Status of the ITER Neutral Beam Test Facility and the first beam operations with the full-size prototype ion source

G. Serianni on behalf of NBTF team and

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

Consorzio RFX, Padova, Italy

Reliability of electrodeposited components for fusion application: A process evaluation of the first kind

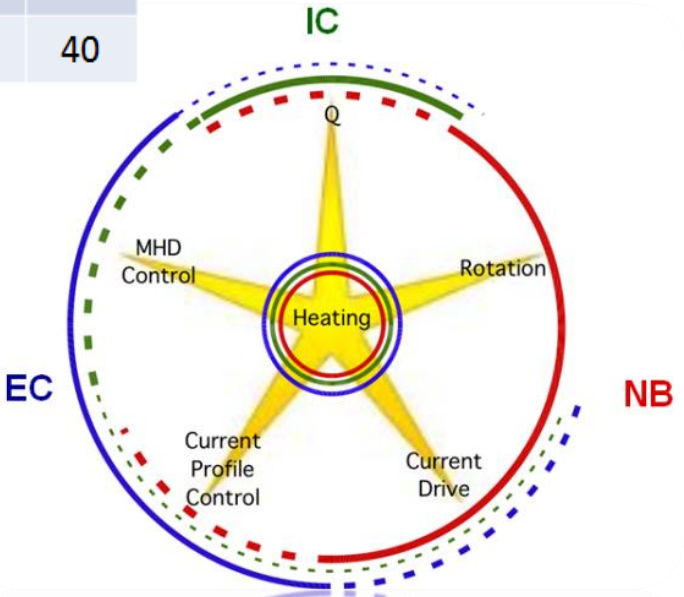
J. Joshi

Institute for Plasma Research (IPR), Gandhinagar, India

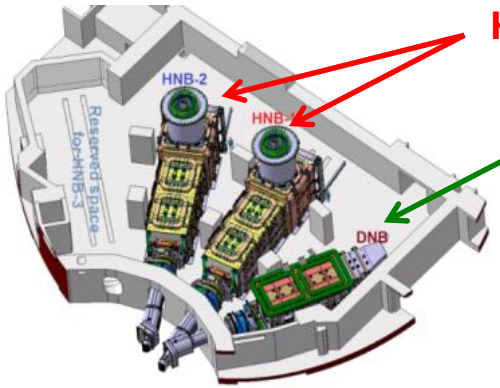
Heating systems at ITER - summary

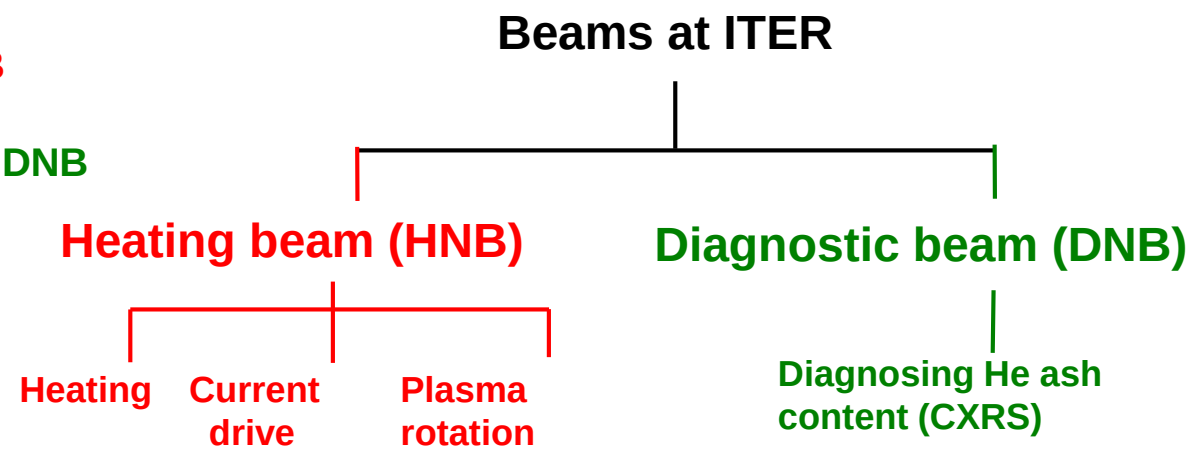
ITER operational phase	Time line	Power requirement (MW)			
		NB	EC	IC	LH
First plasma	2025		6.7		
Pre fusion power op. 1	2028 – 2030 (mid)		20		
Pre fusion power op. 2	2032 (end) – 2034 (FQ)	33	20	20	
Fusion power op (DT)	2036 onwards	33	20	20	
Upgrade potential		50	40	40	40

EC system	IC system	NBI system
170 GHz	40-55 MHz	870 keV H^0, 1 MeV D^0
NTM, ST control, $j(\rho)$ control, EC-assisted startup	High fusion gain, ST control, wall cleaning	Bulk current drive, plasma rotation, plasma heating
24 gyrotrons (24 x 0.8 MW)	2 antennas (2 x 10 MW)	2 injectors (2 x 16.5 MW)



Neutral Beams at ITER: overview of requirements





Parameter	HNB		DNB
Phase	HH/HHe	DD/DT	HH/HHe/DD/DT
Species	H	D	H
Injected neutral beam power [MW]	16.5	16.5	2
Beam energy [keV]	870	1000	100
Accelerated current [A]	46	40	60
Beam uniformity [%]	>90	>90	>90
Acceptable beamlet divergence [mrad]	3÷7	3÷7	3÷7
Pulse length [s]	1000	3600	5Hz; 3s ON /20s OFF

Worldwide effort towards ITER NBI

IPP test facilities ELISE & BUG

Achievements:

