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TRANSPORT AND ENERGY SELECTION OF LASER PRODUCED ION BEAMS FOR MEDICAL AND MULTIDISCIPLINARY APPLICATIONS

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Abstract

Ion beams produced by the interaction of high power laser with thin targets are being characterized experimentally around the world in order to get a reasonable amount of particles with low divergence and narrow energy spread to be used in medical and multidisciplinary applications. Several schemes about the energy selection and transport of laser accelerated beams have been considered and tested, however the energy spread of the selected particles keep rather high and the reproducibility has not been yet achieved. In the framework of ELIMED network [1], we present a study of a possible layout to capture and transport in an efficient and reproducible way, the beams generated by the laser-target interaction. It consists of a combination of quadrupoles based on permanent magnets placed just downstream the target, coupled with a system composed by a series of 4 dipole magnets of inverted polarity which provides the final energy selection of the previous focused beam. Such a system will be tested in 2014 at TARANIS facility to select proton beam in the energy range of 4-8 MeV, and the main scheme can be scaled for high energy beam expected to achieve at next generation high power laser facilities.

INTRODUCTION

ELI is an European large scale infrastructure developed within the ESFRI process and based on three laser facilities located in different countries and dedicated to different research fields from nuclear physics to the attosecond physics. One of this facility is being implemented in Prague (Czech Republic) and it is named ELI-Beamlines [2] and will be mainly dedicated to applications of the laser produced photon and particles beams in several fields such as high-resolution X-ray imaging, exotic physics etc. One of the secondary sources available at ELI-Beamlines will be dedicated to Multidisciplinary Application of laser-Ion Acceleration, thus the acronym used as name for the beam line is ELIMAIA. An experimental hall of the ELI-Beamline building has been already assigned for the development and the realization of a transport beam-line and will be available for users interested in studying the applicability of laser-driven ions in different fields, including future clinical applications. Around the ELIMAIA beam line, a network between groups of researchers from different European and non-European countries has been launched under the name of ELIMED (MEDical application at ELI-Beamlines). One of the motivation of the project is based on the fact that the actual hadrontherapy centres are based on conventional accelerators, such as cyclotrons or synchrotrons which are huge, complex and, hence, expensive machines, both in terms of financial and human resources. These are the reasons why only few centres are available around the world and the request of proton therapy treatments cannot be fully satisfied. On the other hand, laser-based accelerators could be a competitive alternative as they can be smaller in size and less expensive. Design of miniaturized systems have been already proposed in literature [3] in which the laser-driven ion part is combined to a conventional beam transport system.

In this context the researchers of INFN are involved in the conceptual design and realization of prototypes of possible solutions for the selection and the transport of laser produced beams. Moreover, the prototype of Thomson Parabola Spectrometer (TPS) and the Energy Selector System (ESS) have been successfully tested at laser facilities in Europe [4].

COLLECTING AND SELECTION SYSTEM

In contrast to conventional accelerators the combination of very high peak currents with extremely low emittance makes laser-driven beams unique with the promise for compact accelerator development for several applications. However the laser-driven beams are usually characterized by a large divergence and a huge energy spread (close to 100%). In order to make such accelerated particles suitable for several applications, the ion collection, the angular and the energy selection, the energy and intensity reproducibility, as well as the operational reliability and flexibility are key points to be investigated.

Typically the focus and the selection processes of beam produced in the laser-target interaction is characterized by the following steps:

Capturing and Pre-Selection

It starts close to the production point of the charged particles. The aim of this section of the beam transport line is to collect the largest fraction of particles so that to reduce the beam angular divergence, as well. The device must be quite compact since it has to be placed inside the scattering chamber. To fulfill such requirements, solenoid magnets producing pulsed high magnetic field are typically used [5]. Indeed, a solenoid has a large acceptance and ensures focusing on both transverse planes. Moreover, considering that the focal point of a solenoid depends on the particle energies, this system also

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provides a very preliminary selection in beam energy: it is done by placing a collimator at a certain distance from the solenoid. However the particles passing through the solenoid-collimator system are not well selected in energy since part of low and the high energy components are transported together with the selected one. This is due to the fact that the particles emitted from the source with low emission angle are not affected by the solenoid field, therefore they are transported throughout the whole system.

