



ENSTA



Application of laser-driven high energy electrons to radiation biology and medical physics at LOA

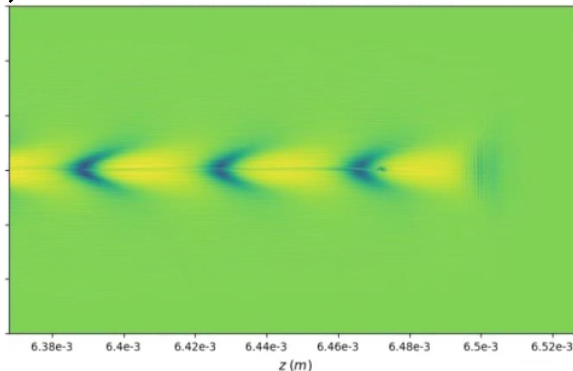
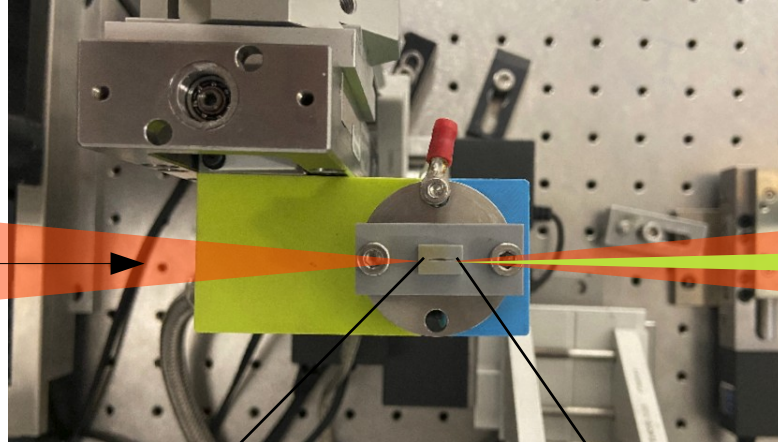
Alessandro Flacco

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Palaiseau, France

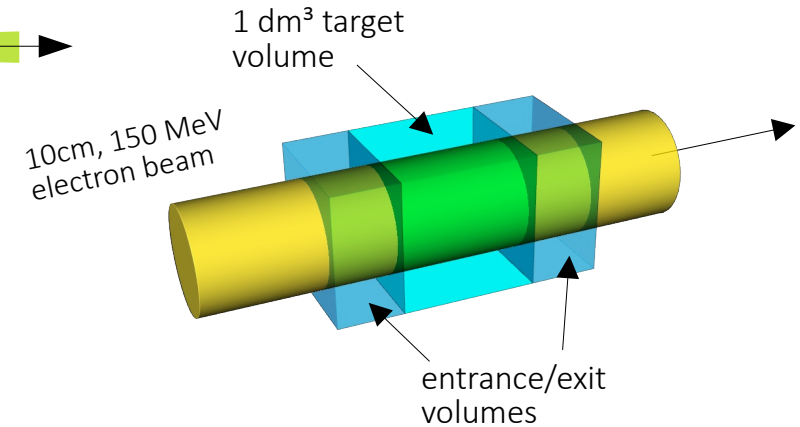
Laser-driven electron source

High power
laser pulse

Electrons,
 $E = 250 \text{ MeV}$



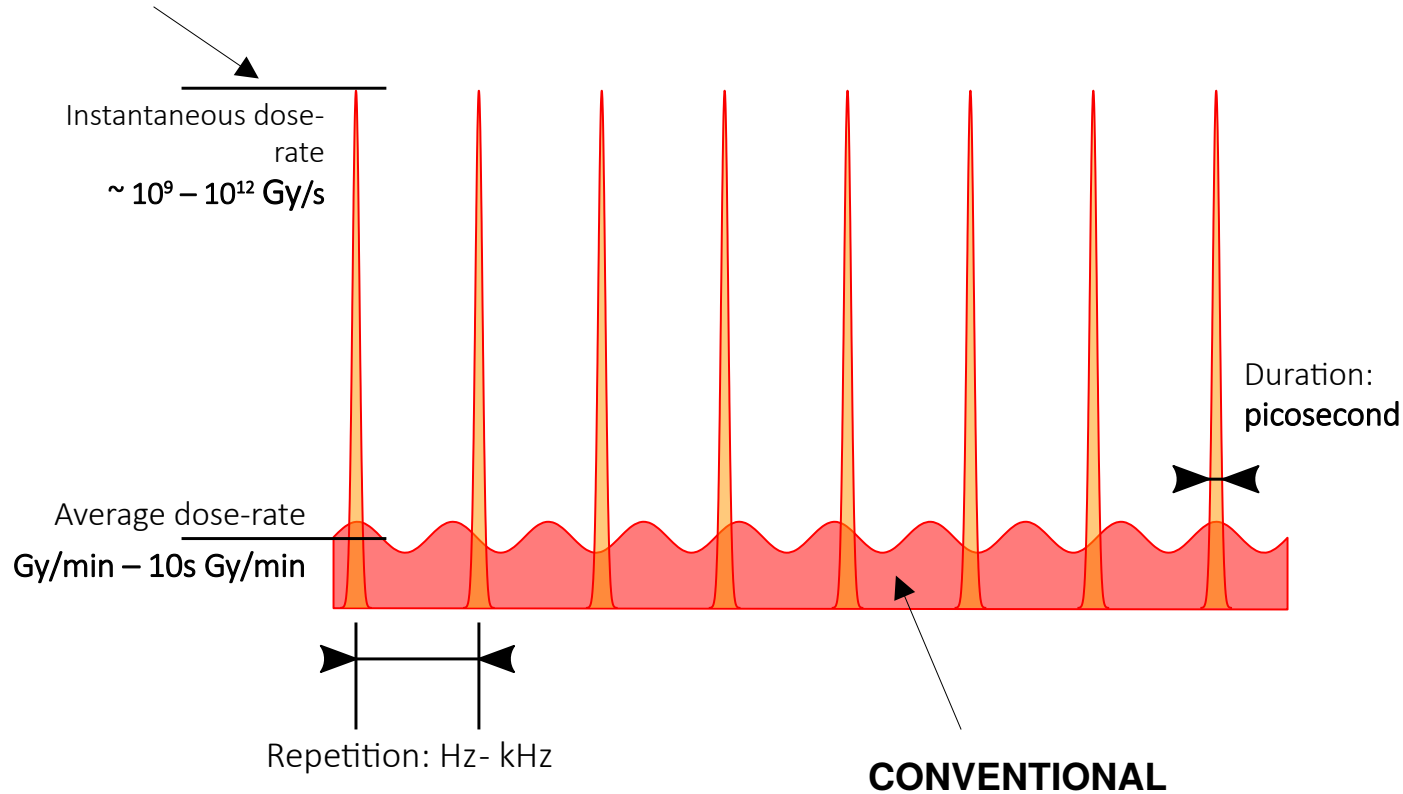
- Short acceleration distance
- Tunable energy and spectral features
- Small and cheap source term
- Acceleration efficiency: up to 10%



Required charge for 10Gy: 500 nC

- Total laser energy at 1% : 7.5 kJ (15 J/nC)
- **Treatment time: 75 s (100 W)**
- What spatial modality?

LASER-DRIVEN



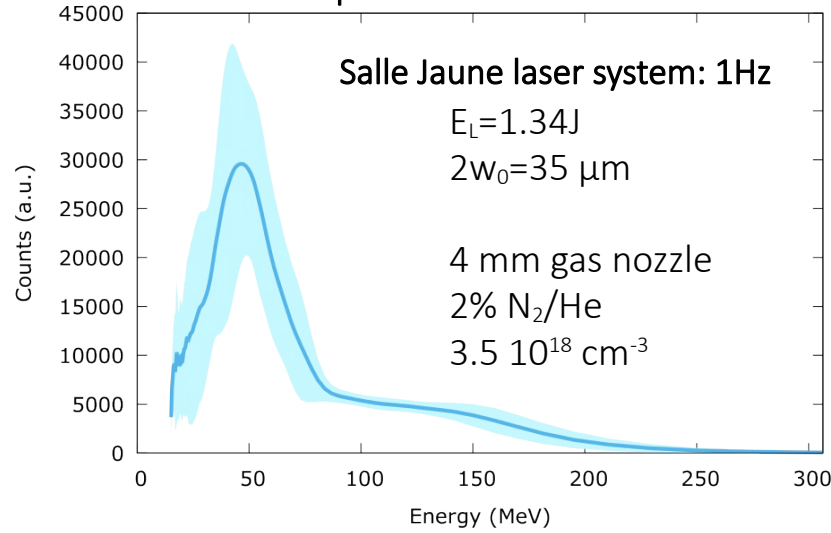
- Dose per fraction: mGy to Gy
- Dose deposition:
short time, high dose-rate
- Delay between fractions: $> \text{ms}$

$$\frac{\dot{D}_{inst}}{\dot{D}_{avg}} > 10^9$$

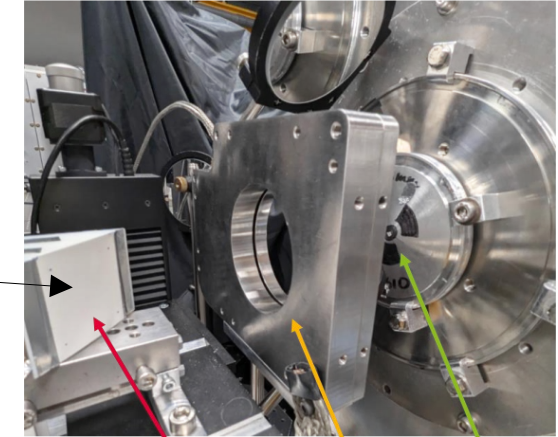
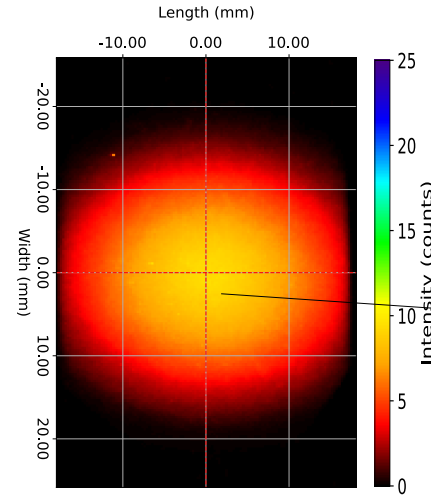
- Average dose-rate: average laser power
- Per-pulse selection
- Perspectives: up to 1 kHz

