Laser Plasma Acceleration Programme at EPAC

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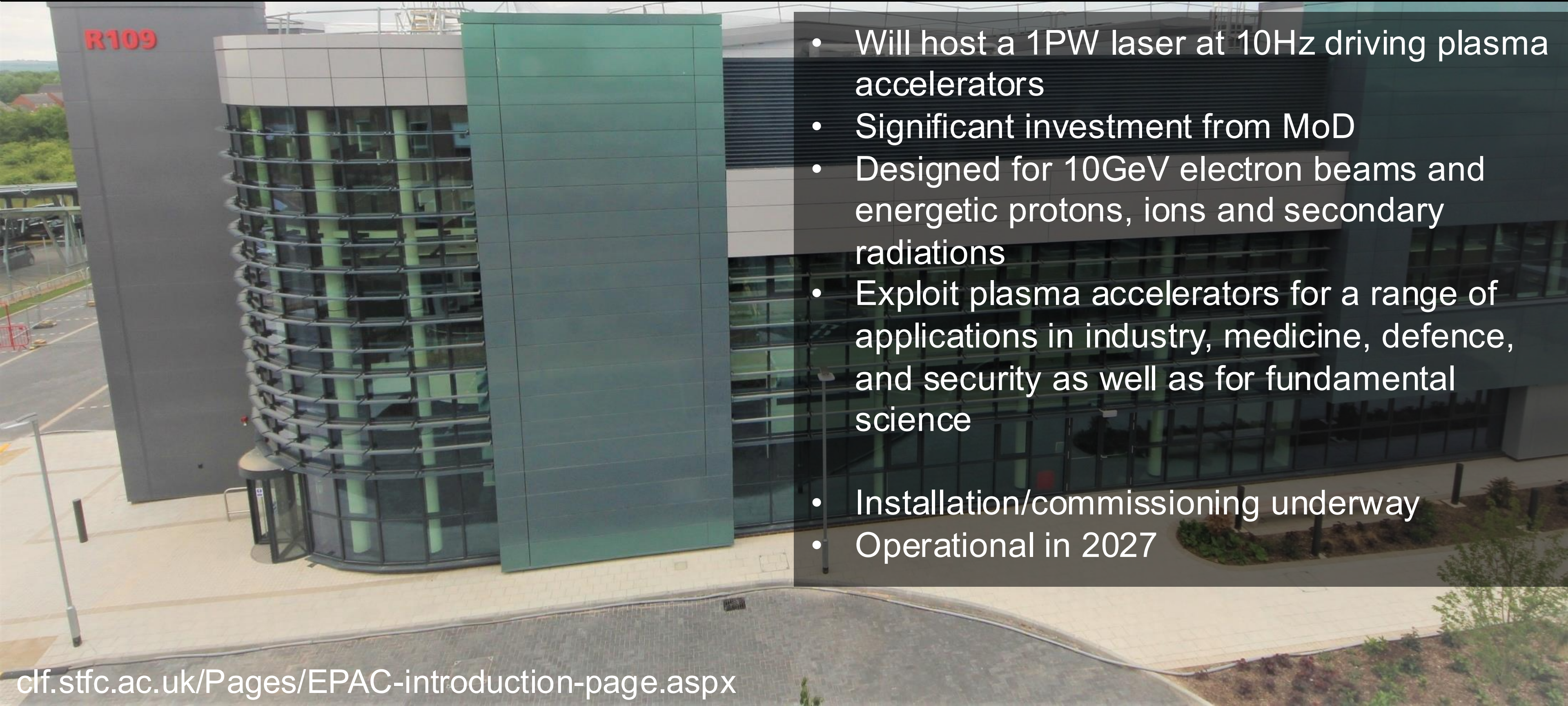
Rutherford Appleton Laboratory, UK

Extreme Photonics Applications Centre (EPAC)

