First operation of SPIDER and integrated power tests in MITICA

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contributing staff of IO, F4E, QST, IPR, IPP and other European institutions

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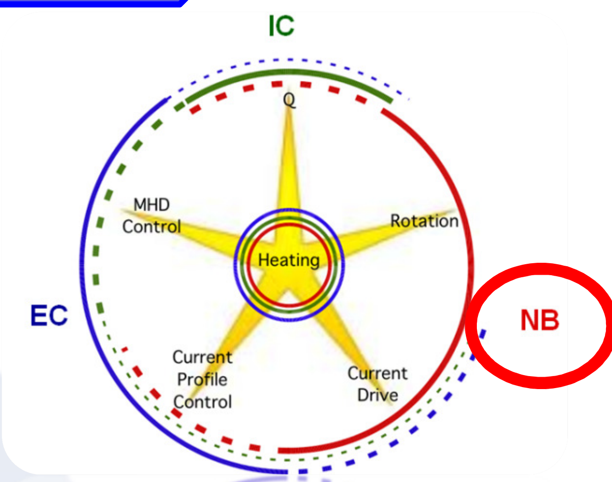
Outline

- Introduction : from Heating systems at ITER to NBTF

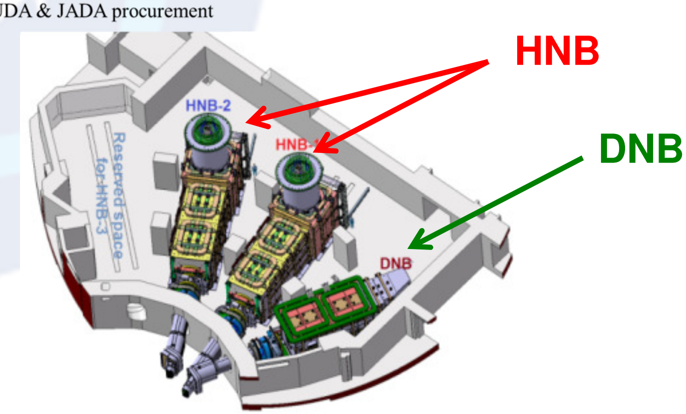


- SPIDER experiment
  - Early results
  - More recent results
- MITICA experiment

FUSION FOR ENERGY

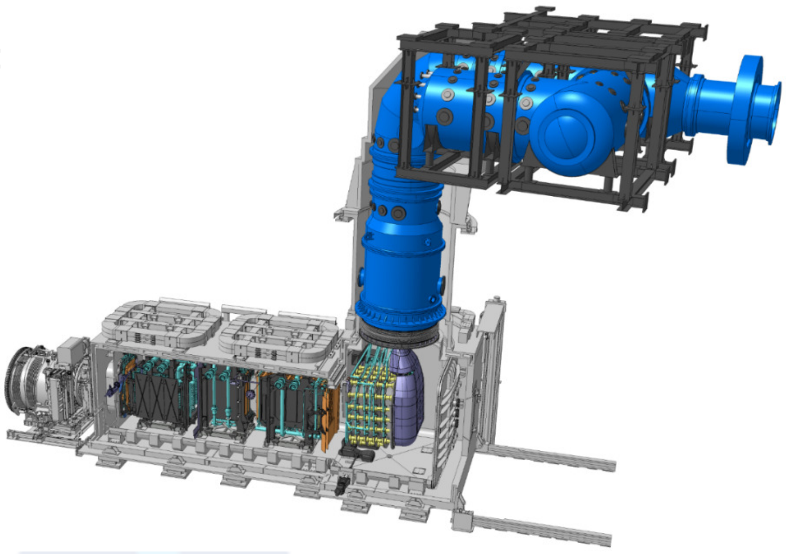
2 HNBs (+1): deuterium
- I = 40 A
- V = 1 MV
- t_{pulse} = 3600 s
- P_{beam} = 16.5 MW

EUDA & JADA procurement



(HNB) Critical components

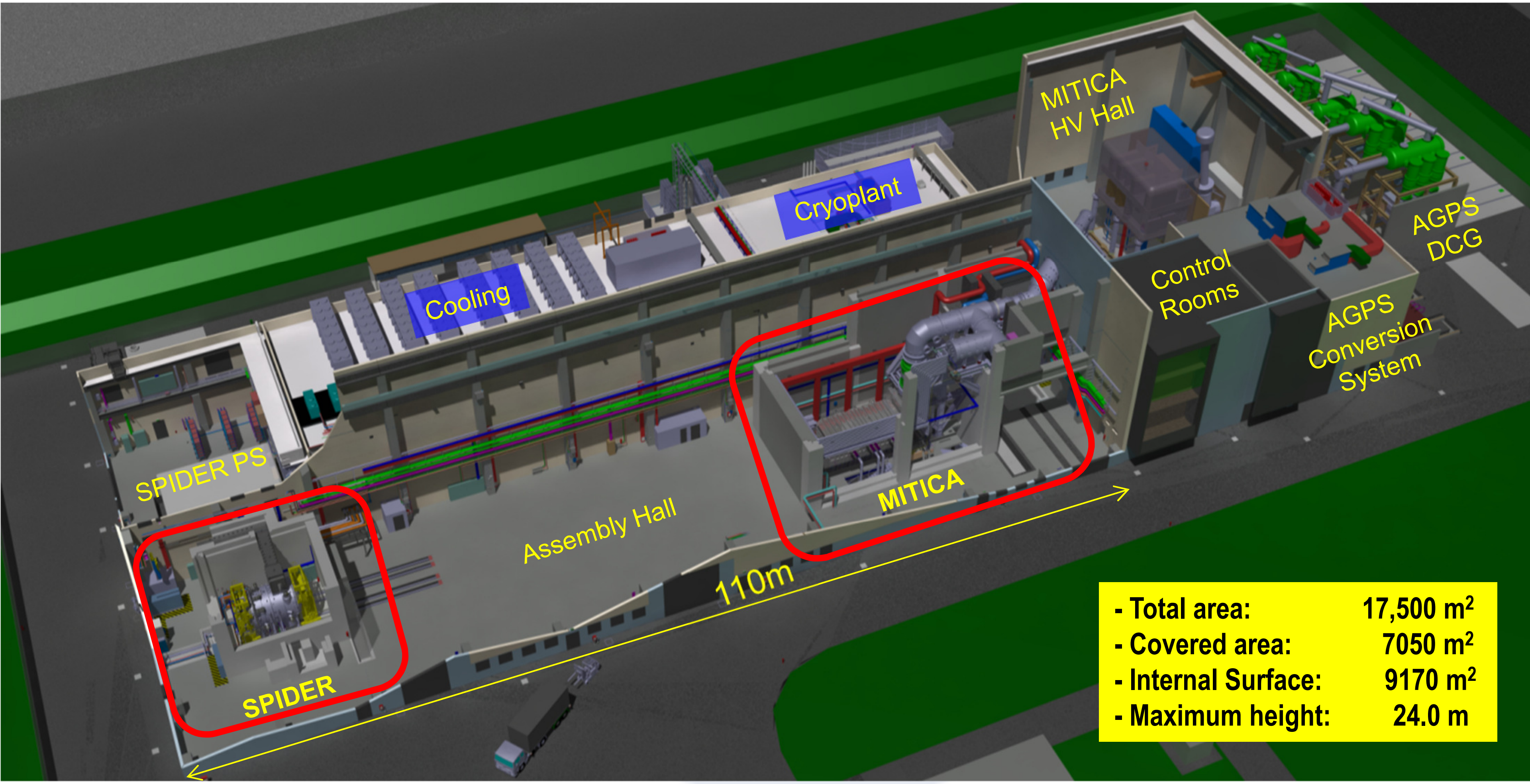
- Critical components which have direct impact on functionality:
  - Negative ion beam source to produce 40A of D-,
  - Caesiated source
  - 1280 beamlets
  - Vacuum insulated source
  - 1MV beam acceleration
  - 1MV voltage holding
  - 1MV Transmission line and feedthrough - HVB
  - Electrostatic RID



- The criticality and step from current technologies used in NBI justified the need for a Neutral Beam Facility (NBTF), aimed mainly at:
  - *achieving nominal parameters of source and beam*
  - *optimizing HNB operation*

- and consisting of:
  - ✓ **SPIDER:** optimisation of ion source: current density, uniformity, stability
  - ✓ **MITICA**: full-size prototype of ITER NBI: high voltage holding, beam optics

The Neutral Beam Test Facility

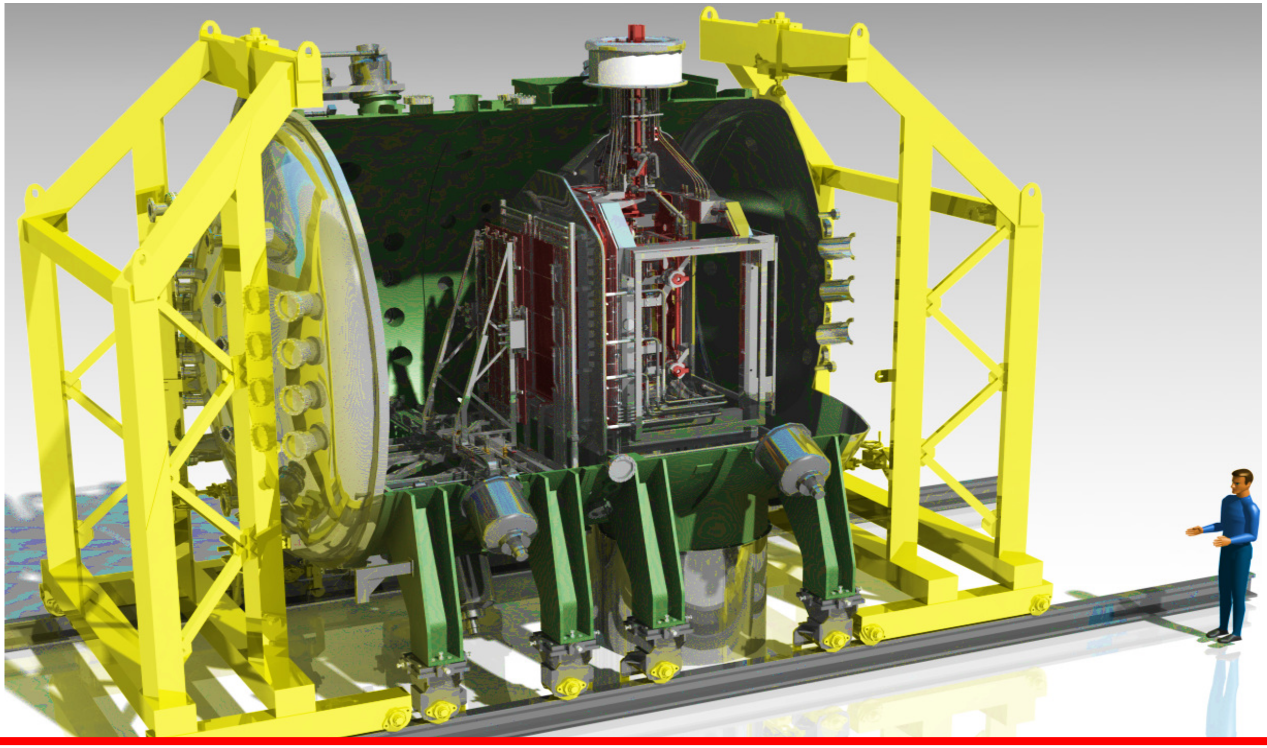


Prima hosts the two experiments: the negative ion source **SPIDER** and the 1:1 prototype of the ITER injector **MITICA**

Each experiment is inside a concrete biological shield against radiation and neutrons produced by the injectors

Thanks to these shielding the assembly/maintenance area will be fully accessible also during experiments

SPIDER: the full scale prototype of the ITER HNB/DNB ion sources



	Unit	H	D
Beam energy	keV	100	100
Maximum Beam Source pressure	Pa	<0.3	<0.3
Uniformity	%	±10	±10
Extracted current density	A/m^2	>355	>285
Beam on time	s	3600	3600
Co-extracted electron fraction (e^-/H^-) and (e^-/D^-)		<0.5	<1

First SPIDER operations

- SPIDER operation started on 4 June 2018
- After some tuning, first plasma ignition on 6 June 2018 with 1/4 source…

