28th ESLS RF Workshop

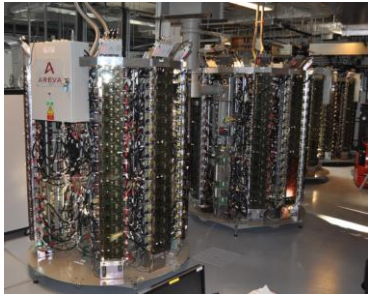
ALBA, 22-24 October 2025

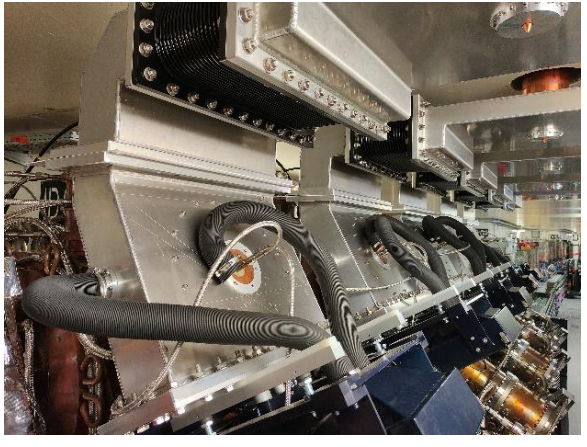
The ESRF RF System update

Including Linac, Injection/Extraction, Booster and Storage Ring 352 MHz systems

Paweł Borowiec

On behalf of the RF Group





ESRF | The European Synchrotron

OUTLINE

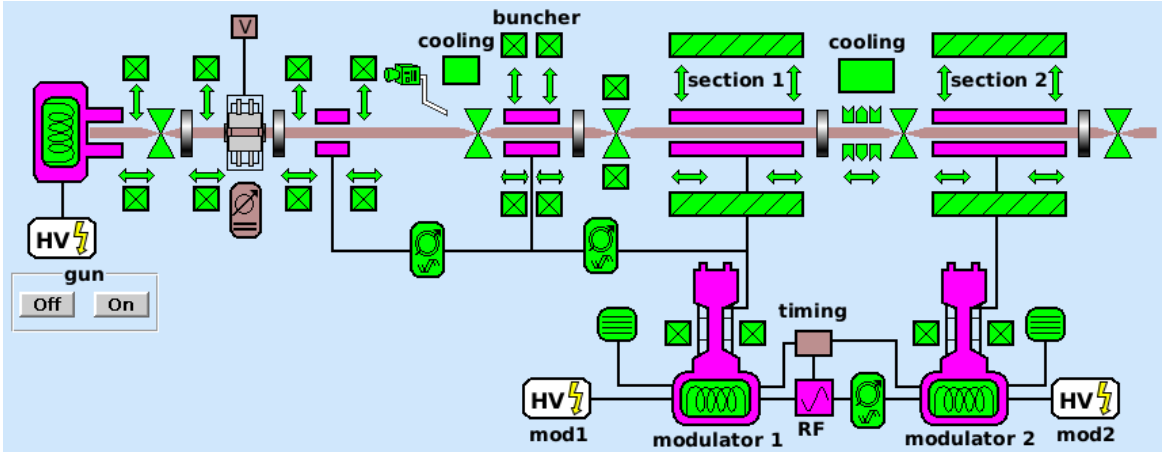
- ESRF RF configuration
- Linac configuration and refurbishment program
- Remarkable issues at Linac and Inj/Ext
- Storage Ring operation and upgrades
- Other activities
- 4th harmonic project

ESRF EBS

2020 New Extremely Brilliant Source: EBS

- First 4th generation high energy light source
- further brilliance increase by a factor 40
- Substantial gain in coherence

LINAC – CONFIGURATION UP TO SUMMER 2025



Modulator 3 (backup for Mod.1 or 2)

Background:

- The Linac is operational since 1988. To anticipate a possible failures the refurbishment program has been introduced.
- Following operational scenarios have been analyzed:
- If section #1 fails, no injection is possible. If section #2 fails, one could try and implement 100 MeV operation with only section #1 active
  - **verified**, 100 MeV injection is possible
- But no spare accelerating structure of the same type available at the ESRF or in Europe, also manufacturer does not offer it.

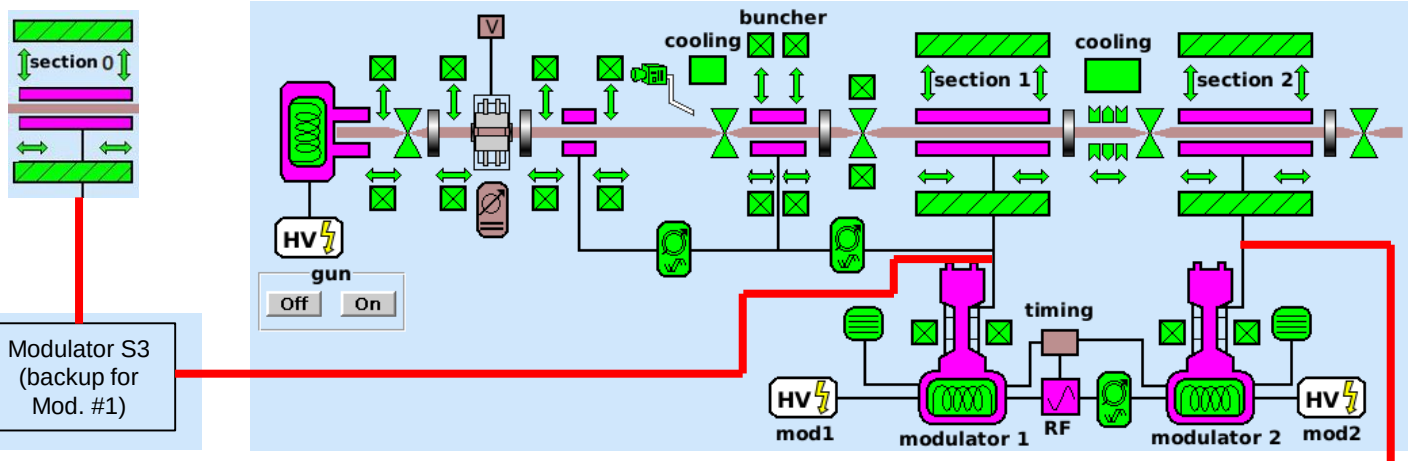
Preventive action:

Among many possible scenarios, the following is proposed as the most interesting:

- Purchase of a new accelerating structure – shorter structure available on the market, a girder adaptation is needed
- Purchase of a complete, solid-state RF Unit

LINAC – FALL BACK SCENARIOS

Each modulator from Linac will have its spare

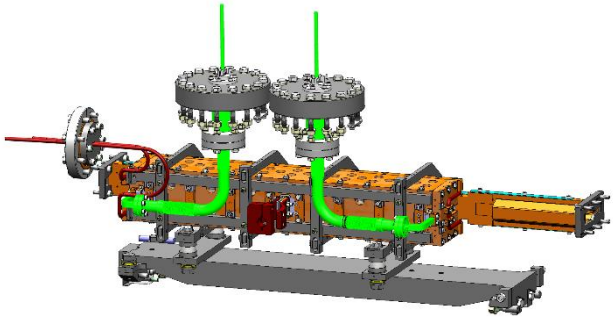


Modulator #3 can operate independently of the Linac operation

Implemented actions:

