Universität Augsburg
Mathematisch-Naturwissenschaftlich-Technische Fakultät

MAX PLANCK INSTITUTE FOR PLASMA PHYSICS

Mach probe diagnostic for determining positive ion fluxes in H^- ion sources

V. Wolf[1], D. Zielke[2], D. Rauner[1], S. Briefi[2], C. Wimmer[2] and U. Fantz[1,2]

[1]EPP Uni Augsburg, [2]IPP Garching

8th NIBS conference, 03rd – 07th Oct 2022, Padova, Italy

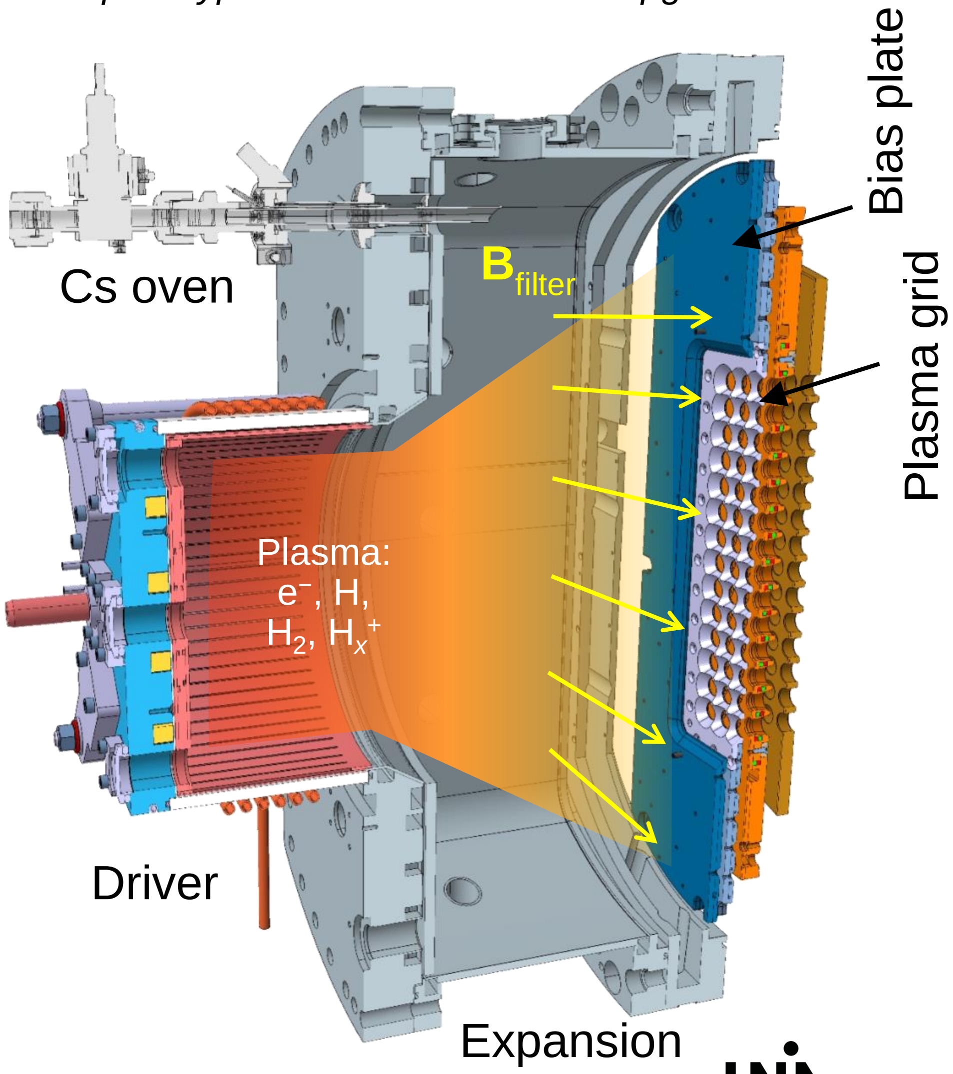
Motivation

- In driver region a plasma is generated, H, H_2, H_x^+ and e^- are being transported to the plasma grid (PG)
- At PG surface H^- are generated by conversion of H & H_x^+
- Where and how do particles reach the PG?

→ Knowledge of positive ion flux is crucial for optimizing ion sources

→ Mach probe (MP): determine Mach number and orientation of positive ions

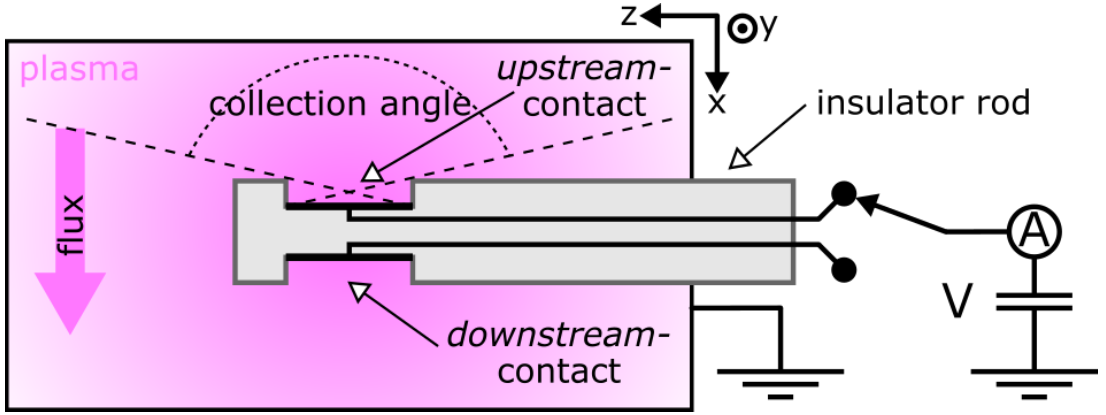
IPP prototype ion source BATMAN Upgrade:



Mach probe (MP)

General measuring method

- Determine flow velocity by comparing ion saturation current on opposed contacts (I_{upstream}, $I_{\text{downstream}}$)
- Determine flow orientation in 2D: At least two contact pairs

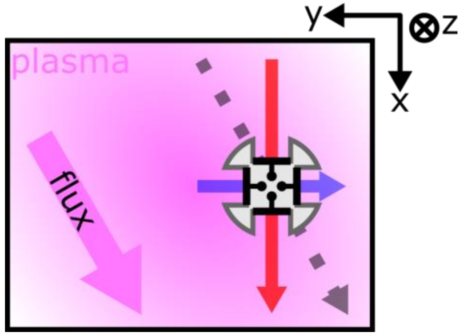


<u>Calculation of Mach number *M*:</u>

$$M = \frac{v}{c_{\text{s,i}}} = \frac{1}{K} \ln\left(\frac{I_{\text{upstream}}}{I_{\text{downstream}}}\right)$$

v: absolute ion flow velocity
$c_{\text{s,i}}$: ion sound velocity

→ Calibration necessary (K):
Correlation between ion flow and detected current via theoretical model

