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Estimation of laser parameters for generating enough number of energetic heavy ions for applying as the injector of the next generation heavy ion synchrotron accelerator

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The National Institutes for Quantum Science and Technology (QST) is currently conducting the quantum scalpel project, which aims to improve the performance and miniaturization of heavy ion cancer therapy devices, which are highly effective in treatment [1,2]. The "Quantum scalpel" means cancer therapy using a quantum beam without a real scalpel in a body. It's a treatment method with minimal side effects, making it possible for patients to go to the hospital (day surgery) and be treated for cancer while working. The fifth generation of heavy ion cancer therapy devices, namely the Quantum Scalpel consists of the laser ion injector, super-conducting synchrotron, and super-conducting rotating gantry as shown in Figure 1. It is required to miniaturize the ion injector and synchrotron to develop compact heavy ion cancer therapy devices. In the quantum scalpel project, the synchrotron and injector will be miniaturized by introducing super-conducting technology and replacing the conventional linear accelerator with the laser ion injector, respectively. Laser ion acceleration has a large acceleration gradient and its technique is expected to develop a compact ion injector [3].

The requirement for the injector of the quantum scalpel is the 10 Hz generation of more than 10^8 of 4 MeV/u C6+ ions with 1% energy bandwidth. However, at the point of the laser acceleration, the 10% energy bandwidth of these ions is allowable. The 10% energy bandwidth of these carbon ions is compressed to 1% using the phase rotation technique after the laser acceleration and then they are transported to the synchrotron.

We have conducted quasi-1D and 2D PIC simulations including collisional and ionization processes to verify the condition of C6+ generation. These simulation results agree with the simple model that roughly predicts the maximum sheath strength and achievable ionization degree. These simulations show the collisional effects on C6+ acceleration. In addition, we have also conducted 3D pure PIC simulations to evaluate C6+ ion energy spectra quantitatively. Finally, considering the results of 2D PIC simulations including collisional and ionization processes and pure 3D PIC simulations, we have discussed the laser condition to generate 10^8 of 4MeV/u C6+ ions with 10% energy bandwidth.

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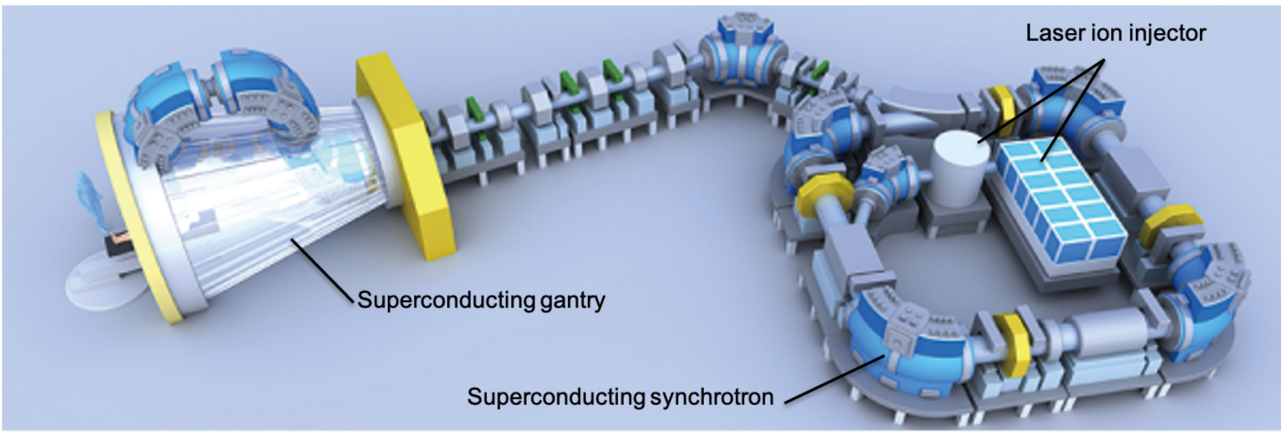

Figure 1. Quantum scalpel system (a fifth generation compact and high-performance heavy ion radiotherapy system). It consists of a laser ion injector, a superconducting synchrotron, and a superconducting gantry, and measures approximately 20 meters by 10 meters.