

Charge Breeding Experiment of Stable Ion Beams in EBIS Charge Breeder for RAON Facility

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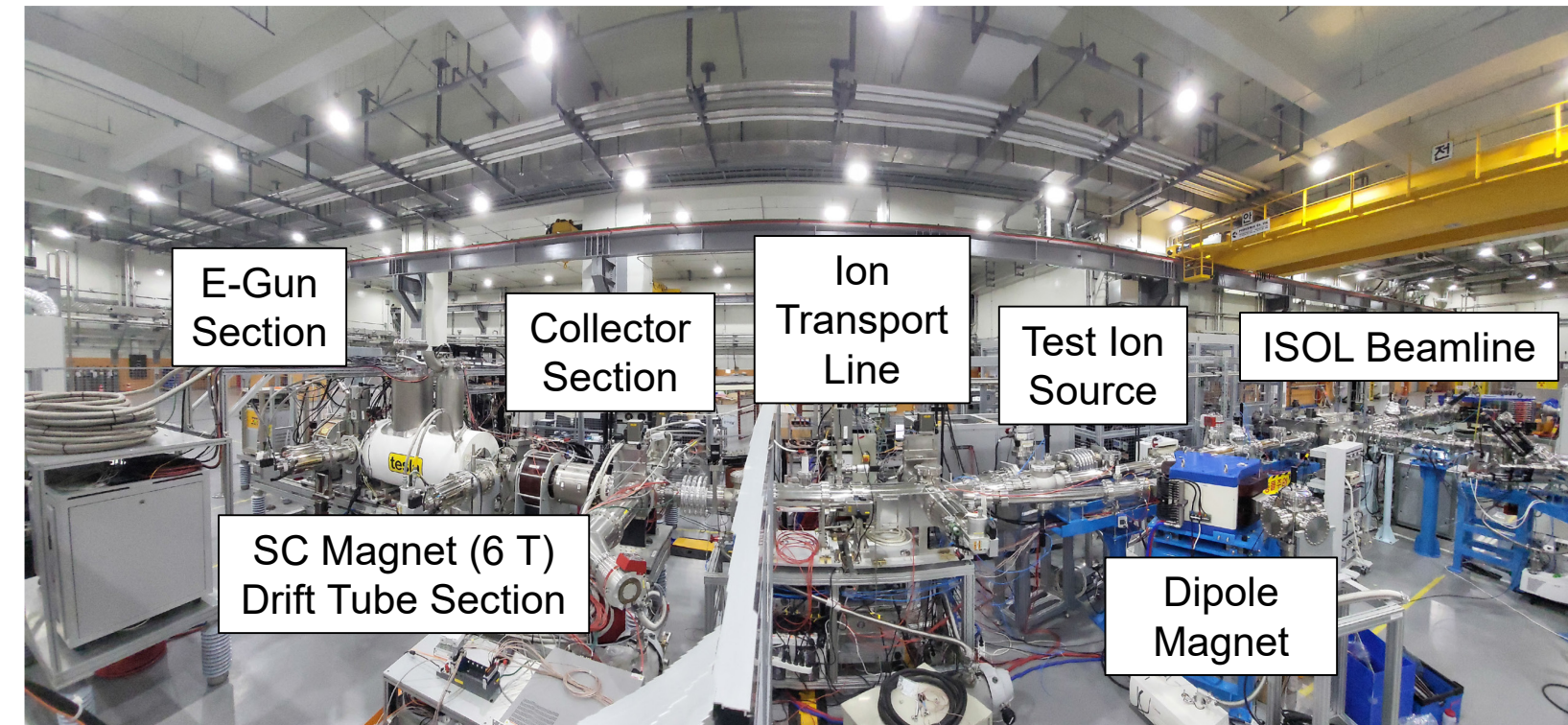
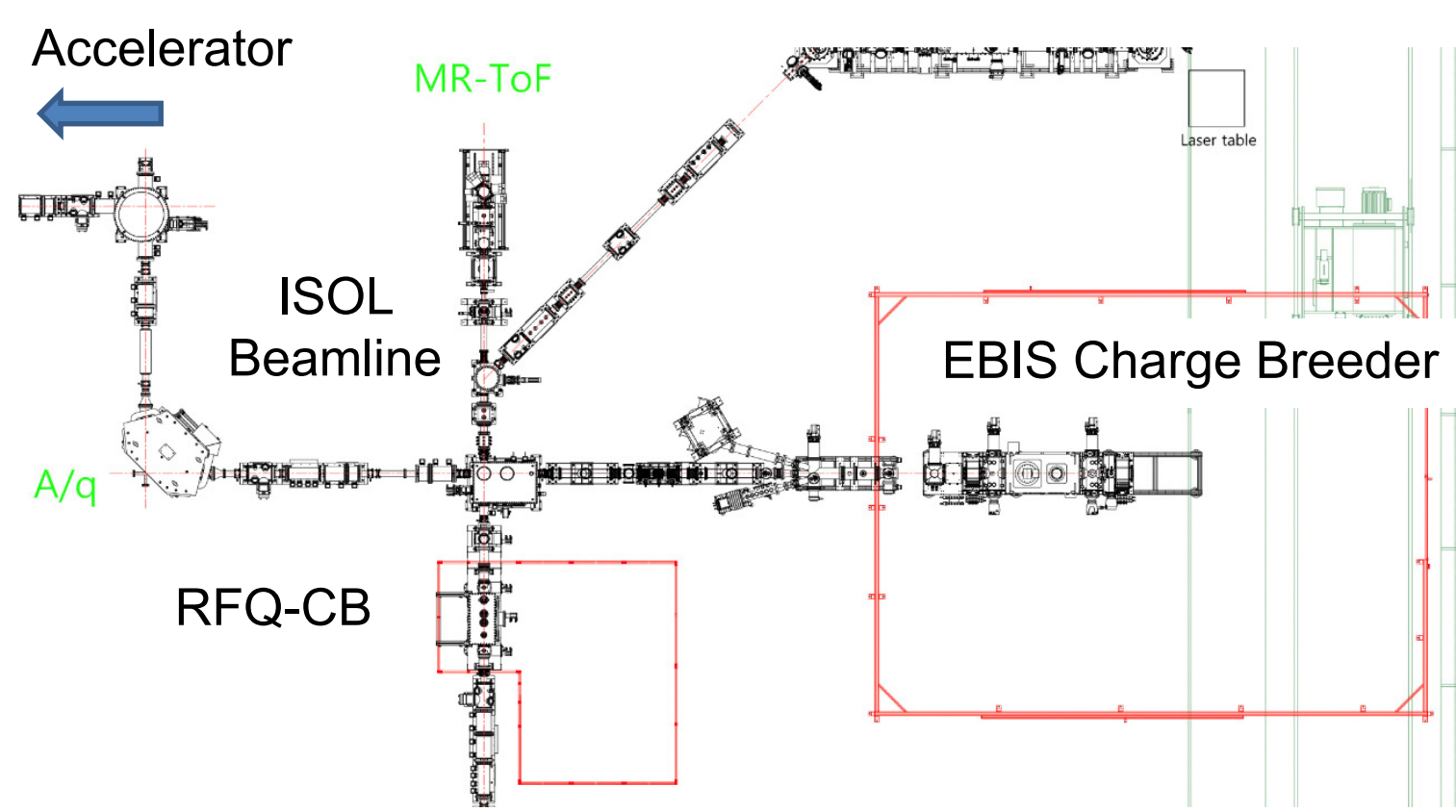
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Abstract

