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CLARA LLRF and Cavity Conditioning

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Libera Workshop 2018

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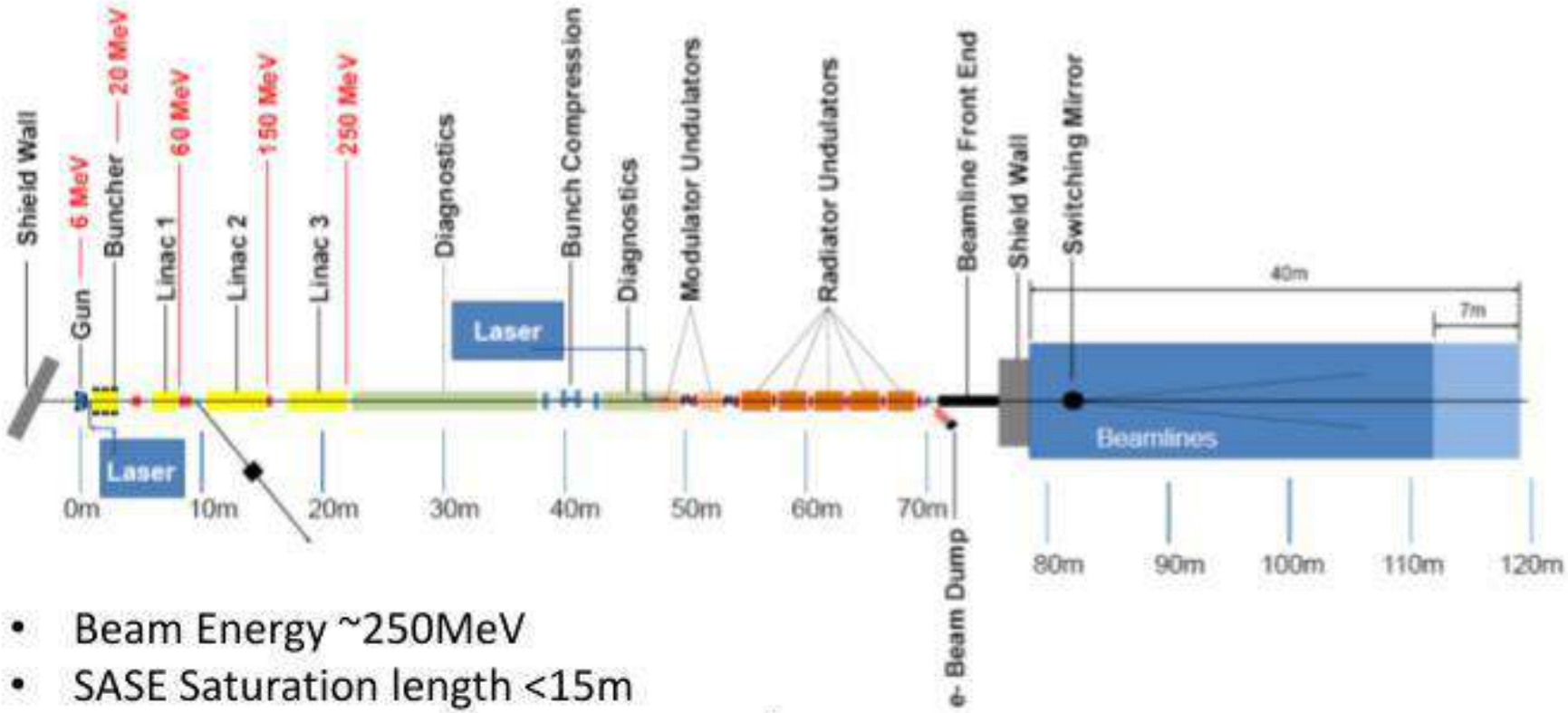
CLARA

Compact Linear Advanced Research Accelerator



- Beam Energy ~250MeV
- SASE Saturation length <15m
- Seed with Ti:Sa 800nm, lase up to 8th harmonic
- Seeding with HHG at 100nm also possible
- Single spike SASE, electron bunch length ~50fs FWHM and charge <20pC
- Seeding, peak current ~400A, flat top ~300fs and charge <200pC

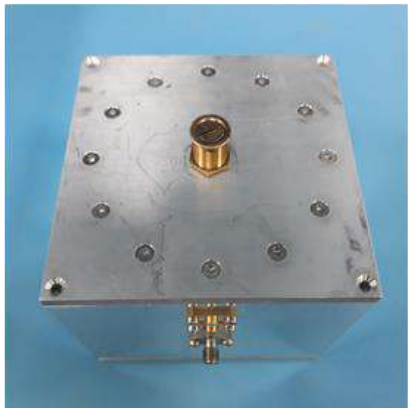
RF master oscillator

- Made by Ralab, includes output cavity to reduce far out phase noise
- Located close to the laser system in temperature stable room
- 2998.5MHz with divided frequencies down to 83MHz
- Electron beam performance needs to be measured – beam jitter

Phase noise plot of oscillator showing oscillator performance

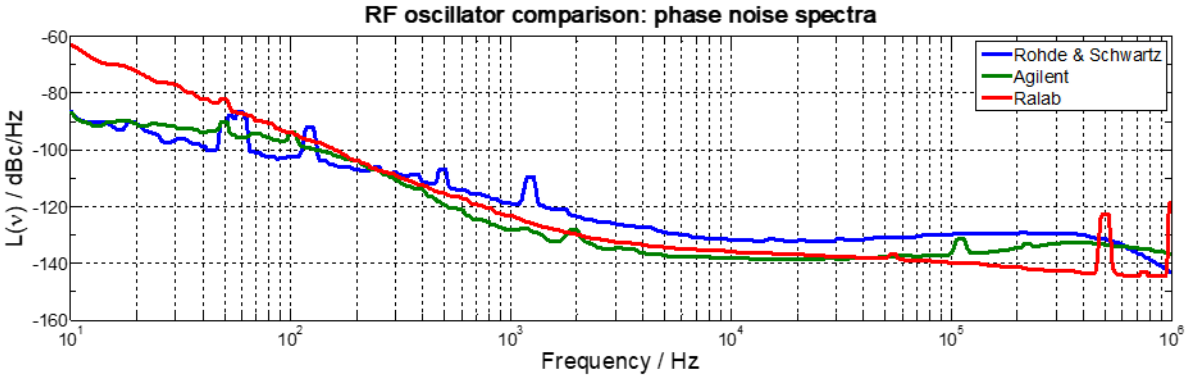
Rhode & Schwarz FSWP
Phase noise analyser

