Deuterium Results at ELISE

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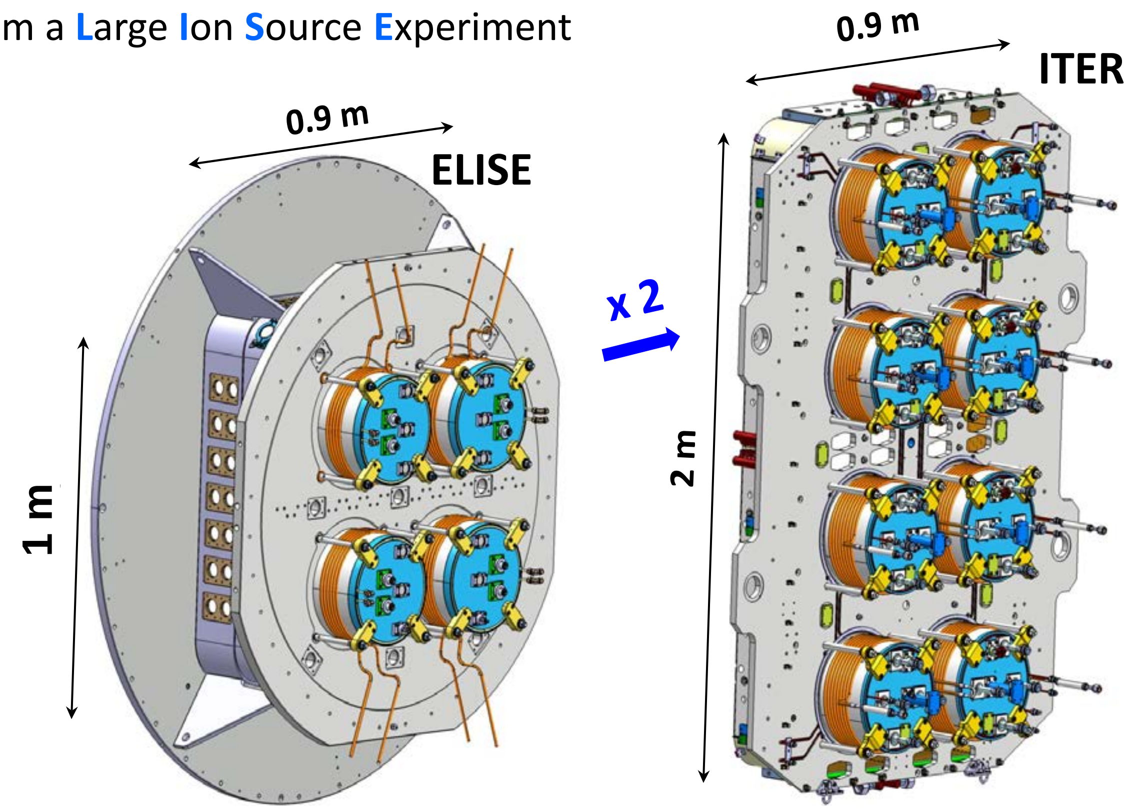
ELISE

Extraction from a Large Ion Source Experiment



Since 2013 at IPP:

Test of a RF driven negative ion source of half size of the ITER sources

which are under construction at NBTF (Padua) for the heating injector (commissioning SPIDER in 2018) and at ITER India for the diagnostic injector.

Goal of the ELISE experiment

- Gain **experimental experience** with a negative RF source of ITER relevant dimensions.
- Identify and solve **technical issues** of the operation at high power and in long pulses, the solutions to be implemented into the design of the ITER size sources.
- Find **physical solutions** to achieve the challenging ITER requirements

  32.9 mA/cm² H^- extracted for 1000 s

  28.6 mA/cm² D^- extracted for 3600 s

  both at 0.3 Pa and with an electron/ion ratio below 1.

Outline

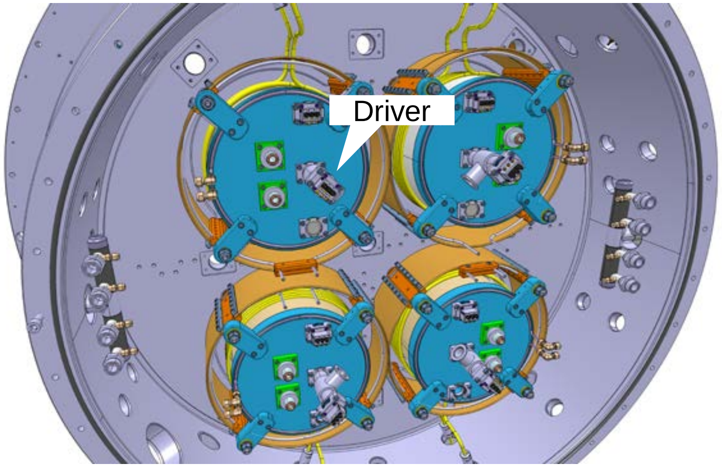
- The ELISE source
- Technical improvements for high power and long pulse operation
- Conditioning and results in hydrogen
- Deuterium results at elevated Cs density
- Asymmetry of the co-extracted electrons
- Dynamics of the electron currents with pulsed beam extraction
- Conclusion

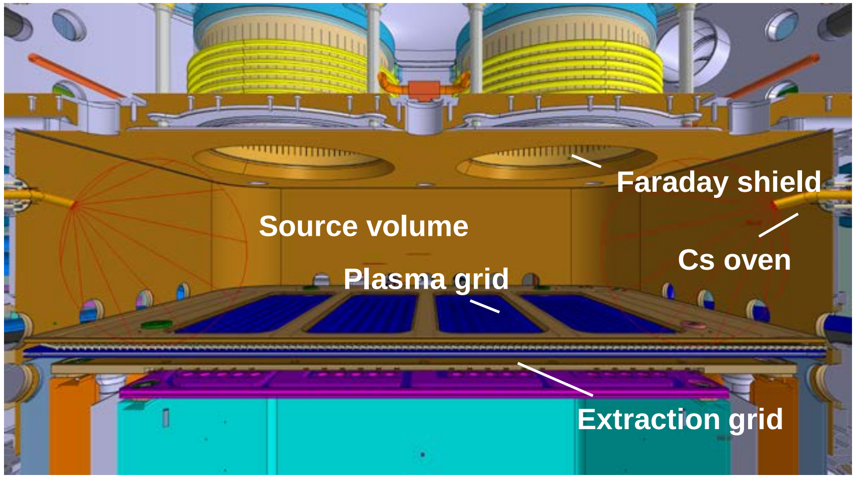
The ELISE source

RF source with 4 drivers (ø 300 mm) supplied with two 150 kW/1 MHz RF generators

- Plasma expands into a volume of $0.87 \times 1\ m^2$
- Continuous plasma operation up to 1 h
- Negative ions produced by surface conversion on the plasma grid surface covered by caesium
- Plasma grid positively biased to reduce current of co-extracted electrons
- 2 Cs ovens
- Filter field generated by the PG current of up to 4 kA (4 mT maximum field), return connectors close to the drivers