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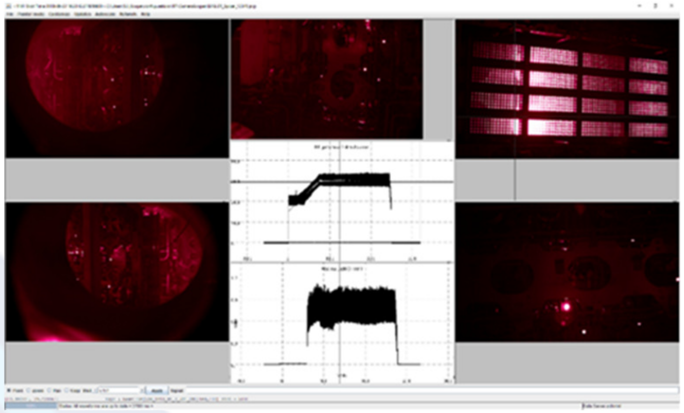
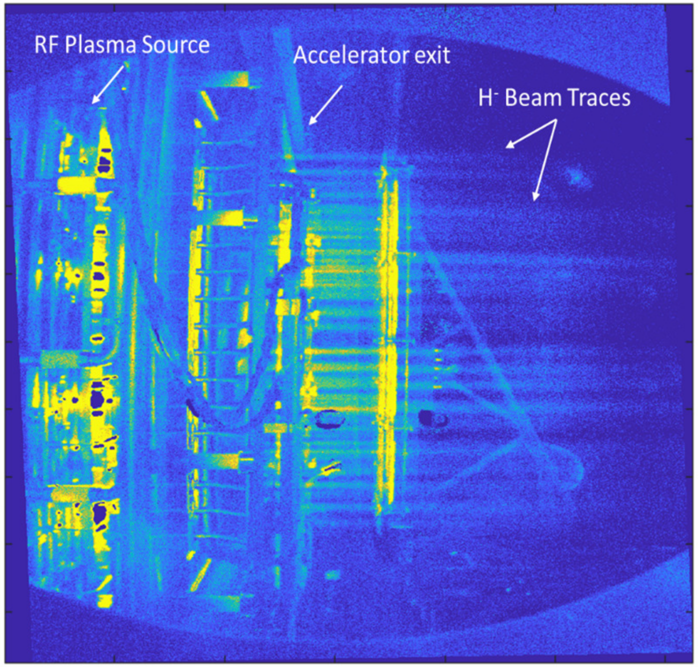


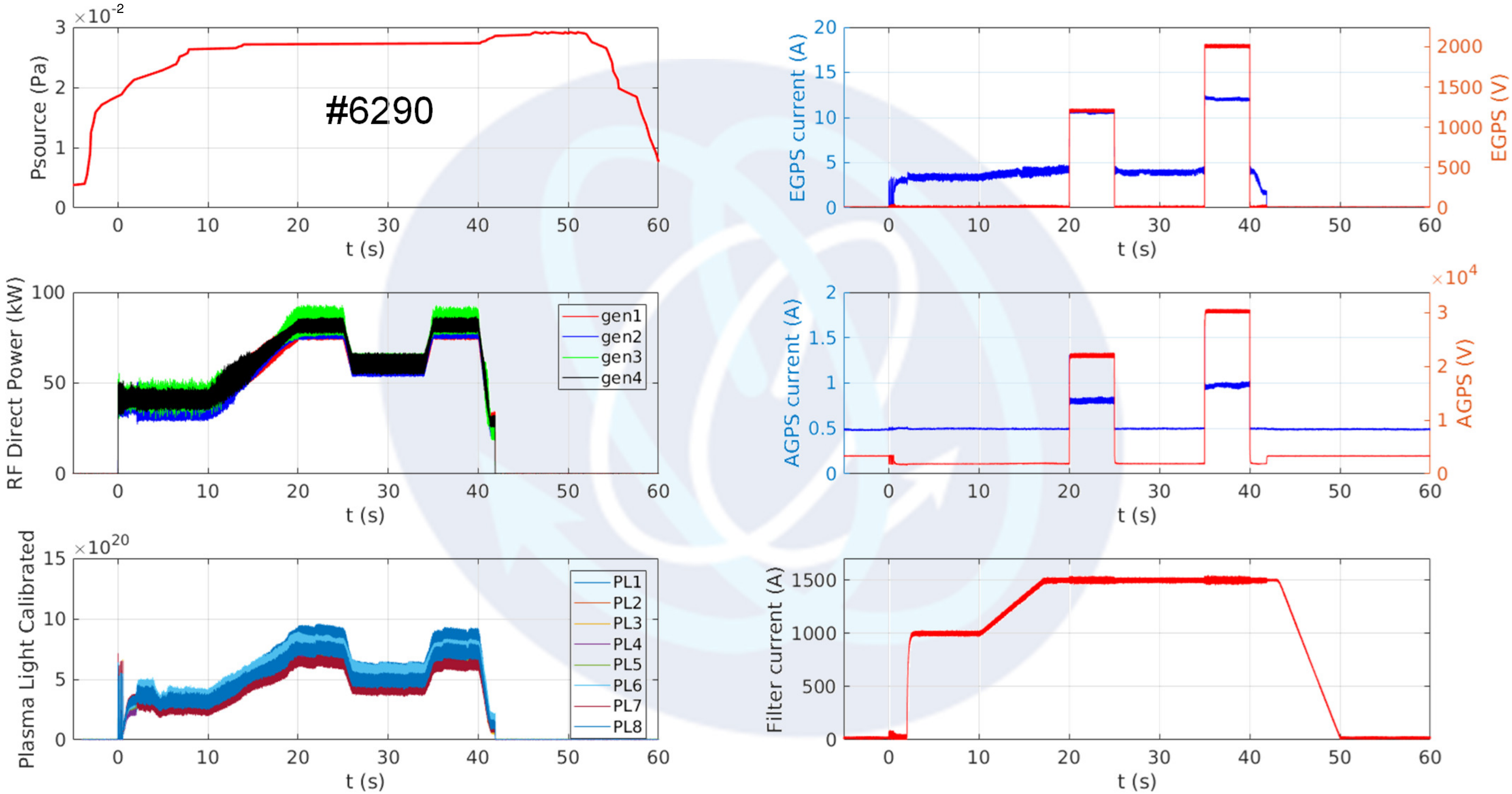
June 2018 first plasma…



….. 24 May 2019 first beam

First SPIDER results

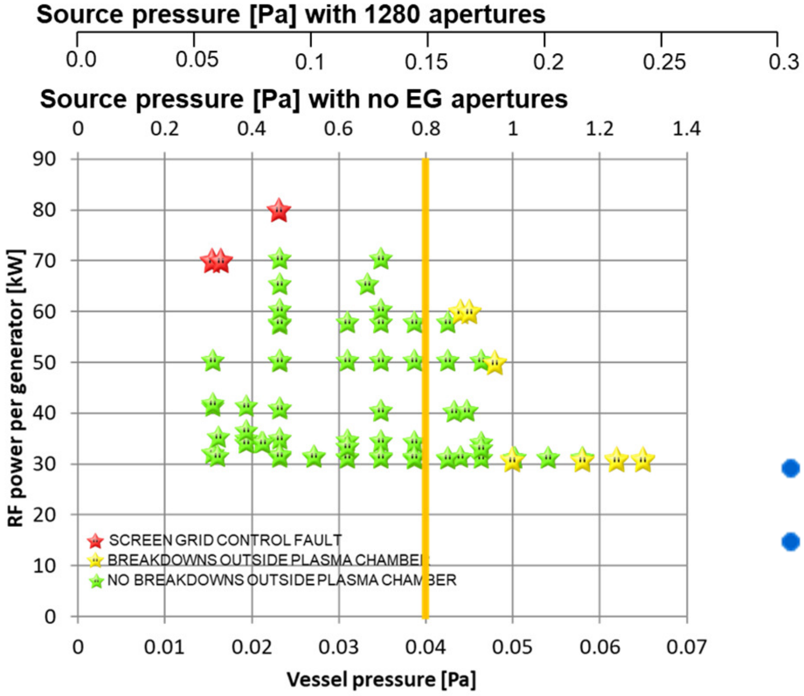
- Large flexibility of SPIDER control system

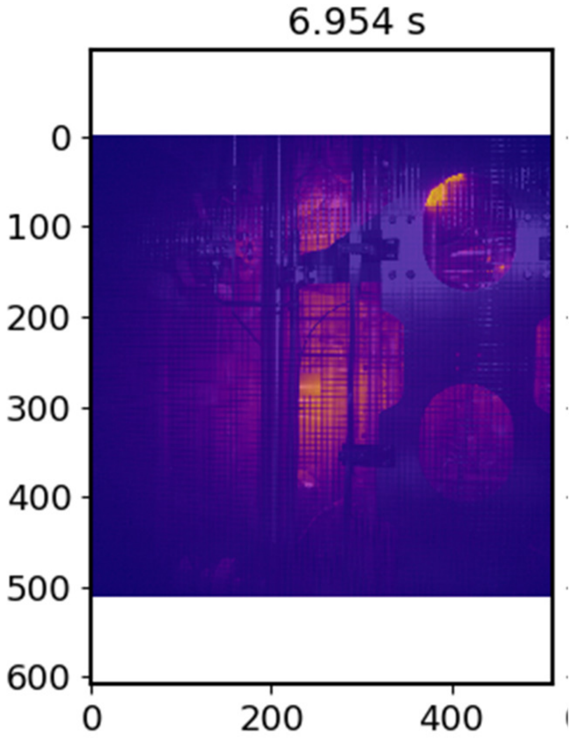


- *But also…*

RF breakdown outside plasma chamber

- Beam source in vacuum
- Breakdown on source rear side due to RF:
  - analysis by fast cameras
  - investigation of pressure effect
- Hypothesis: RF breakdowns induced by large background gas pressure





STRATEGY

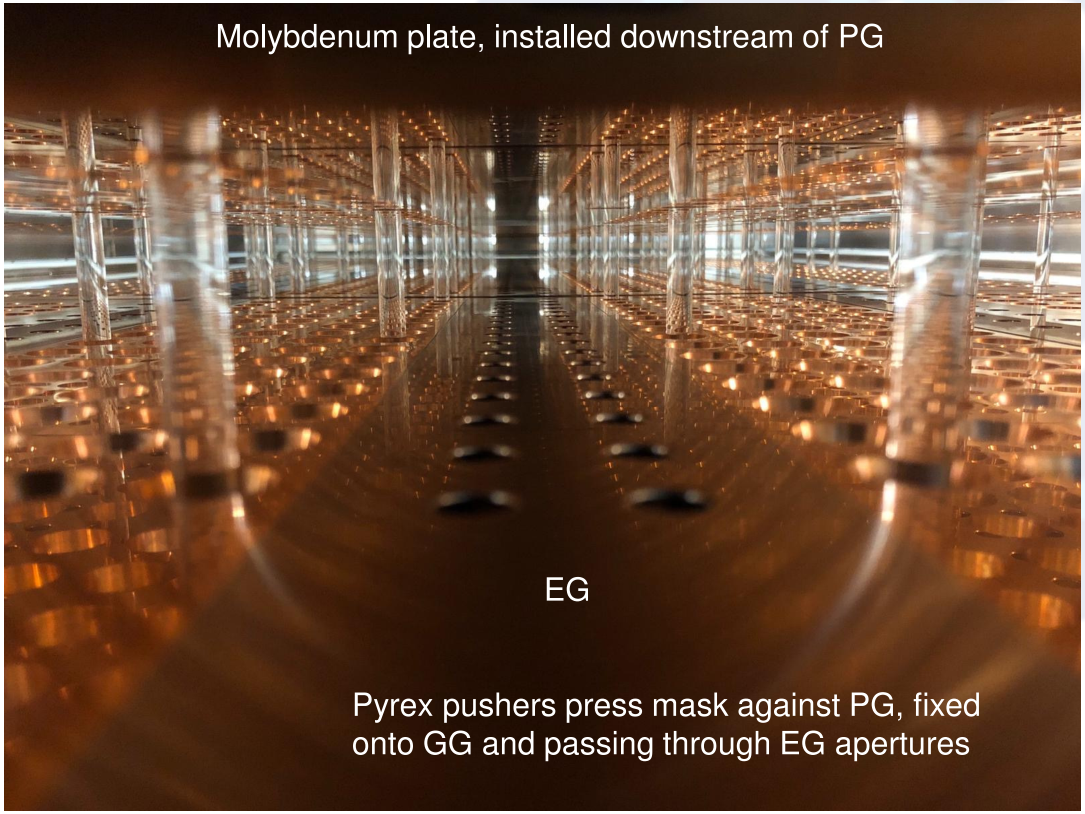
- Long term solution: enhancement of vacuum speed
- Temporary solution: Installation of mask on downstream side of PG (only 80 beamlet open)

