The major upgrade projects EPAC and Vulcan 20-20

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Contents

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

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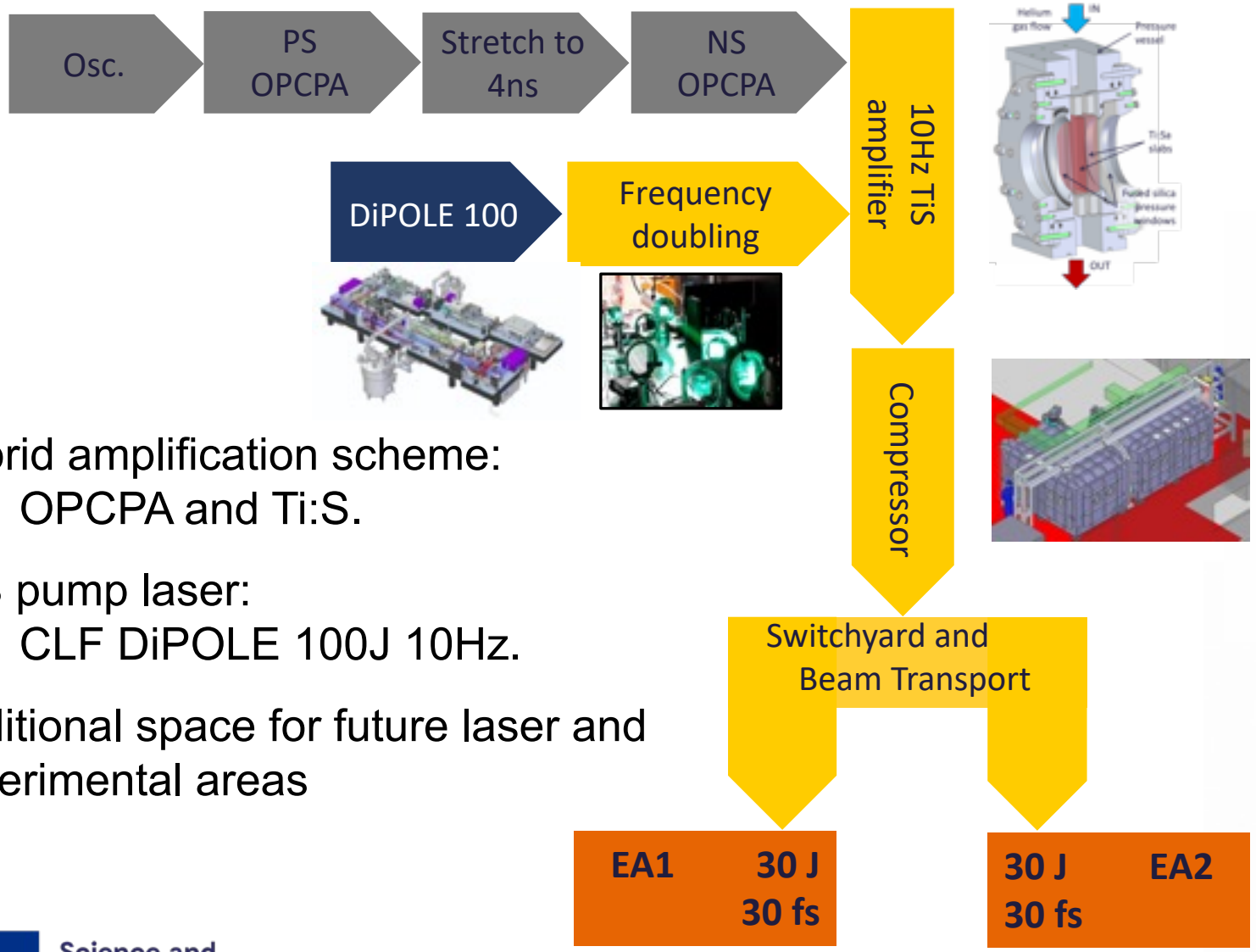
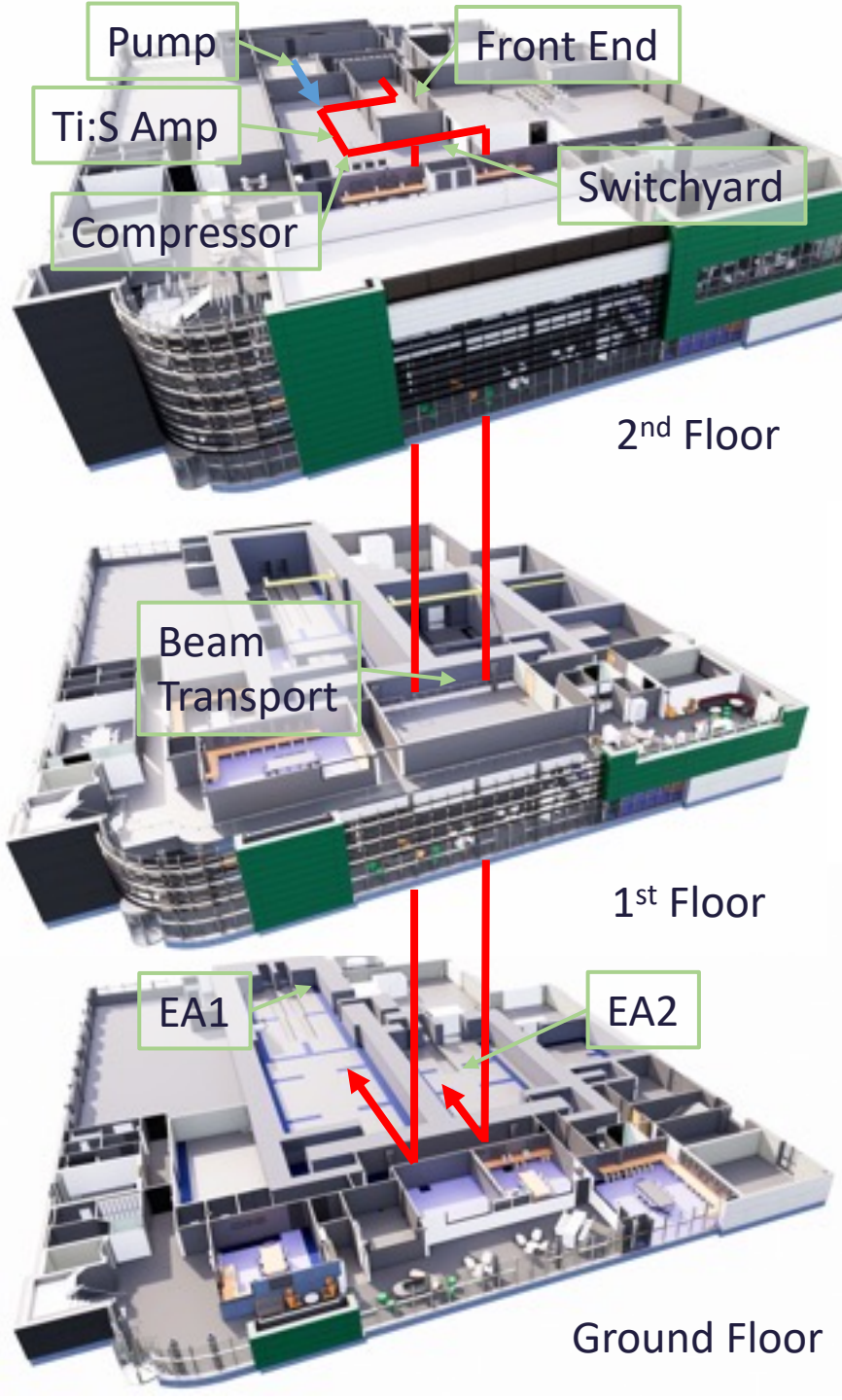
EPAC Facility Schematic



- Hybrid amplification scheme:
  OPCPA and Ti:S.
- Ti:S pump laser:
  CLF DiPOLE 100J 10Hz.
- Additional space for future laser and experimental areas



