Science & Technology Facilities Council

Towards a UK X-FEL

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IoP PAB Group Annual Conference

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Light Sources

- We have identified an accelerator-driven Free Electron Laser light source as our highest priority for a new accelerator based facility
  - Ultra-bright, coherent x-rays
  - UK participation in the European XFEL in Hamburg as a first step towards a UK FEL
  - CLARA as a technology testbed and development platform
  - Collaboration with SwissFEL

- Complemented by a Diamond Lattice upgrade to maintain the competiveness of our national light source

John Womersley, CEO, STFC, Particle Accelerator Engineering Network meeting, Oct 2015

Priorities

- Maximally exploit our existing investments through accelerator upgrades to maintain the cutting edge (LHC, ISIS, Diamond…)
- An RF accelerator based FEL is our highest priority for a new accelerator based facility
- Require R&D investments and dedicated facilities (CLARA, FETS, MICE) to help to develop and make decisions

- ESS and XFEL are very important new UK commitments but not much scope for involvement in their accelerators
- Place is a consideration – Daresbury is key location for accelerator R&D
- If had to choose between R&D for a European facility and UK-based facility, would prioritise UK-based

John Womersley, CEO, STFC, Particle Accelerator Engineering Network meeting, Oct 2015

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CLARA

- **CLARA will be a purpose built dedicated flexible FEL Test Facility**
  - Capable of testing the most promising new schemes
- **We have strategically decided to focus on *stability*, *synchronisation*, and *new FEL capabilities***
  - We are focussing on ***the longer term capabilities*** of FELs, not just short term incremental improvements
  - Taking FELs into a new regime
  - By demonstrating these goals we will have to tackle all the challenges currently faced by state of the art FELs so we will be very well placed to meet the needs of the UK users when we design and build a national X-ray FEL

CLARA

Compact Linear Accelerator for Research and Applications

An upgrade of the existing VELA Photoinjector Facility at Daresbury Laboratory to a 250MeV Free-Electron Laser Test Facility

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

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

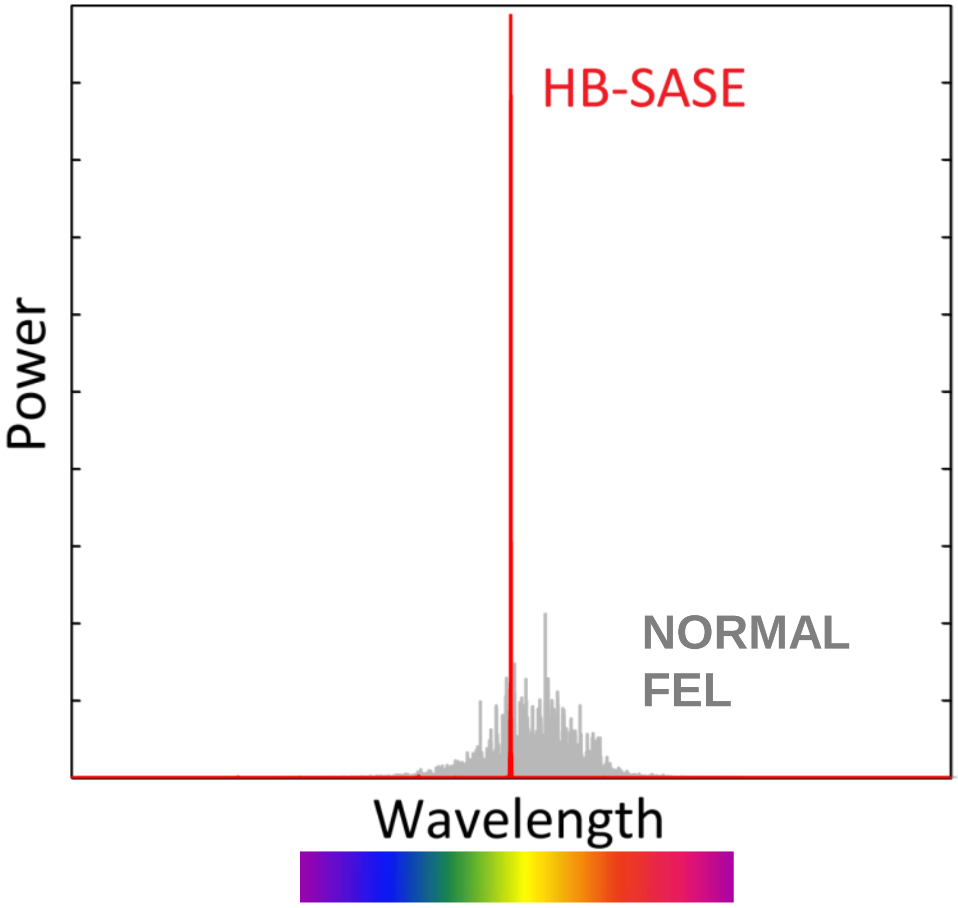
Do any other countries build test facilities?

- Japan built SCSS then SACLA
- Germany built FLASH then European XFEL
- Italy built SPARC then FERMI
- Switzerland built SwissFEL Injector then SwissFEL
- China has built SDUV-FEL and are planning SXFEL test facility
- SCSS & FLASH have now transitioned to user facilities, SwissFEL Injector has been decommissioned
- SPARC and SDUV-FEL are still running as test facilities
- NLCTA in the USA is a test facility that runs alongside LCLS and is informing the design of LCLS-2

What will CLARA be able to do?

