Max-Planck-Institut für Plasmaphysik

NNBI for ITER: Status of long pulses in deuterium at the test facilities BATMAN Upgrade and ELISE

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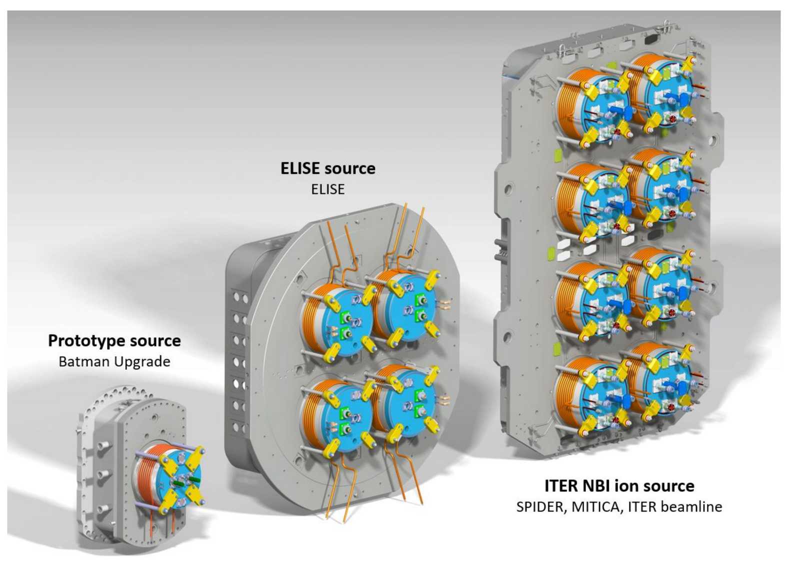
RF driven NNBI sources towards ITER NBI

Stepwise development process defined by F4E

Neutral beam heating for ITER
- 33 MW power, two injectors.
- 1 MeV, 40 A Deuterium.
  ⇒ 285 A/m^2 extracted current density.
- Electron-ion ratio ≤1
  to protect the extraction system.
- Pulse length:
  400 s, Q=5 baseline scenario.
  3600 s, Q=10 advanced scenario.



IPP test facilities
BATMAN Upgrade and ELISE
- Early operational & physics experience supporting NBTF, ITER NBI and towards DEMO.

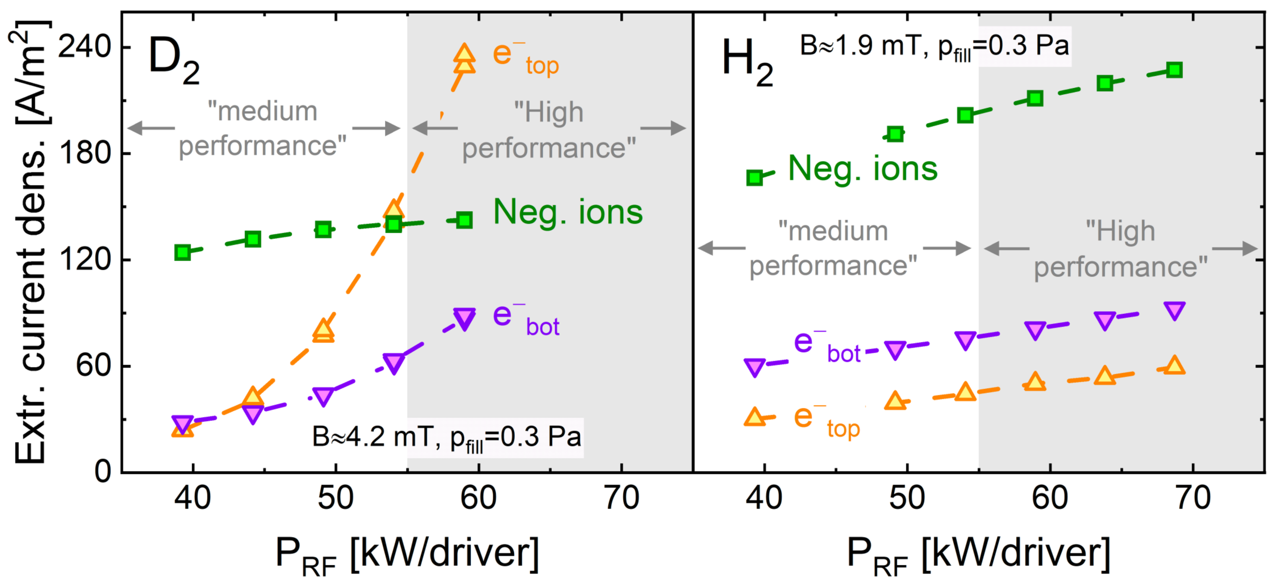
Operation of RF driven ion sources for NBI

