Cryogenic Gas Cooling of High Energy Lasers

Paul Mason

HEPTech – Cryogenics Meeting, Grenoble, France
4-5th June 2015

paul.mason@stfc.ac.uk
STFC Rutherford Appleton Laboratory,
R1 2.62 Central Laser Facility, OX11 0QX, UK
+44 (0)1235 778301

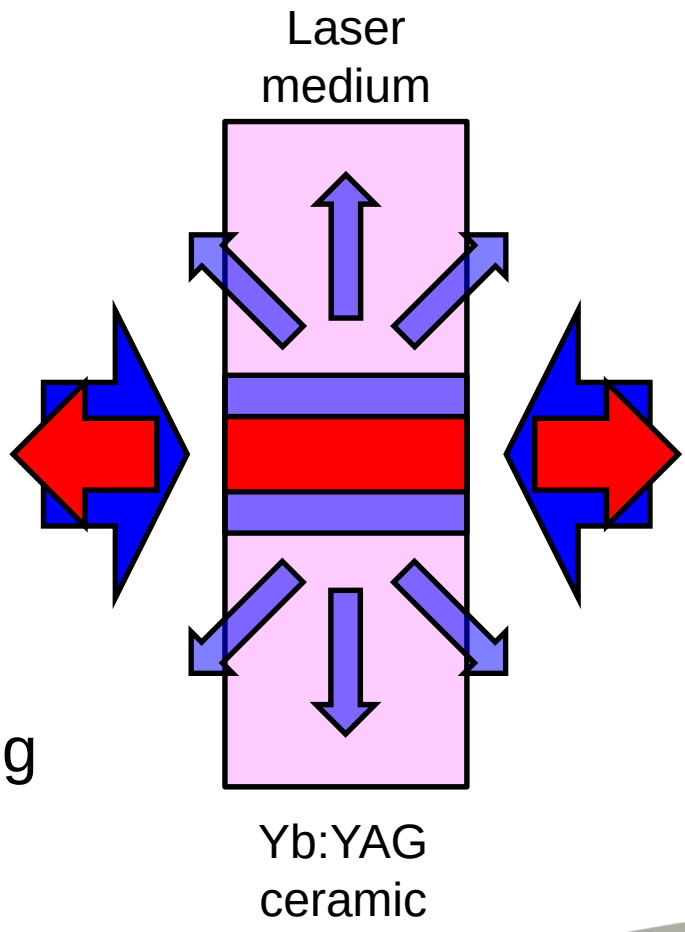
Science & Technology Facilities Council
Central Laser Facility

Outline

- Why cryogenic gas cooling?
- Current projects
- Cryo-cooling system design
- Performance
- Key technologies
- Future projects & requirements

