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ML Feedback for HI Jena Laser plasma accelerators

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High Energy Lasers

JETi200

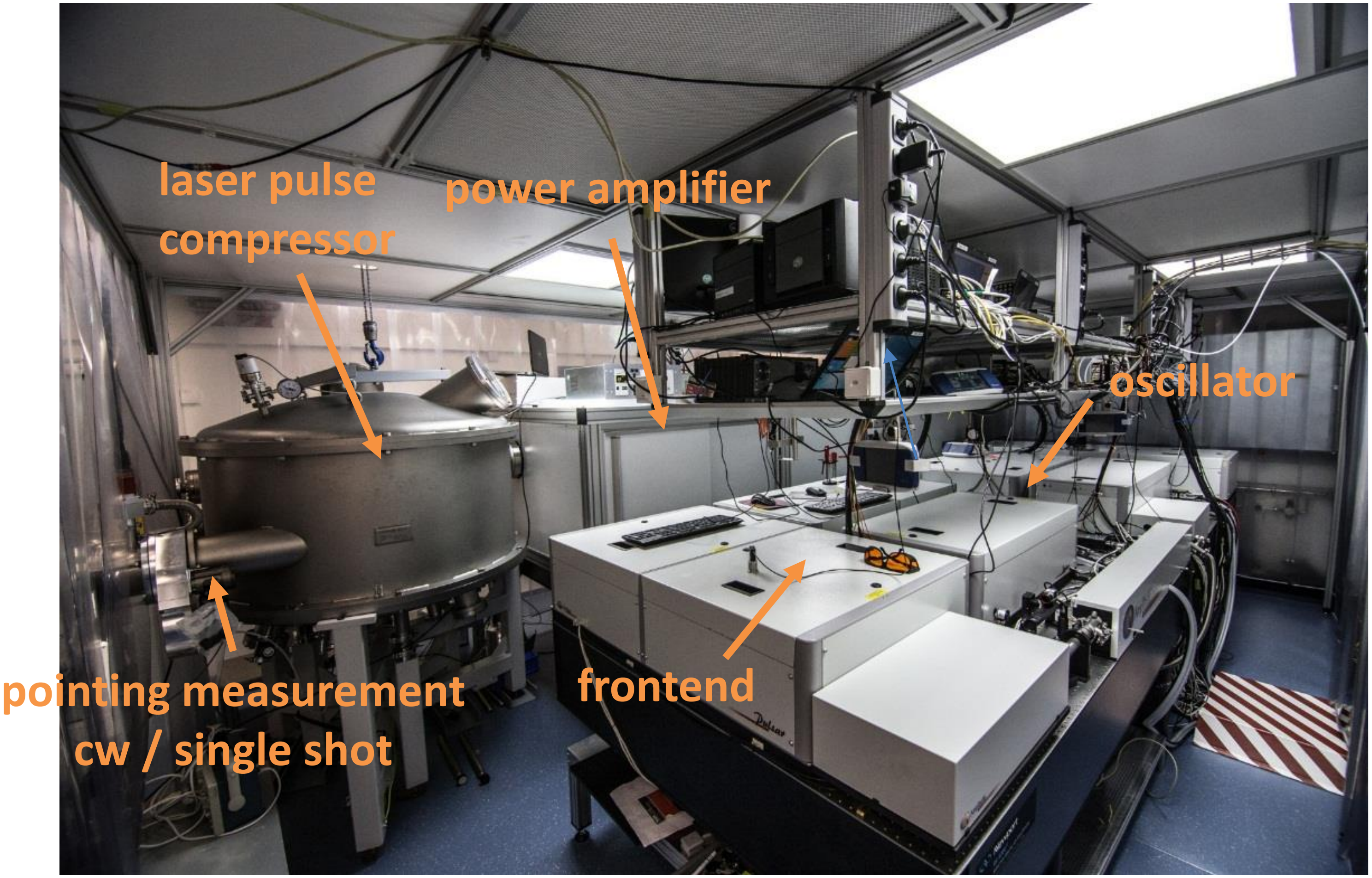
Wavelength: 800 nm
Medium: Ti:Sapphire
Energy on target: up to 5 J (4 J typical)
Pulse duration: 17 fs (20 fs typical)
Peak power: 300 TW
Repetition rate: 5 Hz
Probe beam: 5 fs

POLARIS

Wavelength: 1030 nm
Medium: Yb:CaF2, Yb:Glass
Energy on target: up to 20 J (Comp. limited)
Energy uncompressed: 54 J
Pulse duration: >90 fs
Peak power: >200 TW
Repetition rate: 1/40 Hz

JETi 200 – 200 TW Jenaer Titan Saphir Laser

Amplitude TECHNOLOGIES
Nothing but ultrafast.



