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Effects due to Cs injection upon the beam current oscillation extracted from the J-PARC negative hydrogen ion source

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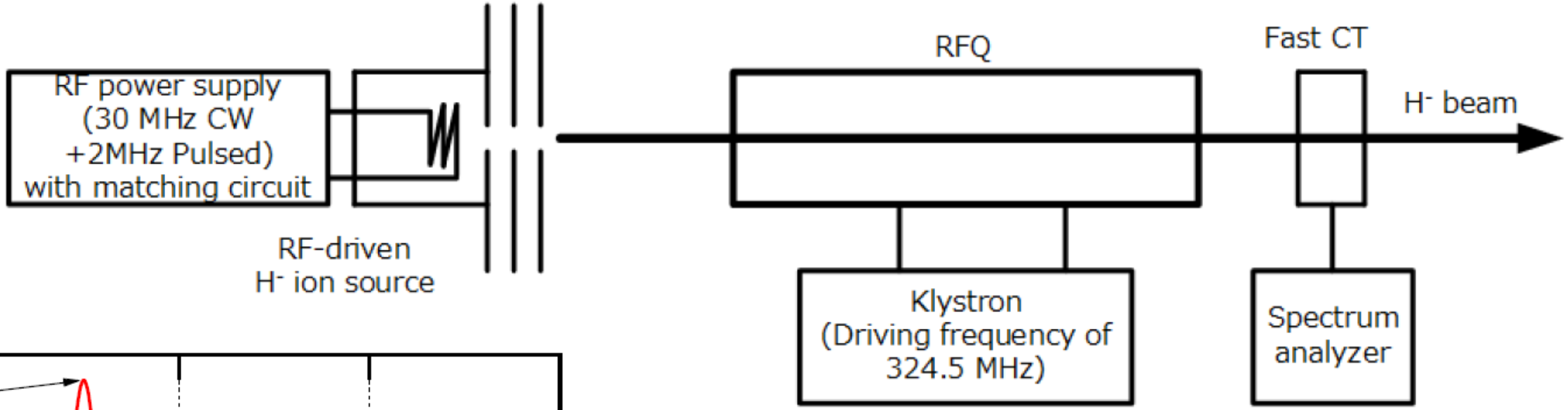
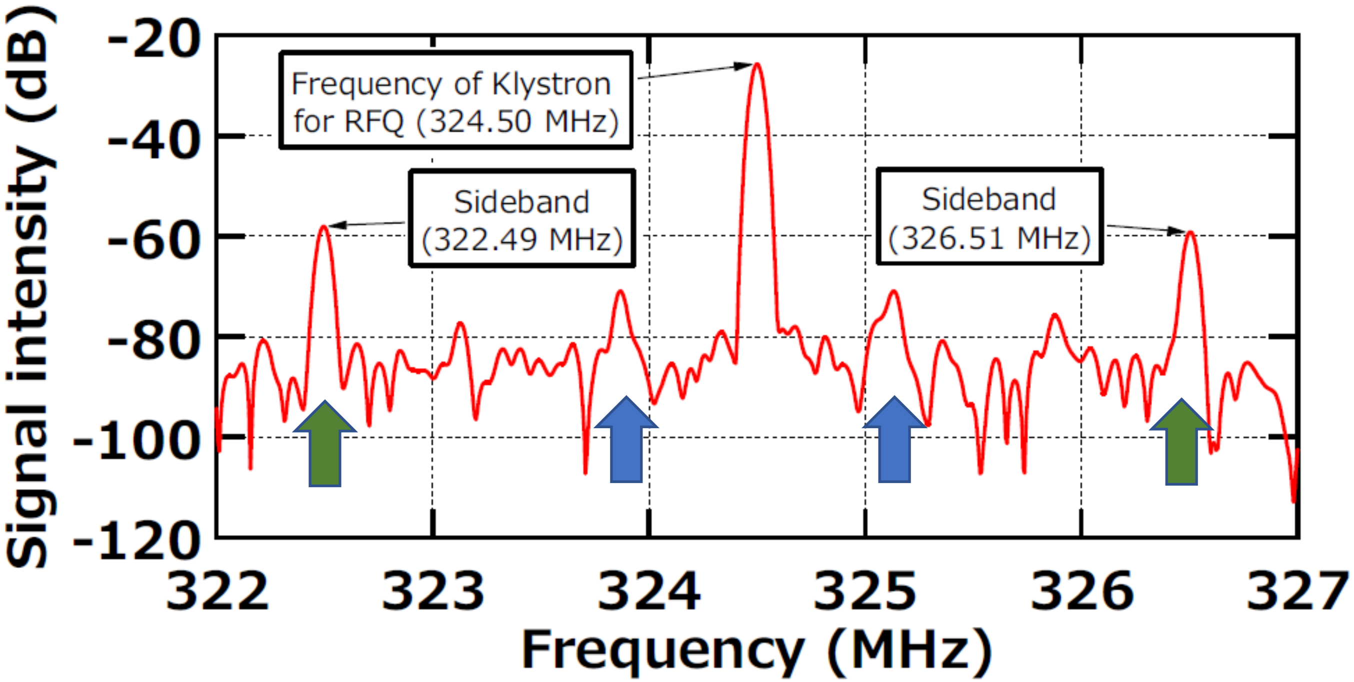
Motivation of the experiment

- Negative ion extraction across a magnetized sheath can often cause beam fluctuation. (Belchenko *et al*: 2nd NIBS, Takayama, AIP Conf. Proc. 1390, 401 (2011).)

