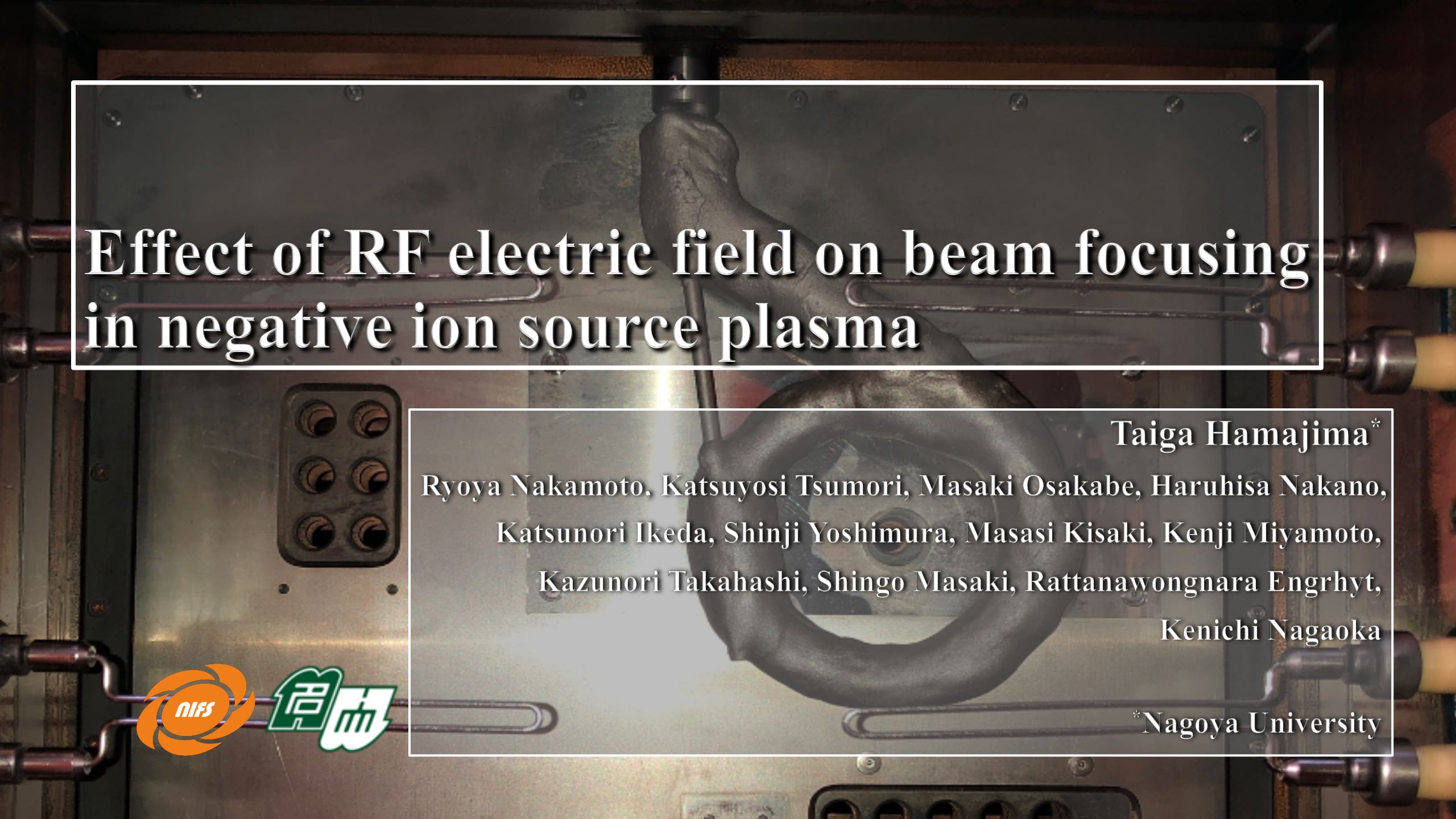

Effect of RF electric field on beam focusing in negative ion source plasma

Taiga Hamajima*

Ryoya Nakamoto, Katsuyosi Tsumori, Masaki Osakabe, Haruhisa Nakano, Katsunori Ikeda, Shinji Yoshimura, Masasi Kisaki, Kenji Miyamoto, Kazunori Takahashi, Shingo Masaki, Rattanawongnara Engrhyt, Kenichi Nagaoka

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Contents and Conclusion of This Talk

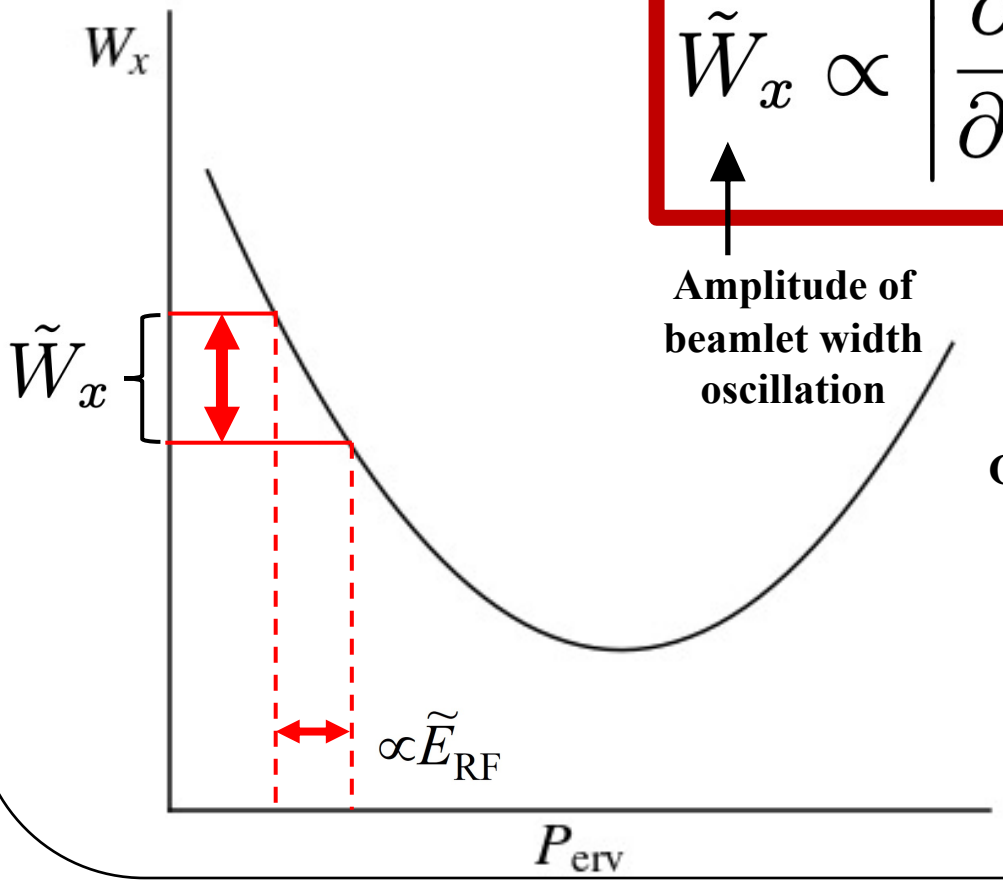
Conclusion

$$\tilde{W}_x \propto \left| \frac{\partial W_x}{\partial P_{\mathrm{erv}}} \right| \cdot \tilde{E}_{\mathrm{RF}}$$

Amplitude of beamlet width oscillation

Gradient of perveance curve

Amplitude of RF electric field

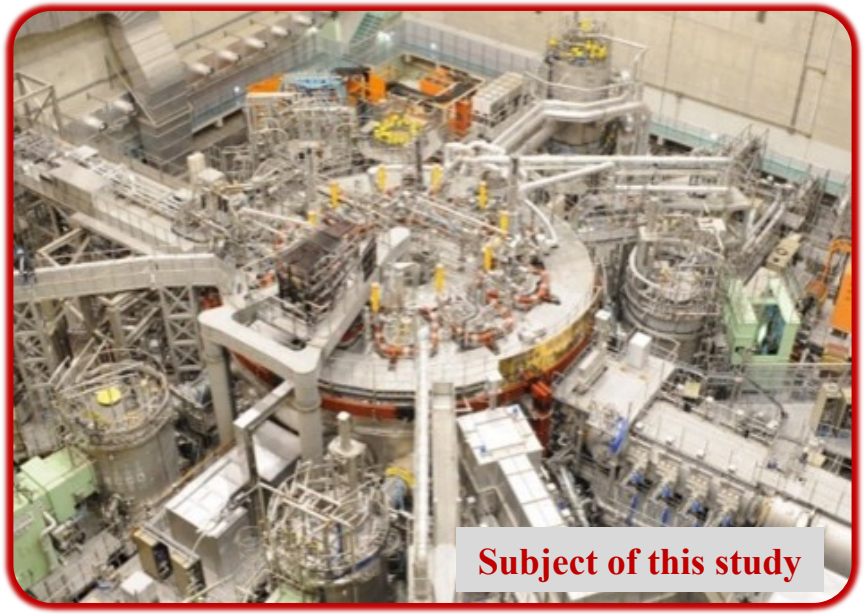


- Introduction
- Experimental Setup
- Results
- Summery

Applications

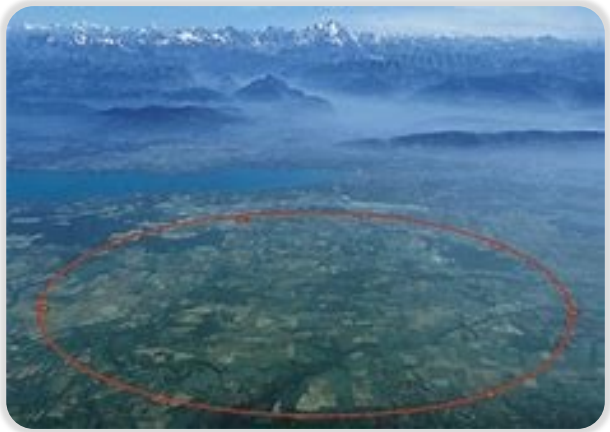
Negative ion beams are a fundamental technology in modern society.

