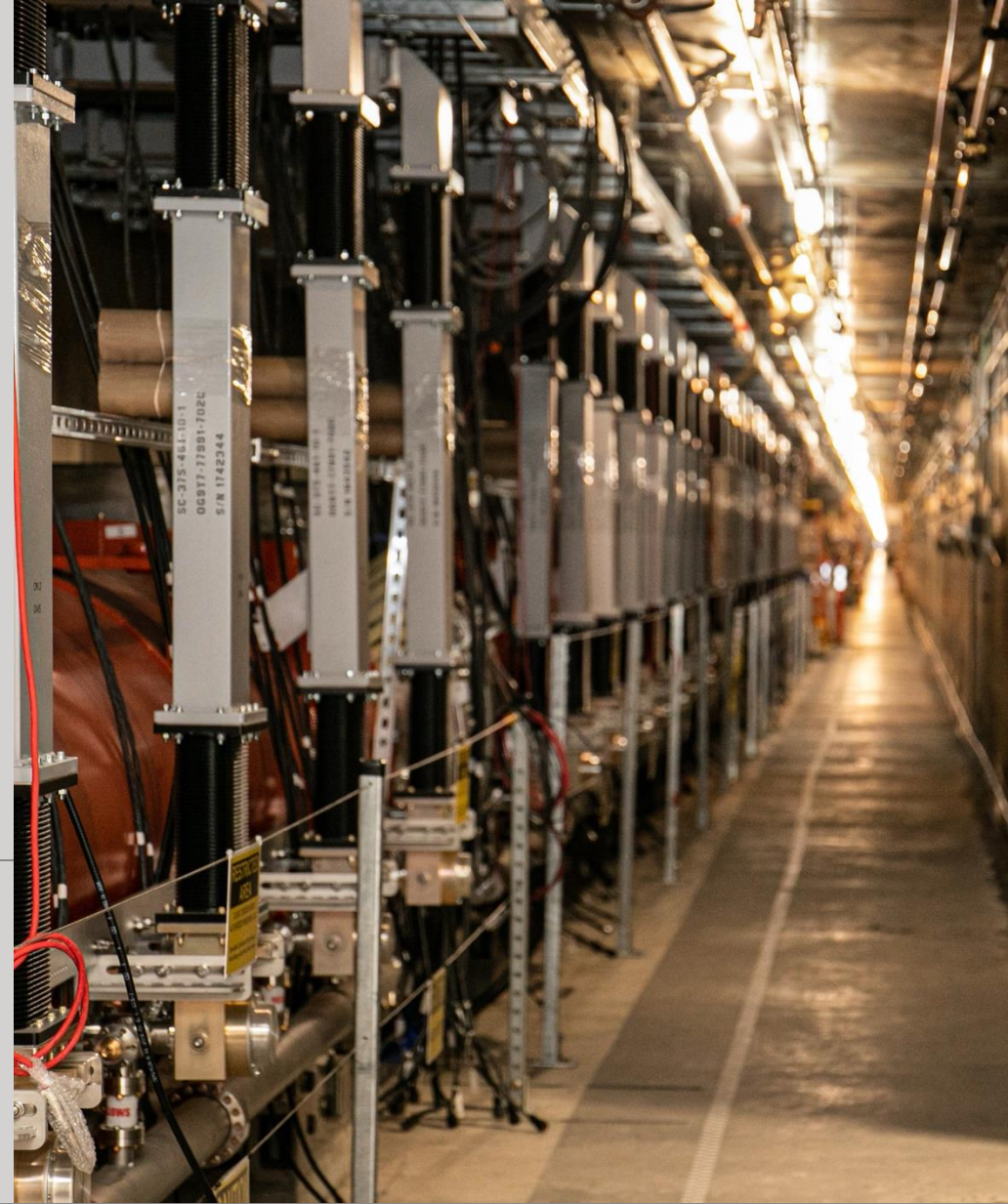


CM01 Field Emission Workshop

CM01 Summary and History

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Timeline of events

- 09/23/2023
 - Higher than expected beam losses were observed during commissioning of the beam loss monitor system near the injector and were found to be dependent on cavity CM01-4 amplitude
- 09/27/2023
 - During then next access for planned maintenance, the decarad system was moved next to CM01 in the morning
 - In the evening, re-characterization of CM01 found radiation in cavities 2 through 5
 - CM01-2: Had previously been offline since initial commissioning for beam optics reasons. Brought back online and observed radiation during the first power rise. Radiation onset at 13MV, 50mR/hr limit at 15.6MV
 - CM01-3: Radiation onset at 9.5MV, 50mR/hr limit at 10.9MV
 - CM01-4: Radiation onset at 9MV, 50mR/hr limit at 10MV
 - CM01-5: Radiation onset at 10MV, 50mR/hr limit at 12.3MV

Timeline of events - continued

- 09/27/23
 - No radiation measured in cavities CM01-1, CM01-6, CM01-7 and CM01-8
 - Beam program was resumed with lowered amplitudes in affected cavities until a buncher trip during the night
- 09/28/23
 - Measurement in the morning showed radiation in CM01-4 increased by orders of magnitude compared to measurement the day before, all other cavities remained unchanged. Lowered amplitude in CM01-4 to 5MV to prevent further degradation.
- Re-measurements of CM01 field emission roughly every two weeks (before and after planned maintenance periods)
- 10/25/23
 - Observed radiation in CM01-8 for the first time. Radiation onset around 15.5MV with levels just above background. No impact on operational amplitude limit.
- Have re-measured CM01 in regular intervals since, no significant further changes observed

CM01 test and performance history

F1.3-19, one of the best performing CMs of LCLS-II production

- No field emission in either Vertical Test Stand (VTS), acceptance test or during commissioning
- All cavities limited by quench
 - In acceptance test and during commissioning likely some multipacting-induced quenches that did not get processed
- Typical operational parameters pre-FE onset:
 - CM01-1 at 6.5MV, CM01-2 off
 - CM01-3 at 10.5MV
 - CM01-4 through CM01-8 at 14 to 15MV
 - Total amplitude of 89MV
 - Defined by laser heater parameters

