The Apollon laser: performances and diagnostics overview

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GDR Appel: 14/10/2020

Outline

- Apollon laser diagnostics overview
- Qualification diagnostics in the experimental areas in more detail
- Laser performances
- Your questions… some of them
- Conclusions

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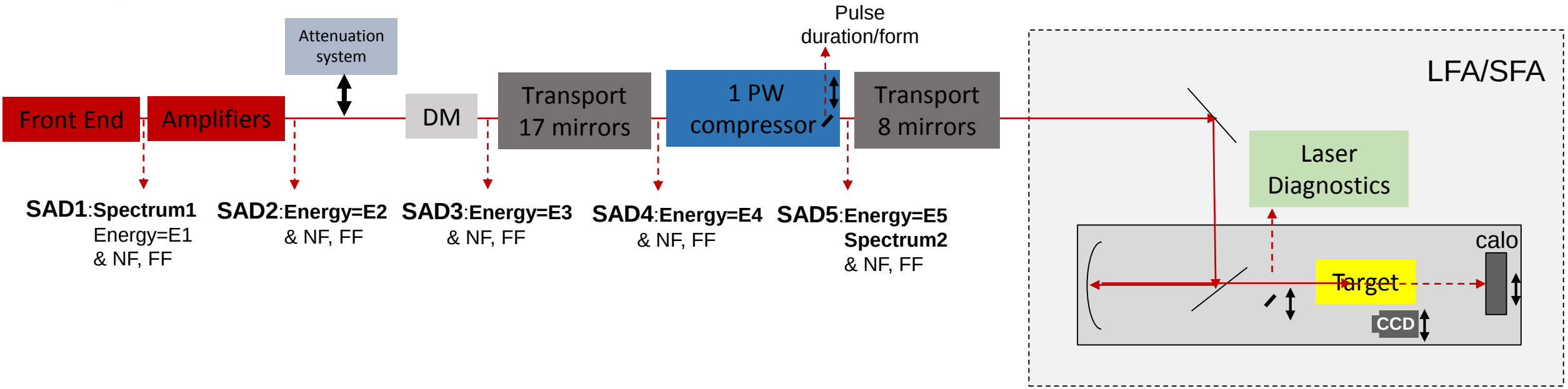
Overview of laser diagnostics

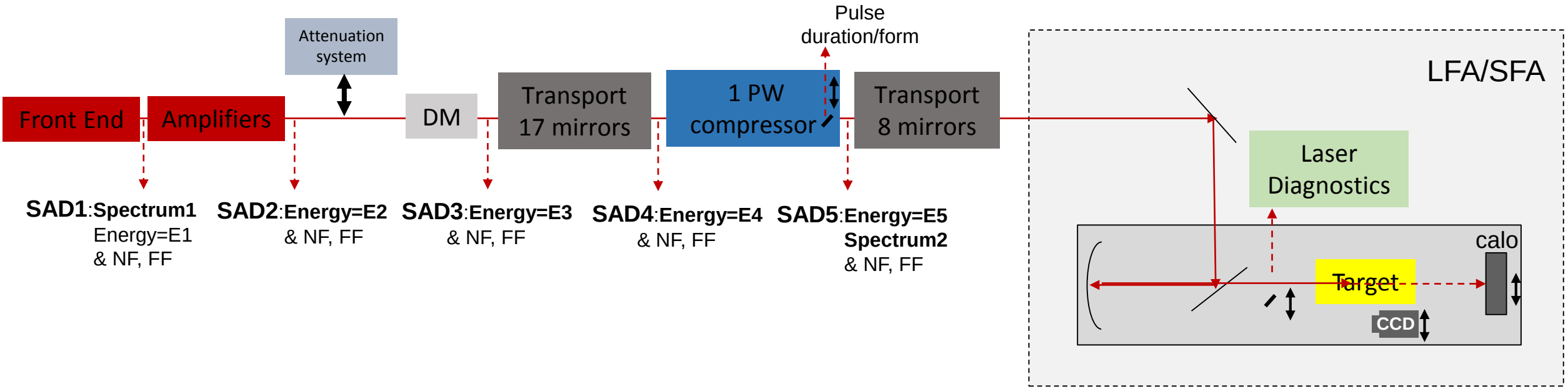


- **The SADs**: Distributed diagnostics in the laser chain to monitor/save the key laser parameters “on-the-shot” during the operation of the laser and the experiments

- **Experimental area laser diagnostics**: Insertable low aberration attenuation + Insertable beam sampling in vacuum ➔ **Laser qualification diagnostics**: All the laser parameters are precisely measured (temporal / spectral / spatial domains)

- **On demand direct vacuum diagnostics**: Prosilica CCD (focal spot), QE110 (divergent beam after focus)

Overview of laser diagnostics: Energy measurements



E2 is the reference energy: continuous and calibrated measurement behind a leakage mirror:

- Real energy measured with a QE150 gentec (ELFIE loan) at the output of the amplifiers (~30 Joules)
- Leakage measured behind a specified large bandwidth MLD (>180 nm) with a QE12 (~3mJ)

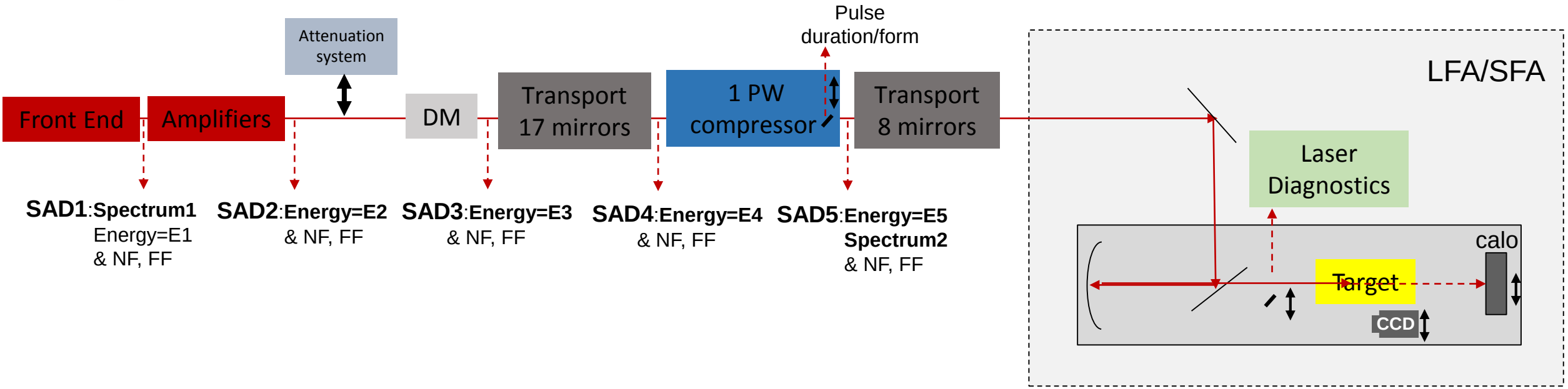
E3-5 calibrated intermediate measurements based on the energy transmission of the chain:

- Used as intermediate reference points of the status of the transport system (damage, degradation…)

E6 direct full energy shot measurement in vacuum:

- Qualification (on demand) Full aperture/Full energy measurement in vacuum QE110 ➔Realized: Target: **~5.4 Joules ⇔ T~42%**

Overview of laser diagnostics: Focal spot

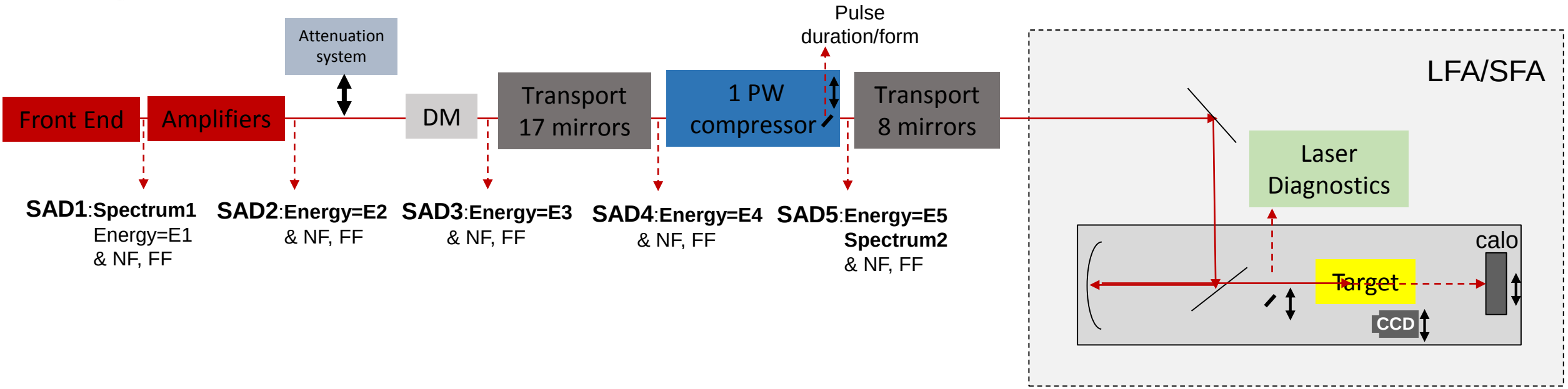


- The “on-the-target” focal spot characterization is **not available/possible on the shot**
- The intermediate FF acquisitions are used: 1) for the alignment 2) the optimization procedure 3) reference of day to day operation
- **Focal spot qualification:**

  1) On the qualification end chain diagnostics: Insertable high quality optics➔ Basler-acA1300 (12 bit) (x10 mag)

  2) Qualification in vacuum: a) LFA: On demand operation ➔ Insertion of a wedge ➔ Acquisition with a Prosilica GT1290 (14 bit) with or without objective (x5, x10, x20) b) SFA insertable Prosilica GT1290 + Objective (x20)

Overview of laser diagnostics: Pulse duration



- The pulse duration is measured either **directly at the output** of the compressor (4mm sub-aperture) or on the **qualification end chain diagnostics** (full aperture): single shot autocorrelator, Wizzler

- **Measurement in LFA/SFA:**
  - **Full aperture** measurement can be realized in air through about **1.5 cm total thickness material** (GDD ~1400 fs^2) for LFA and **0.5 cm total thickness material** (GDD ~200 fs^2) for SFA at 10 Hz and 30 J (1/min) (+attenuation in LAM)
  - The pulse duration is first optimized on the diagnostics and then the **Dazzler is adjusted for optimal compression on the target** based on the **estimated spectral phase** on the inserted material (GDD, TOD, FOD correction)

