Study of negative ion beam optics in real and phase spaces

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Introduction

- The pulse duration of high-current and high-energy negative ion beam for NBI is often limited by the grid heat load.
- Generating the beam with low divergence angle is a straightforward way to reduce the heat load, and the shape of the boundary between ion source plasma and extracted beam, so-called meniscus, plays an important role to the beam divergence.
- The mechanism of meniscus formation in negative ion sources has not been established yet, since many physics processes such as coexistence of electron and negative ion, surface production of negative ion, and magnetic field with complicated topology, play a part in the meniscus formation.
- **To get a better understanding of the meniscus formation in negative ion sources, we identified the dominant plasma parameter for meniscus shape, and established the method to deduce the spatial distribution of negative ions in the vicinity of the meniscus.**

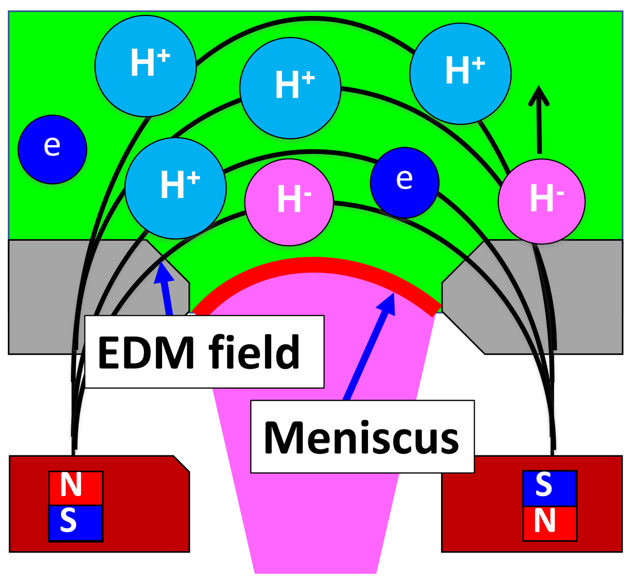


Fig. 1. Schematic illustration of negative ion extraction.

Experimental setup

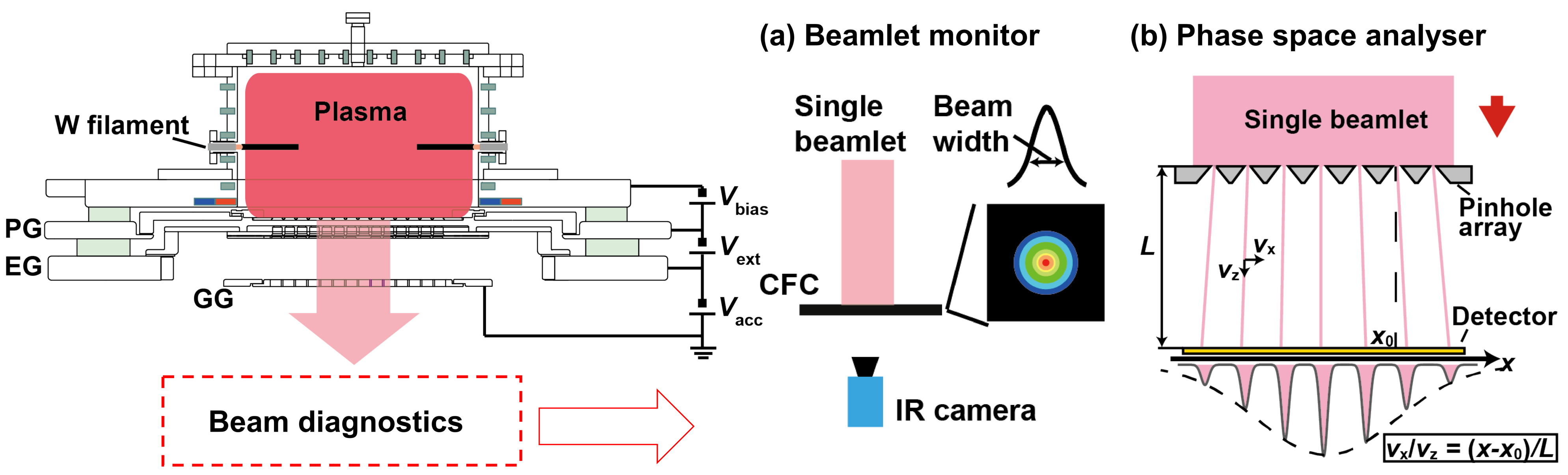


Fig. 2. Schematic illustration of NIFS R&D negative ion source (NIFS-RNIS).

