Plasma Acceleration at EPAC

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Science and Technology Facilities Council

Extreme Photonics Applications Centre

- £88M centre for applications of laser-driven sources in industry, medicine, security etc.

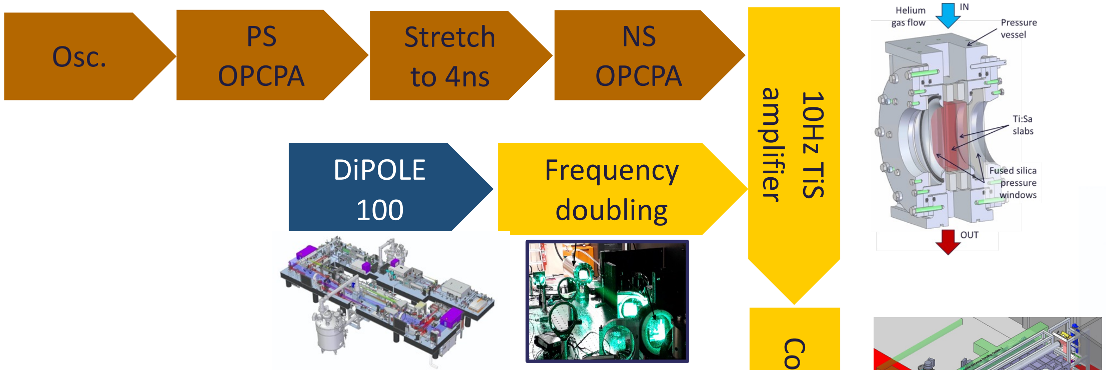
- LWFA driven beams at 1PW, 10Hz: Up to 10GeV beams, x-rays

- Significant Industrial backing based on proof-of-principle tests

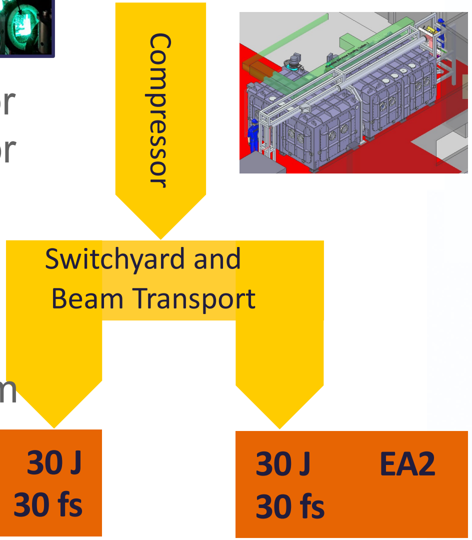
- Significant UK investment in plasma accelerators

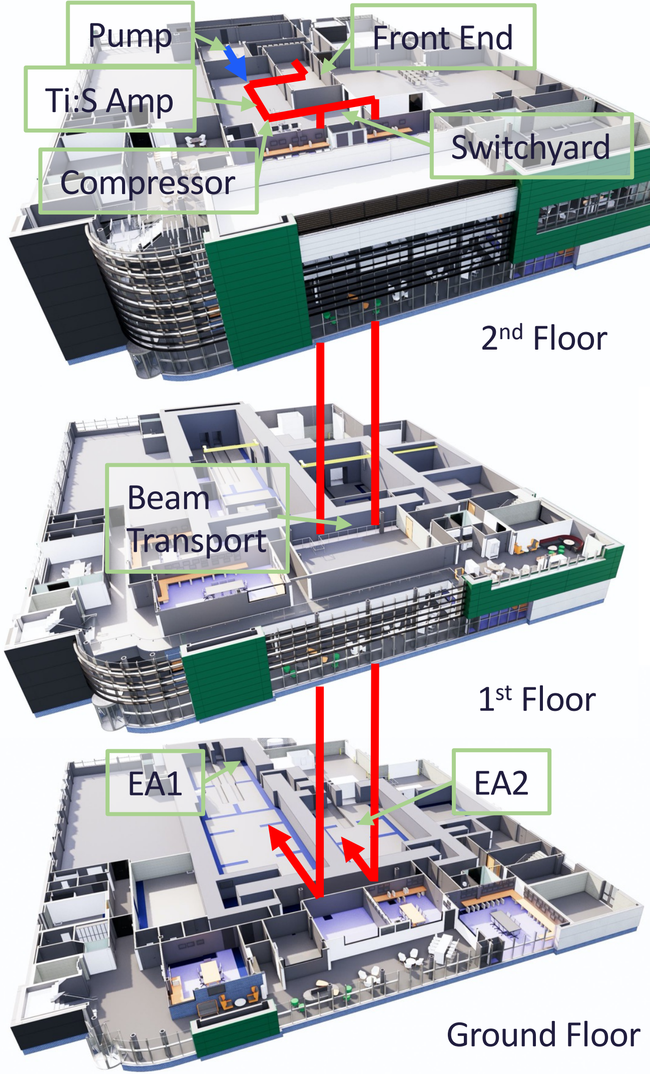
Building completed; installations ongoing; first operations in 2025