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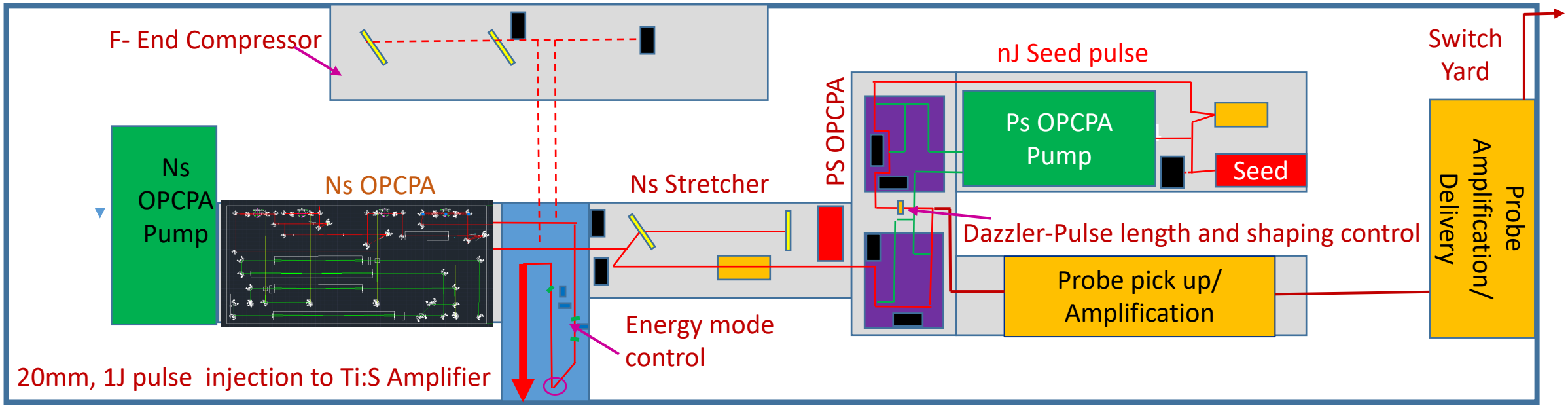
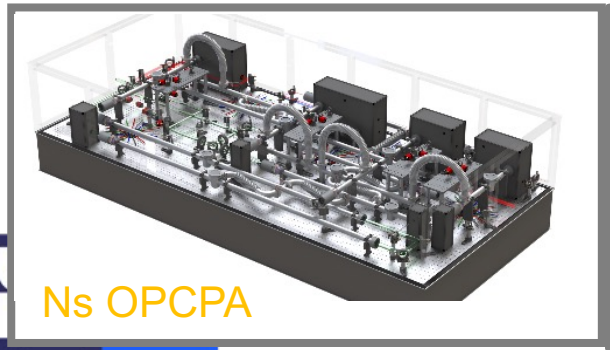
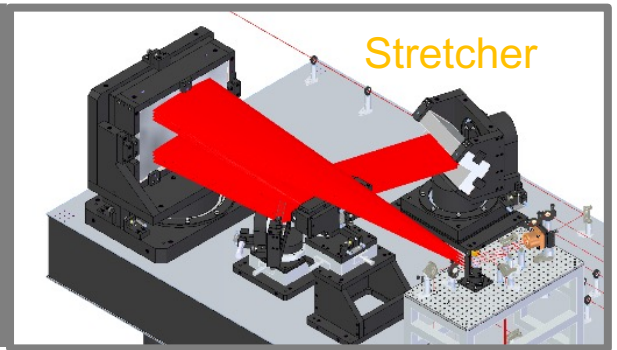
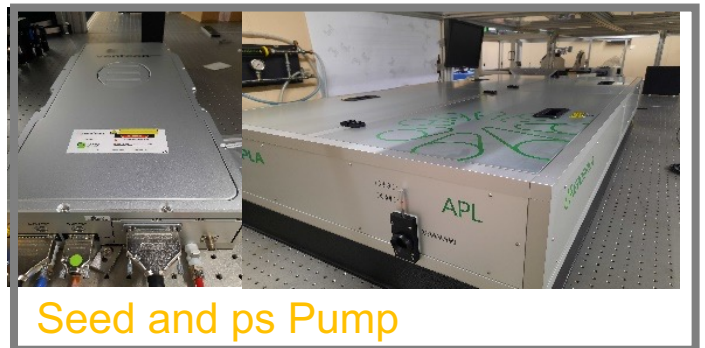
EPAC Front-end Layout

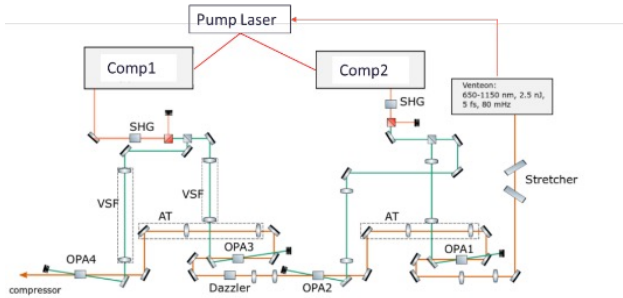
- Designing the capability within the front end to deliver a probe beam ~150 mJ
- Key components have arrived, construction for ps preamplifier underway
- Contrast baseline 10^{-12} @ -100ps



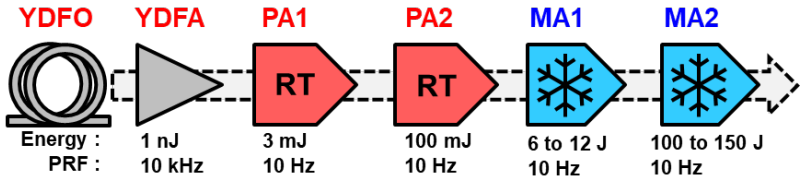


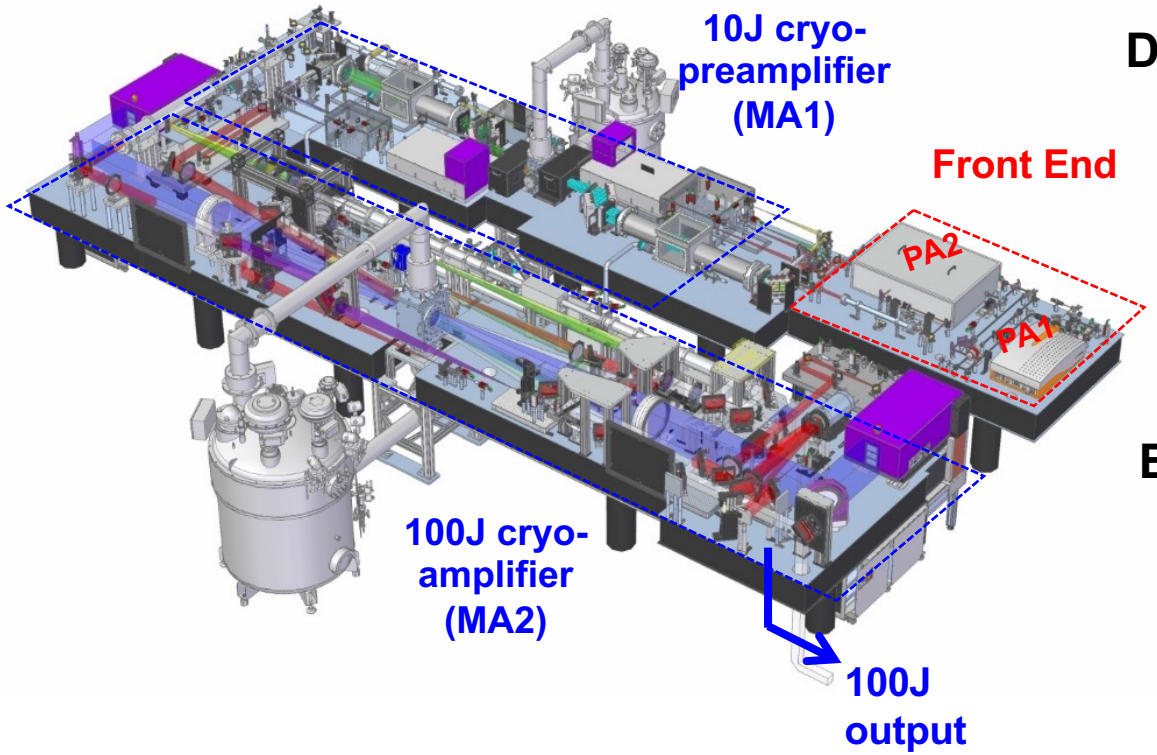






Pump laser for the main amplifier





DPSSL technology CLF based – 'DiPOLE' concept

- Diode-pumped Ceramic Yb:YAG slabs
- Face-cooled by cryogenic He gas

Demonstrated performance:

- Reached 145J @10Hz
- DiPOLE 100 J @ 10 Hz for HiLASE, Czech Republic, Currently Operating
- D100X 100J @ 10 Hz. Under commissioning at High Energy Density (HED) Instrument @ XFEL