Source diagnostics: OES, Langmuir probes, laser absorption spectroscopy



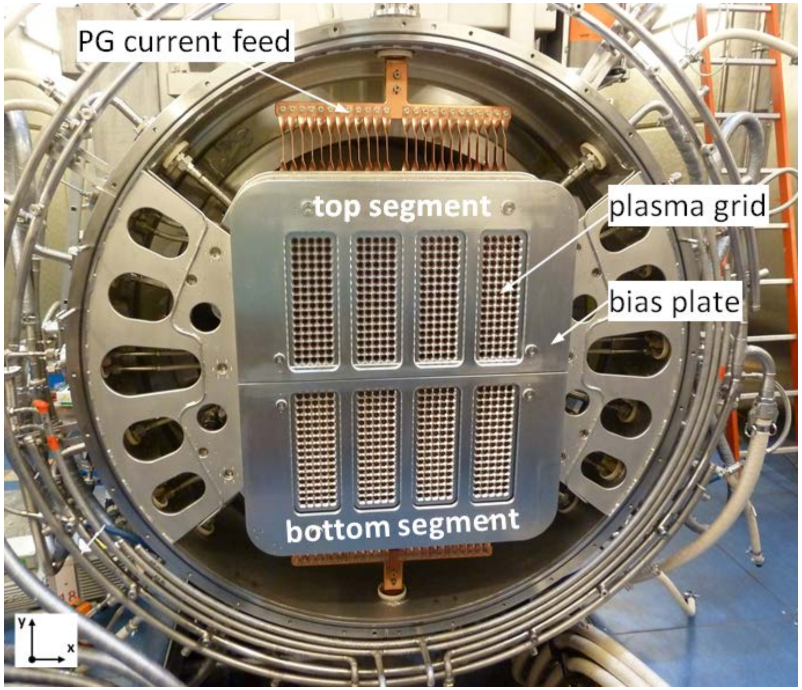


ELISE beam extraction

3 grid extraction system:

- 640 apertures (Ø 14 mm) in 8 beam let groups
- 985 cm^2 in total,
- design close to ITER
- max 60 kV/20 A accelerated
- **Pulsed beam extraction** with duty cycle 10s/180s
- Top and bottom half of the extraction grid insulated

=> **electron currents measured separately** (not foreseen for the ITER source)



Beam diagnostics: current measurements, calorimeter, tungsten wire calorimeter, beam emission spectroscopy

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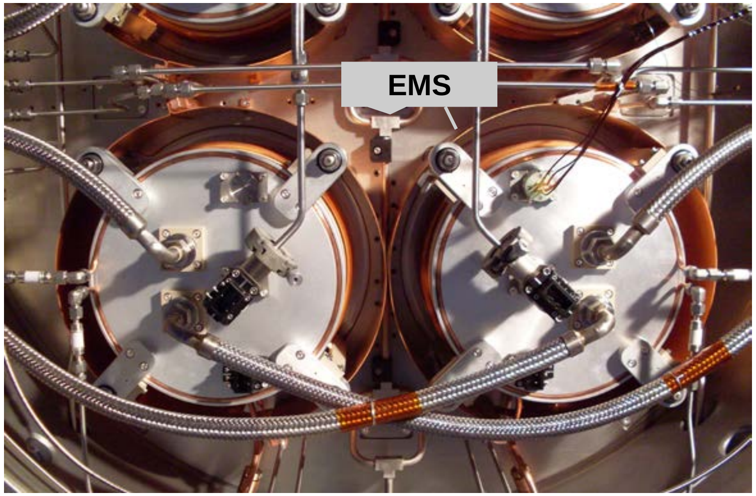
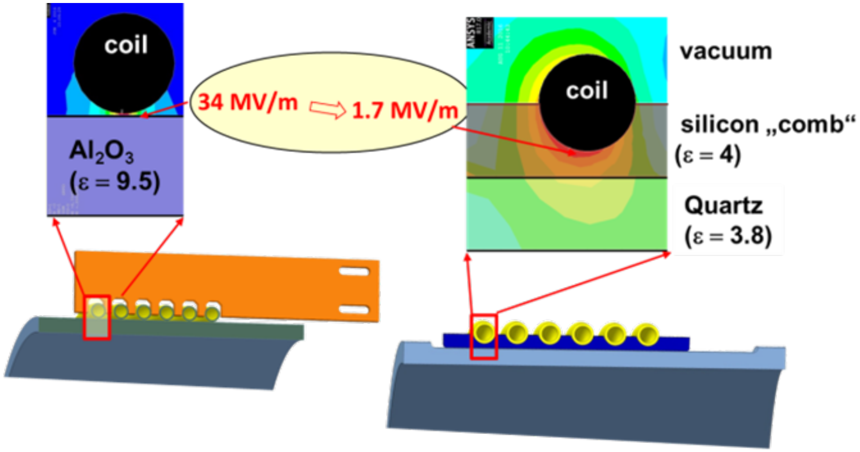
Major technical improvements

- **Electromagnetic shields** EMS (2013)
  ⇒ No mutual inductance of the drivers
  ⇒ prevent damage of the internal Faraday shields
  Active cooling for CW operation
- **Solution of the problem of RF breakdowns** at the RF coil (2016)
  Reduction of E field between RF coil and insulator by using quartz and keep 2 mm distance to the insulator
  ⇒ Reliable operation at high power
- Dispenser Cs ovens replaced by **liquid Cs ovens** (2016)
  => higher evaporation rate enables long pulses
- **Solid-state RF amplifiers** (2017)
  Replaces self-excited oscillators
  ⇒ Stable frequency and better matching

