John Adams Institute for Accelerator Science

Imperial College London

Royal Holloway University of London

UNIVERSITY OF OXFORD

Lecture 21

Laser-hybrid Accelerator for Radiobiological Applications (LhARA)

JAI Student Design Project 2023-2024

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Accelerator Physics Graduate Course
John Adams Institute for Accelerator Science
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Perspectives on laser-driven sources for particle beam therapy

CHALLENGES AND OPPORTUNITIES

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

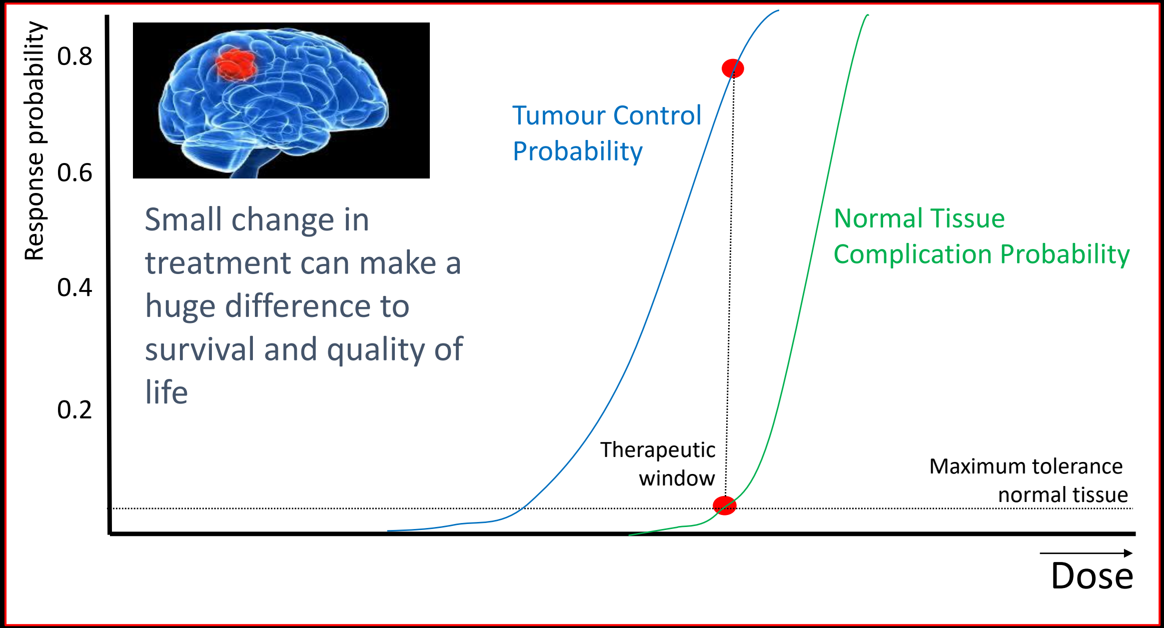
- Scale-up in provision essential:
  - Projections above based on reported cases (i.e. high-income countries)
  - Opportunity: save 26.9 million lives in low/middle income countries by 2035

- 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 benefit of particles

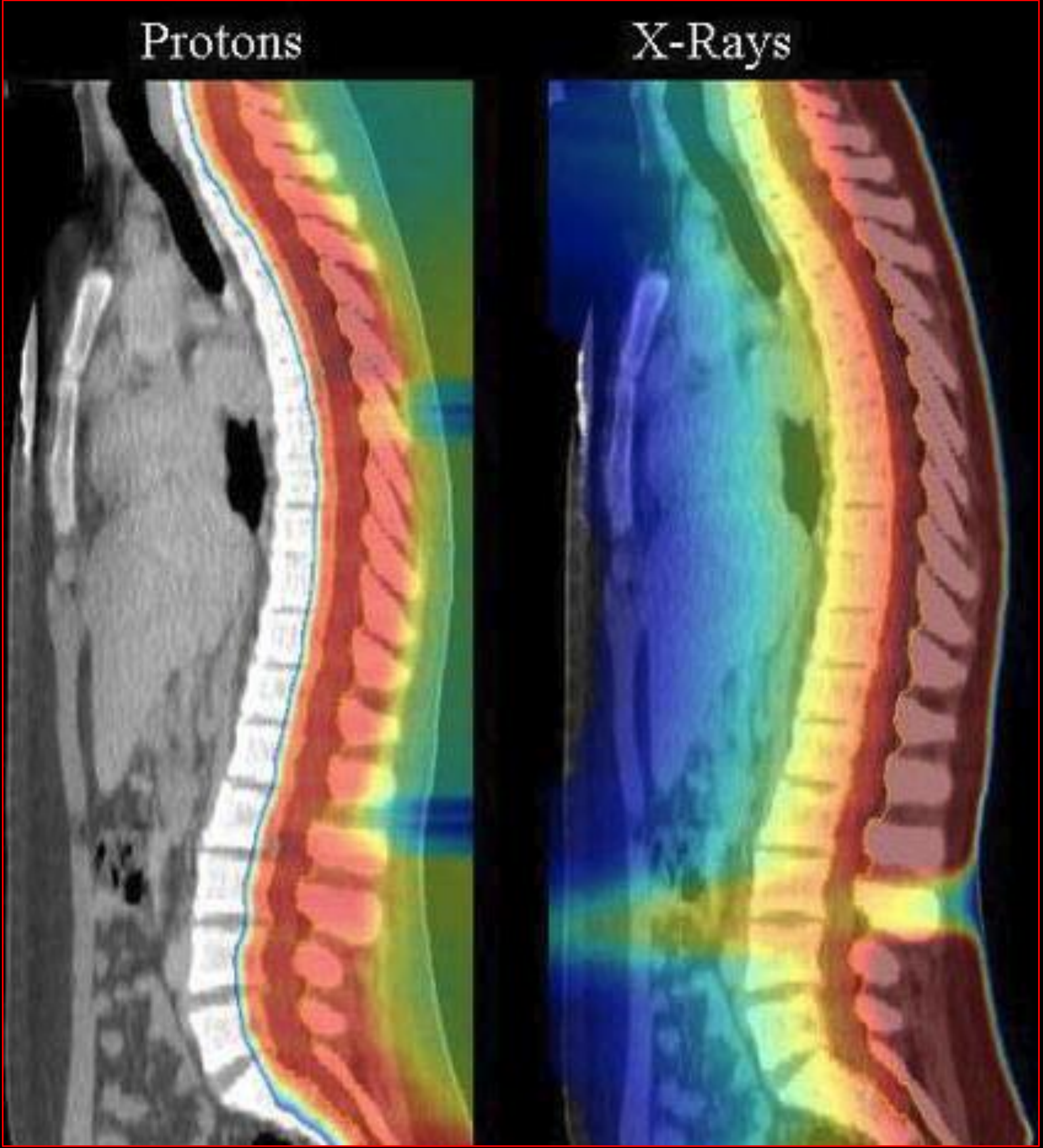
- Maximise therapeutic benefit by:
  - Maximising damage to tumour
  - Minimising damage to healthy tissue

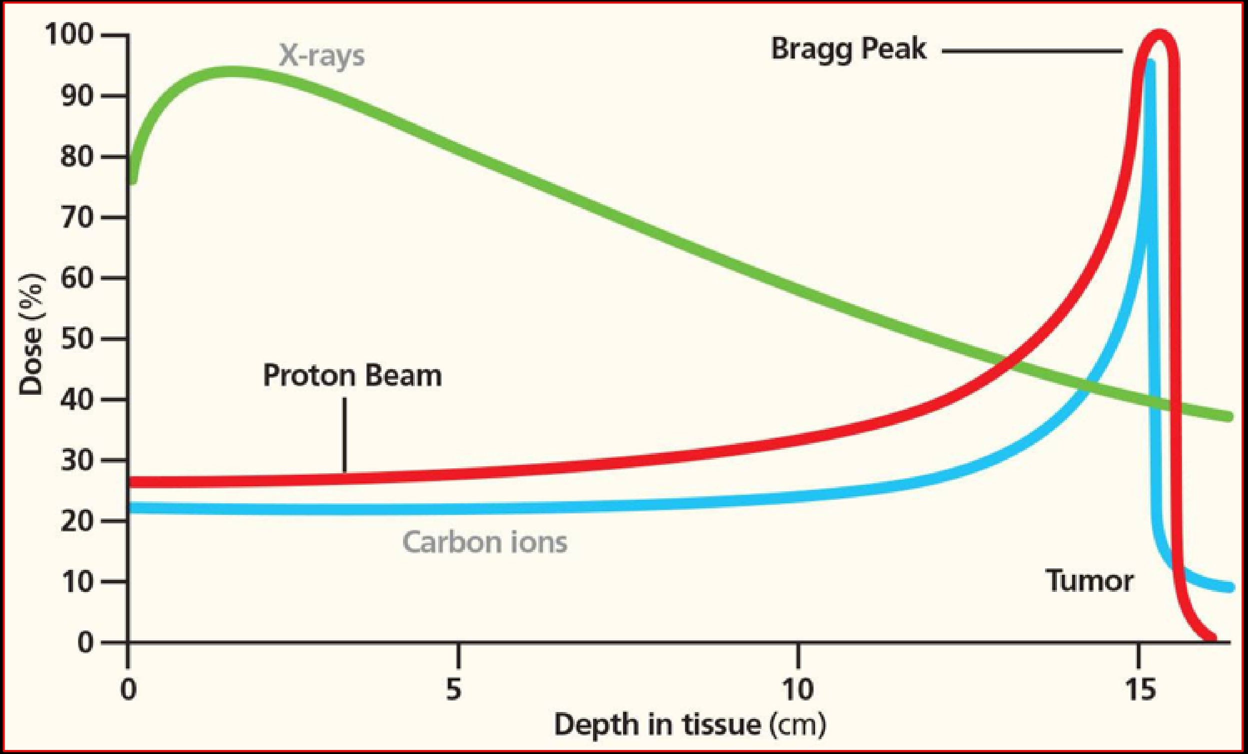


Small change in treatment can make a huge difference to survival and quality of life

- X-ray therapy:
  - Modality used in most radiotherapy
  - Dose falls exponentially with depth
  - Proximity of sensitive organs limits dose to tumour

Particle-beam therapy



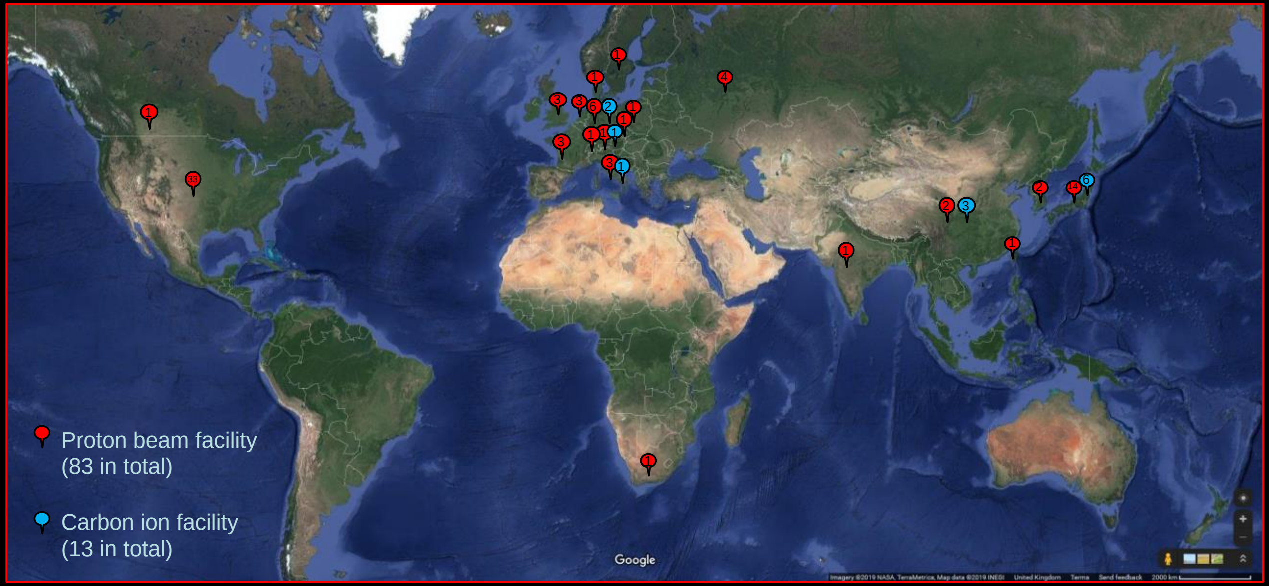


Proton and ion-beam therapy:

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

The need for a step-change in capability

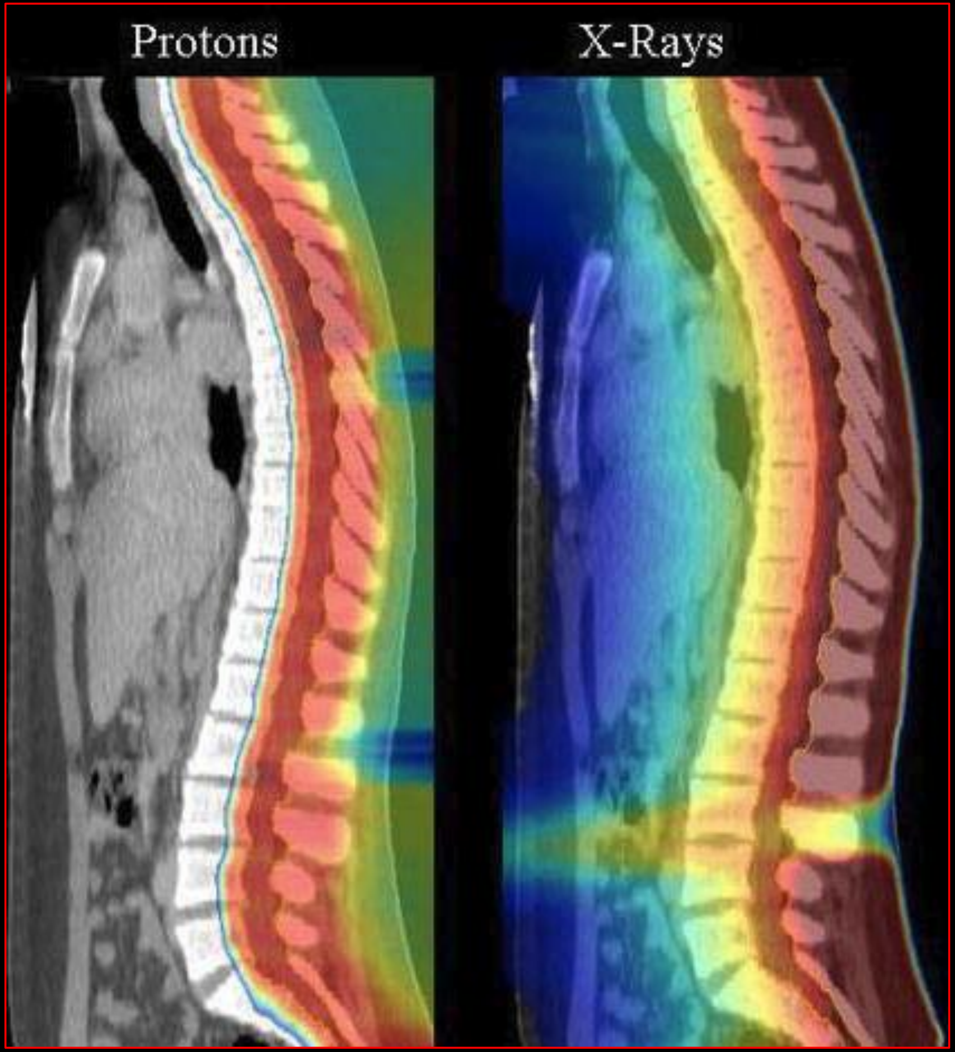
- **Growing recognition of benefits of PBT worldwide:**
  - 70 PBT centres in operation;
    40 under construction
- **‘Incremental’ development of technique**
  - Existing suppliers
  - New initiatives



