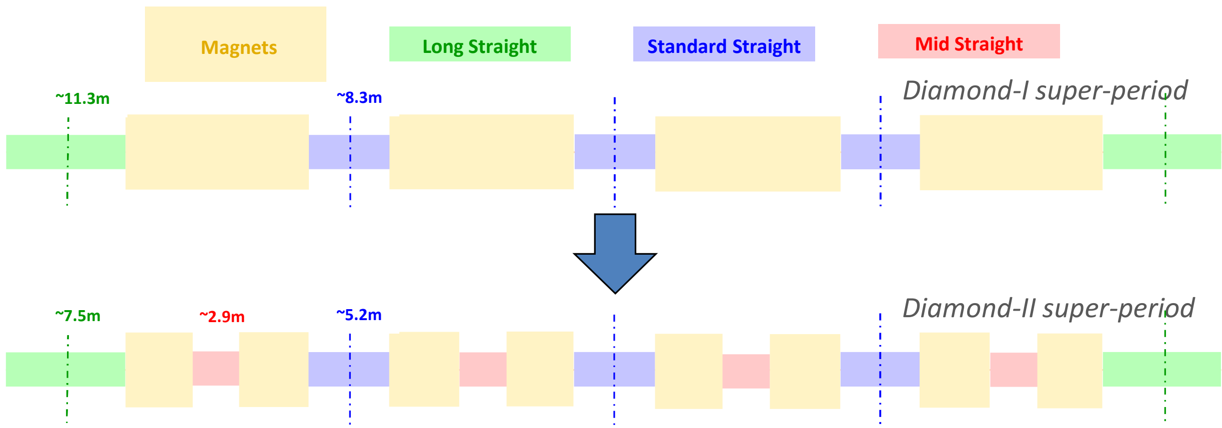
RF PLANS FOR THE DIAMOND-II UPGRADE

C. Christou,
P. Gu, P. Marten, S. A. Pande and A. Rankin

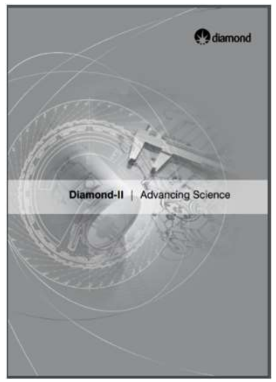
IPAC'21, Campinas, Brazil
24th-28th May 2021

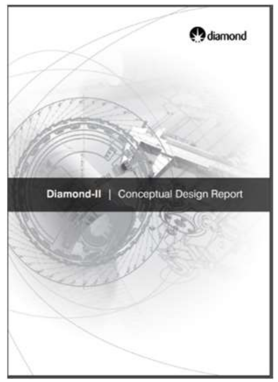
Diamond-II Upgrade

- Diamond-II improves quality of photon beams delivered to users
  - Increase spectral brightness and transverse coherence
  - Reduced source size, line-width
  - Optimise spectral range
- Achieved via reduction in natural emittance, increase in beam energy, new IDs



6 long straights, ~7.5 m long
18 standard straights, ~5.2 m long
24 mid straights, ~2.9 m long





- Conceptual Design Report (May 2019)

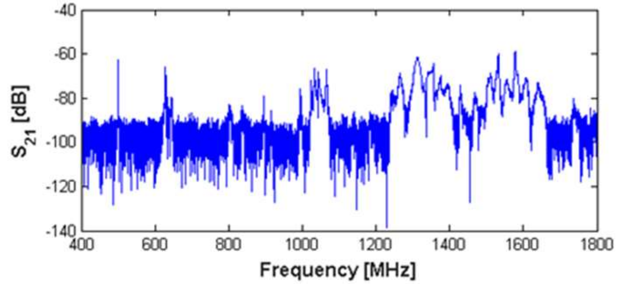
https://www.diamond.ac.uk/Home/About/Vision/Diamond-II.html

