Science and Technology Facilities Council

Lancaster University

UK XFEL and FEL test facilities

Louise Cowie

Accelerator Science and Technology Centre
Science and technology Facilities Council, UKRI, UK

IOP PAB Annual Meeting, 30 September 2020

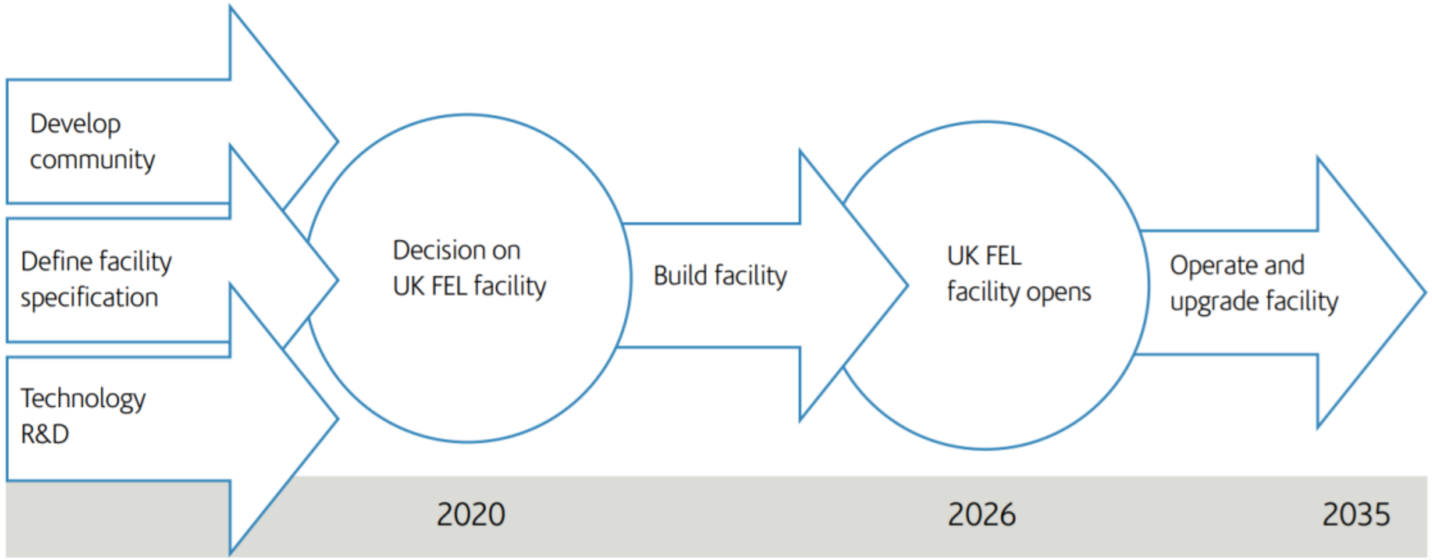
Outline

- UK XFEL introduction and timeline
- CLARA as a test facility
- XARA proposal and benefits as a test facility

UK XFEL

An X-ray Free Electron Laser built in the UK to enable the UK science community to tackle emerging scientific and societal challenges

Science case released July 2020.

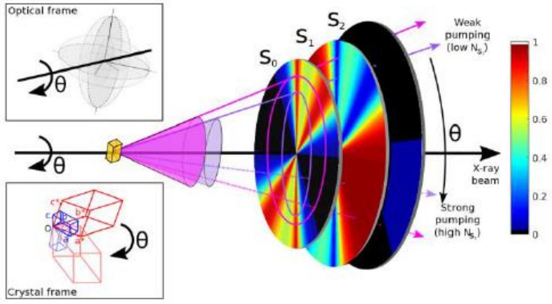


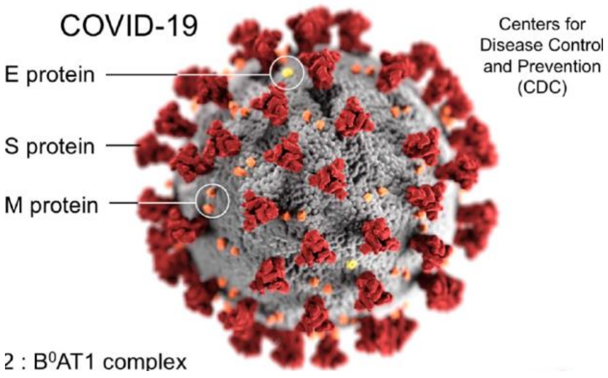
Science and Technology Facilities Council

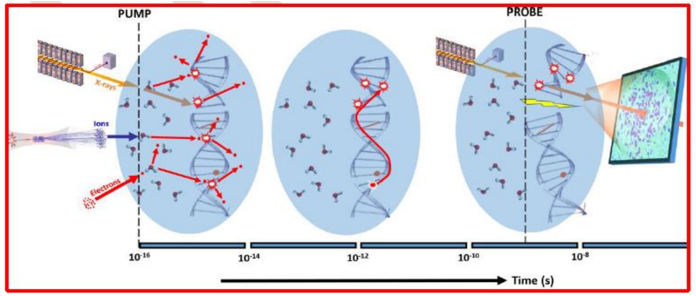
Science case

- Physics and X-ray photonics
- Matter in extreme conditions
- Quantum and nanomaterials
- Chemical sciences and energy
- Life sciences
- UK industry, society and defence

Controlled X-rays and samples will extend the power of serial femtosecond nanocrystallography for advancing knowledge and drug discovery







Ultrafast X-rays probe attosecond electron dynamics, radiation damage of materials & biomolecules & elementary processes in chemical reactions

