Laser Development for LPAs at DESY

EuPRAXIA PP Annual Meeting
September 24, 2024

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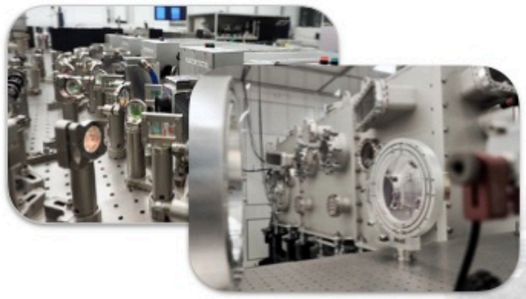
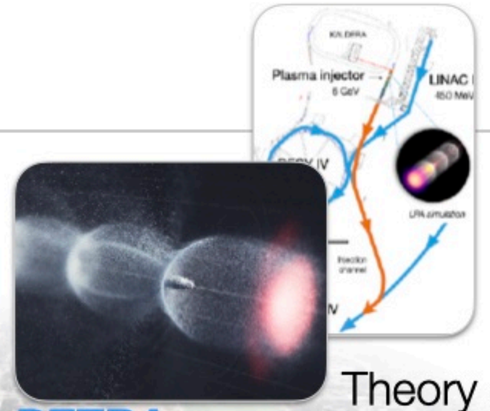
Photo: G. Palmer

