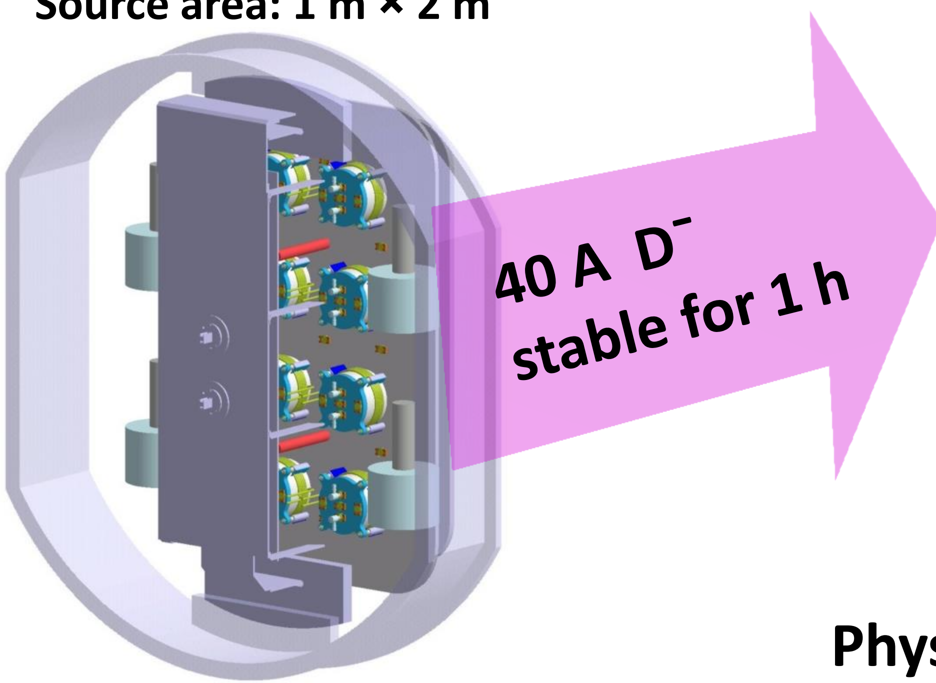
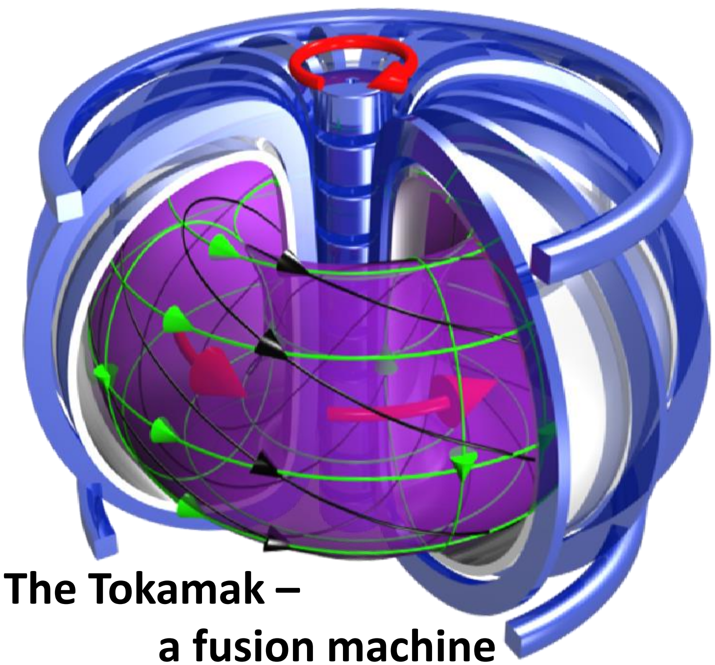
Large and Powerful Sources for Negative Hydrogen Ions

Ursel Fantz

Source area: 1 m × 2 m



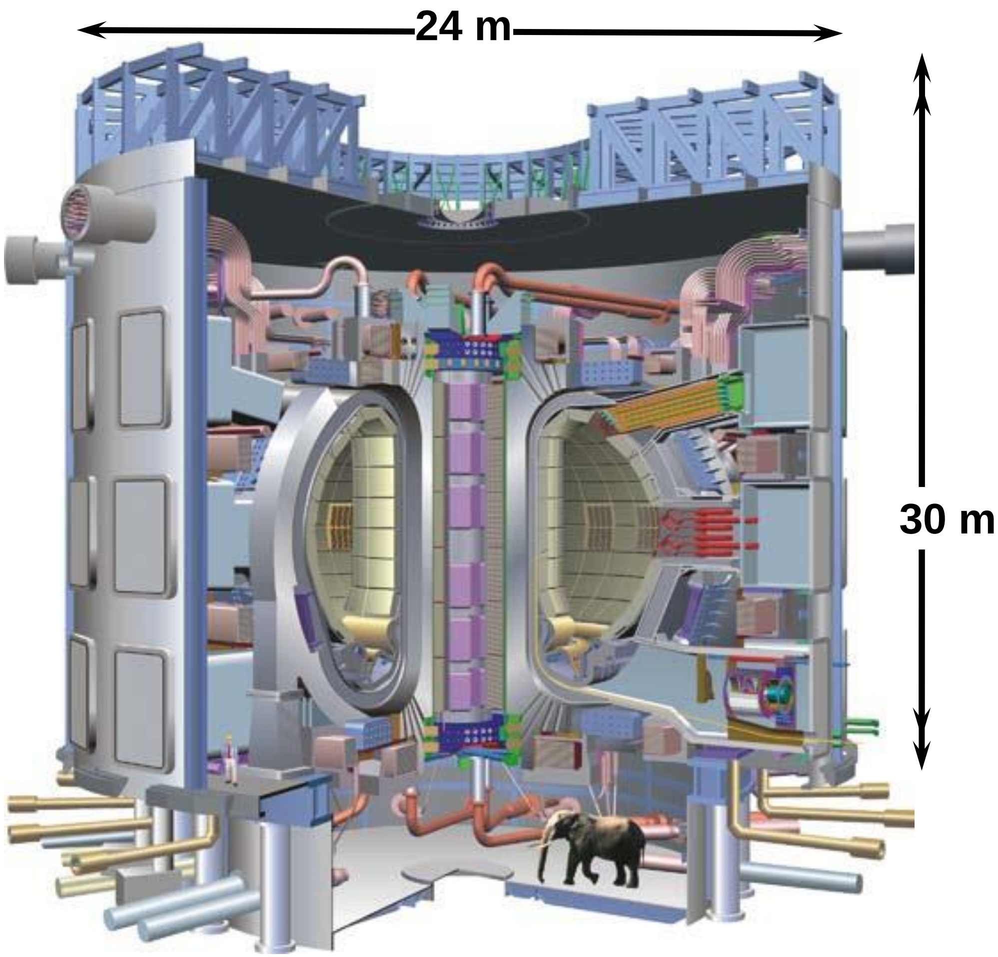


The Tokamak –
a fusion machine

Physics and engineering challenges

An international project that …

… aims to demonstrate that fusion is an energy source for the future!



Main Parameters:	
Total fusion power	**500 MW**
Q (gain)	**≥ 10**
Major radius	6.2 m
Minor radius	2.0 m
Plasma current	15 MA
Toroidal field (at 6.2m)	5.3 T
Plasma volume	837 m^3
Heating and CD power	**73 MW**

NBI	**33 MW**
ICRF	**20 MW**
ECRH	**20 MW**

… is under construction in Europe (France).

… first plasma targeted for 2026.

