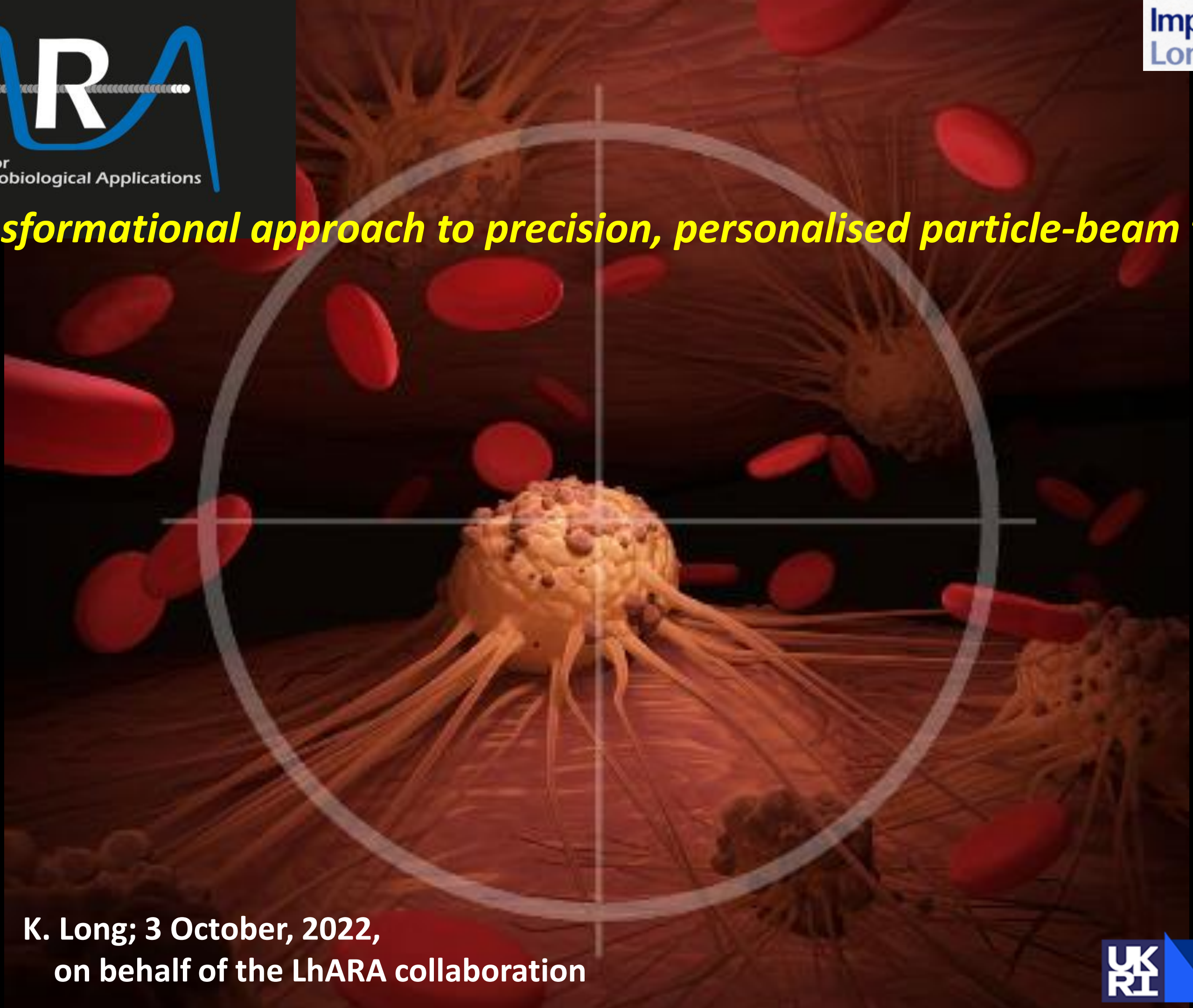
# LhARA

Laser-hybrid Accelerator for Radiobiological Applications

Imperial College London

*a transformational approach to precision, personalised particle-beam therapy*



K. Long; 3 October, 2022,
on behalf of the LhARA collaboration

CCAP
Centre for the Clinical Application of Particles

UKRI Science and Technology Facilities Council

# 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 LhARA initiative

**Vision:**

**Transform clinical practice of proton/ion-beam therapy by creating a fully automated, highly flexible system to harness the unique properties of laser-driven ion beams**

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

CLF central laser facility

ASTeC
Daresbury Laboratory
Particle Physics Department
ISIS Neutron and Muon Source

University of Birmingham | Cyclotron Facility | Positron Imaging Centre

INFN Catania

The Cockcroft Institute of Accelerator Science and Technology

CERN

Corerain 鲲云科技

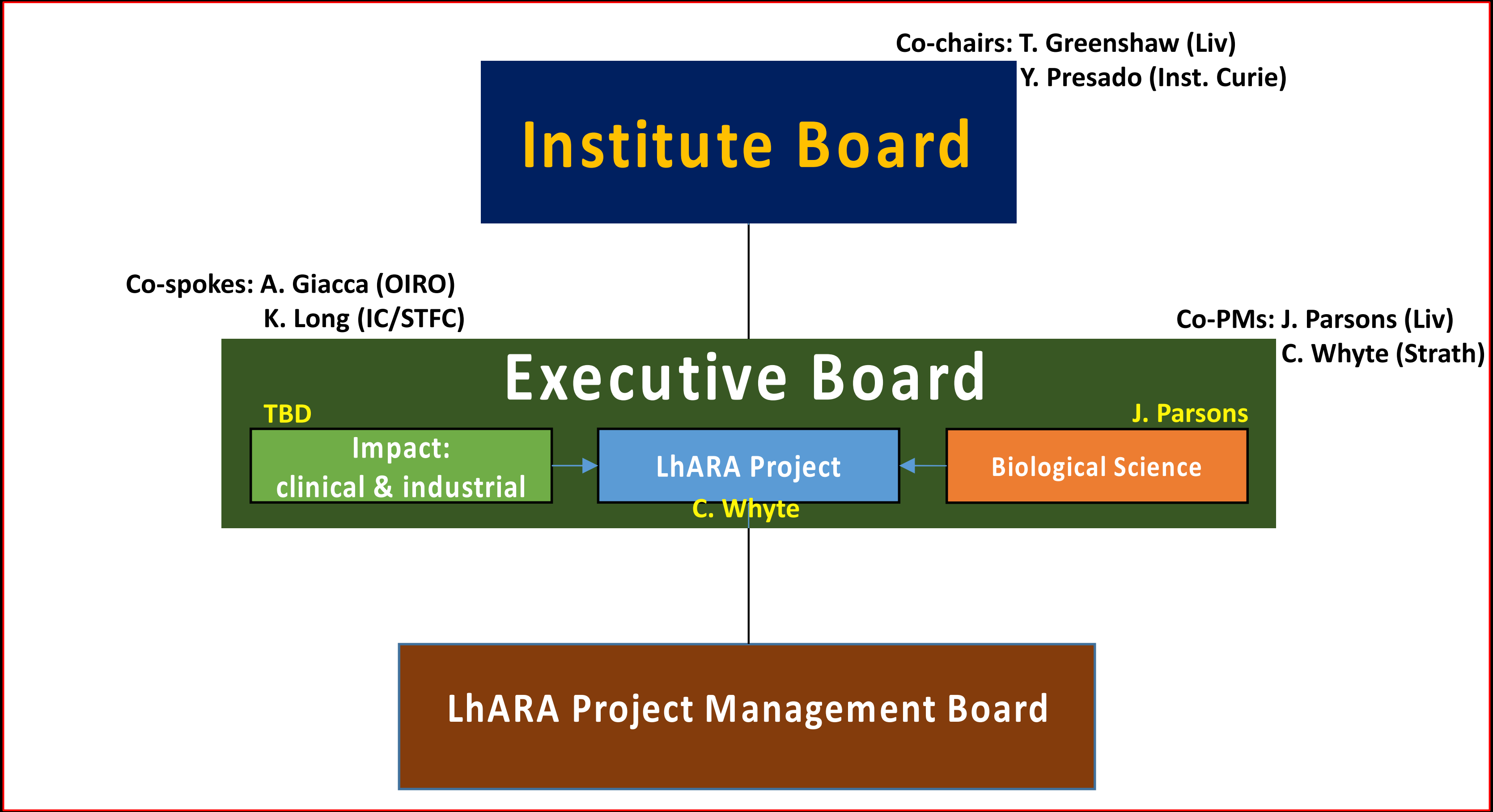
LEO Cancer Care

Maxeler Technologies Maximum Performance Computing

The Rosalind Franklin Institute

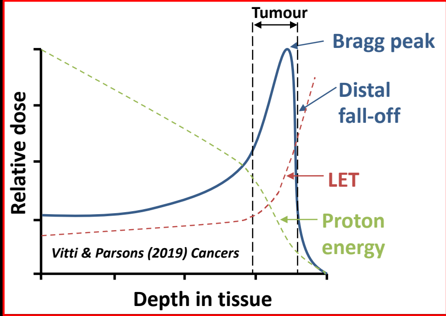
NPL National Physical Laboratory

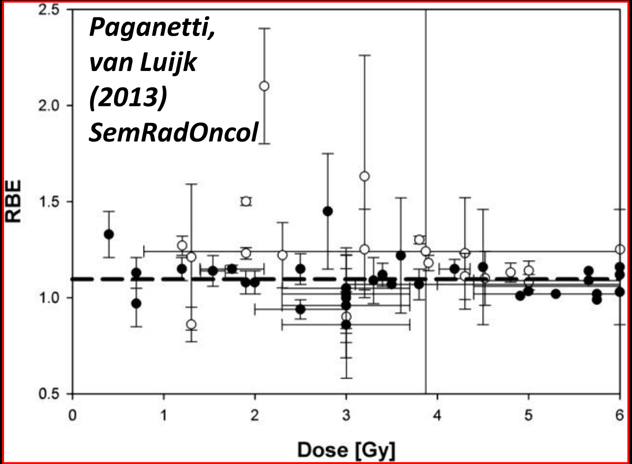
# LhARA initiative Programme org chart

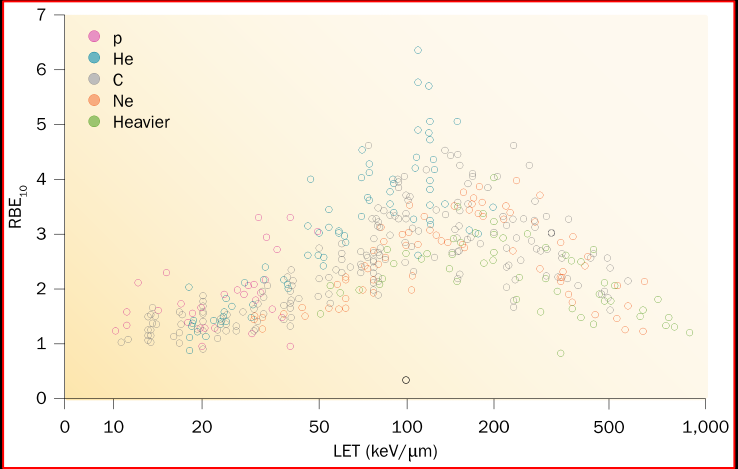


# The case for radiobiology

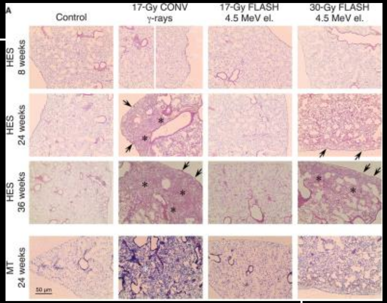
- Relative biological effectiveness:
  - Defined relative to reference X-ray beam
  - Known to depend on:
    - Energy
    - Ion species
    - Dose
    - Dose spatial distribution
    - Dose rate
    - Tissue type
    - Biological endpoint
- Yet:
  - All *p*-treatment planning uses RBE = 1.1
  - Effective values are used for $C^{6+}$
- Maximise the efficacy of PBT now & in future:
  - Systematic programme needed to develop full understanding of radiobiology



