Operation of Diamond Light Source SRF Cavities

Pengda Gu

On behalf of the Diamond RF Group*

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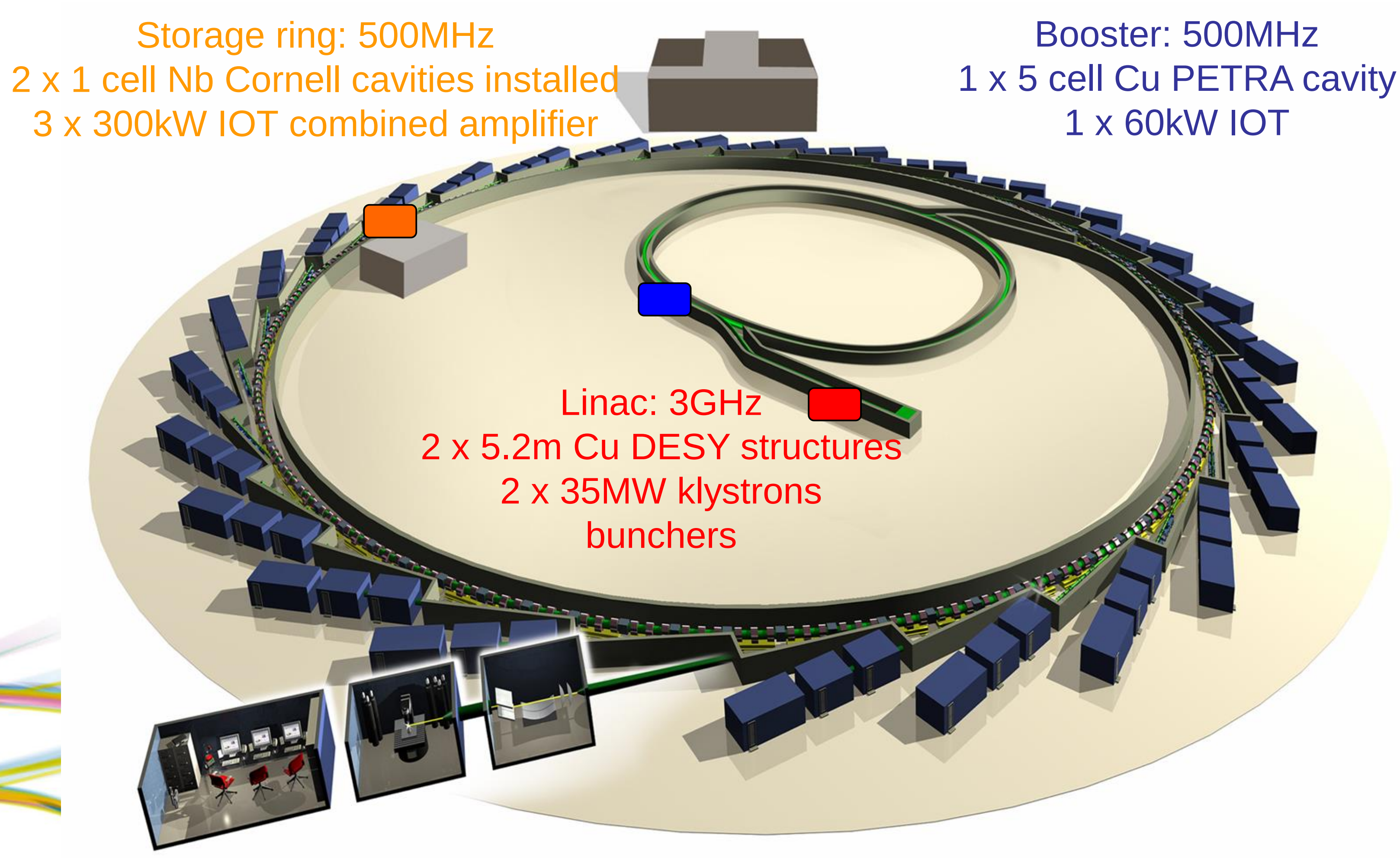
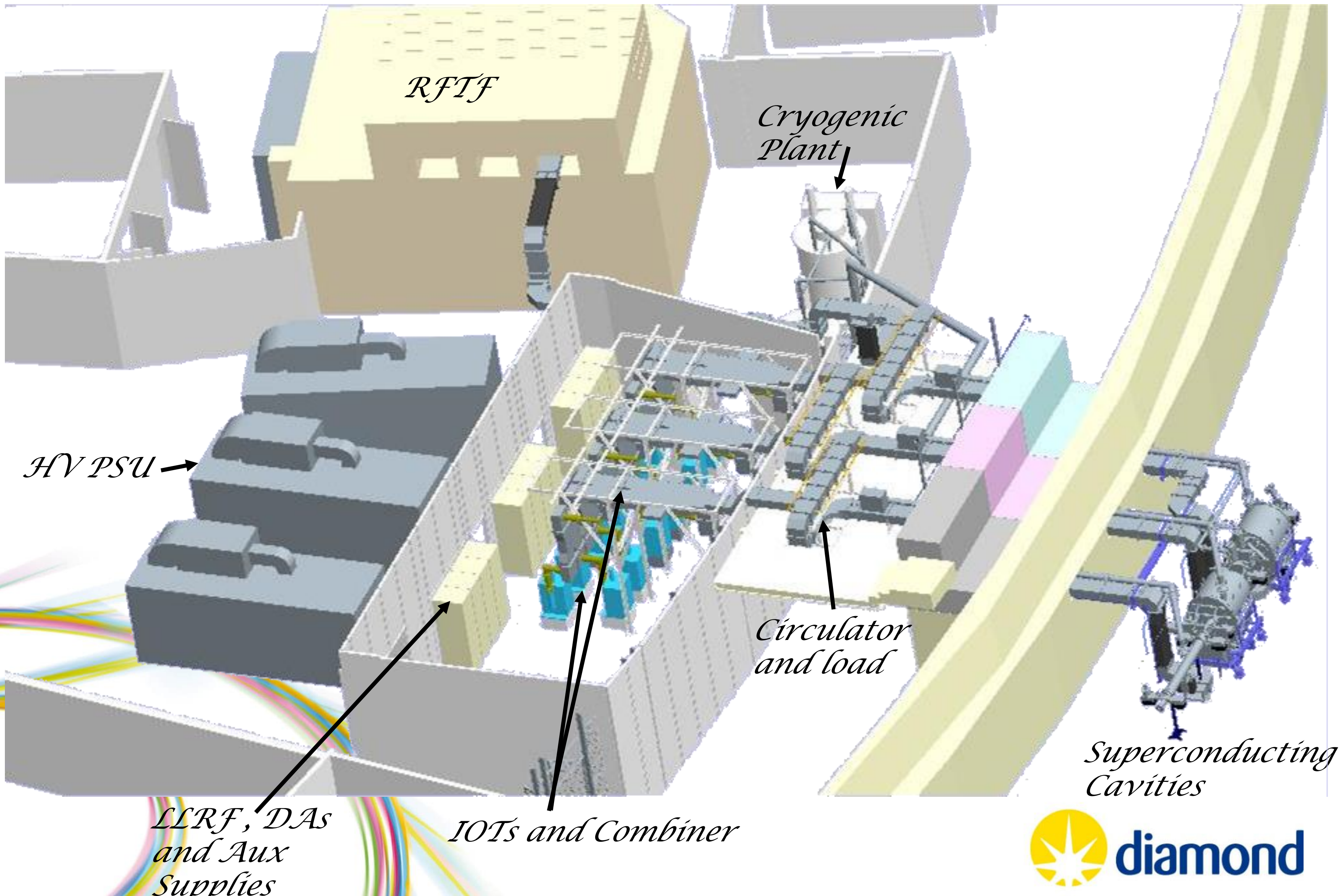
Agenda

- Storage Ring RF and Performance
- Major Cavity Failures Analysis
- Effort to Understand and Improve SRF cavities reliability
- Future Plans

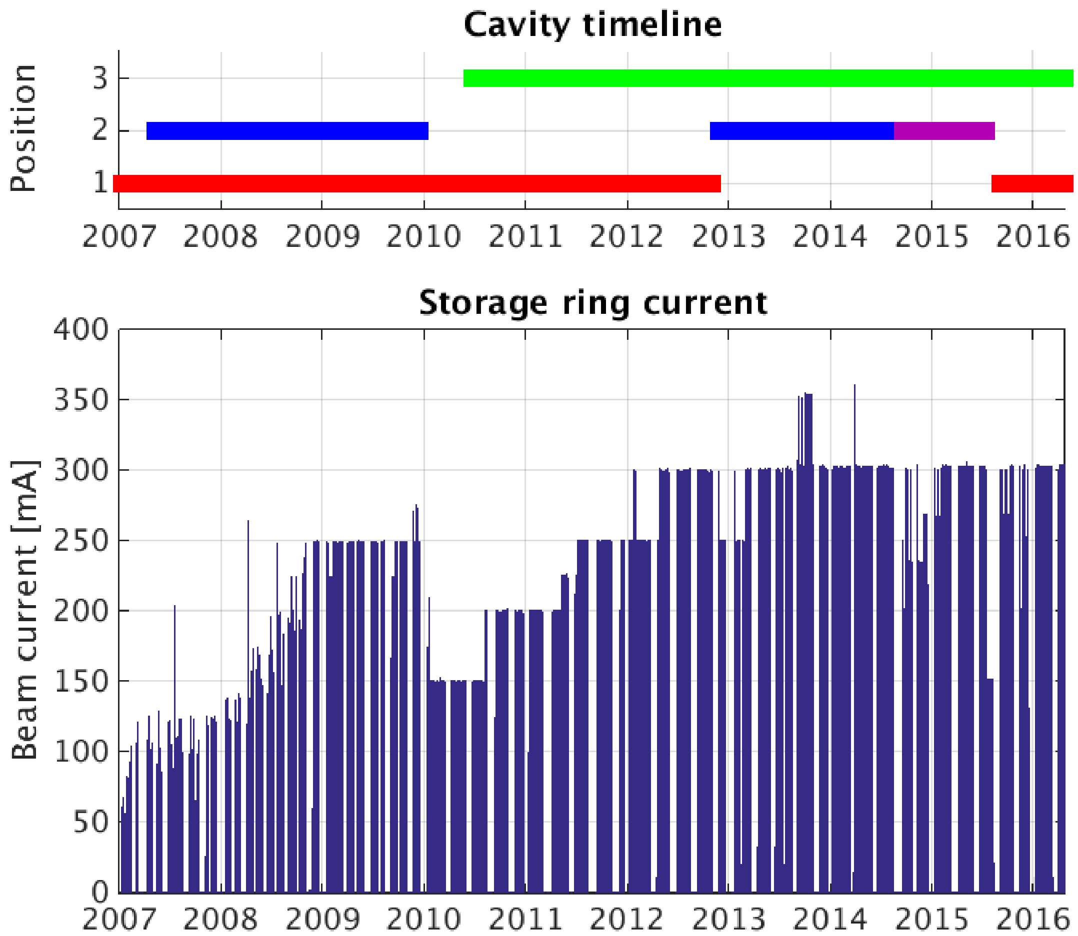
RF Systems


Storage ring: 500MHz
2 x 1 cell Nb Cornell cavities installed
3 x 300kW IOT combined amplifier
Booster: 500MHz
1 x 5 cell Cu PETRA cavity
1 x 60kW IOT
Linac: 3GHz
2 x 5.2m Cu DESY structures
2 x 35MW klystrons
bunchers