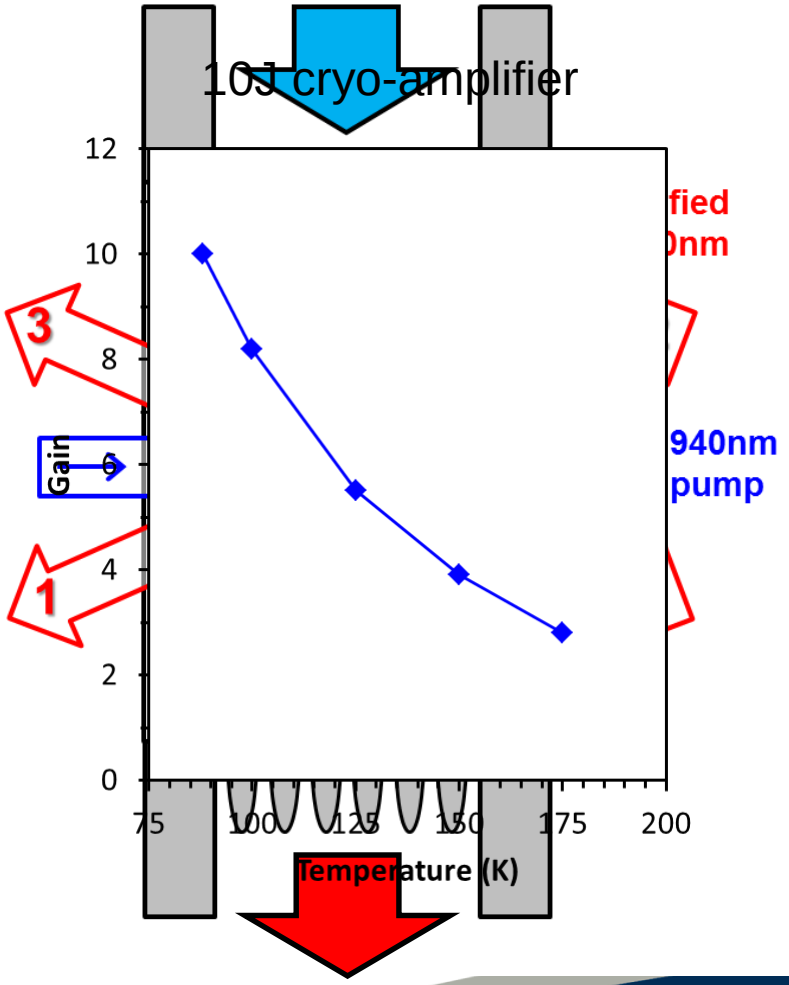
Simple (Pulsed) Laser Amplifier

- **Laser medium** absorbs **pump** light
  - High power pulsed laser diodes
- 50% of **pump** light stored
  - 50% used for **amplification**
  - $\eta_{o\text{-}o}$ ~ 25%
- Remaining energy ends up as heat
  - 50% that wasn't stored originally
  - 25% not amplified
- Heat needs to be removed by cooling
  - 10 J at 10 Hz ~ 400 W heat load
  - 100 J at 10 Hz ~ 5 kW heat load



Cryogenic Gas Cooled Amplifier Design

- Multi-slab geometry
  - Laser medium split into multiple slabs
  - Large overall surface area
- Face cooling with helium gas
  - Efficiently removes heat
  - Minimises transverse temperature gradients
- Operation at near-cryogenic temperatures
  - Improves efficiency of amplification
  - Amplifier gain rises as T reduced
  - Better thermo-mechanical & thermo-optical properties



Mason *et al*, "Scalable Design for a High Energy Cryogenic Gas Cooled Diode Pumped Laser Amplifier," Applied Optics 54, No.18 (2015).

DiPOLE

Central Laser Facility

Current Projects

DiPOLE

DiPOLE100

DiPOLE Prototype

- Proof-of-concept
- 10 J, 10 Hz
- CLF test bed
- 2 x 10J heads supplied (CZ, HZDR)

HiLASE Facility

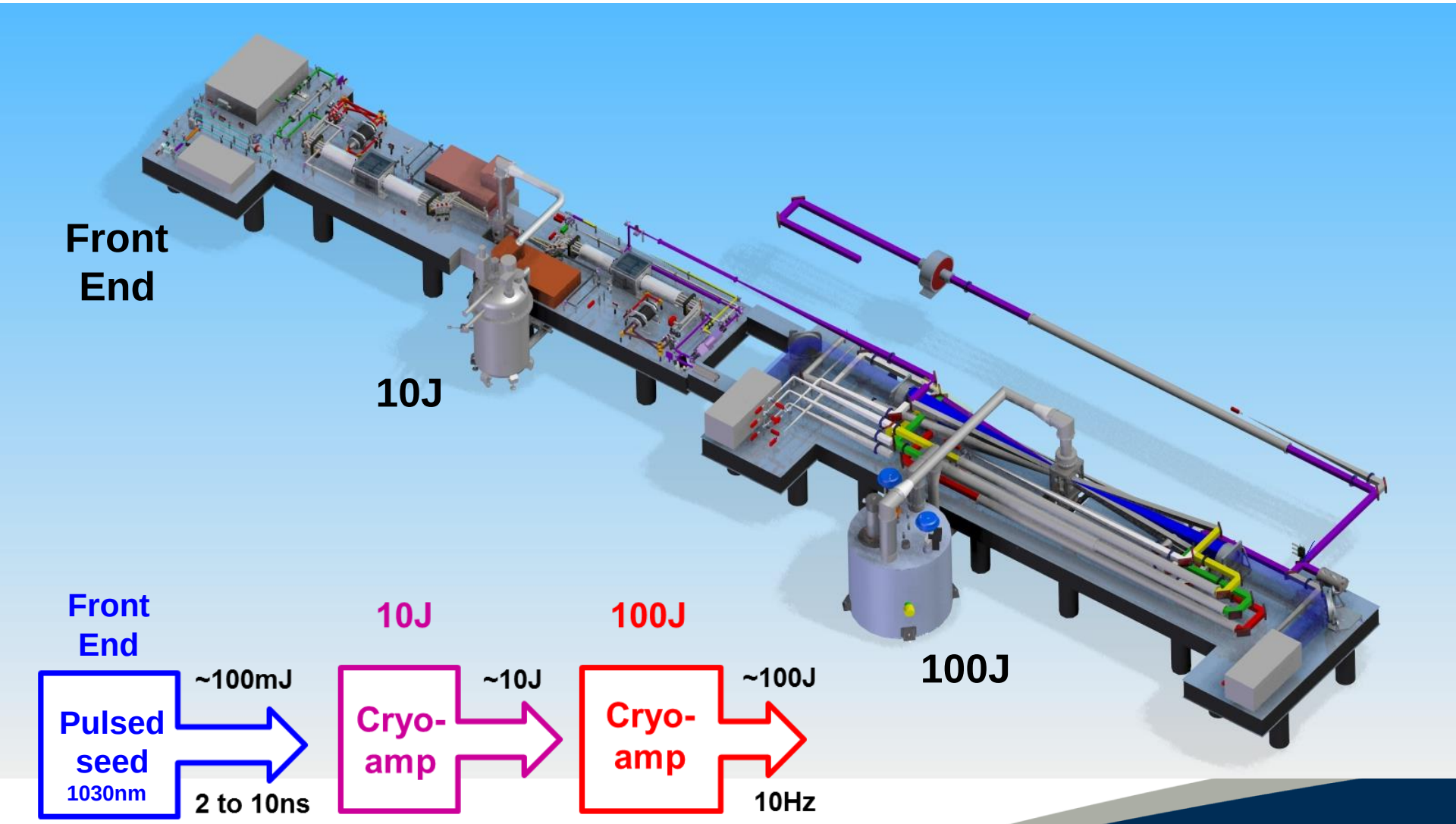
- 100 J, 10 Hz
- Materials processing
- LIDT testing
- £10M 2013-15

