

LhARA to serve ITRF.

Preliminary Activity 2(PA2) – 4 year risk reduction project to prepare for Ion Therapy Research Facility build.

Project organised as 8 work packages:

WP1: Project Management

Work package 1 supports staff at Daresbury Lab, ICL and Strathclyde, managing and monitoring project progress & finance; directing the project in co-operation with the Project Board and the LhARA executive board. Aggregate costs are less than 5% of the funds requested.

Work Package 1 owns the high-level deliverables for the project including:

- LhARA stage 1 TDR
- LhARA stage 2 TDR
- Radiobiology proof-of-principal experiment

Work package 2: Laser-driven proton and ion source.

Laser-target interaction development for the generation of particles has evolved along several paths. LhARA plans to use the TNSA technique, the most studied, most developed and arguably the best understood method. Efforts to date have delivered TNSA systems up to TRL4, in some cases edging into TRL5. This work package will deliver the specification for a system capable of reaching TRL7 crossing the well-known 'valley of death' of development between 'technology demonstrated in a lab' and 'system demonstration in an operational environment'. To achieve this, accurate simulation will be required to guide experimental measurement coupled to machine learning with feedback and feed-forward for enhanced stability and reproducibility. Long term operation at elevated pulse rates creates a whole new suite of debris management challenges and target renewal problems for which the team have a range of potential solutions including a suite of liquid targets.

Key activities include:

- Full 3D PIC and hydro-dynamic simulation to identify key laser parameters. Extend simulations to predict optimised operating conditions for ion generation.
- Experimental optimisation of proton and ion generation at SCAPA to inform build-phase laser specification.
- Integration with, feedback to, adaptation and co-development with capture system.
- Diagnostic development for source characterisation – specification of required integrated facility source diagnostic suite.
- Demonstration of 10 Hz operation of advanced targetry platform at ICL.
- Demonstration of stabilised 5 Hz beam generation on SCAPA.
- Support of proof-of-principal radiobiology experiment, possibly at SCAPA.

Work package 3: Proton and ion capture

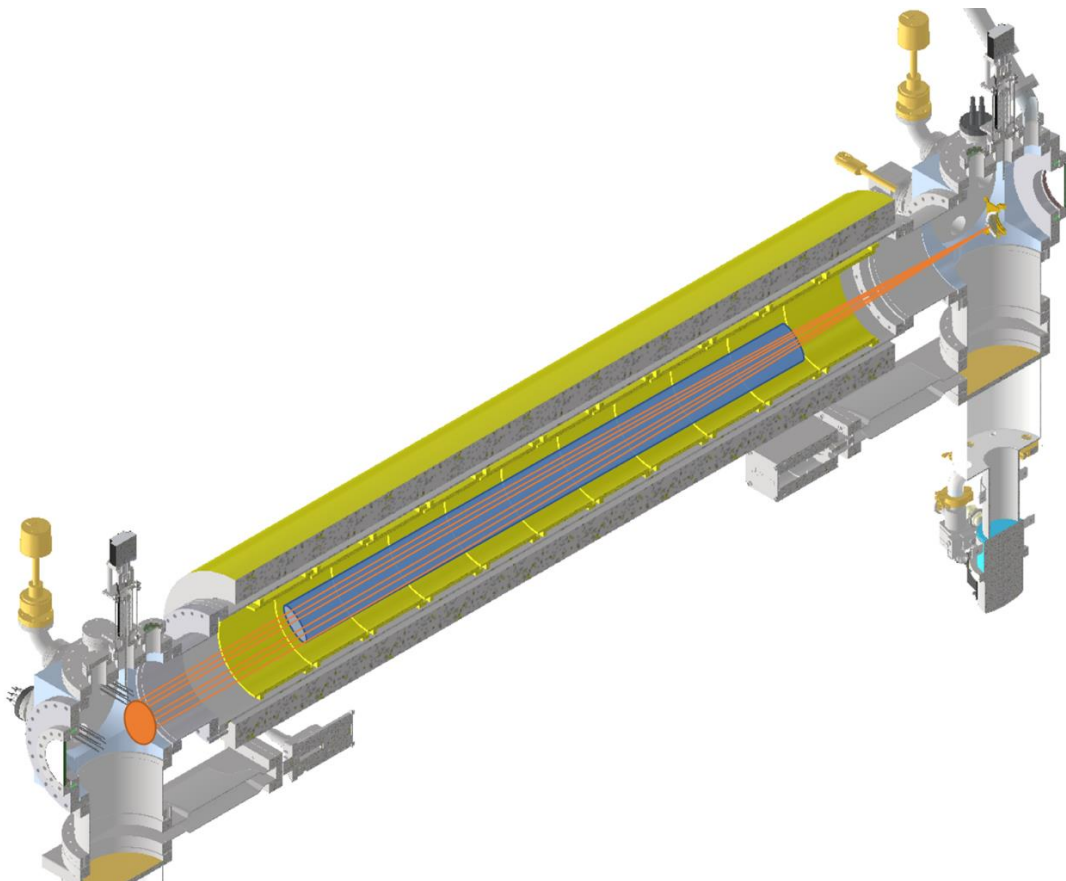
Particle capture efficiency over a range of ion species requires focussing elements which maintain their focal length for heavier species. The electrostatic focussing produced by an electron cloud maintained in a Penning-Malmberg trap, as currently installed in the TRL6 system at the ALPHA experiment at CERN and Swansea, has the desired properties if it can be scaled appropriately in size and density. We aim simultaneously to reduce the axial magnetic field requirements in order to