H: > 90% in long & short pulses

D: > 90% in short pulses
> 65% in long pulses

Wünderlich, Poster session P7

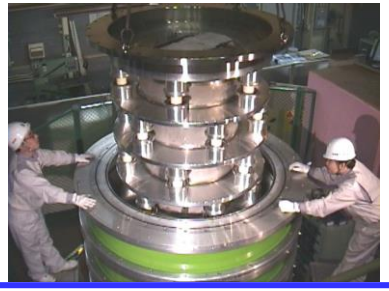
QST

R&D of high energy & long pulse beam acceleration for ITER and JT-60SA

970keV, 190A/m2, 60s; 500keV, 154A/m2, 118s

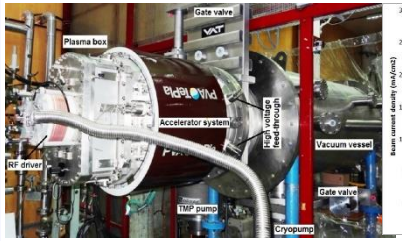
FEC 2016 Kashiwagi, session TECH/3

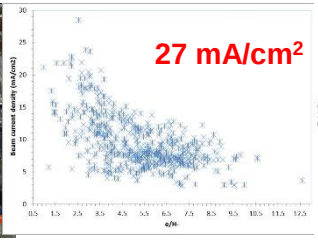
R&D accelerator for ITER

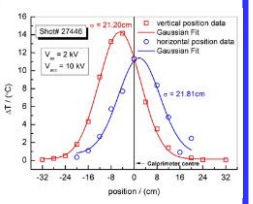


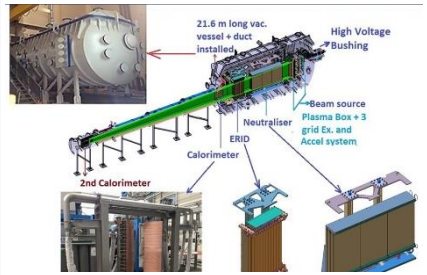
JT-60SA beam source

IPR: ROBIN, TWIN; INTF





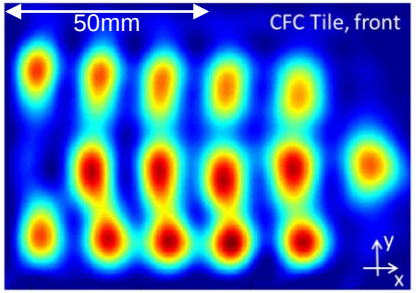




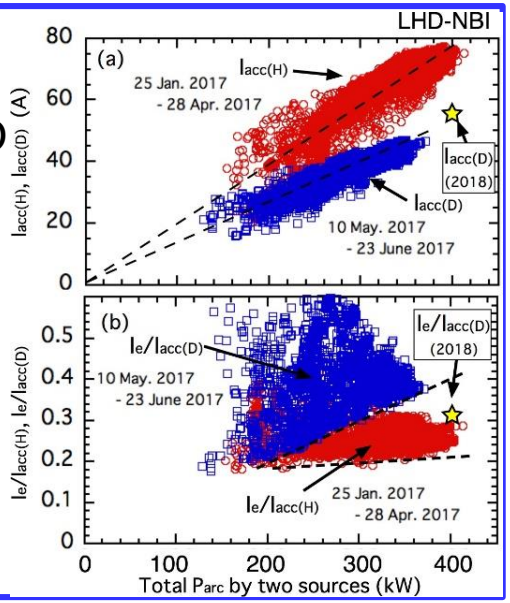
INTF: DNB prototype beam line with ~22 m beam transport path length

NIFS

NBI heating of LHD



Tsumori, session TECH/3



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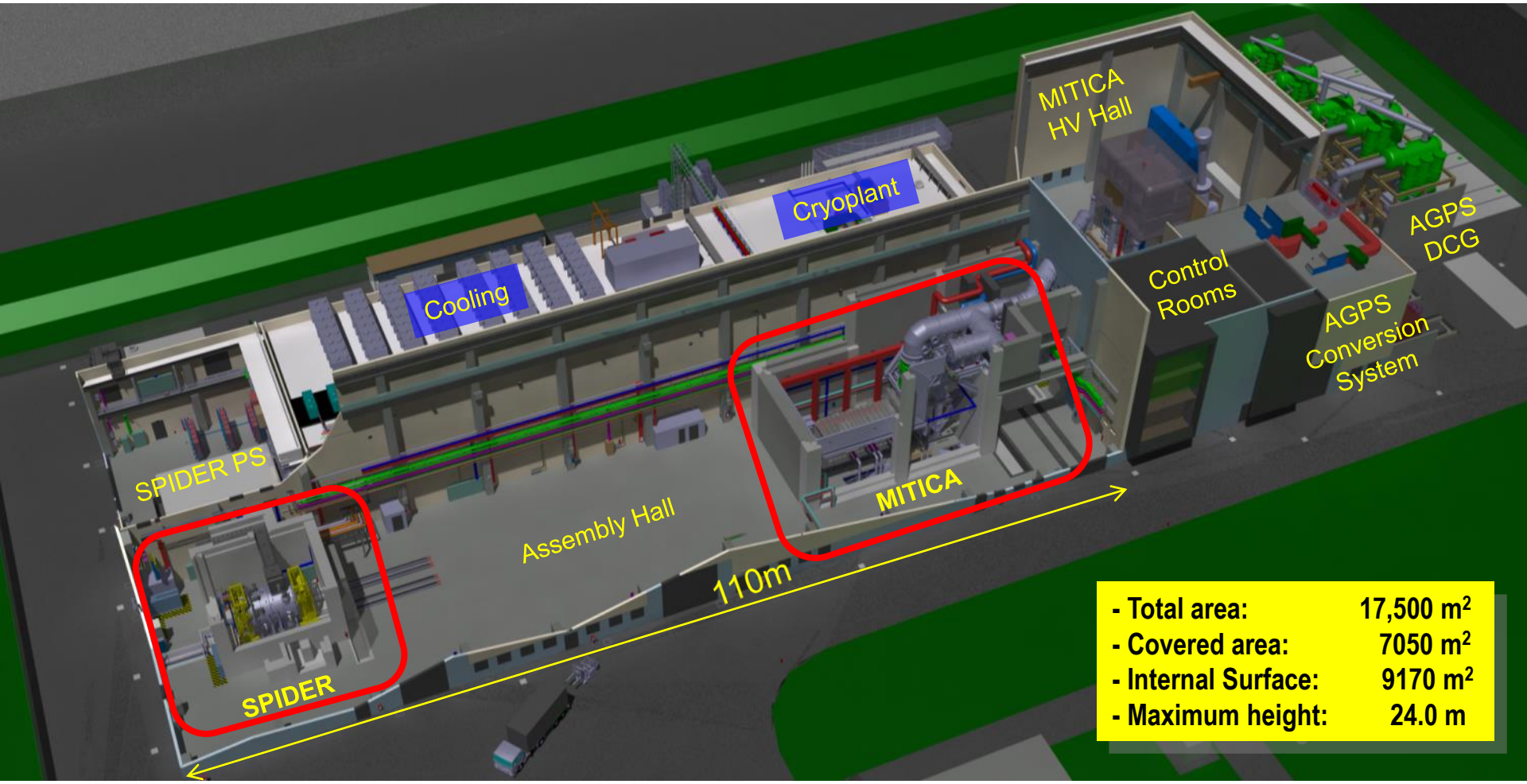
The Neutral Beam Test Facility



