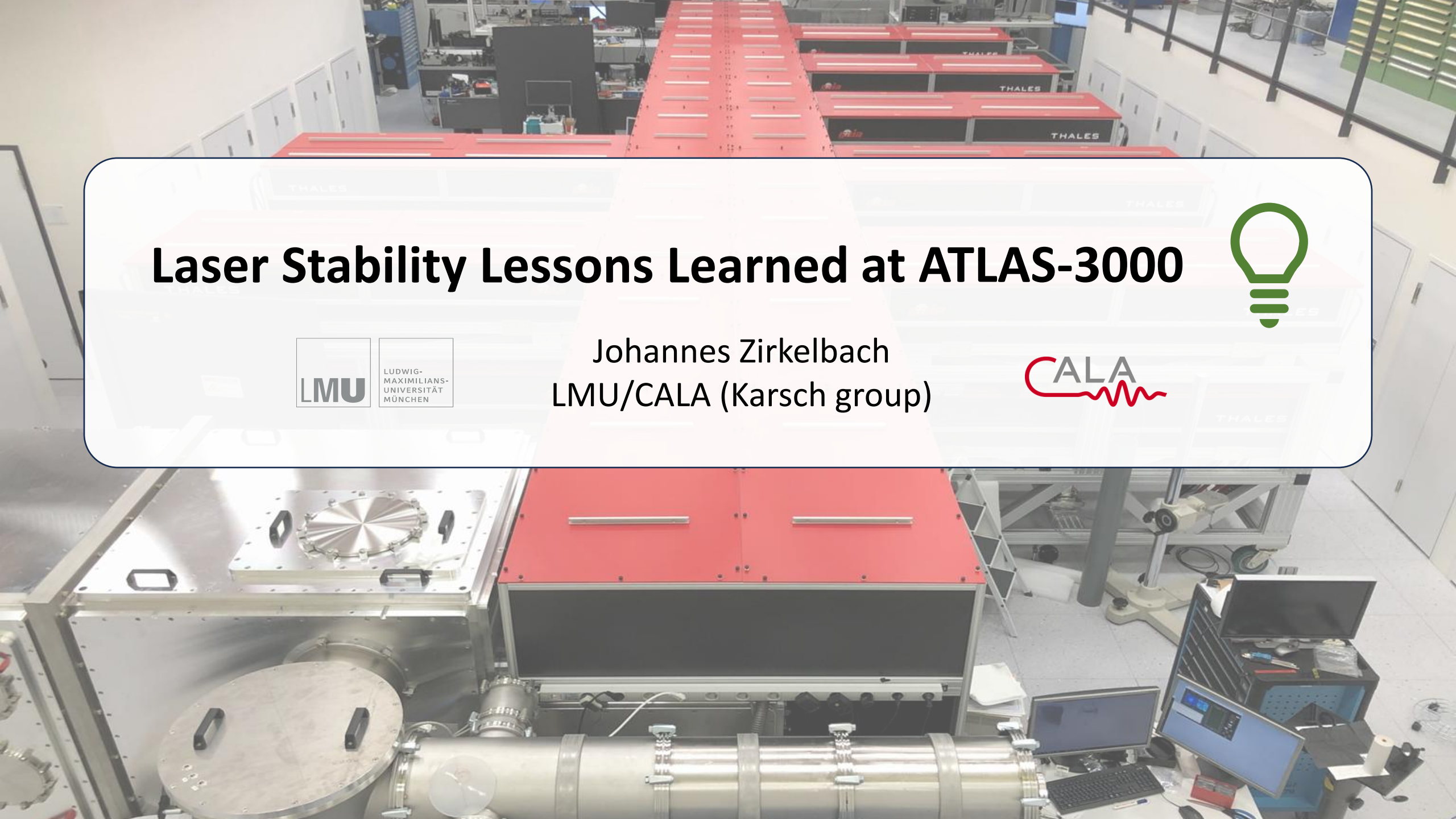
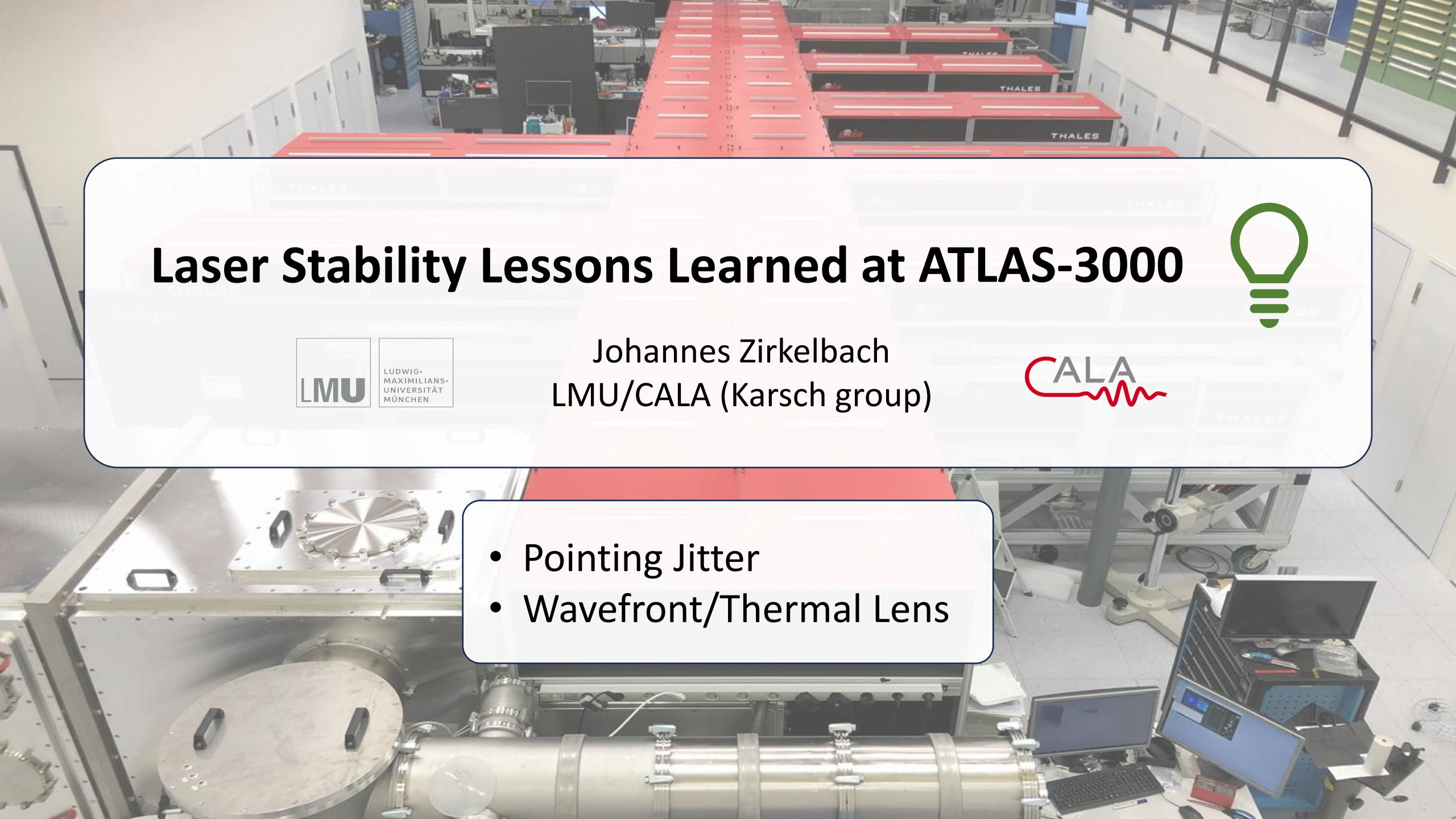


Laser Stability Lessons Learned at ATLAS-3000

LMU LUDWIG-MAXIMILIANS-UNIVERSITÄT MÜNCHEN

Johannes Zirkelbach
LMU/CALA (Karsch group)

CALA



Laser Stability Lessons Learned at ATLAS-3000

LMU LUDWIG-MAXIMILIANS-UNIVERSITÄT MÜNCHEN

Johannes Zirkelbach
LMU/CALA (Karsch group)

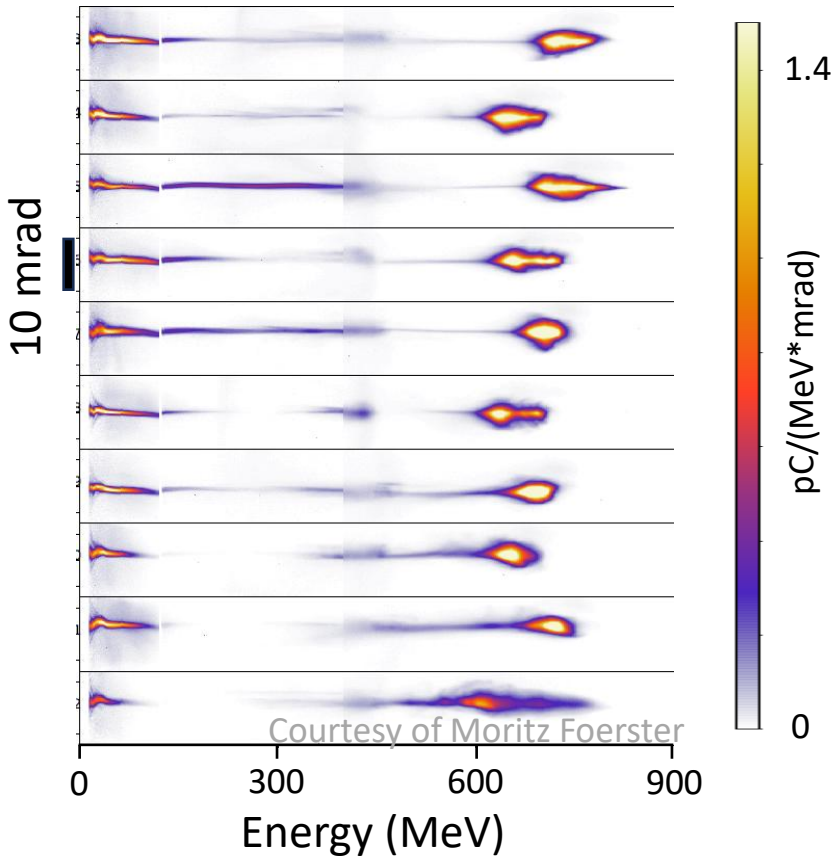
CALA

- Pointing Jitter
- Wavefront/Thermal Lens

From Dream Beams …

“Dream Beams”

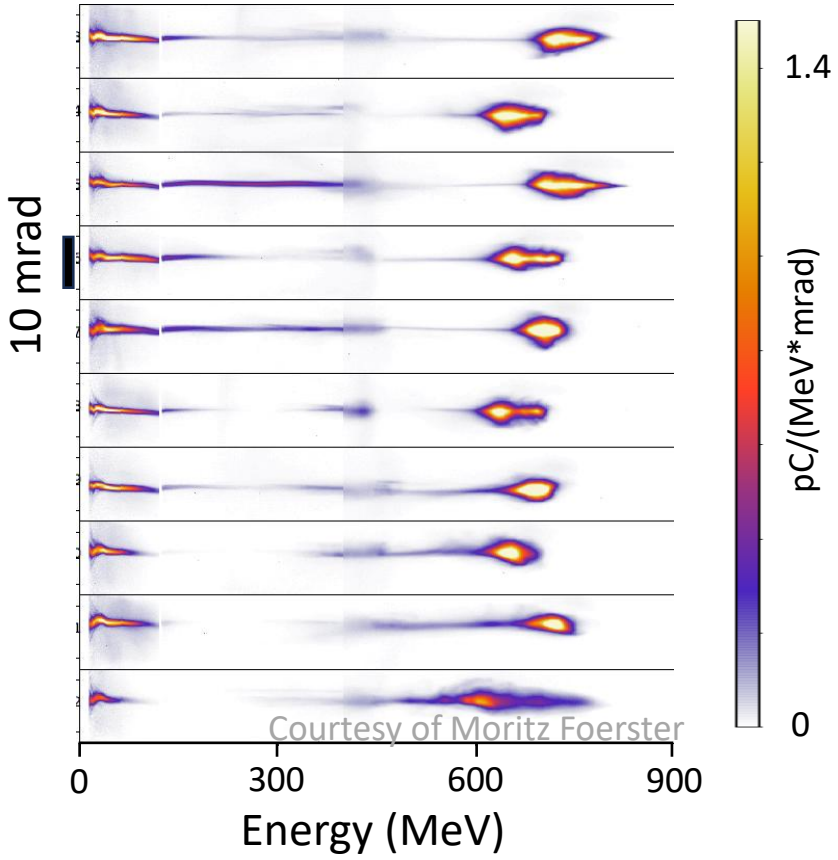
LWFA driven by ATLAS-3000:



From Dream Beams to Dream Accelerators

“Dream Beams”

LWFA driven by ATLAS-3000:



“Dream Accelerators”

Usable for applications.

