TRUMPF

ULTRAFAST THIN-DISK AMPLIFIERS

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TRUMPF Scientific Lasers

05.-07.11.2018
Source Workshop
Talk S35

Content

1. INTRODUCTION



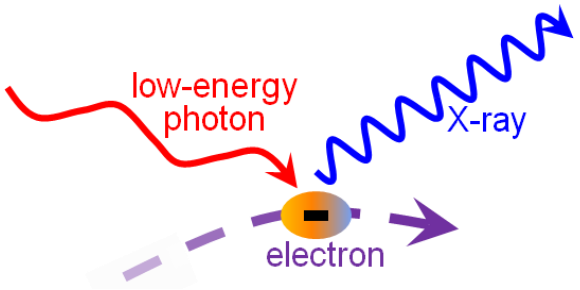


Applications & Motivation

Applications for High Average Power Ultrafast Amplifiers

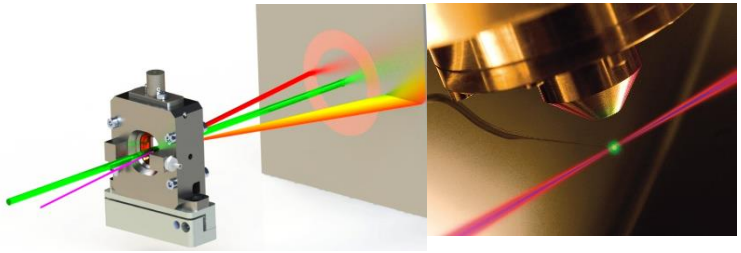
- Inverse Compton Scattering (X-Ray Generation)

Graves et al., “Compact x-ray source based on burst-mode inverse Compton scattering at 100 kHz”, Phys. Rev. ST Accel. Beams **17**, 120701 (2014)



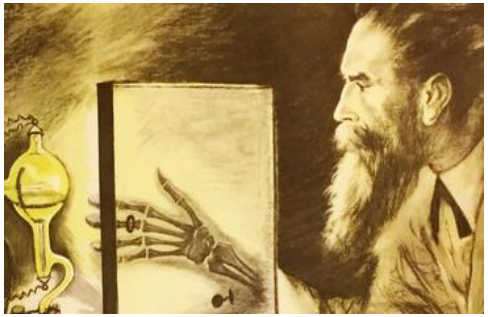
- Optical Parametric Chirped Pulse Amplification

Prinz et al., “Thin-disk pumped optical parametric chirped pulse amplifier delivering CEP-stable multi-mJ few-cycle pulses at 6 kHz”, Opt. Express **26**, 1108 (2018)

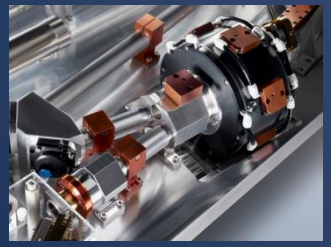


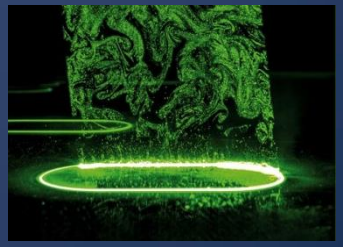
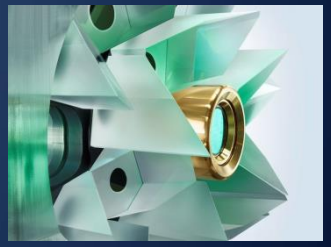
- HHG, EUV and X-Ray Generation

Rousse et al., “Efficient *K*α x-ray source from femtosecond laser-produced plasmas“, Phys. Rev. E **50**, 2200 (1994) – Reagen et al., "High-average-power, 100-Hz-rep.-rate, **tabletop soft-x-ray** lasers at sub-15-nm wavelengths, “Phys. Rev A **89**, 053820 (2014)



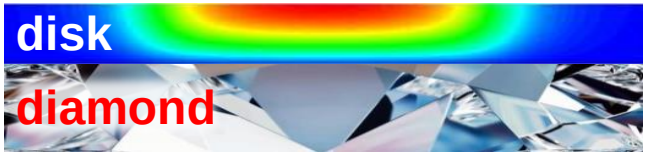
2. THIN-DISK LASER TECHNOLOGY

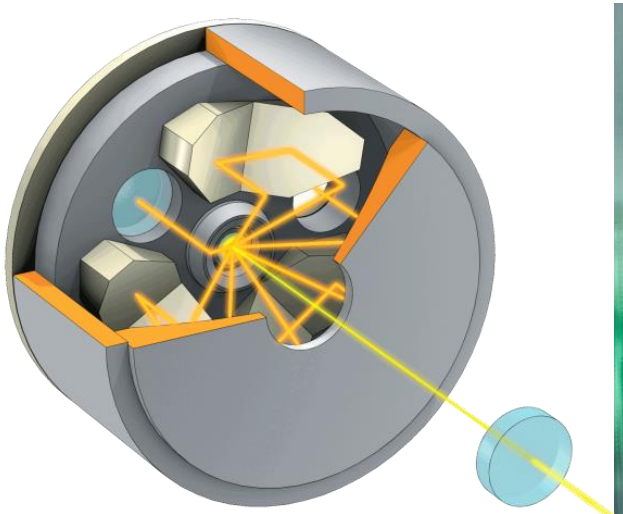



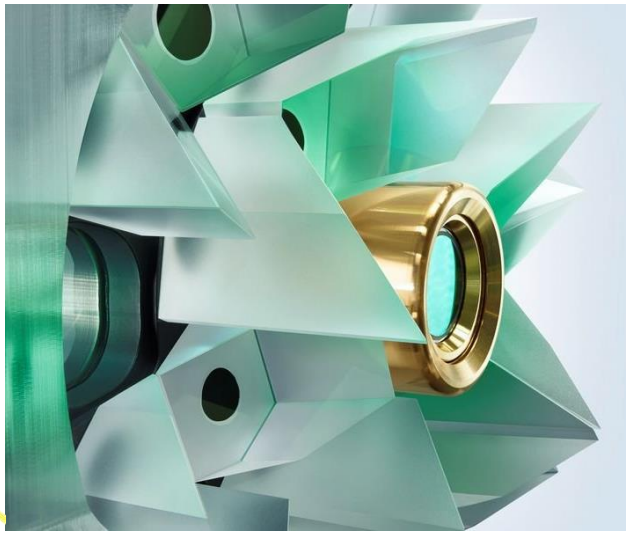
Disk Laser Principles (Prof. Giesen 1994)

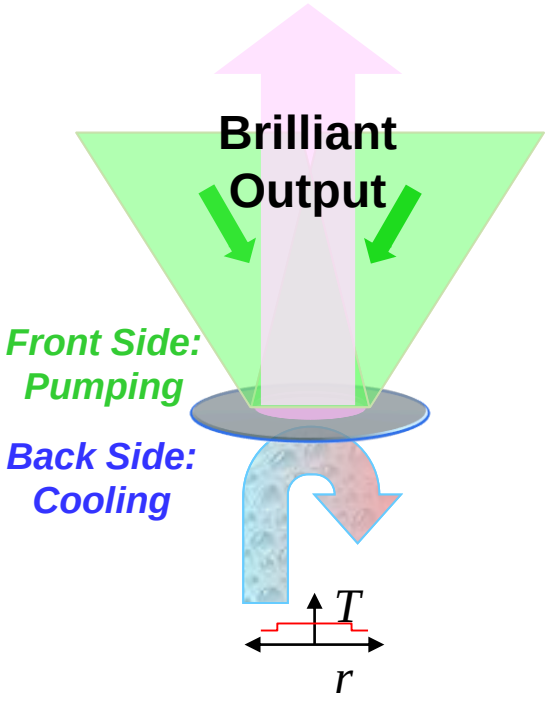
Diameter of pumped area >> disk thickness



