Status of RF at Diamond Light Source and overview of upgrade plans

Chris Christou
on behalf of the RF group

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Contents of presentation

- Statistics and reliability
- Cavity failure and repair
- Cavity reliability
- IOT update
- Plans for hybrid operation

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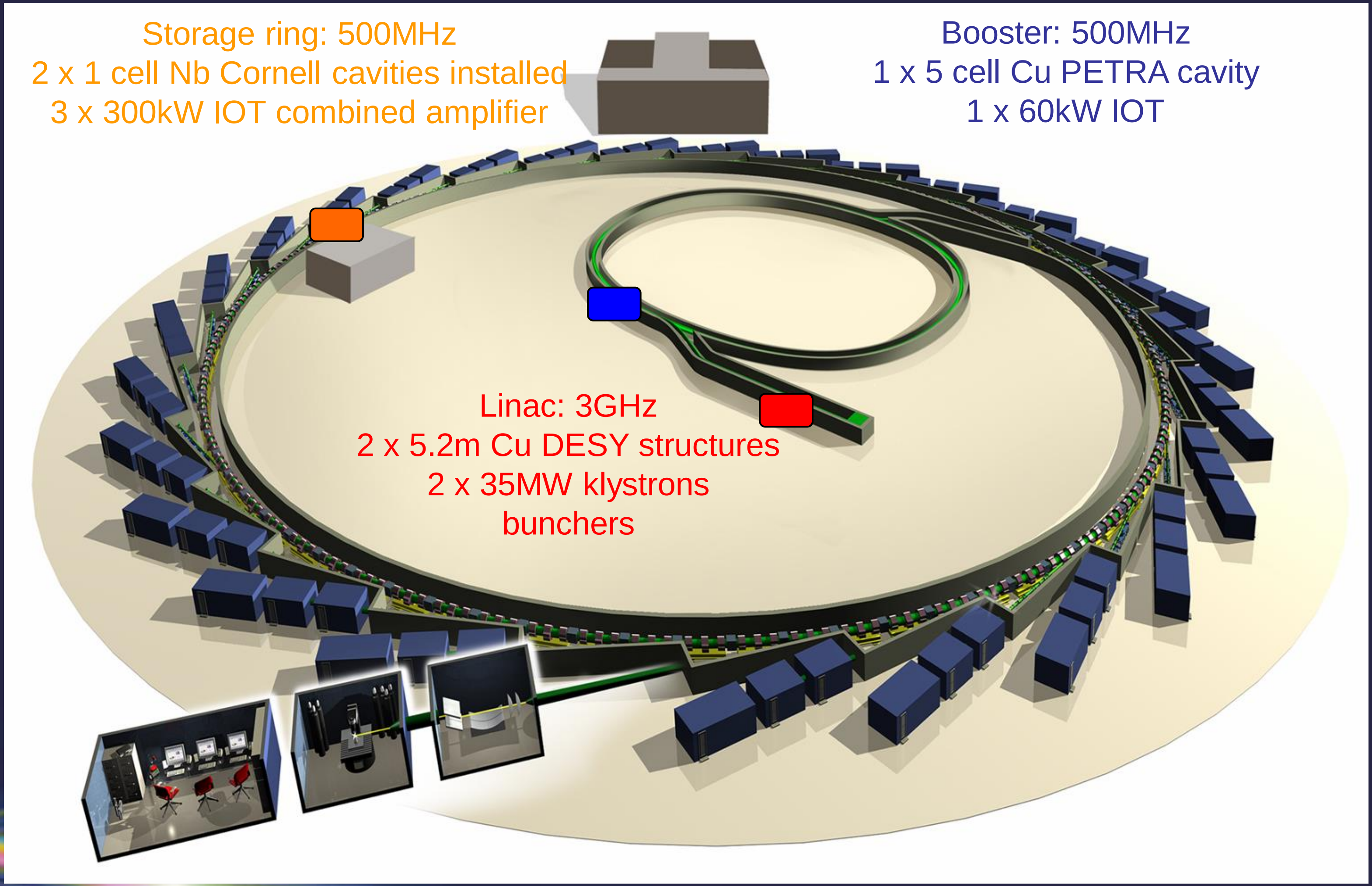
RF group responsibilities



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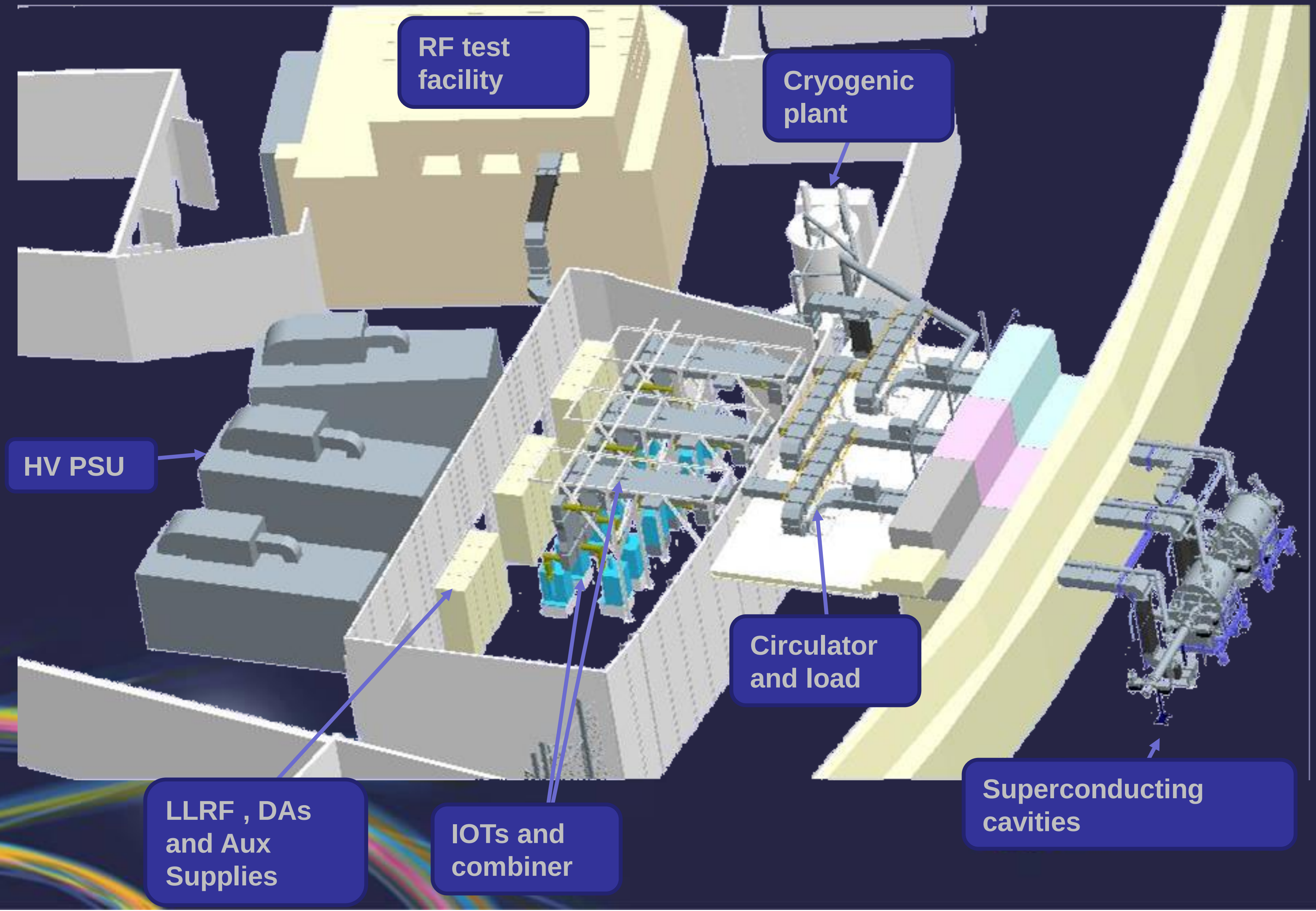
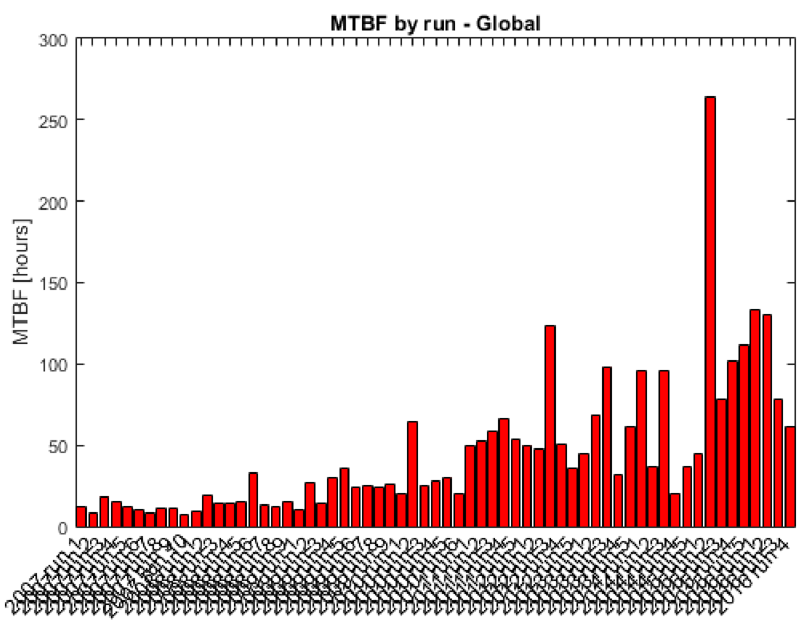
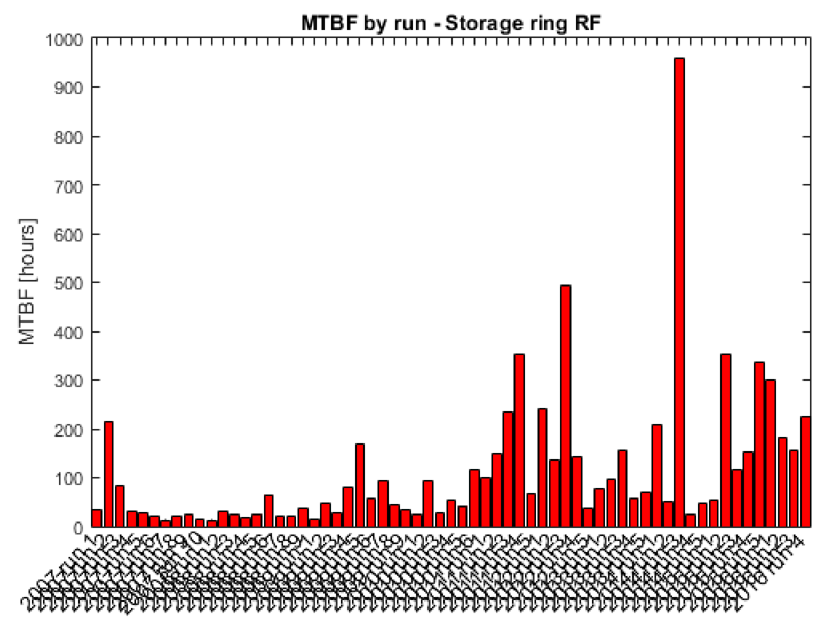
SR RF Systems