# 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

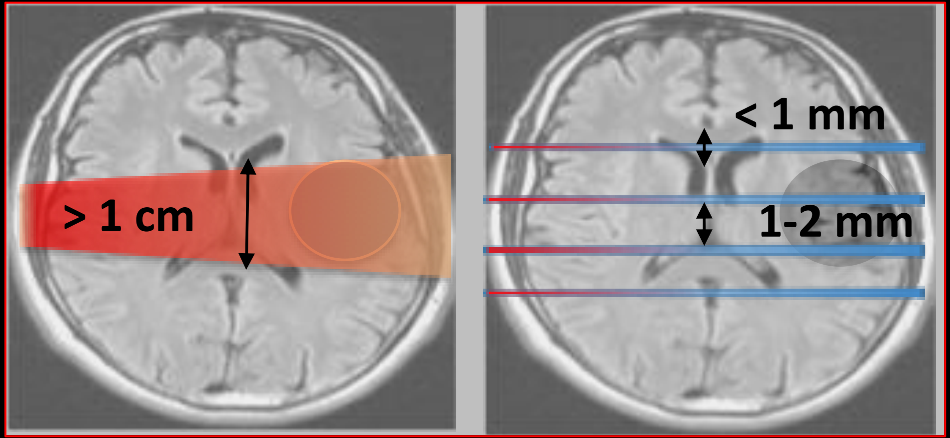
## Time line:

- 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; homogeneous
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 tumour control probability*

# 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

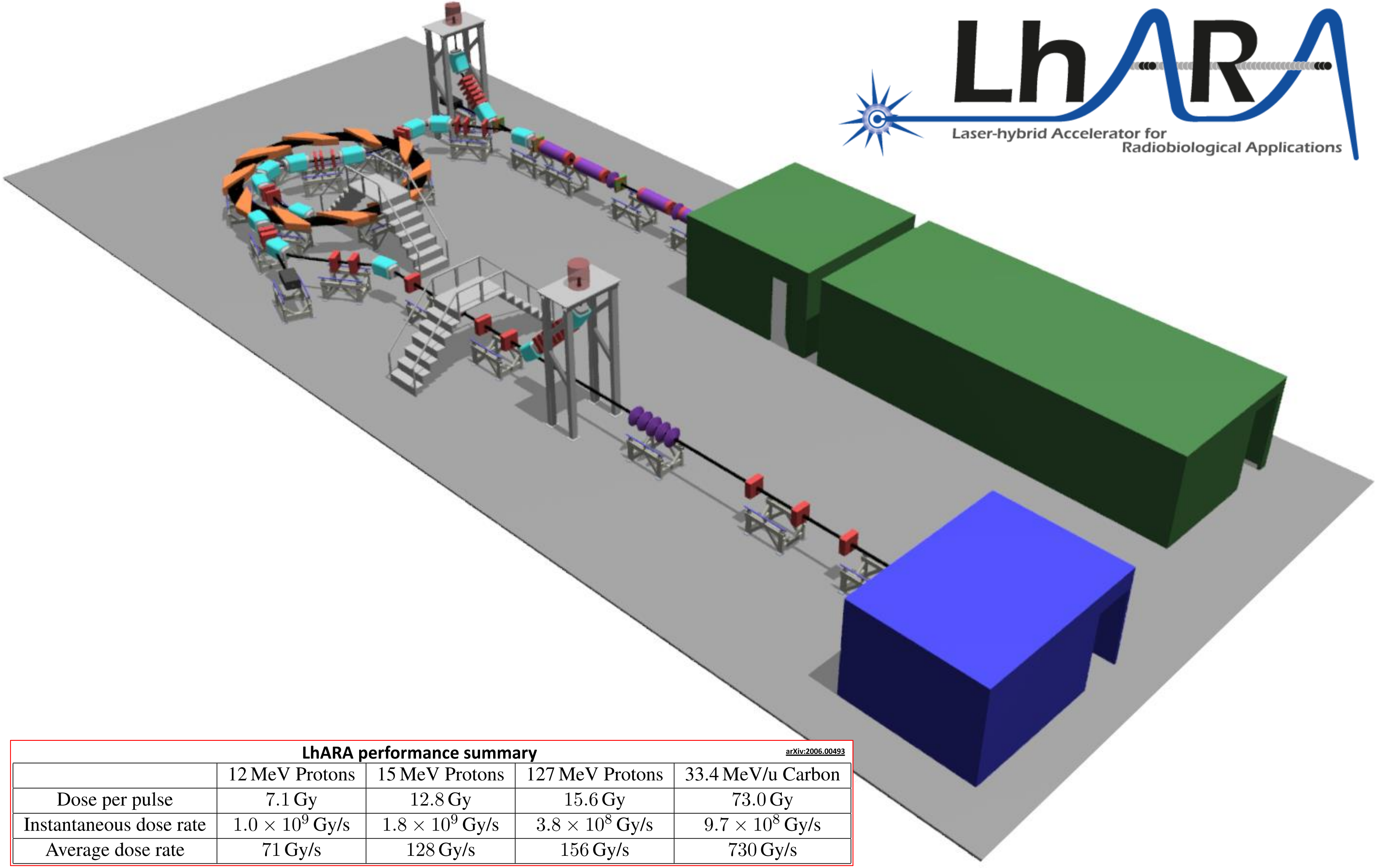
In combination

and with chemo/immuno therapies

# The LhARA collaboration’s present mission

Develop LhARA, serving the ITRF, to:

- Explore the vast “terra incognita” of radiation biology
- Prove the feasibility of the laser-hybrid approach
- Lay the foundations for transformative ion-beam therapy
    - Highly automated, patient-specific; implies:
        - Triggerable source
        - Online imaging
        - Integrated fast feedback and control




**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 | $1.0 \times 10^9$ Gy/s | $1.8 \times 10^9$ Gy/s | $3.8 \times 10^8$ Gy/s | $9.7 \times 10^8$ Gy/s |
| Average dose rate | 71 Gy/s | 128 Gy/s | 156 Gy/s | 730 Gy/s |

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

# Laser-hybrid Accelerator for Radiobiological Applications

***A novel, hybrid, approach:***

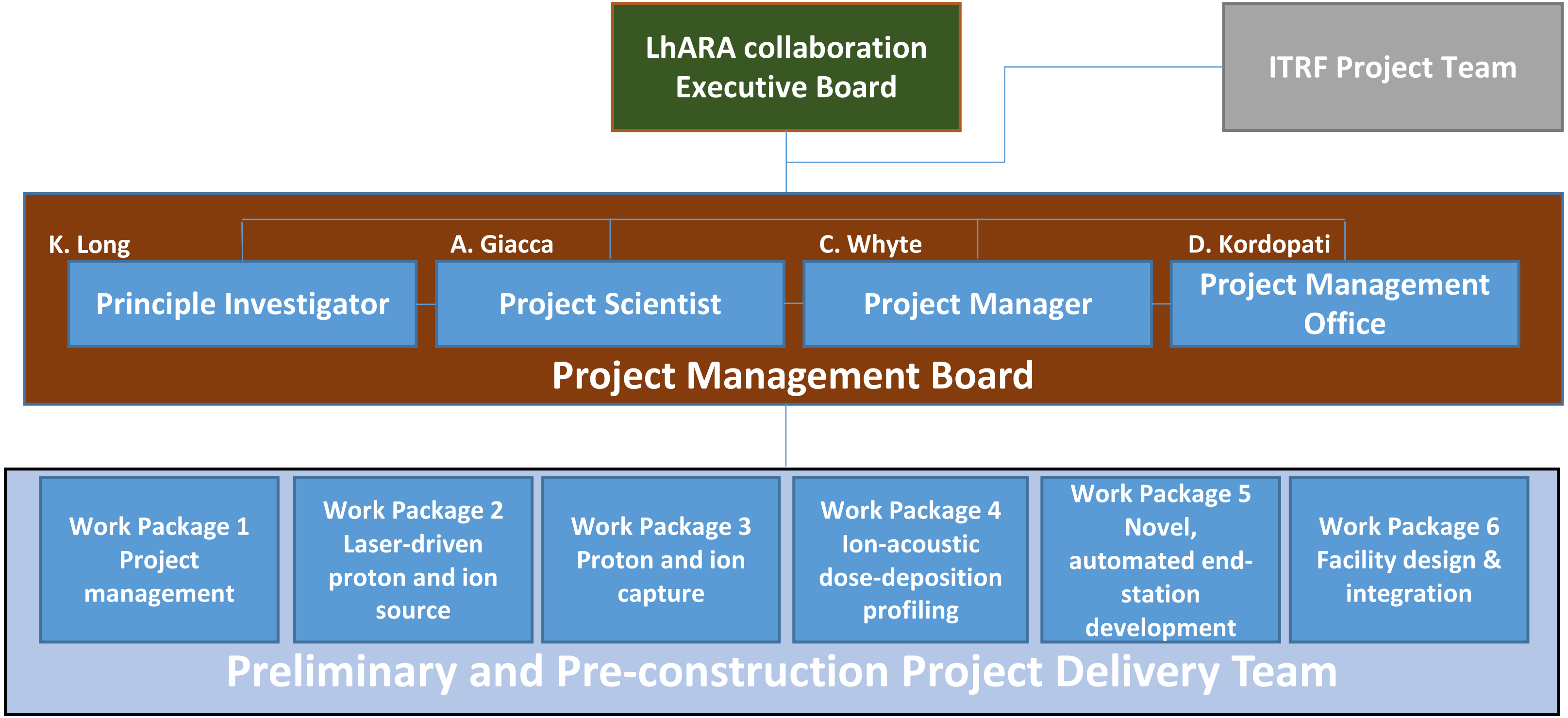
- **Laser-driven, high-flux proton/ion source**
  - **Overcome instantaneous dose-rate limitation**
    - **Capture at >10 MeV**
  - **Delivers protons or ions in very short pulses**
    - **Bunches as short as 10—40 ns**
  - **Triggerable; arbitrary pulse structure**

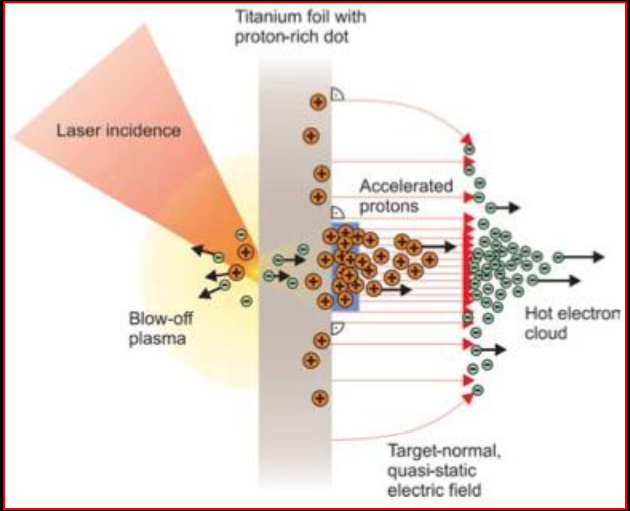
- **Novel "electron-plasma-lens" capture & focusing**
  - **Strong focusing (short focal length) without the use of high-field solenoid**

