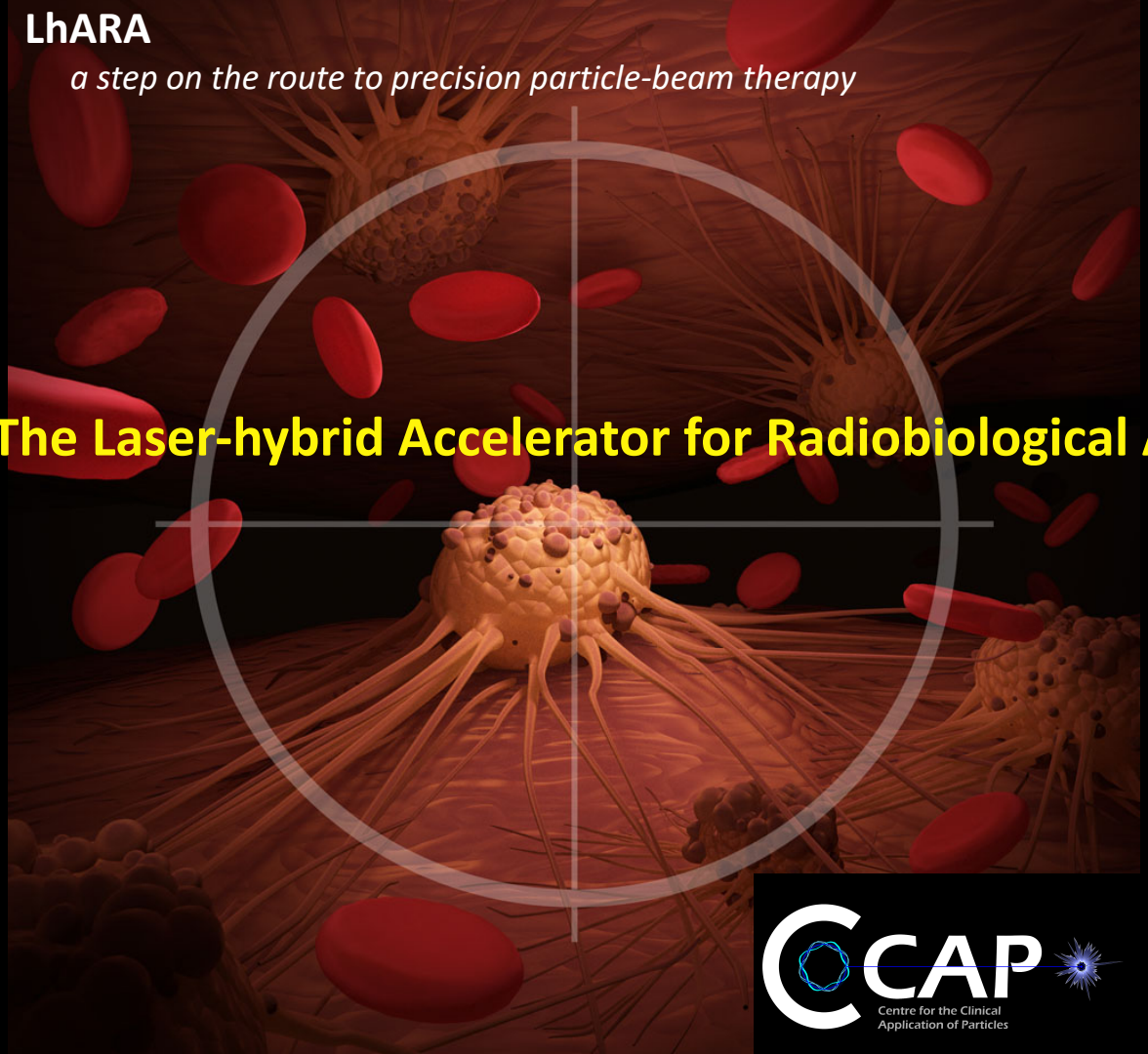
Imperial College London

LhARA

a step on the route to precision particle-beam therapy

Science & Technology Facilities Council



The Laser-hybrid Accelerator for Radiobiological Applications

LhARA

arXiv:2006.00493

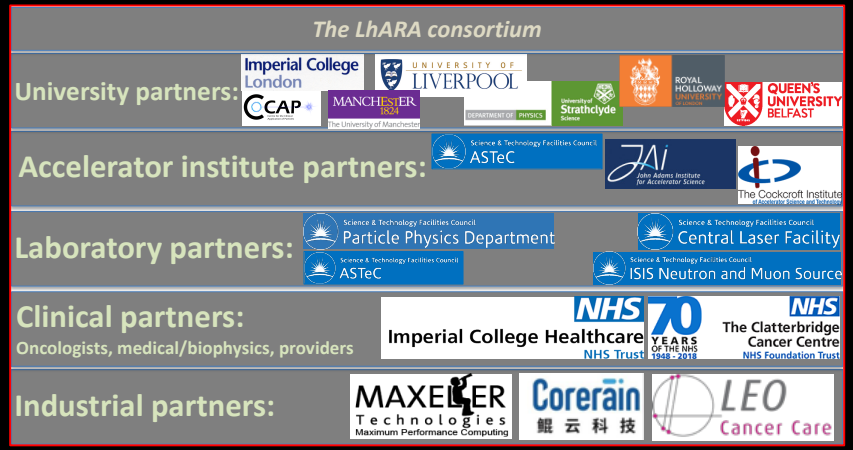
K. Long,

29 June, 2020

CCAP Centre for the Clinical Application of Particles

Acknowledgements

The LhARA consortium!