- Plasma parameters in the vicinity of the PG were measured by means of Langmuir probe and cavity-ring-down method.
- The single beamlet, which was extracted from the masked PG, was measured by a beamlet monitor system consisting of CFC tile and IR camera and a pepper-pot type phase space analyser.

Dominant plasma parameter for meniscus shape

The source plasma and the negative ion beam were simultaneously measured in order to clarify the key plasma parameter for the beam optics.

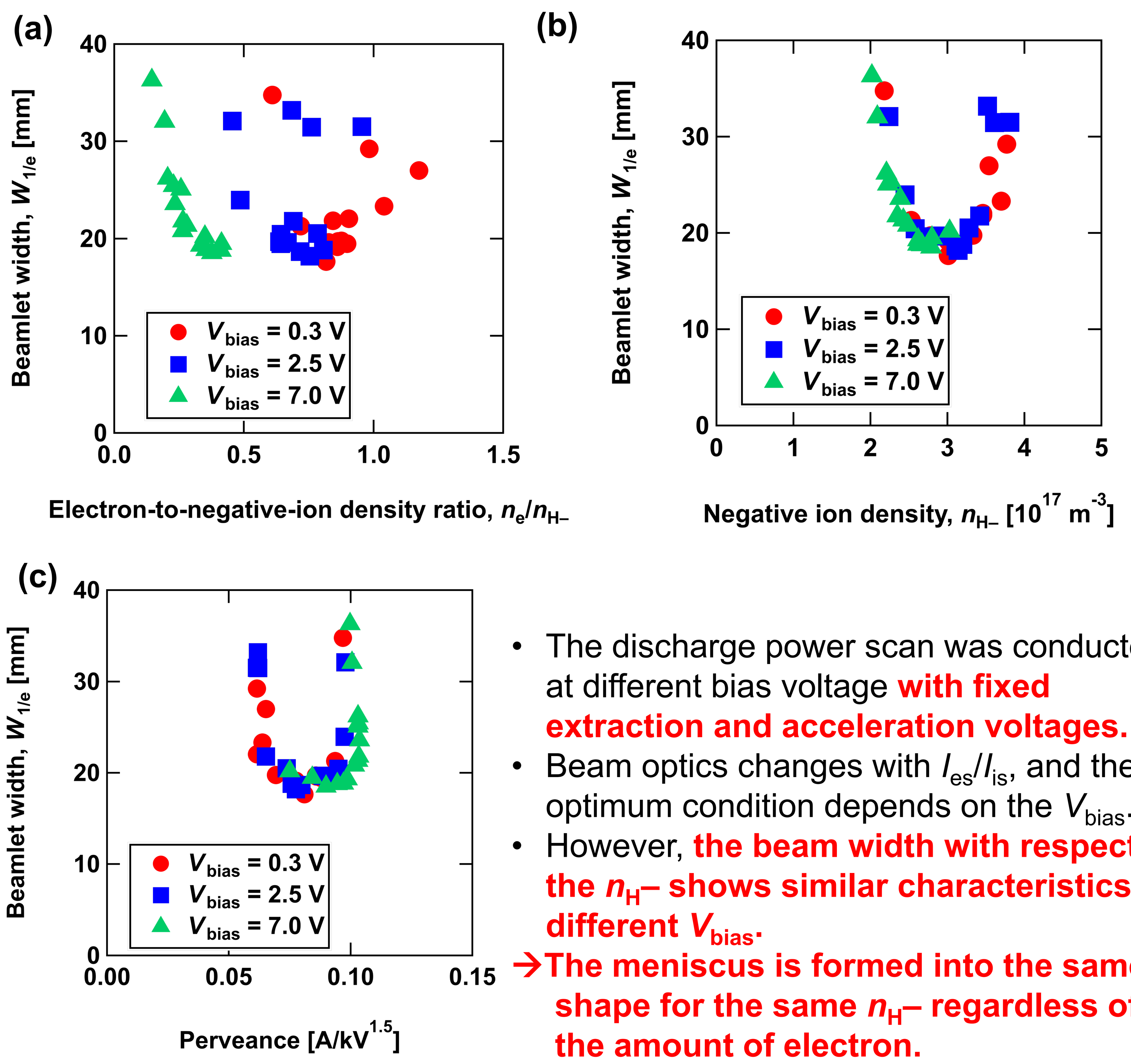


Fig. 3. Dependence of beam optics on (a) ratio of negative and positive saturation currents, (b) negative ion density, and (c) perveance.

- The discharge power scan was conducted at different bias voltage **with fixed extraction and acceleration voltages.**
- Beam optics changes with I_{es}/I_{is}, and the optimum condition depends on the V_{bias}.
- However, **the beam width with respect to the n_{H-} shows similar characteristics for different V_{bias}.**

→The meniscus is formed into the same shape for the same n_{H-} regardless of the amount of electron.

- **The perveance dependence similar to the positive ion extraction was also observed for the negative ion extraction.**