XFEL HED Beamline

- 100 J, 10 Hz
- High-energy density physics
- £8M 2015-17

- Centre for Advanced Laser Technology & Applications (CALTA)

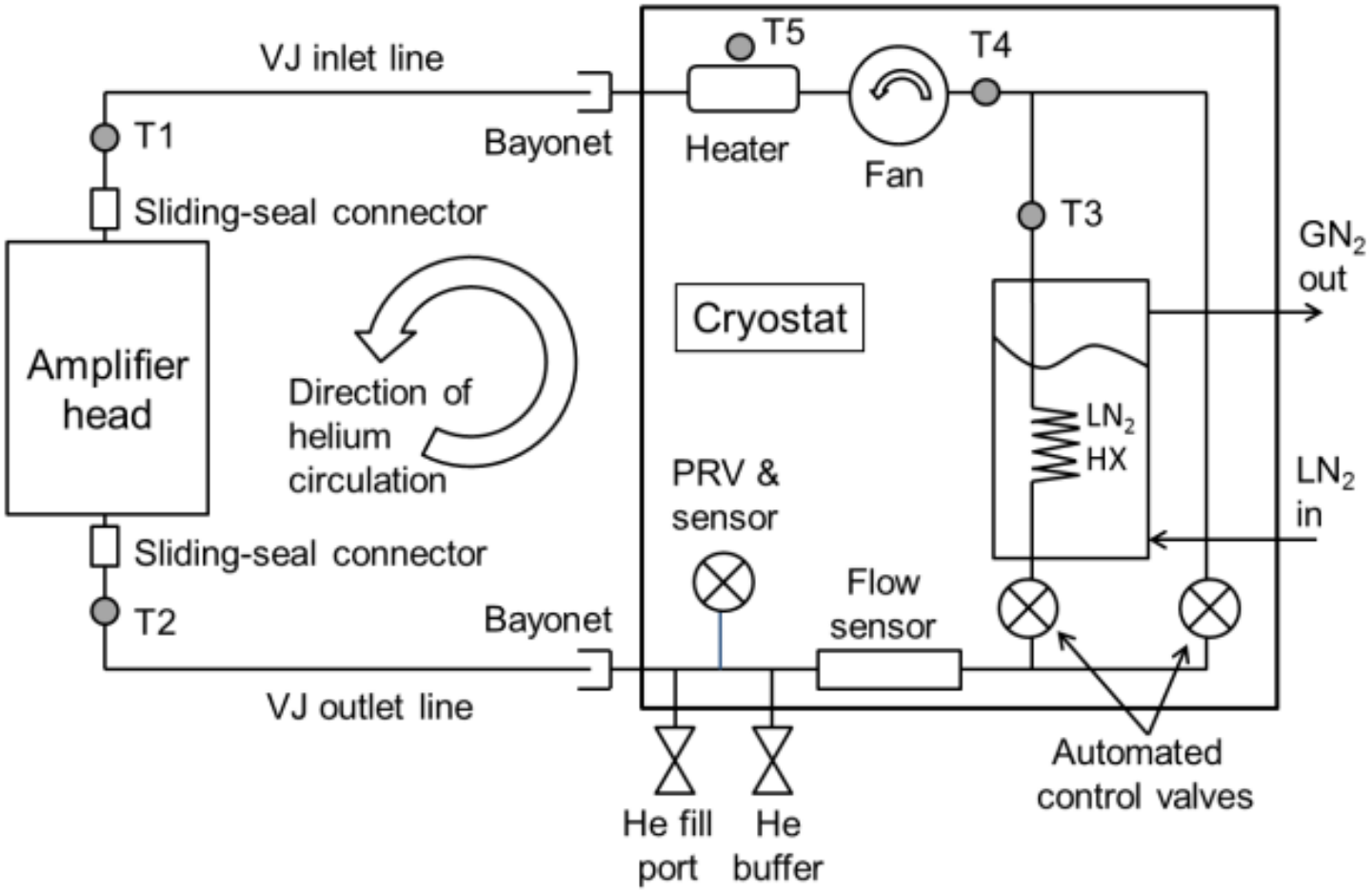
DiPOLE100



DiPOLE100

Science & Technology Facilities Council
Central Laser Facility

Cryo-Cooling System Concept



- Operating pressures > 10 bara (150K)
  - He vented when system warms up