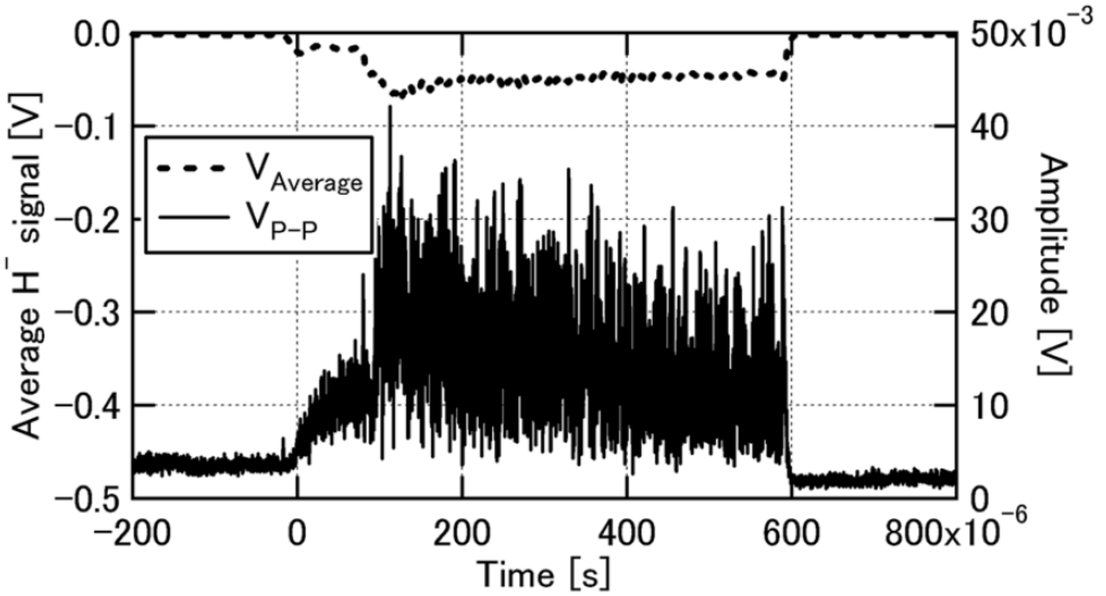


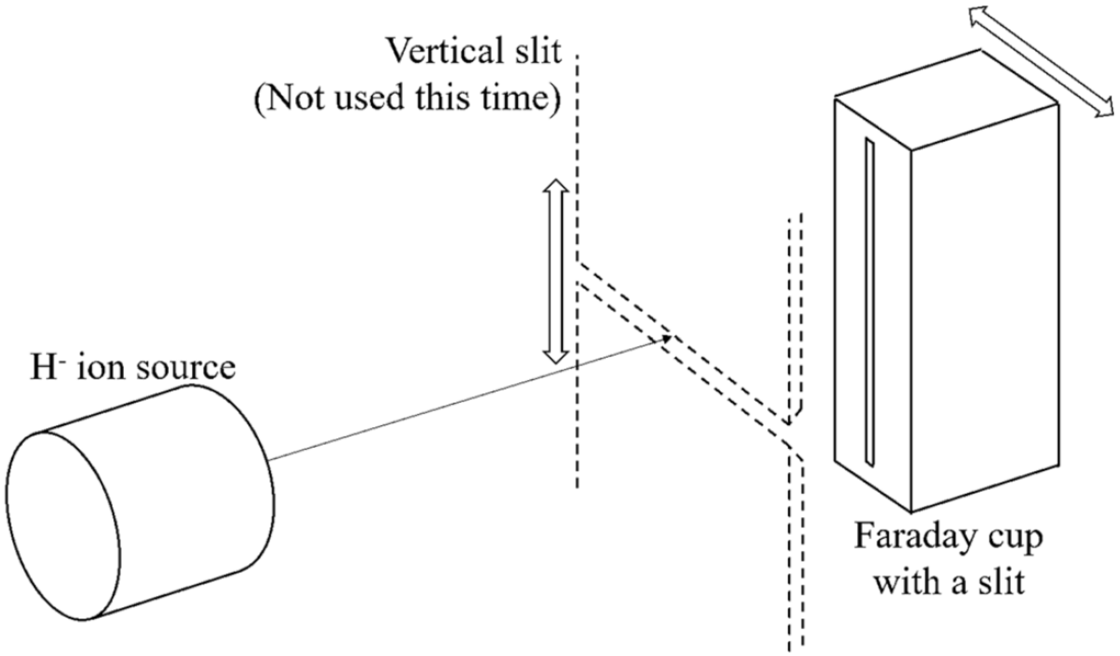


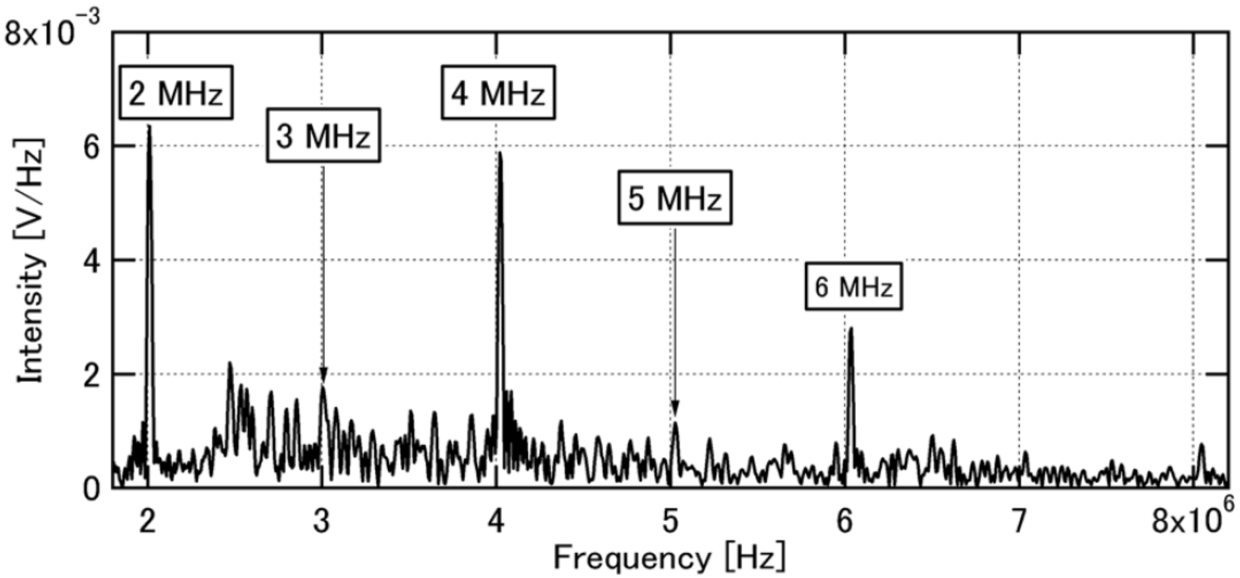
- J-PARC beam showed ~700 kHz oscillation, and the source driving RF at 2 MHz.
- Both oscillations reflects H^- ion extraction conditions. (Formation mechanism/plasma parameters.)

Observation at the source

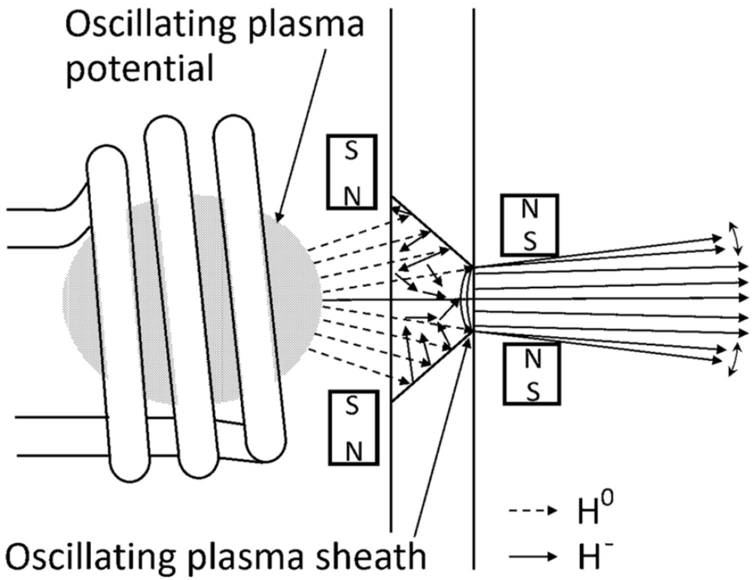
- A slit Faraday cup showed large fluctuation for 50 Ω termination resistor.
- The frequency spectrum of the detected current showed peaks at 2 and 4 MHz.
- It also showed dispersed spectrum between 400-800 kHz. (Cross B field oscillation.)
- Up to the fourth harmonics of driving RF appeared in the frequency spectrum.

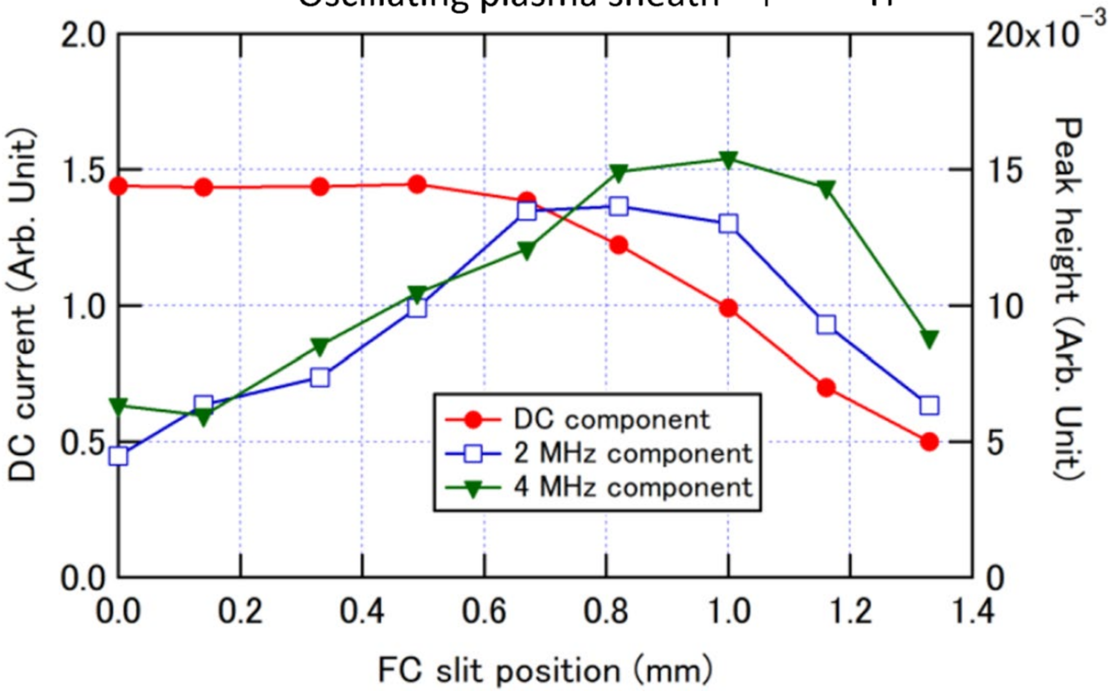






Beam spatial profile





- ➢RF power produces positive ions twice in a cycle;

$$E_\theta = -\frac{1}{2\pi r}\int \frac{\partial \mathbf{B}}{\partial t}\cdot \mathbf{n}\, dS$$

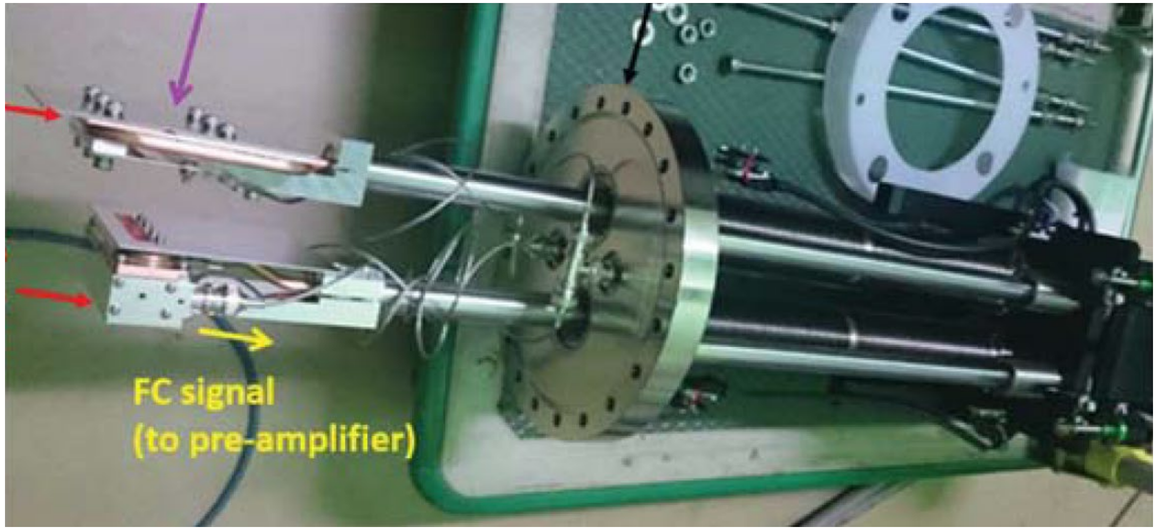
- ➢Plasma sputters out the rod filter cover; the plasma should have high RF sheath potential. (→Shibata:Oral 8, Wed. 11:50.)
- ➢Ion plasma frequency

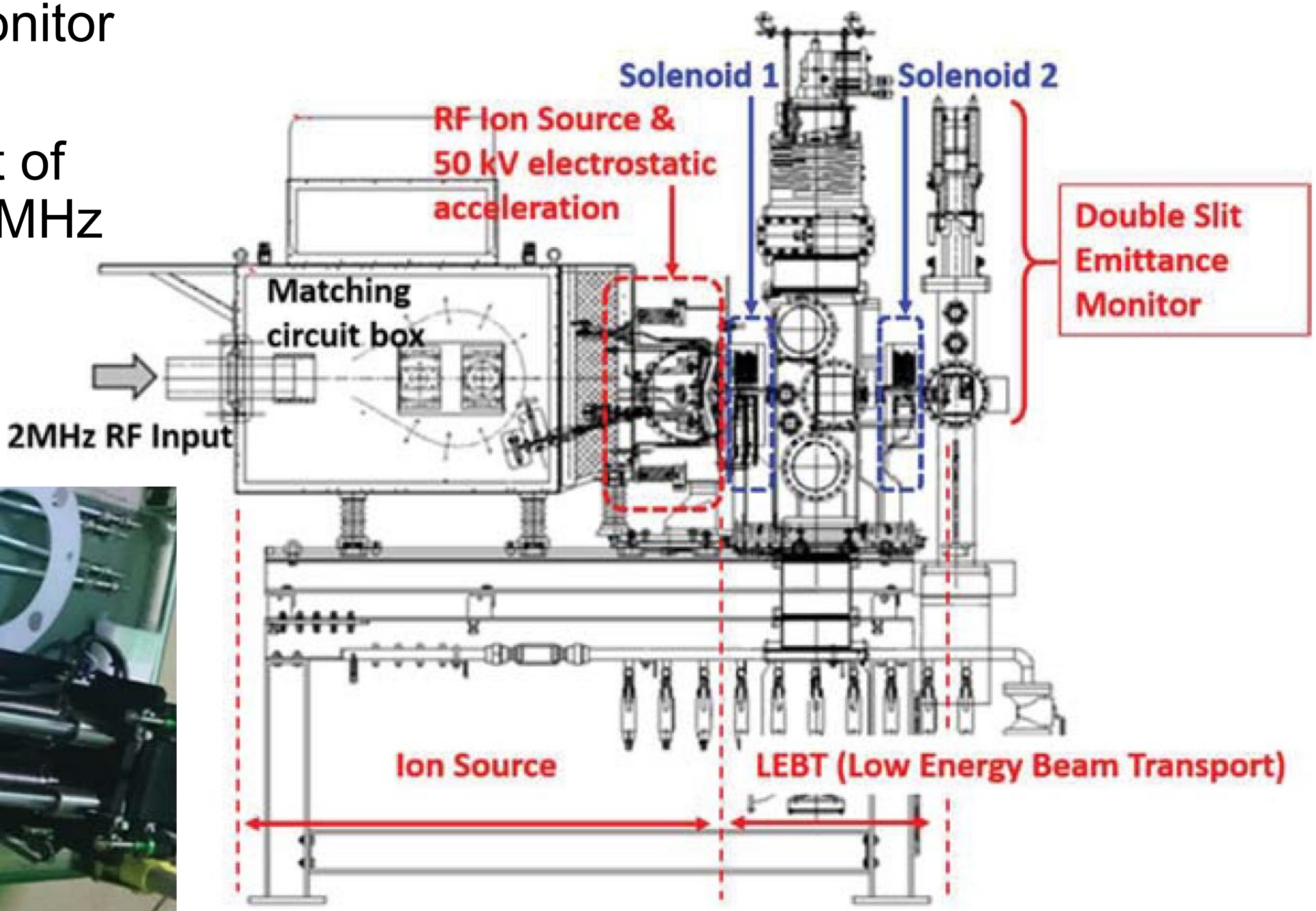
$$\omega_{pi} = \sqrt{\frac{e^2 n_i}{\epsilon_0 M_i}} = 1.32\sqrt{n_i}$$