Electron source parameters (Salle Jaune)

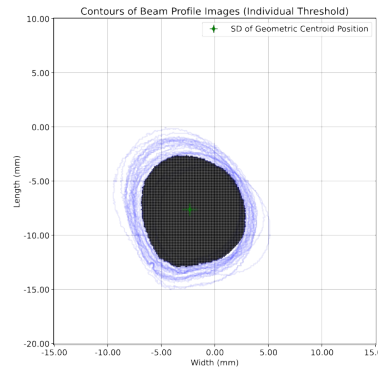
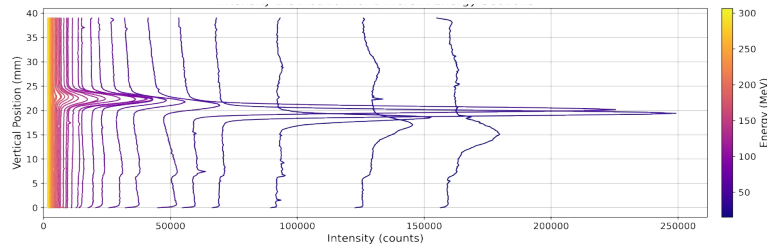
Spectral distribution



Beam monitor



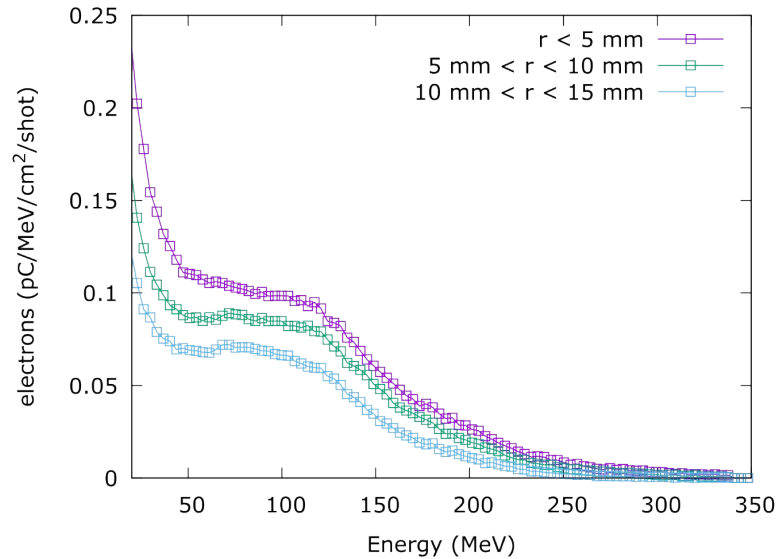
Spectral divergence (1m)



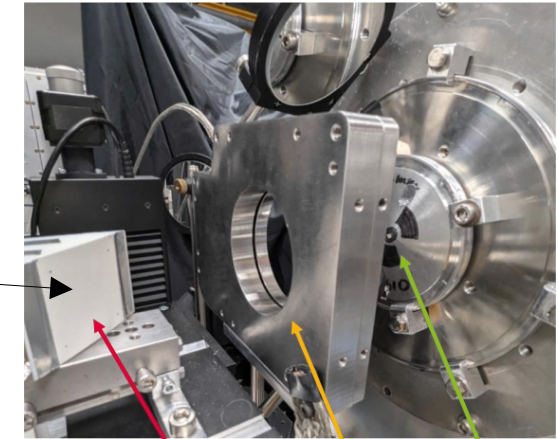
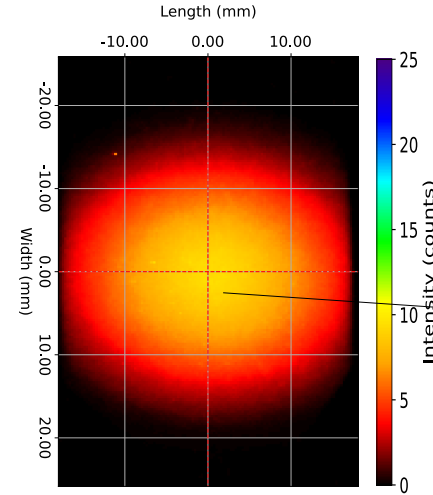
Average charge: 559.58 pC/shot (1.8%)
Divergence: $\sim \text{mrad}$ (spectral dependent)
Average centroid motion: 1.6 mrad
Spot surface variation (fixed threshold): 24.6%

(Credit C. Varma)

Electron spectrum on phantom



Beam monitor

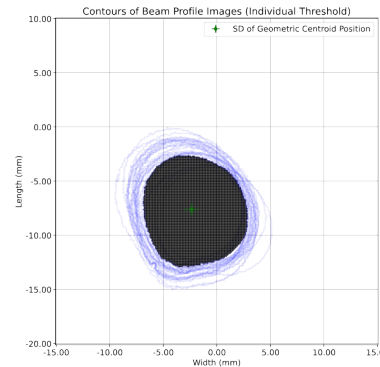
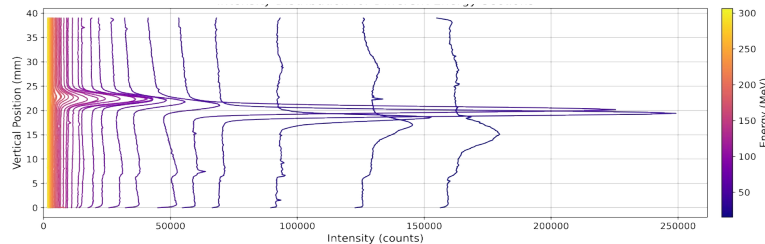


Profile Screen

Turbo-ICT

Exit Flange

Spectral divergence (1m)

