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## APOLLON: a multi-PW laser facility

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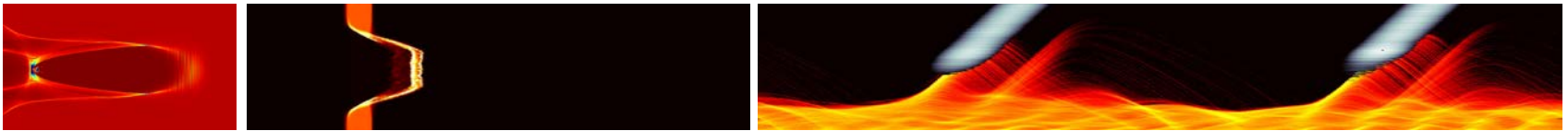
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# **APOLLON**

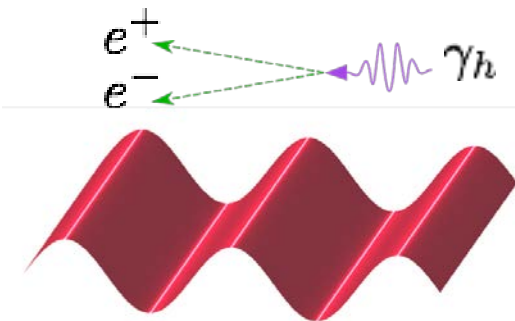
## **a multi-PW laser facility**

**S. Jacquemot (LULI)**  
on behalf of the APOLLON project team  
and of the CILEX consortium

- a Research Infrastructure included in the 2018 French roadmap and operated by the LULI laboratory
- a **user-oriented multi-PW multi-beam laser facility** designed to:
  - reach extreme laser powers (10PW) & intensities
  - produce energetic & ultra-short particle beams and x-rays with unique characteristics



- push forward the limits of fundamental research



- quantum effects in laser-plasma interaction
- high-energy  $\gamma$  production and positron generation

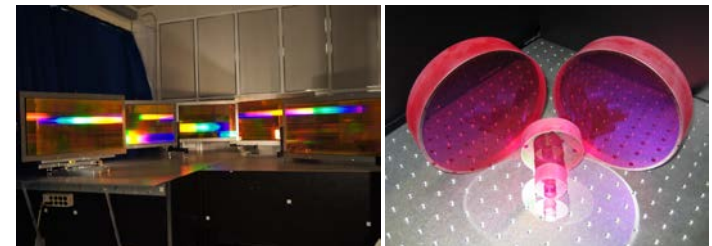
# The APOLLON targeted performances



- 4 independent laser beams delivering 1 shot per minute
  - F1                      15fs / 150J max (10PW)      ↑ contrast: <math>< 10^9 \text{ W/cm}^2</math> for pre-pulses
  - F2                      15 fs / 15J max (1PW)      ↓                      <math>< 10^{10} \text{ W/cm}^2</math> at -100 ps
  - F3 (creation)      uncompressed (ns) remaining energy
  - F4 (probe)            <math>< 20 \text{ fs}</math> / 0.2J (10 TW)
- 2 independent radio-protected experimental areas: SFA & LFA
  - SFA (Short Focal Area:  $f=1\text{m}$ ) - intensities  $> 2 \cdot 10^{22} \text{ W/cm}^2$   
for ion acceleration & strong field physics
  - LFA (Long Focal Area:  $f=8-32\text{m}$ ) - for electron acceleration

## ➤ *unique features*

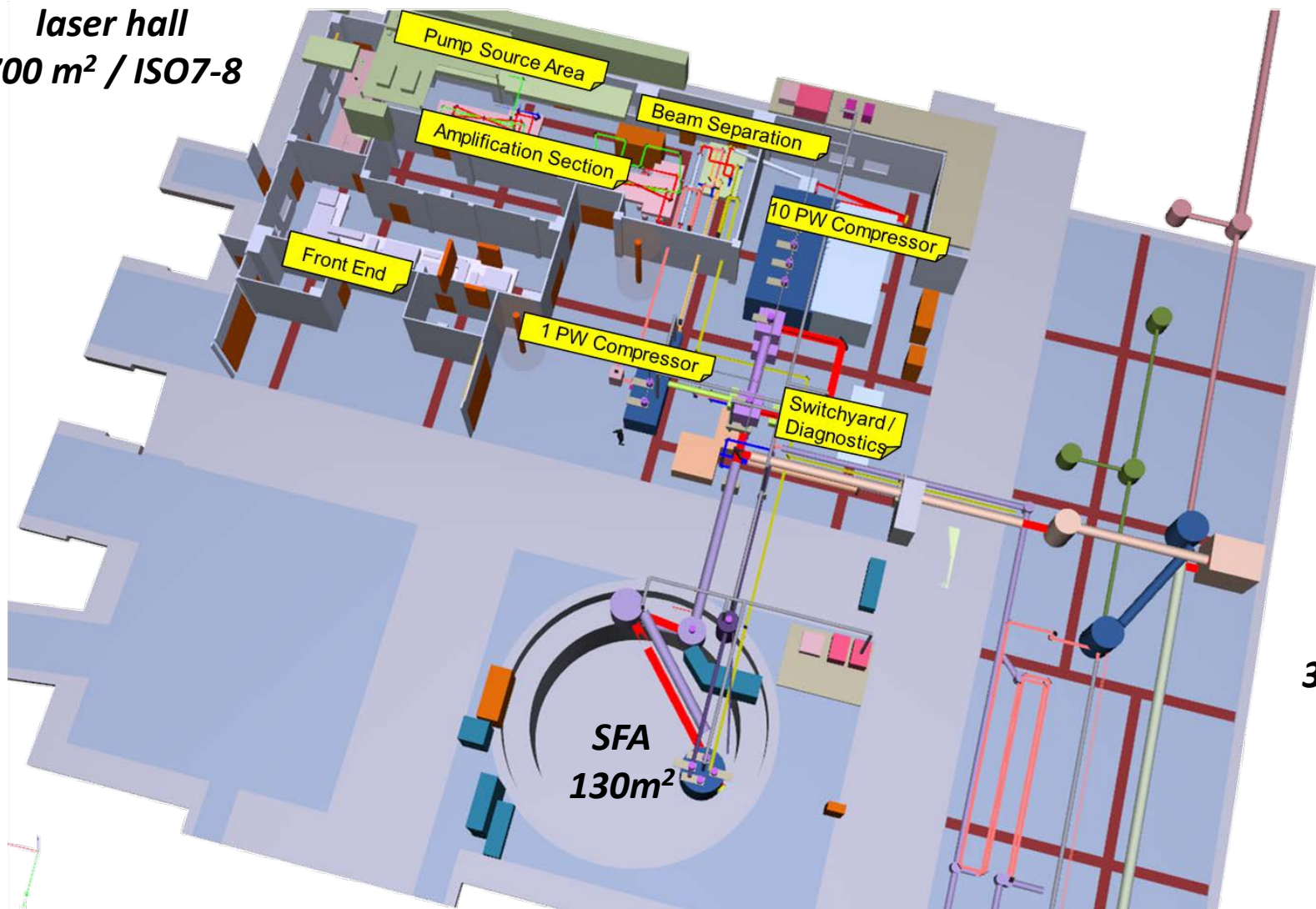
- hybrid architecture: OPCPA + Ti:Sapphire  
➔ contrast + bandwidth + energy
- extreme materials:  $\Phi 10-200\text{mm}$  crystals, meter-size low-TWE gratings, state-of-the-art optics