Requires:

- Stability / Reproducibility

Good to have:

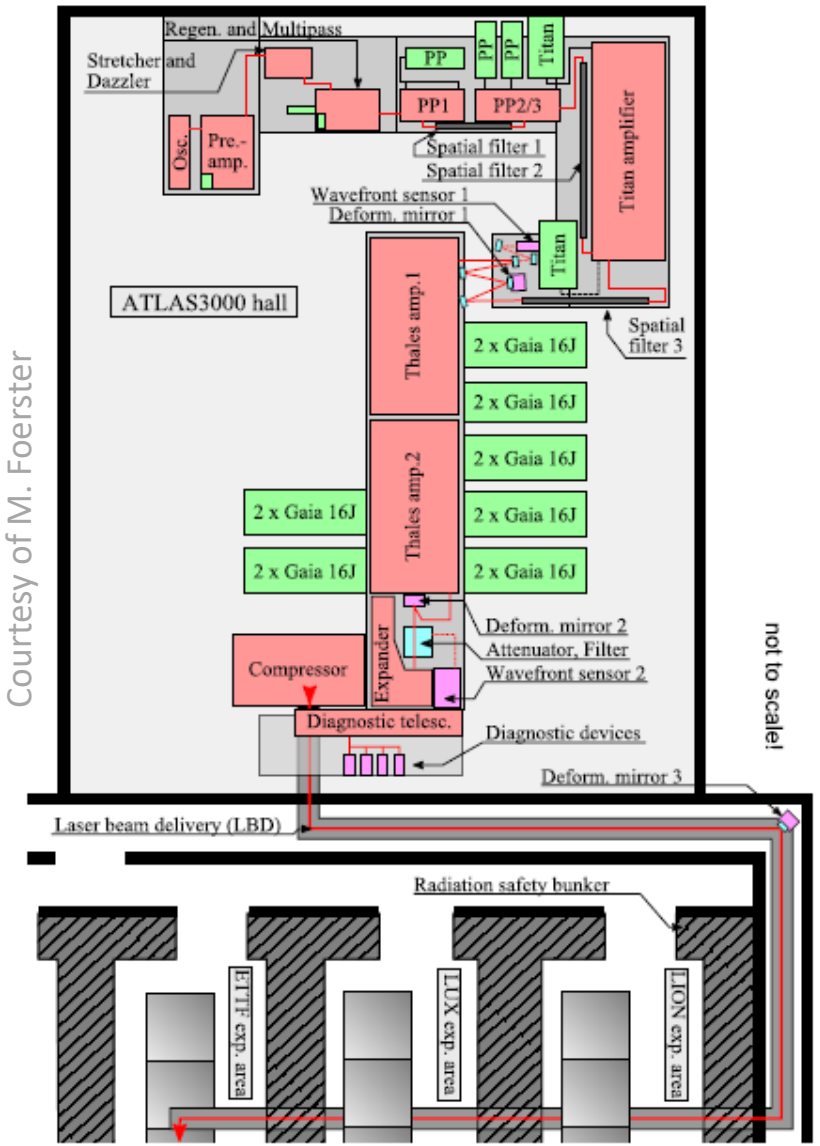
- Competitive beam parameters
- Tunability
- Ease-of-use
- …

Experiments (planned) at CALA:

- Breit-Wheeler pair creation
- Thomson scattering
- Photon-photon scattering
- Stable fast ions for medical applications
- Hybrid LWFA-PWFA acceleration
- …

Ideally:
pointing jitter << focal spot

ATLAS-3000



Courtesy of M. Foerster

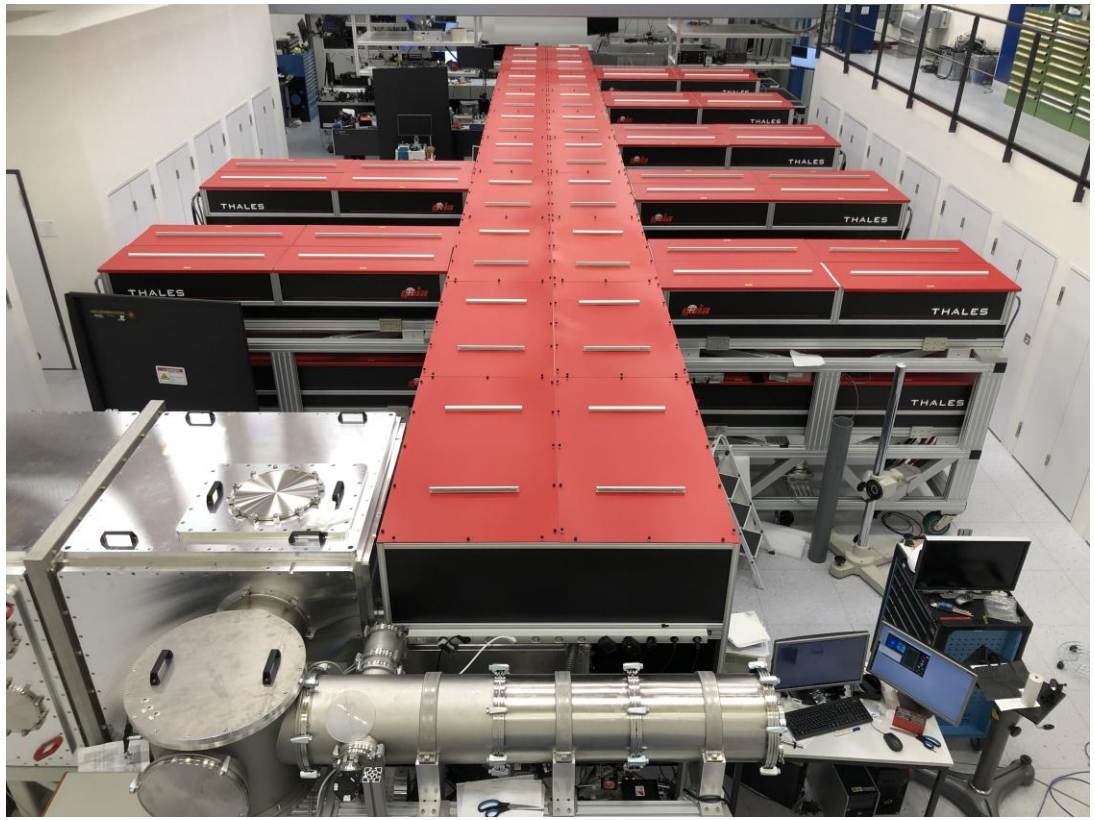
Frontend
(→ 2 J)

Main AMP 1
(→ 20 J)

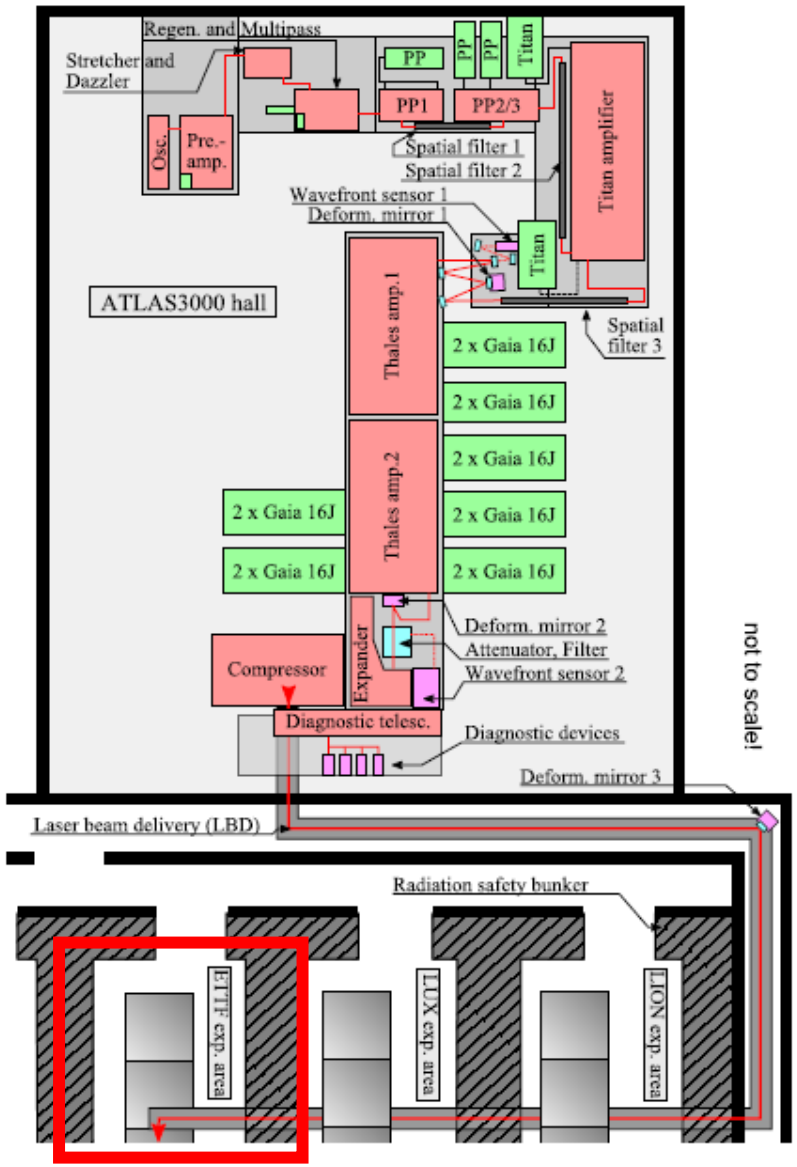
Main AMP 2
(→ 90 J)

Compressor &
Diagnostics

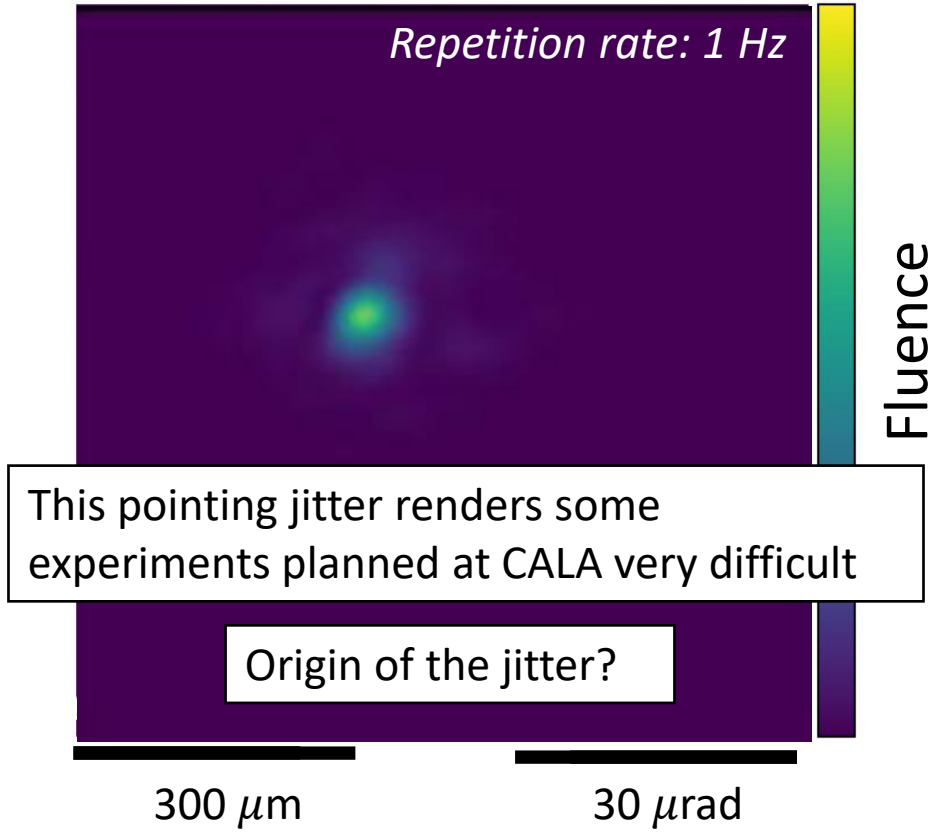
Beamline & Labs



Pointing Jitter at CALA



Focus at the target (f/# = 33, f = 10 m):

