DESIGNING INTEGRATED LASER-DRIVEN ION ACCELERATOR SYSTEMS FOR HADRON THERAPY AT PMRC (PHOTO MEDICAL RESEARCH CENTER

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Abstract

The concept of a compact ion particle accelerator has become attractive in view of recent progress in laser-driven hadrons acceleration. The Photo Medical Research Center (PMRC) of JAEA was recently established to address the challenge of laser-driven ion accelerator development for hadron beam cancer therapy. PMRC considers conceptual designs of such a therapeutic instrument based on the current state in the laser-driven acceleration. We describe a conceptual gantry device that is designed by the general-purpose ion accelerator design code, PARMILA.

INTRODUCTION

The cancer treatment with hadron beams continues as cancer treatment facilities are being developed around the globe with state-of-the-art accelerator technology. The generation of energetic protons and ions from laser-plasma interactions, has made laser-driven hadron radiotherapy a subject of strong interest. Proton bunches with high peak current and ultralow emittance is typical yields from ultrafast laser-foil interactions.

Up to now, simple concepts of laser-driven accelerators for cancer therapy are shown in some laboratories [1,2]. However, a realistic laser-driven medical treatment system for hadron beam therapy (HBT) has not been designed. Our main mission at PMRC is to develop integrated, laser-driven ion accelerator systems (ILDIAS) that demonstrate desired beam characteristics for such therapy. The laser-driven ion therapy will be advanced by PMRC.

Though there is an idea of miniaturizing the treatment apparatus only by the huge power laser technology, here, we do not develop the ion therapeutic instrument only using the laser technology in the first stage. In this stage, PMRC aims at combining conventional accelerator beam transport optics with laser-driven ion technology.

The laser-driven ion part is combined to a conventional beam transport system. In the design of the beam transport system constructed with electromagnets, we use the Phase and Radial Motion in Ion Linear Accelerators (PARMILA) [3] design software which was originally developed as a numerical tool to design and simulate beam performance. Using PARMILA, we explore beam transport design that is appropriate for the medical treatment. In this paper, we present s simple conceptual design of an ILDIAS beam line and one of the results of a PARMILA simulation for this feasibility study..

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CONCEPTUAL DESIGN

Assumption of Laser-Driven Ion Characteristics

To date, the highest energy obtained for laser-accelerated protons is 58 MeV, using a high-power, high-energy laser system at the Lawrence Livermore National Laboratory (LLNL) [4]. At LLNL, the beam divergence was, ±8degrees at >30MeV and ±6degrees at >35MeV. (the divergence angle decreases with increasing particle energy). Near the cut-off or maximum proton energy number of proton was about 10^9.

We consider a cut-off energy of 80 MeV for HBT with a divergence of ±5degree and 10^9 protons near cut-off. These values are used for the conceptual design of a PMRC gantry system.

In general, the 250MeV proton is needed for particle radiotherapy. However, a cancer near the body surface and ocular cancer can be treated by 50MeV proton [5]. Proton is the low linear energy transfer radiation, so irradiating from one direction hurts a normal skin. To minimise radiation dose between skin and tumour, the irradiation from the multiway is greatly recommended. So, we design the gantry that can treat 55MeV with the ions of 80MeV energy peak in this work.

Lattice of Gantry

Laser-driven bunches also exhibit large divergence and energy spread compared with the traditional accelerator.

In the gantry (Fig. 1), the beam line contains two quadrupole magnets, (focus and defocus) downstream the proton target. Those take the beam size matching to the patient point. Next section is composed of a symmetric arrangement of two bending magnets with two quadrupoles at the center and is also known as a double bend achromat (DBA). The DBA lattice is designed to make full use of the minimization of beam emittance. Here, the normal conducting bending magnet is used.

SIMULATION

Initial Beam Generator for PARMILA

The specification of laser-driven acceleration beams from a target is typically investigated by multi-dimensional particle-in-cell (PIC) simulations [6]. These simulations uniquely decide the beam property according to physical theory. Therefore, it is difficult to output an arbitrary beam specification as a numerical result. We

