The Apollon laser: Current status and first commissioning results

D. N. Papadopoulos[1], J.P Zou[1], C. Le Blanc[1], F. Druon[2], K. Genevrier[2], L. Ranc[1], L. Martin[1], A. Fréneaux[1], A. Beluze[1], C. Bonnin[1], J. B. Accary[1], N. Lebas[1], B. L. Garrec[1], F. Mathieu[1] and P. Audebert[1]

[1]Laboratoire pour l'Utilisation des Lasers Intenses, Ecole Polytechnique, Palaiseau, France

[2]Laboratoire Charles Fabry, Institut d'Optique, Palaiseau, France

Forum ILP 2018: 10-15 June 2018 - Saint-Pierre d'Oléron

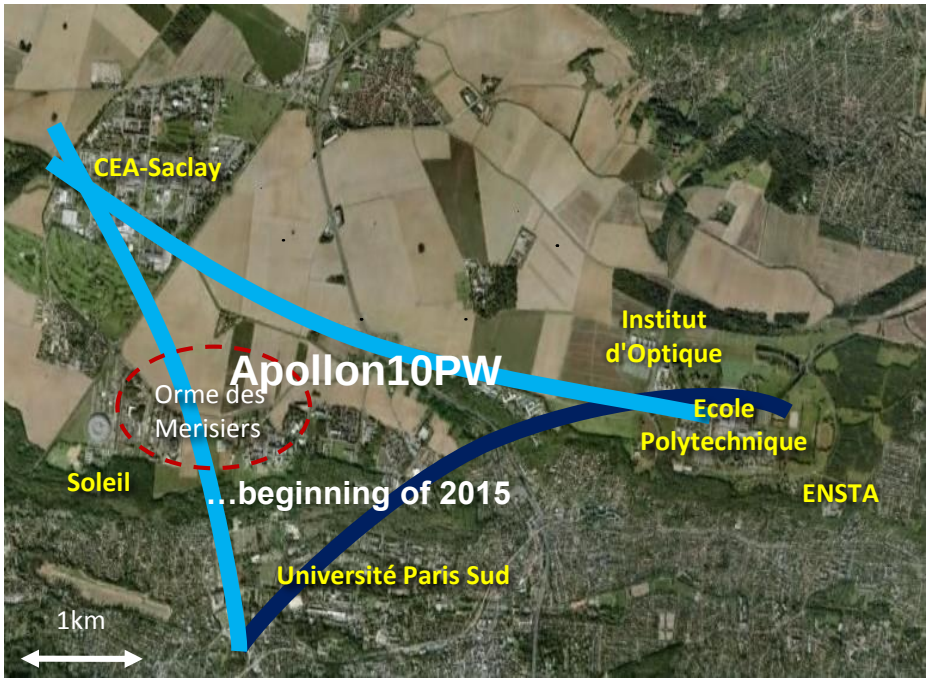
Outline

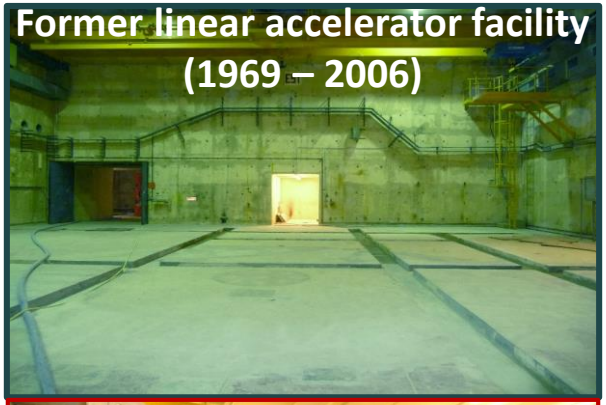
- Introduction
  - Apollon 10PW: Laser system key features
  - Laser facility construction progress
- Laser operation status / performances
  - The Front End commissioning
  - The Power Amplification Section
    - Qualification tests / PW beam line preparation
  - 200 Joules pump source commissioning
- Towards the first commissions experiments
  - Long and Short focus exp. areas preparation
- Conclusions

A multilab project on the Plateau de Saclay

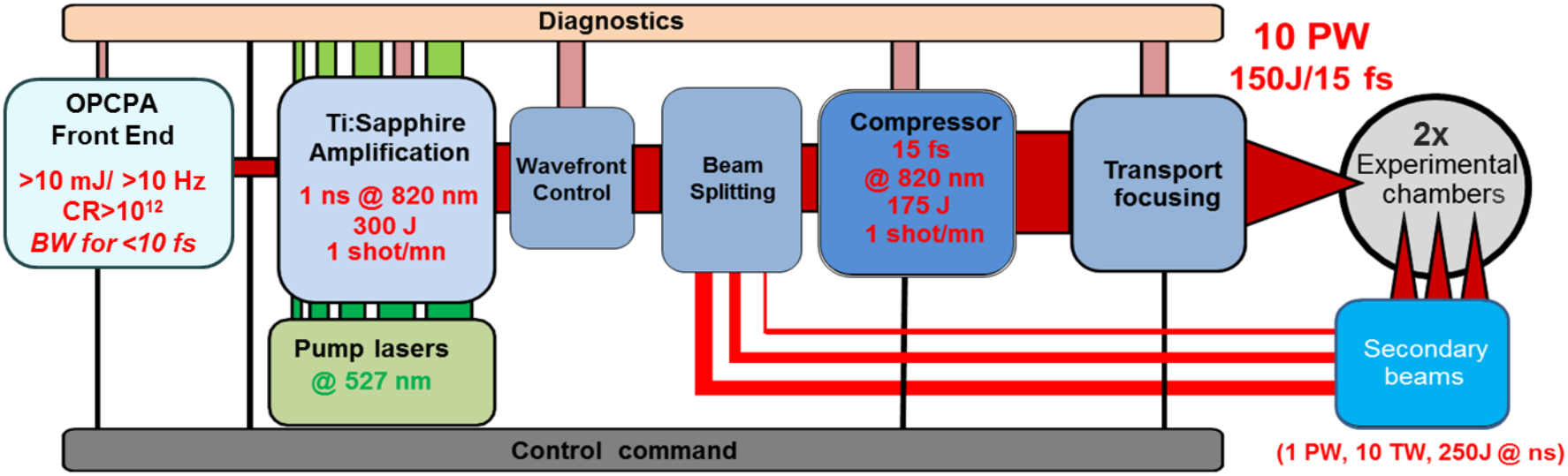
CILEX : Centre Interdisciplinaire de la Lumière Extrême (ex ILE)

aiming to the development of new instruments dedicated to address physics at unexplored laser intensity levels.



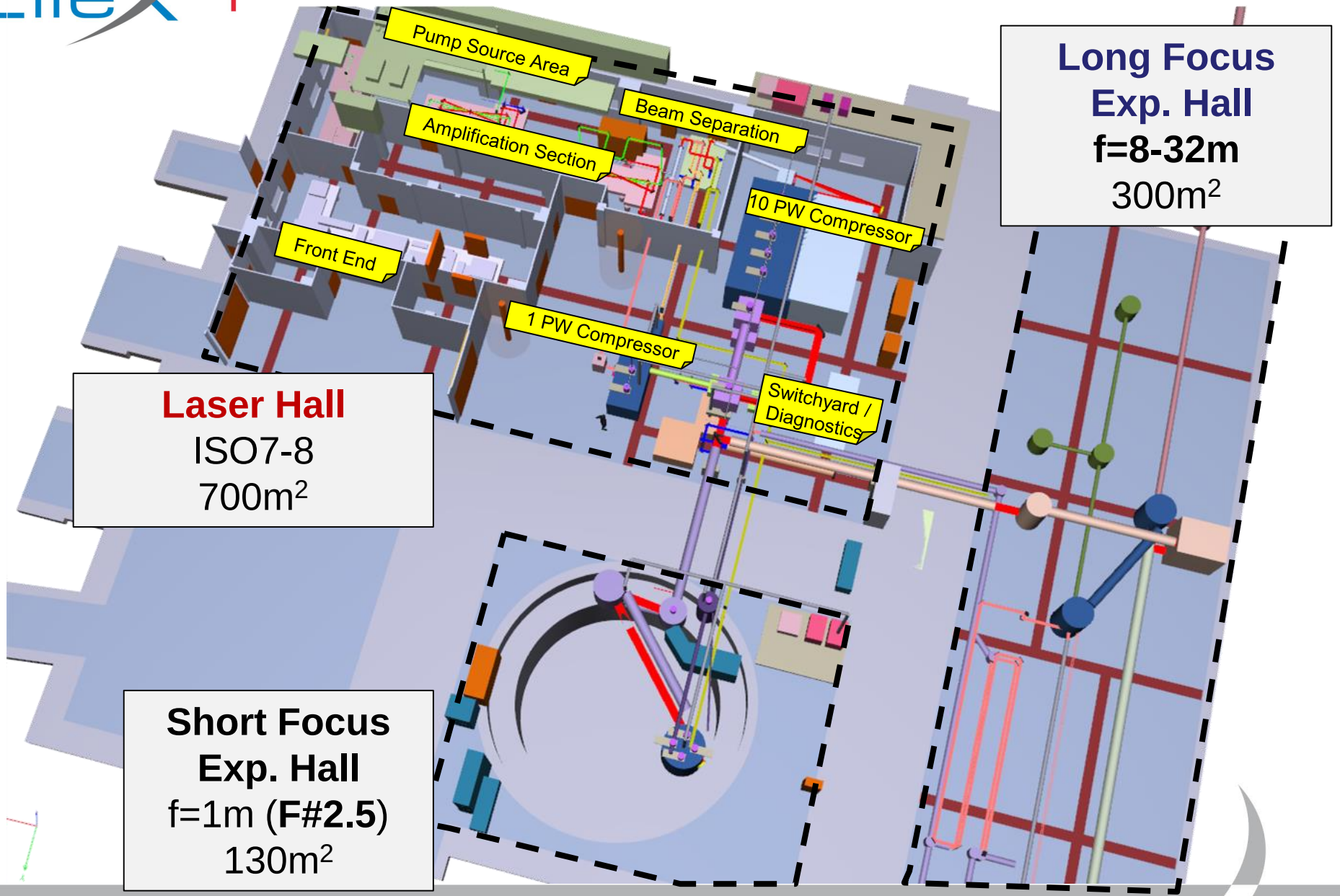


The Apollon laser



- **Apollon key features:**
  - **Hybrid architecture**: OPCPA + Ti:Sa ➔ Contrast + Bandwidth + Energy
  - **Unique Materials**: Φ10-200mm Ti:Sa crystals, Meter size gratings, state-of-the-art optics
  - High energy pump sources: up to **700 Joules/min**
  - **Adaptive control:** spatial (Deformable mirrors) and spectral phase (Dazzler)
  - **4 beam lines/2 experimental areas**

