ACHIEVEMENT AT THE ITER NEUTRAL BEAM TEST FACILITY AND PROSPECTS FOR THE R&D ACTIVITIES WITHIN THE ITER RESEARCH PLAN

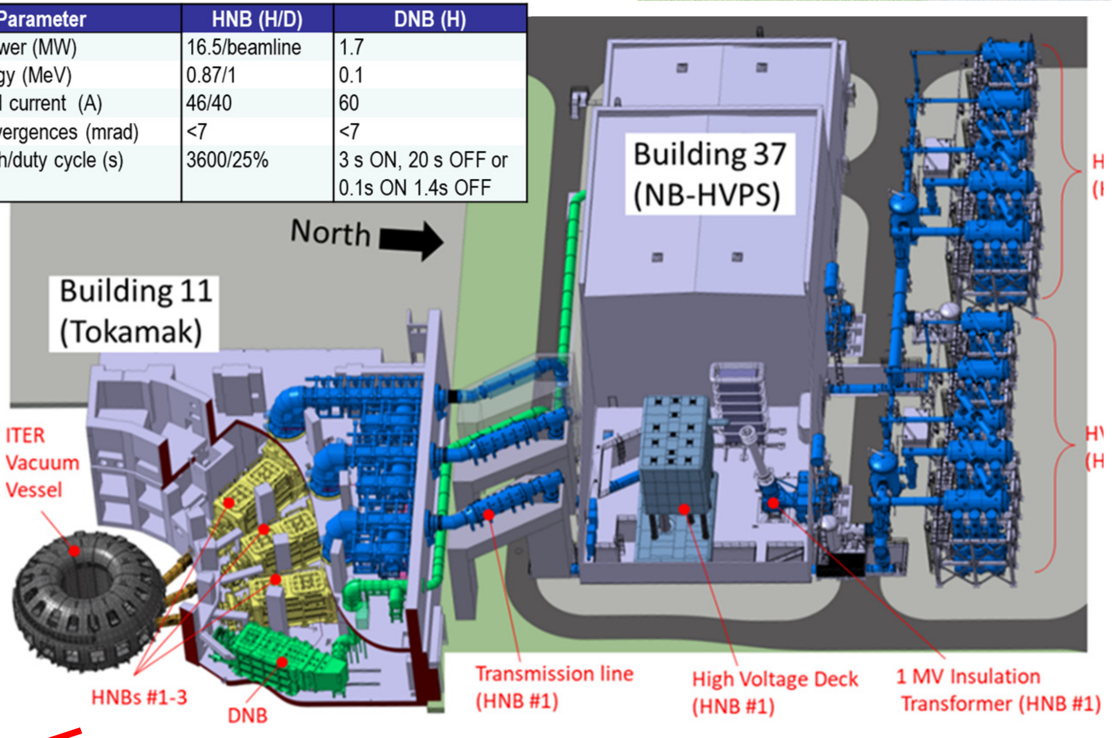
D.Marcuzzi, on behalf of the NBTF team

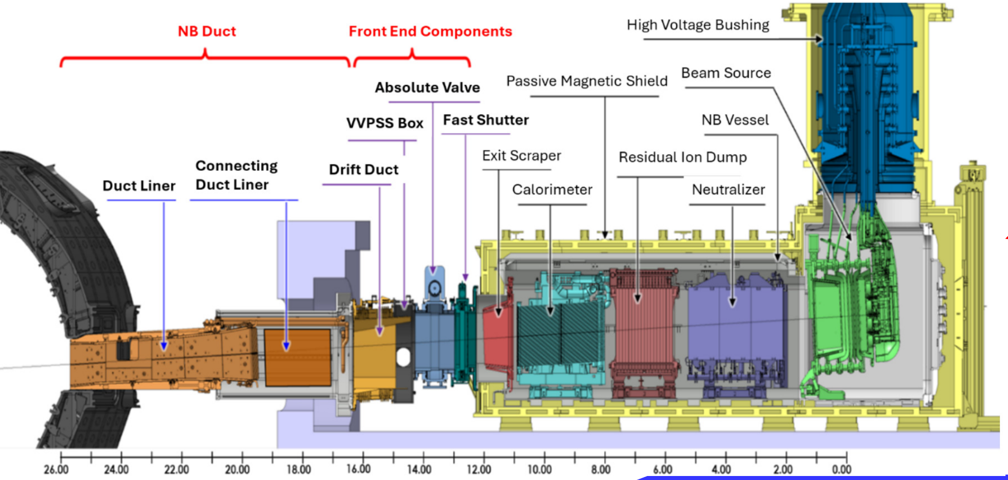
Introduction

Outline

- ITER NBIs & NBTF
- Recent results at NBTF
  - o SPIDER
  - o MITICA
- Long term strategy & contributing labs

Parameter	HNB (H/D)	DNB (H)
Injected power (MW)	16.5/beamline	1.7
Beam energy (MeV)	0.87/1	0.1
Accelerated current (A)	46/40	60
Beamlet divergences (mrad)	<7	<7
Pulse length/duty cycle (s)	3600/25%	3 s ON, 20 s OFF or 0.1s ON 1.4s OFF





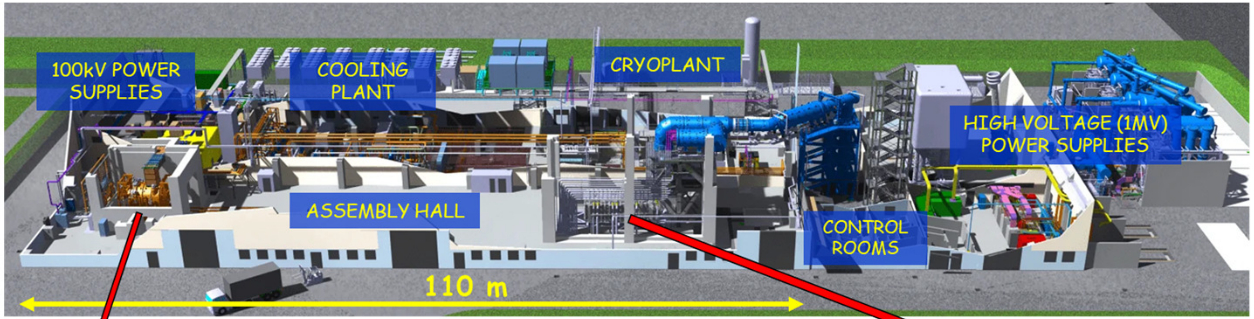
- ✓ 2 (+1) Heating Neutral Beams (HNBs)
- ✓ 1 Diagnostic Neutral Beam (DNB)
- ✓ 33 (50) MW of Power injected
- ✓ Also provide current drive, rotation.
- ✓ Mostly in-kind [EUDA & JADA (HNBs), INDA (DNB)]

From NBIs to NBTF

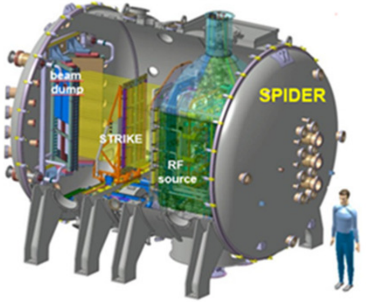
ITER NBIs based on production and neutralization of <u>negative</u> ions. High Voltage, large heat fluxes; High Vacuum; Compensation of ITER B field; Nuclear Confinement, RH

