KALDERA

A high-average power LPA drive laser

EAAC
Sept 22nd, 2025

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kaldera.desy.de

Photo: G. Palmer

The DESY Plasma Group

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And of course Wim,
Director Accelerator Division

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Coordinator
Plasma Injector

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High Average Power LPA

Guido
Team Leader
Laser Development

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Team Leader
High EnergyLPA

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Team Leader
Theory & Simulations

Jon
Team Leader
Beam-Driven Plasma Acceleration

Kris
Team Leader
LPA Applications

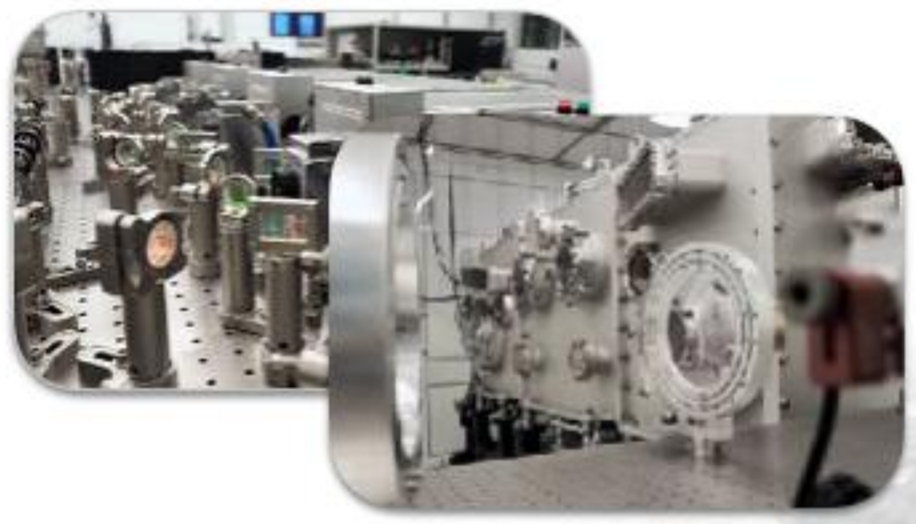
Lutz
Team Leader
Scientific Engineering

Andi
Coordinator
Scientific Infrastructure

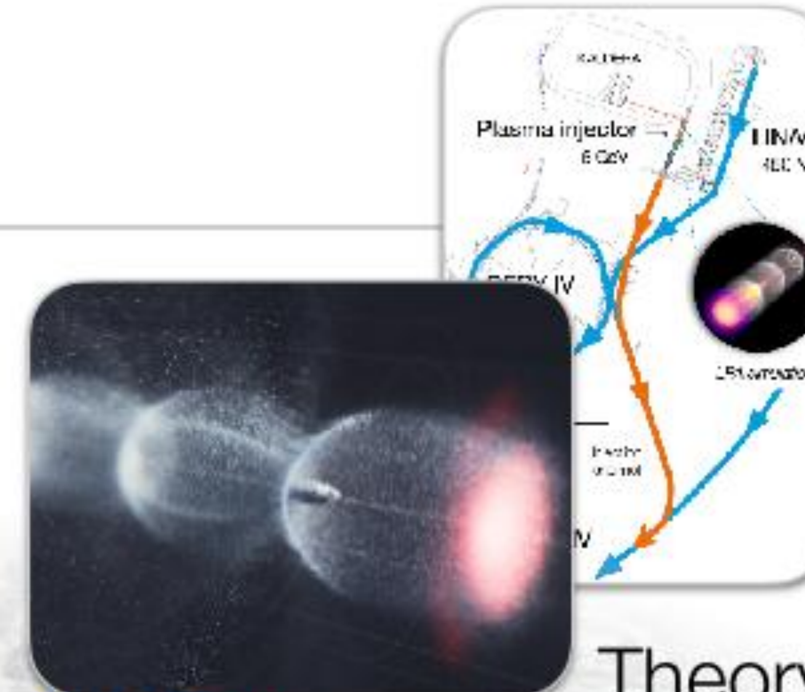
Kaja
Scientific Project Management

Plasma R&D at DESY

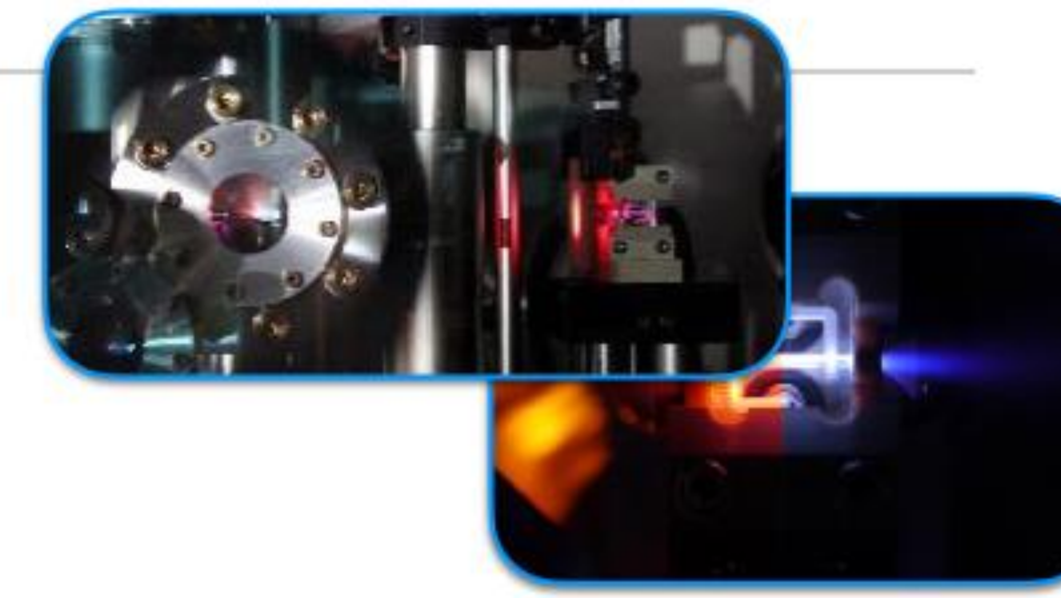
Our portfolio at plasma.desy.de



Scientific Engineering

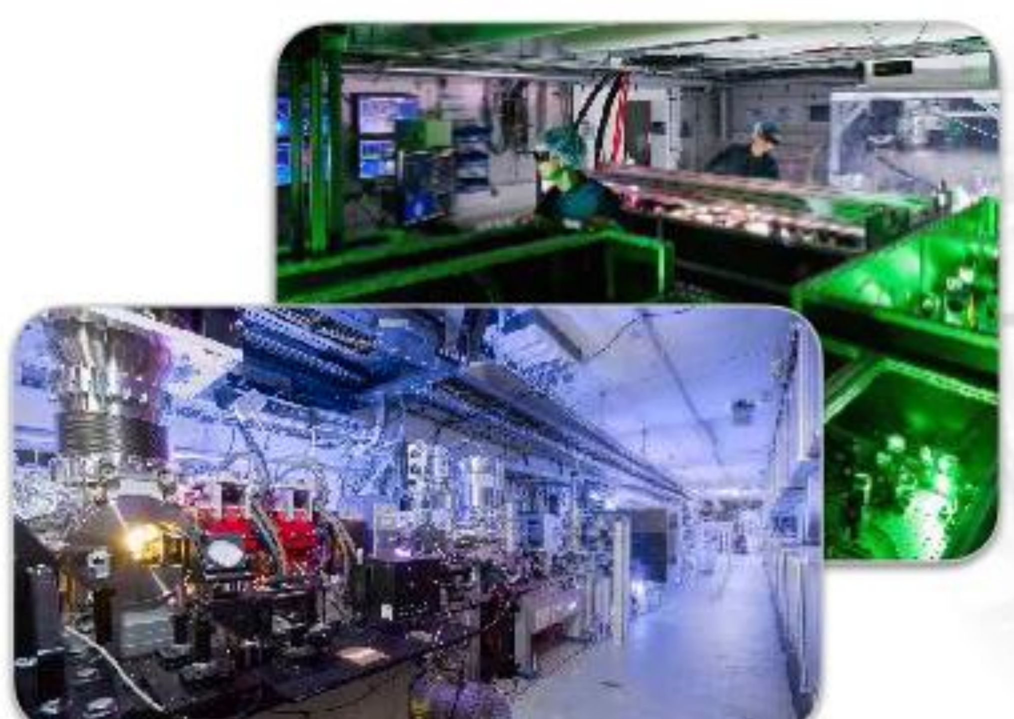


Theory & Simulations



LPA Applications

- RF accelerators
- plasma accelerators



LUX Laser-Plasma Accelerator

KALDERA High Rep-Rate LPA

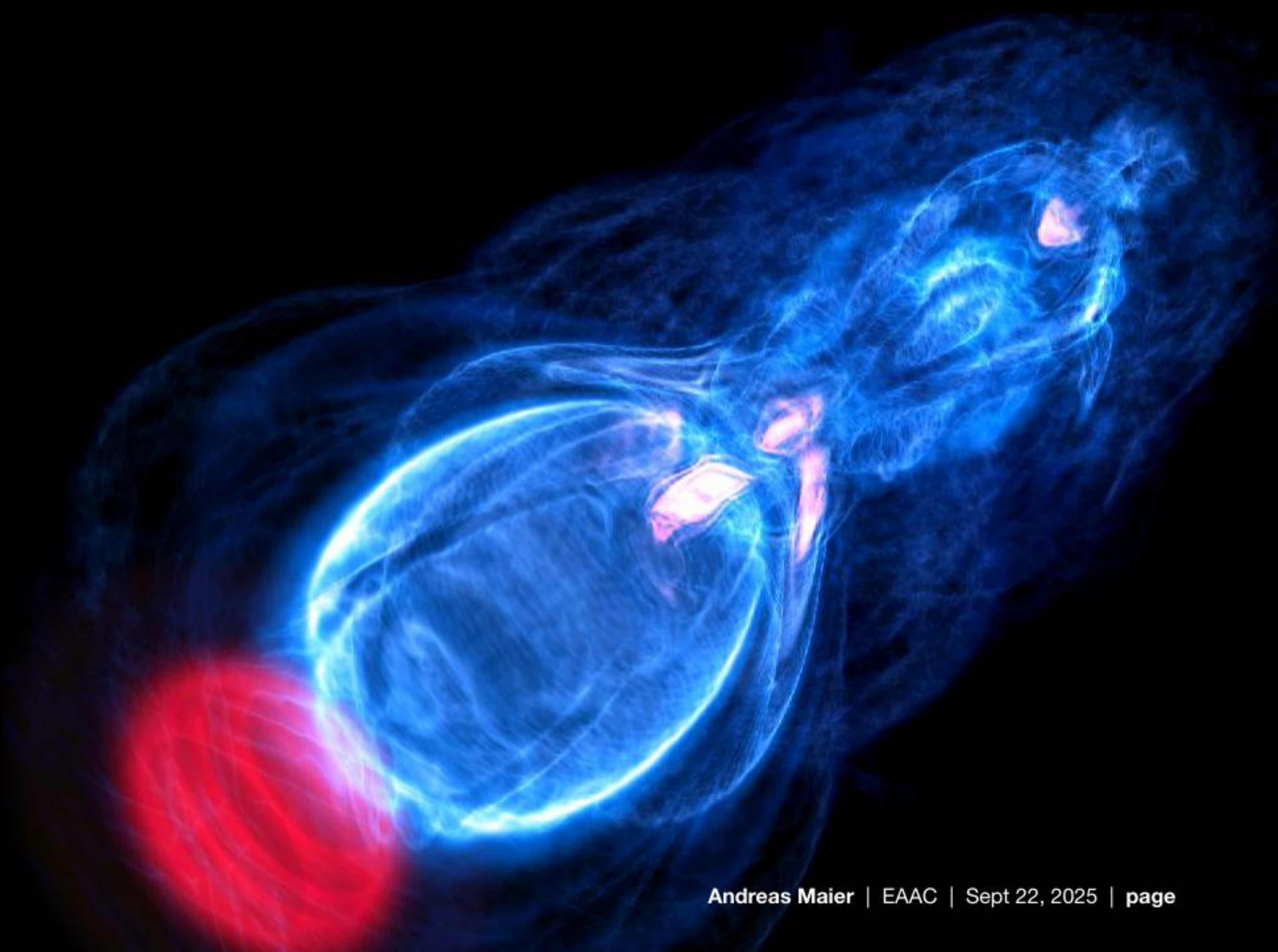
FLASHForward Beam-Driven Plasma Acc.

Laser-Plasma Acceleration

Details matter

A new accelerator cavity with every shot

Subtle variations in the drive laser pulse effect the electron beams.