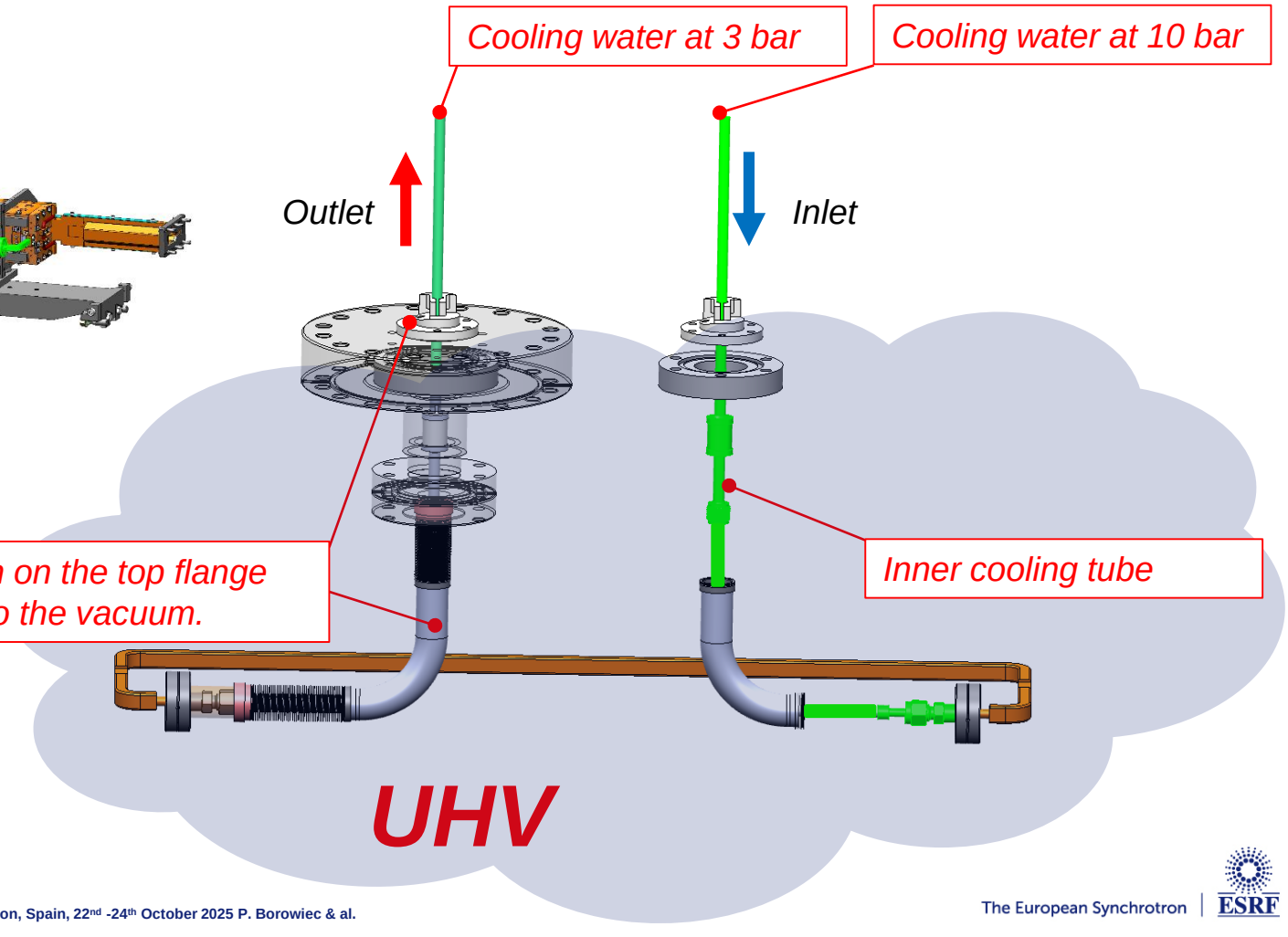
- Modulator #3 moved to a new position to provide the RF for:
  - Section #1 in the Linac
  - Spare accelerating section during conditioning
- Spare accelerating section -> CFT awarded by RI GmbH
  - All cavities have been machined
  - Brazing and tuning in November
  - Delayed delivery due to lead time of ceramic for the RF window (input splitter)
- Solid state RF Unit -> CFT awarded by ScandiNova Systems AB
  - Canon klystron has been selected
  - FAT accepted with the electrical grid quality remark. Scandinova will install a filter.
  - SAT in November
- Purchase of vacuum chamber to replace any section -> delivered