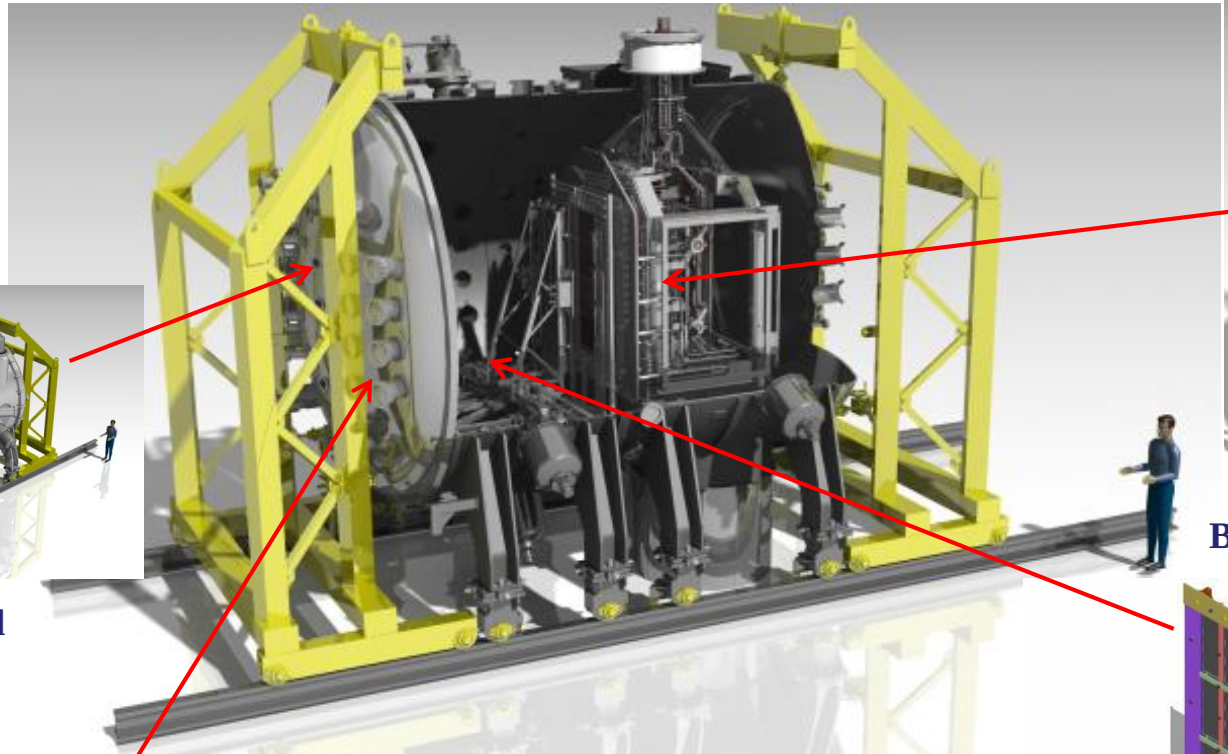
NBTF hosts the two experiments: the negative ion source **SPIDER** and the 1:1 prototype of the ITER injector **MITICA**

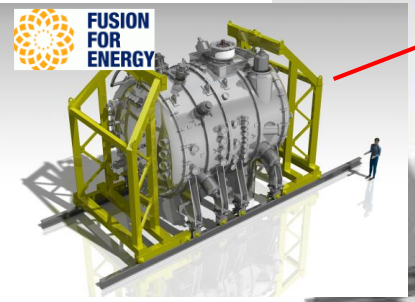
Each experiment is inside a concrete biological shield against radiation and neutrons produced by the injectors

