Imperial Centre for Cancer Technology

Opportunity for the White City Campus development

Overview

The importance of particle-beams for the treatment of cancer is now widely recognised. To maximise the impact of, and access to, this technique requires:

- Advancement in accelerator technology to reduce the foot-print of the facility, to reduce the capital and running costs and to enhance the quality and flexibility of the beam that is delivered;
- The development of novel diagnostic and imaging techniques and real-time feed-back-and-control algorithms; and
- In-vitro and in-vivo measurement of the effect of beams of various energies and ion species on appropriate samples and the exploitation of these measurements in the development of computational tools to speed-up and improve treatment planning.

An interdisciplinary approach is required to achieve these paradigm-shifting advancements.

We have established a collaboration of personnel drawn from the High Energy Physics and Laser/Plasma Groups of the Imperial Department of Physics, the Imperial CRUK Cancer Centre and the Institute of Cancer Research that has the expertise to address the challenges outlined above. The goal of the collaboration is to:

> *Develop the technologies and capabilities necessary to drive a paradigm shift in the provision of particle-beam therapy.*

Our ambition is to achieve this goal by establishing a particle-beam facility on the White City Campus to serve a programme of radio-biological experiments. The facility would be built around a compact, novel system that will deliver proton beams with a momentum of approximately 50 MeV/c to serve the in-vitro and in-vivo radiobiological measurement programme. The particle accelerator would be built using forward-looking techniques such as laser/plasma acceleration, plasma-lens focusing and high-gradient acceleration.

The accelerator development that will be the heart of the proposed Imperial Centre for Cancer Therapy (ICCT) will allow an exciting and essential portfolio of R&D in diagnostics, imaging, real-time feedback and control, simulation and treatment planning to be developed. Further, by establishing at the White City Campus a capability unique in the UK, Imperial would be positioned to partner with other strong, research-led institutions in mutually beneficial, collaborative partnerships that will benefit the scientific and technological output of the ICCT and increase its long-term sustainability by allowing it to access a variety of sources of research income.

The purpose of this document is to present first-pass estimates of the parameters of the proposed accelerator facility, to give a sketch of the possible layout and to give a rough estimate of the footprint and space requirements.

1 Concept

1.1 Interim parameter set

Table 1 lists the assumed set of parameters that the ICCT accelerator systems must deliver. Beams to serve in-vitro measurements require proton energies in the range 1 MeV to 2.5 MeV. In the case of heavier ions (for example helium, lithium and carbon) an energy range extending to several 10s of MeV may be required.

Table 1: Initial assumed parameters that the accelerator facility must deliver. Beam-energy ranges have been determined based on initial simplified simulations that include the effect of beam windows and, in the case of in-vitro measurements, the sample holder. ΔE is the width of the energy "bin" in which the beam is delivered at the sample. The "flux" is defined as the number of particles required to deliver a maximum dose of 10 Gy to the sample in the energy bin of width ΔE.

Programme	**Ion**	**Energy** (MeV)	**ΔE** (keV)	**Flux**	**Time between shots** (min)
Vitro	Proton	1 – 2.5	100	10^6	1
	Helium	5 – 10	400	10^6	1
	Lithium	10– 20	800	10^5	1
	Carbon	20– 40	1500	10^5	1
Vitro	Proton	10 – 40	1000	10^9	0.5
	Helium	40 – 160	4000	10^9	0.5
	Lithium	60 – 320	8000	10^8	0.5
	Carbon	200 – 1000	20 000	10^8	0.5

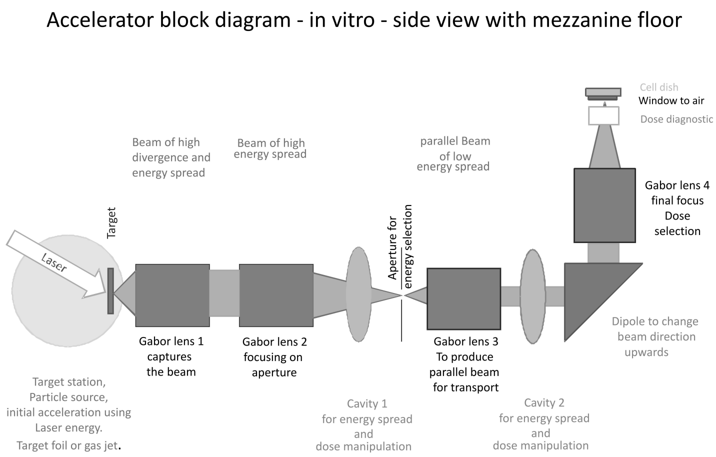
For in-vitro measurements, proton-beam energies in the range 10 MeV to 50 MeV are required. Experiments using heavier ions, again, require higher beam energies, in this case the energy range required extends to several hundred MeV. The parameter table needs to be extended and refined through discussion with the various stakeholders.

