Science & Technology Facilities Council

The CLARA Facility

Jim Clarke

STFC Daresbury Laboratory & The Cockcroft Institute

CLIC Workshop, CERN

9th March 2017

Contents

- Context: UK XFEL Strategy
- UK XFEL Underpinning Technology Programme
- CLARA
- Summary

UK FEL Strategic Review

- Published August 2016
- Available at www.stfc.ac.uk/files/fel-report-2016/

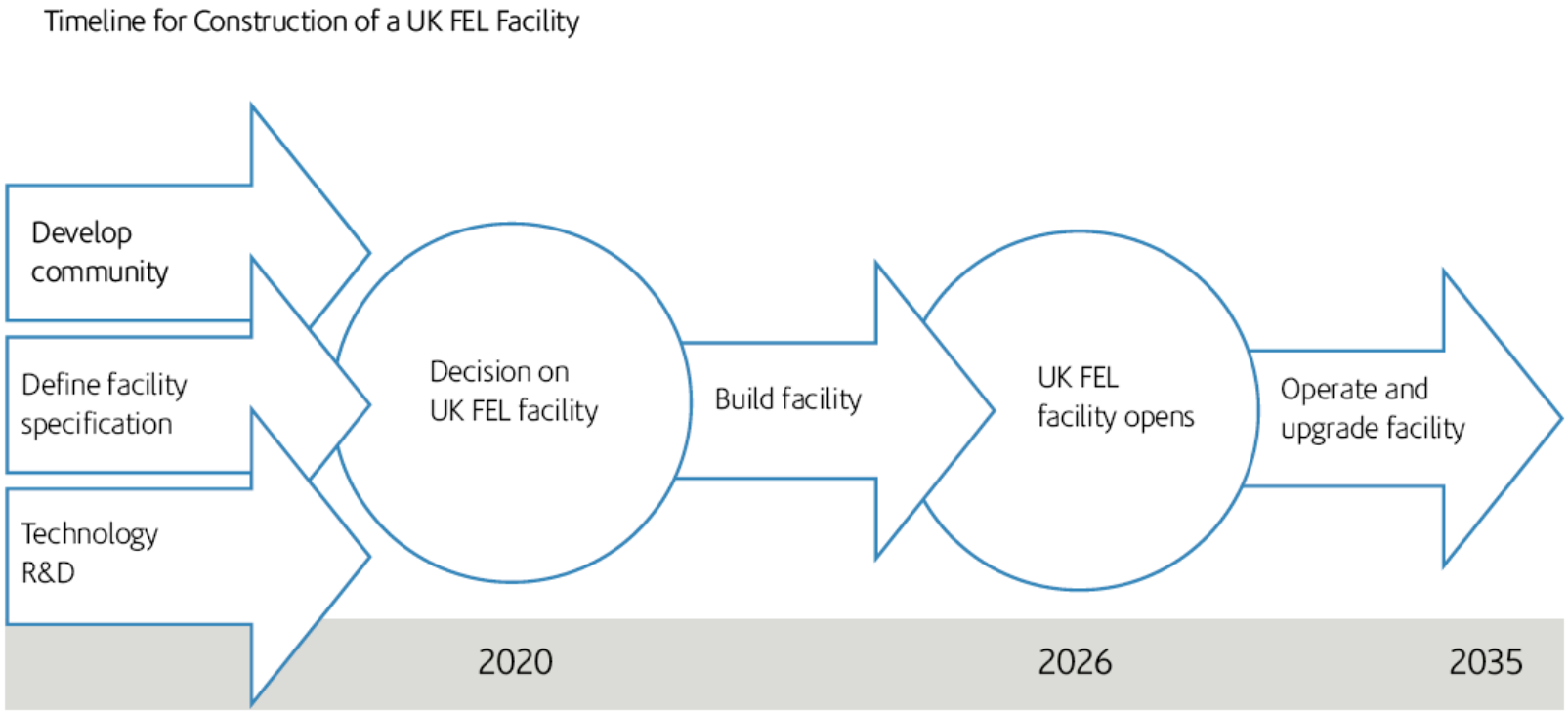
- "This strategic approach for developing a UK FEL focuses on two key objectives:
  - meeting the UK's immediate XFEL needs using existing and near-future facilities;
  - preparing to meet the UK's long-term needs by constructing an XFEL facility in this country."
- "In the long term, the UK's capacity requirements will be best served by **constructing a UK FEL facility** with a specification designed to meet our needs."
- "The **final decision** on whether to build an XFEL in the UK (and to what specification) is unlikely to be taken before **2020**…"
- "The exact specifications of a UK facility will be developed over the next 4 years…"

STFC FEL Strategic Review

- “One of the options is likely to be a SwissFEL-like design…”
- “This would be a **normal conducting XFEL** operating at energies up to **10 keV**, with a repetition rate of **around 100 Hz**.”
- “It would also complement XFEL.EU and LCLS-II, which will remain essential for a small number of applications that demand a high repetition rate…”

- “The **CLARA test facility** at Daresbury Laboratory will address many of these areas directly (**guns, RF structures, laser issues, single shot diagnostics, timing and synchronisation**).”
- “It is very difficult to develop state of the art accelerator technologies in isolation. It is only through **bringing them together in a facility** such as CLARA that they can be **properly tested and proven**.”

UK FEL Timeline



www.stfc.ac.uk/files/fel-report-2016/

UK XFEL Underpinning Technology Programme

- The accelerator community has generated a UK XFEL Underpinning Technology programme to develop the skills and technology required so that when we get the green light for the UK X-ray FEL facility we are ready to make well informed decisions on layout and have solutions to all major technical issues
- The plan has received input from ASTeC, CI, DLS, & JAI and consists of 7 technical work packages
- The heart of the R&D programme is the detailed design, assembly, commissioning, development, and exploitation of the **CLARA FEL Test Facility**
- A very important aspect of the overall programme will be strong connections to the potential FEL user community.

Science & Technology Facilities Council

diamond

The Cockcroft Institute of Accelerator Science and Technology

John Adams Institute for Accelerator Science

The UK XFEL Underpinning Accelerator & FEL Technology Programme

WP0 – Management, Coordination, Connection to the User Community

WP1 – Gun Development

WP2 – RF Development

WP3 – Electron Beam Transport and Optimisation

WP4 – Potential FEL Output Performance Enhancements

WP5 – Diagnostics

WP6 – Synchronisation

WP7 – Undulators

WP2 – RF Development

- Frequency Options
  - Review available RF amplifier sources, including cost and performance
  - Review high gradient accelerating structures (Achievable gradients, Beam-loading effects, Breakdown rates, Beam quality preservation)
  - Includes NCRF & SCRF options
- LLRF Development
  - Perform measurements on the CLARA system (I-Tech) to benchmark current capability
  - Develop further LLRF systems hardware and software to improve upon stability
  - Development of a self-calibration system to provide improved stability – Evaluation of the DESY system.
- Modulator Technology
  - Perform measurements on the CLARA RF modulators (ScandiNova & Diversified Tech) to benchmark current capability
  - Engage with modulator suppliers to improve critical parameters which effect synchronisation and stability of accelerator
- Cavity Optimisation