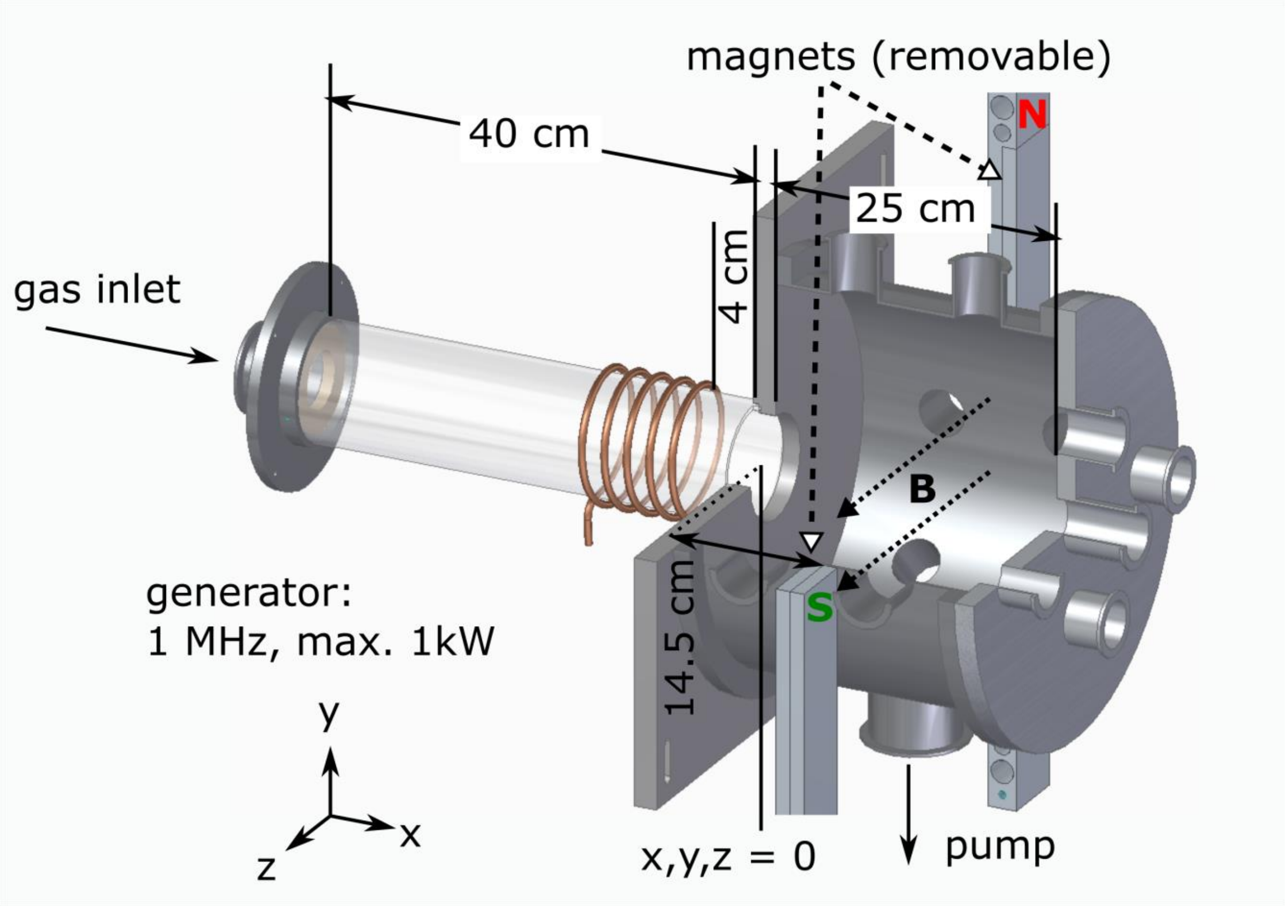


Experimental approach

Overview

- Two – Step approach:
  1. Characterising Mach probe in versatile lab experiment (Uni Augsburg)
  2. With lessons learned, design new probe and apply it to ion source (IPP Garching)

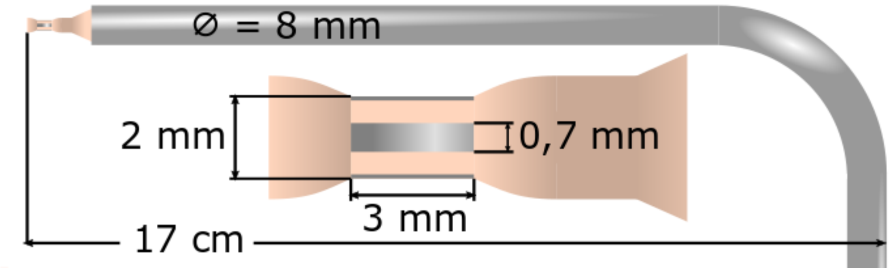
- Step 1: Lab experiment (CHARLIE):
  - ICP – discharge, plasma is expanding in stainless steel vessel
  - H_2 – plasma at low power, pressure in pascal range
  - Additional diagnostics for plasma parameter determination: Langmuir probe, OES



Experimental setup

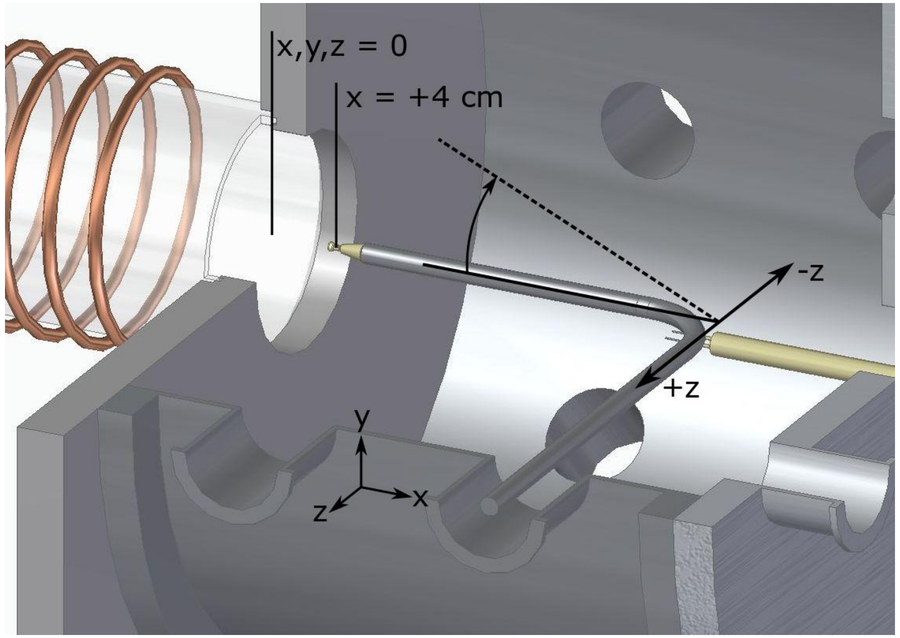
Lab experiment (CHARLIE, Uni Augsburg)

