JAI Design Project: LhARA

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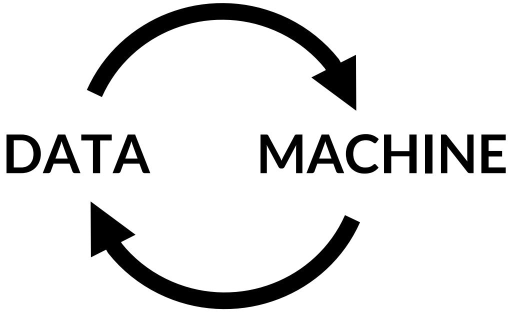
22nd November 2023

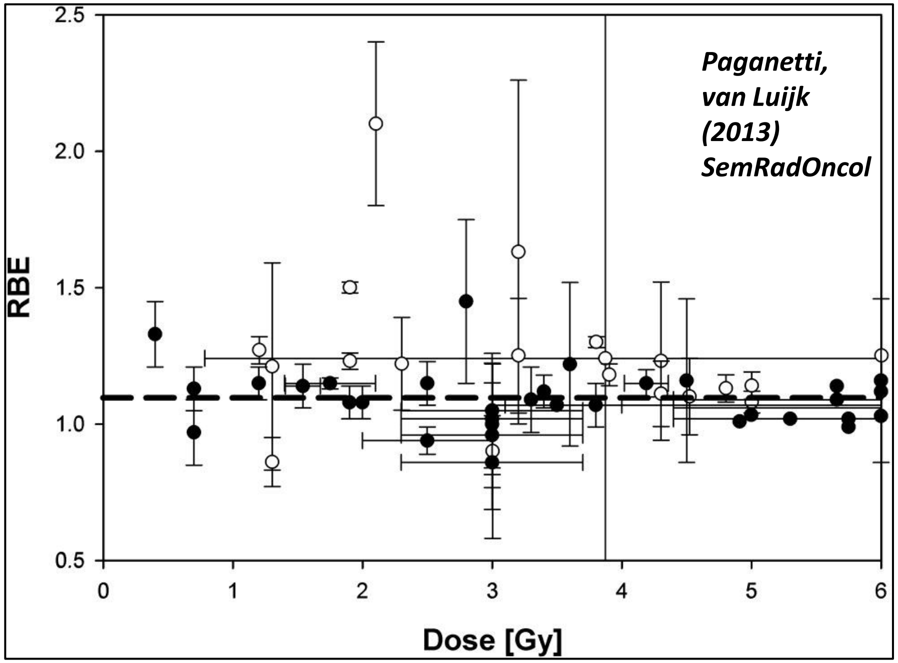
Royal Holloway University of London | Imperial College London | LhARA Laser-hybrid Accelerator for Radiobiological Applications | JAI John Adams Institute for Accelerator Science

The Case for LhARA

- Growing particle therapy demand
  - Improve availability & accessibility with new & cost-effective technologies

- Systematic study of the radiobiology of proton & ion beams
  - Uncertainties due to:
    - Energy, ion species, dose, spatial distribution, dose rate, tissue type, biological endpoint
  - RBE variation
    - Proton treatment planning RBE = 1.1
    - Ion RBE even higher

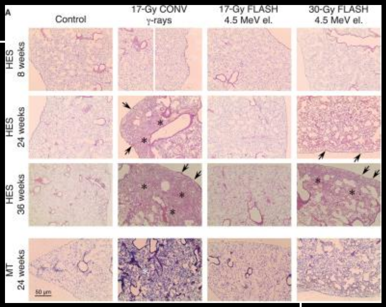




- Novel treatment modalities
  - Ultra-high dose rates: FLASH
  - Spatially fractionated – mini-beams
  - …

- **LhARA: a dedicated radiobiology research facility**

Potential benefit of new regimens



FLASH

Conventional regime: ~2 Gy/min
FLASH regime (p) : >40 Gy/s

Evidence of normal-tissue sparing while tumour-kill probability is maintained:
i.e. enhanced therapeutic window