A new £106M facility at RAL for applications of plasma accelerators

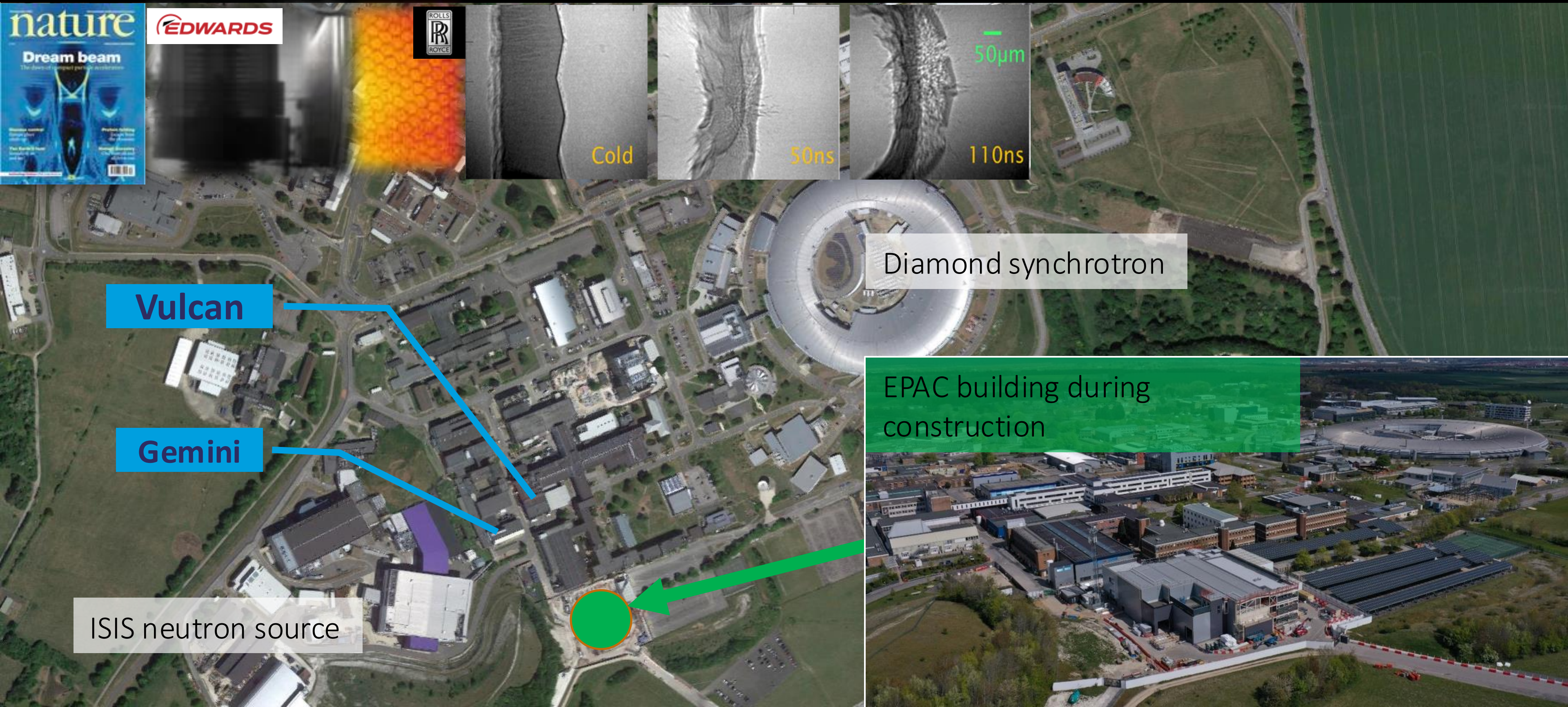


- Will host a 1PW laser at 10Hz driving plasma accelerators
- Significant investment from MoD
- Designed for 10GeV electron beams and energetic protons, ions and secondary radiations
- Exploit plasma accelerators for a range of applications in industry, medicine, defence, and security as well as for fundamental science

- Installation/commissioning underway
- Operational in 2027

clf.stfc.ac.uk/Pages/EPAC-introduction-page.aspx

EPAC builds on the success of Gemini and Vulcan



EPAC Schematics

A 3-storeyd purpose-built building housing the facility

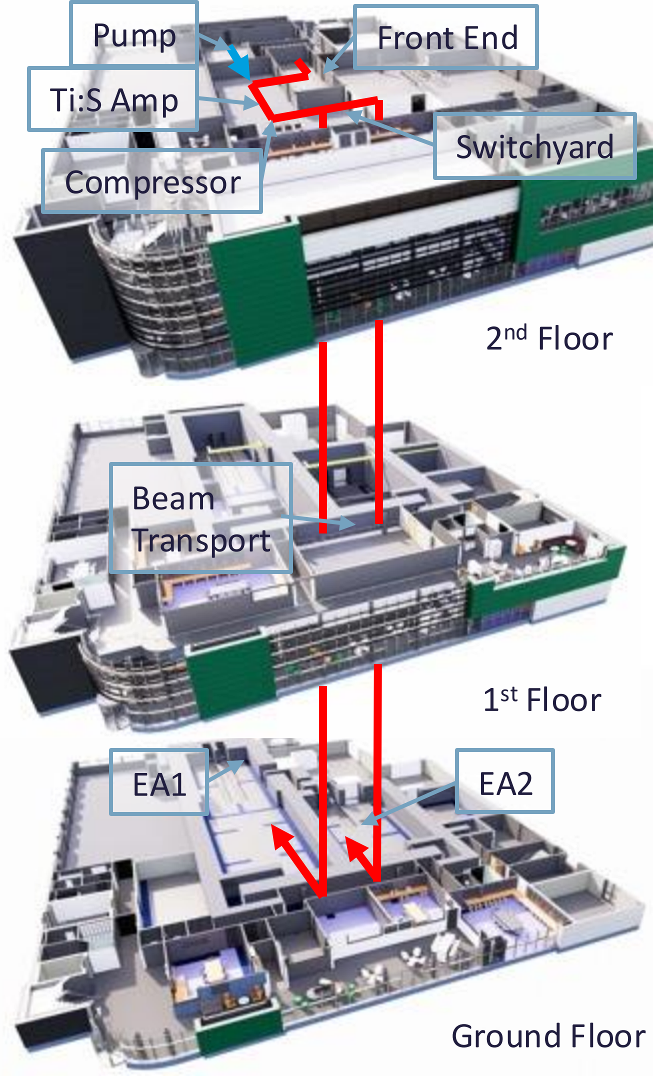
- 1 PW@ 10Hz Laser areas and laser control room.

Space for the addition of new laser systems: 2nd and 3rd synched beamlines

- Office space on 2nd and 1st floors

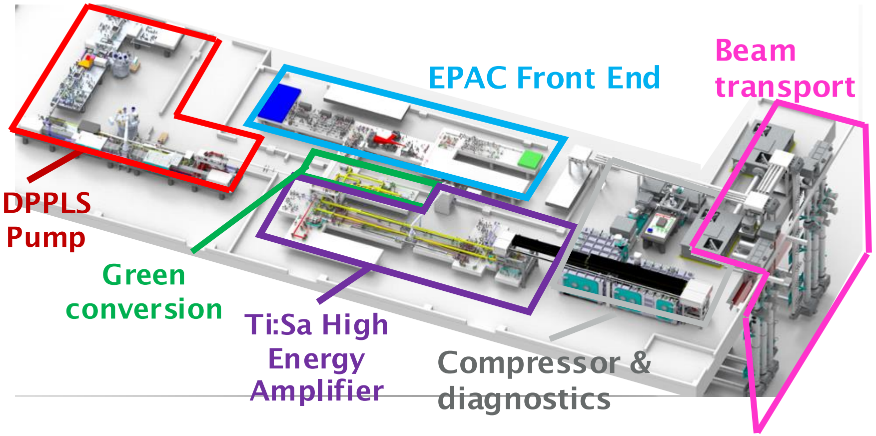
Ground Floor houses three double height radiologically shielded experimental areas

- Experimental area 1 (EA1) ~38 m x 10 m,
- Experimental area 2 (EA2) ~18 m x 10 m
- Future experimental area (EA3)
- Control rooms and auxiliary labs and future cleanroom space and development laser labs



EPAC Laser System

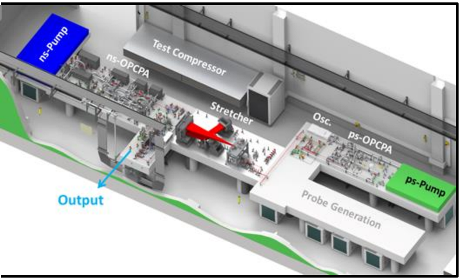
EPAC employs CLF's patented DiPOLE laser technology



EPAC specification

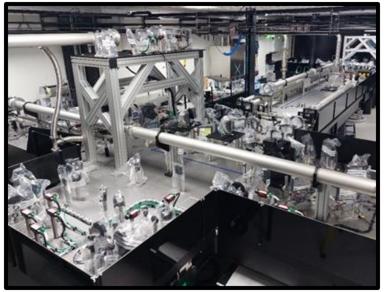
1PW@10Hz

- **Output Energy 30 J**
- **Pulse duration ≤ 30 fs @ 10 Hz, 1 Hz, SS**
- Pump for Ti:S is CLF developed 100J DiPOLE system.
- Additional space for future laser and experimental areas (eg. a 2-3J, 100Hz system under development)