- Recommissioned Mach probe:
  - L-shaped geometry: Four-Pin-Probe can be rotated up and down
  - Contact sensitivity correction: Symmetry point needed



- Recording of full $I - V$ characteristic: T_e and n_e accessible

- Calibration ($\frac{T_i}{T_e}$, $\frac{\lambda_{debye}}{r_{probe}}$ & $\frac{r_{probe}}{r_{larmor}}$ considered):

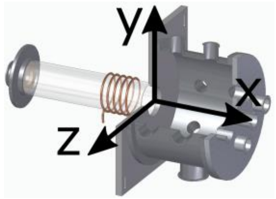


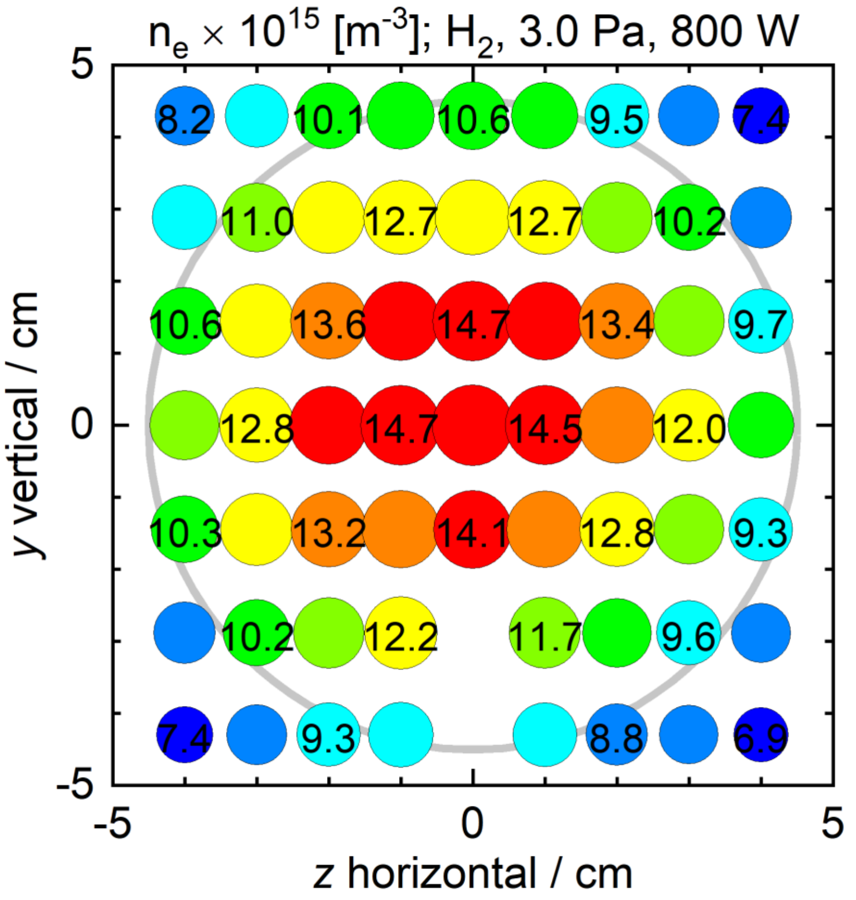
According to Hutchinson model[1]:
→ For |**B**| = 0: $K = 1.34$
→ For |**B**| = $B_0 \approx 8$ mT: $K = 1.37$

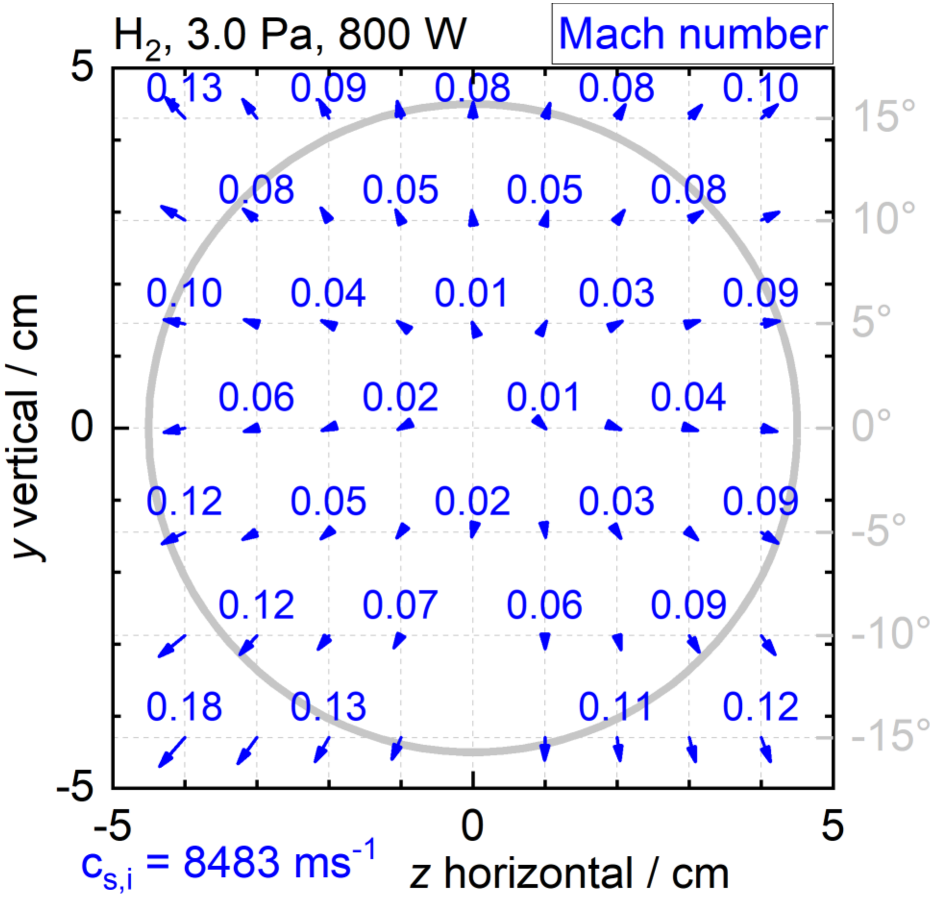
[1]I. H. Hutchinson, *Ion collection by a sphere in a flowing plasma: 1.Quasineutral*, Plasma Phys. Control. Fusion **44** (2002), 1953.