⇨ **www.iter.org**

Large and powerful ion sources for ITER NBI systems

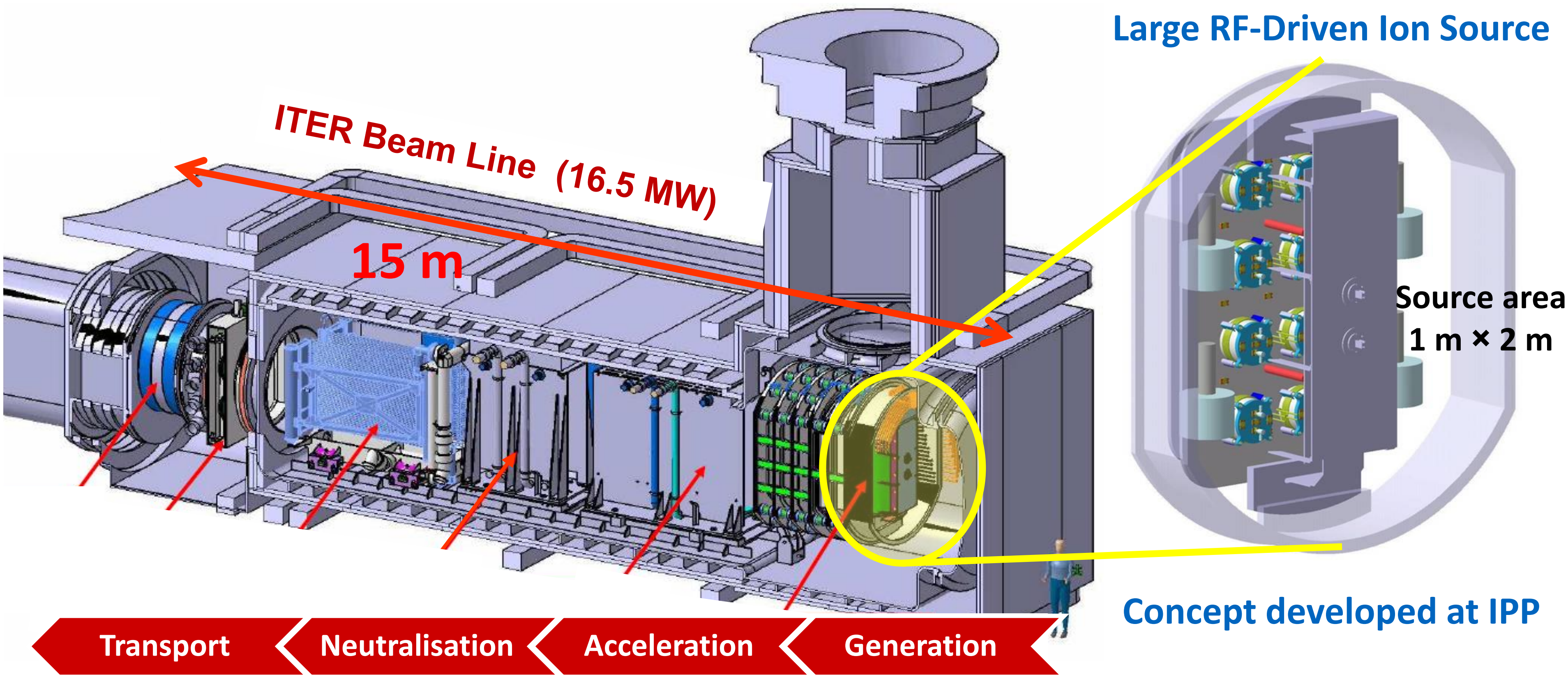
Neutral beam injection (NBI) for plasma heating and current drive and for diagnostics

Heating beams (50% EU, 50% JA)

- **33 MW** injected power from 2 injectors
- 3600 s, **1 MeV Deuterium**

Diagnostic beam (100% IN)

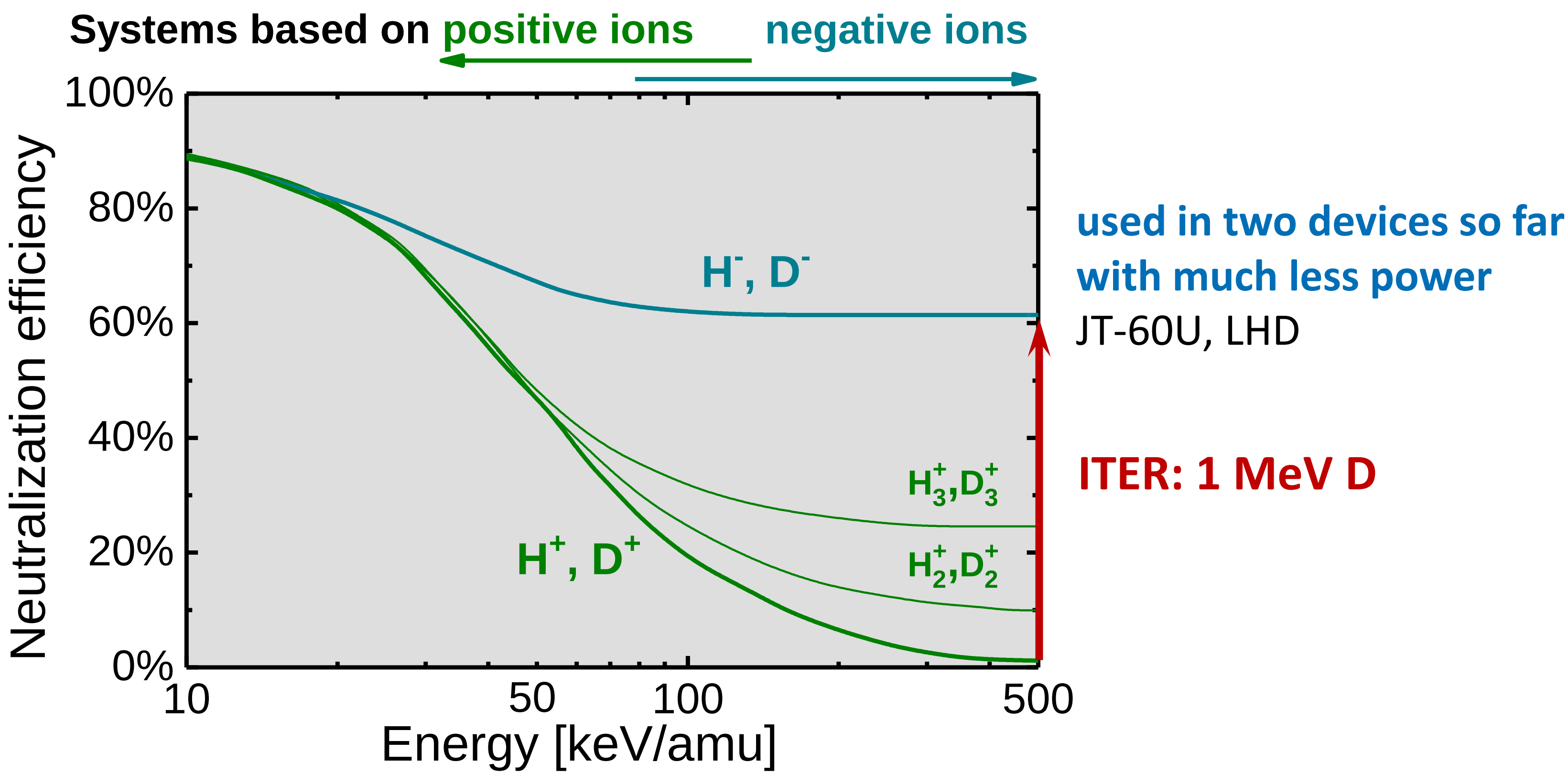
- **3 MW**
- **100 keV Hydrogen**



Transport	Neutralisation	Acceleration	Generation
7 mrad divergence	60% via gas neutralizer	1 MeV 40 A	57 A ion current (D^-)

