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# The ELIMED transport and dosimetry beamline for laser-driven ion beams

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ABSTRACT

A growing interest of the scientific community towards multidisciplinary applications of laser-driven beams has led to the development of several projects aiming to demonstrate the possible use of these beams for therapeutic purposes. Nevertheless, laser-accelerated particles differ from the conventional beams typically used for multiscipilinary and medical applications, due to the wide energy spread, the angular divergence and the extremely intense pulses. The peculiarities of optically accelerated beams led to develop new strategies and advanced techniques for transport, diagnostics and dosimetry of the accelerated particles. In this framework, the realization of the ELIMED (ELI-Beamlines MEDical and multidisciplinary applications) beamline, developed by INFN-LNS (Catania, Italy) and that will be installed in 2017 as a part of the ELIMAIA beamline at the ELI-Beamlines (Extreme Light Infrastructure Beamlines) facility in Prague, has the aim to investigate the feasibility of using laser-driven ion beams for multidisciplinary applications. In this contribution, an overview of the beamline along with a detailed description of the main transport elements as well as the detectors composing the final section of the beamline will be presented.



## 1. Introduction

Over the last decades, charged particle acceleration using ultra-intense and ultra-short laser pulses has been one of the most attractive topics in the relativistic laser-plasma interaction research [1,2]. Since the first experiments on laser-matter interaction, wide theoretical and experimental progresses have been carried out, confirming the possibility to accelerate multi-MeV ion beams from the interaction of high-intensity laser pulses (from $10^{18}$ to $10^{20}$ W/cm$^2$) on thin solid targets [3–5]. So far different acceleration regimes [6–11], such as the *Target Normal Sheath Acceleration* (TNSA) [12–14], the *Radiation Pressure Acceleration* (RPA) [15–17] and the *Break-Out Afterburner* (BOA) [18], have been studied and several experimental results, obtained mainly within the TNSA regime, have been reported in the literature [12–14]. Some of the peculiarities of the accelerated protons might be of interest for different kind of applications, including the medical ones. In particular, high fluxes per shot a broader energy spectra, if well controlled, could provide an alternative and powerful tool for dose delivery, representing a new opportunity for the therapeutic purposes of charged particles. Indeed, one of the most challenging ideas driving recent activities consists on using laser-target interaction as a source of high-energy ions for possible future medical applications [20,21]. Nevertheless, despite the great enthusiasm driven by the recent results, before clinical application of laser-accelerated particles several tasks need to be fulfilled. Several international collaborations and experiments have been launched in the last years aiming to explore the feasibility of using laser-driven sources for potential medical applications and many research centers have been involved in the investigation of laser driven therapy and applications, as for

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instance the Queens University Belfast Consortium, the OncoRay National Center for Radiation Research in Oncology, Dresden, The Munich Centre for Advanced Photonics (MAP), the ion Acceleration Program at BNL ATF and UCLA, a more complete and extensive review on these research projects along with the specifications of the laser systems and technical approaches involved can be found in an ICFA Publication [22]. In this framework, a collaboration between the INFN-LNS (National Institute for Nuclear Physics – Laboratori Nazionali del Sud, Catania, Italy) and the ASCR-FZU (Institute of Physics of the Czech Academy of Science), in charge for the ELI-Beamlines facility implementation, has been established in 2011. ELI-Beamlines started in 2012 the realization of a high-power laser facility, where one of the experimental hall, named ELIMAIA (ELI Multidisciplinary Applications of laser-Ion Acceleration) will be dedicated to the multidisciplinary experiments with laser-accelerated protons and ions. ELIMED (ELI-Beamlines MEDical and multidisciplinary applications) represents the beam transport and dosimetric section of the ELIMAIA room and will be designed, realized and installed at ELI-Beamlines by LNS-INFN within the end of 2017. Its purpose is to provide to the interested scientific community a user-oriented facility where accurate dosimetric measurements and radiobiology experiments can be performed [23].

In the following sections, a description of the ELIMED beamlines, with a detailed discussion of the transport elements as well as of the detectors, will be presented.

## 2. The ELIMED transport beam line

To fulfil the mentioned goals and deliver the accelerated beams with the requirements necessary for multidisciplinary applications, the following issues have to be taken into account designing the ELIMED beamline: to make the optically accelerated beams suitable for multidisciplinary applications and to find innovative solutions for the detectors development for laser-driven ions.