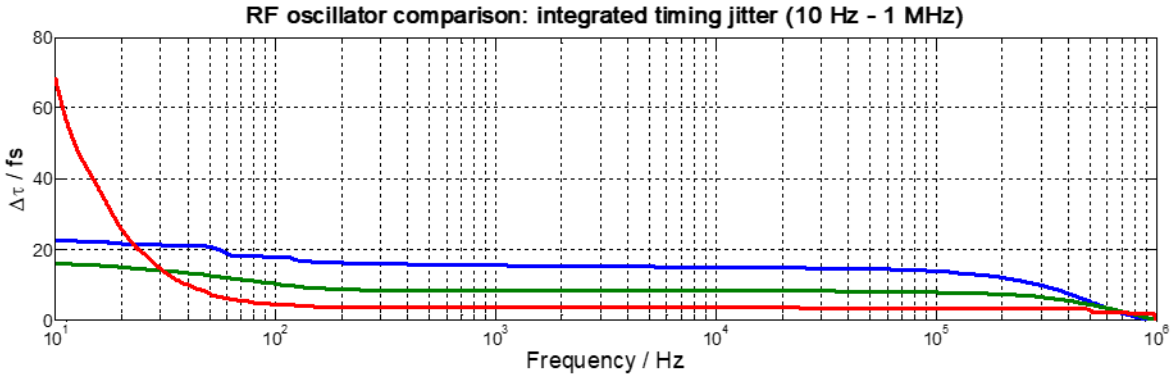
Output cavity



Laser system

- Many tests done on laser system that show the phase lock loop in the laser system only locks to <1KHz
- This means that the close in phase noise is most important to the laser
- Commercial signal generators have better performance close in to the carrier
- Possibility to use the laser as the master oscillator to provide the best of both worlds and produce the lowest oscillator noise from 10Hz to 10MHz
- No had chance yet to test any oscillator electron beam so far



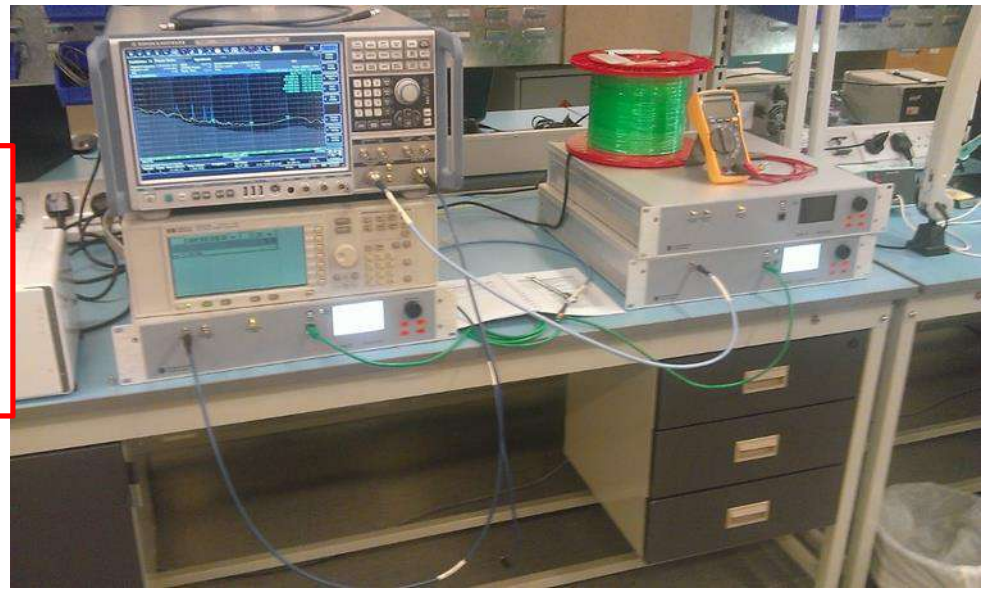


Element laser oscillator

RF Distribution – Libera Sync 3

- RF modulator room is 30 metres from laser and master oscillator
- Libera sync 3 used to transmit 3GHz over long distances with low added jitter and minimum drift
- First sync 3 provides reference to the Gun and Linac 1 LLRF systems
- Further five modulator rooms will all be equipped with sync 3 systems
- Laser timing will also use two sync 3 systems to transmit reference as these are critical parameters

Integrated (10 Hz – 1 MHz): $\underline{\Delta\tau_{rms} = 8.2\ fs}$
Close in (<1 kHz): 1.1 fs
Far out (> 1 kHz): 7.1 fs



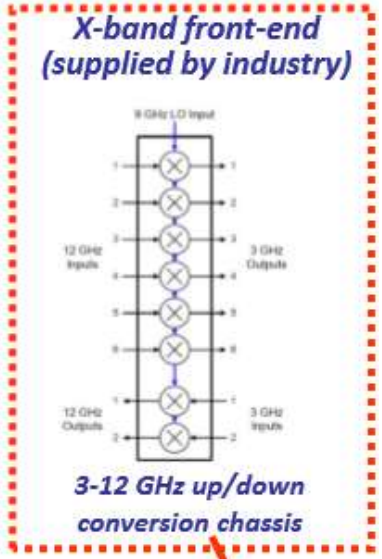
Using the FSWP to measure additive phase noise, FSWP supplies and reads output from system under test

