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On confinement and plasma acceleration from a small ECR plasma source.

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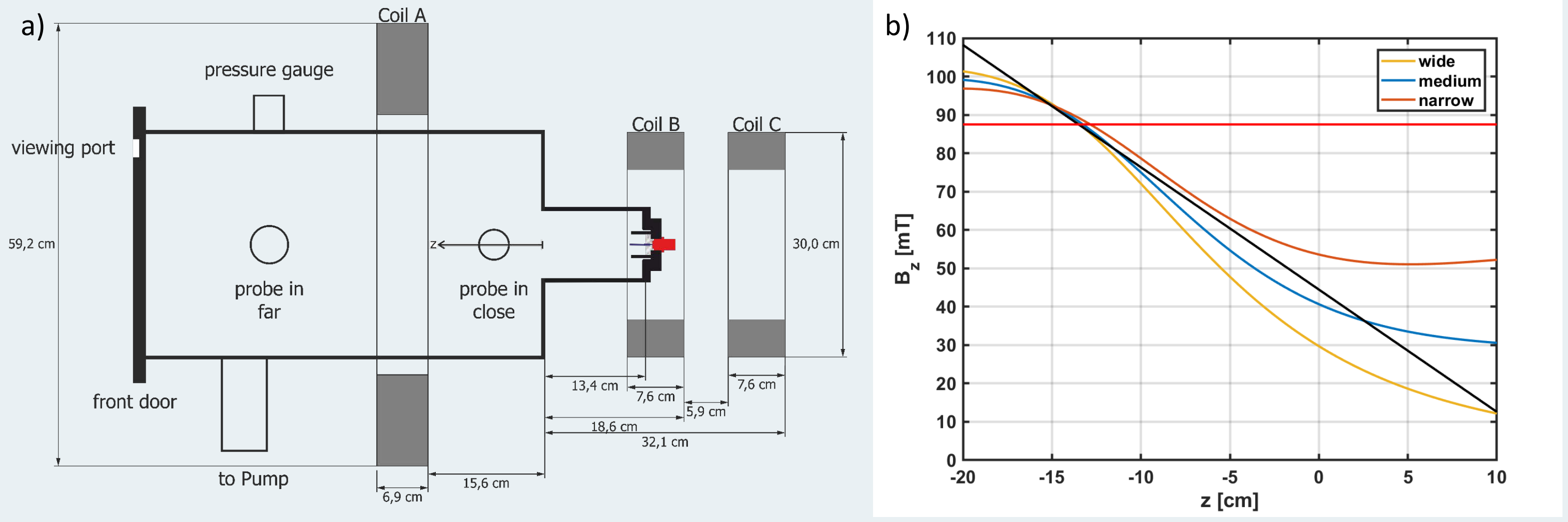
/ INTRODUCTION

Electron Cyclotron Resonance (ECR) is a technique to create high density, low temperature plasmas that do not depend on a cathode, like arc discharges and are therefore easier to maintain and have a longer lifespan [1]. The use of the Electron Cyclotron Resonance (ECR) for electron heating for Magnetic Nozzle (MN) thrusters have recently received increased interest, as they have been shown [2] to provide improved thrust efficiency up to 16 % at only 30 W input power. Such performance make such thrusters viable for use on small, e.g. Cubesat, spacecraft.
An ECR plasma source similar to that described by [3], was recently installed in a 30 cm diameter and 60 cm long cylindrical chamber at UiT. This source is grounded, as opposed to the previously described one, which is shielded from ground. The source consists of a cylindrical sleeve antenna of diameter 2.6 cm, and was operated at 10 - 20 W, at mass flow rates from 0.2 – 0.8 mg/s, which result in pressures ranging from 0.08 – 0.3 Pa. High-resolution radial profiles of plasma parameters were obtained by means of Langmuir, ion energy analyzer and Mach probes, at two different axial positions 20 cm and 50 cm from the source, i.e. in the far plume of the source. The configurations were i) a monotonous expanding magnetic field, ii) a bottle-shaped magnetic field, and iii) a nearly homogeneous magnetic field with straight lines.