Joule-class OPCPA Front-end

DiPOLE 100J, 10Hz pump

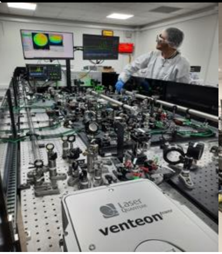


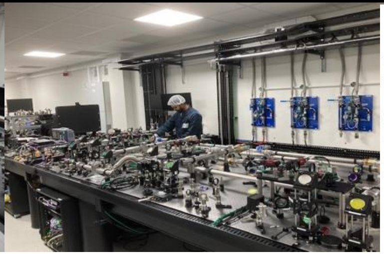
Ti:Sa high-energy amplifier

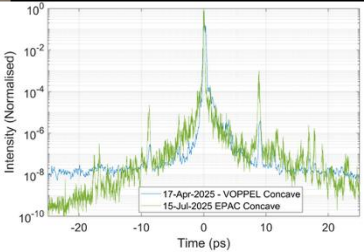
Compressor chamber

EPAC Laser System Status

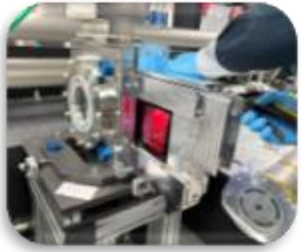
Commissioning underway

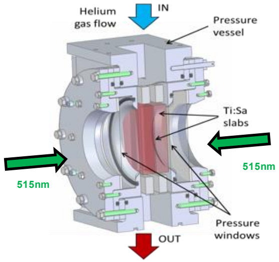




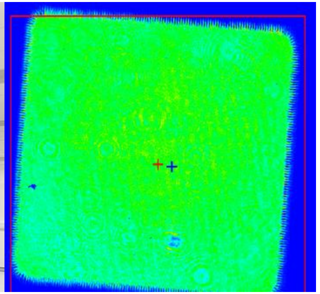


ps and ns amplifiers nearly finished
Short pulse with test compressor
Contrast looks very good

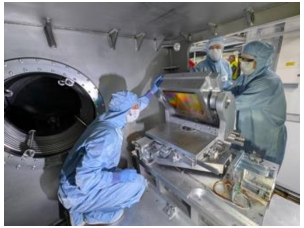




Amplifier head assembled; initial pumping underway
Pump beam shaping –Square-to-circle (SQUIRCLE)



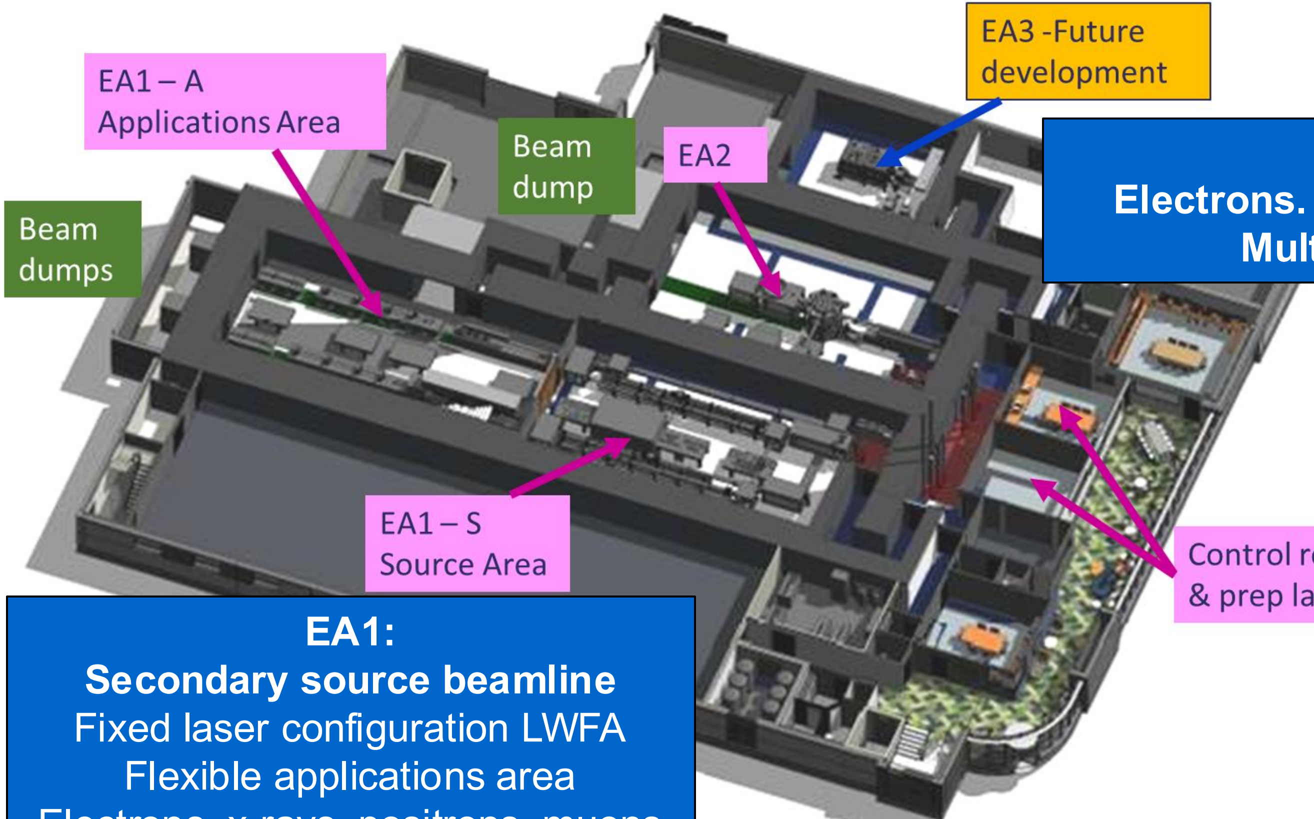
1Hz commissioning of the 10J amplifier – completed
100J diode stacks undergoing acceptance tests



Have all MLD and Gold gratings – starting with Gold
Installed all Gold gratings – alignment/stability tests ongoing
MLD damage tests ongoing