Chasing quality on shaky ground

Percent-level jitter prevents further performance improvements

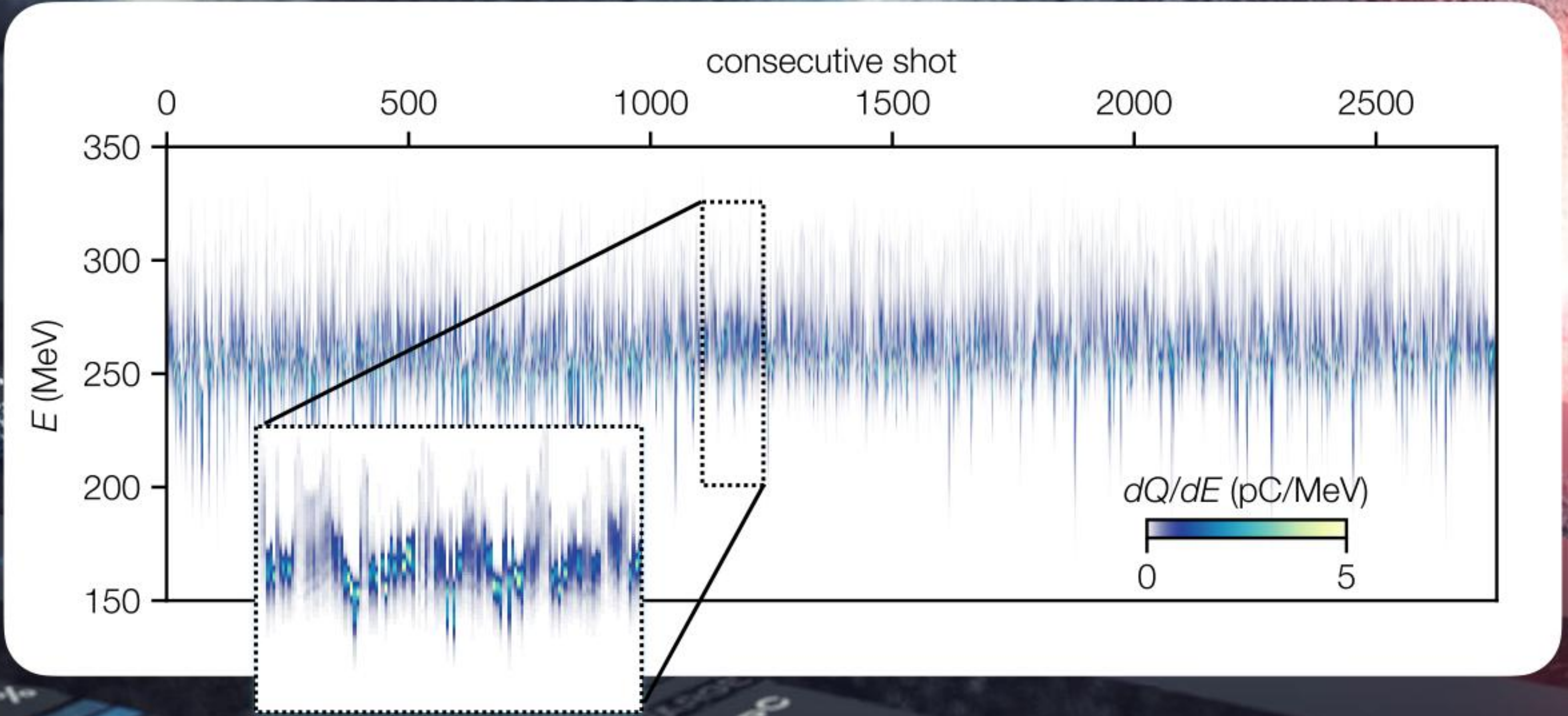
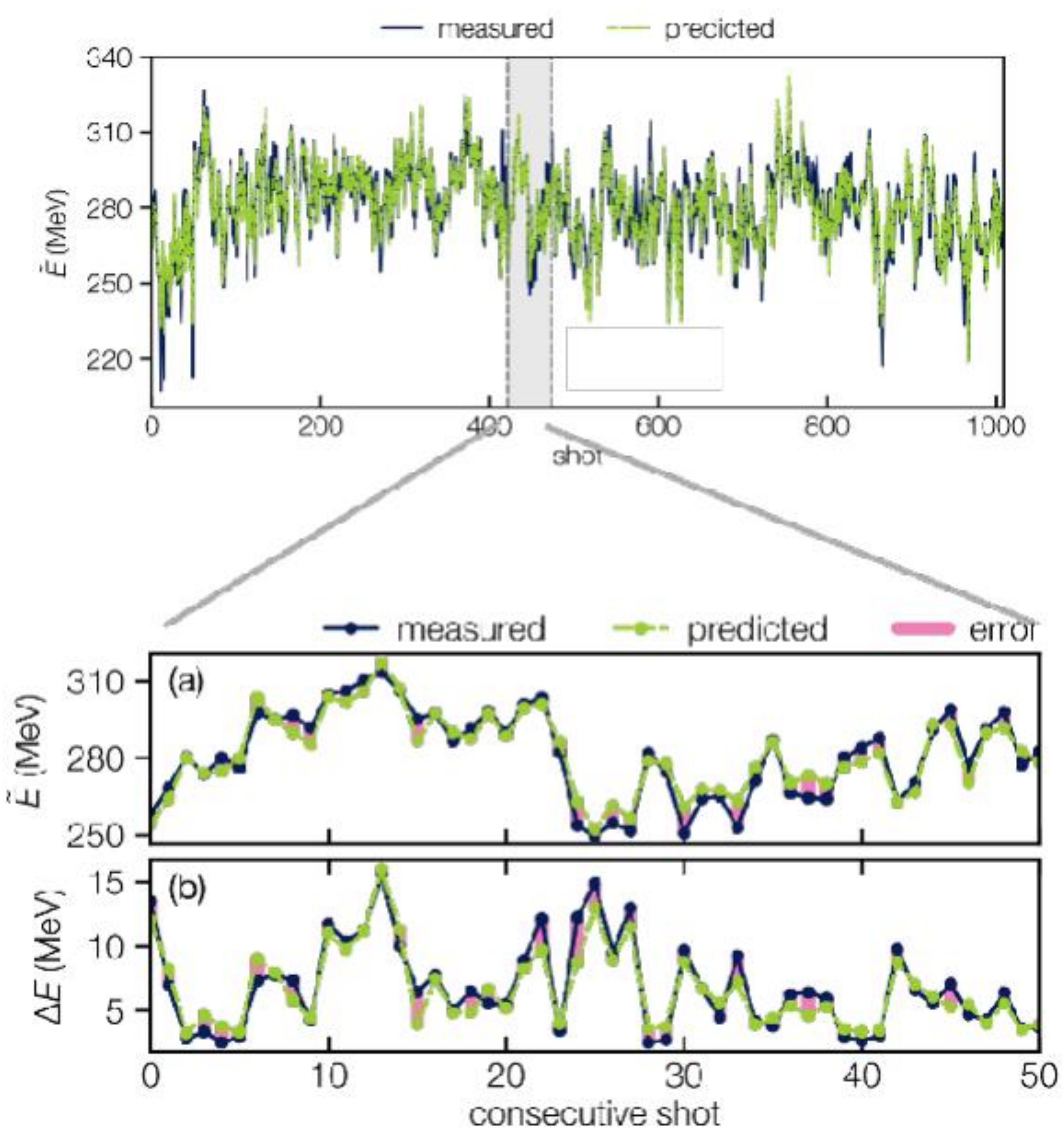


Illustration: SciComLab
Slides: M. Kirchen

Experiments make the case for high rep rate

Active stabilization and feedback will enable high-quality LPA electron beams

M. Kirchen et al., Phys. Rev. Lett. 126, 174801 (2021)



> We can correlate laser properties and electron beam properties on a single-shot basis
> (Good news: Physics is still deterministic)

> We have a recipe how to improve the electron beam performance:

1. Optimize injected phase space, e.g., optimum beam loading, controlled injection, …
2. Deploy active stabilization and feedback to get the good beams more often

KALDERA: High Rep-Rate LPA at 100Hz and Above

Deploy active stabilization and feedback

Initiated by Wim

High rep-rate LPA

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

Goal

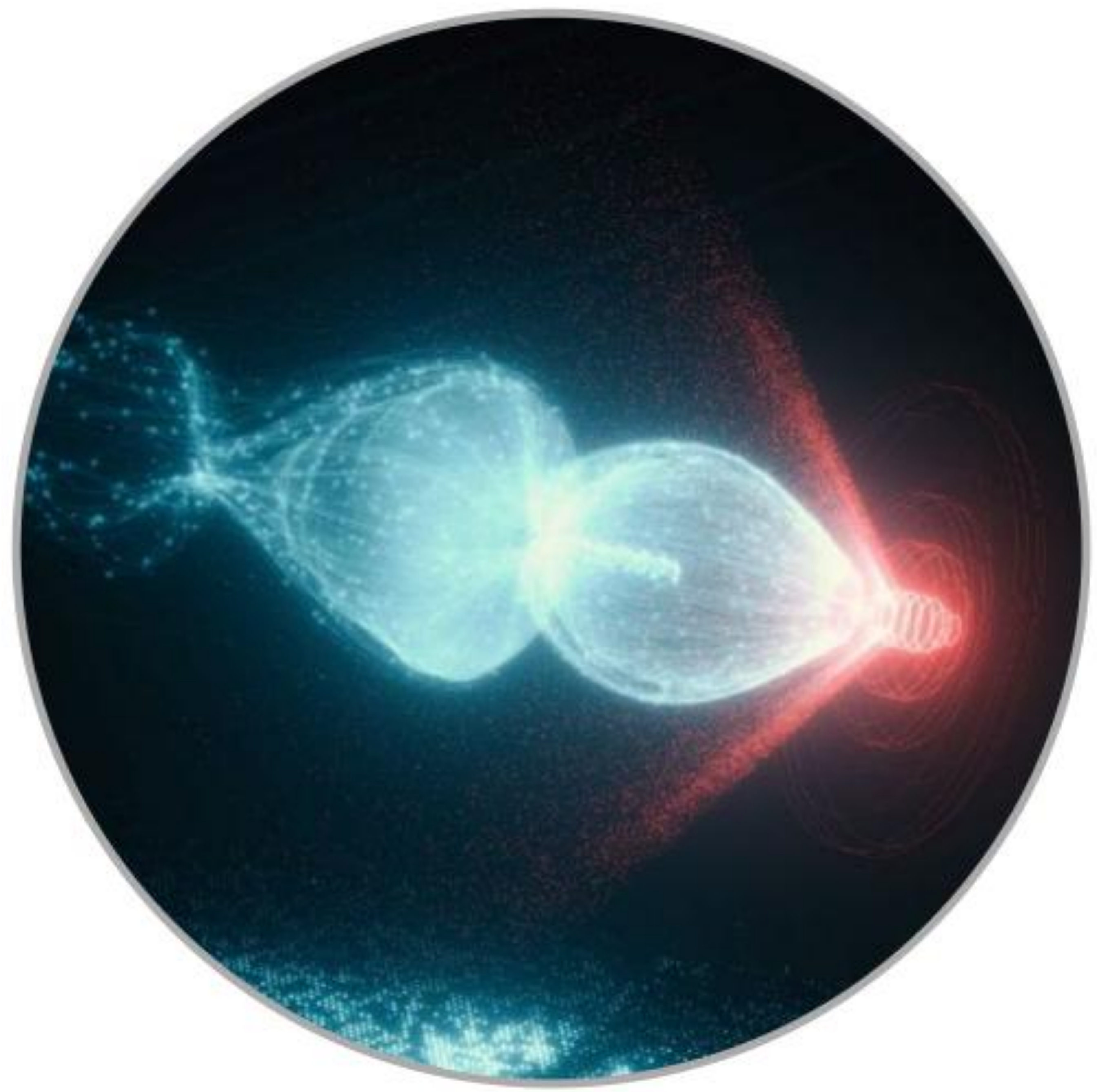
- 100TW at up to 1kHz
- High quality electron beams
- Success is defined by LPA performance, not by laser performance

