Diode-pumped Laser Drivers for Plasma Accelerators

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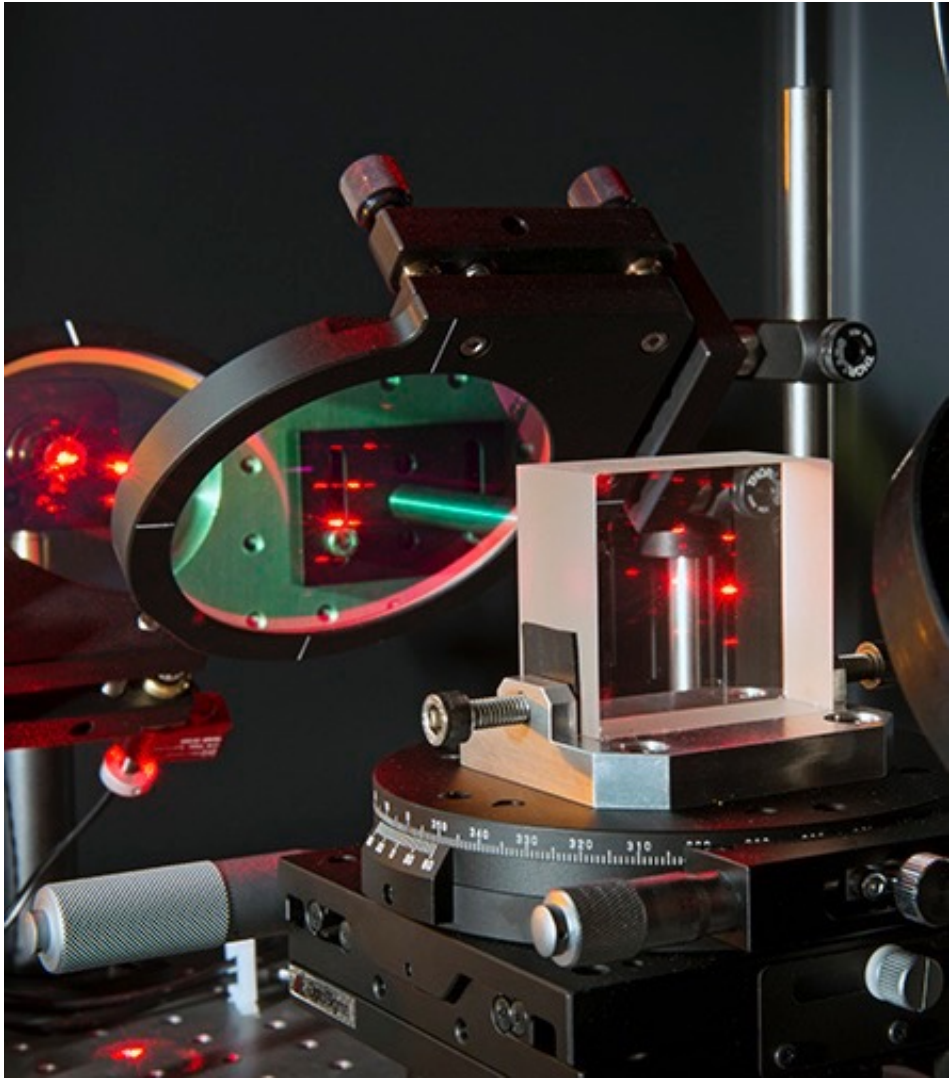
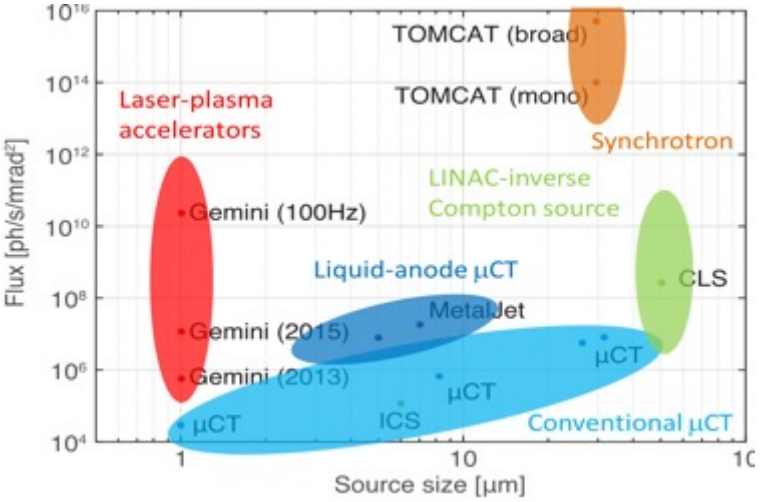
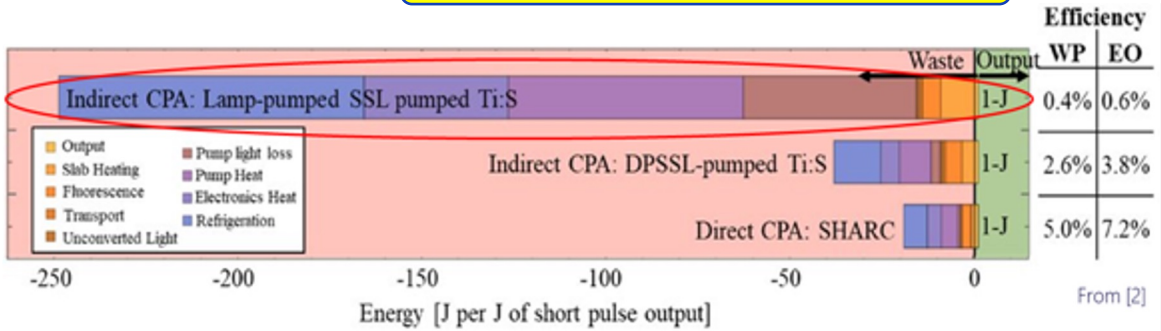


Laser-driven plasma accelerators are maturing

- Producing high-quality beams from LWFA is central to proving their suitability for future large-scale facilities (eg. x-ray sources, FELs……colliders)
- X-ray source size can be maintained - applications of plasma accelerators require high repetition rates
- Ti:Sapphire lasers may continue to be the main workhorse in the interim (not ideal and other technologies are coming up: BAT, Direct CPA, OPCPA, thin disk, fibres…) Laura's talk(s) on Thursday