Double CPA system with XPW filter
installation in 2013-2015

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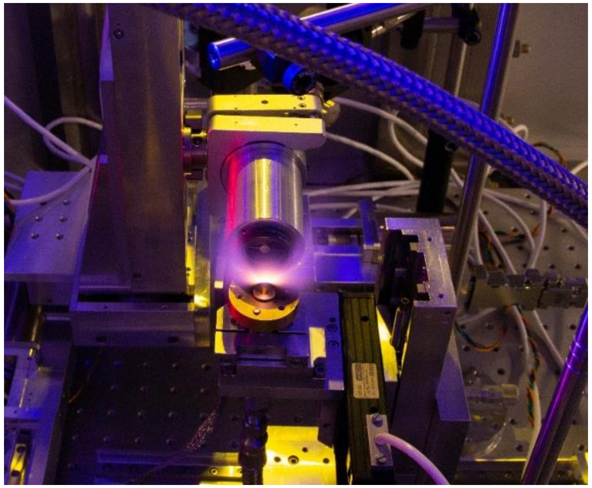
Optimizing Laser driven particle acceleration



Laser parameter for optimization

- energy
- focus (shape, position)
- pulse duration (chirp)
- temporal intensity contrast

Experimental parameters for optimization

- target gas
- target length
- focus position
- pre plasma conditions

PIC simulations

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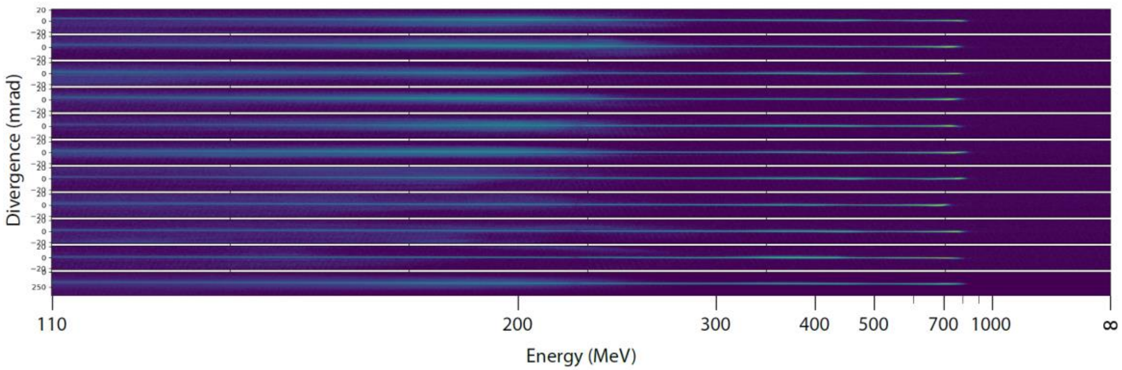
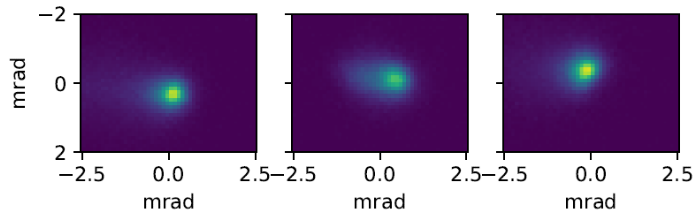
Acceleration electron bunches to GeV level

Electron bunch spectrum



Optimization parameter for particle beams

- peak energy
- bandwidth
- charge
- pointing



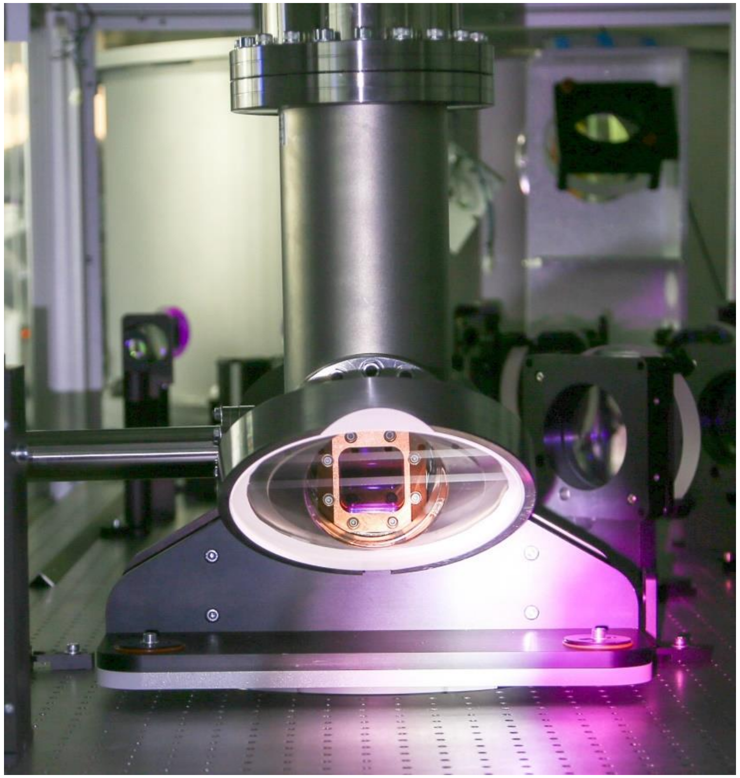
- GeV beams with ultra low beam divergence < 0.5 mrad^2
- pointing fluctuations on same order as divergence