NBI systems based on positive or negative ions

Decision based on the required energy of the particles



Positive ion based systems

- **are routinely operating world wide**

  JET, AUG, TFTR, DIII-D, JT-60U, …

U_{acc}<≈ 100 kV, **j ≈ 200 mA/cm²**, t ≈ 10 s

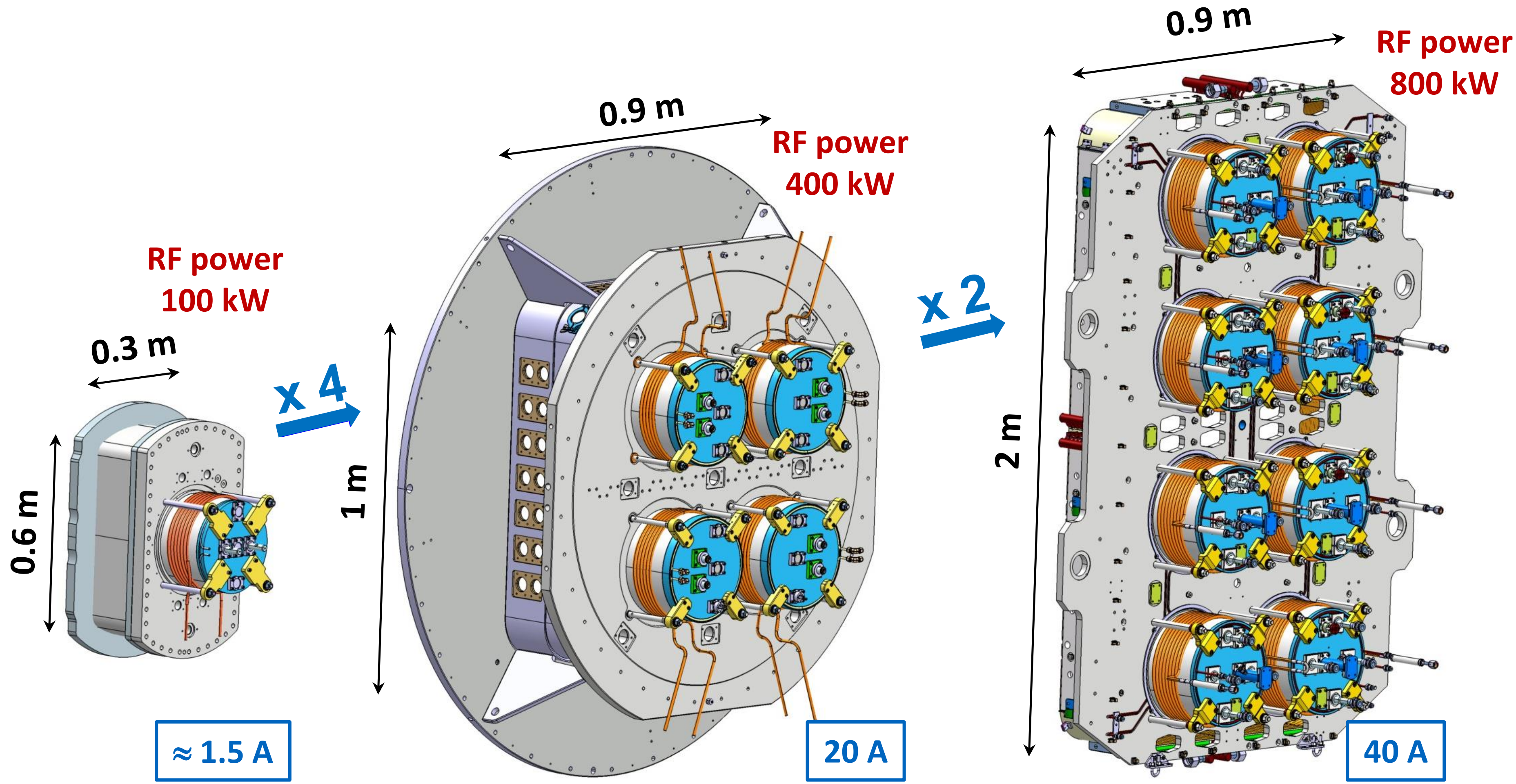
Negative ion based systems

- **make high energy range accessible**
- **are essential for large devices**

U_{acc}>≈ 150 kV, **j = 20 mA/cm²**, t = 10 s

Sources for negative hydrogen ions (H^-, D^-) for ITER NBI

Size scaling following the modular RF-driven ion source concept



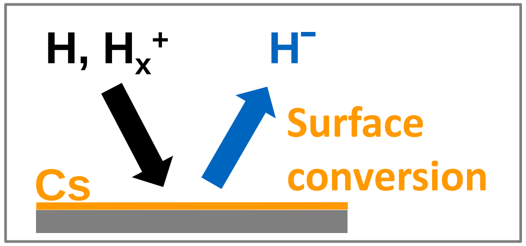
Prototype source BATMAN ← **Facilities at IPP** → **ELISE source**

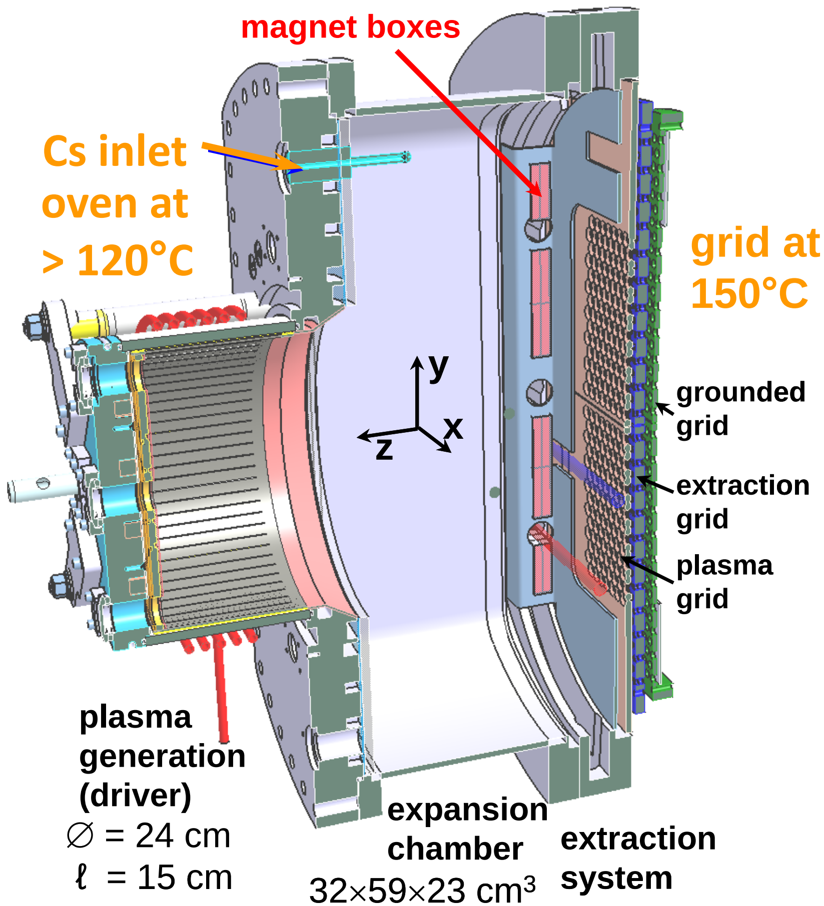
ITER sources: NBTF, HNB & DNB

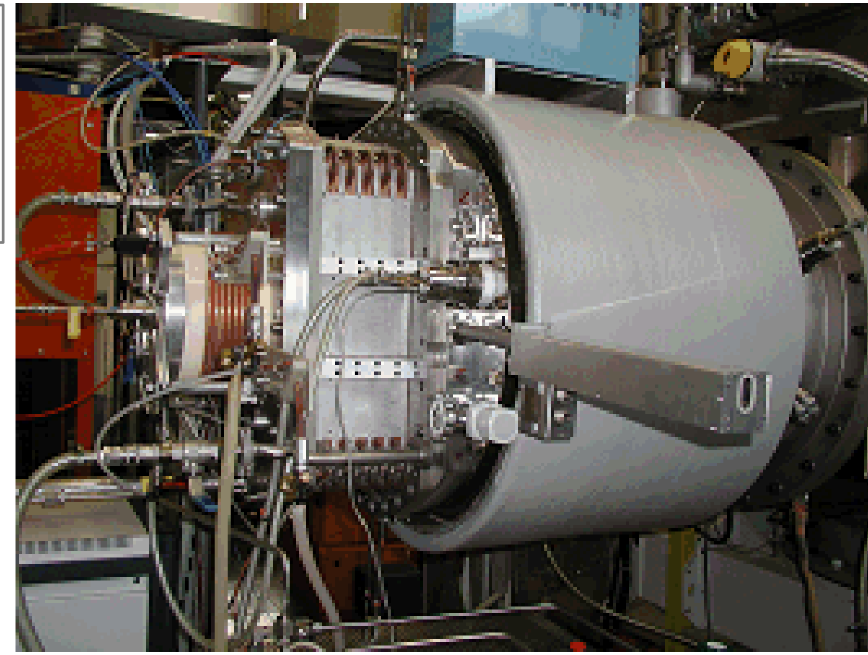
Neutral **B**eam **T**est **F**acilities (Padua, Italy)

