Cavity Fault Analysis Summer 2020 Data Set

Tom Powers

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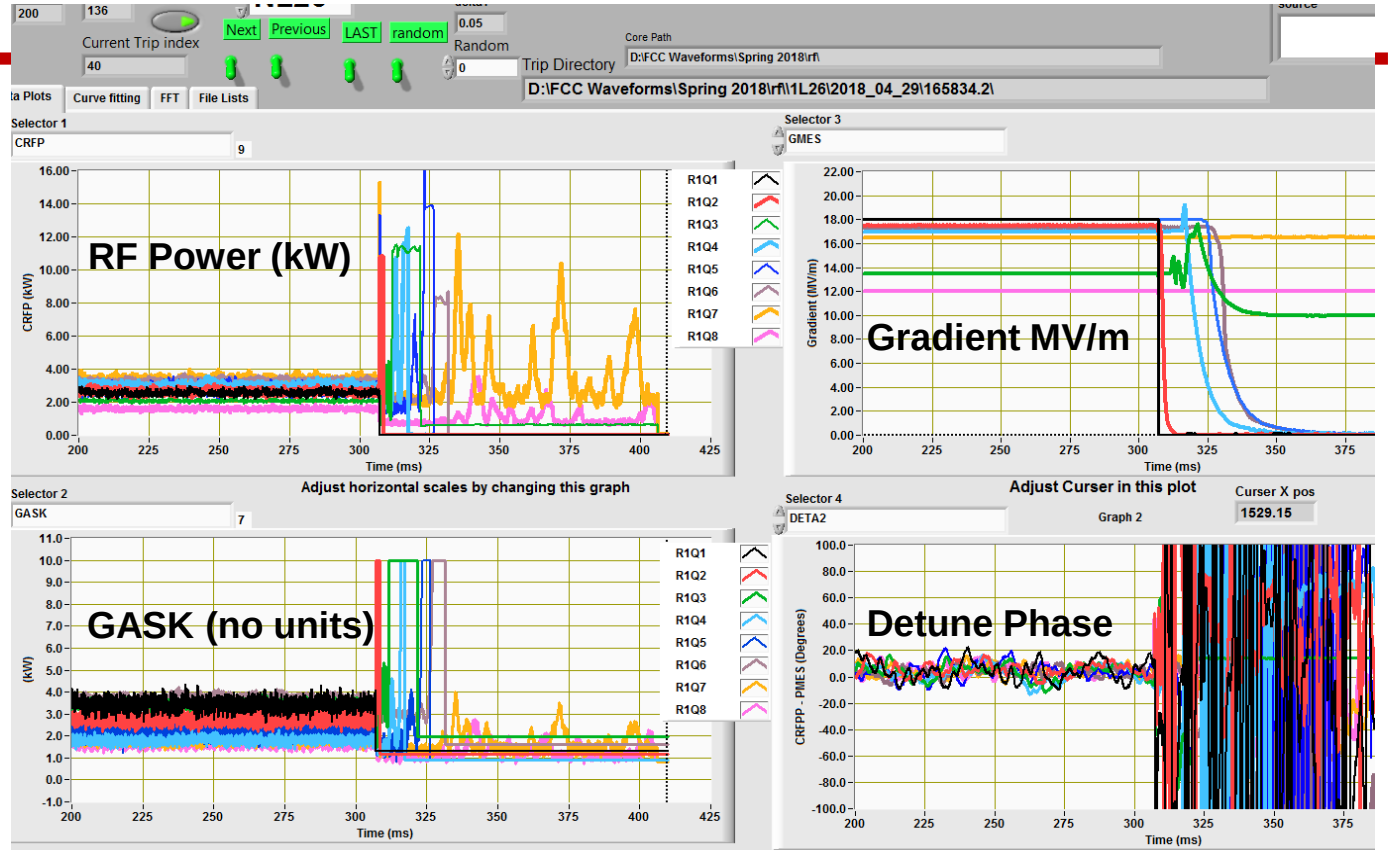
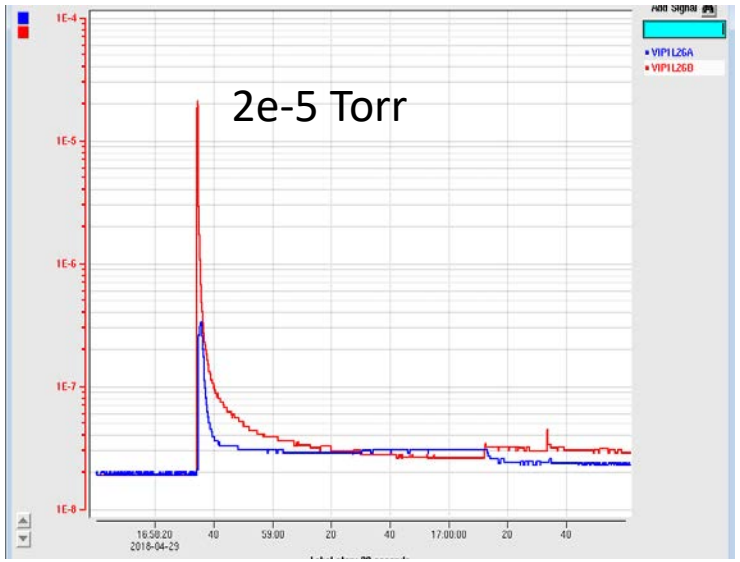
Fast “Electronic Quench”

- Fall time of cavity gradient faster than 50 us (one point at this acquisition rate).
- Cavity seemed to be operating normally up until this point.
- Theory -- vacuum burst in cavity releases large quantities of electrons which absorb the energy within the cavity.
- 93% of the fast quenches in the Fall 2019 run were in cavities 1 or 8 the rest were distributed between the other 6.
- Extensive leak checking was done without finding a problem. FE radiation induced photo-desorbtion is likely.

