Science and Technology Facilities Council

Imperial College London

K. Long, 23 August, 2023

on behalf of the LhARA/ITRF collaboration

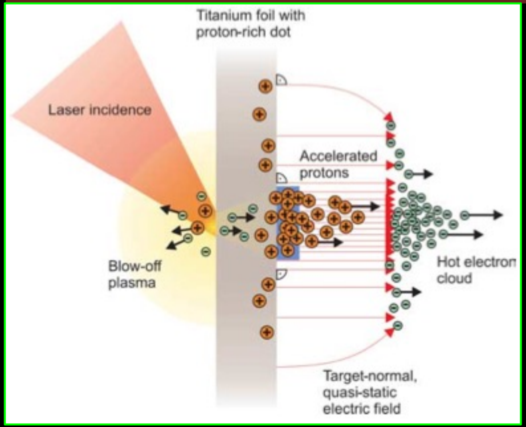
LhARA

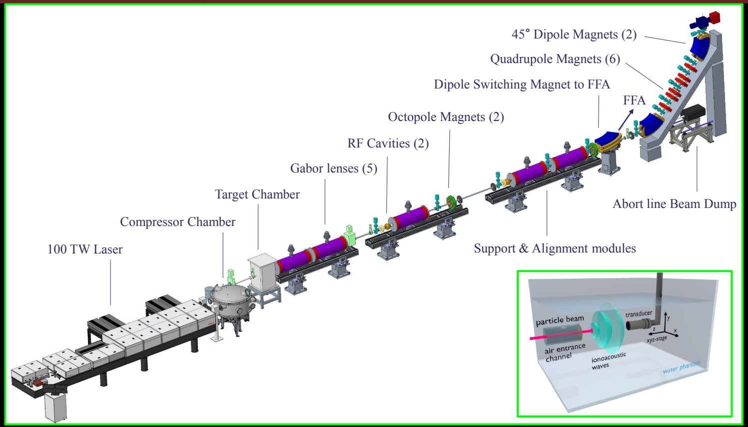
the Laser-hybrid Accelerator for Radiobiological Applications

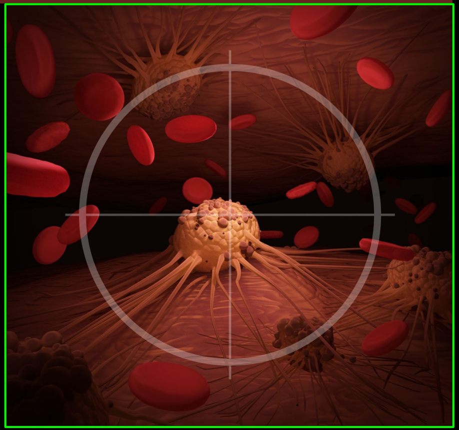
Our ambition is to:

- ***Deliver a systematic and definitive radiation biology programme***
- ***Prove the feasibility of laser-driven hybrid acceleration***
- ***Lay the technological foundations for the transformation of PBT***
  - automated, patient-specific proton and ion beam therapy

LhARA
Laser-hybrid Accelerator for Radiobiological Applications







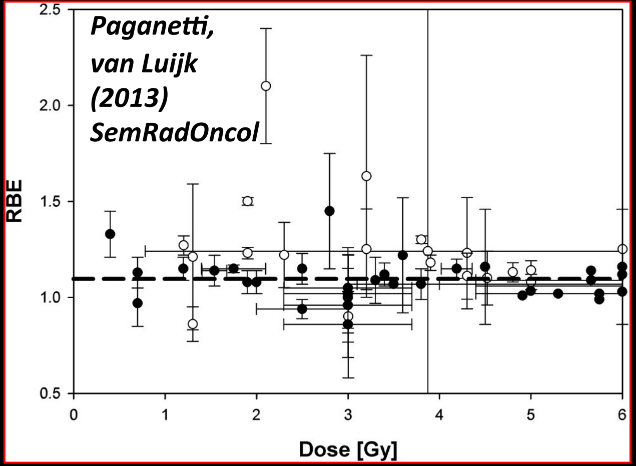
Radiotherapy; the challenge

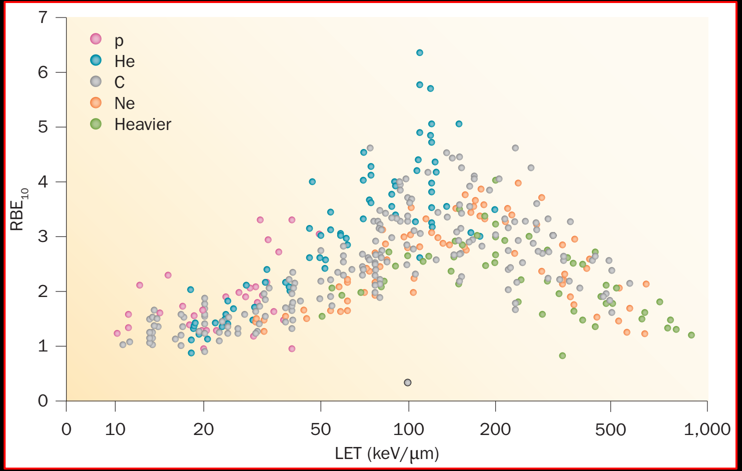
- Cancer: second most common cause of death globally
  - Radiotherapy indicated in half of all cancer patients
- Significant growth in global demand anticipated:
  - 14.1 million new cases in 2012 ⇢ 24.6 million by 2030
  - 8.2 million cancer deaths in 2012 ⇢ 13.0 million by 2030
- Scale-up in provision 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