- Example: Reducing the spread of wavelengths
- Prove that a new idea called HB-SASE actually works
  - Could then build it in from the start of the UK FEL

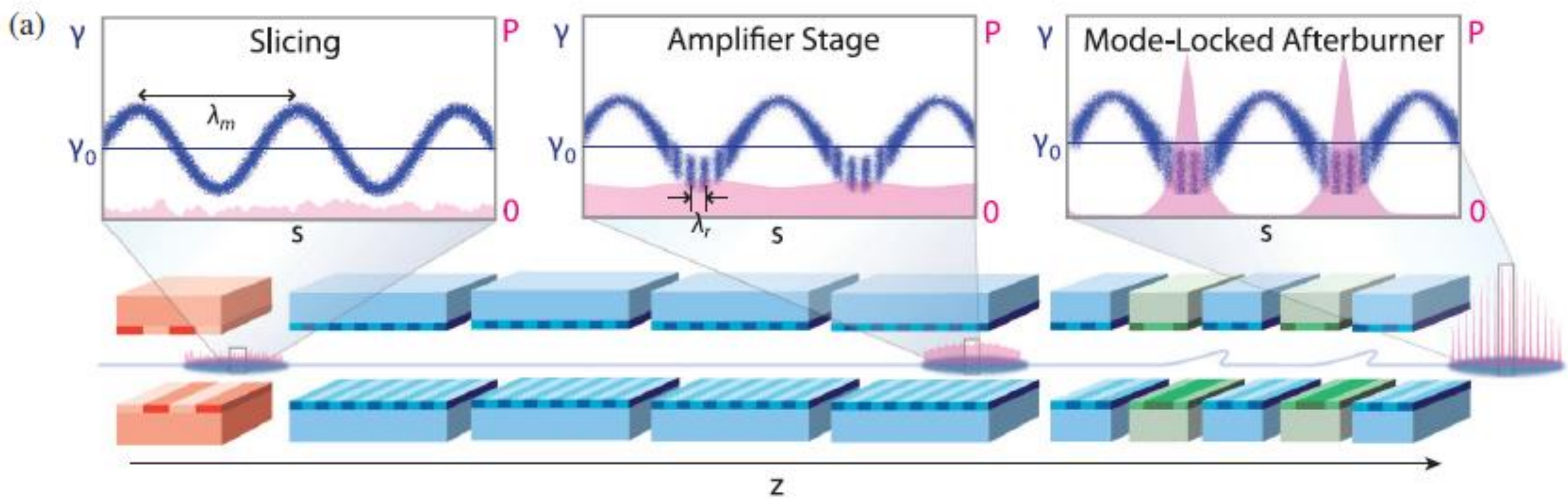
Will work at any wavelength and any repetition rate, no fancy optics required!



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

What will CLARA be able to do?

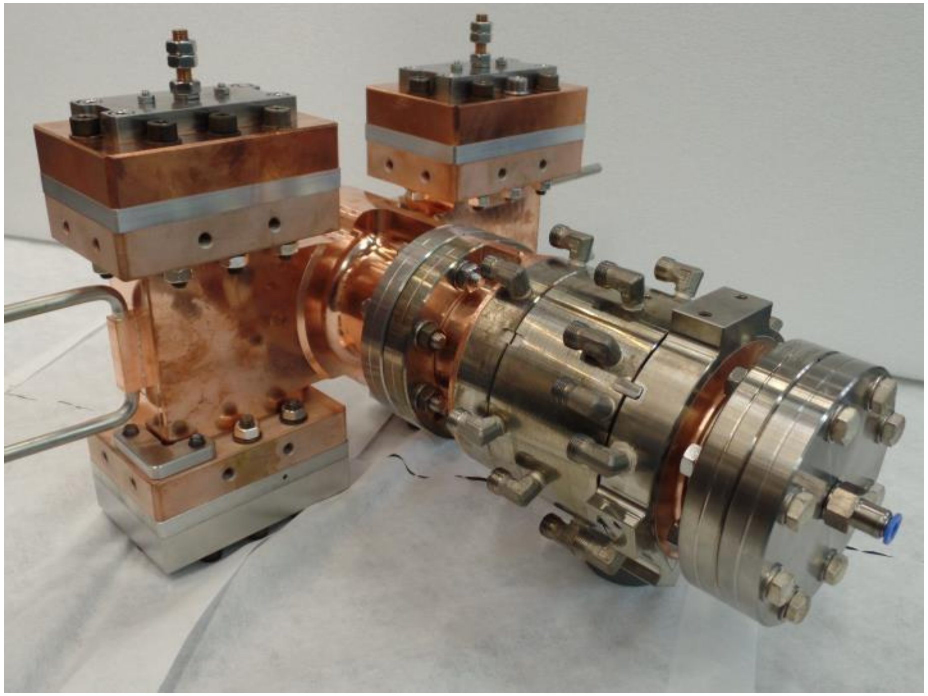
- Example: Generate few cycle pulses
- Prove that a new idea called Mode-locked afterburner actually works
  - Could then build it in from the start of the UK FEL
  - Able to probe ever faster processes (sub-attosecond)

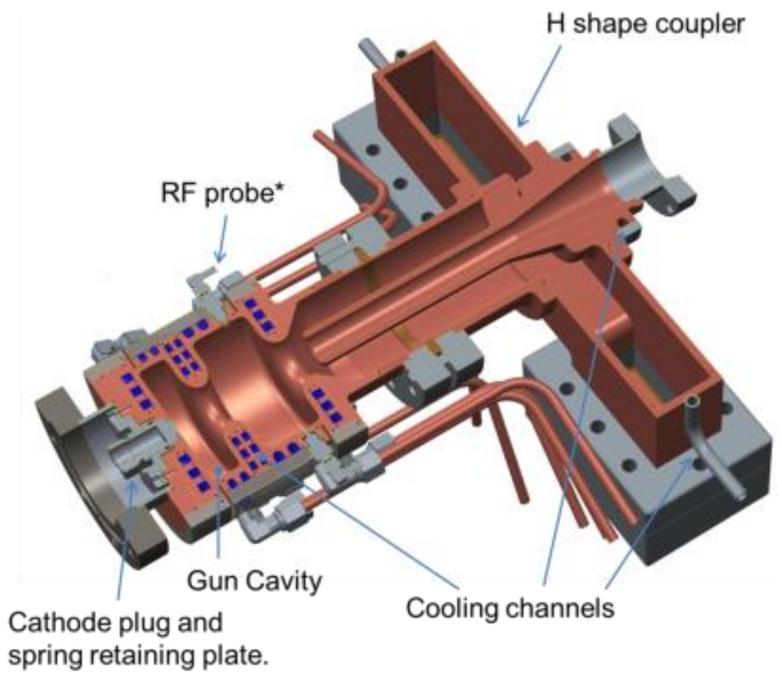


D.J. Dunning, B.W.J. McNeil, & N.R. Thompson
PRL 110, 104801 (2013)

What will CLARA be able to do?