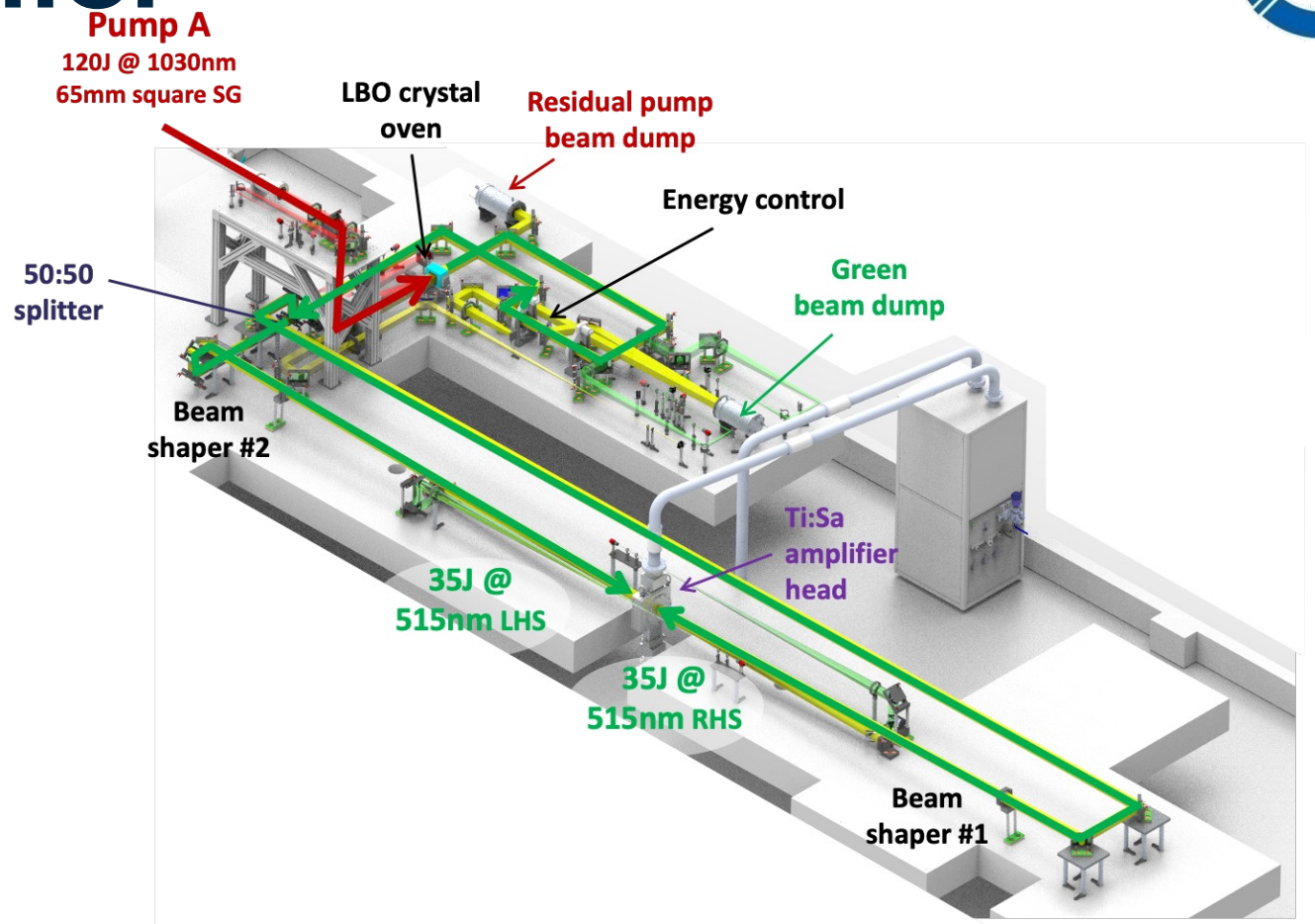
EPAC Design Parameters

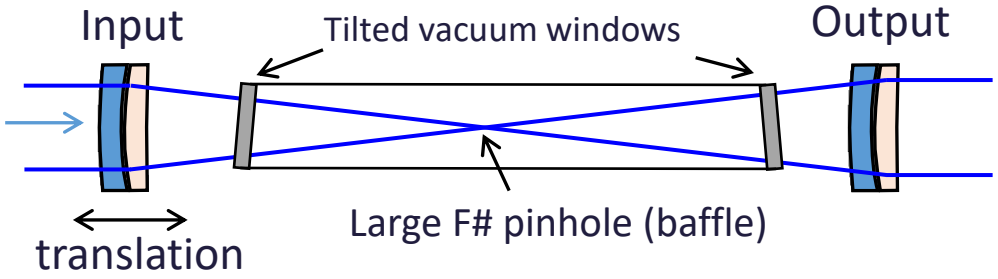
- 1030nm wavelength
- 120J, 75mm square beam
- 1 or 10Hz operation
- 15ns pulse duration, temporal shape
- Energy stability < 2.5% RMS `

Ti: Sapphire Amplifier

TiSa Multi pass amplifier

- 4-pass relay imaged scheme with achromatic telescope design.
- Amplifier pumped from both sides with energy recycling (single-pass absorption ~ 90%)
- Energy output ~30J for initial phase then ramp up ~50J
- Designed to operate @10Hz -@1 Hz
- Input lens translation on each pass to compensate for amplifier thermal lens
- Improved baffling in the propagation for stray light management
- Incorporation of pulse front tilt compensator
- Include adaptive mirror at the output

