HR laser: A high average power research tool at ELI-ALPS

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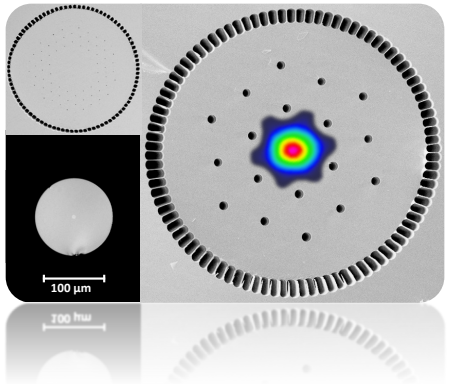
Online workshop Hungarian embassy

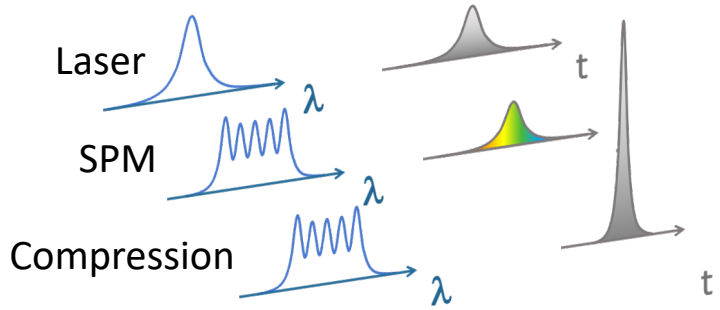
Introduction

Key technologies have been developed for high-power femtosecond fiber laser systems

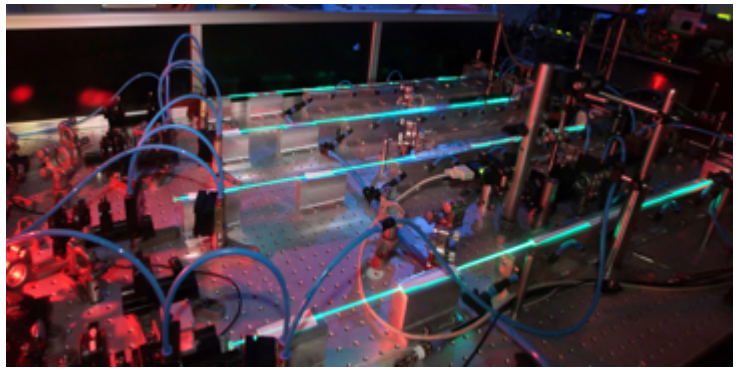
Microstructured fibers with large area cores



Nonlinear pulse compression down to few-cycle pulses



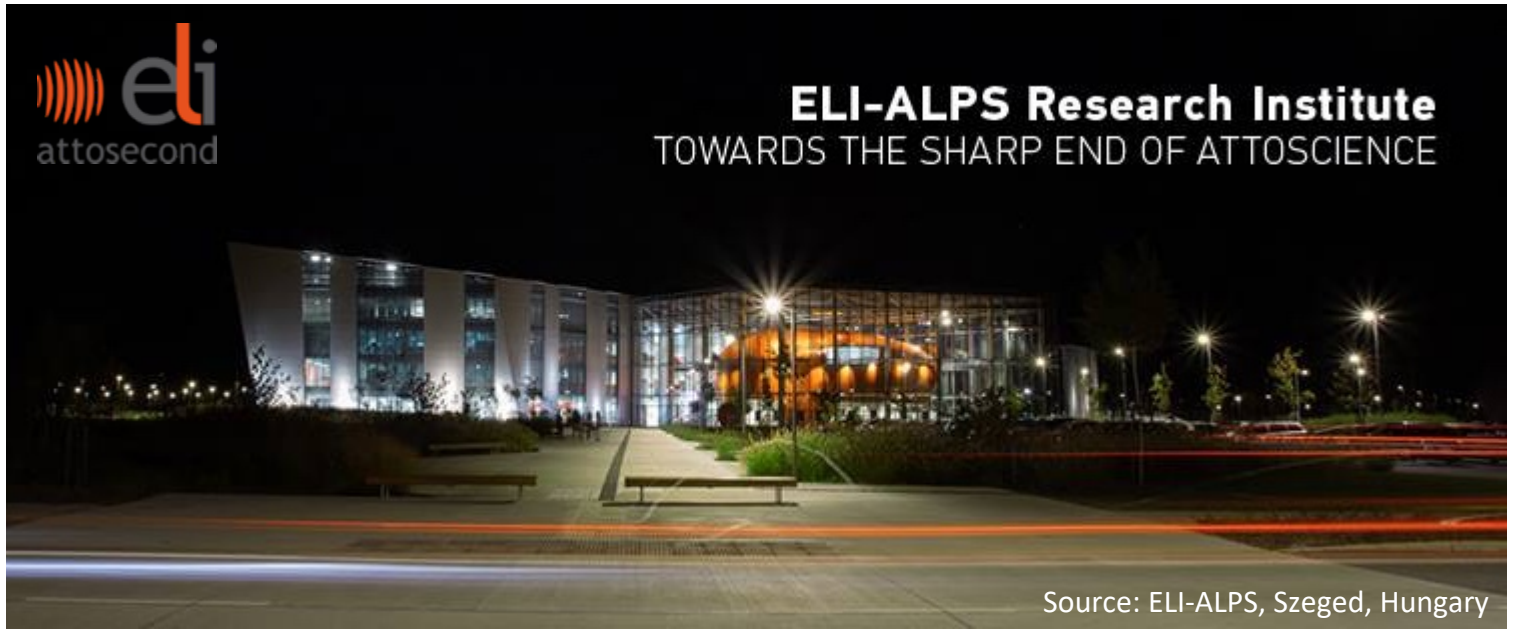
Spatial and temporal pulse combination techniques for power scaling



High repetition-rate and high average power operation enables a variety of scientific applications