- **Example: Prove performance of 400 Hz Photoinjector Prototype**
- 1.5 cell S-band gun with RF probe designed and fabricated
- 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
- Will be installed April 2016

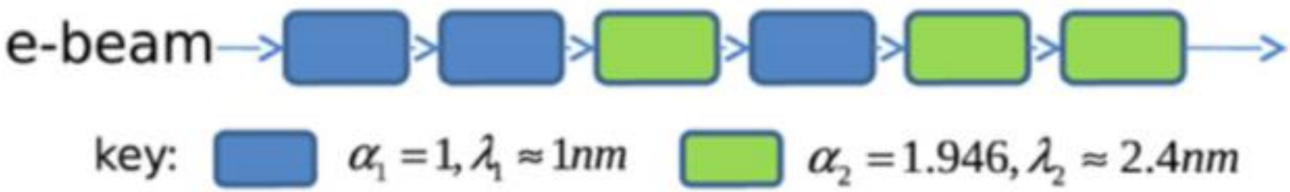




Two-colour free electron laser with wide frequency separation using a single monoenergetic electron beam

L T Campbell[1,2,3,4], **B W J McNeil**[3] **and S Reiche**[5] SwissFEL

New Journal of Physics **16** (2014) 103019



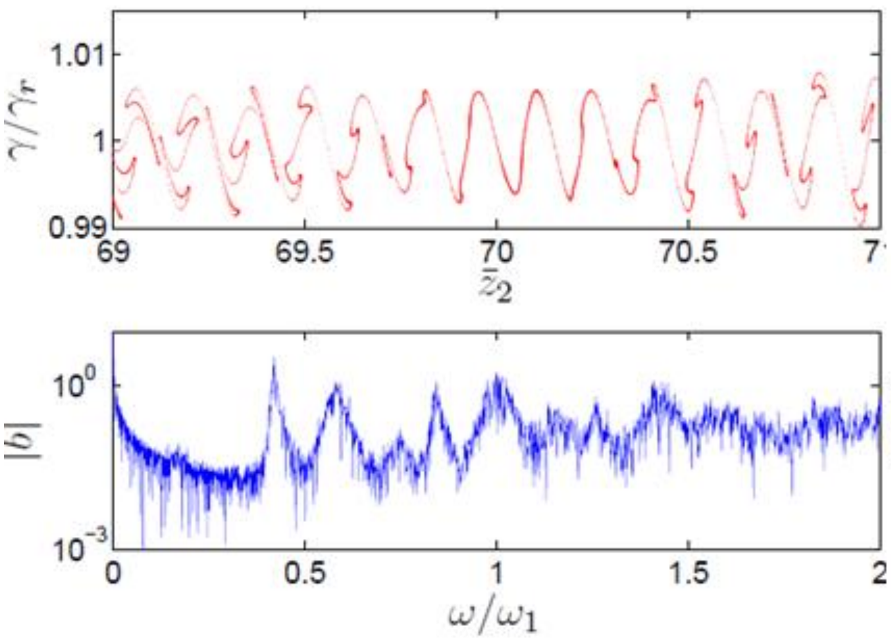


Figure 6. Electron parameters at output of 9^{th} undulator module for SASE Detail of electron phase space between $69 < \bar{z}_2 < 71$ (top); and modulus o spectral bunching parameter $\tilde{b}(\bar{\omega})$ (bottom) at the output of the 9^{th} undulato module at $\bar{z} = 14.12$.

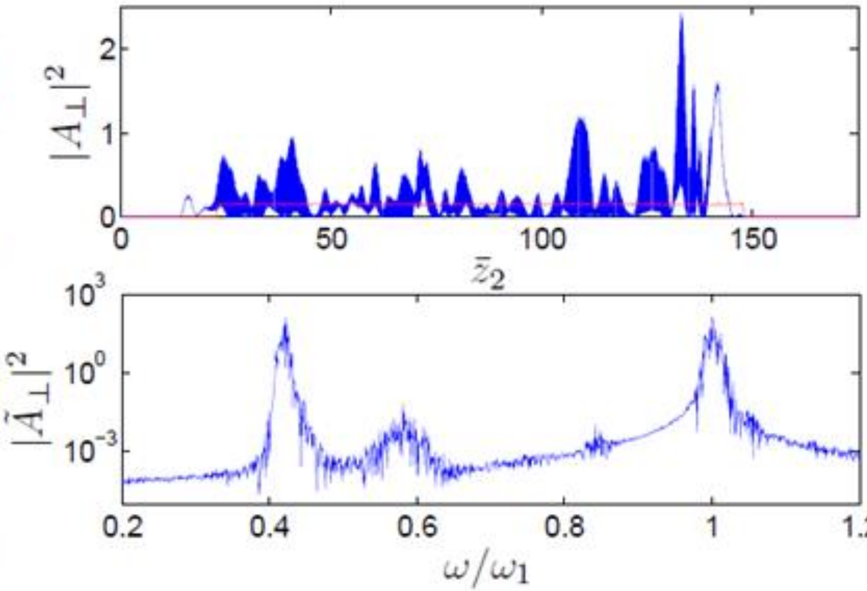


Figure 7. Scaled radiation SASE intensity $|A_\perp|^2$ as a function of the scaled temporal coordinate $\bar{z}_2$ (top) and the scaled spectral intensity $|\tilde{A}_\perp|^2$ (bottom) at the output of the 9^{th} undulator module at $\bar{z} = 14.12$. The red line in the temporal intensity plot indicates the current profile of the electron beam.