is much higher than ω_{RF}.

High-speed system

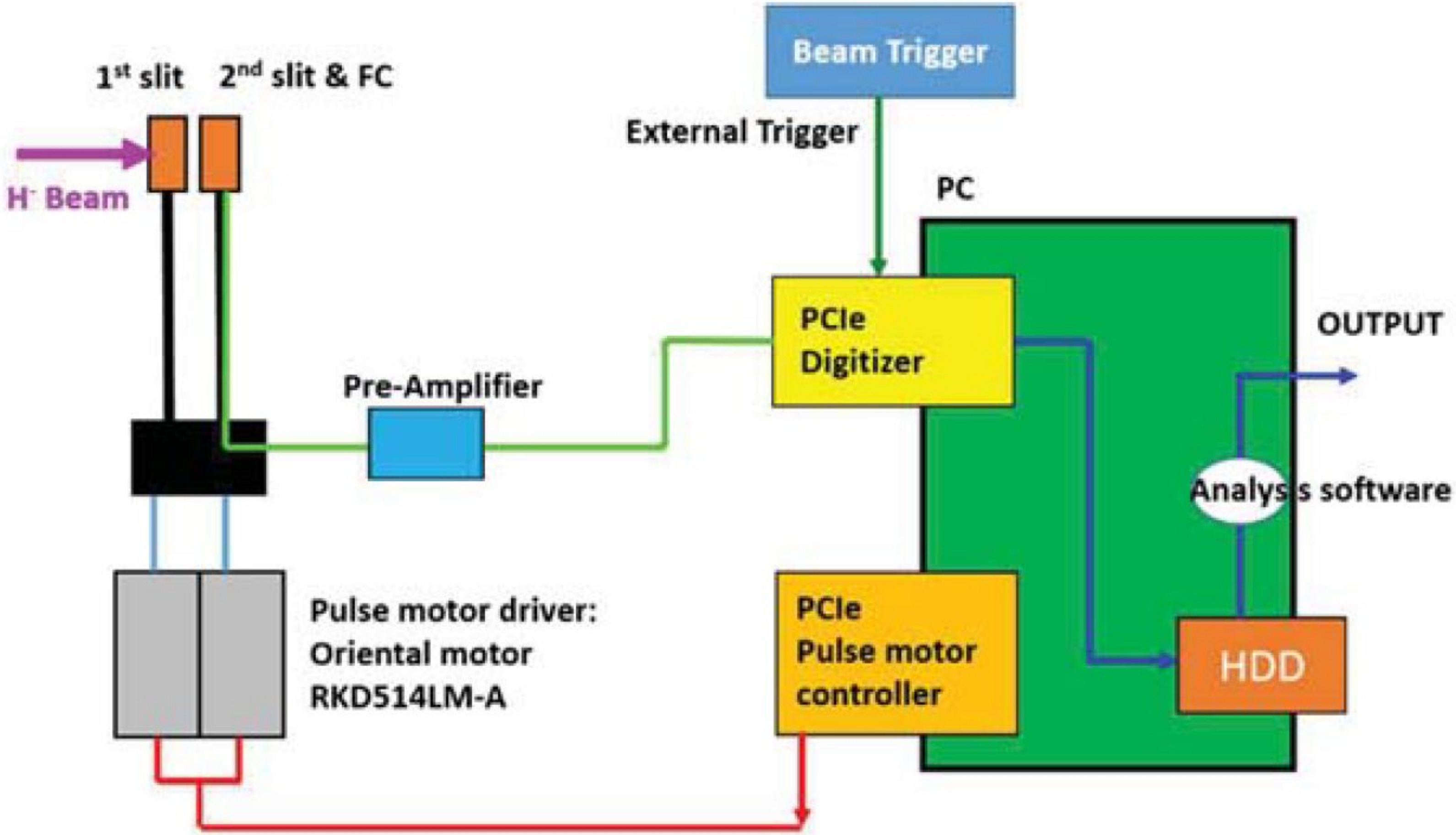
- Signal detection sensitivity of the J-PARC double slit emittance monitor was improved.
- Time-dependent measurement of emittance is possible up to 60 MHz time resolution.





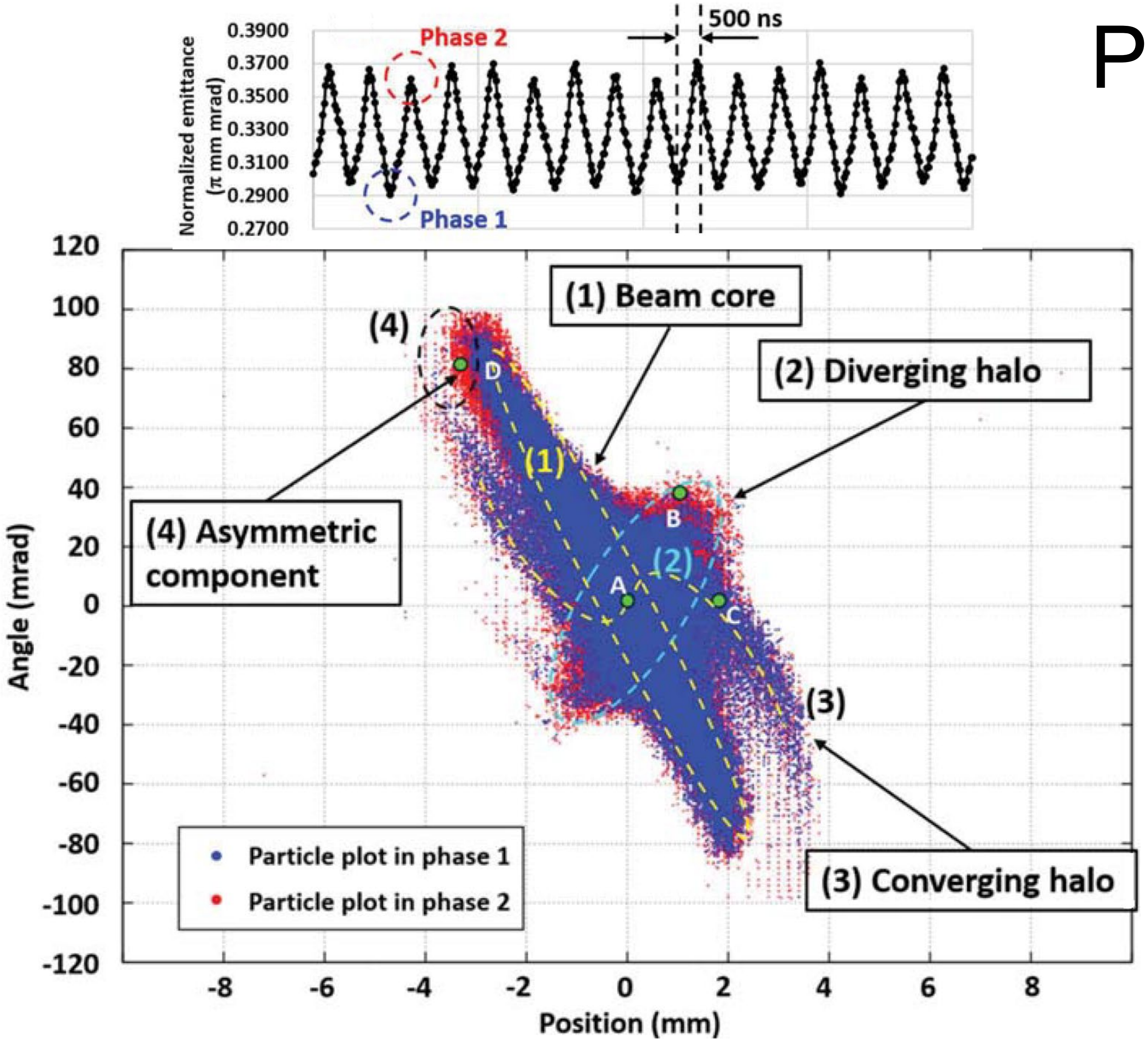
Specification of the diagnostic system

- **High-speed signal amplification and storage is the key for this beam diagnostics.**
- **Small signal intensity must be compensated with a high speed preamplifier.**
- **Special care must be made with noise from power supplies.**



Slit width: 0.1 mm
Slit length: 66.7 mm
Distance between the 1st and the 2nd slits: 61.0 mm
Electron suppression voltage to the Faraday-Cup: -500 V
Faraday-Cup signal termination: 100 Ω