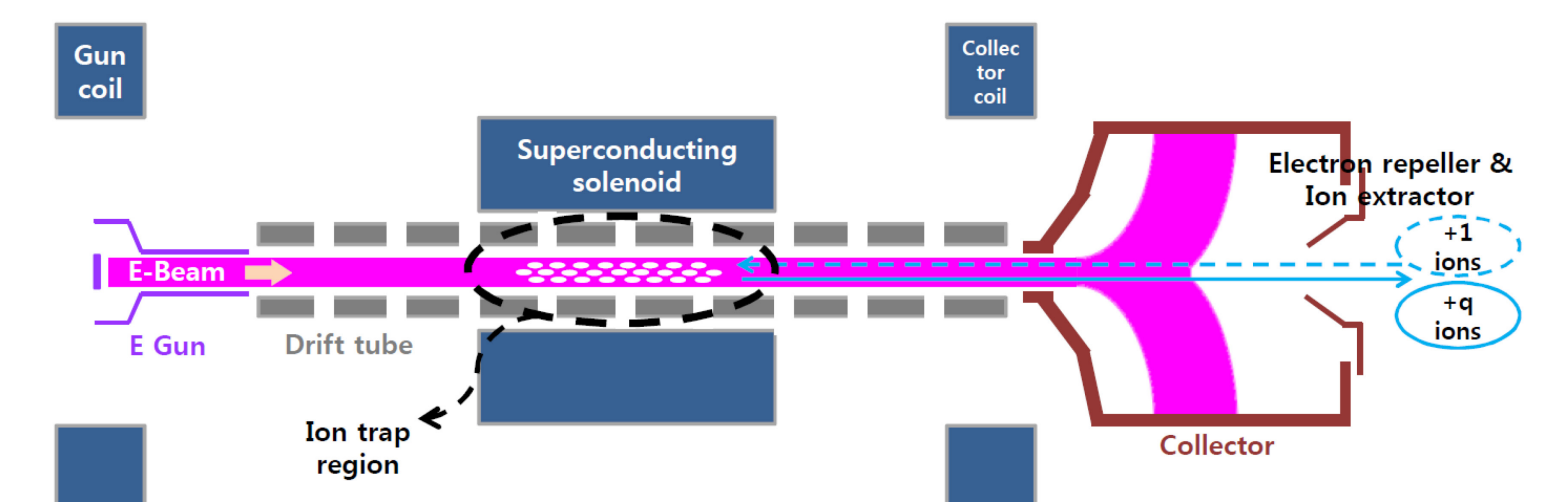
The Electron Beam Ion Source (EBIS) charge breeder is utilized to produce highly charged ions in Isotope Separation On-Line (ISOL) system of Rare isotope Accelerator complex for On-line experiments (RAON). Beam tests of EBIS are performed by using stable ion beams, which are Cs, Sn, and Na. $^{133}\text{Cs}^{27+}$ ions from a test ion source were injected into the EBIS to measure the breeding effect with the electron beam whose current can be used up to 2 A in various breeding times. The resultant relative abundance of $^{133}\text{Cs}^{27+}$ was 25.0 % and the extraction energy per charge was 49.3 keV/q. A charge breeding test of ^{120}Sn ions was also carried out. The Sn ions were extracted from the TIS using a laser ion source of the ISOL system. The charge fraction of $^{120}\text{Sn}^{24+}$ was 23.0% and the energy per charge with 50 keV/q, and the ions were transported to the end of ISOL beam line which is the start position of reacceleration. These results fulfilled the input beam condition of the RFQ accelerator ($A/q < 6$ and 10 keV/u). To find the operating condition for light ions, we are performing the optimization with Na ions. Additionally, the highly charged ion beam with various pulse lengths is required for some experiments, so the length of the beam from the EBIS should be possible to be determined. In the experiment, $^{133}\text{Cs}^{27+}$ ions charge-bred by the EBIS are extracted with a pulse length up to 10 ms (FWHM) by applying the time-varying voltage on drift tubes in the breeding section when they eject. The main experimental results will be described in this presentation.