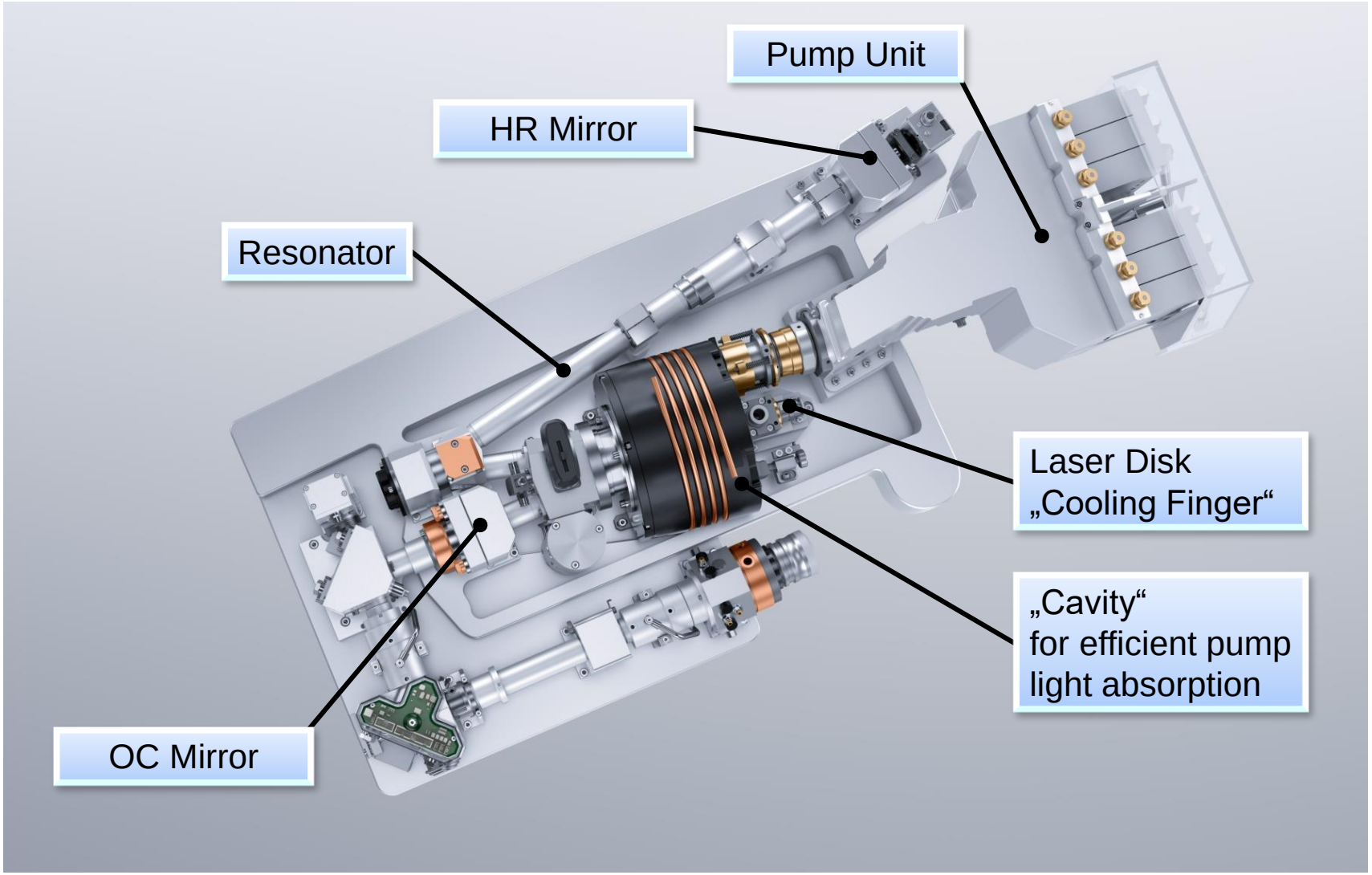
+ uniaxial heat flux: Low thermal lensing → High brightness
+ Low brightness constraints for pump diodes
+ High gain saturation: Insensitive to back reflections
+ Scalability by increase of beam cross section
+ Negligible nonlinearities at high peak powers





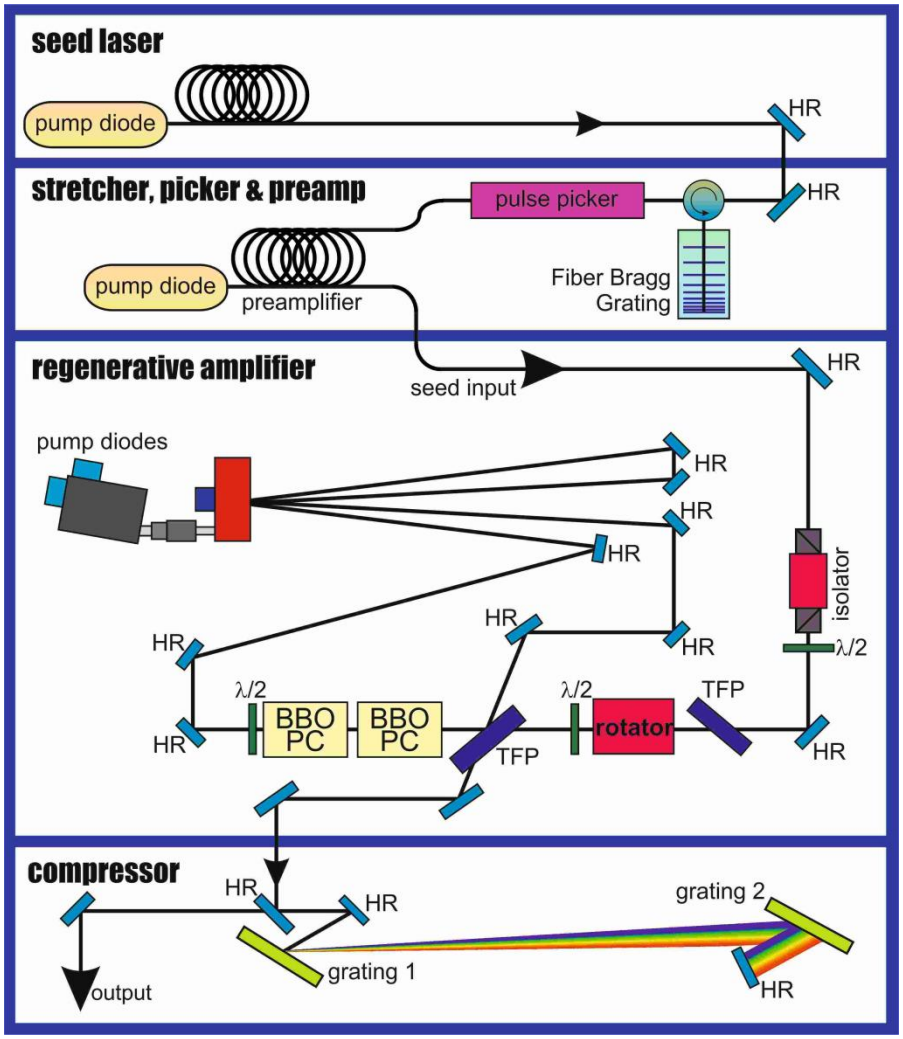


Optical setup of cw disk laser (>10kW, Yb:YAG, 1030 nm)



