Design of a 100 Joule, 10 Hz HEC-DPSSL Power Amplifier

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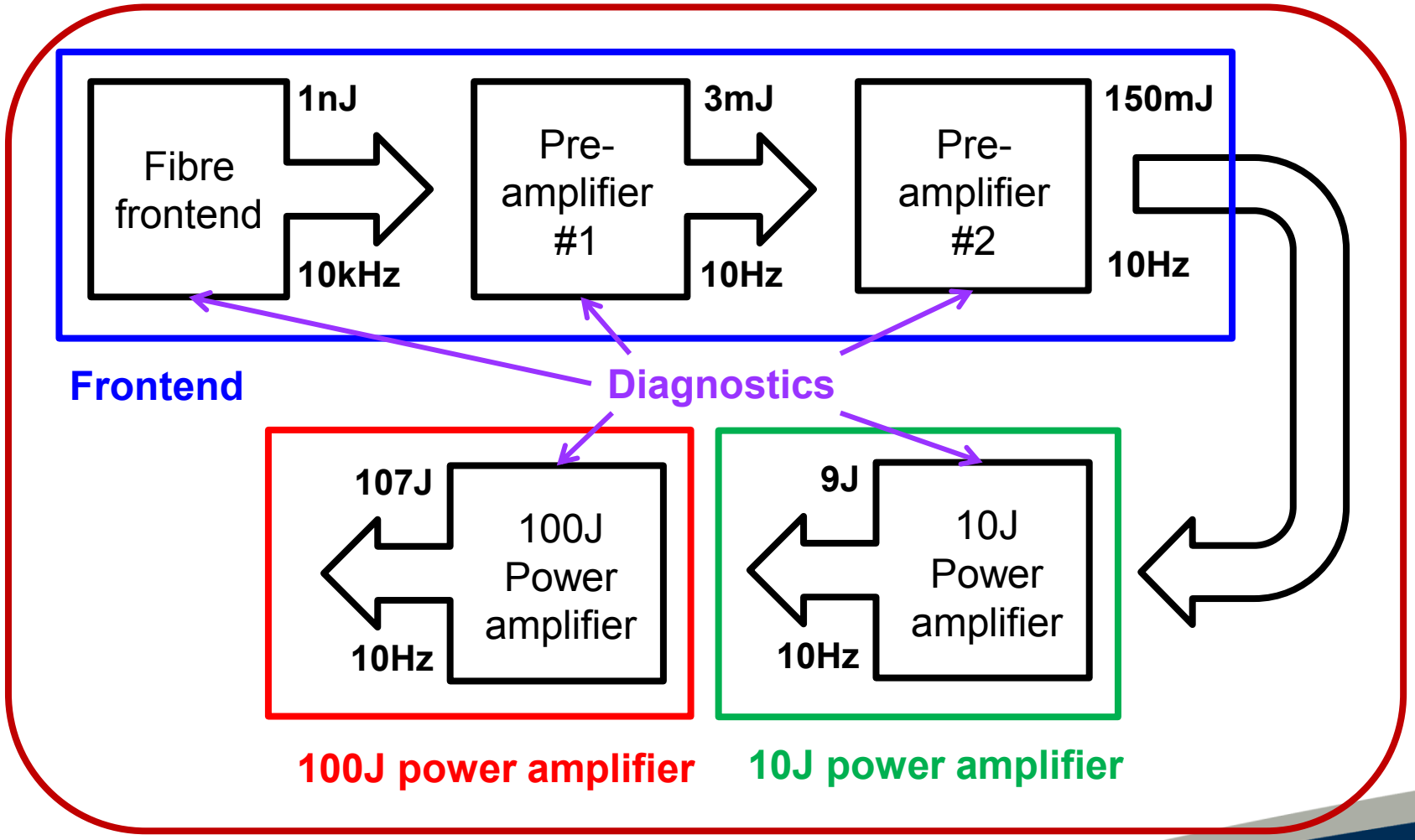
Motivation

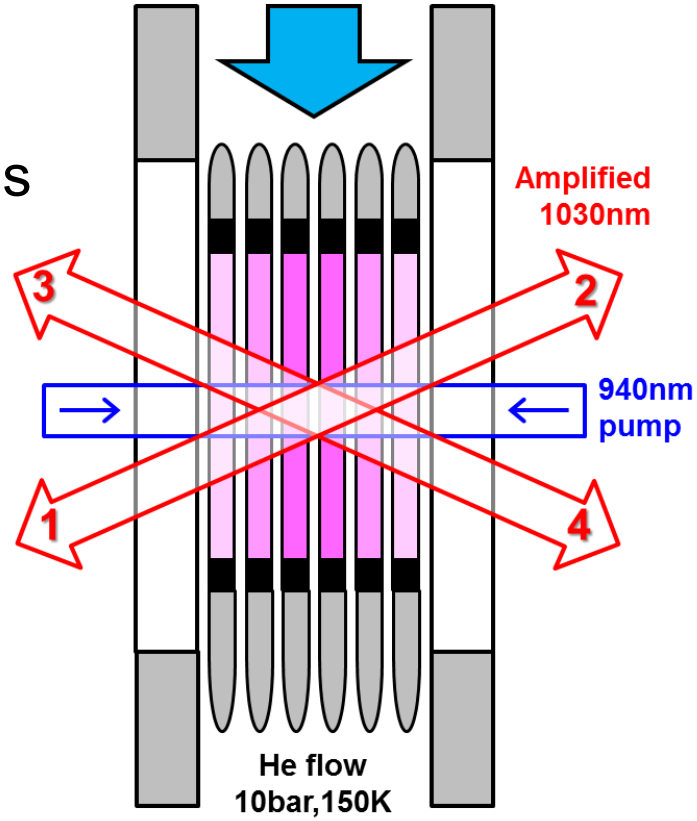
- Develop next generation high-energy PW-class lasers
  - Multi-J to kJ, multi-Hz, multi-% efficiency
- New generation of laser-matter interaction facilities
- Develop real world applications
  - Industrial materials processing
  - Laser driven X-ray & proton sources
  - Inertial confinement fusion
- High-energy DPSSL amplifiers needed
  - Direct & indirect sources