LhARA consortium Nov19

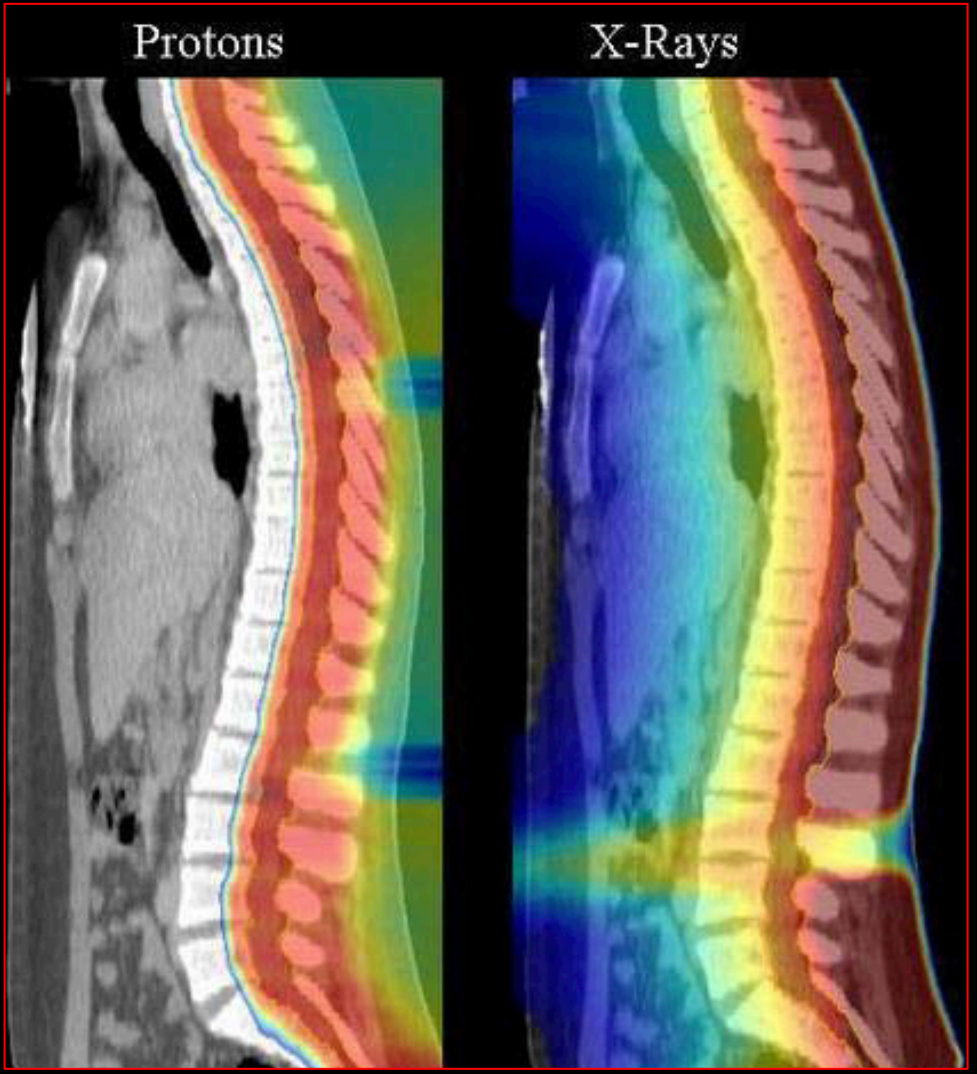
Since completion of pre-CDR (Apr20) the following groups have joined the consortium;

- The National Physical Laboratory
- Surrey
- Birmingham:
  - School of Physics and Astronomy
  - University Hospitals Birmingham NHS
  - Foundation Trust
  - Birmingham Cyclotron Facility
  - Positron Imaging Centre at the University of Birmingham
- Institut Curie (Paris)

