FUSION FOR ENERGY

Progress Status of the Activities in EU for the Development of the ITER Neutral Beam Injector and Test Facility

Antonio Masiello

G. Agarici[1], D. Boilson[2], T. Bonicelli[1], H. Decamps[2], U. Fantz[3], P. Franzen[3], J. Graceffa[2], B. Heinemann[3], R. Hemsworth[2], D. Marcuzzi[4], F. Paolucci[1], M. Simon[1], V. Toigo[4], P. Zaccaria[4]

[1]*Fusion for Energy, C/ Josep Pla 2, 08019 Barcelona, Spain*

[2]*ITER Organization, Route de Vinon sur Verdon, 13115 Saint Paul-lez-Durance, France*

[3]*Max-Planck- Institut für Plasmaphysik (IPP) - D-85740 Garching, Germany*

[4]*Consorzio RFX, Euratom-ENEA Association, C.so Stati Uniti 4,I -35126, Padova, Italy*

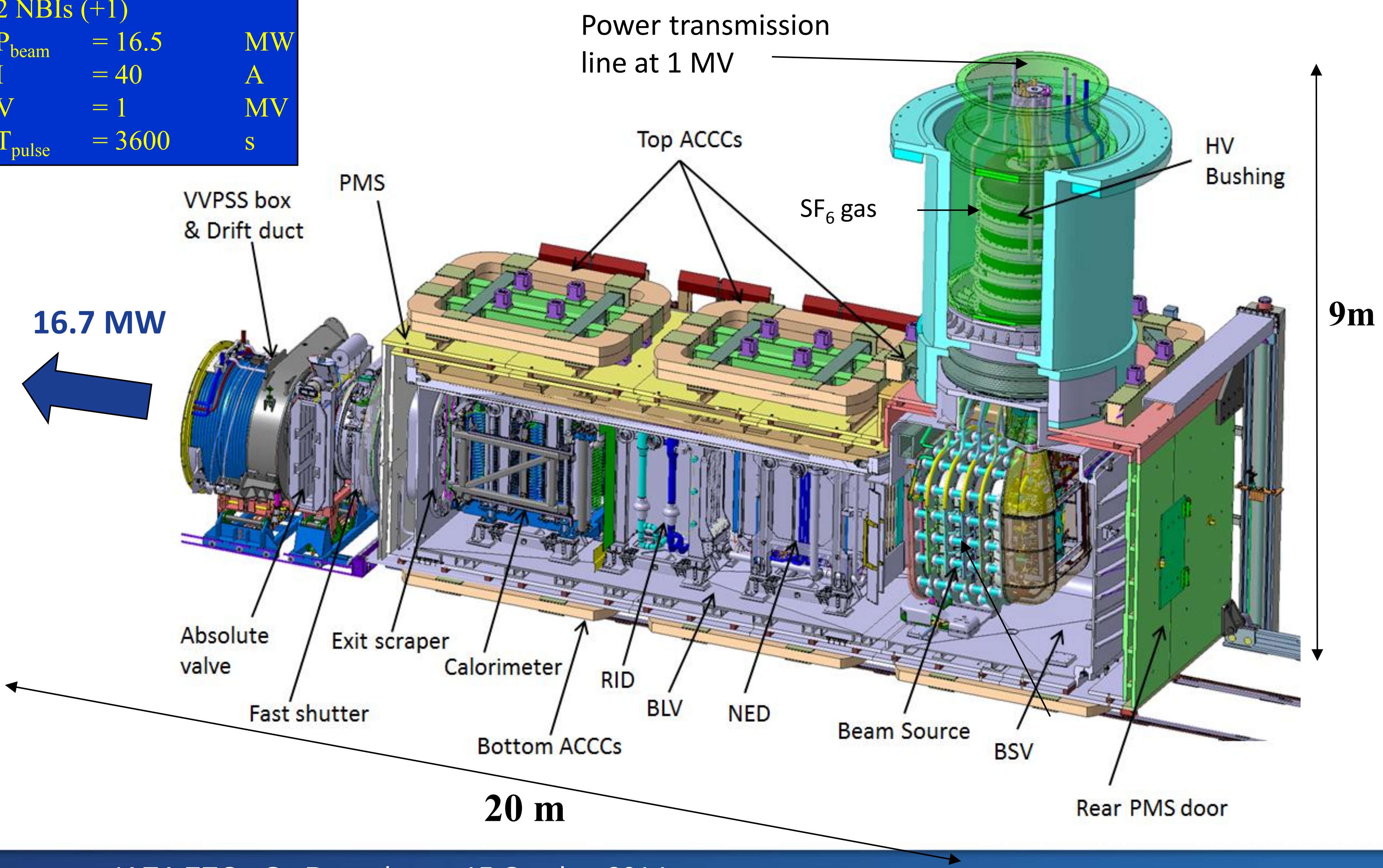
Outline

FUSION FOR ENERGY

- ✓ **The ITER neutral beam and the test facility**
- ✓ **The development of the beam source**
  - — Results of the ELISE experiment
  - — Status of the SPIDER experiment
  - — Design and R&D of the MITICA beam source
- ✓ **The development of the beam line components**
- ✓ **The ITER Heating Neutral Beam front end components**
- ✓ **Conclusions**

The ITER HNB

2 NBIs (+1)		
P_{beam}	= 16.5	MW
I	= 40	A
V	= 1	MV
T_{pulse}	= 3600	s



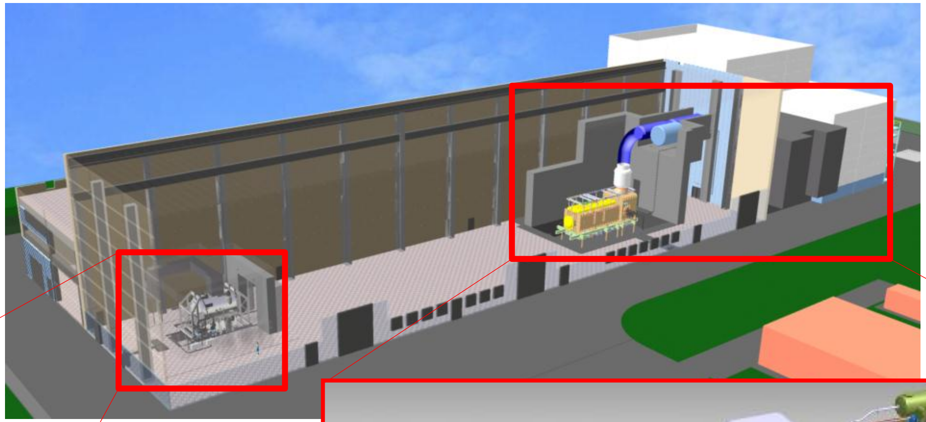
The Neutral Beam Test Facility

FUSION FOR ENERGY

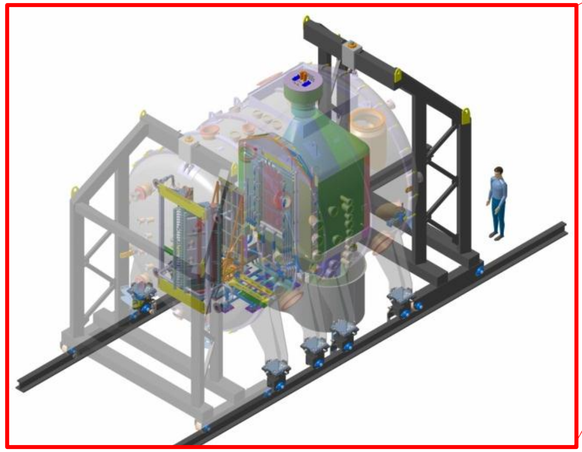
The Neutral beam test facility, established in Padua – Italy at the PRIMA site , provides a comprehensive strategy to mitigate technical and operational risks for the NB systems at ITER

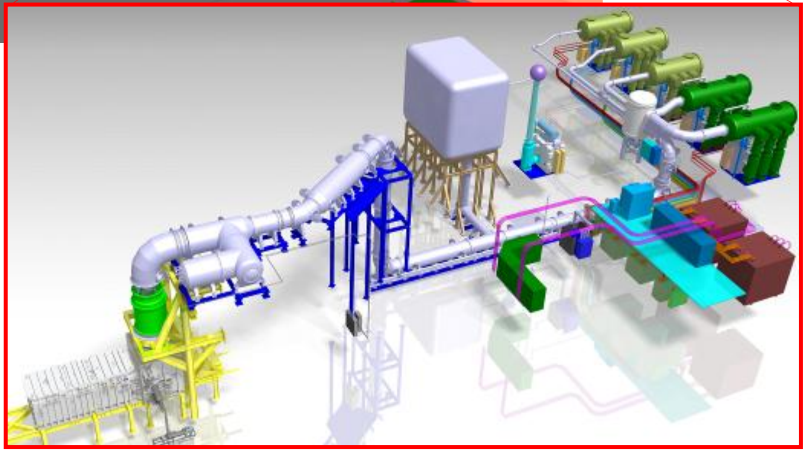
Phase 1: The NBTF design – Being COMPLETED!