EBIS Charge Breeder for RAON Facility



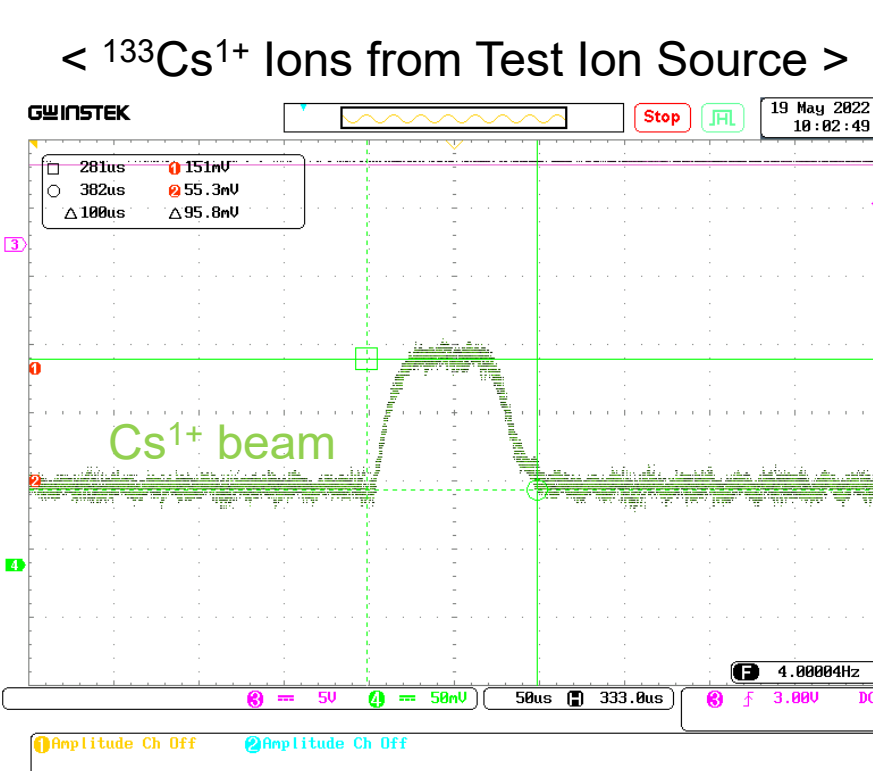
Requirement of RAON EBIS

Extracted Beam Energy	10 keV/u
A/q	< 6
Electron Beam Current	≤ 3 A
Magnetic Field at Trap	≤ 6 T
Trap Capacity	Up to 10^8 ions / bunch

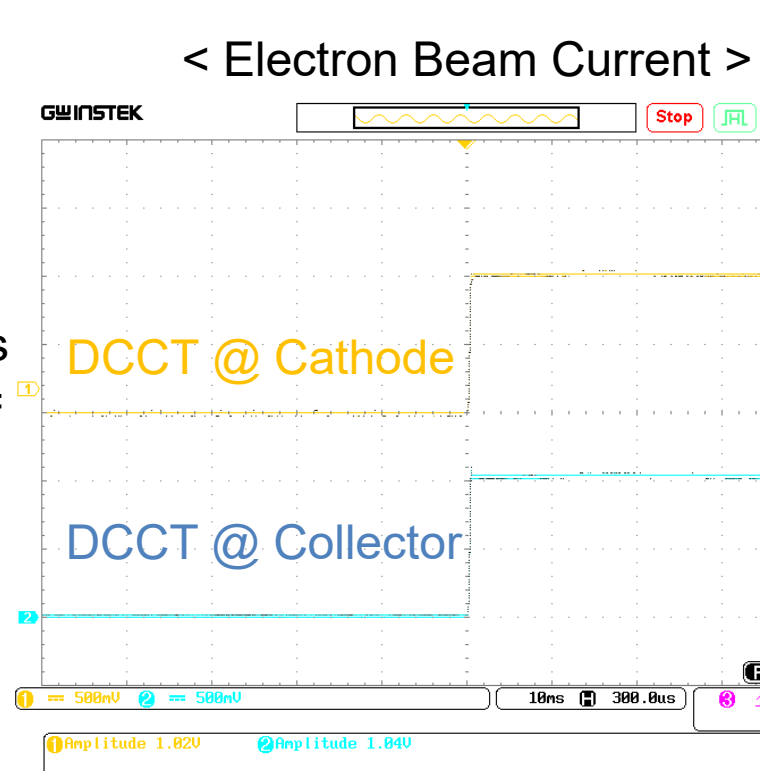


- E-gun is magnetically immersed type using IrCe Cathode of 4.2 mm diameter.
- The center field of SC solenoid magnet is up to 6 T with homogeneity of ± 0.4 % within ± 35 cm.
- On the Ion transport line, there are 3 directions where the ion beam comes from the Test ion source, goes to the Diagnostics line, and comes and goes ISOL Beamline.
- In the drift tube section, injected ions are captured and interacted with the electron beam extracted from the E-gun
- Trapped ions lose their electrons by the collision with the electron beam, and its effect depends on the electron current density and breeding time.
- After breeding ions to the targeted charge state, they are extracted by 10 keV/u as changing the voltage of the EBIS platform.
- The charge-bred-ions are transported to the diagnostics line to measure the charge state distribution, or to the ISOL beamline for the online operation.