EPAC Facility Schematic

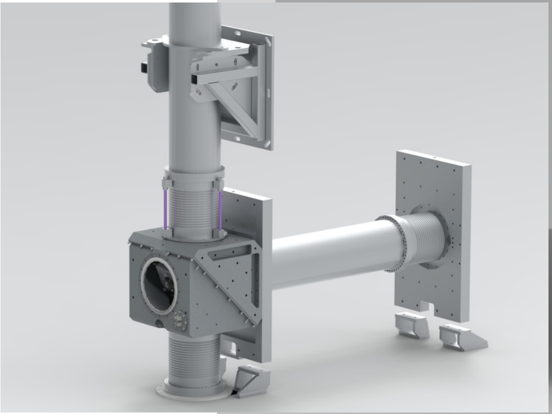


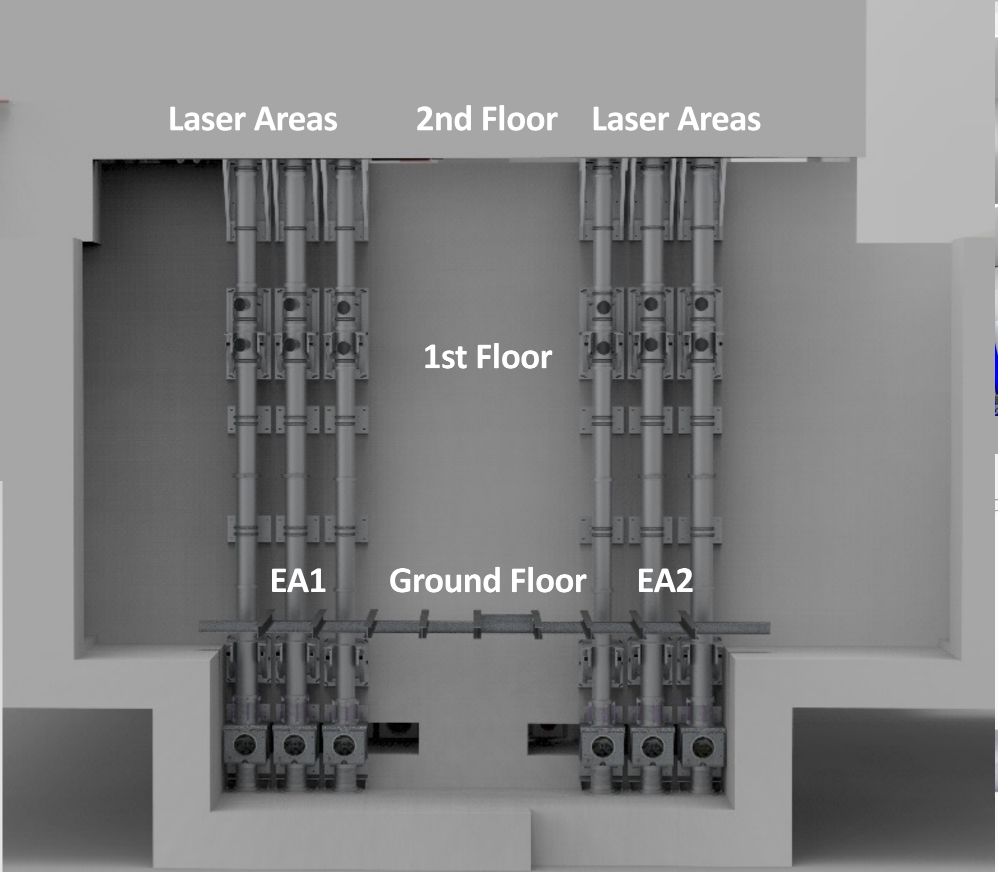
- Hybrid amplification scheme: OPCPA for bandwidth for front-end and then Ti:S for energy.
- Pump for Ti:S is CLF developed 100J DiPOLE system.
- Additional space for future laser and experimental areas (eg. a 100Hz system under development)