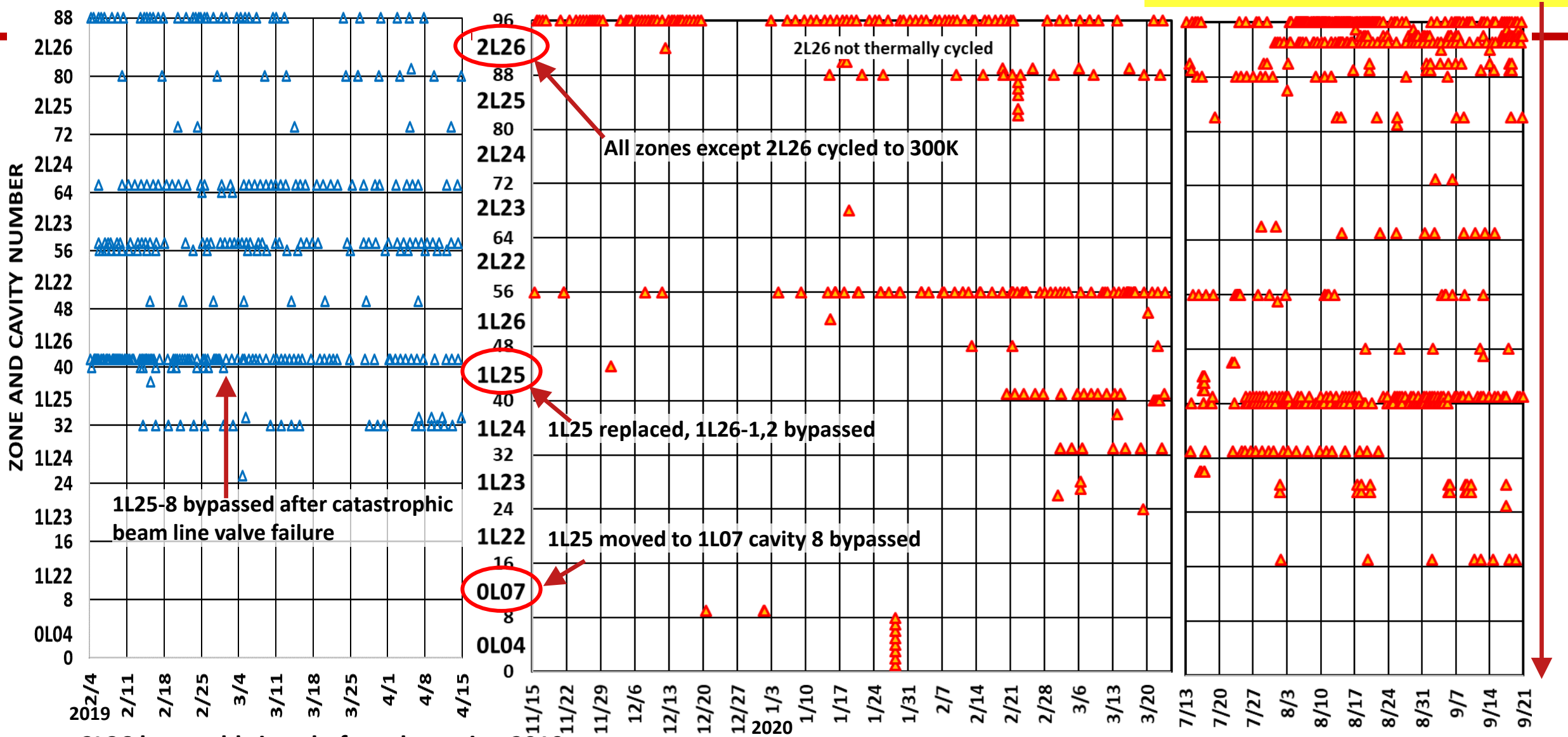




- Corresponding beamline vacuum excursion.
- Red trace is pump next to cavity 1 blue trace is at the upstream end of the girder.
- Peak vacuum signal adjacent to cavity 2e-5 Torr at the other end of the girder was 3e-7 Torr.
- No events were recorded where cavity 1 in one zone and cavity 8 in the adjacent zone had the same fault at the same time which indicates that the event was not due to a vacuum burst in the girder between the cryomodules.

The Effects of Warming Up Cryomodules On Frequency of Electronic Quenches

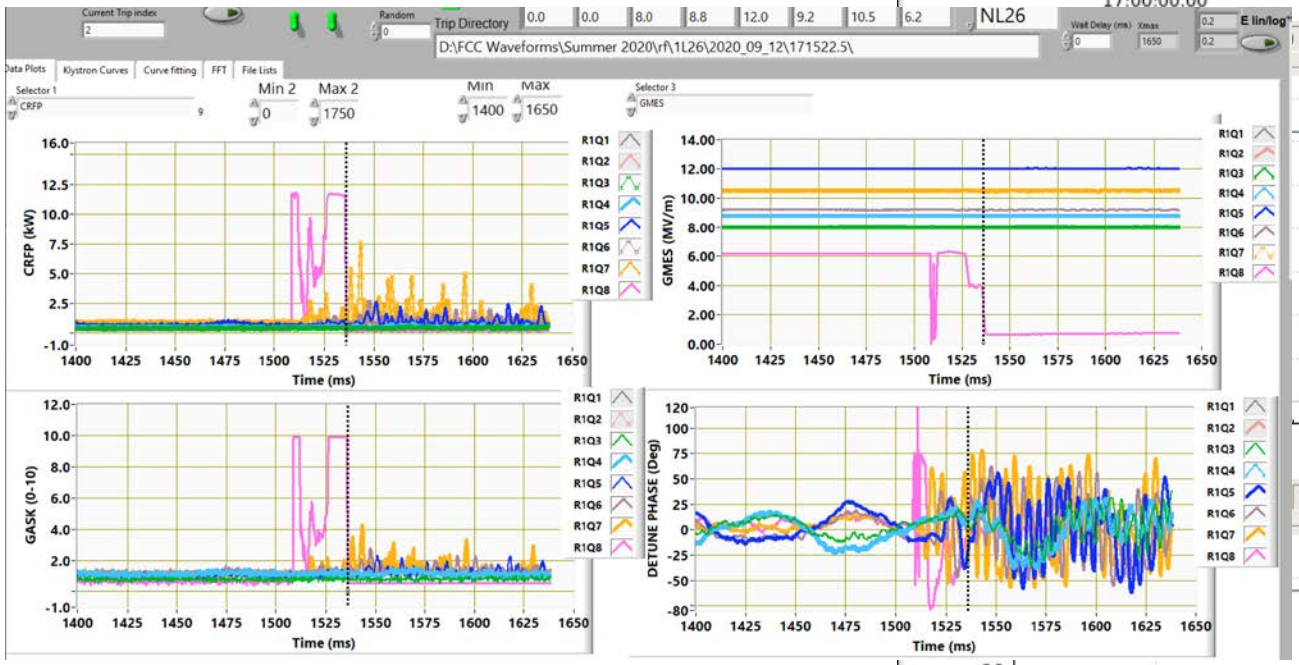
North Linac being thermally cycled to 300K
2L26 will be cycled to 300K



- 2L26 kept cold since before the spring 2019 run
- All other cavities warmed up to 300K and girders were pumped on for 2 or 3 months, 1L26 was warm for 5 weeks.