Charge Breeding of $^{133}\text{Cs}^+$ Ions

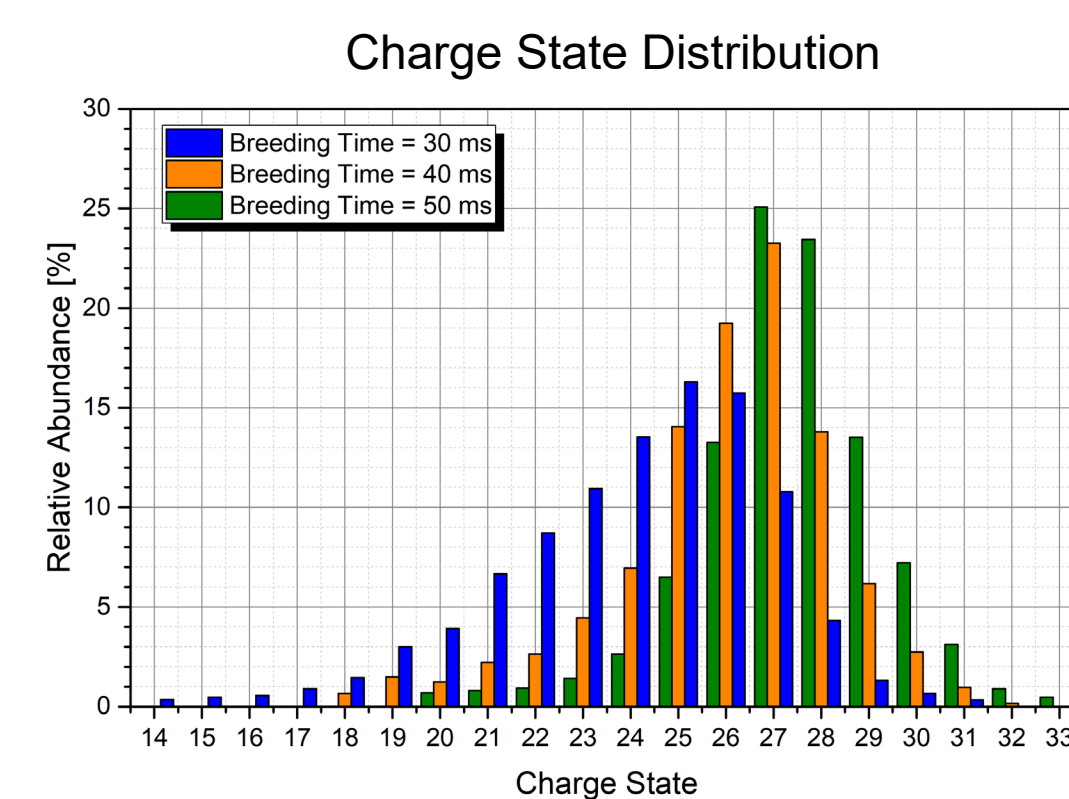
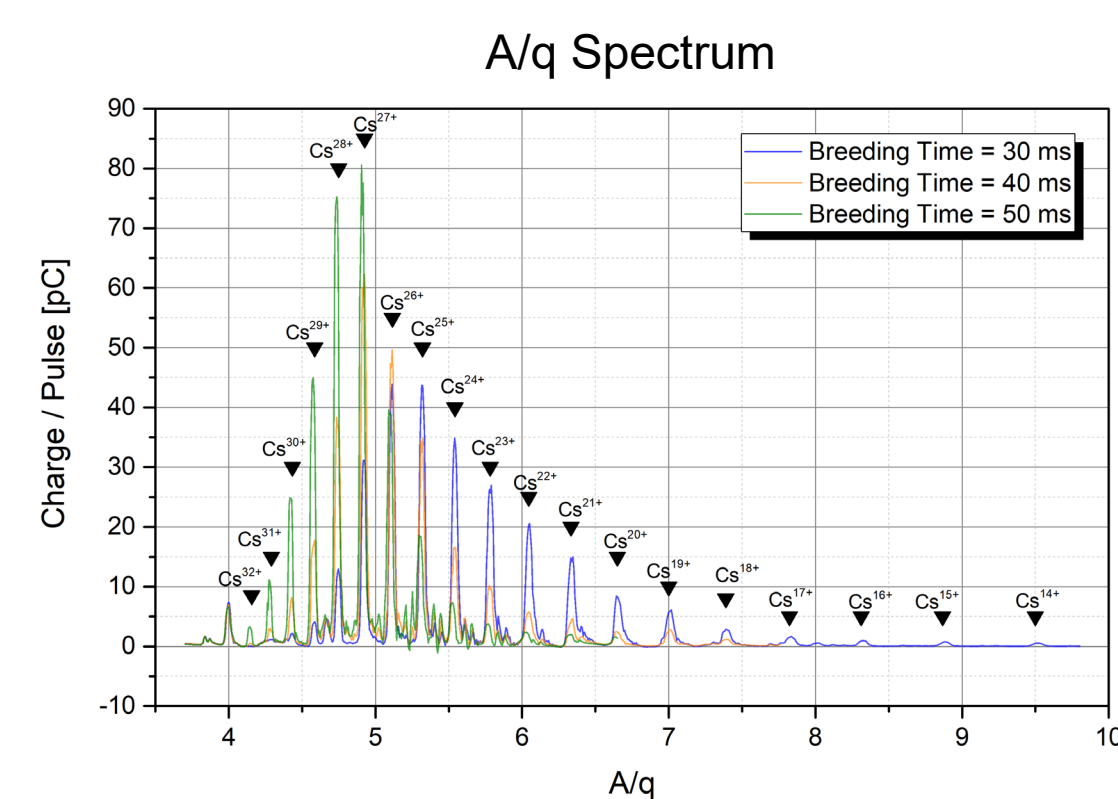


