PWIE Meeting 2025

TOMAS: Status and plans for 2025

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LPP-ERM/KMS

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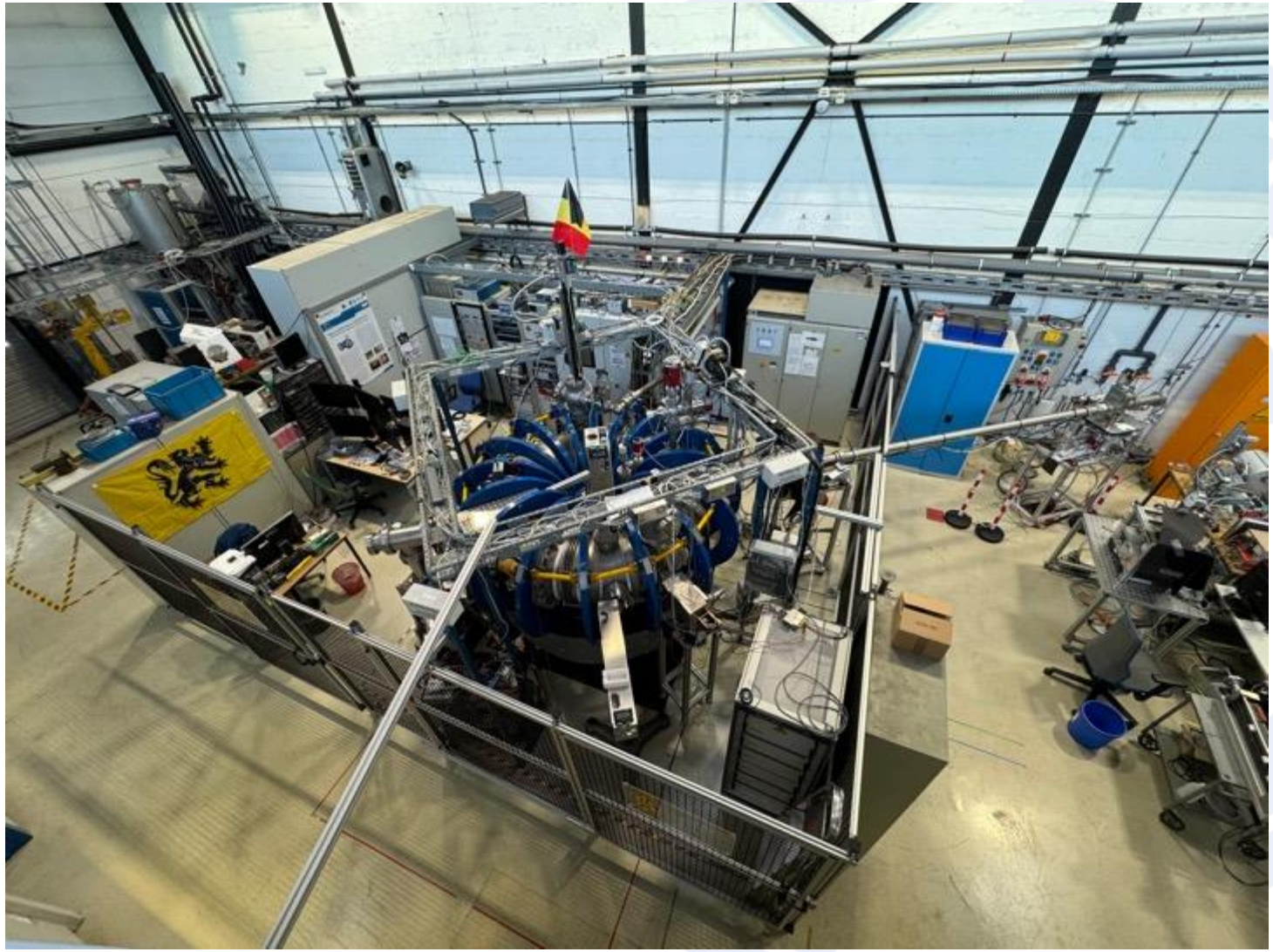
Outline

- Upgrades of the device
  - Technical upgrades
  - Upgrades to the diagnostics
  - Upgrades to the heating systems
- Plans for physics studies
  - Characterization of wall conditioning plasmas
  - Studies of boron layer erosion
  - Implementation of in-situ boronization studies
  - Further plans

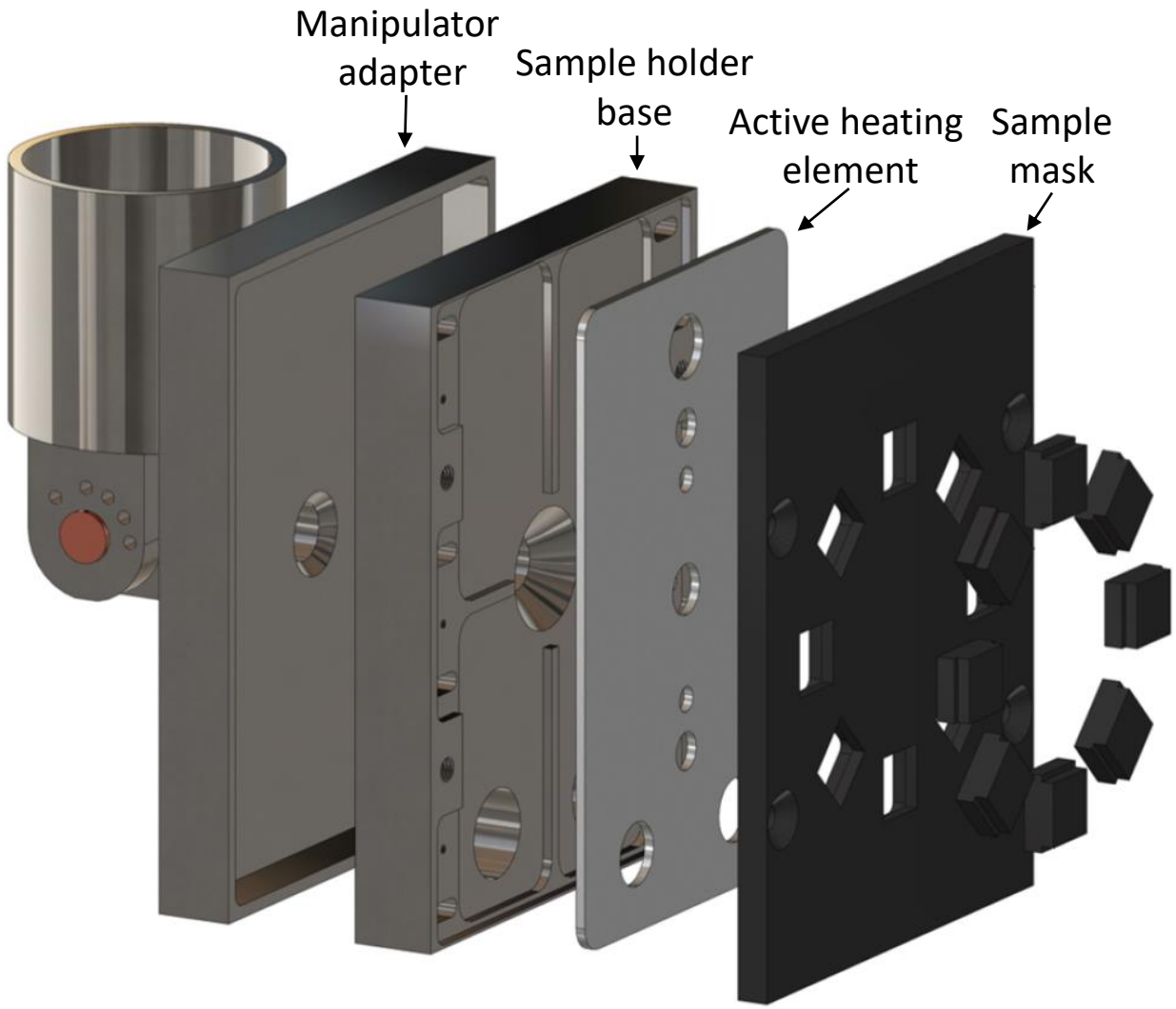
Upgrades to the TOMAS device

Technical upgrades

- Magnetic field system
  - Full integration of the magnetic field system to the TOMAS control system
  - Installation of temperature, pressure, and conductivity sensors for safety routines
- Gas injection system
  - Upgrades to the vacuum pump and valves
  - Improvement of the control and safety
- Building of maintenance stage
  - Progress to improve the safety and separate electrical cables and pipes



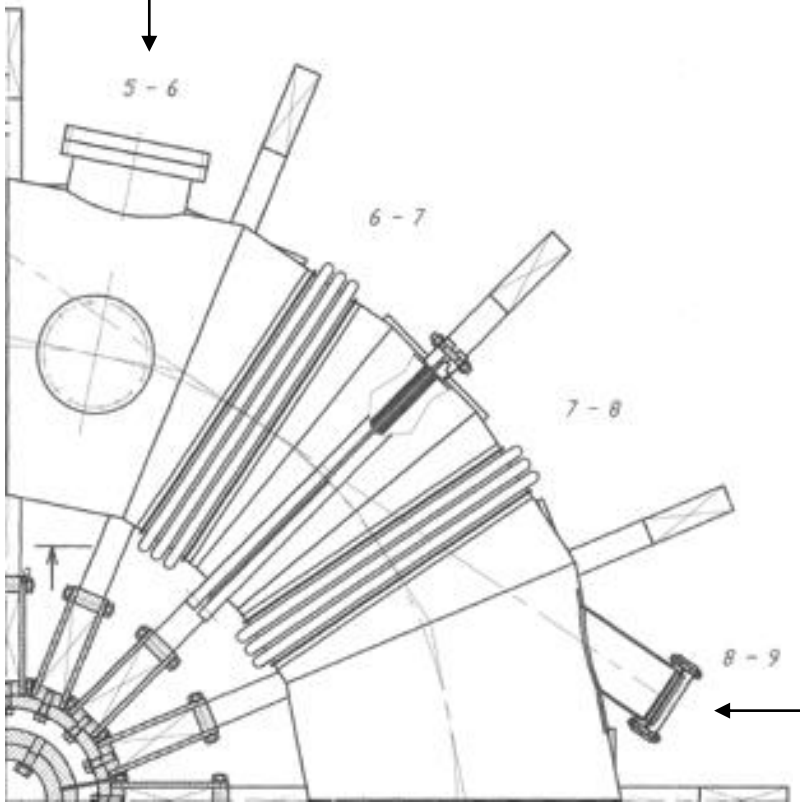
Upgrades to the diagnostics



- Sample load-lock system
  - Addition of active water cooling
  - Exchangeability between Residual Field Energy Analyzer (RFEA) and active heating element
  - Implementation of the three-dimensional movement
  - Integration to the control system
- Video diagnostics
  - Installation of high-resolution video cameras and integration to the control system

Upgrades to the heating systems

Current ECRH launching port



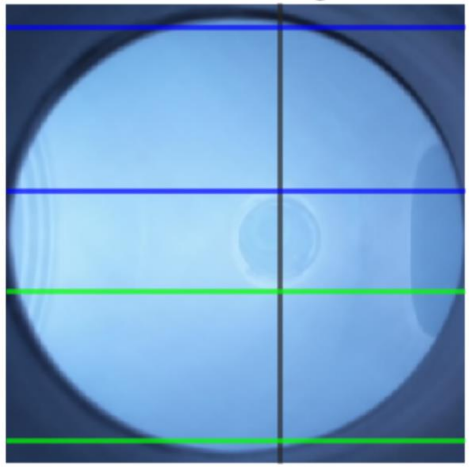
Port for tangential launching

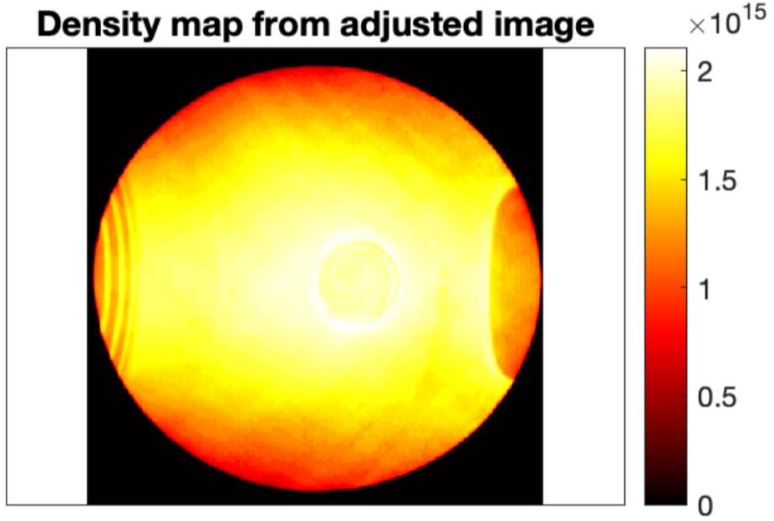
- Extension of the ECRH system
  - Addition of a 2 kW gyrotron to increase the total power
  - Use of the tangential port
  - Installation of waveguide tuners, mode convertors, polarizers, vacuum windows, cooling elements
  - Integration of the new gyrotron to the control system