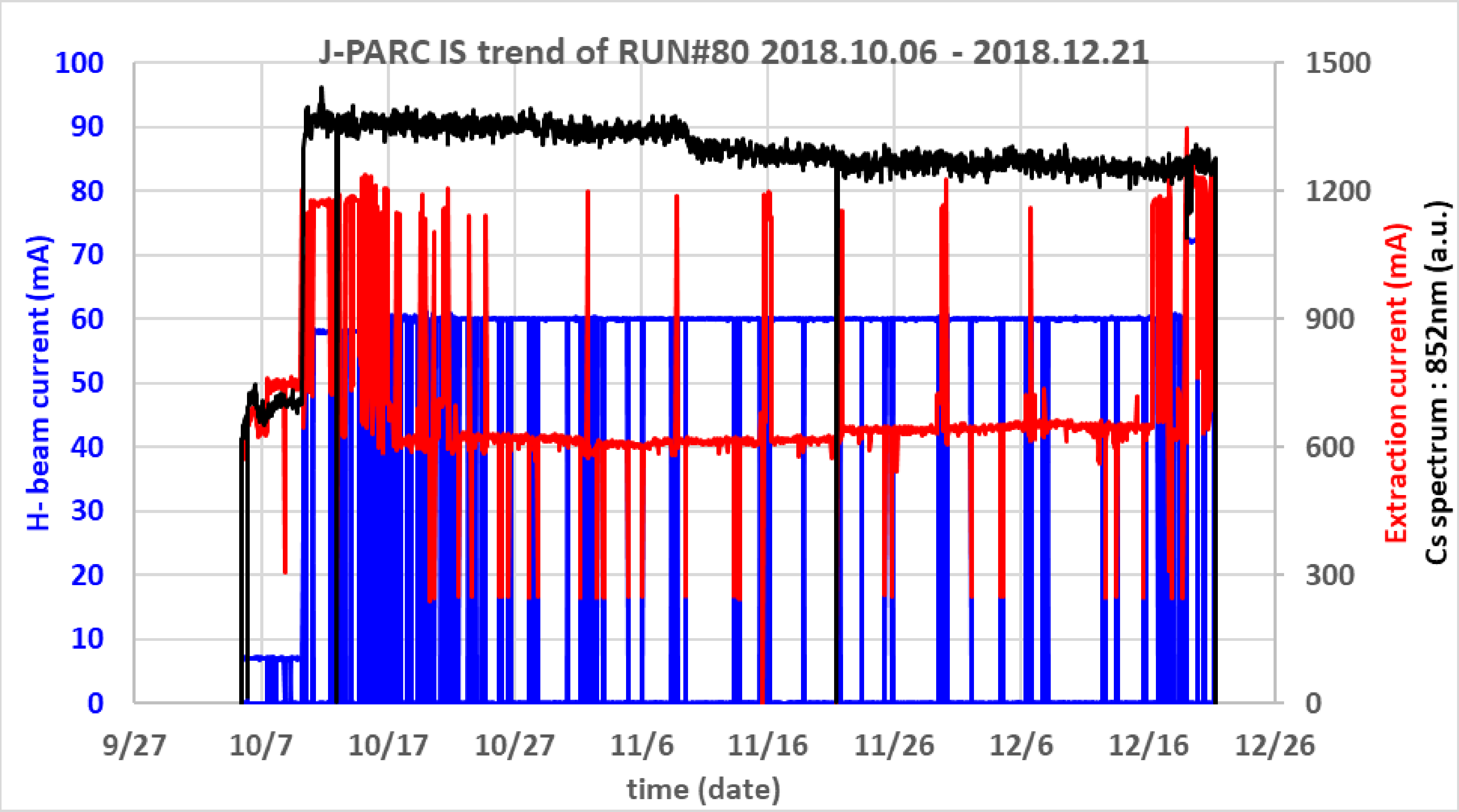
Phase dependent measurement



- Time dependent emittance diagram can now be drawn. (Shibata *et al*. AIP Conference Proceedings, **2373**, 030006 (2021).)
- Time-dependent changes of Twiss parameters are obtained from the system.
- The detailed structure of the beam may be studied using the system.
- This time, effects due to addition of Cs are investigated.

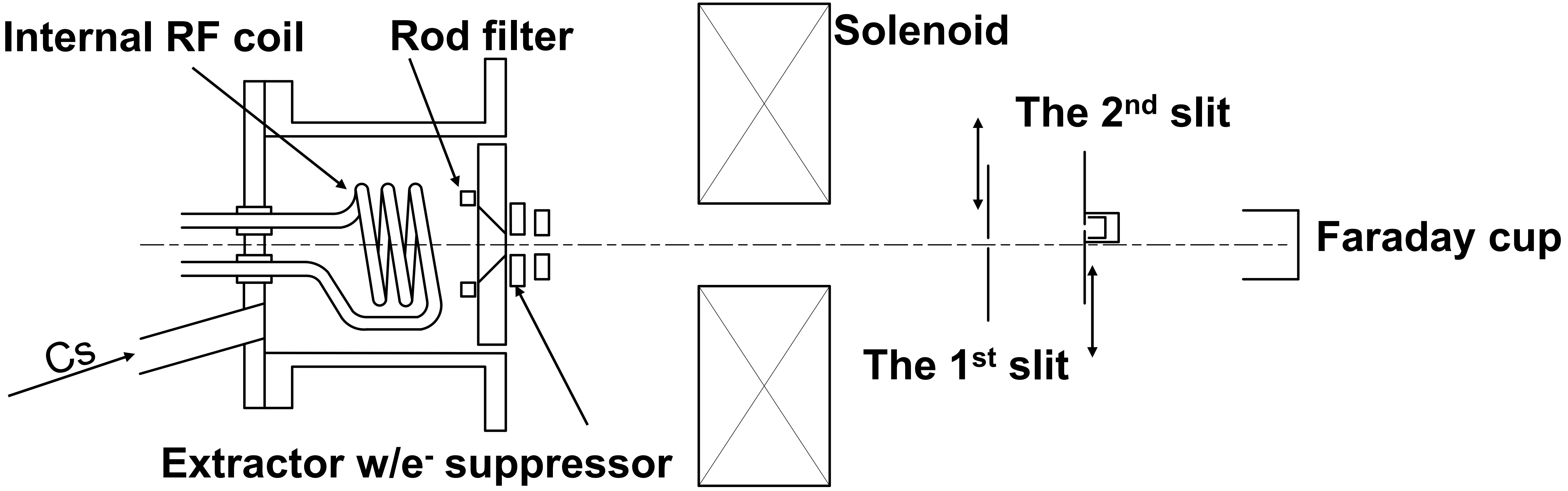
Positive effect of Cs

- Cs injection reduces extraction current and the heat loads to the electrodes.



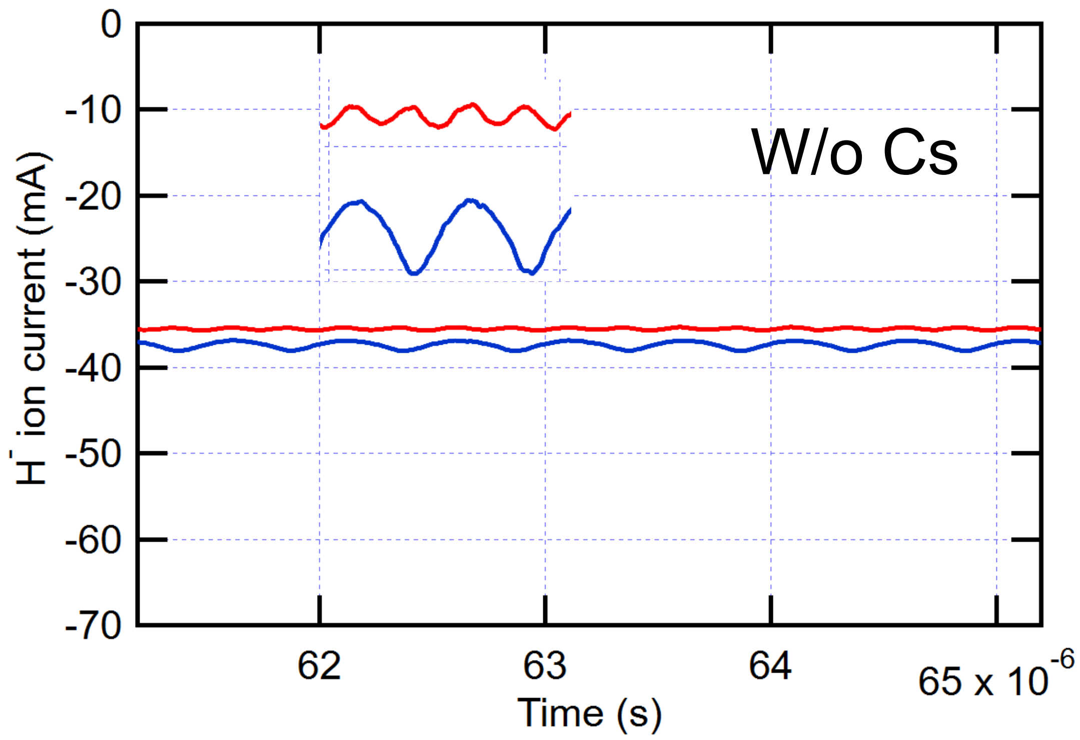
Experimental procedure

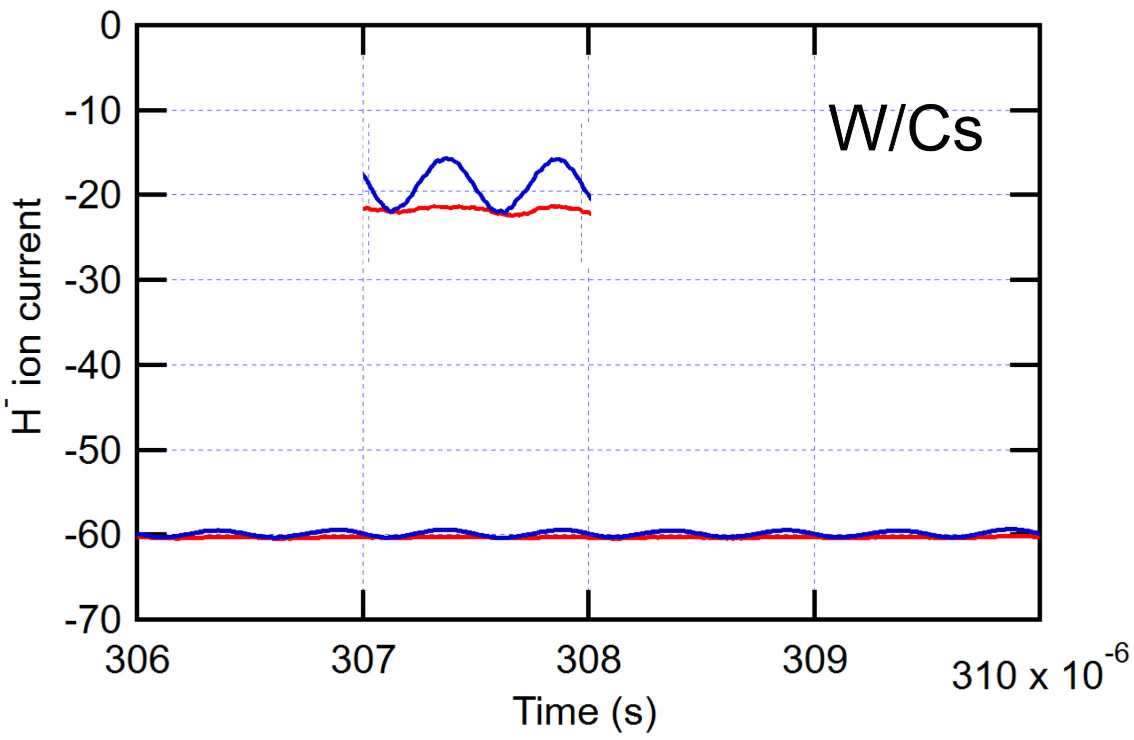
- Align the first and the second slit parallel to the beam axis, and move the entire collimation system perpendicularly to the beam axis.
- Fix the first slit and move the second slit to observe angular distribution.



