High power Laser Systems at the Central Laser Facility

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Central Laser Facility, RAL

UK and EU facility

Experiment Planning

Link scientist assigned responsible for project managing the experiment with Principle Investigator of visiting research group (Users)

Dedicated support team per experimental area: Engineering designer, target fabrication rep, laser operations rep, target area mechanical and electrical technicians

- 6 month cycle
- Introduces formal checks
- Aids resource management (staff and equipment)
- Ensures readiness for scheduled time
- Allows flexibility to carry out unexpected extras
- Full engineering drawings viewable over web based portal anticipated

Experiment Execution

- ***2009 New course for Experiment Area Operators*** to enhance experienced Users' skills at managing their team, managing their science project and safety awareness:
  - 2 days - project & people management
  - 3 days - vacuum & gases handling safety, lasers & ionising radiation safety and STFC work place safety awareness

- ***2002 – present Training Weeks course*** for new facility Users
  - 2 week course
  - practical experiment techniques, diagnostics, chamber set-up etc
  - Introduction to aspects such as fabricating targets to how to characterise laser pulses
  - Lectures from experts in field on topics from laser plasma interactions to safety
- ***Daily operations meetings*** for every active experiment area
  - Sets priorities for support teams and achievable goals for the experimenters
  - Aids resource management (staff and equipment)
- ***Operations diary*** and video phones to ensure effective communication
- ***Development of web based safety testing*** accessible before scheduled time
- ***Standardised*** safety equipment and instructions

Laser Systems & Project

- *Lasers For Science/ULTRA*
- *Dipole*
- *Artemis*
- *Vulcan*
- *Astra-Genimi*
- *10PW*

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Artemis

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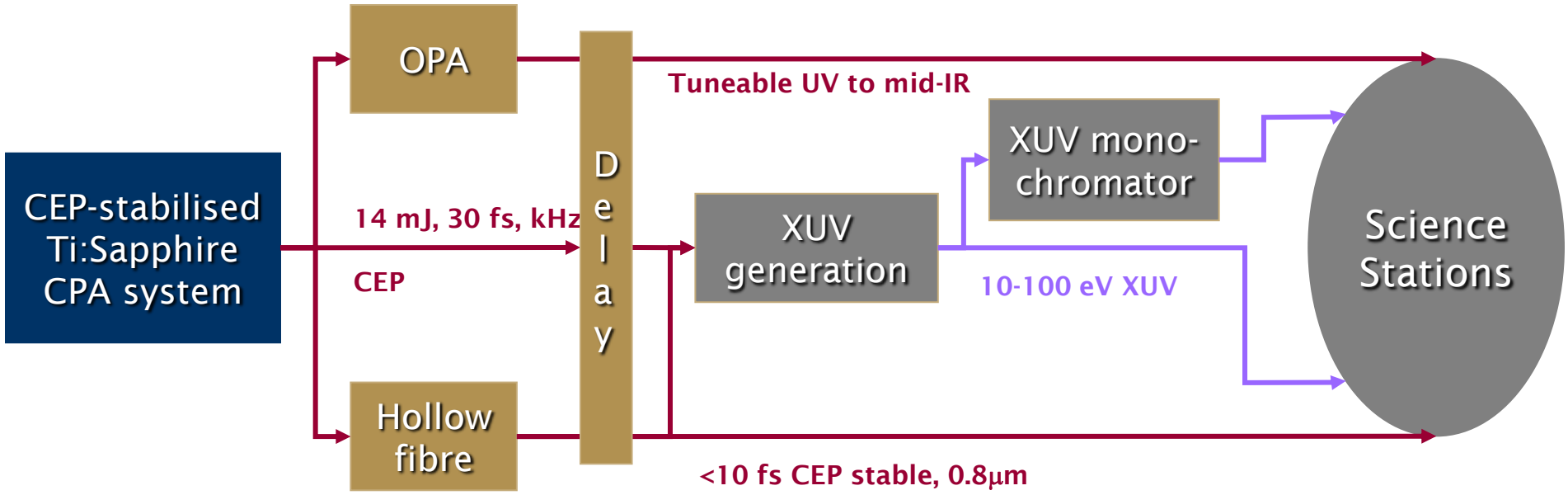
Artemis Facility

- **Three femtosecond laser beams**
  - 14 mJ, 30 fs, 1-3 kHz CEP-stabilised
  - <10fs 800nm pulses
  - 30 fs, tuneable UV to mid-IR
- All beams synchronised and independently configurable

- **Two femtosecond XUV beamlines**
  - Broadband 10-100 eV XUV
  - Monochromatic short pulse (10-50 fs)
  - Future attosecond capability
- **Two End-Stations**
  - Materials science
  - Atomic & molecular physics



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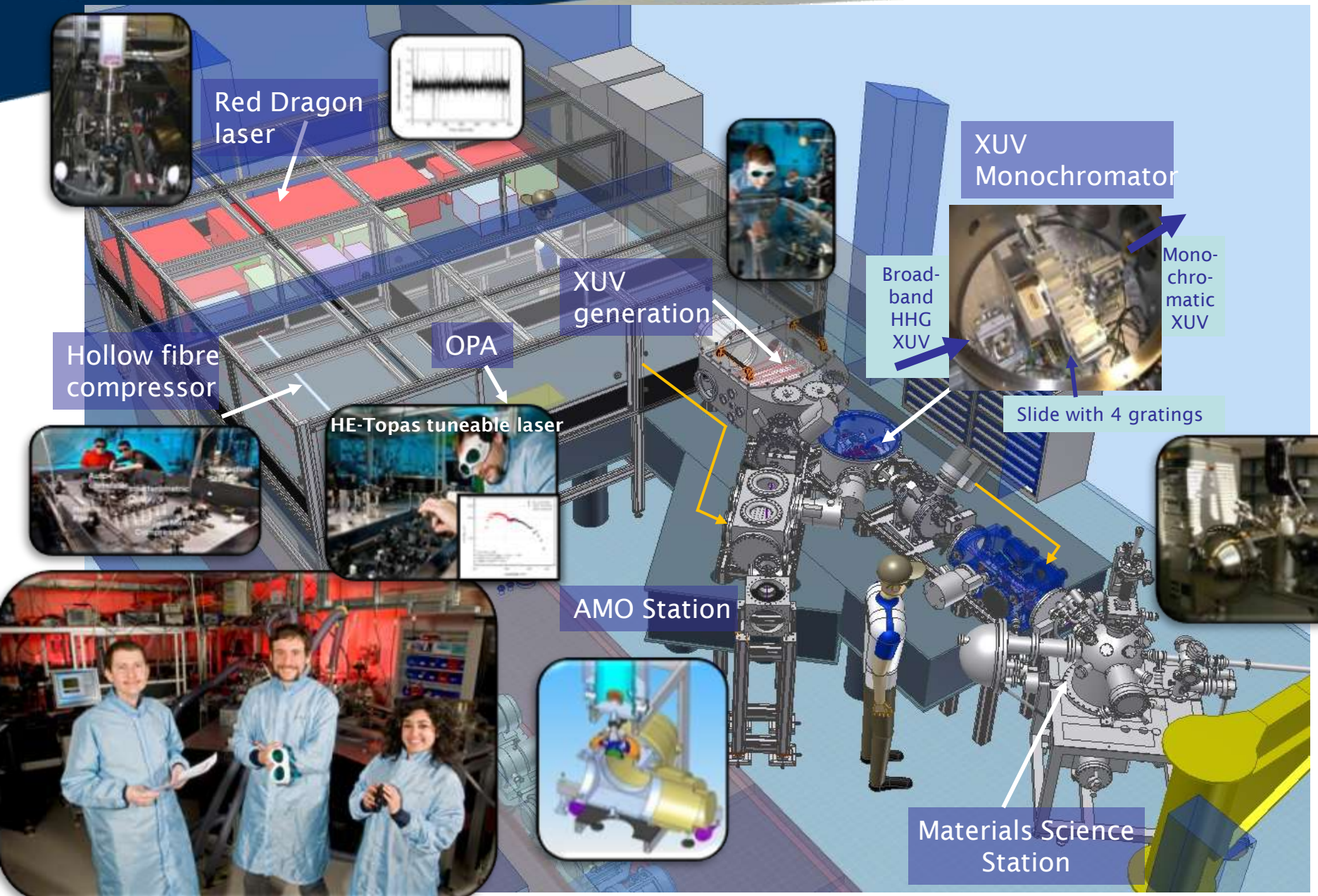
Facility Layout



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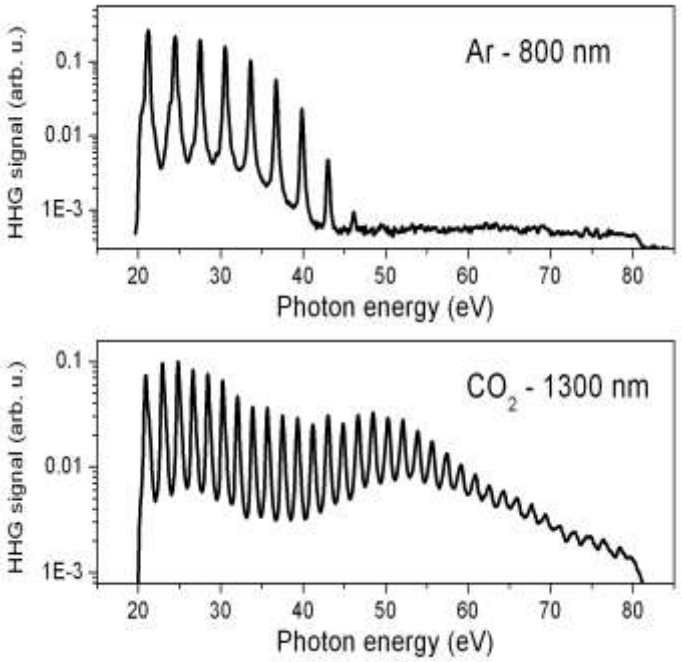
XUV Beamlines

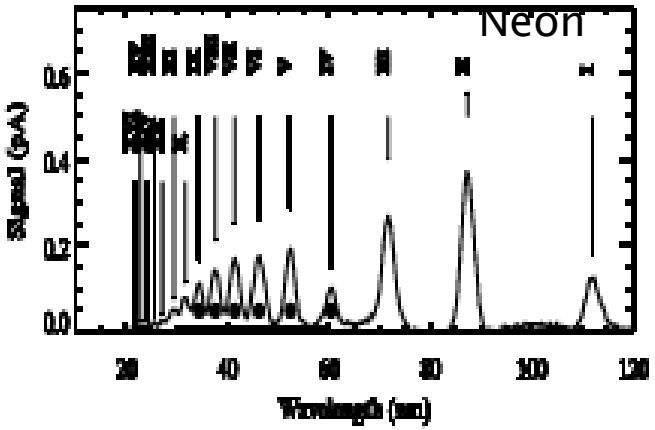
XUV broadband beamline for Atomic and Molecular Physics End-Station

- HHG from 800nm or 1300nm
- Flat-field spectrometer –diagnostics



XUV monochromatic beamline for Materials science End-Station

- $>10^9$ photon/sec @ 40eV
- Tunable in the 10 eV -100 eV
- XUV bandwidth ~ 20 -100 = $\lambda / \Delta\lambda$
- XUV pulse duration ~10 – 40fs



Laboratory for UV and X-ray Optical Research

10fs XUV Monochromator

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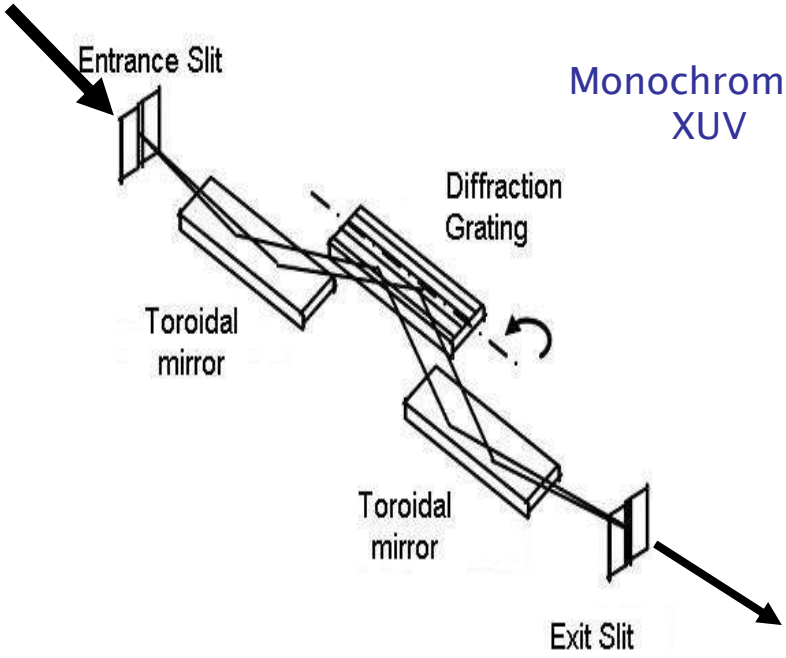
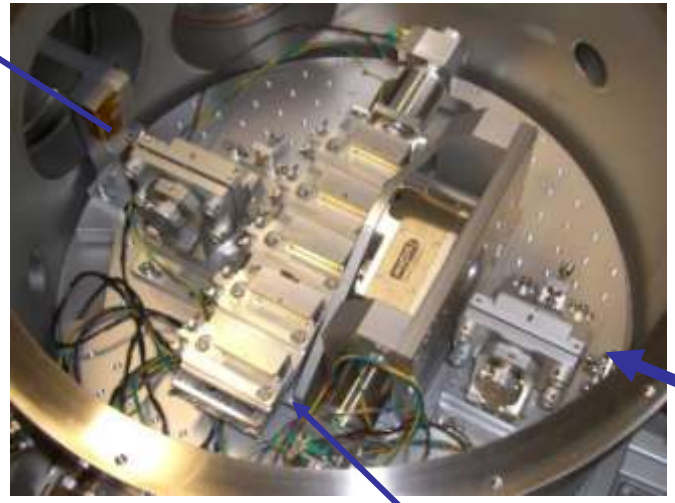
Laboratory for UV and X-ray Optical Research

Monochromator will select a single harmonic within a broad band XUV spectrum while preserving pulse-length.





