# Langmuir-probe measurement through the plasma grid aperture of hydrogen negative ion source

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# Neutral Beam Injection (NBI) is an essential tool for plasma heating and current drive

- To satisfy the Lawson criteria of fusion plasmas, we need to realize high performance plasmas of $T_i$=10keV and $n_i$=$10^{20}$ [$m^{-3}$] with external plasma heating. In addition, current drive by external power injection is necessary in tokamak device.
- In order to fulfill these requirements, NBI can be robustly applied as an external power source.
- Realization of efficient NBI system is one of the key issues in realizing efficient fusion power plant.

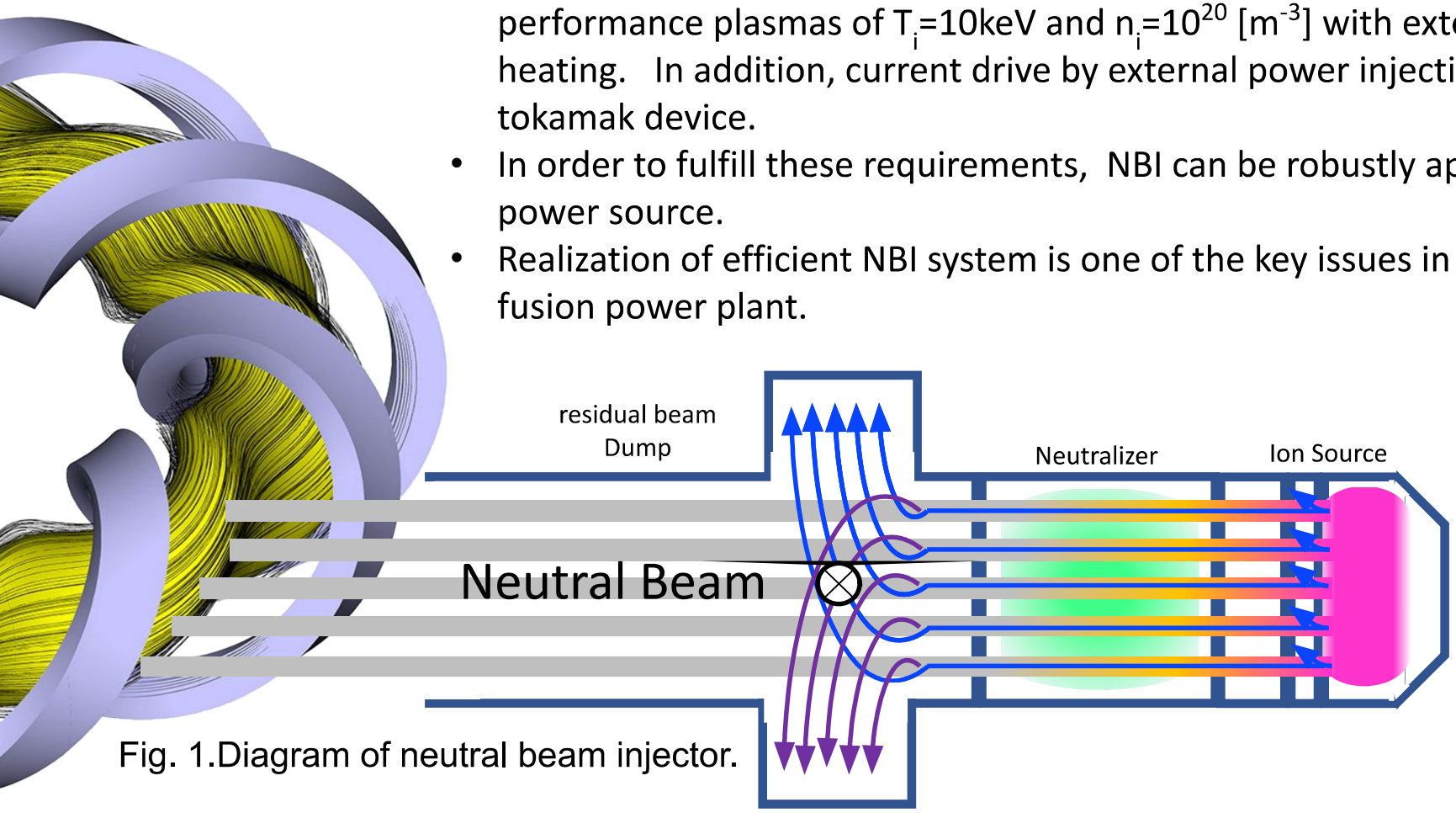



Fig. 1.Diagram of neutral beam injector.

# Beam Extraction Boundary

- In the vicinity of the PG aperture called “extraction area”, a meniscus is the plasma-beam interface (meniscus) is shown in Fig. 3.
- Beamlet focusing is strongly affected with the meniscus shape, which is dependent on the variations of negative-ion density and applied extraction voltage
- Our ion source is a single stage acceleration we define extraction voltage Vext and don’t apply acceleration voltage in this experiment.

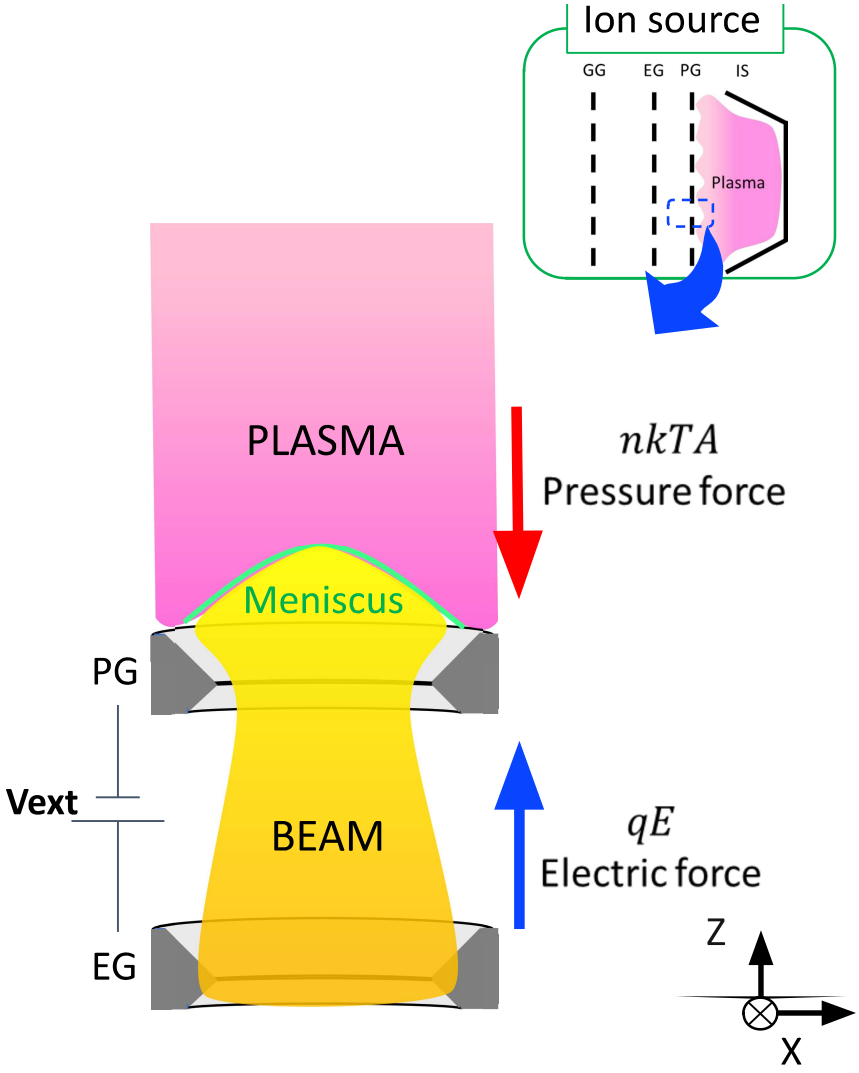



Fig. 2. Definition of the meniscus in the vicinity of the PG aperture.