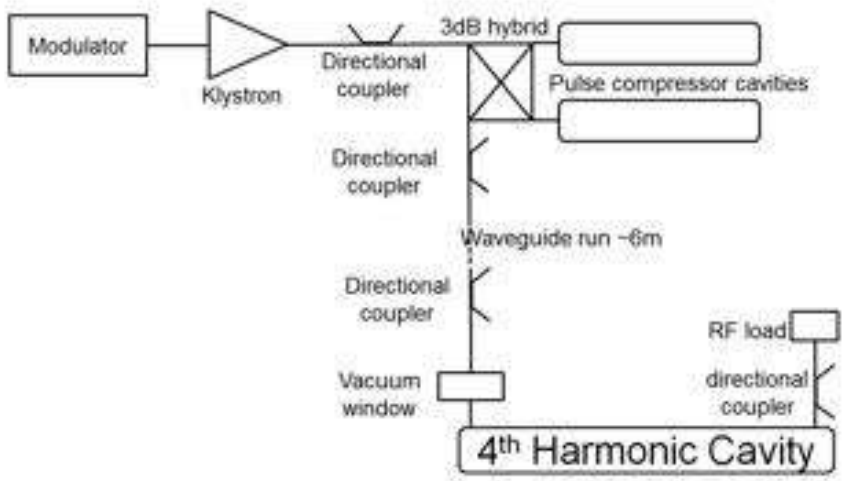
Low Level RF systems

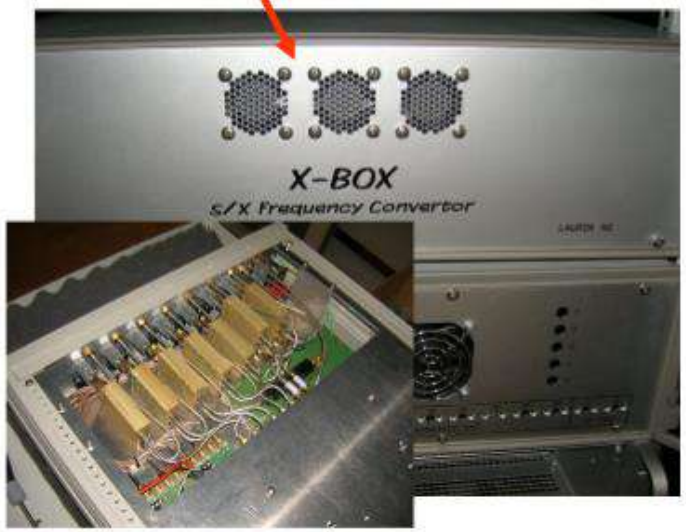
- Bottom unit is Libera sync 3 receiver unit bringing 3GHz reference signal over 30 meters of fibres
- Libera LLRF systems with stabilised front end down/up convertors
- Originally we used multiple RF power detectors/meters to measure forward and reflected power from the waveguide systems, this gave differing results despite rigorous calibrations
- After many measurement's of harmonic power and accuracy, we now only use the LLRF for power measurement's
- We continue to design and build our own LLRF systems, because its interesting work, however for CLARA we need a proven design with known performance

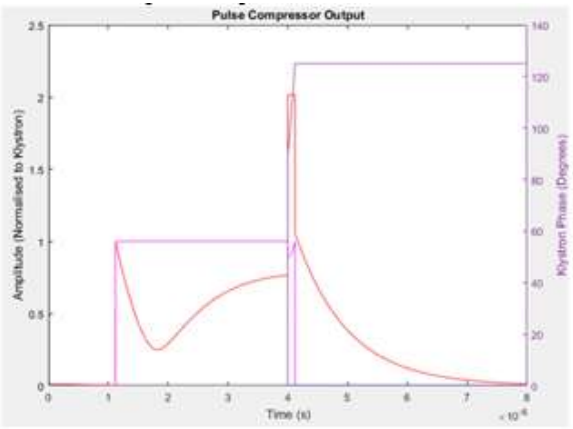
12GHz LLRF system

- For 4th harmonic cavity using a pulse compressor
- Using frequency convertor to 12GHz which are commercially available
- Use 3GHz LLRF with phase flip to drive pulse compressor
- Pulse compressor being built at CERN now
- Frequency convertors used at fermi@electtra and Swissfel





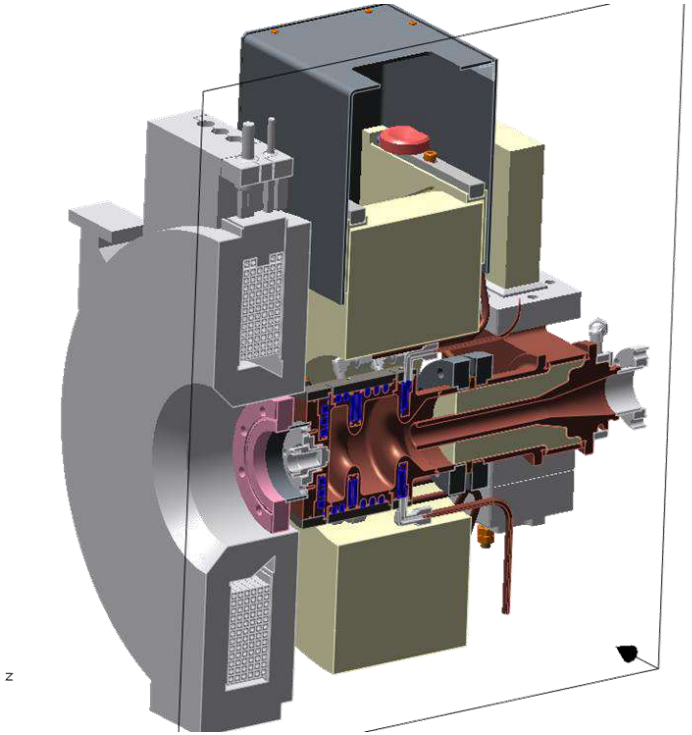




Showing the klystron out, phase flip and resulting output of the pulse compressor