Experimental areas on the ground floor

Three heavily shielded areas – only two to be operational in the first phase



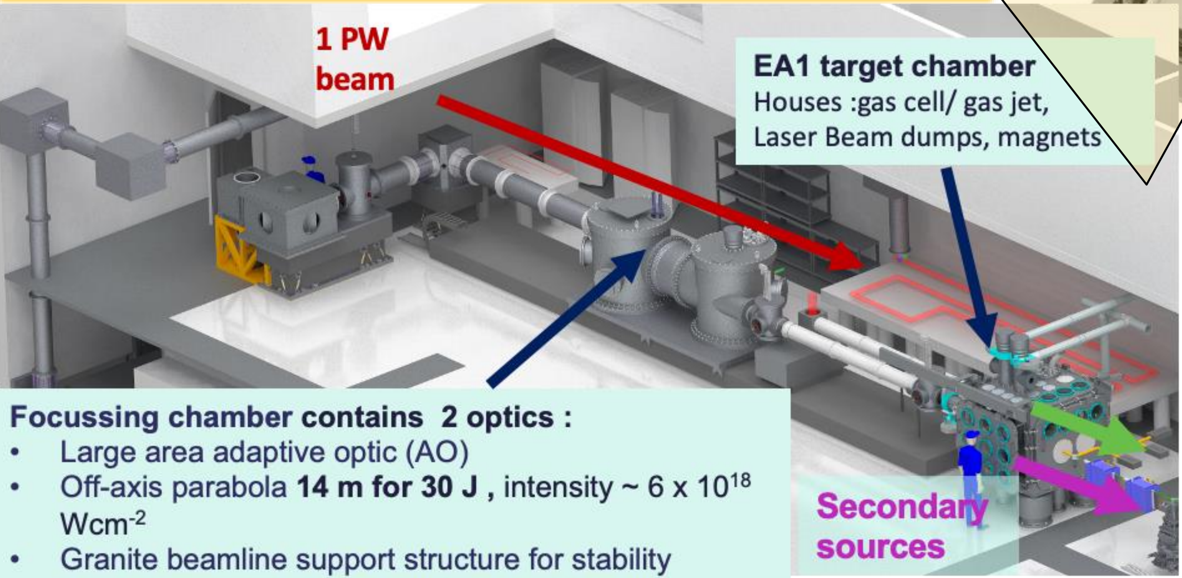
EA2:
Electrons. Ions. Protons & x-rays
Multimodal imaging

EA1:
Secondary source beamline
Fixed laser configuration LWFA
Flexible applications area
Electrons, x-rays, positrons, muons

EA1 is configured for LWFA

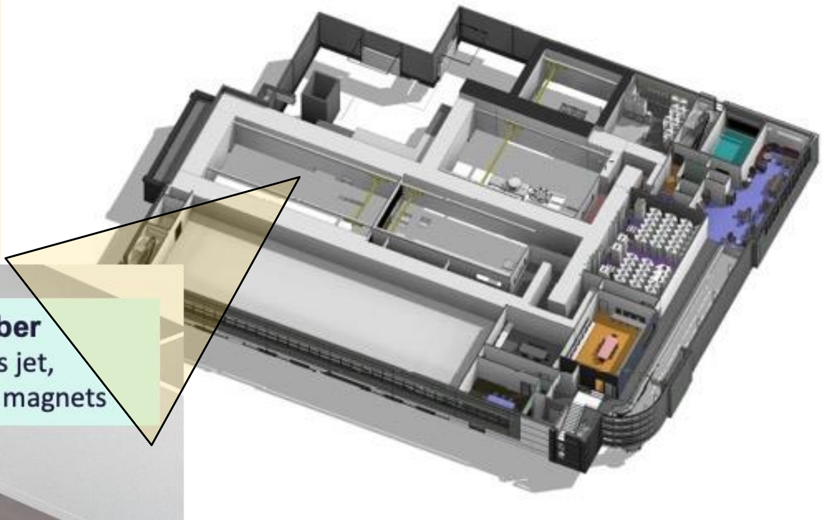
EPAC 1 PW drives a laser plasma accelerator

- Focused to relativistic intensity (above 10^{18} Wcm^{-2})
- Target is a few cm of gas
- Creates a plasma with extremely high accelerating fields
- Generates multi-GeV electron beams and x-rays



Focussing chamber contains 2 optics :

- Large area adaptive optic (AO)
- Off-axis parabola **14 m for 30 J** , intensity ~ 6 x 10^{18} Wcm^{-2}
- Granite beamline support structure for stability



Timeline:

2025: Commissioning with internal laser
2026: Pulsed beam delivery and commissioning
2026: Secondary source optimization
2027: Operational user facility