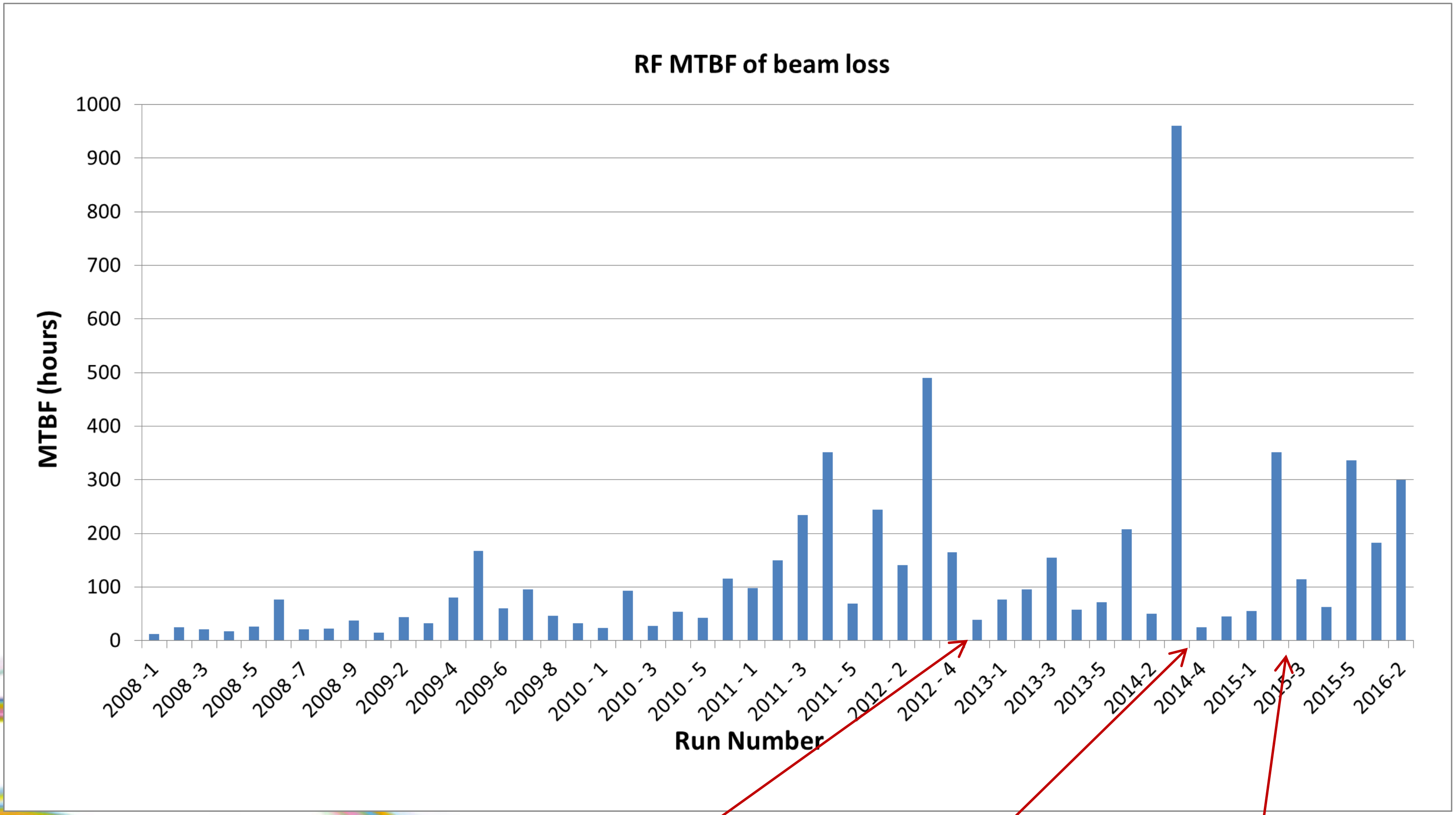
SR RF Systems



Several cavity changes since operation started



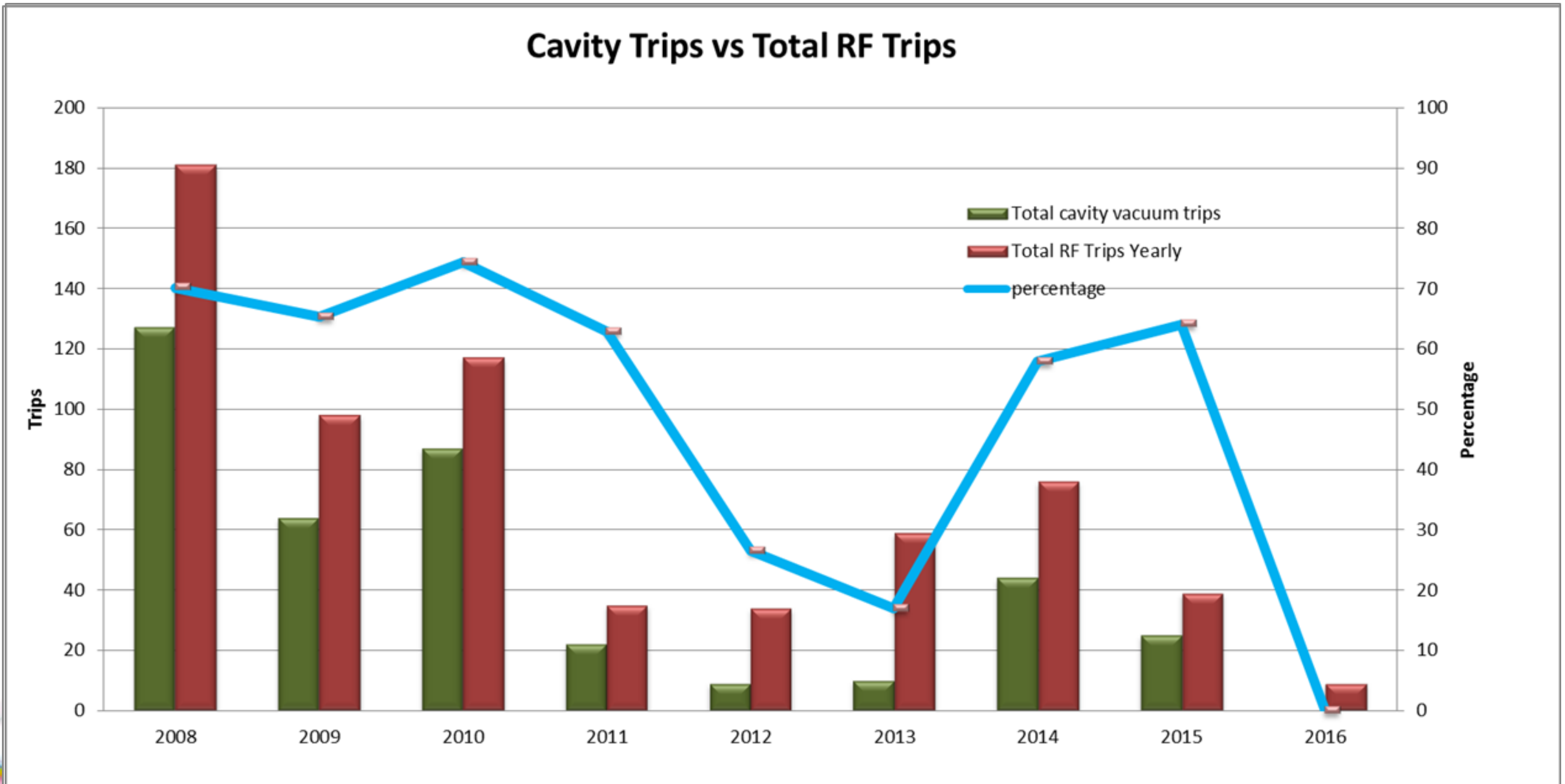
Storage Ring RF MTBF over the Years



Cavity 1 & 2 swap

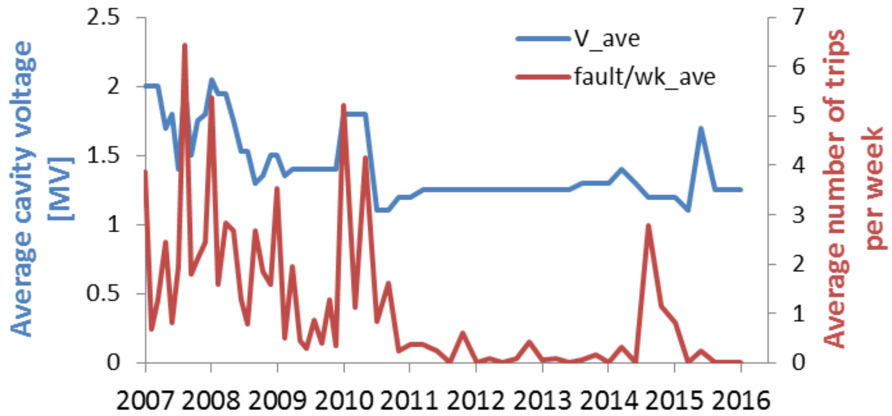
Cavity 2 failure, Cavity 4 installed

Cavity 4 failure



Cavity Trips vs Total RF Trips
Trips
Percentage
200
180
160
140
120
100
80
60
40
20
0
100
90
80
70
60
50
40
30
20
10
0
2008
2009
2010
2011
2012
2013
2014
2015
2016
Total cavity vacuum trips
Total RF Trips Yearly
percentage

Managing cavity “fast vacuum” trips



Trips have been eliminated by operating cavities below threshold voltages

Cavity 4 has the lowest threshold and operation suffered in 2014 before safe voltage was established

Reliable operating voltages	
Cavity 1	1.1 MV
Cavity 2	1.2 MV
Cavity 3	1.4 MV
Cavity 4	0.8 MV

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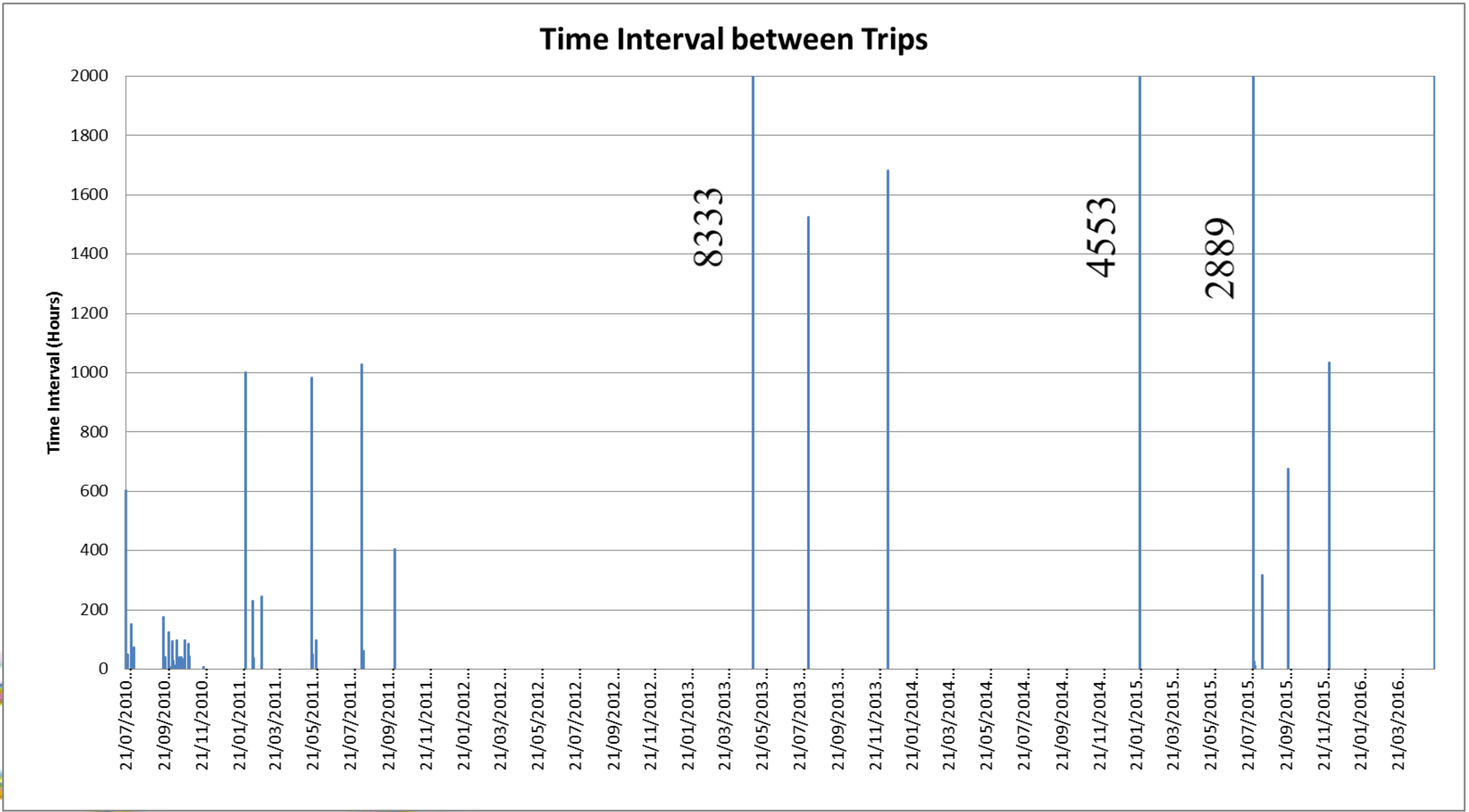
Cavity 3 Performance since Installation



Once good operation is established performance can be maintained.
Cavity 1 hasn't had any trips after re-installed in August 2015.