Fusion research



Large Helical Device (NIFS)

High energy particle accelerator



Large Hadron Collider (CERN)

Medical care

BNCT (TAE Life Sciences)

Beam focusing is a common issue for all applications.

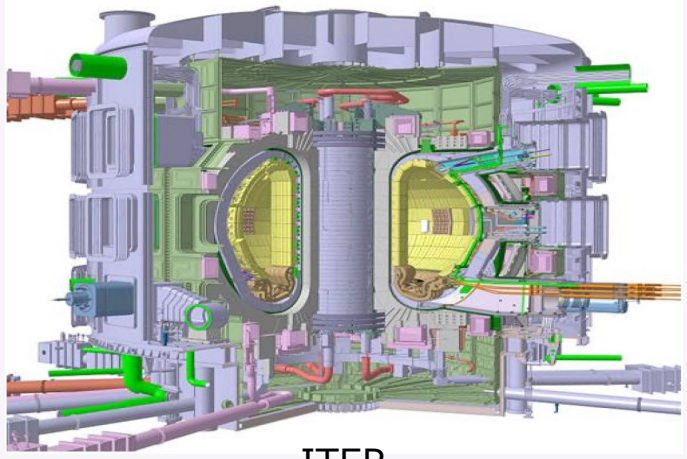
Current Status and Issues of Negative Ion Beam Focusing in Fusion Research

Item	Dimension	NIFS	ELISE/ BATMAN	ITER requirement
Type		FA	RF	RF
Kind of beam		H^-	H^-	H^-
Current Density	[A/m^2]	340	304	230
Divergence angle	[mrad]	4.1(h), 6.1(v)	**~15** (0.3Pa)	3-7
Pulse Length	[s]	100	1000	1000

Large divergence angle makes it difficult to inject the beam.
port-through-power is decreased and in-beamline equipments may be damaged.

ITER project

Because of necessity of maintenance free and long pulse operation,
ITER is applied RF-type NBI.



ITER

[2]M. Kikuchi 2012 Fusion Physics (Vienna: IAEA)

What causes the difference in beam focusing between FA and RF type negative ion sources?

Importance of Meniscus in Beam Focusing

The meniscus is an equipotential interface between the plasma region and the beam region.

Meniscus is formed by balances between penetration E field and Debye shield.

⇩

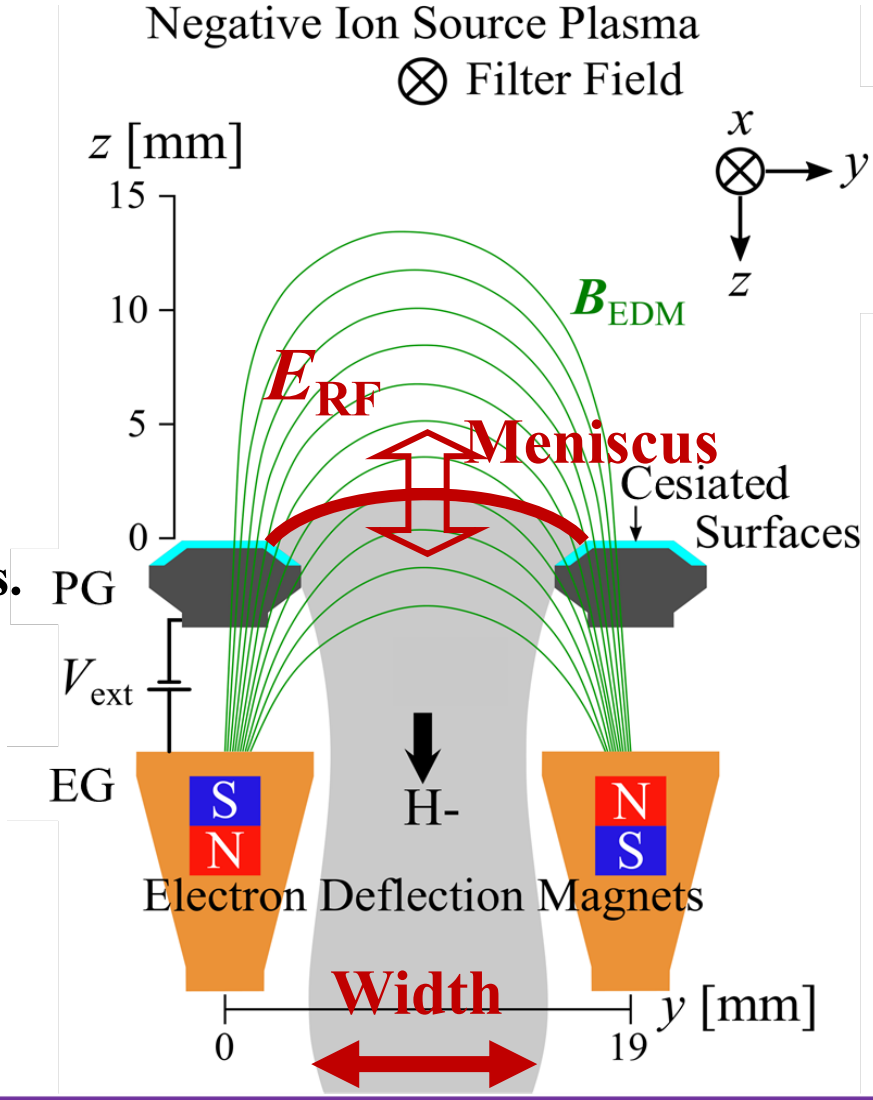
Meniscus shape works as an electrostatic lens for the beam focusing.

⇩

RF electric field may change beam focusing through meniscus responses.

Purpose of this study is

Investigation of the RF electric field effect on beam focusing.



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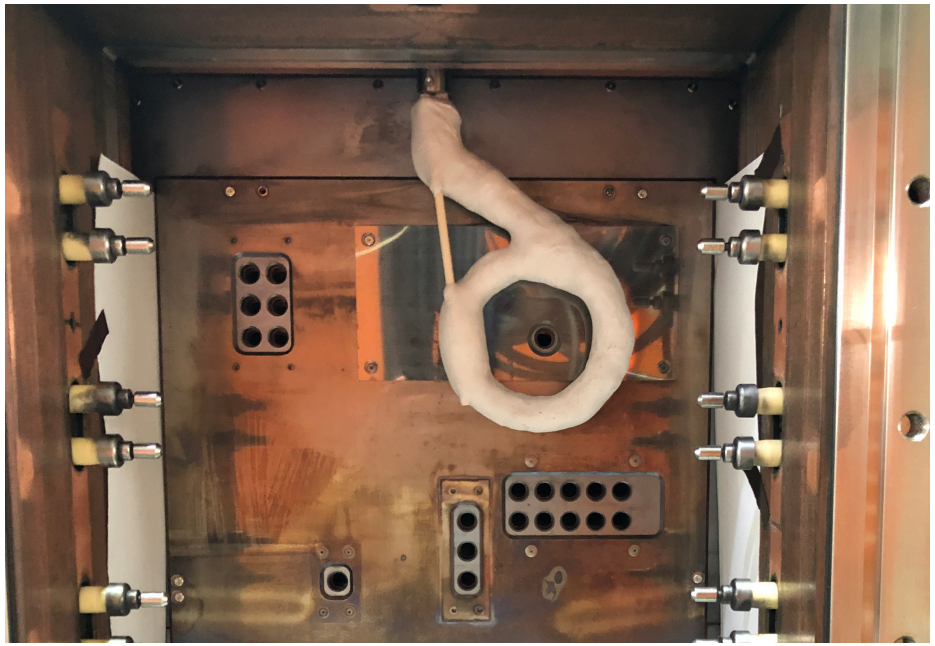
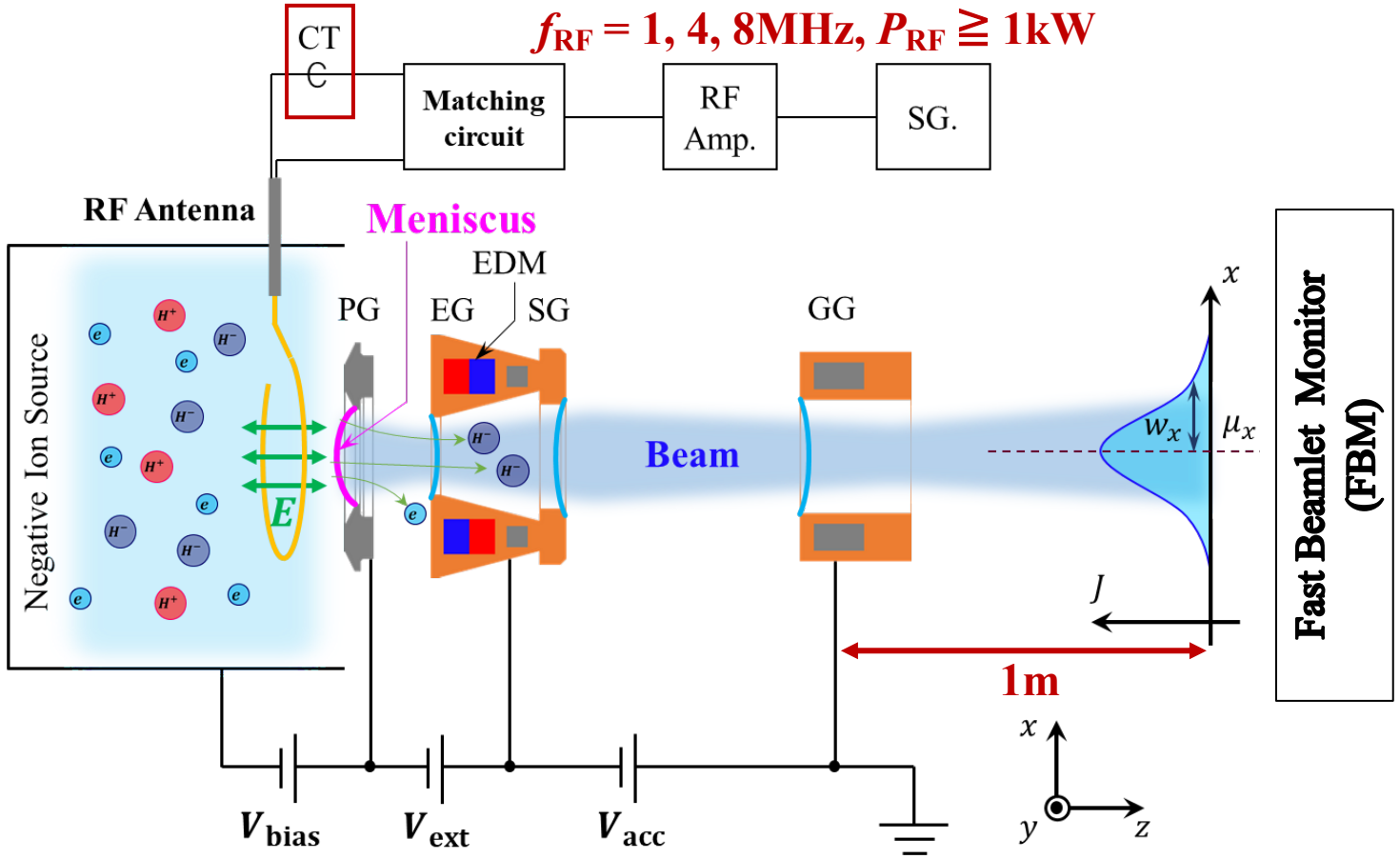
Overview of the Experimental Concept