EA2 will be a versatile area

Short focus

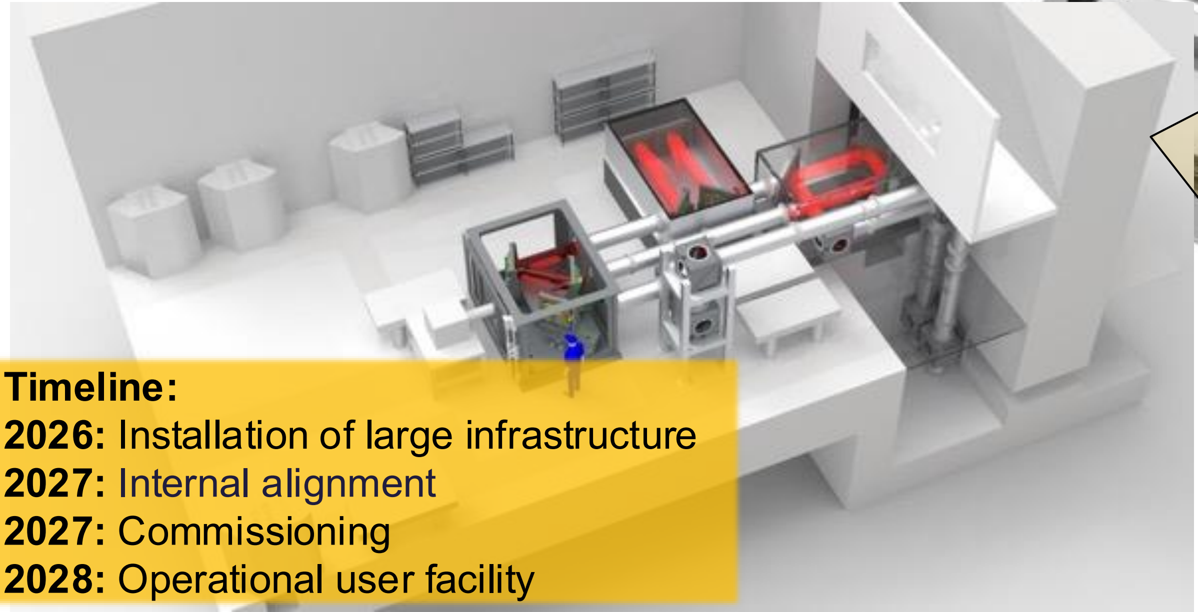
~4x10^{21} Wcm^{-2} a0 ≈ 40

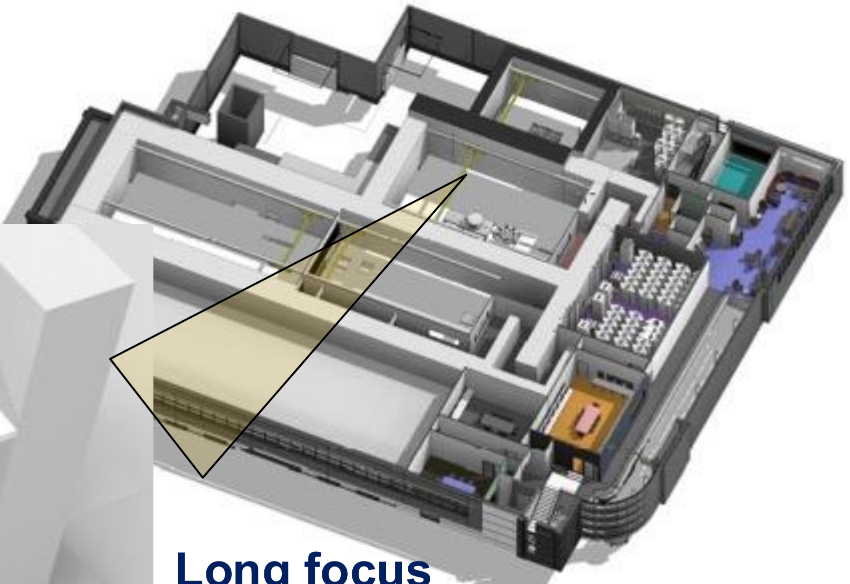
- RPA / RTA Proton/Ion acceleration (~ 100 MeV?)

Medium focus

~4x10^{20} Wcm^{-2} a0 ≈ 14

- TNSA Ion acceleration
- Bremsstrahlung
- Thermal neutron production





Timeline:
2026: Installation of large infrastructure
2027: Internal alignment
2027: Commissioning
2028: Operational user facility

Long focus

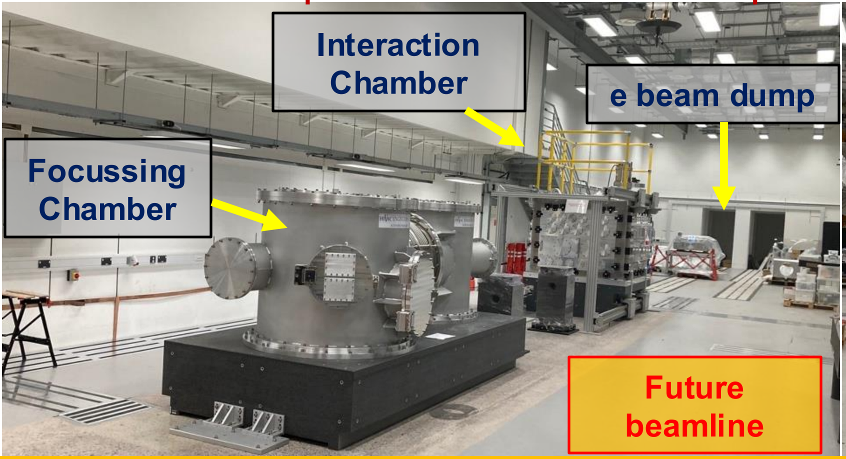
~2x10^{19} Wcm^{-2} a0 ≈ 3

- LWFA source development
- Betatron source for imaging and probing

Science and Technology Facilities Council

EA1 beamline getting ready

All beam transport chambers are in place now



Source area

Applications area

A versatile LWFA beamline for industrial/bio-medical/security applications and fundamental science

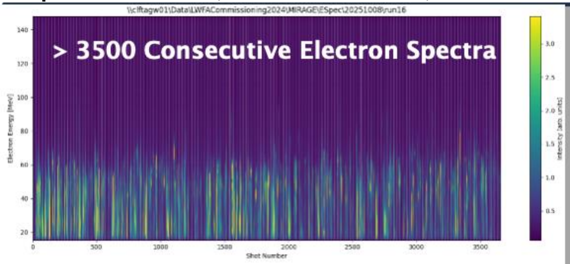
The plasma source area could be separated from the applications area mimicking a synchrotron beamline

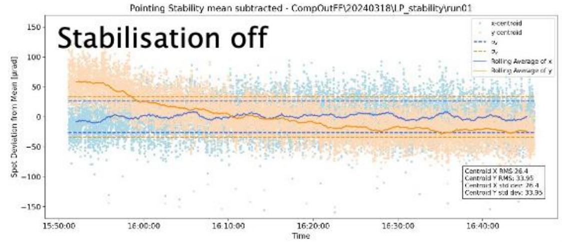
- Electron diagnostics
- X-ray detectors
- Sample stages
- Specialist rigs

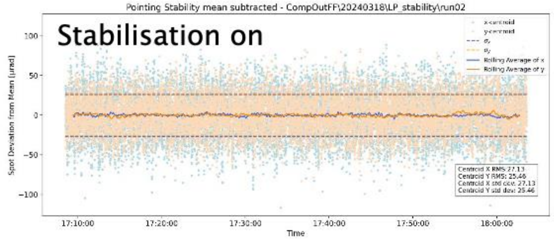
A second beamline in future

Prototyping before EPAC is online

TA2 and TA1 are being used as testing grounds for various developments required for EPAC: electron beam optimisation, stabilisation, ML-based feedback loops, data management mock-up





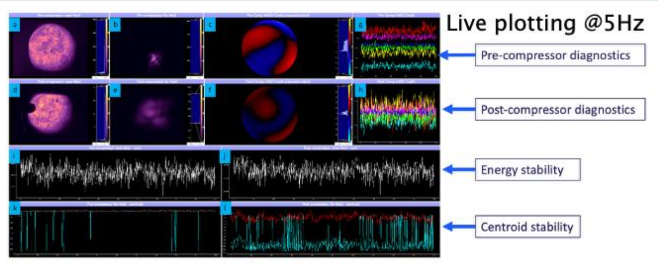


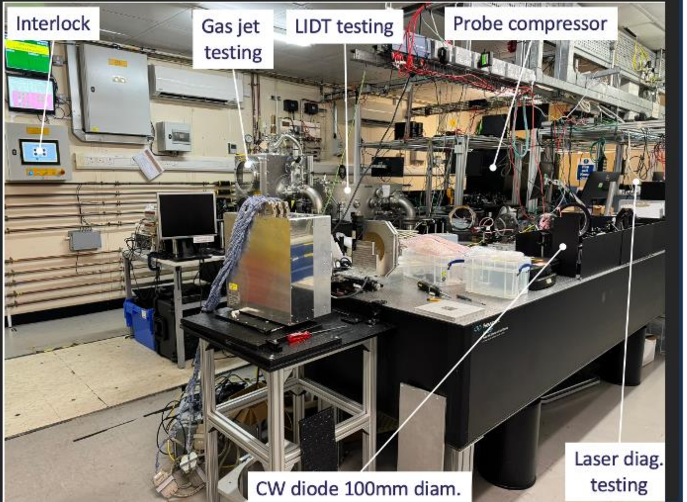
Wakefield accelerator @5Hz in TA2

- Feedback stabilisation implemented on laser pointing, energy, spatial and spectral phase, and gas density.
- Investigating solutions to target aperture damage for extended operations
- Testing machine learning techniques for stabilisation and LWFA optimisation

