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STATUS OF THE LASER ION SOURCE UPGRADE (LION2) AT BNL*

T. Kanesue†, B. Coe, S. Ikeda, S. Kondrashev, CJ. Liaw, M. Okamura, R. Olsen, T. Rodowicz, R. Schoepfer, L. Smart, D. Weiss, Y. Zhang, Brookhaven National Laboratory, Upton, NY, USA
A. Cannavò, Nuclear Physics Institute of CAS, Prague, Czech Republic

Abstract

A laser ion source (LION) at Brookhaven National Laboratory (BNL) has been operational since 2014 to provide low charge state heavy ions of various species for Relativistic Heavy Ion Collider (RHIC) and NASA Space Radiation Laboratory (NSRL). Pulsed ion beams (100~300 µs) with beam current ranging from 100 µA to 1 mA from any solid-state targets can be supplied without memory effect of previous beams at pulse-by-pulse basis. LION is an essential device for the operation of a galactic cosmic ray simulator at NSRL together with high-performance beams for RHIC. Because the importance of LION has been widely recognized, an upgraded version of LION, which is called LION2, is being developed for improved performance and reliability. The design and status of the LION2 will be shown.

INTRODUCTION

LION is a laser ablation ion source which utilizes a nanosecond laser to generate ions from any solid-state materials. The heavy ion source has provided various heavy ions with fast switching capability since 2014. LION generates singly charged ions for further ionization by an electron beam ion source called RHIC-EBIS. RHIC-EBIS works as charge breeder and highly charged heavy ions are further accelerated by the following RFQ and IH linac [1]. LION has two independent lasers and target systems to provide different beams for RHIC and NSRL at the same time. For NSRL, LION can switch ion species in as fast as a few seconds by switching target position. For galactic cosmic ray (GCR) study at NSRL target room, ion species are switched within 1 min to simulate GCR exposure [2]. This switching time is not limited by LION.

Demands of various heavy ion species has been growing significantly since the beginning of LION operation. When LION operation was started in 2014, there was only one laser line and target system for NSRL. This was the first operational laser ion source to provide stable heavy ions for user facility for months. LION demonstrated excellent beam performance and reliability, and the second laser line and target system for RHIC was developed and installed in 2015. The number of ion species prepared in a vacuum chamber has been increased from 5 in early times to currently around 10 for NSRL in addition to 1 or 2 species for RHIC. NSRL beam time was originally only daytime during weekdays. Recently, NSRL uses beams until night from Monday to Saturday. Occasionally beams are used even overnight and Sundays. A GCR simulator mode has been implemented since 2016 which requires much more frequent species change. With this mode, LION species for NSRL changes as much as over 100 times per day. In addition, some RHIC operation for low energy collider experiments requires much more frequent beam injection into RHIC at every 30 minutes compared to more than 10 hours for nominal 100 GeV/u beam energy.

LION2

LION2 will replace the entire LION1 except for target systems to provide better beam performance, operational capability, and maintainability. We aim to install LION2 during summer shutdown in 2023, which is the next year after the installation of the Extended-EBIS (July 2022 to the end of 2022), which will replace the existing RHIC-EBIS [3]. Figure 1 shows the location of LION2 in RHIC-EBIS pre-injector. LION2 design follows the basic design of LION1. It consists of lasers, a target chamber, target systems, a solenoid magnet to guide laser produced plasma, and an extraction chamber. We will use the same target systems as LION1. One is a two-dimensional linear stage (xy

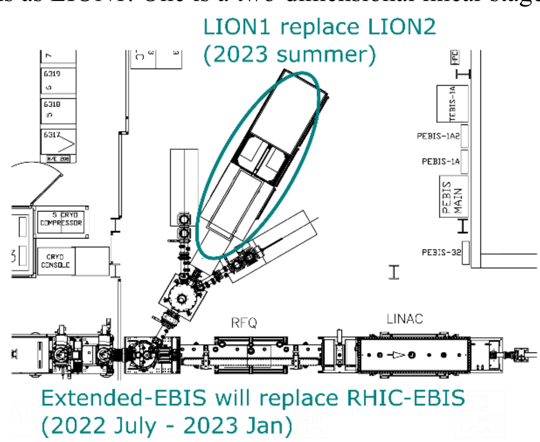

Figure 1: Future of BNL heavy ion pre-injector.