The HR laser systems as high repetition rate attosecond sources

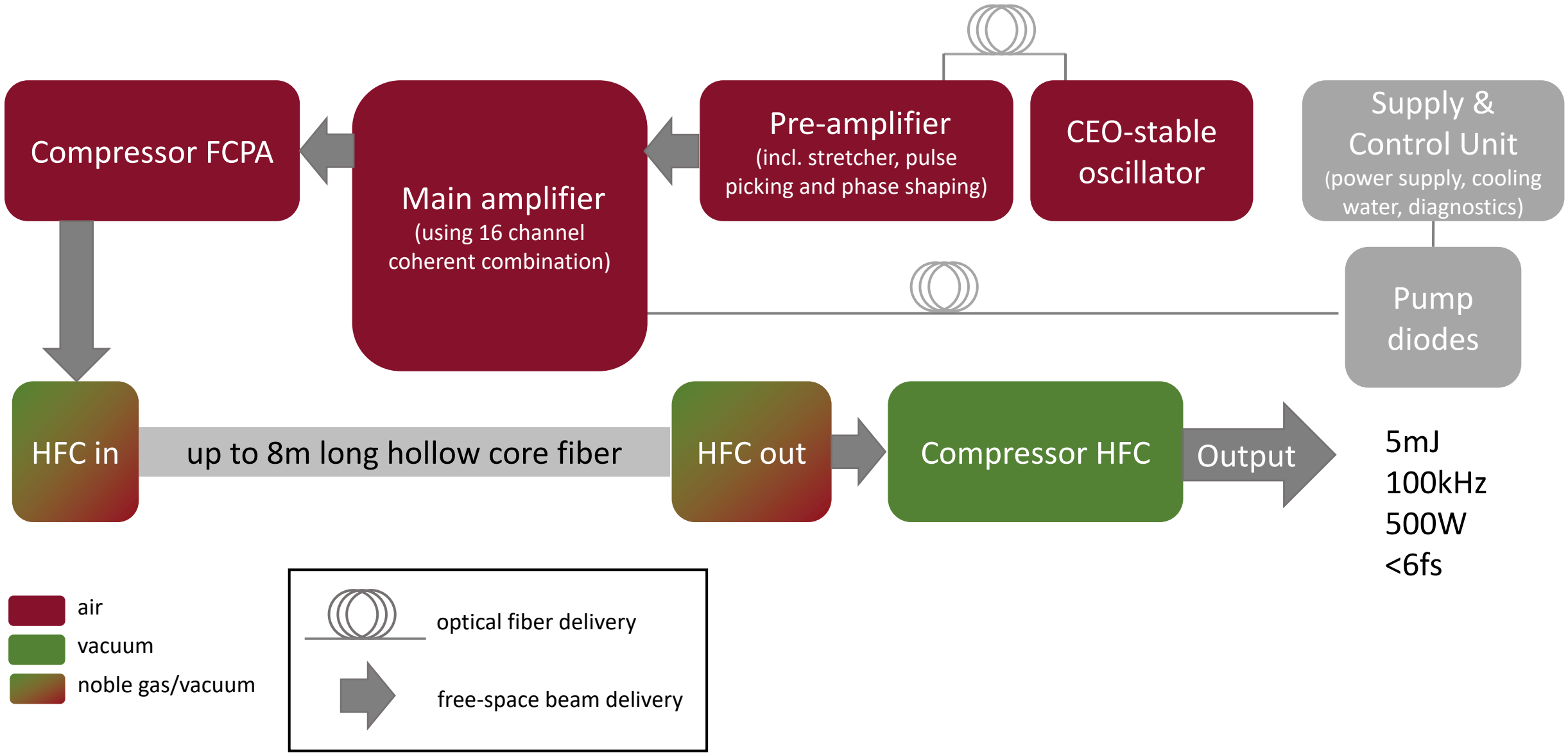
- ELI-ALPS-HR: 2 of 6 main laser systems (primary sources) used in the facility
- Driving laser for attosecond beam line
- HR1 already delivered (CEP-upgrade soon)
- HR2 installation in Q1 2021



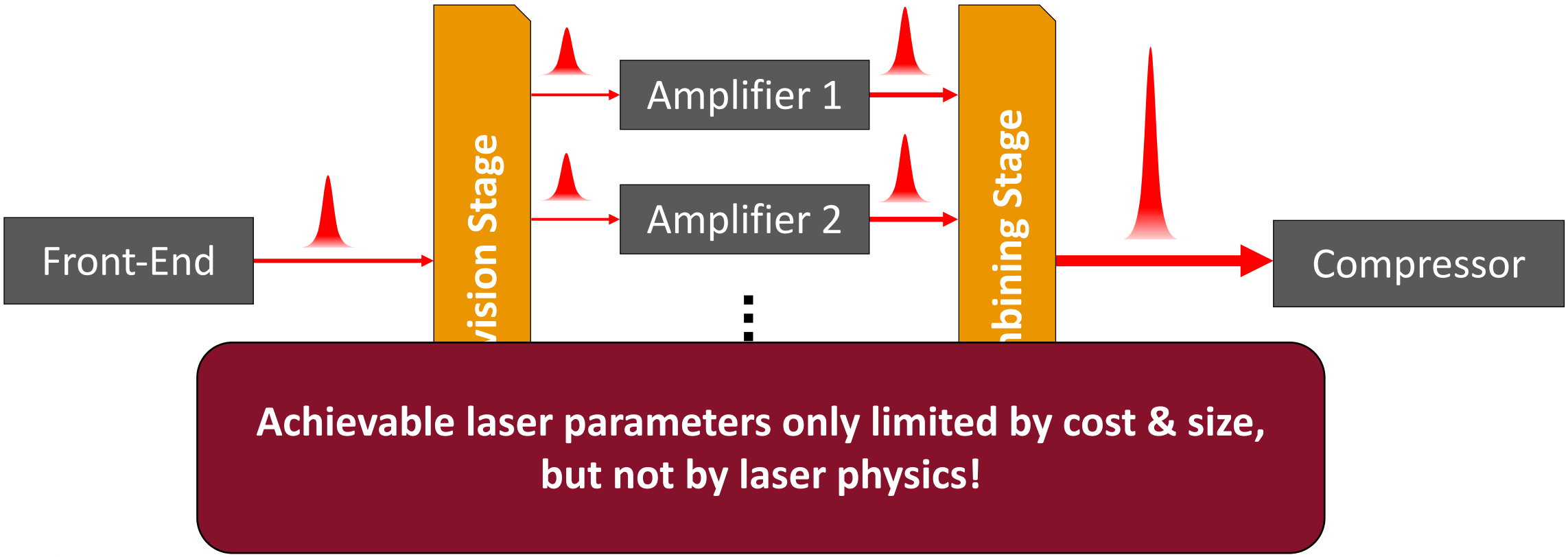
Source: ELI-ALPS, Szeged, Hungary

	HR1	HR2 (final phase)
Pulse energy	1mJ	**5mJ**
Pulse repetition rate	100kHz	**100kHz**
Average power	100W	**500W**
Pulse duration	6.2fs	**<6.0fs**
CEP-stability	yes	**yes**