Gun RF Modulator

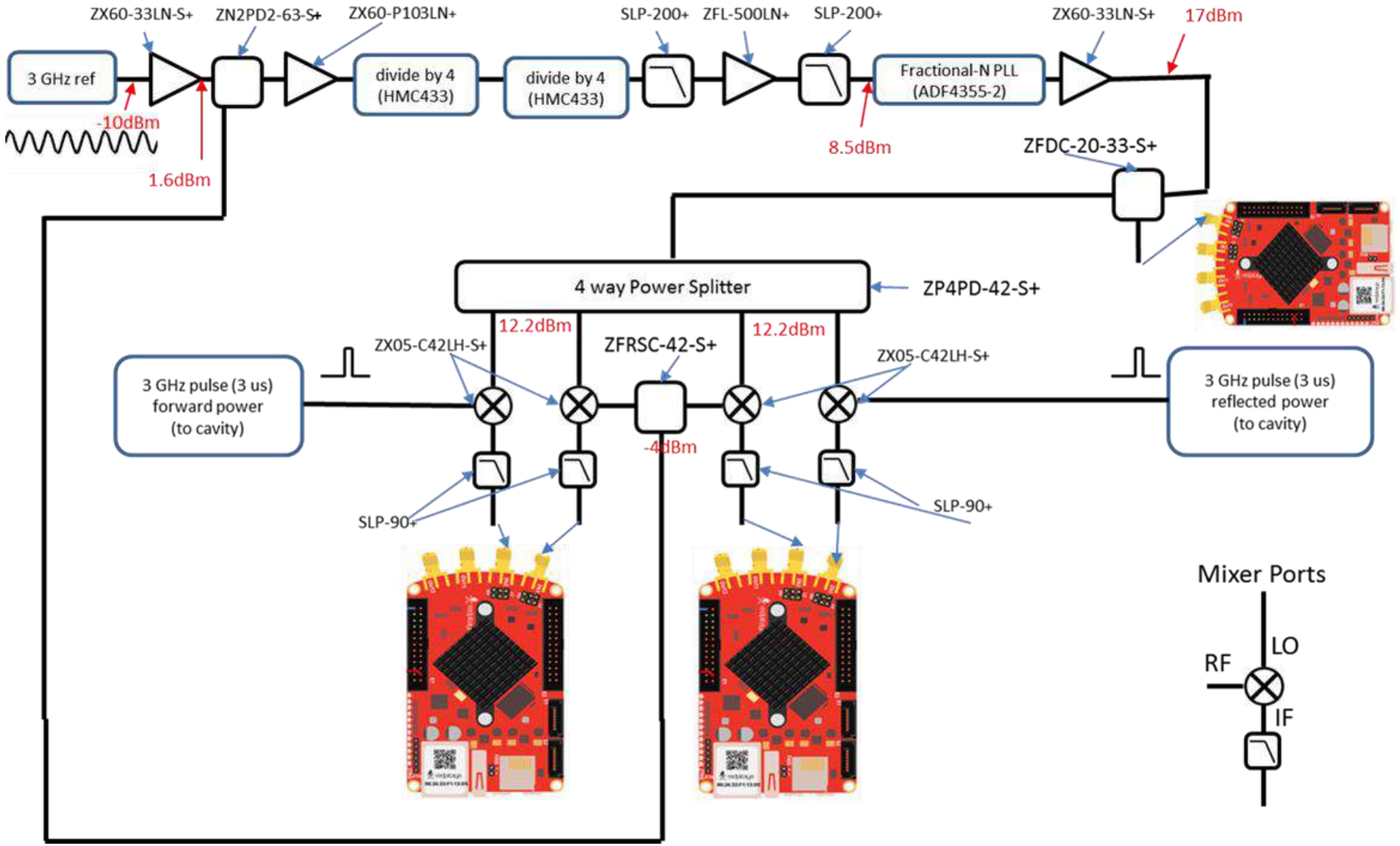
- Gun modulator (Scandinova) can be switched between the low rep rate (LRRG) and high rep rate (HRRG) gun cavity structure
- LRRG is currently installed on CLARA, HRRG is installed on VELA, Gun modulator powers either cavity
- VELA beamline has a lot of injector diagnostics to assess gun performance
- Modulator is 10MW at 3uSec pulse at up to 400Hz for the HRRG
- Thales klystron



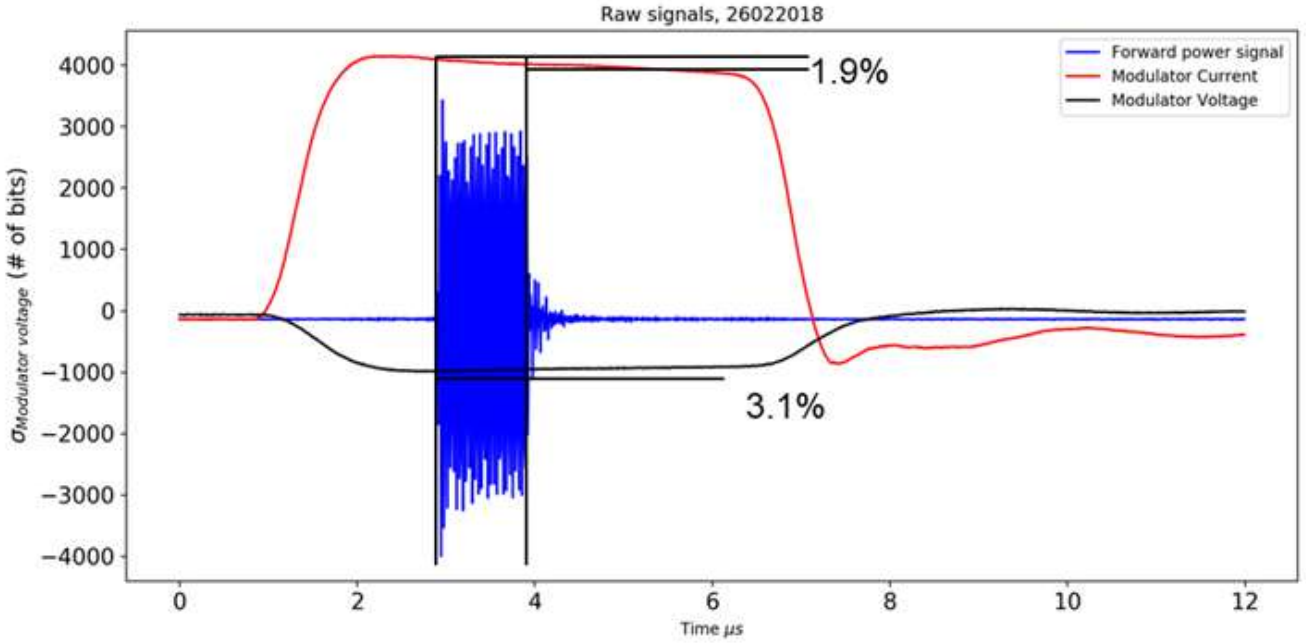
	Units	Operating mode	
Repetition Rate		100 Hz	400 Hz
Frequency	GHz	2.9985	
RF peak power max	MW	<10	
RF average power max (estimate)	kW	10	
Gun gradient	MV/m	120	100/80
Bunch charge	pC	20-250	250
Operating mode		Pulsed/Train pulsed	Pulsed
RF feedback	Required		