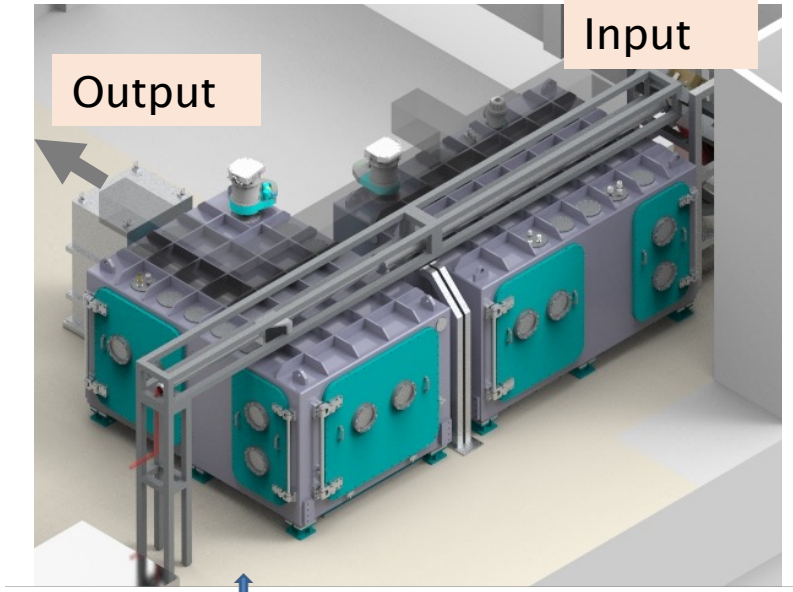


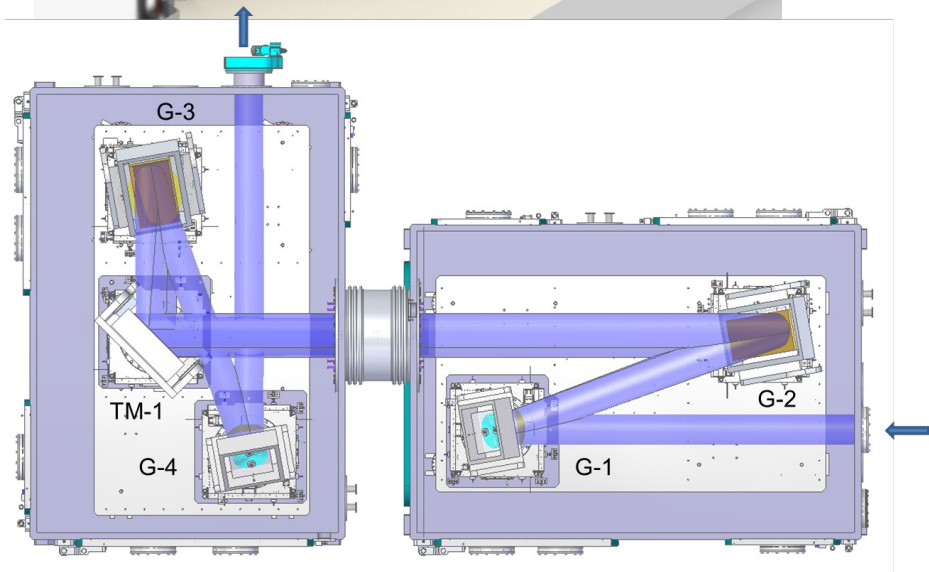


Compressor

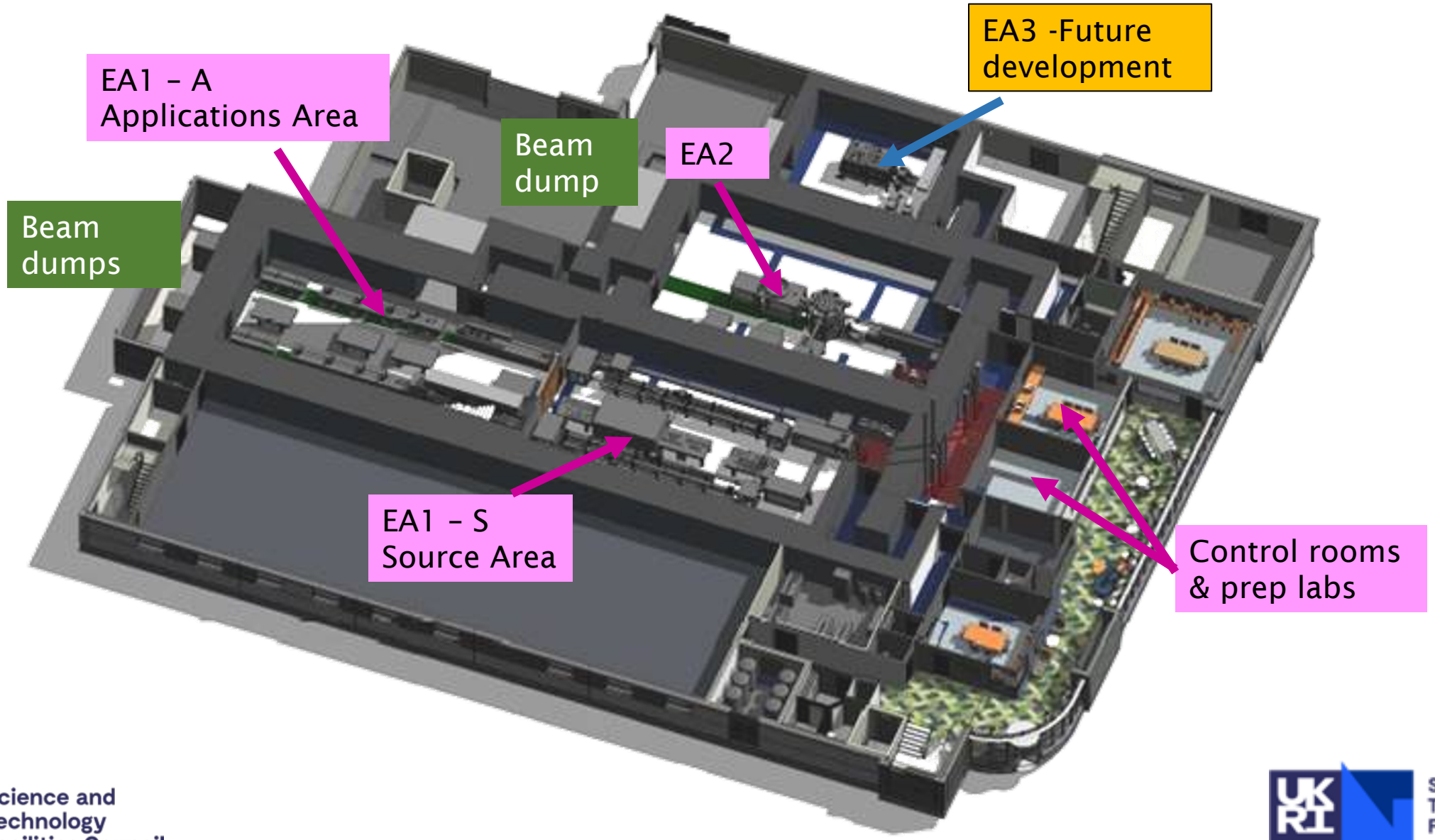
The compressor design: 4 Grating scheme at Littrow with an out-of–plane angle of ~ 10 degrees, will use 1480 l/mm gratings

- Compressor is formed by 2 sub-compressors in a L Shape design
- Input beam will be expanded to a 220mm beam diameter
- A multi-wavelength CW system will be used to align the compressor with a retro diagnostic channel.
- After compression will have a suite of diagnostics to characterise the pulse (duration, nearfield, spectral phase, contrast).