Machine reliability





2016 to date:

- Global MTBF is 94 hours
- SR RF MTBF is 202 hours
- Storage ring RF has contributed 20 of 43 beam trips this year
  - 9 vacuum faults, 6 controls faults, 8 others
- Virtually all RF beam trips have been amplifier faults
  - No more spontaneous “fast vacuum trips” in normal operation

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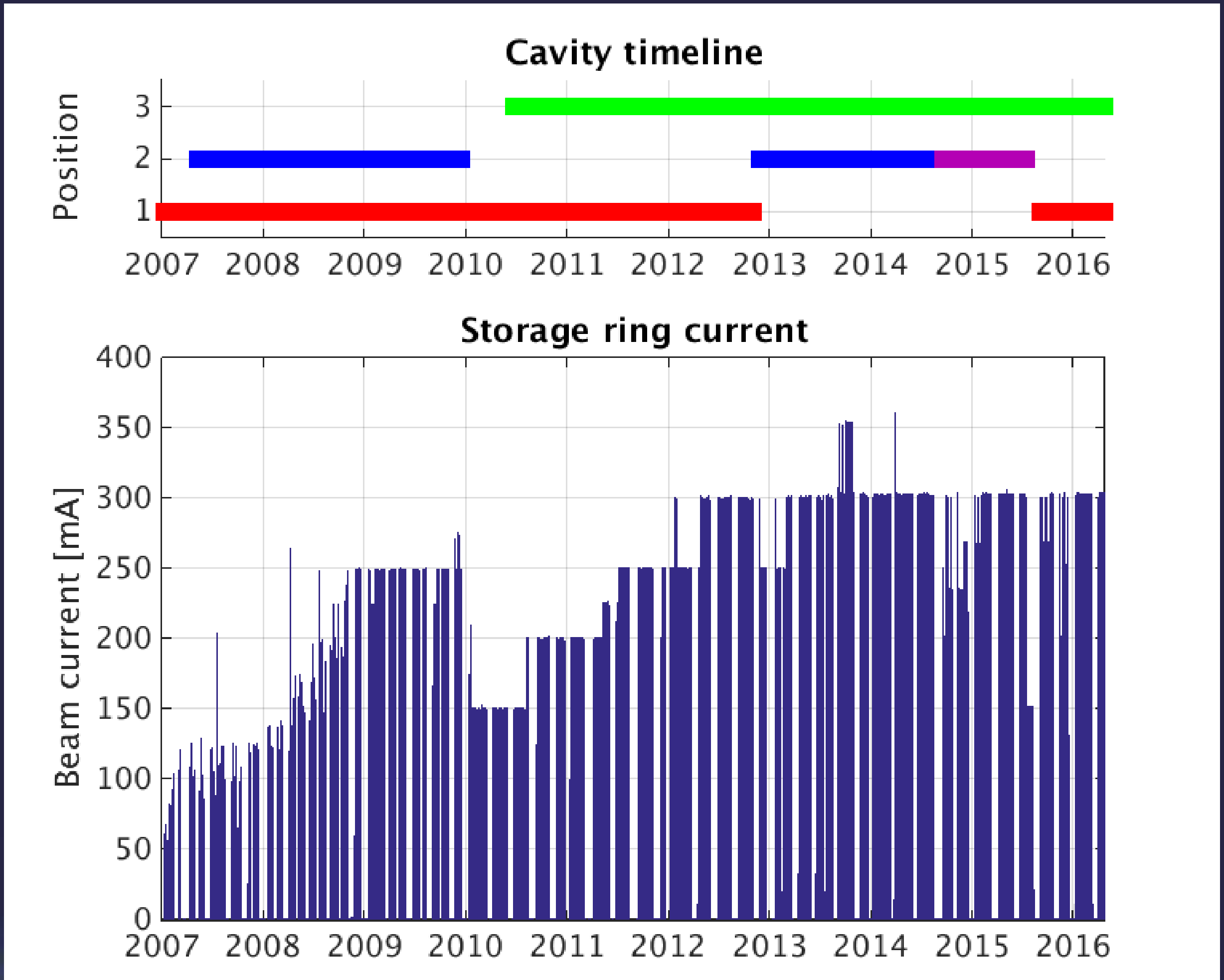
Cavity changes since 2007



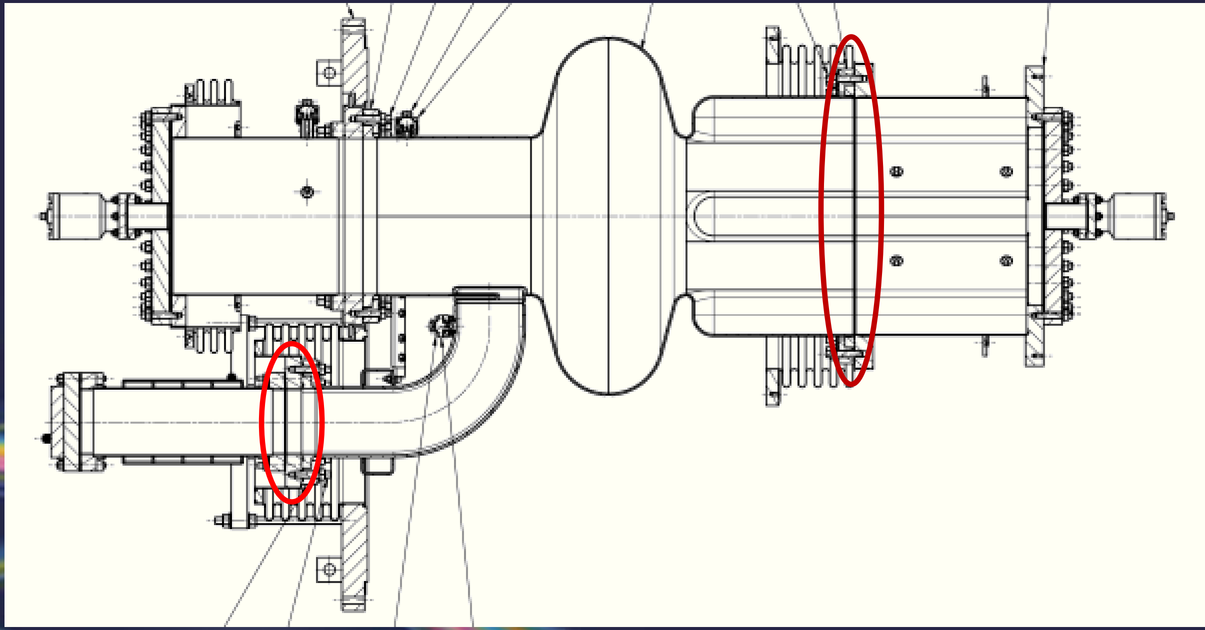
DLS owns 4 CESR-B cavities, all from Accel/RI:

- Cavities installed in 2 of 3 spaces in RF straight
- Cavity failure can have a lasting effect on machine performance
- Repair of cavities can be painfully slow

Cavity failure September 2014

Helium leak into UHV

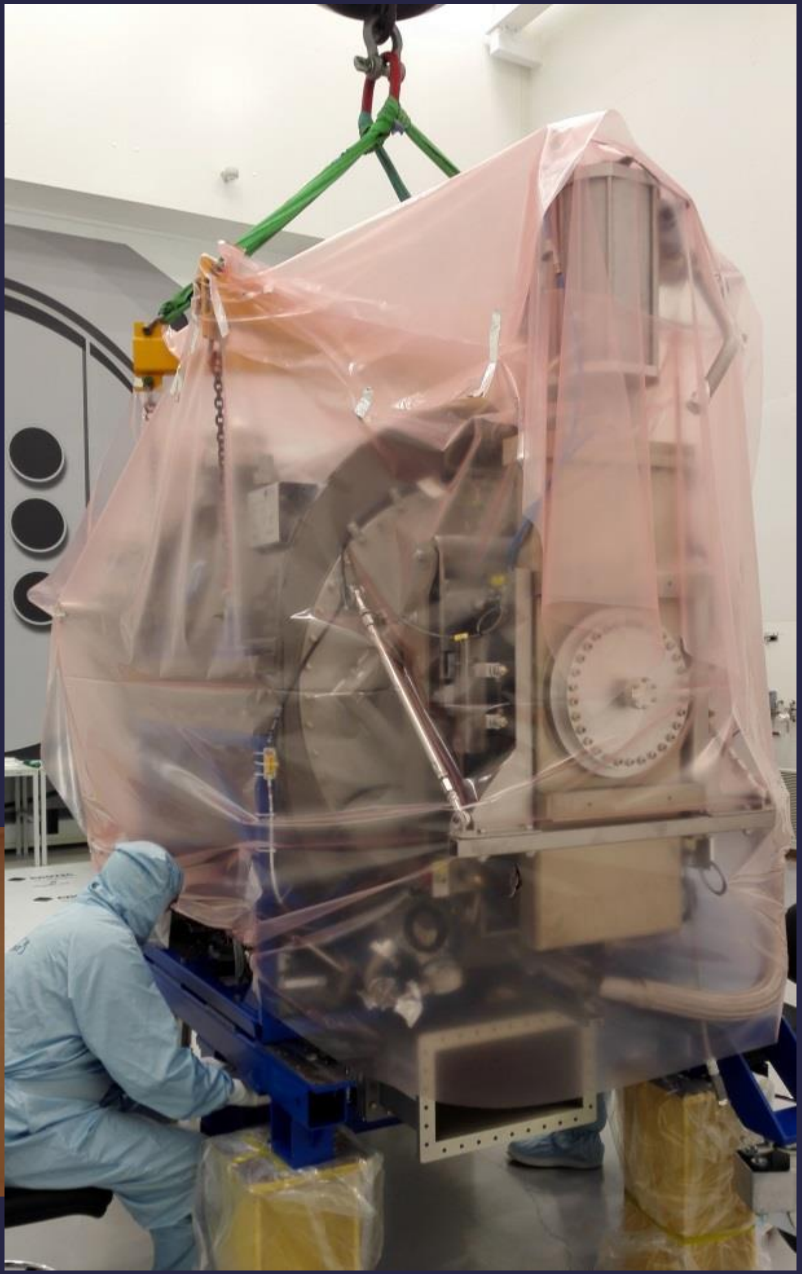
- Failed during cool-down from room temperature
  - No more warm-ups unless absolutely necessary
- Indium seal at waveguide flange
- Returned to RI in December 2014
  - Cavity returned to DLS in 2016
  - Failed acceptance test with leak at indium seal on FBT
  - Fault is still not resolved



Cavity failure July 2015

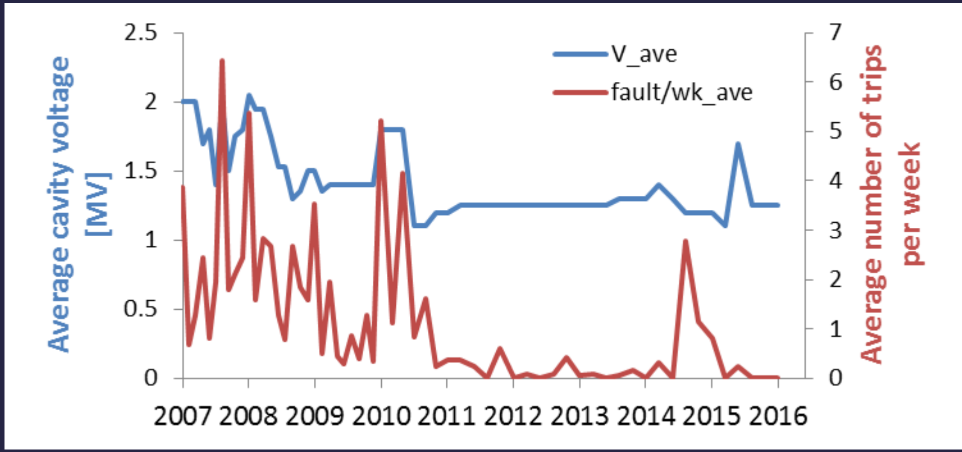
Failure of ceramic-metal braze at window

- 10 months after abbreviated acceptance test
- During normal operation after standard conditioning
- Repaired on-site at RAL in February 2016
    - Installed spare window assembly
    - Used RAL Space satellite assembly cleanroom
    - ISO class 5 cleanroom with 5 tonne crane
- Tested to 2.1MV operation in RF test facility



Fast vacuum trips

Cavity fast vacuum trips are no longer a problem in normal operation



Trips have been eliminated by operating cavities below threshold voltages

Each cavity has a different "safe" operating voltage

- Cavity 4 has the lowest threshold
- 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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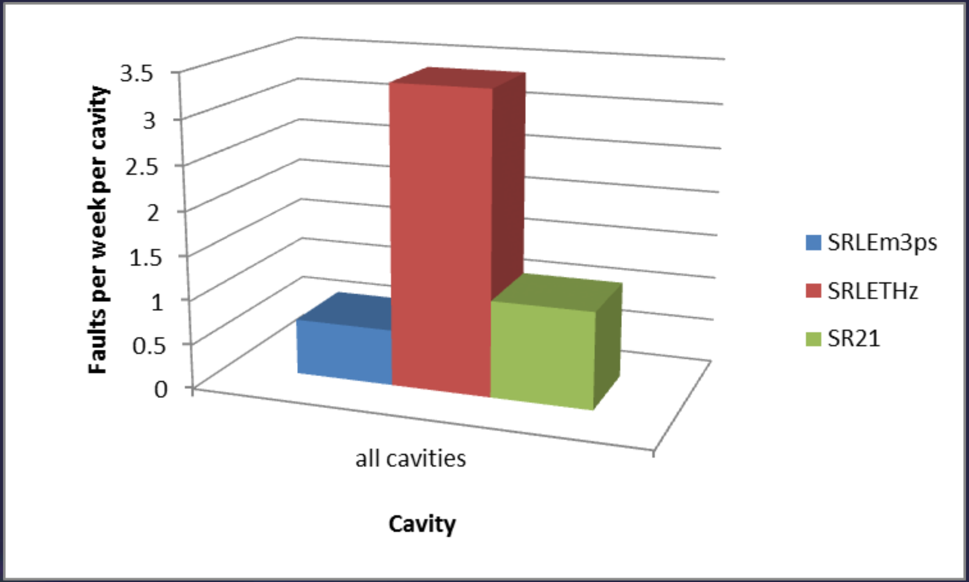
Fast vacuum trips