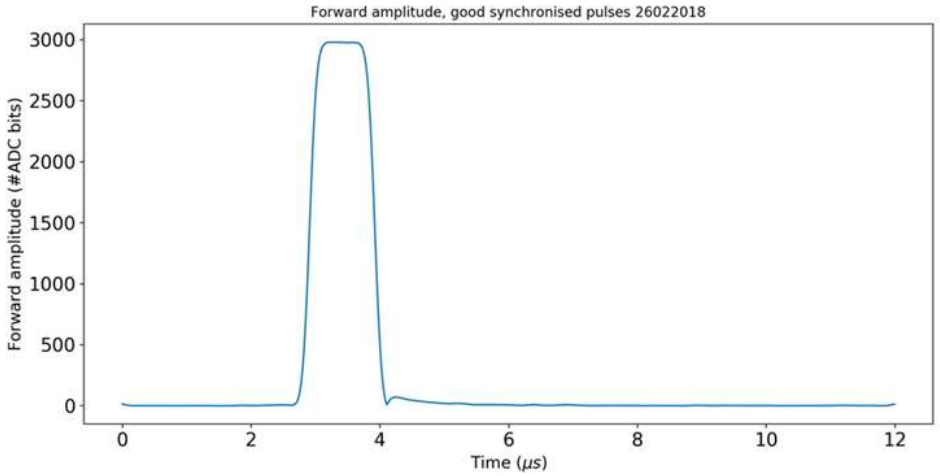
Digitiser to monitor Gun Modulator

- Monitors
  - Forward and reflected power
  - Down mixes from RF system 3GHz so that RF signals are phase matched
  - Modulator voltage and current
  - Mains 3 phases
  - Klystron drive signal
  - 6 red pitaya boards
  - Timestamps all signals to search for repetitive effects that could be corrected



Results of digitizer





- Modulator current flatness = 1.9%
- Modulator voltage flatness = 3.1%
- Smoothed-ModVoltage = 0.094%
- Smoothed-ModCurrent =0.022%
- Driver and klystron characterised
- Slow 20 minute drifts seen
- More data needed and plans to improve SNR by filling ADC to maximum level

Linac 1 modulator

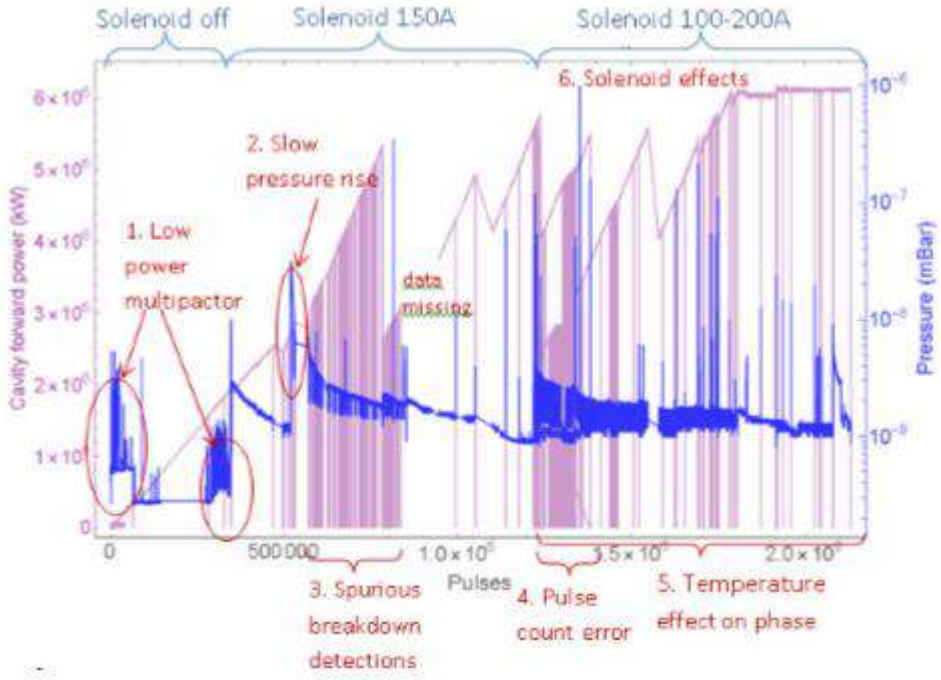
- Diversified Technologies 45MW modulator with Thales klystron
- Waveguide pressurized with SF6, however problems with breakdown due to incorrect pressure setting and flange misalignment problems that needed to be corrected
- Safety paperwork and procedures rewritten to prevent further occurrence's
- The 45MW klystron seems to be saturated at an indicated 33MW, however electron momentum has been achieved