Repeated Quenches

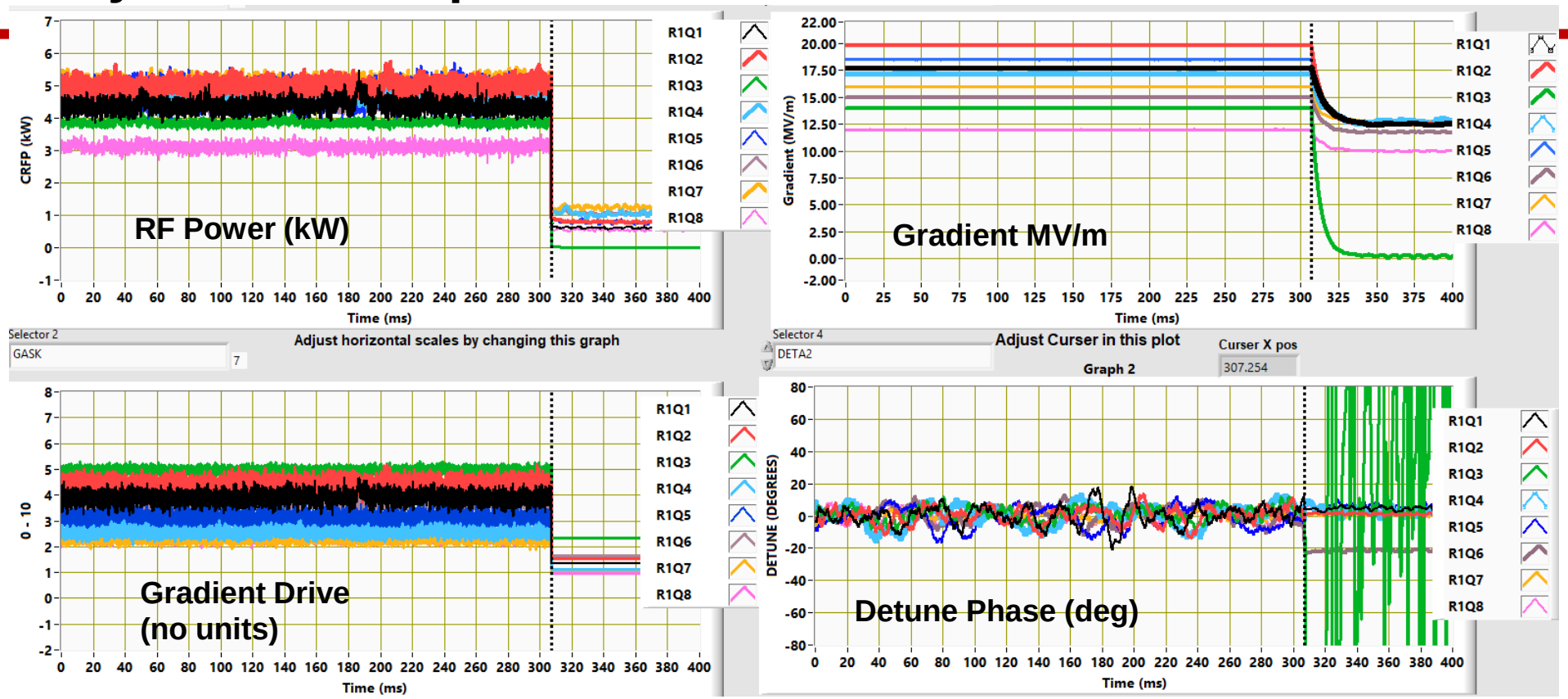
- On a few zones cavity 1 or 8 would have repeated thermal quenches
- In this instance it took about 20 minutes for the zone to recover.



Repeated Turn on tries

- The system tries to ramp the gradient up to 6.5 MV/m and has substantial RF power 500W to 1 kW dissipated in the bath.
- The system finally recovered after the cavity was left off for about 1.5 minutes.
- Observation - Cavities 1 and 8 have different boundary conditions where the beam pipe on the HOM end is attached to the warm to cold transition.
- On other cavities the HOM beam pipe is connected to a cavity at 2K.
- Similar events were observed in 2L26 and 1L23.
- Somehow this type of event needs to be flagged and a delay before turn on should be applied.

Single Cavity Interlock Trip



- Zone running fine and at about 300 ms cavity 3 trips off going to a zero RF power even while GASK is not at zero. This is an indication that the RF switch was open.
- The gradient decays with a nominal turn off decay time.
- Note that the forward power did not jump up before the fault.
- Detailed analysis of the archived fault data indicated that >60% of these faults are quench faults (QNCH) detected by the field control chassis.
- This fault is supposed to be triggered by a 15% reduction in gradient for several milliseconds.

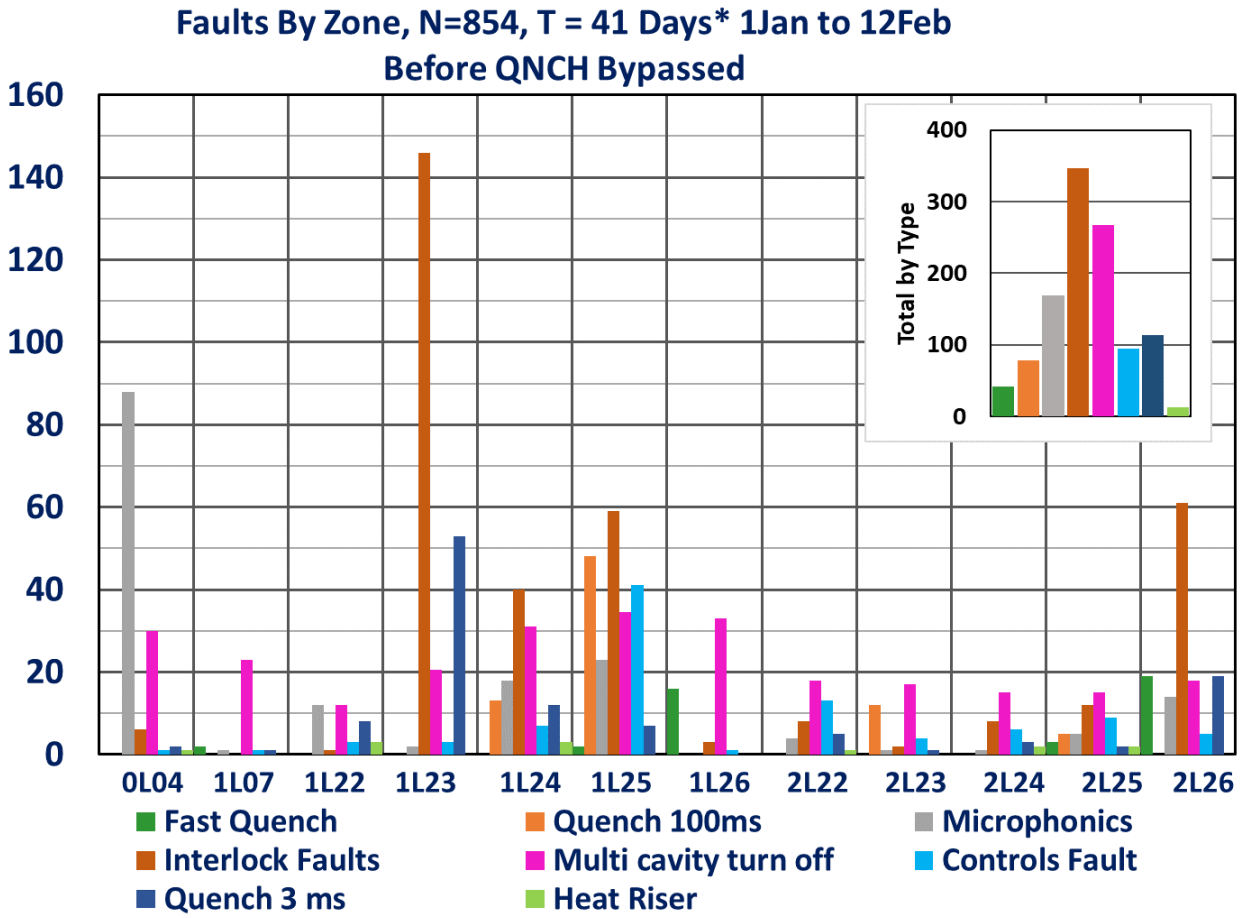
QNCH Fault Issue (Understanding what to fix)

- In the summer of 2018 I compared the fault logger and archiver indicated that 61% of the waveform indicated interlock faults were due to QNCH faults.
- Lots of other fault types show up as QNCH faults
- This was one of the first data sets so I was potentially identifying 3ms quenches as interlock faults. (e.g. the total number of single cavity interlock trips was over counted.
- A test was run on a single cavity in the fall of 2018 to see if the faults could be reduced by bypassing the QNCH fault.
- On Feb. 2020 the quench fault was bypassed in 5 zones.
- This was later expanded to the rest of the C100s.
- IOC reboots, may have caused some zones to revert.
- Working on a permanent fix during the current long down.