Typical Ultrafast Amplifier Schematic

Regenerative thin-disk amplifier:1030 nm; 1ps

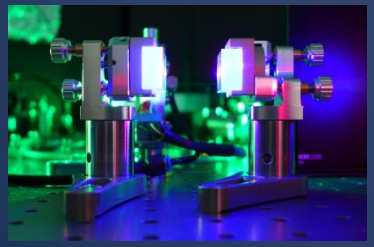


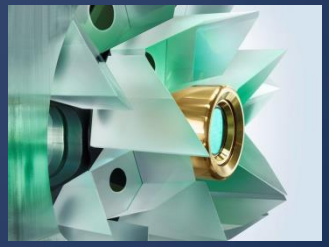
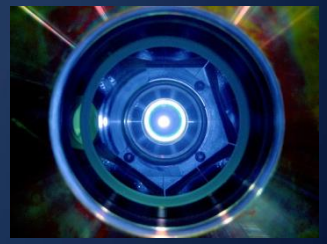
Low Energy (2mJ, 200W)

Medium Energy (50mJ, 200W)

Energy + Power (200mJ, 1kW)

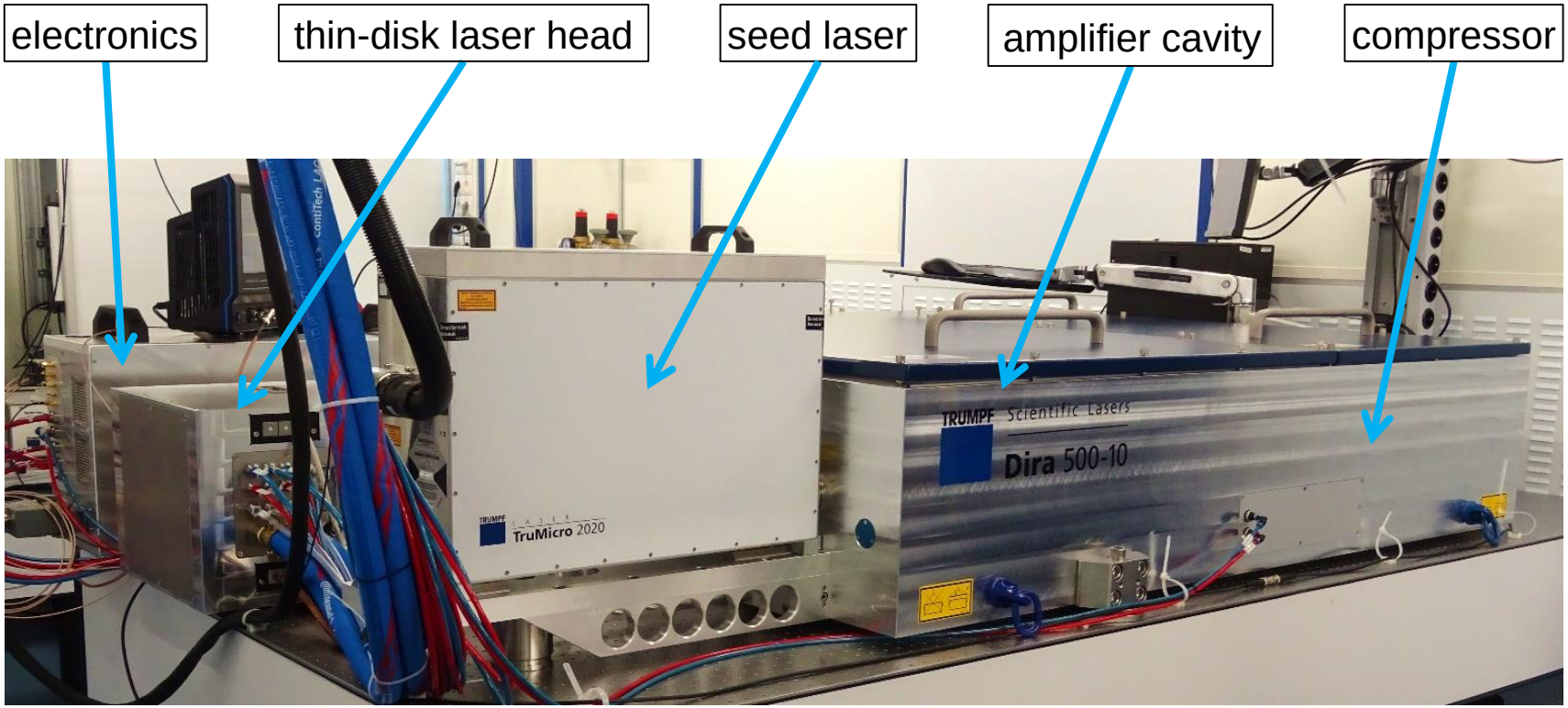
3. THIN-DISK REGEN AMPLIFIERS

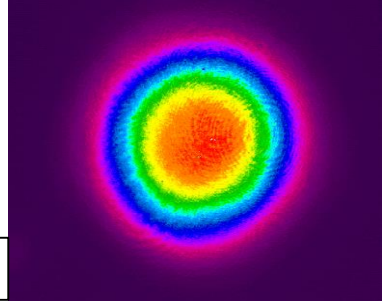
Dira 500-10 (600W; 70mJ; <1ps; M^2 < 1.4)

Picture of the System at TSL

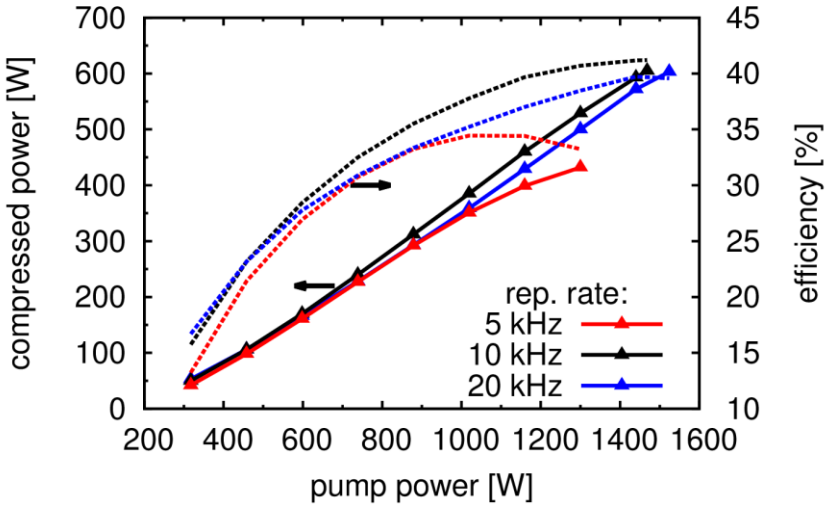


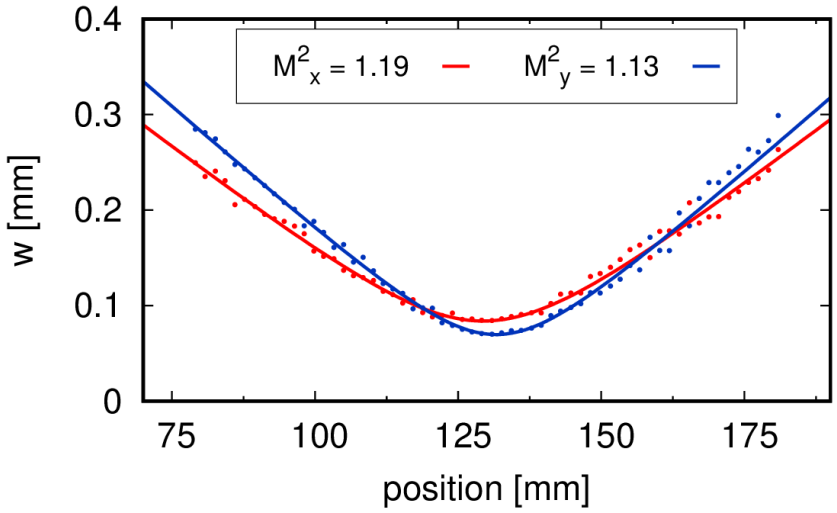
Dira 500-10 (600W; 70mJ; <1ps; M² < 1.4)