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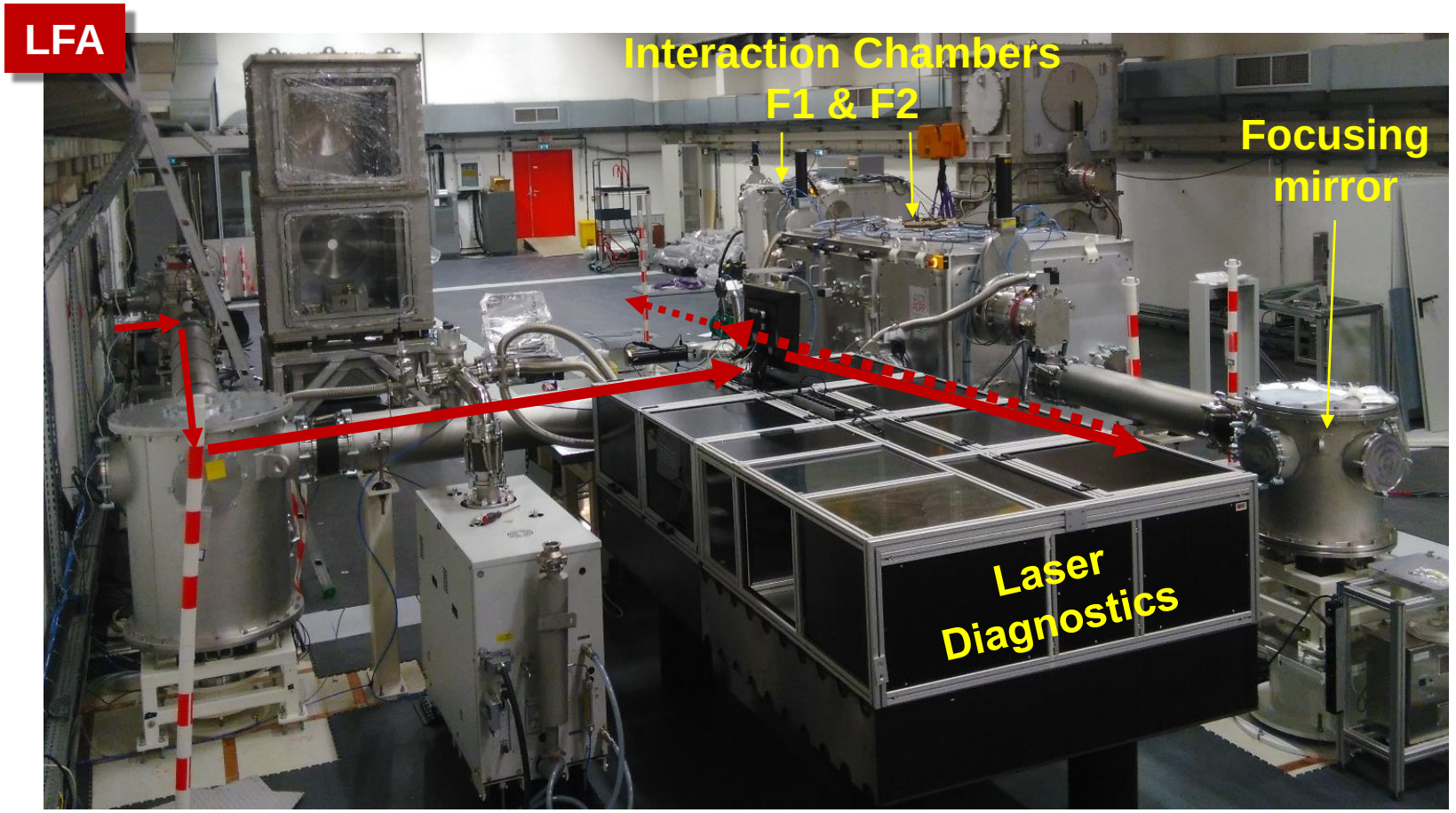
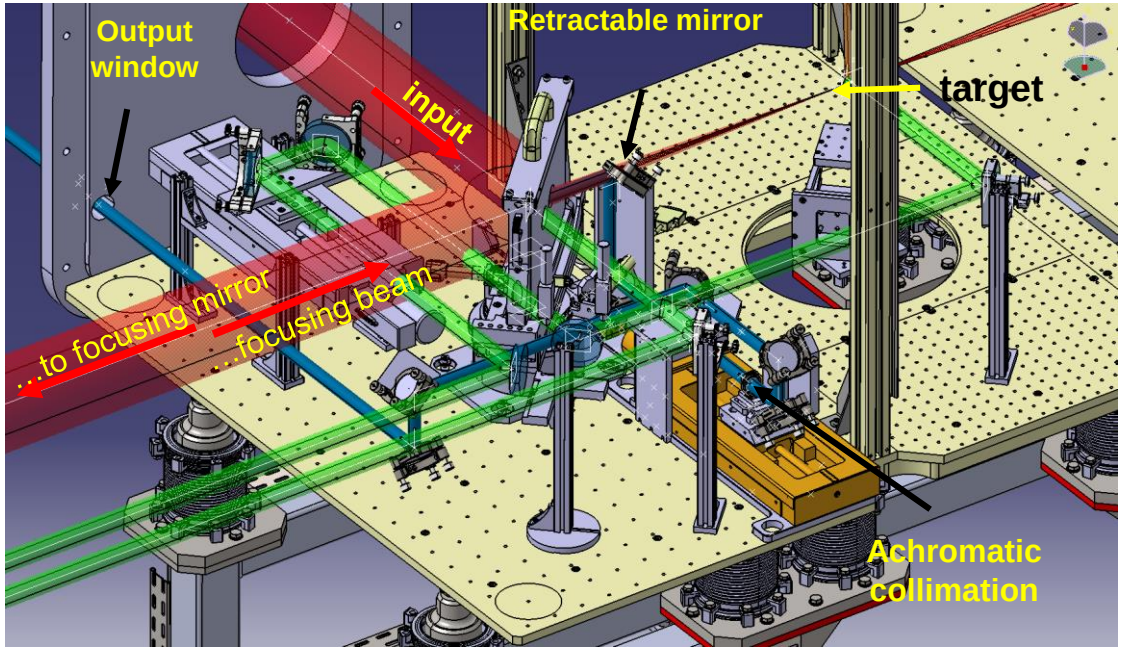
Laser diagnostics in LFA: fully operational (2019)

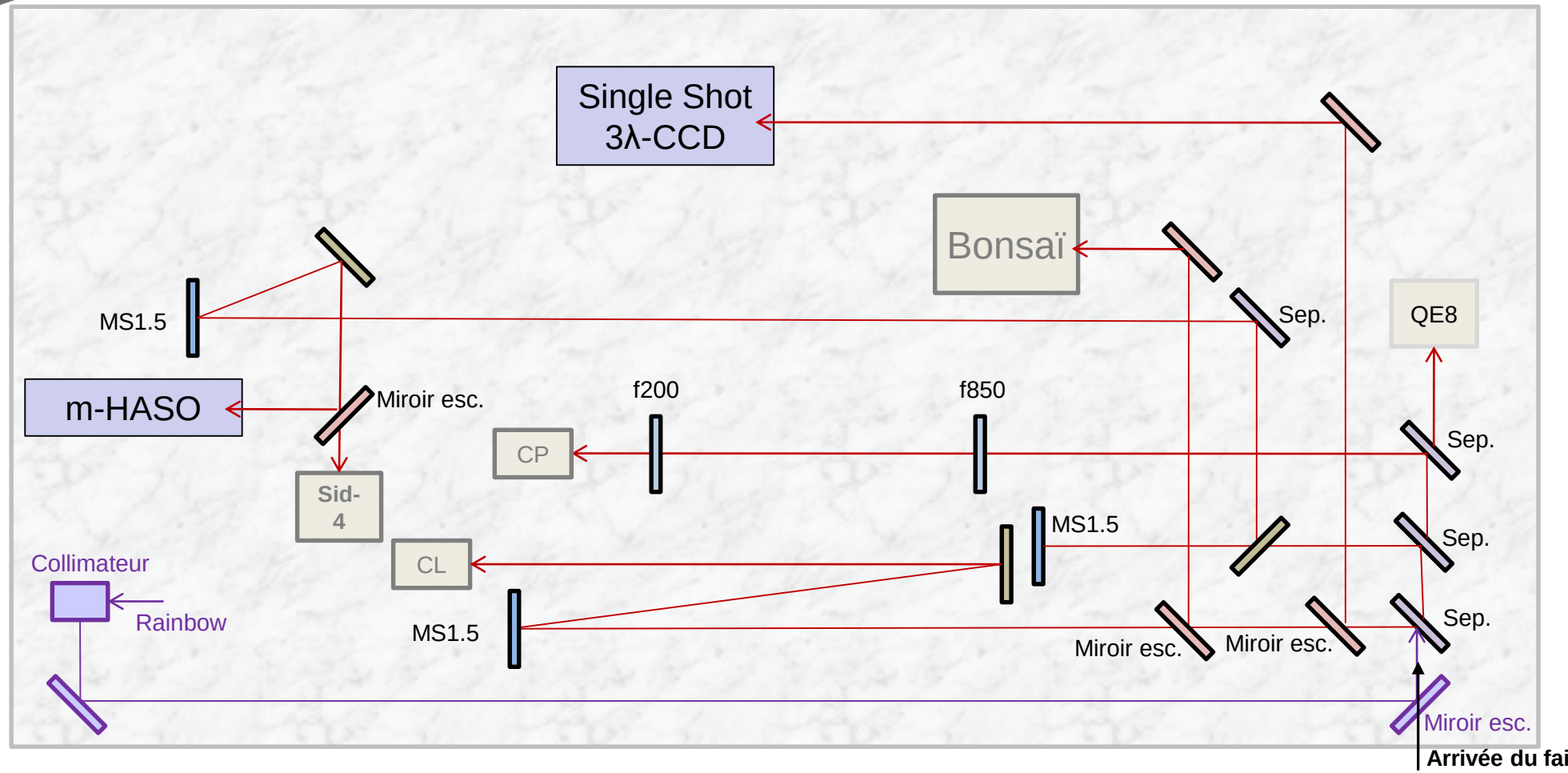


Laser diagnostics in LFA



- **Reliable characterization/**optimization of the laser **close to the target**
- Use of the **LFA focusing system as part of the diagnostics imaging system**
- **Low aberration** (PtV<λ/6), **high attenuation** (~10^{-5}) ➔ Focal spot measurements at “full” energy

