Exploring high-charge irradiation conditions with laser-driven very high energy electrons for radiation biology

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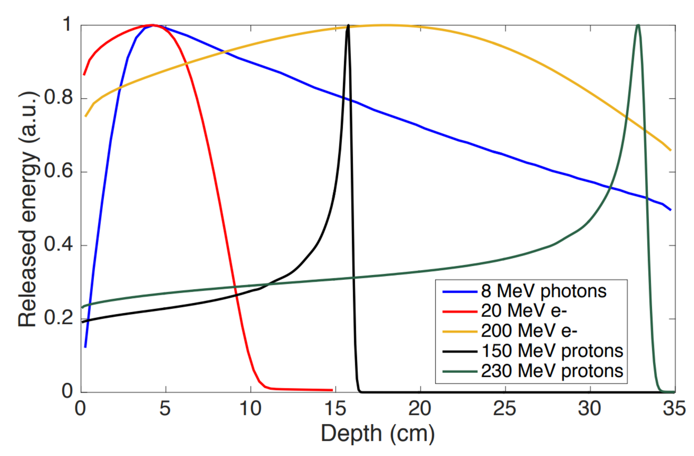
Very High Energy Electrons (VHEE)

The main goal of radiotherapy is to kill cancer cells while sparing healthy tissue. The need to achieve better dose deposition reliability and to limit damage to healthy tissue is still a challenge for conventional treatments (e.g. Low-Energy Electrons (LEE) and MeV photons). VHEE (E>70 MeV) are emerging as a promising alternative modality for radiation therapy.



In-depth energy deposition in water for different radiations [1].

Why VHEE?

- Easier beam steering [2]
- Treatment of deep-seated tumours in contrast to LEE
- Better sparing of surrounding healthy tissue compared to photons [3]
- More reliable beam delivery around inhomogeneous media compared to protons [4]

Limitations:

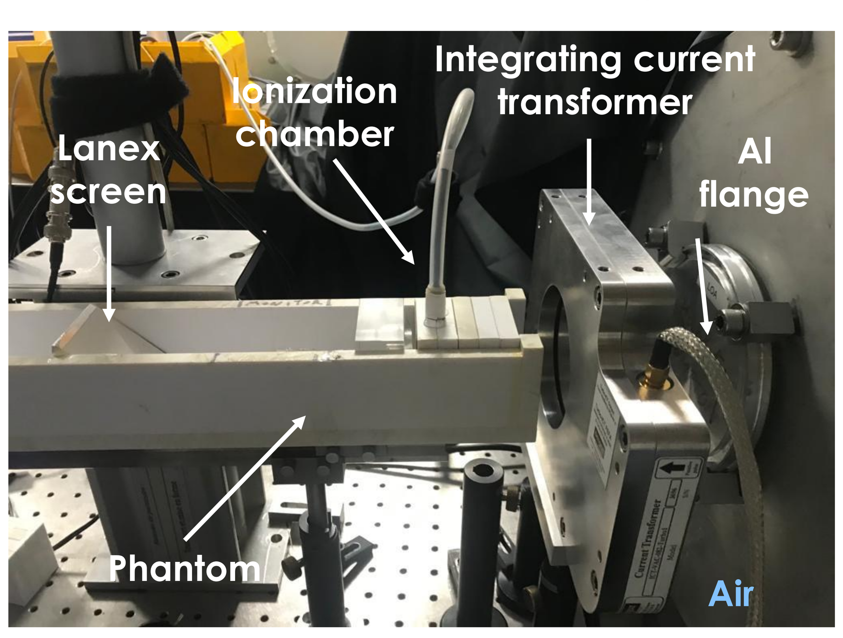
- Technological limitation for clinical use
  - Laser –plasma wakefield accelerator technology
- Few experiments performed
  - Source characterization and optimization
  - Radiation quality assessment
  - Radiation biology experiments

