

CLAPA PROTON BEAM LINE IN PEKING UNIVERSITY

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Abstract

Comparing with the conventional accelerator, the laser plasma accelerator can accelerate ions more effectively and greatly reduce the scale and cost. A laser accelerator—Compact Laser Plasma Accelerator (CLAPA) is being built at Institute of Heavy Ion physics of Peking University. According to the beam parameters from proof of principle experiments and theoretical simulations, we design the beam line for ions transport which is being built now and in the near future we will carry out experimental study with it.

The beam line is mainly constituted by quadrupole and analyzing magnets. The quadrupole triplet lens collects protons generated from the target, while the analyzing magnet system will choose the protons with proper energy. The transport is simulated by program TRACK. The beam line is designed to deliver proton beam with the energy of 1~40MeV, energy spread of $\pm 1\%$ and 10^{6-8} protons per pulse to satisfy the requirement of different experiments. The transmission efficiency is about 94% when the energy spread is $\pm 1\%$.

INTRODUCTION

Over the past few years, outstanding progress has been made in high-power laser technology with laser powers reaching petawatt (PW) values. These facilities can generate high energy particles when laser interacts with the plasma [1]. Interaction between laser and plasma has the potential to acquire 10^{12} V/m accelerating electric field gradient [2] and realize compact and economical accelerations.

Proton (and ion) cancer therapy is today only possible with large scale accelerator facilities which are very difficult to install at existing hospitals. Hence, laser accelerations have immense promise for innovation and been thought of as a way out of this dilemma.

In recent years, lots of theoretical simulation works have achieved encouraging results [3, 5], paving the way for widespread application of laser acceleration to offer a robust, compact, and low-cost alternative. However, laser accelerated proton beams have inherent disadvantages, in particular, their broad energy spectra and large angular divergence [6]. Many applications need a narrow energy spectrum, therefore, selecting out particles to get desired energy spectra is necessary. Many kinds of elements have been tried to handle chromatic aberration caused by wide energy spectrum, such as permanent magnet quadrupole lens [7, 8], solenoid magnet [9, 10], laser triggered microlens [11], bending magnet [12], a set of dipole magnets

[13, 14] or combination of magnets [15].

A compact laser accelerator (CLAPA), according to RPA-PSA mechanism [16, 17] or other acceleration mechanisms [18], is being built in Peking University. To solve the problems above, we design a beam line for CLAPA. The beam line is mainly constituted by common transport elements to deliver proton beam with the energy of 1~40MeV, energy spread of $0\sim\pm 1\%$ and current of 10^{6-8} proton per pulse.

BEAM LINE

At present, the beam line is designed chiefly to transport proton beam on request of biomedical irradiation. The beam parameters are shown in Tab. 1.

Table 1: beam parameters of CLAPA

ion	proton
energy	15MeV
current	1×10^8 proton/punch
initial energy spread	$\pm 15\%$
final energy spread	$0 \sim \pm 1\%$
initial transverse radius	0.005mm
initial longitudinal length	1.06mm
Final transverse radius	0.83mm
Final longitudinal length	70mm

Schematic diagram of beam line is shown in Fig. 1

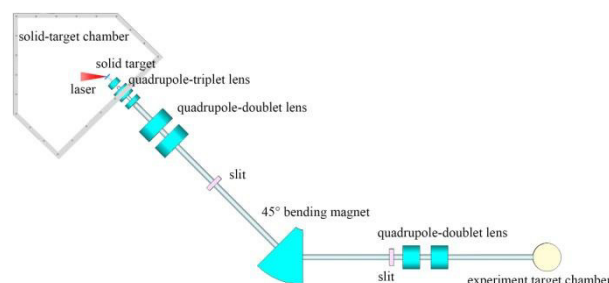


Figure 1: Schematic diagram of beam line.

Aperture: After ultra-short ultra-intense laser interacts with targets and generates energetic particles, an aperture is used to remove big divergence angle particles before protons enter collecting lens. The distance between laser target and aperture is 14cm in our case, to reserve space for detecting instruments. The proton beam enters quadrupole-triplet lens with divergence angle of ± 50 mrad, transverse emittance of 0.25π mm.mrad and current of $1 \times 10^{6-8}$ proton/pulse.

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Collecting lens: The proton beam with divergence angle of $\pm 50\text{mrad}$ will expand rapidly. A quadrupole-triplet lens is an efficient and effective design to focus and control the beam. The quadrupole-triplet lens is inserted into chamber to close to target. Taken into account the requirement of our laser target chamber and transport of beam, in the first stage, the inner radius of quadrupole-triplet lens is respectively designed as 15mm, 32mm, 32mm. The length of lens is respectively 100mm, 200mm, 100mm. For protons with energy of 15MeV, the matched magnet field gradients is 2.75, -1.75 and 2.02 kG/cm when the distance between laser target and aperture is 14cm. All magnetic strength at pole face is not more than 0.7 T, which makes the manufacture of the magnets easily achievable.