Creation of sufficient negative hydrogen ions at 0.3 Pa

Prototype source:
f = 1 MHz
P < 100 kW







Source on high voltage
typ.50 kV

BATMAN ✓(4 s)

Physical parameters

- j_{H^-} > 30 mA/cm²
- j_{D^-} > 20 mA/cm²
- j_e/j_{D^-} < 1

MANITU

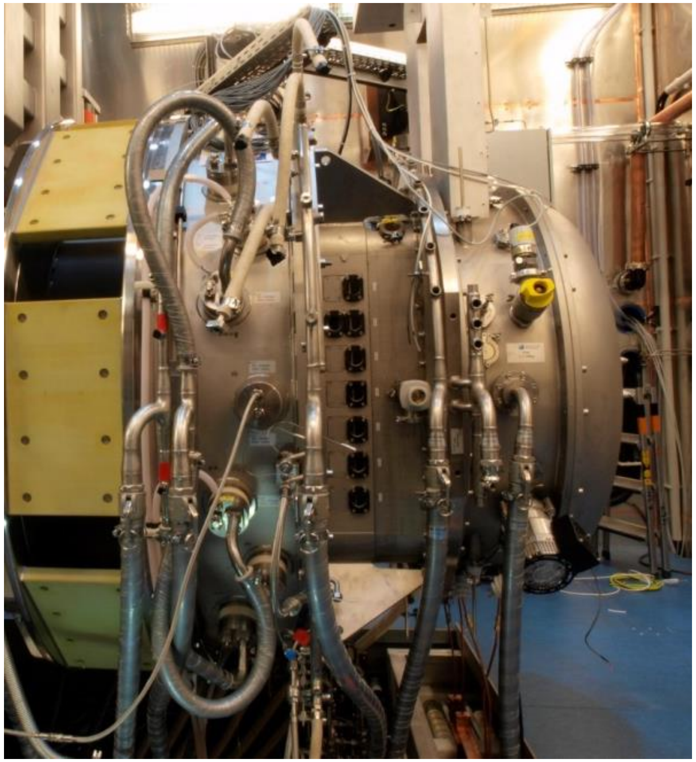
Long pulse extraction

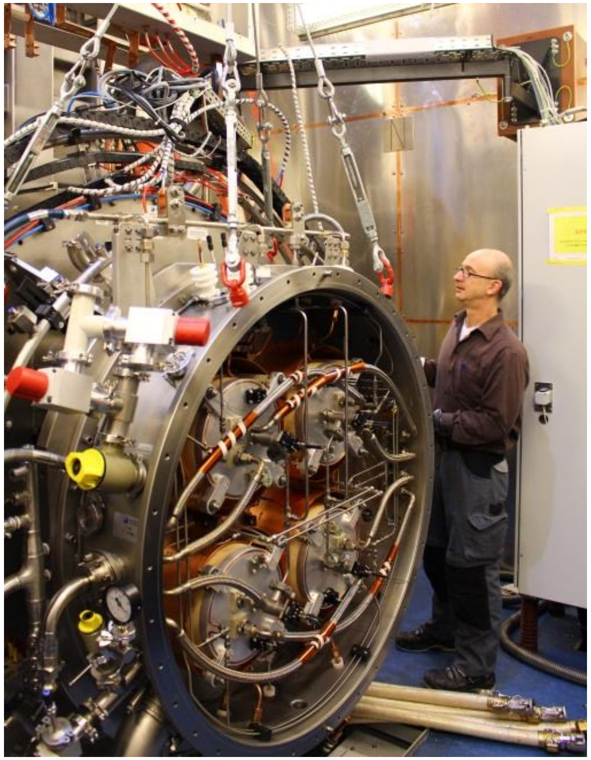
- 3600 s ✓ (H$^-$)
- D$^-$ operation ✓
  at reduced parameters

The size scaling experiment ELISE

Size scaling following the modular RF-driven ion source concept

The half size ITER source at the ELISE test facility

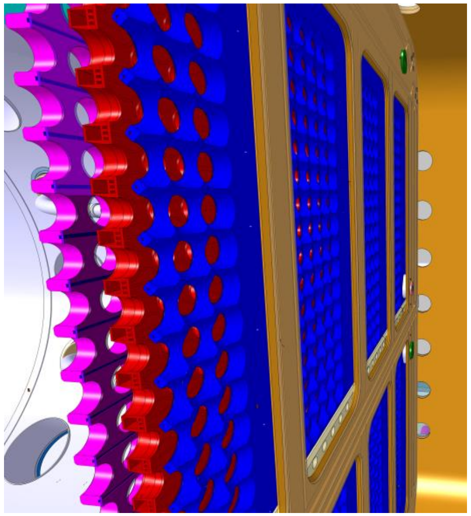




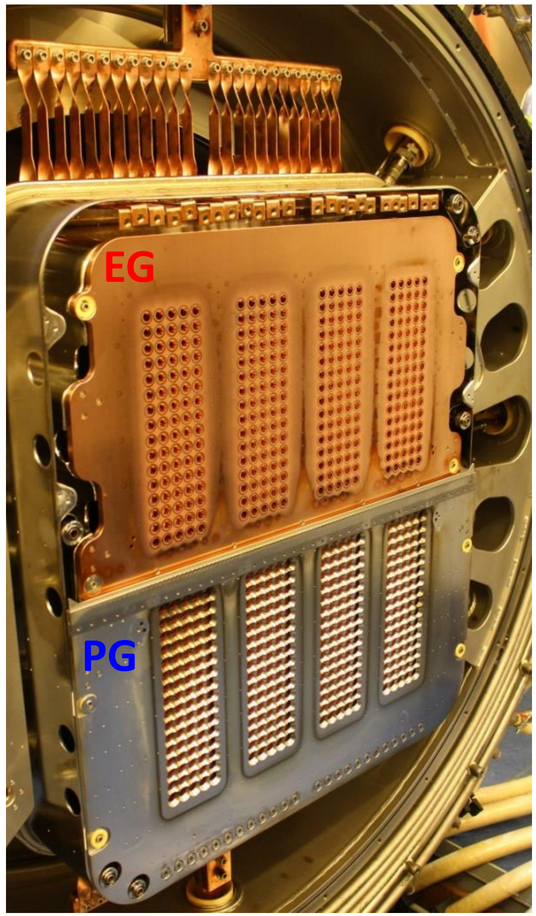
In operation since 2013

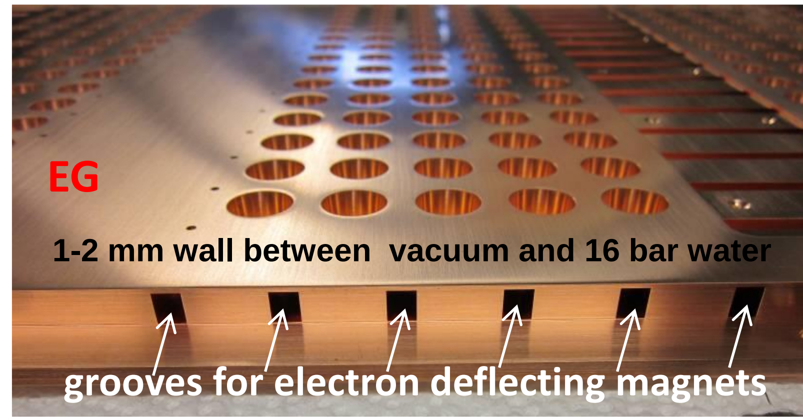
Main components of the ELISE test facility

