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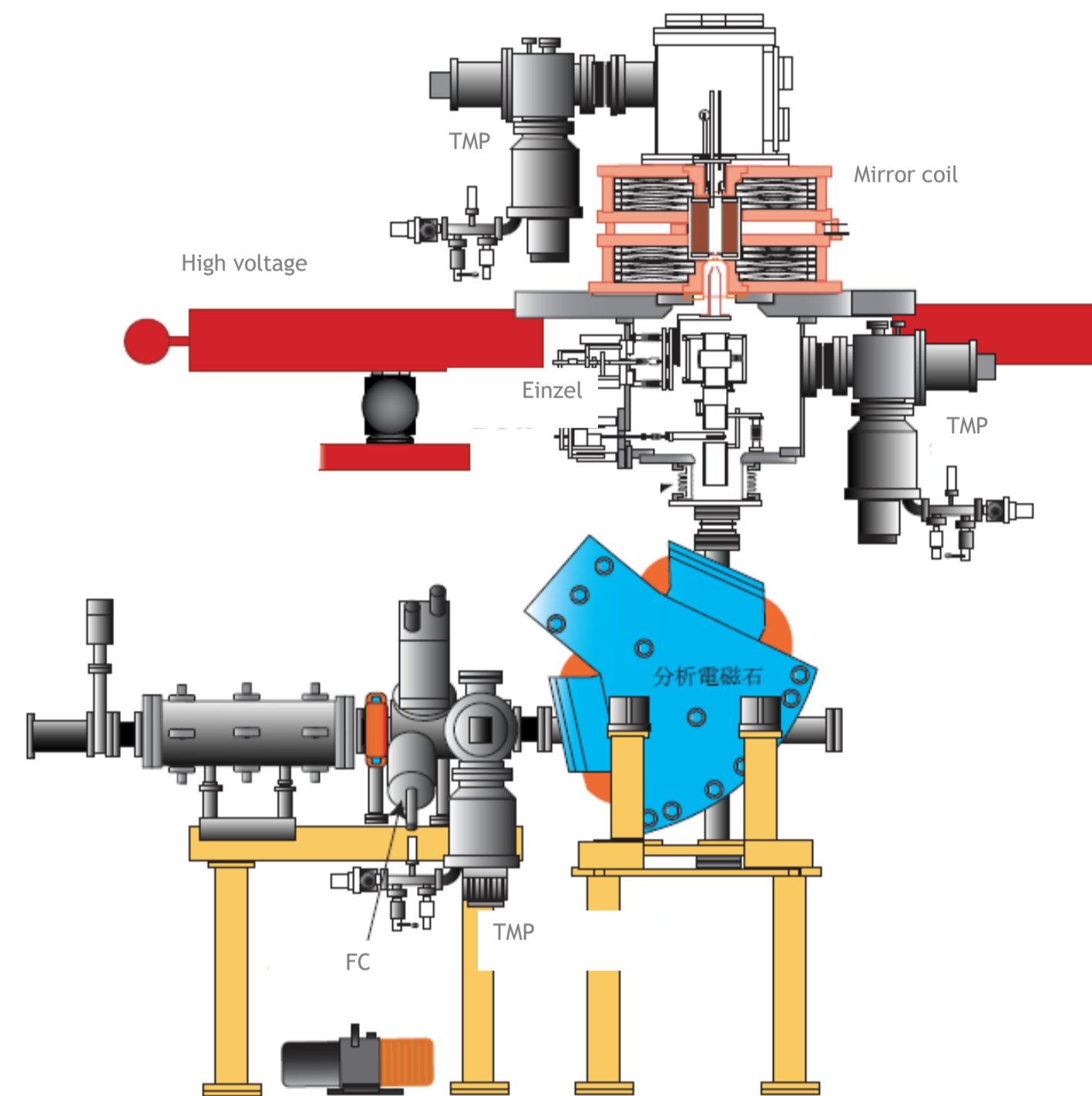