→ large extrapolation from existing **<u>NBI → NBTF</u>**

Neutral Beam Test Facility (NBTF) @ Consorzio RFX, Padova, Italy



<u>Integrated R&D strategy</u> for the establishment of HNB at ITER meeting the target performances and the long-term schedule: recent activities at NBTF and contributing labs



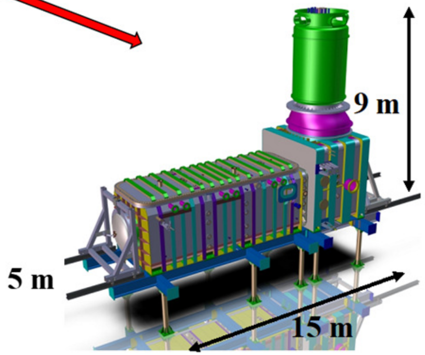
SPIDER (H/D)

J= 355 / 285 A/m2
E= 0.1 MeV
P= 0.3 Pa
Ele/Ion < 0.5 / 1
Uniformity > 90%
Beam on time= 1000 / 3600s

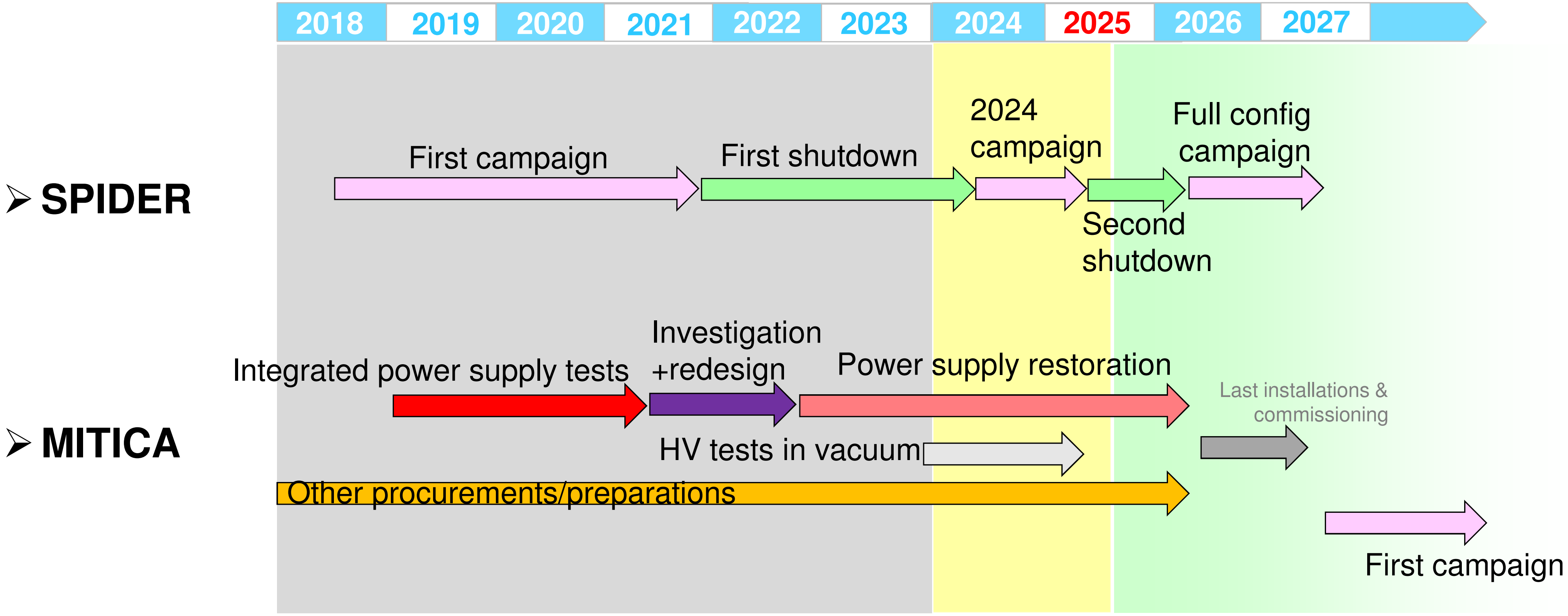
MITICA (H/D)

Ion Source Parameters

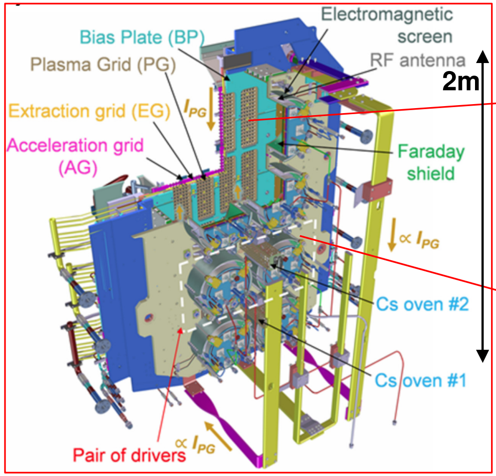
I = 46 / 40 A
E= 0.87 / 1 MeV
Divergence <7mrad