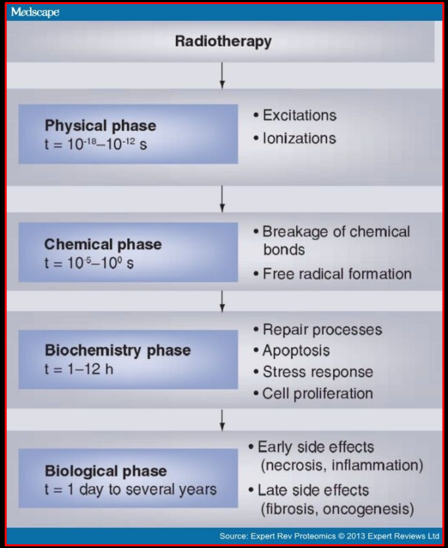
The case for fundamental radiobiology

- **Relative biological effectiveness:**
  - Defined relative to reference X-ray beam
  - Known to depend on:
    - Energy, ion species
    - Dose & dose rate
    - Tissue type
    - Biological endpoint
- **Yet:**
  - *p*-treatment planning uses 1.1
  - Effective values are used for C^{6+}
- **Maximise the efficacy of PBT now & in the future:**
  - Require systematic programme to develop full understanding of radiobiology





Radiobiology in new regimens



Time domain

Space domain

The ideally flexible beam facility can deliver it all!

⇒ substantial opportunity for a step-change in understanding!

Energy

Ion species

Multidisciplinary approach essential

In combination
and with chemo/immuno Therapies

Imperial College London

ICR The Institute of Cancer Research

Medical Research Council

UKRI Oxford Institute for Radiation Oncology

University of Oxford

JAI John Adams Institute for Accelerator Science

LhARA Laser-hybrid Accelerator for Radiobiological Applications

CCAP Centre for the Clinical Application of Particles

Imperial College Academic Health Science Centre

Cancer Research UK | Imperial Centre

NHS Imperial College Healthcare NHS Trust

Manchester 1824 The University of Manchester

University of Birmingham

University of Liverpool

NHS University Hospitals Birmingham NHS Foundation Trust

NHS The Clatterbridge Cancer Centre NHS Foundation Trust

NHS The Christie NHS Foundation Trust

institut Curie

Queen's University Belfast

Swansea University Prifysgol Abertawe

UCL Medical Physics & Biomedical Engineering

Netherlands Cancer Institute Antoni van Leeuwenhoek

Hampton University Proton Therapy Institute Fighting Cancer, Saving Lives

University of Strathclyde Glasgow Department of Physics

Royal Holloway University of London

Lancaster University

UKRI Science and Technology Facilities Council

ASTeC
Daresbury Laboratory
Particle Physics Department
ISIS Neutron and Muon Source

CLF central laser facility

University of Birmingham | Cyclotron Facility | Positron Imaging Centre

INFN Catania

The Cockcroft Institute of Accelerator Science and Technology

CERN

Corerain 鲲云科技

LEO Cancer Care

Maxeler Technologies Maximum Performance Computing

The Rosalind Franklin Institute

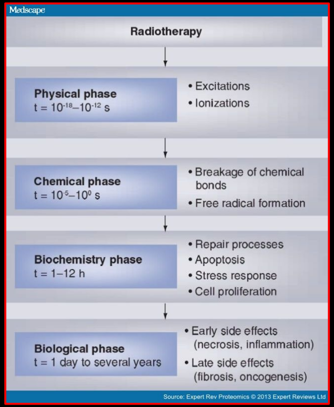
NPL National Physical Laboratory

Laser-hybrid Accelerator for Radiobiological Applications

Front. Phys., 29 September 2020; DOI: 10.3389/fphy.2020.567738

A novel, hybrid, approach:

- Laser-driven, high-flux proton/ion source
  - Overcome instantaneous dose-rate limitation
    - Capture at >10 MeV
  - Delivers protons or ions in very short pulses
    - Bunches as short as 10—40 ns
  - Triggerable; arbitrary pulse structure



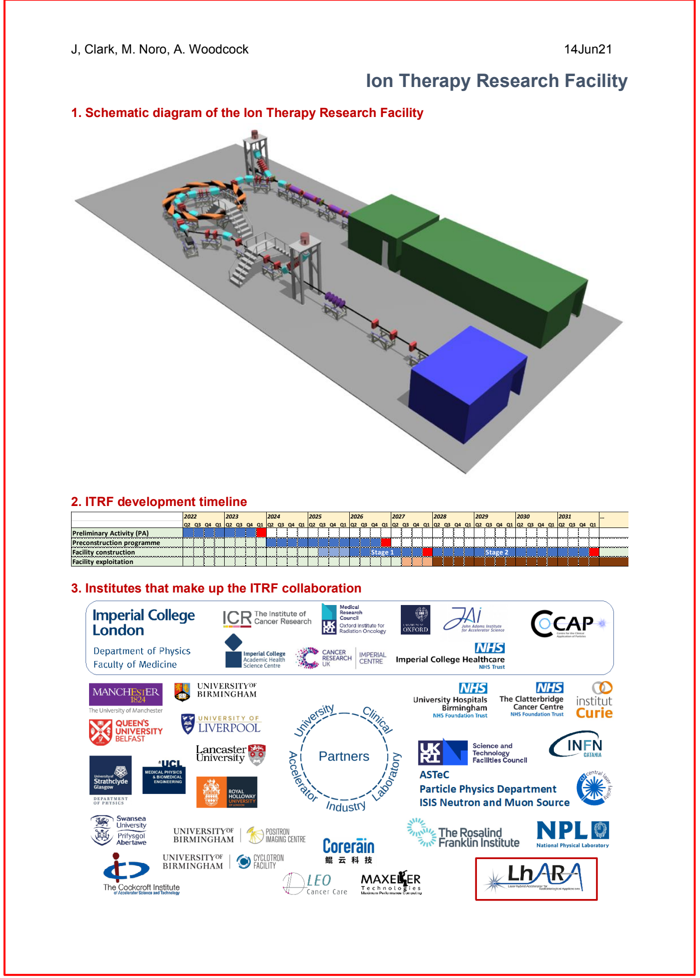
- Novel "electron-plasma-lens" capture & focusing
  - Strong focusing (short focal length) without the use of high-field solenoid