RF Antenna

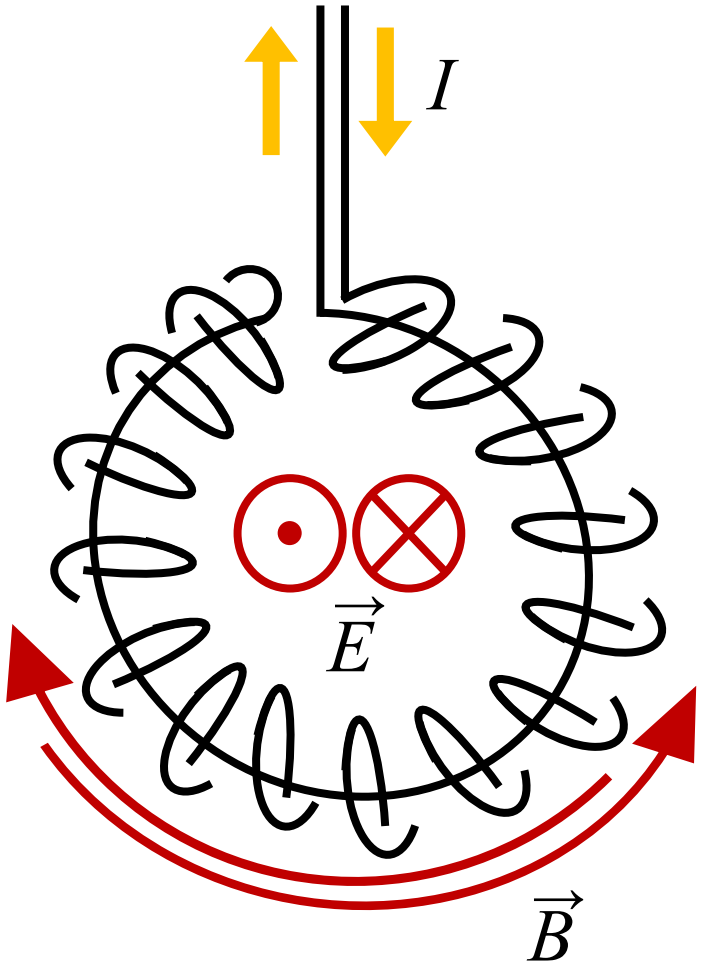


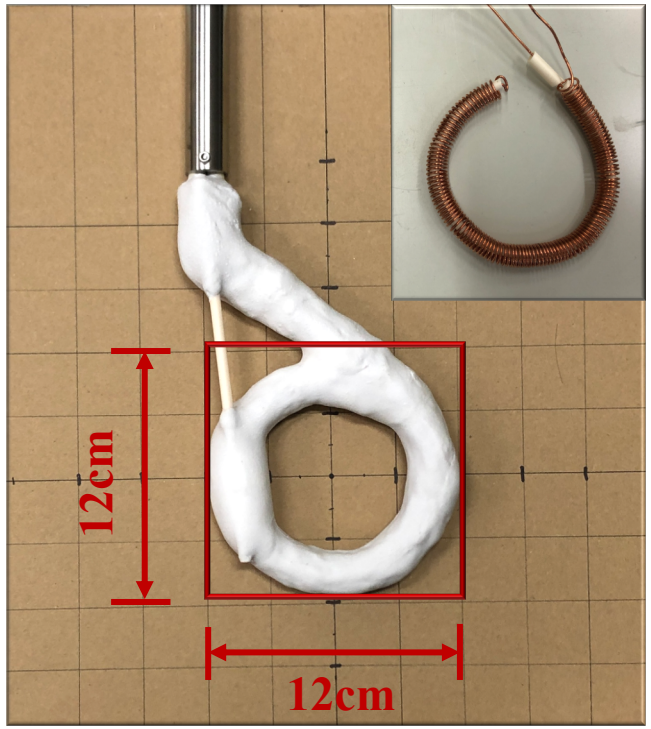


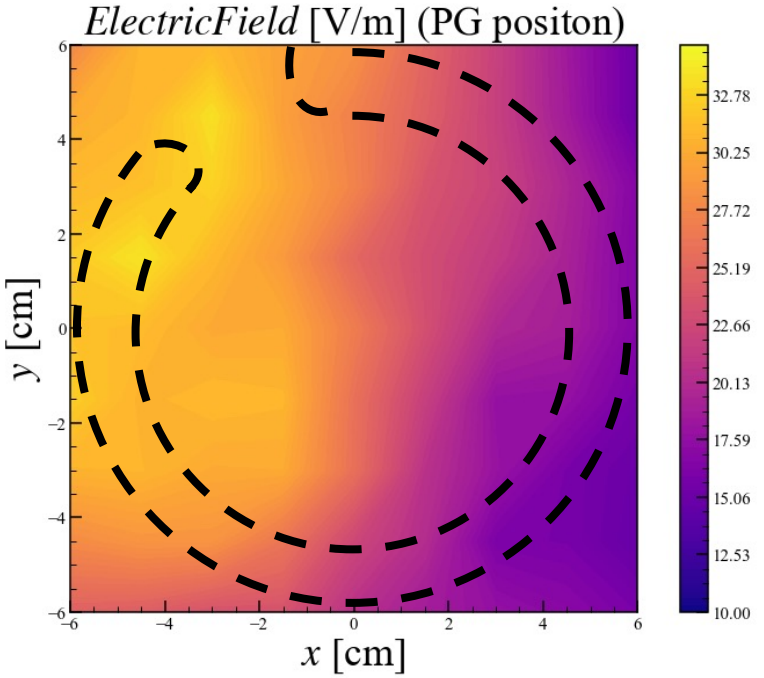
An RF electric field is applied to the plasma in front of the meniscus,
and the responses of the beamlet is experimentally investigated in this study.

RF Antenna

Rogosky-type RF antenna.



