Science and Technology Facilities Council

LhARA

LhARA Collaboration Meeting

WP6 – Facility Design & Integration (part 2)

Technical Infrastructure

STFC DL Contributions

Neil Bliss 15th December 2021

Content

1. Status of the WP6 Technical Infrastructure

2. Overview of the proposal deliverables:
   - Years 1 & 2
   - Years 3 - 5

3. Work package goals for year 1

4. Facility layout considerations

Science and Technology Facilities Council

Status of the WP6 Technical Infrastructure

- Great progress made on the pre CDR but incomplete technical specification for a CDR
- Illustrative CAD model exists of the LhARA facility with approximate space volumes but not yet including enough detail:
  - Accelerator & End Station equipment
  - Technical systems & services
- Cost estimate exists but with a large error bar that is in good shape for a pre CDR but not for a CDR
- A basic schedule exists but more detail required to remove uncertainties and mitigate risks of delivering on time
- A very basic safety management section is included in the pre CDR but more detail is required
- No detail on the EPICs control system and personnel safety systems
- Not enough detail on the vacuum system, vacuum chambers, RF, diagnostics and support systems
- No assessment of the radiation shielding requirements
- A building concept exists the low energy and high energy stages is one accelerator vault that has some advantages and some disadvantages

Overview of the proposal Deliverables

	Year 1	Year 2	Year 3	Year 4	Year 5
	Stage 1 & 2 CDR		Stage 1 TDR	Stage 2 Technical Design Studies	
Specification of systems & schematic diagram stage 1	✓				
Specification of systems & schematic diagram stage 2		✓			
2D CAD Layout of Facility	✓				
Vacuum flow diagram stage 1		✓			
Vacuum flow diagram stage 2			✓		
3D CAD Model stage 1		✓	✓		
3D CAD Model stage 2			✓	✓	
Radiation protection study stage 1		✓			
Radiation protection study stage 2			✓		
Manufacturing drawings				✓	✓
Building specification & concept design			✓		
CDR Stage 1 & 2		✓			
Stage 1 Technical Design Report			✓		
Stage 2 Technical Design studies				✓	✓

Overview of the proposal Deliverables

Scope of Work document: LhARA-WP6 STFC-DL-SoW-v1.0

- A team of STFC DL staff including a dedicated work package manager, discipline activities group leaders and team members responsible for the tasks described in this Scope of Work working within the Daresbury Laboratory (DL) ISO9001 Quality Management System.
- Contributions by the DL work package manager to the LhARA project overall project management planning, cost model and risk management activities.
- Management of a Health Physics radiation assessment by a commercial company to study and report on the bulk shielding thickness calculations, labyrinth designs assessment for personnel access, equipment access and services penetrations. Providing advice on the designation of radiation areas, radiation monitoring and personnel safety system.
- Input to the proposed Safety Management Plan based on STFC safety policy and safety codes. Input from a STFC Radiation Protection Advisors, Laser Responsible Officers, Authorising Engineers and Radiation Test Facility (RTF) management expertise. STFC operates similar complex laser - accelerator complex’s with established methods to identify potential hazards, mitigate the risk with operation of permit to work systems.
- The DL CDR contributions will include ideas to minimise energy consumption, energy losses and impact on the environment.

Science and Technology Facilities Council

Resource Table

STFC Technology (DL) Groups Included:

- WP Management
- Mechanical Engineering
- Electrical Engineering
- Controls

STFC ASTeC Groups Included:

- Vacuum
- Facility Radiation Management
- Technical Services

STFC ASTeC resources Not Included:

- Accelerator Physics
- Lasers
- RF
- Diagnostics

			Year 1	Year 2	Year 3	Year 4	Year 5
CDR & Technical Design Studies Only			**FY 22-23**	**FY 23-24**	**FY 24-25**	**FY 25-26**	**FY 26-27**
Integration staff estimate (SY)		**Total**	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**
	STFC activity lead, Group, Department.		**Stage 1 & 2 CDR**		**Stage 1 TDR**	**Stage 2 Technical Design**	
WP management	N Bliss, PGM, Technology.	1.20	0.20	0.25	0.25	0.25	0.25
Mechanical engineering design specification	T Jones, P&ME (DL), Technology.	4.70	0.50	0.80	1.00	1.20	1.20
Electrical engineering design specification	S Griffiths, EE, Technology.	3.70	0.05	0.55	0.90	1.10	1.10
Controls specification	G Cox, CS&SI, Technology.	2.00	0.05	0.25	0.35	0.65	0.70
Technical services specification	A Goulden, BP&F, ASTeC.	1.90	0.00	0.40	0.50	0.50	0.50
Vacuum specification	A Vick, VS, ASTeC.	1.30	0.00	0.20	0.50	0.30	0.30
Radiation protection specfication	A Goulden, BP&F, ASTeC.	0.40	0.025	0.075	0.10	0.10	0.10
STFC Technical Staff Total		**15.20**	**0.83**	**2.53**	**3.60**	**4.10**	**4.15**
Non staff		**£k**	**£k**	**£k**	**£k**	**£k**	**£k**
Radiation Protection Study (specialist company)		**90**		45	45		

Notes

1. If funded as a construction project in April 2025, significant additional resource would be required in year 4 & 5 for construction design, procurement, assembly and installation activities.
2. If project is not funded in April 2025 resource in years 4 & 5 is an estimate for continued technical design studies only.

1. Mechanical, Alignment and Integration

Conceptual Design Report & Technical Design Study Topics

- The building design and internal infrastructure concept to take account of the staged construction of the project as described in the pre-CDR.
- Schematic layout, 2D CAD layouts and 3D CAD model of the facility that also considers the optimum arrangement for auxiliary rooms and technical services.
- General space management and optimisation to determine building size and requirements.
- Access and ingress
- Radiation shielding solutions
- Integration and interface management of systems of the various work packages and disciplines
- Equipment support and adjustment conceptual design
- Survey and alignment methodology of equipment within the facility
- Procurement, assembly, test and installation methodology

Science and Technology Facilities Council

2. Vacuum

Conceptual Design Report & Technical Design Study Topics

- General design objectives and design principles
- Assessment of the vacuum specification for the various vacuum regions of the laser-accelerator complex.
- Vacuum flow diagram
- Vacuum pumping
- Pressure measurement
- Cleanliness
- Particulate Control
- Valves
- Bakeout
- Vacuum control system

3. Controls

Conceptual Design Report & Technical Design Study Topics

- Control System Architecture
- Network Infrastructure
- EPICS Environment
- Equipment Interfaces
- Controls Hardware
- User Interface Software
- Control Room
- Signal Distribution
- Naming Convention
- Timing and Synchronisation System
- Interlocks & Protection Systems
- Feedback Systems

4. Electrical Engineering

Conceptual Design Report & Technical Design Study Topics

- Estimated power consumption for services and accelerator equipment
- Electrical distribution scheme, integrity and diversity
- Cable management, quantity, segregation and route optimisation
- Safety and functional earthing schemes
- Assess technical challenges of specialist electrical equipment, pulse power supplies
- Quantity, size and limitations of accelerator equipment, power supply, control & Instrument
- Layout, size and location of infrastructure, rack rooms, RF systems
- Impact of energy efficiency against performance on services and accelerator equipment
- Reliability, maintainability and replace ability of accelerator electrical equipment

5. Technical Services

Conceptual Design Report & Technical Design Study Topics

- Cooling load – Estimated load for environmental stability and accelerator equipment.
- Cooling system – Number of circuits and types (coolant properties), estimate of coolant flow rates, pump and primary pipe sizes based on cooling load.
- Heating, Ventilation and Air Conditioning (HVAC) – Environmental stability requirements and proposed solution(s)
- Room services requirements table
- General building services; artificial lighting, telecommunications and data, security systems, building management system, lightning protection, public address system, information display systems, lifts, cranes.
- Environmental sustainability – consideration of alternative primary cooling equipment, alternative sustainable concrete types and other energy efficiency and sustainability options.