Technologically most demanding: grid system, especially the extraction grid

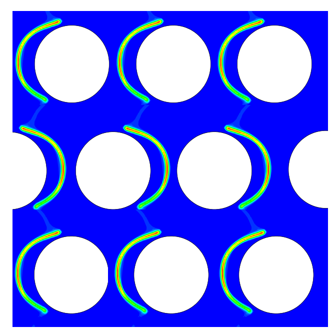


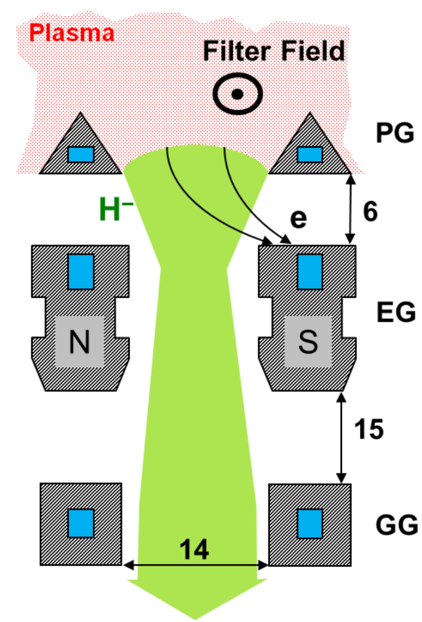
GG EG PG BP
Plasma Bias
Extraction Plate
Grounded Grid





Power density of
32 MW/m²
by co-extracted electrons

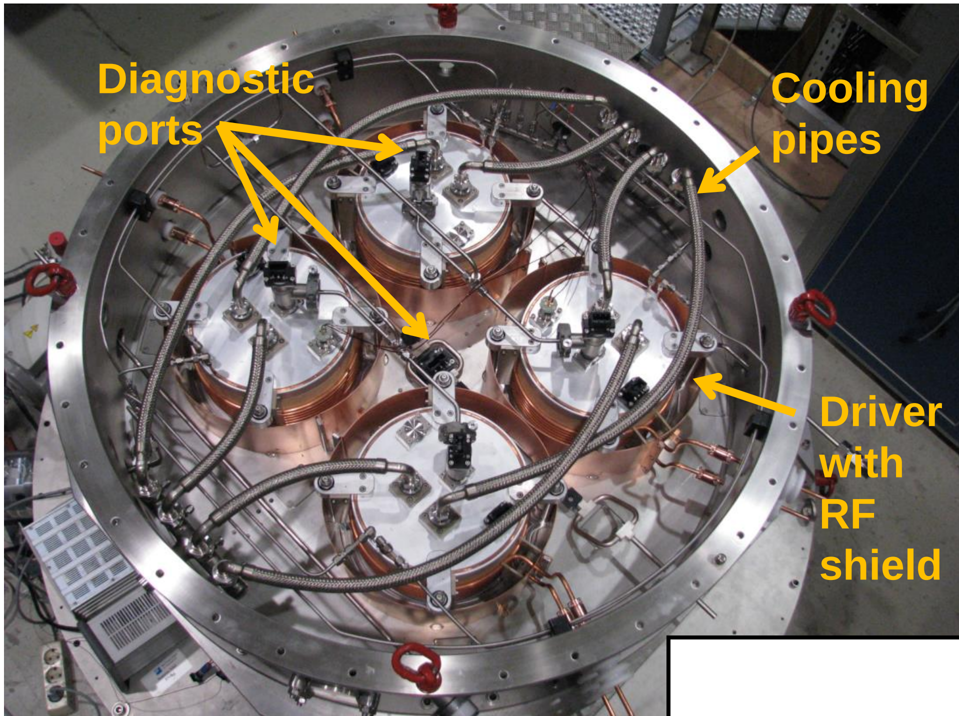




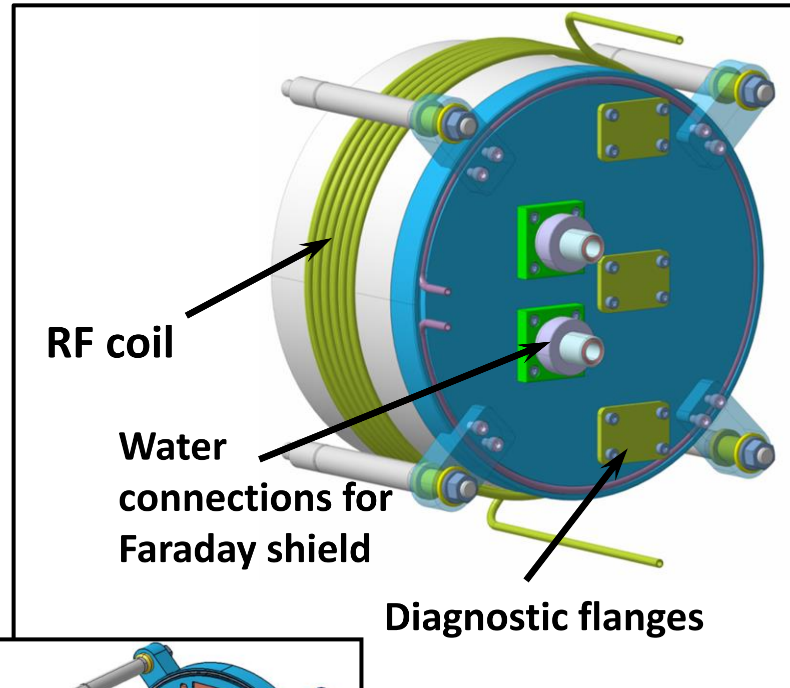
Technology of grid manufacturing and assembly confirmed !

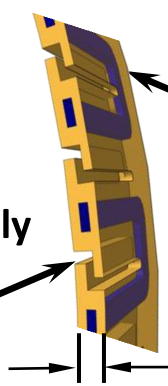
Main components of the ELISE test facility

