# SOLEIL RF Systems

Lu ZHAO, on behalf of RF/LINAC team

Special thanks to Patrick Marchand for his valuable guidance.

ESLS RF Workshop and the HarmonLIP Workshop
ALBA Synchrotron

**22-24 Oct. 2025**

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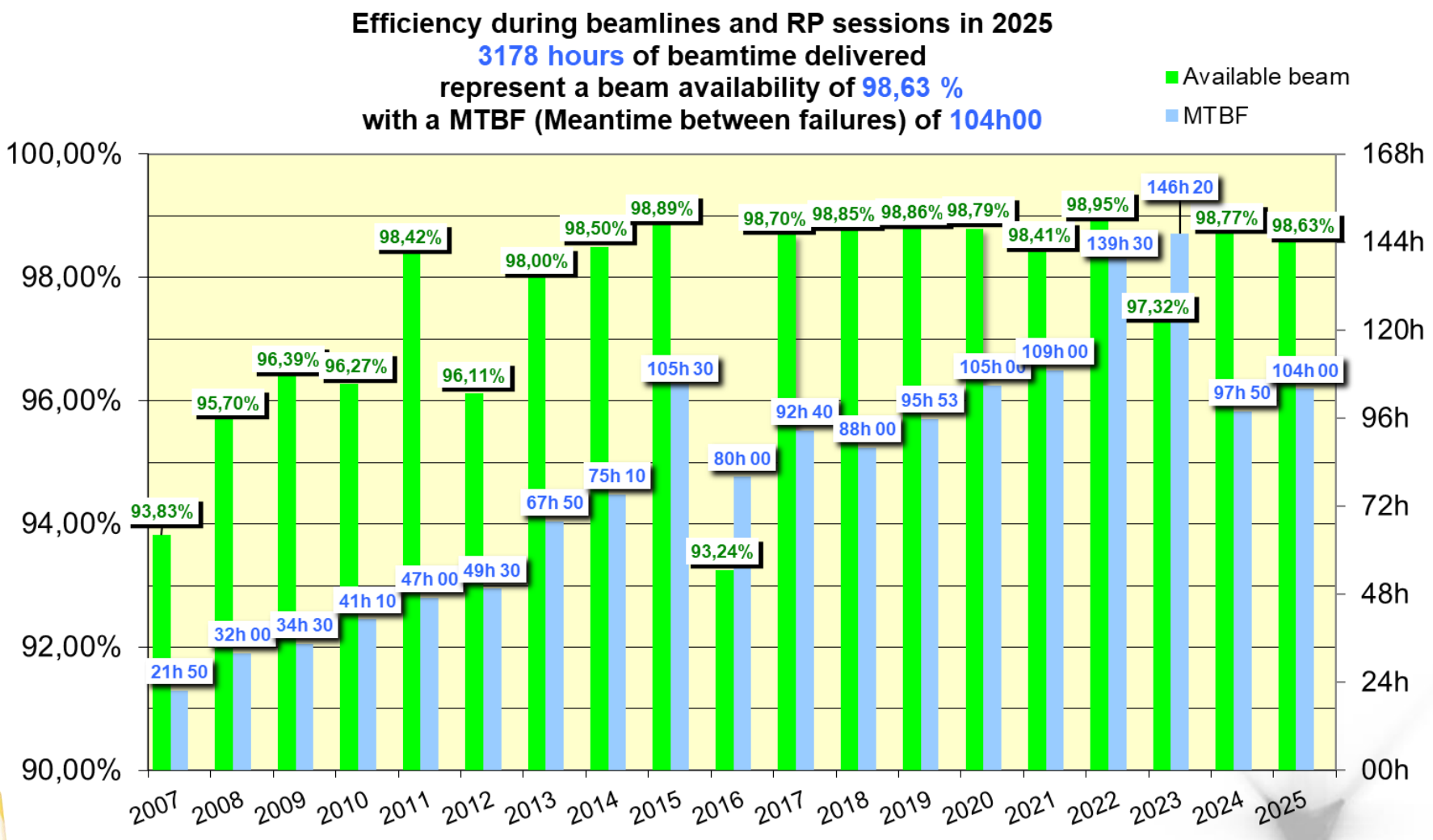
# From Soleil to Soleil II — Climbing Higher Together

# Outline

- **Current SOLEIL machine**
  A. Machine and RF status
  B. Experience with the SOLEIL 352 MHz updated SSPA's
  C. LINAC
- **SOLEIL Ⅱ with double RF system (352 MHz and 1.4 GHz)**
  A. NC HOM-damped cavities
     a) Main cavity and power coupler
     b) Harmonic cavity (passive then active if necessary)
     c) Instabilities Predicted
  B. RF control & Supervision system (Digital-LLRF system)
  C. Longitudinal bunch-by-bunch feedback
- **Testing and validation of SOLEIL Ⅱ cavities on the current SOLEIL SR**
  RF test stand

# SOLEIL Beam Availability



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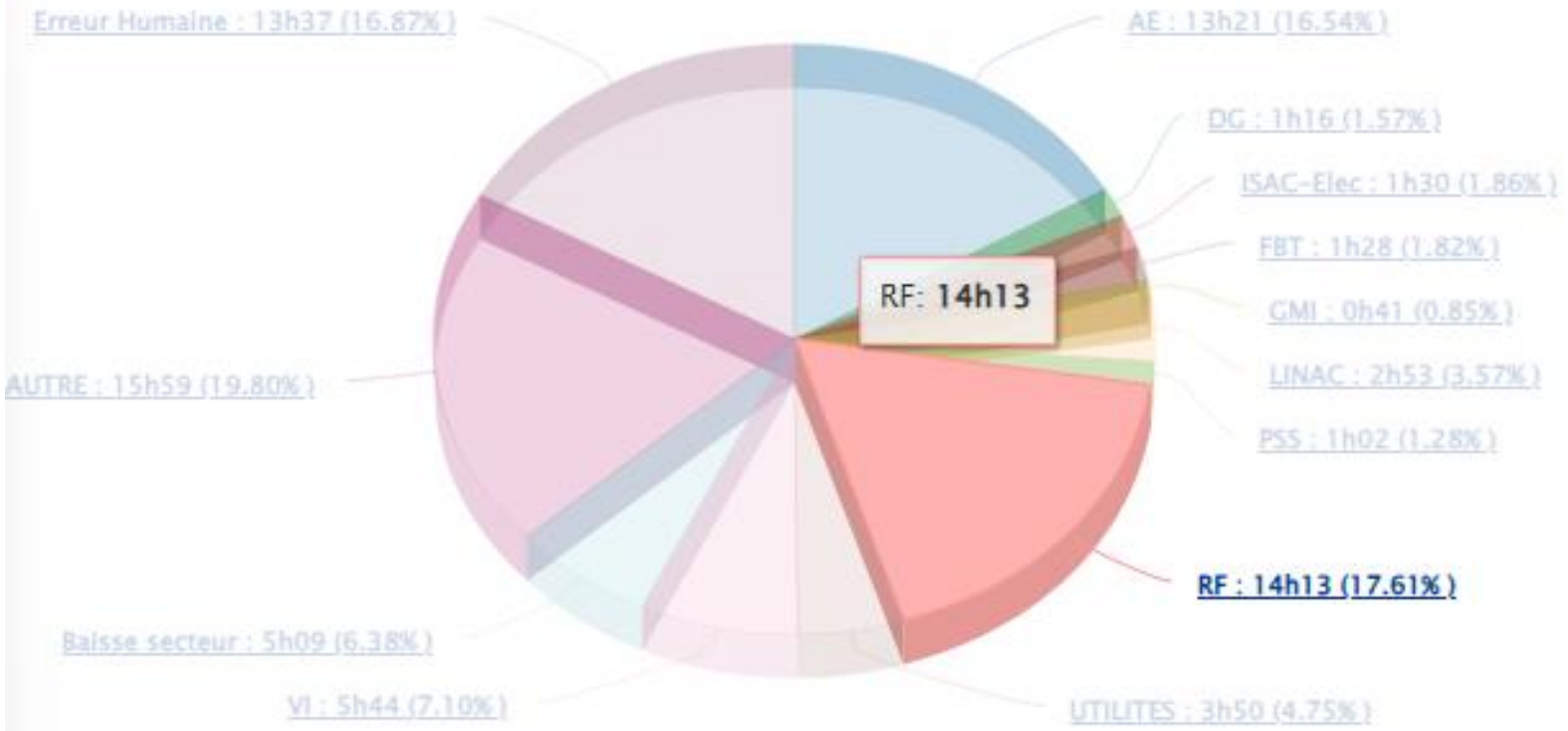
# RF Incidents