  - Option for buffer

Cooling System Designs

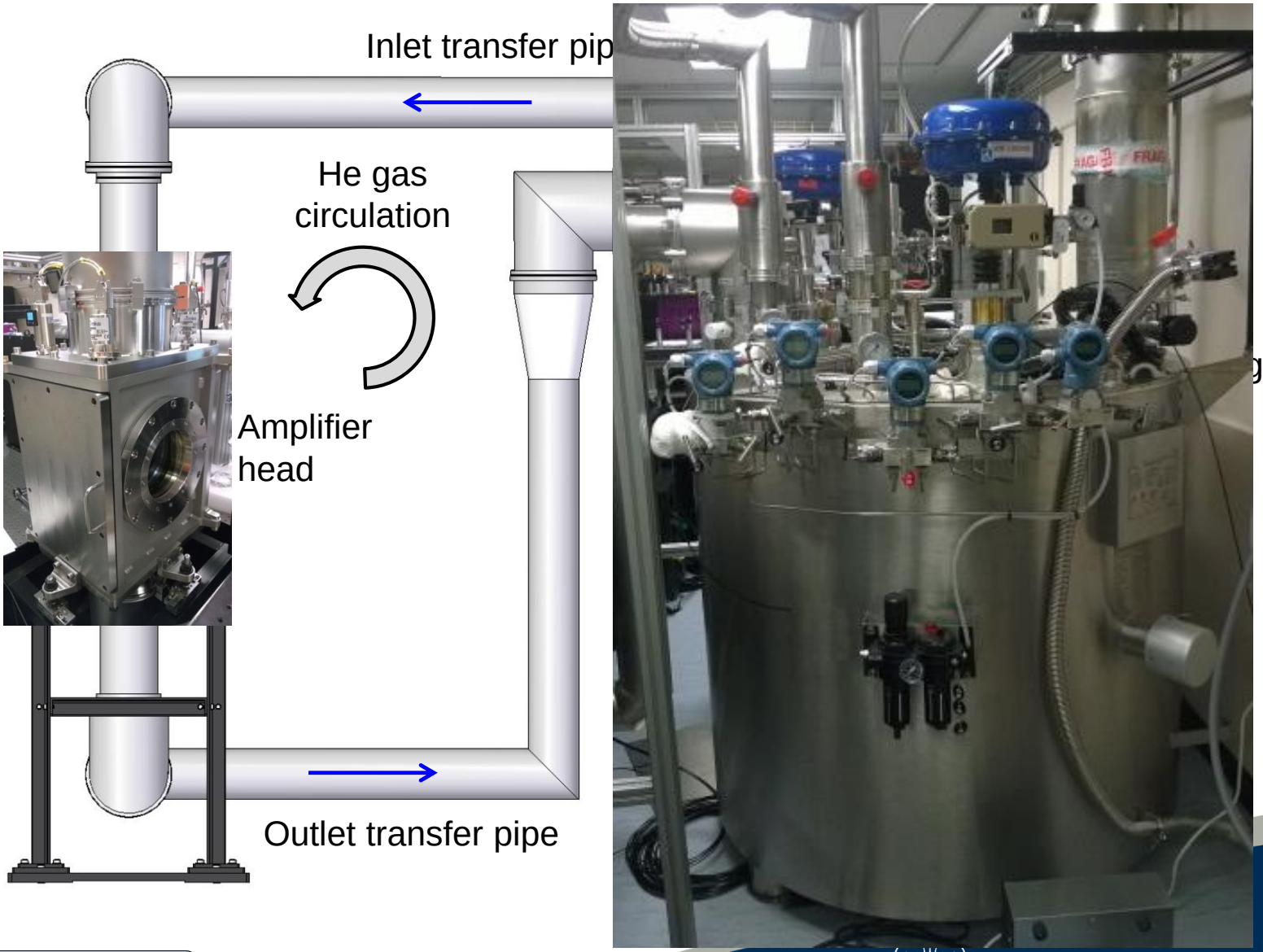
Property	10J	100J
Working temperature	150 K	150 K to 175 K
Stability (better than)	± 0.5 K	± 0.5 K
He flow rate	35 g/s	135 g/s
He pressure	10 bara	10 bara
Cooling/warming rate	< 10 K/min	< 10 K/min
Cooling capacity	~ 1.5 kW	~ 6 kW
Amplifier pressure drop	~ 1.5 kPa	~ 2.5 kPa