# The APOLLON laser architecture & layout



**laser hall**  
**700 m<sup>2</sup> / ISO7-8**



**SFA**  
**130m<sup>2</sup>**

**LFA**  
**300m<sup>2</sup>**

# The APOLLON building

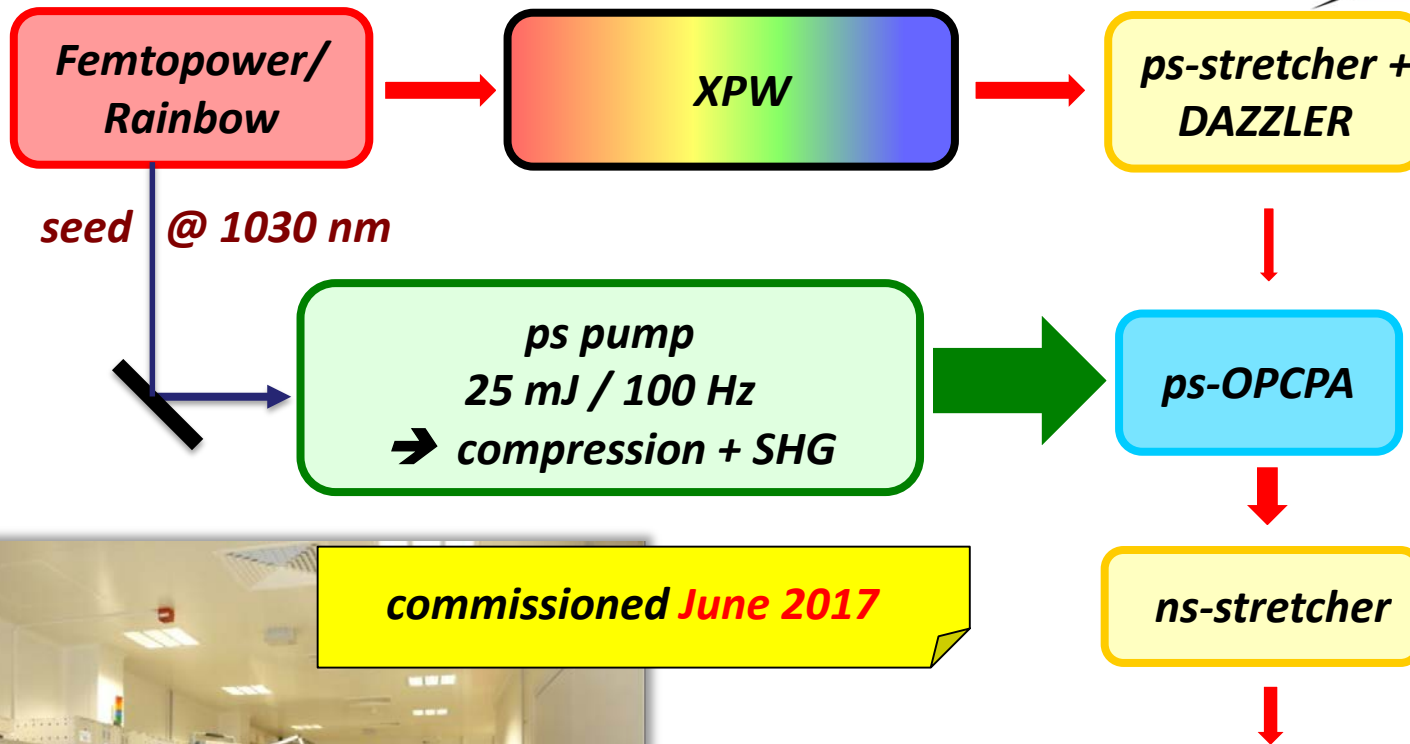


2011



2015

# The APOLLON front-end architecture



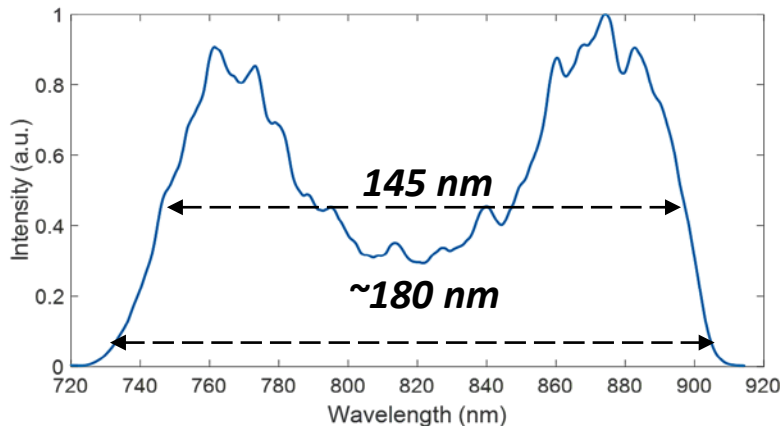
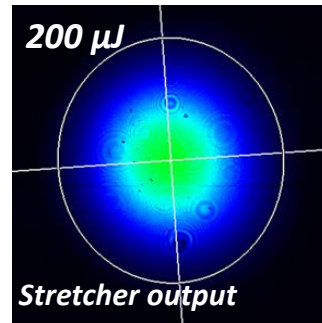
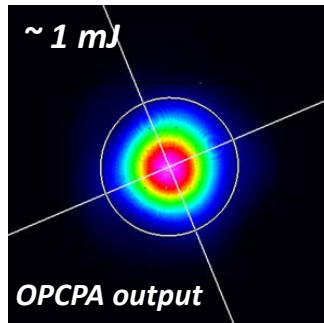
**commissioned June 2017**

*...to Ti:Sapphire based amplifiers (5x)*

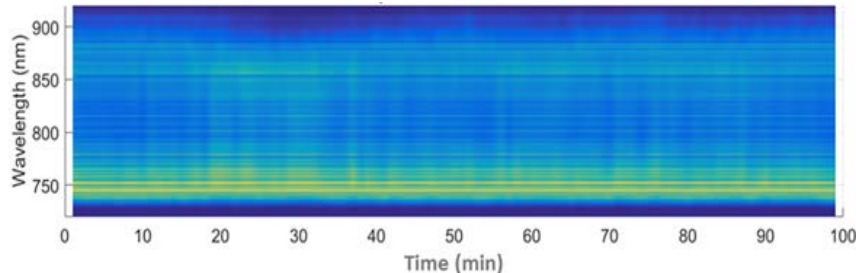


*D. Papadopoulos et al., Optics Lett. 42, 3530 (2017)*  
*L. Ramirez et al., J.O.S.A. B 30, 2607 (2013)*