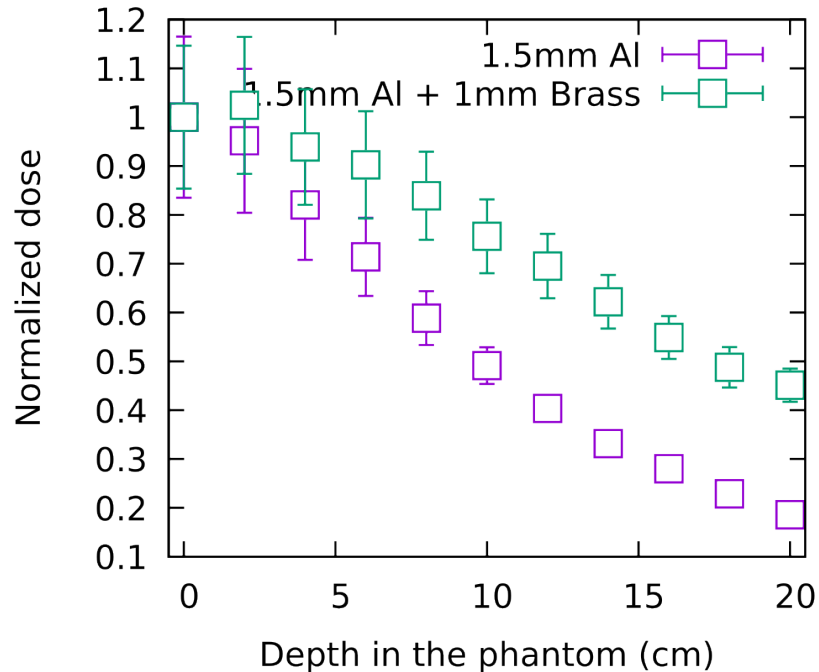


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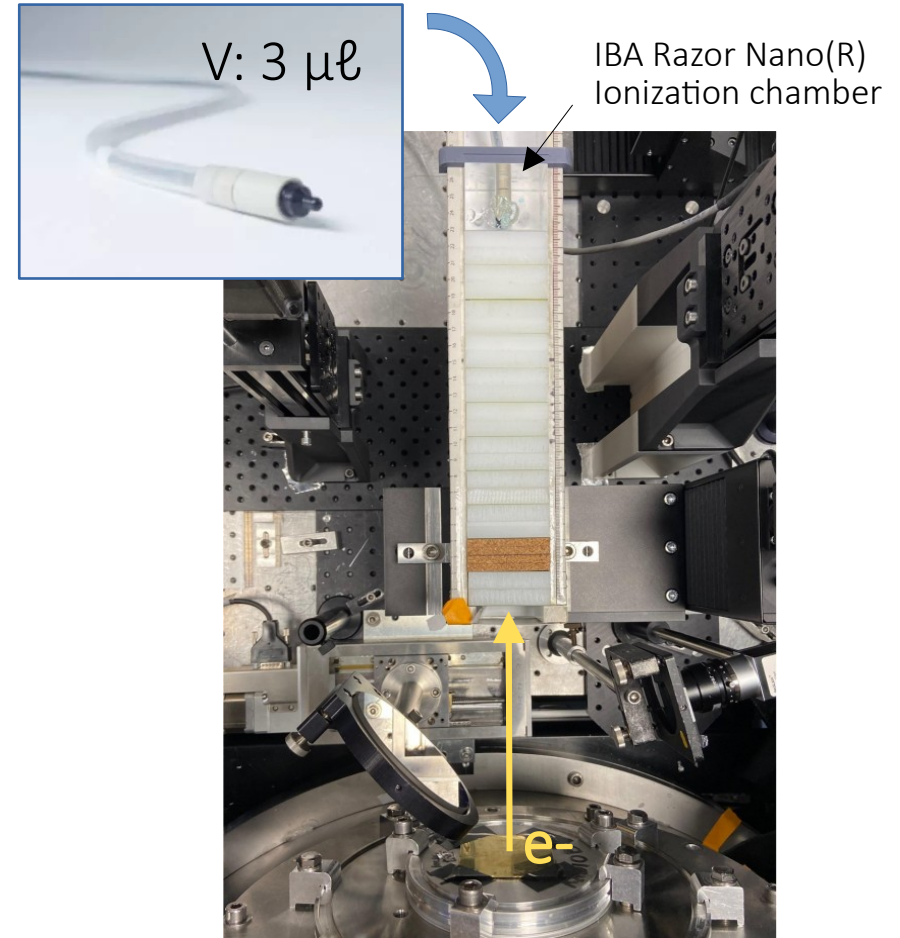
(Credit C. Varma)

Dosimetry in water equivalent phantom

D: 200 – 600 mGy/shot
(2 – 5 cm depth)



ROI: 10 mm diameter
 Δz : 16cm



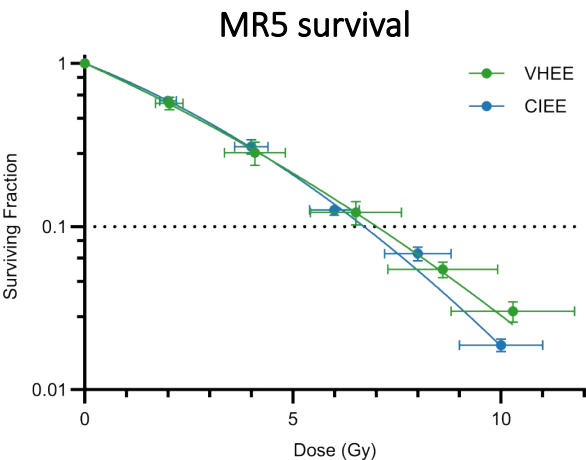
Penetration test phantom

(Credit C. Giaccaglia)

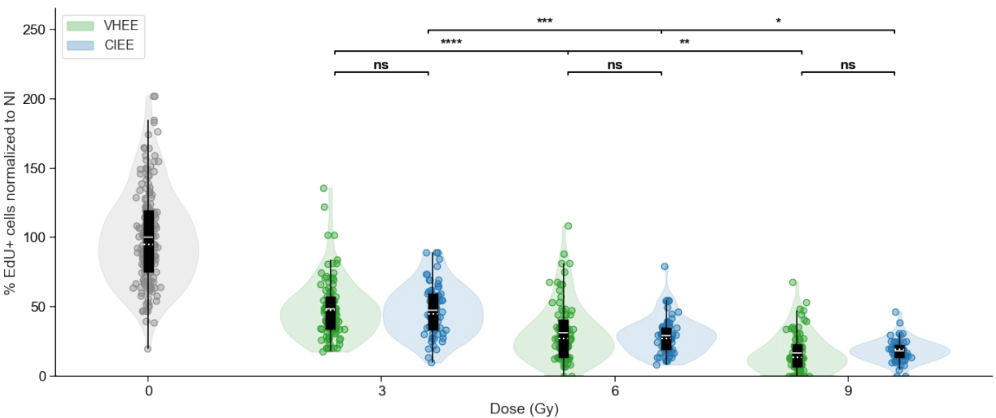
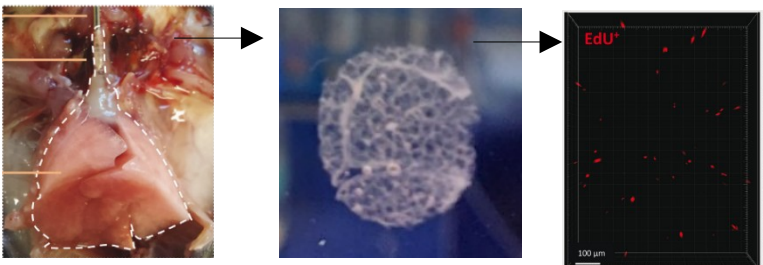
VHEE (LOA) vs CIEE (SIT, Curie)



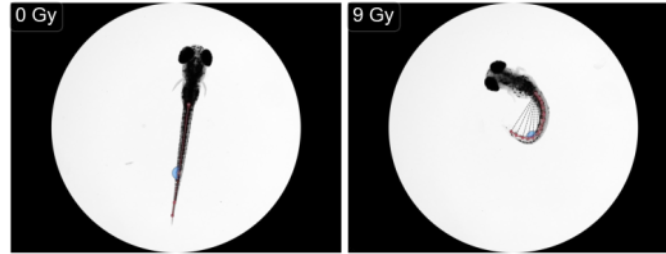
	LOA (Salle Jaune) VHEE	ElectronFLASH Linac (SIT@Curie)
Energy	50-300 MeV	7 MeV
Average dose rate	15 Gy/min	30 Gy/min
Peak dose rate	500 mGy / 1ps fraction 10^{13} Gy/s	50mGy / 1us fraction 10^4 Gy/s
Repetition	0.5 Hz	10 Hz



Ex-vivo mice lung slices

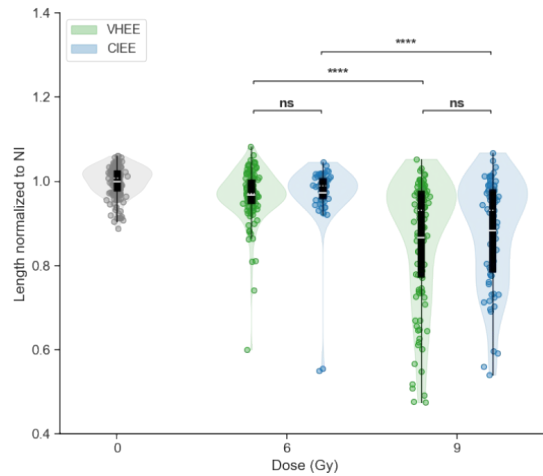


Giaccaglia et al., Multiscale radiobiological assessment of laser-driven very high energy electrons versus conventional electrons,
<https://doi.org/10.1101/2025.05.27.656200>