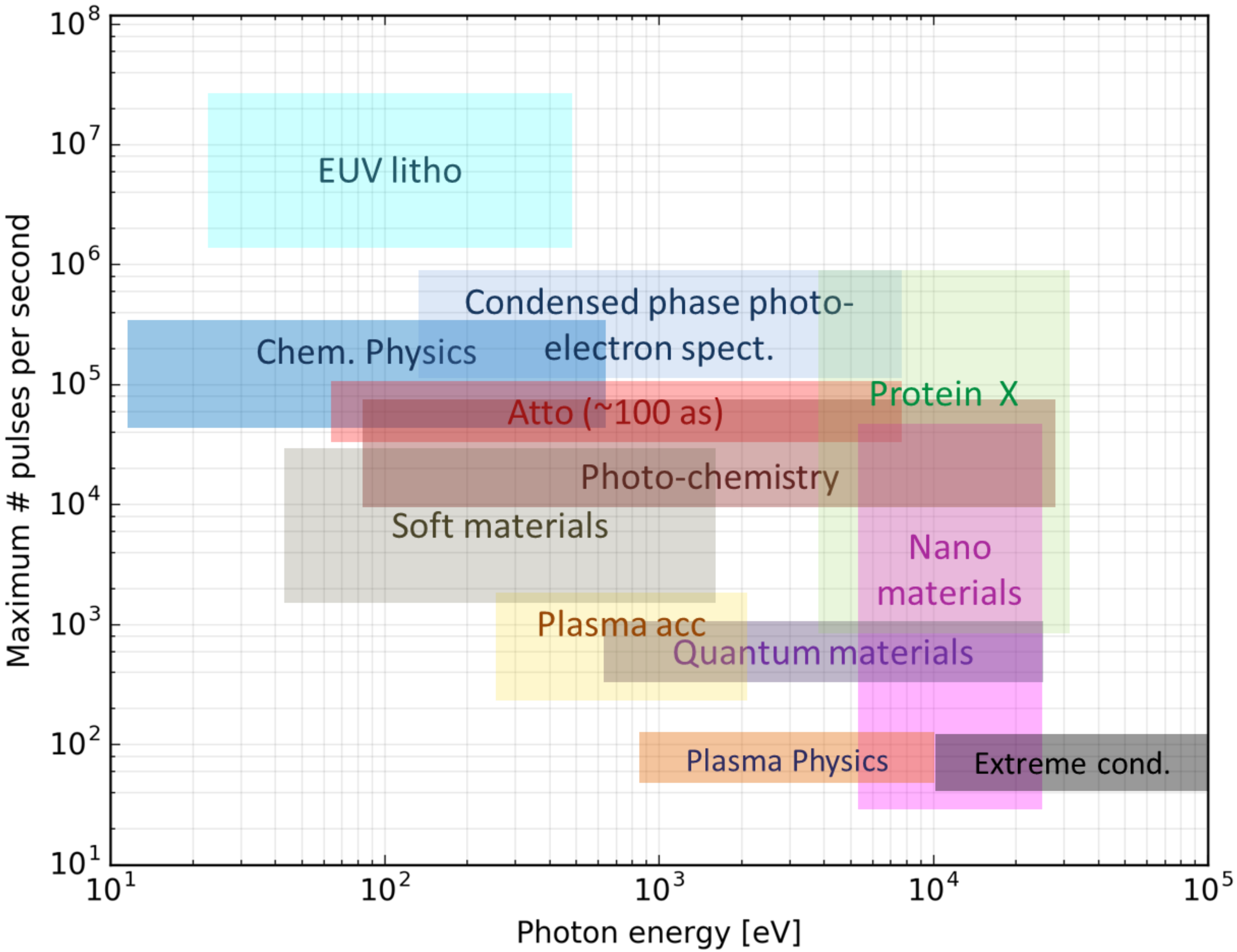
Science and Technology Facilities Council

Facility X-ray requirements

- Soft and hard X-rays at up to MHz repetition rate
- Very hard X-rays with high pulse energy (at lower repetition rate)
- High power EUV/gamma source (multi-MHz repetition rate)

+

- Reproducibility, high spectral purity and control of other pulse properties
- Attosecond pulses at all photon energies, synchronised to external sources
- Multi-colour modes and combination between sources