Low alpha operation requires high cavity voltage: generally 1.7MV per cavity

- Usually one or two weeks low alpha operation per year
- No low alpha operation in 2016

Compare two low alpha modes with normal optics operating at the same voltage

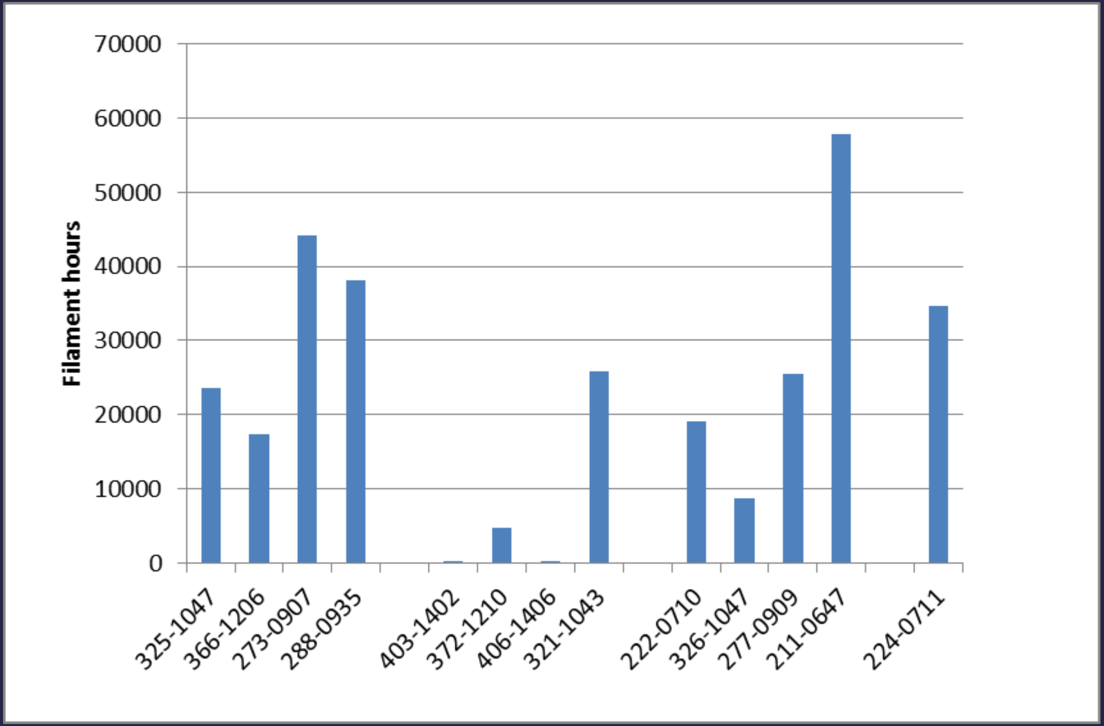


- SRLEm3ps
  - Stable short bunch low α
  - 1.7MV, 3.5ps
- SRLETHz
  - Bursting short bunch low α
  - 1.7MV, 3.5ps
- SR21
  - Normal operation at high V
  - 1.7MV, 16ps

Bunch structure strongly influences trip rate

IOT performance

Filament hours of IOTs in operation



e2v IOTD2130

- Two 4-IOT amplifiers driving cavities for normal operation
- One 4-IOT amplifier for test/conditioning/standby
- Single IOT booster amplifier

- One IOT >57,600 hours operation
- Several >20,000 hours

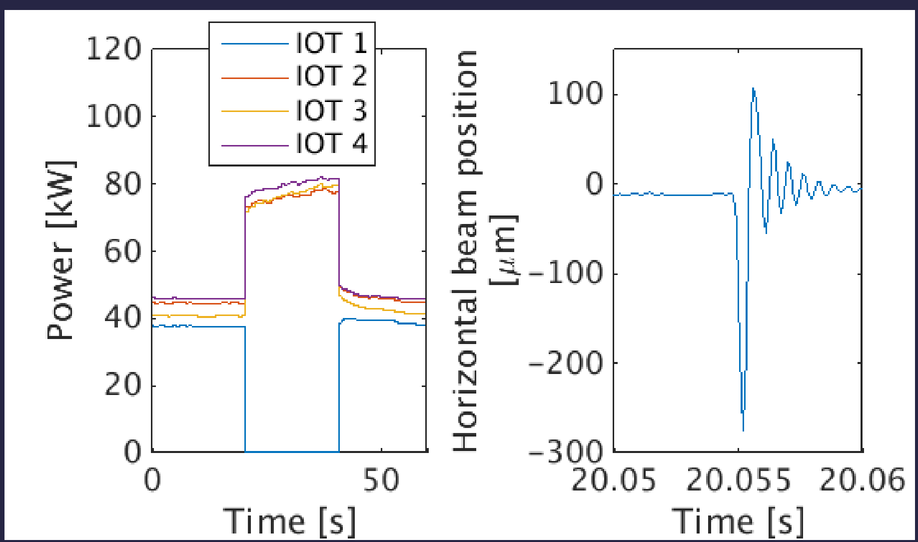
IOT switching

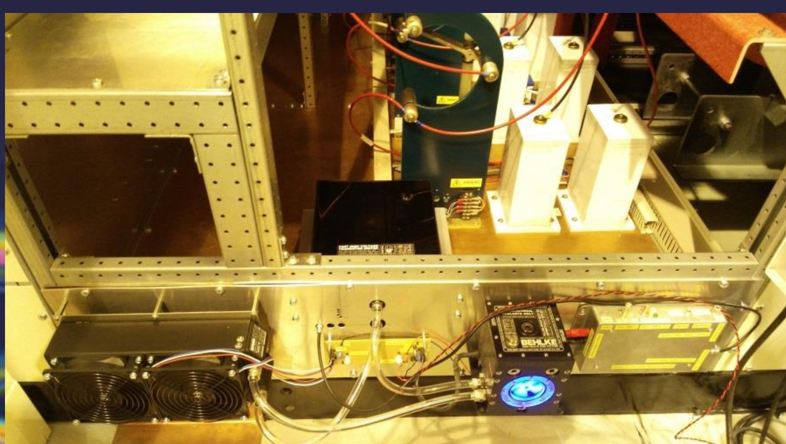
One high voltage power supply is used for all four IOTs in an amplifier

- Voltage is removed from all four IOTs when a fault is detected on any IOT in order to protect the tube
- Amplifier turns off and beam is lost for every IOT fault

Can we isolate an IOT by another mechanism?

- Investigating high voltage MOSFET switch





Switch has been installed on test amplifier

- Tests are ongoing

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Booster amplifier upgrade

Booster IOT failed during January 2016 start-up

- Still using Thales TH793 tube
- Excessive ion pump current on operating tube
- Spare IOTs failed, some catastrophically

DCX Millennium amplifier modified

- Changed to e2v IOTD2130
    - New trolley conflicted with amplifier firmware
    - Amplifier expected two cavity broadcast configuration
- Same as storage ring tubes
    - Ready supply of spares

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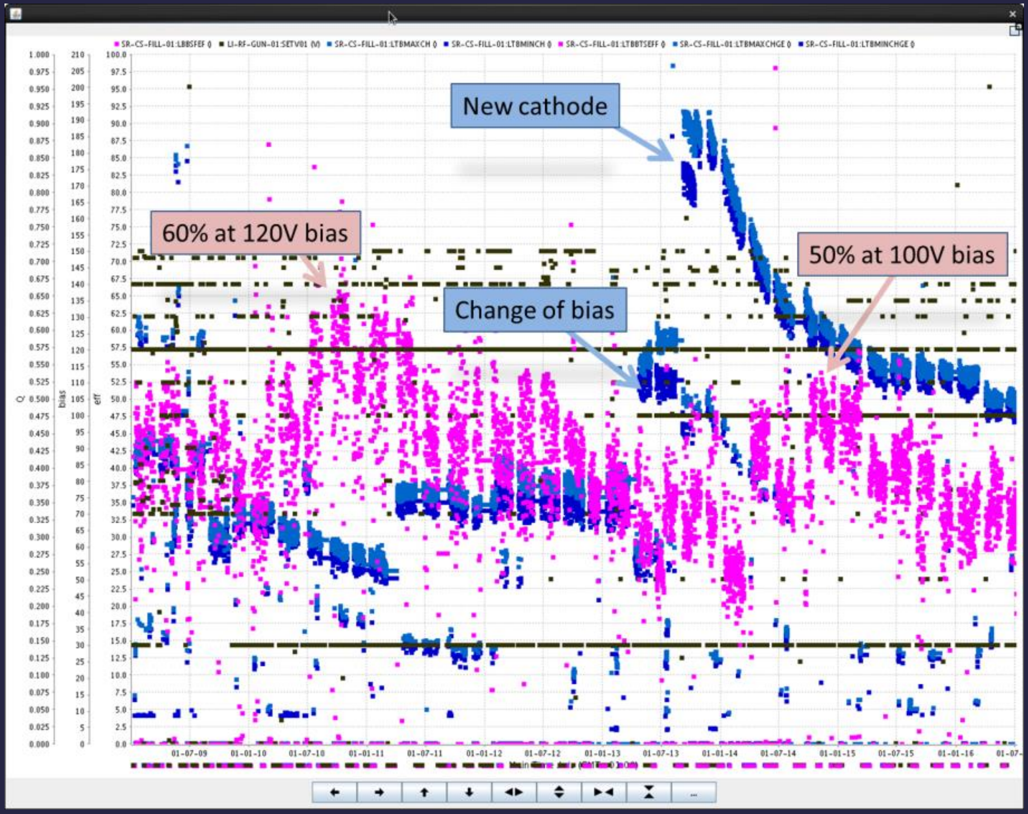
Linac maintenance