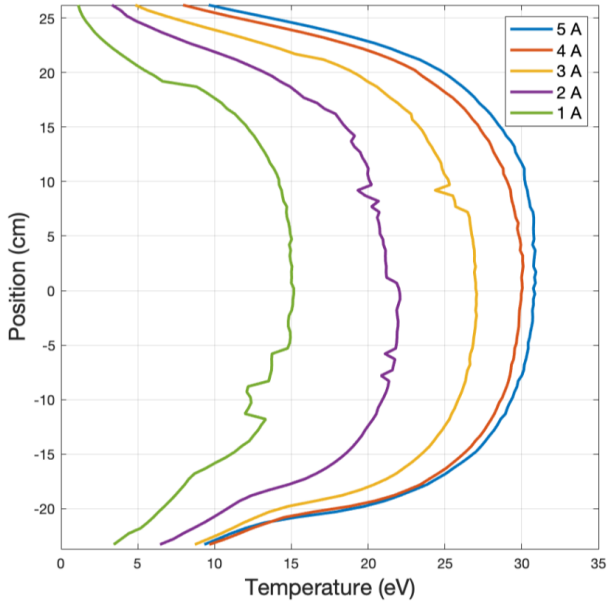
Plans for physics studies on TOMAS

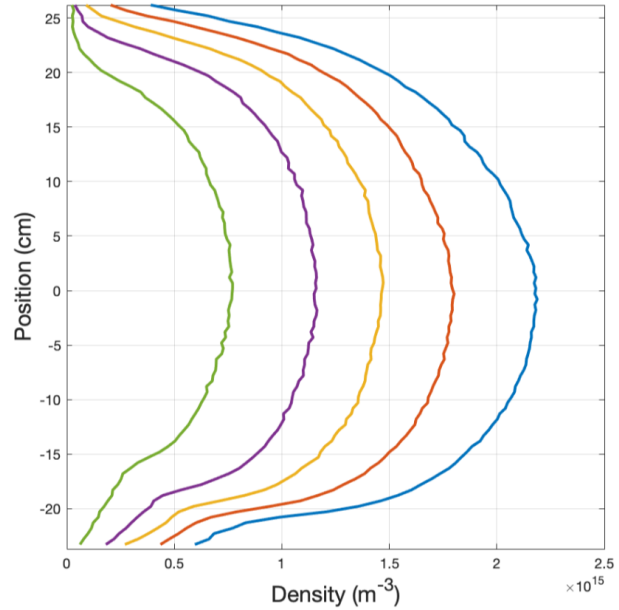
Glow discharge characterization

- Measurement of electron density and temperature profiles
  - In hydrogen, helium, argon, and deuterium
  - Use of a movable triple Langmuir probe for radial and vertical profiles
  - Use of camera images for estimating the 2D density map





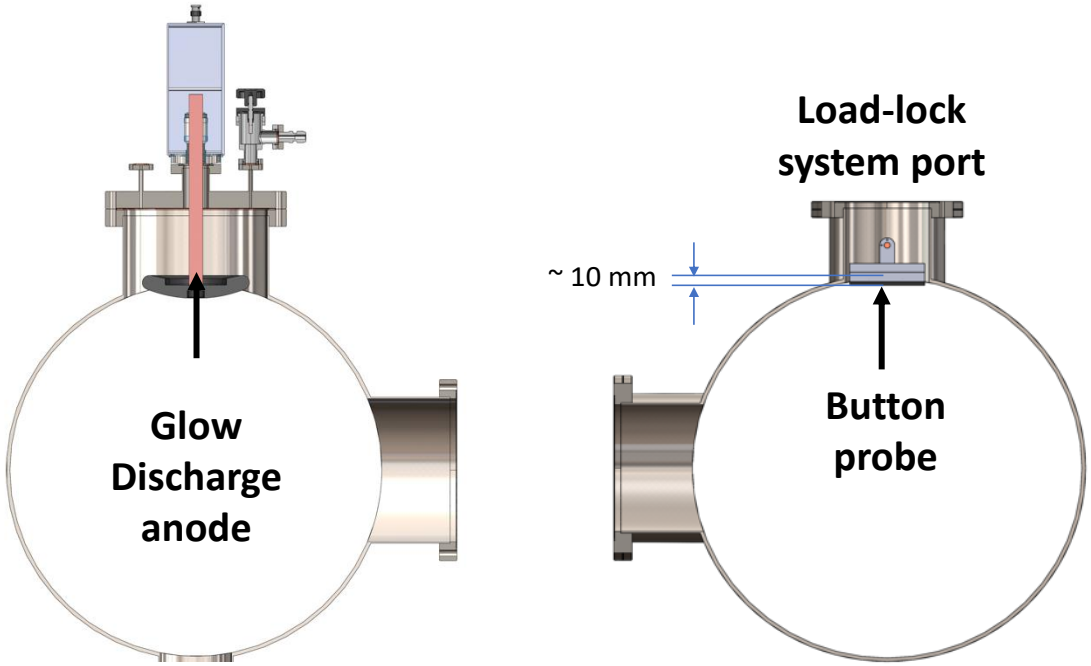


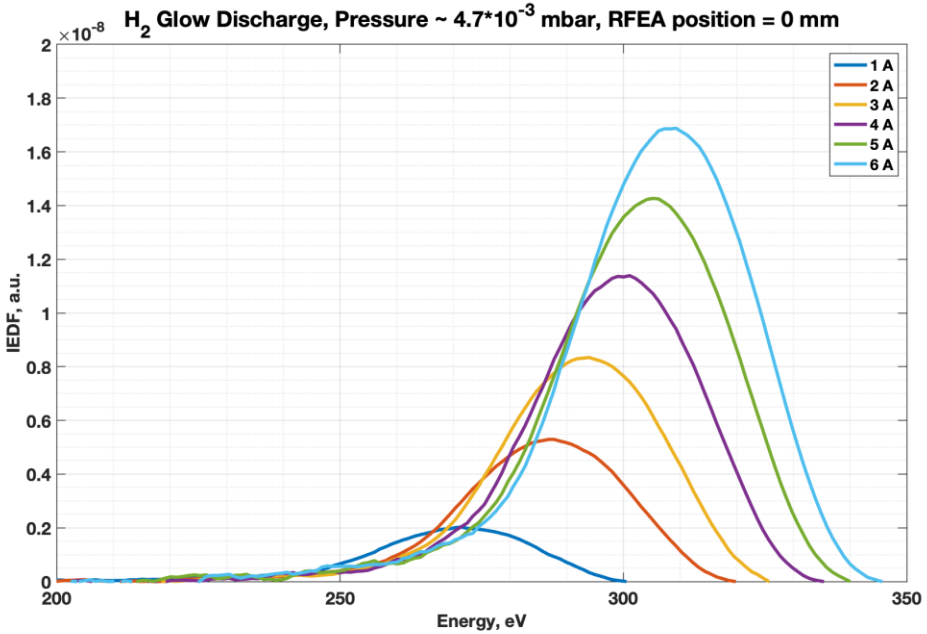


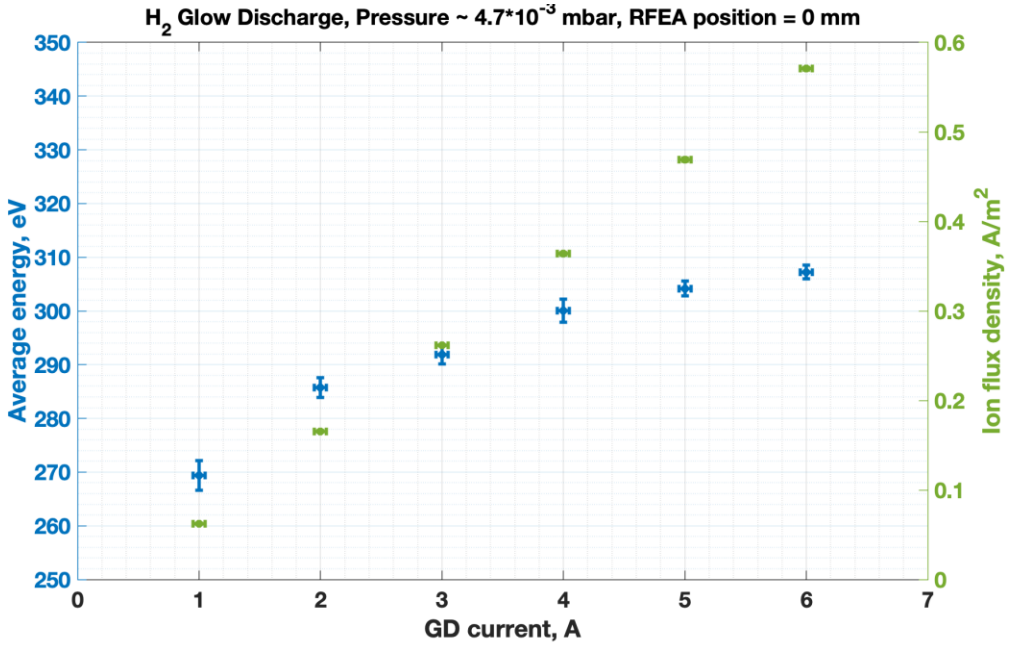
N. Desmet, "Determination of the Vertical Density and Temperature Profiles in an ECRF Plasma in the TOMAS Device", Master thesis, LPP-ERM/KMS (2023)

Glow discharge characterization

- Measurement of local glow discharge ion energy distribution
  - Use of Residual Field Energy Analyzer (RFEA) with the new probe
  - Estimation of the local flux of ions