E. Sistrunk, et al. Proc. of SPIE Vol. 11034 1103407-1 (2019).

One of the main bottlenecks is the repetition rate of the laser driver (and poor efficiency)

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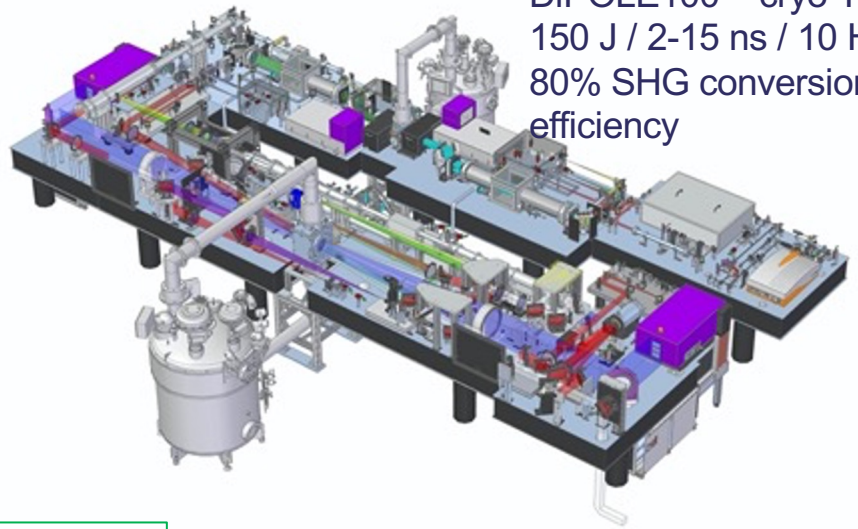
New, scalabe, high-power laser technologies

New generation of efficient, high energy and high repetition rate diode-pumped lasers can deliver the performance to pump PW-class amplifiers.



DiPOLE100 – cryo Yb:YAG
150 J / 2-15 ns / 10 Hz
80% SHG conversion efficiency

Ref: Talks by Jan Pilar and Andrea Knigge on Monday

- DiPOLE100 - Yb:YAG (CLF)
- HAPLS pump - Nd:glass (LLNL, ELI-Beamlines)
- HAMAMATSU - Yb:YAG
- Amplitude, Thales…

…. with projects on further scaling being pursued

Diode Pumped Laser → SHG → Ti:S amplifier

Improved efficiency and pulse rate if pumped with high energy, high pulse rate DPSSLs + advanced cooling schemes

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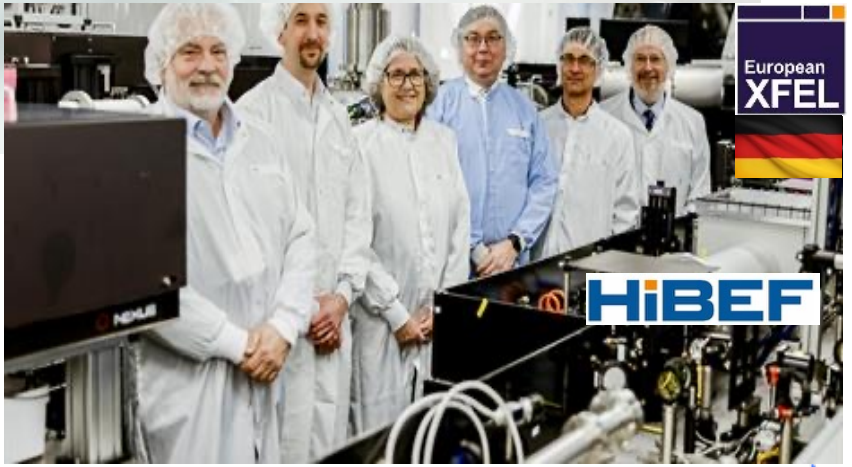
CLF has world-class expertise in DPSSL technology

First system ~ £10.4M for the Czech “Hilase” project

Second system just used for the first experiment at EU-XFEL, Hamburg just 3 weeks ago – highly successful experiment

150J, 10 Hz temporally shaped (conversion to 2w and 3w)