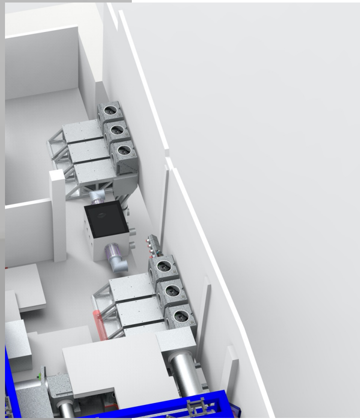


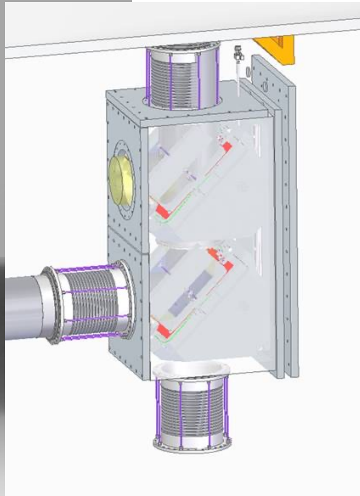


Beam Transport

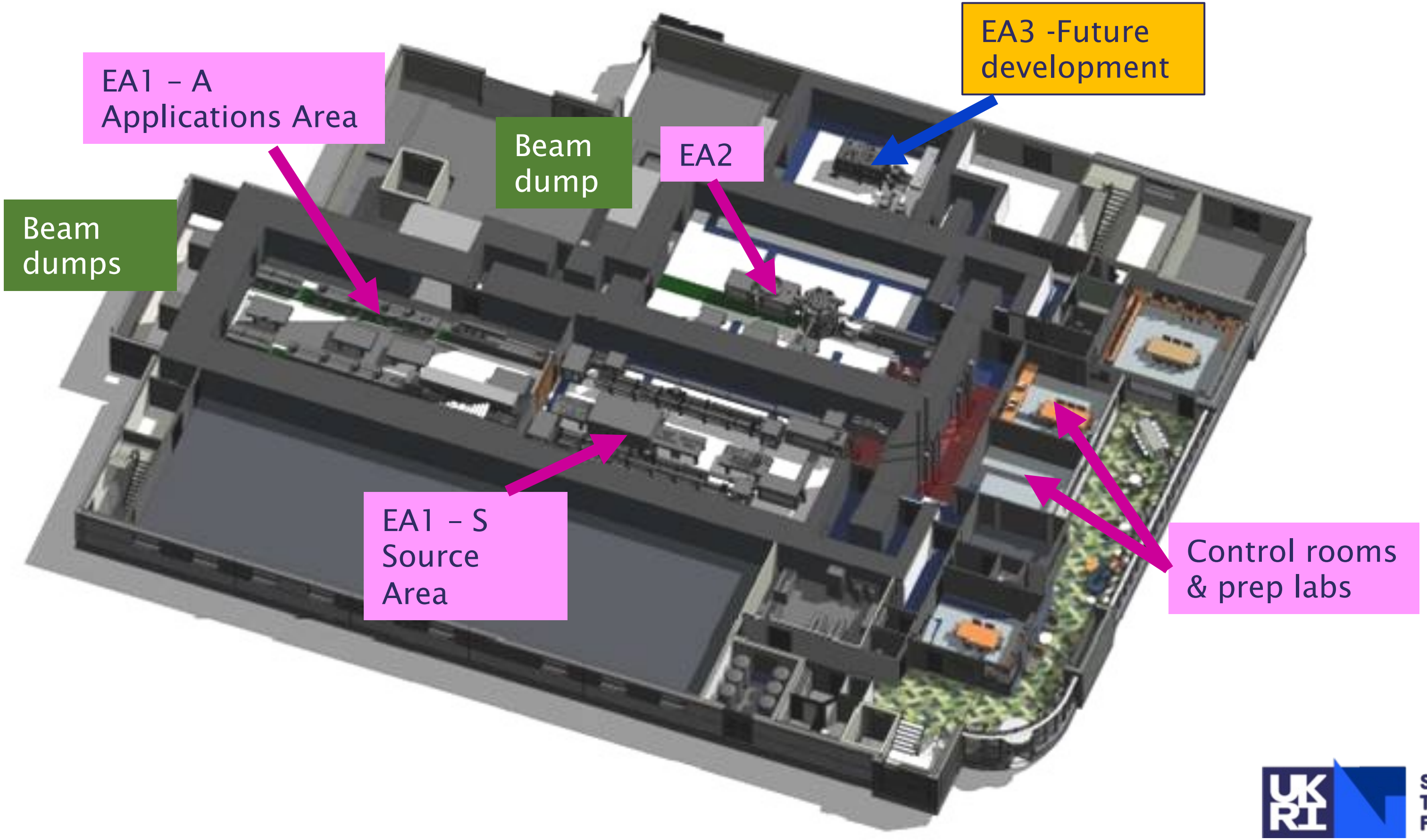






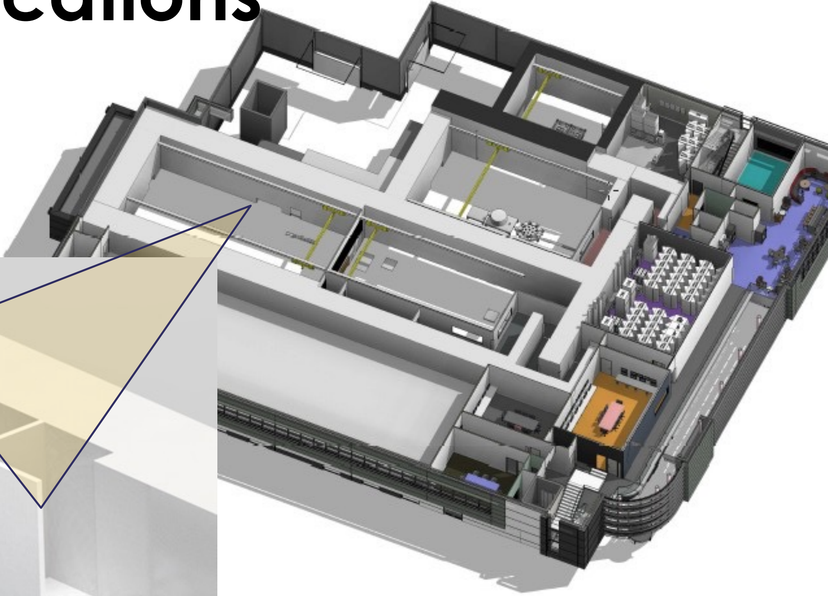


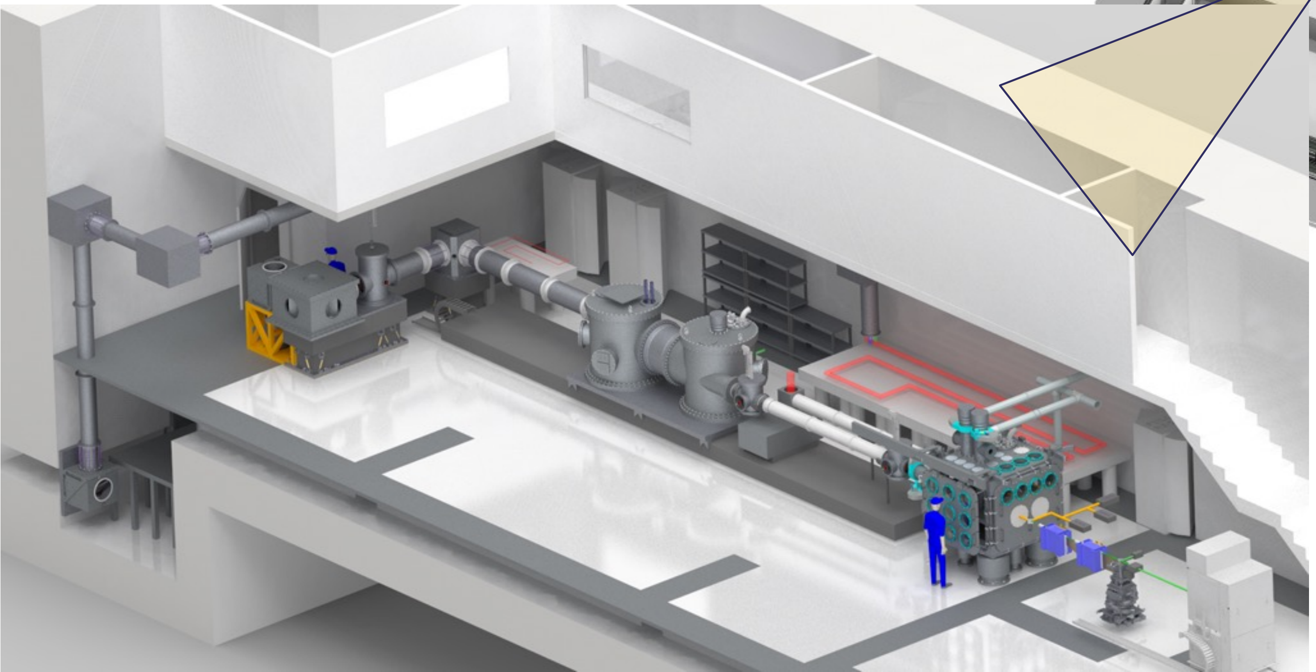
Shielded Experimental areas on the ground floor



Experimental Area 1 will be configured for LWFA research and applications

- Maximum focal length 14 m (*f* / 65)
- Laser a_0 ~ 1.8, expect up to 10 GeV electron beams





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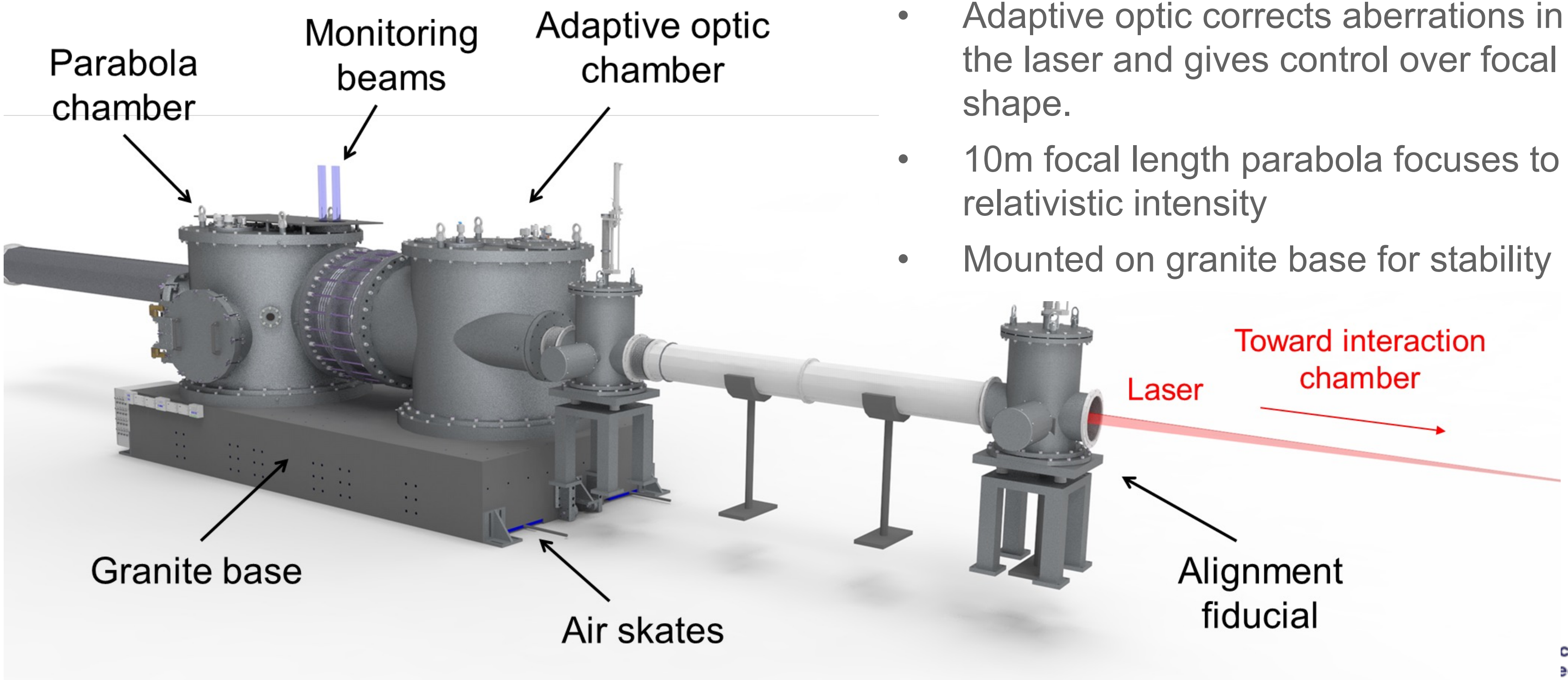
EA1 – Focusing chamber



