Vertical cavity testing at RRCAT

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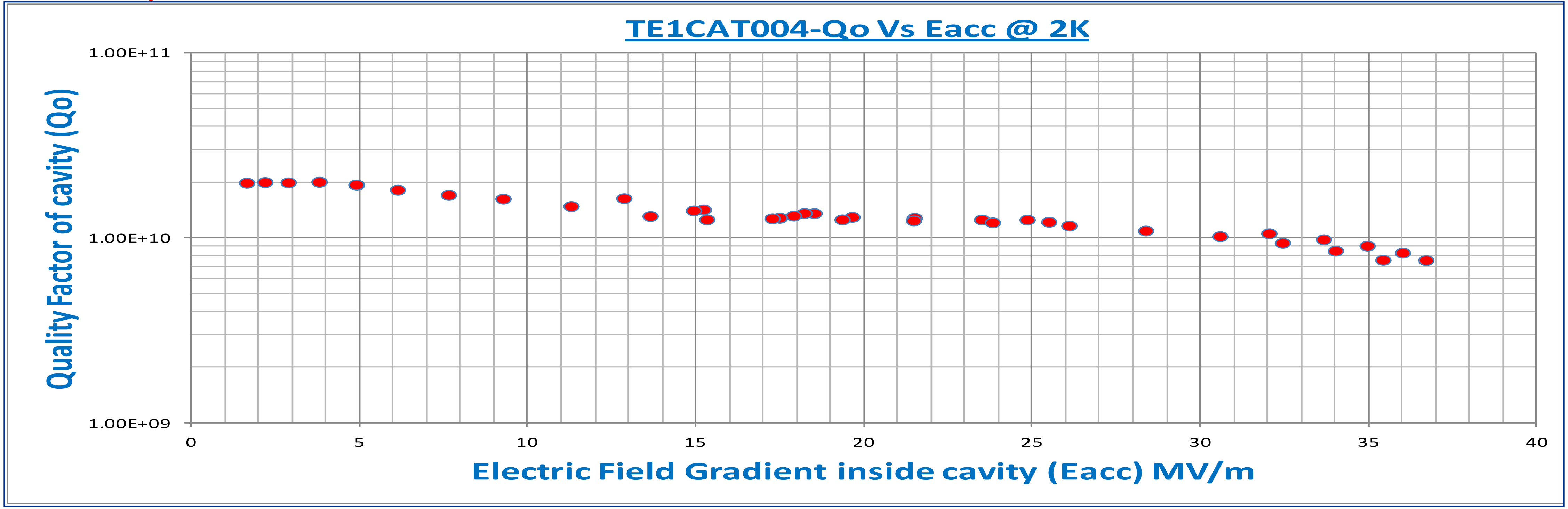
A Partnership of:
- US/DOE
- India/DAE
- Italy/INFN
- UK/UKRI-STFC
- France/CEA, CNRS/IN2P3
- Poland/WUST

Introduction to RRCAT VTS facility

The Vertical Test Stand (VTS) at RRCAT was commissioned in 2014, and since then it has been in used along with several upgrades, based on the operational experience. The RF system of the facility was developed in collaboration with FNAL. Till date, we have tested single cell 1300 MHz and 650 MHz cavities, and 5-cell 650 MHz (Beta 0.92).

The first successful test at RRCAT VTS was conducted on 31 Jan 2014 on a single cell 1.3 GHz cavity (TE1CAT004) which was previously tested at FNAL and was provided to us in sealed condition for benchmarking our facility.