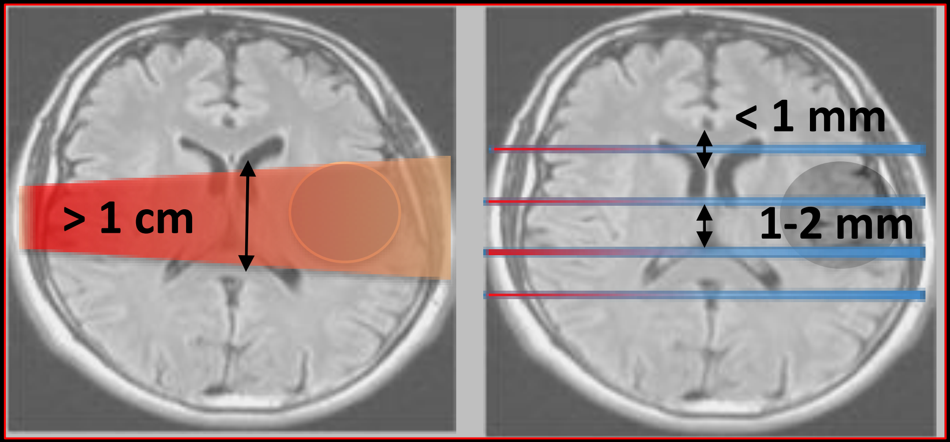
Time line:

- Reports: 2014 (e.g. Flauvadon et al, STM Jul 2014)
- Confirmation in mini-pig & cat: 2018 (Clin. Cancer Research 2018)
- First treatment 2019 (Bourhis et al, Rad.Onc. Oct 2019)

Potential benefit of new regimens

Worked example: micro beams

Conventional regime: > 1 cm diameter; homogenous
Microbeam regime : < 1 mm diameter; no dose between 'doselets'

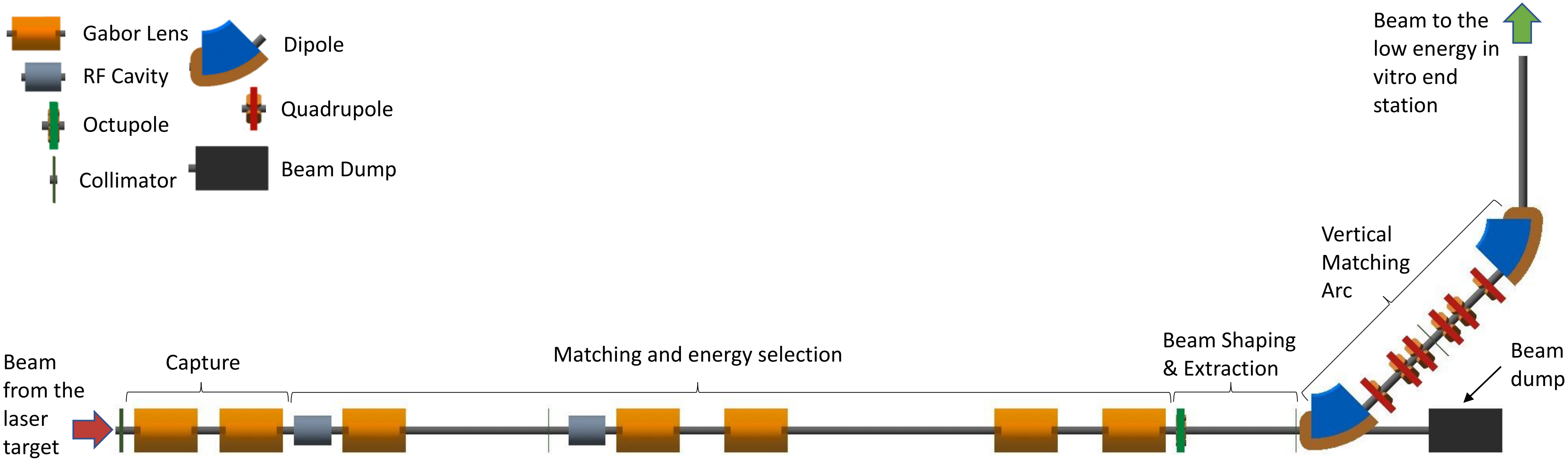


Remarkable increase of normal rat brain resistance.
[Dilmanian et al. 2006, Prezado et al., Rad. Research 2015]