The Apollon Facility



Apollon laser: construction progress

2013: beginning of reconstruction work…

03/2015 reception of the building

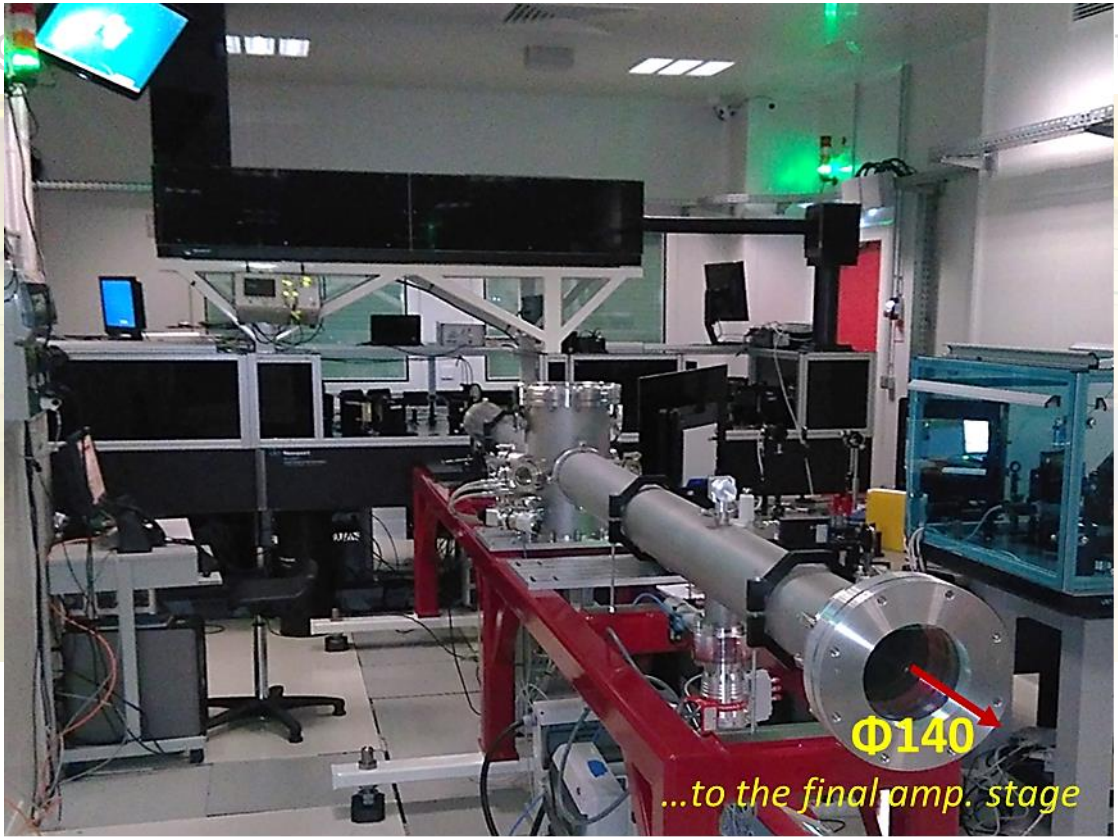
Apollon laser: construction progress

The Front End: **Commissioned**

Apollon laser: construction progress

Amplification section: Fully operational to the **30 Joules level**

Apollon laser: construction progress



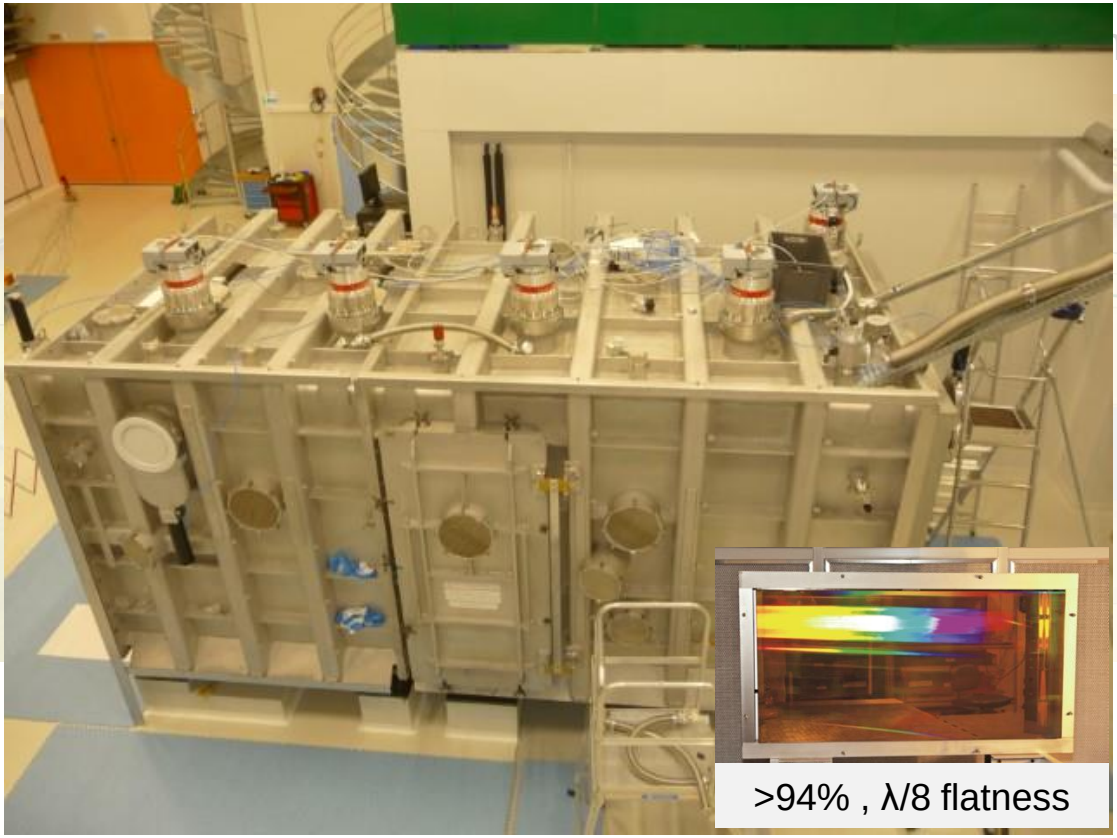
Amplification section: Fully operational to the **30 Joules level**