Plasma R&D at DESY

Our portfolio at plasma.desy.de

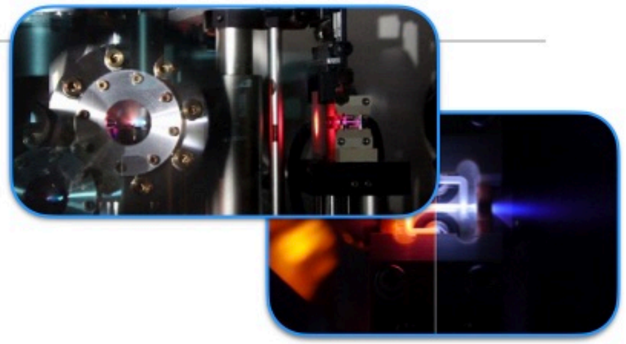
Scientific Engineering





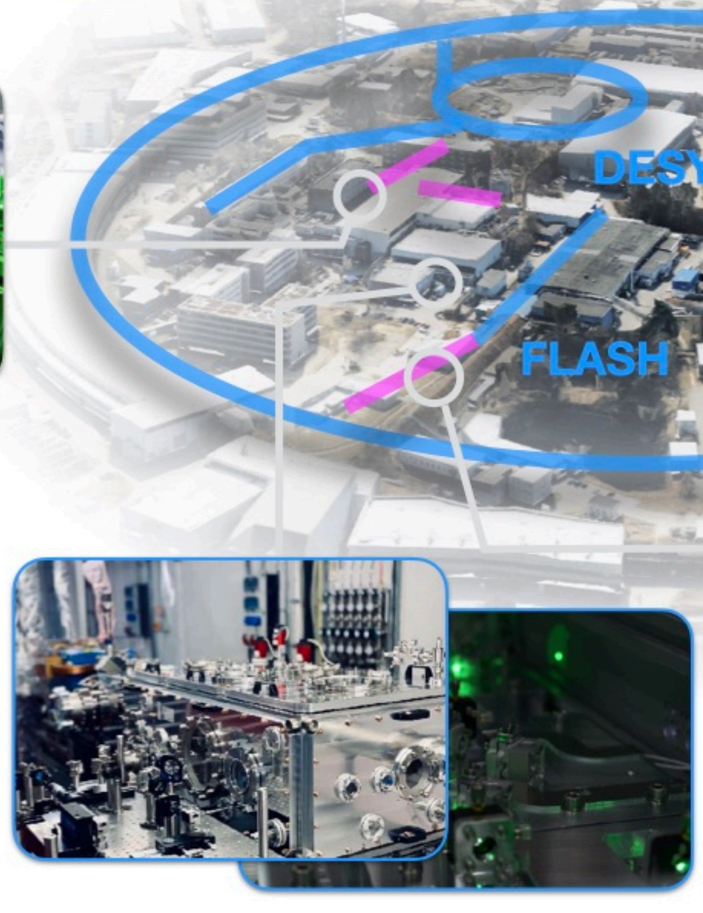
PETRA

Theory & Simulations



LPA Applications

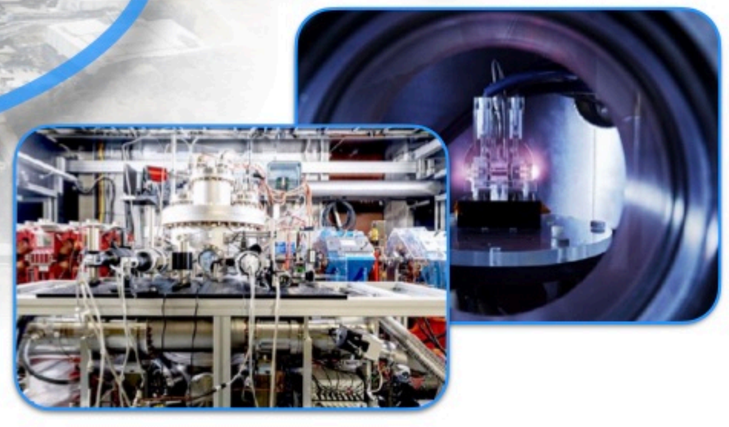
LUX Laser-Plasma Accelerator



RF accelerators

plasma accelerators

KALDERA
High Rep-Rate LPA



FLASHForward
Beam-Driven Plasma Acc.

The DESY Plasma Group

About 50 People and Growing

And of course Wim,
our division director

Maxence Thévenet
Team Leader
Theory & Simulations

Talk on Tuesday

Manuel Kirchen
Team Leader
High Average Power LPA

Talk on Tuesday

Guido Palmer
Team Leader
Laser Development

Lutz Winkelmann
Team Leader
Scientific Engineering

This talk is mostly on Guido's, Lutz', and Manuel's team

See our webpage at
plasma.desy.de
for a full list of teams
and activities.

Fig: Marta Mayer (DESY)

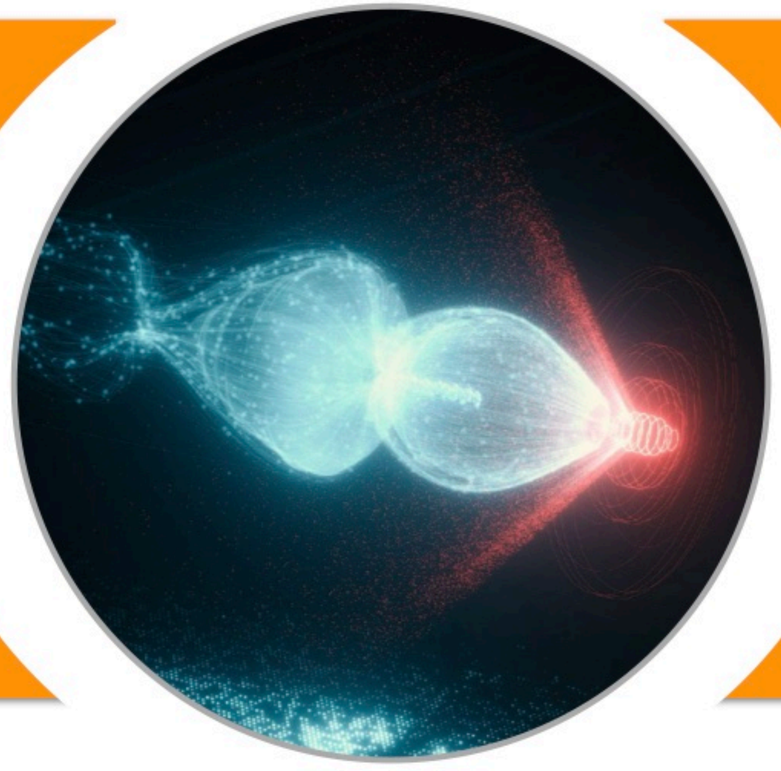
Challenges

As defined by the community in previous workshops, the CDR, the WP12 kick-off, …

Pump Lasers

Amplifier Design

Performance Model



Lab Infrastructure

Compressor

Operations

With our laser development and scientific engineering team, we contribute to developments in all those areas.