Experimental results

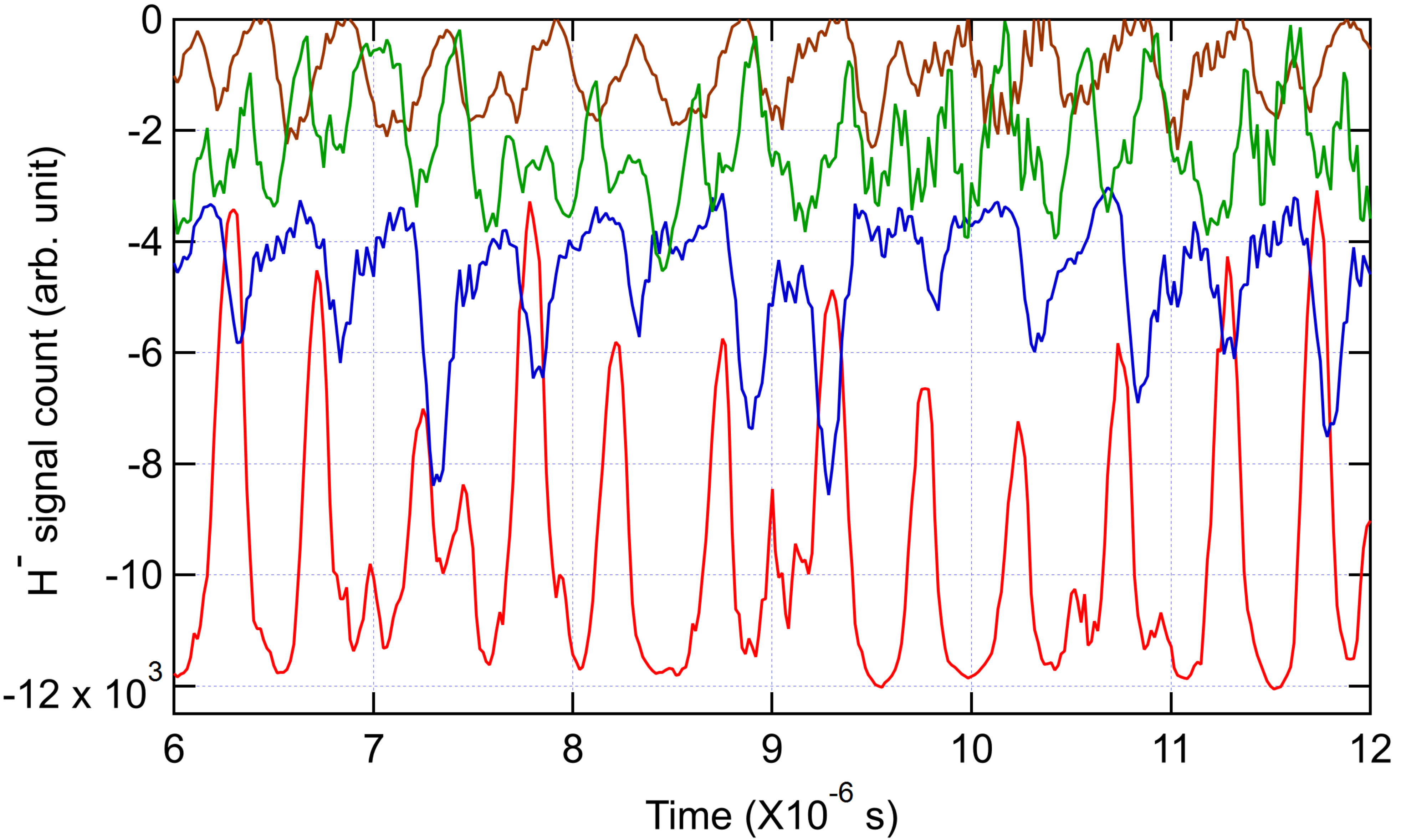
- Measurement of the total beam from the H^- ion source exhibits a quasi-steady state beam with -32 dB 2 MHz oscillation.
- FC signal indicates small perturbation due to RF; magnitudes of oscillation components changed with the intensity if axial magnetic field. (Red: AMF off, blue: AMF on.)





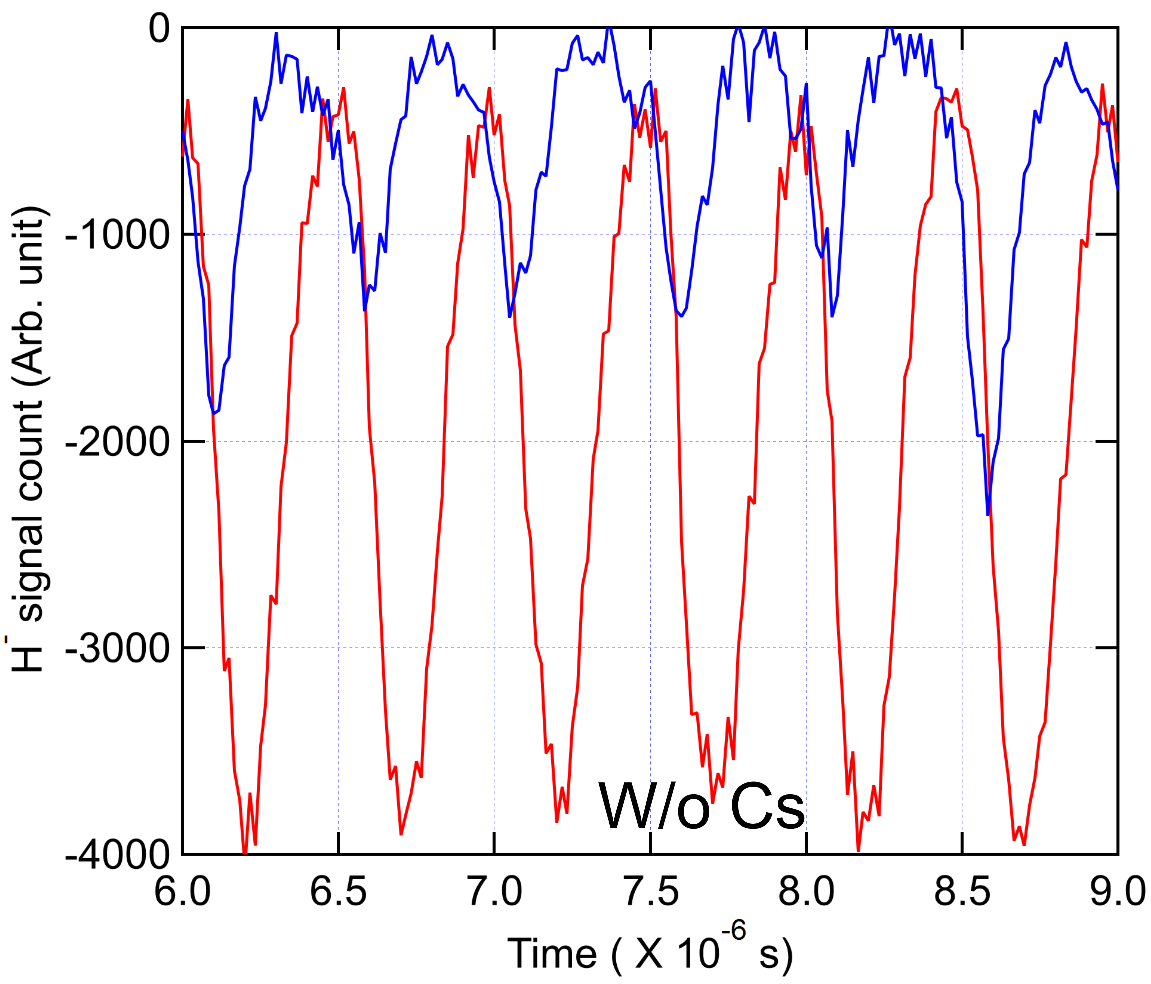
Spatial dependence: 4 mm.