# Negative ion plasma

- Negative ion plasma consists of negative ion, positive ion and electron. Mainly, negative ion and positive ion conserve charge neutrality properties.
- Negative ion plasma is produced on the PG surface with lowered work function by adsorption of caesium atoms on the surface.
- The shielding mechanism to electrostatic fields in the negative-ion rich plasma can be different from ordinary plasma. This affects the formation and shape of the meniscus.

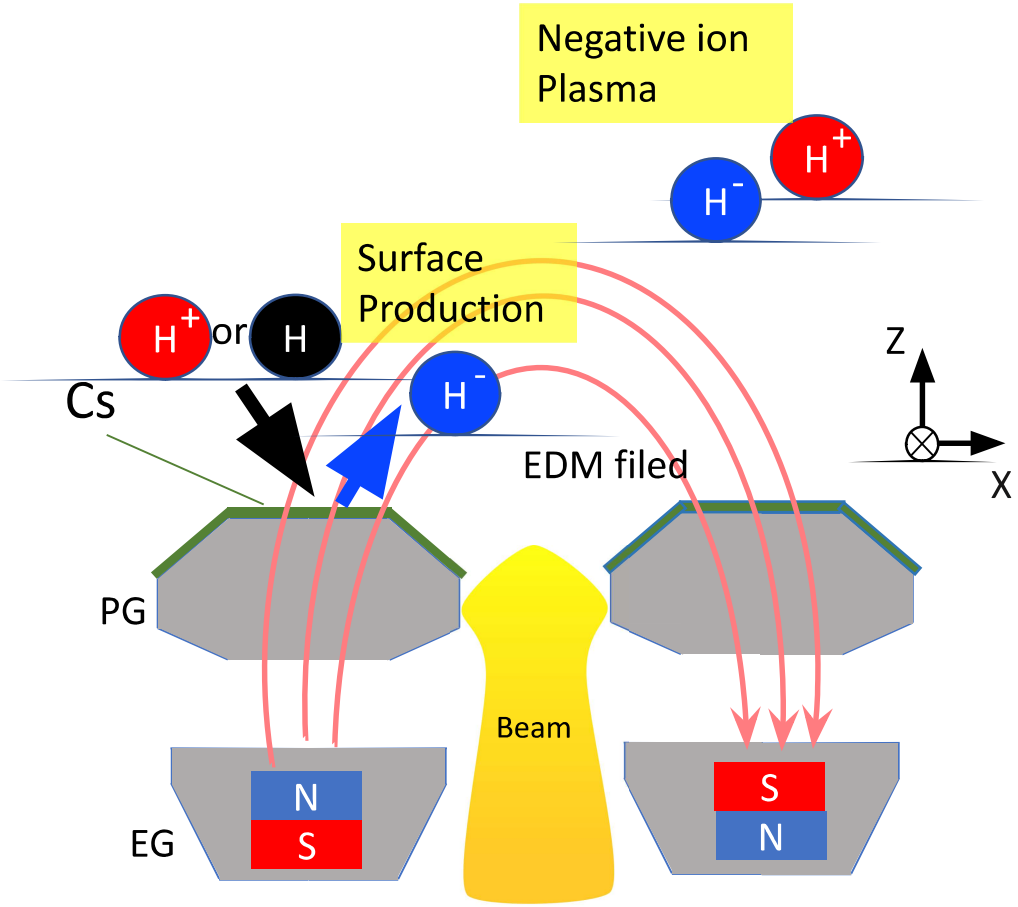



Fig. 3.Mechanism of negative ion production.

# Experiment Setup

# Ion Source Condition

Negative ion source at NBI-Test Stand

- Ion Source : filament-arc type
- Input discharge power: 50kW
- Plasma density: 2 x 10^17 m-3
- Puffing gas H2 :0.8 Pa
- with and without Cs seeding

- Accelerator Grid: PG, EG, and GG
- Bias voltage 0.4V
- Extraction voltage 0,150,250,300,500V

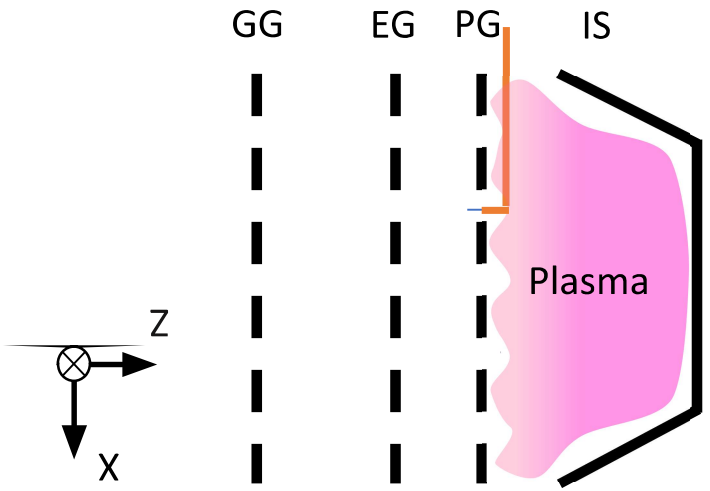
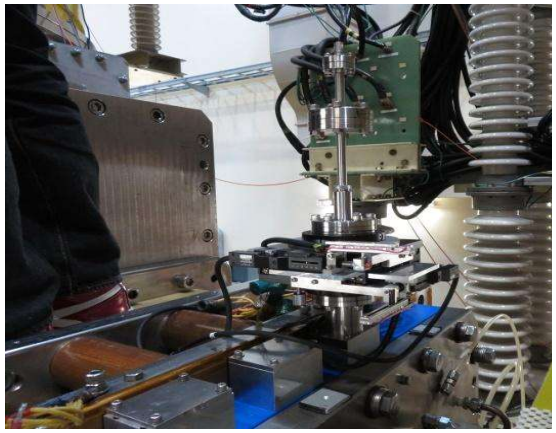



Fig. 4. Diagram of the ion source setup.