KALDERA: High Rep-Rate LPA

We are project-driven

Initiated by Wim

SciCom Lab, M. Kirchen; S. Jalas; DESY

High rep-rate LPA

> Active stabilization and feedback
> Full control-system integration
> Technology demonstrator

Phased approach

> Initially, 0.5J/30fs on target @ 100Hz (Phase 1, 2025)
> In 2026, upgrade to 3J/30fs @ 100Hz (Phase 2)
> Later, 100 TW @ up to 1 kHz (Phase 3)
> Success is defined by LPA performance, not by laser performance

KALDERA — Frontend

Status Summer 2024

credit: G. Palmer & team

The laser front-end operates at the final repetition rate of 1 kHz

MASUBI

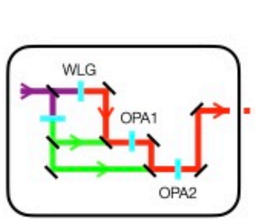
OPA seed
and front-end
Pump laser: Pharos
1 KHz, 25 fs BW, 40 µJ

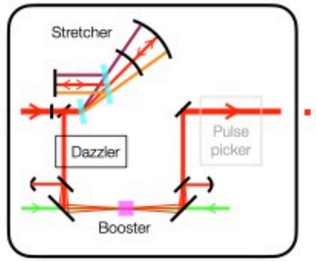
PICO

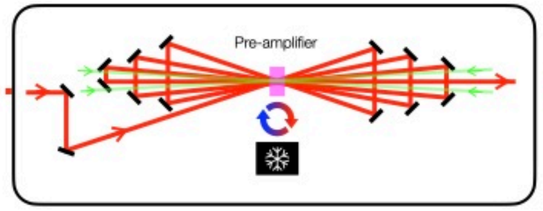
4-pass stretcher &
Booster Ti:Sa amplifier
Pump laser: Revolution
1 KHz, 600 ps, 1 mJ

MERAPI

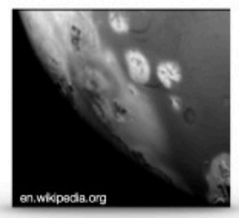
7-pass cryogenic
Ti:Sa amplifier
Pump laser: Revolution80
1 KHz, 600 ps, 40 mJ







Output:
40 mJ
600 ps
1 kHz
Completed



Seed laser (MASUBI)
T. Eichner et al., Opt. Express 31, 36915 (2023)
T. Hülsenbusch et al., Opt. Express 32, 23416 (2024)

Stretcher
C. Werle et al., Opt. Express 13, 37437 (2023)