10J Amplifier Cryo-Cooling System

DiPOLE

Science & Technology Facilities Council
Central Laser Facility

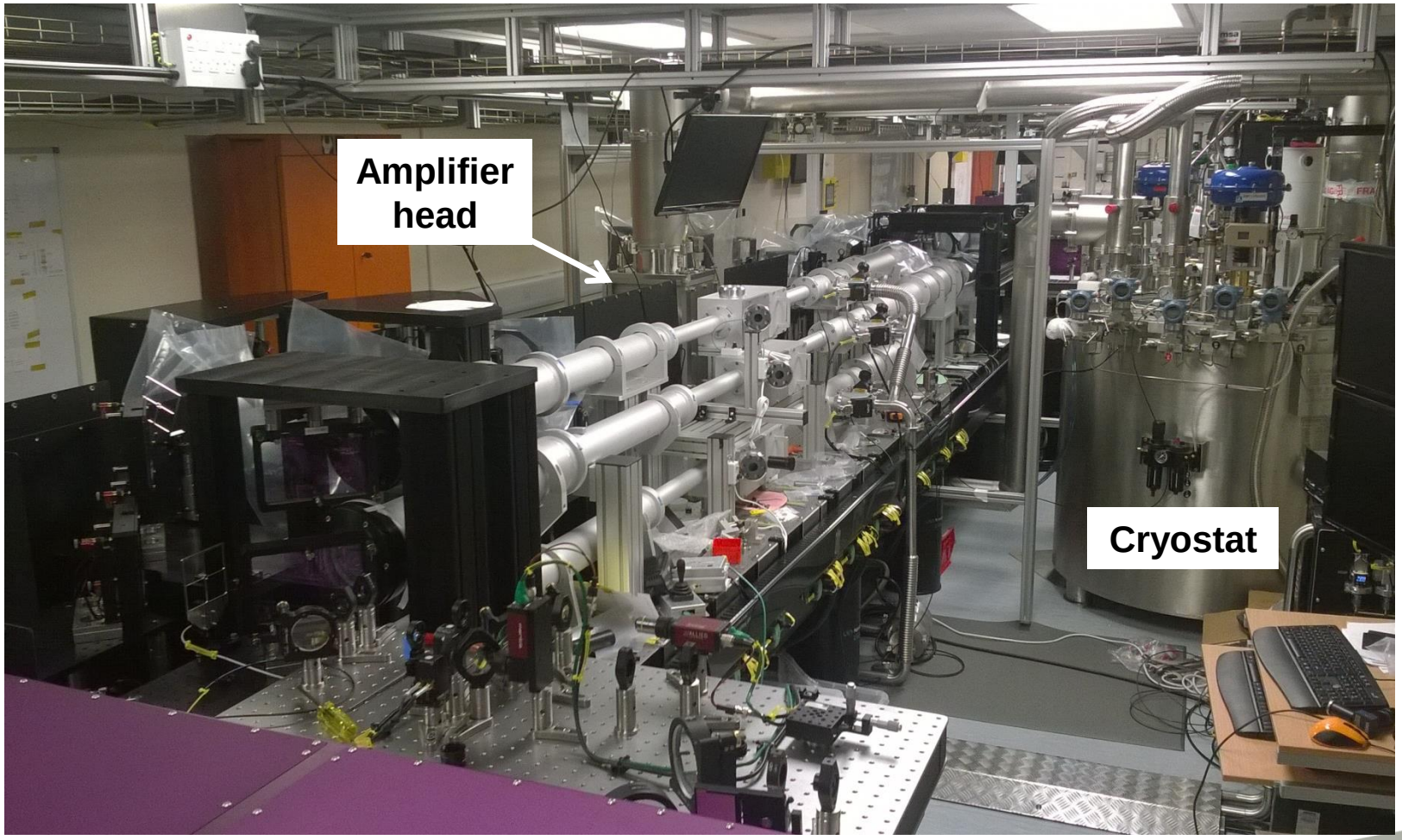
100J Amplifier Cryo-Cooling System



DiPOLE100

Science & Technology Facilities Council
Central Laser Facility

100J Cryo-Amplifier

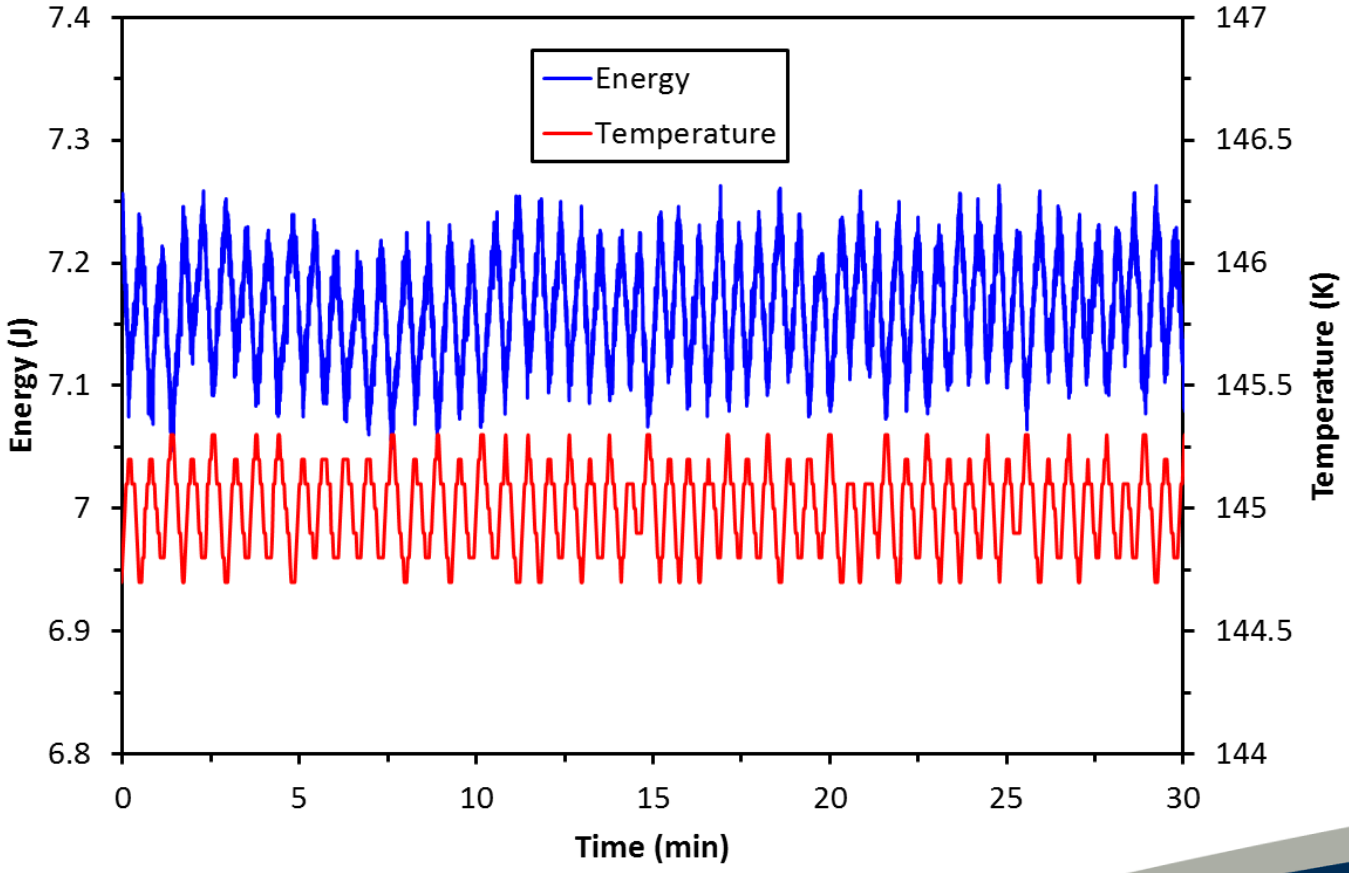


DiPOLE100

Science & Technology Facilities Council
Central Laser Facility

