UK accelerator programme

Philip Burrows

Director, John Adams Institute for Accelerator Science

On behalf of

The UK accelerator community

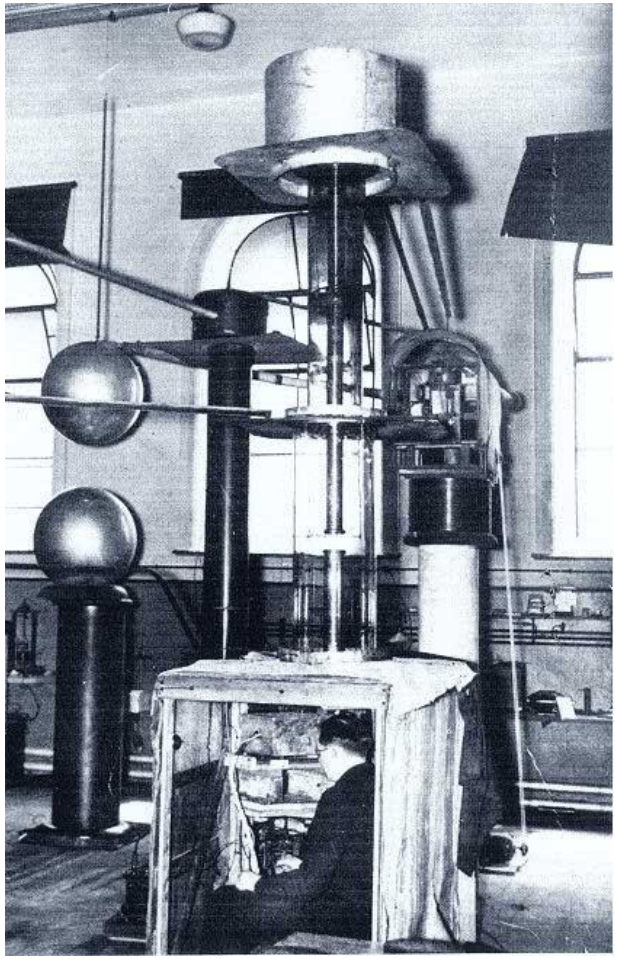
Outline

- History + context
- National facilities
- Contributions to overseas Particle Physics facilities
- Future colliders
- Summary

History

John Adams Institute for Accelerator Science

UK pioneered accelerator development from the very beginning



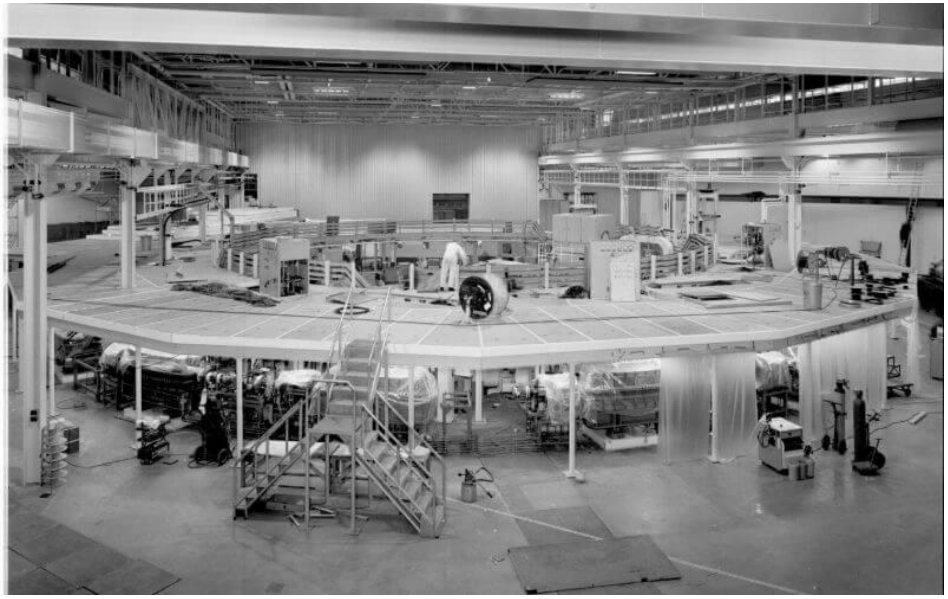
Cockcroft-Walton: 800kV

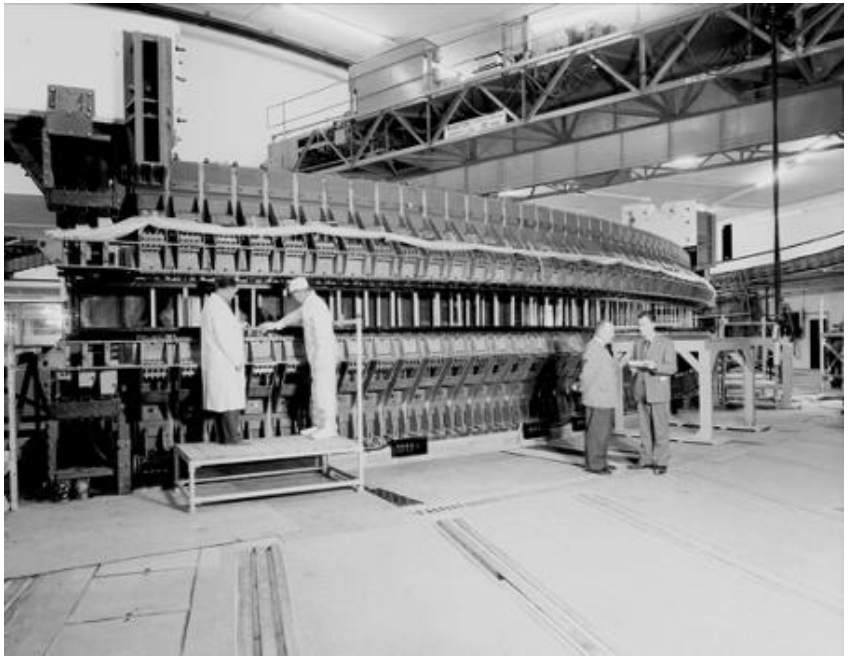
Folded tandem
Van de Graaff
(Oxford): 20MV

Tandem
Van de Graaff
(Daresbury): 20MV

UK PP accelerators

UK operated particle-physics accelerators until late 1970s:





NINA: 4-6 GeV e- synchrotron

1966-77

Daresbury Laboratory

NIMROD: 7 GeV p synchrotron

1964-78

Rutherford-Appleton Laboratory

Today's large accelerators

ISIS

spallation neutron source:

800 MeV p linac + synchrotron

Diamond Light Source:

3 GeV e- synchrotron

UK accelerator landscape

National facilities:

- **Diamond Light Source – upgrade approved**
- **ISIS – upgrade planning**
- **UK X-FEL – conceptual design**
- **CLARA/FEBE – commissioning**
- **CLF/EPAC – commissioning**

- ***SCAPA (Strathclyde)***
- ***RUEDI (Daresbury)***
- ***Proton therapy (London, Manchester)***
- ***Ion Therapy Research Facility / LhARA***