1.2 Accelerator facility concept

The conceptual design of the accelerator facility is shown in figure 1. The energy required to serve the in-vitro measurement programme is lower than that required for in-vivo measurements. The scheme that is proposed therefore exploits a simplified accelerator system to serve the in-vitro programme. The injector for the accelerator system proposed to serve the in-vivo programme is identical to the in-vitro accelerator. This approach has been taken to facilitate a staged approach to construction and to increase the productivity of the ICCT in operation since it will allow the two accelerator systems to be run in parallel.

Generation of the beam starts with the bombardment of a foil with a laser. This causes a variety of particle species to be produced and accelerated. The particles are captured in a pair of Gabor lenses and focused on an aperture to collimate the beam. A cavity before the aperture is used to control the energy spread of the beam and as part of the system to tune the dose to the sample. The collimated beam emerging from the slit is transported and, for the in-vitro set up, focused on the sample using Gabor lenses. A second cavity completes the energy-control and dose-manipulation system.

For the accelerator serving the in-vivo programme, the beam emerging from the injector is accelerated by a fixed-field alternating-gradient (FFAG) accelerator, which increases the beam energy by a factor of up to 10. A novel system is proposed to control the dose and to tune the energy distribution of the beam delivered to the sample. The system exploits a series of superconducting cavities the relative phase of which can be set independently. The goal of this section of the accelerator system is to exploit the energy dependence of the Bragg peak by tuning the energy distribution of the beam such that the energy deposited in the target by a single pulse matches, as far as possible, the desired depth profile.