ELI HR2: system design of a high-power few-cycle laser



Coherent Combination a key enabling technology

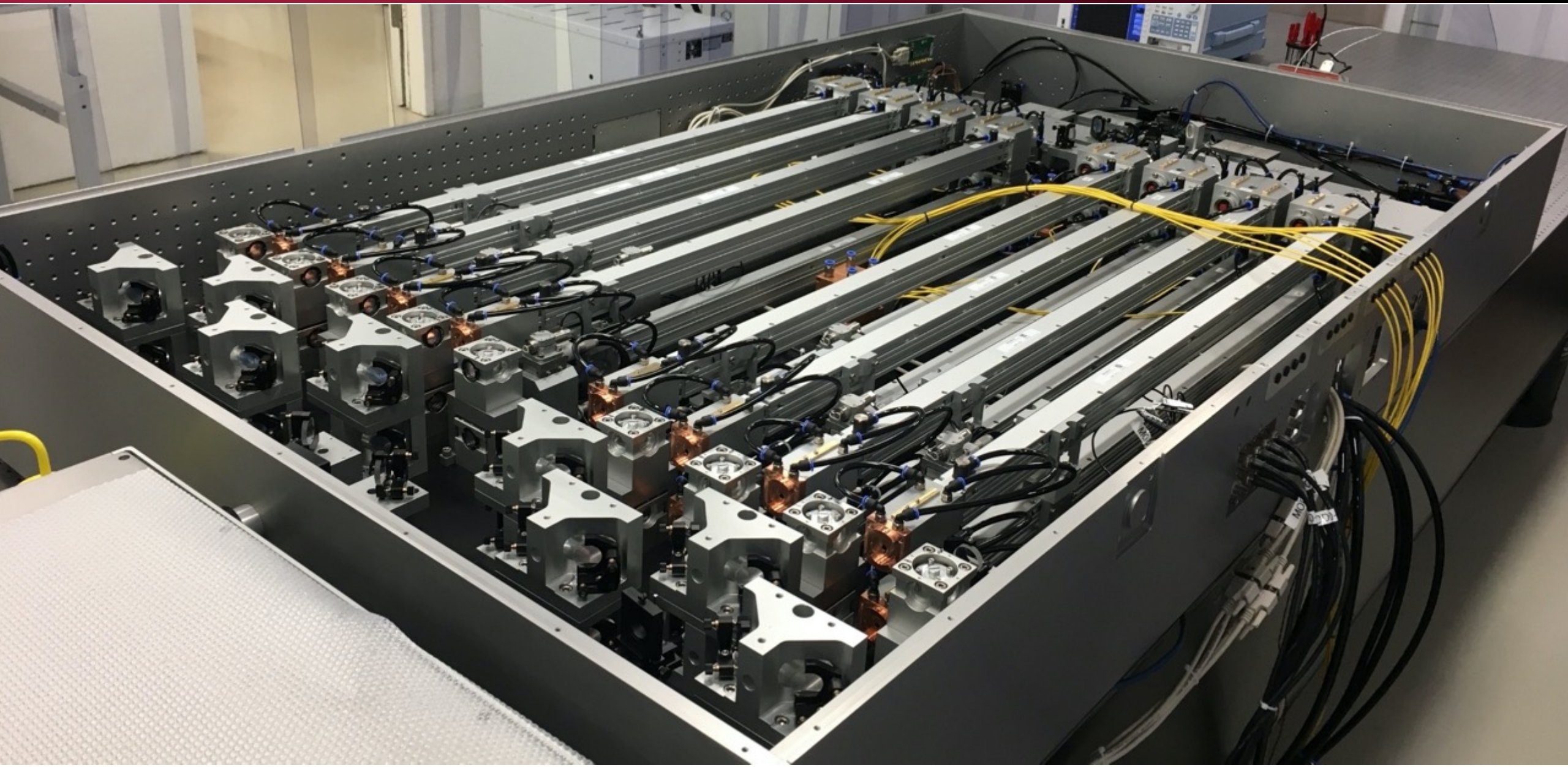


Achievable laser parameters only limited by cost & size, but not by laser physics!

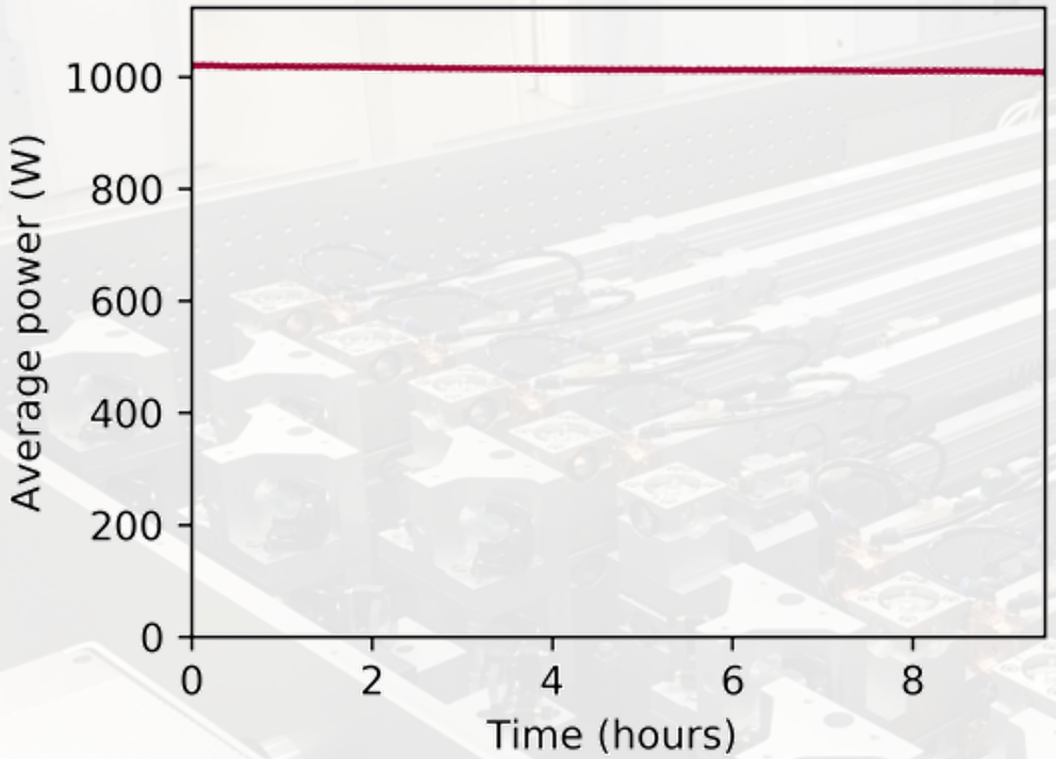
- Use ***N*** amplifiers and combine the spatially separated pulses
- Best case: Improvement of the pulse energy and average power by a factor of ***N***
- Ideally suited to fiber lasers (parallelization)