All bespoke Engineering; All IP retained

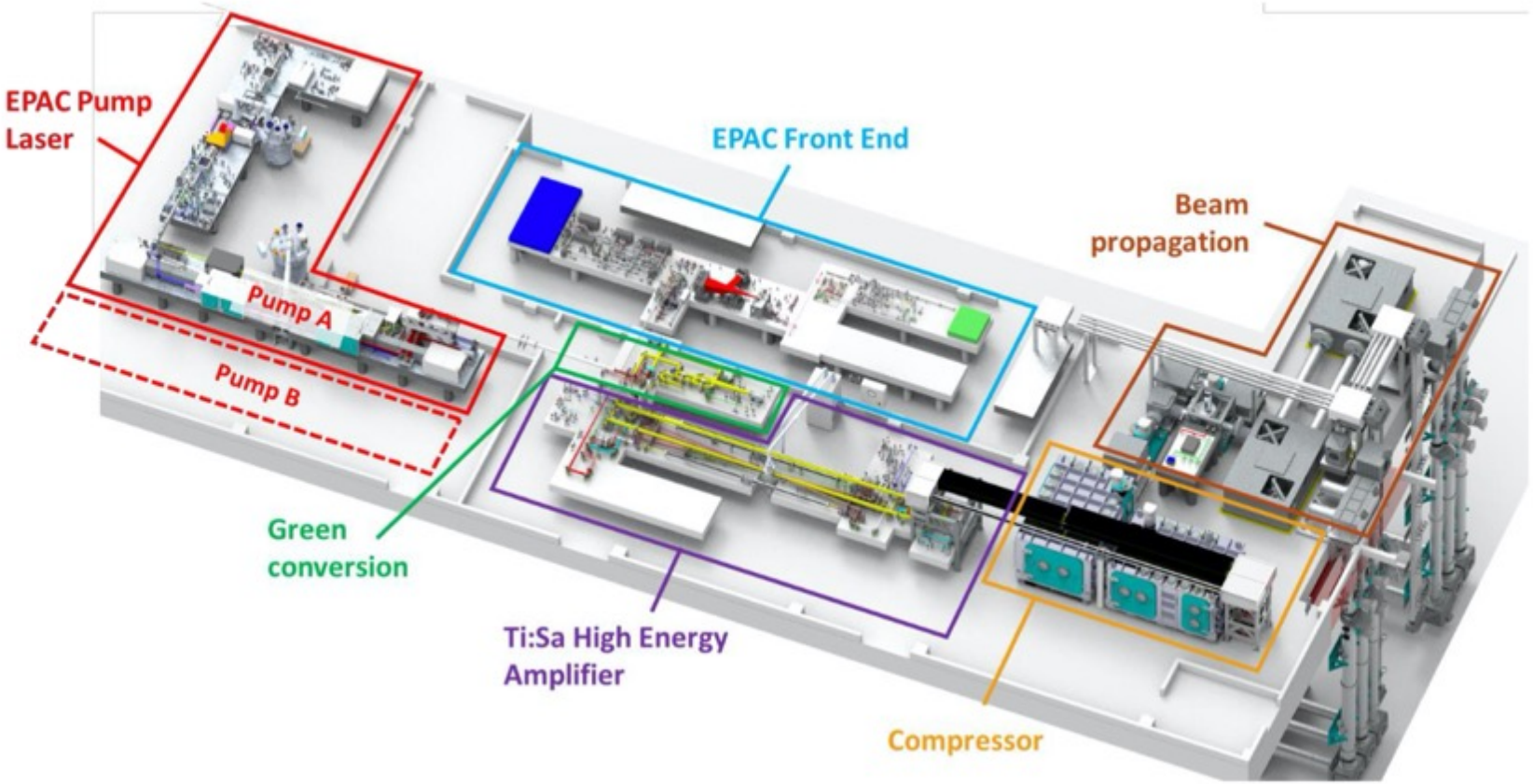


Extreme Photonics Applications Centre

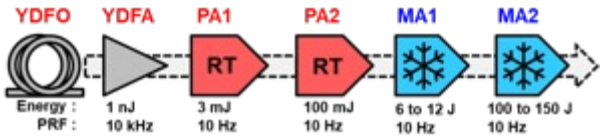
- £100M centre for applications of laser-driven sources in industry, medicine, security etc.
- LWFA driven beams at 1PW, 10Hz: Up to 10GeV beams, x-rays
- Significant Industrial backing based on proof-of-principle tests
- Significant UK investment in plasma accelerators

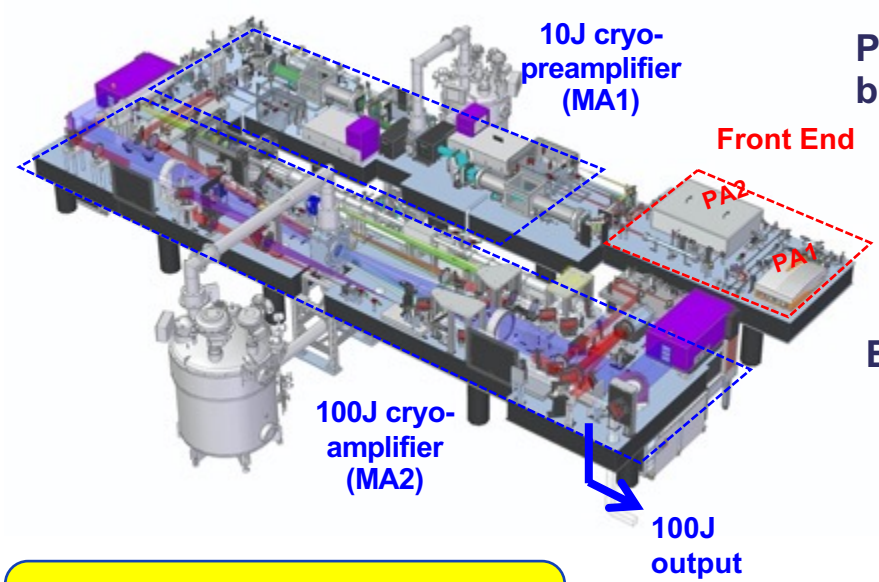
Building completed; installations ongoing; first operations in 2026

EPAC Laser Layout



DPSSL Pump laser for the main amplifier





Ref: Talk by Jan Pilar on Monday

EPAC PUMP - DPSSL technology developed by the CLF based – 'DiPOLE' concept

- Diode-pumped multi-slab amplifier using Ceramic Yb:YAG
- Face-cooled by cryogenic He gas

Performance demonstrated on previous DPSSL systems built by the CLF (demonstrated 145J @10 Hz)

- DiPOLE 100 J @ 10 Hz for HiLASE(Czech Republic) Currently Operating
- D100X 100J @ 10 Hz. Successfully demonstrated @ XFEL

EPAC Pump Design Parameters

- 1030nm wavelength
- 120J at the output of single arm (75mm square beam)
- 1 or 10Hz operation
- 15ns pulse duration, temporal shape
- Energy stability < 2.5% RMS

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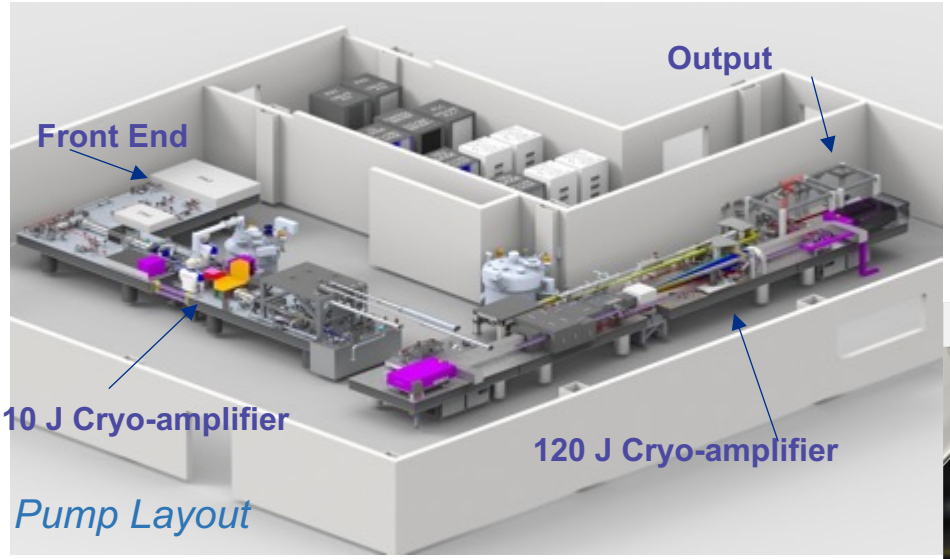
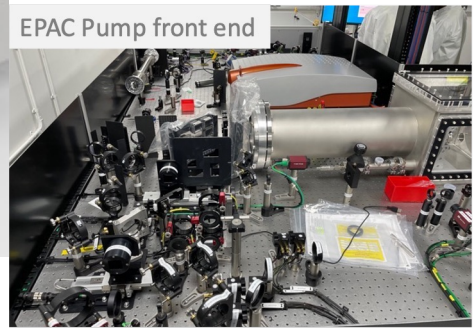
Pump laser for the main amplifier