Some Challenges

Specifically for a Ti:Sa-based kW-class LPA drive laser

Pump Lasers

Amplifier Design



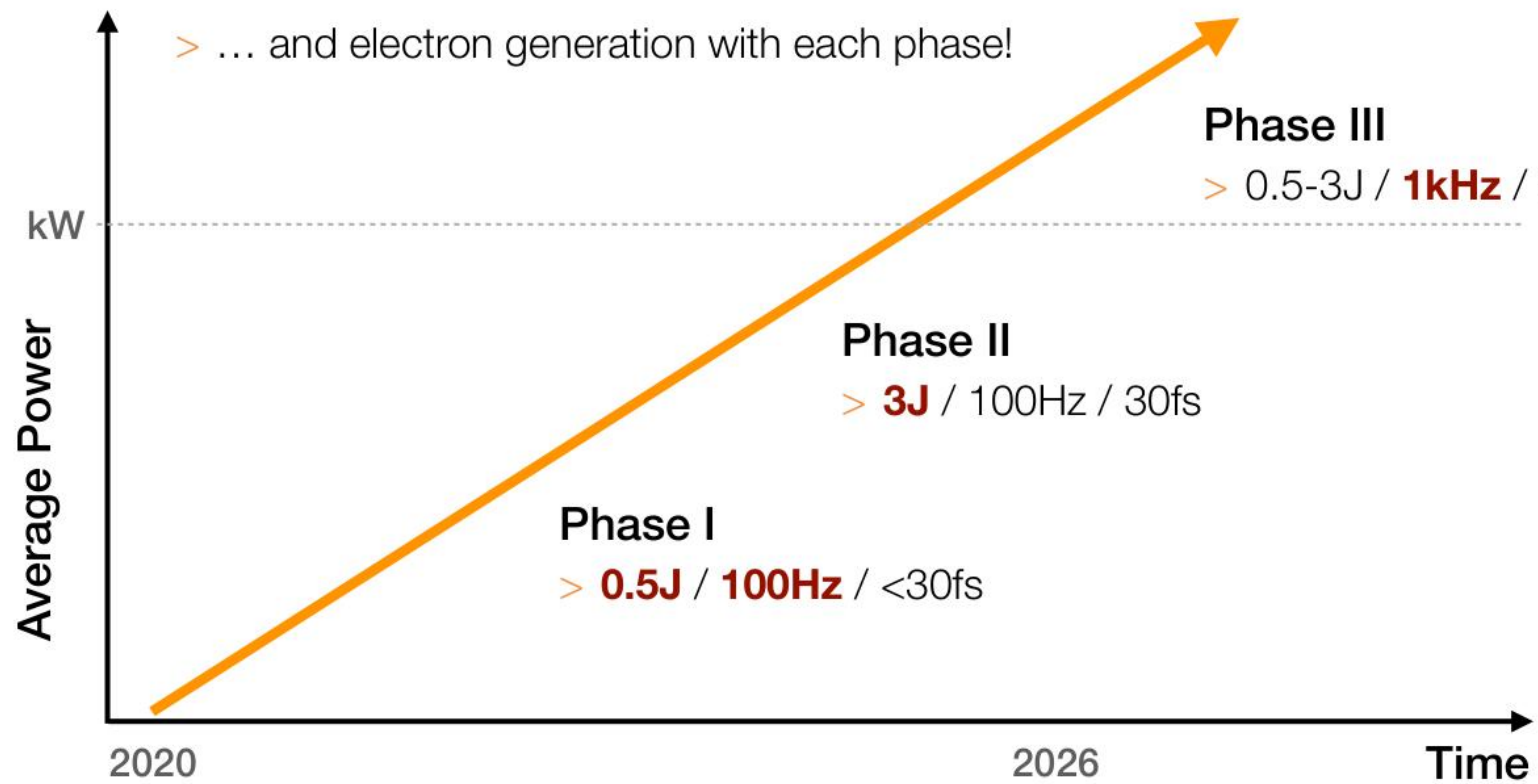
Compressor

Operations

Laser Development

Roadmap

G. Palmer, L. Winkelmann, K. Schubert



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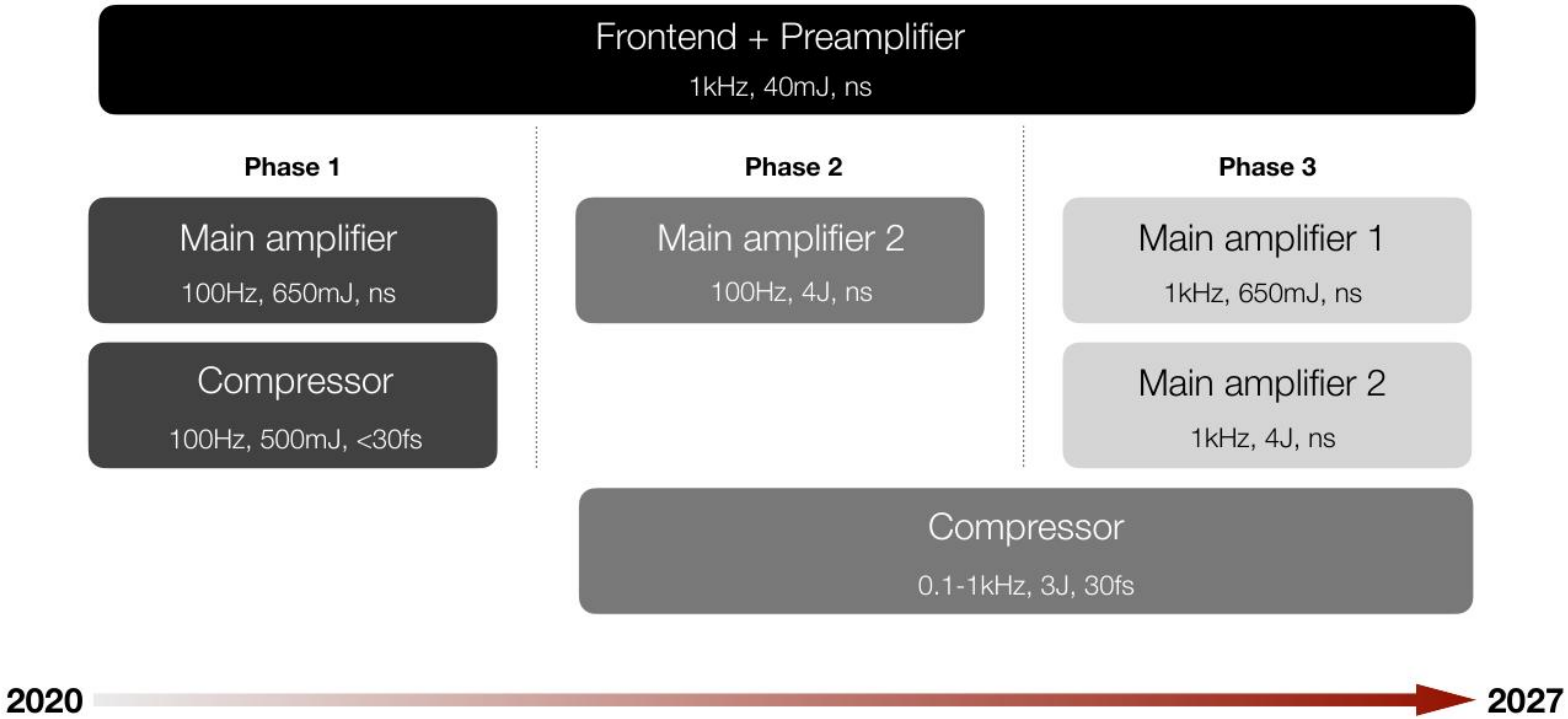
Laser Architecture



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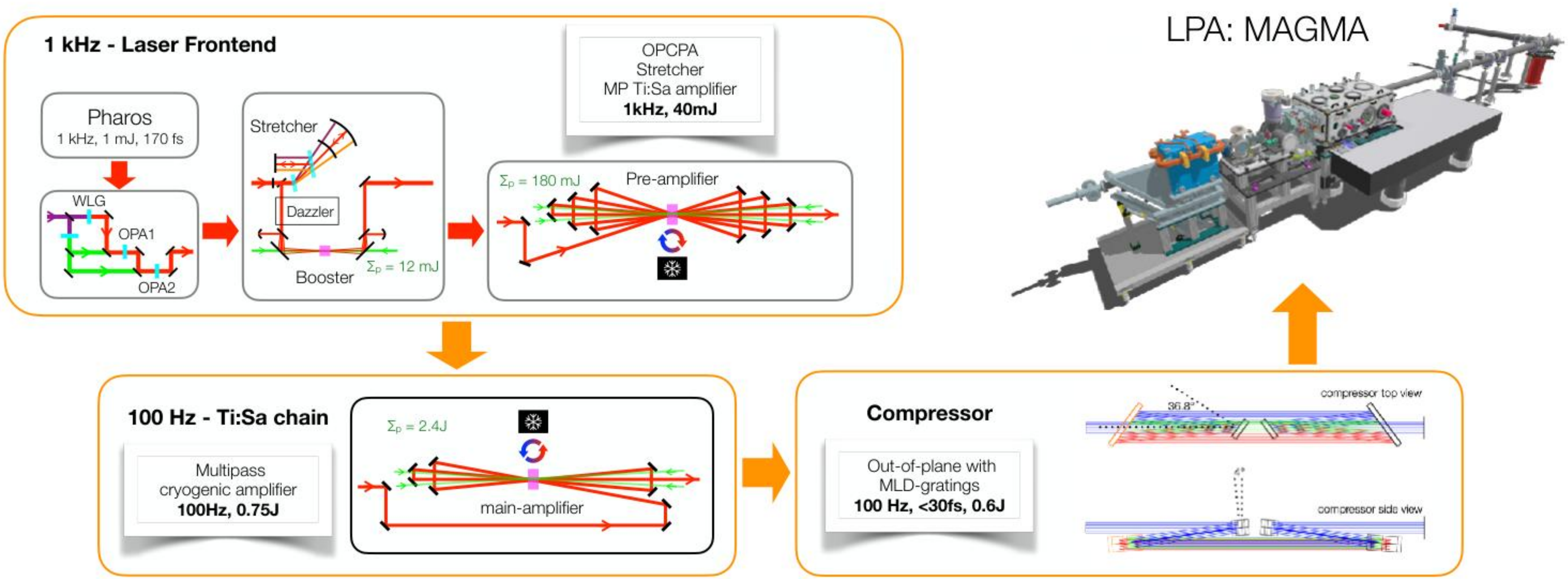
Phase 1: 0.5J on target at 100Hz

credit: G. Palmer & team



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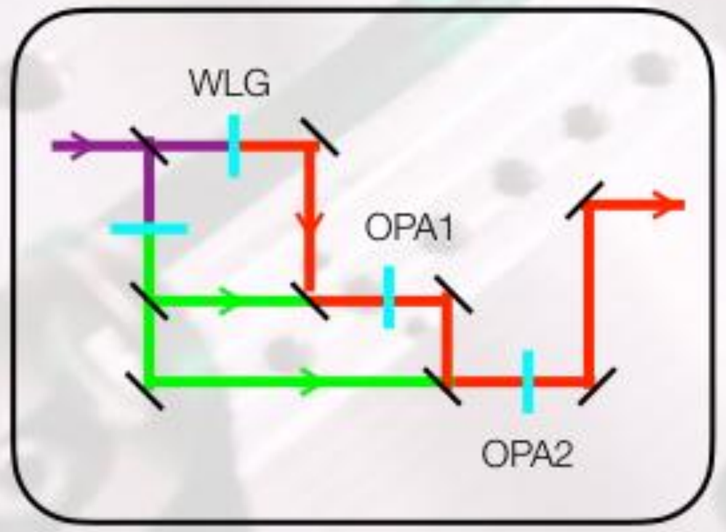
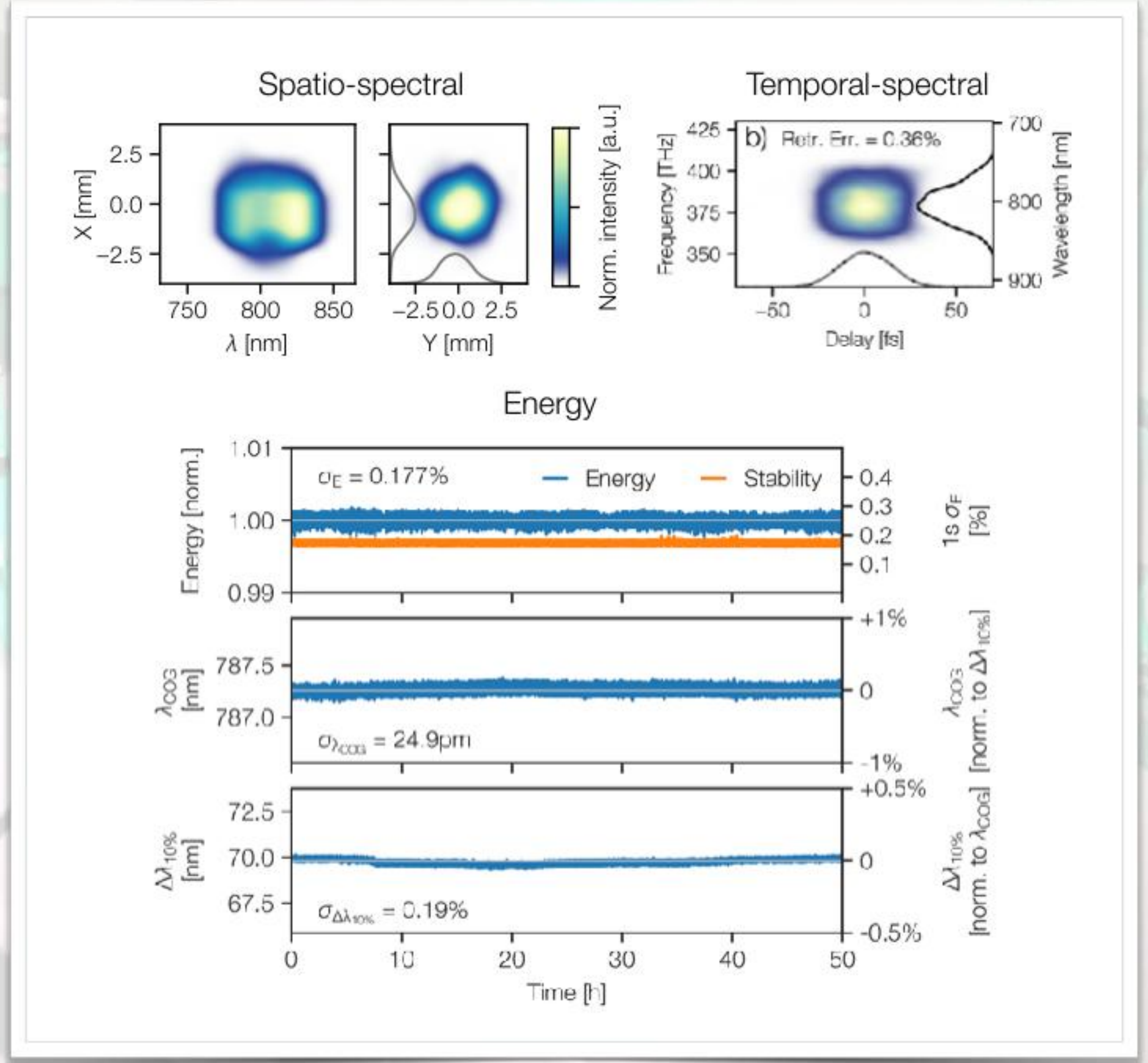
Frontend

T. Eichner et al., Opt. Express 30, 3404 (2022)
T. Eichner et al., Opt. Express 31, 36915 (2023)
T. Hülsenbusch et al., Opt. Express 32, 23416 (2024)

OPCPA seed „MASUBI“

> Pharos drive/seed laser (Light Conversion)
> White light seeded OPCPA
> Up to 60µJ @ kHz
> 25fs bandwidth
> 0.17% energy stability over 50hrs
> Automated-tuning to reproducible working points
> High contrast higher 10^{-10}