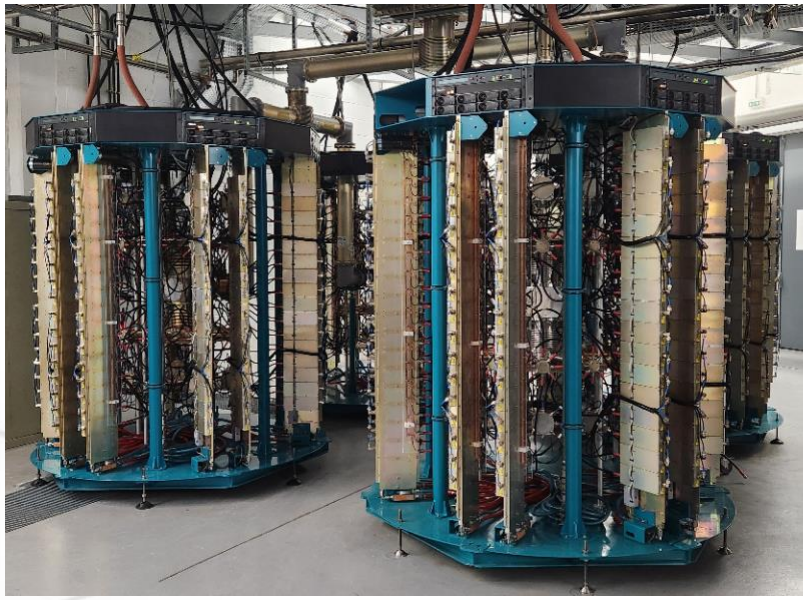
Duration of beam availability incidents over the course of 2025




- Power supply
- Fire incidents
- Amplifier control issue
- Others (false RF problems)

# Power Amplifier Upgrade

- **Status**
  - 2 x 60 kW BOO SSPA's and 2 x 200 kW SR SSPA's completed



*Upgraded AMP2 (4 x 50 kW towers)*

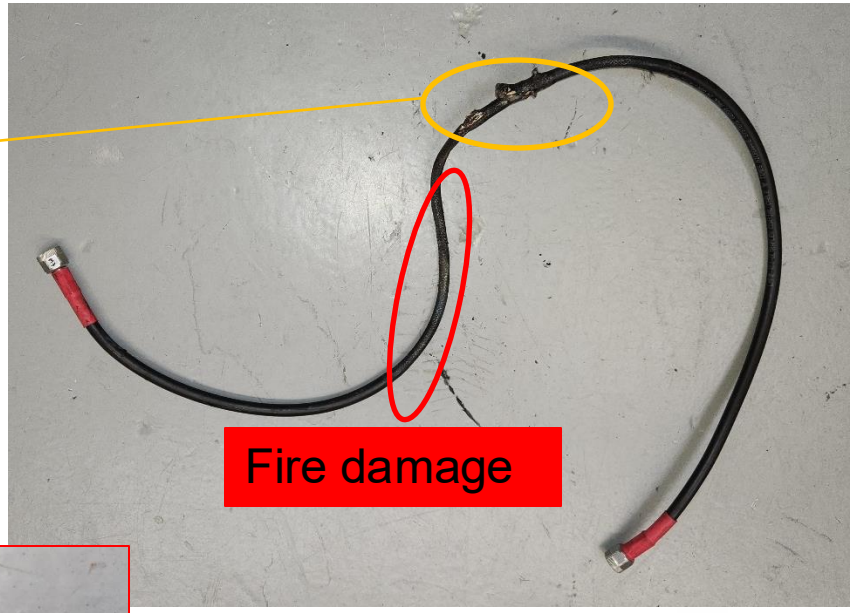
**Storage Ring Power supply upgrade plan**

From beginning of 2024, 1 x 50 kW tower will be installed every 2-3 months in the SR to benefit from **four fully upgraded 200 kW SSPA'S by mid 2027 for SOLEIL II.**

# FIRST Fire on RF Power Amplifier

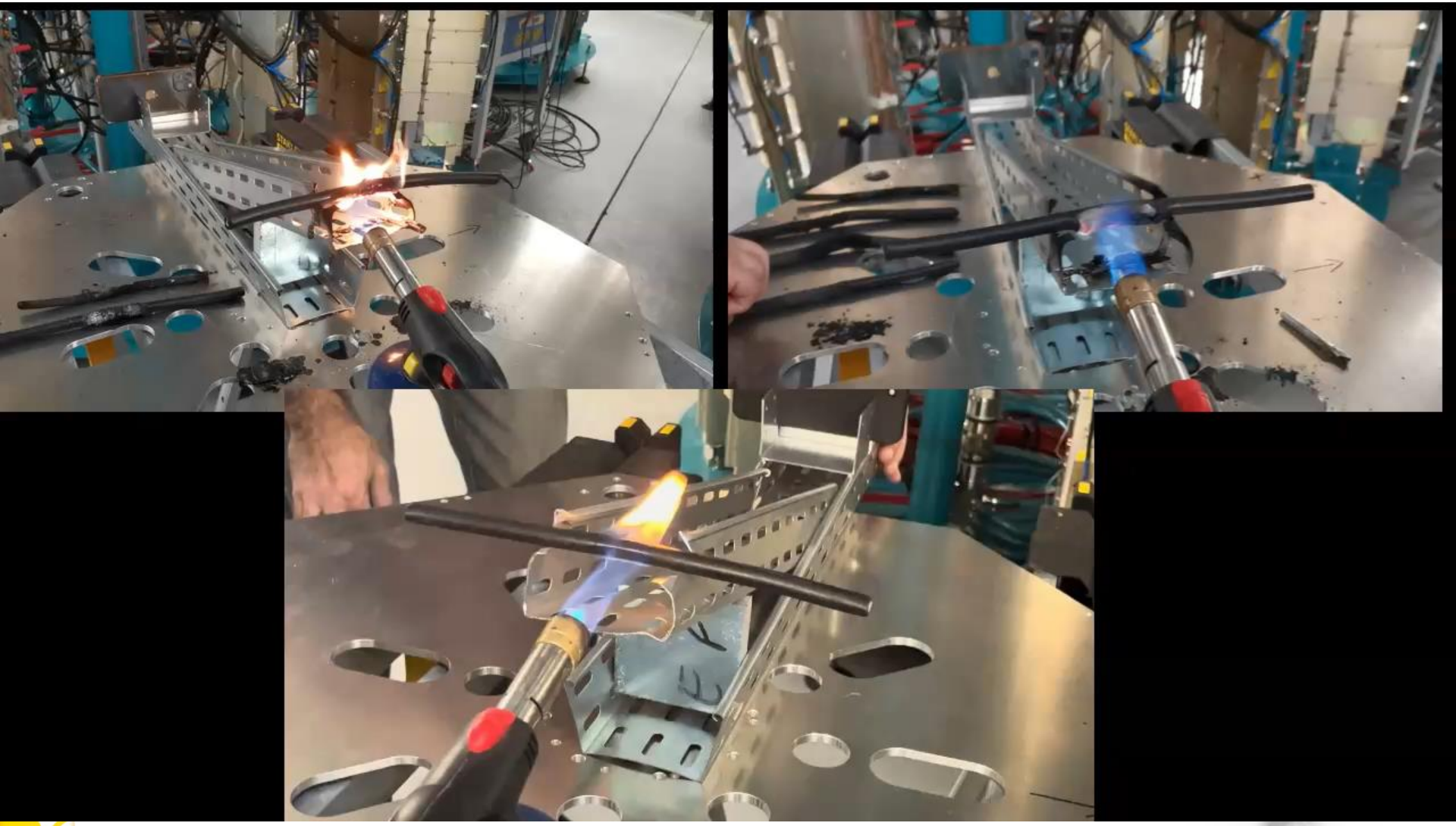
First fire outbreak in one of our old RF power amplifiers, 11/2024