Exciting indications of benefits of novel beams …

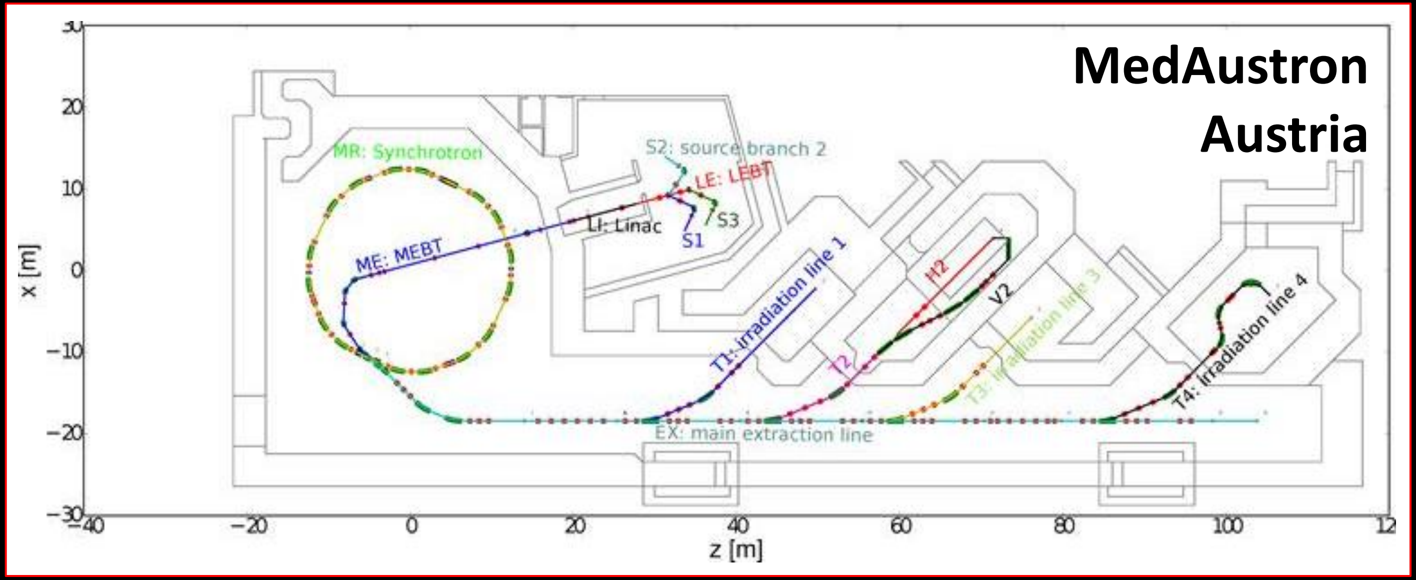
Particle beam therapy today

- Cyclotron based



Christie Hospital Manchester

- Synchrotron based



MedAustron
Austria

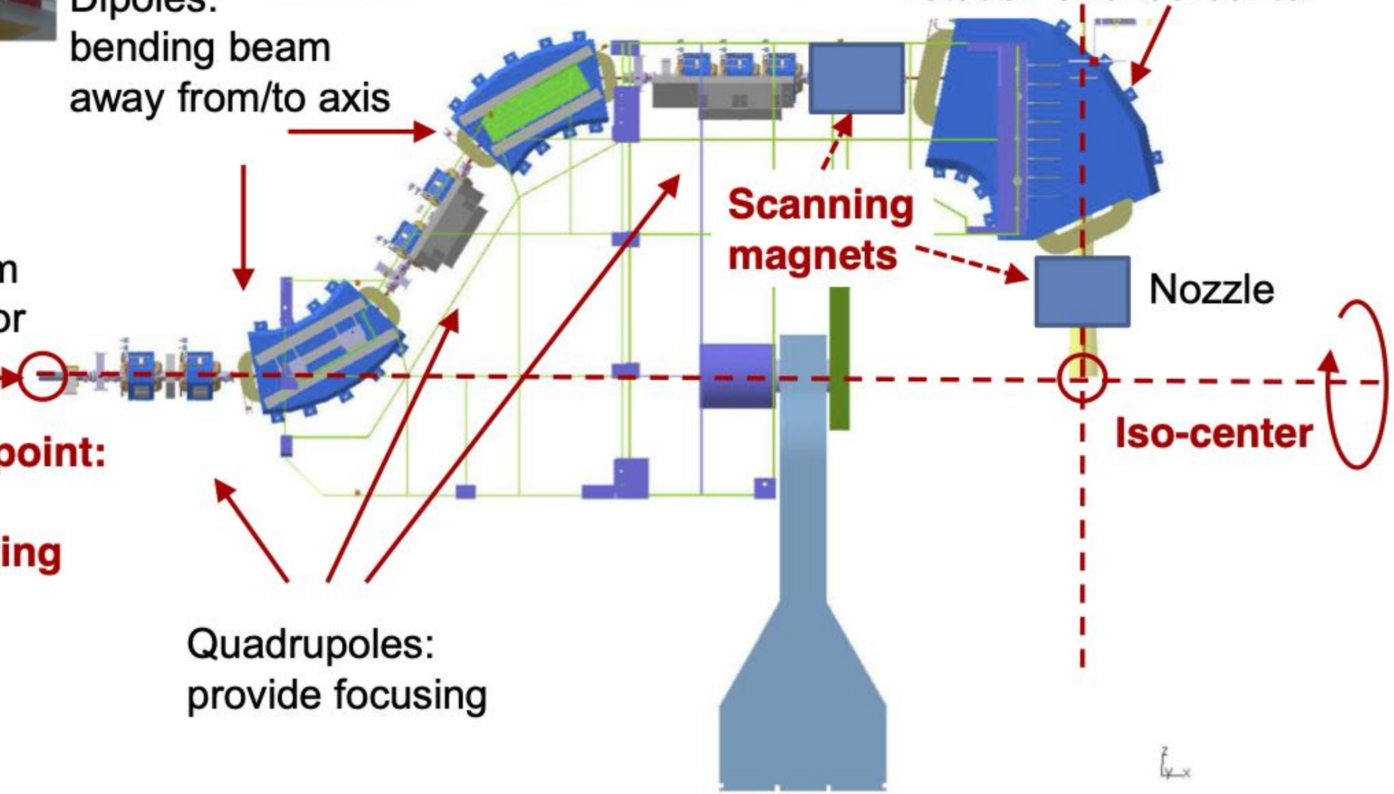
Beam delivery

PSI gantry

- Engineering tour de force!
- 360-degree irradiation

- At a price:
  Size, complexity, maintenance

PSI gantry



Last bending dipole: bends beam into plane of rotation and iso-center

Dipoles: bending beam away from/to axis

Particle beam from accelerator

Scanning magnets

Nozzle

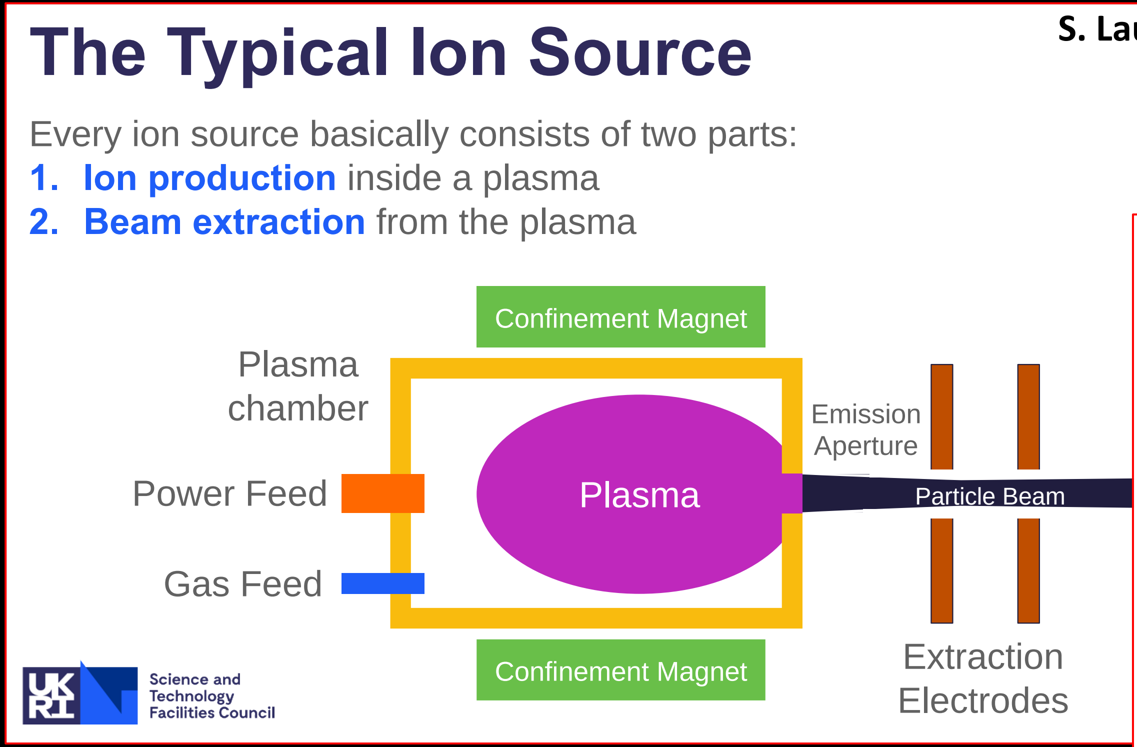
Iso-center

Coupling point: junction fixed/rotating beamline

Quadrupoles: provide focusing

H. Owen

Particle source

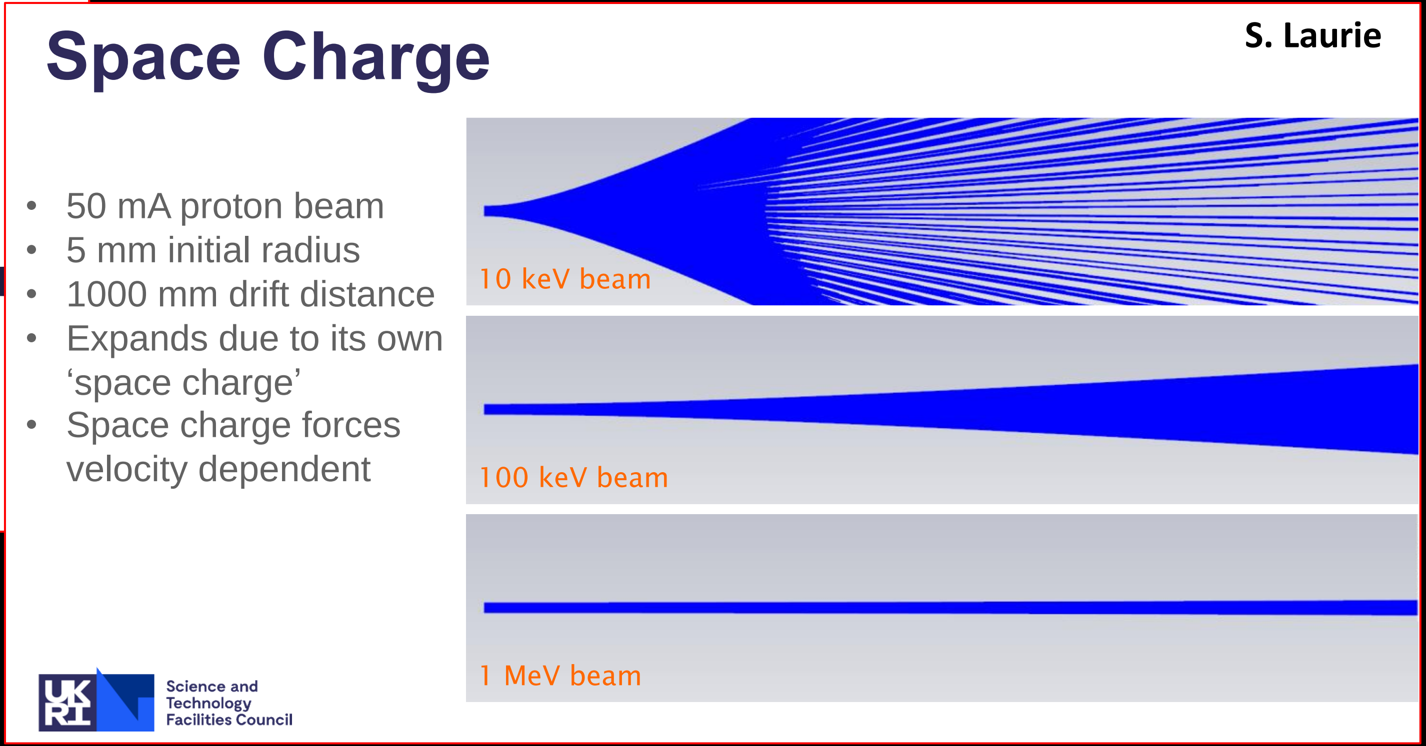


The Typical Ion Source

S. Laurie

Every ion source basically consists of two parts:
1. **Ion production** inside a plasma
2. **Beam extraction** from the plasma

Science and Technology Facilities Council



Space Charge

S. Laurie

- 50 mA proton beam
- 5 mm initial radius
- 1000 mm drift distance
- Expands due to its own 'space charge'
- Space charge forces velocity dependent

Science and Technology Facilities Council

- **Extraction energy:**
  - 30—80 keV
    - Limited by extraction voltage
- **Instantaneous flux (current or dose):**
  - Determined by acceptance of first accelerator structure
    - Limited by mutual repulsion of protons (ions) … "space-charge effect"

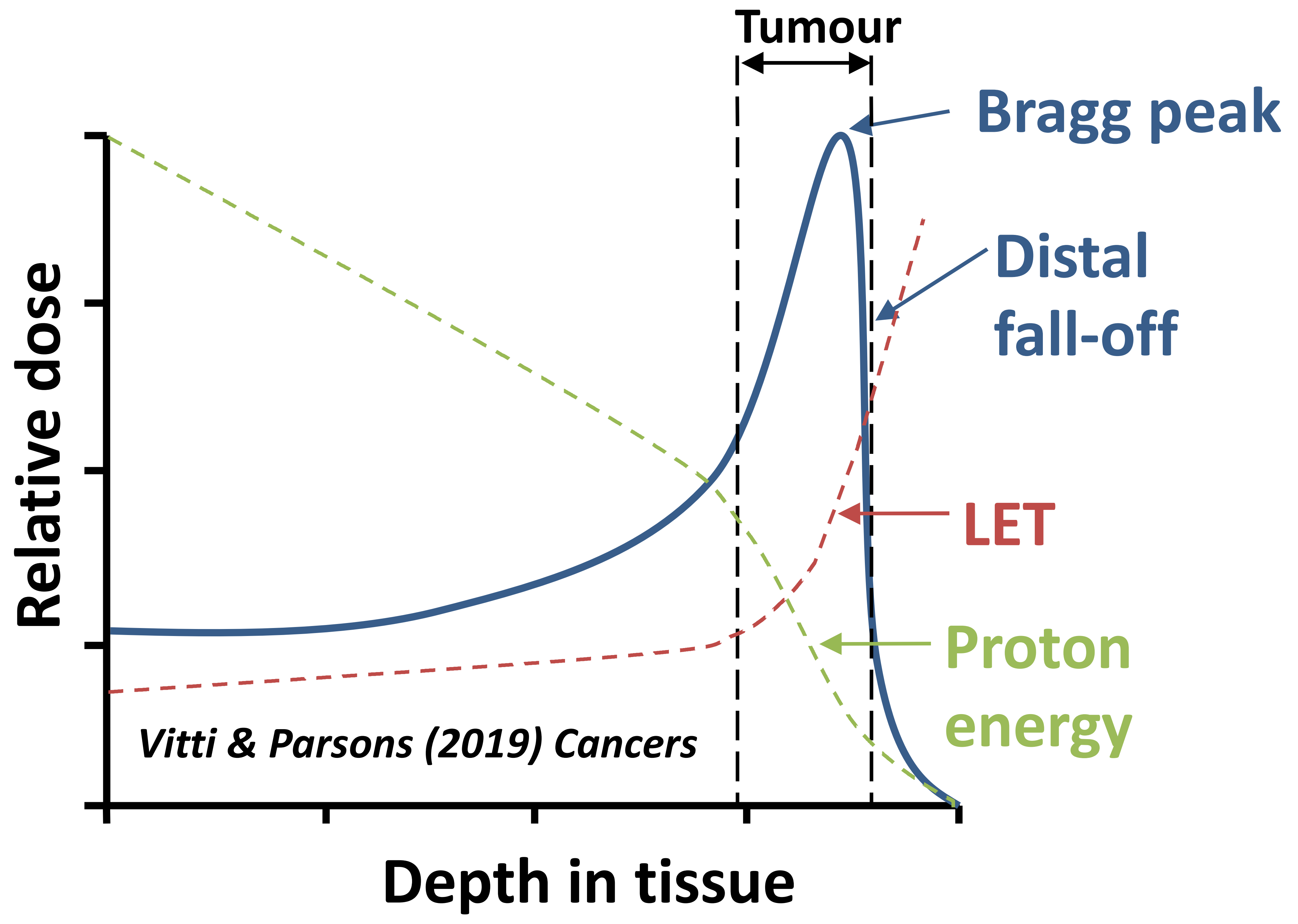
The technological challenge

- Cancer is the second leading cause of death globally (WHO)
  - Radiotherapy indicated in half of all cancer patients
- Growing requirement for radiotherapy:
  - High-income countries: anticipate significant growth in demand
  - Low/middle income countries; enormous unmet need:
    - Opportunity to save ~30 million lives by 2035
- Scale-up in provision essential:
  - 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 Laser-hybrid Accelerator for Radiobiological Applications (LhARA)