CLARA

Compact Linear Accelerator for Research and Applications

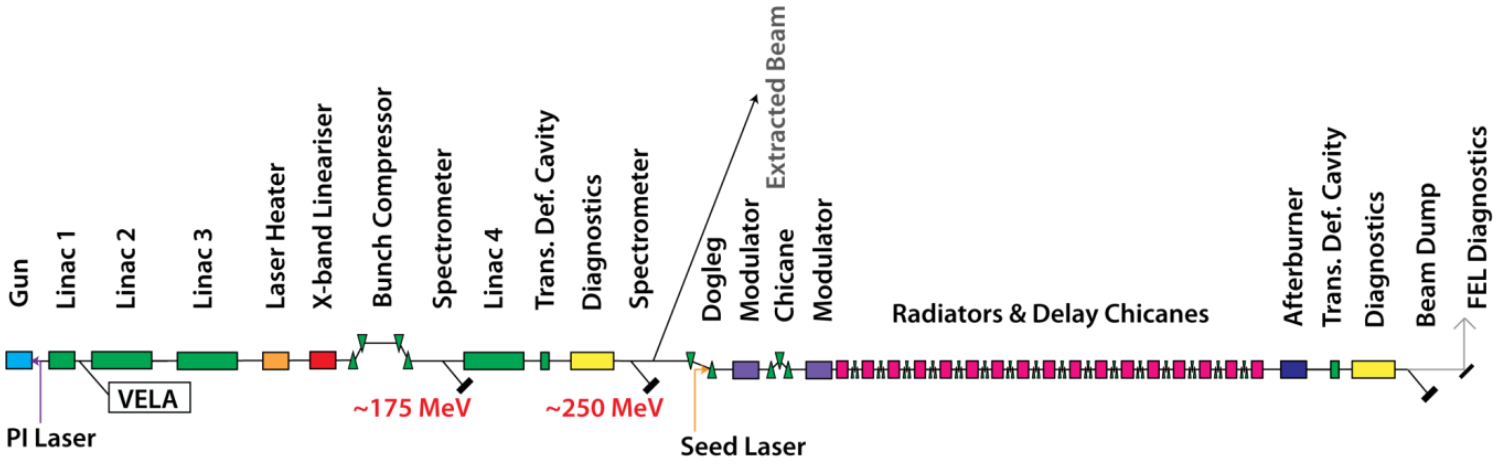
A flexible FEL Test Facility

Proof-of-principle demonstrations of novel FEL concepts and development of future accelerator technologies

Emphasis on ***Stability, Synchronisation and new FEL capabilities***

CLARA

- CLARA is a purpose built dedicated flexible FEL Test Facility
- CLARA is a scaled down version of an X-ray FEL containing all of the key technical components, where all lessons learnt can be directly applied to any future UK XFEL.
- The key objectives are:
  - To develop new methods for improving the quality of the light output from FELs
  - Prove new technologies
  - Develop the UK skill base
  - Lower the total cost of a UK XFEL
  - Lower the risks associated with UK XFEL.



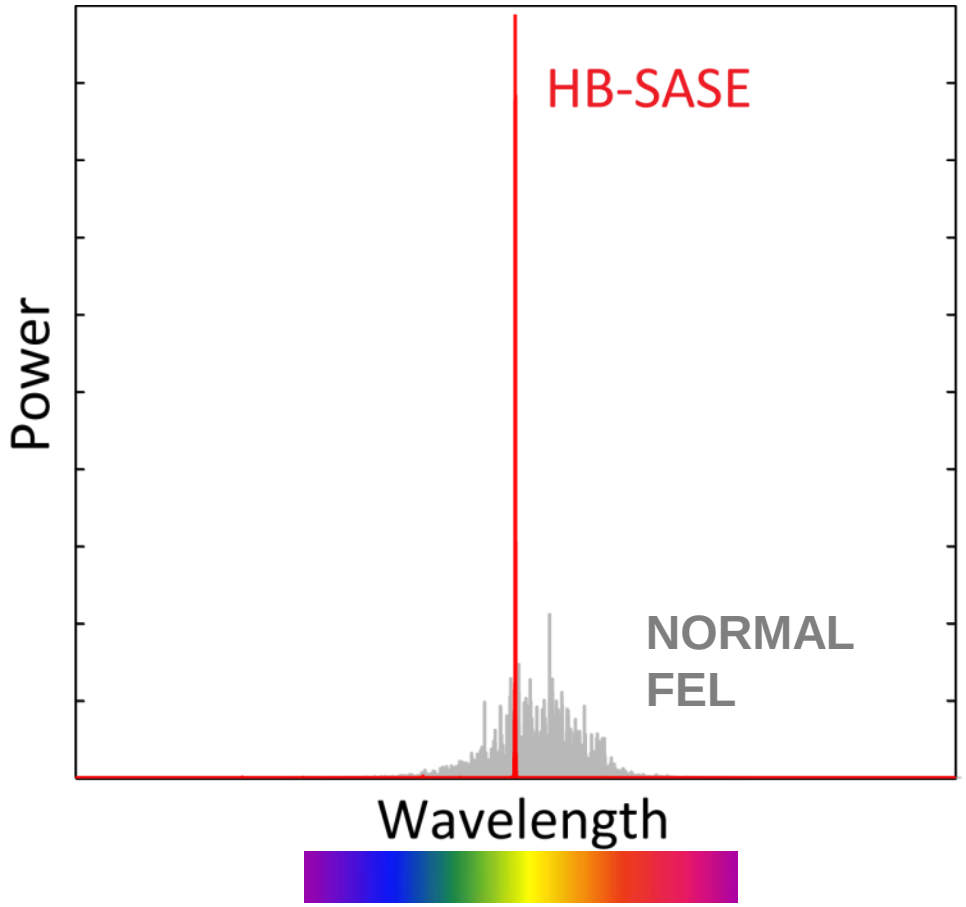
Summary of Operating Modes

MODE	*FLAT – Seeded HG*	*ULTRASHORT – SSS*	*SHORT – HB-SASE*	*LONG – ML*
Energy	240 MeV	240 MeV	150—**240** MeV	**150** – 240 MeV
Pulse Duration	250fs flat region	50 —35 fs FWHM	585 fs FWHM	1.875 ps FWHM
Charge	250 pC	25—50 pC	250 pC	250 pC
Peak Current	400 A	500 — 1500 A	400 A	125 A
Norm Emittance (mm-mrad)	0.5 (Target) 1.0 (Max)	1.0 (Target) 1.5 (Max)	0.5 (Target) 1.0 (Max)	0.5 (Target) 0.8 (Max)
RMS Energy Spread (keV)	25 (Target) 100 (Max)	100 (Target) 150 (Max)	25 (Target) 120 (Max)	25 (Target) 75 (Max)
Purpose	• 800nm Seeding and Harmonic Generation	• Single Spike SASE (+ mode-locked single spike SASE)	• 100nm saturation • Schemes only requiring spectral characterisation, • Highest harmonic upconversion potential • Shortest pulse durations in absolute terms.	• 266nm schemes requiring long wavelength modulation of the pulse energy (Mode-Locking, Mode-Locked Afterburner, Slice + Taper).