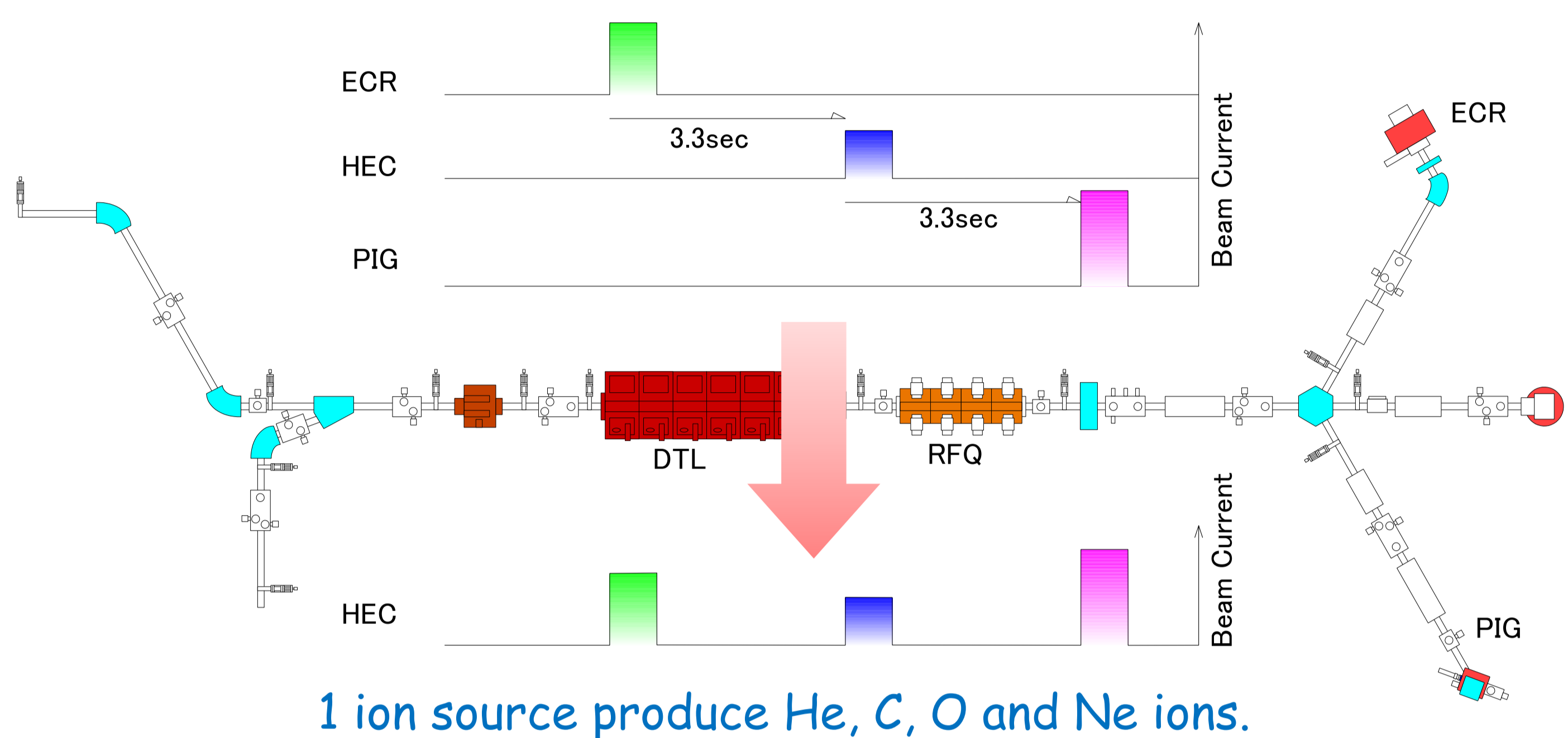
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Introduction