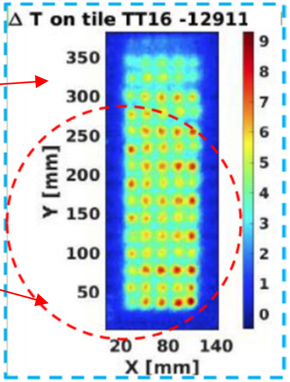


General timeline

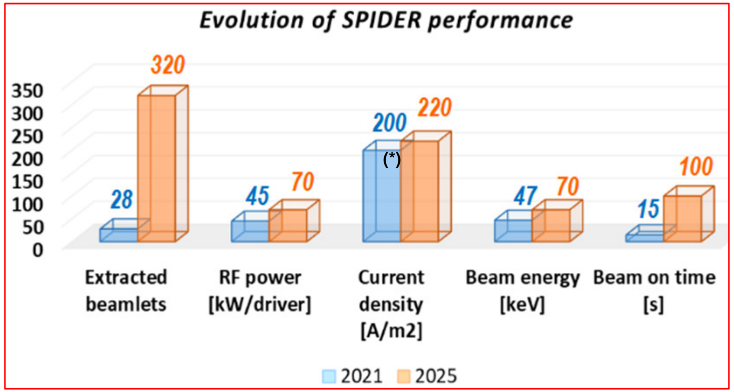


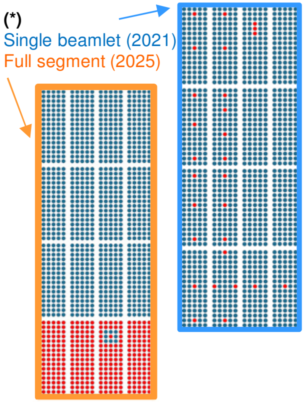
SPIDER recent operation

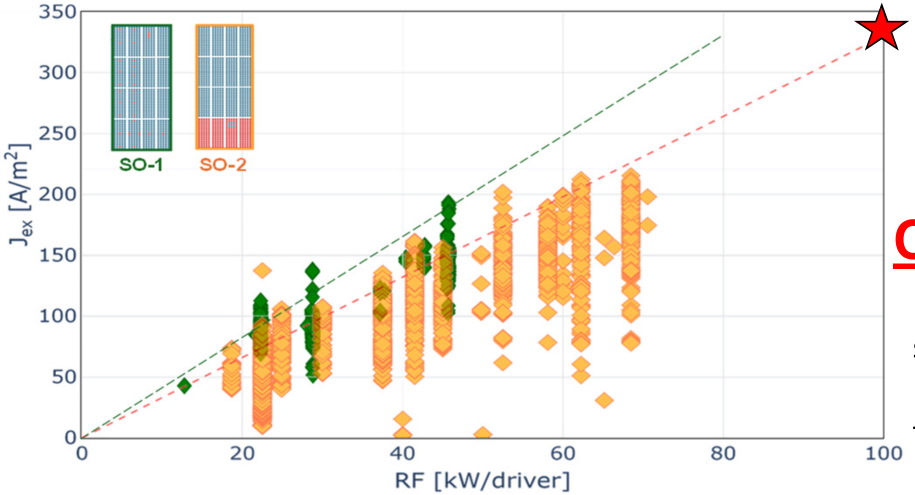




Beam pattern by a 1D-CFC calorimeter
Spatial resolution as good as 2 mm

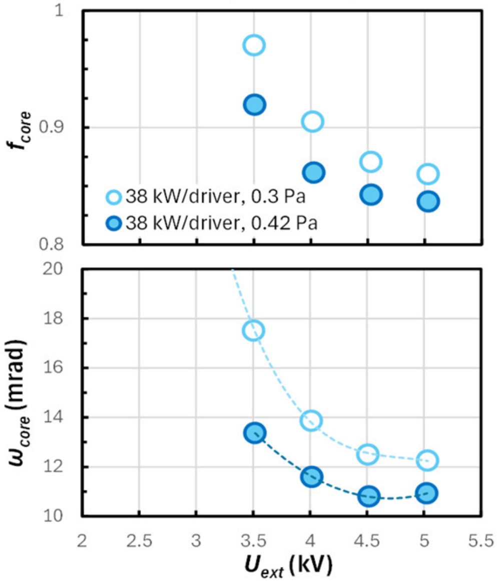






DIVERGENCE

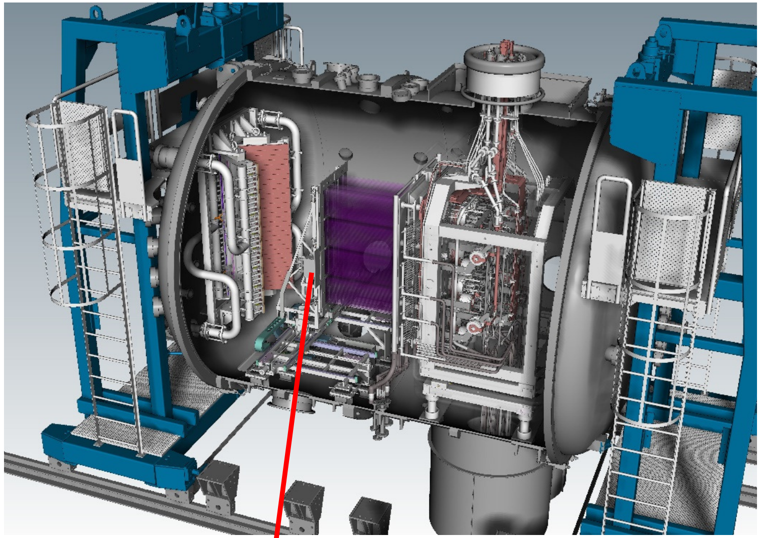
Core fraction
and divergence

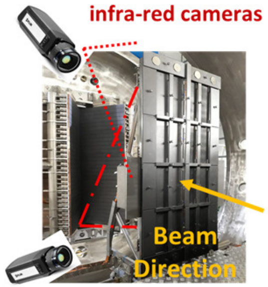


CURRENT DENSITY

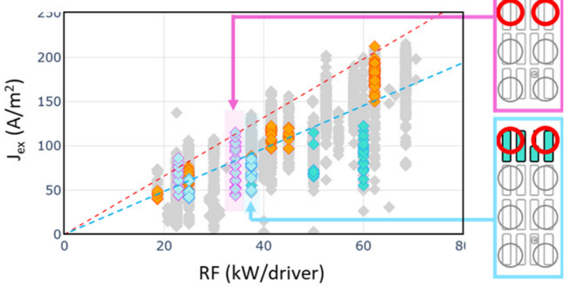
Note that Current density in single segment operation is intrinsically lower: top 3 rows not illuminated by the 3rd pair of drivers

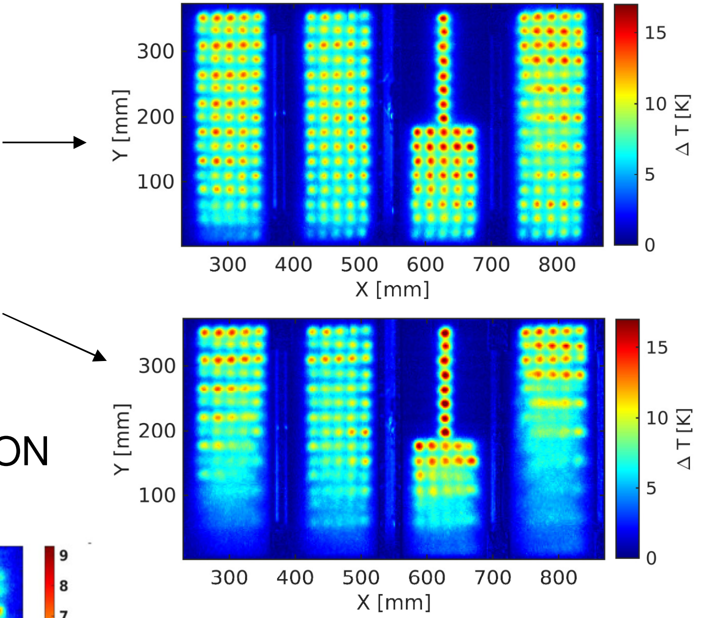
BEAM UNIFORMITY



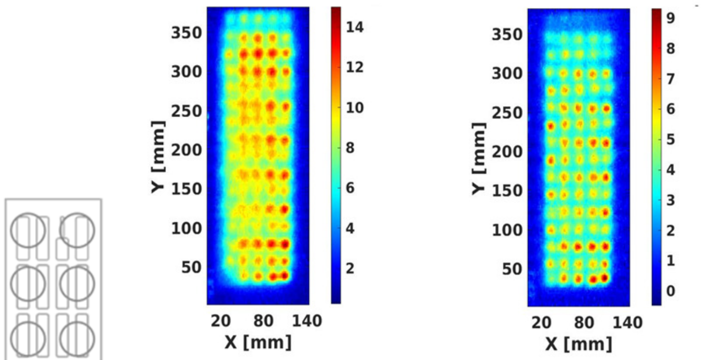


STRIKE closed, front view





TOP SEGMENT:
1 or 2 RF circuits ON



#13040, 75kW/driver, p=0.3 Pa, I_{PG}=1.5kA, ISBI 110 A, ISBP=120A
U_{ex} = 5.5 kV- U_{acc}/U_{ext}= 9.5