# Mechanical part





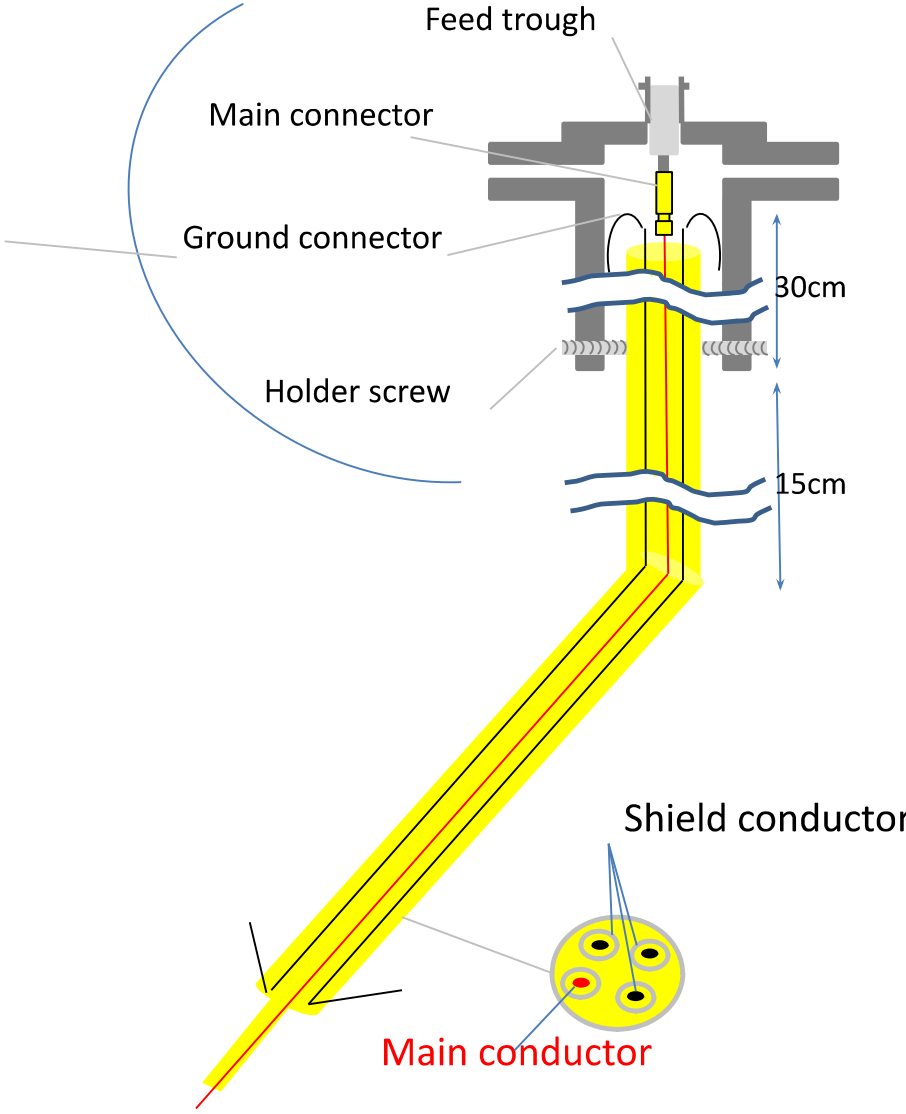
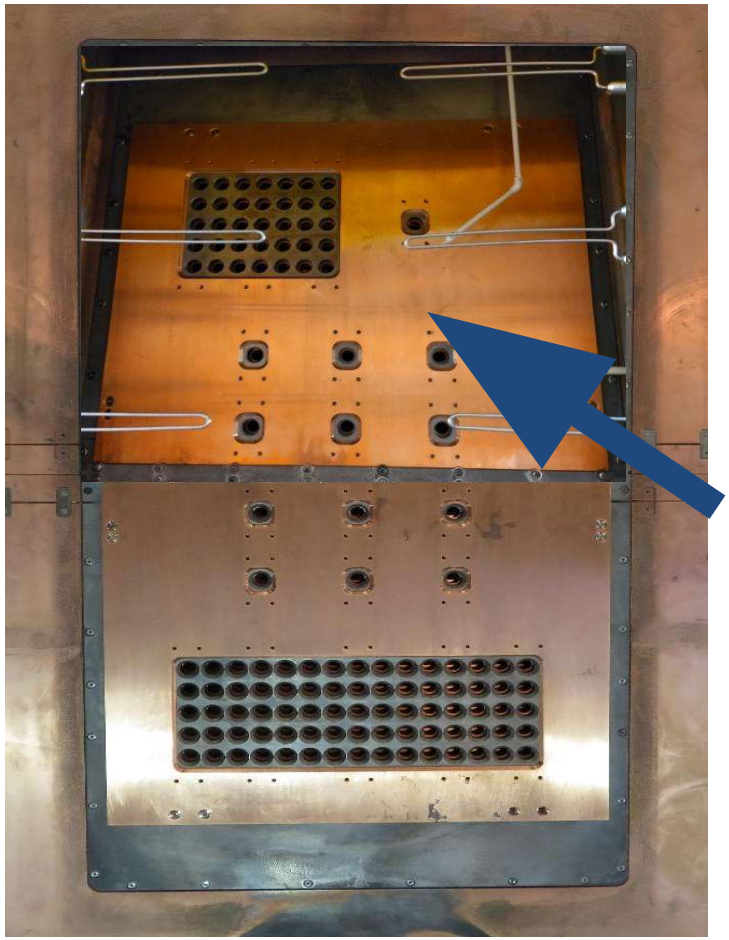
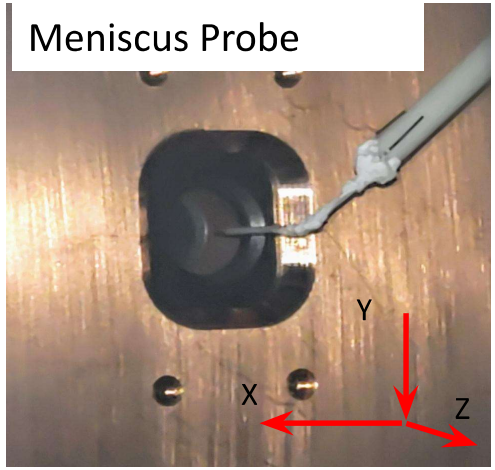
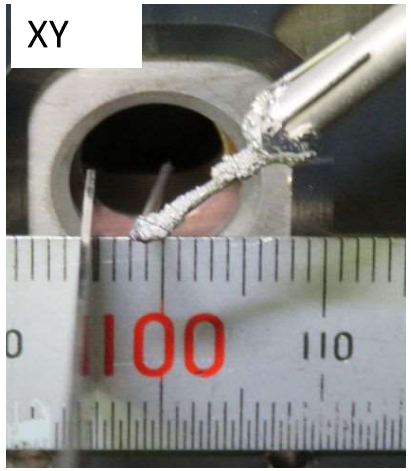



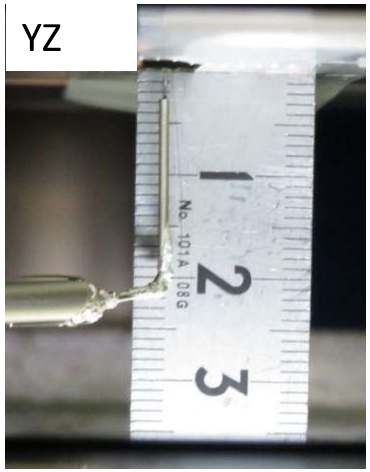

Fig. 6. Diagram of mechanical parts.