- Energy = ~20 keV
- Pulse length = 100 us
- Number of particles = 4.3×10^7



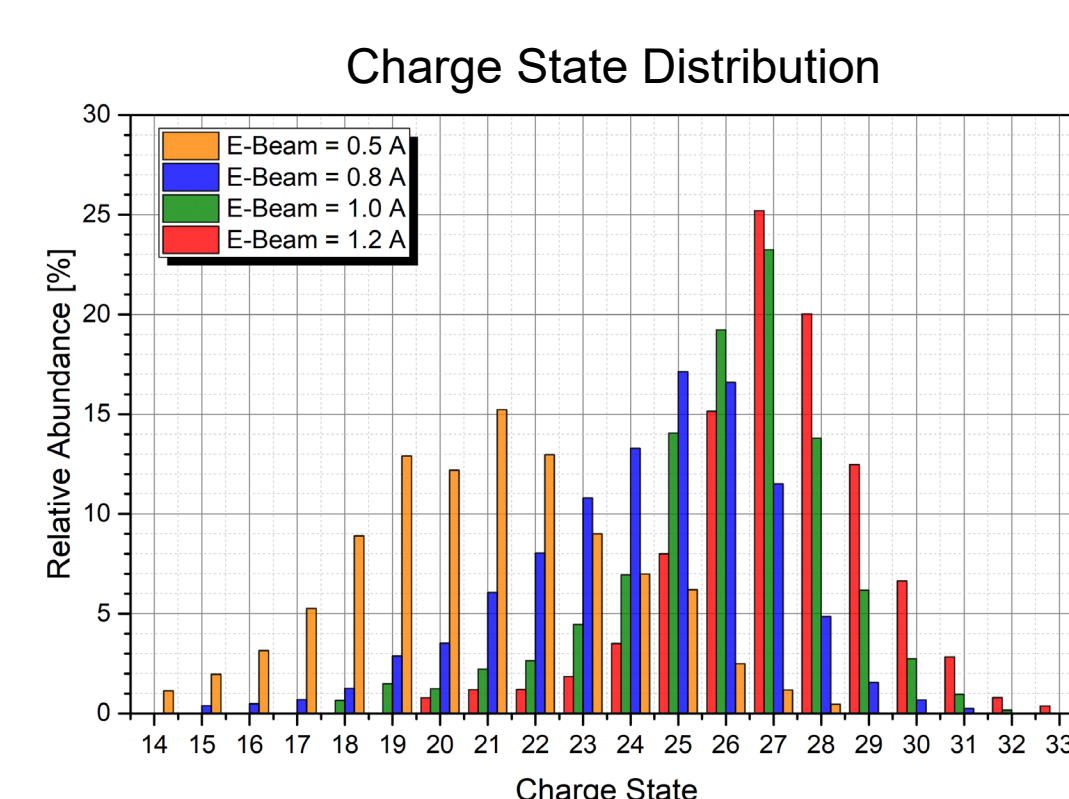
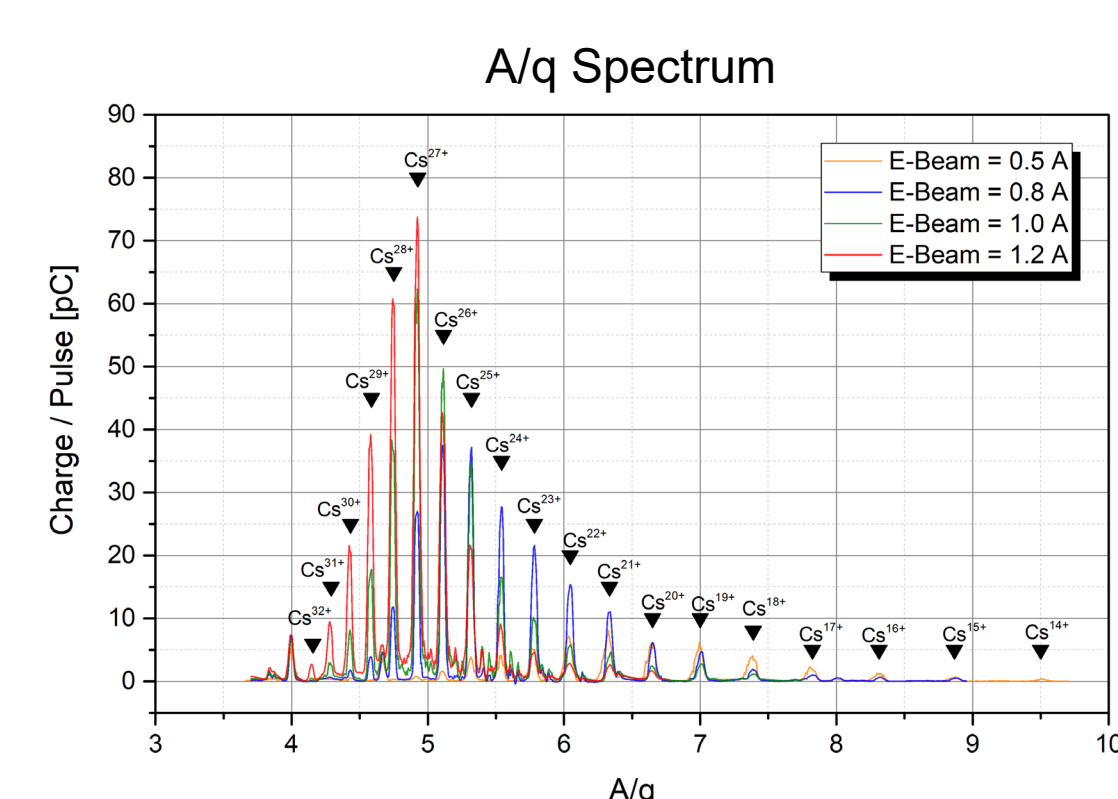
- Energy = 13 keV on breeding region
- Current = 0.5 ~ 1.2 A
- Breeding time = 30 ~ 50 ms

[Charge Breeding with Various Breeding Time]



- The test with the breeding time from 30 to 50 ms was performed to check the performance of the RAON EBIS.
- The EBIS HV platform is pulsed to make the potential of the breeding region 49.26 kV so that it can satisfy extracted energy of 10 keV/u for $^{133}\text{Cs}^{27+}$ ($A/q=4.926$).
- For the case of the breeding time of 50 ms, the relative abundance of $^{133}\text{Cs}^{27+}$ is about 25 %.

[Charge Breeding with Various E-beam Current]

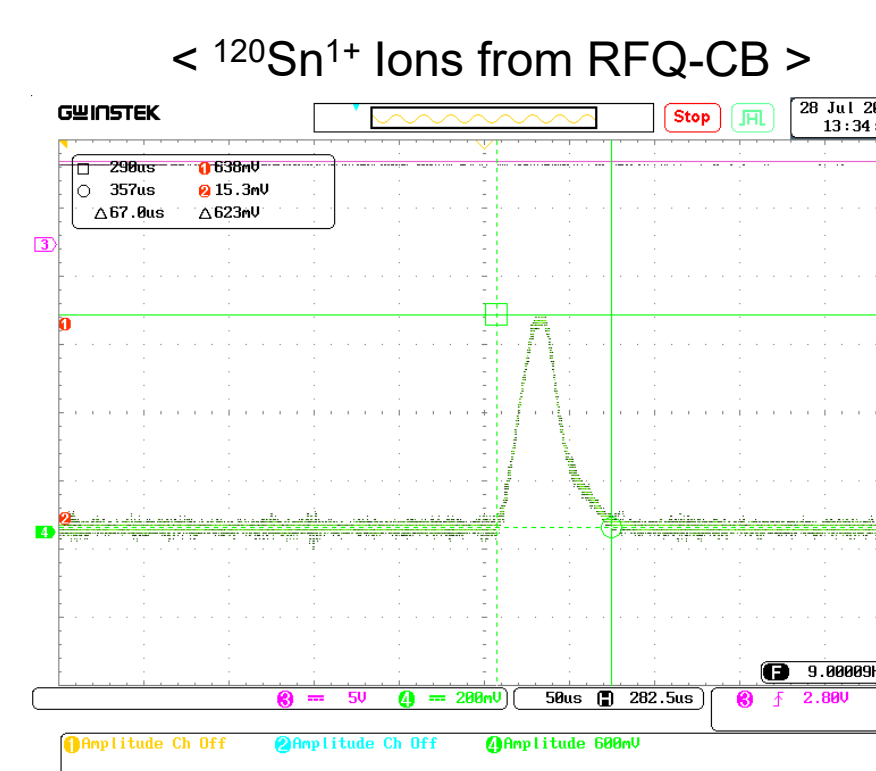


- The performance test was done with the E-beam current from 0.5 A to 1.2 A
- The fraction of 27+ is more than 25 % when the E-beam is 1.2 A
- There is the inverse proportionality between the breeding time and the E-beam current density.