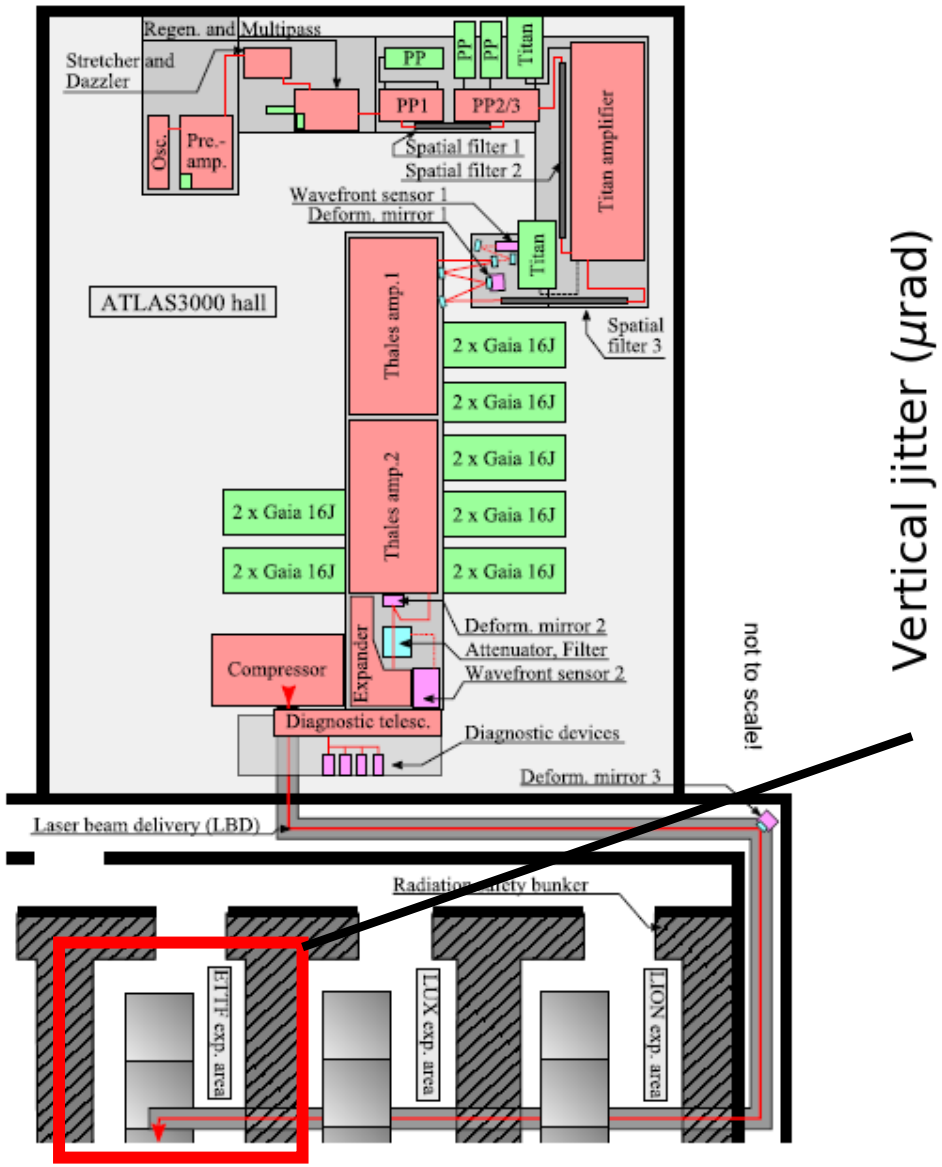


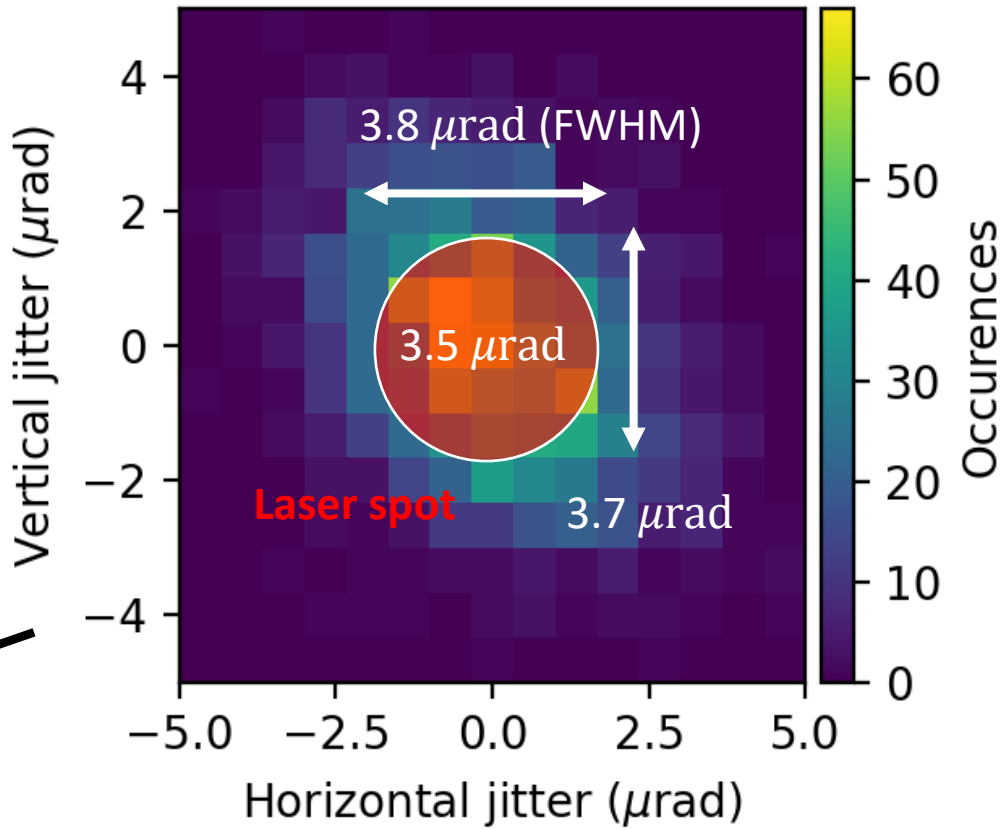
This pointing jitter renders some experiments planned at CALA very difficult

Origin of the jitter?

ETTF lab: ~20 J before compression

Pointing Jitter at CALA: Rough Search

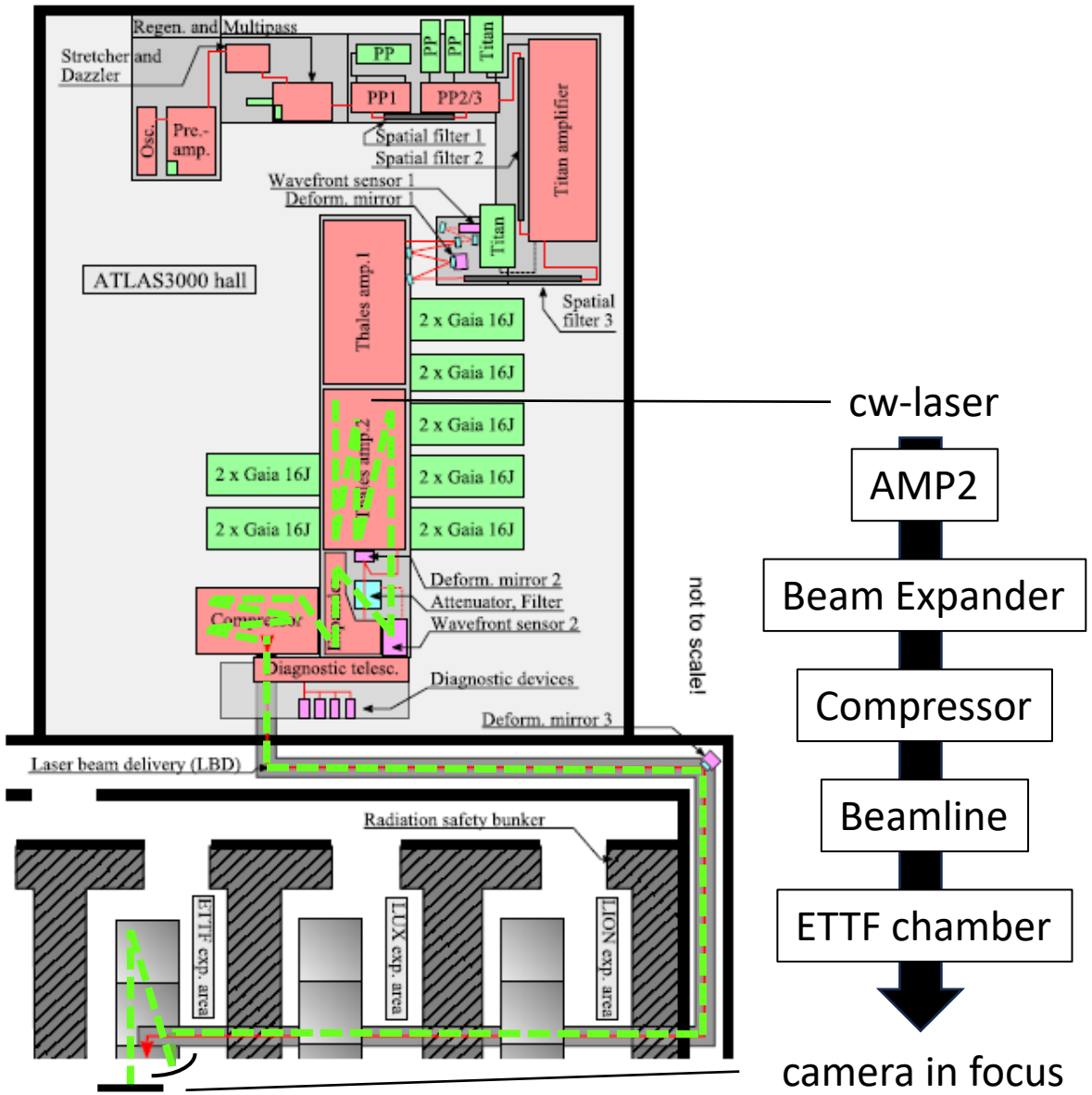




The majority of the jitter is incurred after the main amplifiers.

→ look at this part first

Pointing Jitter at CALA: Fast Measurement



not to scale!

cw-laser

AMP2

Beam Expander

Compressor

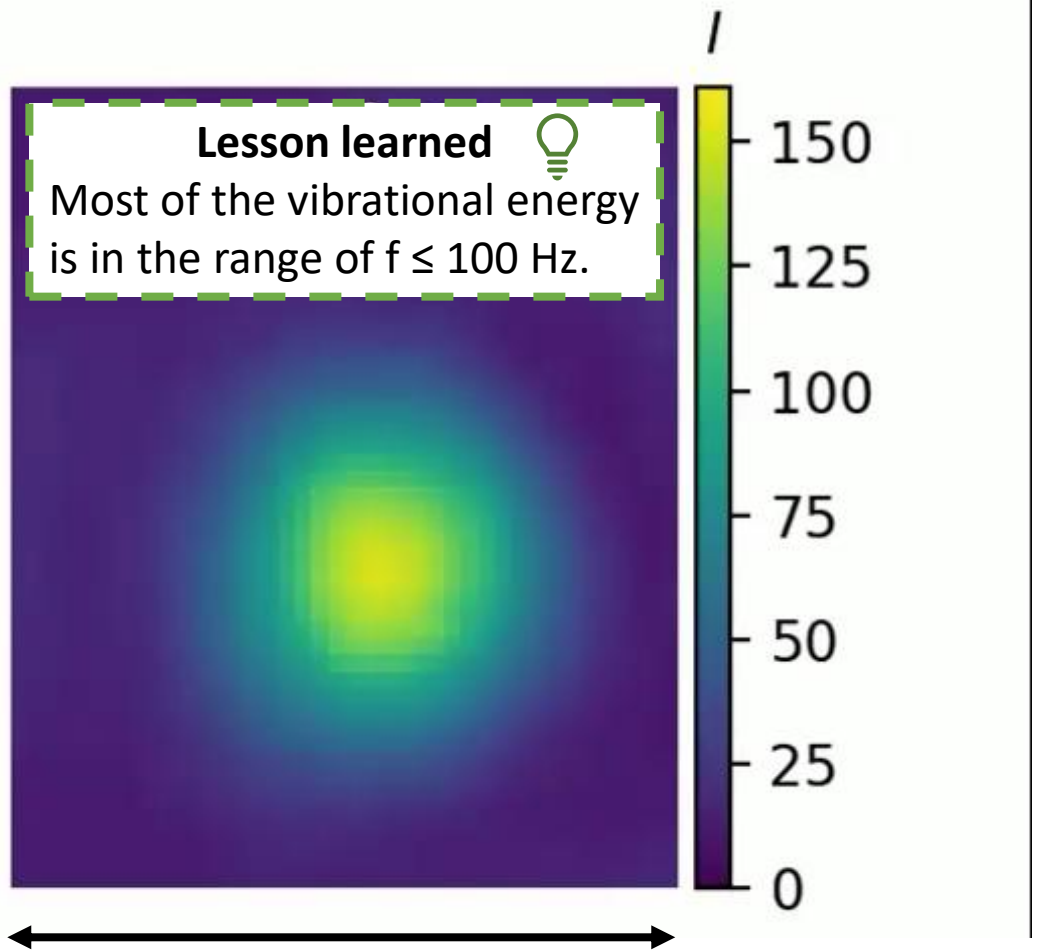
Beamline

ETTF chamber

camera in focus

Lesson learned

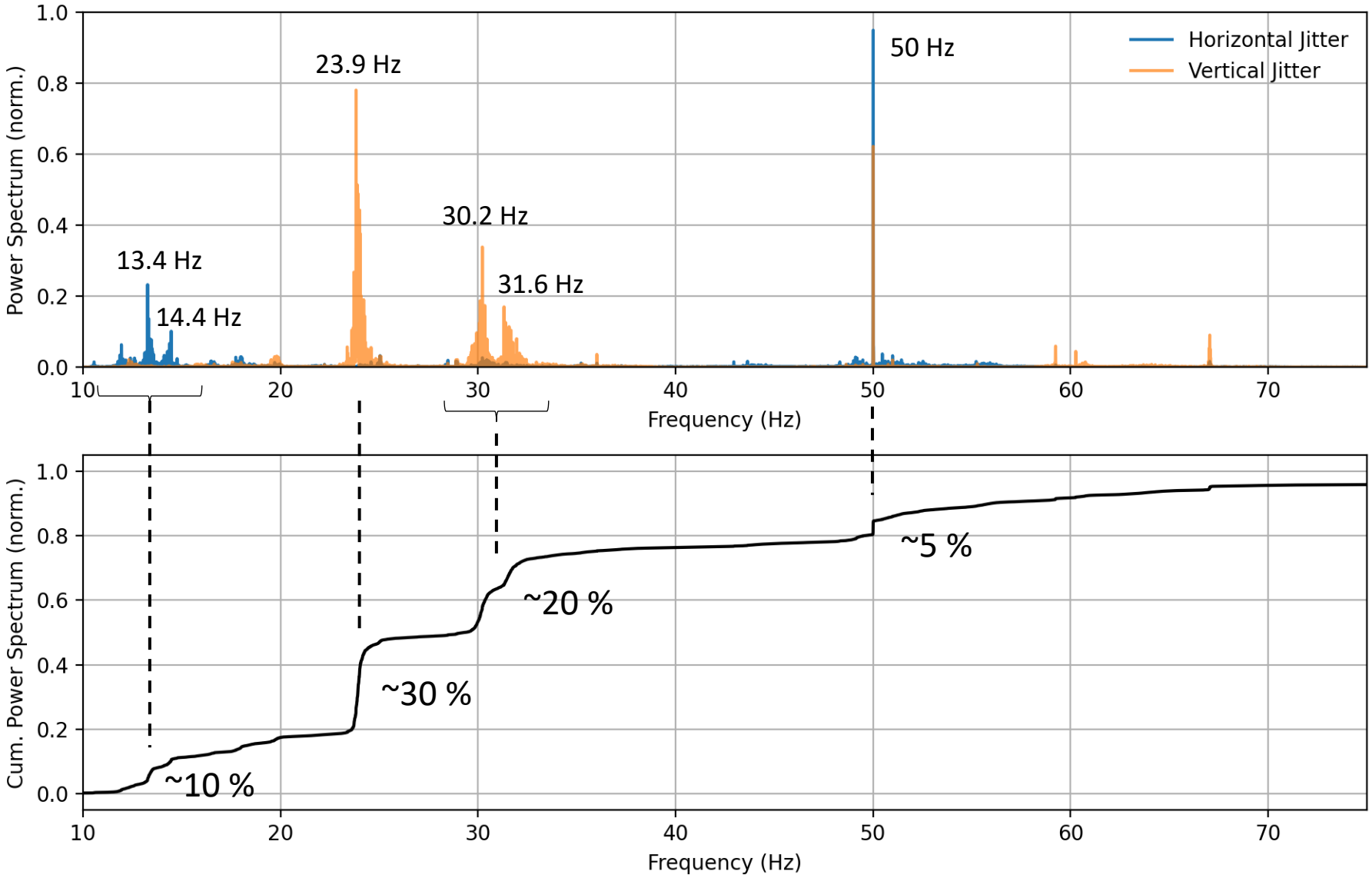
Most of the vibrational energy is in the range of f ≤ 100 Hz.