International PP facilities

- **LHC + HL-LHC**
- **AWAKE**
- **FNAL/PIP-II**
- **KEK/ATF2**
- **CLEAR**
- ***Physics Beyond Colliders***
- ***KEK/JPARC***
- ***DESY/FLASHforward***
- ***Electron Ion Collider (EIC)***

Future:

- **ILC, CLIC, FCC, CEPC**
- **HALHF**
- **Muon collider**

Diamond + Diamond-II

https://www.diamond.ac.uk/Home.html

New storage ring optimised for higher brightness photon beams ('4th generation')

£500M project

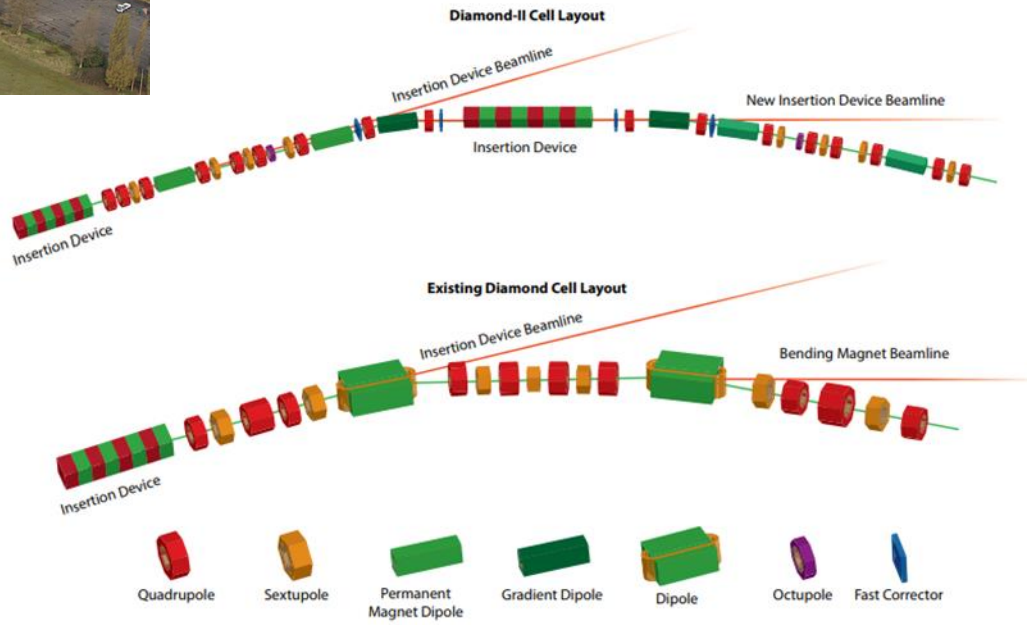
e- energy → 3.5 GeV

Double triple-bend achromats

1000x increase in hard X-rays

24 straights for Insertion Devices

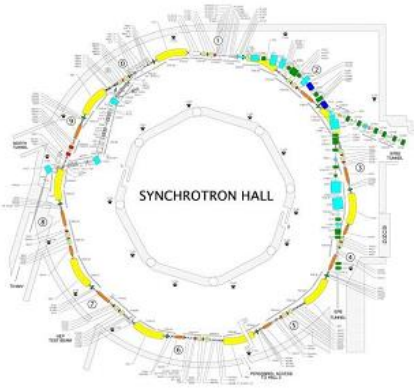
Operating from Sept. 2029

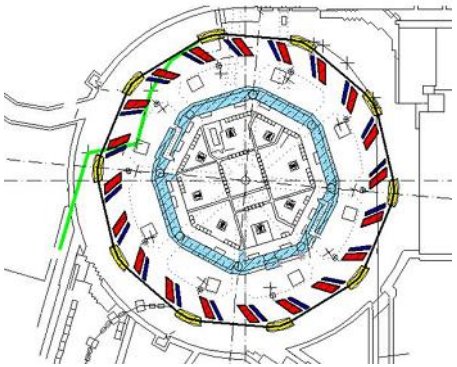


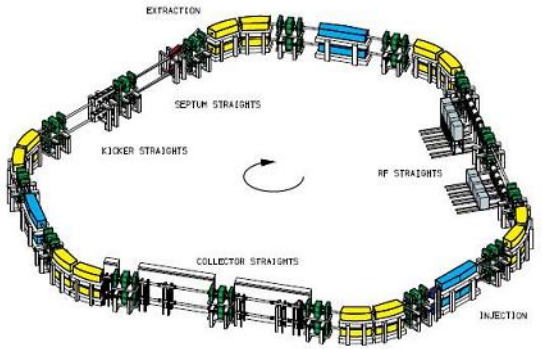
ISIS + ISIS2

https://www.isis.stfc.ac.uk/Pages/ISIS-II-webinar-13-March-2024.aspx

New accelerator with capability to produce neutrons via MW proton beams on target







O(£B) project

p energy → 1.2 GeV

3 options under consideration

- **Rapid-cycling synchrotron (RCS)**
- **Fixed-field alternating gradient (FFA)**
- **High-energy linac + accumulator ring (AR)**

Operations from 2040

UK X-FEL

https://xfel.ac.uk/

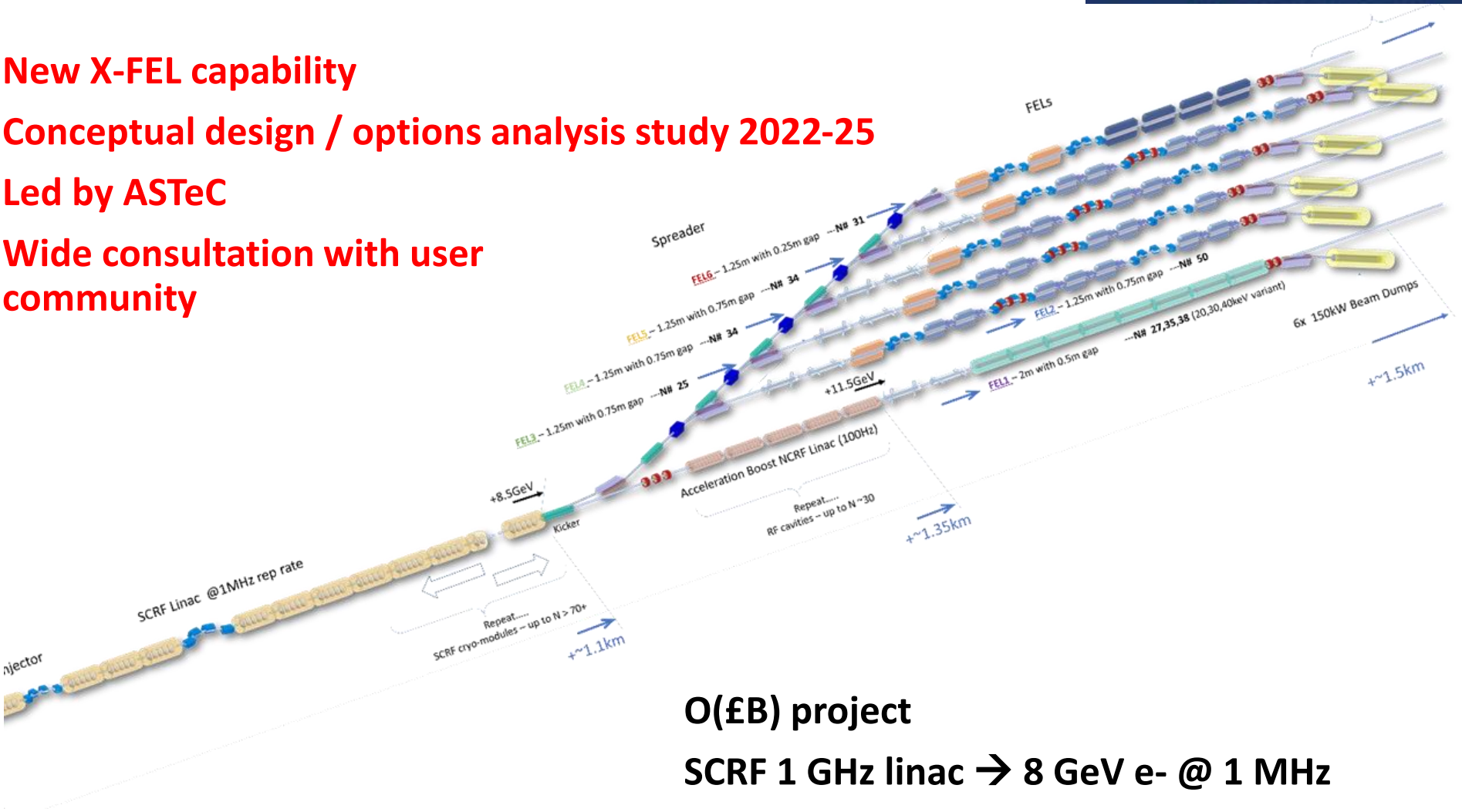
John Adams Institute for Accelerator Science