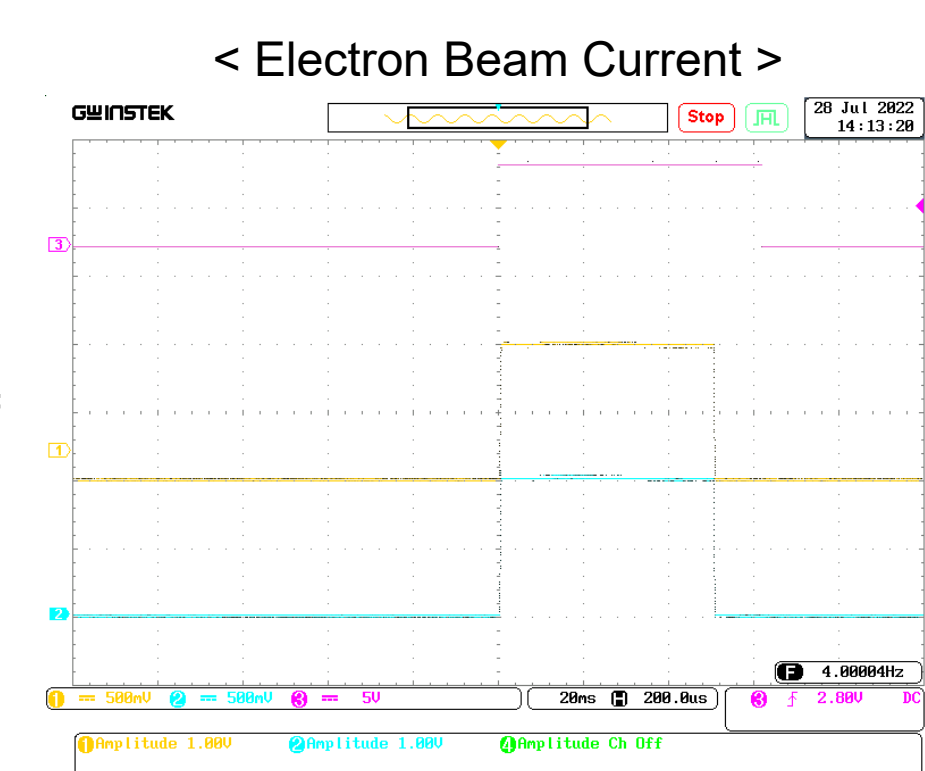
Summary and Plan

- The resultant relative abundance of $^{133}\text{Cs}^{27+}$ was higher than 20 % with electron beam of 1.2 A and breeding time of 40 ms, and satisfy 10 keV/u.
- The charge fraction of $^{120}\text{Sn}^{24+}$ was 23.0% and the energy per nucleon with 10 keV/u as achieving the EBIS efficiency of 89.1 %.
- $^{133}\text{Cs}^{27+}$ ions from the RAON EBIS are extracted with a pulse length up to 10 ms (FWHM) by applying the voltage in logarithmic forms with respect to time on drift tubes.
- The RAON EBIS satisfies the conditions of the accelerator ($A/q < 6$ and 10 keV/u).
- The commissioning using RI beam from the ISOL beamline is planned.