Phase 2: The NBTF Construction – On-going



Phase 3: HNB Design Operation - technological/scientific exploitation of NBTF with the aim to achieve the final design and specifications for the HNB



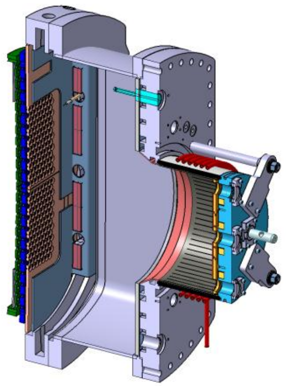


The beam source development

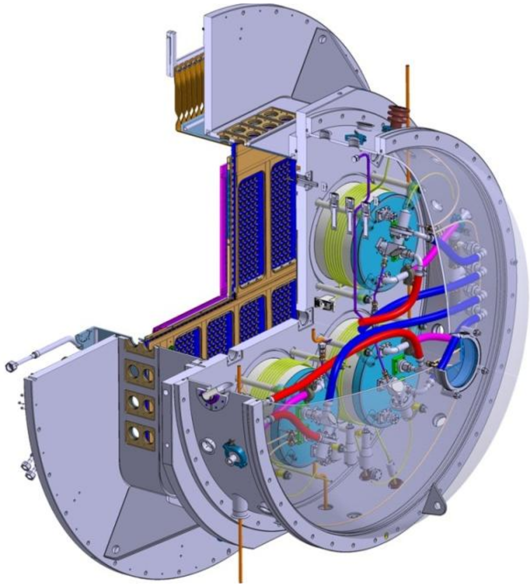
ELISE (Garching Germany) - half-size ITER-type source with beam extraction to assess the possibility of achieving ITER like parameters with a source filling pressure of ~0.3 Pa and spatial uniformity at full ITER current density

SPIDER (at PRIMA site) - Full size ITER source (HNB and DNB), full current extraction at full DNB extraction voltage (100 kV) and full ITER pulse length

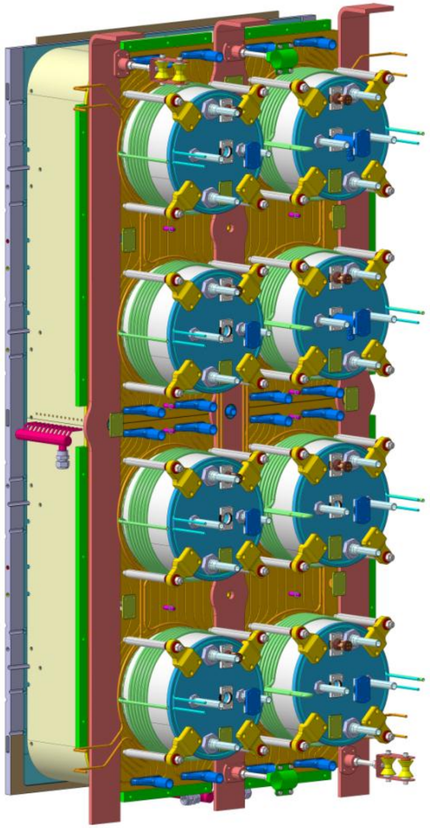
MITICA (at PRIMA site) - Full size, full voltage, full power, full pulse length ITER beam-line



1 Driver – IPP prototype source
$0.52 \times 0.26\ m^2$



4 Drivers – ELISE – IPP
$1.0 \times 0.9\ m^2$

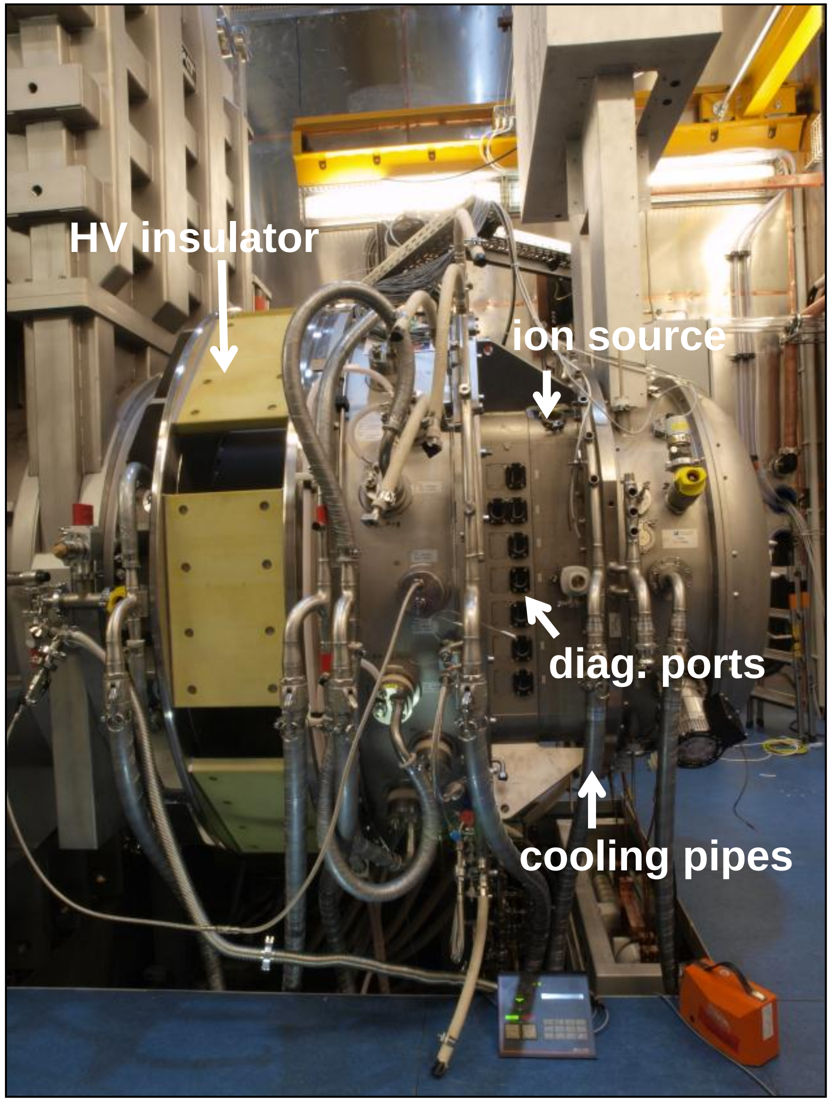


8 Drivers – SPIDER and MITICA (and the HNB/DNB)
$1.9 \times 0.9\ m^2$

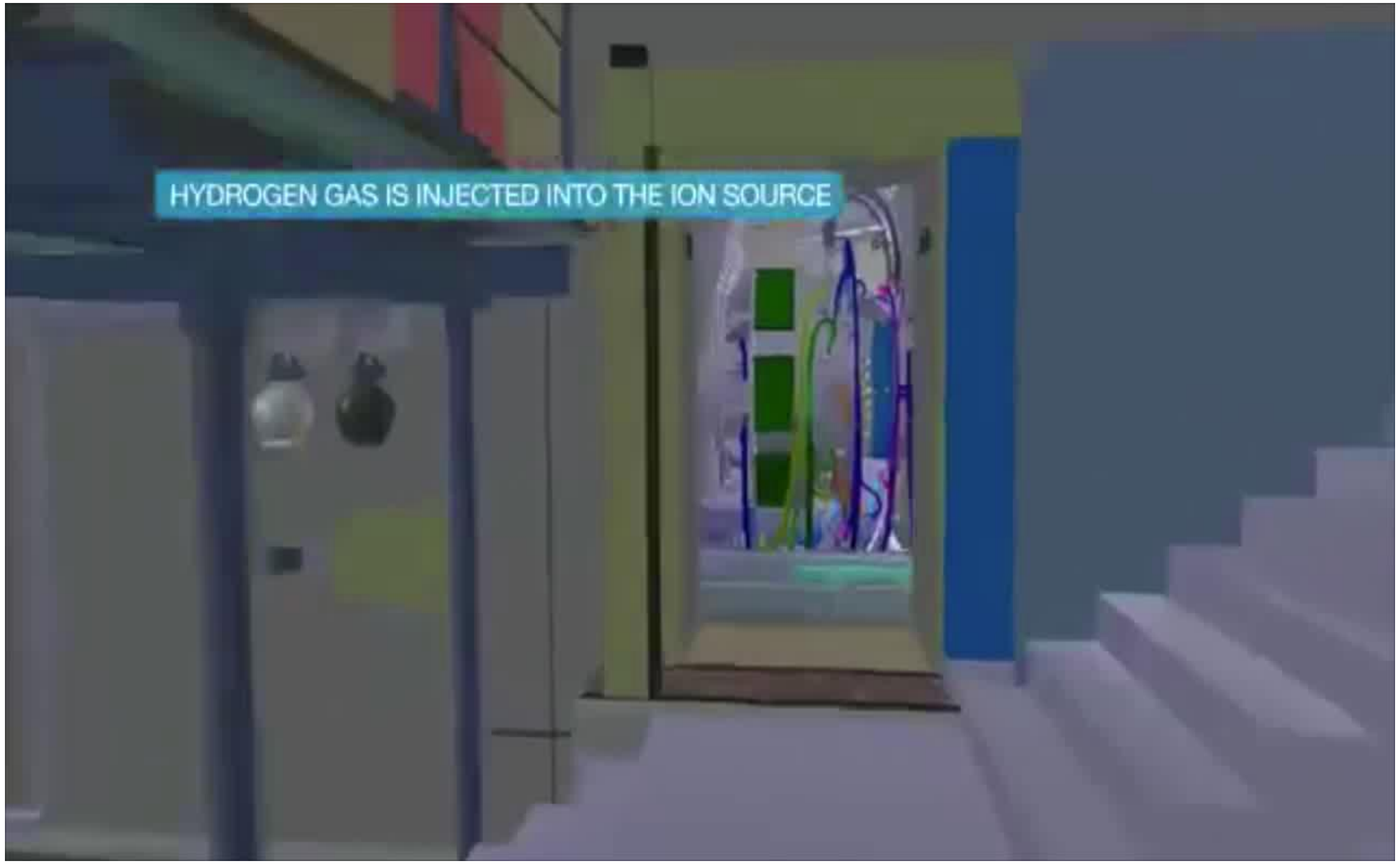
The ELISE experiment

Main parameters	
Isotope	H^-, D^-
Extraction area	1000 cm^2
Total acc. voltage	60 kV
Extraction voltage	<12 kV
Ion current	20 A
RF power	2 x 180 kW
Plasma on time Extraction	3600 s 10 s every 150-180 s

Target operation parameters	
Extracted current density	330 A/m2 (H^-) 250 A/m2 (D^-)
Extracted electrons/ion	< 1
Source pressure	0.3 Pa
Beam uniformity	10%