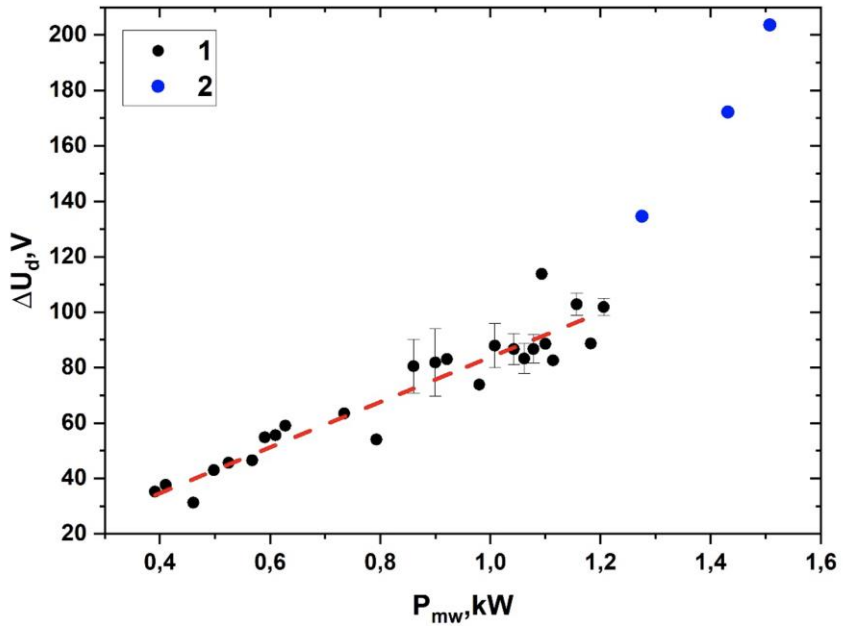


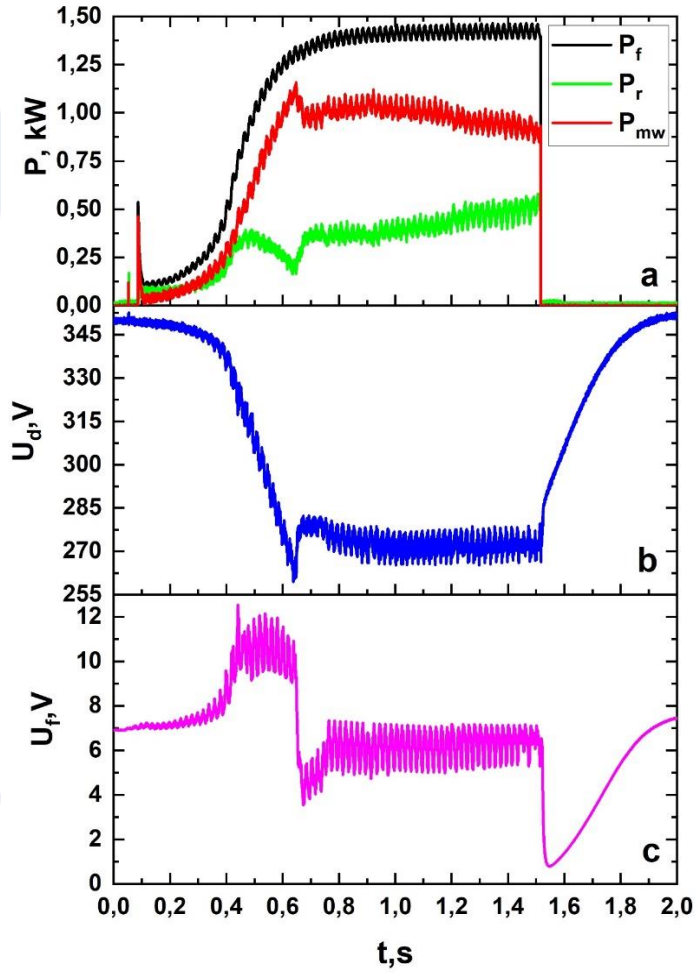


K. Crombé et al., IAEA FEC 2023, London, 2023.

Characterization of combined glow discharges and microwave discharges

- Combination of glow discharges and microwave discharges
  - Use of gyrotron to add microwave power to glow discharges on TOMAS
  - Modification of the glow discharge voltage as a function of the injected microwave power

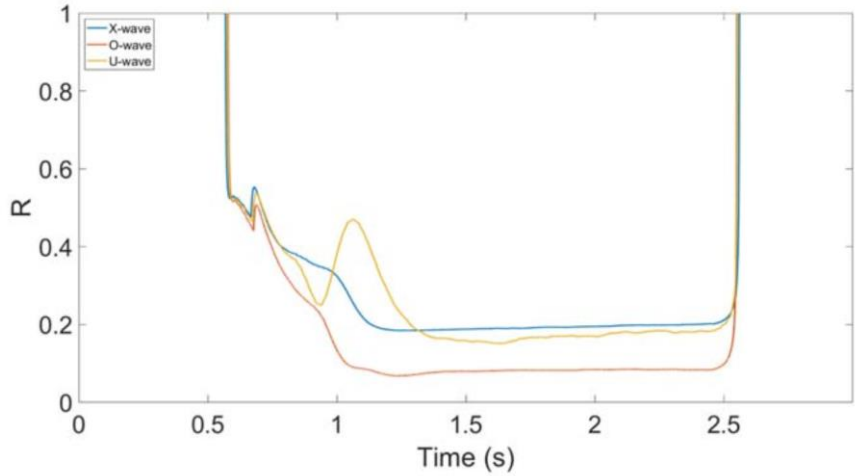


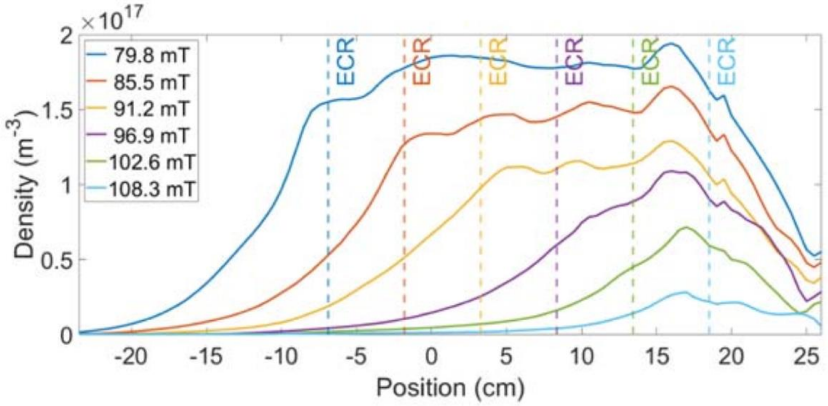


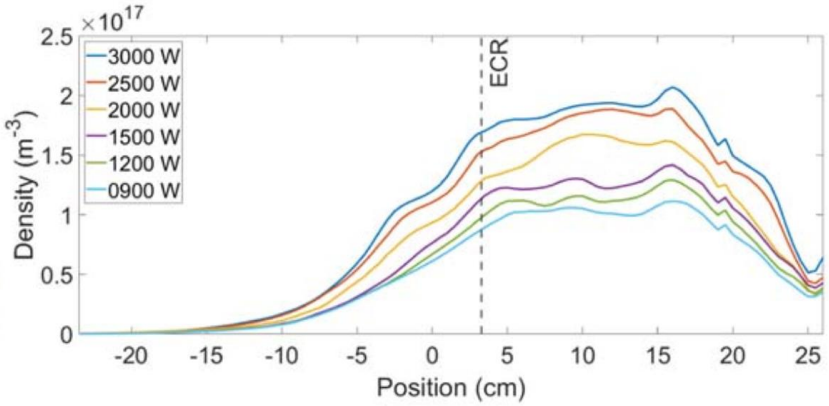
Yu. Kovtun et al., AIP Conference Proceedings 2984, 110001 (2023)

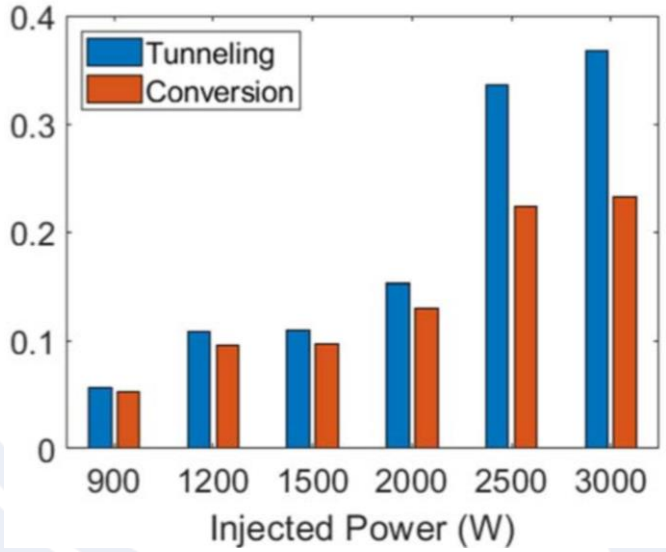
Electron cyclotron wall conditioning characterization

- Studies of wave absorption and propagation
  - Influence of wave polarization
  - Influence of injected power, intensity of the magnetic field, and gas pressure





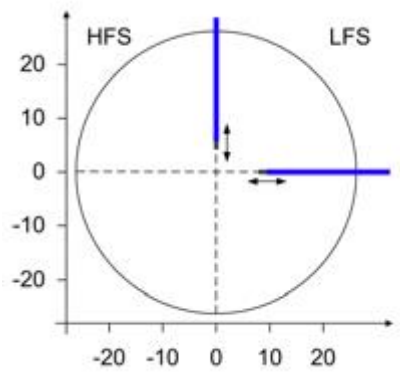


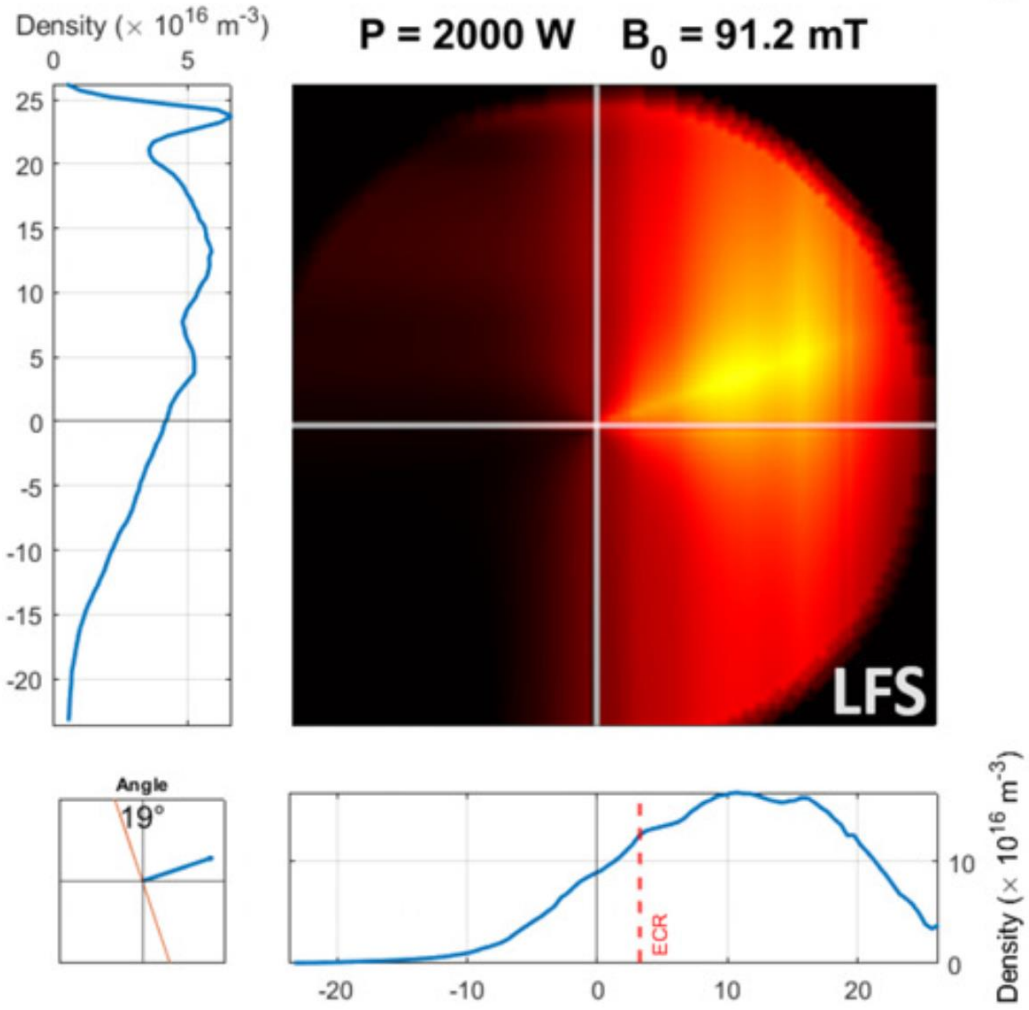


J. Buermans et al., Physica Scripta 99, 085606 (2024)

Electron cyclotron wall conditioning characterization

- Measurement of electron density and temperature profiles
  - Use of a movable triple Langmuir probe for radial and vertical profiles
  - Interpolation to 2D density maps