Linac operates with two Thales TH2100 klystrons

- Rated at 37MW, operating at 18MW
- Both klystrons were last changed in 2009
- Filament hours: 47,000 and 45,000



Eimac YU171 cathode in gun

- First cathode changed after 45,000 hours
- Observed degradation of gun emission
- Second cathode changed this shutdown after 20,000 hours
- Bunch charge has been doubled

Hivolt capacitors in modulator PFN

- Some oil leakage at seal
- To be replaced by spares

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Helium plant performance

System has been very reliable to date

- No significant downtime from any fault in cryogenic plant
- Only warmed up for periodic maintenance by Air Liquide
- Only time when cavities are taken up to room temperature

Contamination introduced during cavity test in RFTF in January 2015

- Degradation of performance noticed immediately
- Contaminants trapped on top heat exchanger
- Performance closely monitored and interlock overridden
- Contaminants cleared during maintenance warm-up in June 2016

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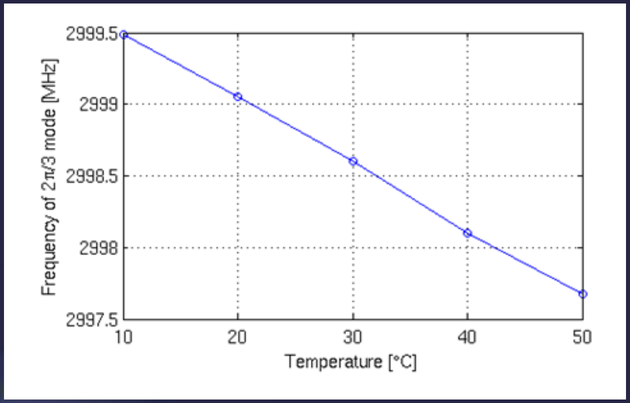
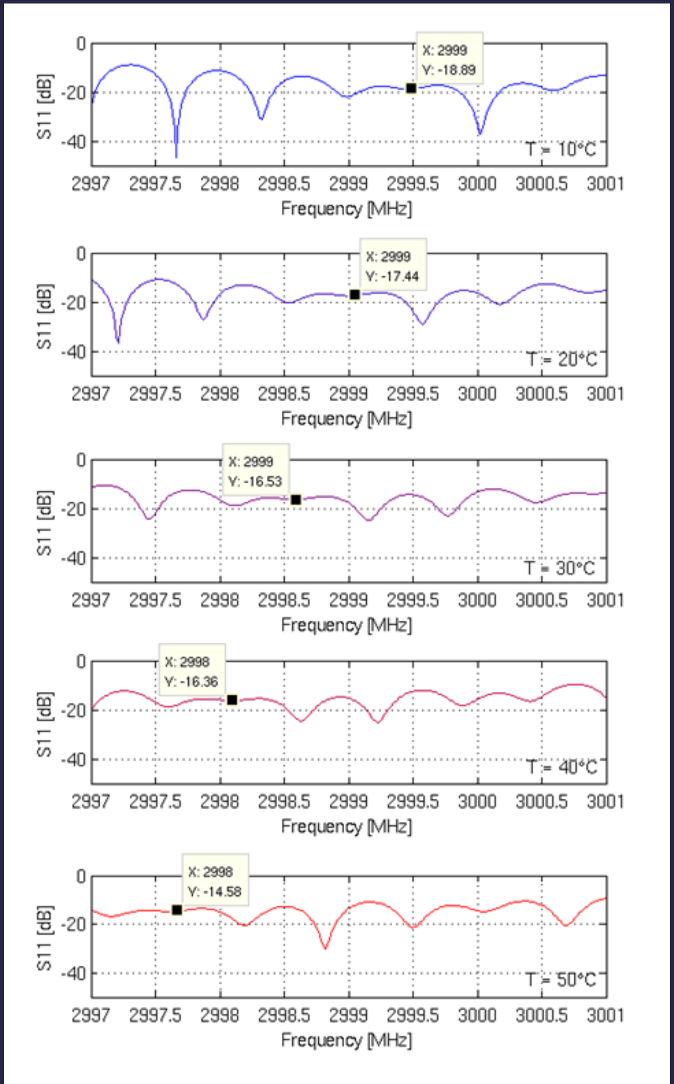
Effect of lattice upgrade on RF

DBA cell is being replaced this shutdown by double DBA achromat

Effects on RF operation are limited

- RF frequency is raised by 25kHz
  - Well within bandwidth of IOTs
  - Cavity tuning range can accommodate this change
  - Linac must be tuned by change of water temperature





Operation at the new frequency has been demonstrated

- Linac and booster have run with beam
- Cavities have been run and conditioned

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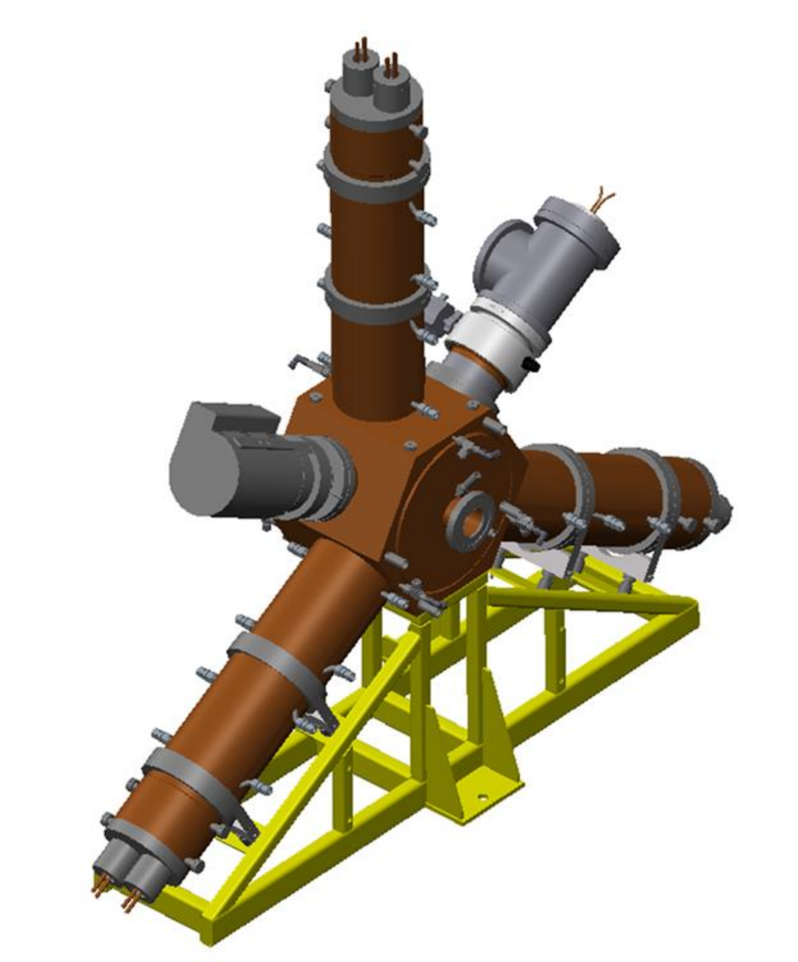
RF resilience upgrade

Superconducting cavities are reliable in operation but can be very disruptive when they fail

- Full warm-up lasting several days is necessary before work is done on any cold component
- Repair can take years to complete
  - Major disassembly is required to access interior of cryostat
  - BCP and HPR surface treatment is required following intervention
  - Cavity UHV leak seen in 2014 is still being repaired



