Status of the pre-CDR

LhARA Steering Group Meeting

Ajit Kurup

1st May 2020

Centre for the Clinical Application of Particles

Imperial College London

Introduction

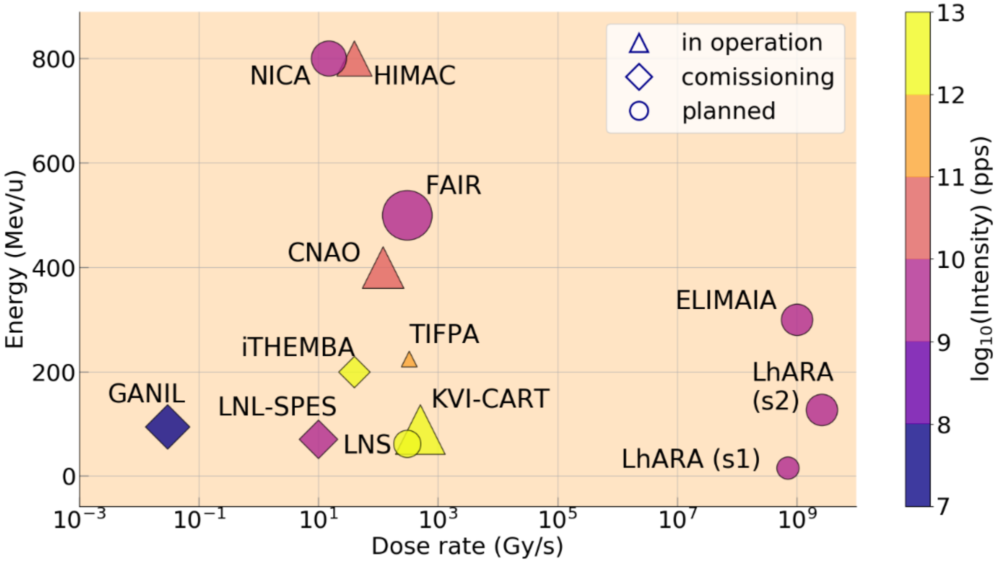
- Status of the pre-CDR.
  - It’s finalised!
  - Published as technical note CCAP-TN-01
    - Technical notes page on the wiki:
      - https://ccap.hep.ph.ic.ac.uk/trac/wiki/Communication/Notes
    - Link to the document:
      - https://ccap.hep.ph.ic.ac.uk/trac/raw-attachment/wiki/Communication/Notes/CCAP-TN-01.pdf

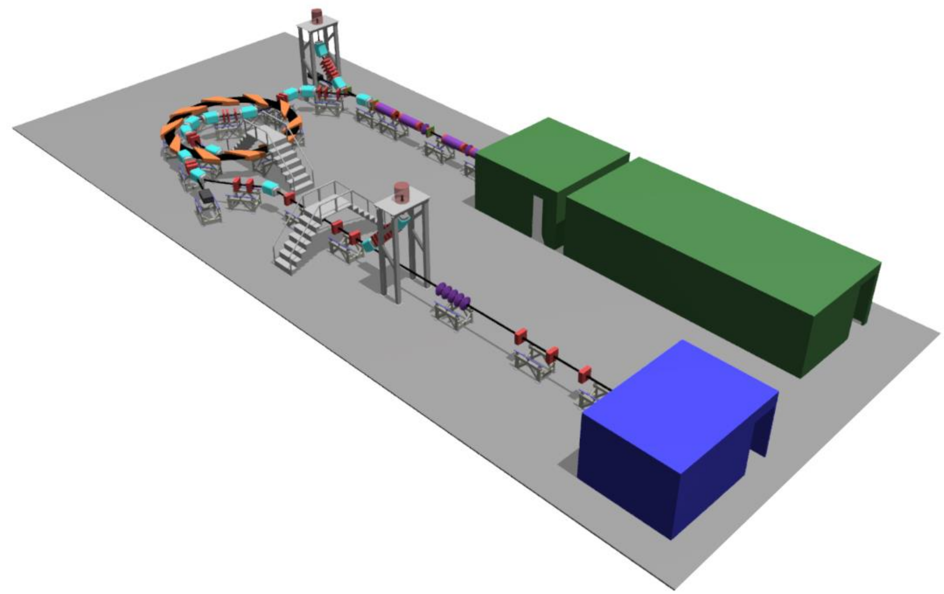
- Overview of the pre-CDR.

- R&D plan and project schedule.