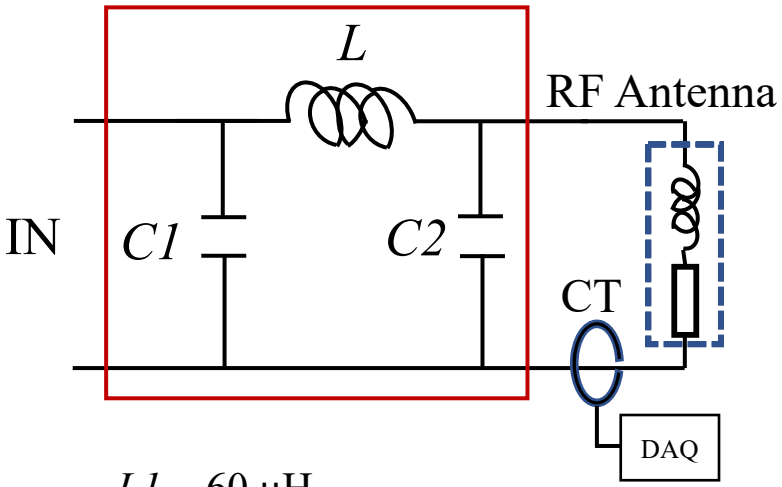




P_{RF} = 100 mW , Center position E_{RF} ~ 30 V/m

RF Matching Circuit

π-matching circuit

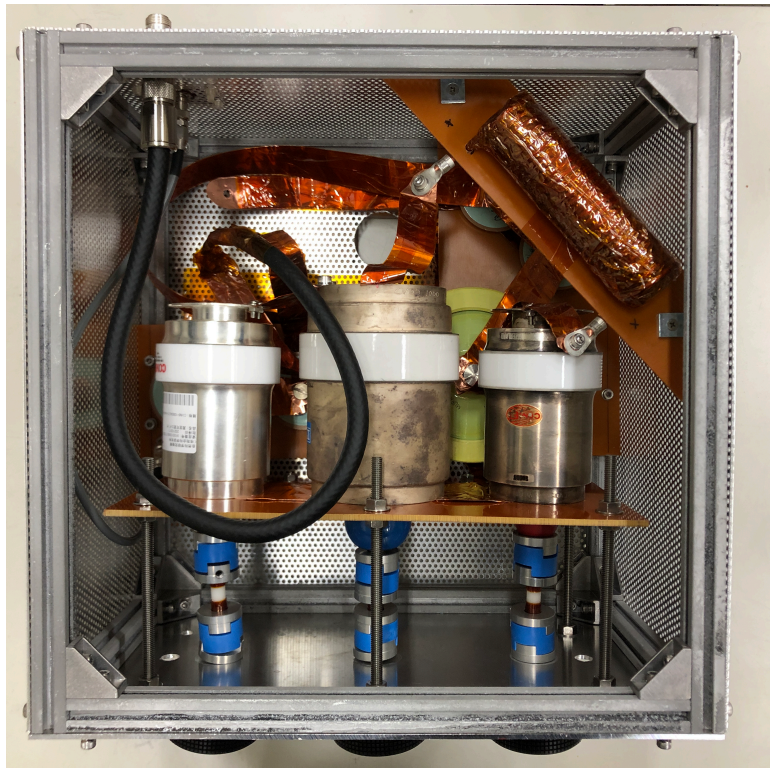


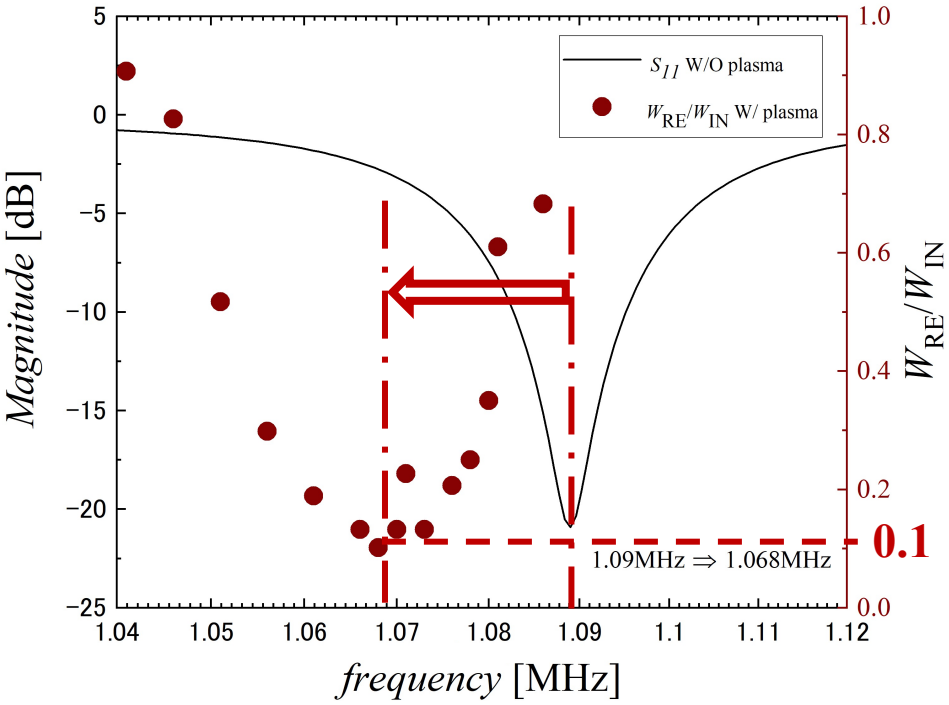
L1 ~ 60 μH

C1 = 2000-4000 pF

C2 = 3500-4500 pF

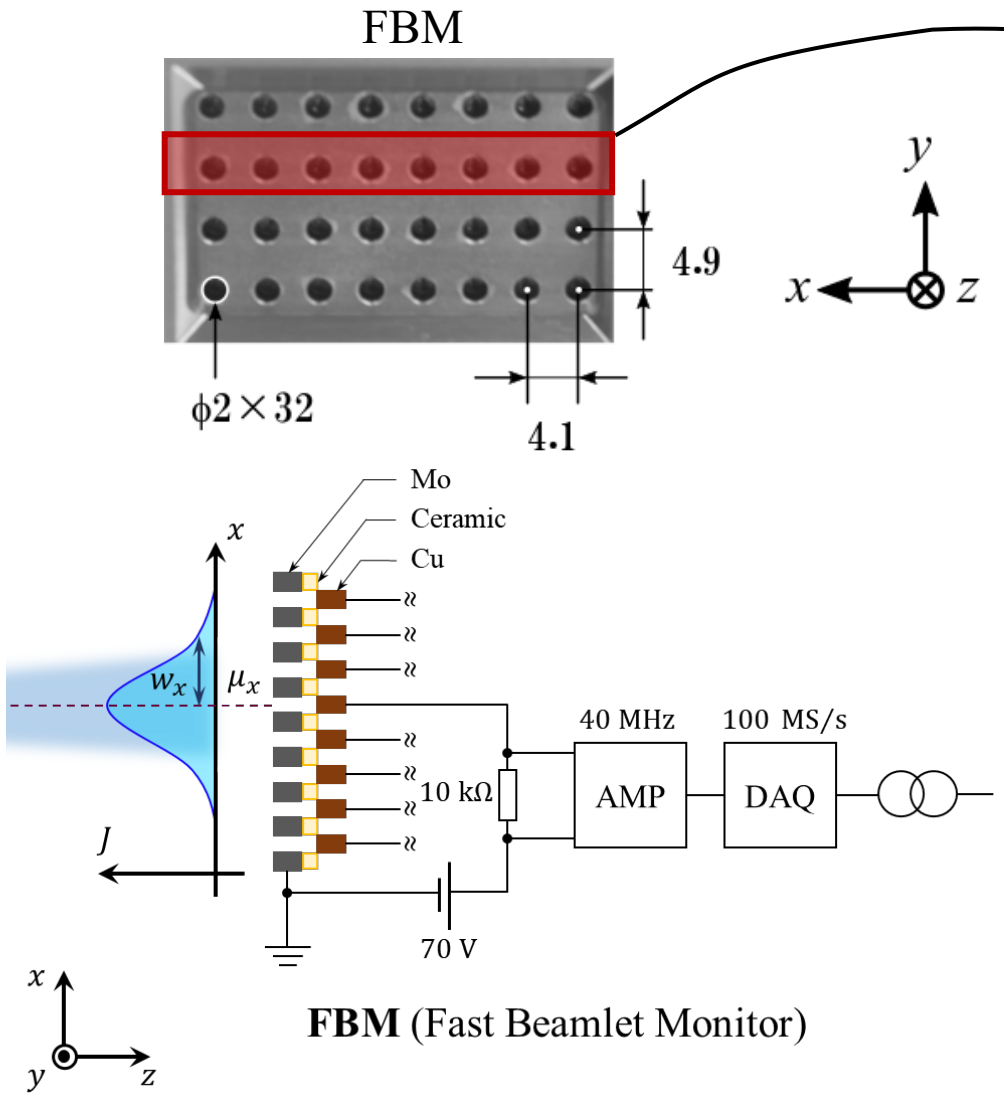
RF Antenna = 7.3 μH, 2.7Ω



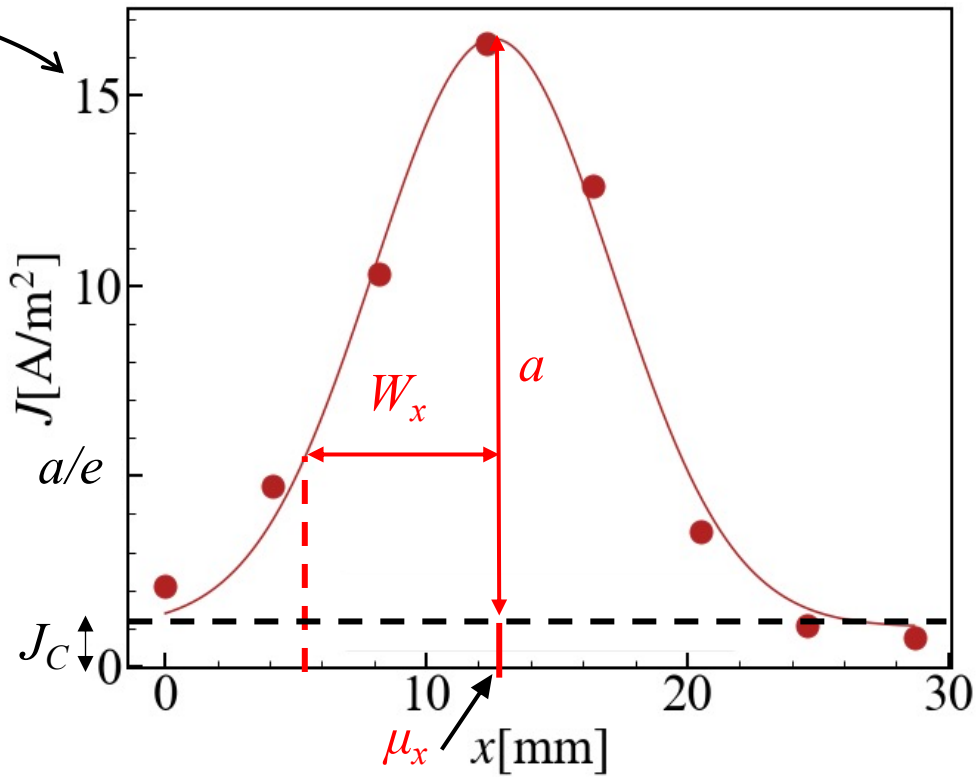


Although matching frequency is slightly(~0.02MHz) shifted between w/ and w/o the plasma.
Reflection rate is suppressed less than 20% in this experiment.