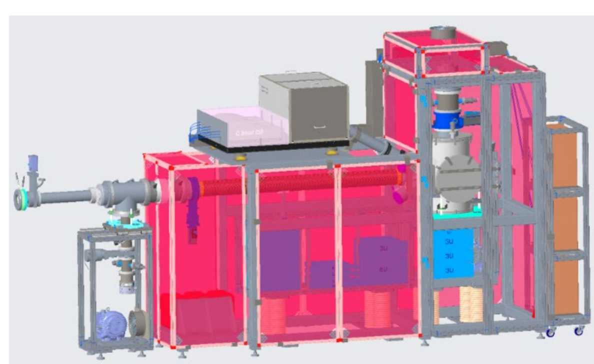

Figure 2: Future of BNL heavy ion pre-injector.

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† tkanesue@bnl.gov

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target) for NSRL and the other is a rotating target for RHIC. The new design includes increased beam extraction voltage from 20 kV to 40 kV, new ion extraction system, a twice larger target holder for NSRL, independent safety enclosure for each laser to continue user operation during laser maintenance, increased distance between LION2 to the existing beam transport line for better accessibility for vacuum pumps at an extraction chamber, and new beam diagnostics in the increased space. In addition, we plan to shorten the length of a solenoid from 3 m to 2 m. Based on our experience, this length is enough to provide sufficient beam for EBIS. The shortened space will be used to increase the distance between the existing beam line to LION2. In addition, we plan to increase the solenoid bore from 73 mm in diameter to 102 mm. The function of the solenoid is to transversely confine adiabatically expanding laser produced plasma moving towards normal direction to the target surface. The behavior of ions in laser ablation plasma is not understood well and could show unexpected results. Therefore, it is essential to experimentally verify ion properties with different solenoids.

EXPERIMENT

We experimentally compared ion properties transported by LION1 and LION2 configurations. A typical experimental setup is shown in Fig. 3. A 2m-long solenoid magnet with inner diameter of 102 mm was newly built for LION2 design. The existing LION1 test bench has the combination of a 2m-long solenoid and a 1m-solenoid with inner diameter of 73 mm. The gap between solenoid coils were 24 mm due to flange thickness. When LION1 was developed, this gap was verified not to affect ion flux within an extraction aperture at the end of solenoid. Note that LION1 uses a 3m-long solenoid with no gap. First, we evaluated the difference of ion flux between LION1 and LION2 configuration. Then we investigated the effect of solenoid bore using solenoids with the same length of 2 m. We also tested if a vacuum valve can be installed between two solenoids by increasing the distance between two solenoids to 85 mm. The valve can keep an extraction system in vacuum while targets are replaced, which greatly decrease pumping time and the chance of break down at an extraction chamber. In general in laser ion source, it is not feasible to install a vacuum valve at either ends of a solenoid. This is because the distance between a target and the solenoid entrance should be as close as possible to capture more ions from target, and also the distance between the solenoid exit and extraction aperture should be as short as possible to extract more ions before diverging. We used Al, Fe, and Ta in this paper to cover from light to heavy species. Table 1 shows laser parameters we used. Laser power density on targets were 4.2E8 W/cm^2 for Al, 4.2E8 W/cm^2 for Fe, and 4.9E8 W/cm^2 for Ta. For all experiments, the distance between a target and a solenoid coil was 312 mm as same as LION1 and LION2. The distance between a solenoid coil and an extraction aperture at LION1 and LION2 is 30 mm. We measured ion signals along the solenoid axis from 60 mm inside of the end of a solenoid coil to 135 mm outside of the solenoid using a Faraday cup with 5 mm aperture in diameter biased at -3.5 kV. Figure 4 summarizes all tested configurations.