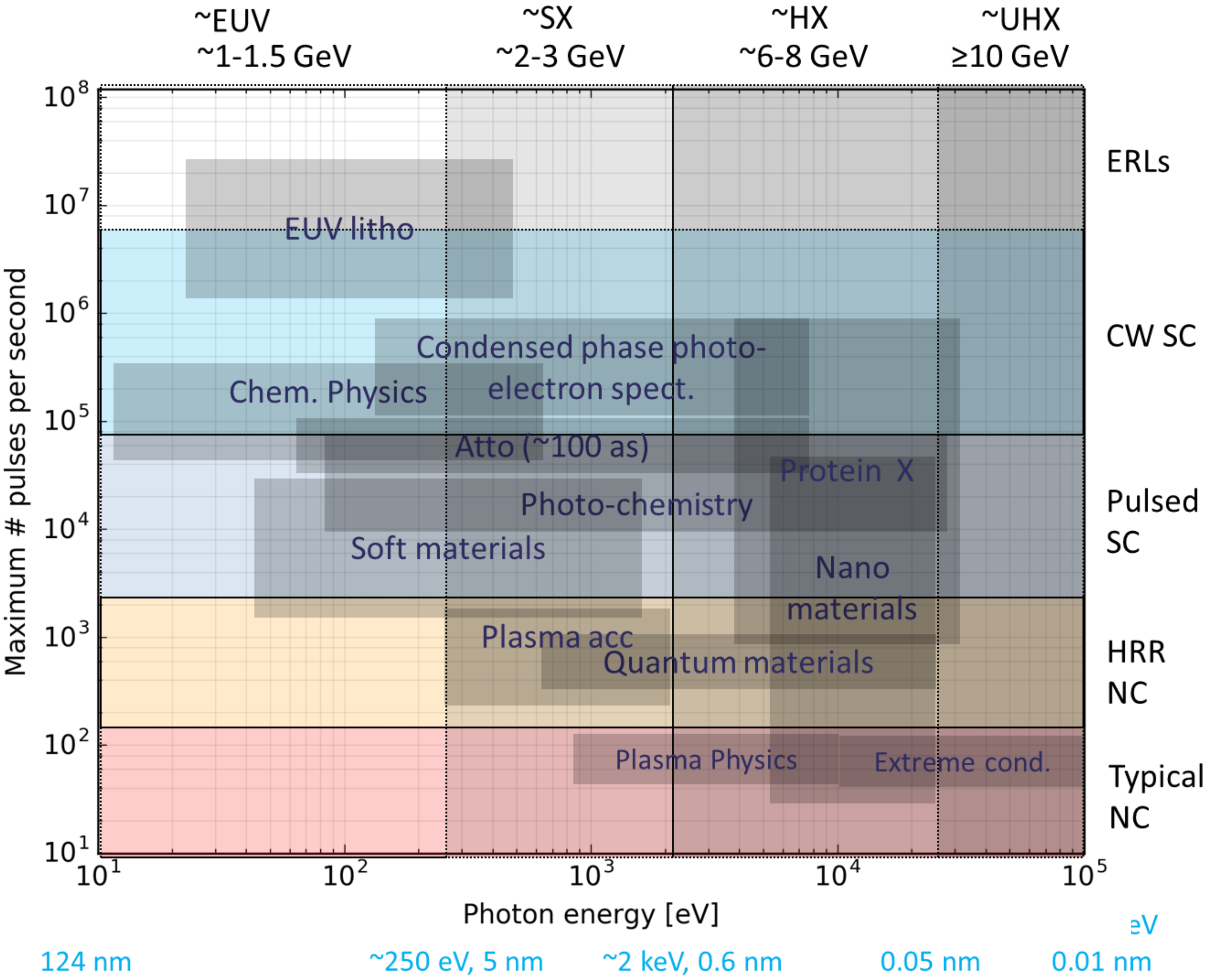
Overlay

Overlaying the science requirements with the facility considerations suggests that:

- SC ~essential for SX
- SC ideal for HX
- NC well suited to VHX

\+

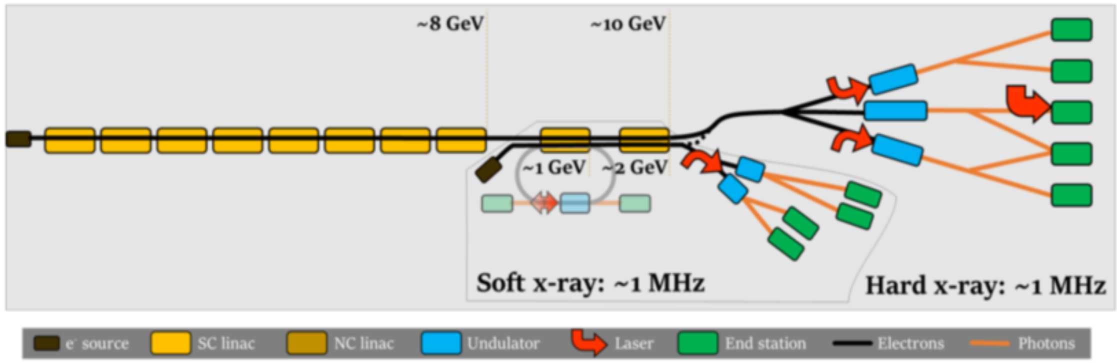
- ERL for EUV?

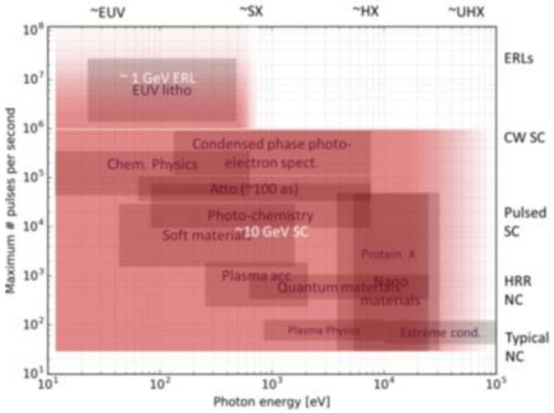


Science and Technology Facilities Counci

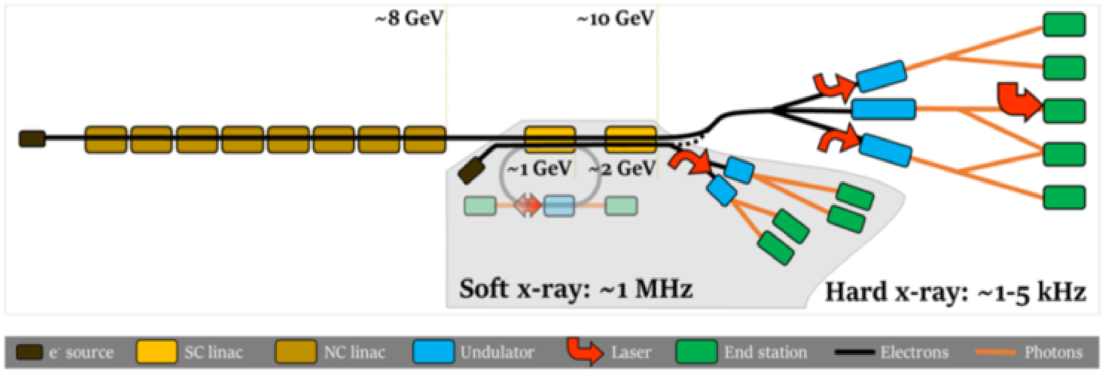
Reference Science Case Concepts

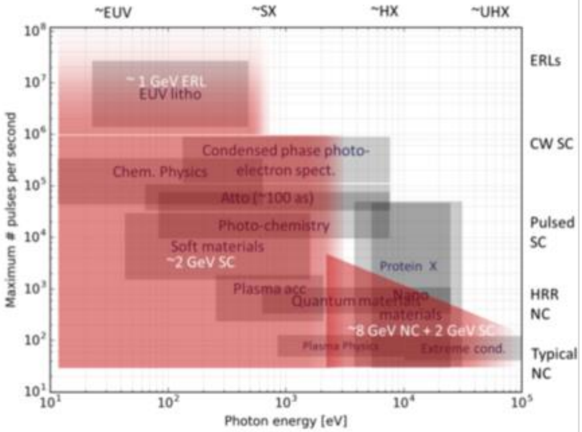
Concept outline 1: Superconducting accelerator



