This work has been carried out within the framework of the ITER-RFX Neutral Beam Testing Facility (NBTF) Agreement and has received funding from the ITER Organization. The views and opinions expressed herein do not necessarily reflect those of the ITER Organization.

This work has been carried out within the framework of the EUROfusion Consortium, funded by the European Union via the Euratom Research and Training Programme (Grant Agreement No 101052200 — EUROfusion). Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Commission. Neither the European Union nor the European Commission can be held responsible for them

Study and development of diagnostic systems to characterise the extraction region in SPIDER

Beatrice Segalini[1,2], Valeria Candeloro[1,2], Luca Franchin[1], Roberto Pasqualotto[1], Carlo Poggi[1], Gianluigi Serianni[1,3], Lauro Trevisan[1], Marco Tollin[1] and Emanuele Sartori[1,2]

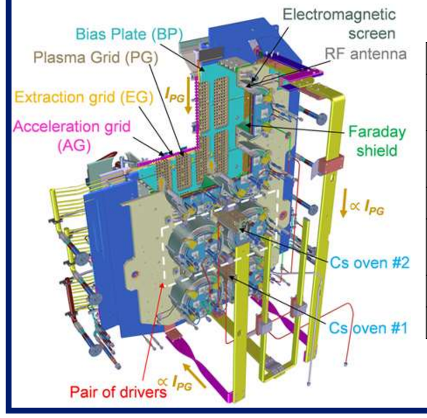
[1]Consorzio RFX (CNR, ENEA, INFN, UNIPD, Acciaierie Venete SpA), Corso Stati Uniti 4 – 35127 Padova, Italy [2]Università degli Studi di Padova, via VIII Febbraio 2, 35122 Padova, Italy [3]ISTP-CNR, Institute for Plasma Science and Technology, corso Stati Uniti 4 – 35127 Padova, Italy

Corresponding author email: beatrie.segalini@igi.cnr.it

SPIDER

PRIMA Test facility for **ITER**[1] in Padova houses **SPIDER**[2] and **MITICA**[3]

→ Beam formation and acceleration studied in the full-scale ion source **SPIDER** (Source for Production of Ions of Deuterium Extracted from an Rf plasma).
→ Operations started in 2018.
→ In 2021 it firstly operated with caesium seeding.
→ Now: major shutdown → general upgrades and installation of new diagnostics.



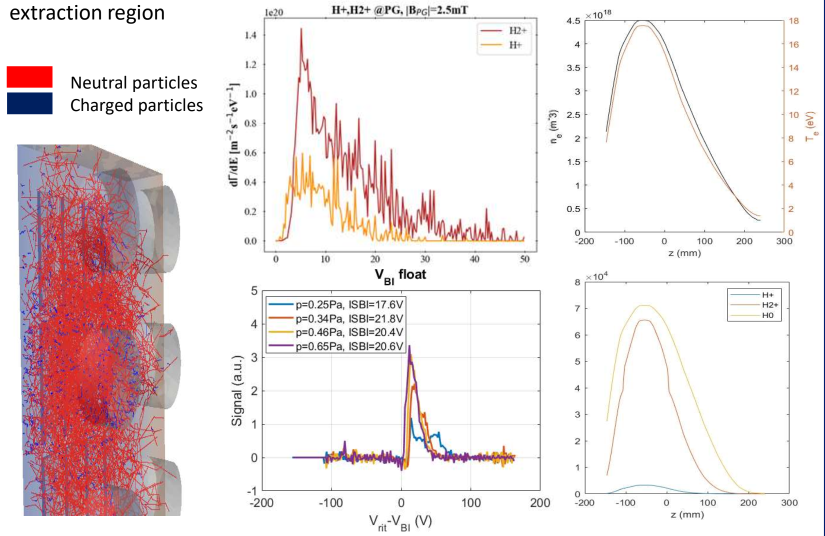
SPIDER REQUIREMENTS FOR ITER

Beam energy	100 keV
Extracted current density	355 (H) – 258 (D) A/m²
Maximum Beam Source pressure	0.3 Pa
Beam uniformity	>90%
Beamlet divergence	≤7 mrad
Beam on time	3600 s
Co-extracted e⁻/D⁻	<1