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

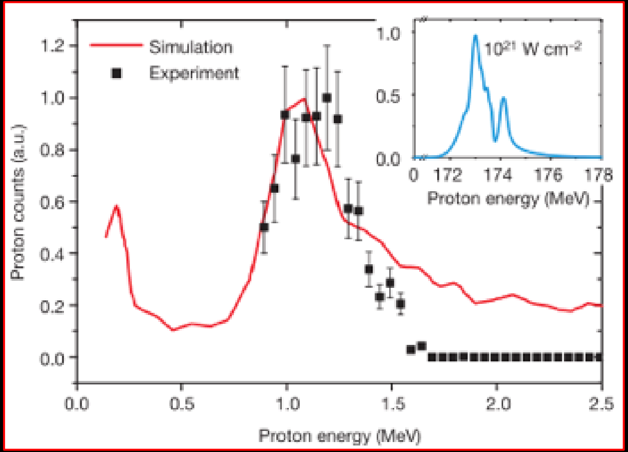
Front. Phys., 29 September 2020; DOI: 10.3389/fphy.2020.567738

# LhARA Project
# Organisational Breakdown Structure






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




# Sheath acceleration

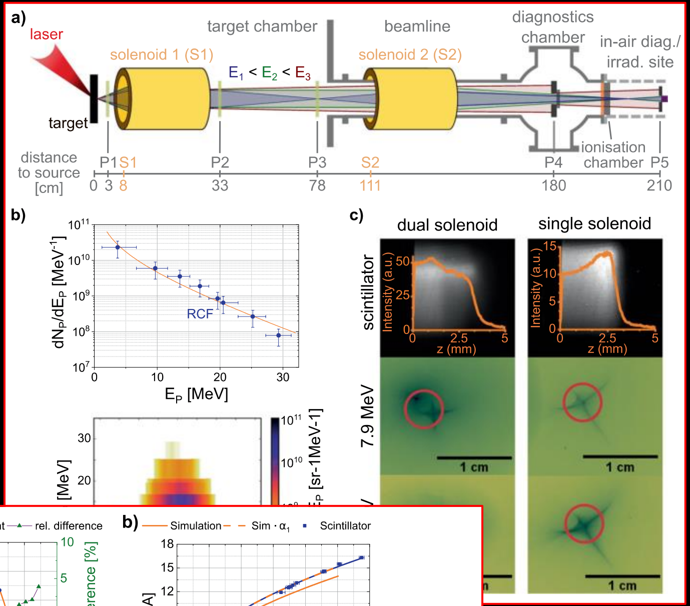
- Laser incident on foil target:
  - Drives electrons from material
  - Creates enormous electric field
- Field accelerates protons/ions
  - Dependent on nature of target
- Active development:
  - Laser: power and rep. rate
  - Target material, transport

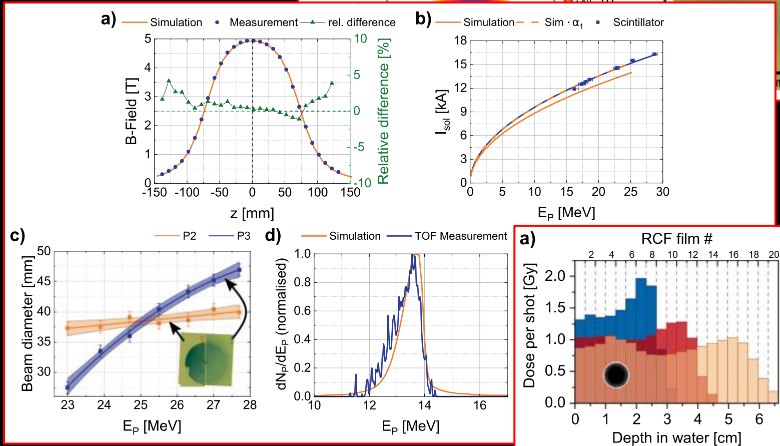
# Laser-driven beams for rbio: example 1

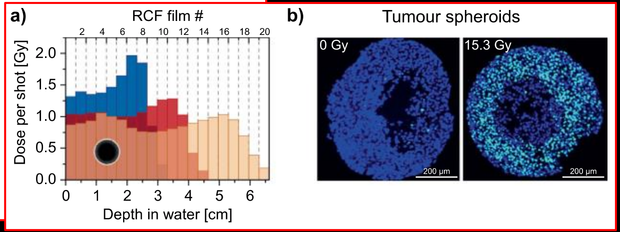
*On Draco @ HZDR*

DOI: 10.1038/s41598-020-65775-7

- **Draco:**
  - **Petawatt laser**
    - **E = 13 J, τ = 30 fs, 3 μm FWHM**
- **Beam line:**
  - **Target Normal Sheath Acceleration (TNSA)**
  - **Pulsed solenoid focusing**
    - **19.5T, 2 or 3 pulses/min.**
    - **S1, S2: 40 mm bore**
    - **Half angle acceptance 14°**
  - **Measured transmission (18.6 MeV *p*)**
    - **50.6% (dual solenoid)**
    - **28.6% (single solenoid)**



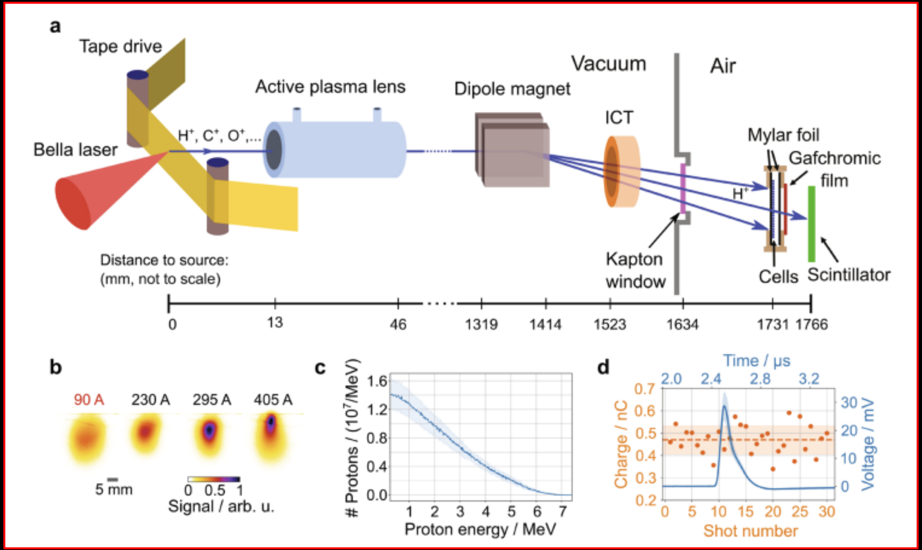



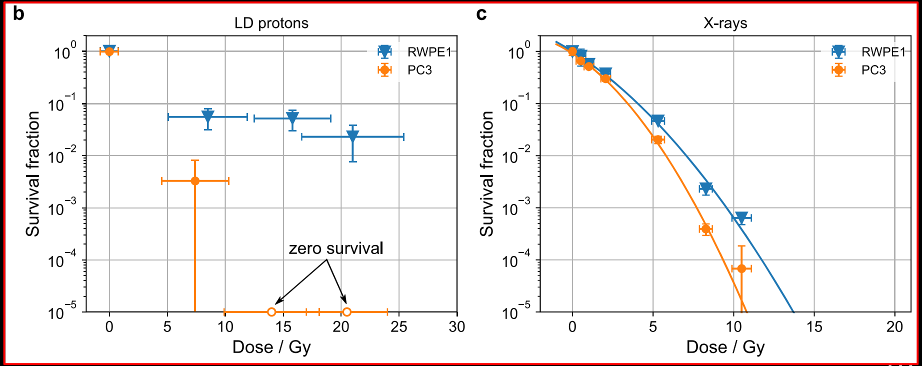
# Laser-driven beams for rbio: example 2

## *On BELLA @ Berkeley*

DOI 10.1038/s41598-022-05181-3

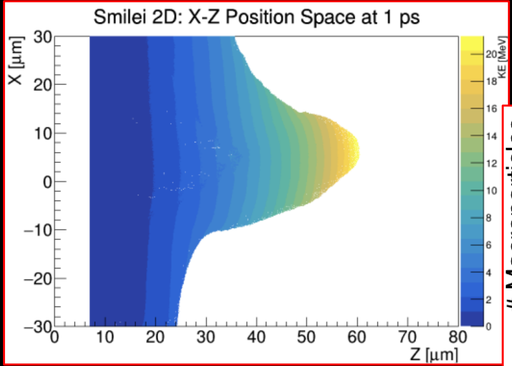
- Berkeley Lab Laser Accelerator (BELLA):
  - Petawatt laser
    - E = 35 J, τ = 35 fs, 52 µm FWHM
- Beam line:
  - Target Normal Sheath Acceleration (TNSA)
  - Active plasma lens focusing
    - 1 mm diameter Ar gas filled capillary
    - 33 mm length
    - 13 mm behind the tape drive target
    - ~0.2% transport efficiency for protons with *E* > 1.5 MeV



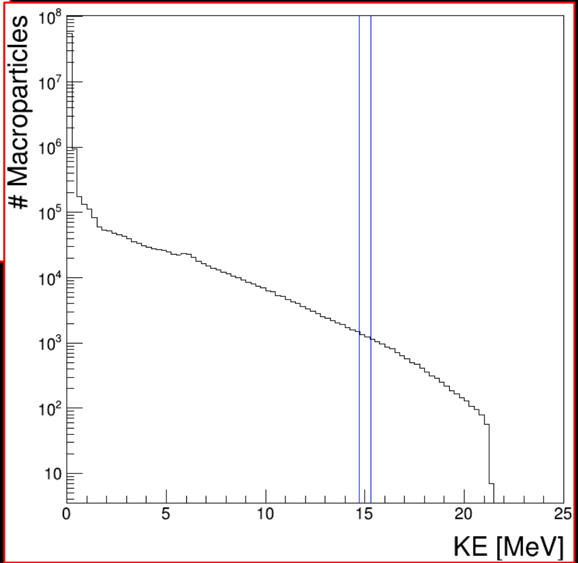



# Laser-driven proton/ion source

- **Commercial laser:**
  - **Motivation: risk management**



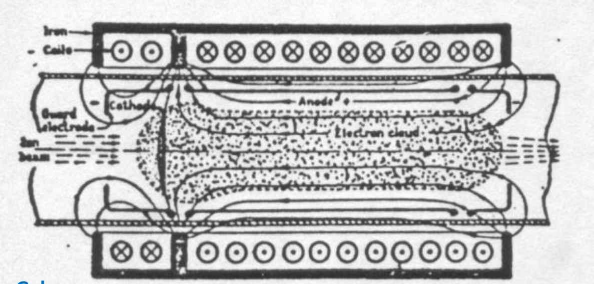

HT Lau
Thesis, 2022



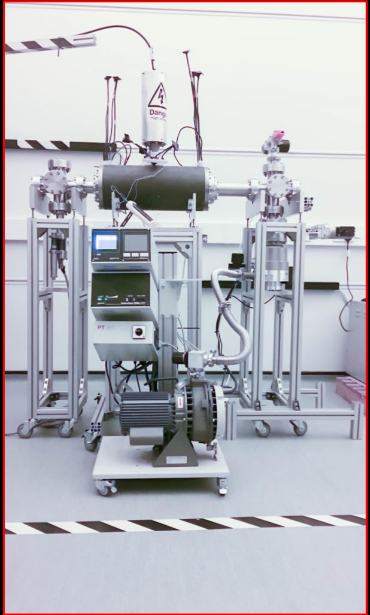

**Ti:Sapphire commercial system > 150 TW**
**Pulse ~35 fs at rep-rate of at least 10Hz**
**At least 500mJ laser energy - $I_L$ ~ $10^{20}$ $Wcm^{-2}$**

