Development of the directional Langmuir probe for the charged particle flow measurement

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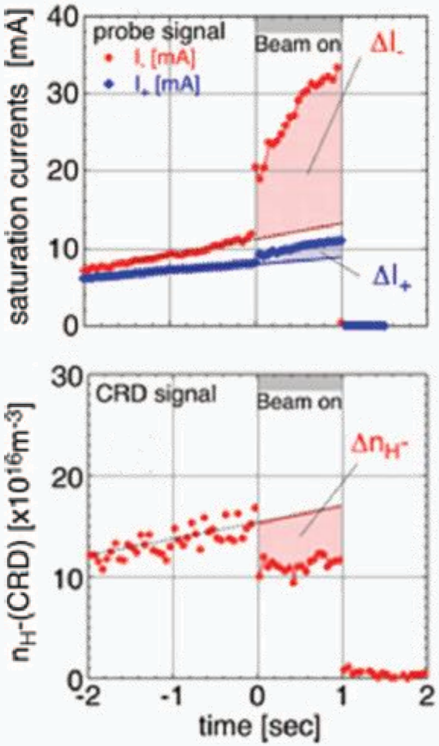
Motivation

- Charged particles in the beam extraction regions are affected by extraction field.
- In the previous works, obvious ion-density difference between hydrogen and deuterium plasmas was observed at beam extraction region.
- Origin of the difference is considered to be the diffusion of hydrogen isotope and such macroscopic motion detected as ion "flow".

Measurement of the charged particle flow in the extraction region with directional Langmuir probes

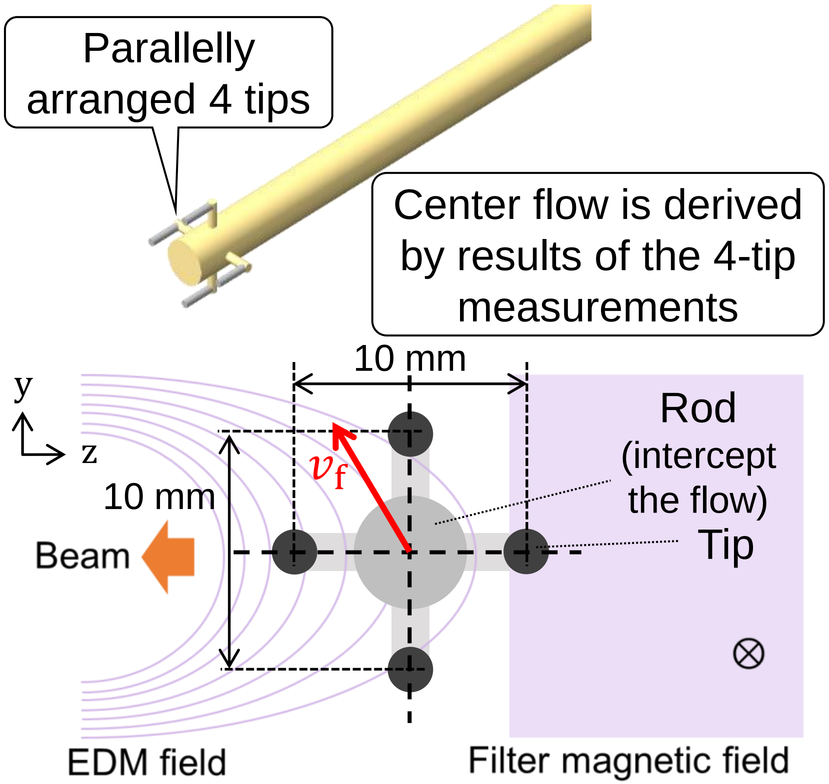


Time evolutions of negative and positive saturation current (I_-, I_+), and negative hydrogen ion density (n_{H^-}) measured by CRD near the plasma grid [1].

[1] K. Tsumori *et al.*, Rev. Sci. Instrum. **83**, 02B116 (2012).

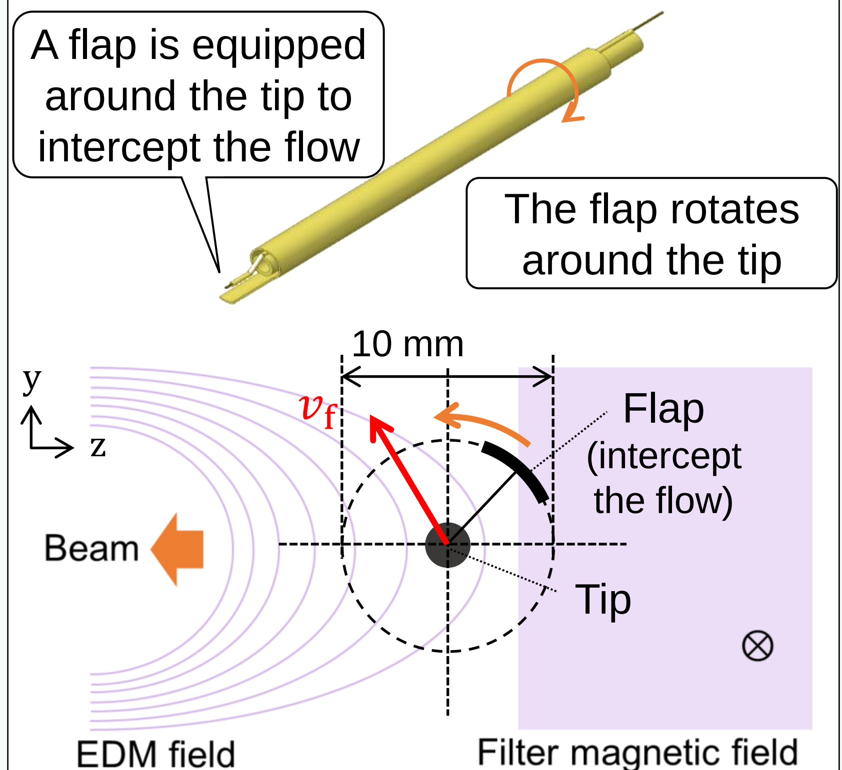
Flow measurement of positive ion with the directional probe

Previous directional probe



Density gradient between tips can cause error for flow measurement.