Short circuit damage




- Aging and degradation of cable crimps reduce the mechanical and electrical integrity, potentially leading to short circuits.

# Labo Test

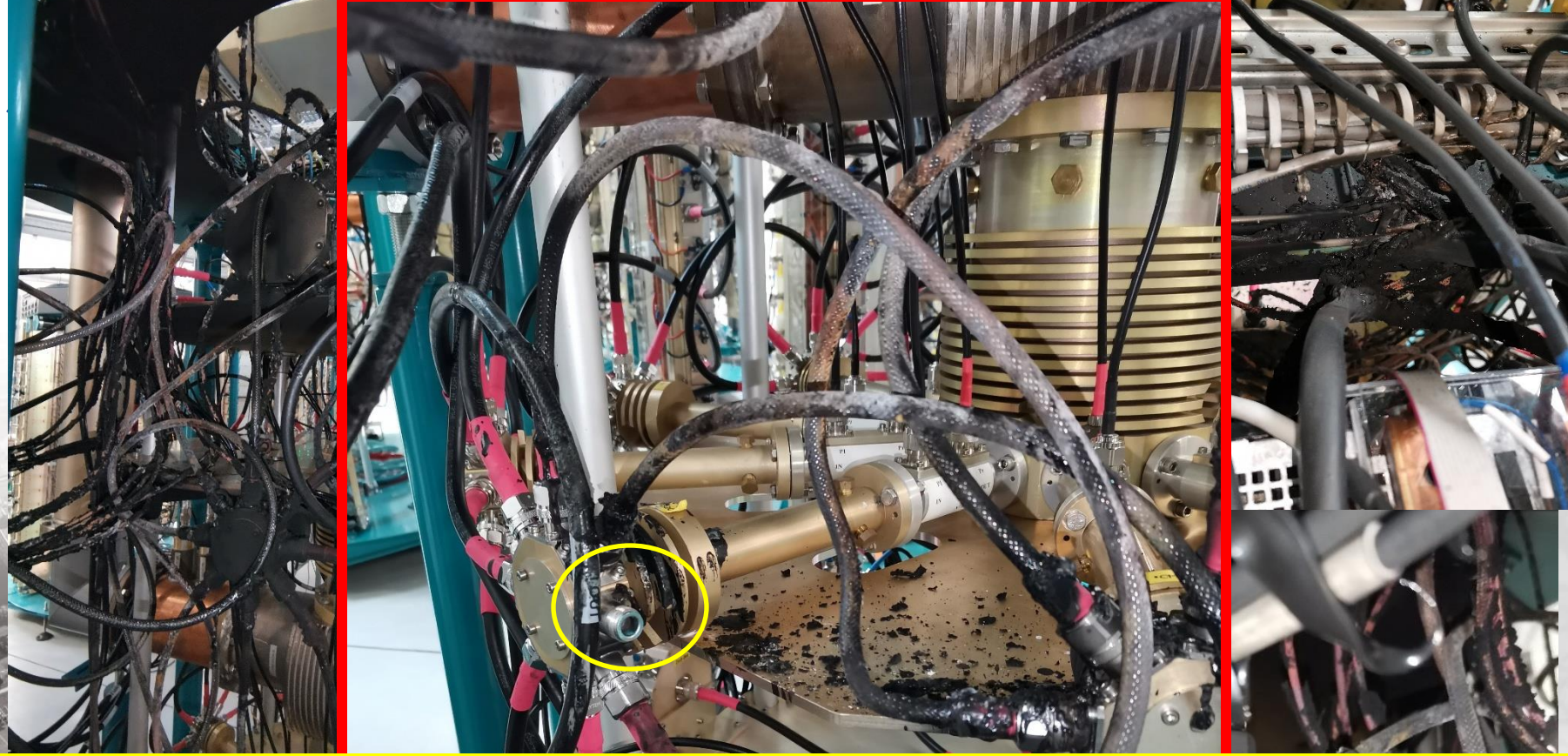


# Key Findings

- LMR400UF FR and LMR400FR deliver excellent thermal resistance and RF endurance, drastically lowering the probability of ignition.
- Adding FR heat-shrink to existing LMR400 UF also addresses fire-propagation risk at a very attractive cost while preserving **excellent flexibility**.

| Solution | Cable type | Flexibility | Cost |
|---|---|---|---|
| 1 | LMR400UF FR | - | 54% more expensive |
| 2 | LMR400FR | - - | Expensive |
| 3 | FR heat-shrink on existing LMR400 UF | ++ | 69% Less expensive |

Conclusion: option 3 is the best compromise. Decision of equipping all power cables with FR heat-shrink over 18 months.