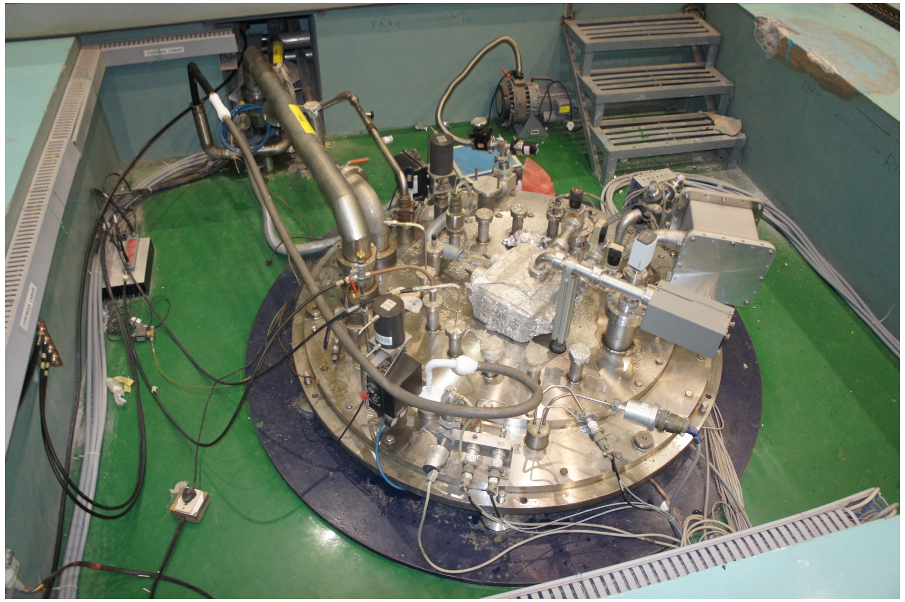
Introduction to RRCAT VTS facility

At present three independently operational RF systems are developed and out of which two are being used at the VTS (Left) and the third is installed at the Horizontal Test Stand (HTS) (Right). **RRCAT has one operational VTS cryostat and provision for another cryostat.**

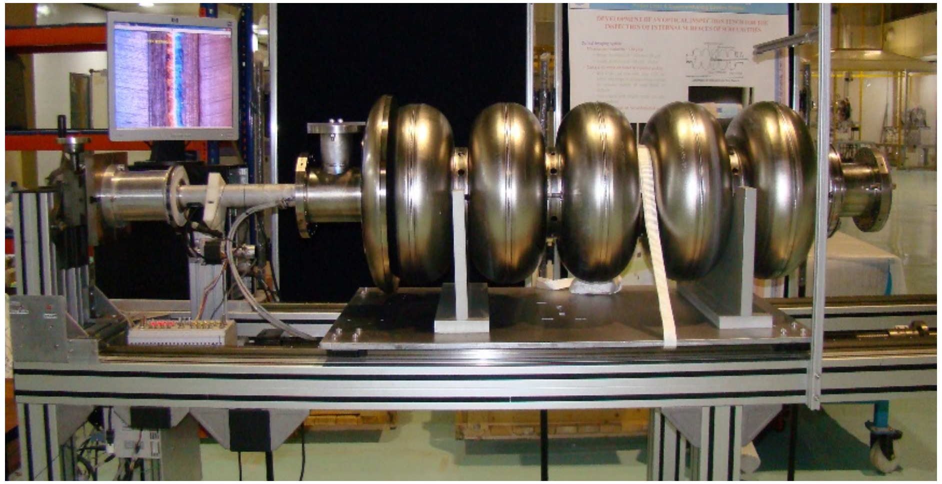
The RF system at HTS was used to test our first dressed cavity with a unity coupler as a part of commissioning trails of the HTS and tuner testing. The availability of this system provides an option to qualify a dressed cavity with critical coupling.

Presently our RF system are capable of handling 650 MHz, 1300 MHz and 325MHz structures.

