}) \rightarrow$ C for treatment, He for imaging

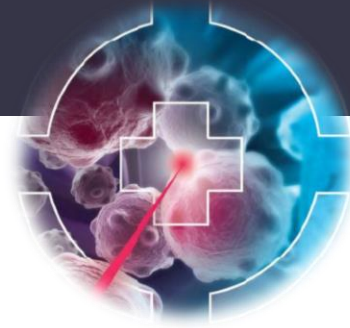


Courtesy C. Graeff

Range telescope

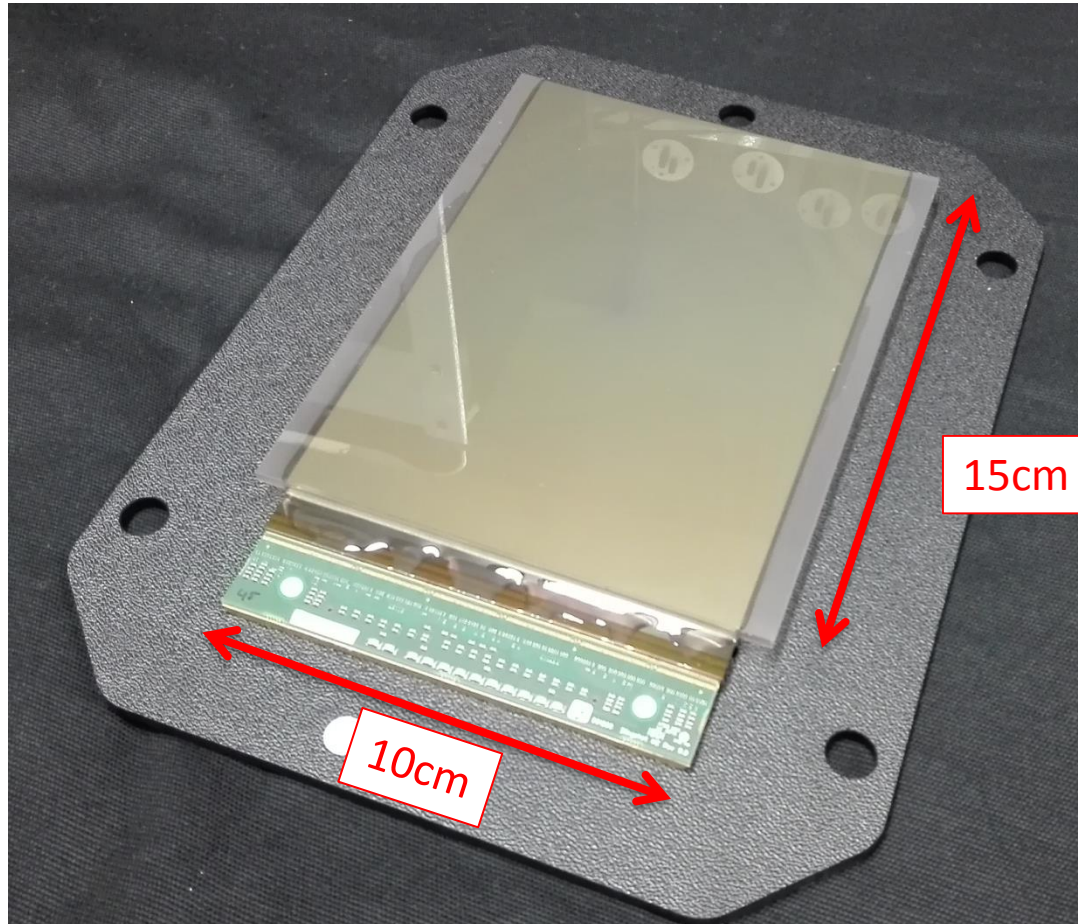
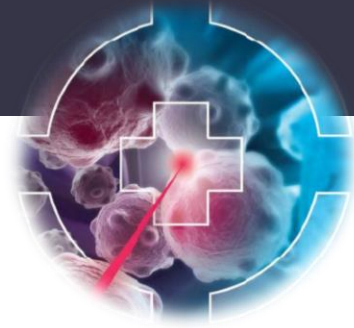


Scintillator Sheets

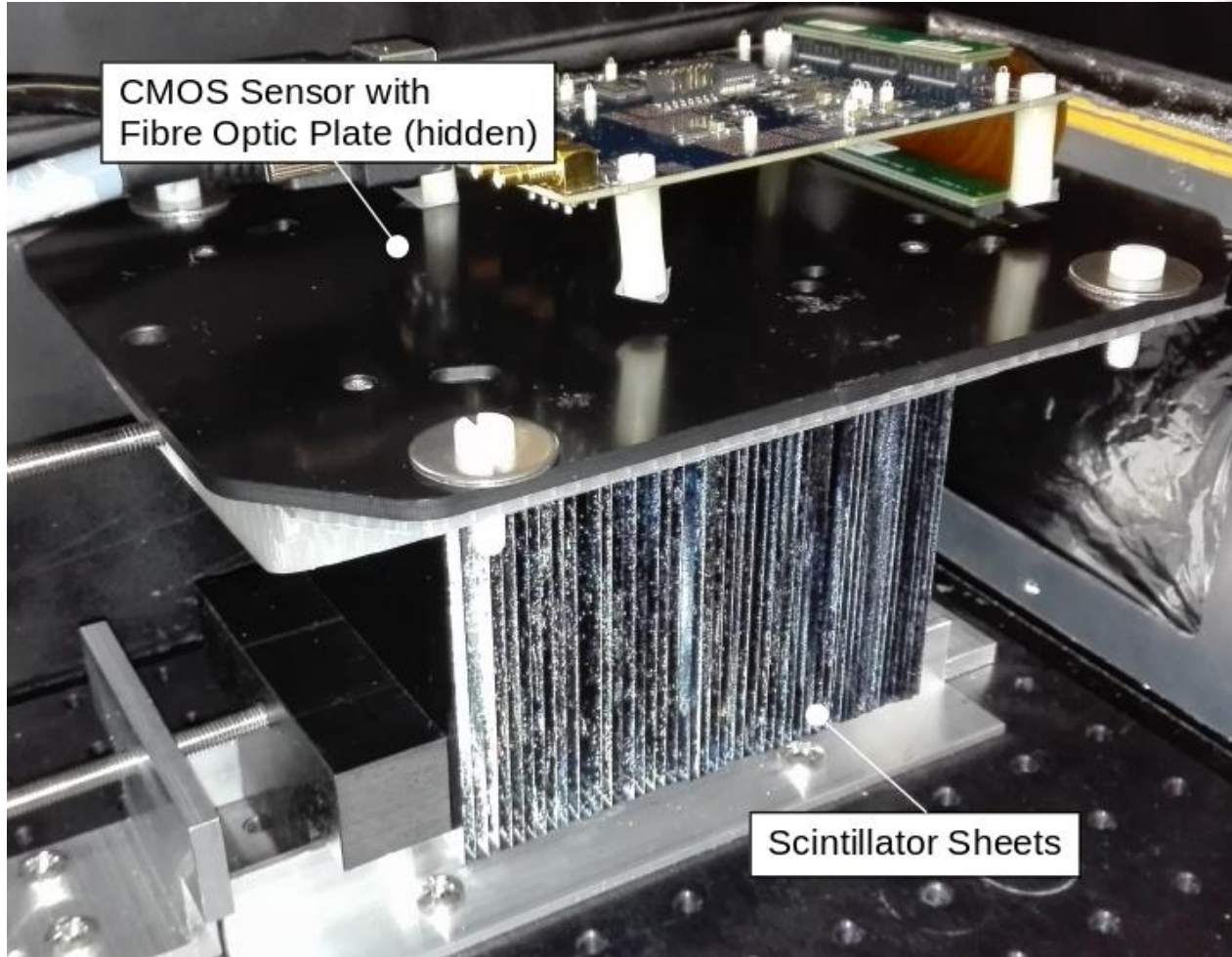
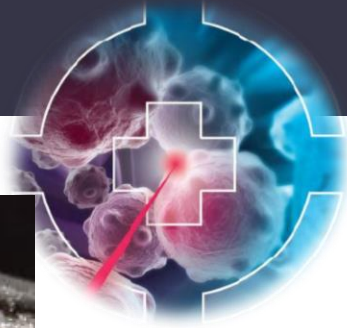


10 cm x 10 cm x 2-3mm

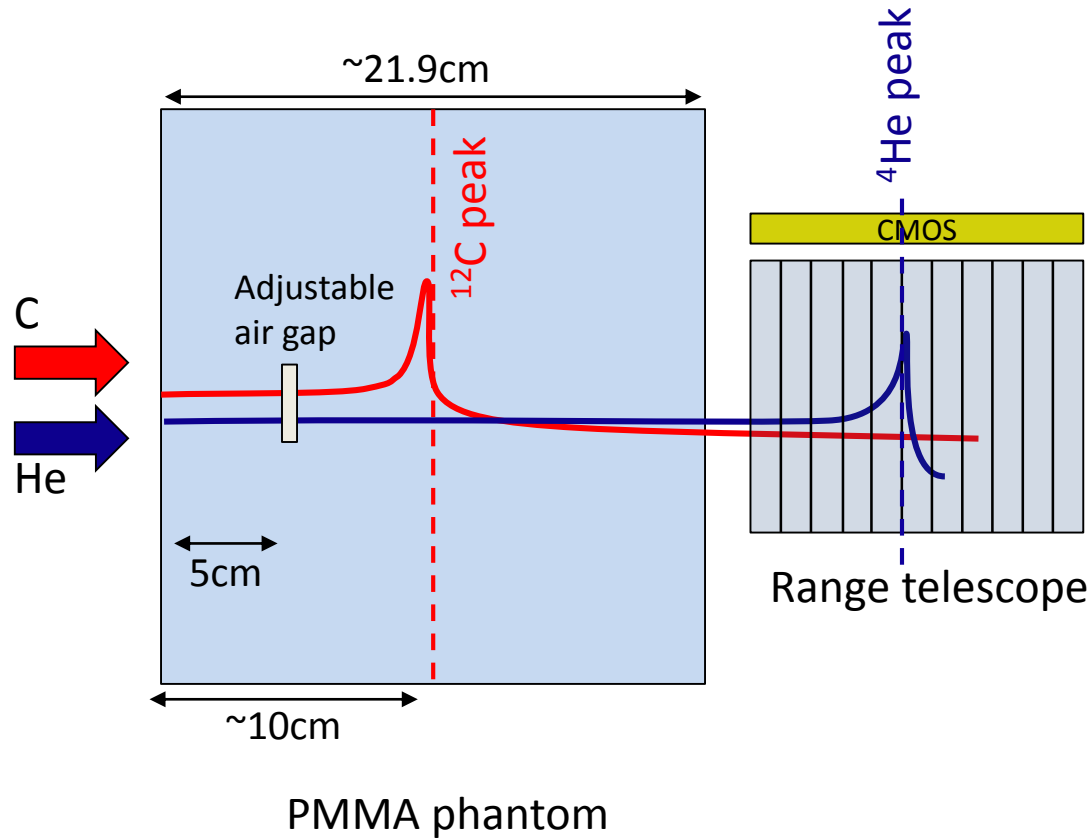
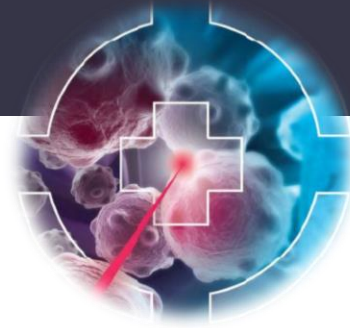
Readout: CMOS Pixel Sensor