SEPTUM S3 - CONDUCTOR WATER COOLING

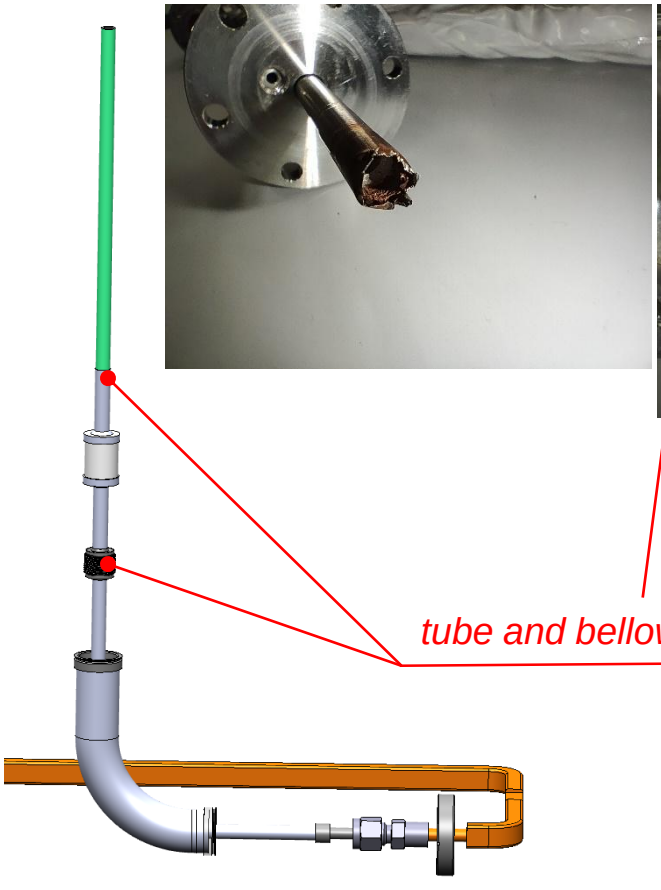


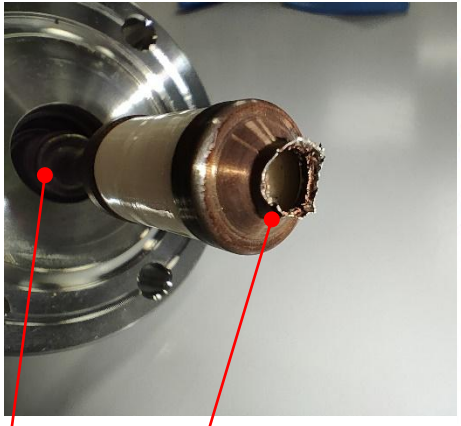
S3 parameters

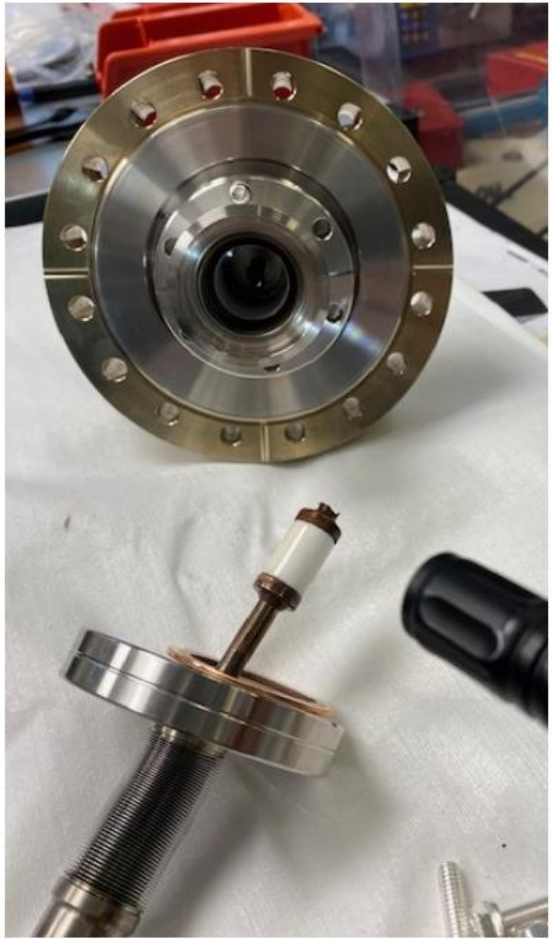
- 1200 V (max. 1500 V)
- 7330 A (max. 10 000 A)
- Pulse length: 66 µs
- Repetition rate: 4 Hz



SEPTUM S3 – FINDINGS







Endoscopic inspection of the outlet tube – no cracks found

SEPTUM S3 – PREPARATION FOR NEXT INTERVENTION

Goal: exchange of the cooling circuit in the tunnel without S3 evacuation

Inventory of spares:

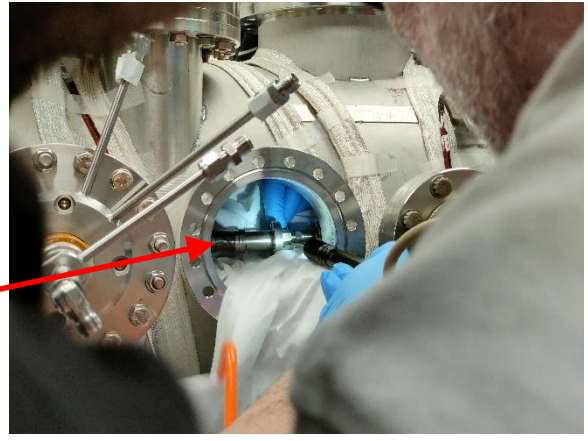
- 2 complete cooling tubes available.
- Assembled septum magnet available but without above mentioned cooling tubes

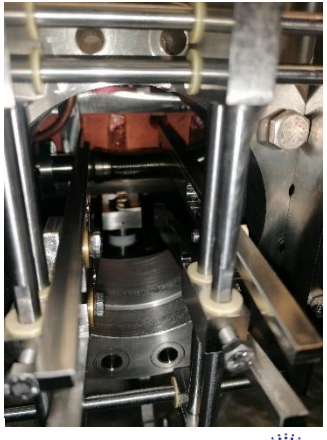
Designing of appropriate tooling to compress outer tube bellow for tightening of the swagelock and tightening of ConFlat16

- No access from the top CF needed
- One person operation

Purchase of identified missing tooling, adapters, unions, quick connectors

Preparation of a dedicated trolley with all necessary tools to minimize an intervention time

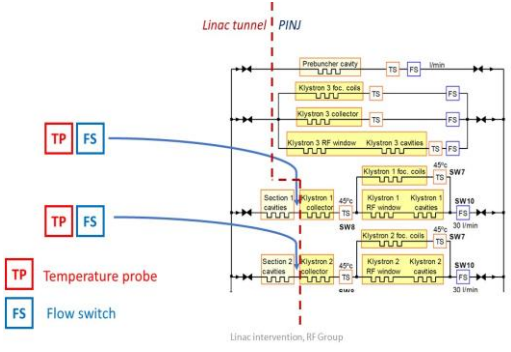




Courtesy: V Serriere, B Cocat, M Dubrulle

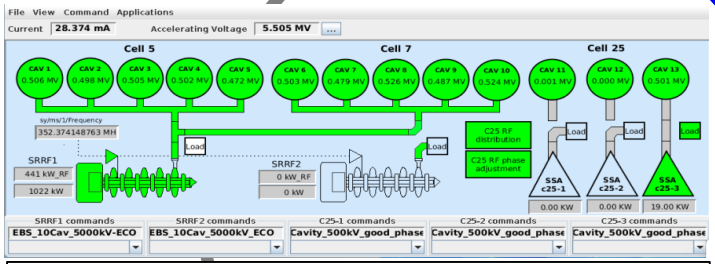
LINAC FAILURES - IMPLEMENTED MITIGATION MEASURES

- Installation of flow-switches with flowmeters on the outlet of each section – modified water manifold. Lack of water flow is triggering an **interlock**, it is visible in the control room.
- Installation of temperature measurements on the outlet of each section. Over-temperature triggers an **alarm**.
- Installation of dedicated PLC to follow also temperatures



- Purchase of the PFN, HV capacitors (custom made) – exchanged.

EBS 352 MHz RF SYSTEM LAYOUT - REMINDER



ECO-mode since October 2022

- 5.5 MeV total RF voltage
- One klystron transmitter feeding 10 cavities
- One SSA amplifier feeds 1 cavity
- Rotation of SSA after each shutdown

Monocell cavities since 2019 (EBS)

Cell 5

Cell 7

EBS Storage Ring

-7 dB

-7 dB

EEV5 klystron since 2000

352 MHz 1.1 MW klystrons

KLYS 1

KLYS 2

EEV4 klystron since 2000

NEW Teststand: in new MTBS-Extension building

75 kW tower

75 kW tower

75 kW tower

75 kW tower

75 kW tower

75 kW tower

3 x 150 kW SSAs

ELTA SSAs since 2019 (EBS)

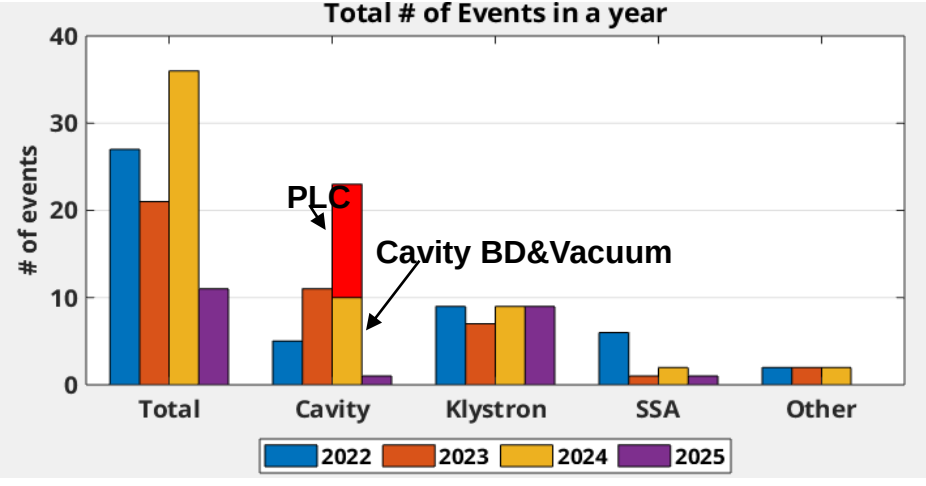
Space for 4th harmonic RF system

Cell 25

OPERATIONAL STATISTIC

SSA **During USM, only one issue with the driver of SSA11 the 14th of February lasted 26 minutes this year.**