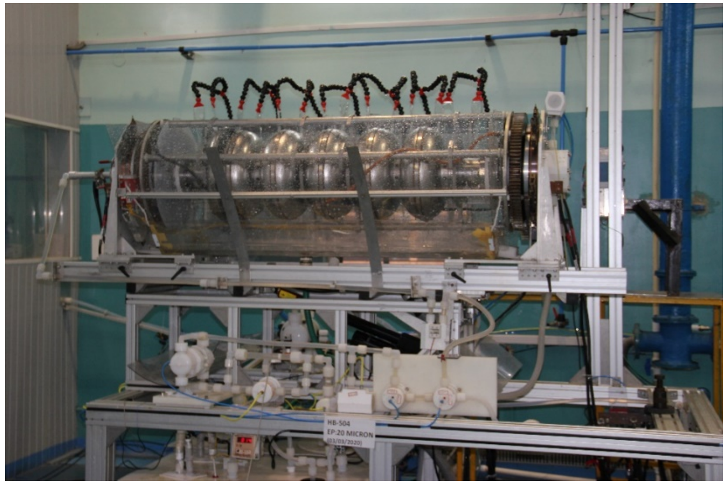
Introduction to RRCAT VTS facility



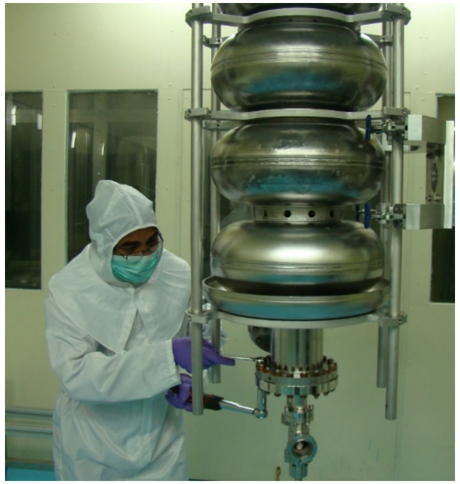
Cavity processing facilities at RRCAT



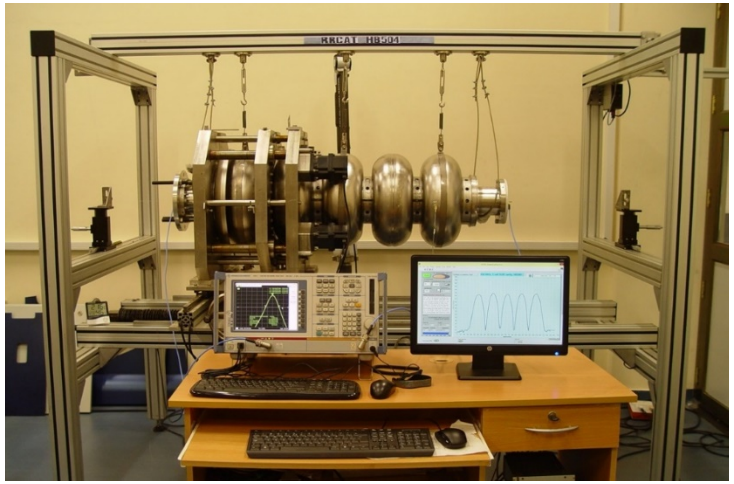
Optical Inspection



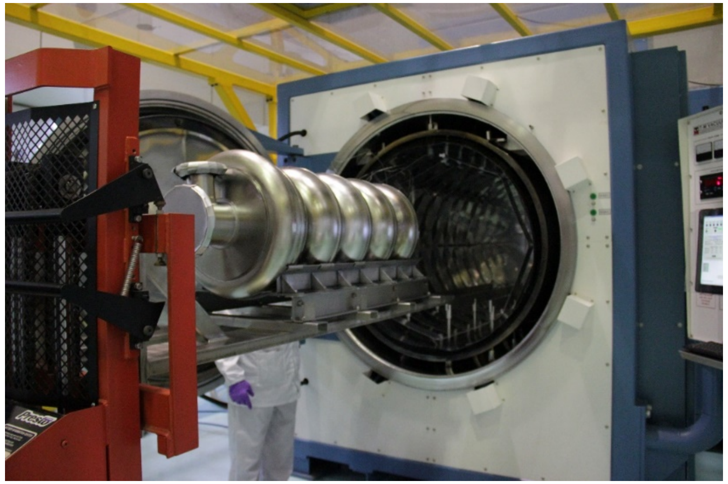
Electropolishing



Clean room preparation



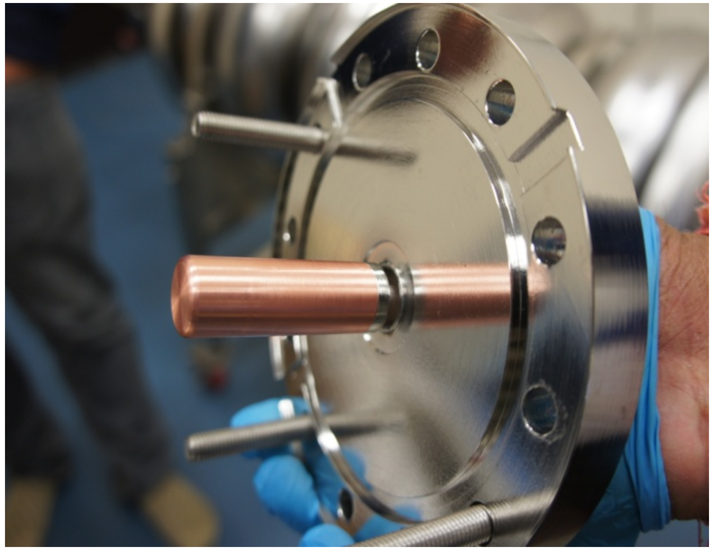
Tuning



Oven cycle

Cold Testing Procedure at RRCAT

After final tuning of the cavity the pickup and fundamental power coupler quality factor are measured and optimized. At present we keep FPC at ~ 1×10^{10} to 2×10^{10} and pickup coupler at ~ 2×10^{12} to 3×10^{12} for 650 MHz cavities. The cavity is then sent for further processing.



After final processing, the cavity is inserted in the Vertical Test Stand. The resonant frequency and through loss of the cavity are then remeasured and compared with the expected loss based on coupler measurements. This step is needed to ensure that RF connections are OK before cooldown.