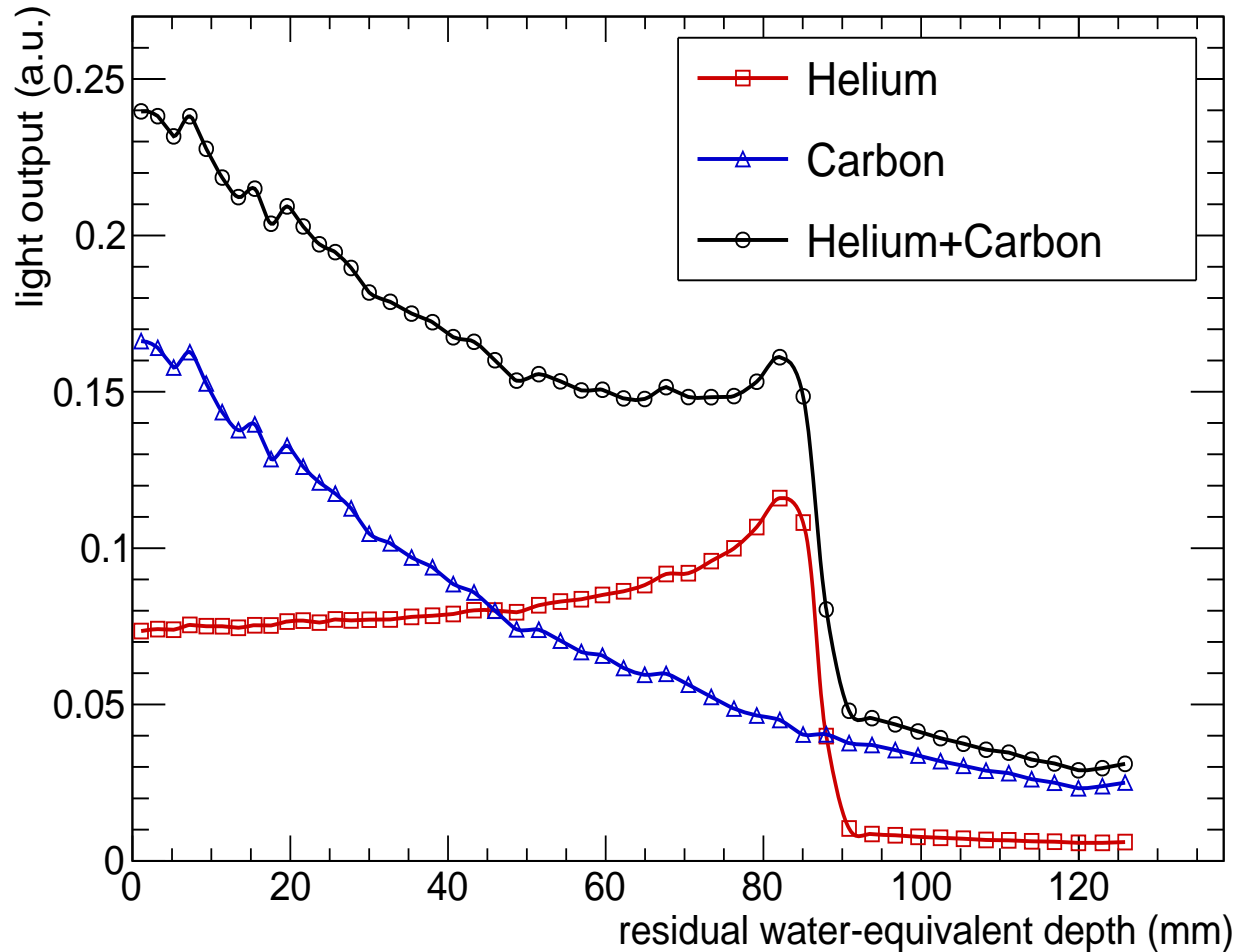
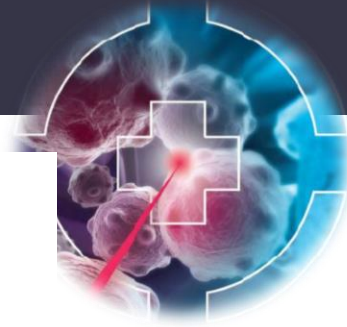
Range telescope



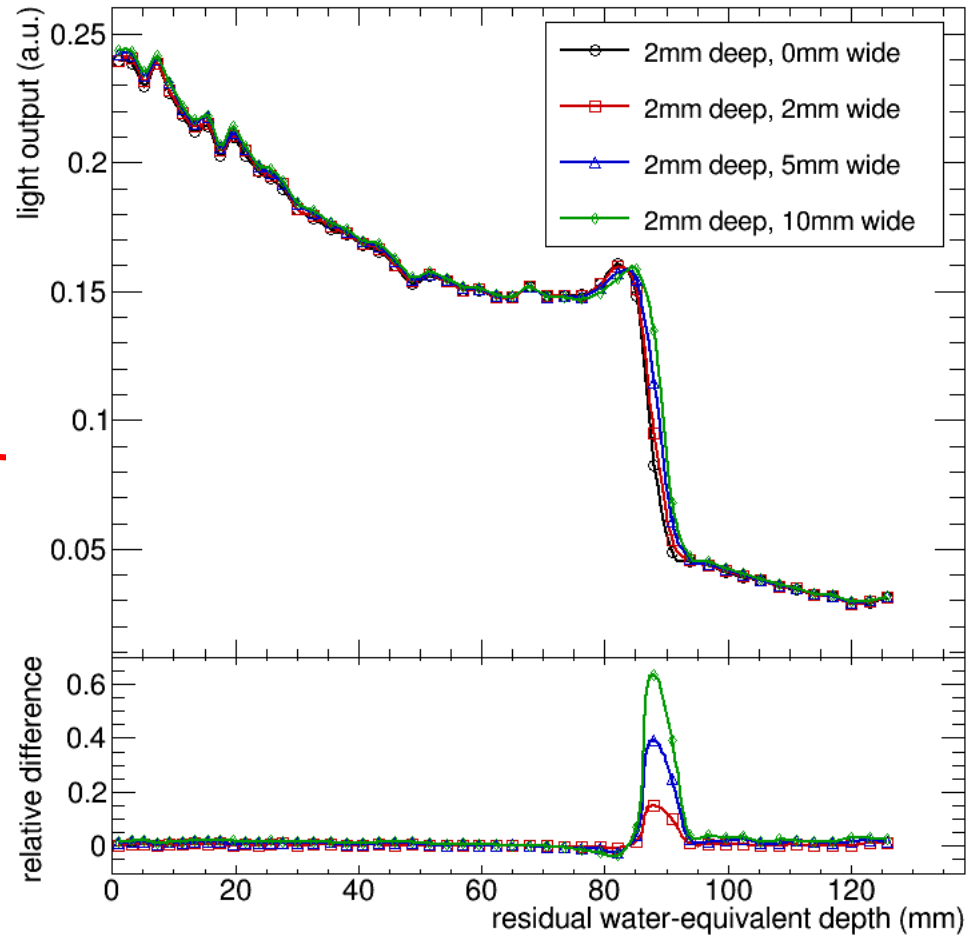
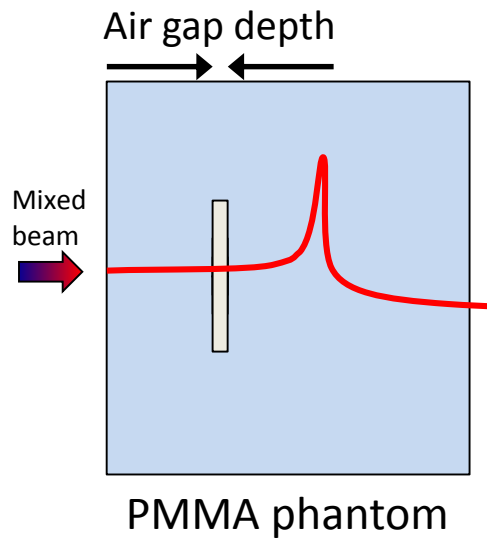
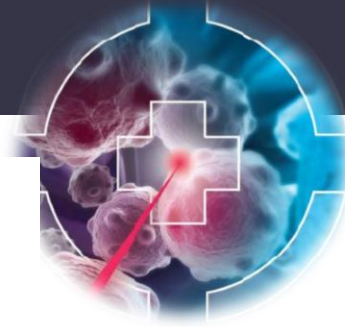
PMMA phantom: setup



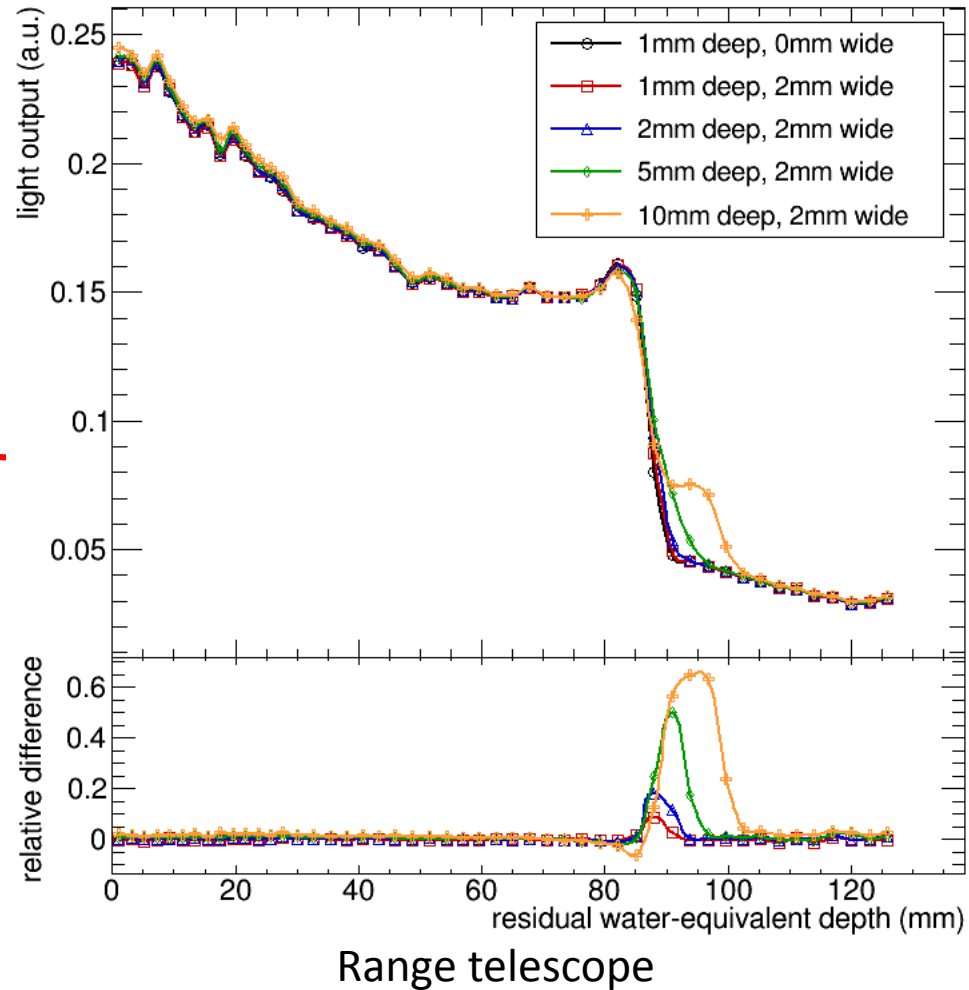
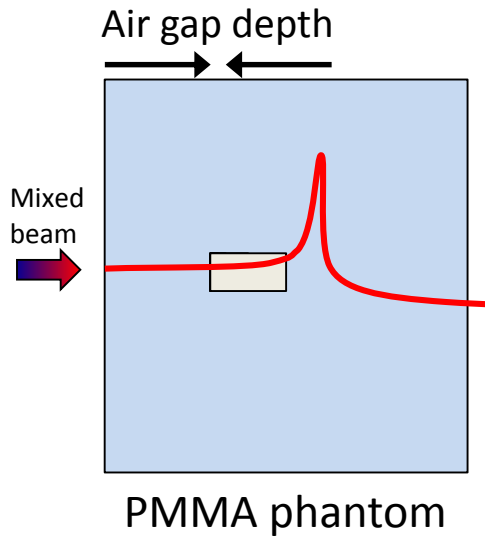
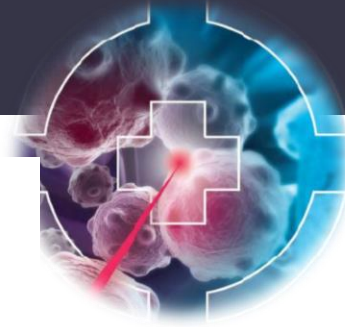
Off-line beam mixing