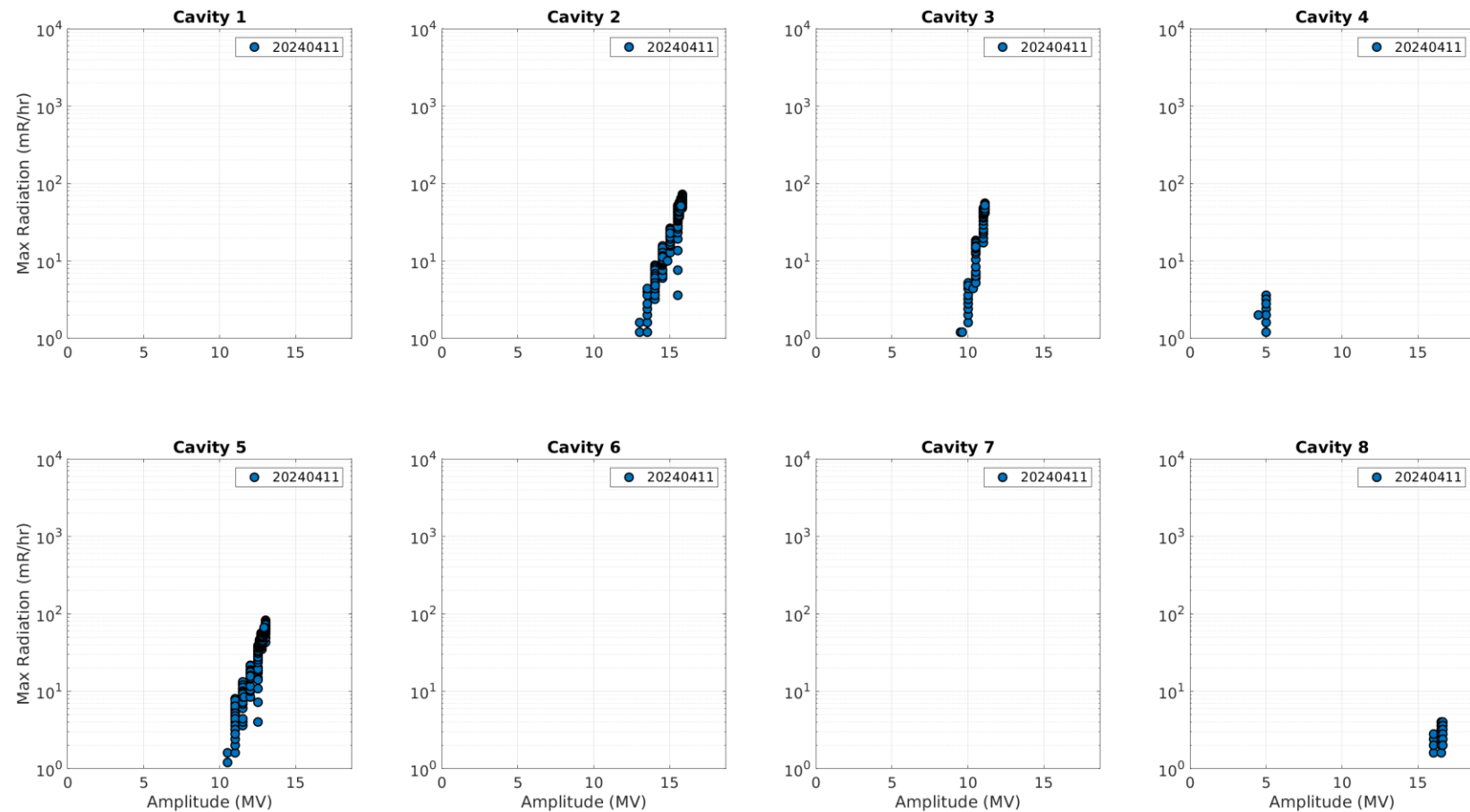
Cavity	VTS (MV)	Acceptance test (MV)	Commissioning (MV)
1	17.3	16.6	16.6
2	20.8	19.7	17.7
3	23.5	19.7	18.2
4	19.9	19.7	18.2
5	29.8	19.2	18.7
6	20.5	17.6	17.5
7	18.1	17.1	17.5
8	17.5	17.1	16.6

Decarad measurement system

- JLab-style radiation measurement system with 10 Geiger-Mueller tubes
- Also used during CM acceptance-testing at partner labs
- All sensors are placed at beamline/cavity height
- One sensor next to each cavity's fundamental power coupler, remaining two sensors at the upstream and downstream big bellows
- Mounted on rail with wheels for mobility, moved from CM to CM by hand