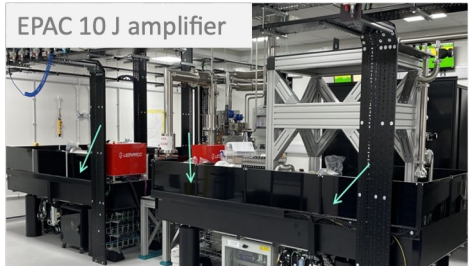


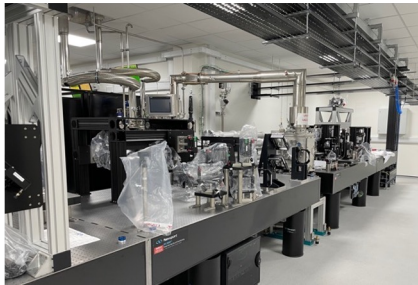
1030nm wavelength
120J at the output
75mm square beam
1 or 10Hz operation
2-15ns pulse duration

EPAC Pump front end



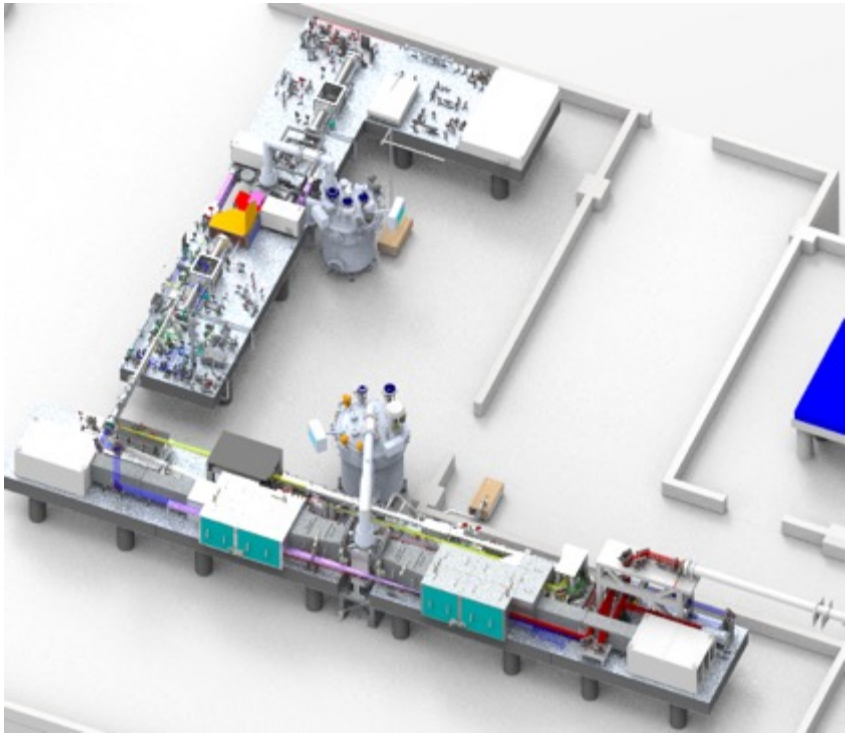
EPAC 10 J amplifier

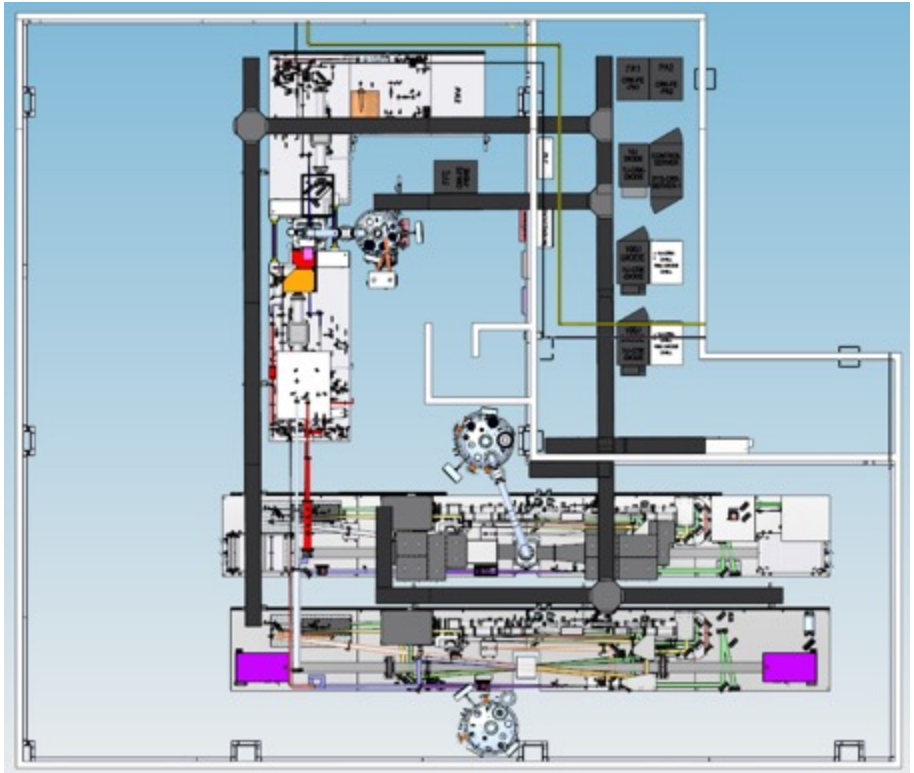




Beam transported to adjacent room where it is frequency doubled and then injected in the Ti:Sa Amplifier