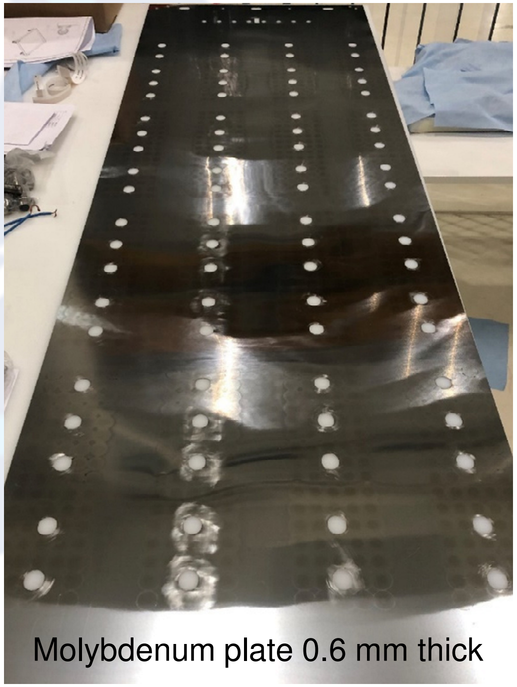
Installation of plasma grid mask

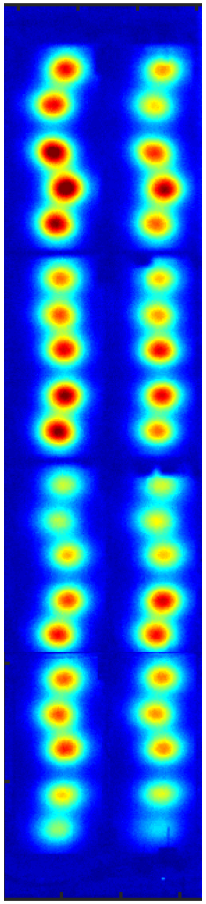
In the meantime:

- installation of plasma grid mask between PG and EG
- number of 80 beamlet determined by numerical simulations

View from top

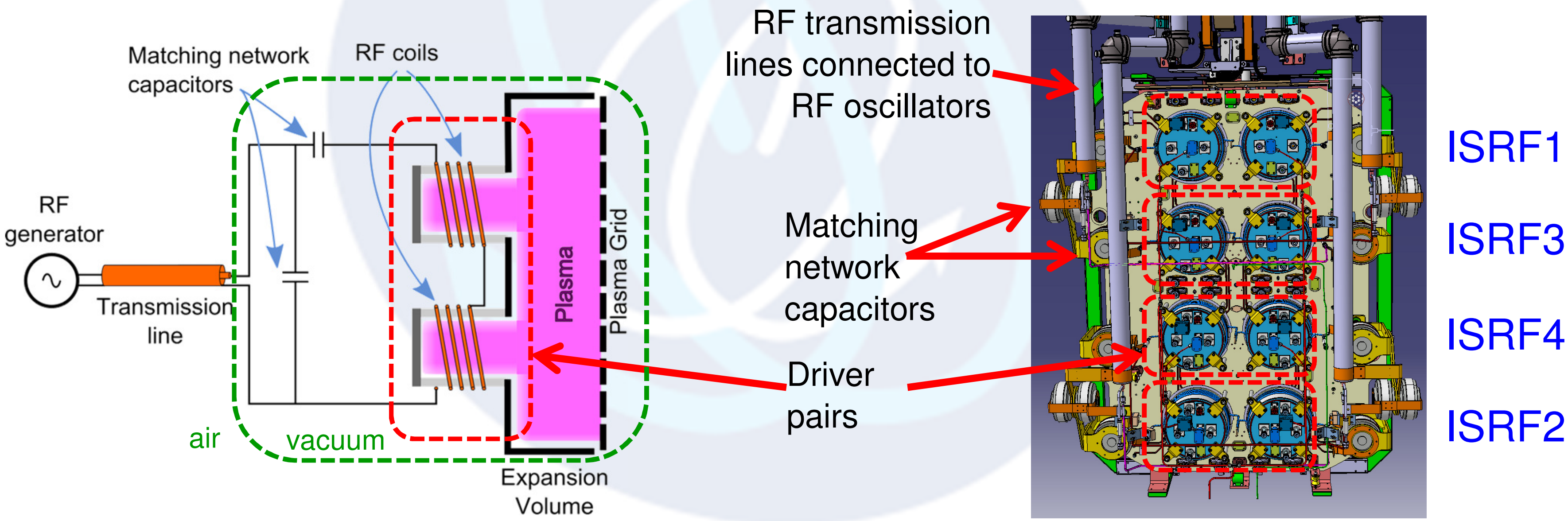






The SPIDER RF system

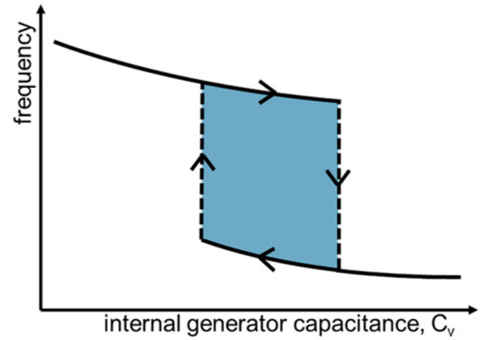
- **4 RF generators** (ISRF-TRF), coaxial line (TL), ion source RF load
- Each RF generator: pair of **power tetrodes** in push-pull connection; **variable capacitor C_v** to tune operating frequency



The SPIDER RF system

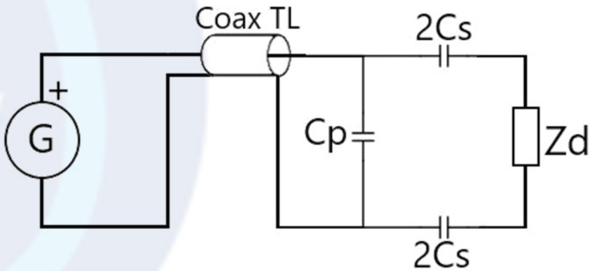
RF power limit identified:

- power transfer **depending** on equivalent load impedance
- sudden **frequency flips** near impedance matching
  - RF power constrained, as observed in other facilities



Strategy:

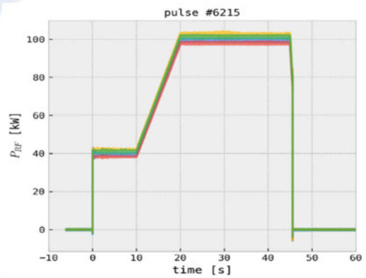
- implementation of **feedforward control** of capacitances inside RF generators
- development of **model** reproducing different behaviours of ISRF system to:
  - support SPIDER operation
  - analyse its performances
  - help in achieving nominal performances



- **experimental campaign** to analyse different matching network parameters

Simultaneous operation of 4 RF generators:

– max RF power 100kW so far



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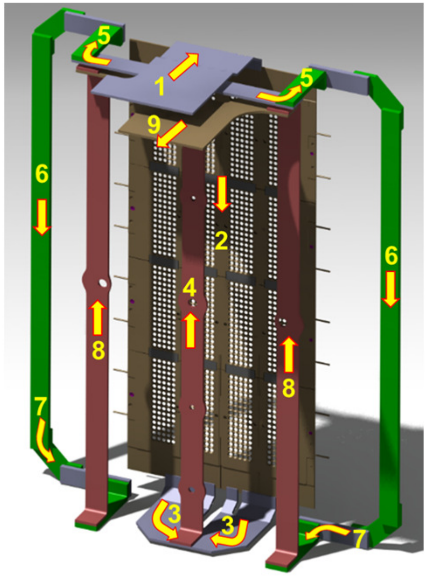
New configuration of magnetic filter field

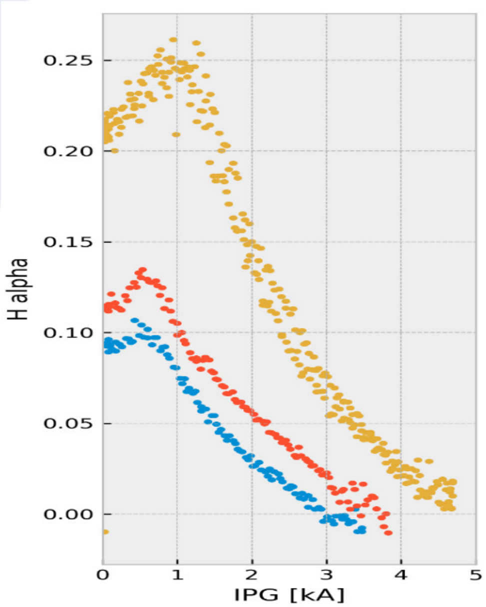
Original filter field configuration:

- PG busbar layout designed for: max B field strength and **uniformity** in plasma source (upstream of PG), B field **parallel** to PG, low B field in drivers
- Non-uniformity of return currents implies high axial component of B field in drivers

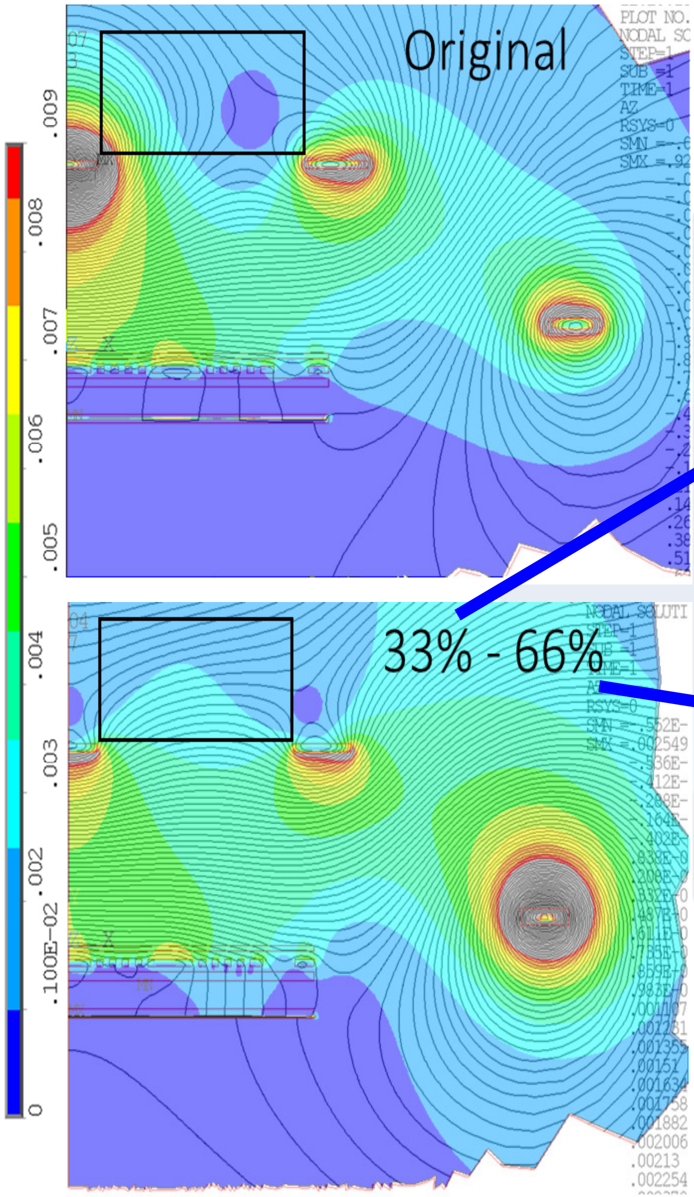


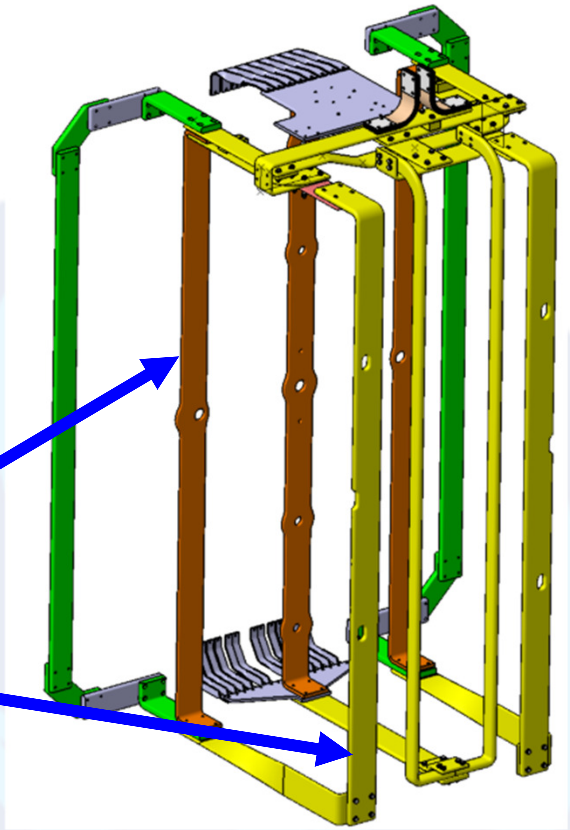
Effect of filter field on driver plasma - Observation:

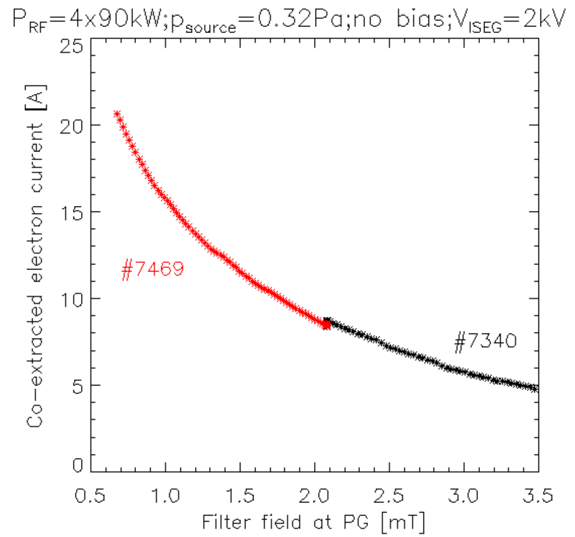
- During plasma experiments a strong dependence of the plasma parameters from the magnetic field generated by the filter field circuit has been demonstrated
- Filter field can quench the plasma in low RF power conditions
- Electrons might be driven towards the walls of the drivers by the filter field

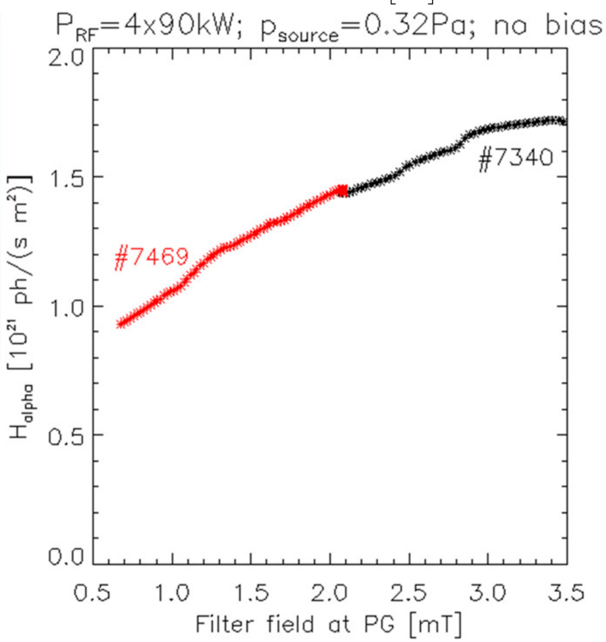


New configuration of magnetic filter field



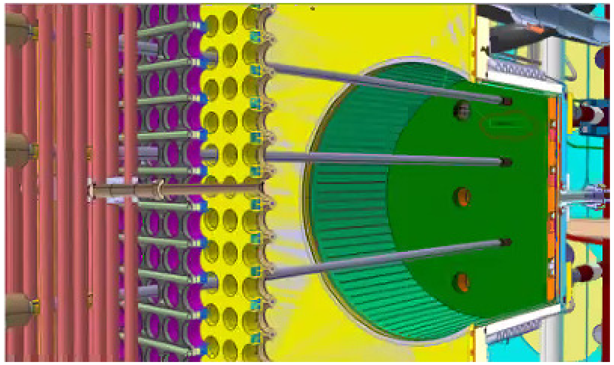


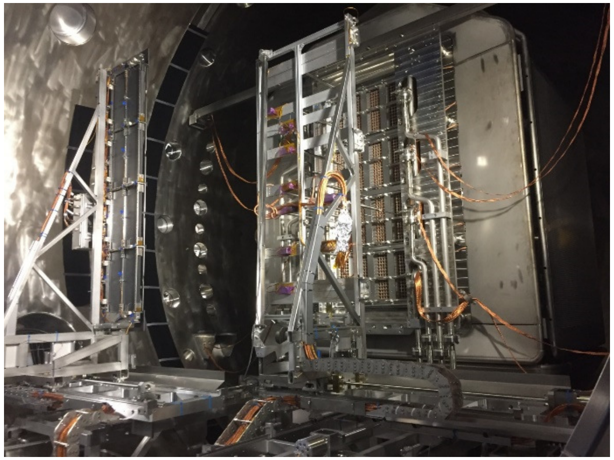


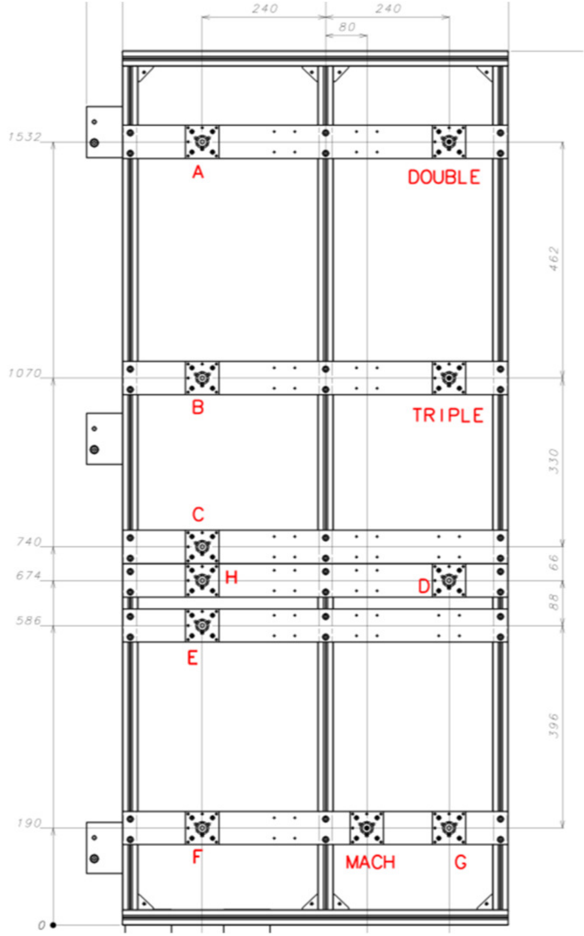


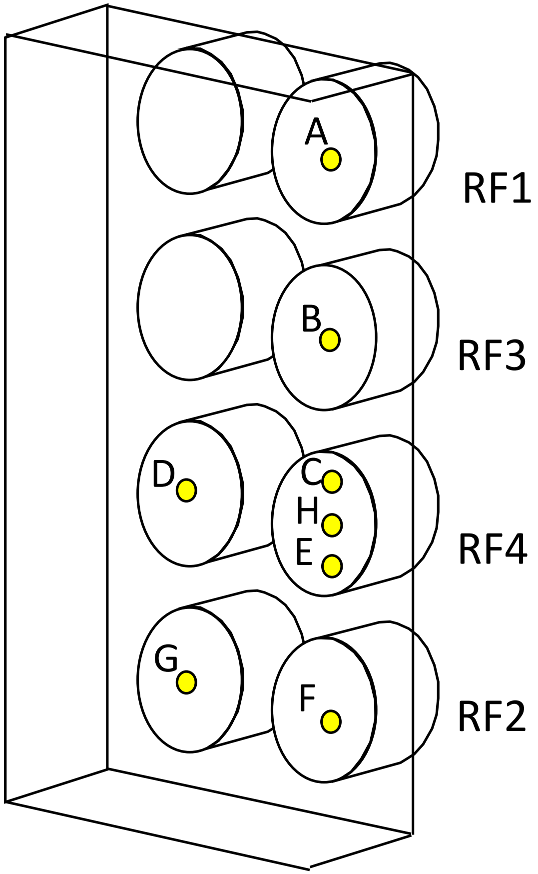
Electrostatic probes & plasma characterization

- Pattern of axially movable probes with respect to drivers
- Probe design improved to withstand thermal gradients