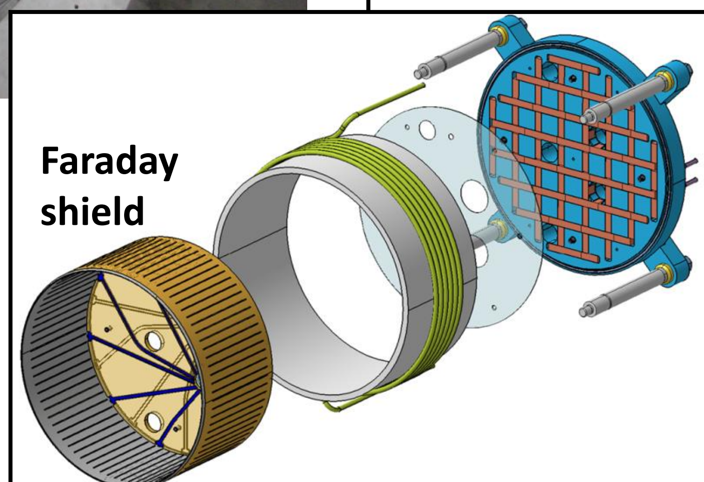
Ion source ∅ = 1.2 m



One RF driver



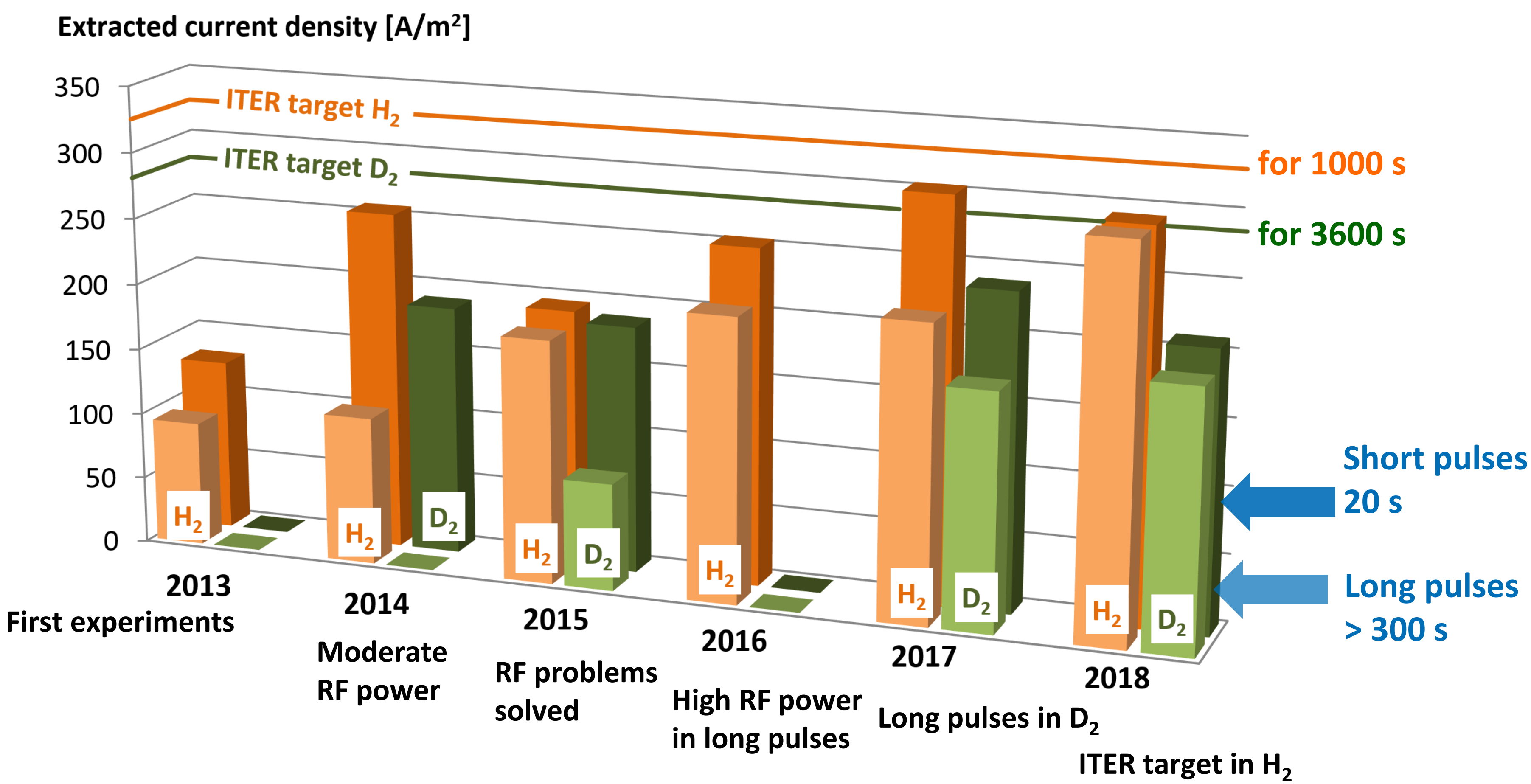




Faraday shield

Typical behavior of ions and electrons in long pulses

Progress at ELISE since the very first experiments



The source performance is limited by the amount of co-extracted electrons!

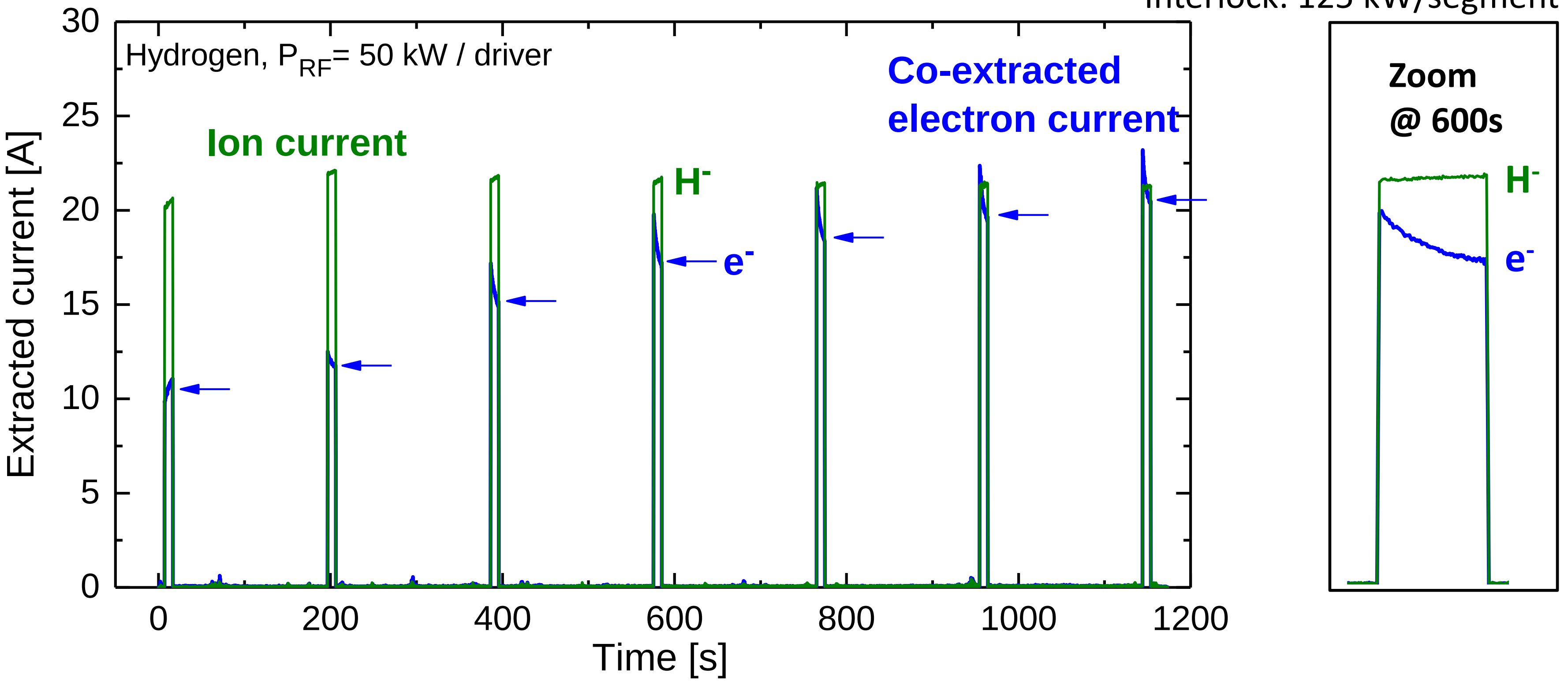
Towards the required ITER parameters with ELISE

Source performance is probed by short pulse extraction

of 10 s every 3 min (due to lack of cw power supply (3.3 MW)

- **Stable negative ion current density (within 10%)**
- **Strong temporal dynamics of co-extracted electrons**

