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APOLLON: a multi-PW laser facility

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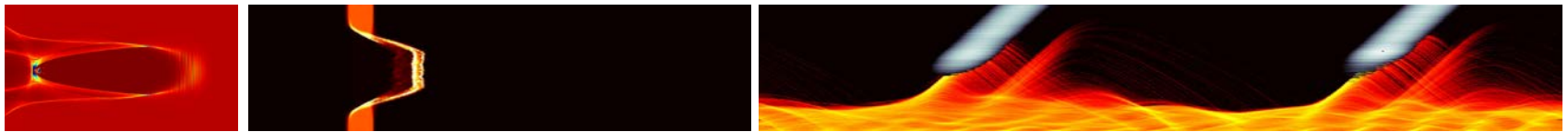
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APOLLON

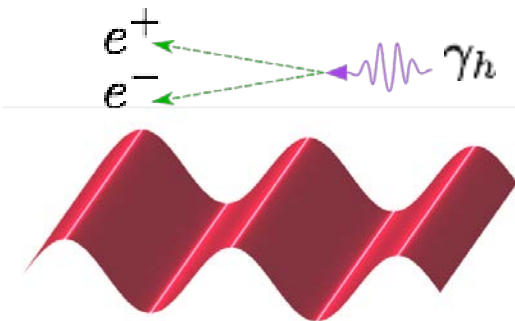
a multi-PW laser facility

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 γ production and positron generation

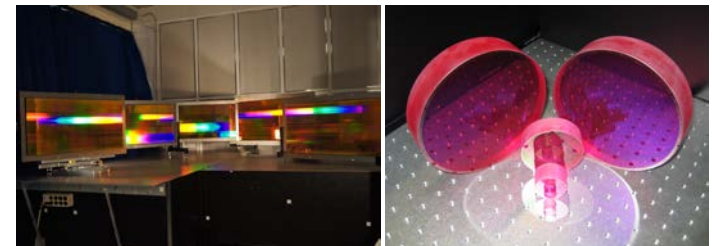
The APOLLON targeted performances



- 4 independent laser beams delivering 1 shot per minute
 - F1 15fs / 150J max (10PW) ↑ contrast: $< 10^9$ W/cm² for pre-pulses
 - F2 15 fs / 15J max (1PW) ↓ $< 10^{10}$ W/cm² at -100 ps
 - F3 (creation) uncompressed (ns) remaining energy
 - F4 (probe) < 20 fs / 0.2J (10 TW)
- 2 independent radio-protected experimental areas: SFA & LFA
 - SFA (Short Focal Area: f=1m) - intensities $> 2 \cdot 10^{22}$ W/cm²
for ion acceleration & strong field physics
 - LFA (Long Focal Area: f=8-32m) - for electron acceleration

➤ *unique features*

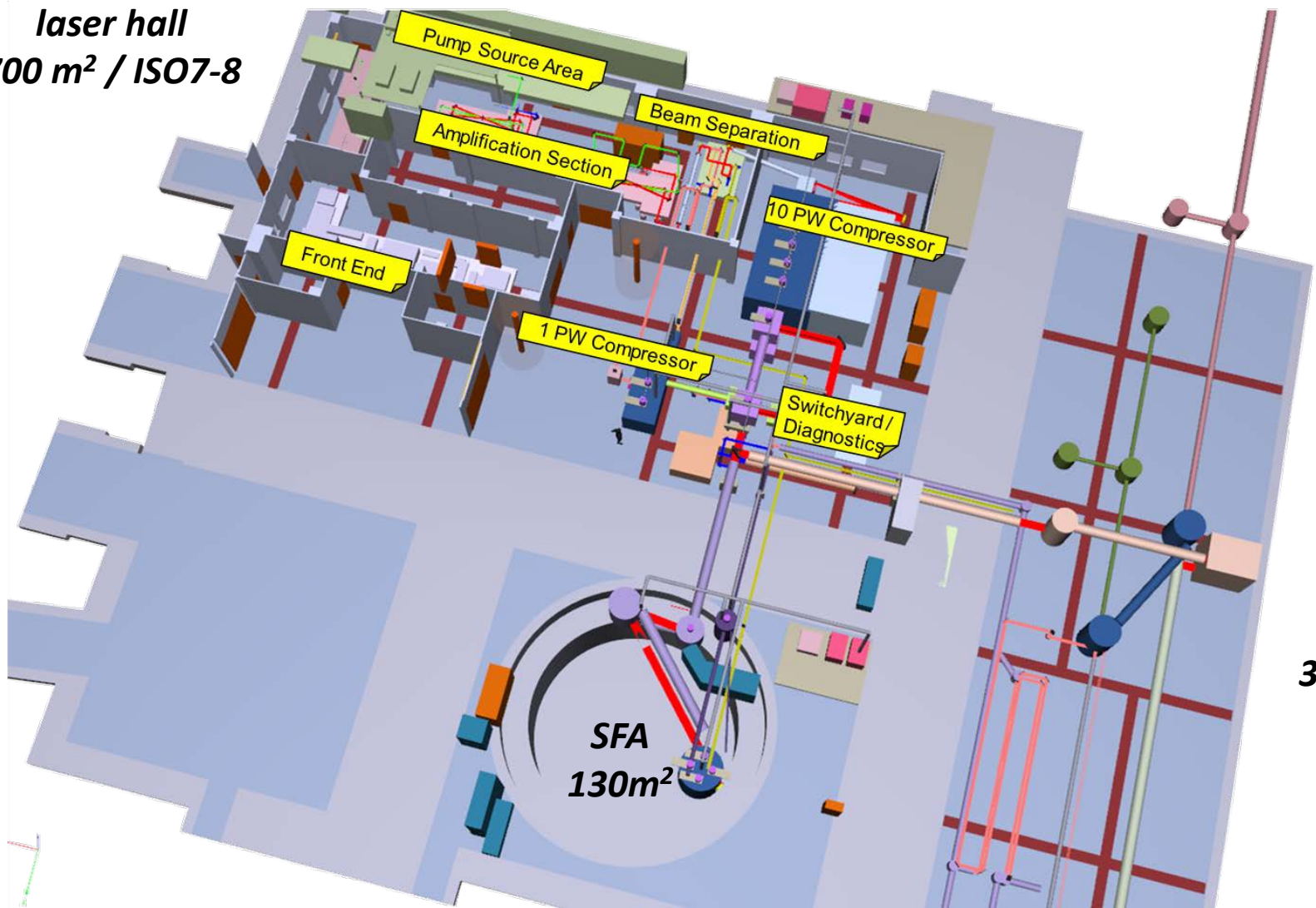
- hybrid architecture: OPCPA + Ti:Sapphire
➔ contrast + bandwidth + energy
- extreme materials: Φ 10-200mm crystals, meter-size low-TWE gratings, state-of-the-art optics