10J Cryo-System Performance

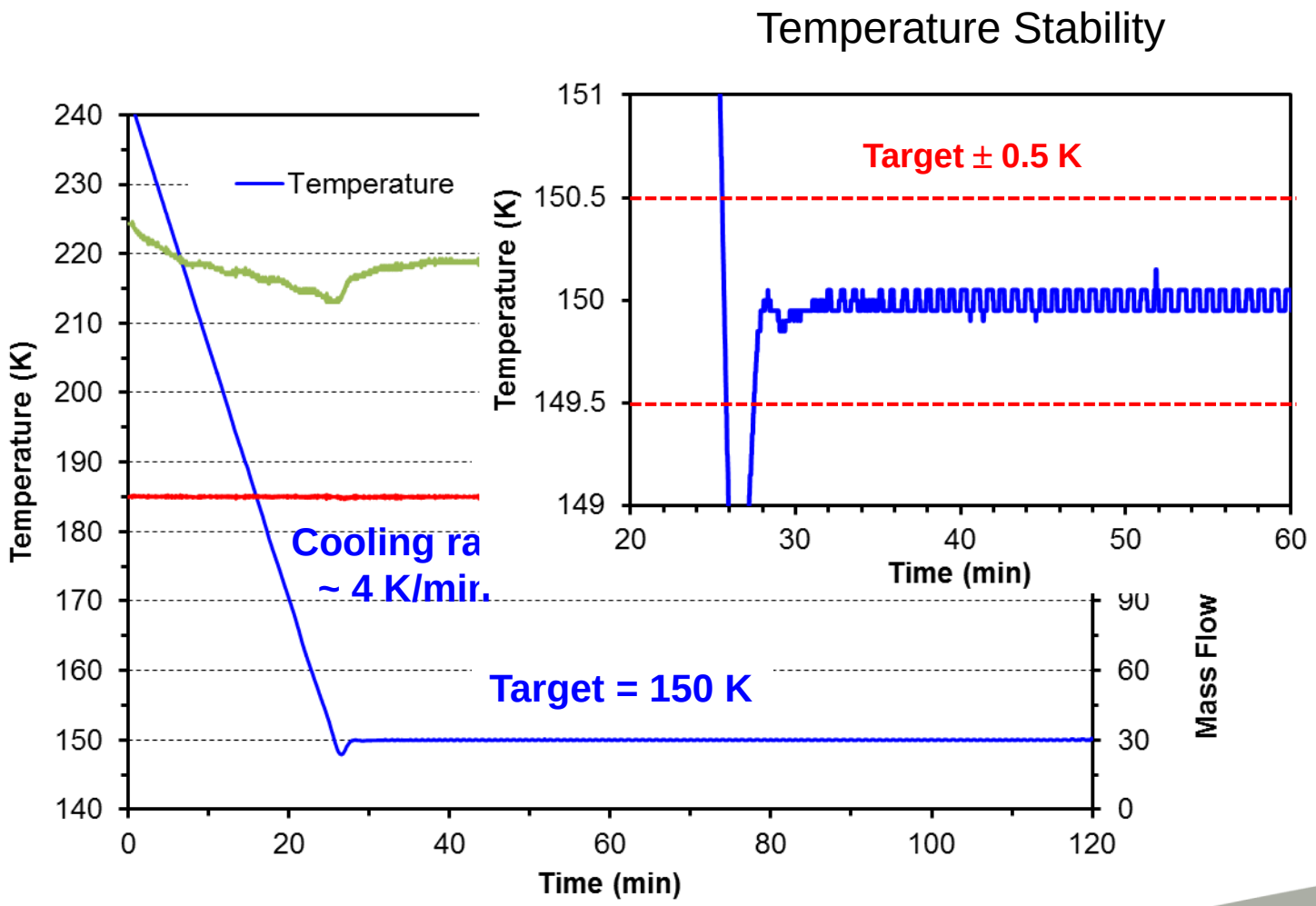
- Amplifier output energy v. temperature



DiPOLE

Science & Technology Facilities Council
Central Laser Facility

100J Cryo-System Performance



DiPOLE100

Science & Technology Facilities Council
Central Laser Facility

Cryogenic Circulating Fans

- CryoZone (10J)
  - Motor inside pressurised volume
  - No rotating seal

CRYOZONE