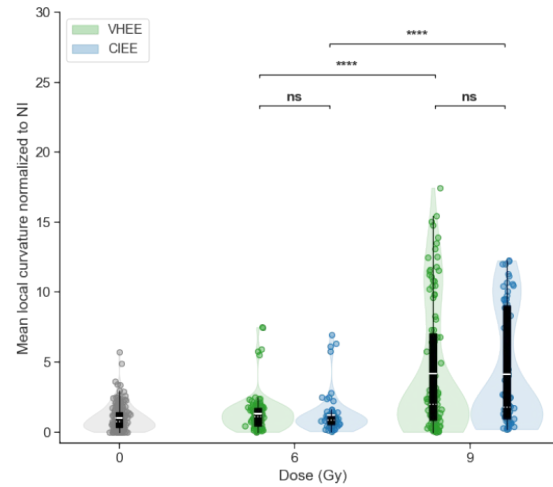


Irradiation 4h pf.
Fixation 5d post

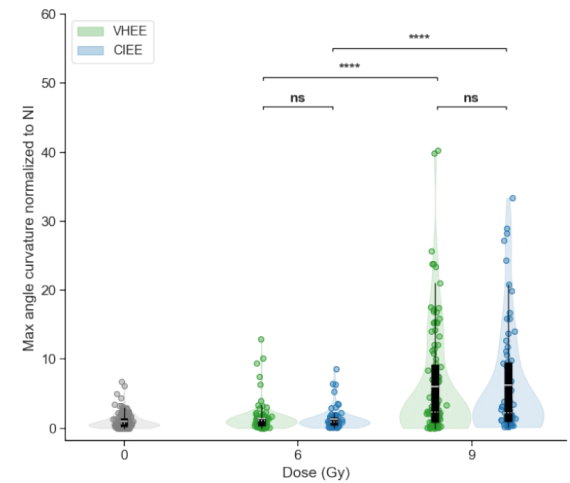
Normalized length



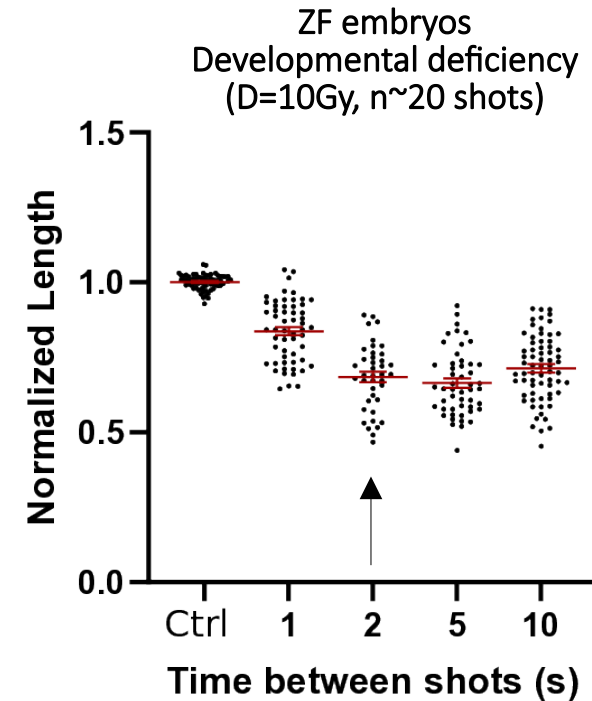
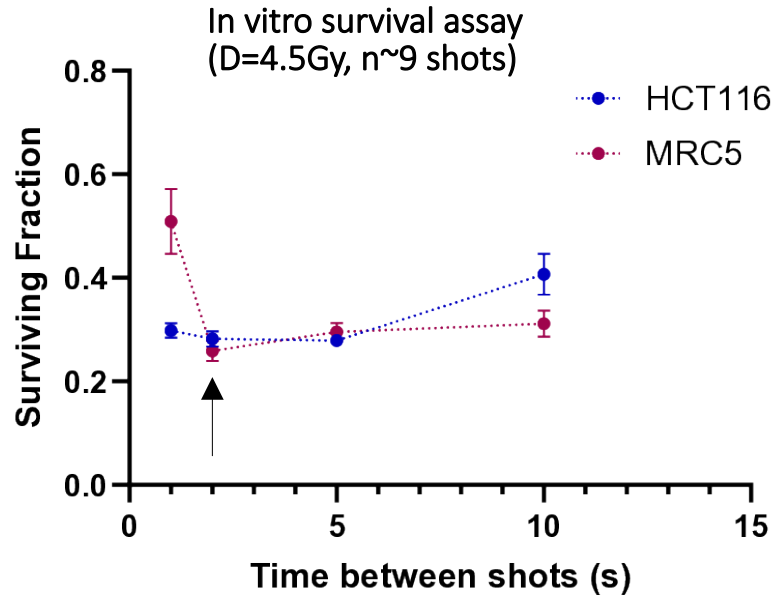
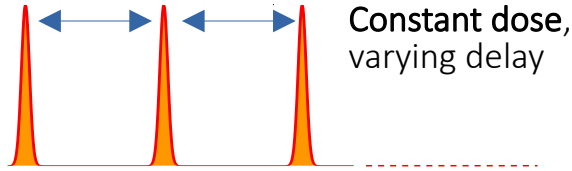
Mean local curvature



Max local curvature



Temporal modality via repetition rate



Bilateral thorax exposure in C57BL/6 mice

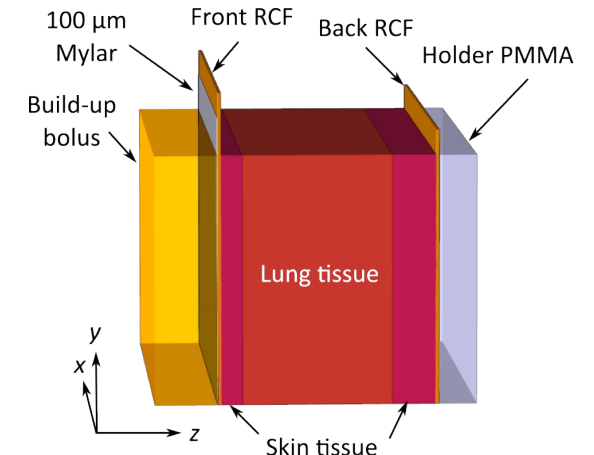
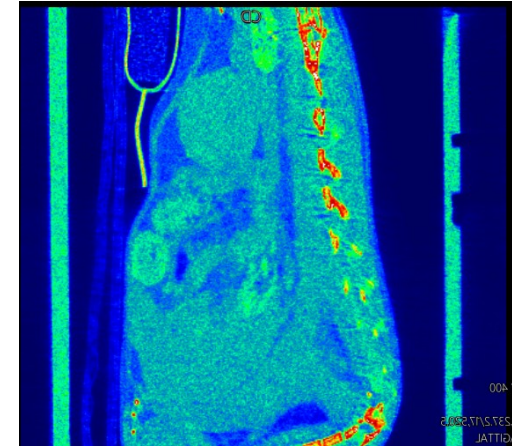
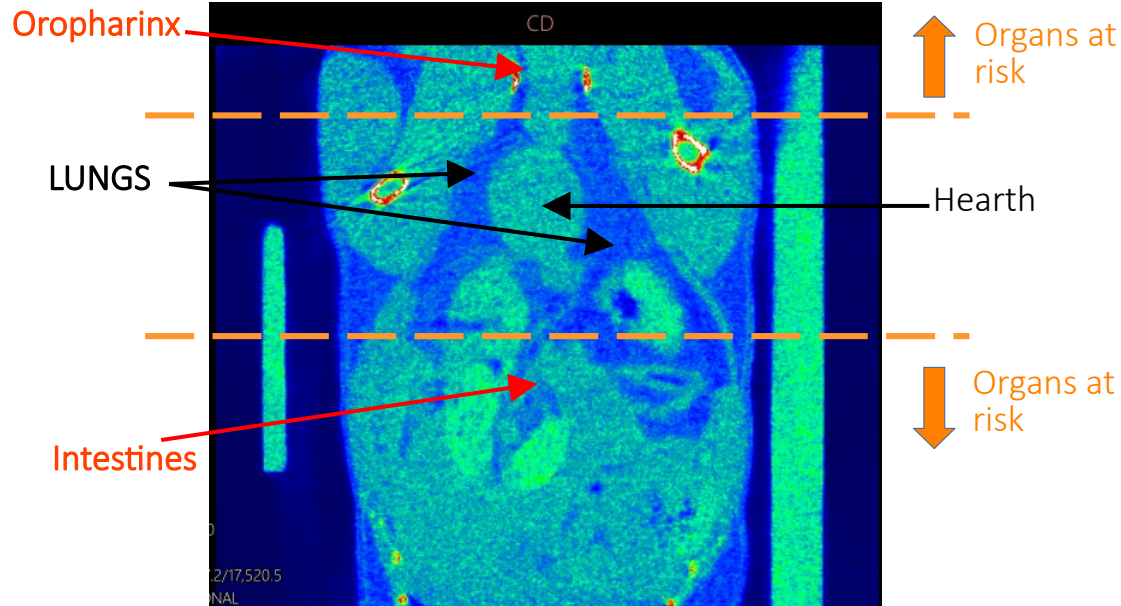
Target dose: 0Gy, 10Gy, 13Gy, 16Gy