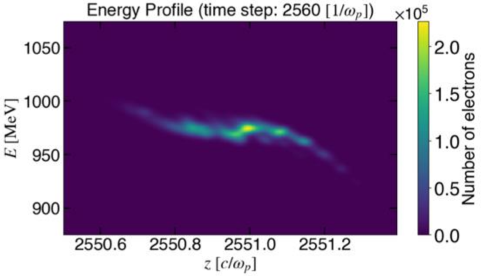
Laser damage testing in TA1

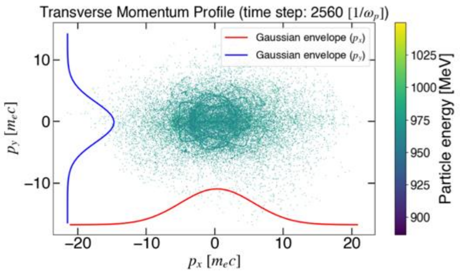
Using the EPAC Data Management Architecture as the test case

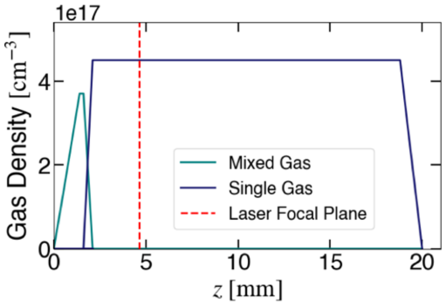




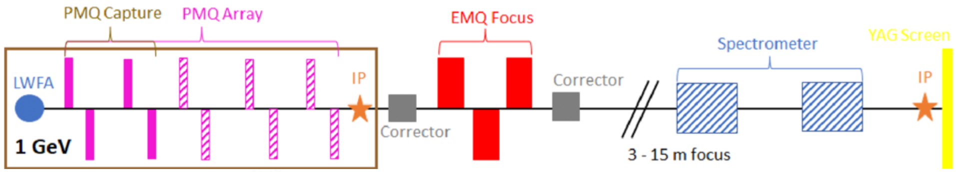
Will commission 1GeV beam first



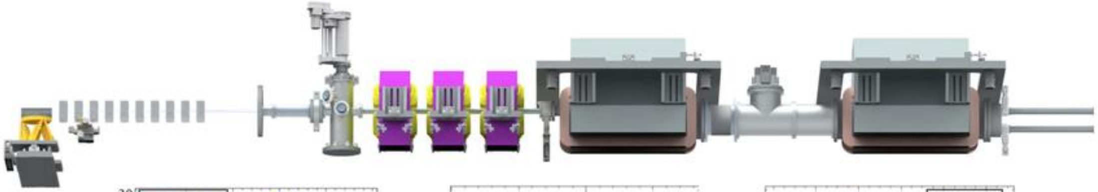


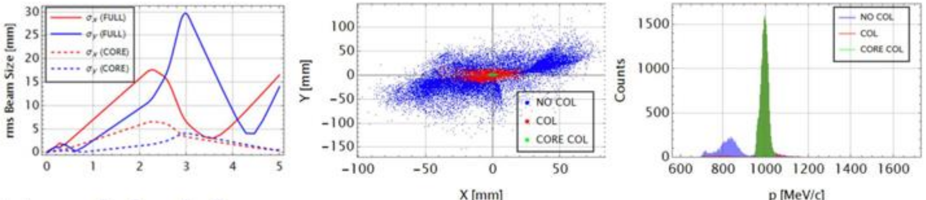


Beam Parameters	Values
Mean energy	0.97 [GeV]
Energy spread	0.9%
Divergence (x/y)	2.83 / 1.70 [mrad]
Emittance (x/y)	4.38 / 1.46 [mm mrad]
Charge	28.8 [pC]
Longitudinal size	2.23 [μm]
Transverse size (x/y)	7.93 / 4.55 [μm]



WP8 update by Jorge





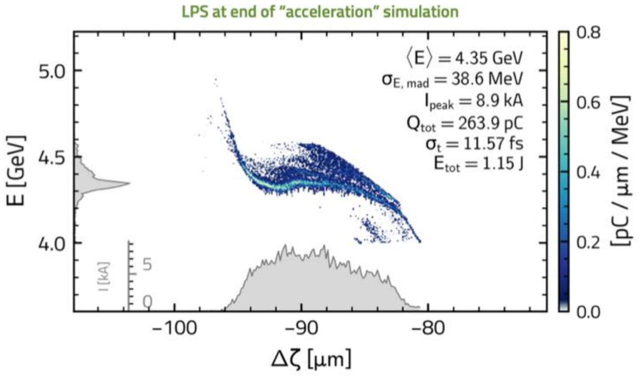
Start-to-end simulations

- FBPIC simulation output fed into magnet tracking code
- 4 x PMQ + 3 x EMQ for 1GeV
- The **core** of the electron beam at 1 GeV forms a <1mm spot at 5 m
- Can improve with plasma lenses
- Magnets partly to be supplied by PSI