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

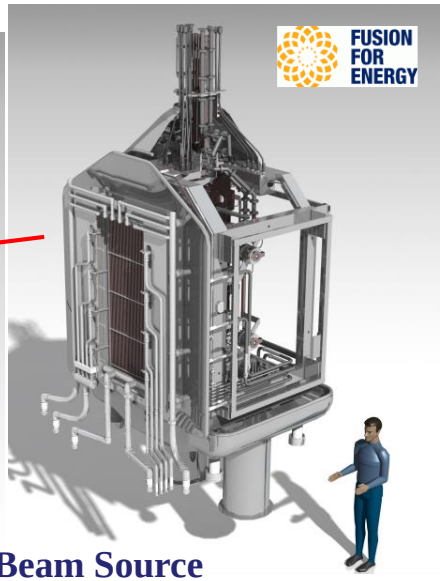
SPIDER mechanical components

Vacuum-insulated beam source

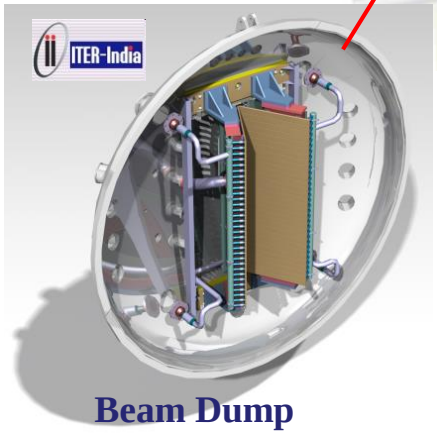




Vacuum Vessel

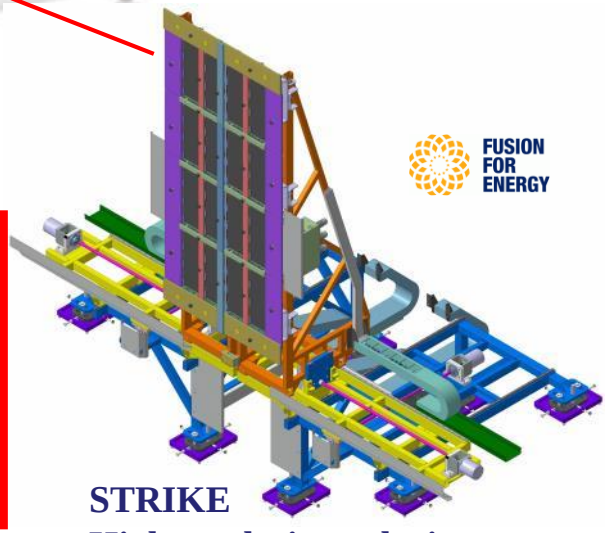


Beam Source



Beam Dump

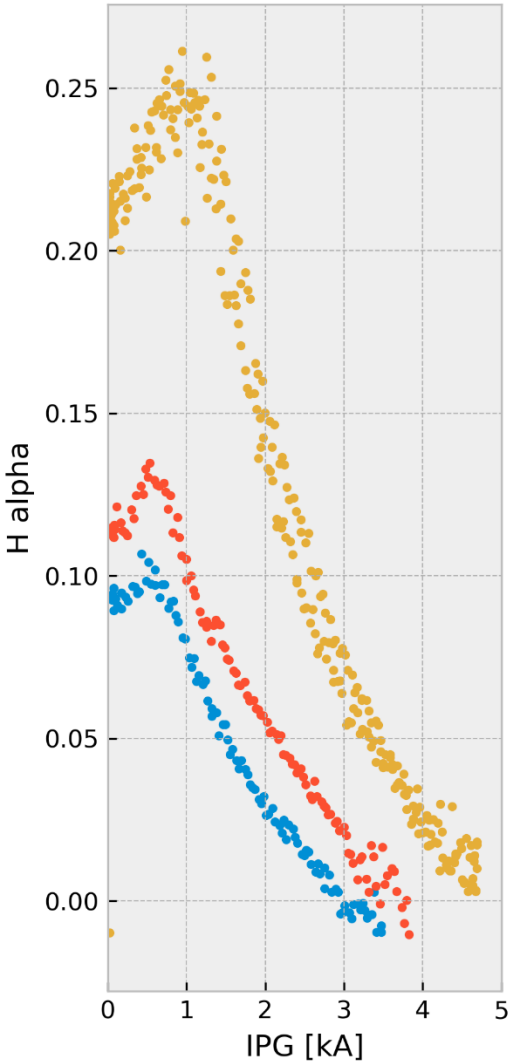
	Unit	H	D
Beam energy	keV	100	100
Maximum Beam Source pressure	Pa	<0.3	<0.3
Uniformity	%	±10	±10
Extracted current density	A/m²	>355	>285
Beam on time	s	1000	3600
Co-extracted electron fraction (e^-/H^-) and (e^-/D^-)		<0.5	<1



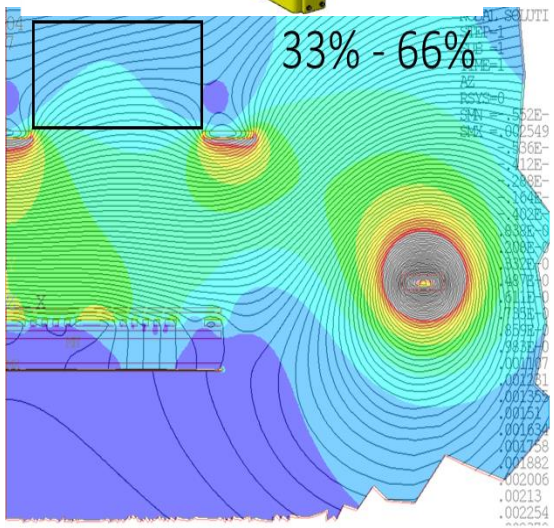
STRIKE
High resolution calorimeter

Effect of magnetic filter field

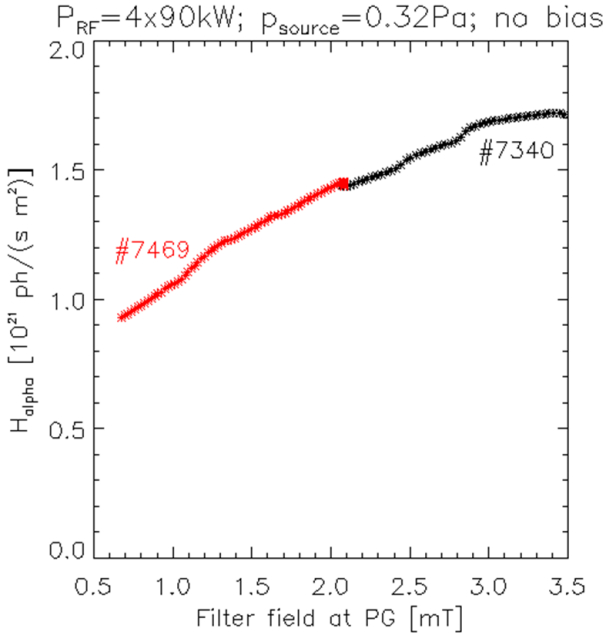
- Quenching of plasma with increasing filter field

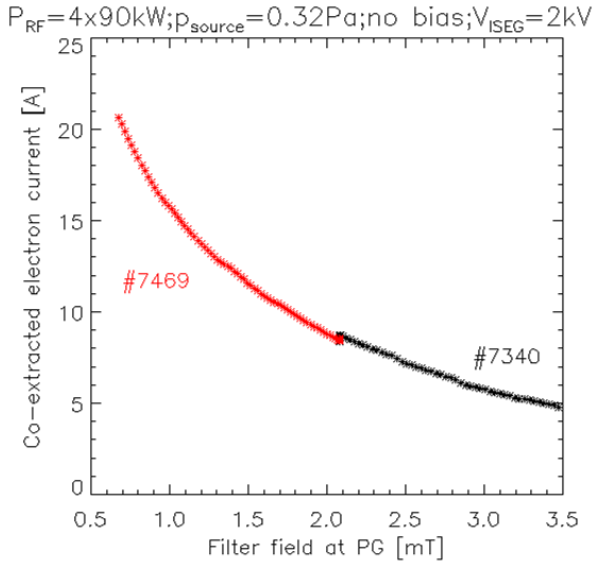


Improved magnetic filter field



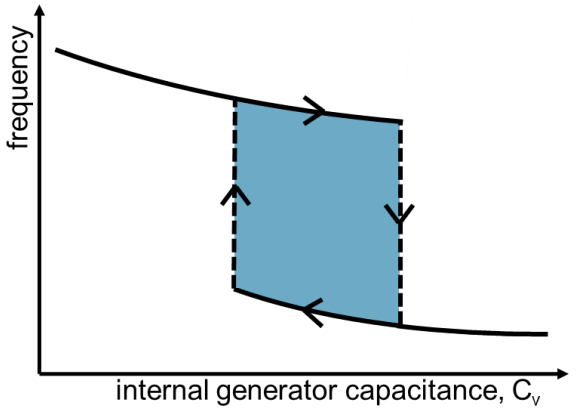
- H_{alpha} signal in drivers increases with magnetic filter field
- Co-extracted electron current slightly decreases with magnetic filter field
- Beam current is almost unaffected