Introductory bits

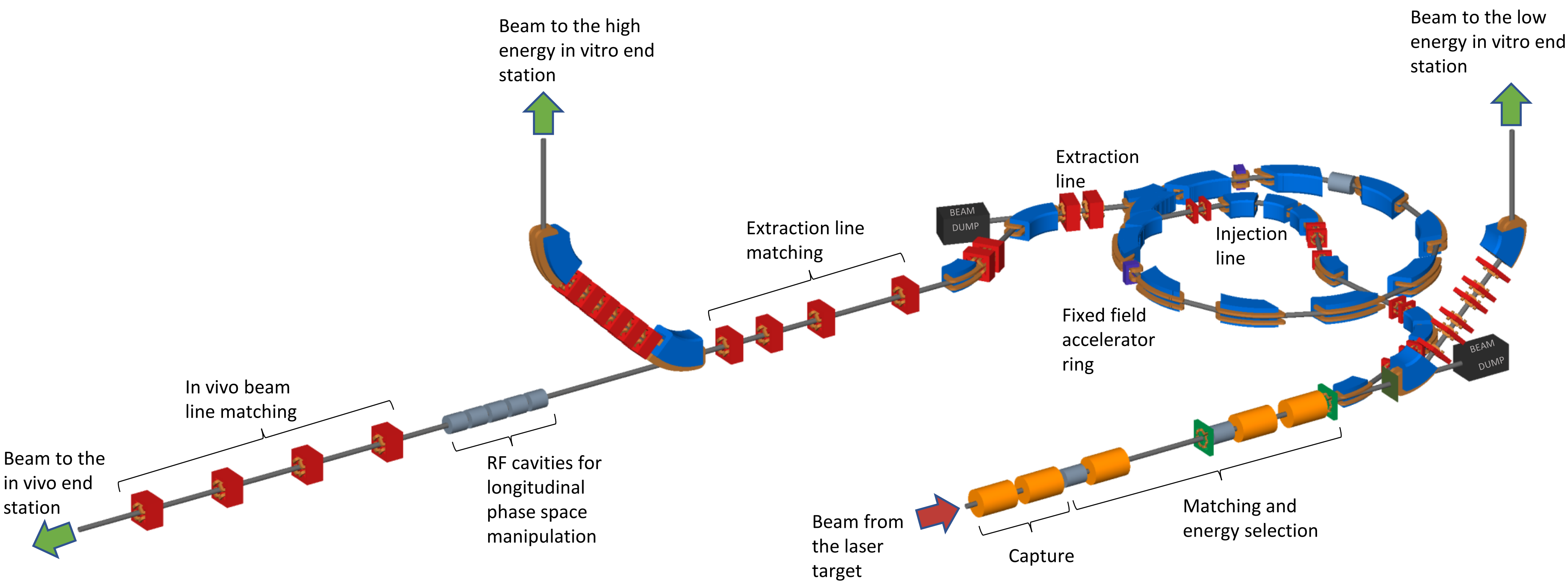
- Executive summary





- Lay summary
  - Written by Gareth Jones (Emeritus Professor in the Physics department, Imperial) who is a member of the Imperial Patient and Public Involvement Group.

The LhARA Facility overview – accelerator



The LhARA Facility overview – design parameters

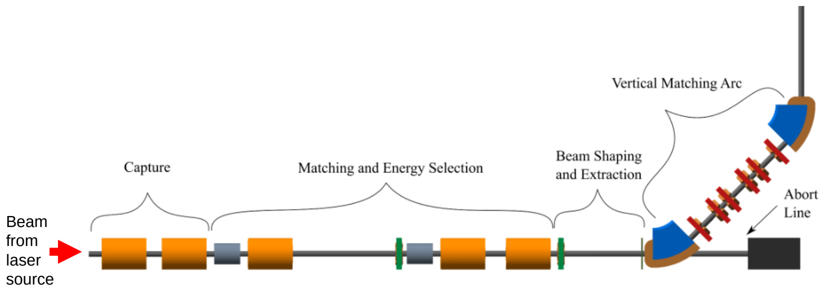
Parameter	Value or range	Unit
Laser driven proton and ion source		
Laser power	100	TW
Laser Energy	1	J
Laser pulse length	30	fs
Laser rep. rate	10	Hz
Proton energy	15	MeV
Proton and ion capture		
Beam divergence to be captured	50	mrad
Gabor lens effective length	0.857	m
Gabor lens length (end-flange to end-flange)	1.157	m
Gabor lens cathode radius	0.0365	m
Gabor lens maximum voltage	65	kV
Number of Gabor lenses	2	
Alternative technology: solenoid length	1.157	m
Alternative technology: solenoid max field strength	1.3	T
Stage 1 beam transport: matching & energy selection, beam delivery to low energy end station		
Number of Gabor lenses	3	
Number of re–bunching cavities	2	
Number of collimators for energy selection	1	
Arc bending angle	90	Degrees
Number of bending magnets	2	
Number of quadrupoles in the arc	6	
Alternative technology: solenoid length	1.157	m
Alternative technology: solenoid max field strength (to serve the injection line to the Stage 2)	0.8 (1.4)	T