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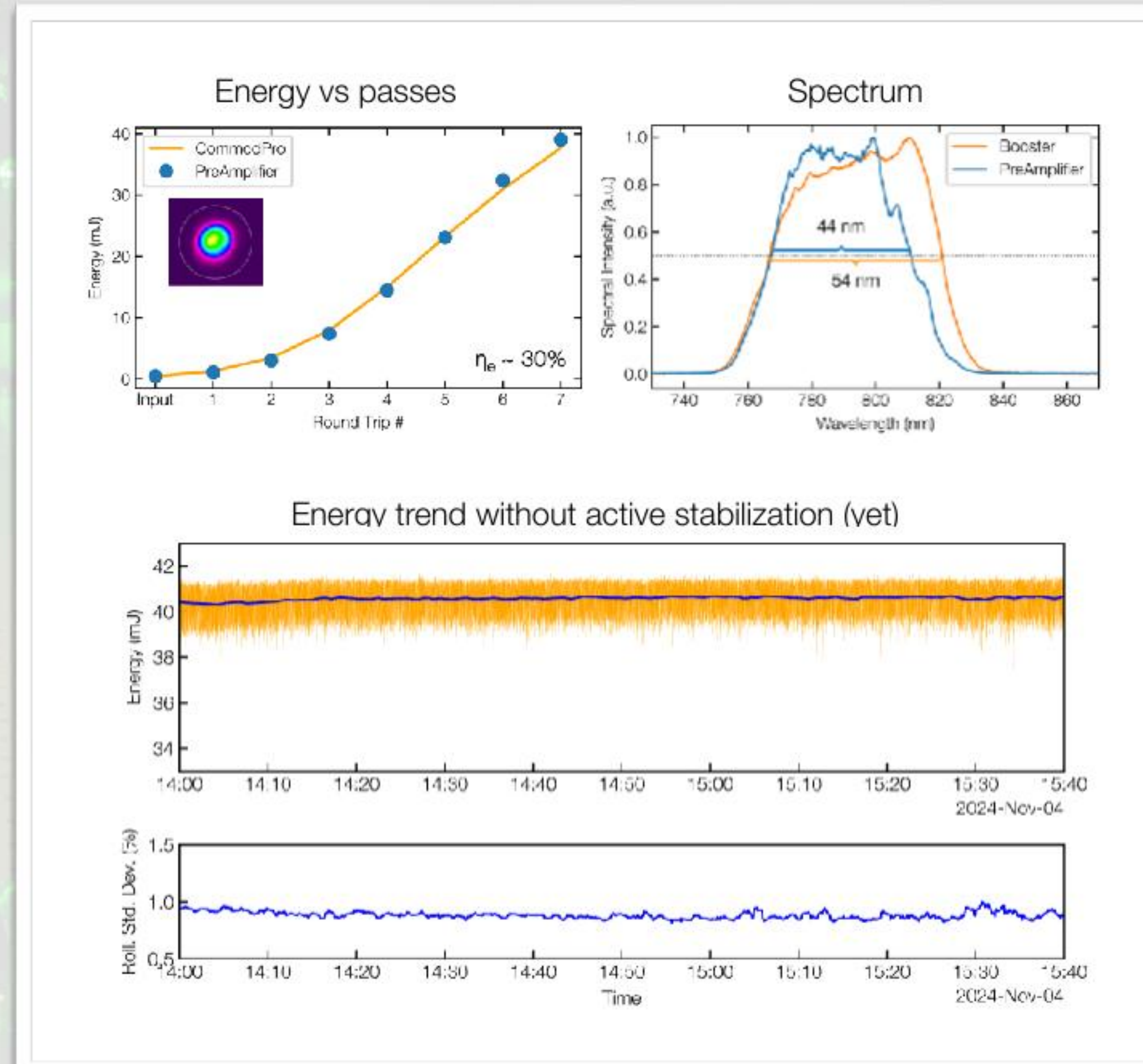
PreAmp (MERAPI)

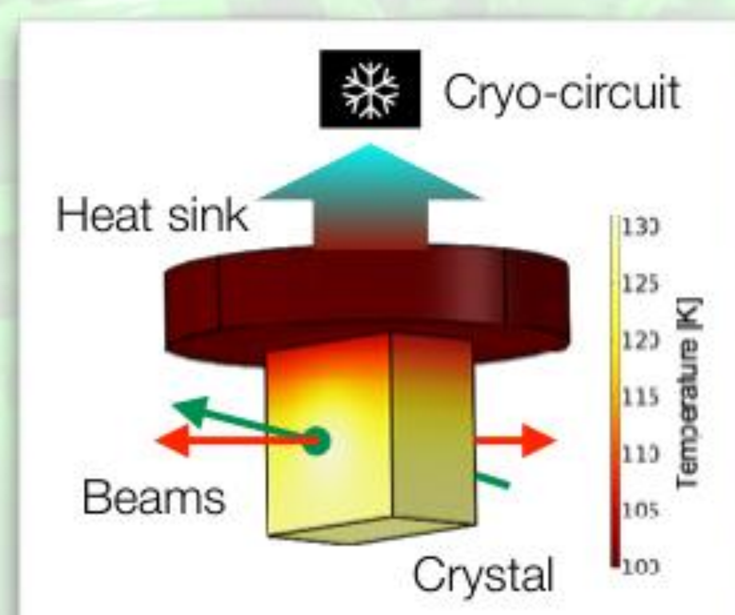
CFEL SCIENCE

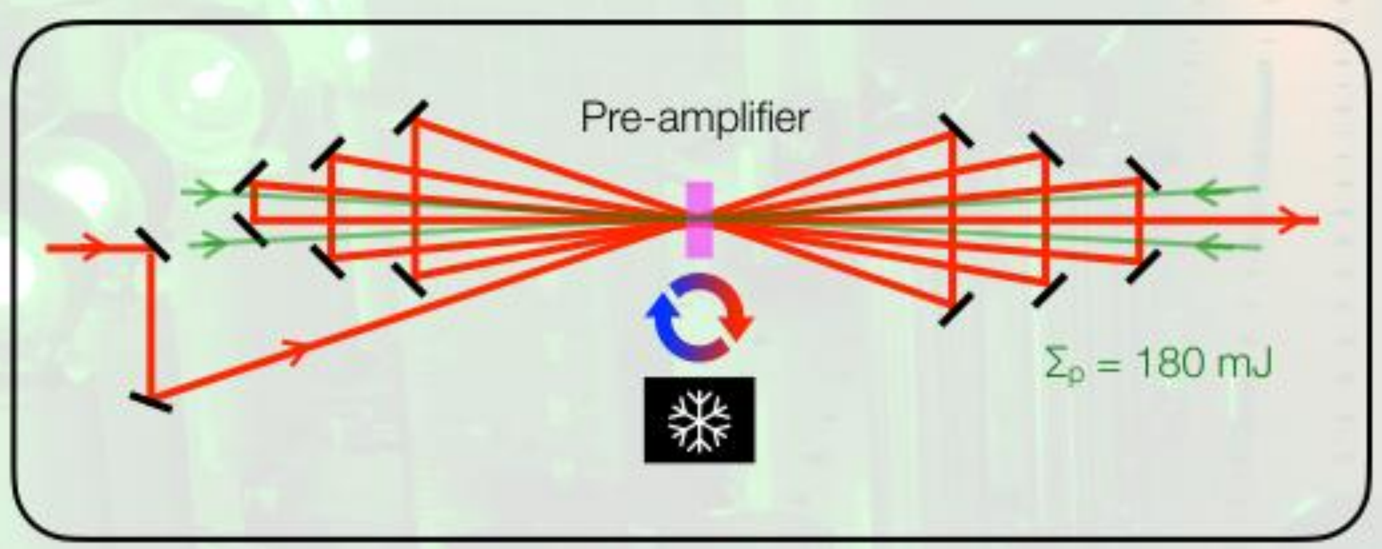
Franz X. Kärtner

Mikhail Pergament

- With MERAPI the amplifier chain is operating at 1 kHz already
- 7-pass cryogenic amplifier
- Up to 40mJ of pulse energy (33% efficiency)
- Supports 25fs bandwidth
- Pumped by 4 x Coherent Revolution80 with up to 180W
- Crystal bonding process from FS-CFEL group at DESY
- Commercial low-vibration solid-state cryogenic cooler







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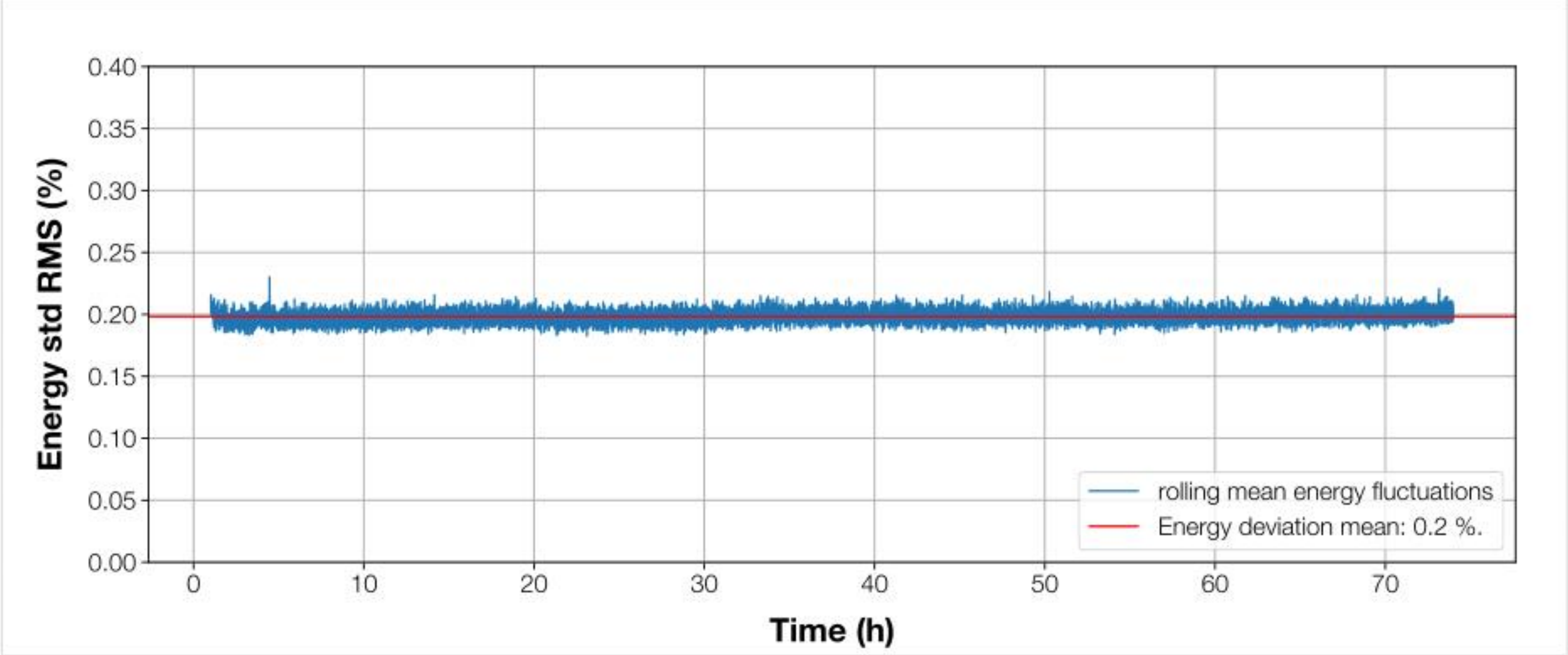
100Hz Pump Lasers

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.



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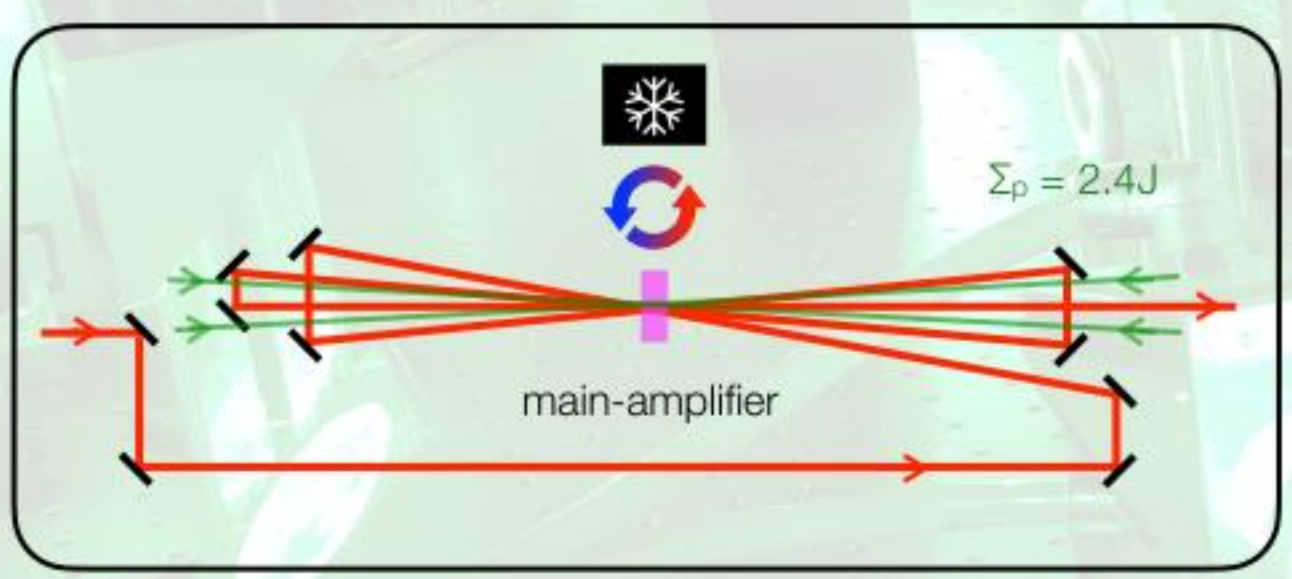
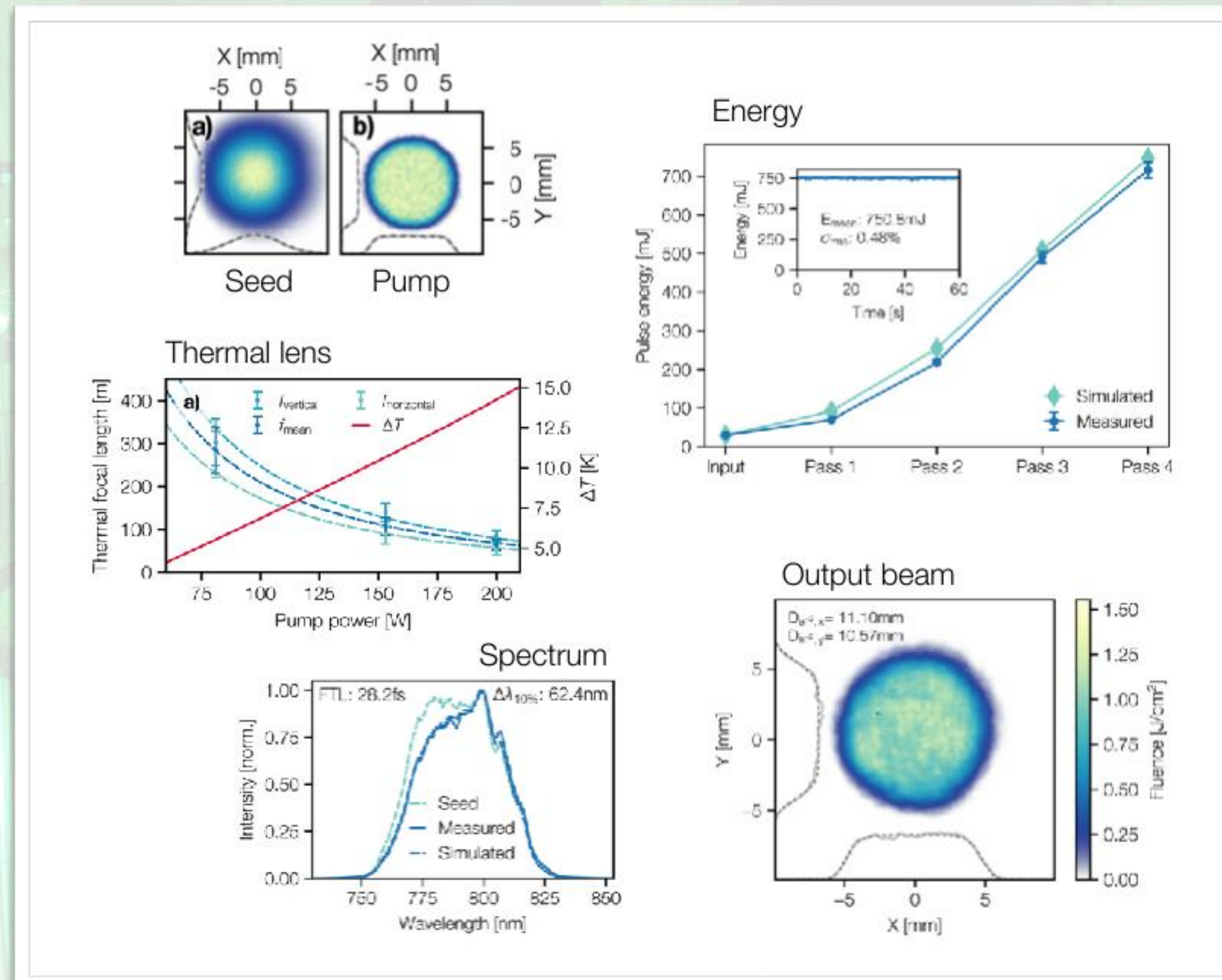
100Hz Amplifier 1