The APOLLON laser architecture & layout



laser hall
700 m² / ISO7-8



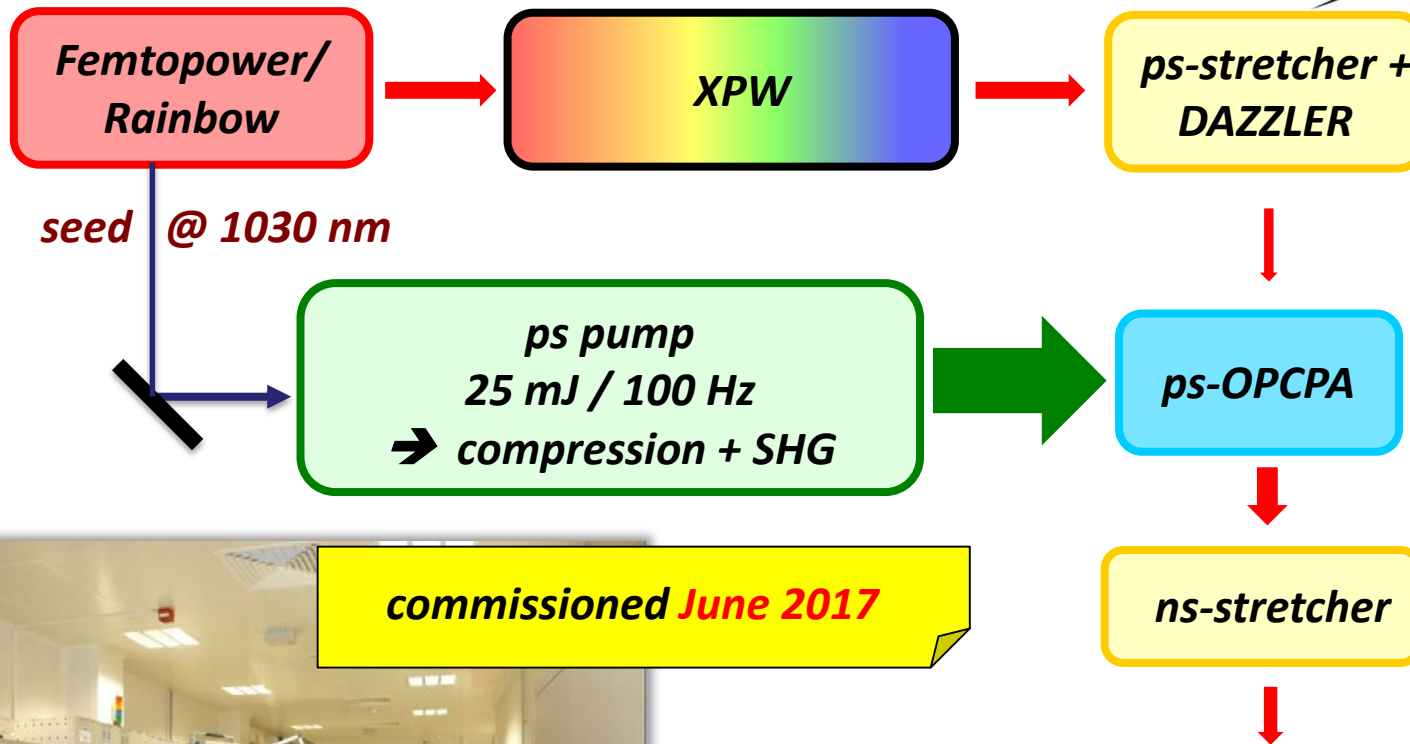
LFA
300m²

SFA
130m²

The APOLLON building



The APOLLON front-end architecture



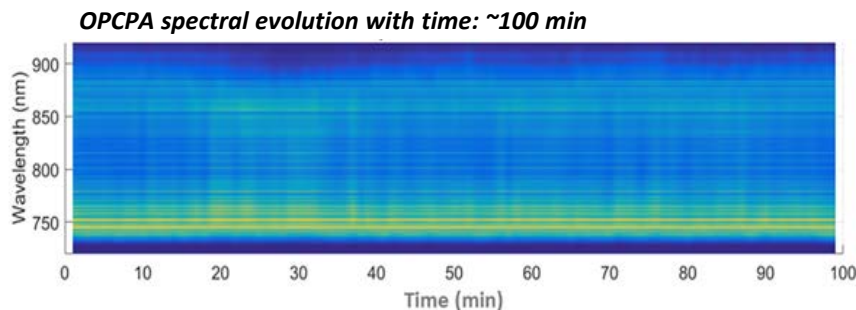
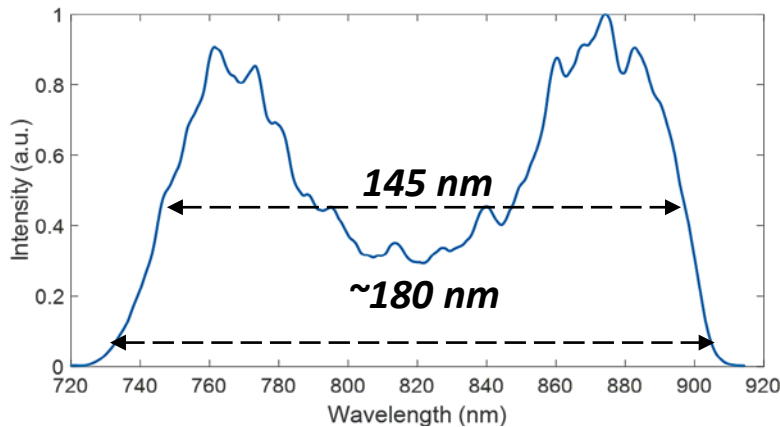
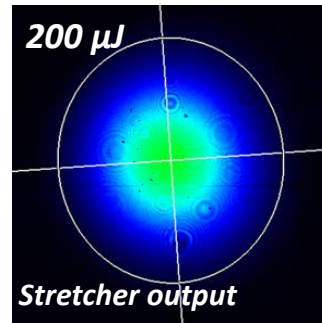
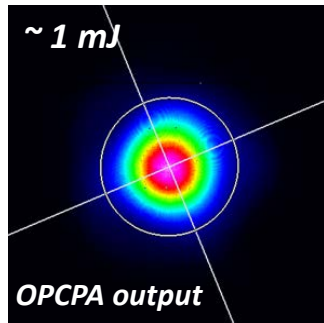
commissioned **June 2017**