- Fast, flexible, fixed-field post acceleration
  - Variable energy
    - Protons: 15—127 MeV
    - Ions: 5—34 MeV/u

LhARA performance summary arXiv:2006.00493

	12 MeV Protons	15 MeV Protons	127 MeV Protons	33.4 MeV/u Carbon
Dose per pulse	7.1 Gy	12.8 Gy	15.6 Gy	73.0 Gy
Instantaneous dose rate	1.0×10^{9} Gy/s	1.8×10^{9} Gy/s	3.8×10^{8} Gy/s	9.7×10^{8} Gy/s
Average dose rate	71 Gy/s	128 Gy/s	156 Gy/s	730 Gy/s

LhARA to serve ITRF Preliminary Activity


J, Clark, M. Noro, A. Woodcock 14Jun21

Ion Therapy Research Facility

1. Schematic diagram of the Ion Therapy Research Facility

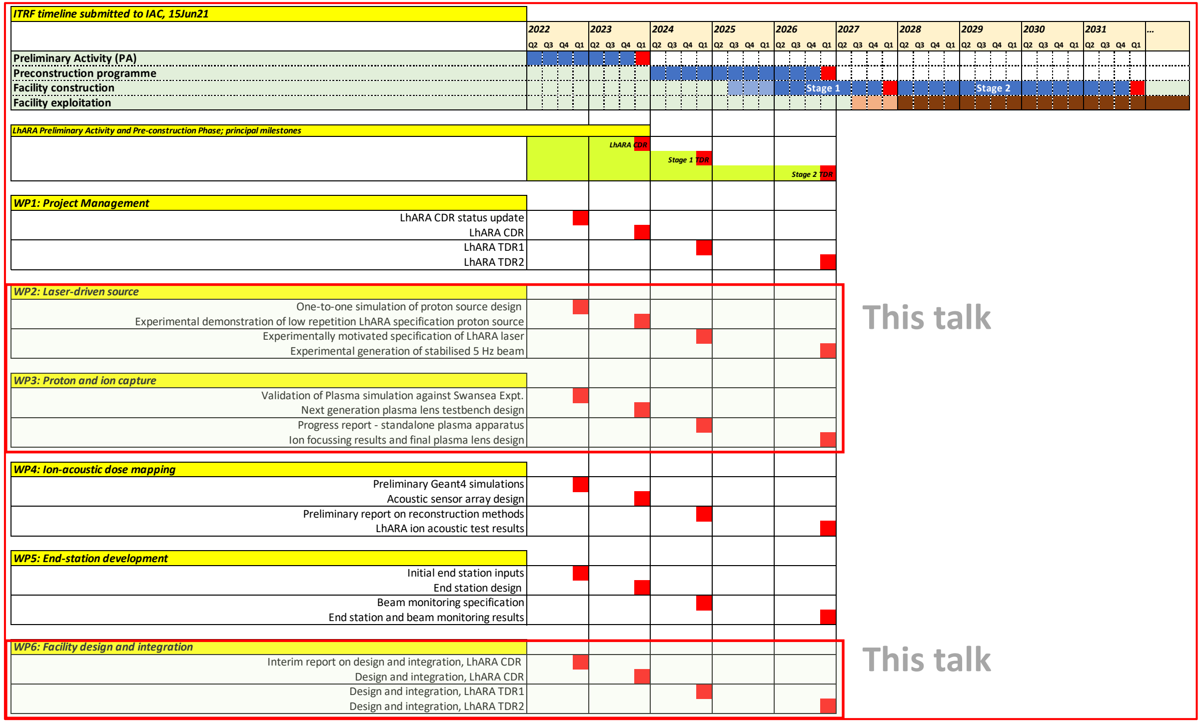
2. ITRF development timeline

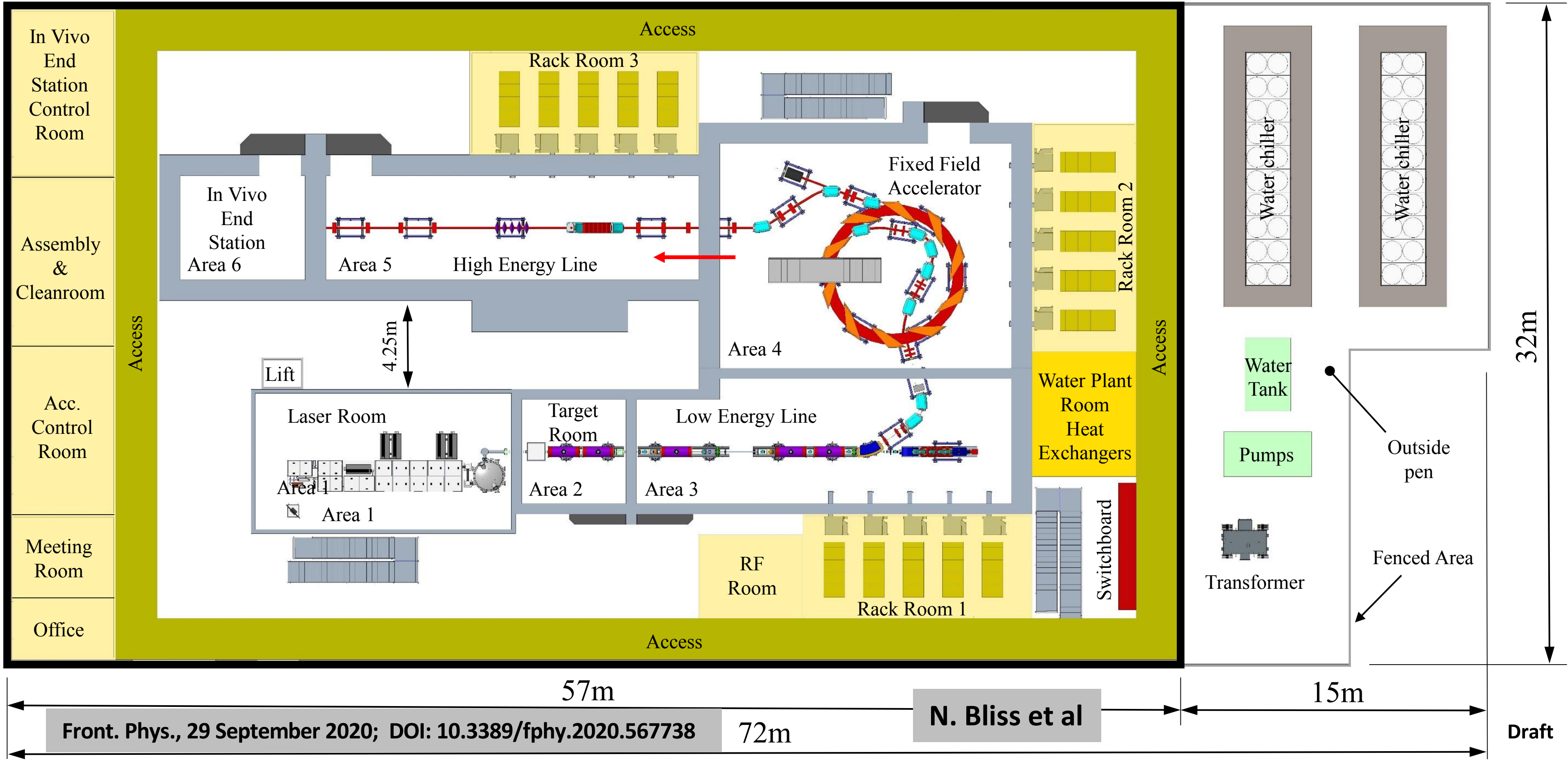
3. Institutes that make up the ITRF collaboration

Preliminary Activity: £2M over 2 years

project start October 2022

Bid for next 4/5 year "pre-construction" project submitted





⇒ *compact, uniquely flexible facility*