As alternative to above system, the capturing phase can be done by means of quadrupole lens. In this case, a set of quadrupole based on permanent magnets are placed on the mechanical system which allow to vary the relative distance from each other, in order to modify the focal point position as function of the energy of the beam. The system has a small acceptance respect to the solenoid, then the transmission efficiency decreases, but this configuration implies less cost in terms of design, construction and reliability.

In order to get the beam focusing on both transversal planes at least two quadrupoles are foreseen to be used. Moreover a third lens is suitable for matching the focal point on vertical and horizontal directions so that a common waist is achieved after the focusing. By using quadrupole devices with 100 T/m gradient, 20 mm bore and length of 40 and 80 mm, the focusing of beams up to 30 MeV of energy is achieved.

The INFN researchers are designing the motorized guide on which 3 or more quadrupole devices can be placed and they move independently along the direction of propagation of the beam. Such a system is located in front of the target as shown in Fig. 1, and the distance between the target and the first quadrupole can be modified to provide the optimal focusing.

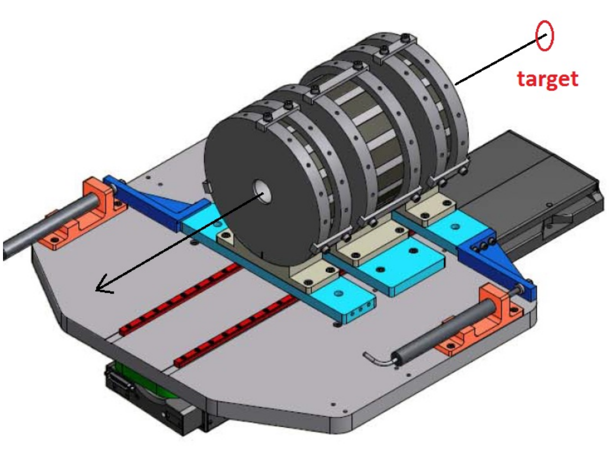

Figure 1: The mechanism for moving the triplet quadrupoles is shown. The quadrupole consists of permanent magnets with Halbach configuration.

Final Selection

Since the beam coming from the capturing system is ever affected by unwanted energy component, an energy selector device providing the final selection has been realized and tested.

The energy selector system consists of a sequence of four dipole magnets with alternating polarity (first and four with same polarity and second and third with opposite sign) that provide the spatial separation of the charged particles with different energies. Therefore, by means of an aperture provided by a slit system and placed in the middle of the magnetic system, the particles with suitable energy are selected and transported to the exit of the device. The energy of the selected particles can be varied by moving radially the slit, whereas the energy spread, considering the size of the aperture constant, increases as the selected energy rises. Moreover, the energy spread and the amount of the transported particles depend also on the aperture size of the selection: the lower the energy spread, the lower the number of particles that pass through the selector because the slit aperture is reduced.

The dipoles based on a hybrid configuration with a combination of soft iron yoke and permanent magnets (NdFeB) provide a maximum magnetic field of 8000 gauss on a gap of 10 mm. The central twin magnets are placed on a roller guide system that allows to move those radially of 50 mm, in order to select the lower energy component of the particle beams. In such a way, the device is able to select protons within the range of 1 MeV and 30 MeV. Moreover, the last dipole can shift 10 mm back and forth along the longitudinal direction in order to compensate the asymmetry of the magnetic field. That permits the radial steering of the beam to correct eventually misalignments of the system as shown in Fig. 2.