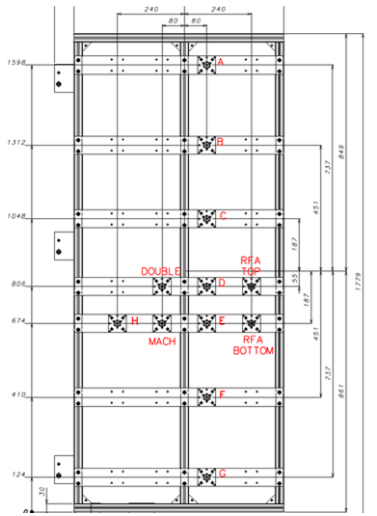


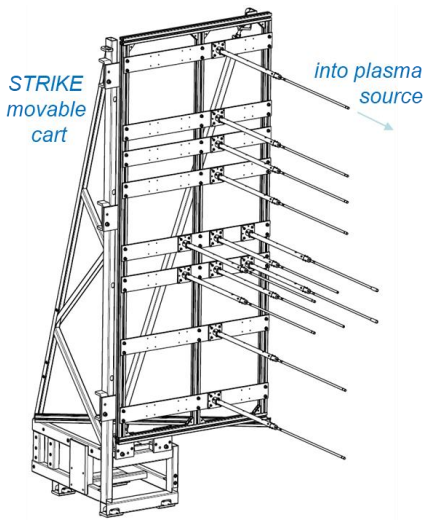
SPIDER RF system

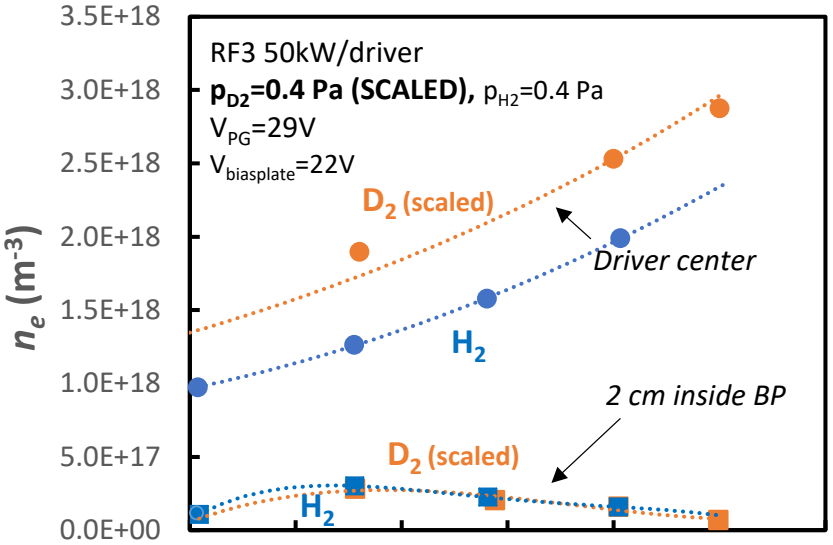
- SPIDER RF generators:
  - pair of power tetrodes in push-pull connection; variable capacitor C_v to tune operating frequency
- RF power limit identified:
  - power transfer depending on equivalent load impedance
  - sudden frequency flips near impedance matching
    - RF power constrained, as observed in other facilities
- Short term strategy:
  - feedforward control of C_v capacitor
  - development of model reproducing different behaviours of RF generator to:
    - support SPIDER operation and analyse its performances
    - help in achieving nominal performances
  - experimental investigation of different matching network parameters
- Longer term strategy: replacement of tetrode-based oscillators with solid-state amplifiers