New X-FEL capability

Conceptual design / options analysis study 2022-25

Led by ASTeC

Wide consultation with user community



O(£B) project

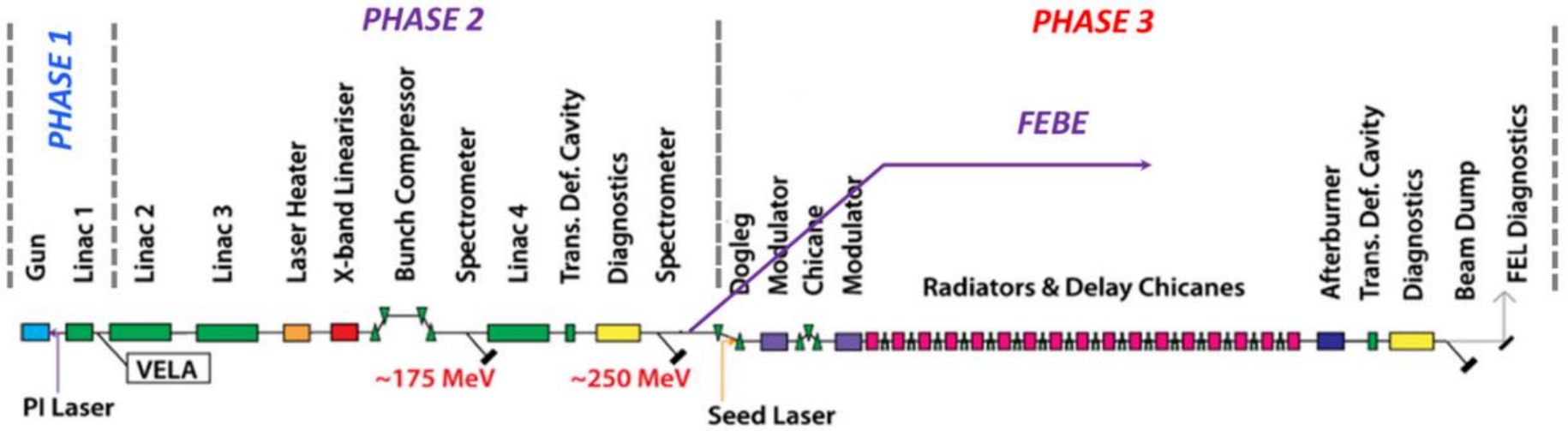
SCRF 1 GHz linac → 8 GeV e- @ 1 MHz

6 FEL beamlines of different wavelengths

CDR in preparation

Compact Linear Accelerator for Research and Applications (CLARA) / Full Energy Beam Exploitation (FEBE)

https://www.astec.stfc.ac.uk/Pages/CLARA.aspx



FEL-quality 250 MeV beam @ 100Hz

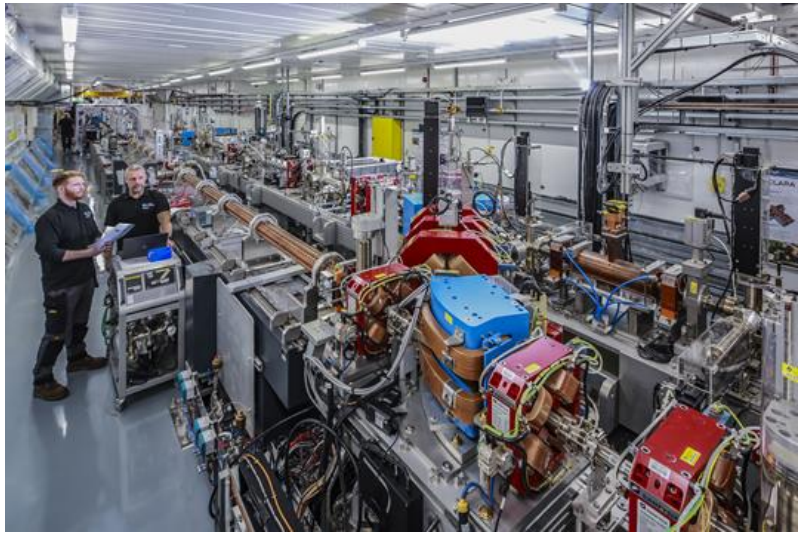
+ 120TW laser system

test capability for UK XFEL

opportunity for wakefield acceleration tests

instrumentation development

medical applications (VHEE/FLASH)



Central Laser Facility:
Extreme Photonics Applications Centre

https://www.clf.stfc.ac.uk/Pages/EPAC-introduction-page.aspx#

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New laser facility with a dedicated experimental area for laser-wakefield acceleration