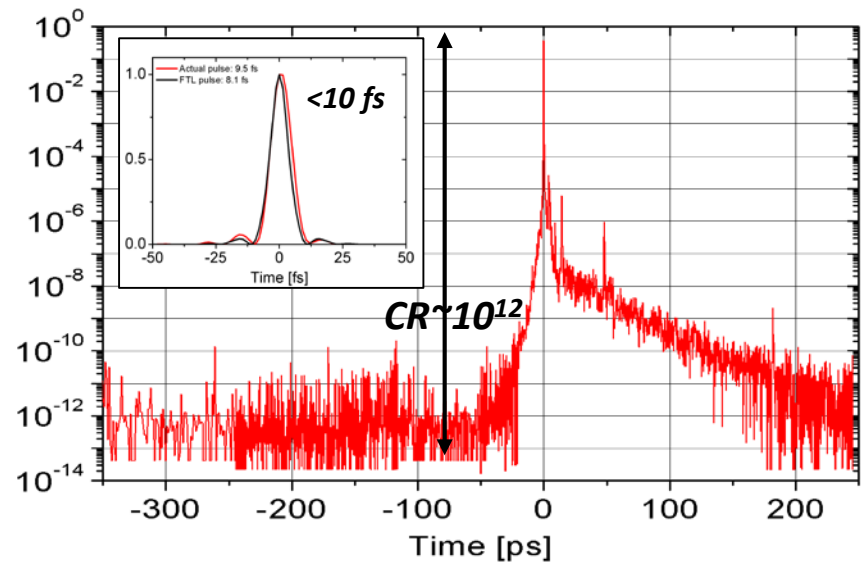
# Commissioning of the APOLLON front-end



OPCPA spectral evolution with time:  $\sim 100 \text{ min}$

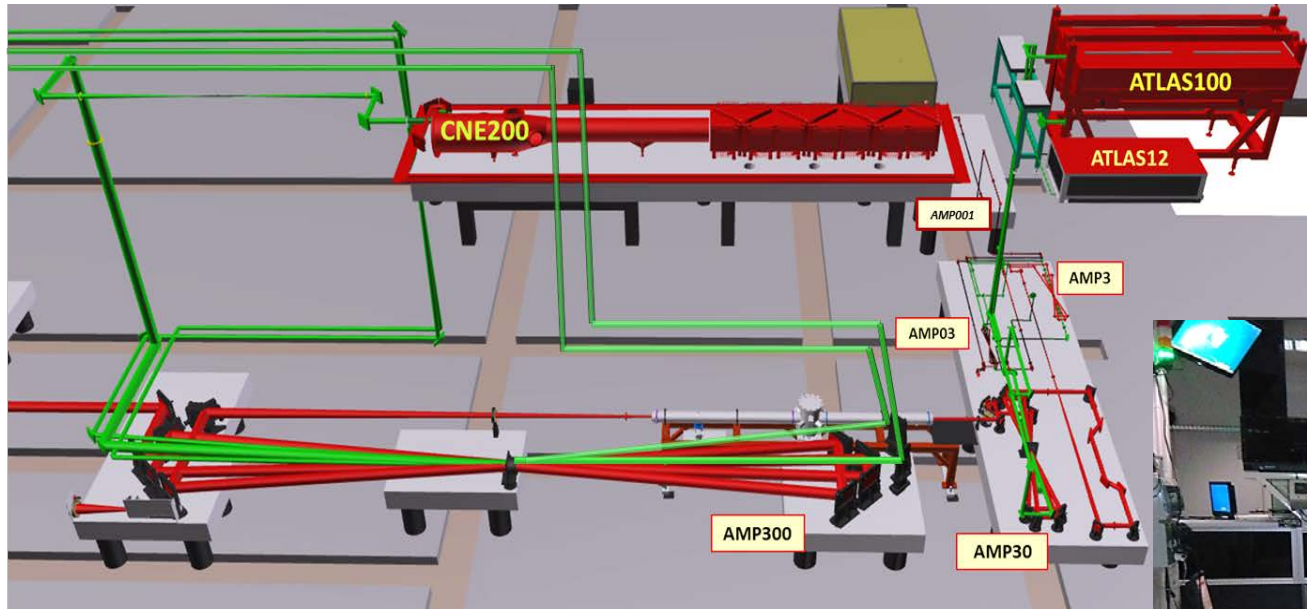


- ✓ **Reliable operation & fast start-up ( $< 30 \text{ min}$ )**
- ✓ **Stable operation:  $\delta\lambda < 2 \text{ nm/hour}$  spectral thermal drift**
- ✓ **1 mJ / 100 Hz with excellent beam quality**
- ✓ **Optimized injection spectrum: 720-920nm  $>$  sub-10 fs**
- ✓ **High contrast pulses  $CR > 10^{12}$**



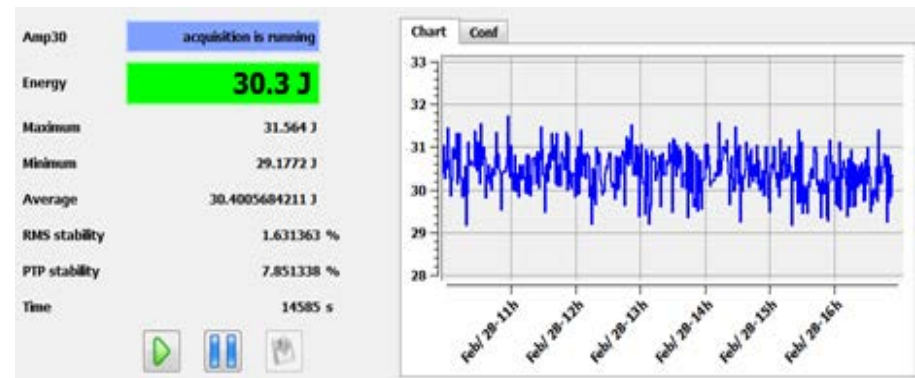
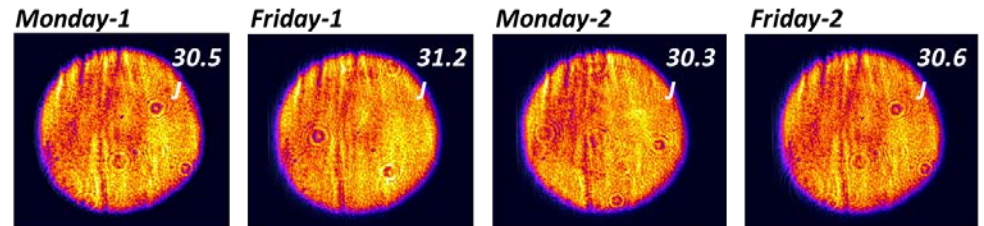
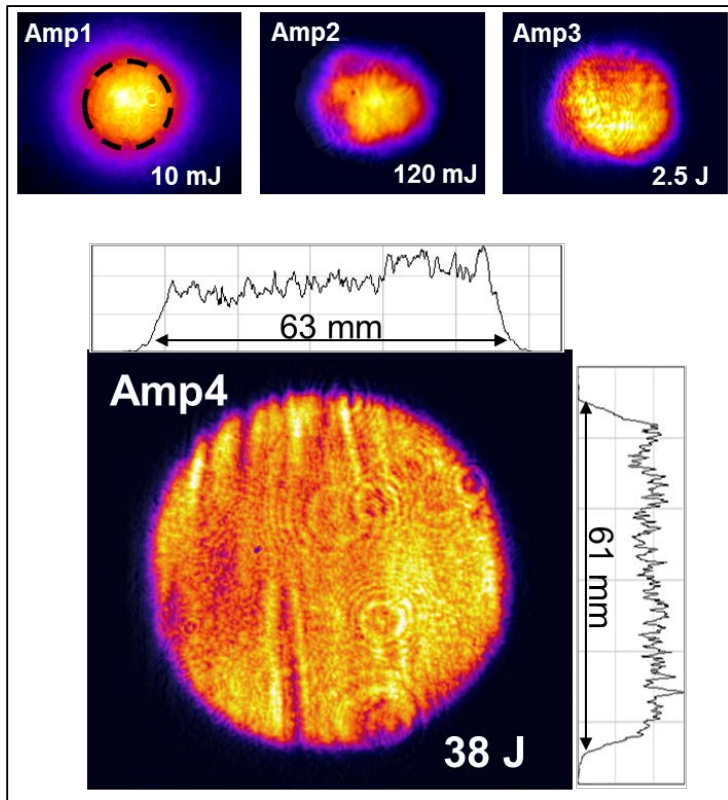