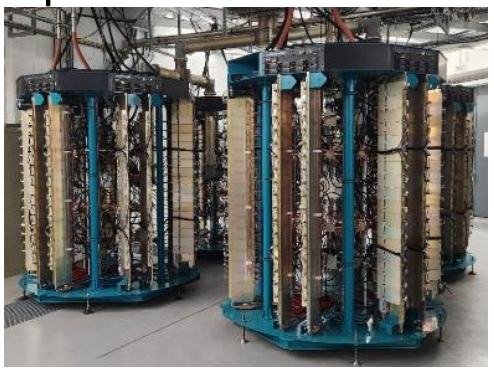


**Even the best technology can't protect me from my own clumsy mistakes.**

# After Second Fire…

## Back to operation:

- 2 hours downtime: back to operation with 450 mA using 3 out of 4 amplifiers.
- Using 3.5 amplifiers (0.5 amplifier = 2 towers) for 500 mA operation for 3 months



## Decision:

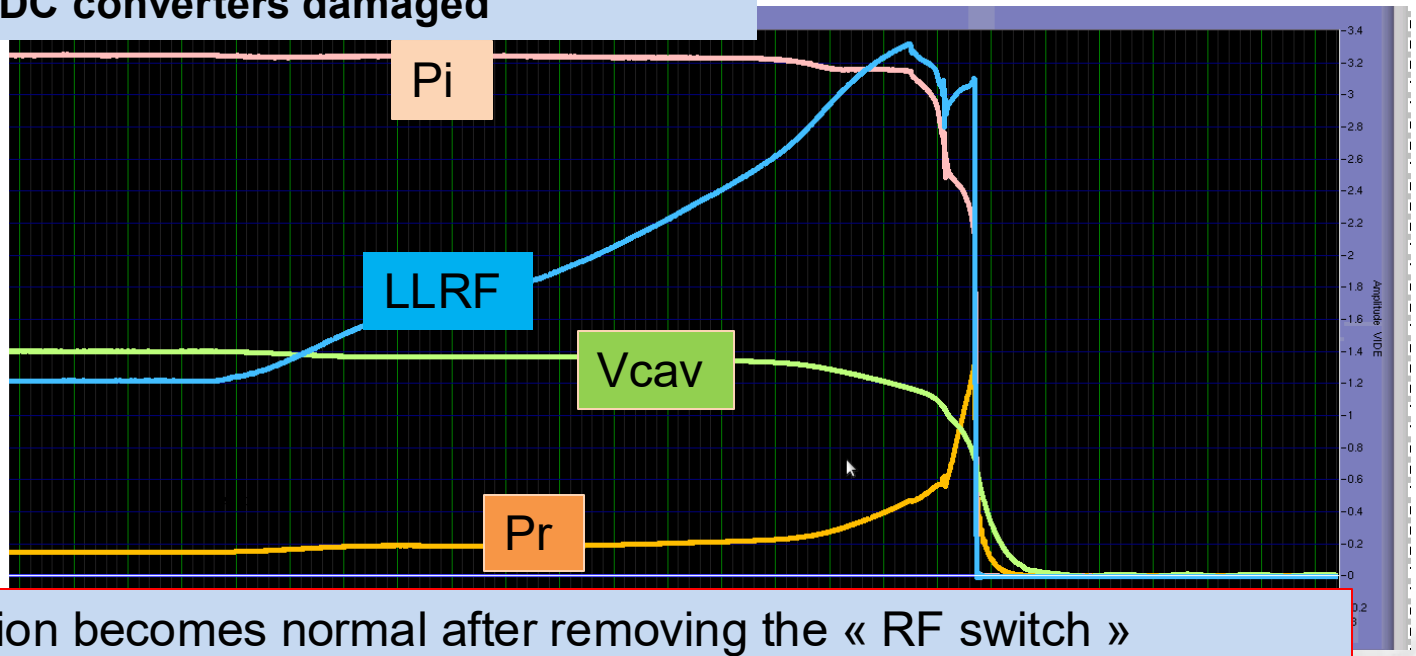
1. Reduce from 18 down to 8 months the power cable modification plan
2. Increase the frequency of thermal inspection with IR-camera
3. Improve sensitivity of fire detection system

# For Reasons that Remain a Mystery

- Frequent trips due to amplifier power drop (8 over 2 days)

**•LLRF increase power output**
**•Reflected power increased** (tuners detuned)
**•AMPLI 1–3** compensated → **Reflected power triggered interlock on AMPLI 4**
**•5 × 3kW AC-DC converters damaged**

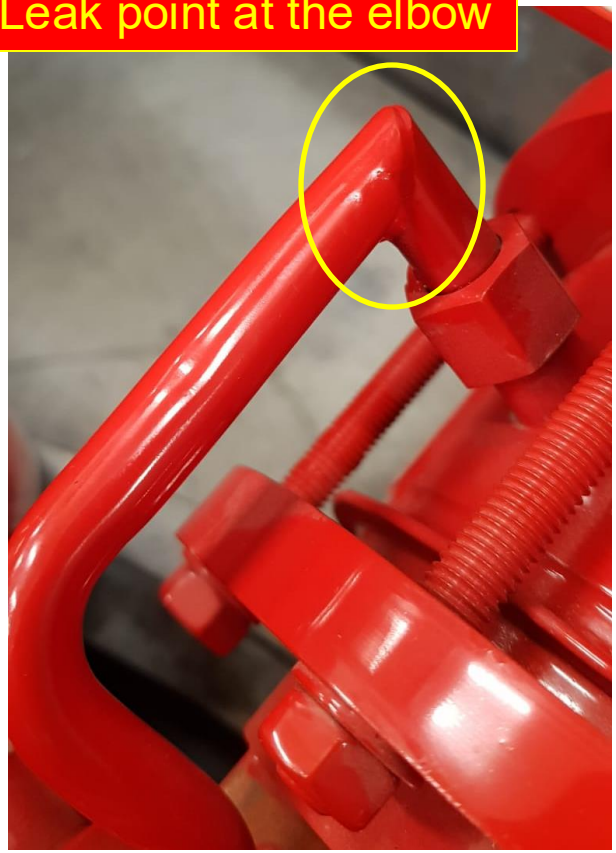
The additional RF switch in the upgraded power amplifier is suspected!




The operation becomes normal after removing the « RF switch »
Labo test of RF switch doesn't show any issue. Further investigation of the RF switch during the next machine session in real operation conditions.

# Water Leak in LINAC

Leak point at the elbow

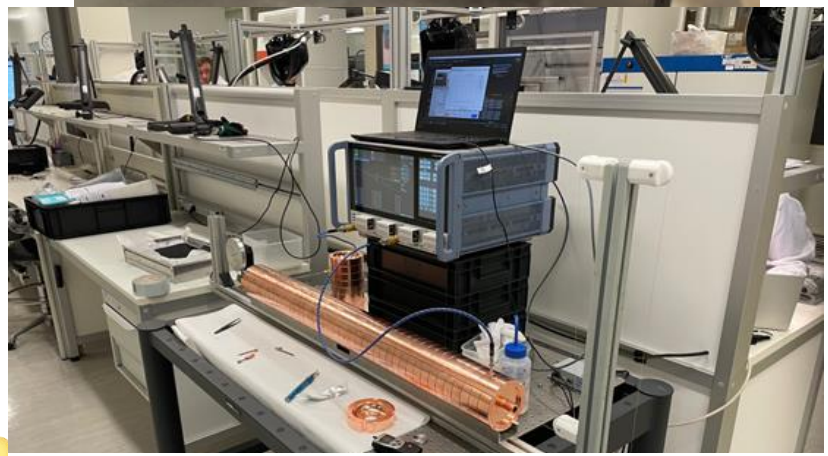


RF Window Cooling Pipe Aging

Leak detected, but no control room alert.