100J Amplifier System

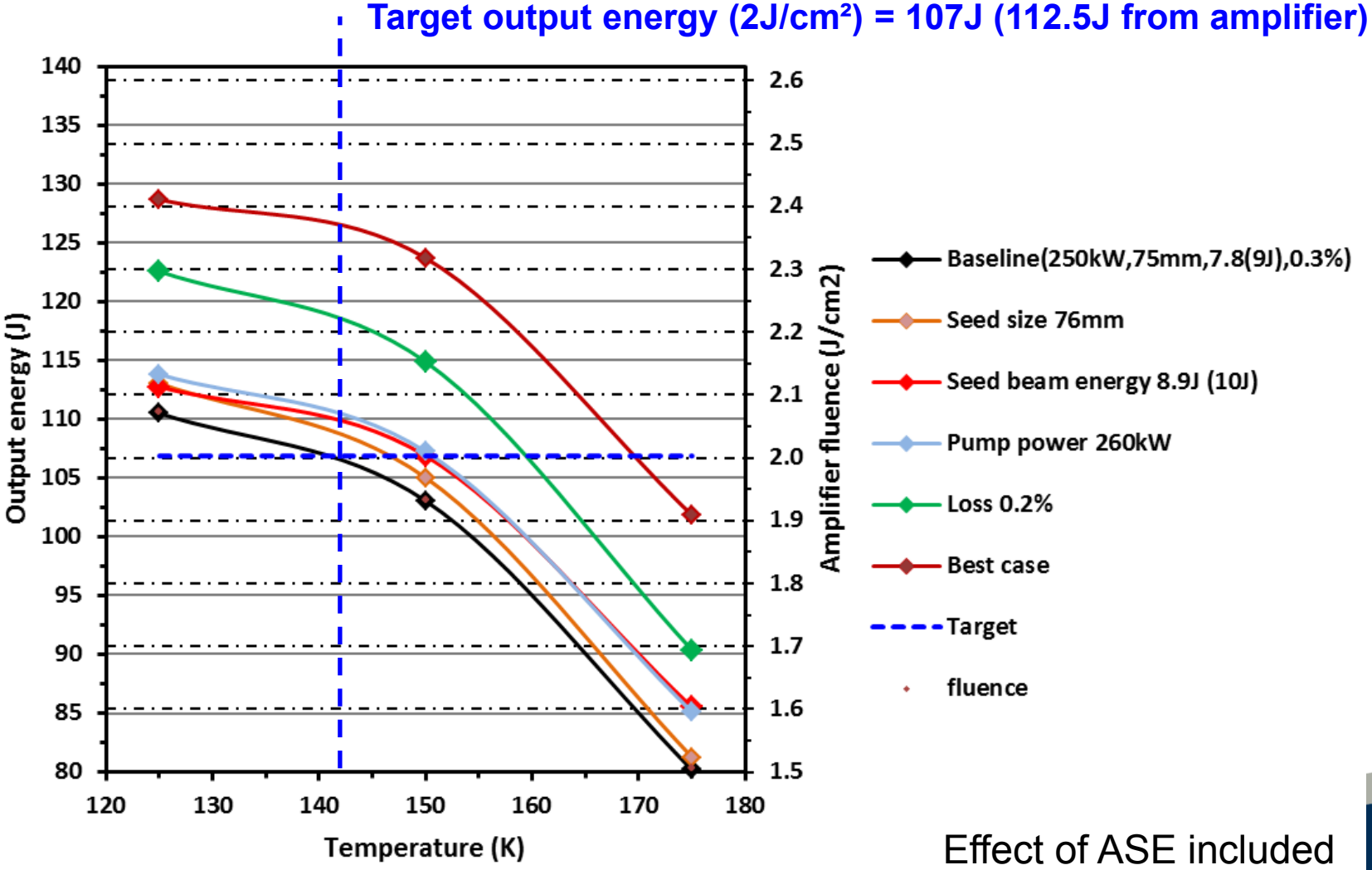


Baseline Design for 100J Amplifier

- Cryogenic gas-cooled multi-slab amplifier DiPOLE
  - Proven DiPOLE technology with $F_{extraction}$ = 2 J/cm^2
  - Single head seeded by 10 J cryogenic pre-amplifier
- 6 x square ceramic Yb:YAG gain slabs
  - 3 x doping conc^n, Cr-doped cladding
- End-pumped by two 940 nm diode systems
  - Angular multiplex coupling > 250 kW each
- LN_2 based helium cooler
  - Low risk, low cost technology
  - Design temperature ~ 150K
- 4–pass extraction architecture
  - Relay imaging
  - Spatial beam stabilisation
  - Active wave front control