- Tunable: 10 eV -100 eV photon energy, 120nm – 12nm wavelength
- Low resolution gratings ($\lambda/\Delta\Lambda$~20): pulse duration ~10fs
- High resolution gratings ($\lambda/\Delta\lambda$~80): pulse duration ~40fs
- Peak efficiency ≈30%

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Vulcan

Vulcan Laser Facility

- 8 Beam CPA Laser
- 3 Target Areas
- 3 kJ Energy
- 1 PW Power

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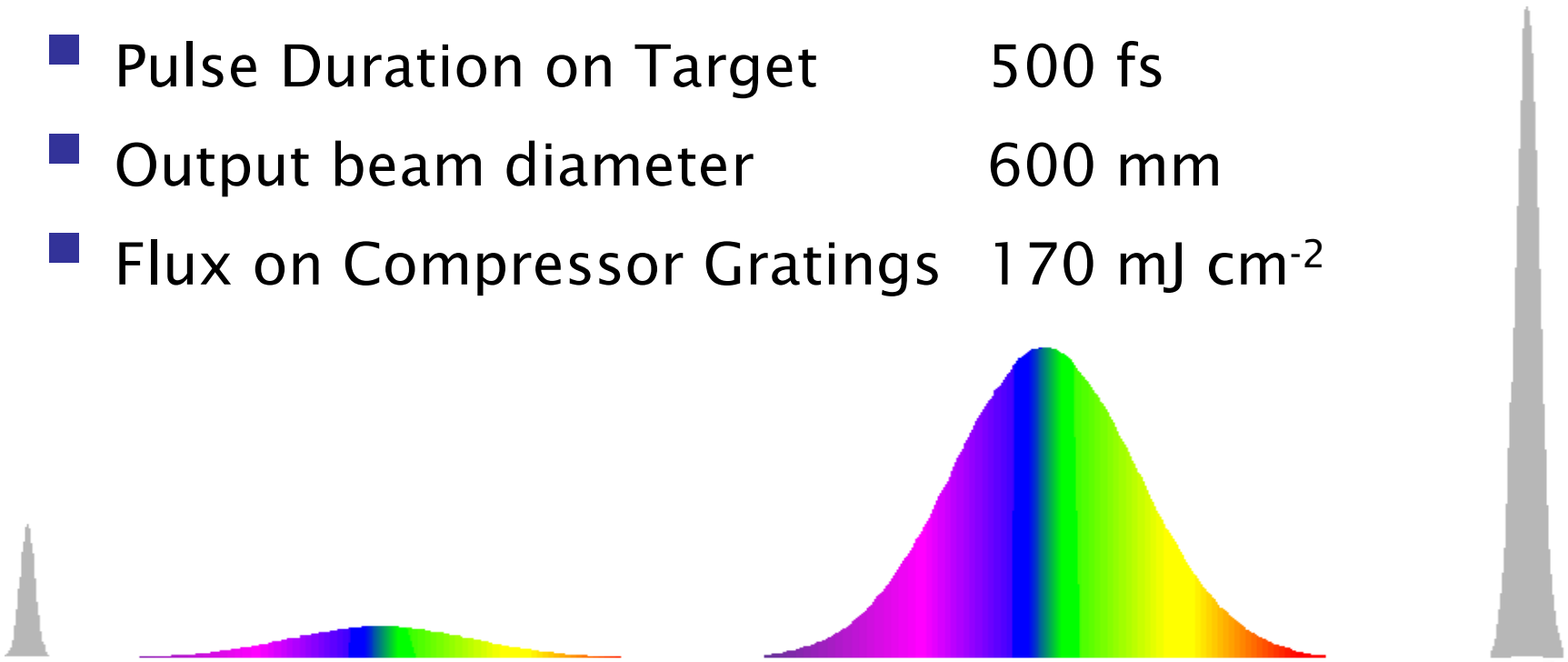
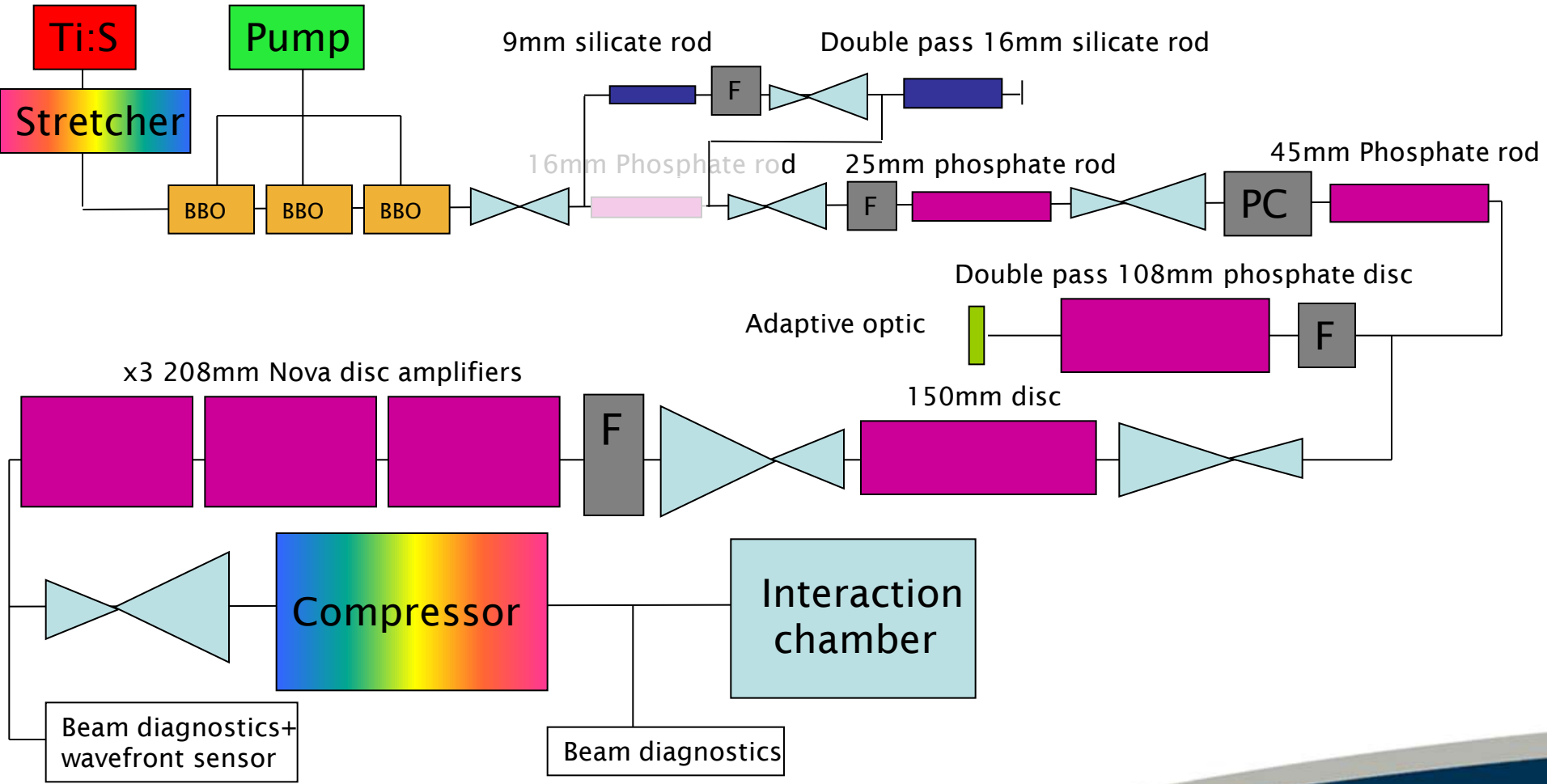
Vulcan Petawatt Specification

- Laser Output Energy 670 J
- Energy on Target 500 J
- Pulse Duration on Target 500 fs
- Output beam diameter 600 mm
- Flux on Compressor Gratings 170 mJ cm^{-2}