E_Quench	41
GLDE	1
PLDE	1
QNCH	39
Microphonics	163
Other or none	23
GLDE	6
PLDE	69
QNCH	65
Quench	126
Other or none	3
GLDE	7
PLDE	61
QNCH	43
DETA	12
Single Cavity Turn Off	140
Other or none	18
GLDE	0
PLDE	0
QNCH	86
DETA	5
CWAT	31

Data from the spring of 2018.

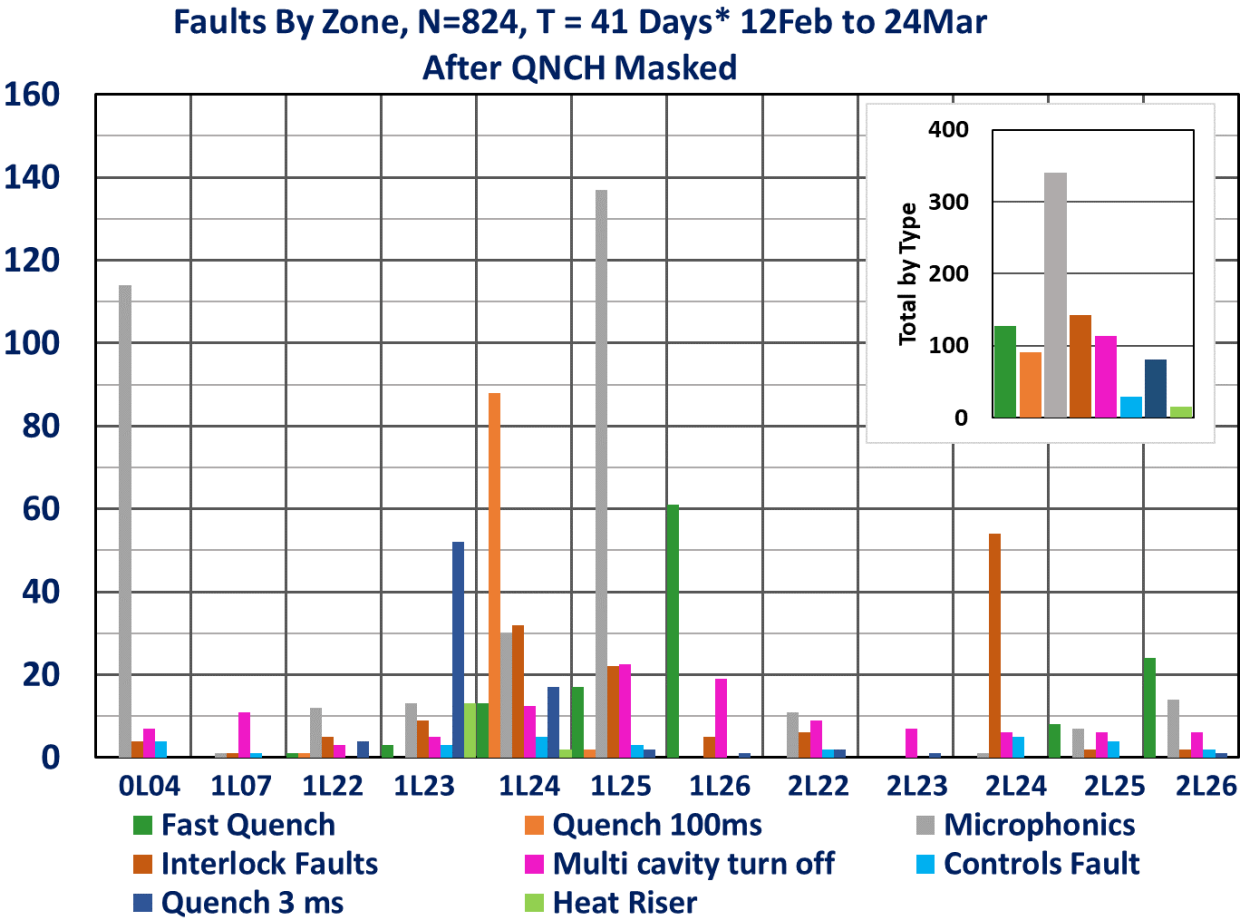
Fault Statistics Prior to Bypassing QNCH Fault on 5 zones.