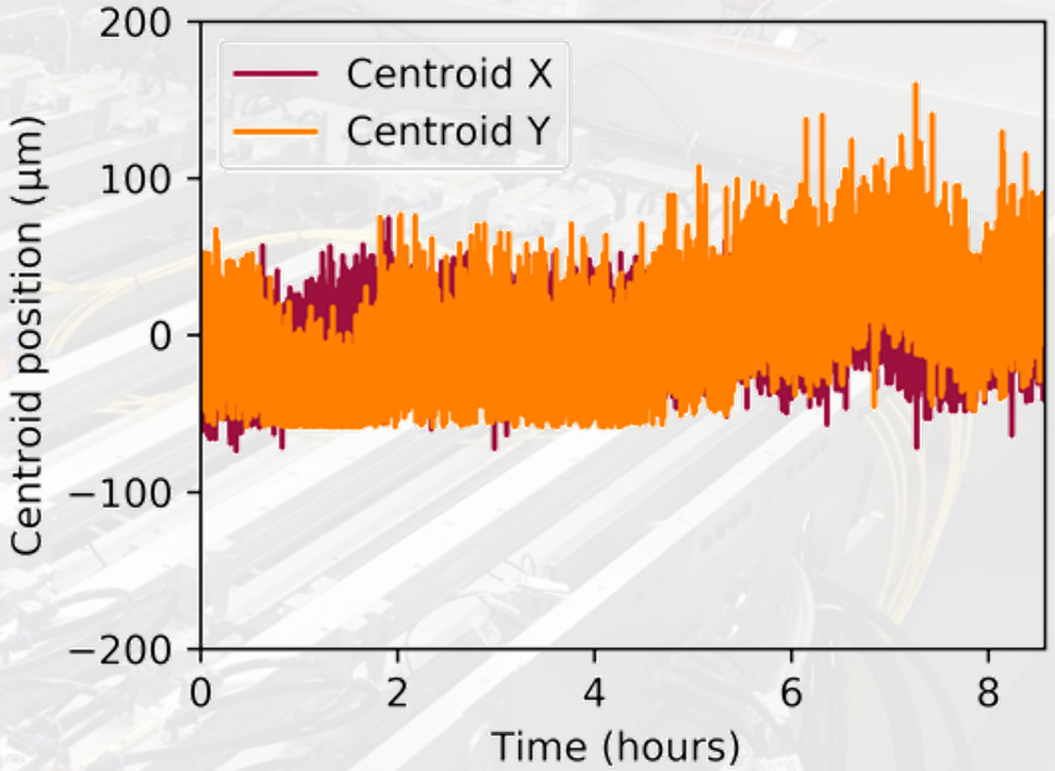
A. Klenke et al., "Coherent Beam Combination of Ultrafast Fiber Lasers," IEEE J. Sel. Top. Quantum Electron. **24**, 1–9 (2018).

CPA stage: 16 channel combining



CPA stage: 16 channel combining (HR2 laser)

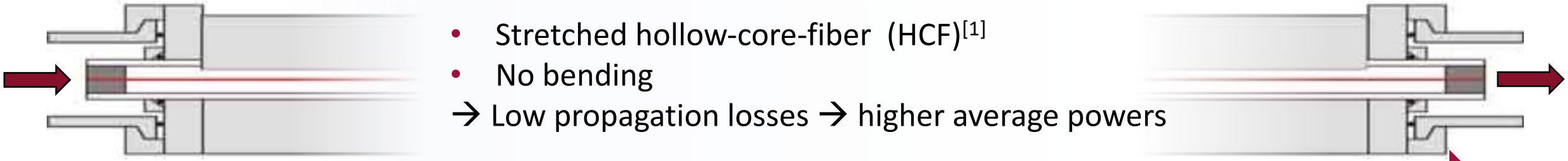




- **>10mJ / >1kW / <300fs**
- **0.31% RMS deviation over >9hours**

- **M^2=1.1**
- **Beam pointing: 6µrad/12µrad over 9 hours**

Nonlinear compression: stretched-hollow-core fibers (HR2)



- Stretched hollow-core-fiber (HCF)[1]
- No bending

→ Low propagation losses → higher average powers

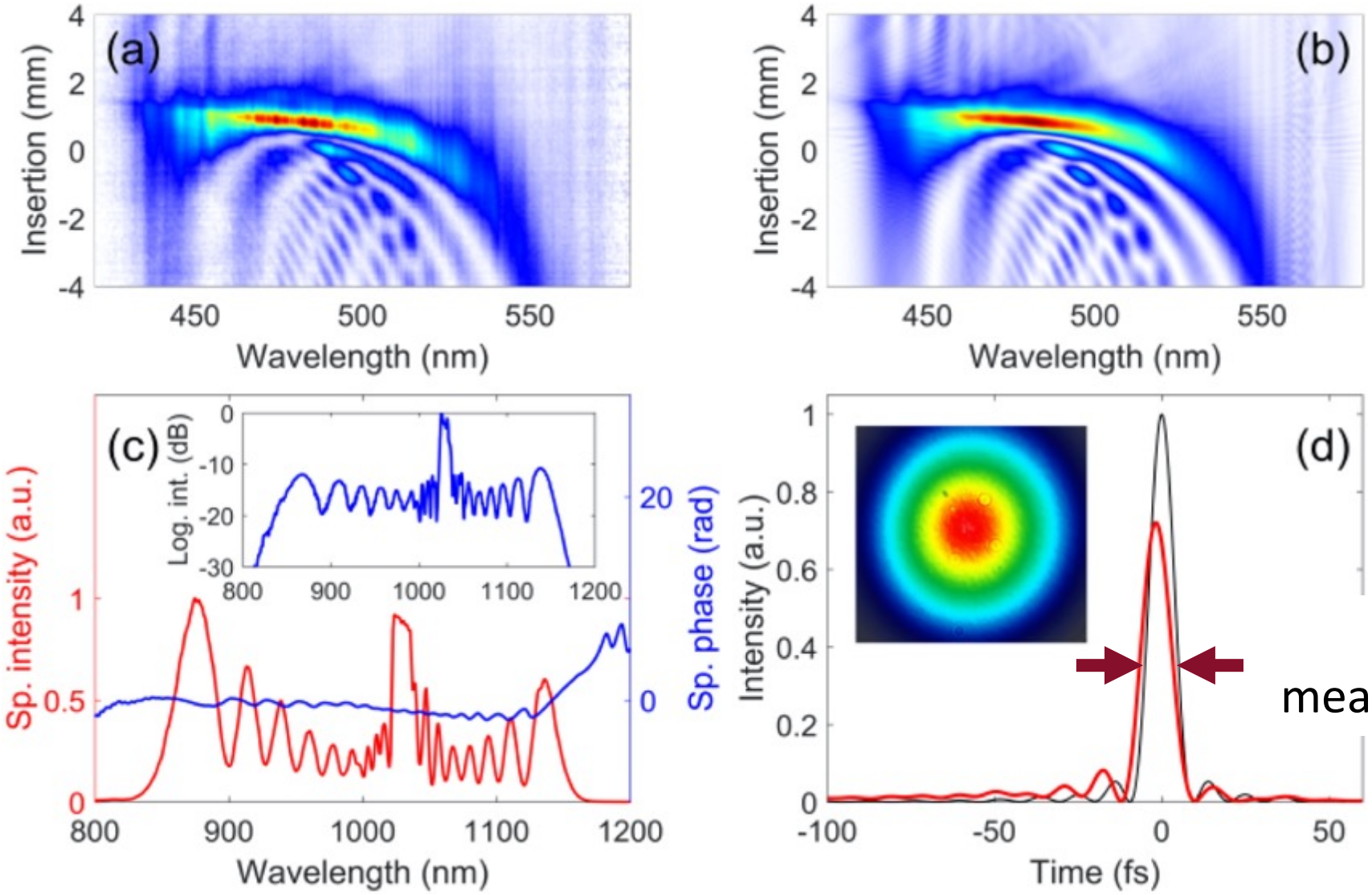
Lower pressure (800mbar) → Higher pressure (1900mbar)