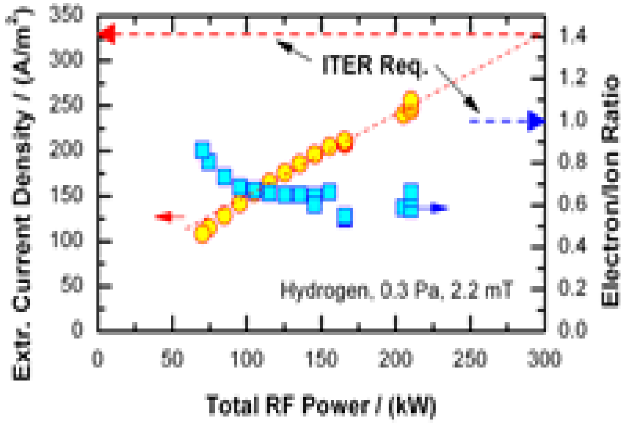
The ELISE experiment



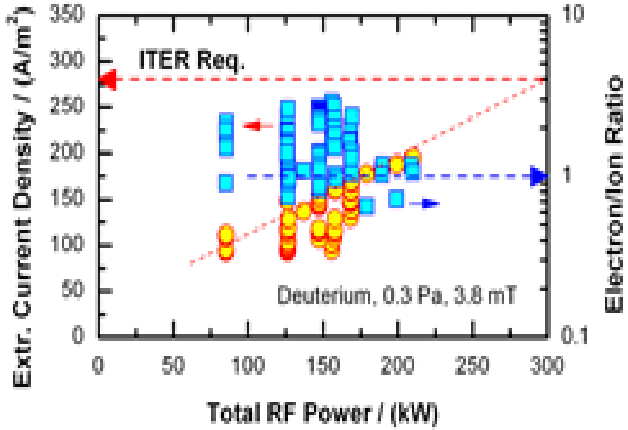
The ELISE results

Parameter	Unit	H	D	
Pulse #	-	#6541	#7761	#7801
Pulse length	s	10	3.4	3.3
Extracted Curr. Dens.	A/m2	256	177	195
Accelerated Curr. Dens.	A/m2	203	144	154
Electron/Ion ratio	-	0.66	0.65	1.06
Filling Pressure	Pa	0.29	0.33	0.33
Extraction Volt.	kV	9.8	9.5	9.5
Norm. Perveance	-	0.176	0.184	0.205
RF power	kW	2X105	2X90	2X105
Bias Current	A/m2	55	55	55
PG current	kA	2.2	4.0	4.0

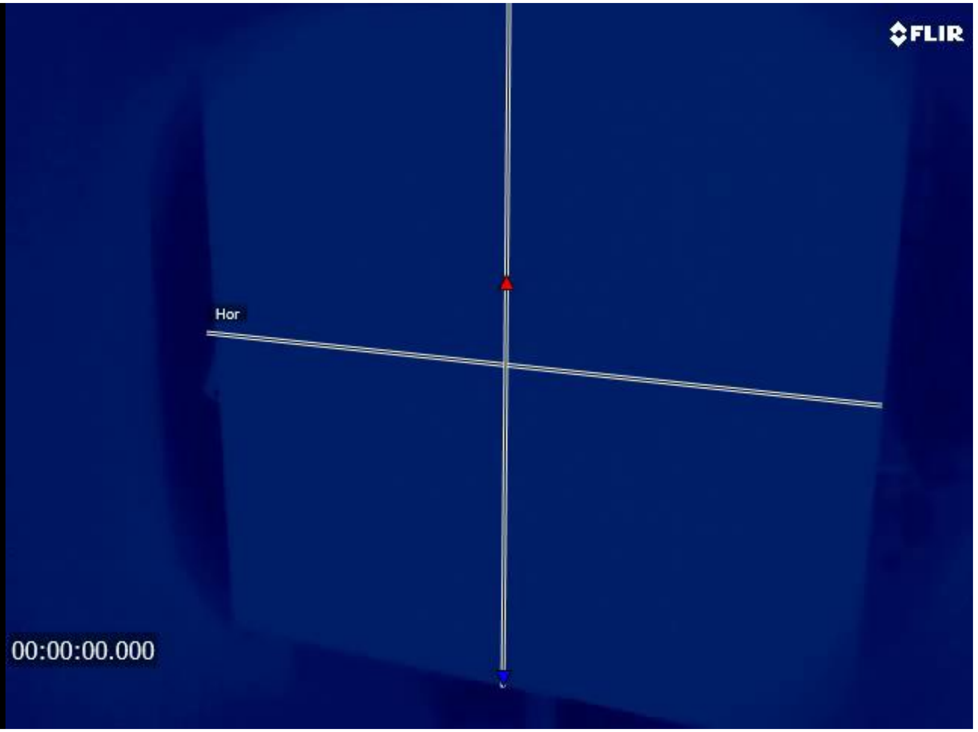
H^- operation



D^- operation



The ELISE experiment



CCD view inside of the ion source

Light starts inside the drivers where the starting filaments are ignited and then propagates in the expansion chamber

Infrared view of the calorimeter

A thick water cooled copper plate in which a chessboard like pattern has been machined allowing the beam footprint to be reconstructed

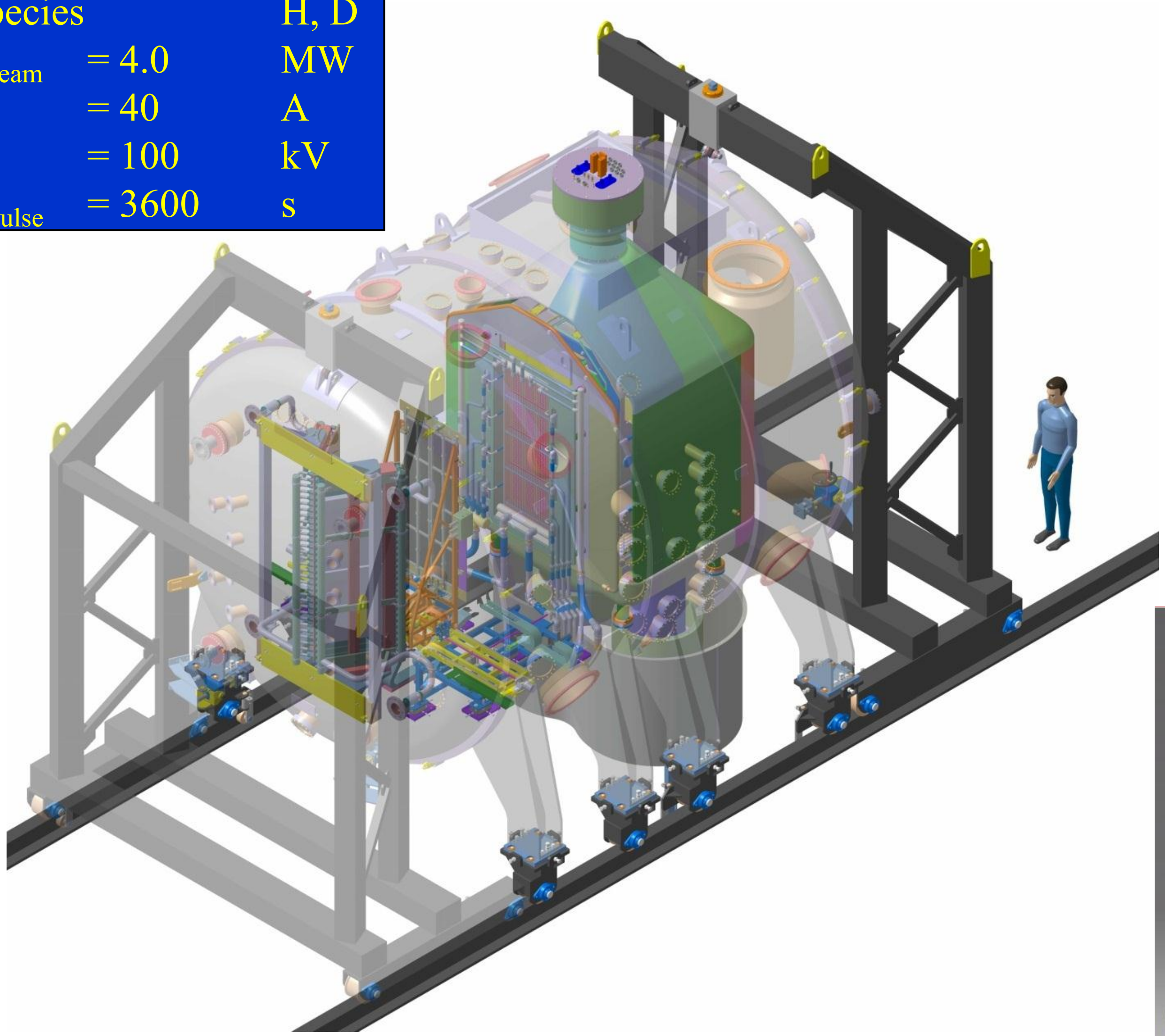
9

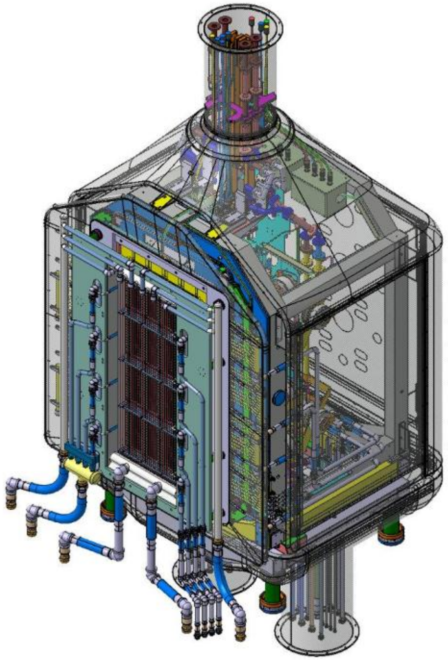
ELISE experimental results

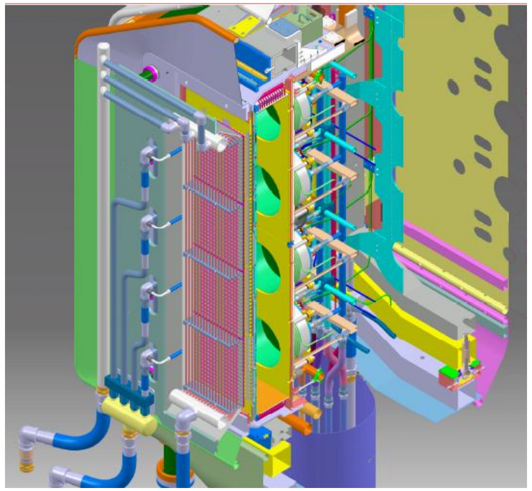
- ✓ **Quick source conditioning** with an electron/ion ratio well below 1, no need for a daily conditioning (absolute valve separates the beam source from the main tank).
- ✓ **Linear scaling of the RF power with the current density.** A total power of 75kW/driver is estimated for the required current density in H (330 A/m2). This should be OK for driver operation.
- ✓ The best performance **in H** was achieved at the required pressure of 0.3Pa with a **high reproducibility**.
- ✓ **D operation suffers from a large variation of the extracted electron currents** and from the deterioration of the grid HV holding, when the Cs influx between pulses is too large.
- ✓ **Enhanced electron current in D** has to be still properly understood, one possible cause could be the **reservoir of Cs accumulated** during the H campaign that are removed during D pulses.