Dose escalation in the tumour possible – larger tumor control probability

LhARA: Stage 1

- Laser-target acceleration via TNSA mechanism
  - 15 MeV protons, ~ 4 MeV/u ^{12}C ions
  - 10^9 protons / pulse, 10^8 ions / pulse
- Gabor lens focusing & capture
  - Confined electron cloud – solenoid-like focusing from radial electric field
- Beam transport & delivery to an end station for in-vitro radiobiology studies
  - Spot-size flexibility



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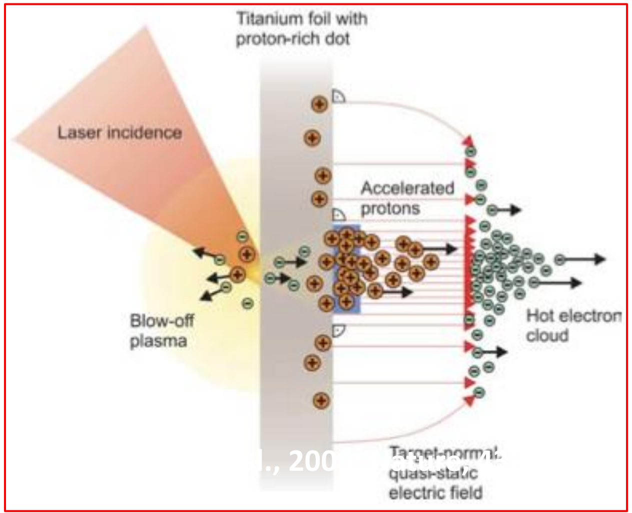
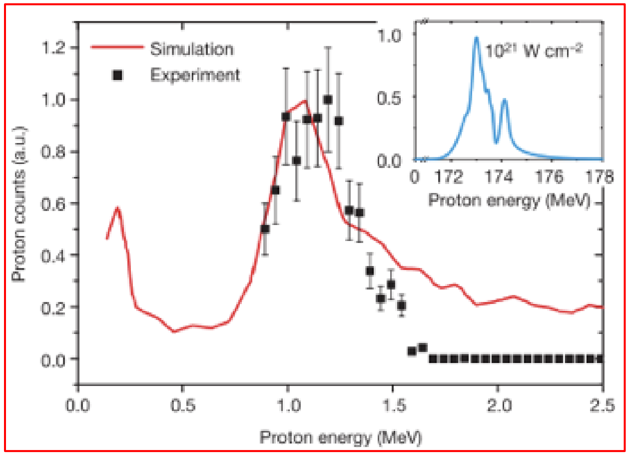