Apollon laser: construction progress

10 PW compressor: **Installation**

Apollon laser: construction progress

2013: beginning ... building



10 PW compressor: **Vacuum qualification**

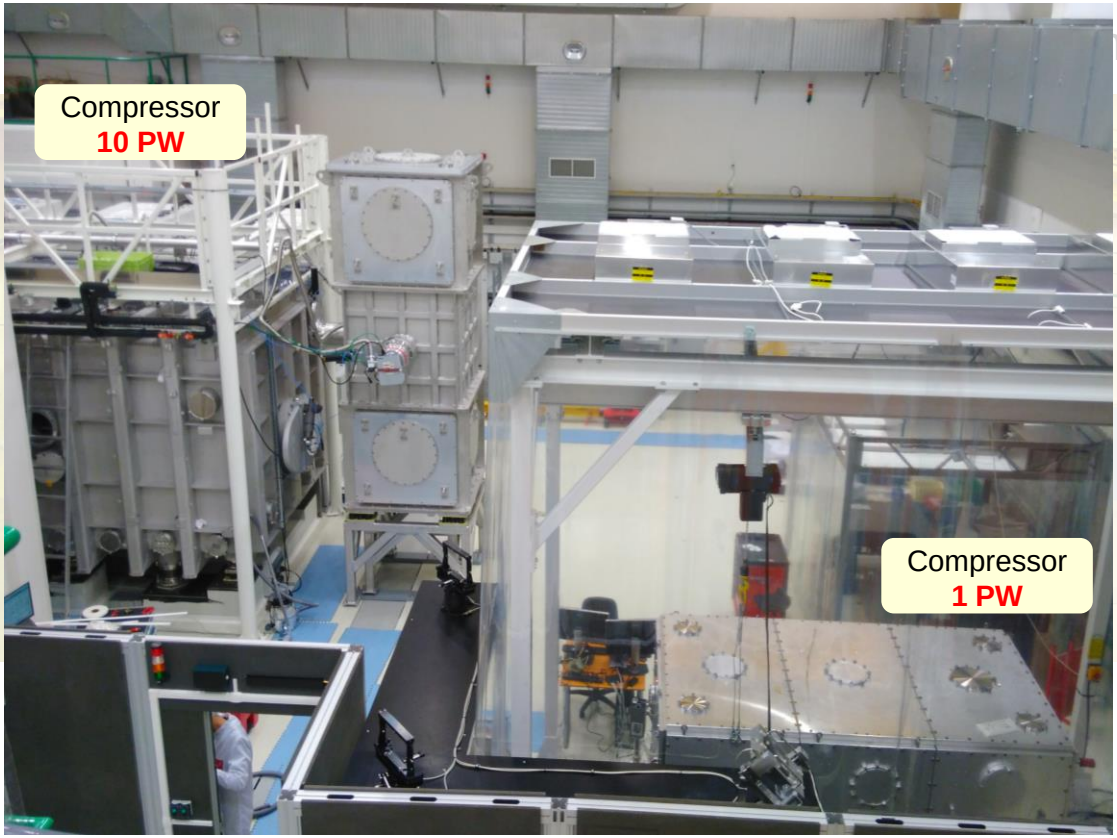
Apollon laser: construction progress

2013: beginning ... building

10 PW compressor: **Clean access** / **beam transport**

Apollon laser: construction progress

2013: beginning ... building



Post amplification section: **1 PW** & **10 PW** **compressors ready**

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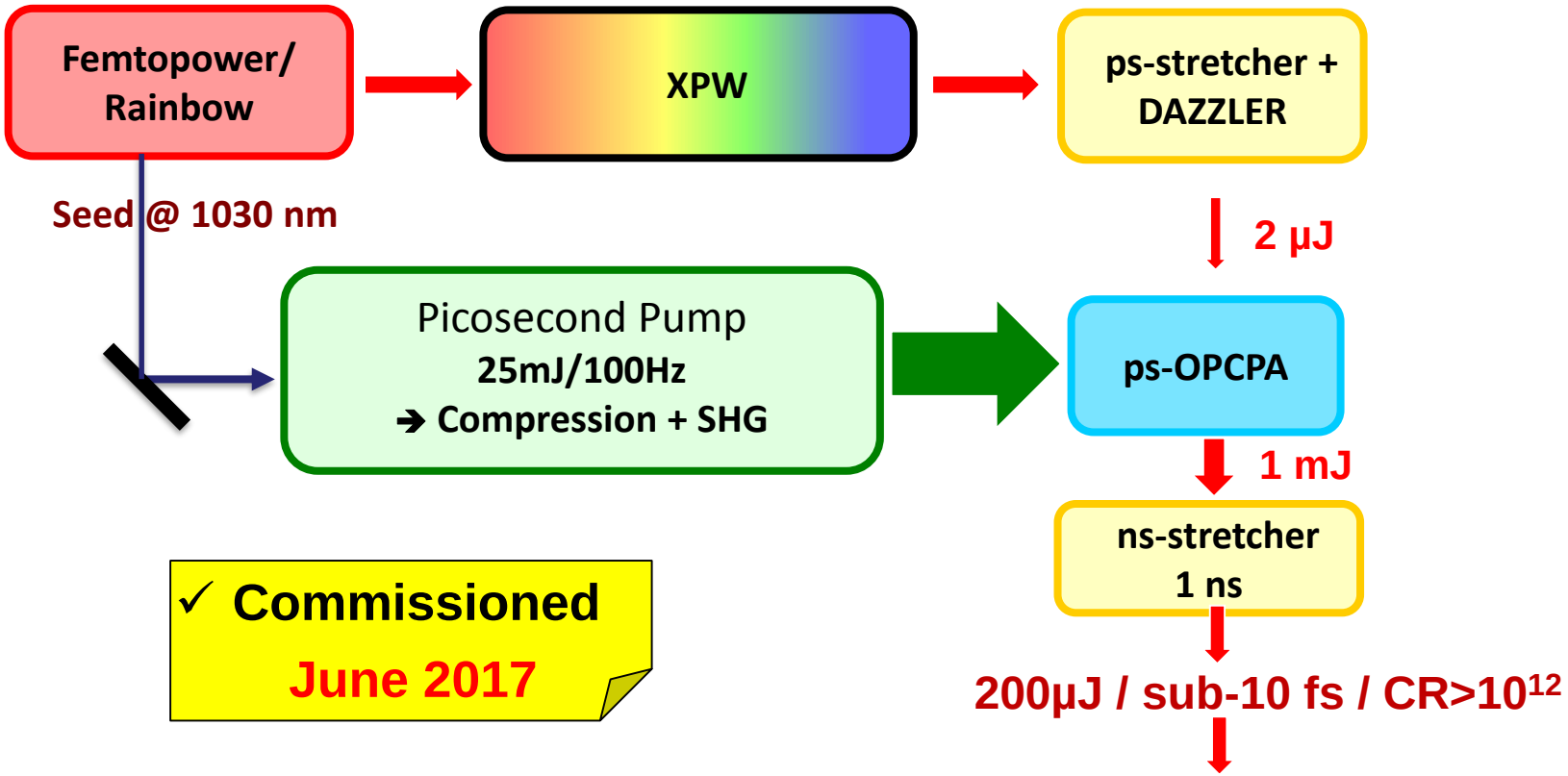
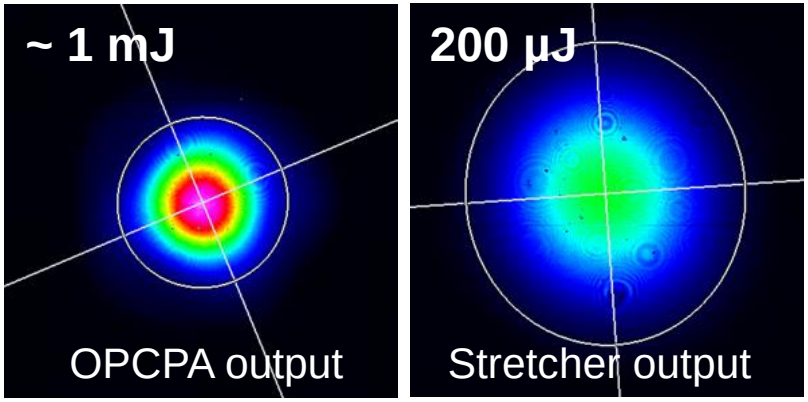
The Front End: XPW and ps-OPCPA high contrast source



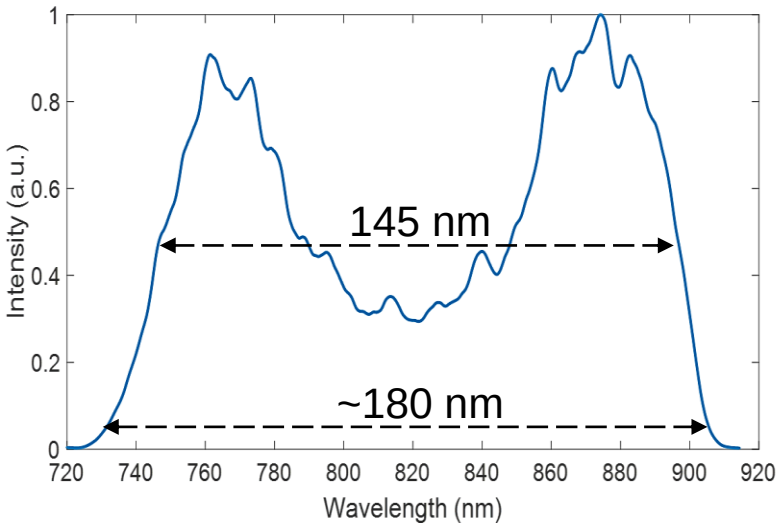
…to the power amplification in Ti:Sapphire based amplifiers (5x)