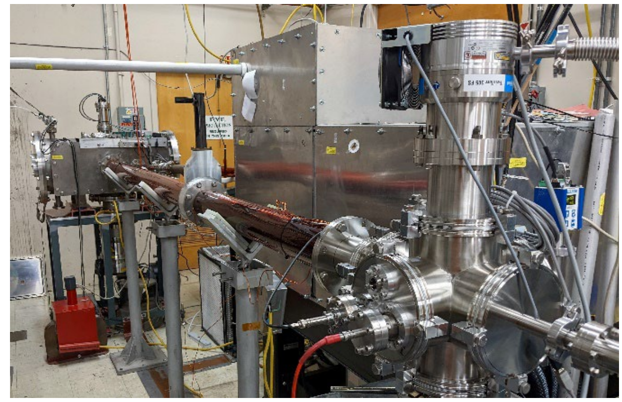

Figure 3: Experimental setup.

Table 1: Laser Parameters

Wavelength	1064 nm
Pulse width	6 ns
Energy for aluminium	550 mJ
Energy for iron	550 mJ
Energy for tantalum	760 mJ

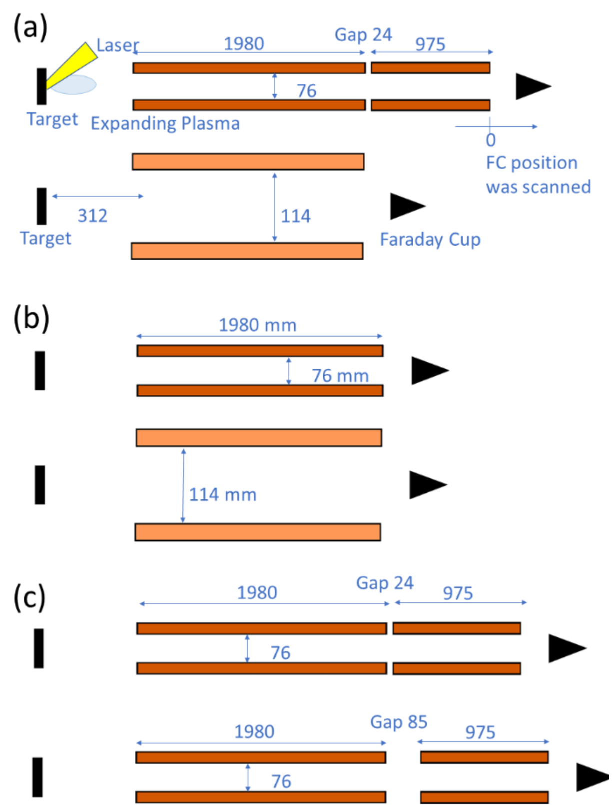

Figure 4: Schematic of experiments. (a) comparison between LION1 (top) and LION2 (bottom). (b) Effect of solenoid inner diameter. (c) Effect of gap (85 mm) for vacuum valve.

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RESULTS AND DISCUSSION

LION2 Design vs LION1

Figure 5 shows typical Fe waveform at extraction point (30 mm outside of solenoid coil) when 61 gauss of solenoid field was applied. Peak current with LION2 configuration (red) was just slightly higher than that of LION1 (black) though LION2 has shorter plasma drift distance. Pulse width was shorter at LION2 almost proportional to plasma drift distance as expected. Full pulse width of about 100 µs is sufficient for the injection into EBIS. Figure 6 shows Fe peak current along the solenoid axis, where positive direction means going out of the solenoid. Standard deviations over 5 shots are shown together. The results for all species showed that LION2 design can provide slightly more ion density than LION1. To achieve the same peak current as LION1 which has an extraction aperture of 15 mm in diameter, it is estimated that 12~14 mm aperture is needed. Note that because the effect of solenoid was not saturated at 61 gauss in LION2 design, peak current can be increased by applying more solenoid current. We plan to increase solenoid field in LION2 compared to LION1.