Assistant collecting lens: The collecting lens can collect the protons with the energy not more than 19 MeV. A quadrupole-doublet lens is set 40cm from the collecting lens outside the target chamber to assist collection when the energy is high. The inner radius of lens is set as 50mm and length is 250mm. The distance is 150mm between each other.

Bending magnet: To select protons accurately, a 45° bending magnet is used. After overall consideration, the radius of bending magnet is designed as 650mm. The object distance of bending magnet equals to image distance, which is 1575mm in program Track. Then the beam is analyzed by bending magnet and converges to form a beam waist on the back end of image distance in the X direction. At this point, protons with different energy have been separated in the X direction and a slit is placed to remove unwanted particles, just as shown in Figure 1. The analyzing ability of bending magnet is simulated by program Track [19] (Fig. 2). 5 different energy proton beams transporting at the same time is simulated by program Track to test the analyzing ability (Fig. 2). From the results we can find that the bending magnet is able to analyze and get $\pm 1\%$ energy spread beam.

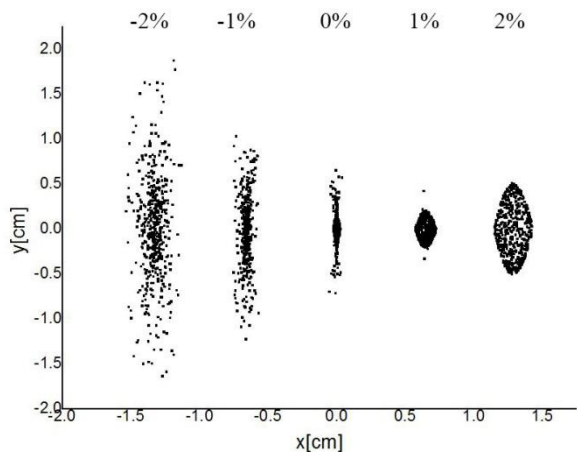


Figure 2: Simulation of analyzing ability of bending magnet. Standard beam is 15MeV (0% beam) and the others have $\pm 1\%$, $\pm 2\%$ energy difference comparing with standard beam.

Back focus lens: After being analyzed and screened at the beam waist at the end of image distance, the proton beam needs to be focused by a quadrupole-doublet lens to the experiment target. Quadrupoles can be adjusted to get different location of final beam waist in different experiments.

Finally, protons are delivered to the experiment target and have a distribution of protons. Uniformity of particle density distribution is very important in some applications, such as proton cancer therapy.

It generates a relatively well distribution of protons with an energy spread of $\pm 1\%$ at the experiment target. The transport efficiency of protons with energy spread of $\pm 1\%$ is about 94%.

The simulation results including distribution of protons at experiment target are shown in Fig. 3.

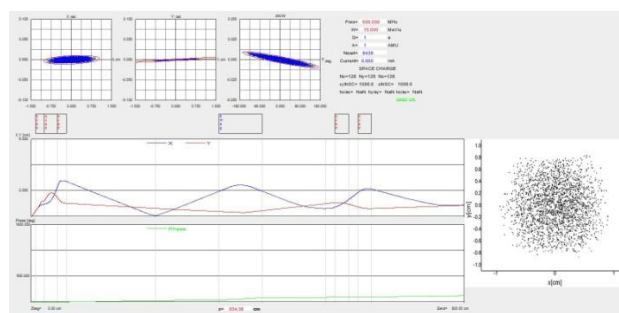


Figure 3: The transport of 15 MeV proton beam with energy spread $\pm 1\%$.

TRANSPORT OF HIGHER ENERGY BEAM

In the preliminary design phase, protons with energy up to 40MeV can be delivered with the help of assistant collecting lens, as we need the radius of bending magnet to be 65cm.

The transport of 40MeV protons with energy spread $\pm 1\%$ is shown in Fig. 4, as well as the distribution of protons at the experiment target. The transport efficiency of protons with energy spread of $\pm 1\%$ is about 94%.

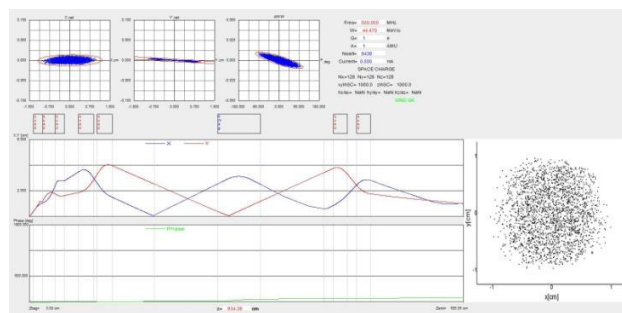


Figure 4: The transport of 44.47 MeV proton beam with energy spread $\pm 1\%$.

CONCLUSION

The beam line of CLAPA is designed with common transport elements. From the simulations of program Track, the beam line is able to deliver the proton beam with energy of 1~40MeV and energy spread within $\pm 1\%$. According to the beam parameters from this simulations, our beam line for ions transport is being built now and in a few months we will perform experiments in application of laser plasma acceleration.

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