Results

Lab experiment (CHARLIE) – density distribution and flow velocity & orientation







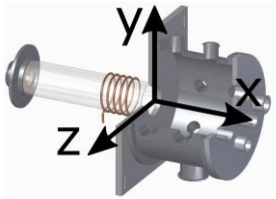
Fick‘s law: $\Gamma = -D\nabla n$

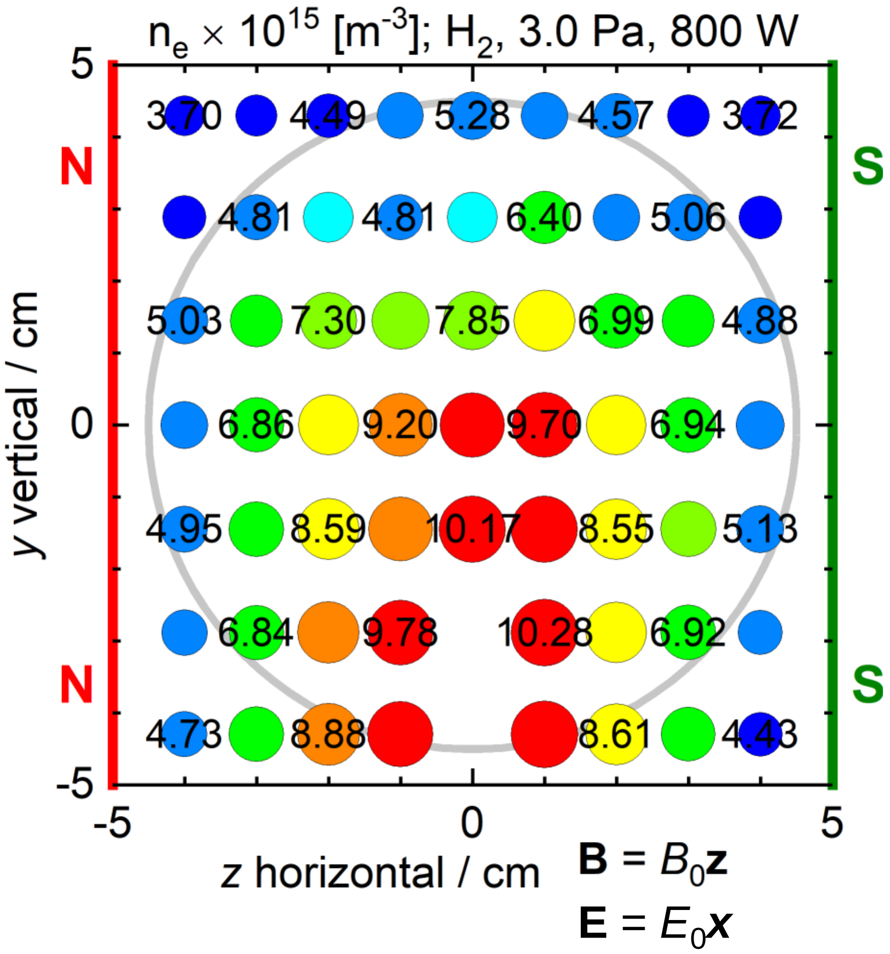
→ density gradient leads to according flux

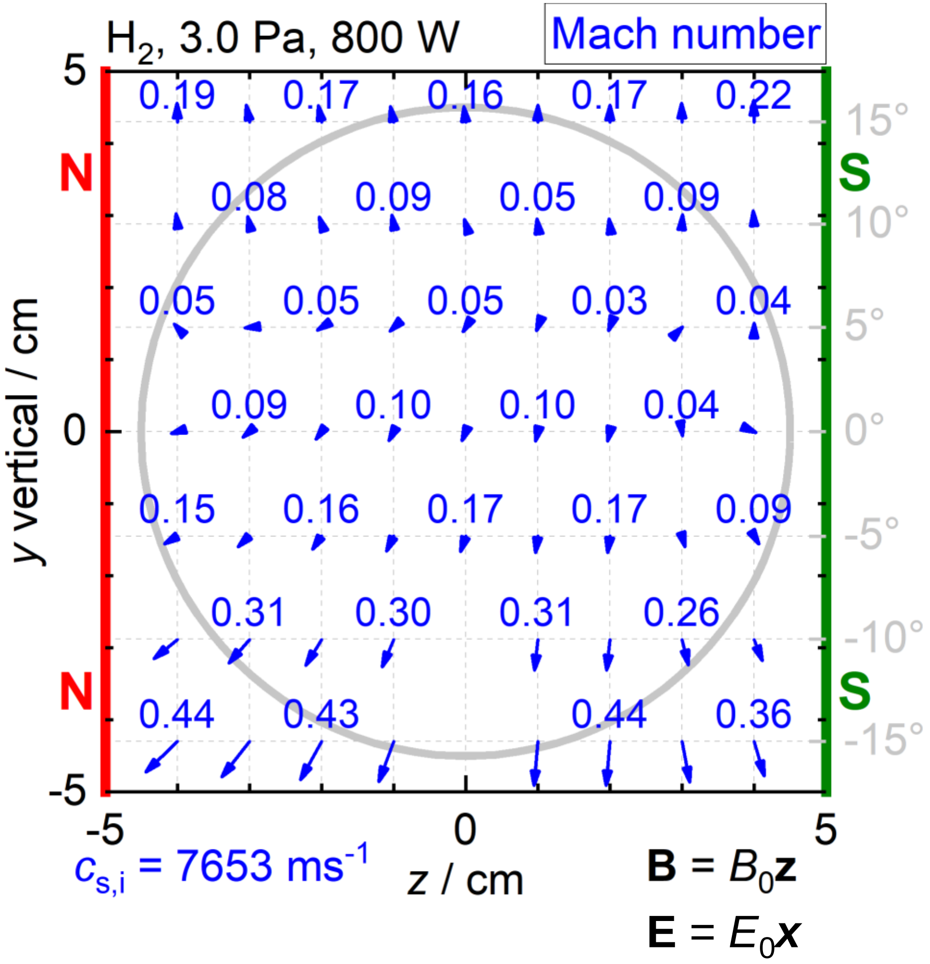
→ Both density gradient and flow velocity increase with distance to plasma centre

Results

Lab experiment – density distribution and flow velocity & orientation with magnetic field







→ Plasma drifts due to magnetic field and gradients in *x*:

E × B: $\vec{v}_D = \frac{\vec{E} \times \vec{B}}{B^2}$

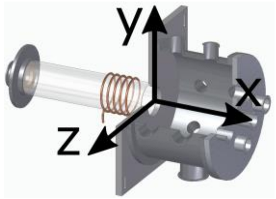
diamagnetic: $\vec{v}_D = -\frac{\vec{\nabla} p \times \vec{B}}{enB^2}$