Future provision; two 120J sections





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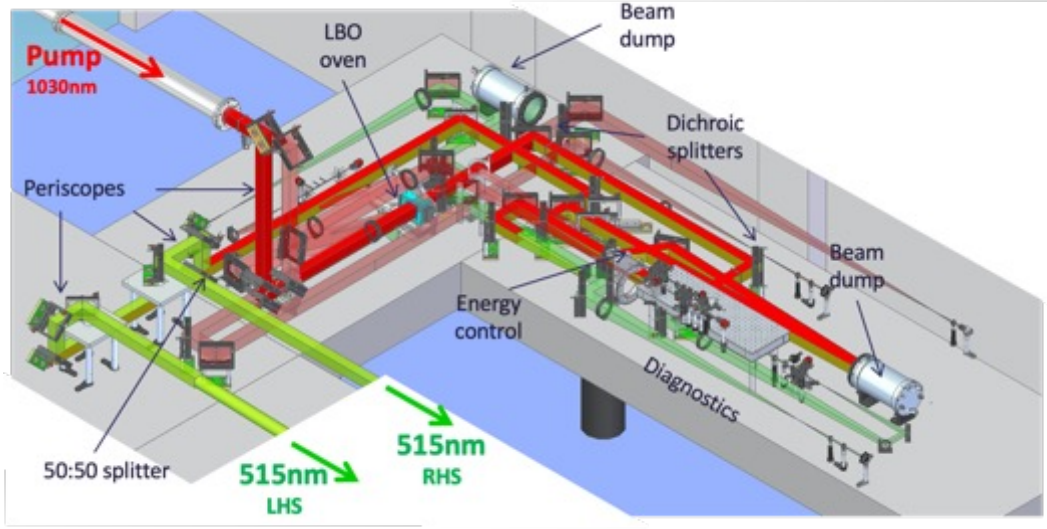
Frequency doubling

EPAC PUMP will use LBO as SHG crystal



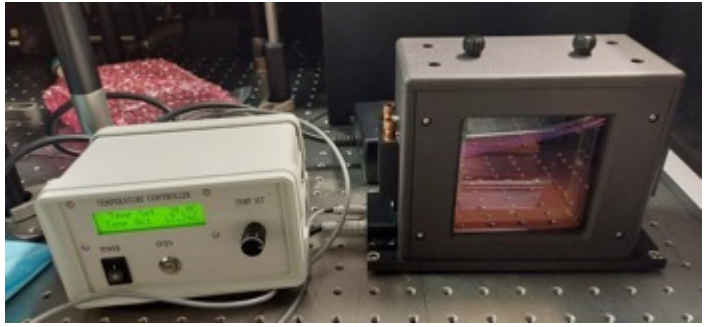
DiPOLE100 SHG @ HiLASE -Widespread Teaming project

Conversion efficiencies >70% demonstrated at high average power

For initial phase 80J, ramped up 120 J

Recent SHG results show **95 J @ 10 Hz @ 515 nm**

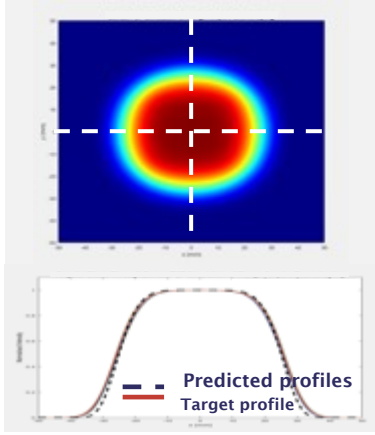
Phillips *et al.*, Optics Letters 46, No.8, p1808 (2021)



Second Harmonic Crystal oven has arrived

Finalise the procurement of components

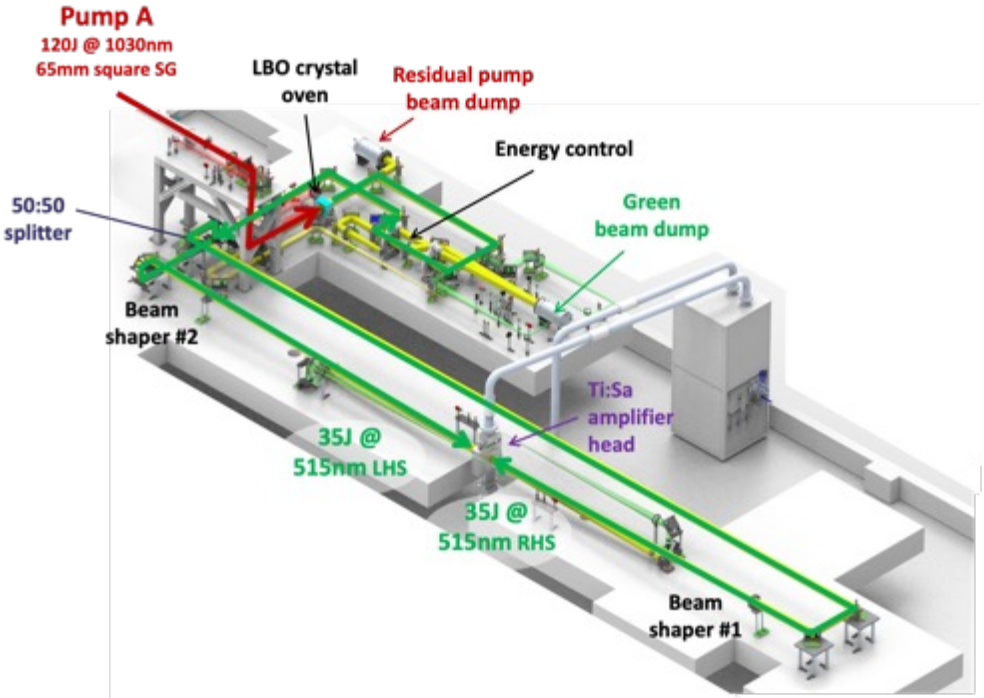
"*Circling a Square*" is the present challenge