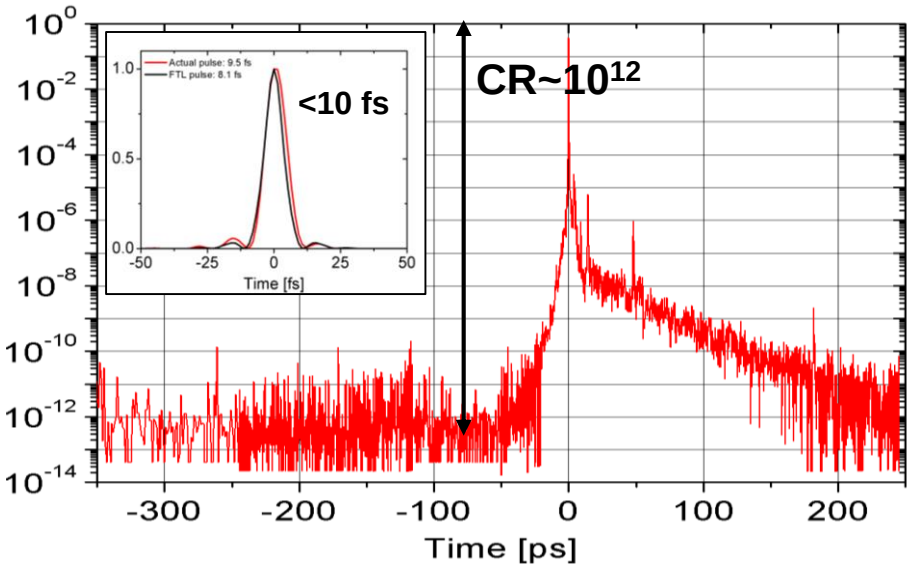
The Front end: OPCPA operation

- Operation of OPCPA stage at the Apollon facility



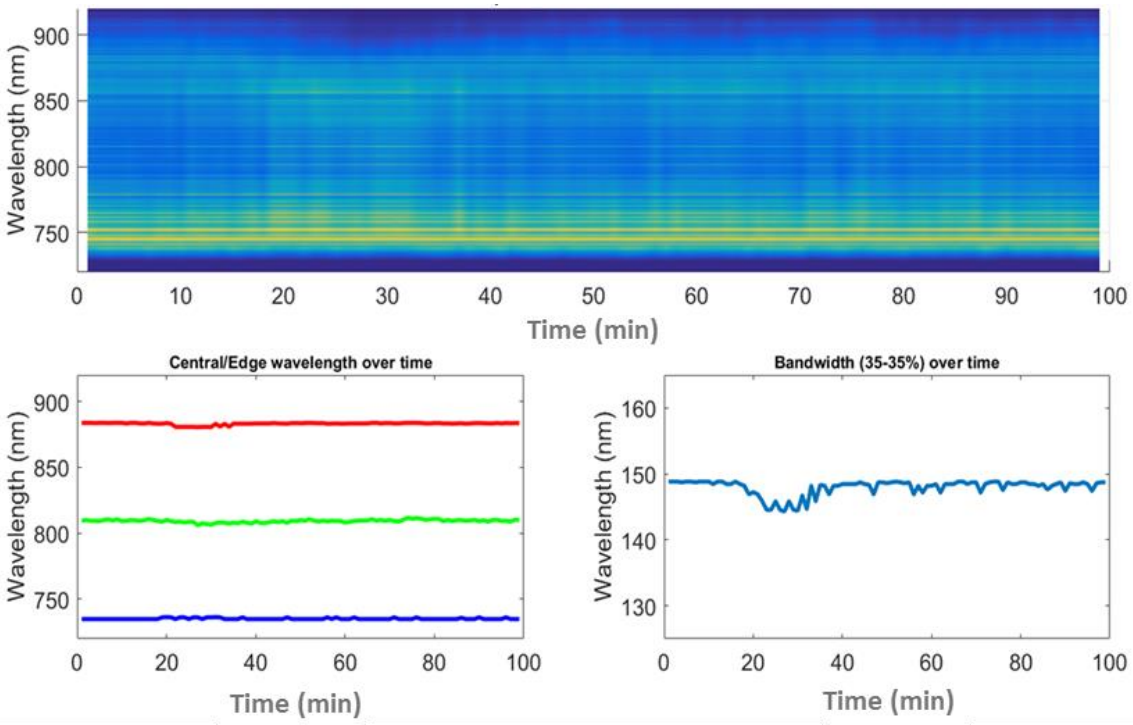
- ✓ **Reliable operation** / fast start-up (<30min)
- ✓ Excellent beam quality
- ✓ Correct injection energy level
- ✓ Optimized Injection Spectrum: **720-920nm**
- ✓ Sub-**10 fs** / High contrast pulses **CR>10^{13}** (**estimated**)



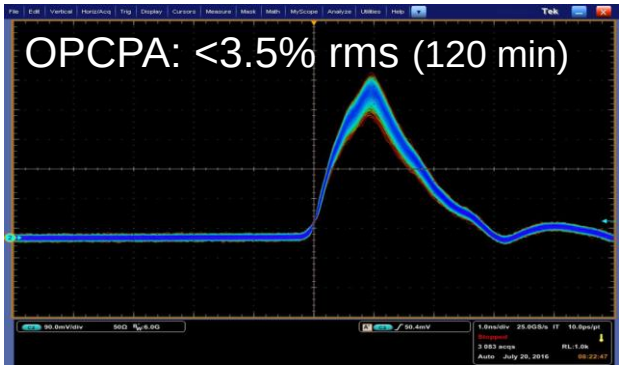


The Front end: Stability & Reliability

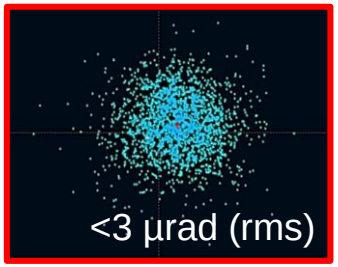
- **OPCPA spectral evolution: 100 min**



- **Energy stability:**



- **Pointing stability:**



- ✓ Output energy stability: **~3-4%** at the input (OPCPA)
- ✓ Output pointing stability: **<3µrad**
- ✓ Output spectral stability: Instabilities are related mostly to the signal/pump OPCPA pulse jitter/drift: **$\delta\lambda_0$<5 nm/hour**

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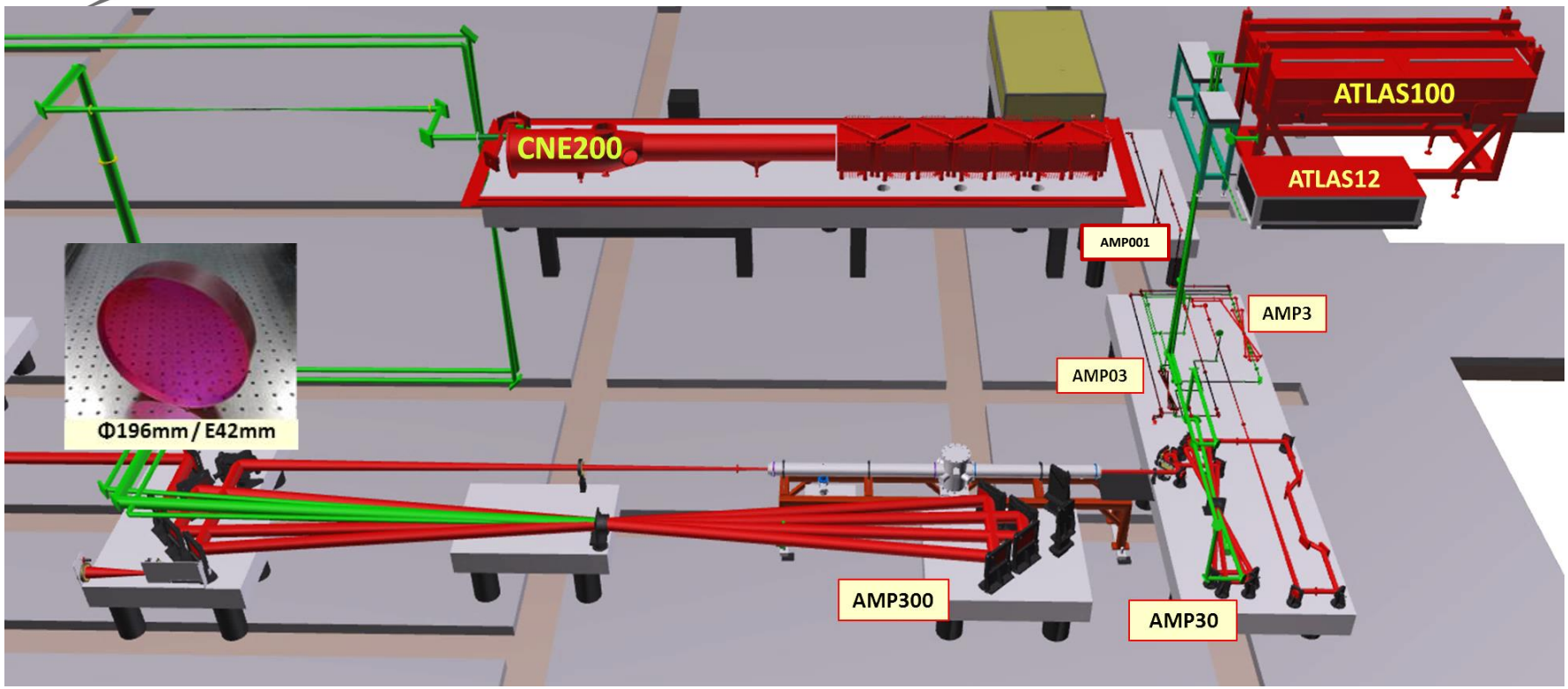
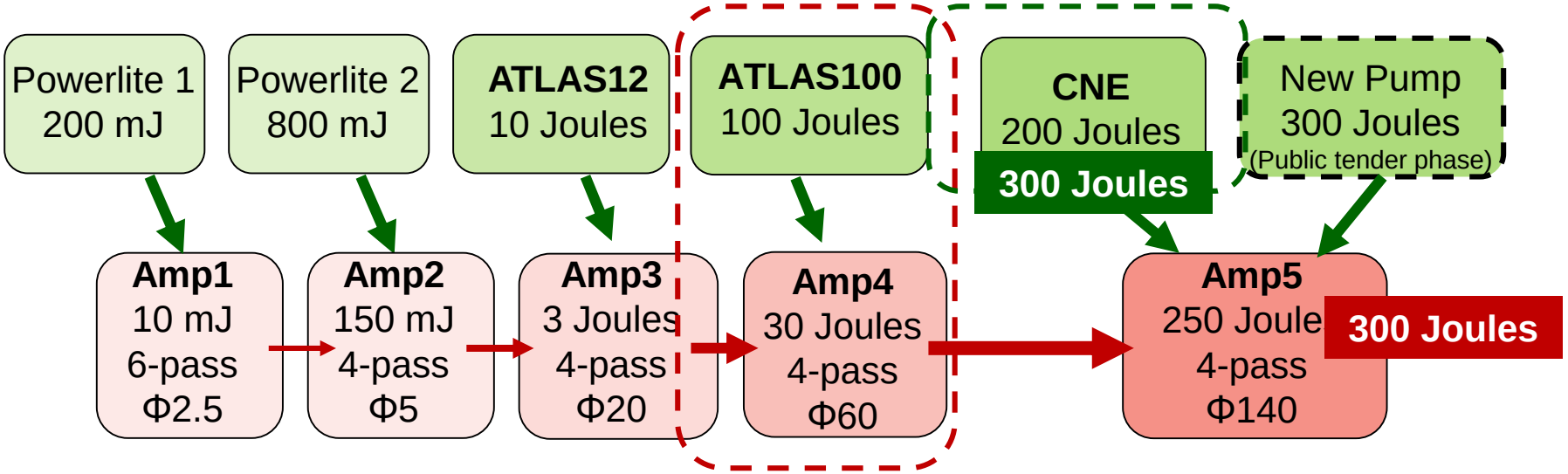
Power Amplification: current configuration