The LhARA Facility overview – design parameters

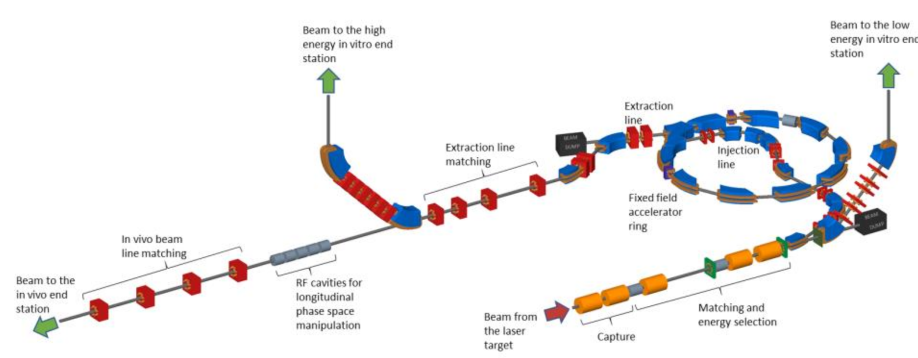
Parameter	Value or range	Unit
Stage 2 beam transport: FFA, transfer line, beam delivery to high-energy endstations		
Number of bending magnets in the injection line	7	
Number of quadrupoles in the injection line	10	
FFA: Machine type	single spiral scaling FFA	
FFA: Extraction energy	20-127	MeV
FFA: Number of cells	10	
FFA: Orbit R_{min}	2.92	m
FFA: Orbit R_{max}	3.48	m
FFA: External R	4	m
FFA: Number of RF cavities	2	
FFA: RF frequency	1.46-6.48	MHz
FFA: spiral angle	48.7	Degrees
FFA: Max B field	1.4	T
FFA: k	5.33	
FFA: Magnet packing factor	0.34	
FFA: Magnet gap	0.047	m
FFA: Number of kickers	2	
FFA: Number of septa	2	
Number of bending magnets in the extraction line	2	
Number of quadrupoles in the extraction line	8	
Arc bending angle	90	Degrees
Number of bending magnets in the vertical arc	2	
Number of quadrupoles in the vertical arc	6	
Number of cavities for longitudinal phase space manipulation	5	
Number of quadrupoles in the in vivo beam line	4	
In vitro biological end stations		
Maximum input beam diameter	1-3	cm
Input beam energy spread	< 2	%
Input beam uniformity	< 5	%
Scintillating fibre layer thickness	0.25	mm
Air gap length	5	mm
Cell culture plate thickness	1.15	mm
Cell layer thickness	0.03	mm
Cell nutrient solution	15	mm
Number of end stations	2	
In vivo biological end station		
Maximum input beam diameter	1-3	cm
Input beam energy spread	< 2	%
Input beam uniformity	< 5	%
Beam options	Spot-scanning, passive scattering, micro-beam	

Staging

- Construction will be done in two stages.