Cold Testing Procedure at RRCAT

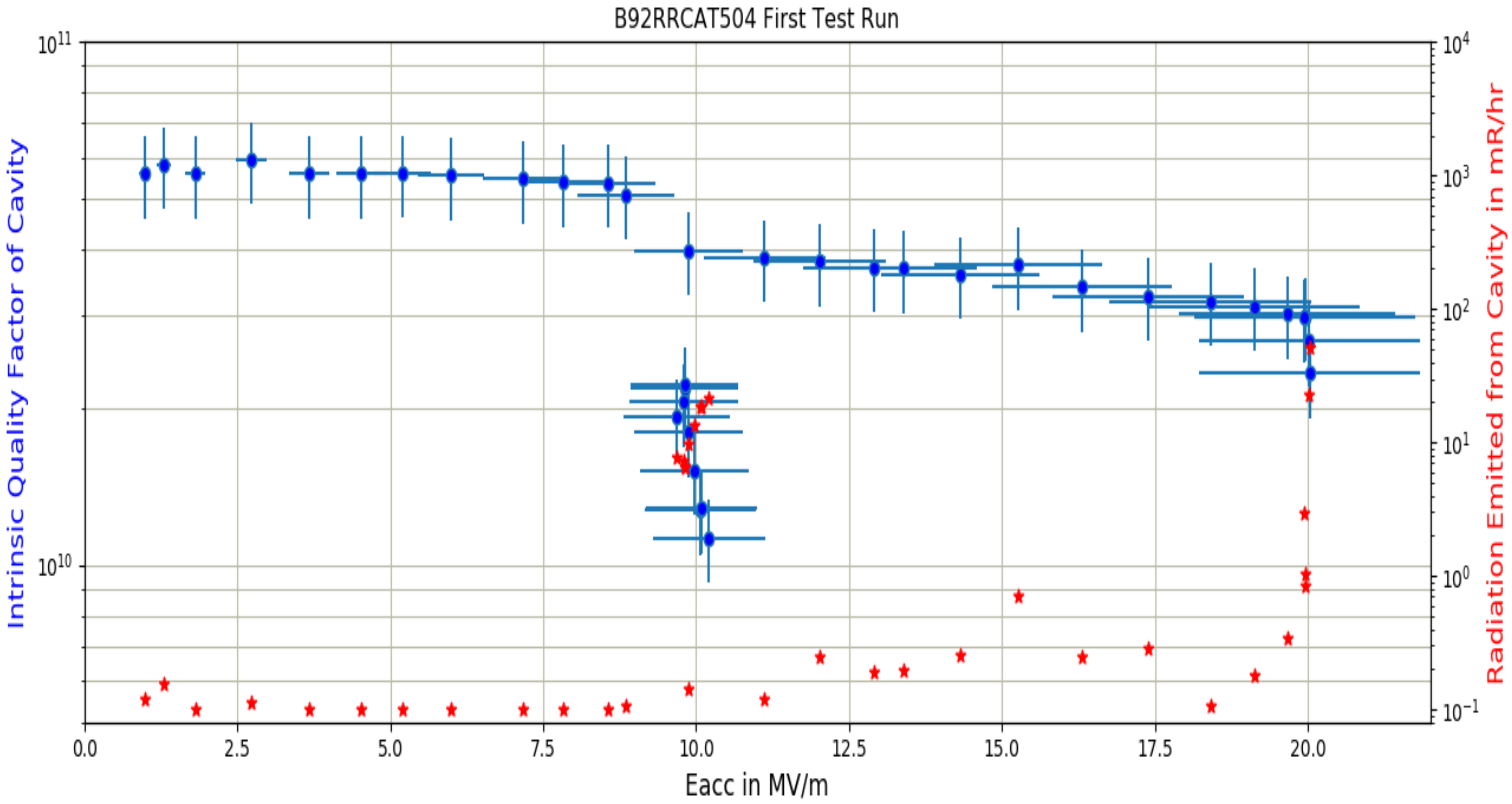
When cavity is fully immersed in the liquid Helium, cold testing of the cavity is first conducted at 4.2K. The test is conducted to verify the functioning of the LLRF system, amplifier and the interconnects. It is needed since presently few tests are being conducted per year at RRCAT and significant gap can occur between two cold tests.

After the 4.2K test, pumping is done to reach 2K at which resonant frequencies for all the modes are recorded, followed by cable calibration and decay measurement to identify Q_{ext2}. After the decay measurements under/over coupling is verified. External radiation shield is then moved to its place after which, testing is first done with 1 W amplifier and then with the high-power amplifier.

At present we are using SiO_2 based half (1/2) inch cable assembly for incident power, incident cable loss is calibrated several times during the test with changes in the power level.

Test Results of 5-cell, Beta-0.92 Cavities at RRCAT Facility

Cavity No.	Test date	Max Eacc (MV/m)	Initial Q	Final Q	Radiation	Comment
B92A-RRCAT-501	02-02-2018	17.5	4.00E+10	5.00E+09	High field emission after 11MV/m	Without nitrogen doping
B92A-RRCAT-501	08-02-2018	18	4.00E+10	5.00E+09	High field emission after 11MV/m	Retest Without Pull