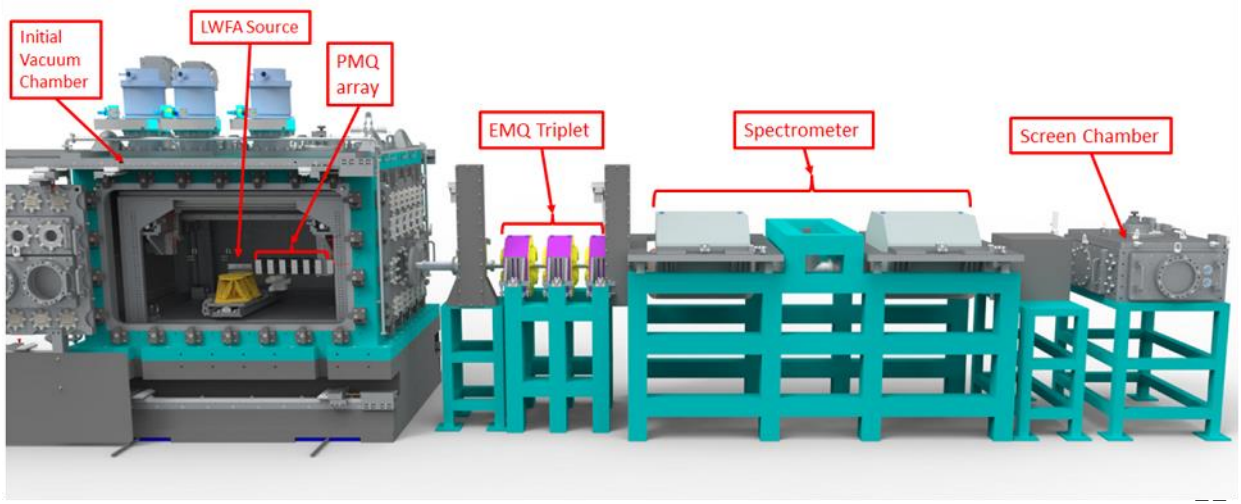
Supported by UK wakefield community

10 Hz PW laser

1-10 GeV e- beams

Operations from 2025

Candidate for EuPRAXIA LWFA site



Particle physics possibilities

ISIS-II:

Beamlines for muon + flavour physics (eg. PSI)

UK X-FEL:

Light dark matter (LDM) searches via ‘dark bremsstrahlung’ (eg. SLAC/LDMX)

CLARA, EPAC, UK XFEL:

Strong-field QED tests (eg. DESY/LUXE)

Accelerator technology synergies with Particle Physics machines

John Adams Institute for Accelerator Science

ISIS/ISIS-II:

- High-power targets and beam dumps (JPARC, PIP-II, ILC, muon collider …)
- Novel ring design (NuStorm, muon collider …)

Diamond/Diamond-2:

- Low-emittance ring design (ILC, CLIC, FCCee …)
- Magnets (ILC, CLIC …)
- Beam position monitors (FCCee)
- Damping ring injection/extraction kickers (ILC)

UK XFEL:

- RF, beam instrumentation, feedback + control (ILC, CLIC …)

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HL-LHC-UK2

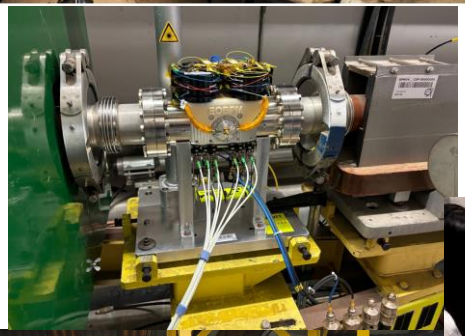
‘Phase 2’: £26M project 2020-26

STFC, John Adams, Cockcroft, Dundee, Southampton, CERN

- Beam dynamics
- Crab cavity cryomodules
- Beam diagnostics
- Cold powering distribution feedboxes
- Laser engineered surface structures

Discussion of ‘phase 3’ started with STFC

Also work on LHC optics + BPMs (JAI/Oxford)



AWAKE-UK2

https://www.awake-uk.org/

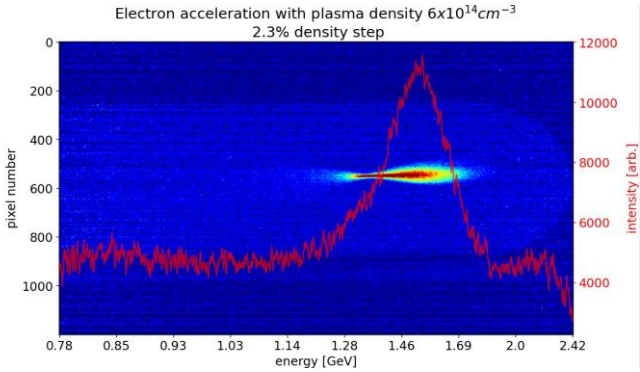
‘Phase 2’: £4M project 2020-25

STFC, John Adams, Cockcroft, Strathclyde

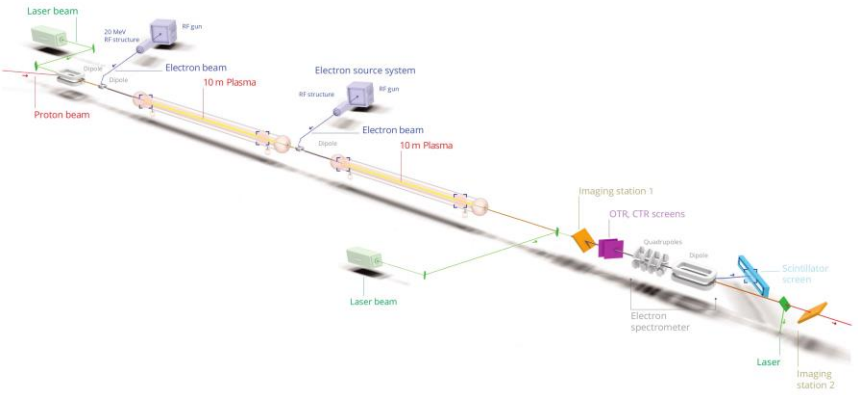
Design + optimisation of witness e- bunch

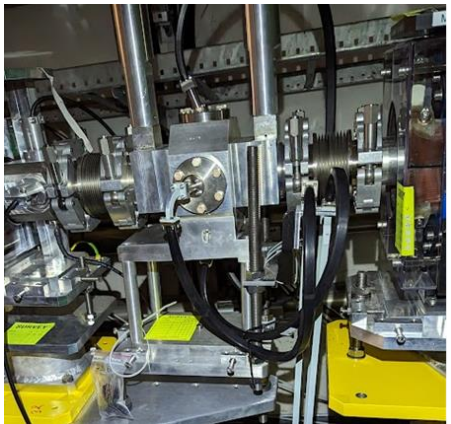
Measuring e- bunch properties

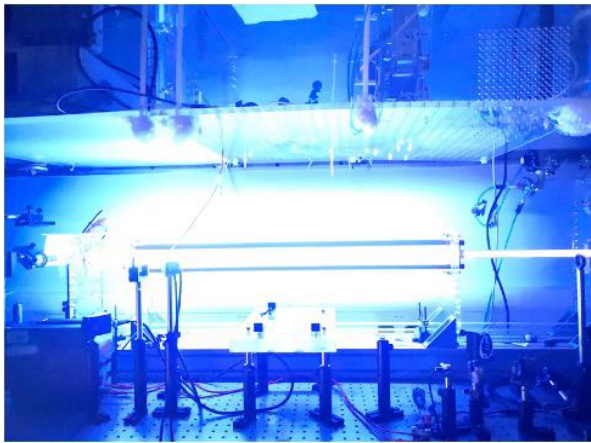
Scalable plasma cell + diagnostics



Discussion of ‘phase 3’ (Runs 2c,d) started with STFC







PIP-II

https://www.astec.stfc.ac.uk/Pages/UK-US-PIP-II-Collaboration.aspx

Key element of UK £79M DUNE/LBNF project
Builds on ESS + ELI/NP SRF projects
→ SRF capability @ Daresbury Lab
Synergies with SRF for UK-XFEL, ILC, FCCee …

WP1 SRF Infrastructure

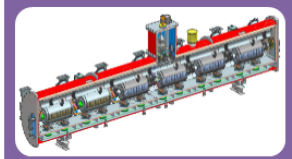
Provision of all preparation, test and assembly facilities.
Modify existing SRF facilities and provision of new cleanroom.
Implementation of new cryomodule vessel assembly fixtures.