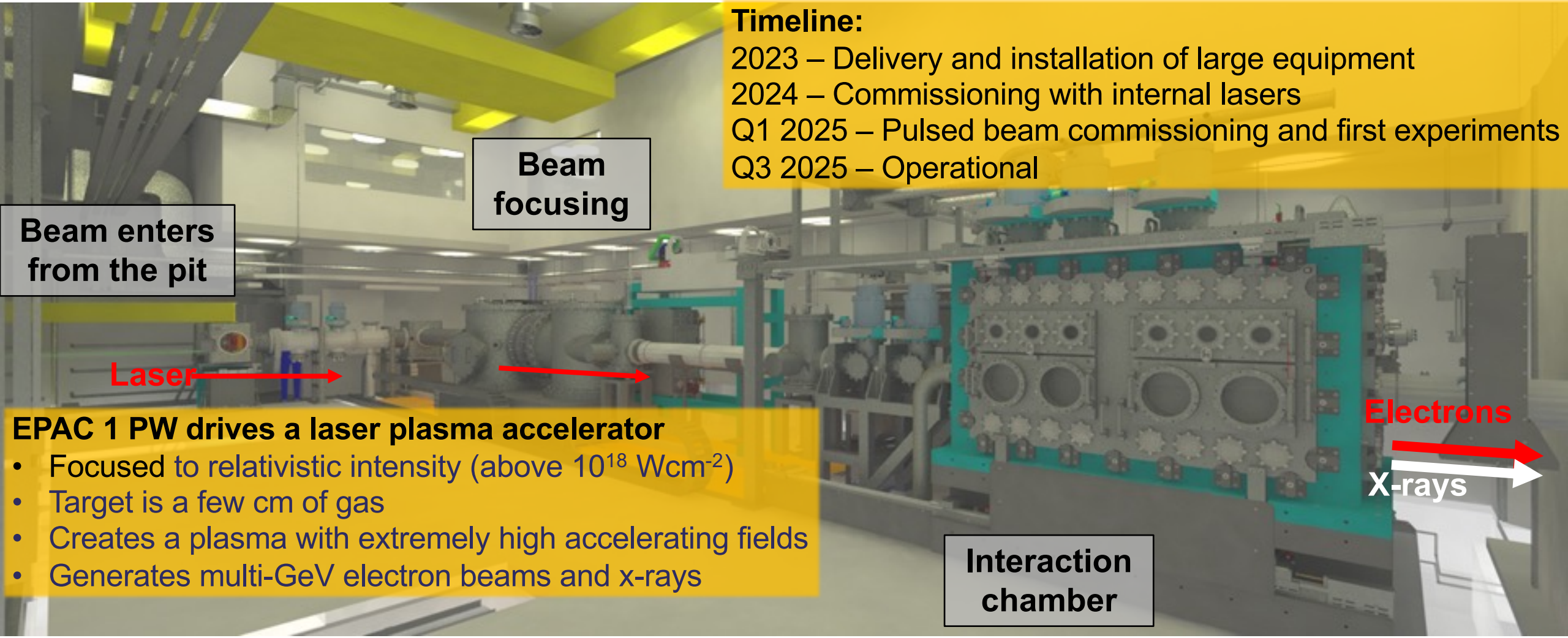




Experimental Areas at Grount Floot



Experimental Area 1



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

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Experimental Area 2

Short focus

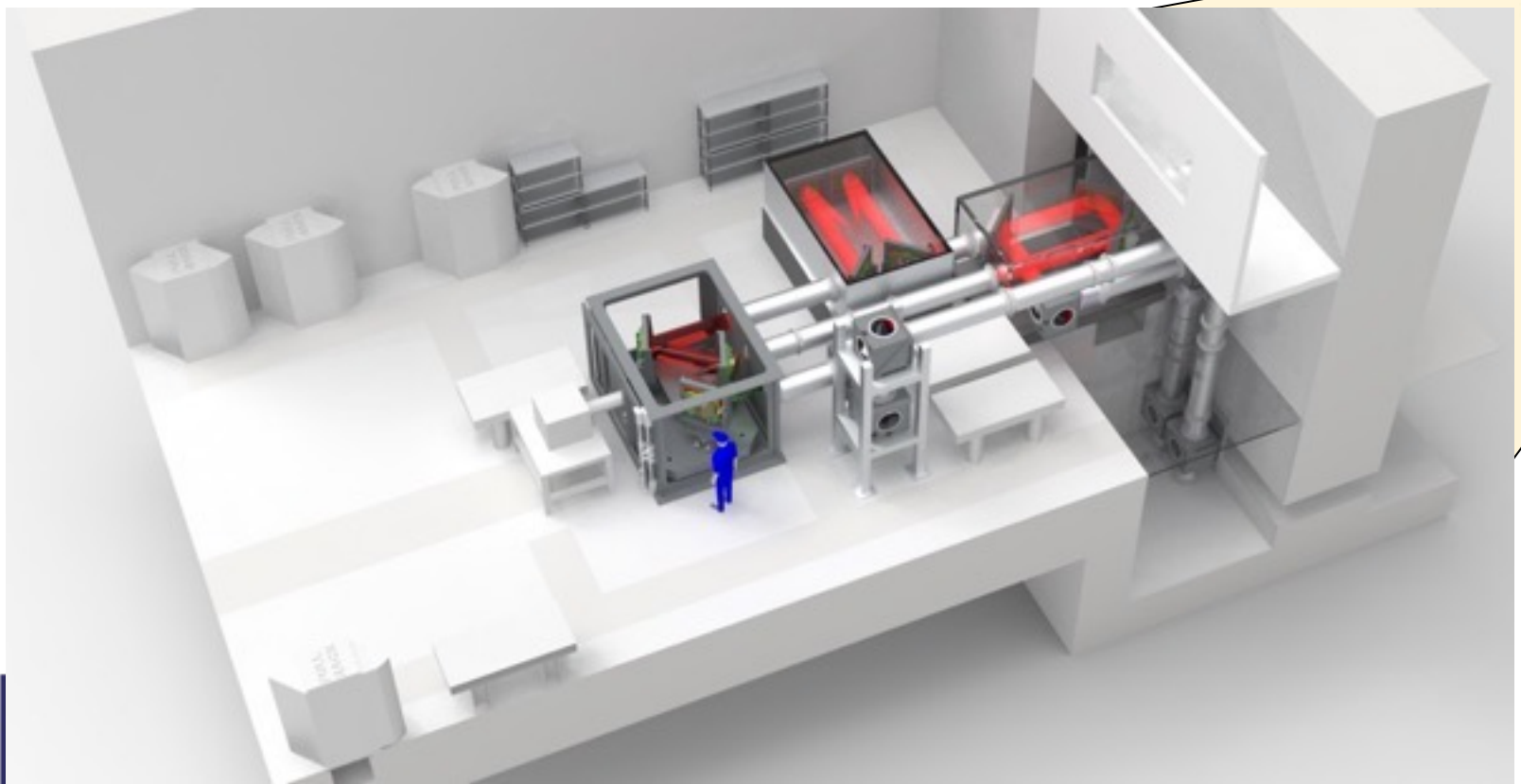
~$4x10^{21}$ Wcm^{-2} a0 ≈ 40

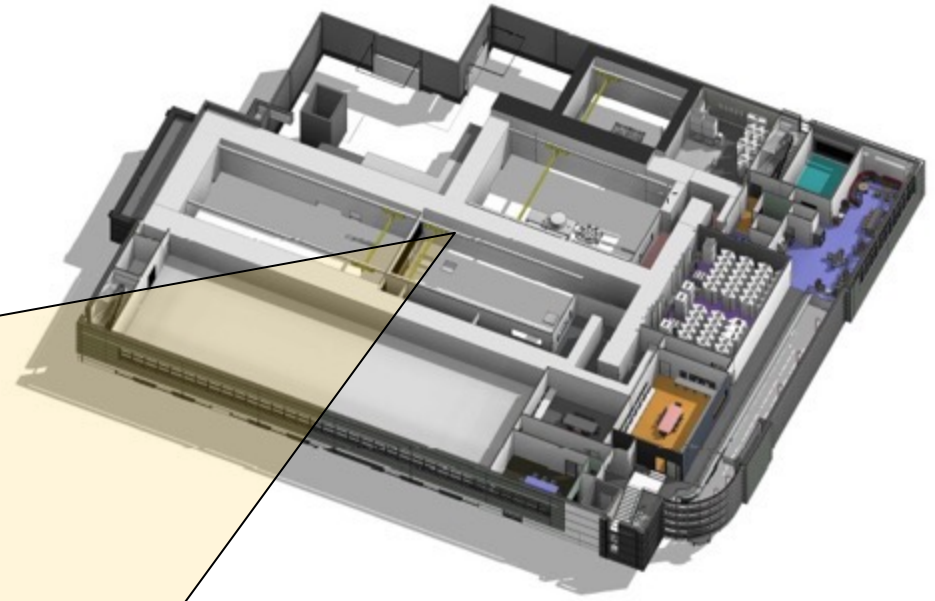
- RPA / RTA Proton/Ion acceleration (~ 100 MeV?)

Medium focus

~$4x10^{20}$ Wcm^{-2} a0 ≈ 14

- TNSA Ion acceleration
- Bremsstrahlung
- Thermal neutron production





Long focus

~$2x10^{19}$ Wcm^{-2} a0 ≈ 3

- LWFA source development
- Betatron source for imaging and probing

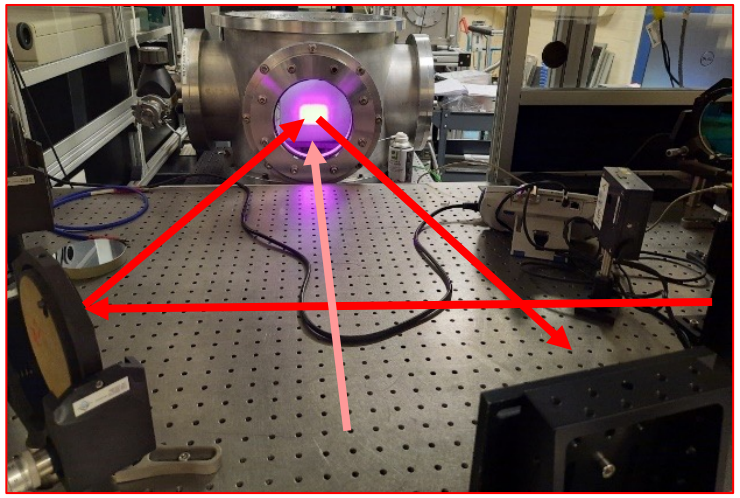
Compressor Gratings

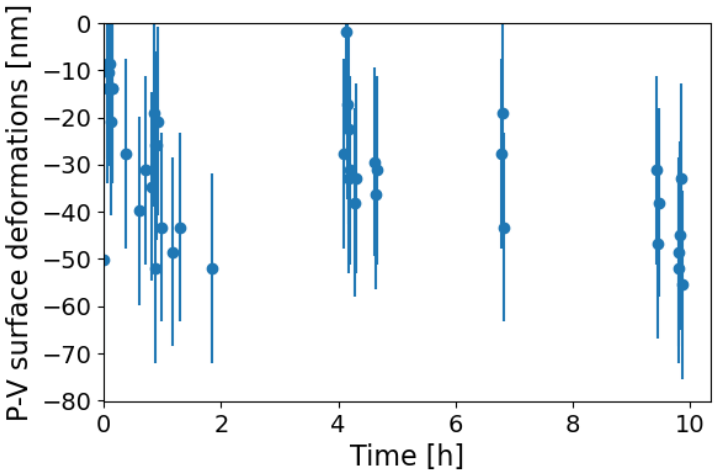
Require 1480 l/mm gratings with good diffraction efficiency >90% Δλ 100nm centred at 800 nm. They need to have be robust for operations @ 10Hz.

There are two options: Cooled Gold coated and MLD coated gratings.

- Developing a cooled substrate approach for gold gratings
- Investigating MLD grating - good efficiency for 800nm (above 95%)
  - Testing operational requirements for LiDT and diffraction efficiency
  - Medium size grating will be tested in Gemini
- Polarisation different between hybrid and gold. This has been taken into account in design of EA2 specifically