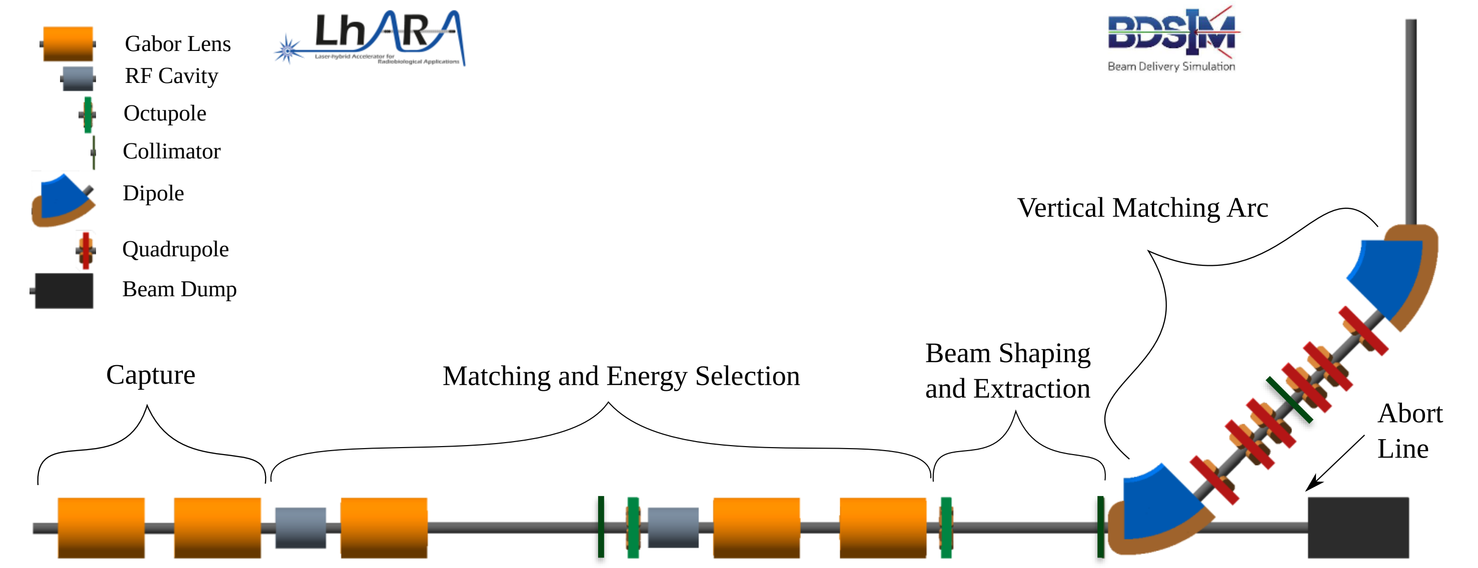
# LhARA Capture

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




Gabor 1957






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

applied sciences
MDPI

*Article*

# Anomalous Beam Transport through Gabor (Plasma) Lens Prototype

**Toby Nonnenmacher [1,*], Titus-Stefan Dascalu [1,*], Robert Bingham [2,3], Chung Lim Cheung [1], Hin-Tung Lau [1], Ken Long [3,4], Jürgen Pozimski [3,4] and Colin Whyte [2]**

1 Department of Physics, Imperial College London, Exhibition Road, London SW7 2AZ, UK; chung.cheung14@imperial.ac.uk (C.L.C.); h.lau17@imperial.ac.uk (H.T.L.)
2 Department of Physics, SUPA, University of Strathclyde, 16 Richmond Street, Glasgow G4 0NG, UK; bob.bingham@stfc.ac.uk (R.B.); colin.whyte@strath.ac.uk (C.W.)
3 STFC Rutherford Appleton Laboratory, Harwell Oxford, Didcot OX11 0QX, UK; k.long@imperial.ac.uk (K.L.); j.pozimski@imperial.ac.uk (J.P.)
4 John Adams Institute for Accelerator Science, Imperial College London, London SW7 2AZ, UK
* Correspondence: toby.nonnenmacher14@imperial.ac.uk (T.N.); t.dascalu19@imperial.ac.uk (T.S.D.)

**Abstract:** An electron plasma lens is a cost-effective, compact, strong-focusing element that can ensure efficient capture of low-energy proton and ion beams from laser-driven sources. A Gabor lens prototype was built for high electron density operation at Imperial College London. The parameters of the stable operation regime of the lens and its performance during a beam test with 1.4 MeV protons are reported here. Narrow pencil beams were imaged on a scintillator screen 67 cm downstream of the lens. The lens converted the pencil beams into rings that show position-dependent shape and intensity modulation that are dependent on the settings of the lens. Characterisation of the focusing effect suggests that the plasma column exhibited an off-axis rotation similar to the $m = 1$ diocotron instability. The association of the instability with the cause of the rings was investigated using particle tracking simulations.

**Keywords:** plasma trap; space-charge lens; beam transport; instability; proton therapy

check for updates

**Citation:** Nonnenmacher, T.; Dascalu, T.S.; Bingham, R.; Cheung, C.L.; Lau, H.T.; Long, K.; Pozimski, J.; Whyte, C. Anomalous Beam Transport through Gabor (Plasma) Lens Prototype. *Appl. Sci.* **2021**, *11*, 4357. https://doi.org/10.3390/app11104357

Academic Editor: Paolo Branchini

Received: 13 April 2021
Accepted: 4 May 2021
Published: 11 May 2021

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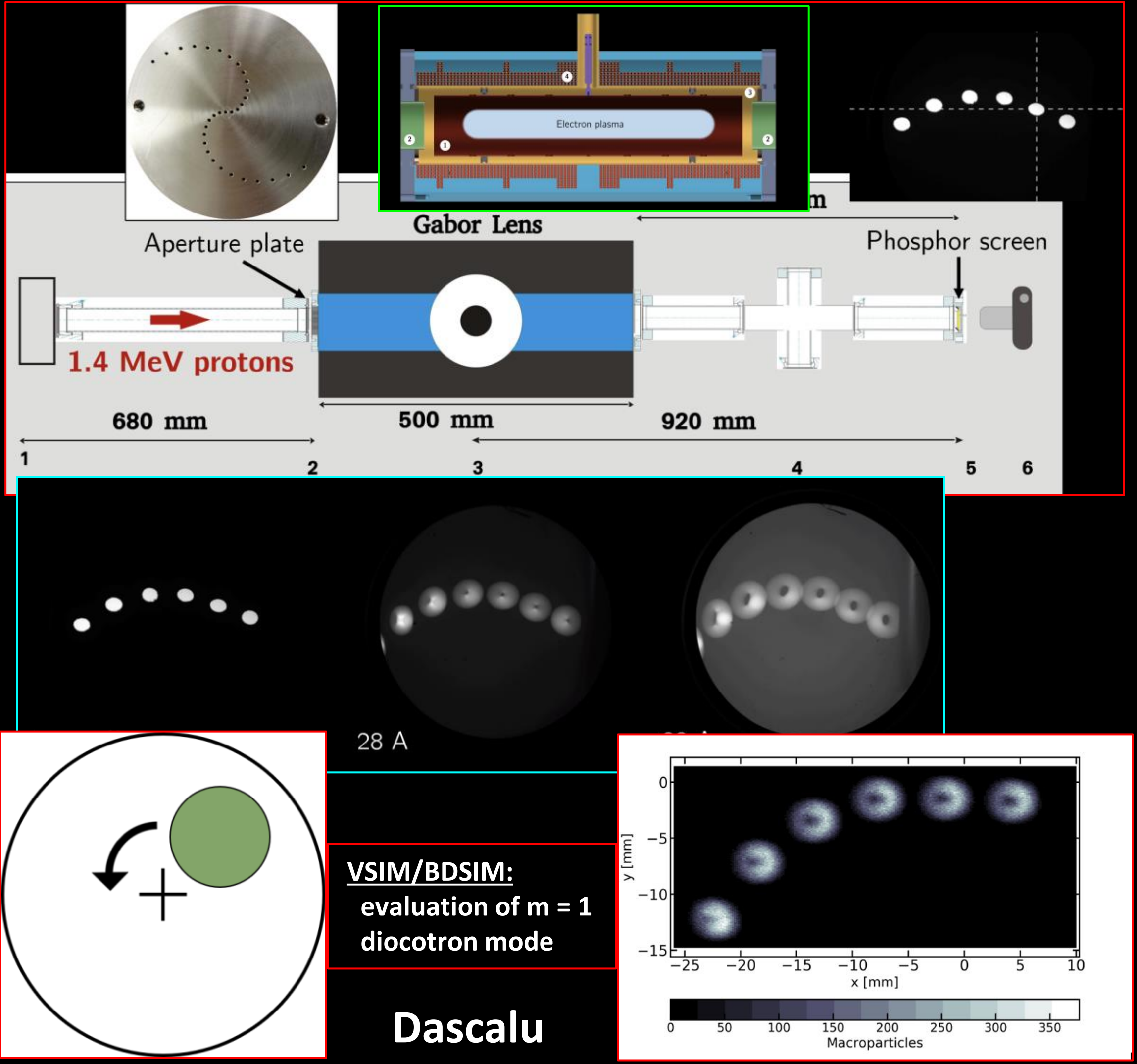
## 1. Introduction