WP2 UK Industry Development

Demonstration of UK PIP-II cavity fabrication.
Development of EBW processes for Nb material.
Provision of all SRF cavity fabrication facilities.

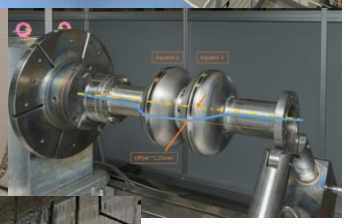
WP3 Cavity Qualification

Qualification of 18 (+2) x HB650 cavities.
Procurement of Nb material and cavity fabrication from industry.
Integration into testing infrastructure and validate.



WP4 Cryomodule Integration

Assembly of 3 x HB650 cryomodules.
Prepare HB650 cavities and assemble cavity string in cleanroom.
Integrate cavity string into HB650 cryomodule vessel.
Transport integrated cryomodules to FNAL and acceptance test.



2021-27

pCM off-loading at Daresbury

KEK/ATF2

https://www-atf.kek.jp/atf/

Final-focus ‘nanobeam’ test facility for future e+e- (linear) colliders

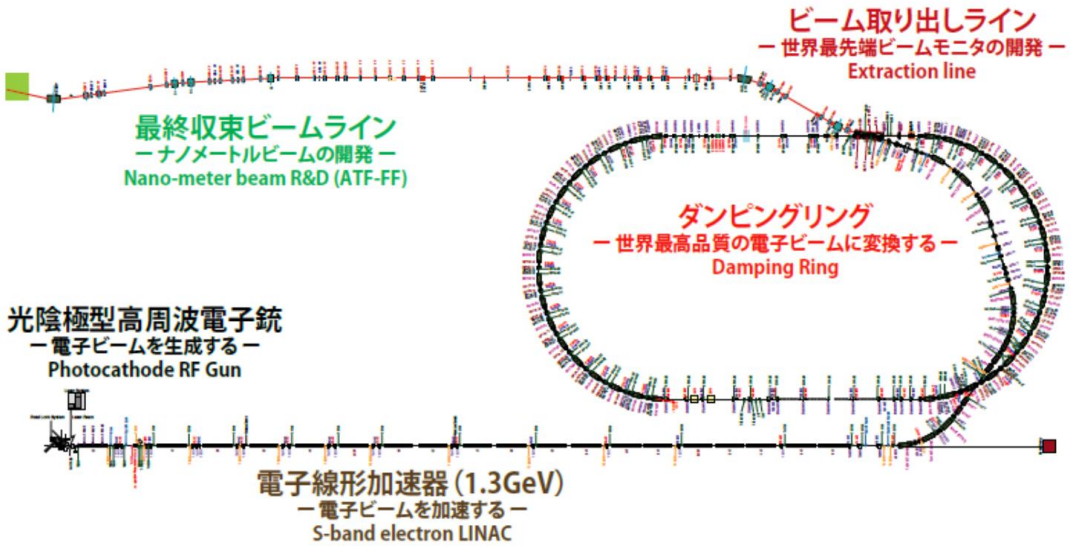
Strong investment (2005-10) from John Adams, Cockcroft, ASTeC:

- Beam dynamics
- Fast beam feedback/control (FONT)
- Beam instrumentation

Demonstrated 40nm beam = 7nm @ ILC

Ongoing JAI programme via EAJADE:

- Feedback optimisation (FONT)
- Cavity BPMs
- Automated:
  - Beam-based alignment
  - Dispersion-free steering
  - Wakefield-free steering
- Development of ML techniques in Linac, Damping Ring, Beam Delivery System + Final Focus



CLEAR

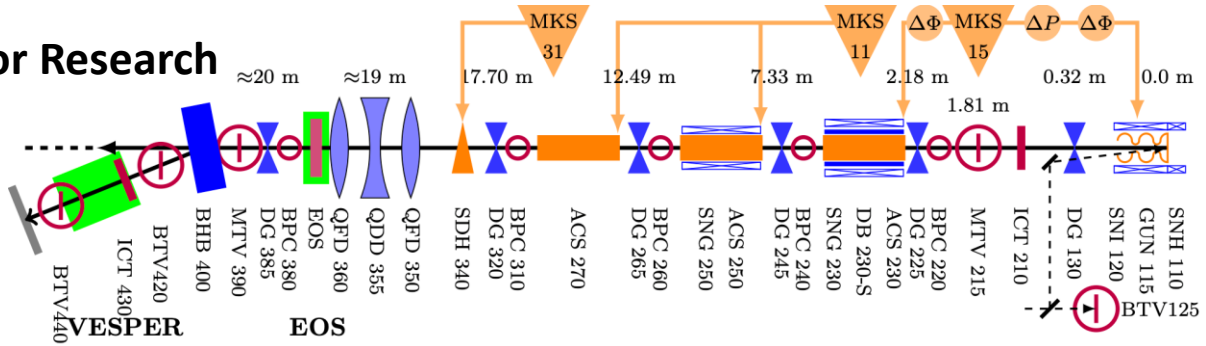
https://clear.cern/

CLIC Test Facility (CTF3) →

CERN Linear Electron Accelerator for Research

Versatile user facility

- 200 MeV beam
- 20m experimental area
- flexible access
- 38 weeks operation (2023 + planned 2024)