6. Safety Systems

Conceptual Design Report & Technical Design Study Topics

- Radiation Shielding (IRR17) estimated thicknesses, material selection and construction methods.

- Personnel safety system compliance with IRR17 and Accelerator Code of Practice in accordance with IEC61508. Adopting current best practise for accelerator access control and key exchange systems, that will shielded areas to be searched prior to operation of the laser and accelerator system.

- Local Exhaust Ventilation requirements – Extract / Exhaust systems (COSHH 2002)

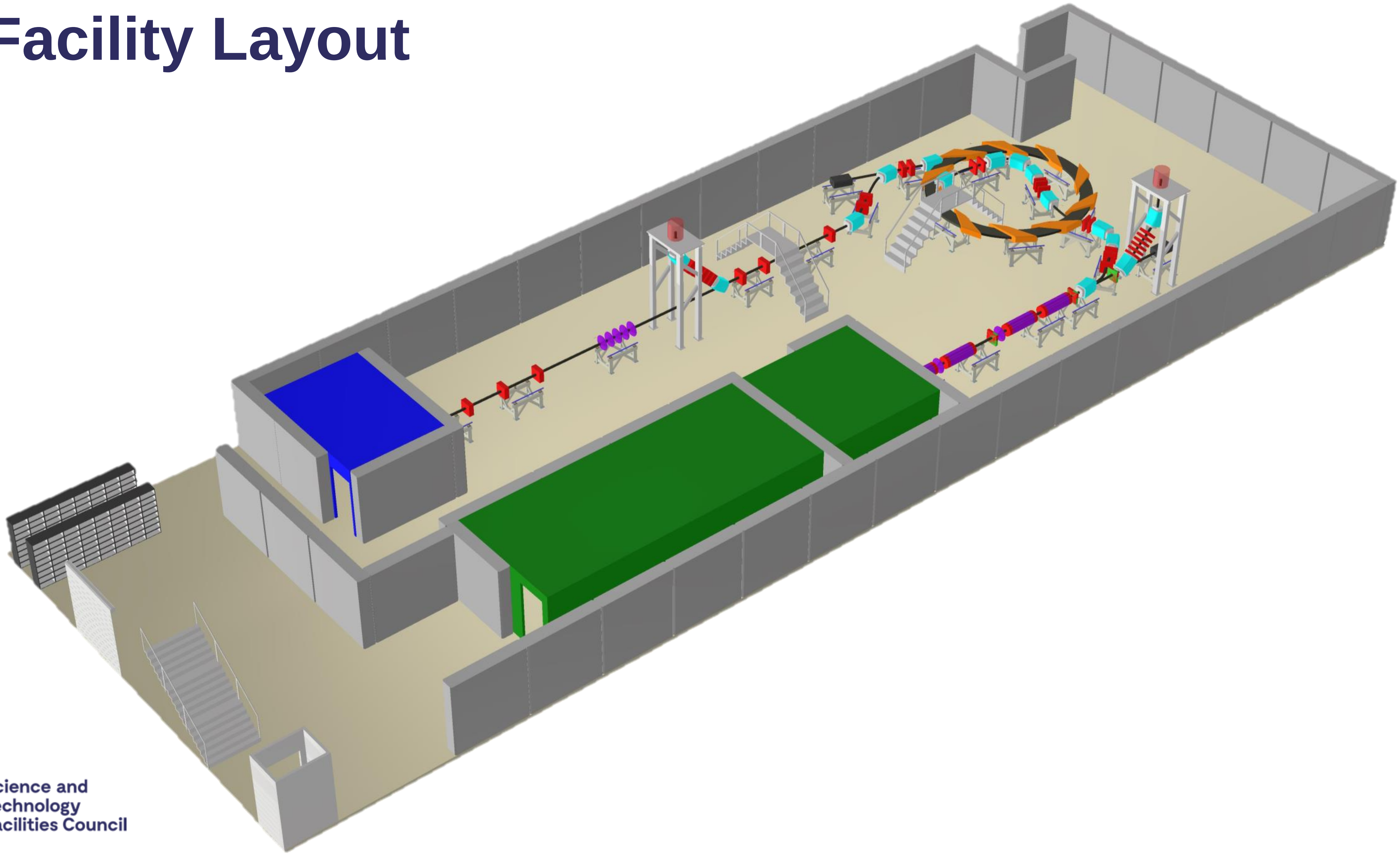
- HAZoP Process outline for systems integration

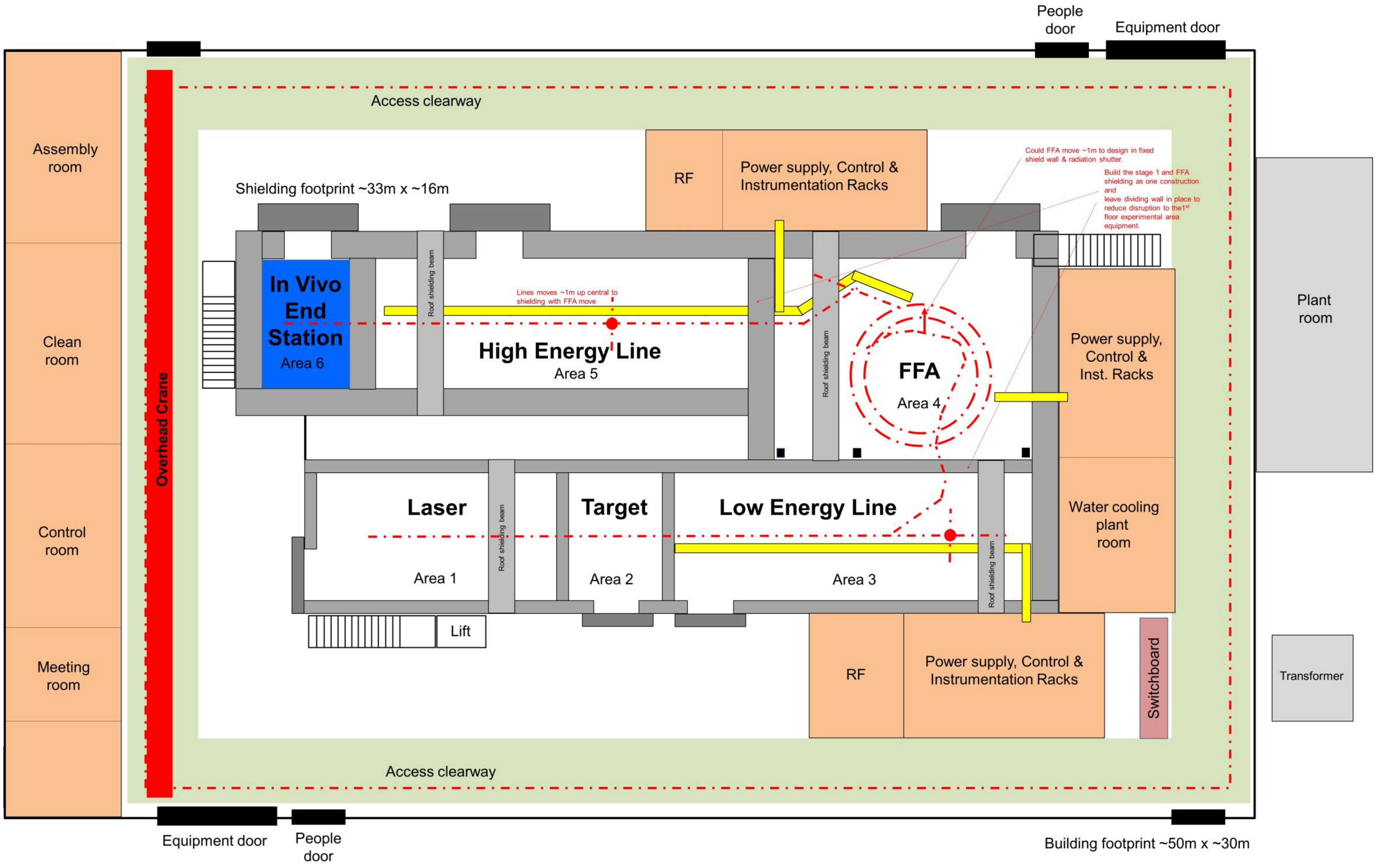
- Emergency lighting, Fire alarm and Fire suppression systems