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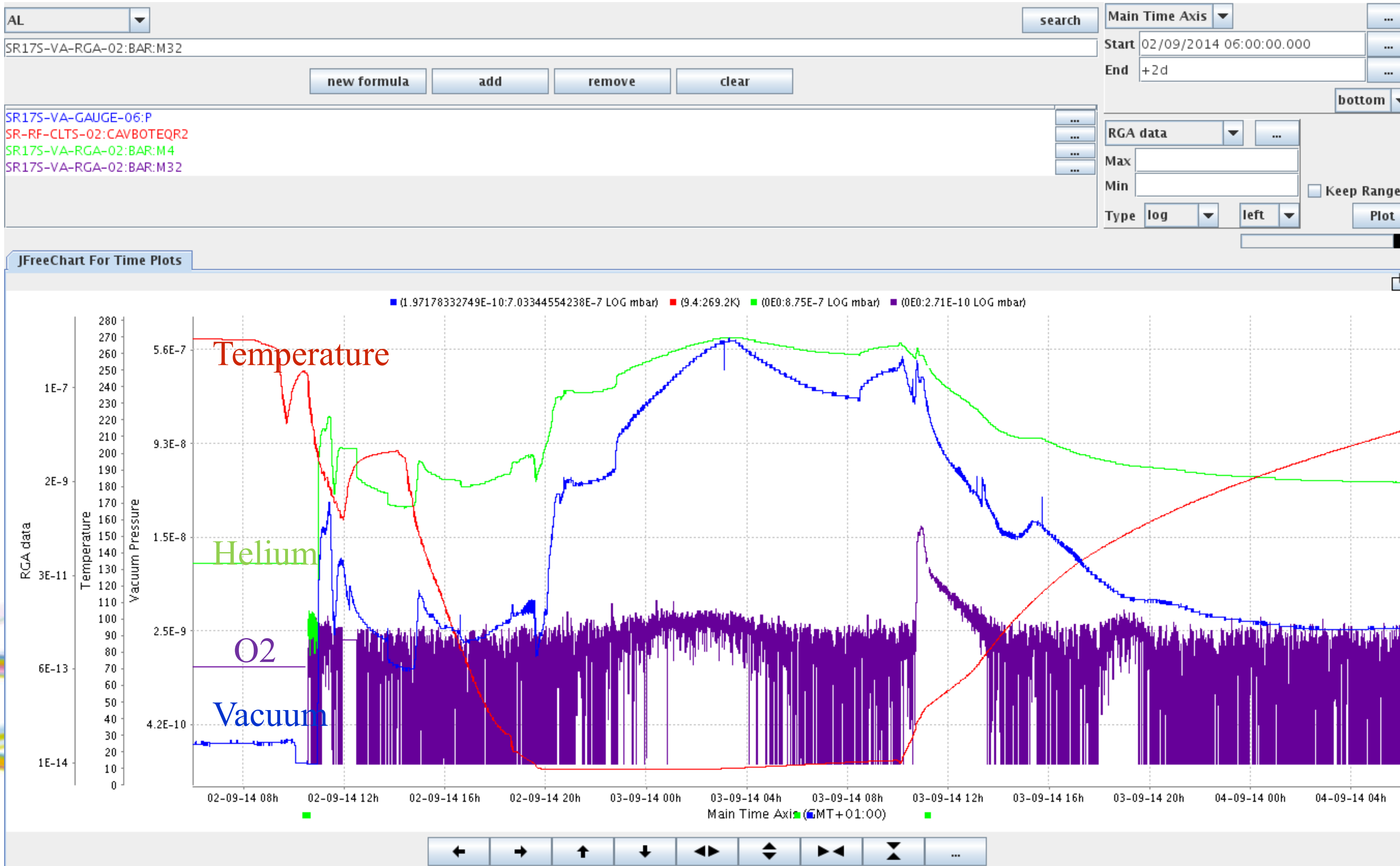
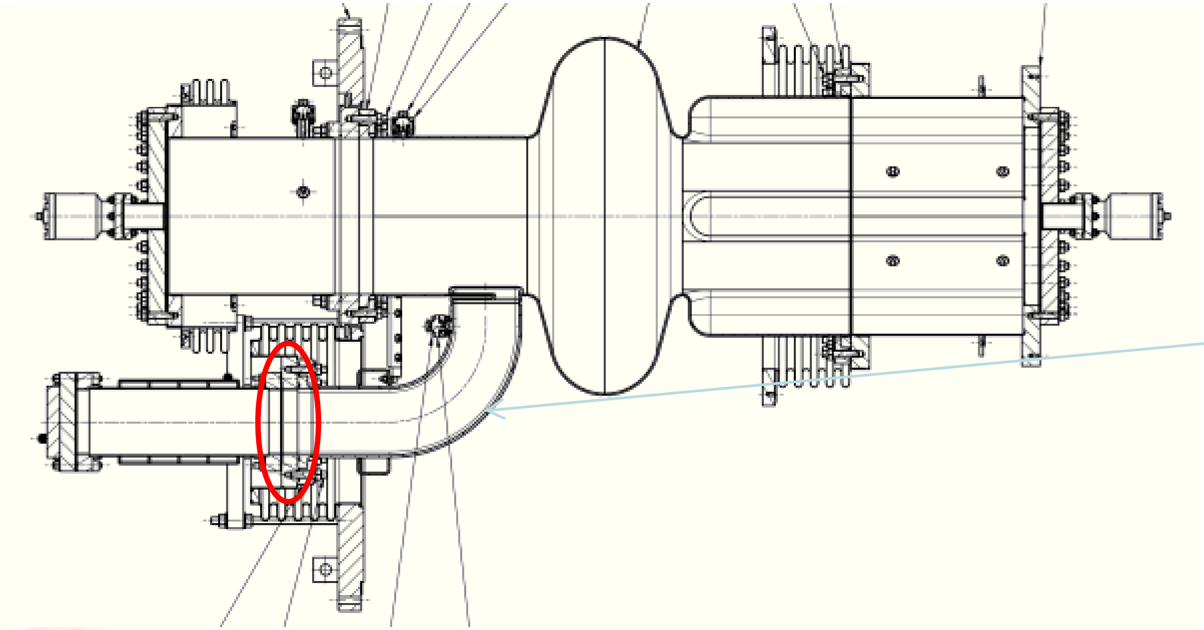
Cavity 2 Failure during Cool-down



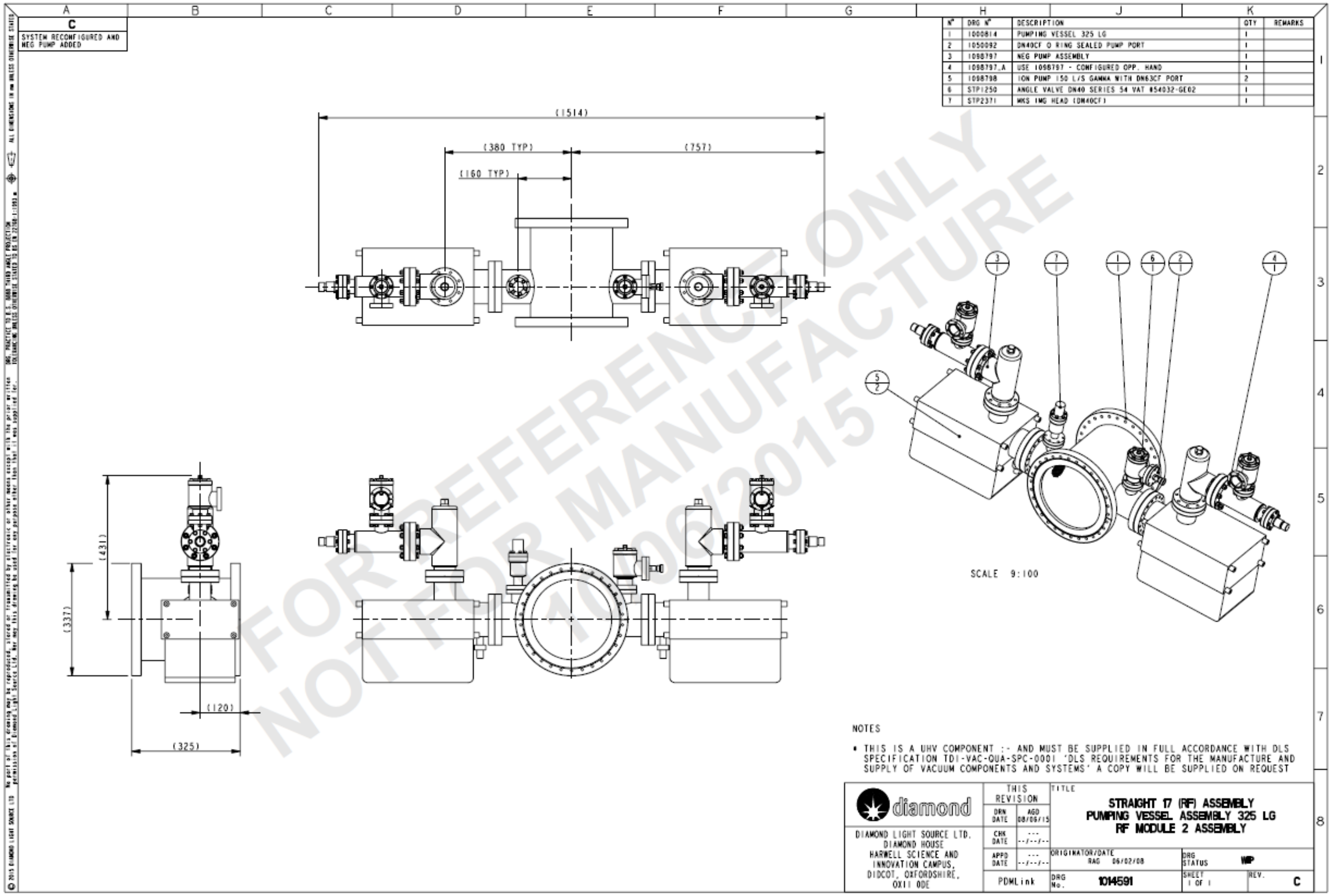
Investigation at RI



Leak rate 2x10^{-8}mbar*l/s

Repair and modification:
Add AB sensor along niobium waveguide bend.
Add TSPs with isolation valve on RBT side.
Modify helium fill tube to achieve more uniform cooling.

