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Daresbury Laboratory RF update

Andrew Moss June 2021

Contents

- Recent RF work on CLARA
  - Major waveguide issues – 6 months of work
- Installation of linac modulators
- European Spallation Source RF work

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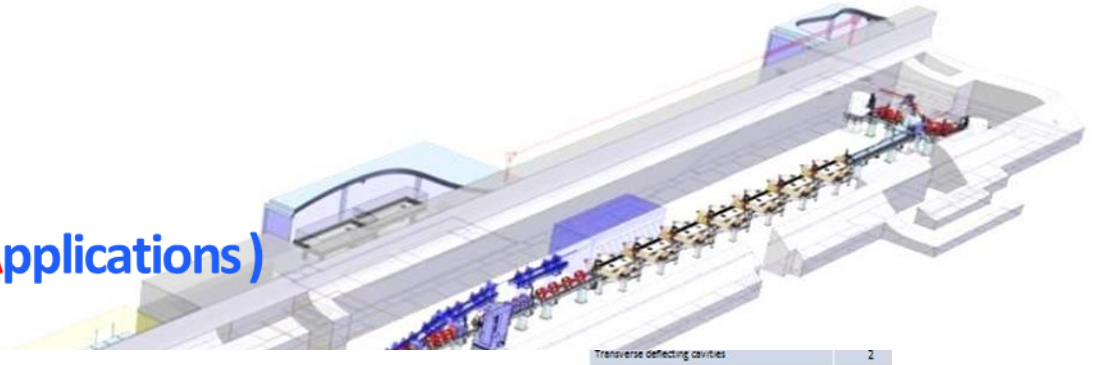
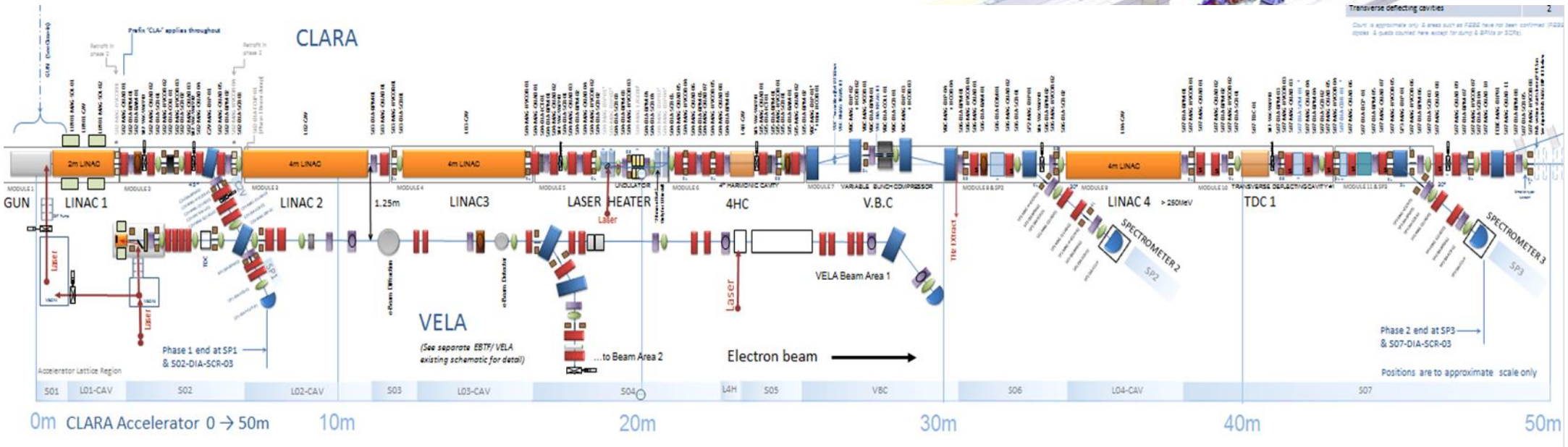
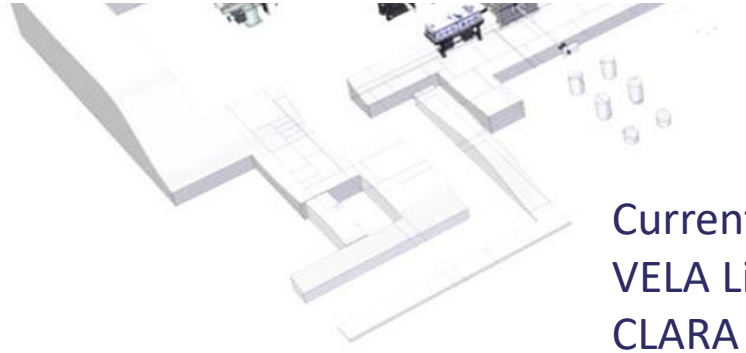
CLARA