USM Trend 2022-2025



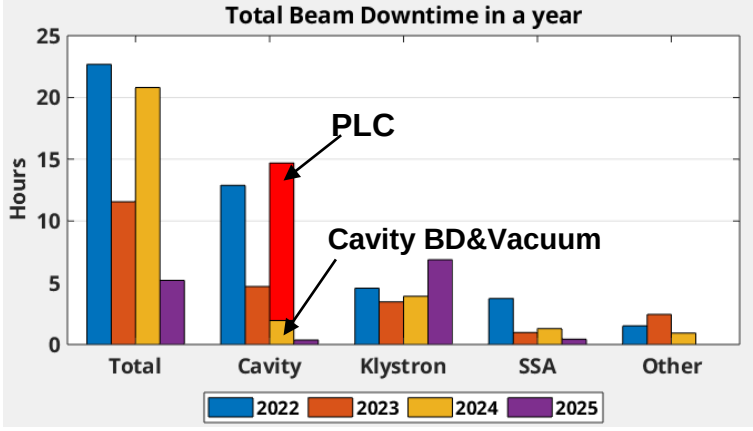
Remarks:

1. ECO-Mode implemented in October 2022. This probably explains the significant reduction of the SSA faults from 2023 (only one SSA – cavity system active in operation instead of all three);
2. Cavity breakdowns look very much reduced but that is just a matter of luck: almost all breakdowns (7 in total), this year, happened during MDT and are not counted in this statistics;

2025:

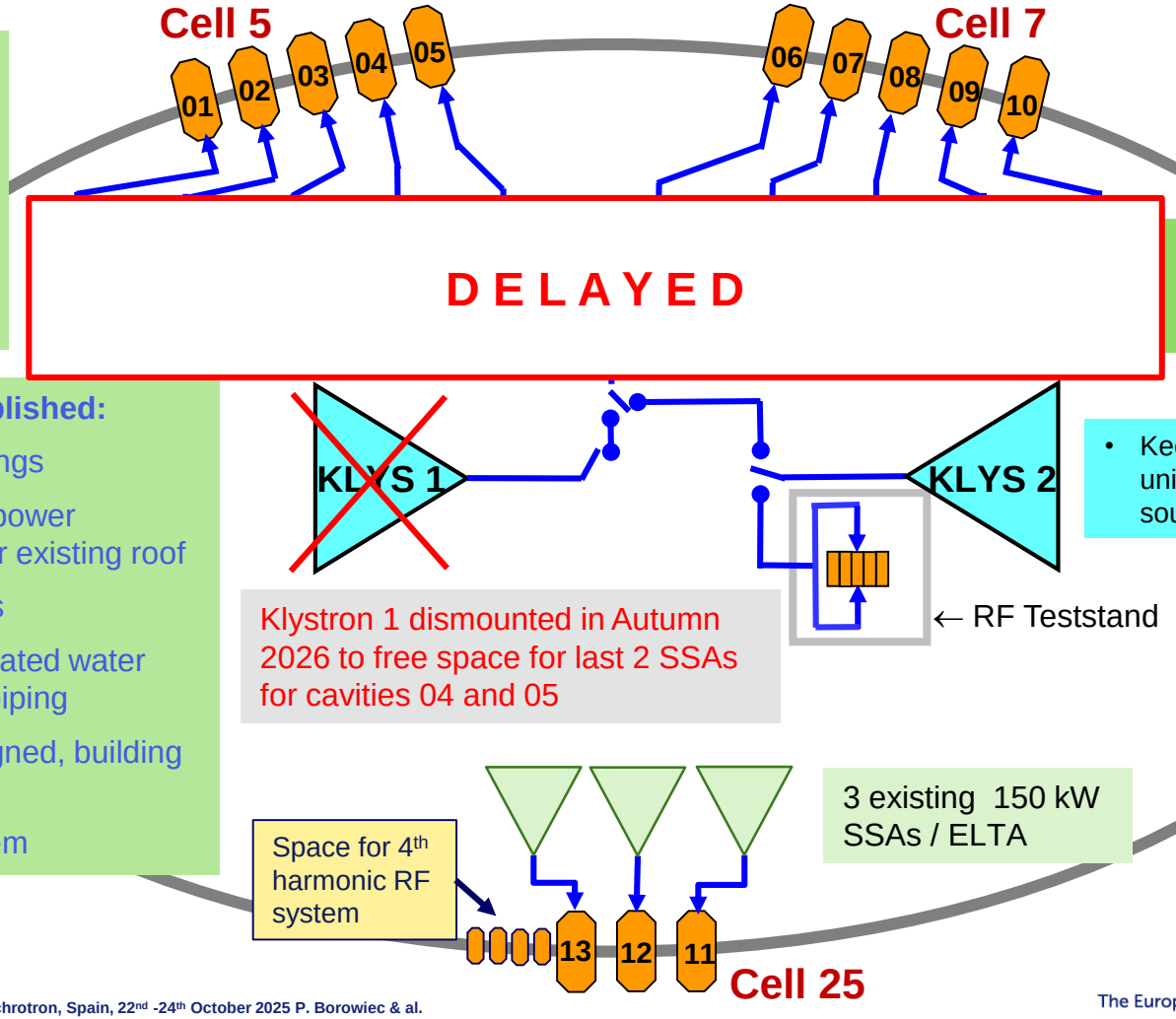
- **Mean time** of the failures: <45 minutes;
- **Max duration**: <2 hours cumulative – TRA 2 Ion Pump issue*.

* Two consecutive interlocks form IP1 happened starting from 6:00 am. Around 7:00 am the decision to swap to TRA1 is taken but the operator decided to start the MDT instead, due to the time needed for switching transmitters and have a stable beam: at 8:00 am, MDT would have anyway started.



Courtesy of A. D'Elia

GRADUAL IMPLEMENTATION OF 10 SSA (EACH 110 KW RF, MAX 250 KW AC)



SAT for each SSA connected to RF power **teststand**, switching between:

- load with variable mismatch (EH tuner)
- cavity in teststand

Site preparation accomplished:

- All within existing buildings

✓ New transformers and power switchgear rooms under existing roof

✓ 20 kV and 400 V cables

✓ Installation of pre-fabricated water cooling manifolds and piping

✓ Waveguide layout designed, building adaptation

✓ LLRF and Control system

10 new 110 kW 352 MHz SSAs by JEMA France

- Keep Klystron 2 as a unique high power RF source for the teststand

Klystron 1 dismounted in Autumn 2026 to free space for last 2 SSAs for cavities 04 and 05

Space for 4th harmonic RF system

3 existing 150 kW SSAs / ELTA

TESTING OF SPARE KLYSTRONS

Due to a significant delay of JEMA SSAs the program of the spare klystron tests has been relaunched

- EEV-3 klystron installed in Tra2 garage during summer shutdown 2025 – it is operating well after 24 years at storage.
- Modification of the external waveguide network to adjust a distance between a klystron output and a circulator input for harmonics compression. It allows an adjustment without opening/closure a klystron garage, which requires a validation by the Radiation Safety each time.