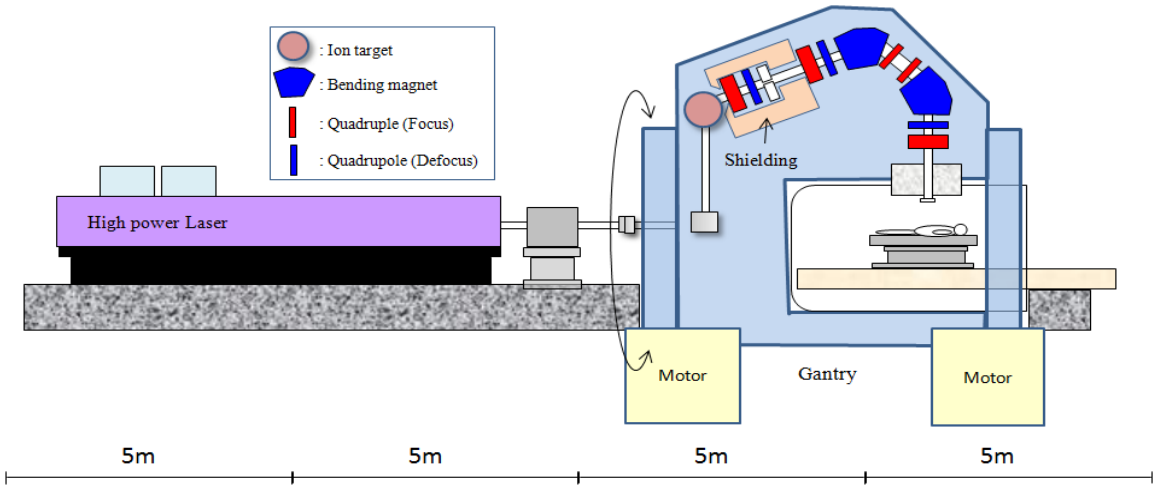

Figure 1: A schematic design showing the laser-driven ion therapy system with a gantry.

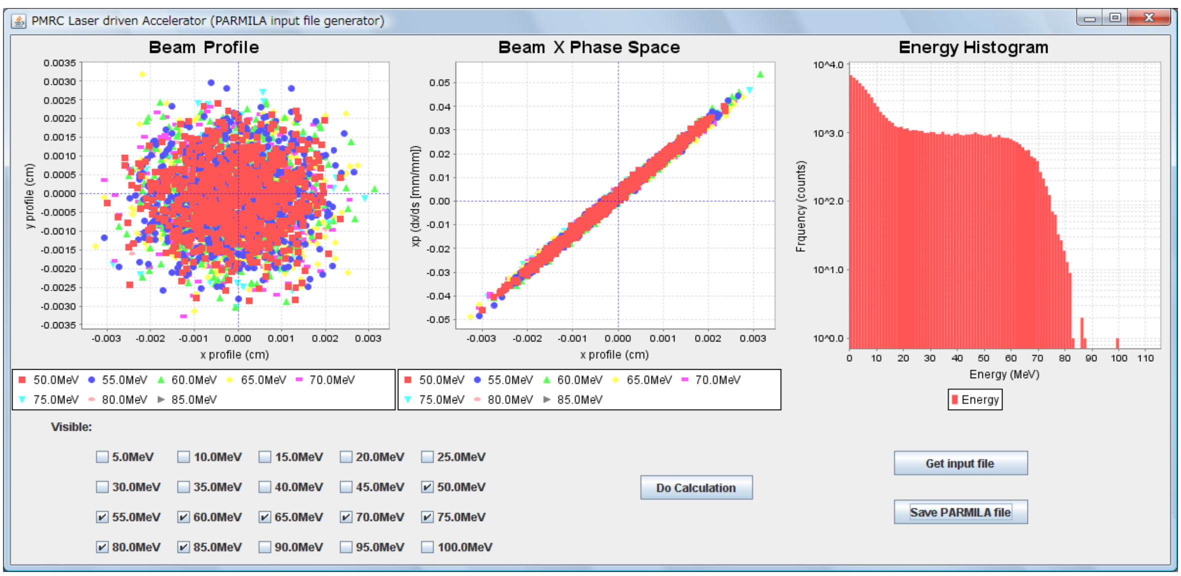

Figure 2: An input particle to PARMILA is displayed in the beam initialization file generator.

developed the software that generates an initial particle of an arbitrary beam specification by Monte Carlo methods. The generated data conform the PARMILA format file.

Figure 2 shows the result of the initial data generated under our conditions with a beam size of 25um and the emittance is 0.01π mm-mrad (un-normalized). This figure shows from the left side, the beam size, the phase space and the energy spread.

Simulation Results

The geometry of the gantry of Fig. 1 was input to PARMILA. It is 10.12m long from this ion target to patient's body surface. Figure 3 reveals the beam property after passing the first DBA bending magnet, and Fig. 4 shows the beam property on patient's body surface. The upper right of both figures show beam size (cm) and lower right show the energy spread (MeV: zero=55MeV and ±offset). The upper left gives the bunch length. From Fig. 4, a short pulse can be generated by passing this gantry line. The total particle count used by the simulation is 10^9. Figure 5 shows a comparison of the energy spread of an initial beam and the final beam and Fig. 6 shows the final x-y profile of the beam. The beam total transmittance in the gantry is 1.21%. The final monochromatic beam is generated by spectral filtering the initial beam. Moreover, the beam size irradiated to the patient with DBA is suppressed to about 1mm.

CONCLUSION

We propose a conceptual beam line design for a laser-driven ion therapy accelerator system with a gantry using PARMILA. Our simulations can be checked with lower energy evaluation beam line at 2.5-3MeV.

Moreover, discussing with the laser-driven ion source developer about the characteristics of ion sources, we will design the beam line compatible with characteristics of various source types.