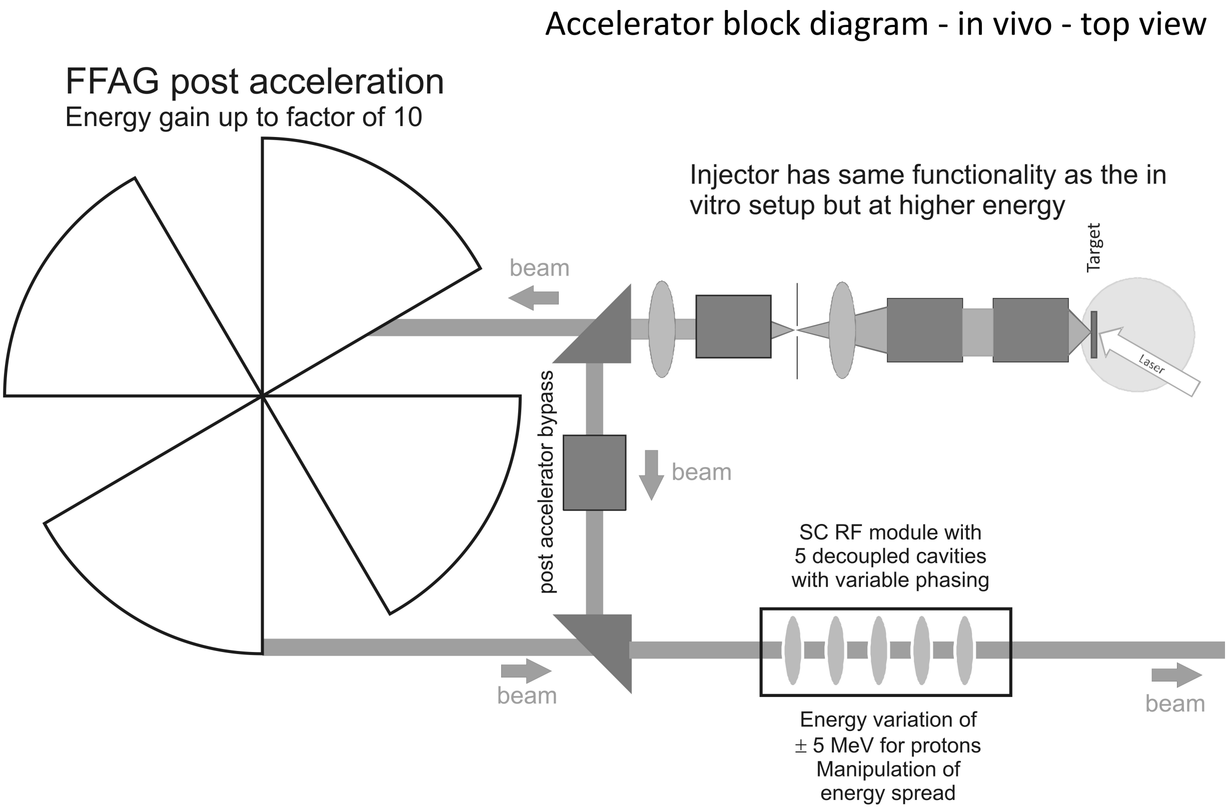


Figure 1: Top panel: System to provide in-vitro measurement capability. Particles are produced using a laser to excite a foil in the target station (the target station is indicated by the grey circle). Two plasma (Gabor) lenses (grey rectangles) transport and focus the beam into the first accelerating cavity (vertical ellipse) that is used to control the energy spread of the beam and is the first step in the dose-control system. After an aperture to collimate the beam (vertical line) a third Gabor lens focuses the beam onto a second cavity before the beam is transported and brought to a focus on the sample. Bottom panel: System to provide in-vivo measurement capability. The injector to the accelerator system is a copy of the in-vitro set-up. The beam leaving the third Gabor lens is injected into a fixed-field alternating gradient (FFAG) accelerator, which increases the beam energy by a factor of up to 10. The beam is then transported through a set of cavities which are set up to tune the energy distribution and dose arriving at the sample.

2 Floor plan

The precise layout of the facility will be determined by the constraints of the building in which it is to be housed. The heavy equipment, including the FFAG and the laser, need to be installed on a stable concrete floor. The energy of the beam serving the in-vitro programme will be above the neutron-production threshold and therefore concrete shielding will be required. It has therefore been assumed that the accelerator facility serving the in-vivo programme will be in the basement. Sample preparation and other experimental areas may be on the basement level or on a mezzanine depending on space constraints.

2.1 Floor plan

Figure 2 shows a possible layout of the accelerator facility in the basement. The in-vitro and in-vivo accelerator systems are laid out so that the irradiation laboratories are located at one end of the facility and the FFAG at the other. This provides for separate access to the accelerator for installation, commissioning and maintenance, and the irradiation laboratories for sample preparation and measurement. As presently laid out, the accelerator facility occupies a floor space of $26 \times 11\,\mathrm{m}^2$.

Figure 3 shows a possible layout of the mezzanine floor. It is not essential for the items shown to be located vertically above the accelerator facility. Should it be more convenient for these items to be placed alongside the accelerator facility this is equally possible. The present layout ($26 \times 11\,\mathrm{m}^2$) minimises the horizontal extent of the facility. The mezzanine level as presently conceived houses the laser and its power supply, sample-preparation rooms and the in-vitro irradiation facility. Crane access to the FFAG is indicated; the mezzanine floor extends over only two-thirds of the basement level.

Laboratory space will be essential. An estimate of the space required is shown in figure 4. Space has been indicated for accelerator operations and support, laser amplifiers and sample preparation. Further discussions with possible stakeholders and users is required to refine the proposed layout.

Figure 5 shows an estimate of the office space needed for the ICCT when it is in operation and producing data. Space is indicated not only for the facility staff and users but also for the computing required to carry out simulations, the development of real-time feedback and control and R&D into efficient treatment planning.

3 Services

In addition to the usual office services (heat, light and power), the ICCT will require:

- Access for equipment and crane cover for the accelerator facility;
- Three-phase mains for the accelerator facility. A detailed power budget has not yet been calculated, but, it is likely that power at the level of 10 kVA to 50 kVA will be required;
- Cyrogens, or a fridge capable of liquefying helium, will be required for the super-conducting cavity module;
- Water cooling for a variety of equipment. Estimates have not yet been made of temperature, flow rate, demineralisation etc.; and
- Air conditioning to remove heat generated in the accelerator hall and service areas.