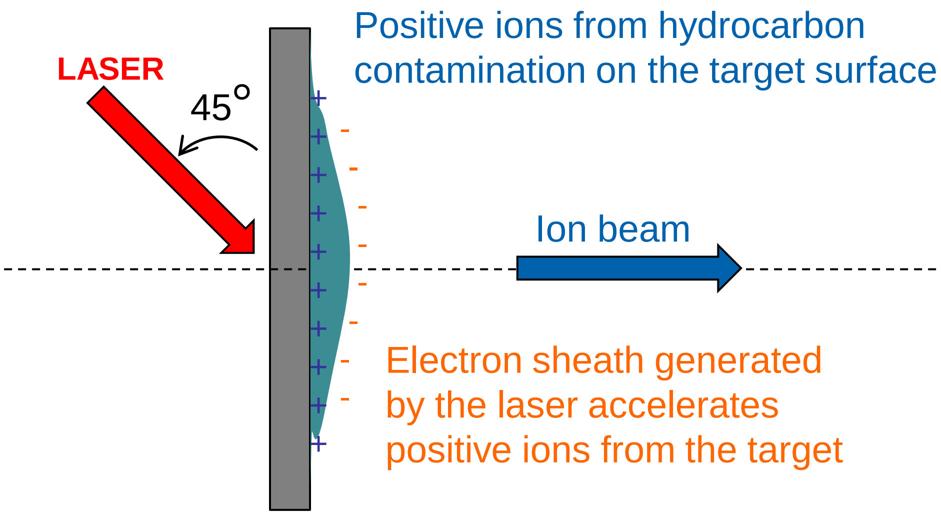
Stage 1



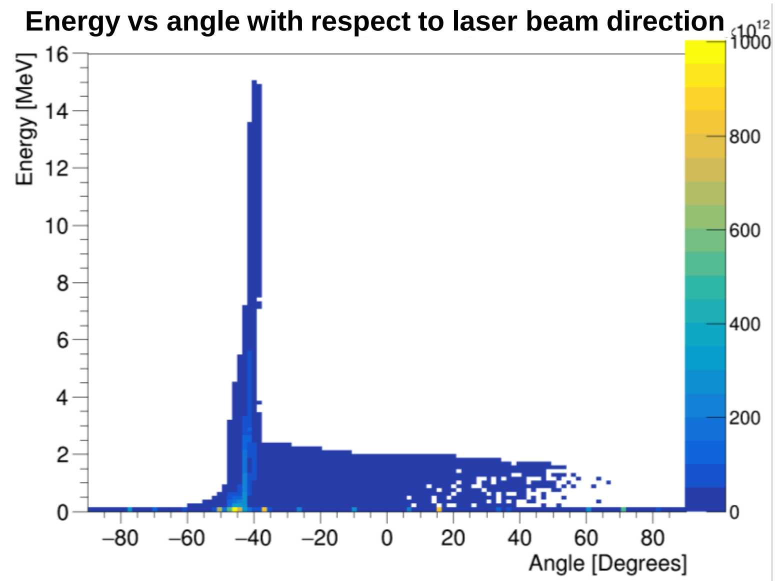
Stage 2

- The goal is maximise scientific output.
  - Generate scientific output during construction of Stage 1.
  - Radiobiology programme using Stage 1 whilst constructing Stage 2.

Laser source



Principle of target normal sheath acceleration (TNSA) using a thin foil target.

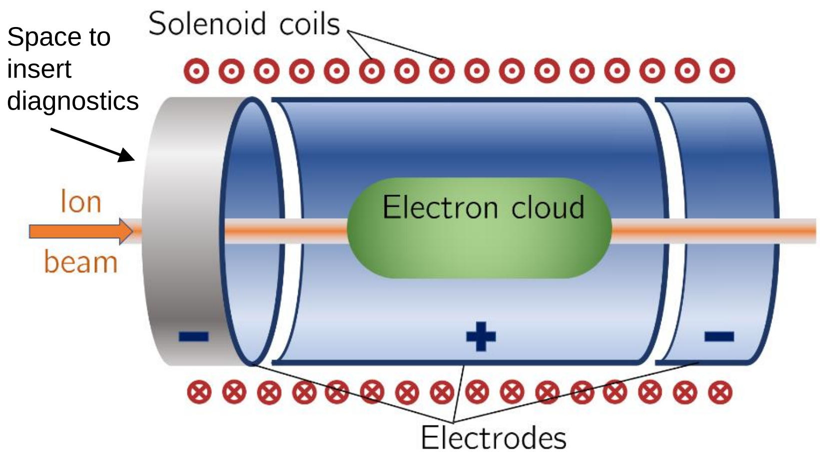


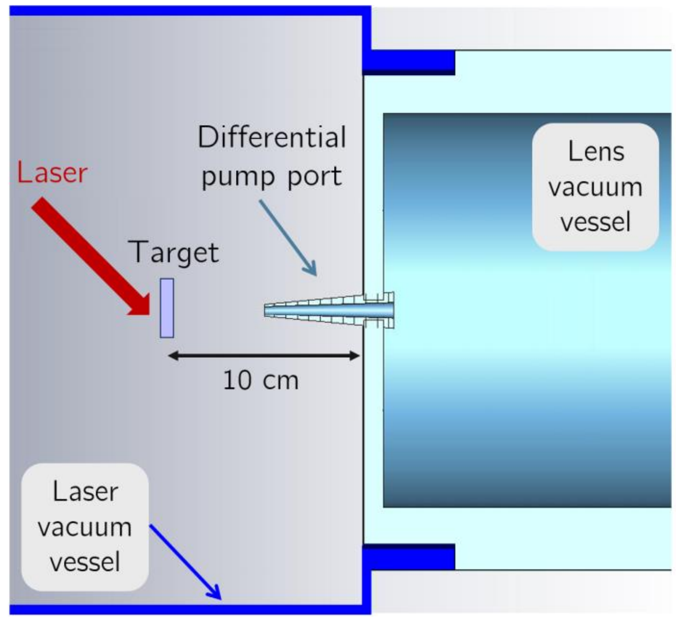
Laser driven ion beam simulation using EPOCH.