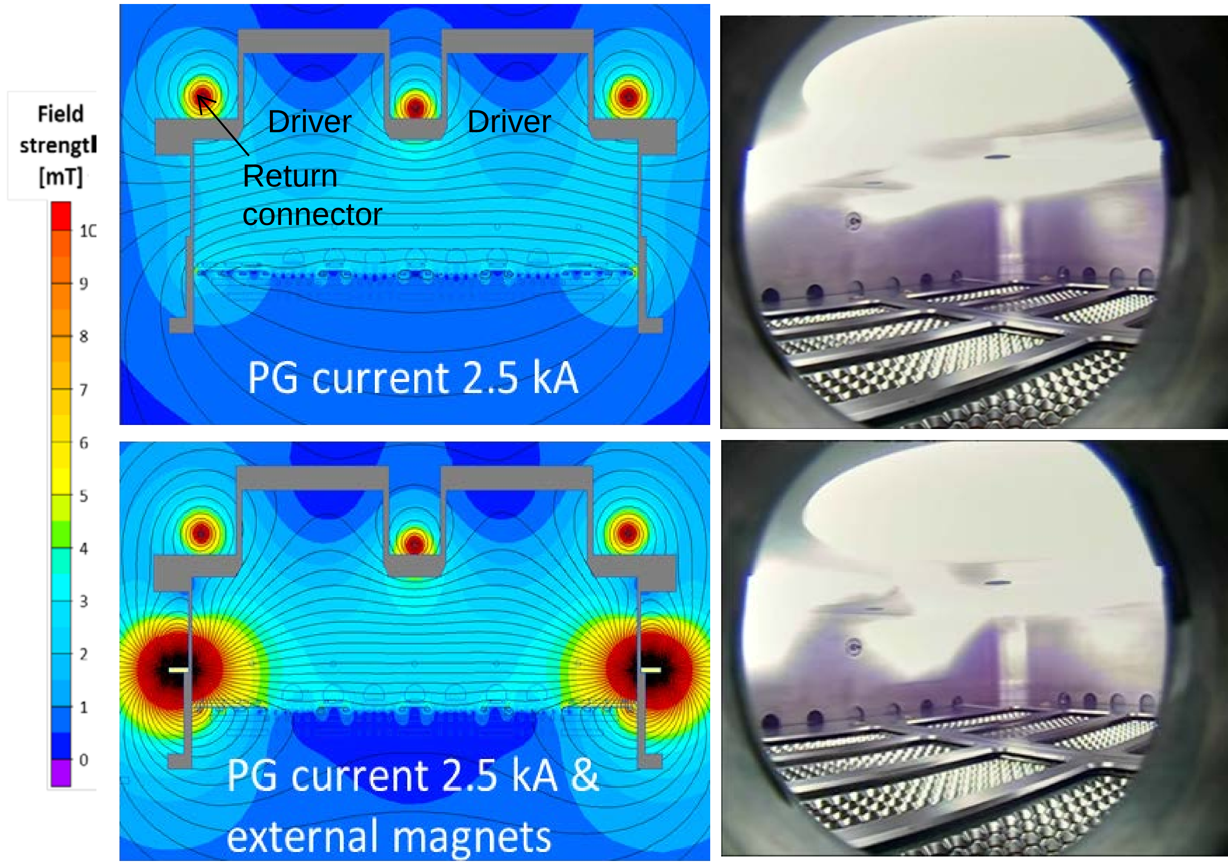




Improvement of the source performance and long pulse stability: Magnetic filter field

Field strenghtened by **permanent magnets at the lateral sides** (2015)

- ⇒ Reduction of j_{el} and only moderate reduction of j_{ion}
- ⇒ Higher stability of j_{el} in long pulses in particular in deuterium



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Cs conditioning

Cs evaporation and distribution
=> Development of conditioning procedures

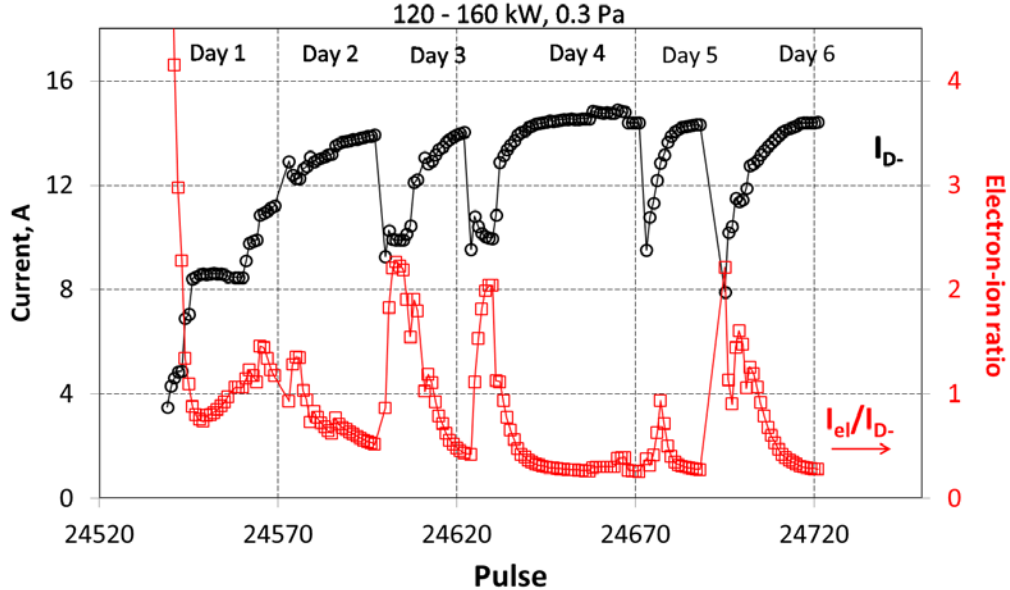
Parameters

- Cs evaporation rate,
- pulse duration and interruption time,
- bias current,
- temperatures of wall and plasma grid