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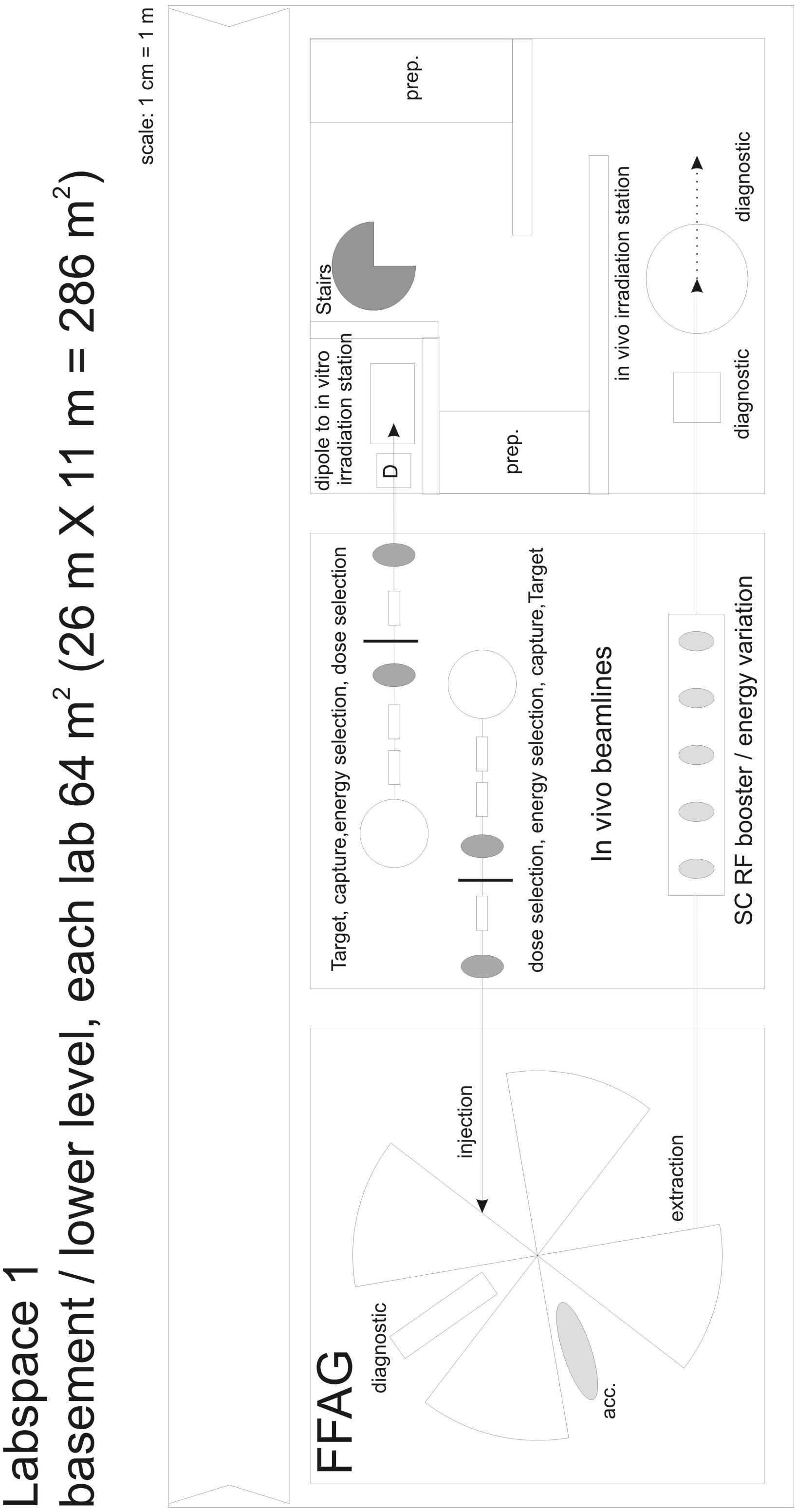

Figure 2: Possible layout of the ICCT accelerator facility in the basement. The components of the facility are drawn to scale, additional space for services and for access will be required. Stairs to the mezzanine level for sample preparation etc. are indicated.