Spatial distribution of negative ions in the vicinity of meniscus

a. Backward trajectory calculation

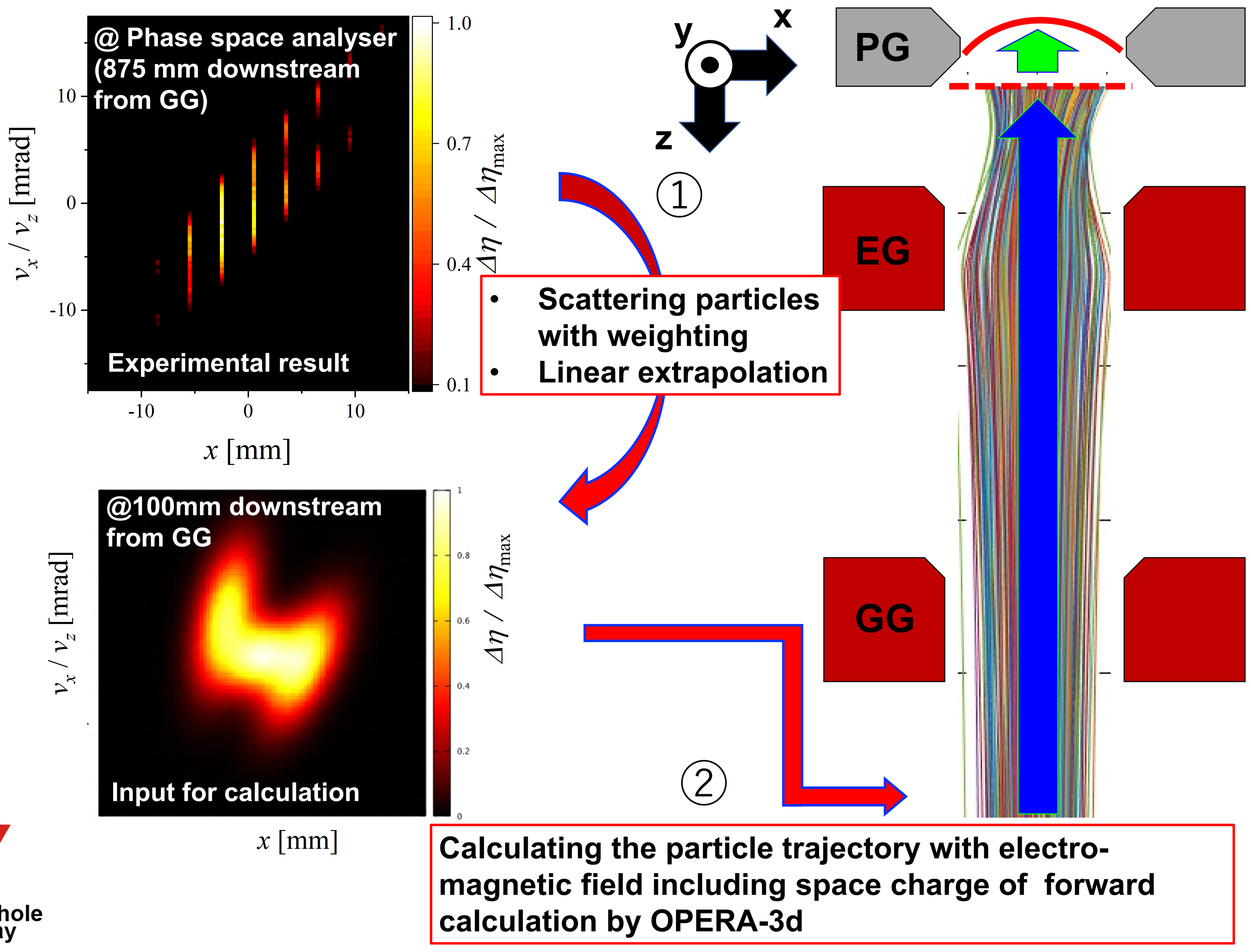
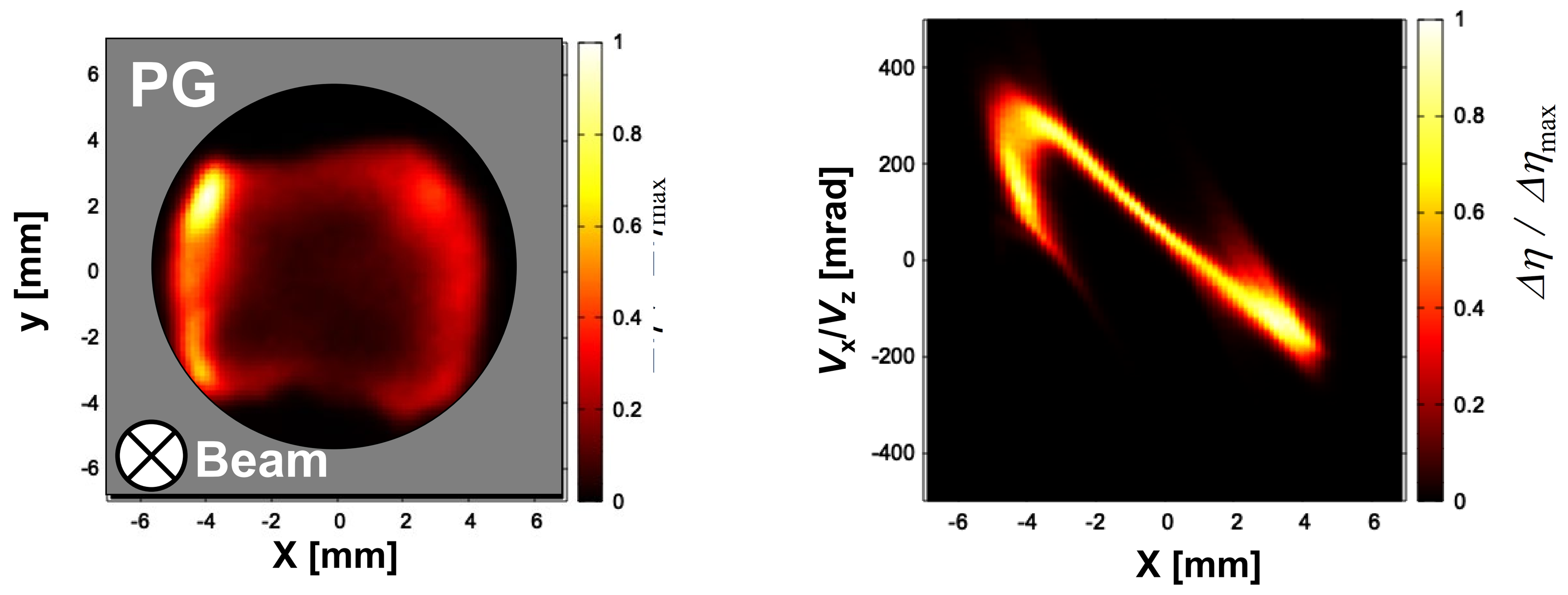


Fig. 4. Procedure of backward trajectory calculation.