We will support superconducting cavity operation with two normal conducting cavities of the EU HOM-damped design

  - Advice from Alba and BESSY has been invaluable

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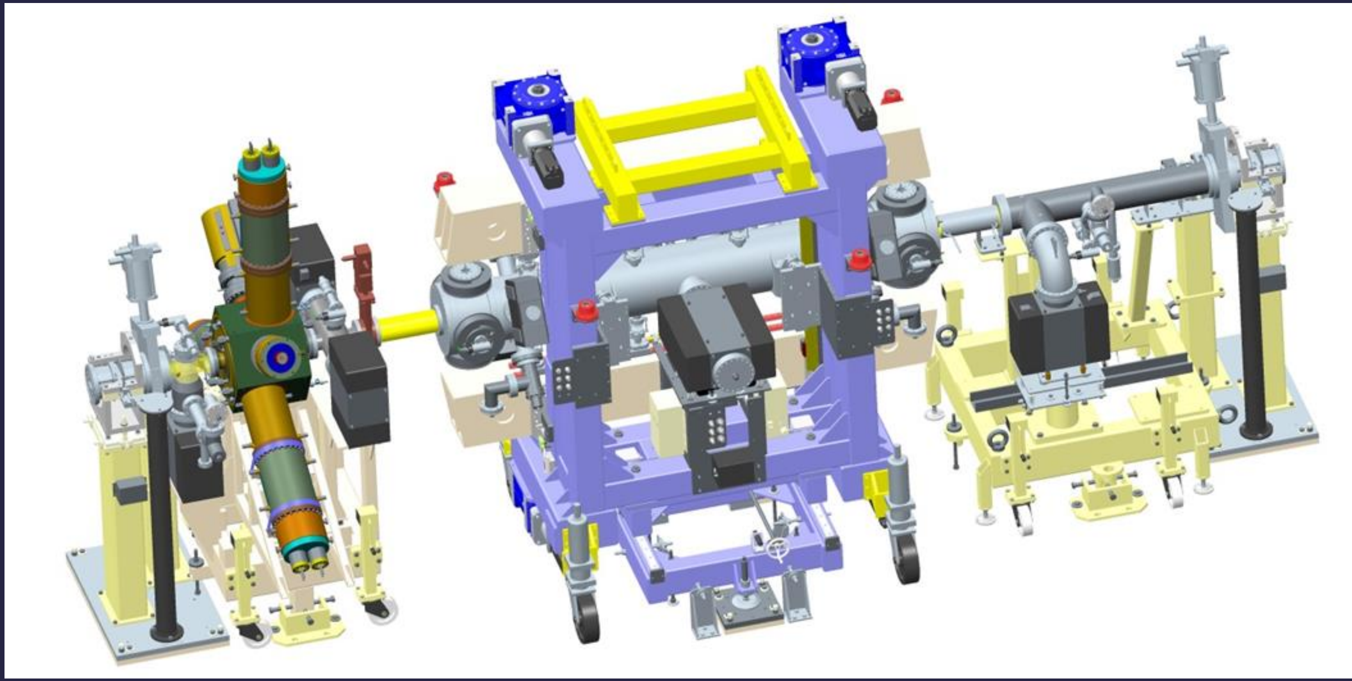
Location of NC cavities



Two cavities have been ordered from RI for delivery in early 2017

- 50cm flange-to-flange distance gives some freedom in location
- Pumped tapers on either side of the cavities increases length required
- Would prefer not to be close to the superconducting cavities because of risk of contamination of SC cavities by gas evolved from warm NC cavities
- Will locate upstream of IDs in straights immediately before and after RF straight

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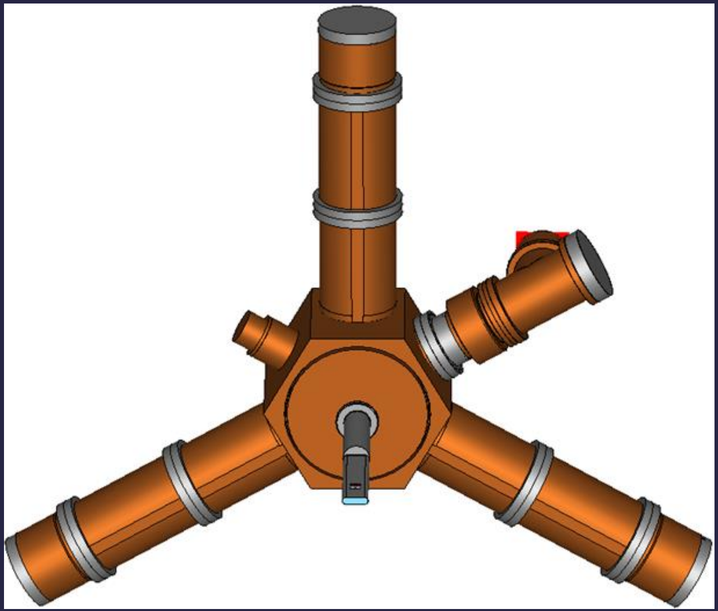
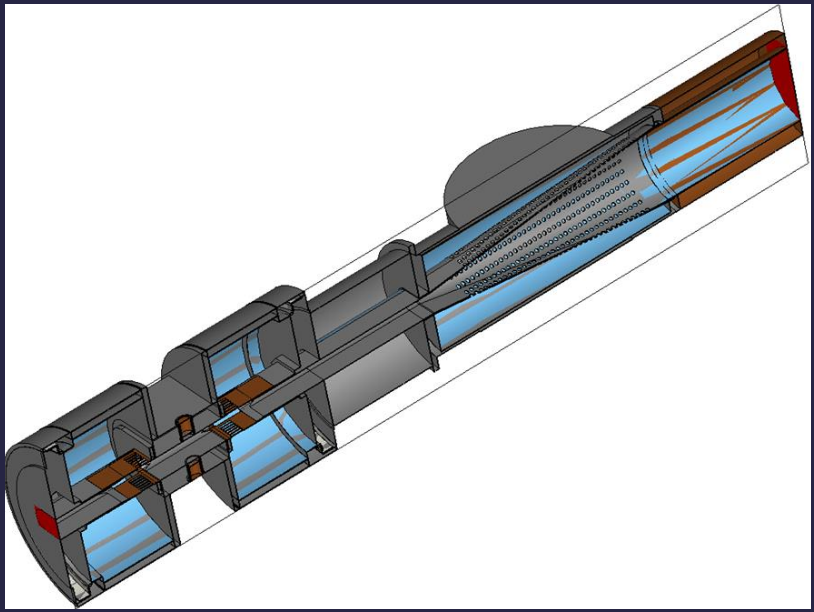
Interaction with BPM in RF straight

If interference from cavity disturbs the BPM reading then the beam will be shifted in the ID and the beamline will be misaligned





CST simulations have been carried out to investigate interaction

- BPM is 734mm from cavity centre
- TM01 modes and TE11 modes are below cut-off and are strongly attenuated
- Model indicates well over 200dB attenuation of all modes along beam pipe from cavity to BPM
- At limits of simulation but no effects are foreseen