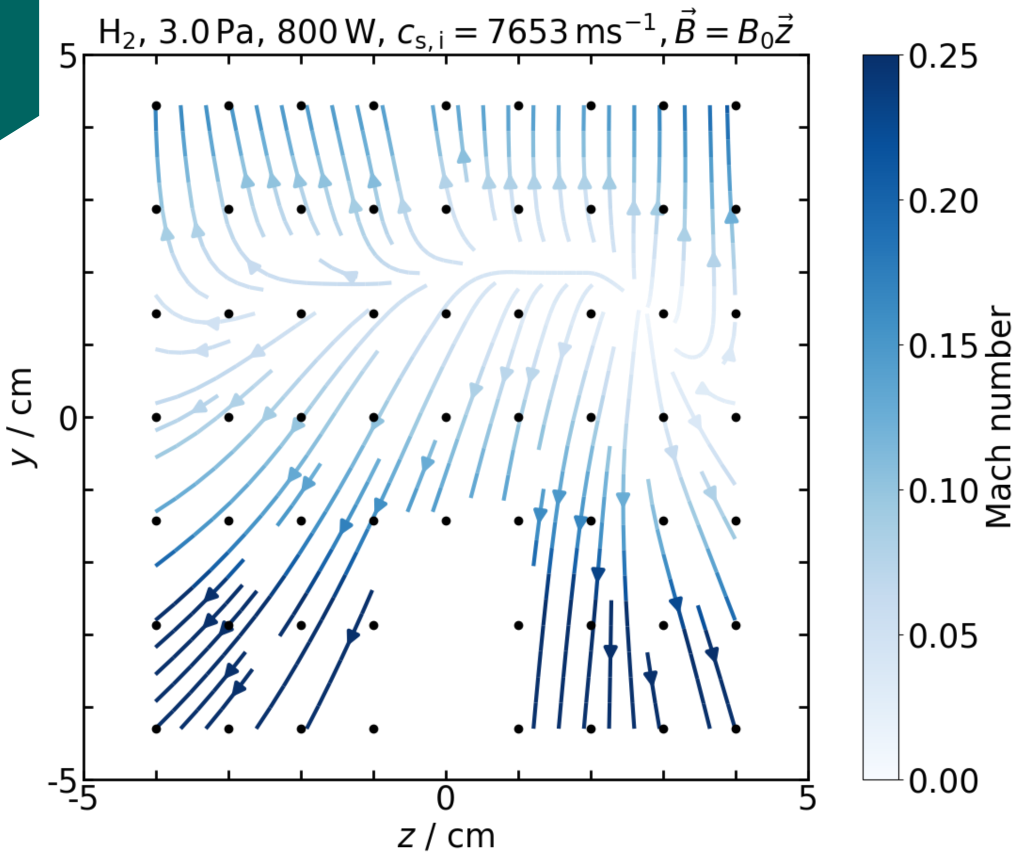
grad(**B**): $\vec{v}_D = -\frac{mv_\perp^2}{2eB^3} \vec{\nabla} B \times \vec{B}$

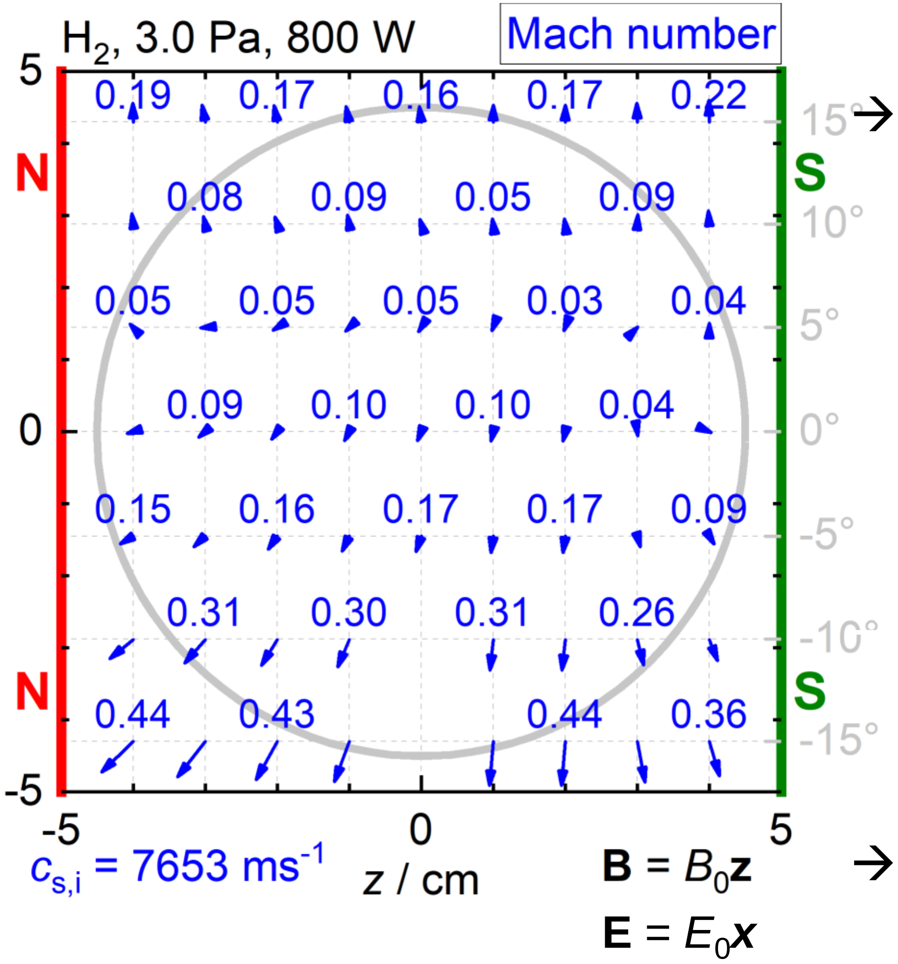
→ Drift down for positive ions

Results

Lab experiment – density distribution and flow velocity & orientation with magnetic field







→ Plasma drifts due to magnetic field and gradients in *x*:

E × B: $\vec{v}_D = \frac{\vec{E} \times \vec{B}}{B^2}$

diamagnetic: $\vec{v}_D = -\frac{\vec{\nabla} p \times \vec{B}}{qnB^2}$

grad(**B**): $\vec{v}_D = -\frac{mv_\perp^2}{2qB^3} \vec{\nabla} B \times \vec{B}$