B92A-RRCAT-501	22-03-2018	13.5	4.00E+10	3.00E+09	High field emission after 9.5MV/m	HPR redone
B92A-RRCAT-501	17-04-2018	13.5	4.00E+10	3.00E+09	High field emission after 9.5MV/m	Retest Without Pull
B92A-RRCAT-501	12-12-2018	15.6	4.00E+10	1.40E+10	Quench Limited. No radiation due to filed emission or multipacting observed	Cavity was nitrogen doped, Quench signature recorded on thermometery
B92A-RRCAT-502	04-04-2019	10.1	4.00E+10	2.00E+09	High field emission, after 6.5MV/m, cavity quenched	Cavity was nitrogen doped
B92A-RRCAT-503	18-10-2019	6.5	2.00E+10	1.00E+09	High field emission	Cavity was Nitrogen doped
B92A-RRCAT-503	14-12-2019	11	3.00E+10	2.00E+10	Limited by quench and then mulitpacting Field Emission Reduced. (Multipacting ~7MV/m occurred, one day after test (15/12/19)earlier cavity was quenching at 11MV/m))	HPR redone of longer duration
B92A-RRCAT-503	16-01-2020	7.5	3.00E+10	2.00E+10	Limited by Multipacting, multipacting started at around 6.5MV/m. Phenomeon of low Eacc breakdown present during tests.	Retest Without Pull
B92A-RRCAT-504	20-03-2020	21.5*	6.00E+10	3.00E+10	Quench Limited. *After quench the Eacc decreased to ~20MV/m.	No nitrogen doping
B92A-RRCAT-504	26-08-2020	20.2	6.00E+10	3.00E+10	Quench Limited (cavity quenched during multipacting)Phenomeon of low Eacc breakdown present during tests not in pi-mode.	Retest Without Pull