- Produces intense beams and multiple species, e.g. proton and carbon ions.
  - Overcome space charge limit of conventional sources since beams are produced with energies *O*(10) MeV.
- Issues to consider
  - Large energy spread.
  - Large divergence.
  - Beam instability, especially if laser operated near the limits of its specifications.

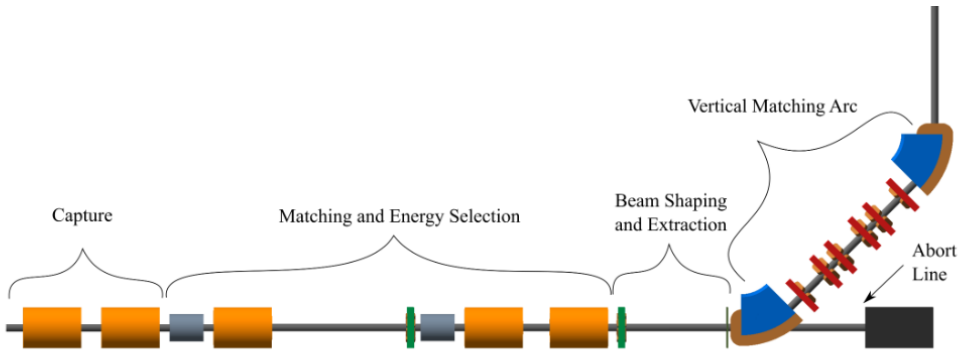
Capture

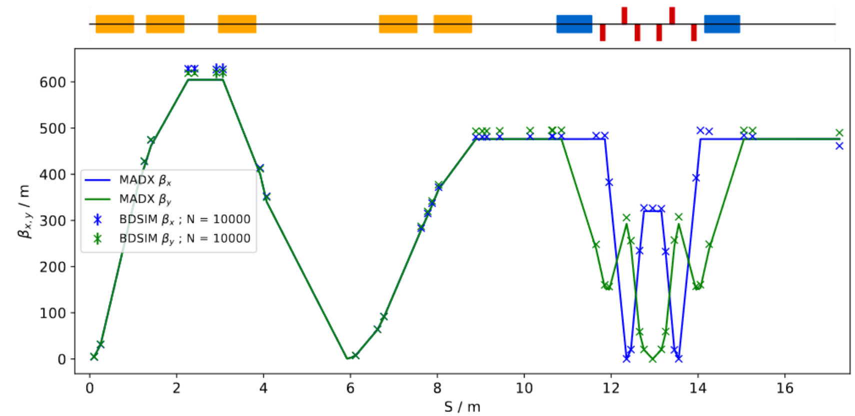
- The Gabor lens uses a plasma to generate a strong electro-static focusing field.
- Focal point is energy dependent.
- R&D programme includes:
  – First generation prototype.
  – Second generation prototype.
  – Theoretical studies.
  – Development of diagnostics.