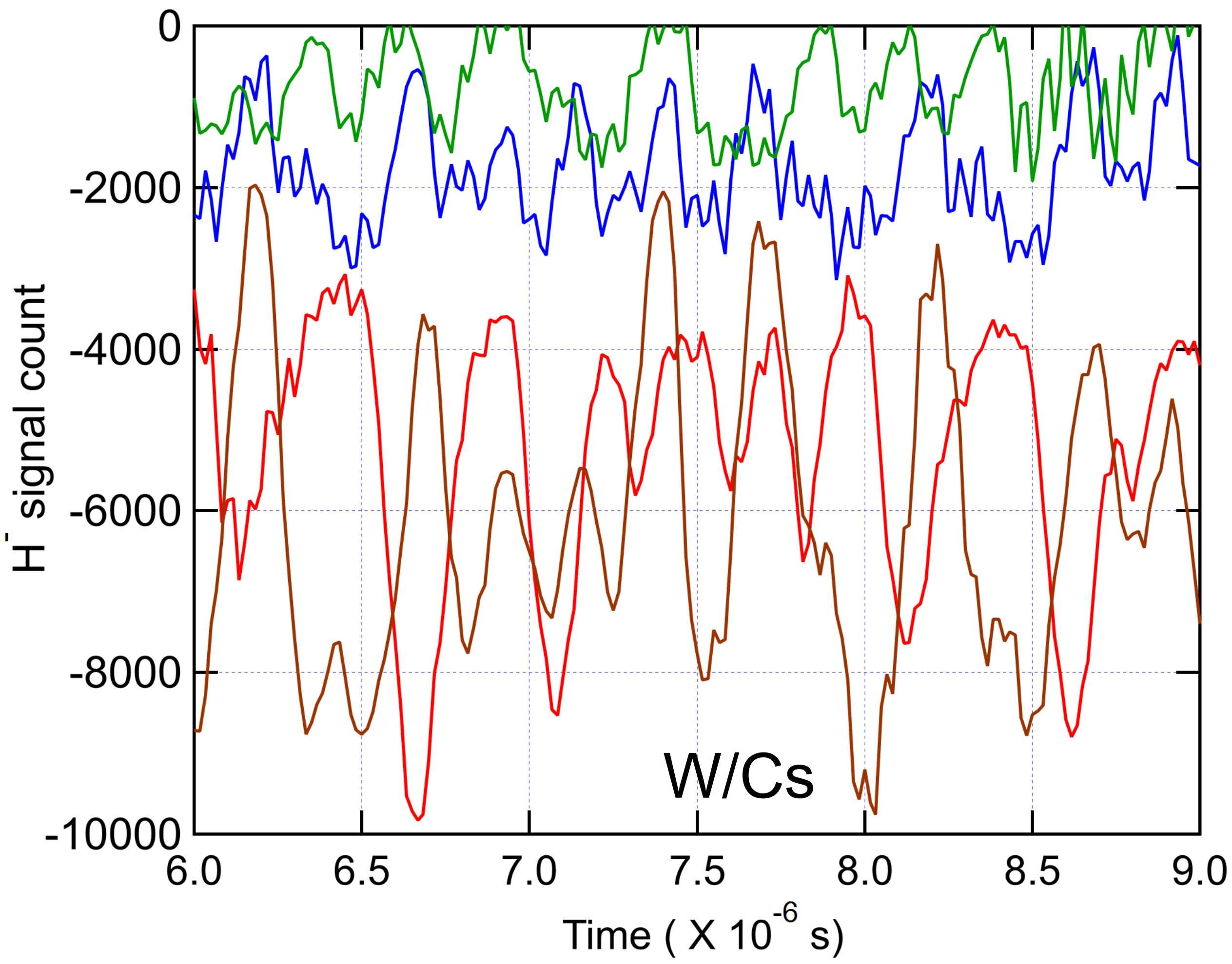
- With Cs, DC component appears larger.
- The beam size was about 2 mm for the condition with Cs and 1 mm (?) without Cs.
- Out of raw data with limited data length (1024) Fourier components are calculated.



Direct comparison (vertical direction)

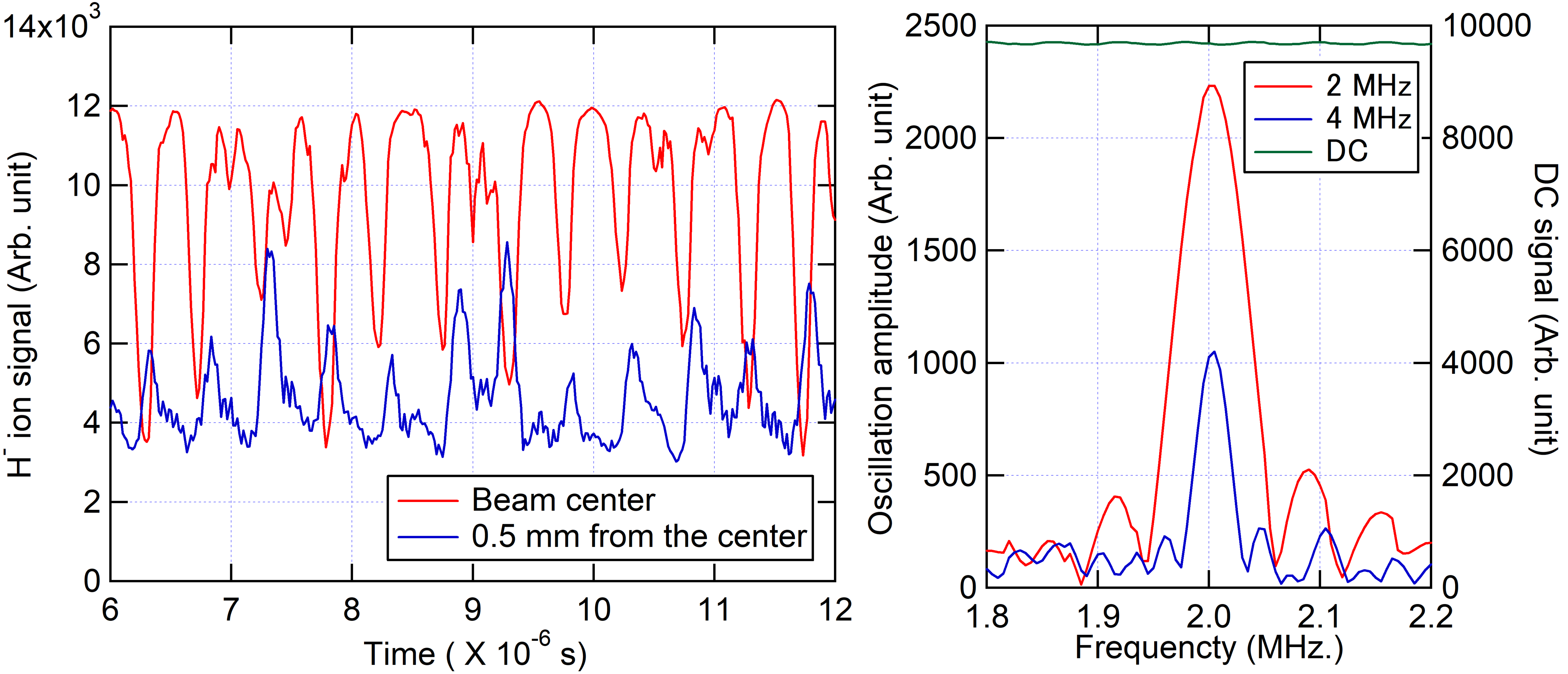
- Difference in beam size and existence of beam halo are clearly detected.
- A tendency was observed that beam edge exhibited higher frequency component.





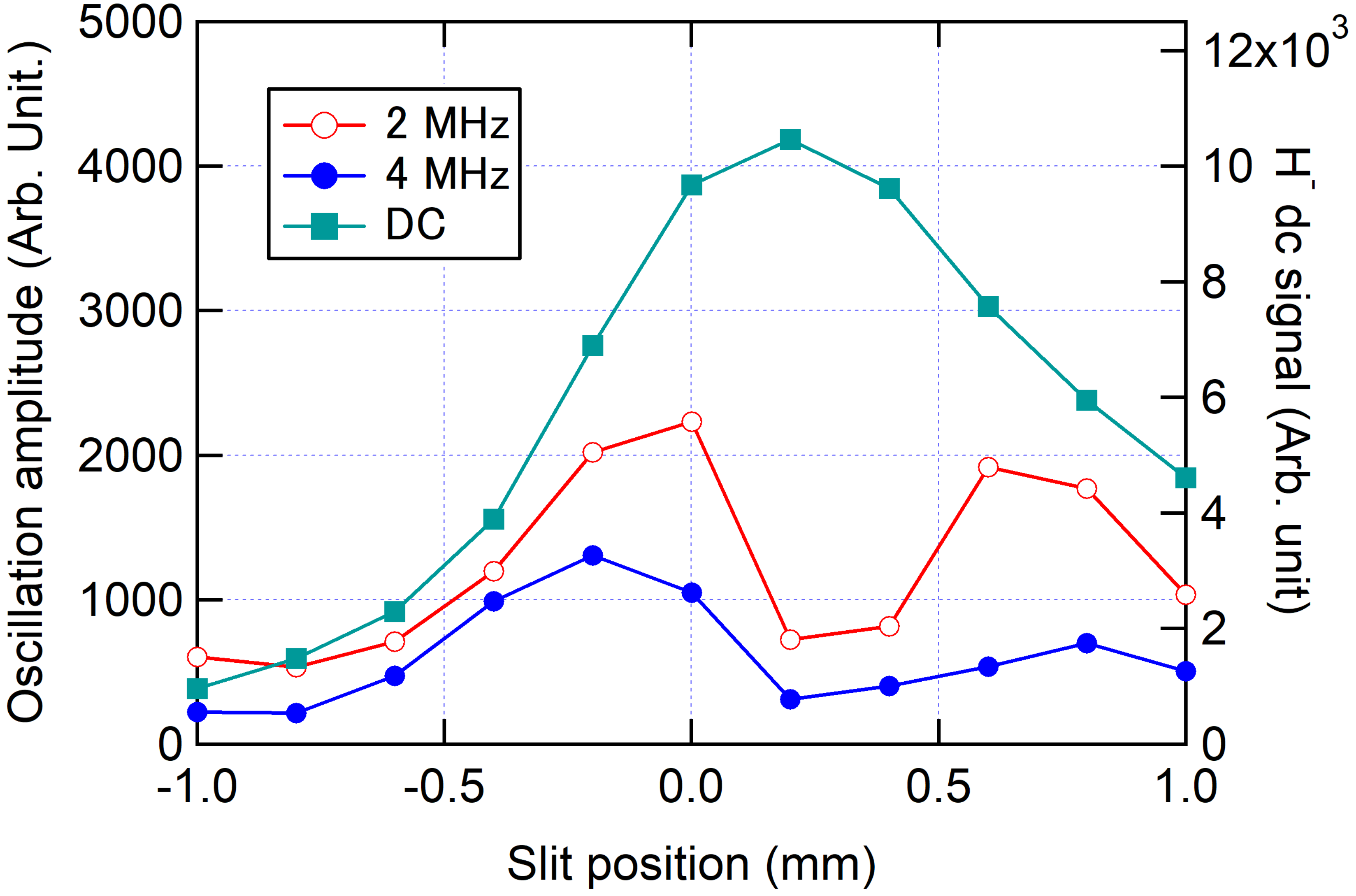
Beam intensity modulated by the primary RF

- ➢Data size reduction for high-speed analysis (real time beam monitoring)