High-energy carbon-ion radiotherapy is being carried out at Heavy Ion Medical Accelerator in Chiba (HIMAC). Over 11000 cancer patients have been treated with carbon beams having energies of between 56-430 MeV/u since 1994. At present, multi-ion irradiation method by various ion species is being studied for optimization of LET and dose distribution. An ion source has to produce the helium, carbon, oxygen and neon at pulse by pulse for this method. Requirement currents for He²⁺, C²⁺, O³⁺ and Ne⁴⁺ are 500, 150, 230 and 300 eμA, respectively. We obtained beam current of 482, 151, and 270 eμA for He²⁺, C²⁺ and O³⁺ with mixed helium and CO₂ gases under the extraction voltage of 27 kV. Beam current of 27 and 15 eμA for C⁵⁺ and O⁷⁺ ions were also obtained in this time. He²⁺ beam include full striped ion such as C⁶⁺, N⁷⁺ and O⁸⁺. We have to increase the purity of He²⁺ beam. The gas feed system was modified for making pulsed gas by using a solenoid valve for switching different gas.

Purpose

The multi-ion irradiation with dose distribution and Liner Energy Transfer (LET) optimization is being studied at NIRS. Helium, carbon, oxygen and neon ions are considered as ion species for multi-ion irradiation. When we use more than one ion sources, it is possible to switch different ion species easily. However, we considered the switching method with only one ion source.

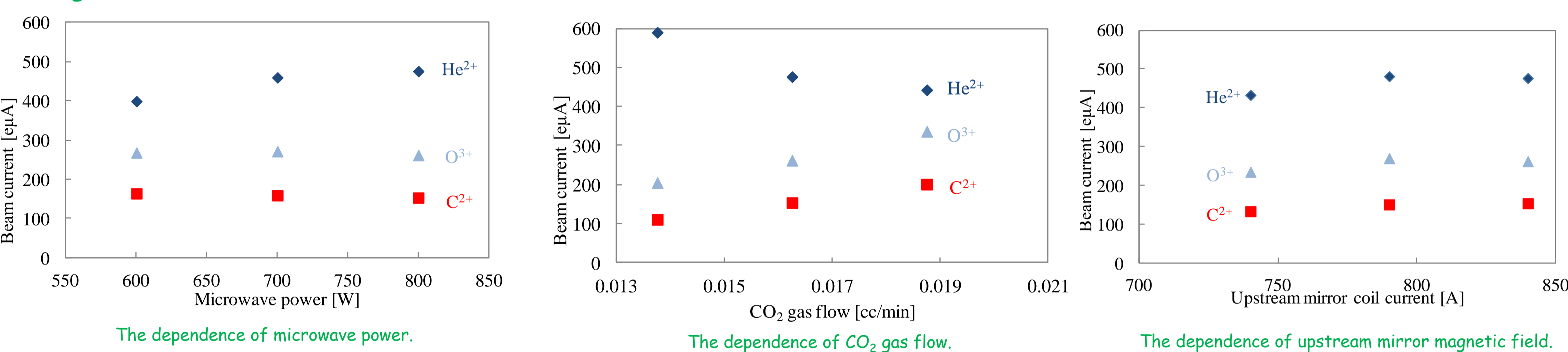


How to change ion species

- Case 1: mixed gas (gas mixing exp.)
 -> short switching time
 -> not optimal source parameter
- Case 2: each gas (gas switching exp.)
 -> optimal parameter
 -> long switching time