The SPIDER experiment

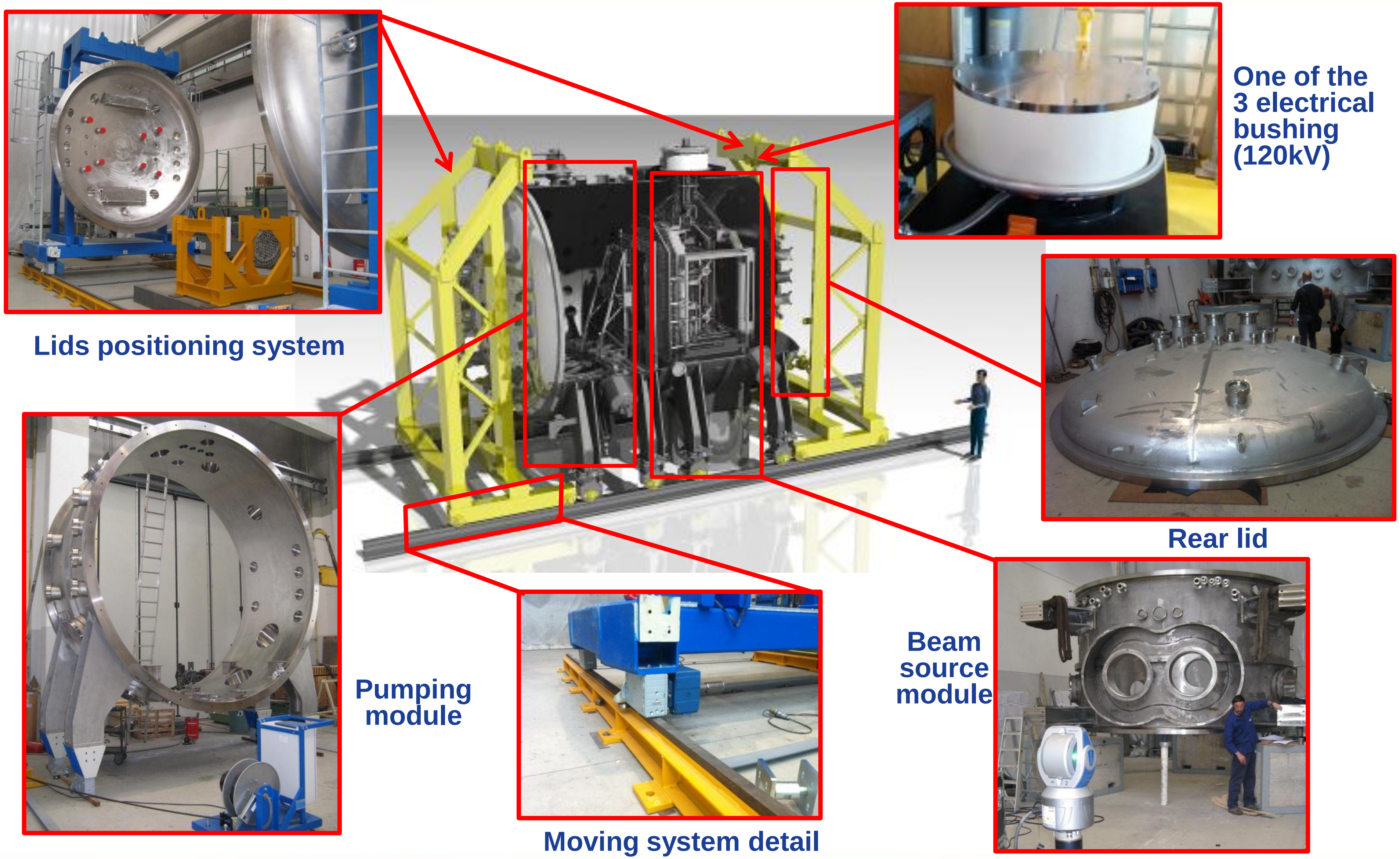
Species		H, D
P_{beam}	= 4.0	MW
I	= 40	A
V	= 100	kV
T_{pulse}	= 3600	s





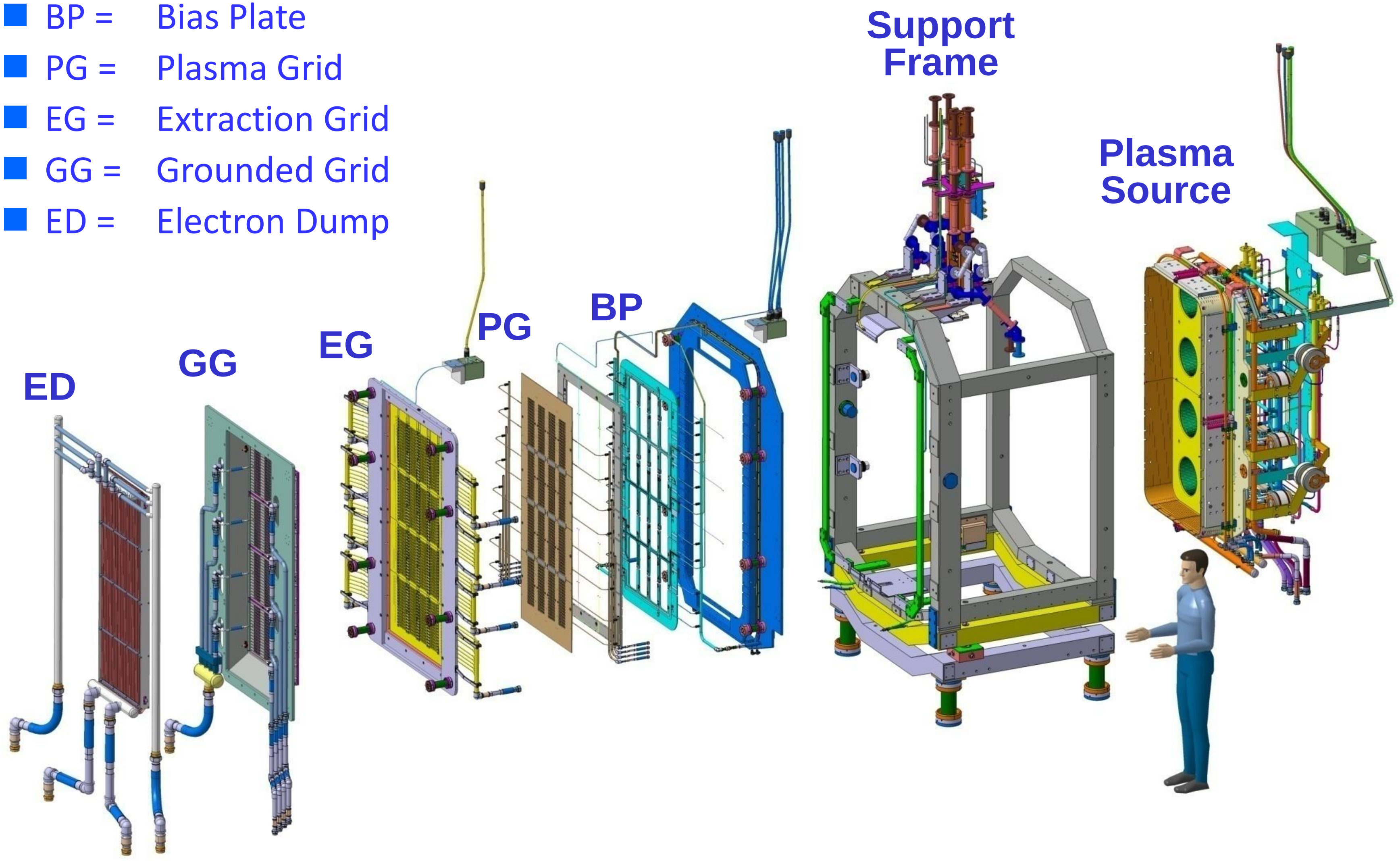


SPIDER VV manufacturing

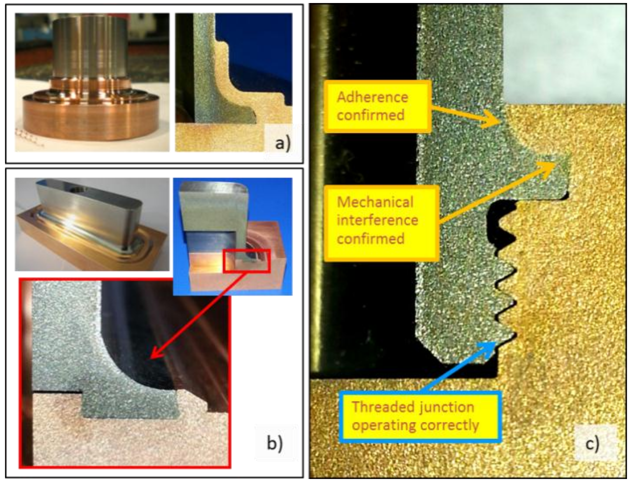


The SPIDER beam source

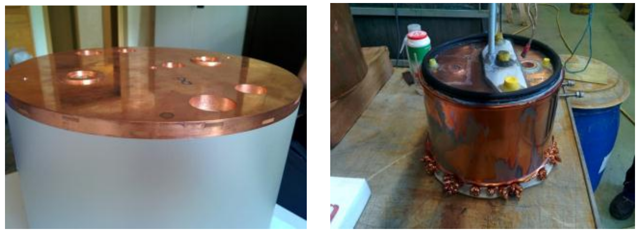
- BP = Bias Plate
- PG = Plasma Grid
- EG = Extraction Grid
- GG = Grounded Grid
- ED = Electron Dump