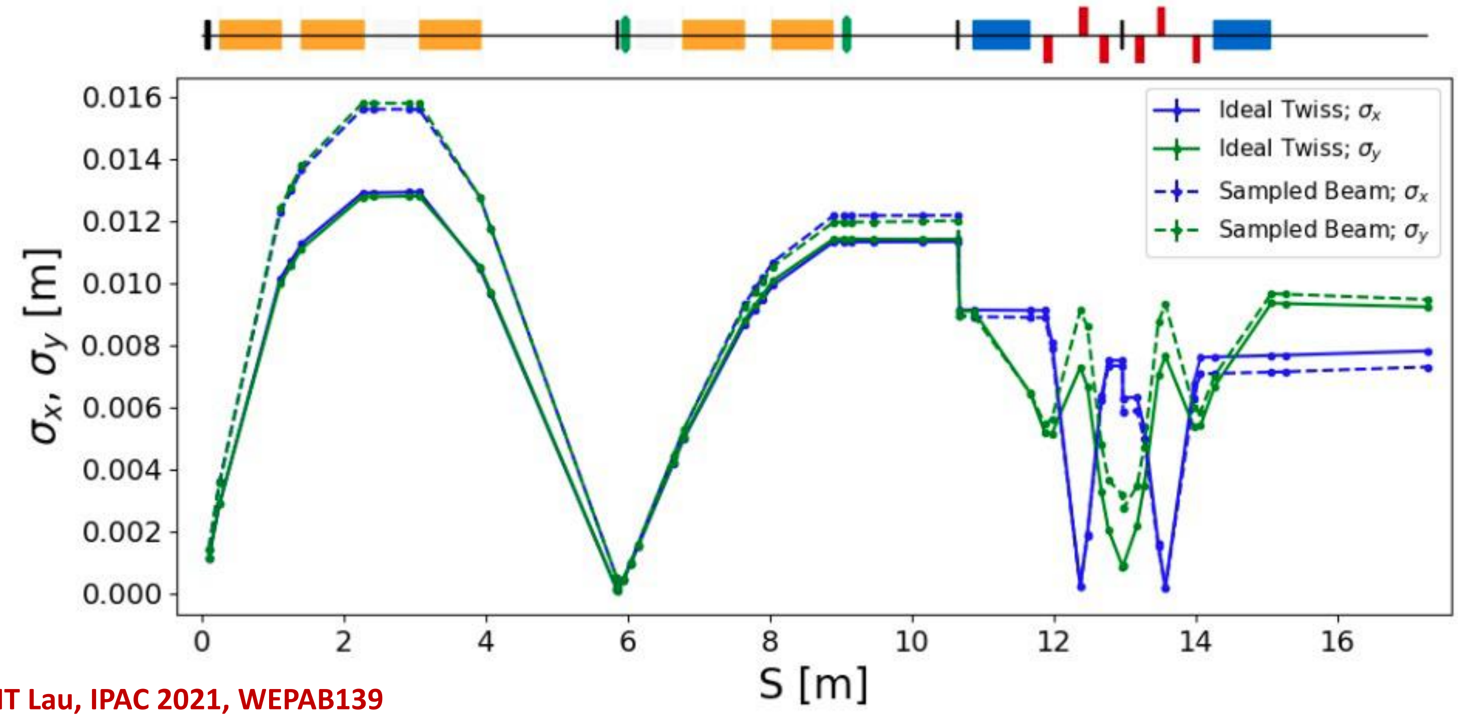
One of the principal challenges that must be addressed to deliver high-flux pulsed proton or positive-ion beams for many applications is the efficient capture of the ions ejected from the source. A typical source produces protons with kinetic energies of approximately 60 keV [1–3] and ions with kinetic energies typically below 120 keV [4,5]. At this low energy the mutual repulsion of the ions causes the beam to diverge rapidly. Capturing a large fraction of this divergent flux therefore requires a focusing element of short focal length. Proton- and ion-capture systems in use today employ magnetic, electrostatic, or radio frequency quadrupoles, or solenoid magnets to capture and focus the beam [2,6–8].

Laser-driven proton and ion sources are disruptive technologies that offer enormous potential to serve future high-flux, pulsed beam facilities [9–16]. Possible applications include proton- and ion-beam production for research, particle-beam therapy, radio-nuclide production, and ion implantation. Recent measurements have demonstrated the laser-driven production of large ion fluxes at kinetic energies in excess of 10 MeV [17–20]. The further development of present technologies and the introduction of novel techniques [21,22] makes it conceivable that significantly higher ion energies will be produced in the future [13,23,24]. By capturing the laser-driven ions at energies two orders of magnitude greater than those pertaining to conventional sources, it will be possible to evade the current space-charge limit on the instantaneous proton and ion flux that can be delivered. While in some situations the high divergence of laser-driven ion beams can be reduced [25,26], for the tape-drive targets proposed for medical beams [16,20] it necessary to capture the beam using a strong-focusing element as close to the ion-production point as possible.





# Beam envelopes Stage 1

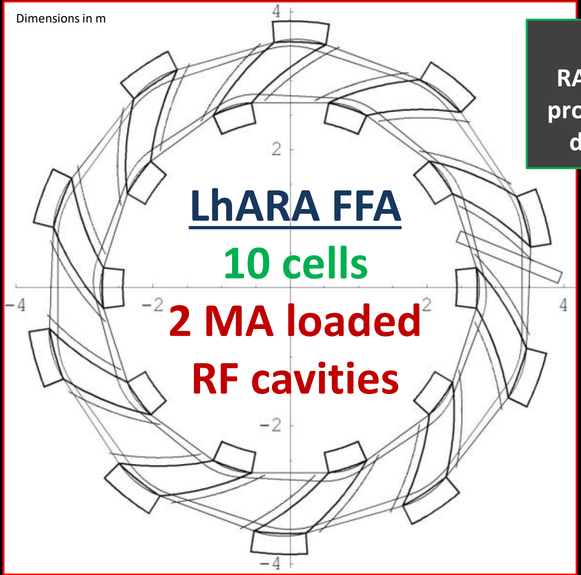



HT Lau, IPAC 2021, WEPAB139

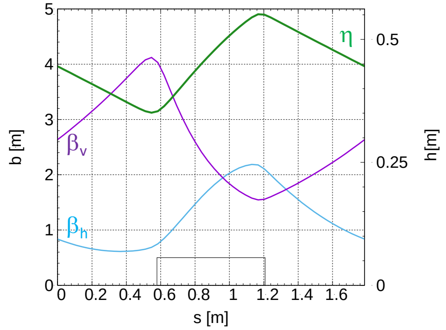
- **Propagation of "semi-realistic" source distribution:**
  - **Generated using SMILEI**
  - **Optimisation studies on going**

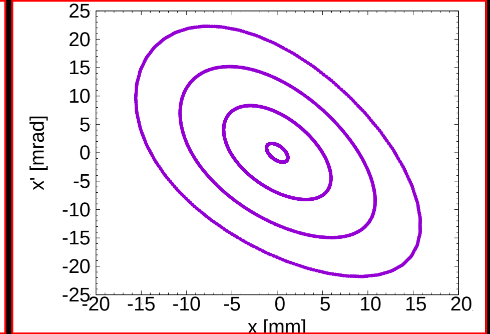
# Rapid, flexible acceleration for stage 2

- **Fixed-field alternating-gradient accelerator (FFA):**
  - Invented in 1950s
    - Kolomensky, Okhawa, Symon
  - 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)




Evolution of RACCAM design; prototype magnet demonstrated



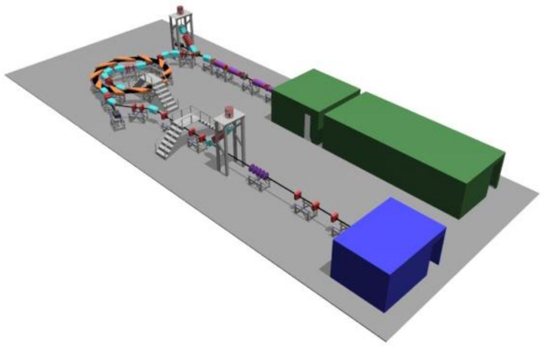

Front. Phys., 29 September 2020; DOI: 10.3389/fphy.2020.567738

# LhARA @ the *Ion Therapy Research Facility*

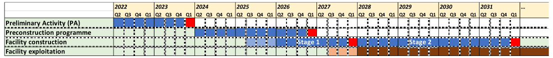
J, Clark, M. Noro, A. Woodcock 14Jun21

## Ion Therapy Research Facility

**1. Schematic diagram of the Ion Therapy Research Facility**



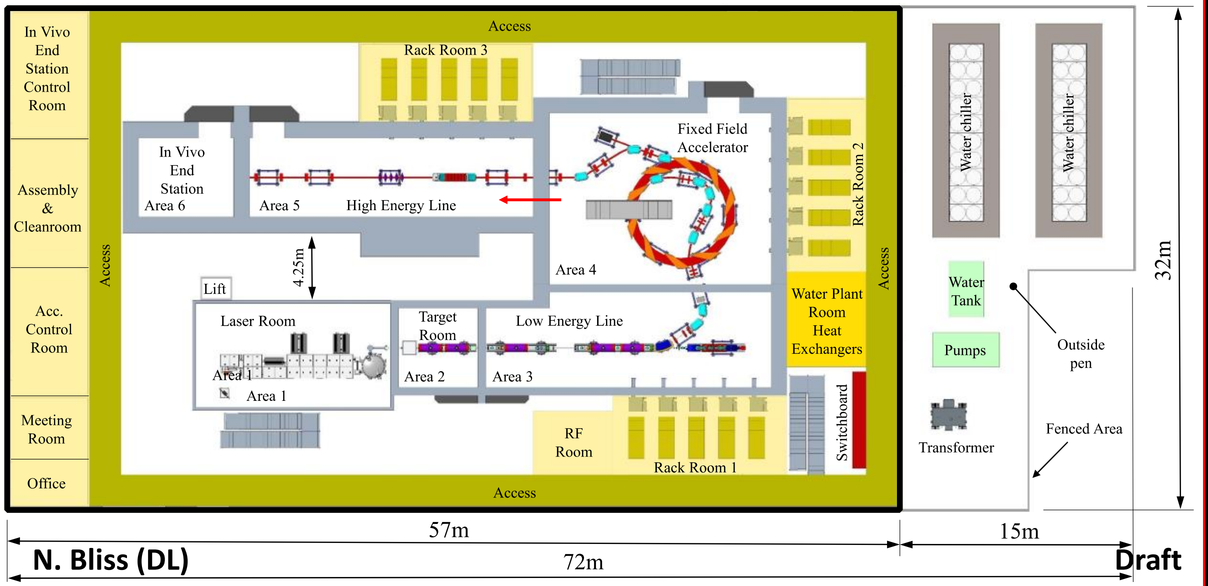
**2. ITRF development timeline**

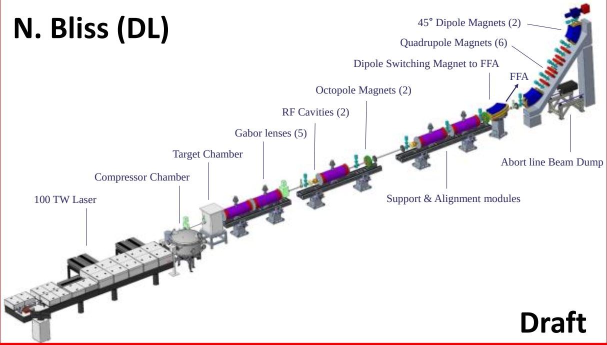


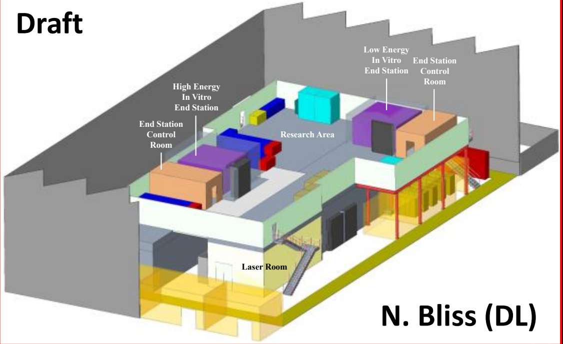

**3. Institutes that make up the ITRF collaboration**

Partners: University, Clinical, Laboratory, Industry, Accelerator

**Submitted to UKRI Infrastructure Advisory Committee**
**14 June 2021**



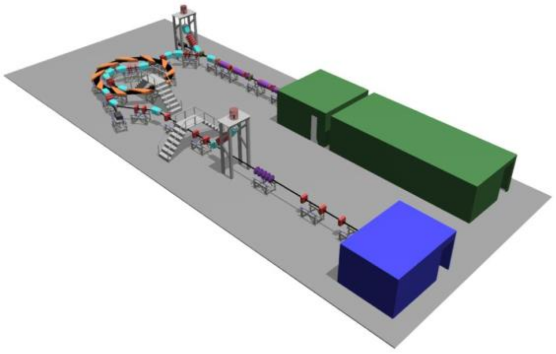



# Proposal for LhARA contributions to Preliminary Activity and ITRF Preconstruction Phase

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

## Ion Therapy Research Facility

**1. Schematic diagram of the Ion Therapy Research Facility**



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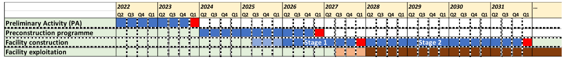