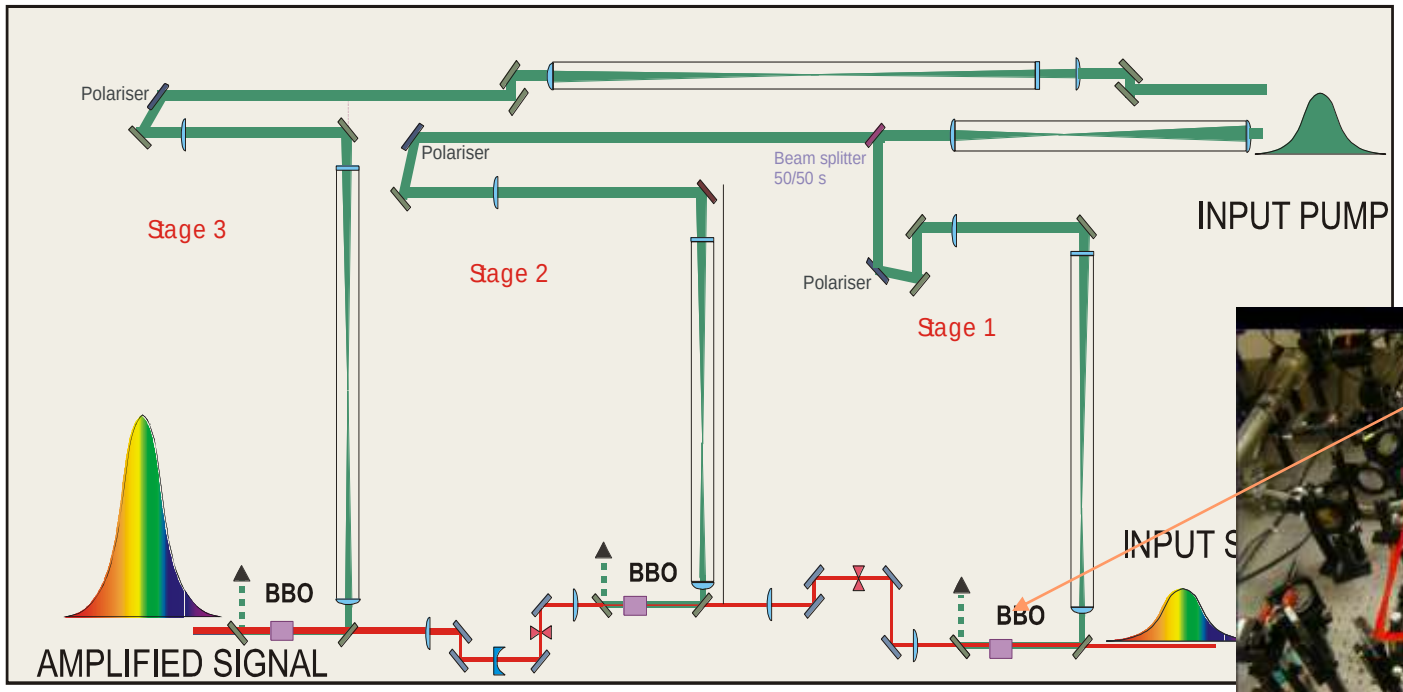
Vulcan Petawatt

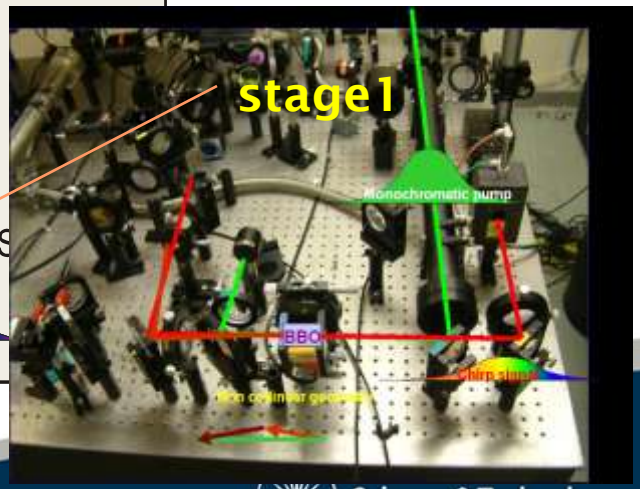


OPCPA

Stretched pulse → OPCPA amplifier
Pulse energy 14mJ,
with 13nm bandwidth

3 stage BBO system,
Total gain ~10^8
Operational since 2002





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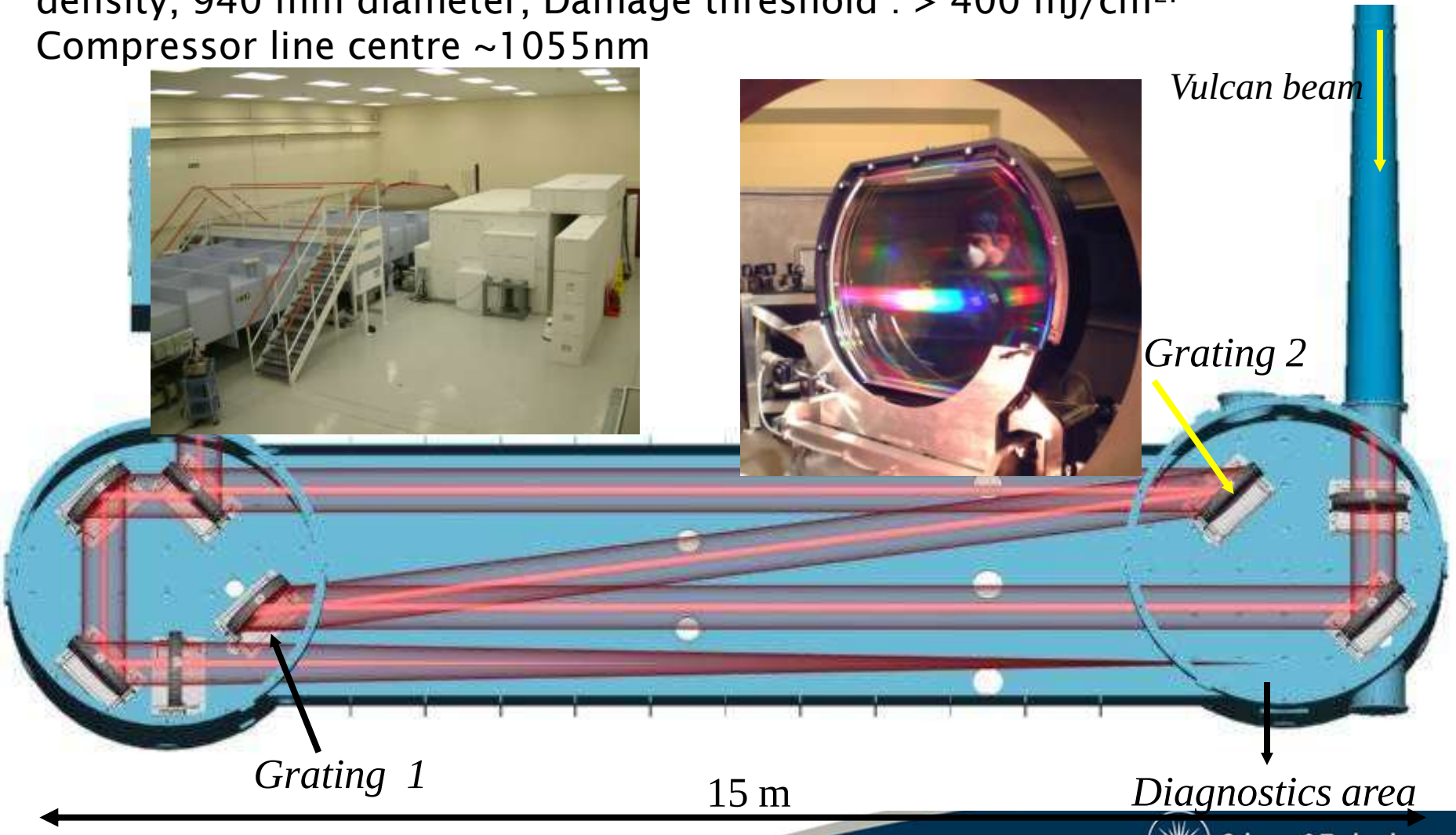
Compressor chamber beam layout

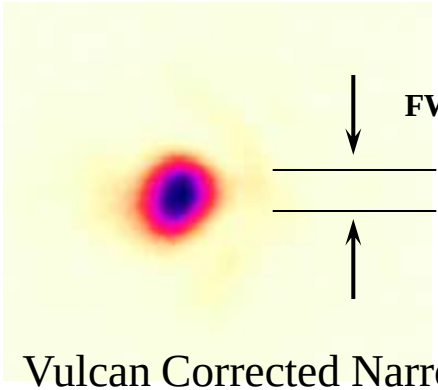
- Single pass grating compressor- gold coated gratings,1480 l/mm line density, 940 mm diameter, Damage threshold : > 400 mJ/cm^{2}.
- Compressor line centre ~1055nm



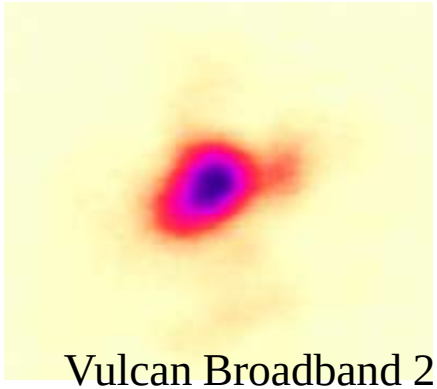
Parabola performance

- 650mm clear aperture F3.1 off axis parabola primary focusing optic for the Petawatt beam line

Vulcan Focal spot

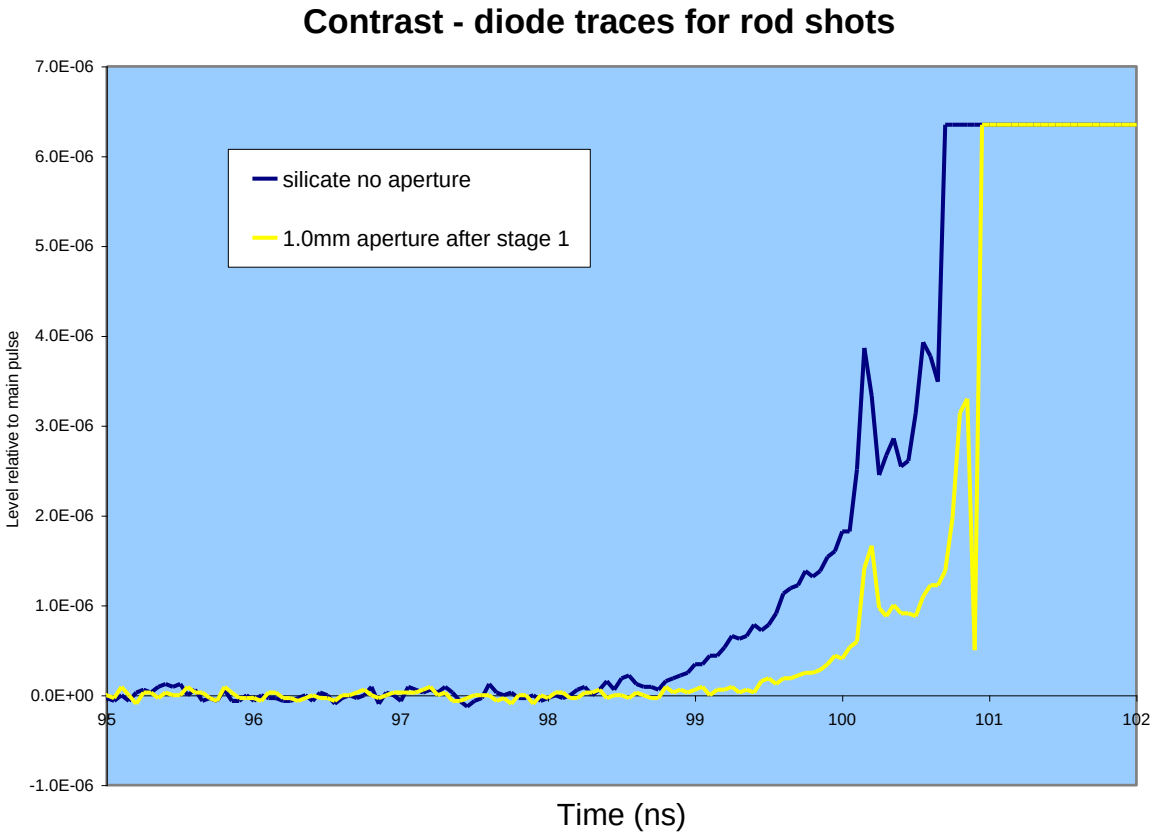


Vulcan Corrected Narrowband CW Beam



Vulcan Broadband 2 J Shot (Rods)

Nanosecond contrast



- Beam amplified to 2 J by OPCPA and mixed glass rod chain for normal Petawatt operations

- Best contrast for low energy shots ~4×10^{-8} of the peak of the main pulse in intensity in the ns regime before the main pulse

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Target Area West

CPA beams:

Beam 7:

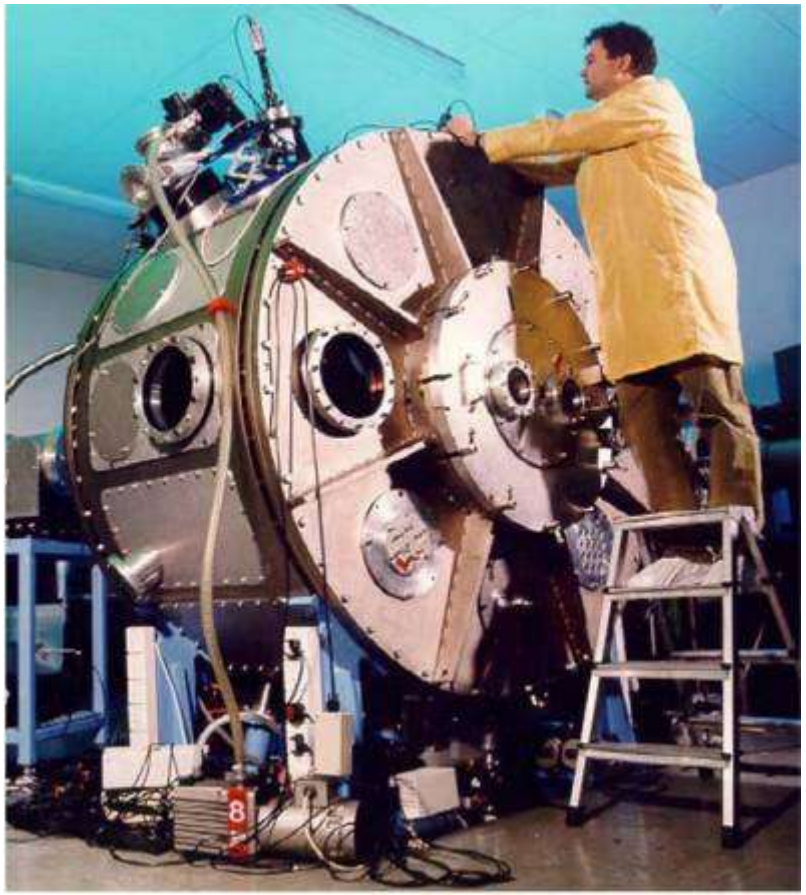
Compressor under vacuum

1ps, 100J

Beam 8:

Compressor under vacuum

1ps-10ps, 100J or >10ps, 300J



Long Pulse Beams:

Up to 6 beams

80ps (40J) to 4ns (300J) per beam

1053nm or 527nm

Shaped long pulses

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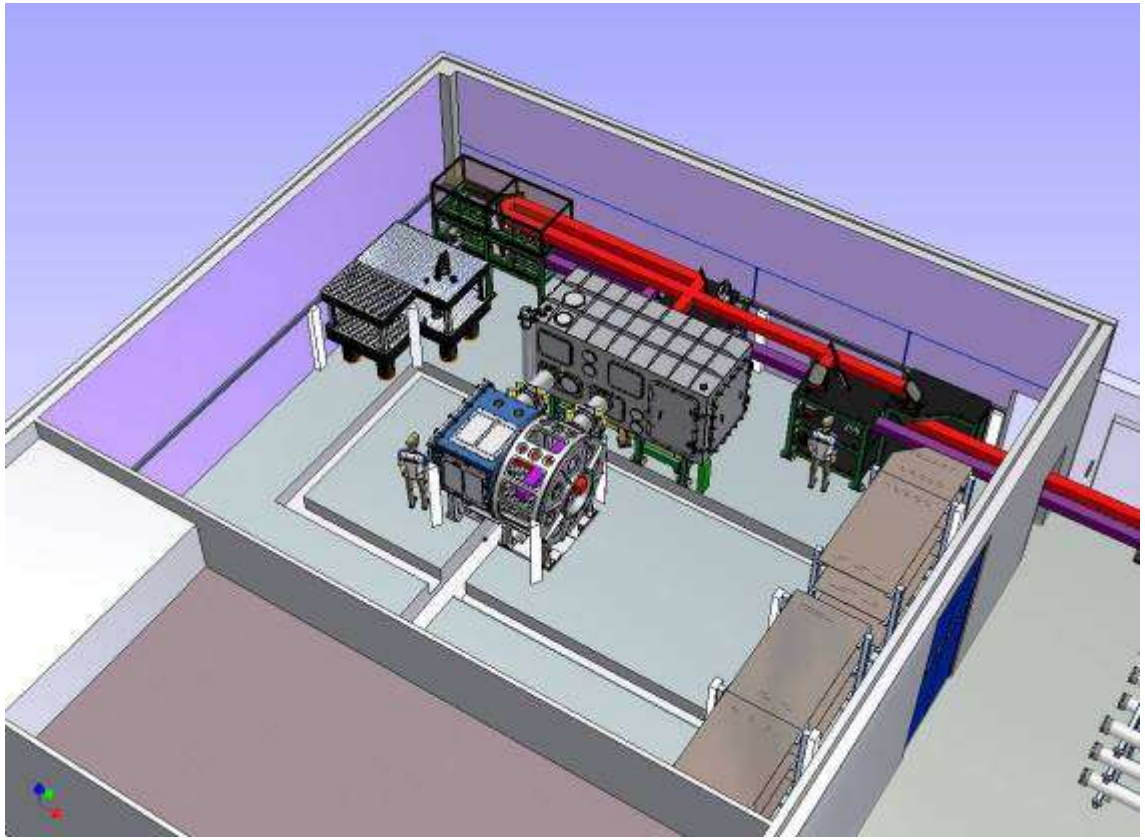
TAW Layout