Laser diagnostics in LFA: acquisitions table



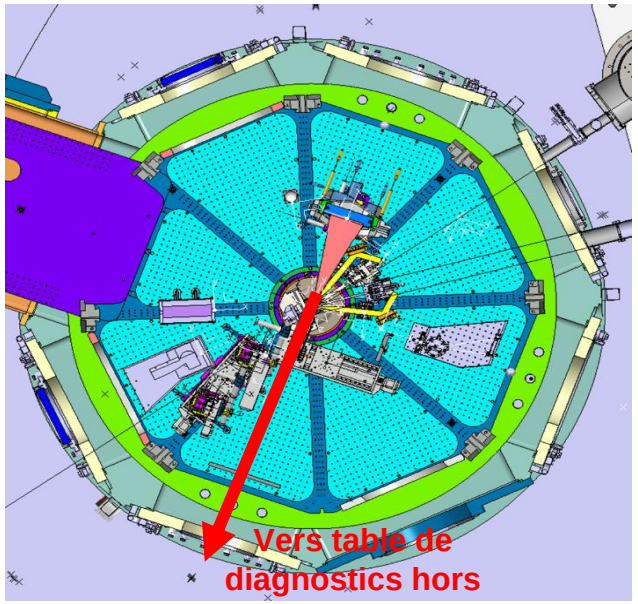
Diagnostics: **Spatial aspects**: (Near & Far field), Spot evolution through focus, Wavefront (SID4)

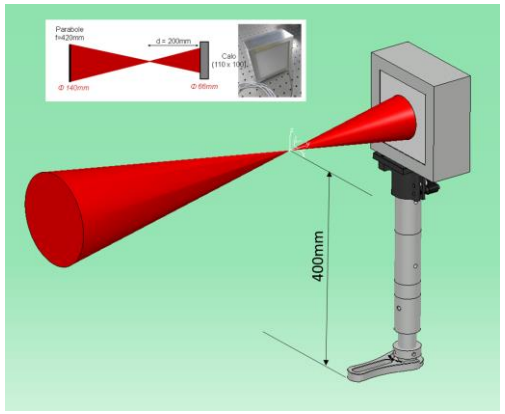
Temporal aspects: Duration (Bonsai), spectral phase (wizzler)

Spatiotemporal aspects: few shot diagnostics (m-HASO, IO), Single shot (3λ-CDD)

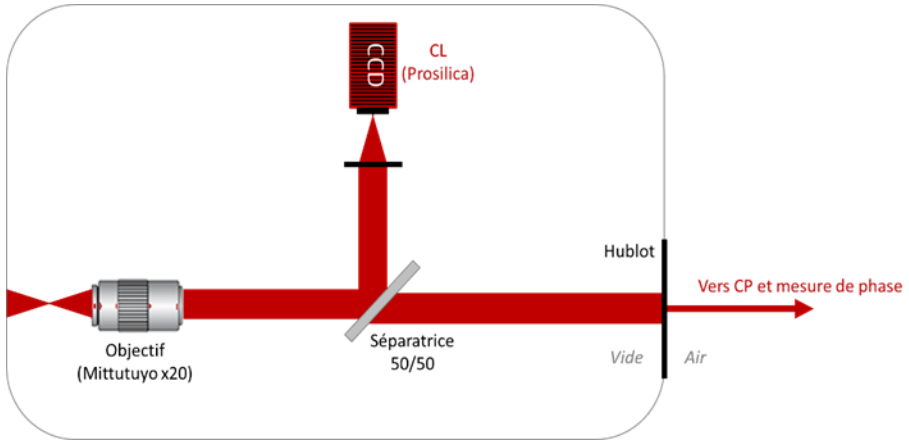
Laser diagnostics in SFA: qualification phase only

- **Same approach as in LFA** (end of conceptual phase): Insertable collimation after focusing parabola➔ Diags in vacuum and in air (Ready in January 2021)
- **Energy qualification**: direct measurement of the full energy after focus
- **Spatial parameters**: FF in vacuum (insertable, 2 versions), NF, WE in air
- **Temporal parameters**: Low dispersion full aperture collimation, High energy (>1mJ)) ➔ Duration, Spectral phase, Contrast
- **Space-time**: m-HASO (static), polarization P(λ), other techniques (with F. Quere)

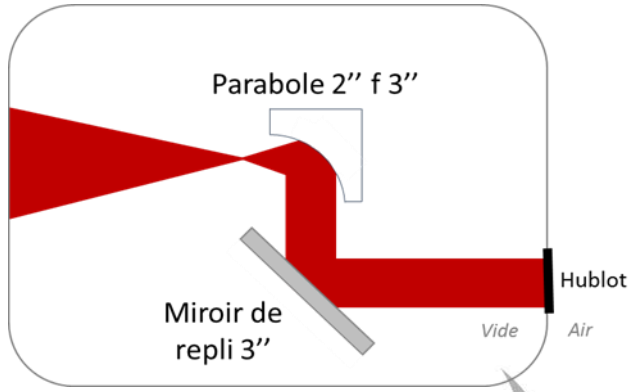




QE110 energy in vacuum



Focal spot in vacuum / NF&WE in air



Reflective collimation low dispersion temporal characterization

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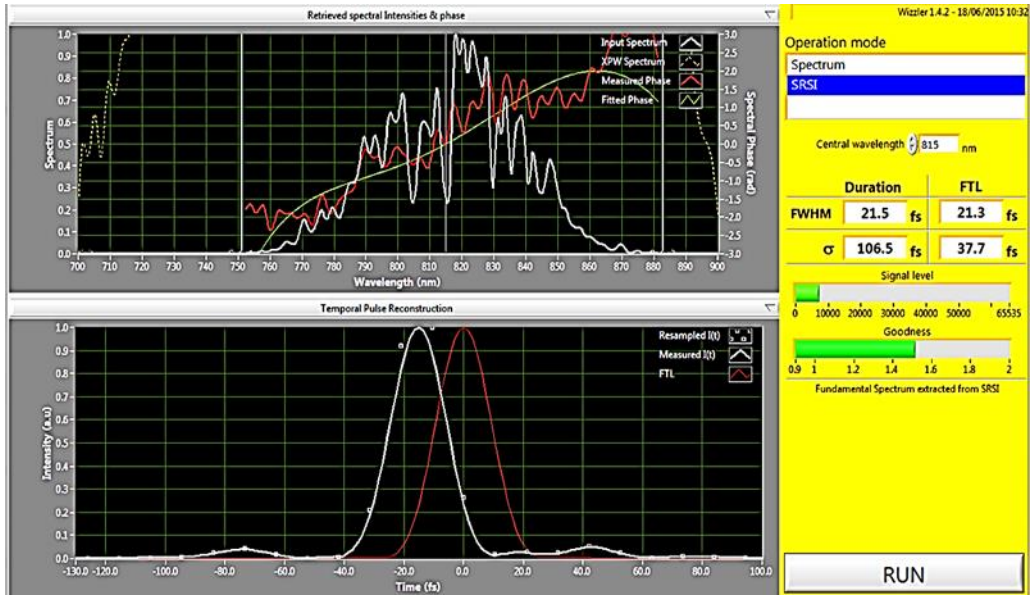
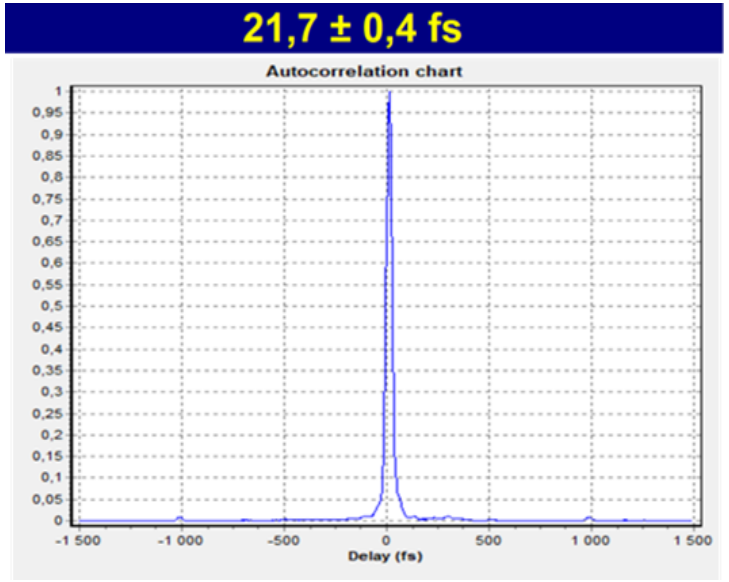
Laser performances: Pulse duration

- Full aperture compression in the 1PW compressor



Single shot autocorrelation



Best obtained measurements at the output of the compressor:

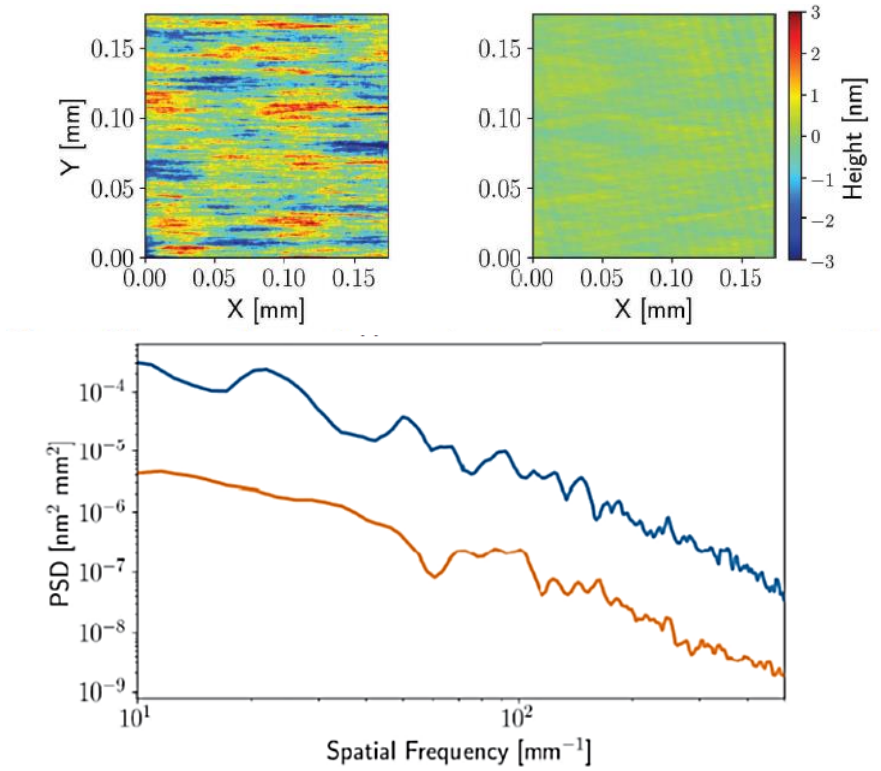
- Wizzler/Dazzler manual optimization (b2-b4) ➔ **21.5 fs** / **21.3 fs FTL** (At >35 Joules shot). For more than 1 hour of shots: **Δt=21.7±0.6 fs**