Cavity conditioning

- Linac 1 was the first structure to be conditioned although this had to be abandoned at 28MW klystron power when the SF6 waveguide started arcing
- This resulted in the entire waveguide system being removed for cleaning and to have the flanges pinned to cure alignment problems
- When conditioning recommenced a python script was used to automate the process in preparation for the HRRG, which would require more careful conditioning to avoid surface damage from breakdowns
- The python script looked at the forward and reflected power at the cavity to detect breakdowns in conjunction with cavity vacuum signals
- The 2 metre cavity was subject to 12 million pulses of 750nSecs at 50 Hz and achieved an acceleration gradient of 21.5MV/m and has accelerated electron beam

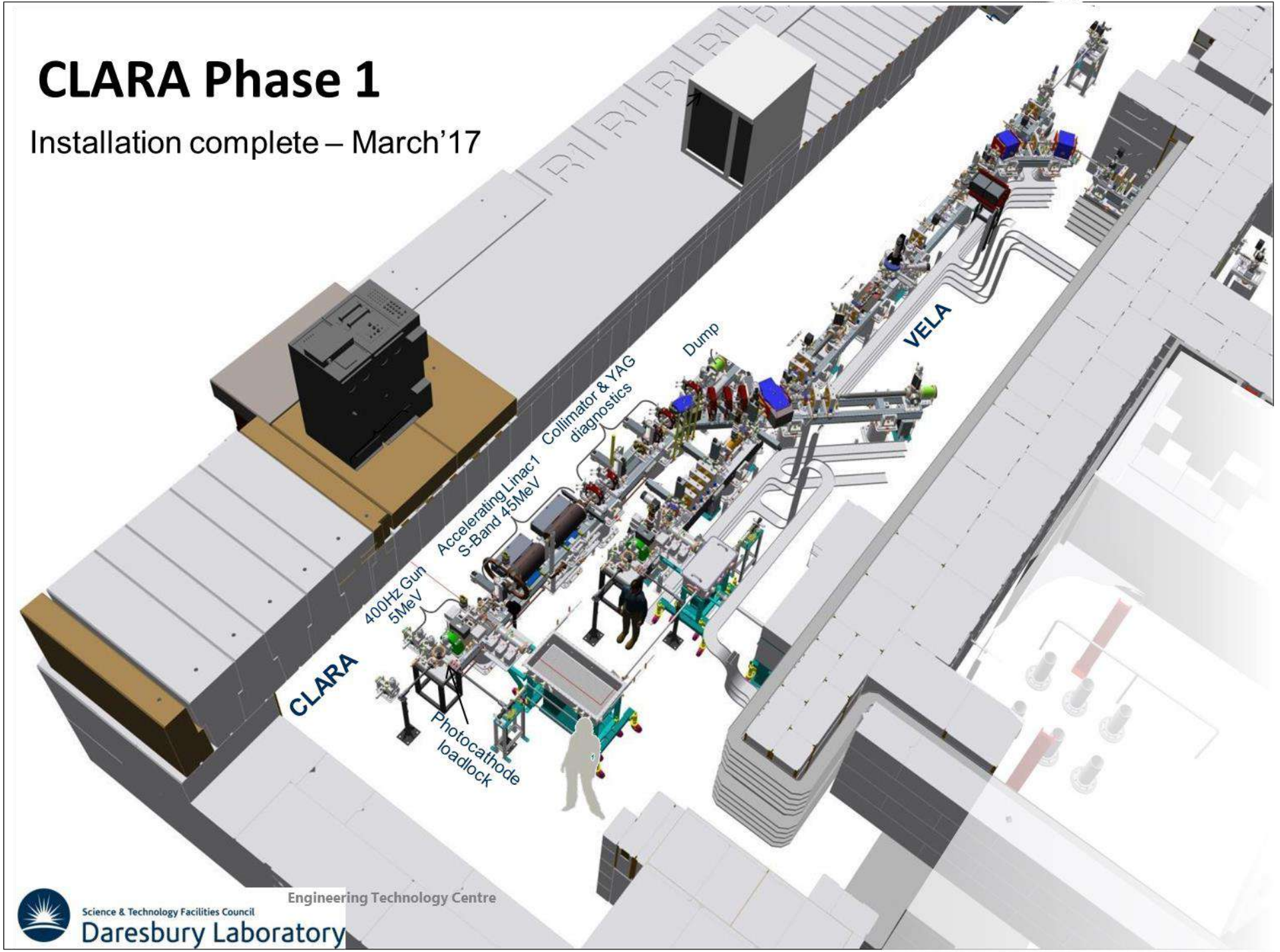
Gun conditioning

- The LRRG has been in operation for 6 years, however an new cathode and cleaning process meant that the cavity would need reconditioning
- A new script was developed that looked at the phase signals of the RF traces, this provides an accurate indication of cavity breakdown particular of the reflected cavity power
- However too many RF trips can lead to the cavity temperature moving away from its setpoint ,and the condition program can become stuck
- Cavity temperature is critical and needs to be controlled to 0.01 degrees to maintain frequency tuning ideally
- Many iterations of the script later when a breakdown is observed the program pauses the power just below the power level of the last breakdown for a few pulses to maintain cavity conditions before restarting the process
- The solenoid surrounding the gun also provided a significant disturbance the conditioning process by altering the vacuum conditions and adding to the breakdown rate