- **5x "low-gain" / image-relayed multipass amplifiers**: Φ6-Φ140 mm => **0.01-300 Joules**
- Employs one of the **largest Ti:Sapphire crystals in the world: Φ196 mm**
- Distributed **high energy pump sources** (up to 700 J) installed on a separate area

Power Amplification : design & status update



- **All the equipment is already installed**
- The last **300 Joules new pump** source: in public tender process (**June 2019**)

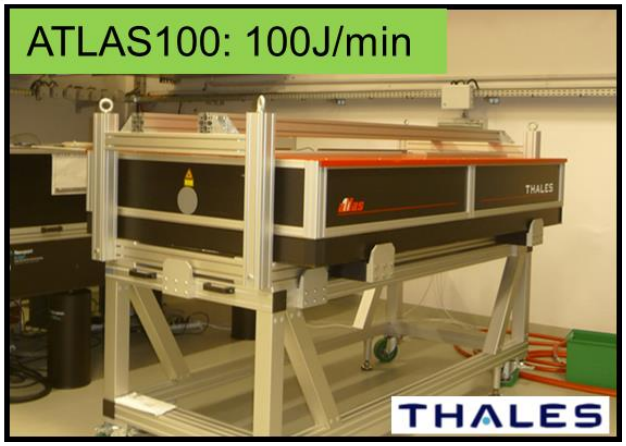
  Current equipment capacity: **300 J** ➔ **110 J** ➔ **3-4 PW** (end 2018)

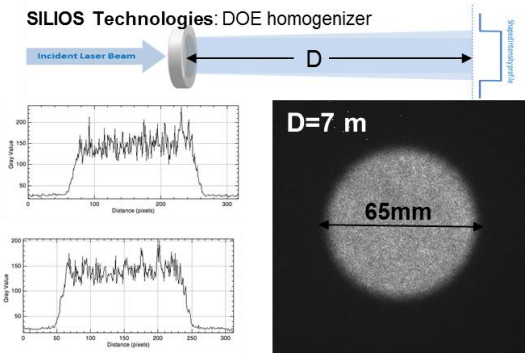
  …Budget assured capacity: **600 J** ➔ **250 J** ➔**9 PW** (summer 2019)

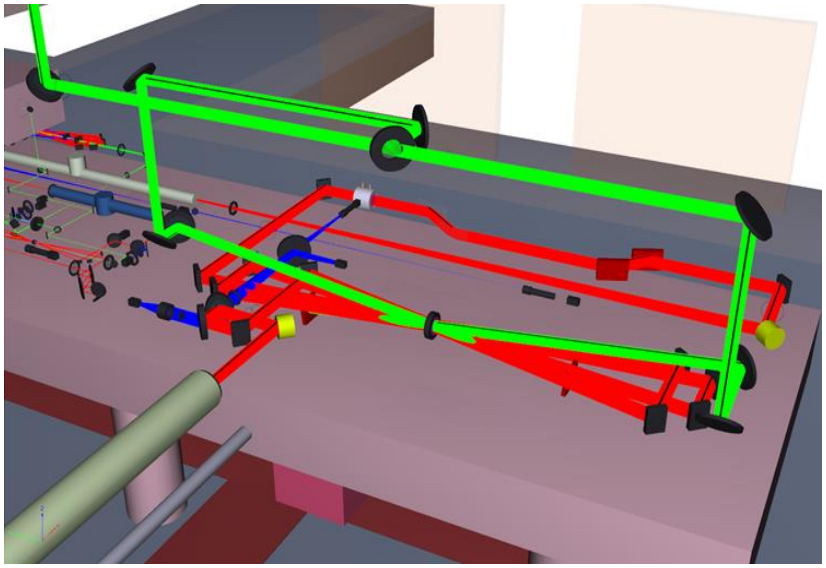
  …Technically compatible capacity: **700 J** ➔ **300 J** ➔ **11 PW** (…2020)

- ✓ **Commissioning** phase for the **Amp4** ➔ 1 PW beam line preparation
- ✓ **Commissioning** of the **CNE 200 J** source

Amp4: PW level amplification

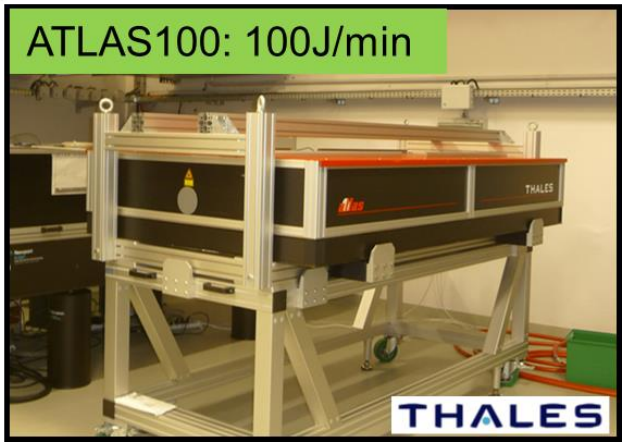


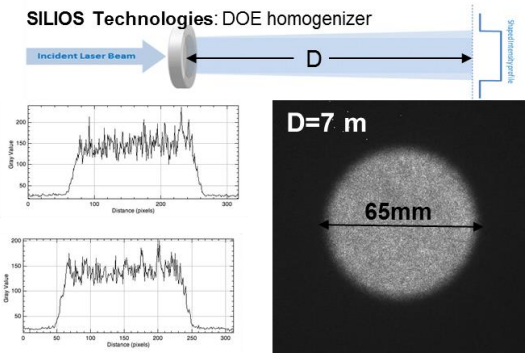


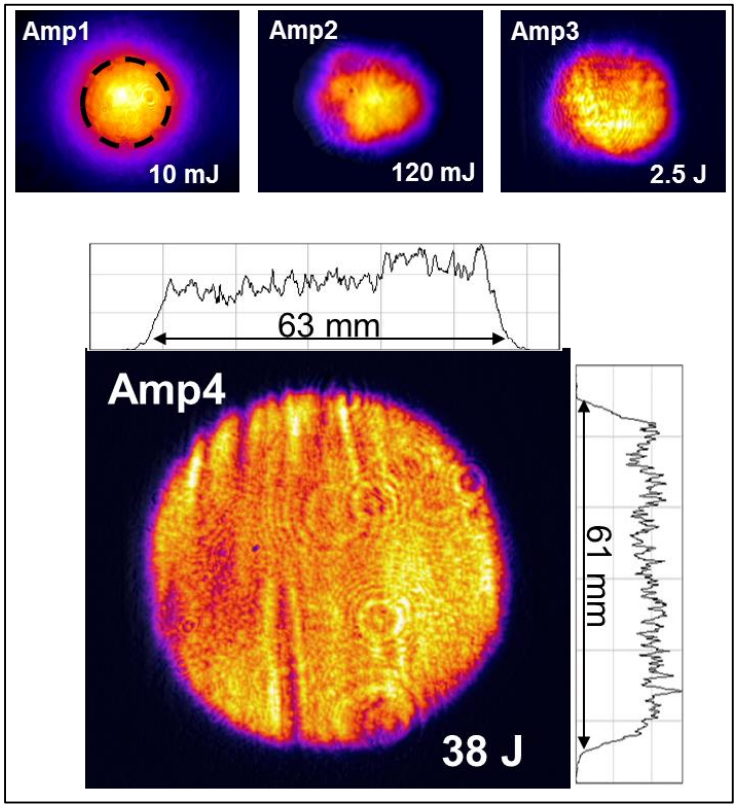


- ✓ Simple and compact **4-pass configuration** at **Φ60** (Φ65 for the pump)
- ✓ **ATLAS100** pump source: **>100 J/min**. DOE homogenizer for beam transport: robust operation
- ✓ Output energy: >**38 Joules** for **89 Joules** of pump on the Ti:Sa crystal ⇔ **~41%** efficiency
- ✓ Beam quality: **Uniform flat-top like beam**

Amp4: PW level amplification







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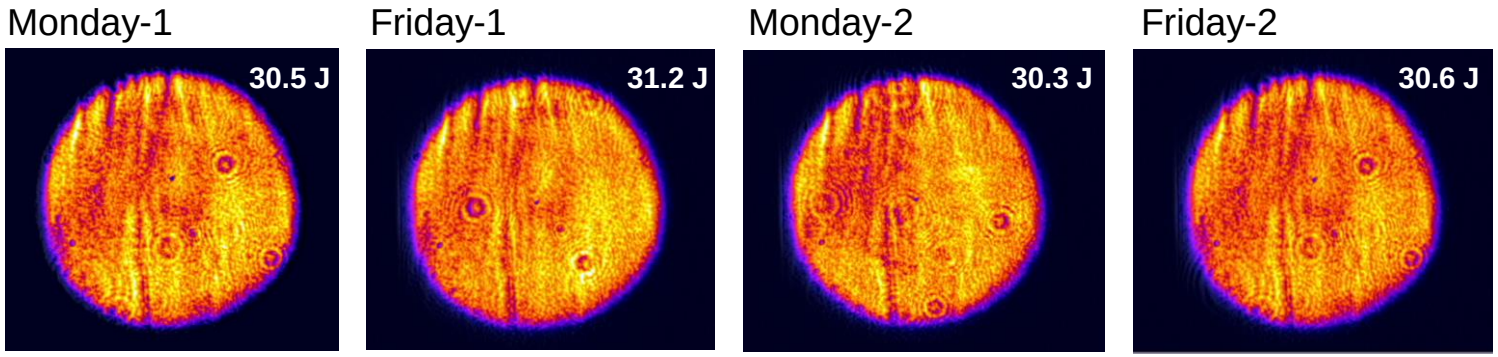
Amp4: Reliability / Stability