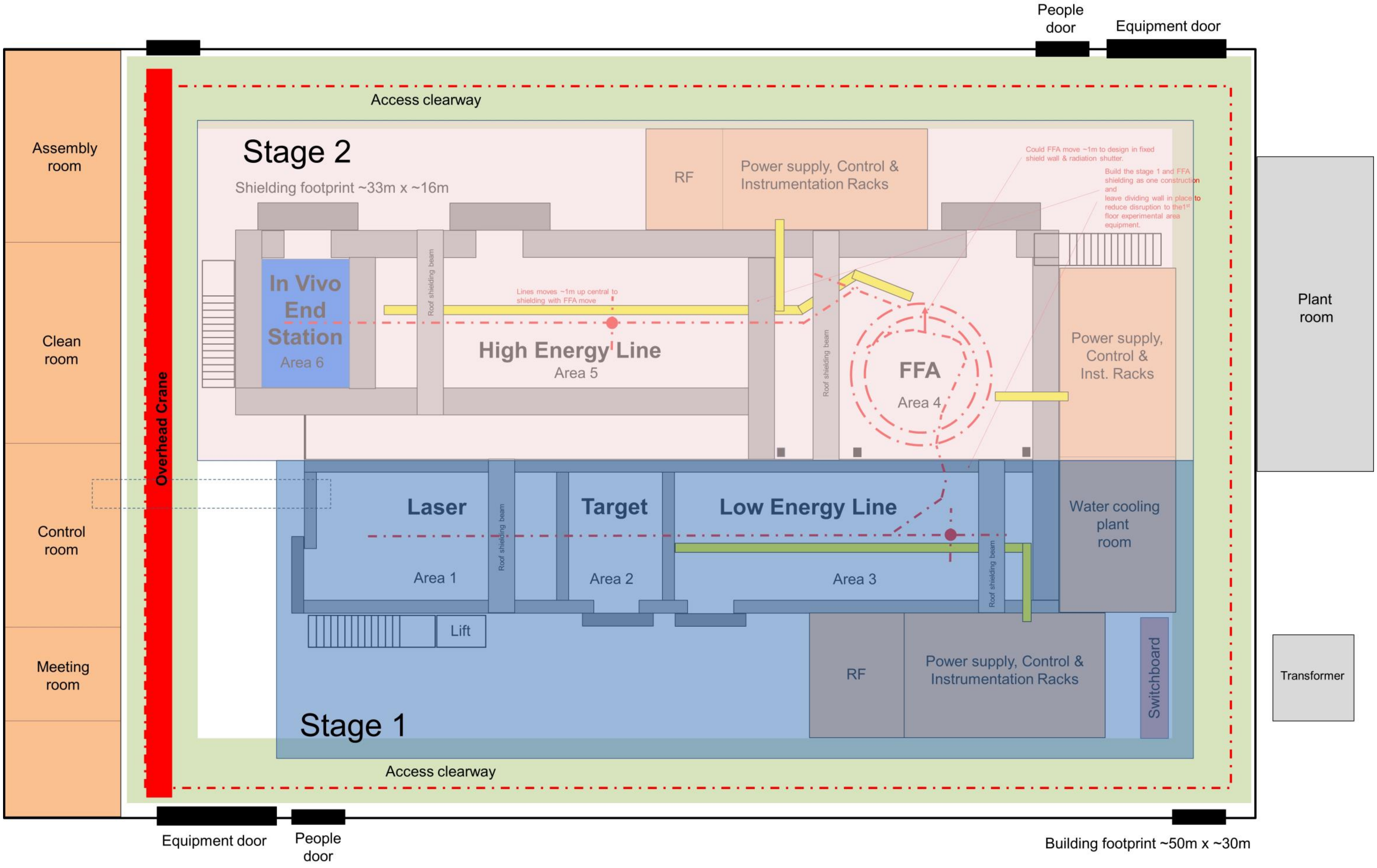
Goals for Year 1 (0.8 FTE)

- Develop the specifications for the Facility Technical Infrastructure and Systems
- **Deliver** a firm equipment schematic diagram for stage 1
- Develop the provisional equipment schematic diagram for stage 2
- Develop the provisional vacuum flow diagram for stages 1 & 2 for delivery in 24 months
- **Deliver** the 2D CAD Layout of the Facility for stages 1 & 2
- Develop the provisional 3D CAD Model of the Facility for stages 1 & 2 for delivery in 24 months, but should be well advanced by the end of year 1.
- Input to the Cost Model, Project Planning & Risk Management that develops over the CDR and TDR phases of the project.

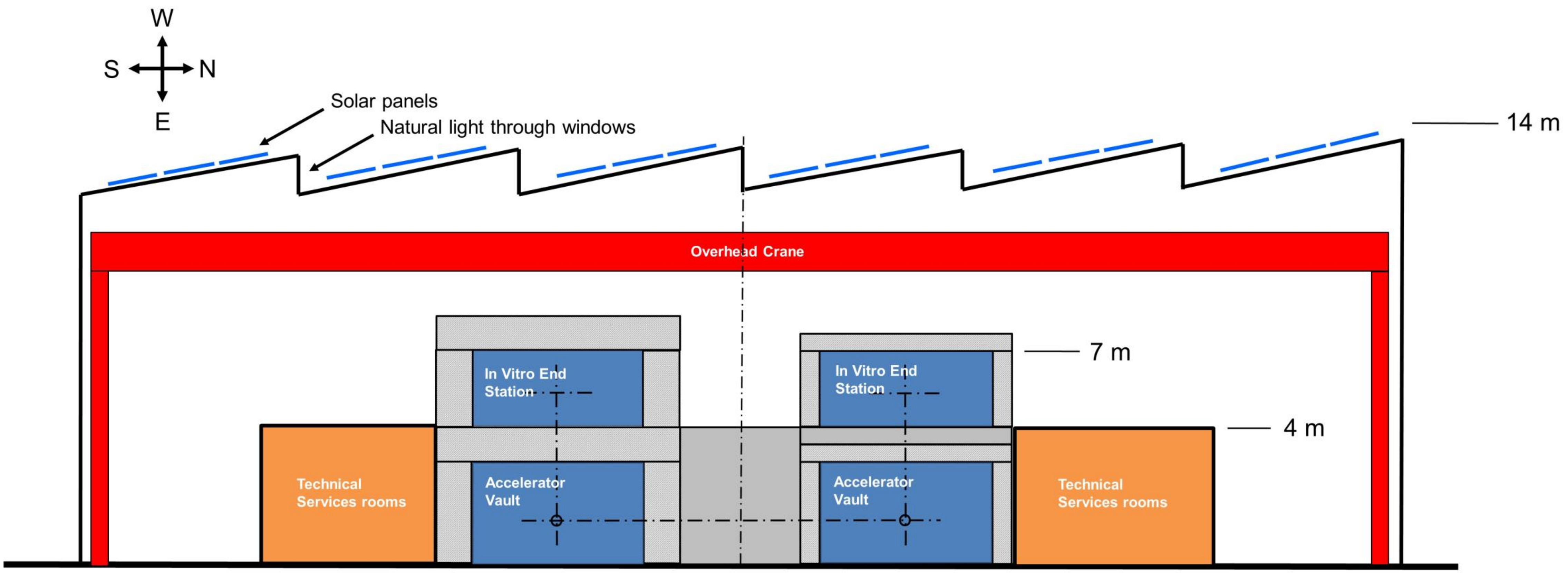
Facility Layout




People door
Equipment door
Assembly room
Clean room
Control room
Meeting room
Overhead Crane
Access clearway
Shielding footprint ~33m x ~16m
RF
Power supply, Control & Instrumentation Racks
Could FFA move ~1m to design in fixed shield wall & radiation shutter.
Build the stage 1 and FFA shielding as one construction and leave dividing wall in place to reduce disruption to the1st floor experimental area equipment.
Plant room
In Vivo End Station
Area 6
Roof shielding beam
Lines moves ~1m up central to shielding with FFA move
High Energy Line
Area 5
FFA
Area 4
Power supply, Control & Inst. Racks
Laser
Area 1
Target
Area 2
Low Energy Line
Area 3
Water cooling plant room
Lift
RF
Power supply, Control & Instrumentation Racks
Switchboard
Transformer
Access clearway
Equipment door
People door
Building footprint ~50m x ~30m