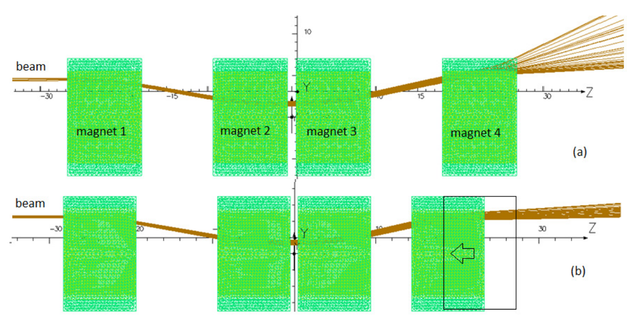

Figure 2: The figure represents the comparison between two configurations of the magnetic system of the energy selector. With a symmetric arrangement of the magnets, the monochromatic beam coming from left side leaves the device with a wide angular spread. To minimize such effect, the 4th magnet may be shifted few cm upstream.

The whole magnet system is almost 600 mm length and this compactness makes possible the use inside the scattering chamber. On the other hand, the system has a dedicated vacuum chamber which can be placed along a beam transfer line (Fig. 3). When the device is used in proximity to the target source, hence the input beam has a broad angular distribution, a collimator placed upstream the selector, must be used to minimize the spatial mixing

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of the particles passing through the magnetic system. An additional collimator placed downstream the device, allows to tune both the fluency and the final energy spread of the selected particles.

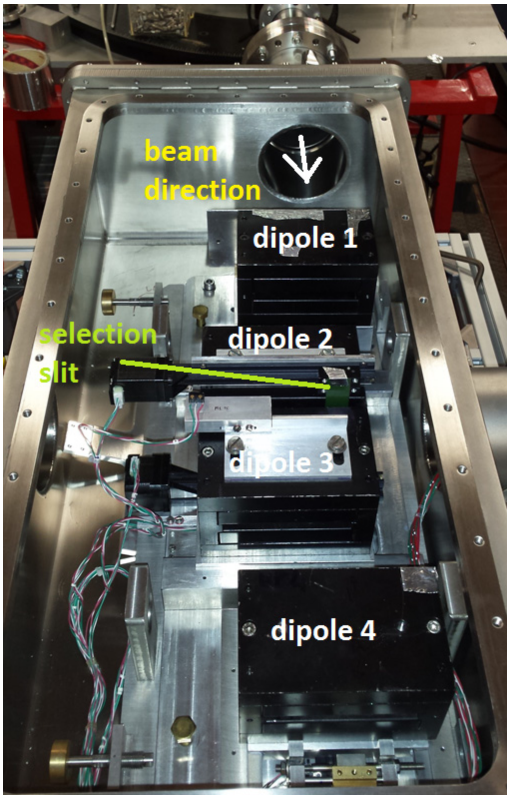

Figure 3: The picture shows the energy selector system into own vacuum chamber, during the calibration session at LNL.

The whole system consisting of quadrupoles and energy selector system should allow to get an efficient transport and selection as well, of the laser-driven beams with a selected energy up to 30 MeV with spread of 5-10%.

The energy selector has been calibrated with monochromatic proton beams provided by electrostatic accelerators at LNS and LNL laboratories of INFN in the range of 2-12 MeV.

CONCLUSION

The INFN is involved in the developing of advanced technics for selection and transport of beams produced by high power laser and target interaction. The prototype of the energy selector system has been already constructed and calibrated with monochromatic beams. The quadrupole devices that provide the capturing of the beam are under construction and will be ready on 2014 fall. After the calibration and the preliminary test which will be held in the national laboratories of INFN, the system shall be used in experimental campaigns at high power laser facilities.

REFERENCES

[1] G.A.P. Cirrone et al., "Medical Research and Multidisciplinary Applications with Laser-Accelerated beams: The ELIMED network at ELIbeamlines" ,WEPRO085, IPAC'14, Germany (2014)
[2] Eli-beamlines Project, www.eli-beam.eu.
[3] Schollmeier et al. "Controlled and Focusing of laser-accelerated protons with miniature devices", Phys. Rev. Lett. 101 (2008).
[4] G.A.P. Cirrone et al., "High-energy resolution Thomson Parabola spectrometer for laser plasma diagnostics", 2nd ELIMED workshop, AIP Conference Proceedings, Volume 1546, pp. 50-53 (2013).
[5] T. Burris et al., "Laser accelerated protons captured and transported by a pulse power solenoid", Phys. Rev. ST, Acc. And Beams 14, 121301 (2011).