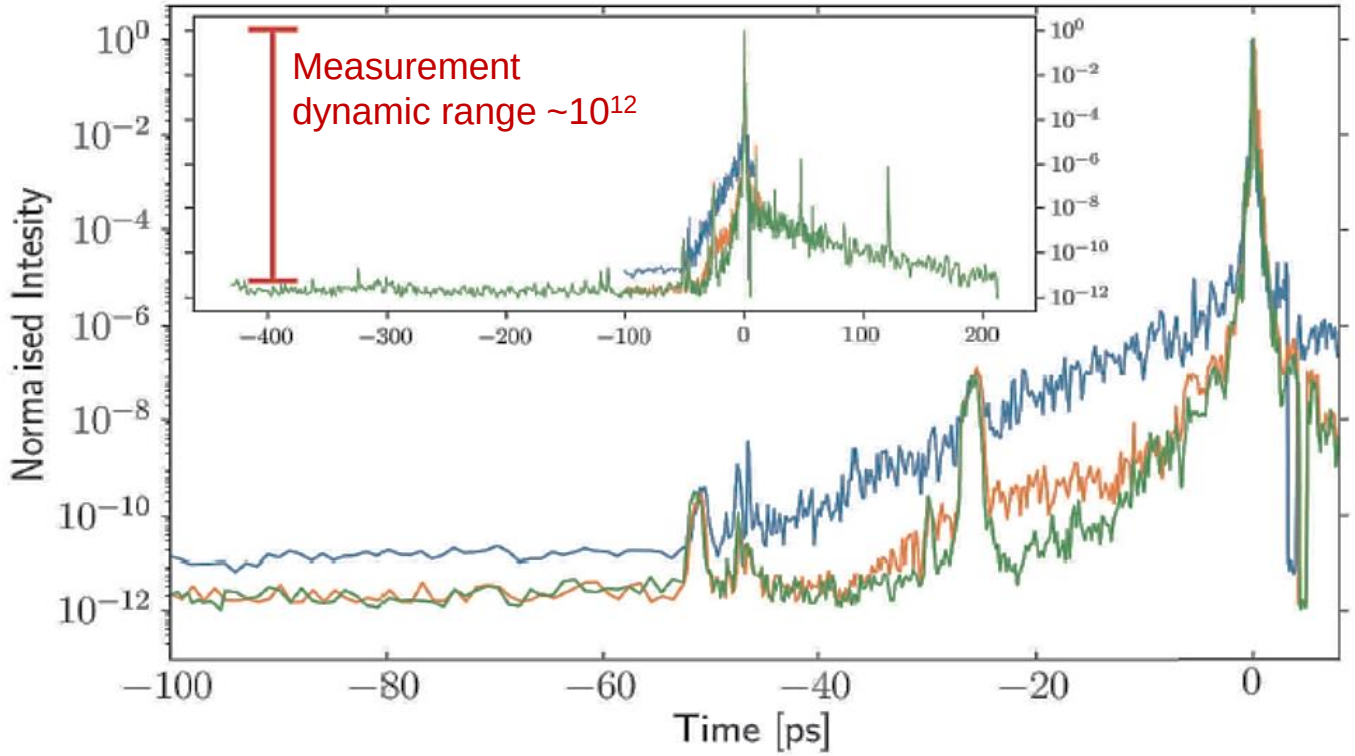
The pulse duration is directly related to the status of the Front End and the obtained injection spectrum:

- Current performances **24-25 fs at LFA** always **<1.05xFTL**➔ The spectrum is an excellent indication of the duration
- Optimization for 1st SFA experiments is scheduled to reach again **~22 fs in January 2021**.

Laser performances: Pulse contrast

- Upgrade of the Offner Stretcher: **New convex mirror**



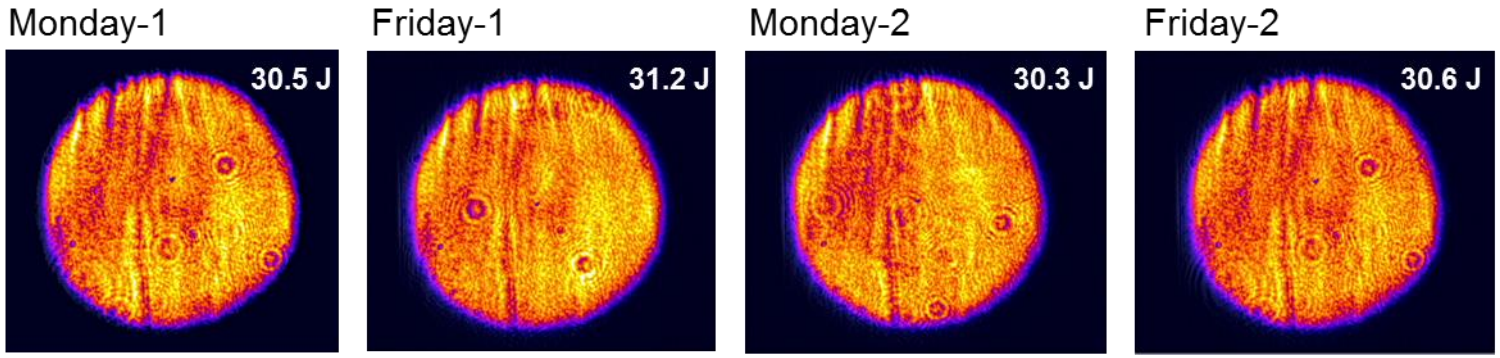


- Measurements realized after the 1st TiSa amplifier (10mJ/10 Hz)
- **ASE<10^{-12}** (dynamic range limited) / Picosecond pedestal **2-3 orders of magnitude improvement** / Some pre-pulses (under investigation/probably not fully axial non-linearly coupled post-pulses)

*Lucas Ranc et al "Improvement in the temporal contrast in the tens of ps range of the multi-PW Apollon laser front-end," Opt. Lett. **45**, (2020)*

Laser performances: Energy/Energy stability

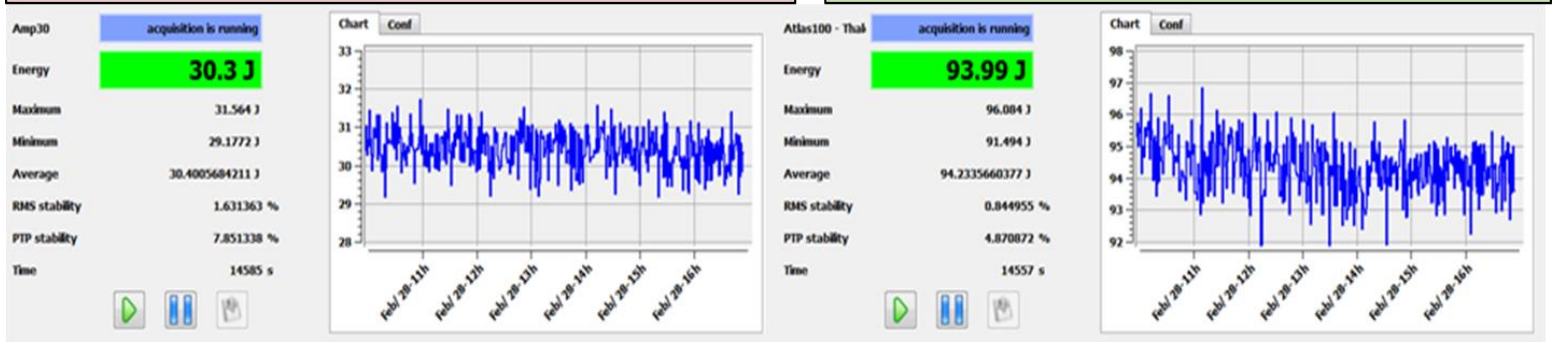
➢ Reliability tests in LAM (2019): Over two weeks / 6-7 hours/day => **>4000 shots**



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

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

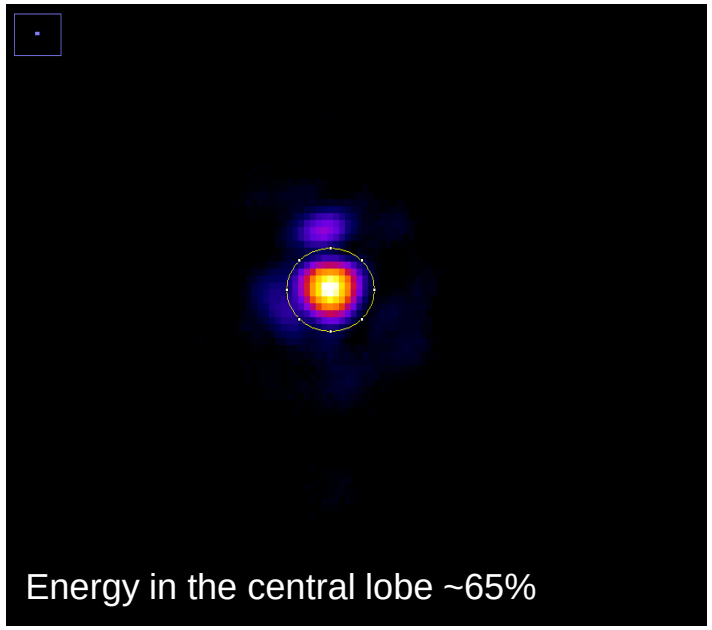
ATLAS100
E_{ave} = **94J** / 0.8% rms / 4.8% PtP