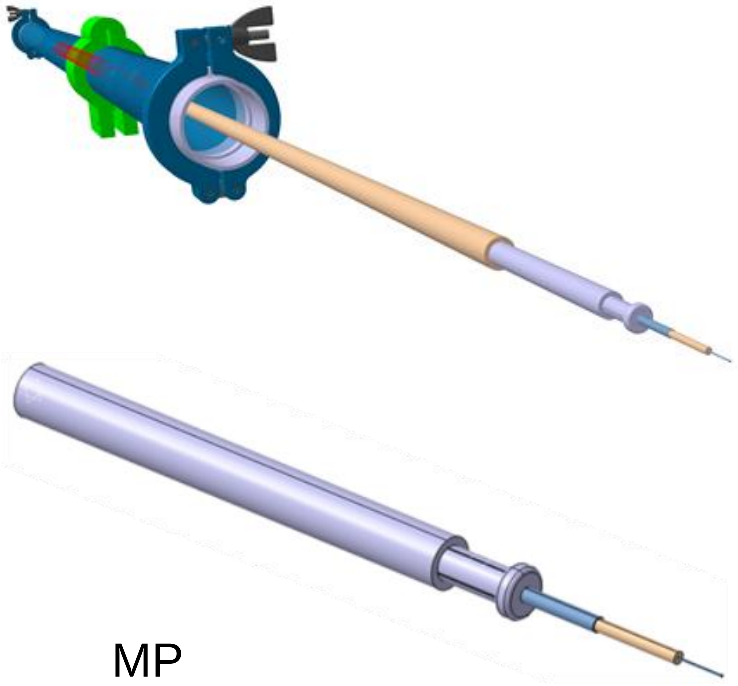
→ Drift down for positive ions

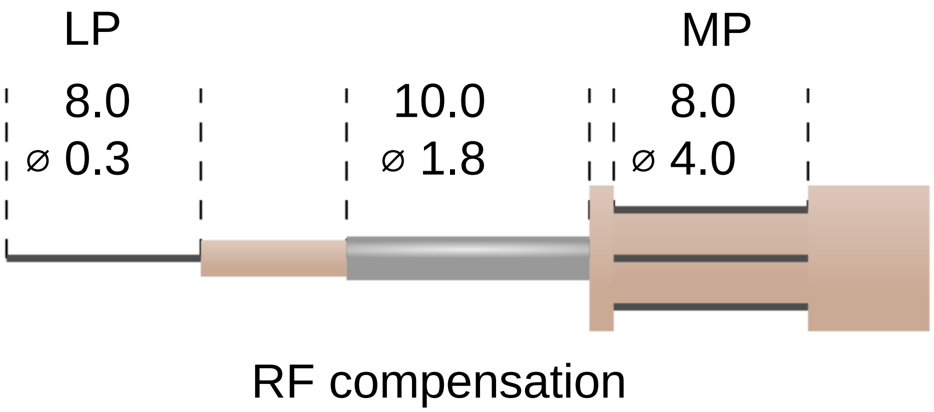
Experimental setup

Ion source (BATMAN Upgrade, IPP Garching)

- Step 2: new probe design, linear four-pin Mach probe
- Incorporating lessons learned at lab experiment:
  - Rotatability used for correction of contact sensitivity imparities
  - Langmuir probe (LP) at the tip with RF compensation electrode (simultaneous determination of T_e, n_e, n_i, V_float, V_plasma)
- Calibration ($\frac{T_\mathrm{i}}{T_\mathrm{e}}$, $\frac{\lambda_\mathrm{debye}}{r_\mathrm{probe}}$ & $\frac{r_\mathrm{probe}}{r_\mathrm{larmor}}$ considered):

According to Hutchinson model[1]:
→ For $|\mathbf{B}| = 0$: $K = 1.34$
→ For $|\mathbf{B}| = B_1 \approx 6$ mT: $K = 1.38$