Fast Beamlet Monitor



FBM (Fast Beamlet Monitor)



$$J(x) = a \exp\left[-\left(\frac{x-\mu_x}{w_x}\right)^2\right] + J_C$$

Beam width is measured by Gaussian fitting

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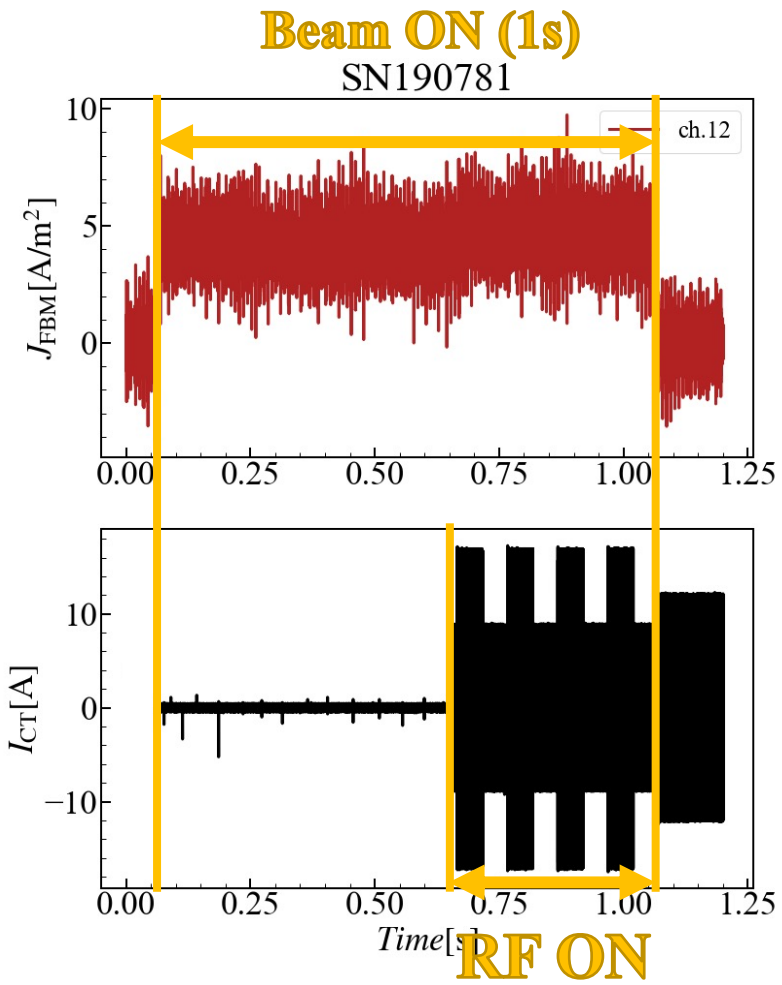
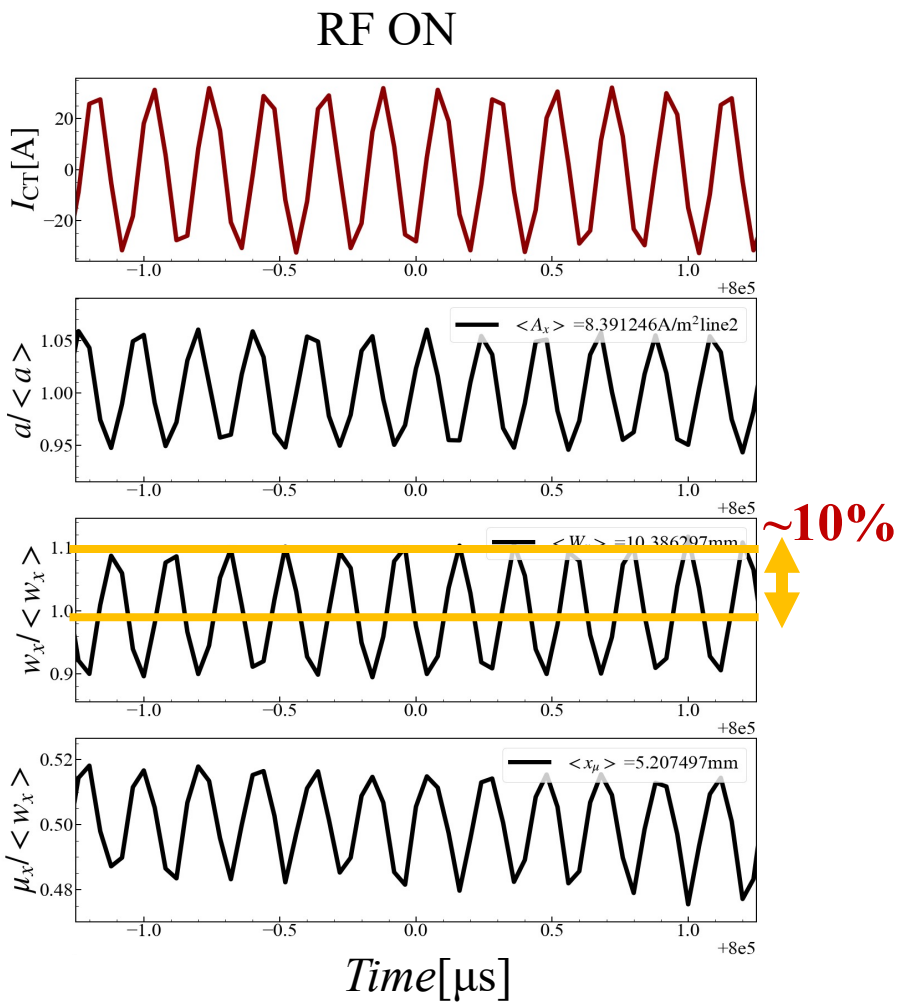
Beamlet Responses to RF Electric Field