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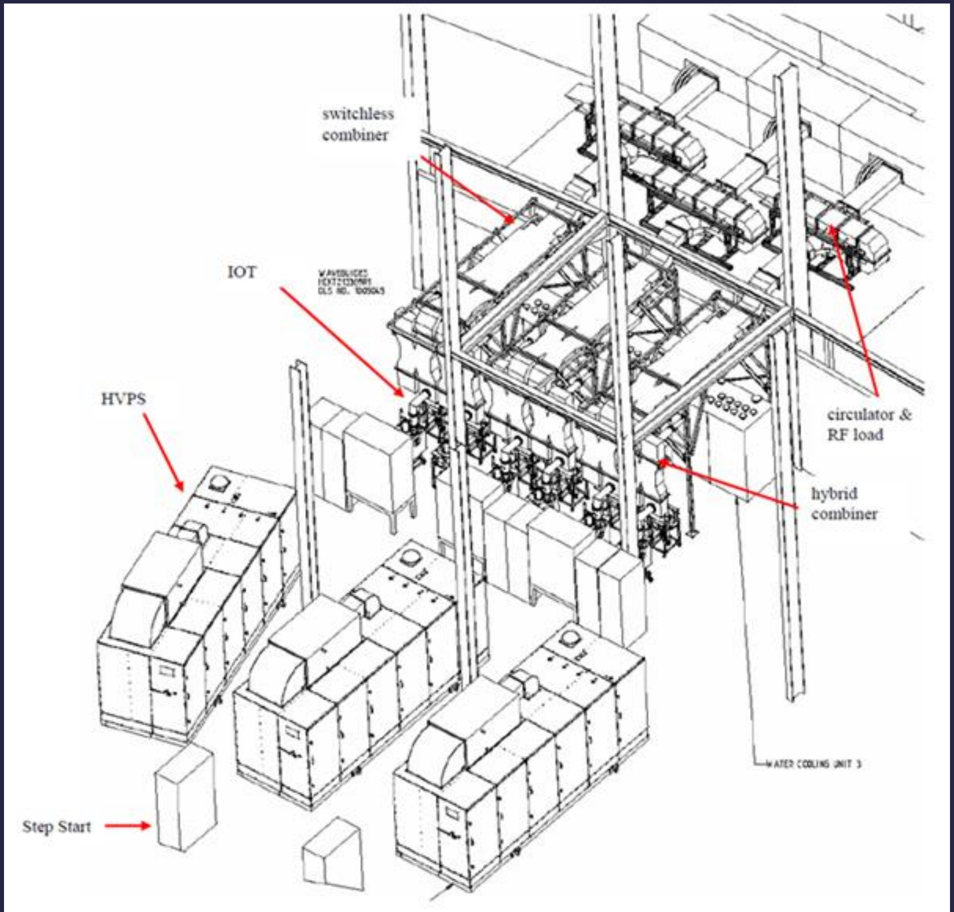
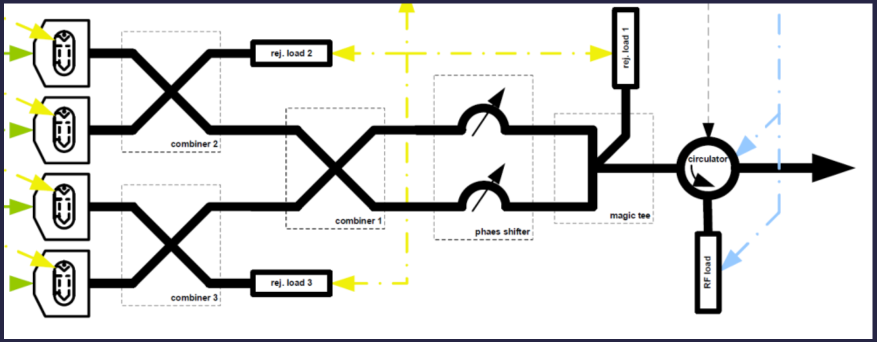
Amplifier modifications



- 300kW amplifier comprises four nominal 80kW IOTs
- Two amplifiers power our two SC cavities, one amplifier is in reserve
- NC cavities rated at 150kW maximum
- Third amplifier can be used to power both NC cavities
  - Need a new amplifier for RF test facility



- Combiners, circulators and loads are too large and complex to remove
- Must accommodate any one of three cavities failing

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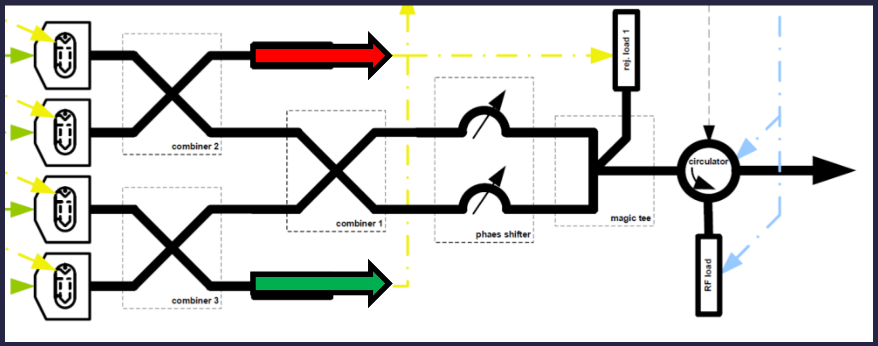
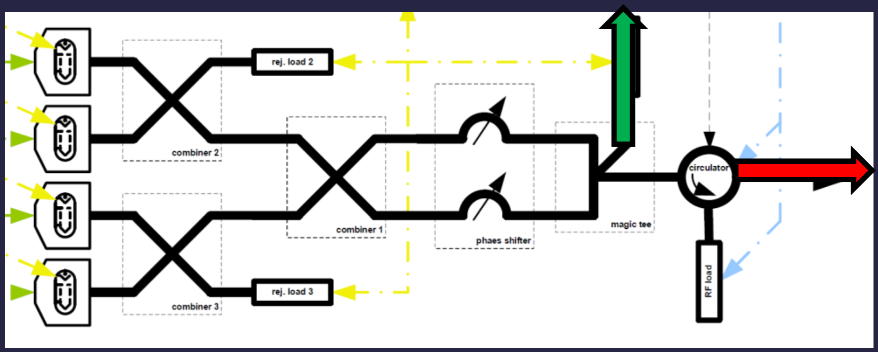
Splitting the power





- Ignore higher power combination and take line off first stage rejection load

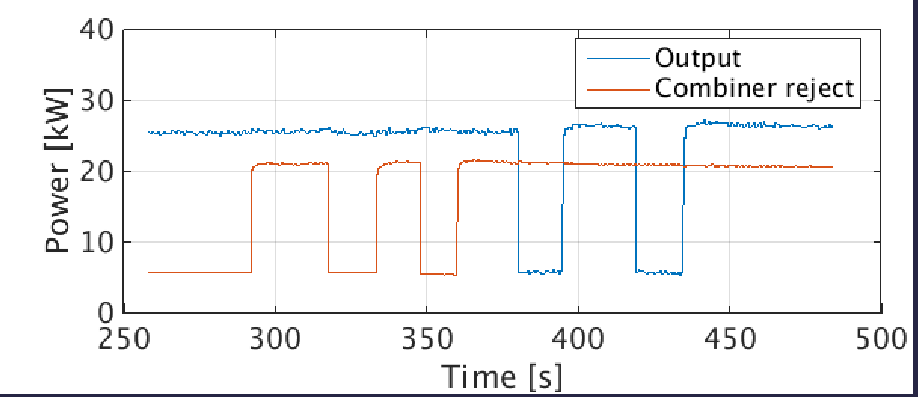
- Combine-dephase-split and take off second stage rejection load
- Can use existing circulator and load
- Only one new penetration into tunnel
- First stage rejection load available if isolation is imperfect

Tests of power splitting

Comark tests

Input (dB)				Phaser (degrees)		Reject Load Power (dB)						Output (dB)	
IOT1	IOT2	IOT3	IOT4	S1	S2	REJ1	%	REJ2	%	REJ3	%	OUT	%
0	0	0	0	0	0	-59.2	0.0%	-53.8	0.0%	-50.3	0.0%	5.95	98.4%
0	0	0	-60	0	38	-57.2	0.0%	-3.05	12.4%	-51.6	0.0%	3.92	61.7%
0	0	-60	0	0	38	-49.7	0.0%	-3.03	12.4%	-51.7	0.0%	3.92	61.7%
0	-60	0	0	38	0	-3.02	12.5%	-54.6	0.0%	-43.6	0.0%	3.91	61.5%
-60	0	0	0	38	0	-3.02	12.5%	-54.2	0.0%	-41.7	0.0%	3.91	61.5%
0	0	-60	-60	0	90	-49.4	0.0%	-92	0.0%	-46.9	0.0%	2.96	49.4%
0	-60	0	-60	0	0	-3.02	12.5%	-3.05	12.4%	-48.6	0.0%	-0.05	24.7%
-60	0	0	-60	0	0	-3.02	12.5%	-3.05	12.4%	-47.1	0.0%	-0.05	24.7%
0	-60	-60	0	0	0	-3.02	12.5%	-3.02	12.5%	-57	0.0%	-0.03	24.8%
-60	0	-60	0	0	0	-3.03	12.4%	-3.03	12.4%	-68.3	0.0%	-0.04	24.8%
-60	-60	0	0	90	0	-100	0.0%	-55.5	0.0%	-56.3	0.0%	2.95	49.3%
0	-60	-60	-60	0	90	-3.02	12.5%	-100	0.0%	-52	0.0%	-3.04	12.4%
-60	0	-60	-60	0	90	-3.03	12.4%	-98	0.0%	-53.2	0.0%	-3.069	12.3%
-60	-60	0	-60	90	0	-100	0.0%	-3.04	12.4%	-62	0.0%	-3.08	12.3%
-60	-60	-60	0	90	0	-100	0.0%	-3.03	12.4%	-61.6	0.0%	-3.04	12.4%
-60	-60	-60	-60	0	0	-100	0.0%	-100	0.0%	-100	0.0%	-100	0.0%

Diamond tests



With two IOTs off (-60dB)