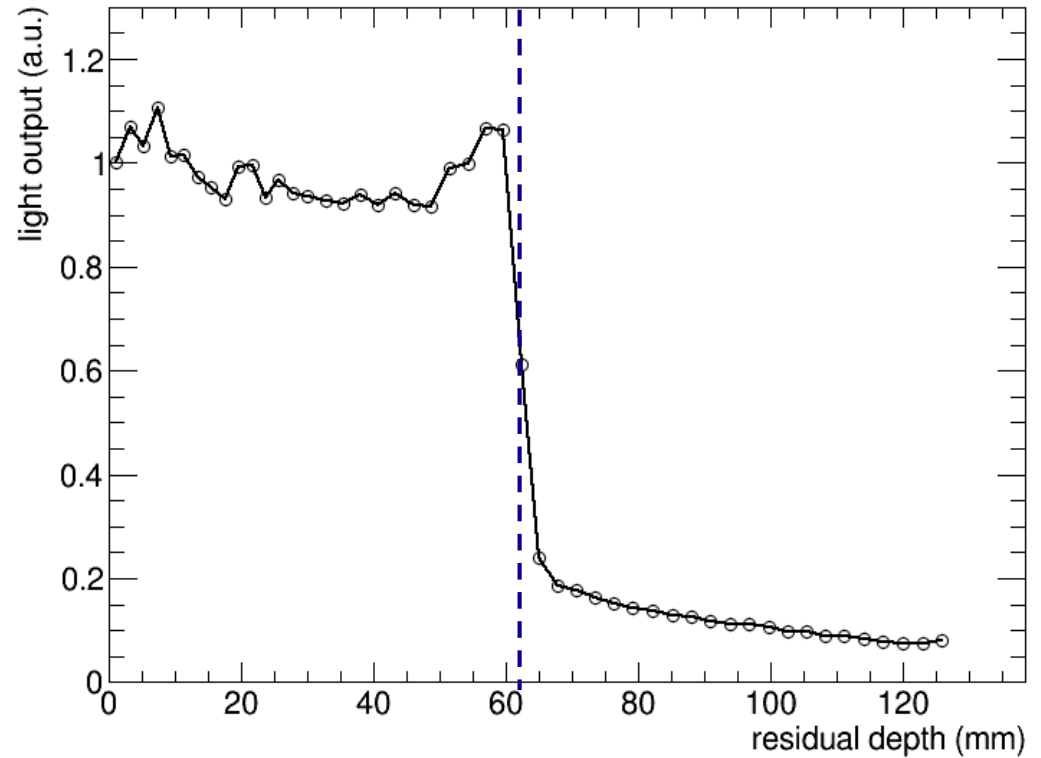
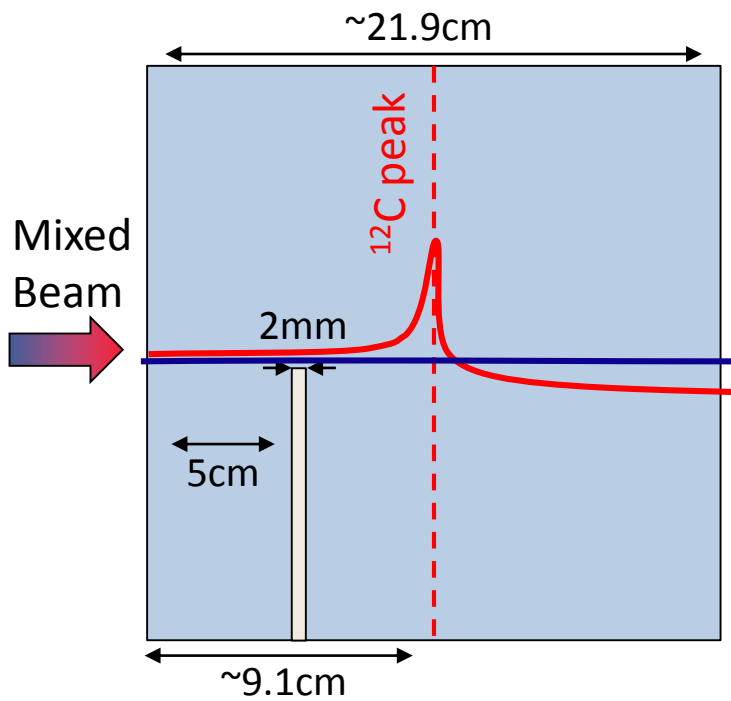
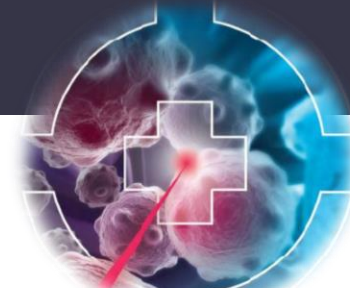
PMMA phantom: results



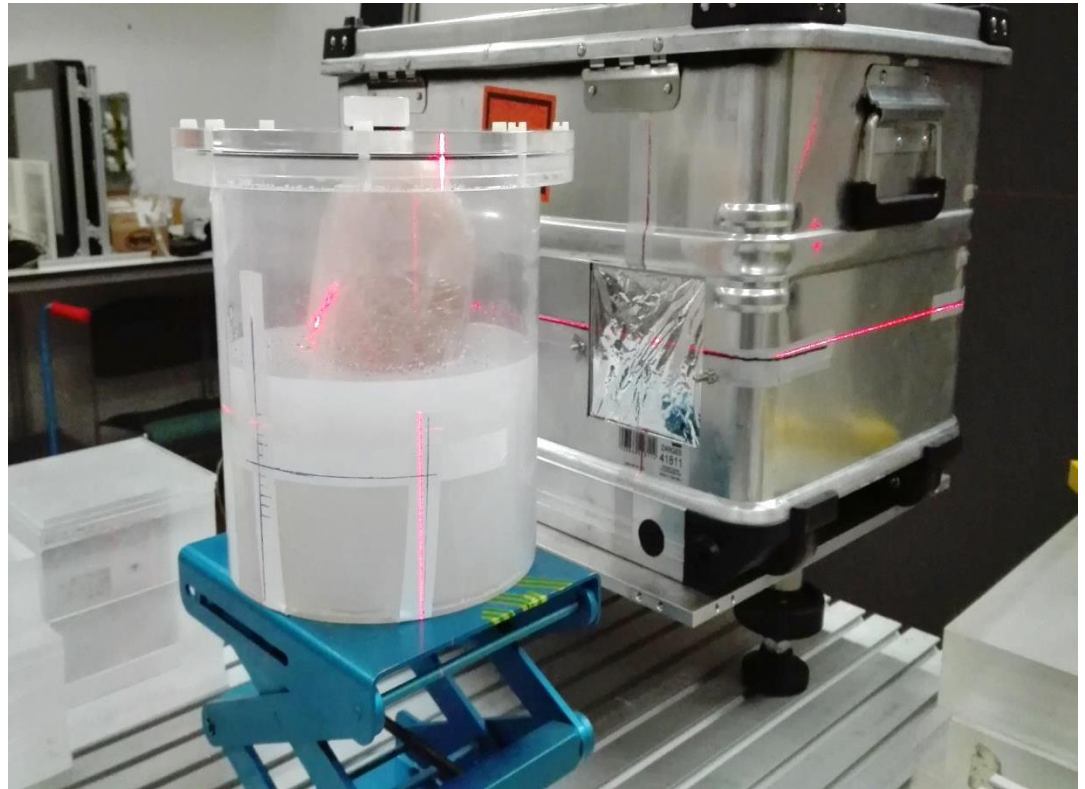
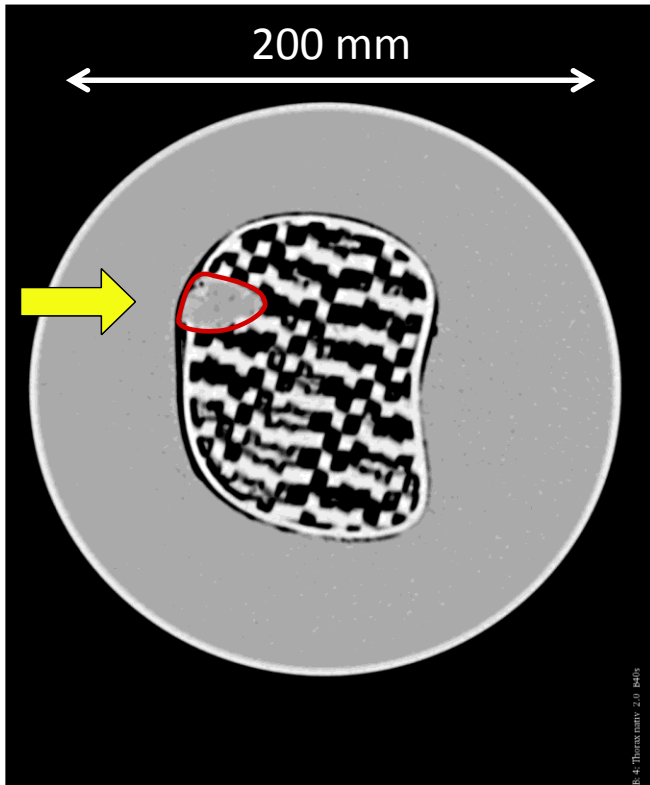
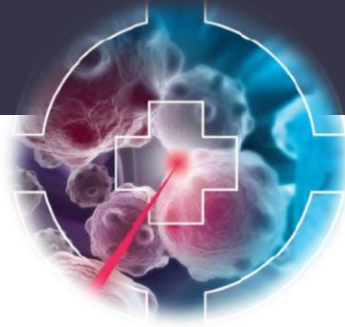
PMMA phantom: results