#12911 50kW/driver, 0.43 Pa, I_{PG}=1.2kA, ISBI 190 A, ISBP=145A
U_{ex} = 3.75 kV, U_{acc}/U_{ext}= 9.5

BOTTOM SEGMENT:
Different parameters scan

SPIDER activities – RF generators

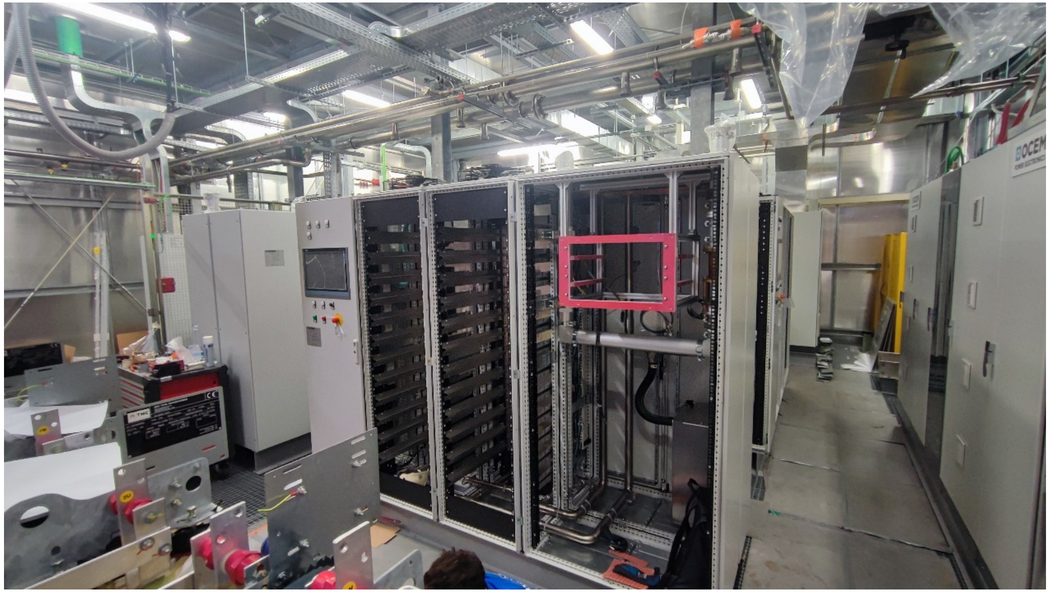
RF Solid State Amplifiers

From tetrode oscillators to solid-state amplifiers, WHY?

- **Superior matching** (e.g. no instabilities - frequency flips)
- **No cross-talking between generators**
- **No high voltage in the power supply** (hence no conditioning, easier maintenance)
- **Higher efficiency**
- **No risk of obsolescence of components**
- **Modularity**

4 x 200 kW generators, 1 MHz ± 10%, 50 Ω, water cooled

RF generator based on **24 x 10 kW @ 1 MHz amplifier power modules**



Onsite installation activities on SPIDER units ongoing

SPIDER activities – vacuum enhancement

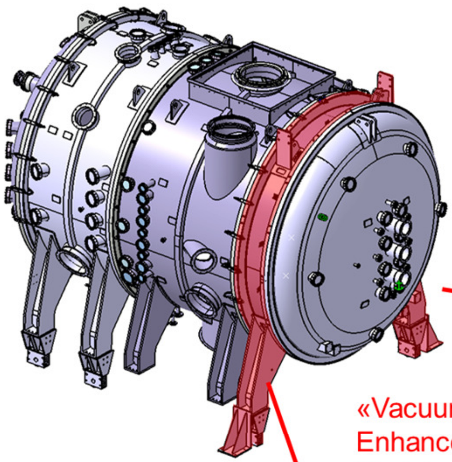
Vacuum Enhancement

Onsite installation of the pumps ongoing

Adding pumping capabilities, WHY?

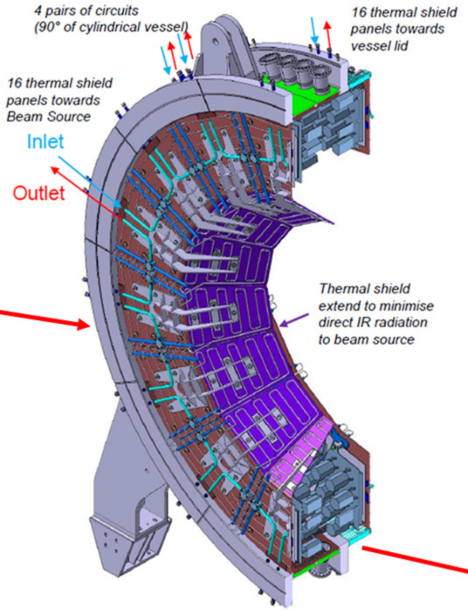
- Design range of pressure/conductance vs actual operation
- Commercial cryopump performances
- **RF discharges in vacuum** (1st source ever fully immersed in vacuum)

No occurrence of discharges under a known vessel pressure threshold, hence…



«Vacuum Enhancement Module»

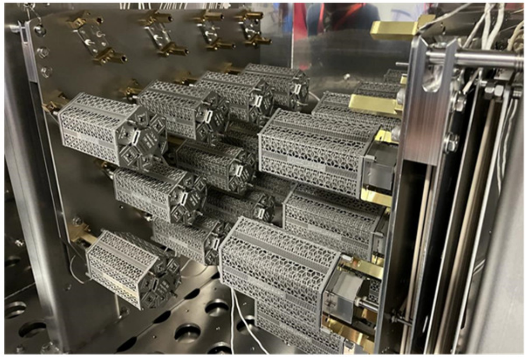
VEM at NBTF site, ready for NEG support pannels installation



384 NEG cartridges have a pumping speed for H_2 of ~**300 m^3/s**

H_2 Capacity for 384 NEG cartridges **440000 Pa*m^3**

DC Power Cabinets and Control Units (tested in May 2024)