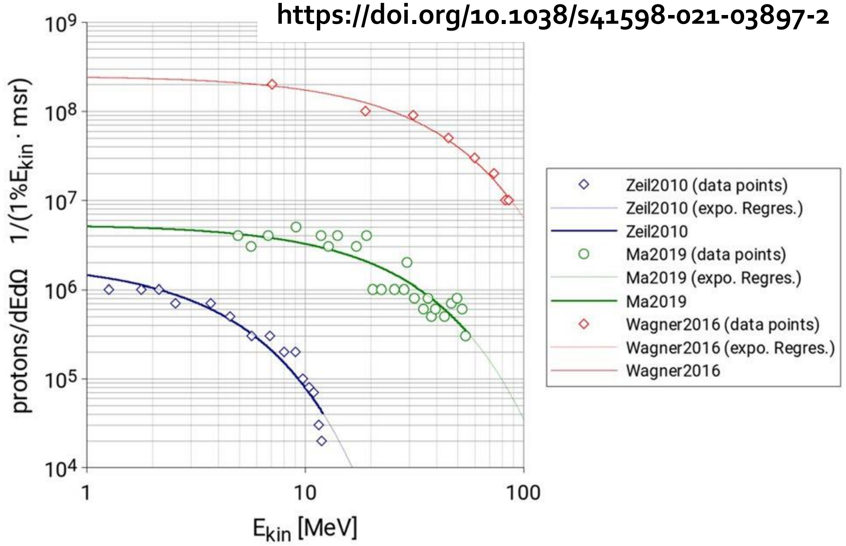


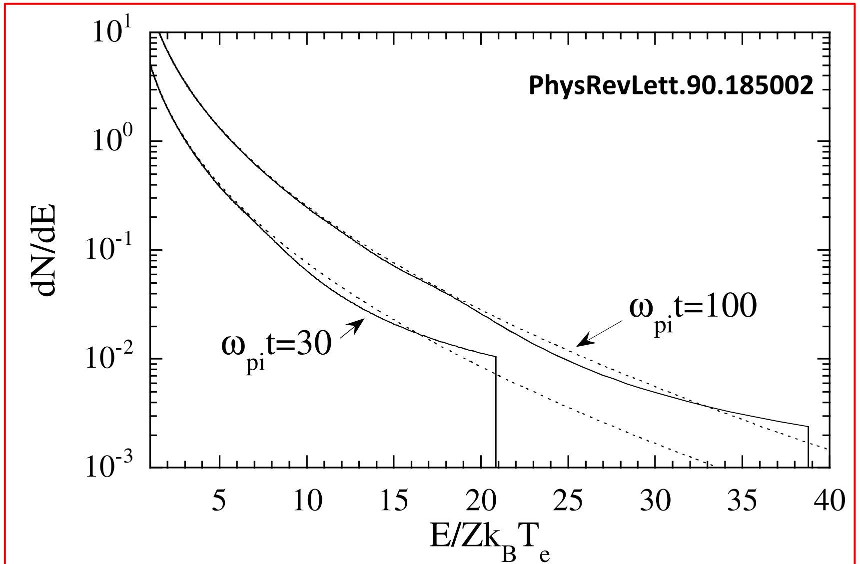
Sheath acceleration

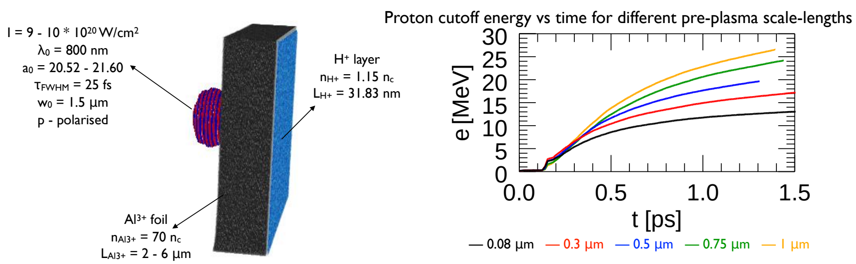
- Laser incident on foil target:
  - Drives electrons from material
  - Creates enormous electric field
- Field accelerates protons/ions
  - Dependent on nature of target
- Active development:
  - Laser: power and rep. rate
  - Target material, transport

Source [2]

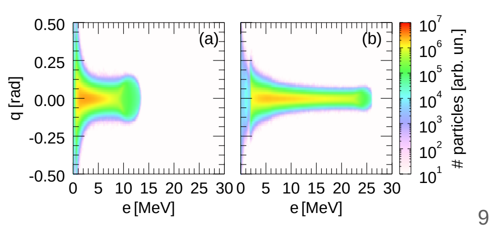
Phase space at source







- 3D simulations predict generation of ion beam parameters similar to LhARA baseline
- Optimal density profile will boost ion energies