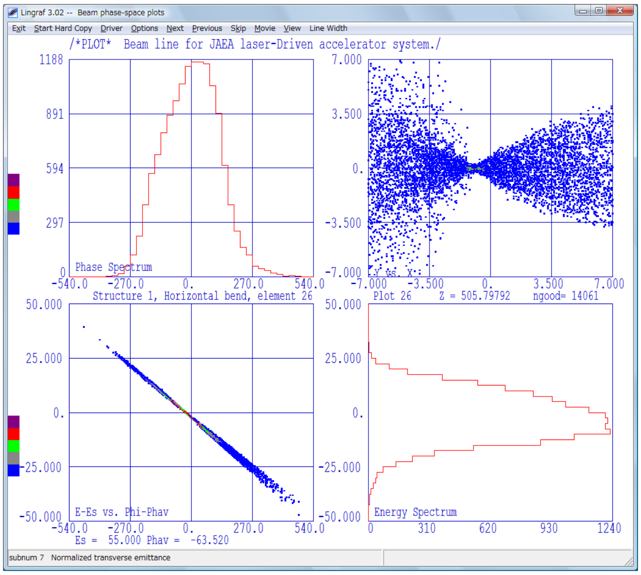

Figure 3: Beam profile after first bending magnet.

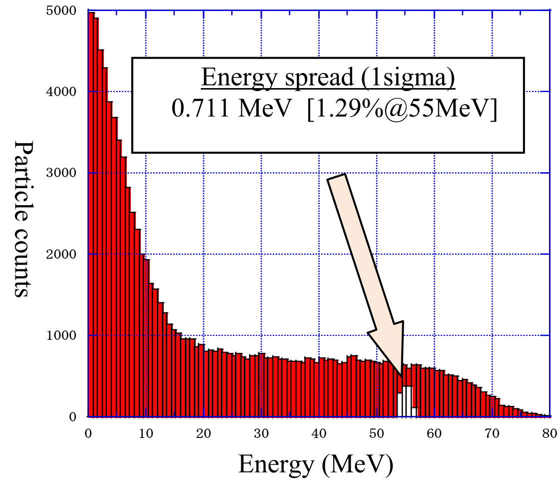

Figure 5: Comparison of energy spreads of initial beam (red) and the final beam (white).

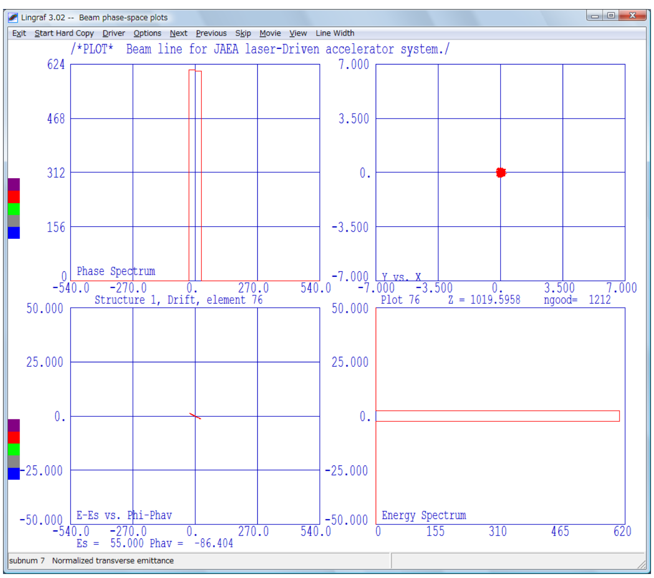

Figure 4: Beam profile at the patient.

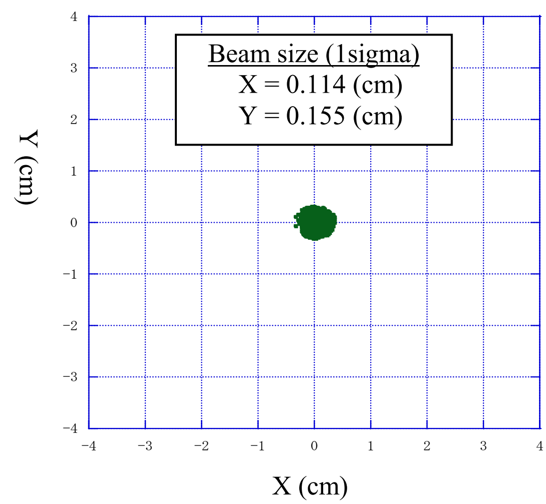

Figure 6: Beam size to patient in irradiation point.

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REFERENCES

[1] S. V. Bulanov et al., Plasma Phys. Rep., **28**, 453 (2002).
[2] C. Ma et al., Laser Physics, **16**, 639 (2006).
[3] H. Takeda et al., “PARMILA”, LA-UR-98-4478, (1998).
[4] R. A. Snavely et al., Phys. Rev. Lett. **85**, 2945 (2000).
[5] M.Murakami et al., “Radiotherapy using a laser proton accelerator”, AIP Conf. Proc., **1024**, 275 (2008).
[6] T. Morita et al, PRL **100**, 145001 (2008).