⇒ Improvement within a day and day by day

⇒ Conditioning necessary after long pulses

⇒ Limited reproducibility



Conditioning in deuterium in 10 s pulses at moderate power after 2 months break

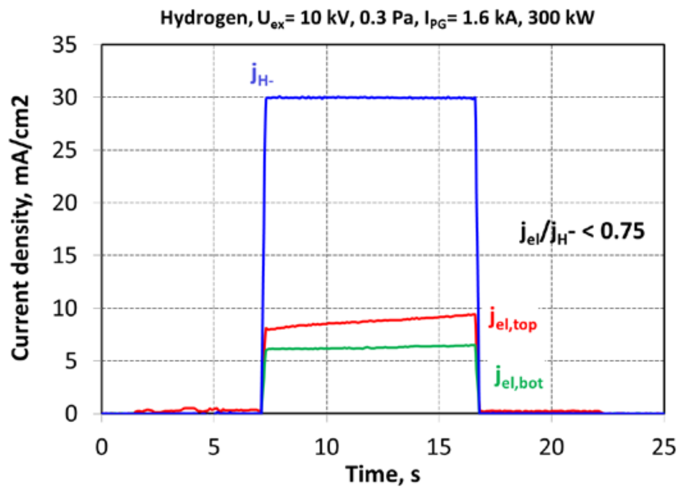
Results in hydrogen: Short pulses

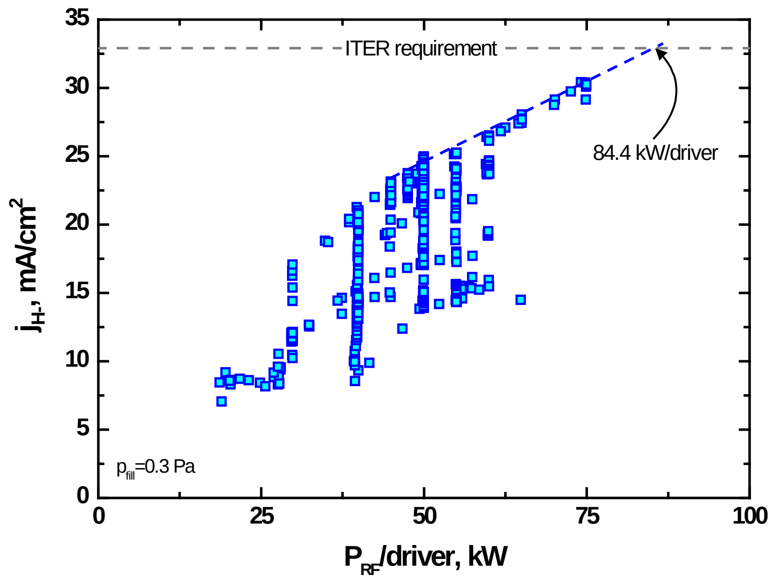
30.4 mA/cm² (29.8 A) and j_{el}/j_{ion} = 0.4

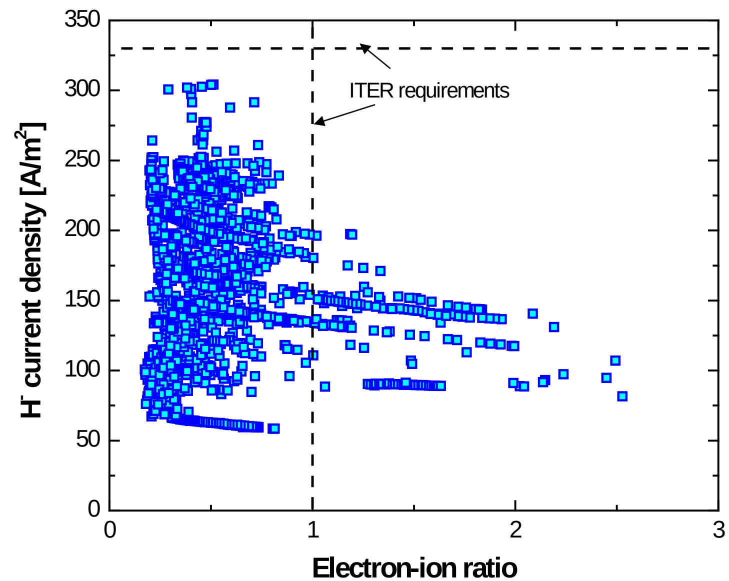
at 0.3 Pa, U_{ex} = 10 kV and 300 kW total power

Ion current limited only by HV power supply

- 33 mA/cm² required for ITER would be achievable with < 85 kW/driver (for ITER 100kW/driver available)
- Electron/ion ratio well below 1







Results in hydrogen: Long pulses

Currents of co-extracted electrons increase from beam pulse to beam pulse

Power of the electron current on the extraction grid limited to < 125 kW/grid half

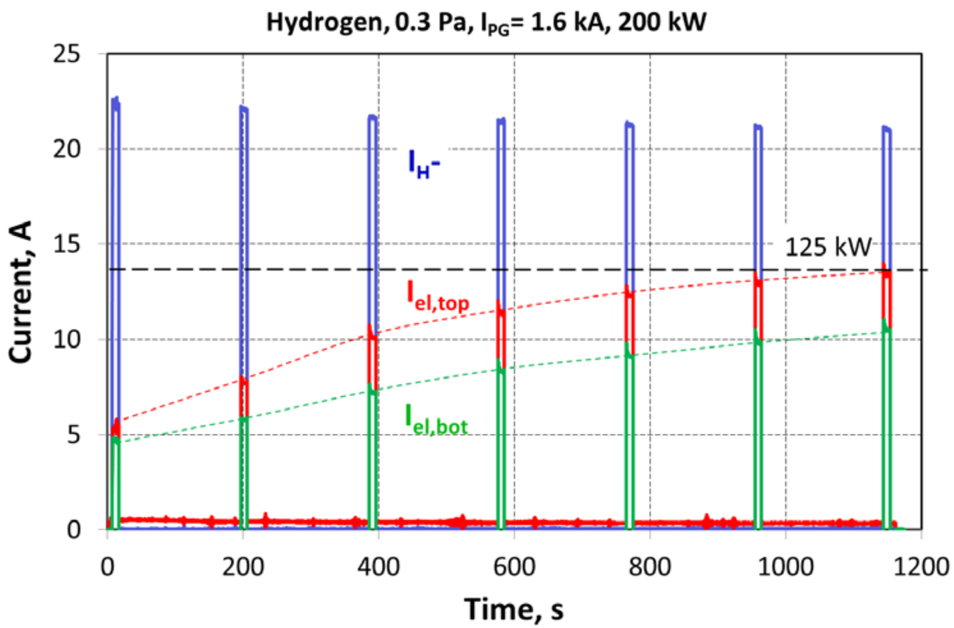
Higher load on the top grid due to the **plasma asymmetry**

⇒ RF power has to be reduced

⇒ Achievable ion currents in hydrogen below ITER value:

22 mA/cm^2 and

j_{el}/j_{ion} < 0.75 for 1160 s



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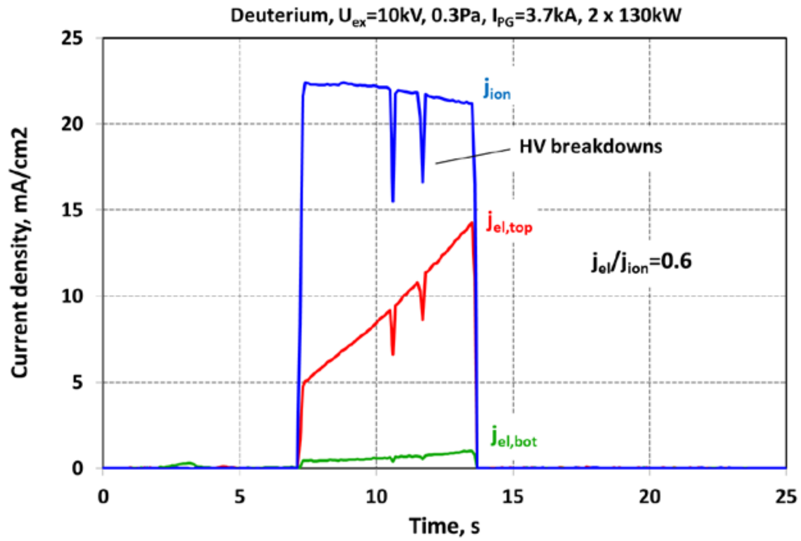
Short pulses in deuterium

Difference to hydrogen:

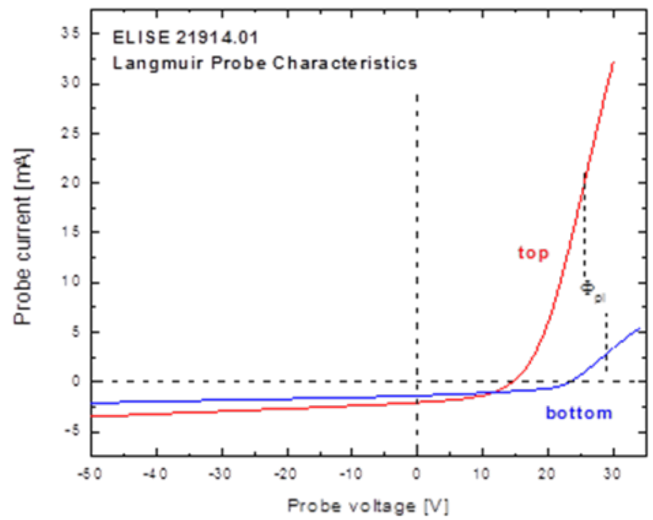
- **Much higher asymmetry** of the electron currents
- **Steeper increase of the electron currents** on the top grid
- Much **more Cs** necessary (10x higher Cs density)
- **Higher filter field** necessary to suppress I_{el} (reduces also I_{ion}), maximum field at the PG

  2 mT (hydrogen) => 3.5 – 4.5 mT (deuterium)



Best pulse: 22.0 mA/cm² for 6.4 s limited by $I_{el,top}$

Asymmetry of I_{el} confirmed by probe measurements:
Bottom: characteristics of an **ion/ion plasma**



Beam symmetry measured beam diagnostic:

$I_{ion,top}$ is almost equal to $I_{ion,bot}$
but different beam divergence

=> Poster F. Bonomo Tu_51

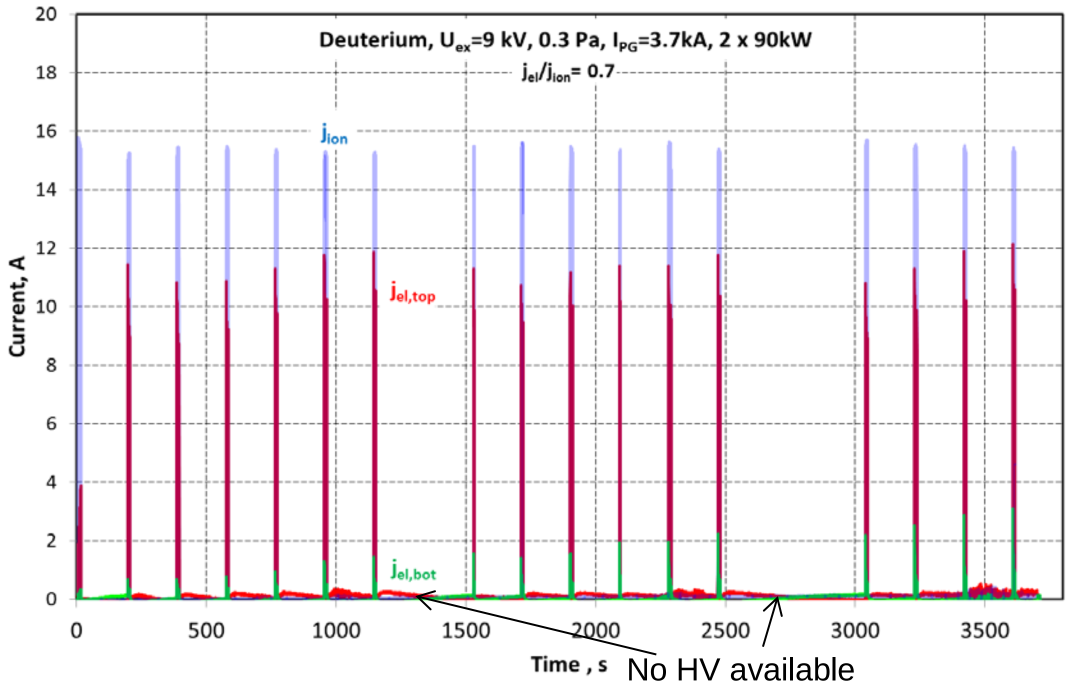
One hour pulse in deuterium

Main problems in long pulses:

- Asymmetry of the electron currents limits the RF power
- Increasing electron currents due to depletion of Cs from the plasma grid (change of work function)

  => Conditioning with **highest possible Cs flux**

- Higher Cs density leads to **HV breakdowns,** HV deconditioning of the extraction system and RF matching problems



J_{ion} > **15.4 mA/cm²**, j_{el}/j_{ion} < 0.7

achieved with liquid Cs oven,

with the dispenser oven only 6 mA/cm²

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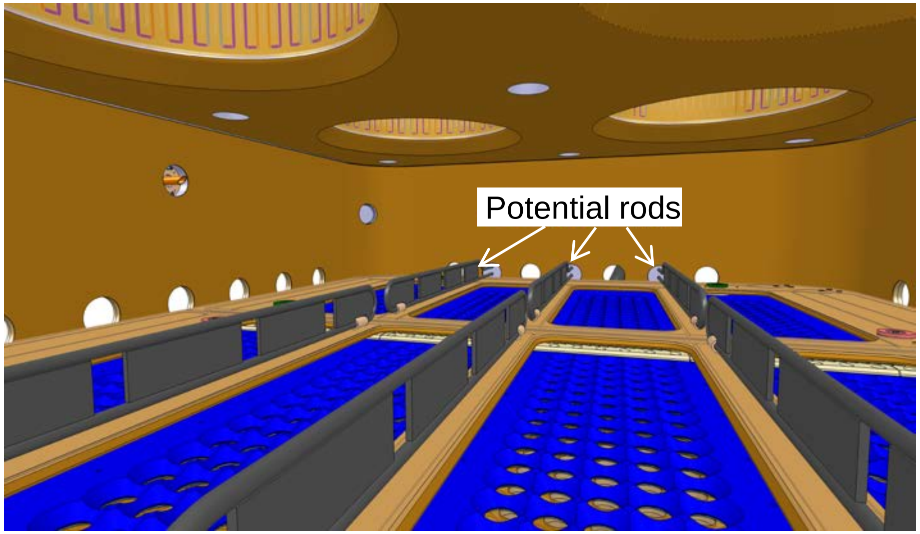
Installation of vertical potential rods to change the plasma drift