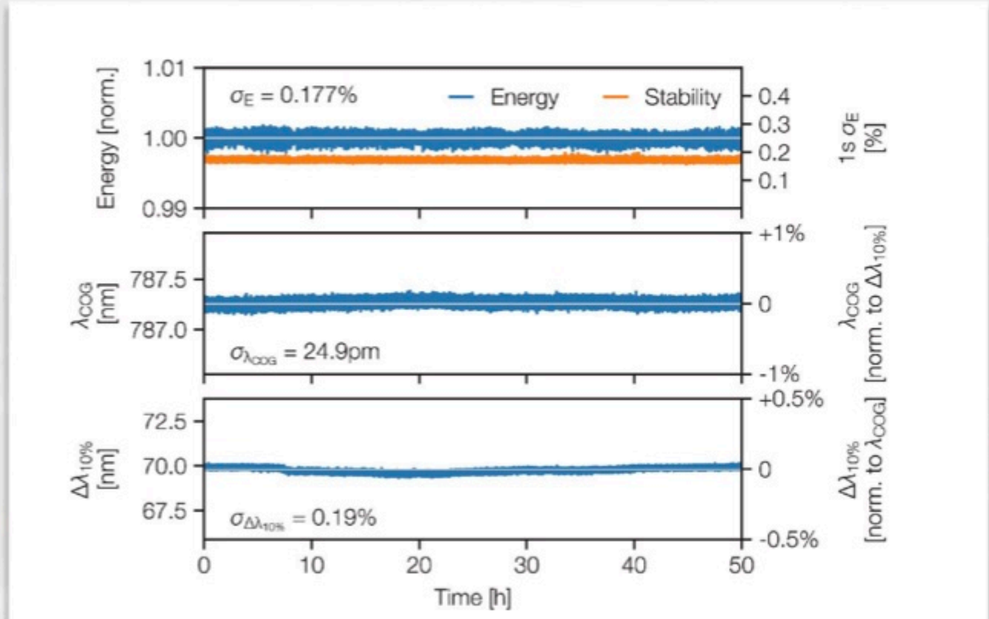
KALDERA — Frontend

Status Summer 2024

Frontend

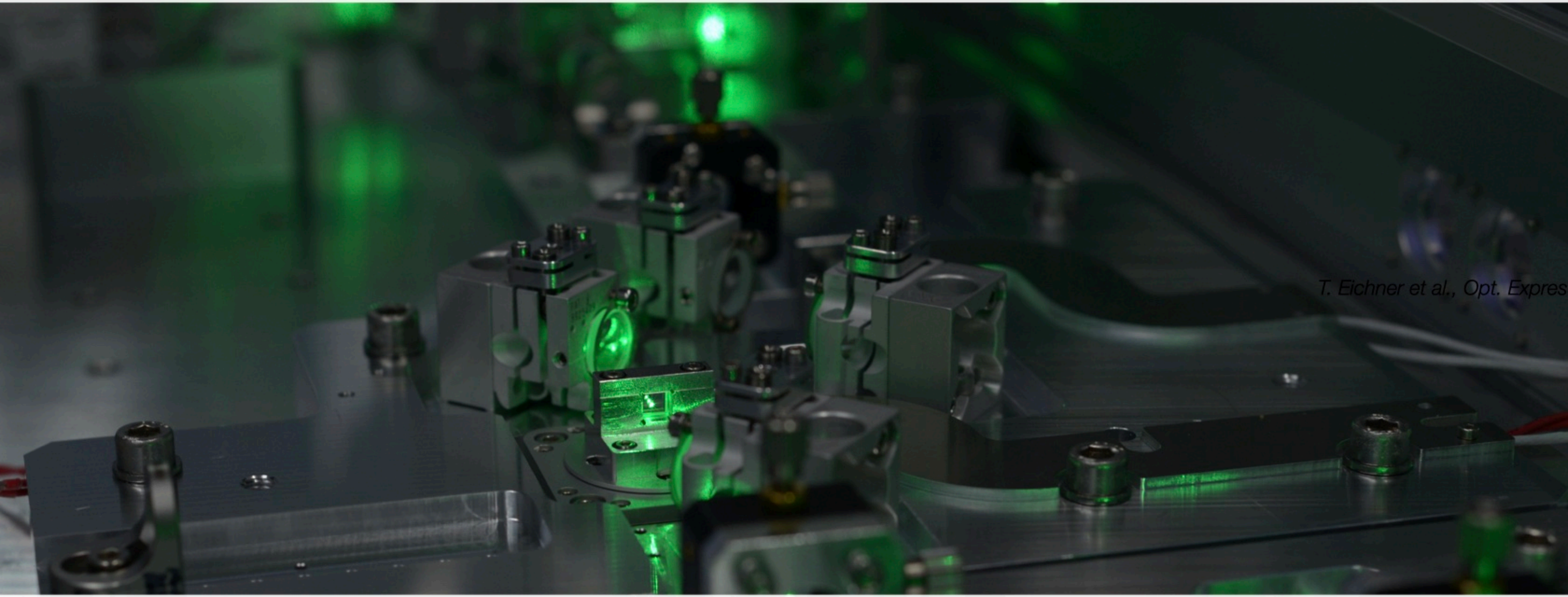
> White light seeded OPCPA
> 40µJ @ kHz
> 25fs bandwidth
> 0.17% energy stability over 50hrs
> Auto-tuning to reproducible working points using machine learning