What will CLARA be able to do?

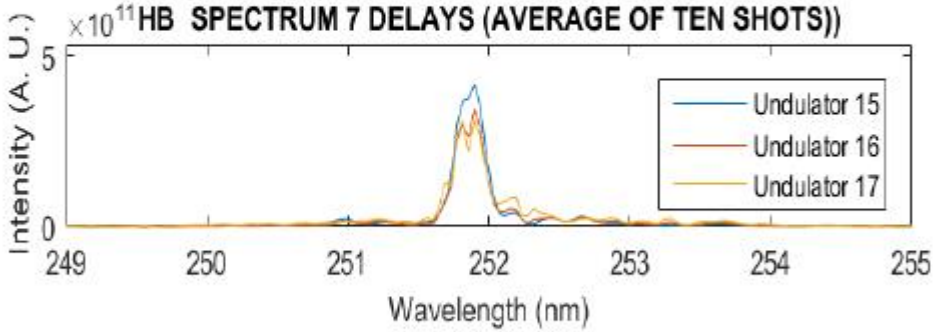
- **Example 1: Reducing the FEL output bandwidth**
- Prove that a new idea called **HB-SASE** actually works
  - Could then build it in from the start of the UK XFEL

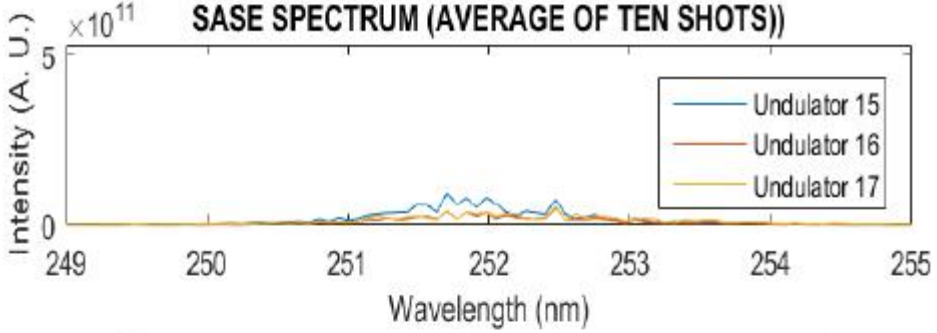
Will work at any wavelength and any repetition rate, no fancy optics required!

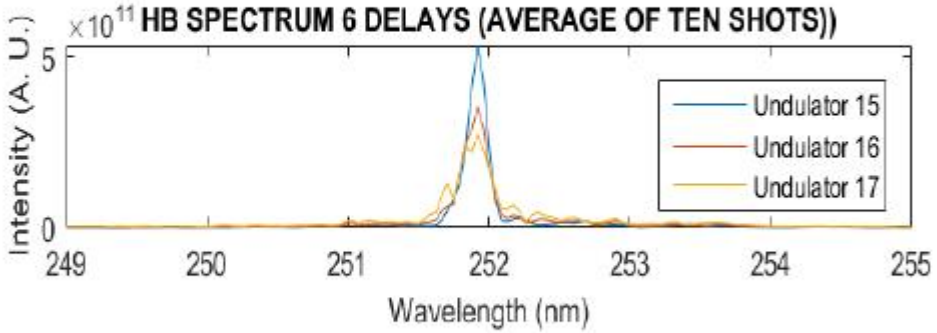


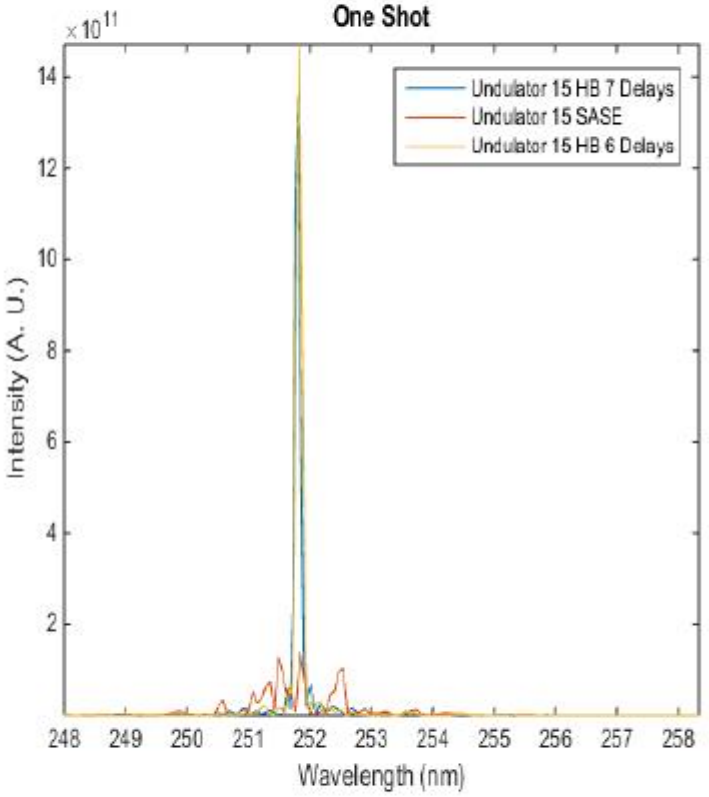
B.W.J. McNeil, N.R. Thompson & D.J. Dunning, PRL 110, 134802 (2013)