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

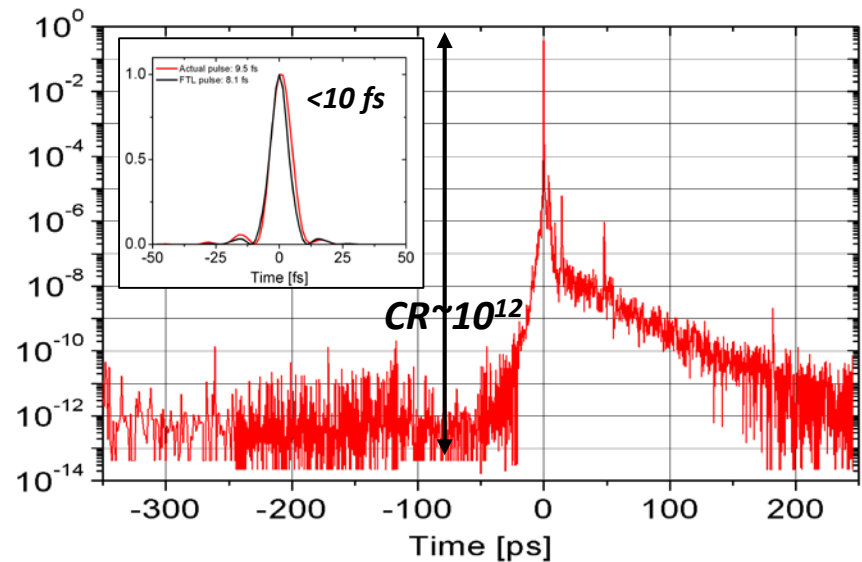


D. Papadopoulos et al., *Optics Lett.* 42, 3530 (2017)
L. Ramirez et al., *J.O.S.A. B* 30, 2607 (2013)

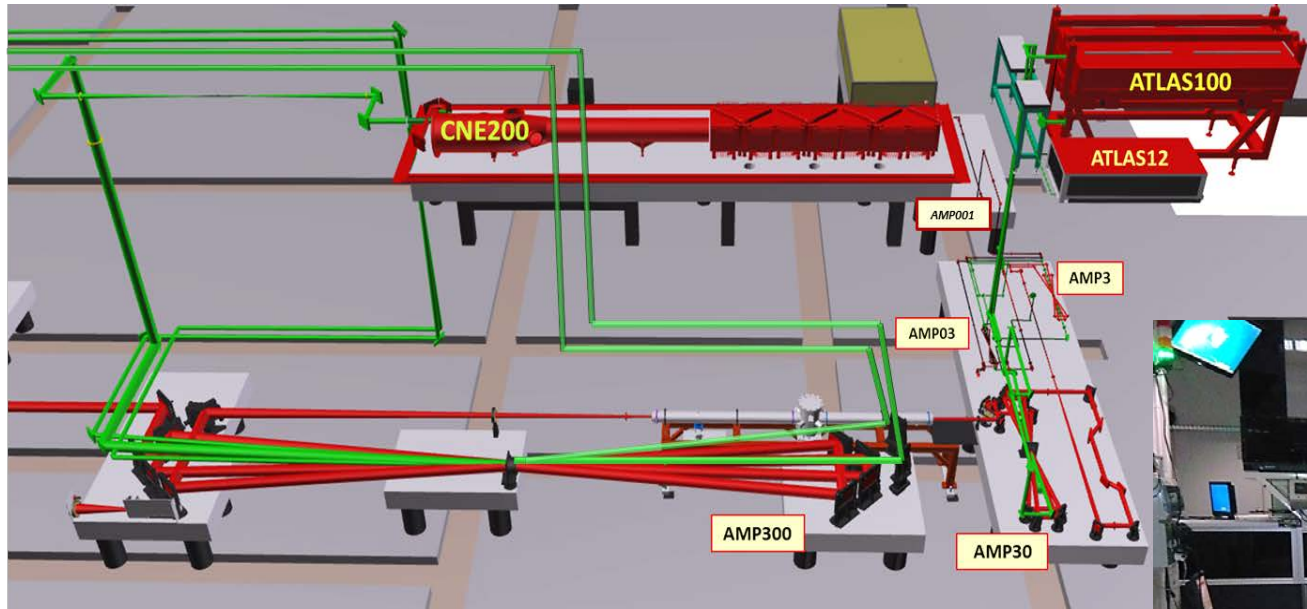
Commissioning of the APOLLON front-end



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