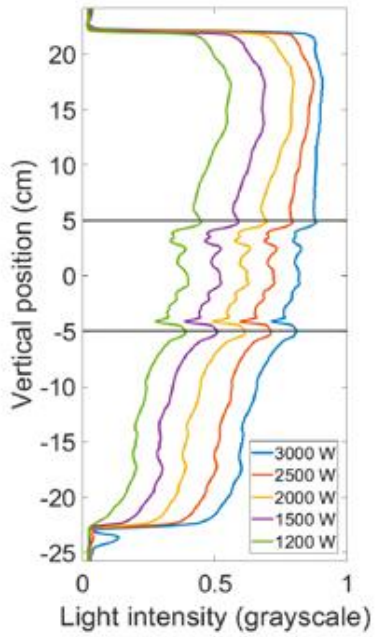


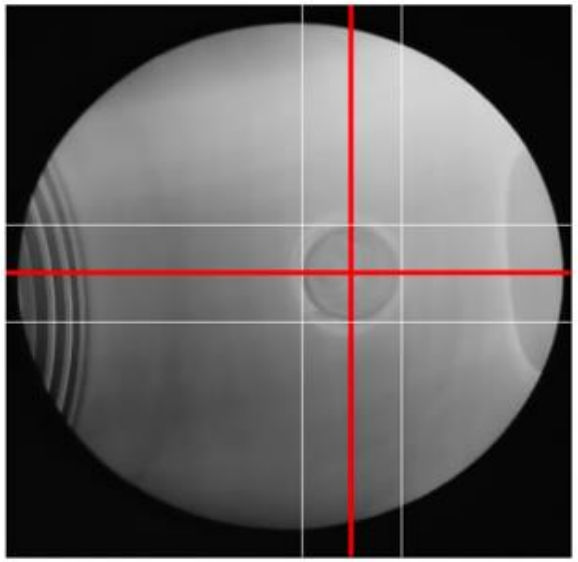


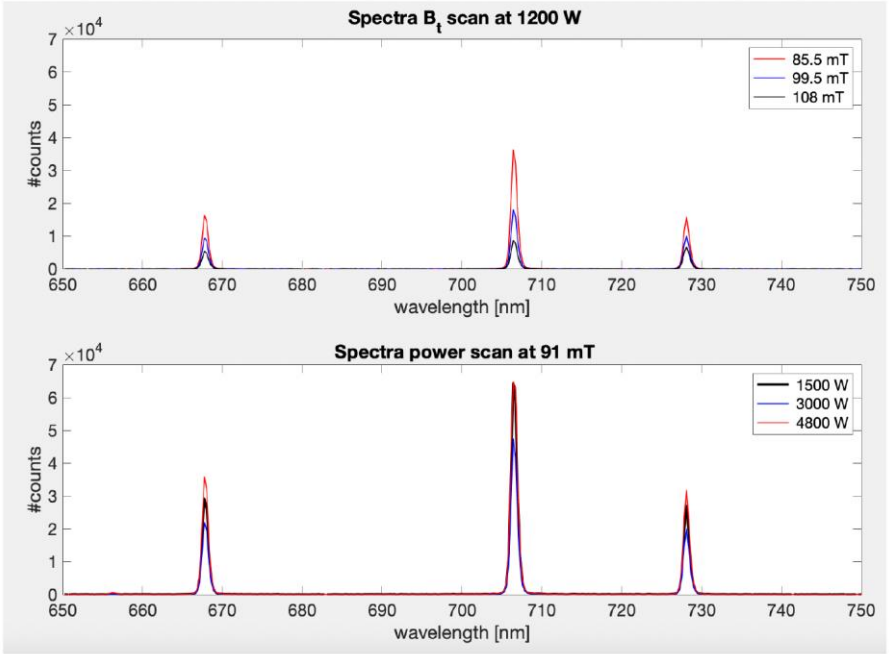
J. Buermans et al., Physics of Plasmas 31, 052510 (2024)

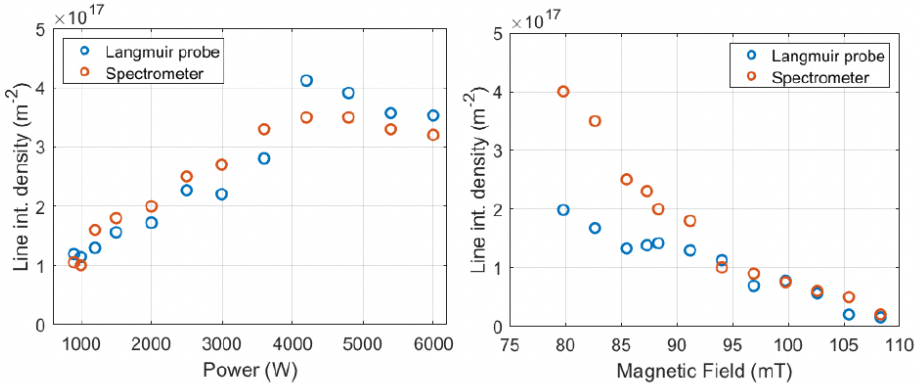
Electron cyclotron wall conditioning characterization

- Measurement of electron density and temperature profiles
  - Comparison with other diagnostics: optical spectroscopy and microwave interferometry
  - Use of camera images for estimating the 2D density map





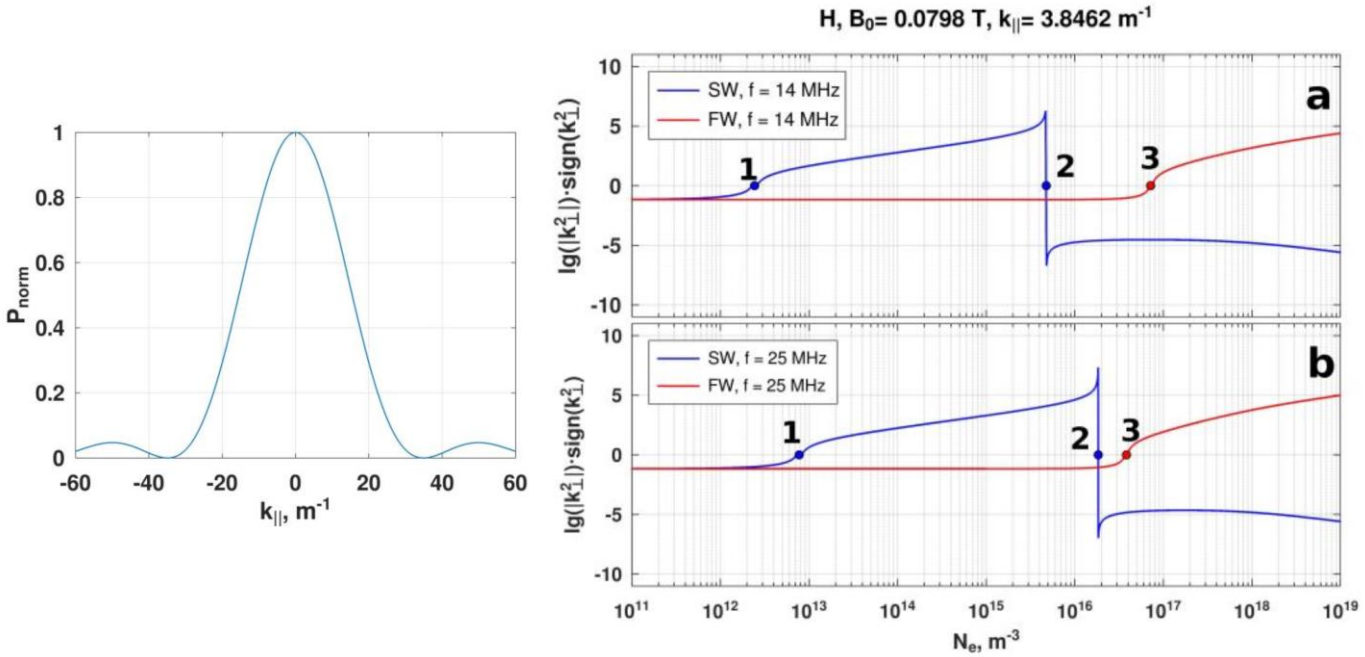


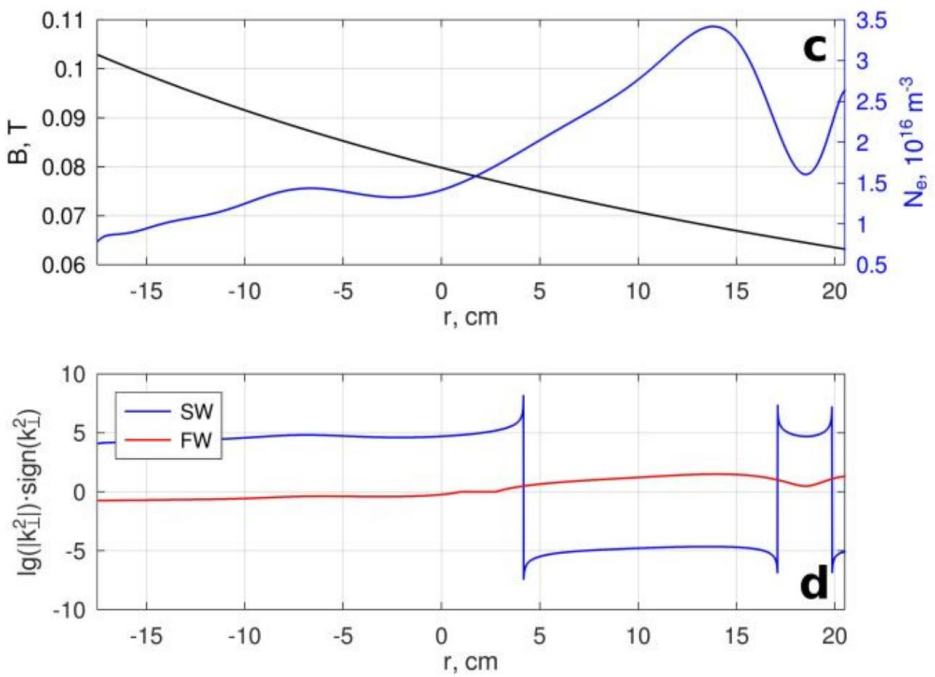


J. Buermans et al., Physics of Plasmas 31, 052510 (2024)

Ion cyclotron wall conditioning characterization

- Studies of wave absorption and propagation
  - Analysis of the propagation of radio frequency (RF) waves in hydrogen plasmas in a weak magnetic field
  - Identification of critical densities and propagation regimes for fast waves (FW) and slow waves (SW)



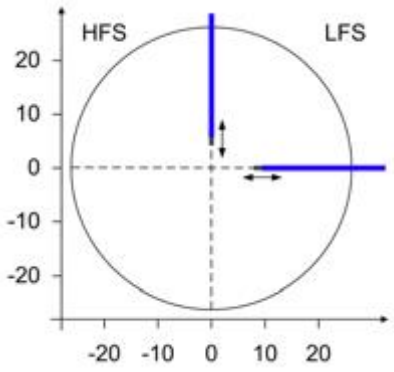


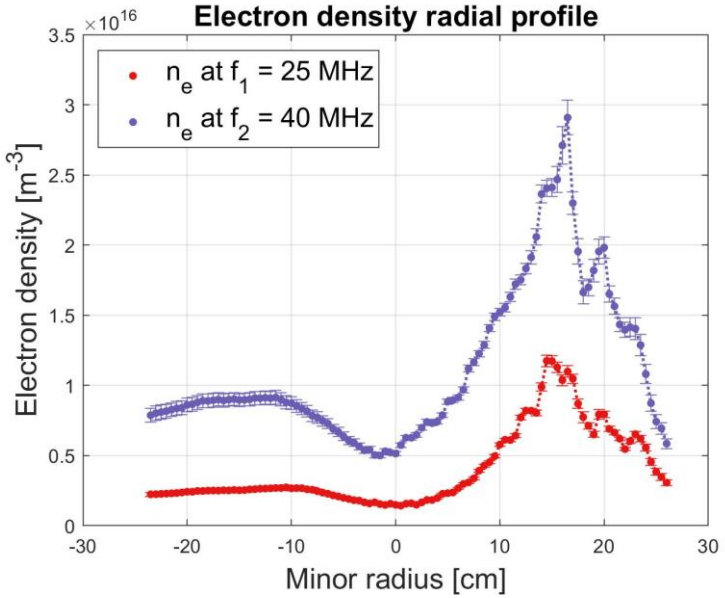
→ Position of the Lower Hybrid Resonance (LHR) from experimental measurements determines the propagation of SW