**3. Institutes that make up the ITRF collaboration**

## *Finalised 01Jun22: CCAP-TN-10*

June 1, 2022 CCAP-TN-10 (2022)

### The Laser-hybrid Accelerator for Radiobiological Applications

*R&D proposal for the preliminary, pre-construction phases*

The LhARA collaboration


P. Allport[1], A. Aymar[2], C. J. Baker[3], J. Bamber[4], P. Beard[5], T. Becker[6], S. Benson[7], A. Beqiri[8], W. Bertsche[9,10], R. Bingham[11,12], N. Bliss[13], E. Boella[14,10], S. Boogert[15,16], M. Borghesi[17], P.N. Burrows[18,19], A. Carabe[20,21], M. Charlton[3], J. Clarke[13], B. Cox[5], T.S. Dascalu[22], M. Dosanjh[23,18], N.P. Dover[24,22], S. Eriksson[3], O.C. Ettlinger[24,22], A. Giaccia[25,26], S. Gibson[15,16], R. Gray[11], S. Green[27], T. Greenshaw[28], D. Gujral[29], H.C. Hall[30], E.M. Hammond[25], C. Hardiman[31], E.J. Harris[4], L. Holland[32], A. Howard[24], W.G. Jones[24,30], K.J. Kirkby[33,34], A. Kirkland[32,35], A. Knoll[36], T. Kokalova[1], D. Kordopati[24], T.J. Kuo[22], A. Kurup[22,2], J.B. Lagrange[2], H.T. Lau[24], K.R. Long[24,22,37], W. Luk[38], A.E. MacIntosh-LaRocque[24], R. Mamutov[39,40], T. Masilela[41,42], J. Matheson[37], M. Maxouti[22,37], J.M. McGarrigle[24,41], P. McKenna[11,43], R. McLauchlan[31,24], I. McNeish[44], M. Merchant[33], Z. Najmudin[24,22], S.R. O'Neill[14], U. Oelfke[4], H. Owen[13], C. Palmer[17], J.L. Parsons[45,46], J. Pasternak[22,2], H. Poptani[47], J. Pozimski[24,22,2], Y. Prezado[41,42], P. Price[44], T. Price[1], K.M. Prise[48], P.P. Rajeev[12], P. Ratoff[14,10], C. Rogers[2], F. Romano[49], G. Schettino[50,51], W. Shields[15], R.A. Smith[24], D. Spiers[11,43], R. Taylor[22], J. Thomason[2], S. Towe[52], P. Weightman[28], C.P. Welsch[28,10], C. Wheldon[1], C. Whyte[11,43], R. Xiao[53]

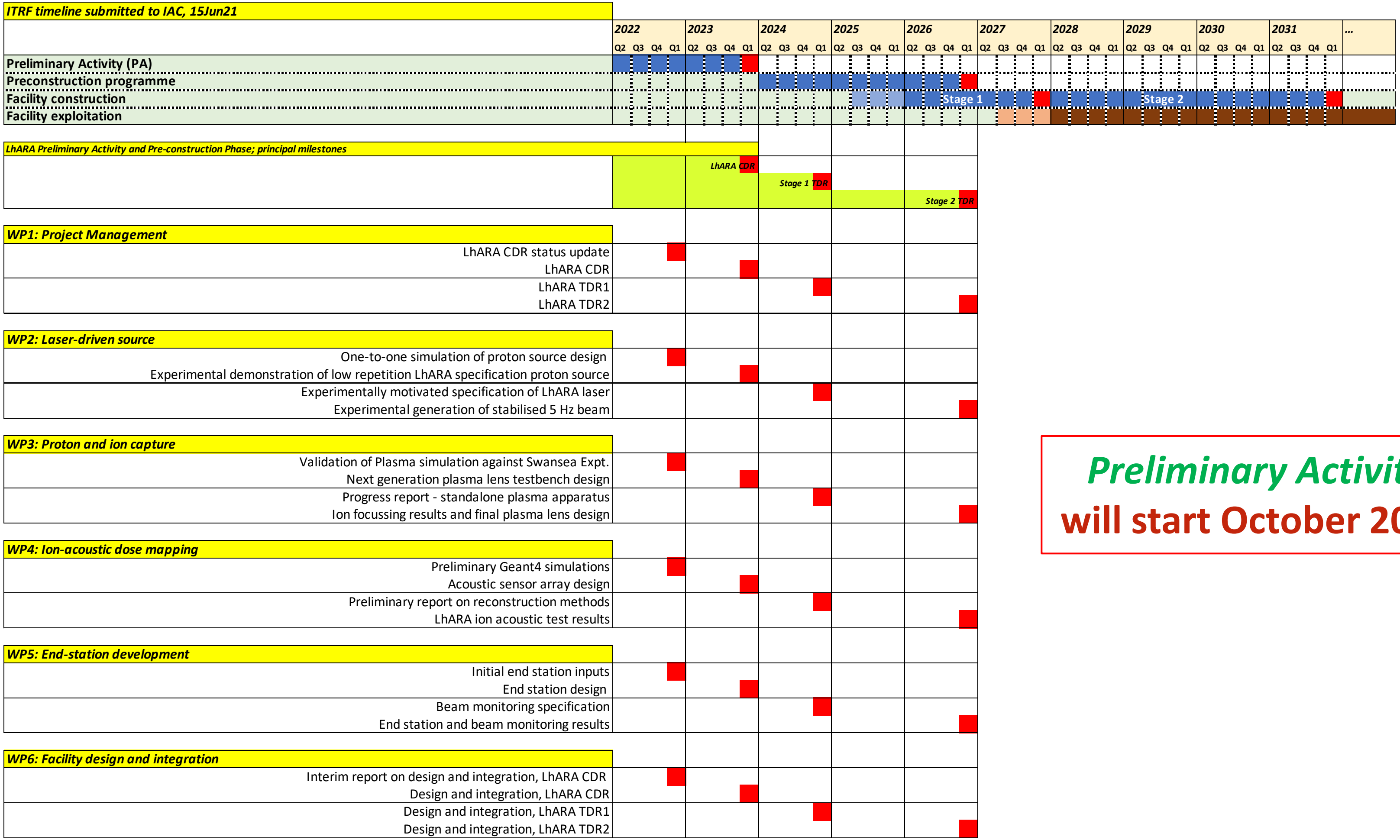
1 *School of Physics and Astronomy, University of Birmingham, Edgbaston, Birmingham, B15 2TT, UK*
2 *ISIS Neutron and Muon Source, STFC Rutherford Appleton Laboratory, Harwell Oxford, Didcot OX11 0QX, UK*
3 *Department of Physics, Faculty of Science and Engineering, Swansea University, Singleton Park, Swansea, SA2 8PP*
4 *The Institute of Cancer Research, 123 Old Brompton Road, London, SW7 3RP, UK*
5 *Dept of Medical Physics and Biomedical Engineering, University College London, WC1E 6BT, UK*
6 *Maxeler Technologies Limited, 3 Hammersmith Grove, London W6 0ND, UK*
7 *Department of Radiology, Netherlands Cancer Institute-Antoni Van Leeuwenhoek, Amsterdam, The Netherlands*
8 *Faculty of Mechanical Engineering, Ss. Cyril and Methodius University, Ruger Boshkovikj, Skopje 1000, Republic of North Macedonia*
9 *Department of Physics and Astronomy, The University of Manchester, Oxford Rd, Manchester, M13 9PL, UK*
10 *Cockcroft Institute, Daresbury Laboratory, Sci-Tech Daresbury, Keckwick Ln, Daresbury, Warrington UK*
11 *Department of Physics, SUPA, University of Strathclyde, John Anderson Building, 107 Rottenrow East, Glasgow G4 0NG, UK*
12 *Central Laser Facility, STFC Rutherford Appleton Laboratory, Harwell Oxford, Didcot OX11 0QX, UK*
13 *STFC Daresbury Laboratory, Daresbury, Cheshire, WA4 4AD, UK*
14 *Department of Physics, Lancaster University, Bailrigg, Lancaster LA1 4YW, UK*
15 *Department of Physics, Royal Holloway University of London, Egham, Surrey, TW20 0EX, UK*
16 *John Adams Institute, Department of Physics, Royal Holloway, University of London, Egham, TW20 0EX, UK*
17 *School of Mathematics and Physics, Queen's University Belfast, University Road, Belfast, BT7 1NN, Northern Ireland, UK*
18 *John Adams Institute, University of Oxford, Keble Rd, Oxford, OX1 3RH.*
19 *Particle Physics, Denys Wilkinson Building, Keble Rd, Oxford, OX1 3RH*
20 *Department of Medical Physics, Hampton University Proton Therapy Institute, Hampton, VA 23666*
21 *Hampton University*
22 *John Adams Institute for Accelerator Science, Imperial College London, London SW7 2AZ, UK*
23 *DG Unit, CERN, CH-1211 Geneva 23, Switzerland*


## To serve ITRF: 2 + 3-year project in 6 work packages:

1. Project Management
2. Laser-driven proton and ion source
3. Proton and ion capture
4. Real-time dose-deposition profiling
5. Novel, automated, end-station development
6. Facility design and integration

**Requested resources for 2-year preliminary phase;**
**Identified need for further 3-year preconstruction phase**

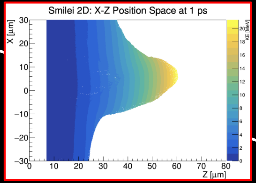
# Preliminary & Preconstruction Phase proposal summary

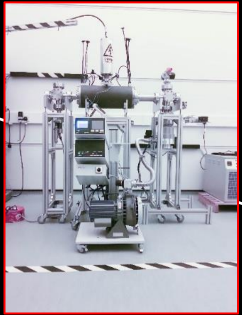


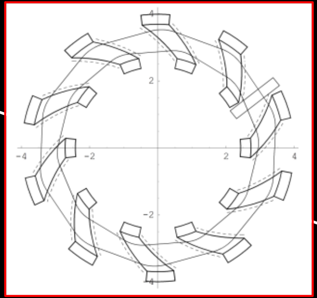

***Preliminary Activity***
**will start October 2022**

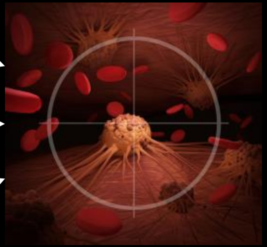
CCAP
Centre for the Clinical Application of Particles

Novel accelerator techniques



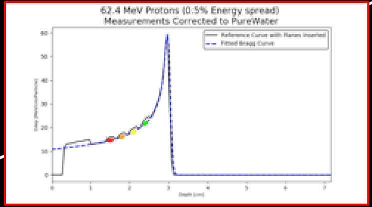







System: image processing
fast feedback, control

Fundamental
biology & biochemistry




LhARA
Laser-hybrid Accelerator for Radiobiological Applications

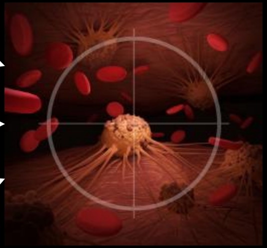
# Conclusions

- Laser-driven sources are disruptive technologies …
  - With the potential to drive a step-change in clinical capability
- 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; time; and spatial distribution
  - Be used in automated, triggerable *system* → reduce requirement for large gantry
    - Disruptive/transformative approach to "distributed PBT for 2050"
- By serving the ITRF, the LhARA collaboration now seeks to:
  - Prove the novel laser-hybrid systems in operation
  - Contribute to the study of the biophysics of charged-particle beams
    - Enhance treatment planning
  - Create novel capabilities to 'spin back in' to science and innovation