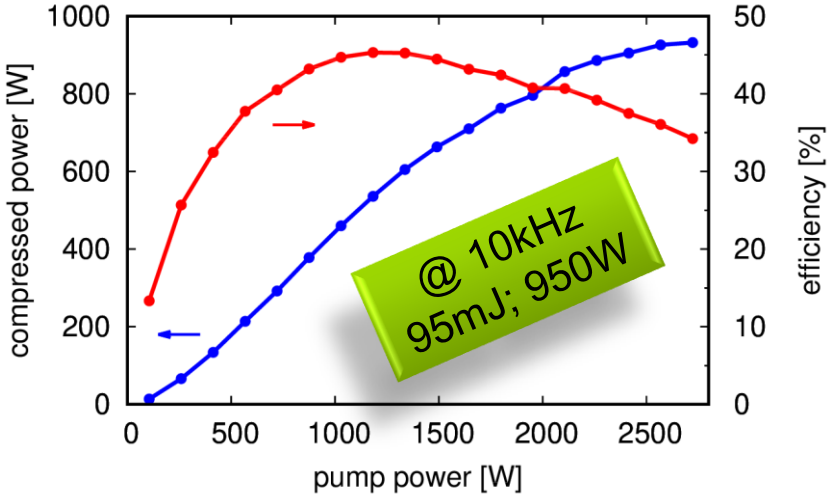
Measurements



$M^2 = 1.2$







Dira 500-10 (600W; 70mJ; <1ps; M² < 1.4)

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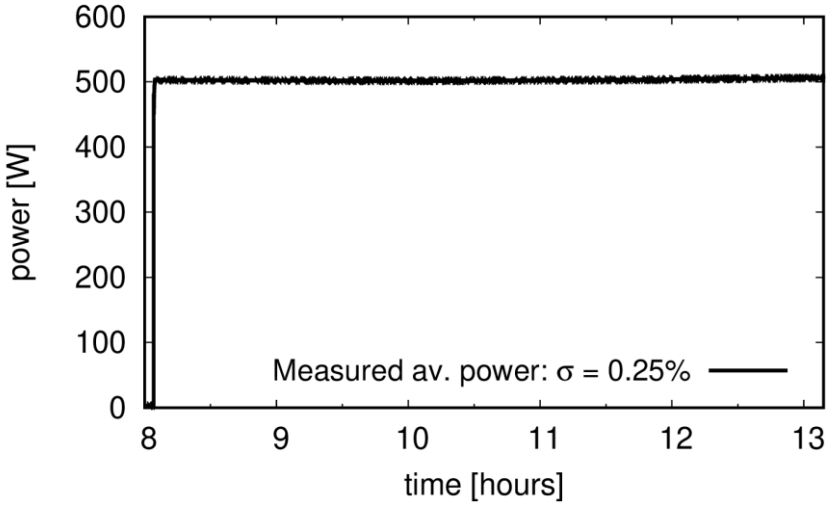
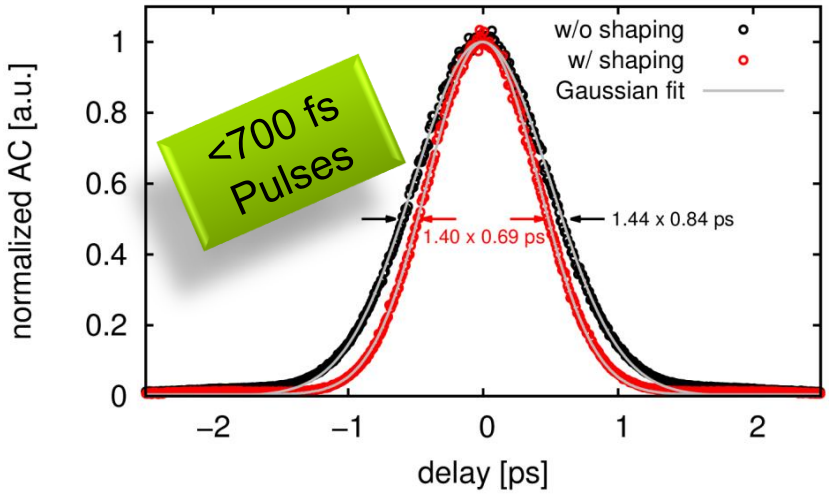
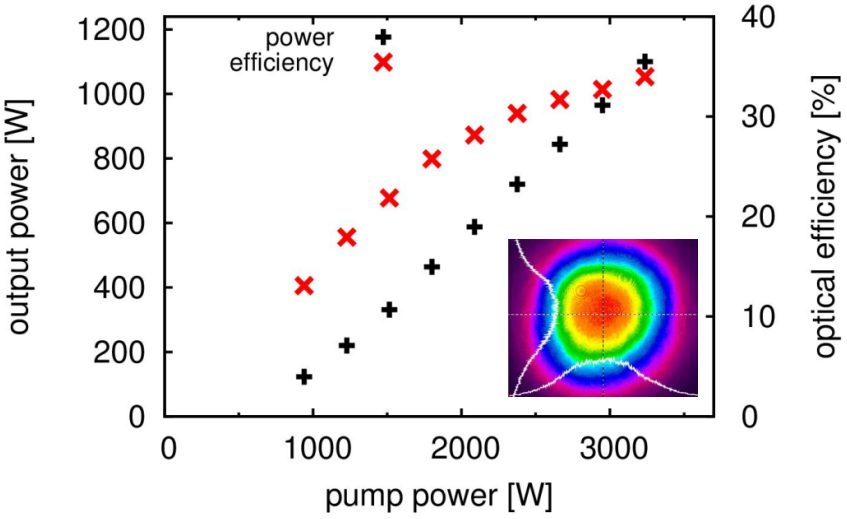
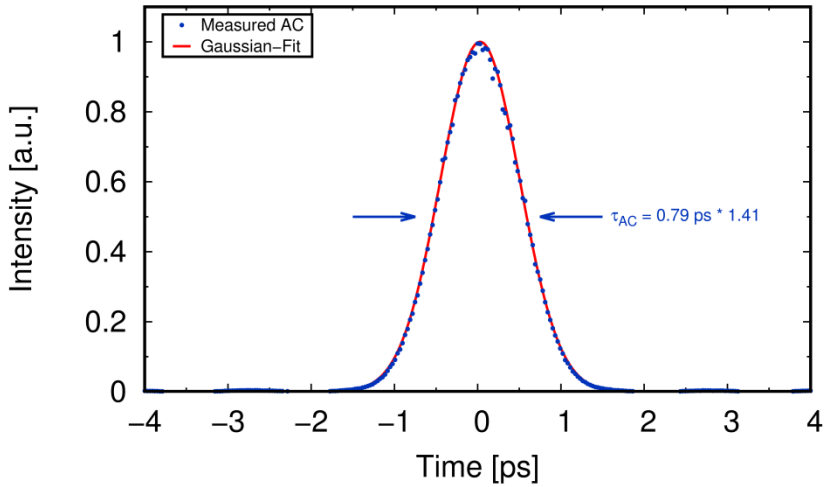