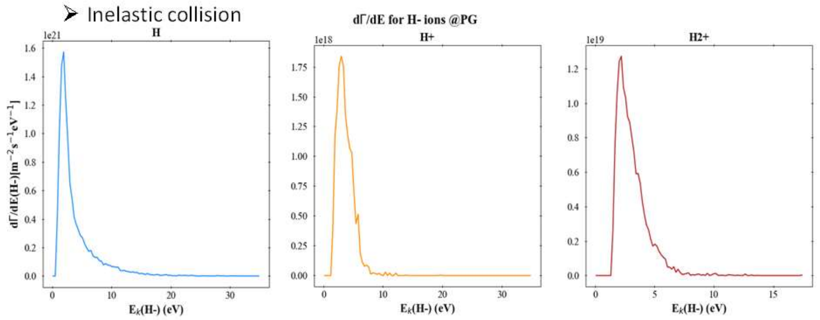
[1] L.R. Grisham, et al., Fus. Eng. Des., 87(11):1805-1815 (2012)
[2] P. Sonato, et al., Fus. Eng. Des., vol. 84 (2009), pp. 269–274
[3] P. Sonato et al., AIP Conf. Proc. 1515 (2013) 5497

POSITIVE IONS DISTRIBUTION - simulations

3D test-particle Monte Carlo code to track particles from the driver through the extraction region

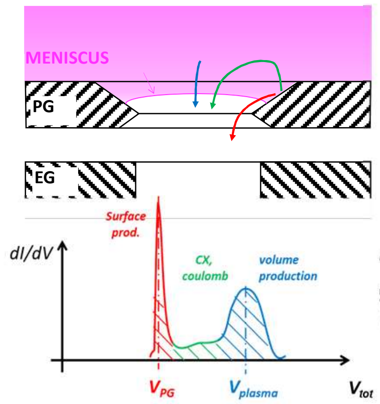


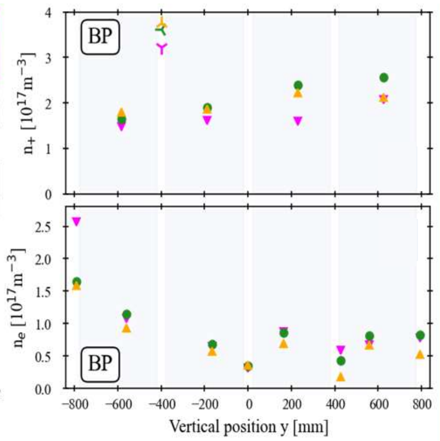
- Goal: determine **positive ion energy distributions** and compare it with RFEA data
- Code uses null-collision method and follows positive ions, taking into account of:
  - Magnetic filter field conditions
  - Coulombian collisions (elastic)
  - Inelastic collision



NEGATIVE ION EXTRACTION IN SPIDER

- In beam sources for neutral beam injectors, when high beam energies are needed, negative hydrogen ions (NI) are extracted from a caesiated plasma discharge.
- H- ions are generated from volume and surface processes.
- The surface production is enhanced by Cs deposition on the source walls and in particular on the plasma electrode of the accelerator, made of molybdenum and kept at high temperature to maximize the caesium effect.