Compact Linear Accelerator for Research and Applications

CLARA (Compact Linear Accelerator for Research Applications)







250 MeV

Current Set-up

VELA Line contains the high repetition rate gun (Gun 400)

CLARA Line contains the low repetition rate gun (Gun 10)

RF Gun operations on CLARA

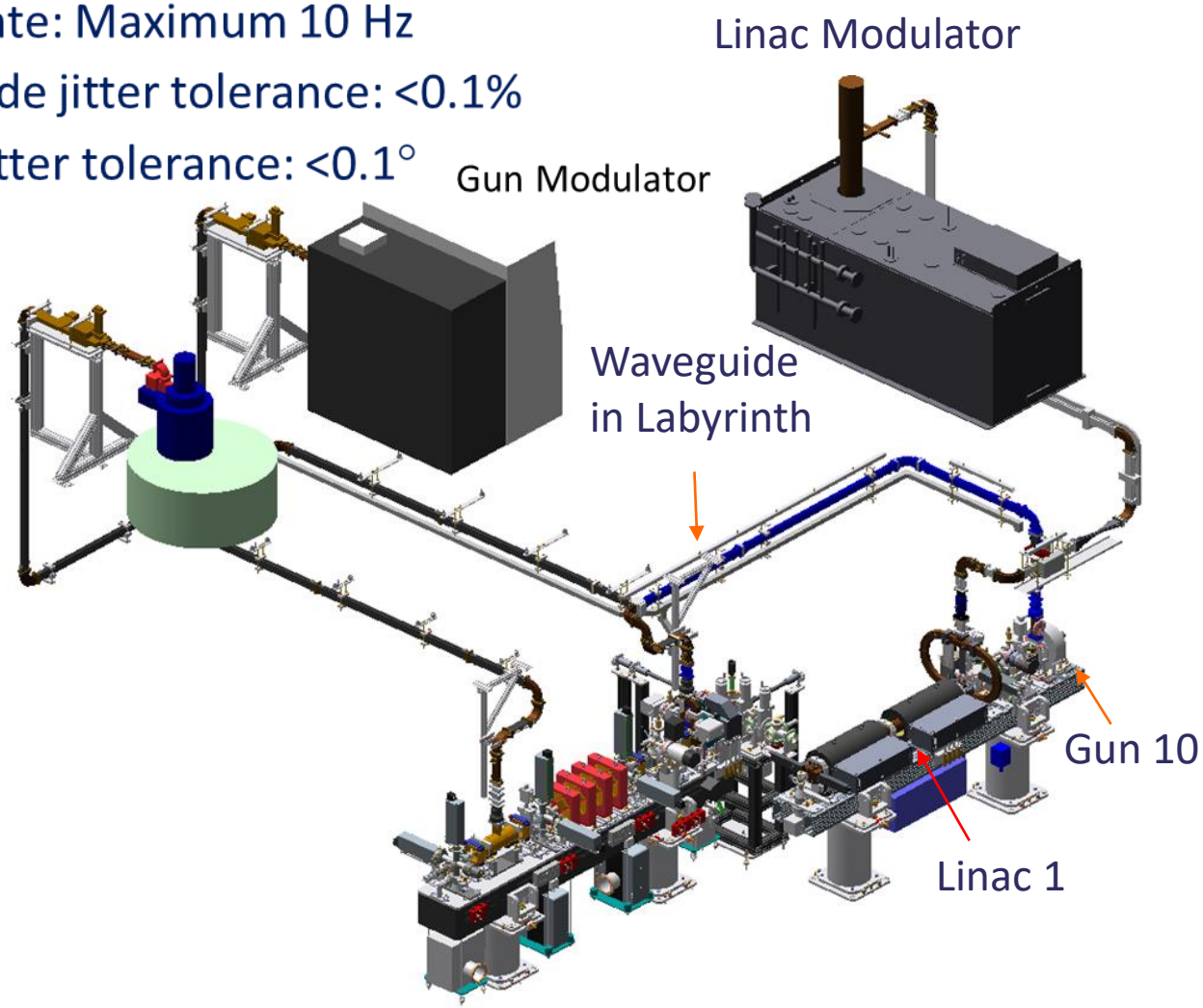
Alpha X (from Strathclyde University)