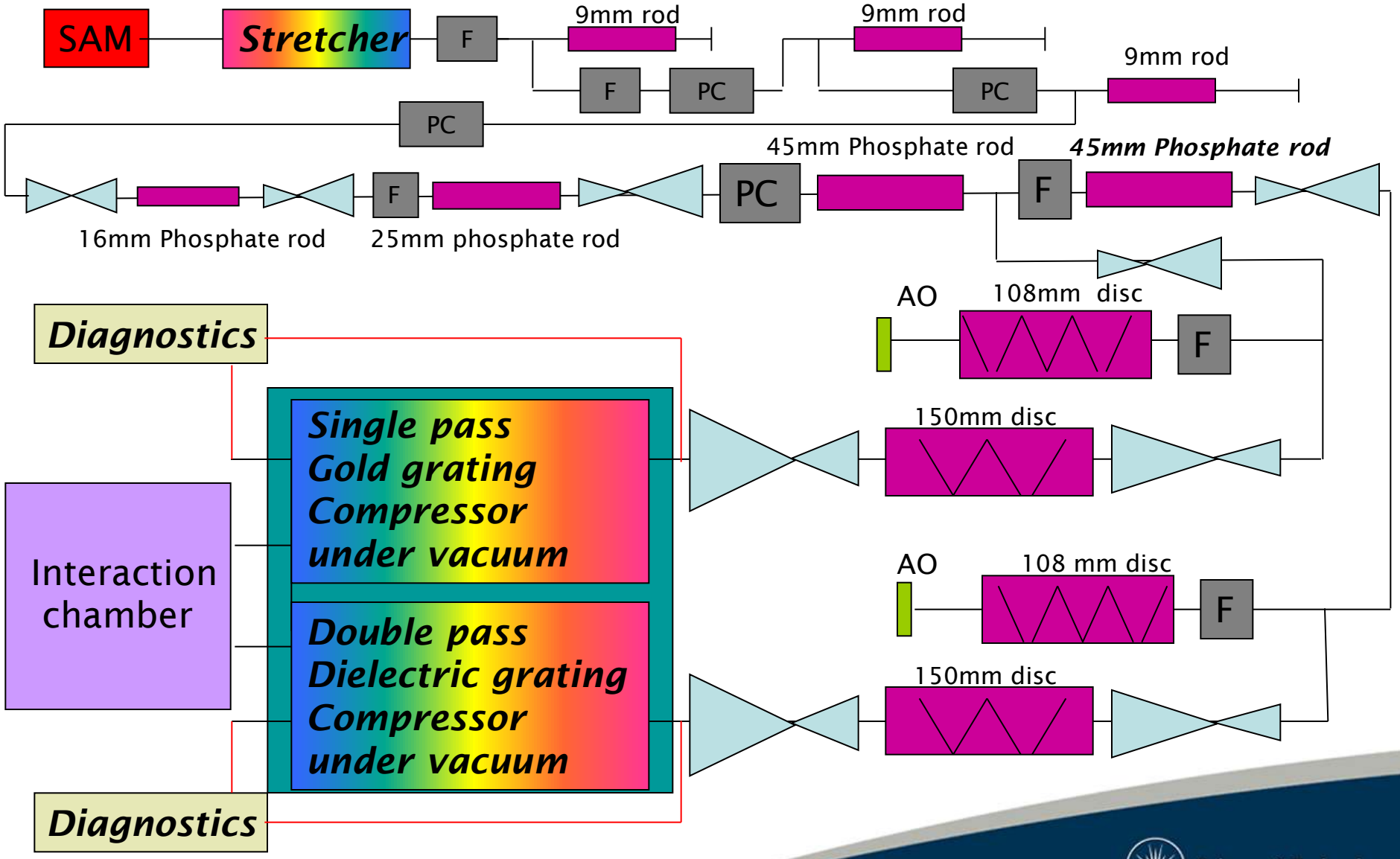
Compact layout to leave space free for the users

The two CPA beam lines are on different level

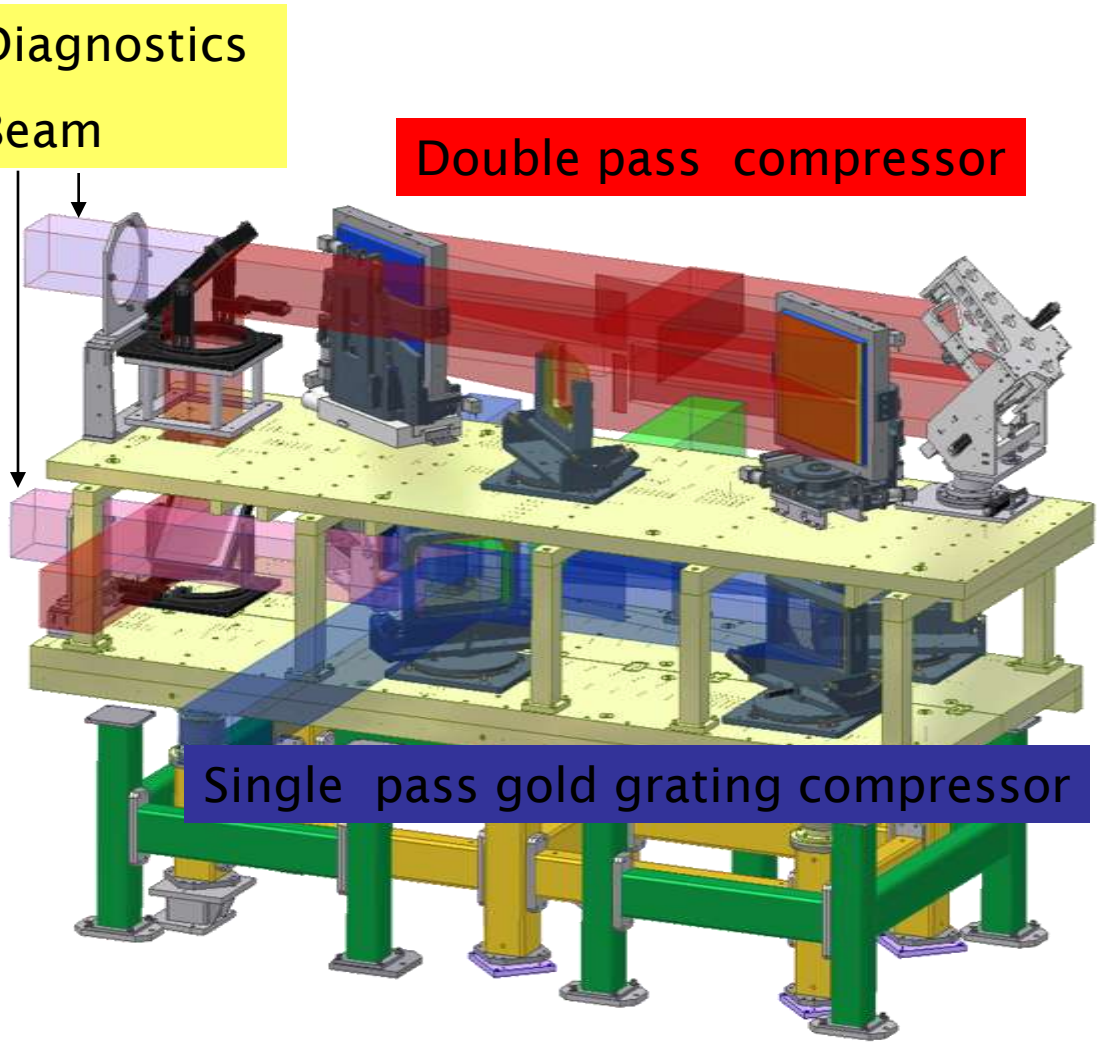
Separate delay lines for each beam

Most of the mirrors have remote control

Laser Layout



Compressor



Double deck vacuum compressor

Upper compressor: double pass with variable gratings separation

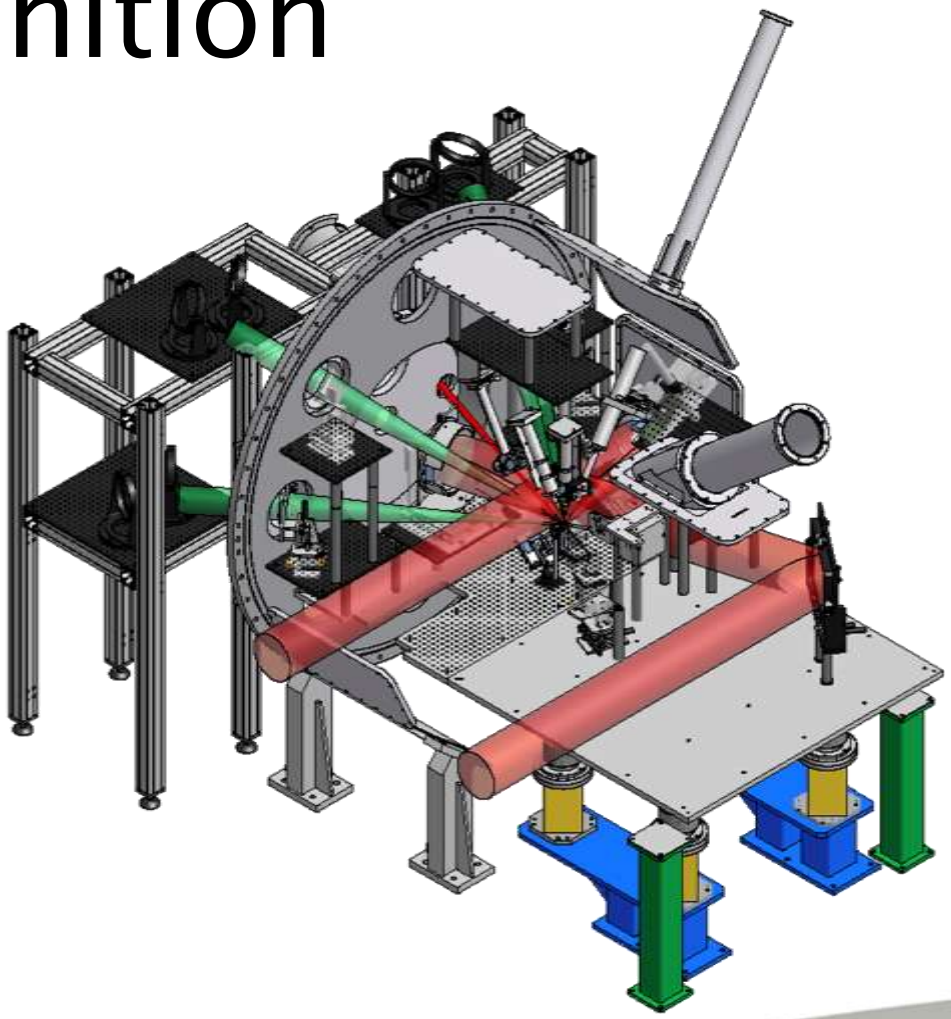
Lower compressor: single pass with folding mirror

Laser Channeling for Fast Ignition

Phase 1:
Interact 10ps, 300J beam with gas jet to image channel at 10^{19} to 10^{21} cm^{-3}