T. Eichner et al., Opt. Lett. 50, 4890 (2025)

First main amplifier (COLIMA)

- All fully diode-pumped@100Hz
- Saturated 4-pass cryogenic amplifier
- 750mJ of pulse energy with efficiency 37%
- Pumped by 4xEVO_4 from INNOLAS
- Both gain and thermal behavior understood and engineered by simulations





KALDERA Compressor

Multi-layer gratings in an out-of-plane geometry

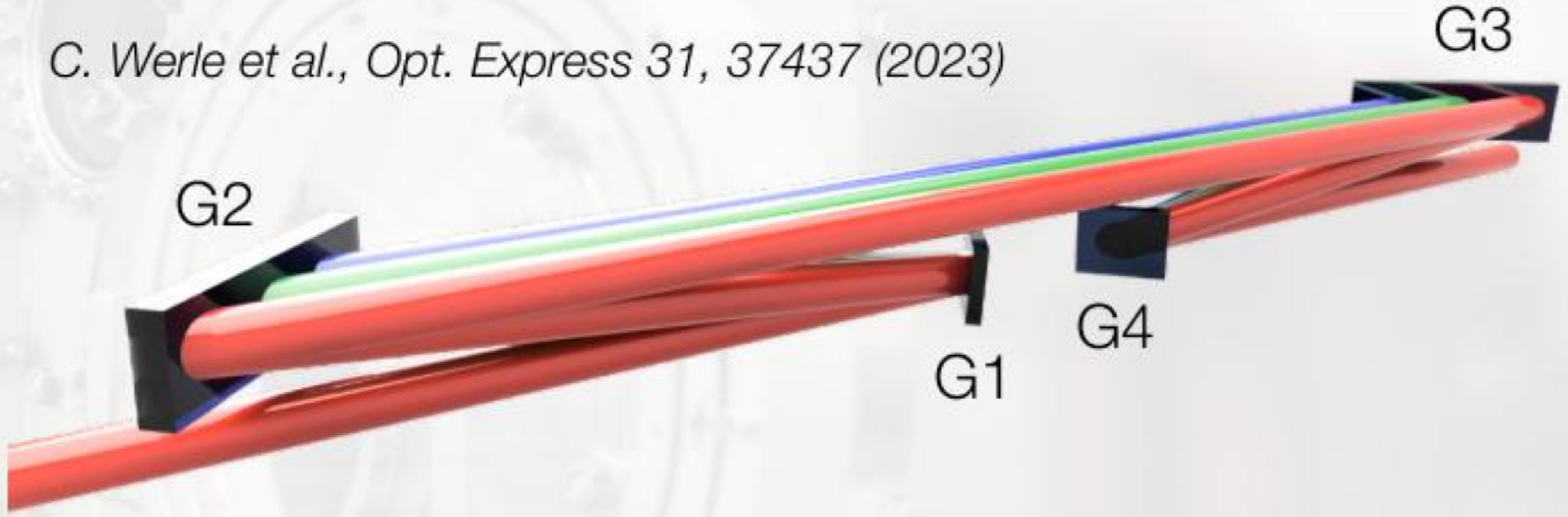
credit: C. Werle

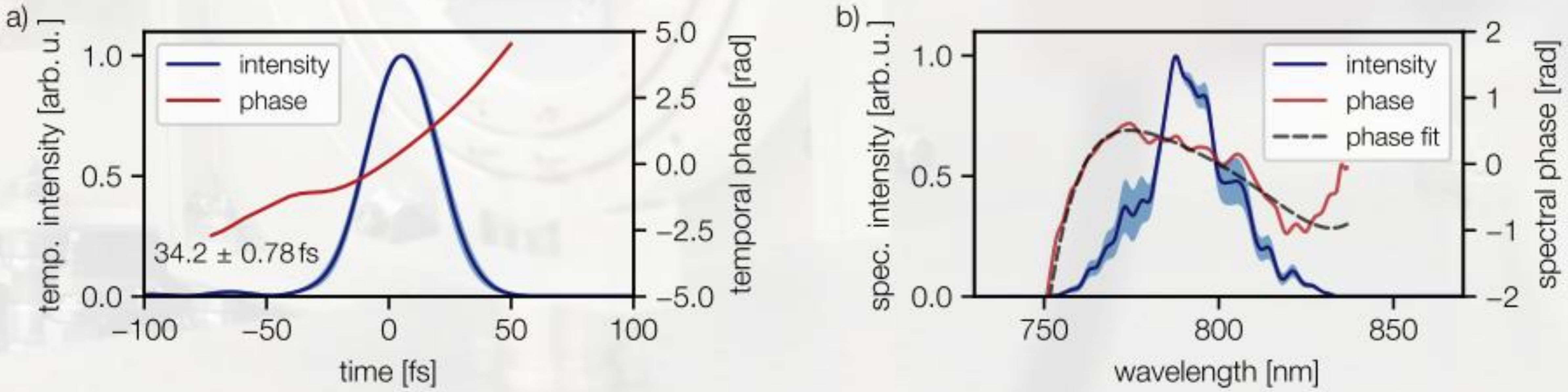
Current status:

- Compressor supports 35fs, 100Hz, 1J-level
- Many days of beam time with 10^6 shots / shift
- Contrast measurement currently better than 10^6
- (Integrated) compressor transmission >80%
- Supports out of the box 34fs w/o any dazzler tuning (we expect <30fs after final tuning)

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

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





KALDERA & MAGMA

Scientific Engineering

Credit: L. Winkelman & team

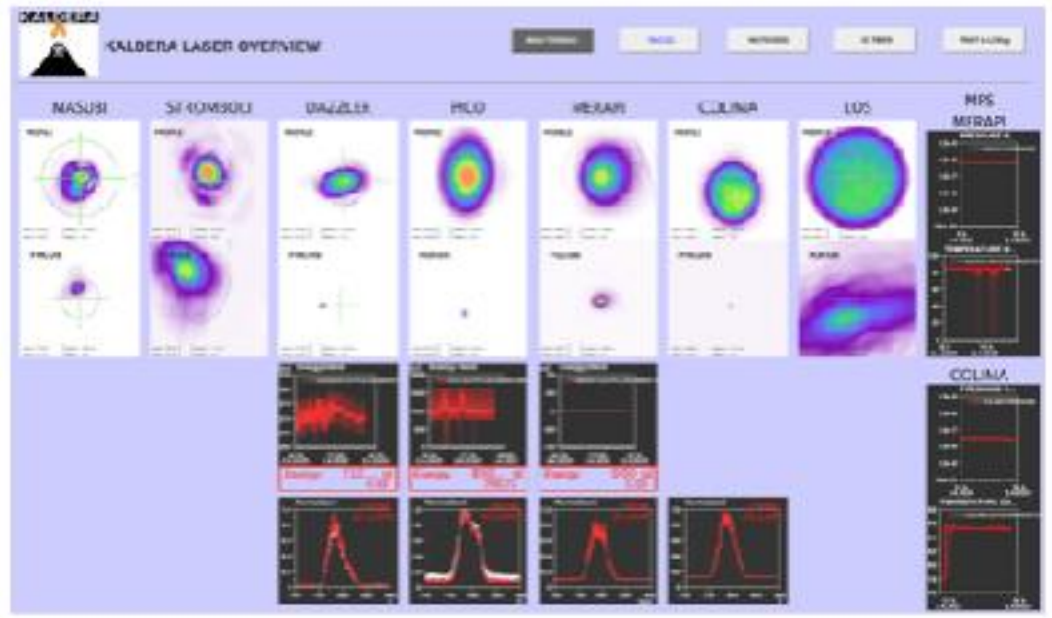
- Laser engineering and development
- Full DESY-control integration from laser to LPA
- Passive and active stabilization
- Machine protection system (cryo-system, vacuum,…)
- Support real time data analysis and DAQ with shot-to-shot capabilities, e.g., kHz cameras
- FPGA data processing
- In-house CAD engineering and FEM simulations