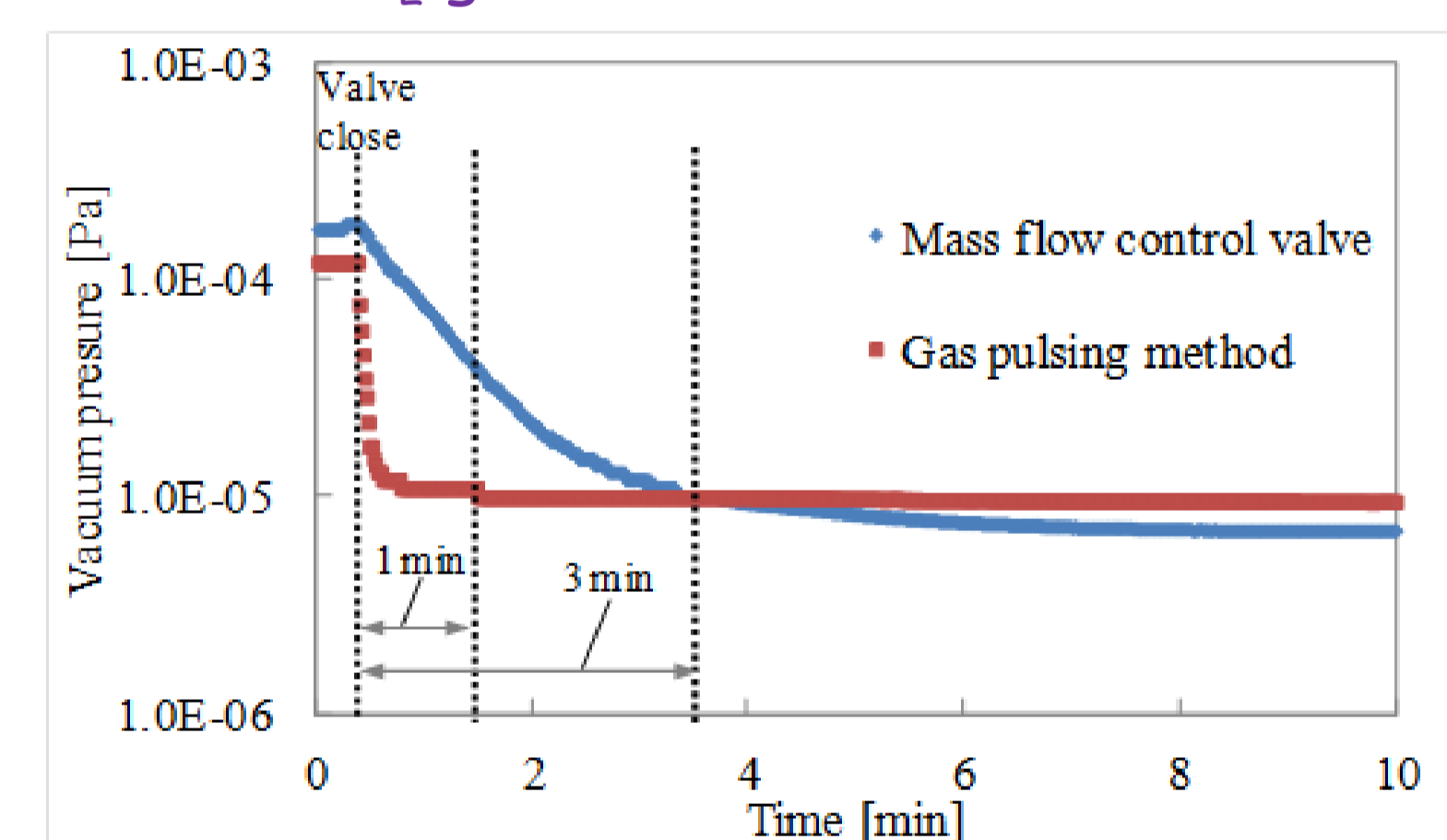
Gas mixing experiment

The CO₂ and helium gases were introduced at the same time to the plasma chamber for production of the He²⁺, C²⁺, O³⁺ at this experiment. The microwave frequency was 18.0 GHz. The gas flow of helium was 0.075 cc/min. The extraction voltage was 27.0 kV. The downstream coil current was 500 A.