HB SASE on CLARA: Spectra









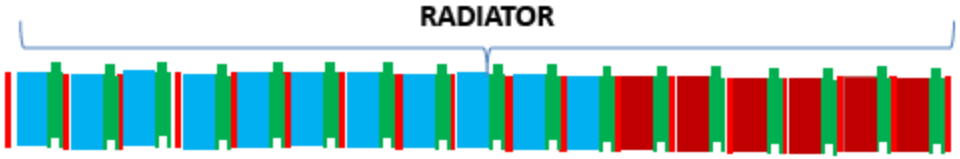
Slide courtesy Simone Spampinati

Two Colour SASE and HB-SASE

The Cockcroft Institute of Accelerator Science and Technology

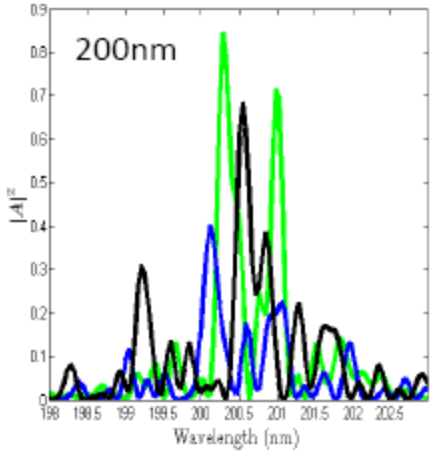
Two colour SASE

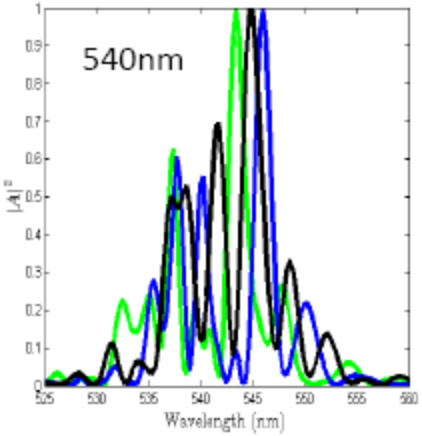
150 MeV / 400 A



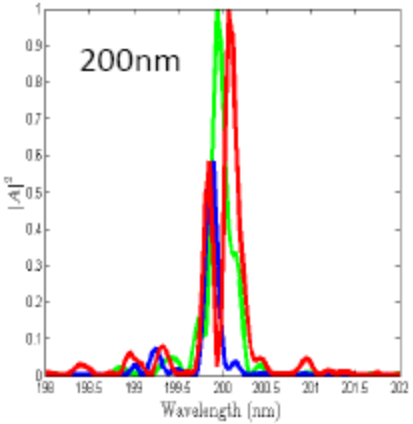
Two colour HB-SASE

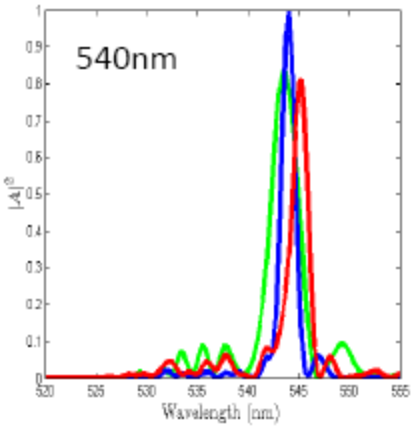
Two colour SASE, 3 shots





Two colour HB-SASE, 3 shots





Slide courtesy Simone Spampinati

Lancaster University

University of Liverpool

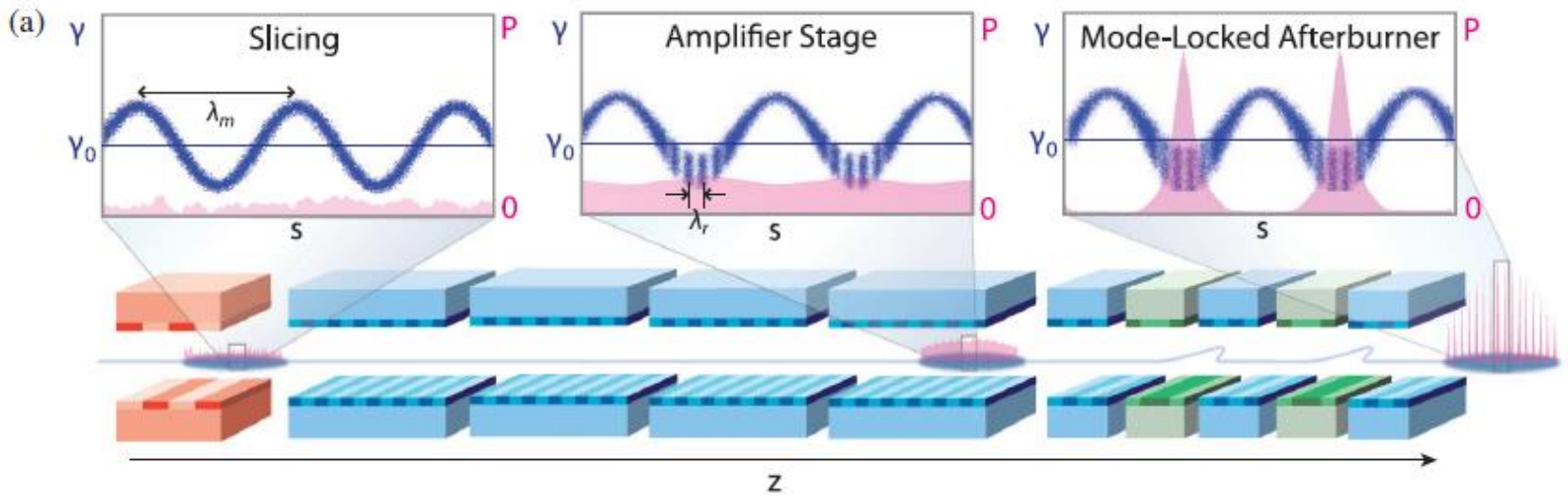
Manchester 1824 The University of Manchester

Science & Technology Facilities Council

University of Strathclyde

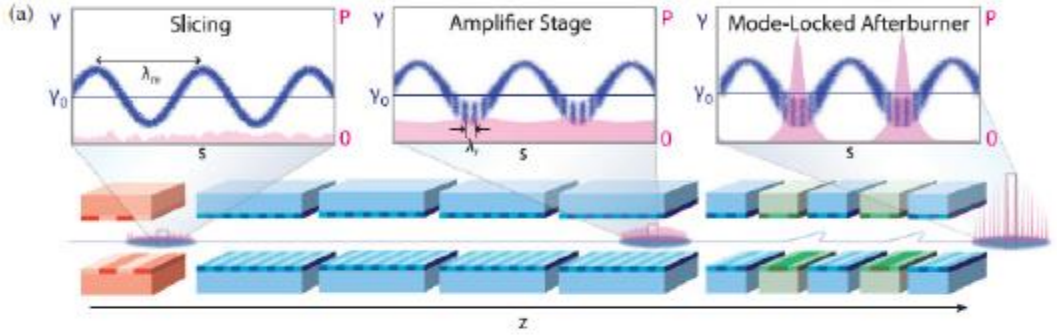
What will CLARA be able to do?

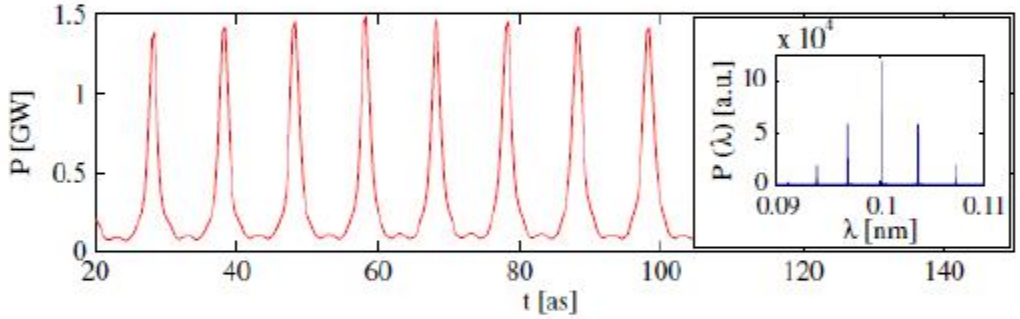
- **Example 2: Generate few cycle pulses**
- Prove that a new idea called **Mode-locked Afterburner** actually works
  - Could then build it in from the start of the UK XFEL
  - Able to probe ever faster processes (down to *sub-attosecond*)