Experiment

Online laser diagnostic (Xinhe´s talk) & control

PIC simulations

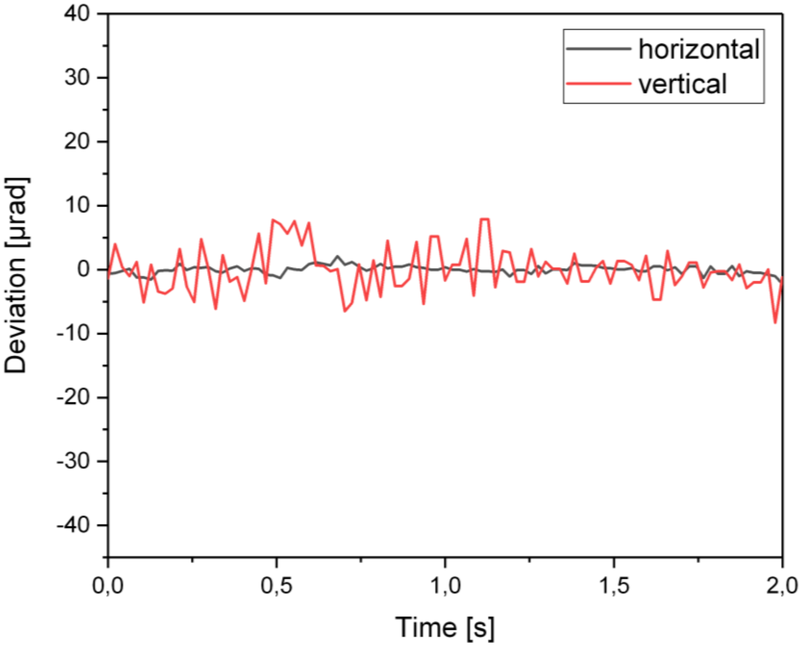
Cryo cooled power amplifier

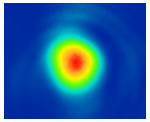


- 100 W pumping power @532 nm
- target temperature 90 K to reduce the thermal lens of the Ti:Sapphire crystal
- Helium expander cryo head

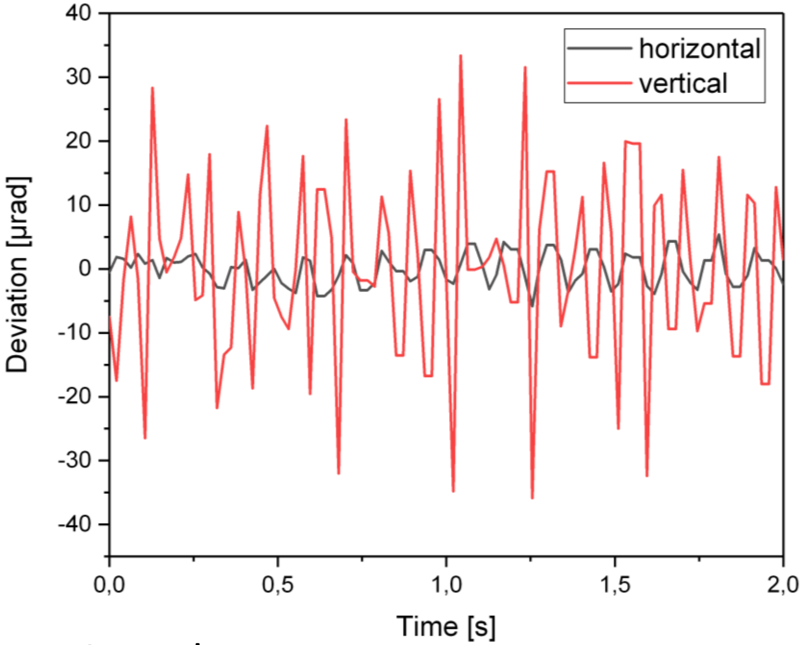
Beam stabilization (short term drift)

just laser & laboratory alone





cryo cooling switched on



Focal spot diameter: ~10 µrad

- **Short term jitter > 30 Hz**
- **Long term drift only depends on environment (temperature, humidity, air pressure)**