Cooled Substrate Up to 150W of CW 800nm, T=21 C





Surface displacement below 80nm as modelled

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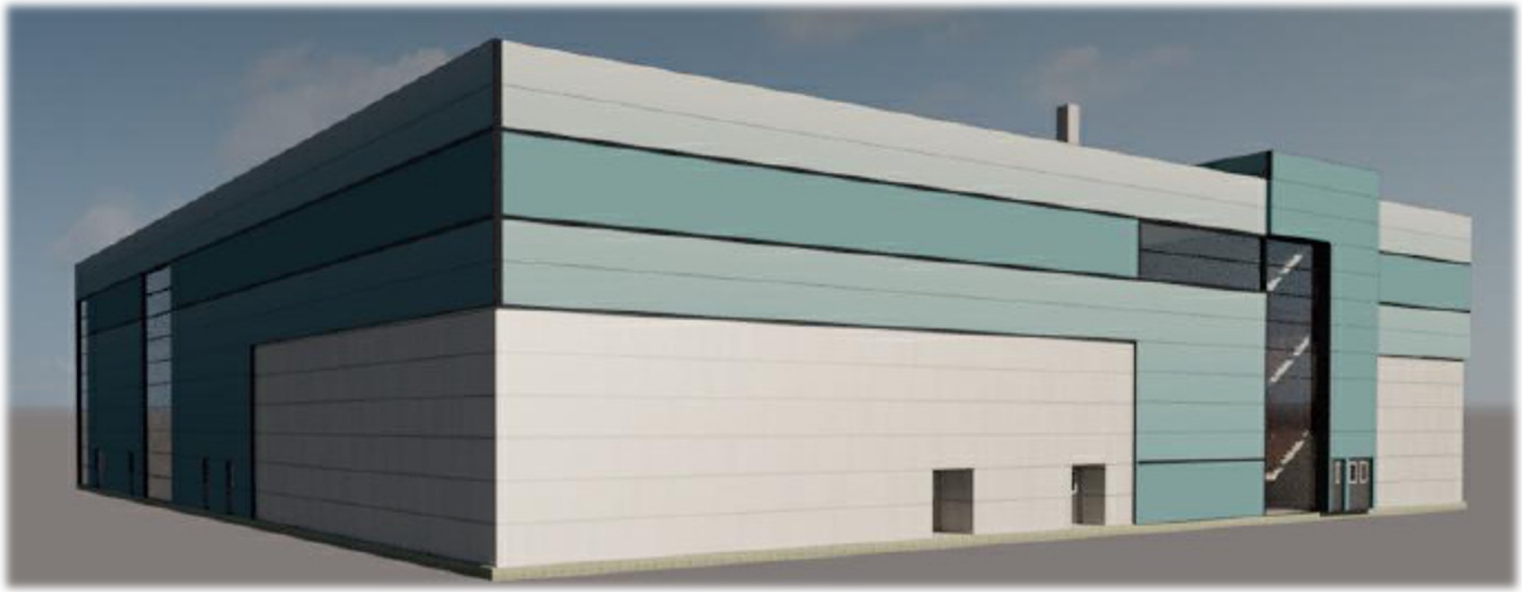
Vulcan 20 – 20 laser

Major upgrade of Vulcan laser for basic high intensity research and fusion oriented experiments

Overall budget £80M, with ~£20M for the building expansion

Main Beamlines:

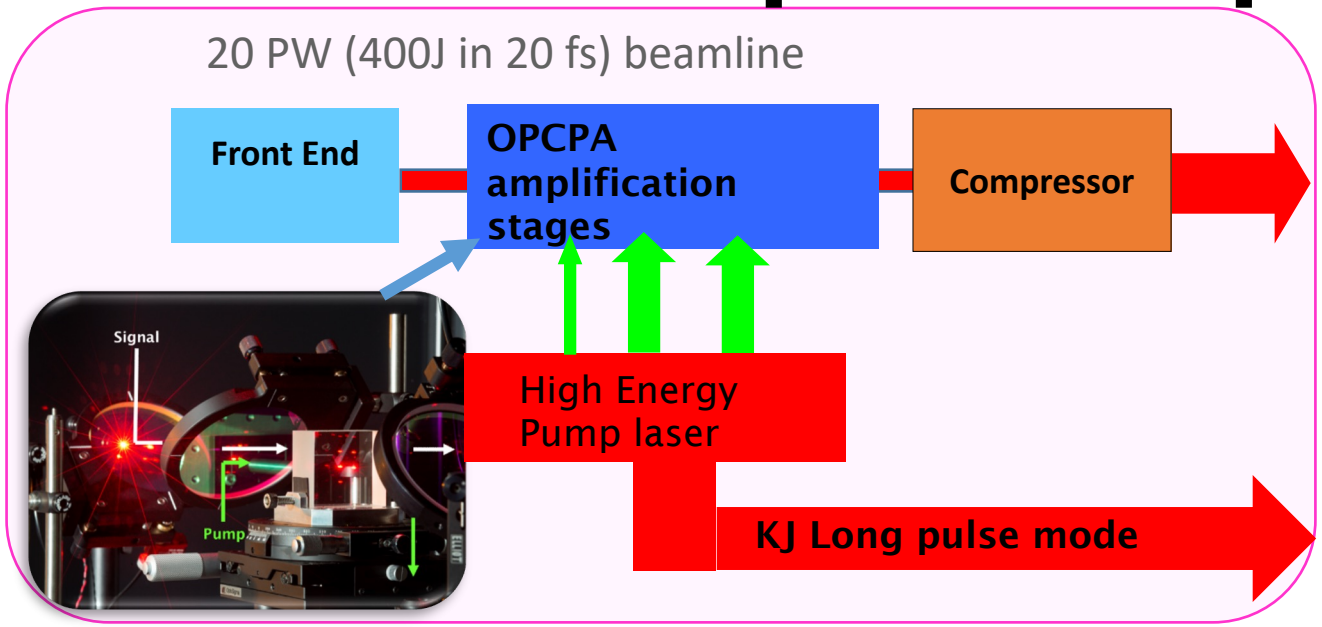
- 20PW:
  400J is 20fs after compressor
  rep. rate 5min
- Long pulses:
  6 beams (rep. rate 30min)
  aux beam (rep. rate 30min)
  3 pump beams (rep. rate 5min)



Auxiliary beamlines:

- VOPPEL: 30J in 30fs, rep. rate 5min
- 100TW: 80J 1ps or 200J in 10ps before compressor, rep. rate 20min (TAW Beam 8)

20PW short pulse capability



Based on original 10PW concept

Fully OPCPA capable to deliver 400J in 20fs

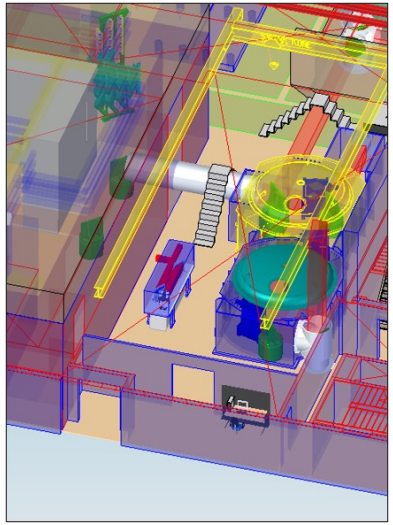
Two crystals under evaluation: DKDP and LBO

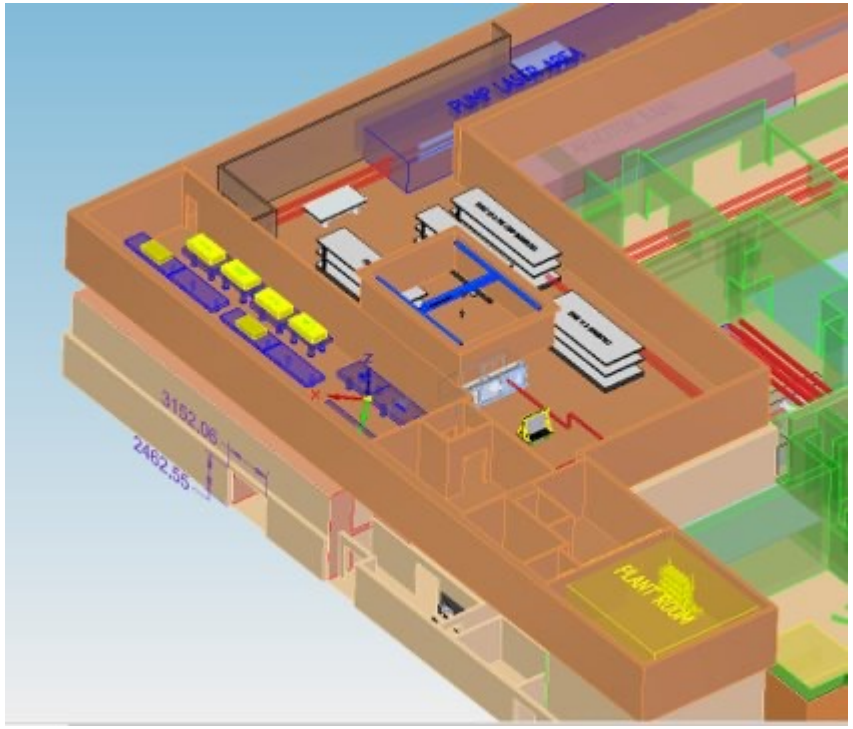
Two Nd:Glass gas-cooled disk amplifier chain used as laser pump, aiming to 2kJ in SHG