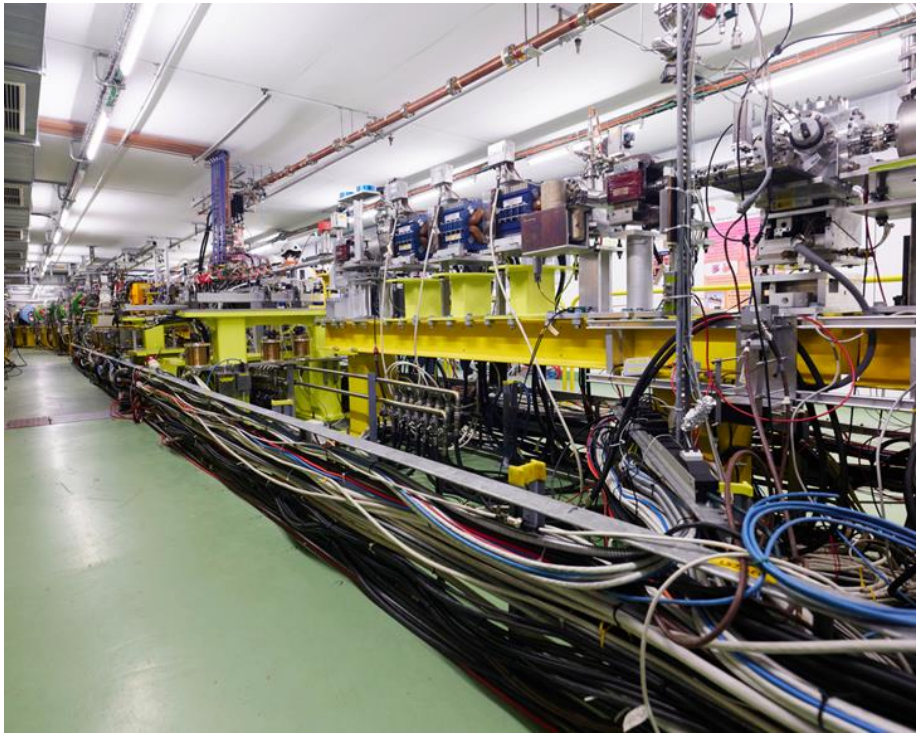


Heavily used by UK accelerator groups:
Manchester, Oxford, RHUL, Liverpool, Strathclyde, UCL

Supports AWAKE, FCCee, CLIC, ILC …

Operations directly supported by UK PDRAs + students @ CERN → unique training facility

Vital electron capability/expertise @ CERN



Accelerator sustainability

John Adams Institute for Accelerator Science

Exploring national Centre of Excellence for Sustainable Accelerators (CESA)

	Thin Film SRF cavity development	Fast reactive tuners for SRF cryomodules	High Efficiency Klystrons	Permanent Magnets for beamline magnets and klystrons	HTS Magnets	Machine Learning and AI applied to accelerators	High Efficiency Laser Wakefield Accelerators
Cost	💰💰💰	💰	💰💰	💰	💰💰	💰	💰💰
Lab space	🏢🏢	🏢	🏢🏢	🏢🏢	?	(none)	?
CO_2 and opex savings	☁☁☁	☁	☁☁☁	☁☁	☁☁	☁☁	?
Other benefits*	🏭👷	🏭⚙	🏭	🏭👷💡	🏭⚙	👷	🏭⚙

* 🏭 partnership with industry; 👷 skills development; 💡 development/exploitation of IP; ⚙ enabler for other green technologies

Strong community support

Options analysis in progress with STFC

STFC/CERN agreement signed 22/3/24

R&D in key sustainability technologies

Tools, expertise and support of UKRI's Net Zero 2040 target

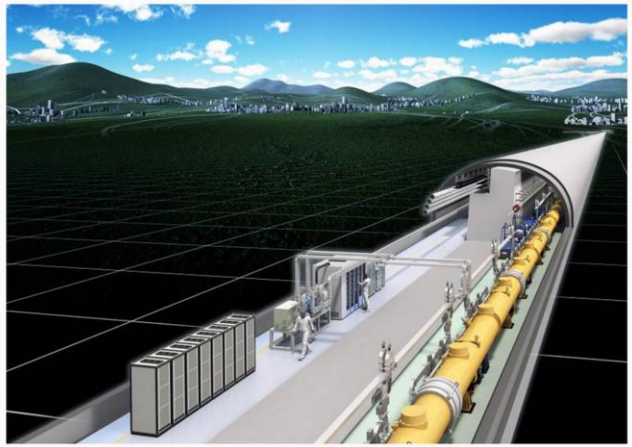
Strong international collaborations with accelerator institutes and industrial partners

Training in sustainable design + knowledge sharing

Education and outreach on sustainable accelerator technology

Future colliders (1)

UK strongly committed to European Strategy priority of an e+e- 'Higgs Factory'



2004-12: £18M investment in Global Design Effort → ILC TDR

UK capability:

- **Positron source**
- **Damping rings**
- **Beam Delivery + Mach/Det Interface**
- **Beam dumps**

International Development Team

ILC Technology Network (with CERN)

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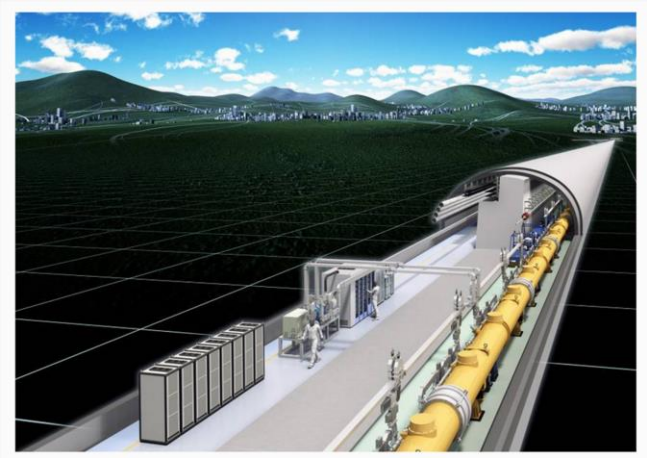

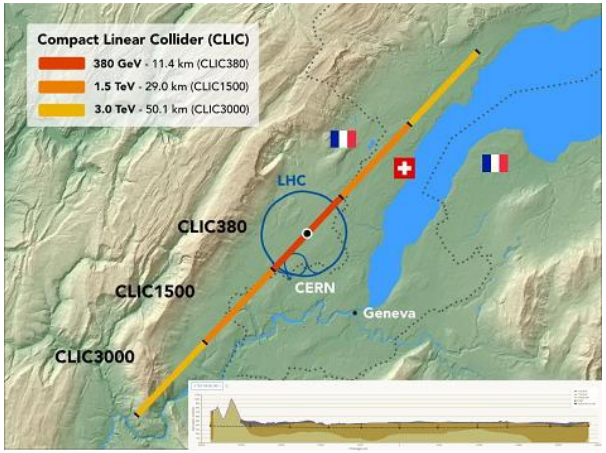

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- **Permanent magnets**
- **Linac RF systems**
- **Beam Delivery + Mach/Det Interface**
- **Instrumentation**

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CLIC Project Readiness Report

Input to EPPSU 2026

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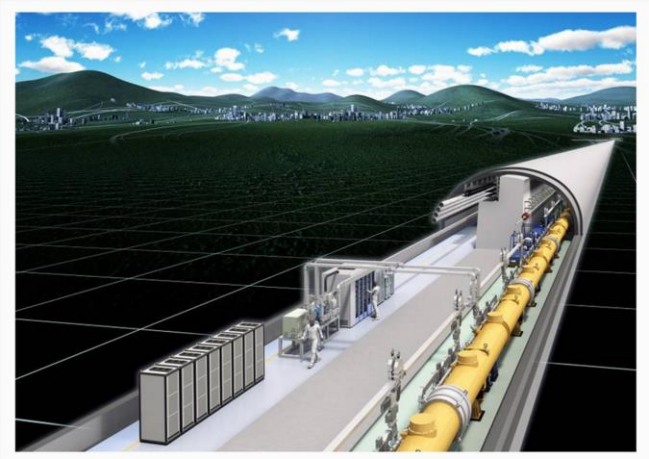