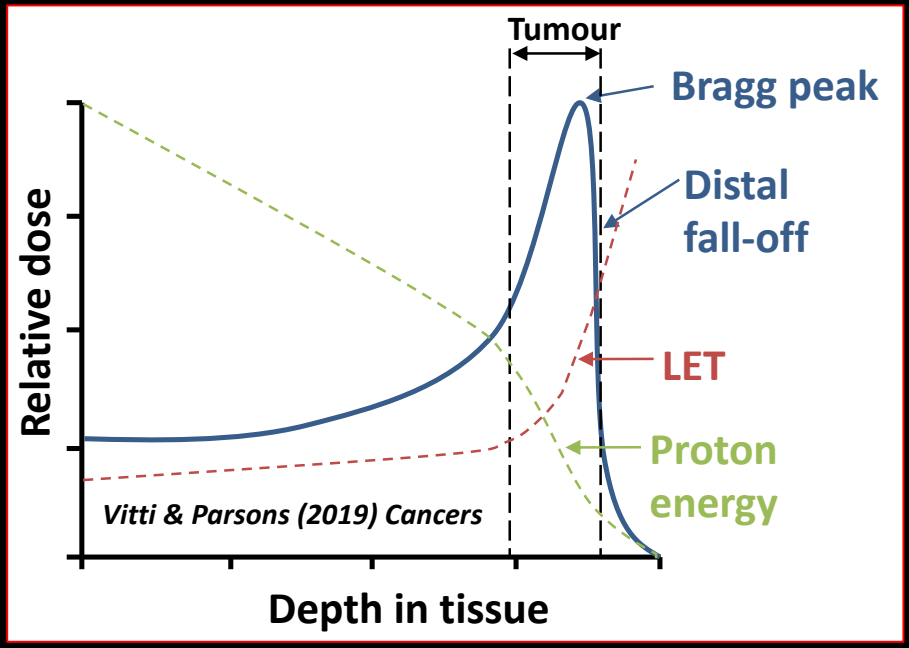
Radiotherapy; the challenge

- Cancer: second most common cause of death globally
  - Radiotherapy indicated in half of all cancer patients
- Significant growth in global demand anticipated:
  - 14.1 million new cases in 2012 ⇢ 24.6 million by 2030
  - 8.2 million cancer deaths in 2012 ⇢ 13.0 million by 2030
- Scale-up in provision essential:
  - Projections above based on reported cases (i.e. high-income countries)
  - Opportunity: save 26.9 million lives in low/middle income countries by 2035
- Provision on this scale requires:
  - Development of new and novel techniques … integrated in a
  - Cost-effective *system* to allow a distributed network of RT facilities

Atun, Lancet Oncol. 2015 Sep;16(10):1153-86



Particle-beam therapy



Proton and ion-beam therapy:

- Bulk of dose deposited in Bragg peak
- Significant normal-tissue sparing (entry)
- Almost no dose beyond the Bragg peak

LhARA … the vision

The execution of the LhARA programme will:

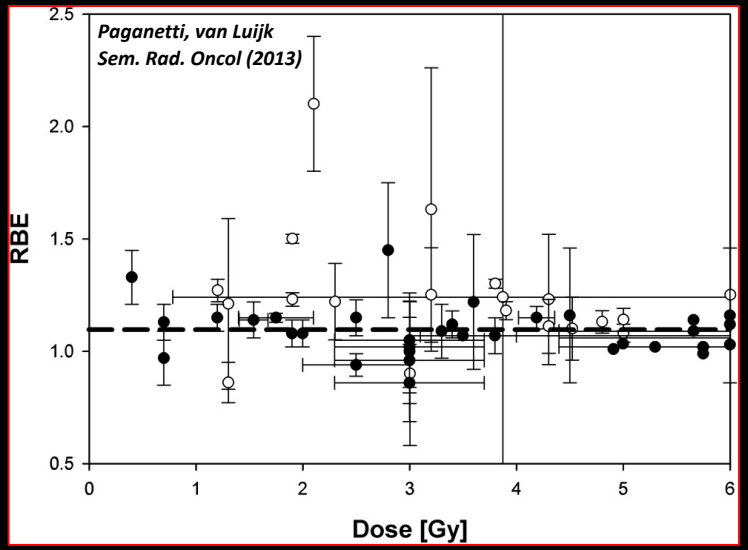
- Create the capability to deliver particle-beam therapy in completely new regimes
  - by combining a variety of ion species in a single treatment fraction and exploiting ultra-high dose rates and novel spatial-fractionation schemes.

- Make "best in class" treatments available to the many
  - by demonstrating in operation a system that incorporates dose-deposition imaging in a fast feedback-and-control system thereby reducing the requirement for a large gantry.