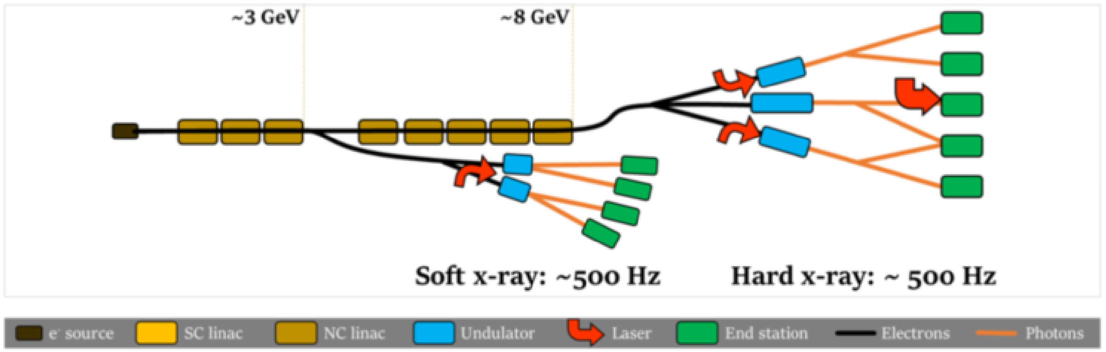


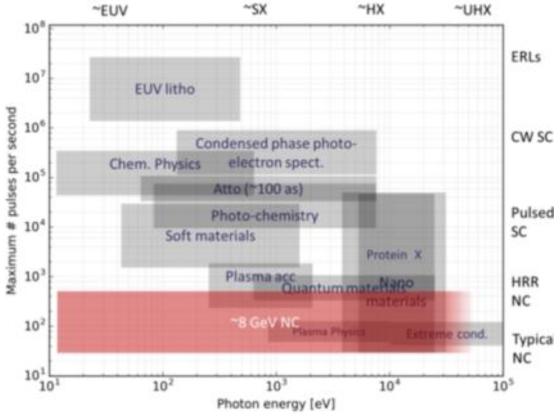
Concept outline 2: Hybrid accelerator





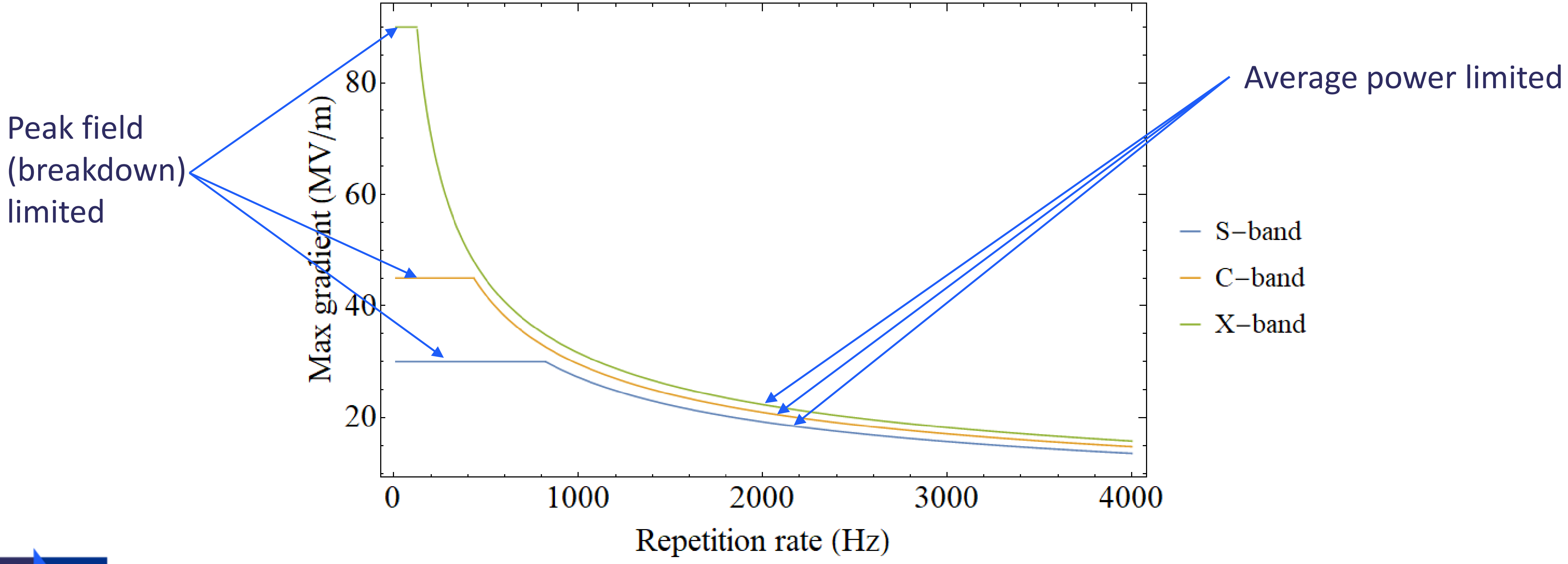
Concept outline 3: Normal conducting accelerator