Harmonic Lasing in a FEL

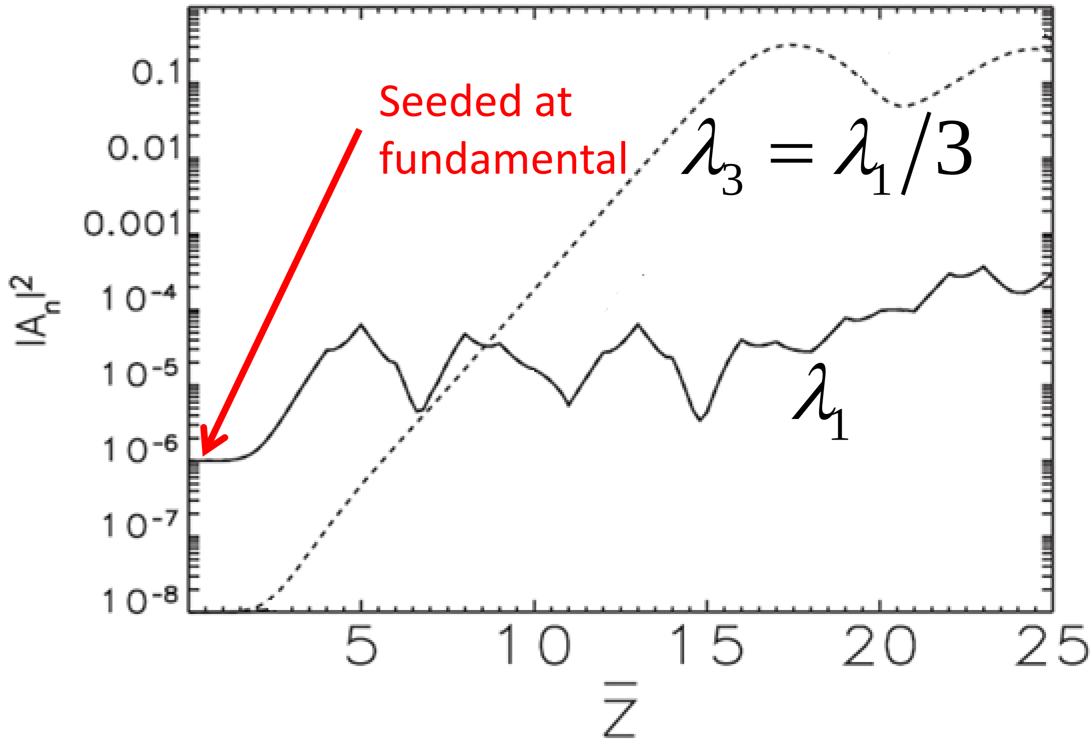
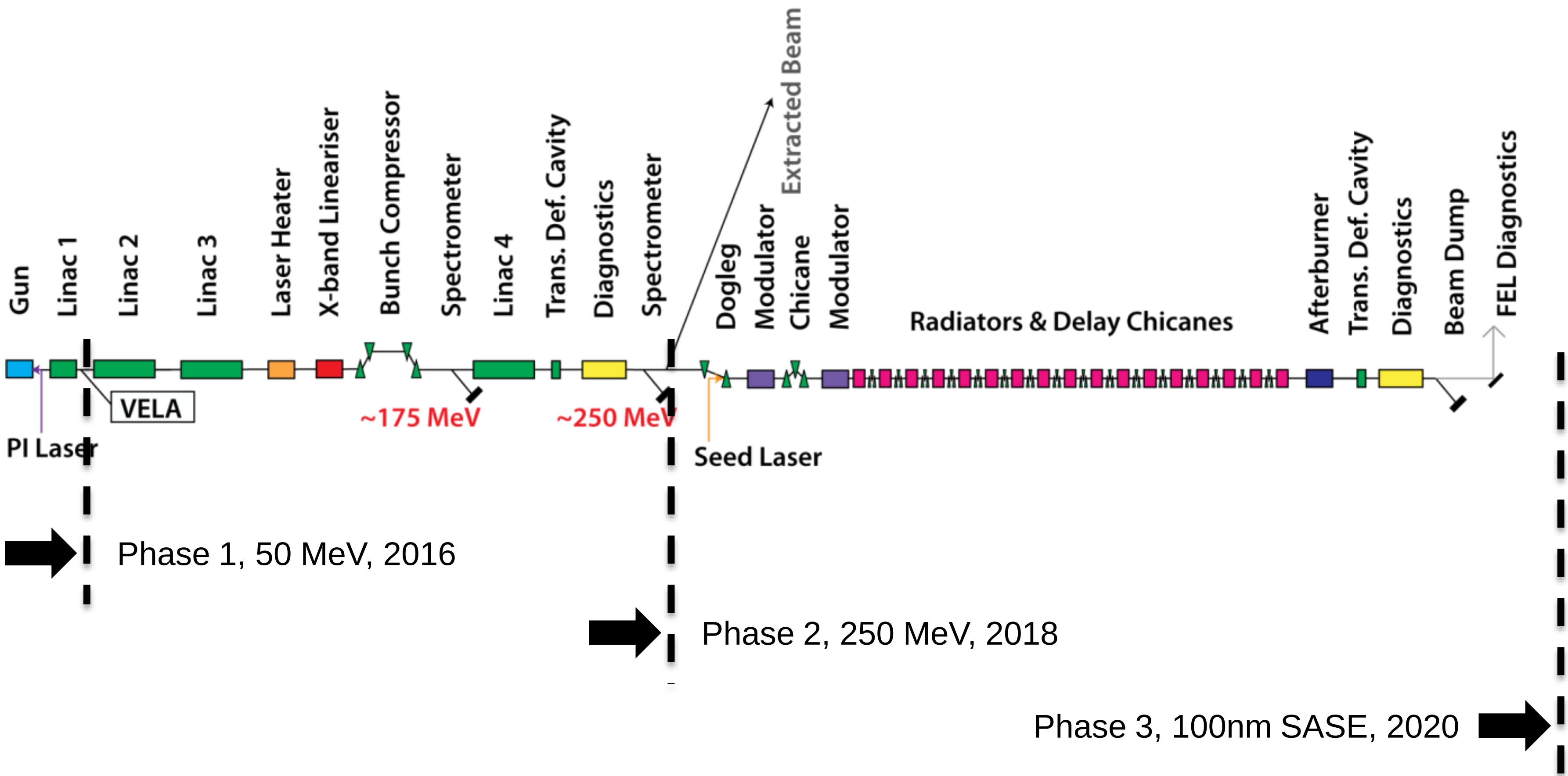