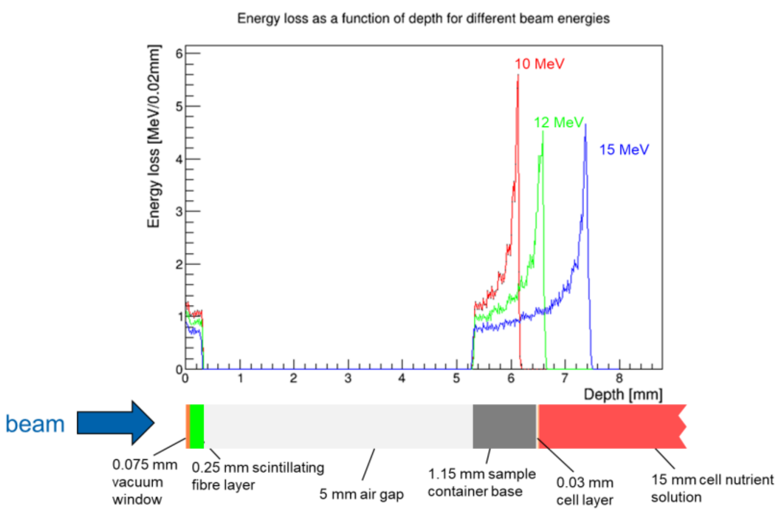


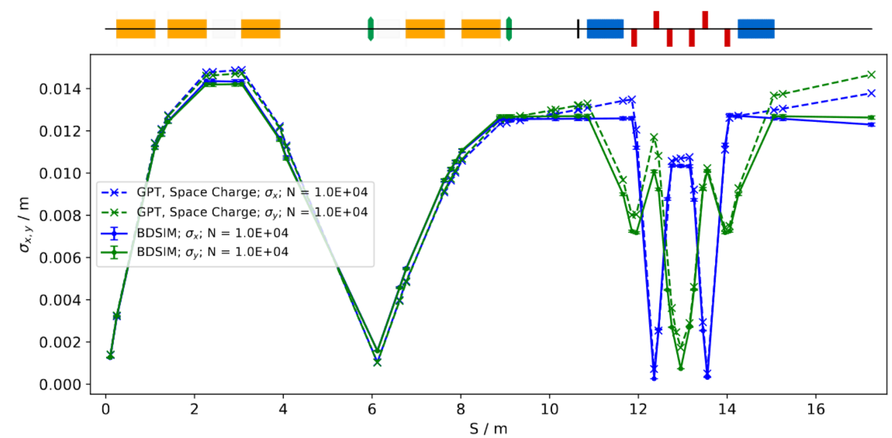


Beam transport – Stage 1

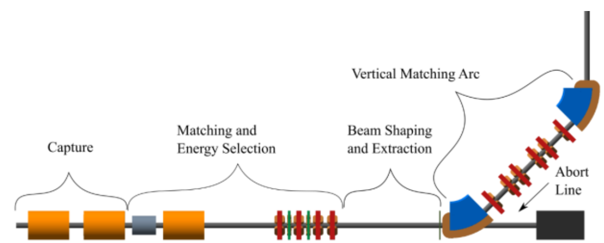








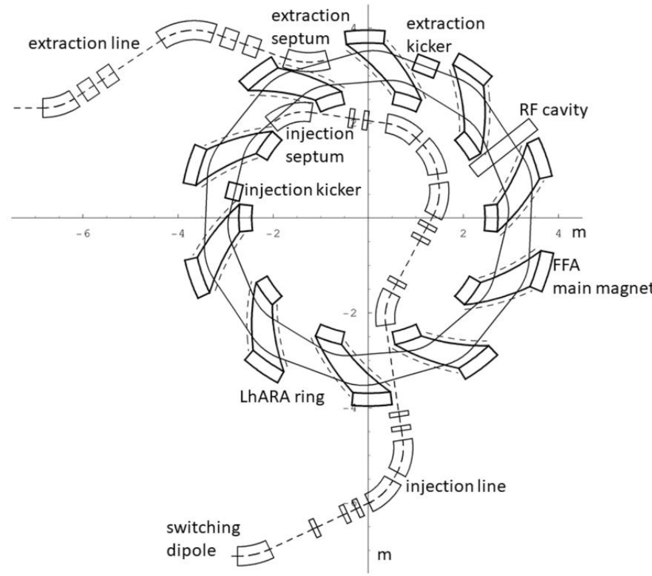
- Optics design: BeamOptics and MADX.
- Particle tracking simulations: BDSIM and GPT.
- Energy deposition in the end station: BDSIM.



Alternative design

Beam transport – Stage 2

- Post acceleration done using an Fixed field accelerator (FFA).
  - Spiral FFA.
- Injection and extraction lines for the FFA.
- High energy arc for in-vitro end station.
- In-vivo beam line.



	40 MeV protons (Nominal)	127.4 MeV protons (Nominal)	127.4 MeV protons (Pessimistic)
RMS Emittance (ϵ_x, ϵ_y) [π mm mrad]	0.137	0.137	1.37
β [m] for a 1 mm spot size	0.46	0.46	0.039
β [m] for a 10 mm spot size	46	46	4.5
β [m] for a 30 mm spot size	410	410	40