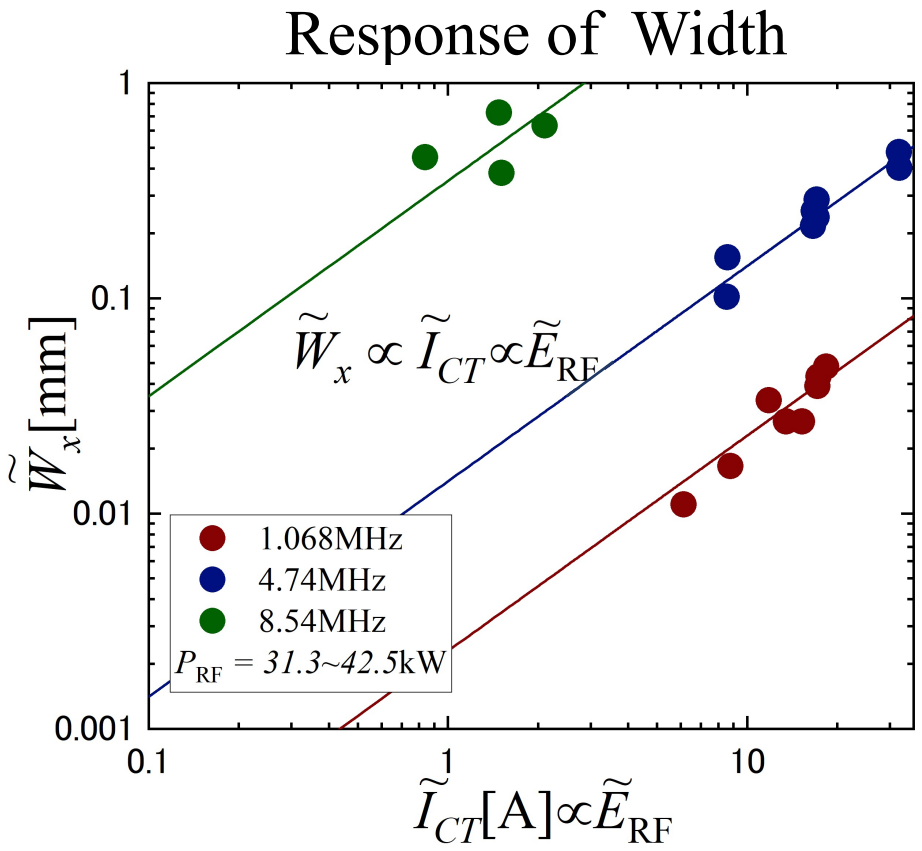


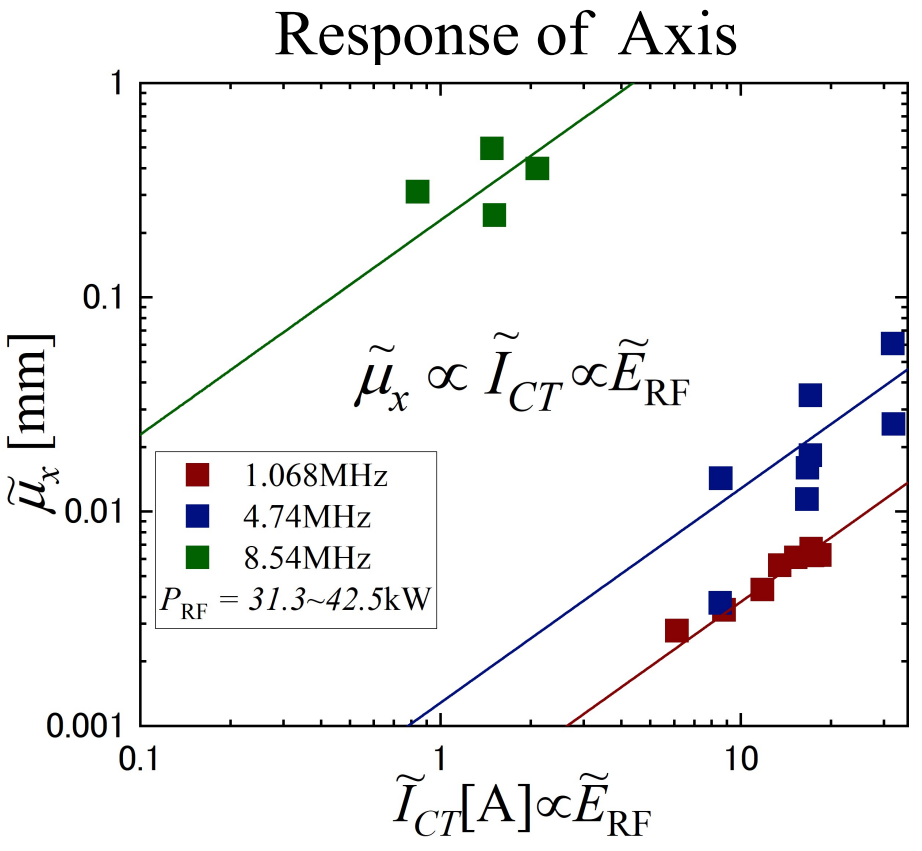


~10%

RF electric field may cause the degradation of the beamlet focusing.

RF Power Dependence

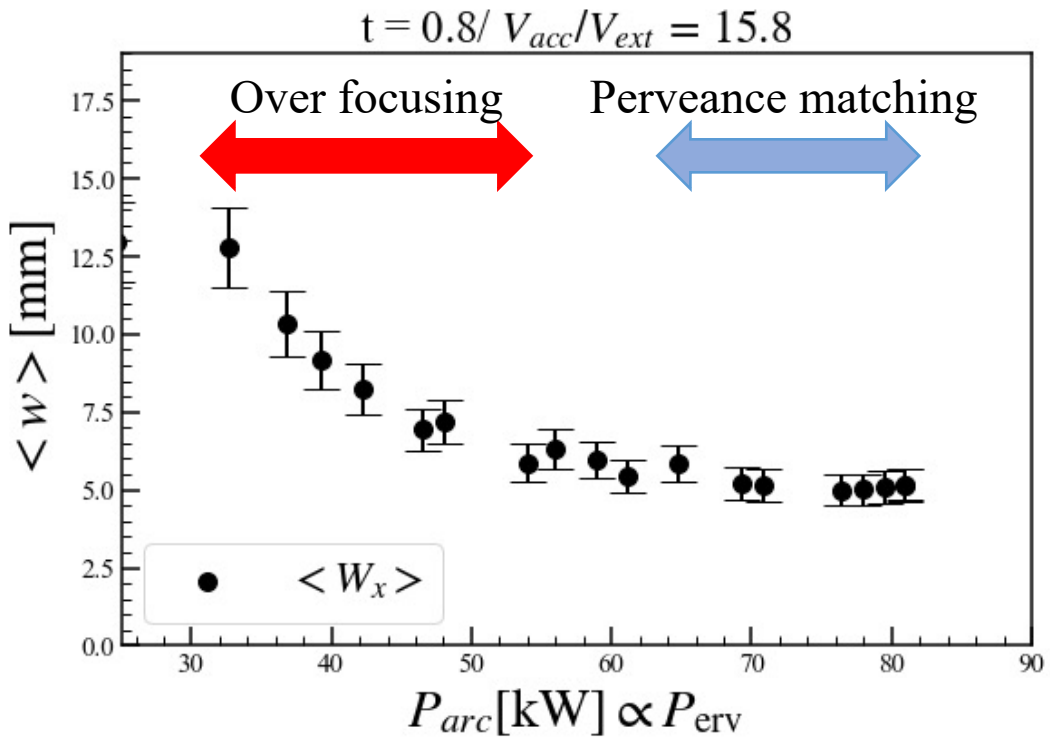




The responses of the beamlet width is proportional to RF electric field.
The similar response can be seen in the responses of beamlet axis position.
The higher frequency of the RF, the stronger response of the beamlet.

$$\tilde{W}_x \propto \tilde{E}_{\mathrm{RF}} \qquad \tilde{\mu}_x \propto \tilde{E}_{\mathrm{RF}}$$