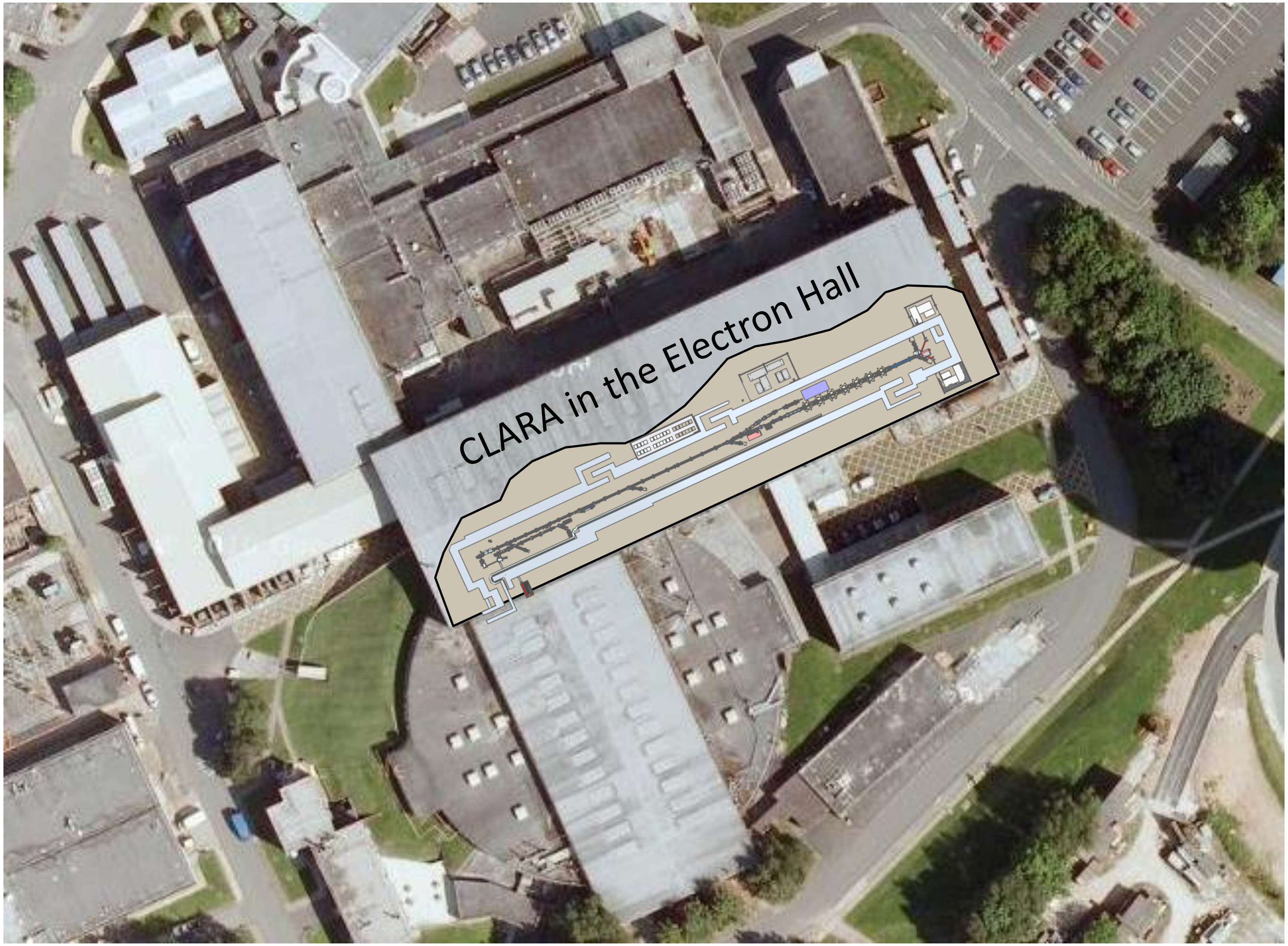
FIG. 2. Scaled powers of fundamental $|A_1|^2$ (solid line) and third harmonic $|A_3|^2$ (dotted line) for wiggler parameter $a_1 = 4$ demonstrating the effects of relative phase changes of $\Delta\theta = 2\pi/3$ at $\bar{z} = 4, 5, 6, \ldots, 24$.

