LASER ION SOURCE WITH LONG PULSE WIDTH FOR RHIC-EBIS*

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Abstract

The Electron Beam Ion Source (EBIS) at Brookhaven National Laboratory is a new heavy ion-projector for RHIC and NASA Space Radiation Laboratory. Laser Ion Source (LIS) with solenoid can supply many kinds of ion from solid targets and is suitable for long pulse length with low current as ion provider for RHIC-EBIS. In order to understand a plasma behavior for fringe field of solenoid, we measure current, pulse width and total ion charges by a new ion probe. The experimental result indicates that the solenoid confines the laser ablation plasma transversely.

INTRODUCTION

The Electron Beam Ion Source (EBIS) at Brookhaven National Laboratory is a new ion source in the place of Tandem Van de Graaff accelerators as the heavy ion pre-injector for Relativistic Heavy Ion Collider (RHIC) and NASA Space Radiation Laboratory (NSRL) science programs [1, 2]. EBIS can supply many species of ions for multiple users for several months.

Laser Ion Source (LIS) is matched with a primary ion source provider for RHIC-EBIS because previous experiments show that LIS with defocused Nd:YAG laser has low charge state [3], and a long time operation for beam property and for target consumption was demonstrated [4]. In order to supply a requirement of limited current with long pulse width by LEBT of RHIC-EBIS, we need LIS with solenoid. The design study with solenoid was reported [5] and transverse ion distribution along the beam axis from the end of solenoid was measured [7].

In this manuscript, we measured the beam property by a new ion probe from inside to outside of solenoid to understand the behavior of laser ablation plasma for the fringe field of solenoid. That can help a design of extraction system for RHIC-EBIS.

EXPERIMENTAL SETUP

Fe target in the vacuum chamber was irradiated by a Nd: YAG laser at 1064 nm with 7 ns pulse length. The laser was partially defocused by a convex lens (f = 800 mm) and the diameter of spot size was 5 mm on Fe. The laser power density on the target was 4.9×10^8 $\mathrm{W/cm^2}$. In the power density, we can assume that more than 95 % of ions are singly charged ions from the previous experiment [6]. A sketch of experimental setup is shown in Fig. 1.

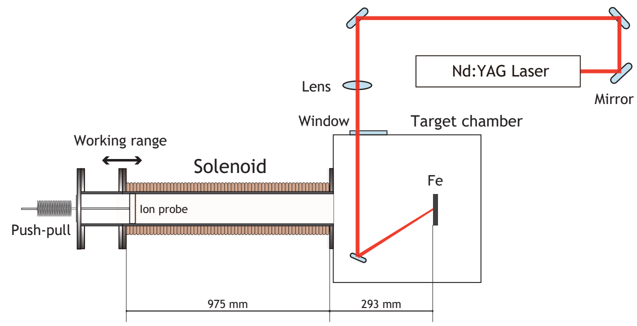

Figure 1: LIS experimental setup sketch. The push-pull allows the ion probe to be moved along the beam axis.

Figure 2: The ion probe with bias voltage can measure the ion current distribution simultaneously for 13 radial positions.

The magnetic field has a divergence, which is ”fringe field”. We have a new ion probe with a bias voltage of -1 kV to investigate a behavior of laser plasma for the fringe field. The detector has 13 pins with a distance of 5 mm between pins to measure current distribution for radial positions. Each pin diameter is 1 mm. The new detector is hollow except the ion probes for the drift plasma not to stagnate as shown in Fig. 2. The push-pull can measure peak ion current, Full Width at Half Maximum (FWHM) of beam pulse length, and total ion yield along the beam axis.

Solenoid, which is able to have low peak current with

* This work was supported by the National Aeronautics and Space Administration and the U.S. Department of Energy.
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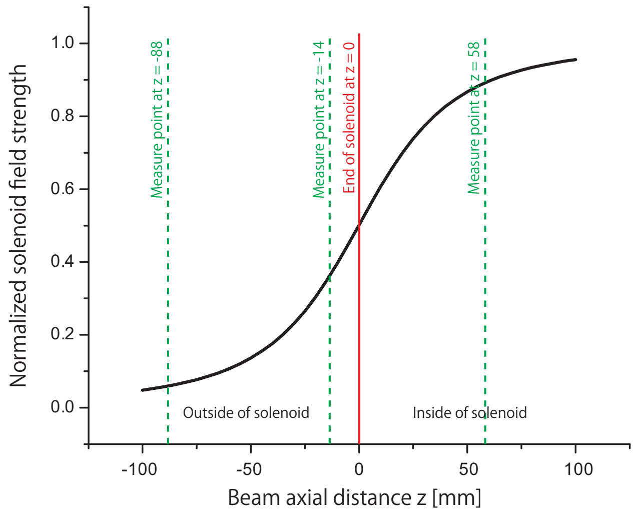

Figure 3: Normalized magnetic distribution around the end of solenoid (red line) and three scanned positions of the beam axis (green dash lines).