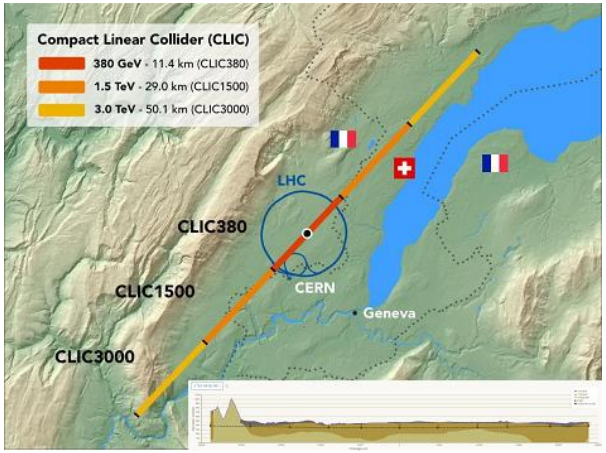

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→ deployed on HL-LHC, AWAKE, FCCee, Diamond, UK-XFEL

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CLIC Project Readiness Report

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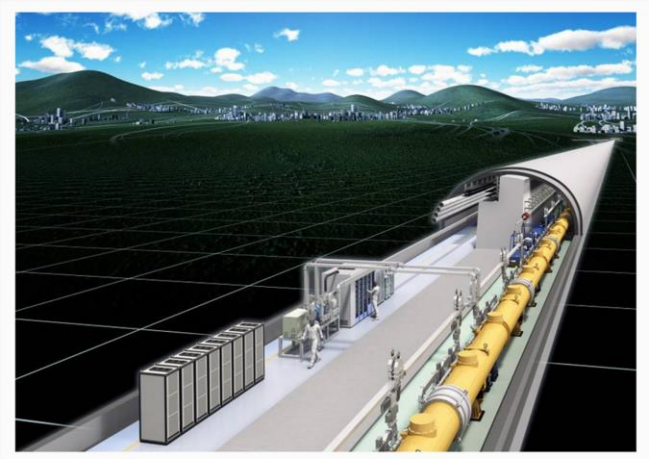

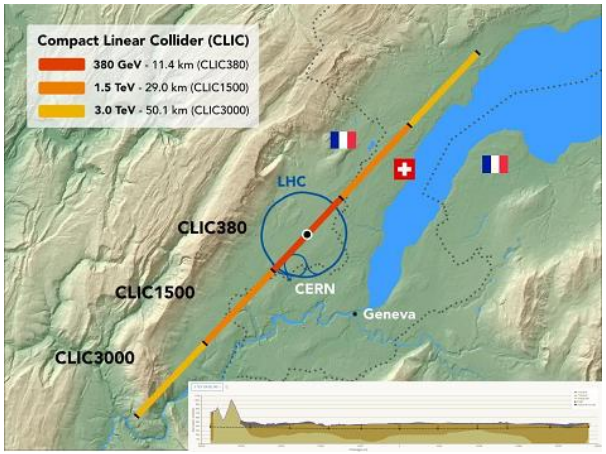

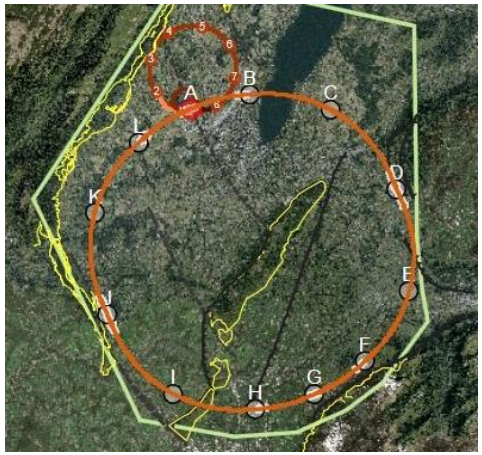

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2015-19: EuroCircol: Beam dynamics + lattice design

2021-25: FCCIS

→ deployed on HL-LHC, AWAKE, FCCee, Diamond, UK-XFEL

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ILC Technology Network (with CERN)

CLIC Project Readiness Report

Input to EPPSU 2026

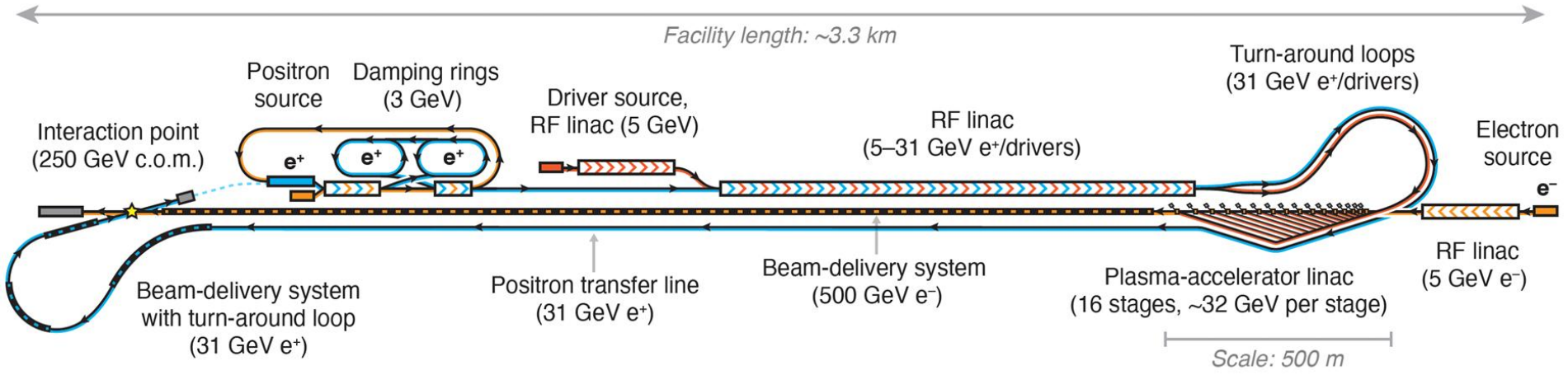
Feasibility study:

JAI students working on main ring BPMs and collision feedback

Future colliders (2)

Hybrid Asymmetric Linear Higgs Factory (HALHF)

Foster, D'Arcy and Lindstrøm, New J. Phys. 25, 093037 (2023)
Lindstrøm, D'Arcy and Foster, arXiv:2312.04975



Directly capitalises on UK expertise in wakefield acceleration and linear collider systems