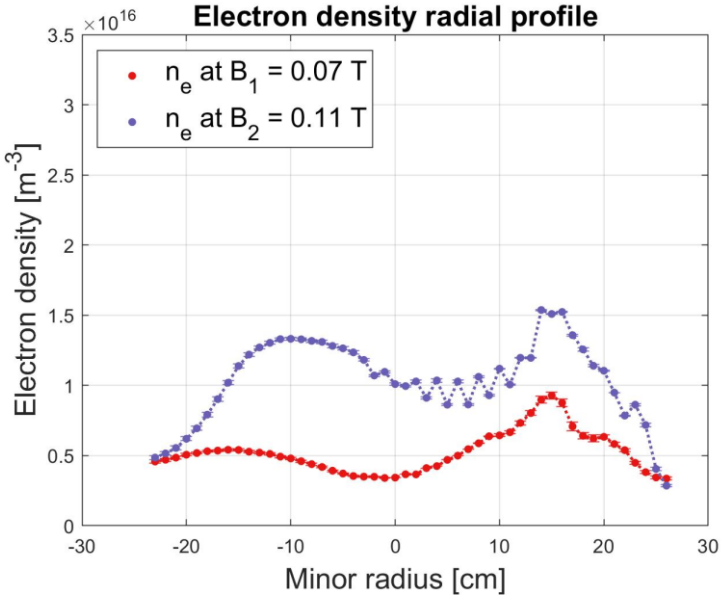
Yu. Kovtun et al., Physics of Plasmas 32, 032512 (2025)

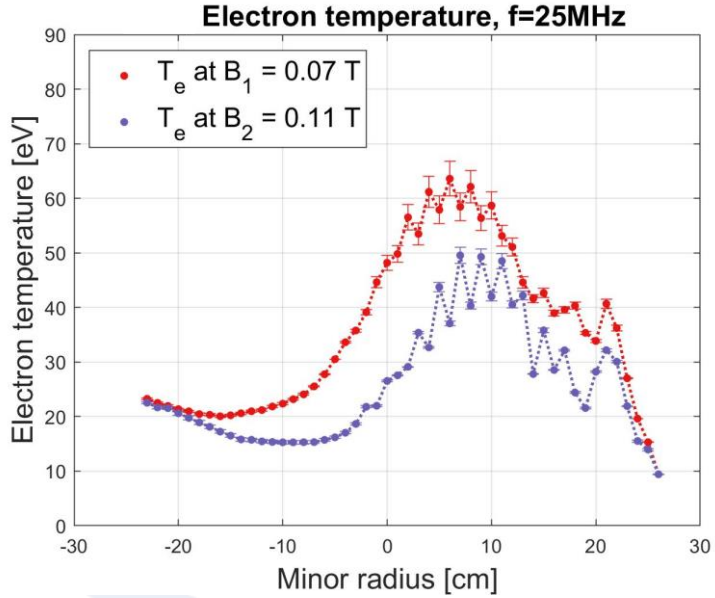
Ion cyclotron wall conditioning characterization

- Measurement of electron density and temperature profiles
  - Use of a movable triple Langmuir probe for radial and vertical profiles
  - Variation of plasma parameters as a function of power, gas pressure, magnetic field intensity, and antenna frequency





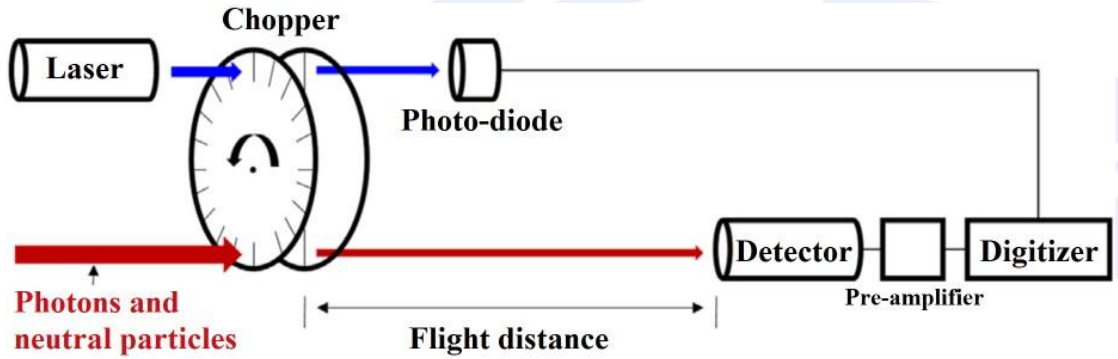


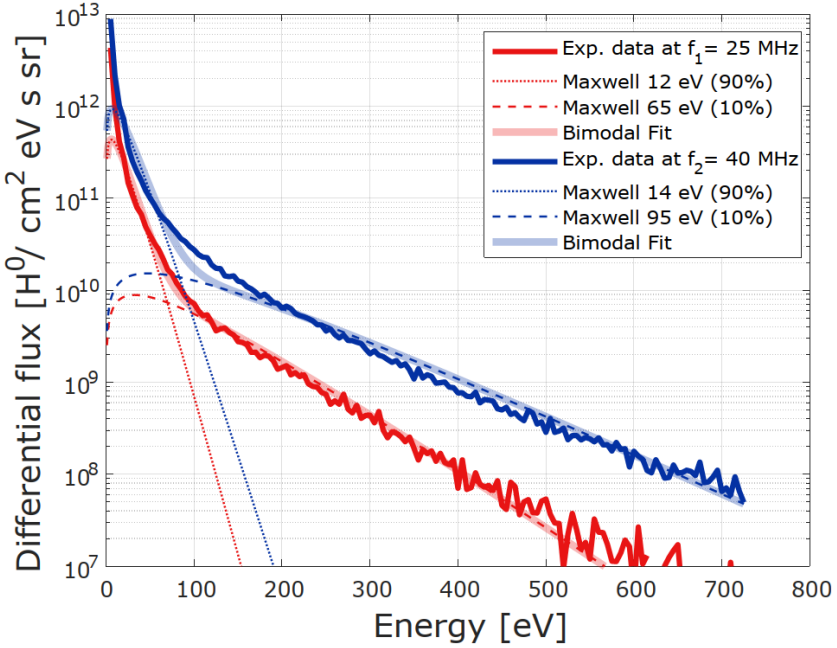


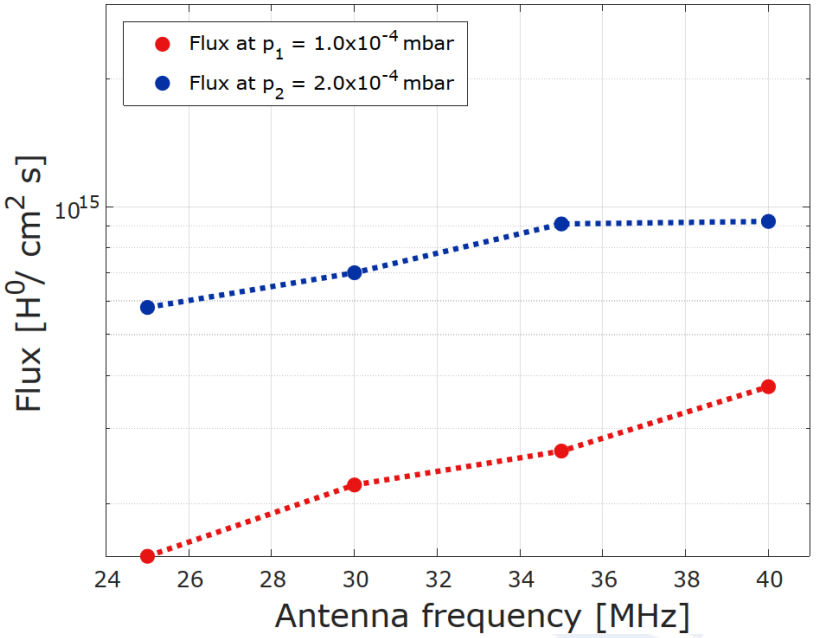
D. López-Rodríguez et al., Review Scientific Instruments 95, 083542 (2024)

Ion cyclotron wall conditioning characterization

- Measurement of neutral particle energies and fluxes
  - Use of a Neutral Particle Analyzer (NPA)
  - Variation of plasma parameters as a function of power, gas pressure, magnetic field intensity, and antenna frequency



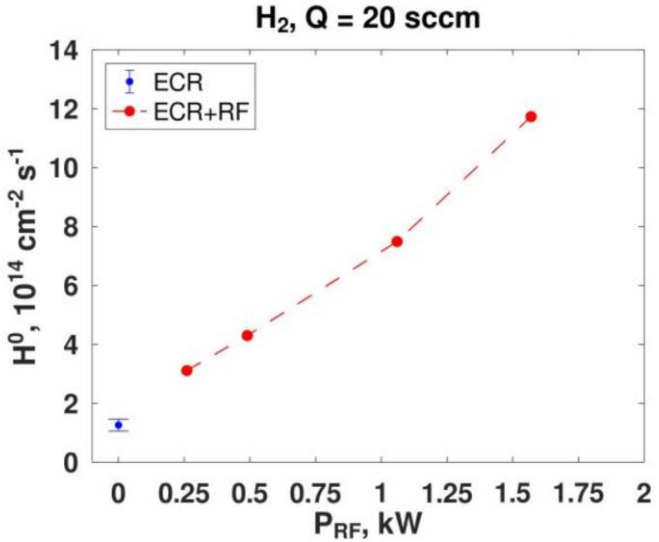


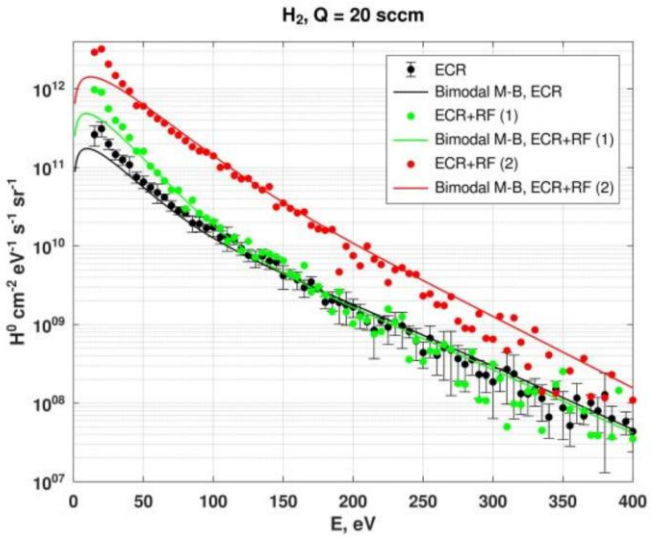


D. López-Rodríguez et al., Review Scientific Instruments 95, 083542 (2024)

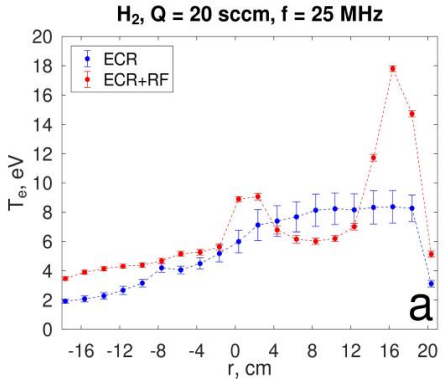
Characterization of combined EC+IC discharges

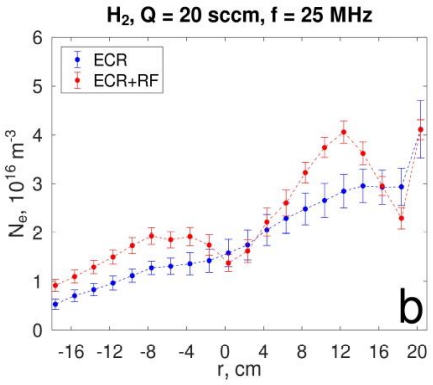
- Additional RF power injection into the ECR discharge allows changing neutral particle flux and distribution function.

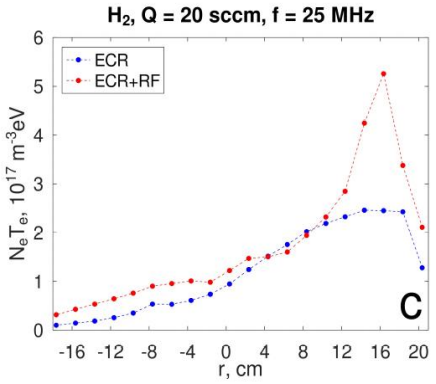




Differential flux spectra of neutrals for ECR and ECR+RF discharges. The experimental data: ECR, ECR+RF (1) for PRF ≈ 0.26 kW, ECR+RF (2) for P_{RF} ≈ 1.57 kW.