Reason for asymmetric electron currents are vertical xB-drifts

Six rods placed between the beamlet groups perpendicular to the magnetic filter field

Goal

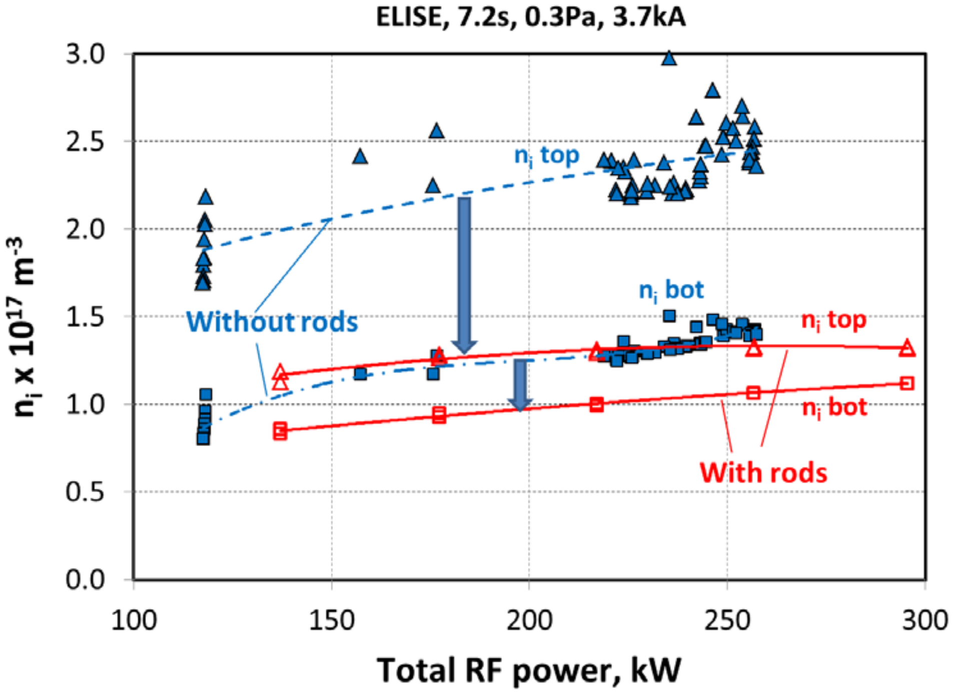
- Reduction of the electron density in front of the plasma grid
- Lower power load on the plasma grid

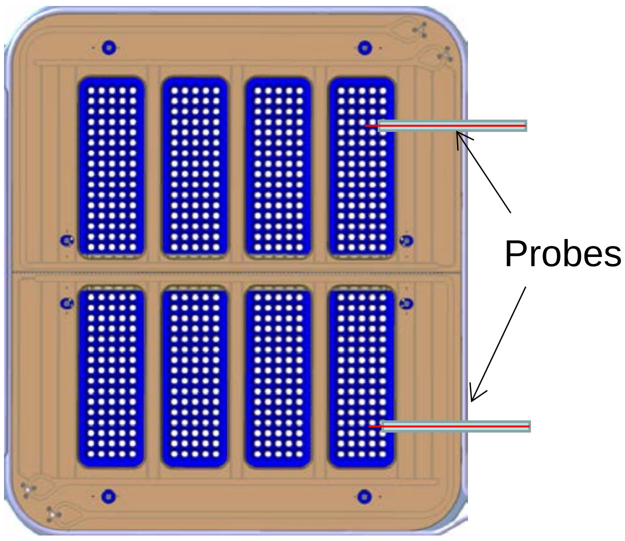


Similar rods had been successfully tested in a smaller source (1/8 of the ITER size)

The potential with respect to the plasma grid can be changed.