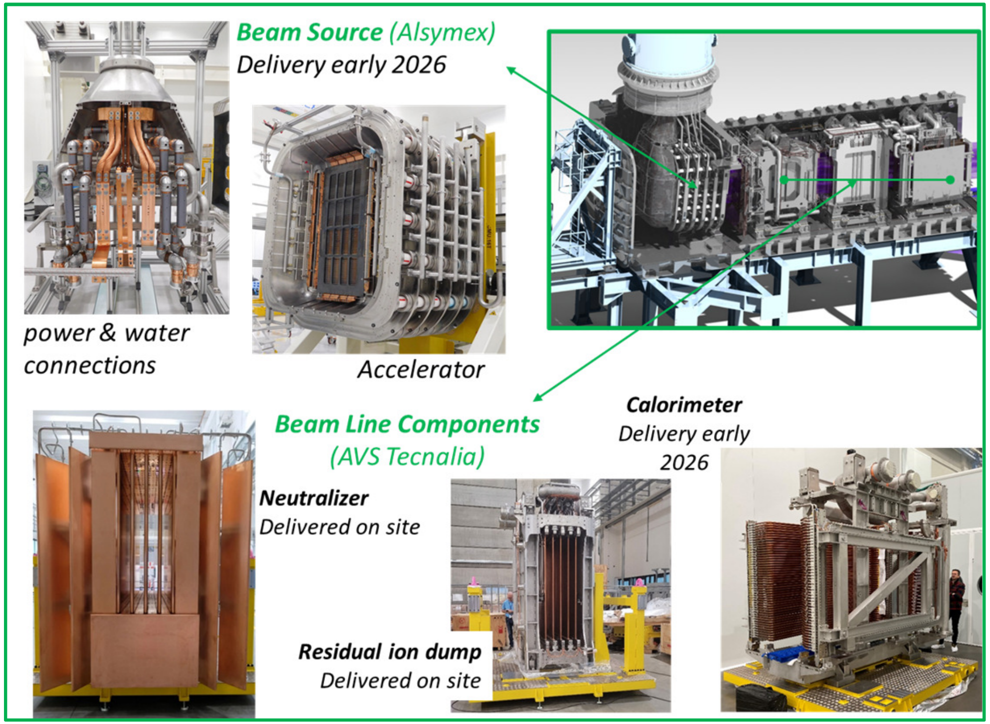


NEG pump installed on panels (at SAES during tests)

MITICA Activities

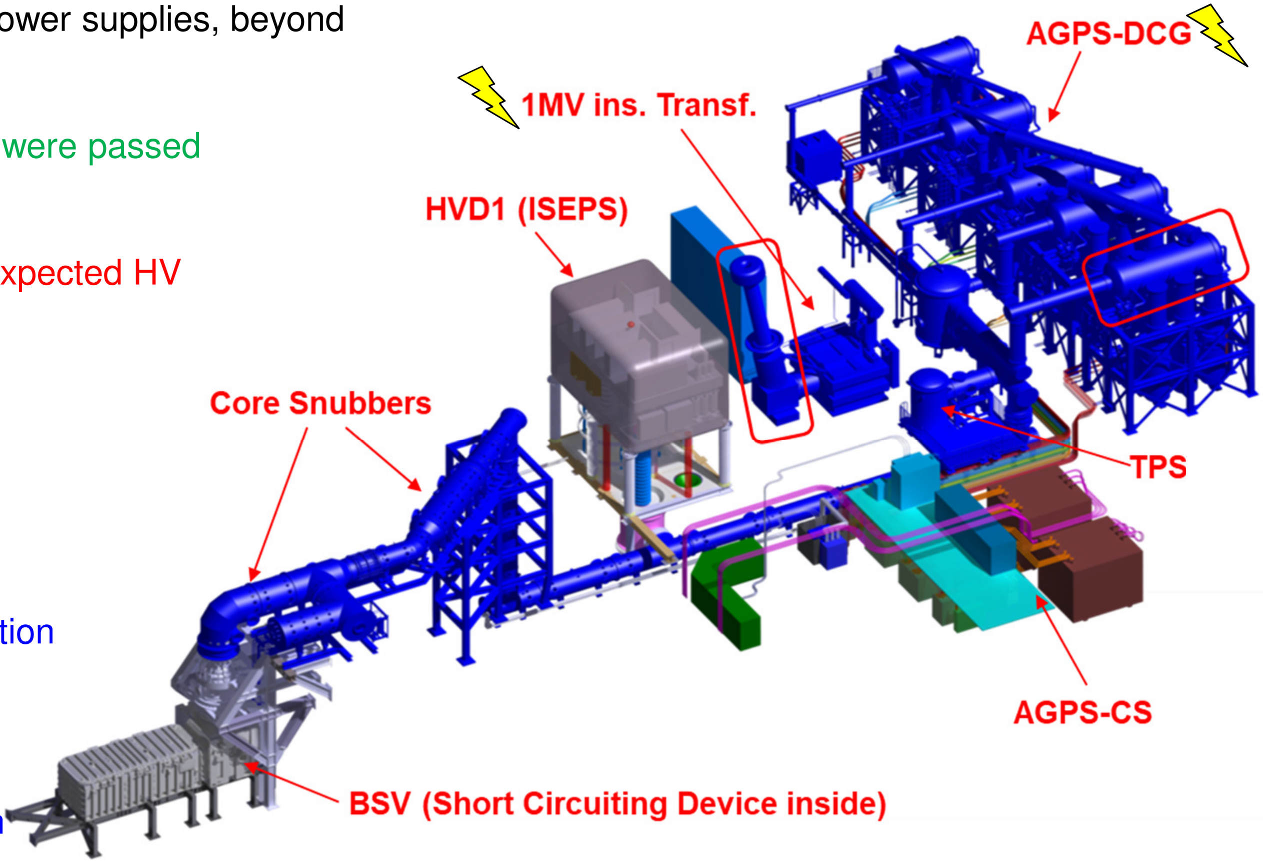
OVERVIEW

- Restoration of power supply ongoing
- Meanwhile, HV insulation tests in vacuum completed the campaign C and D
- *Many preparations/procurements ongoing, in view of future activities (diagnostics, controls,…)*
- Prosecution of procurements for in vessel components, by F4E
- Trial installation of cryopumps and integration with cryoplant



MITICA PS restoration

- HNB operation with D- ions requires acceleration voltages of 1 MV
  - development of technologically advanced power supplies, beyond the limit of present technologies
- Insulation tests @ 1.2 MV for 1 h & 1 MV for 5 h were passed successfully
- During integrated power tests (spring 2021), unexpected HV breakdowns damaged parts of the system

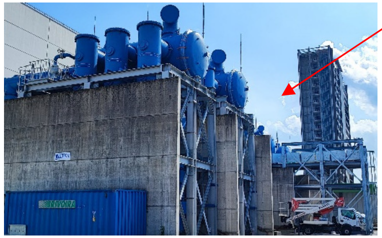


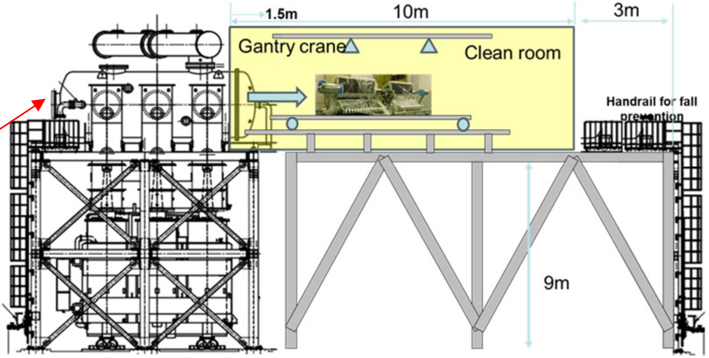
Recovery strategy undertaken

- Thorough review of the PS system
- Development and implementation of recovery solutions including introduction of additional protection systems
- Procurements delivered by June 2025
- Completion of PS restoration+integrated tests in Q2/2026