Frame rate: 500 Hz

Exposure time: 0.2 ms

ATLAS-3000: Pointing Jitter – Spectrum

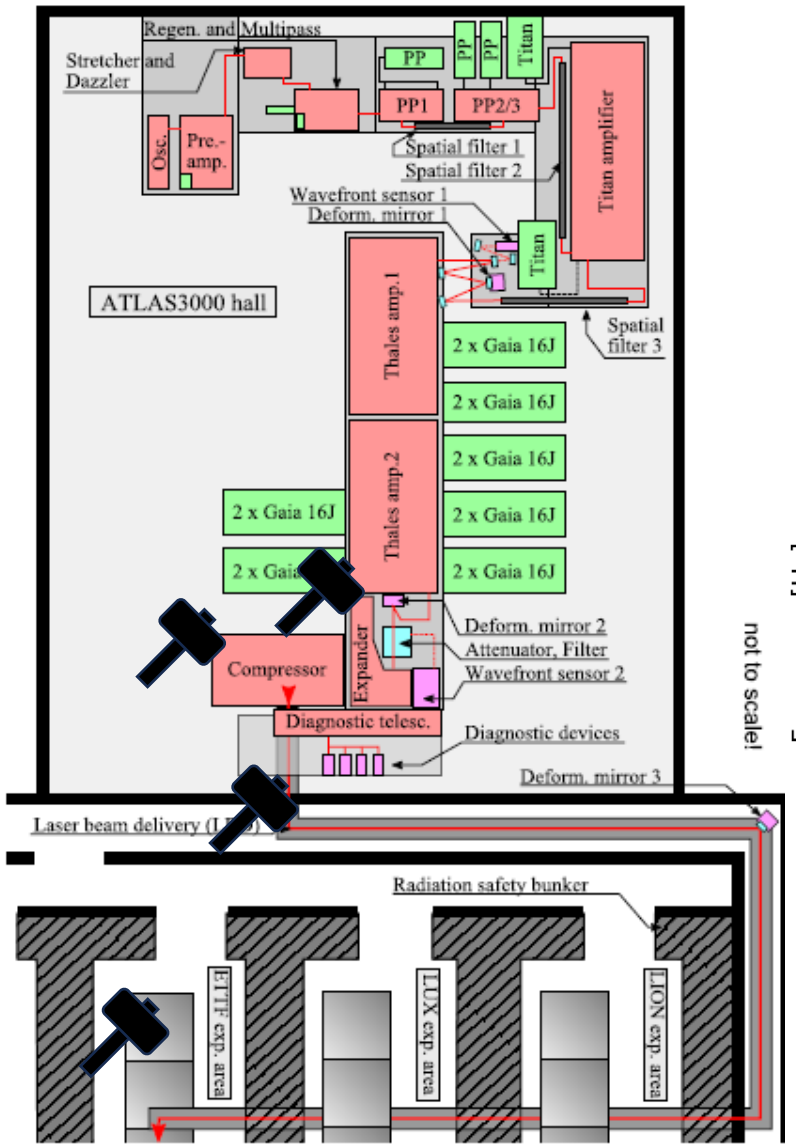


Lesson learned

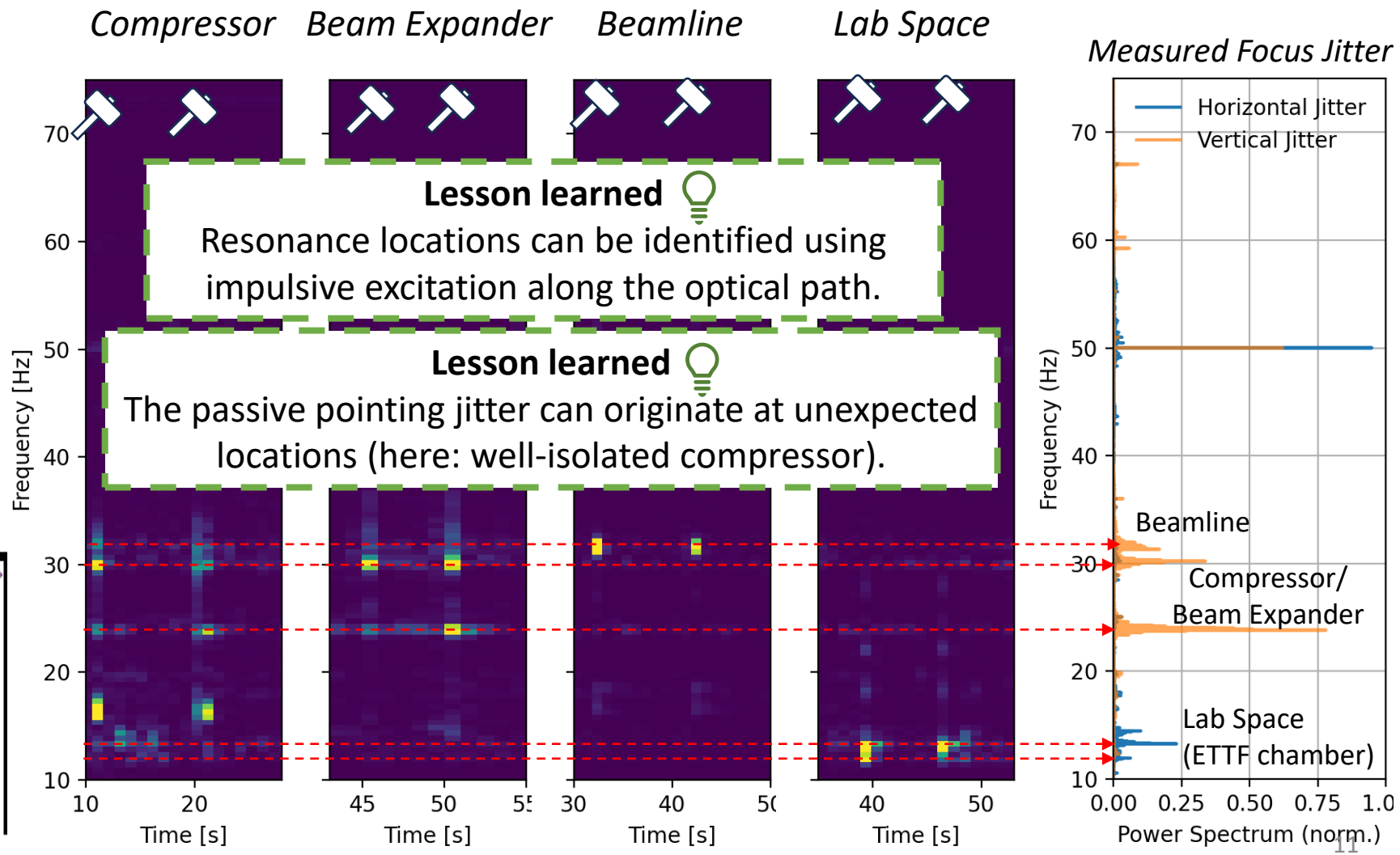
Most of the vibrational energy is concentrated to a few well-defined resonances.

Which components are vibrating at those frequencies?

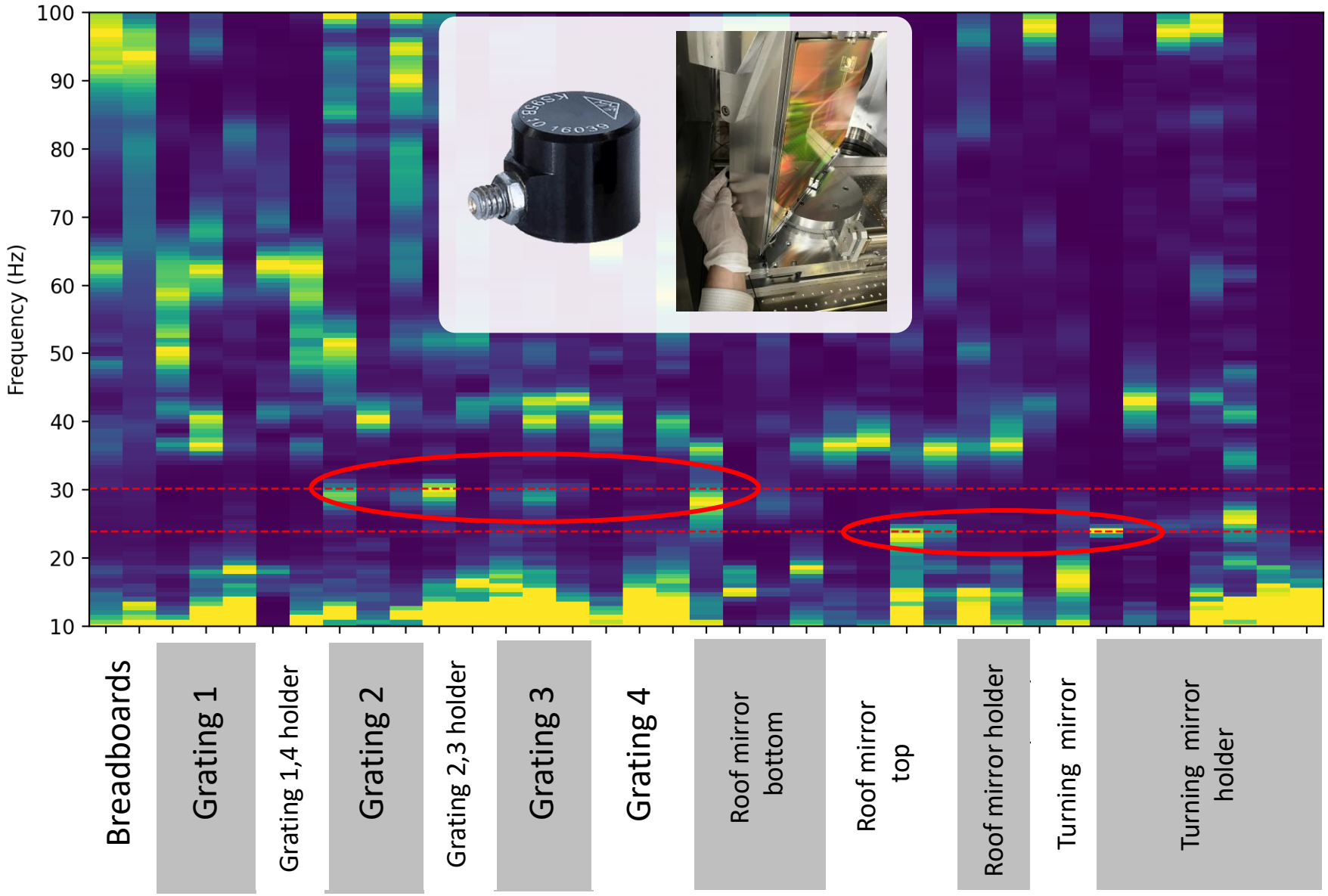
Looking for Resonance Locations



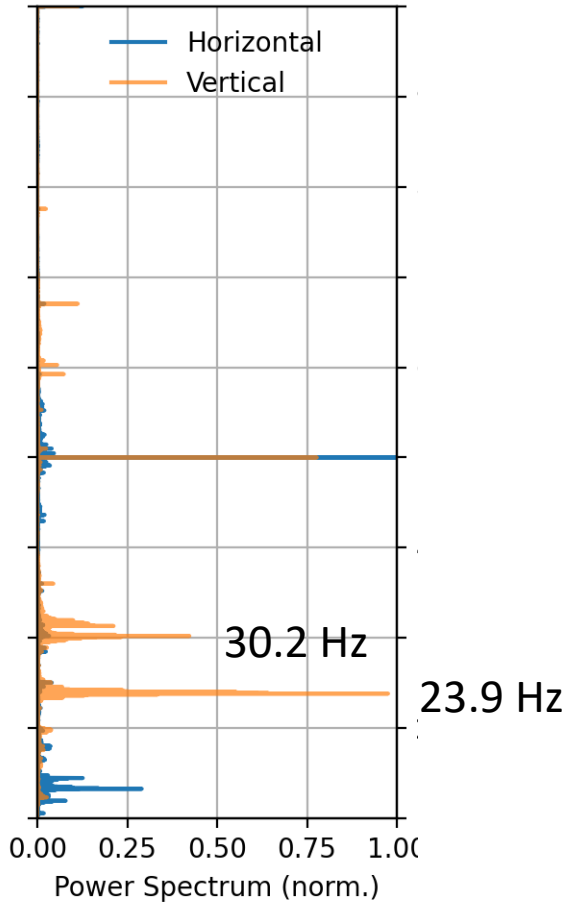
Short-term FFT of impulsive excitations along the optical path:



Resonance Measurement in the Compressor



Measured Focus Jitter

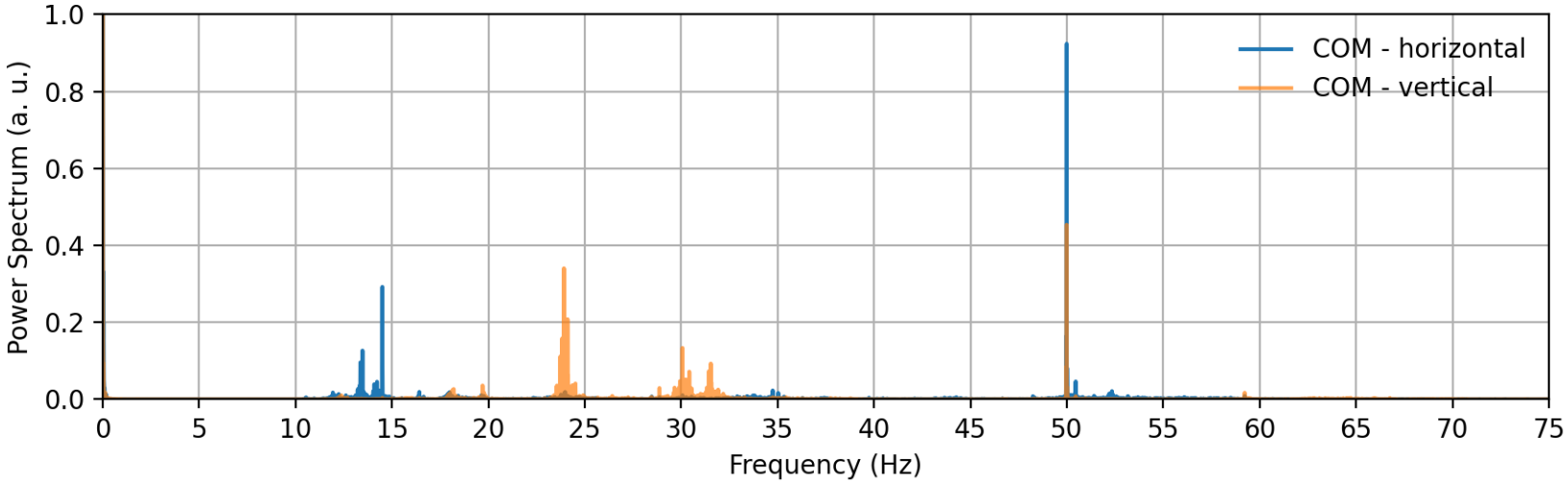


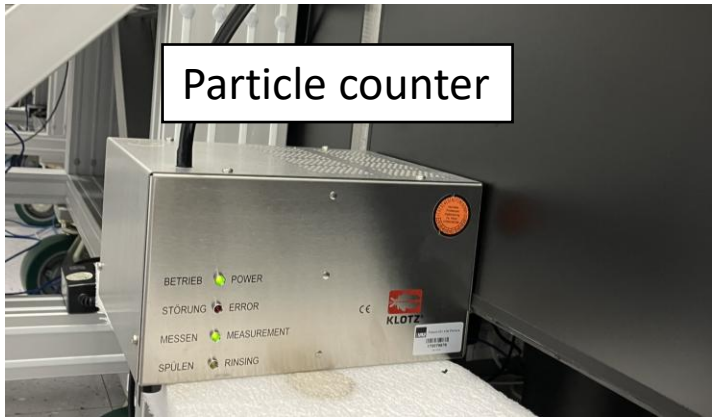
Lesson learned

Not all available resonances contribute to the passive jitter spectrum.

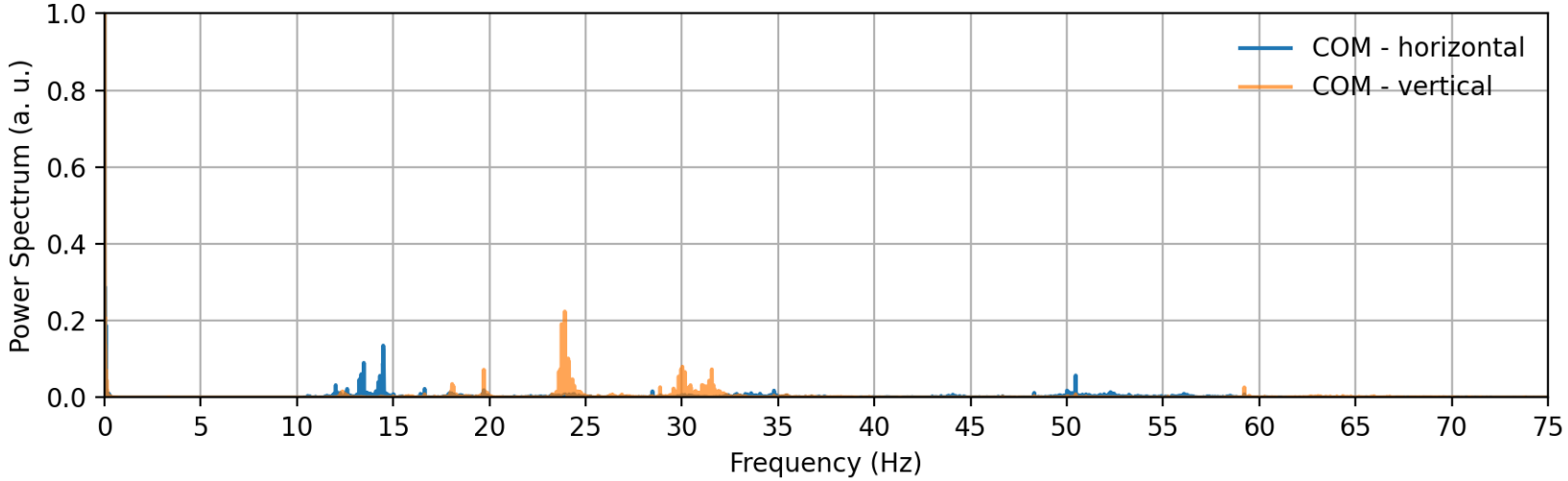
Jitter Reduction by Turning off an Excitation Source

Particle counter on:



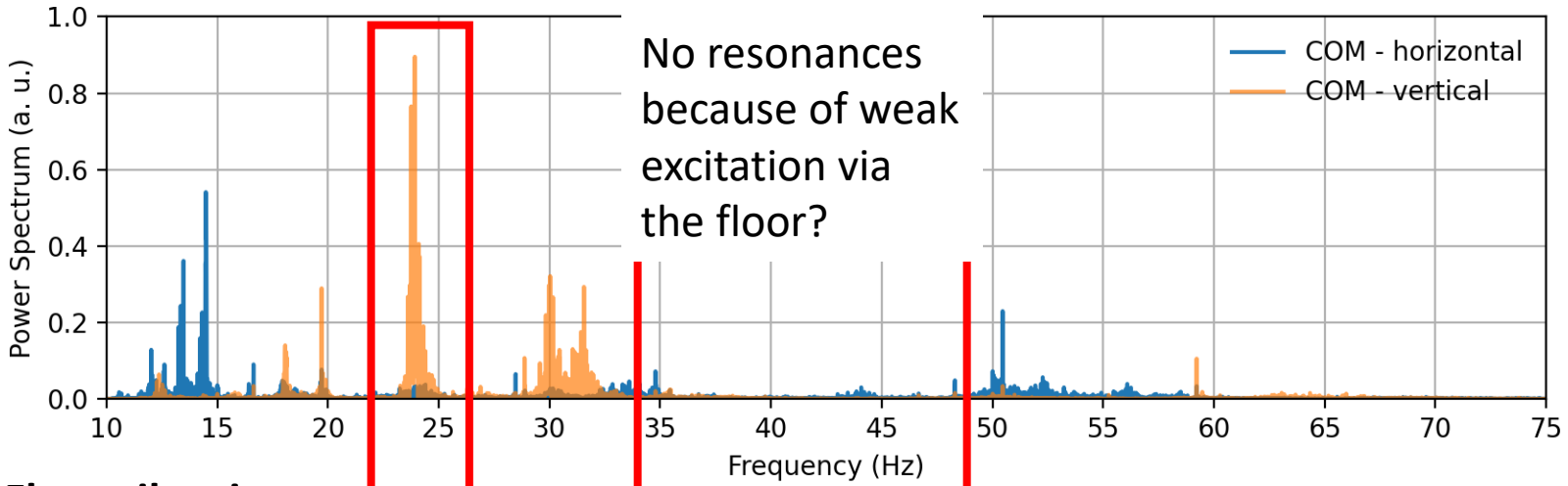


Particle counter off:



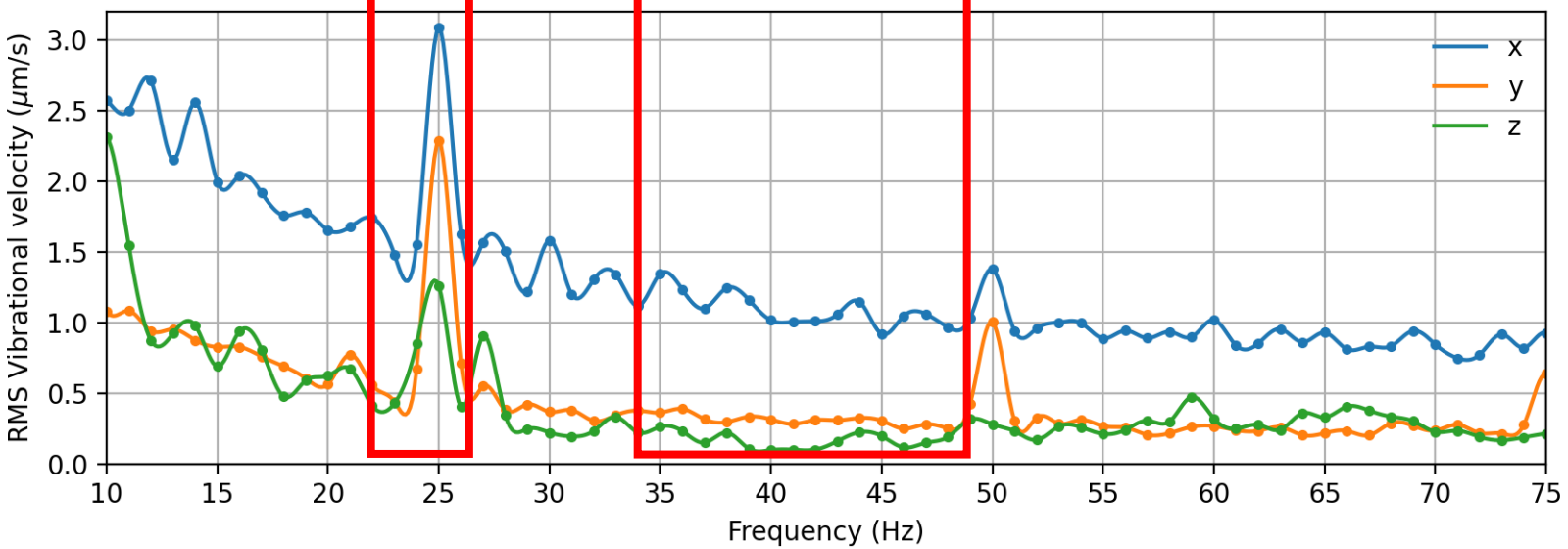
Are Floor Vibrations the Most Relevant Excitation Source?

Measured focus jitter:



No resonances because of weak excitation via the floor?

Floor vibration spectrum



Turned off a lot of devices around the compressor and in the utility area.

No significant change…

The resonances might mostly be excited by building/floor vibrations.

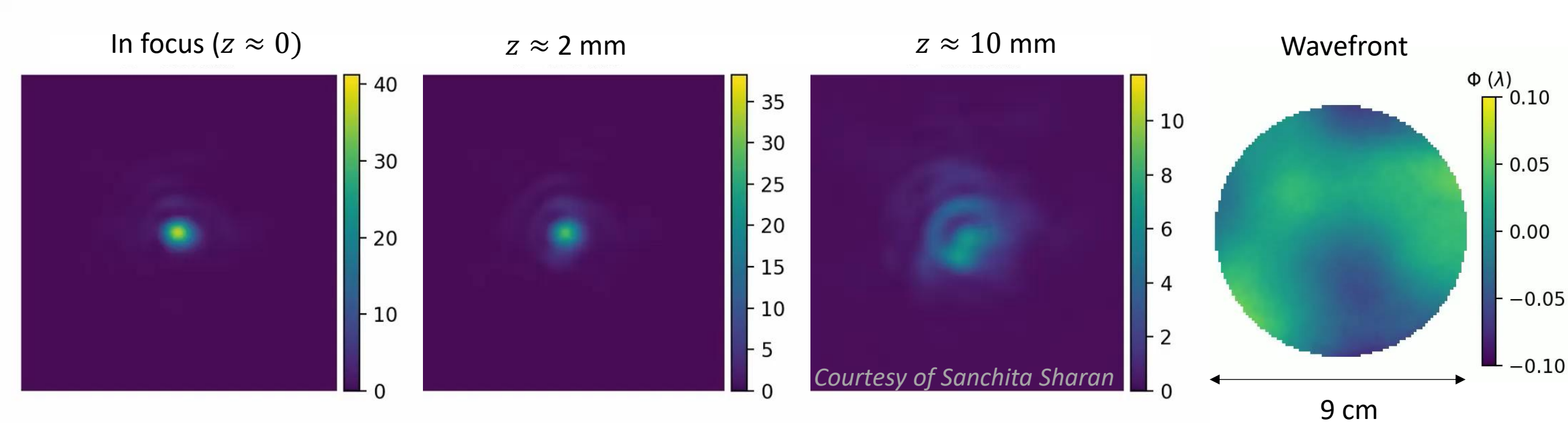
Next steps:

- Either: decouple from the floor.
- Or: make structures stiffer to move resonances to higher frequencies.