# The APOLLON amplification architecture



- 5x “low-gain” / image-relayed multipass amplifiers  
 $\Phi 6\text{-}\Phi 140\text{ mm} \Rightarrow 0.01\text{-}300\text{ J} / 1\text{ shot min, } 1\text{ ns @ } 820\text{ nm}$
- pump energies @ 527 nm : 300 J available (3-4PW), +300 J budgeted (9PW)  
+100 J technically possible (11PW)
- AMP300 not yet operational (bypassed)

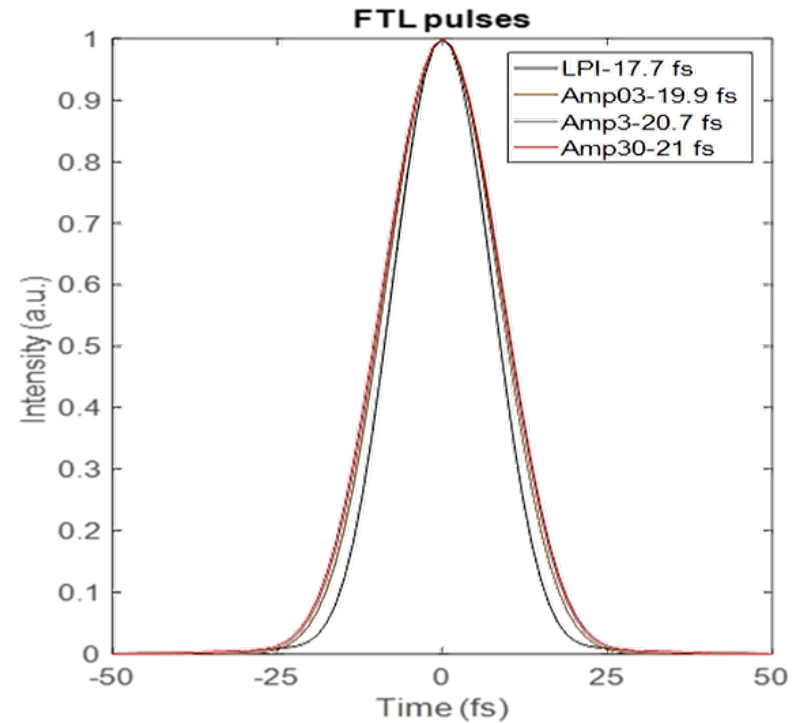
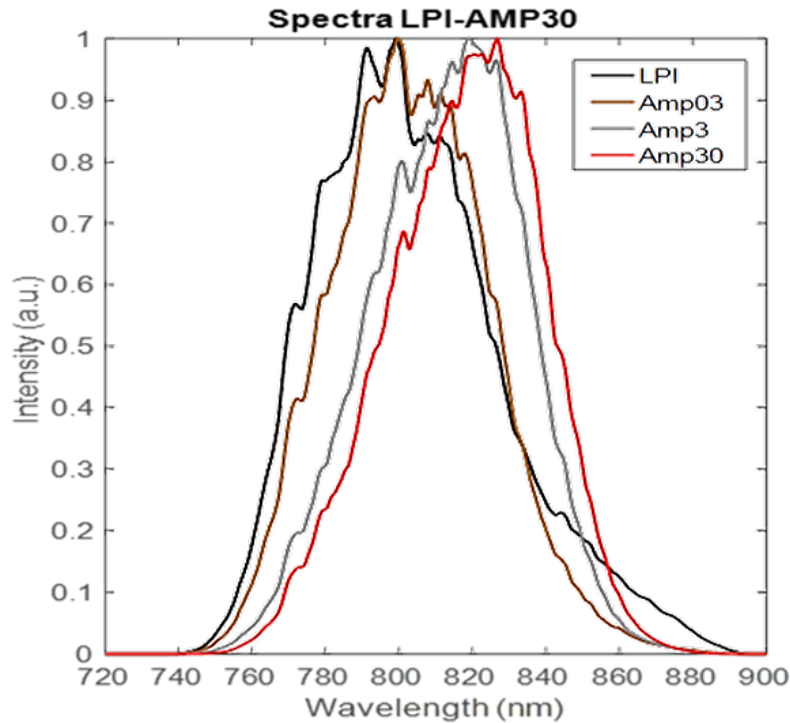
# Commissioning of the APOLLON AMP30 section



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

> **38 J** for a pump energy of **82 J**  $\Leftrightarrow$  ~44% efficiency into an uniform flat-top like beam  
reliable energy delivery over > 4000 shots (2 weeks, 6-7 h/day) & stable operation  
over > 7h (1 day)