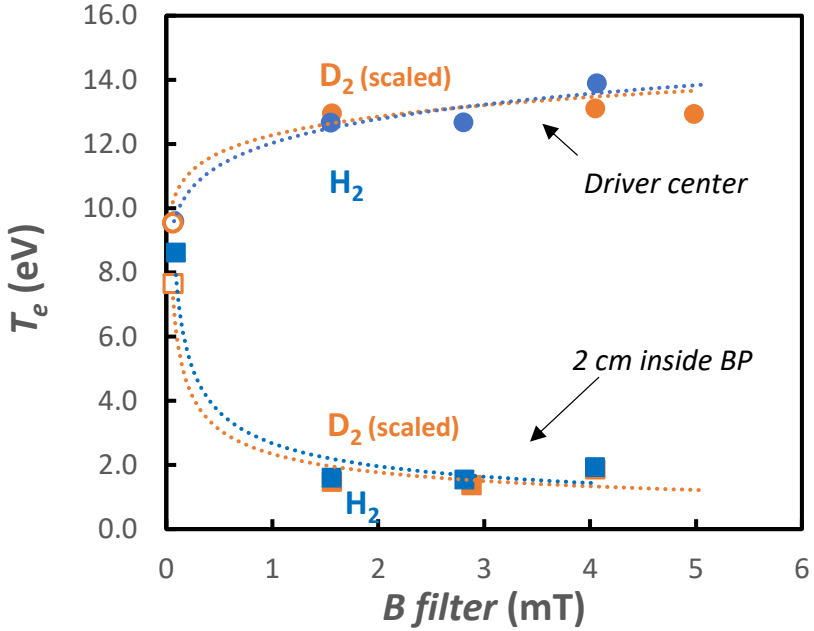


Source characterisation





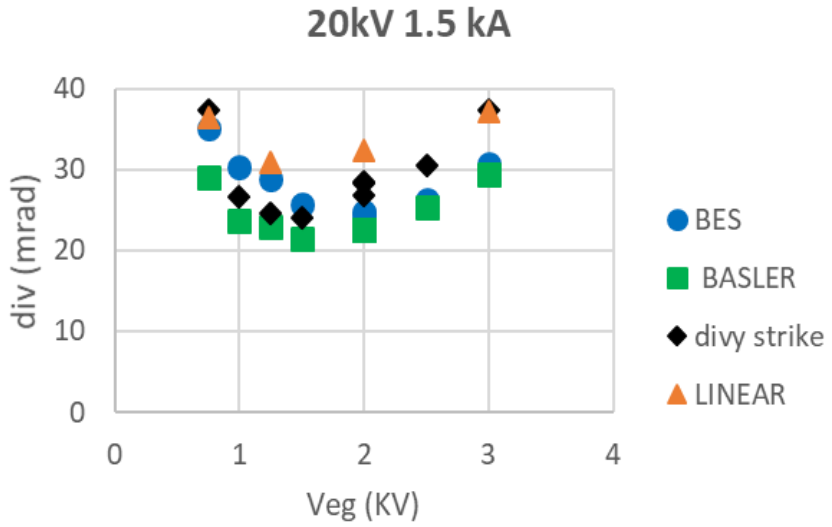




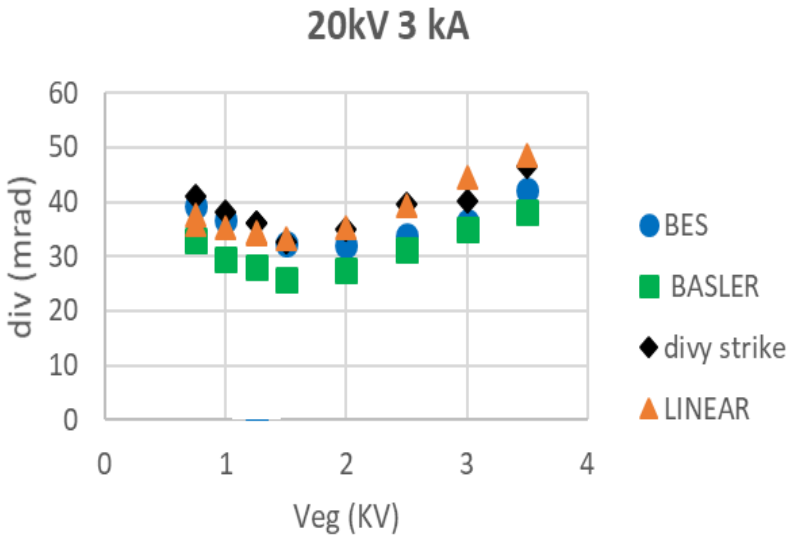
- Measurements inside driver and in extraction region
- Filter field scan in D_2 and H_2
  - Electron density increases with filter field in driver and decreases in extraction region
  - Electron temperature decreases with filter field in extraction region
  - Electron density higher in D_2 inside drivers