The radiobiology needs to be understood

- **Treatment planning:**
  - **Based on 'Relative Biological Effectiveness (RBE)**
    - **Proton-treatment planning uses RBE = 1.1**
    - **Effective values are used for C^{6+}**

RBE:
Ratio of dose required to gain same biological response as reference photon beam



RBE known to depend on:

- Energy, ion species
- Dose & dose rate
- Tissue type
- Biological endpoint

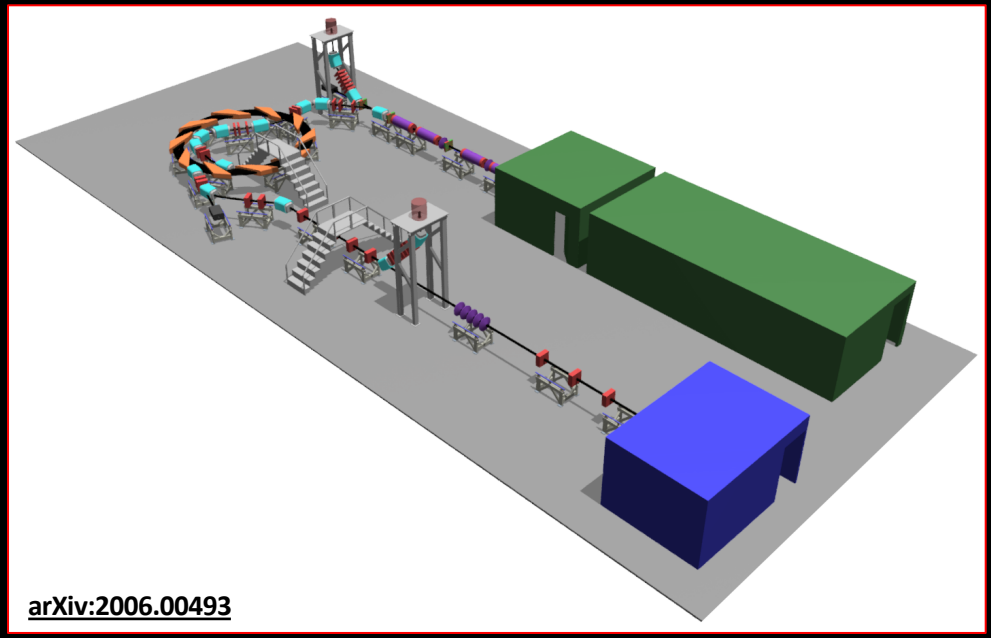
Essential: improved, fundamental, understanding of radiobiology

Radiobiology in new regimens

Laser-hybrid Accelerator for Radiobiological Applications

LhARA; a novel, hybrid, approach:

- **High-flux, laser-driven proton/ion source:**
  - Overcome instantaneous dose-rate limitation
  - Delivers protons or ions in very short pulses:
    - Pulse length 10 – 40 ns
  - Can provide arbitrary pulse structure
- **Novel plasma-lens capture & focusing**
- **Fast, flexible, fixed-field post acceleration**
  - Protons up to 127 MeV p;
  - Ions up to ~35 MeV/u



arXiv:2006.00493

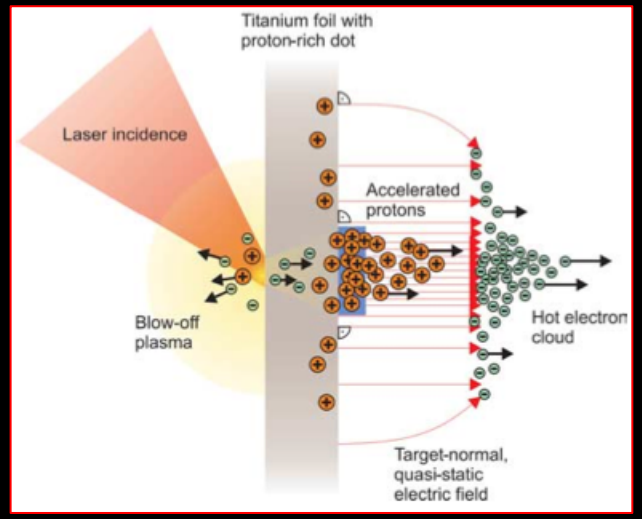
LhARA consortium

- **Staged implementation:**
  - Stage 1: In vitro studies with protons at energies up to 15 MeV
  - Stage 2: In vivo & in vitro studies with protons up to 127 MeV and ions up to 33 MeV/u