- RF power up to 100 kW per cylindrical RF driver (volume: a few liters).
- Plasma cooled down (T_e= ≈10 eV → ≈1 eV) by horizontal magnetic filter field.
- Gradients in electrostatic potential.
- Positive plasma grid bias potential for reducing co-extracted electrons.
- Grounded bias plate around PG for increasing non-biased surface.
- Production of H^- at caesiated low work-function surface of plasma grid.

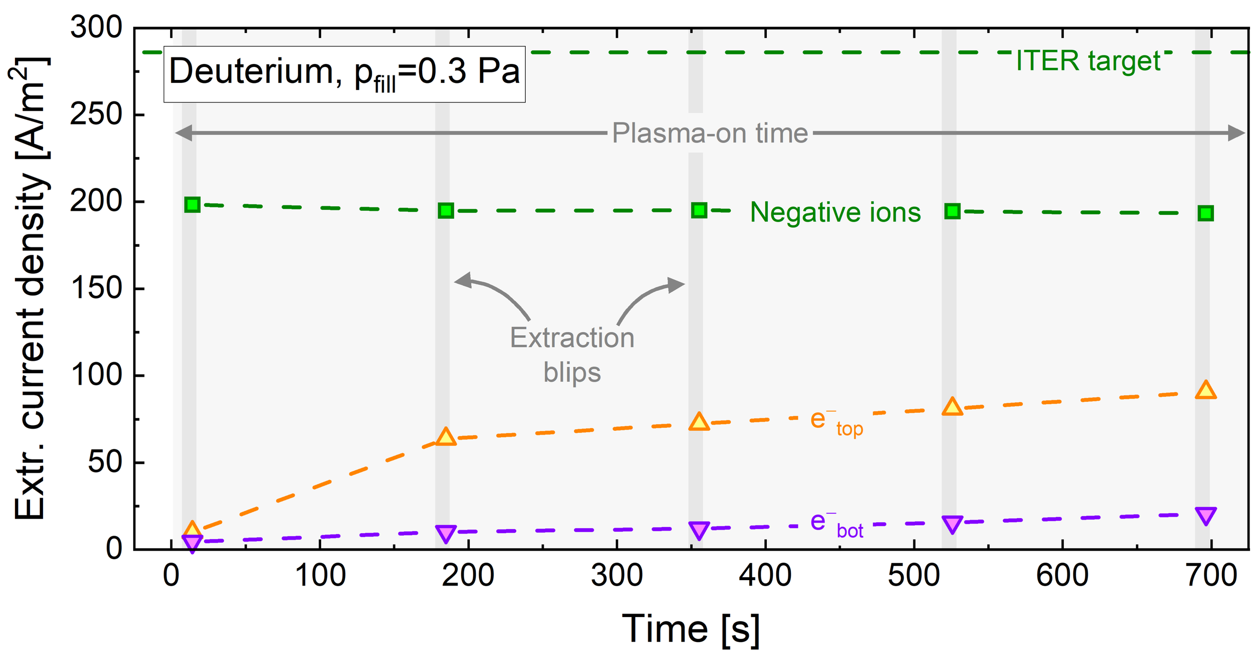
} Vertical plasma drifts

Operation in deuterium

RF power variation for short pulses in deuterium and hydrogen:



Best deuterium pulse with ITER-relevant length (>400 s) done at ELISE till now:



Reached for 700 s: 66 % of the ITER target for the extracted current density.

Achievable performance in deuterium is limited by:
- Higher co-extracted electron current compared to hydrogen ⇒ **static effect.**
- Co-extracted electrons can show a strong vertical asymmetry ⇒ **static effect.**
- Temporal instability of co-extracted electrons and their symmetry ⇒ **dynamic effect.**

ELISE focusses on development of advanced operational scenarios for long pulses in deuterium.