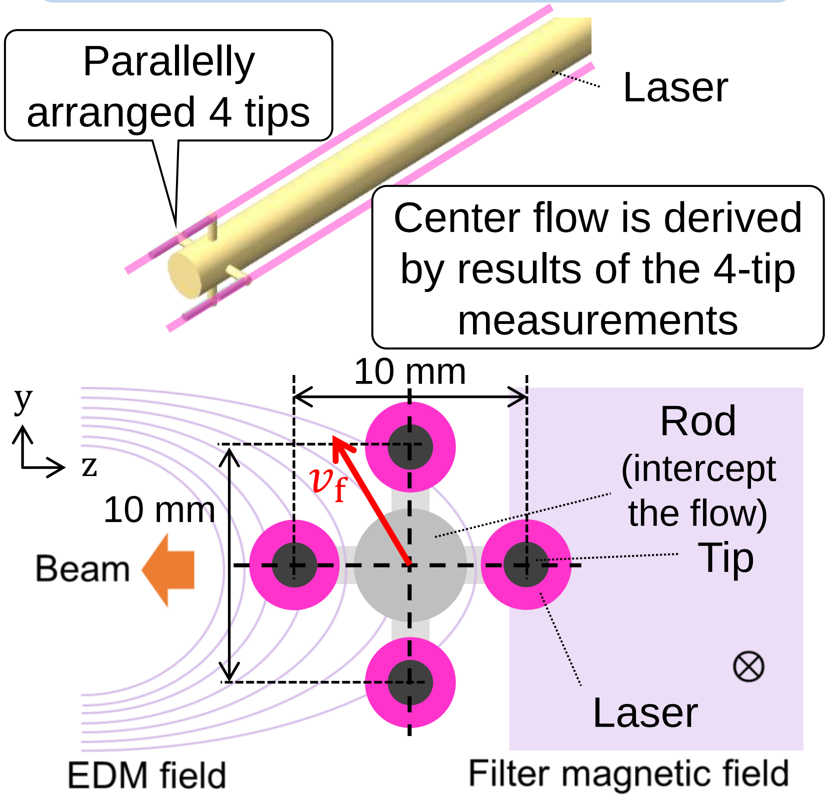
New directional probe



Single probe tip can measure the flow without the density gradient problem.

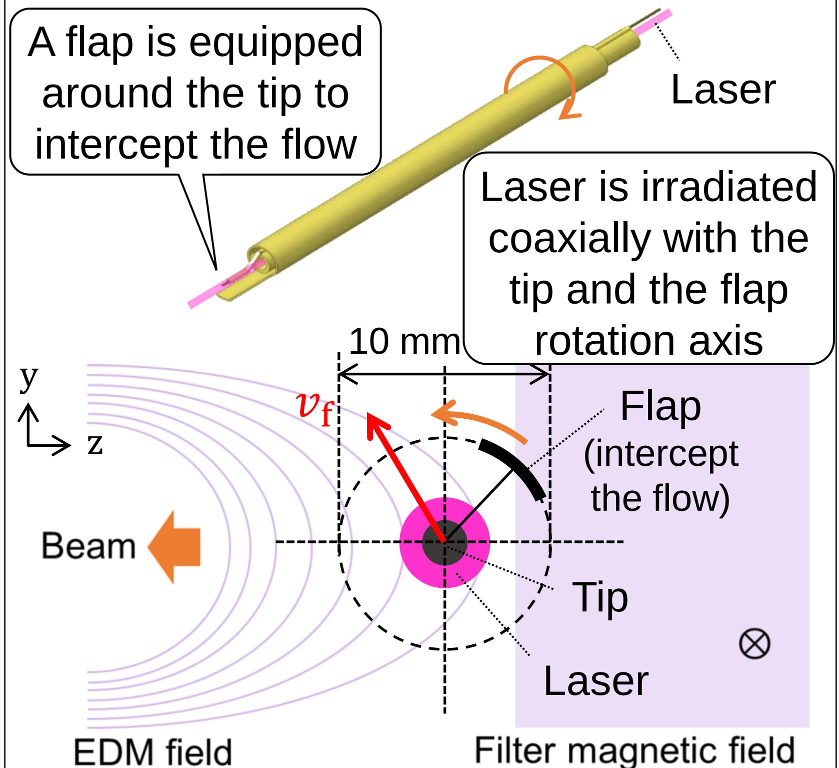
Flow measurement of negative ion with the directional probe

Previous directional probe



Negative-ion flow is obtained from the signals detected at 4 tips of the Langmuir probe.