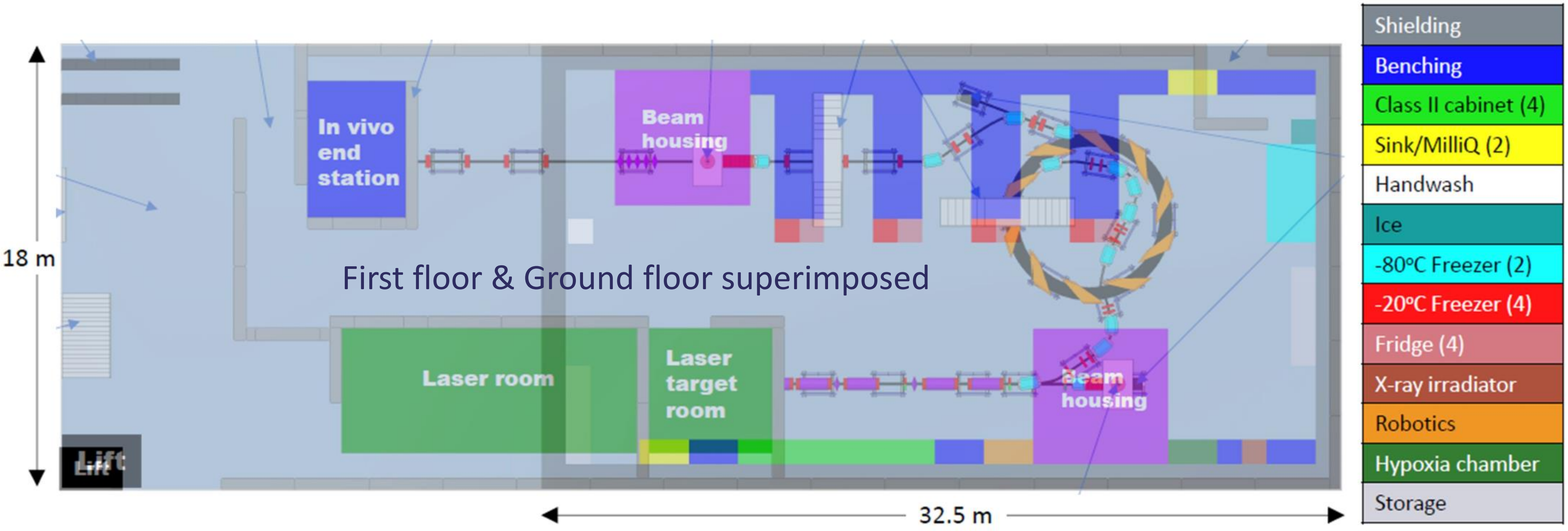


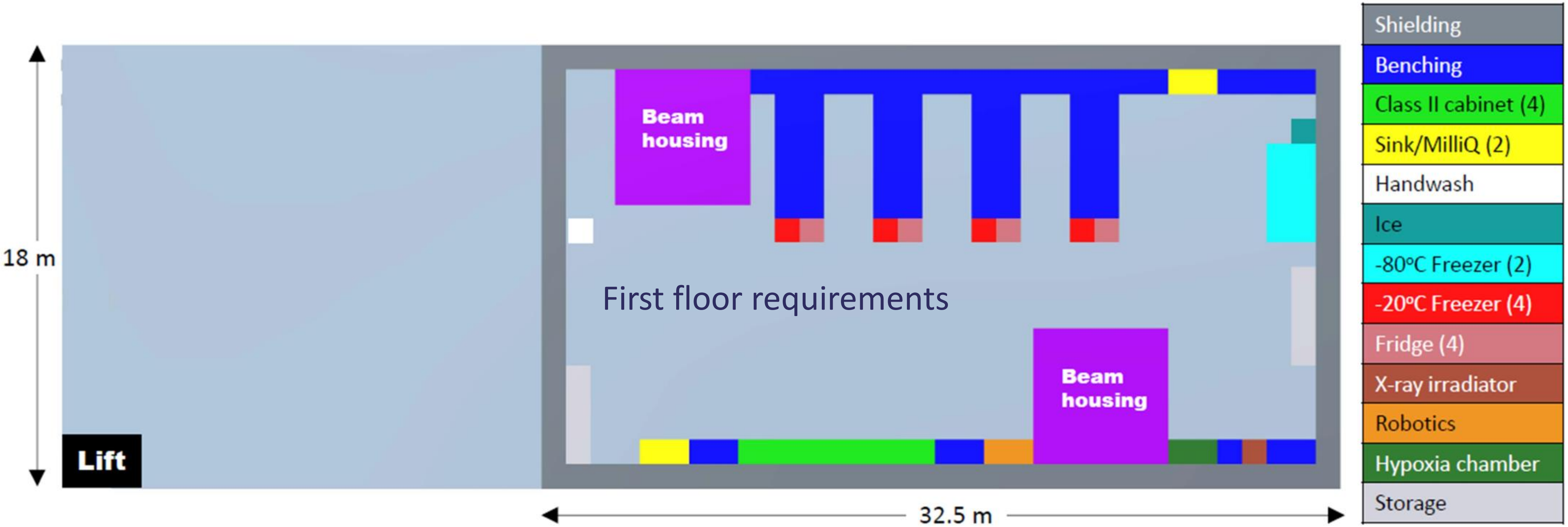
People door
Equipment door
Access clearway
Assembly room
Clean room
Control room
Meeting room
Overhead Crane
Stage 2
Shielding footprint ~33m x ~16m
RF
Power supply, Control & Instrumentation Racks
Could FFA move ~1m to design in fixed shield wall & radiation shutter.
Build the stage 1 and FFA shielding as one construction and leave dividing wall in place to reduce disruption to the1st floor experimental area equipment.
In Vivo End Station
Area 6
Roof shielding beam
Lines moves ~1m up central to shielding with FFA move
High Energy Line
Area 5
Roof shielding beam
FFA
Area 4
Power supply, Control & Inst. Racks
Plant room
Laser
Area 1
Roof shielding beam
Target
Area 2
Low Energy Line
Area 3
Roof shielding beam
Water cooling plant room
Lift
RF
Power supply, Control & Instrumentation Racks
Switchboard
Transformer
Stage 1
Access clearway
Equipment door
People door
Building footprint ~50m x ~30m



Building cross section with solar panel roof (building ideally facing south)

Science and Technology Facilities Council


18 m
32.5 m
In vivo end station
Beam housing
Laser room
Laser target room
Beam housing
Lift
First floor & Ground floor superimposed
Shielding
Benching
Class II cabinet (4)
Sink/MilliQ (2)
Handwash
Ice
-80ºC Freezer (2)
-20ºC Freezer (4)
Fridge (4)
X-ray irradiator
Robotics
Hypoxia chamber
Storage