Novel accelerator techniques

System: image processing
fast feedback, control

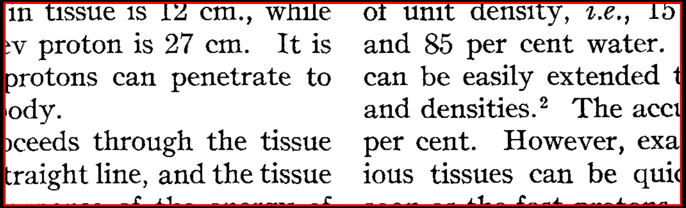
Fundamental
Biology & biochemistry



# Hadron beams for radiation therapy

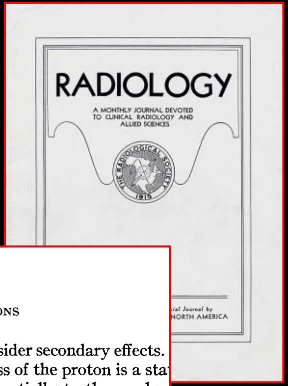
Robert R. Wilson

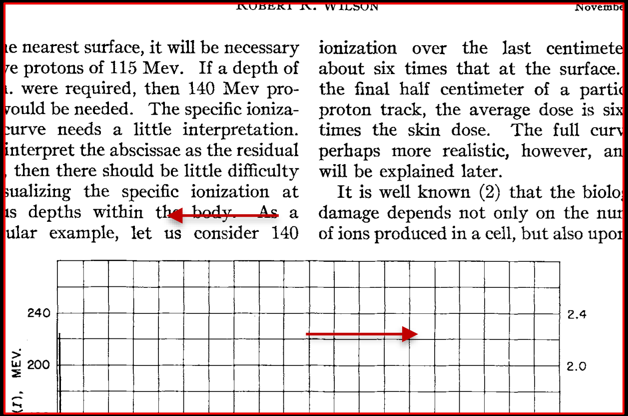
Radiology 47:487–91 (1946)



in tissue is 12 cm., while
ev proton is 27 cm. It is
protons can penetrate to
ody.
oceeds through the tissue
traight line, and the tissue

of unit density, *i.e.*, 15
and 85 per cent water.
can be easily extended t
and densities.[2] The accu
per cent. However, exa
ious tissues can be quic



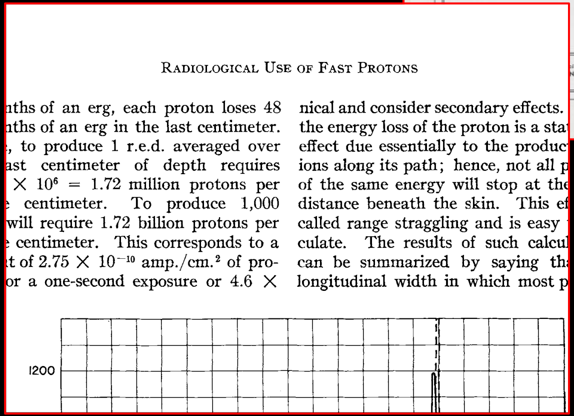



ROBERT R. WILSON November

e nearest surface, it will be necessary
e protons of 115 Mev. If a depth of
. were required, then 140 Mev pro-
vould be needed. The specific ioniza-
curve needs a little interpretation.
interpret the abscissae as the residual
, then there should be little difficulty
sualizing the specific ionization at
s depths within the body. As a
ular example, let us consider 140

ionization over the last centimete
about six times that at the surface.
the final half centimeter of a partic
proton track, the average dose is six
times the skin dose. The full curv
perhaps more realistic, however, an
will be explained later.
It is well known (2) that the biolo
damage depends not only on the nu
of ions produced in a cell, but also upo





RADIOLOGICAL USE OF FAST PROTONS

nths of an erg, each proton loses 48
nths of an erg in the last centimeter.
, to produce 1 r.e.d. averaged over
ast centimeter of depth requires
$\times 10^6$ = 1.72 million protons per
e centimeter. To produce 1,000
will require 1.72 billion protons per
e centimeter. This corresponds to a
t of $2.75 \times 10^{-10}$ amp./cm.[2] of pro-
or a one-second exposure or 4.6 ×

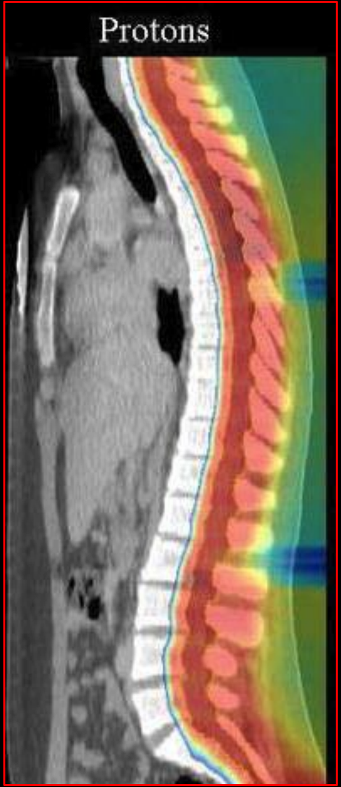
nical and consider secondary effects.
the energy loss of the proton is a sta
effect due essentially to the produc
ions along its path; hence, not all p
of the same energy will stop at the
distance beneath the skin. This ef
called range straggling and is easy
culate. The results of such calcul
can be summarized by saying tha
longitudinal width in which most p

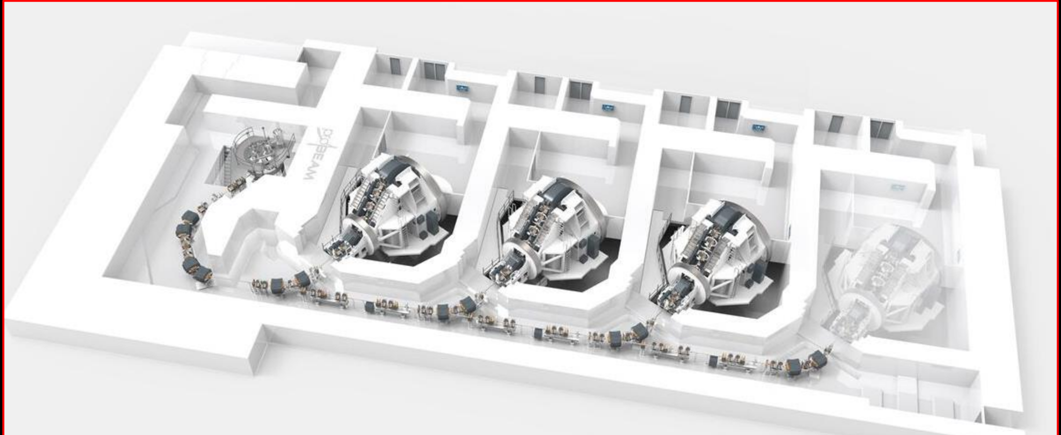


- **Wilson, then at Harvard designing 150 MeV cyclotron:**
  - **Identified benefits and properties of proton beams for RT**
  - **Pointed out potential of ions (carbon) and electrons**

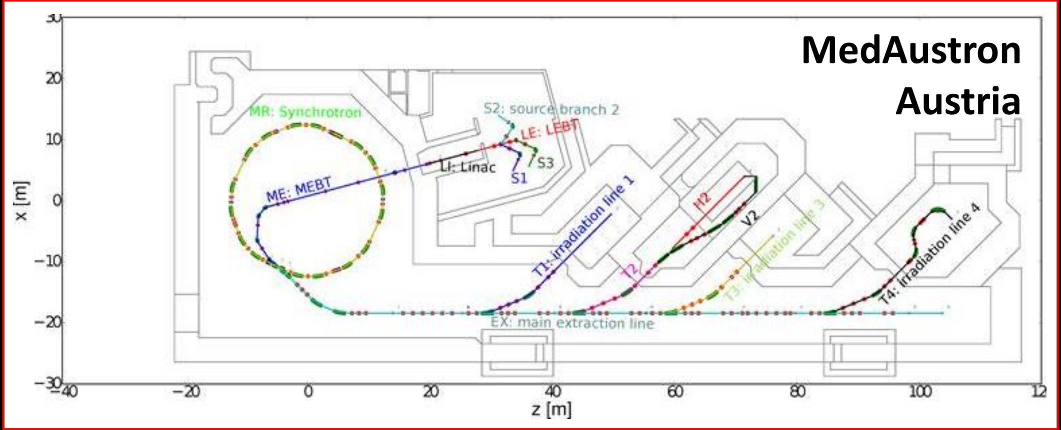
# Particle beam therapy today

## Cyclotron based



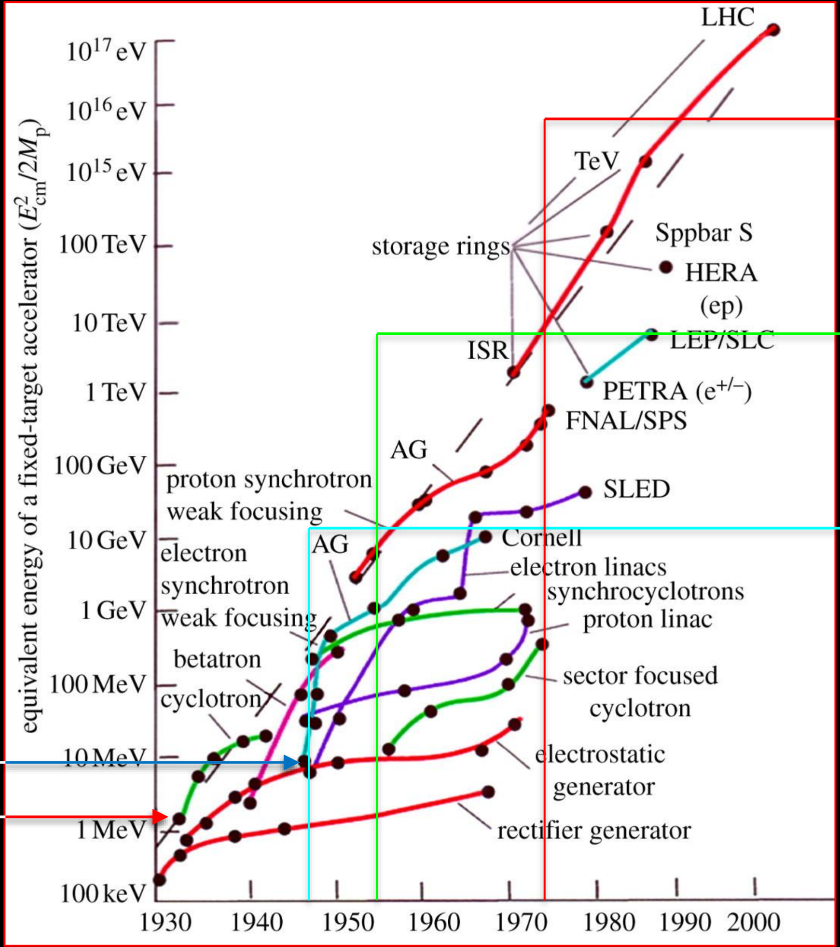
Christie Hospital Manchester




MedAustron Austria

## Synchrotron based

# Evolving state of the art




Cancer therapy (Mass Gen Hosp) 1974

Clinical studies (pituitary gland); 1954

Biological studies; 1948

Synchrotron Goward, Barnes; 1946

Cyclotron Laurence; 1932

# Many initiatives in Americas, Europe, Asia

**Applications in biological research, ambition to push toward clinical application …**

A selection …

- Phys Lett A. (2002) 299:240–7. doi: 10.1016/S0375-9601(02)00521-2
- Med Phys. (2003) 30:1660–70. doi: 10.1118/1.1586268
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- New J Phys. (2010) 12:85003. doi: 10.1088/1367-2630/12/8/085003
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- Phys Rev Acceler Beams. (2017) 20:1–10. doi: 10.1103/PhysRevAccelBeams.20.032801
- J Instrum. (2017) 12:C03084. doi: 10.1088/1748-0221/12/03/C03084
- A-SAIL Project. (2020). Available online at: https://www.qub.ac.uk/research-centres/A-SAILProject/
- Vol. 8779. Prague: International Society for Optics and Photonics. SPIE (2013). p. 216–25.
- Vol. 11036. International Society for Optics and Photonics. SPIE (2019). p. 93–103.
- Nuovo Cim C. (2020) 43:15. doi: 10.1393/ncc/i2020-20015-6
- 10th International Particle Accelerator Conference. Melbourne, VIC (2019). p. TUPTS005
- …