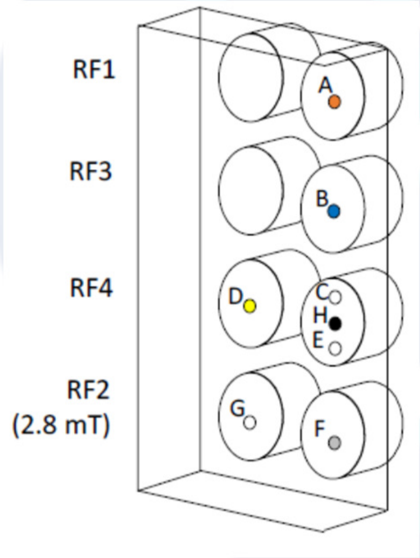


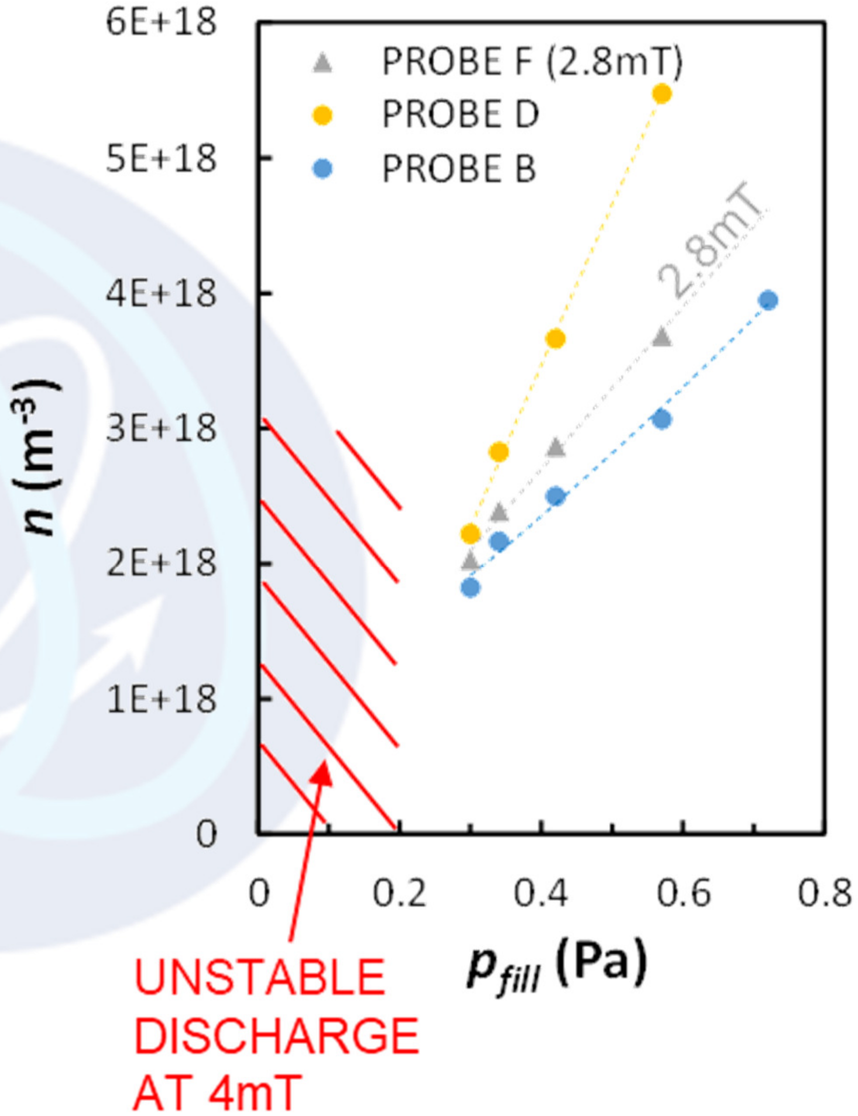




Electron density vs filling pressure

- Electron density quite linear with filling pressure

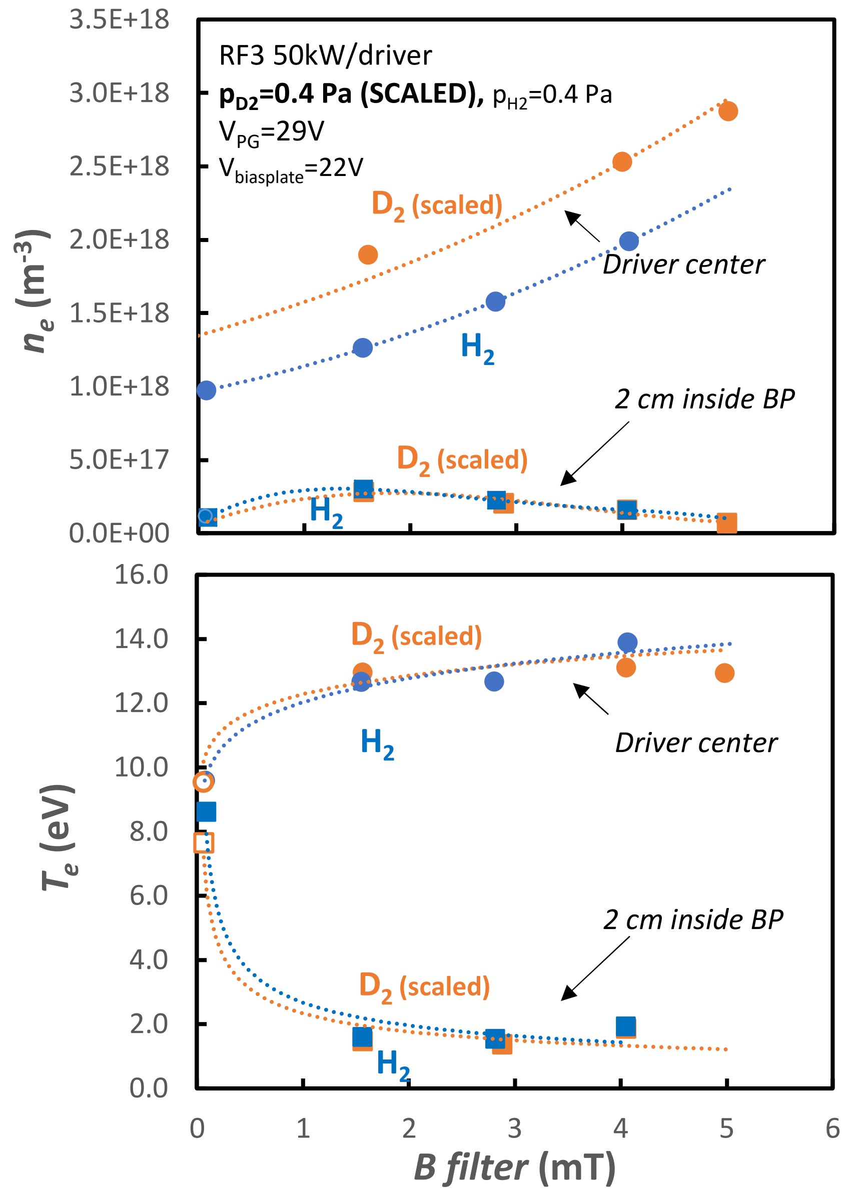




Plasma parameters vs filter field

- Measurements inside driver and in extraction region

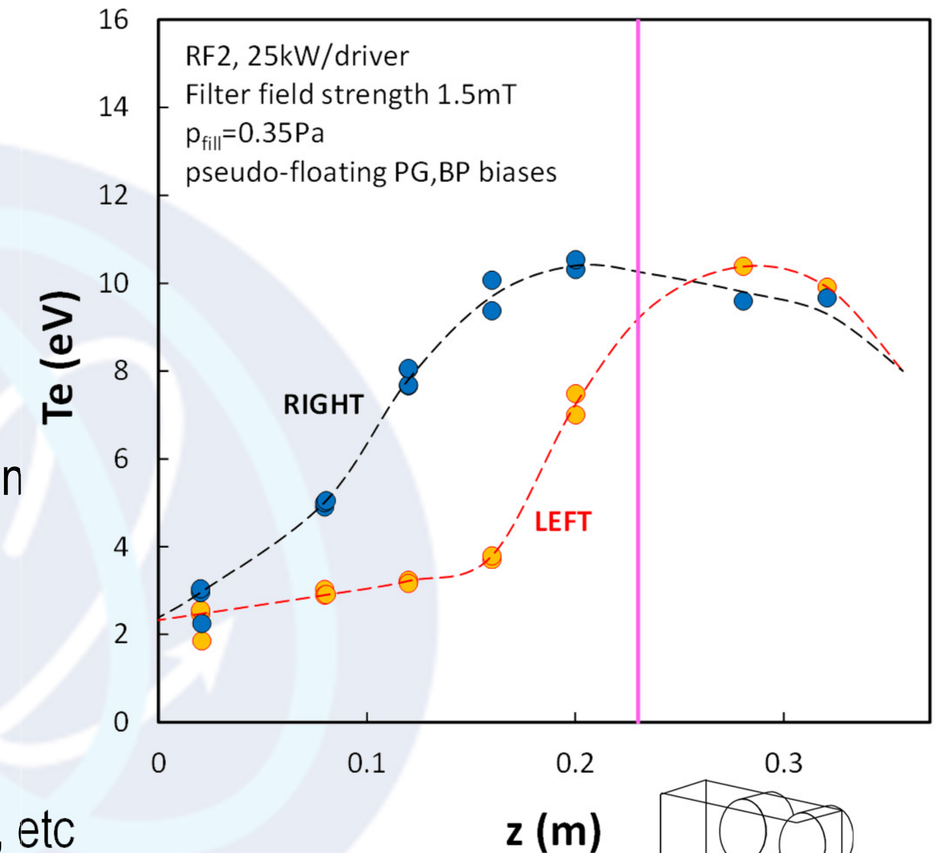
- Filter field scan in D_2 and H_2
  - Electron density increases with filter field in driver and decreases in extraction region
  - Electron temperature decreases with filter field in extraction region
  - Electron density higher in D_2 inside drivers

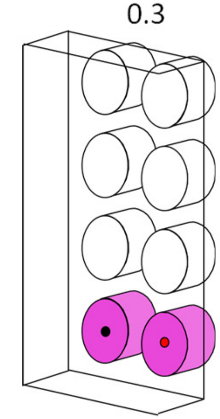


Profile of electron temperature

- Rightmost driver has different behaviour: High T_e in wider region of expansion region (consequently lower ne in driver)

- No qualitative change with pressure, bias, etc

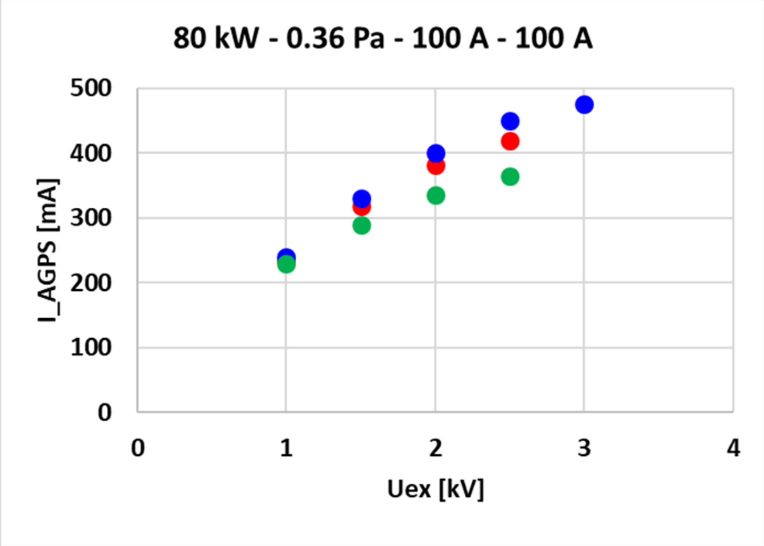


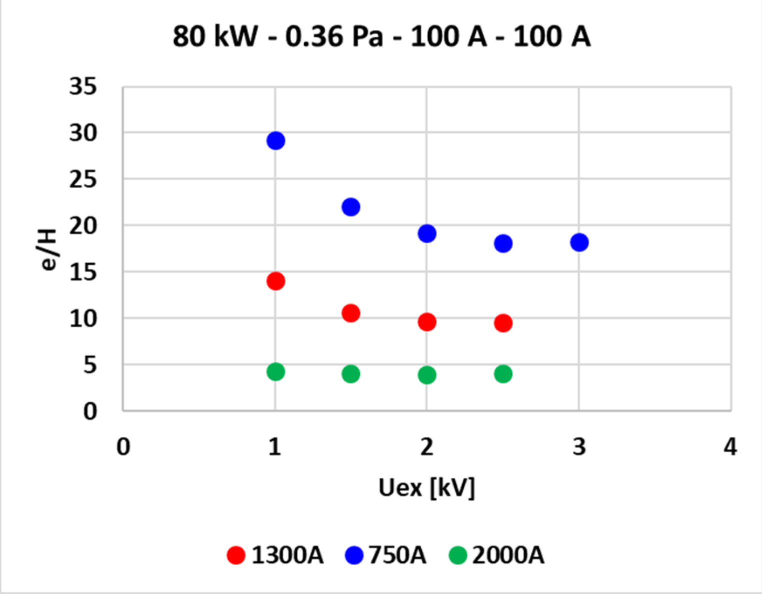


Currents of co-extracted electrons and negative ions

- Currents of co-extracted electrons and negative ions increase with extraction voltage and decrease with magnetic field

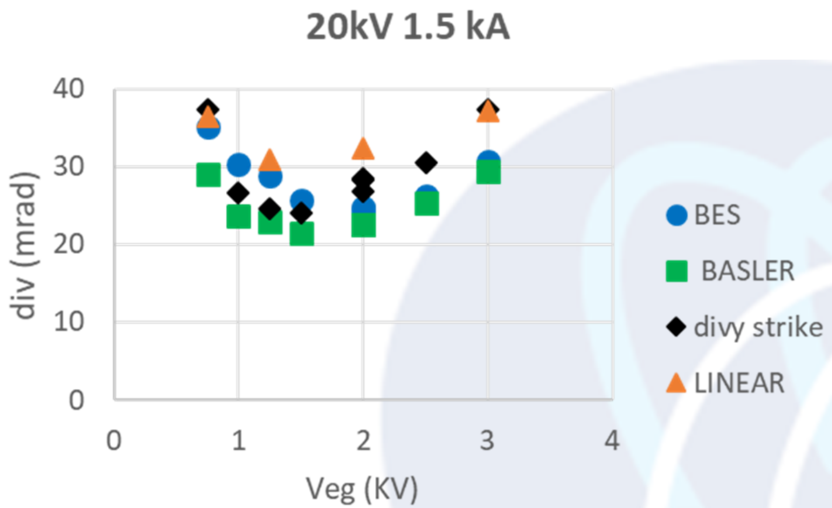
- Current ratio increases at low extraction voltages (beam interception of accelerator grids?)