Charge Breeding of $^{120}\text{Sn}^+$ Ions

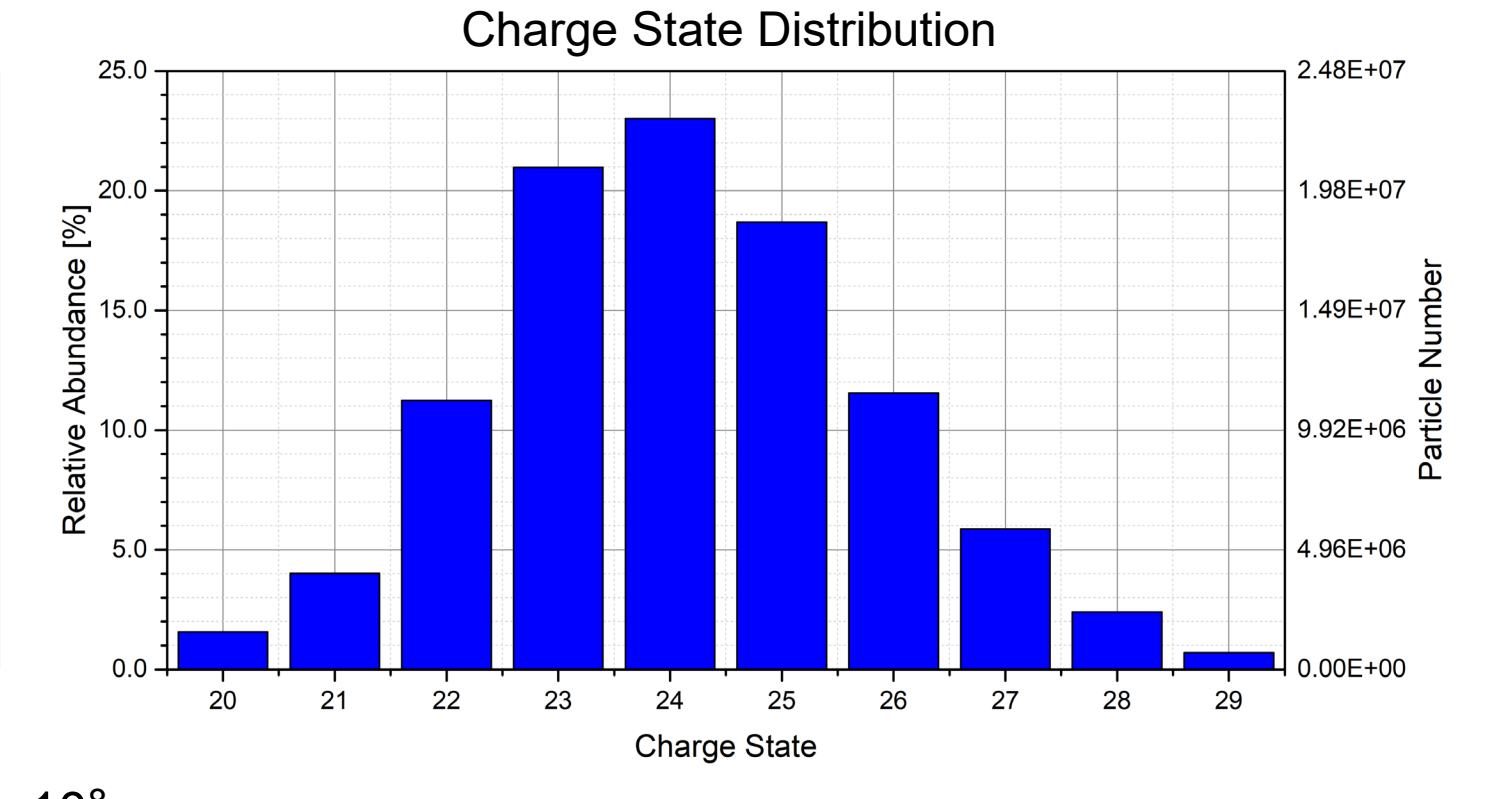
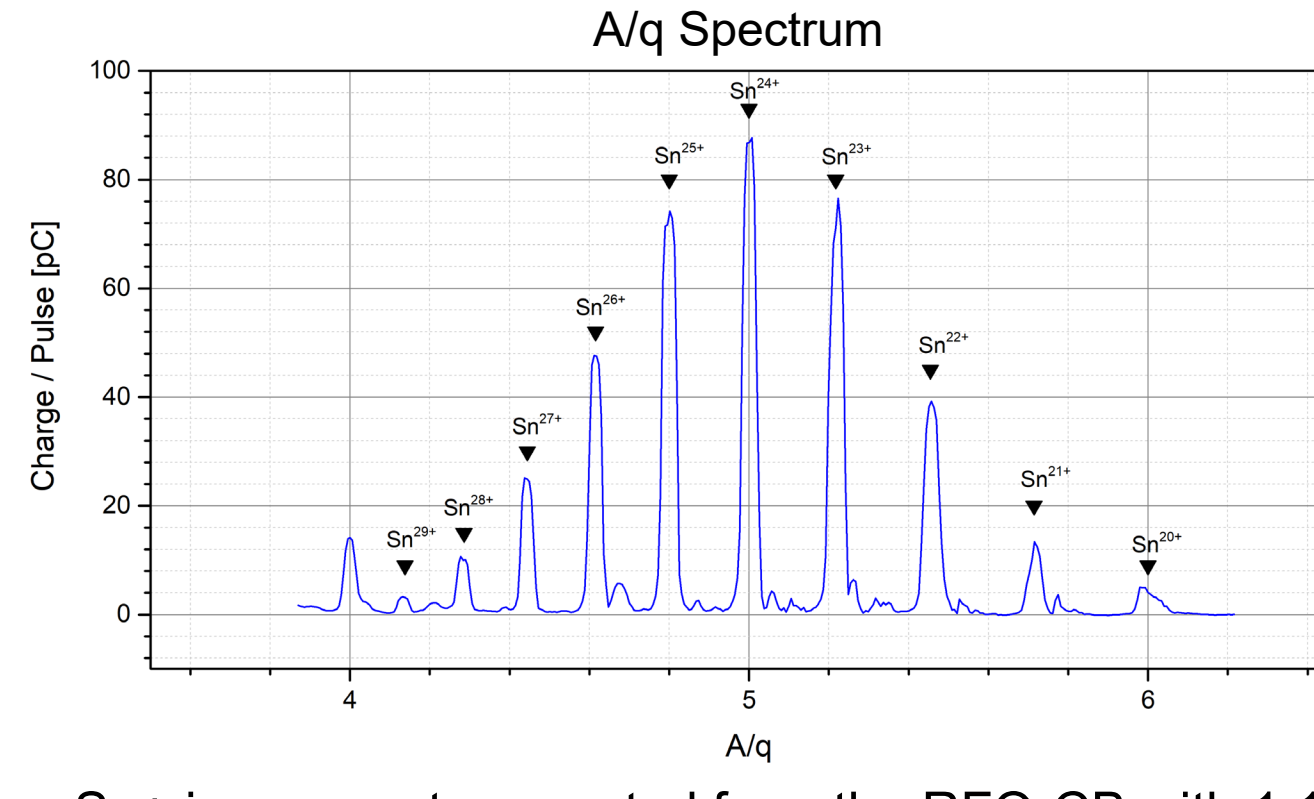


- Energy = ~20 keV
- Pulse length = 67 us
- Number of particles = 1.11×10^8



- Energy = 13 keV on breeding region
- Current = 1 A
- Breeding time = 40 ms

[Charge Breeding Result of RAON EBIS]