Lateral irradiation size: > 30 mm
Vertical size: limited to 20-25 mm

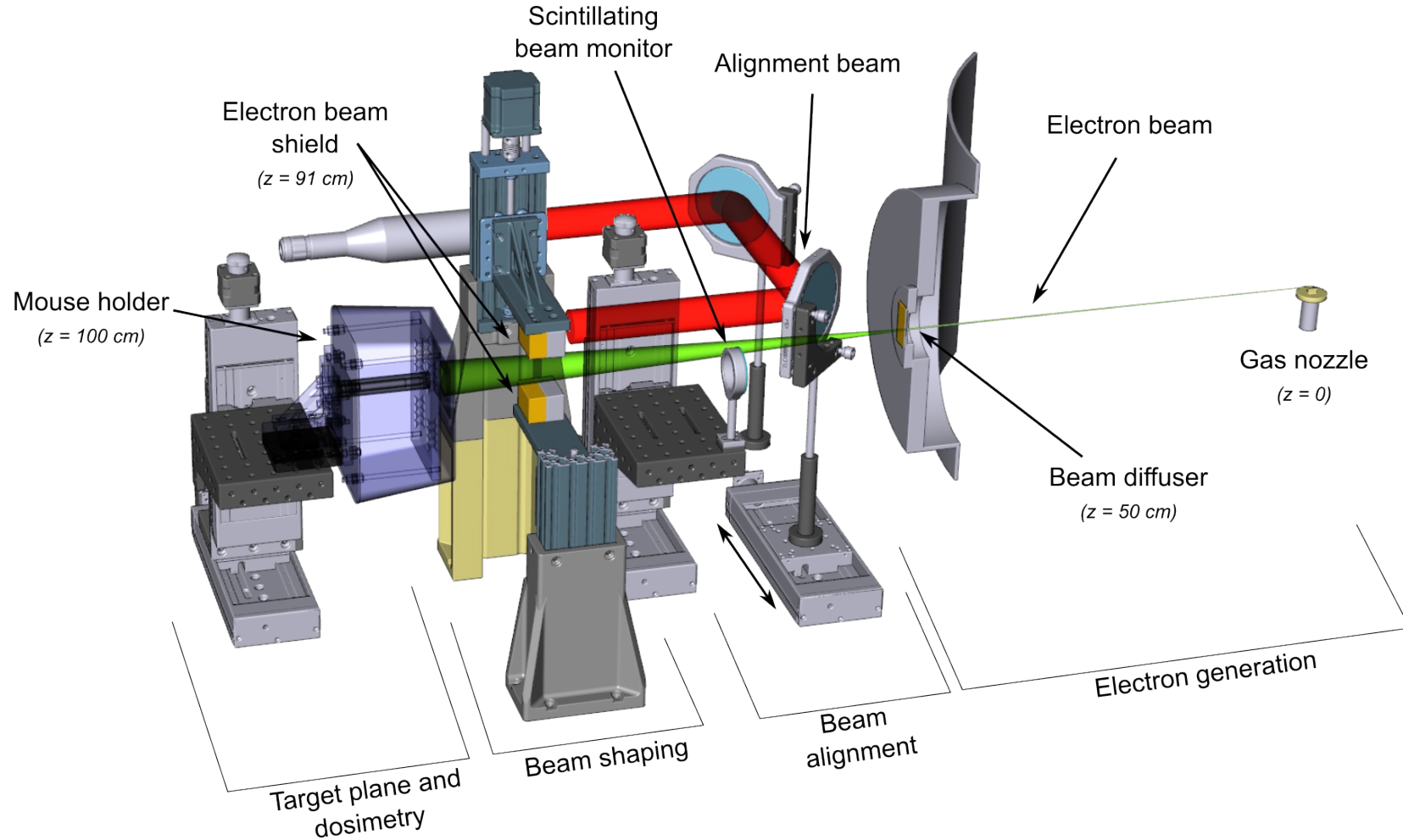
Coorte: 24 mice (6 weeks old)

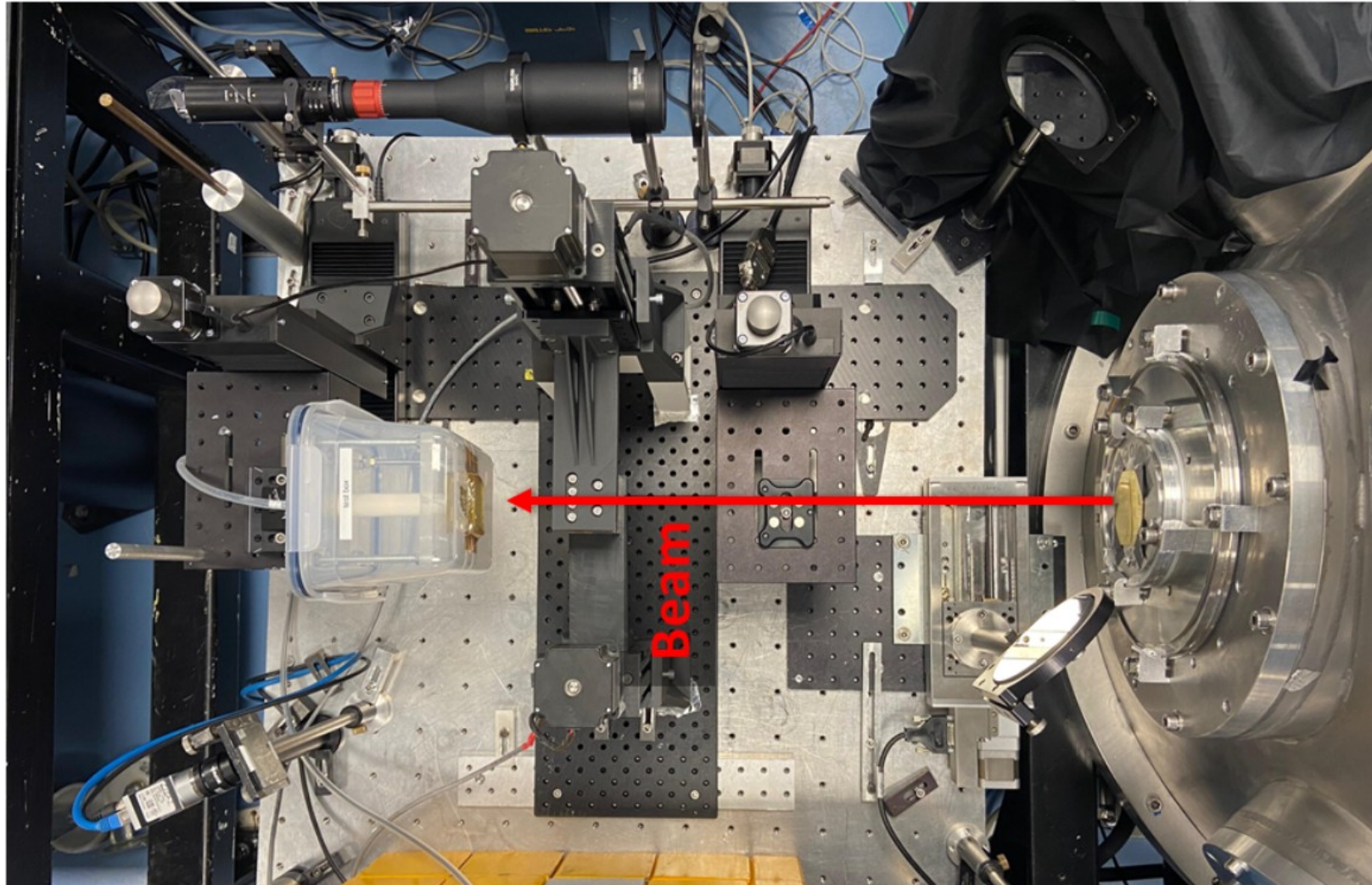
Dose at intestines < 1 Gy

CT scan, C57BL6/J Mouse



(Credit C. Giaccaglia)

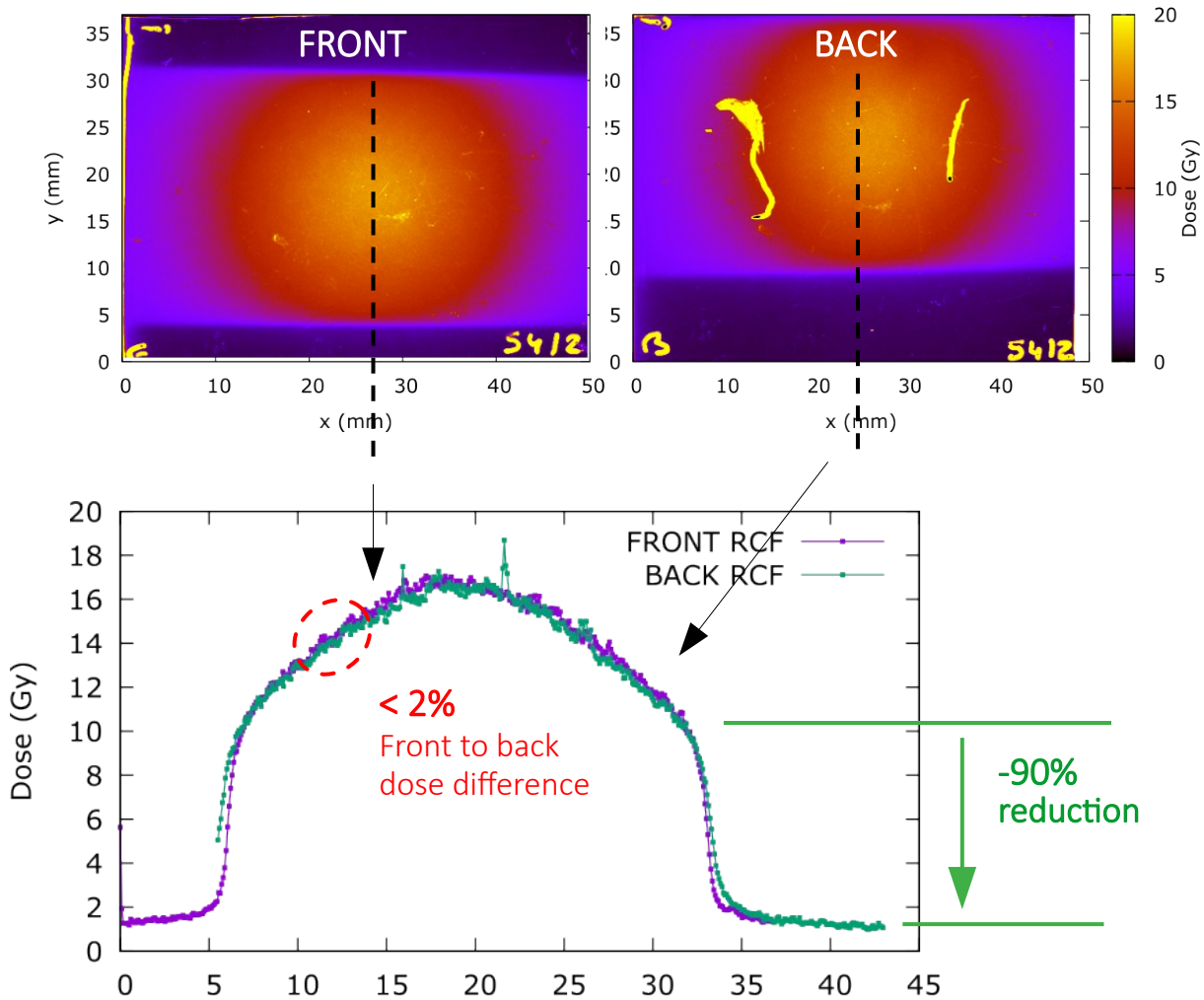
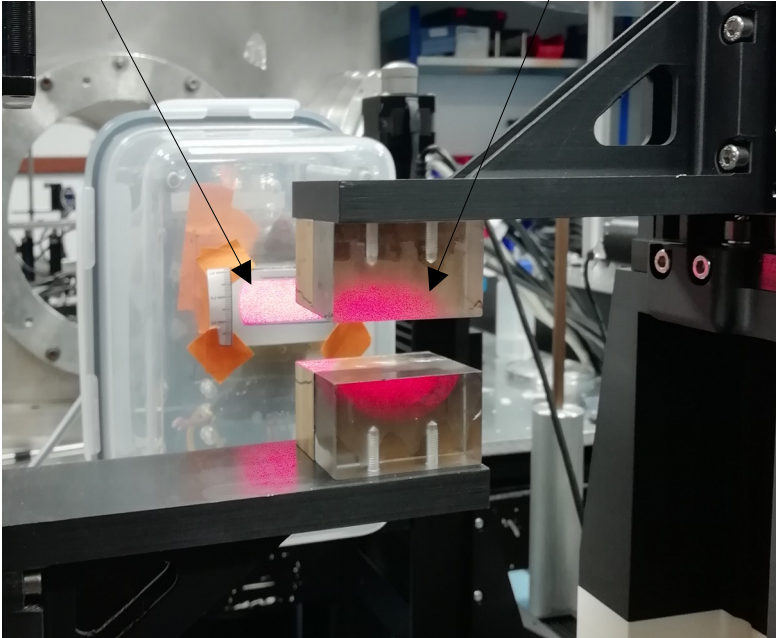