Repetition rate fixed by the pump laser: expected 1 shot / 5 min

Front End, Pump lasers and OPCPA amplifiers on the second floor

Compressor and beam delivery on ground floor





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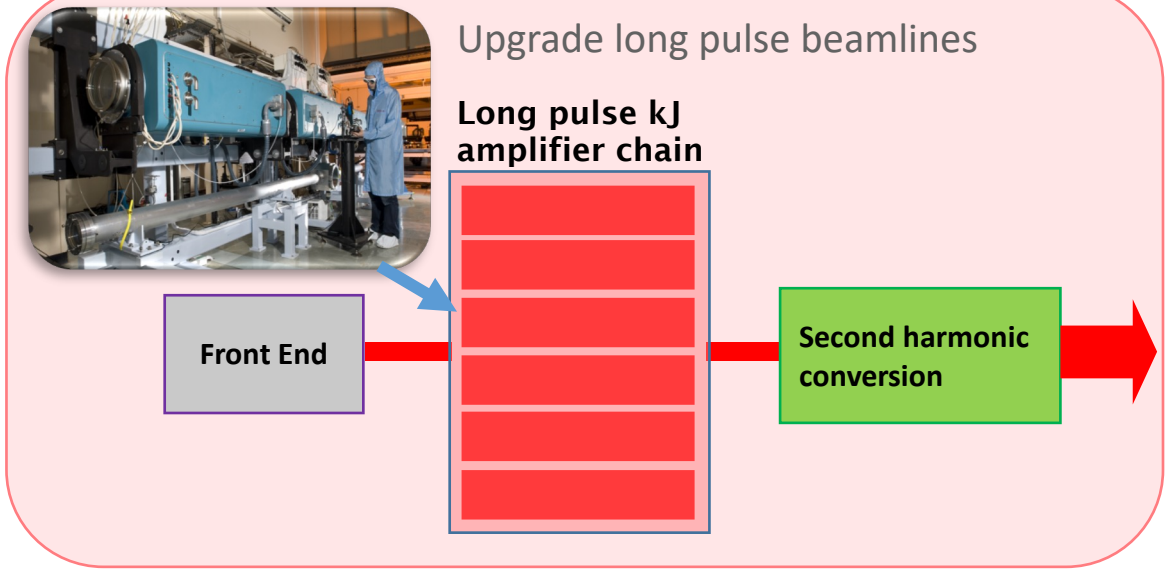
Vulcan 20-20 Long Pulse capability



6 long pulse beam to deliver up to 10kJ in IR with SHG prior to deliver to target

Based on existing and new 208 disk amplifiers

Temporal shaping capability

Repetition rate 30min

Broadband option under investigation (~5nm)

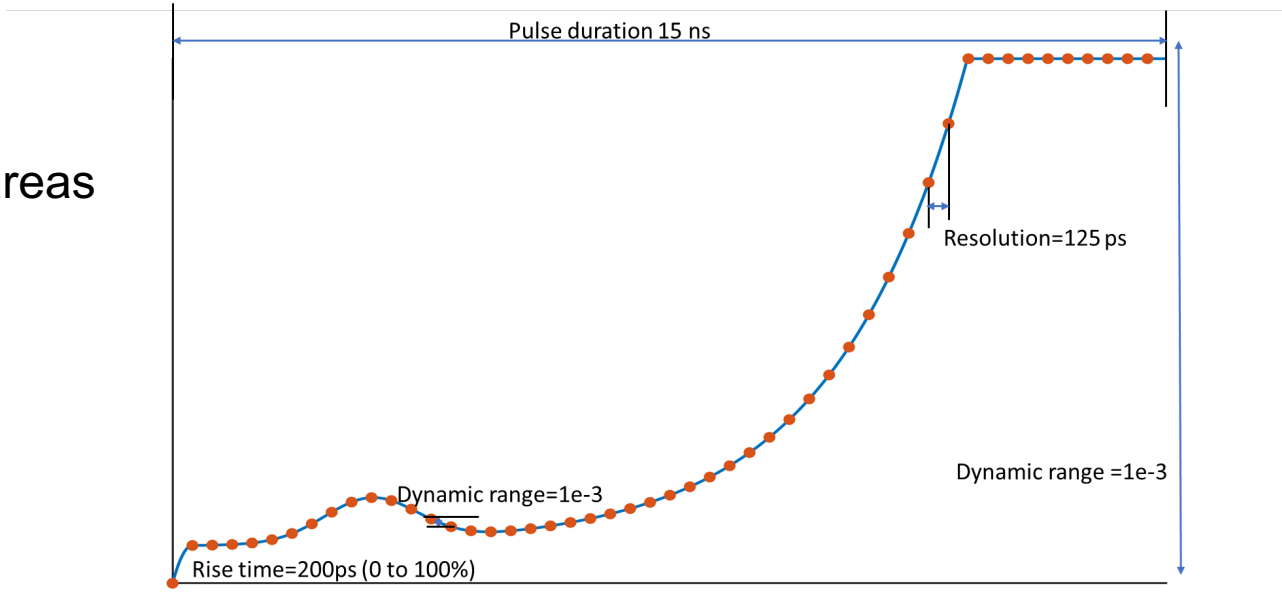
20PW pump beams will be delivered to experimental areas

VOPPEL pump beam could be delivered

Optimized for narrow band and 3ns

Available energy on longer pulse under investigation

100TW beam could be delivered as long pulse



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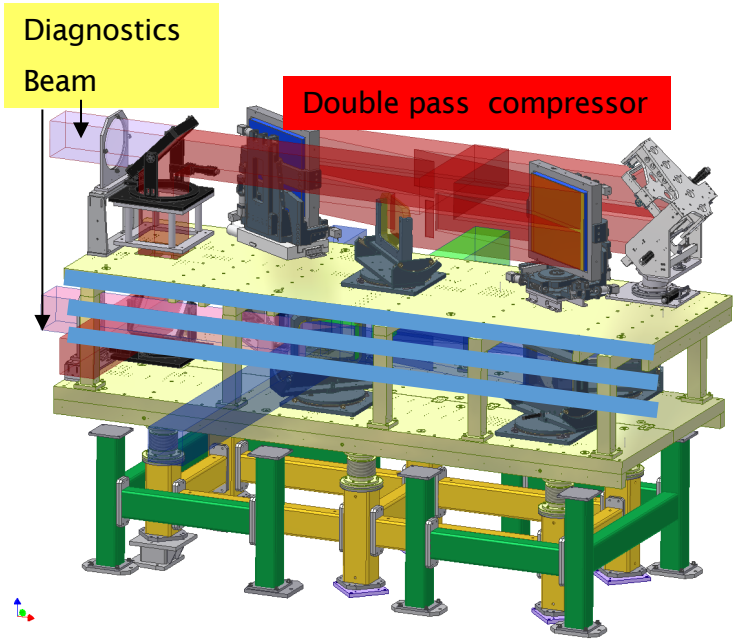
Auxiliary beams