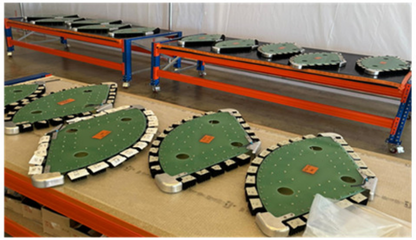
New PS components and ongoing activities

Step-up transformer diodes





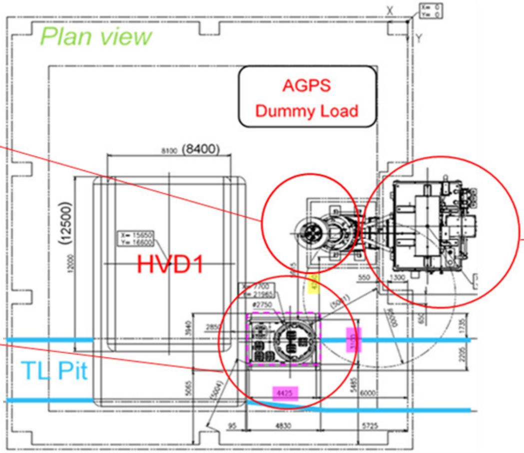
External yard → *Transport & disassembly of diode units* → *Warehouse*



Diode module processing & refurbishment with enhanced snubbers

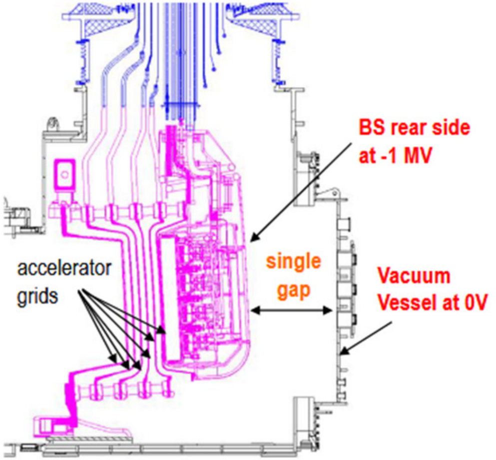
← *Reassembly & reinstall* ←

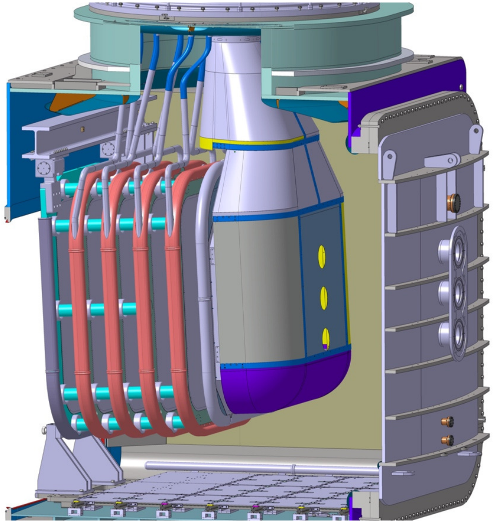
1 MV insulating transformer



High Voltage Hall

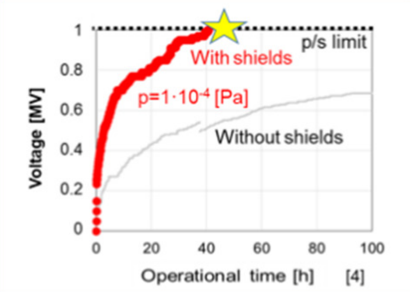
MITICA - HV insulation tests in vacuum





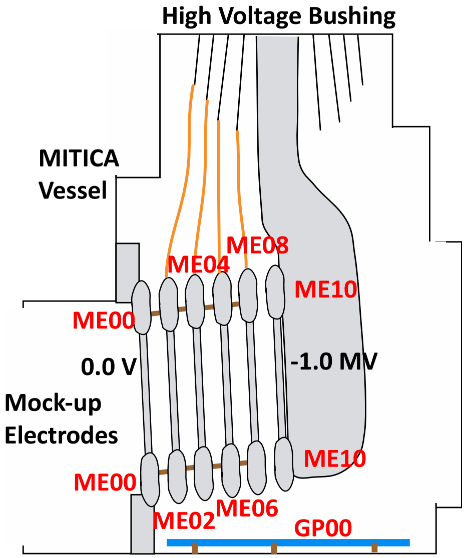
Exploiting the time window for power supply restoration, to investigate voltage insulation in vacuum

A dedicated recent experiment at QST indicates that in order to hold 1 MV voltage holding intermediate shields are definitely effective

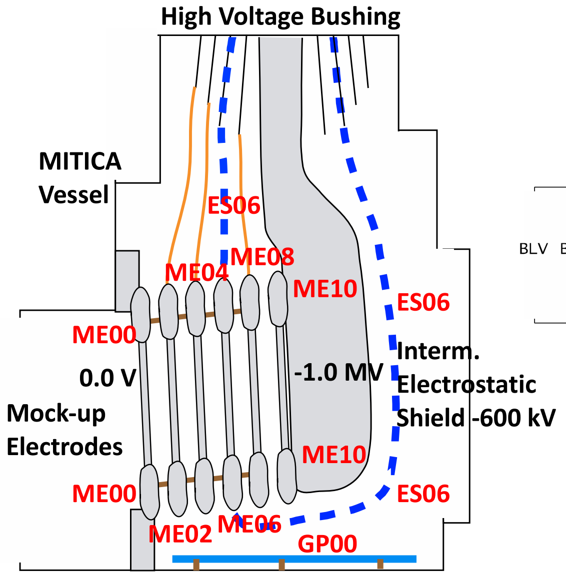


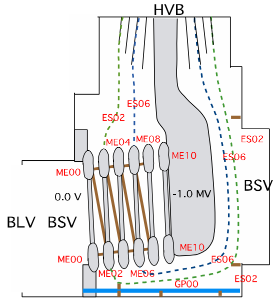
Tests @ QST

Config. 1 +. 2:



Config. 3:





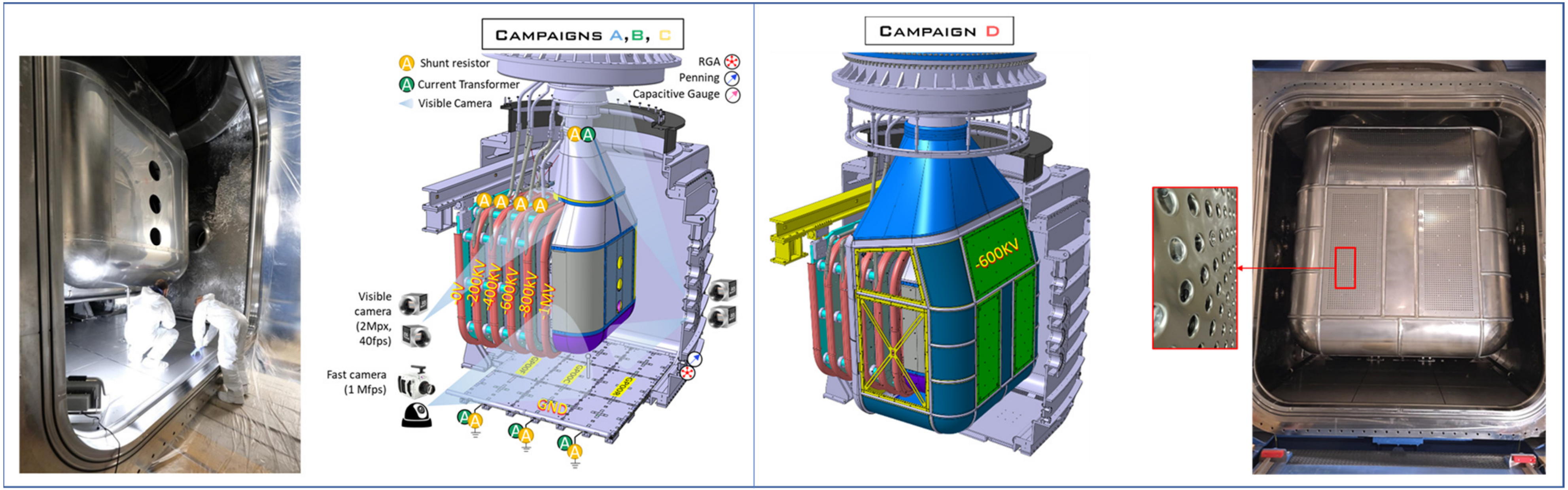
The intermediate shield divides the volume into two independent regions, with higher holding capabilities