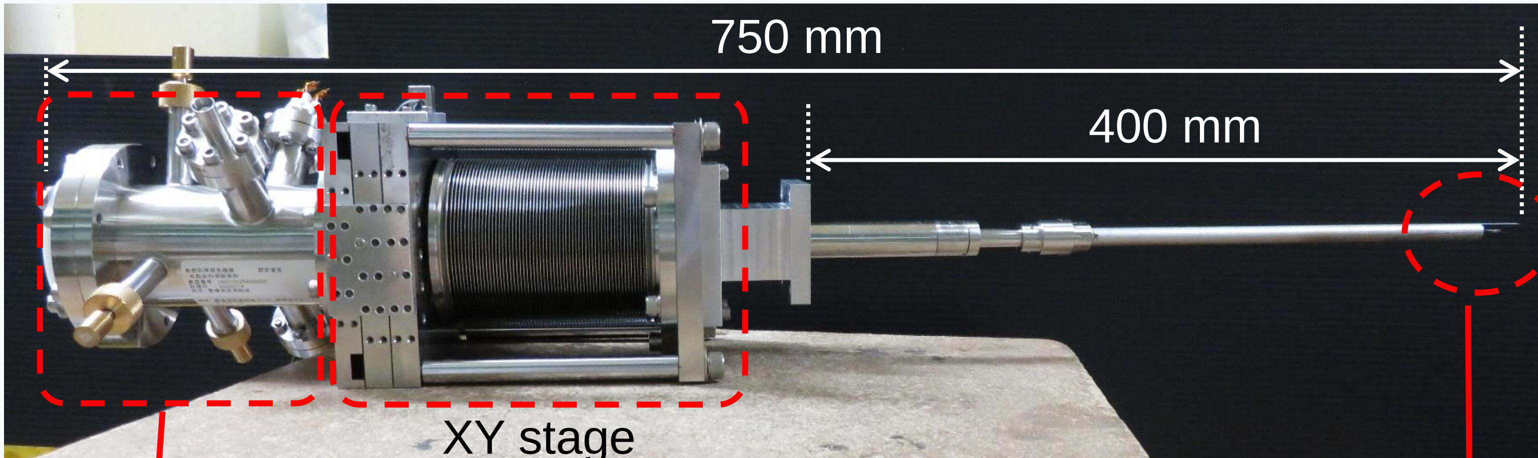
New directional probe



By irradiating laser, this probe works as a directional photo-detachment probe without the ambiguity to average 4-tip data.

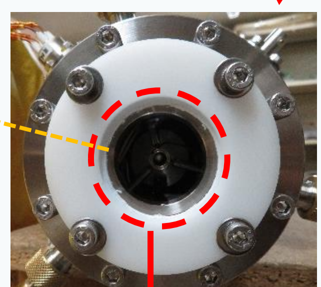
New directional probe

Nd:YAG Laser inlet

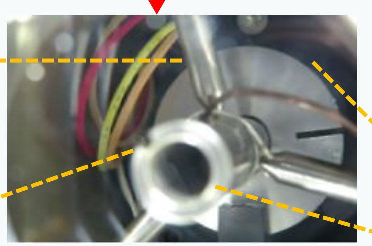


Motor chamber

Window port



Prop



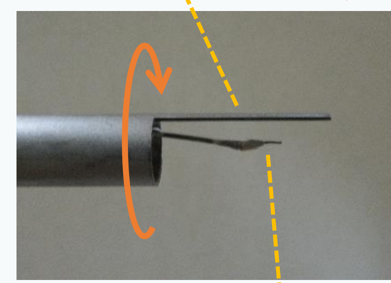
Groove

Stepper motor

Inner tube supporting probe wire

- A stepper motor with hollow axis rotates the flap.
- Inner tube supporting probe wire is fixed by three props.
- Laser passes through the stem tube.
- Probe wire insulated with a ceramic tube is set in a groove engraved on the inner tube.

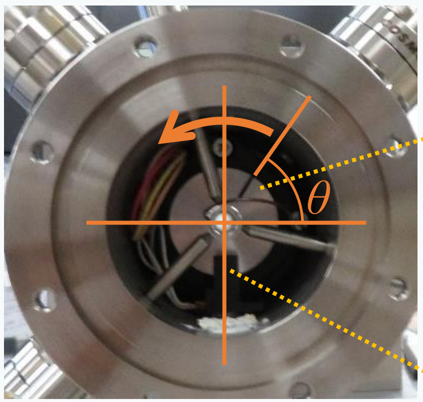
Rotatable flap



<u>Probe tip (fixed)</u>
made of Mo
0.3 mm diameter
2 mm length

Detection of the flap rotation

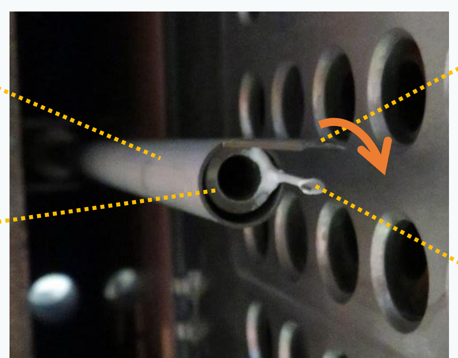
The shielding flap angle is detected with
a photocoupler and rotating slit.



Slit (chopper)

photocoupler

Motor chamber



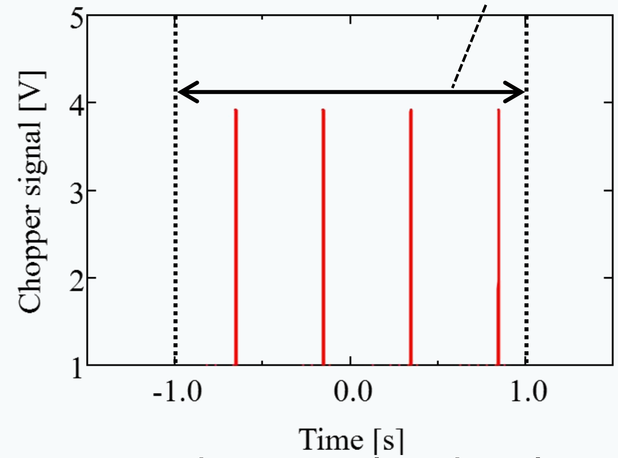
Outer tube

Inner tube

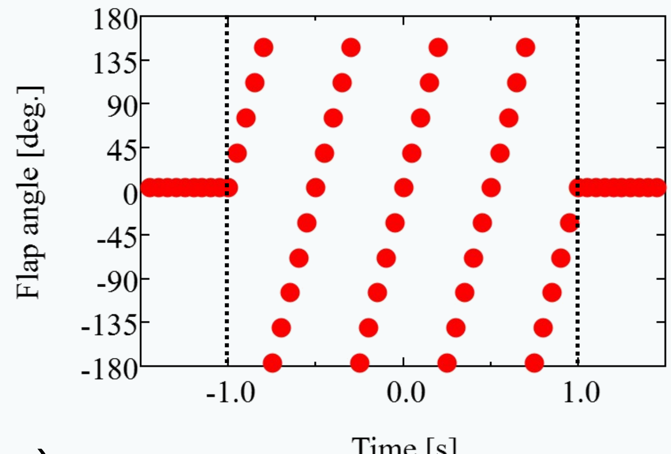
Rotatable shielding flap

Probe tip
(fixed at inner tube)

rotation period (2 s, 2 Hz)