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Active beam stabilization

fast mirror ~ 1 kHz

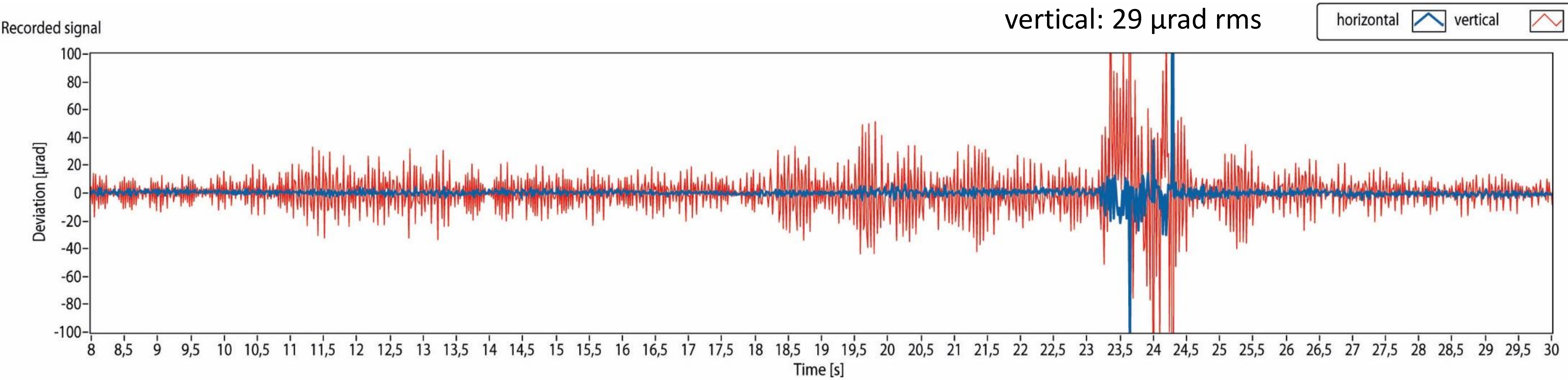
For online measurement: Use transmitted light through high reflective mirrors and focus the beam on the 4Q diode.

Challenge: - **cw**- pilot beam for continuous signal
- **single shot** full power beam for experiments

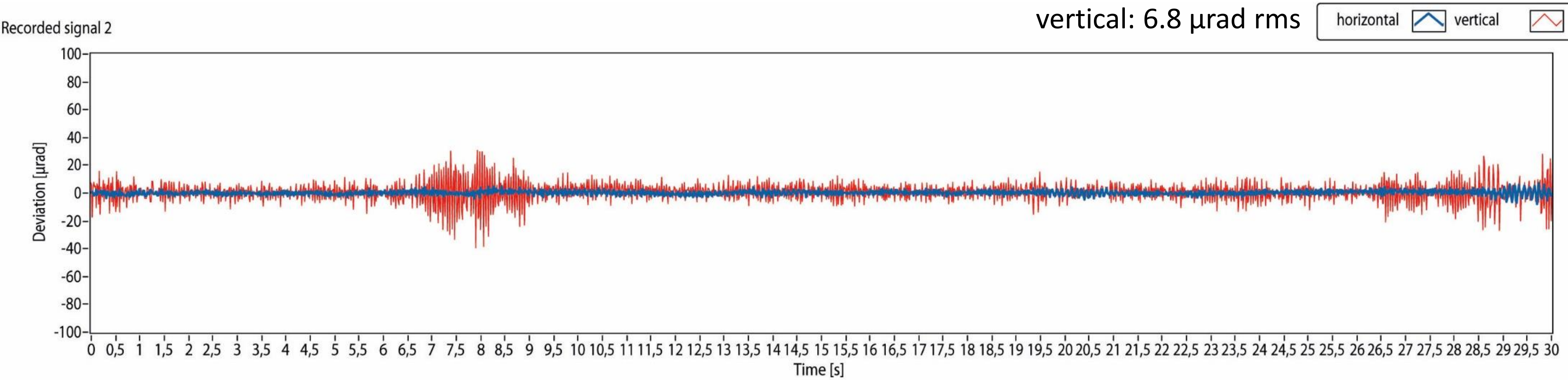
→ fast shutter to protect 4Q diode, but robust enough to withstand full power focused beam (closing time 30 ms, mirror stays put)

Active beam stabilization with cryo cooling

stabilization OFF
horizontal: 6 µrad rms
vertical: 29 µrad rms



stabilization ON
horizontal: 1.5 µrad rms
vertical: 6.8 µrad rms



Active beam stabilization

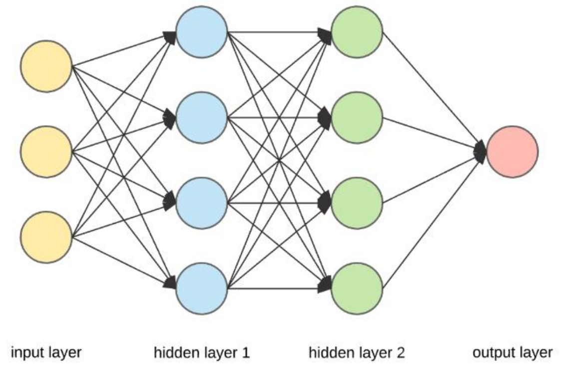
- needs an continuous online signal
- without pilot beam → put in hold position

- Shutter closing time > typical jitter period (>30 Hz)

- → **no active stabilization during high power shots**

Methods for prediction

- has to be fast enough (analysis + mirror motion+ spare time) < 30 ms

Machine learning / Neural network	Autocorrelation search
„real“ prediction 	searching for similar signals from a database fast but not accurate