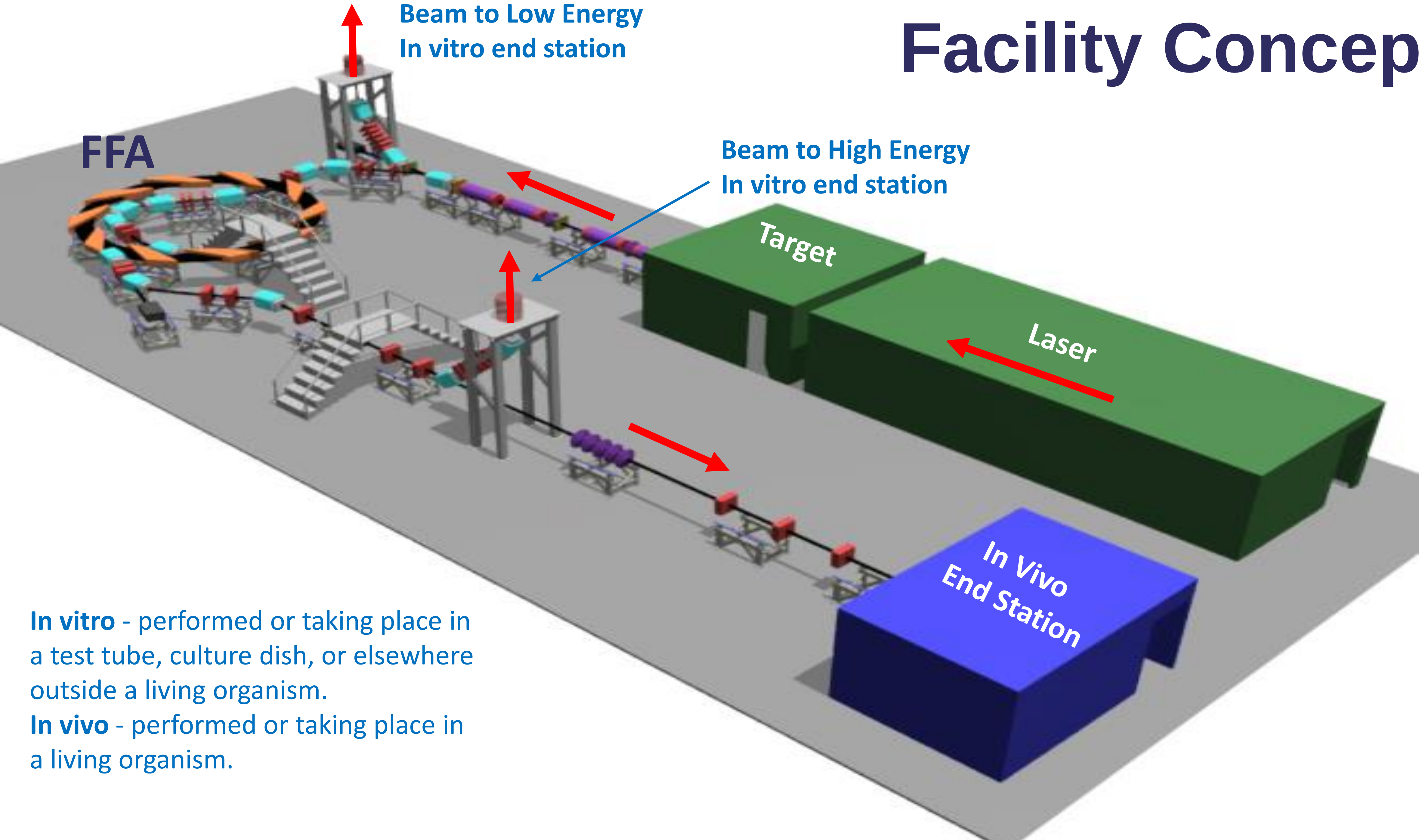

18 m
32.5 m
Beam housing
Beam housing
Lift
First floor requirements
Shielding
Benching
Class II cabinet (4)
Sink/MilliQ (2)
Handwash
Ice
-80ºC Freezer (2)
-20ºC Freezer (4)
Fridge (4)
X-ray irradiator
Robotics
Hypoxia chamber
Storage

End

Science and
Technology
Facilities Council

Reference slides

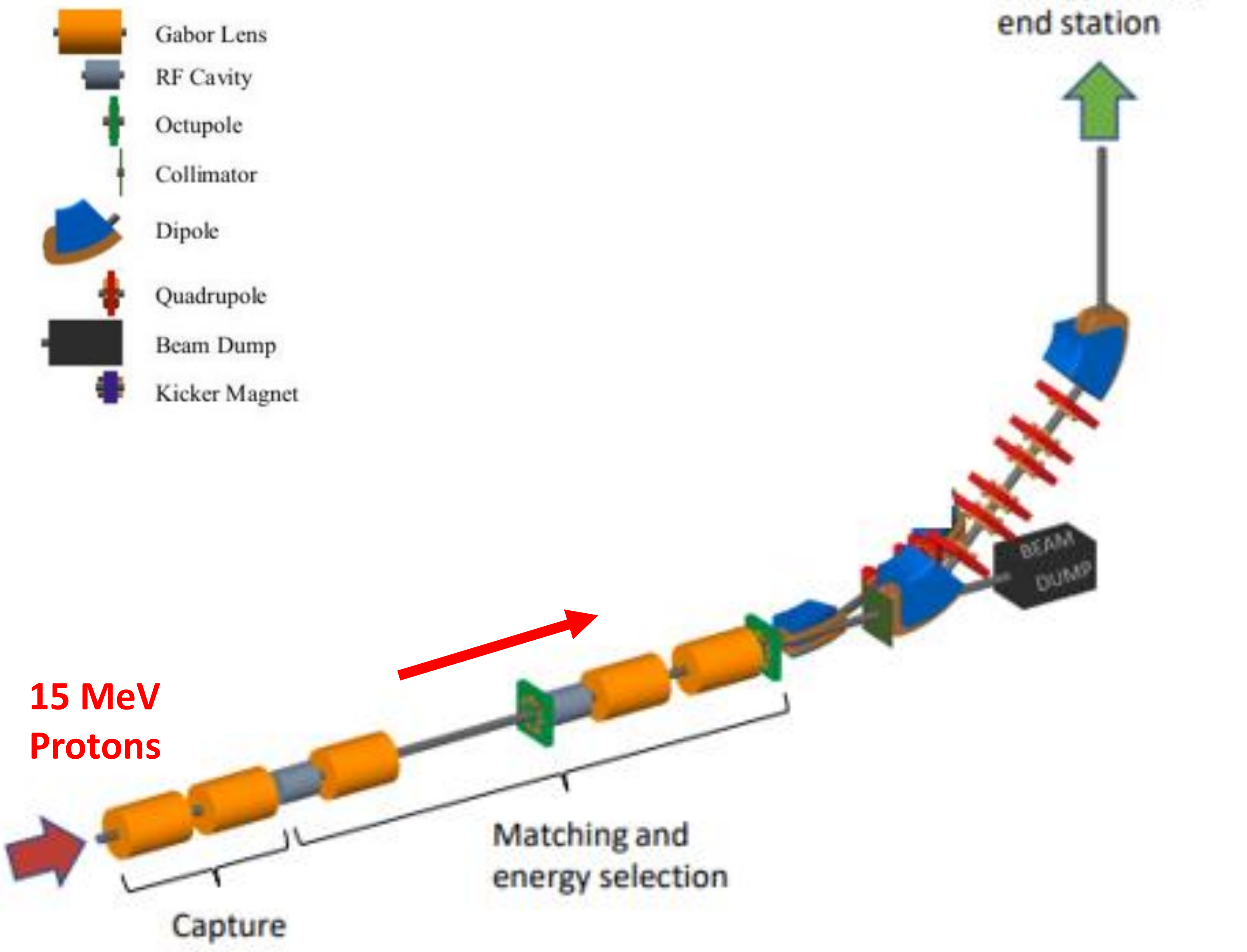
Facility Concept



In vitro - performed or taking place in a test tube, culture dish, or elsewhere outside a living organism.
In vivo - performed or taking place in a living organism.