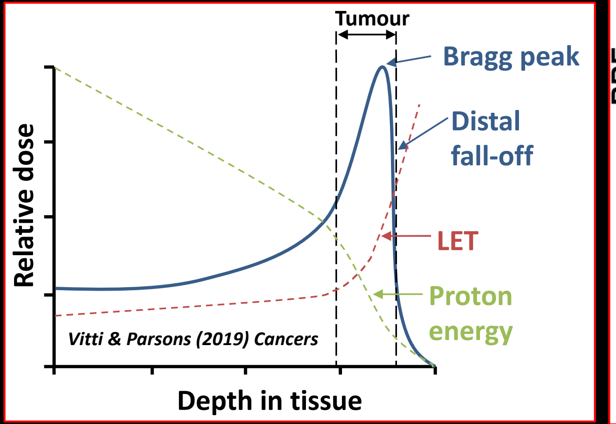
RADIOBIOLOGY



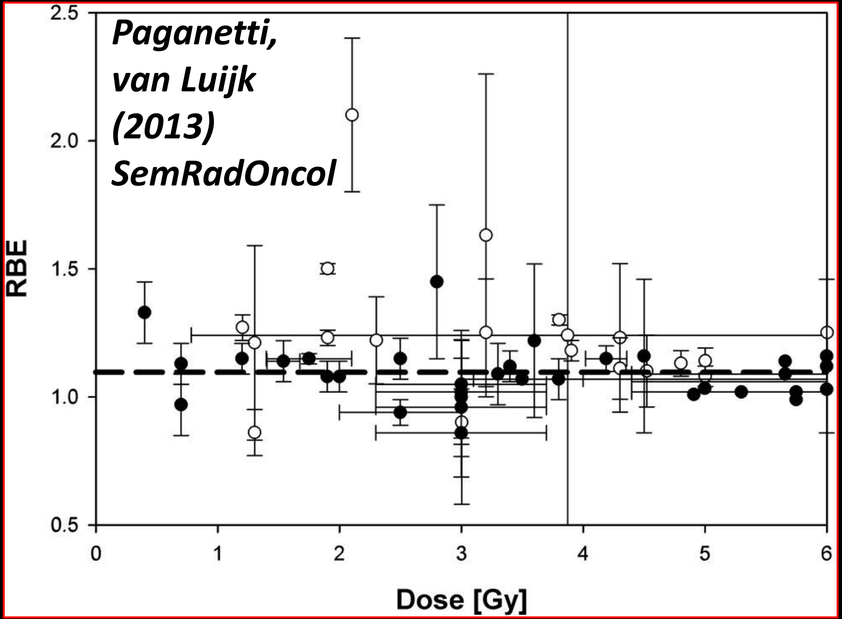
Vitti & Parsons (2019) Cancers

The case for fundamental radiobiology

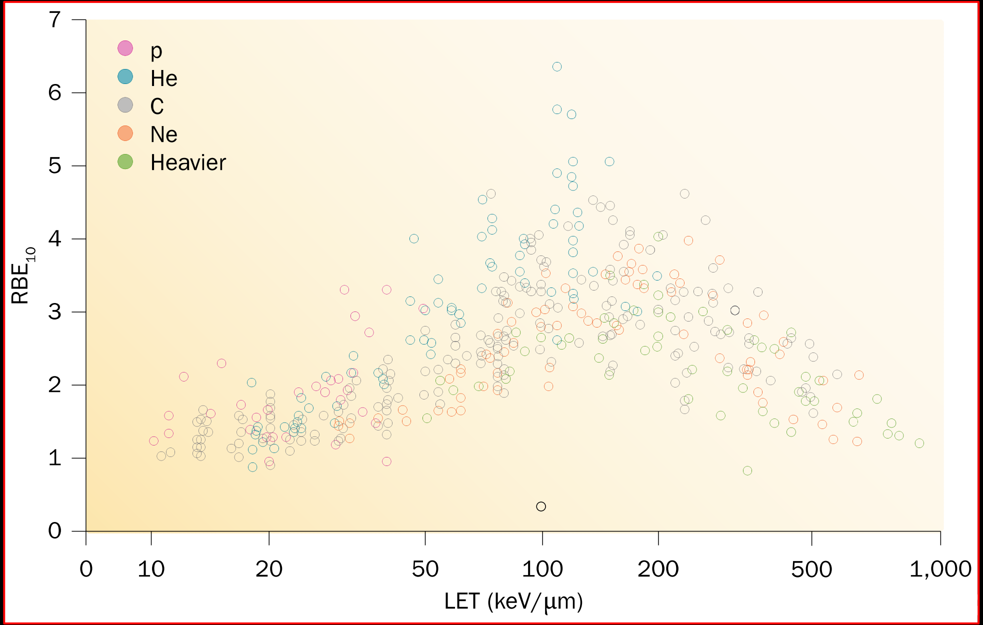
- Relative biological effectiveness:
  - Defined relative to reference X-ray beam
  - Known to depend on:
    - Energy, ion species
    - Dose & dose rate
    - Tissue type
    - Biological endpoint
- Yet:
  - *p*-treatment planning uses 1.1
  - Effective values are used for C^{6+}
- Maximise the efficacy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



Vitti & Parsons (2019) Cancers

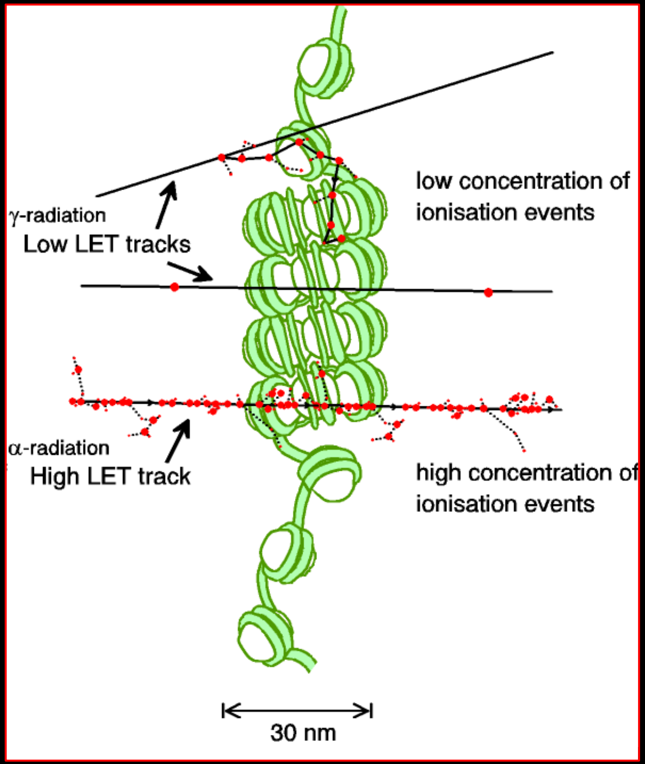


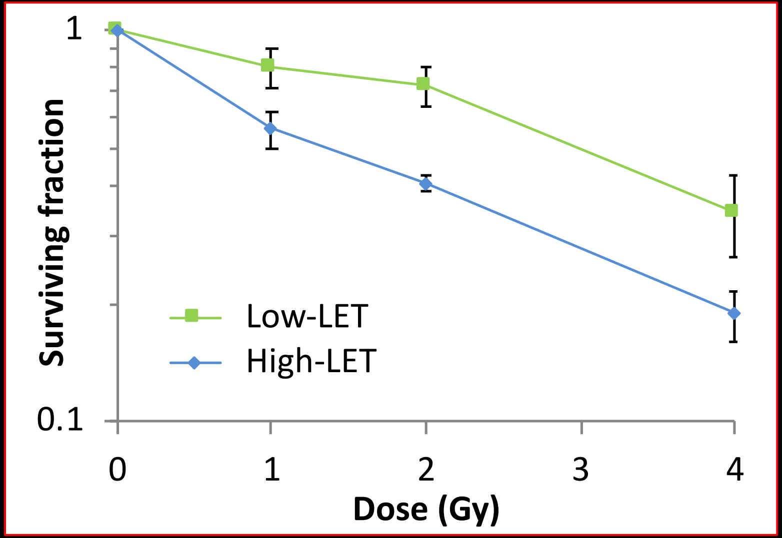
Paganetti, van Luijk (2013) SemRadOncol

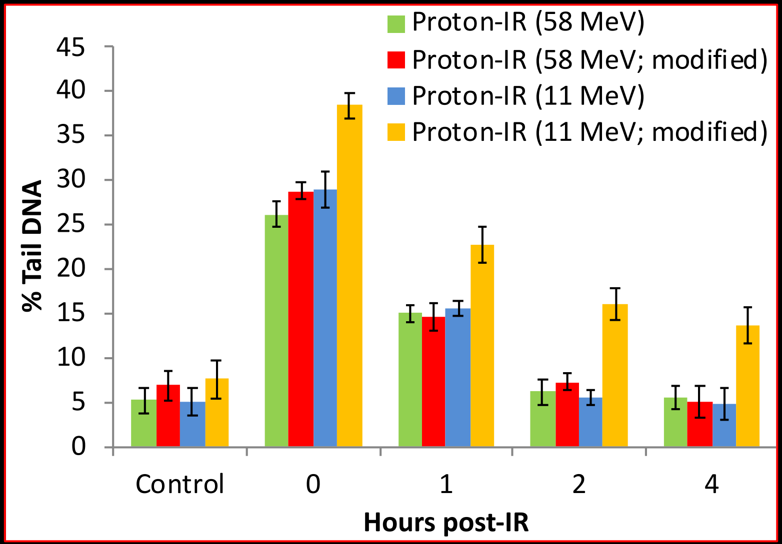


Biological impact from the physics of ionisation

- **Low-LET radiation:**
  - *Repairable* single/double strand breaks
- **High-LET radiation:**
  - *Complex* DNA lesions
    - Multiple DNA pathways
    - More difficult to repair
    - Enhances cell death

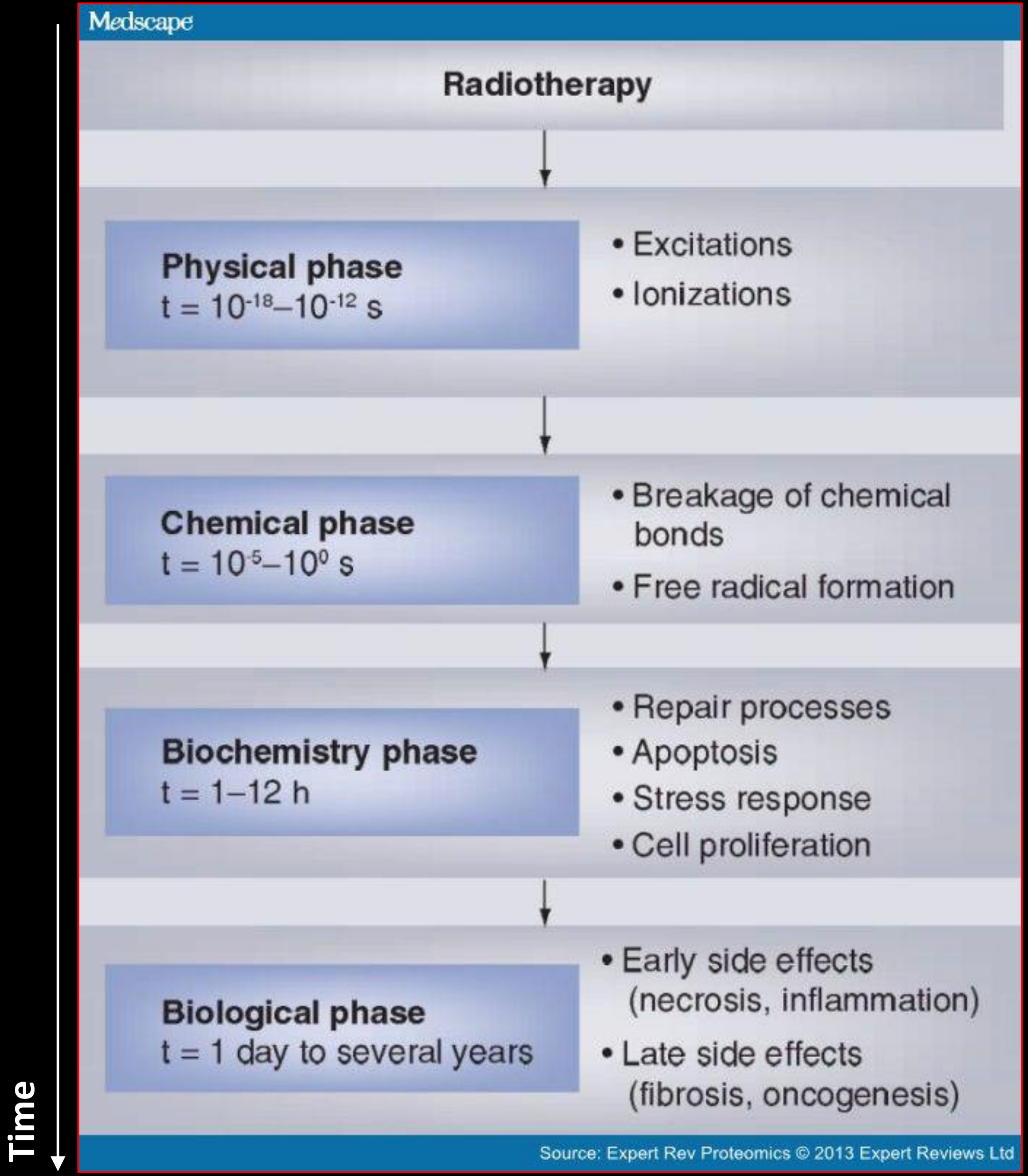






- **Programmatic approach:**
  - Dynamic studies of impact of radiation
  - Interpret with advanced computer models (e.g. G4DNA)

A complex, multi-facetted problem



Radiotherapy

Physical phase
t = 10^{-18}–10^{-12} s

- Excitations
- Ionizations

Chemical phase
t = 10^{-5}–10^{0} s

- Breakage of chemical bonds
- Free radical formation

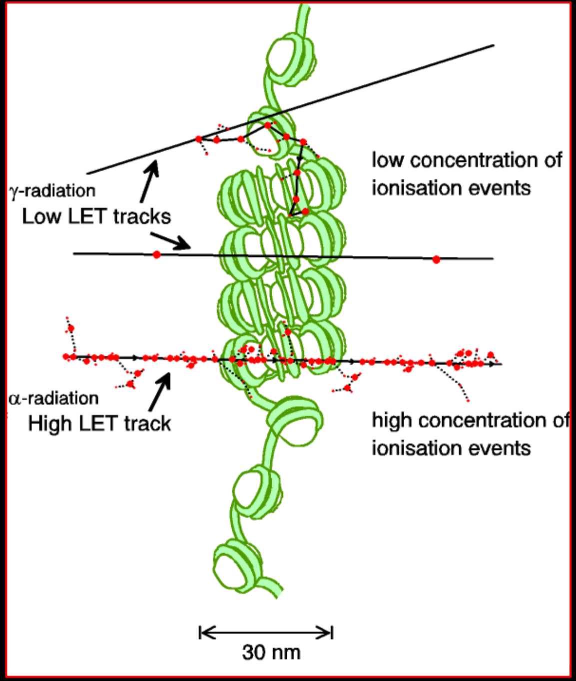
Biochemistry phase
t = 1–12 h

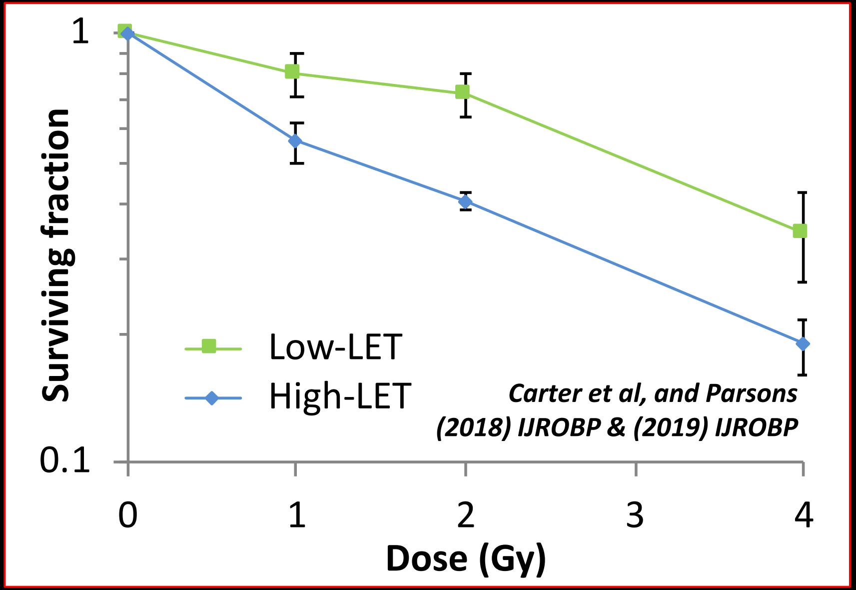
- Repair processes
- Apoptosis
- Stress response
- Cell proliferation

Biological phase
t = 1 day to several years

- Early side effects (necrosis, inflammation)
- Late side effects (fibrosis, oncogenesis)

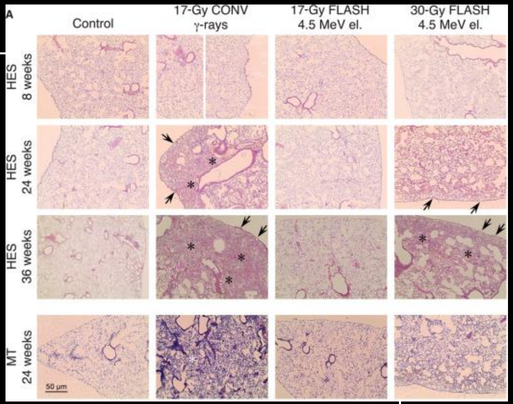
Source: Expert Rev Proteomics © 2013 Expert Reviews Ltd





Carter et al, and Parsons (2018) IJROBP & (2019) IJROBP

Radiobiology in new regimens



Worked example: FLASH

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

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

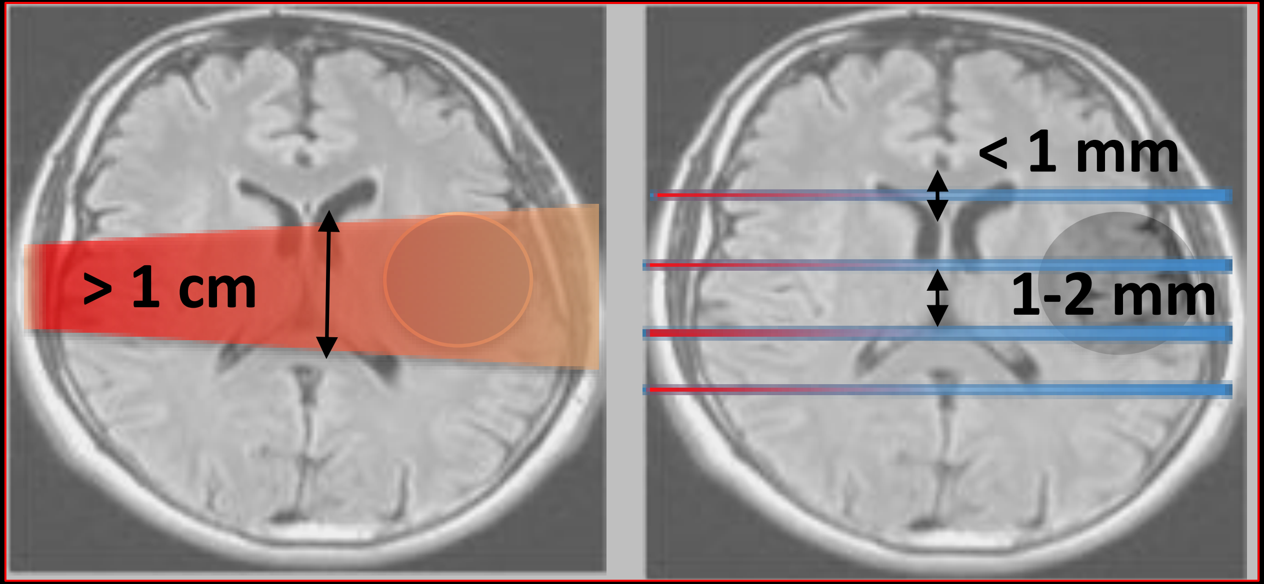
Time line:

- **Initial 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)**

Radiobiology in new regimens

Worked example: micro beams

Conventional regime: > 1 cm diameter; homogeous
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 prob.