- Fundamental frequency: 2998.5 MHz (TM 010-π mode)
- 2.5 cells S-band
- Operating temperature is 31.8 °C.
- Q_0 =10900

- Repetition Rate: Maximum 10 Hz
- RMS amplitude jitter tolerance: <0.1%
- RMS phase jitter tolerance: <0.1°

Parameter	Specification
Frequency	2998.5 MHz
Nominal Bandwidth	5 MHz
Peak output power	> 10 MW
Power gain	> 45 dB
Efficiency	> 45 %
Pulse Repetition Rate Range	1 – 400 Hz
RF Pulse Width	Up to 3.0 µs
Maximum beam voltage	200 kV
Maximum beam current	150 A

Gun Klystron parameters



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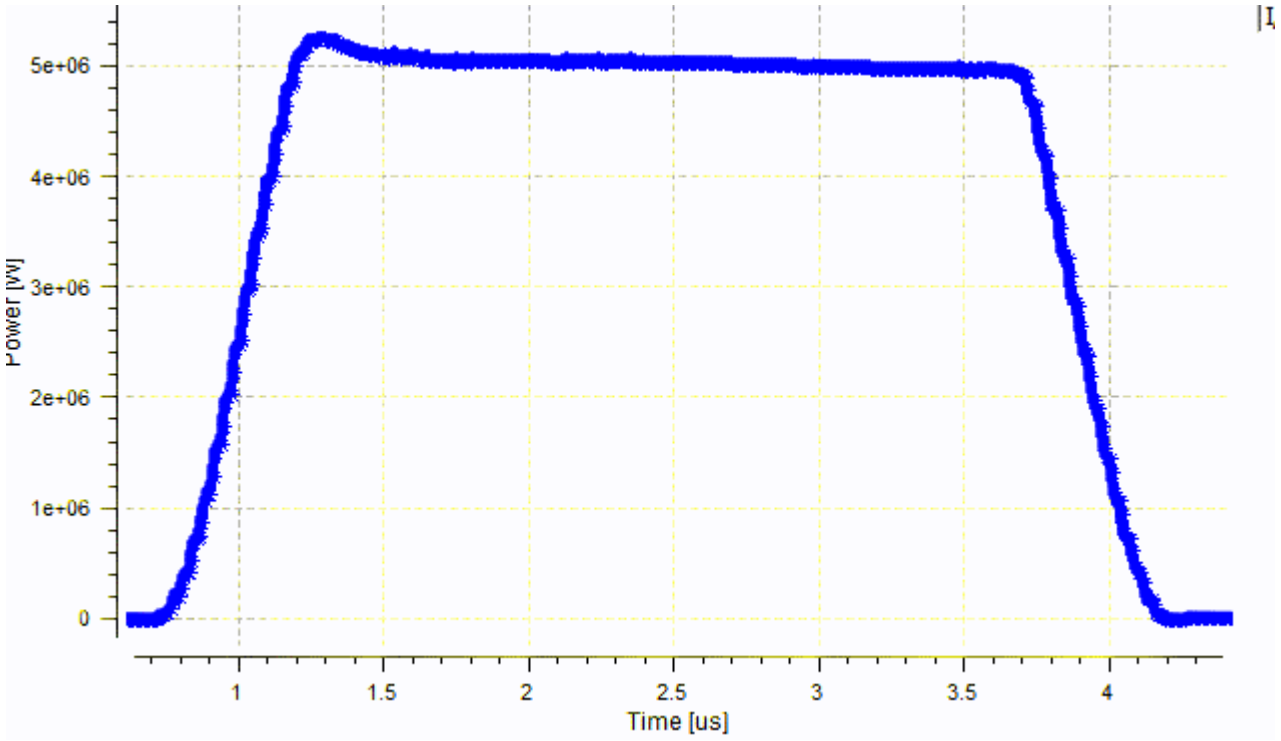
Waveguide issues since October 2020

- On machine start-up in autumn 2020, RF traces showed noise – present on Gun FWD, but not klystron FWD directional couplers, which we did not understand
- Using Libera LLRF we analysed the data for the forward power leaving the klystron and arriving at the gun – the jitter was much worse at the end far end of the waveguide
- No breakdown products detectable in SF6, pressure level 1 bar
- After 3 weeks of operations and attempts to understand where the noise was coming from, catastrophic SF6 loss in waveguide occurred
- Arcing found on many sections of the waveguide flanges