/ THE EXPERIMENT

Figure 1

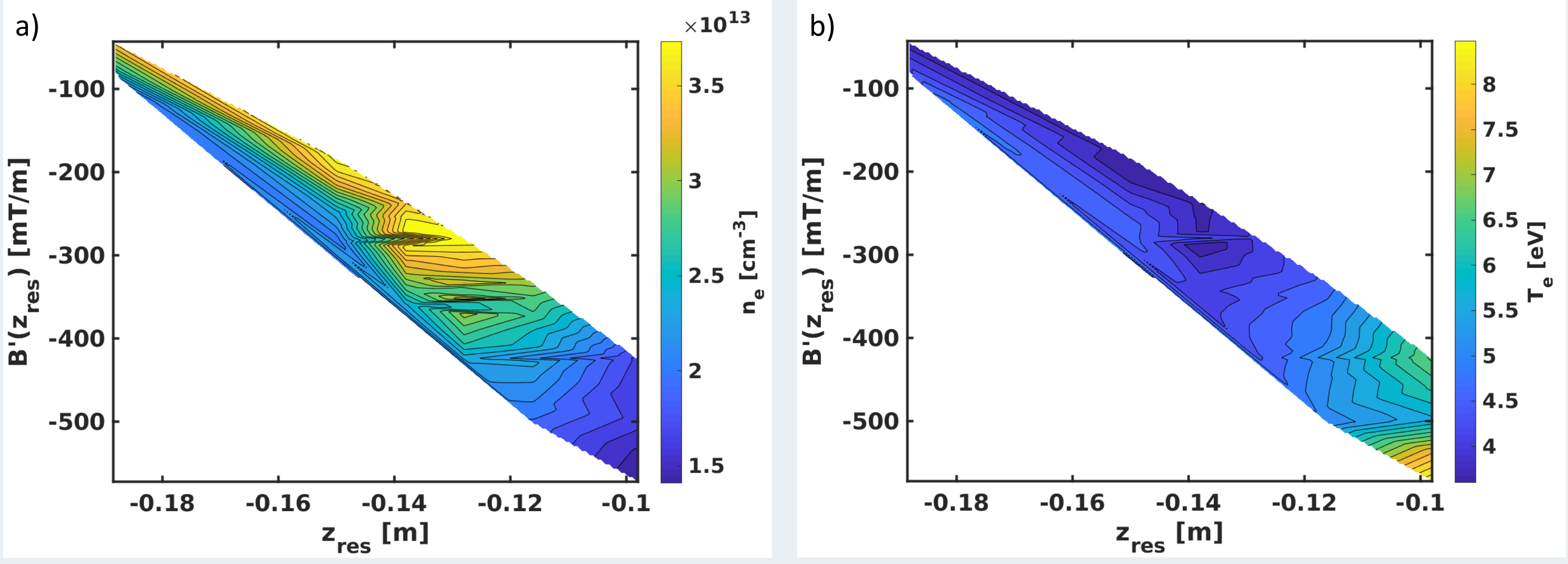


a) The Menja device with magnetic field coils, ECR source, and probe positions.
Antenna dimensions: *21 mm long and 2,1 mm wide tungsten rod with sleeve of D: 27 mm, L: 21 mm.*
ECR power source: *Sairem GMS solid state microwave generator of max 200 Watt, operated at 10 W and 20 W, with frequency 2.43 - 2.47 G in steps of 0,1 Mhz.*
Background and working pressure*, argon gas: P = 5 mPa and 100 (4 sccm)- 400 mPa, respectively*
Probes *were moved by means of a step-motor positioning system, and data were obtained by means of a Labview program controlling bias, averaging the signal and storing to disk.*

b) The magnetic field can be varied by adjusting the currents in the coils. To make comparisons easier, the magnetic field was calculated for each configuration and the position of the resonance zone and the slope of the field at that position were used as a parameter for the measurement.
The image shows the magnetic field in z-direction along the z-axis for the 3 configurations that were used in most of the experiment. The position of the resonance zone at 87,5 mT (red) is kept constant along the antenna but the slope (example shown for the medium configuration in black) can be varied.