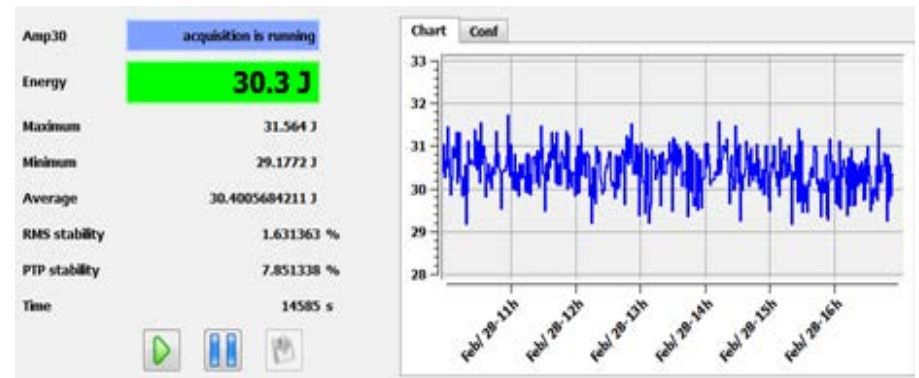
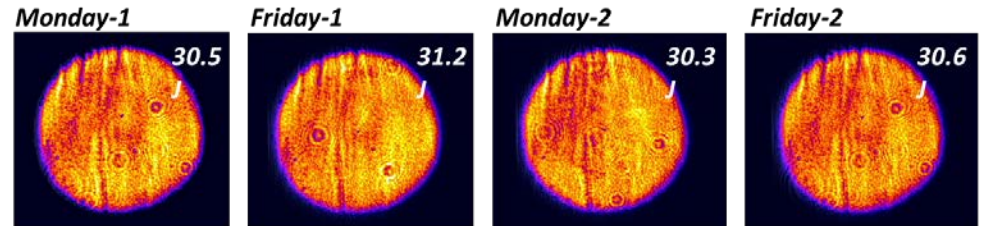
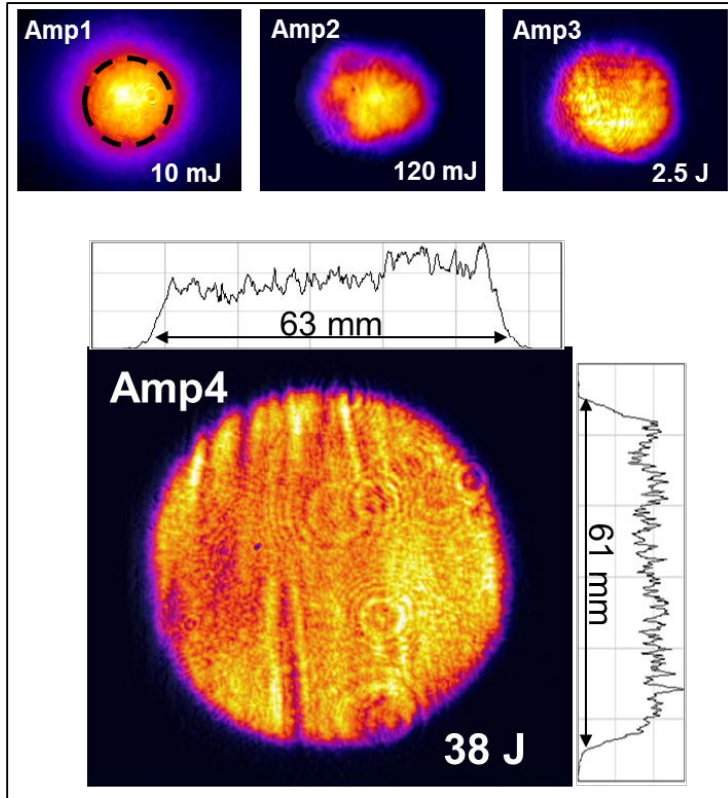


The APOLLON amplification architecture



- 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)

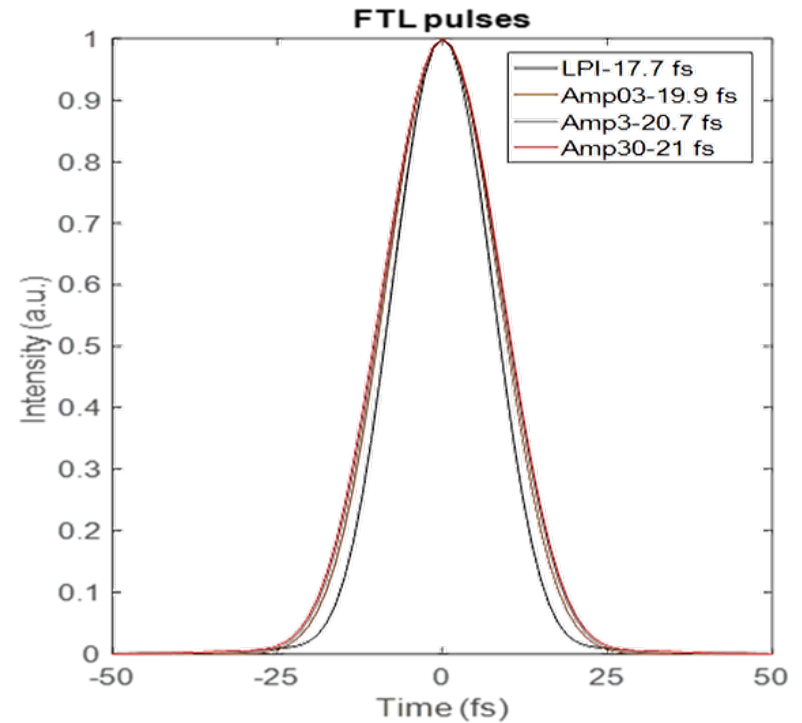
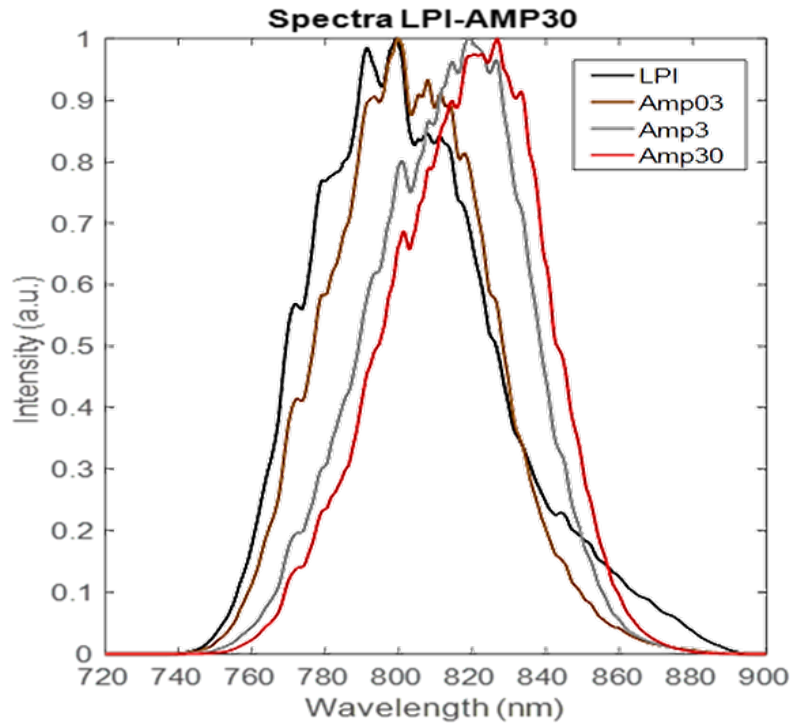
Commissioning of the APOLLON AMP30 section