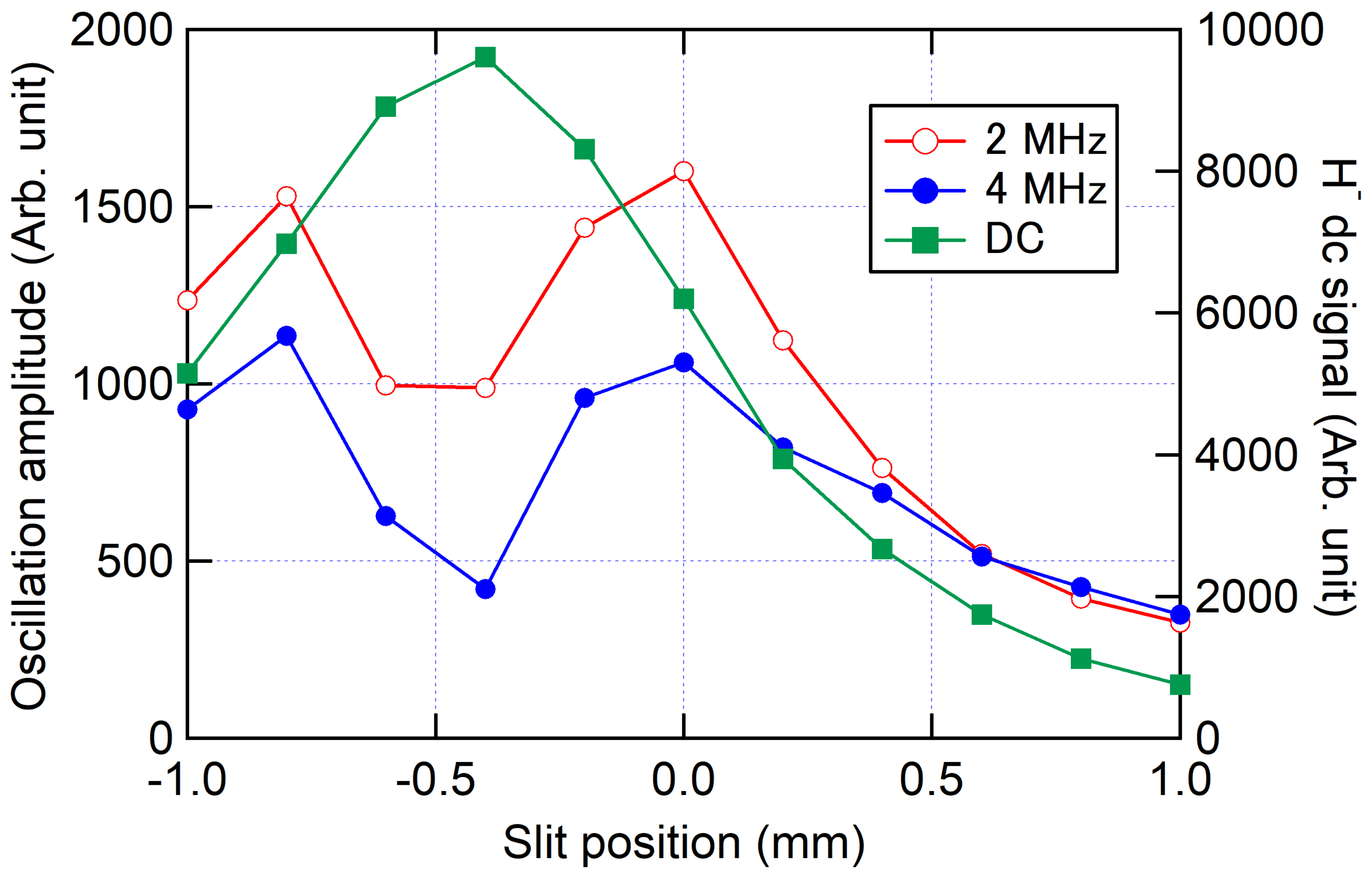


Horizontal profile (operation with Cs)

- About 2 mm beam radius.
- Amplitudes of oscillation components are smaller at the beam center of the dc component.
- 2 MHz component intensity exceeds 4 MHz component intensity throughout the entire region.



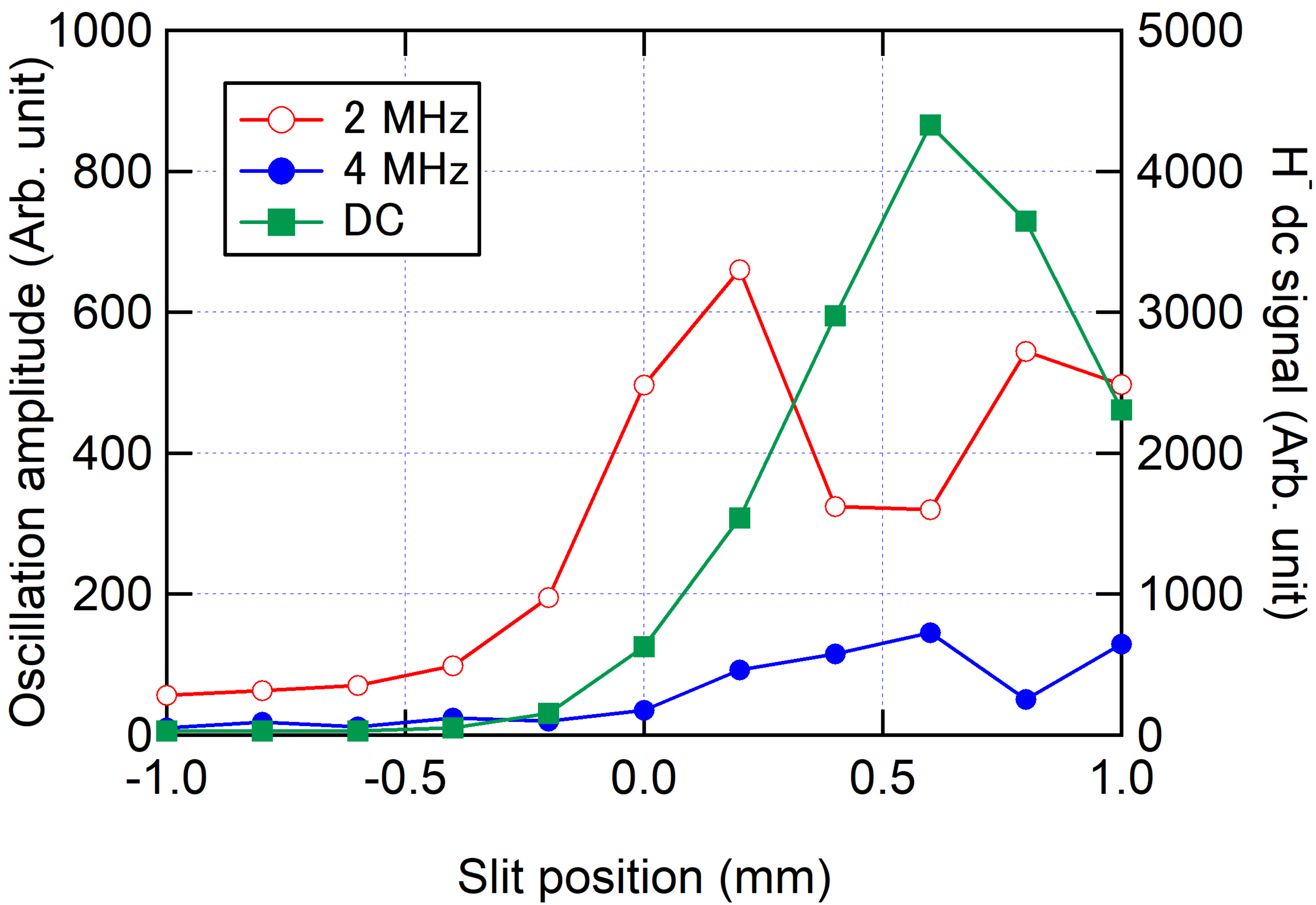
With Cs vertical



- Beam intensity appears smaller compared with the horizontal scan. (Longer elliptic radius in vertical direction?)
- 4 MHz component intensity becomes comparable to the 2 MHz component intensity near the beam edge.
- Dipps of oscillating components are clear.

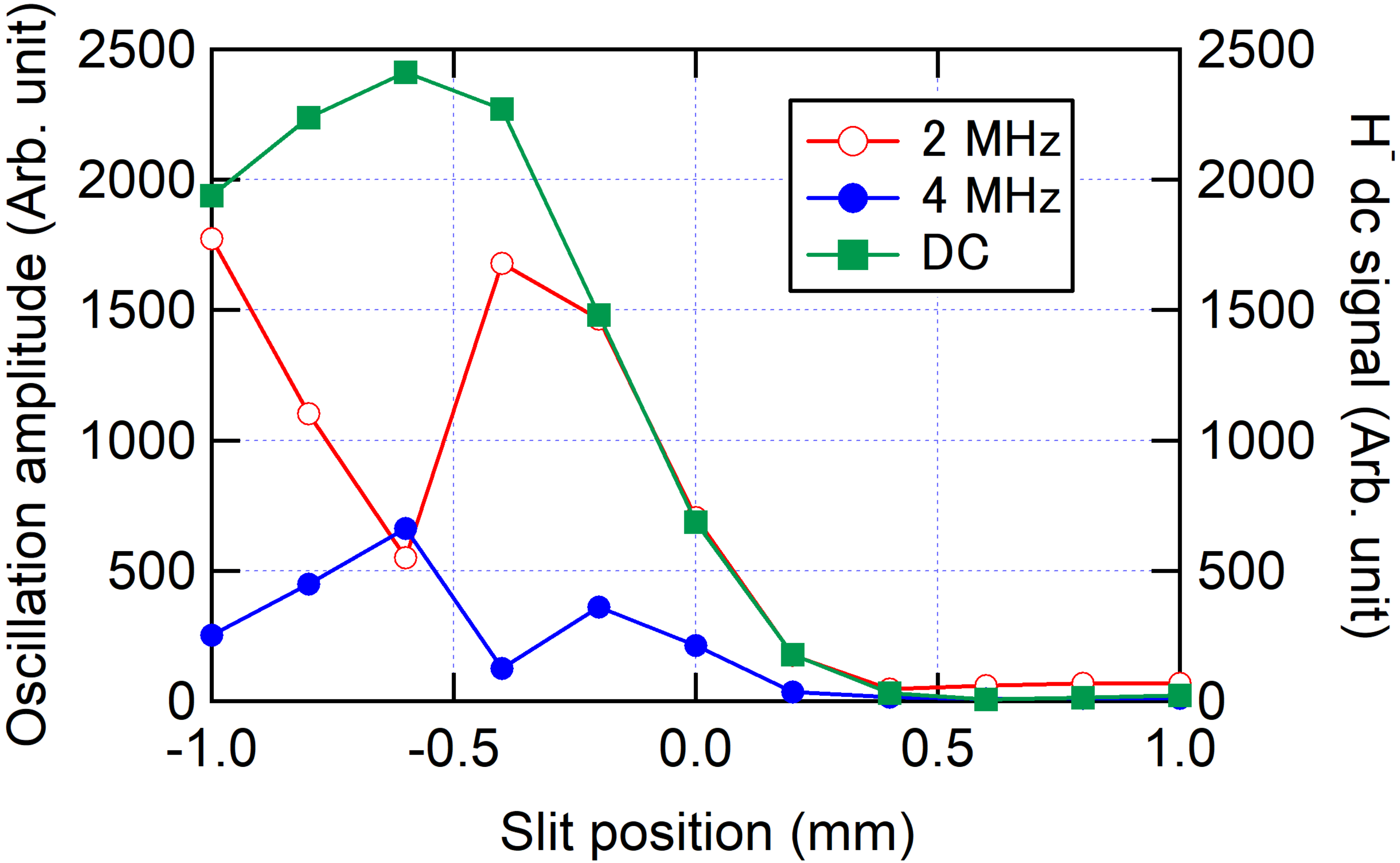
Less Cs vertical

- Substantially smaller intensity of 4 MHz component as compared with 2 MHz component.
- Beam profile seems sharper compared with a Cs rich condition.
- Smaller DC halo.
- Dip positions of oscillating components appeared at the opposite sides from the center. (2M/4M)