LhARA Laser-hybrid Accelerator for Radiobiological Applications

2-year Programme: Characterising Source and Benchmarking Simulations

Established Diagnostics…

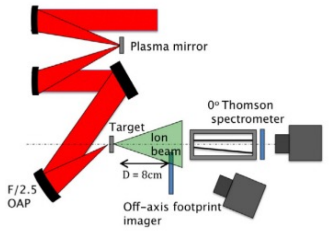
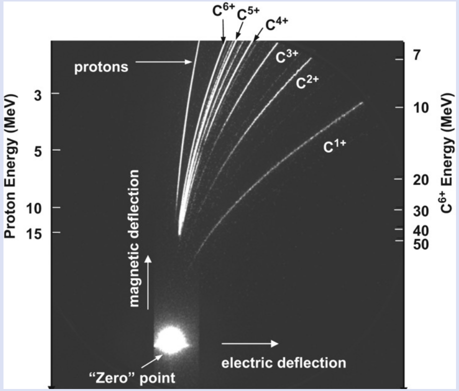


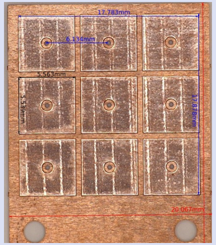
Figure 1. Experimental setup. A Thomson spectrometer deflects the ions onto a piece of plastic scintillator, which is imaged using an EMCCD camera. A second sheet of scintillator images the off-axis portion (>6° off-target normal) of the ion beam.

J.S Green *et al.,* NJP. 12 (2010) 085012

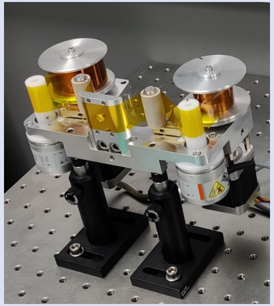


R. Prasad *et al.,* Nucl. Instrum. Methods. 623.2 (2010): 712-715.

Established Targetry…moving toward Hz-level targetry



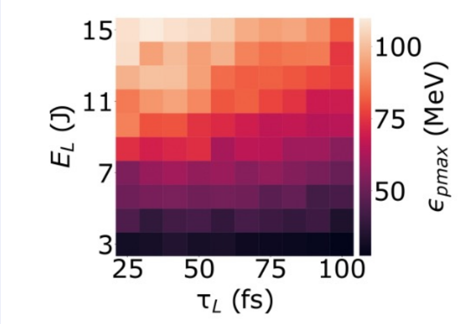
Typical 9-target array



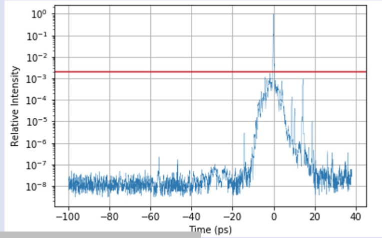
Tape targetry system (online in SCAPA 2022)