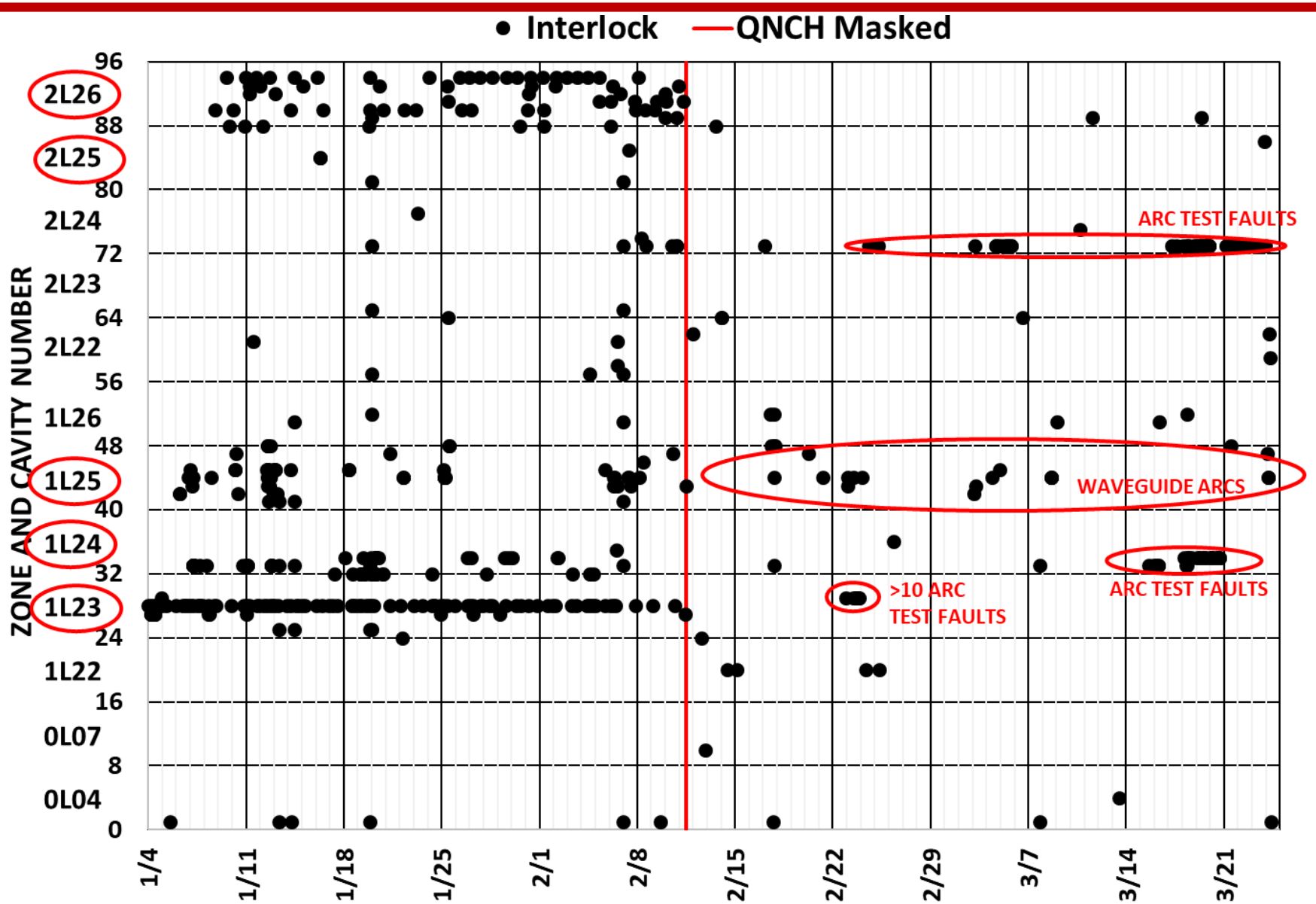
41 days prior to bypassing QNCH faults, 40% of faults were interlock faults

After bypassing the zones

- **Most of the faults were Microphonics, or in 1L25 arcs or vacuum faults induced by Microphonics.**
- **15% were interlock faults**



Reduction in Interlock Trips When QNCH Interlock Was Bypassed



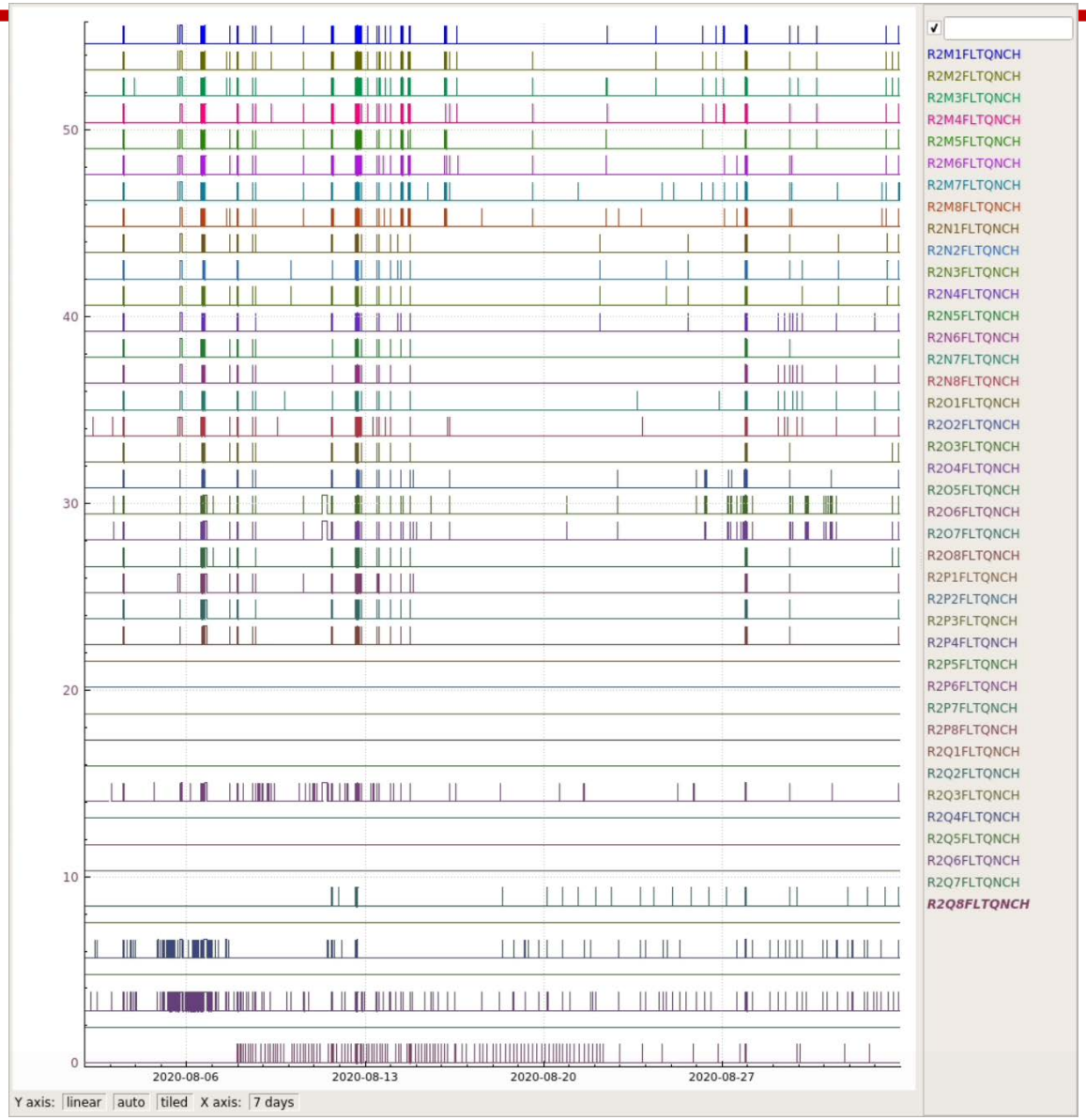
After 5 zones had the QNCH fault bypassed.