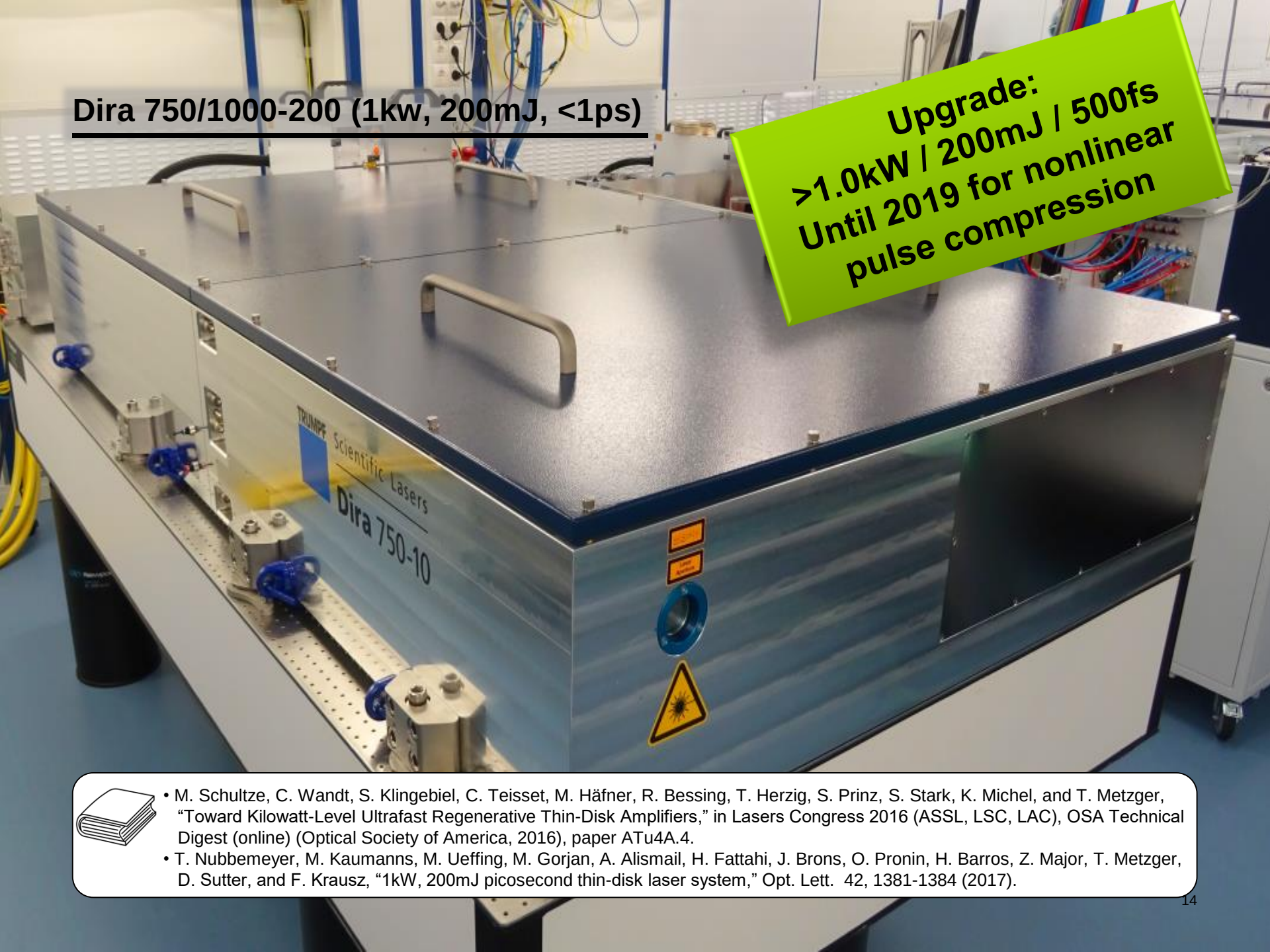


High Power Amplifier >1kW (200mJ; 5kHz; 800fs; M² = 1.3)





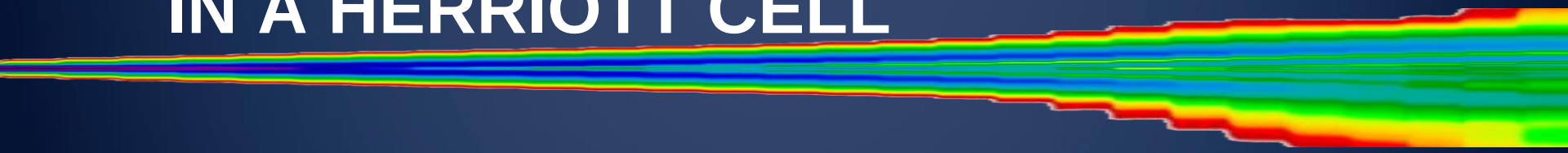
Dira 750/1000-200 (1kw, 200mJ, <1ps)



Upgrade:
>1.0kW / 200mJ / 500fs
Until 2019 for nonlinear pulse compression

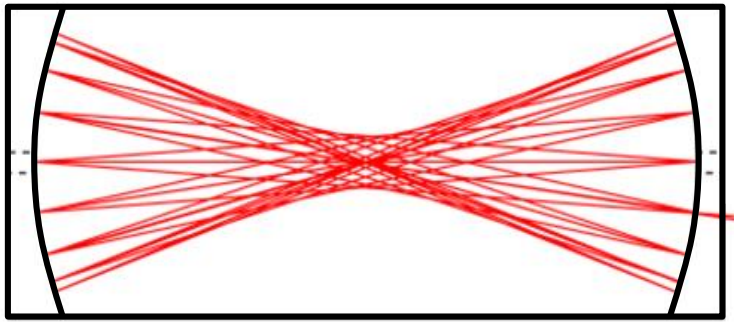
- M. Schultze, C. Wandt, S. Klingebiel, C. Teisset, M. Häfner, R. Bessing, T. Herzig, S. Prinz, S. Stark, K. Michel, and T. Metzger, "Toward Kilowatt-Level Ultrafast Regenerative Thin-Disk Amplifiers," in Lasers Congress 2016 (ASSL, LSC, LAC), OSA Technical Digest (online) (Optical Society of America, 2016), paper ATu4A.4.
- T. Nubbemeyer, M. Kaumanns, M. Ueffing, M. Gorjan, A. Alismail, H. Fattahi, J. Brons, O. Pronin, H. Barros, Z. Major, T. Metzger, D. Sutter, and F. Krausz, "1kW, 200mJ picosecond thin-disk laser system," Opt. Lett. 42, 1381-1384 (2017).