Cavity type

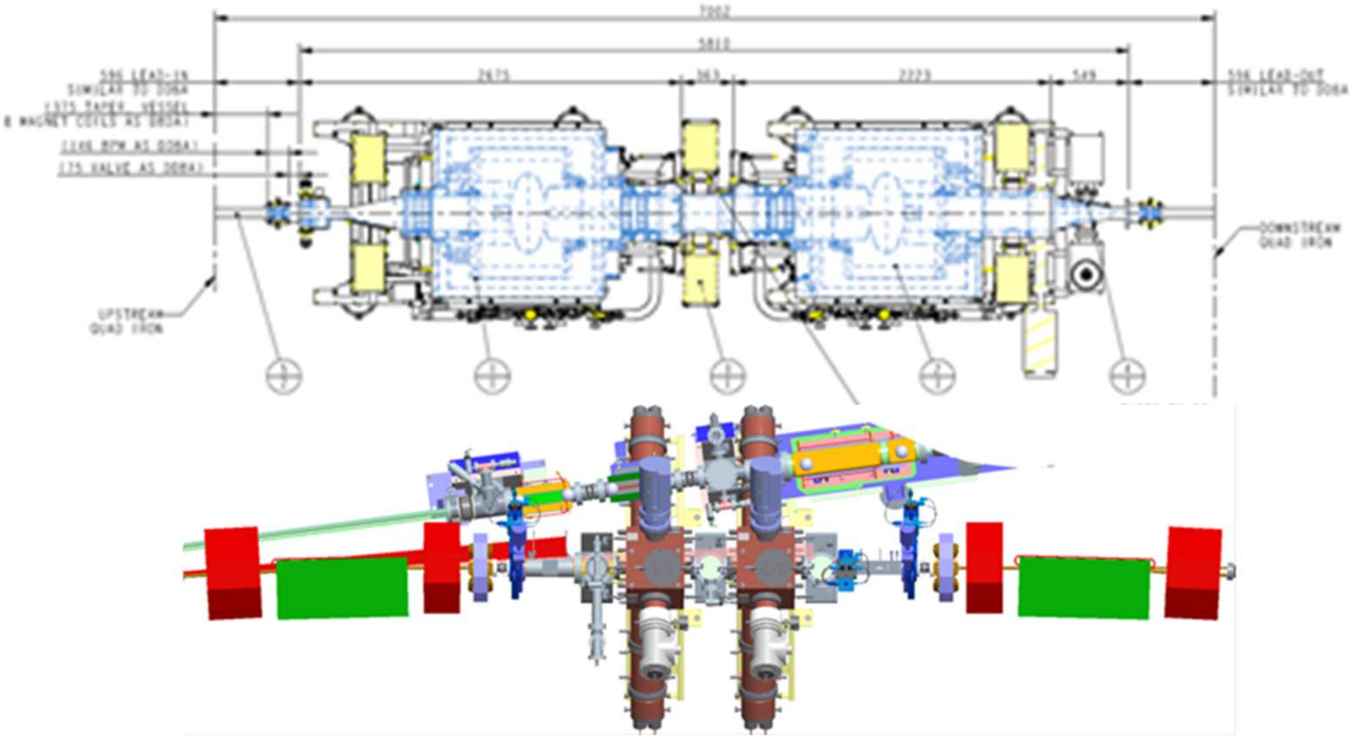
	Superconducting	Normal conducting
Wall power losses	Minimal	Significant
Infrastructure	Complex	Simple
Field gradient	Higher	Lower
Fault tolerance	Vulnerable	Robust
Footprint	Large	Small
Maintenance	Complex	Simple
Higher order modes	Weak	Managed
Taper	Long	Short