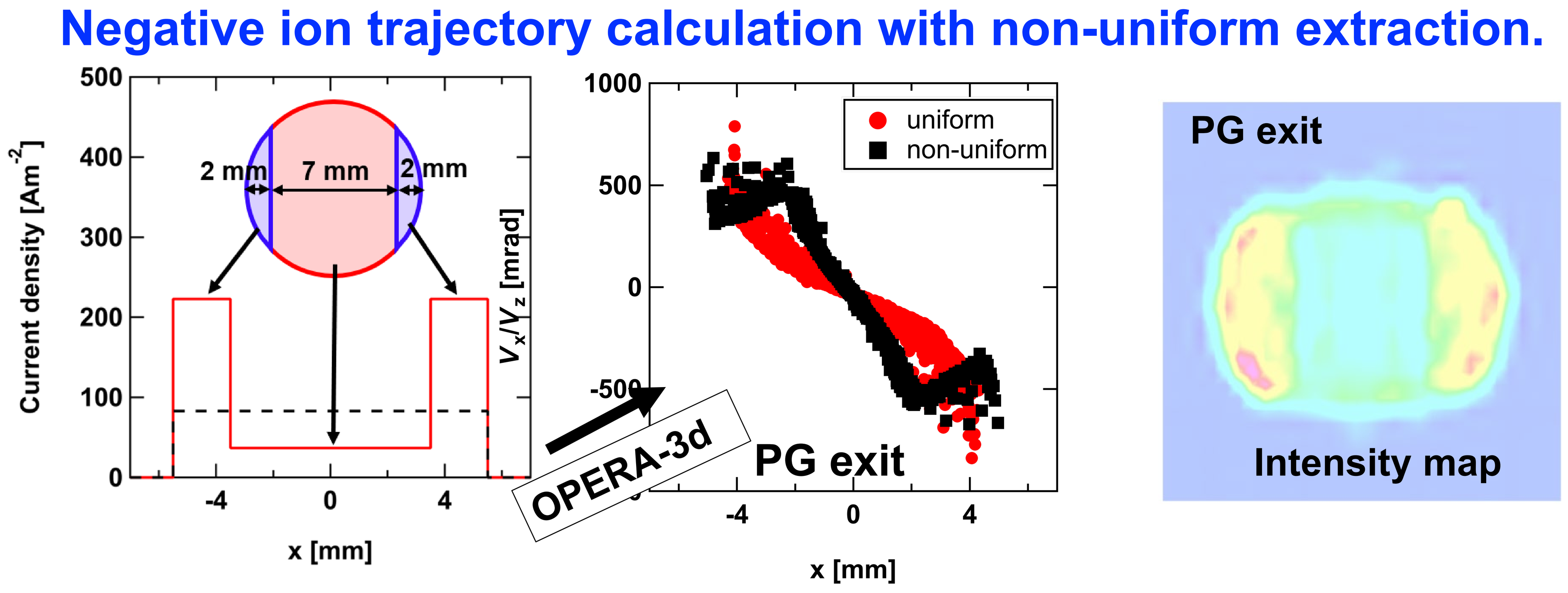
b. Calculation results



The negative ion density in horizontal periphery of aperture is higher than that in the central region. The beam aberration was observed in the horizontal periphery.

→ Conical shape created upstream of the PG aperture plays an important role on the meniscus formation as well as extraction efficiency of the H⁻

Negative ion trajectory calculation with non-uniform extraction.



- Clear similarities to the results obtained through backward calculation were observed both in the phase space structure and the intensity map.

→ Consistency of the backward calculation was validated.

Summary and future works

The meniscus formation in negative ion sources was studied experimentally and numerically.

- **The dominant plasma parameter for determining the meniscus shape was identified.**
- **The spatial distribution of negative ions at the meniscus was elucidated for the first time.**
- **The conical shape created upstream of the PG will be redesigned.**
- **Effect of the magnetic field on the negative ion transport is remained issue → will be investigated experimentally.**

References

1. M. Kisaki, H. Nakano, K. Tsumori, et al., Rev. Sci. Instrum. **91**, 023503 (2020).
2. Y. Haba, K. Nagaoka, K. Tsumori et al., New J. Phys. **22**, 023017 (2020).