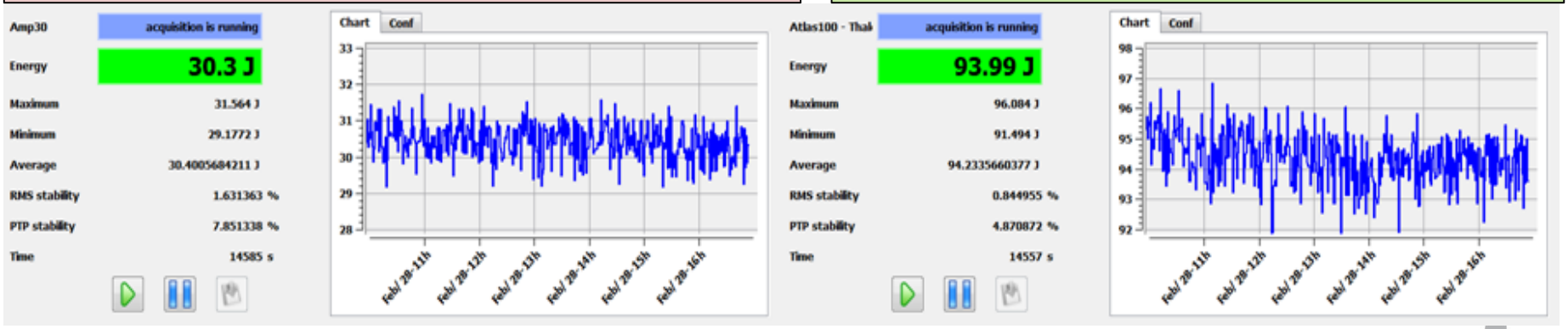
- Reliability tests: Over two weeks / 6-7 hours/day => **>4000 shots**



- Stability tests: over a day for **>7 hours** (450 shots)

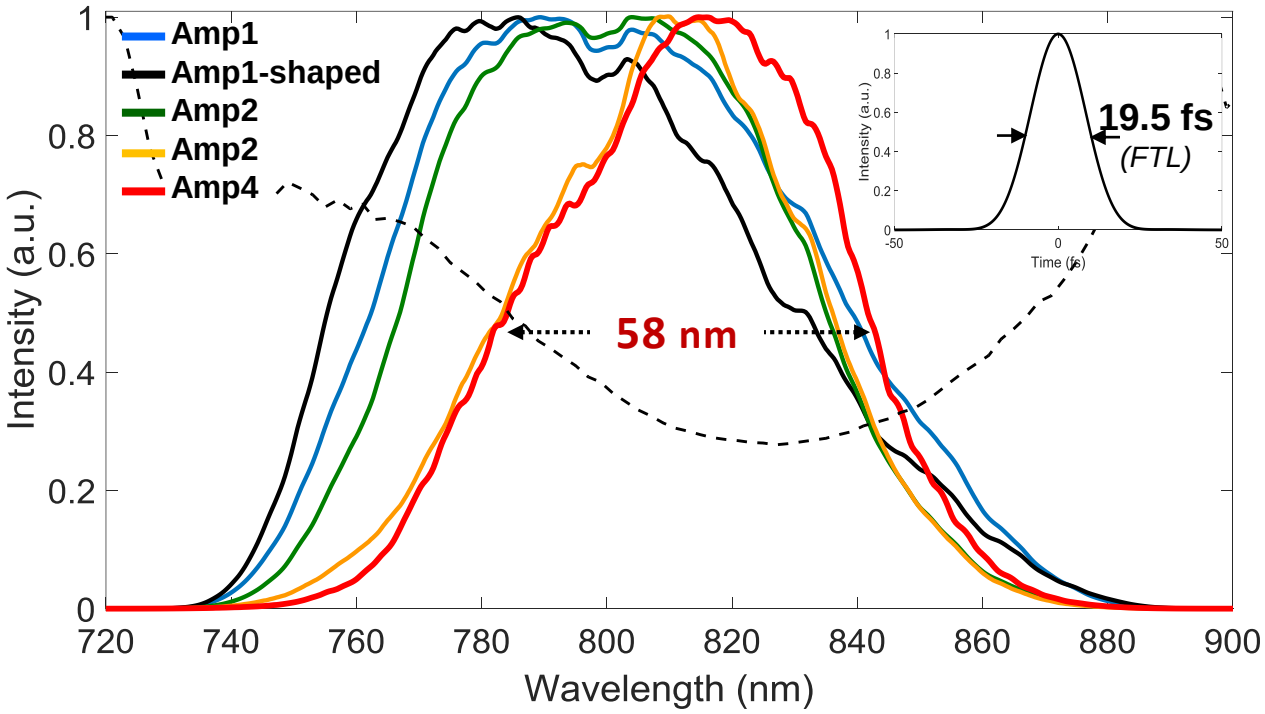
AMP-30
E_{ave} = **30.5J /** 1.6% rms / 7.8% PtP

ATLAS100
E_{ave} = **94J /** 0.8% rms / 4.8% PtP



Spectral characterization

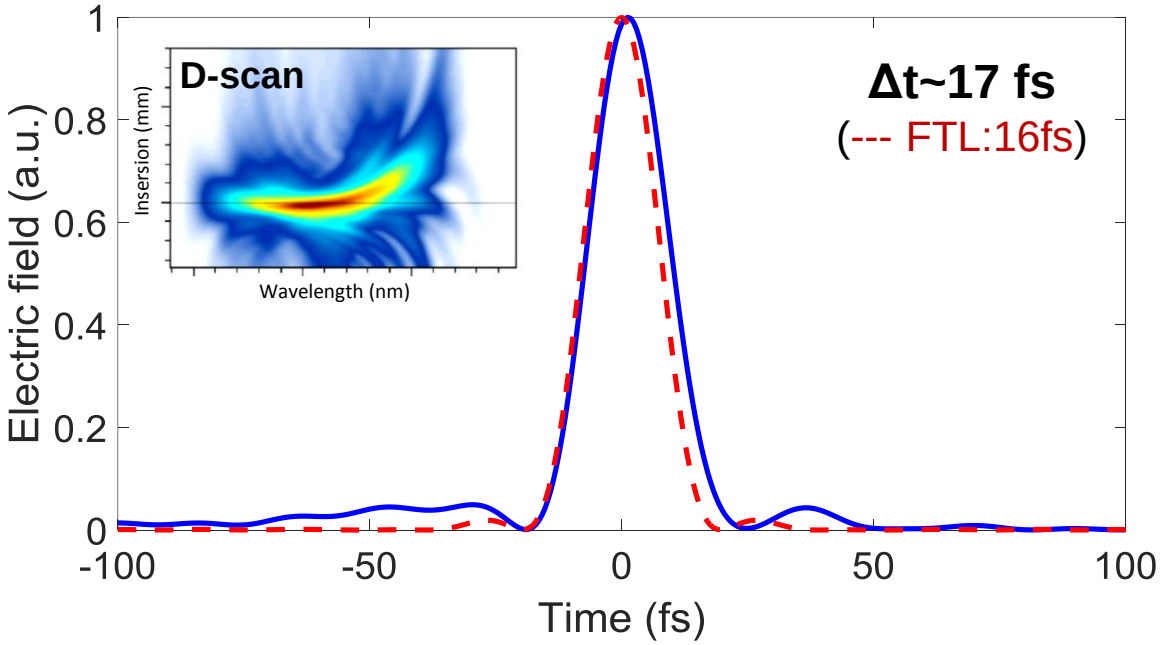
- Spectral evolution throughout the Ti:Sapphire stages:



- **Spectral filtering strategy**: compensation of gain narrowing and red-shifting
- Non optimized current filtering configuration: **1 stage missing** (Amp3-Amp4)
- Amp4 spectrum: **58 nm** at FWHM / **130 nm** at 1% ➔ FTL duration **19.5 fs**
- **1.1 PW capacity** assuming 20% transport losses and 70% compression efficiency
- **Spectral filtering optimization**➔ FTL **16-17 fs** (2019) ➔All-OPCPA Front End➔ FTL **<15 fs** (2020)