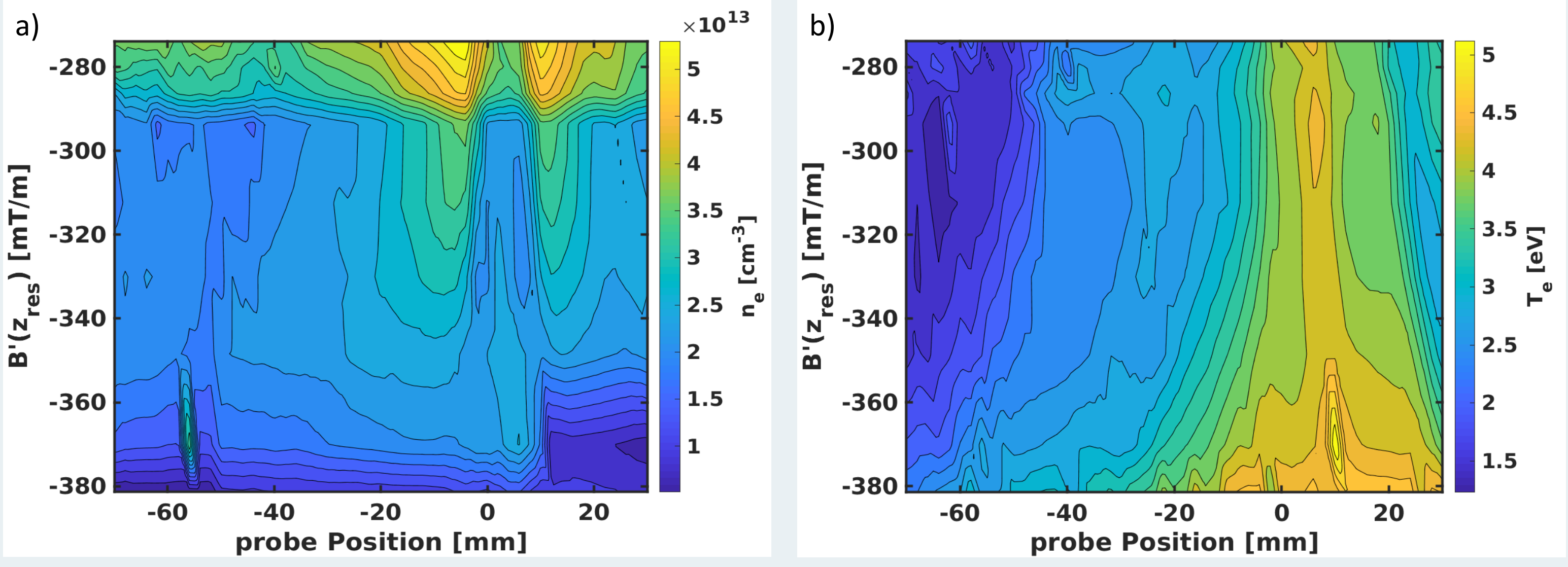
/ CHANGES IN PLASMA PARAMETERS WITH ECR POSITION AND B-FIELD GRADIENT

Figure 2



a) shows the electron density of the plasma, and b) the temperature of the elctrons. Measurement were obtained for Pμw = 20W, flow = 4sccm. The position of the resonance zone at the antenna and the slope of the magnetic field at the resonance have been varied. The x-axis shows the position of resonance, where the position of the antenna is z = -13 cm. The gradient of the magnetic field in the z-direction at this position is displayed along the y-axis. Due to restrictions imposed by the power supply to the coils not all configurations were possible.

Figure 3



a) The electron density and b) the temperature of the electrons measured by a Langmuir probe, obtained at 20W, 4sccm. The slope of the magnetic field at the position of resonance (fixed at the antenna) have been varied. The x-axis shows the radial position of the probe and the y-axis the gradient of the magnetic field in z-direction at resonance. The temperature and electron density agree with particle and energy balance models, respectively.