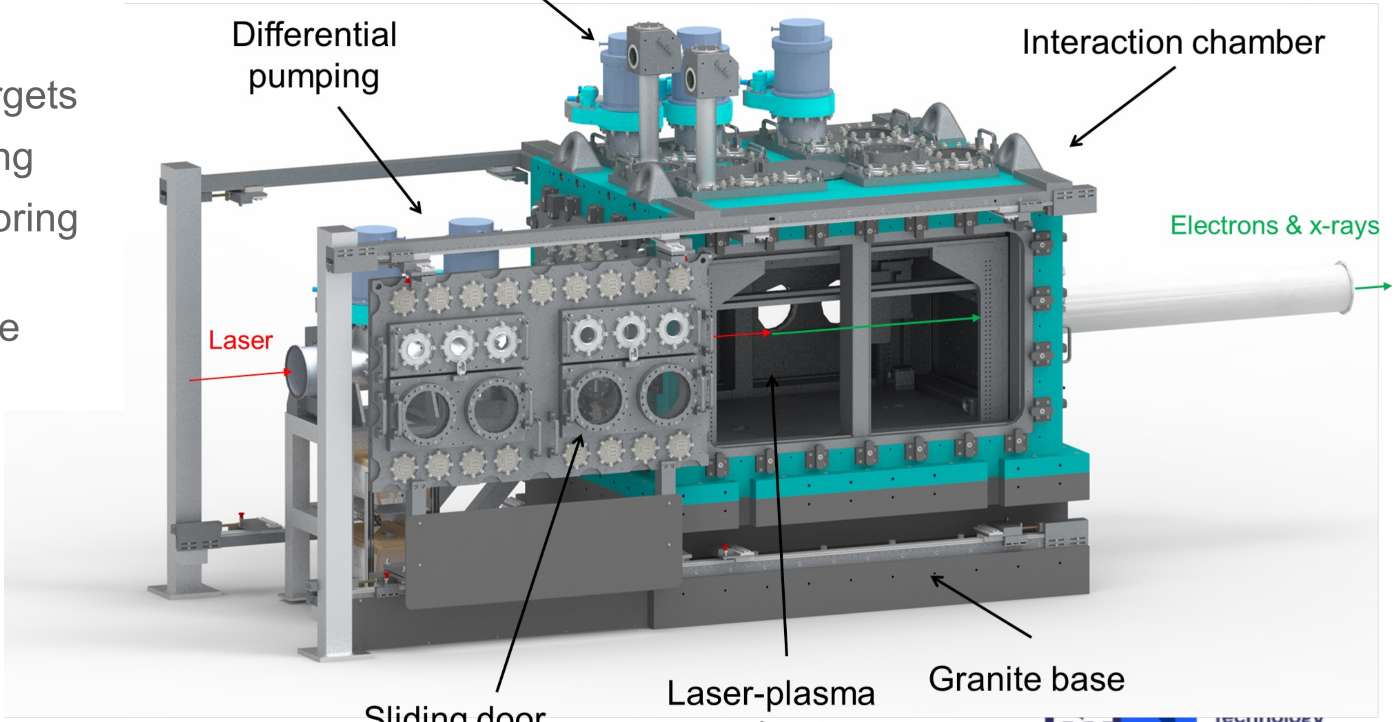
EPAC beam focused to a 50 micron spot

- Adaptive optic corrects aberrations in the laser and gives control over focal shape.
- 10m focal length parabola focuses to relativistic intensity
- Mounted on granite base for stability

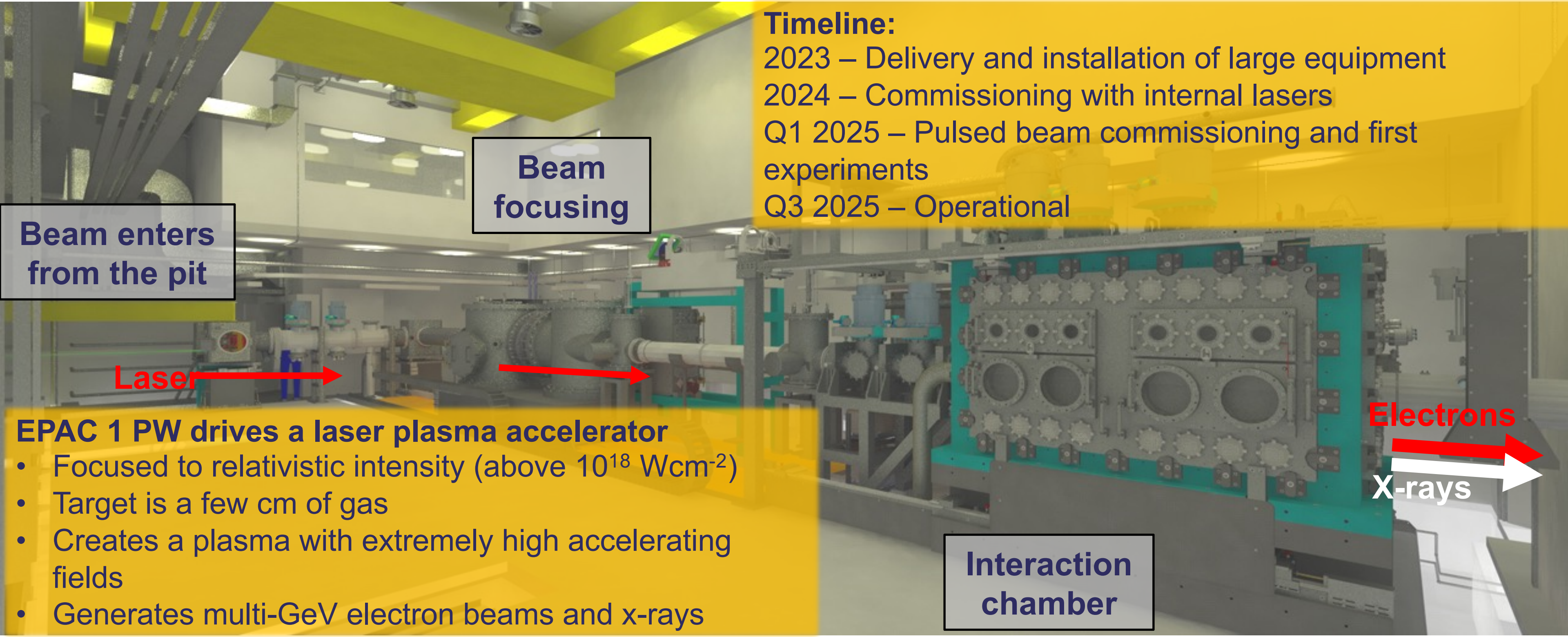
EA1 – Interaction chamber

Houses the laser-plasma accelerator

- Gas cell or gas jet targets
- Optical plasma probing
- Alignment and monitoring cameras
- Magnets to control the electron beam