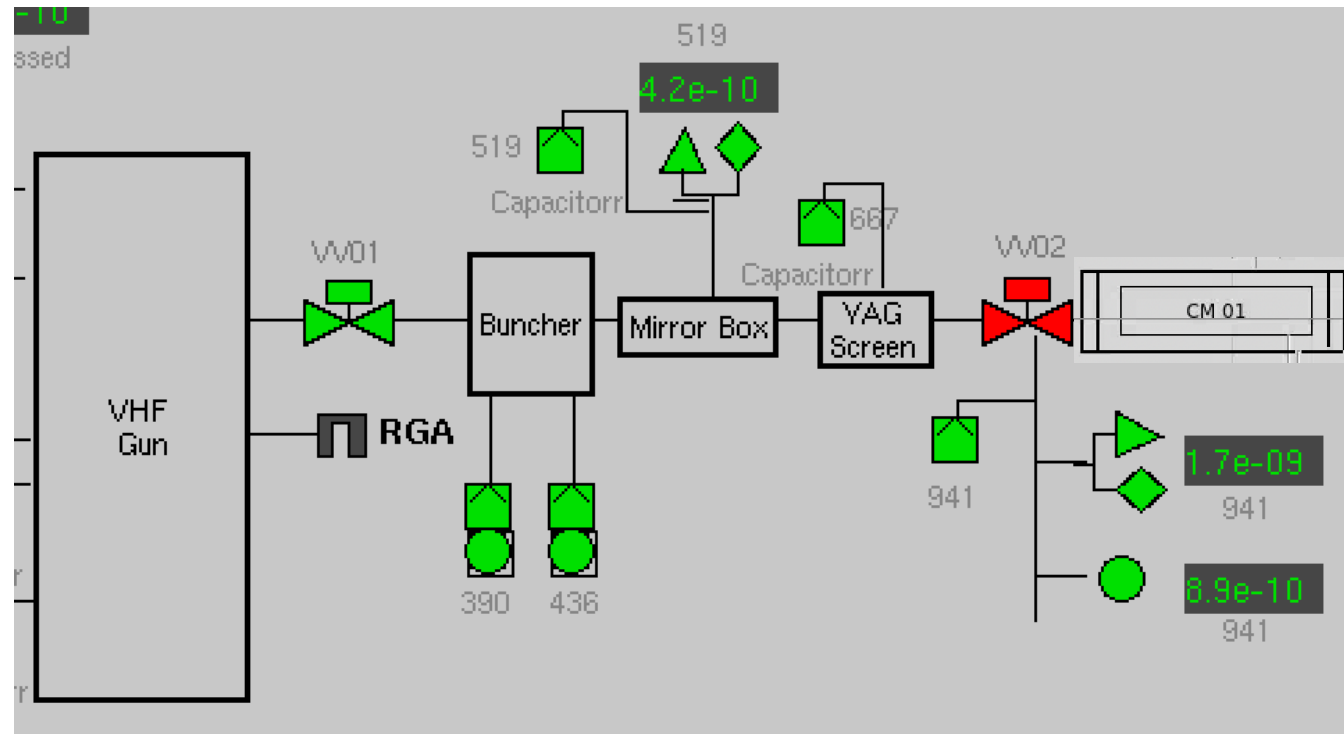
Typical measurement of CM01 with latest performance

- Radiation is measured with DecaRad system (10 Geiger-Mueller tubes located next to the CM at beamline height)
- Admin limit of 50mR/hr based on accelerator lifetime radiation damage
- Cavities 2, 3 and 5 have been limited in amplitude to stay within admin limit