4. NONLINEAR COMPRESSION IN A HERRIOTT CELL

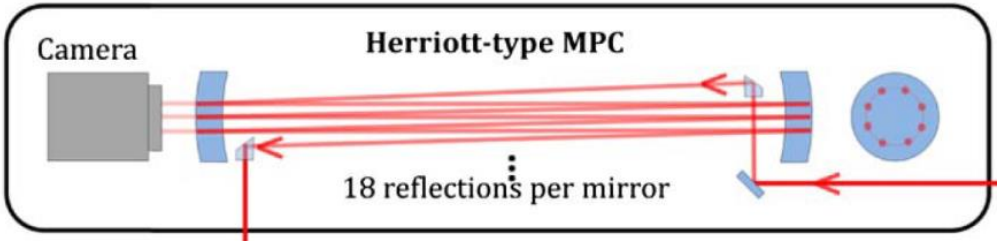


Nonlinear Pulse Compression of ~1ps output of thin-disk lasers

Spectral broadening via SPM in a Herriott-Cell

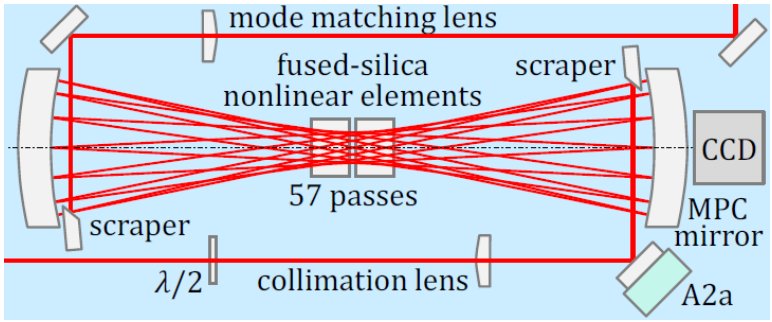


Idea:
Consecutively foci inside a gas filled cell to increase nonlinearities & to broaden the spectrum via self phase modulation (SPM). Final compression with chirped mirrors or gratings



Opt. Lett. 41, 4511 (2016)

0.9ps → 170fs
375W, 10MHz, 37.5µJ

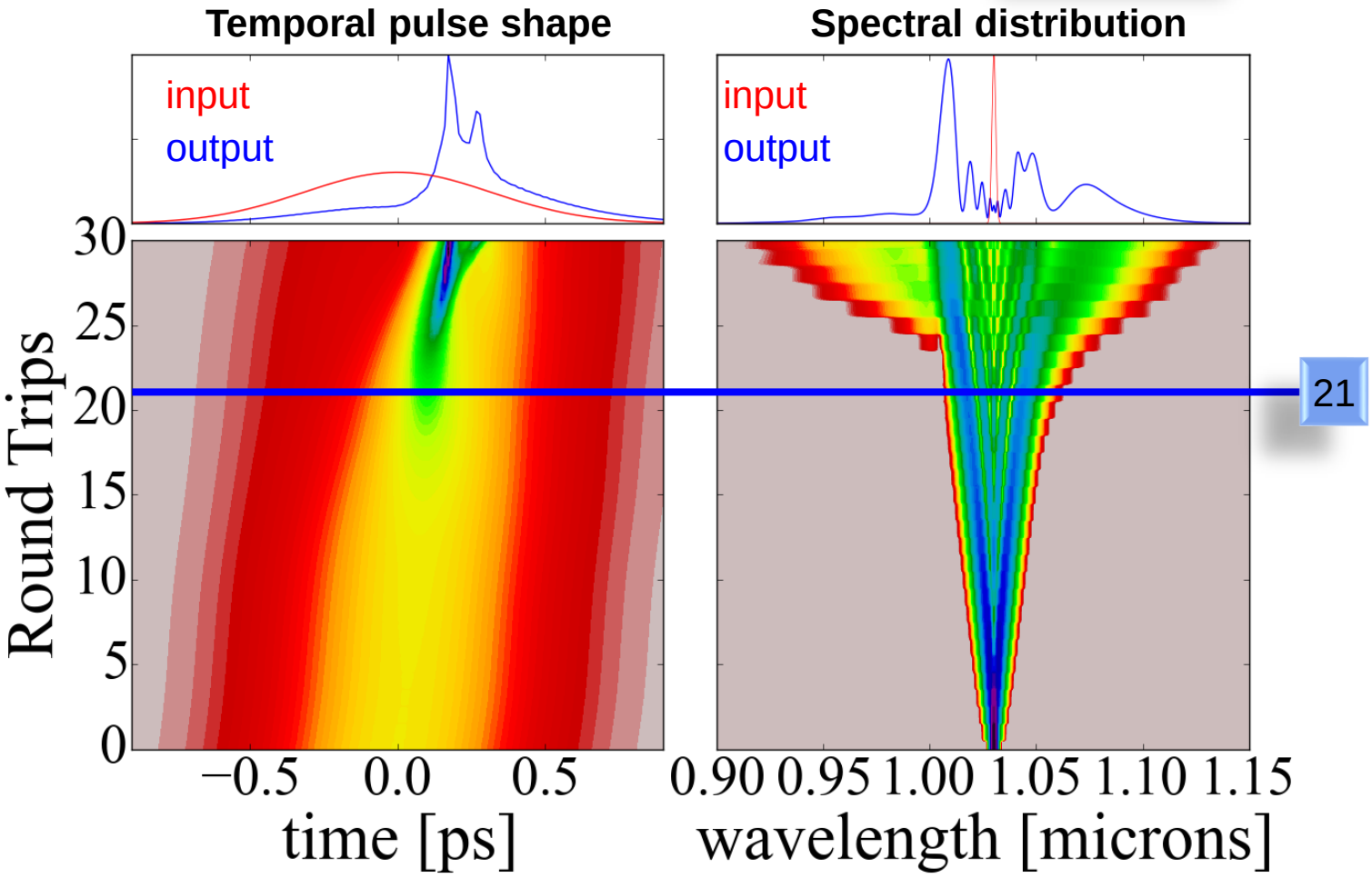


Opt. Expr. 25, 20502 (2017)