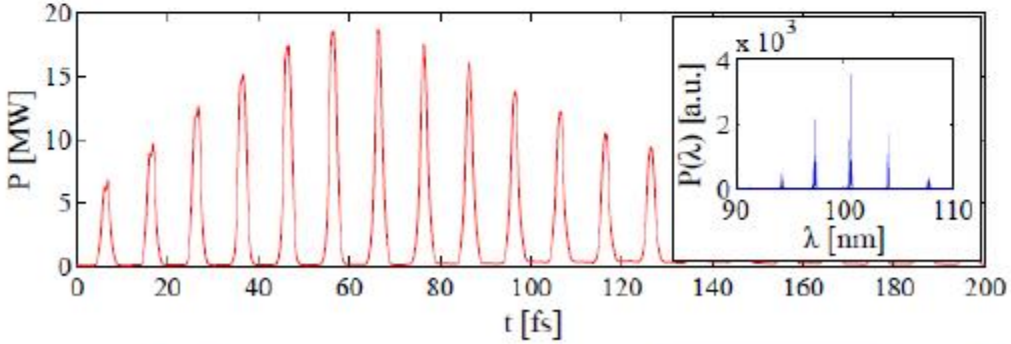
D.J. Dunning, B.W.J. McNeil, & N.R. Thompson
PRL 110, 104801 (2013)

Mode-Locked Afterburner





Hard X-Ray @0.1nm
700zs Pulse Duration (rms)
or 5 cycles FWHM

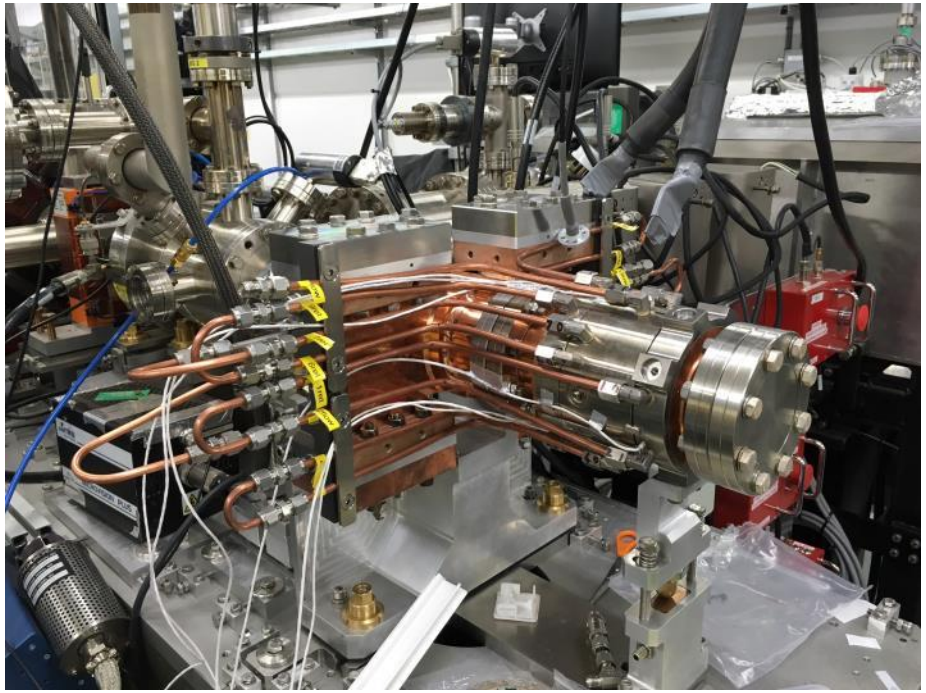


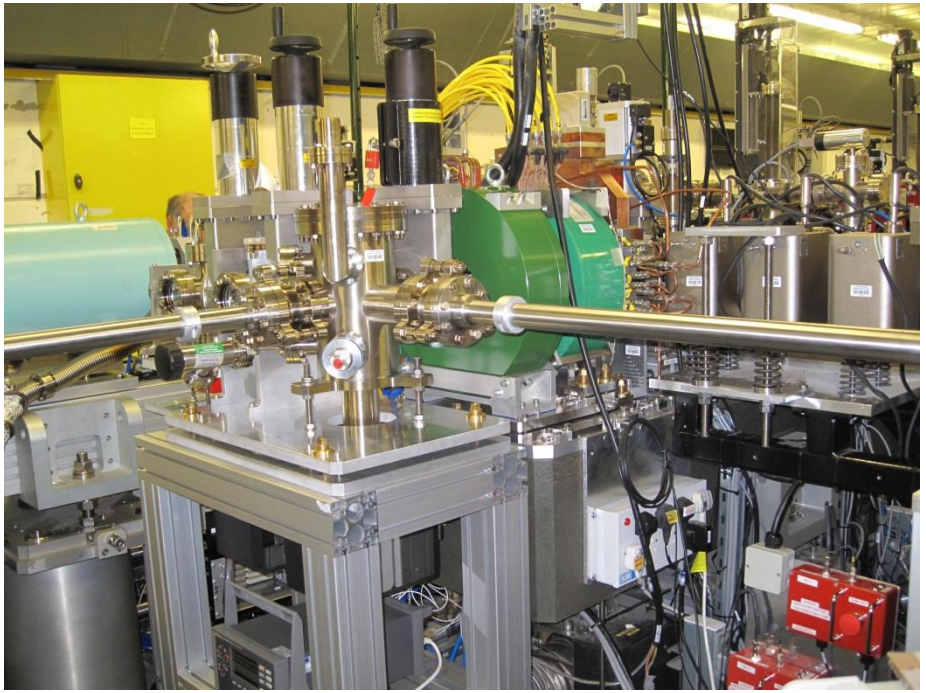
CLARA Parameters @100nm
700as Pulse Duration (rms)
or 5 cycles FWHM SHORT MODE

Slide courtesy Neil Thompson

What will CLARA be able to do?