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

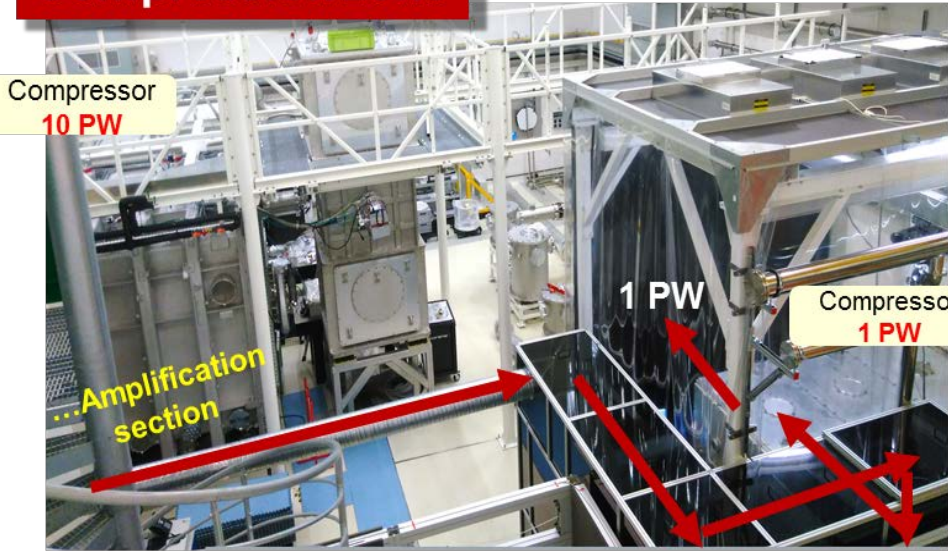


~50 nm at FWHM and ~130 nm at 1% → 21 fs FTL → >1 PW expected
15 fs possible once spectral filtering optimized (2020)

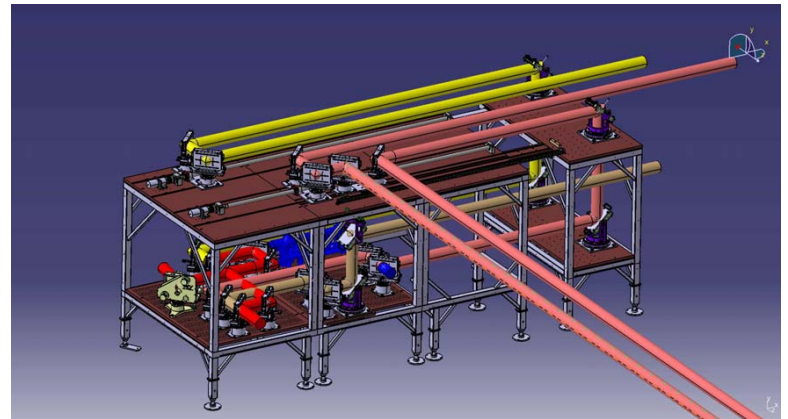
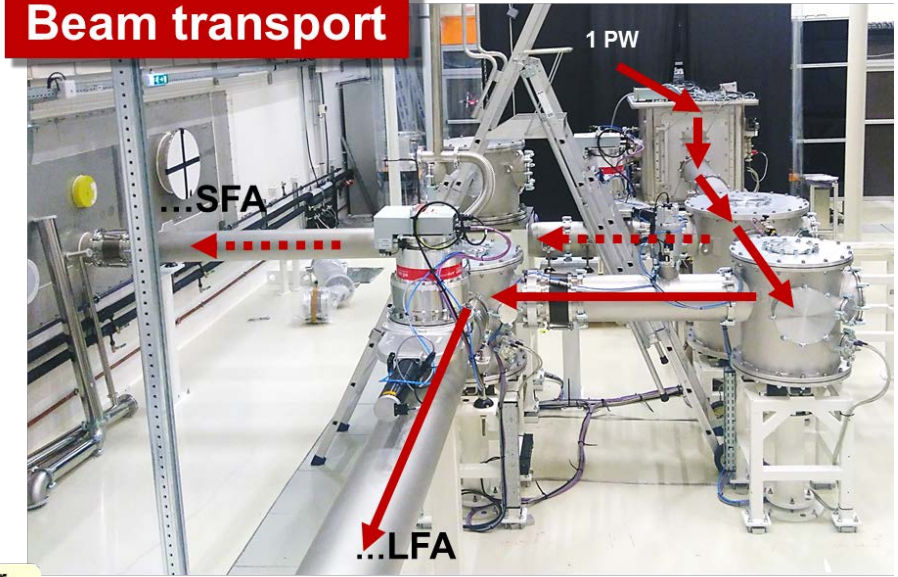
The APOLLON compression zone & beam transport