Laser-driven sources are disruptive

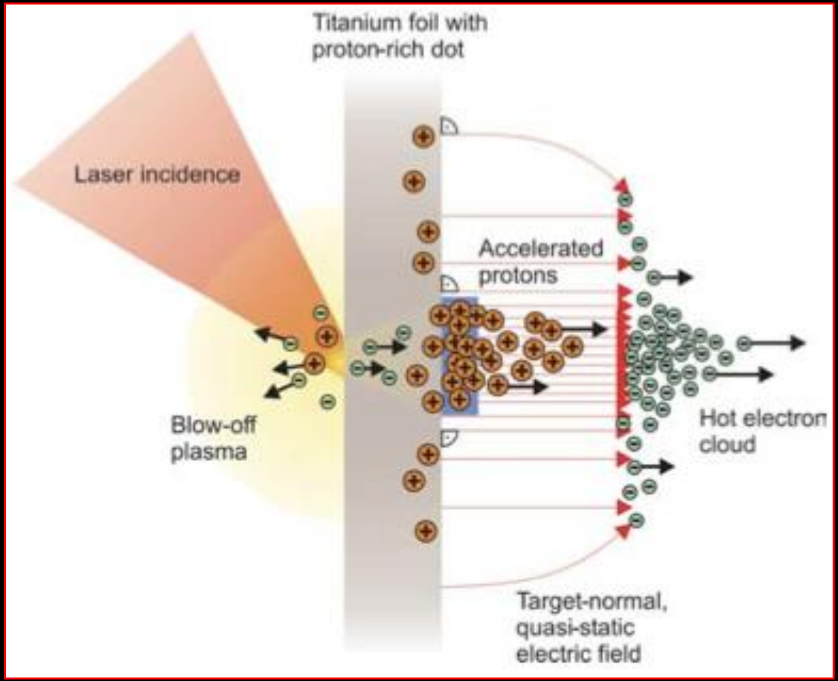
I will argue that laser-driven sources have the potential to:

- Create the capability to deliver particle-beam therapy in completely new regimens
  - Flexibility!
    - Combine a variety of ion species in a single treatment fraction, exploiting ultra-high dose rates in novel spatial- and spectral-fractionation schemes
- Make "best in class" treatments available to the many
  - Automated, triggerable system → remove requirement for large gantry:
    - System incorporating dose-deposition imaging in fast feedback-and-control system; track movement, deliver dose at optimum tissue alignment

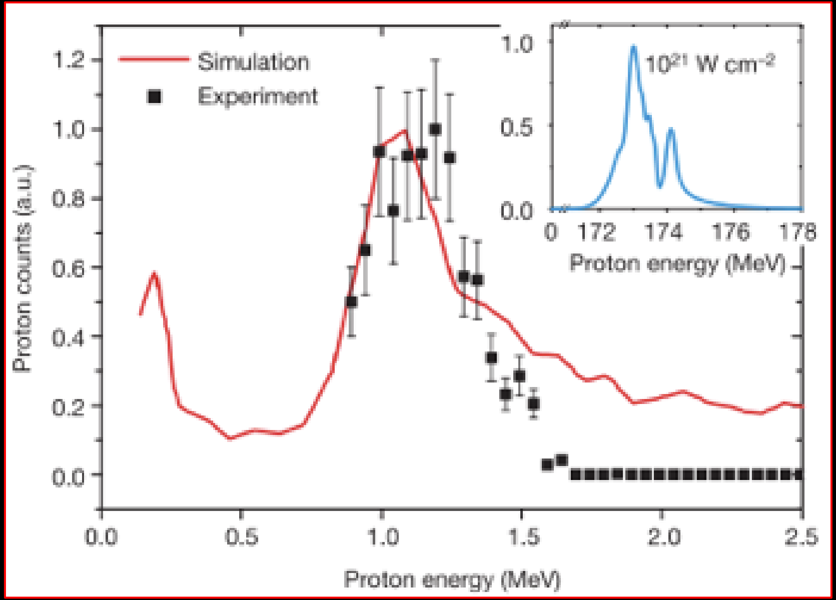
Perspectives on laser-driven sources for particle beam therapy

THE IN-PRINCIPLE ADVANTAGE OF THE LASER-DRIVEN SOURCE

Sheath acceleration



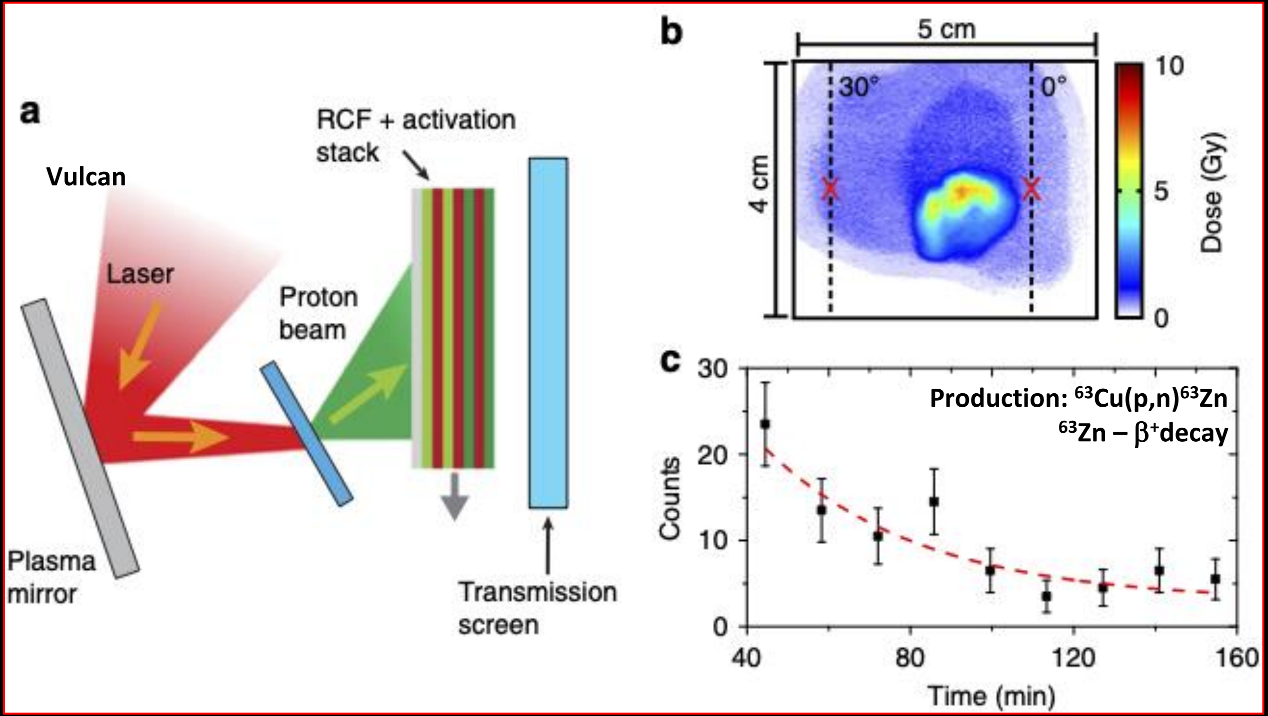
Schwoerer, H. et al., 2006; Nature, 439(7075).

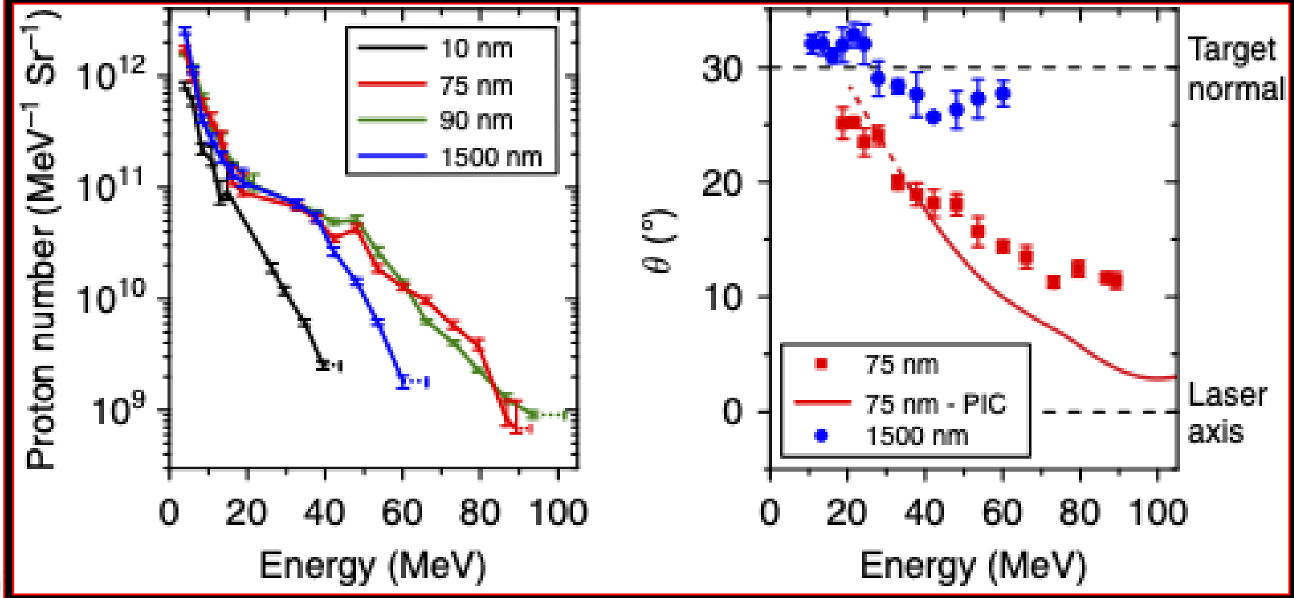


- Laser incident on foil target:
  - Drives electrons from material
  - Creates enormous electric field
- Field accelerates protons/ions
  - Dependent on nature of target
- Active development:
  - Laser: power and rep. rate
  - Target material, transport

nature COMMUNICATIONS (2018)9:724 DOI: 10.1038/s41467-018-03063-9

Advances





- **Ultrathin foil irradiated by "long", linearly-polarised laser pulse**

- **Mechanism:**
  - **Radiation-pressure/target-normal sheath acceleration**
  - **High-energies confined to narrow angular range by radiation-induced transparency**

Advantages

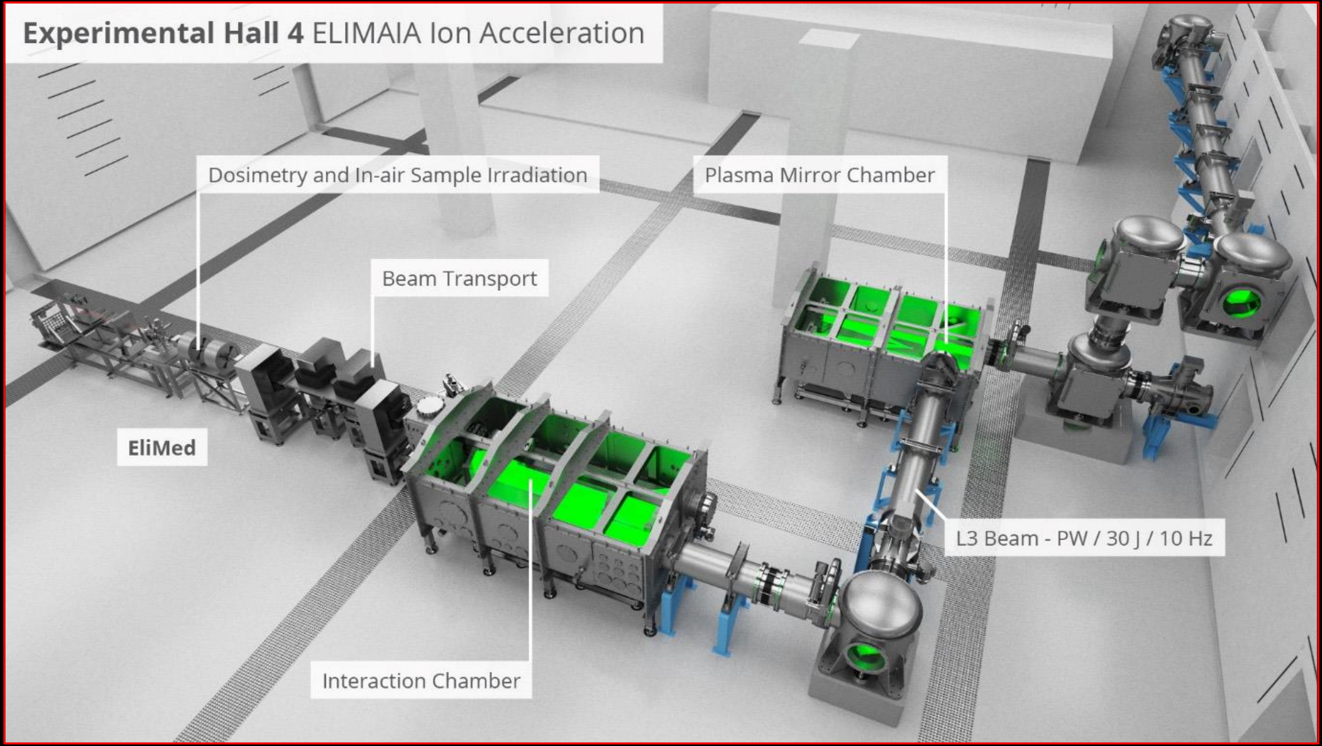
- Protons (and ions) produced at “high energy”:
  - e.g. 15 MeV → 250 times energy of conventional proton source
    - High energy substantially reduced impact of space charge
      - Allows evasion of instantaneous dose-rate limitation of today’s sources

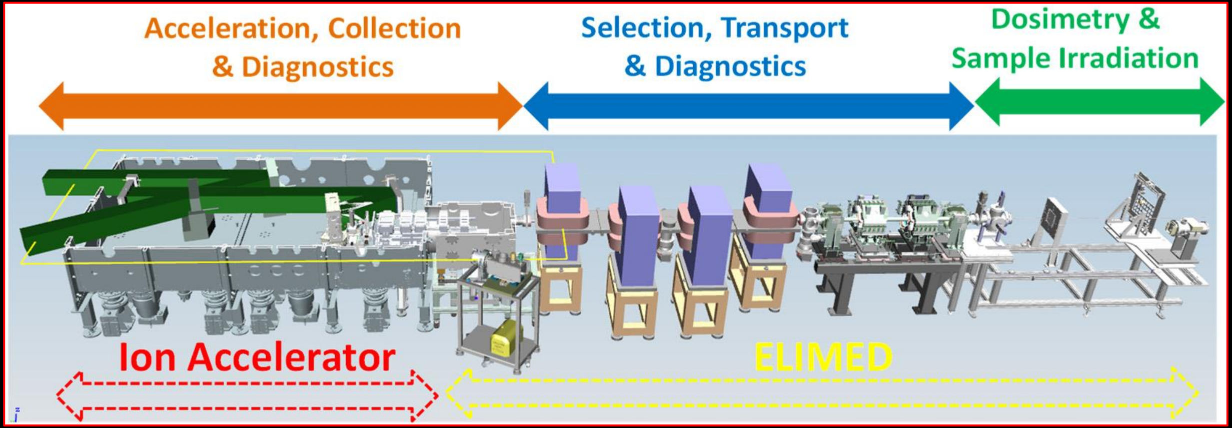
- Pulsed operation “natural”:
  - Discharge sources are DC; accelerator imposes time structure
  - Pulsed operation determined by laser:
    - A triggerable, “on demand”, source

- Critical issues:
  - Efficient capture of divergent, high-energy ion flux
  - Transformation of captured flux into useful beam