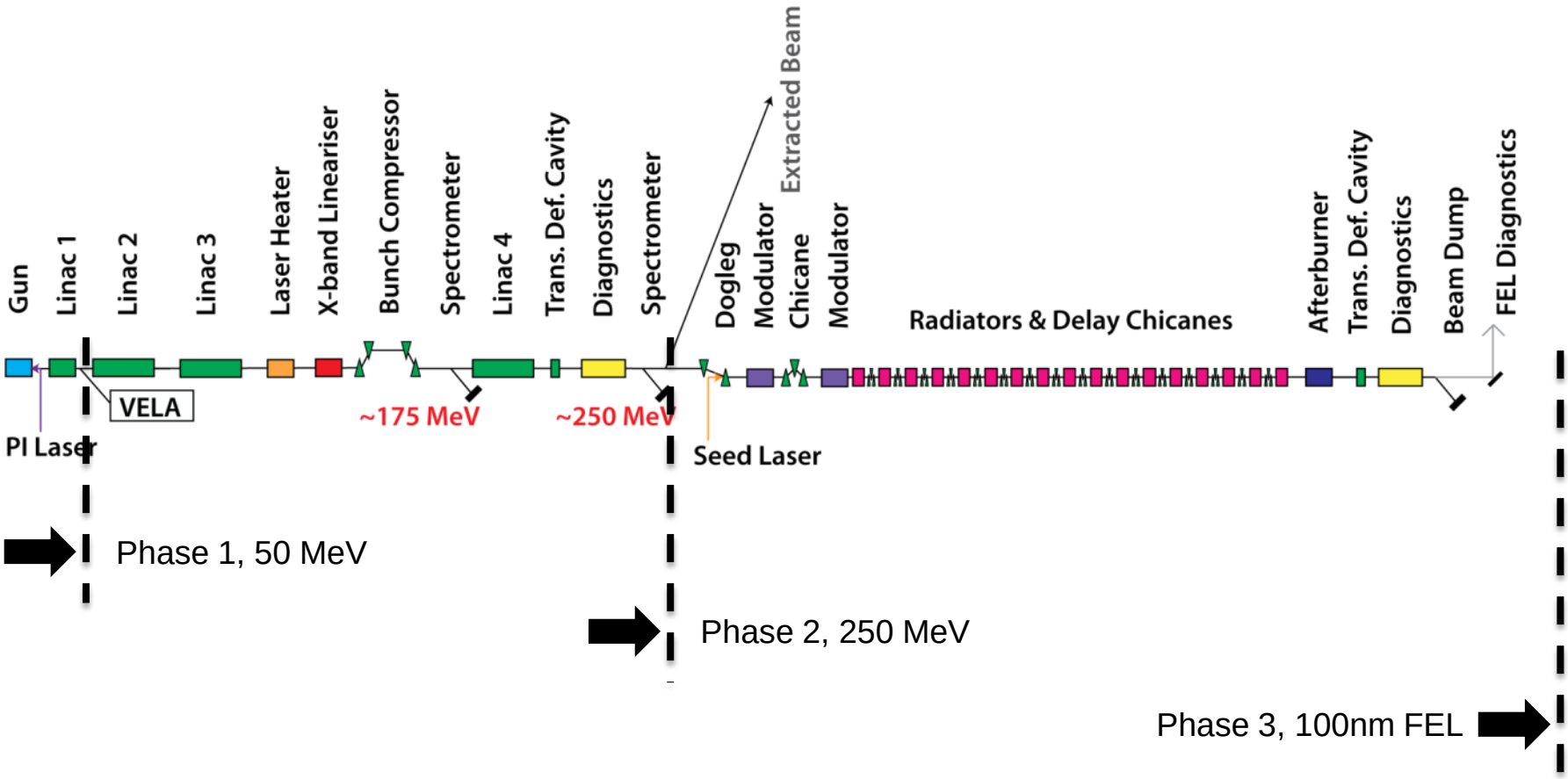
- **Example 3: Prove performance of 400 Hz Photoinjector Prototype**
- 1.5 cell S-band gun with RF probe
- Maximum gradient of 120 MV/m @100 Hz, or 100 MV/m @400 Hz
- 10kW cooling capacity
- Vacuum load lock system for easy replacement of cathode (e.g. Cu, CsTe, …)
- RF conditioning starting next week





CLARA Schematic & Project Phases

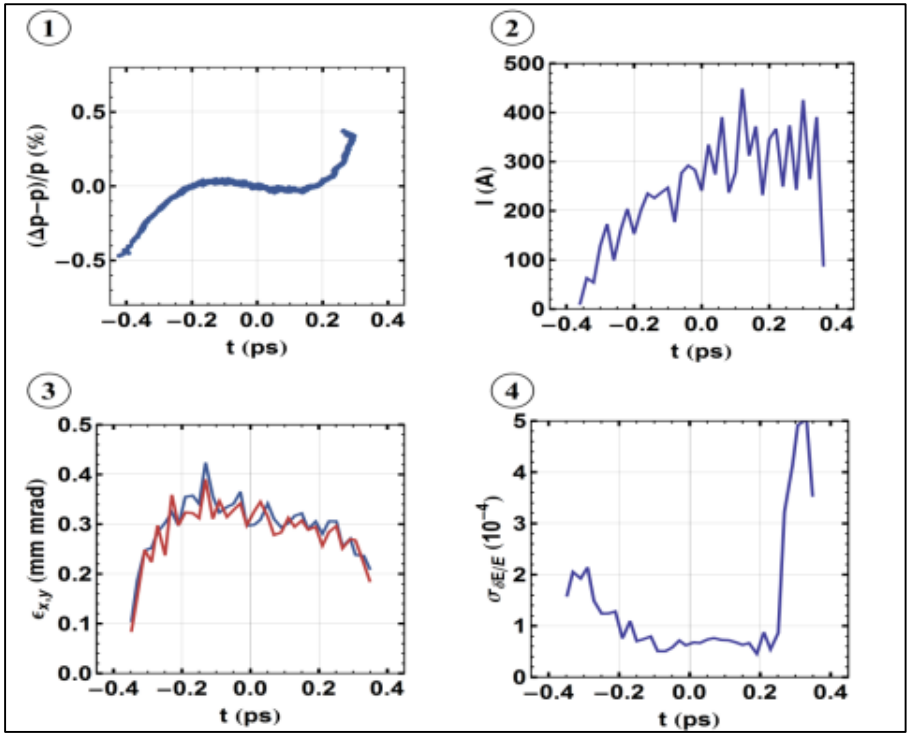
CLARA uses S-band acceleration and deflecting cavities with **X-band linearization**. Simulations show that **Linac 4 could be swapped for X-band** - would be excellent demonstration for FEL community.



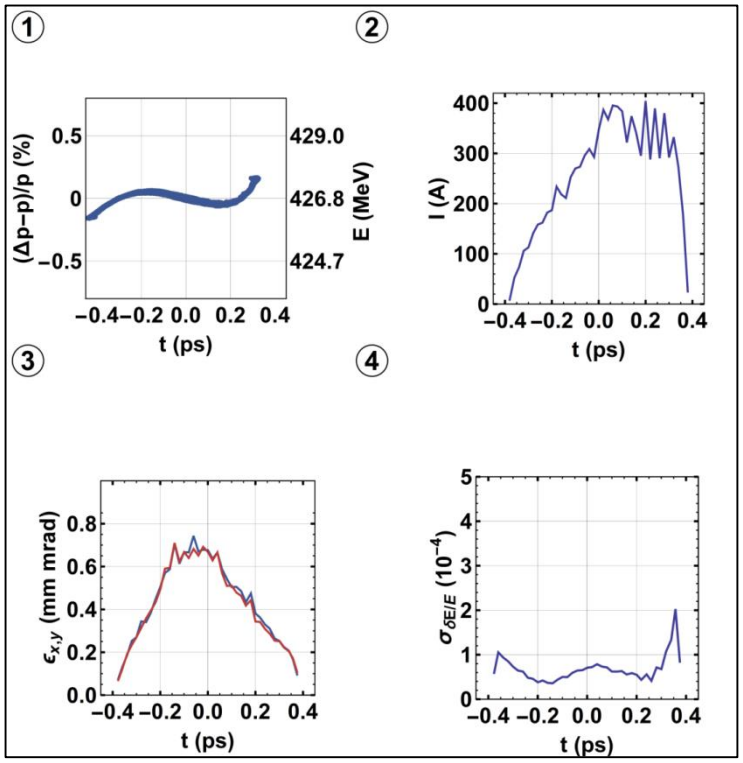
Tracked Bunch - Entrance of FEL

- Simulation of final linac replaced by 4m X-band linac
- No special optimisation, simple replacement in model with 65 MV/m
- Negligible impact on bunch