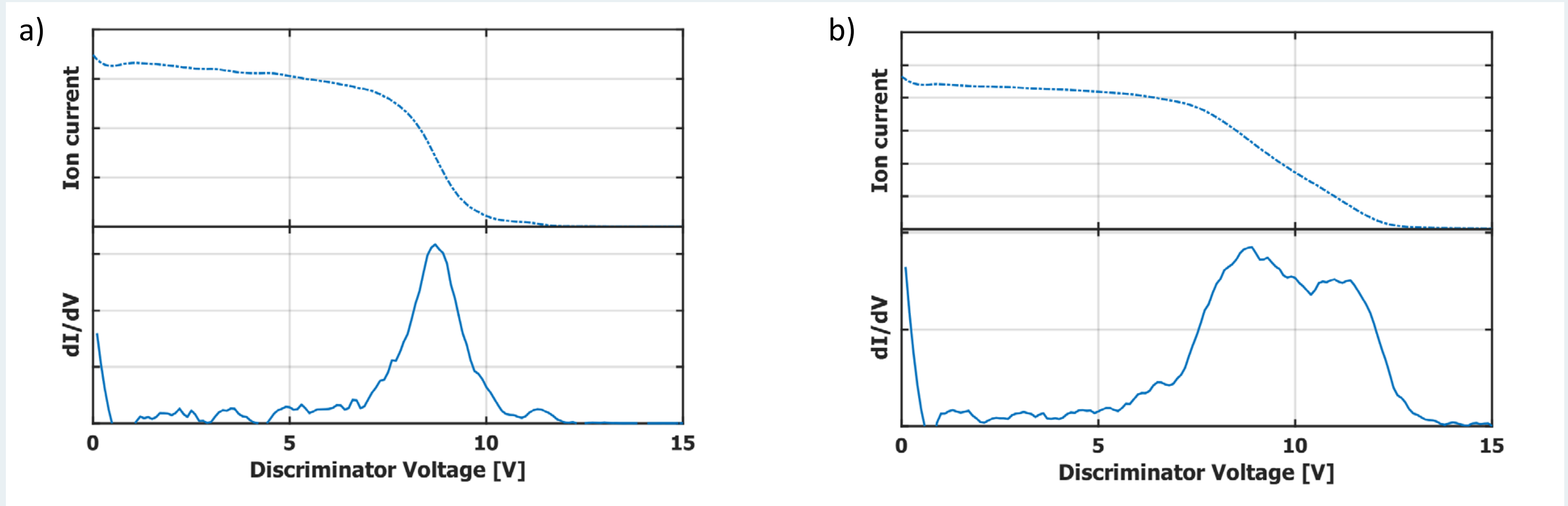
/ CONCLUSIONS

- Results in terms radial profiles of density n_e, electron temperature T_e, plasma potential V_p, and ion energy with respect to the background plasma potential is reported.
- We find that the slope of the field can then be used for tuning as long as the position of the resonance zone stays constant.
- The density profile depends on the shape of the magnetic field and shows signs of inhomogeneity for certain configurations.
- Medium and narrow fields show increasing-energy flanks in the IEDF pointing away from the center of the stream.
- The plasma stream from the source has come to a complete halt at 50 cm from the source, while at 20 cm the speed of the ions equals the ion sound speed of about 4.4 km/s.

This work was supported in full by Dep. Phys. and Technol., UiT The Arctic University of Tromsø