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**

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
Med Phys. (2004) 31:1587–92. doi: 10.1118/1.1747751
Science. (2003) 300:1107–111
New J Phys. (2010) 12:85003. doi: 10.1088/1367-2630/12/8/085003
Phys Med Biol. (2011) 56:6969–82. doi: 10.1088/0031-9155/56/21/013
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AIP Adv. (2012) 2:011209. doi: 10.1063/1.3699063
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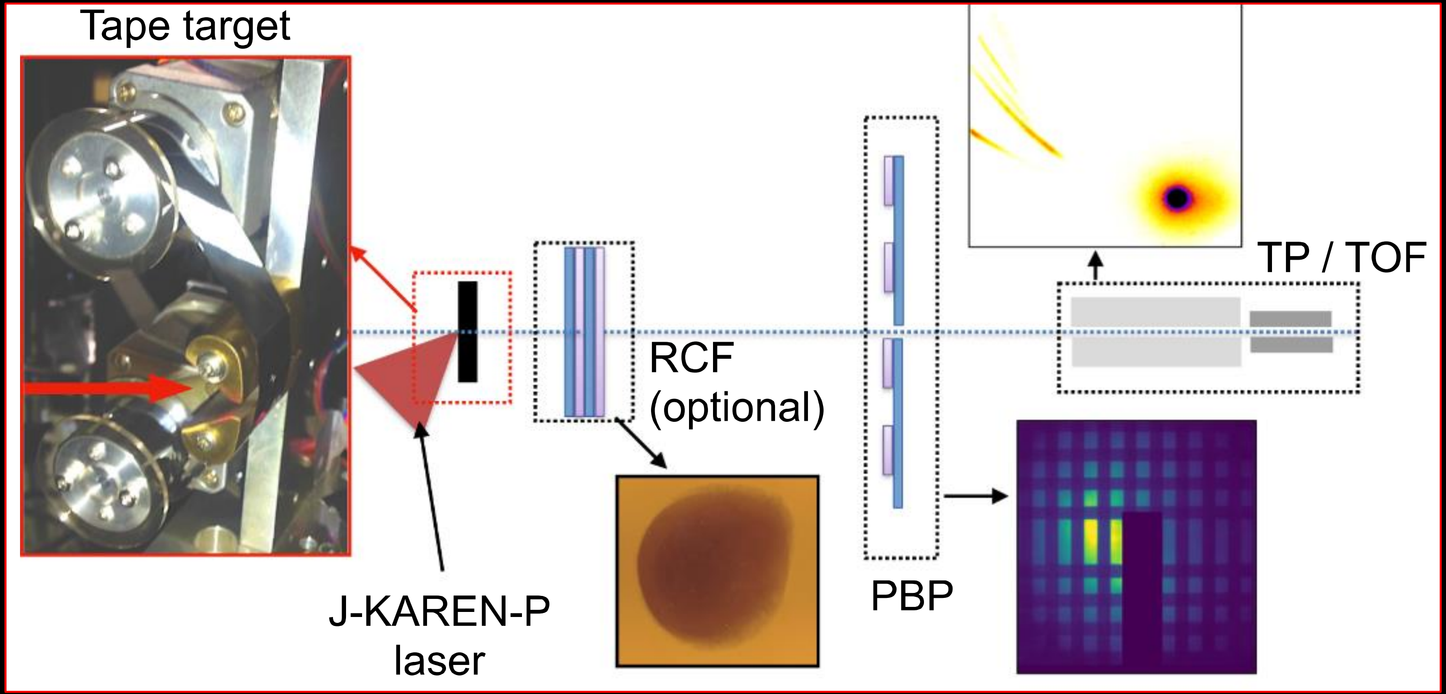
Appl Phys B. (2014) 117:41–52. doi: 10.1007/s00340-014-5796-z
Radiat Res. (2014) 181:177–83. doi: 10.1667/RR13464.1
Phys Rev Acceler Beams. (2017) 20:1–10. doi: 10.1103/PhysRevAccelBeams.20.032801
J Instrum. (2017) 12:C03084. doi: 10.1088/1748-0221/12/03/C03084
A-SAIL Project. (2020). Available online 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.

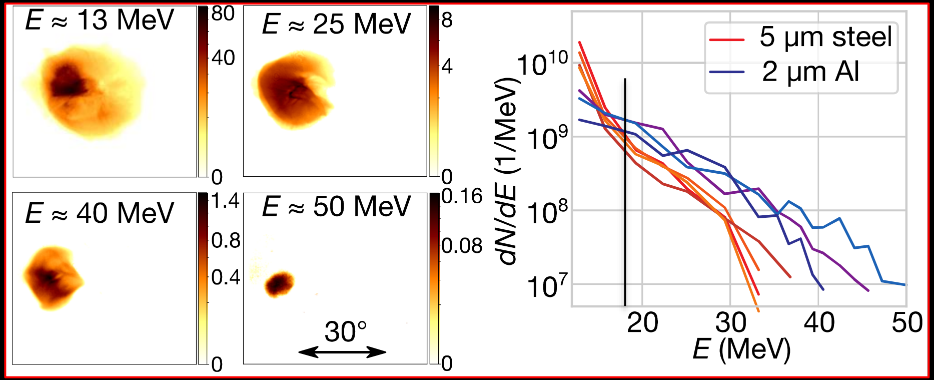
I will not attempt a review, choosing instead to focus on opportunity …

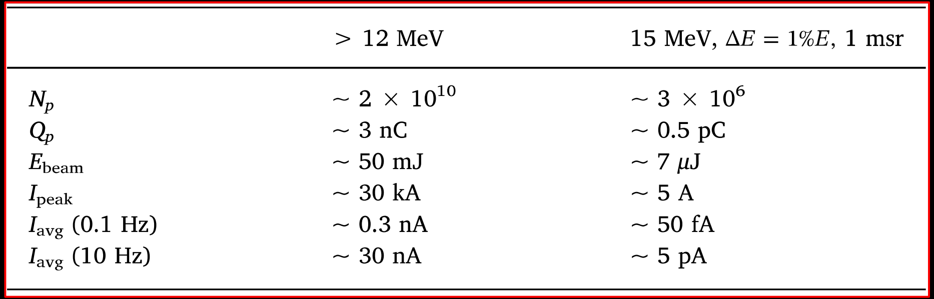
Opportunity; a hybrid approach

- Create protons (ions) at “modest” energy:
  - Consider 10—15 MeV; high flux, “plateau” region
- Capture and manipulate proton (ion) flux:
  - Inject into post accelerator for biomedical application

High Energy Density Physics 37 (2020) 100847







	> 12 MeV	15 MeV, $\Delta E = 1\%E$, 1 msr
N_p	$\sim 2 \times 10^{10}$	$\sim 3 \times 10^{6}$
Q_p	~ 3 nC	~ 0.5 pC
E_{beam}	~ 50 mJ	~ 7 μJ
I_{peak}	~ 30 kA	~ 5 A
I_{avg} (0.1 Hz)	~ 0.3 nA	~ 50 fA
I_{avg} (10 Hz)	~ 30 nA	~ 5 pA

Laser-hybrid Accelerator for Radiobiological Applicatons

- **Vision:**

  LhARA will be a uniquely-flexible, novel system that will:
  - *Deliver a systematic and definitive radiobiology programme*
  - *Prove the feasibility of the laser-driven hybrid-accelerator approach*
  - *Lay the technological foundations for the transformation of PBT*
    - automated, patient-specific: implies online imaging & fast feedback and control

- **Ambition:**
  - **Develop:**

    necessary techniques, technologies, and *systems*
  - **Exploit:**

    system approach to novel bring techniques into clinical practice as they mature
  - **Integrate:**

    production prototypes in a production *system* for radiobiological research
  - **Engage:**

    industry and clinical PBT centres

    during development of techniques, technologies, and systems

Perspectives on laser-driven sources for particle beam therapy

LHARA

Laser-hybrid Accelerator for Radiobiological Applications

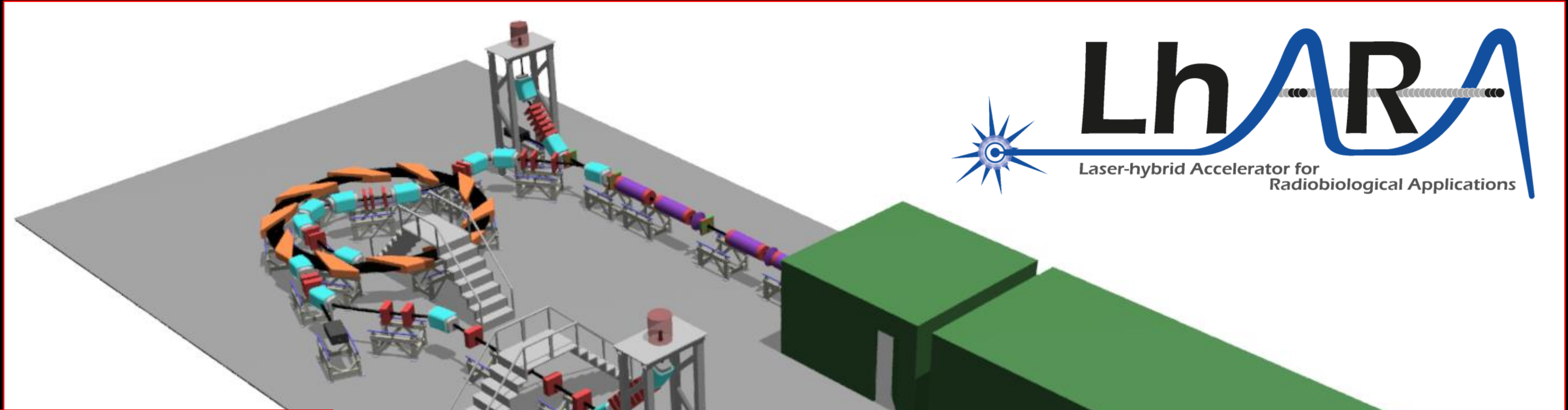
A novel, hybrid, approach:

- **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

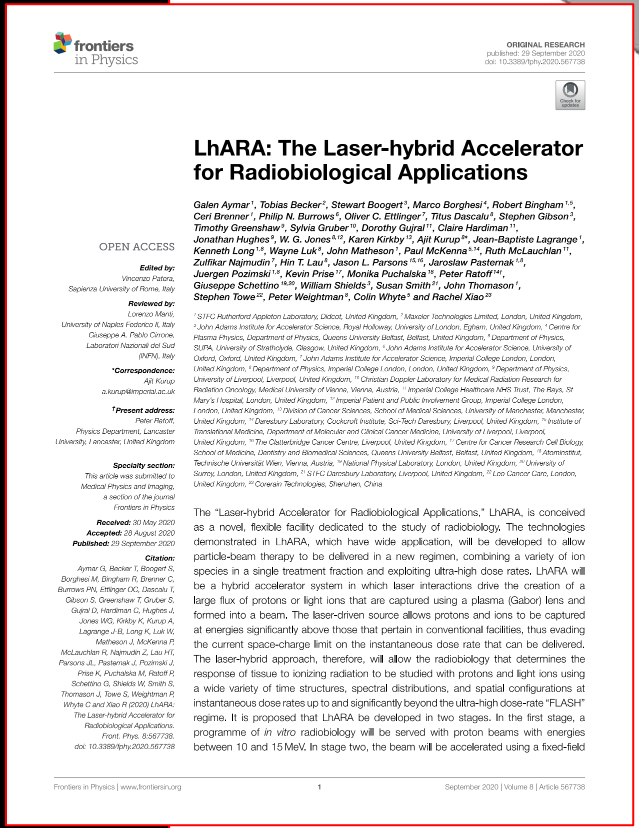
Front. Phys., 29 September 2020; DOI: 10.3389/fphy.2020.567738



LhARA

Laser-hybrid Accelerator for Radiobiological Applications

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



frontiers in Physics

ORIGINAL RESEARCH
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LhARA: The Laser-hybrid Accelerator for Radiobiological Applications

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The "Laser-hybrid Accelerator for Radiobiological Applications," LhARA, is conceived as a novel, flexible facility dedicated to the study of radiobiology. The technologies demonstrated in LhARA, which have wide application, will be developed to allow particle-beam therapy to be delivered in a new regimen, combining a variety of ion species in a single treatment fraction and exploiting ultra-high dose rates. LhARA will be a hybrid accelerator system in which laser interactions drive the creation of a large flux of protons or light ions that are captured using a plasma (Gabor) lens and formed into a beam. The laser-driven source allows protons and ions to be captured at energies significantly above those that pertain in conventional facilities, thus evading the current space-charge limit on the instantaneous dose rate that can be delivered. The laser-hybrid approach, therefore, will allow the radiobiology that determines the response of tissue to ionizing radiation to be studied with protons and light ions using a wide variety of time structures, spectral distributions, and spatial configurations at instantaneous dose rates up to and significantly beyond the ultra-high dose-rate "FLASH" regime. It is proposed that LhARA be developed in two stages. In the first stage, a programme of *in vitro* radiobiology will be served with proton beams with energies between 10 and 15 MeV. In stage two, the beam will be accelerated using a fixed-field

Laser-hybrid Accelerator for Radiobiological Applications (LhARA)

Conceptual Design Report

The LhARA collaboration

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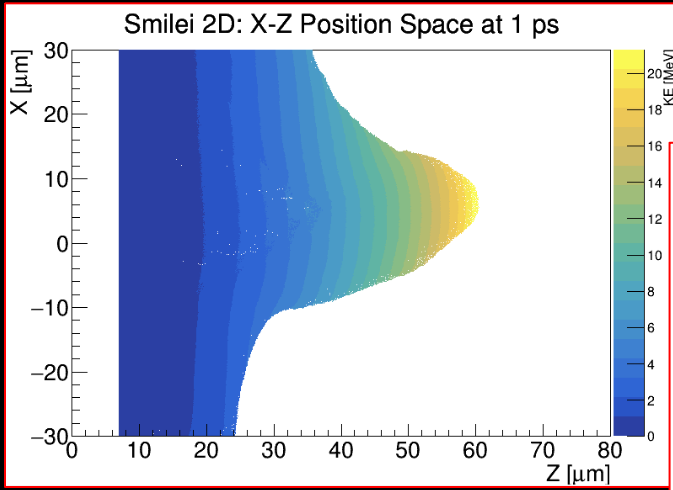
Laser-driven proton/ion source

- **Advantage:**
  - Enormous proton/ion flux at 10—15MeV in tiny (30 fs) pulse at 10 Hz



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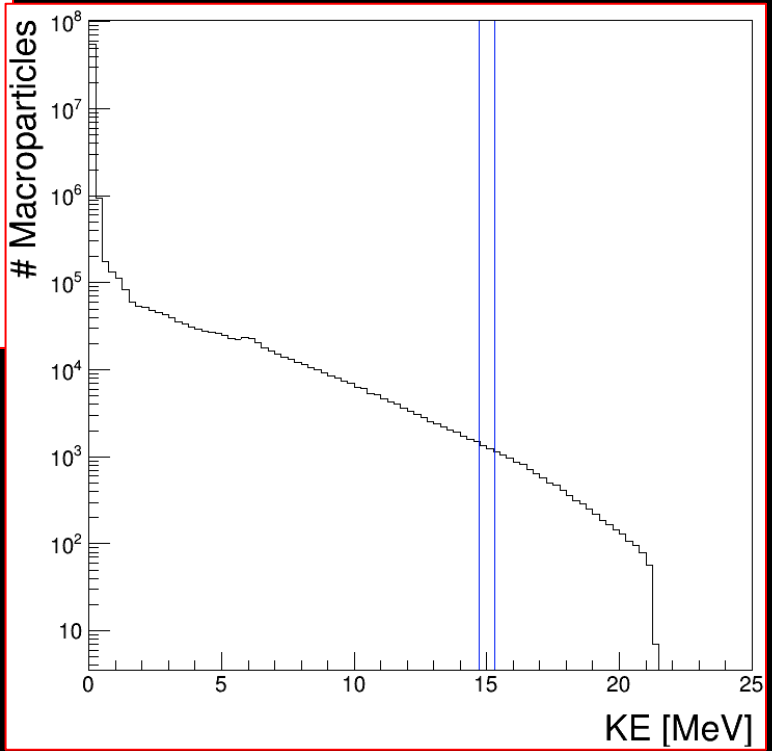
HT Lau



Ti:Sapphire commercial system >15TW
Pulse ~35fs at rep-rate of at least 10Hz
At least 500mJ laser energy - I_L ~ 1020 Wcm^{-2}

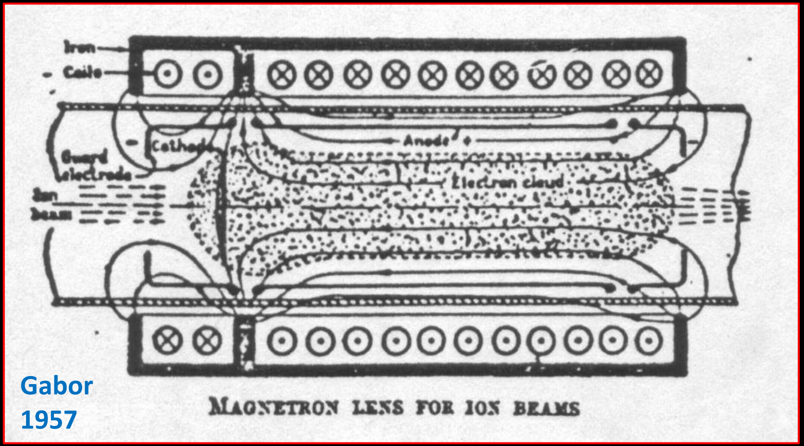
- **Requirement:**
  - Efficient capture, focusing, selection and manipulation of divergent ion beam