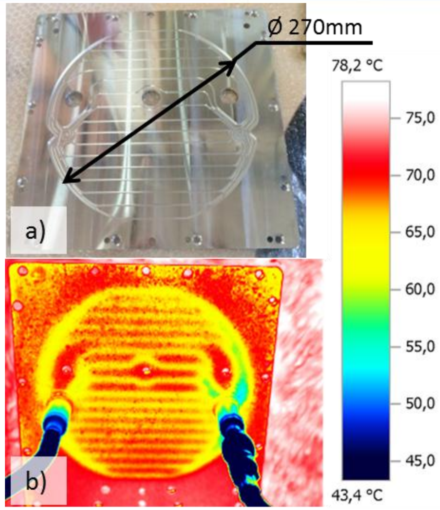
SPIDER BS manufacturing



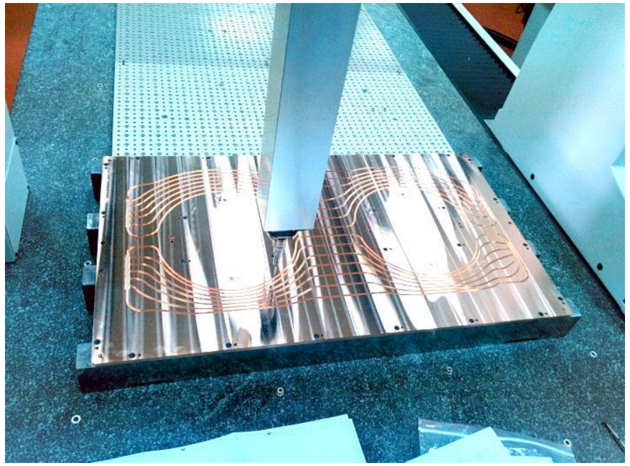
Heterogeneous joint prototypes



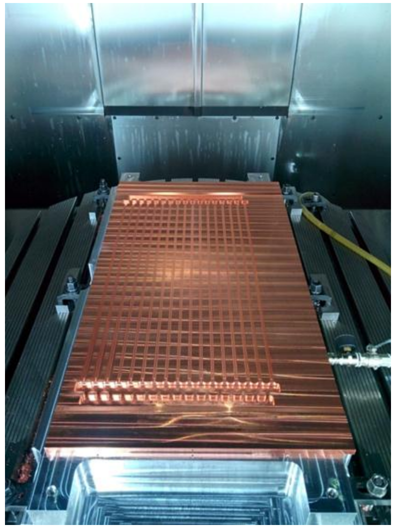
Steps of the fabrication of the Faraday shields



De-waxing check of a Faraday shields back plate



CMM verification of the plasma a drivers' plate

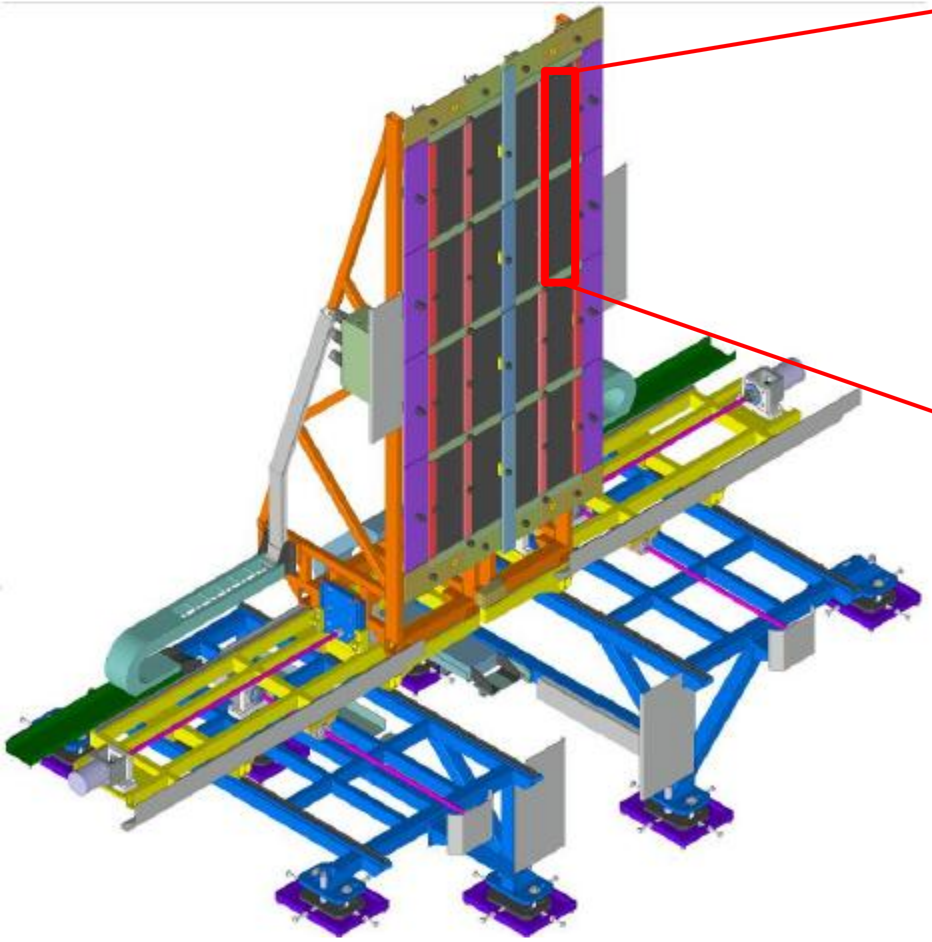


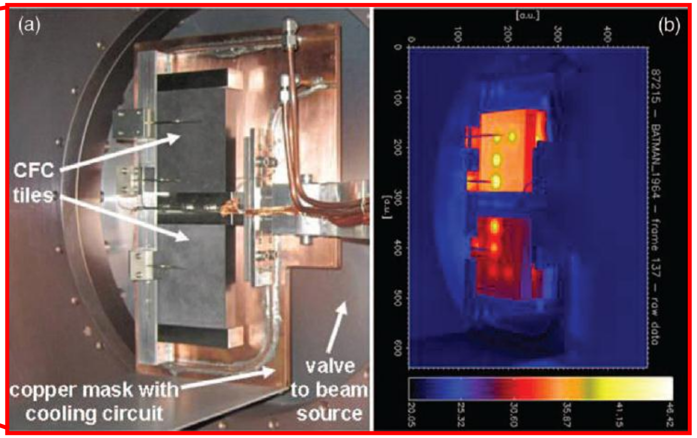
Machining of the cooling channels on a extraction grid segment

Alumina insulator prototypes

14

SPIDER Diagnostics





Embedded diagnostics

TCs and Langmuir probes – mainly in the beam source

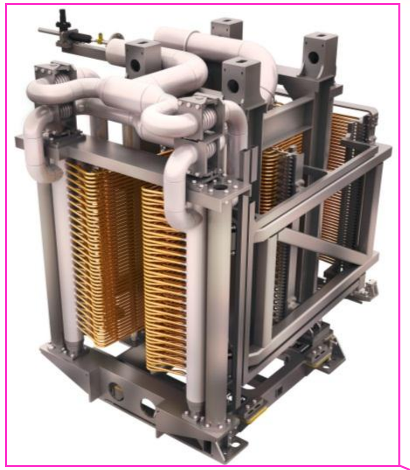
Interfaced diagnostics:

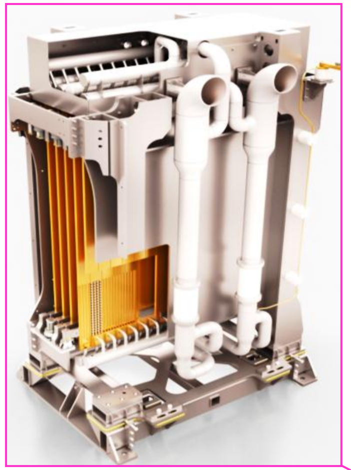
- Optical emission spectroscopy (beam and ion source)
- Tomography
- CRDS
- Neutrons (GEM detectors)
- IR thermography
- imaging beam
- CCD+IR monitor