/ RFEA PROBE DIAGNOSTICS

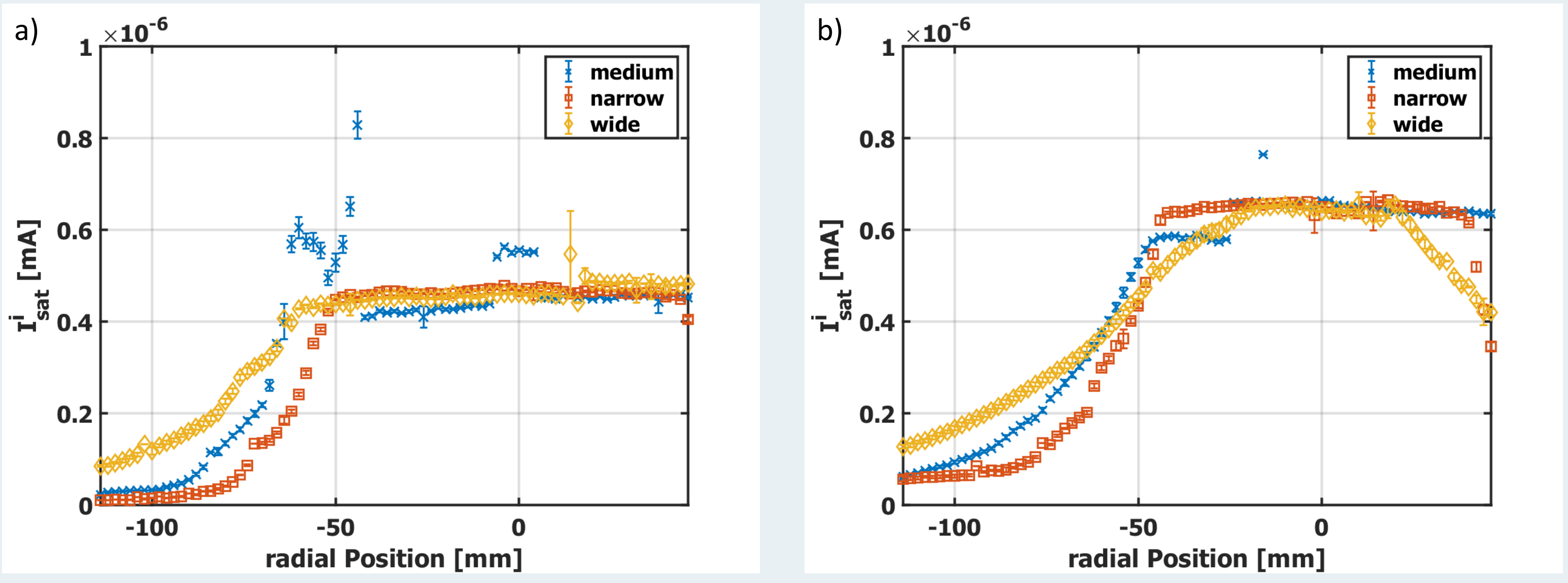
Figure 4



Two examples of RFEA curves. The intensity of the derivative of the current (top) by the discriminator voltage gives the ion velocity distribution function in units of volt (bottom) [4]. In a) is shown a distribution with a single peak around the plasma potential, in b) a distribution that is usually found if two ion-species with different energies is displayed. The sharper the drop on the left hand side of the distribution the lower is the acceptance angle of the probe [5].