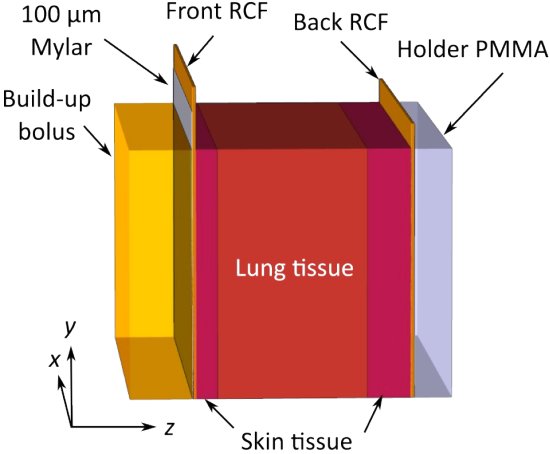


In vivo mice experiment (May 2024)

Scintillating screen
(beam monitor)
+ bolus & RCFs

Alignment laser &
e- Beam shaping

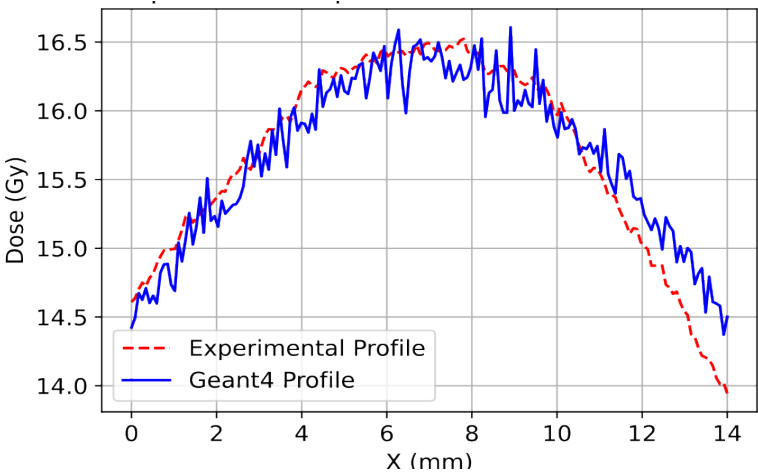




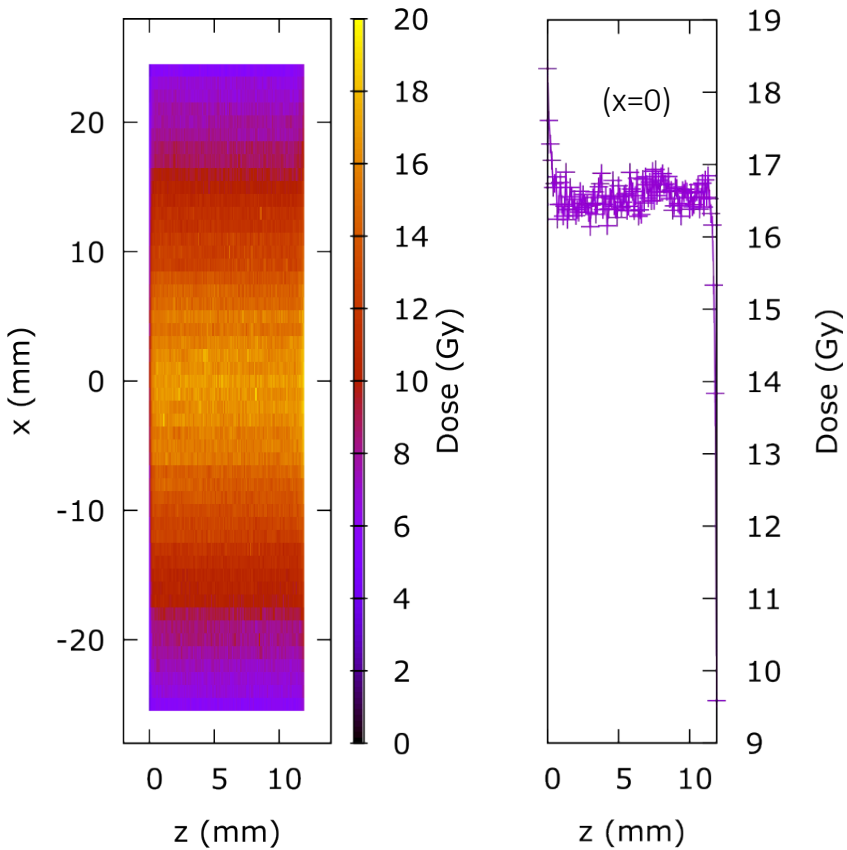
Average exposure dose: **15.67 Gy**
Num shots: 542

Sim: $4.9 \cdot 10^{-5}$ Gy/pC
Average Dose: **28.9 mGy/shot**
Average Charge: **589 pC/shot**

Transverse dose distribution (exp & MC)



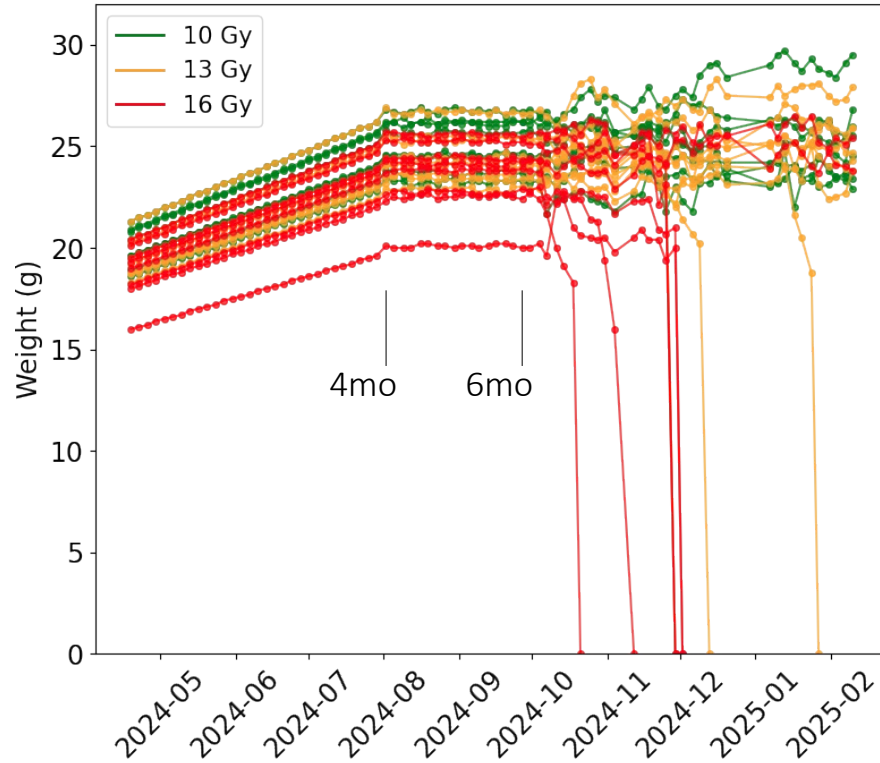
Longitudinal dose distribution (MC)