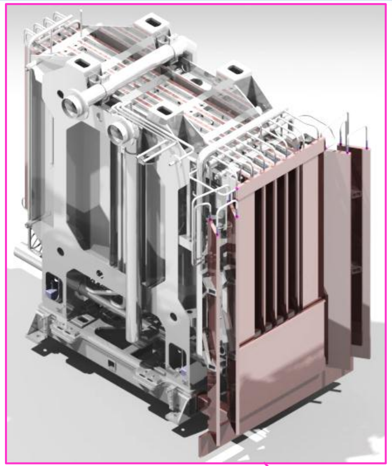
The short pulses calorimeter STRIKE

CFC tiles monitored on the back by infrared cameras

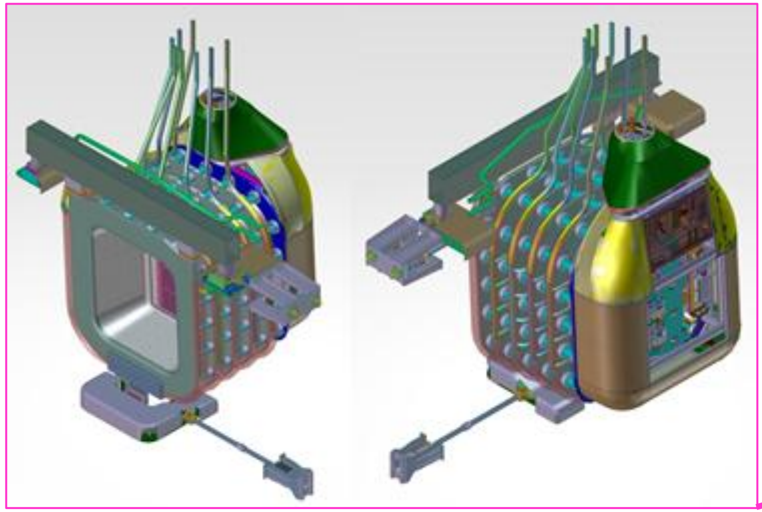
The MITICA experiment

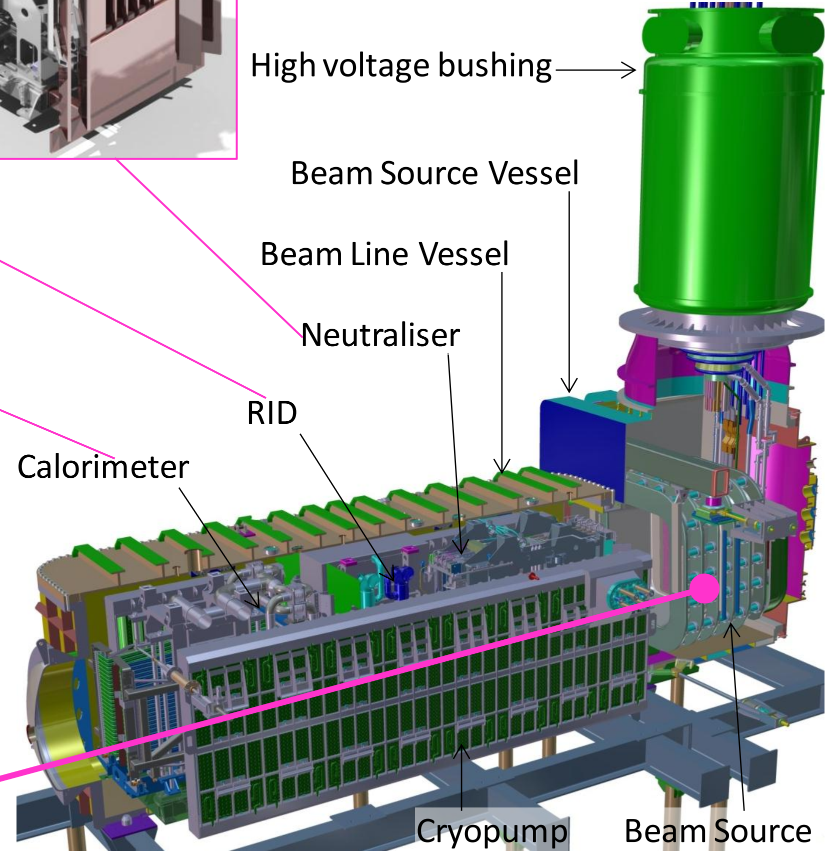






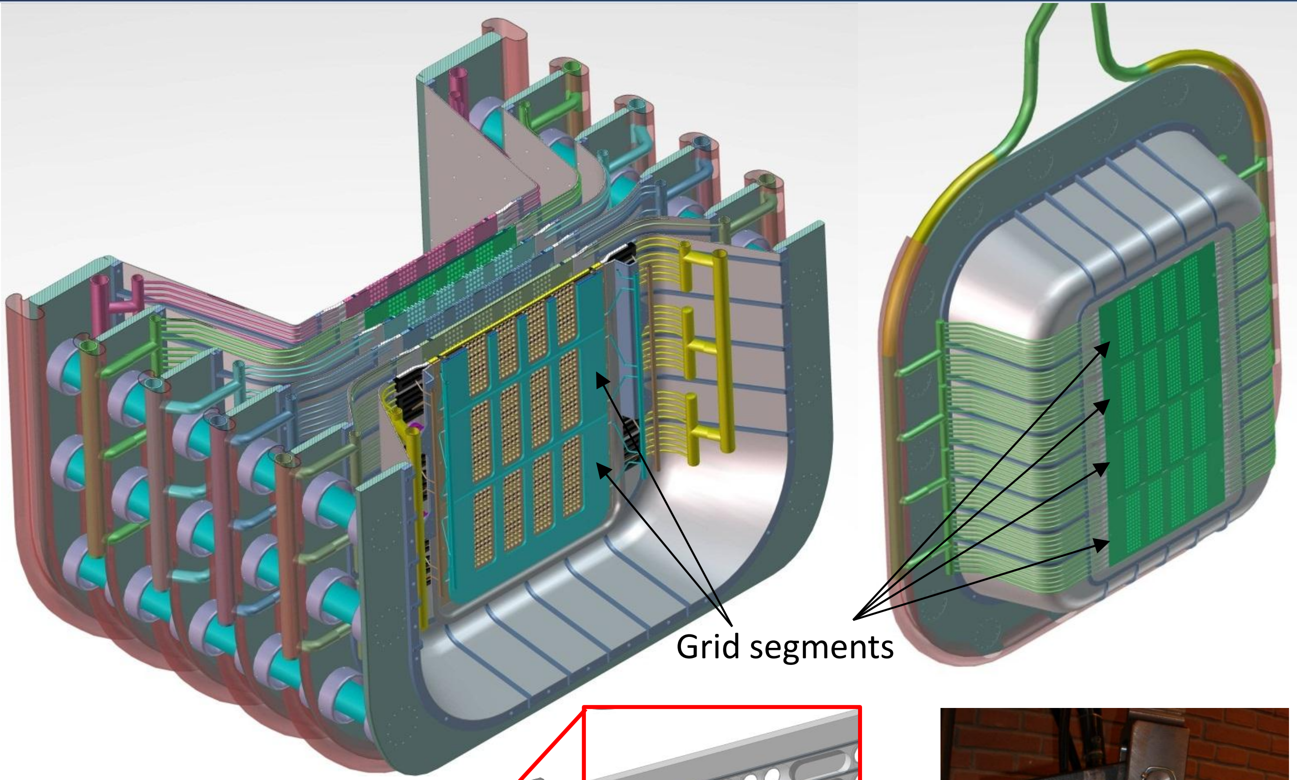
Species		H, D
P_{beam}	= 40	MW
I	= 40	A
V	= 1000	kV
T_{pulse}	= 3600	s

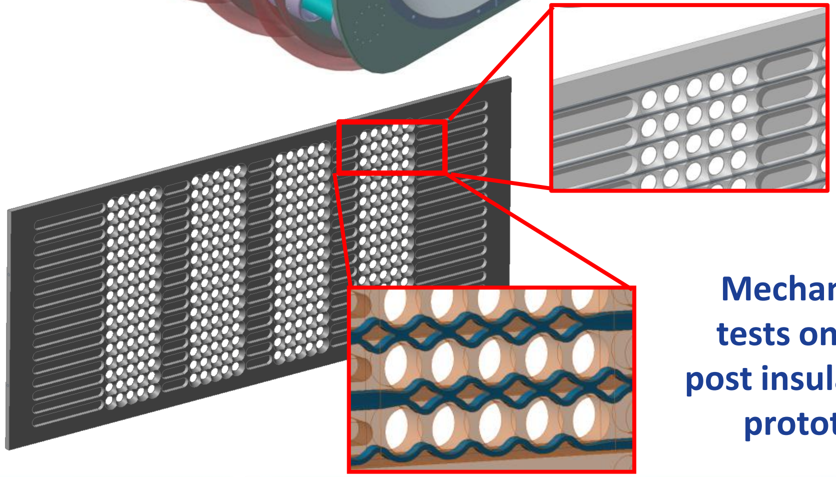




16

The MITICA beam source (1)



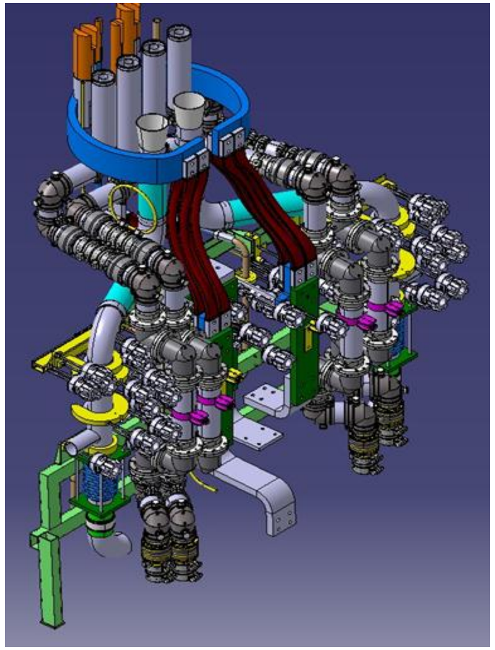


Mechanical tests on the post insulator prototype

- **Beam optics** - maximisation of aperture clearance and minimisation of beamlet divergence
- **Sensitivity analyses** of the effect of the grid misalignment and grid deformation
- **Optimised magnetic field configuration** - as uniform as possible magnetic field
- **Co-accelerated electrons** - Power associated @ accelerator exit <700kW
- **Thermo-mechanics** - power deposited on accelerator grids <2MW
- **Gas pressure profiles** – background gas pressure as uniform across grids and as low as possible
- **Evaluation of the power load** on the rear vertical surface of the ion source due to BSI^+

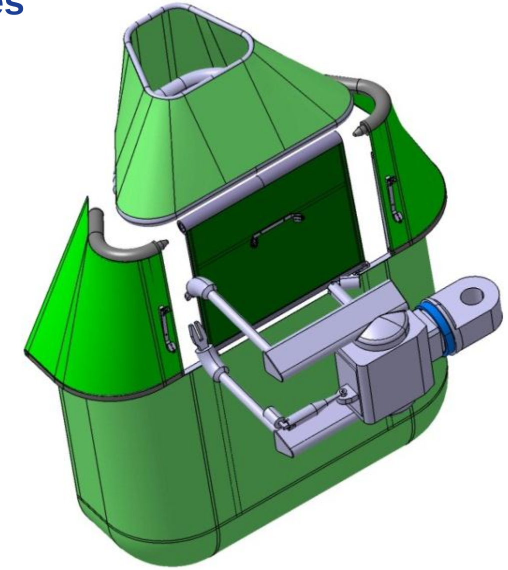
The MITICA beam source (2)