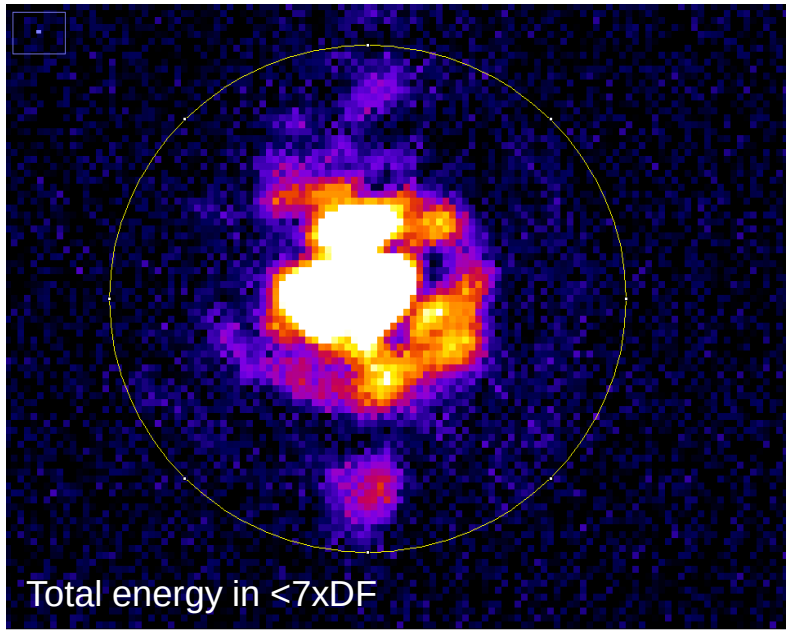


- Reliable and stable operation: **ΔE<8% PtV** depending on the pump source
- **>30 Joules** can be regularly obtained for **~95 Joules** of Pump
- Count for **~42%** and **~50%** transmission efficiency to the target for **LFA** and **SFA** respectively➔ E_{max}=**12.5 J** and **15 J**
- Near field beam modulations are **~2xAverage fluence**➔ Moderate risk of LID at full power➔ Economy of full energy shots is suggested
- LIDT tests realized for most of the components / Operation of the chain at **E_{max}/2** for **~1000 shots** without damage

Laser performances: Focal spot in LFA

- 10 Hz typical performances





- Direct measurement in vacuum (Prosilica GT) after manual optimization of the DM in the amplification zone

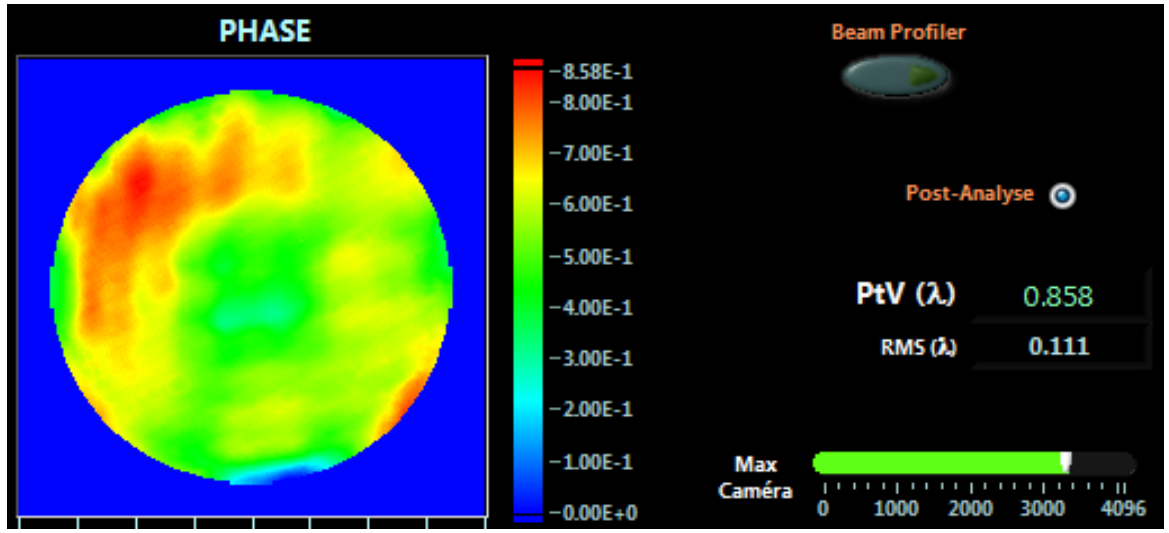
*Energy in the px max= 0.2 J ➔ **Imax=5.7*10^{19} W/cm^2**
*For Ideal beam (SG2/11cm@1/e2) ➔ Imax=9.5*10^{19} W/cm^2
*For real beam (exp. NF) ➔ Imax~9*10^{19} W/cm^2

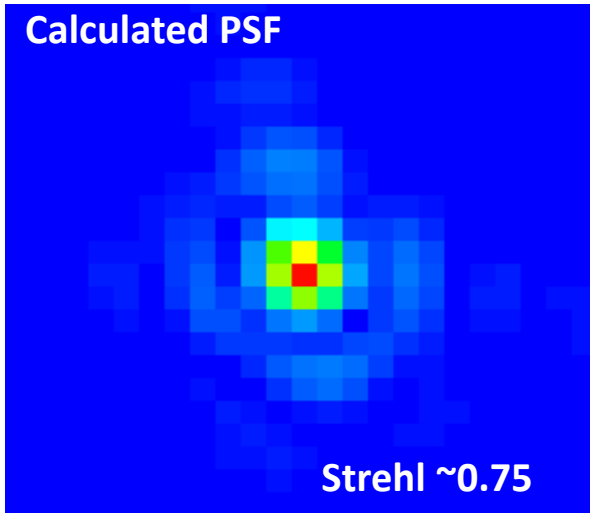
⇒ **Strehl ratio~60-64%**

*(*Calculation assumption: 15 J in the focal spot and 25 fs pulsed duration)*

Focal spot in LFA: 10 Hz typical performances

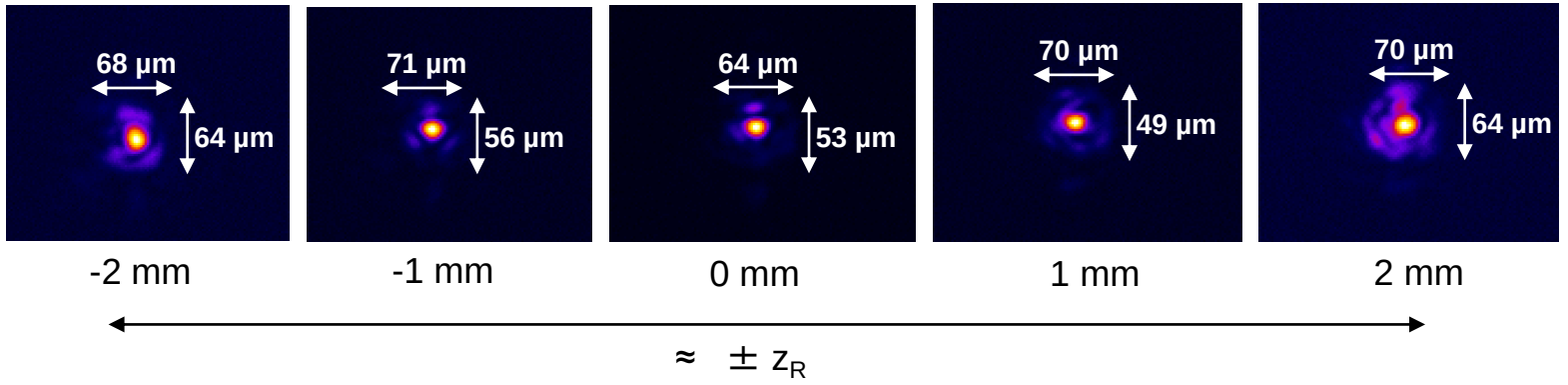
- Wavefront aquititions (SID4/dignostics table)

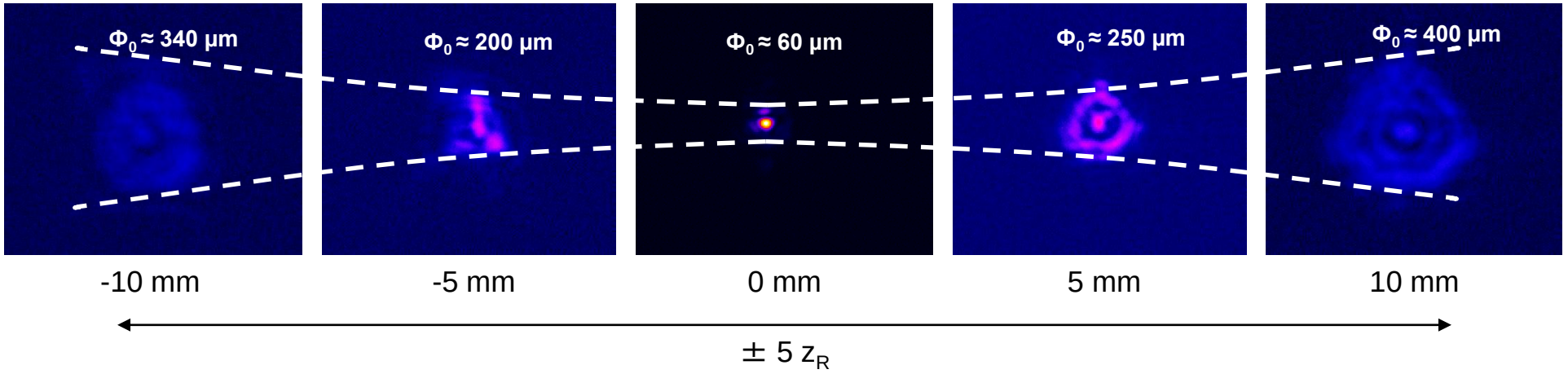




✓ Satisfactory quality for a single DM without closed loop correction: Measured WE **~λ/10 rms** residual error ➔ **Strehl > 70%**

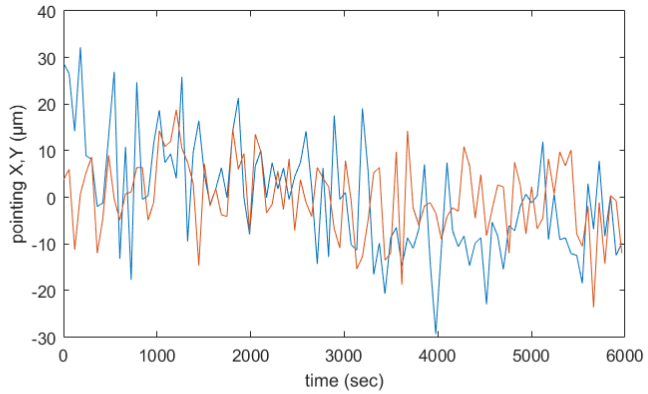
Focal spot in LFA: 10 Hz caustic through focus

