Experience with SPS RF and outlook

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10/12/2024

Introduction and outline

6 x 200 MHz cavities in SPS

2 x tetrode systems

1 x solid state

- Single exceptional failures
- High failure rate
- Siemens update

Cavity 1 & 2

Cavity 4 & 5

Cavity 3 & 6

Introduction

One Transmitter is composed of

- 16 x 144 kW RF amplifiers

One RF amplifier is composed of

- 1:80 cavity splitter
- 80 x 1.8 kW RF blocs (160 transistors)
- 80:1 cavity combiner

In total

- Two transmitters
- 32 RF amplifiers
- 2560 RF blocs
- **5120 transistors**

Introduction

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One RF ar

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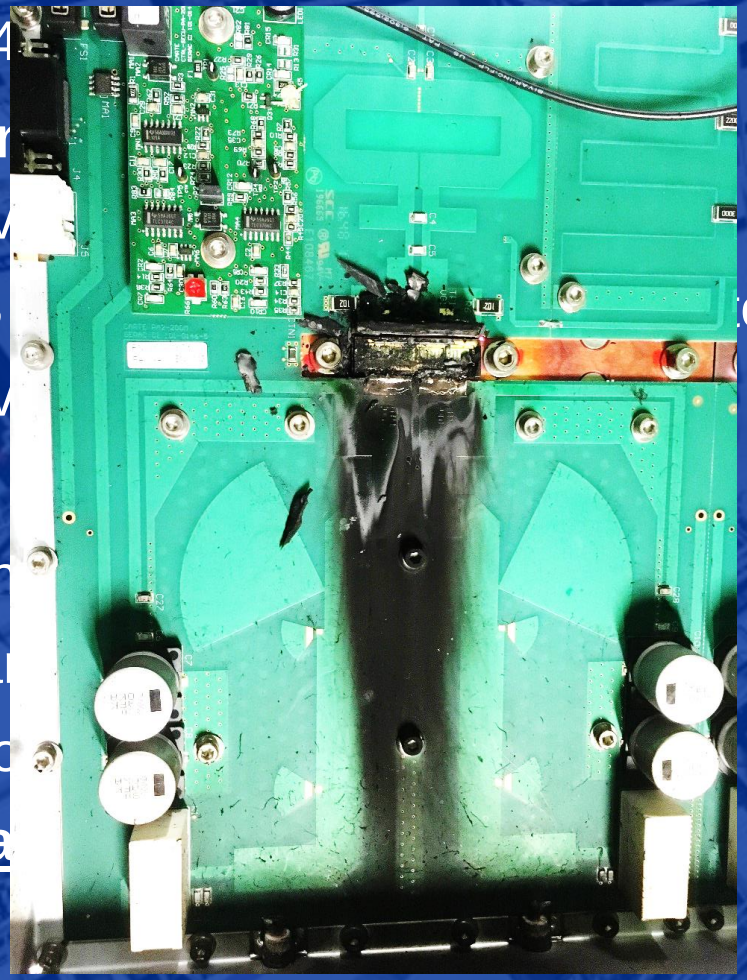
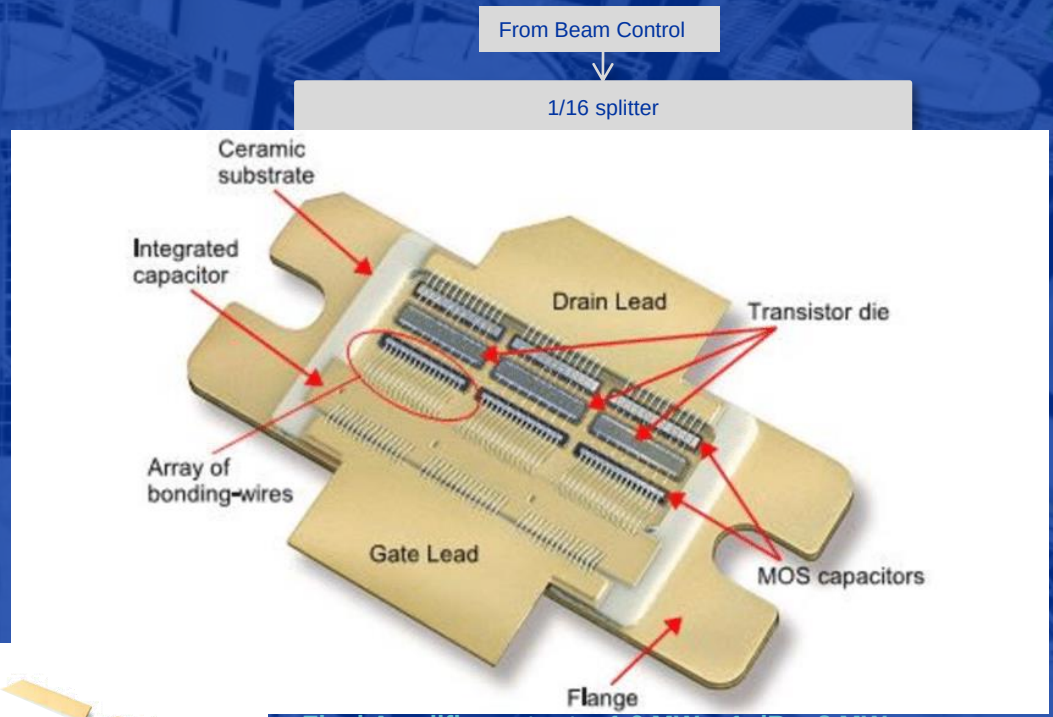
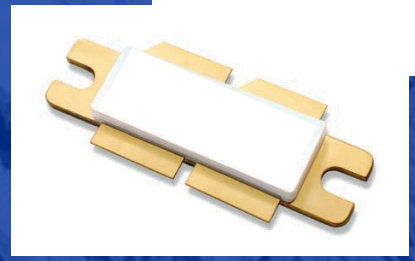