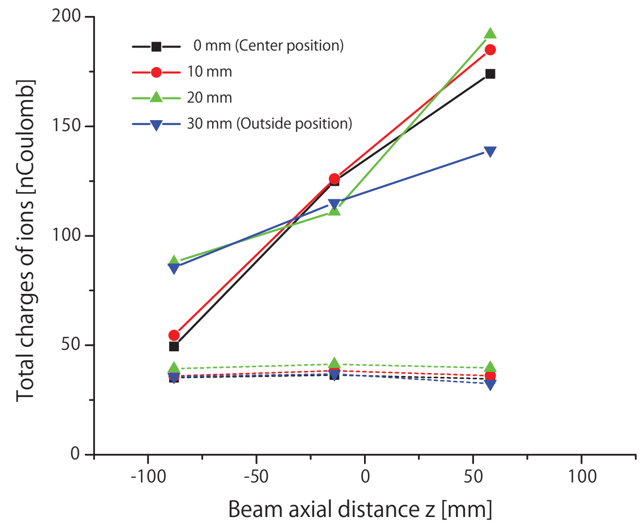

Figure 4: These lines show total ion charges for radial position with beam axial distance. Solid lines are for maximum magnetic field of 260 Gauss and dash lines are for no magnetic field. Each color represent a radial position from the center of beam.

long pulse, was applied to LIS for transverse confinement of plasma. The magnet with inner diameter of 76 mm and a length of 975 mm has 475 layers with 9 turns by copper wire of 2 mm diameter. The distance between target and solenoid is 280 mm as shown in Fig. 1. Based on the experimental condition, the magnetic field distribution was calculated by OPERA 3D [8]. The maximum magnetic field of solenoid at center position are 53, 160, 260 Gauss. Figure 3 represents the magnetic distribution, which is normalized by the maximum magnetic field, around the end of solenoid and three scanned positions on the beam axis in this experiment.

RESULTS AND DISCUSSION

The total ion charges with the radial position, which is from center of beam, to three scanned beam axial position are shown in Fig. 4. A experimental conditions with maximum magnetic field of 260 Gauss and without magnetic field stand for solid and dash lines, respectively. For no magnetic field, there are no dependence for transverse and longitudinal directions.

On the other hand, the experimental results with solenoid show that the total ion charges were reduced with beam axial distance. The total charges at outside of solenoid (green and blue lines) decay less than those near the center of solenoid (black and red lines) in Fig. 4. Subsequently in this manuscript, we consider only the center position of solenoid for brevity.

Figure 5 shows a relationship between peak current and beam axial distance with magnetic field strength. The three behaviors with magnetic field don't depend on the field strength and the peak current decays with axial distance each magnetic field. The behaviors are similar to previous experiment [7]. Without magnetic field, the peak current for the position is constant.

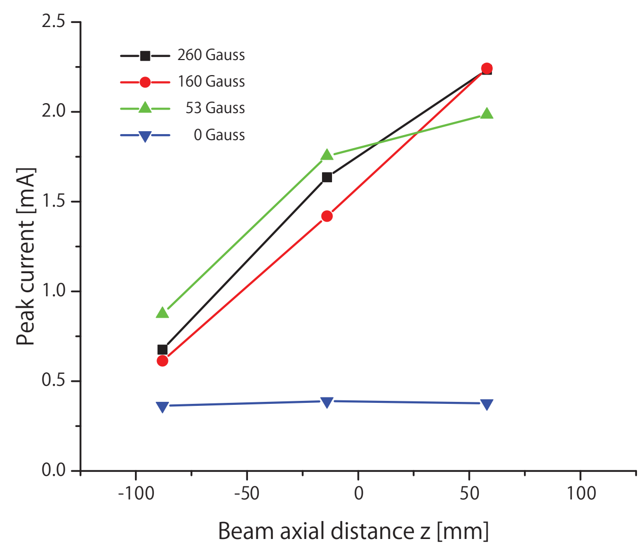

Figure 5: Peak current for magnetic field strength vs beam axial distance. No magnetic field represents blue line and that is constant for z position.