Vacuum chambers

Laser and electron beam line design

Custom opto-mechanics

Control system: DOOCS

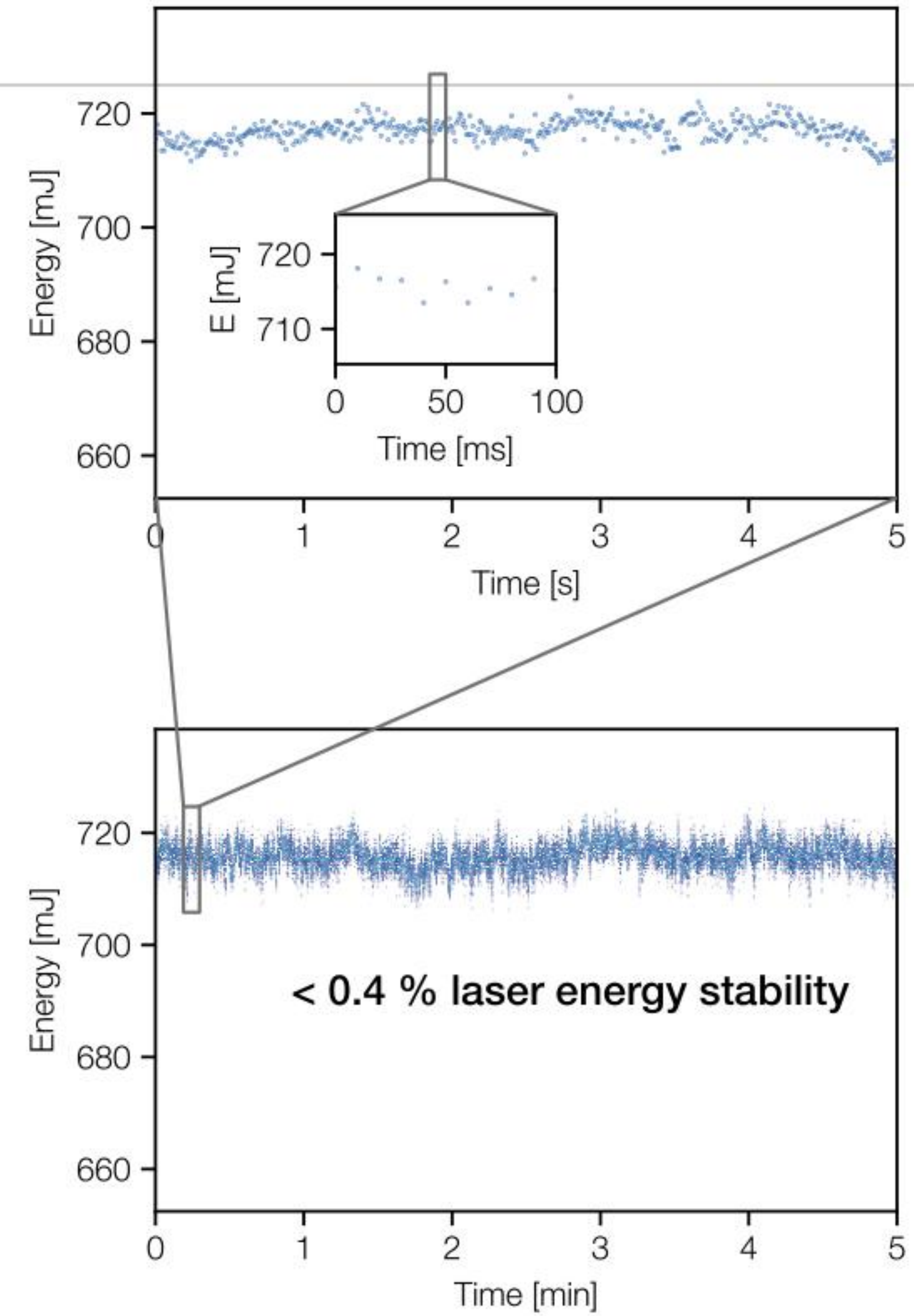


KALDERA Commissioning

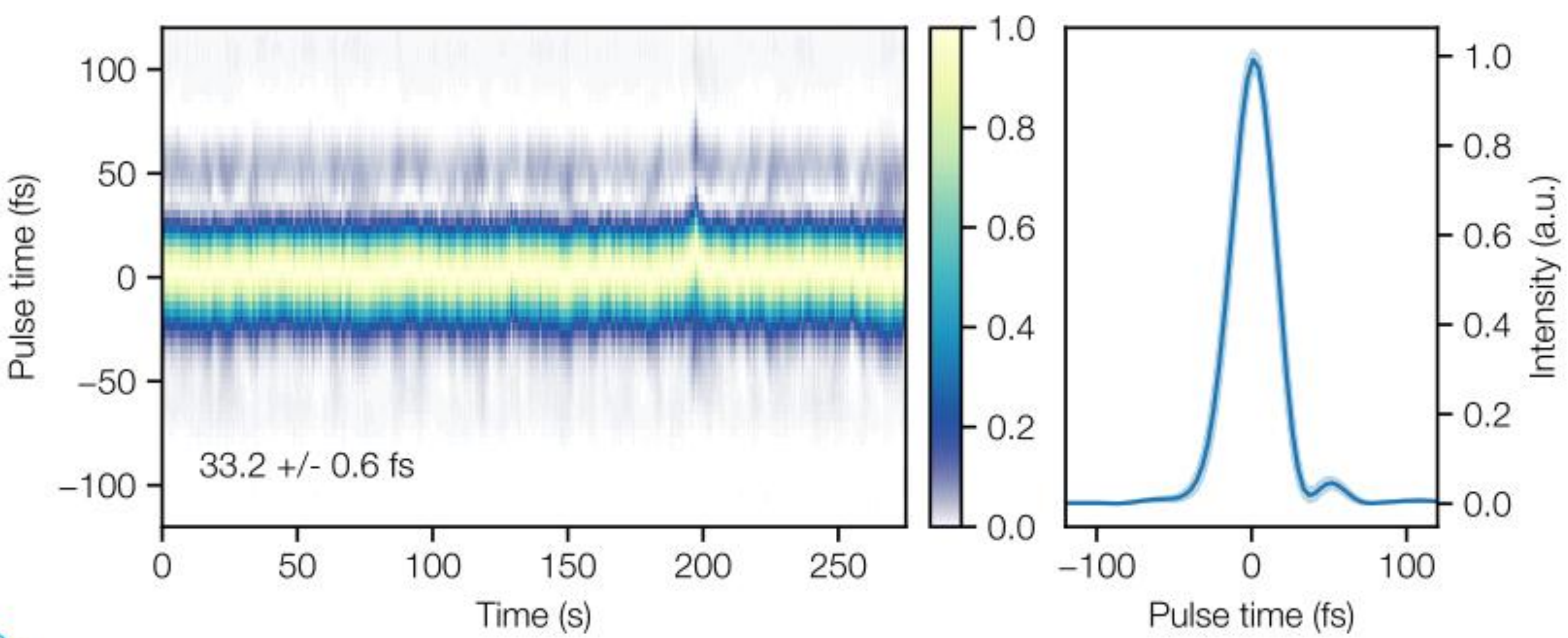
Laser performance & long-term operation

- Stable 100Hz operation over hours already possible
- Online monitoring of laser performance in control system
- Commissioning of 100 Hz diagnostics & DAQ
- So far, we use only passive stabilzation

Shot-to-shot laser energy stability @ 100 Hz
Yet without active stabilization



Shot-to-shot pulse length stability @ 100 Hz
and full (phase 1) energy



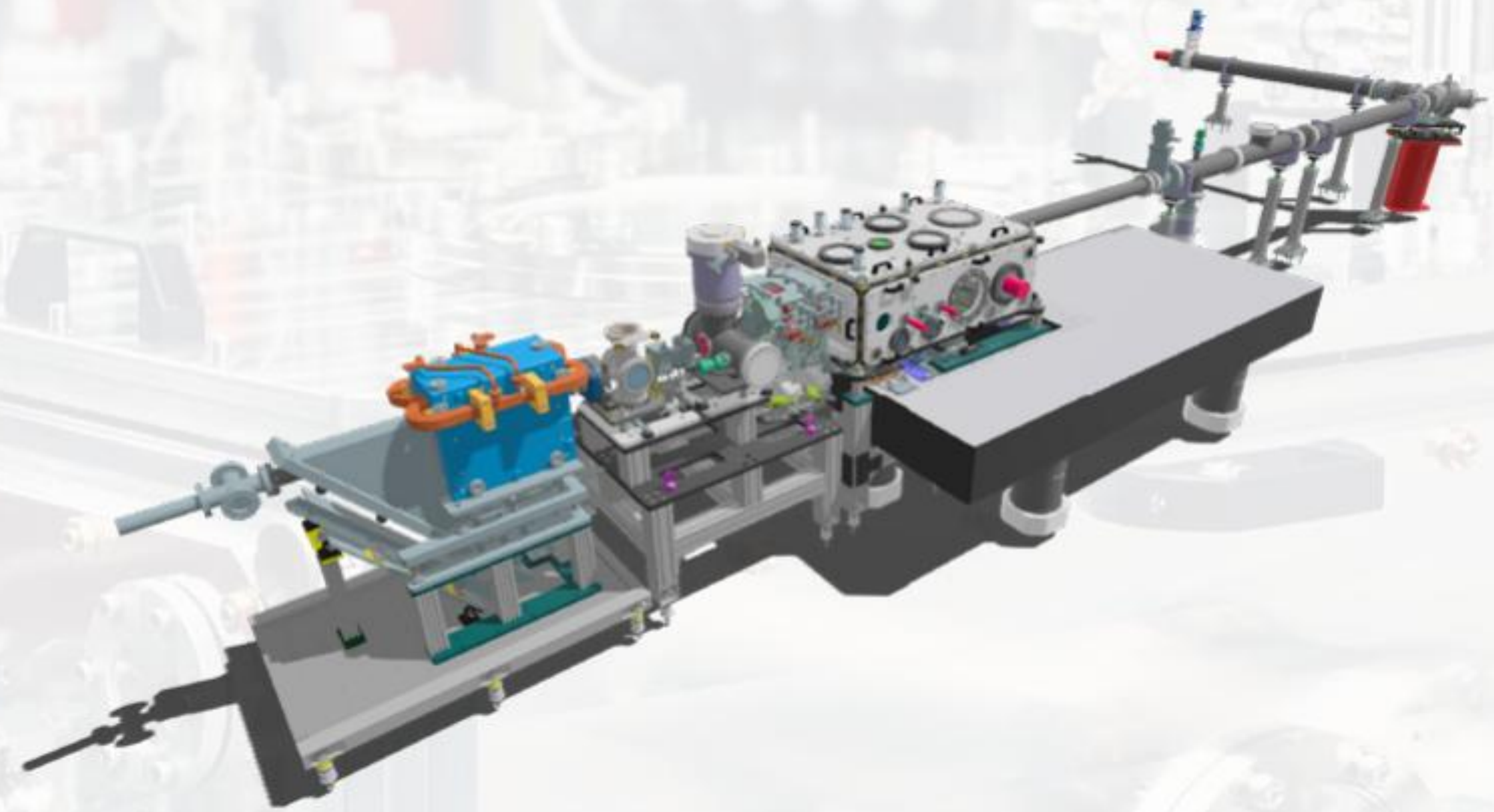
MAGMA

KALDERA Phase 1: LPA

Talk:
M. Kirchen, Mon 5:00pm,
Sala Biodola (Hotel Biodola)

Our mission

- Phase1: 100 MeV @ 100 Hz
- Completely integrated with laser system
- Testbed for active stabilization systems



MAGMA

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- Phase1: 100 MeV @ 100 Hz
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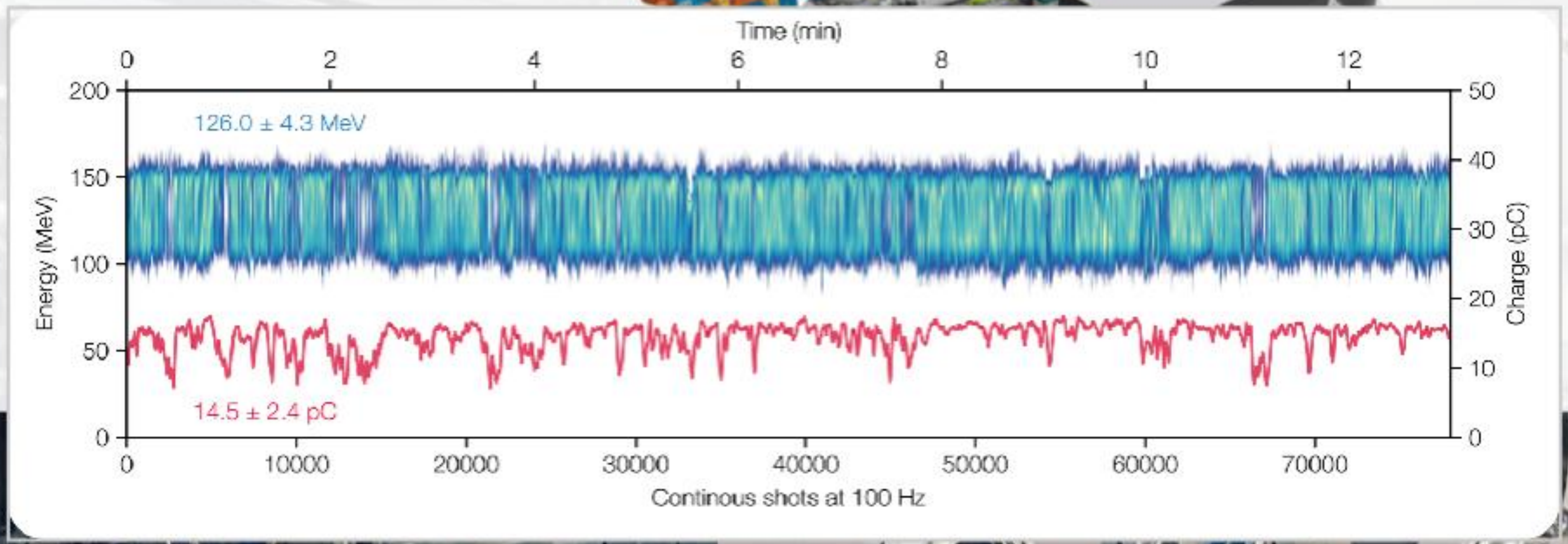
Today

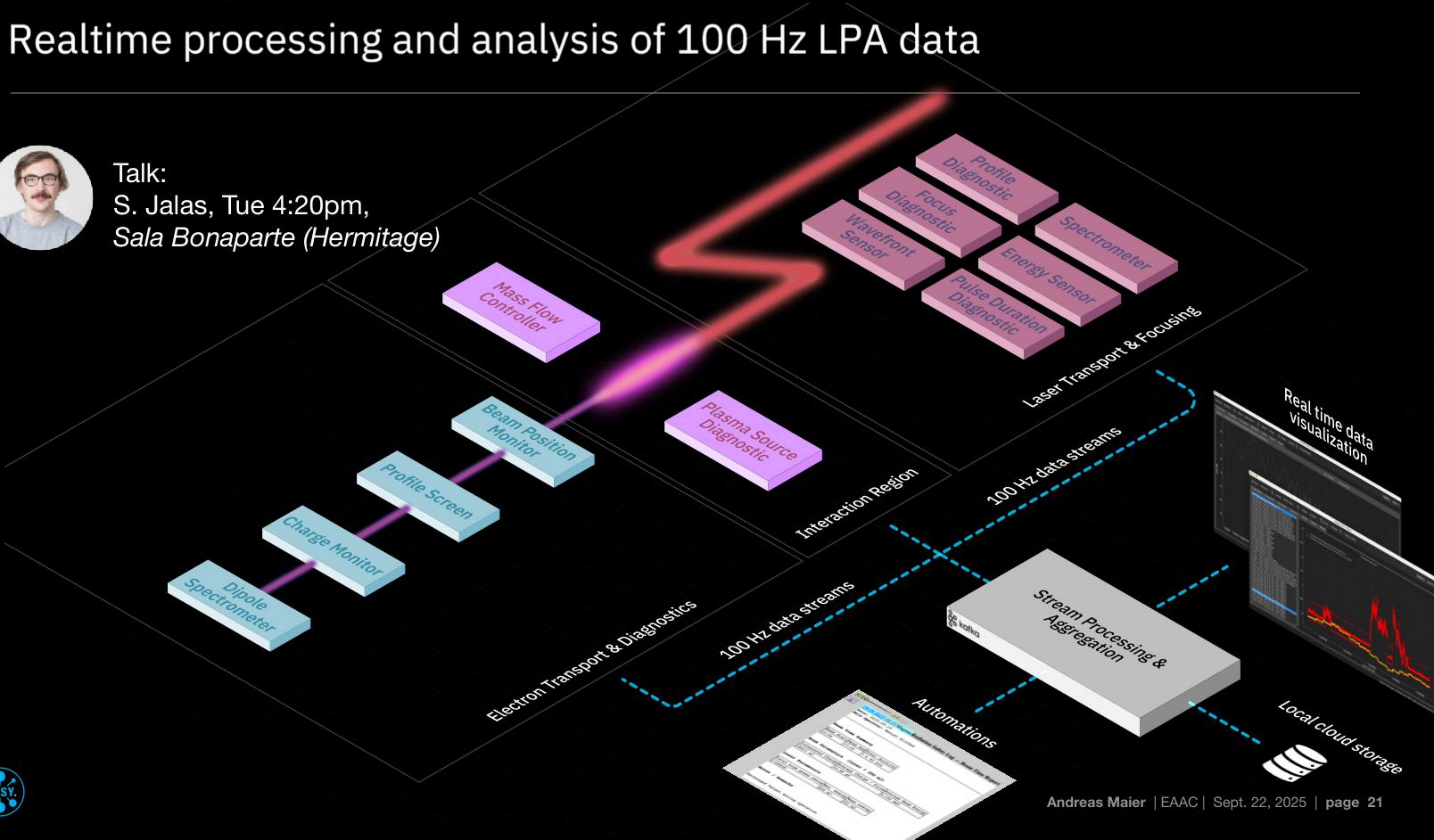
- 1MShot and several μC integrated charge per shift
- Around 120MeV, few-10pC
- 100k shots in 10 minutes (which took us previously a full 24h shift
- See Manuel's talk for more details