Experimental Area 1 – Source



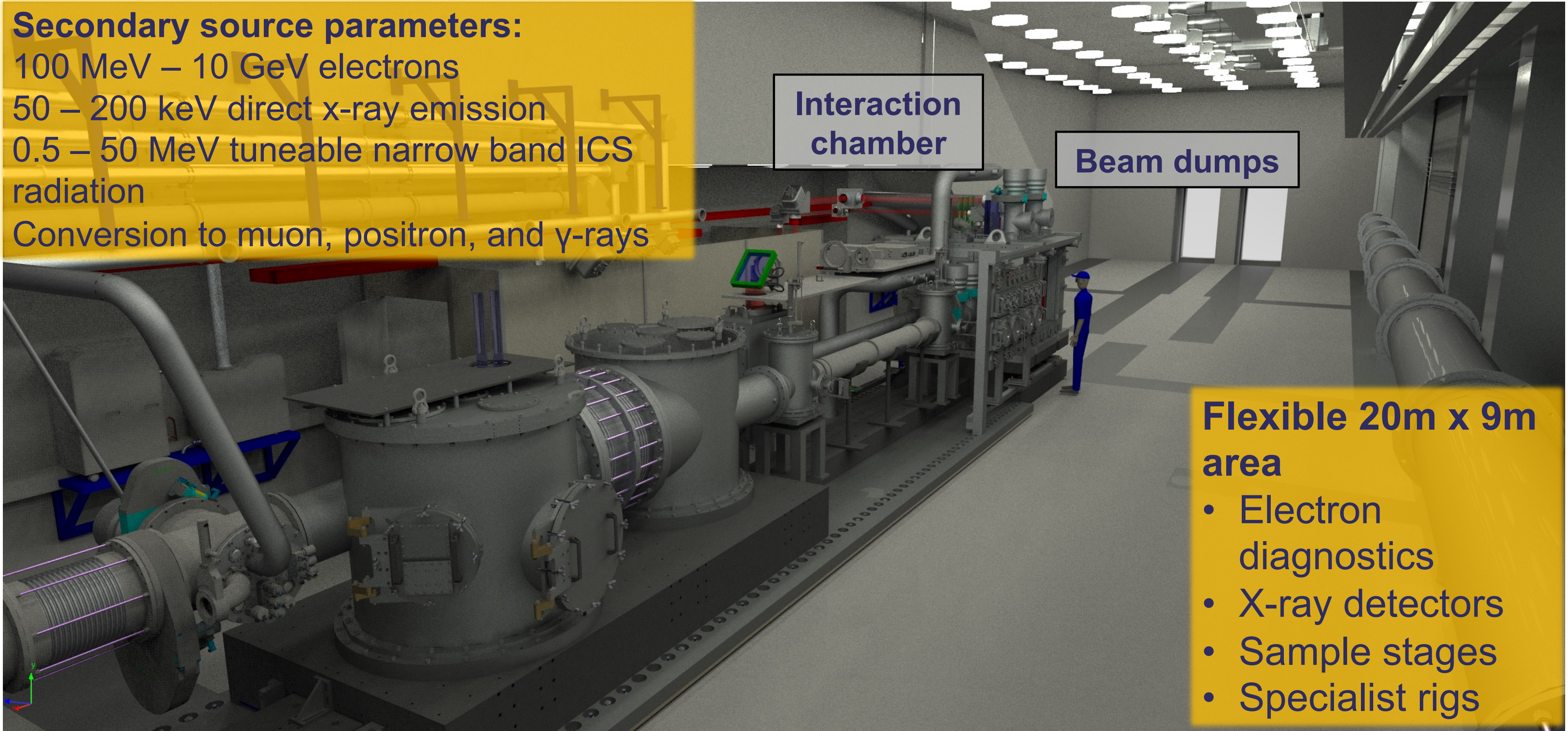
Timeline:

2023 – Delivery and installation of large equipment
2024 – Commissioning with internal lasers
Q1 2025 – Pulsed beam commissioning and first experiments
Q3 2025 – Operational

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

Experimental Area 1 – Applications



Secondary source parameters:

100 MeV – 10 GeV electrons

50 – 200 keV direct x-ray emission

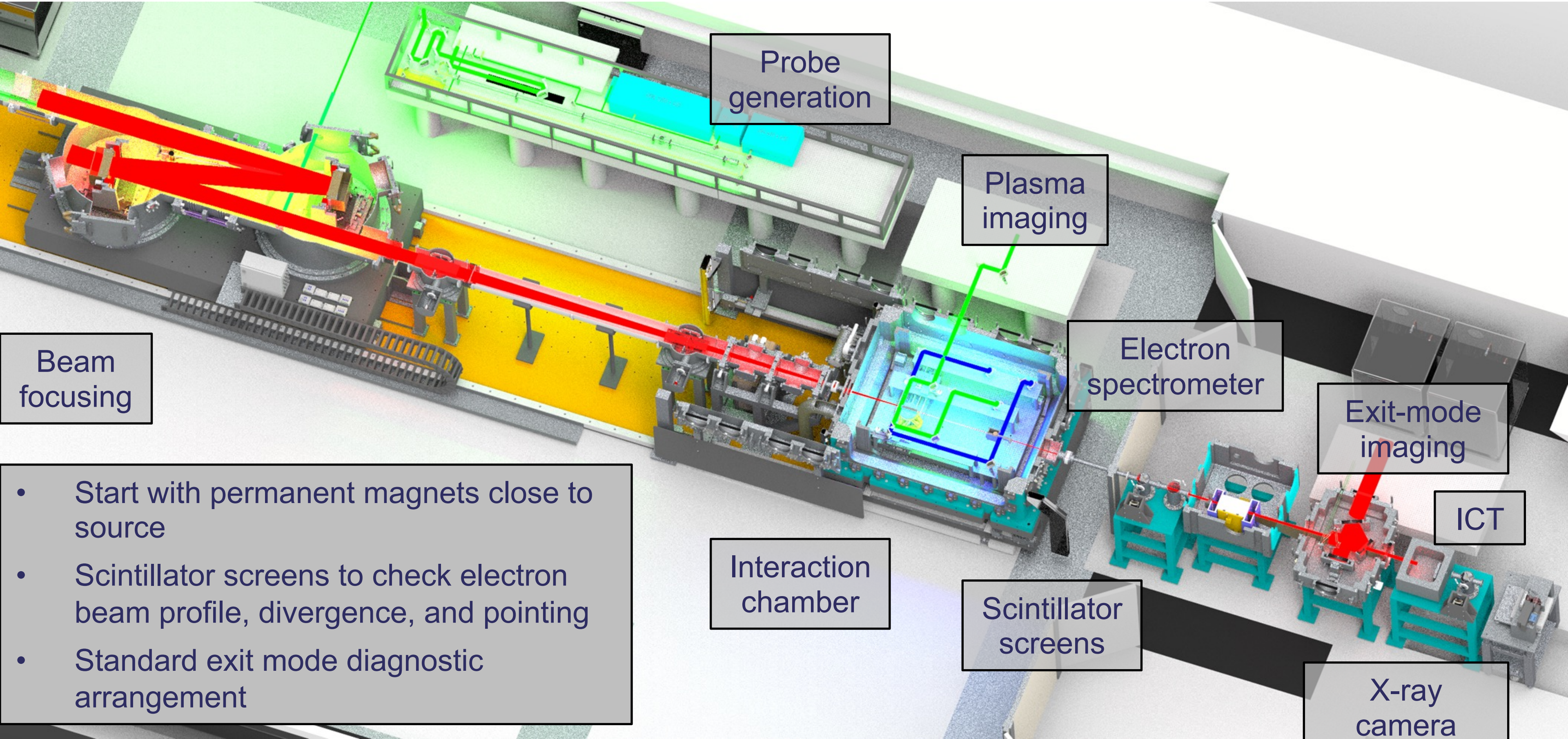
0.5 – 50 MeV tuneable narrow band ICS radiation