# APOLLON spectral performances at max. energy

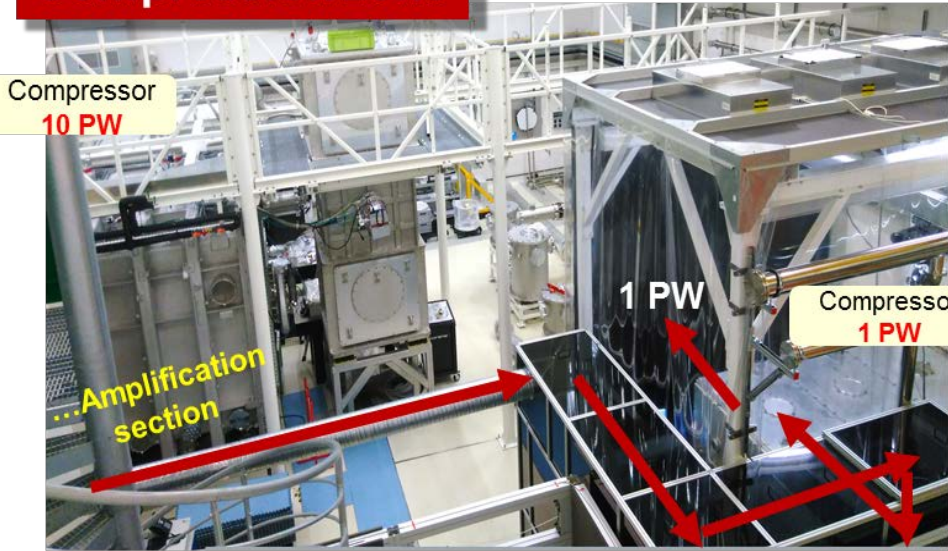


**~50 nm at FWHM and ~130 nm at 1% → 21 fs FTL → >1 PW expected**  
**15 fs possible once spectral filtering optimized (2020)**

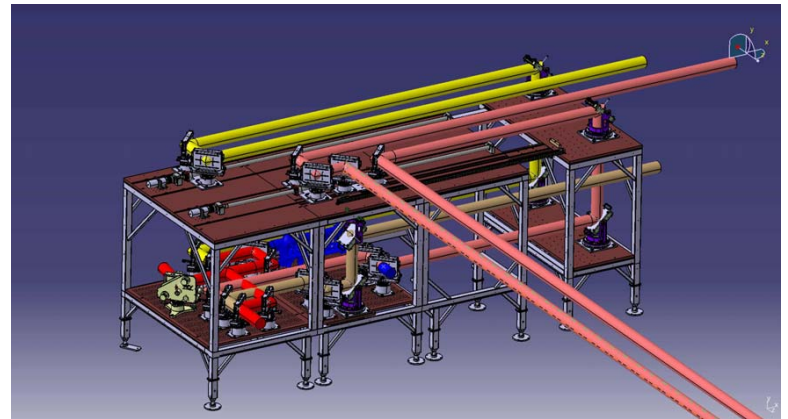
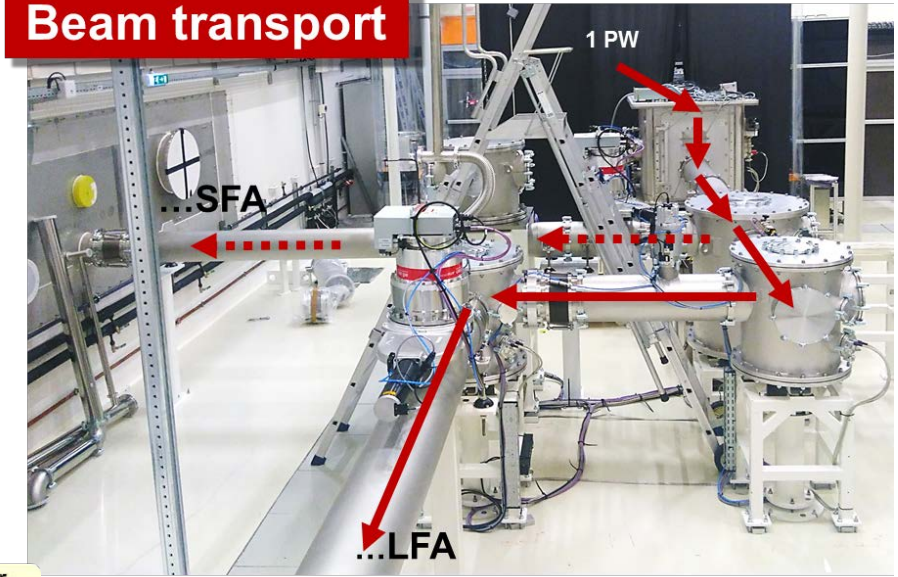
# The APOLLON compression zone & beam transport