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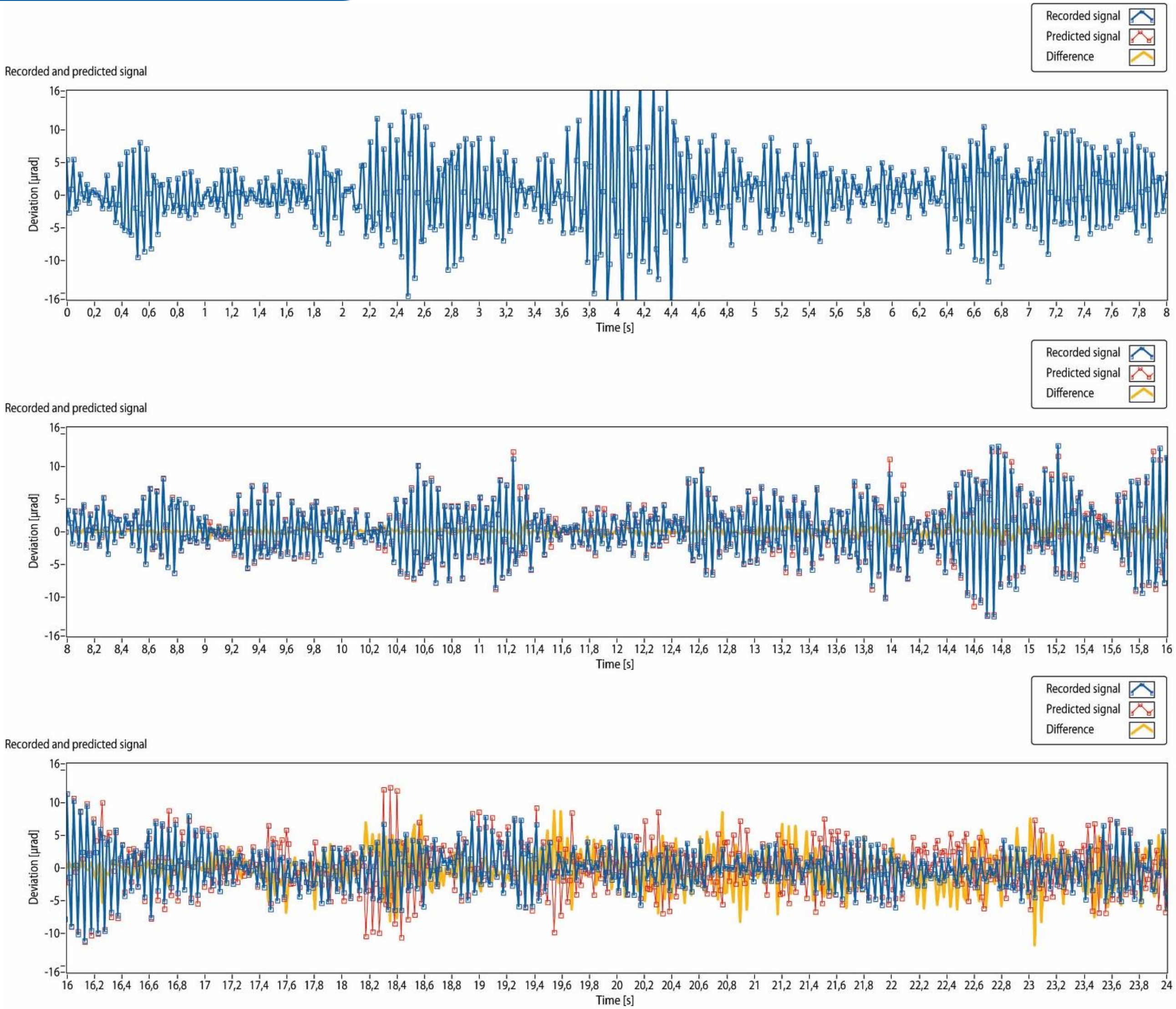
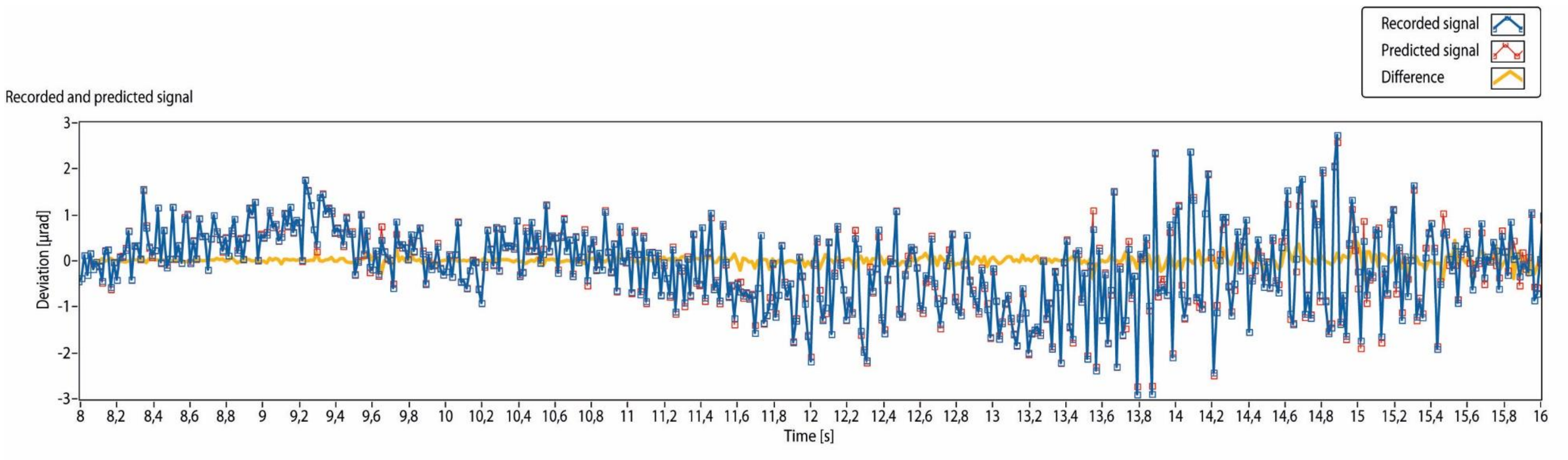
Results: neural network (vertical dev. medium jitter)