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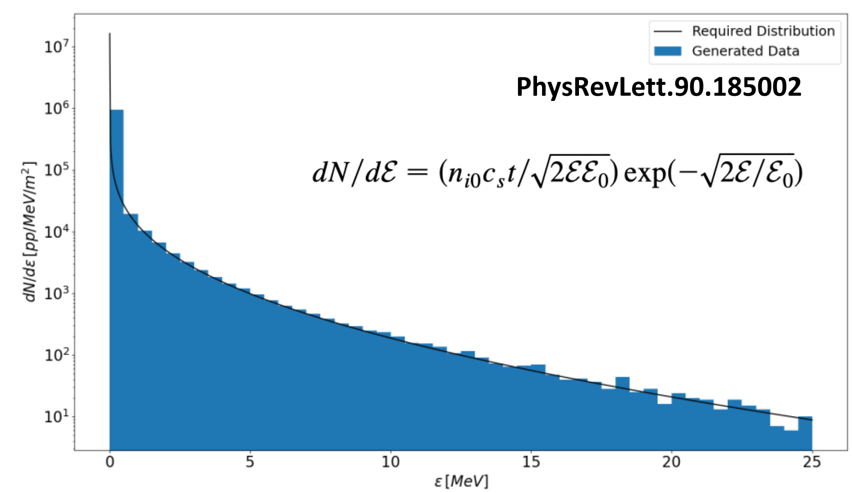
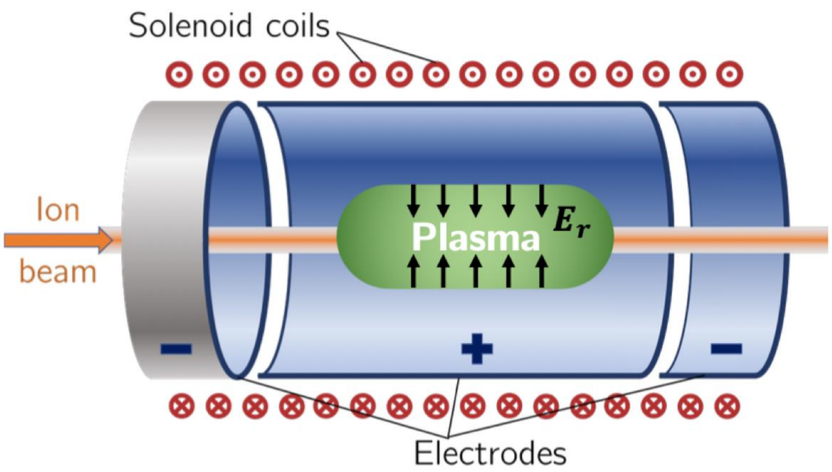


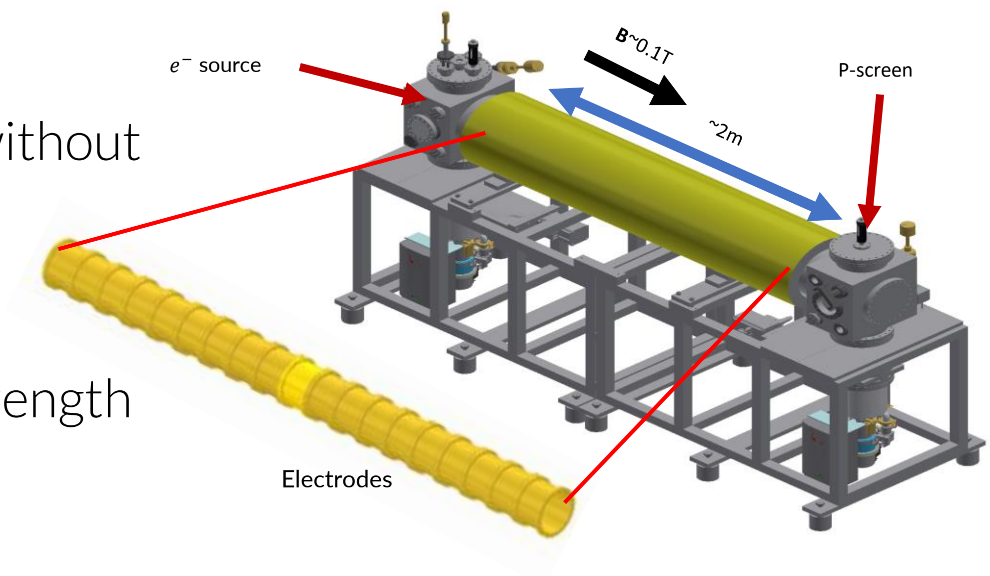
Proton & Ion Capture

- Novel Gabor electron-plasma-lens
  - Penning-Malmberg trap
  - Solenoid field for radial confinement, electric field for longitudinal confinement