Stage 1

Parameter	Value or range	Unit
Laser driven proton and ion source		
Laser power	100	TW
Laser energy	2.5	J
Laser pulse length	25	fs
Laser rep. rate	10	Hz
Required maximum 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 and 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

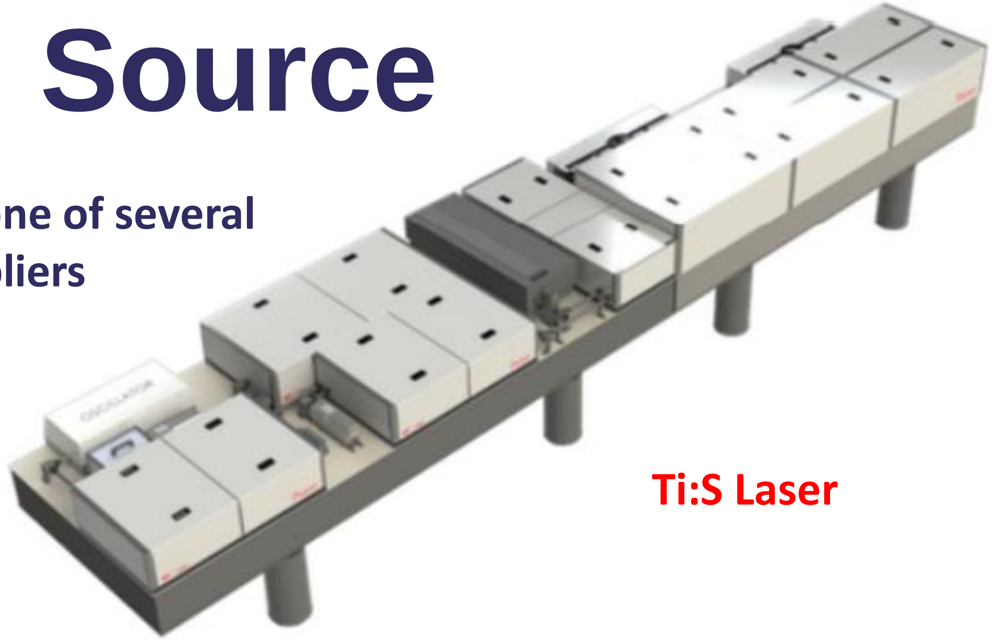


Science and Technology Facilities Council

Laser Driven Proton & Ion Source

- High instantaneous dose rates - full treatment doses possible in a single shot
- Flash dosing with ultra-short particle beams - sub ps duration
- Source flexibility - simple switching of ion species
- More compact and less expensive accelerators - higher accelerating gradients

Amplitude is one of several potential suppliers



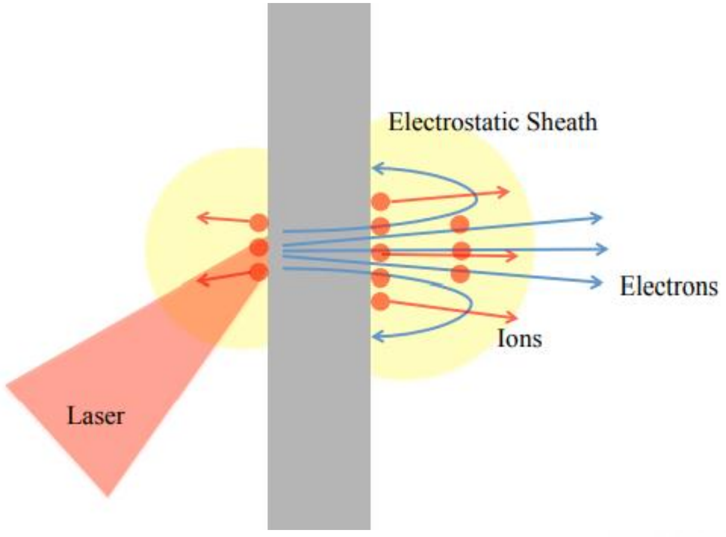
Ti:S Laser

	Pulsar 60	Pulsar 140	
Rep. rate		5 Hz (1)	10 Hz
Pulse Duration		< 25 fs (2)	
Peak Power (3)	> 60 TW	> 140 TW	100 TW
Contrast (4)		> 1: 10^{10}	
Energy Compressed	1.5 J	> 3.5 J	2.5 J
Energy shot-to-shot Stability		< 1% RMS	
Strehl ratio (5)		> 0.85	

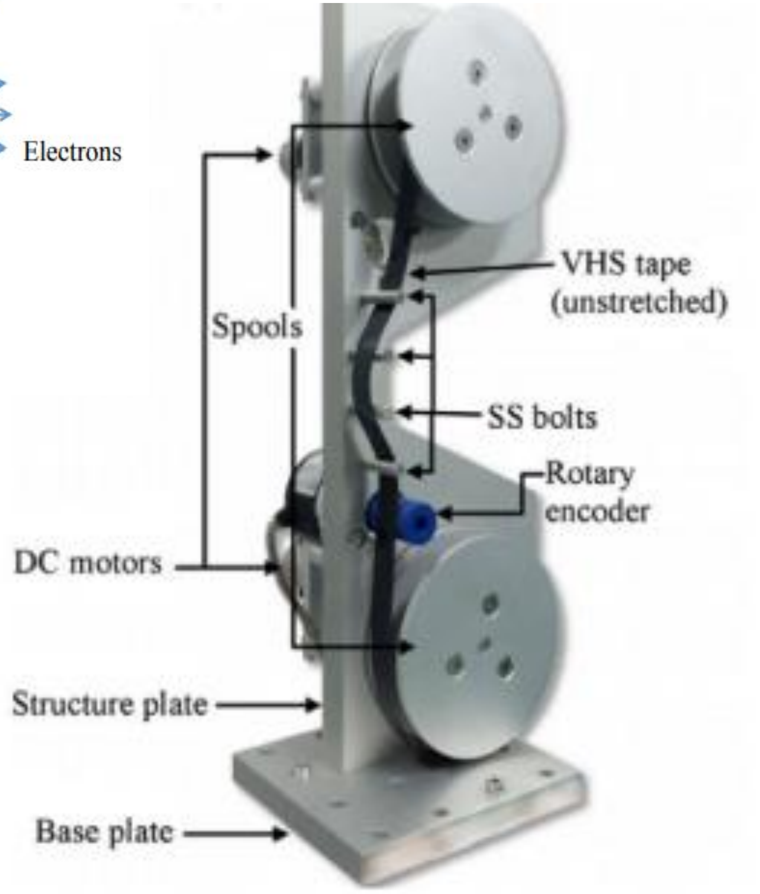
Science and Technology Facilities Council

Laser Driven Proton & Ion Source

- Many acceleration methodologies, but mos studied and best characterised is **sheath acceleration**
- 45º laser incidence to target studied
- Tape targets one of several options
- Well established technology - relatively sim
- Selection of tape materials available - Mylar, Kapton, Ti…
- More advanced, etched targets possible - enhanced acceleration?
- R&D requirements in progress