- 6-8m long, 400µm inner diameter HCF
- Filled with Argon gas
- Pressure gradient

[1] T. Nagy et al. Appl. Opt. 47, 3264 (2008).

Nonlinear compression: stretched-hollow-core fibers (HR2)

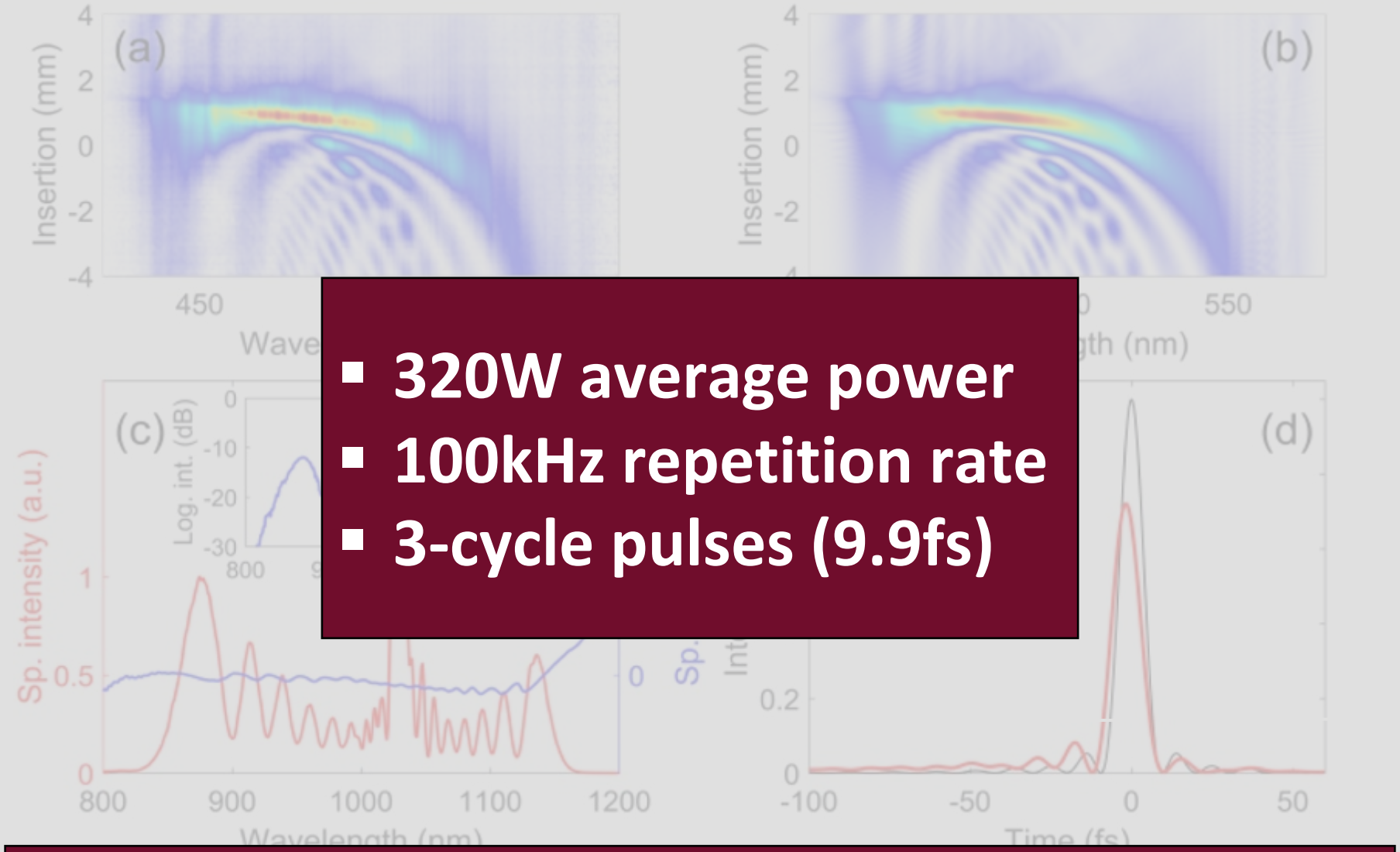
Nonlinear compression: 6m stretched fiber



9.9fs
measured via D-scan

[1] Tamas Nagy, Steffen Hädrich, Peter Simon, Andreas Blumenstein, Nico Walther, Robert Klas, Joachim Buldt, Henning Stark, Sven Breitkopf, Péter Jójárt, Imre Seres, Zoltán Várallyay, Tino Eidam, Jens Limpert, "Generation of three-cycle multi-millijoule laser pulses at 318 W average power," Optica 6, 1423-1424 (2019)