Trace showing noise at Gun end of waveguide

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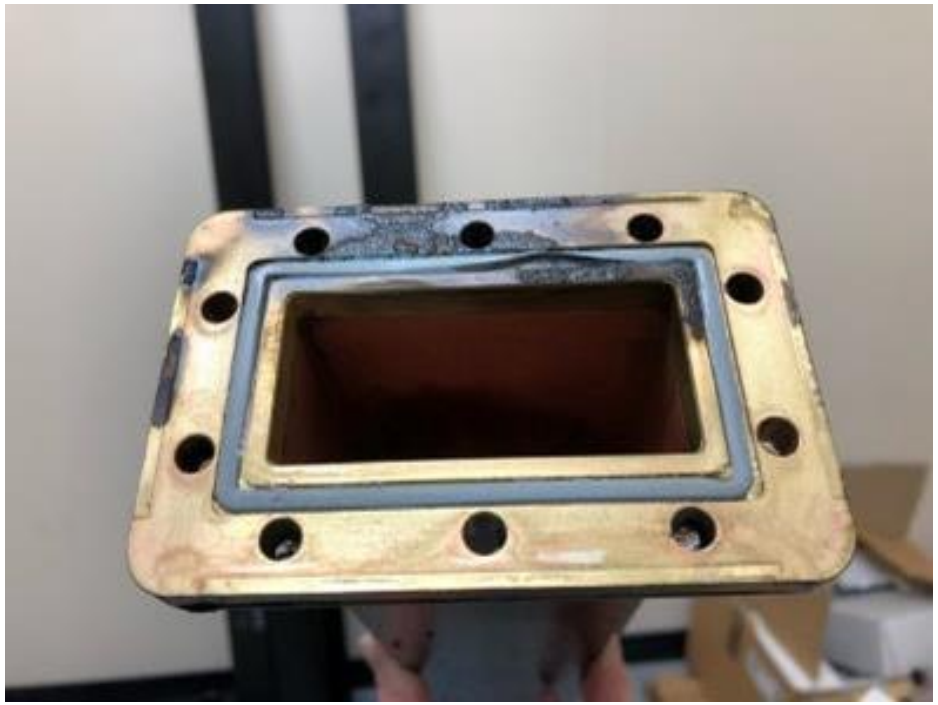
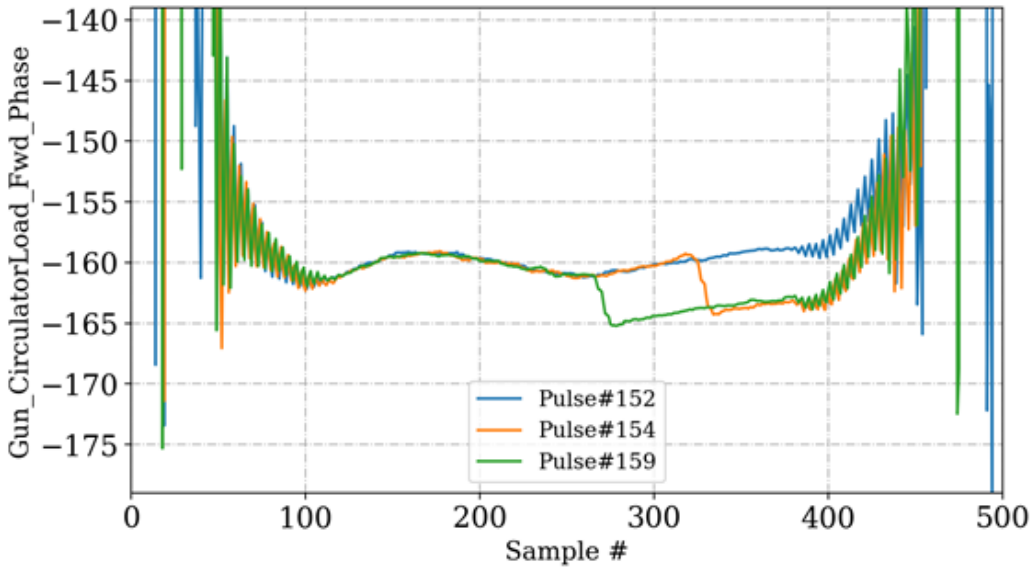
Waveguide sections



- The whole waveguide had to be removed and checked
- Some of this waveguide had not been touched for 5 years inside the concrete labyrinth
- Other sections had shown multiple examples of flange arcs
- Flange faces needed cleaning and flatting
- Procedure for waveguide is to pin the alignment to ensure flanges are aligned as good as possible
- Rebuild began once all flanges had been checked