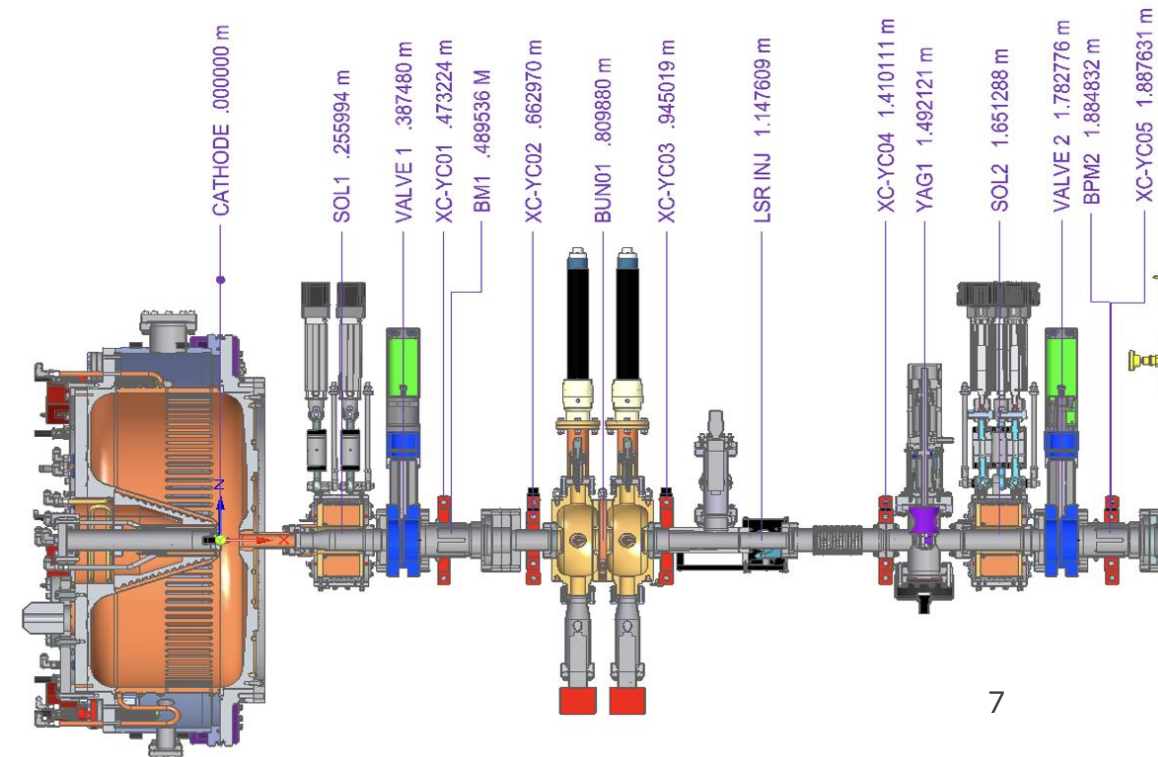
Cavities powered one at a time, shown is the highest reading sensor for each cavity

Beamline vacuum layout upstream of CM01

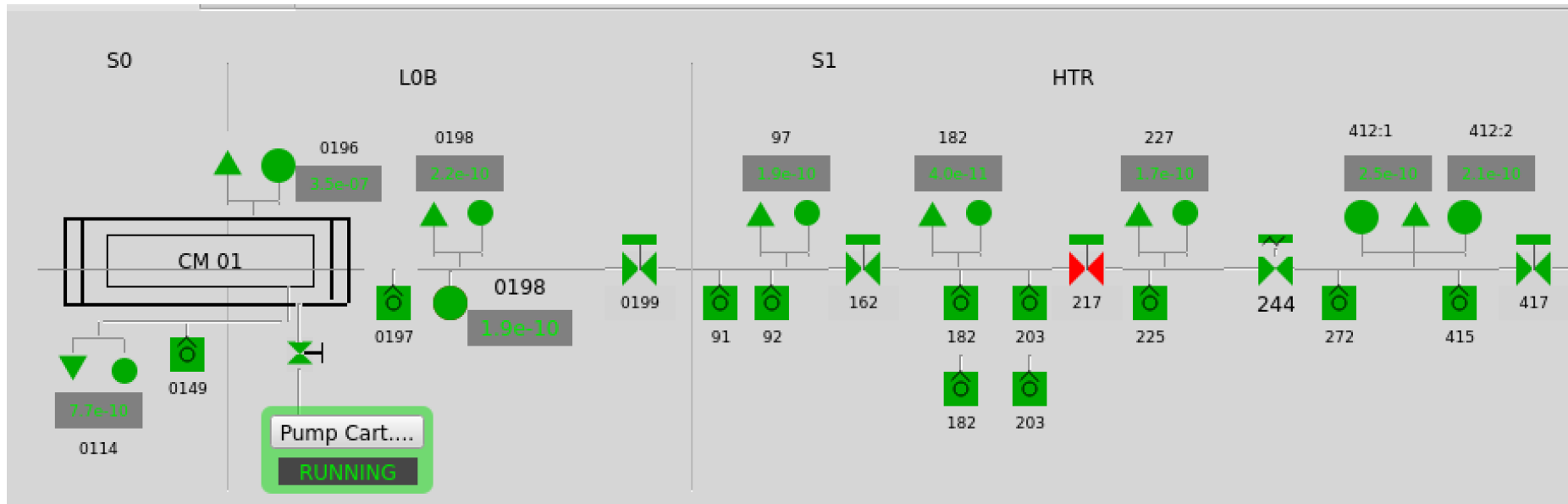


- APEX-style gun built by LBNL (186MHz QWR NC RF gun)
- 1.3GHz two-cell NC buncher
- Cs₂Te photocathode