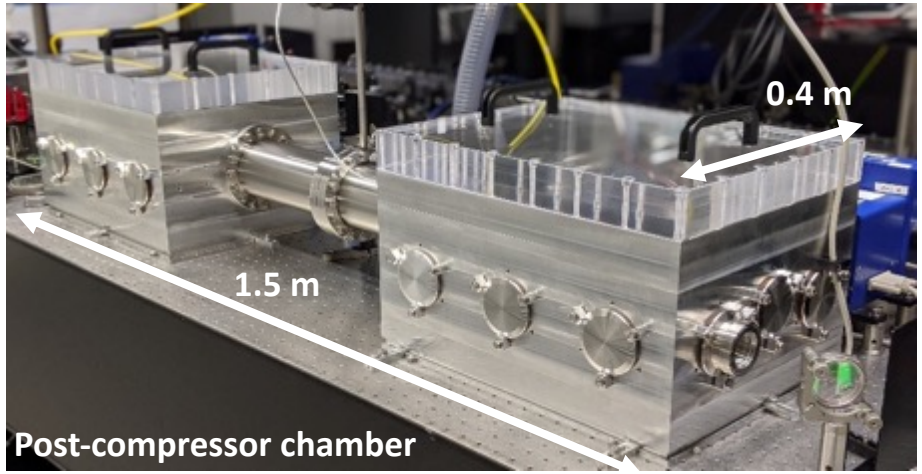
Nonlinear compression: 6m stretched fiber

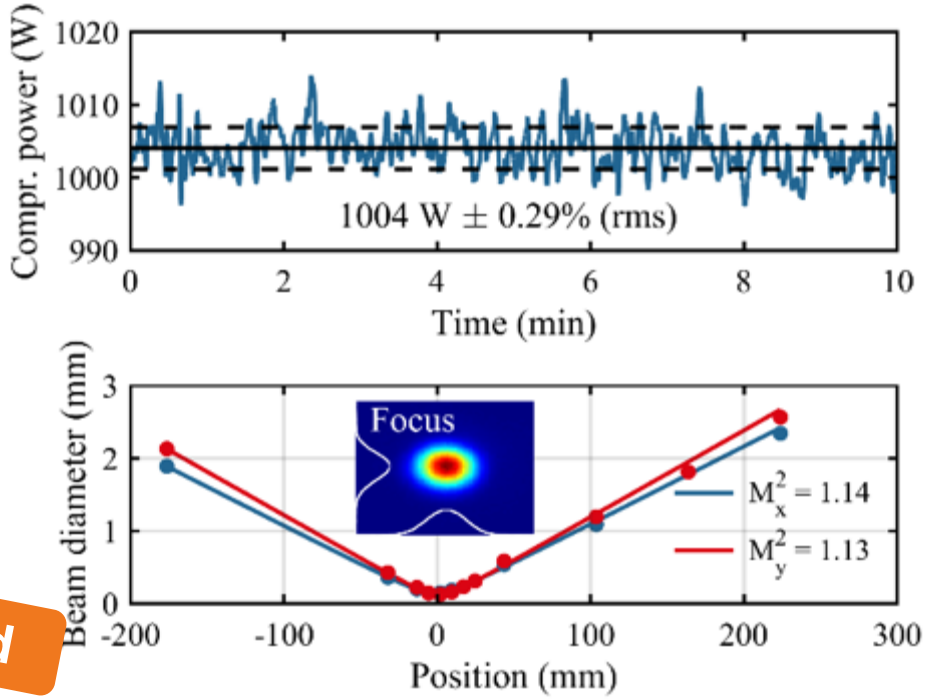


- **320W average power**
- **100kHz repetition rate**
- **3-cycle pulses (9.9fs)**

[1] T. Nagy et al. 'Generation of 3-cycle multi-mJ laser pulses at 318 W average power', Optica 6 1423-1424 (2019)

Pulse post-compression in multi-pass cell (MPC)





World record

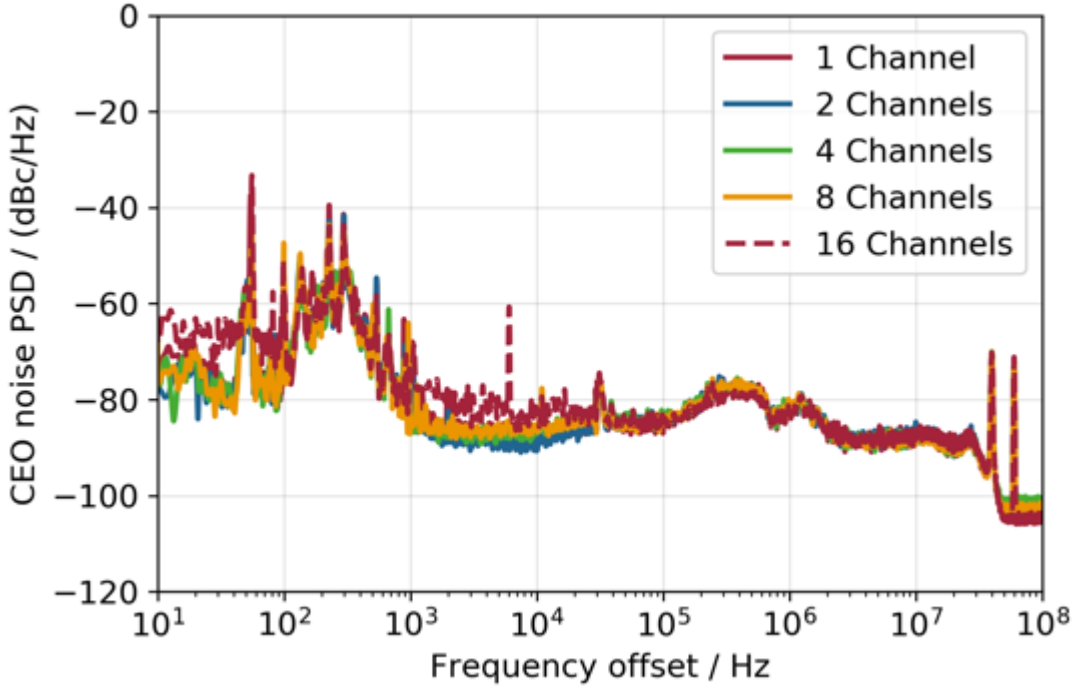
96% compression efficiency
world record in av. power for sub-100 fs pulses
no beam quality degradation