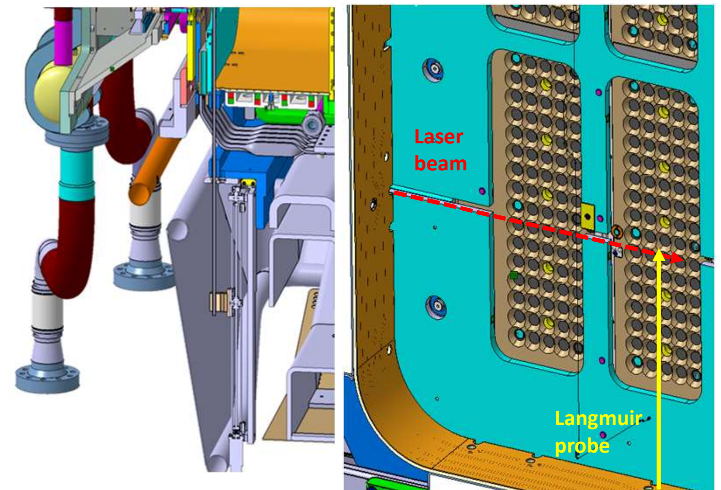
Vertical profile of the number density of positive ions (top) and electrons (bottom) at BP estimated by combined application of the collisional–radiative model for Cs to OES data, Langmuir probes, and laser absorption spectroscopy. Caltrop-shaped points are collected via a triple Langmuir probe on the source back. Figure taken from *G. Serianni et al., Rev. Sci. Instrum. 93, 081101 (2022); https://doi.org/10.1063/5.0084797*

- The **plasma properties in the region of extraction**, the **mechanisms of negative ion production and extraction** in the magnetic field, and the **formation of the single beamlets and their optics** should be investigated, focusing especially on beam **divergence** and **uniformity**.
- In SPIDER, several diagnostic aimed at this tasks are already installed, but more **vertical** resolution could help in providing a deeper understanding of the physics of beam formation → **dis-uniformity** experimentally detected not on different beamlet groups → could it be also within a single one?

- Retarding Field Energy Analyser (**RFEA**) probes can provide a direct estimation of (positive) ion energy distribution (precursors of negative ions in surface processes) →
- A **movable Langmuir probe** can provide a **vertical** scan of main plasma parametersing the extraction area →

MOVABLE LANGMUIR PROBE

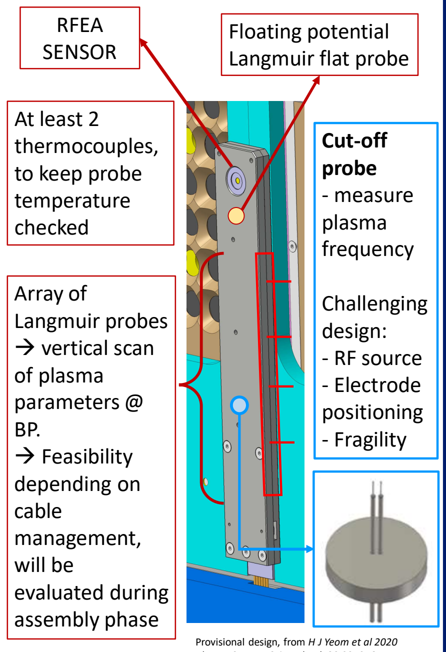
- **Movable:** characterize uniformity vertically in a full beamlet group
- Close to beam extraction, with Cs on surface
- Laser intercepts probe → *electron photodetachment*[4]
- Measurements of T(H-) and n-
- **Vertical scan** of plasma parameters in extraction region
- **Local** measure of T(H-), n- via electron photodetachment



[4] Bacal, Marthe. (2000) Review of Scientific Instruments - REV SCI INSTR. 71. 3981-4006. 10.1063/1.1310362.

VICTOR (Very Important Chaotic Tool for Observing the extraction Region)