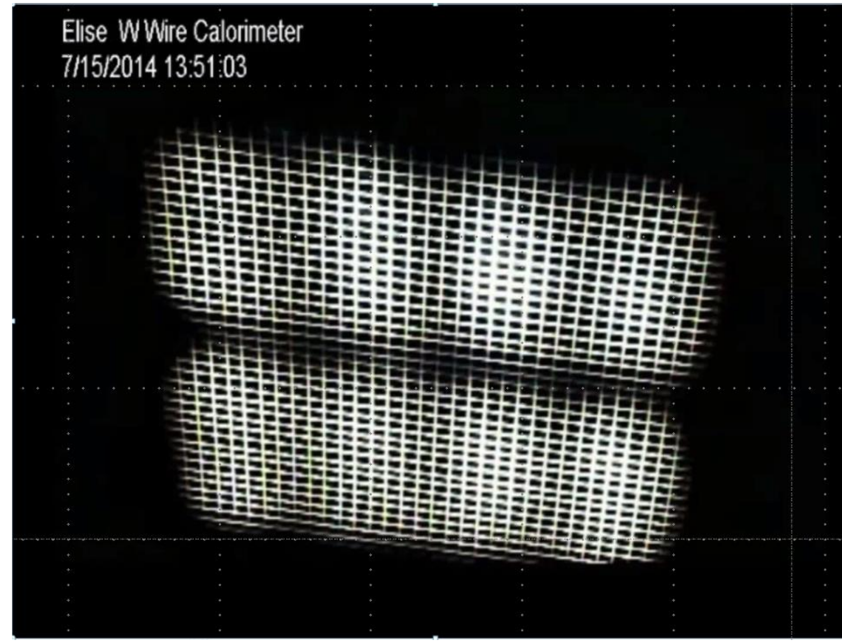
Interlock: 125 kW/segment

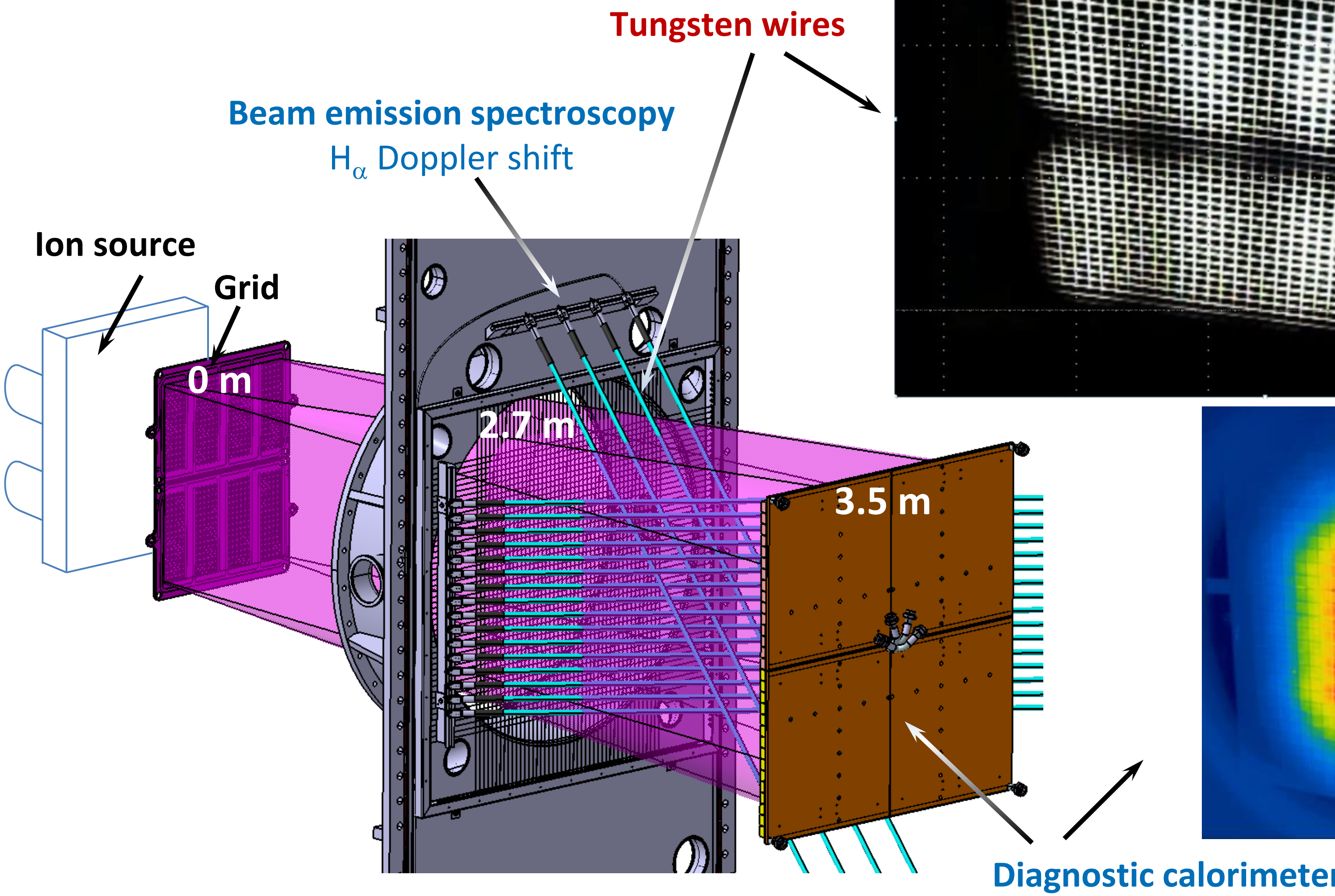


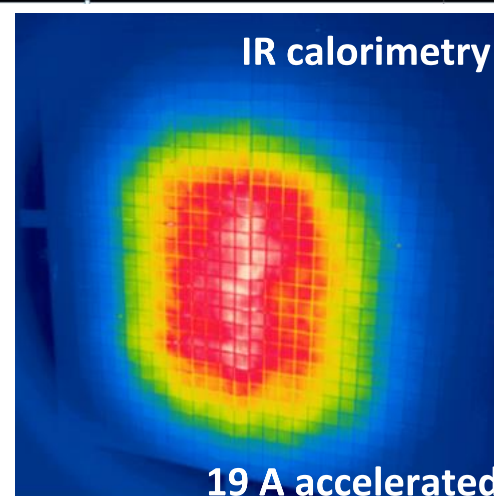
Amount of co-extracted electrons factor 2 – 4 higher in deuterium than in hydrogen

Diagnostics of the beam (1×1 m^2)

Advanced beam diagnostics to determine beam divergence and beam uniformity



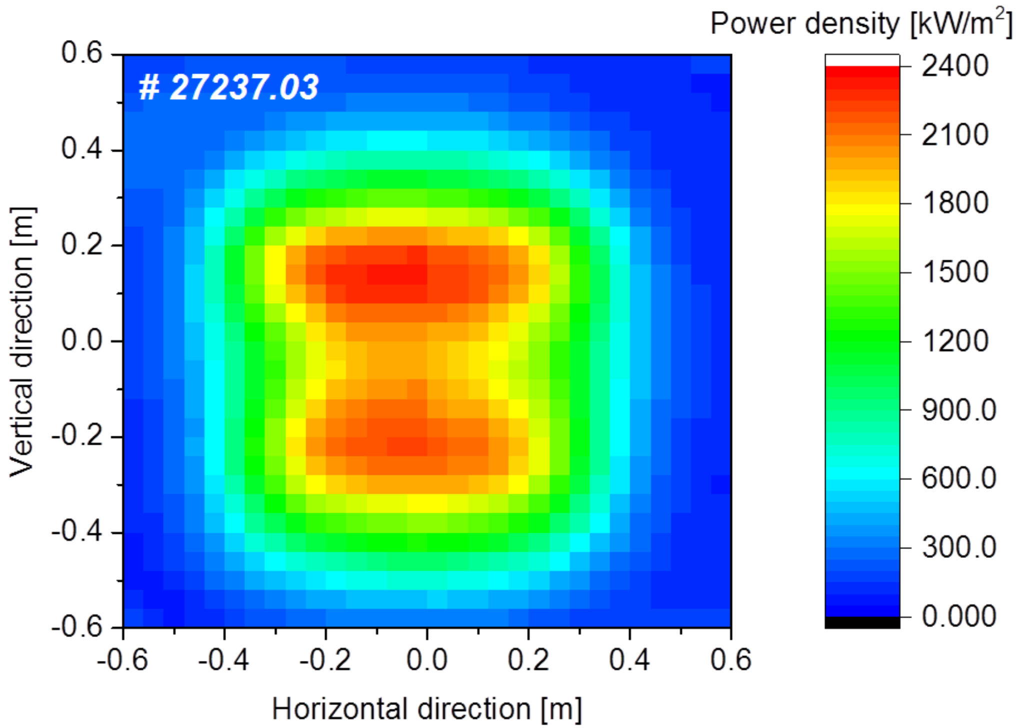




2018: ELISE achieved ITER parameter in hydrogen!