# Probe Position






Position of probe tip is measured with position sensor .
We set orientation of the tip to
X positive is west
Z positive is south (upstream side)

Fig. 7. Probe position calibration.

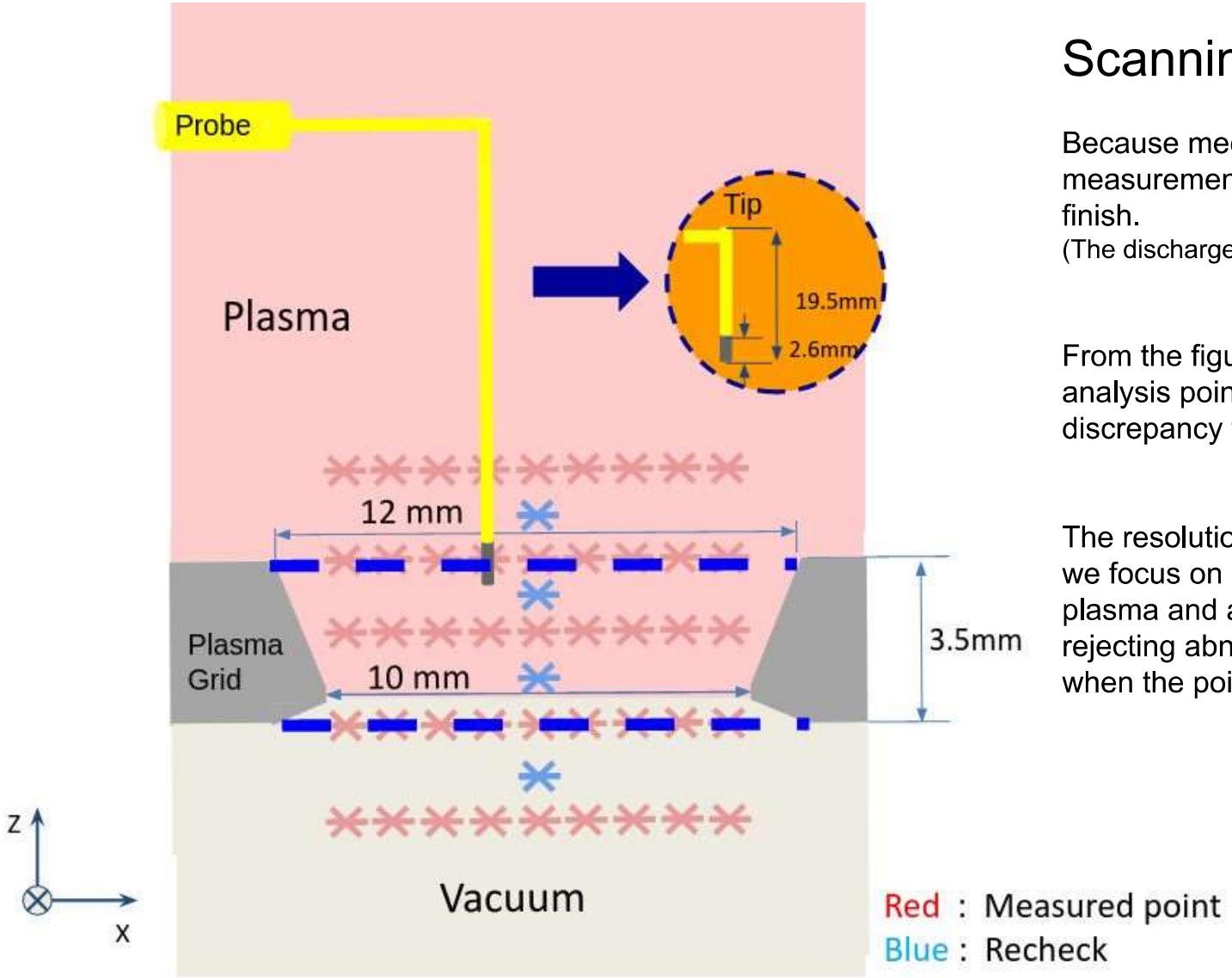



Fig. 7.Diagram of measurement point.

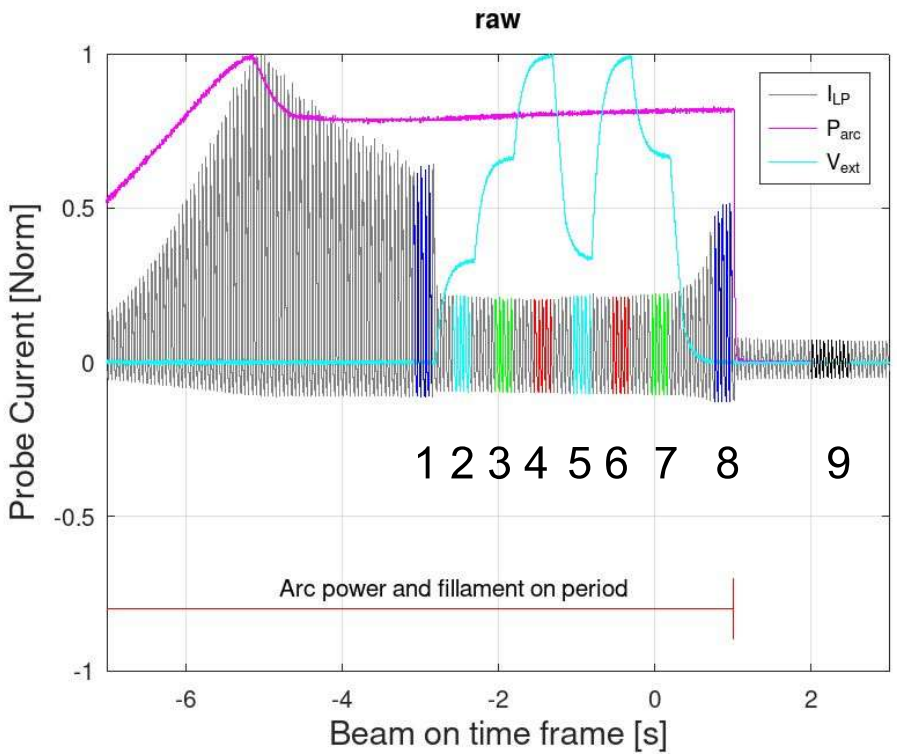
# Scanning Position

Because mechanical movement is slow, the measurement point are changed after discharge finish.
(The discharge is 14 second and cooldown for 3 min.)

From the figure 8, asterisk in red is a map for data analysis point and in blue is quality check the discrepancy from begin and finish of the batch.