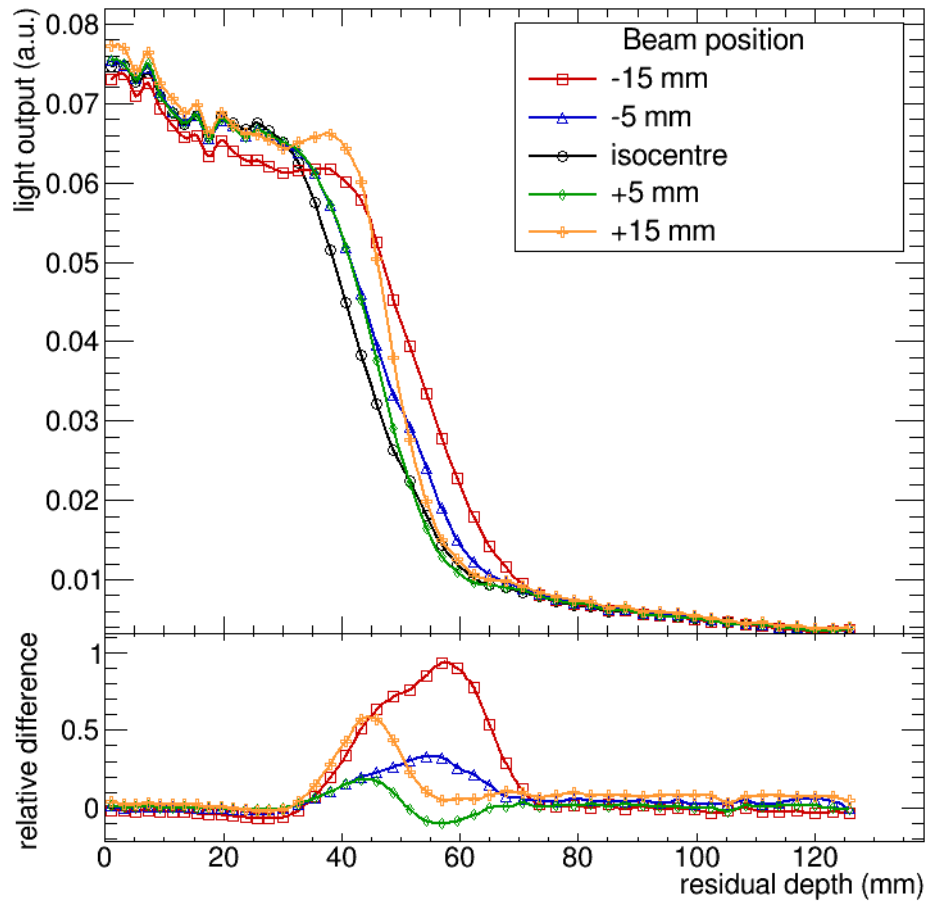
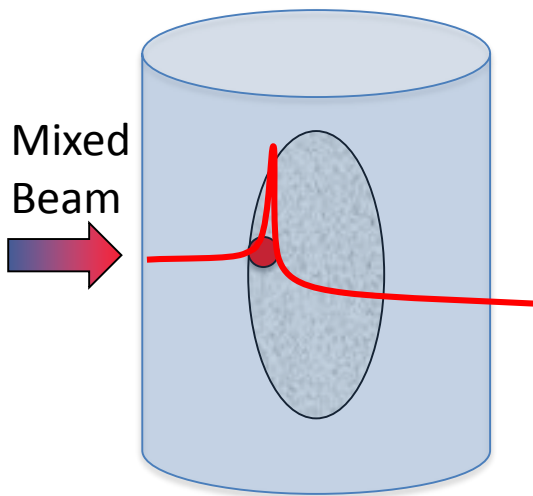
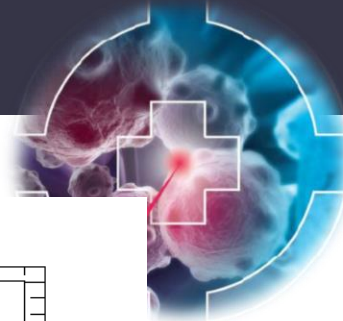
PMMA phantom: results



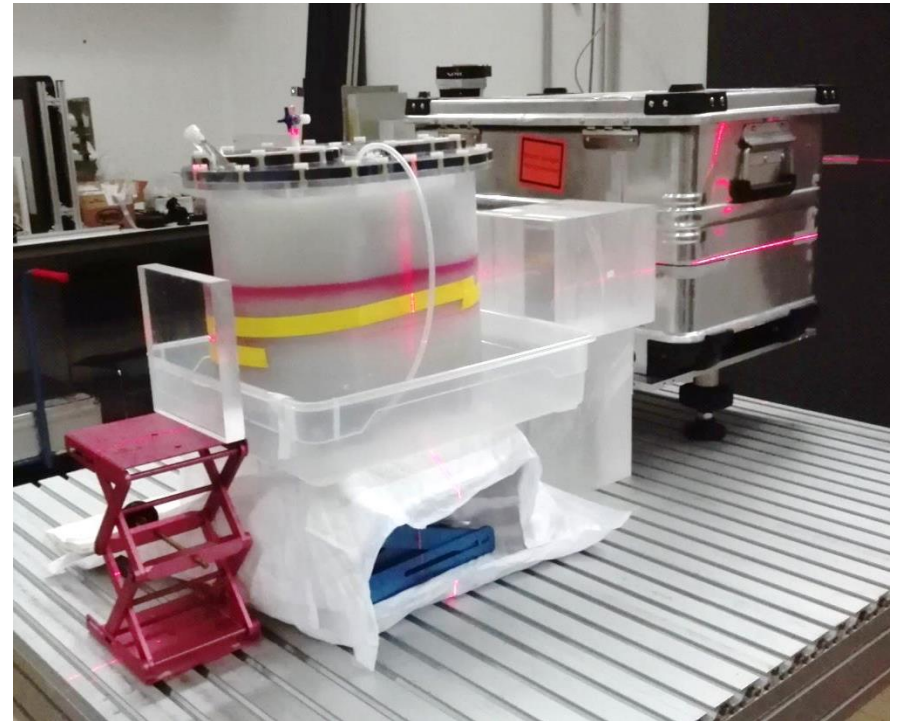
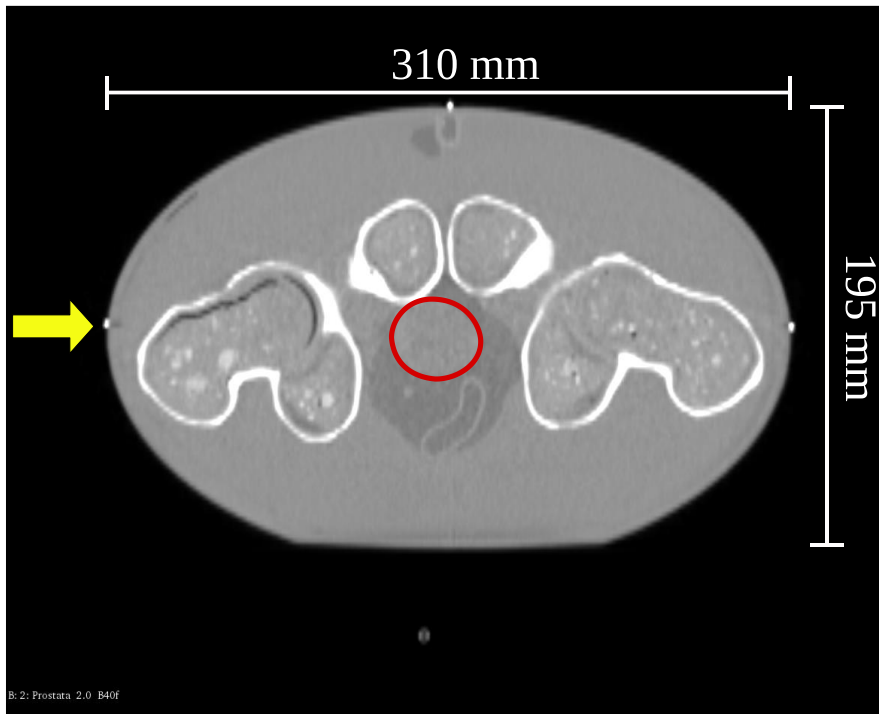
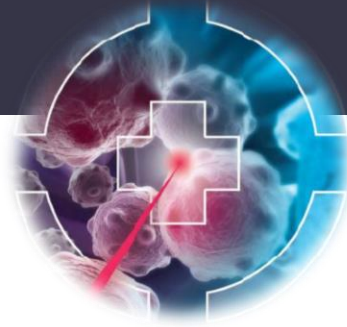
Lung phantom: setup



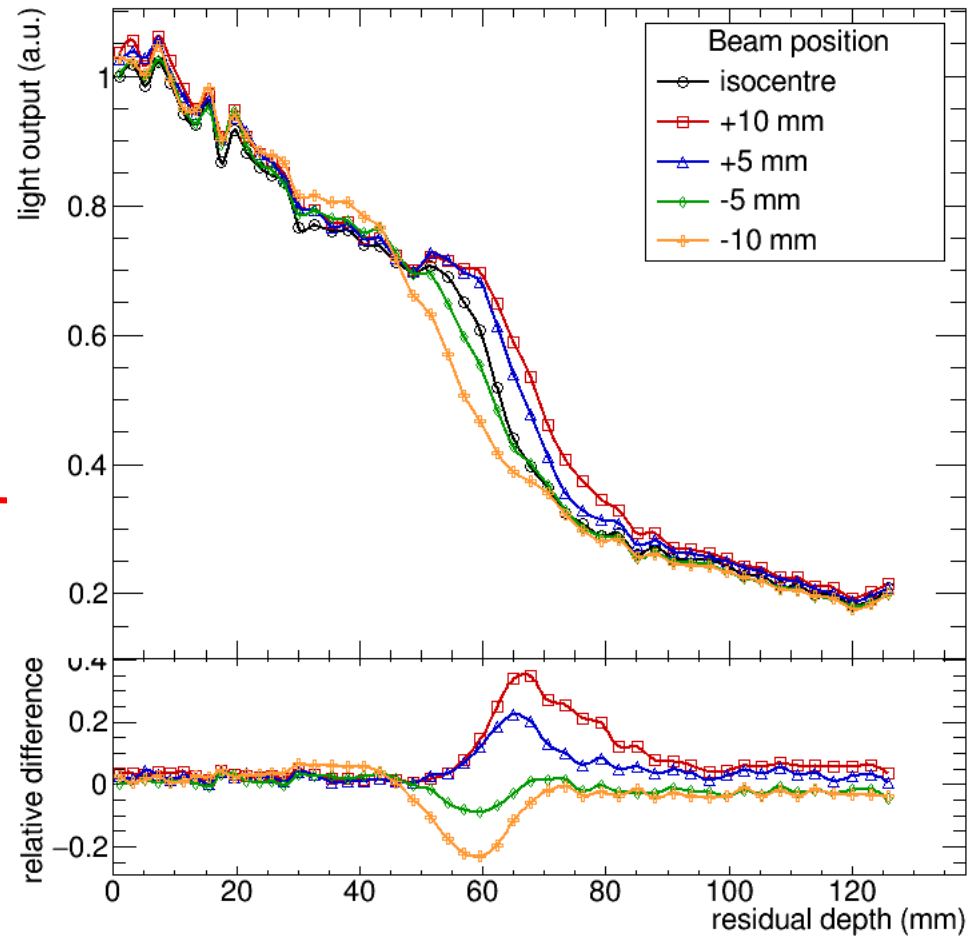
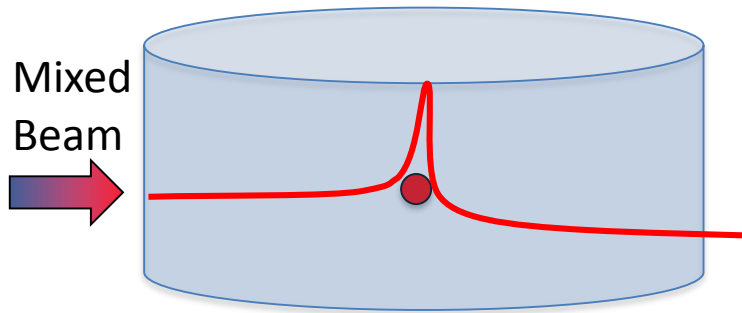
Lung phantom: results