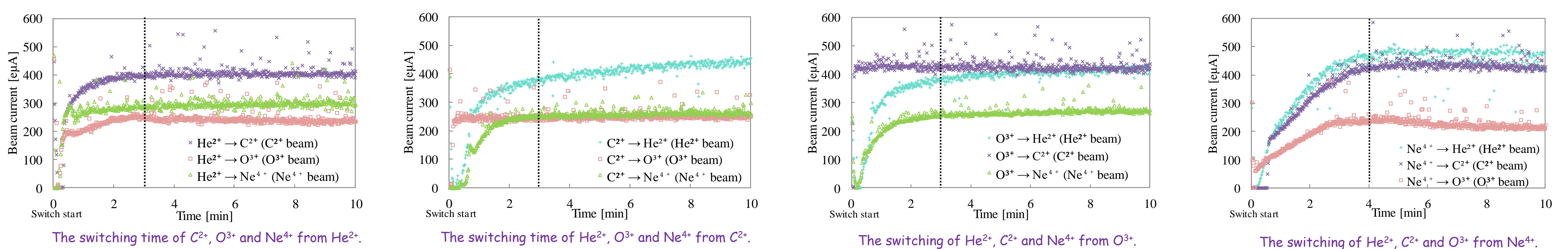
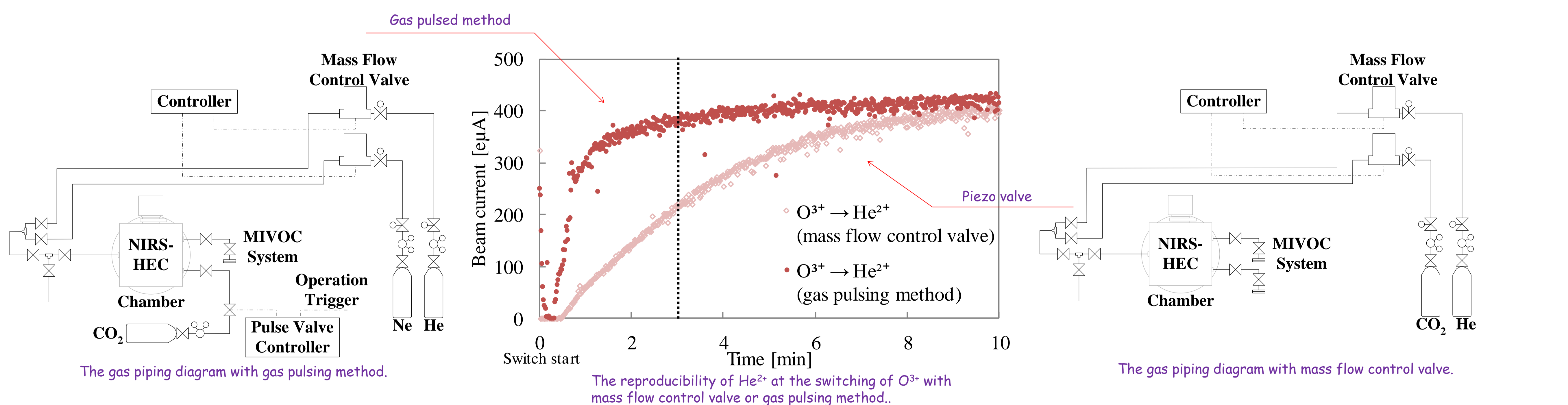
Gas pulsing

We try to produce He²⁺, C²⁺, O³⁺ and Ne⁴⁺ ions by using helium, CO₂ and neon gases. The high speed solenoid valve (Parker, Series 9) and controller (Parker, Iota One) were used for CO₂ gas line.



Gas switching experiment

The solenoid valve was set in CO₂ line. The helium and neon gases were regulated by piezo valve (Mass Flow Control valve: MFC). We have to wait about 10 minutes for stable beam current of He²⁺ by using MFC. There were residual CO₂ gas in the gas line and vacuum chamber. In the case of solenoid valve, wait time is about 3 minutes. The solenoid valve opens 120 msec before the microwave ignition. Pulse width was 0.22 msec. The influence of residual CO₂ gas is big to the production of He²⁺ ion. The gas pulsing method is effective in a changing ion species.



Conclusion and next step

The result of the gas mixing experiment, we obtained beam current of 482, 151, and 270 eμA for He²⁺, C²⁺ and O³⁺ with mixed helium and CO₂ gases. The optimal microwave power and upstream coil current were 800 W and 790 A, respectively. From the results of gas pulsing experiment, the switching time from He²⁺, C²⁺ and O³⁺ to other ions were 2 or 3 minutes, however, from Ne⁴⁺ to other were 4 or 5 minutes. We will set the solenoid valve to all of gas line.