- -2.95dB (49.3%) transmission: 158kW
- -56.3dB (0.0%) pollution: 0.75W

What are the effects of imperfect tuning, temperature fluctuations…

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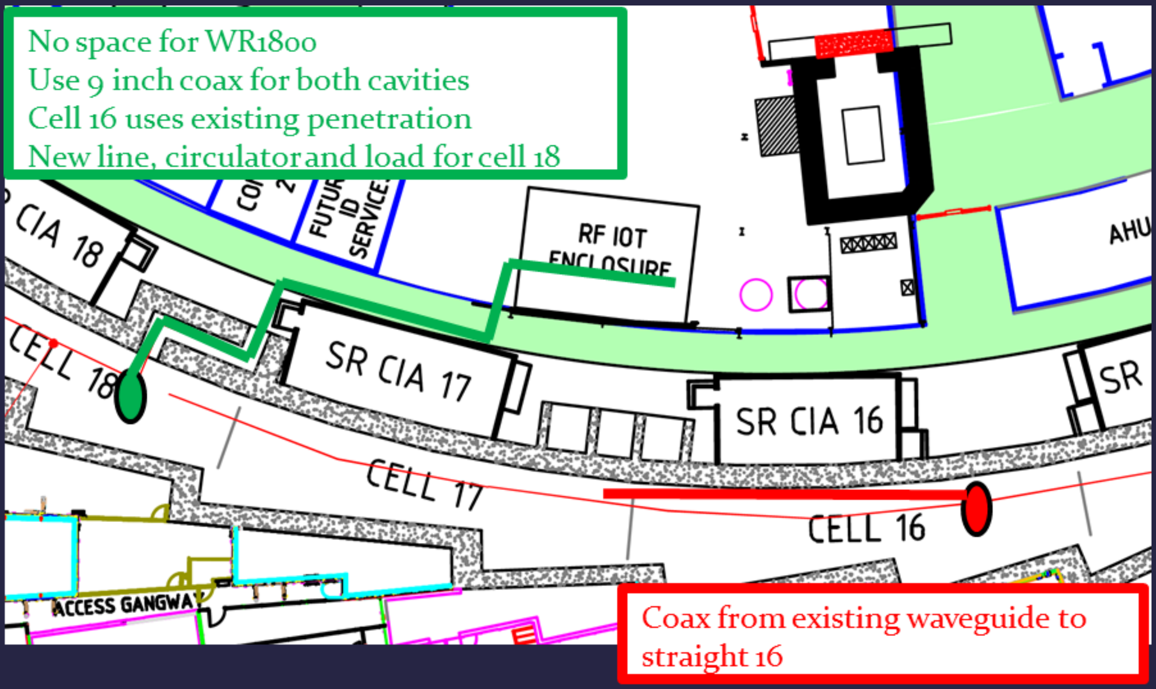
Power distribution



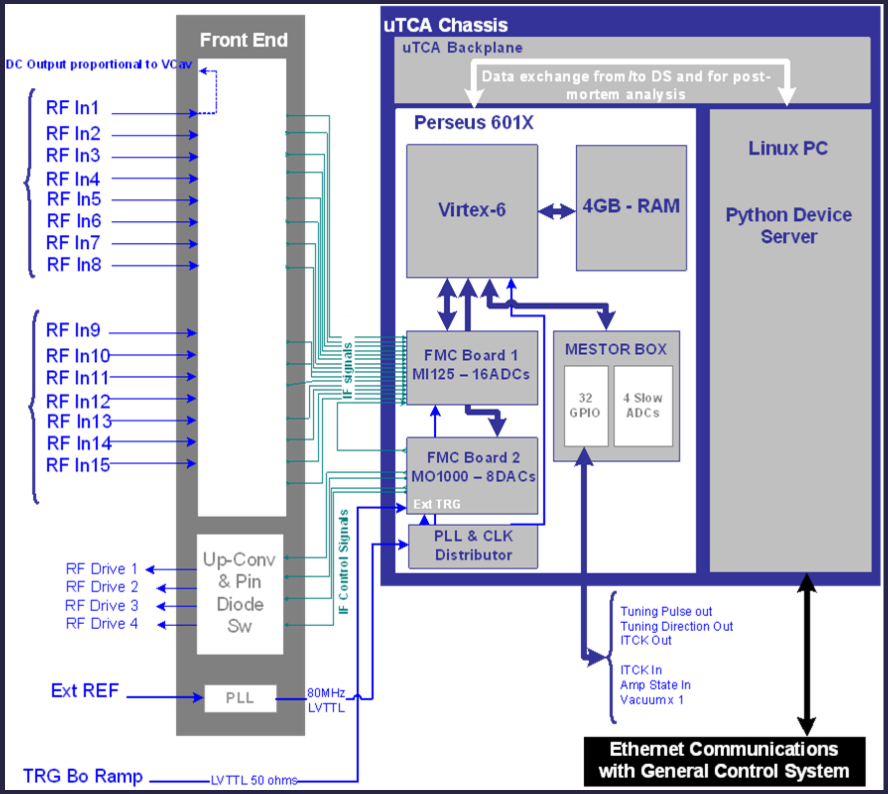
- Cavity in straight 16 uses existing circulator, load and penetration
- Cavity in straight 18 needs new circulator: load and transmission line comes in through personnel labyrinth
- Use 9 inch coaxial line instead of 18 inch waveguide

Additional benefits

- Power and voltage requirements on four cavities are modest
  - 1.0MV, 150kW on superconducting cavities
  - 0.3MV, 100kW on normal conducting cavities
- Superconducting cavity trip rate increases rapidly with operating voltage
  - Reducing voltage reduces risk of cavity trip
  - Need to accommodate any combination of “safe” voltages of superconducting cavities
    - 1.1MV, 1.2MV, 1.4MV, 0.8MV
- Normal conducting cavity wall losses can be considerable
  - Low voltage to minimise power demand
- Reduced power gives sufficient overhead in amplifiers to allow live switching of individual IOTs

Digital low-level RF

- New cavities will require new LLRF
  - Collaboration with Angela Salom at Alba to adapt the Max IV DLLRF to Diamond
  - Enormous "thank you" to Angela and all at Alba for providing the DLLRF design and code
- To be rolled out to all RF cavities at Diamond
  - Normal conducting cavities
  - Superconducting cavities
  - Booster cavity
- Use one DLLRF unit per cavity in the first instance



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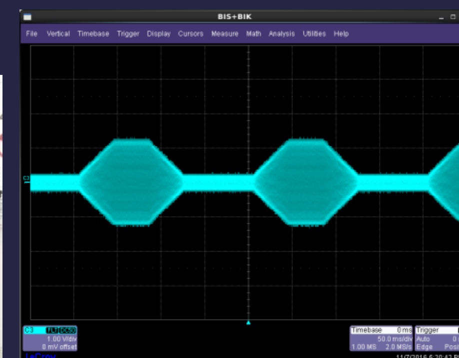
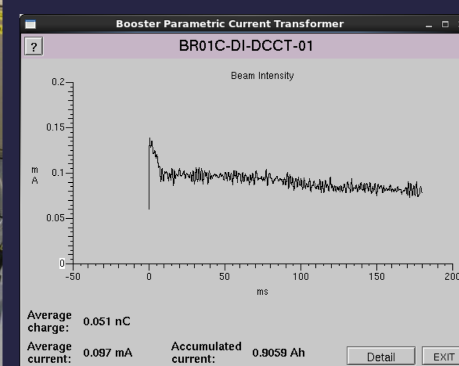
DLLRF tests on the Diamond booster

Diamond booster is in separate tunnel from storage ring, allowing beam tests to be carried out in a machine shutdown

- DLLRF operation has been demonstrated in the last month
    - Code has been modified and EPICS interface developed
    - Interfaces allow rapid switch between analogue and digital systems
    - Loops have been closed and RF can be maintained
    - Beam has been accelerated from 100MeV to 3GeV using DLLRF



Field



Current

Summary

- Statistics and reliability
  - Year-on-year improvement in machine reliability
  - RF performance is improving but we still constitute almost half of all machine trips
- Cavity failure and repair
  - Two cavity failures in recent years
    - One repaired in on-site cleanroom
    - One cavity still to be repaired
- Cavity reliability
  - Cavity fast vacuum trips are under control
- IOT update
  - Now use exclusively e2v IOTs
  - IOTs and klystrons have now accumulated many hours of operation
- Plans for hybrid operation
  - Two normal conducting cavities will be installed in 2017
  - Preparations for installation are well developed
  - New DLLRF has been tested on the booster

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The Diamond RF Group

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- Matt Maddock
- Peter Marten
- Shivaji Pande
- Adam Rankin
- David Spink

Thank you for your attention
Any questions?