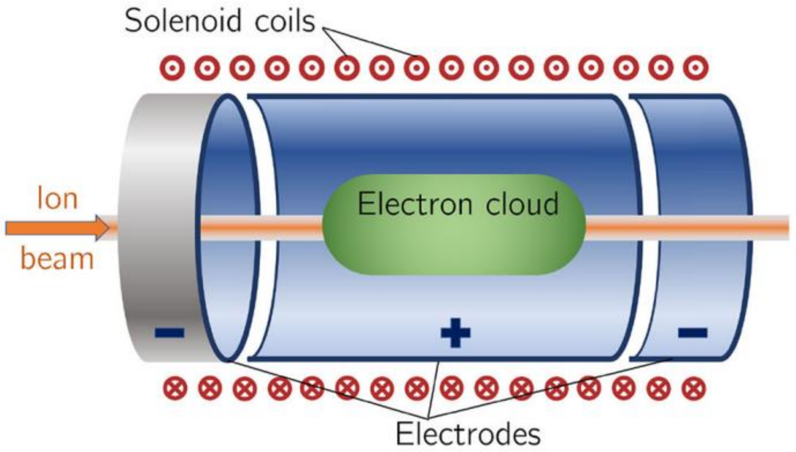
Target

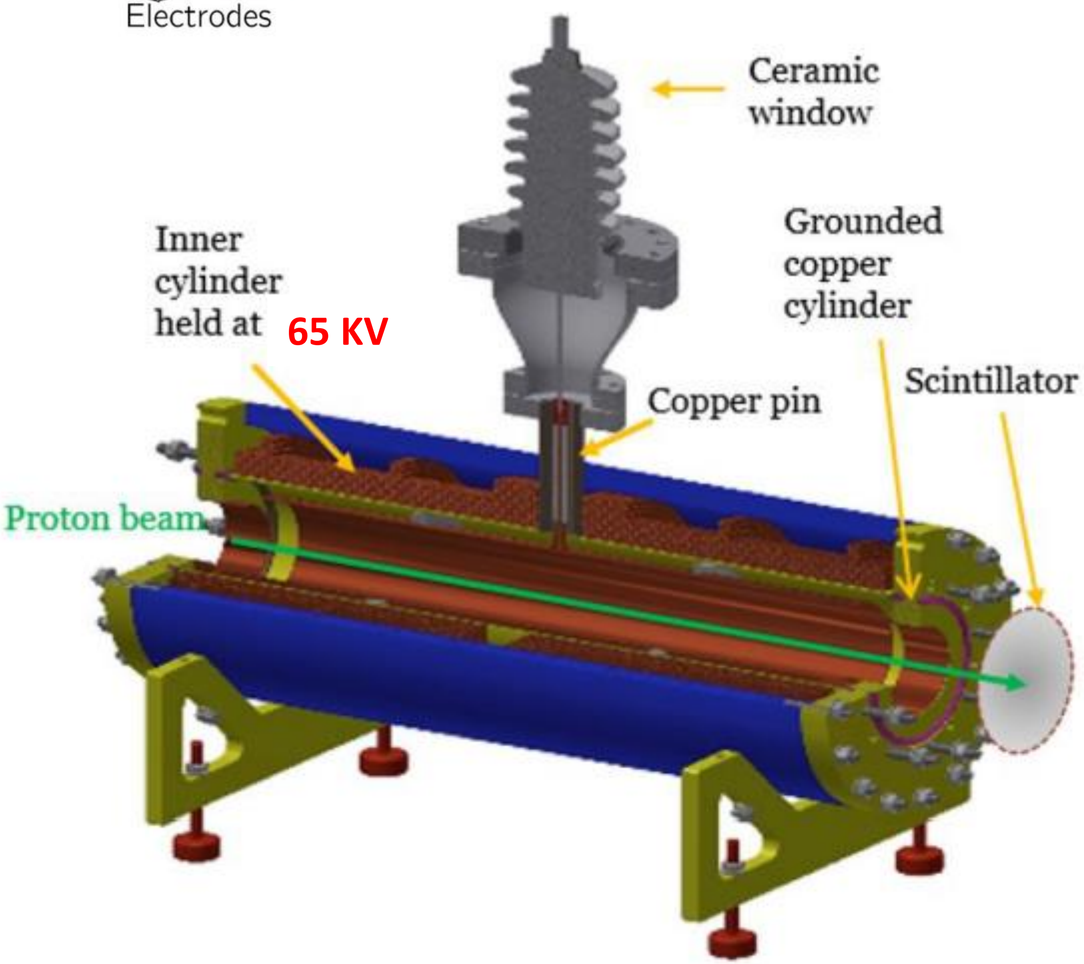


Noaman-ul-Haq et al. PRAB (2017)

Gabor Lens

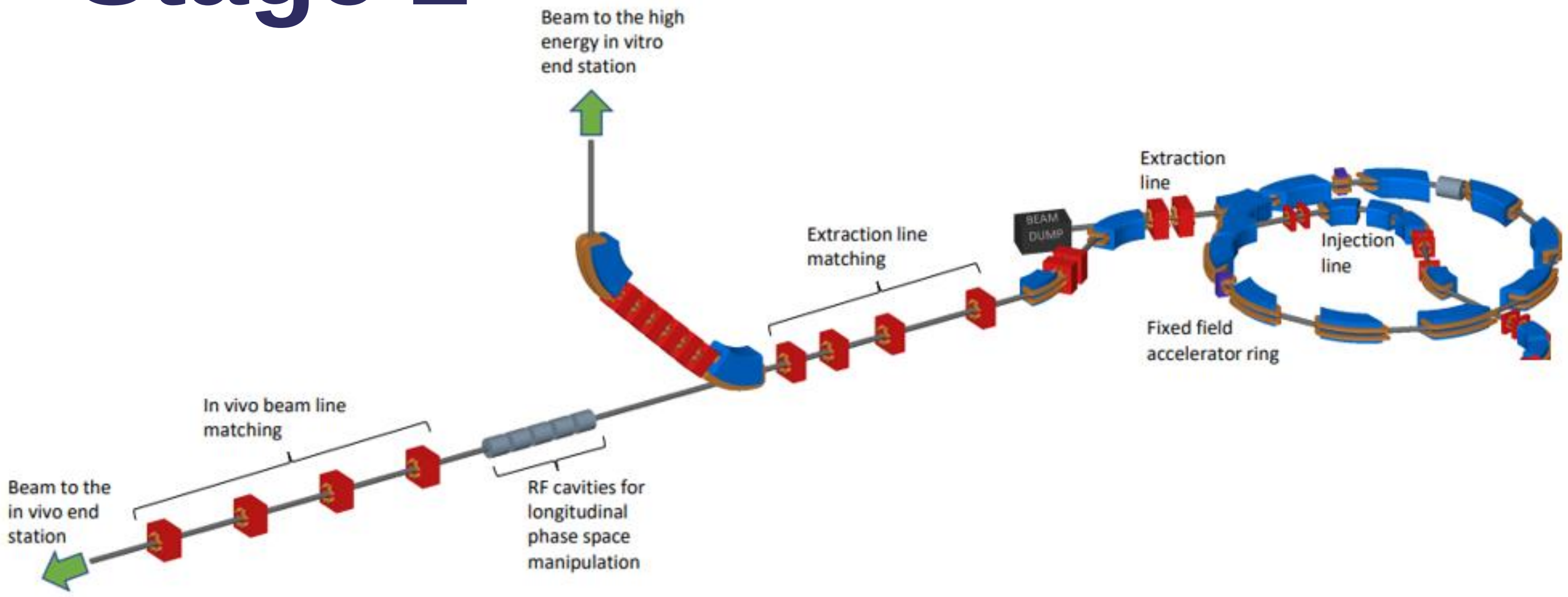
- Beam capture requires strong focusing close to the target to produce a rectilinear beam
- Lenses of similarly short focal length are required at other points in the beamline
- The Gabor lens provides a cloud of electrons trapped within a cylindrical volume by crossed electrical & magnetic fields
- Such lens have the potential to decrease the magnetic field required for a conventional beam-capture solenoid by more than a factor of 40, resulting in a significant length reduction.
- R&D already conducted, but more required to study:
  - Operation of the Gabor lens at the design parameters for LhARA and verification of its focusing characteristics
  - An electrode system capable of reliable high-voltage operation as well as a vacuum system which can maintain the required vacuum in the Gabor lens.
  - Measurement of the; electron density, beam parameters at the input and output of the Gabor lens…….
  - Verification of the stability of the Gabor lens.