THE CRYO CREATIVES

Nodin 85 mm impeller

- AL-AT (100J)
  - Active magnetic bearing
  - Hermetically sealed
  - Oil free

AIR LIQUIDE
ADVANCED BUSINESS & TECHNOLOGIES

Future High Energy Laser Applications

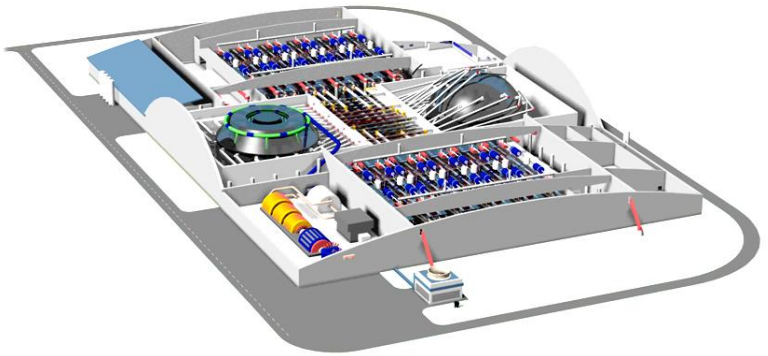
- Commercial opportunities
  - Materials processing
  - Medical applications (x-rays, proton beams, γ-rays)
  - More compact (mobile), rugged, lower-cost systems