EEV-3 example harmonic #2 compression from -10 dBc to -36.8 dBc by shifting 159 mm (Distance from 2001 did not work)

Spare klystrons status

Klystron	Operating hours counter (40 000 hrs life time)	Remarks
EEV-1	36410	Next one to be verified in Tra2
EEV-3	8374	in Tra2
Philips 54-301-53	~~36 277~~	Up to 500 kW only, not for EBS
Thales - TH 89018-2	36340	
Thales - TH 89022-2	~~18 428~~	Breakdowns, not for use. May be a cold conditioning could help.
EEV-5	18683	Removed from Tra2 08/2025
EEV-4	~~115153~~	in Tra1. Over its lifetime

Theoretical, remaining klystrons' operational period ~ 10 years but also aging of auxiliaries.

OTHER ACTIVITIES

RF power coupler repair procedure:

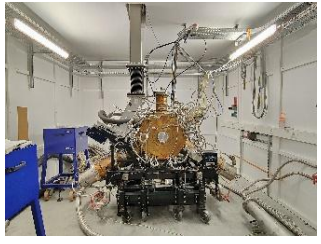
- In-house development technology to exchange a ceramic
- Precise machining and TIG welding a ceramic metal lip to a body
- Dedicated tooling to be used only to this task (UHV conditions)
- **Succesfuly** conditioned up to 150 kW of RF power

RF power coupler order:

- To qualify manufacturers because of the last order in 2008

Test stand for two RF system fed simultaneously from independed power sources:

- SSA (i.e. during SAT) and klystron transmitter (i.e. coupler conditioning)

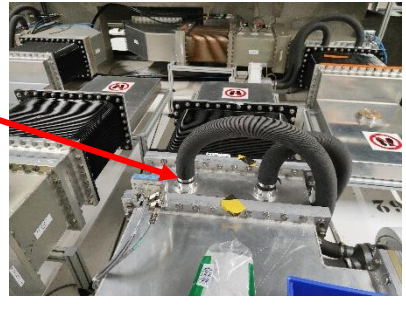


Refurbishment of the essential RF laboratory measurement equipment, CFTs accomplished for:

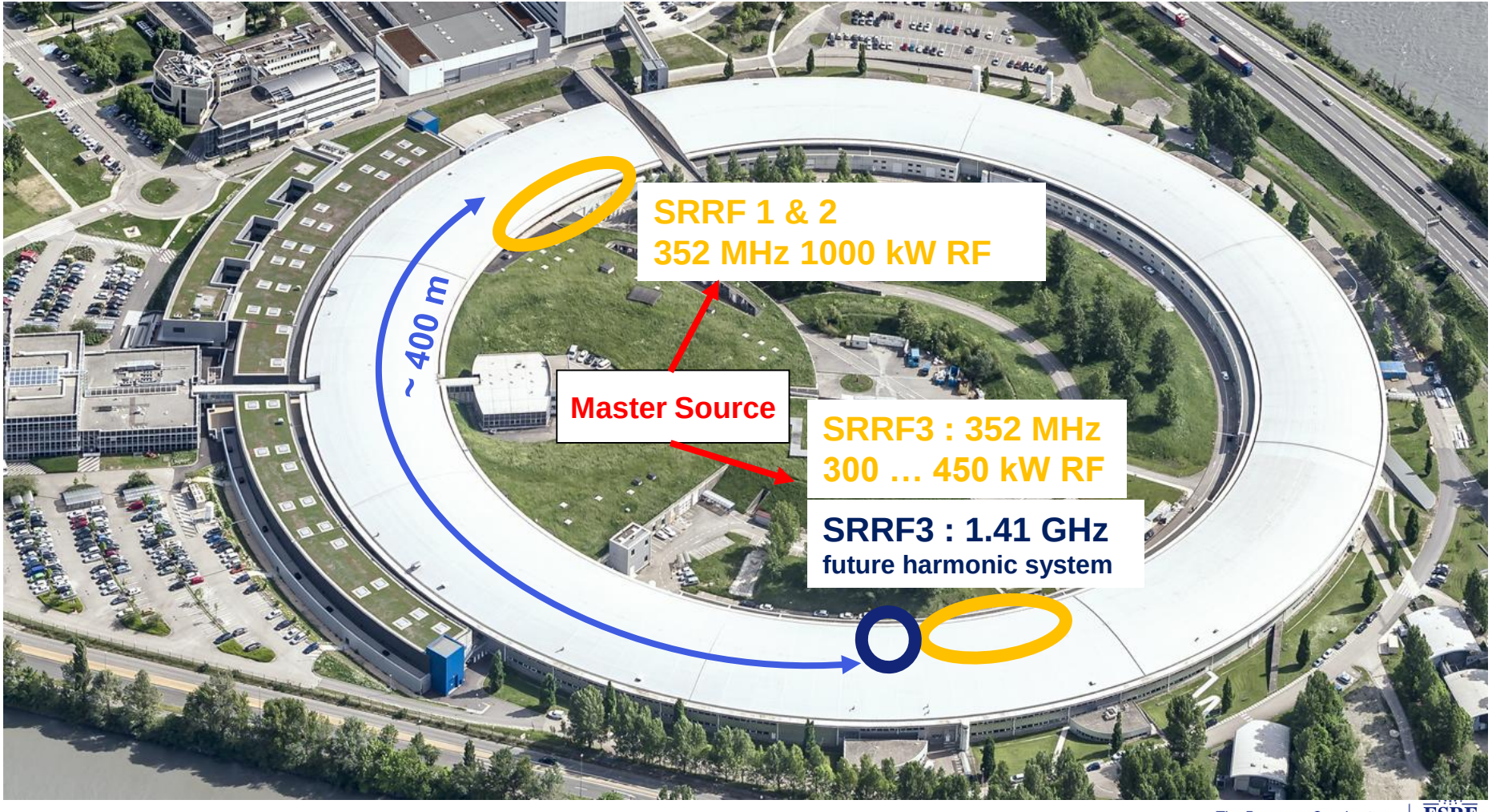
- VNA with a ports multiplexer, up to 12 channels will be available
- RF phase noise analyzer - shipped
- spectrum analyzer – delivered

Wifi interferences from RF system:

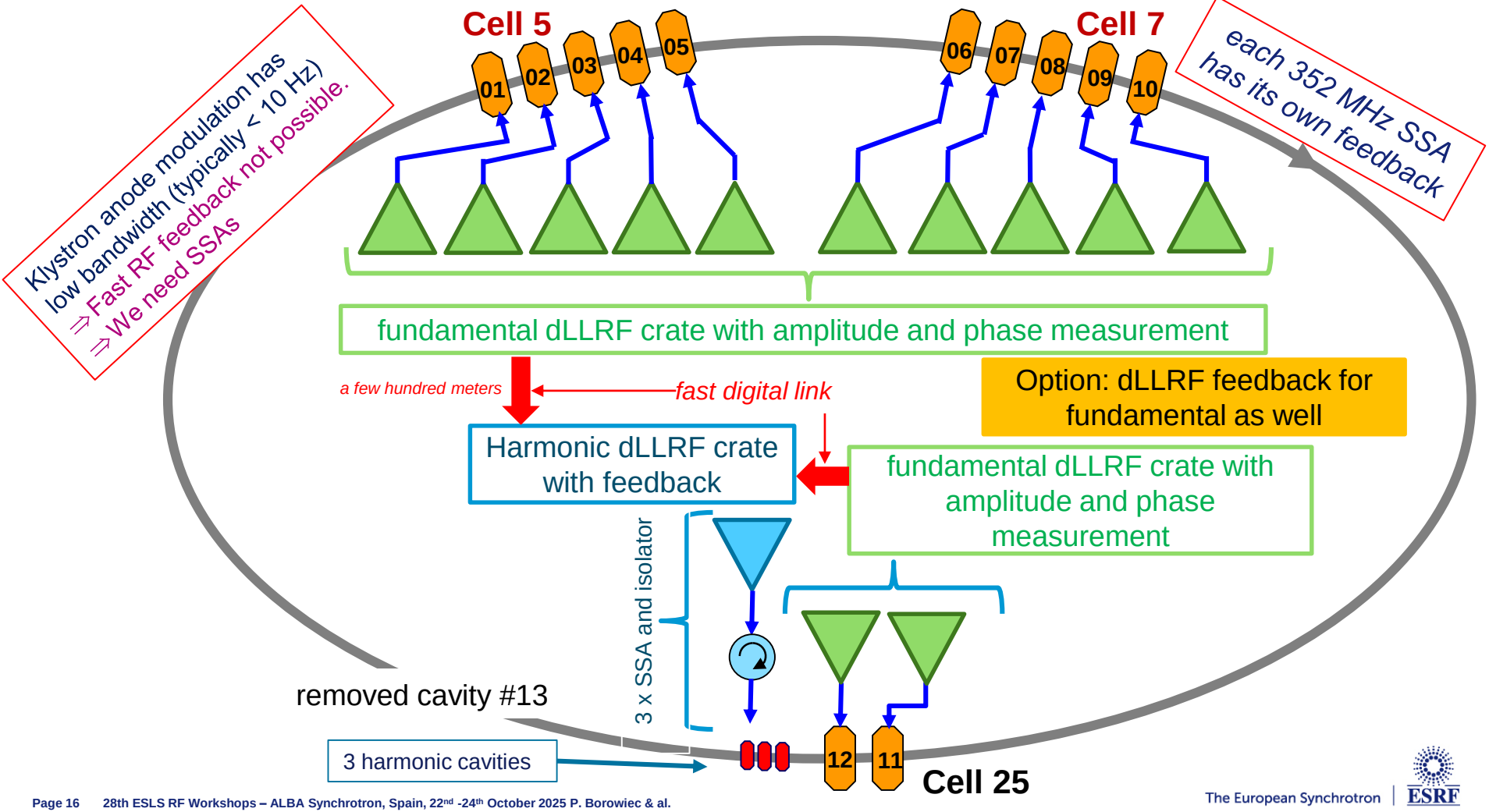
- RF leak point identified – a cavities' ceramic air cooling passage in the waveguides
- Low pass filter – grid installed



RF SYSTEM FOR THE EBS STORAGE RING - 352.37 MHz and 1.41 GHz



FUNDAMENTAL AND HARMONIC SYSTEM PROPOSAL



HARMONIC SYSTEM COMPONENTS SUPPLIERS

industry

ESRF in-house

In collaboration with SOLEIL

crate cards

front-ends

RF pallets, cavity combiner production

cavity production

Master Source 1.41 GHz

dLLRF

firmware

Power Amplifier

Waveguide

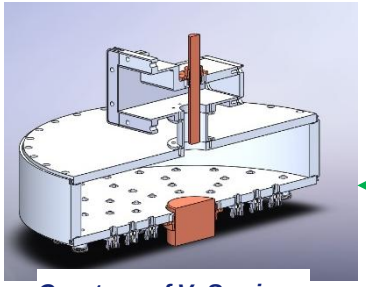
+ RF window

Cavity design

RF pallet design

Cavity combiner design

- Cavity tuning loop
- Cavity protection



Courtesy of V. Serriere

COLLABORATION WITH SOLEIL

- The ESRF is providing the complete cavity design to SOLEIL II machine - **accomplished**

SOLEIL II requirements:

- Two TM_{020} single cell cavities @ 1.409 GHz,
- R/Q = 30 Ω per cell,
- Q0 > 30000,
- V_{max} = 350 kV,
- Longitudinal Impedance < 6 kΩ.GHz per cell,
- One coupler port for RF conditioning.

Main challenges:

- Strong LOM & HOM damping,
- High Copper Cavity Power to be dissipated.

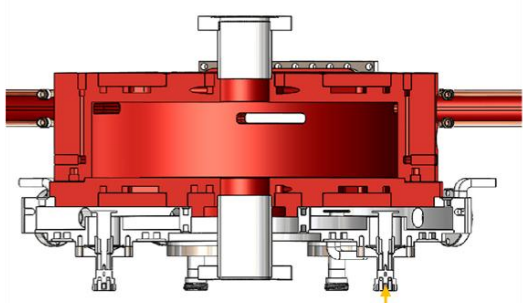
Additional challenge:

- Could we design such a cavity without ferrite for HOM & LOM damping?
- Variable β coupler.

Courtesy of V. Serriere

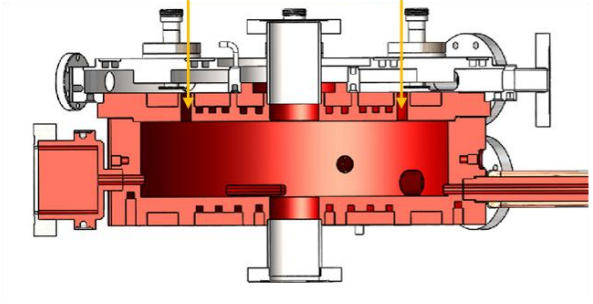
COLLABORATION WITH SOLEIL – THE ESRF CAVITY DESIGN

HHC Design for SOLEIL II - LOM Damping

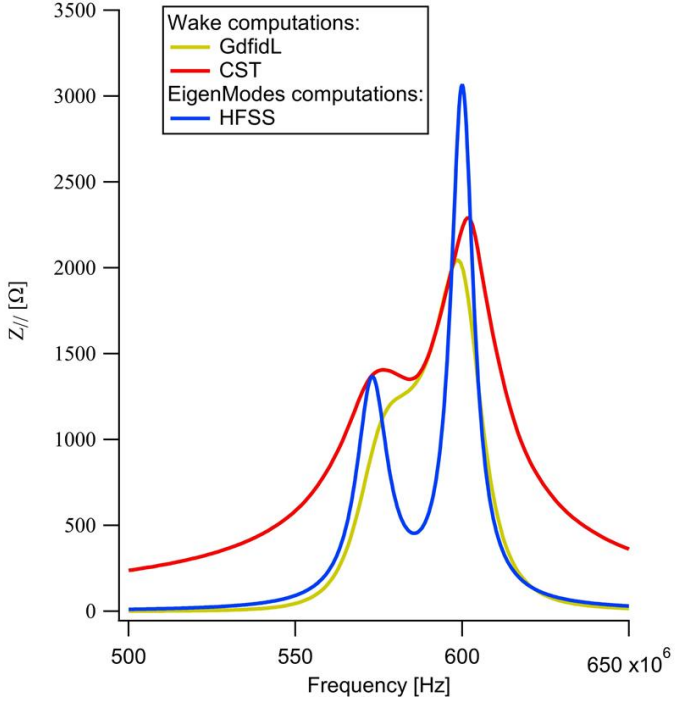


Damping of LOM
by coaxial cavity:

- over loaded by 6 E-Antennas + vacuum feedthrough & 7-16 Spinner connector
- tuned to have no mode closed to 1.409 GHz
- coupled to the cavity by 2 iris placed on the 'zero' H of the TM_{020} mode



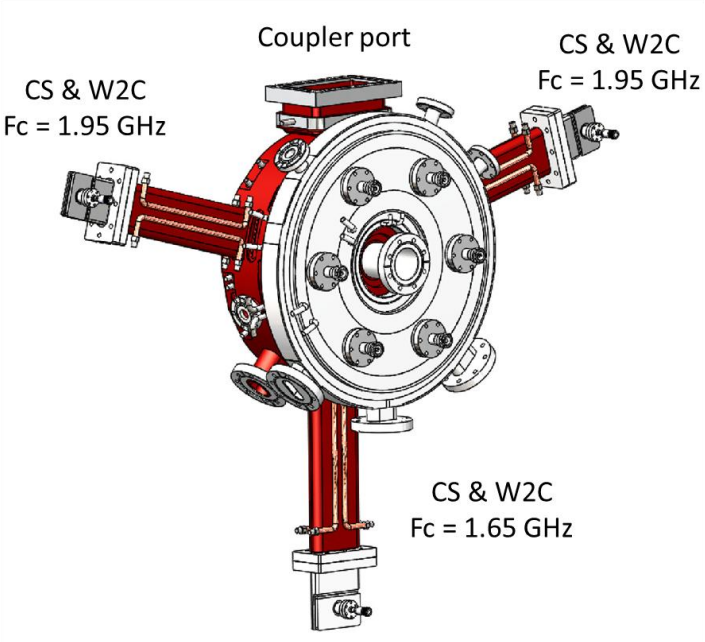
Impedance < 5 times LCBI threshold



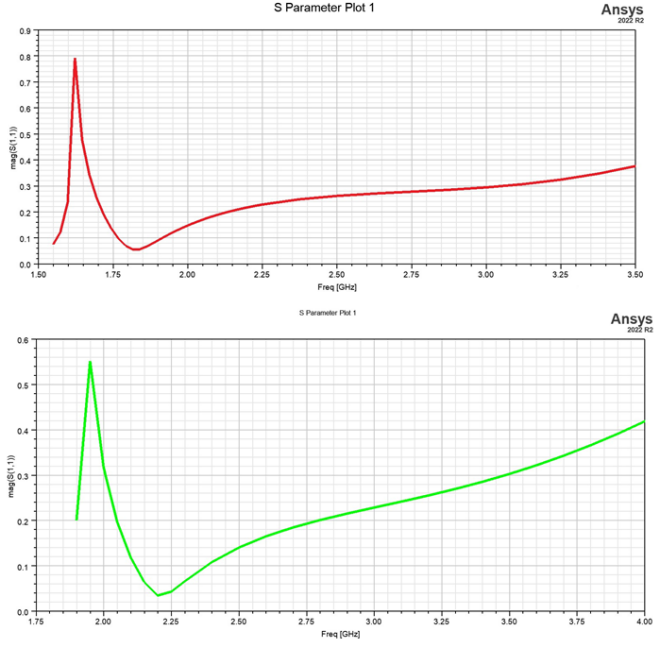
Courtesy of V. Serriere

COLLABORATION WITH SOLEIL – THE ESRF CAVITY DESIGN

HHC Design for SOLEIL II - HOM Damping



W2C designed to have low reflection closed to cut-off frequency



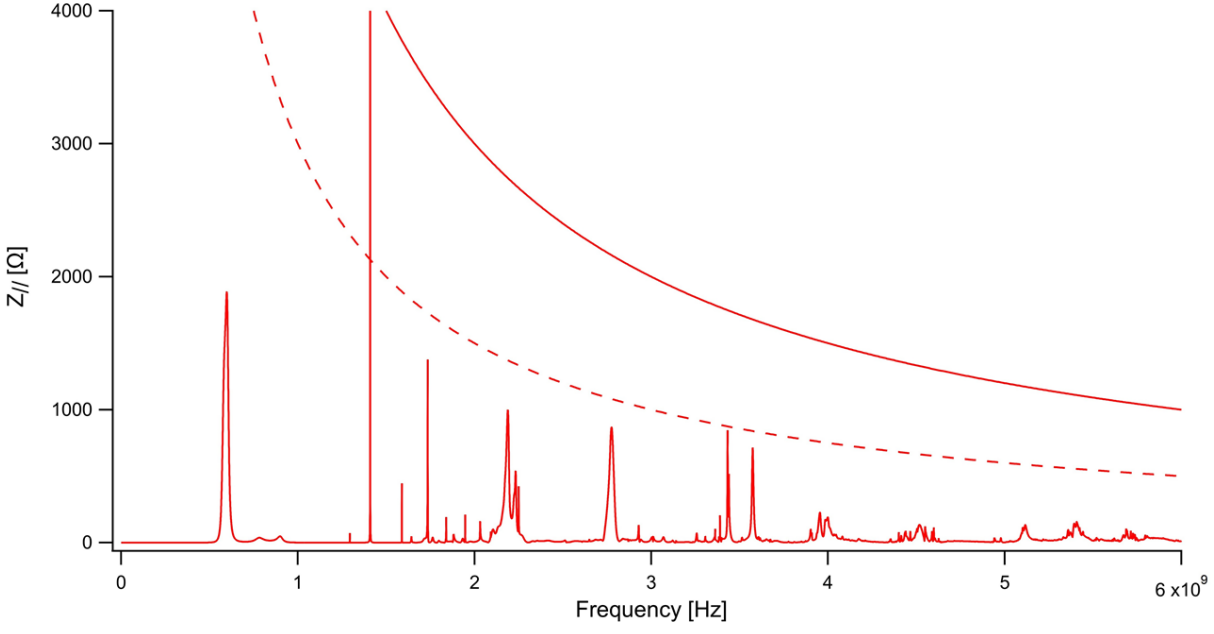
CS: Coupling Section
W2C: Waveguide to Coaxial transition + E-Antenna + Vacuum Feedthrough + N connector
Fc: cut-off frequency

Courtesy of V. Serriere

COLLABORATION WITH SOLEIL – THE ESRF CAVITY DESIGN

HHC Design for SOLEIL II – Longitudinal Impedance

LOM & HOM Impedances below a factor 2 of the LCBI Threshold (SOLEIL II - 2 Cavities Monocell – 500mA)



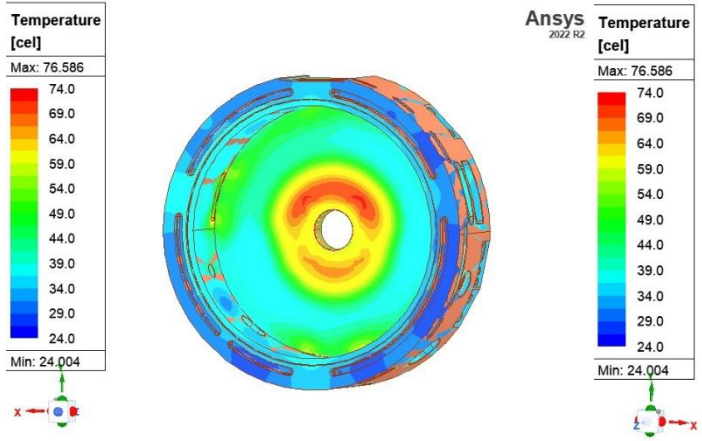
Final TM_{020} Impedance: R/Q = 30 Ω & Q0 = 31500