NCRF gradient

Extrapolated gradients of current high average power structures



Science and Technology Facilities Council

A long term view

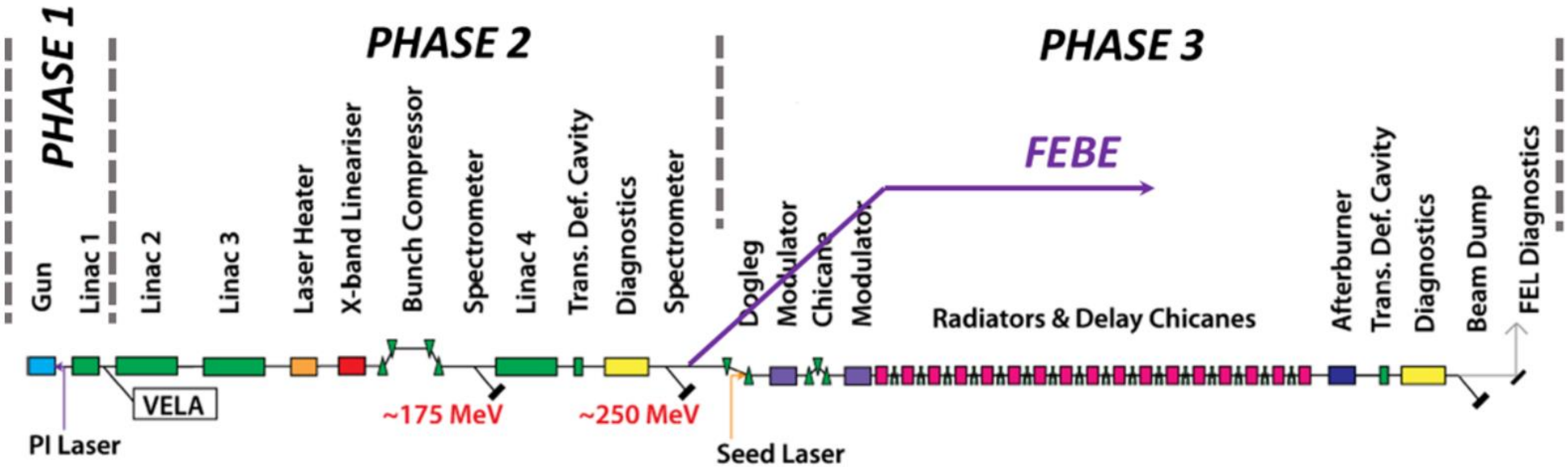
Emerging technologies we are considering:

- High repetition rate NCRF
- Permanent magnets
- Fast ferroelectric SRF cavity tuners
- New FEL schemes (XFELO, HB-SASE, direct X-ray seeding…)
- High repetition rate injectors
- Helical SC undulators

The takeaway: R&D required!

Science and Technology Facilities Council

CLARA



- S-band linear acceleration up to 250 MeV
- Bunch charge 20-250 pC
- High repetition rate up to 400 Hz
- Electron bunch lengths 250-850 fs
- FEL wavelengths in the UV
- Phase 2 shutdown in 2022 will include FEBE line

CLARA as a test bed for a UK FEL

A dedicated facility for testing FEL schemes:

- Ultra short photon pulse generation
- Increasing FEL output intensity stability, wavelength stability and longitudinal coherence
- Higher harmonics of a seed source

Accelerator technology development

- Very bright (in 6D) electron bunch generation
- High repetition rate NCRF technology
- Timing and synchronization
- Short pulse diagnostics
- Infrastructure

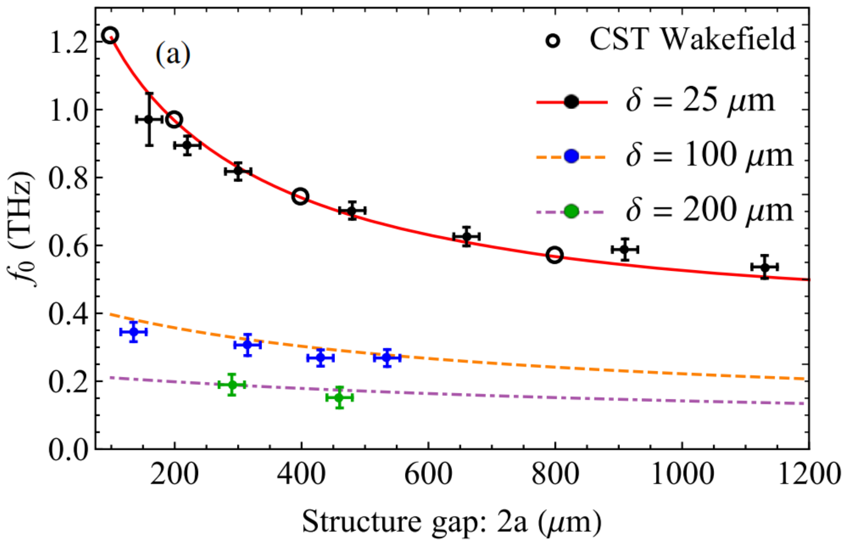
UKRI Science and Technology Facilities Council

CLARA front end exploitation

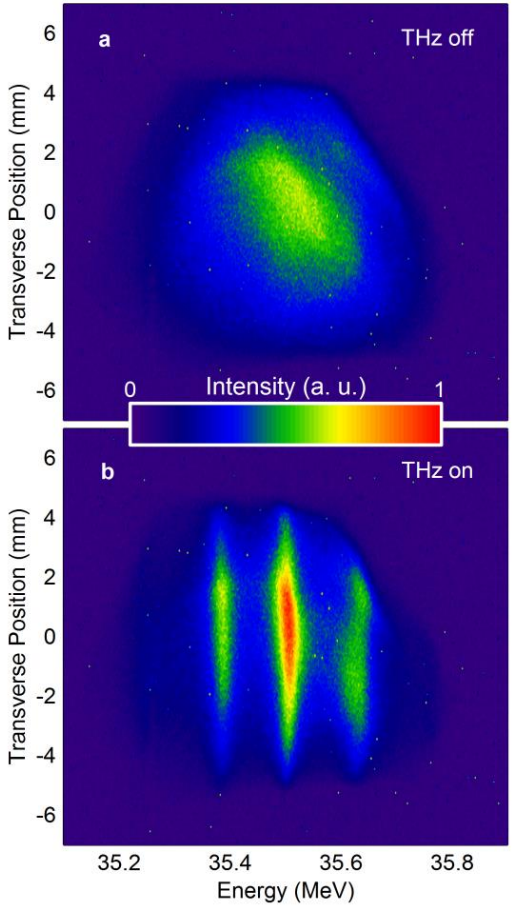
12 experiments completed in 2018/19 covering:

- Novel acceleration techniques
- Accelerator systems development
- Medical physics applications

First demonstration of continuously tunable THz generation with dielectric wakefield structure
T. Pacey et al.
PRAB 22, 091302, 2019



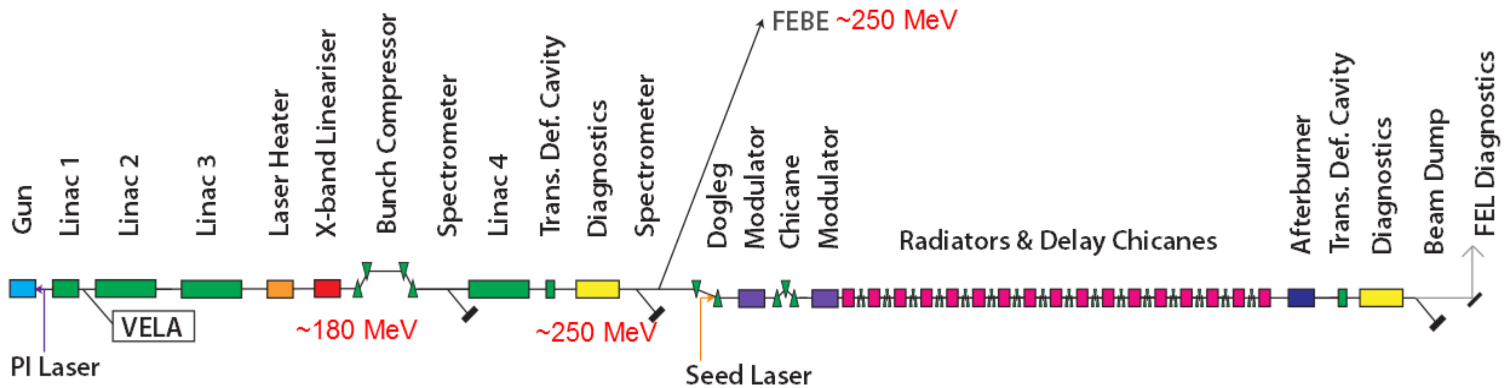
THz-driven Manipulation of Relativistic Electron Beams
M. Hibberd et al.
Nature Photonics, 10.08.2020

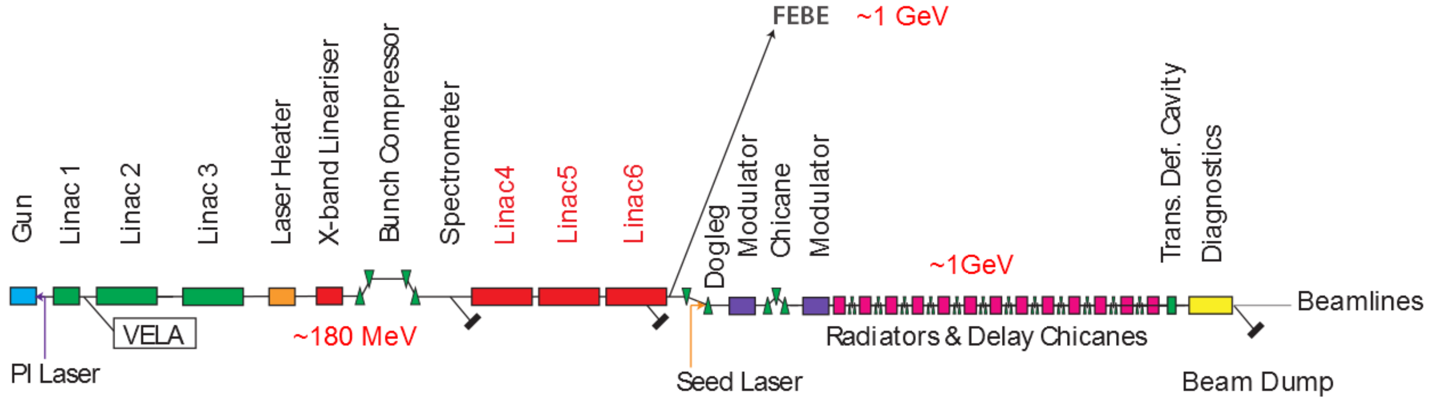


Science and Technology Facilities Council

Upgrade proposal: XARA

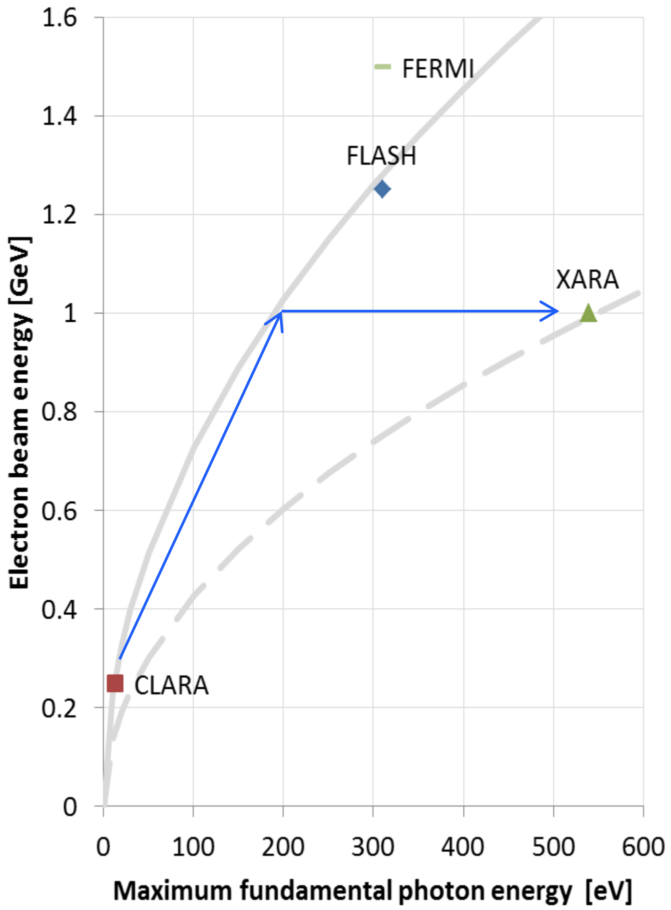
- X-band Accelerator for Research and Applications
- Inexpensive upgrade to CLARA
- The 4th CLARA linac is replaced by an X-band accelerating section to reach 1 GeV
- Novel FEL technology
- An EUV/soft x-ray FEL facility for ultra fast chemistry and biology, and a centre of accelerator R&D.