maximise the sustainability benefits of the Gabor lens design. This is a challenging set of objectives; plasma stability and control electrode voltage are linked to both density and size and we aim for an improvement of more than an order of magnitude in each. The team has expertise in designing, constructing, and operating particle traps, stability theory and high voltage engineering and a long track record of experimental excellence.

This work package will co-develop experimental and theoretical threads, building the design developed in PA1, operating at high particle numbers and feeding results back to the theory team. We require the ultimate in precision reproduction of simulated configurations as the driving factors limiting performance are heavily linked to the non-uniformities inherent in the experimental realisation, hence the need for tightly coupled theory and experiment. WP3 links to the source work package in that the first Gabor lens must be placed close to the source if efficient coupling is to be achieved, which intrudes into space normally reserved for other purposes by the source team. This work is progressing well in PA1 through meetings co-ordinated by WP6 – Design and Integration. We expect to continue this arrangement and there will be a requirement for engineering resource to facilitate this. WP3 will support the proof-of-principal radiobiology experiment through the studies using the stand alone test bench

Key activities include:

- Build and commission stand-alone test bench.
- Develop simulation capability to study confinement strategies.
- Test theoretical predictions on test bench to validate large particle number confinement.
- Experimentally measure ion focussing in test bench.
- Support proof-of-principal radiobiology experiment at an existing laser facility.
- Complete final plasma lens design.



Work package 4: Ion-acoustic dose mapping

LhARA for ITRF requires live dose measurement for as part of the instrumentation required as feedback to the accelerator control system. A novel, non-destructive and fast technique is required due to the high instantaneous dose. Whilst the non-destructive beam diagnostics envisaged in WP5 can satisfy these requirements, they deliver information only on the impinging beam and not the interaction itself. Ion-acoustic dose mapping can deliver both magnitude and position information on the dose delivered in a non-invasive diagnostic given a sufficiently intense source of short duration. The technique has been used, time-averaged over many pulses to increase signal to noise ratios but has not as yet been demonstrated in the single shot regime. A complete understanding of signal generation, propagation and measurement is required to allow reconstruction of the delivered dose from the measured signals, this work is progressing well in PA1. The challenge in PA2 will be to build and operate the required detector array, correlating the large number of received signals and processing the data in a timely manner to produce live results.

Key activities are

- Build of ultrasonic detector array designed in PA1.
- Study of iterative methods to reconstruct the delivered dose from the measured signals.
- Integration of ultra-sonic array with radiobiology station.
- LhARA ion-acoustic test results and validation.
- Test of Ion-acoustic technique in proof-of-principal radiobiology experiment.

Work package 5: Novel end-station development.