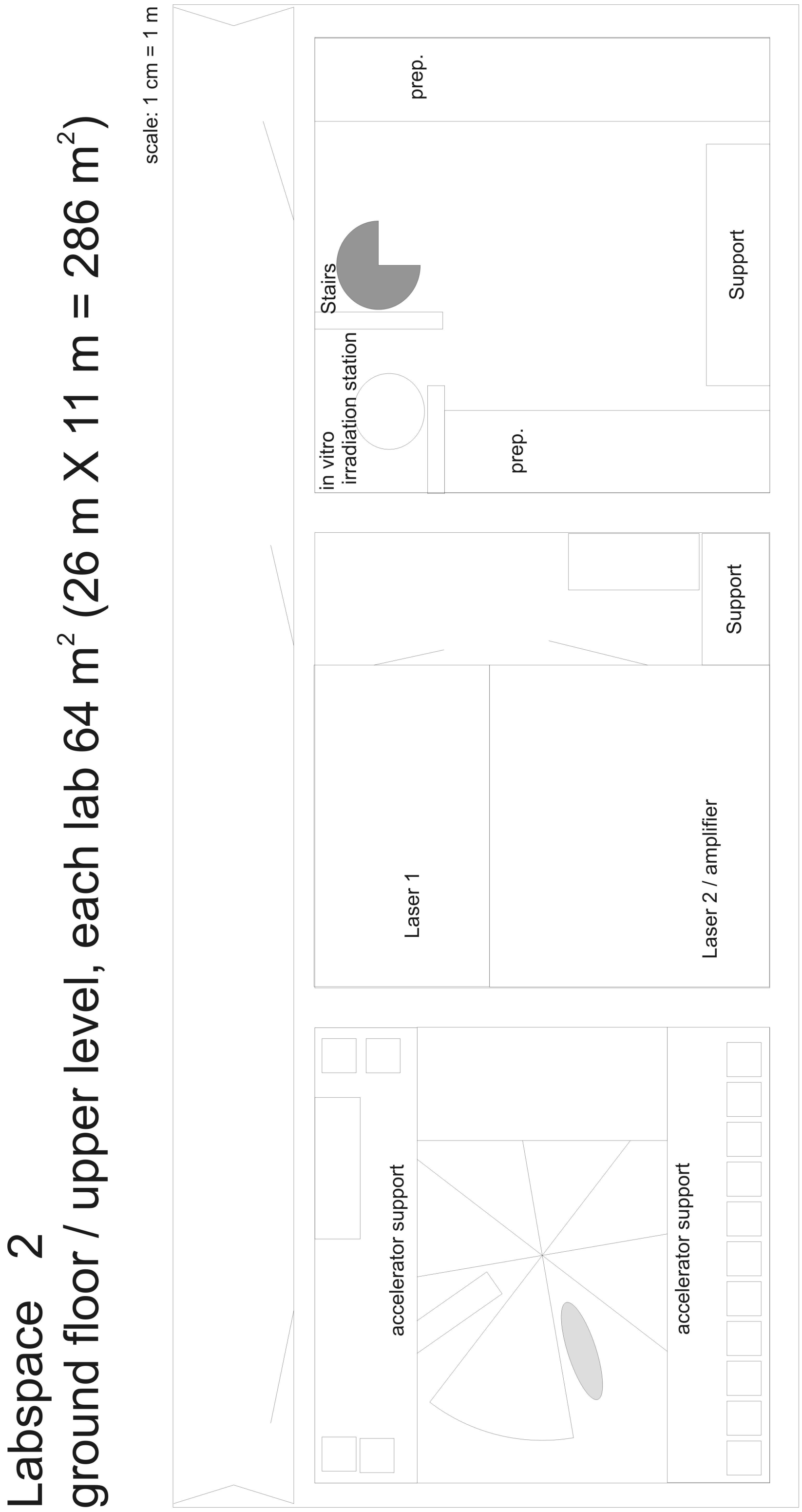

Figure 3: Possible layout of the mezzanine level of the ICCT accelerator facility. Crane access to the FFAG is provided by limiting the mezzanine floor to one third of the span. The mezzanine floor holds the laser and its power supply and sample preparation rooms. The in-vitro radiation area and stairs to the basement level are also indicated.