The first goal will be achieved studying and designing specific transport elements that allow collecting and selecting the accelerated particles. The second one will be achieved developing new solutions to perform accurate dose and energy spectra measurements and, consequently, well-controlled sample irradiations. According to these requirements, three main sections are foreseen for the ELIMED beamline: the first and the second one, in vacuum, composed by magnetic elements for the transport and selection of the accelerated particles, and the third section in air, a dosimetric system for real time monitoring of the delivered dose on samples at the irradiation point (Fig. 1). Moreover, detectors for diagnostics will be placed respectively after the collection system and at the end of the in-vacuum transport beamline to measure the properties of the transported beams, namely beam emittance, fluence and energy spectra.

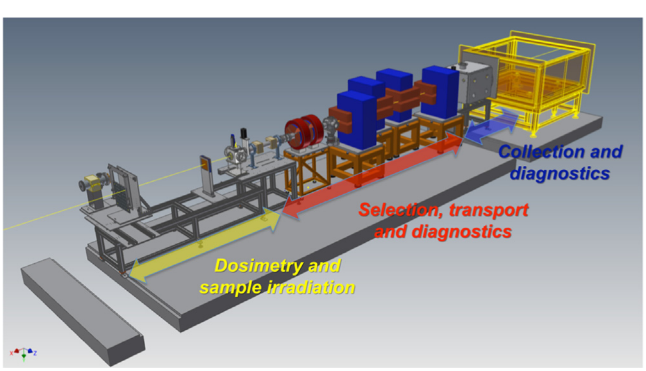


**Fig. 1.** Layout of the ELIMED beamline with the three different sections.

Concerning the collection and selection, the in-vacuum transport beam-line that will be installed at ELIMAIA consists of three main elements: a collection system, namely a set of Permanent Magnet Quadrupoles (PMQs), placed close to the laser-target interaction point, an Energy Selection System (ESS) based on four resistive dipoles, and a set of conventional electromagnetic transport elements, two quadrupoles and two steering magnets. The beam-line has been designed to deliver laser-driven ions up to 60 MeV/u, offering, as output, a controllable beam in terms of energy spread (varying from 5% up to 20% for the highest energies), angular divergence and, hence, variable beam spot size between 0.1–10 mm with a reasonable transmission efficiency (namely $10^6-10^{11}$ ions/pulse). The final beam dimension can be achieved using a conventional doublet of quadrupoles with a maximum gradient of 5 T/m and a bore of 70 mm and eventually using collimators.

In order to fulfil the project requirements, the two main elements of the in-vacuum section, the PMQs system and the ESS, have to be optimized. The aim of the collection system is to collect the largest fraction of the accelerated ions within a certain energy range, reduce their angular divergence and inject them into the selection system, which will cut the particles outside the energy range of interest. The beams coming out from this first part of the beam-line (PMQs+ESS) will have reduced angular and energy spreads, therefore, they are easier to be transported and shaped with conventional magnetic lenses, such as resistive quadrupoles and steerers. They will be placed in the last part of the in-vacuum beam-line. However, although the transport elements will allow to obtain beams selected in energy and with small divergence, the beam properties are still far from the typical features characterizing the conventional accelerated beams, from the point of view of the temporal structure. Indeed, the transported laser-accelerated ion beams will be characterized by very high intensities per pulse, i.e. up to $10^7-10^{10}$ particles per bunch, and very short temporal profile (ns), compared to $10^8-10^9$ particles/s accelerated by conventional clinical machines. This results in an extremely high dose rates, i.e. $10^6-10^9$ Gy/min (vs 10–50 Gy/min in conventional proton therapy). In these conditions, innovative detectors have to be developed and new dosimetric procedures need to be assessed in order to deliver the dose with an accuracy as closer as possible to the one required in medical applications.

Moreover, the whole ELIMED beamline has been simulated with the Monte Carlo Geant4 code for particle tracking in the matter [24,25]. Monte Carlo simulations have been widely used to support the design of some elements composing the beam line and to preliminary study the response of detectors [26]. Moreover, once the final configuration of the beamline is accurately reproduced, the Geant4 simulations will be used to predict the particle transport at specific positions along the beam line and to evaluate dose, fluence and particle distribution in the in-air section, where the experiments will be performed.

### 2.1. The collection system

The PMQs system consists of five quadrupoles as described in Table 1 [27,28]. The system has to collect a wide range of ion energies,

**Table 1**
PMQs main features.

| No. of PMQs | Geometric length (mm) | Field gradient (T/m) | Bore diameter (mm) |
|---|---|---|---|
| 1 | 160 | 101 | 30 |
| 2 | 120 | 99 | 30 |
| 2 | 80 | 94 | 30 |

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