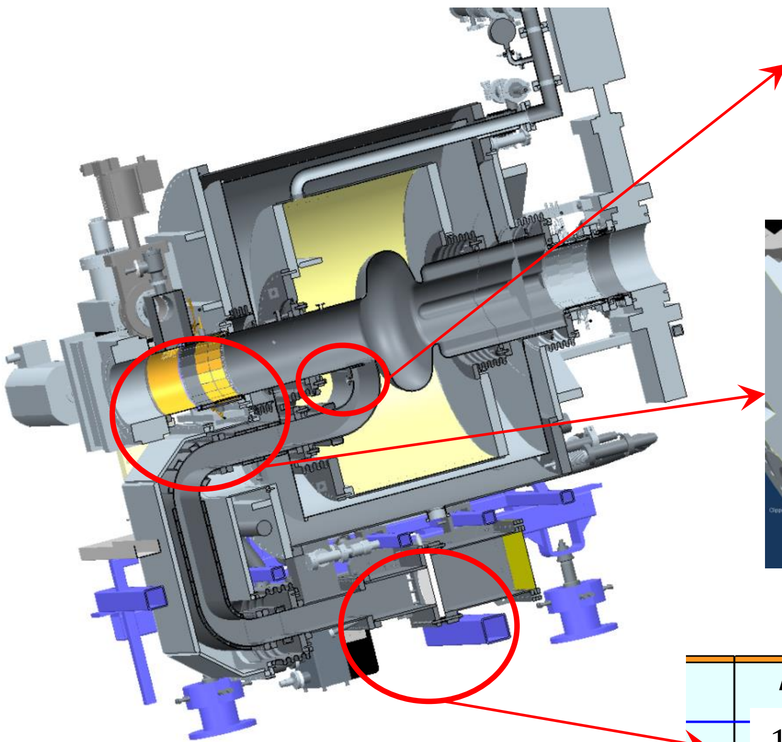
Cavity 2 Modification

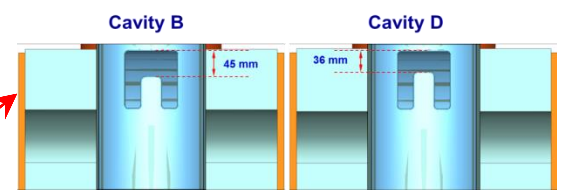


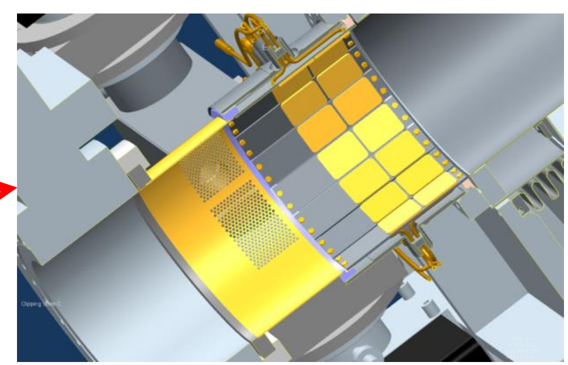
Cavity 2 was back in Diamond Feb 2016 after 15 months of repair, but had to be sent back to RI again due to a leak from Helium can to cavity UHV.

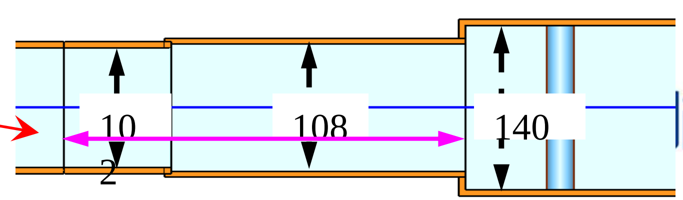
Cavity 4 Modifications

1. HOM loads at RBT side
2. Shanghai Coupler tongue
3. CLS Pump out box (Qe~1.5×10^5)
4. TSPs with isolation valve on RBT side
5. Position sensors on two sides
6. New LN2 flow controller









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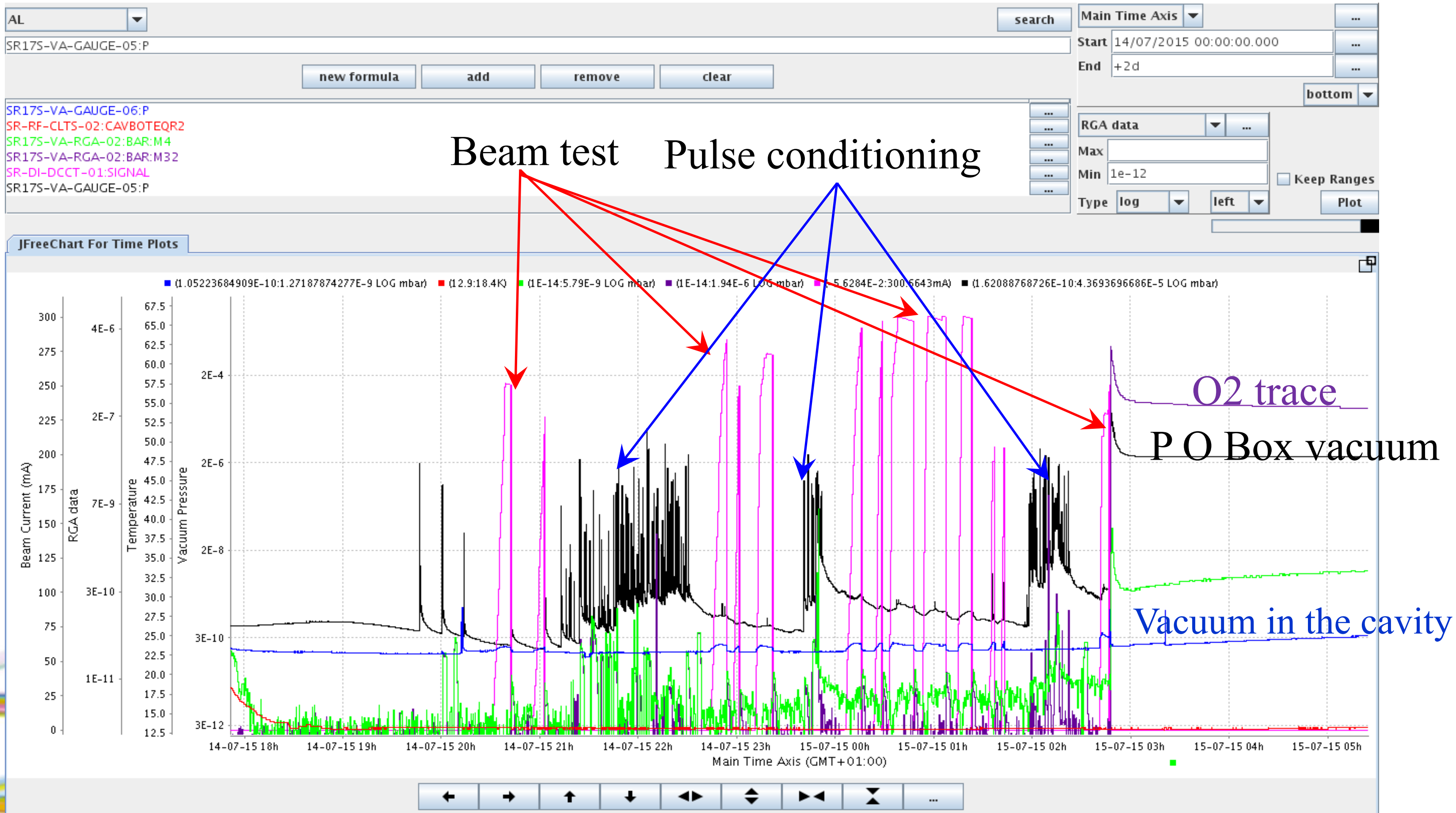
Cavity 4 RF Window Leak

Cavity 4 was rushed through the SAT to replace cavity 2 in September 2014.
It suffered many fast vacuum trips from the start.
Qext was pushed very low to 9×10^4 by using stub 1&3 of the 3-stub tuner.
Stronger and more lasting out gas even at low power level when both stub 1&3 were pushed in.
Pulse conditioning and beam conditioning were performed before it failed during beam test.

Cavity 4 RF Window Leak

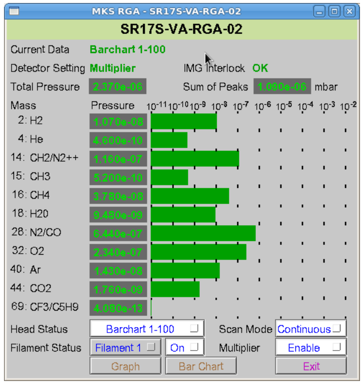


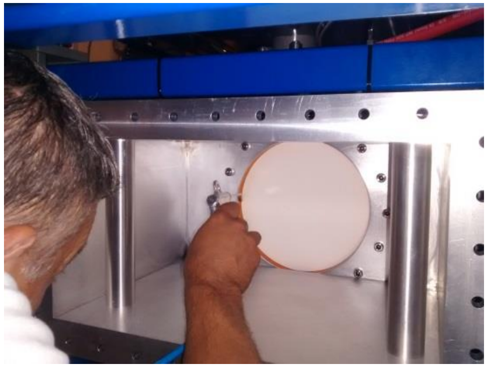
Vacuum at valve box went up to 10^{-5}mbar at pump out box.

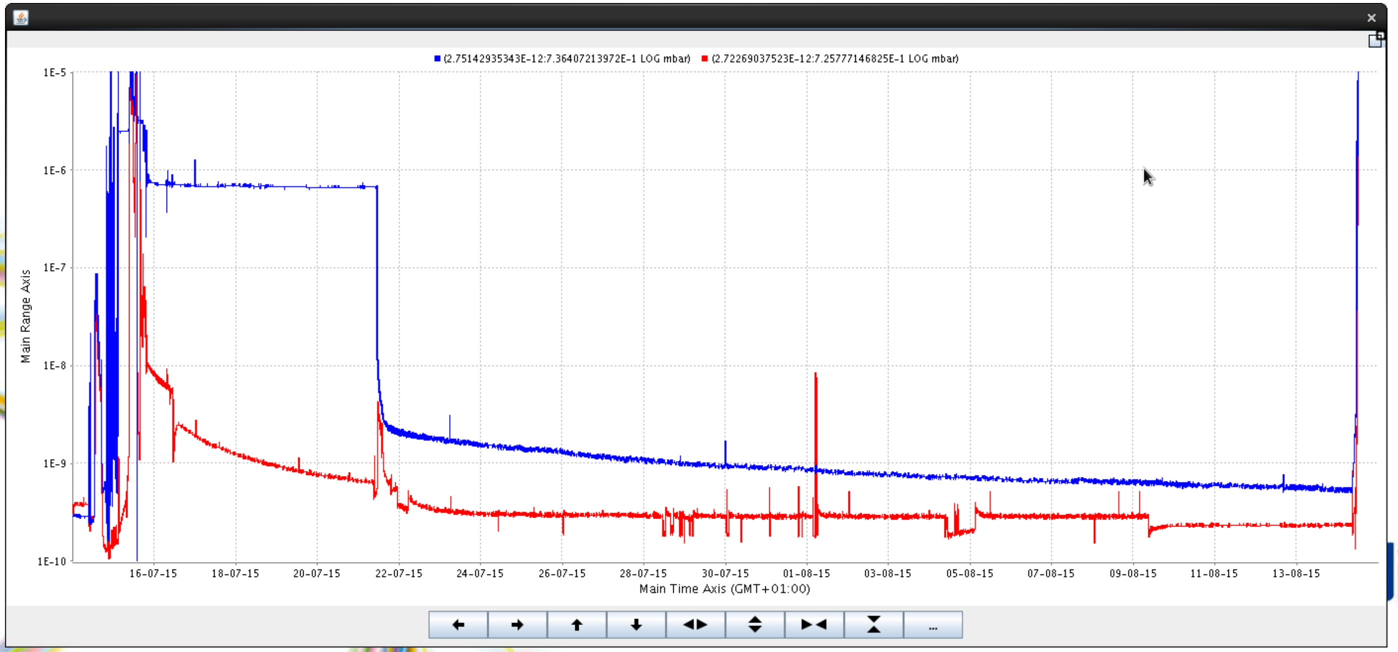
No big change inside the cavity.