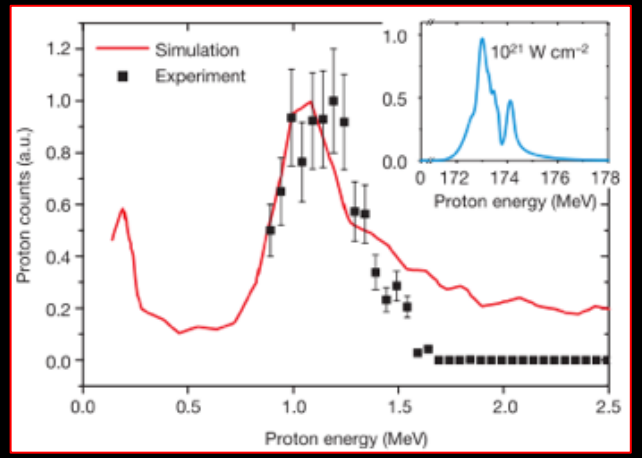
→ compact, uniquely flexible facility

CCAP Centre for the Clinical Application of Particles

Sheath acceleration

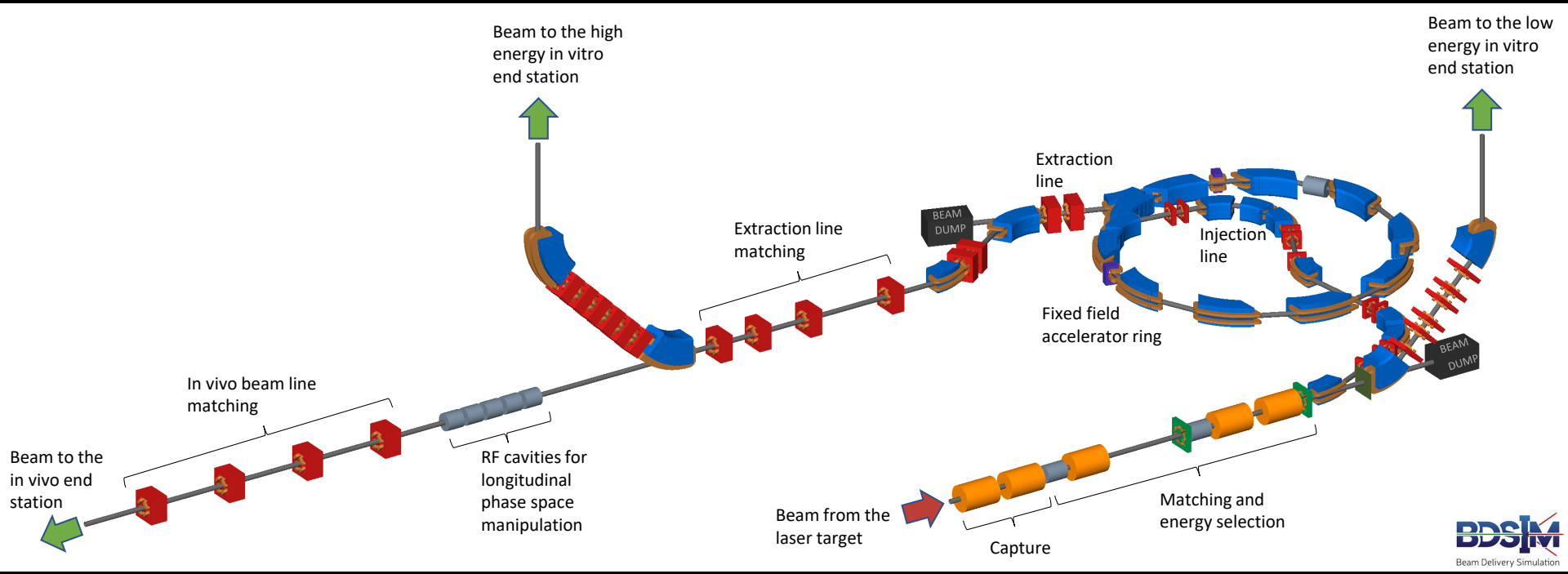


Schwoerer, H. et al., 2006; Nature, 439(7075).



- Laser incident on foil target:
  - Drives electrons from material
  - Creates enormous electric field
- Field accelerates protons/ions
  - Dependent on nature of target
- First observation ~2000
- Active development:
  - Laser: power and rep. rate
  - Target material, transport