- Large-scale laser facilities
  - Fundamental science
    - 250 J, 10 Hz

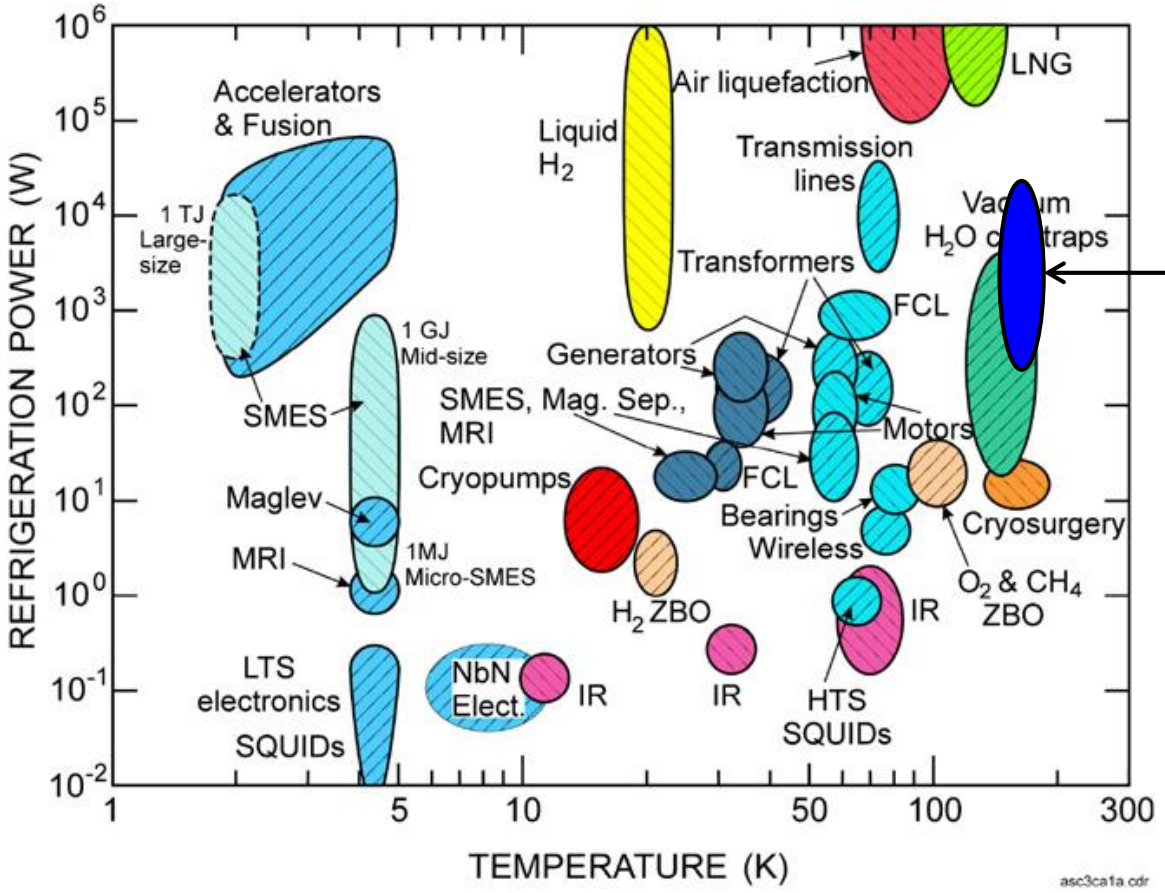
eli beamlines

HiPER

  - Laser fusion energy generation
    - 1 kJ x 10 x 60 beamlines, 10 Hz



Cryocooler Technology



R. Radeburgh, “Cryocoolers: the state of the art and recent developments”, J. Phys.: Condens. Matter 21, 164219 (2009)

Future Cryo-Cooling Requirements

- Remove reliance on LN_2 with closed-cycle cooling
  - Low cooling capacity
    - Mechanical cryocoolers
    - Cryogenic refrigeration systems
  - High cooling capacity
    - (Reverse) turbo-Brayton
    - Up to 50 kW

- Combined systems
  - Single cooler servicing multiple amplifier heads

DiPOLE100

AIR LIQUIDE
ADVANCED BUSINESS & TECHNOLOGIES

Science & Technology Facilities Council
Central Laser Facility

DiPOLE100