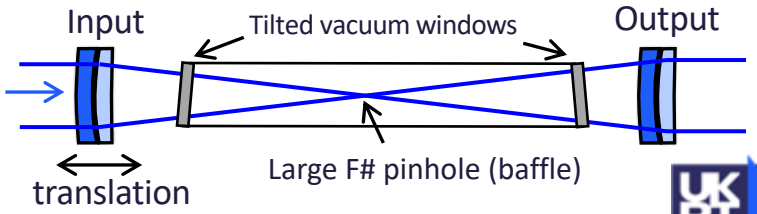


Ti: Sapphire Amplifier

TiSa Multi pass amplifier

- It is a 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





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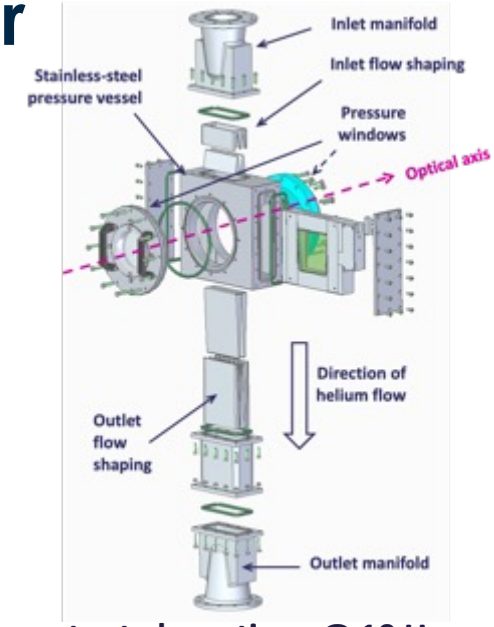
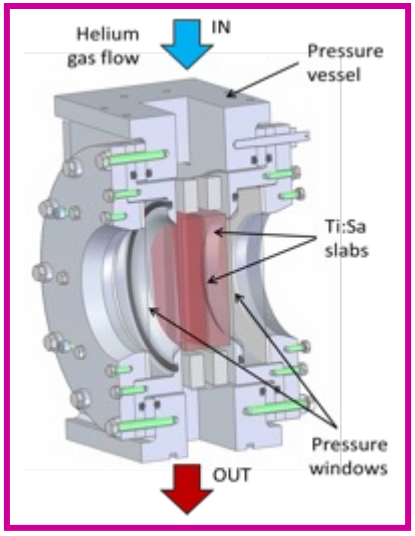
Ti: Sapphire Amplifier

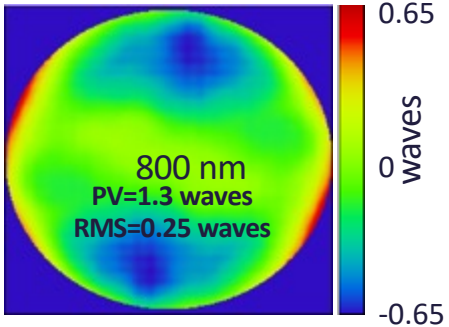
Large Ti:Sa crystals will be cooled using similar approach to DiPOLE gas cooling

- Single amplifier head with two Ti:Sa slabs with **100 mm** clear aperture,
- Crystals are contained within a pressurised amplifier head and cooled by passing a high velocity stream of helium across the slab surfaces