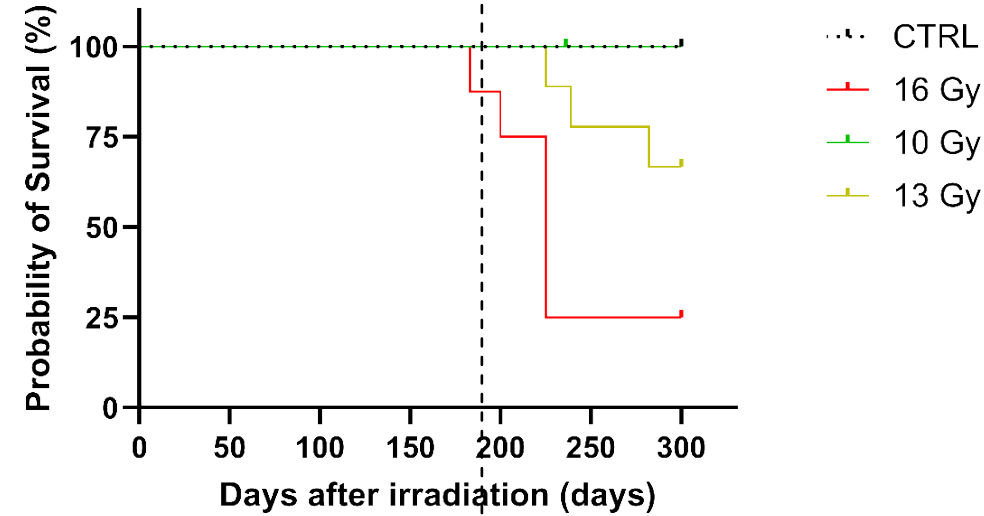
(Credit J. B. Amakkattu)

Mice followup: 10 months

Mice weight follow-up



Mice survival



6 months

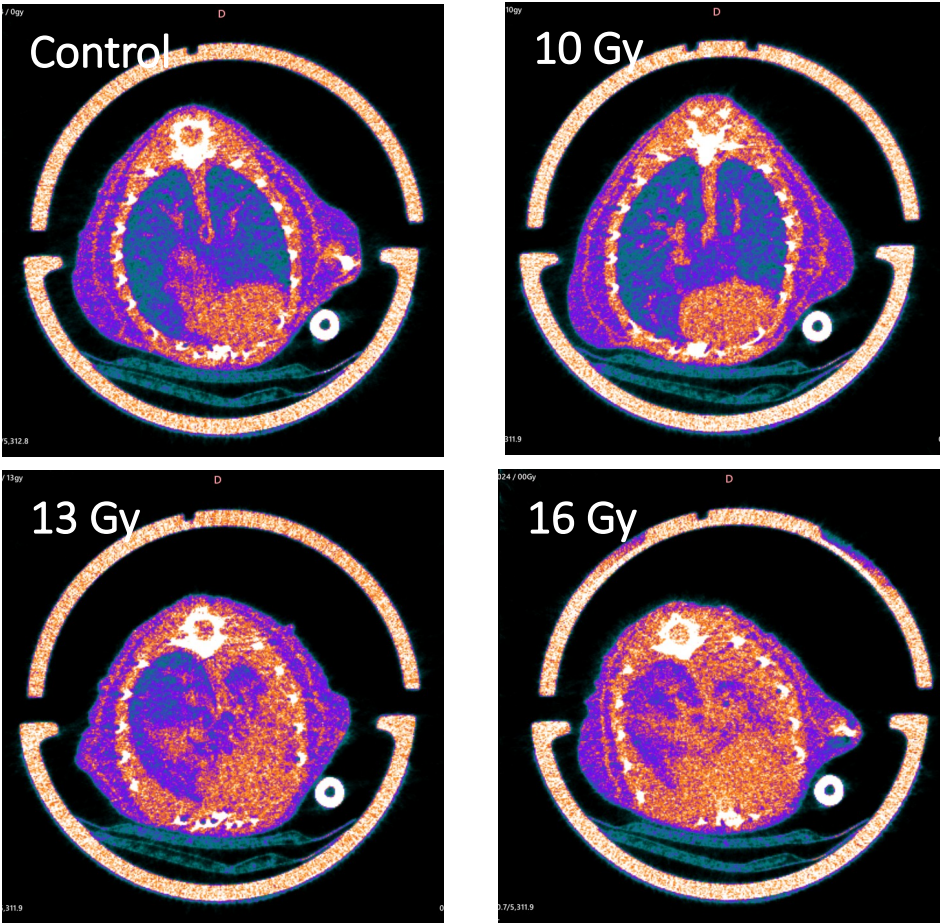
- No sudden death for dose at intestine
- No head/larynx/esophagus complications
- No cardiac problems for excess dose
- No volume effect

(Credit C. Giaccaglia)

Irradiated mouse, 16Gy full thorax, 4mo. post
Dose per pulse: 50 mGy/shot @0.5Hz (1.5 Gy/min)



Coronal cut, 7mo post-exposure



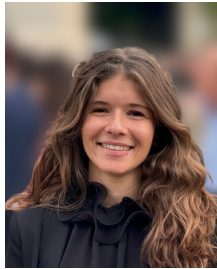
(Credit C. Giaccaglia)

- Performed pre-clinical studies with broad-band laser-driven VHEE
- Systematic comparison with CIEE beam at Curie. No significant difference within the explored conditions
- Frequency effect: toxicity varies with fractionation modality, both in vitro and in vivo.
- Performed exploratory deep small animal irradiation: bilateral lung irradiation in mice
 - Quantitative analysis ongoing
- Limiting factor
 - Uniformity → double diffuser being studied
 - Average dose rate → novel laser under commissioning, 100Hz. **See you in VHEE27!**

Acknowledgments



J. B. Amakkattu



C. Giaccaglia



E. Bayart



Ch. Fouillade



S. Heinrich

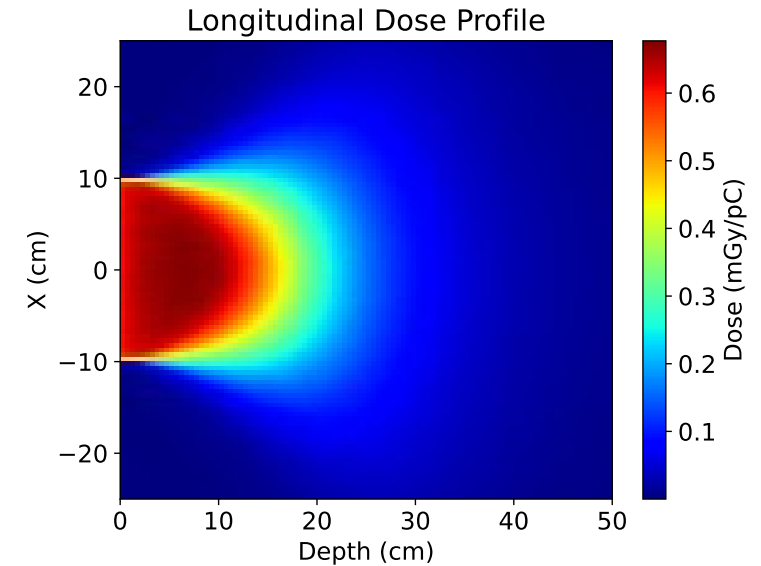
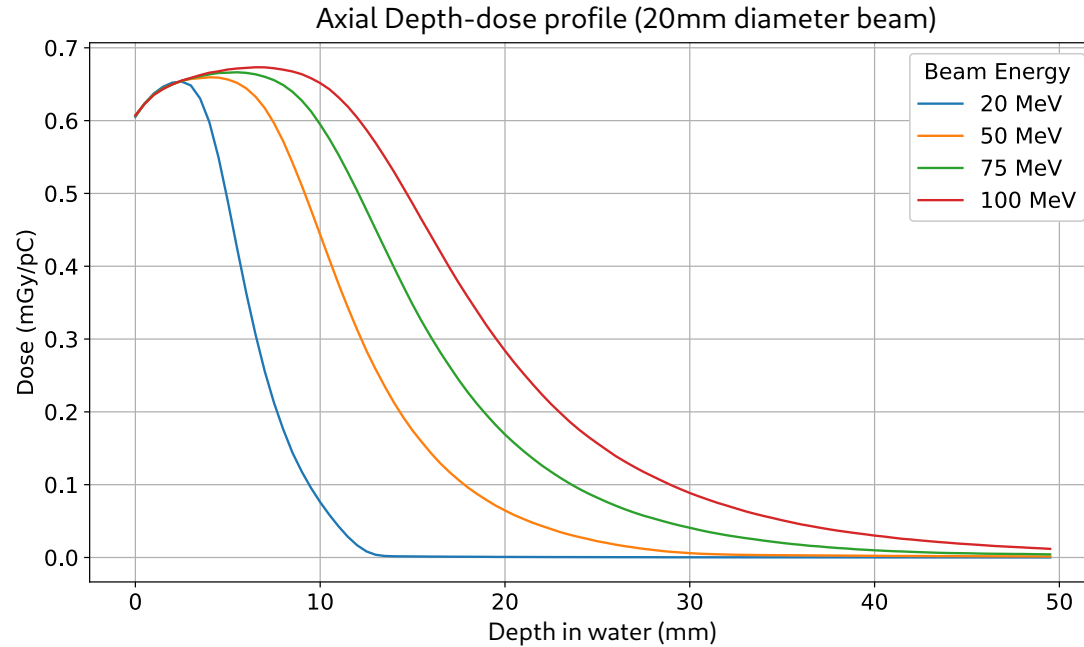