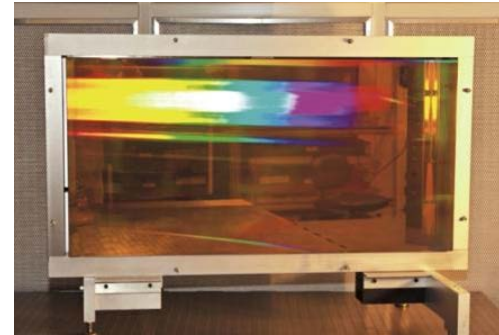
Compression zone



Beam transport

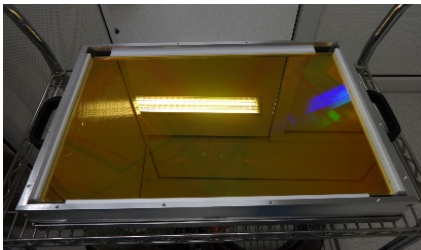


The APOLLON pulse compressors



*6x LLNL Au gratings
910 x 455 mm²
 $\lambda/6$ - $\lambda/8$*

10 PW compressor ($\Phi 400$)



HORIBA JOBIN YVON

gold gratings 530 x 380mm², $\lambda/33$

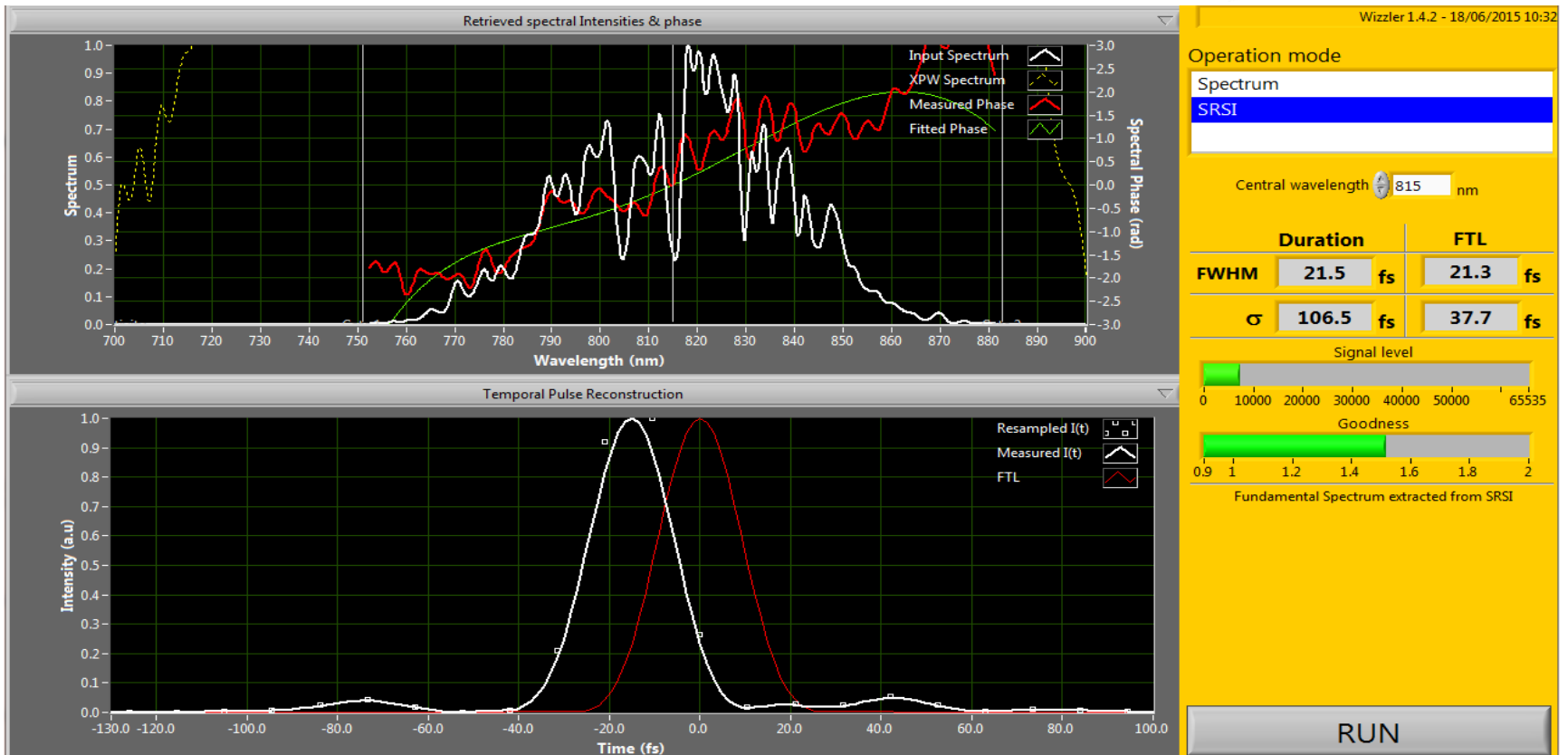
1 PW compressor ($\Phi 140$)

fully operational

67% full aperture efficiency



APOLLON pulse duration

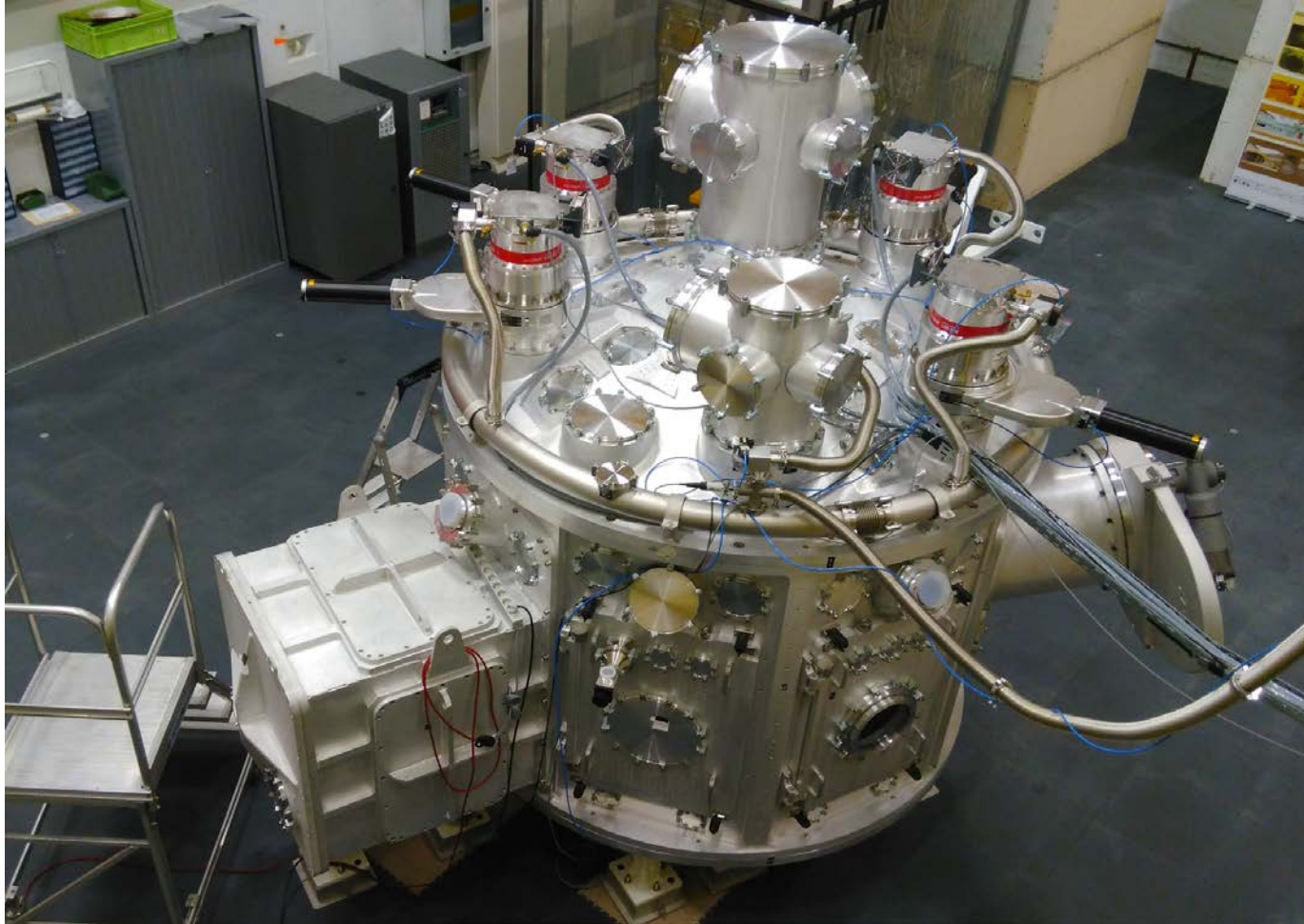


21.5 fs measured (FTL=21.3 fs) for an energy of 22.6 J (AMP30)