Waveguide rebuild and testing



Gun waveguide at 500kW showing 5 degree changes in phase

- We fitted a RF waveguide load in place of the cavity
- However attempts to restart RF was problematic with noise even at power levels below 500kW
- We had to move the load further back up the waveguide path to try to isolate the issue
- Completely removed the waveguide again

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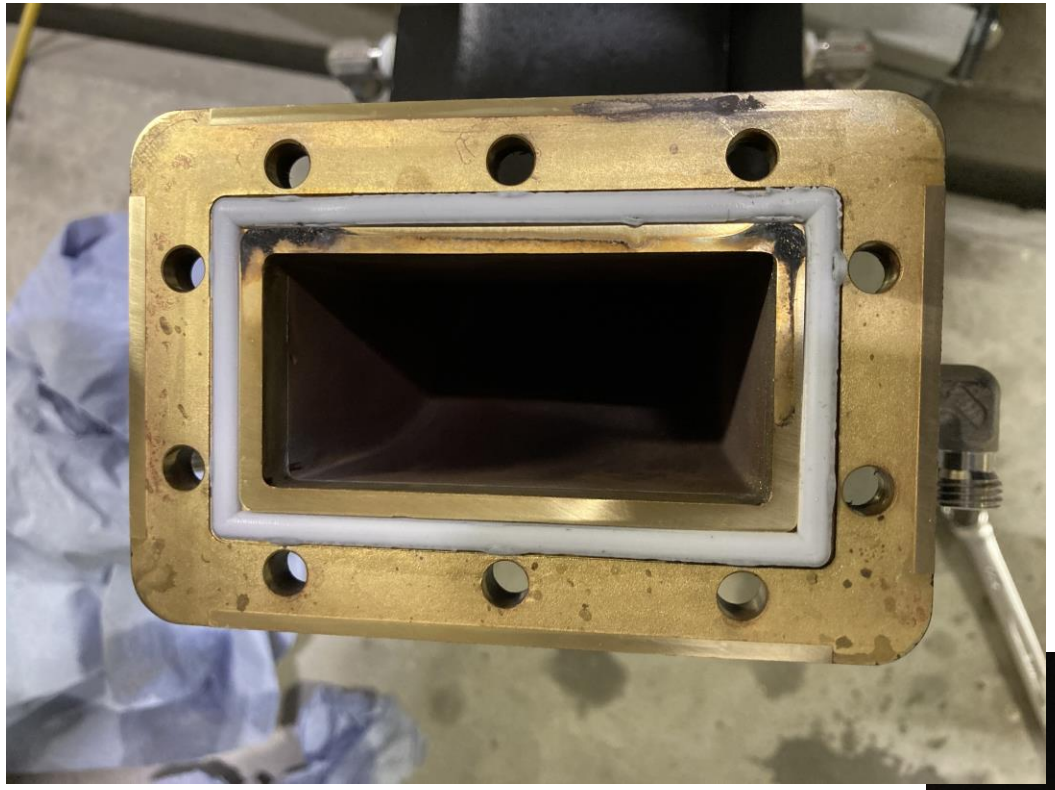

- We noticed that the gasket was being pinched and where ever this happened we had a potential problem
- Eventually we changed the gasket for a different type, a thinner gasket from a different manufacturer
- May 2021 operations have started again with no further breakdown issues
- Libera LLRF is used to check jitter routinely to provide a warning
- Experimenting with microphones