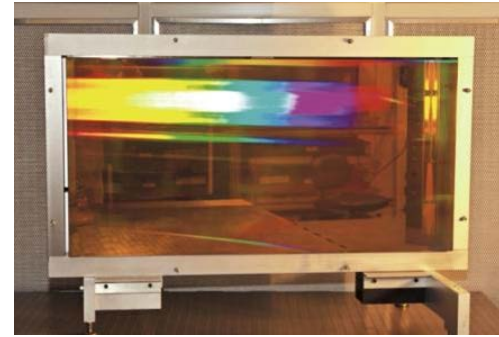
## Compression zone



## Beam transport

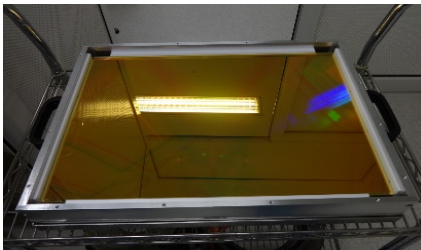


# The APOLLON pulse compressors



*6x LLNL Au gratings  
910 x 455 mm<sup>2</sup>  
 $\lambda/6$ - $\lambda/8$*

*10 PW compressor ( $\Phi$ 400)*



**HORIBA** JOBIN YVON

*gold gratings 530 x 380mm<sup>2</sup>,  $\lambda/33$*

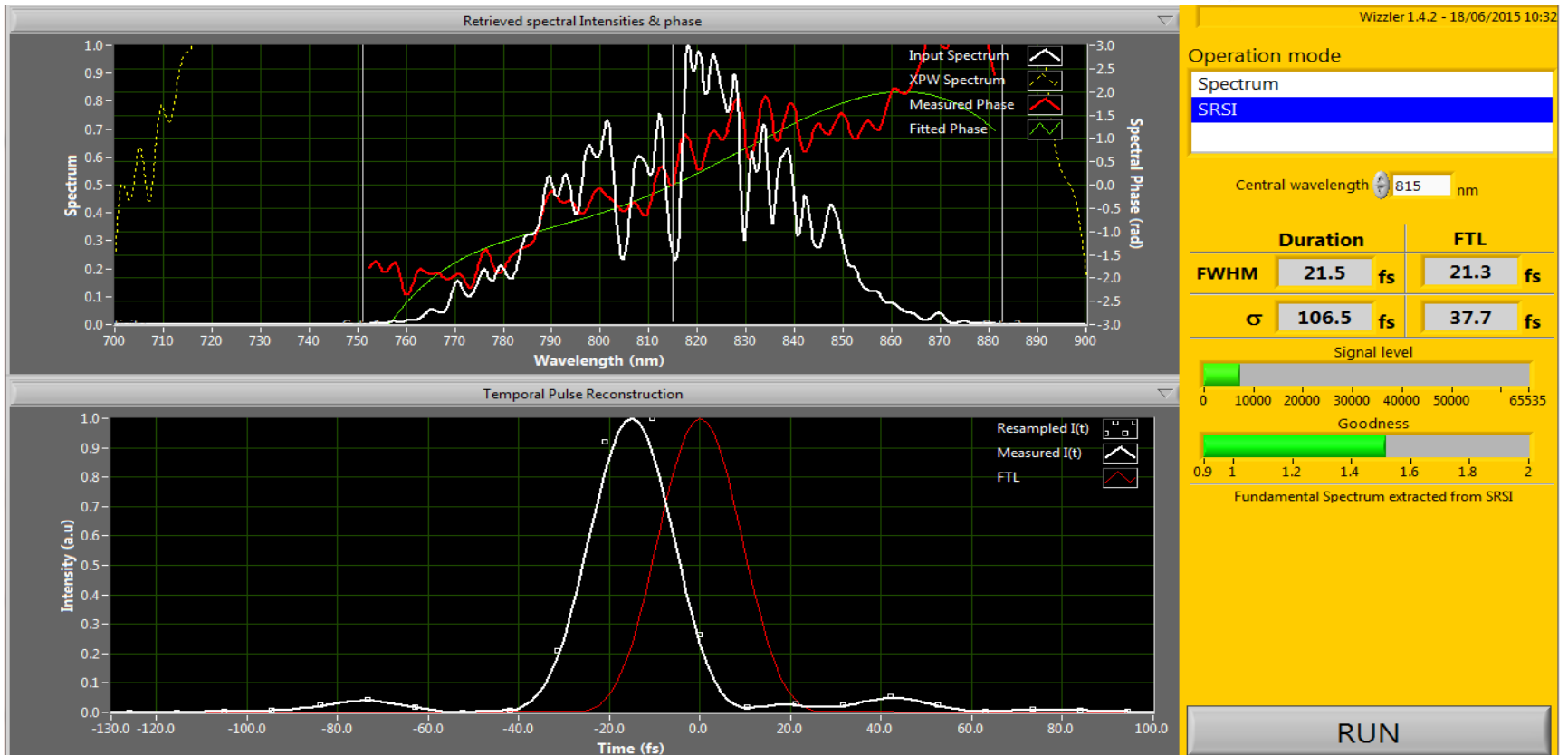
*1 PW compressor ( $\Phi$ 140)*

*fully operational*

*67% full aperture efficiency*



# APOLLON pulse duration

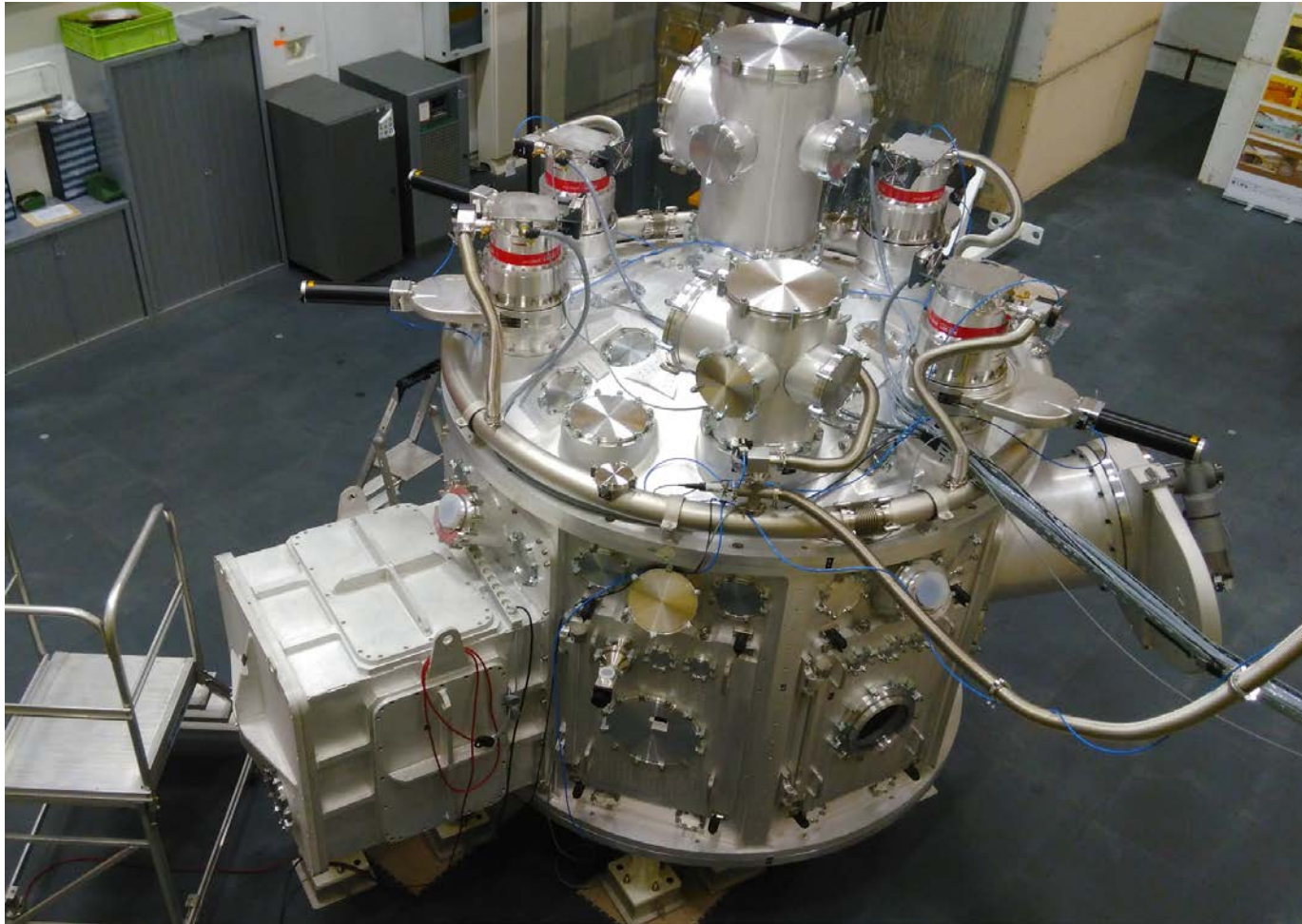


**21.5 fs measured** (FTL=21.3 fs) for an energy of 22.6 J (AMP30)

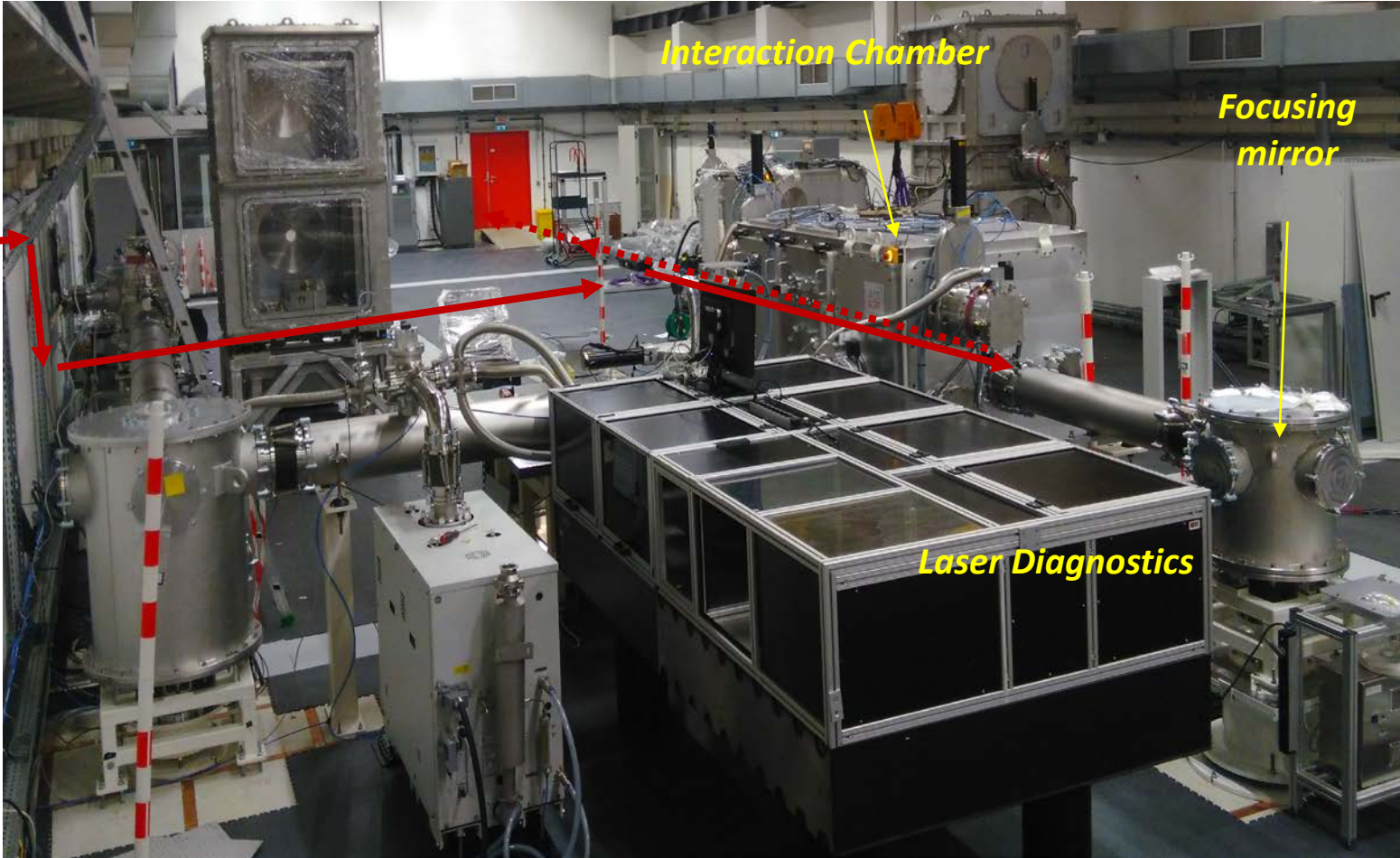