9 cm water in the HV tank at 2:00 AM

Project Buncher with **Thales AVS**



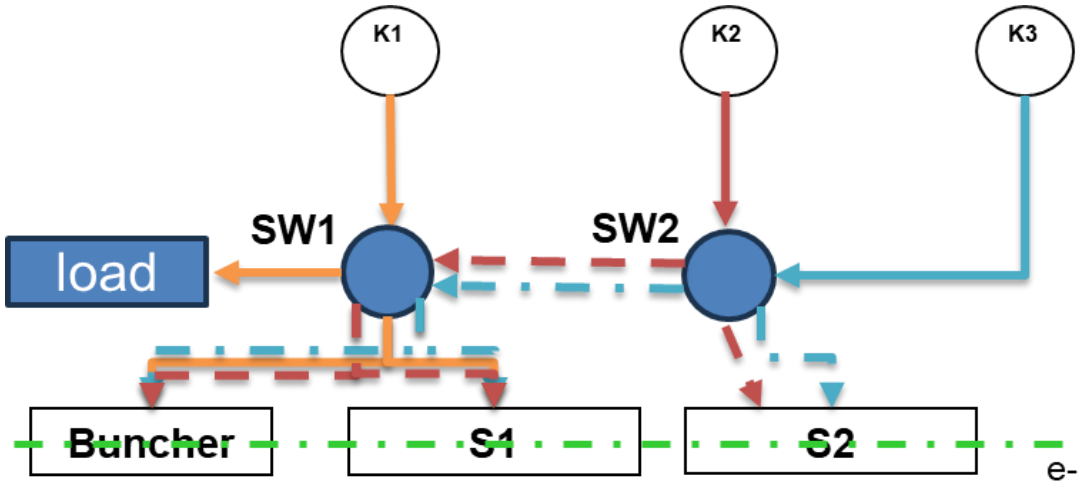
FAT: 2024 September
SAT: Next technical stop during 2025 Dec. to 2026 Jan.

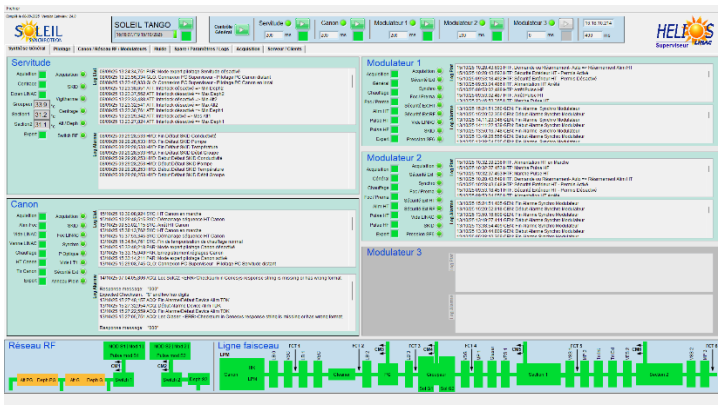
Project Modulator (JEMA) + Klyston


Solid-state Modulator (IGBT)

# LINAC 2026

- Increase LINAC energy from 110 MeV to 150 MeV to adapt BOOSTER in SOLEIL Ⅱ by increasing the power of S1 and S2.(10 MW to 20 MW)



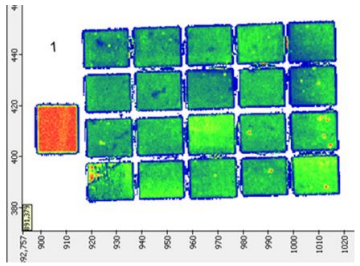



In case of a failure of one or the other klystron, two waveguide switches (SW1, SW2) allow to maintain the power in LINAC. The objective is to reach 150 MeV, which insure a correct injection into the future Booster.

# SOLEIL II

# 352 MHz Fundamental Cavities

- **Fundamental system - *5 x 352 MHz HOM-damped cavities***
  - Final Design Review last summer with the latest improvements
  - Ongoing studies with Institut de Soudure to test brazing samples of absorber ferrite and define the acceptance criteria
  - Tuner CFT launched in mid-September (8 tuners expected by May 2026)
  - Ancillaries CFT's (pick-ups, support frame…) to be launched by November 2025



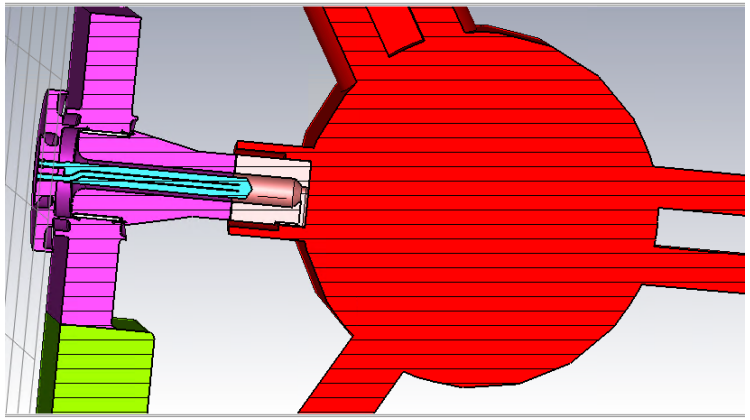
*Microsonic scan of a ferrite plate sample*

**250 kW FPC's**: built in the framework of a collaboration with CERN; first prototype under power tests at APS.

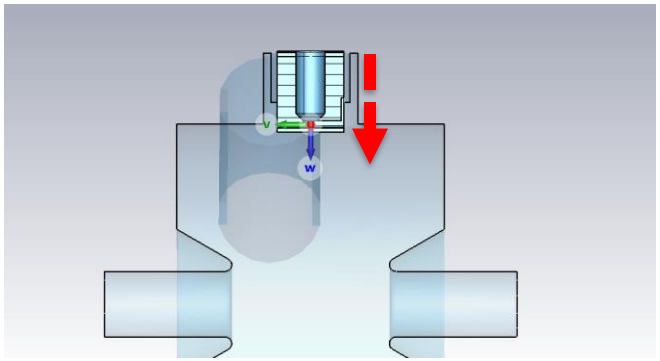
# 352 MHz Fundamental Coupler

- Lengthening of the antenna + depth penetration and loop rotation parametric study → With a loop insertion depth of 0 mm, the coupling factor (β) reaches a maximum of 7 at 90° and becomes 1 at 21°.

*(The loop is flush with the cavity edge for 0 mm depth penetration and is parallel to the H-field for 0° rotation angle.)*