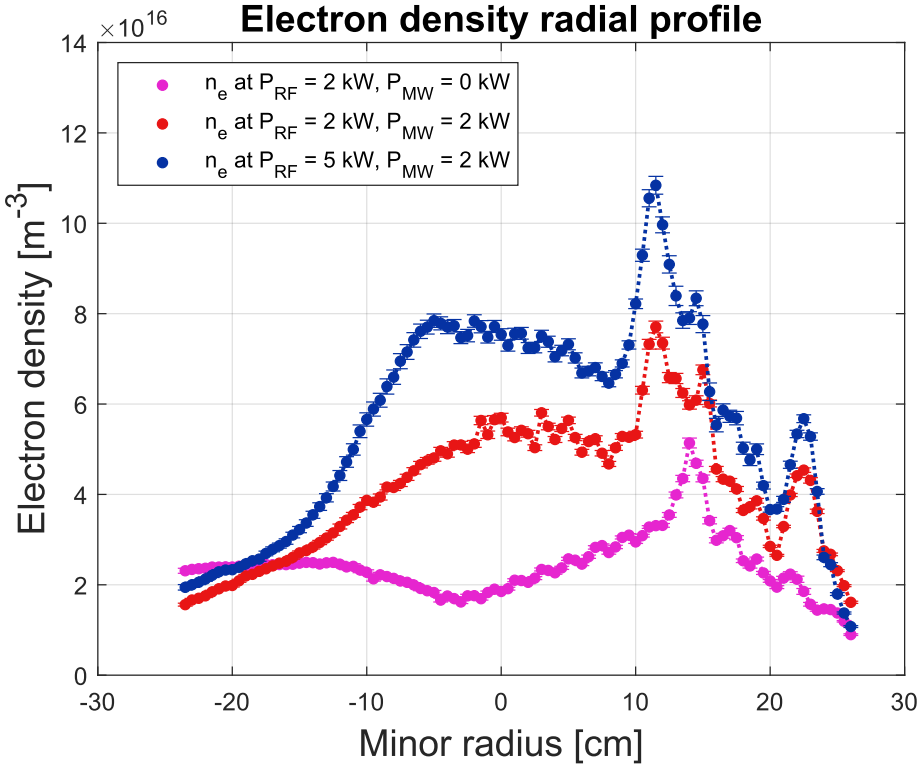


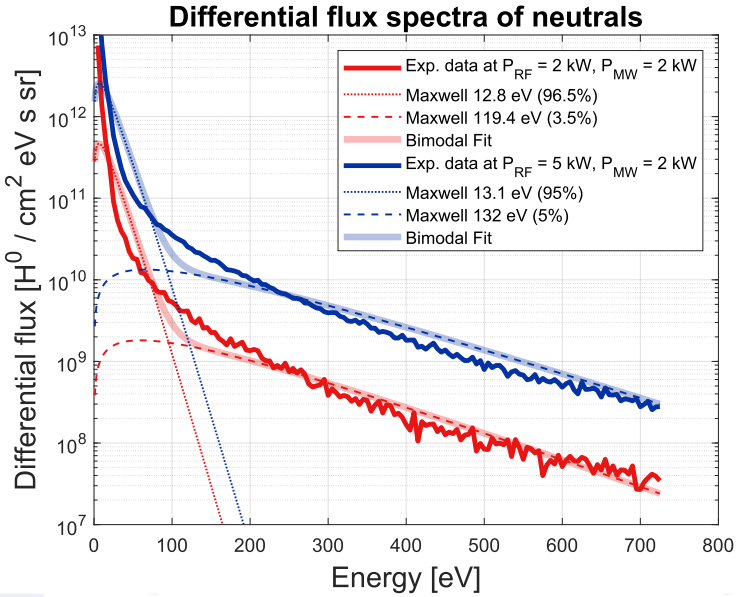


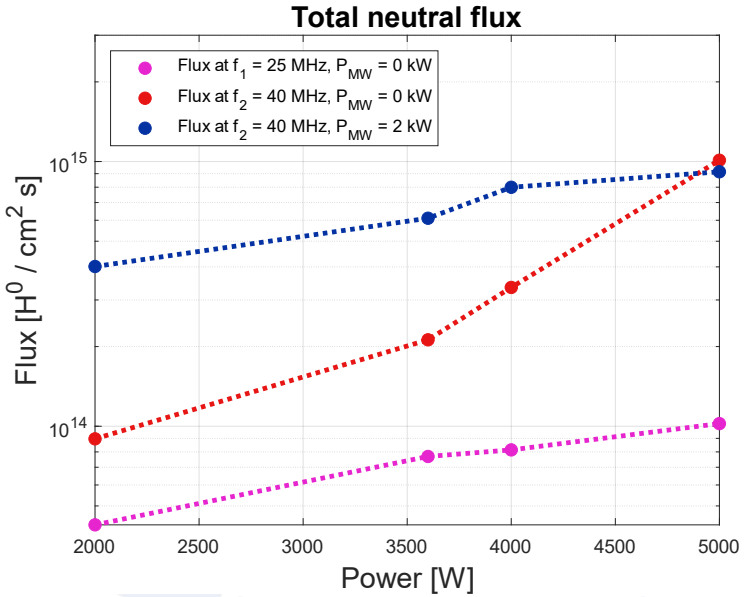
Yu. Kovtun et al., Physics of Plasmas 32, 032512 (2025)

Characterization of combined EC+IC discharges

- Measurements using the triple Langmuir probes and the Neutral Particle Analyzer







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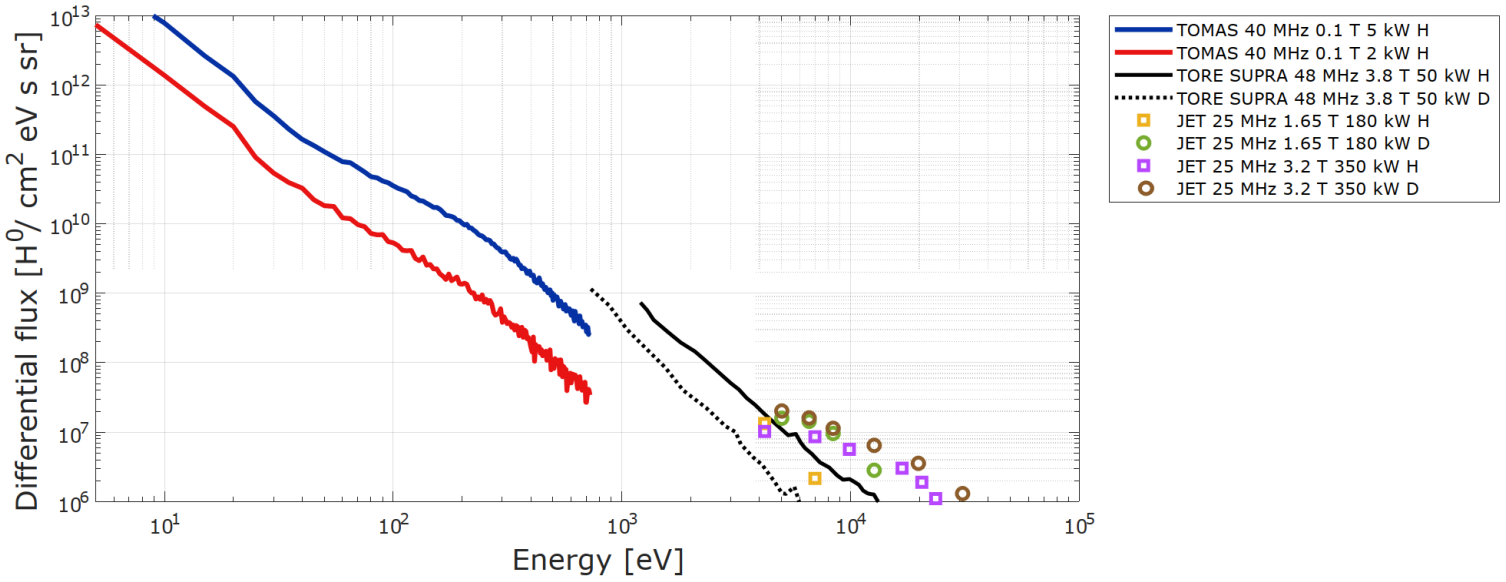
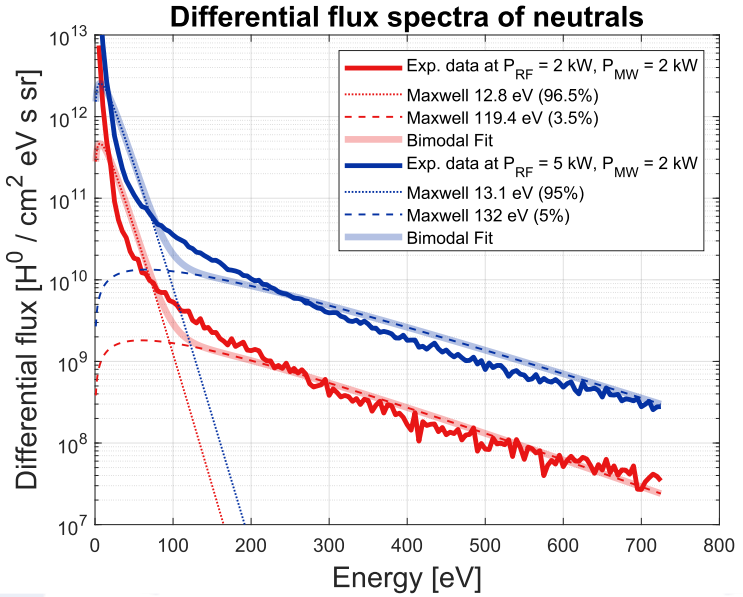
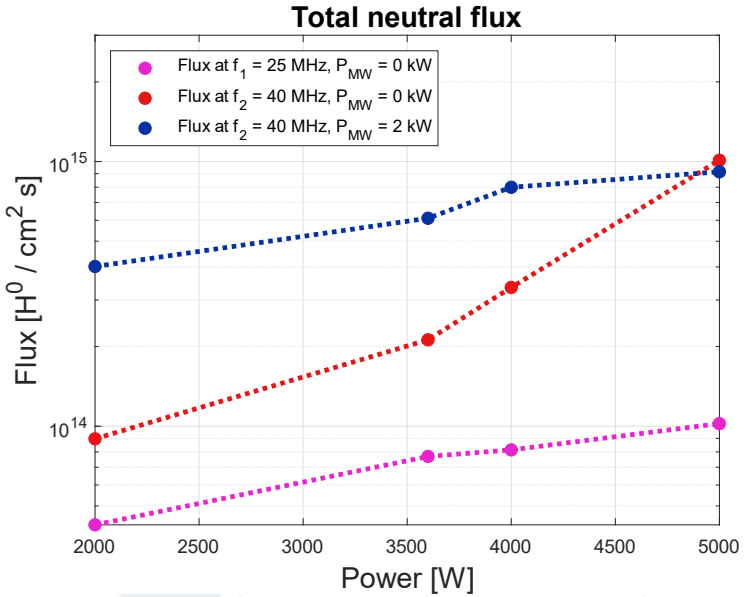
Characterization of combined EC+IC discharges

- Measurements using the triple Langmuir probes and the Neutral Particle Analyzer







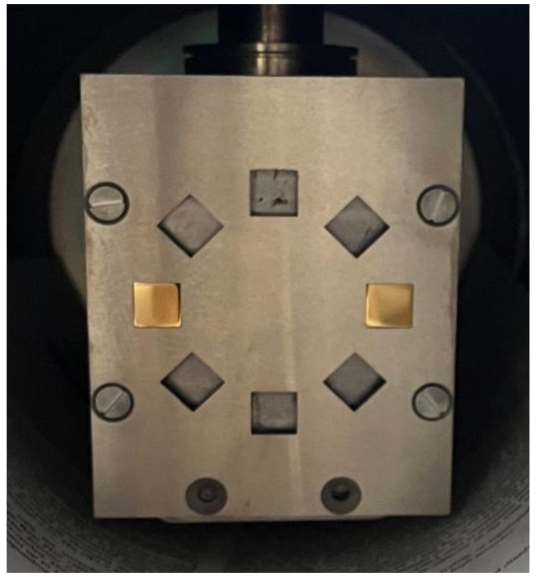
D. López-Rodríguez et al., Review Scientific Instruments 95, 083542 (2024)

Studies of boron layer erosion

- Preparation of samples with quasi-uniform boron deposits

➢ Graphite

Samples from W7-X, polished and coated with B (100 nm) in Forschungszentrum Jülich