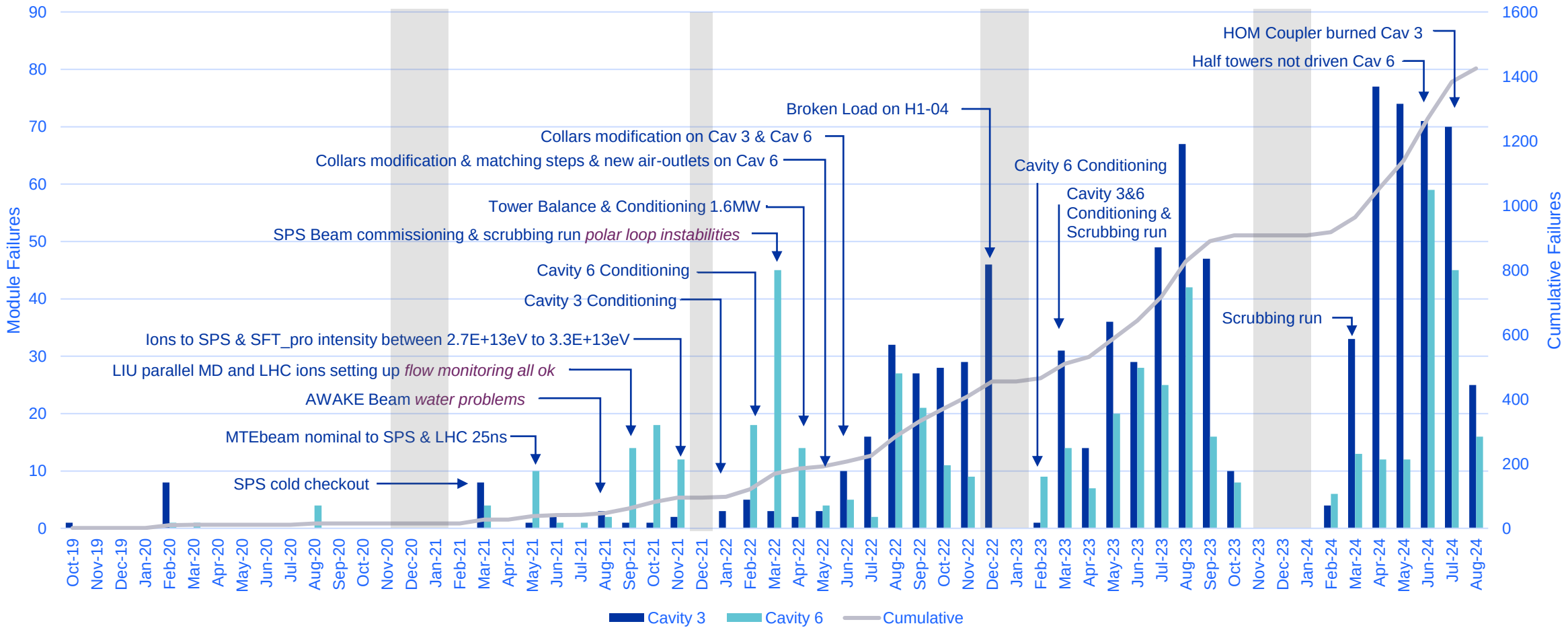
2 x





Final Amplifier output = 1.6 MW + 1 dB = 2 MW

16 towers of minimum 125 kW


Module Failures
Cumulative Failures
HOM Coupler burned Cav 3
Half towers not driven Cav 6
Broken Load on H1-04
Collars modification on Cav 3 & Cav 6
Collars modification & matching steps & new air-outlets on Cav 6
Cavity 6 Conditioning
Cavity 3&6 Conditioning & Scrubbing run
Tower Balance & Conditioning 1.6MW
SPS Beam commissioning & scrubbing run polar loop instabilities
Cavity 6 Conditioning
Cavity 3 Conditioning
Scrubbing run
Ions to SPS & SFT_pro intensity between 2.7E+13eV to 3.3E+13eV
LIU parallel MD and LHC ions setting up flow monitoring all ok
AWAKE Beam water problems
MTEbeam nominal to SPS & LHC 25ns
SPS cold checkout
Cavity 3
Cavity 6
Cumulative

SSPA exceptional failures

1 Scrubbing

Large vacuum spike on cavity 3, 14 modules broken within 30 minutes, around 30 in total.

Degraded mode for 4 days, scrubbing at flat bottom only.

Reduced number of modules that can break before calling piquet to 3

2 Half towers unpowered

LLRF signal cable disconnected from half towers, around 100 modules lost (over around 3 months)