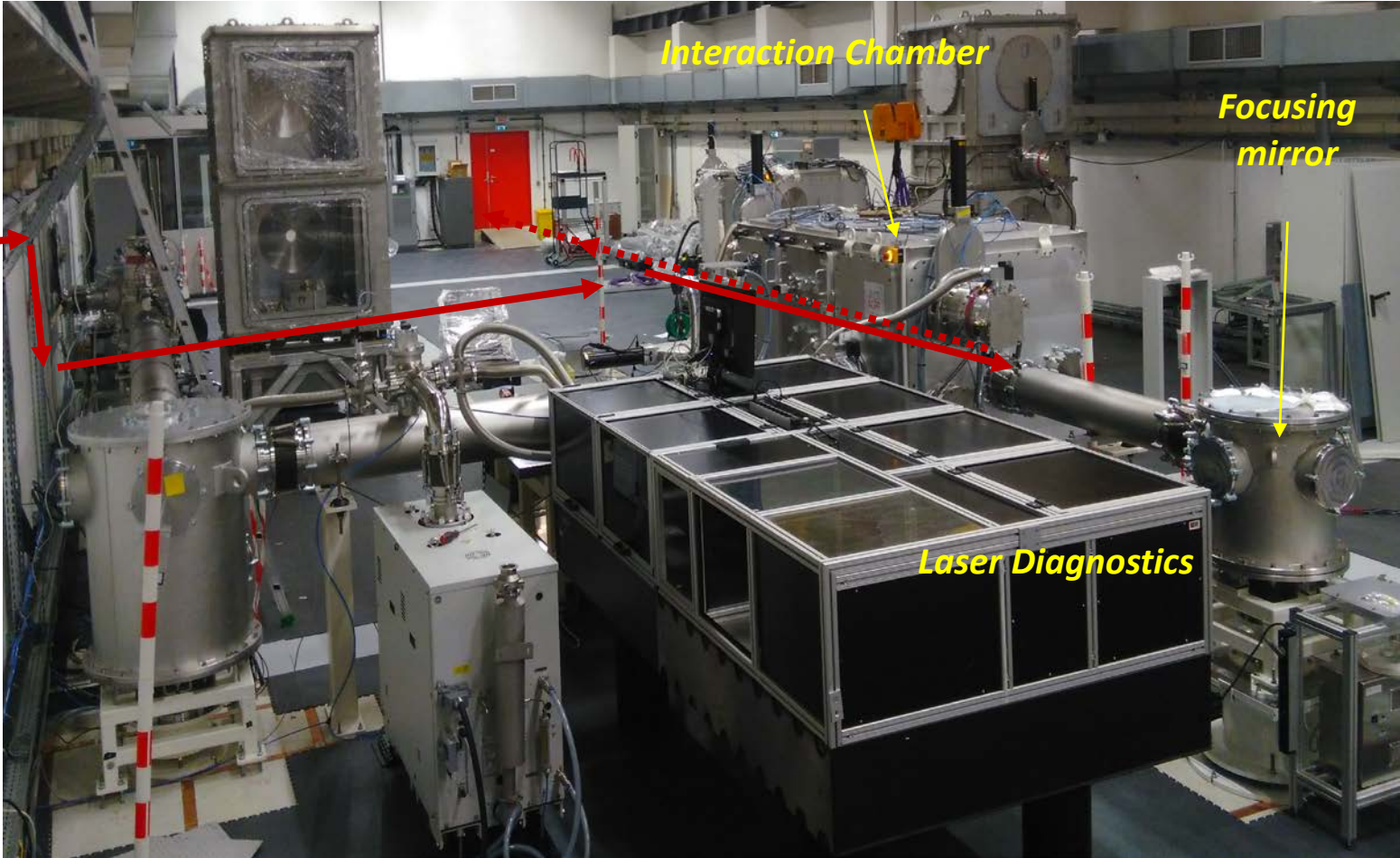
over more than 1 hour of shots: $\Delta t = 21.7 \pm 0.6$ fs for $E = 36.1 \pm 1.2$ J

=> 1 PW on "target"

The APOLLON Short Focal Area



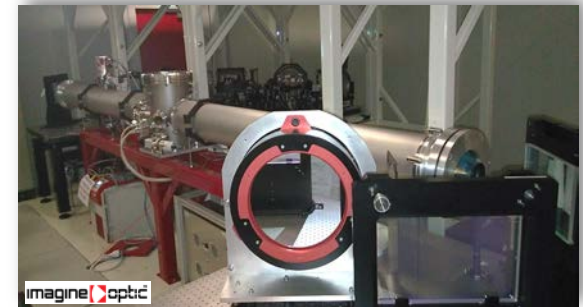
The APOLLON Long Focal Area



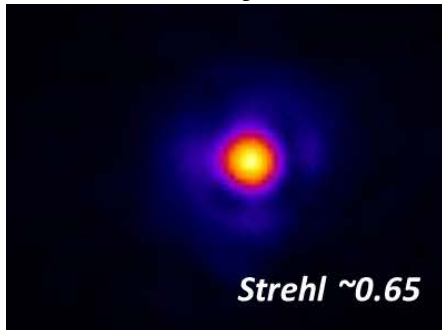
The APOLLON performances on LFA TCC



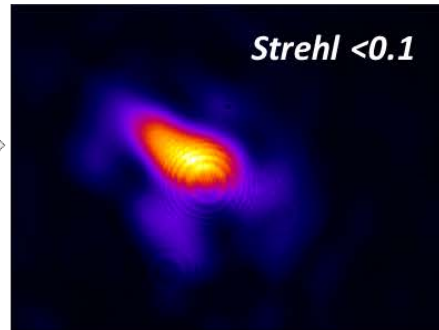
- single AO loop installed in the amplification zone, before compression, ~60 m away from the target, using an **ILAO STAR** deformable mirror
- satisfactory correction efficiency: $\sim\lambda/10$ rms residual error / **Strehl > 50%**