Experience with this?
Please let me know! ☺

Without Pointing Jitter…

... wavefront fluctuations still translate to fluence fluctuations around the focus:



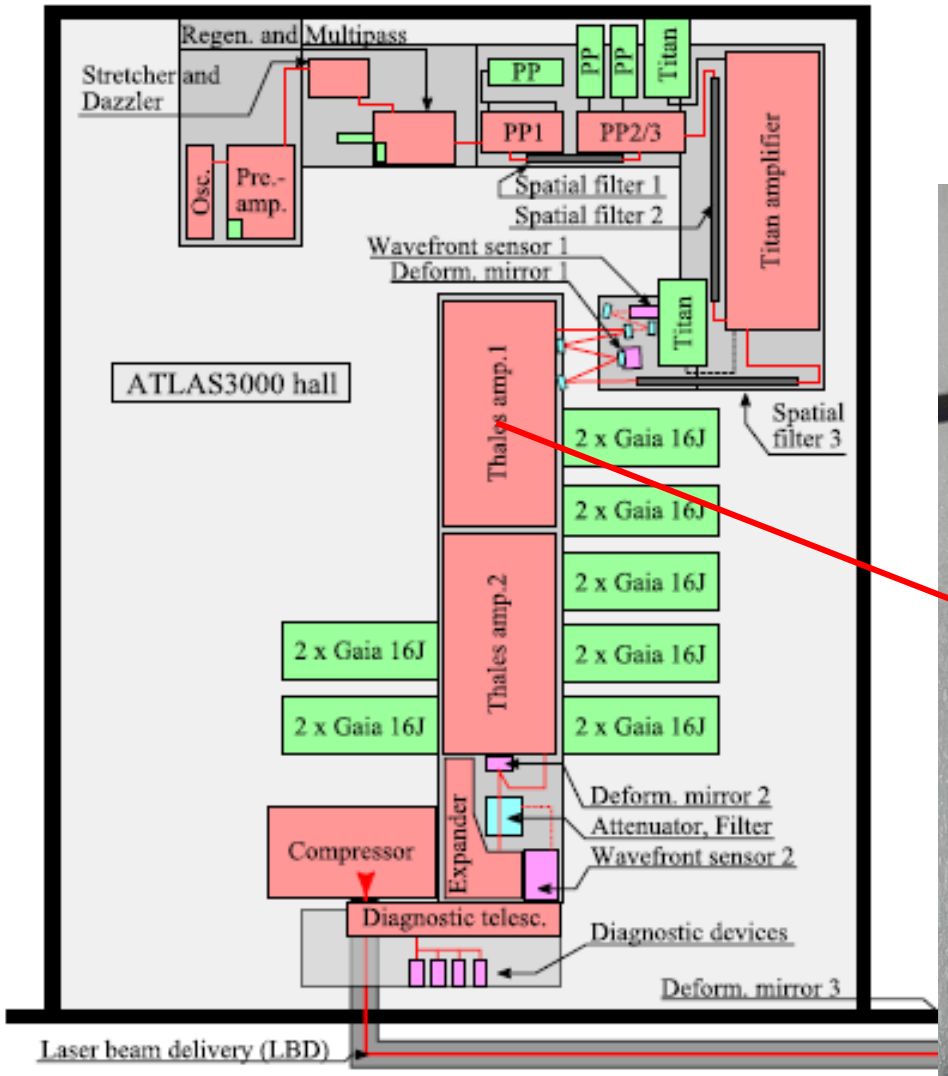
Wavefront fluctuations:

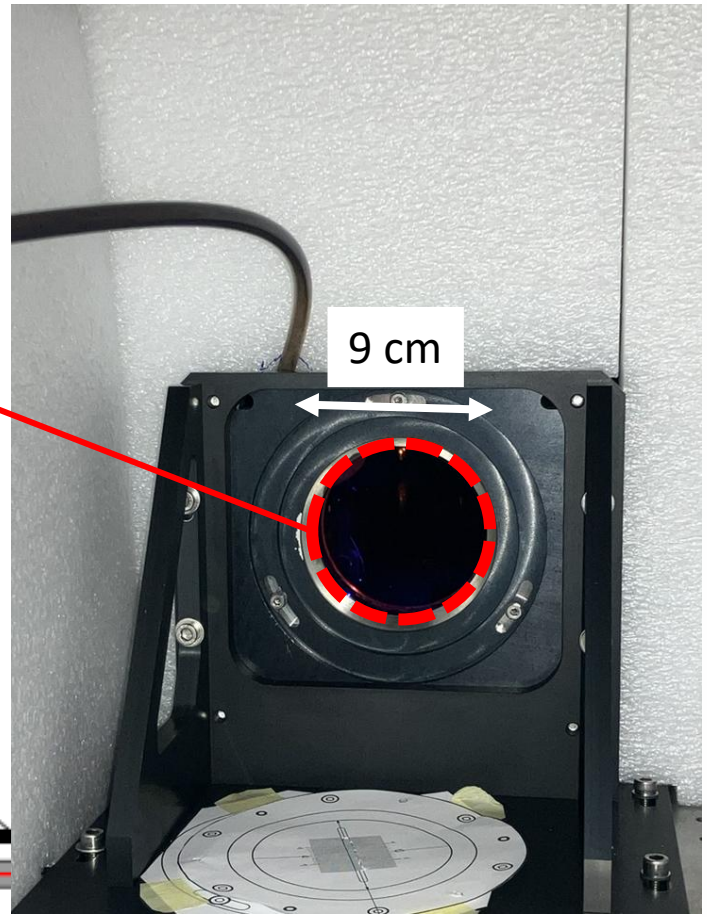
- Change the fluence distribution around focus.
- Axial jitter/Defocus: affects electron energy in LFWA.
- Can cause filamentation (?)

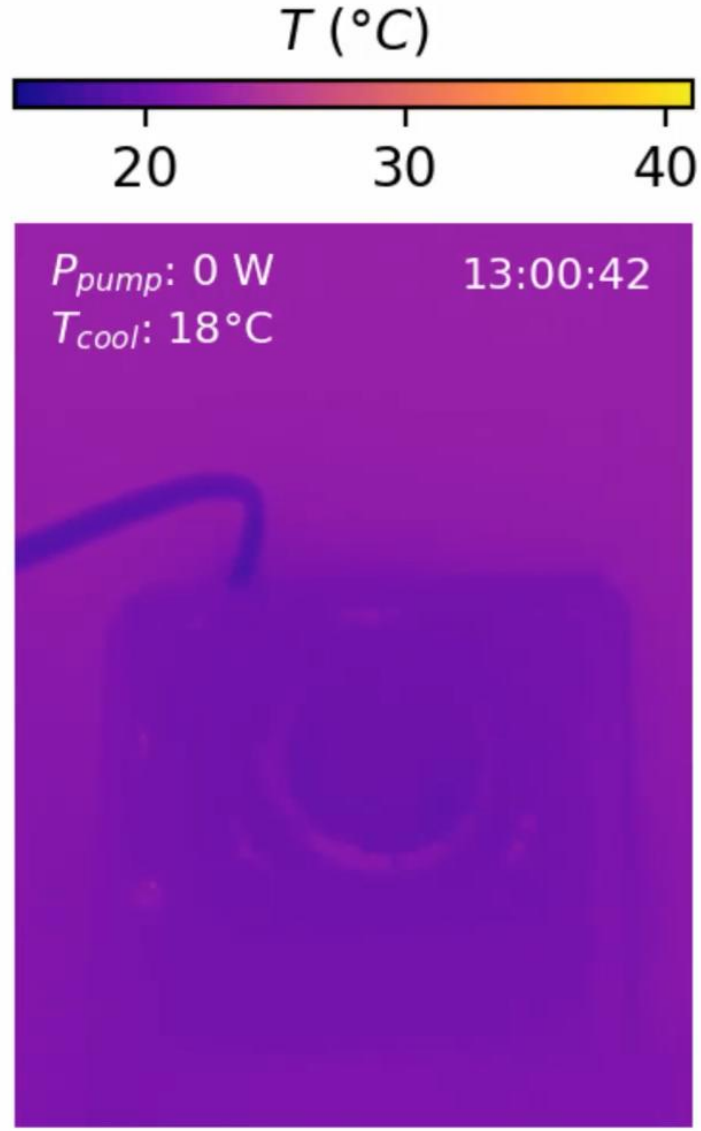
Sources:

- Air turbulence / “weather” in the laser lab.
  Becomes more critical for larger beam diameters.
- Temperature in the laser crystals / thermal lens?
- …

Temperature of the Main Amplifier Crystal of ATLAS-3000







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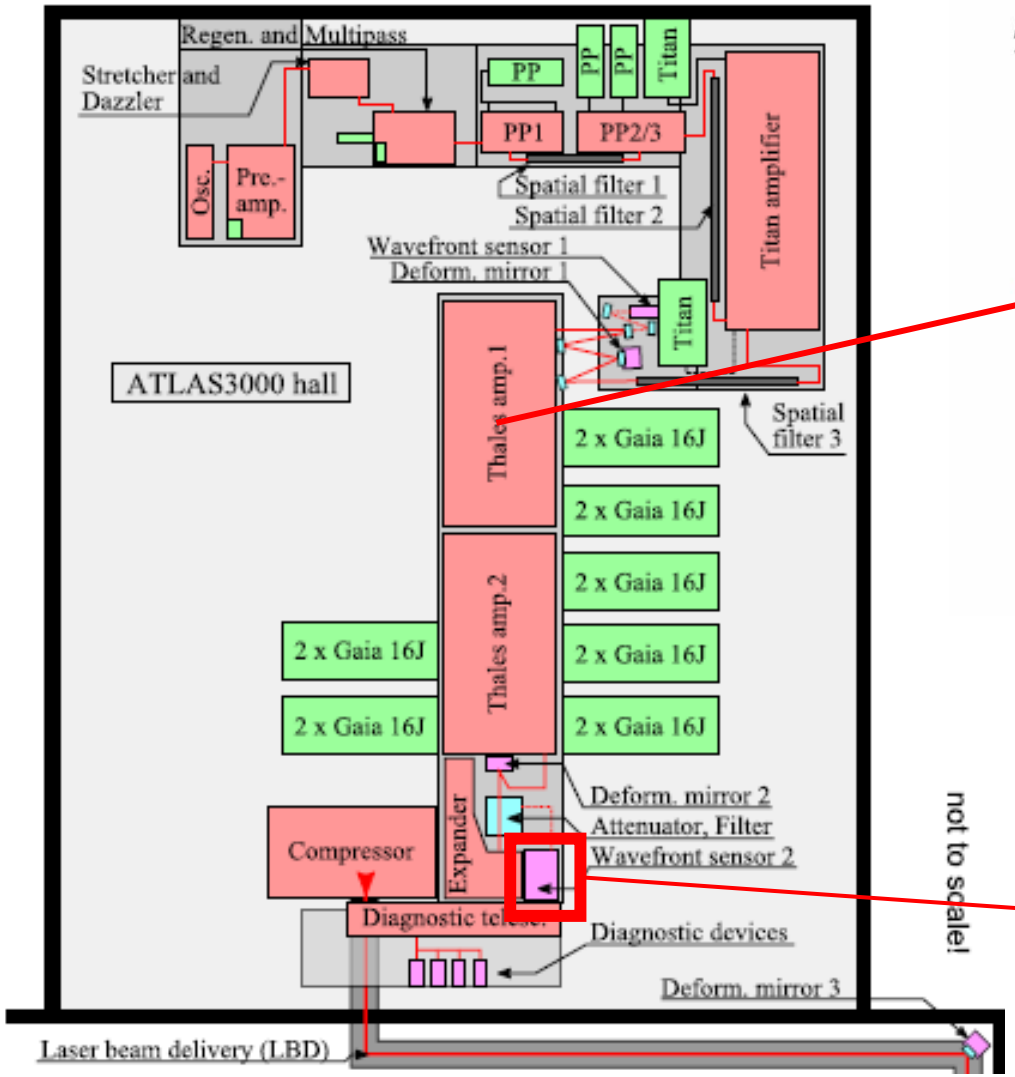
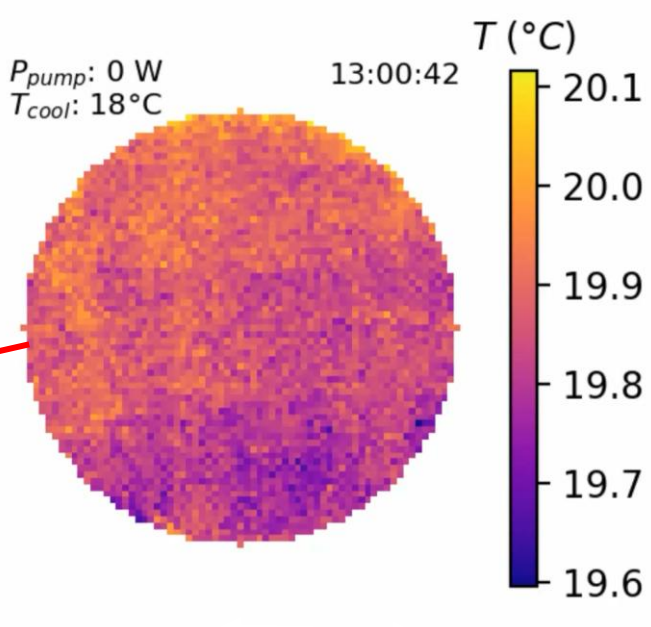
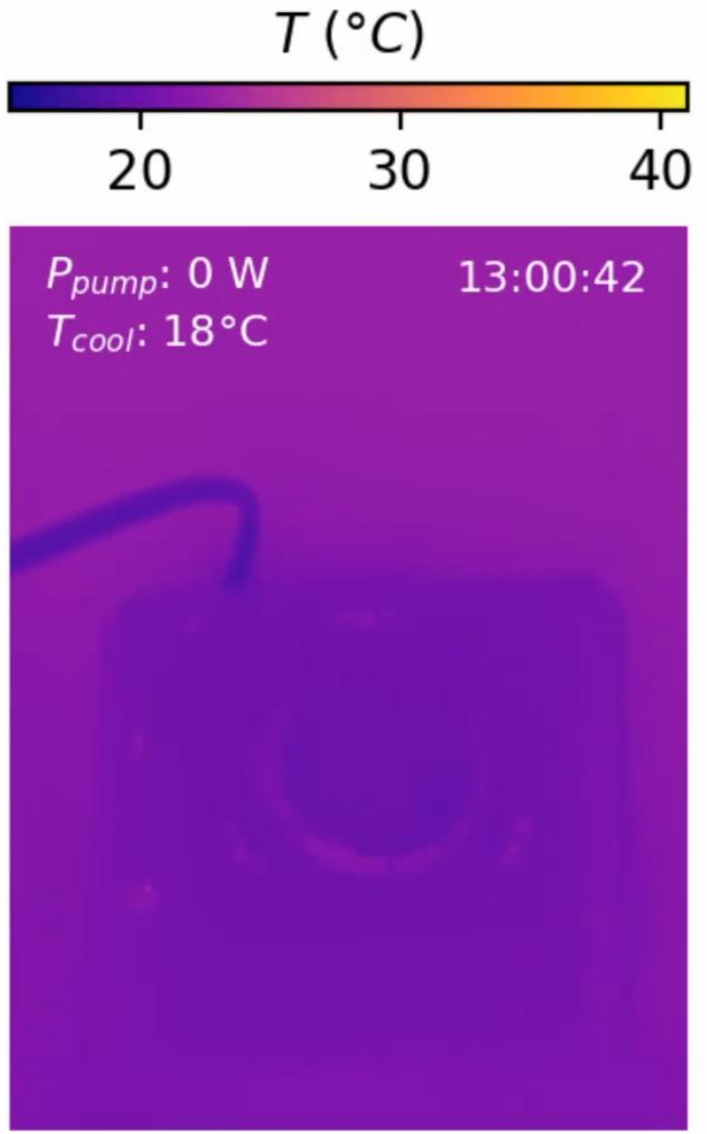


not to scale!