2 x high power loads broken

Towers are thought to have been overdriven

Interlocks have since been connected to prevent this happening again

3 No AM modulation

AM turned off in HIRADMAT cycle – 14 modules lost at once

For 2 batches to be spaced half a ring apart

Peak power only achievable with AM – Mandatory not interlocked

Working on average power interlock

4 HOM coupler burned

10 modules lost in 30 mins prior to HOM burning

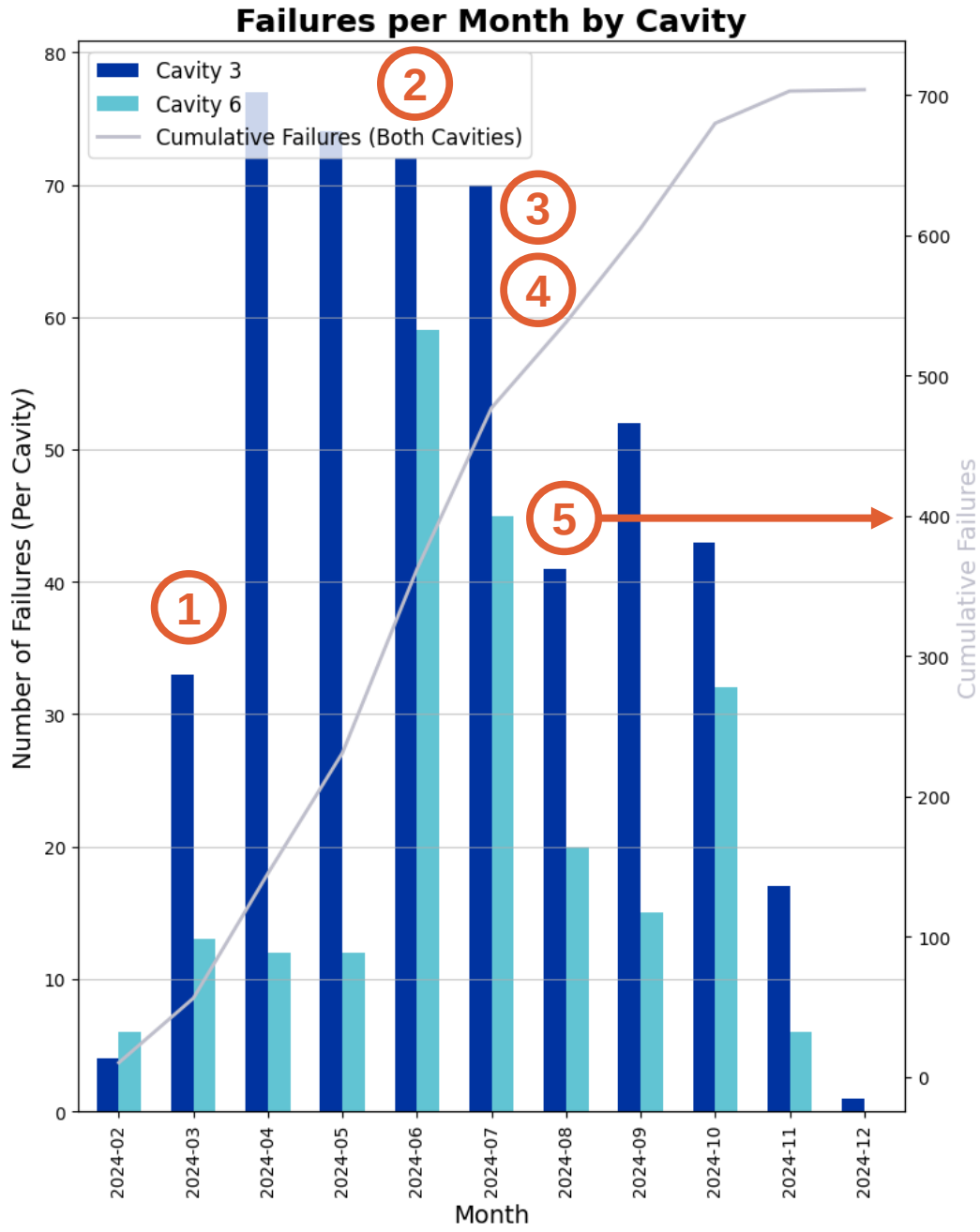
Same coupler in Cav 6 to be inspected in YETS

5 Broken Loads

Loads on isolated port of combiners have been broken

Not clear what impact this had on failure rate

All loads to be replaced in YETS (14/30 replaced during the run)



Measures taken

Improved brazing	Tightened acceptance criteria	Installed additional logging	Commissioned test bench
Cleaned cooling water circuit	Line length analysis	Measurements of whole system	Reduced gain of individual towers
Isolating problem tower	Modules PCB improvements	Module position analysis	Changed high power loads

SSPA Failures

What we know

- **Overdrive**
  - Modules are very sensitive to overdrive. Overdriving a small amount on the test bench resulted in rapid failure.
  - Instances of known overdrive have correlated with high rates of module breakage.
- **Cavity 3 has higher failure rate than Cavity 6**
  - Cavity 3 has poor impedance matching step
  - Higher baseline vacuum level
- **Loads need maintenance**
- **Thermal problems lead to high loss.**
  - Brazing to coldplate is essential
  - Integrity of the cooling system