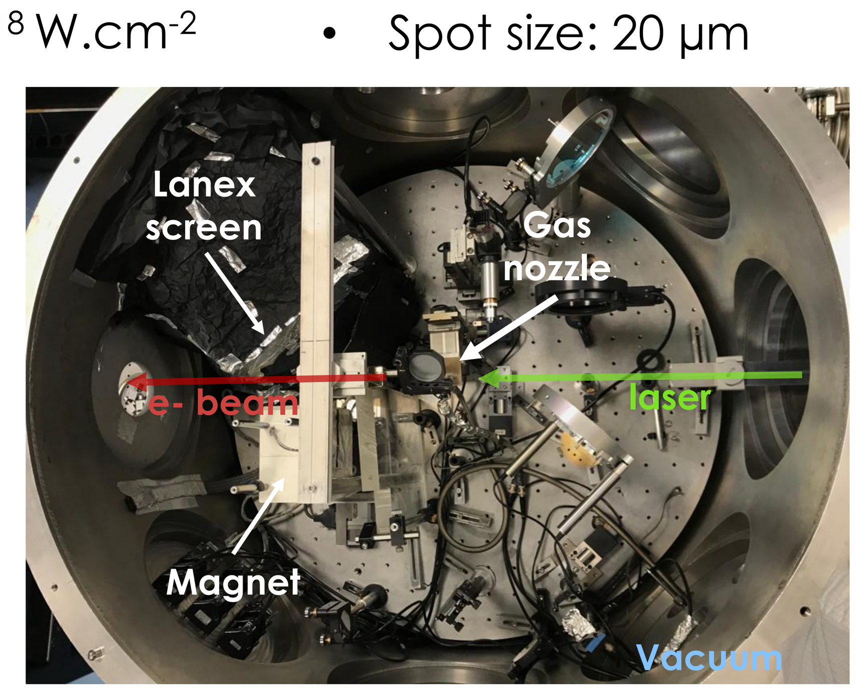
Experimental Set-up

Electrons are accelerated by a travelling electric field generated by the high power (150 TW), short laser pulse propagation in an underdense, gaseous target (Laser WakeField Acceleration).

Laser parameters:

- Energy on target: 1.33±0.12 J
- Intensity: 3.54×10^{18} W.cm^{-2}
- Pulse duration: 30 fs
- Spot size: 20 µm