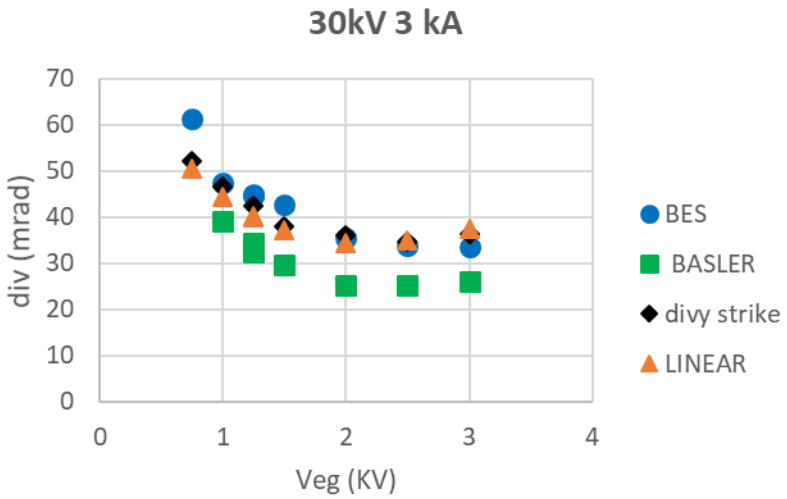
Comparison of divergence measurements

- Values and trends are similar despite different principles of operation

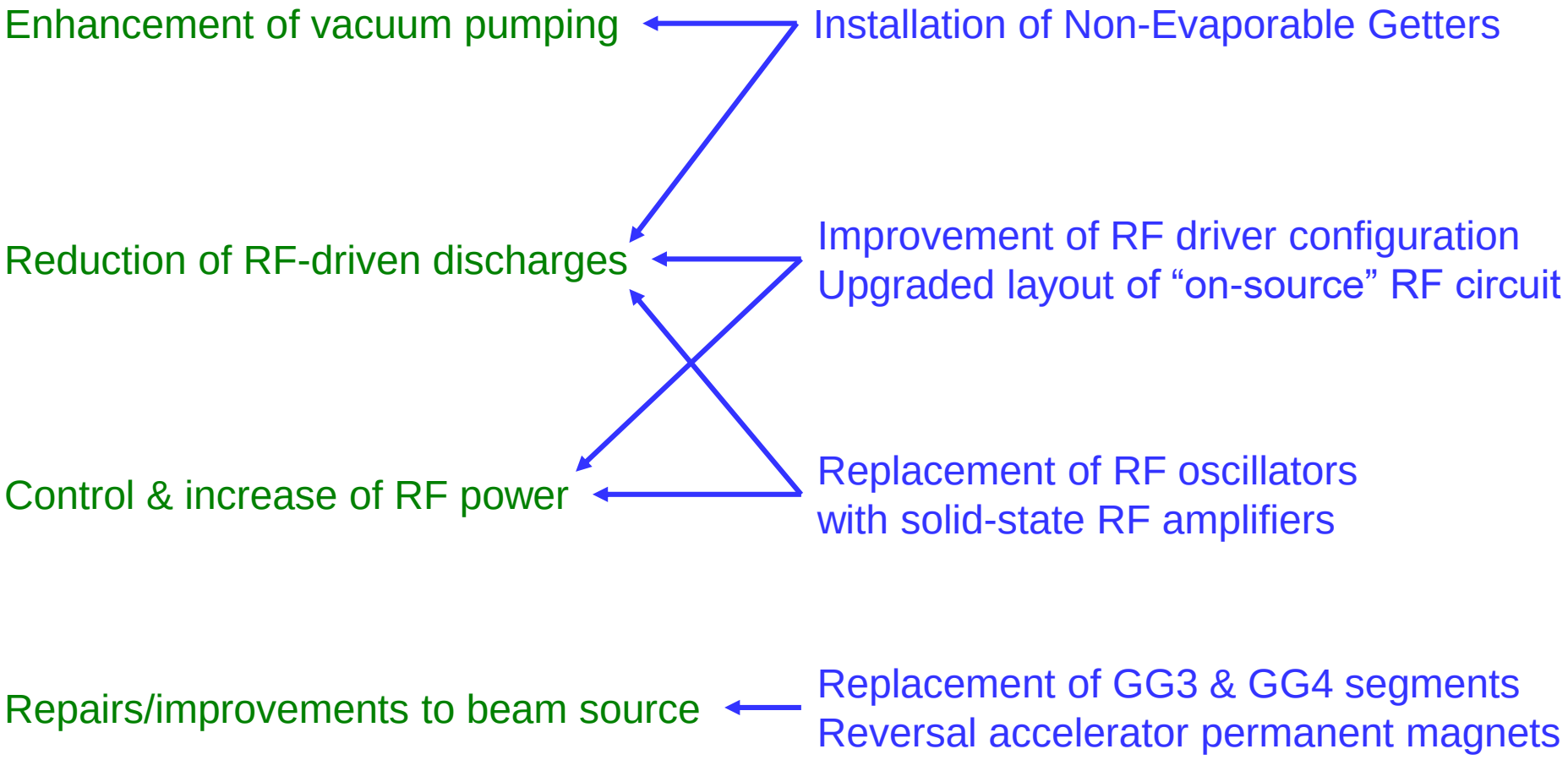


- Divergence increases with magnetic filter field
- Optimal voltage ratio ~10





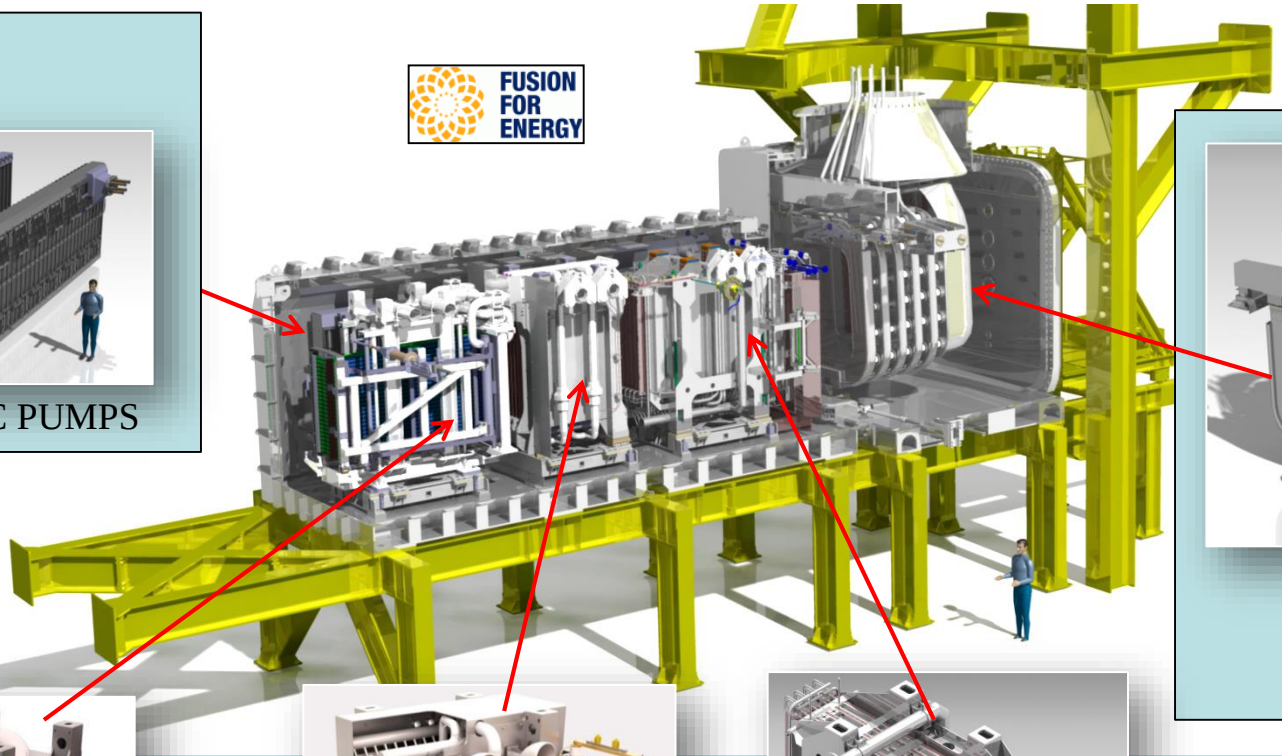
Improvement of main SPIDER plants During major shutdown from mid-2021

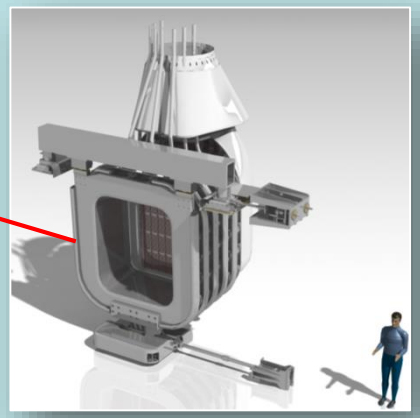


MITICA in-vessel components

OPE-307

CRYOGENIC PUMPS



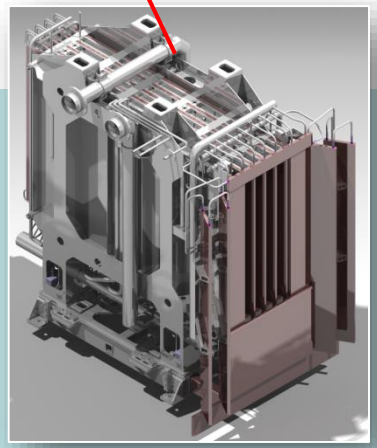


BEAM SOURCE

OMF-605

CALORIMETER

RESIDUAL ION DUMP



NEUTRALIZER

OMF-795

MITICA Power Supplies

1MV Faraday Cage
(hosting Ion Source PSs)