Insertion depth: 1-5 mm



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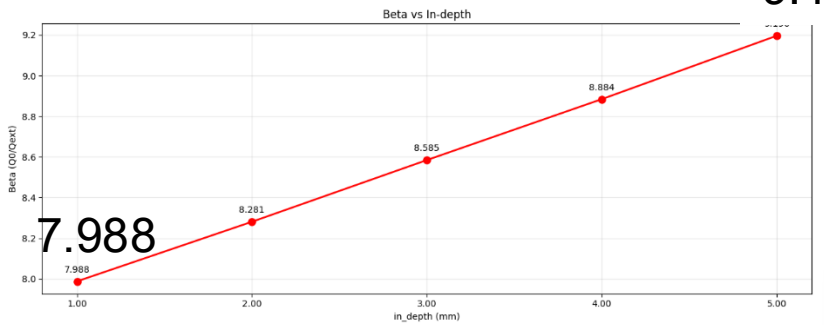
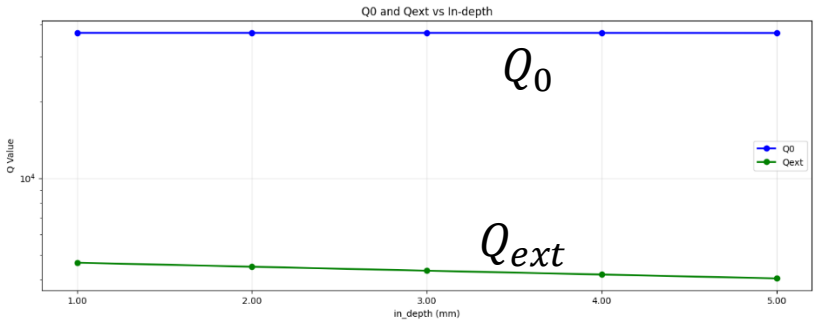
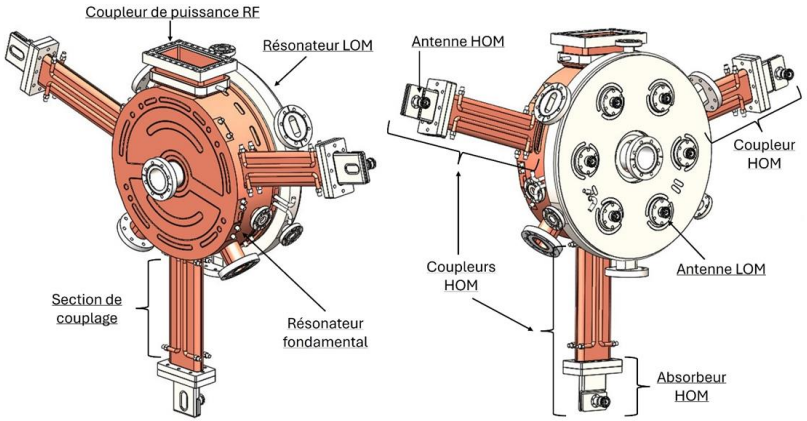


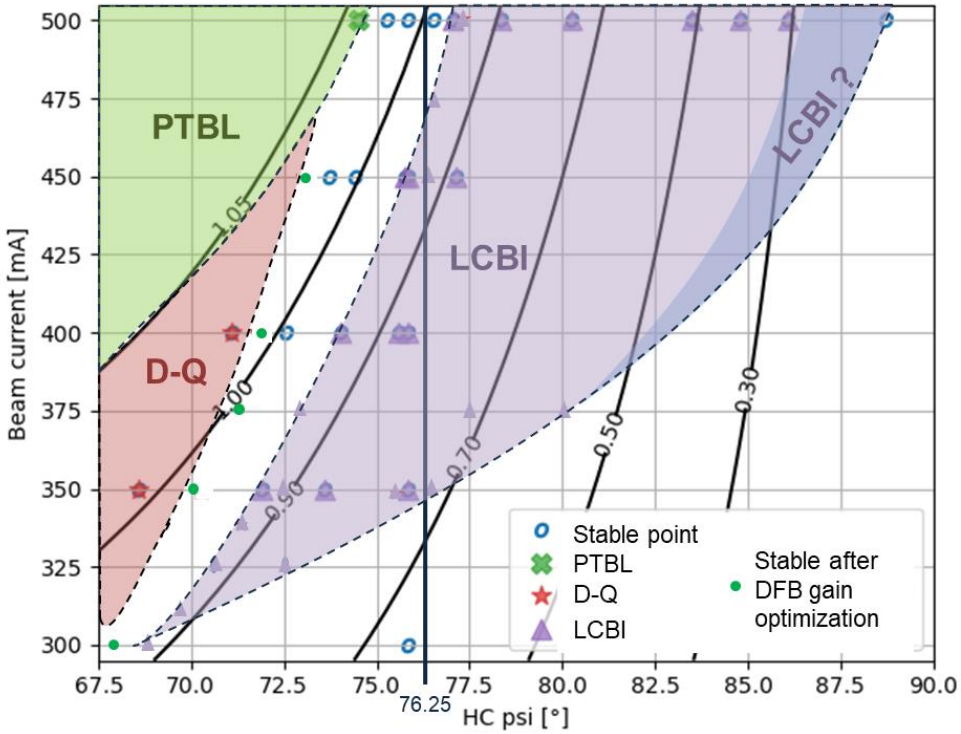
# 1.4 GHz Harmonic Cavity

- Designed in the framework of a collaboration with ESRF(presented by Pavel Borowiec)




– **Objective: Call for tenders for 3 x HC's**
  - Delivery of first HC mid-2027
  - Conditioning of the first HC in test area in fall 2027
  - Installation and tests of first HC in SOLEIL by beg. 2028
  - Launch fabrication of the 2 remaining HC's

# Instabilities Predicted by mbtrack2




In the left corner is the **PTBL instability** area (green) for high $\xi$ and $I_b$.

**There is a stable area in between the PTBL and LCBI ones.**

Unfortunately, it is significantly reduced by the **Coupled D-Q instability** (red area), which limits the achievable lengthening at lower current.

In the right upper corner, instability occurs (dark purple) but has not been analyzed yet. It might be LCBI.

**Tracking with direct RF feedback on MC**

4 MCs ($V_1$ = 1.7 MV, optimum tuning)
2 passive 1.4 GHz HCs ($R_s$ = 0.9 MΩ/cav, $Q_o$ = 31000)
Worst case for the MC HOM (8.8 kΩ at 1.7 GHz) and for the ID's, which are all open

- **Simulations with MC voltage optimization are under progress** and first results with 1.4 MV instead of 1.7 MV on each MC and DFB gain optimization show **stable areas for $\xi \approx 1$ and currents down to 300 mA**.
- Mode 0 phase feedback is being modelled to cope with Coupled D-Q instability

Courtesy of Patrick MARCHAND, Alexis GAMELIN

# A Backup Plan for Coupled Bunch Instabilities

- Longitudinal Bunch-by-Bunch Feedback study → the specific dedicated team (AP/RF/Diag/ISAC) to FBT/FBL has been set up in beg. 2025
- Collaboration with BESSY/Diamond for electronic system
- FBL kicker designs
  - Over-loaded cavity (Micha Dehler, SLS 2.0)
  - Resonant Stripline kicker (Nakamura Takeshi, KEK)

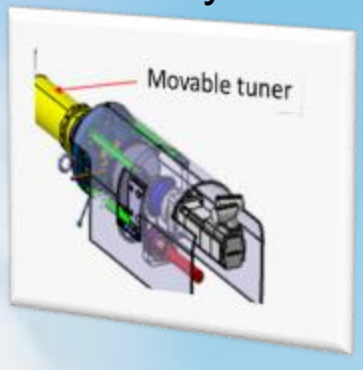
An RF expert is welcome to rescue the kicker design before it kicks back!