over more than 1 hour of shots:  $\Delta t = 21.7 \pm 0.6$  fs for  $E = 36.1 \pm 1.2$  J

**=> 1 PW on "target"**

# The APOLLON Short Focal Area



# The APOLLON Long Focal Area

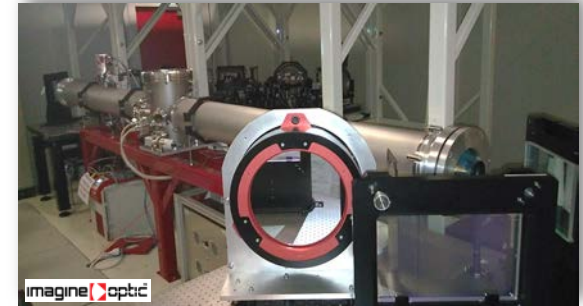




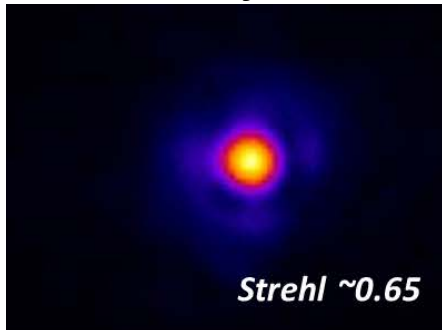
# The APOLLON performances on LFA TCC



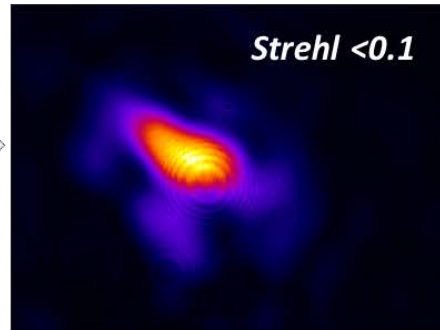
- single AO loop installed in the amplification zone, before compression, ~60 m away from the target, using an **ILAO STAR** deformable mirror
- satisfactory correction efficiency:  $\sim\lambda/10$  rms residual error / **Strehl > 50%**