What we don’t understand

- **Reflected power**
  - Installed scopes to monitor reflected power to towers on Cav 3
  - Could not correlate reflected power transients to module breakage (ongoing)
- **Different tower breakage rates**
  - No understanding of why some towers experience next to no loss, and some very high loss.
- **Failure rate vs Cycle**
  - Difficult to analyse as SFTPRO1 is running all of the time

YETS & Future Operation

YETS

Cavity 3 matching

Reduce reflected power back to modules but also maximise power into cavity.

Inspection of HOM coupler in Cav 6

Replacement of high-power loads

New mechanical passive gain and phase adjustment.

Overdrive protection upgrade

Average power interlock

This should enable us to operate with nominal power values from 2025

Spares

Spares management is what has limited us operating at full power this year.

Worst case 3 modules broken per day we would need to replace 1500 transistors in 25-26 run.

We will have 1430 spares

>1000 need to be brazed to baseplate

Ceramic transistors

More robust

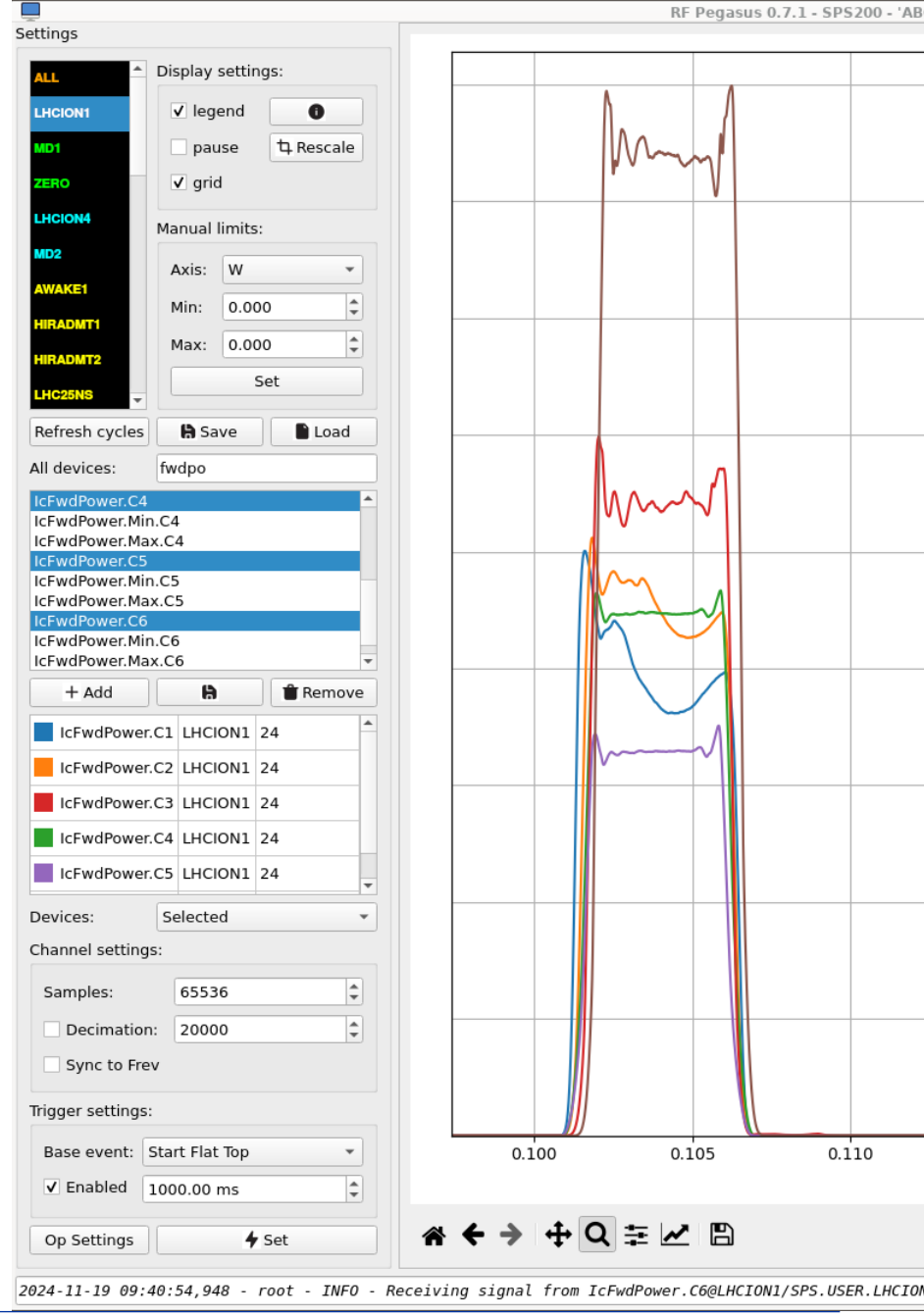
Better for pulsed power operation

plastic case absolute maximum drain-source voltage
133 V

ceramic case absolute maximum drain-source voltage
177 V

C1&2 missing power

- Reduction in gain within pulse for C1 and C2 needs to be addressed
  - See I.Karpov at JAP23
- Filament voltage was reduced to expand the lifetime of the tubes
  - See E. Montesinos at IEFC23
- This means less gain and less peak power
- Can be increased if we are prepared to consume more tubes
  - Would need to be discussed with supplier
  - Would also require more person power
- No filament transformer spares
  - About to launch a tender for delivery in 2025