Phase 2:
Create plasma column with 800J,1ns

Interact 10ps 300J beam with plasma column



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Astra-Gemini

Astra Gemini laser system

Two independent 800 nm beamlines

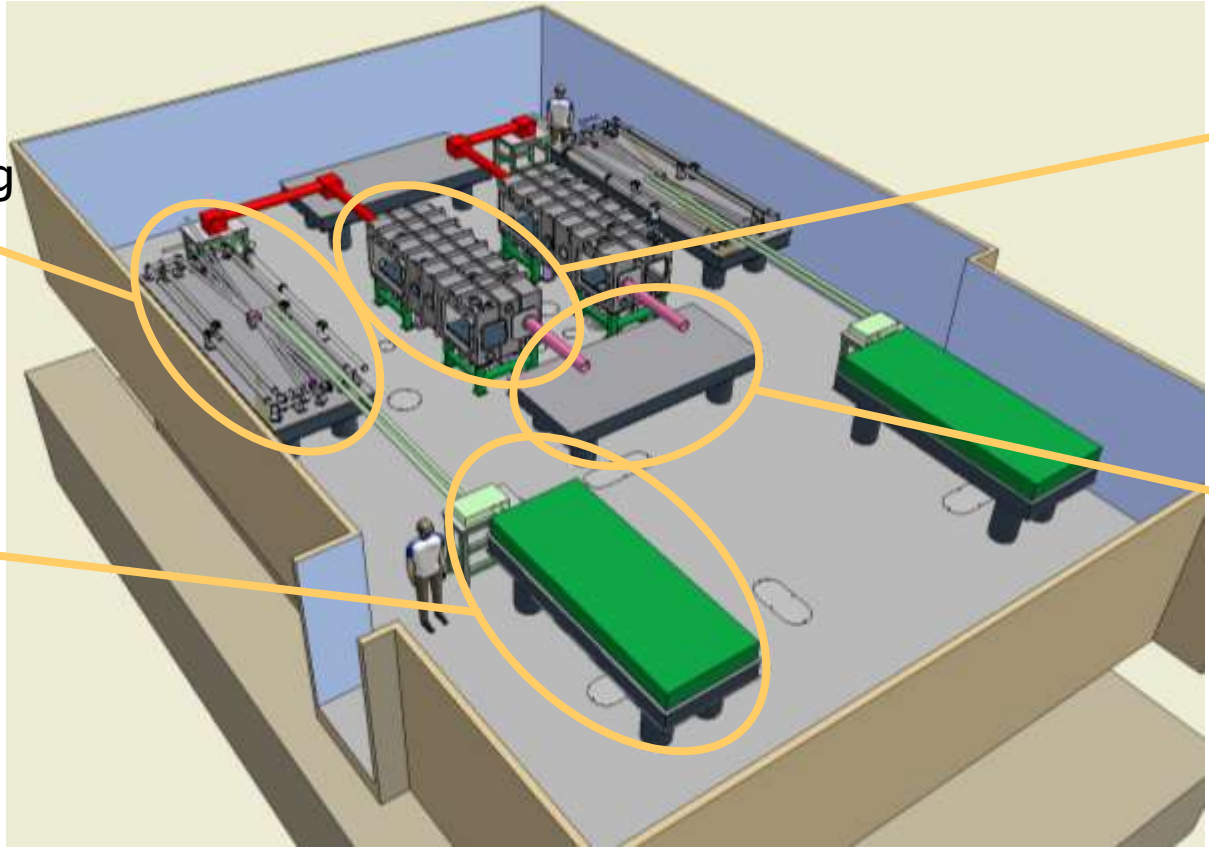
15 J per beam, 150 mm diameter

30 femtoseconds pulse duration: 2 x 0.5 PW

Shot interval 20 seconds

Layout of the Astra Gemini

4-pass Ti:S amplifier with image-relaying spatial filters



Compressor vacuum chamber

Diagnostics

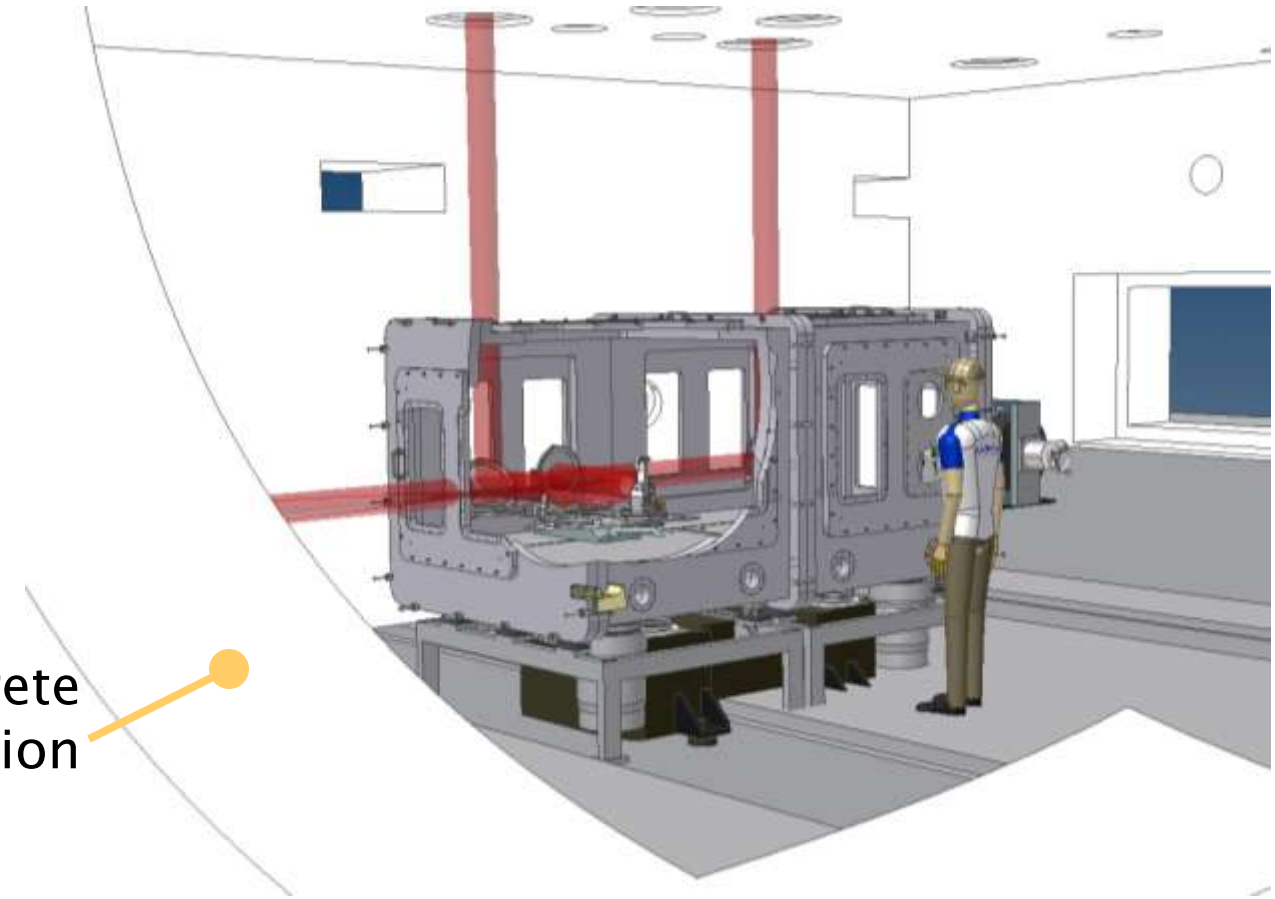
Pump laser

60 joules @ 527 nm in 2 beams of 45 mmØ

The experimental area

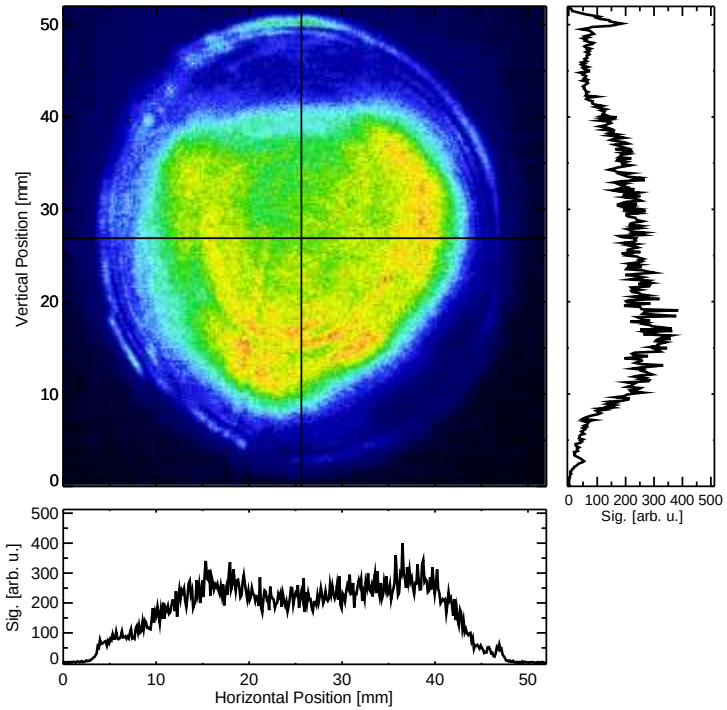
360˚ access around the interaction chamber

1 metre concrete wall for radiation shielding

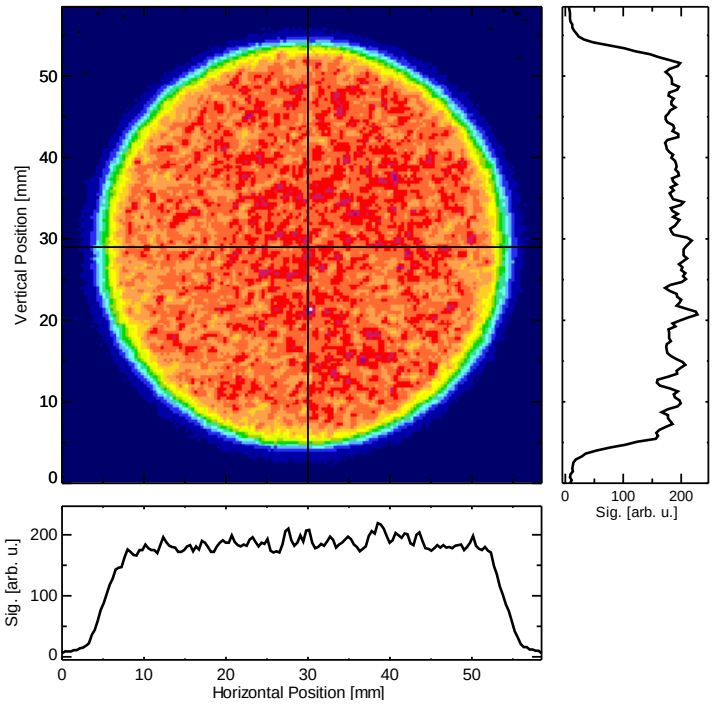


Astra Gemini laser area

We use DOEs to homogenise the pump beams

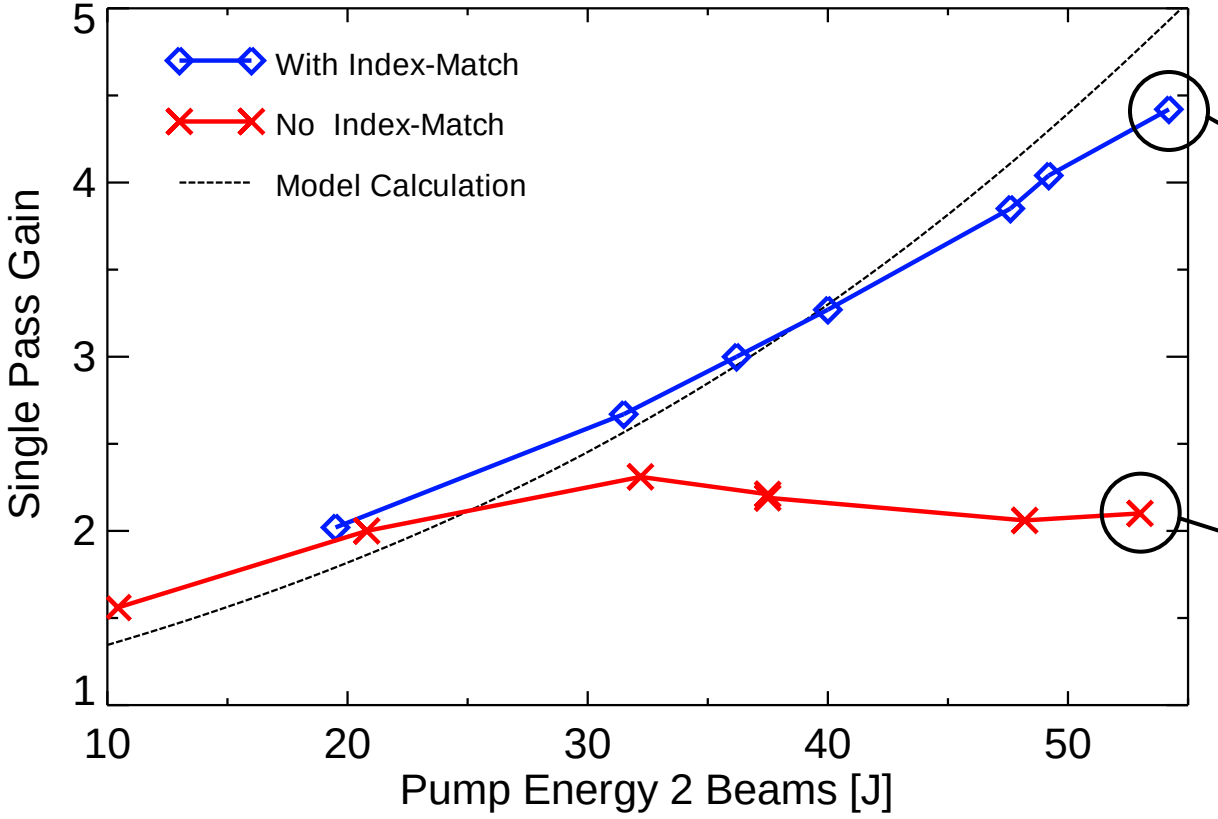


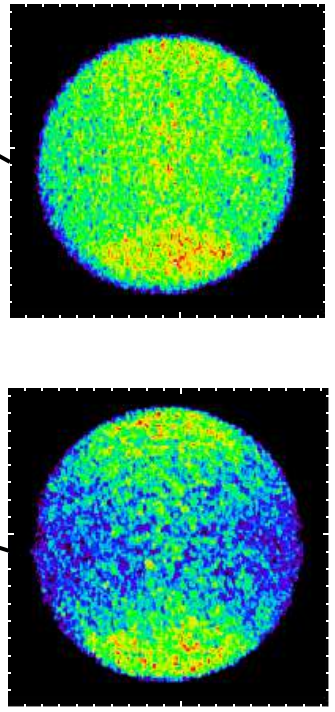
Raw pump beam profile
527 nm, 26 joules



Homogenised pump beam profile
527 nm, 26 joules, 6% rms modulation

Suppression of ASE

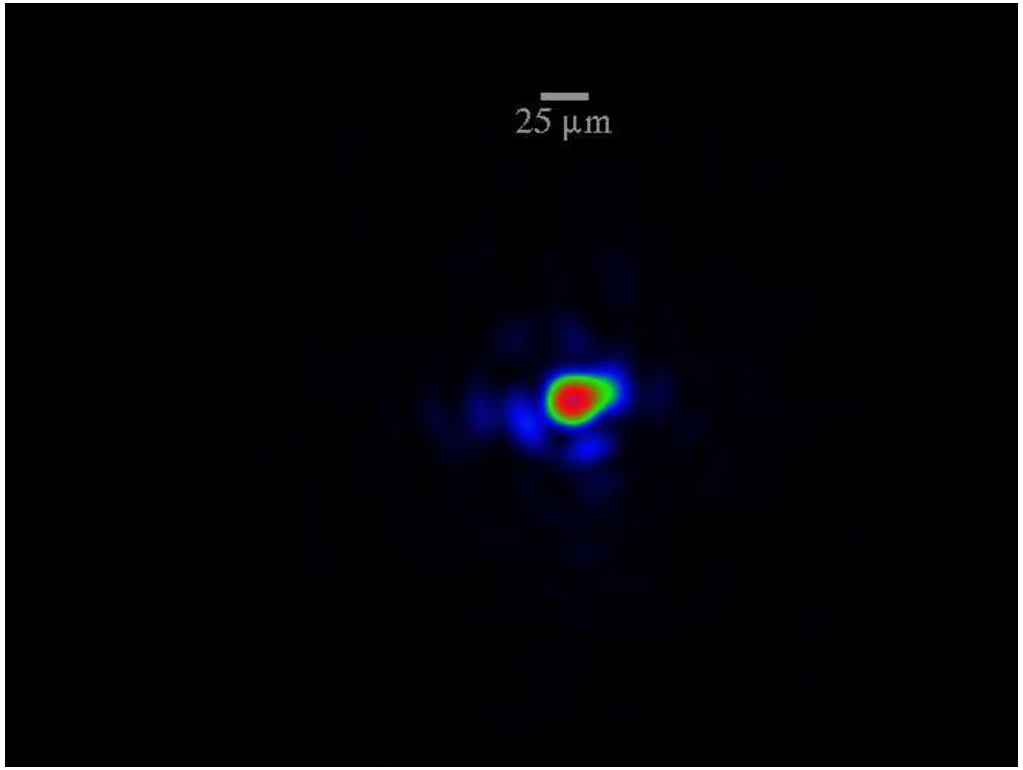




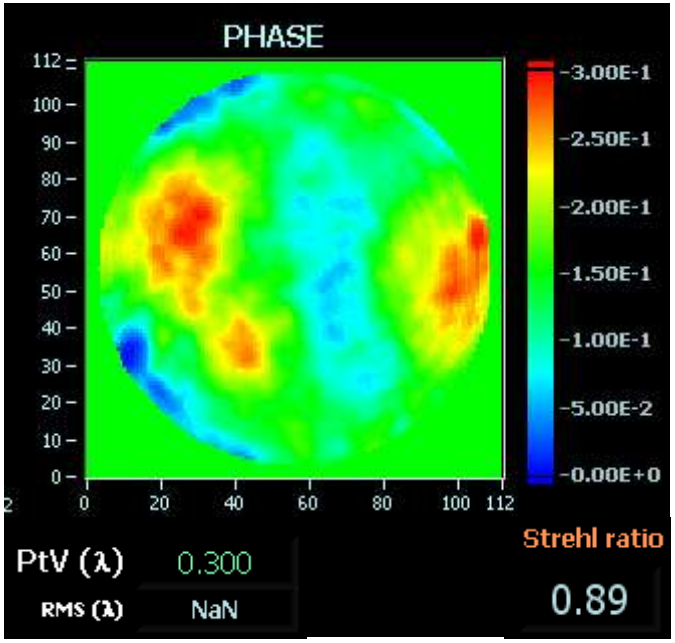
Fluorescence of Ti:S crystal

Index-matching liquid (1-bromonaphthalene) has n = 1.658 (sapphire n = 1.76)