$$B_{GPL} = B_{sol}\sqrt{Z\frac{m_e}{m_{ion}}};$$

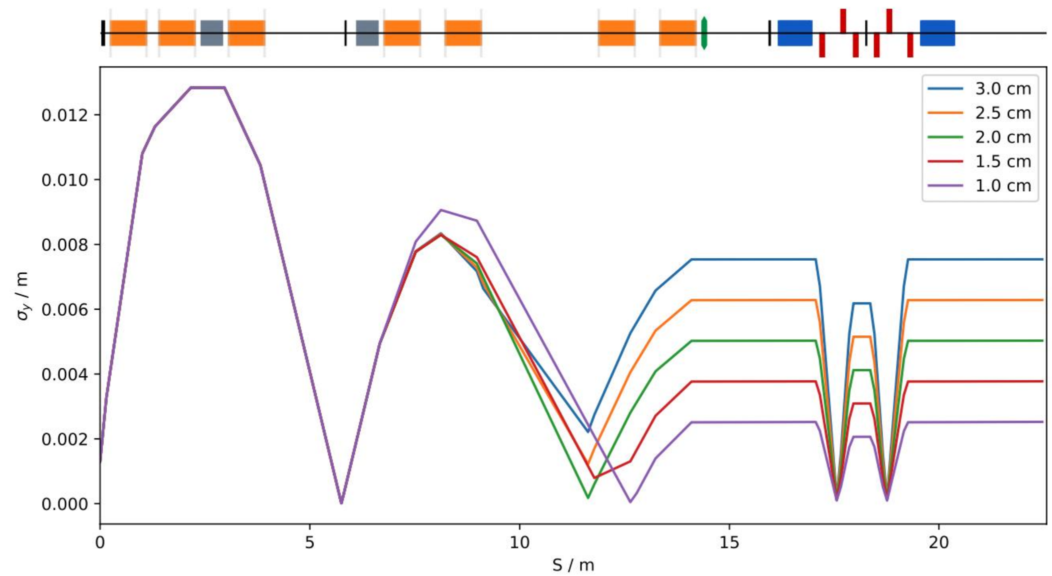
- LhARA capture & focusing
  - Solenoid-like strong focusing without high power, high-field magnet
  - Radial focussing in both planes simultaneously
  - Energy-dependent focusing strength



LhARA: Stage 1 Beam Transport

- 5 optics configuration for 1-3 cm spot sizes (2σ diameter)
  - $\alpha = 0$, $D = 0$ m, $\sigma_x = \sigma_y$ at the end station – pencil beam
- Additional configuration known of $\beta = 50$m, $\alpha=0$ after 7th Gabor lens
  - LhARA stage 2 – FFA injection line
- Beam parameters exiting the laser-target housing (15 cm upstream of 1st Gabor lens):

Beam Parameter	Value (RMS)
Mean RMS emittance [m]	**8.25×10^{-8}**
Mean beta [m]	**20.24**
Mean alpha	**-204.99**



LhARA: Design Project Objectives

- Meet end station beam requirements + flexibility
  - Maintain:
    - Variety of spot sizes – full well plate irradiation
    - > 95% spatial distribution uniformity with octupolar focusing

- **Demonstrate:**
  - **Optimised** source/capture/transport efficiency
  - **Mini-beam** spot sizes
  - **Painting / spot-scanning schemes**
  - **Longitudinal phase space manipulation**
    - <= 2% energy spread - **control**
    - Bunch length ~ 10 ns – **control**
    - **RF cavity design**
  - Vertical arc **magnet design**