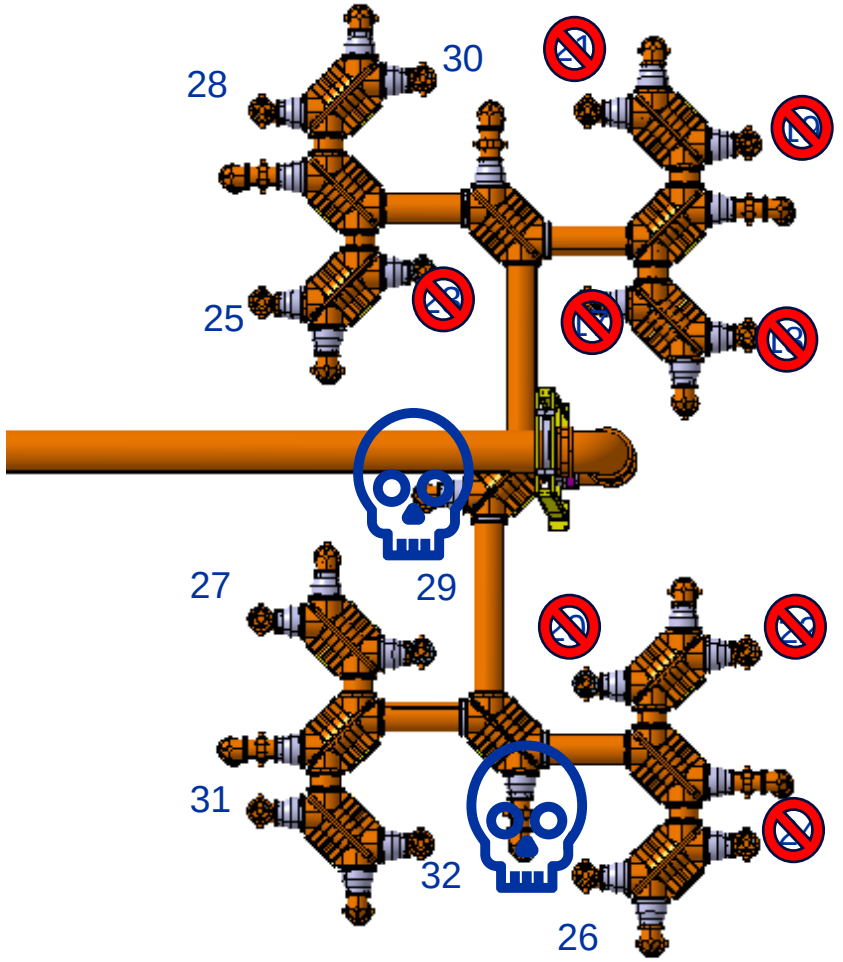
Summary

- **SPS high power RF caused a lot of downtime and degraded operation this run**
- **Some events were unavoidable, those that were avoidable have informed improvements already actioned or to be done in this YETS**
- **Ongoing efforts to understand the root causes of the high failure rate**
- **Nonetheless improvements are being made to reduce the failure rate**
- **More spares should enable us to run at nominal values next run**
- **Excluding exceptional events, we have benefitted from the granularity of the system**
  - Broken modules changed mostly in shadow
  - Opportunity to benefit even more from this next run by reviewing piquet procedure

home.cern

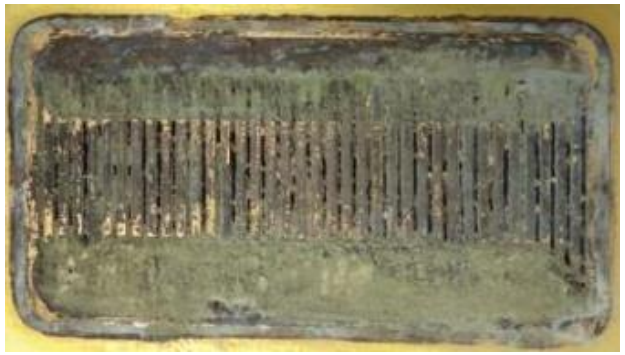
Technical stop event

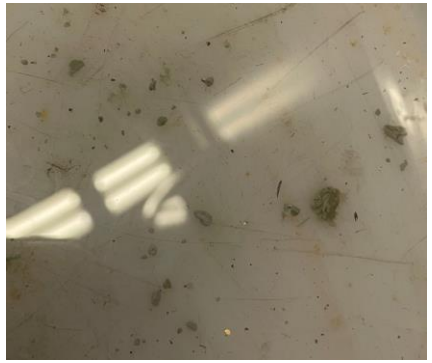
- A connection error lead to the LLRF signal being missing on one half of system
- Some towers were full power and some zero
- This was very unbalanced due to the integration
- T26 first lost 13 modules
- Then the load broke
- Next the final load broke
- Finally the signal was re-established to the other towers
- Around 100 modules broken as a result of this event