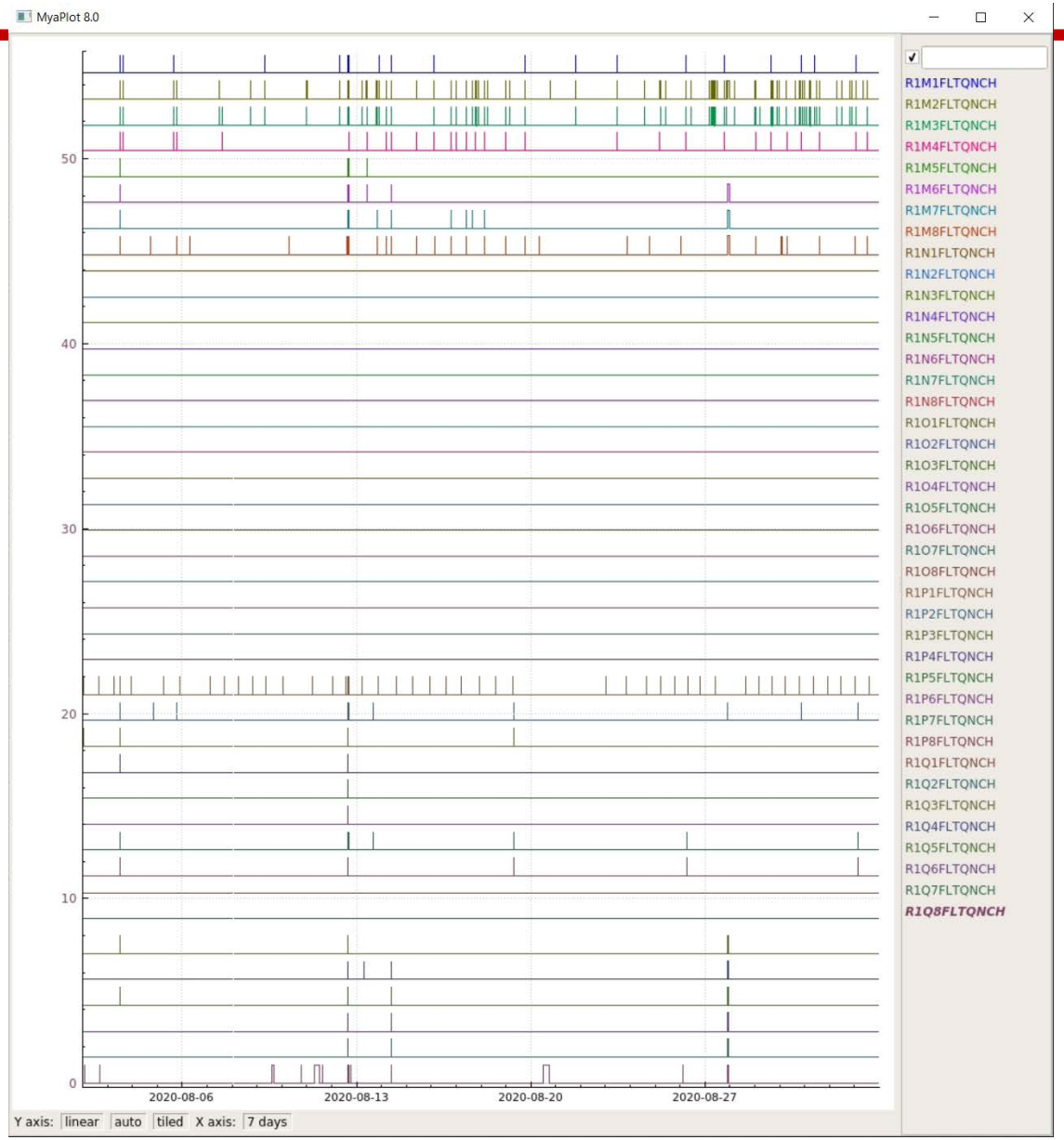
- Of the 129 faults identified as interlock faults
- 70% were arc test faults
- 18% were arc or waveguide vacuum faults
- 10% were QNCH faults on zones where it was not bypassed
- 4% were gradient or phase error faults

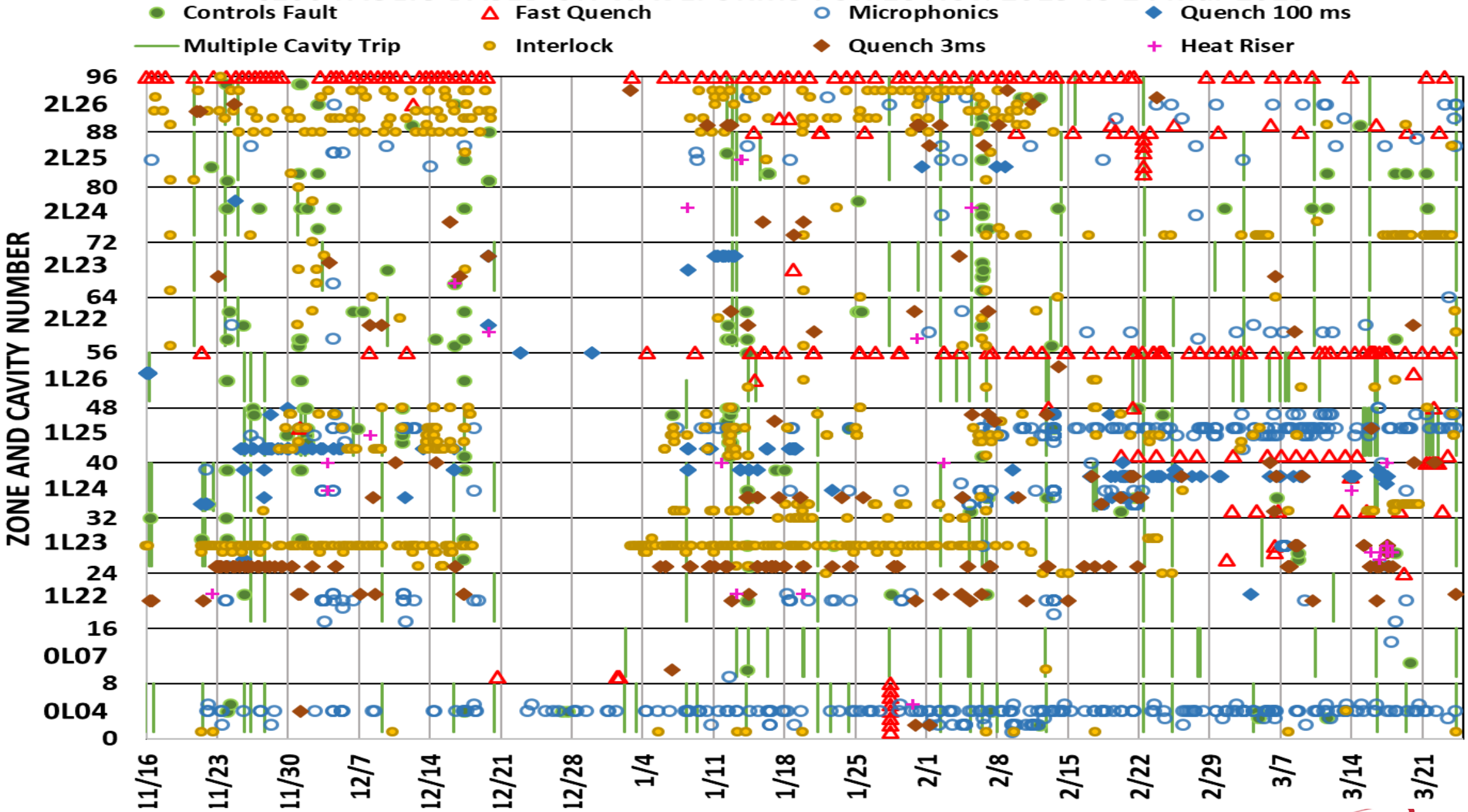
The QNCH faults were on zones that were not bypassed.