….to build a systematic parameter space map of the source performance

- Energy, Flux, Divergence across multiple ion species



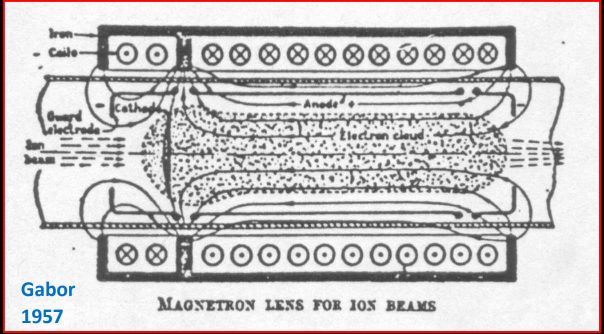
..but also need to consider some other experimental contributions like temporal contrast

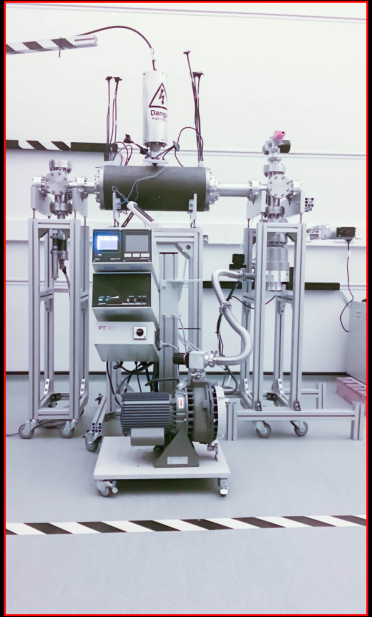


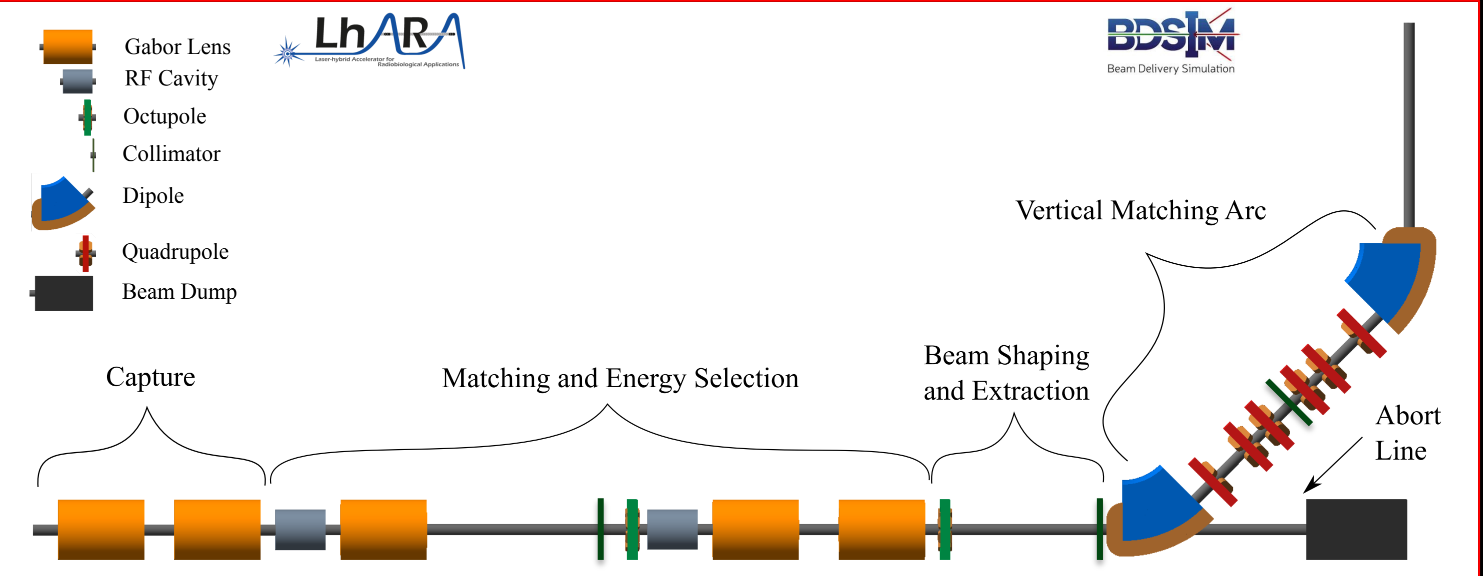
E. Boella, N. Dover, R. Gray, C. Palmer et al

LhARA Capture

- "Electron-plasma" (Gabor) lens:
  - Strong focusing exploiting electron gas in "Penning/Malmberg" trap