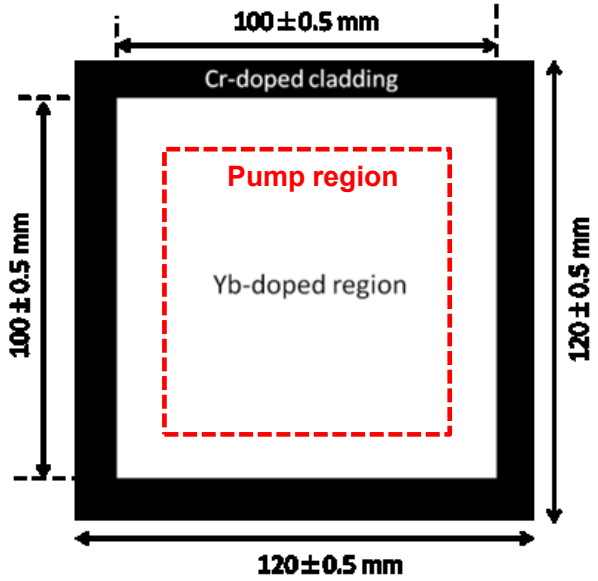
Baseline Modelling

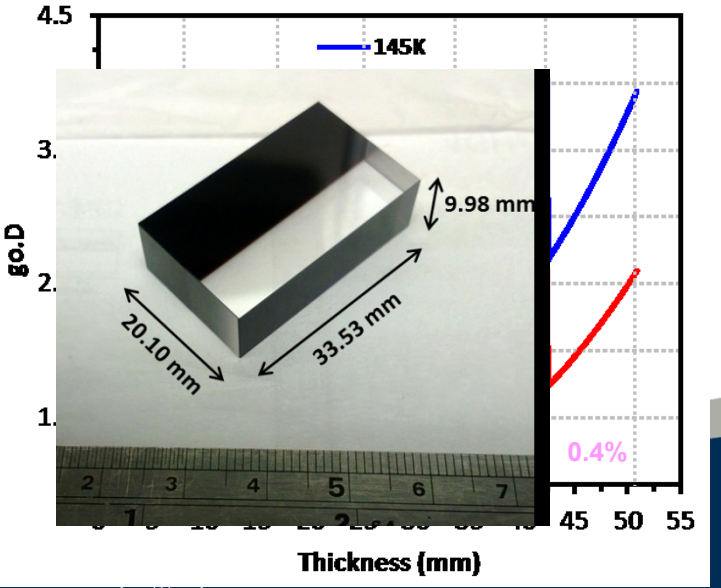


Effect of ASE included

Ceramic YAG Gain Media

- 6 x Yb:YAG ceramic slabs
  - 120 mm x 120 mm square x 8.5 mm thick
  - Yb-doped region 100 mm x 100 mm
  - Doping 0.4, 0.6 & 1.0 at.%
  - Cr^{4+} cladding 10 mm wide
  - Attenuation = 3 ± 1 cm^{-1} @ 1030 nm
    - T_{1030}^{ext} = 2 to 11% for 10 mm
  - PSD specification to minimise spatial inhomogeneities in transmitted wave front