0.9ps → 115fs
300W, 40MHz, 7.5µJ

Simulation Results for 200mJ; 750fs

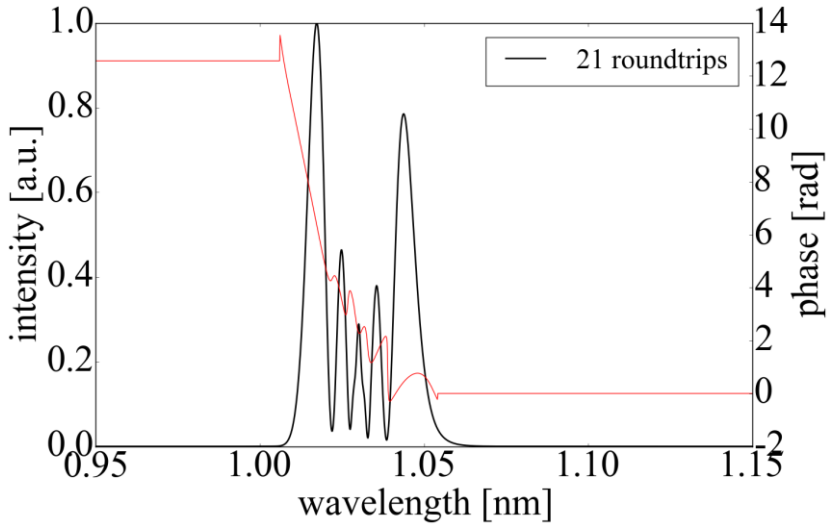
Neon
100 mbar
200mJ
750fs

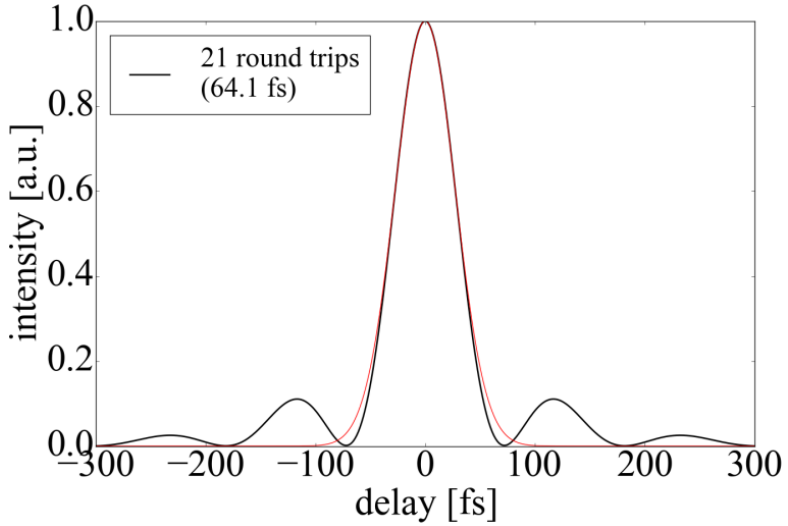


Simulation Results for 200mJ; 750fs

Neon
100 mbar
200mJ
750fs

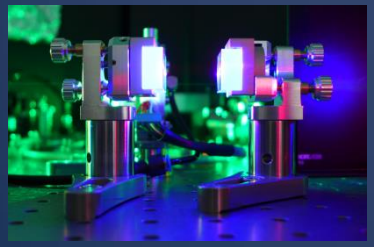
21 Round Trips

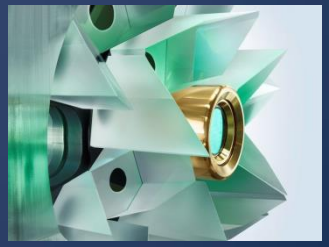
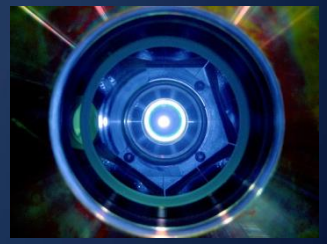




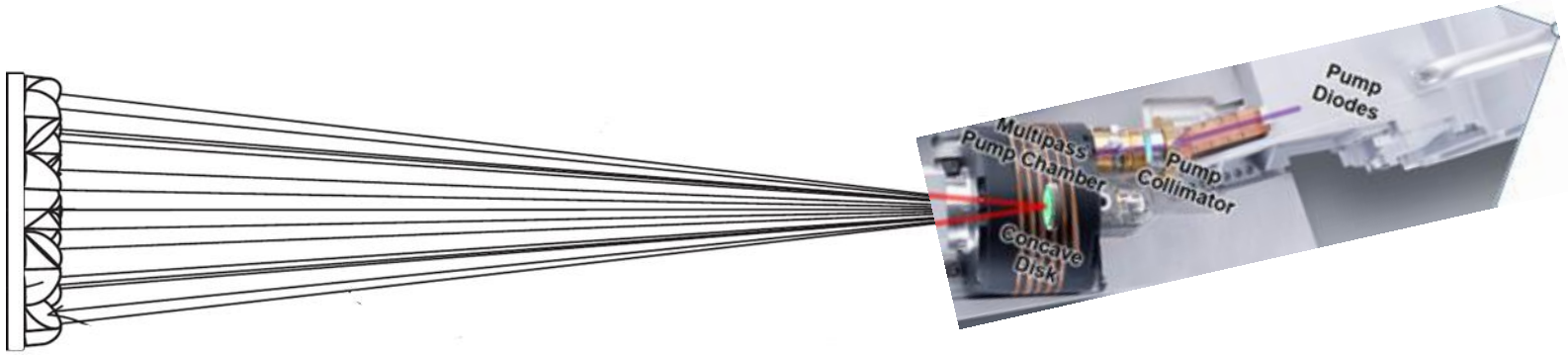
- Typical spectrum for SPM, very clean
- Spectral phase of very good nature
- Straight forward to compress
- Compressed pulse duration (65fs) a little too long