Cavity 4 RF Window Leak

Vacuum sealant was applied to the RF window.
Cavity was detuned and kept cold during the rest of the run for more than 4 weeks.

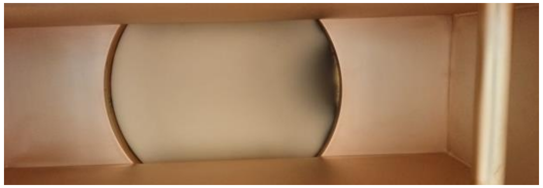






Cavity 4 RF window Swap

The broken RF window was swapped with our spare RF window inside a clean room of RAL Space.
The cavity has been successfully tested to 2.1MV in RFTF.



Some Observations on the Operation of SRF Cavities

In the early days of service, all SRF cavities suffered recurrent fast vacuum trips.
Vacuum activities can be seen during normal operation. At least some can be associated with activities on the probes, for example on waveguide electron pickup.
Vacuum activities fewer after full/partial warmup.
Probe blips are seen in many SRF cavities and they can trip the beam.
Gas adsorption and its effect can be seen during test and conditioning time.
(Quench at high cavity voltage, out-gassing in the waveguide, X-ray dose rate goes up….)
Cavity performance tend to improved with the time in service.

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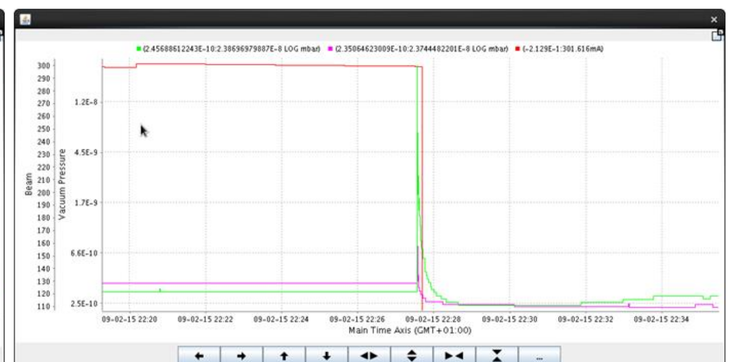
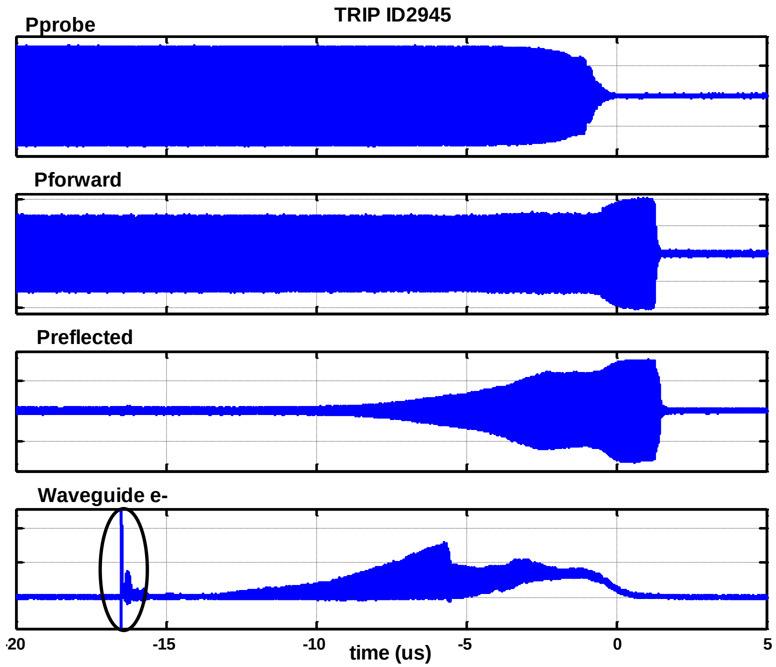
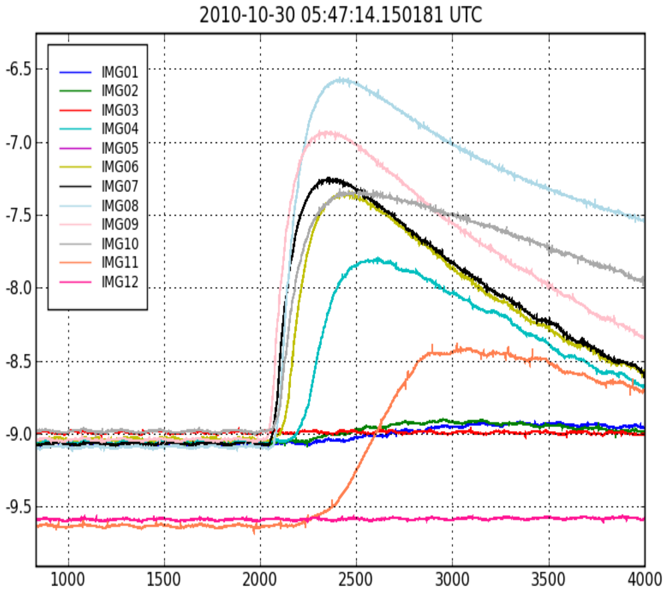
YOKOGAWA
2015/02/12 21:22:43
Running
Normal
1.25GS/s
Edge CH4 54mV
Normal
Main : 125 k
10us/div
ACTION
Abort
YOKOGAWA
2015/02/09 22:28:09
Running
Normal
1.25GS/s
Edge CH4 54mV
Normal
Main : 125 k
10us/div
ACTION
Abort


Beam
Vacuum Pressure
Main Time Axis (GMT+01:00)


Beam
Vacuum Pressure
Main Time Axis (GMT+01:00)

Typical Fast Vacuum Trip





- Cavity routine management

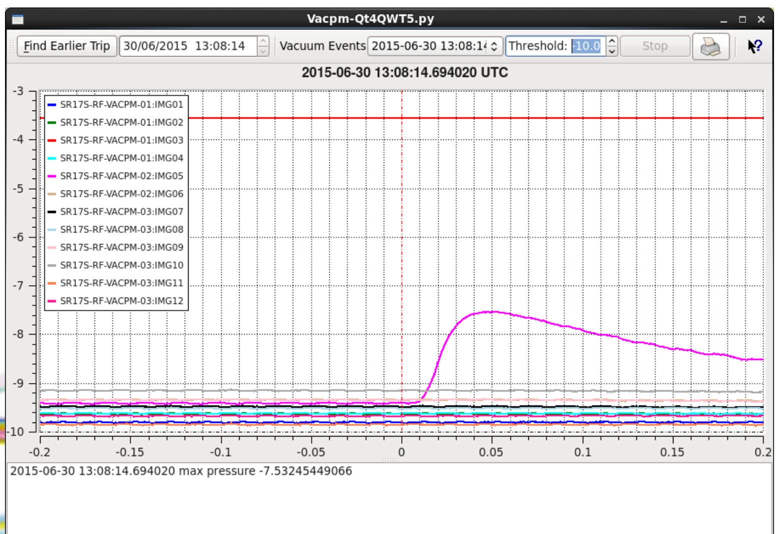
  Weekly conditioning to check and maintain the performance.

  Partial warm-up during every shutdown, full warm up only when absolutely necessary.

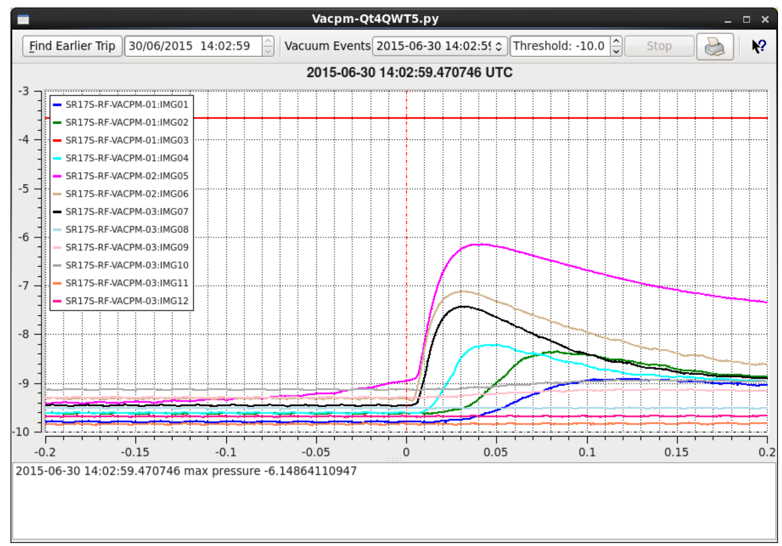
  Cavity voltage and power balance between systems.

3-stub Tuner Position and Cavity Trips

- Cavity 4 trip problem was cured by reducing voltage from 1.0MV to 0.8MV
  - Some loss of beam lifetime but interlock levels were cleared
  - Required change in 3-stub tuner position to maintain good coupling
- As a test, a beam trip was provoked by overloading cavity with the two 3-stub tuner configurations
  - Followed same procedure in both cases



Stub 3 in

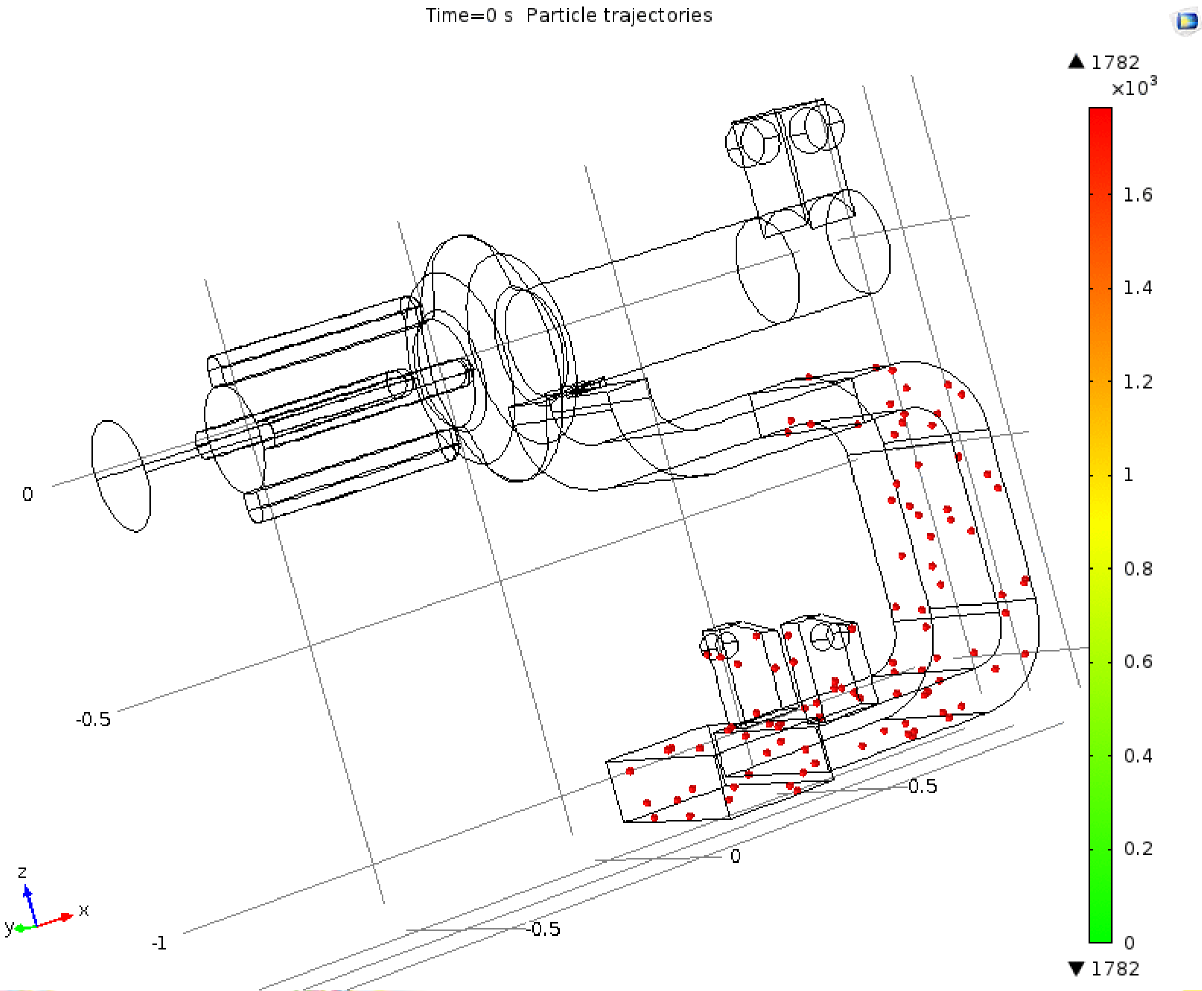


Stub 3 out

Pressure profiles correspond to standing wave pattern and do not signify different processes