# RF Control & Supervision system

RF ecurity


Note: AI generated images

Tuner system

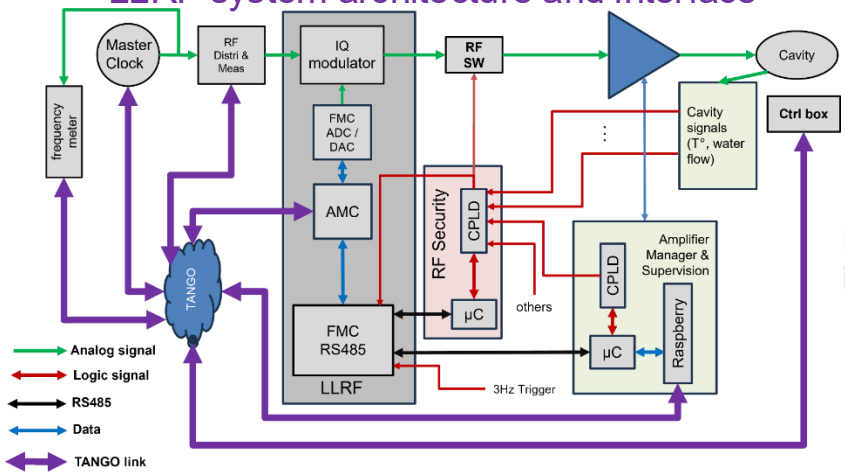


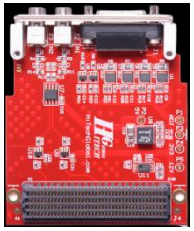

LLRF system

Power amplifier

# Digital LLRF System

LLRF system architecture and interface



FMC 4-Channel RS485/RS422
Module HTG-25PMD-SMB

FMC LXD31K4-DC 4 channel
16-bit ADC/DAC (Logic-X )

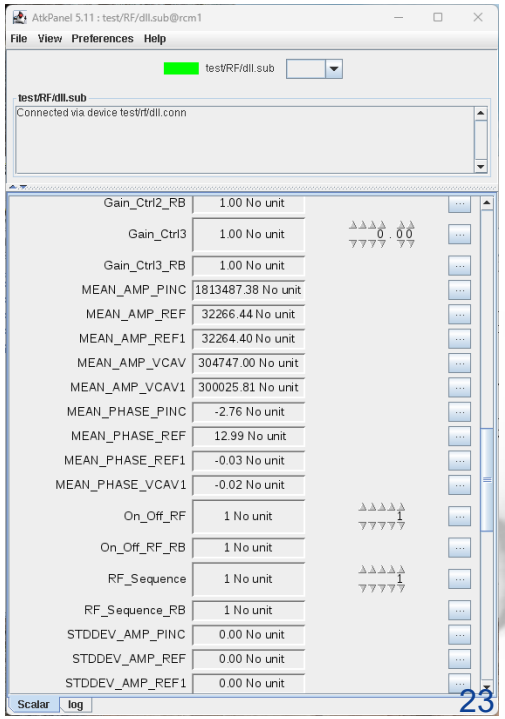
DAMC-FMC2ZUP (CAENels)

The cavity tuner is controlled completely by a cross-compiled C program which is running in the PS of the ZU+.

This function was successfully tested on the machine, with the full beam loading.

The ChimeraTK firmware from DESY is also implemented in order to communicate with the TANGO control system.

The DLLRF system will be installed in the booster at the end of 2025 and in the storage ring in mid-2026.



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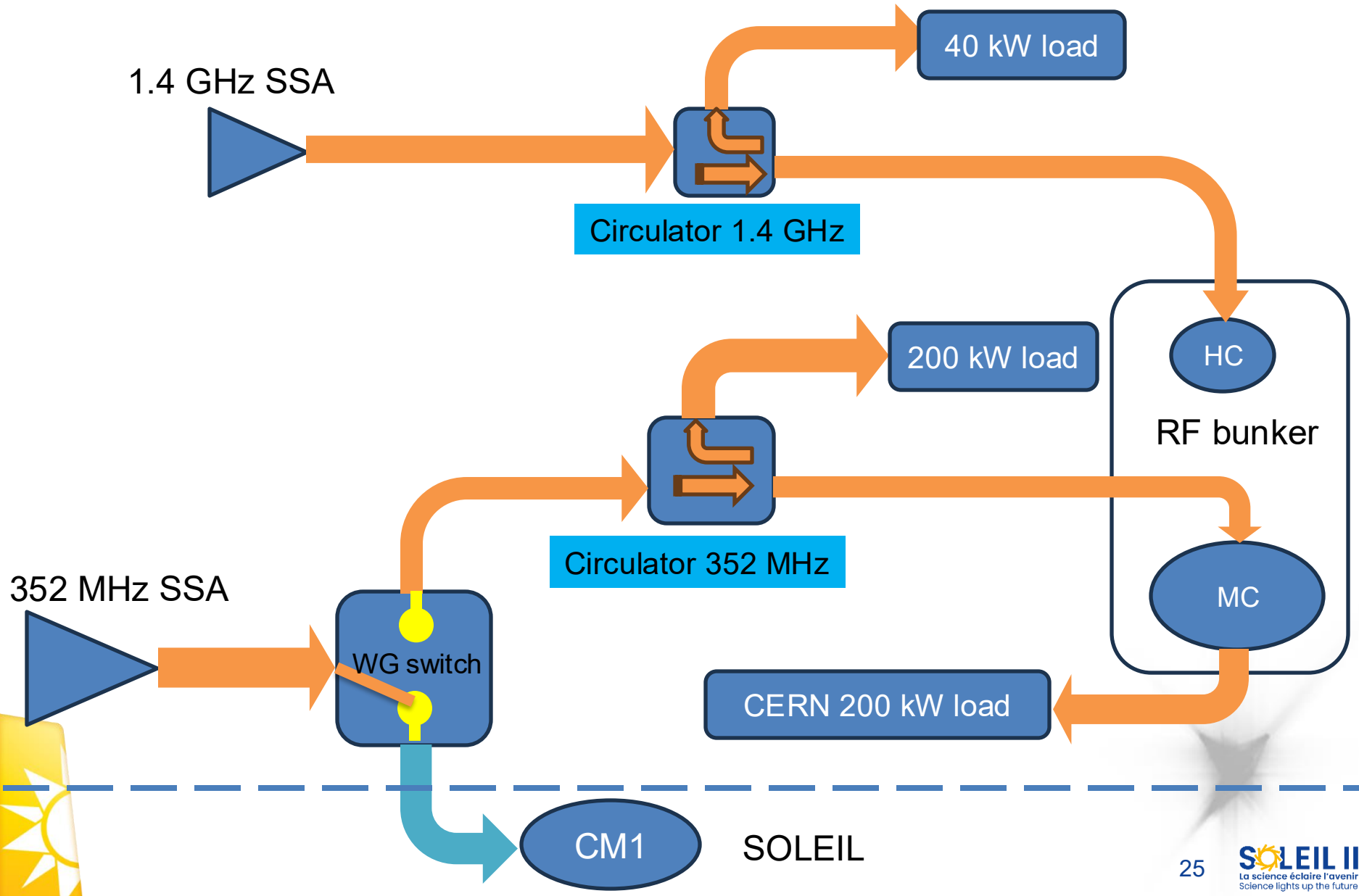
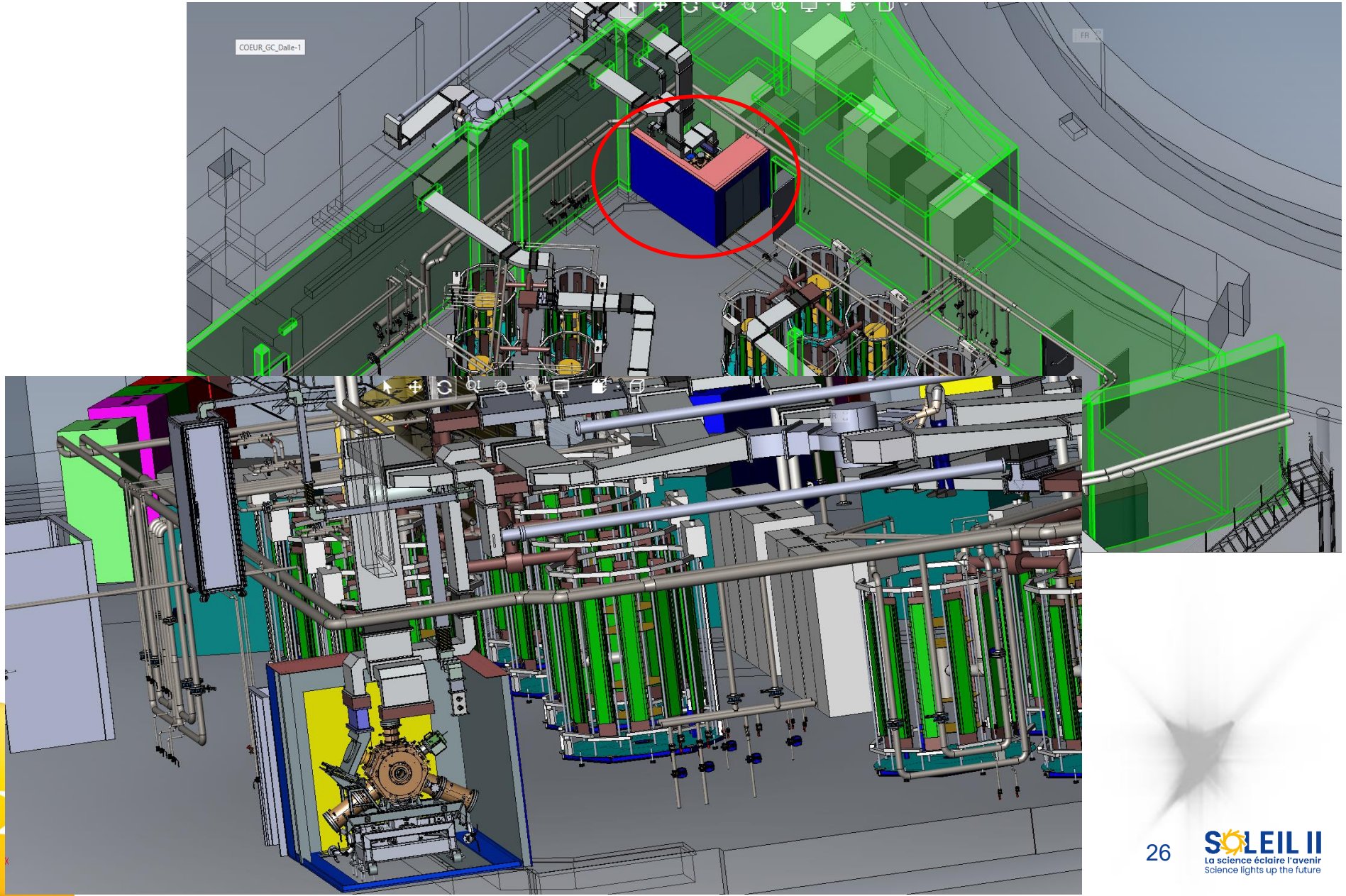
# 352 MHz and 1.4 GHz Test stand