Stable pulses for 1000 s at 0.3 Pa and at electron/ion ratio below one

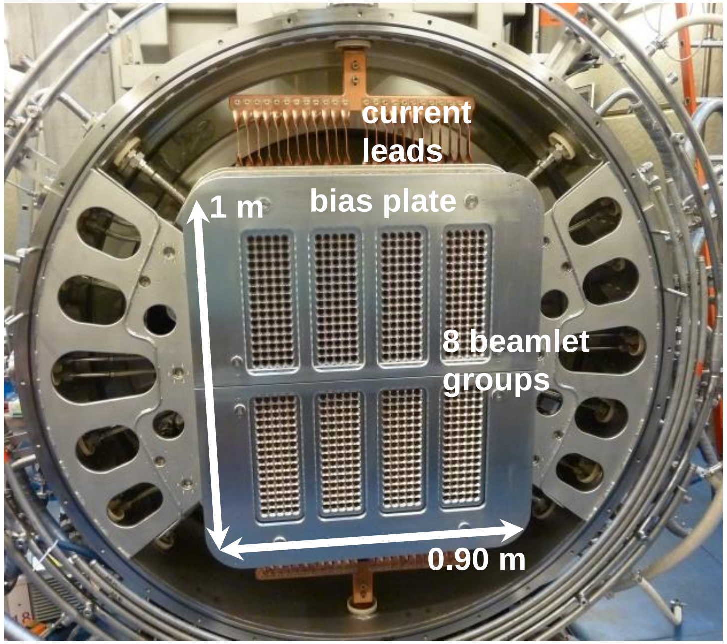
Picture of the infrared camera
with view on the calorimeter



23.8 A at the calorimeter (ITER value: 23 A)

Symmetric beam with 1.2 MW

View onto the grid system



Next steps & challenges

- Reduction of co-extracted electrons
- Sufficient supply of Cs to the grid
- Steady state power supply
- Reliable operation scenarios for ITER

Negative hydrogen ion sources for ITER NBI

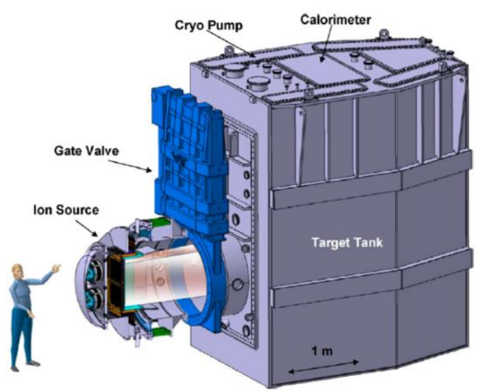
The European roadmap towards ITER NBI

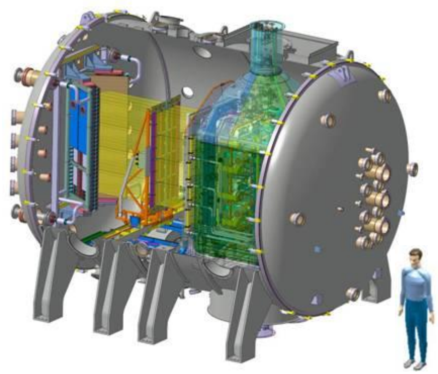
Half size ion source test facility with 60 kV extraction

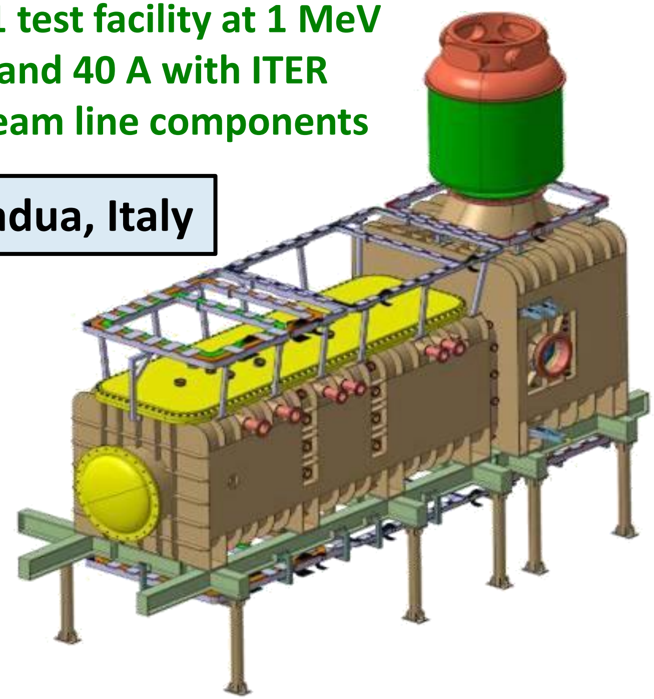
Full size ion source test facility with 100 kV extraction

1:1 test facility at 1 MeV and 40 A with ITER beam line components

NBTF test facility in Padua, Italy

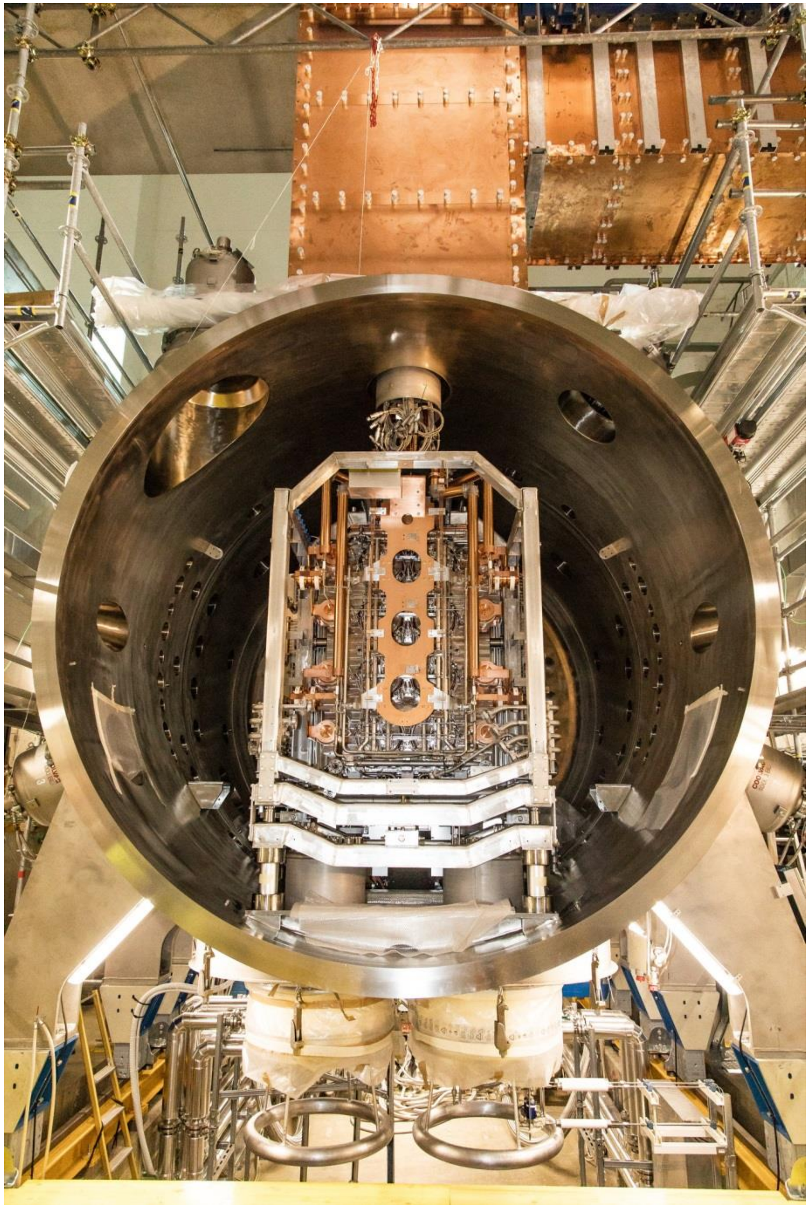






ELISE	SPIDER	MITICA	NBI at ITER
Assess spatial uniformity of neg. ions Validate or alter source concept	Validate or alter source and extractor	Validate or alter accelerator and beam line components	
2012 +	**2018 +**	**2022 +**	**2031 +**

First Plasma in SPIDER: 11 June 2018 at Consorzio RFX, Padua



Inauguration ceremony

In fact the first plasma of the ITER project !