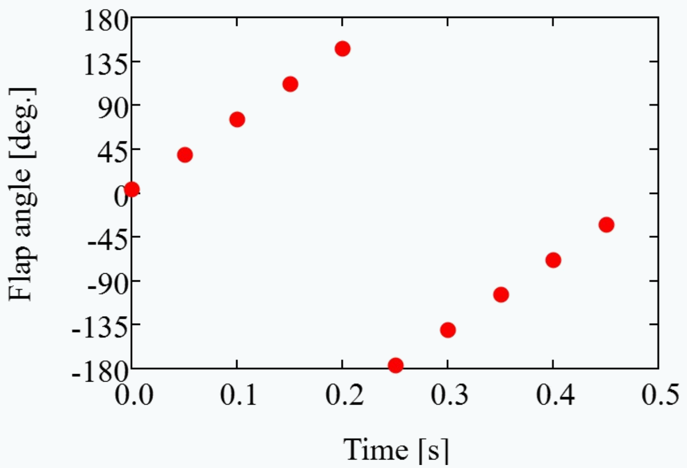


Photocoupler signal

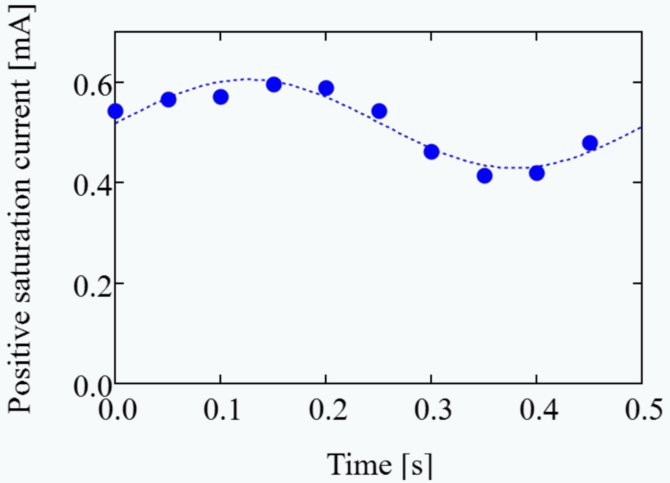


Flap angle (θ)

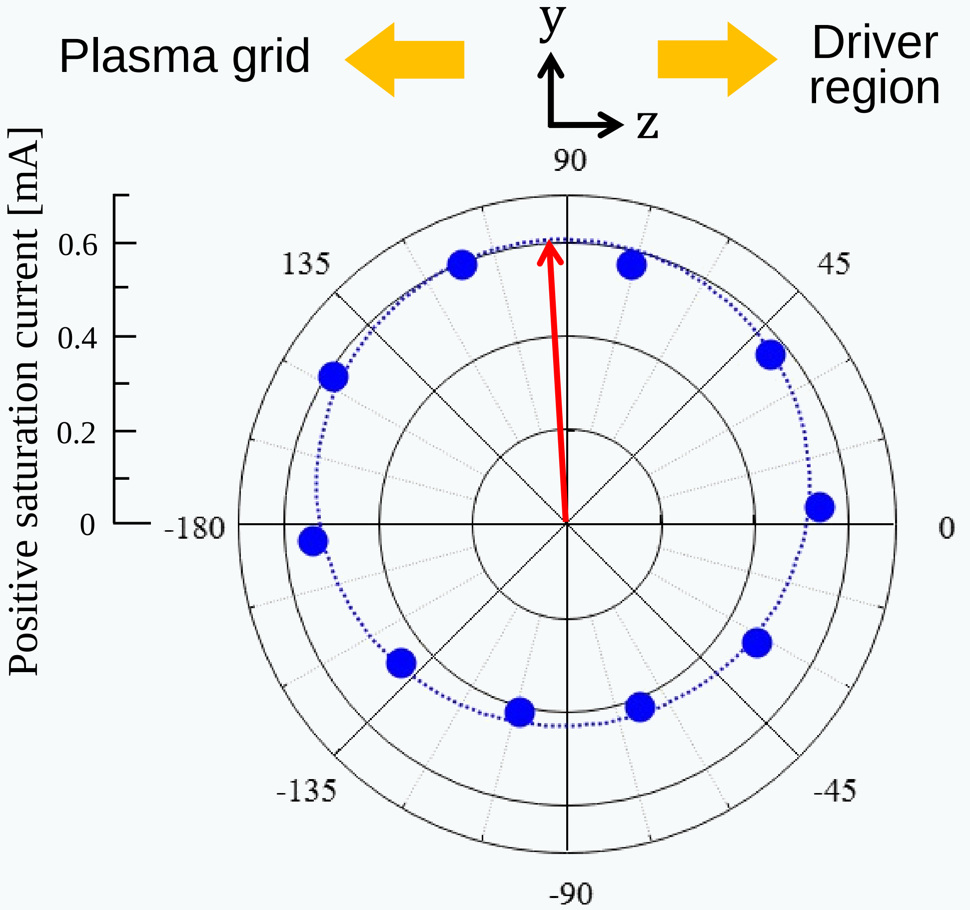
Evaluation of the flow direction



Time evolution of the flap angle



Time evolution of positive saturation current



The flow direction is obtained from the positive saturation or photo-detachment currents and the angle of the shielding flap.