# Overview of the New Test Area



# Test Area: RF Bunker



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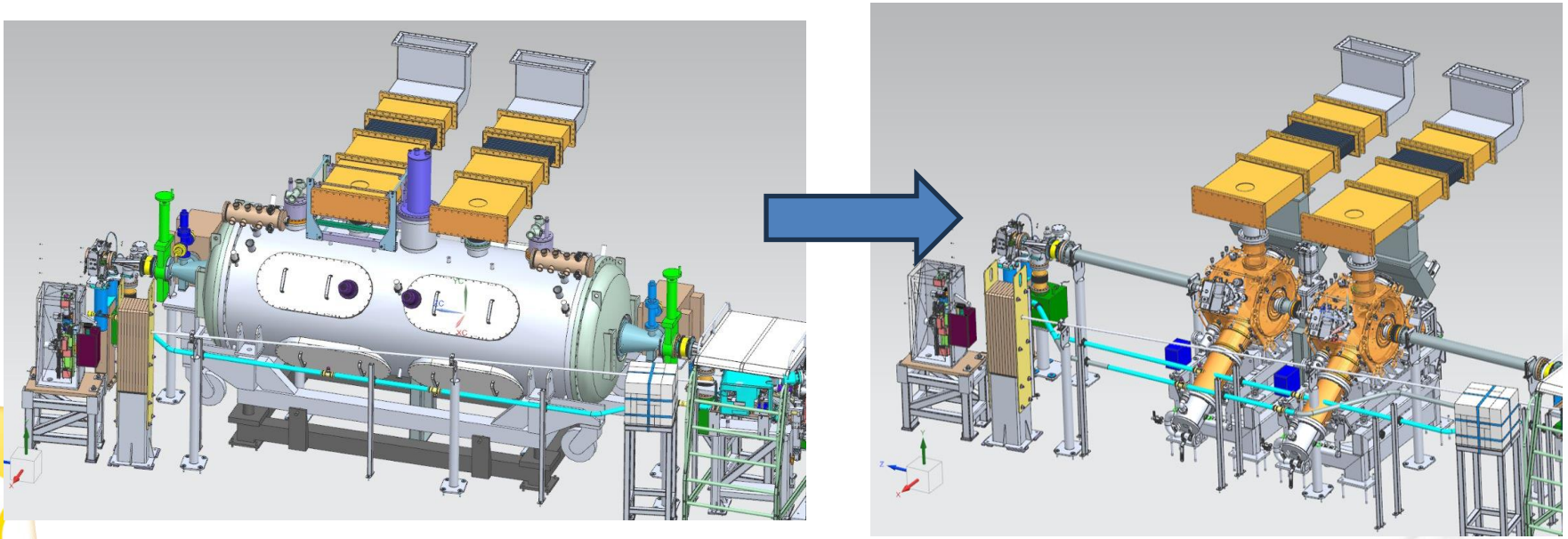
# 2 x 352 MHz Cavities in SOLEIL

## Work Description:

- Conditioning of 2 x 352 MHz power couplers in the test area – En of Summer 2026
- Conditioning of the 2 first 352 MHz cavities in the test area – Fall 2026
- Disassembly of CM#1 and replacement by the 2 new cavities – Mid 2027
- Use of SOLEIL II DLLRF system and upgraded SSPA's – from mid 2026 onwards
- Test and validation of the two new RF plants with beam up to 500 mA – 2027/2028
- Shutdown of summer 2027 is considered to install the cavities.



# RF Planning for SOLEIL II

- A multi-year RF roadmap, with specific construction milestones
  - RF conditioning: August 2026-Shutdown
  - MC (main cavity) and HC (harmonic cavity) testing in the present storage ring + DLLRF

**Aug. 26**
RF Bunker ready

**Aug 26 / Dec. 26**
RF Conditioning
-300 kW Coupler
- First 2 RI 352 MHz Cavities

**July-August 27**
Installation in SOLEIL SR of the 2 first RI 352 MHz Cavities

**Fall 2027**
RF Conditioning
*-1st HC cavity*
*- Cont. of RF systems*

**January 2028**
1st 1.4 GHz HC installed into SOLEIL

**October 2028**
Shutdown of SOLEIL

In parallel to operation
Stored Beam reduced to **450 mA**

3-6 months for validation
3 more cavities to manufacture

RF conditioning of the 3 other MCs

Construction, then RF conditioning of the 2 other HCs

Fall 2025
**New DLLRF in** operation for Booster

Summer 2026
**New DLLRF** in operation for SR

# Thanks for your Attention!