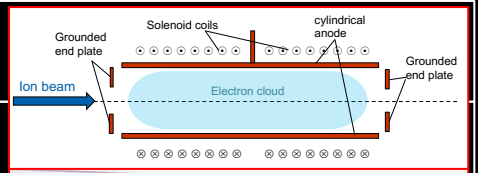
LhARA

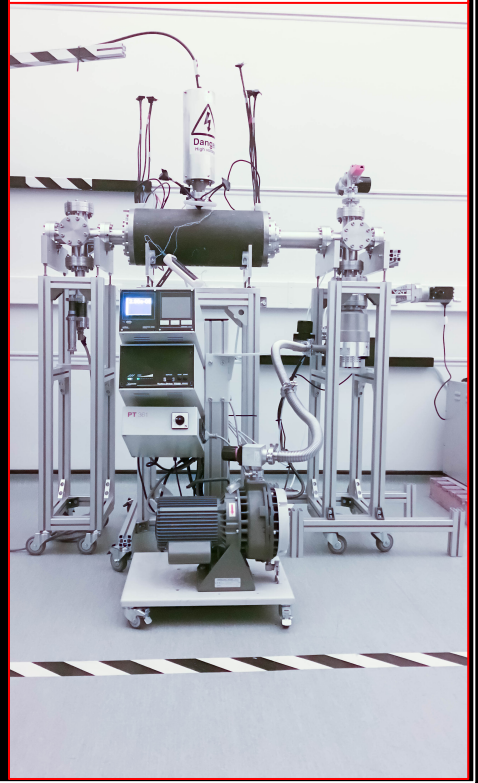

Beam to the high energy in vitro end station
Beam to the low energy in vitro end station
Extraction line
Extraction line matching
BEAM DUMP
Injection line
Fixed field accelerator ring
BEAM DUMP
In vivo beam line matching
Beam to the in vivo end station
RF cavities for longitudinal phase space manipulation
Beam from the laser target
Capture
Matching and energy selection
BDSIM
Beam Delivery Simulation

LhARA: ion-source development

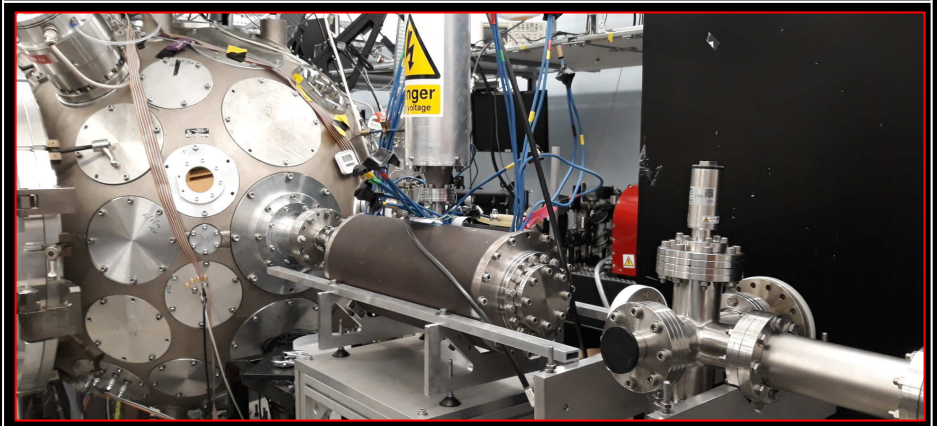
Capture

- Electron plasma:
  - Strong focusing of +ve ions
- 1st prototype:
  - 1 MeV protons Surrey Ion Beam Centre
  - Aberrations observed
- Upgraded prototype:
  - Under development Imperial



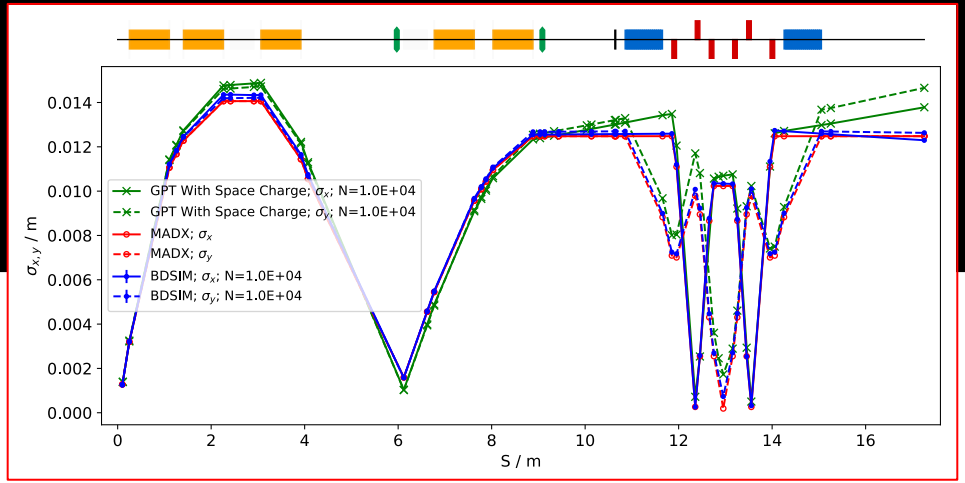


Laser source/capture test

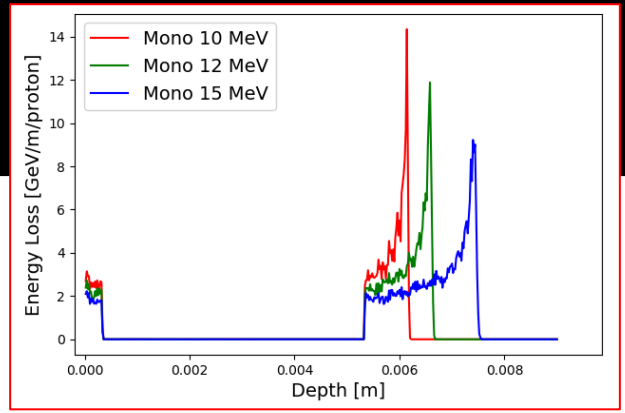


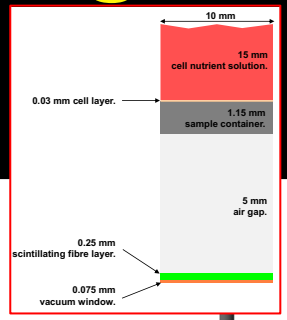
- Integration test:
  - Gabor lens on cerberus Laser at Imperial
- Plan:
  - "Now": prepare to validate lens with α
  - Next: test using laser-driven source