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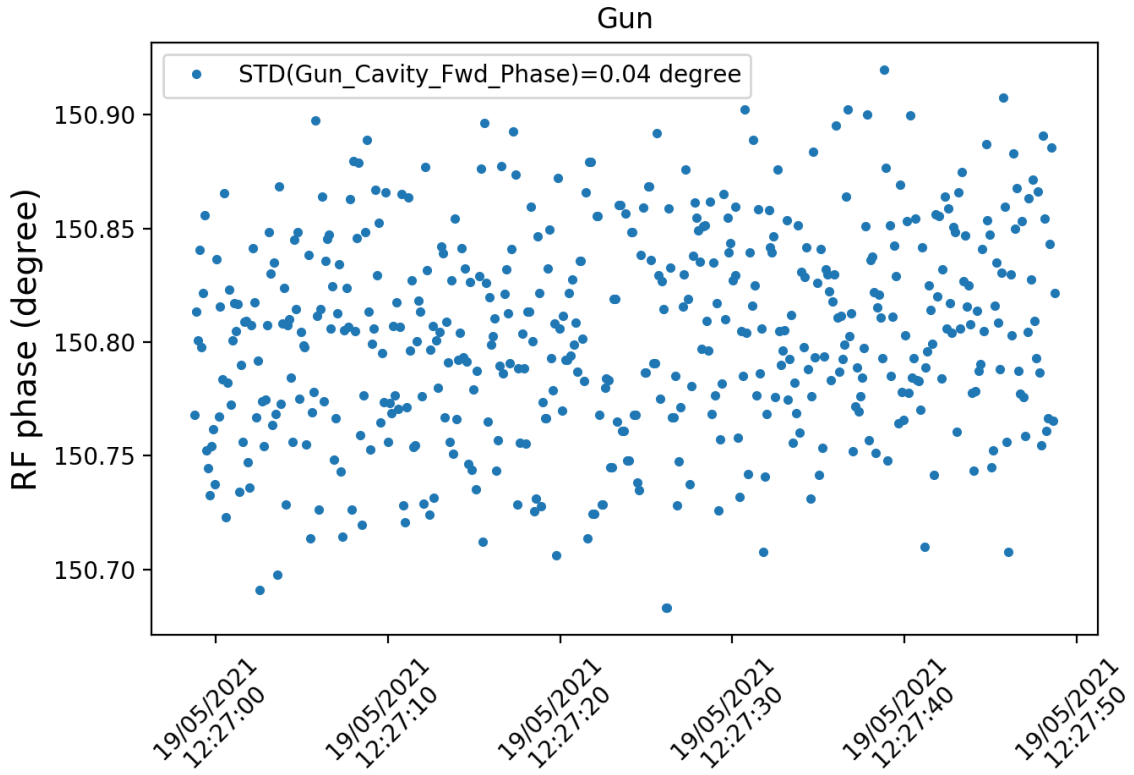
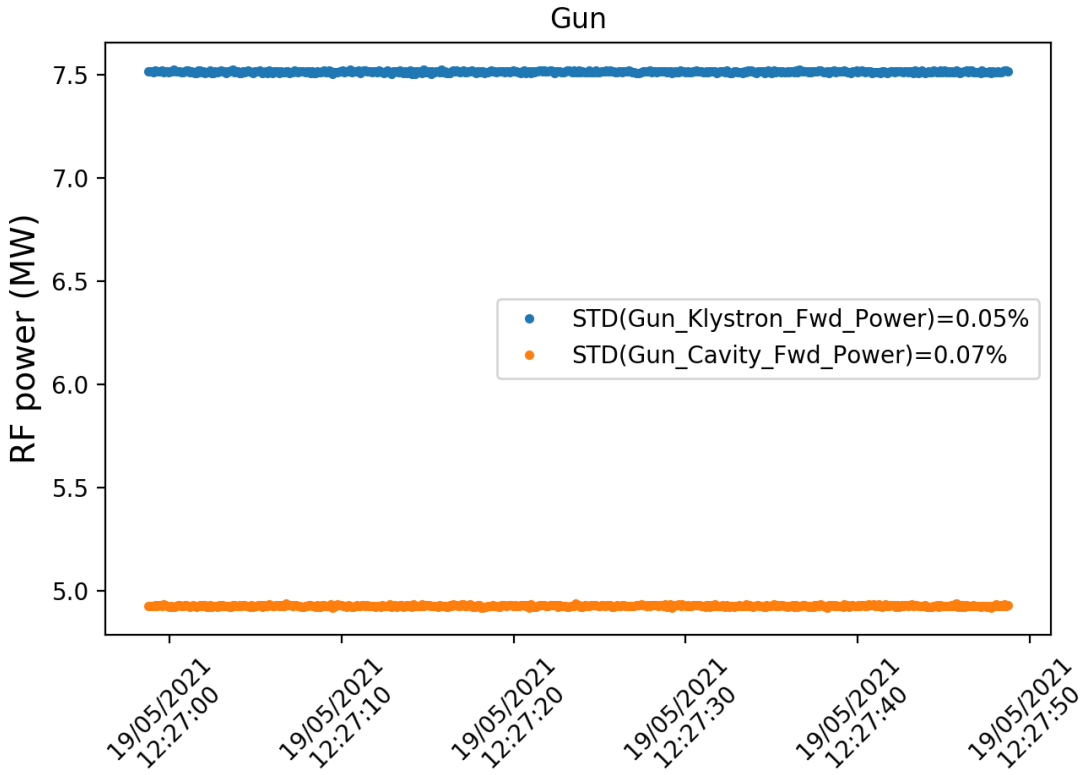
Operation May 2021





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Linac 2, 3, 4 and TDC installation