Data Driven LPA research

Realtime processing and analysis of 100 Hz LPA data

Talk:
S. Jalas, Tue 4:20pm,
Sala Bonaparte (Hermitage)



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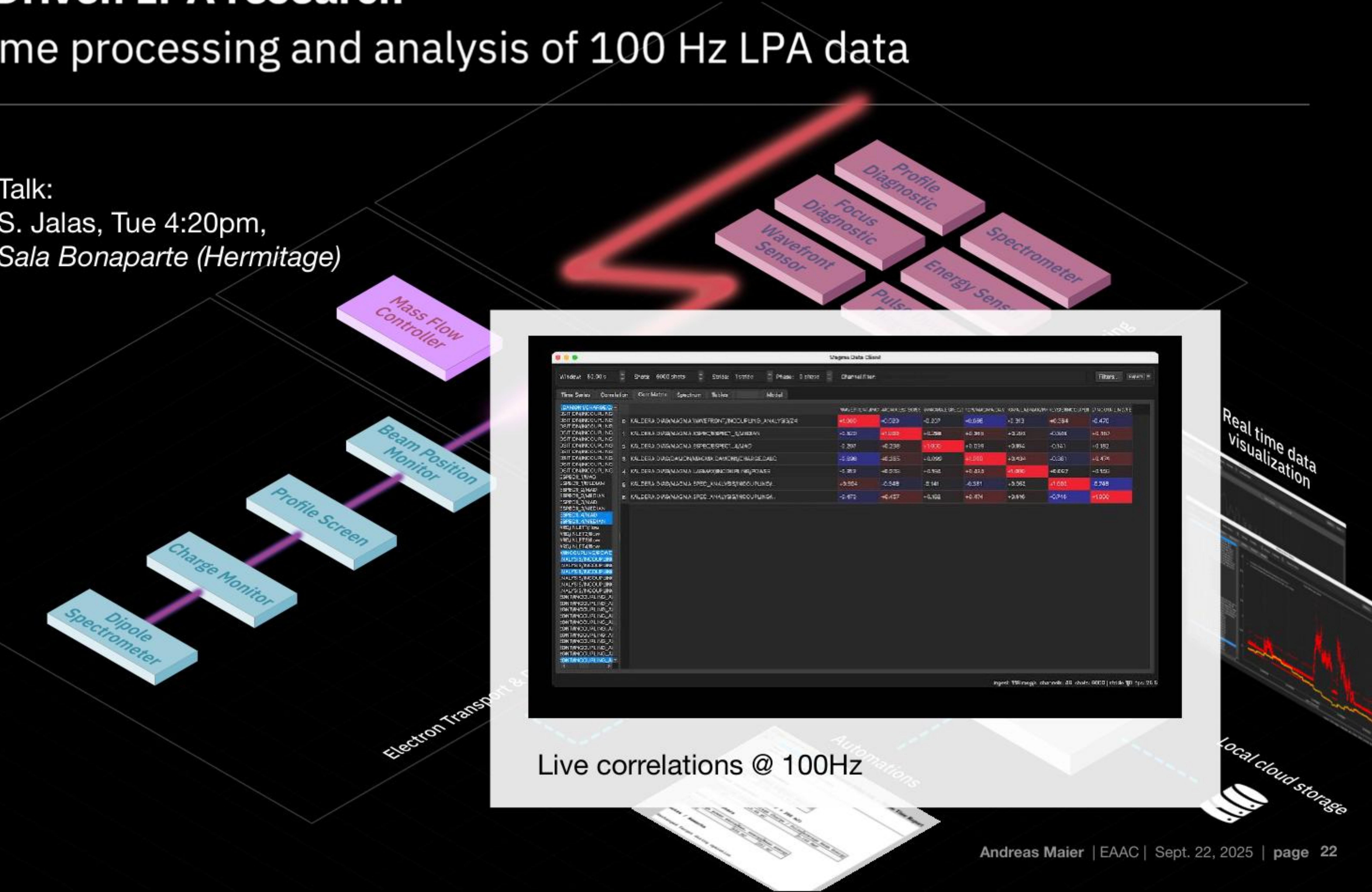
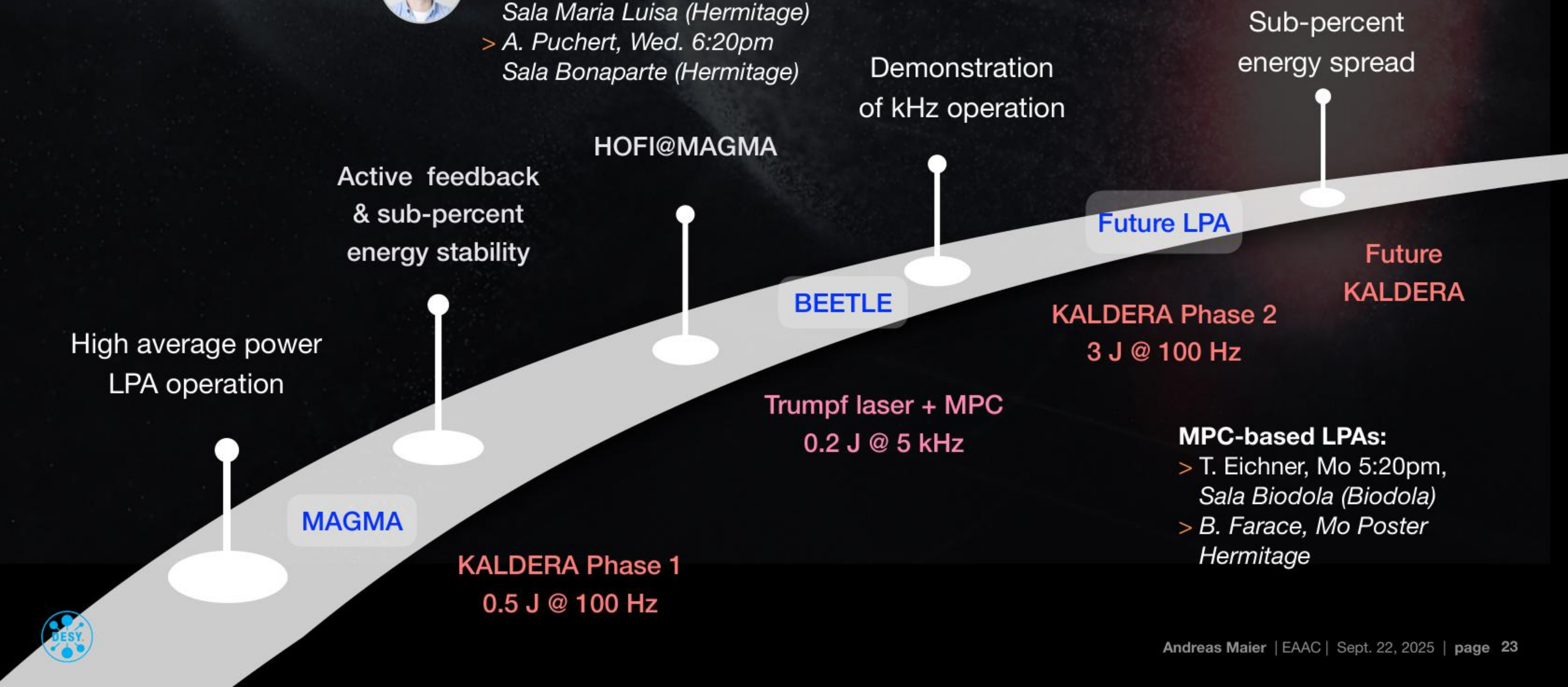


LPA Development Roadmap

Where to go from here

> R. Shalloo, Tue 5:40pm, *Sala Maria Luisa (Hermitage)*

> *A. Puchert, Wed. 6:20pm Sala Bonaparte (Hermitage)*



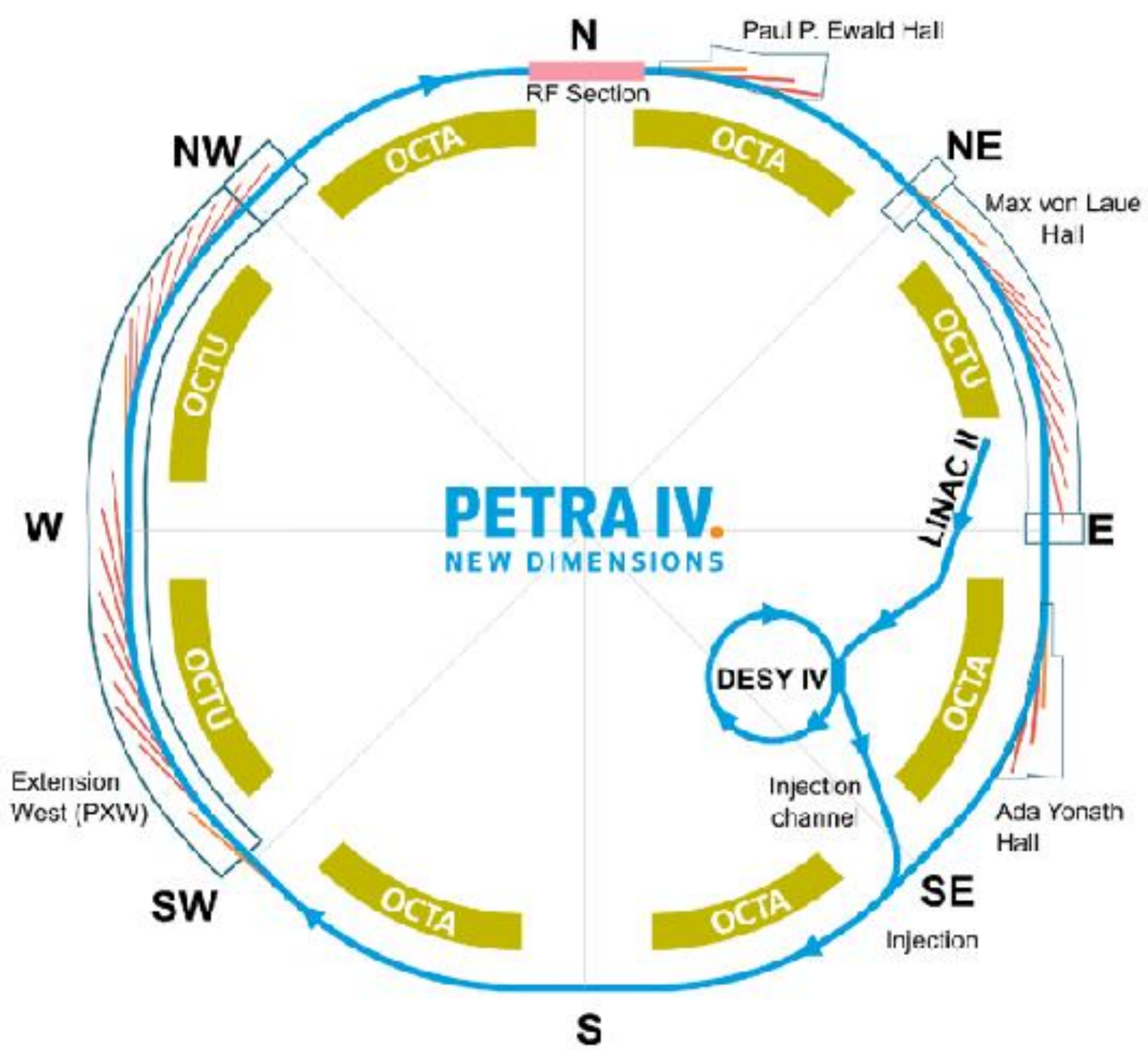
MPC-based LPAs:

> T. Eichner, Mo 5:20pm, *Sala Biodola (Biodola)*

> *B. Farace, Mo Poster Hermitage*

Plasma Injector for PETRA IV
Based on KALDERA Laser Technology

> A. Maier, Tue 4:20pm, *Sala Bonaparte (Hermitage)*
> M. Thévenet, Wed 7pm, *Poster*
> S. Antipov, Fri 11:30am, *Plenary*