CLARA Phase 1

Installation complete – March'17



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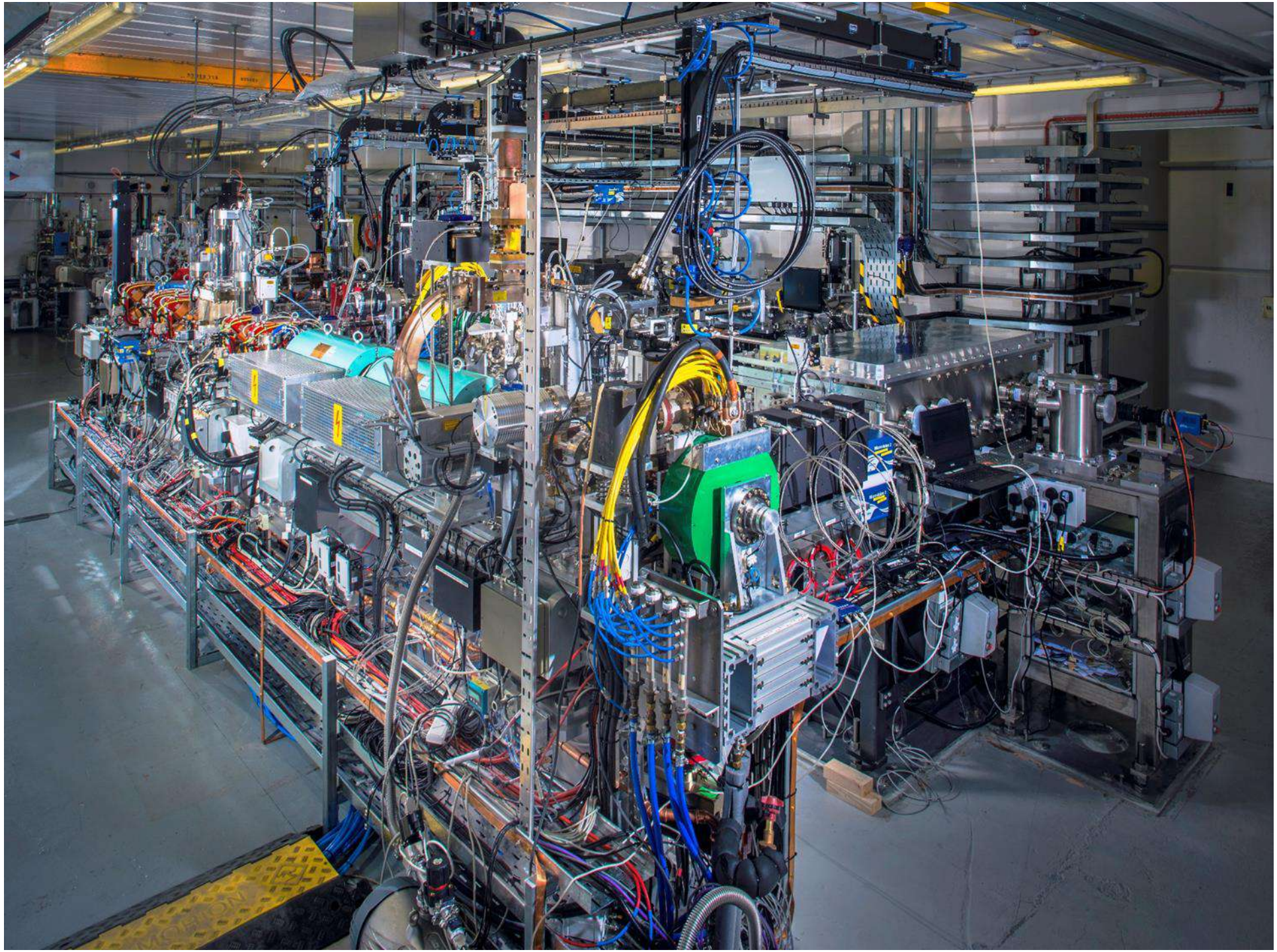
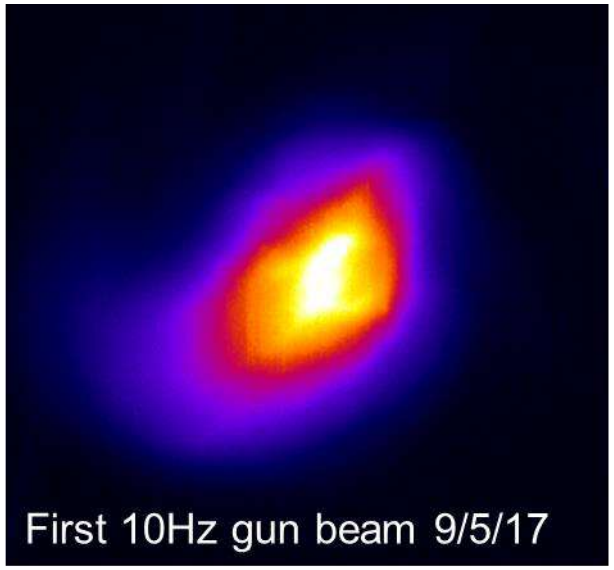
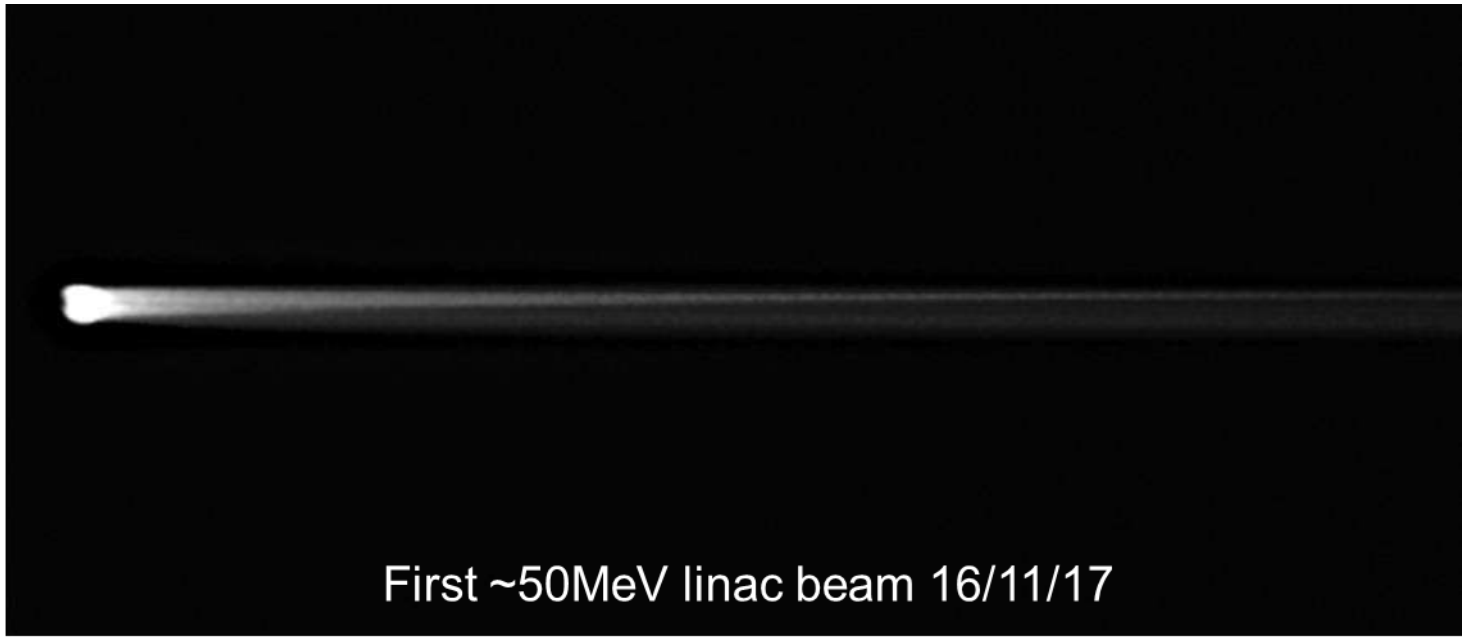