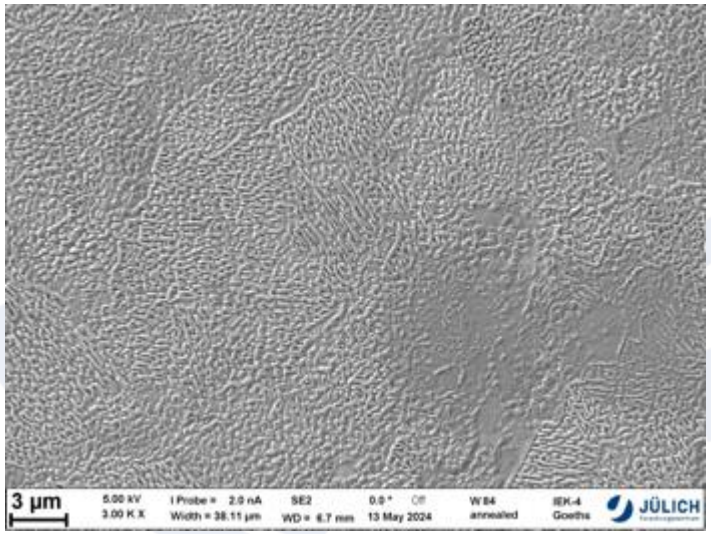
➢ Tungsten

Samples used for W7-X and ITER studies

- Pure W
- W95Ni3.5Cu1.5
- W97Ni2Fe1
- W95Ni3.5Fe1.5

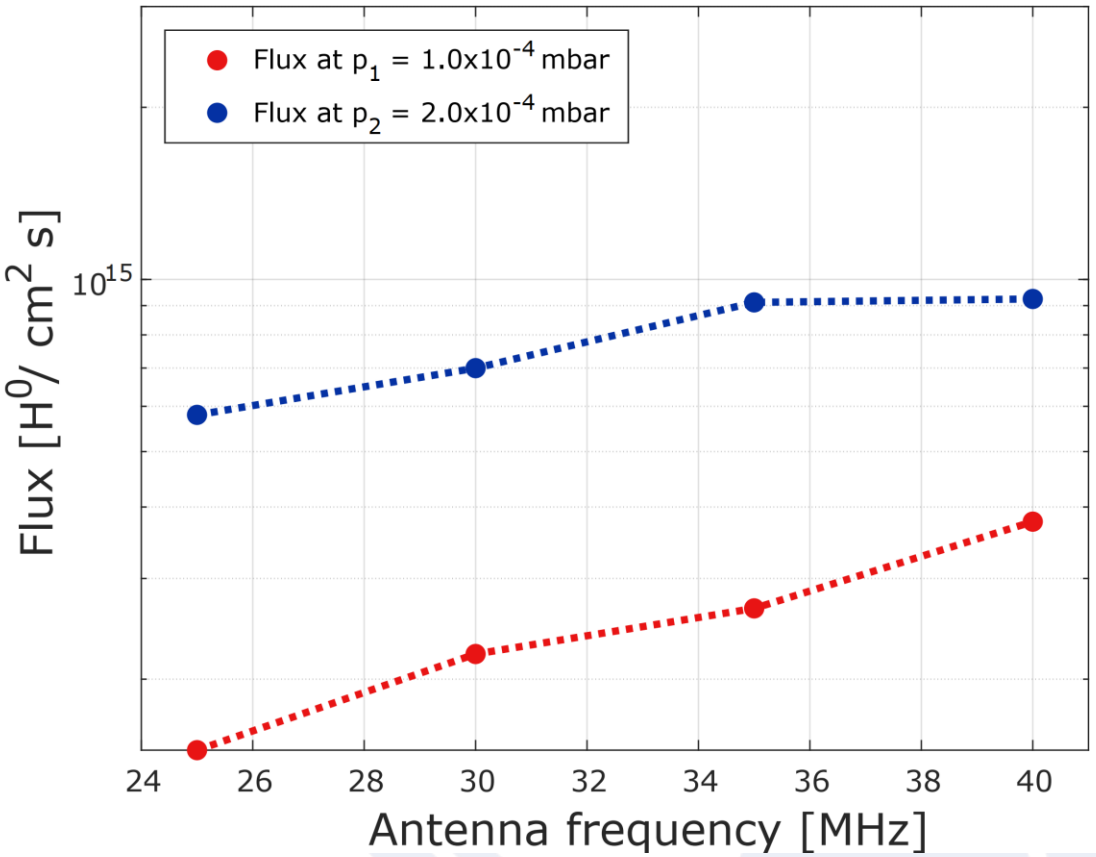
Samples manufactured, polished and coated with B (100 nm) in Forschungszentrum Jülich

- Dopped coating



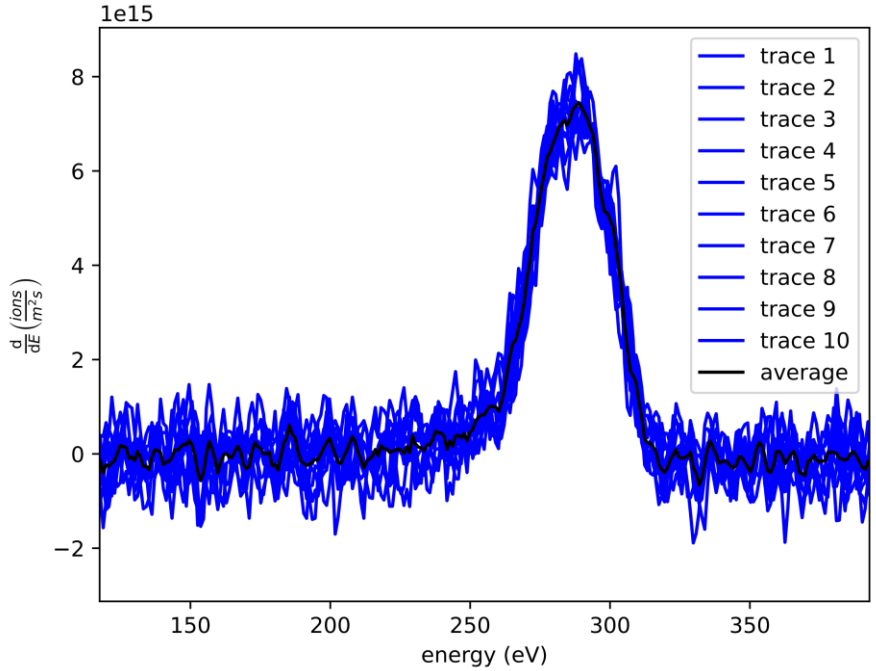
Studies of boron layer erosion

- Selection of exposure parameters
  - Glow discharge parameters
    - Definition of anode current and base pressure
    - Duration of the discharge
  - ICWC plasma parameters
    - ~ 40 MHz
    - Different power levels
    - Gas mixtures: H_2 + He (W7-X) and H_2 + D_2 (ITER)
  - Modelling of erosion rates
    - Neutral particle energy distribution (NPA)
    - Ion energy distribution (RFEA)
    - Comparison with experimental results

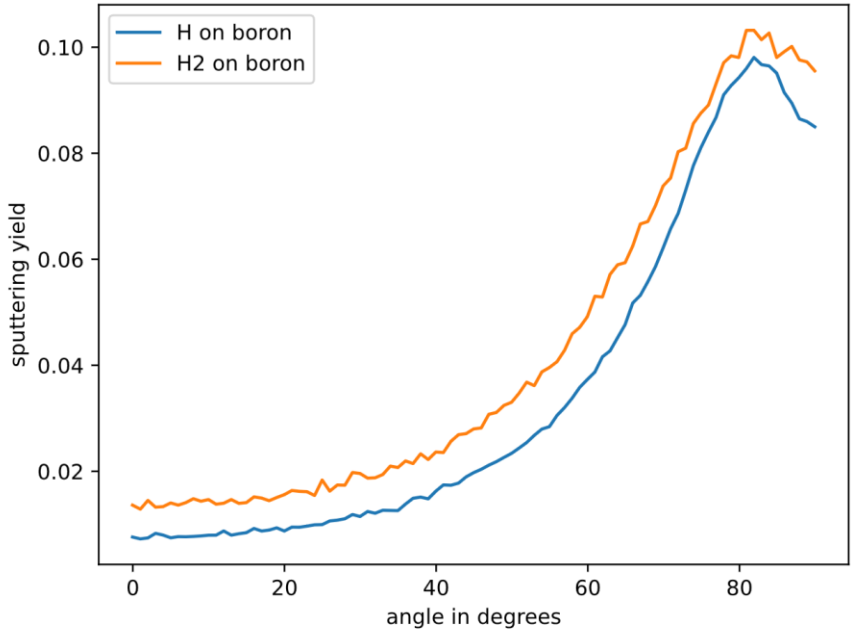


Studies of boron layer erosion

- Selection of exposure parameters
  - Use of a Neutral Particle Analyzer (NPA), movable triple Langmuir probe, and Residual Field Energy Analyzer (RFEA) data
  - Estimation of the sputtering yields



RFEA data



Sputtering yield

Studies of boron layer erosion

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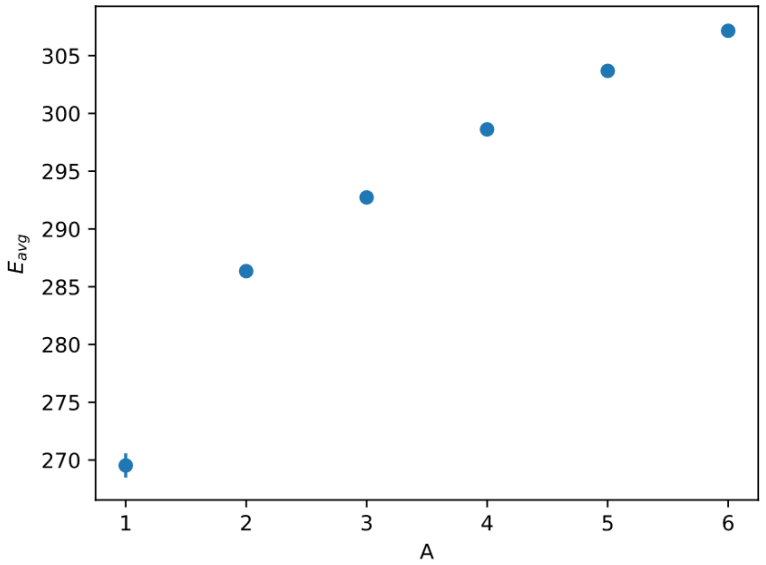
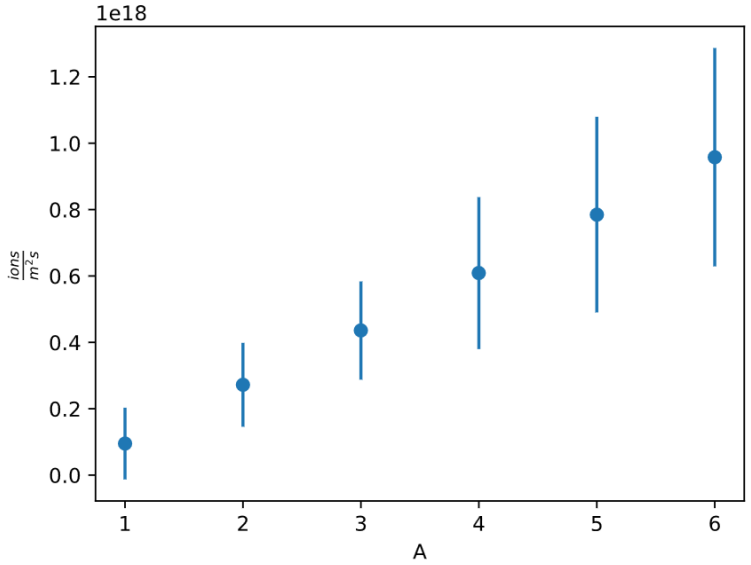
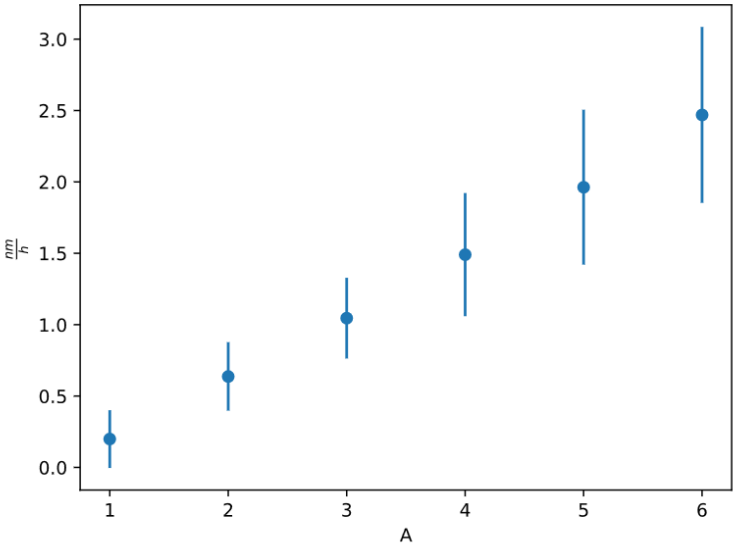
  - Estimation of the boron erosion rates