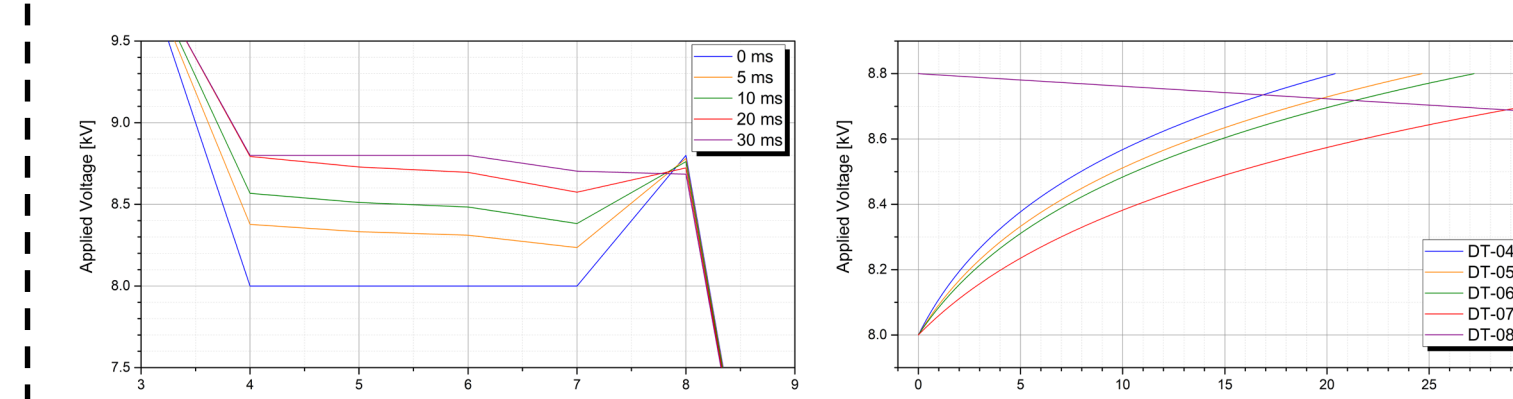


- Sn^+ ions were transported from the RFQ-CB with 1.11×10^8
- The targeted charge state was 24+ ($A/q=5.0$), so the charge-bred-ions were ejected from the platform of 50 kV.
- The charge fraction of $^{120}\text{Sn}^{24+}$ was 23.0% and the energy per nucleon with 10 keV/u

Injected Number	Number of $^{120}\text{Sn}^{24+}$	Relative Abundance	Total Bred Ion Number	EBIS Efficiency
1.11×10^8	2.28×10^7	23.0 %	9.92×10^7	89.1 %

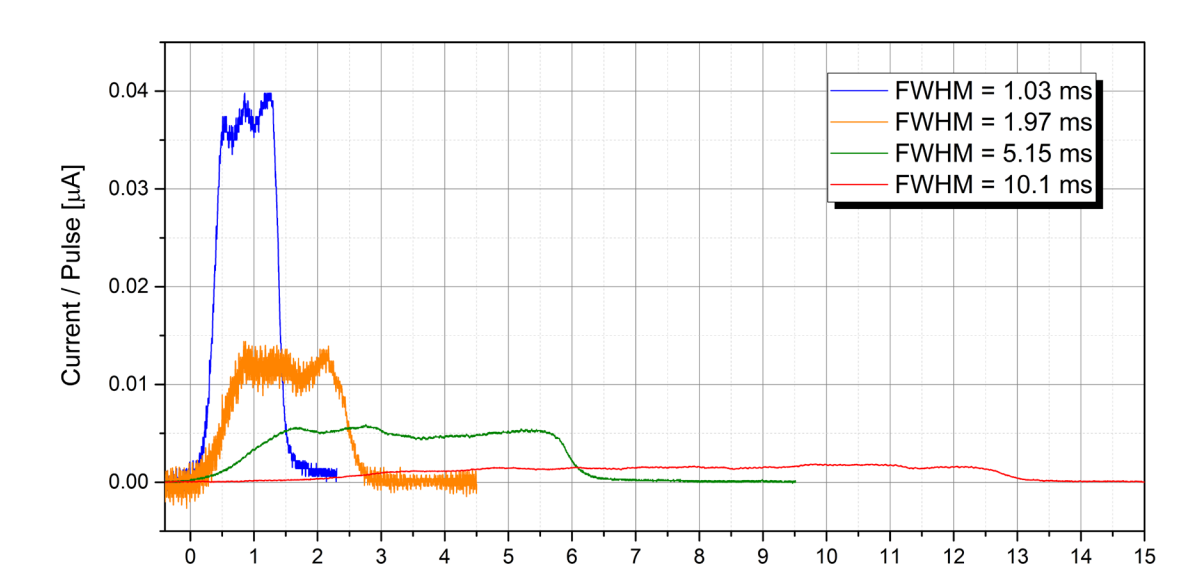
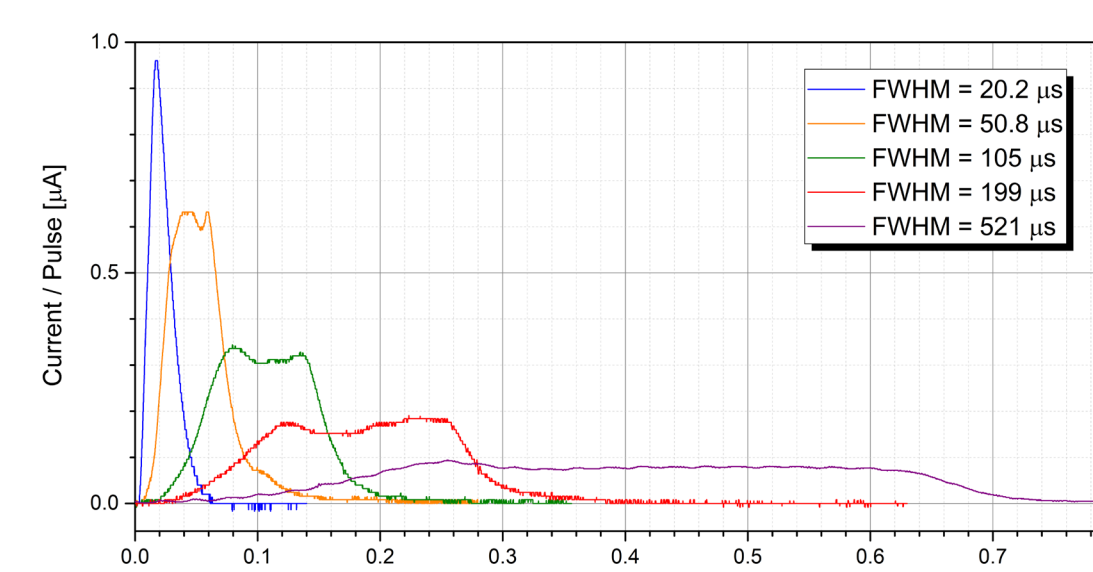
Preliminary Test of Pulse Stretching

[Voltage Setup in Breeding Region]



- The preliminary test about pulse stretching of $^{133}\text{Cs}^{27+}$
- The voltage in logarithmic forms with respect to time is applied on the electrodes (DT #04-07) in the breeding region.
- The voltage at the gate electrode (DT #08) decreases very slowly and linearly over time.

[Result of Pulse Stretching]



- Changing the time scale of applied voltage function, the pulse length of Cs^{27+} ions was measured.
- Various length of the beam pulse from 20 us to 10 ms (FWHM) can be produced.
- But it's not perfectly flat top shape, more sophisticated method is needed.