Plasma density w/wo rods



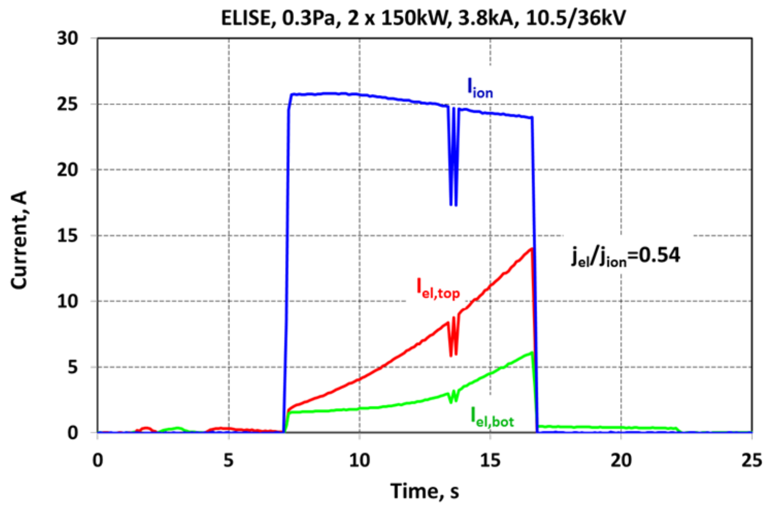


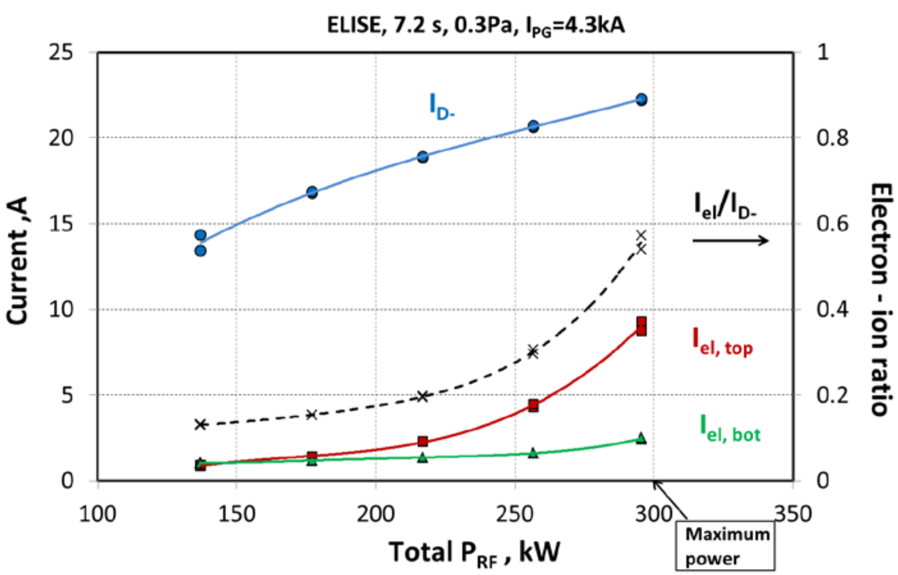
- Reduction of the plasma density in particular at the top side
- Much higher symmetry

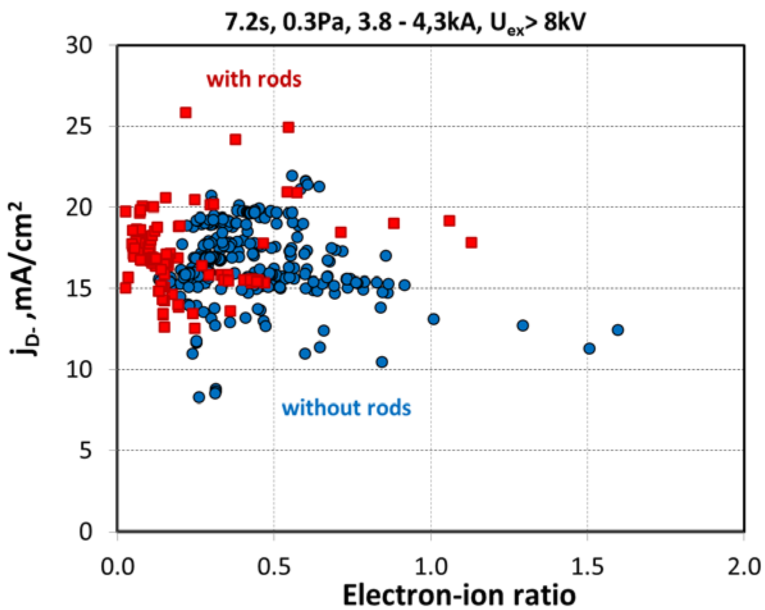
Shorts pulses in D_2 with rods

- Best results achieved with rods on PG potential
- **Electron currents are lower and more symmetric**
- Lower electron currents allow higher power

  => Best pulse: **25 mA/cm² for 10s**
- $I_{el,\,top}$ still increasing at high power
- No saturation of the ion current