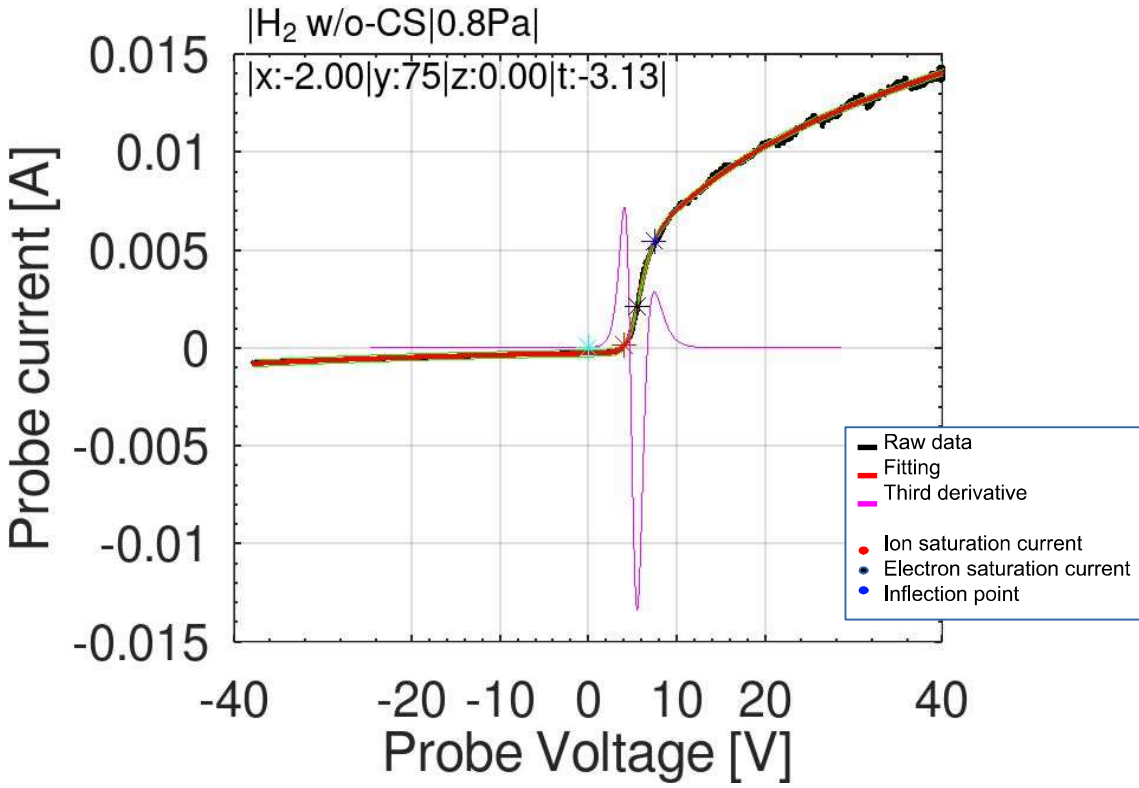
The resolution in x direction is higher than z because we focus on precision of movement in z direction of plasma and avoid plasma parameter fluctuation by rejecting abnormal point and get more resolution when the point is valid.

# Raw data selection




Probe bias is sweeping for diagnostic through out the time of discharge.

The color change on the probe current and number indicate group of sample we take for each Vext level.

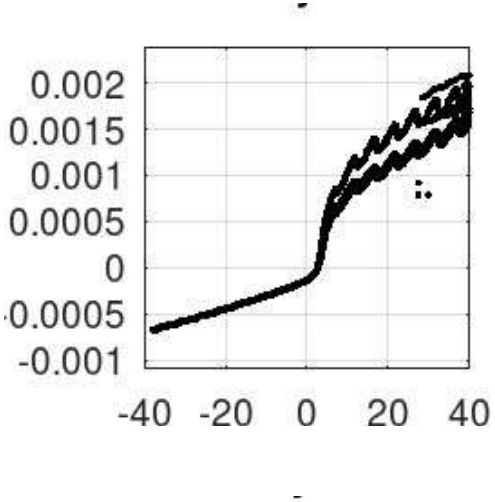



Each I-V curve sample are fitted by specific curve. The function will track voltage position of the retard region.
Third derivative is calculated from the fitted function. The positive peak of third derivative on lower value and higher probe bias voltage is use as saturation voltage for electron saturation current and location of ion saturation current.

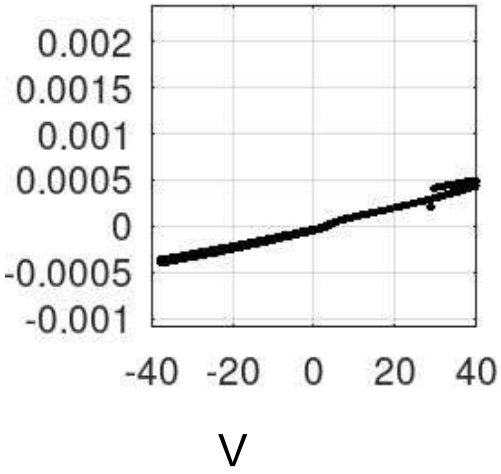
# Preliminary saturation current measurement through a beam extraction hole