Photon energy range

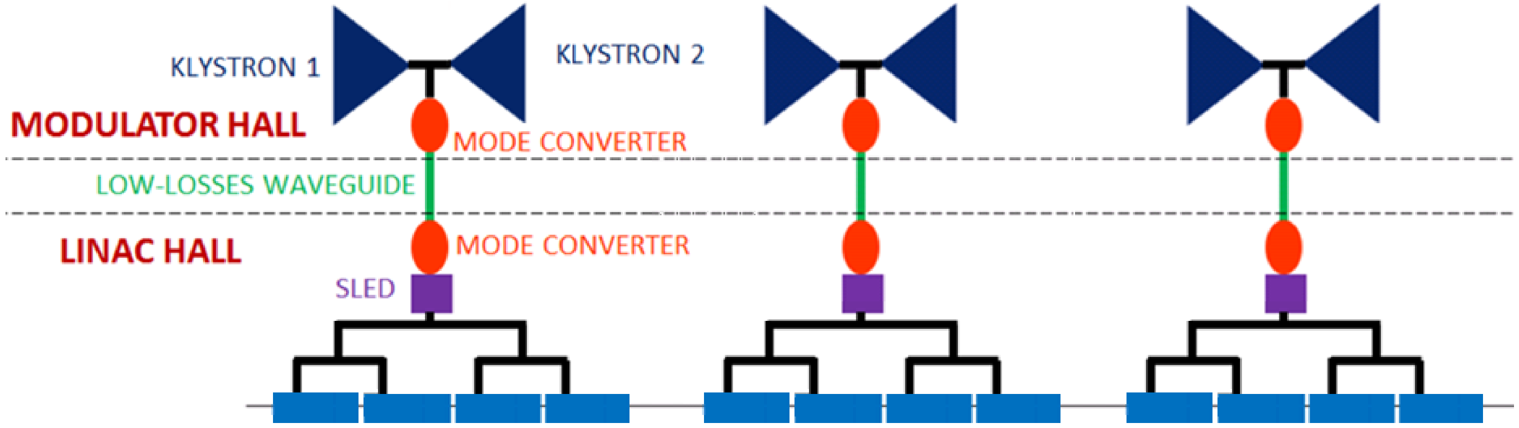
- The photon energy of FEL radiation is proportional to the electron beam energy squared.
- CLARA at 250 MeV was designed for a shortest wavelength of 100 nm (12.4 eV)
- Increasing to 1GeV would therefore give a factor of 16 change to 6 nm (200 eV)
- Utilising more ambitious undulator technology would allow a significant further reduction, potentially as far as ~2.3 nm (540 eV), so as to cover the ‘water-window’ region of particular scientific interest.



Science and Technology Facilities Council

X-band linac

- Based on EuPRAXIA@SPARC_LAB/CompactLight/Electrons into SPS RF module
- 4 x 1 m 80 MV/m x-band cavities per module
- 3 modules
- Could be used at lower gradients to achieve longer pulse lengths