31fs pulses with
1mJ pulse energy and 1kW average power

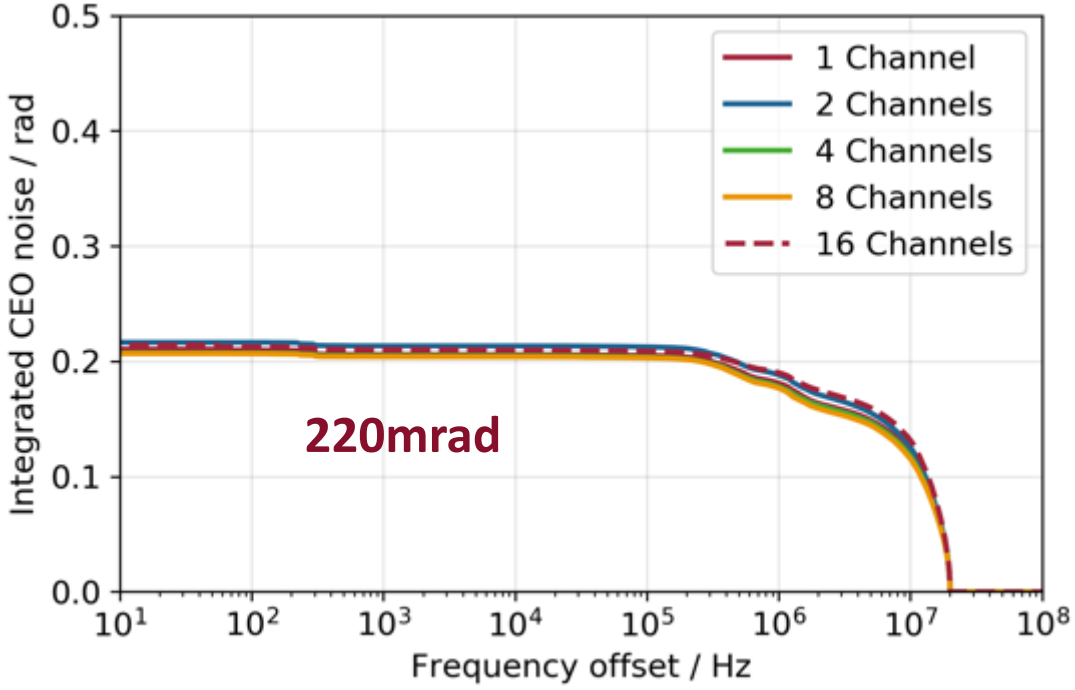
Investigation of few-cycle MPCs underway
- HR1 and HR2-type parameters

*C. Grebing, M. Müller, J. Buldt, H. Stark, and Jens Limpert, Kilowatt-average-power compression of millijoule pulses in a gas-filled multi-pass cell, Opt.Letters **45**, 6250 (2020)*

CEP stabilization of high-energy systems: coherent combination



80 MHz

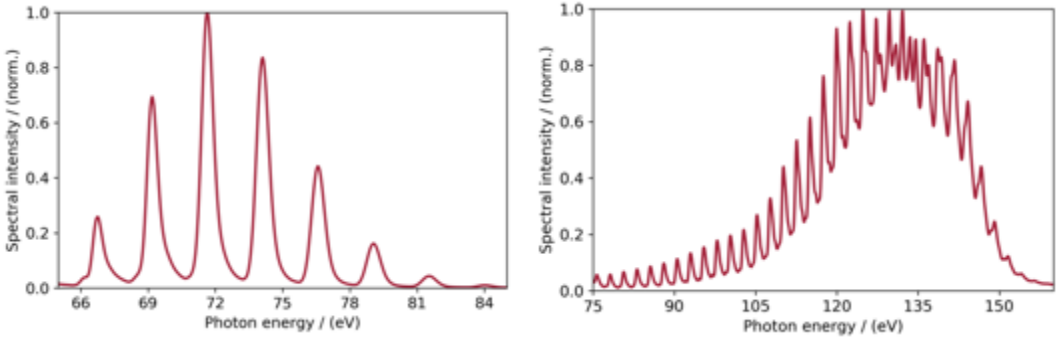


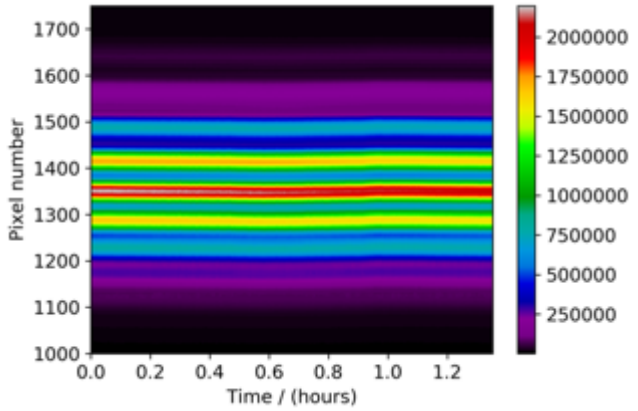
- Measurement of CEO noise with varying number of channels
- Virtually no difference
- **Coherent Combination does not affect the CEO noise of the system!**

Shestaev et al. “Carrier-envelope offset stable , coherently combined ytterbium-doped fiber CPA delivering 1kW of average power“, Opt. Lett. (accepted)

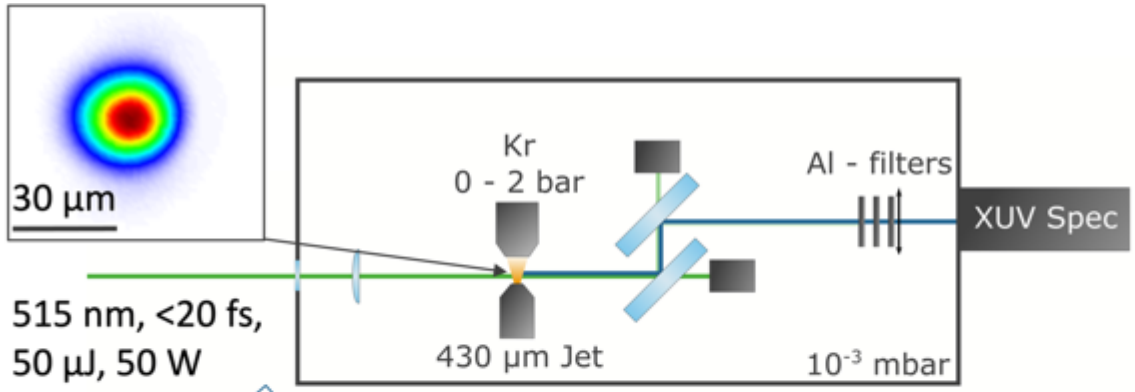
Applications besides isolated attosecond pulses

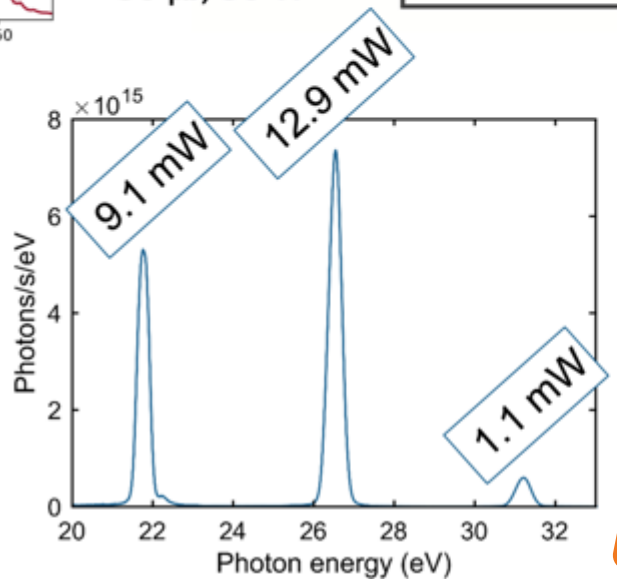
HHG with high repetition rate fiber lasers