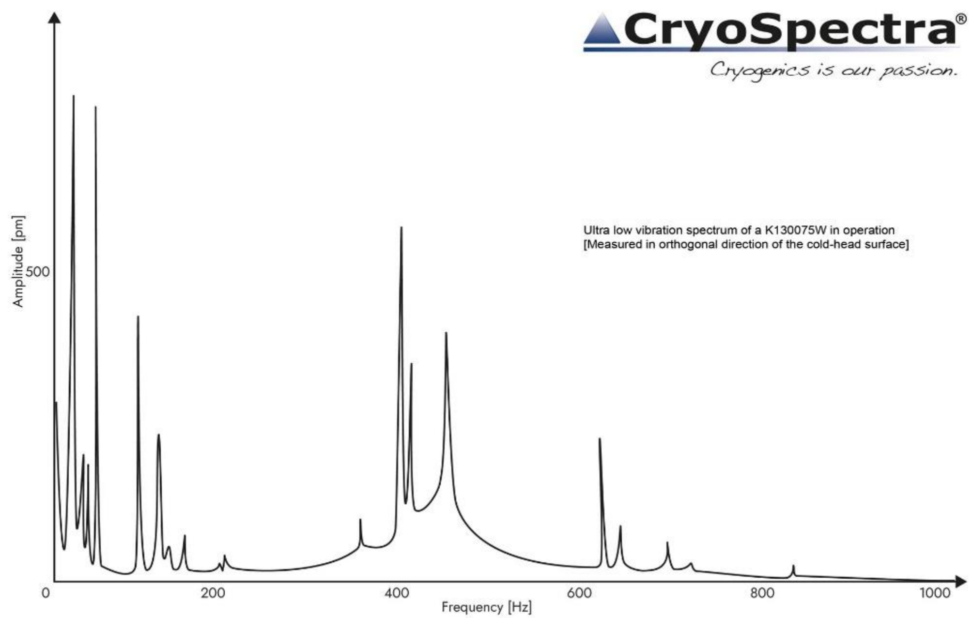
Results: neural network (horizontal dev. small jitter)



Eliminating the root cause

Remove the source of the vibrations ;)