Compression tests

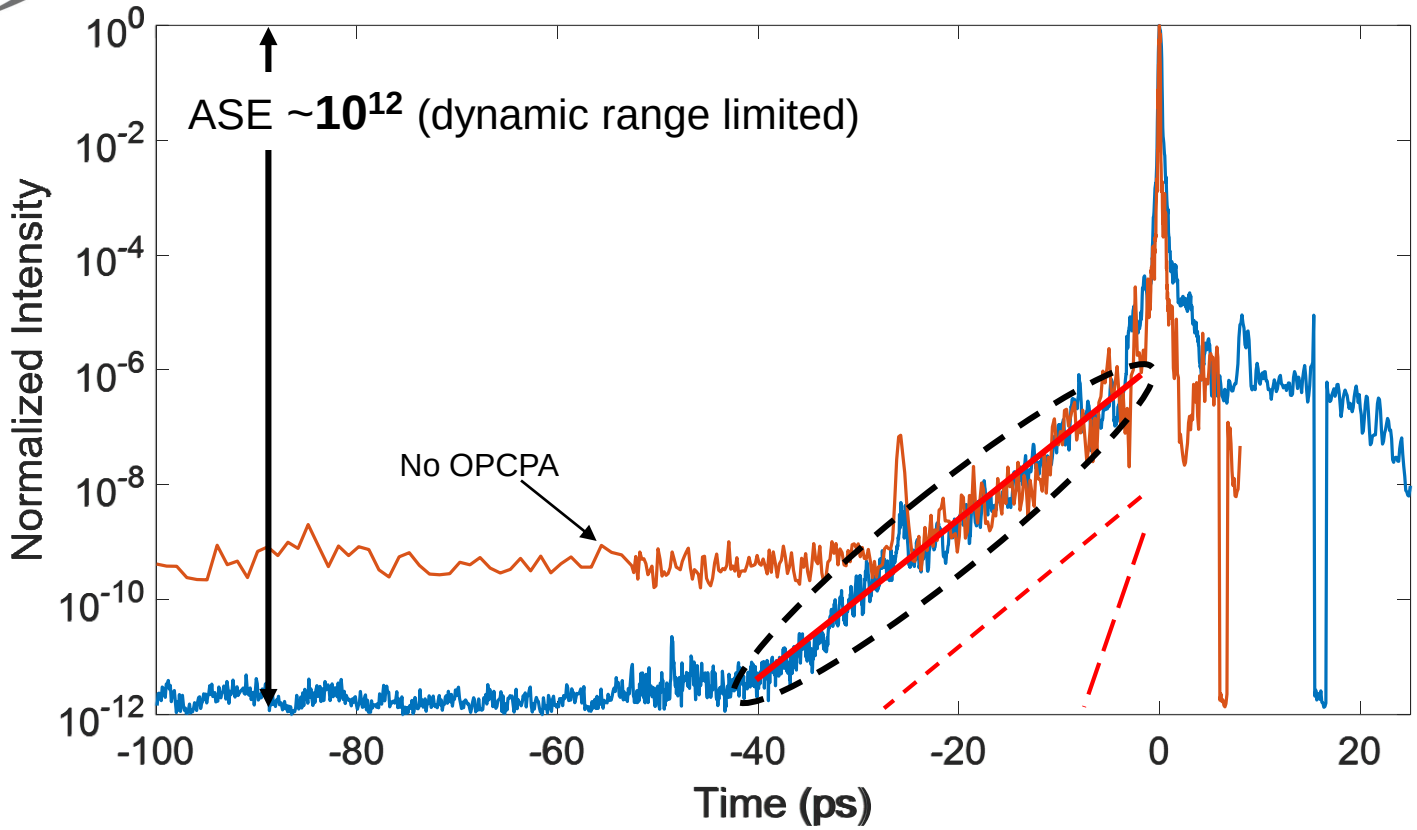
➢ Local compression tests: attenuated / sub-aperture beams



- Local compression to qualify the pulses compressibility at each amplification stage
- D-scan measurement: **~17 fs** (FTL:16fs) after the 1st Ti:Sa amplifier. Only **3rd order phase** manual phase correction with the **Dazzler**

➢ Demonstration of the Amp4 sub-aperture compression at **sub-20 fs** in the 1 PW compressor / Full phase active correction (June 2018)

Contrast characterization



Spatiotemporal coupling in the Stretcher

$$I(t) = I_0(t) + \varepsilon_0 \left|\delta\tilde{\varphi}(t)\right|^2$$

$\left|\delta\tilde{\varphi}(t)\right|^2$ ~ PSD of the cx-mirror in the stretcher

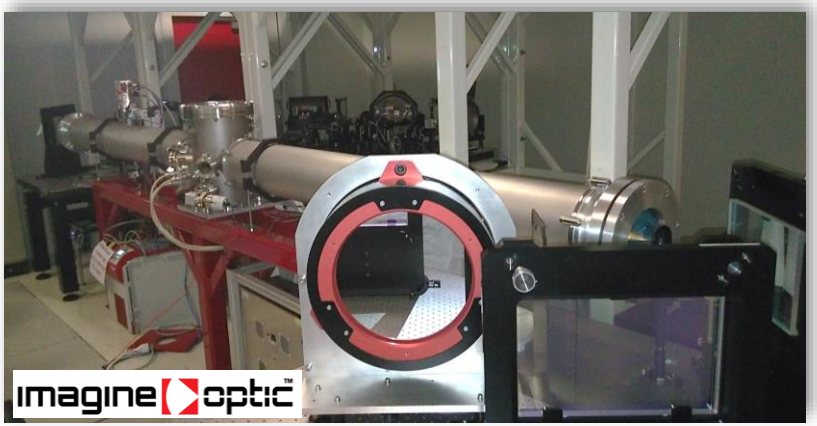
C. Dorrer, J. Bromage, Opt. Express, 16, **2008*

J. Bromage, J. Opt. Soc. Am. B, 29, **2012

- Moderate optical quality cx-mirror of **~2 nm** rms roughness
- Study of the improvement of the mirror quality :
  ➔0.1 nm rms is possible**➔>10² CR improvement**
- Ongoing study on **spatio-temporal averaging effect: PhD thesis starting in July (CIFRE/Thales)**

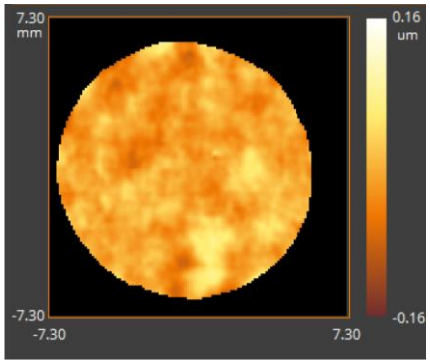
Wavefront Correction

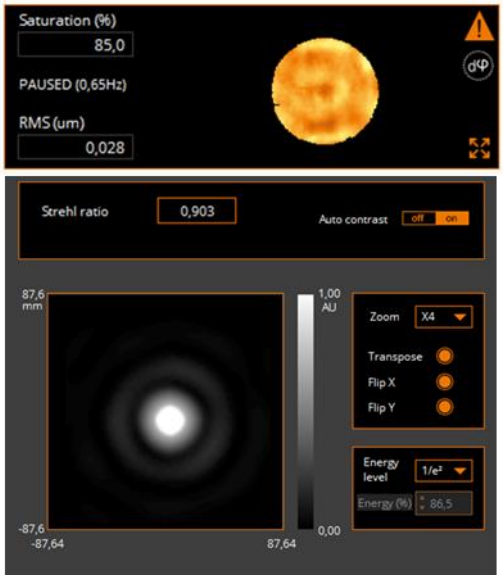
- Correction of the wavefront at the end of the amplification section (Φ140):



- **ILAO STAR**: AOI: **45°** / Useful zone: **180x250 mm²** / **52 mechanical actuators** / High dynamic range: **50λ**
- The DM is integrated in the laser chain / imaged to the phase detection
- Control loop optimization using a CW alignment beam throughout the amplification chain

OSAT: Active flat quality
6.5 nm rms / 40 nm PtV





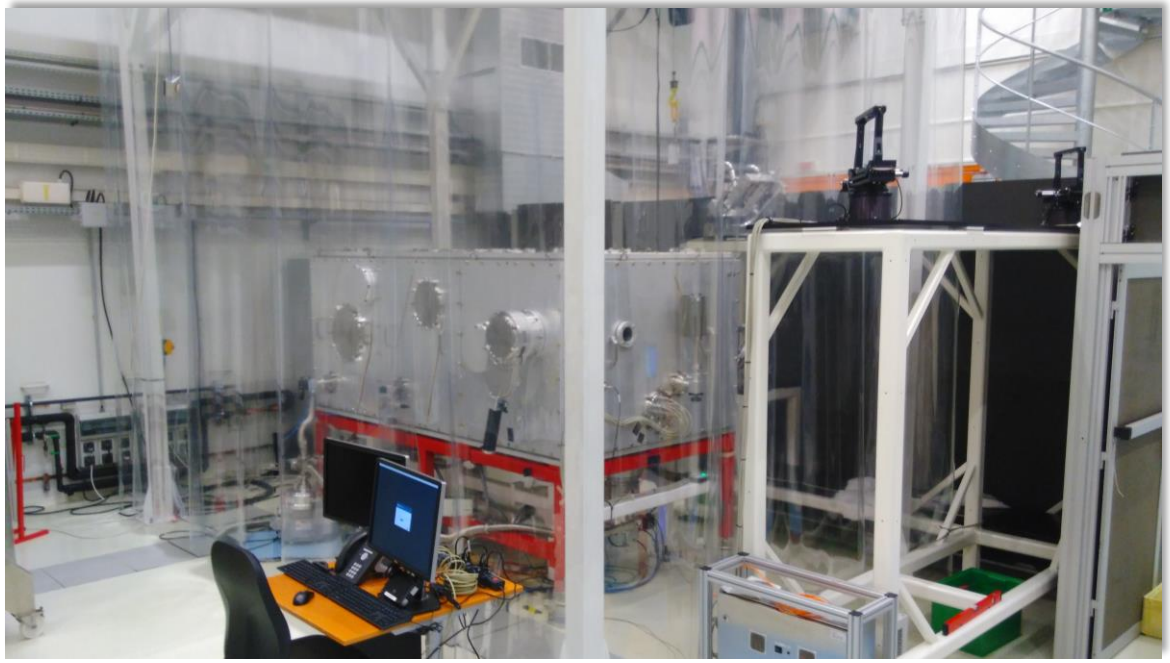
So far: Wavefront residual error down to **28 nm rms**/Strehl ratio >0.9 with the alignment beam (partially through the amplification section)

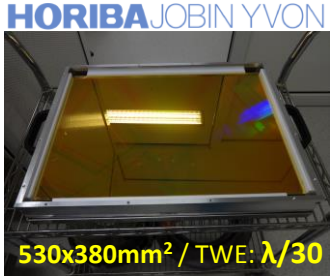
- High energy beam correction: June 2018 ➔ **Strehl ratio > 0.9**