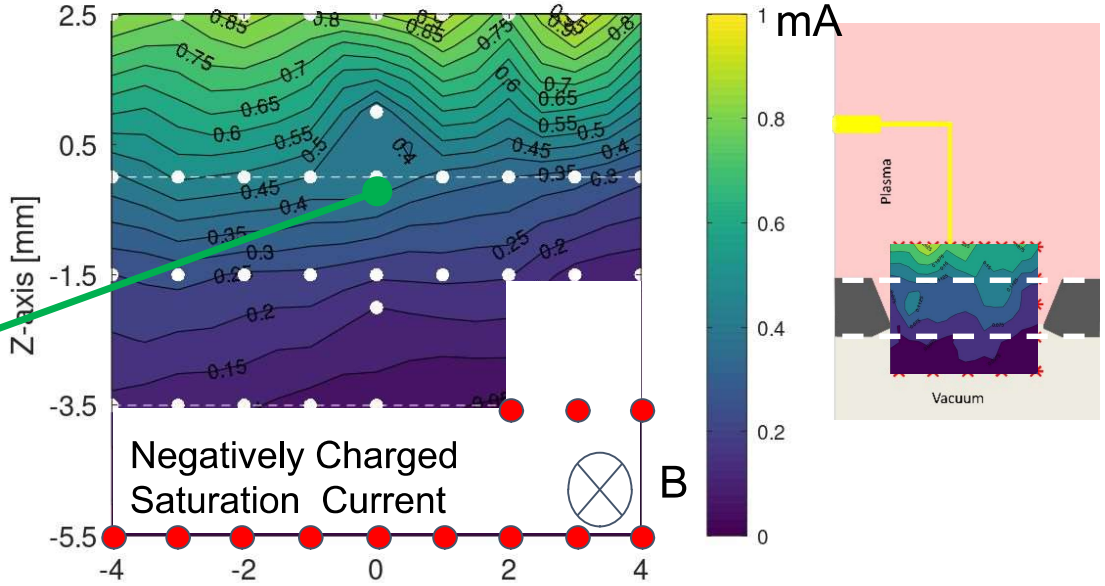
# w-Cs Vext=0

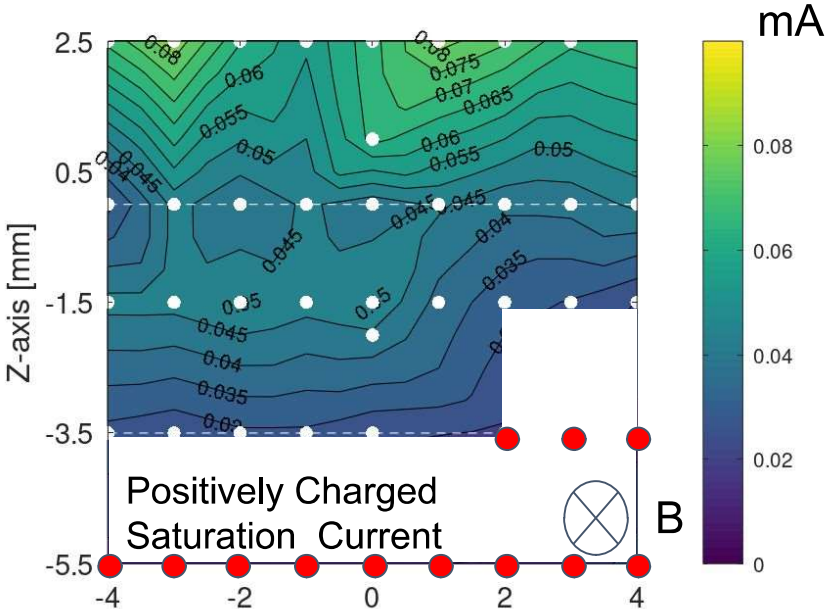
Normal IV curve




Anomaly IV curve

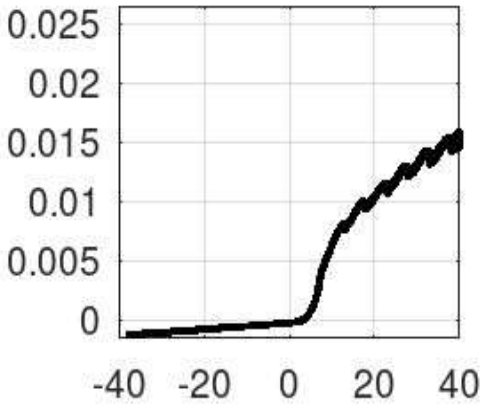


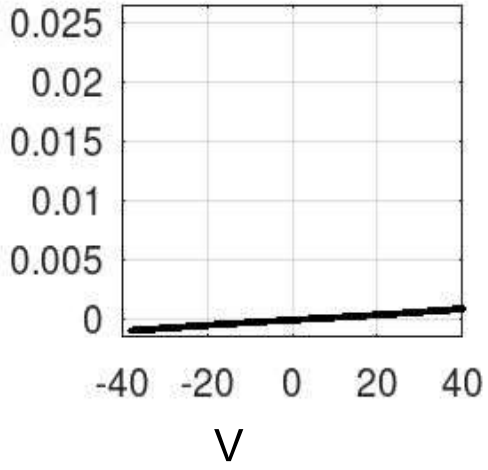



# w-Cs Vext=450V

Normal IV curve




Anomaly IV curve

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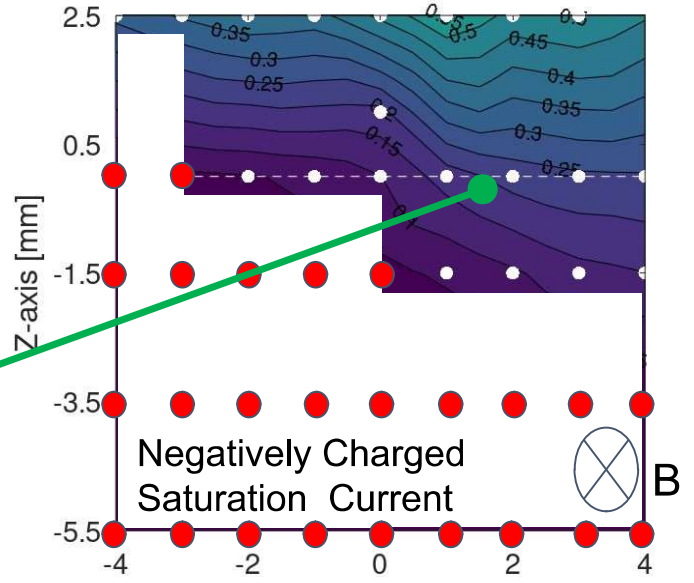
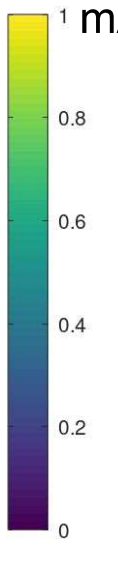
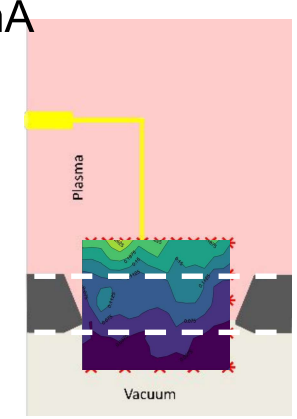
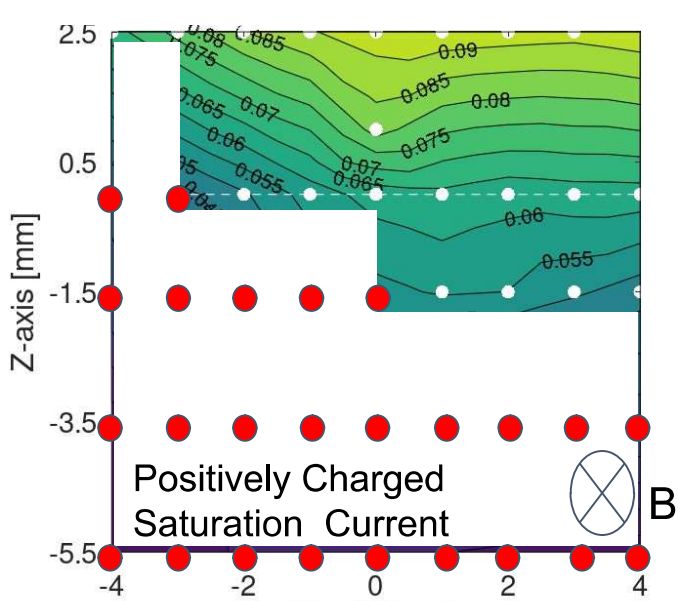
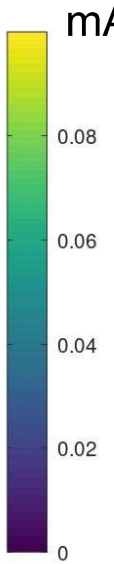
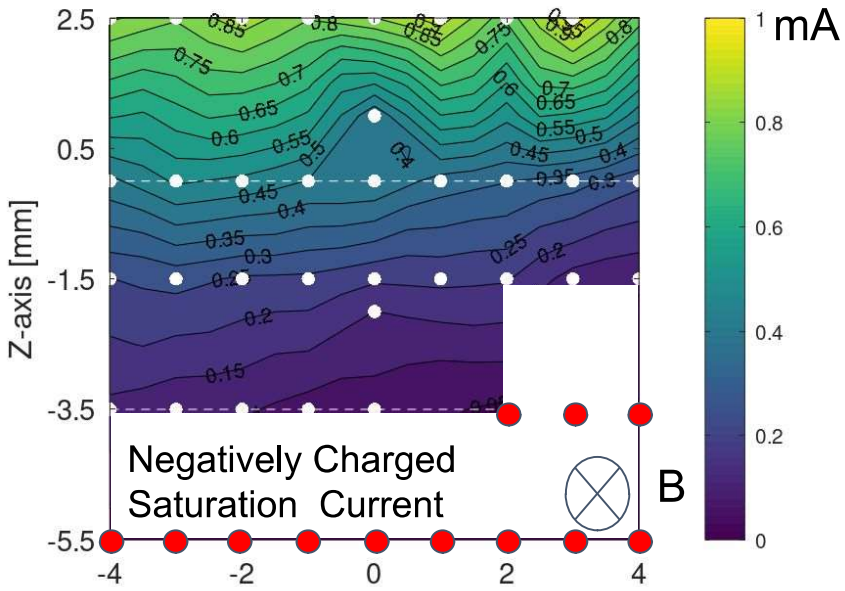