Reducing the co-extracted electrons

Modified magnetic field strength and topology:
- Typically in deuterium a stronger magnetic filter is used (≈4.6 mT vs. ≈2.8 mT).
- Adding external permanent magnets enabled 3600 s pulses at ELISE at all.

Increased Cs evaporation:
- Possible to a certain extent only ⇐ increased risk of HV breakdowns.

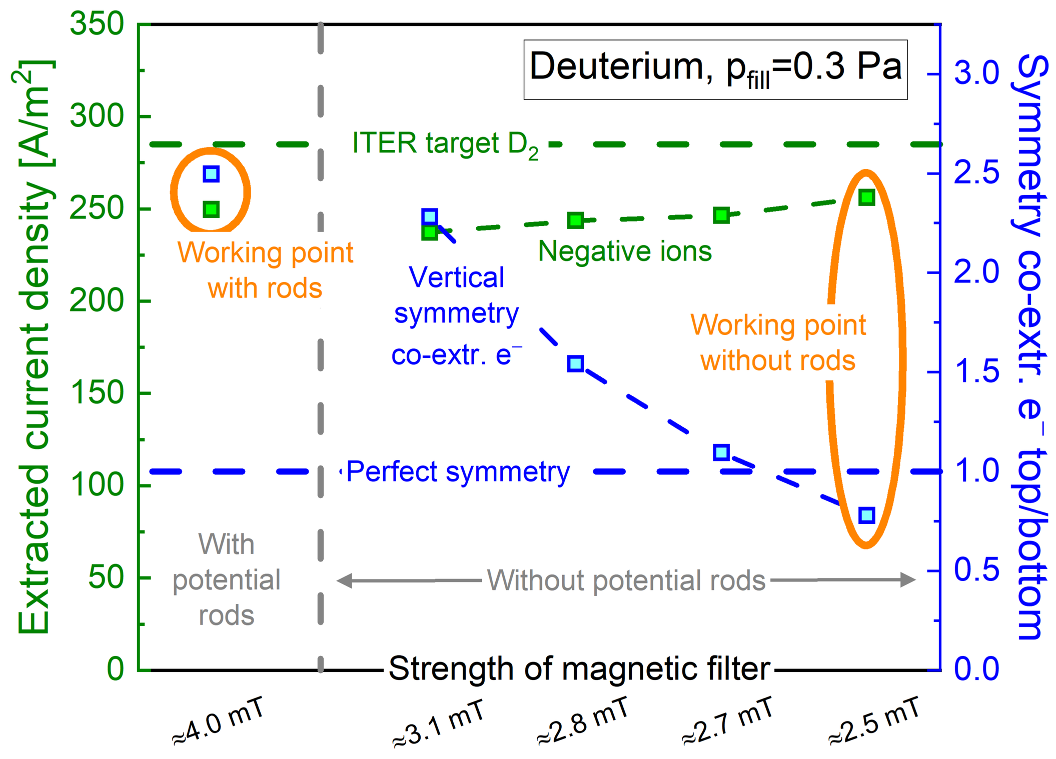
Symmetrizing the co-extracted electrons

Aim: counteract vertical plasma drift in order to symmetrize the co-extracted electrons.

Knobs close to the plasma grid:

① **Electrostatic potential**
- Successful test of internal potential rods.
- Best solution: rods electrically connected to plasma grid, i.e. increasing biased surface.
- Co-extracted electrons stabilized and symmetrized, also during long pulses.

② **Magnetic field**
- Apply potential to bias plate.
- Reduction of extracted negative ions and electrons.
- Makes possible a strong reduction of filter field strength.



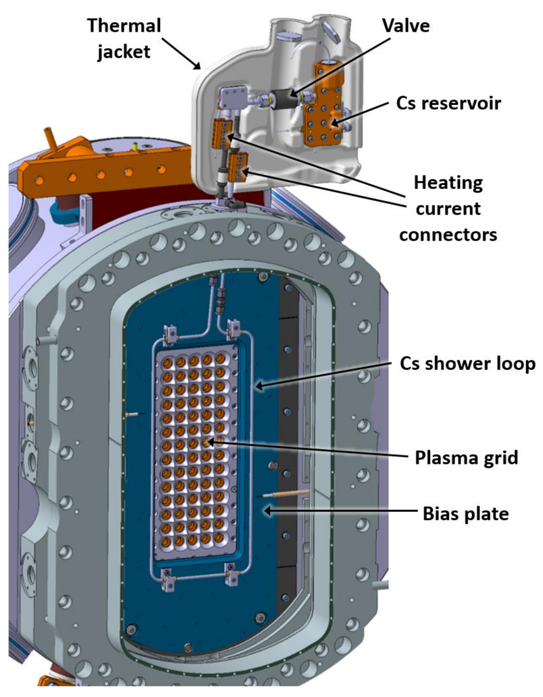
Short pulses: 90 % of ITER target at almost perfect vertical symmetry of co-extracted electrons.