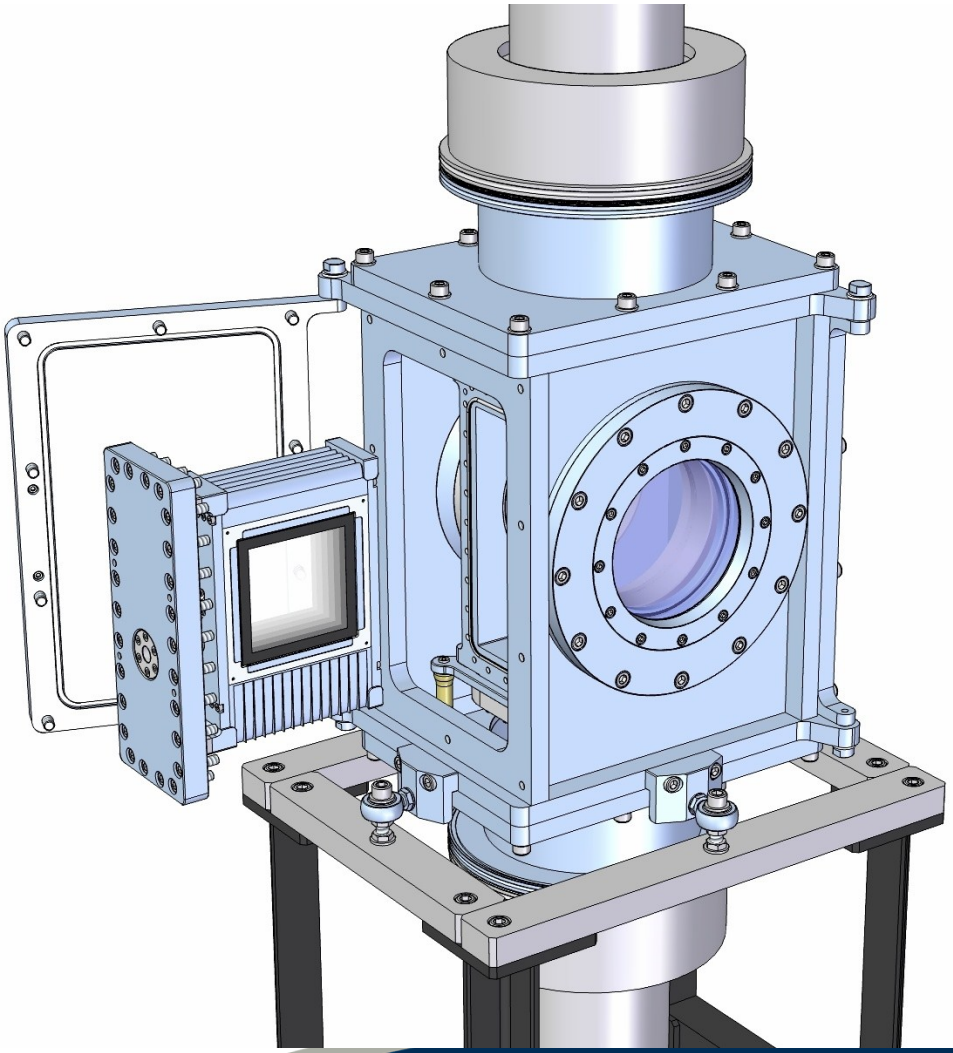




- Supply of test samples
  - Confirm required Cr attenuation level
    - T_{1030}^{ext} ~9%, α_{1030}=2.3 cm^{-1}
  - Uniformity of cladding attenuation

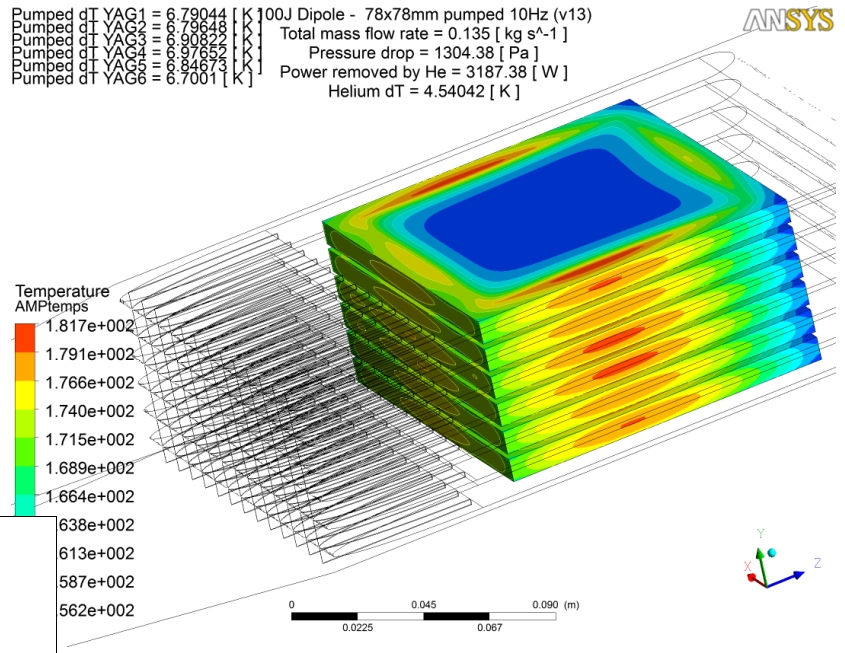
Amplifier Head Design

- Key features
  - Ease of access to gain cartridge
  - Re-usable pressure seals
  - Compact
  - Improved angular acceptance
  - Option for internal alignment reference
  - Optimised inlet gas flow conditioning
  - Independent vacuum in head