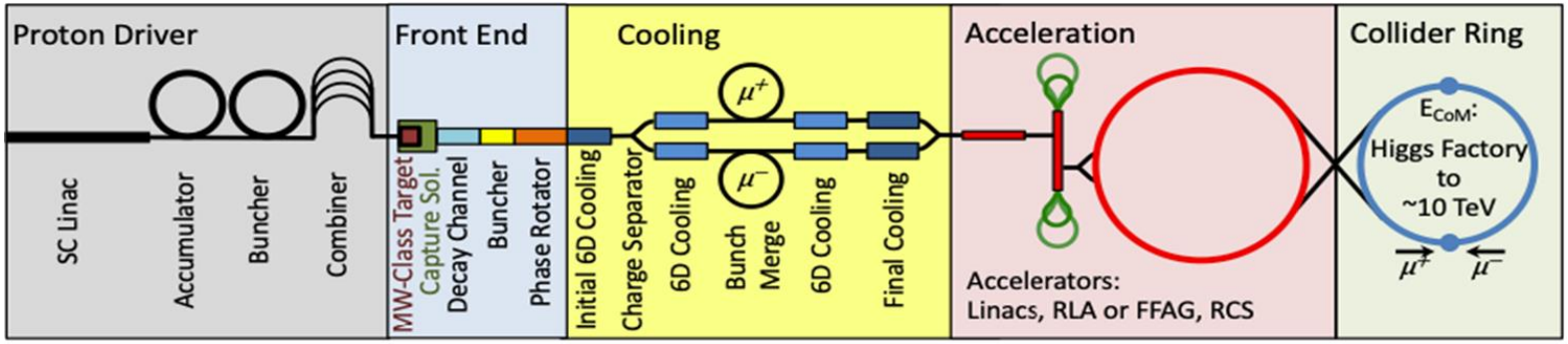
(Currently no direct funding)

Future colliders (3)

John Adams Institute for Accelerator Science

Muon Collider

International MUON Collider Collaboration



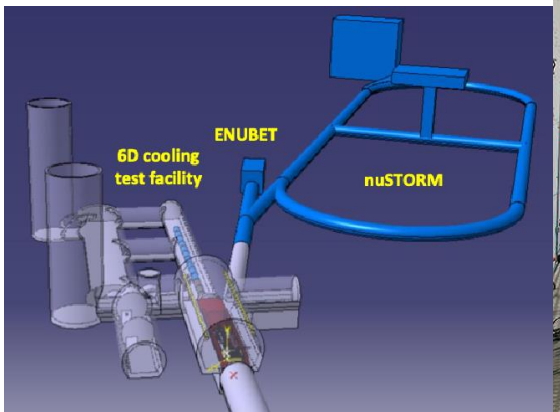
UK expertise in intense beams (ISIS) + high-power targets

ISIS muon beam → Muon Ionisation & Cooling Experiment (MICE)

I.FAST: horn pion capture

MuCol: p driver,
6D cooling
Target
Muon accelerator

NuStorm



Laboratory Directors' Group

LDG Composition

- Laboratory representatives
  - S. Bentvelsen (NIKHEF)
    - Will be replaced during 2024
  - F. Bossi (LNF)
    - -> Paola Gianotti from August 2024
  - J. Clarke (DL)
  - N. Colino (CIEMAT)
  - F. Gianotti (CERN)
  - B. Heinemann (DESY)
    - Will be replaced during 2025
  - D. Newbold (RAL)
    - -> Sinead Farrington from January 2025
  - E. Previtali (LNGS)
  - F. Sabatie (IRFU)
  - M. Seidel (PSI)
  - A. Stocchi (IJCLab)
- Standing observers
  - P. Sphicas (ECFA Chair)
  - M. Lamont (CERN Directorate)
  - J. Mnich (CERN Directorate)
  - H. Montgomery (SPC Chair)
- Secretary
  - E. Tsemelis (CERN)
- Extended LDG members
  - G. Bisoffi (RF) + P. Macintosh
  - W. Leemans (LPA) + R. Patahill
  - S. Stapnes (Muons) + D. Schulte
  - J. D'Hondt (ERL) + M. Klein
  - P. Vedrine (HFM)
  - C. Bloise + M. Titov (Sust. panel)

Max Klein (1951-2024)

Summary – needs work!

UK has strong history of accelerator development

World-leading national user facilities for synchrotron radiation (Diamond) and neutron production (ISIS):
upgrades are approved (Diamond-2) and in planning (ISIS-II)

UK-XFEL in consideration, CLARA/FEBE in commissioning

Particle Physics: strong contributions to overseas facilities @ CERN, FNAL, KEK …

Two national academic centres: John Adams Institute + Cockcroft Institute
train PhD students + postdocs, research @ national/overseas facilities

Accelerator R&D community is small:
ASTeC + JAI + CI + universities: 400 (including students)

Resources are limited: **STFC Programmes accelerator R&D line ~ £11M/year (CHECK):**
→ core funding for JAI, CI + ASTeC
→ HL-LHC, AWAKE projects (H3+Beams due to start)

Benefit greatly from EU project funding via Horizon Europe

Thanks to UK colleagues

Jim Clarke, Stewart Boogert, Stephen Gibson, Dave Newbold

Extra material

EU projects

https://www.awake-uk.org/

John Adams Institute for Accelerator Science

ARIES

I.FAST

FCC.IS

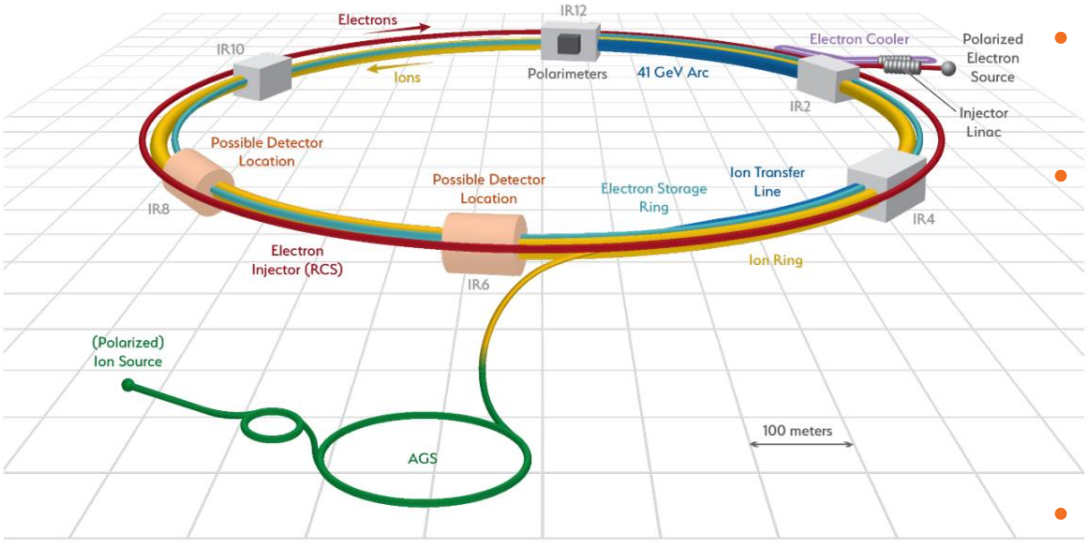
EAJADE

EUROLabs

MuCol

PACRI

Electron Ion Collider



- *UK expertise is directly applicable at EIC*
- *UK EIC proposal submitted to UKRI:*
  - *Combined proposals from detector and accelerator communities*
  - *Detector + crab cavity work funding recently announced, £59M*
- *UK EIC accelerator consortium formed with potential for future contributions:*
  - ***Diagnostics**: Electro-optical techniques developed at HL-LHC*
  - ***Fast timing** expertise developed at FONT*