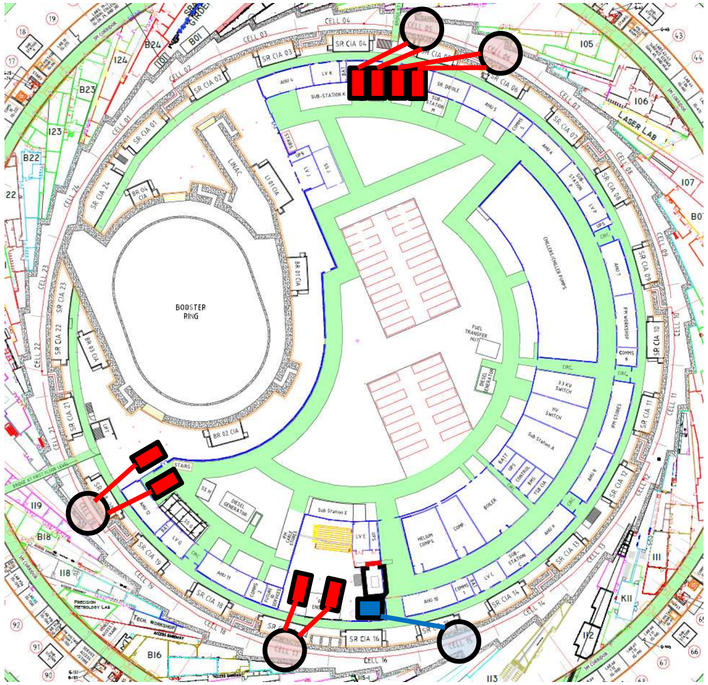
- EU HOM-damped cavity
  - Latest iteration of cavity installed at BESSY, Alba and ESRF (scaled)
    - Flanged joint at base of HOM damper removed to address trapped mode
    - Pickup coated at ESRF
  - Two cavities have recently been installed in Diamond

Cavity	Coupling	Q_0	R_s
N16	5.17	33,000	3.75 MΩ
N18	5.25	33,000	3.75 MΩ



Cavity layout



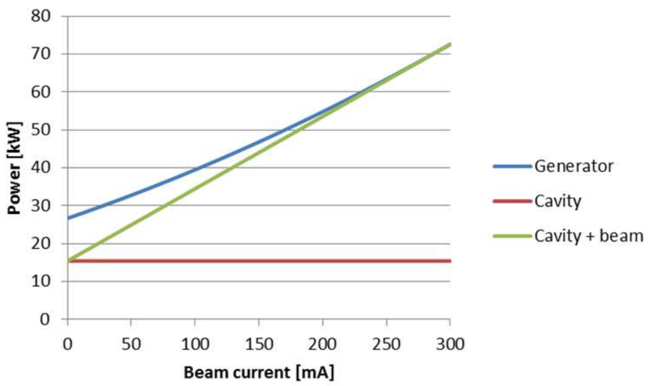


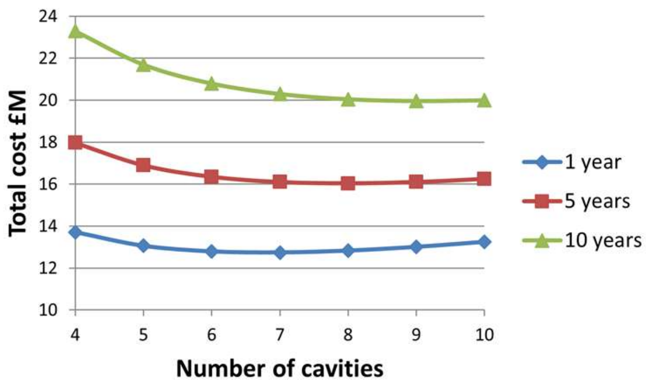
- A new beamline will be installed in what is now the Diamond RF straight
- Cavities must move to mid-section straights
  - Cryostat cannot fit in shorter straight and provide clearance for front ends
  - HOM-dampers of NC cavity can fit around a modified front-end support
  - Space must be provided for amplifiers
  - Easier to fit multiple smaller amplifiers than smaller number of large amplifiers

Cavity operating parameters

- 460kW required for 300mA beam with all IDs

Number of cavities	6	7	8	9
Optimal cavity coupling	3.8	4.3	4.7	5.2
Individual cavity voltage	450 kV	386 kV	338 kV	300 kV
Generator power per cavity	104 kW	85 kW	73 kW	63 kW
Power dissipated per cavity	27 kW	20 kW	15 kW	12 kW
Power dissipated in all cavities	164 kW	140 kW	123 kW	109 kW