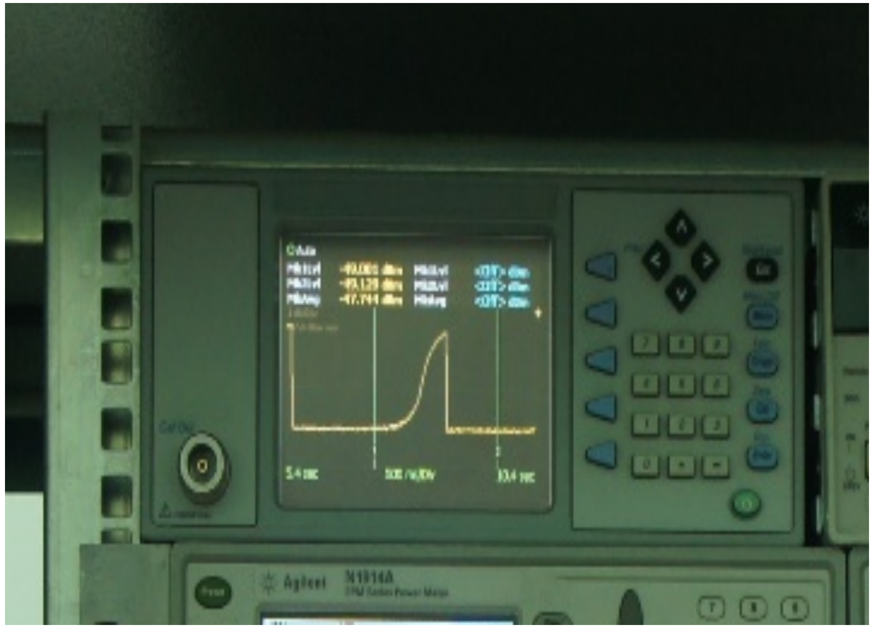
Test result of 504 cavity in Aug 2020

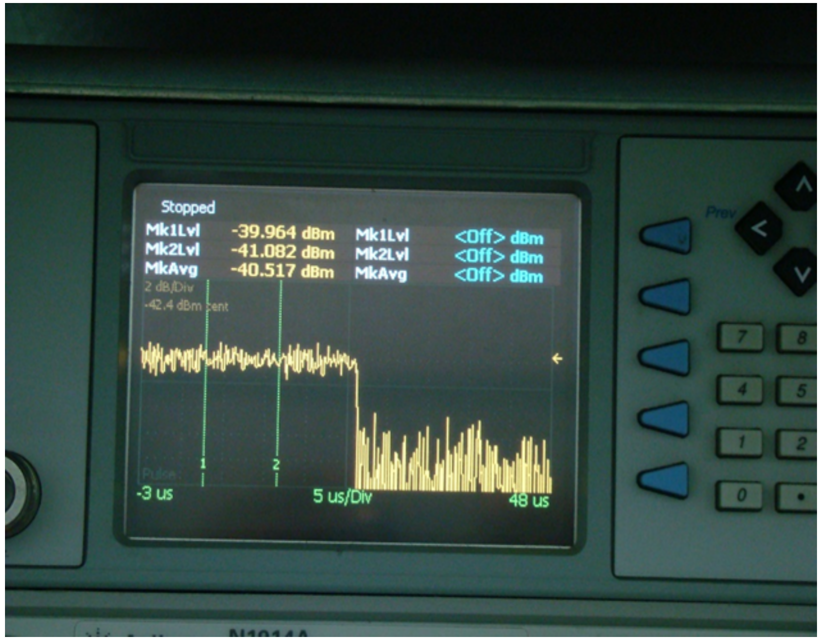
Problems encountered/Discussion

1. Helium Leak (encountered twice in about twenty tests). Interestingly only in single cells, but not in multi-cell so far.

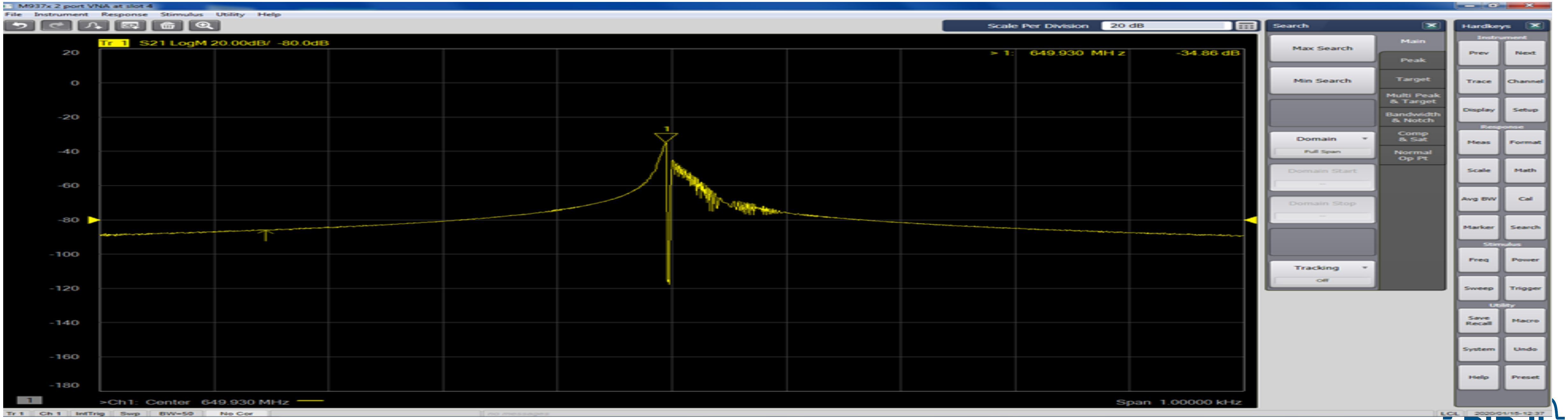
2. Low 'field quench/gas breakdown' like signal (encountered twice during five cell 650 MHz cavity tests): This problem is still not fully understood; it appears to be specific to our facility as FNAL has not encountered such phenomenon.
   The RF cavity shows a signature which is similar to what is expected in case of cold leak/low field quench, i.e. the transmitted power signal increases gradually and then suddenly falls at power levels close to ~100 mW. During our last test, this phenomenon did not occur for π-mode but occurred at other modes. Previously, it occurred at π-mode also. Interestingly, if the power is suddenly increased when the field inside the cavity is gradually increasing, it is possible to overcome this phenomenon, as if it were a kind of multi-pacting barrier. But its origin still remains unknown.