Average energy



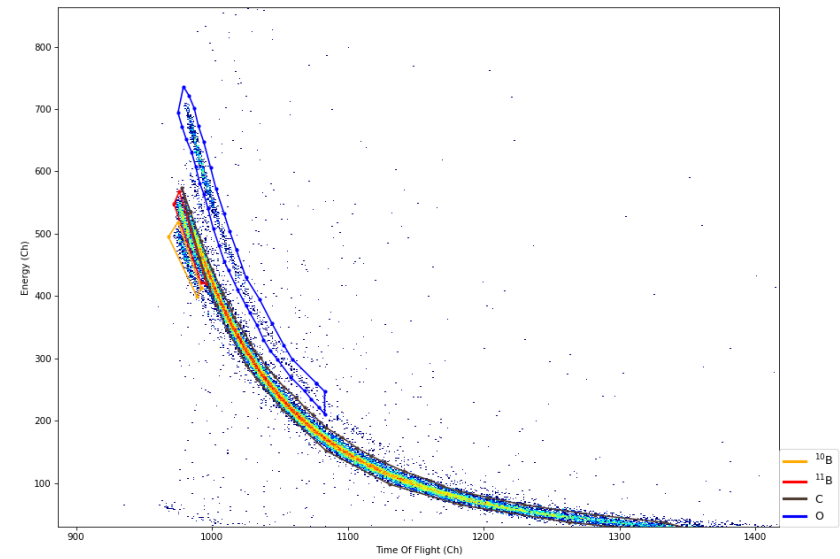
Flux of ions

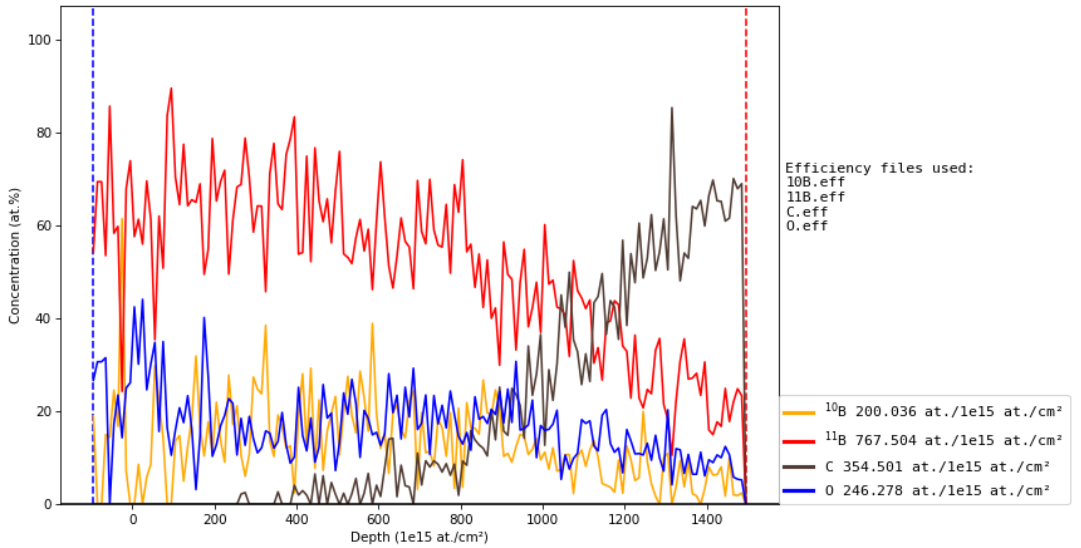


Erosion rate

Studies of boron layer erosion

- Pre-characterization and post-mortem analysis
  - Boron coating thickness by Focused Ion Beam Scanning Electron Microscope (FIB/SEM) and ellipsometry
  - Boron coating roughness by profilometry
  - Boron coating elemental composition by ion beam analysis
    - ➢ Elastic Recoil Detection Analysis (ERDA)
    - ➢ Nuclear Reaction Analysis (NRA)
  - Analysis of composition by Thermal Desorption Spectroscopy (TDS)
  - Monitoring of impurity release during exposure by Quadrupole Mass Spectrometry (QMS) and optical spectrometry

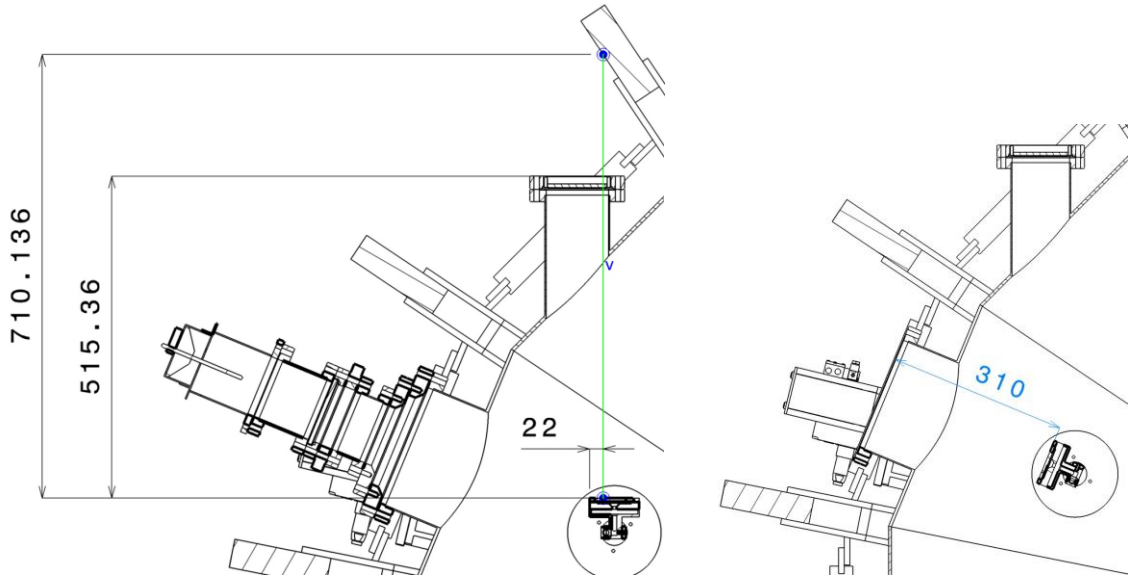


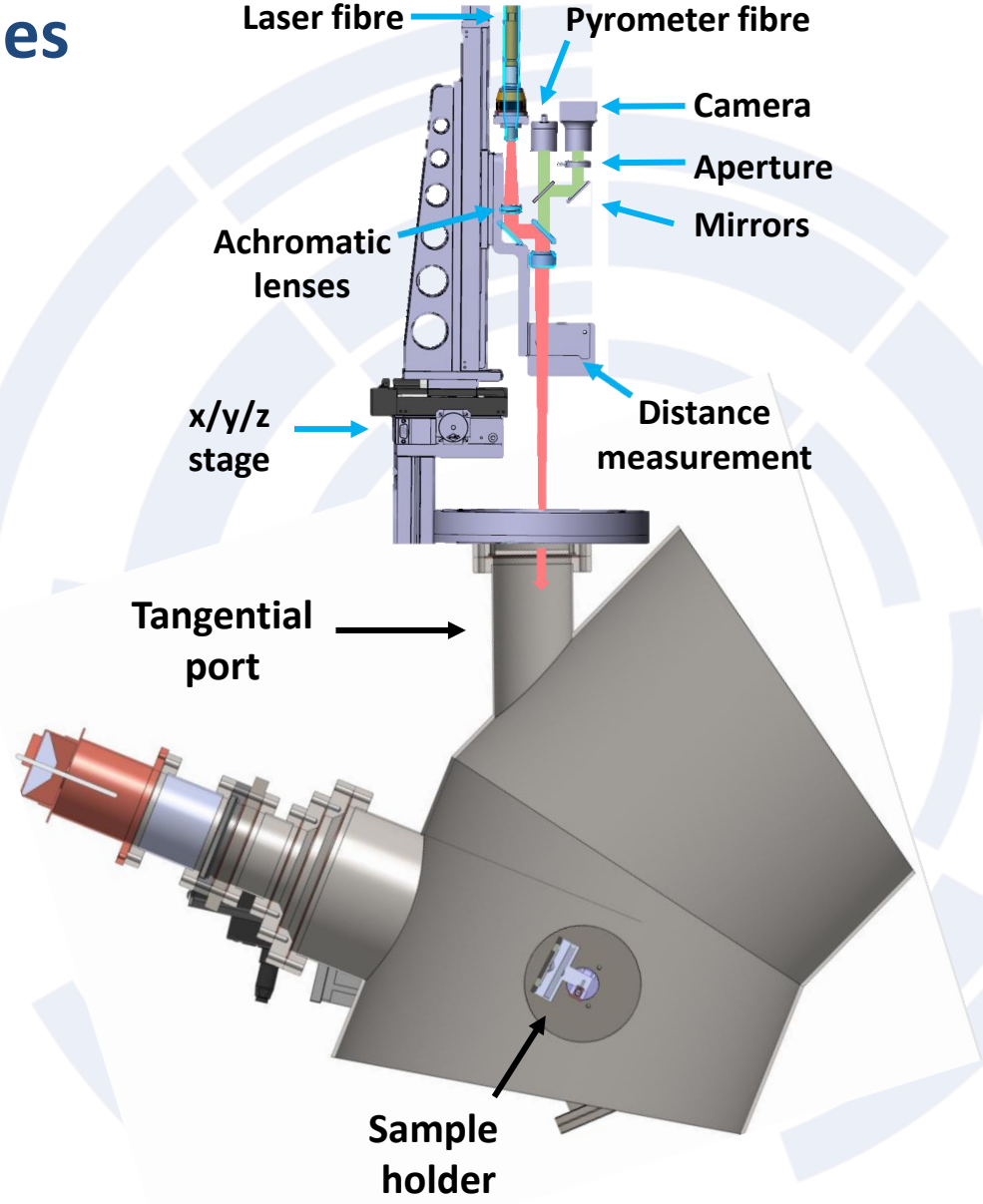


Results obtained by ERDA

Implementation of in-situ boronization studies

- Preparation for the installation of laser-induced desorption - quadrupole mass spectrometry (LID-QMS)
  - Adaptation of laser-detector geometry
  - Design and assembly of support structures for fiber optics
  - Selection of optical elements





M. Zlobinski et al., Nuclear Fusion 64, 086031 (2024)

Publications and other achievements

- J. Buermans et al., “Study of the Electron cyclotron power deposition in TOMAS”, Physica Scripta 99, 085606 **(2024)**
- D. López-Rodríguez et al., “Characterization of plasma parameters and neutral particles in microwave and radio frequency discharges in the Toroidal Magnetized System”, Review of Scientific Instruments 95, 083542 **(2024)**
- J. Buermans et al., “Characterization of ECRH plasmas in TOMAS”, Physics of Plasmas 31, 052510 **(2024)**
- A. Adriaens et al., “An automatic matching system for the ICRF antenna at TOMAS: Development and experimental proof”, Fusion Engineering and Design 212, 114840 **(2025)**
- Yu. Kovtun et al., "Combined electron-cyclotron resonance and radio-frequency discharges in the TOMAS facility”, Physics of Plasmas 32, 032512 **(2025)**

- L. Mestdagh, “Analyse van lichtintensiteit en dichtheidsprofielen in een ECR-plasma in het TOMAS-apparaat”, Master thesis, University of Antwerp, **2024**
- J. Buermans, “Characterization and Modelling of ECRH Discharges in Magnetic Confinement Fusion Devices”, PhD thesis, Ghent University, **2024**