Effect of Solenoid Inner Diameter

Figure 7 shows the effect of solenoid inner diameter on Fe when solenoid length is 2 m. Smaller inner diameter gave more beam inside of a solenoid. This indicate more moving plasma could be captured from target, or plasma density near solenoid axis is higher. Interestingly, peak current out of solenoid converged into similar value outside of a solenoid. Further study is required to understand the behavior of ions in moving laser produced plasma.

Valve Between Solenoids

Figure 8 shows the effect of a 85-mm gap between solenoids. We confirmed that the gap does not introduce major difference and a vacuum valve can be installed between solenoids.

CONCLUSION

We verified LION2 solenoid configuration can work slightly better than LION1. We found a 85 mm gap between two solenoid coils does not show major influence on ions at ion extraction point. LION2 will have a valve between 2 solenoids to separate target chamber and extraction chamber. Further study will be required for better understanding on moving laser-produced plasma in solenoid magnetic field. LION2 design will be finalized using the achieved data.

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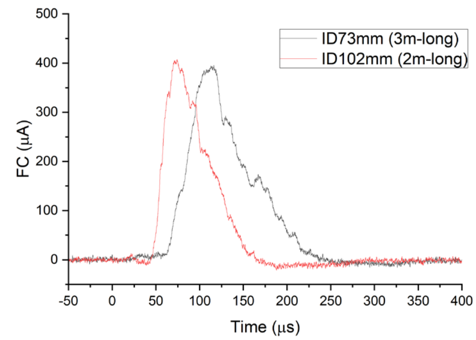

Figure 5: Fe waveform measured at 30 mm outside of a solenoid coil with 61 gauss of solenoid field.

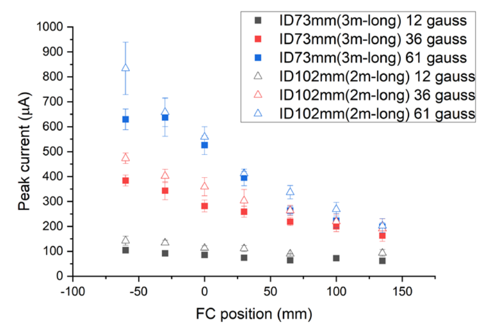

Figure 6: Difference of Fe peak current along solneoid axis between LION1 (closed symbols) and LION2 (open symbols).

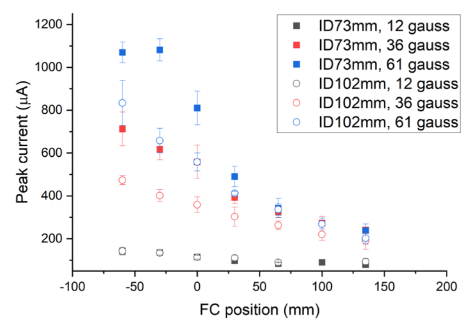

Figure 7: Effect of inner diameter on Fe. The length of solenid was 2 m.

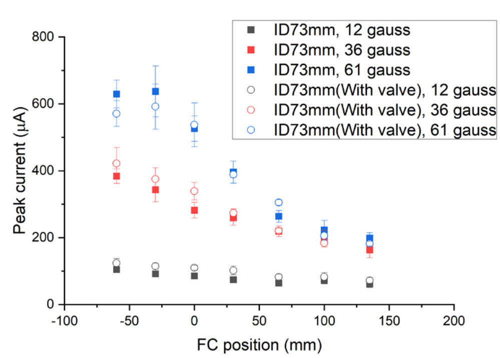

Figure 8: Effect of a valve between solenoids on Fe.