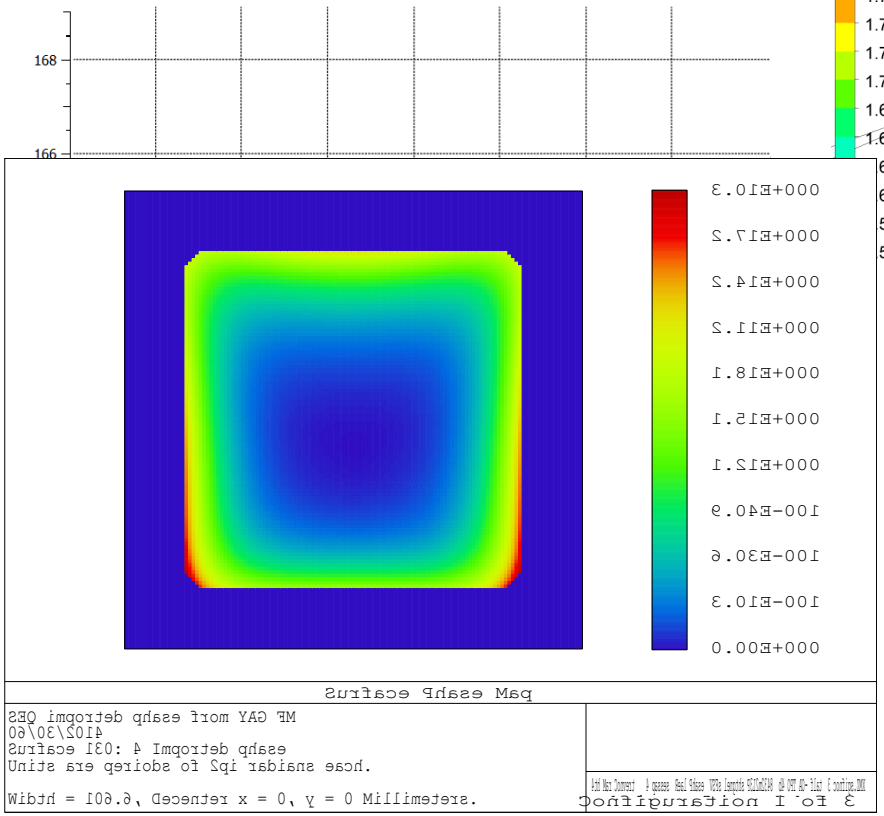


CFD Modelling & Thermal Aberrations

- CFD Modelling
  - 135 g/s
  - 10 bar He
  - $\Delta T \sim 5$ K



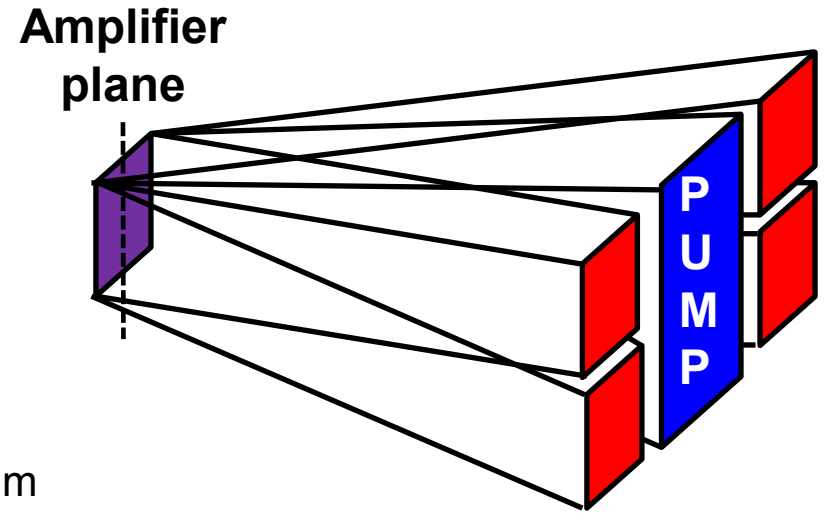
He flow



- Thermal phase map
  - Wave front distortion ~3 waves over 75mm x 75mm area

Pump Diode Sources

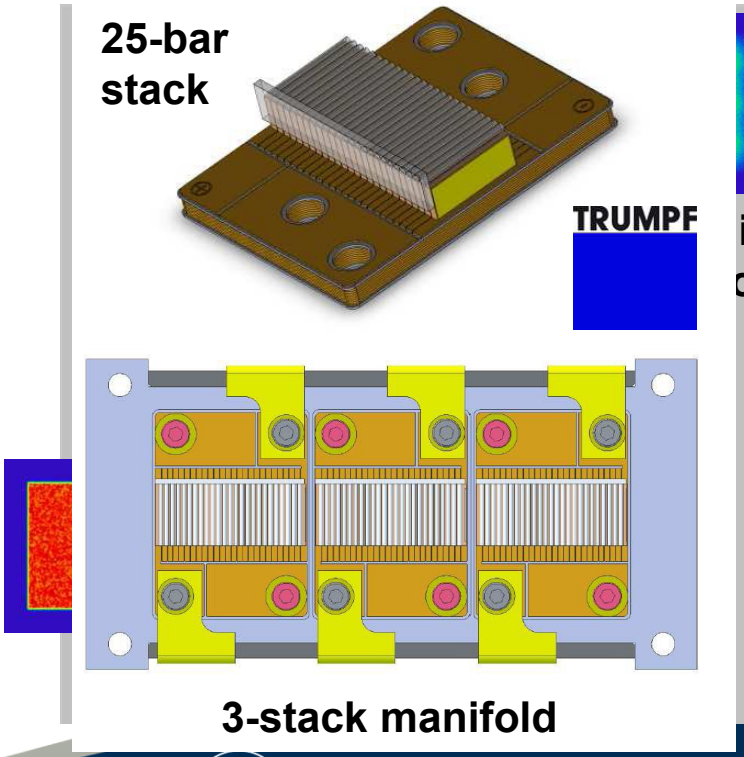
- Pump coupling scheme
  - Improvements in diode brightness allow angular multiplex coupling
  - Removes need for polarisation sensitive dichroic coupling mirrors
- Specification
  - 2 x 250 kW peak power
  - 0.5 to 1.5 ms pulses
  - Single-shot to 10 Hz
  - Square 78 mm x 78 mm beam
  - Working distance ~2.5 m
  - Centre wavelength 939.5 nm
    - 30% energy within ± 1 nm
    - 76% energy within -3.5 nm to +2.5 nm
  - Target brightness ≥ 1.3 MW/cm²/sr
  - Divergence ratio 2.5° : 5.0° (H : V)
  - Built-in optical diagnostics
  - Integrated alignment laser



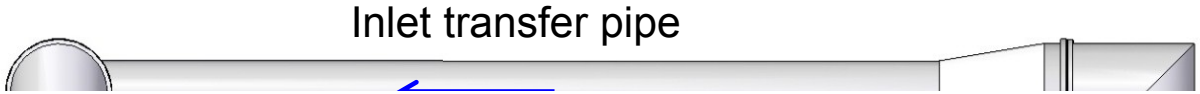
Pump Diode Sources

- Industrial consortium led by Ingeneric
  - Ingeneric – Optical design & integration
  - Amtron – Drivers, control system & cooling
  - Trumpf – Diode stacks