Conversion to muon, positron, and γ-rays

Flexible 20m x 9m area

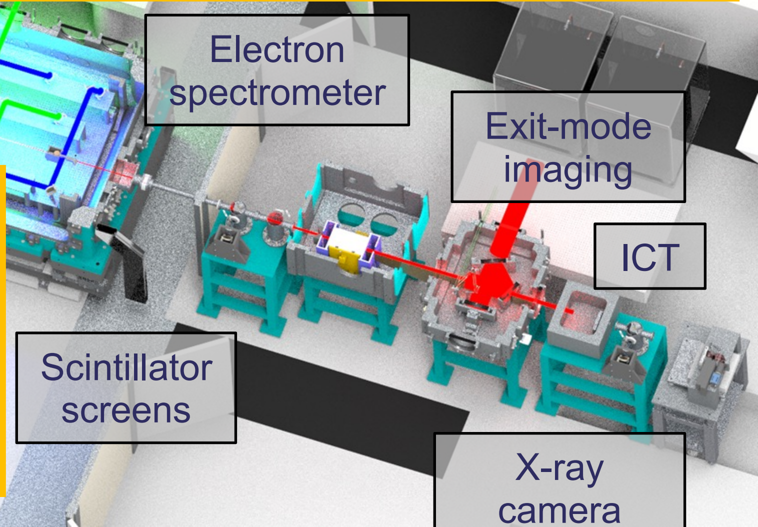
- Electron diagnostics
- X-ray detectors
- Sample stages
- Specialist rigs

Initial experiment layout



- Start with permanent magnets close to source
- Scintillator screens to check electron beam profile, divergence, and pointing
- Standard exit mode diagnostic arrangement

Initial experiment layout

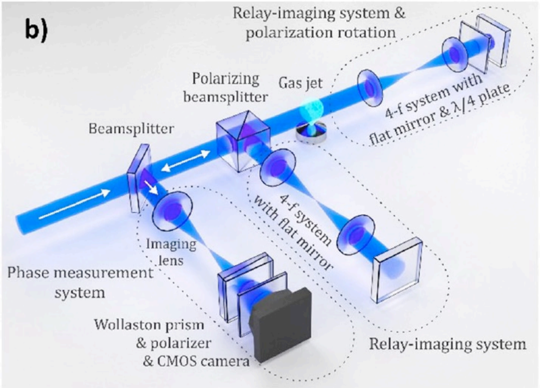


focusing

Gas density

4-pass imaging interferometer

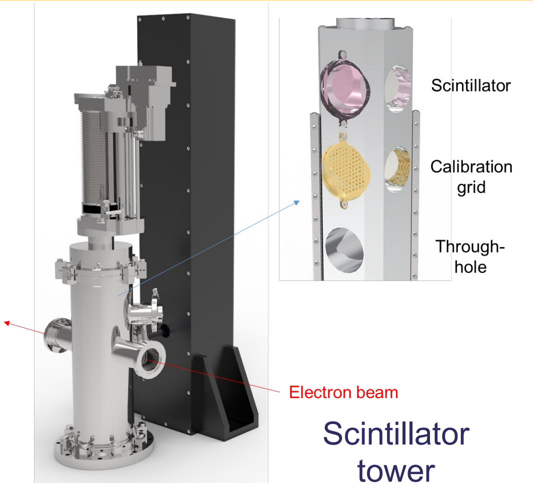
CW illumination



Karatodorov et al Sci. Rep. **11**, 15072 (2021)