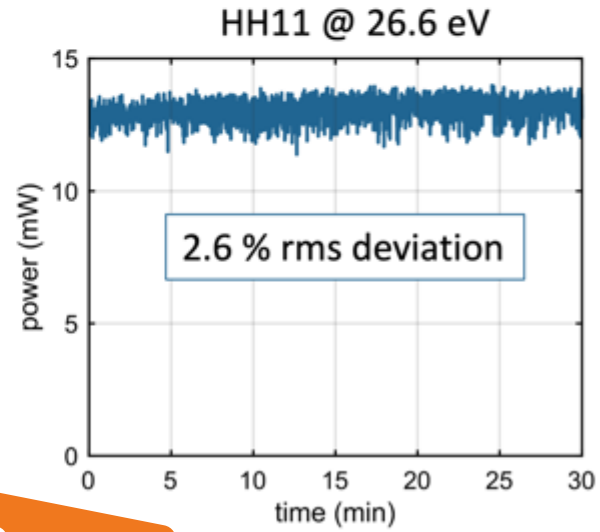




Highly stable HHG with commercial source (AFS)







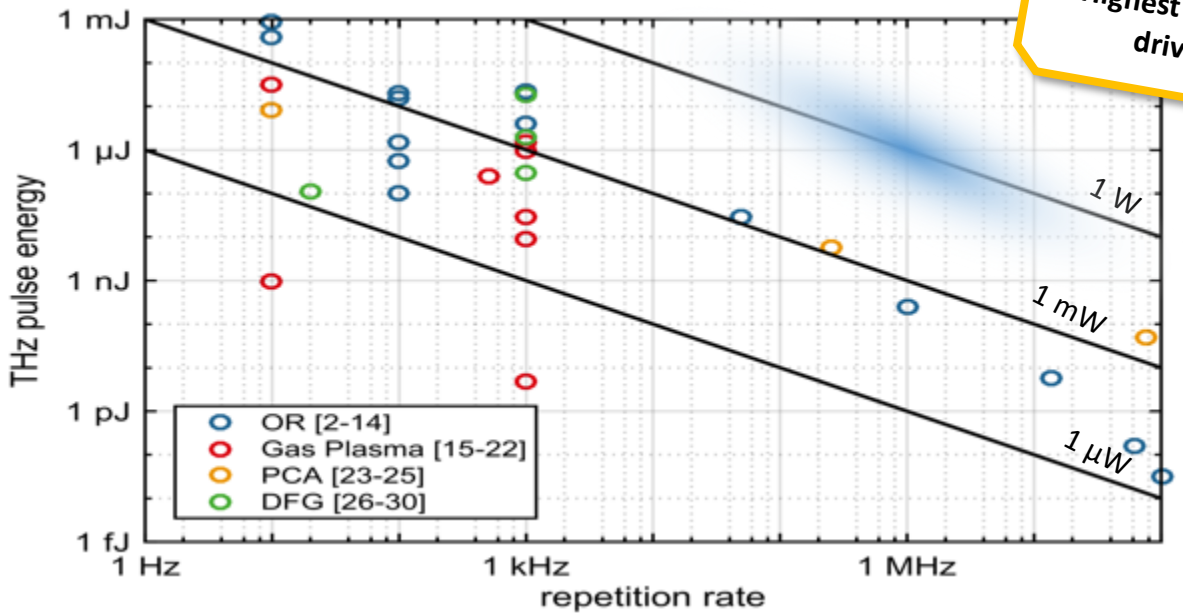
World record

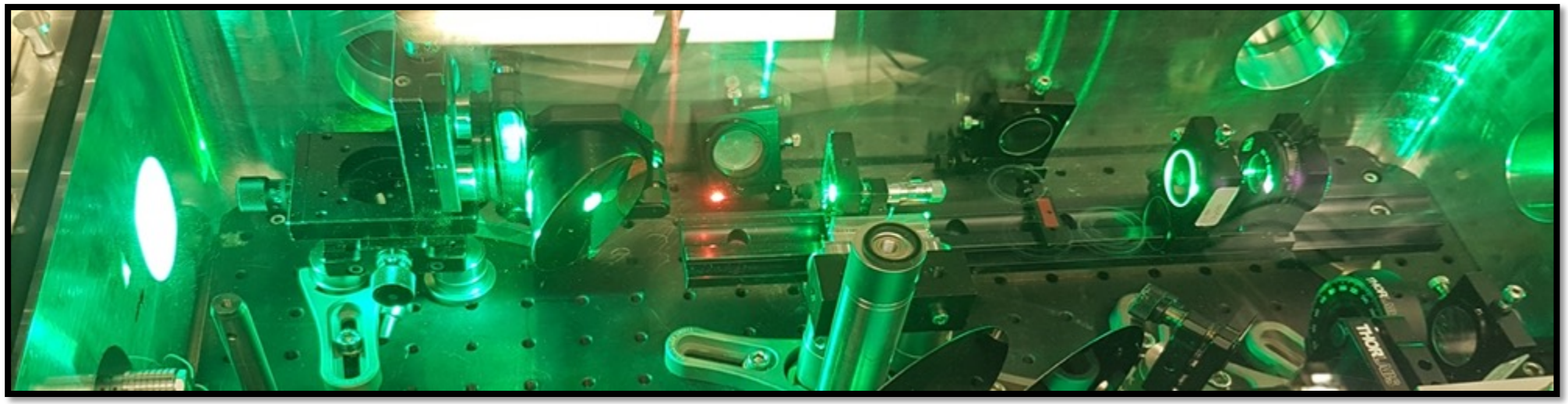
most powerful HHG source at 26eV

potential: 100mW coherent XUV emission

THz generation

Highest reported power of laser driven THz generation!





J. Buldt, M. Mueller, H. Stark, C. Jauregui, and J. Limpert Appl. Phys. B **126**, 2 (2019).

Summary

Coherent combination + stretched hollow core fiber technology

Enabling technology for high average power and repetition rate few-cycle lasers

HR Laser @ ELI-ALPS

IAP

HHG

THz

X-ray

Institute of Applied Physics
Friedrich-Schiller-Universität Jena

activefiber systems

Fraunhofer IOF

Thank you for your attention