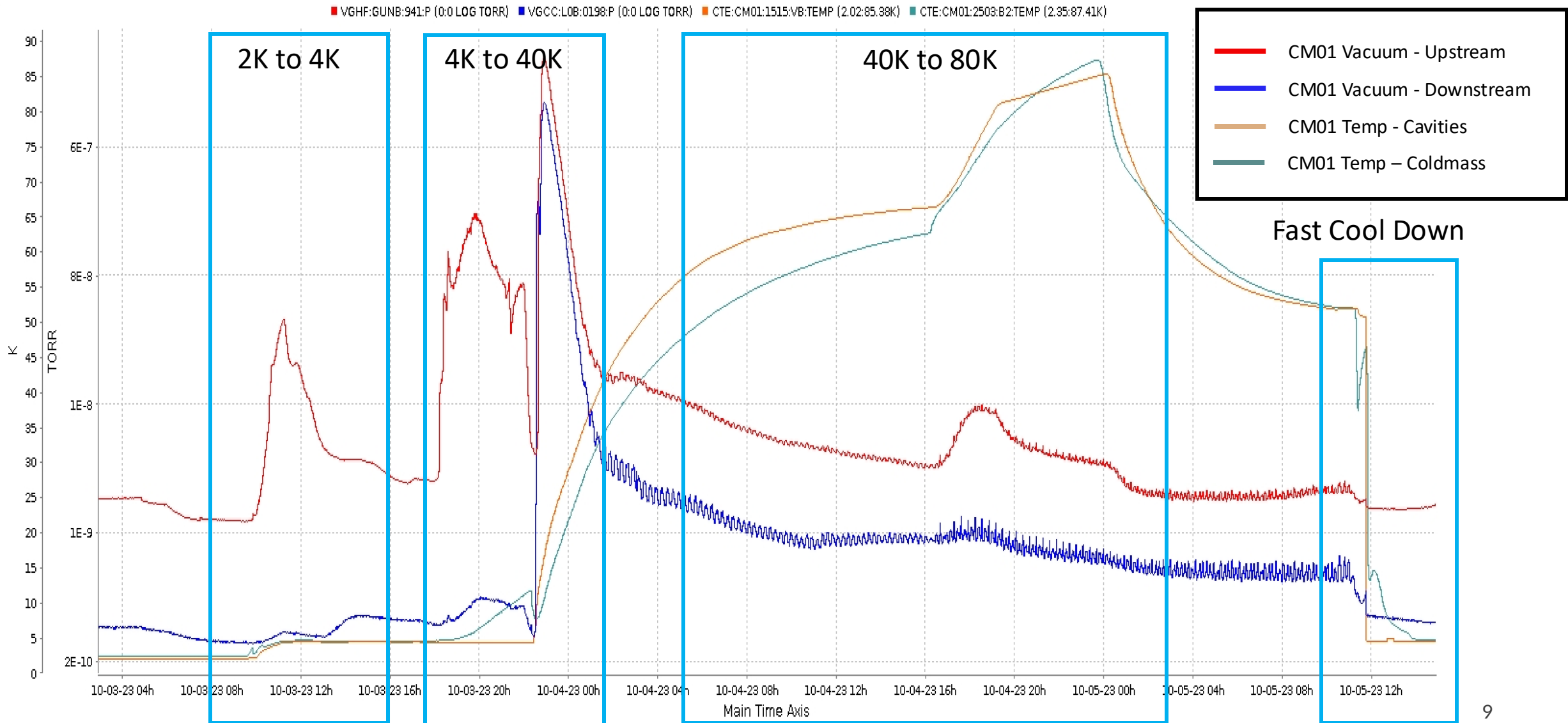
- History of dark-current from the gun (~3uA up to 10uA)
- Likely originating from cathode nose opening
- ~90% of dark current typically collimated before reaching CM01