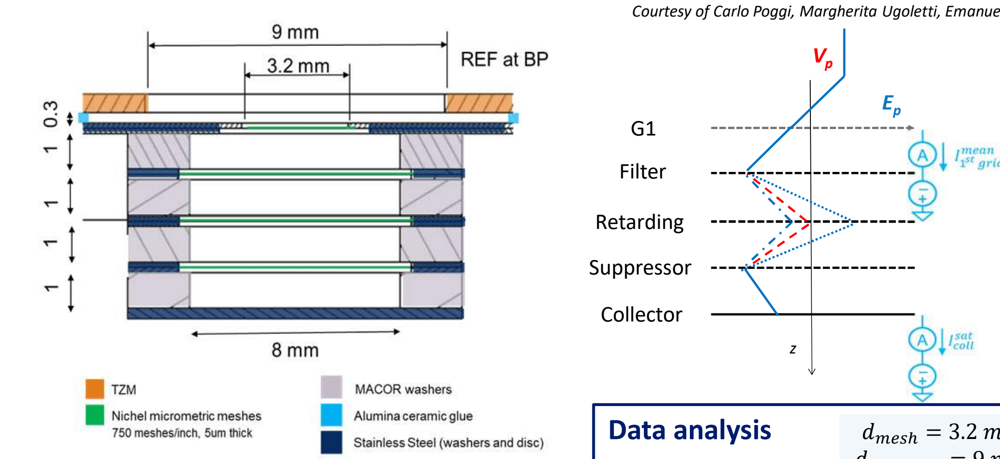
- The **RFEA sensor** will be hosted on a TZM support
- Fixed on the BP → can be useful for adding other sensors

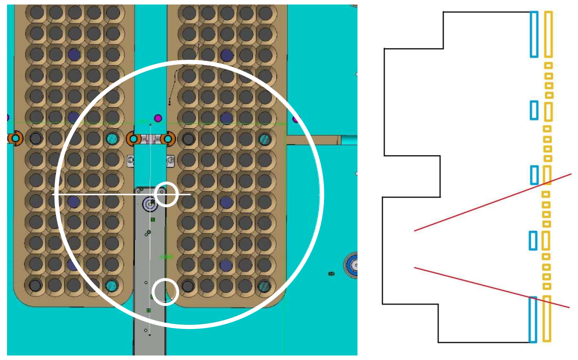


Provisional design, from *H J Yeom et al 2020 Plasma Sources Sci. Technol. 29 035016*

RETARDING FIELD ENERGY ANALYSER – key design aspects

Courtesy of Carlo Poggi, Margherita Ugoletti, Emanuele Sartori





Data analysis

$d_{mesh} = 3.2\ mm$
$d_{aperture} = 9\ mm$

Current density estimation:

Ion current density measured at the RFEA entrance

$$j_{H^+} = j^{sat}_{1^{st}grid} = \frac{I^{mean}_{1^{st}grid}}{A_{aperture} - A_{mesh} * T_{grid}}$$

with $T_{grid} = 0.55$ *Nominal transparency of the grid*

Ion current density estimated at the RFEA entrance

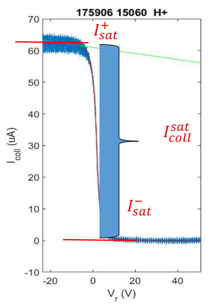
$$j_{H^+} = j^{sat}_{coll} = \frac{I^{sat}_{coll}}{A_{mesh} * T_{tot}}$$

with $I^{sat}_{coll} = (I^+_{sat} - I^-_{sat})|_{V \equiv V_p}$

From the current density it is possible to give an estimation of the positive ion density, by using the sheath theory:

$$n_{H^+} = \frac{j_{H^+}}{c_s} * \frac{1}{0.6}$$ with

$$c_s = \sqrt{k_B * T_e / m_i}$$



- Identical design tested previously in extraction region plasma at NIFS: no issues detected (probe bias -20V, T=1 eV, n=1.5e17 m-3) (short pulses, PG @ 300°C)
- On SPIDER movable probe: Ni mesh not damaged despite being 20 cm into plasma and biased -80V (short pulses)
- Requires magnetic filters in ignition phase, especially if ISBP=0V

CONCLUSIONS

- **Two** new diagnostic systems will be installed on SPIDER during the long shutdown;
- One is a **movable Langmuir probe** → vertical scan @extraction of main plasma parameter;
- It will intersect a laser → electron photodetachment
- Second is a **RFEA** → measure **positive ion energy distribution** to investigate the **mechanism of extraction** in **negative ion beam sources**;
- Design supported by 3D Monte Carlo simulations;
- Future work: installation and testing, simulation analysis, design finalisation for VICTOR, experimental campaign.