Gemini focal spot quality is good



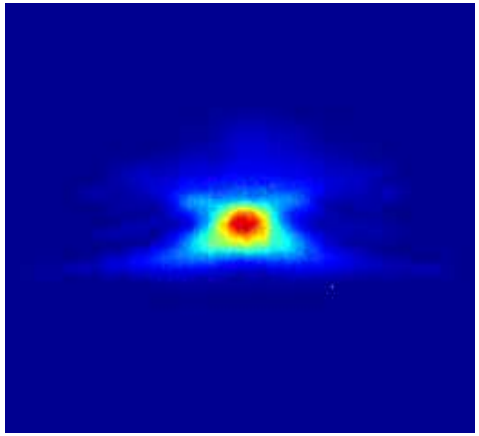
Data from Plasma Physics group, Imperial College, London

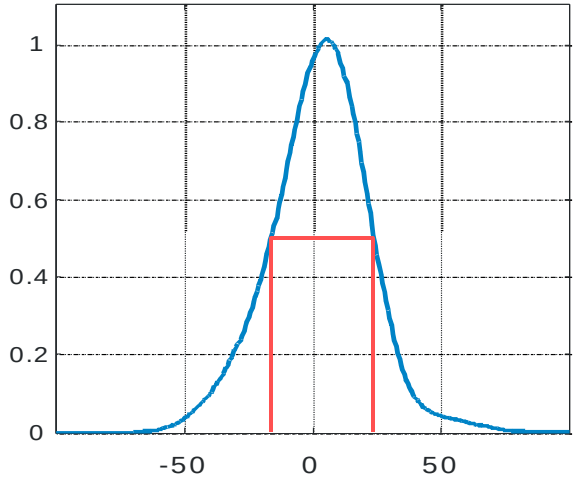


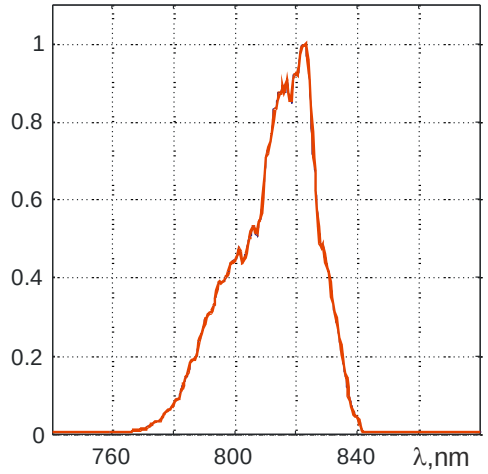
Wavefront of input pulse measured with SID4 sensor

Sequence of far-field images captured during an experimental run at F/20

Pulse duration







fwhm = 40 fs

FROG trace, derived optical pulse and spectrum of a compressed 12.6 J pulse

Pulse contrast measured with a third-order correlator was $\leq 10^{-8}$ at 10 ps

10 PW

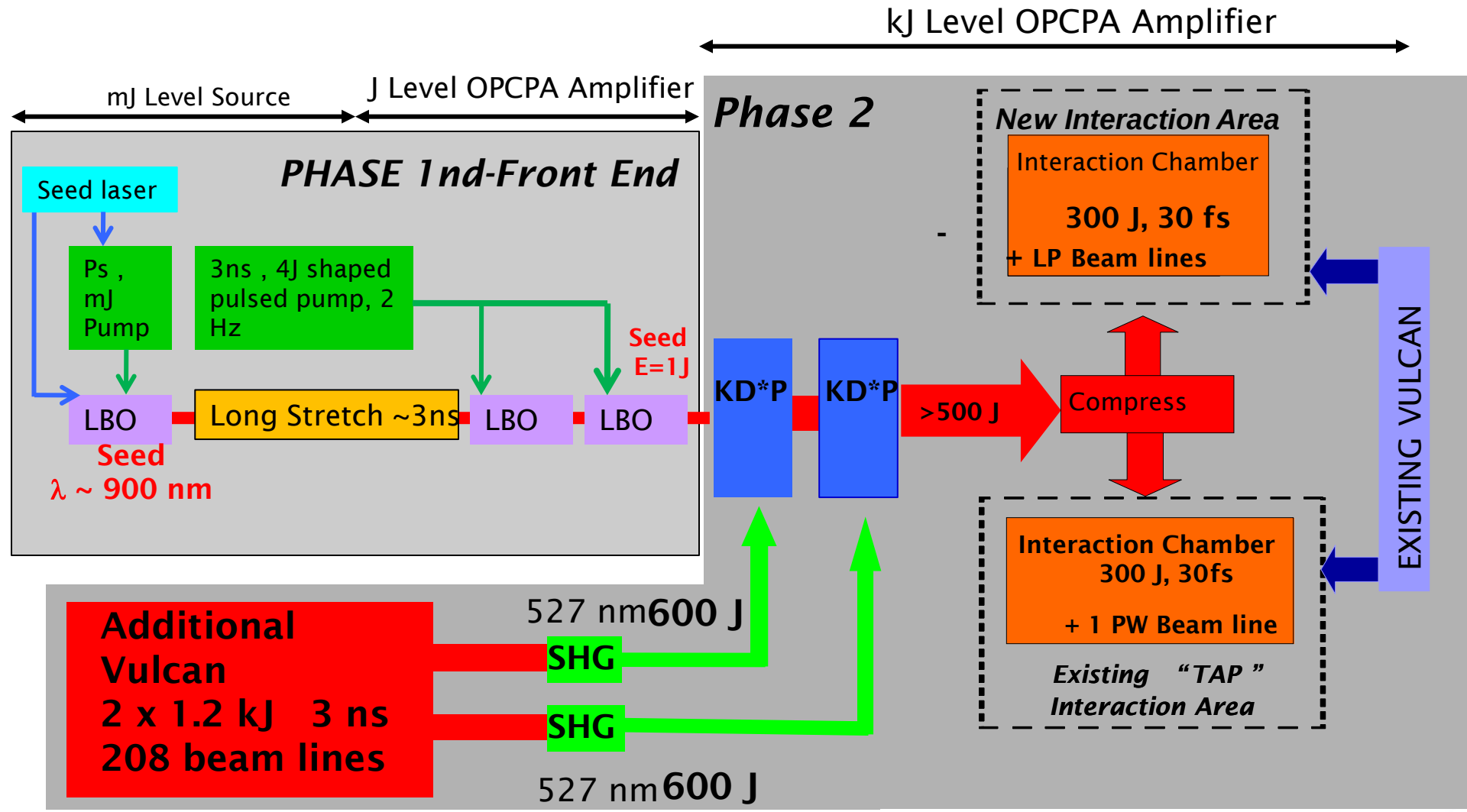
The Vulcan 10 PW Project

- 6 year Project to establish an integrated 10 PW:

  300J, 30 fs, $>10^{23}$ Wcm^{-2}

- Based on the OPCPA technique
- Project was divided in two phases due to risk
- Phase 1: Develop unique 10 PW Front end : **1J, 900 nm**, **few Hz,** an ultra-broad band **~20 fs**, high contrast
- **Phase 2: Establish a 10 PW User Facility –** Building and radiological protection, upgrade Vulcan long pulse beams, develop large large aperture OPCPA, new compressor and interaction chamber

10PW Schematic



- Based on a combination of LBO and KD*P
- 3 stages of amplification
- High contrast source

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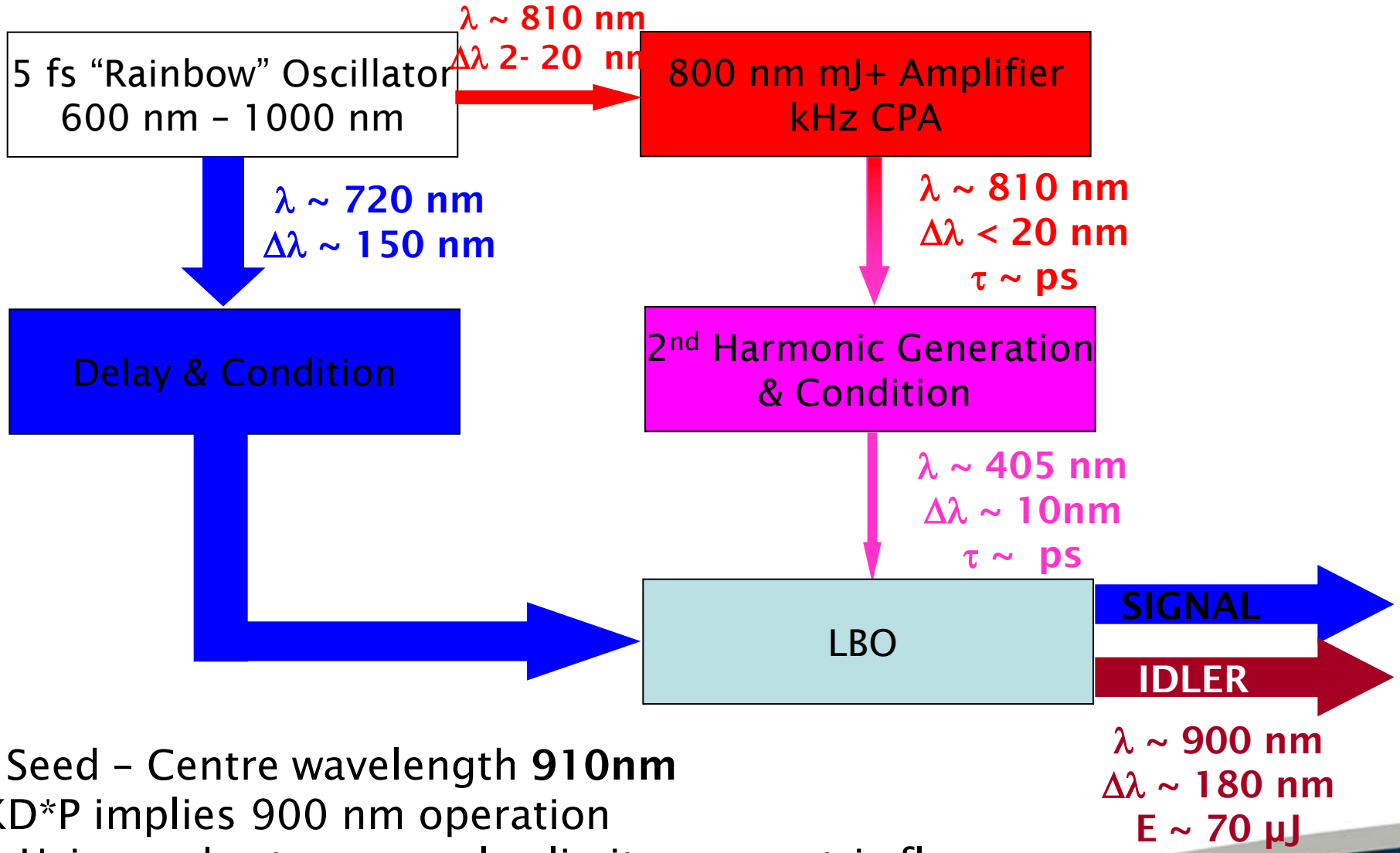
High Contrast mJ Front End Scheme



- Seed – Centre wavelength **910nm**

KD*P implies 900 nm operation

- Using a short pump pulse limits parametric fluorescence
- Optically Synchronised