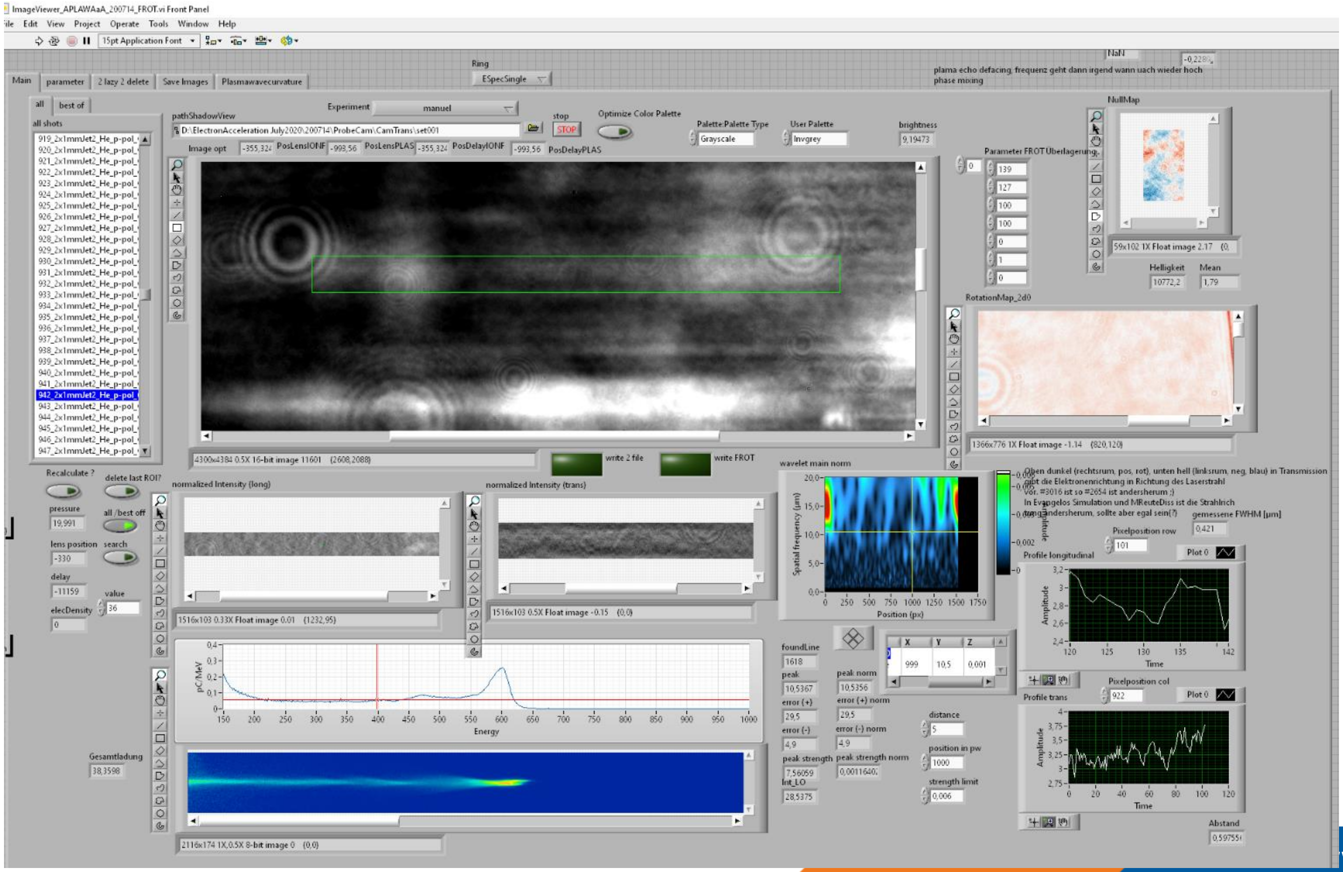
150 W @ 90K



+ use NN knowledge to reduce beam pointing jitter even further

Outlook for 2022

- So far: logging of laser parameter
- In 2022: Using Tango environment for control of experiments but a lot of legacy LABVIEW programs



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HI Jena extension (finished in 2022)

September 2021

Target Area Fraunhofer (TAF)

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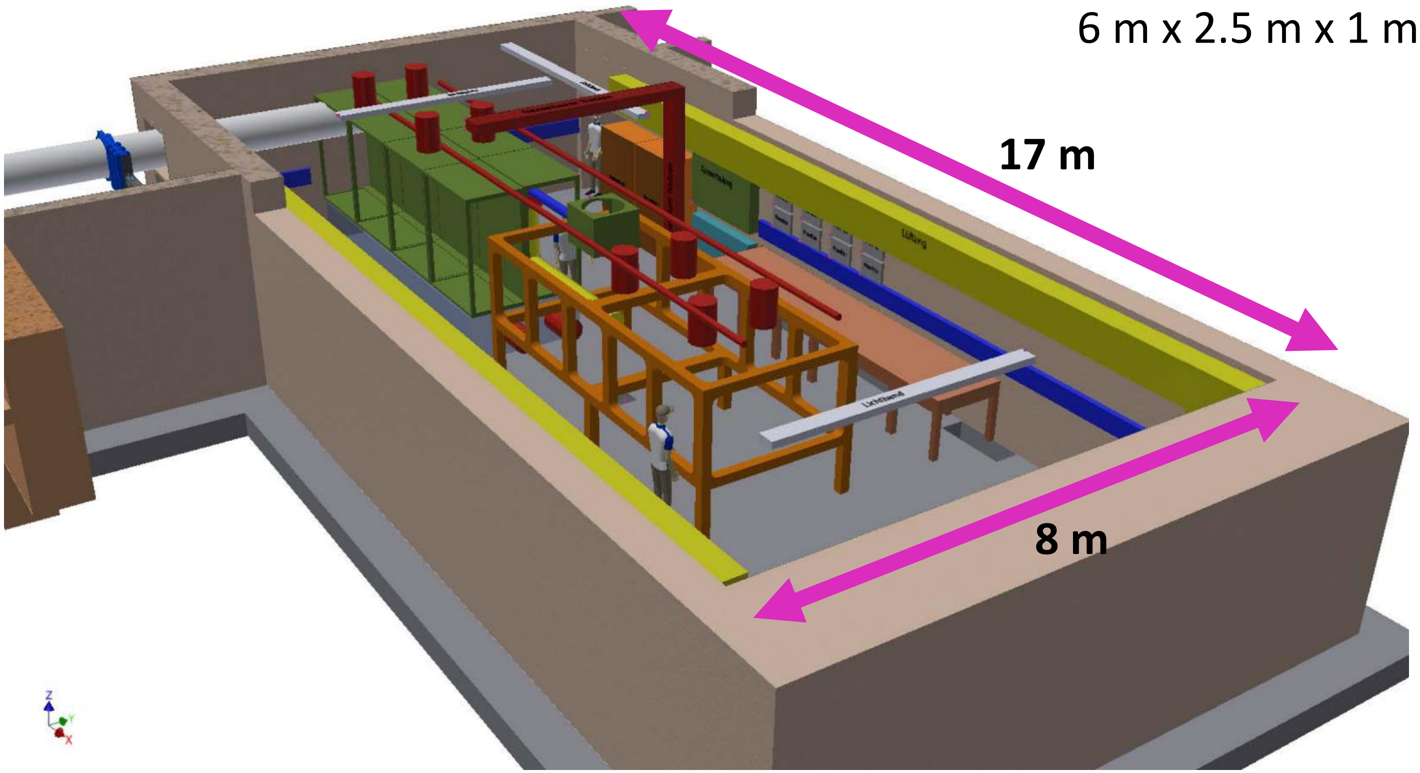
Target Area Fraunhofer -TAF