Electron charge and beam profile

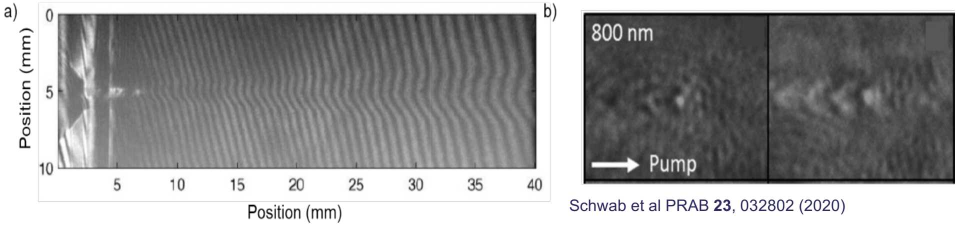
Bergoz Turbo-ICT



Scintillator tower

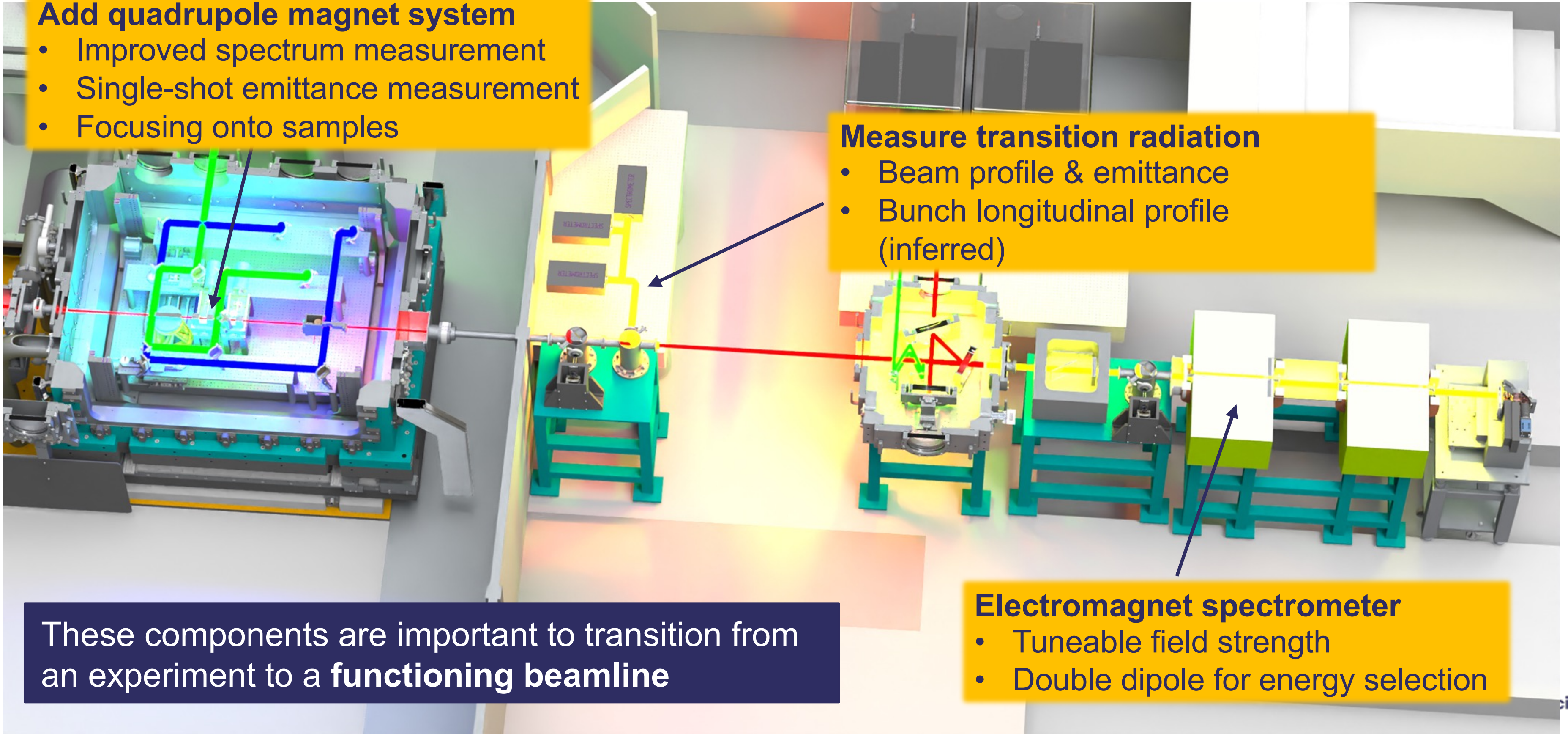
Electron density

High and low magnification imaging



Schwab et al PRAB **23**, 032802 (2020)

Electron beamline development



Add quadrupole magnet system

- Improved spectrum measurement
- Single-shot emittance measurement
- Focusing onto samples

Measure transition radiation

- Beam profile & emittance
- Bunch longitudinal profile (inferred)

Electromagnet spectrometer

- Tuneable field strength
- Double dipole for energy selection

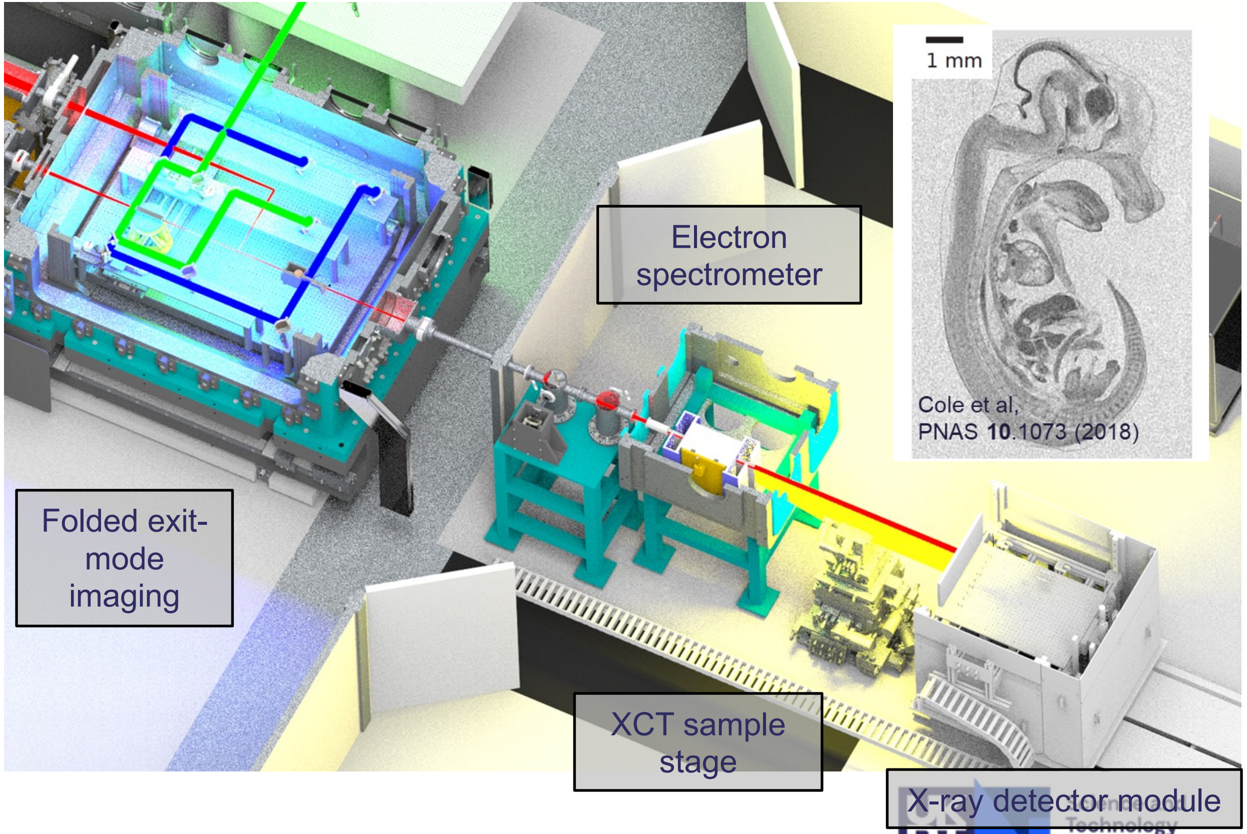
These components are important to transition from an experiment to a **functioning beamline**