Gradient error faults is the interlock that replaced the functionality of the QNCH fault.

Quench Fault Still Occurring Repeatedly Even in Zones Where it was Bypassed






C100 FAULTS BASED ON WAVEFORMS FOR 16 Nov. 2019 To 24 Mar 2020
Controls Fault
Fast Quench
Microphonics
Quench 100 ms
Multiple Cavity Trip
Interlock
Quench 3ms
Heat Riser
ZONE AND CAVITY NUMBER
96
2L26
88
2L25
80
2L24
72
2L23
64
2L22
56
1L26
48
1L25
40
1L24
32
1L23
24
1L22
16
0L07
8
0L04
0
11/16
11/23
11/30
12/7
12/14
12/21
12/28
1/4
1/11
1/18
1/25
2/1
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3/7
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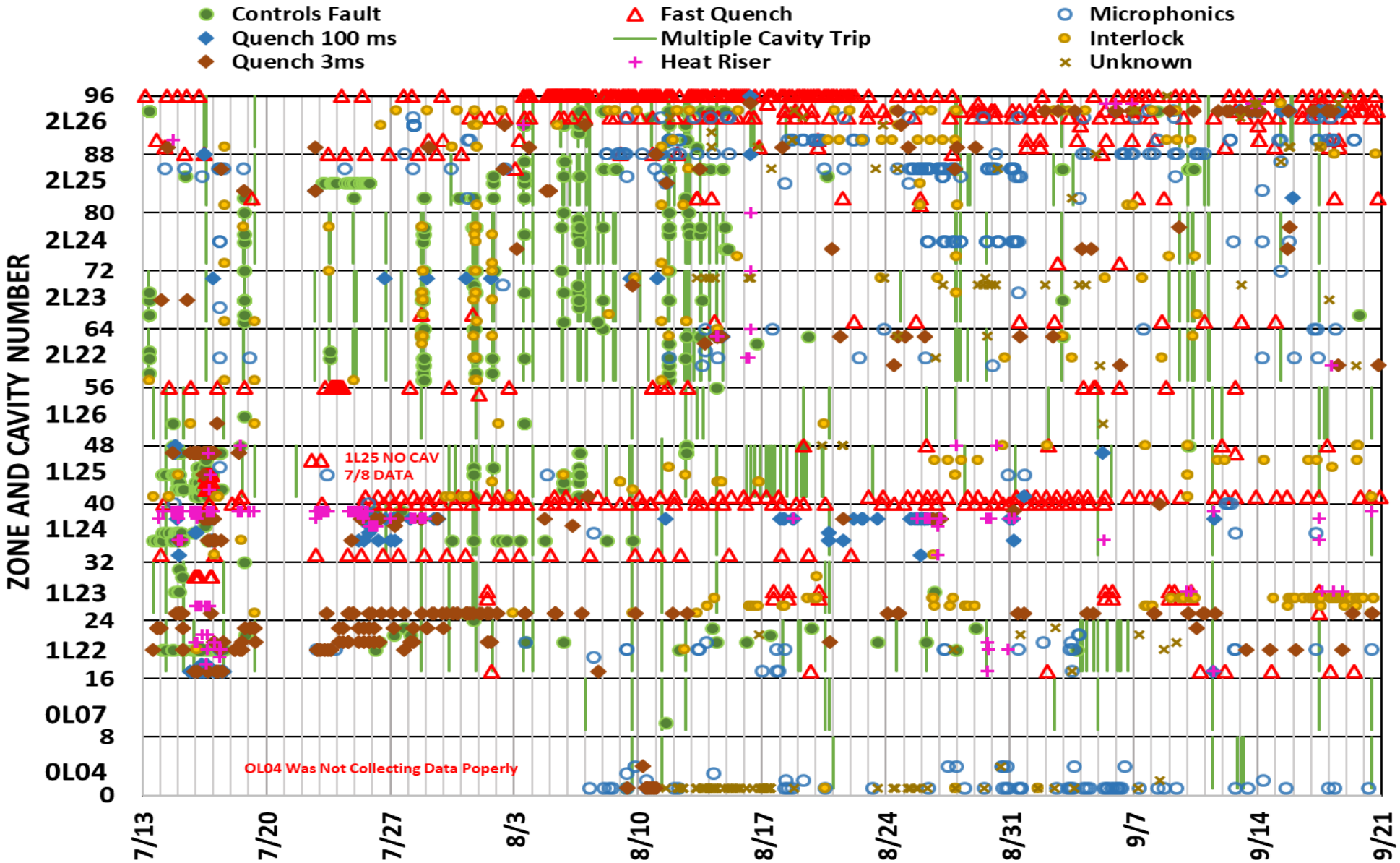
3/21

C100 FAULTS BASED ON WAVEFORMS FOR 14 July To 21 Sept 2020



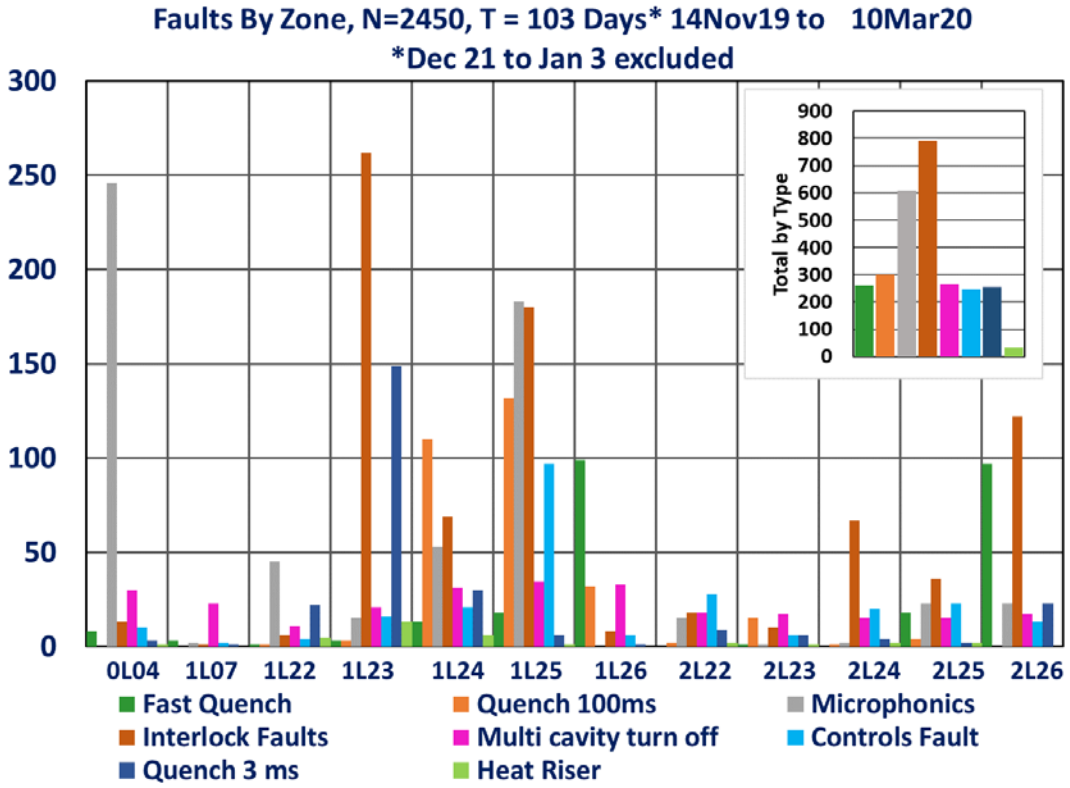
Starting in early August, 2L26 got worse even after we reduced gradients.