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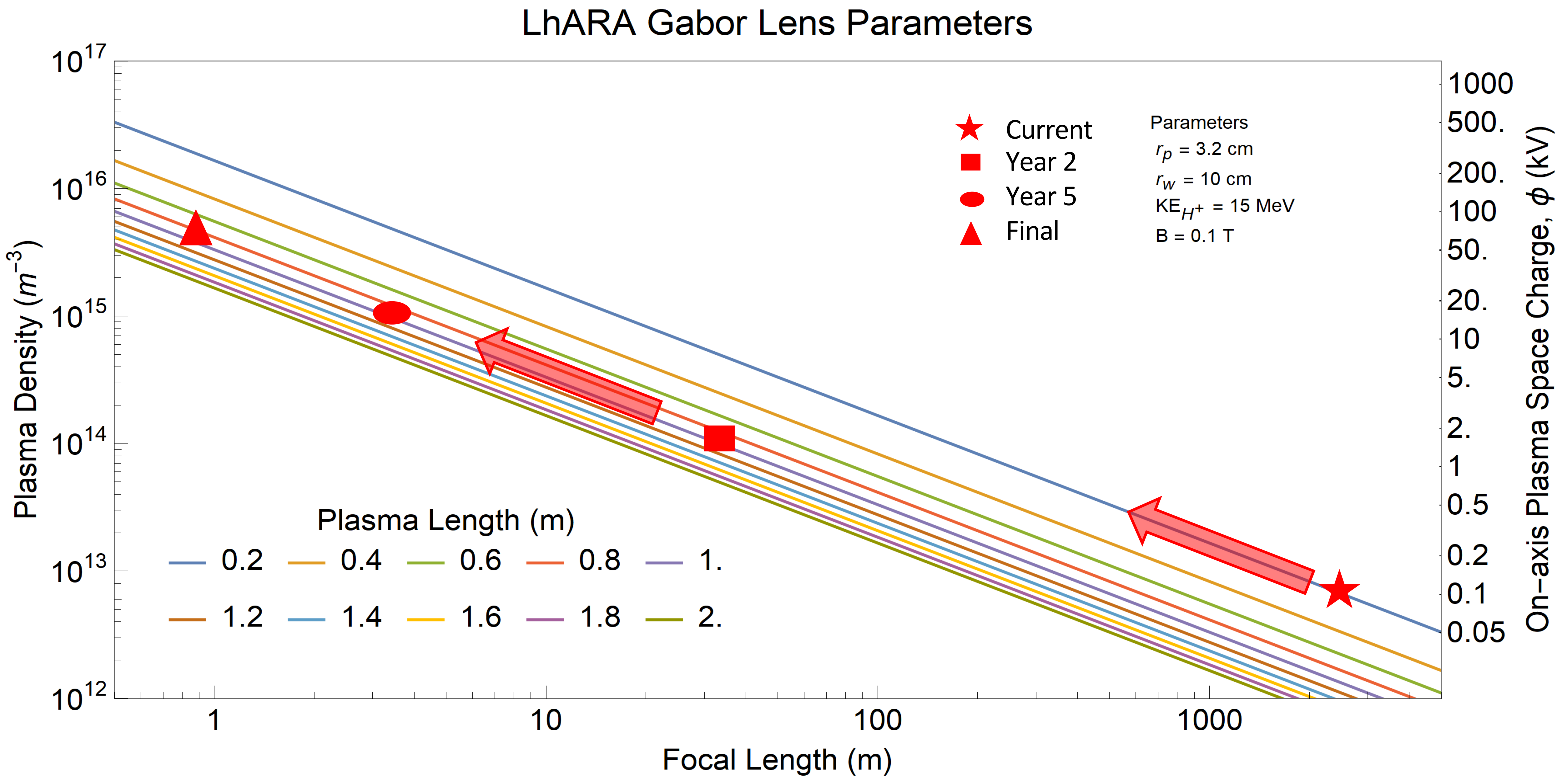
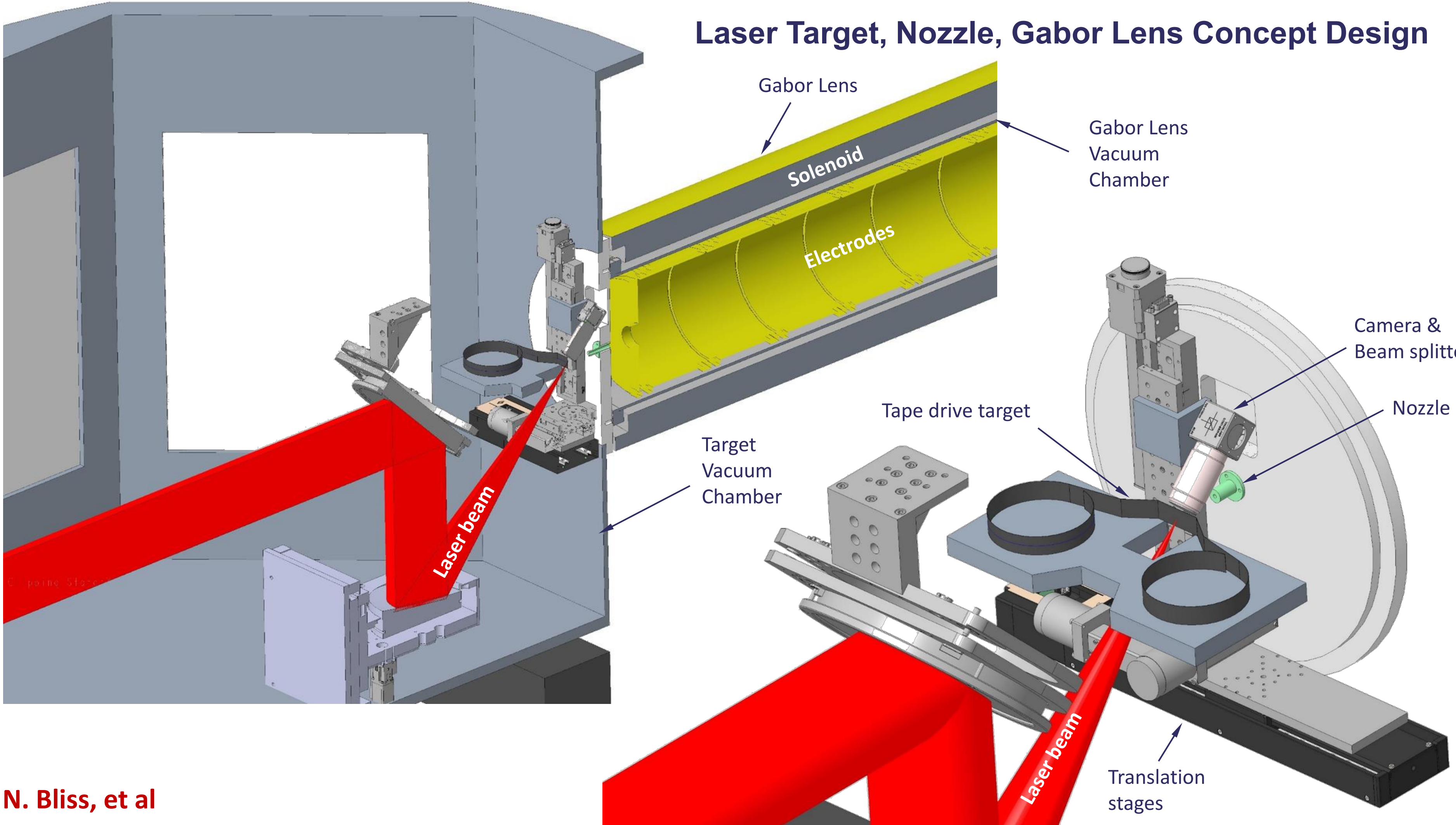
Subsequent 3-year Programme: develop plasma parameters required for LhARA