Evaluation of the flow velocity

- Flow velocity v_{f+} (positive ion)

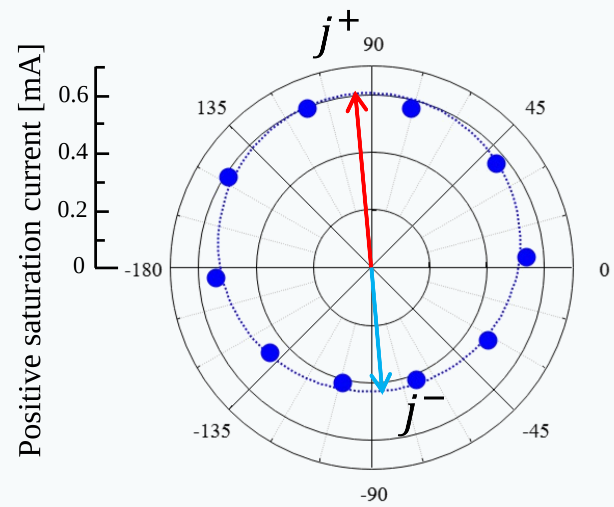
$$v_{f+} = MC_s$$

$$= \frac{T_e}{2}\sqrt{\frac{k}{2m_i T_i}}\ln R \quad where \quad R = \frac{j^+}{j^-}$$

M : Mach number
C_s : ion sound speed
k : Boltzmann coef.

T_e: electron temp. (0.8 eV)
T_i : ion temp. (0.3 eV)
m_i: ion mass

assumed



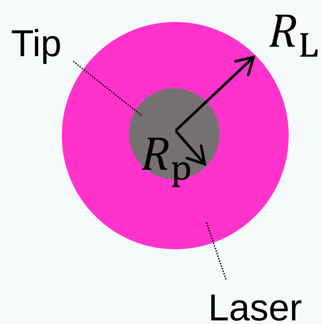
Positive saturation current

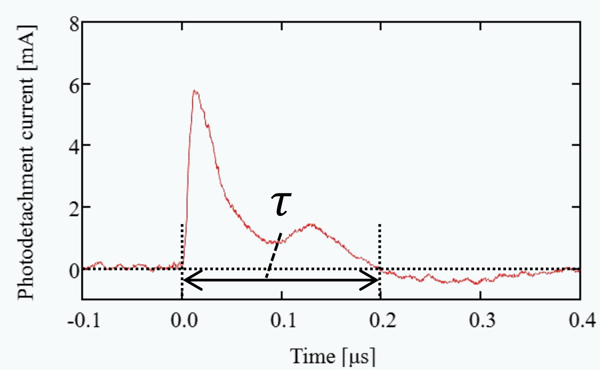
- Flow velocity v_{f-} (negative ion)

$$v_- = \frac{R_L - R_p}{\tau}$$

$$= v_{th-} + v_{f-}$$

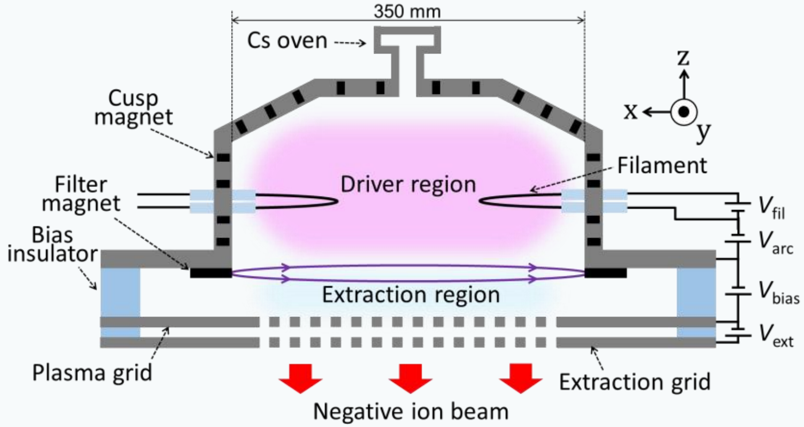
R_L : Laser beam radius (1.5 mm)
R_p : probe radius (0.15 mm)
τ : recovery time
v_{th-}: thermal velocity (～0.3 eV)



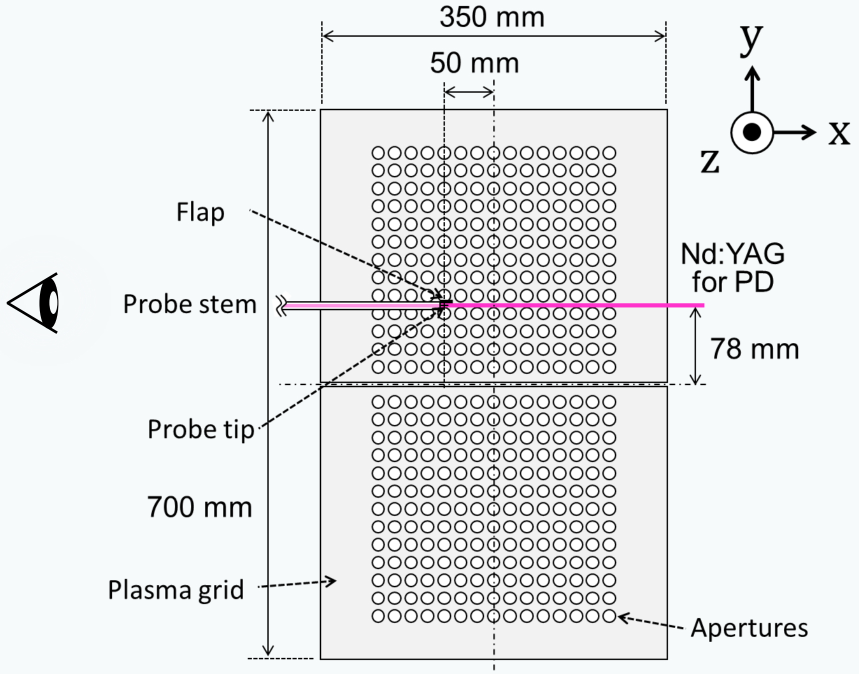


Photodetachment current

Experimental setup



NIFS R&D Negative Ion Source (NIFS-RNIS)