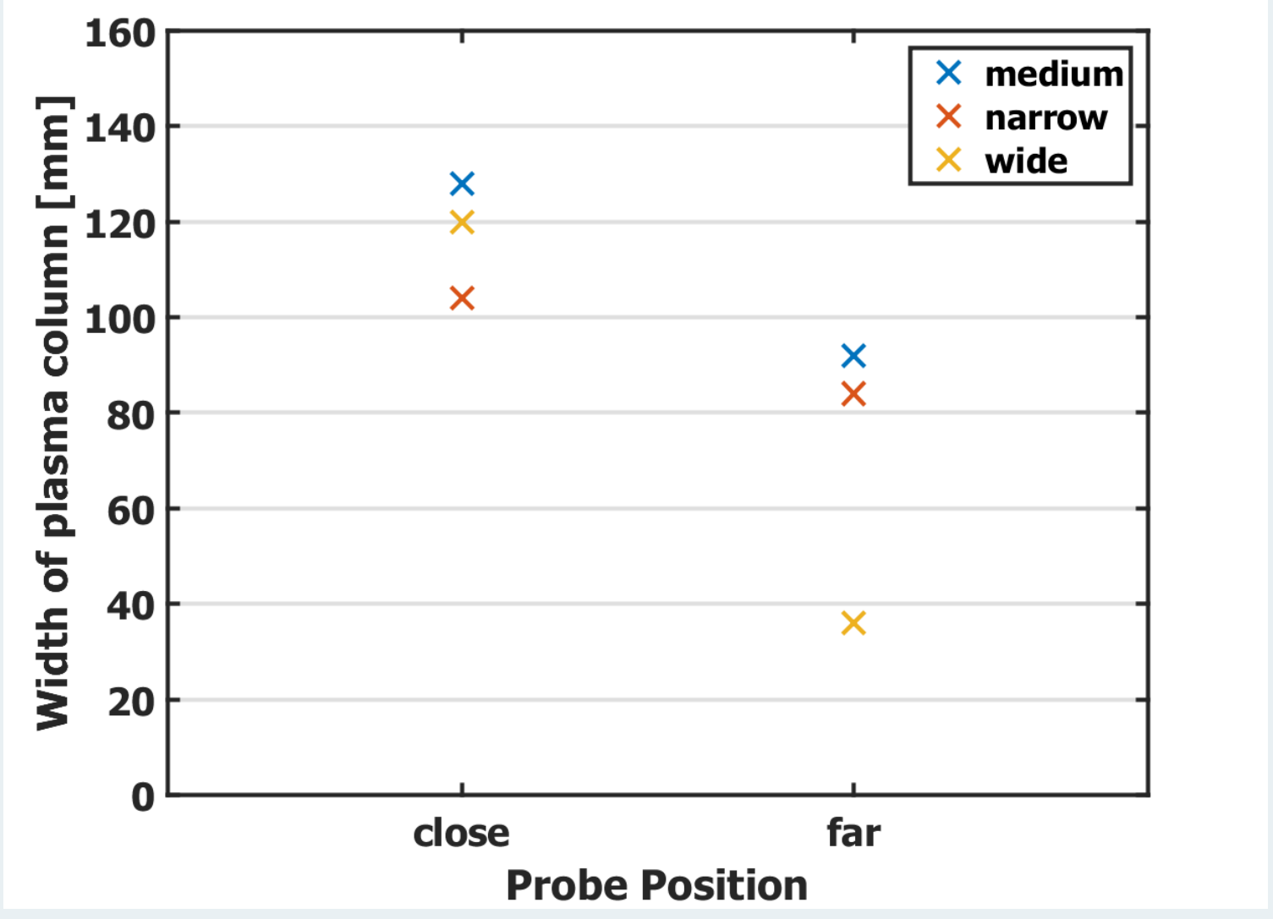
/ WIDTH OF PLASMA

Figure 5



Ion saturation current in radial direction for 20 W, 4 sccm taken at z = 20 cm from (close to) the source (a) and at z = 50 cm (far) from the source. (b). Note: Probe current is not calibrated vs the measurements close to the source.