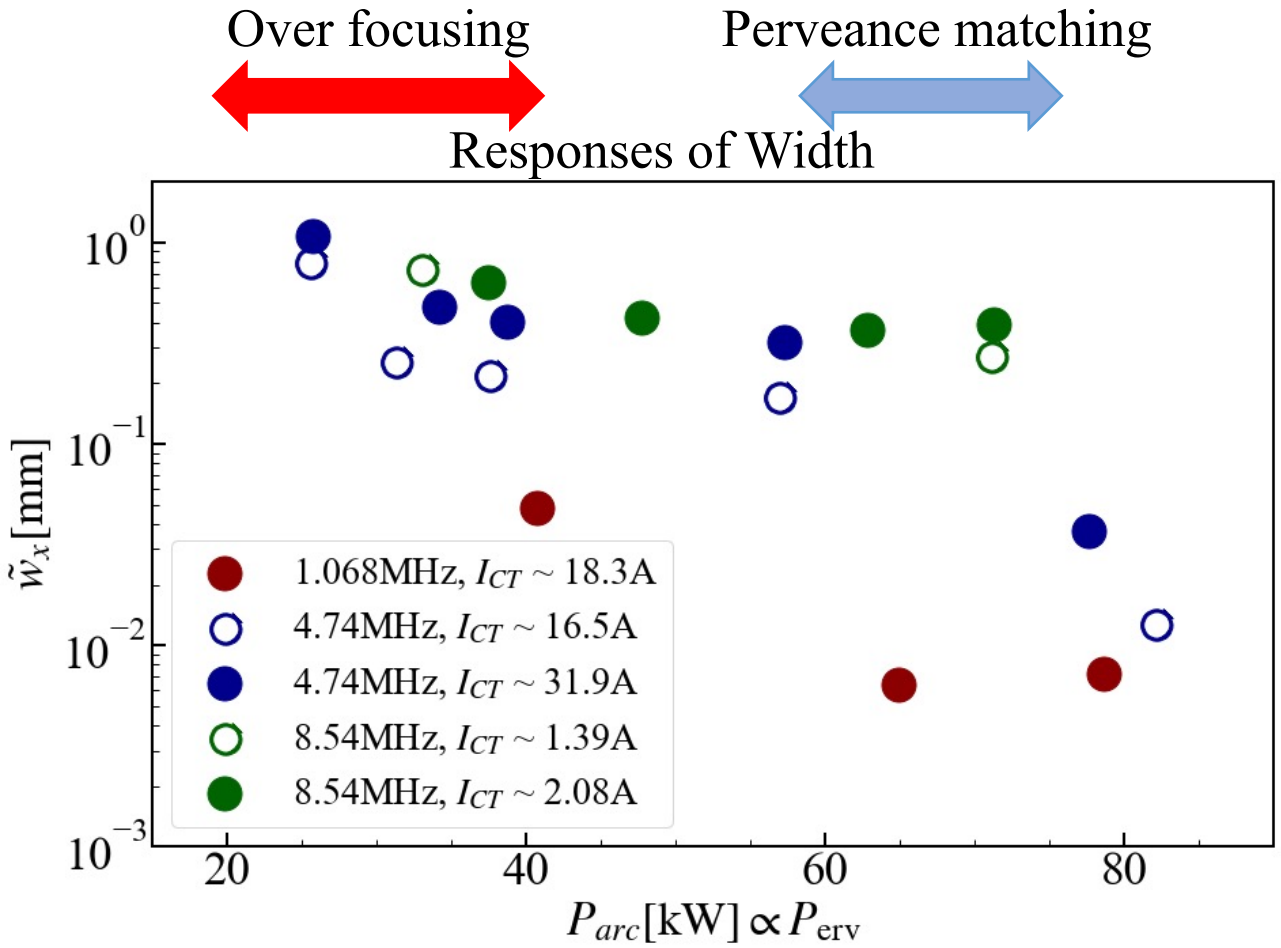
Characteristic of Beam Focusing



Meniscus ⇒ Perveance

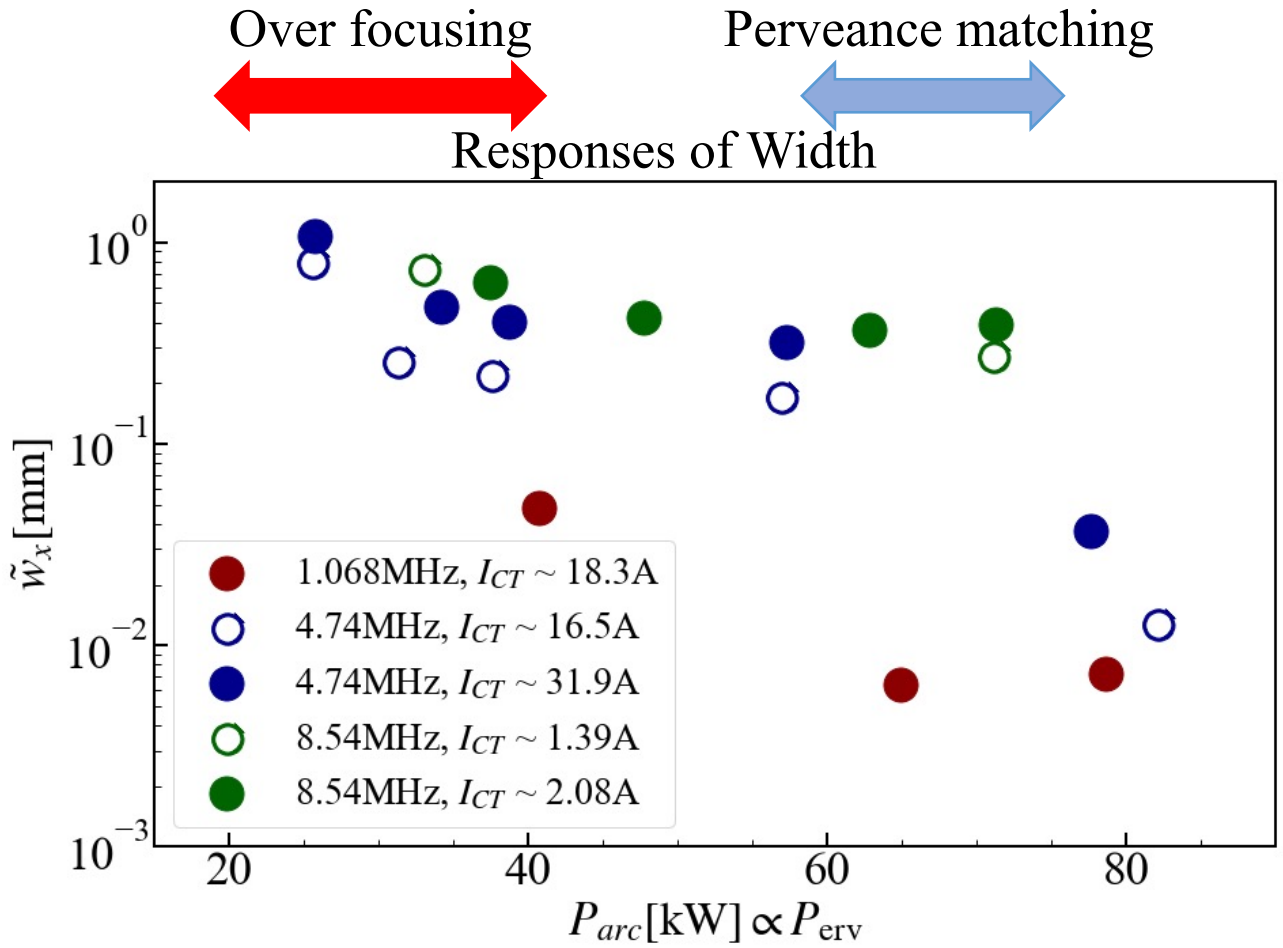
$$P_{\mathrm{erv}} = \frac{I_{\mathrm{beam}}}{{V_{\mathrm{ext}}}^{1.5}} \propto \frac{P_{\mathrm{arc}}}{{V_{\mathrm{ext}}}^{1.5}}$$

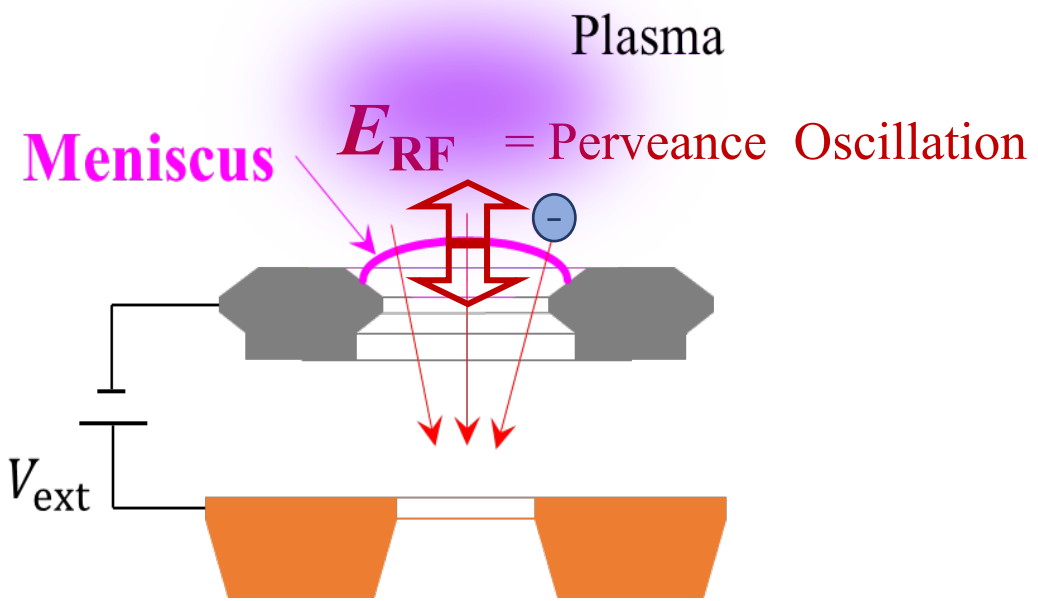
Arc power Dependence



In the region where beam is over focusing, the responses are large.
In the perveance matching region, the responses become weaker.

Arc power Dependence





In the region where beam is over focusing, the responses are large.
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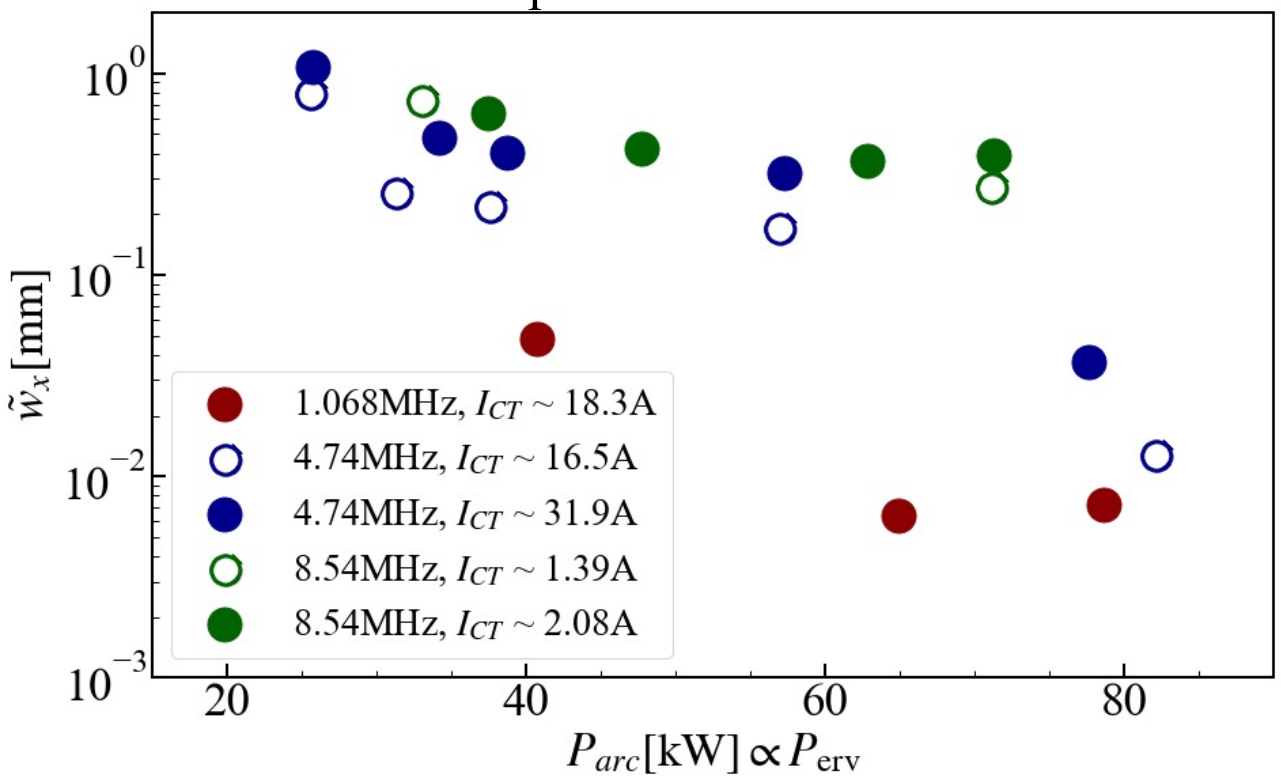
Arc power Dependence