Beamline vacuum layout downstream of CM01

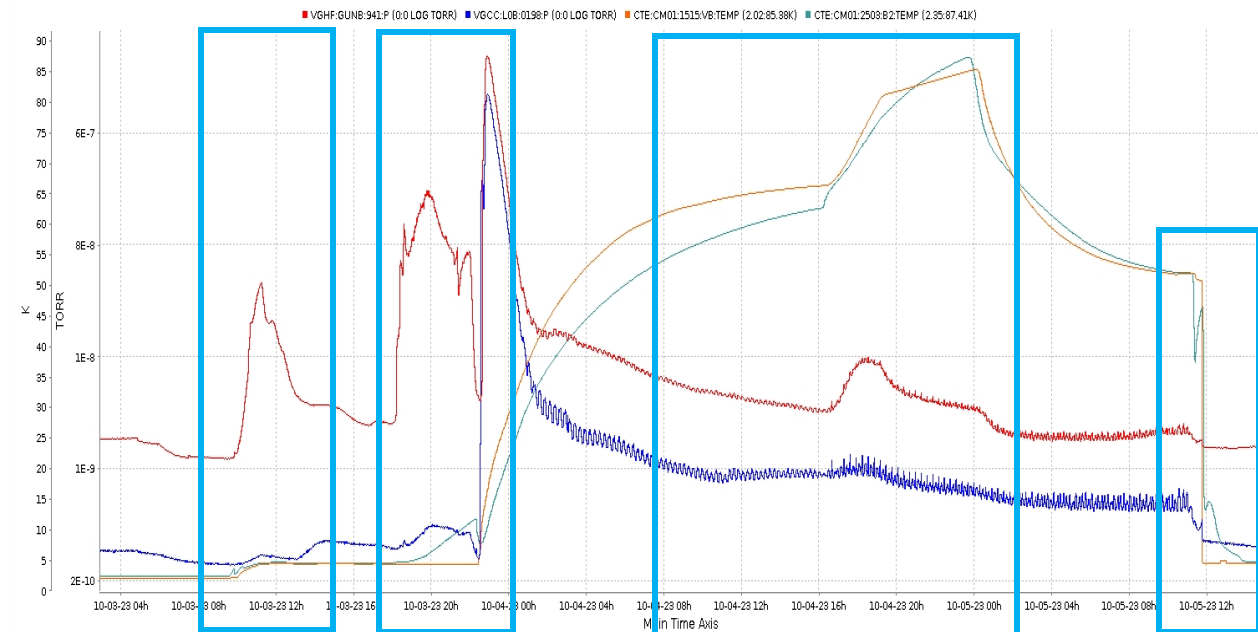


Warming CM01 to 80K

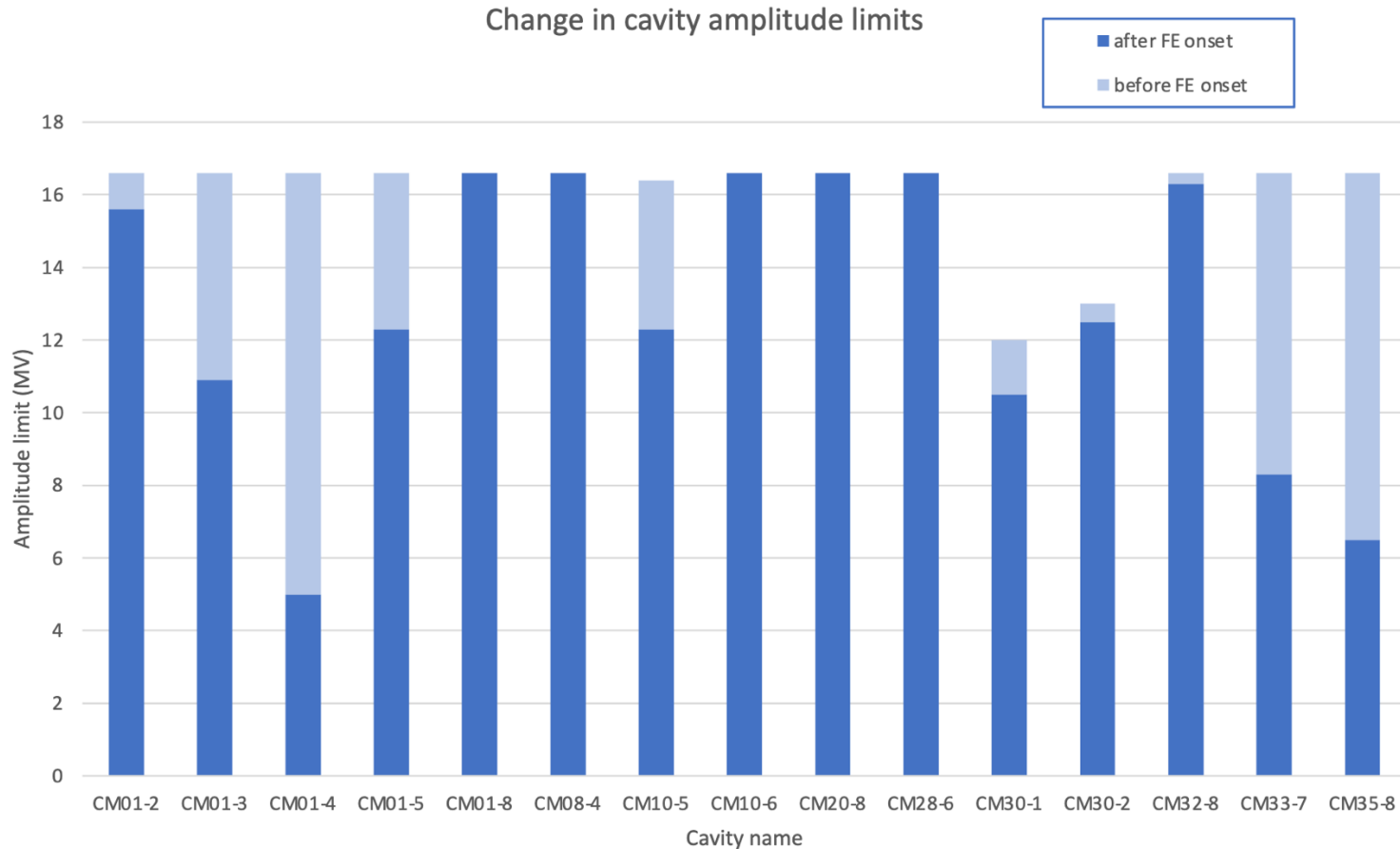


Review of vacuum data during warmup

- 2K to 4K: Outgassing is observed, but probably at ends of CM and not meaningful.
- 4K to 40K: The actual cavities are warming. Likely overwhelmingly Hydrogen. This might affect the cavity surface conditions and work function.
- 40K to 80K: Only little additional vacuum activity in this range.
- **Fast Cool Down:** Performed per standard procedure. Final vacuum condition is comparable to where we started.
- **No change** in FE characteristics measured afterwards.
- Two possible scenarios:
 - FE not related to adsorbed gases
 - 80K is not sufficient to release the offending gas species



New field emission in other CMs in the linac



Total cavities in linac	296
Cavities re-characterized for FE	192 (65%)
Number of affected CMs	9 (out of 23 re-characterized)
Cavities where the change impacts operational setpoint	8 (3%)

Total amplitude lost : 47.4 MV