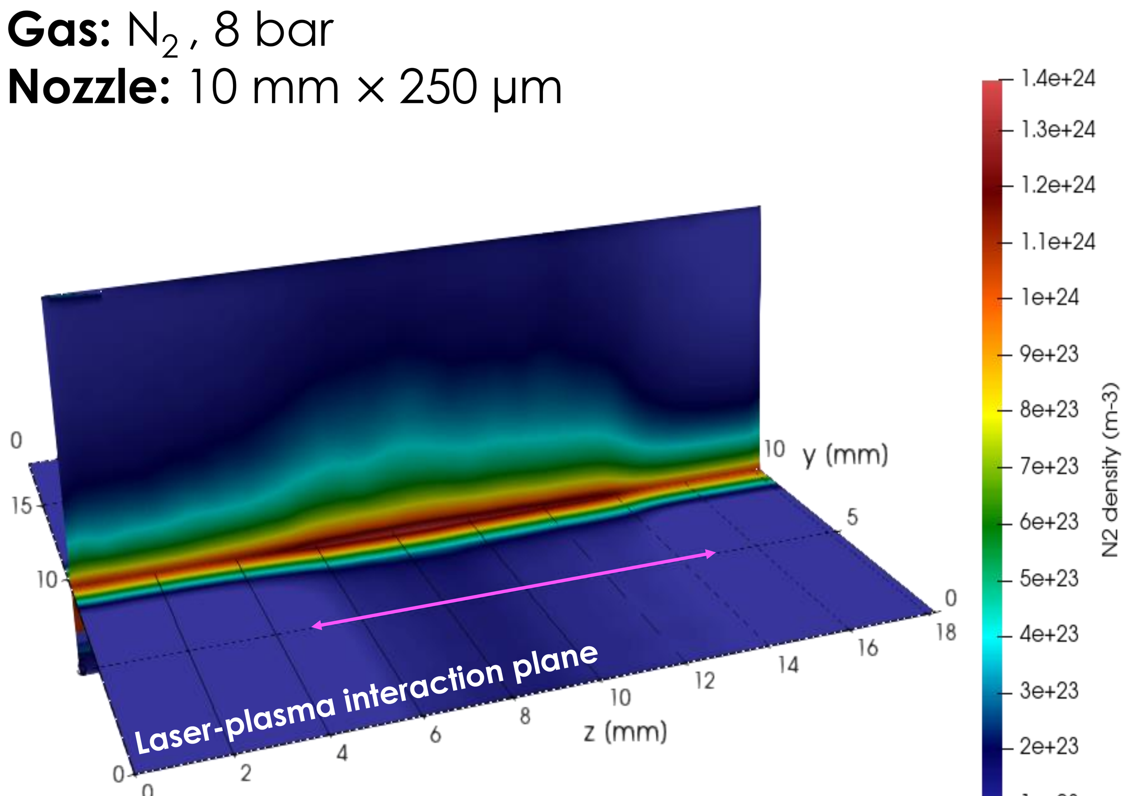




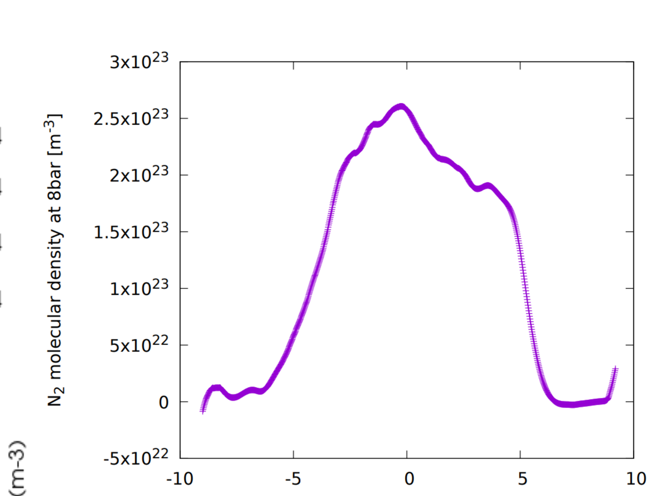
Gas Nozzle Characterization

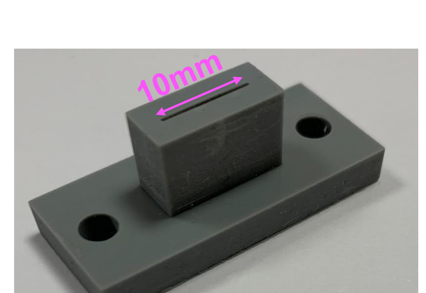
3D printed gas nozzles of various dimensions have been tested: 2.5 – 5 – 7 – 10 mm × 250 µm. In addition, different electronic and atomic densities were studied by exploiting different gases: pure He, pure N_2 and 5% N_2 in He mixture.

Gas: N_2 , 8 bar
Nozzle: 10 mm × 250 µm



Tomography of gas density profile.



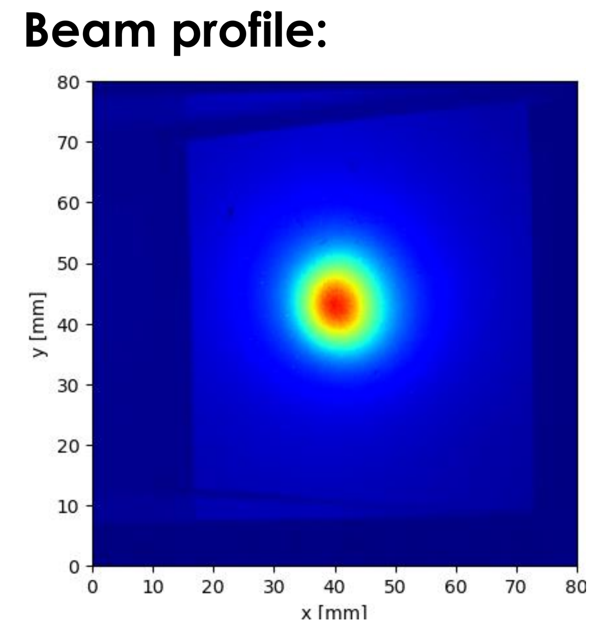


Electron Beam Characterization

The electron beam is characterized in terms of profile, through a LANEX screen placed outside the experimental chamber, and energy spectrum, through a magnetic dipole spectrometer.

