Beam diagnostics for Laser-induced proton generation at KAERI

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1. Introduction

With an advent of femto-second lasers, a laser-accelerated ion generation has been world-widely studied for medical and nuclear applications. It is known that protons with the energy from several tens MeV to a few hundreds MeV require for a cancer therapy and nuclear reaction. Even though, up to present, the maximum energy of laser-accelerated proton is about 60 MeV, it is expected that the energy of protons generated can be obtained at least up to 150 MeV.

According to theoretical and experimental works, it turns out the energy distribution and the flux of ions strongly depends on the intensity of a fs laser at a target. However, physics on laser-plasma interaction is still not clear. The precise measurements of parameters of a fs laser and ions are important to figure out the physics and develop the theoretical interpretation. Typically, beam diagnostic system includes measurements and/or monitoring of the temporal and spatial profiles of lasers at the target as well as the energy spectrum and density profile of protons, which are critical for the analysis of mechanism and the characterization of protons generated.

We fabricated and installed the target chamber for laser-accelerated proton generation and are now integrating beam diagnostic system. For laser diagnostics, beam monitoring and alignment system has been installed. For a charged particle, CR-39 detectors, Thomson parabola spectrometer, and Si charged-particle detectors are installed for density profile and energy spectrum.

In this paper, we discuss the laser beam monitoring and alignment system. We also estimates expected spectrum of protons from Thomson parabola spectrometer, depending on the parameters of protons.

2. Laser beam monitoring and alignment system

For a beam alignment, a He-Ne laser is used for the coarse adjustment and low energy beam from the oscillator of a fs laser is for the fine adjustment. A He-Ne laser is collimated to its beam size of 1.2 cm and delivered to the target through the transport mirror optics and the parabolic focusing mirror. The laser will be reflected and imaged at a CCD camera with 1:6 imaging optics, as shown in Figure 1.

There are several advantages of this scheme. First, the laser beam direction can be prealigned using visible light. Secondly, the parabolic mirror for focusing can be aligned by monitoring the beam shape. Thirdly, the target can be positioned with a high accuracy.

This scheme enables us to measure the spot size in real time, at the expense of the accuracy of the spot size. But, the uncertainty of few μm is tolerable for a laser spot of 20 – 30 μm.

Before installation, we tested the quality of the parabolic mirror with the focal length of 76 mm at 90° and the 1:6 imaging optics for real-time laser monitoring system.

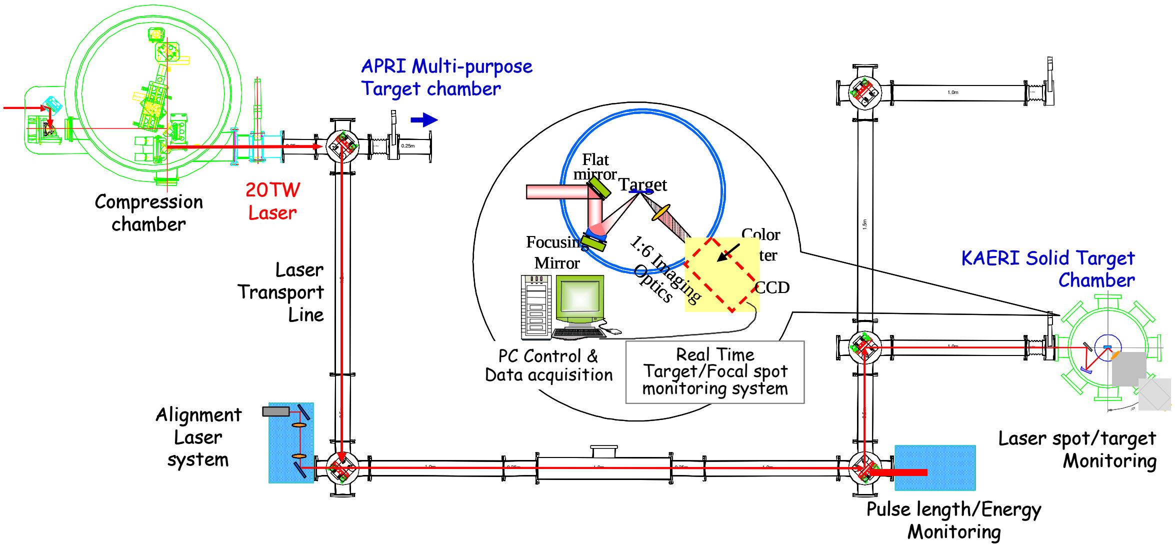

Figure 1. Layout of Laser beam transport line, alignment system, and laser spot monitoring system.

3. Thomson parabola spectrometer

A charged beam is deflected by the electric and magnetic fields. Thomson parabola spectrometer is comprised of a dipole magnet and electric parallel plates. A proton is bent in the horizontal plane by uniform magnetic field and deflected in the vertical plane by uniform electric field. At a screen, such as CR39 plate, protons with different energies are traced at the different position. By analyzing the trace as well as the density of spots, we can get the spectrum of protons generated by laser-plasma interactions.

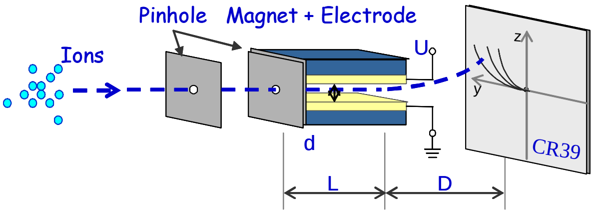

Fig. 2. Schematic of Thomson parabola spectrometer

Since laser-accelerated protons have their own angular and energy spread, it is better to use two pinholes to increase the accuracy, at the expense of low flux. The Lorentz force equation of the relativistic charged particles can be written as like:

$$\frac{d\vec{\mathbf{p}}}{dt} = \frac{d}{dt}\left(\gamma m\vec{\mathbf{v}}\right) = qE\hat{\mathbf{z}} + \frac{qB}{c}\vec{\mathbf{v}}\times(-\hat{\mathbf{z}})$$

$$\frac{d\gamma}{dt} = \frac{qE}{mc^2}\vec{\mathbf{v}}\cdot\hat{\mathbf{z}}\text{, where } E = \frac{U}{d}$$

The simulation code is developed to analyze the collected data, by solving the above Lorentz force equation. It includes the energy spread and angular spread of charged particles so that the effects of the angular spread and energy spread on the trace can be estimated.

To design the Thomson parabolar spectrometer, the strength of the electric and magnetic fields, the length L, and d should be selected depending on the expected energy range of protons. The higher energy proton need higher field, while the lower energy protons need a gap d wide enough to pass the length L. The distance D from field region to screen should be long enough to increase the resolving power of energy. All parameters are compromised to fit inside the target chamber. The expected trace on the screen is shown in Fig. 3.

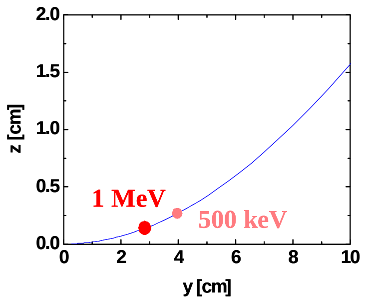

Fig. 3. Trajectory of protons on a screen after Thomson parabola spectrometer. (B=5.1 kG, U=-1kV, d=3mm, L=4.5 cm, D=15cm)

REFERENCES

[1] M. Reiser, Theory and design of charged particle beams, JohnWiley & Sons, Inc., 1994