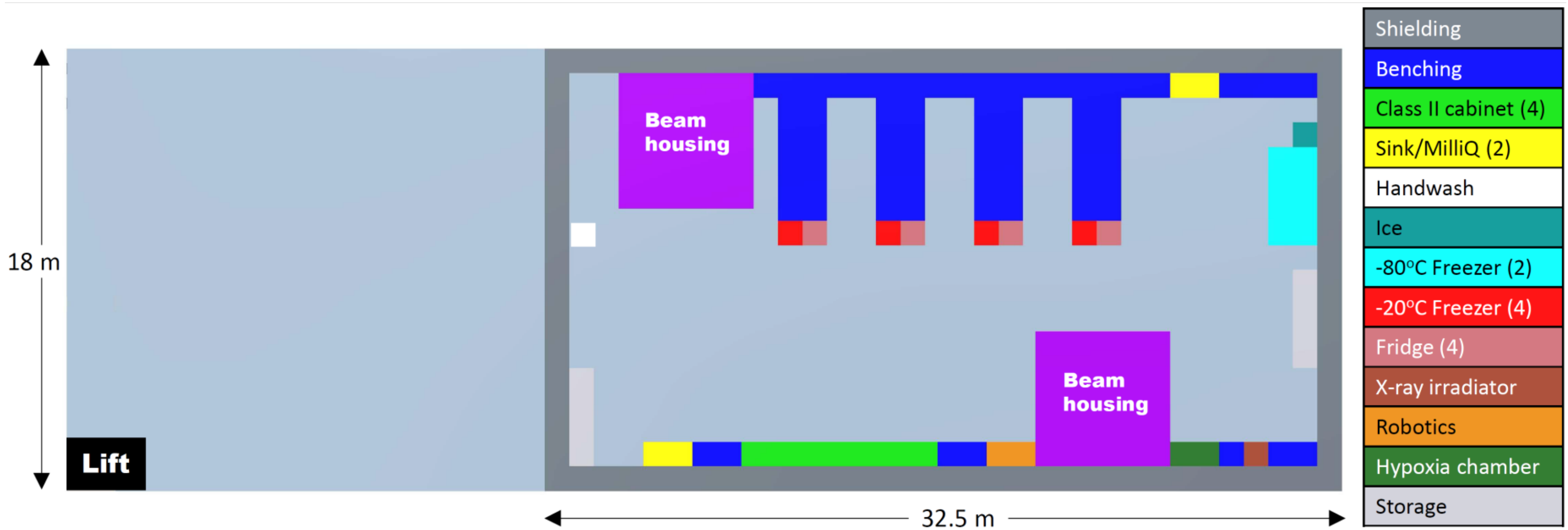
Instrumentation

- Various areas requiring instrumentation.
  - Laser.
  - Low-energy beam diagnostics.
  - High-energy beam diagnostics.
  - Dose calibration and monitoring.
  - Fast feedback and control.

- Combination of off-the-shelf commercial devices and development of new devices and techniques.
  - Conventional BPMs, CTs, Faraday cups.
  - Scintillating fibres, thin ceramic films.

End Stations

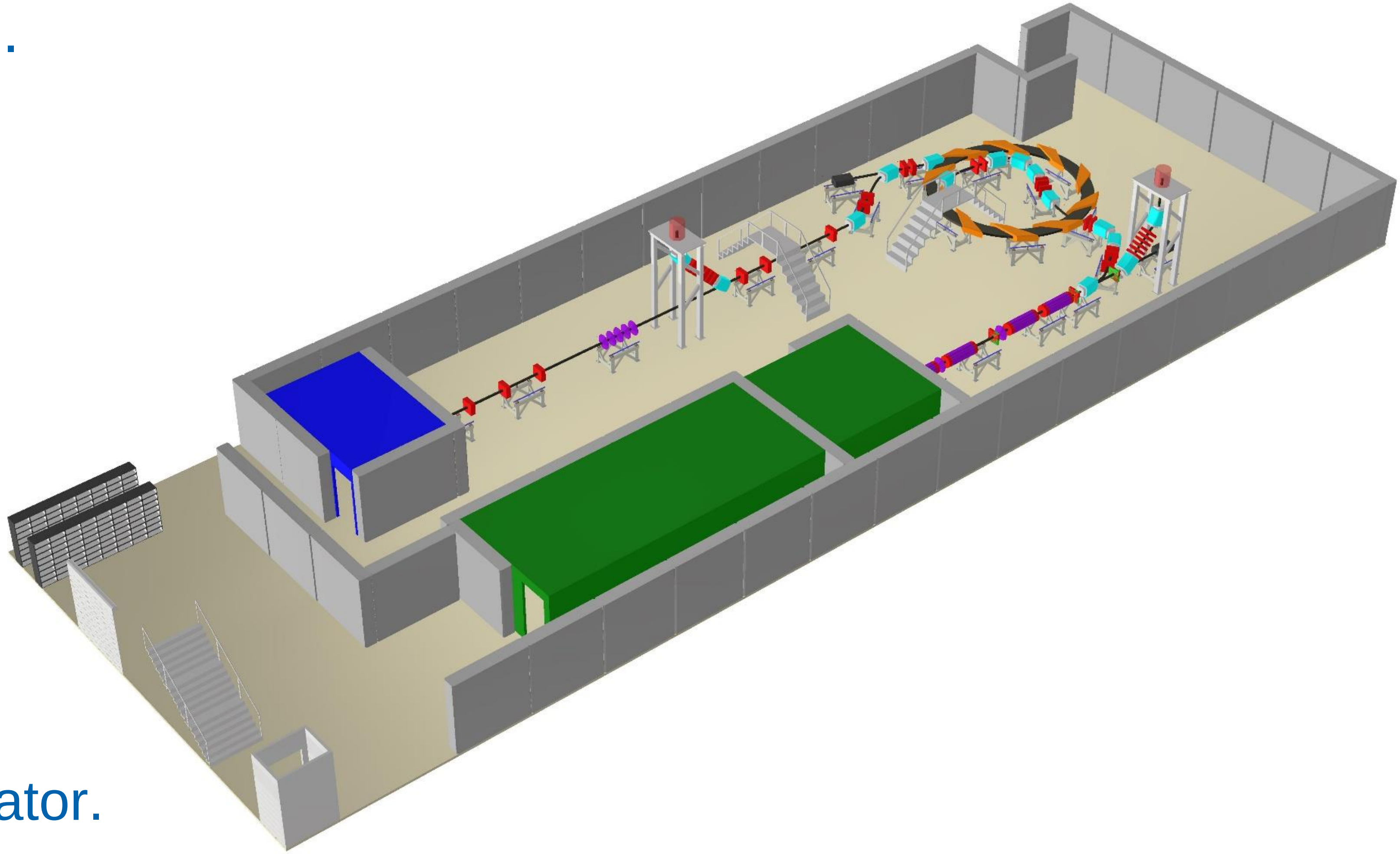
- Two in-vitro end stations.
  - Low-energy: up to 15 MeV protons.
  - High-energy: 15–127 MeV protons and up to 33MeV/u carbon ions.
  - State-of-the-art lab facilities and robotics for automated sample positioning.