Experimental condition

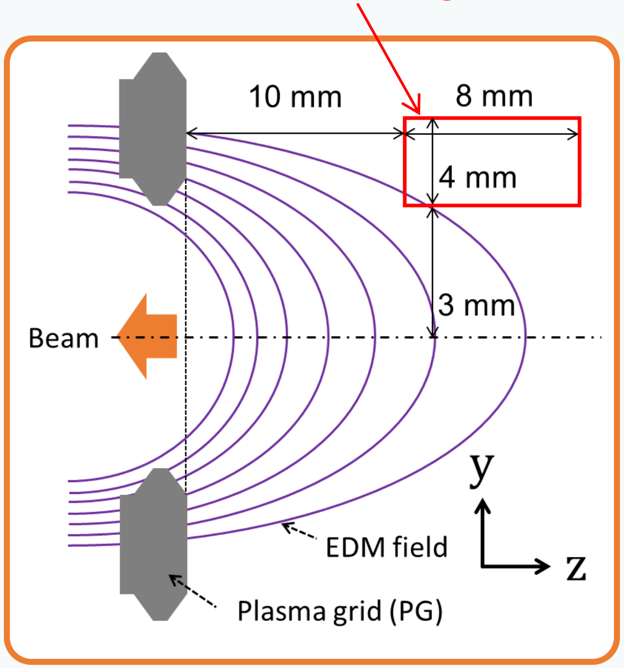
Gas : Hydrogen, 0.3 Pa

V_{arc} : 80 V

P_{arc} : 50 $\pm$ 2.5 kW

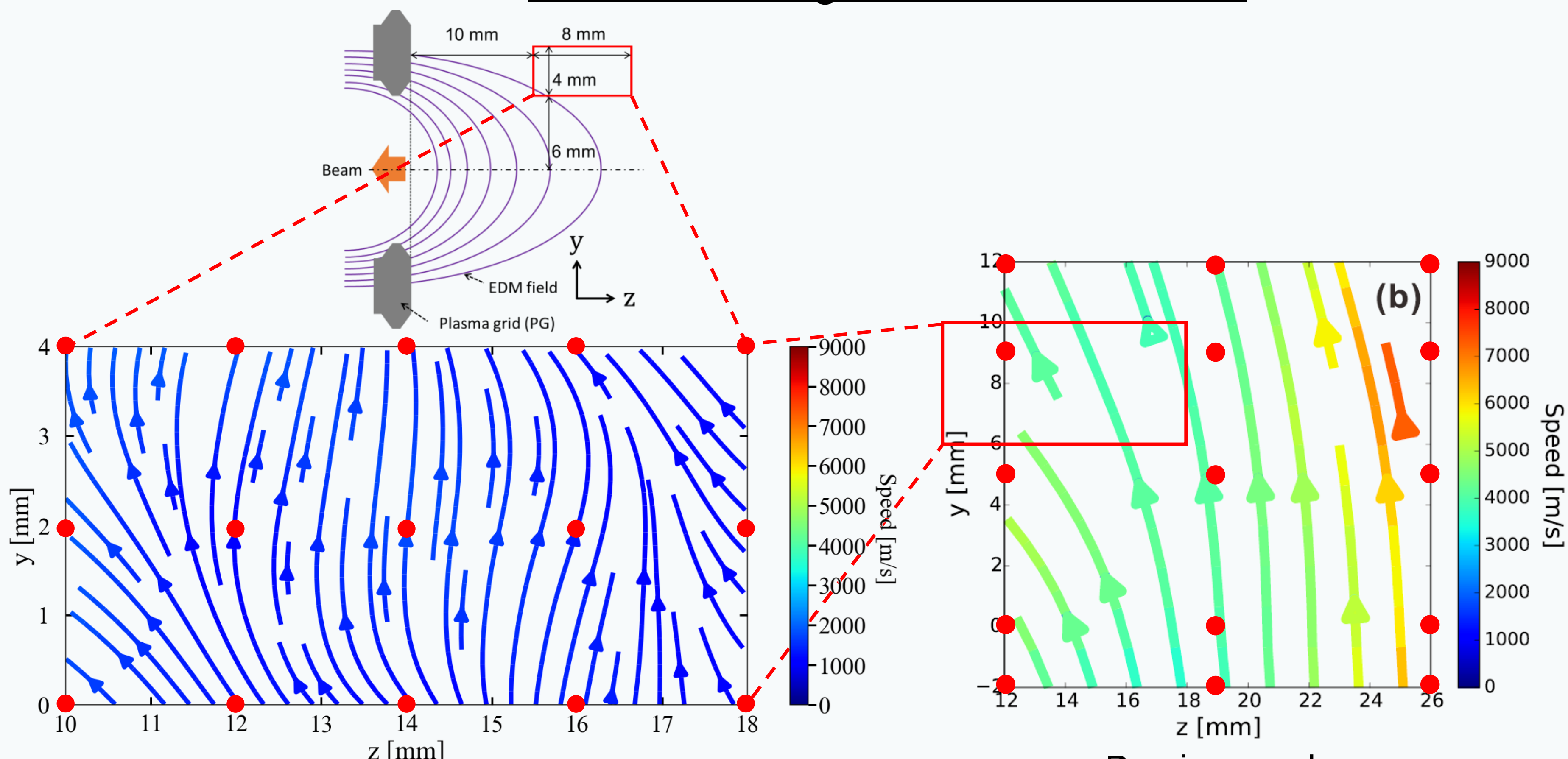
V_{ext} : 3 kV

Measured region



Comparison with the previous probe (H^+ case)