LhARA
Laser-hybrid Accelerator for Radiobiological Applications

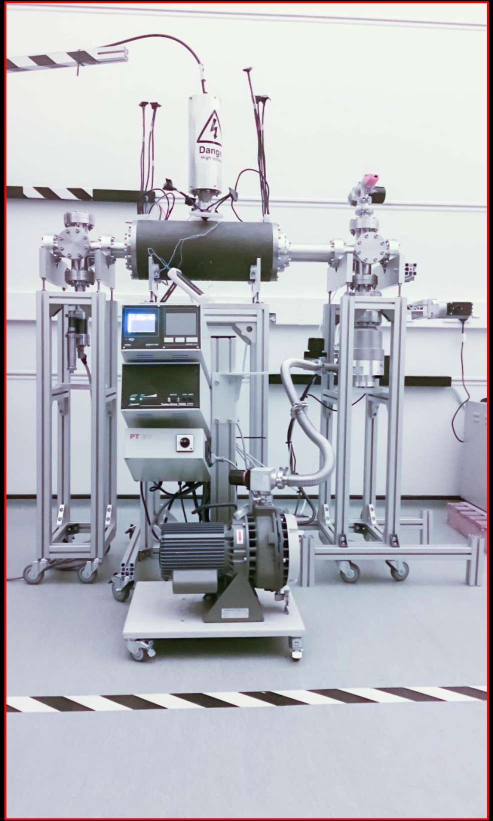
Posocco, Pozimski

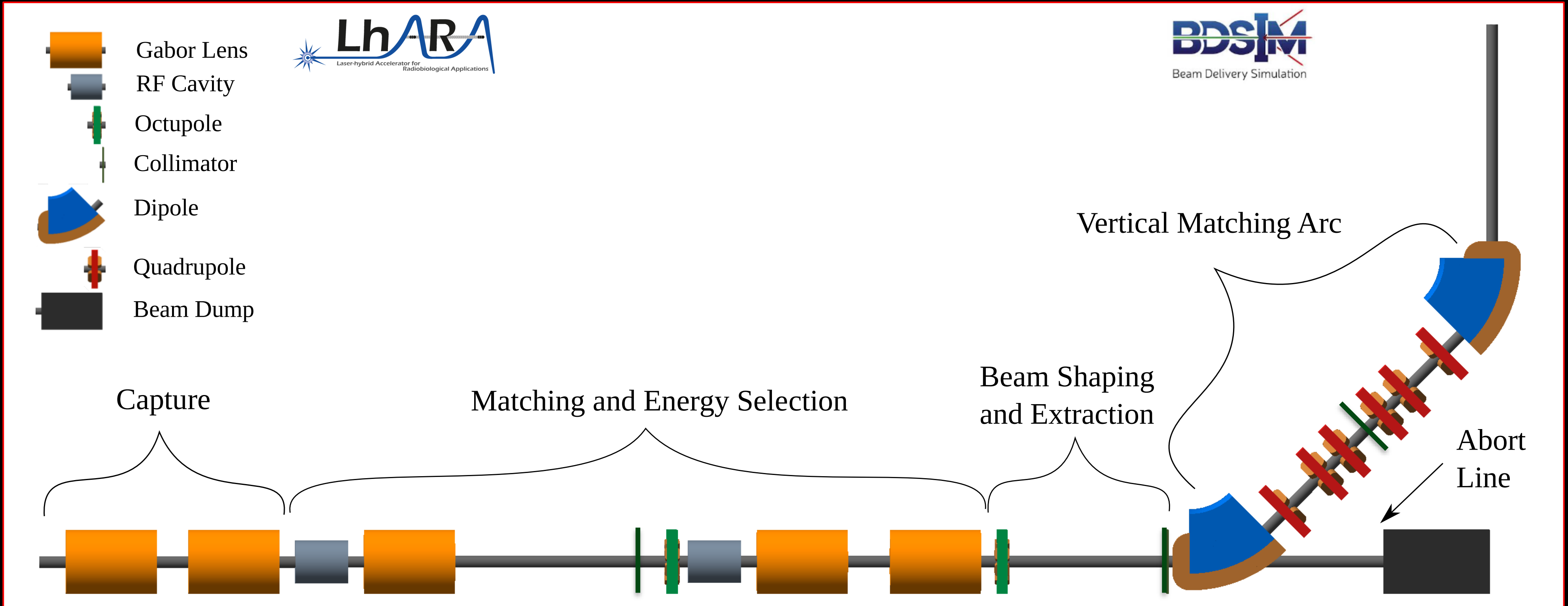
Beam capture/production principle

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



Gabor 1957





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applied sciences

MDPI

Article

Anomalous Beam Transport through Gabor (Plasma) Lens Prototype

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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

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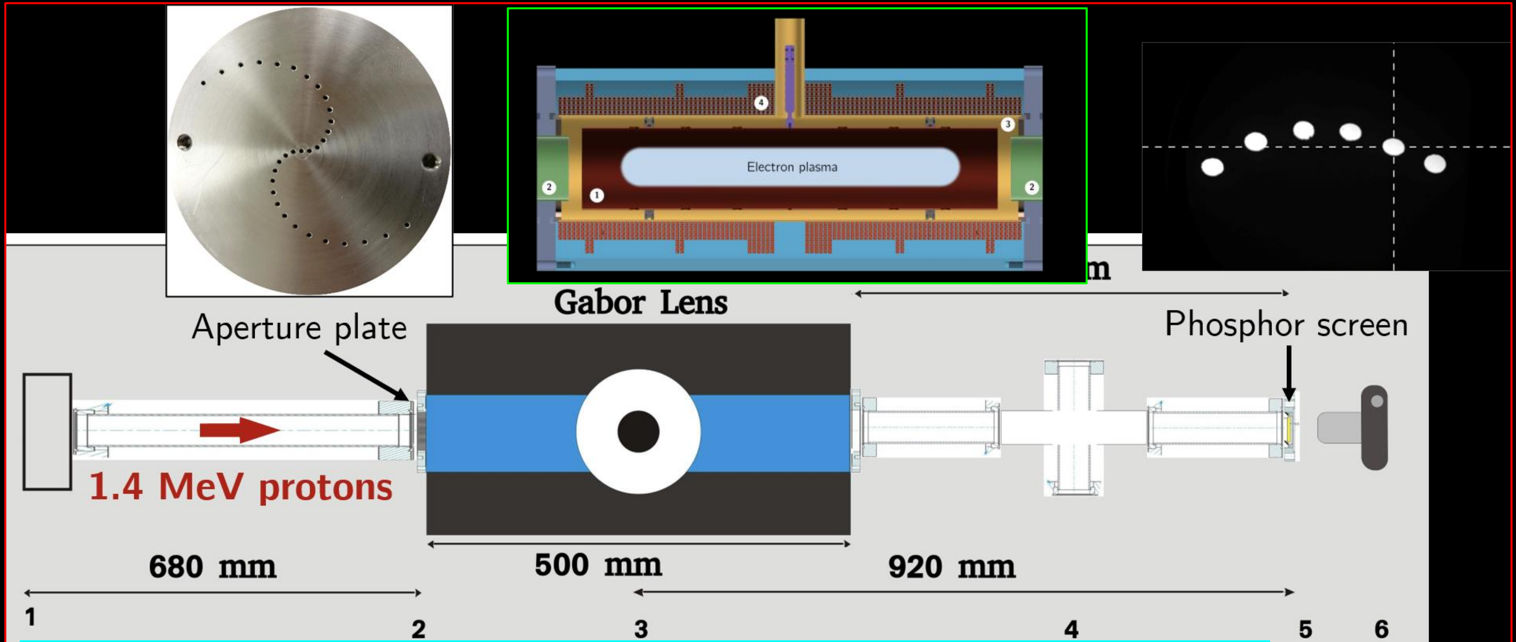
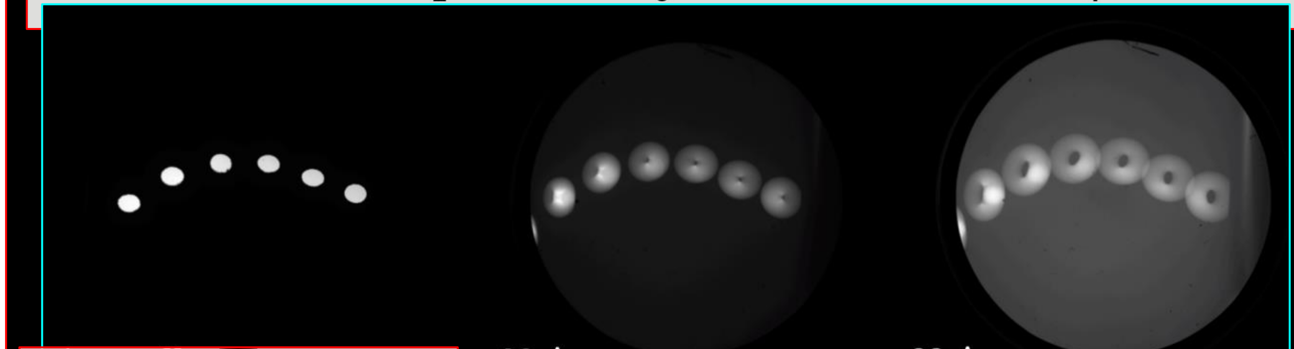
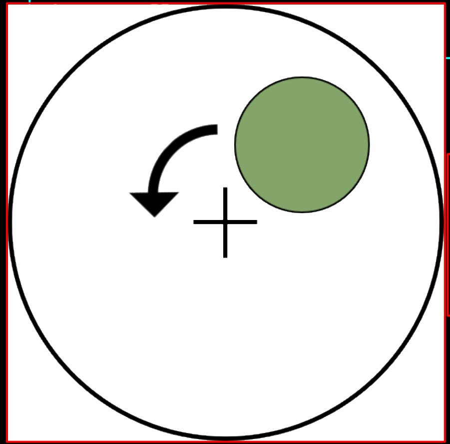
1. Introduction

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].

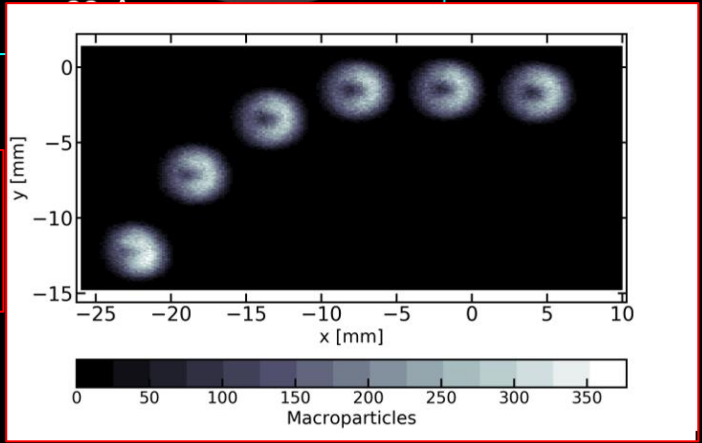
Laser-driven proton and ion sources are disruptive technologies that offer enormous potential to serve future high-flux, pulsed beam facilities [9–16]. Possible applications include proton- and ion-beam production for research, particle-beam therapy, radio-nuclide production, and ion implantation. Recent 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.







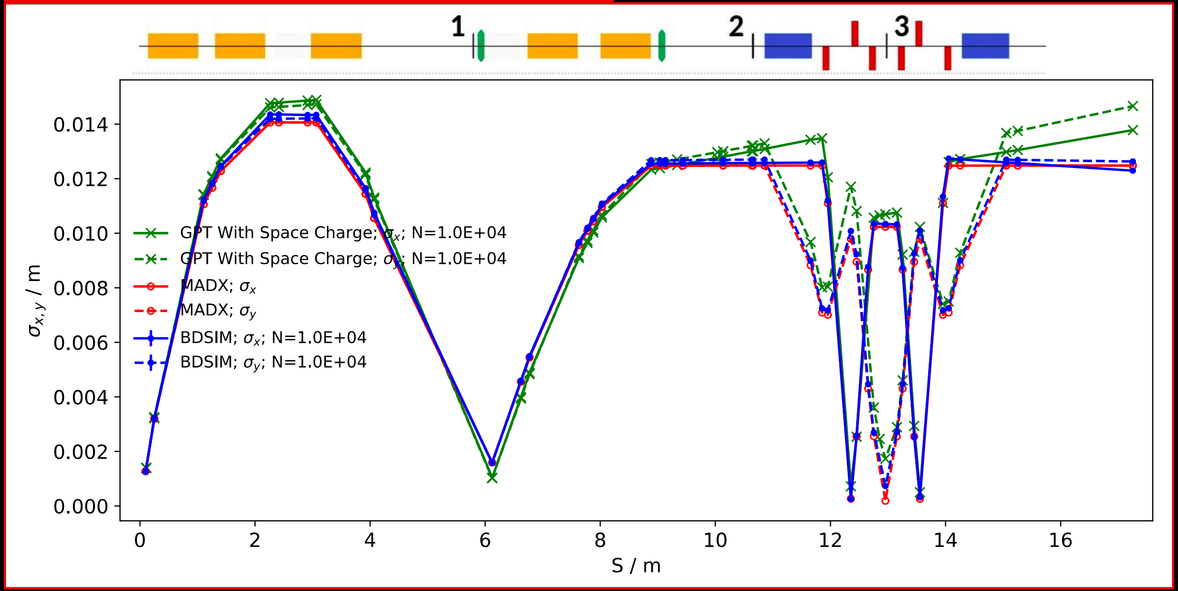
VSIM/BDSIM:
evaluation of m = 1 diocotron mode