CLARA phase 1 update

- 10Hz gun RF conditioned and electron beam generated in May 2017.
- Significant dark current from the gun in May'17
  - Diamond turned Cu photocathode
  - Argon Plasma cleaned
  - Difficult to draw conclusion due to other problems/uncertainties and issues experienced during RF conditioning



- Linac 1 RF conditioned with no issues except RF power level seems low. Could be calibration error?
- Measured gun momentum ~5 MeV/c and gun + Linac ~ 50 MeV/c recently.



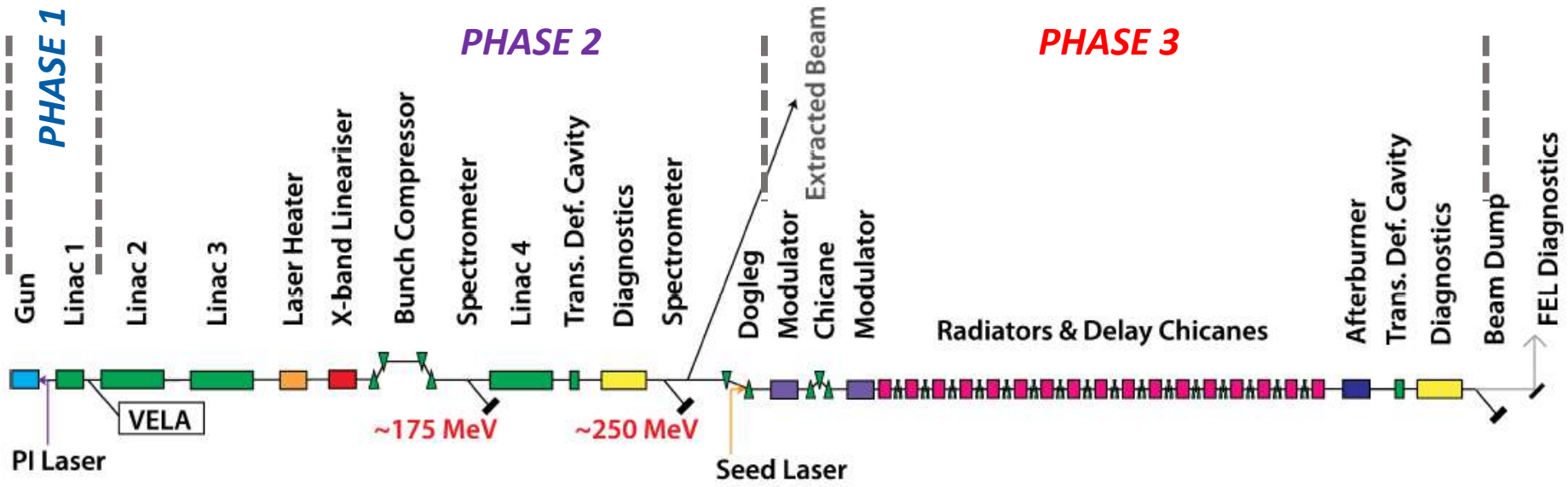
Component's arriving in 2018/19

- 2 DTI modulators 45MW
- 2 Scandinova modulators 20MW for Time Deflecting Cavities (TDC)
- 4^{th} harmonic cavity and pulse compressor
- So far we have received funding year by year, from STFC internal funds, which makes it difficult to manage the project
- We are now applying directly to UKRI Strategic Priorities Fund for £28.9M to complete the project over the next 4 years
- Funding decision July 2018

The Electron Hall

- Building refurbishment completed successfully and temperature control excellent ~ 0.3 degrees – experiment hall 0.1 degrees
- New concrete blocks and roof beams stacked in hall and ready to be assembled into complete 95m bunker for machine

CLARA: FEL Layout and Status



PHASE 1:
50 MeV, INSTALLED AND NOW COMMISSIONING

- 2018: Beam characterisation, machine development and exploitation with 10Hz gun
- 2018: Conditioning and characterisation of 400Hz gun

PHASE 2:
250 MeV, BEING PROCURED AND ASSEMBLED

- 2018: Module assembly offline
- 2019: Shielding changes
- 2020: Installation

PHASE 3:
100 nm FEL, NOT YET FUNDED

- 2018: Full release of funds…?
- 2021: Installation
- 2022: Lasing!!

CLARA Exploitation

- Now that Phase 1 has achieved 250pC and 50MeV we are looking to release some time for electron beam exploitation
  - For UK researchers from the Cockcroft Institute, John Adams Institute, etc
  - For European researchers via Trans-National Access, funded by ARIES (H2020)
  - For industry
- We want to run reliably for 2 weeks with beam and then we will trigger the beam application process and solicit proposals
- Current plan is to allocate 3 months of beamtime between Sept and Dec 2018
- We are then planning a major shutdown (~4 months) to reconfigure the shielding at the downstream end of the existing facility at the start of 2019
- Following this shutdown, and the subsequent recommissioning, we are planning additional exploitation time in 2019