*McNeil, Robb, Poole & Thompson, PRL **96**, 084801 (2006)
Schneidmiller & Yurkov, PRST-AB **15,** 080702 (2012) DESY
Penn, PRST-AB **18**, 060703 (2015) LBNL

CLARA Schematic & Project Phases

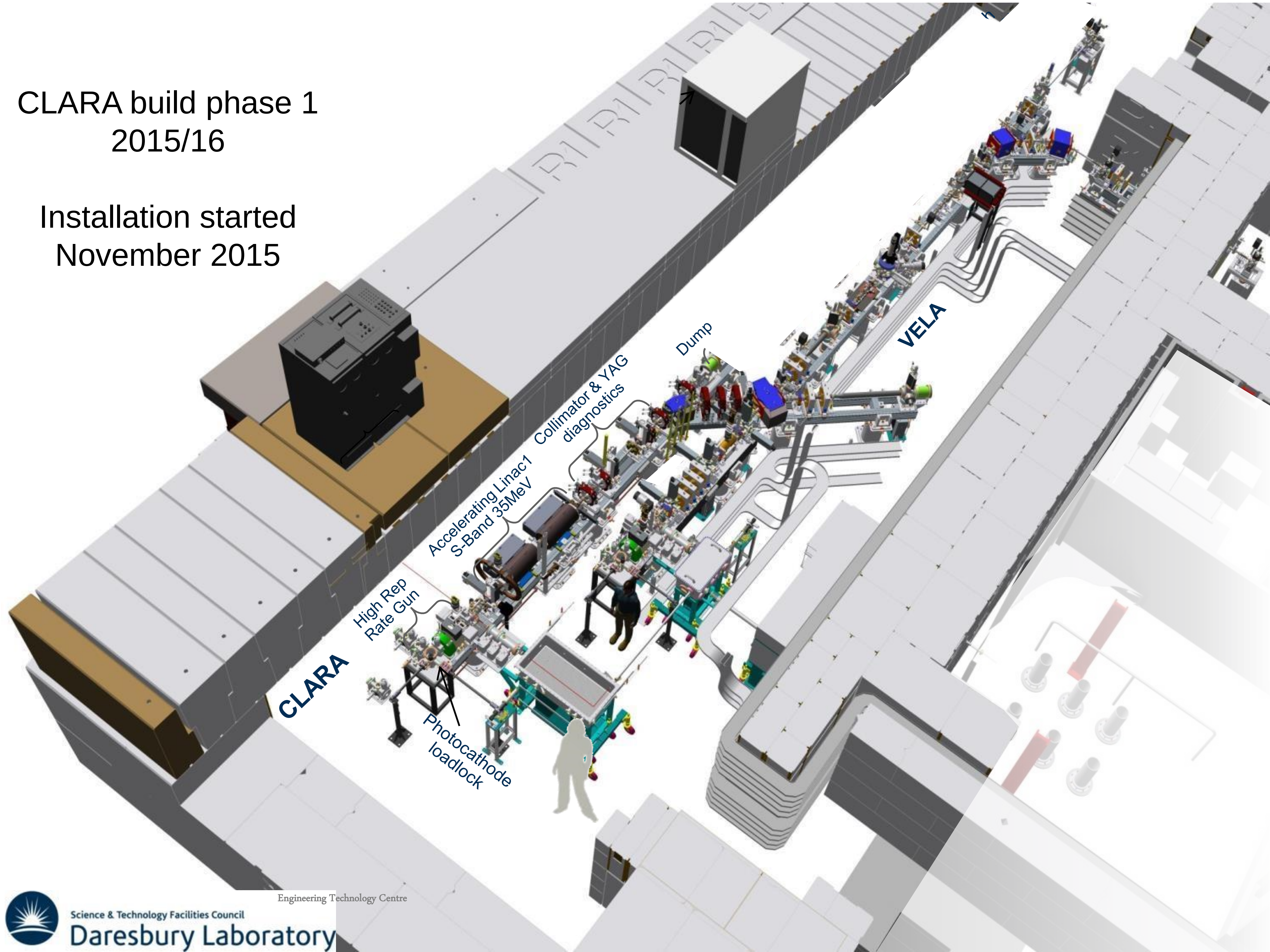


Where is CLARA being built?