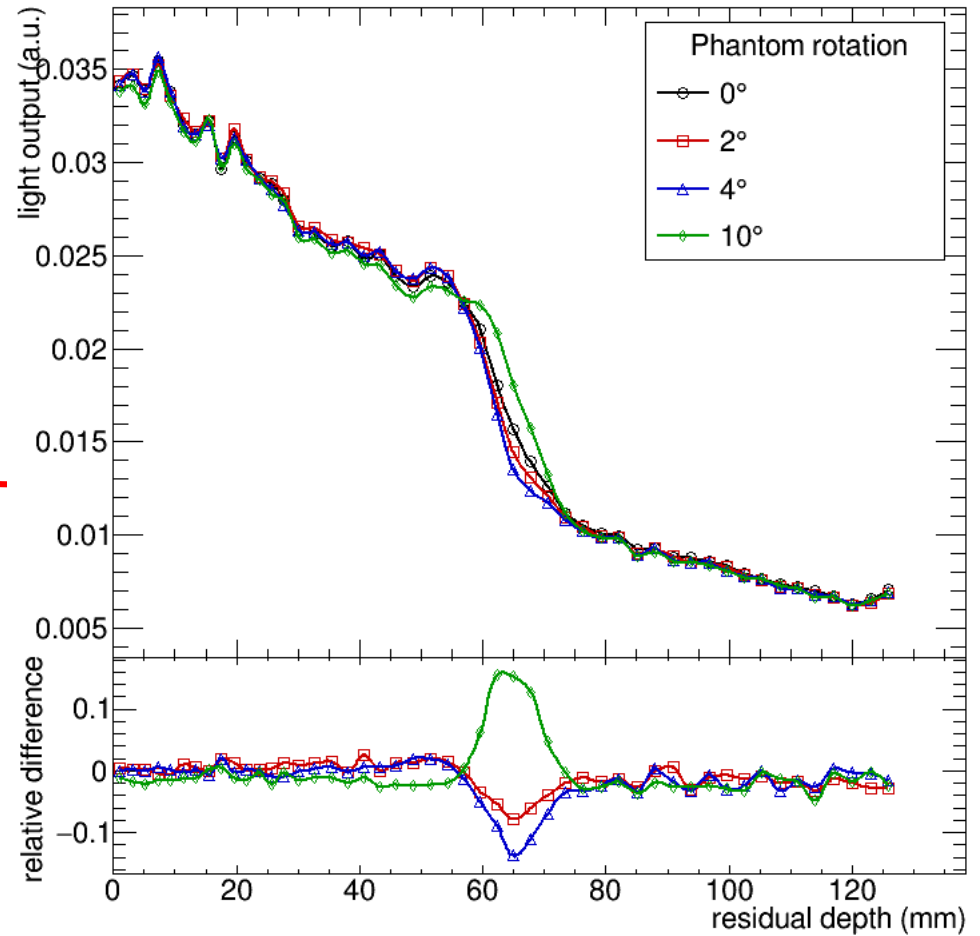
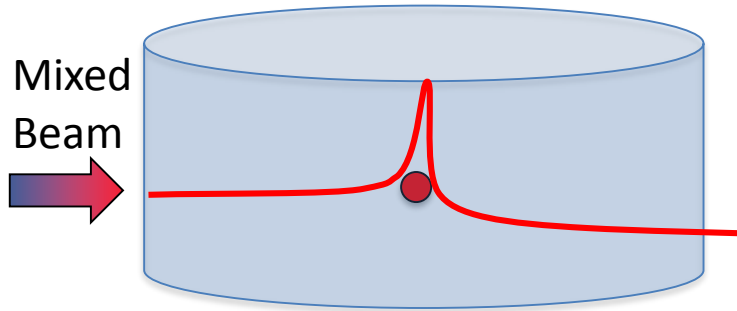
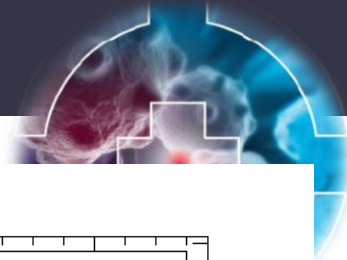
Pelvis phantom 1: setup



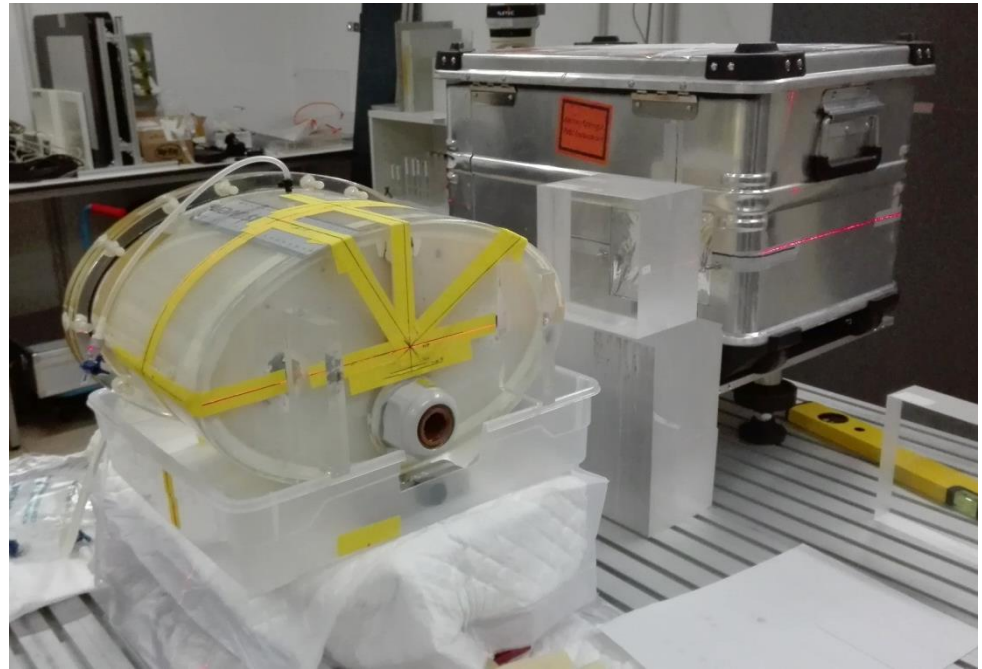
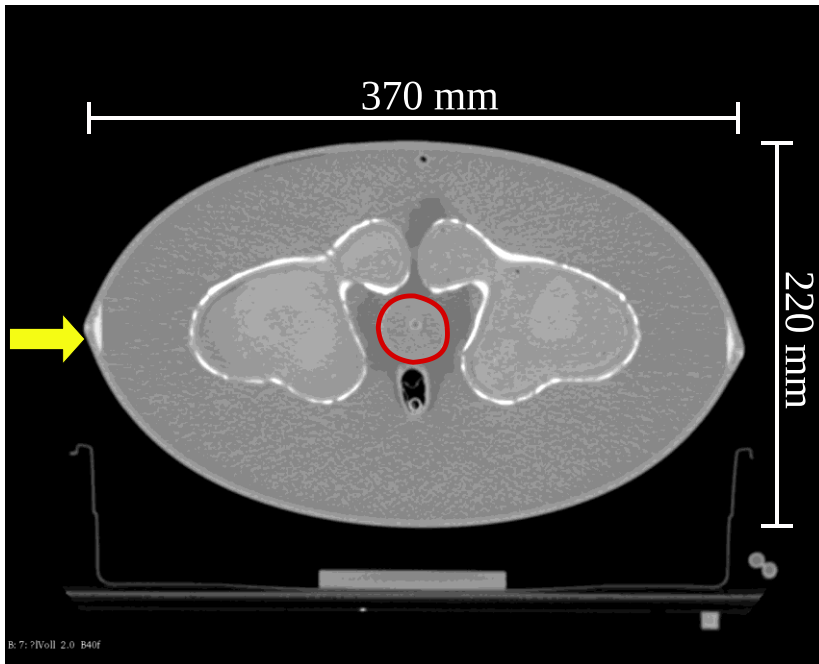
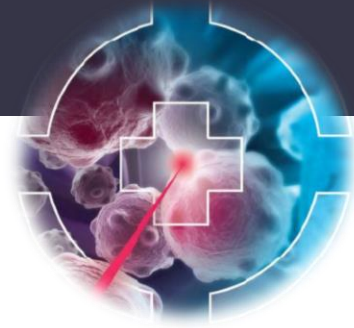
Pelvis phantom 1: translation