◆ The flow during the beam extraction



New probe

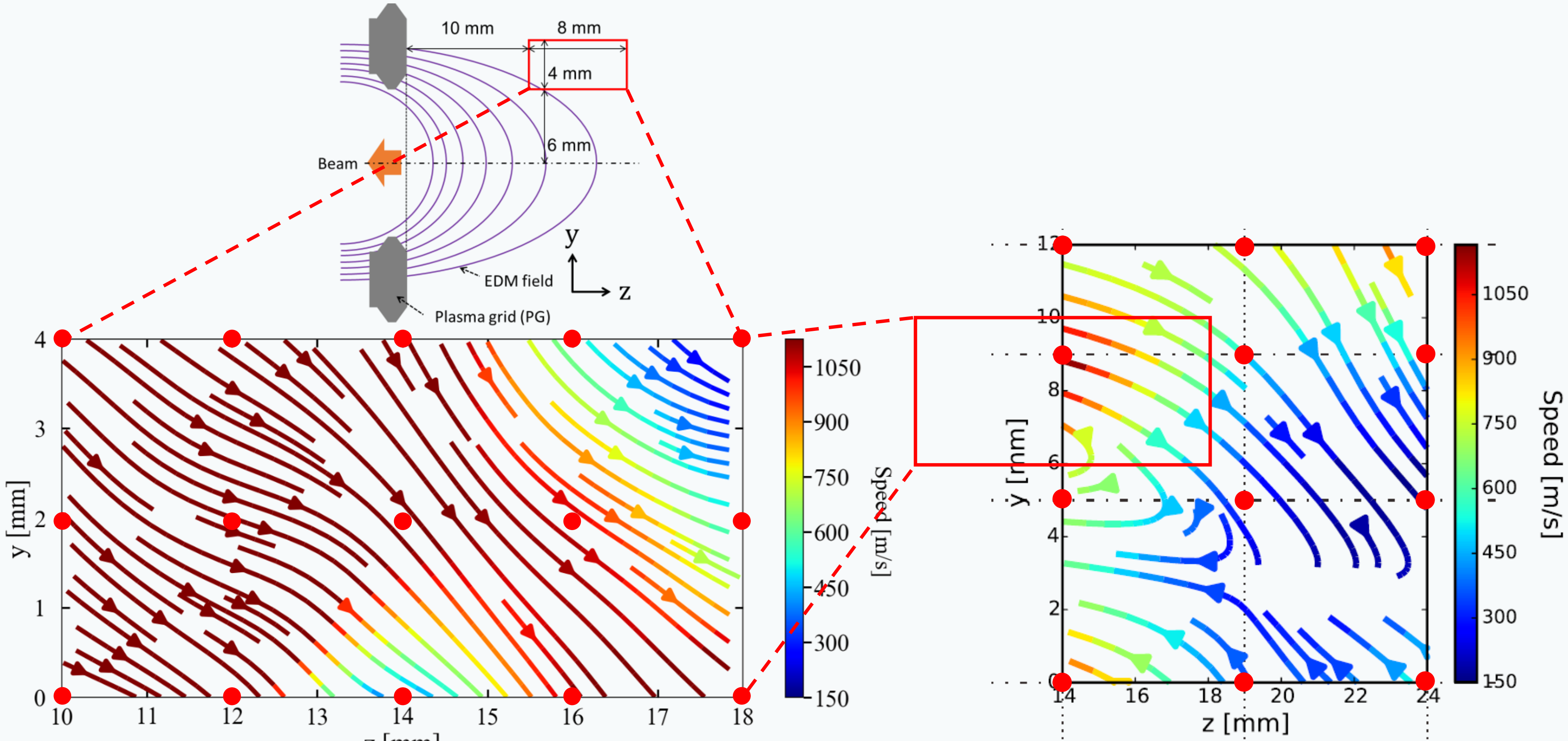
Previous probe[2]

- ✓ Global flow structure is consistent with the previous result
- ✓ New probe observed finer flow structure

[2] S. Geng, Ph.D. thesis, SOKENDAI (2016).

Comparison with the previous probe (H^- case)

◆ The flow during the beam extraction



New probe

Previous probe[2]