T. Eichner et al., Opt. Express 31, 36915 (2023)



KALDERA — Frontend

Status Summer 2024



T. Eichner et al., Opt. Expres

The frontend is our testbed for laser engineering and ´monolithic design concepts.

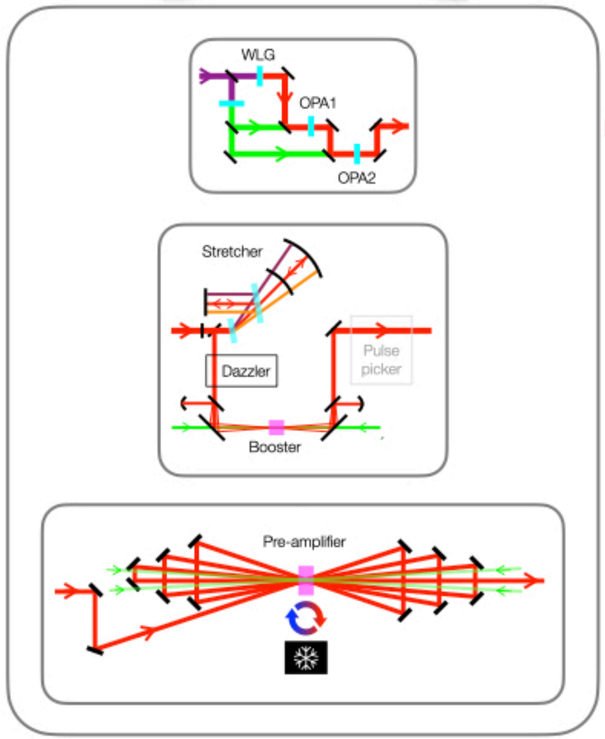
KALDERA — First Amplifier

Status Summer 2024

credit: G. Palmer & team

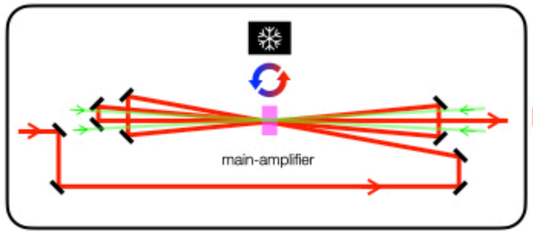
Laser Frontend

OPCPA
Stretcher
Ti:Sa amplifier
1 kHz, 600 ps, 40 mJ



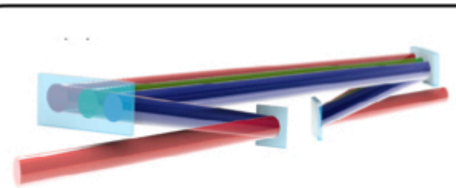
COLIMA

4-pass cryogenic
Ti:Sa amplifier
Pump laser: EVO4
100 Hz, 600 ps, > 0.5 J



TAUPO

In-vacuum
out-of-plane
MLD compressor
100 Hz, 25 fs BW



Goal:

On target:
>0.3 J
30 fs
100 Hz
Expected 2025

Compressor
C. Werle et al., Opt. Express 13, 37437 (2023)