- Design
  - 3 x 3 array of diode manifolds each manifold with 3 x 25-bar stacks
  - Target 12.5 kW per stack
    - i.e. 500W per bar at ~ 550 A
  - Homogenisation using combination of conventional optics & micro-lens array
  - Working distance ~ 2.5 m from field lens to target plane
  - 1/3rd scale pilot laser demonstration
    - end April 2014

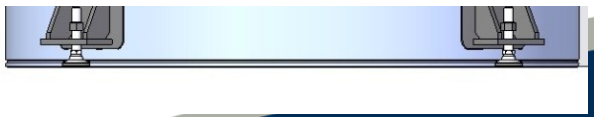


Cryo-Cooling System



- Cryostat under construction
  - Air Liquide Advanced Technologies, Grenoble, France
- Design concept similar to DiPOLE 10J
  - Similar temperature & pressure ranges
  - Low risk
- Increased cooling capacity
  - Up to 6 kW
- Magnetic bearing circulating fan technology
  - Maintenance free & long lifetime
- Continuous filtering of helium gas flow
- Independent vacuum in transfer lines

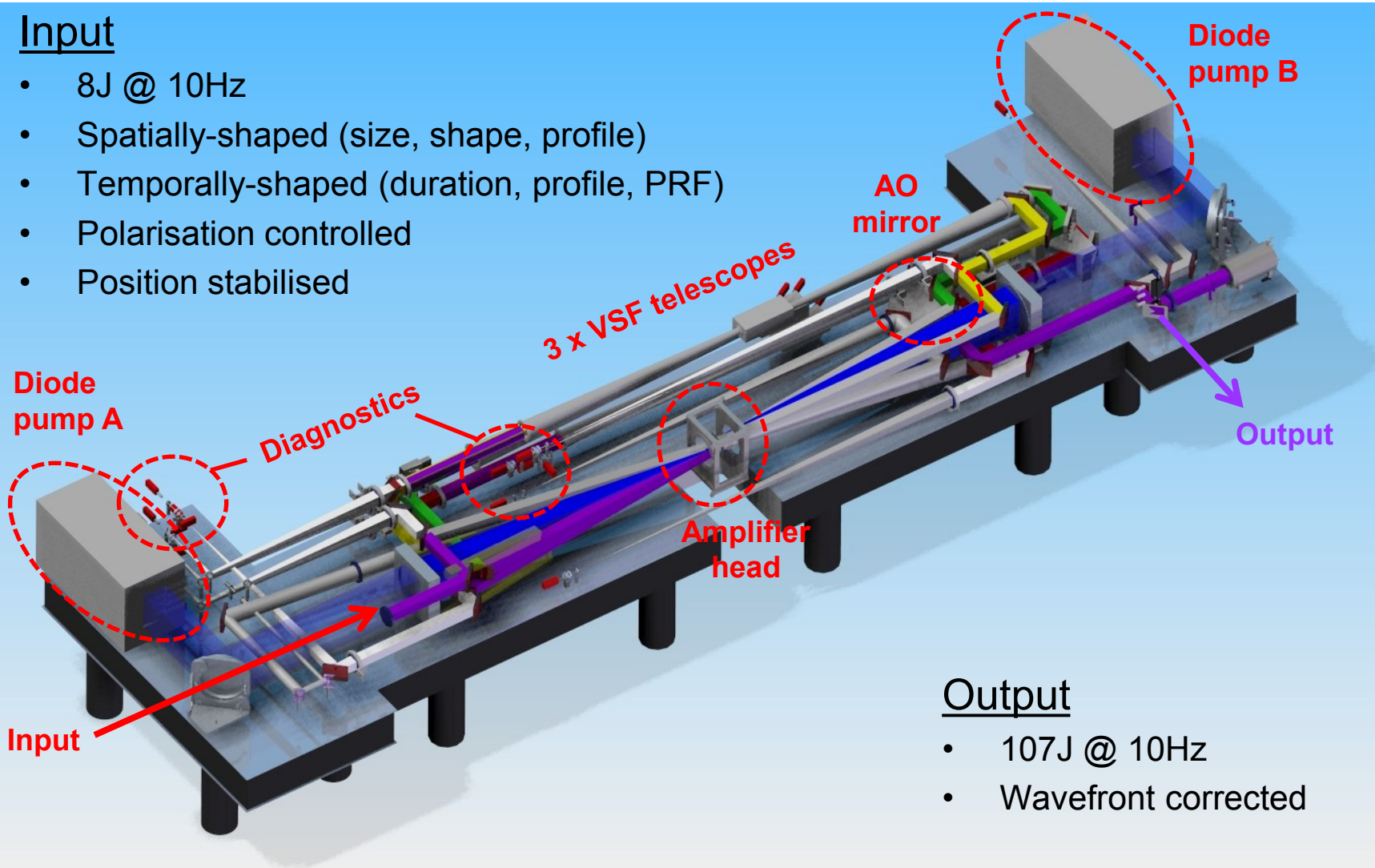
Outlet transfer pipe



100J Power Amplifier

Input

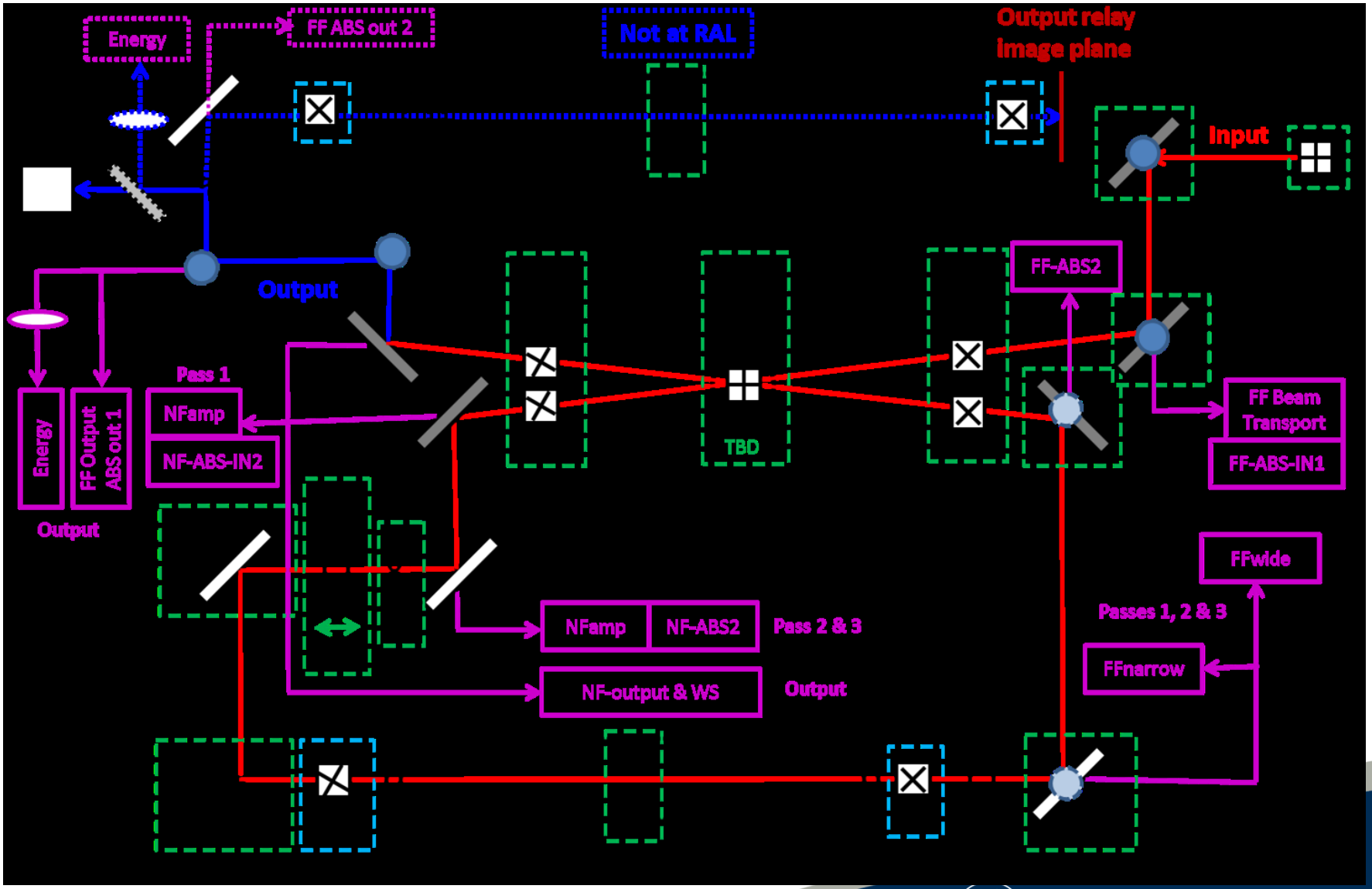
- 8J @ 10Hz
- Spatially-shaped (size, shape, profile)
- Temporally-shaped (duration, profile, PRF)
- Polarisation controlled
- Position stabilised