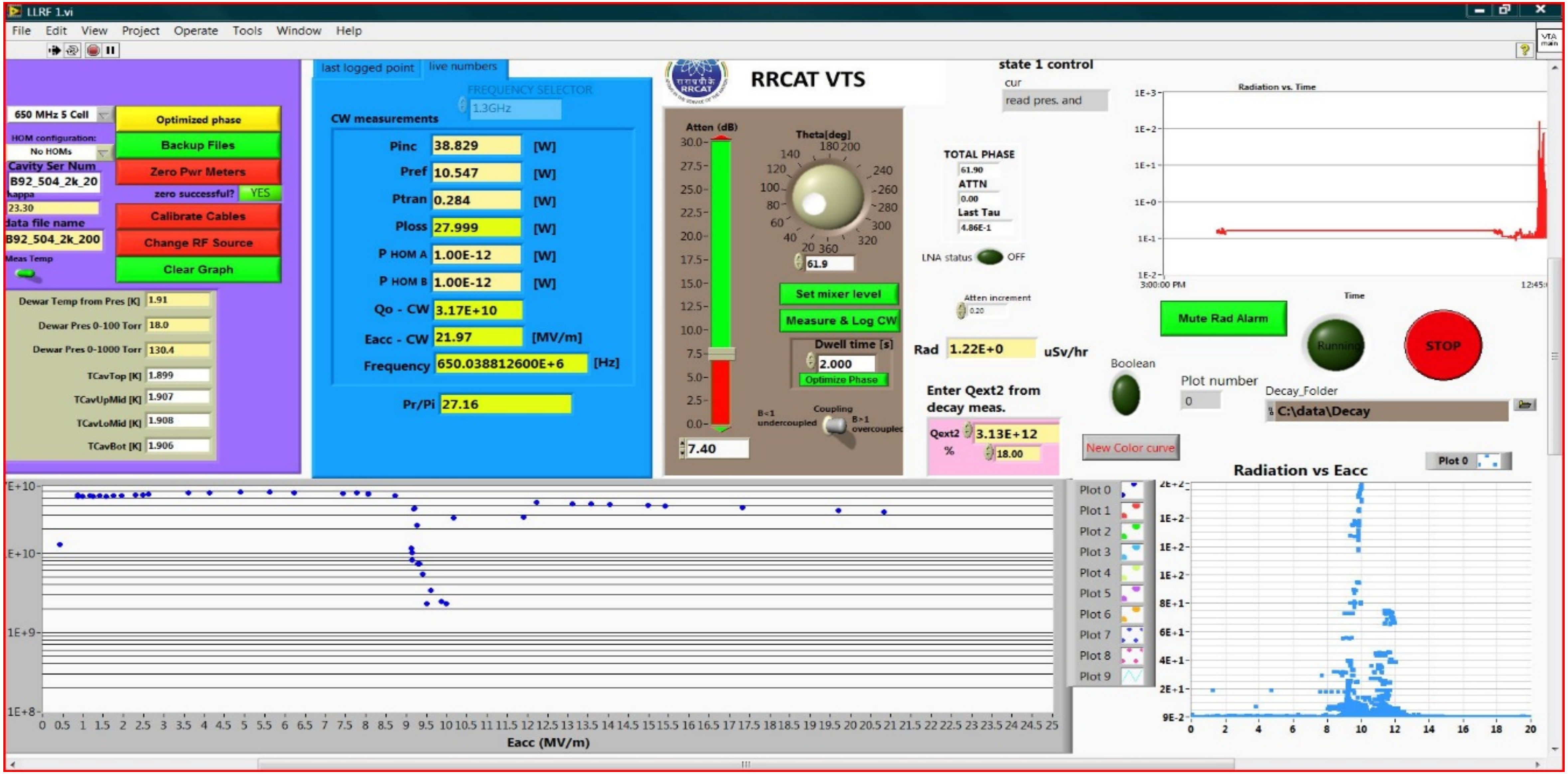
Thanks





Breakdown inside RF cavity at 4.2K at 100 mW input power. At 2K, the phenomenon was subdued. (test of 503 cavity)





Screenshot of the Test results of 504 cavity in March 2020

Processing Receipe

- Bulk EP (120 micron)
- HPR 3 pass
- Thermal degassing, annealing 800C 3 Hrs (hydrogen removal)
- Nitrogen doping
- Tuning in closed environment
- Light EP (20 micron)
- HPR final 3+1+3 (power coupler side beam port)
- Low temp bake 120 C 48 Hrs active pumping