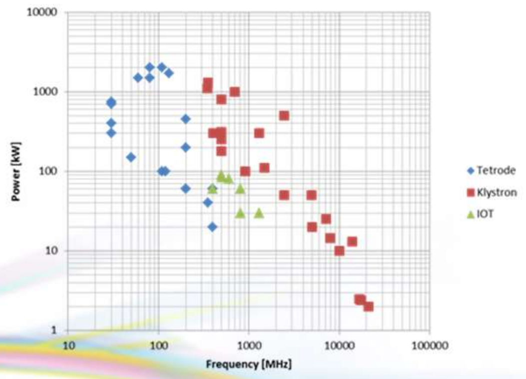


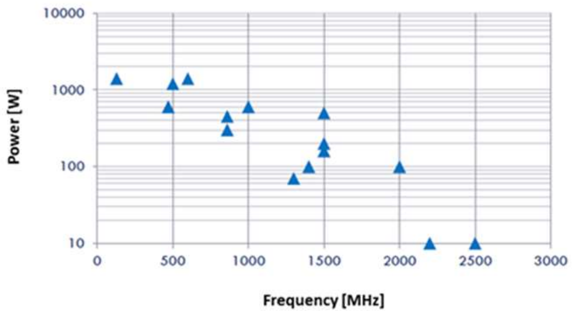


- Operation with 8 normal conducting cavities
  - Reduces voltage per cavity to conservative level
  - Minimises running costs
  - Gives acceptable total wall power losses
  - Allows redundant operation should one cavity fail
  - Enables cavities to fit in storage ring

Amplifier design

- Vacuum tubes
  - Proven IOTs or klystrons at 500 MHz
  - Tens of kV in HVPS
  - Limited redundancy
  - Obsolescence may become an issue
- Solid state amplifiers
  - LDMOS power transistors up to 1kW
  - Typically use 50V supplies
  - Easier to work with and less noise on beam
  - Extreme redundancy for fault tolerance
- Well over half of all Diamond faults are IOT related
  - There is no redundancy in Diamond IOT amplifiers
  - Amplifier must shut down to protect any IOT
  - Separate power supplies would be beneficial
  - Solid state amplifiers would provide necessary redundancy
- All light sources using solid state amplifiers report superior amplifier MTBF
- Several possible industrial suppliers exist





E. Montesinos, LLRF2017

Low level RF

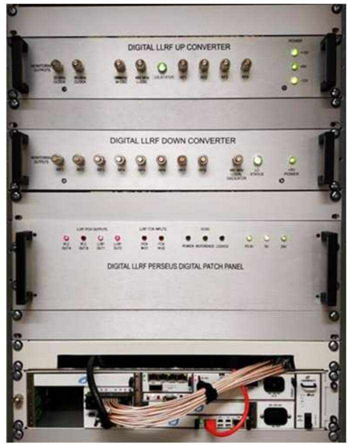
Digital LLRF offers flexibility and adaptability

Using Alba DLLRF in Diamond

- IQ or polar PI loops of the cavity field for amplitude and phase.
- Cavity tuning
- Fast interlock handling.
- Automatic start-up and conditioning
- Monitoring of RF signals
- Recording of main digital processing signals for post-mortem analysis

Features

- Based on the MicroTCA standard
- Perseus 601X advanced mezzanine card with Virtex6 FPGA
- 16 Channel 14-bit ADCs and 8 channel 16-bit DACs