Simulation of Gas Deposition on Cold Surfaces

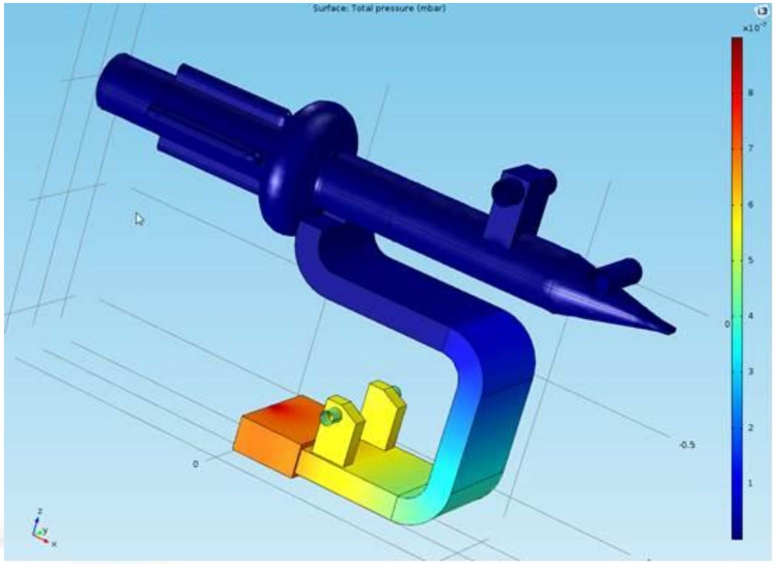
Courtesy of Matthew Cox



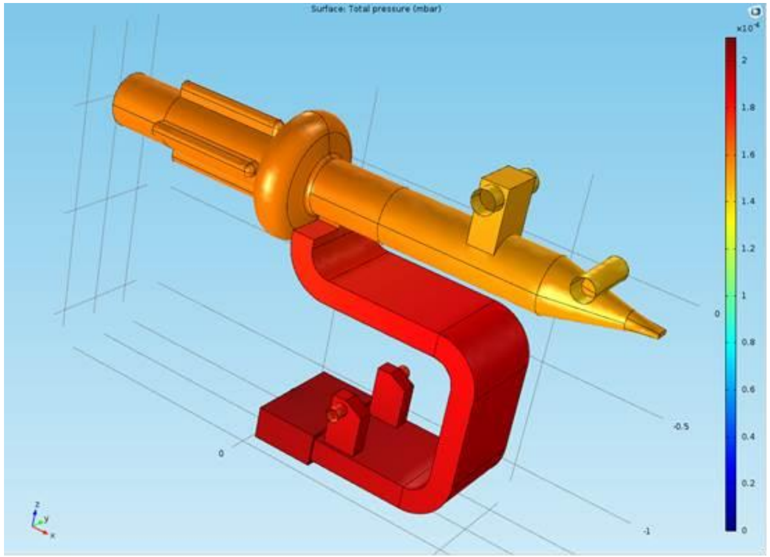
Simulation of Gas Deposition on Cold Surfaces

Courtesy of Matthew Cox

Nitrogen

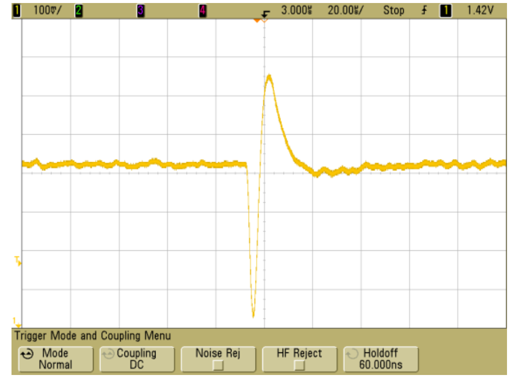


Helium

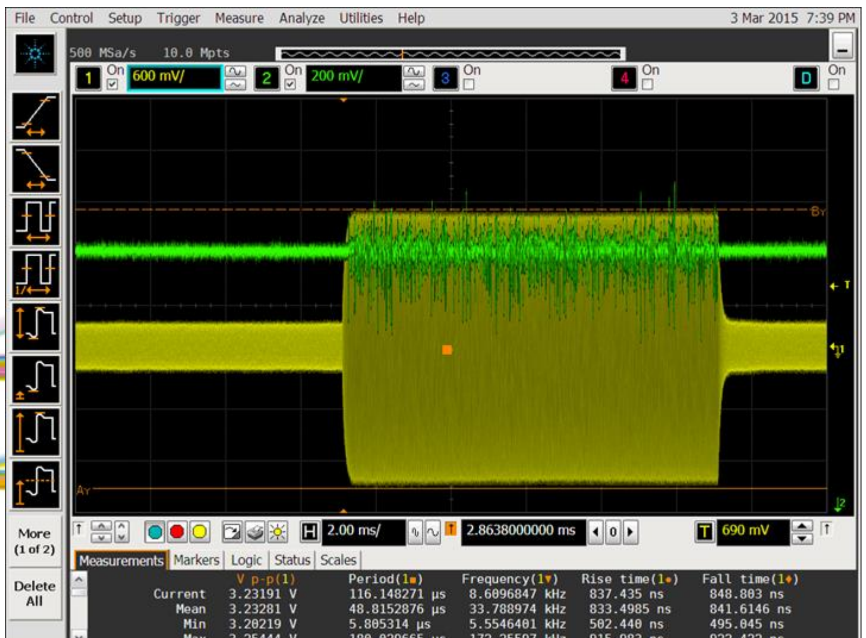


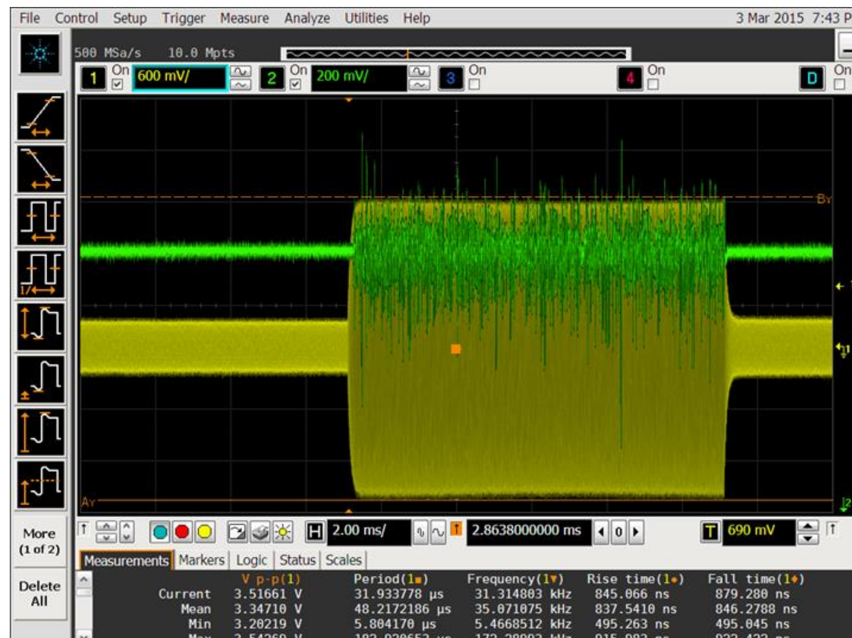
PIN Diode X-ray Detector

Hamamatsu S1223



Single radiation event





Radiation during pulse conditioning at different peak cavity voltage

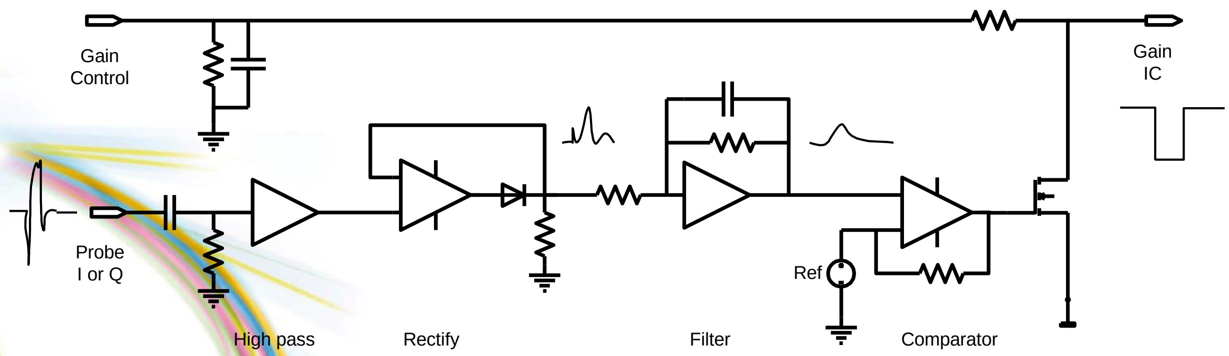
Cavity Probe Blips

Problem:

- fast rise-time spikes causing loss of RF signal on cavity HF pickup (and spare probes). Up to 4 blips/day/probe.
- LLRF interprets this as reduction in cavity volts and pushes up the forward power to compensate, causing a beam trip in some circumstances.

Actions taken:

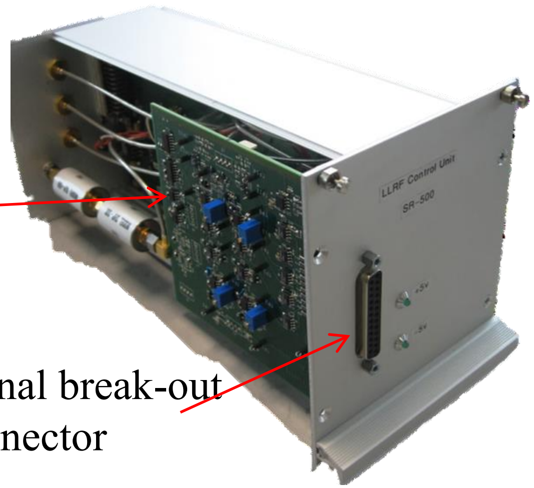
- Addition of filtering in the LLRF to reduce the bandwidth from 1MHz to 50 kHz. This has been successful at preventing trips at low loop gains. No probe blip trips since January 2014.
- Trial of a additional circuitry to detect the blip and reduce the loop gain during the period of the blip (~2 to 6us typically).