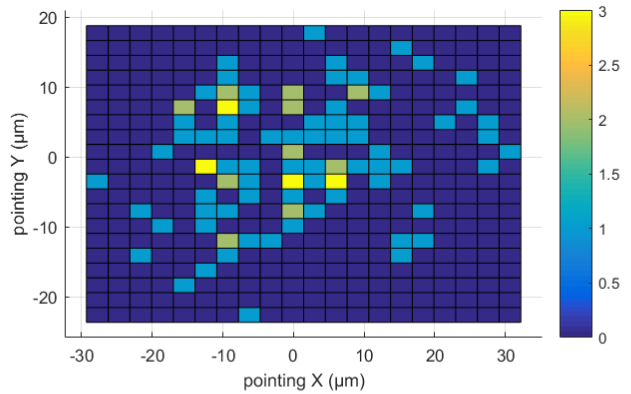


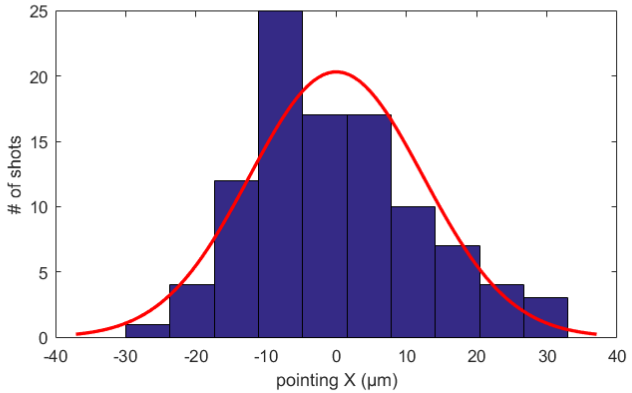


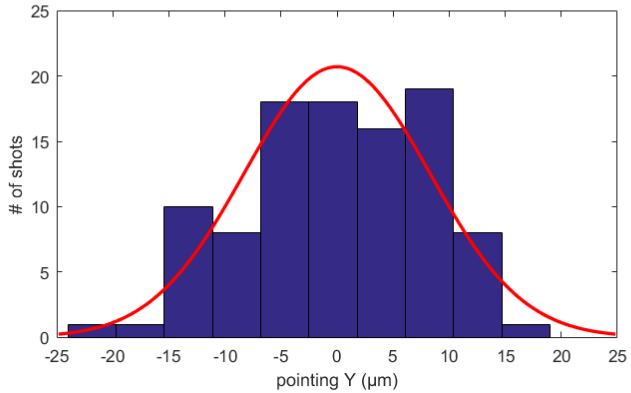
- Acquisitions in vacuum (Prosilica GT) with variable position of the focusing mirror (Δz=20mm)
- Same tests scheduled at 30 Joules for… tomorrow!

Focal spot in LFA: 10 Hz pointing stability



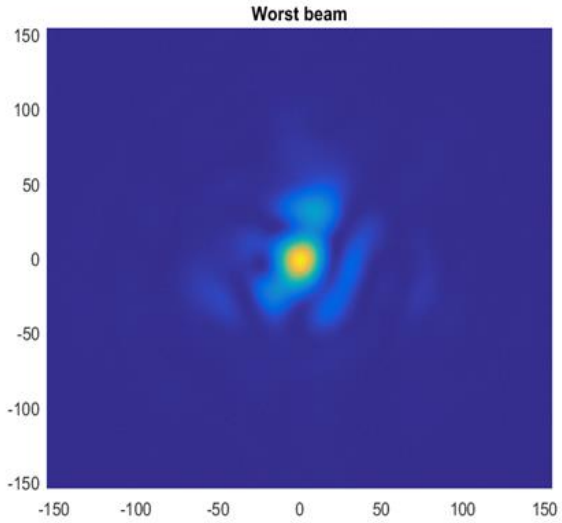


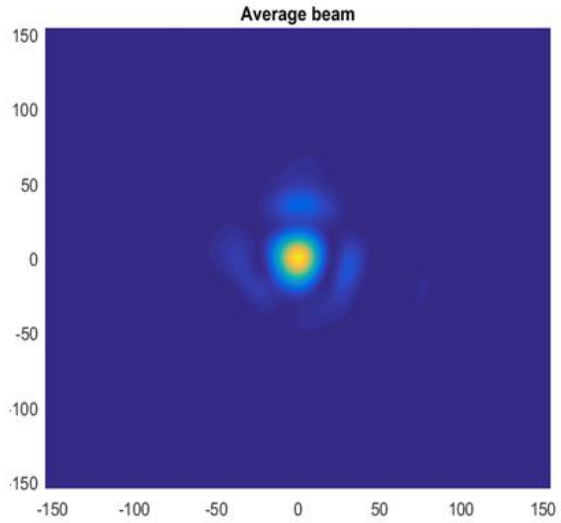


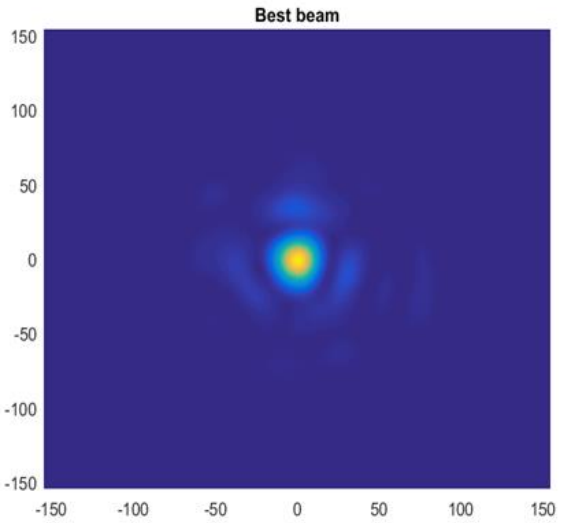


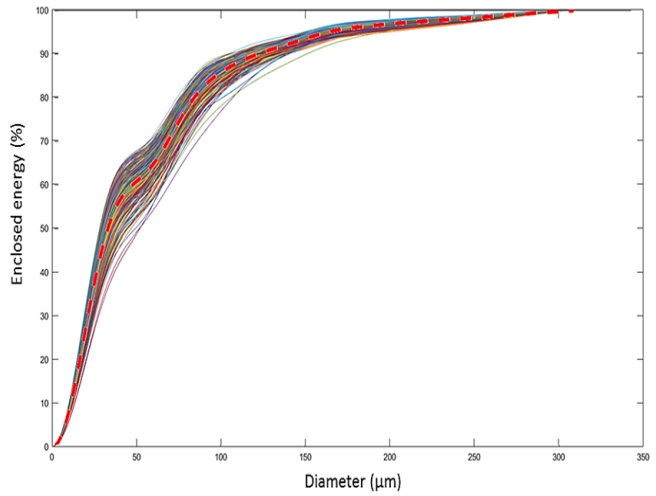
- Operation at 10 Hz but acquisitions 1/min over 100 min of operation
- The FF is « confined » in the first Airy ring (~2-3 µrad rms)
- Same test scheduled at 30 Joules for… tomorrow