**I will not attempt a review, choosing instead to focus on opportunity**

# Variety of initiatives; some key examples

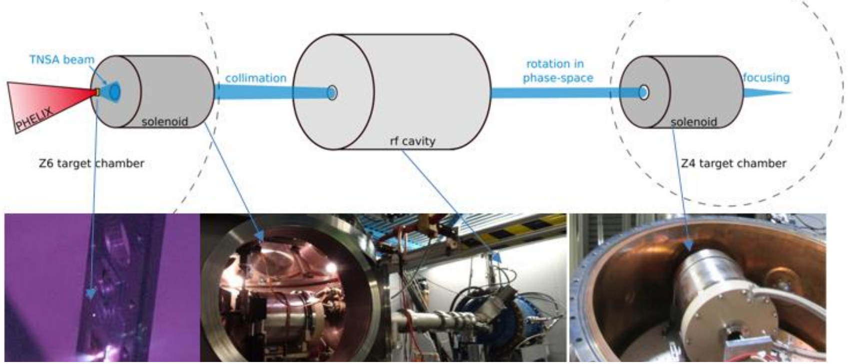
# Capture

## *On PHELIX @ GSI*

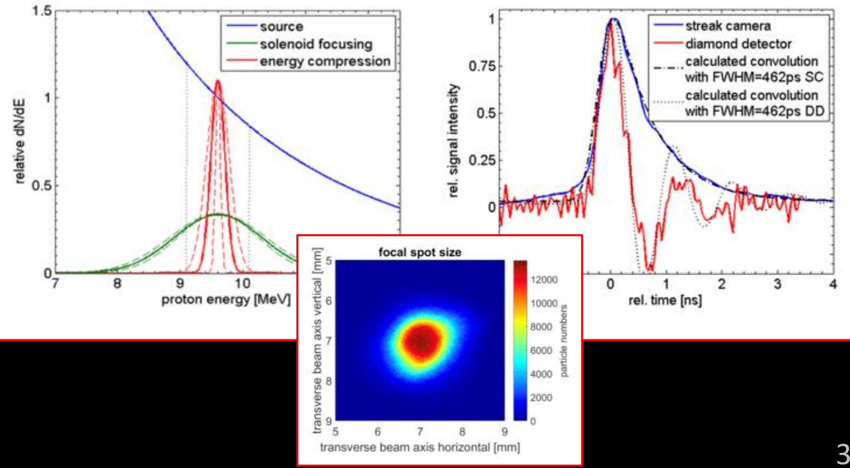
DOI: 10.1063/1.3299391
DOI: 10.1103/PhysRevSTAB.14.121301
DOI: 10.1103/PhysRevSTAB.16.101302
DOI: 10.1103/PhysRevSTAB.17.031302
NIMA 909 (2018) 173–176

- **PHELIX:**
  - Petawatt High-Energy Laser for Heavy Ion EXperiments
    - E < 25 J, τ = 500 fs, I > $10^{19}$ J/cm2
- **LIGHT:**
  - Target Normal Sheath Acceleration (TNSA)
  - Ion beam is collimated by a pulsed high-field solenoid
  - Phase rotation in RF cavity
  - Final focus with a second pulsed high-field solenoid

LIGHT – Laser Ion Generation, Handling and Transport




https://www.gsi.de/work/forschung/appamml/plasmaphysikphelix/experimente/light



Variety of initiatives; some key examples

# Capture

## On CLAPA @ Peking University

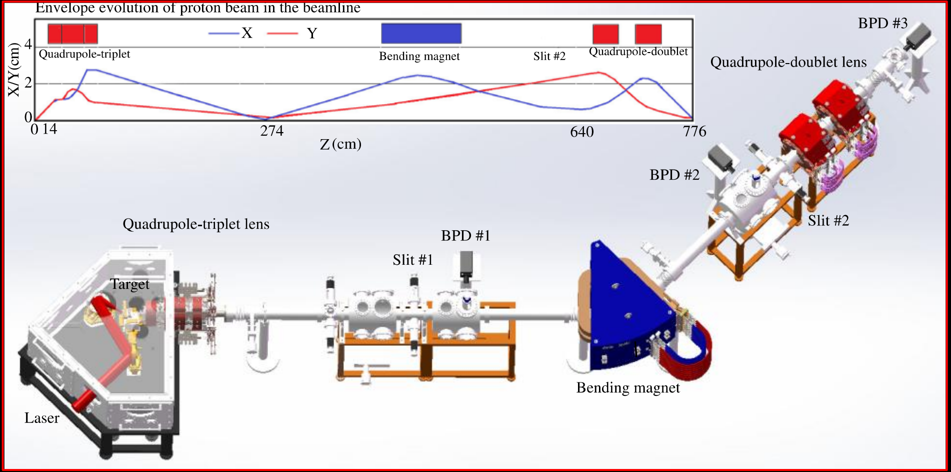
DOI: 10.1103/PhysRevAccelBeams.22.061302
DOI: 10.1103/PhysRevAccelBeams.23.121304

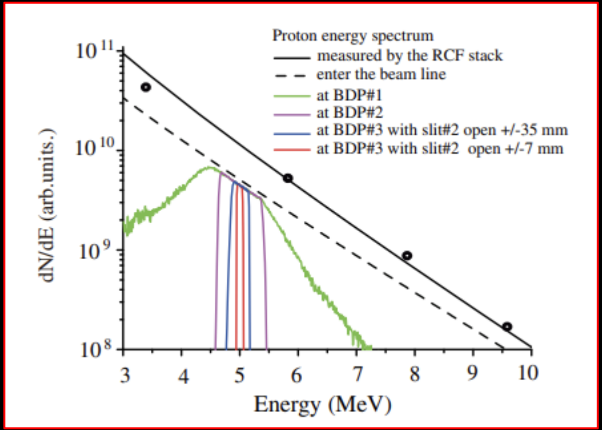
- Compact Laser Plasma Accelerator (CLAPA):
  - Petawatt laser
    - E = 1.3 J, τ = 30 fs, 5 μm FWHM
- Beam line:
  - Target Normal Sheath Acceleration (TNSA)
  - Quadrupole triplet focusing

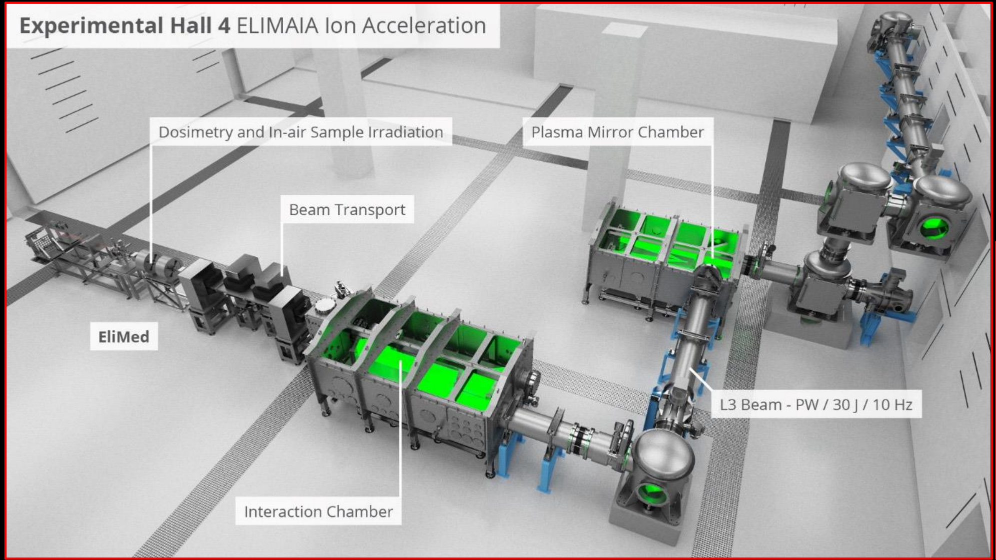
TABLE I. The CLAPA beam line parameters.

| Type | Length | Aperture | Max B | # turns | Current |
|---|---|---|---|---|---|
| Q1 | 100 mm | 30 mm | 5 KGs/cm | 16 | 300 A |
| Q2 | 200 mm | 64 mm | 2.5 KGs/cm | 20 | 540 A |
| Q3 | 100 mm | 64 mm | 2.5 KGs/cm | 20 | 540 A |

  - Measured transmission:
    - 88% transmission through triplet
    - ±50 mrad collection angle @ 5 MeV

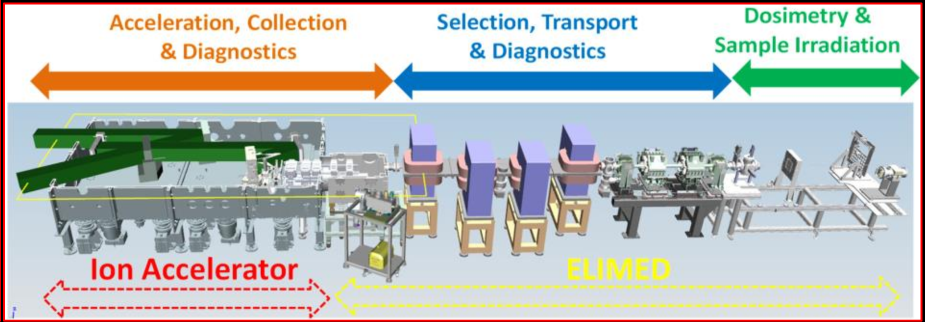





# ELIMAIA-ELIMED

Quantum Beam Sci. 2018, 2, 8; doi:10.3390/qubs2020008
Frontiers in Phys. Med. Phys. & Imag. – doi: 10.3389/fphy.2020.564907




Extreme Light Infrastructure, Prague, Czech Republic:

- **ELI Multidisciplinary Applications of laser-Ion Acceleration (ELIMAIA)**
  - **ELI MEDical and multidisciplinary applications (ELIMED)**
    - **ELIMAIA section dedicated to ion focusing, selection, characterization, and irradiation**
  - **Proton energies from 5 to 250 MeV transported to in-air section**