M. Dubail

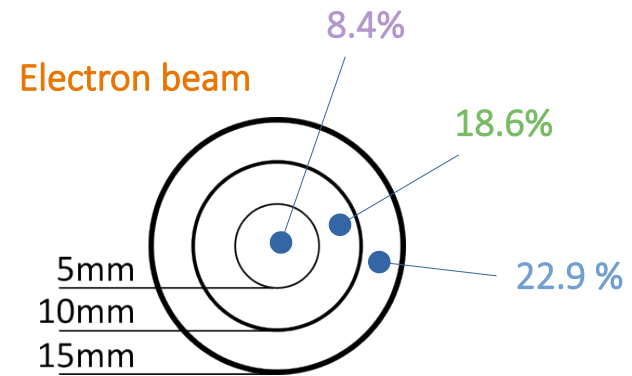
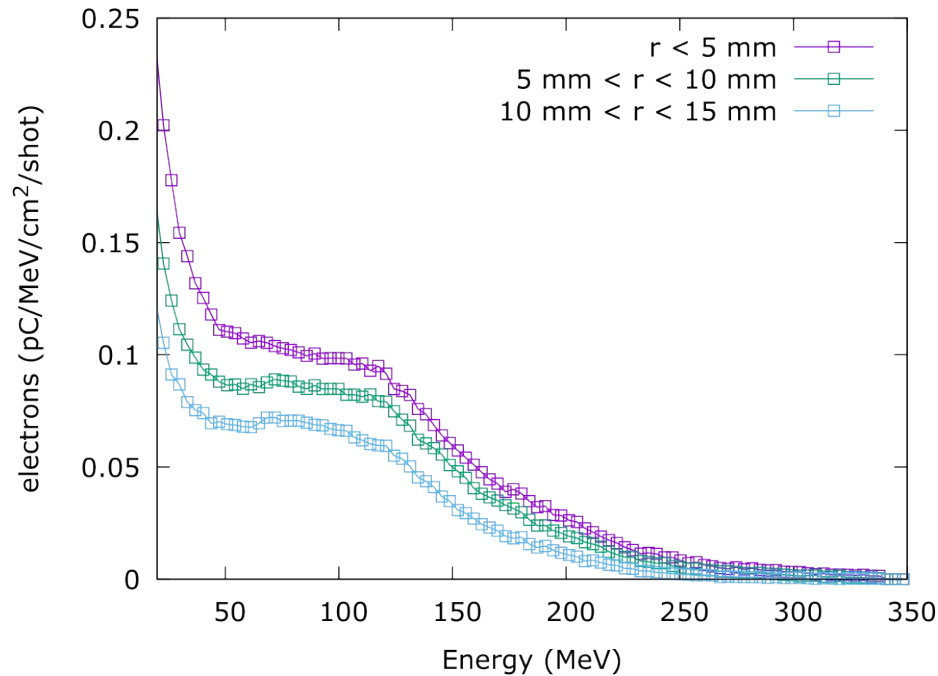


C. Varma

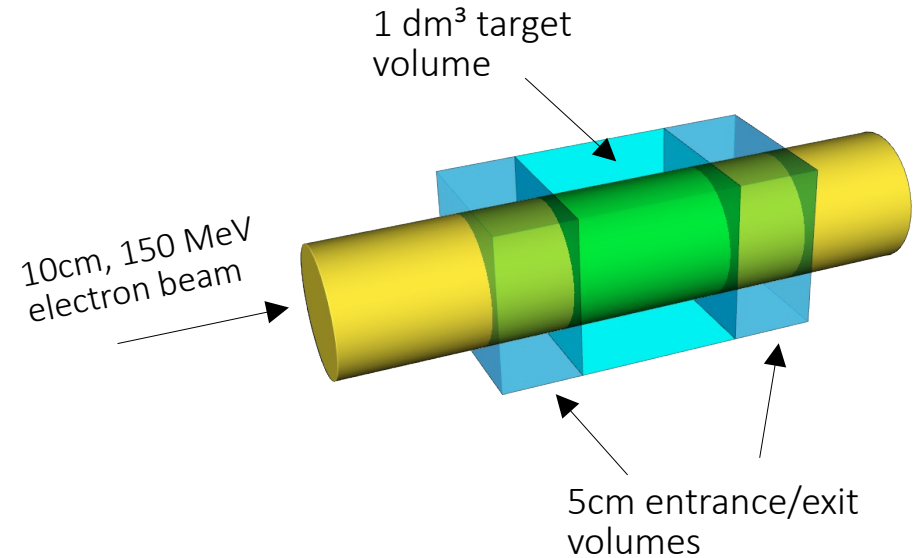
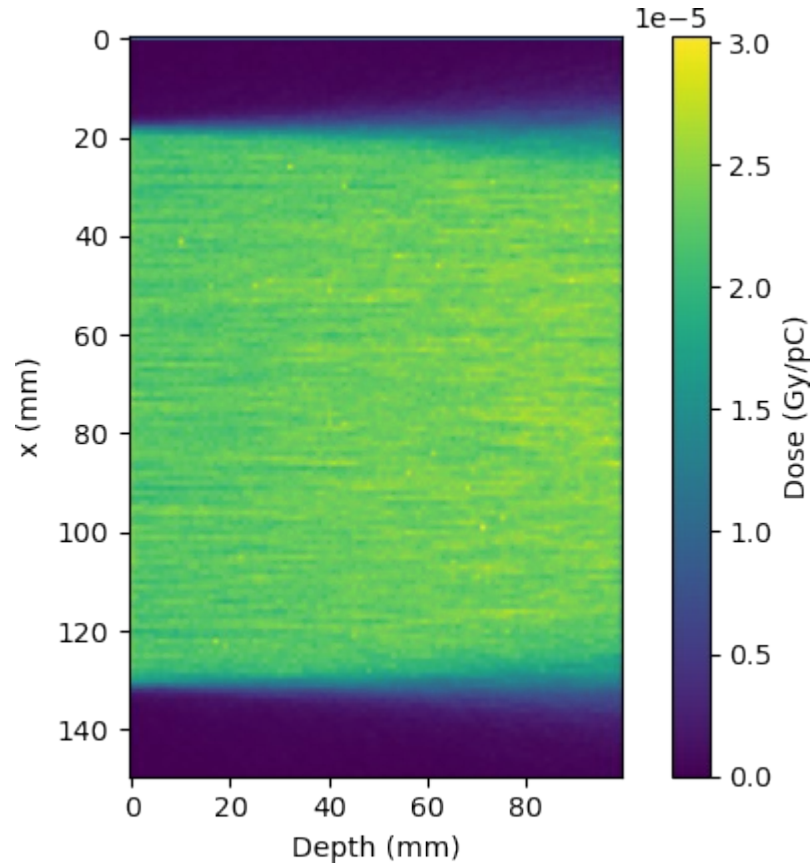




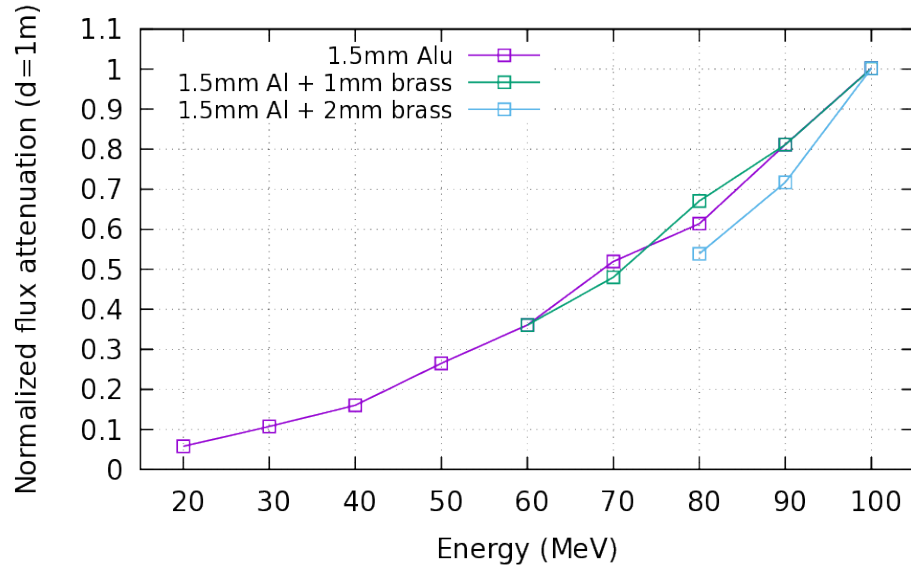
Electron spectral components on bolus



(Credit J. B. Amakkattu)



Spectral attenuation at irradiation site



Beam size at irradiation site