Focal spot in LFA: 10 Hz quality stability



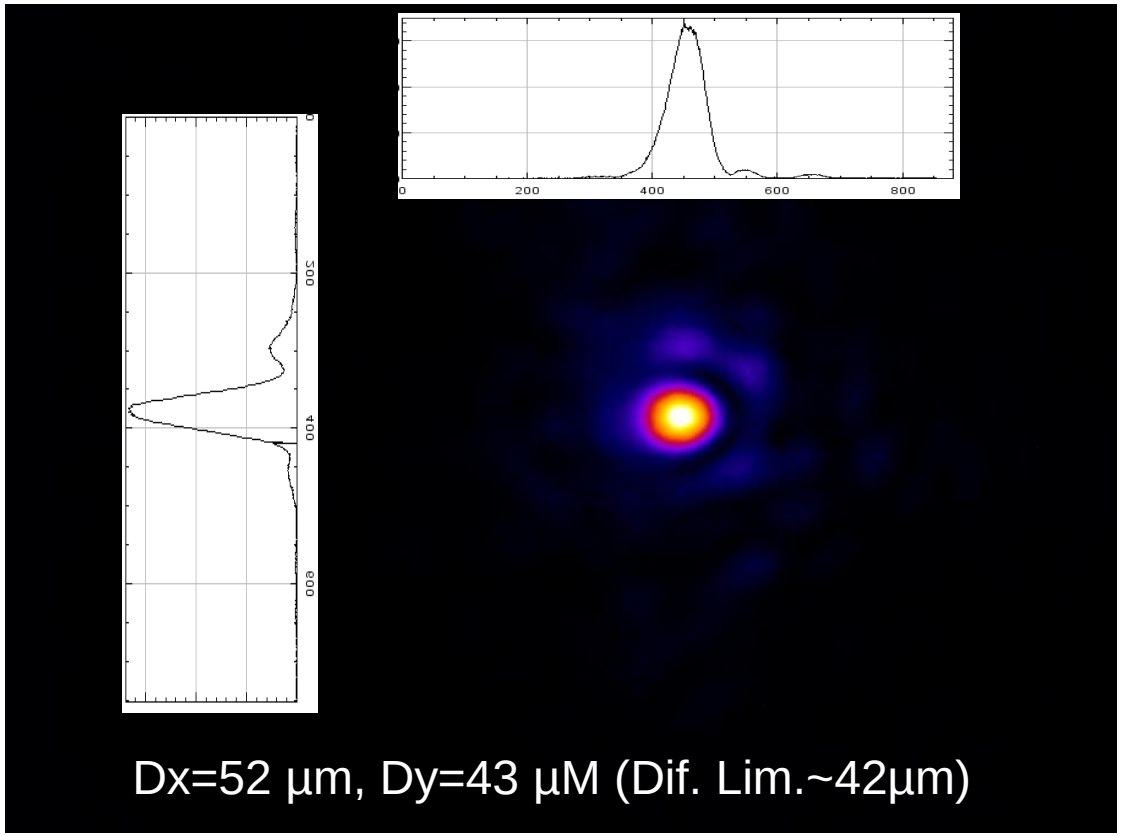


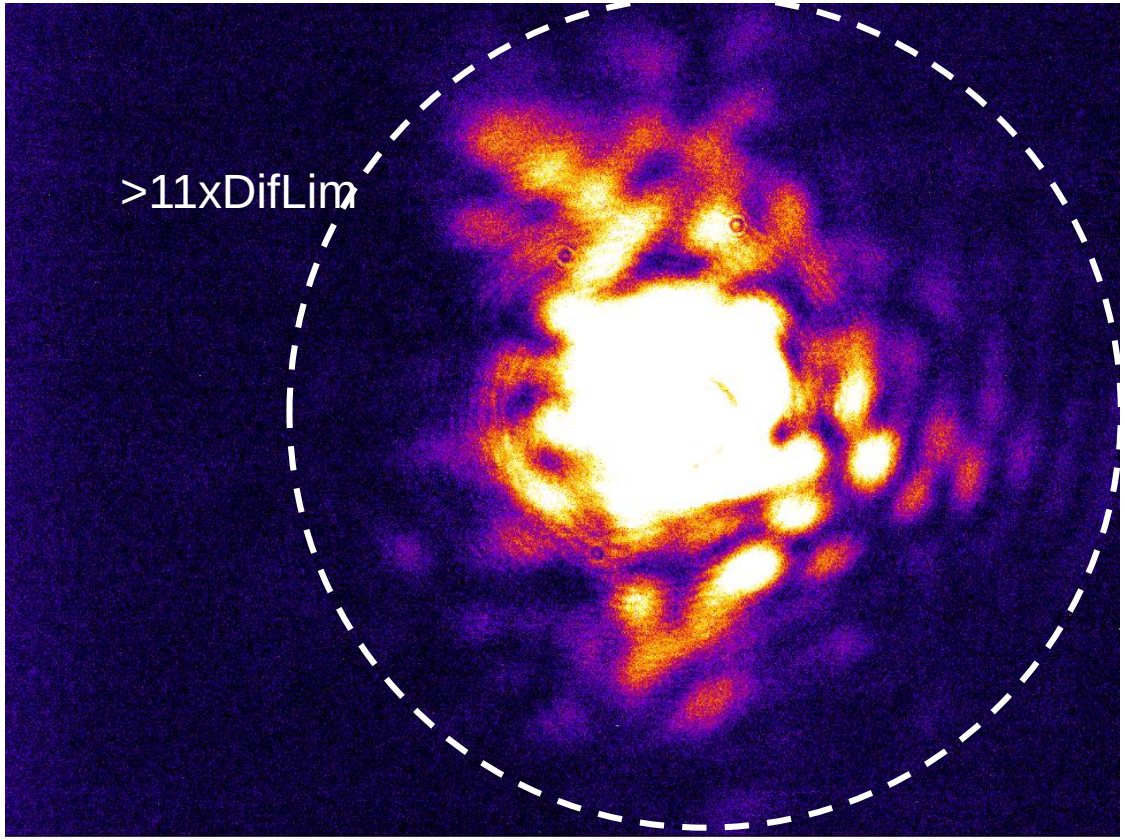




- **Air turbulence** is responsible for shot-to-shot focal spot quality variations: Most of the impact concerns the intermediate spatial frequencies *(compare average and best images)*
- In this 100 shots acquisition (100 min) we observed ~50% variation of the enclosed energy and a **Strehl~0.1 to 0.6**
- Measures have been taken since: covering of the amplification and separation area ➔ Improved behavior (…to quantitatively characterize). Further measures are to be taken (…2021)

Focal spot in LFA: 30 Joule Hz first results (old DM)



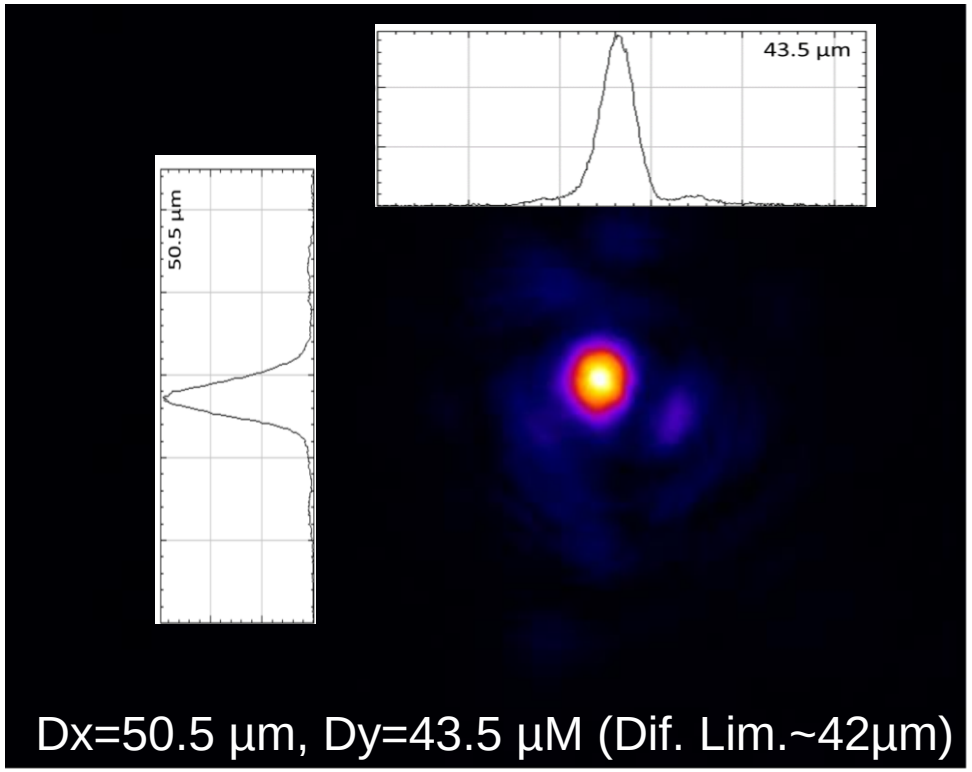


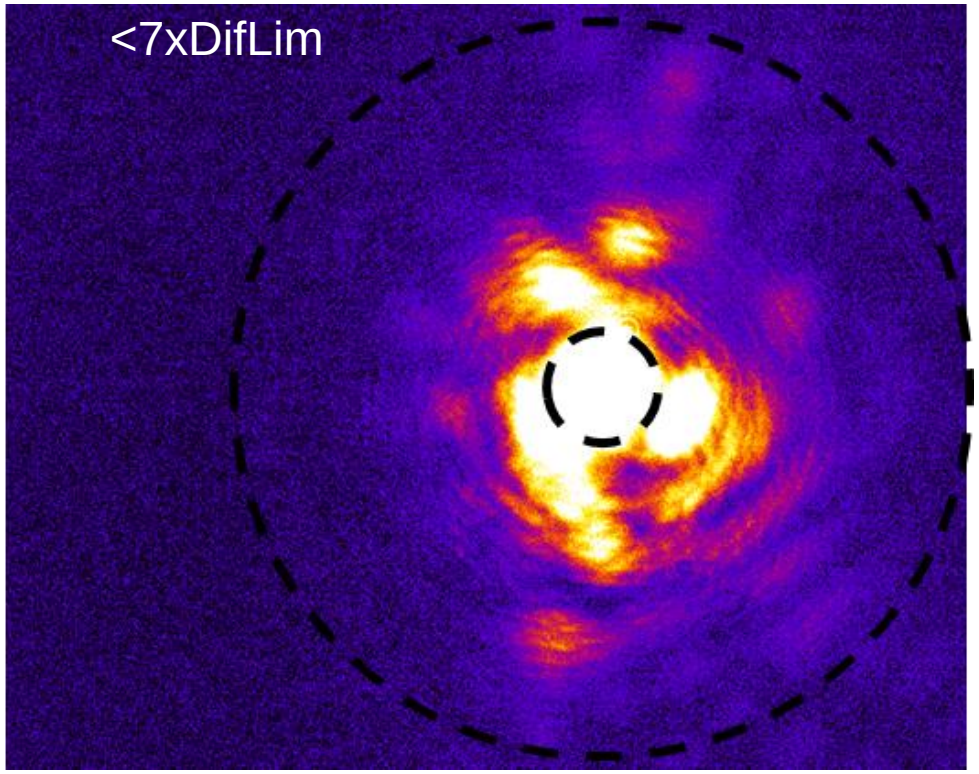
- Measurement on the diagnostics table (Bassler, x10) after manual optimization of the DM at 10 Hz (2019)

Energy in the px max= 0.00234 J ➔ **Imax=6.3*10^{19} W/cm^2**
For Ideal beam (SG8/14cm@1/e2) ➔ Imax=14*10^{19} W/cm^2

⇨ **Strehl ratio~45%**

Focal spot in LFA: 30 Joule Hz last results (new DM)





- Measurement at 30 J on the diagnostics table (Bassler, x10) after manual optimization of the DM at 10 Hz (2020)

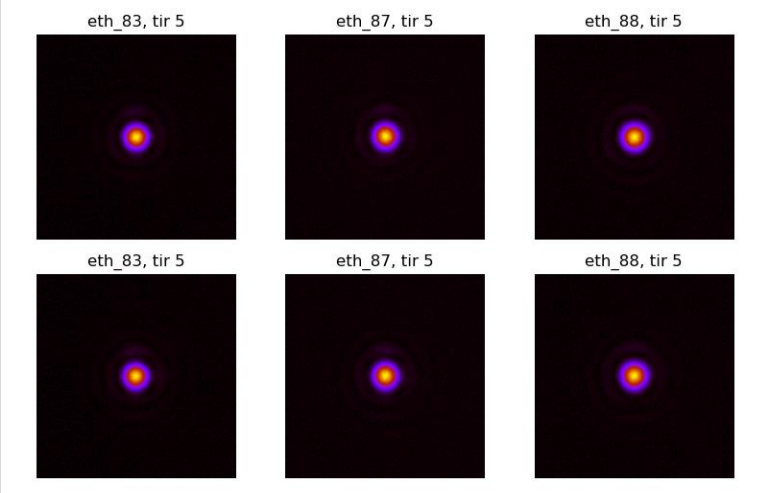
Energy in the px max= 0.0032 J ➔ **Imax=9.1*10^{19} W/cm^2**
For Ideal beam (SG8/14cm@1/e2) ➔ Imax=14*10^{19} W/cm^2

⇨ **Strehl ratio~65%**

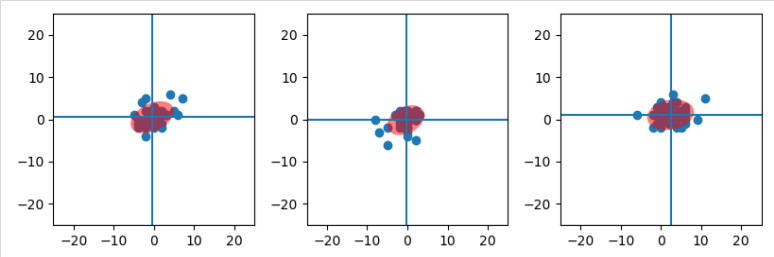
Spatio-spectral coupling in LFA: Single shot 3λ-CCD