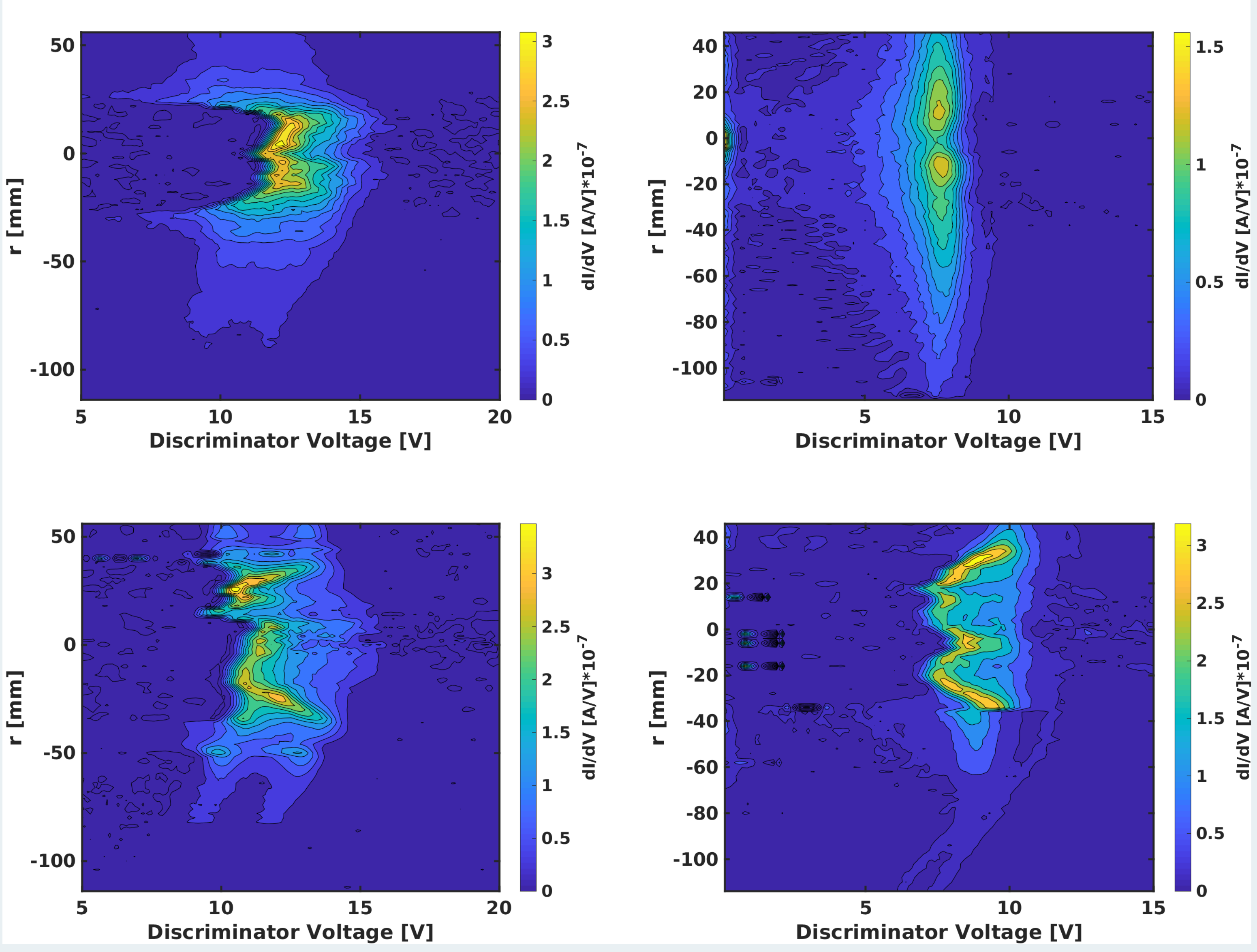
Figure 6



Comparison of the width of the plasma column for the cases shown in Figure 5, at z= 20 cm and z = 50 cm, respectively.
The width was taken as the radial position of the edge of the drop, assuming the plasma is symmetric about r = 0 cm. In all field configurations, the beam is narrower in the far position. The same trend is seen for the half value width in the slope of the density profile.
In the wide configuration the density is spread outwards in the far position, while the region of maximum density becomes narrower. In the other two cases, the overall shape of the density profile is similar in both positions, but narrower in the far position. This may be due to a focusing effect of the magnetic field, or that the density erodes faster near the edge.

/ ION ENERGY DISTRIBUTIONS ALONG THE RADIAL CROSS-SECTION

Figure 7



Ion energy distribution in the radial direction. Left column: close position, Right column: far position. Top row: wide configuration, bottom row: narrow configuration. Measurements were taken with P = 10W, flow = 4sccm.
Close to the source we see a double-distribution when going away from the middle of the stream. Especially for the narrow configurations we see peaks in the distributions starting in the middle at lower energies and moving towards the higher energy peak when going radially outwards. The magnetic field also plays a huge role in confinement as the iedf from the wide configuration has almost evened out behind the second coil. Note: Radial scales in near and far positions are not equal.

/ REFERENCES

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