Existing beamlines

Vulcan beam 8 to TAW will be reused

100J or 250J prior compression, 1ps to 10ps

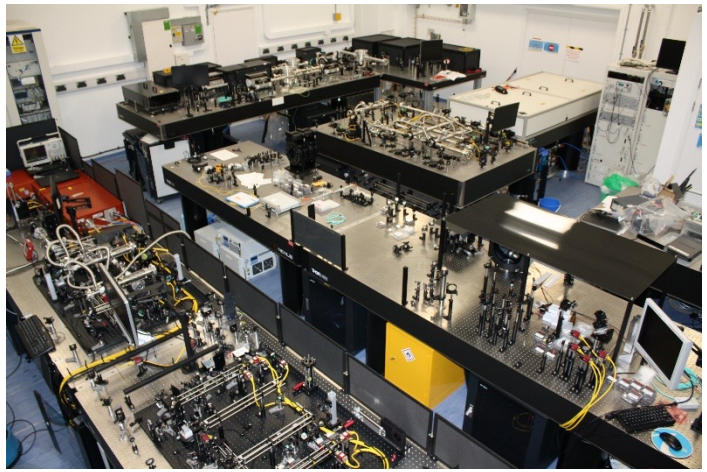
Beam 8 compressor in TAW will be reused

Evaluating OPCPA front end to improve pulse length and contrast

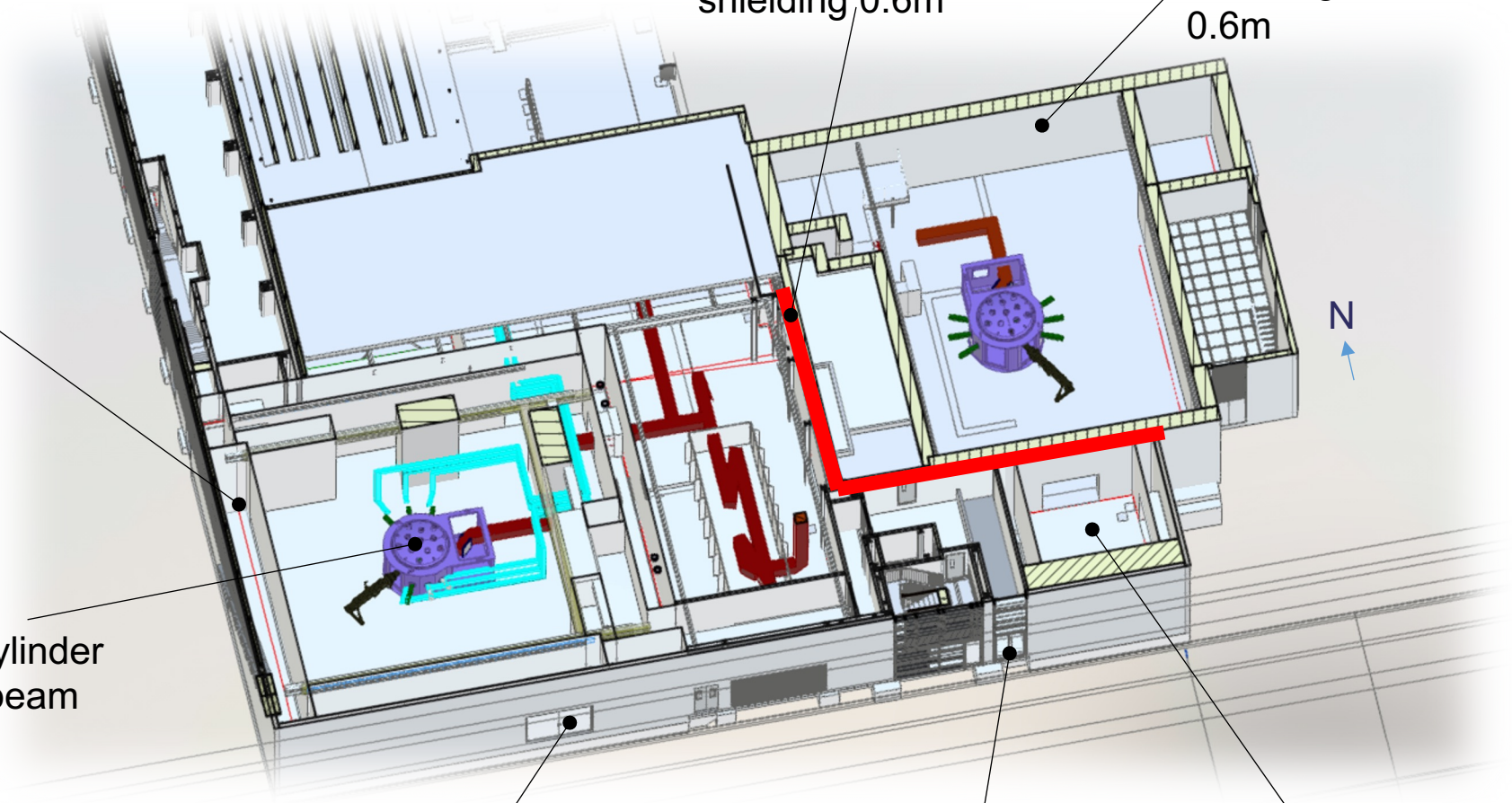
Recently developed VOPPEL 1 PW (30J in 30fs)

VOPPEL will be moved on the second floor, including the compressor

Rep. rate improved to 5min by gas cooled disk amplifier



Experimental Areas



New experimental bunker.
- 1m floor & roof;
- 1.5m side walls (N&E);
- 2m side walls (S &W)

New Chamber.
- ~3m external diameter cylinder
- Cube section for 20PW beam
- Domed roof

Service entry (shield door)
- ~3.5m (w) x 2.5m (h)

Maintain straight line entry through existing TAP shield door

- New e-beam dump area.
- 1m side walls, roof & floor;
- 1.5m end wall

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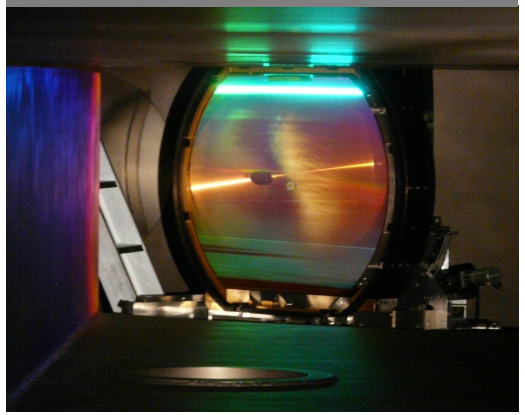
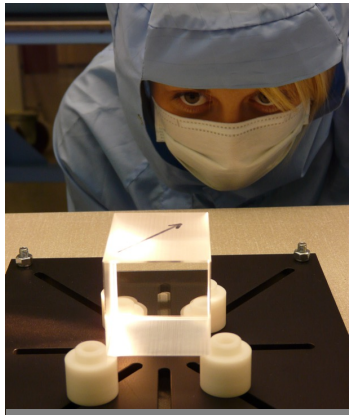
Key technologies

- Front End: Broad band, stability, contrast
- Temporal Synchronization:
  - Stabilized Hollow Core fibre link
  - Stabilized optical path
- Large Crystals
  - Large LBO
  - High deuterated KD*P
- Flash-lamp disc amplifiers: air-cooled disk amplifier shot 5 min
- Large Broadband Gratings with good efficiency and suitable LIDT
- Large Broadband Mirror with suitable LIDT
- Complex beam transport

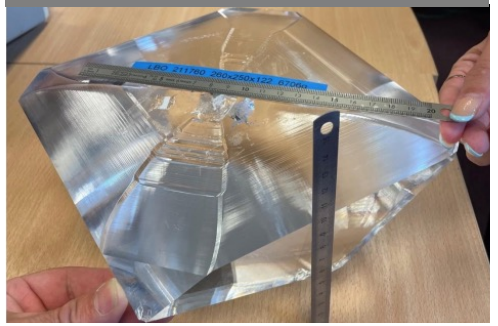
Gratings





DKDP Crystal

LBO crystal



Hollow Core

Disc Amplifier air cooled prototype

Long complex beam transport

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Planned Project Timescales

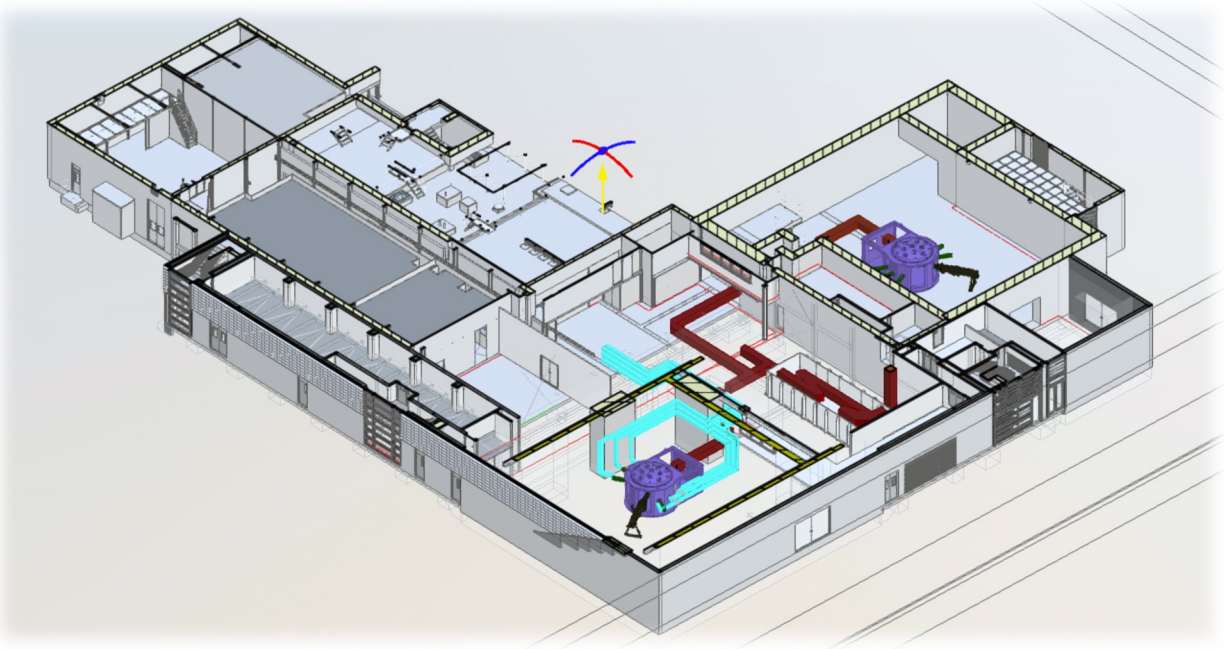
Project kick-off in July 2023

Vulcan switch off in September 2023

Building work to start in January 2024

Building completed by October 2025

Begin installation in November 2025



Commissioning work to start at the end of 2027

Facility ready for access mid 2029

Conclusions

EPAC building ready and installation started, completion ~ 2026

Vulcan 20-20 approved, completion ~ 2029

Vulcan end of operation September 23

Gemini facility still operating