Multiple cavity trip events and controls faults occurring in multiple zones due to noise in the MO system. Indicated by Green vertical lines and green circular symbols.

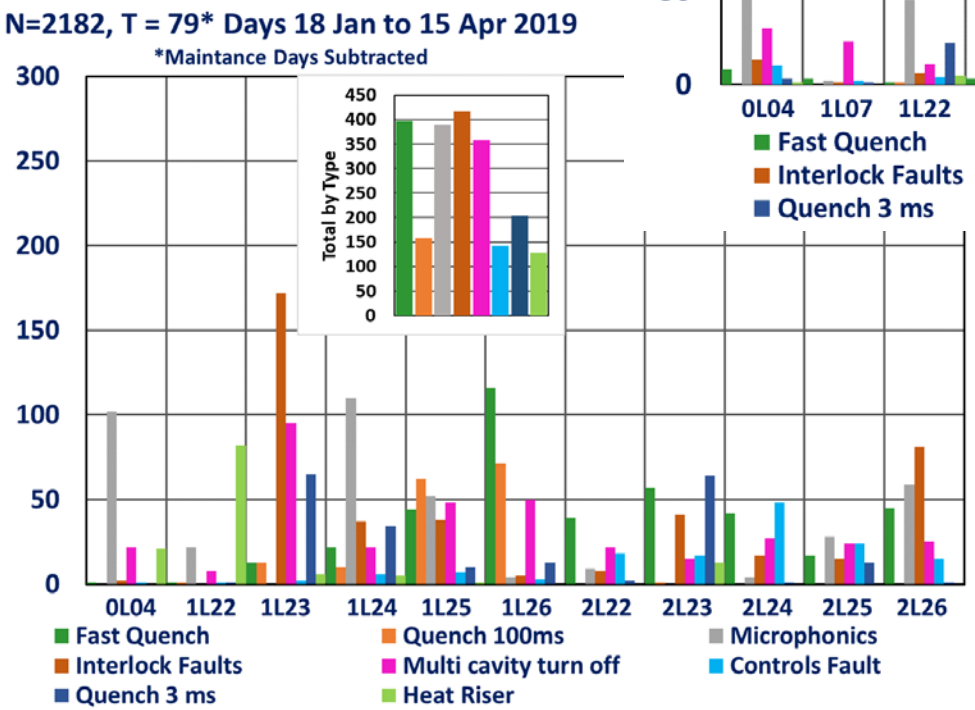
1L25 Microphonics mitigations installed before run improved things.

Faults by Zone

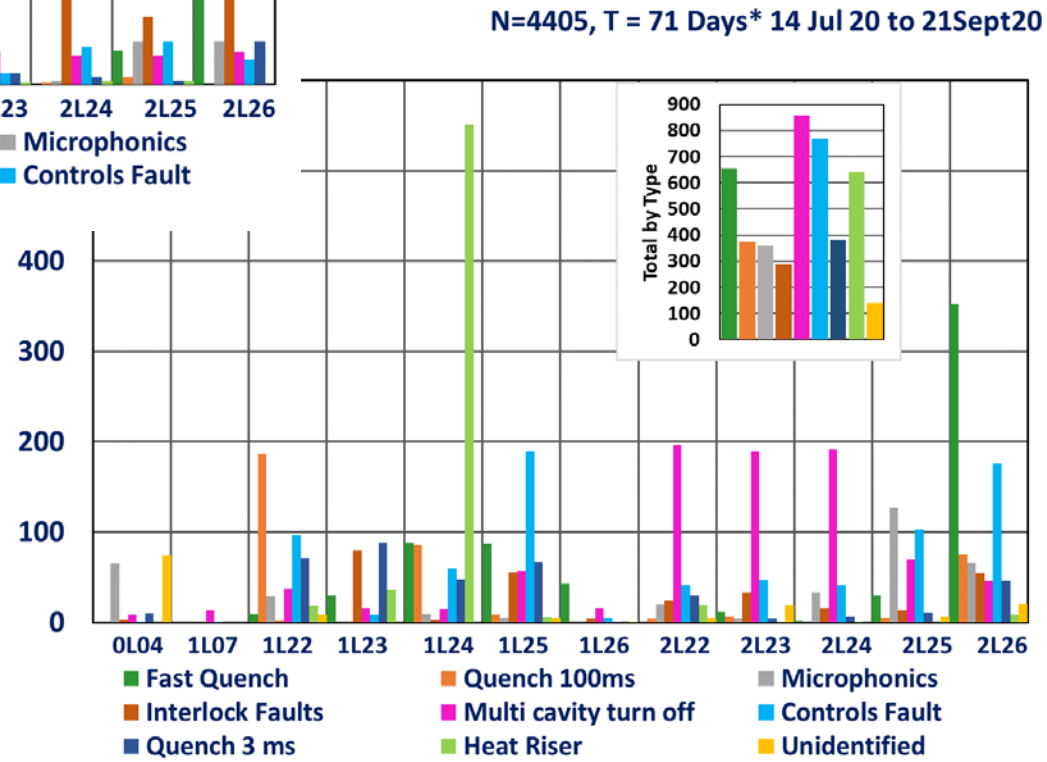
- Additional microphonics mitigations applied to 1L24, 2L25 and 2L26
- C100 cryomodules except for 2L26 thermally cycled to 300K



- Summer 2020
- Microphonics mitigations applied to 0L04, 1L25 and 1L24, 2L25 and 2L26.
- QNCH fault bypassed in the 5 worst zones. Reduced interlock faults but some came back?
- Approximately 1000 faults are due to the MO noise issue. (controls and multi cavity faults)
- The excessive number of heat riser faults was due to a pressure oscillation in cryogenic plant which was corrected 3 weeks into the run.



Are there any plans to do something different if they can not resolve the ground system problems.



Concerns / Plans

- **We are working on a plan to further harden cryomodules for microphonics. -- Install waveguide dampers, tuner dampers and come up with something other than bead bags for tuner stacks.**
- **We are planning on thermally cycling 2L26 to room temperature.**
- **Request that the QNCH fault be bypassed globally or fixed so that it works as advertised (GMES low by 15% for several milliseconds.)**
- **Rama has a way to o recognize that a cavity is quenched when in SEL mode. Suggest using this interlock and the fact that it is cavity 1 or 8 to wait until the beam pipe can recover after second repeated trip. (Done in EPICS?)**
- **Hopefully the investigations into the grounding system find problems that can be resolved. If they do not succeed what corrective action / design changes can be done as the MO noise problem is getting worse and worse and is impacting machine operations.**