Reference beam calibration

760nm 788nm 820nm

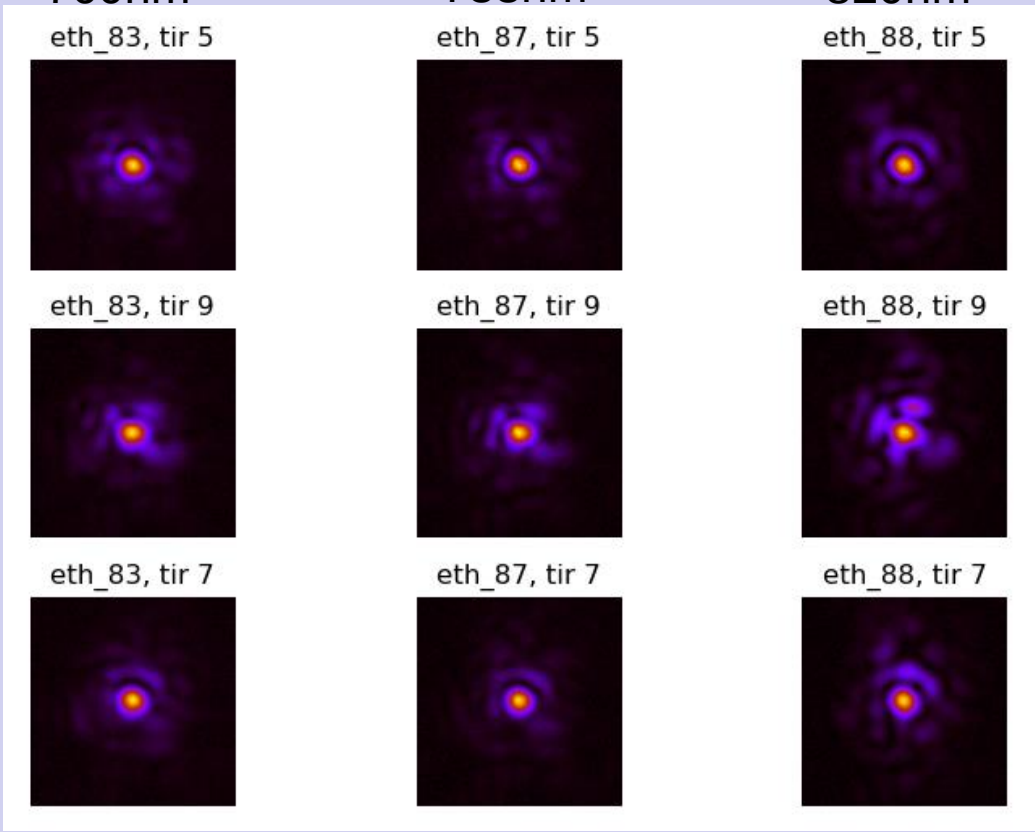


Centroid precision ~DF/20



Single shot aquititions: 0.016Hz – 30J

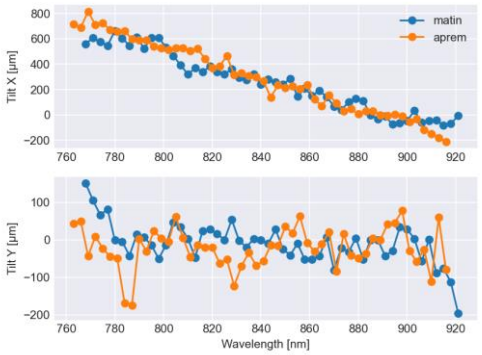
760nm 788nm 820nm



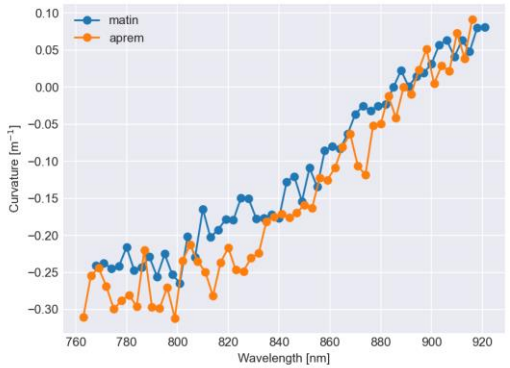
- **Very low chromatic coupling effects**: non-measurable angular chirp, indication of very low chromatic defocus!

Spatio-spectral coupling in LFA: m-HASO

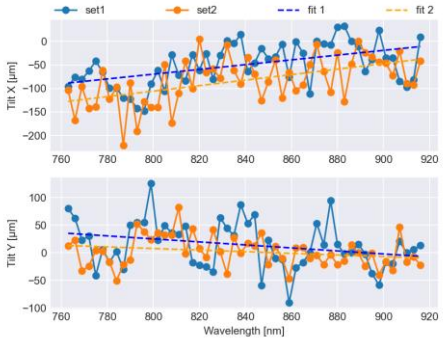
Chromatic tilts initial



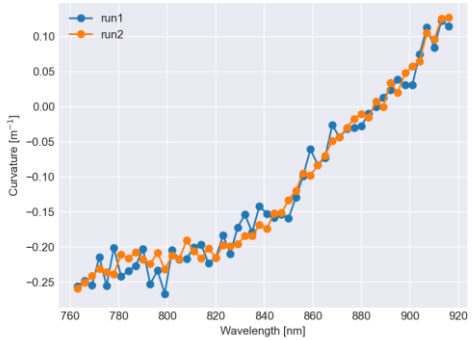
End Chain chromatic curvature



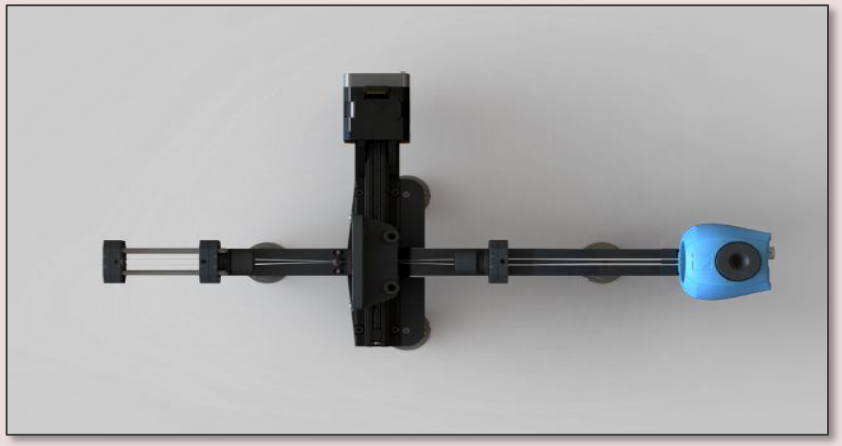
Chromatic tilts optimized

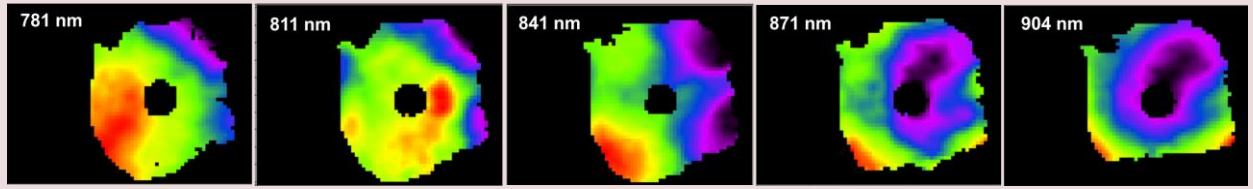


End Chain chromatic curvature



m-HASO: Automatised Wavefront aquitition at spectrally filtered fraction of the pulse (PALM 2impacts 2018):





- Used for the analysis and the optimization of the Apollon chain
- Chromatic tilts and defocus are very low and very well compared with the theoretically expected values (analysis ongoing): **<4nrad/nm**, **<Rayleigh length/4** over 100 nm bandwidth (lens based AF3 contribution)

Outline

- Apollon laser diagnostics overview
- Qualification diagnostics in the experimental areas in more detail
- Laser performances
- Your questions… some of them
- Conclusions

Your questions (1/2)

- What are the measured values of laser parameters? (energy, duration, stability shot-to-shot, focal length, focal spot size….)
  All these parameters are measured, but not on the shot. On the shot we have solid indications of the energy, the duration and the stability. The really missing information is the exact focal spot quality… even if an indication of its stability can be obtained from preceding acquisitions in the chain.
- What are the laser diagnostics, shot to shot, available and where are they located? Close to the focal point? In the laser preparation room? Before the deformable mirror?
  The diagnostics are distributed in the chain. The main limitation of our approach (internationally common for this kind of lasers) is that diagnostics are not directly linked to the “on-the-target / on-the-shot” parameters… It is technically possible but practically difficult in our facility.
- On an old presentation, it has been mentioned that, at 30J, the deformable mirror could worked for a limited number of shots (less than 1000 maybe)… Is there any news about this limitation?
  No, the DM has “seen” >5000 full energy shots without any issue. The only recommendation to the users is related to the full energy shots on the vacuum components (compressor, transport mirrors). Although reliable LIDT tests show that our optics can handle the max fluence, we prefer to ramp up the energy on them progressively and with a rational, economy spirit for the number of full energy shots

Your questions (2/2)

- What will be the maximum energy at the focal point?

  ~12.5 Joules for LFA and ~15 Joules for SFA

- What are the parameters of alignment beams that will be available in the experimental areas? How will they become available (request in advance?, how long?, during set-up weeks?

  There are several alignment beams available: 10 Hz 22fs/20 mJ (or attenuated) / CW (few mW @790 nm) full aperture diode (15 min preparation), 80 MHz large bandwidth (740-905 nm) full aperture injection (1 hour preparation). Yellow laser axis indication (~5mm diam) locally in LFA (instantaneous use).

- Tunability of parameters such as beam size et energy,…

The energy can be varied either with fixed steps (75%, 50%, 30%, 10%, 1%) (<1 hour operation) or continuously with the variation of the pump energy. However this last possibility will have an "unknown but low impact" on the spectrum and the beam profile… We have limited experience on this procedure.

The beam size is fixed. It can be set at lower diameters… but this should be considered as a specific demand requiring long preparation and tests.

The pulse duration can be modified as well through the adjustment of the compressor. The spectrum however remains.

The spectral phase can be adjusted also through the Dazzler. Please communicate in advance your phase file to verify the compatibility with our Dazzler capacity.

- What solution is proposed if one piece of the equipment brought by the lab for a given experiment is not validated by "BD gas tests"?

  If cleaning of the equipment is not possible or efficient, the equipment cannot be used in the vacuum chamber. The replacement of the equipment is the only solution.

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Conclusions

- The Apollon laser is fully functional and qualified for the first experiments in LFA. Qualification in SFA is programmed for January 2021.
- Remaining last tests on the focal spot stability are scheduled before the 1st experiment in November
- Critical laser beam parameters are monitored throughout the chain for the integrality of the shots
- “On-shot”, “on-the-target” diagnostics are not available in our system. Only indirect measurements of the actual shot parameters are provided.
- All laser parameters data can be provided to the users before their experiments
- Dedicated control tests of the laser parameter can be realized if the users whish to but as part of their experimental beam time…