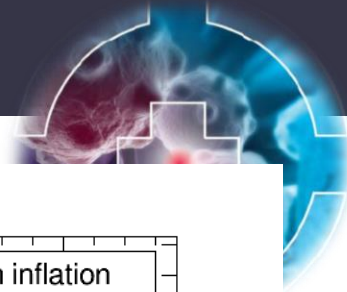
Pelvis phantom 1: rotation



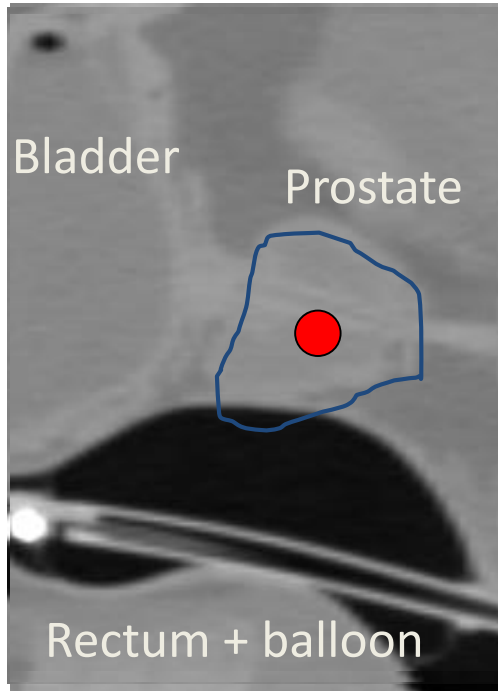
Pelvis phantom 2: setup



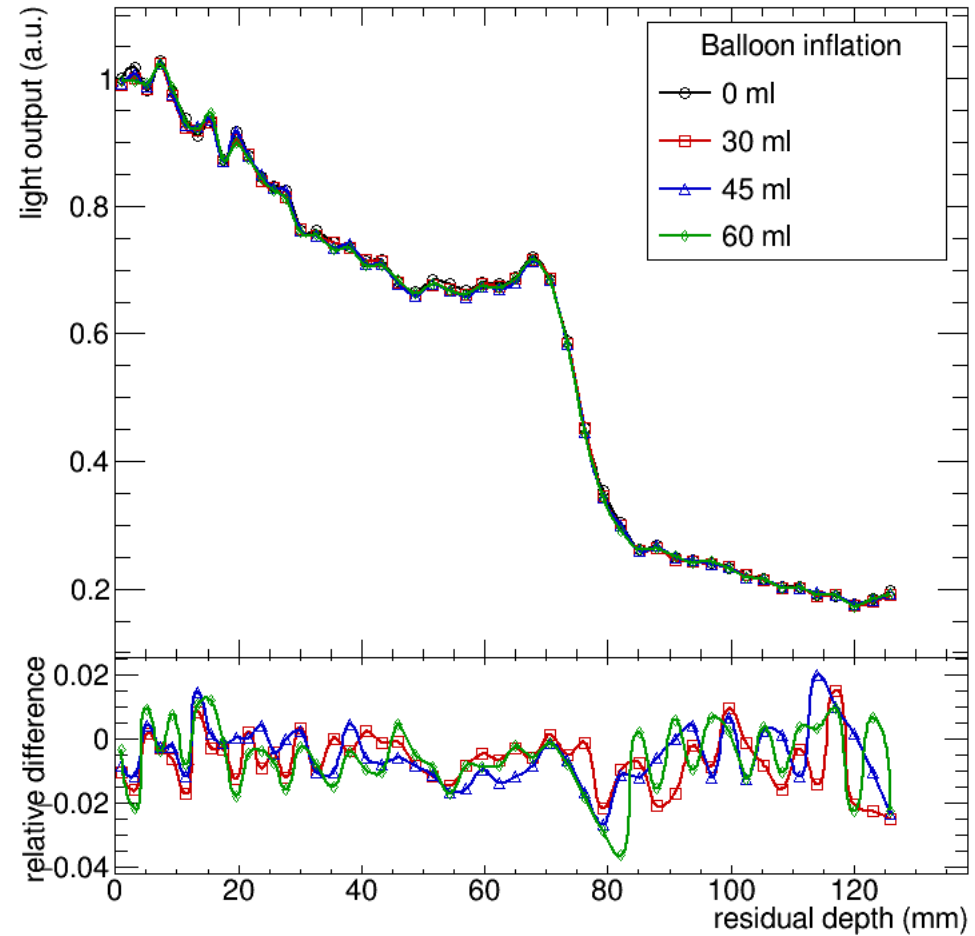
Pelvis phantom 2: results



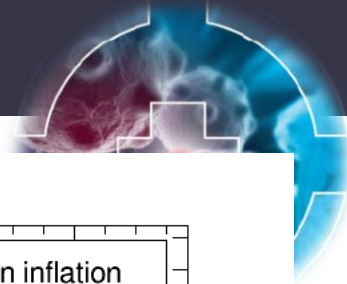
Beams eye view



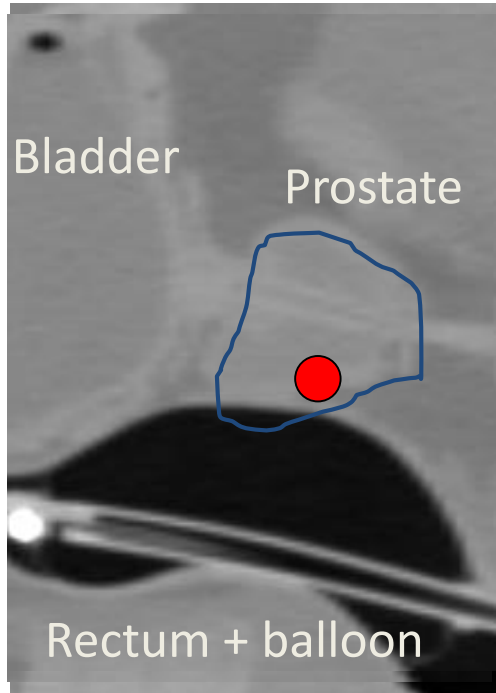
60 ml



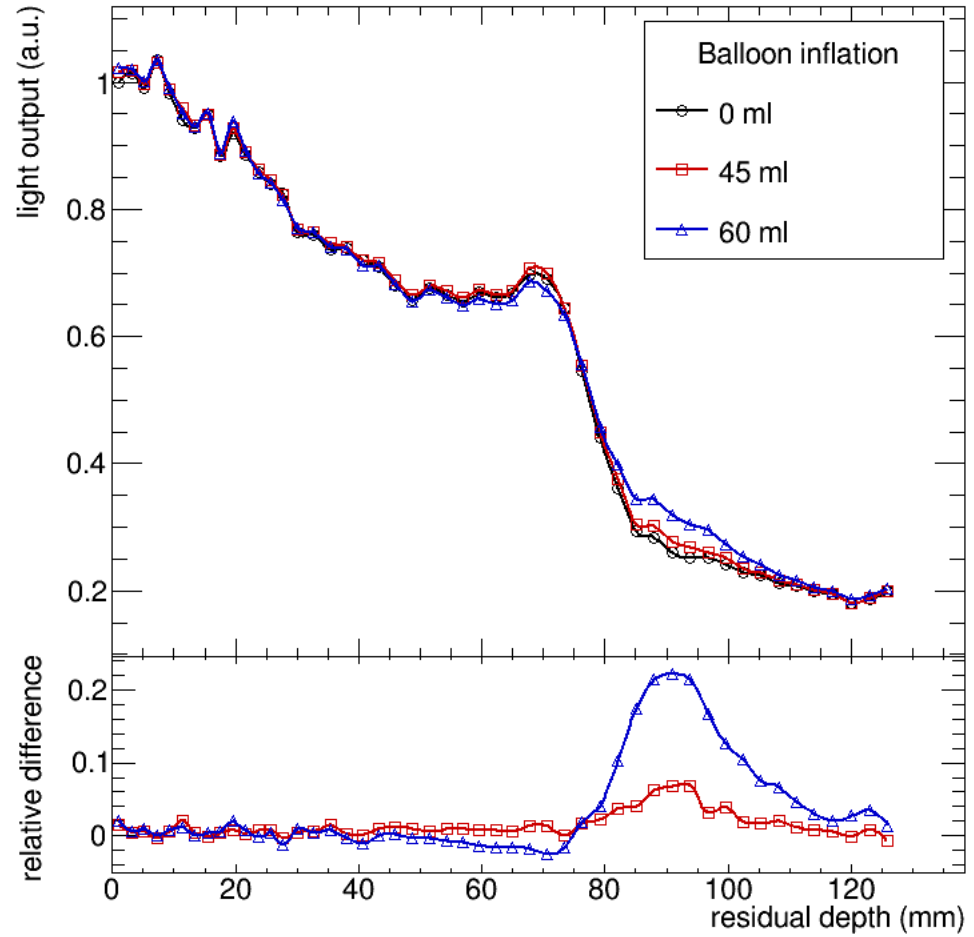
Pelvis phantom 2: results



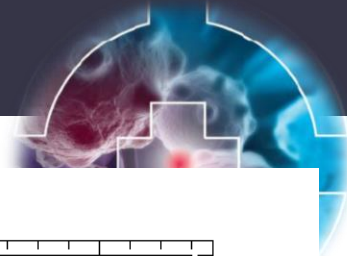
Beams eye view



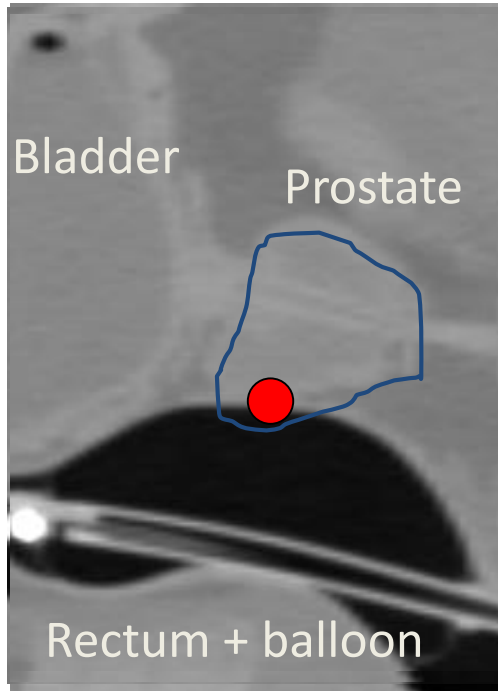
60 ml



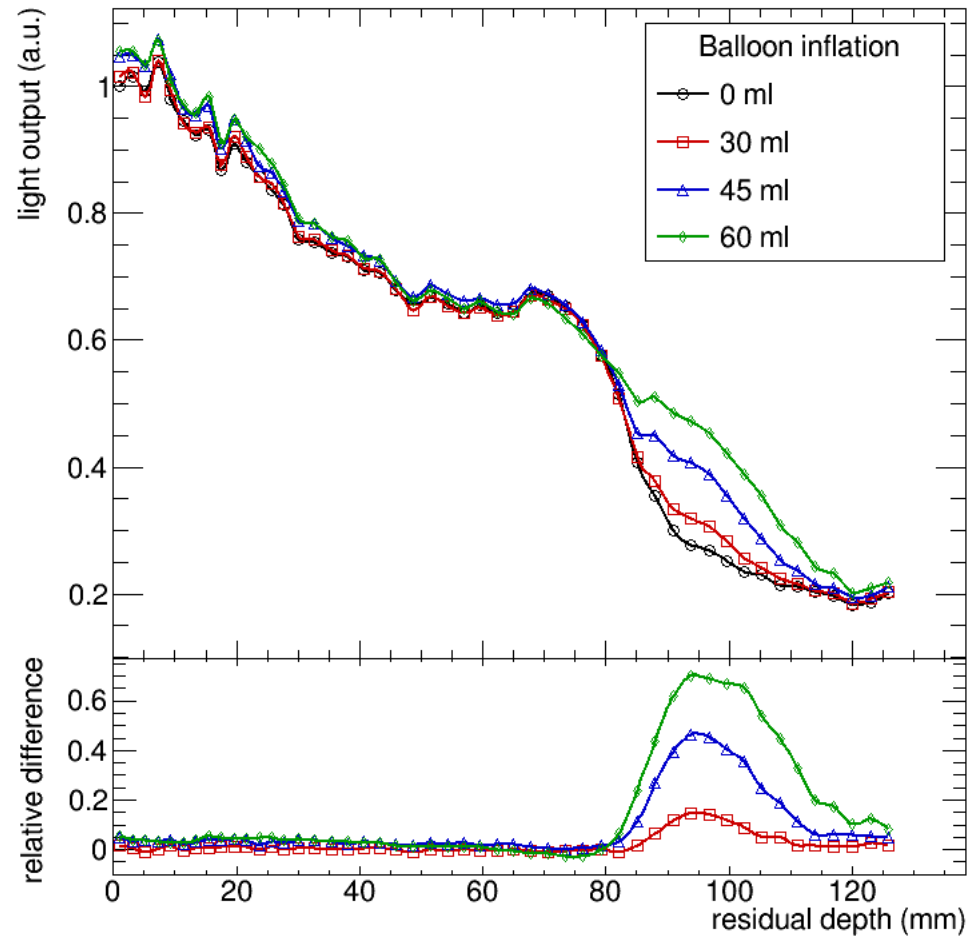
Pelvis phantom 2: results



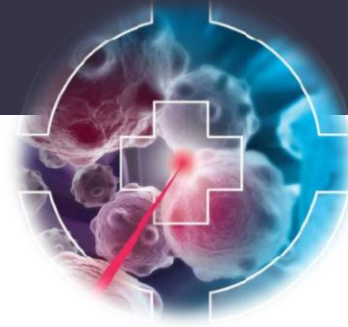
Beams eye view



60 ml



He/C mixing in clinics



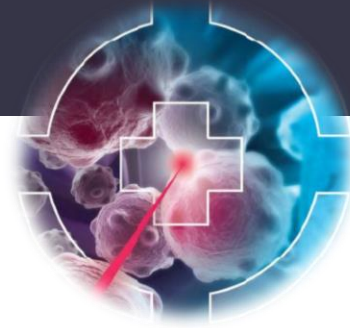
- Advantages:
 - High sensitivity
 - No extra room time
 - Negligible extra dose
- Disadvantages:
 - Not extendable to proton therapy
 - Changes behind C peak still affect He signal
 - Helium beam range might be too low to exit patient
- Open questions:
 - How to quantify changes?
 - How to generate a reference curve?
 - How to react if there is a change?
 - Which tumours can benefit?