- One in-vivo end station.
  - 15–127 MeV protons and up to 33MeV/u carbon ions.

Infrastructure and Integration

- Floor plan.



- Safety.
  - Laser.
  - Accelerator.
  - End stations.
  - Radiation.

Schedule

- 10 year programme.
  - Radiobiology.
    - At other facilities.
    - Experiments whilst Stage 2 is being constructed.
  - System/near clinical aspects and outreach.
    - Spin offs.
    - Patient and public involvement.
    - Outreach.

- 5 year R&D plan.

- Construction.
  - 2 years for Stage 1.
  - 5 years for Stage 2.

Five year R&D plan

- Aims to address the technical challenges highlighted in the pre-CDR and deliver technical designs for the LhARA facility.

- Facility design.
  - Development of conceptual design.
  - Development of technical design.
  - CDR (detailed for Stage 1).
  - TDR Stage 1.
  - TDR Stage 2.

- End stations.
  - Automation, sample handling, imaging.
  - Simulation of the end stations.

Five year R&D plan – Stage 1 specific activities

- Gabor lens.
  - First generation prototype to study steady state operation.
    - Verify high voltage operation in a relatively high vacuum.
  - Second generation prototype to study pulsed operation.
    - Electron emitter will be used to generate the plasma.
  - Theoretical studies to investigate plasma instabilities and electron emitter design.
  - Diagnostics.
    - Measure electron density.
    - Measure beam transport properties using an alpha source.
- Laser-driven source.
- Laser-capture interface.
- Investigation of space charge algorithms.
- Stage 1 beam line performance evaluation.
- Vertical bend.
- Capture technology milestone.

Five year R&D plan

- FFA.
  - Design and simulation.
  - Detailed magnet design.
  - Magnet prototype.
  - RF cavity design and performance evaluation.
  - Injection and extraction design.
- Stage 2 performance evaluation.
- Longitudinal phase space manipulation design, simulation and prototyping.
- Final beam preparation for in vivo end station.
- Instrumentation.
  - Low-energy beam diagnostics.
  - Online dosimetry and dose profile.
  - Absolute dosimetry at ultra-high dose rates.
  - Fast feedback and control.
  - High-energy beam diagnostics.
- Software and Computing.
  - Development of a global data acquisition and processing system.
  - Development of the controls and monitoring system.

Summary

- Pre-CDR is now published as technical note CCAP-TN-01.
  - Thanks to everyone involved!
  - Technical notes page on the wiki:
    - https://ccap.hep.ph.ic.ac.uk/trac/wiki/Communication/Notes
  - Link to the document:
    - https://ccap.hep.ph.ic.ac.uk/trac/raw-attachment/wiki/Communication/Notes/CCAP-TN-01.pdf
- Review by international panel was successful.
- Push forward on the technical challenges highlighted in the R&D plan.