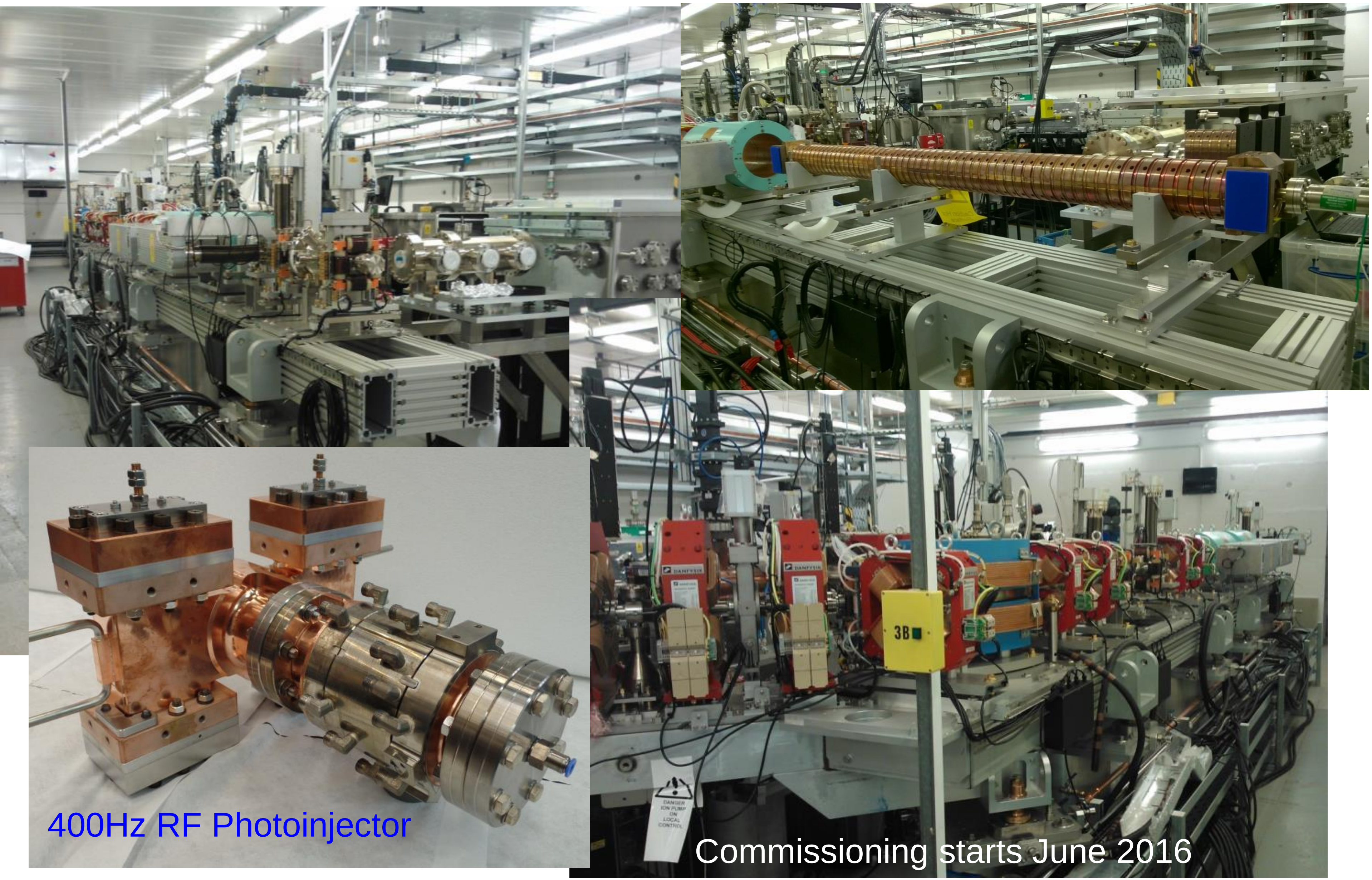

CLARA in the Electron Hall

CLARA build phase 1
2015/16

Installation started
November 2015

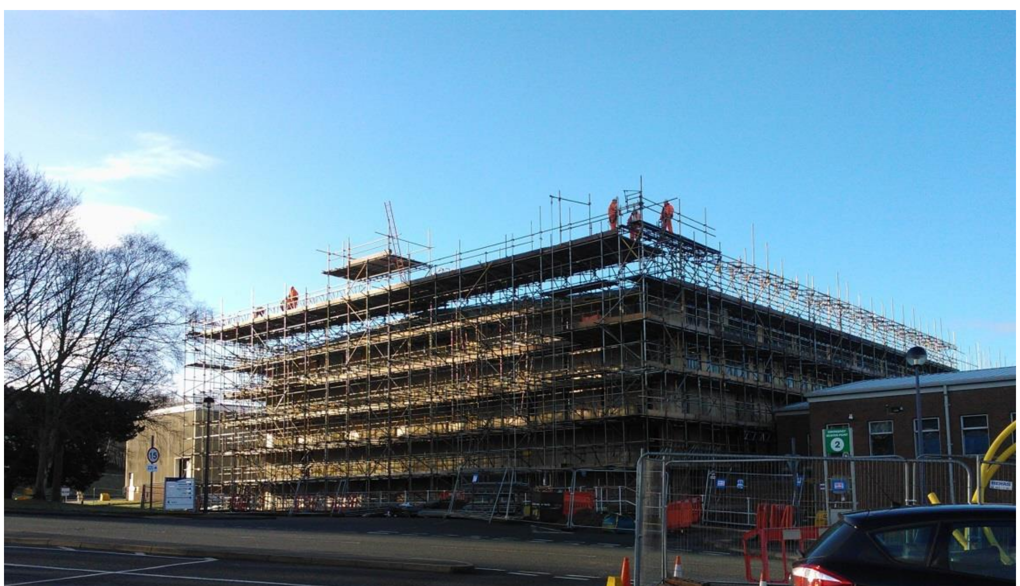


CLARA Phase 1



The Electron Hall

- CLARA is currently being installed in the Electron Hall
- The Electron Hall is not fit for purpose so is being upgraded
  - Since we want to build a very stable FEL, we need the temperature of the facility to also be very stable
  - Currently the temperature within the building varies by at least 15 °C over the year
  - Refurbishment will reduce this to only ±1 °C within the building
  - Within the shielded enclosure it will be ±0.05 °C



UK X-FEL R&D Planning

- The accelerator community is generating a UK FEL R&D 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
- The six goals identified will need to be confirmed after the STFC FEL strategy is published and digested
- The heart of the R&D programme will be 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.

Agreed FEL R&D Goals

*Colour coded to highlight where **CLARA is impacting** on achieving these goals*

#1: Gun development

Optimised electron source:

- designs for minimum emittance at low charge, minimum emittance at high charge etc.

#2: RF

- RF frequency choice
- Low level and high level RF control and stability
- RF structure design & optimisation
- Economic optimisation of accelerating gradient
- Multibunch operation

#3: Electron Beam Transport Simulation and Optimization

Delivering appropriate quality electron bunches at the entrance to the FEL and transporting through the FEL:

- Start to end simulations from cathode to FEL, optimizing performance and stability
- Understanding and mitigating (or potentially exploiting) collective effects such as space charge, wakefields, and CSR
- Alignment and tuning strategies within the FEL
- Beam switching between FELs (slow and fast)

Agreed FEL R&D Goals

#4: FEL Output Simulation and Optimization

Critically examine potential FEL output performance enhancements over current generation of X-ray FELs:

- Achieving the best FEL output stability shot to shot (intensity and wavelength).
- Generation of flexible FEL output pulse structures (eg two colour, two pulse, …).
- Generating ultra-short photon pulses (sub fs).
- Generating transform limited FEL output (time-bandwidth product).
- Other potential enhancements (higher peak power, generating useful high harmonics of fundamental, polarisation control, …)

#5: Electron & Photon Diagnostics

- Bunch (slice) measurements at all charge levels
- Transverse and longitudinal profiles (e.g. cSPR, …)
- Diagnostic for ultra-low charge operation, (cavity BPM)
- Feedback systems (trajectory, optics, energy, charge, …)
- FEL pulse wavelength, pulse length, profile, etc.