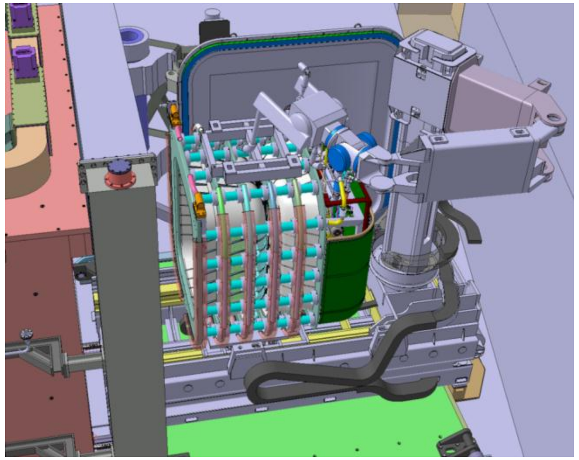
Explosive bonding of Mo on CuCrZr – back plates of the ion source

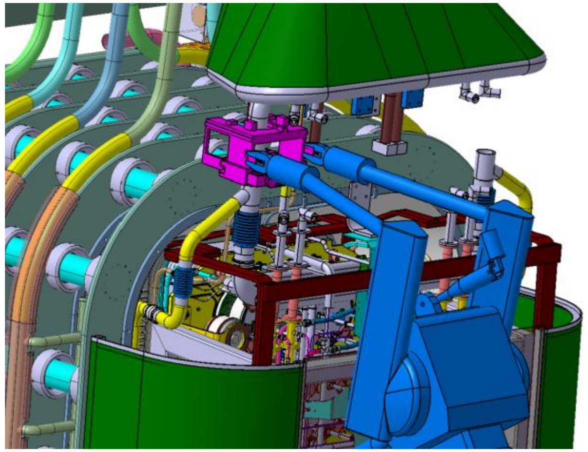


Routing of the water and electrical line including flexible connection for beam source tilting (on and off-axis beam injection)

Remote handling studies of the installation and maintenance. Removal of the screens, cut&weld of coolant lines

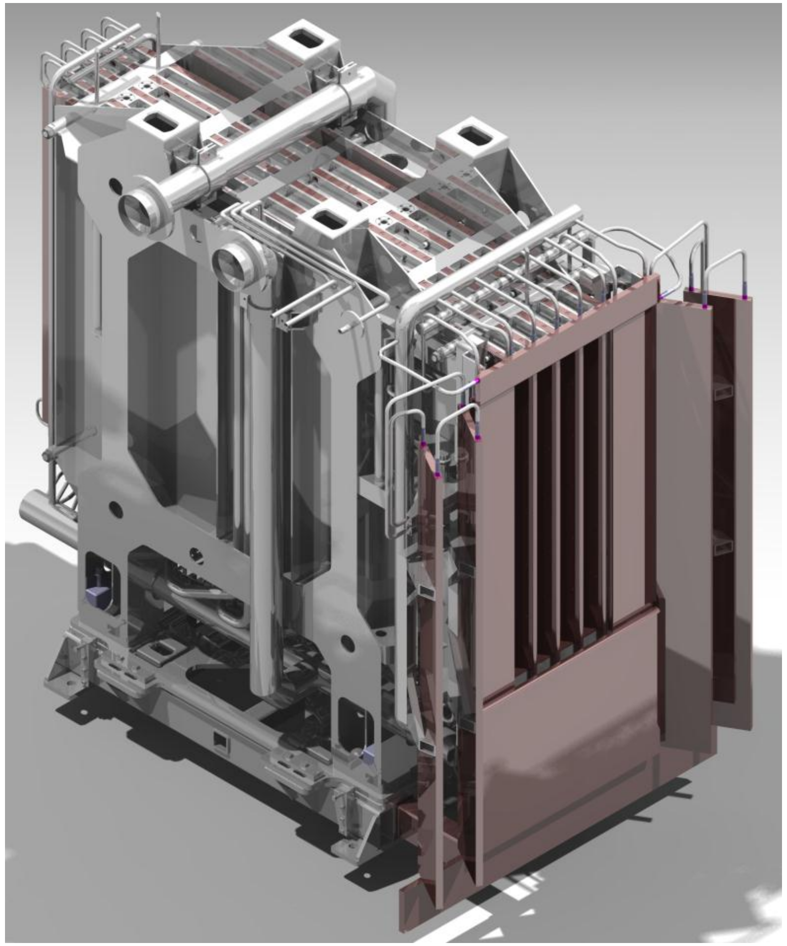






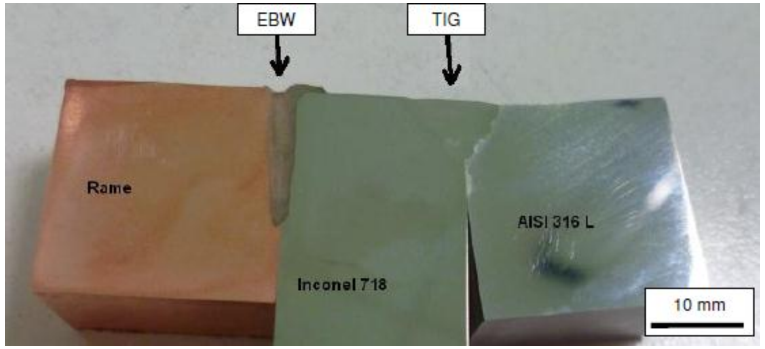
18

The neutraliser and electron dump (NED)



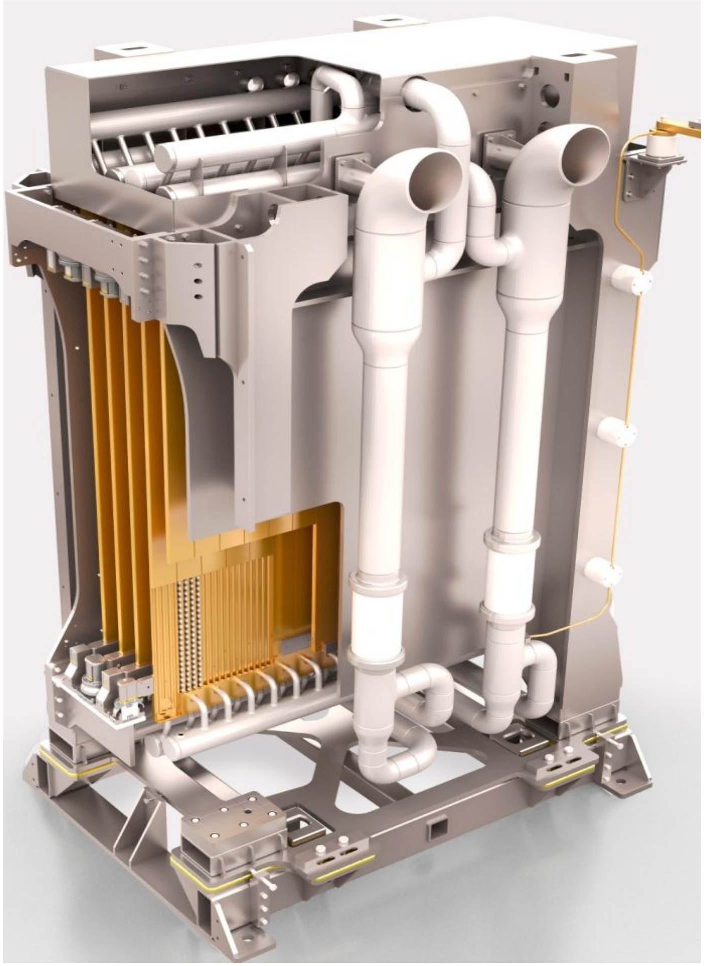
Neutraliser - 0,5 MW/m^2 to 5MW/m^2 on the leading edges
5,5MW -15 tons

The heat power of the co-accelerated electrons are taken by the **electron dump** (in the front of the NED), whose panels have been optimised with respect to the different aspects: **maximization of the gas conductance** from the Beam Source to the cryogenic pump, **protection of cryogeinc panels** from the scattered electrons, **foldable panels** geometry for installation and maintenance.



Butt welding with the ITER vacuum requirements SS to OF copper with the interposition of an Inconel element

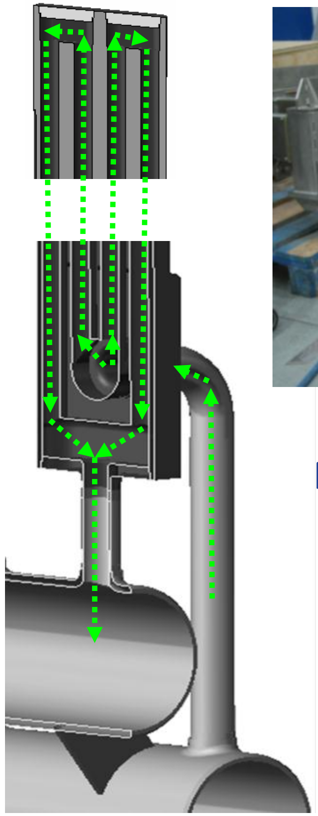
The MITICA RID



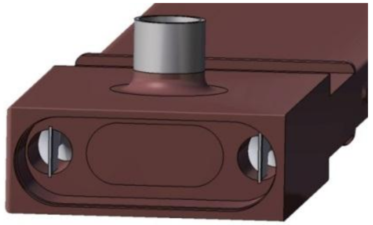
Electrostatic Residual Ion Dump (6MW/m^2)
19MW - 5 tons

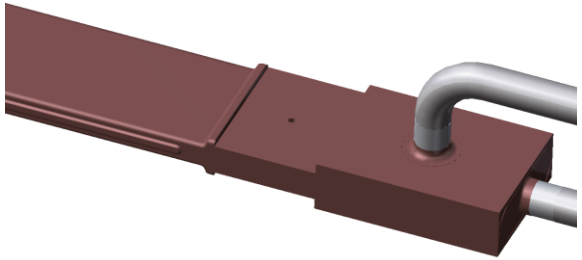
Double side **deep drilling of 2m long** CuCrZr plates