FWHM of beam pulse length to axial position for magnetic field strength is shown in Fig. 6. FWHM without magnetic field doesn't depend on the distance of beam axis. Even if there are magnetic field, the FWHM is not related to the field strength from Fig. 6. These experimental results show that the plasma is free expanding for longitudinal direction regardless of solenoid magnetic field.

The relationship between total charges and beam axial distance for solenoid field strength is shown in Fig. 7. The total ion charges q are given using current I and time t as

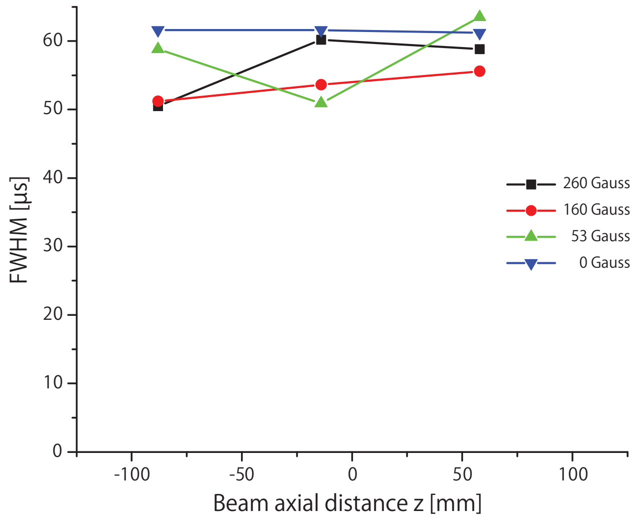

Figure 6: FWHM of beam pulse length for magnetic field strength vs Axial position. The results show no dependence on field strength.

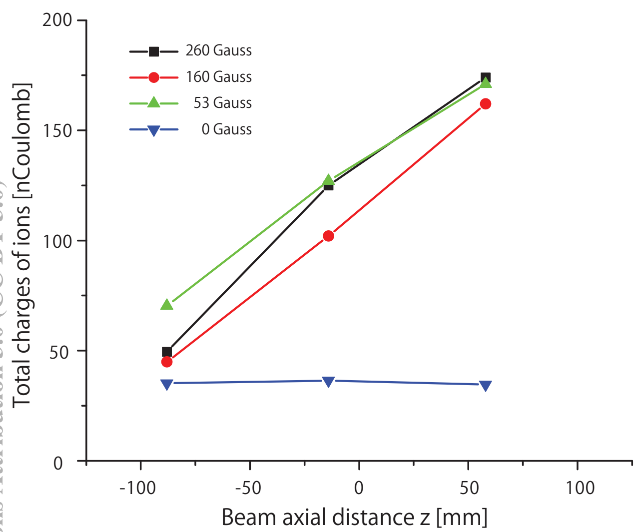

Figure 7: Total charges of ions for magnetic field strength vs Axial position. The total charges with magnetic field (black, red, and green lines) decay with distance from the end of solenoid.

below

$$q = \int I dt. \quad (1)$$

As Eq.1 shows, the behavior in Fig. 7 is consistent with peak currents and FWHM of beam pulse length in Figs. 5 and 6.

The reductions of peak current and total charges were less than that of normalized field strength in Fig. 3, which is agree with last experiment [7]. These experimental results indicate that solenoid confines the plasma not longitudinally but transversely because solenoid field strength doesn't effect pulse length but the field divergence around the end of solenoid reduces the current and ion charges.

CONCLUSION

Laser ion source needs long pulse length with limited current as primary ion provider for RHIC-EBIS. New ion probe can measure current distribution for the radial positions along z axis. The beam pulse length is not effected by magnetic field strength. However, the currents and charges decay with the distance from the end of solenoid. These results indicate that solenoid field has important role for plasma confinement not longitudinally but transversely and solenoid is able to have long pulse length with sufficient total ion charges. Moreover, the results are useful for a design of the extraction system for RHIC-EBIS.

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