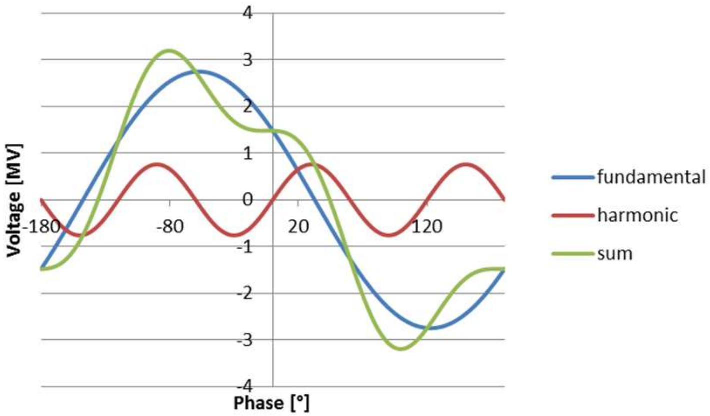
Developing upgrade for Diamond-II

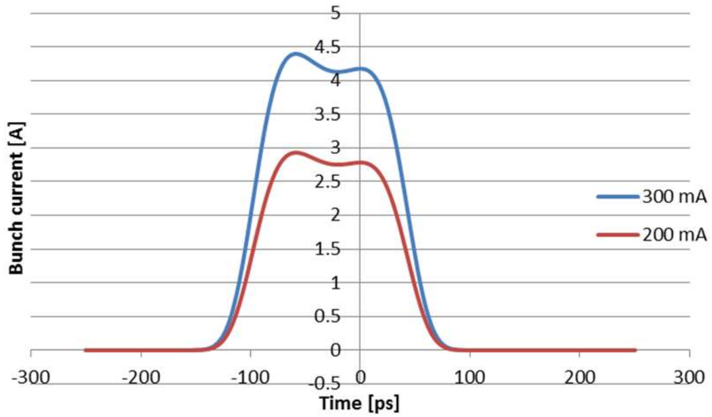
- MicroTCA 4 downconverter/vector modulator RTM
  - Manufactured by Struck under licence from DESY
  - 8 channel downconverter
  - 1 channel vector modulator
  - 350 MHz - 500 MHz (DWC8VM1LF)
  - 500 MHz - 3500 MHz (DWC8VM1)

Higher Harmonic Cavity

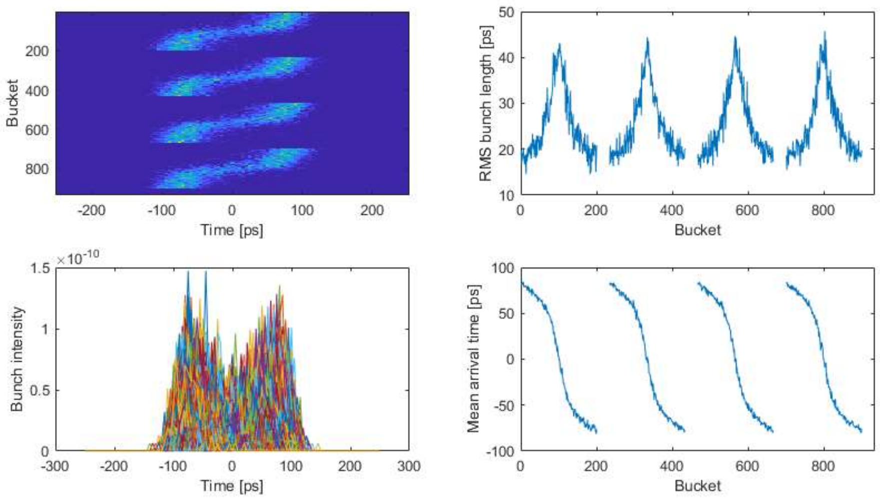
- Higher harmonic cavity is needed to
  - Minimise heating
  - Alleviate collective instabilities
  - Maximise beam lifetime
- Proven elsewhere
- Considering passive superconducting third harmonic cavity
  - CEA/SLS/Elettra design available from industry
  - Using cryogenic plant for Diamond
  - Detune is almost constant for all conditions allowing wide range of operating currents
  - Robinson destabilisation is small and can be damped by fundamental cavity detune

	Passive NC	Active NC	Passive SC
Pro	Simple	Can be optimised for any beam current	Operates to low current Weaker Robinson instability term
Con	Optimal only at one beam current Strong Robinson instability term Sensitive to fill transients	RF amplifier required Strong Robinson instability term Sensitive to fill transients	Cryogenic system required Narrow bandwidth