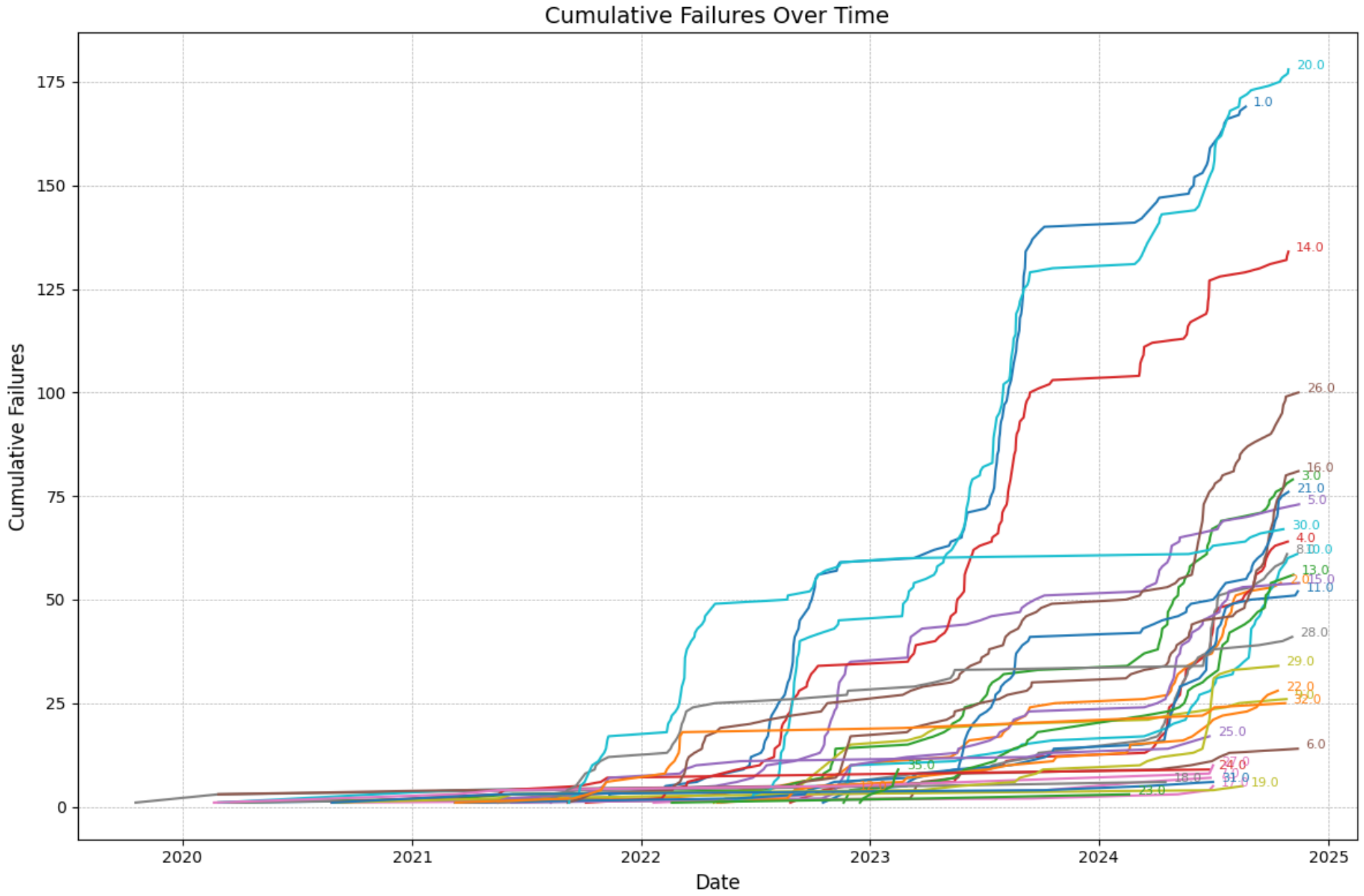


Thermal Paste

- Thermal paste was introduced to the cooling system
- This blocked the cooling channels of the transistors and caused overheating
- System was flushed of impurities
- Uncertain if there are still blockages causing problem
- We still see burned transistors






Cumulative Failures Over Time
Cumulative Failures
Date
0
25
50
75
100
125
150
175
2020
2021
2022
2023
2024
2025
20.0
1.0
14.0
26.0
16.0
3.0
21.0
5.0
30.0
4.0
13.0
15.0
11.0
28.0
29.0
22.0
25.0
6.0
35.0
18.0
19.0
23.0

SPS Downtime

- >200h downtime for SPS attributed to RF Power
  - For downtime and fault statistics see G. Papotti at RF internal Operations Review on 21.11
- Significant faults:
  - SSPA module failures
    - See next slides
  - Cavity 1 elbow arcing, exchanged and solved
    - See F. Killing at SPS MPC on 30.07
  - Cavity 3 burned HOM coupler
    - Single event – not linked to beam intensity
  - Cavity 6 half towers not powered
    - Human error, covered by interlock now.