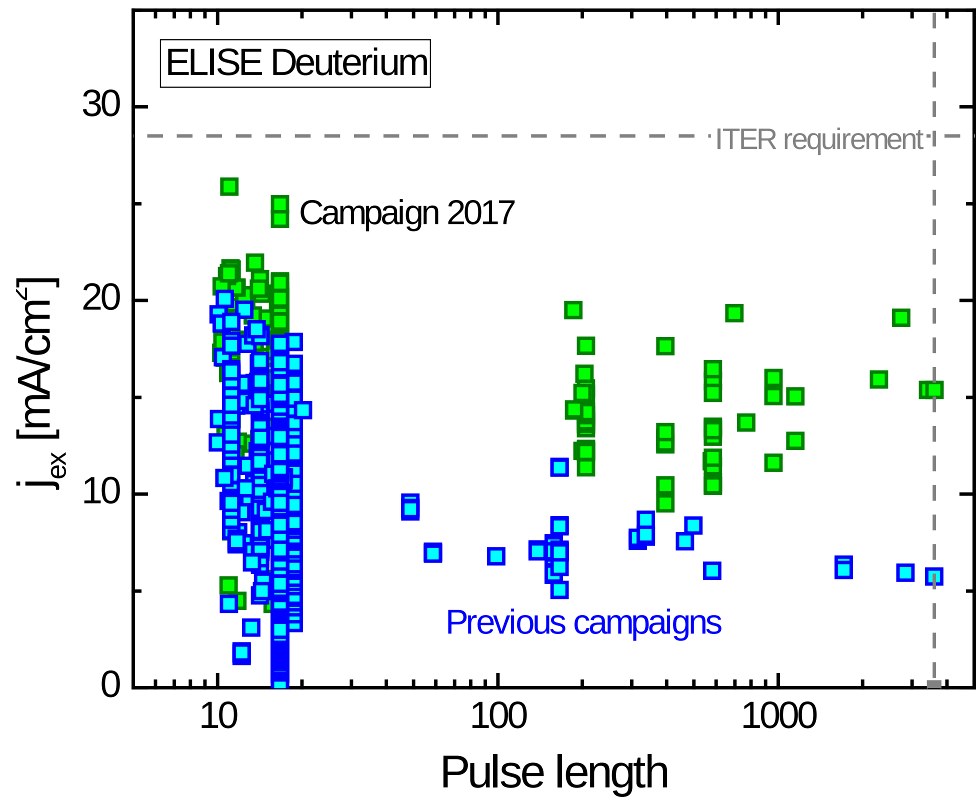




Improvement of source performance in long pulses in D_2

Improvement achieved in the 2017 deuterium campagn by

- High Cs density
- Refined conditioning procedures
- Potential rods



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Best long pulse in D_2

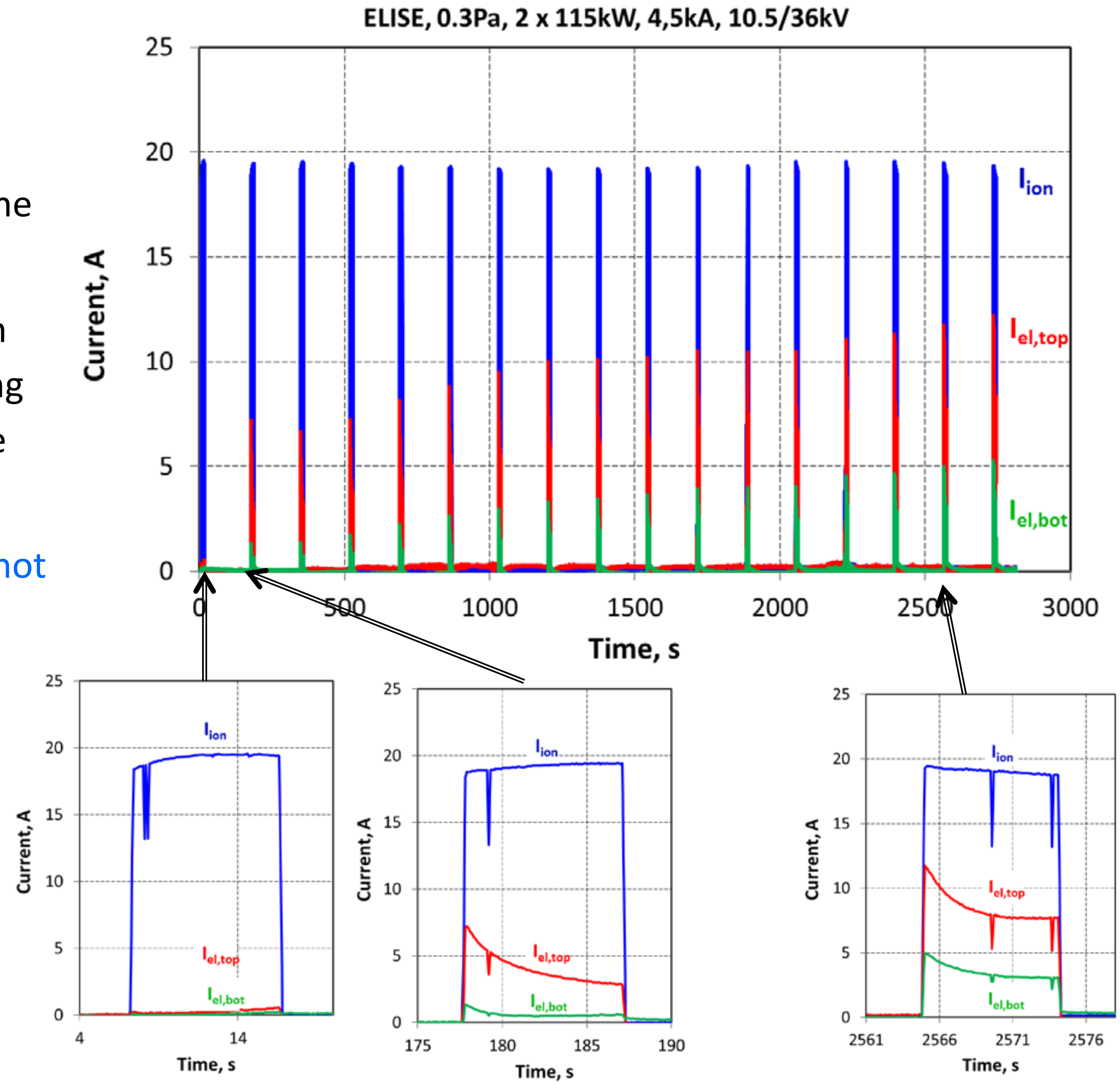
19 mA/cm² for 2700 s

66 % of ITER requirement

- Almost no electron current in the first beam pulse
- Dynamic within the other beam pulses possibly due to sputtering of Cs from the source backplate by backstreaming ions

  => results of pulsed extraction not transferable to cw extraction

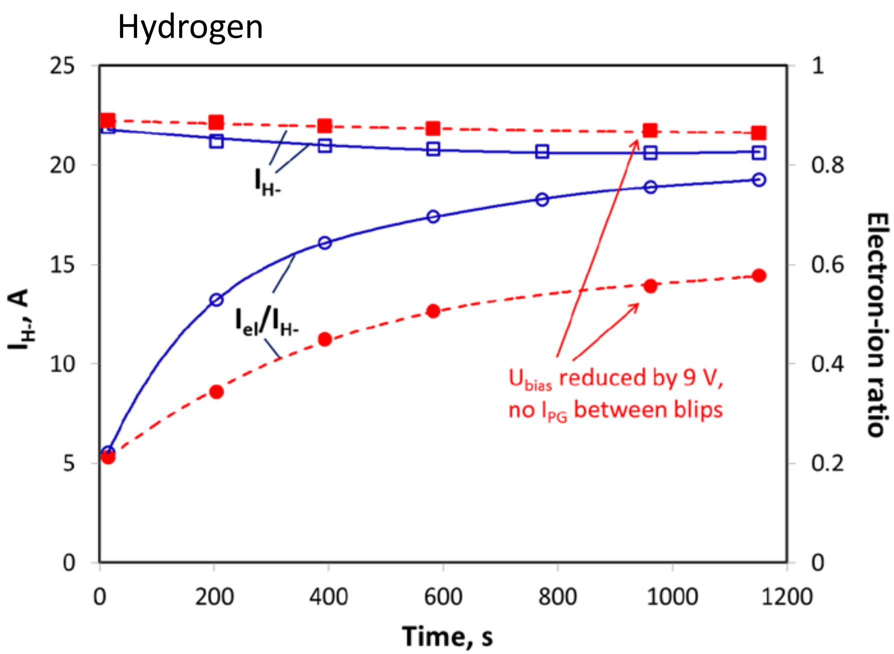
⇒ Talk U. Fantz on Tuesday



Future experiments to improve the long pulse stability

- Best results were achieved by high caesium density in the plasma to generate a "Cs reservoir".
- Raising the caesium density <u>during</u> the pulses did not affect the currents (Cs ions can not reach the positively biased plasma grid).

=> Control of Cs coverage of the plasma grid during long pulses is required to compensate the Cs depletion



By reduction of the PG bias <u>between</u> the beam blips the performance was improved

=> Acceleration of Cs ions towards the PG overcome the potential barrier can be a solution

Conclusion

- **Considerable progress** has been made towards the ITER requirements for the deuterium ion current densities, 66 % have been reached in long pulses.
- The source performance is in long pulses limited by the **increase of the electron currents** caused depletion of the caesium from the PG.
- **Inhomogeneous distribution of the electron currents** caused by the plasma drift could partly been diminished by internal rods.
- The dynamics of the currents during the short beam extraction phase shows that for realistic results a **continuous beam extraction** is necessary.
- Best results have been achieved by **high caesium density,** but stabilization of the Caesium layer on the plasma grid **during the pulses**, possibly by accelerated Caesium ions, is the main issue of future developments at ELISE.