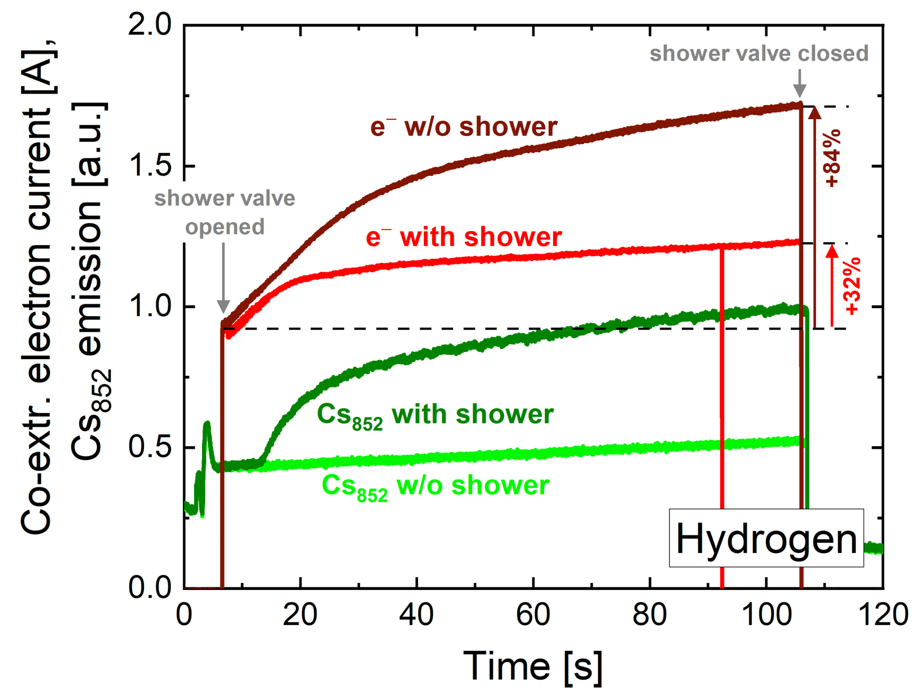
Stabilizing the co-extracted electrons

Aim: sufficient influx of fresh caesium for homogeneous and stable plasma grid work function.

Approach ①, "Cs overconditioning"
- Increase strongly caesium amount available for re-distribution during long pulses.
- H_2: enabled reproducible 1000 s pulses with 90 % of the ITER target for j(H^-).
- Not a solution for D_2 due to increasing risk for HV breakdowns.

Approach ②, caesium evaporation directly onto the PG
- Initial tests conducted at BATMAN Upgrade of a "cesium shower".
- Directed caesium evaporation works and suppresses the co-extracted e^-.
- Several technical details to be dealt with before application at ELISE.





Upgrade to CW operation

CW extraction is the ITER scenario and investigations at the test facilities are mandatory.

BATMAN Upgrade:
Pulse length presently limited by thermal effects (heating of flexible plasma grid inset).

ELISE:
- CW plasma pulses possible, but only extraction blips (9.5 s each ≈180 s).
- Upgrade to CW extraction ongoing, will be finished in first half of 2021.
- New long-pulse diagnostic calorimeter with an upgraded cooling system.

Conclusions

- Performance of ITER relevant long pulses in D_2 limited by static and dynamic effects regarding the vertical asymmetry and the amount of co-extracted electrons.
- Symmetrizing the electrons is important for operational safety of ITER NBI system.
- BATMAN Upgrade and ELISE give valuable insight.

Long deuterium pulses are still a challenge.
Measures for the static and dynamic behavior of the co-extracted e^- are mandatory.

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[1]: Parts of this work were conducted while F. Bonomo and I. Mario were at IPP Garching.
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