MITICA HV tests in vacuum

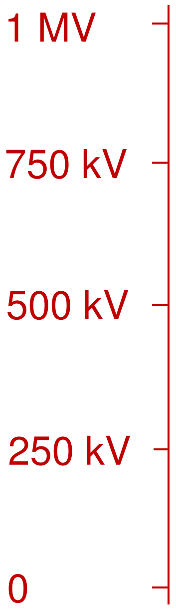
Two configurations tested: (1) base source, (2) adding one intermediate shield

Two operating states tested, mostly in (2) at higher values of voltage: (a) high vacuum, (b) gas injection at a filling pressure relevant for future beam operation in hydrogen

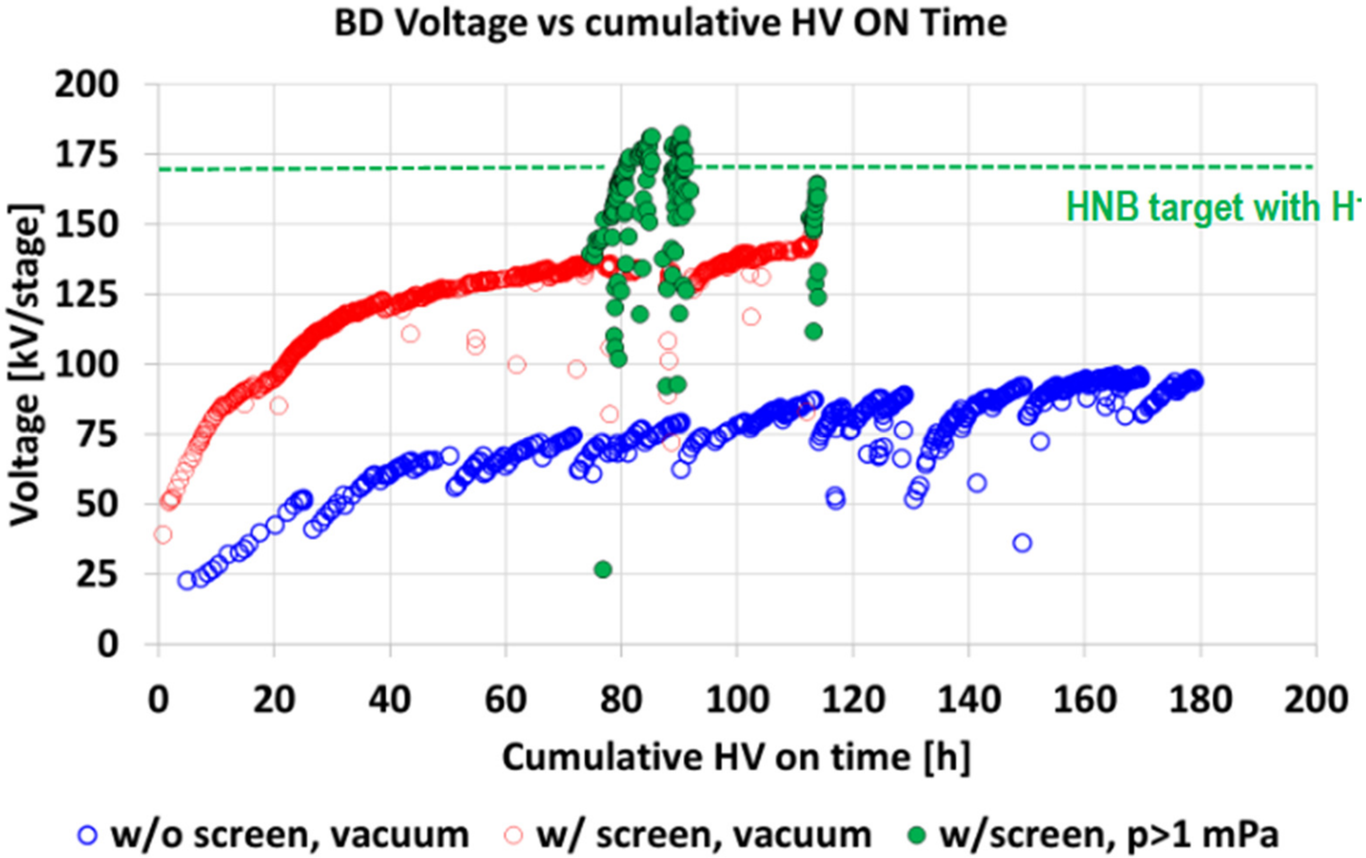
Arrival of new components from Japan for PS restoration forced the final part of the campaign to focus the conditioning on the part of the volume outside the intermediate shield, i.e. 3 accelerator stages out of 5



MITICA HV insulation tests in vacuum



on 5 stages



Record values (on 5 stages)

<500 kV

716 kV

910 kV

Other highlights:

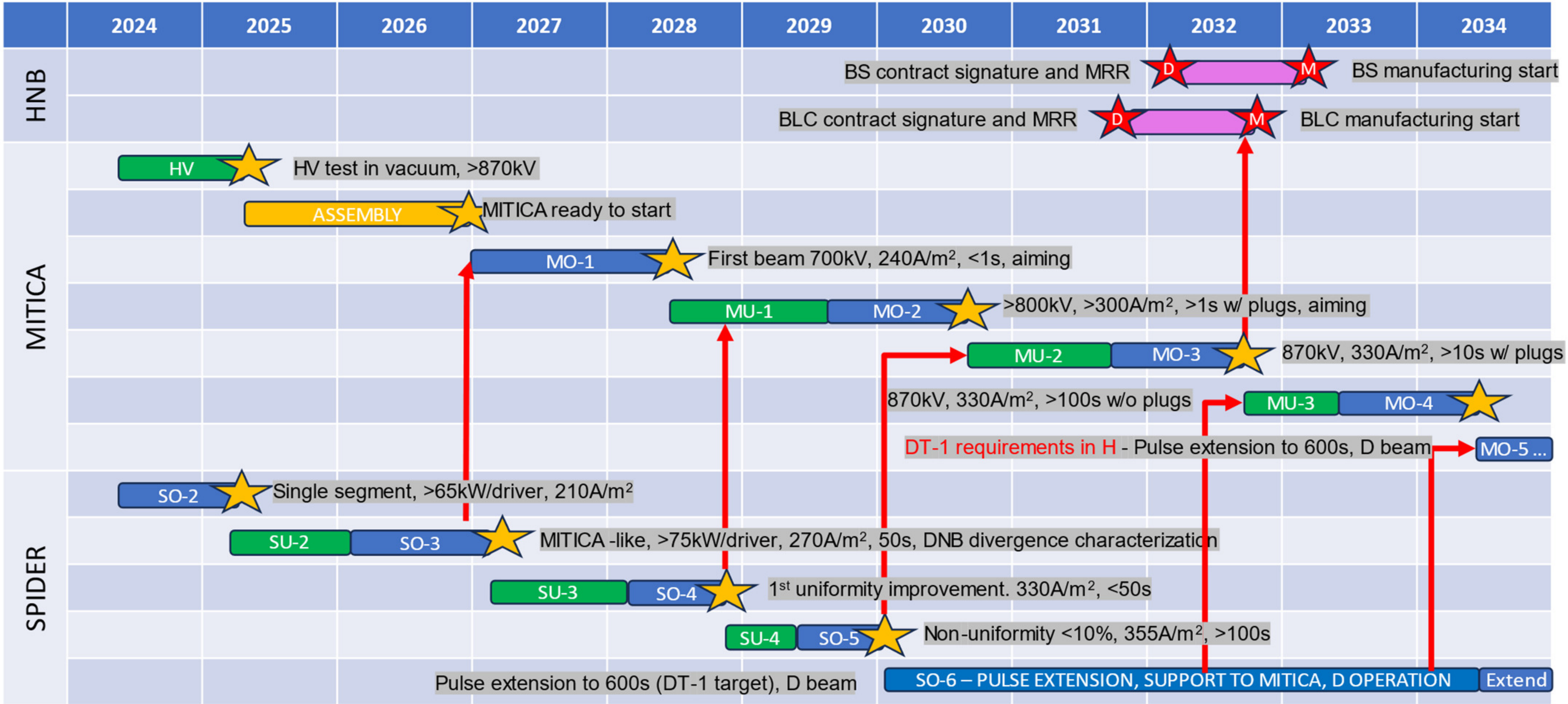
Max value (vacuum) held for >1h

Low loss of conditioning during night/weekends/short shutdowns

Conditioning duration ~ tens of hours

Long term schedule & ITER Research Plan

ITER Organization plan includes an integrated plan for SPIDER & MITICA, with identified milestones tightly linked to ITER development & operation *[performance in H before SRO; final goal: HNB to be ready in DT-1]*



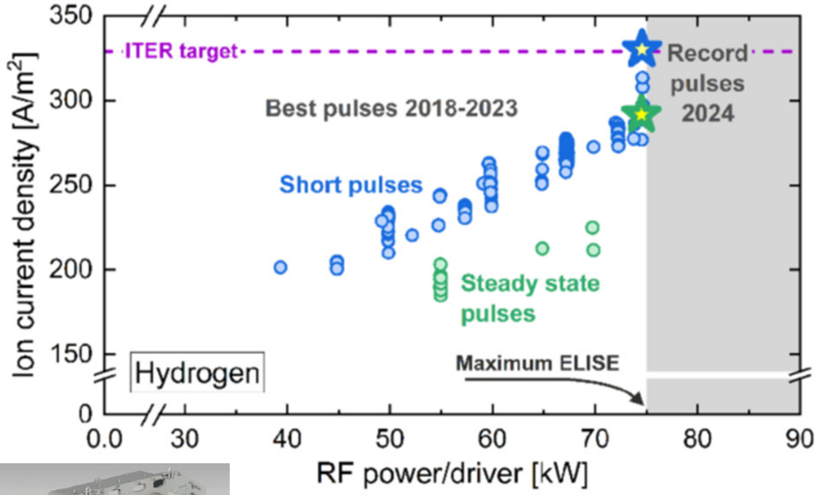
••• => DT-1

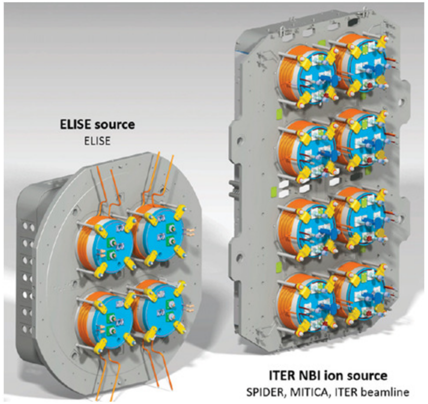
Switch of focus on D

Integrated Experimental Plan with partner labs

Main examples of labs contributing to NBTF main challenges with experiments :

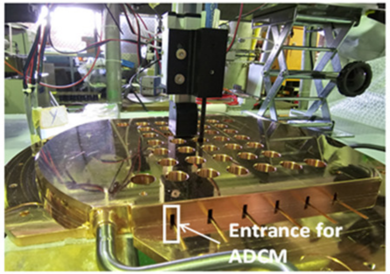
ELISE @ IPP





100% ITER target for H- current density in short pulses,
90% for long pulses

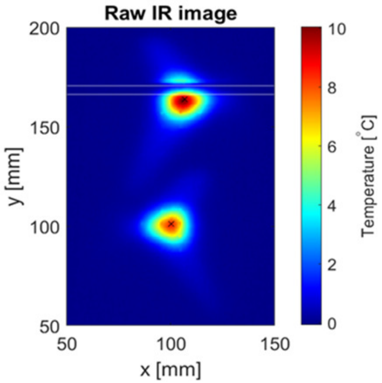
MTF @ QST

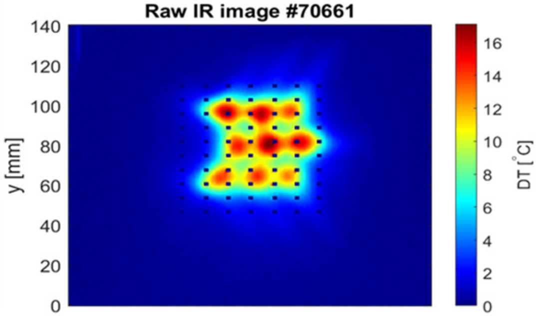


1) Voltage holding

2) Optics at high voltage

Pre-test of MITICA EG concept for ion deflection compensation





Conclusions

- ITER NBI program
  - The NBTF long term schedule is fully integrated in the ITER research plan
  - Community joint effort in providing inputs to NBTF
- SPIDER
  - Results in the latest operation progressing nicely towards ITER target parameters
  - Ongoing shutdown, towards next campaign exploiting full configuration & prepare 1° MITICA campaign
- MITICA
  - Power supply restoration well advanced
  - HV tests in vacuum demonstrating results already relevant for H campaigns in MITICA and HNB

NBTF keeps demonstrating its importance for ITER goals

Thank you for your attention

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