Technical aspects of beam mixing



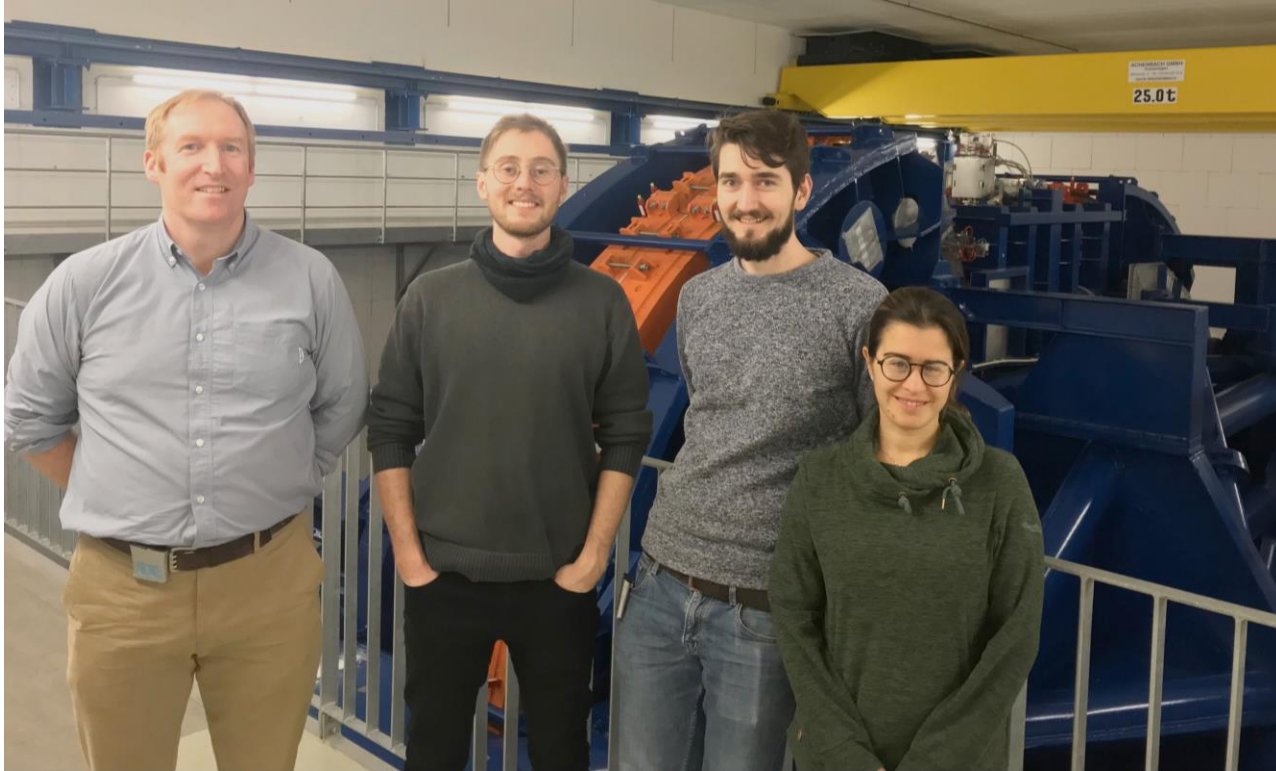
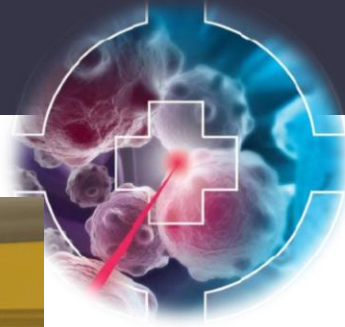
- Ion source: use e.g. methane as main gas and helium as support gas
- Several possibilities for beam generation:
 - Extract $C6+$ and $He2+$ ($A/Q=2$) but low current
 - Extract $C3+$ and $He+$ ($A/Q=4$) but Linac too weak
 - Extract one ion after another and mix in synchrotron
- Simulations needed to prove that mixed beam is stable in synchrotron

Take-home message

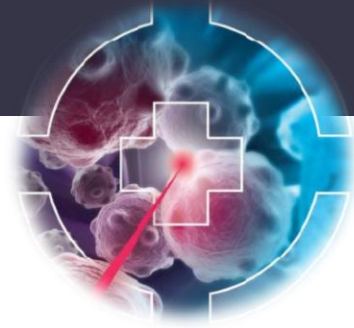


- He/C mixing offers online motion monitoring
- We demonstrated feasibility by conducting first measurements with a He/C beam on anthropomorphic phantoms
- Extremely high sensitivity
- Many open questions (technical, workflow...)

Thank you for your attention

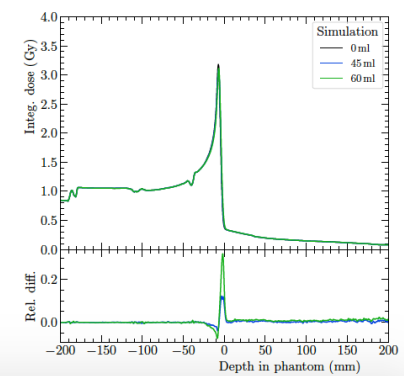
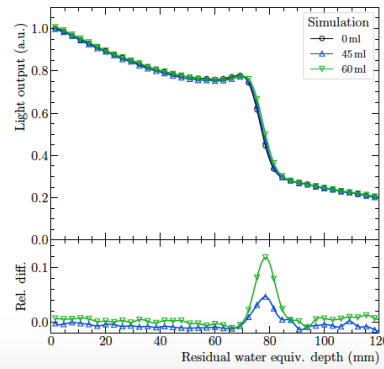
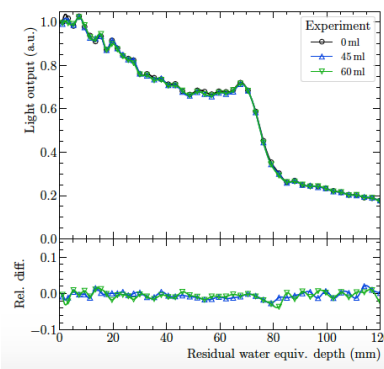
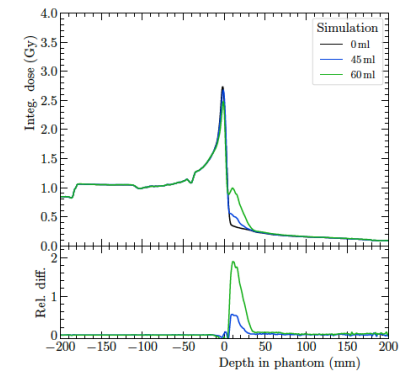
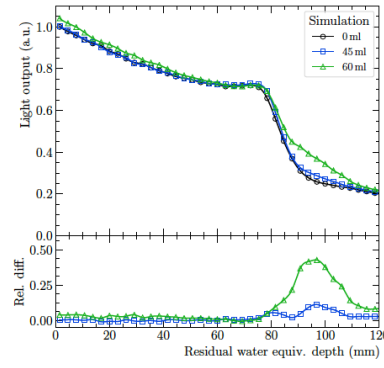
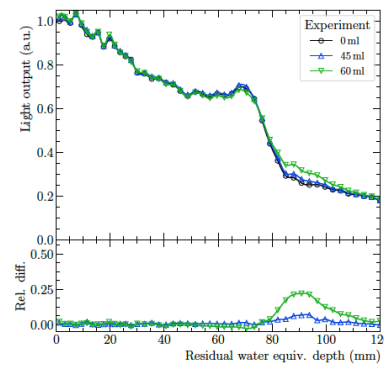
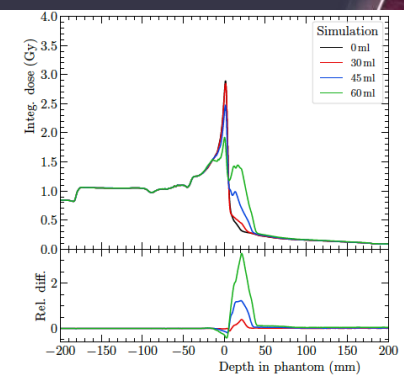
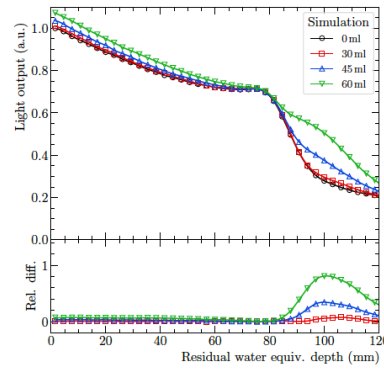
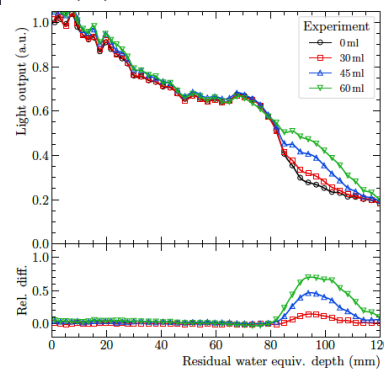
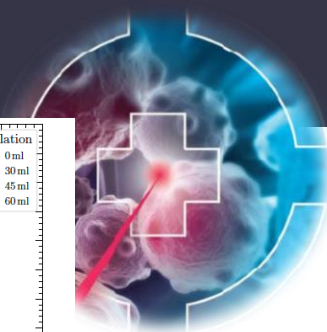


This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 675265, OMA – Optimization of Medical Accelerators.