The ITRF will operate 24/7 to maximise the return on investment. At 10 Hz repetition rate and with many items requiring only a single shot to achieve the required dose, the logistics of supply will be considerable. The additional access constraints resulting from personnel exclusion from high radiation zones further complicates matters. Adding the mandatory identification, tracking and dose-rate tagging to the cell environment controls on temperature and hypoxia levels leads to a logistical and data management problem of considerable size. Such a task can only be mastered by designing the requirements into the user end-station as a primary requirement. PA1 is completing the work of collecting and collating the user requirements as well as defining the instrumentation. PA1 will also report on the testing of end-station components at kGy/s dose rates allowing the specification of the required beam monitoring technology. As LhARA will be delivering ion beams in new spatial and temporal regimens, the science accessible will be new and diagnostics new to radiobiology will be required. PA2 will design the user end station complete with instrumentation tested at kGy/s dose rates as well as identifying and integrating new diagnostic apparatus to illuminate radiobiology effects in the new regimens.

Key activities include

- Report on testing of LhARA beam monitoring system.
- Delivery of LhARA beam monitoring system.
- Beam monitoring for proof-of-principal radiobiology experiment.
- Conventional radiobiology irradiation at Birmingham – control for roof-of-principal radiobiology experiment.

Work package 6: Design and integration

Work package 6 is a complex work package including the majority of the engineering effort as well as critical elements such as the FFA design with the significant risks attached to its major components. Many of the major project decisions will be informed by work package 6 and, in that respect, there is a co-dependency with the overall project management of work package 1.

PA1 will complete a CDR of the LhARA design to deliver ITRF. For the build to be successful LhARA stage 1 and 2 must complete Technical Design Reviews by the end of PA2.

Critical to the two TDRs will be prototyping of the FFA magnets and acceleration cavities, both of which will be key risk reduction deliverables for PA2. These deliverables require extensive particle tracking simulation coupled closely with engineering design to ensure the viability of the designs. Typically, we can expect factors driving improved particle tracking performance to bin in tension with engineering demands. Selection of the balance point between these is critical to the success of the overall project. TD is expert in this type of trade-off and Work Package 6 is one of the key interaction points for engineering. The lead of Work Package 6 will be integrated with TD and should ideally have a strong existing relationship with TD.

Work package 6, as the key source of engineering effort, will be a contributor to the integration of the proof-of-principal Radiobiology experiment

Key activities in this project are

- LhARA Phase 1 TDR.
- Technical report on FFA main magnet prototype.
- Technical report on MA RF cavity prototype.
- LhARA Phase 2 TDR.
- Engineering of Proof-of-principal Radiobiology Experiment.

Work Package 7: Radiobiology

This work package seeks to deliver proof-of-principal radiobiology experiments at an existing laser facility and publish the first paper during PA2. It is the subject of much development effort, the intention being to acquire key radiobiology data starting in the third year of PA2 and continuing, as a minimum, through to the end of PA2. These experiments will focus on acquisition of radiobiological data on analysis of cell survival (RBE) and levels of DNA damage and repair (e.g. γ H2AX/53BP1 foci, comet assays for DNA single/double strand breaks) in previously well characterised cell models. Indeed, a wealth of data has already been acquired using established models (head and neck, and glioblastoma cell lines) following photon (X-ray) and proton irradiation (using the 60 MeV and 40 MeV cyclotron facilities at both Clatterbridge and Birmingham). These will form the basis for comparison against new data acquired using laser-driven ions.

The experiments will demonstrate all the key components that LhARA seeks to deliver in the ITRF, integrating across several work packages including experimental design (WP6) and simultaneously kick-starting involvement of the radiobiology research community which is vital in end-station development (WP5). This will generate the type of operational feedback that would normally only be available once a facility comes on-line at the end of the build phase, so we can ensure that we work in advance of the overall project goals.

Key activities

- Design proof-of-principal radiobiology experiment.
- Co-ordinate experiment design integration through WP6.
- Interact with user community through WP5.
- Deliver radiobiology experiments and acquire key research data.
- Publish first radiobiological data with laser ions in comparison to photons and protons delivered using conventional cyclotrons.

Work package 8: Outreach and engagement.

This work package takes the work earlier planned as part of Work Package 1 and delegates it with its budget to personnel with the expertise and contacts in the clinical cancer therapy community to make impact not only in radiobiology research but also through the difficult transition to the clinical sphere. This work package does not represent additional work beyond that envisaged in <file:///C:/Users/Colin/Downloads/CCAP-TN-10-3.pdf>.