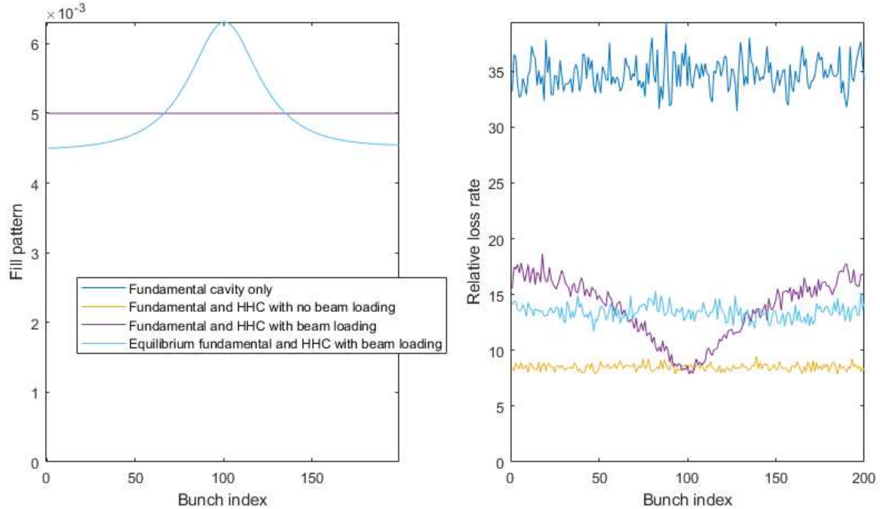


Transients with HHC

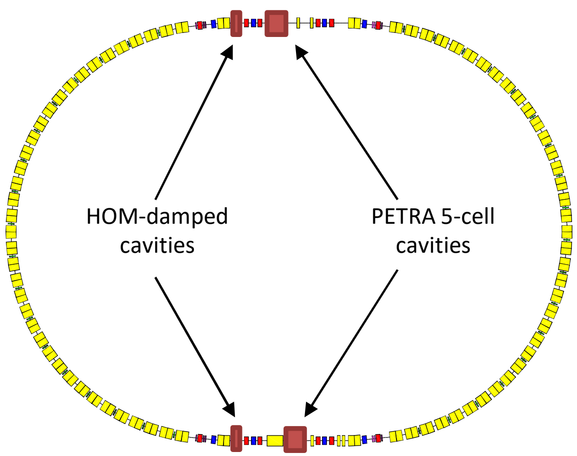


- Shorter bunch trains allow multibunch top-up
  - Multibunch charge is much higher than single bunch
  - Central bunch has longest lifetime
  - Effect is self-correcting as lifetime is lower for more populated bunches
  - Flat losses can be replaced by a multibunch top-up

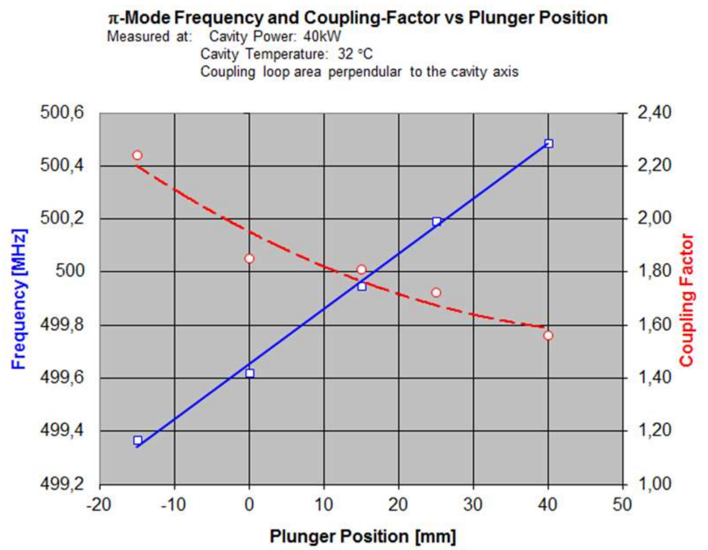
- Gap in fill pattern induces a transient in HHC
  - Unequal bunch lengthening around ring
  - Optimal HHC operation for one bunch only
  - Effect can be reduced with multiple short gaps
  - What is the minimum gap required for ion clearing?



Booster RF



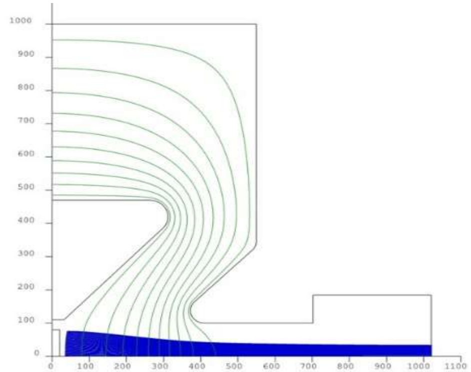
- Booster cavity is required to operate near the lower end of its frequency range
  - Can extend range to lower frequencies by raising temperature of cavity
    - Average operating power is low and cavity self-heating is limited
    - Elaborate water distribution system is used to regulate operating temperature
  - Can extend frequency range by mounting tuner further off-axis