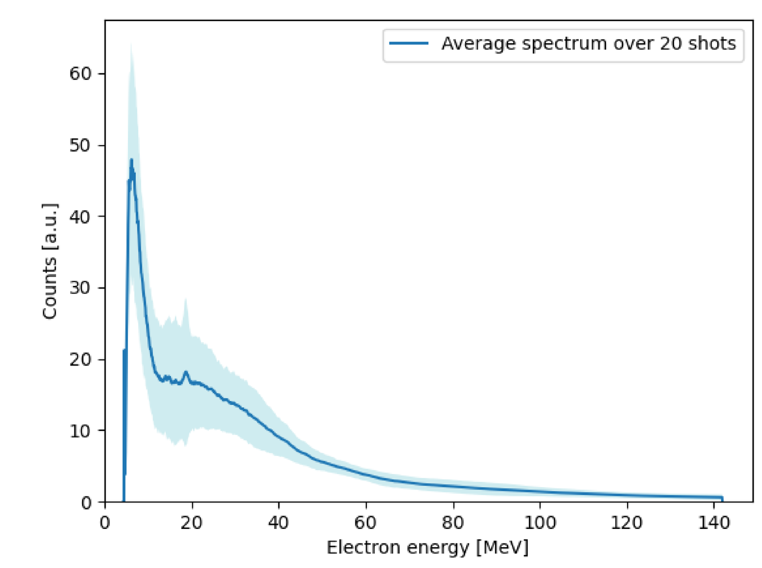
→ Experimental conditions: 8 bar N_2, 5 mm × 250 µm nozzle

Beam profile:



- Divergence: 10 mrad FWHM
- Spot size: ~ 1 cm FWHM

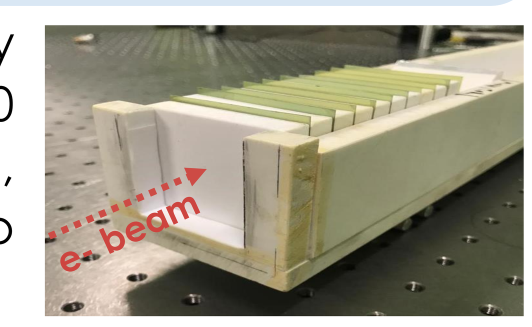
Energy spectrum:



- Electron energy: 4.4 – 142 MeV

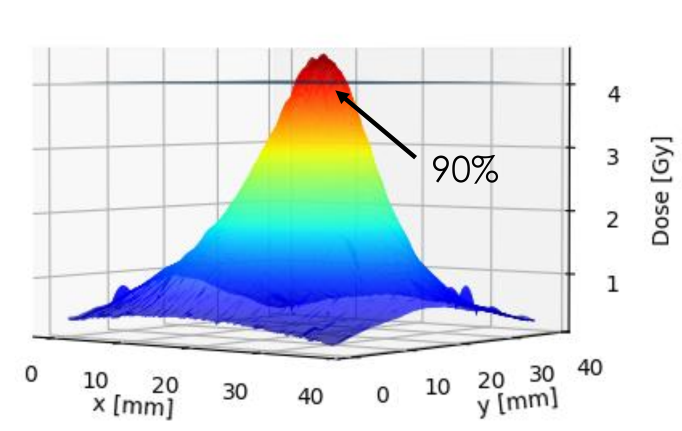
Dosimetry measurements

A water-equivalent phantom simulating a living body is used for dosimetric studies. It can hold up to 30 bricks each 1 cm thick, radiochromic films (EBT3 RCFs), and a customised brick to house a Razor nano chamber.