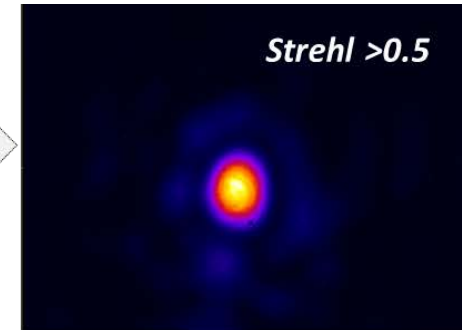
at the exit of AMP30



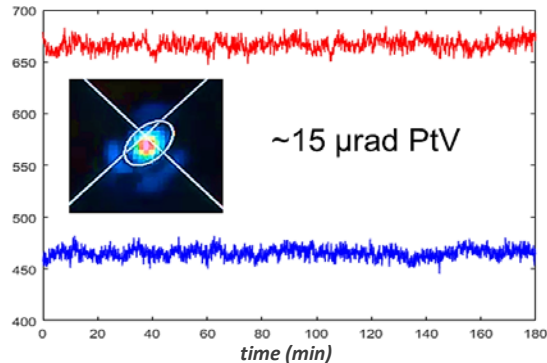
in LFA before correction



in LFA after correction



$\Phi 45-50\mu\text{m}$



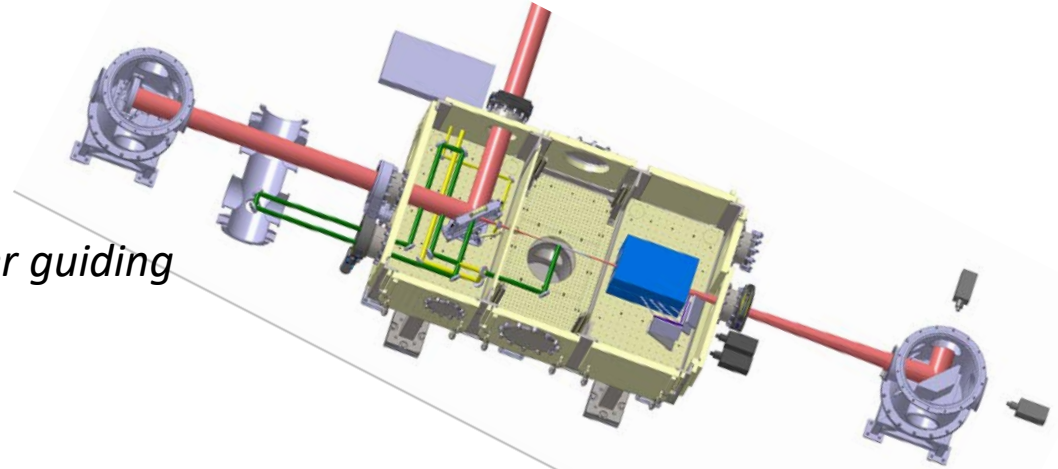
- **good stability:** practically no pointing drift over  $\sim 3$  hours,  $\sim 1$  focal spot PtV shot-to-shot instability

# Commissioning experiments @ 1PW (f: 3m) : LFA



## ❖ single-stage electron acceleration (PI: C. Thaury LOA, A. Specka LLR)

- “bubble” regime
- gas: He+1%N<sub>2</sub>
- nozzle: 10x0.3 mm<sup>2</sup>
- stable acceleration without laser guiding
- peak e energy: ~2.7 GeV

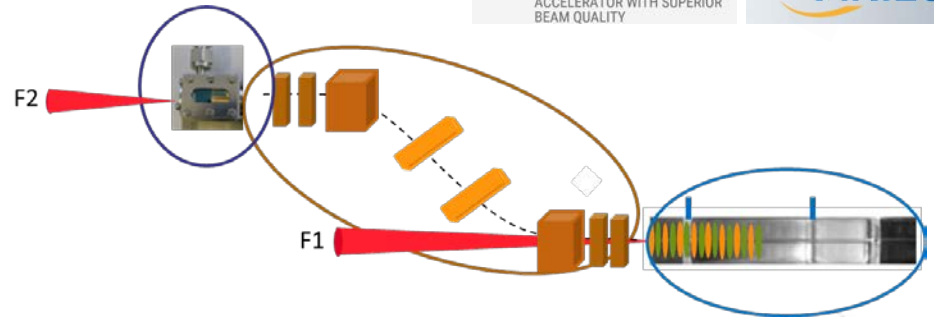


## ❖ 2-stage electron acceleration (PI: B. Cros LPGP)

*context: development of future high-energy physics accelerators*

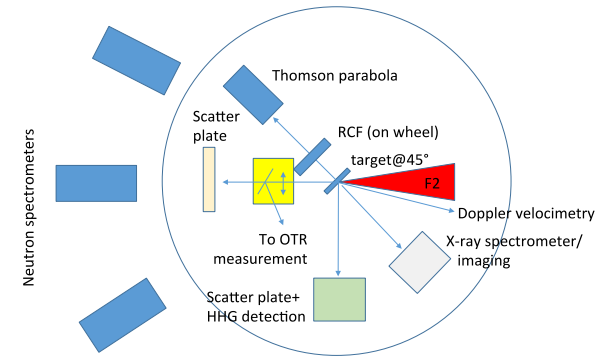
*1<sup>st</sup> step: prepare the seeding source*

- dedicated gas cell (ELISA)
- gas: H<sub>2</sub>+1%N<sub>2</sub>
- high charge (nC) @ 450 MeV



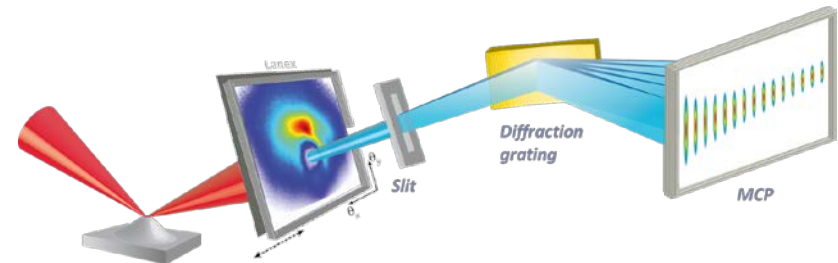
## ❖ proton acceleration (PI: J. Fuchs LULI)

- *thin (5nm) to thick ( $\mu\text{m}$ ) solid targets*
- *peak p energy:  $\sim 20$  MeV*



## ❖ high-order harmonics generation from solids (PI: F. Quéré LIDyL)

- *$\text{SiO}_2$  thick (0.5cm) targets*



both strongly binding in terms of contrast

- ❖ **facility opened to national & international users (with a fraction of the beam time allocated to the CILEX consortium)**
- ❖ **experimental programs decided on an annual basis following recommendations of an independent Program Committee**
- ❖ **once facility completed, 20 experimental projects per year (10 per area)**
  - **60 days / year for maintenance & configuration changes**
  - **50 days / year for laser development**
- ❖ **fixed duration of the experimental campaigns: 6 days (1800 shots) + 9 days for setting up (incl. 7 without laser) + 2 days for dismantling**
- ❖ **laser sequences on demand (from 1 to 100 shots) over 5 hours per day**
- ❖ **operation teams to change configurations & laser parameters**

## ❖ July 2020 – June 2021

- ✓ first user experiments
  - 4 experiments @ 1PW (2 SFA, 2 LFA)
  - call for proposal to be launched next December

*have a look to the LULI website or contact me to be included in the mailing list*

<https://portail.polytechnique.edu/luli/fr>

- ✓ pump energy ramping up & MPW demonstration

## ❖ July 2021 – June 2022

- ✓ continuation of the user experiments @ 1PW
- ✓ commissioning experiments with the MPW beam

## ❖ July 2022 – June 2023

- ✓ user experiments combining the MPW & the 1PW beams

- ❖ **1 PW peak power demonstrated**
  - ✓ **> 38 J pulses with sub-22 fs pulses delivered on “target”**
  - ✓ **contrast ratio >  $10^{12}$**
- ❖ **1<sup>st</sup> PW commissioning experiments this autumn**
- ❖ **1<sup>st</sup> call of proposals to be launched end of the year**
- ❖ **MPW operation in 2020**

Thanks for your attention