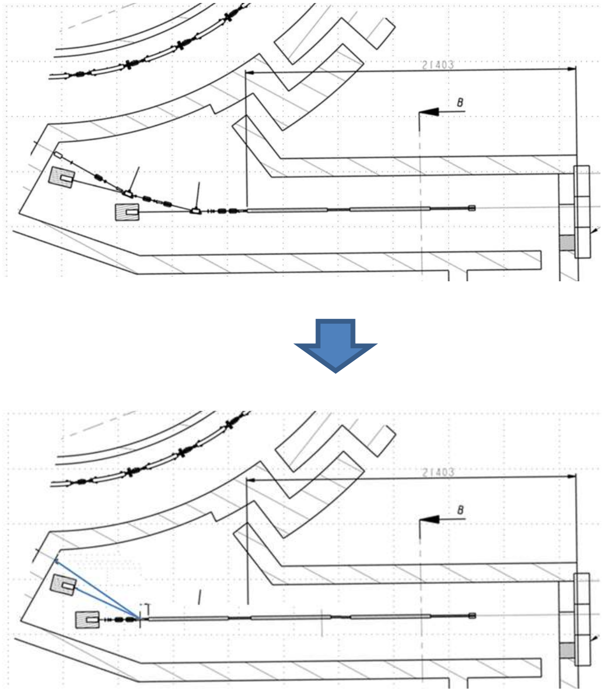


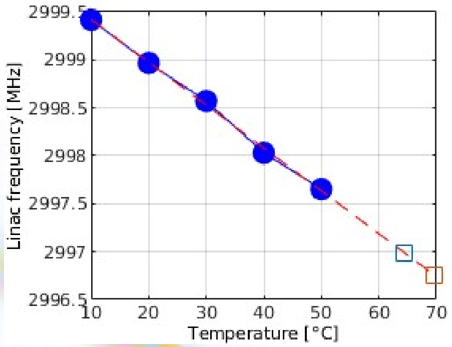
- Booster ring uses both currently installed PETRA 5-cell cavities
  - Can use existing Solid State Amplifiers to power cavities up to 1 MV each
  - Space for two EU HOM-damped cavities as back-up

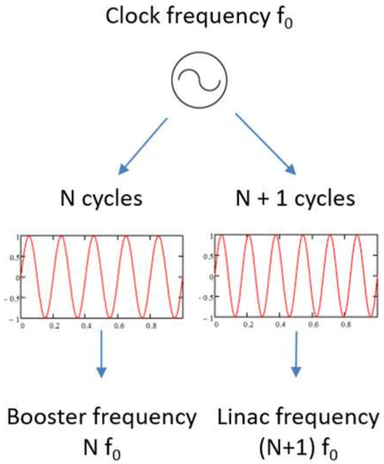
Linac upgrade

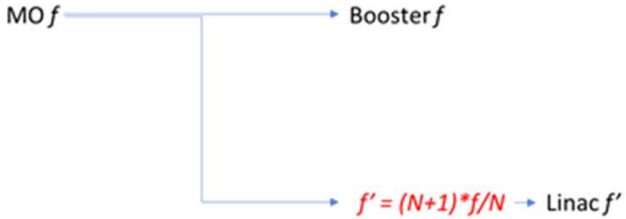
- Top- up injection on Diamond disturbs users
  - Maximise bunch charge to minimise top-ups
    - Studying gun upgrade
  - Losses are greatest on injection into booster
    - 50% to 60% efficiency for SB injection
  - Better efficiency with higher linac energy
    - Also reduces dynamic range of booster
- Frequency change impacts most severely on linac
  - Bunch charge and beam energy fall off rapidly
  - Options:
    - new structures, temperature tuning, maintain original frequency











Summary

- RF plans for Diamond-II are advanced
- 499.511MHz, 2.7MV 460kW to beam in storage ring
- Eight EU HOM-damped cavities distributed in pairs around storage ring
- One solid state amplifier per cavity
- Digital LLRF operating on a microTCA platform
- 2.0MV in booster RF
- Using two PETRA 5-cell cavities and two single cell cavities for redundancy
- Linac upgrade from 100MeV to 150MeV to improve transmission into booster
- Linac gun upgrade will increase charge per shot
- Linac frequency can be changed with new structures or with temperature tuning
- Can manage operation at old frequency by controlling synchronisation of booster injection