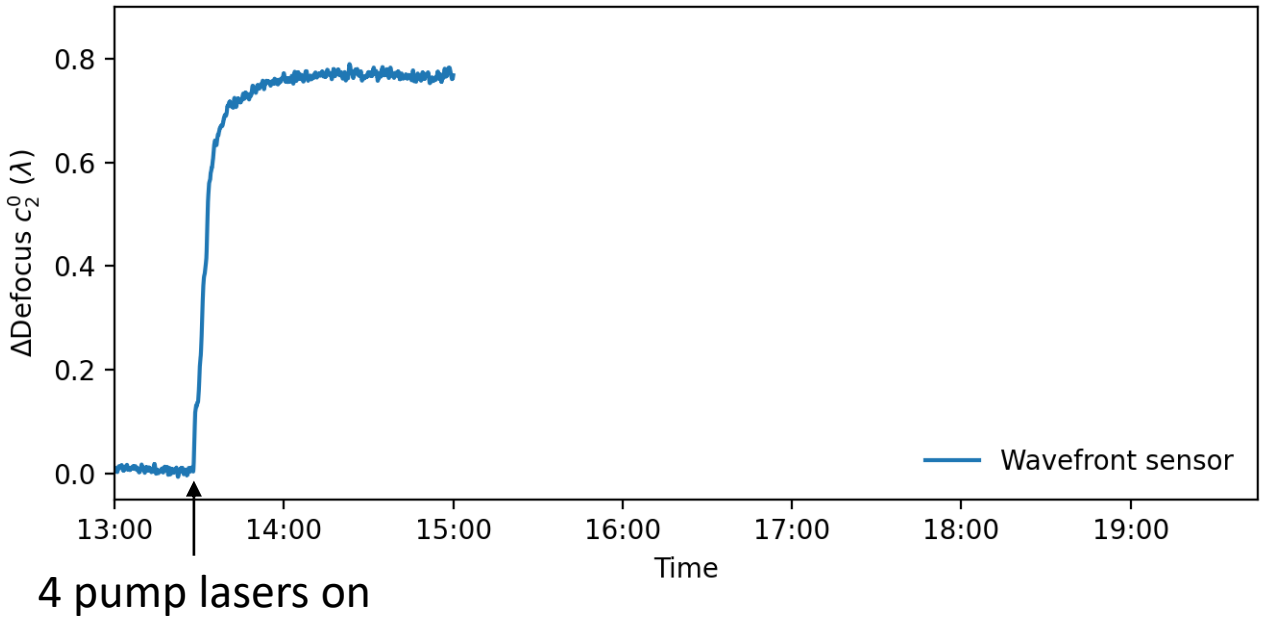
How well can the thermal lens be predicted?

Wavefront sensor

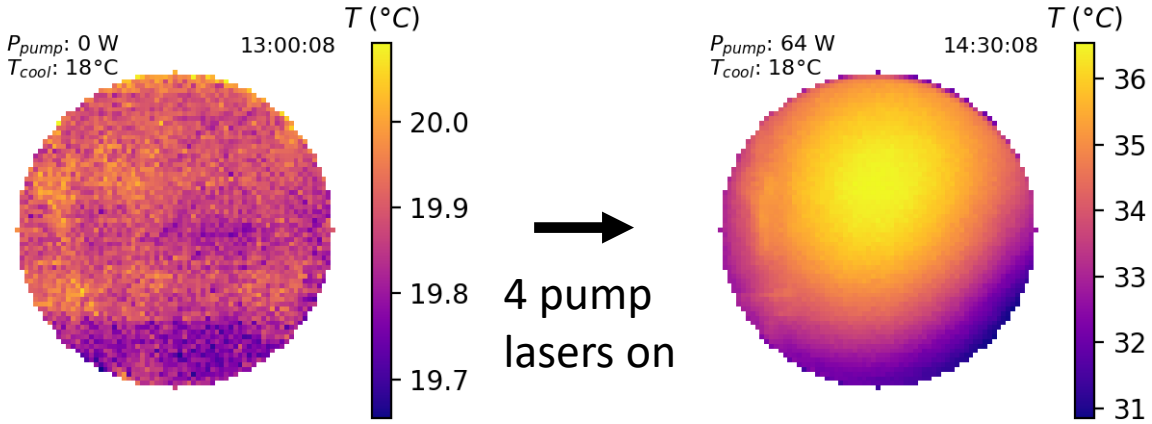


Wavefront Prediction Based on Crystal Temperature

Quantitative prediction of the thermal lens based on temperature measurement on the crystal surface:



4 pump lasers on



Model

Wavefront change upon single pass through the crystal:

$$\Delta W_1(x,y,t) = \int_0^L n(T(x,y,z,t))\,dz$$

With:

- $n(T) = 0.994 + 2.51 \cdot 10^{-5} \cdot T + 5.1 \cdot 10^{-9} \cdot T$
  Tapping, J. and Reilly (1986).
- $T(x,y,z,t) = \underbrace{T(x,y,z=0,t)}_{\text{Surface temperature (measured using IR-cam)}} \cdot \frac{\exp\left(-\frac{z}{L_0}\right)+\exp\left(\frac{(z-L)}{L_0}\right)}{1+\exp(-L/L_0)}$

↓

Wavefront change after 4-pass amplification:

$$\Delta W(x,y,t) = 2 \cdot W_1(x,y,t) + 2 \cdot W_1(-x,y,t)$$

↓

Zernike decomposition at seed position

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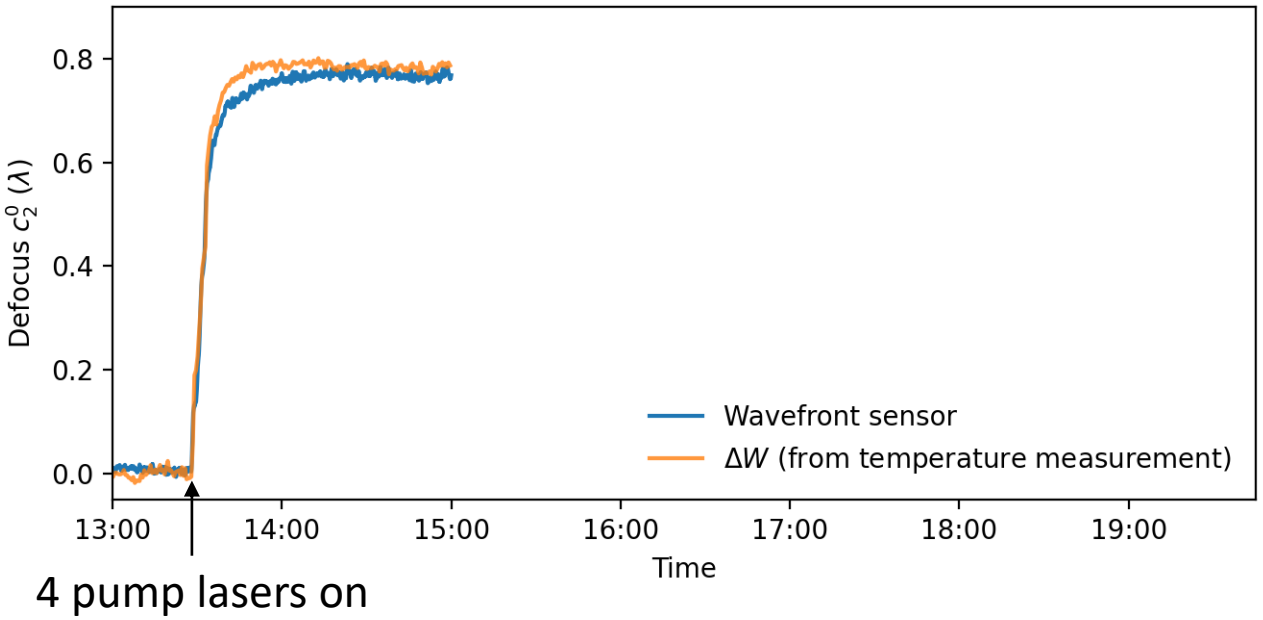

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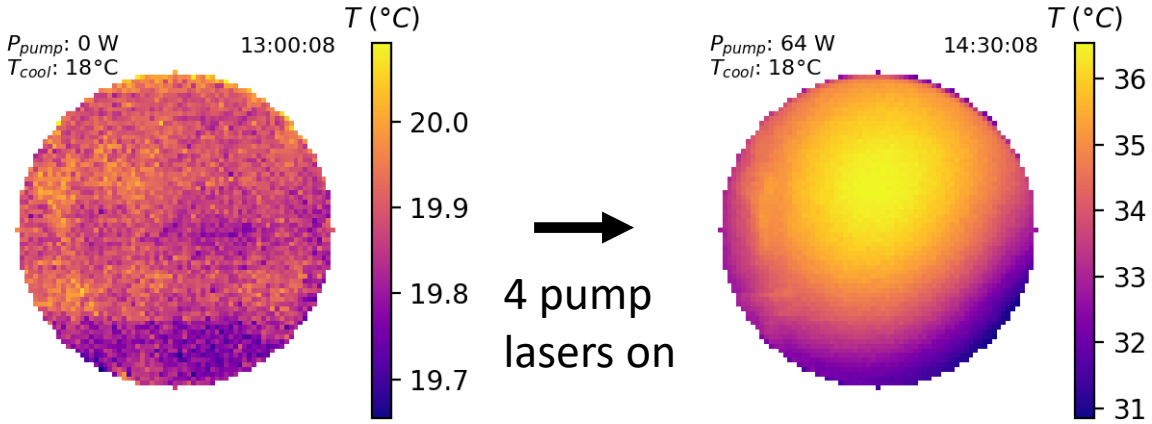

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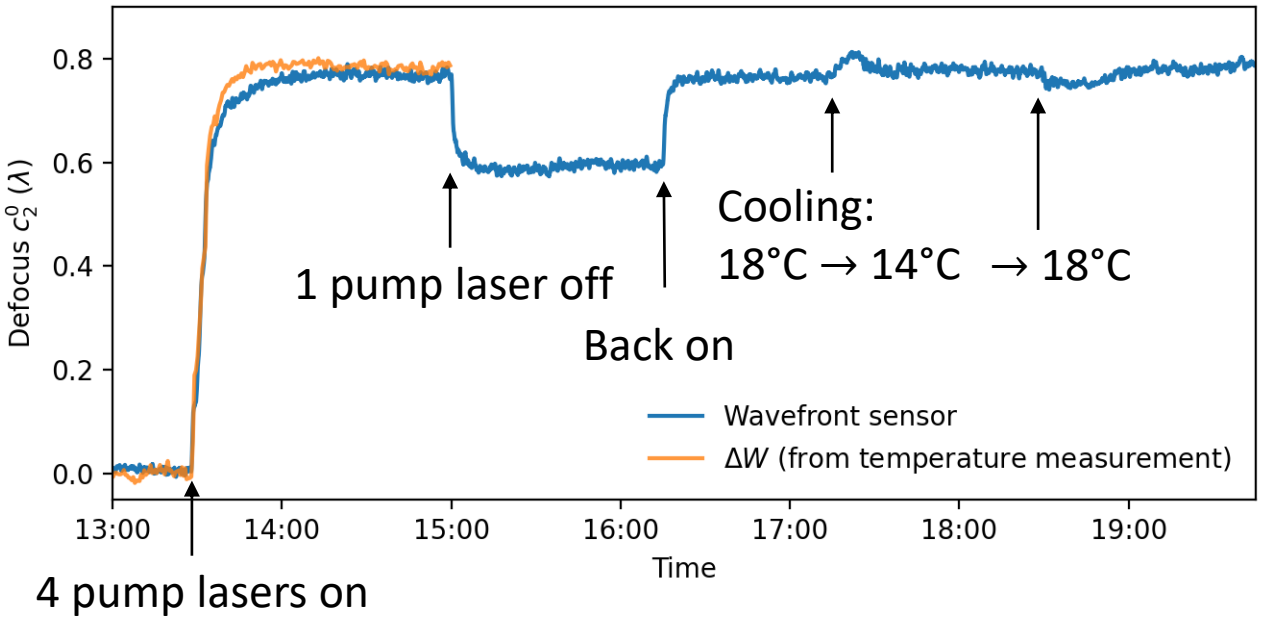