Enhanced heat transfer in subcooled boiling conditions provided with twisted tapes as turbulence promoters

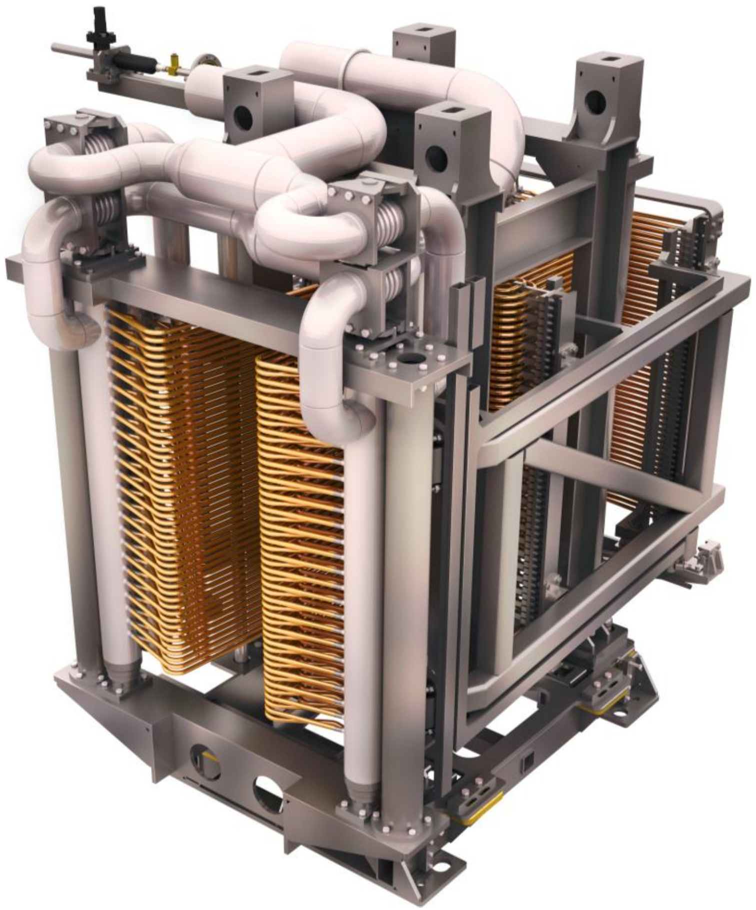


RID beam stop element



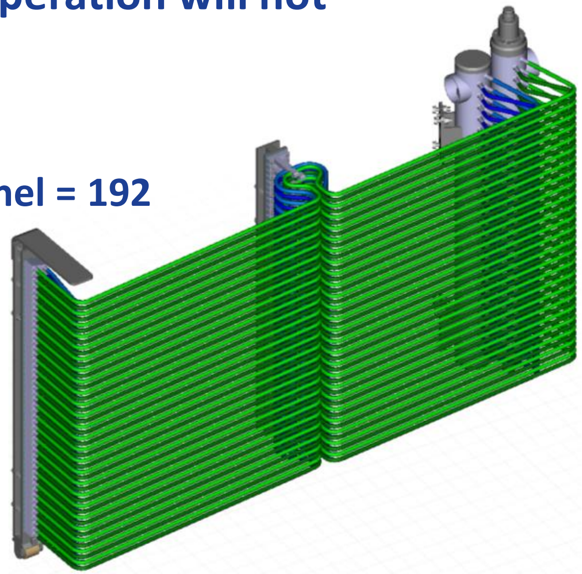


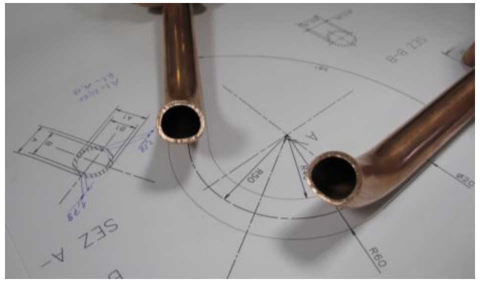
The MITICA Calorimeter

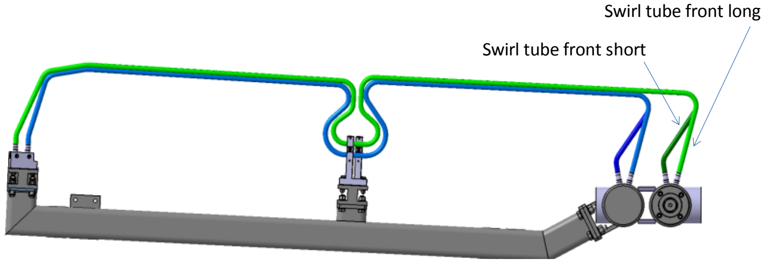


Production feasibility of the swirl tubes was validated by bending of CuCrZr tubes into the required shape. Tests confirmed that stress relaxation during beam operation will not occur.

Tube diameter = 20 mm
No. of EB connection per panel = 192
Total EB weld length = 24m

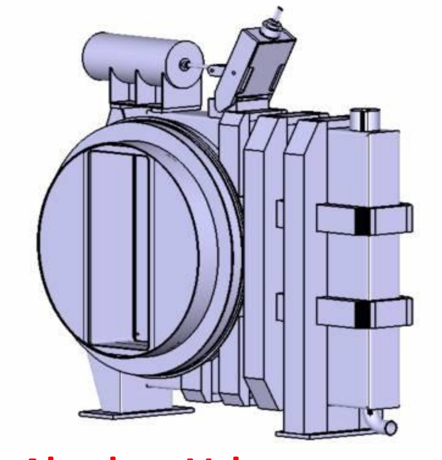




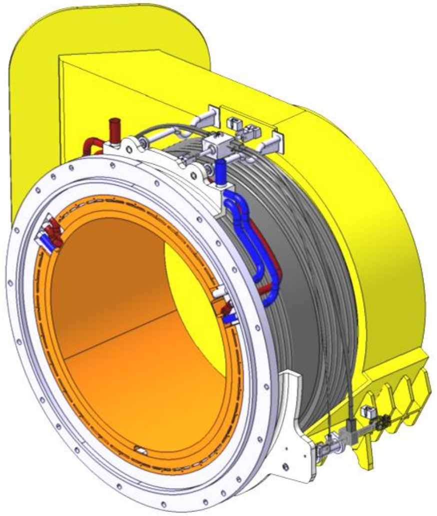


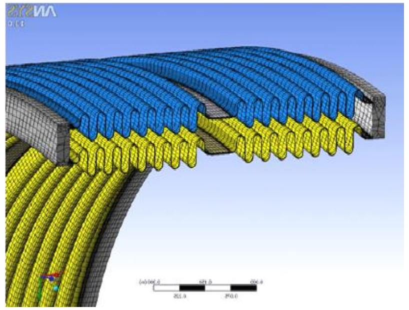
Calorimeter (14MW/m^2)
18MW- 7tons

ITER HNB components
(Front End components)

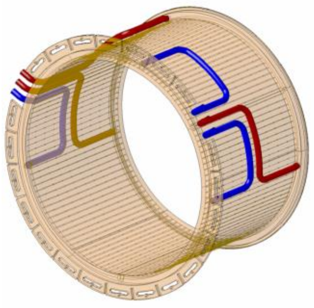


Absolute Valve
Stainless Steel Casing
SIC1- (RCC-MR code)
High vacuum



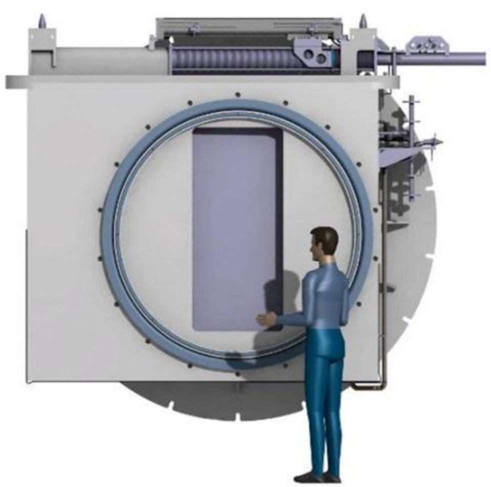


Bellows

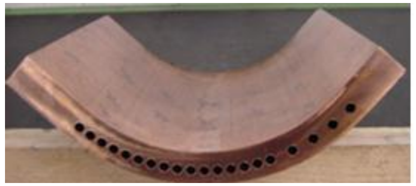


Liner

Drift Duct - SIC1 – (RCC-MR code) Stainless Steel Double Bellows - Deep Drilled liner CuCrZr



Fast Shutter
Stainless-Steel Casing SIC1- (RCC-MR code)– High Vacuum



Exit Scraper
Stainless Steel Support + Deep Drilled Panel CuCrZr
High Vacuum (Non -SIC)

Conclusions

- ✓ Experiments on ELISE has shown that the one driver concept can be transferred to an ITER relevant size source
  - Achievement of the required parameters in hydrogen on ELISE seems possible
  - Results of the first operations in deuterium suffer from the difficulty of controlling the co-extracted electrons
- ✓ The fabrication of the SPIDER beam source is well in progress after completion of the manufacturing design, which required a long time due to the complexity of the system and the challenging requirements
- ✓ Even more tight requirements are being fulfilled in the preparation of the tech specs for the procurement of the MITICA beam source and beam line components, replicating the HNB ones in almost all details, including RH features.

The development of the core components of the HNB is being pursued putting in place the planned strategy. Having obtained so far encouraging results gives some confidence that the HNB is on track to be developed for the second phase of the ITER experiments.

FUSION FOR ENERGY

Thank you for your attention

Follow us on:

www.f4e.europa.eu

www.twitter.com/fusionforenergy

www.youtube.com/fusionforenergy

www.linkedin.com/company/fusion-for-energy

www.flickr.com/photos/fusionforenergy