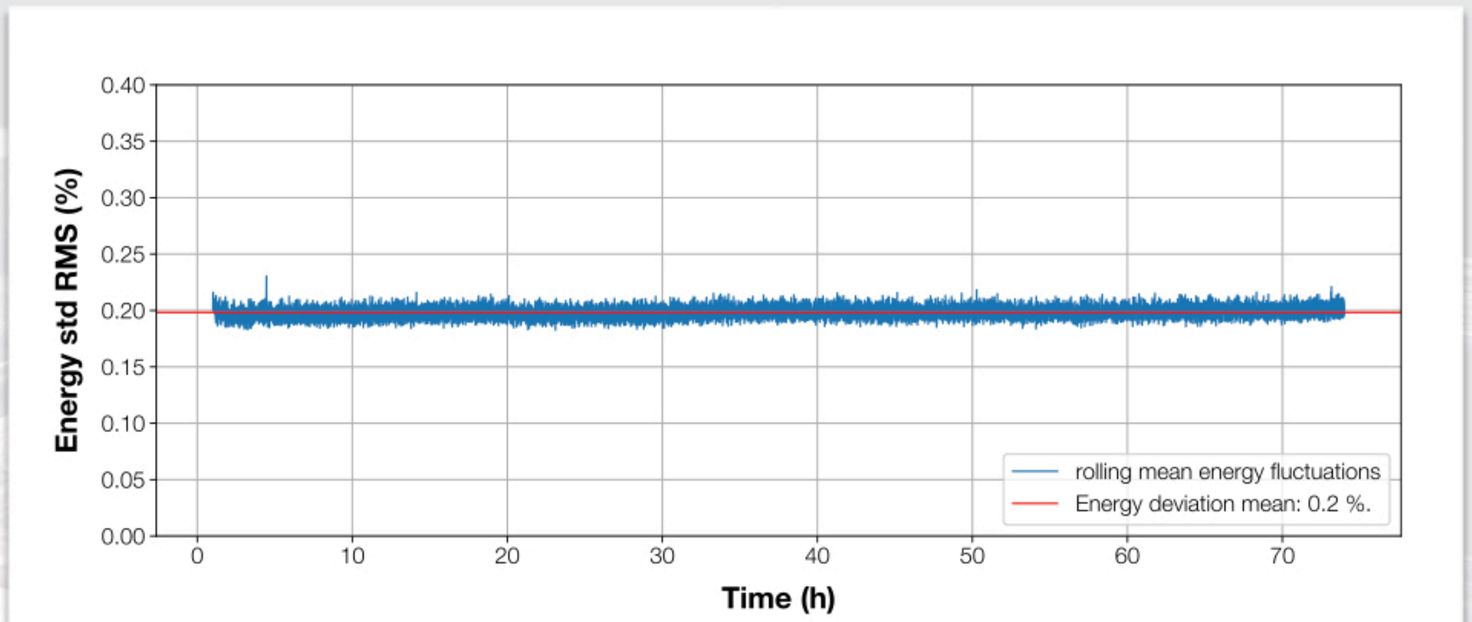
KALDERA — Pump Laser

Status Summer 2024

Thanks to Matthias Resch and his team

Selected pump lasers for 100 Hz operation
> Innolas EVO Series
> 1 kW (green) total pump power
> 100W per system
> Diode pumped
> Excellent performance

Continuing to evaluate pump laser options for future kHz operation.