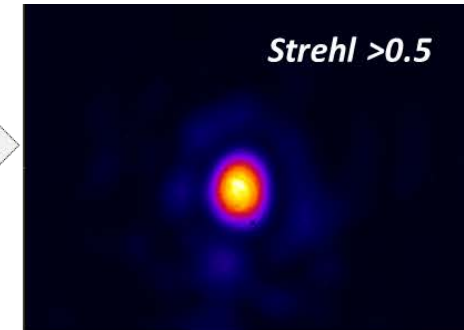
at the exit of AMP30



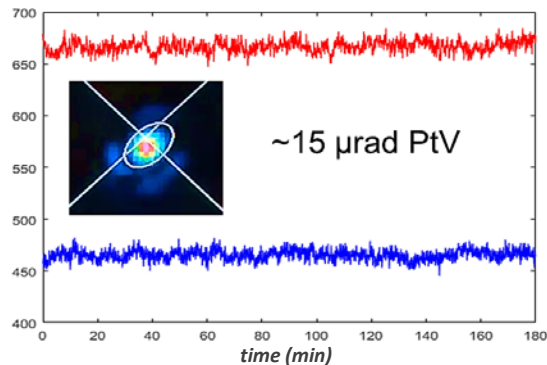
in LFA before correction



in LFA after correction



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



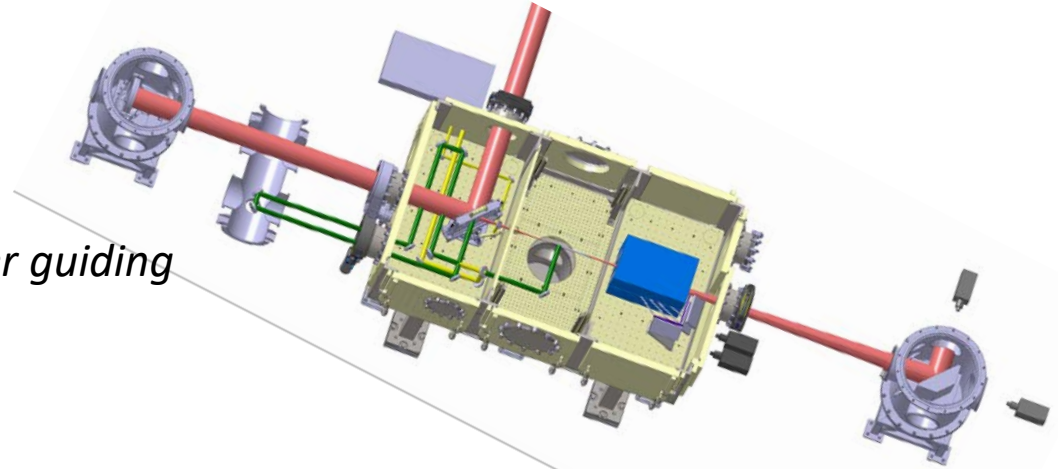
- **good stability:** practically no pointing drift over ~ 3 hours, ~ 1 focal spot PtV shot-to-shot instability

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



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

- “bubble” regime
- gas: $\text{He}+1\%\text{N}_2$
- nozzle: $10\times 0.3\text{ mm}^2$
- stable acceleration without laser guiding
- peak e energy: $\sim 2.7\text{ GeV}$

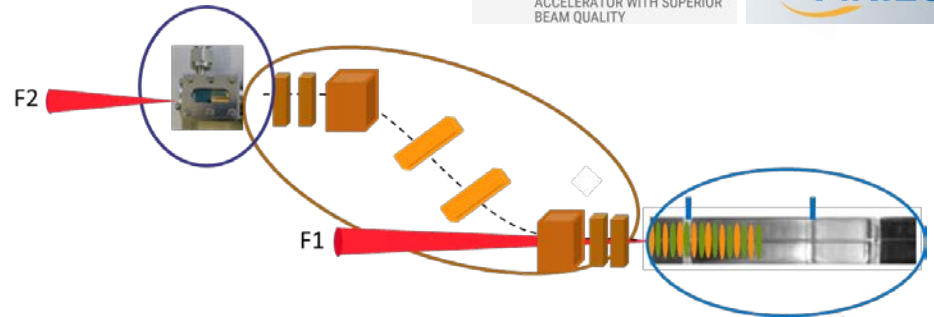


❖ 2-stage electron acceleration (PI: B. Cros LPGP)

context: development of future high-energy physics accelerators

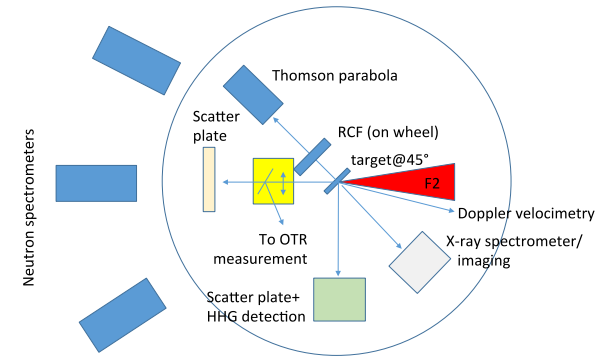
1st step: prepare the seeding source

- dedicated gas cell (ELISA)
- gas: $\text{H}_2+1\%\text{N}_2$
- high charge (nC) @ 450 MeV



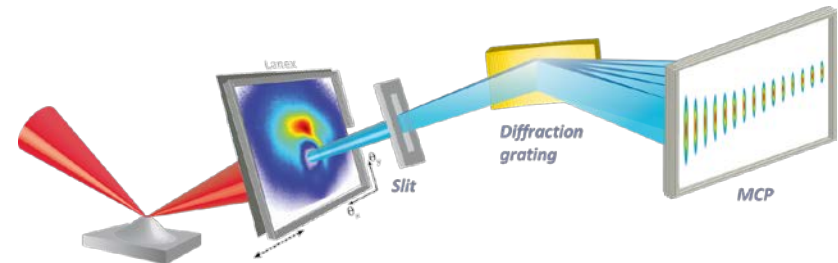
❖ proton acceleration (PI: J. Fuchs LULI)

- *thin (5nm) to thick (μm) solid targets*
- *peak p energy: ~ 20 MeV*



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

- *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}**
- ❖ **1st PW commissioning experiments this autumn**
- ❖ **1st call of proposals to be launched end of the year**
- ❖ **MPW operation in 2020**

Thanks for your attention