Simplified schematic of probe blip detection circuit

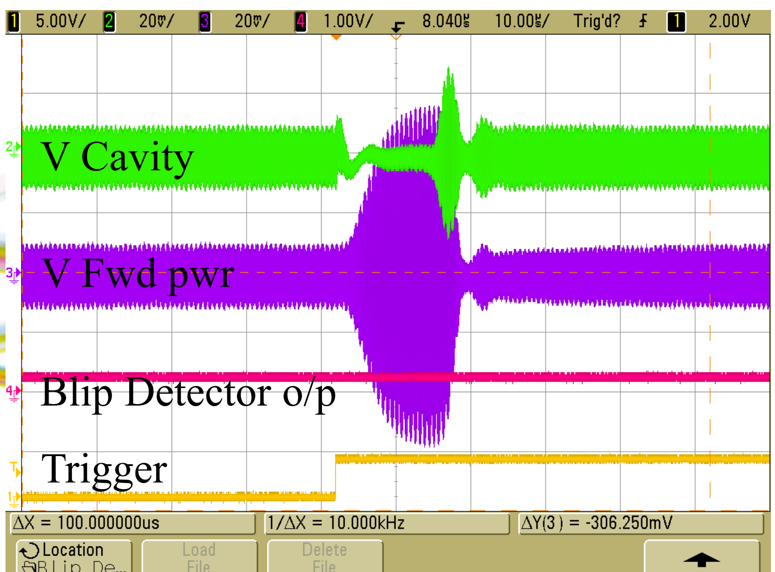
Cavity Probe Blips

Probe blip detector PCB mounted in LLRF module

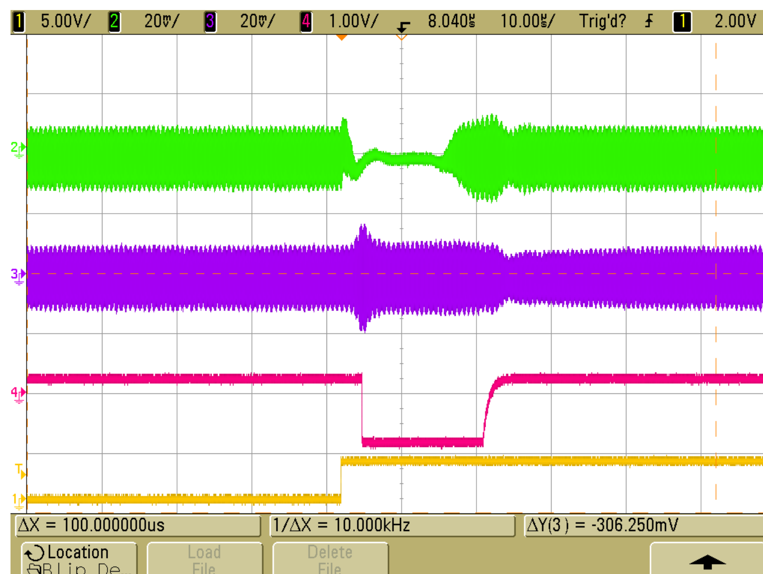


Signal break-out connector

Tests using cavity simulator and blip simulated by blanking probe signal for 10us:



Circuit disabled

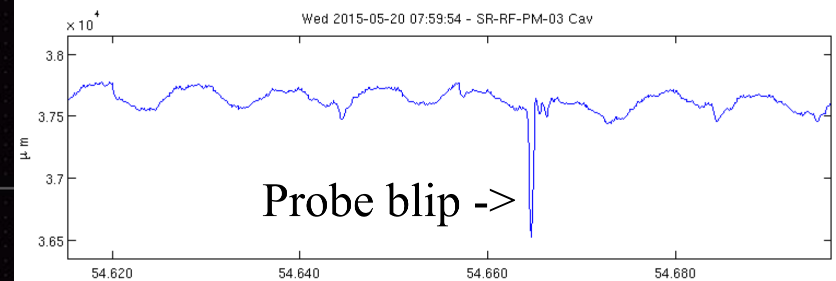


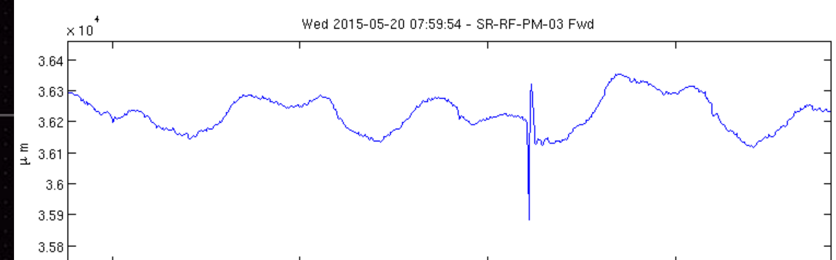
Circuit enabled

Cavity Probe Blips

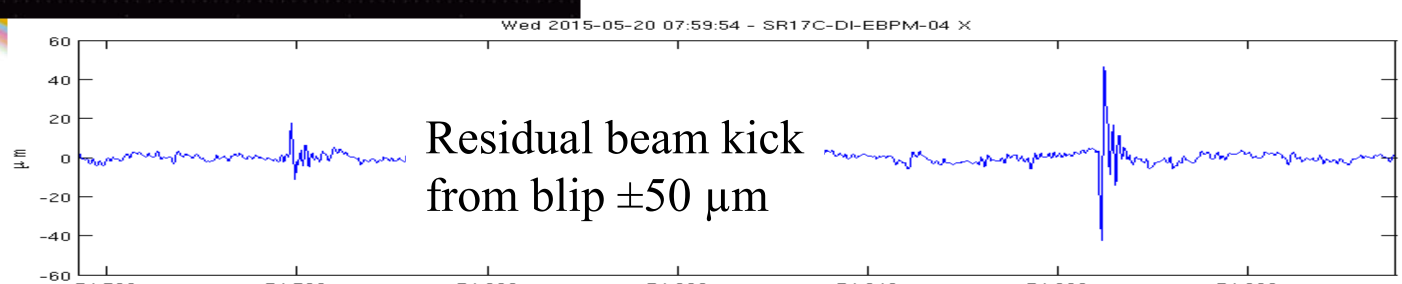
Storage ring tests @ 300mA with LLRF#3 modified to include blip circuit:

LIBERA box, Cavity , PFwd and beam (X) motion signals:





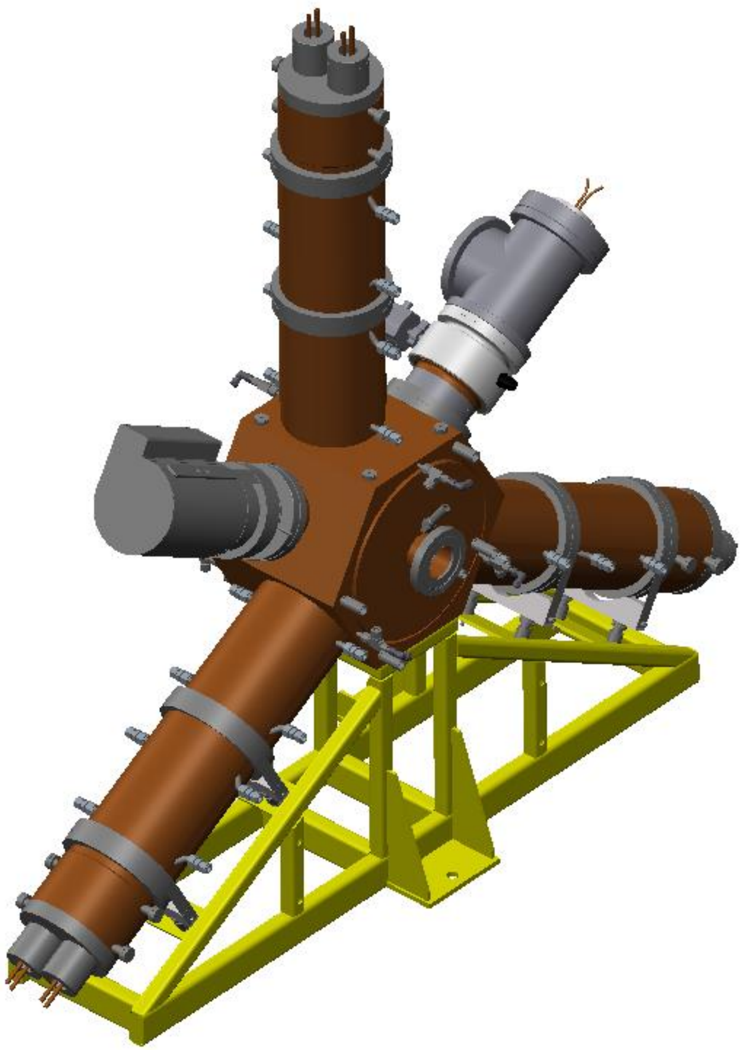
Attack and decay time-constants of gain reduction need optimisation to minimise beam disturbance.



Hybrid normal/superconducting RF

- Cavity failure is a catastrophic event putting Diamond out of action for several weeks
  - Lifetime to failure of cavities is around 6 years
  - A simple cavity repair can take 2 years
    - Currently have 2 working cavities, 1 spare and 1 under repair
  - Cavity 2 UHV leak caused 3 week downtime
    - Cavity 4 had to be rushed into service with knock-on problems
    - One week recovered by extending following run
  - Cavity 4 window failure resulted in 24 hours downtime and extended period of 150mA operation

Hybrid normal/superconducting RF



We will add two normal conducting cavities to our superconducting cavities

- Can run at modest voltages and reduce power requirements of present amplifiers
- Removes common mode of failure of superconducting cavity or cryo system
- EU HOM-damped cavities as at BESSY and ALBA
- Requires amplifier modification and new LLRF
  - LLRF to be upgraded to digital system
  - Plan to retrofit digital LLRF to present RF systems

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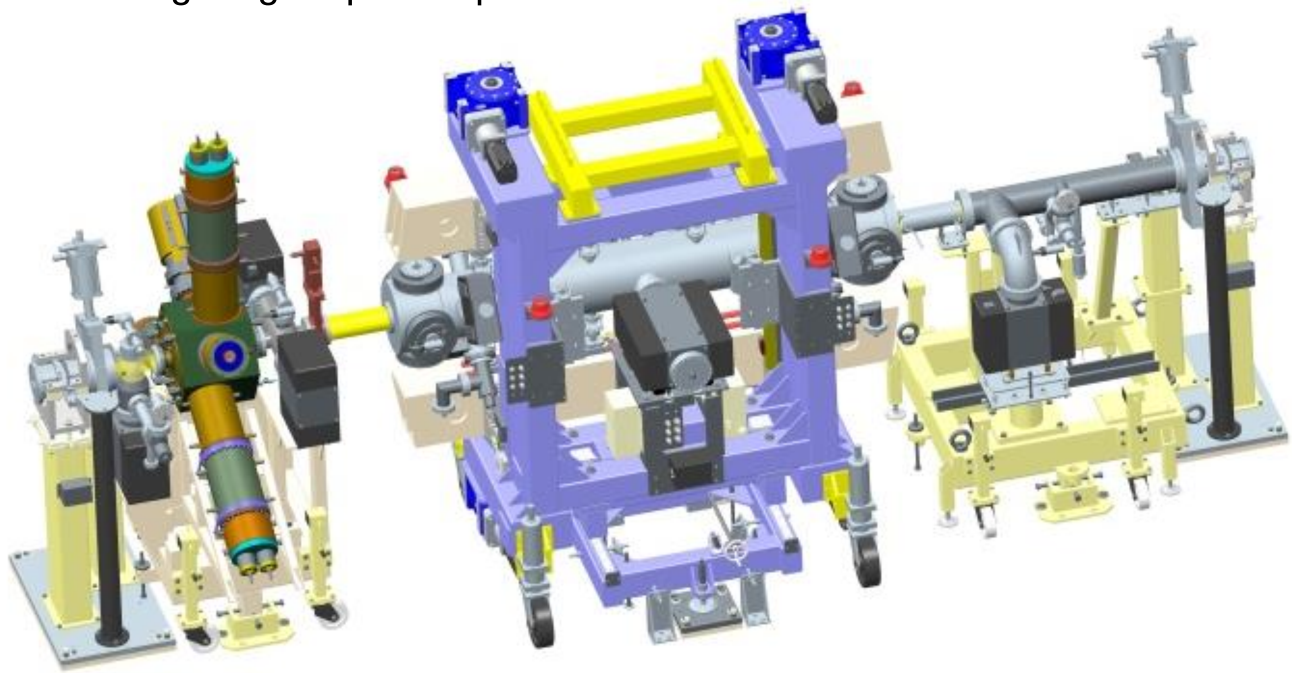
Hybrid normal/superconducting RF