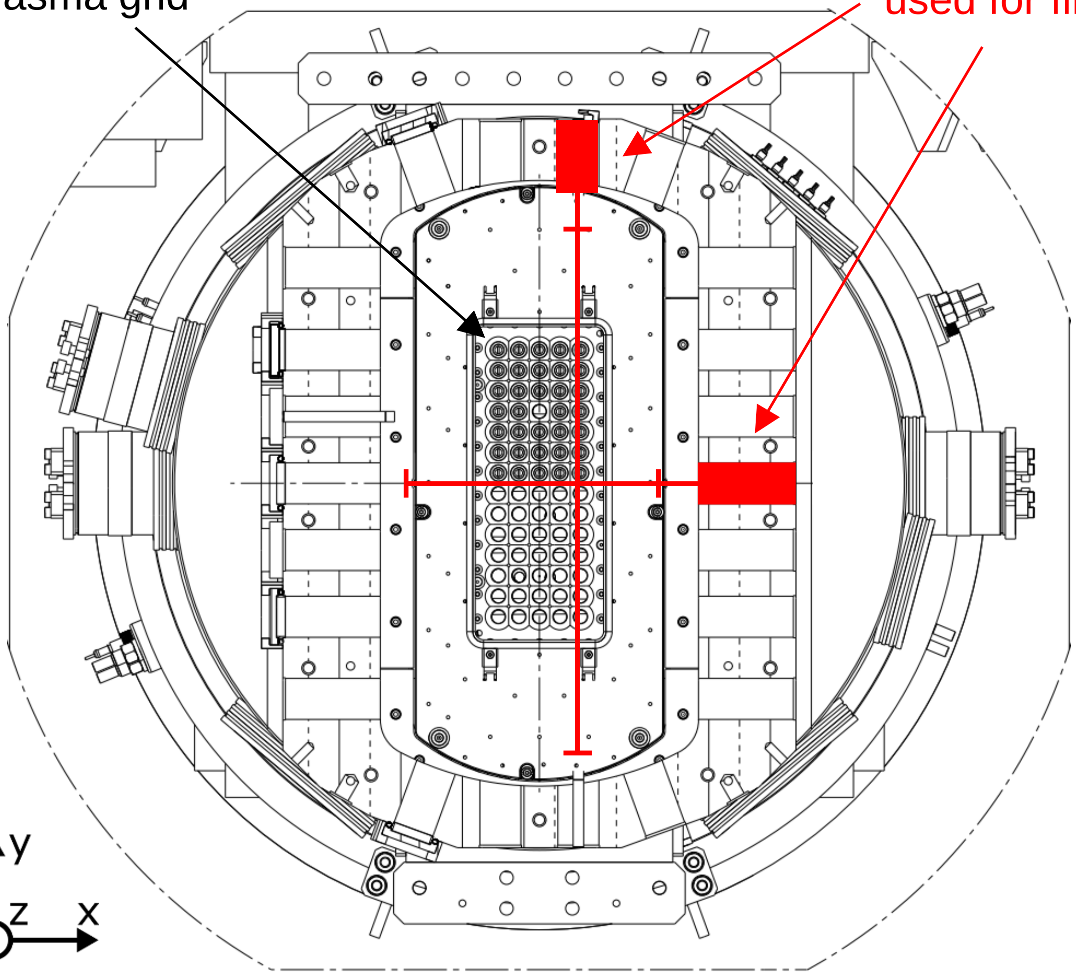


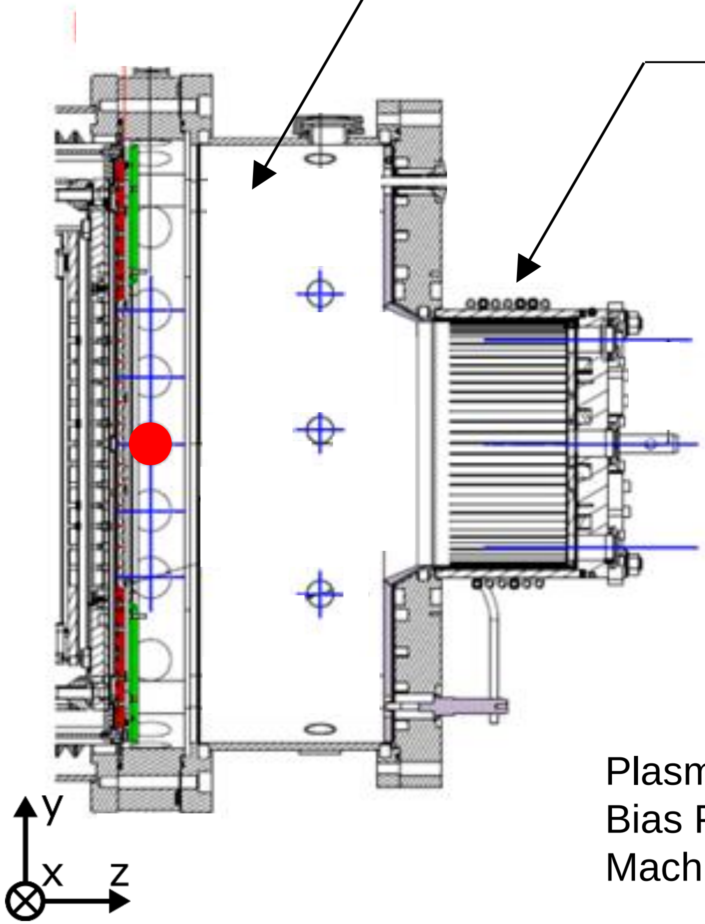


[1] I. H. Hutchinson, *Ion collection by a sphere in a flowing plasma: 1.Quasineutral*, Plasma Phys. Control. Fusion **44** (2002), 1953.

Experimental setup

Ion source (BATMAN Upgrade)





H_2 plasma settings:

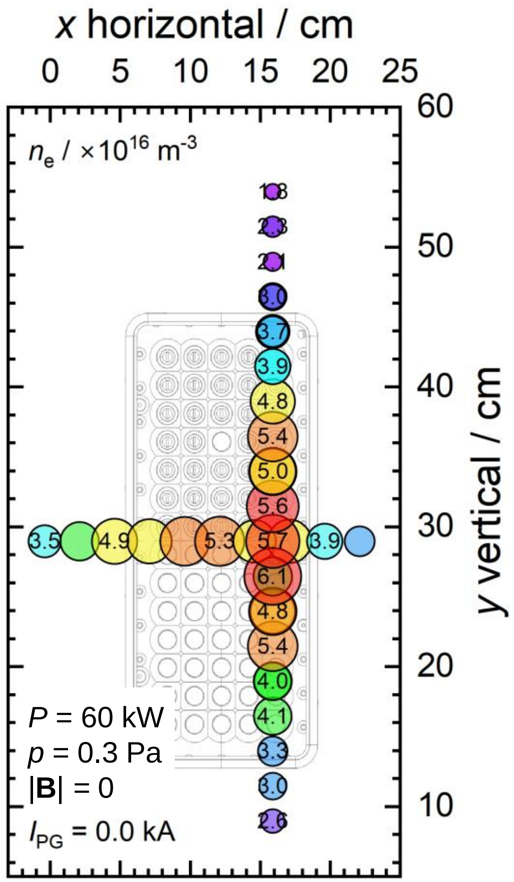
Power	60 kW
Pressure	0.3 Pa
B	0 – 6 mT

Without Cs
No Extraction

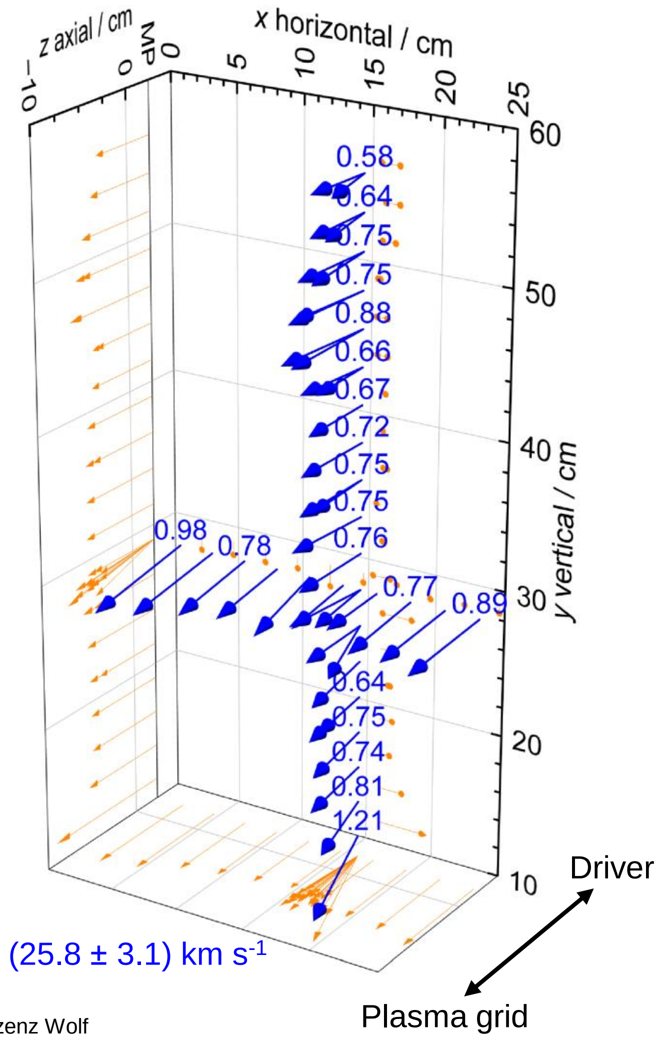
Plasma Grid (PG): $z = 0.0$ cm
Bias Plate (BP): $z = 1.3$ cm
Mach Probe (MP): $z = 2.5$ cm

Results

Ion source (BATMAN Upgrade) – density distribution and flow velocity & orientation (|**B**| = 0)



V_{bias} = (13.4 ± 0.8) V
V_{plasma} = (26.7 ± 3.3) V



$c_{s,i}$ = (25.8 ± 3.1) km s^{-1}

Successfull probe commissioning:
Flux and plasma parameters can be derived with new device