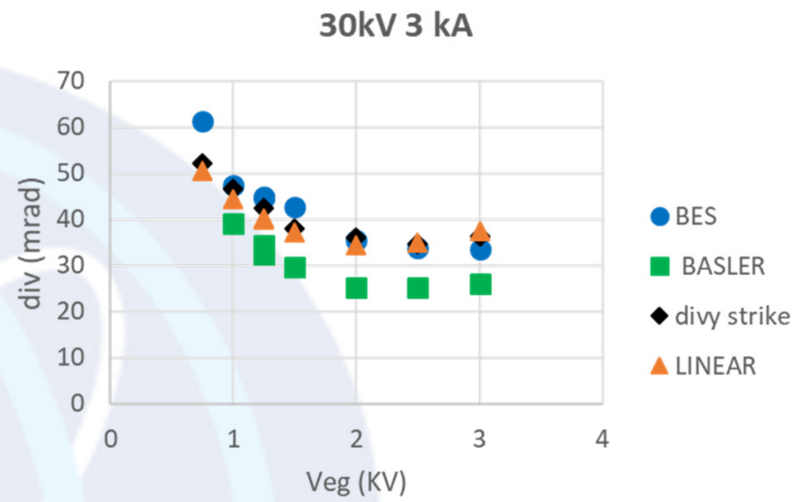


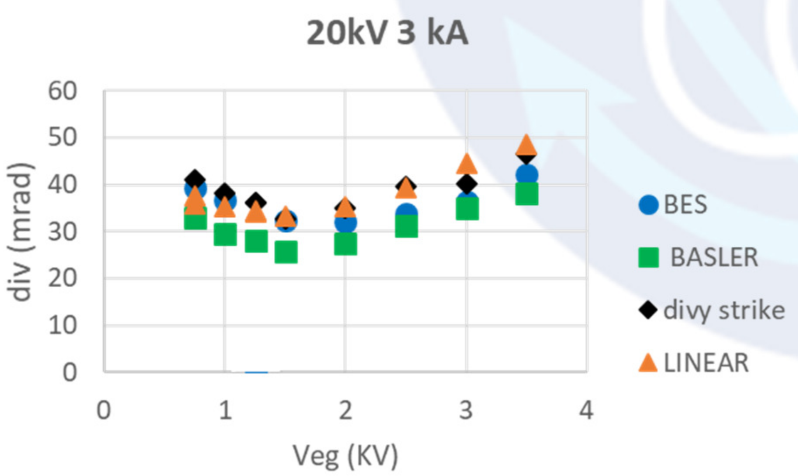


Comparison of divergence measurements

- Values and trends are similar despite different principles of operation

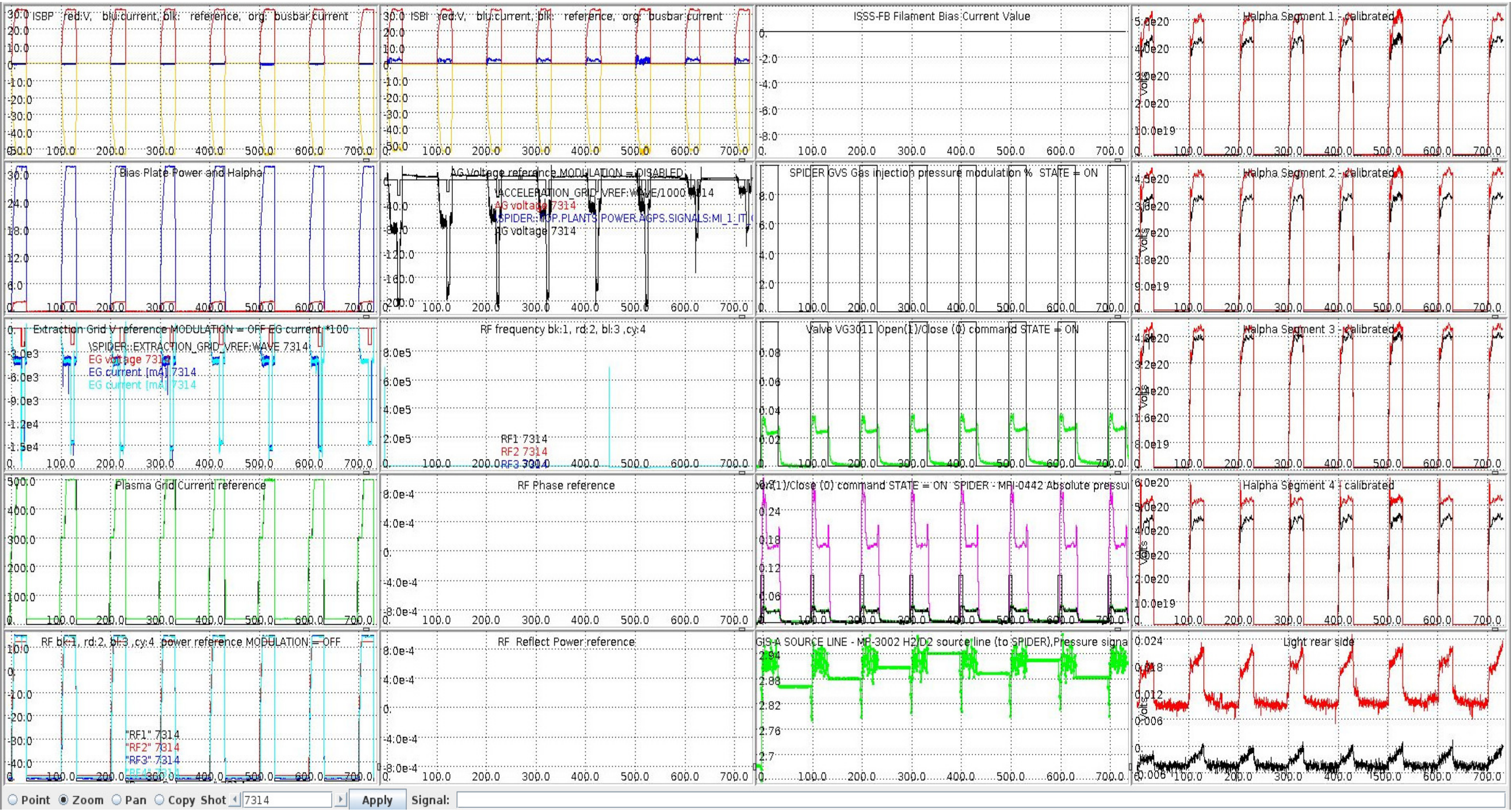






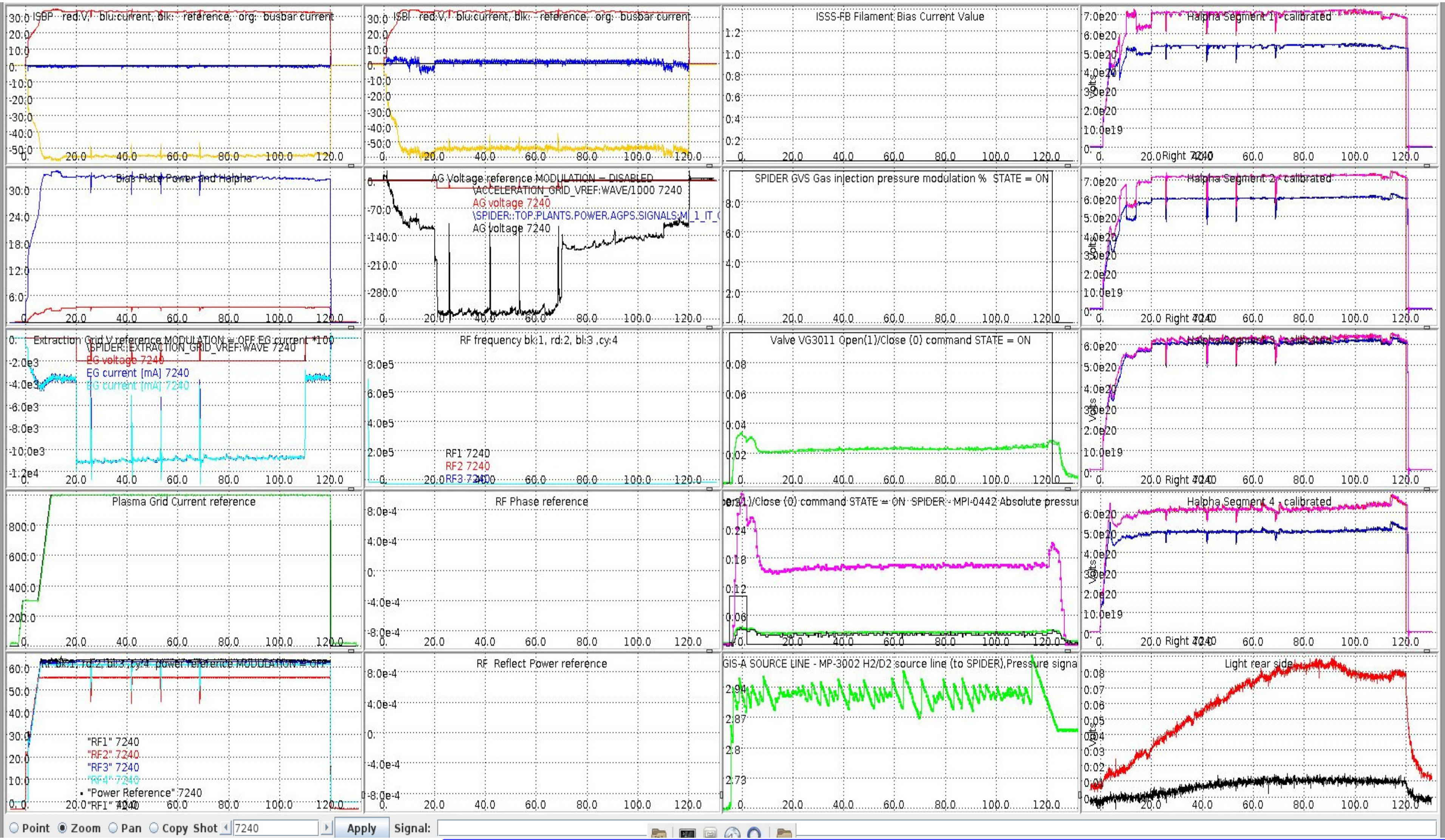
Operation with frequent pulses in view of caesiation

- First tests of short pulses with high duty cycle: 8 consecutive plasma pulses: 30s plasma; 5s acceleration, every 100s



Extension of plasma and beam duration

- 120s with 4×60kW; 70s extraction; 50s acceleration



Outline : strategy for SPIDER improvement

Improvements to address RF driven discharges:

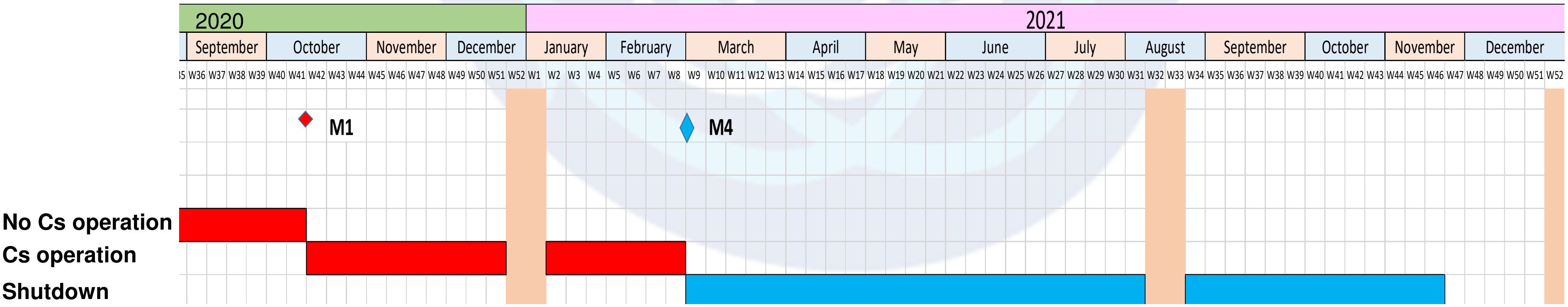
- Driver configuration
- "On-source" RF circuit upgrade
- Vacuum pumping enhancement

Other BS modifications during the shutdown:

- GG4 segment replacement
- GG permanent magnets reversal

Further modifications during the shutdown or earlier:

- AGPS from 30 kV to 100 kV
- RF generators output power and voltage measurement



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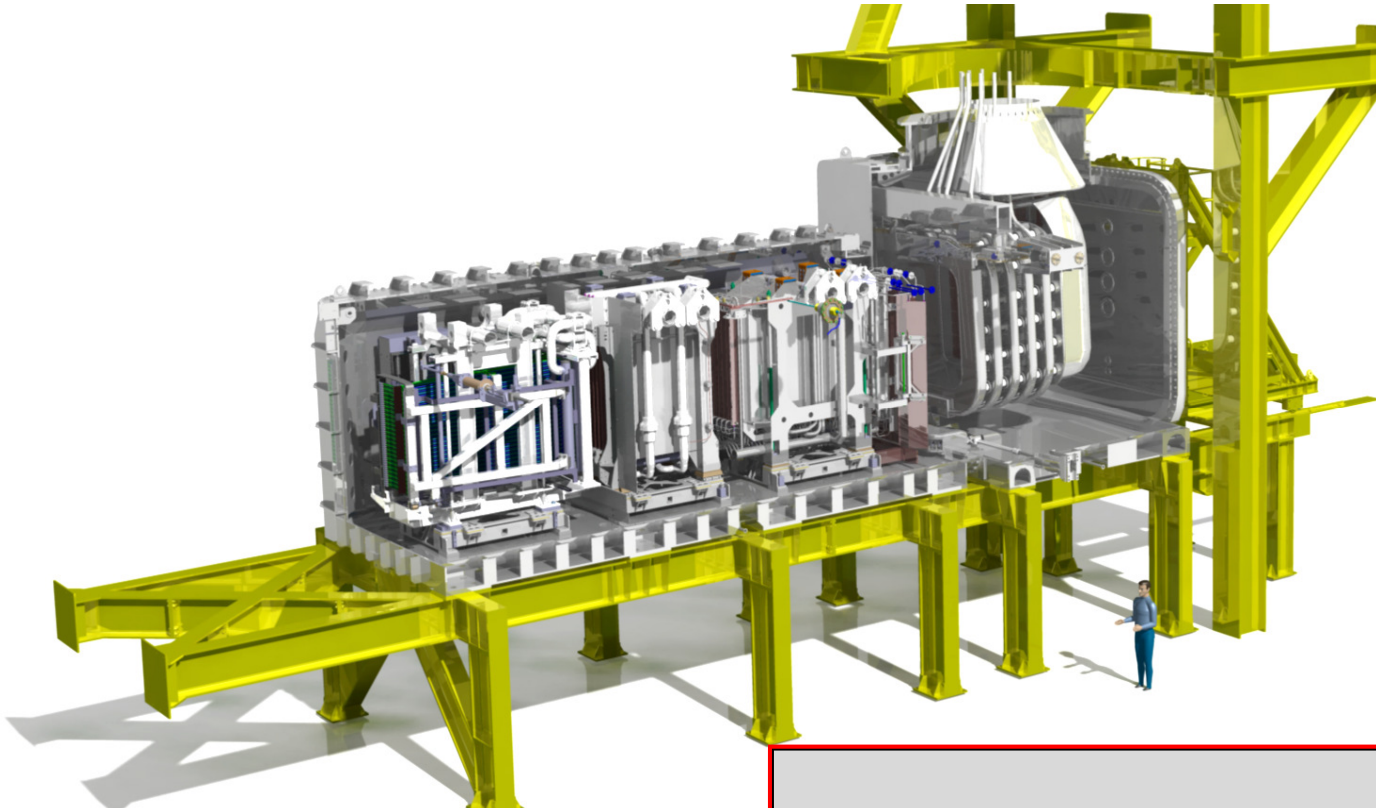
MITICA full scale prototype of ITER HNB



Optimisation of neutral beam in terms of:

- Performances
- Reliability
- Availability

	Unit	H	D
Beam energy	keV	870	1000
Acceleration current	A	46	40
Max Beam Source pressure	Pa	0.3	0.3
Beamlet divergence	mrad	≤7	≤7
Beam on time	s	3600	3600
Co-extracted electron fraction (e^-/H^-) and (e^-/D^-)		<0.5	<1

MITICA Power Supplies

The insulation tests performed in successive steps, adding each part of the system. The process lasted 1.5 years. The overall insulating tests were completed up to 1.2MV for one hour in Nov 2019.

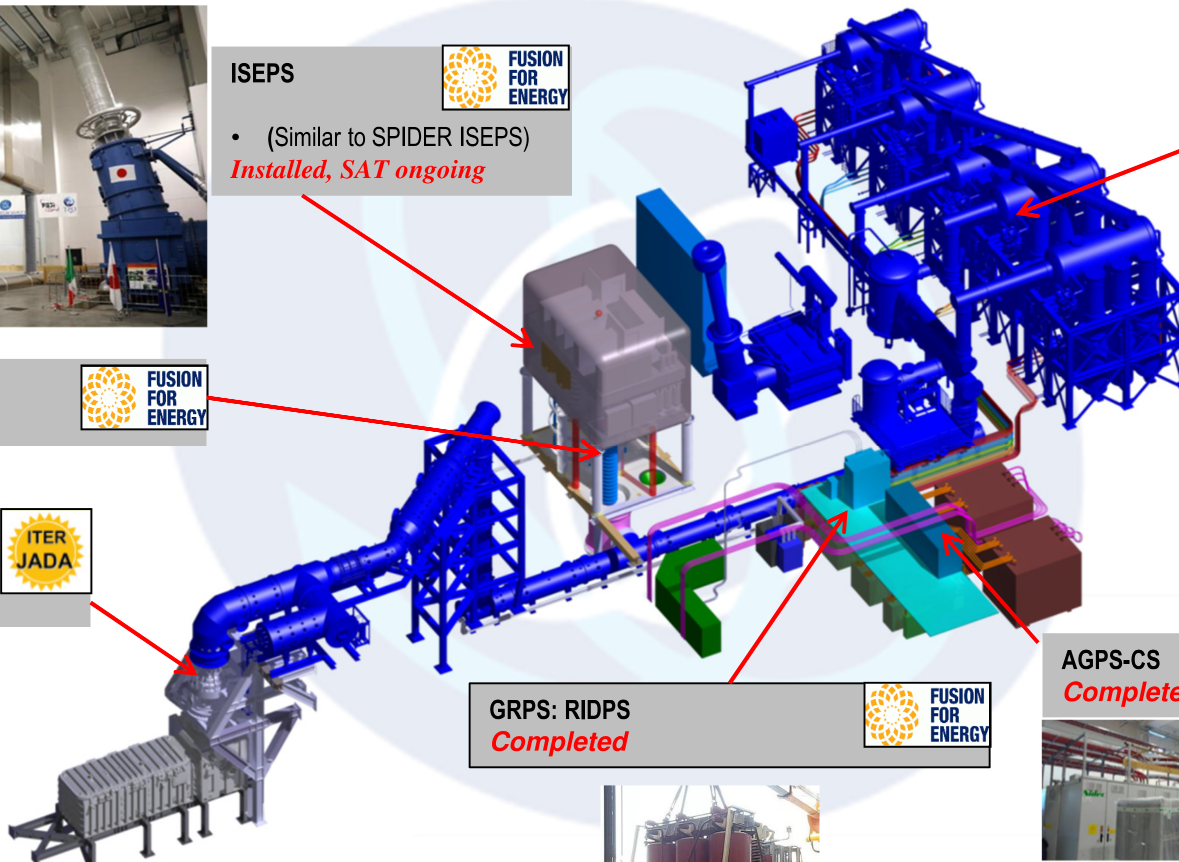
ISEPS (FUSION FOR ENERGY)

- (Similar to SPIDER ISEPS)

Installed, SAT ongoing

JADA components (ITER JADA)

Integrated power TESTING ongoing



HVD1 & 1MV air/SF6 Bushing (FUSION FOR ENERGY)

Completed

HV Bushing (ITER JADA)

Completed

AGPS-CS (FUSION FOR ENERGY)

Completed

GRPS: RIDPS (FUSION FOR ENERGY)

Completed

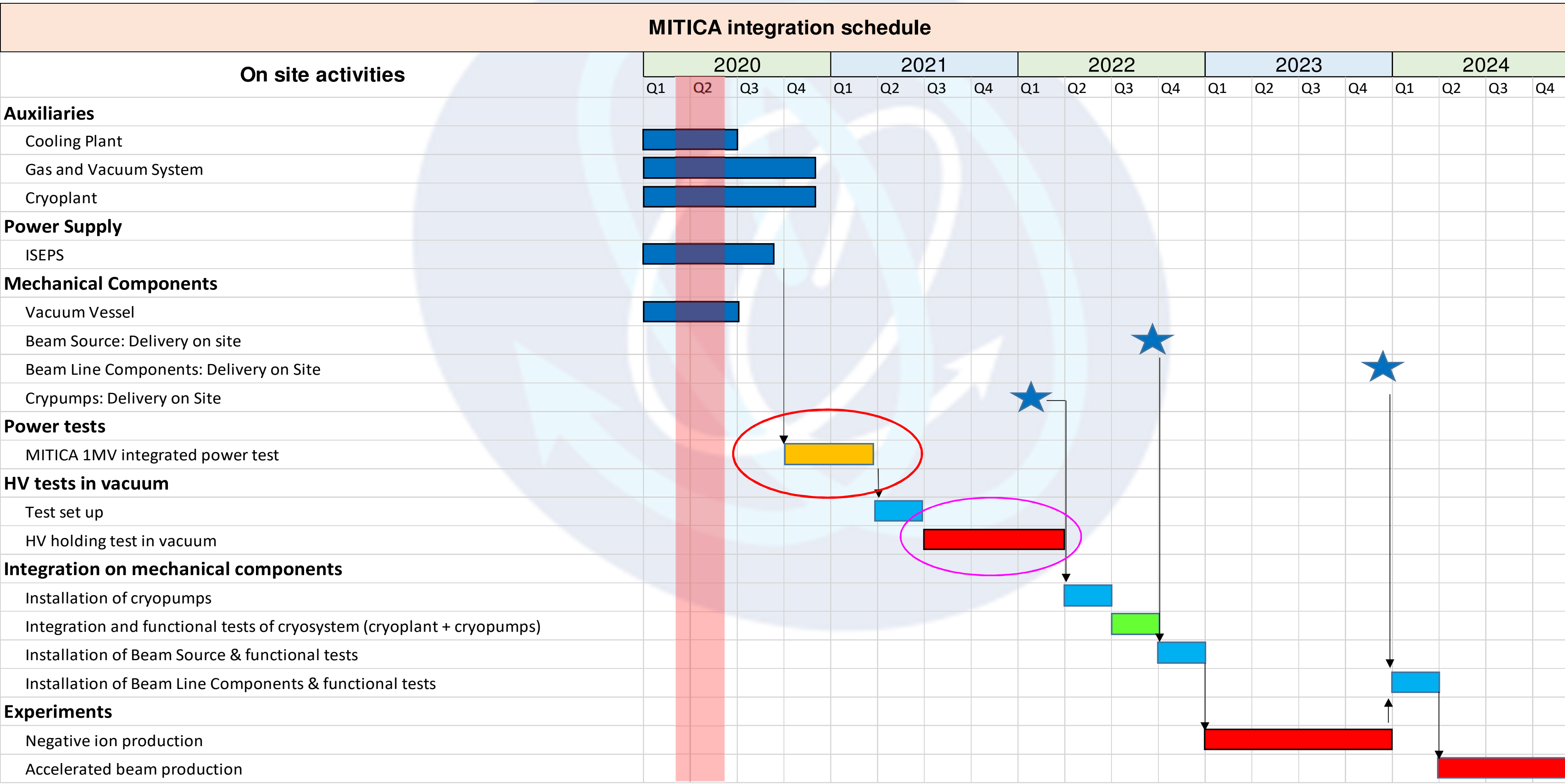
SF6 Gas Handling and Storage Plant (FUSION FOR ENERGY)