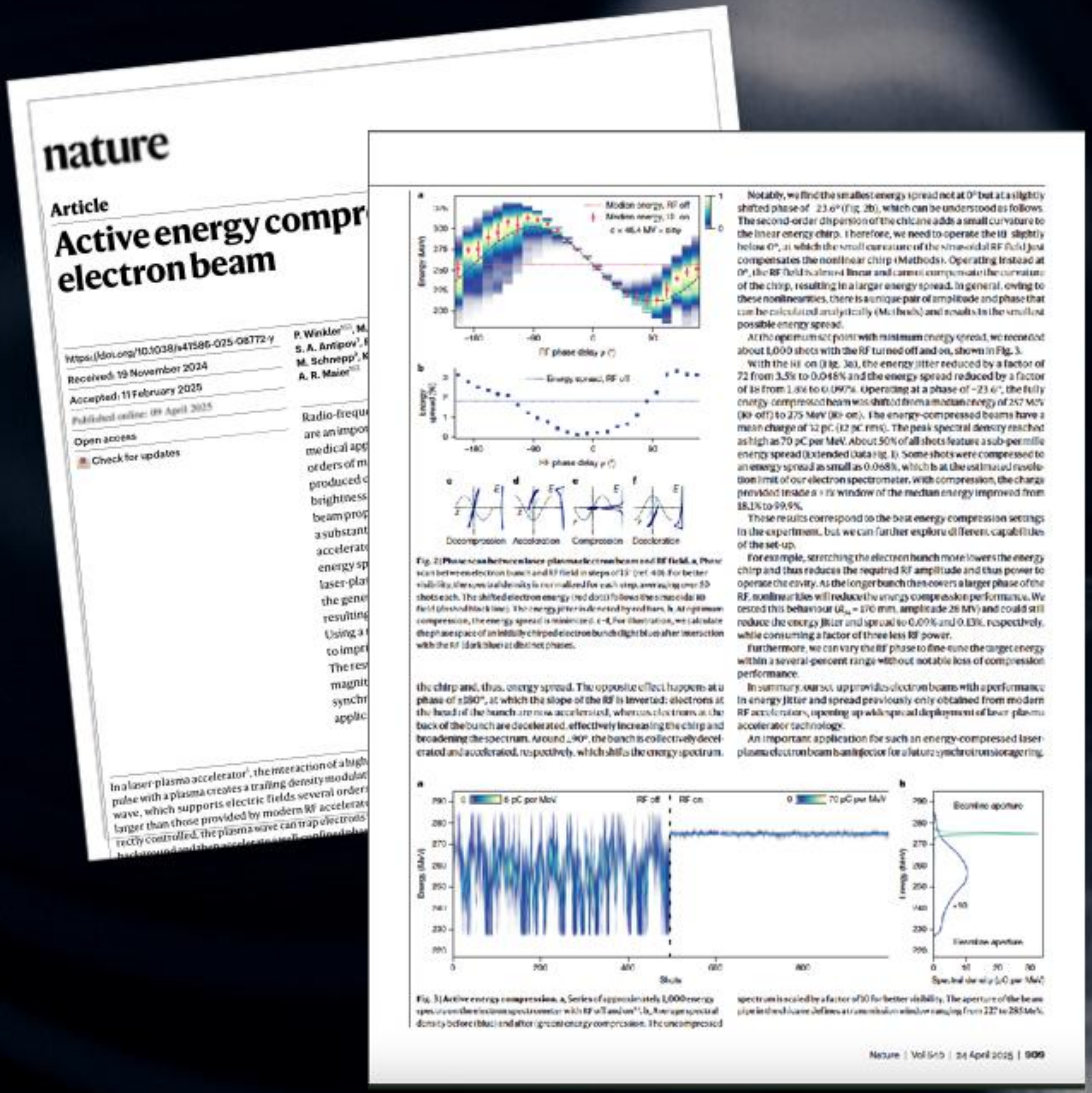
Credit: A. Martinez de la Ossa et al., PETRA IV Plasma Injector Conceptual Design Report

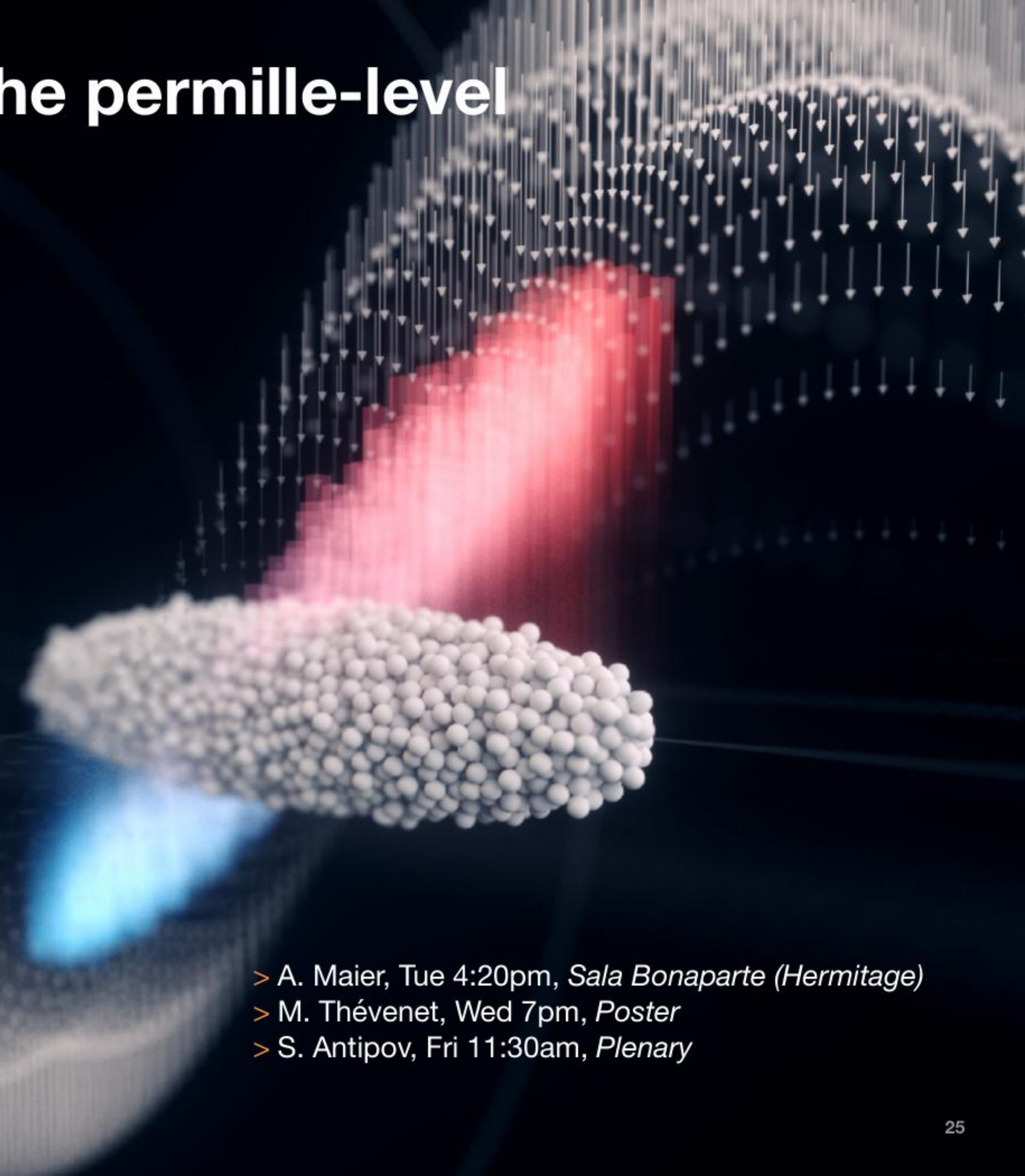
PETRA III to PETRA IV Upgrade
> 1.7 B€ project
> Now a German infrastructure priority project
> Completely refurbish the 2.3 km ring

We need to master
> Laser technology: 30J class laser @ 10Hz
> HOFI guiding
> Active energy compression

Energy compression to the permille-level demonstrated at LUX

P. Winkler et al. Nature 640, 907 (2025)





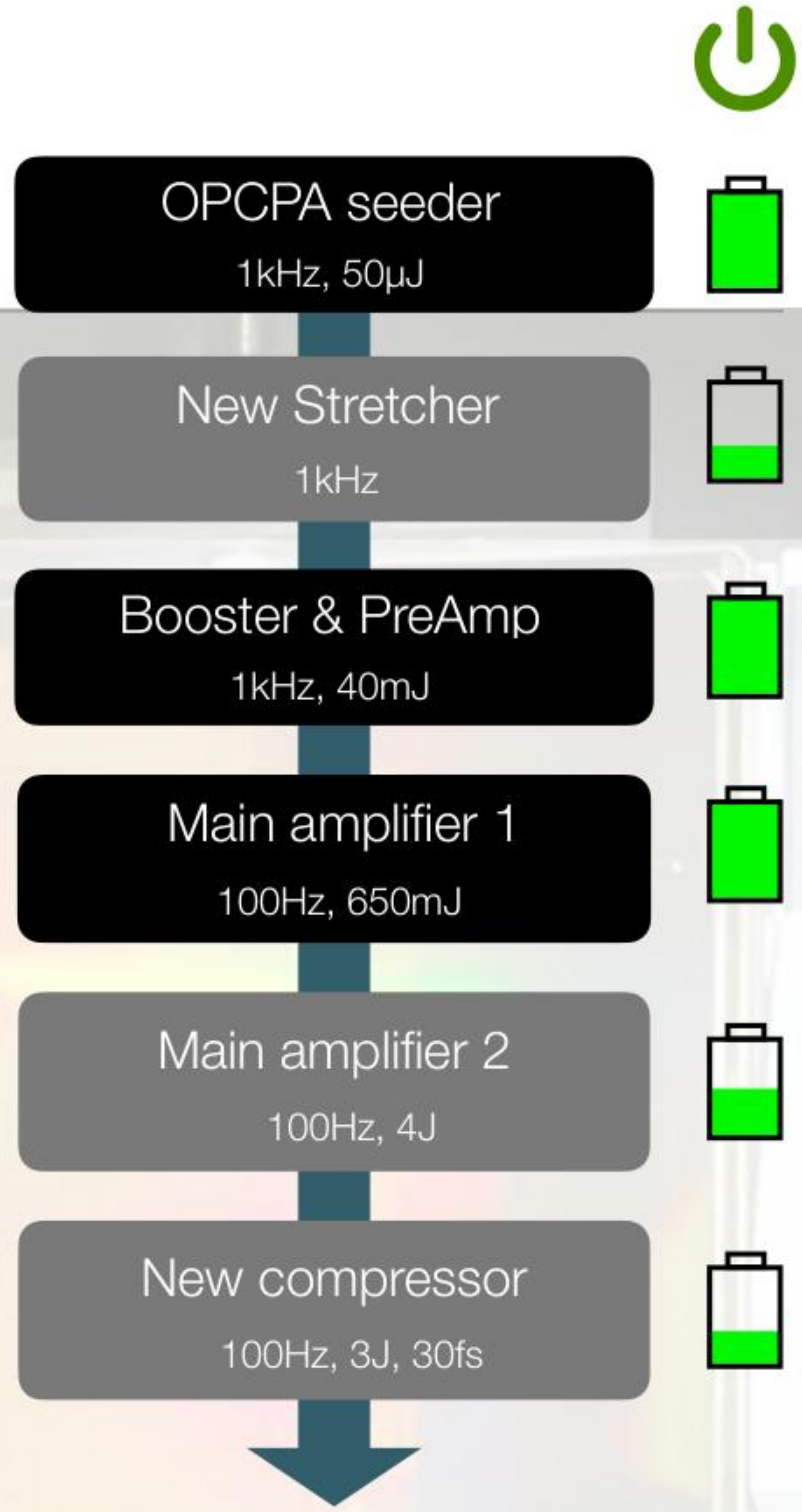
> A. Maier, Tue 4:20pm, *Sala Bonaparte (Hermitage)*
> M. Thévenet, Wed 7pm, *Poster*
> S. Antipov, Fri 11:30am, *Plenary*

KALDERA

Status Phase 2

Phase 2: 100 Hz, 3J, 30 fs

- New Stretcher under development
- Main amplifier 2 („ARENAL“):
  - Under develpment
  - All pump lasers are ready (almost 1 kW)
- 4J / kW-ready compressor
  - Scaled version of TAUPO
  - under development (expected 2026)



Related Contributions From DESY Group

(not yet highlighted)

Theory & Simulations

Xingjian Hui, Mon 4:20pm, *Sala Elena,*
"All-optic In-plasma Staging of Laser-Wakefield Accelerators Using Density Tailoring"

M. Thévenet, Mon 5:40pm, *Sala Maria Luisa*
"Resonant Emittance Mixing of Flat Beams in Plasma Accelerators"

M. Thévenet, Tue 5:40pm, *Sala Elena*
"Mainstreaming Start-to-End Realistic Simulations in Plasma Accelerator Research"

M. Thévenet, Wed Poster
„The plasma injector for Petra IV: Conceptual Design Report"

FLASHForward

JP Diaz, Mon Poster
„Temperature diagnostics for high-repetition-rate plasma accelerator sources"

J. Björklund Svensson, Mon Poster
„Experimental Generation of PWFA-suitable Bunch Current Profiles by Arc-like Bunch Compressors"

J. Wood, Mon Poster
„Physics Considerations for a Plasma Booster Stage for the European XFEL"

J. Beinortaitė, Mon Poster
„Long-duration ion motion effects in beam-driven plasma-wakefield accelerators"

L. Boulton, Tue 5:40pm, *Sala Bonaparte*
"Advanced Controls and Machine Learning at FLASHForward"

J. Wood, Wed 4:40pm, *Sala Maria Luisa*
„Latest Results from the FLASHForward Experiment"

Applications

K. Poder, Tue 5:00pm, *Sala Bonaparte*,
"Muon scattering tomography with laser-plasma-accelerator-driven muon source"

K. Poder, Tue 5:40pm, *Sala Bonaparte*,
"Compact all-optical precision-tunable narrowband hard Compton X-ray source"

C. Mariani, Wed. Poster
„Optimisation of Inverse Compton Scattering via spatio-temporal tailoring of the scattering pulse"

S. Bohlen, Wed Poster
„Radiation Safety Challenges and Detector Solutions for Plasma Accelerators"

Andreas Maier

Lead Scientist
Group Leader

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Thanks

To the whole plasma crew at DESY

Fig: SciCom Lab