Year 5 milestone



C. Baker, W. Bertsche et al

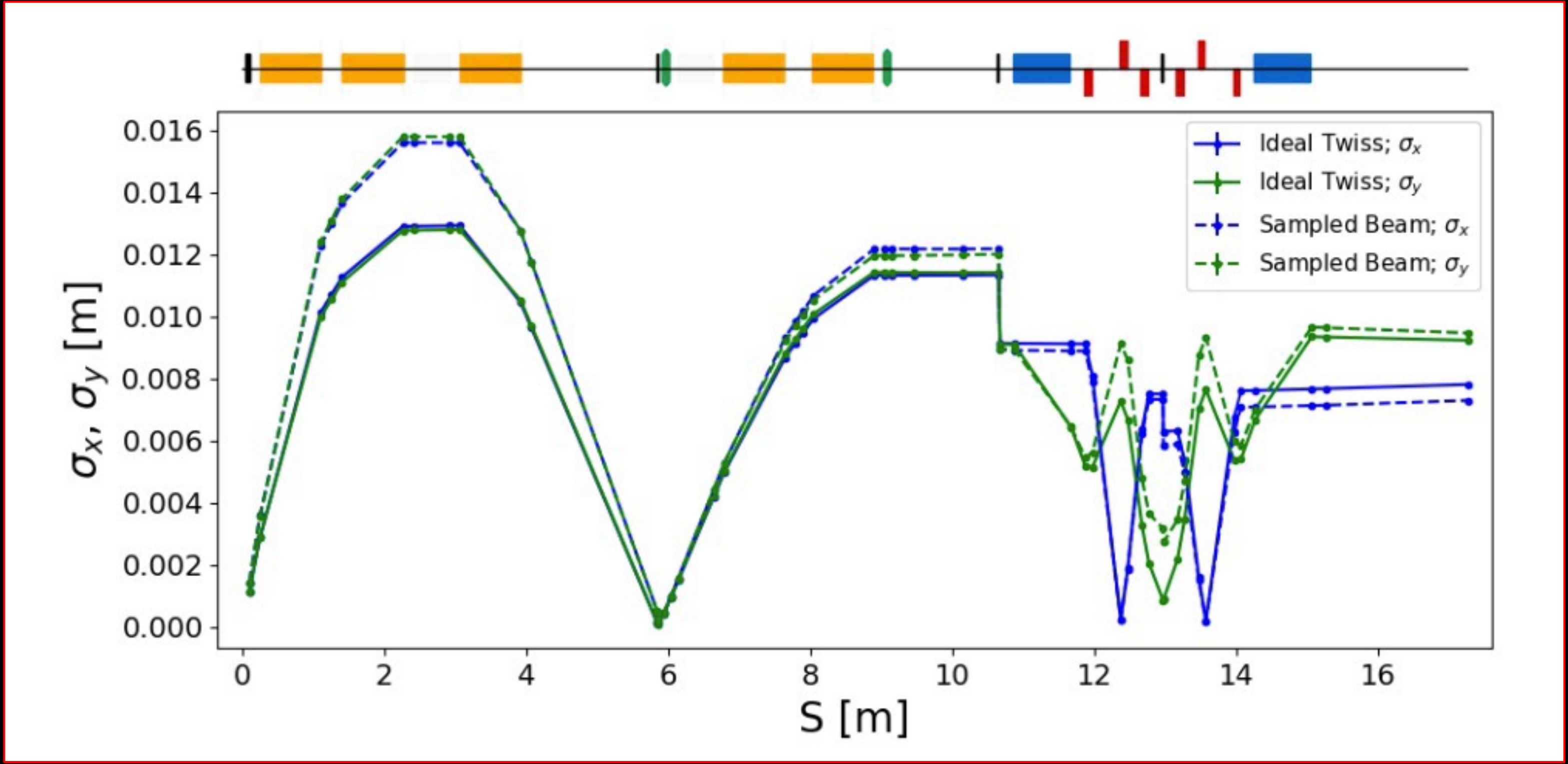
Laser Target, Nozzle, Gabor Lens Concept Design