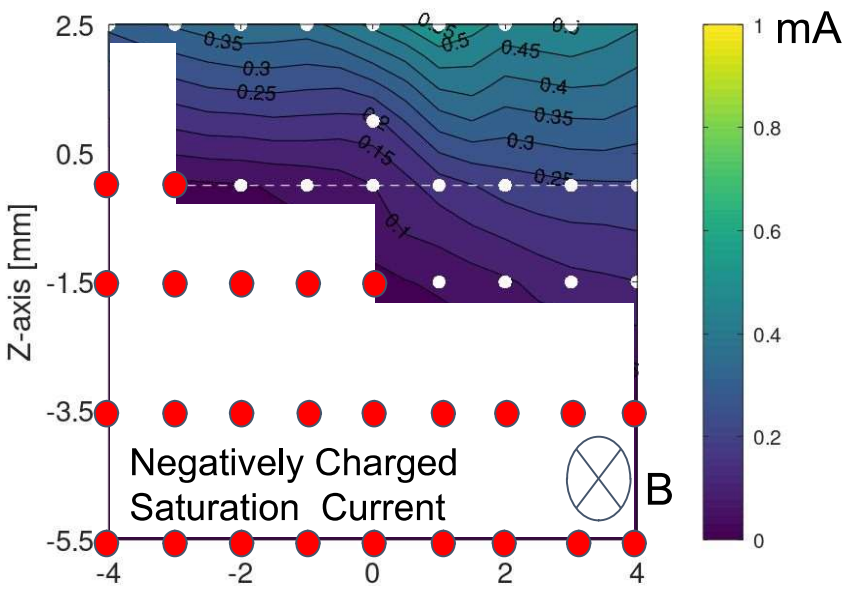




Z-axis [mm]
2.5
0.5
-1.5
-3.5
-5.5
-4
-2
0
2
4
Negatively Charged
Saturation Current
B
mA
1
0.8
0.6
0.4
0.2
0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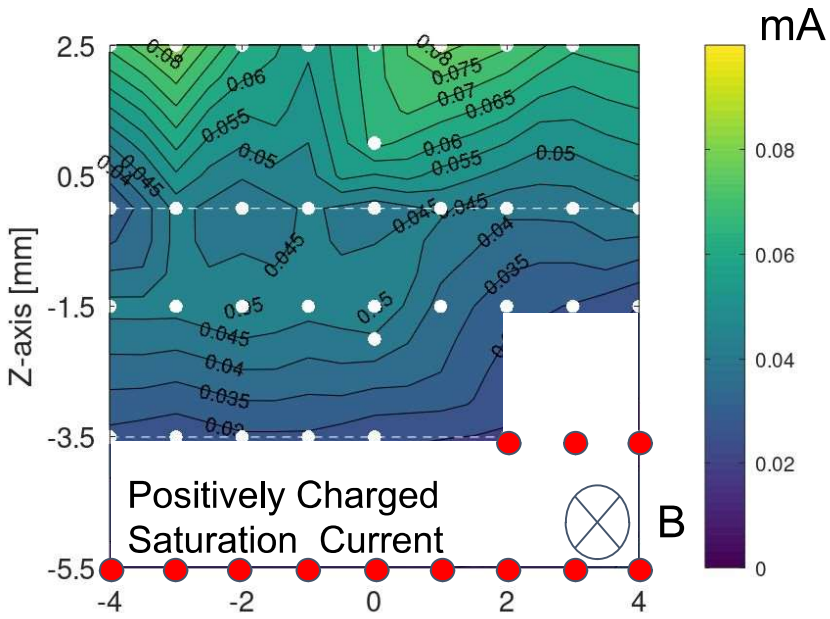
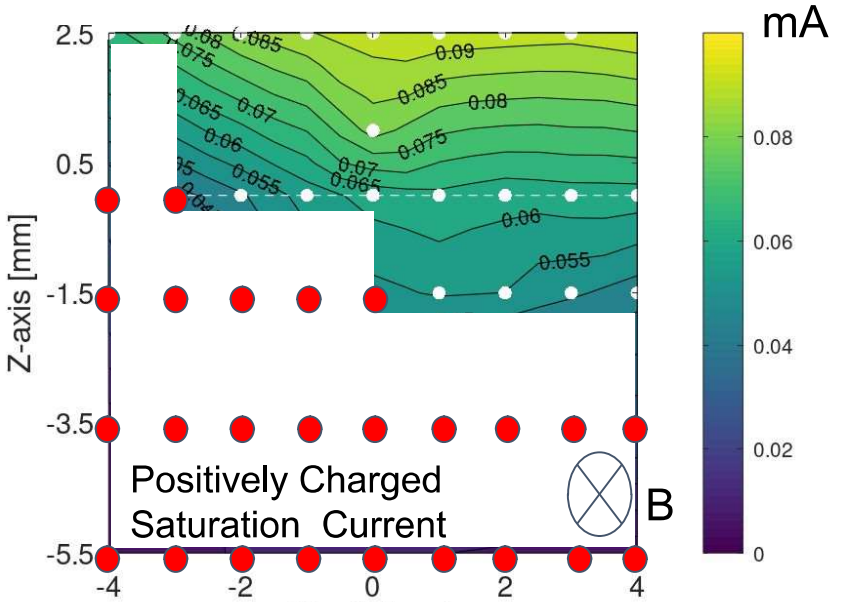
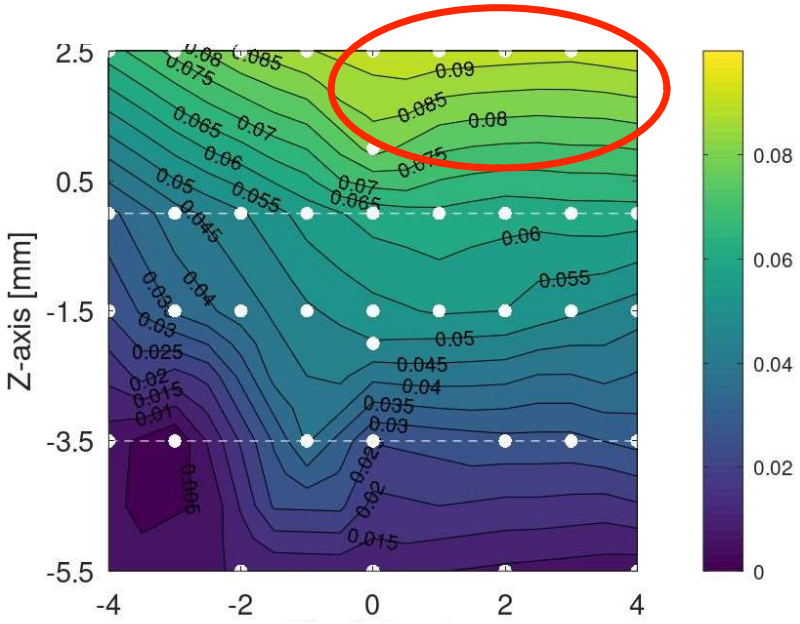
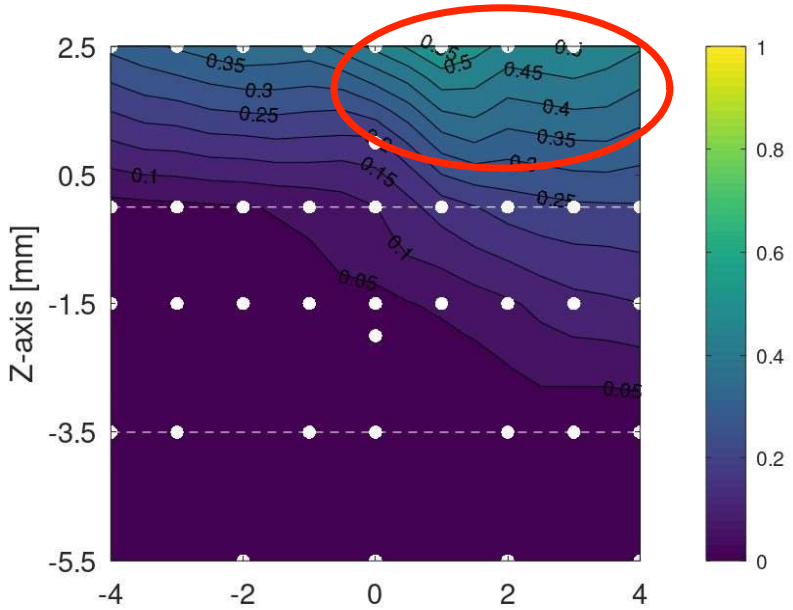