Courtesy of V. Serriere

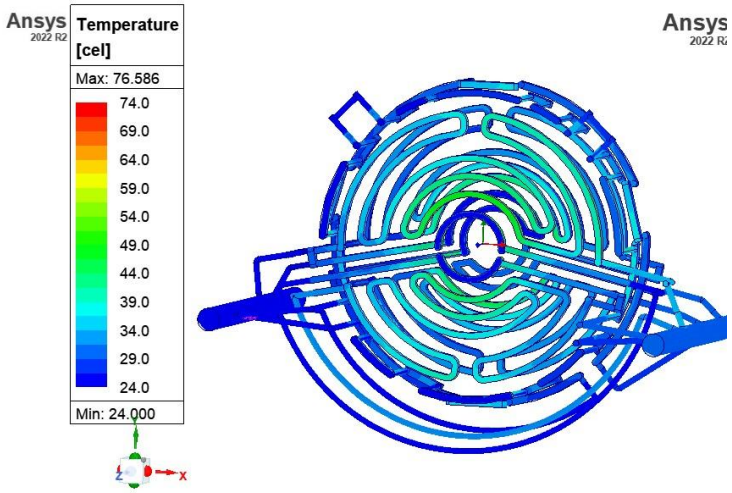
COLLABORATION WITH SOLEIL – THE ESRF CAVITY DESIGN

HHC Design for SOLEIL II – Cooling Design

Icepack Simulation with Pc=65 kW and Dp=5 bars on water manifold (DN 30)



Copper temperature < 74 degC

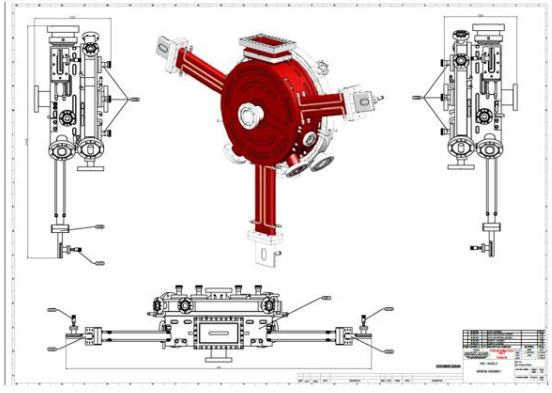


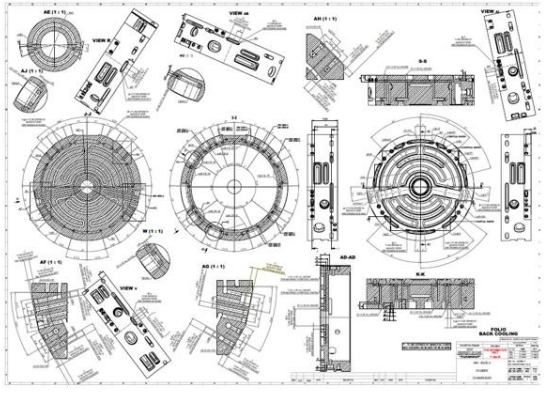
Watter temperature < 60 degC

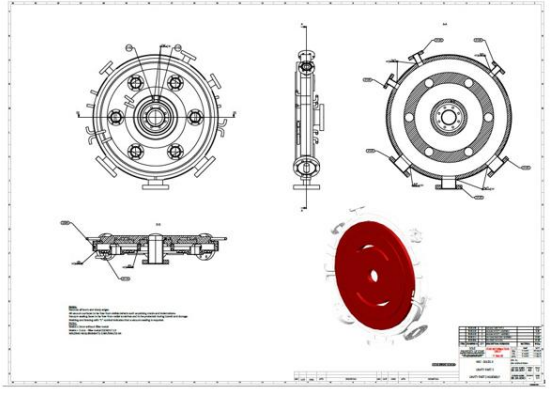
Courtesy of V. Serriere

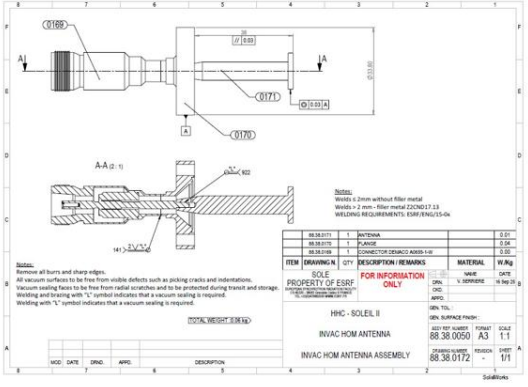
COLLABORATION WITH SOLEIL – THE ESRF CAVITY DESIGN

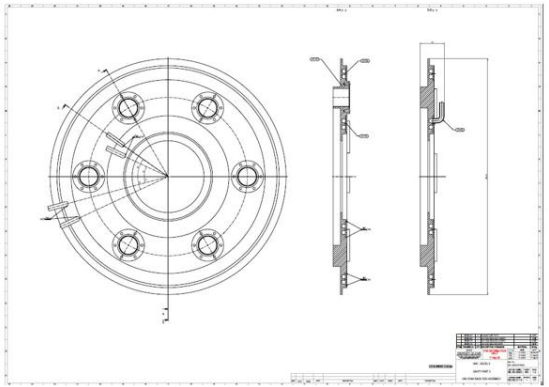
HHC Design for SOLEIL II – Set of 2D drawings

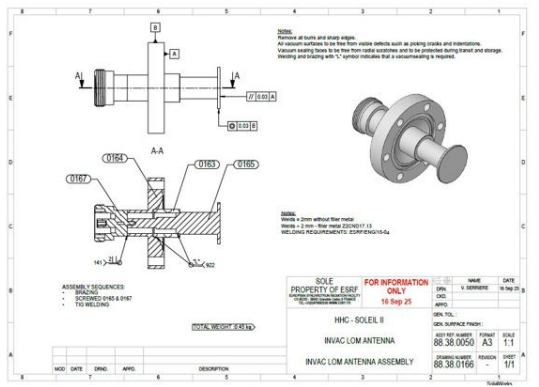












Courtesy of V. Serriere

COLLABORATION WITH SOLEIL – THE ESRF CAVITY DESIGN

HHC Design for SOLEIL II – Assembly procedure

TIME

E-Beam Welding: 88.38.0053
88.38.0095

TIG Welding: 88.38.0076
88.38.0107
88.38.0100
88.38.0114

Brazing Step @ temperature T1: 88.38.0072
88.38.0081
88.38.0087
88.38.0090
88.38.0102
88.38.0094

Brazing Step @ temperature T2: 88.38.0052 TIG Welding: 88.38.0093

Water Leak Test on: 88.38.0052 & 88.38.0093

RF Tuning (adjust frequency by machining the internal radius of 88.38.0052 if needed)

Brazing Step @ temperature T3: 88.38.0051 T1 > T2 > T3

Vacuum Leak Test on: 88.38.0051

FAT

Courtesy of V. Serriere

MANY THANKS FOR YOUR ATTENTION