LhARA; stage 1

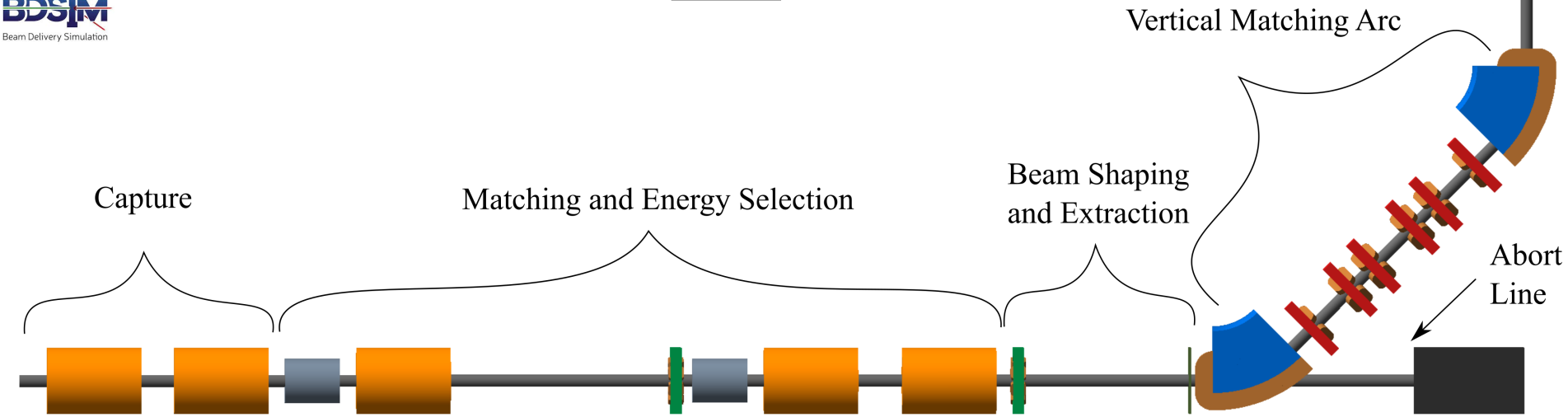


arXiv:2006.00493



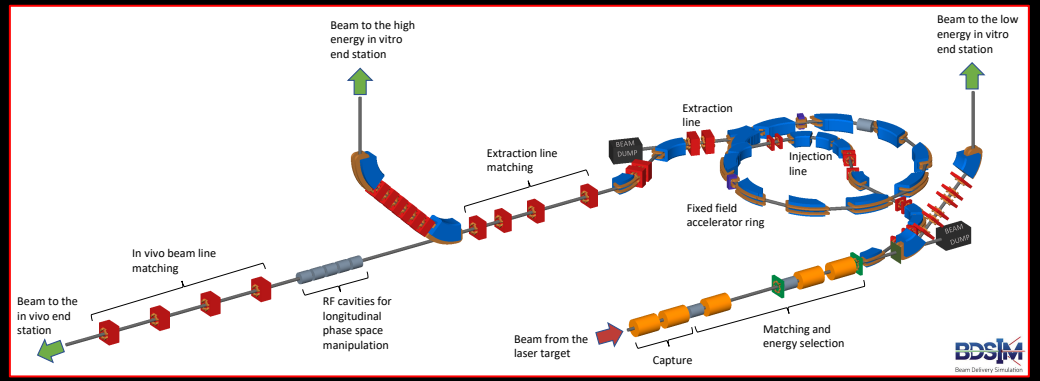


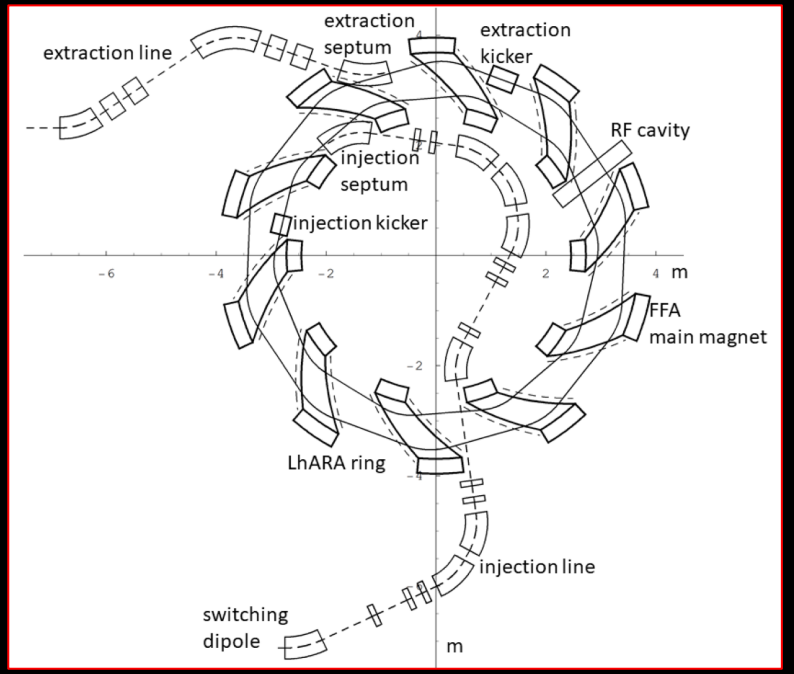
BDSIM
Beam Delivery Simulation



LhARA – Stage 2

- In-vitro radiobiology using animal models:
  - Post-acceleration required





- Baseline: fixed field accelerator:
  - x3 increase in momentum
    - 15 MeV protons accelerated to 127 MeV
    - 3.8 MeV/u carbon 6+ ions accelerated to 33 MeV/u

arXiv:2006.00493

Next steps; 5-year R&D plan

- 5-year plan presented in pre-CDR designed to:
  - Address technical risks presented in pre-CDR
    - Especially source and plasma-lens capture
    - Instrumentation and diagnostics
  - Deliver technical designs for the LhARA facility
  - End stations.
    - Automation, sample handling, imaging
    - Simulation, including impact on tissue/tissue response

arXiv:2006.00493

→ Capability to start Stage 1 in-vitro programme

K.Long@imperial.ac.uk

Conclusions

- Laser-hybrid approach has potential to:
  - Overcome dose-rate limitations of present PBT sources;
  - Deliver uniquely flexible facility:
    - Range of ion species, energy, dose, dose-rate
  - Disruptive/transformative approach ‘for 2050’ …

- Opportunity:
  - Develop and prove novel systems in production system;
  - Deliver research facility dedicated to radiobiology;
  - Contribute to study of biophysics of charged-particle beams

- First and next steps:
  - Initial concept developed and prototype evaluation underway
  - Seeking resources to execute R&D programme laid out in ‘pre-CDR’
  - Wonderful opportunity to build novel techniques to spin back in!

CCAP Centre for the Clinical Application of Particles

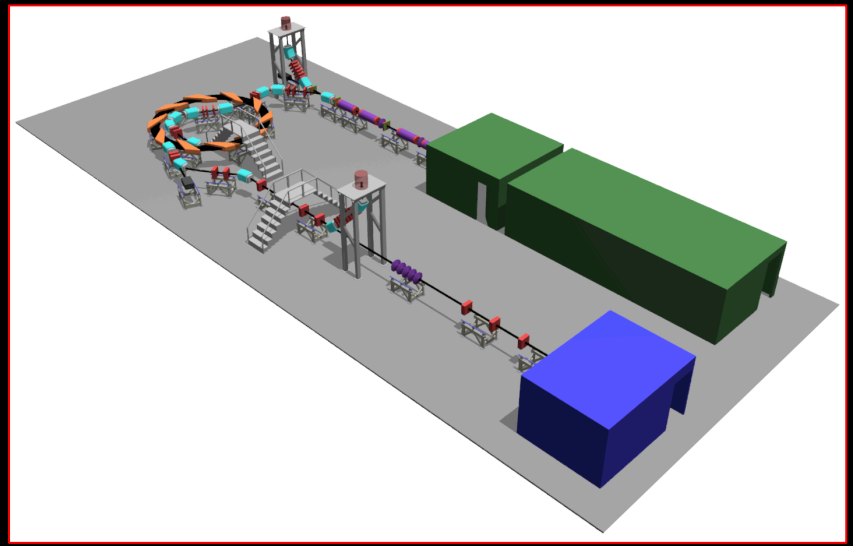
Laser-hybrid Accelerator for Radiobiological Applications (LhARA)

BACKUP

LhARA status

Modest resources to date have delivered LhARA "pre-CDR":

- **STFC Opportunities 2019 award; and consortium**



Milestone: pre-CDR by April 2020:

- **Completed.**
  - **Review by international panel 25&31 Mar20**
    - **Peer-endorsement subsequent to 2019 PPRP review**
- **Publication based on the pre-CDR:**
  - **Submitted to Frontiers in Physics Medical Physics and Imaging**
  - **Uploaded to the arXiv as arXiv:2006.00493**