Z-axis [mm]
2.5
0.5
-1.5
-3.5
-5.5
-4
-2
0
2
4
Positively Charged
Saturation Current
B
mA
0.08
0.06
0.04
0.02
0


Z-axis [mm]
2.5
0.5
-1.5
-3.5
-5.5
-4
-2
0
2
4
Positively Charged
Saturation Current
B
mA
0.08
0.06
0.04
0.02
0

# Accumulation of charge particle



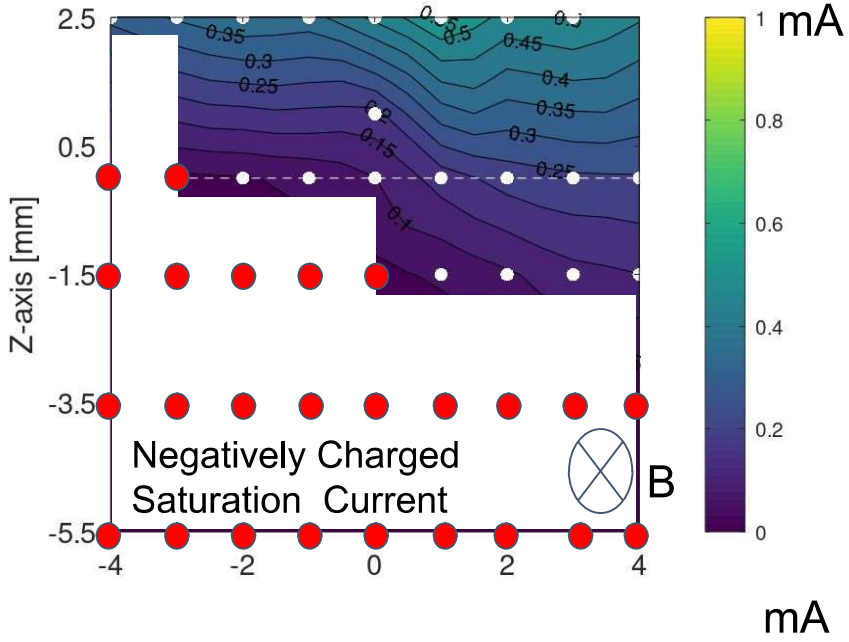

The increasing of saturation current means positive charge density is increase inside extraction area.




The increasing of saturation means Negative charge density is decrease inside the extraction area.

# Meniscus Boundary

The boundary of plasma can consider by appears of anomaly I-V curve which is correspond to current contour.



# ExB drift

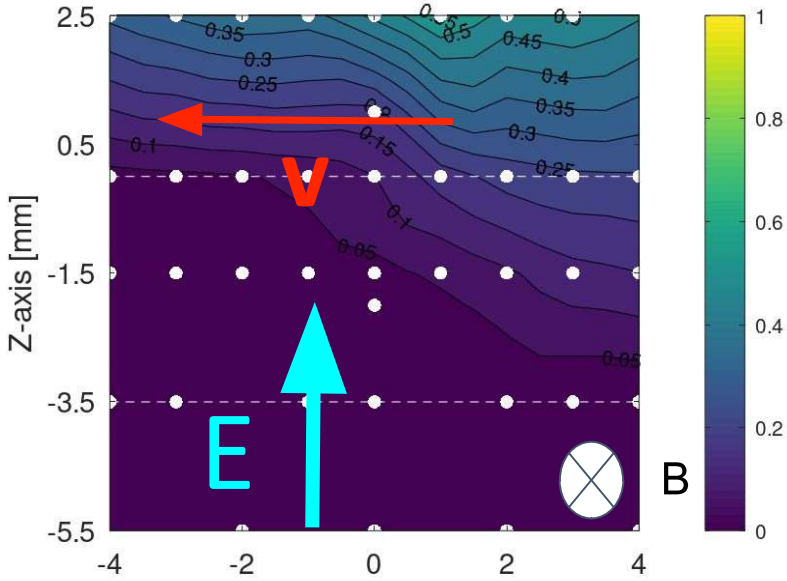
Because in the extraction area we apply magnetic field for electron deflection, the ExB drift is corresponding application of extraction field and the deflection field.

r=mv/qB  v=(kT/m)^0.5

With estimated ion temperature 0.01-0.05eV

Larmor radius is 0.6-1.5mm

Radius is smaller than plasma drifting length. However, the drift direction of plasma is opposite to right hand rule.



# Summary

1. We conducted the Langmuir probe measurement through plasma grid aperture.
2. Analytical method was developed for evaluation of the saturation current from *I-V* curve in the negative ion plasma.
3. Preliminary measurement of plasma distribution is demonstrated in this research.

# Future Plan

- The 3D spatial scan of the LP measurement will be performed to investigate the shape of plasma-beam boundary (meniscus) and the non-uniformity of negative ion densities inside the beam extraction aperture.
- The measurement of the LP will be performed at higher extraction voltage in order to observe the influence of the extraction electric field to the meniscus formation, more clearly.