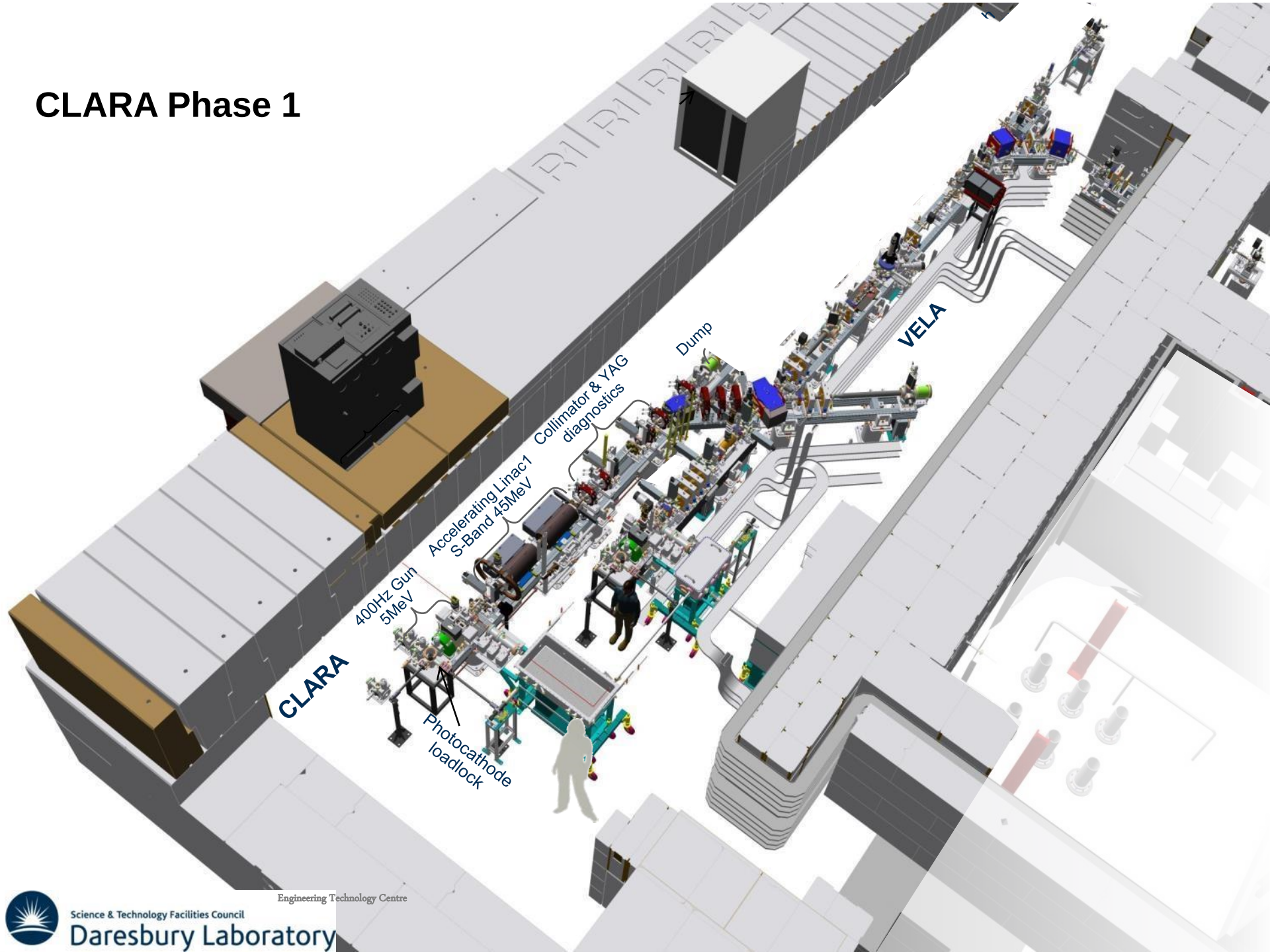
Linacs – SSSS (230MeV)



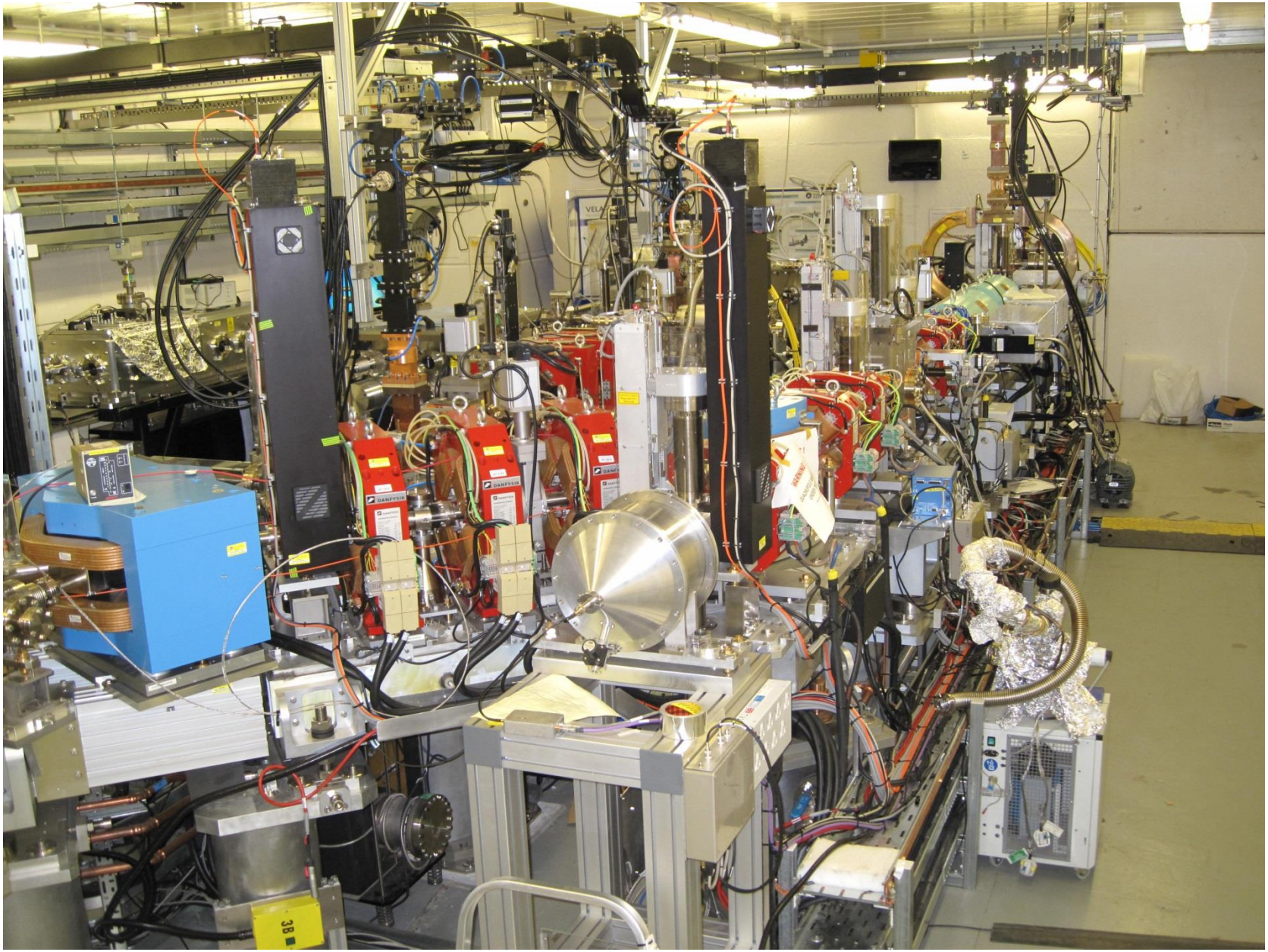
Linacs – SSSX (430MeV)