- Modulator testing now, DTI PowerMod, Canon E37333 80MW klystron
- Linacs installed 2022 from SwissFel
- TDC modulator is a Scandinova K200 for X band 8MW klystron CANON E37113E with CERN pulse compressor
- Libera LLRF systems on site, frequency convertor for X band system being built in house
- Modulator rooms are distributed along the length of CLARA machine
- Waveguide is vacuum type with precision flanges as higher peak powers are needed, equipment is on site

Linac 2,3,4 Modulator & Klystron Requirements

SwissFEL Linacs (Research Instruments)

- Fundamental frequency: 2998.5 MHz
- Active length : 4.066 m
- Maximum operational gradient: 25 MV/m
  - 20 MV/m – 48 MW
  - 22.5 MV/m – 60.5 MW
  - 25 MV/m – 75 MW
- Repetition Rate: Maximum 400 Hz,
- Fill time: 995 ns
- RMS amplitude jitter tolerance: <0.1%
- RMS phase jitter tolerance: <0.1°

Modulator Specification

Parameter	Specification
Operational voltage range	45 - 450 kV
Operational current range	50 – 545 A
Pulse repetition rate range	1 – 400 Hz
HV pulse width	1.5 to 4.0µs
Klystron peak voltage flatness (400Hz)	± 0.1 % (1 µs) - ±0.02 %
Klystron peak voltage flatness (100Hz)	± 0.1 % (2 µs) - ±0.02 %
Nominal voltage rate of rise	> 300 kV/µs - > 400 kV/µs
Voltage stability (10% to 100%)	± 0.1 % - ± 0.05 %
Voltage reproducibility (of Vmax)	± 0.2 % - ± 0.05 %
Pulse to pulse timing jitter	< ± 4 ns - < ± 1 ns

Klystron Specification

Parameter	Specification
Frequency	2998.5 MHz
Nominal Bandwidth	5 MHz
Peak RF output power	> 70 MW (80 MW)
Average RF output power	> 20.5 kW (25 kW)
Power gain	> 45 dB
Efficiency	> 45 %
Pulse Repetition Rate Range	1 – 400 Hz
RF Pulse Width	0.25 - 3.0 µs
Maximum beam voltage	410 kV
Maximum beam current	495 A

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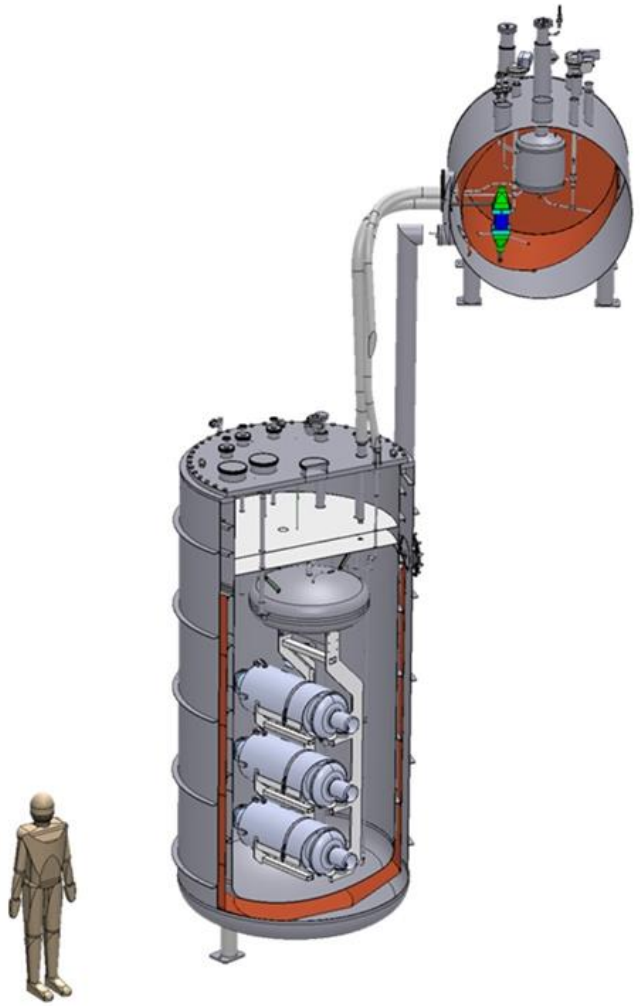
ESS cavity testing

- 88 high beta SCRF cavities to be qualified
- Produced at CEA Saclay France
- Initial pre production cavity tests at DESY
- Cryogenic plant and RF system installed to test three cavities at a time



