UK FEL R&D Plans

Jim Clarke
STFC Daresbury Laboratory & The Cockcroft Institute

IoP PAB/STFC Workshop Towards a UK XFEL
16th February 2016
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  – 4GLS
  – ALICE
  – NLS
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4GLS Key Features

- **Superconducting RF based CW Energy recovery linac**
- **Three FELs**
  - XUV: Single pass HHG seeded (750MeV, kHz)
  - VUV: High gain oscillator RAFeL (550MeV, MHz)
  - IR: Low gain oscillator (25 to 60MeV, MHz)
- Also several spontaneous synchrotron radiation beamlines
- **THz to ~500eV**

2000 Studies commence
2002 Science Case
2003 ALICE test facility funded
2006 CDR published
2008 Project stopped
ALICE Key Features

- **Superconducting RF based Pulsed Energy recovery linac**
- Prototype for 4GLS technology and beam dynamics
- FEL included to disrupt beam (4% energy spread) to test return arc design
  - IR: Low gain oscillator (~30MeV, MHz pulsed)
- **THz and ~5 to 11μm**
- Not used for accelerator R&D since 2014
- Now operated for cancer research, funded by EPSRC
- Mid Range Facility proposal supported by 116 scientists from 59 departments in 33 UK universities, hospitals and companies
- Would expand science research to cover Quantum Technology, Electronic Materials, Catalysis, Dynamics of Non-Crystalline Systems, as well as ongoing cancer studies

2003 ALICE test facility funded
2010 First lasing of IR FEL
2011 First proof of principle experiments
2014 ScanCan grant awarded by EPSRC
2016 Mid Range Facility Proposal
NLS Key Features

• **Superconducting RF based Linac, 2.25GeV**

• Three FELs
  - Single pass HHG seeded cascade (50 – 300eV, MHz)
  - Single pass HHG seeded cascade (250 – 850eV, MHz)
  - Single pass HHG seeded cascade (430 – 1000eV, MHz)

• **THz to 1keV (with harmonics to 5keV)**

2008 Studies commence
2009 Science Case & Outline Facility Design
2010 CDR published
2010 Project put on hold
SwissFEL

• 2011 MoU Signed and Work Packages agreed
  – Collimator System for ARAMIS
  – Self-seeding and Afterburner for the hard X-ray FEL Aramis
  – EPICS Control Software
  – Construction of laser heater undulator
  – Two-colour FEL Modelling
  – Mode locked FEL Modelling

• 2016/17 Assistance with SwissFEL commissioning (accelerator and FEL)
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 goals identified will need to 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.
- An important aspect of the programme will be strong connections to potential user community and working groups on lasers, optics, detectors, beamline & endstation layout, science case, UK-XFEL Hub etc.
# FEL R&D Goals
*(can map to work-packages)*

**Common slide 1 of 3**

*Outcome of the meeting of accelerator experts 28 Jan 2016*

#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)
#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 (e.g. 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.
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!

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
CLARA will be able to lase between 100nm and 400nm
CLARA Layout

Linac 1 is 2m long, S-band from Research Instruments

Linacs 2 to 4 are 4m long S-band devices provided by SwissFEL

Can replace Linac 4 with X-band linac as test bed for this technology
Where is CLARA being built?
CLARA build phase 1
2015/16

Installation started
November 2015
CLARA Phase 1
The Electron Hall

- The biggest building on site (34m x 110m)
  - Big enough for CLARA (which is about 10m x 90m)
- But the Electron Hall was 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
CLARA Gantt Chart
FEL R&D Goals

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

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FEL R&D Plan Next Steps

- Iterate the proposed plan once the STFC FEL Strategy is published
- Establish a management and coordination structure
- Scope out plan in detail (tasks, resources, timescales, people)
- Review and Implement
Summary

- The UK has experience of several FEL design studies and one operating oscillator FEL
  - The NLS design was established quickly due to the previous FEL design experience of the teams involved
- The accelerator and FEL community has generated 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 but not yet fully funded
  - Electron Hall refurbishment has started
  - First lasing in 2020
- The proposed R&D programme will be iterated once the FEL Strategy becomes clear