IMPULSE

FLAIM experimental platform at ELIMAIA

CAPABILITY FOR FLAGSHIP EXPERIMENTS

Title: Flash and ultrahigh dose-rate radiobiology with Laser Accelerated Ions for Medical research

Short Title/ ID of Project: FLAIM

Contact Person: D. Margarone (ELI Beamlines)

ELI Facility: ELI Beamlines

Experimental Area: E4

Experimental chamber / station: ELIMAIA beamline (Ion Accelerator + ELIMED)

Phase: Flagship Experiments

Estimated Duration (preparation & beamtime): 8 weeks (2 + 6)

Risk estimation & quantification: this assumes that the Ion Accelerator and the ELIMED section of ELIMAIA is technically commissioned before the start of the experiment

LASER SYSTEM PARAMETERS

Pulse duration (fs): ~30 fs **Wavelength (nm):** HAPLS 1ω

Pulse energy (J): >10 J on target (>10^{21} W/cm^2, f/1.5 OAP) **Repetition rate (Hz):** 0.01-1 Hz

Others: ultrahigh contrast needed for RPA acceleration regime (ultrathin targets)

Laser Diagnostics: currently available at L3 (compressor output) and E4 (full-power, on-shot): near/far field, pulse duration (ns, ps, and fs ranges), focal spot (low power), closed loop wavefront control, spectroscopy of back-reflected beam

Ion and Plasma Diagnostics: currently available at ELIMAIA: TP spectrometers, TOF detectors (Diamond, SiC, ion collectors), RCF and CR39 stacks, optical plasma imaging, XUV spectrometer, gamma-ray spectrometer, electron spectrometer

Special Technical Requirements for the beams: use of the plasma mirror setup (available at ELIMAIA)

OTHER TECHNICAL INFORMATION

Expected EMP: Yes, but moderate level (GEMINI-RAL energy/intensity regime) as already characterized at ELIMAIA during the basic commissioning campaign**.**

Compatibility with vacuum: yes, all the equipment is already running at the ELIMAIA vacuum section

Vacuum contamination risks: no major risk (equipment already operational at ELIMAIA)

Special technical works requested on-site: technical commissioning of double plasma mirror setup in E4/ELIMAIA (the hardware is already available, but at two weeks of L3 beamtime are required for its technical commissioning); use of available infrastructures (chemical or biology labs for simple cell culture and microscopy).

PROPOSAL

Aims / Objectives:

- ✓ demonstrate innovative regimes for ion acceleration (protons and C-ions) with a PW-class, high rep. rate laser (e.g. using ultrathin targets to increase ion beam energy in the RPA regime) at ELIMAIA
- ✓ improve beam quality through dedicated ion beam transport at ELIMAIA/ELIMED to fulfil strict user requirements for irradiation of biological samples
- ✓ perform novel clinical dosimetry through dedicated and unique cutting edge, on-shot diagnostics available at ELIMAIA/ELIMED (absolute dosimetry according to clinical protocols, online relative dosimetry, dose-rate independent)
- ✓ perform in-vitro cell (cancer and healthy tissues) and in-vivo (zebra fish) irradiation with well-controlled, tunable (energy and species) high quality ion beams at ELIMAIA/ELIMED using an ultrahigh dose rate and "flash" radiotherapy approach (>10^9 Gy/s)

Brief description of the scientific background and rationale of the project:

Laser-driven ion acceleration is attracting particular interest from the research community unique properties such as ultrashort burst emission, high brilliance and low emittance, which are very attractive for future applications, e.g. in cancer therapy. ELI-Beamlines will play a particularly important role for the field of ultra-intense laser-matter interaction and ion acceleration at ELIMAIA (ELI Multidisciplinary Applications of laser-Ion Acceleration), enabling new extremes of laser power and intensities, as well as providing new capabilities for applications. Thanks to the cutting edge technologies available at ELI-Beamlines, a unique (flagship) experiment in flash and ultrahigh dose-rate radiobiology with laser-accelerated ions (protons and carbon) for medical research can be realized with the main goal to widen the use of the ELIMAIA beamline in the field of radiobiology and medicine, thus achieving a step-change in its capabilities and enabling applications of high societal and scientific relevance. Acceleration of protons and C-ions with a PW-class, high rep. rate laser in the RPA regime can be realized during the flagship experiment at the ELIMAIA beamline and the beam quality can be improved through dedicated ion beam transport at the ELIMED section to fulfil strict user requirements for irradiation of biological samples. Novel clinical dosimetry can be performed through dedicated and unique innovative diagnostics available at ELIMED. In-vitro cell (cancer and healthy tissues) and in-vivo (zebra fish) irradiation with well-controlled, tunable (energy and species) high quality ion beams can be carried out using ultrahigh dose-rate and flash radiotherapy approaches.

Proposed experimental method and working plan:

The proposed flagship experiment should consists of different phases aimed to reach the following milestones

- **Milestone 1 *(propaedeutic run)* - Innovative regimes for ion acceleration with a PW power laser**
  New interaction regimes should be explored thanks to the higher power laser features accessible at ELIMAIA. The investigation of such innovative ion acceleration mechanisms for protons and C-ions, will result in higher beam energies, and can be accessed using ultrathin (down to a few nm) targets.
- **Milestone 2 *(propaedeutic run)* - Ion beam transport and dosimetry**
  Protons/C-ions should be transported and characterized from the source (target) up to the irradiation point (in air) where user samples would be located. The goal should be to enhance the

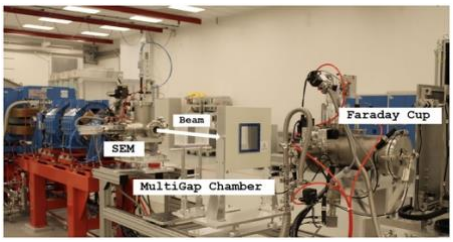
homogeneity of the ion beam lateral distribution and to degrade the beam energy according to the experimental requirements.

- **Milestone 3 *(core activity)* - In-vitro irradiation of biological cells at ELIMAIA**
  The main goal should be to demonstrate the readiness of the beamline to carry out multidisciplinary application experiments, especially in the field of radiobiology as a first step towards potential clinical applications. In fact, clinical dosimetry and radiobiology experiments are the most demanding in terms of user requirements. The ultimate goal of the flagship experiment should be to perform in in-vitro cell irradiation with well-controlled, high quality proton beams, as well as irradiation of Zebra-fish samples.

Description of the experimental arrangement including main optics, targetry, and diagnostics

A detailed description of the equipment to be used is available in a number of technical reports and peer-reviewed articles:

- D. Margarone et al., ELIMAIA-ELIMED Commissioning experiments (Draft 2.3)
- D. Margarone et al., "ELIMAIA: A Laser-Driven Ion Accelerator for Multidisciplinary Applications", Quantum Beam Science 2 (2018) 8
- G.A.P. Cirrone et al., "ELIMED-ELIMAIA: The First Open User Irradiation Beamline for Laser-Plasma-Accelerated Ion Beams", Frontiers in Physics 8 (2020) 564907



Expected outcome / yield:

Widening the use of the ELIMAIA beamline in the field of radiobiology and medicine with laser driven ions (protons and C-ions) by demonstrating its capabilities to carry out user experiments with high societal and scientific relevance.