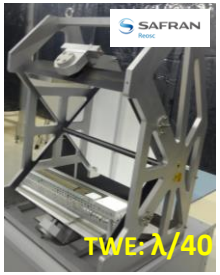
1 PW beam line: transport & compression

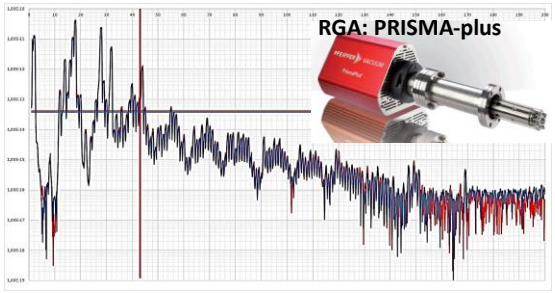
- **Project priority:**
  1 PW level demonstration
  - facility operation capacity
  - laser characterization on the target

- **Bypass the final Amplifier** and send the Amp4 output (30 J / Φ140) **to the 1 PW compressor**









- ✓ The compressor is **installed and qualified** for Vacuum, Cleanliness, Optomechanics
- ✓ Employs **high quality optics**: Low TWE Gold-Gratings and a Retroreflector
- ➢ Compression optimization of the 1 PW beam (July 2018)

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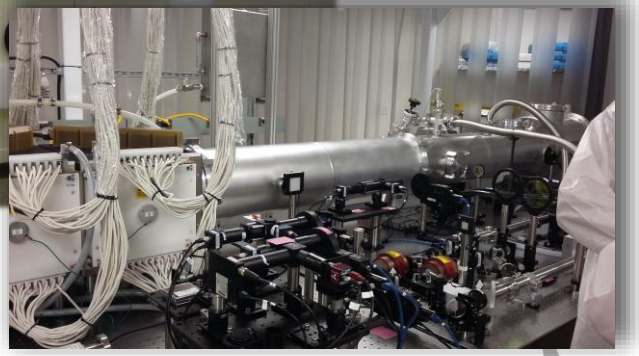
CNE pump source reception

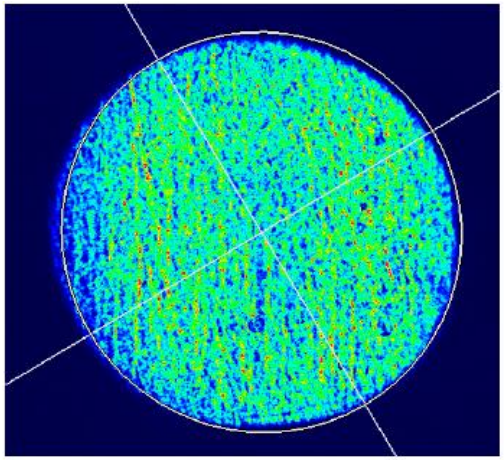
- A single beam of **200 J/min** in the green
- Innovative **Multi-slab / liquid-cooled** Nd:glass technology

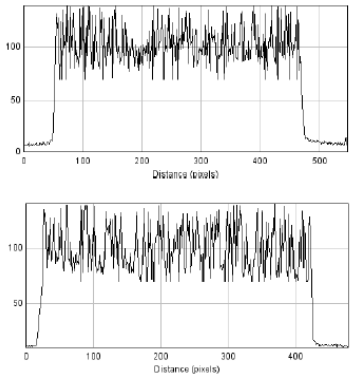


Delivery in France: **09/2016**
Acceptance tests: **07/2017**
Commissioning: 10/2017

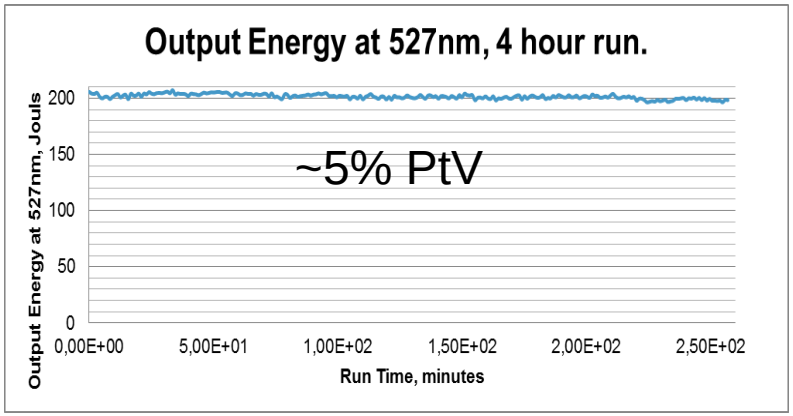
CNE commissioning

- Emphasis on the E_{out}, the near field profile, propagation properties and the reliability





- Flattop, 59 mm (1%)
- 50% modulation PtV



- Total number of commissioning shots ~**2000**
- E_{out}=**200 Joules** (300 J @ 1053 nm) / Stable operation: ~**5% PtV** (3 hours)
- Flattop nearfield/Highly modulated ➔ Modification of beam transport imaging to the Amp5 Ti:Sapphire crystal

➢ **…Amplification** at **>110 Joules** (end 2018) ➔ **multi-PW** capacity demonstration (summer 2019)

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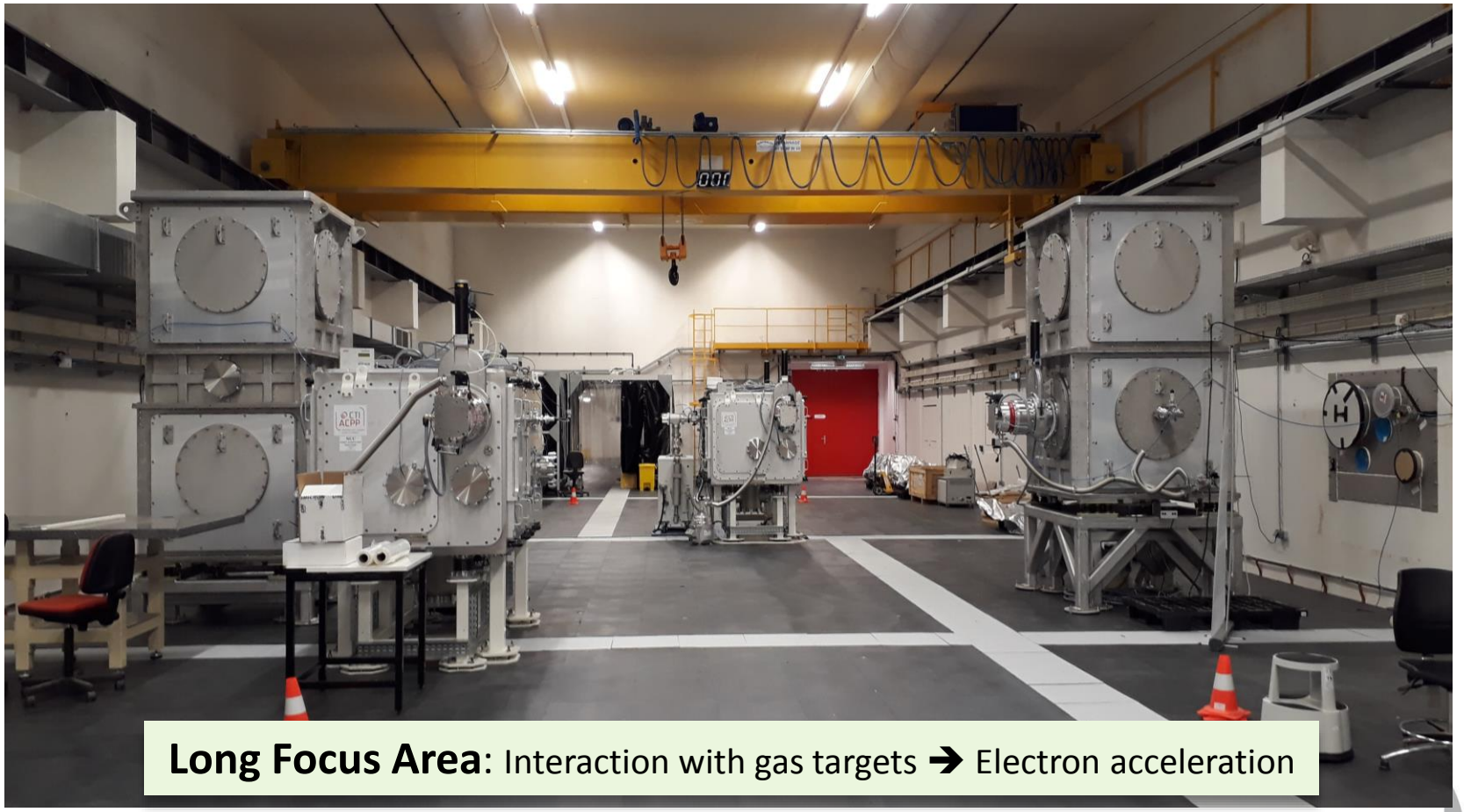
Commissioning experiments

End 2018 – Beginning 2019: First “simple” experiments in both experimental areas

- Qualify the **laser performances** and the **operational capacity** of the facility



Long Focus Area: Interaction with gas targets ➔ Electron acceleration

Commissioning experiments

End 2018 – Beginning 2019: First “simple” experiments in both experimental areas

- Qualify the **laser performances** and the **operational capacity** of the facility

Short Focus Area: Interaction with solid targets ➔ UHI physics

Outline

- Introduction
  - Apollon 10PW: Laser system key features
  - Laser facility construction progress
- Laser operation status / performances
  - The Front End commissioning
  - The Power Amplification Section
    - Qualification tests / PW beam line preparation
  - 200 Joules pump source commissioning
- Towards the first commissions experiments
  - Long and Short focus exp. areas preparation
- Conclusions

Conclusions

- The Apollon laser is **moving fast to the PW-class** operation level
- High Contrast/Large bandwidth **Front End commissioned**
- High energy amplification: Demonstration of >**38 Joules** with **sub-20 fs** BW pulses
- **PW beam line** first qualification tests
- **200 Joules pump** system commissioning

➢ **1st PW level experiments** (end **2018**)… **Multi-PW operation** (end **2019**)

Thank you