TOR-beam shaping chamber
6m x 2 m x 2 m

Experimental chamber
6 m x 2.5 m x 1 m

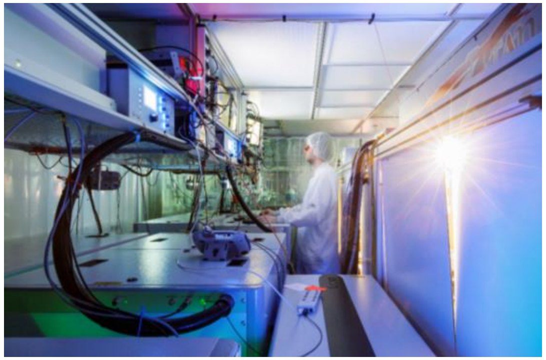


High intensity lasers @ HI Jena (2022)

JETi ONE

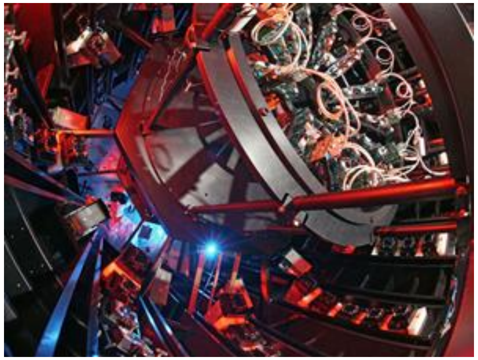
Wavelength: 0.8-7 µm
Energy on target: max. 7 mJ
Pulse duration: few cycle
Peak power:
Repetition rate: 1 kHz

JETi200



Wavelength: 800 nm
Energy on target: 5 J
Pulse duration: 17 fs
Peak power: 300 TW
Repetition rate: 5 Hz

POLARIS



Wavelength: 1030 nm
Energy on target: 16 J (54 J)
Pulse duration: 100 fs
Peak power: 160 TW
Repetition rate: 1/50 Hz

Goal: synchronisation of all beams <20 fs (rms) and < 2 µrad (rms) in new target area

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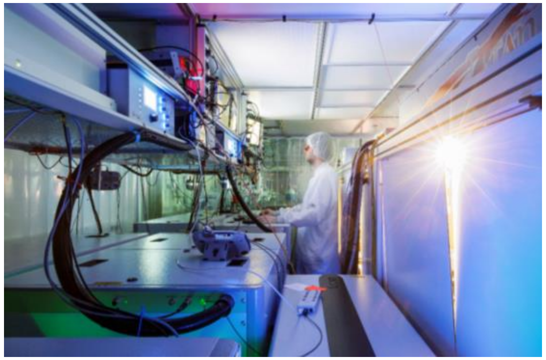
Target Area Fraunhofer -TAF

Targetarea Fraunhofer

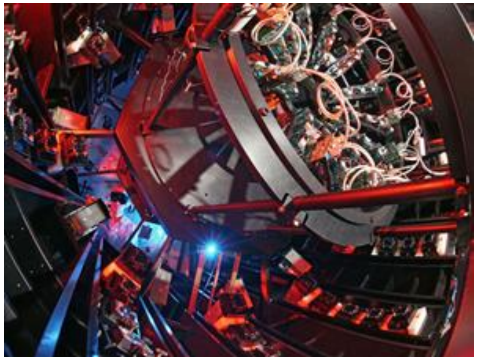
Synchronisation & control: toddler steps (2022)

JETi200



JETi ONE

POLARIS



MASTER

SLAVE

RF-synchronisation ca. 200 fs (rms)

SLAVE

active beam stabilization later

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Laser control system install base

- POLARIS control system adapted from PHELIX /GSI but most LABVIEW legacy
- JETi200 custom made CCM from Amplitude technologies
- JETiONE will be adapted

One control system needed!

Outlook beyond 2022

- Tango control system for controlling the laser, experiments and safety system (Tango + Siemens SPS)

- first steps: experiments & safety system (needed for new Target area,)

- Challenges -> Labview environment (Data aquisition, analysis, acceptance) keep GUI