Completed

RIDPS

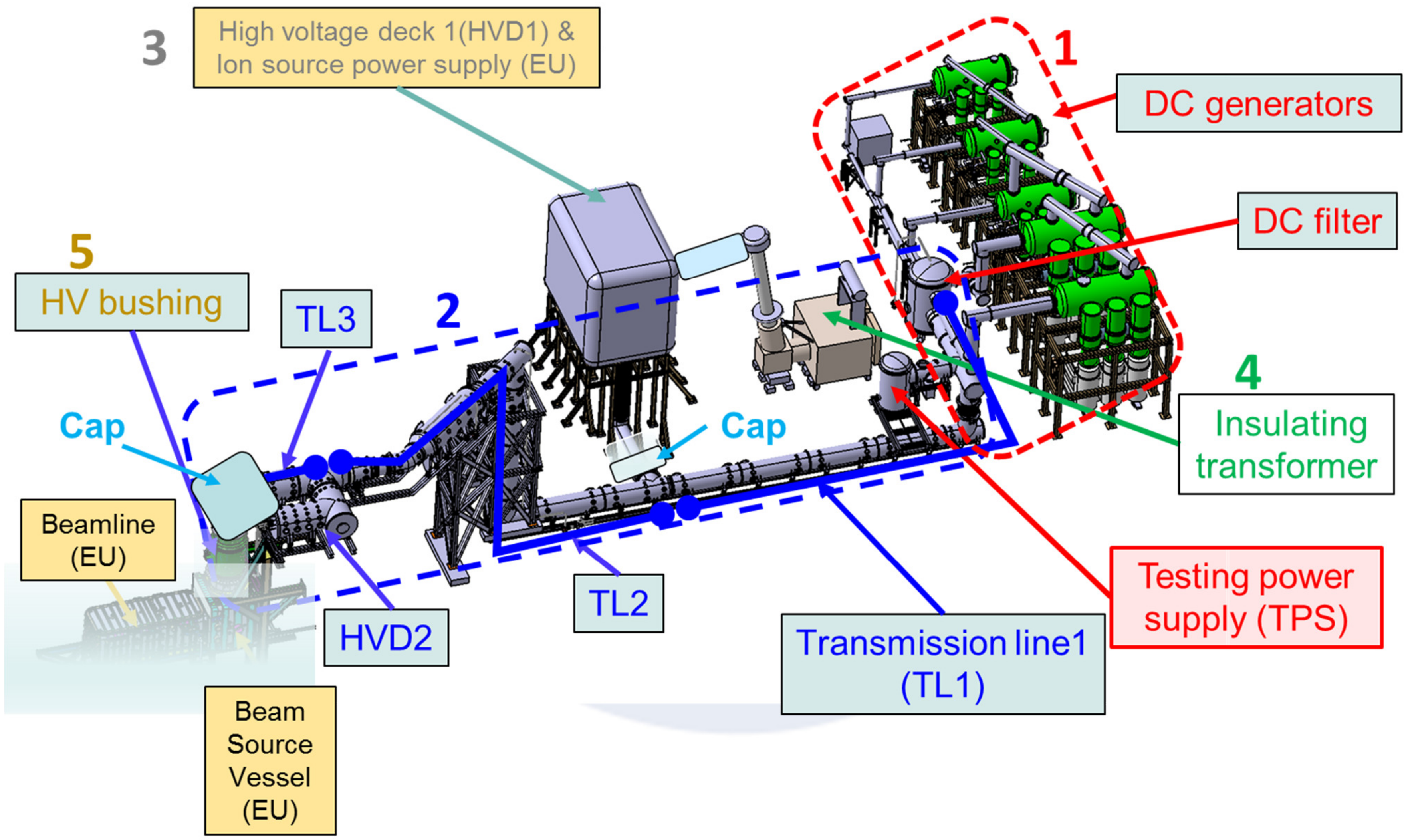
MITICA construction schedule

- The reference schedule of MITICA, before the Covd-19 event, provided for carrying out power integrated tests in Q2-Q3 2020
- Covid-19 affects MITICA schedule: slowdown and interruption of activities in Q1-Q2; non-availability of experts of laboratories and industries from other countries



MITICA Power Supplies – integrated tests

Now power integrated tests on dummy loads (1MV, 50MW, 2s) are under preparation



Optimizing the MITICA schedule

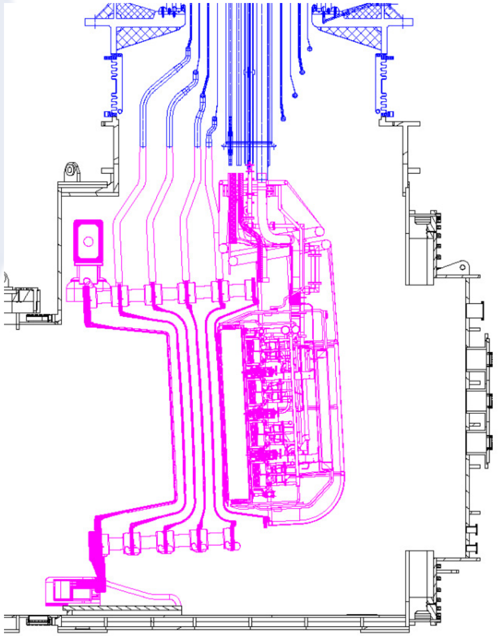
After completion of power supply integrated tests and waiting for arrival of in-vessel components… (BS in particular!)

HV test in vacuum - objectives:

1. verify and improve the insulation of MITICA up to 1 MV in vacuum and low pressure gas, before the installation of the Beam Source
2. establish Voltage Holding scaling laws for large gaps and multiple electrodes

HV Test guidelines:

1. in high vacuum (5 10^{-5} Pa)
2. up to 1 MV, with minimum number of Intermediate electrostatic shields (ref config vs QST exp)
3. intermediate electrostatic shields with apertures for gas conductance
4. a realistic geometry for all the electrodes

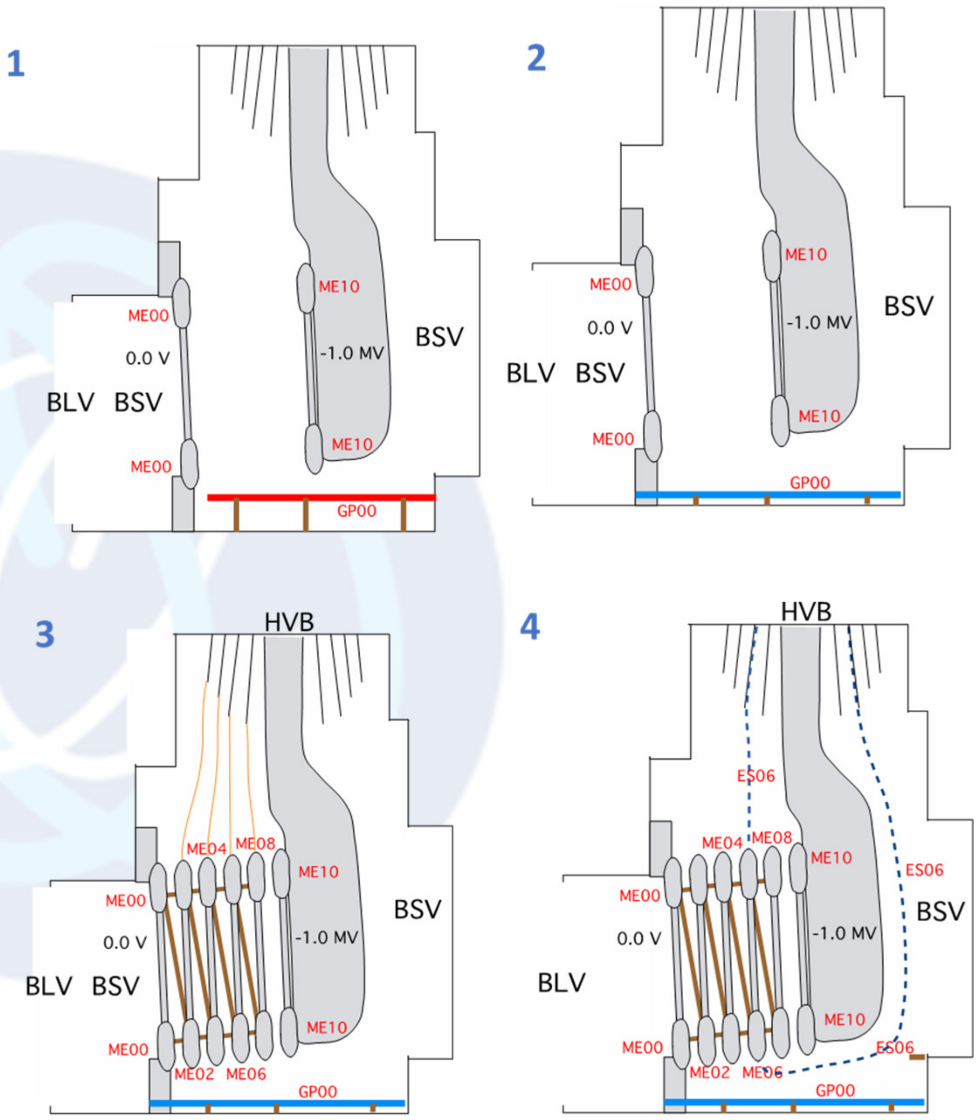


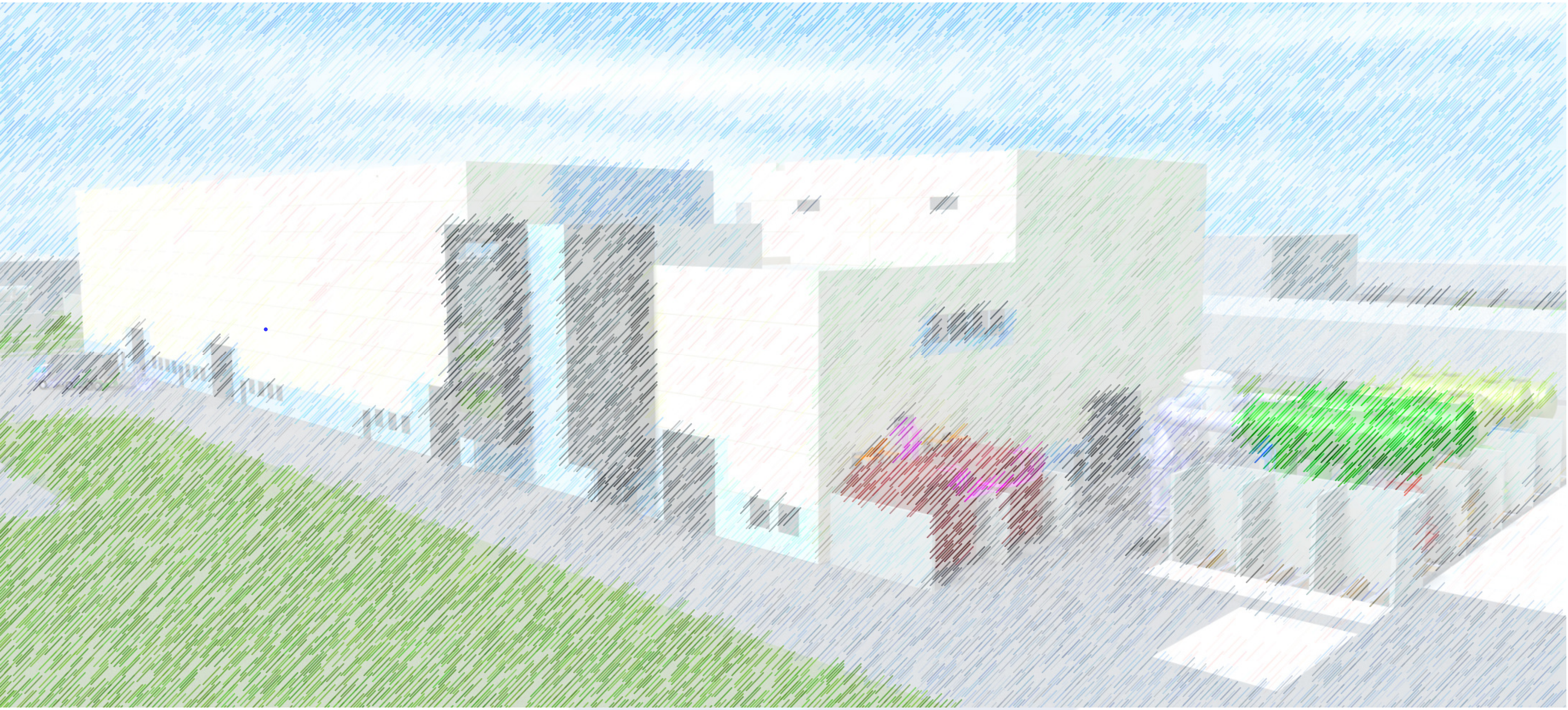
MITICA HV tests in vacuum

features:

- staged approach: start from simple configuration
- surface/size and all details of the electrostatic configuration are as representative of real BS as possible
- lightweight structures, also for reduced manufacturing cost/time
- intermediate electrostatic shield at -600, shape "identical" to reference one

- **Staged approach also for design/procurement**
- **Design of stage 1-2 ongoing**





Thanks for your attention