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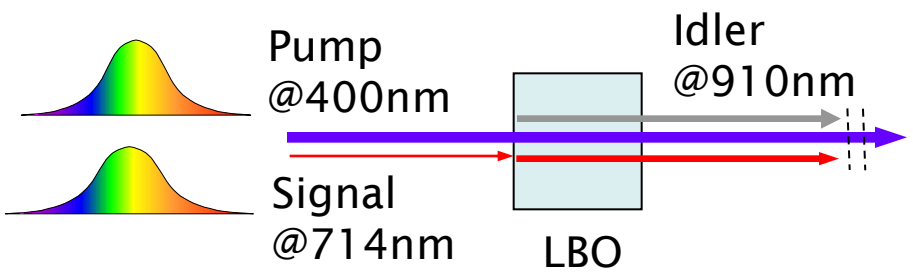
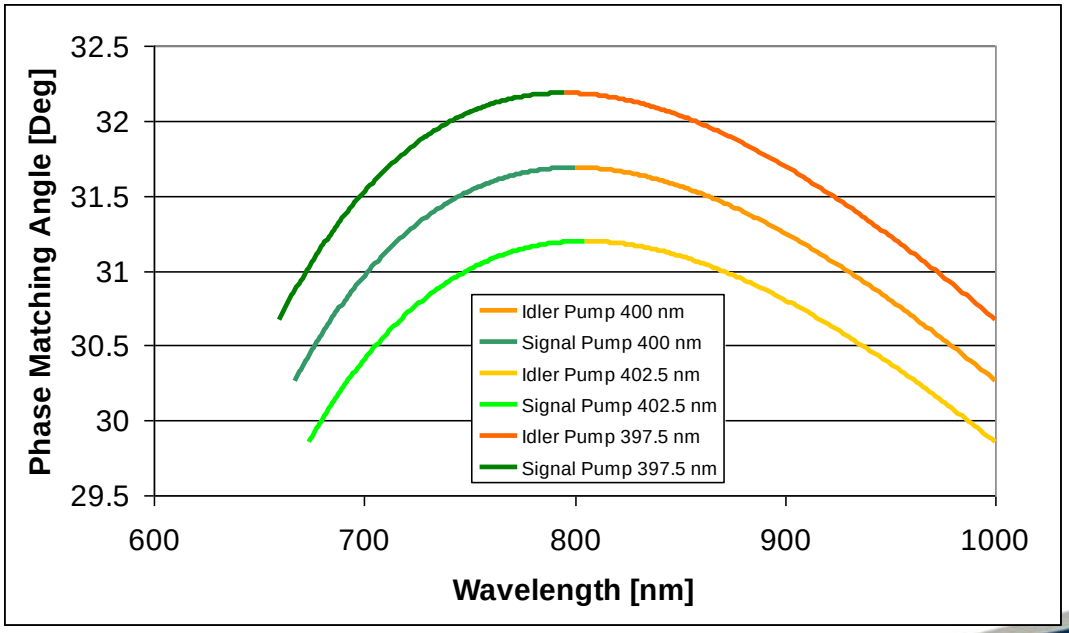
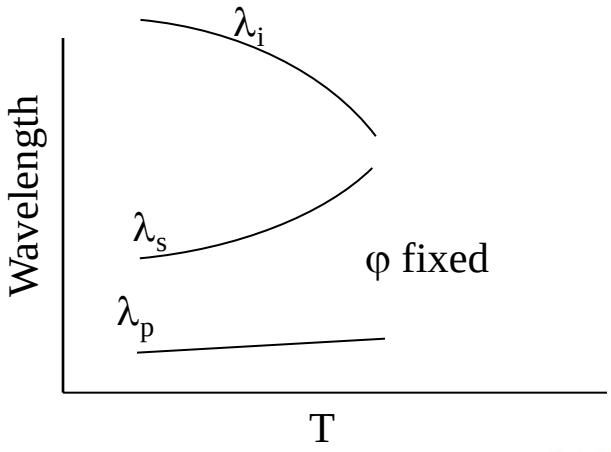
Broadband source generation scheme

Collinear Chirp Compensation scheme: Broadband pumping, Collinear, Non-degeneracy ,No Idler angular dispersion



- Use the fact that the pump can be broadish band – chirp this
- Chirp function on signal to cover wide band is strongly non-linear

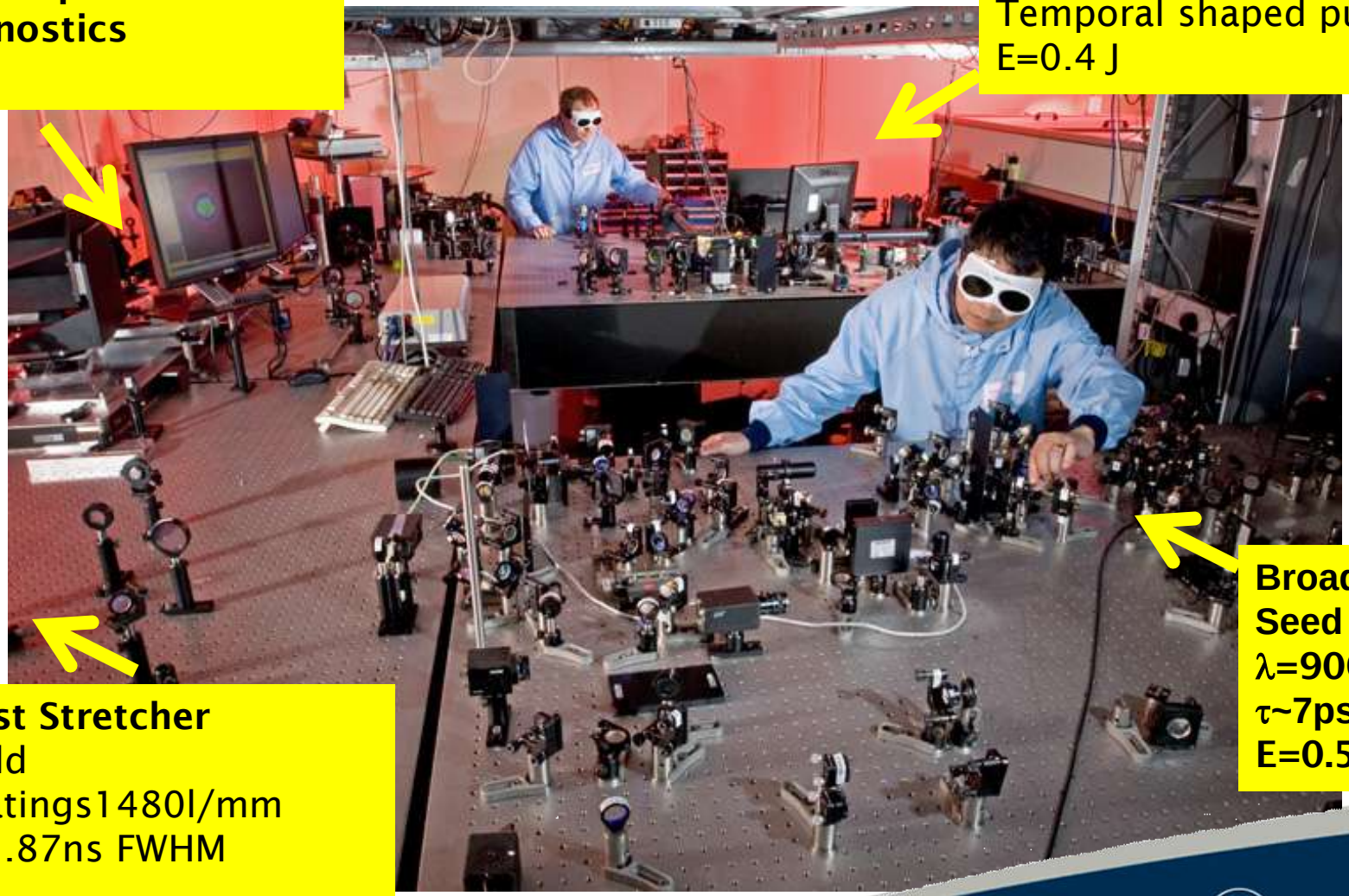




10 PW Front End

Test Compressor & Short pulse Diagnostics

J level OPCPA Stages
2 LBO stages
Temporal shaped pump laser
E=0.4 J



Broadband Seed
λ=900nm,
τ~7ps,
E=0.5 mJ

Test Stretcher
Gold gratings1480l/mm
τ=1.87ns FWHM

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10 PW OPCPA Amplification stages

Front End Signal
1J,λ=905nm
Δλ=150nm, τ 3ns

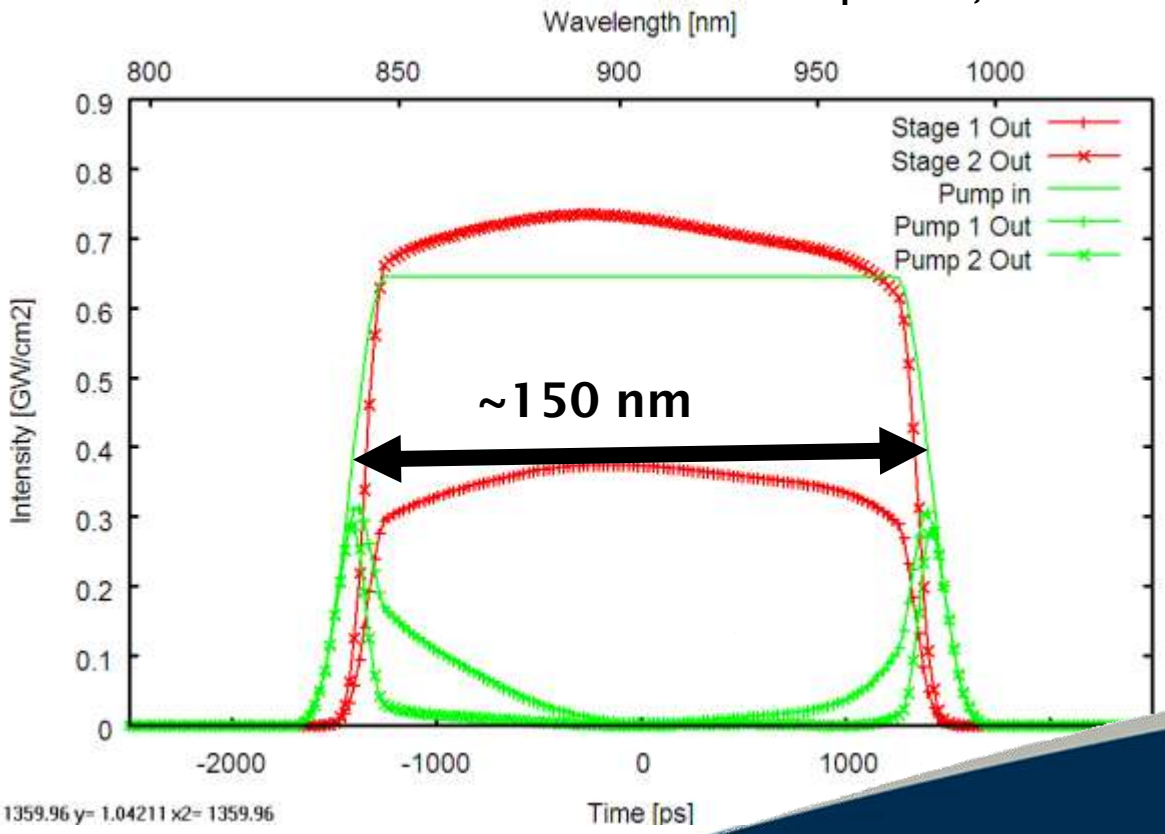
Pump Stage 1 & 2
600J , 180mm square
λ=527nm ,Δt=3ns flat top

Stage 1 → Stage 2

Stage 1: KD*P
220mm Square ,Lc=85mm

Stage 2: KD*P
220mm Square
Lc=26mm

En_S=592J



After Compressor
Eff. 60%
En=369J
Δt=17fs
P=22PW

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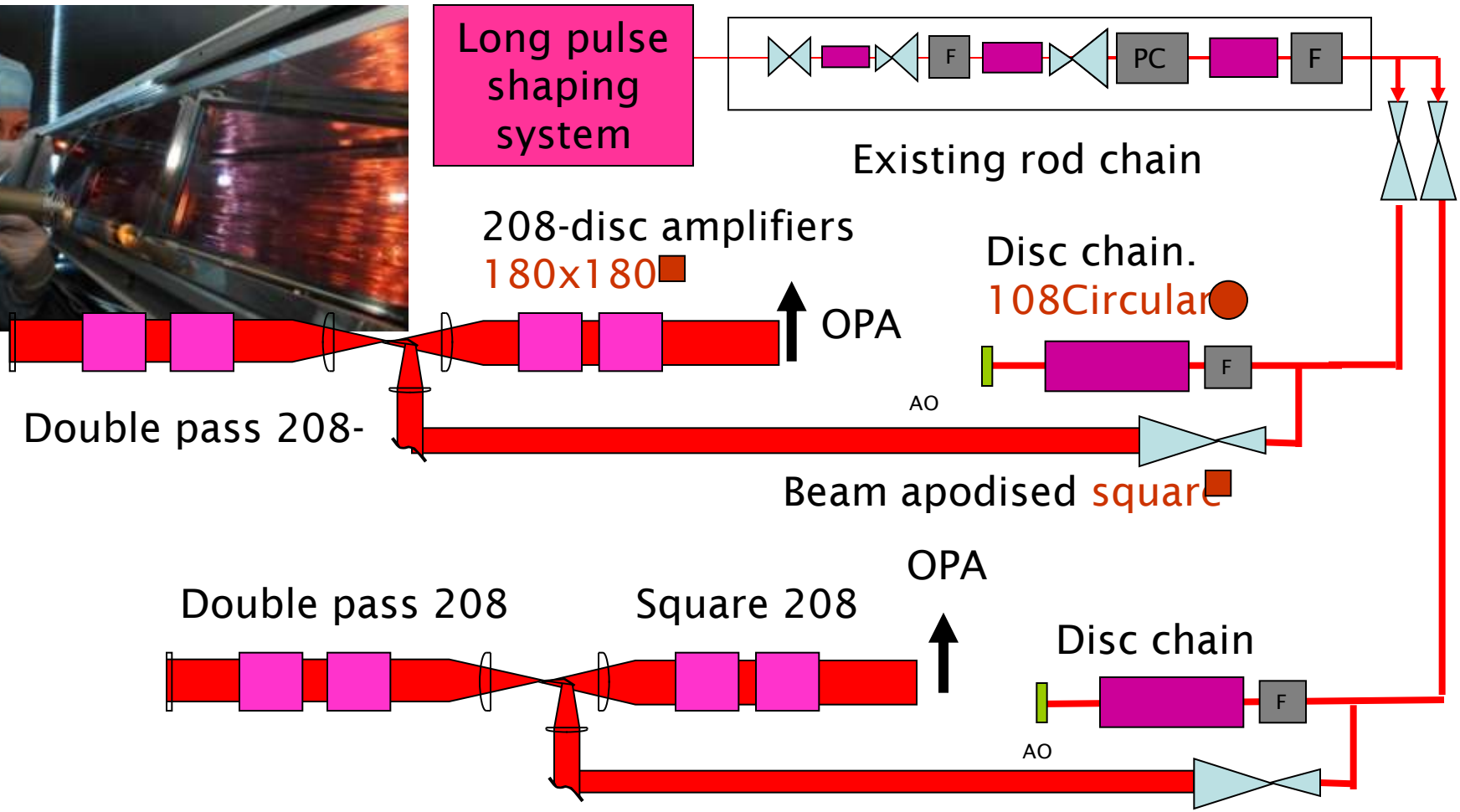
OPCPA PUMP Laser chain