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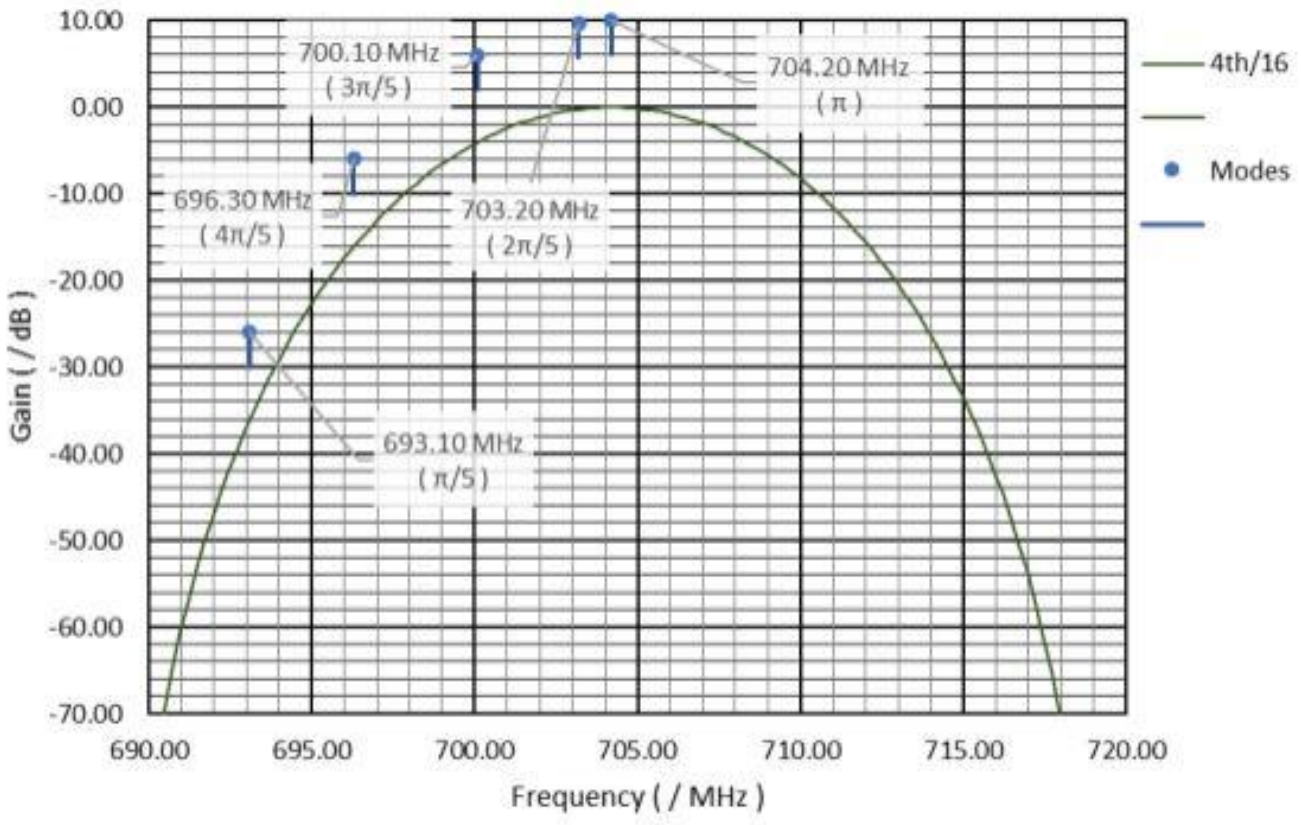
ESS RF developments

- Labview program based on Tom Powers work adapted to form basis of multi cavity test bed
- LLRF function, Self Excited Loop, in house design for electronics and software, however designer has now left, no support
- LLRF function now being taken into Labview so that multiple people can learn/adapt/change/improve design
- Will become the basis for test facilities at Daresbury

ESS cavity modes



- All 5 cavity modes are measured and a file generated mapping each cavities response and characteristic
- Both wideband and narrow SEL filters used to capture the required mode
- Original SEL system could occasional struggle if the phase angles of the modes were too close together
- Labview system is now providing a better solution through constant refinement

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Conclusion

- 6 months of problems with SF6 filled waveguide
  - Discussions with other labs have identified different gaskets
  - Most labs use precision vacuum flanges rather than the type we are using
  - Problem is now solved for the moment
  - Possible upgrade to vacuum type in the future
- Linac modulator testing now, cavity installation in 2022
- ESS team testing run of 88 SCRF cavities prior to build into cryostat
- LLRF function will based on labview for our future test facilities

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Thank you

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Questions?