Proof of Concept: x-ray/gamma ray tomography

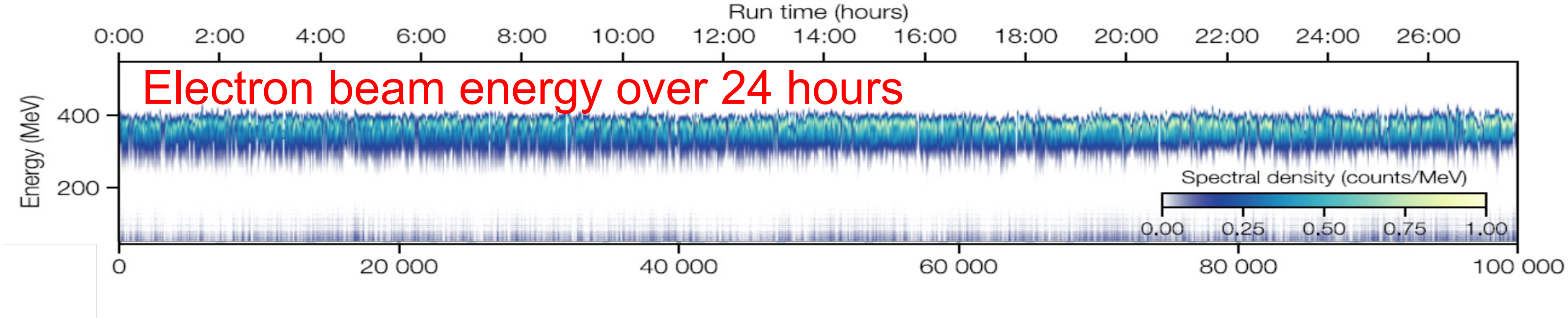
High resolution tomography

- Optimise phase contrast imaging
- Show deep penetration (MeV)
- High resolution
  - Micron @ 100 keV
  - 50 micron @ MeV
- Demonstrate fast XCT scanning (~ minutes)

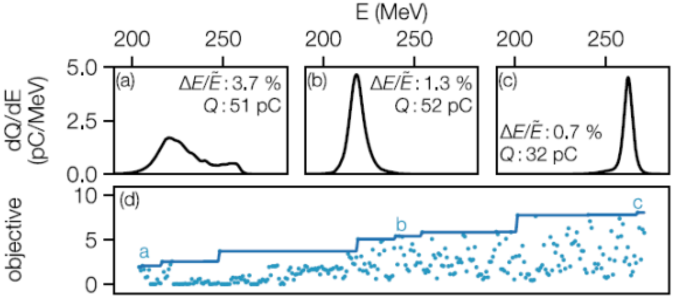
Relatively straightforward XCT demonstrations will highlight USPs of LPA x-ray sources

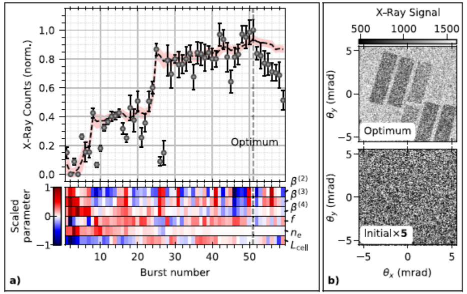


Stable LPA operation over extended periods



They can be optimized with Machine Learning loops





6-dimensional LWFA optimisation

Laser pulse shaping and varying gas target parameters optimises the specified property (e.g. electron energy, x-ray flux etc)

Maier et al PRX **10**, 031039 (2020);
Jalas et al PRL **126**, 104801 (2021)

Shalloo Nature Comm. 11, 6355 (2020)

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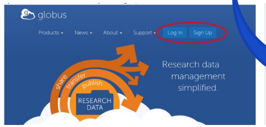
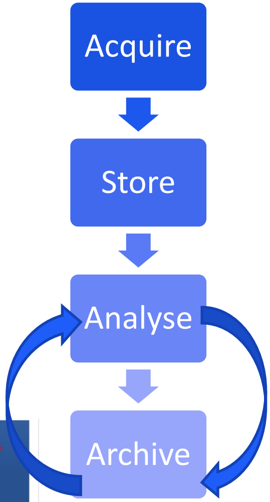
EPAC Data Management

- EPAC's output is *scientific data*
- Many diagnostics and detectors producing data at high repetition rates
  - Current estimates ~ 5 GB/s peak – 10Hz, if we move all data through system
- Data will be centrally held and accessed through STFC-cloud/HPC clusters
  - Annual data volume could be 1-2 PB at the start
- Data analysis packages are being developed
  - Remote analysis may be necessary because of data volumes
  - Not all users will have the capability for specialised data analysis tools (eg. Computer Tomography)
- A new regime for CLF but Campus has expertise





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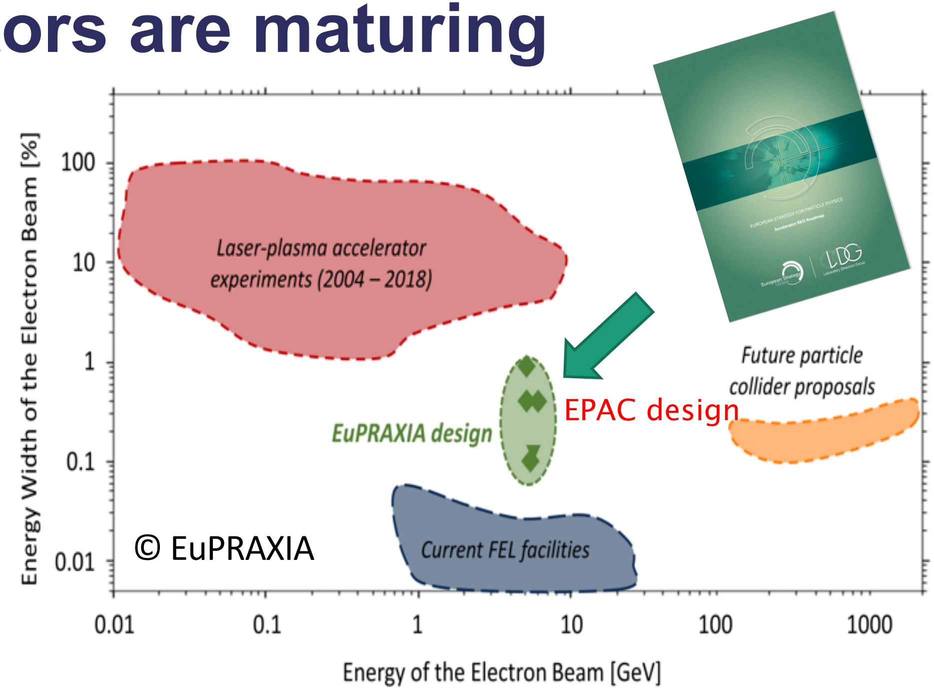
Summary
Laser-driven accelerators are maturing

- LWFA has produced Multi-GeV beams witl reasonably low emittance, low energy spread, and high brightness but not simultaneously and continously

- Producing high-quality beams from LWFA is central to proving their suitability for future large-scale facilities (eg. FELs, colliders…)



EPAC hopes to provide some milestones along the way, along with exploiting their applications

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