KALDERA — Amplifier Commissioning

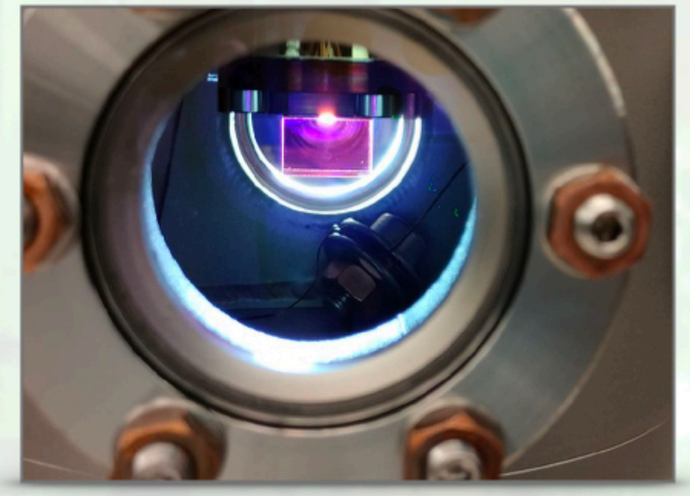
Status Summer 2024

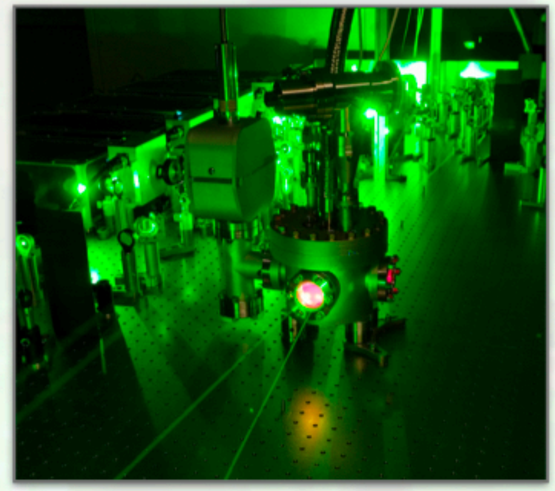
credit: G. Palmer & team

PreAmp (MERAPI)
> 40mJ @ 1kHz up and running
> Cryo-cooled Ti:Sa

AMP1 (COLIMA)
> Just started commissioning
> 500mJ @ 100Hz up and running
> Cryo-cooled Ti:Sa
> Currently optimizing beam properties and implementing beam path stabilization

Great cooperation with Franz Kaertner and Mikhail Pergament group at DESY on crystal and cryo technology.





KALDERA Compressor

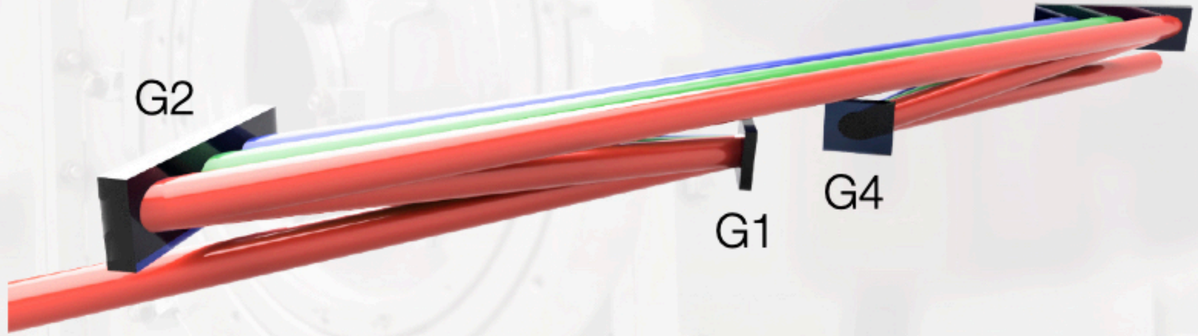
Status Summer 2024

credit: G. Palmer & team

G3

- Multi-layer gratings in an out-of-plane geometry
- Verified concept at low energies — MLD OOP compressors have sufficient bandwidth to support 25fs pulses
- So far, LIDT tests are promising
- 100W-level compressor under commissioning

We plan to use the same concept for a future kHz version.