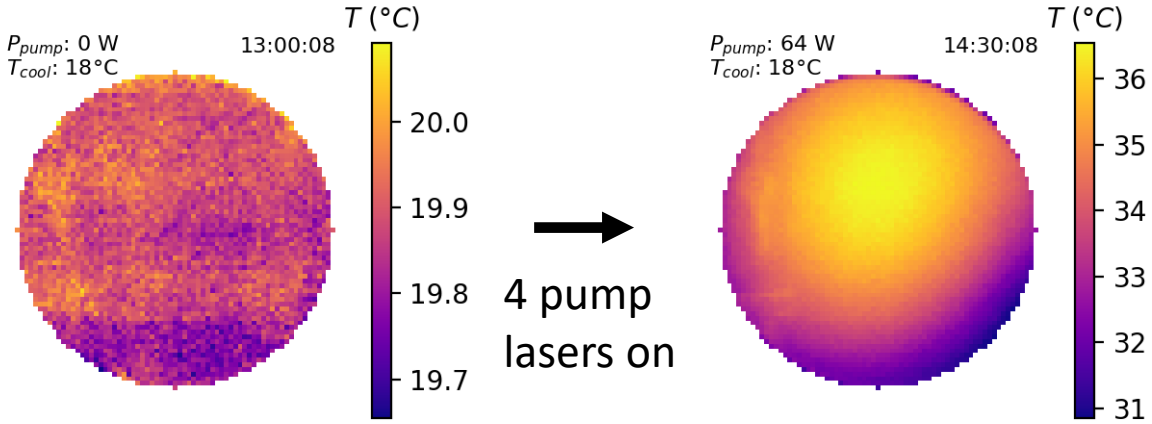

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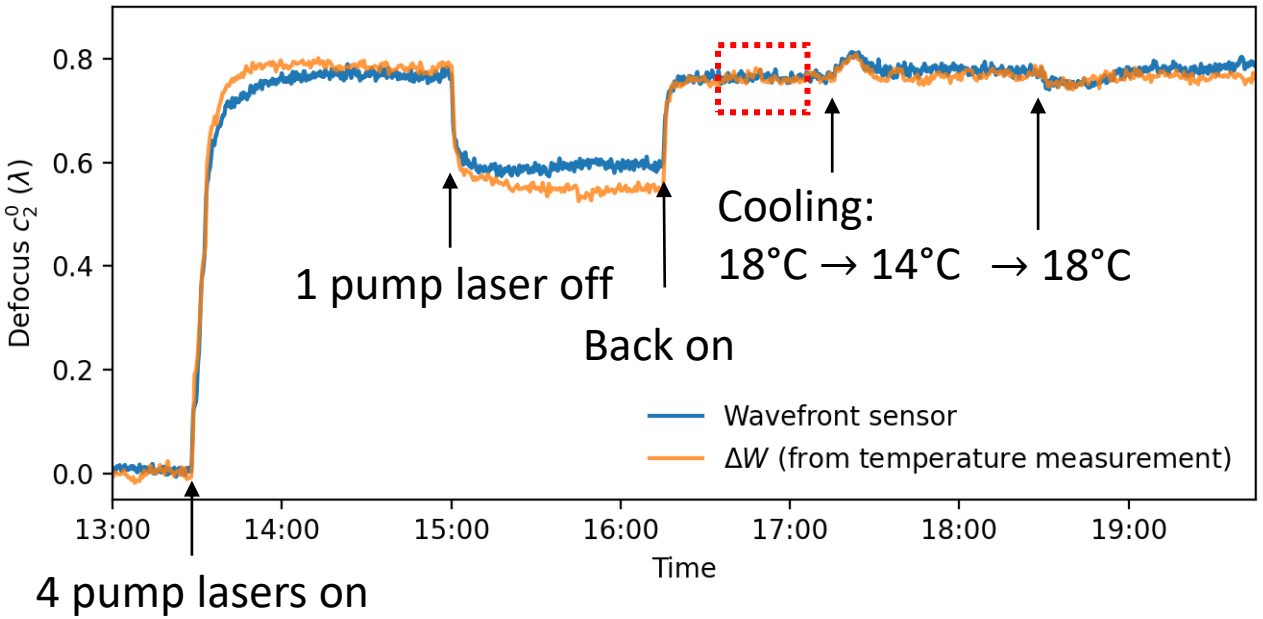

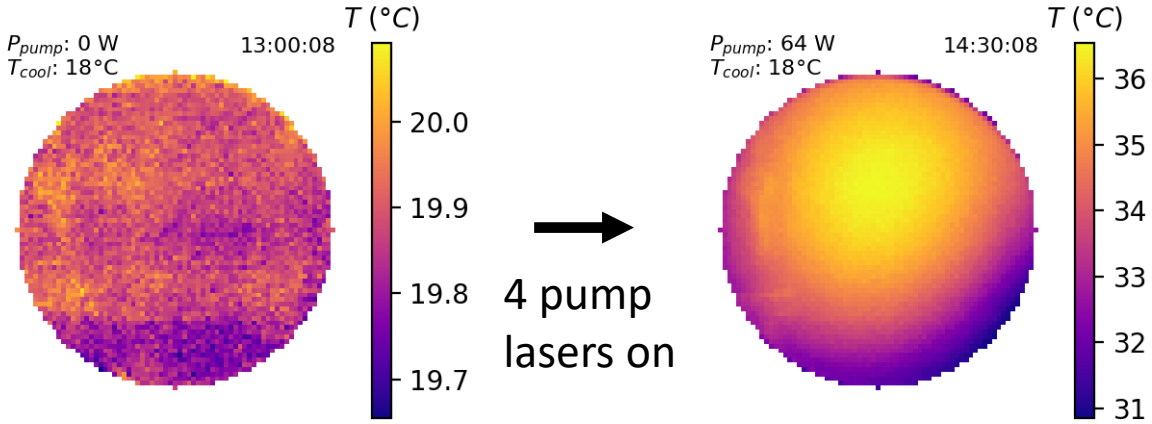

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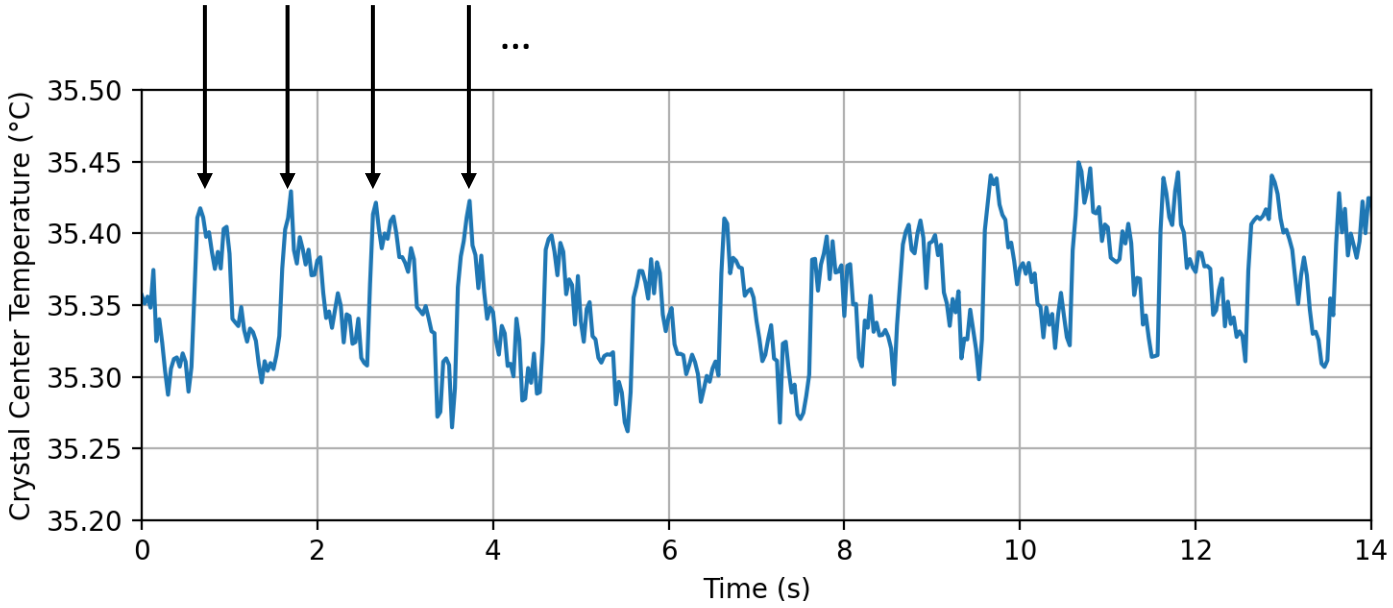
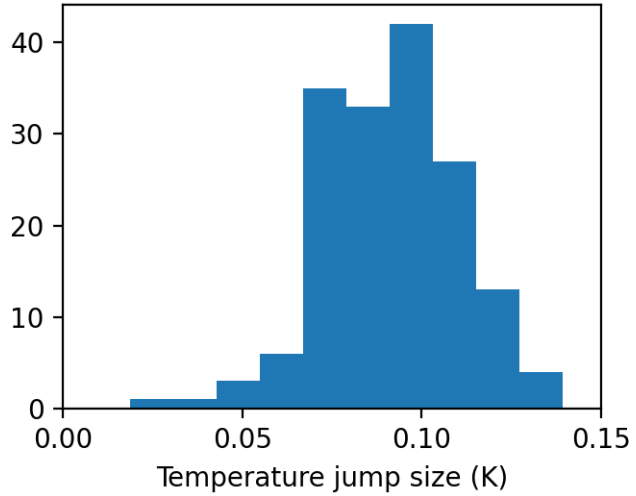
↓

Zernike decomposition at seed position

Pump-Induced Temperature Jumps

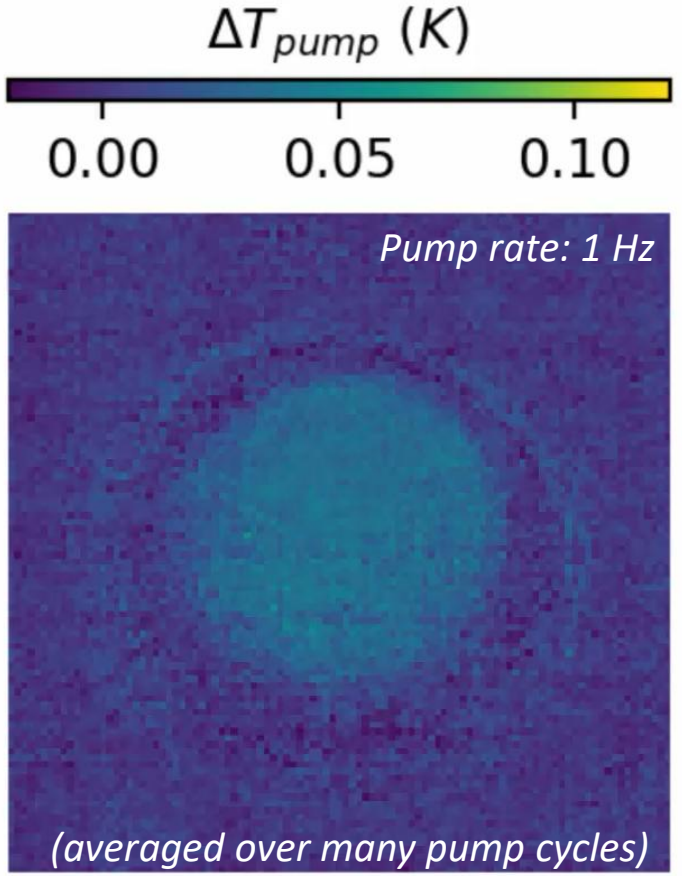
Sudden heating after pump shots



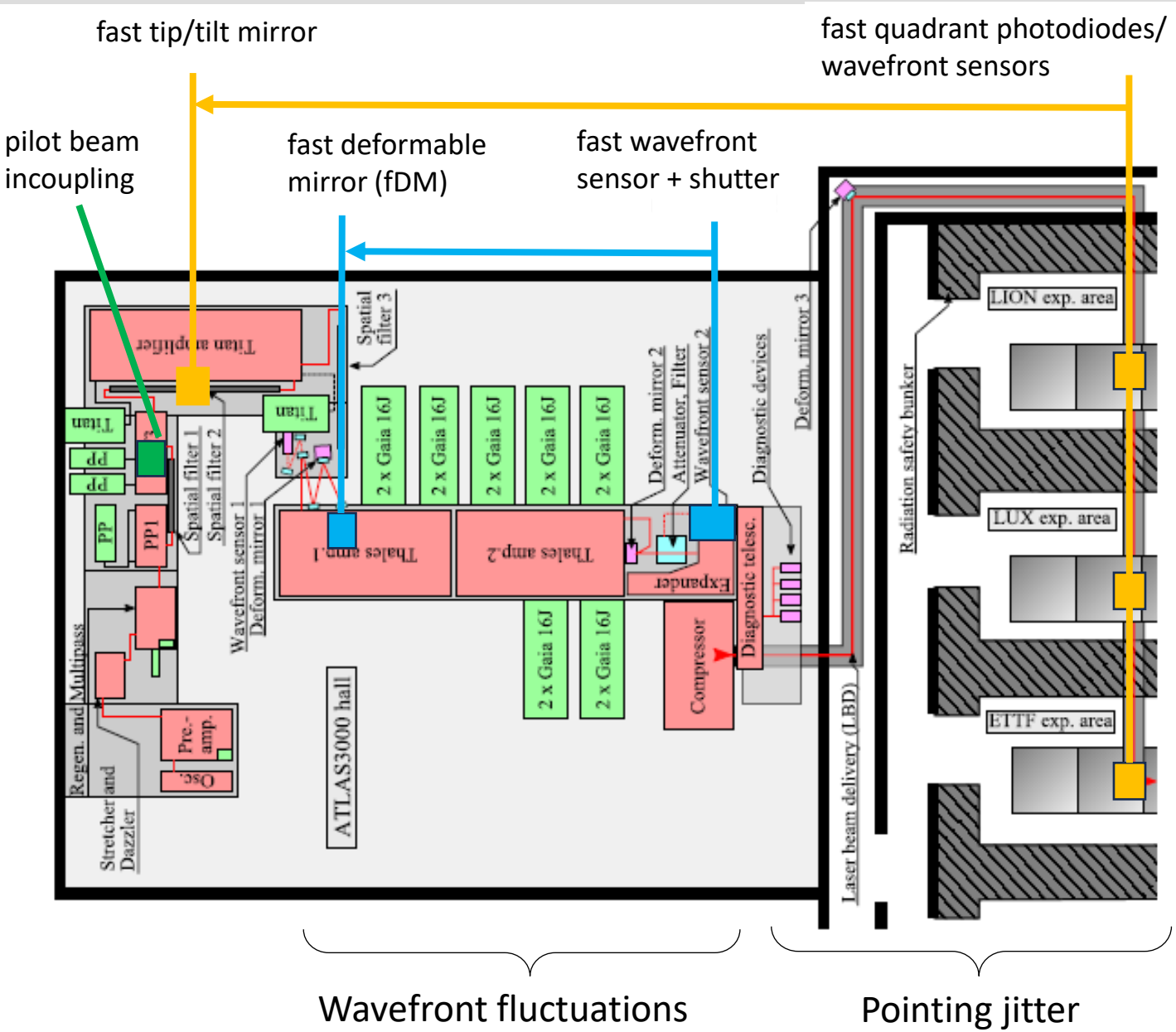


Correlation with defocus jumps?
Work in progress

Pump-induced heating of the crystal surface:



Outlook: Active Stabilization of ATLAS-3000



Currently starting to implement the pilot beam as a first step…