→ First results obtained

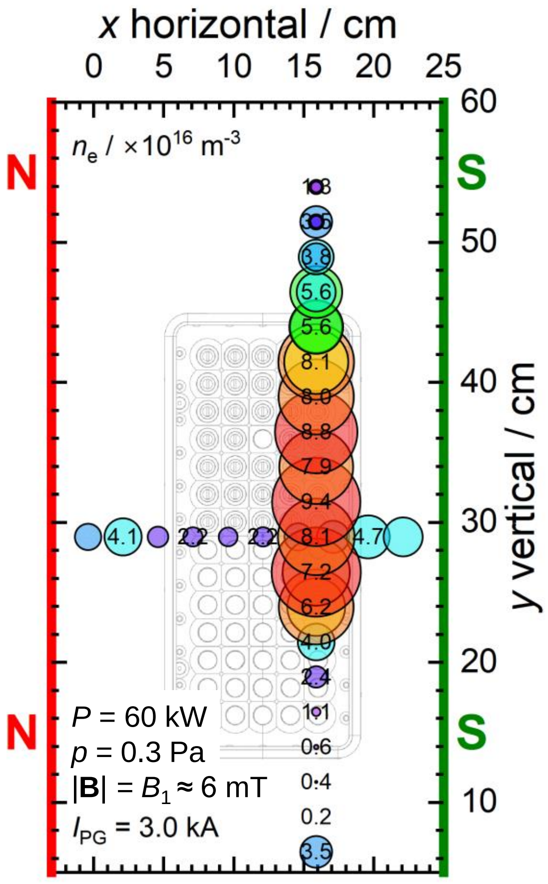
→ Flux oriented towards PG with mostly uniform velocity

→ Radial oriented density gradient (n_e & n_i)

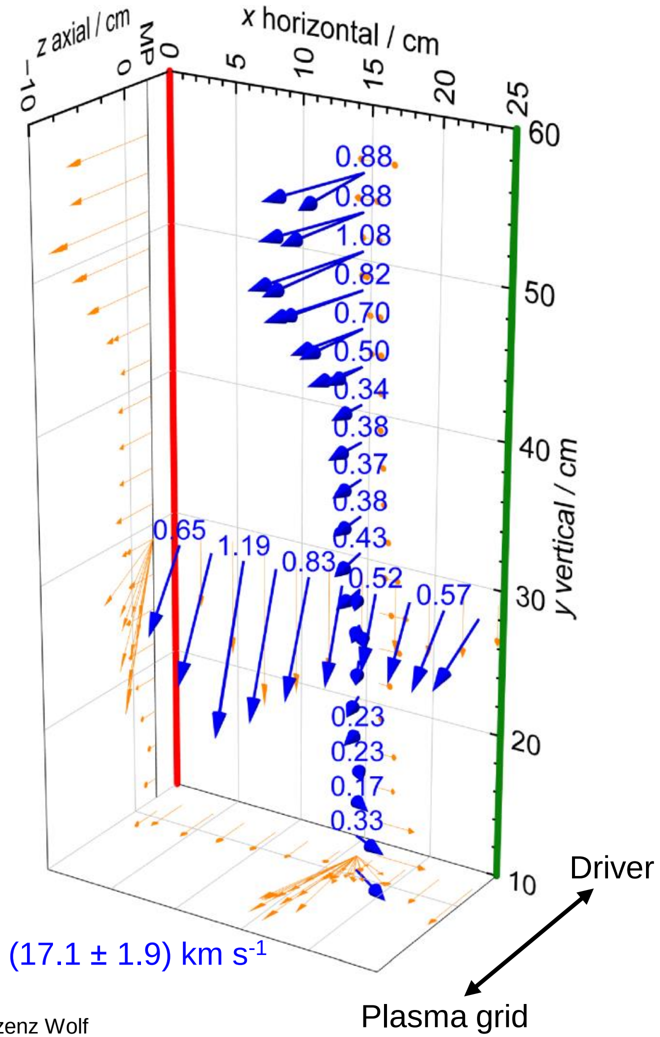
Due to probe geometry:
Cannot resolve flux along measurement axis here!

Results

Ion source (BATMAN Upgrade) – density distribution and flow velocity & orientation (|**B**| = B_1)



V_{bias} = (29.1 ± 0.4) V
V_{plasma} = (25.4 ± 4.2) V



$c_{s,i}$ = (17.1 ± 1.9) km s^{-1}

→ As in lab experiment:
Drifts lead to downward flux (−y)

→ Density maximum shifted upwards (+y)

→ Physical interpretation not straightforward:
Fluid modelling approach necessary

→ *Recommended talks by*
D. Zielke: Tuesday, 10:50
S. Briefi: Tuesday, 11:50

Due to probe geometry:
Cannot resolve flux along measurement axis here!

Summary and Outlook

Lab Experiment:

→ Positive ion flux determined successfully ✓

→ Lessons learned for new probe ✓

Ion Source:

→ MP commissioned at ion source ✓

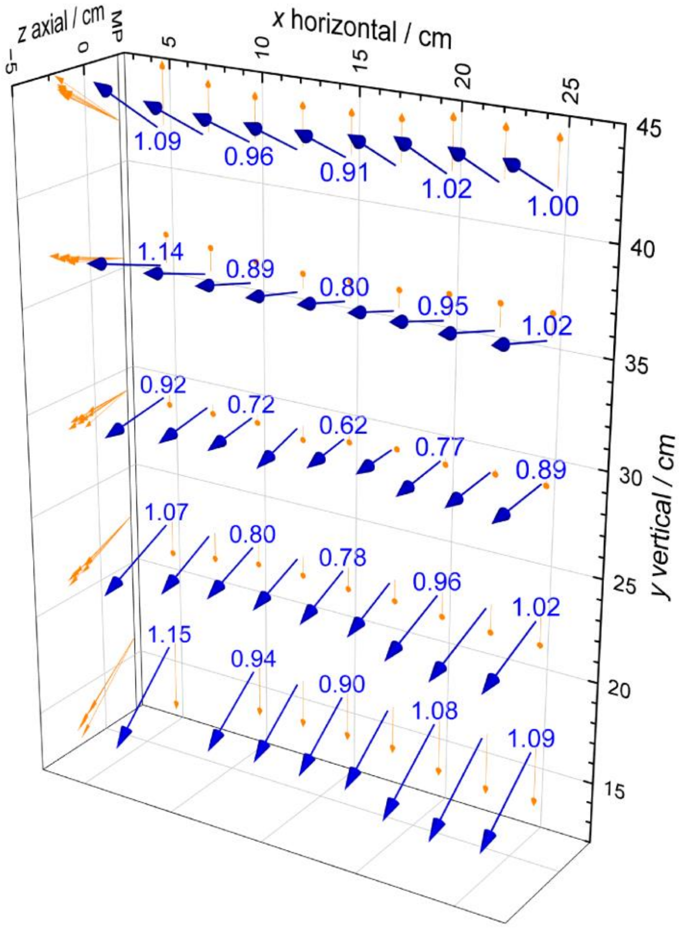
→ First results obtained ✓

Outlook:

→ 2D array scans (see right, **B** = 0)

→ Measurements in expansion region

→ Benchmark fluid simulation



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Many thanks for your attention!

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