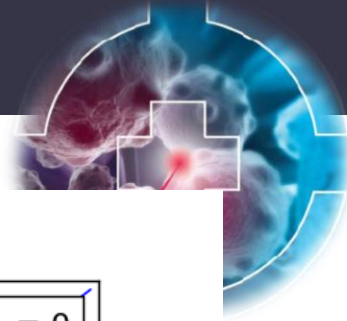


Backup

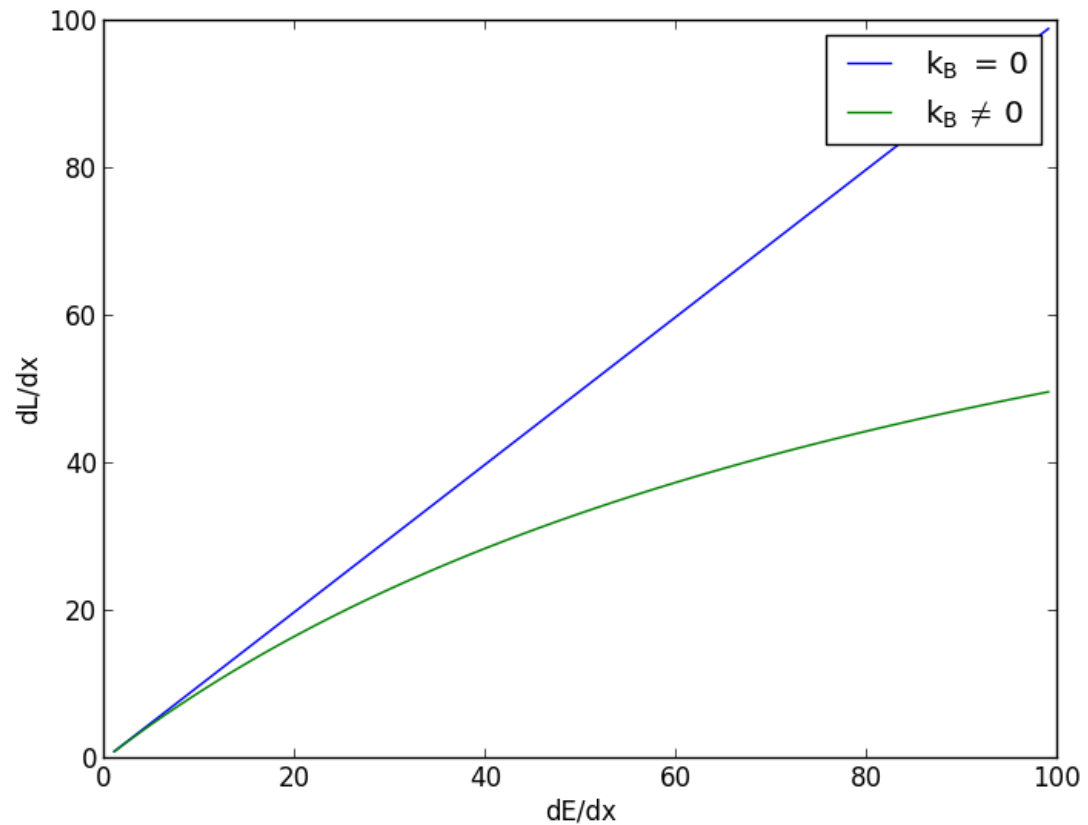
Pelvis phantom: simulation



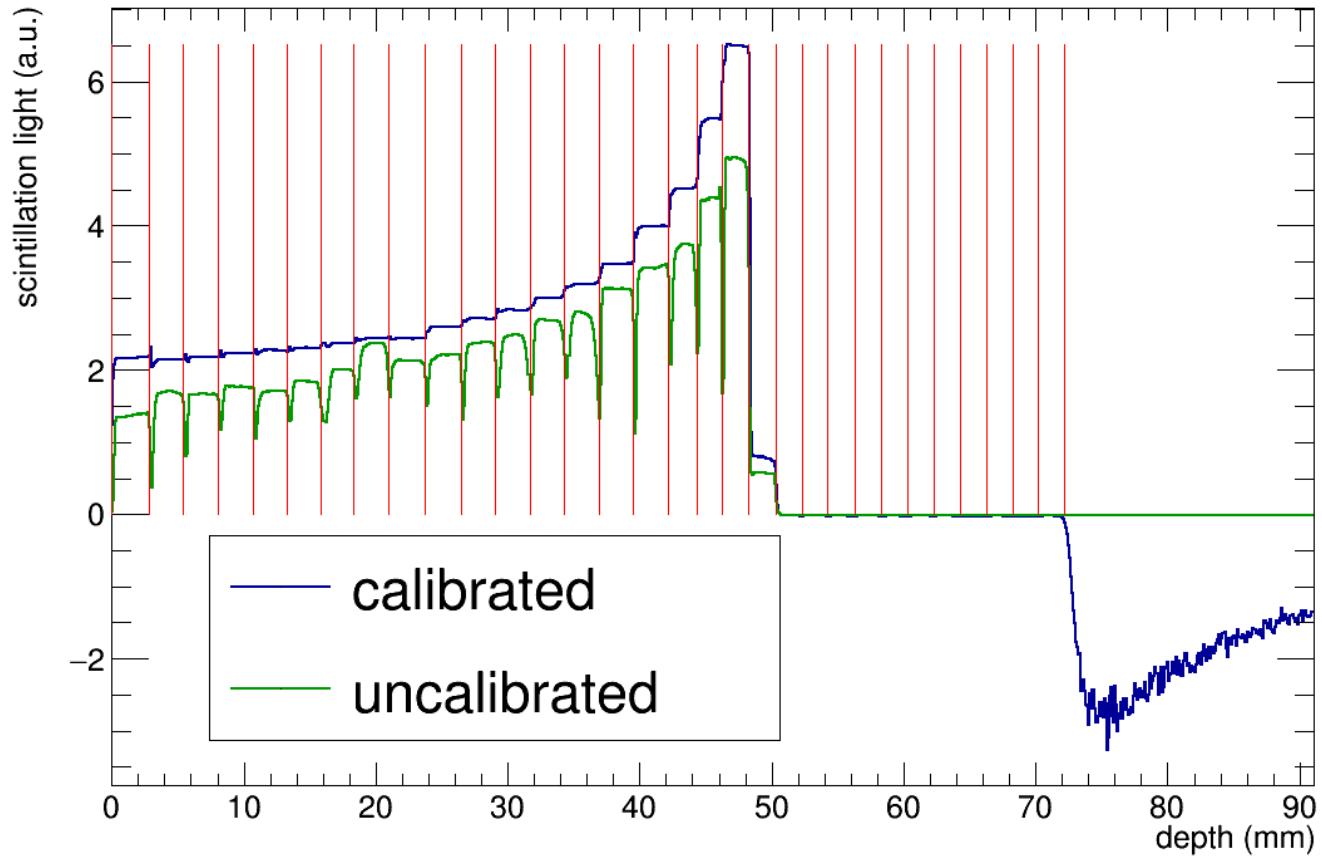
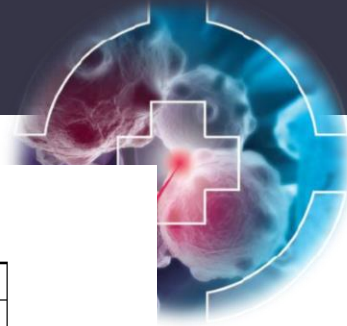
Quenching: Birk's Law



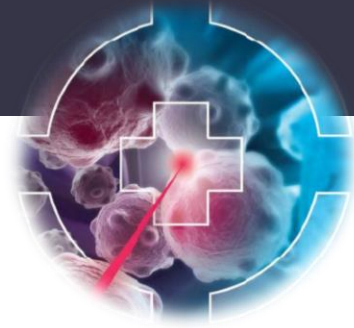
$$\frac{dL}{dx} = S \frac{\frac{dE}{dx}}{1 + k_B \frac{dE}{dx}}$$



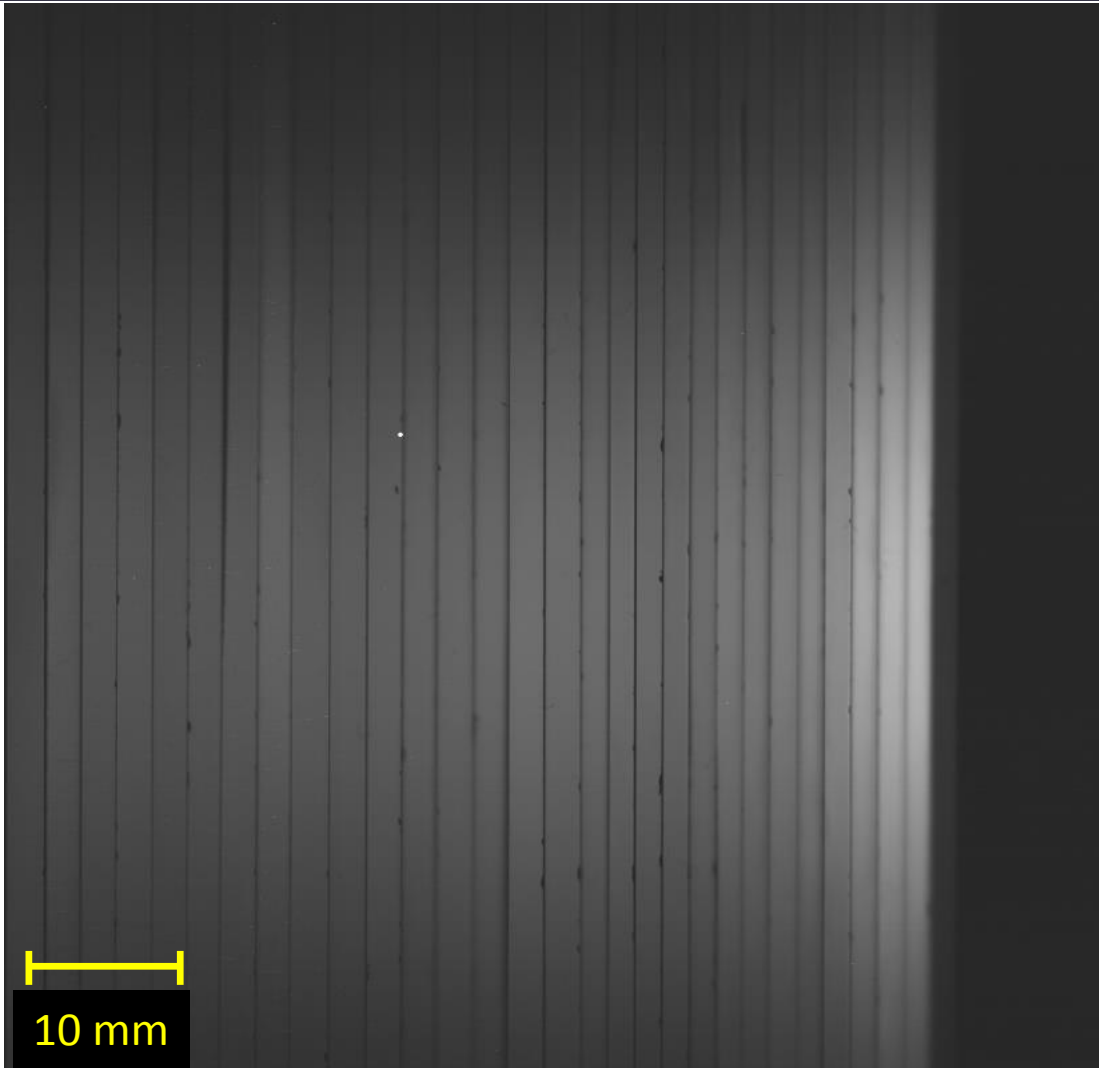
Calibration



97.4 MeV Proton Beam



Beam
→



10 mm