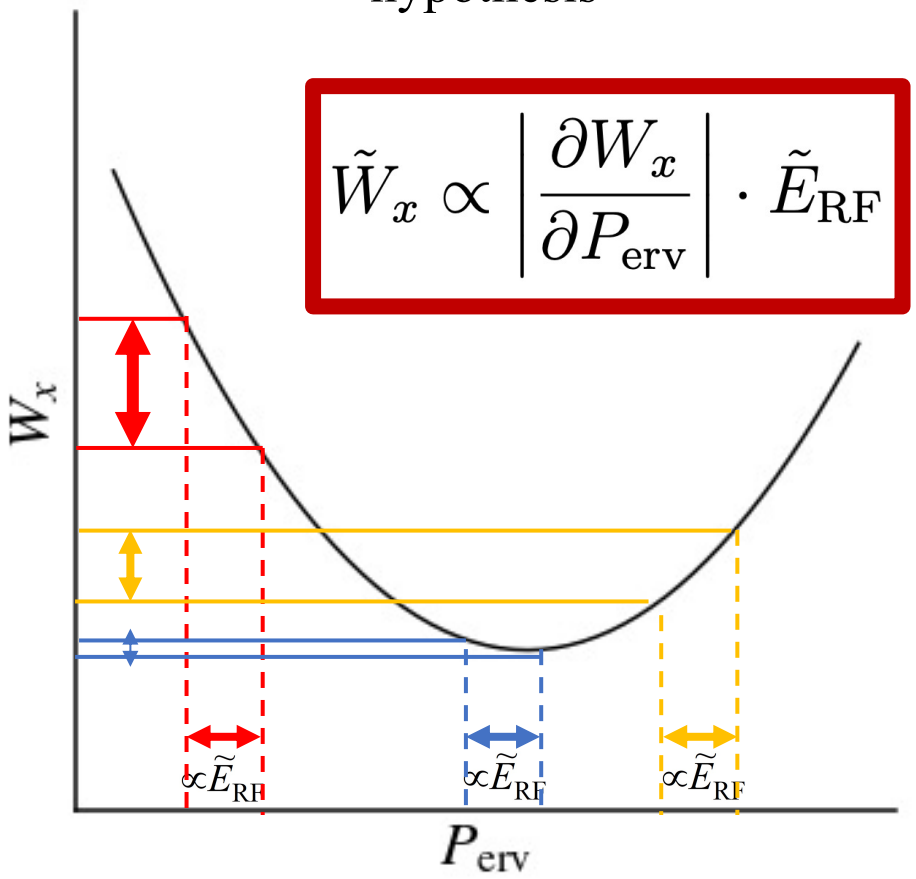
Over focusing

Perveance matching



hypothesis

$$\tilde{W}_x \propto \left|\frac{\partial W_x}{\partial P_{\mathrm{erv}}}\right| \cdot \tilde{E}_{\mathrm{RF}}$$



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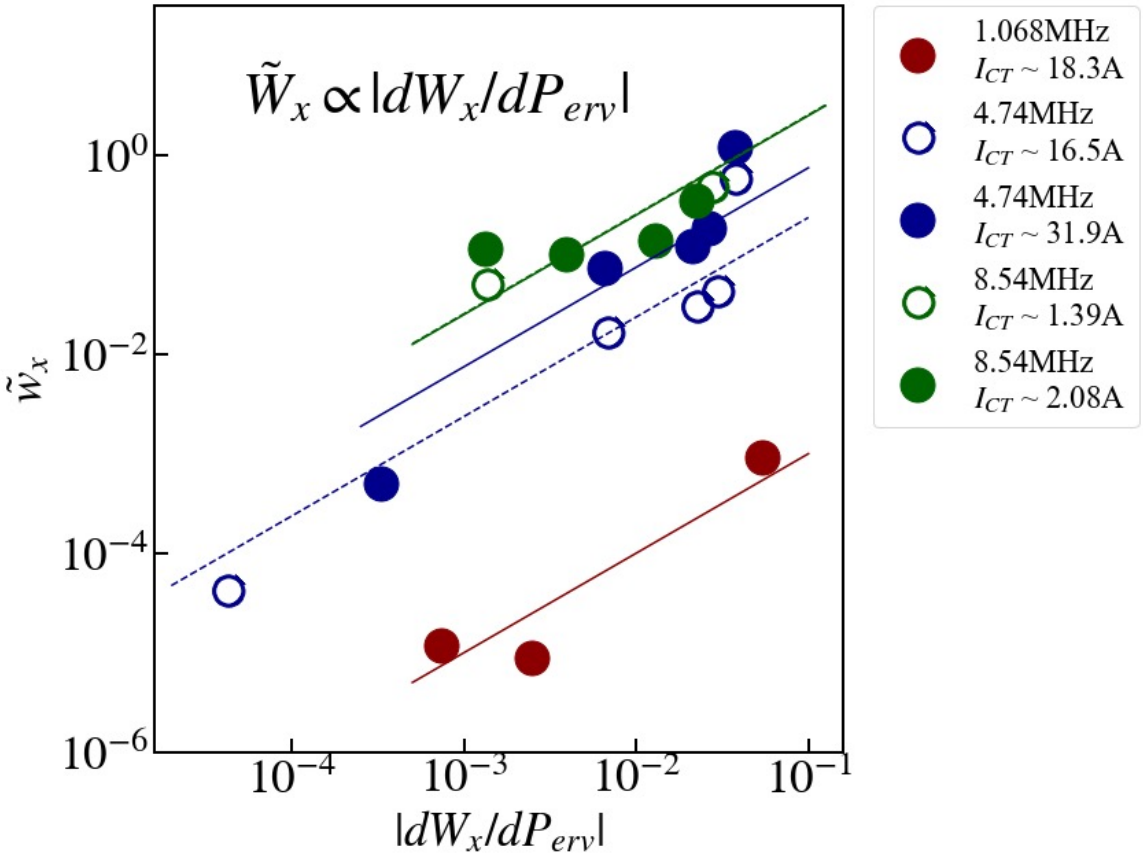
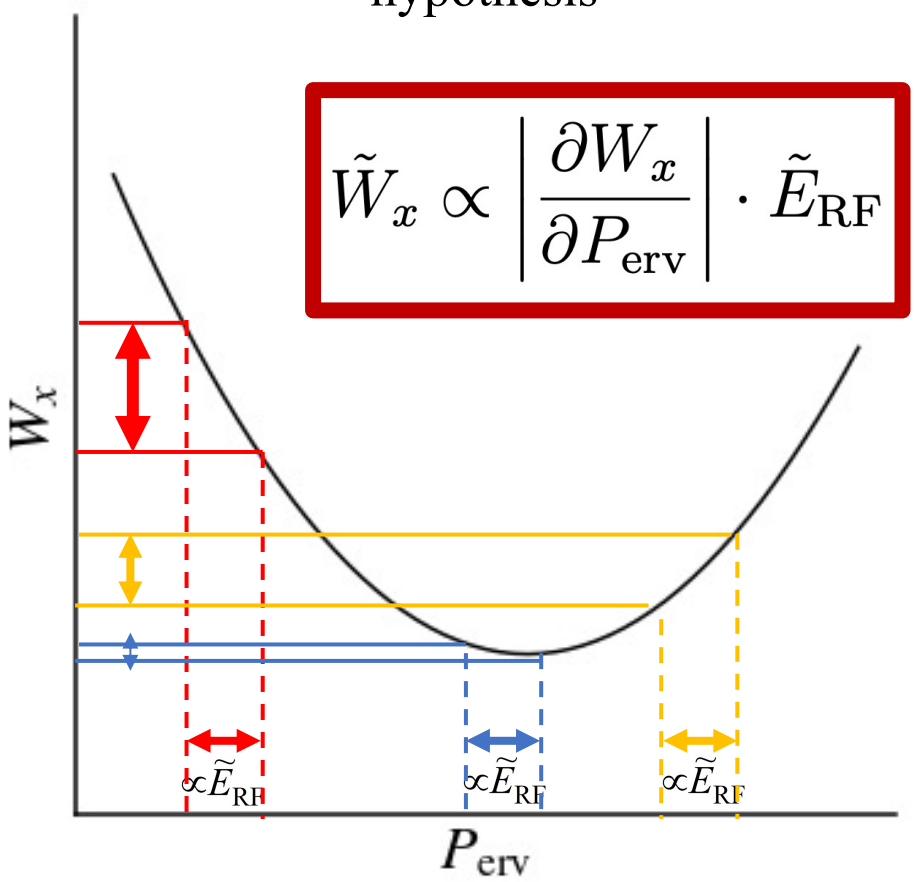
Arc power Dependence



hypothesis

$$\tilde{W}_x \propto \left| \frac{\partial W_x}{\partial P_{\mathrm{erv}}} \right| \cdot \tilde{E}_{\mathrm{RF}}$$



The linear relation can be seen. Our assumption is confirmed.
The effect of the RF electric field on the beam focusing can be suppressed by the optimization of the perveance matching.

Summary

Superpose RF electric field on the plasma in front of the meniscus and measure the responses of the beamlet.

- Beamlet width and beamlet axis position oscillate with RF frequency.
- Amplitude of beamlet width is proportional to RF electric field.
- Amplitude of beamlet width is proportional to the gradient of the perveance curve $\mathrm{d}W_x/\mathrm{d}P_{\mathrm{erv}}$.

$$\tilde{W}_x \propto \left(\frac{\partial W_x}{\partial P_{\mathrm{erv}}}\right) \cdot \tilde{E}_{\mathrm{RF}}$$

⇨ the RF electric field causes the degradation of beamlet focusing through meniscus oscillation.

⇨ the RF effect on beam focusing can be suppressed by perveance optimization

In future study, what causes frequency dependence?

Thank you for your attention!

Acknowledgement:
We would like to thank all staff of NBI group.
This research was supported by JSPS KAKENHI (18KK0080, 17H03002, 19K03783) and NIFS (NIFS20KLER103, NIFS20ULRR031).