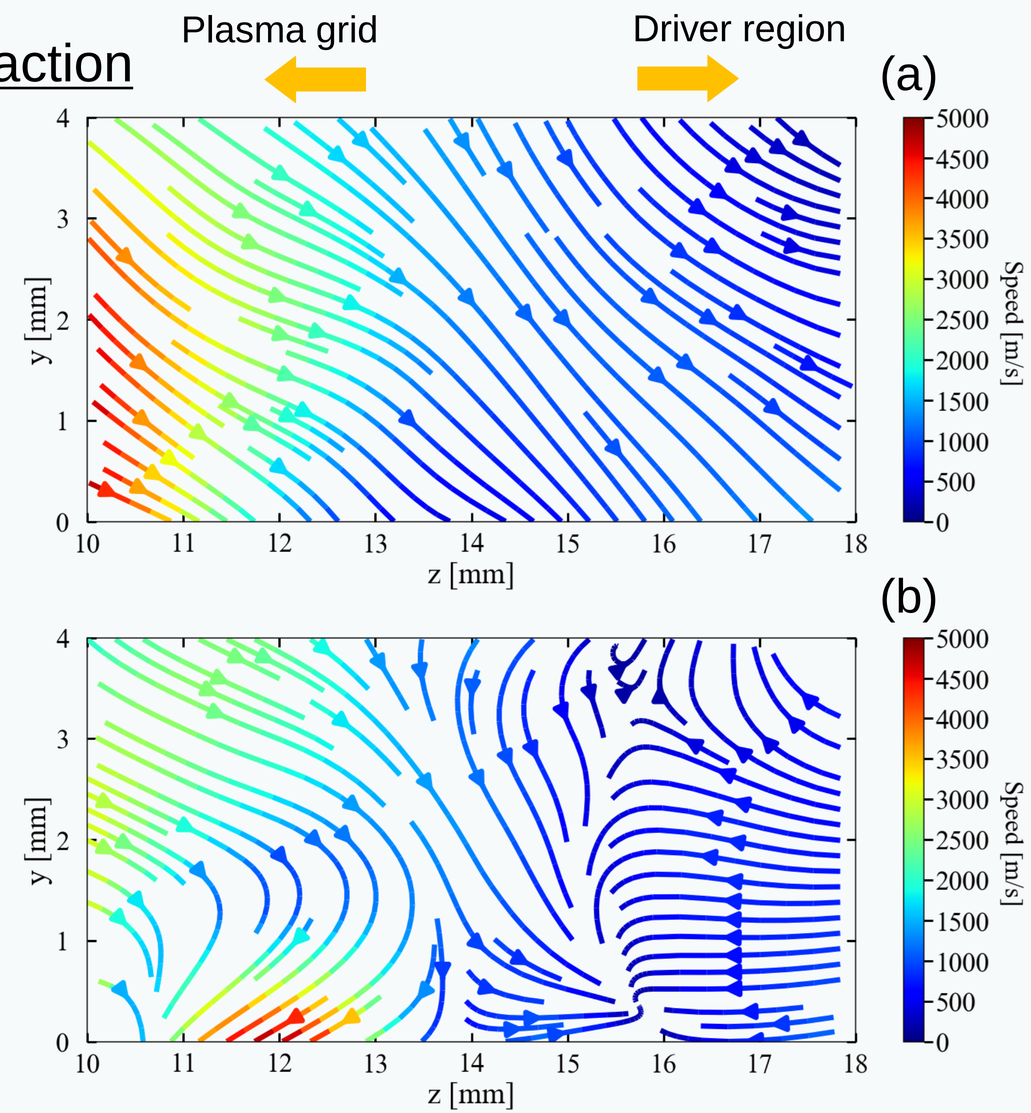
It was verified that the new probe can measure finer flow structure of the charged particles than the conventional one

[2] S. Geng, Ph.D. thesis, SOKENDAI (2016).

Change of H^- flow pattern with the bias voltage

◆ <u>The flow during the beam extraction</u>

- Flow patterns with different bias voltages were measured.
- Electronegativity increases with increasing the bias voltage, V_b, from 3 V to 7 V.
- Pre-sheath penetrates deeper at higher electronegativity.
- Compared with the flow pattern at the bias voltage of 3 V, turning point of the flow shifts on plasma grid side at the bias voltage of 7 V.



H^- flow, (a) V_b : 3 V, (b) V_b : 7 V

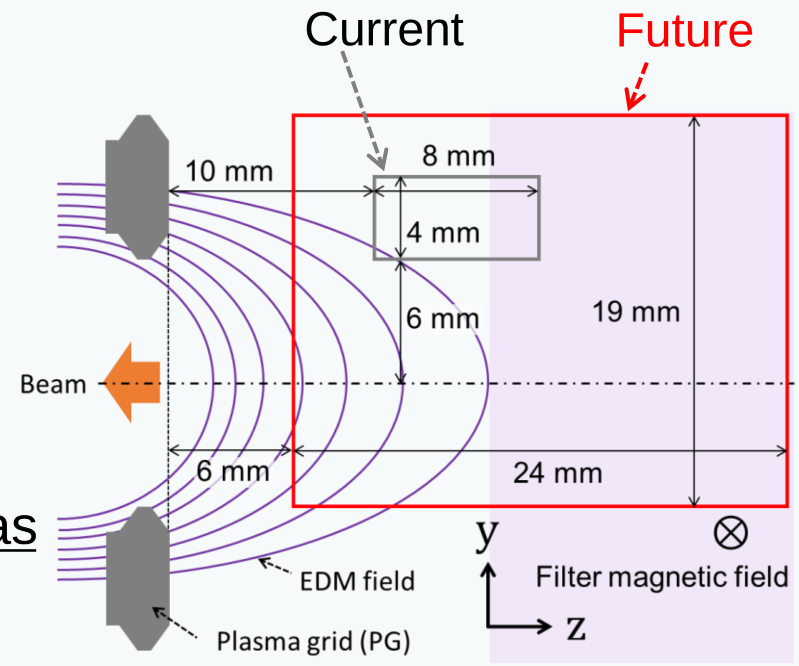
Future work

✓ <u>Remodeling the new directional probe</u>

The measurement range (area) will be extended to scan the charged particle flow closer to the plasma grid by modifying the structure of this directional probe.

✓ <u>Flow measurement in deuterium plasmas</u>

To understand difference of the hydrogen isotope effect at beam extraction region, the charged particle flow will be measured in hydrogen and deuterium plasmas.



Flow measurement range near the plasma grid

Summary

- The single-tip directional Langmuir probe was newly developed and installed to the NIFS-RNIS.
- The initial flow patterns of hydrogen positive ion and negative ion were obtained in the extraction region.
- By increasing the bias voltage from 3 V to 7 V, the turning point of H^- flow becomes closer to the plasma grid.
- After modifying the new directional probe, the flow of the charged particles is scheduled to measure the flow-pattern difference between hydrogen and deuterium plasmas.