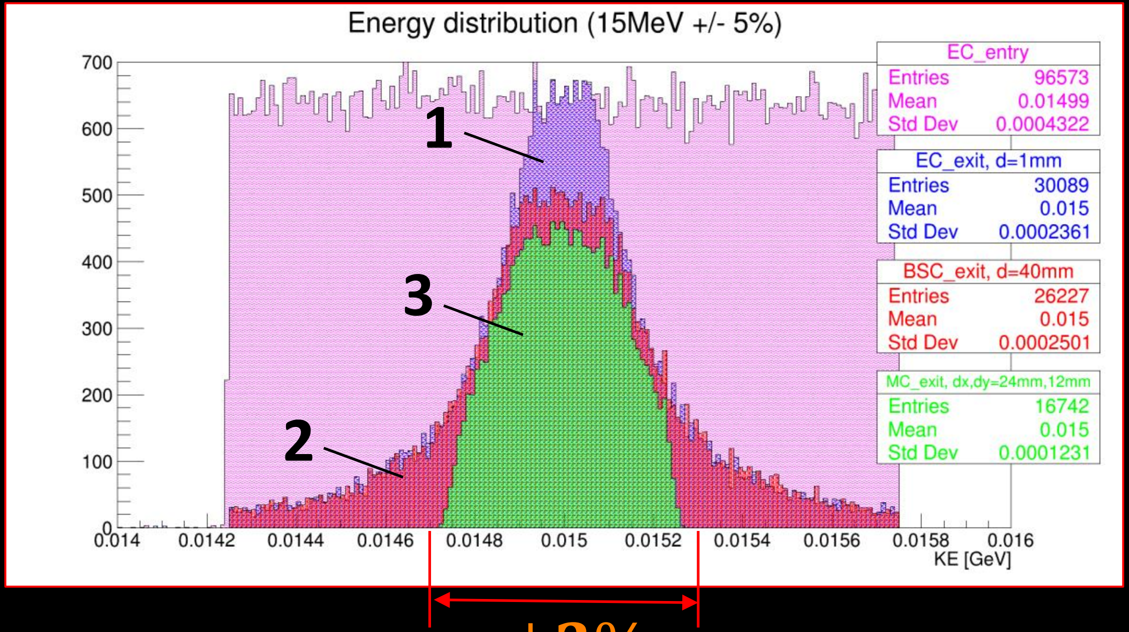


Dascalu

Energy collimation

LhARA Stage 1 beamline

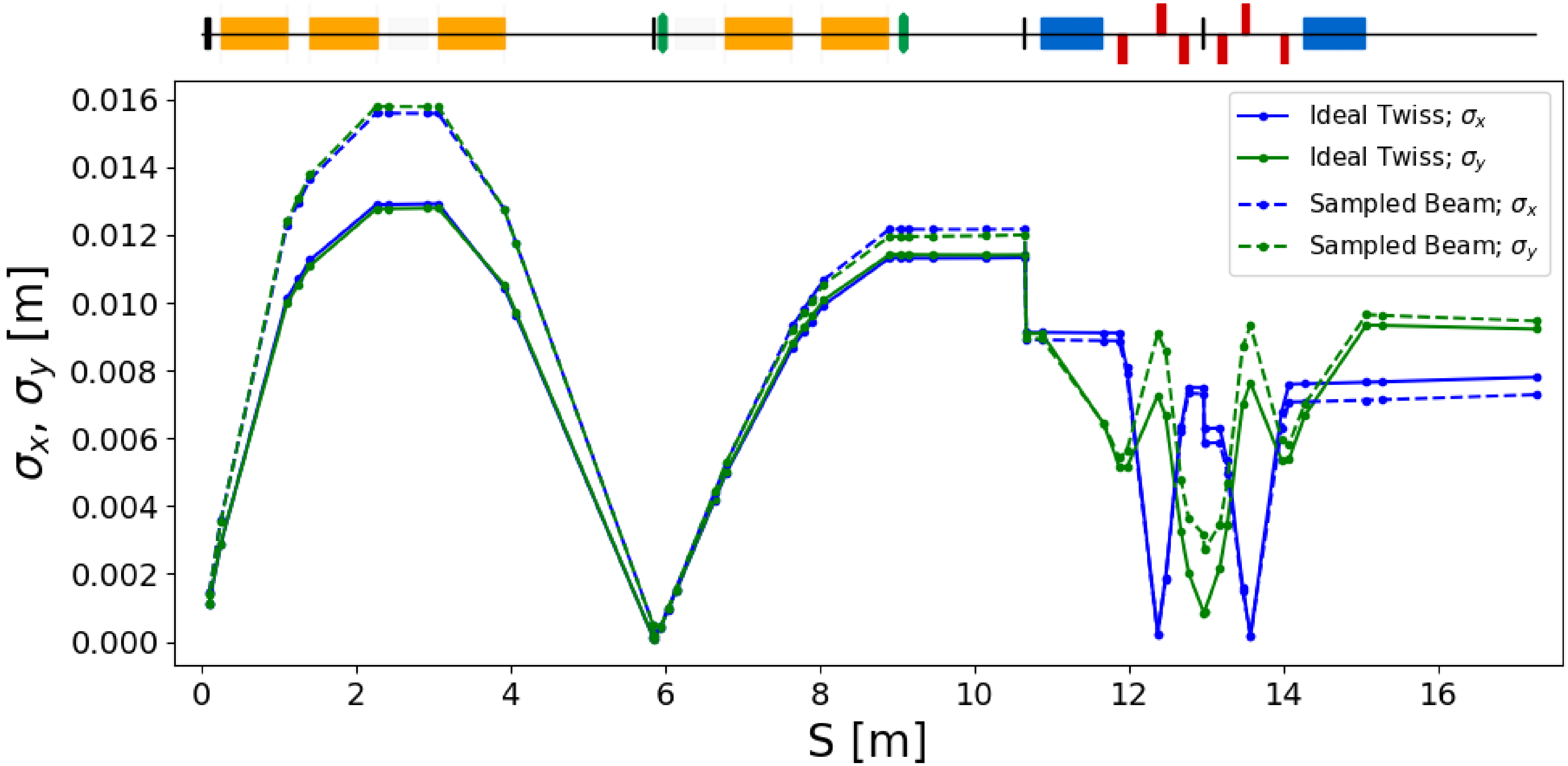




$\pm 2\%$

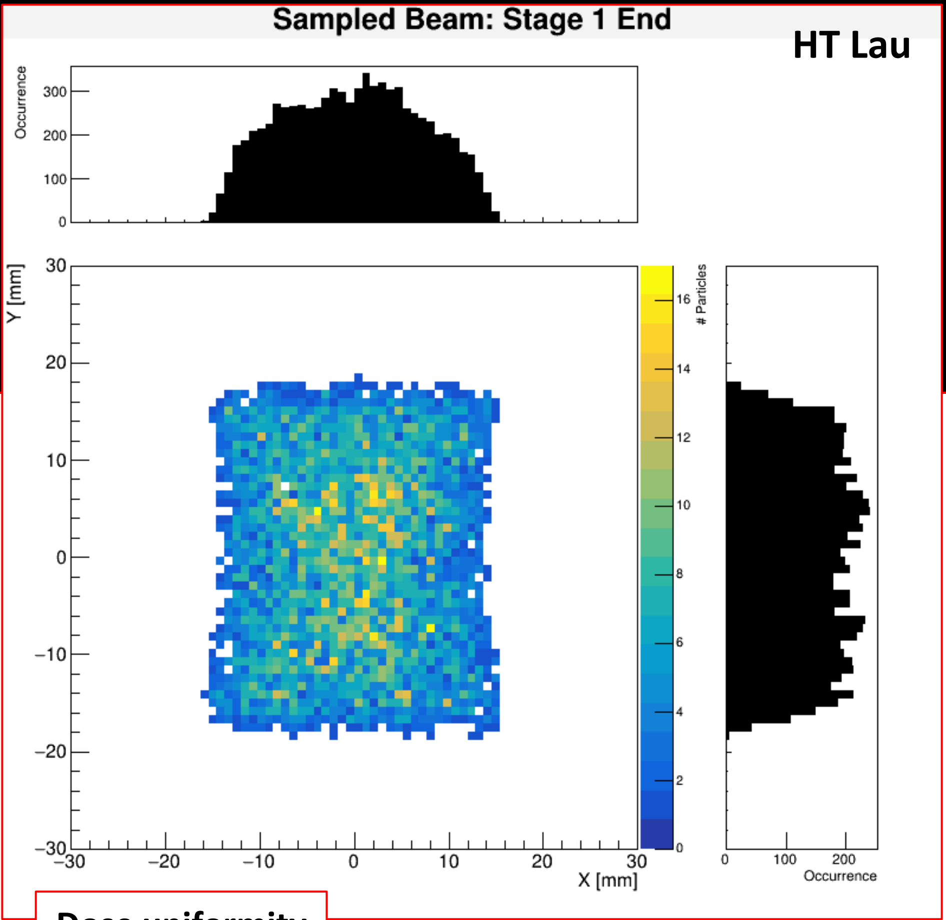
- Flat initial energy profile $15\ \mathrm{MeV} \pm 15\%$
- 3 collimators
  1. Energy collimation (at beam focus, controls energy spread)
  2. Beam shaping
  3. Momentum cleaning (removes energy tails)

Beam Size Evolution Comparison



- Ideal beam simulation repeated but included nozzle and other collimators.
- Space charge effects included for both beams.
- For energies $14.7 < \mathrm{KE} < 15.3\,\mathrm{MeV}$

LhARA; stage 1



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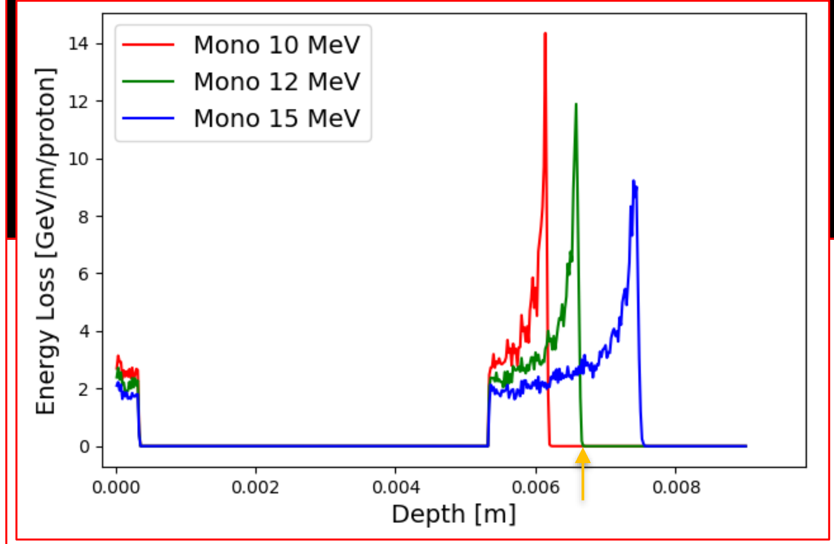
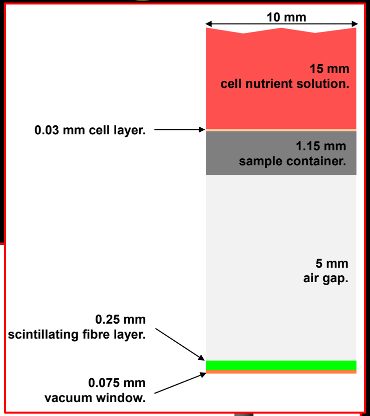
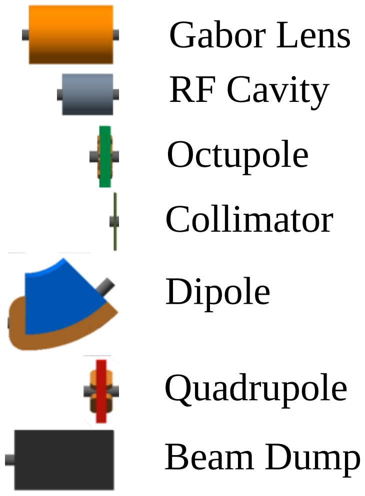
Dose uniformity at end station







Gabor Lens
RF Cavity
Octupole
Collimator
Dipole
Quadrupole
Beam Dump

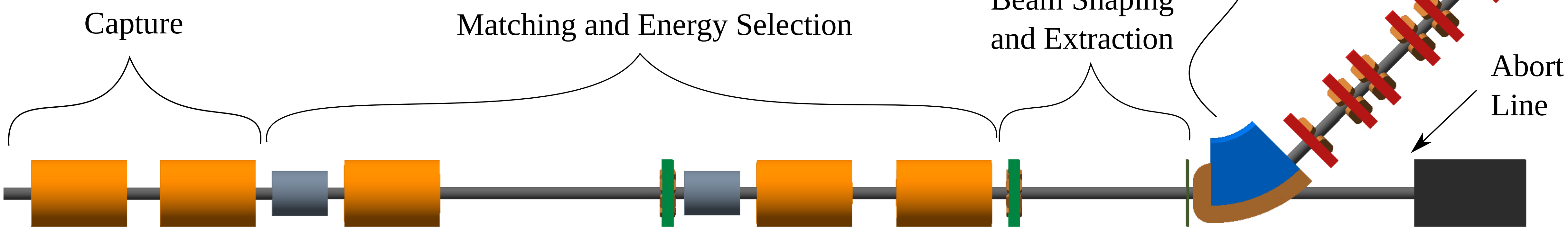
Vertical Matching Arc

Capture

Matching and Energy Selection

Beam Shaping
and Extraction

Abort
Line



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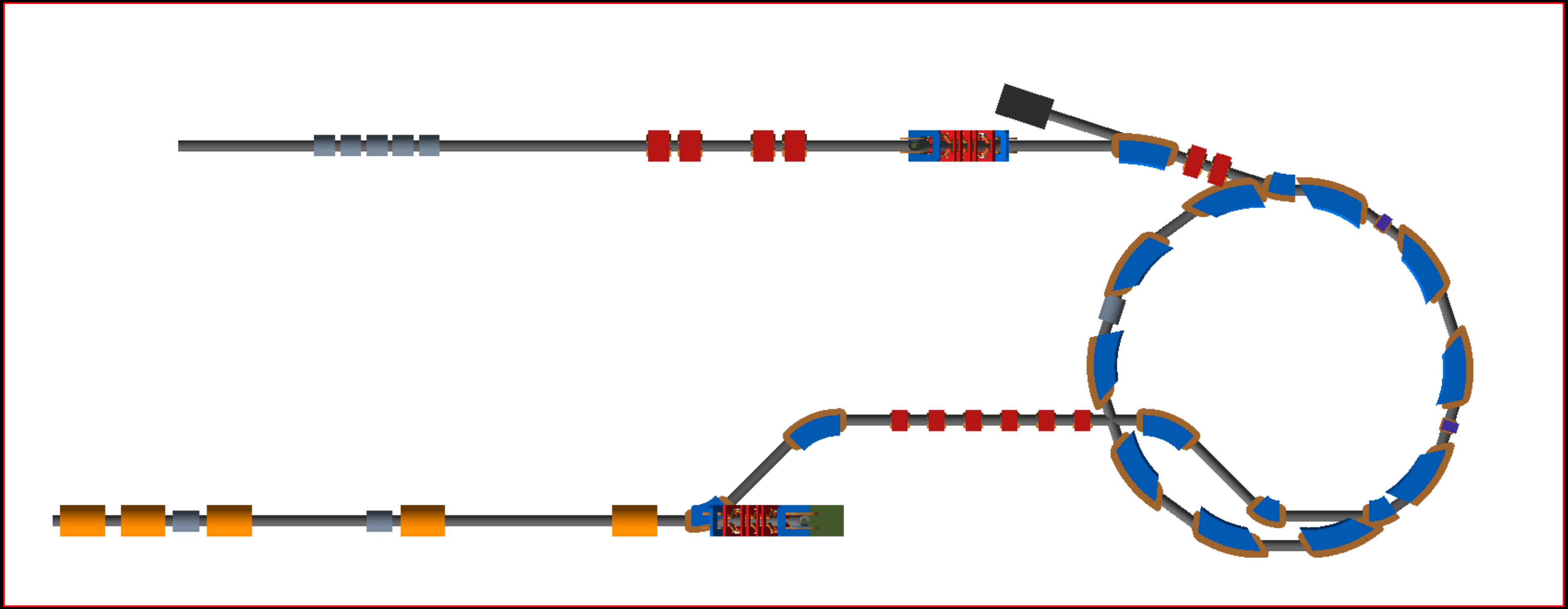
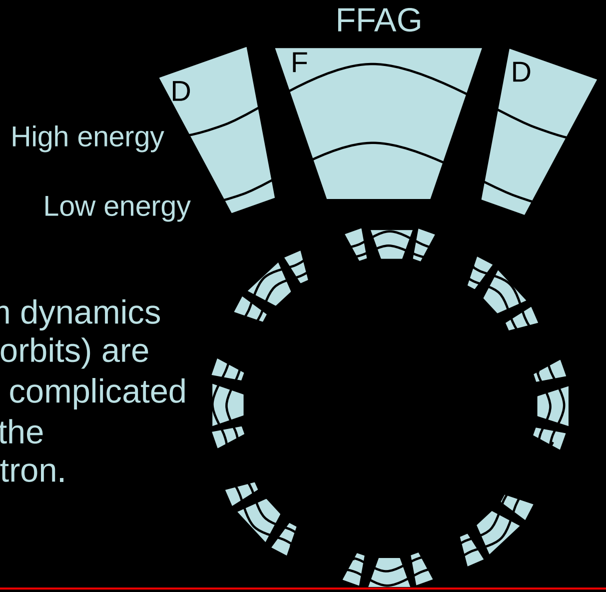
LhARA – Stage 2

- 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



Fixed Field Accelerator

- Bending magnetic fields do not vary in time.
  - Rapid acceleration.
- Alternating gradient gives strong focussing.
- Very large acceptance.
  - Useful, e.g. to accelerate muon beams.

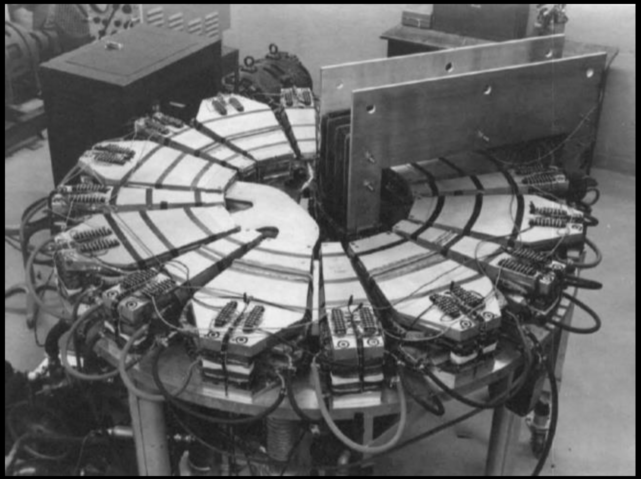


Beam dynamics (and orbits) are more complicated than the cyclotron.

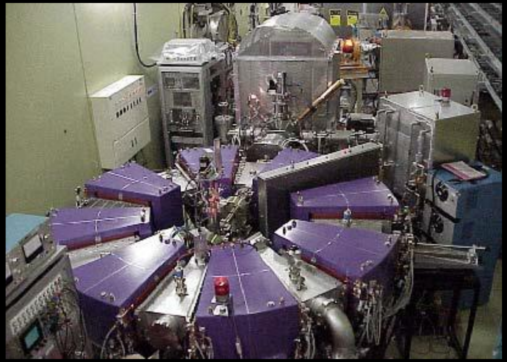
- Advantages over conventional medical cyclotron
  - Variable energy operation without energy degraders
  - Operation with different ions
  - Multiple extraction ports

FFA potted history

- **Early 1950s, FFAG developed independently:**
  - **Japan by Tihiro Ohkawa**
  - **US by Keith Symon**
  - **Russia by Andrei Kolomensky.**
- **The first prototype was operated in 1956**
  - **Jones, Terwilliger, Technical Report MURA-LWJ/KMT-5 (MURA-104), April 3, 1956.**
- **Not much activity until first proton accelerator in 2000**



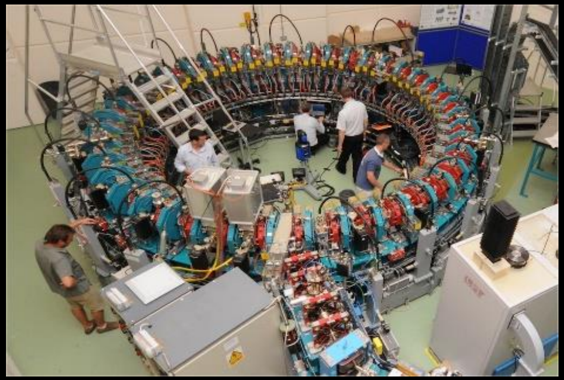
The Michigan Mark I FFA 400KeV electron accelerator was the first operational FFA.



500 keV Proton proof-of-principle FFA at KEK.

Kyoto University FFA for ADSR

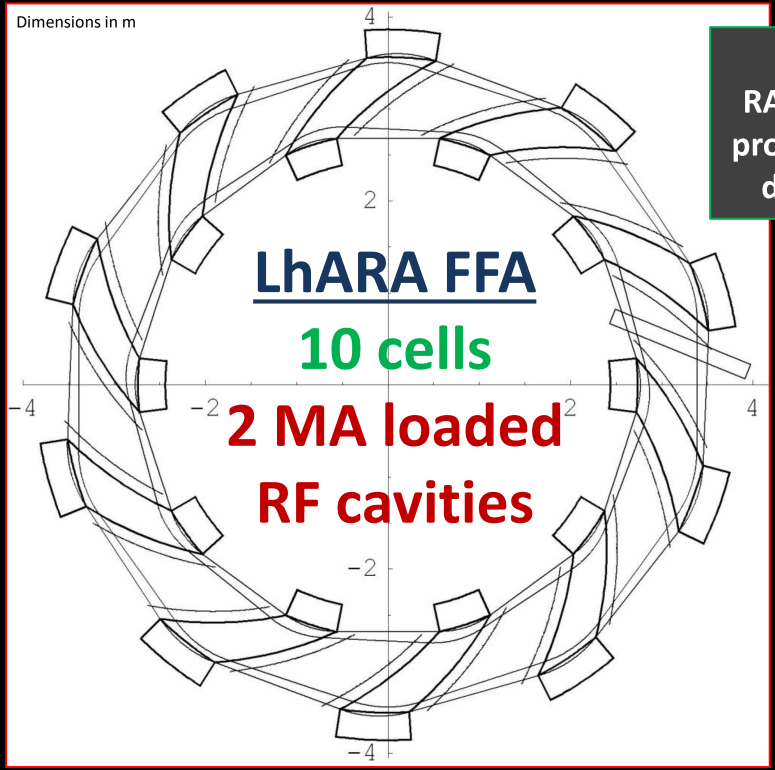
PRISM muon beam phase rotation demonstration ring at Osaka.