M. Diomede et al 2014, NIMA Vol. 909

Science and Technology Facilities Council

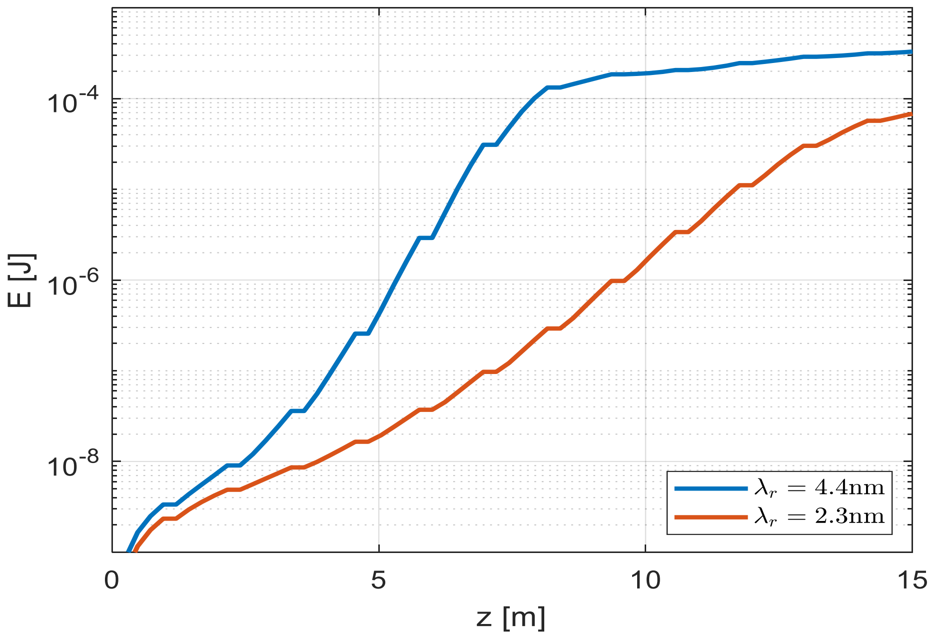
FEL options

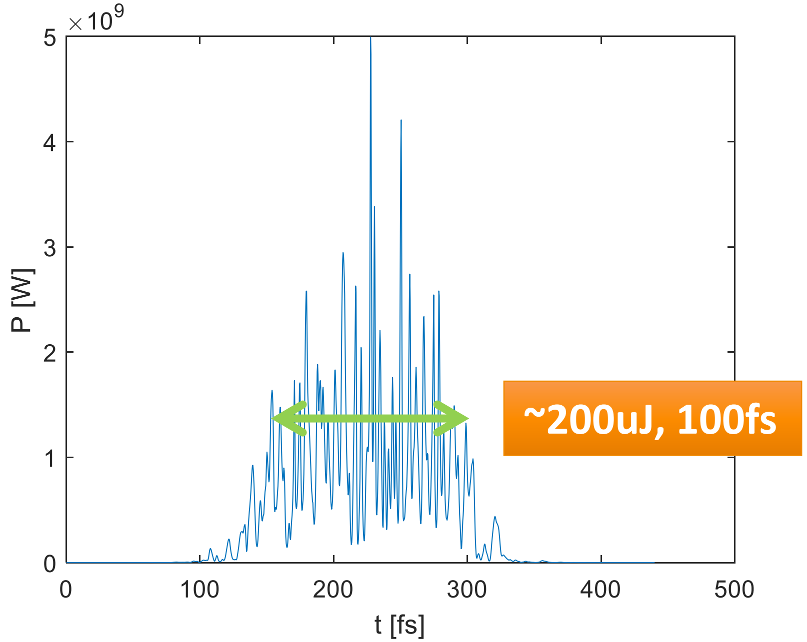
- New FEL techniques for few-cycle pulses would enable attosecond pulses

With ~100nJ pulse energy

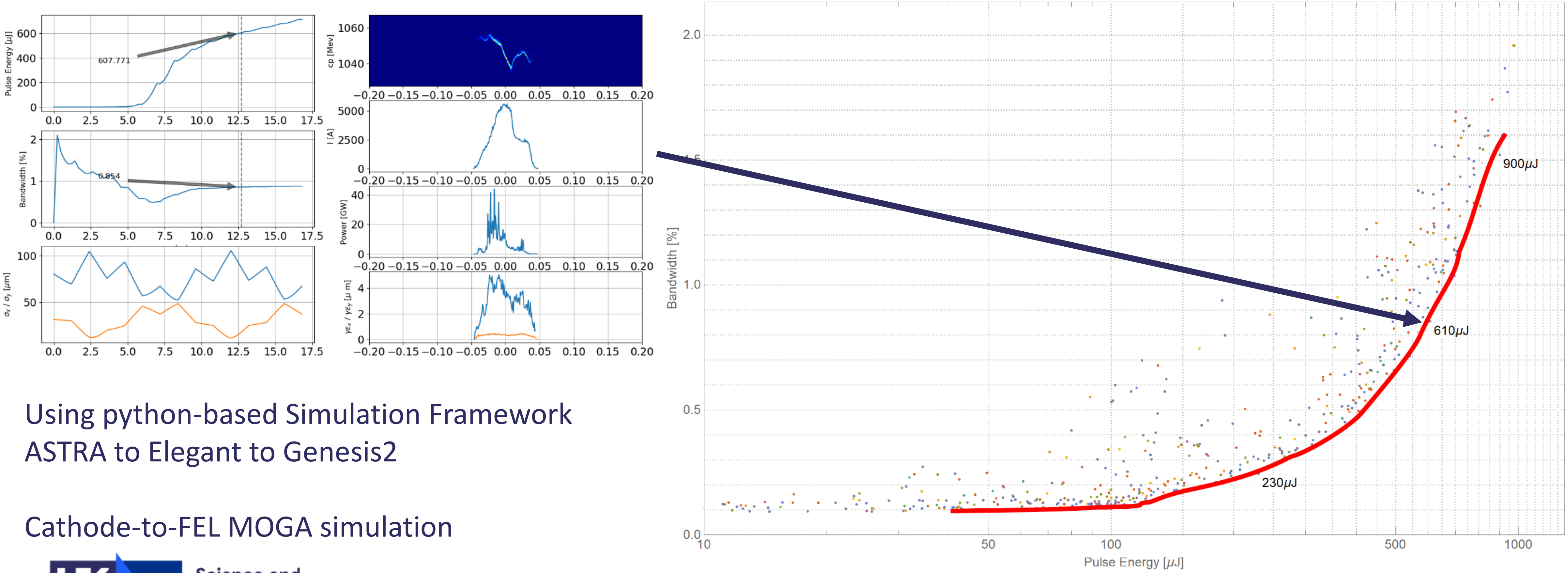
- A longer undulator (~15 m) would allow access to a larger parameter space, including longer pulses with significantly higher pulse energy (>100 uJ). Seeding and associated FEL schemes could be implemented

- Multi-bunch operation with a alkali-antimonide cathode would allow a RAFEL





Start to end simulations



Using python-based Simulation Framework
ASTRA to Elegant to Genesis2

Cathode-to-FEL MOGA simulation

Science and Technology Facilities Council

XARA as a test bed for UK XFEL

All the benefits of CLARA, plus:

- More options for FEL schemes
- Experience of seeding at soft x-ray
- Test NCRF gradient/average power trade off
- Working with soft X-rays
- Build a user base for X-rays

Science and Technology Facilities Council

Conclusion

UK XFEL will benefit the UK accelerator and wider science communities

CLARA is a useful test bed for a UK XFEL

XARA proposed to further increase UK FEL test facility relevance to UK XFEL

Science and Technology Facilities Council

Acknowledgements

Thanks to everyone on the UK XFEL, CLARA and XARA teams, particularly David Dunning & James Jones.

Science and Technology Facilities Council

Lancaster University

Thank you