Concentrate on stable, reproducible beams

EPAC as the R&D Centre for EuPRAXIA

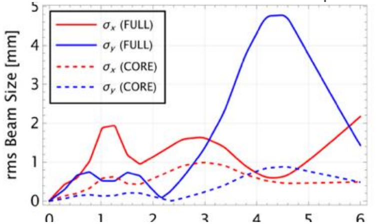
R&D on FEL quality 5GeV beams

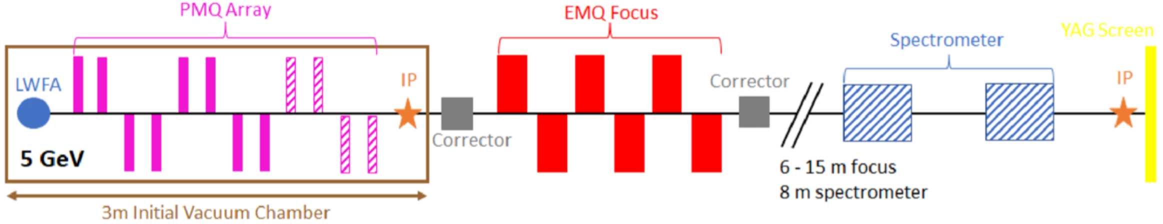


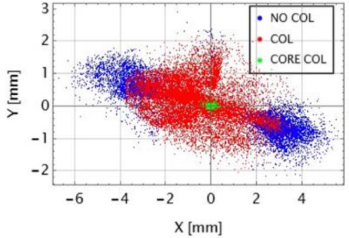
Rms Energy Spread: 0.2% - 1%, depending on the configuration and optimisation routnes	
Charge per bunch: 20pC-300pC, depending on the configuration and optimisation routnes	
Rms pulse length: 10fs – 20fs	
Rms normalized emittance (h/v): ~1 – 5 mm mrad	

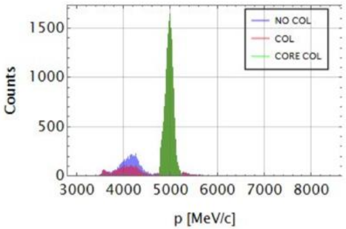
Potential Access modes:

- Programmatic access
- Horizon funding/Lasers4EU type arrangement
- In-kind contribution







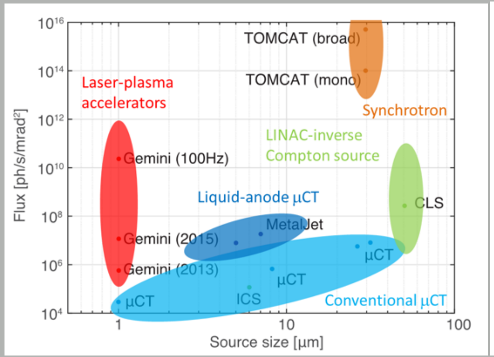


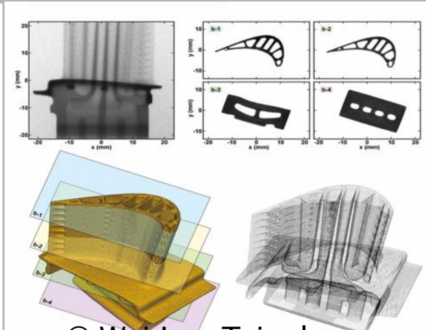
Will need external guiding (eg. HOFI)
Plasma de-chirper scheme might be important
EuPRAXIA collaboration would be mutually beneficial

EPAC will aim to provide a step-change in capabilities

This will enable new fundamental science, industrial and strategic applications of plasma accelerators

Micron-resolution MeV imaging





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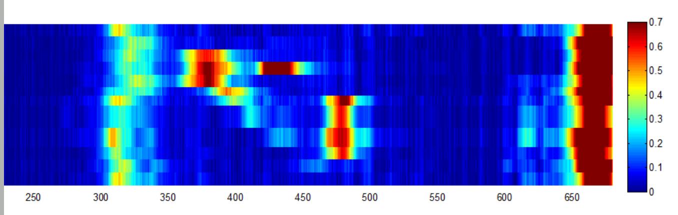
Laser sources maintain µm-source size as average power is increased

Capability to perform secure-level experiments



OUTSIDE INSIDE CONTAINER

Curiosity-driven science *with statistics*

- Non-perturbative QED
- Radiation reaction, pair production, …
- Laboratory Astrophysics
- HED science

EPAC will be a unique facility in this regard

UKRI Science and Technology Facilities Council

Future Capabilities for Fundamental Science and HEP

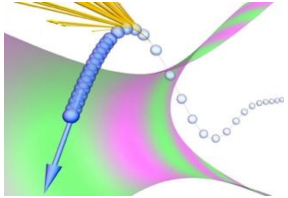
A second high-power beam will multiply scientific output

90% of all experiments in Gemini use its dual beam capability

- An auxiliary short-pulse, high power laser beam (few J)
- A (multi) Petawatt laser beam (10's of J)

Statistically significant QED

Radiation reaction, electron-positron pairs, photon-photon scattering

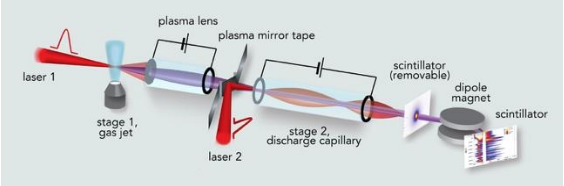


Phys. Rev. X 8, 011020 (2018)

Phys. Rev. X 8, 031004 (2018)

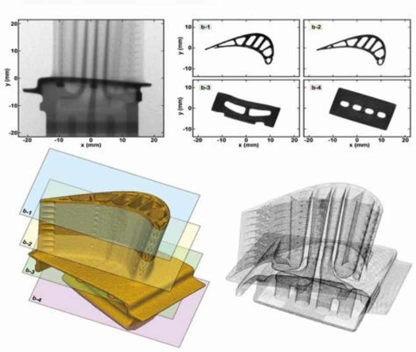
Enabling Plasma-based HEP

Staging of plasma accelerators
Electron energies >> 10GeV
Essential for plasma accelerator applications in particle/high-energy physics



Deep penetration imaging with micron resolution

Bright Compton Sources at MeV energies



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Future Capabilities for HED, Fusion and MoD Programmes

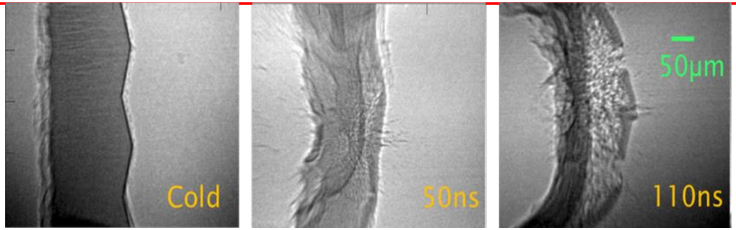
Availability of a long-pulse shock-driver beam

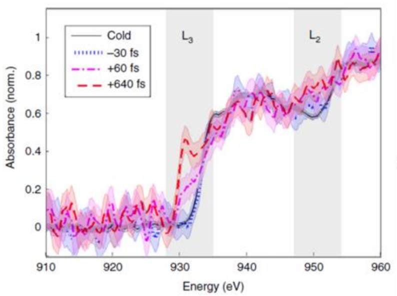
Very popular HED capability in European XFEL