N. Bliss, et al

J. Pasternak, W. Shields et al

Beam envelopes Stage 1

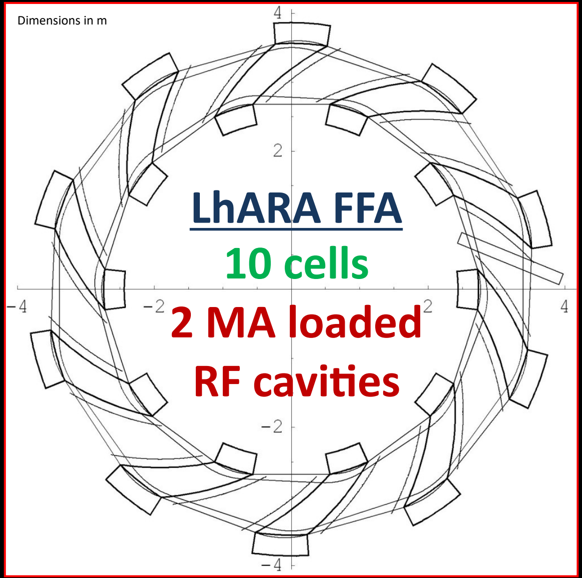


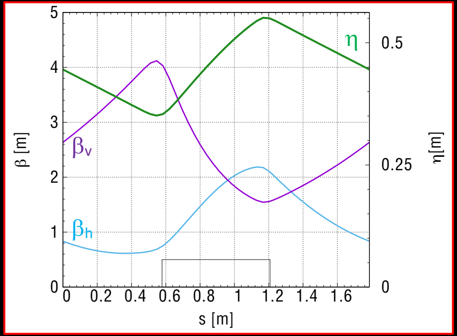
- **Propagation of "semi-realistic" source distribution:**
  - **Optimisation studies on going**

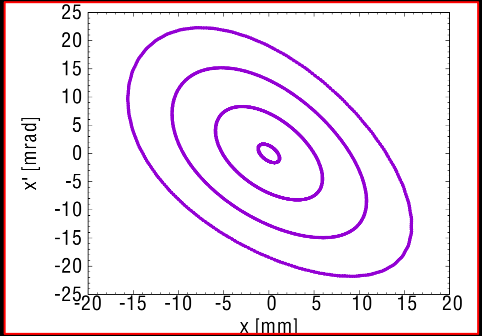
Rapid, flexible acceleration for stage 2

J. Pasternak, W. Shields et al

- Fixed-field alternating-gradient accelerator (FFA):
  - Compact, flexible solution:
    - Multiple ion species
    - Variable energy extraction
    - High repetition rate (rapid acceleration)
    - Large acceptance
  - Successfully demonstrated:
    - Proof of principle at KEK
    - Machines at KURNS
    - Non-scaling PofP EMMA (DL)







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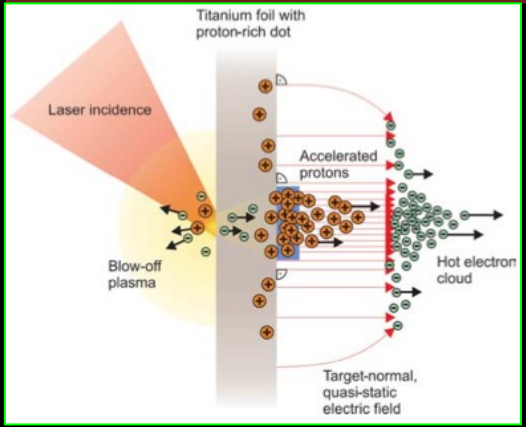

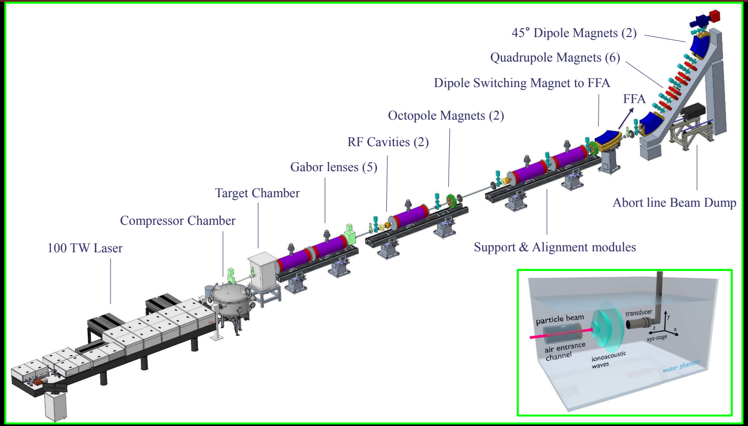

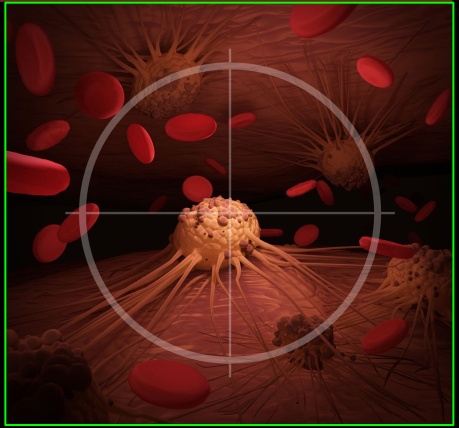

Thank you!