C. Werle et al., Opt. Express 31, 37437 (2023)

KALDERA: Laser-plasma acceleration

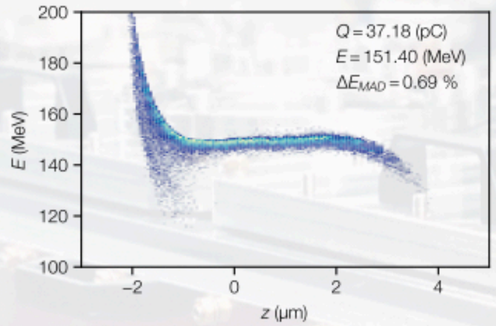
LPA for Phase 1 - MAGMA

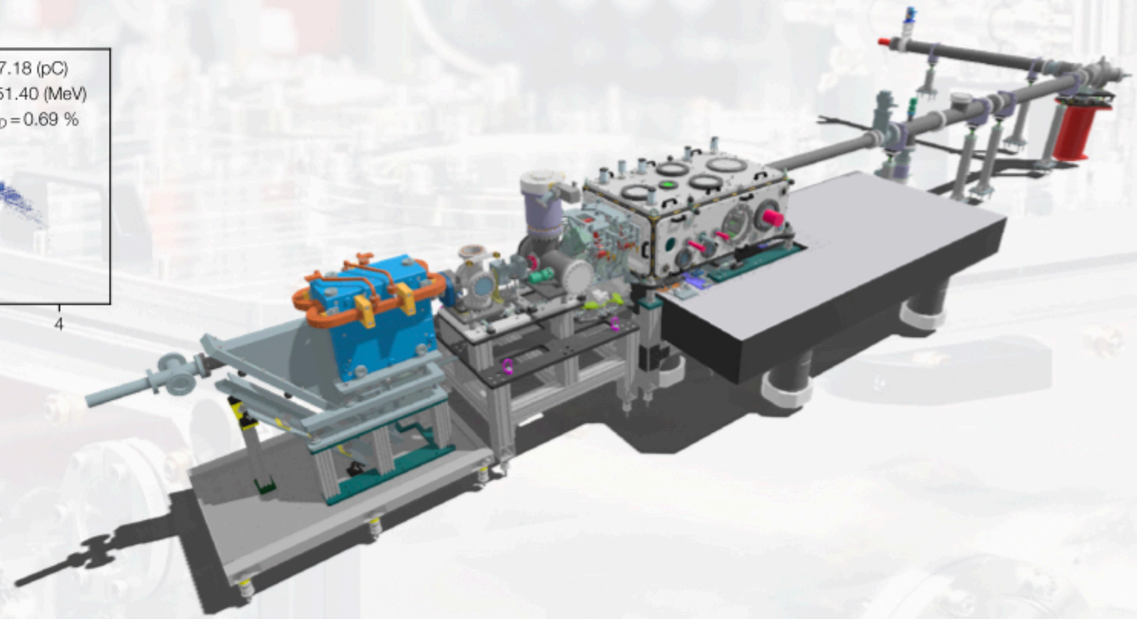
credit: M. Kirchen & team

Our mission

> 100 MeV @ 100 Hz
> Completely integrated with laser system
> Testbed for active stabilization systems
> Demonstration of sub-percent electron energy stability

Currently under commissioning.
Going online later in 2025.





Some Challenges

From the past three years

credit: G. Palmer, L. Winkelmann & their teams

Building a numerical toolbox

> Gain simulations using actual spectra and beam profiles
> Thermal simulations
> Cross-check of simulations and experiments
> Custom codes

Components

> Supply of non-linear and gain crystals
> Quality control of components
> Availability of representative LIDT data

Control System

> kHz data acquisition, especially using cameras (our solution: FPGAs with on-device data processing)
> Event synchronization & timing

Laser development

> Beam propagation and shaping
> Thermal management of components
> Laser safety, beam dumps and shutter concepts
> Diagnostics

Pump lasers

> Commercial solutions available for 100Hz systems
> Our requirements w.r.t. stability are very demanding

Scientific engineering

> Vacuum technology
> Custom optomechanics
> CAD integration
> Cryo technology
> Electronics

We’re looking forward to discuss and share experiences.

Thanks

Special thanks to the whole plasma & laser development group at DESY, and especially all technical groups for support.

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Group Leader

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Fig: SciCom Lab