- Location of extra cavities is significant
  - Risk of total RF failure is too high if three superconducting cavities are in the same straight
    - No space for cryostat outside RF straight
    - EU HOM-damped cavities can be placed in many locations
  - Install NC cavities outside the RF straight
    - Install cavities upstream of IDs immediately before and after the RF straight
    - New transmission lines to be installed
  - Use third amplifier for both cavities
    - Currently powering RF Test Facility
    - Investigating amplifier options for RFTF



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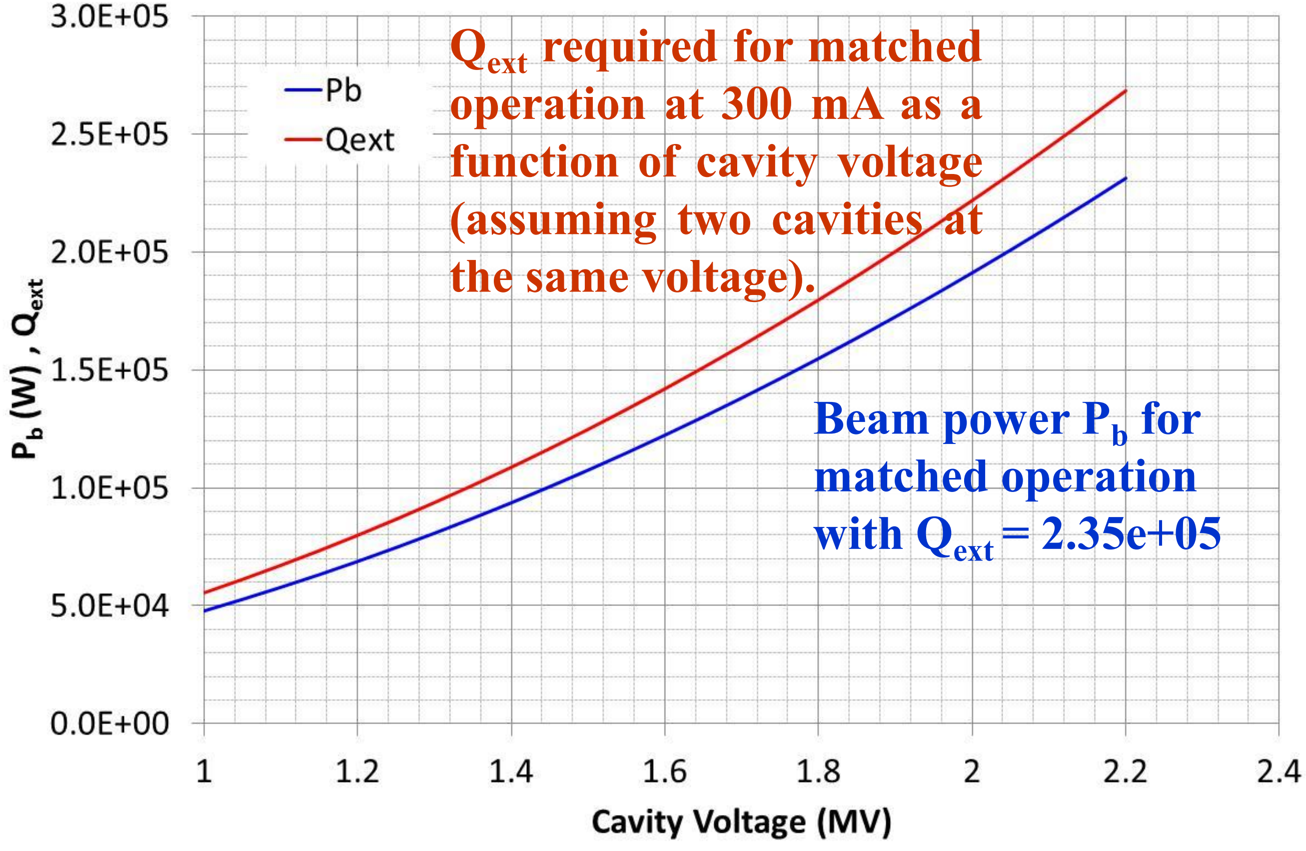
Modification of Pump Out Box for a Lower Qext



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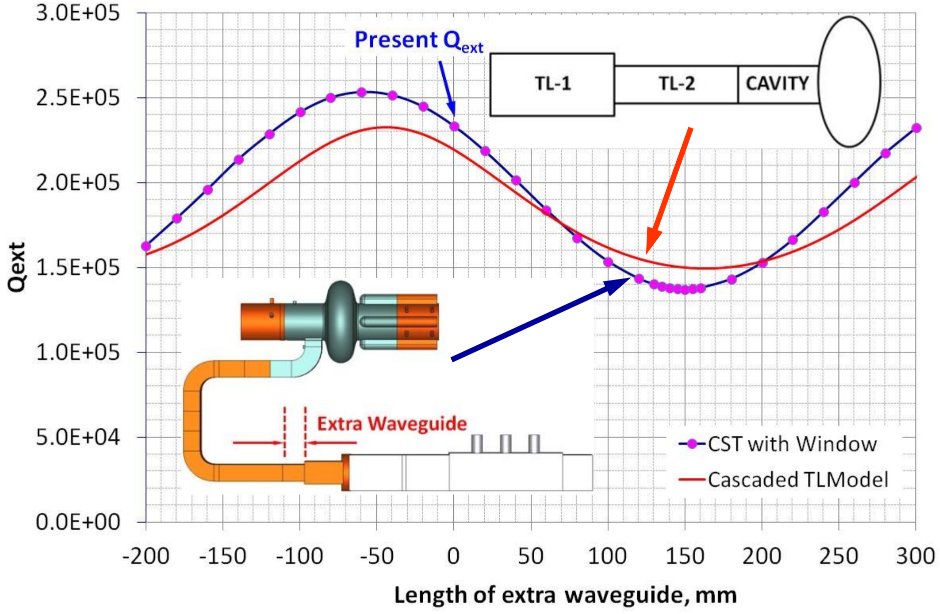
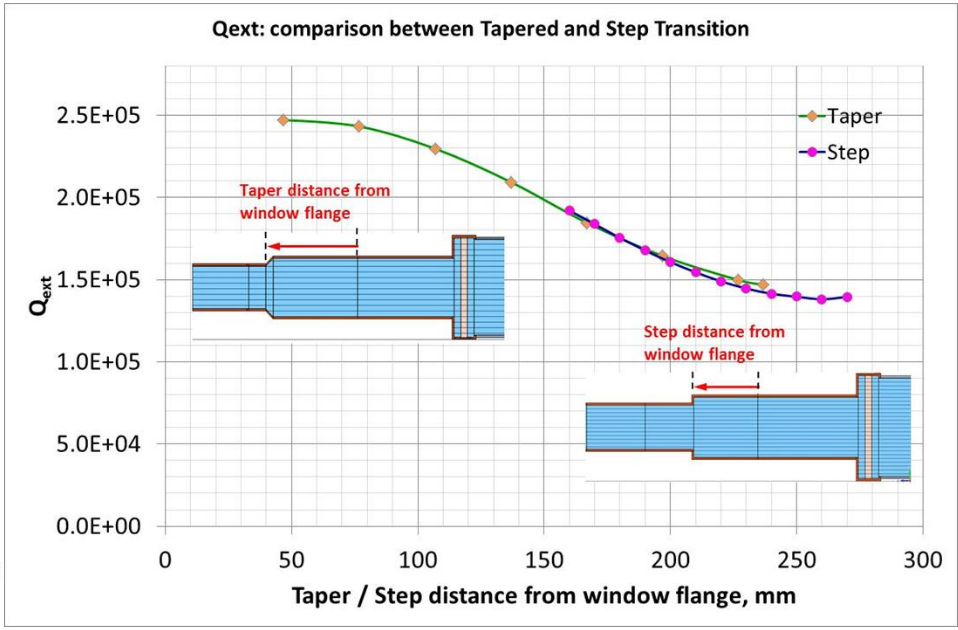
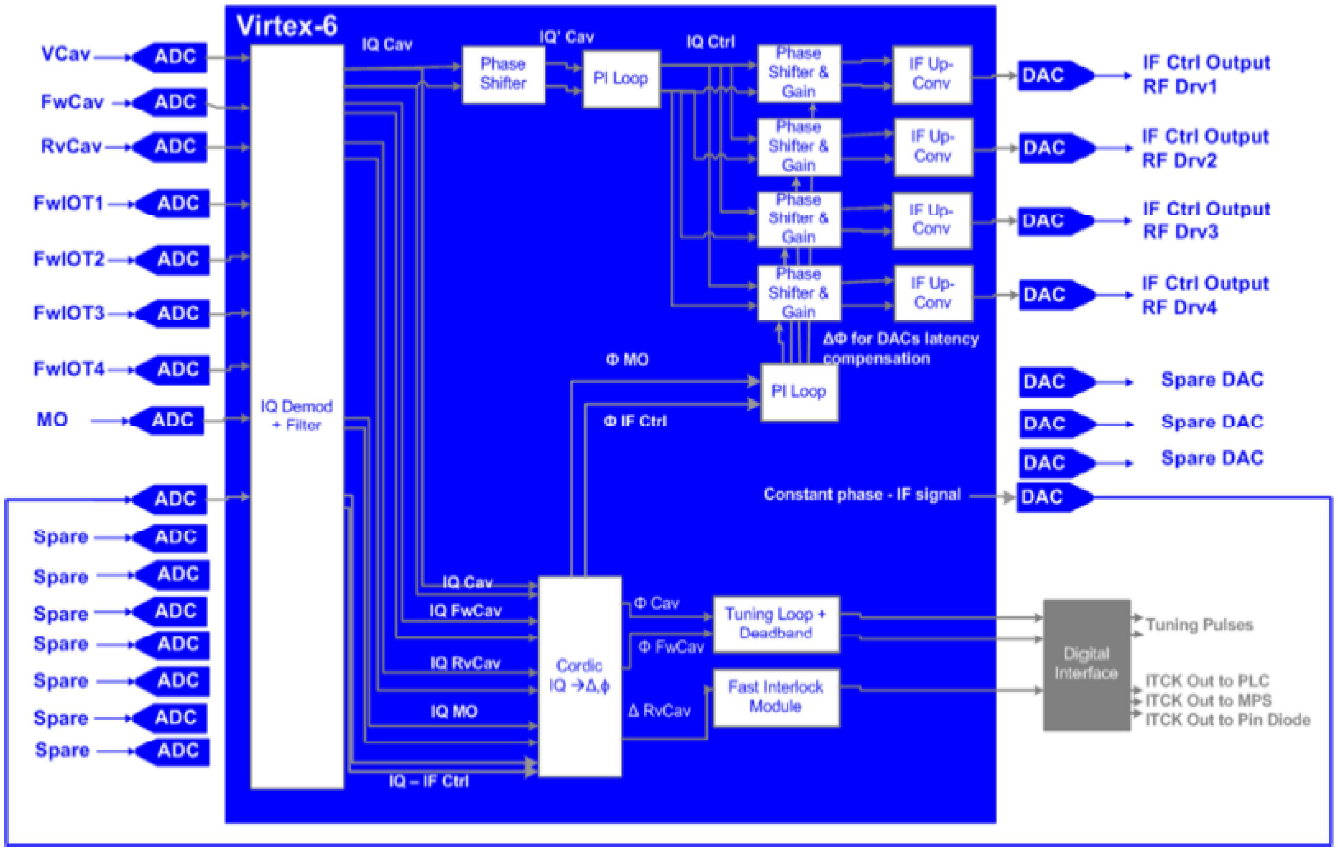


Review waveguide dimensions



Investigate waveguide construction

Digital LLRF System Development



Work with ALBA.
Nutap Perseus 601X μTCA chassis.
FMC MI 125: 16x14 bits ADC sampling at 125MHz.
FMC MO1000: 8x 16bits DAC with 1GSPS.
4 X slow 12 bits ADCs sampling at 250KHz.
4GB RAM for post-mortem analysis.

Thank You!!