EMMA at Daresbury

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 pop, EMMA, at DL

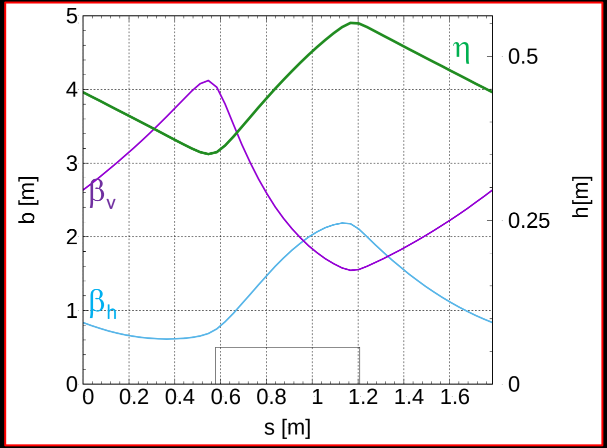


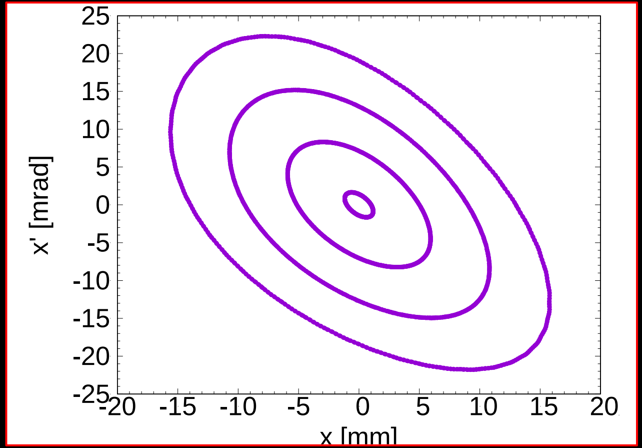
LhARA FFA

10 cells

2 MA loaded RF cavities

Evolution of RACCAM design; prototype magnet demonstrated





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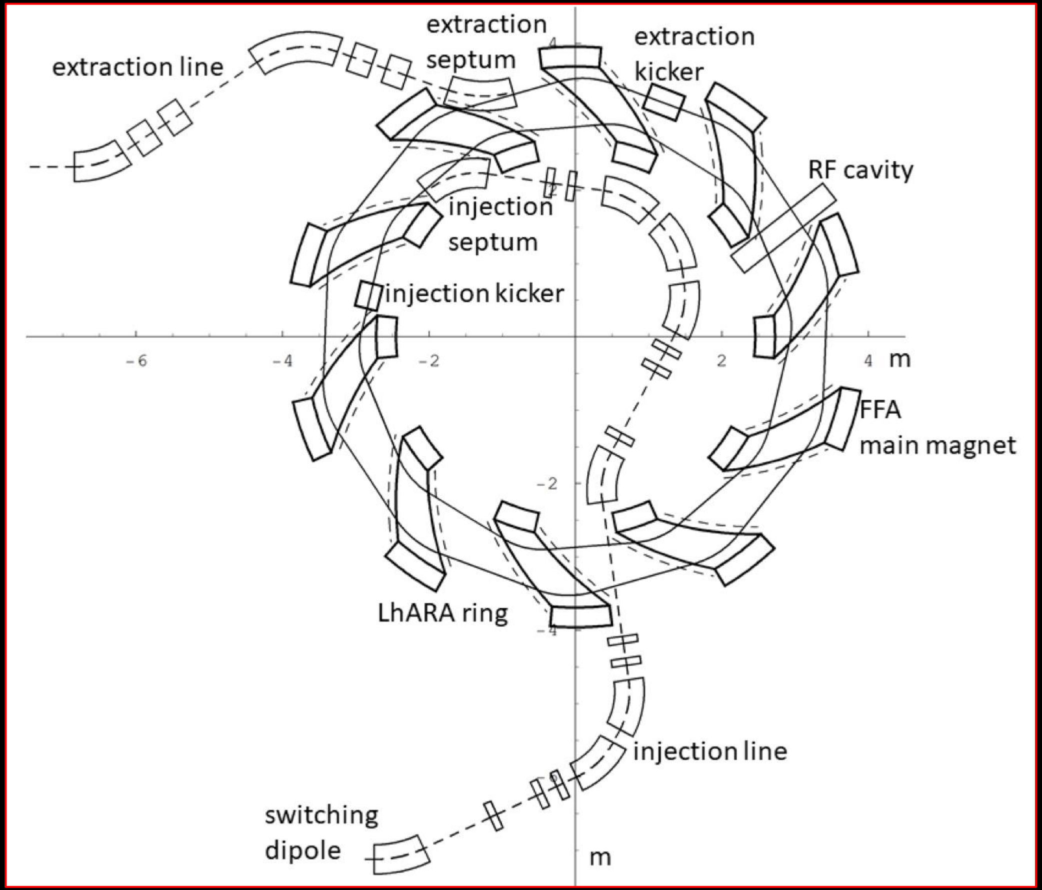
FFA for acceleration in LhARA – Stage 2

- **Baseline:** x3 increase in momentum
  - 15 MeV protons accelerated to 127 MeV
  - 3.8 MeV/u carbon 6+ ions accelerated to 34 MeV/u



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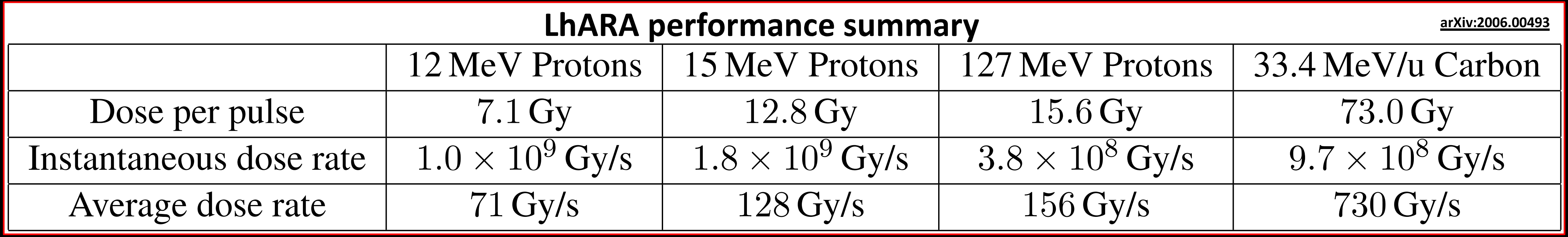
LhARA performance: doses and dose rates



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

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Perspectives on laser-driven sources for particle beam therapy

CONCLUSIONS

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"

- 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

Acknowledgements

Imperial College London

Department of Physics
Faculty of Medicine

ICR The Institute of Cancer Research

Medical Research Council
Oxford Institute for Radiation Oncology

UKRI

University of Oxford

JAI John Adams Institute for Accelerator Science

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

QUEEN'S UNIVERSITY BELFAST

UNIVERSITY OF LIVERPOOL

Lancaster University

University of Strathclyde Glasgow
DEPARTMENT OF PHYSICS

UCL MEDICAL PHYSICS & BIOMEDICAL ENGINEERING

ROYAL HOLLOWAY UNIVERSITY OF LONDON

University – Clinical – Laboratory – Industry – Accelerator

Partners

NHS University Hospitals Birmingham NHS Foundation Trust

NHS The Clatterbridge Cancer Centre NHS Foundation Trust

institut Curie

UKRI Science and Technology Facilities Council

ASTeC
Particle Physics Department
ISIS Neutron and Muon Source

INFN CATANIA

CLF central laser facility

Swansea University Prifysgol Abertawe

UNIVERSITY OF BIRMINGHAM | POSITRON IMAGING CENTRE

UNIVERSITY OF BIRMINGHAM | CYCLOTRON FACILITY

The Cockcroft Institute of Accelerator Science and Technology

Corerain 鲲云科技

The Rosalind Franklin Institute

NPL National Physical Laboratory

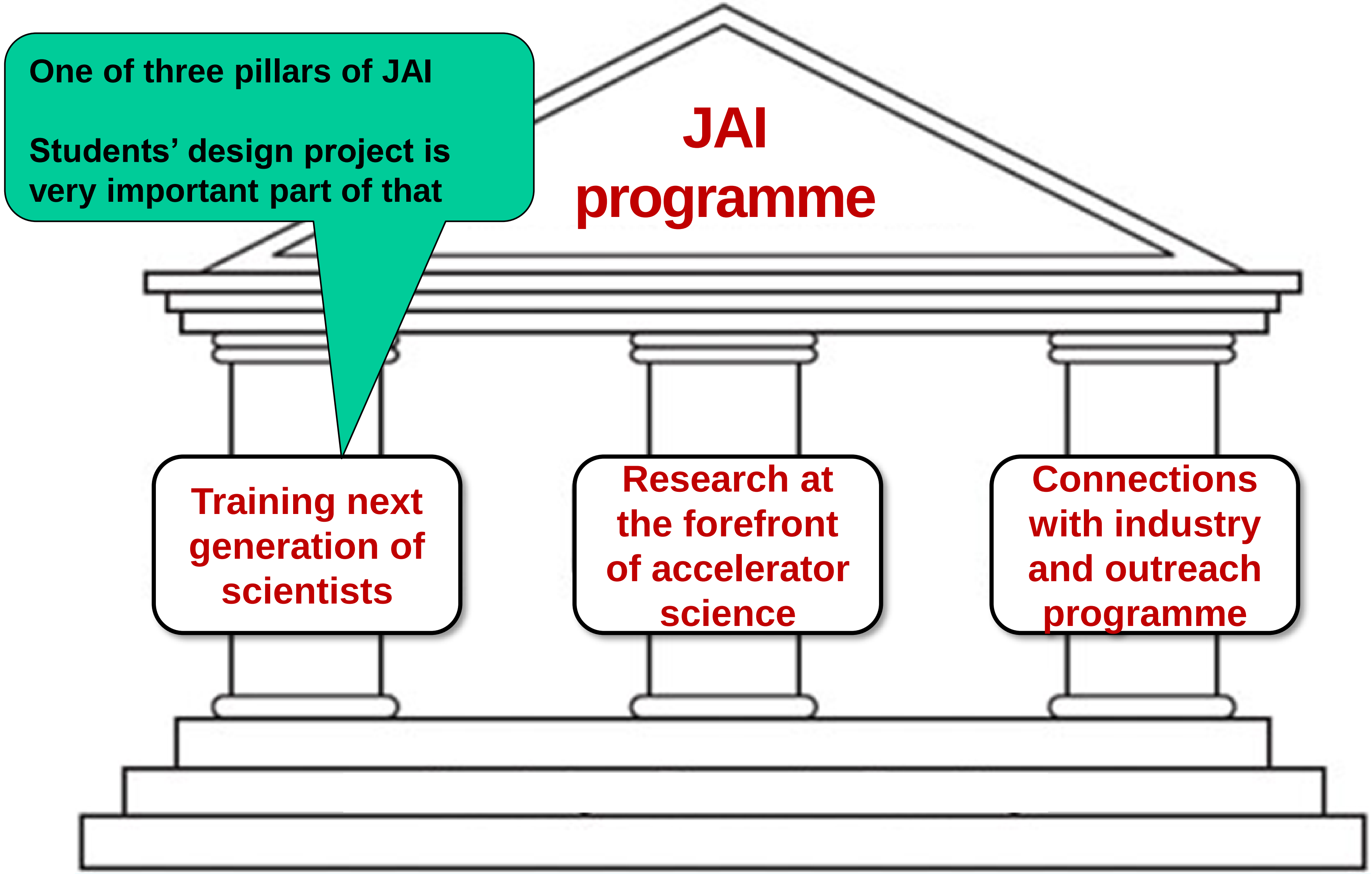
LEO Cancer Care

MAXELER Technologies Maximum Performance Computing

LhARA Laser-hybrid Accelerator for Radiobiological Applications

JAI Training

Foundation of the JAI Programme



One of three pillars of JAI

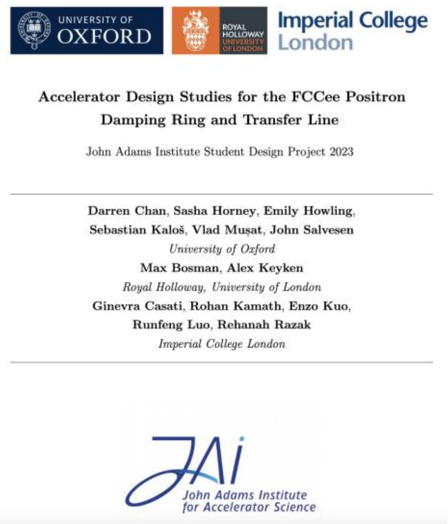
Students’ design project is very important part of that

Accelerator Design Project

- **Accelerator Design Study for**
  - **Electron SPS: 2020-2021**
  - **FCC-ee Booster Ring: 2021-2022**
  - **FCC-ee Positron Damping Ring: 2022-2023**
  - **Design work consisted of study of the lattice, magnet systems and RF cavities.**

"The design project significantly contributes to the value of a PhD at the JAI and is a very effective learning tool ... it played an essential role in helping me to find a postdoc."

"To me, the design project was by far the best part of the course. It puts the material taught into context and bridges the gap between lectures ... and a DPhil project ... ."



Accelerator Design Studies for the FCCee Positron Damping Ring and Transfer Line

John Adams Institute Student Design Project 2023

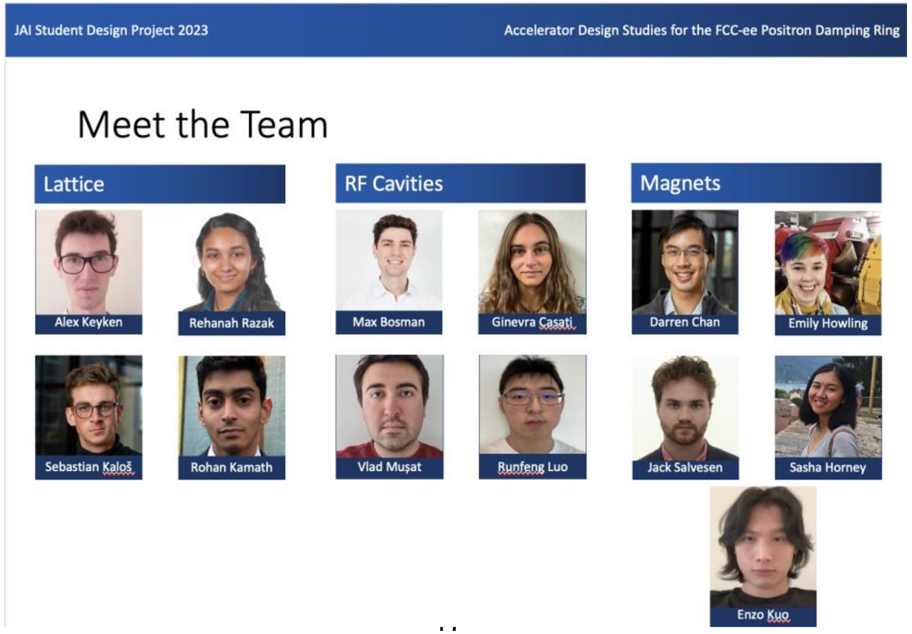
Darren Chan, Sasha Horney, Emily Howling, Sebastian Kaloš, Vlad Mușat, John Salvesen
University of Oxford
Max Bosman, Alex Keyken
Royal Holloway, University of London
Ginevra Casati, Rohan Kamath, Enzo Kuo, Runfeng Luo, Rehanah Razak
Imperial College London

<u>For 2022-2023:</u>

FCC-ee Positron Damping Ring Design Report published on CDS **(10.17181/CERN.E06E.3CHI)**

Students delivered JAI Seminar on 9 March 2023.

Student Poster at FCC Week, London June 2023



JAI Student Design Project 2023 Accelerator Design Studies for the FCC-ee Positron Damping Ring

Meet the Team

Lattice: Alex Keyken, Rehanah Razak, Sebastian Kaloš, Rohan Kamath

RF Cavities: Max Bosman, Ginevra Casati, Vlad Mușat, Runfeng Luo

Magnets: Darren Chan, Emily Howling, Jack Salvesen, Sasha Horney, Enzo Kuo

LhARA Student Design Project Plan

Studies for Stage 1

- Gabor Lens
  - Study particle production/focusing from source
- Optics Studies
  - Optimisation of lattice (phase space, final focusing for beam spot)
- Magnet Design
  - Optimise dipole and quadrupole magnets (sustainable designs).
- RF System
  - Design of RF system.

Many thanks to Prof. Ken Long / Imperial College London for the slides on LhARA.