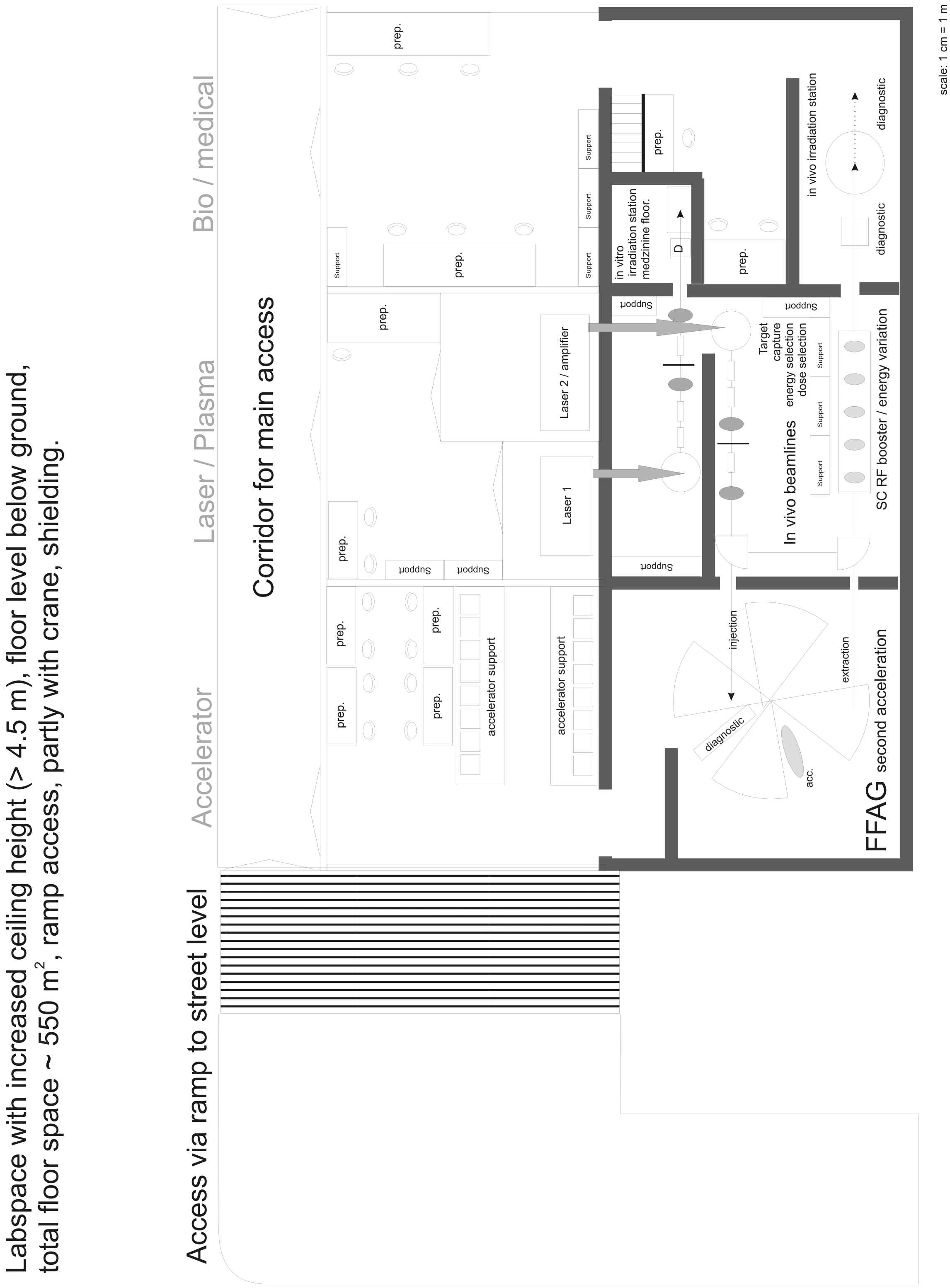

Figure 4: Possible layout of laboratory space at the ICCT accelerator facility. Space for accelerator support and operations, sample preparation and laser amplifiers has been identified.

Figure 5: Possible layout of office, meeting and computing for the ICCT accelerator facility.