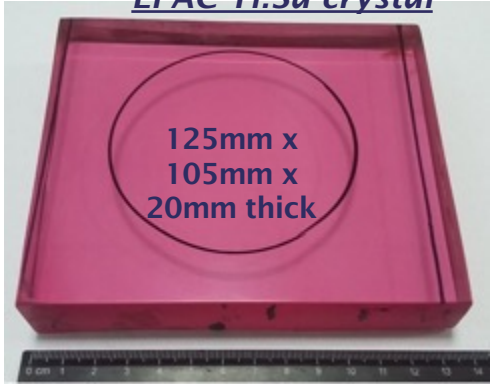




output aberrations @ 10 Hz



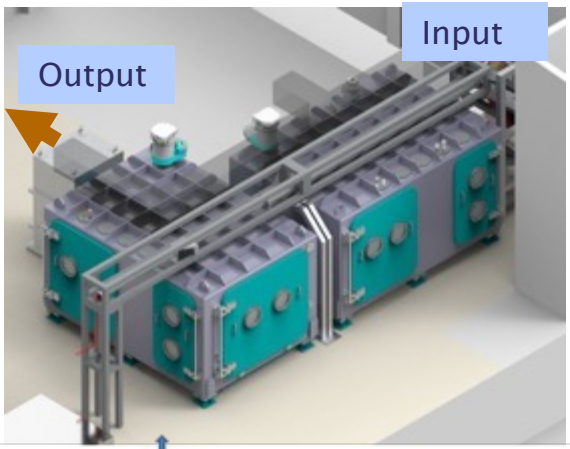
EPAC Ti:Sa crystal

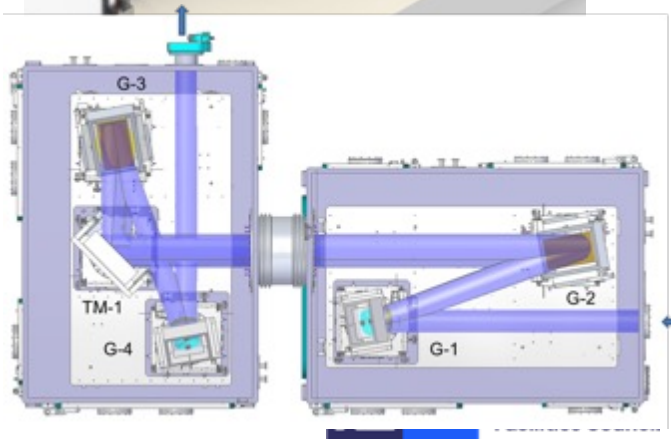


Compressor

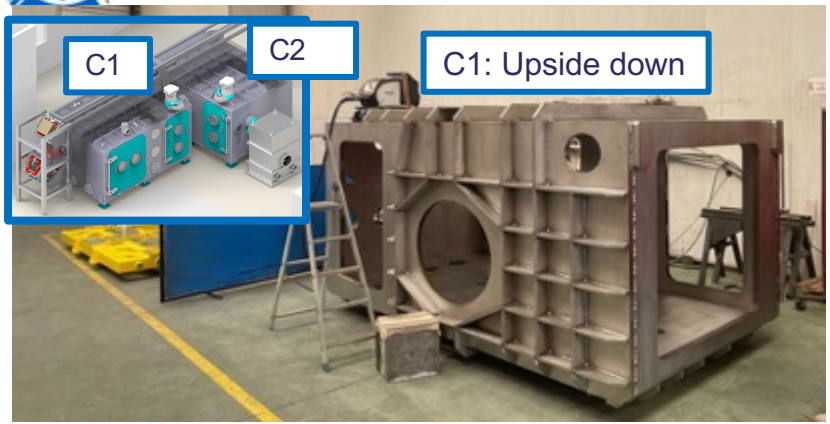
The compressor design: 4 Grating scheme at Littrow with an out-of–plane angle of ~ 10 degrees, will use 1480 l/mm gratings

- Compressor is formed by 2 sub-compressors in a L Shape design, with optics will be side loaded into compression chamber.
- The Grating mounts designed demonstrating good stability (<0.2µRad)
- 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).



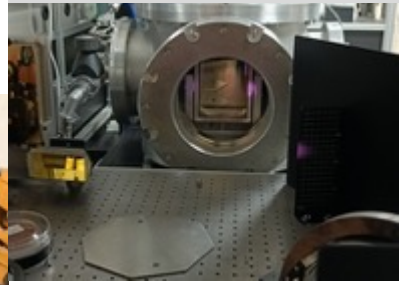


Compressor progress



Grating substrates before polishing

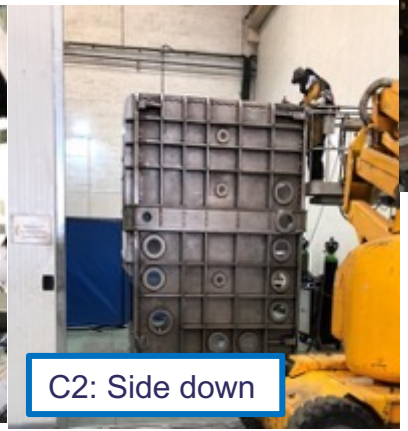
Grating heating test



- Compressor chambers being manufactured in Spain
- Delivery of chambers and breadboards expected in the New Year

Standard gold gratings
Have substrates – need polishing – contract to be placed for gold gratings

MLD gratings
Have a prototype - LiDT and diffraction test are good. Conducting longevity test



Cooled gold gratings
Initial work confirmed that water cooling grating is feasible option to meet the flatness requirement. Testing impact of mounting
Currently testing a prototype; initial results show good cooling

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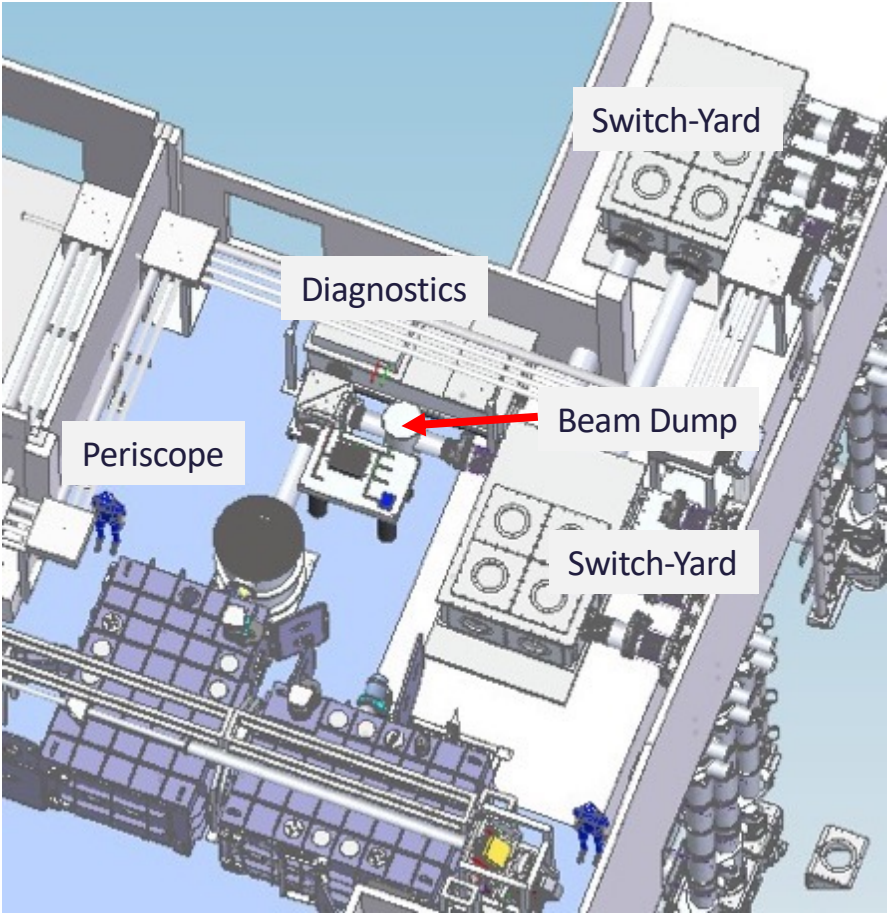
Beam Transport



Beam transport has 3 distinctive parts

- Switch yard is located in the third floor, beams directed outside bunker to experimental areas
- The design includes provision for future beams into EA1 and EA2.

To maintain beam alignment looking at 2 systems tested in Gemini

- Automated alignment system to compensate for slow drifts
- Fast stabilisation scheme to correct jitter up to 100Hz (Feedback Position Sensor and Piezo-Mirror).