#6: Synchronisation

Achieving sub-10 fs synchronisation between the FEL output and an external laser:

- Timing distribution and synchronisation of essential systems.
- Measuring synchronisation level between FEL output and external laser.
- Measuring electron bunch arrival time.
- Minimising electron bunch jitter through passive or active schemes.

Approaches towards a XFEL

PAL XFEL type

adopt existing technology (Linac LCLS, Undulators Eu-XFEL) as much as possible

disavantage: 1100m, high investment and operation cost despite of 60Hz only

advantage: fast

SwissFEL type

R&D program towards facility

disavantage: takes more time & money in preparatory phase

advantage: more advanced and overall cost effective

user input/needs can be better integrated in facility design

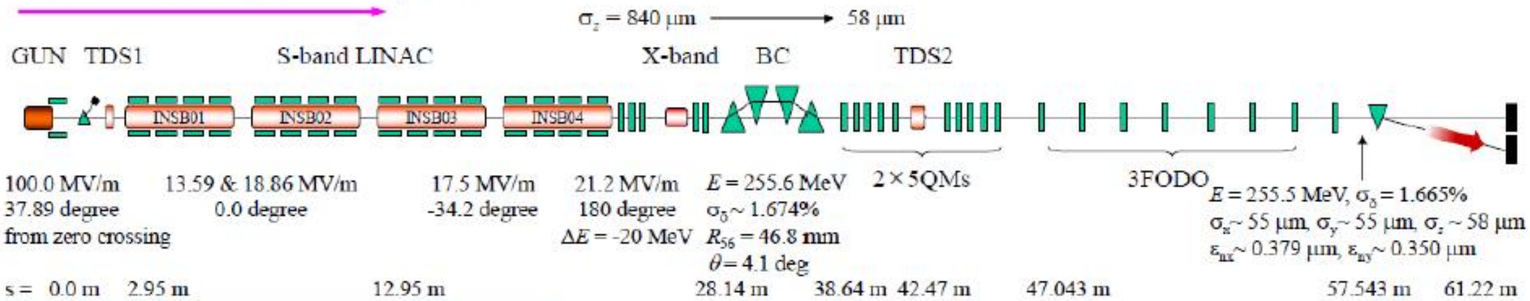
more local competences (institutes & industry) established

SwissFEL Injector Test-Facility

final shut down 13.10.2014

laser beam : $\sigma_{x,y}$ = 270 µm, ΔT = 9.9 ps (FWHM), rise & falling time = 0.7 ps

e-beams : $Q \sim 0.2$ nC, $\varepsilon_{thermal}$ = 0.195 µm, I_{peak} = 22 A



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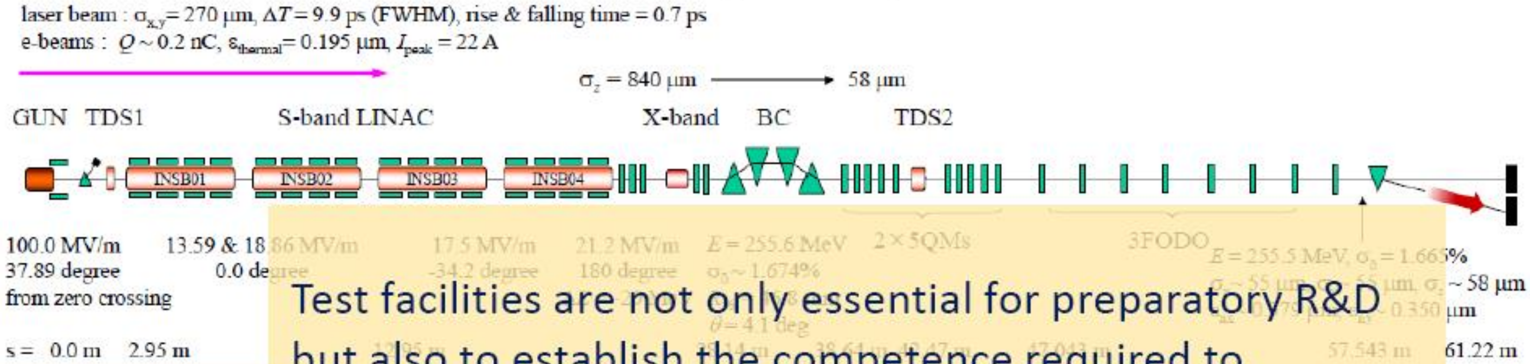
SwissFEL Injector Test-Facility

final shut down 13.10.2014



Test facilities are not only essential for preparatory R&D but also to establish the competence required to design, build, commission and operate state of the art X-FELs in an effective manner

PAUL SCHERRER INSTITUT PSI CLARA

If the UK wants to build an X-FEL with in the near future:

Construction of CLARA as an FEL testbed should get

- a high priority
- a more aggressive schedule
- a test program oriented towards specific features of an UK XFEL
- be realized in a strong collaboration of ASTeC, CI, JAI and Diamond
- work in close coordination with a UK XFEL design team

Goals for FEL related R&D

Support an UK XFEL Collaborative Programme Aimed at Delivering World-class FEL Science within the Next Decade

- UK-XFEL Facility Specification
- Critical FEL R&D Challenges
  - CLARA FEL test facility
- UK XFEL Design, Prototyping and Delivery

Summary

- The STFC aspiration for a UK X-FEL is clear
- The accelerator and FEL community has agreed a number of FEL R&D goals
  - Gun development
  - RF Issues
  - Electron Beam Transport Simulation and Optimization
  - FEL Output Simulation and Optimization
  - Electron & Photon Diagnostics
  - Synchronisation
- CLARA will be at the heart of the FEL R&D programme
  - Front End installation has started
  - Procurement of remaining items for CLARA is ongoing
  - Electron Hall refurbishment is well underway
  - First lasing in 2020
- There is an opportunity for all members of our community to contribute to this exciting application of particle accelerators