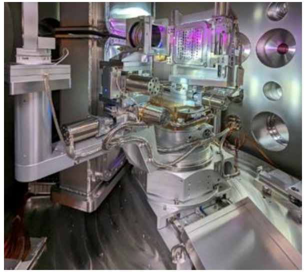
Strong interest from MoD (AWE and Dstl)

Many applications & fundamental science

- Shocks and instabilities
- Warm Dense Matter
- Phase and structural transitions with XANES
- Laboratory Astrophysics







Prototype development for a fusion shock driver

UpLiFT programme developing concepts

Potential to host a test facility for shocks as part of the Inertial Fusion Programme in the UK

Added Throughput for Industrial Applications

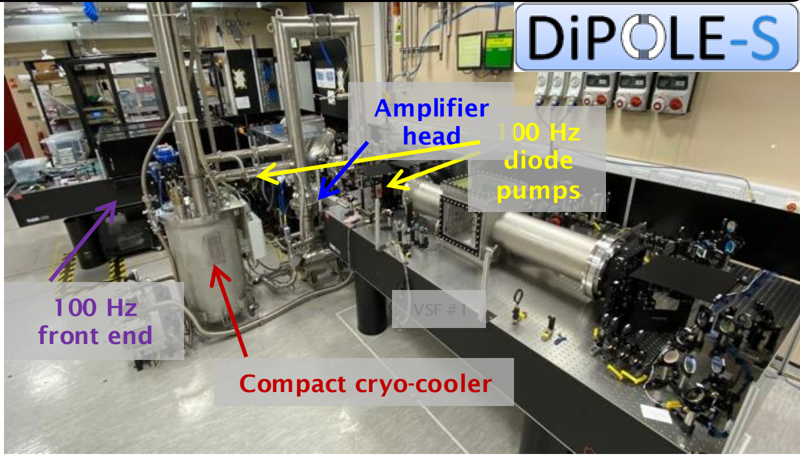
High-average power – kW, 10's of kW – becomes important

CLF developing technology for 100TW-class plasma accelerators at 100Hz (3J, 30fs, 100Hz)

Potential space for the laser development in a converted shell & core area in 2nd floor

Once developed, the beam could be delivered to EA3 (currently shell & core)

Could be a dedicated area for industrial partnerships/joint R&D with spinouts



Part of PACRI WP
Partly internally funded

DiPOLE Systems Ltd

CLF has just spin-out company to commercialise this laser technology

Horizon Europe

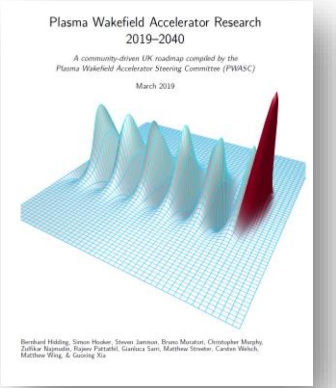
UKRI Science and Technology Facilities Council

Significant expertise in the community

The UK University Centers, Accelerator Institutes and the CLF are leaders in the underpinning science and technology

Most of the open access R&D in EPAC will be led and conducted by the Academic Community

The UK PWASC coordinates activities in this area in the UK

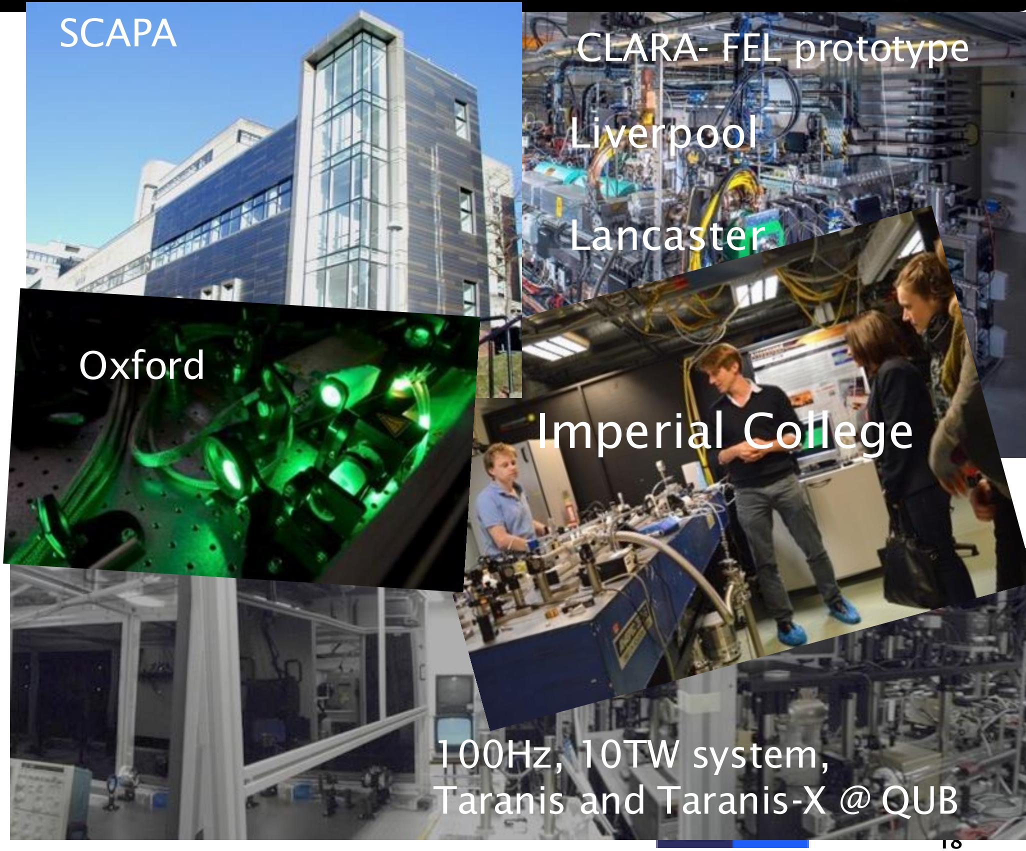


Plasma Wakefield Accelerator Research 2019–2040

A community-driven UK roadmap compiled by the Plasma Wakefield Accelerator Steering Committee (PWASC)

March 2019

Bernhard Hidding, Simon Hooker, Steven Jamison, Bruno Muratori, Christopher Murphy, Zulfikar Najmudin, Rajeev Pattathil, Gianluca Sarri, Matthew Streeter, Carsten Welsch, Matthew Wing, & Guoxing Xia



A large (international) collaboration is involved in building EPAC