Output

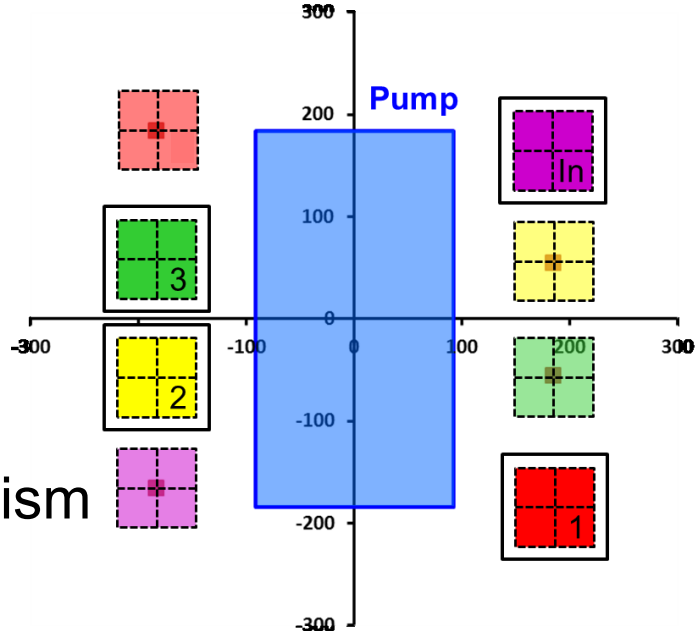
- 107J @ 10Hz
- Wavefront corrected

Diagnostic Systems



Multi-pass Design

- 4F relay imaging design
  - Maintain total telescope length to within 20% (4.2F)
- Asymmetric positioning of telescopes
  - Remove risk of collimated ‘pencil beams’ focusing into amplifier
- Asymmetric angular multiplexing of amplified beams
  - Minimise risk of coupling reflected beams from amplifier optics into other passes
    - Horizontal = ± 5 degrees
    - Vertical (input & pass 1) = ± 5 degrees
    - Vertical (passes 2 & 3) = ± 1.5 degrees
- Tilt telescope lenses to minimise astigmatism
  - Lenses tilted in opposite directions
- Periscope after 2nd pass
  - Compensate for beam rotation
  - Beam stabilisation



View from input mirror plane

Summary

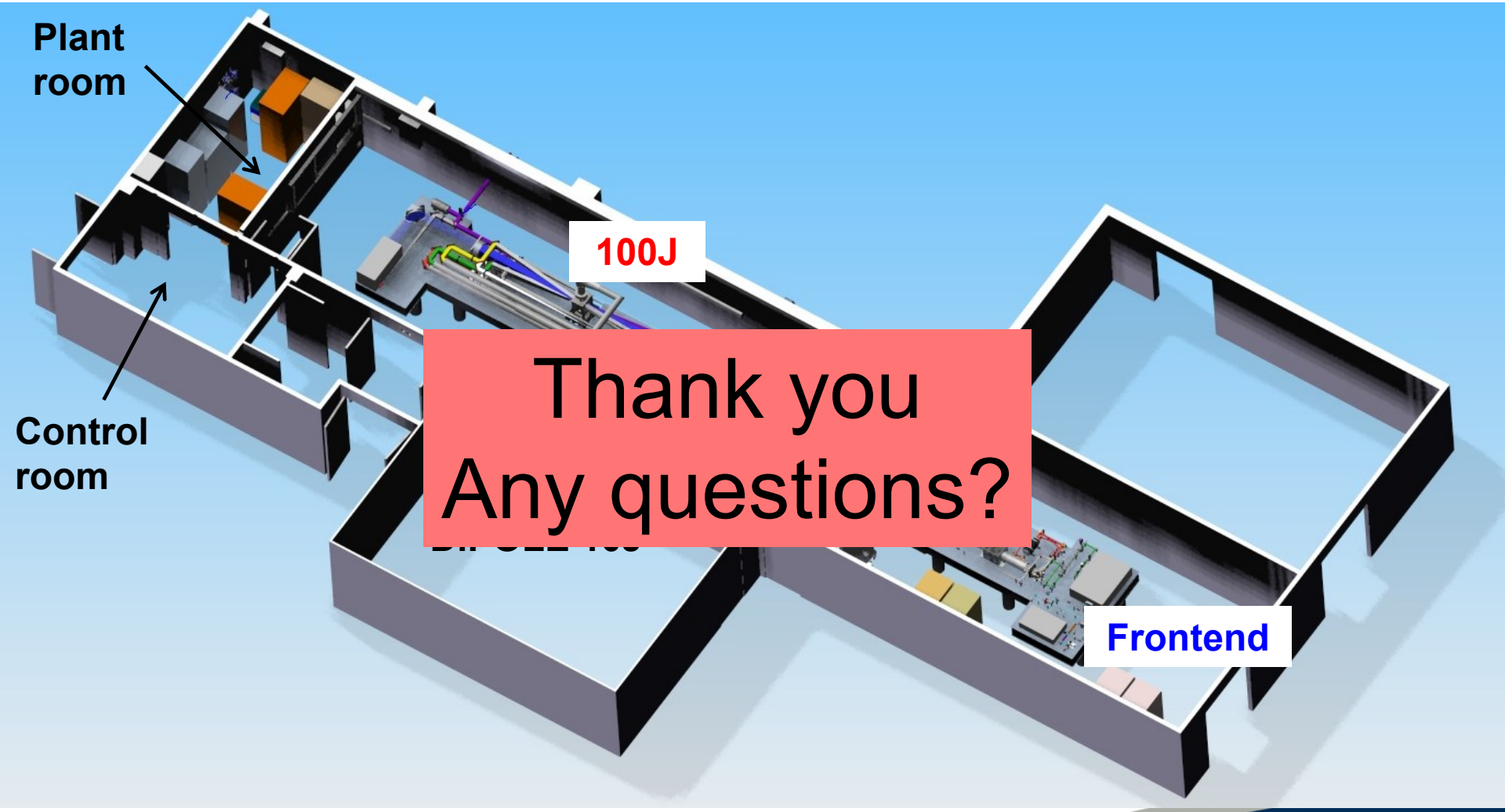
- 100J power amplifier optical design completed
  - Based on proven DiPOLE 10J cryo-cooled Yb:YAG technology
- Mechanical component design commenced
- Optical installation scheduled to begin end July 2014
  - Demonstrate scalability of technology
  - Amplifier, pump diode systems, gain media
- HEC-DPSSL development in CALTA
  - 100J system for European XFEL

European XFEL

Science & Technology Facilities Council

EPSRC
Engineering and Physical Sciences Research Council

100J Laboratory



Thank you
Any questions?