The laser chain will be upgraded to deliver the required 1.2 kJ at 1053.
1 shot Every 10 min

Pulse length 3ns,E_{out}>1.2KJ,B Integral 1.5

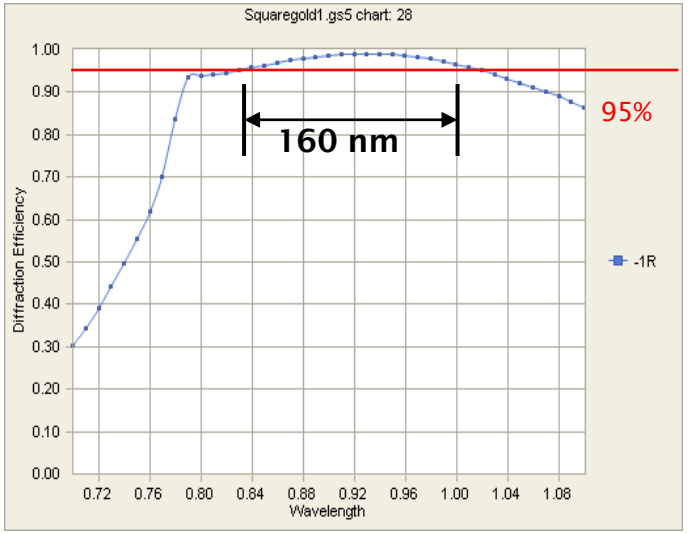


Compression

- Unique Issues
  - ➢Large Beams (>0.6 m) & Large Bandwidths (150 nm)
  - ➢Need Low Line Density Gratings (~900 lines/mm)
  - ➢Must be large (~1m diagonal)

Out of Diff. Plane
i.e. Littrow

OUT OF PLANE LITTROW



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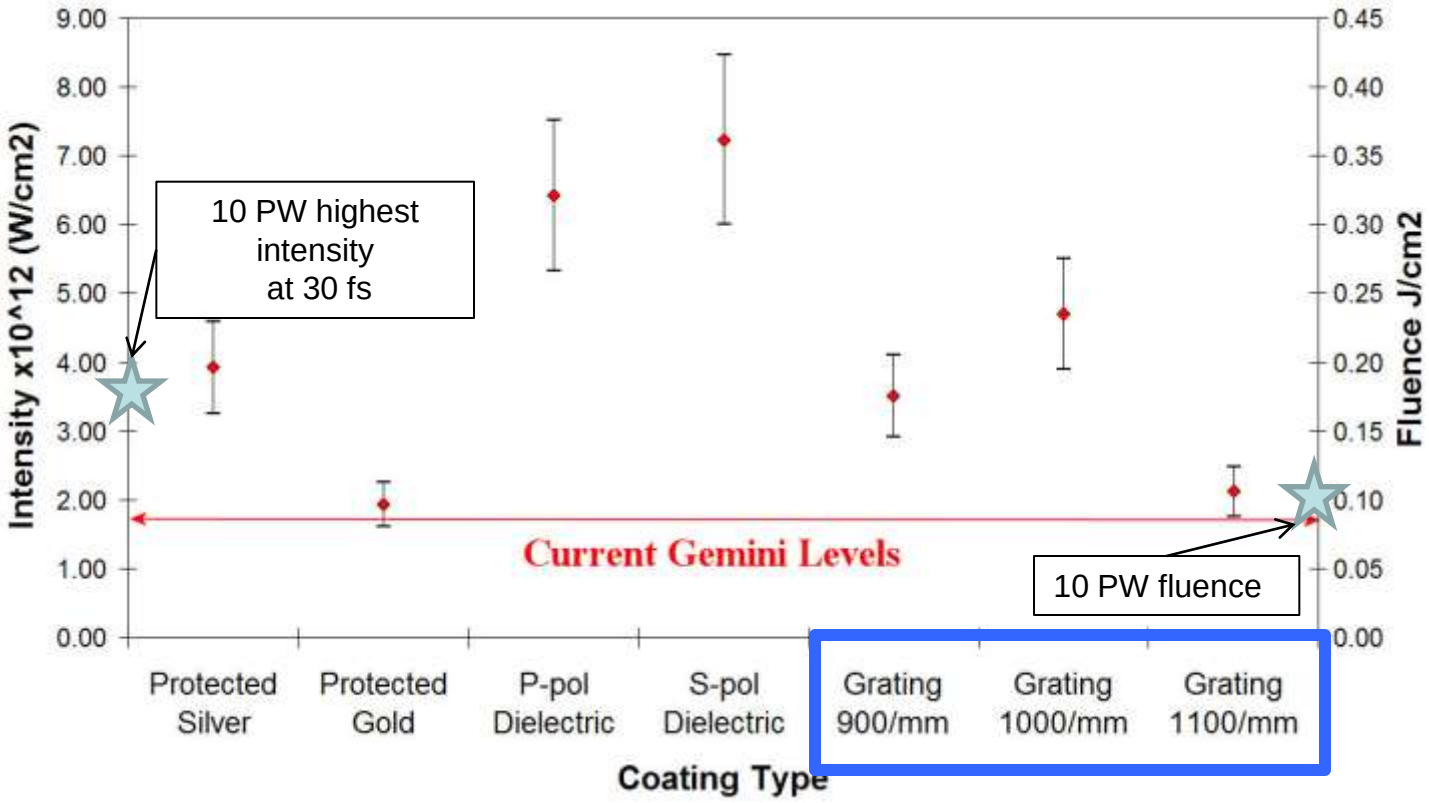
Damage tests

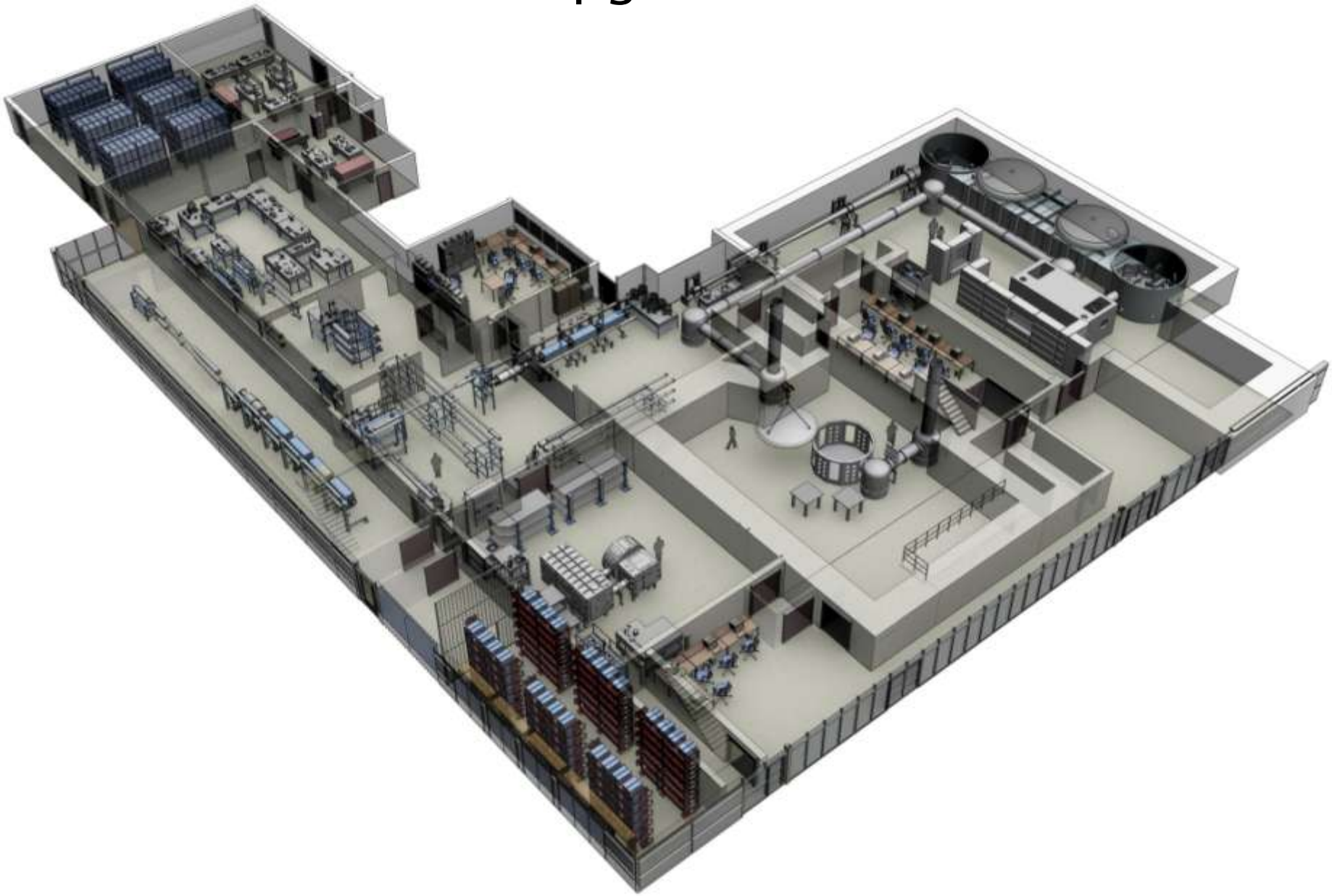
The following coatings were tested in Astra (λ=800nm and τ=50fs)

- PGL Gold Gratings with 900, 1000 and 1100

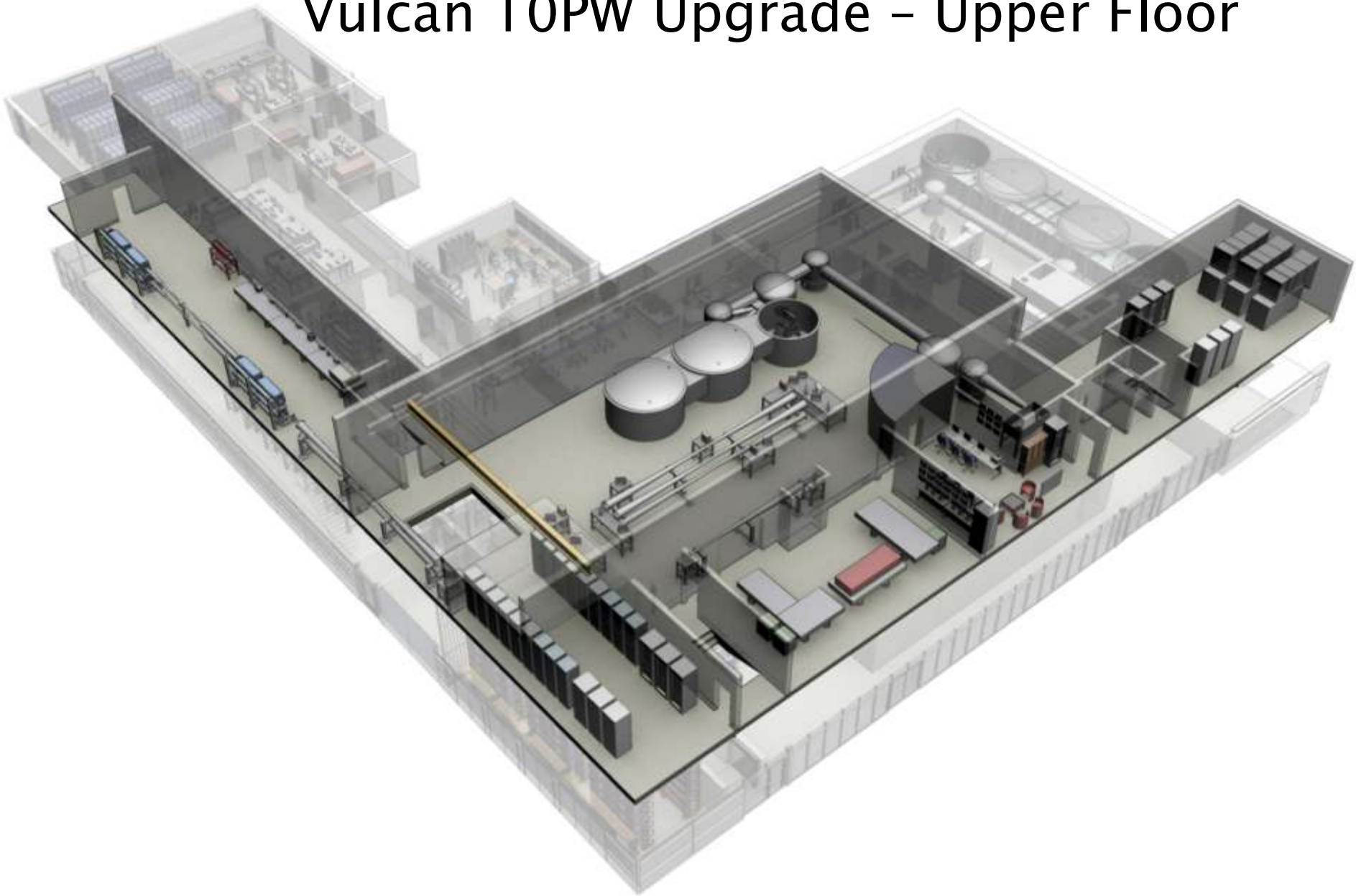
- Laser damage threshold tests carried out by the Vilnius University Laser Research Centre.



Vulcan 10 PW Upgrade - Ground floor



Vulcan 10PW Upgrade – Upper Floor



10 PW capability

10 PW gives unprecedented access to new and extreme conditions

Effects that only occur elsewhere in the cosmos – laboratory tests

Access to new physics

Applications for the future

Conclusion

- Several Laser System are operating at CLF
- Various project are on-going to improve the facility
- 10PW Phase II is started
- The aim is to keep the record of pick intensity

Science & Technology Facilities Council