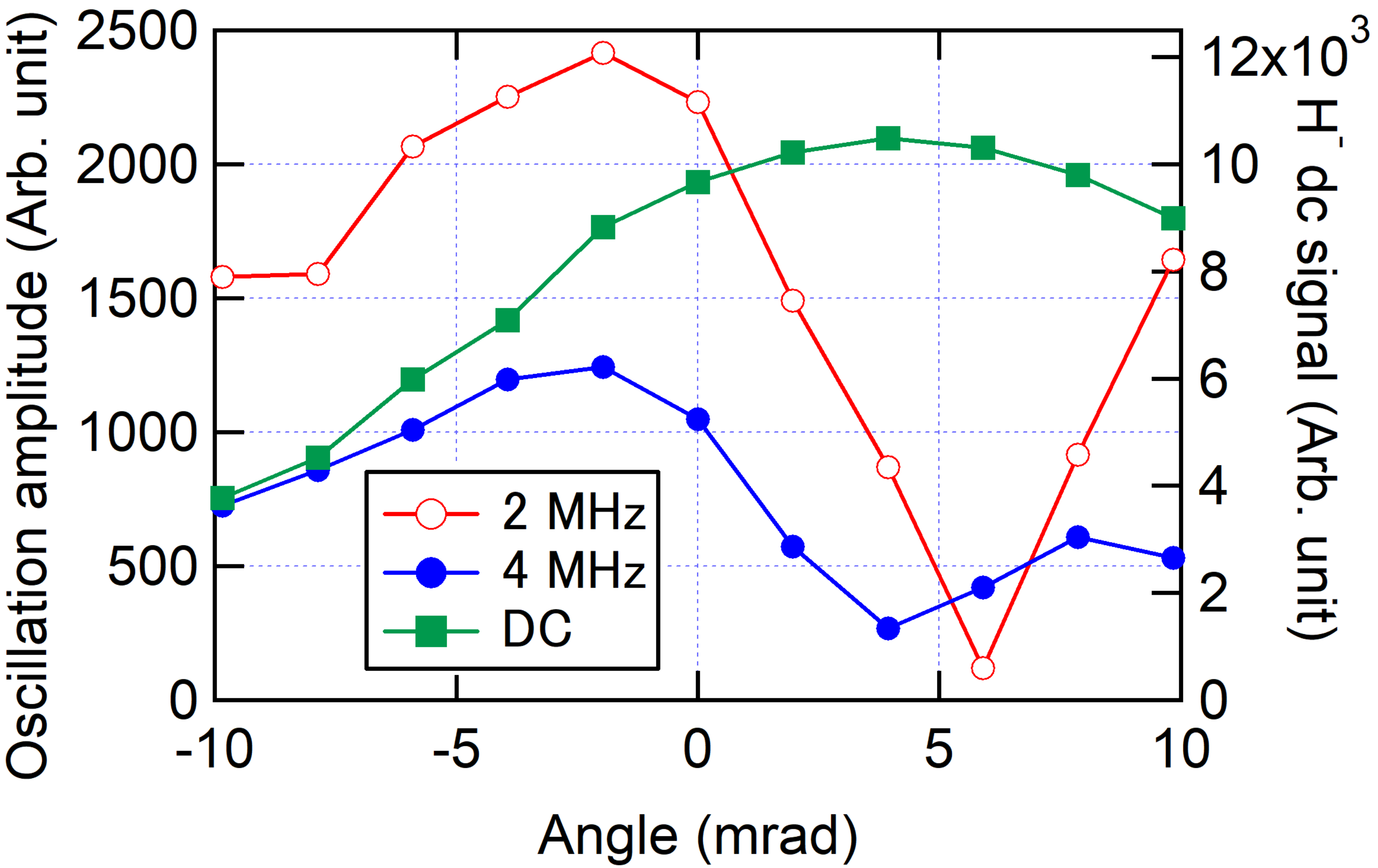
Vertical profile with less Cs

- Some what broader than the horizontal direction, but sharper than a Cs rich condition.
- Smaller halo for all components.
- Intensity of 2 MHz component matches the DC beam intensity.



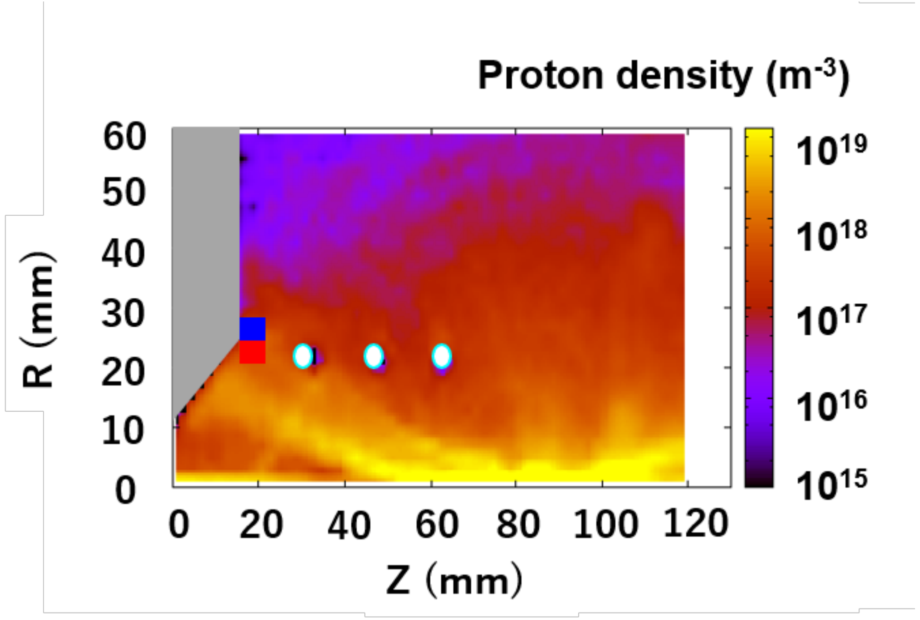
Angular distribution horizontal

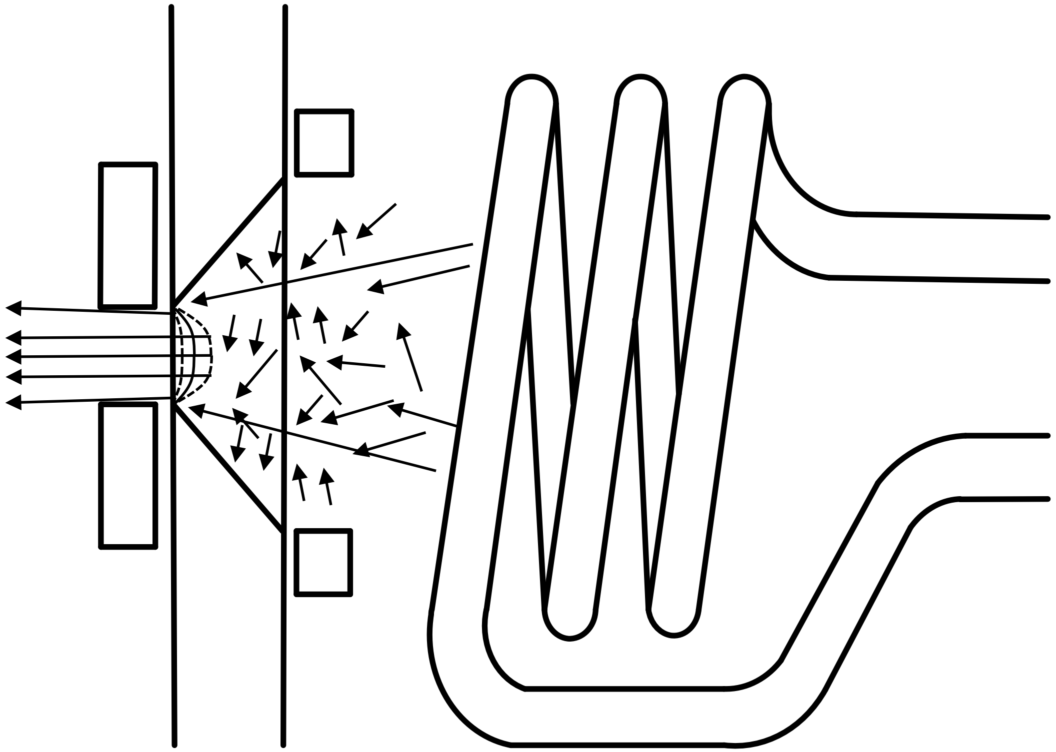
- ➢When plotted as the function of angle, dipps of oscillating component intensities appear more pronounced.
- ➢The beam angular distribution exhibits asymmetry in the horizontal direction.



Discussion

- Oscillating beam components exhibited the intensity maxima at the periphery of the DC beam axis.
- The beam extracted from the ion source center crosses the sheath perpendicularly with a little modulation by the transverse electrid field.
- Near the edge, the beam traverses the extraction sheath with the electri field having the radial component; the oscillating field primary frequency is 2 MHz. Non-linear effect at the sheath can cause 4 MHz.
- Surface H^- ion production at the PE edge can be modulated by the particle production by $\left|\frac{\partial B}{\partial t}\right|$, which takes the intensity maximum twice in a cycle of RF: 4 MHz.
- Cs can modify beam optics in two ways: extraction sheath structure and surface H^- production from the extractor hole periphery.





Summary and outlook

- High speed H^- ion beam diagnostic system showed the beam oscillation at the plasma production RF frequency and at the second harmonics.
- Oscillation amplitudes of both frequencies are smaller at the beam position/angle where dc beam intensity is larger.
- From the observation, plasma oscillation may excite electric field in the direction perpendicular to the beam axis.
- Production of H^- ions near the plasma electrode can excite 4 MHz component as the consequence of non-linear oscillation of the plasma sheath at the primary 2 MHz frequency.
- Cs injection tends to increase 4 MHz second harmonics component at the beam edge. Direct extraction of surface H^- ions is speculated.
- It also reduced the shift of beam axis from the geometrical center. Possible sign of mitigating the electron space charge.