CLARA Phase 1



CLARA Phase 1



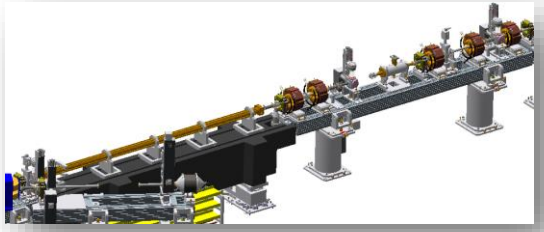
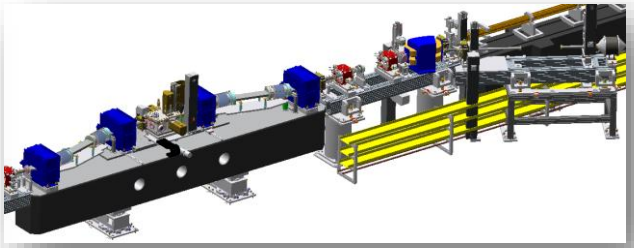
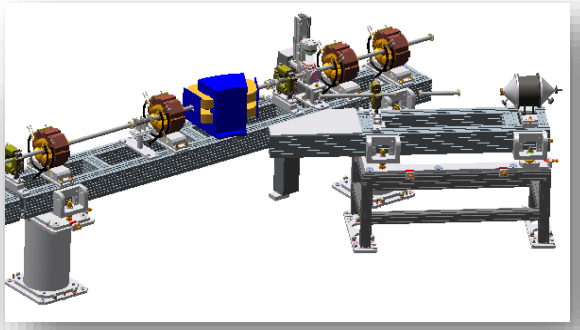
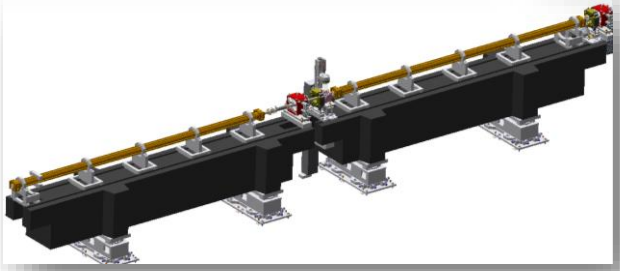
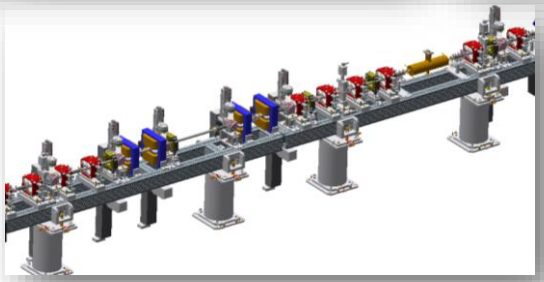
CLARA Phase 1

The Electron Hall

- CLARA is cited within the Electron Hall at Daresbury Laboratory
- The Electron Hall was not fit for purpose so has been completely refurbished
  - For excellent beam stability we need the temperature of the facility to be very stable
  - Previously the temperature within the building varied by at least 15 °C over the year
  - Now the measured variation is less than ±1 °C within the whole building
  - Within the shielded enclosure we routinely achieve better than ±0.05 °C, as required

CLARA Phase 2

- CLARA Phase 2 will complete the accelerator (up to 250MeV)
- Requires a harmonic RF cavity to linearize the phase space – 4th harmonic of 3GHz
- This X-band system is now being investigated (cavity & klystron solutions)
- All of the modules will be built offline in 2017/18 (excluding harmonic cavity and deflecting cavity)
- Construction of remaining shielding enclosure for full facility will also be completed in 17/18

CLARA Status

- ***Phase 1, 50 MeV***
  - Installation complete.
  - Commissioning of both guns has started.
  - Run with beam during 17/18.
- ***Phase 2, 250 MeV***
  - Procurement of all equipment is ongoing.
  - Assembly offline of all modules during 17/18.
  - All shielding assembled by Spring 2018.
- ***Phase 3, 100nm FEL Test Facility***
  - Detailed engineering design stage
  - Procurement of major components to start during 17/18
  - Undulator tender documents being prepared now.

Summary

- The aspiration for a UK XFEL is clear – we are now tasked with technology R&D, and to be prepared to make decisions in ~2020
- The UK accelerator and FEL community has agreed a number of UK XFEL R&D goals
  - Gun development
  - RF Issues
  - Electron Beam Transport Simulation and Optimization
  - FEL Output Simulation and Optimization
  - Diagnostics
  - Synchronisation
  - Undulators

  All are intimately linked to CLARA project
- CLARA is a purpose built dedicated flexible FEL Test Facility at the heart of the FEL R&D programme
  - To develop new methods for improving the quality of the light output from FELs
  - Prove new technologies
  - Develop the UK skill base
  - Lower the financial and technical risks associated with UK XFEL.
  - **We are keen to work with international partners on all aspects of accelerator and FEL technology, including X-band!**
- CLARA Status
  - Phase 1 now being commissioned
  - Procurement of remaining items for CLARA is ongoing
  - Electron Hall refurbishment completed successfully
  - First lasing in 2021

Thanks to everyone who is contributing to the CLARA project