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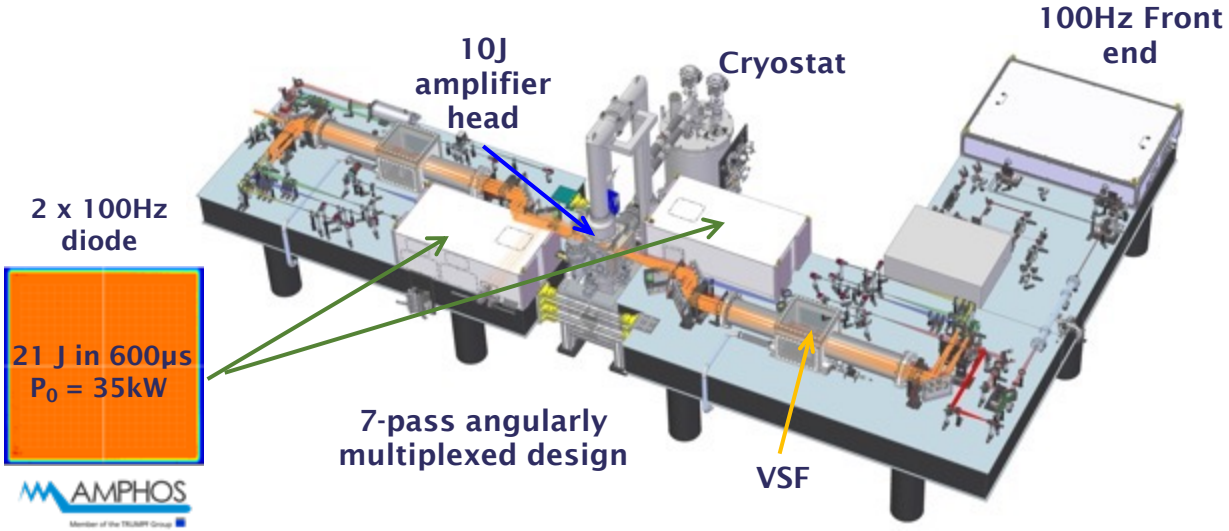
Pulse Rate Scaling

DiPOLE-S **10 J @ 100 Hz** (1 kW)

- 1 kW average power from similar footprint to DiPOLE 10 Hz system
- Industrial & scientific applications requiring:
  - **High** *pulse energy, pulse rate, average power, & production rates*
- Developed as part of Widespread Teaming project



Challenges

- Gain medium thermal management
  - Increased # slabs from 4 to 6
  - More aggressive helium gas cooling (200 g/s) from compact cooler

M. De Vido *et al.*, "Design of a 10 J, 100 Hz diode-pumped solid state laser," Advanced Solid State Lasers, JTu3A. 14 (2019)

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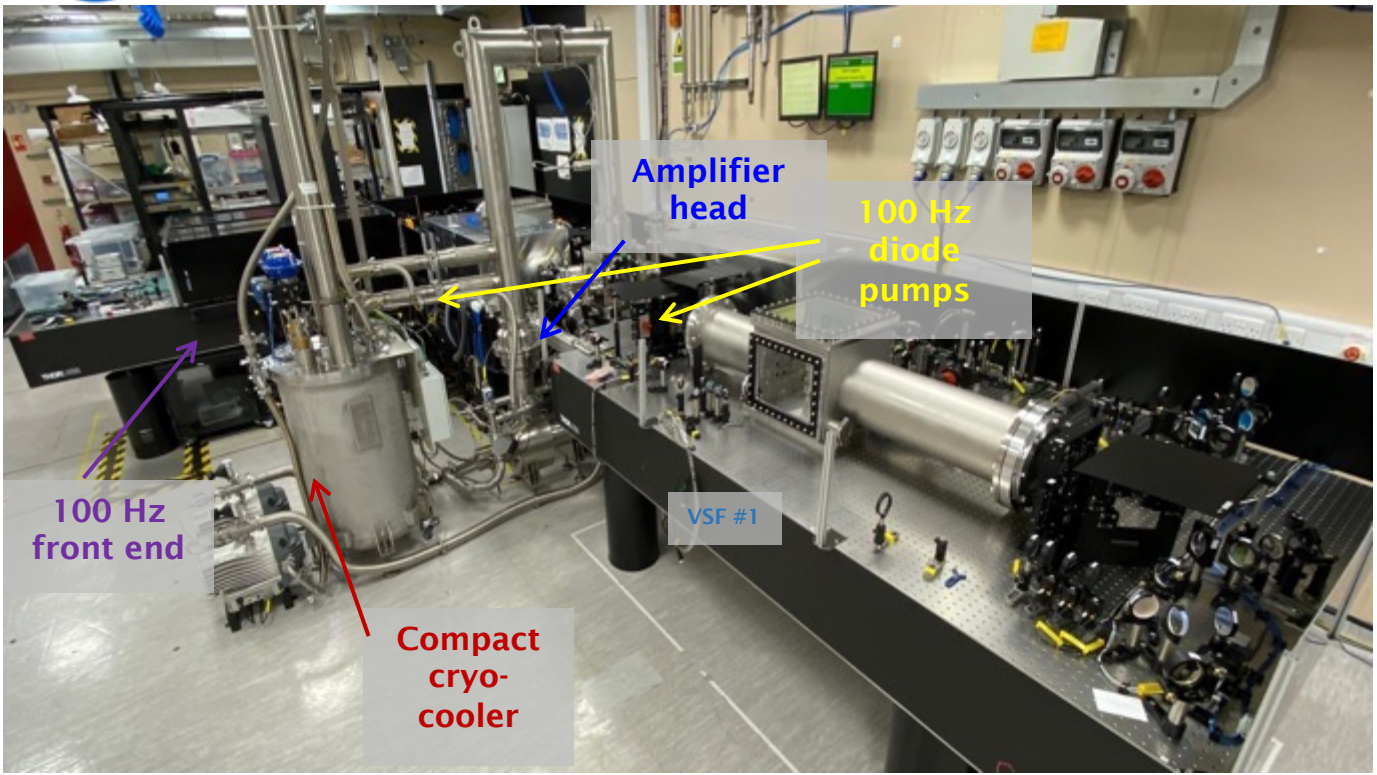
Pulse Rate Scaling



The plan is to incorporate this into EPAC

Next step: using DiPOLE-S to pump a short-pulse system

One of the pathways towards EuPRAXIA laser

System to be delivered to HiLASE by end of 2023

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