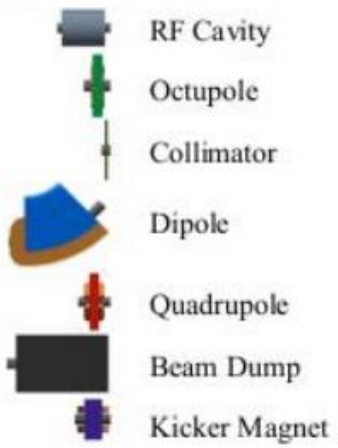




Science and Technology Facilities Council

Stage 2





Stage 2 beam transport: FFA, transfer line, beam delivery to high-energy end stations		
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	15–127	MeV
FFA: Number of cells	10	
FFA: Orbit R_{min}	2.92	m
FFA: Orbit R_{max}	3.48	m
FFA: Orbit excursion	0.56	m
FFA: External R	4	m
FFA: Number of RF cavities	2	
FFA: RF frequency	1.46–6.48	MHz
FFA: harmonic number	1, 2 or 4	
FFA: RF voltage (for 2 cavities)	4	kV
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 opening angle	12.24	degrees
FFA: Magnet gap	0.047	m
FFA: Ring tune (x,y)	(2.83,1.22)	
FFA: γ_T	2.516	
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	
Vertical 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	

Science and Technology Facilities Council

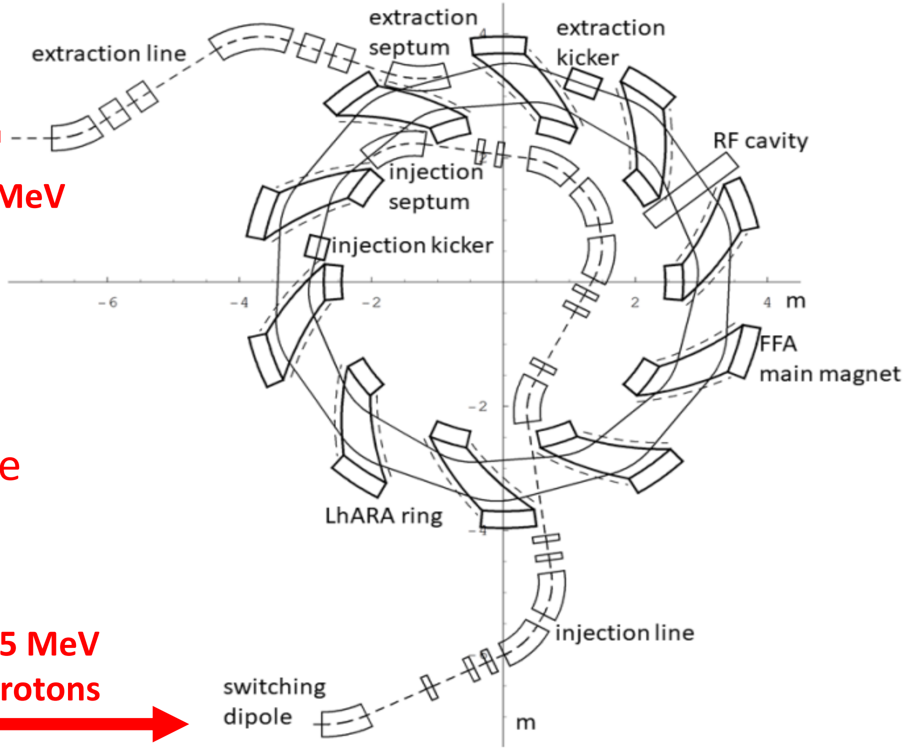
Fixed Field Accelerator

- Variable extraction energy from FFA within 1 s (15-127 MeV) at fixed geometry
- Variable energy operation without energy degraders
- Compact size and low cost
- Simple and efficient extraction
- Stable and easy operation
- Multiple extraction ports possible
- Bunch to Pixel active scanning possible
- Multiple ion capability

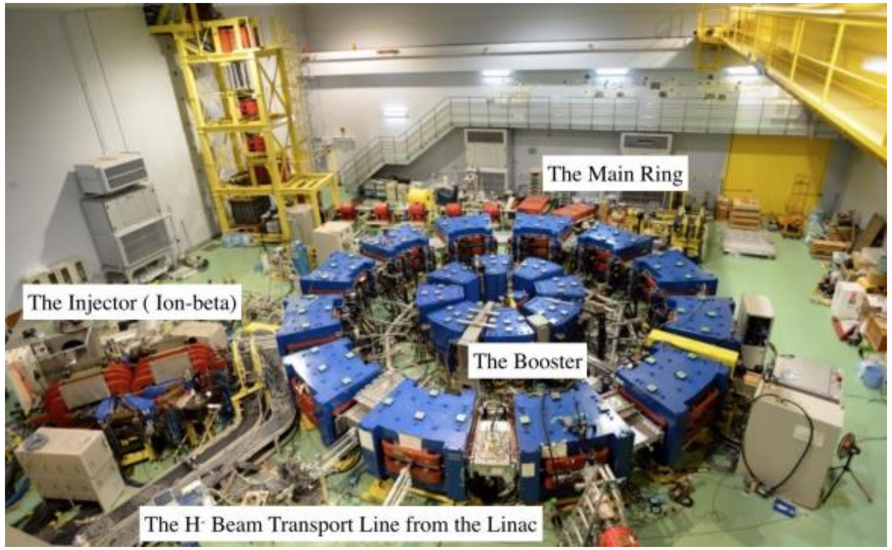
15 - 127 MeV
Protons

R&D reqd.
- Spiral dipole
- MA Cavity

15 MeV
Protons



Baseline design – Single Spiral Scaling FFA



150 MeV proton FFA at KURNS, Japan for the study of Accelerator Driven Sub-critical Reactor (ADSR).

Also PRISM & ERIT

Science and Technology Facilities Council

In vitro and In vivo Parameters

- Three biological end stations (two in vitro and one in vivo)
  - Low energy in vitro – proton beams between 12 – 15 MeV
  - High energy in vitro – proton beams between 15 – 127 MeV ion beams (including C6+) up to 33 MeV/u
  - High energy in vivo – proton beams between 15 – 127 MeV – ion beams (including C6+) up to 33 MeV/u
- Two in vitro end stations – high and low energy
  - Located within a state-of-the-art laboratory, fully equipped with various work spaces
  - Irradiation of a wide range of biological models (2D cell monolayers and 3D spheroids/patient-derived organoids)
  - Investigate a myriad of biological end points (clonogenic survival, spheroid/organoid growth, angiogenesis, inflammation)
  - Additional capabilities include hypoxia studies (0.1 – 1 % oxygen) and high-throughput screening (compound drug libraries, siRNA/CRISPR- Cas9)
- One high energy in vivo end station
  - Located on the ground floor in the accelerator complex

Parameter	Value or range	Unit
Stage 2 beam transport: FFA, transfer line, beam delivery to high-energy end stations continued		
***In vitro* biological end stations**		
Maximum input beam diameter	1–3	cm
Beam energy spread (full width)	Low-energy end station: ≤ 4	%
	High-energy end station: ≤ 1	%
Input beam uniformity	< 5	%
Scintillating fiber layer thickness	0.25	mm
Air gap length	5	mm
Cell culture plate thickness	1.3	mm
Cell layer thickness	0.03	mm
Number of end stations	2	
***In vivo* biological end station**		
Maximum input beam diameter	1–3	cm
Beam energy spread (full width)	≤ 1	%
Input beam uniformity	< 5	%
Beam options	Spot-scanning, passive scattering, micro-beam	

Science and Technology Facilities Council