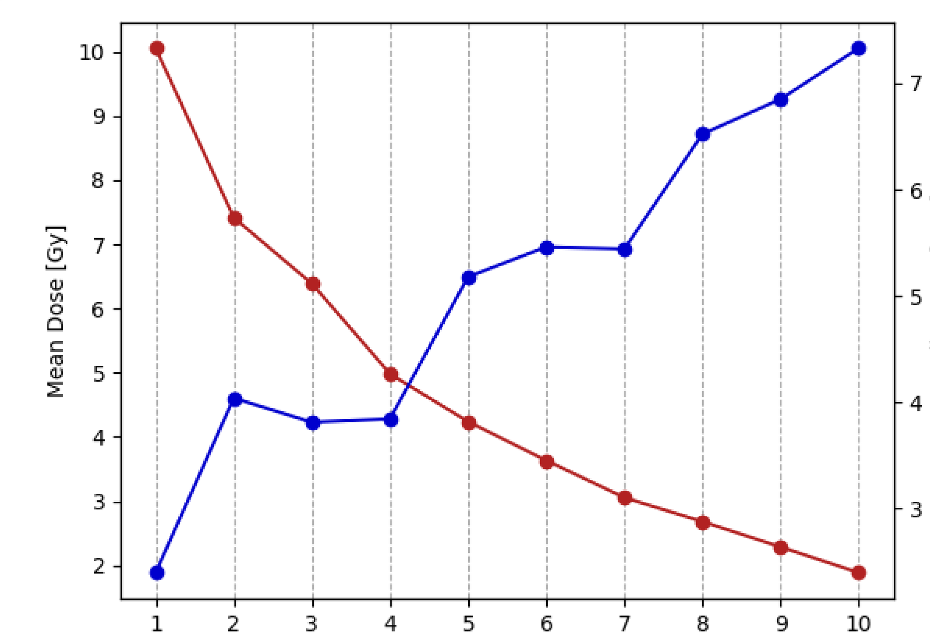


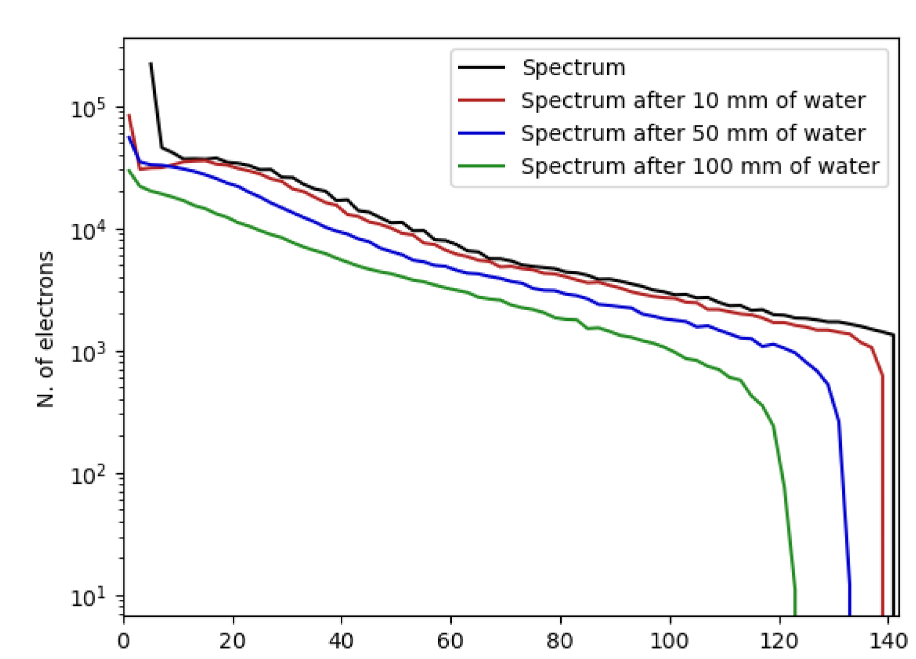
The acceleration conditions have been evaluated in terms of 3D deposited dose profile through 10 cm depth of water-equivalent material. The dose is calculated as the average over a radiochromic surface corresponding to doses > 90% of the maximum.

→ Experimental conditions: 8 bar N_2, 5 mm × 250 µm nozzle



3D dose profile on the 5th RCFs.

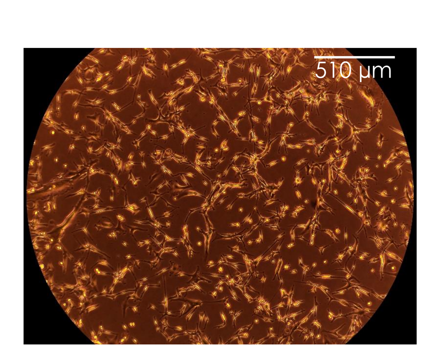


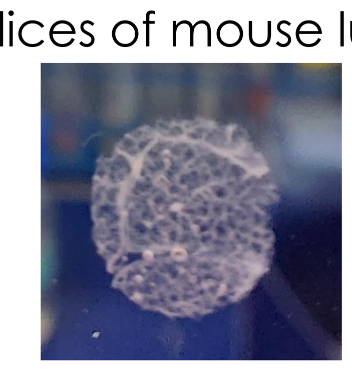


Geant4 simulated spectra over various water depths.

Radiobiological Applications

- **In vitro:** U87-MG
- **Ex vivo:** organotypic slices of mouse lung
- **In vivo:** Zebrafish





References

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[3] T. Fuchs, et al., Phys. Med. Biol. **54**, 3315–3328 (2009)
[4] A. Lagzda et al., THPVA139 (2017)
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