1MV Insulating Transformer

1MV AGPS-DC Generator

HV Bushing

Vacuum Vessel

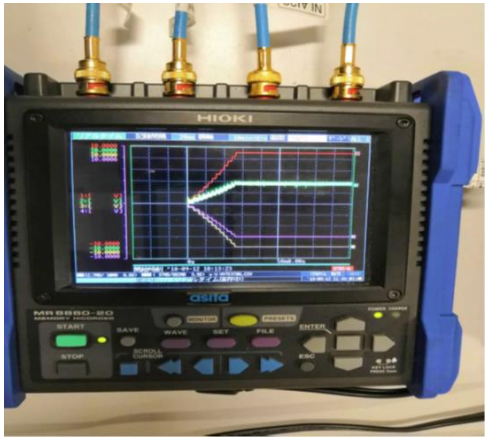
≈ 100m

HV Transmission Line

RIDPS

AGPS Conversion system 60MW CW

AGPS-DCG insulating tests

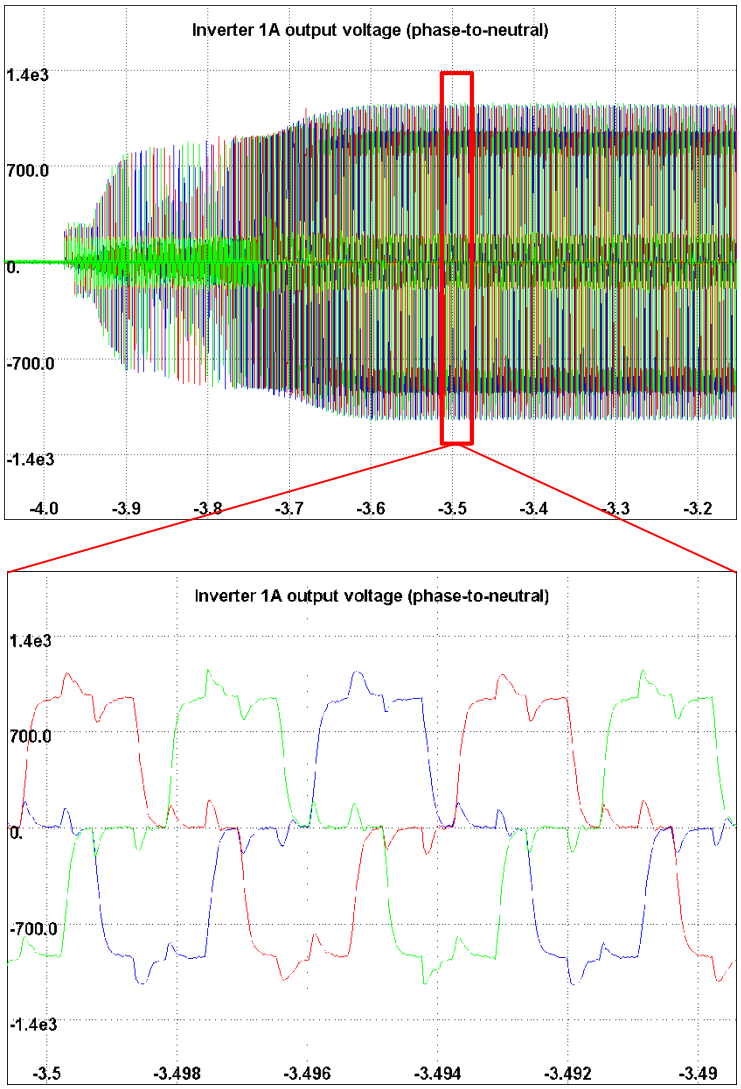


1st STEP 1200kV-1 HOUR

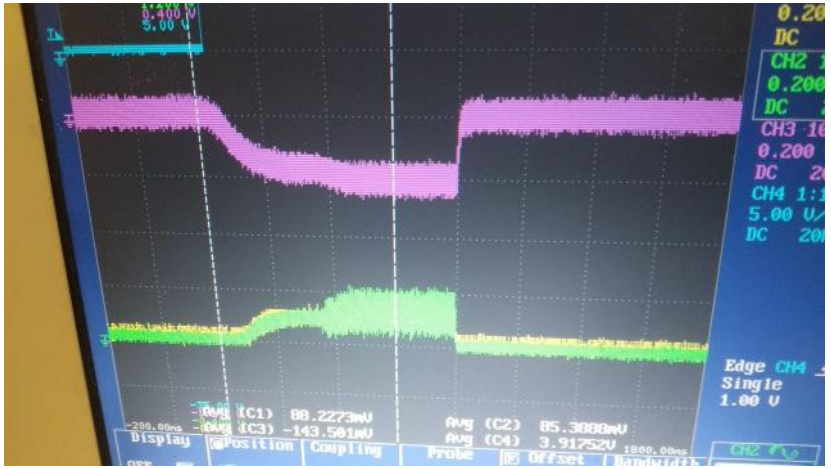
2nd STEP 1060kV-5 HOURS

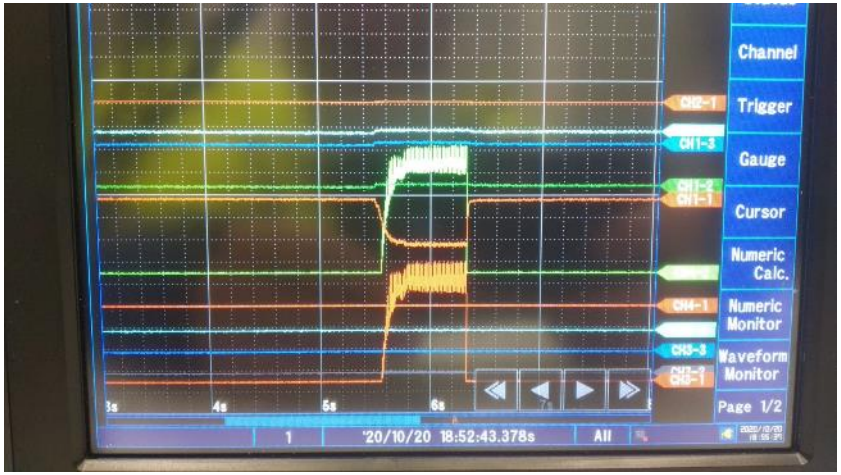
- The insulation tests were performed in successive steps, each time adding a new part of the system provided by a different DA
- The process was long and lasted about 1.5 years. The overall insulating test was successfully completed in Nov 2019

AGPS integrated tests



Converter output voltages





AGPS output voltage and current

MITICA Beam Line Vessel

Delivery on site and installation of the MITICA BLV

- Installation and SAT completed in Q1 2020 just before the Site closure for some weeks due to the Covid-19

Conclusions and lessons learnt

- **MITICA**
- Construction nearing completion; commissioning of plants well advanced. All injector mechanical components in procurement phase; to be delivered in 2022-2023
- 1MV power supply system successfully subjected to insulation tests up to 1.2MV for 1 hour
- Power integrated tests just started (delay by COVID-19) using modified organisational structure
- High voltage holding tests in vacuum planned using MITICA facility and electrostatic mock-up of Beam Source

SPIDER

- Operating since ~3 years, producing interesting results
- In 2020, experimental plan delayed due to Covid-19. First Cs operations postponed to 2021
- RF-induced discharges on rear side of source
  - Cause: residual vessel pressure
  - Temporary solution: partial masking of grid apertures ⇨ operation possible
  - Final solution: increase pumping speed & capacity ⇨ long shutdown required
- Difficult RF control; limited RF power per generator
  - Solution: replacement of RF oscillators with solid-state amplifiers ⇨ long shutdown required
- Mid-2021, long shut down to improve source and plants to increase SPIDER performances