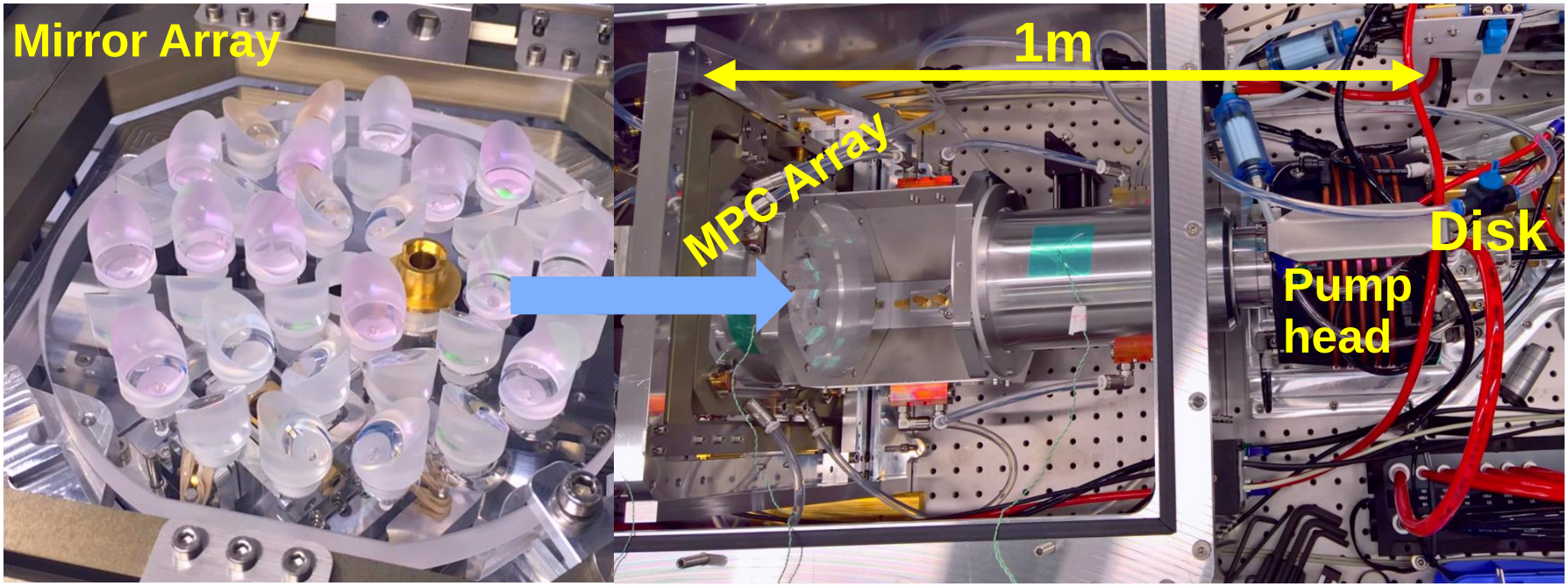
5. MULTIPASS AMPLIFIER

Multipass Cell



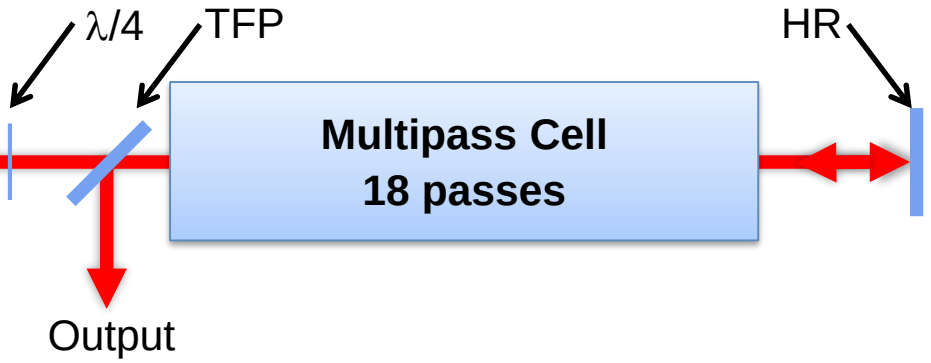


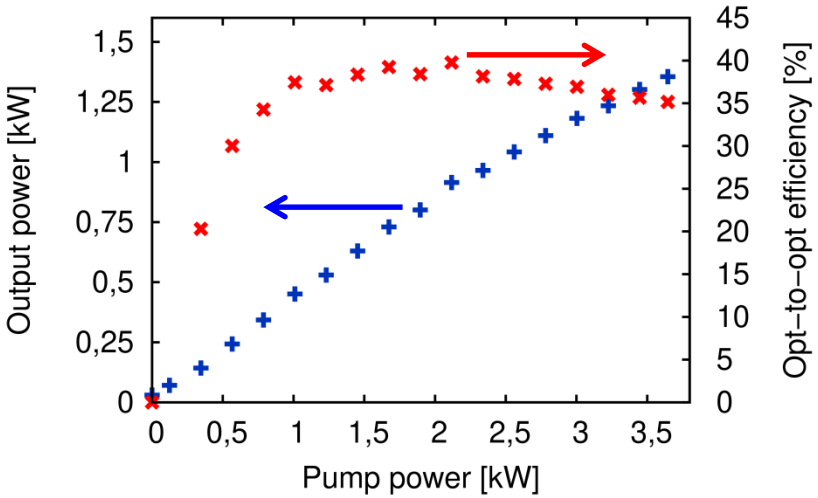
Multipass Cell

Seed Source with 100W (TruMicro 5000)

TruMicro 5000

100W, 300 kHz, 330µJ, 1ps





>1.3kW

> 4mJ (CPA-free)

Beam Quality:
$M^2 = 1.4$

Multipass Cell

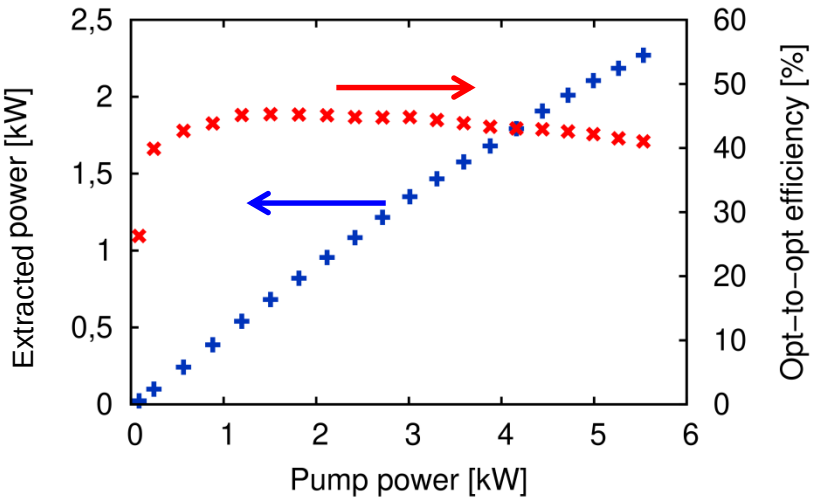
Seeding with 1kW of average power (TruMicro 7000)

TruMicro 7000

1kW, 10 kHz, 100mJ, 10ns

Multipass Cell
18 passes

Output



3kW output power @ 10kHz

Pulse duration ~10ns

Beam quality M^2 ~ 11

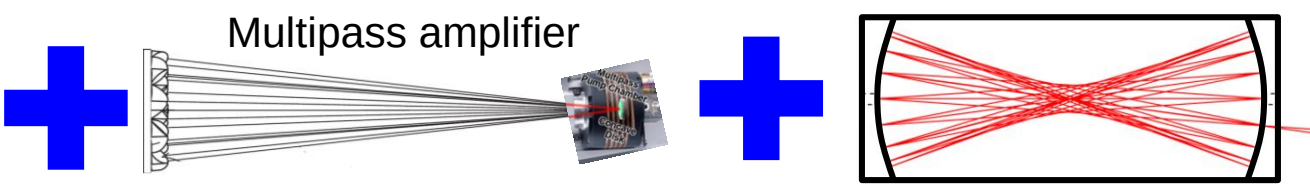
7kW Seed:

20kW output power in cw

Multimode

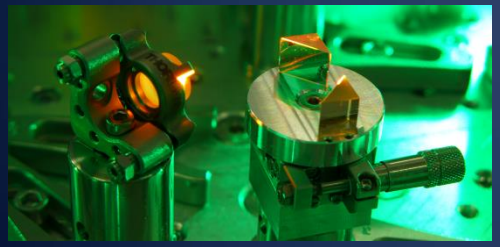
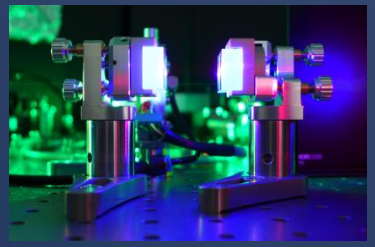
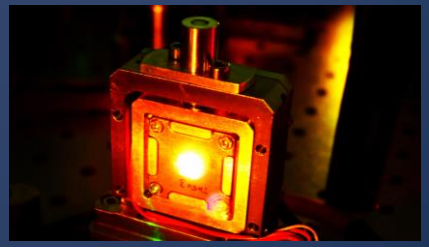
Nonlinear compression experiments: scaling the energy

Combine Regen (1kW, 200mJ, 500fs) with multipass cell



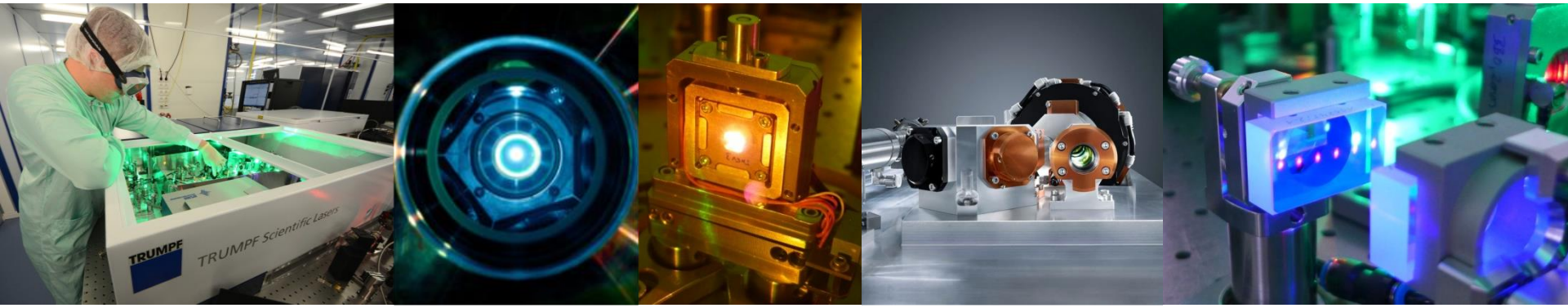
- Shorten the pulse duration to **~50fs (200mJ, 5kHz, ongoing**)
- Scale **to 400mJ; 3kW**; **1ps → <50fs (end of 2020)**
- Coherent combining or further Multipass Amplifiers towards 1J; <50fs; 7-8kW seem feasible

6. SUMMARY


Summary

- Regen. amplifier: **200 mJ; 1kHz (standard)**
  500W ; 6-100 kHz (standard)
  1kW; 5-100 kHz (standard – new goal 500fs)
- Nonlin. Compression: **first ideas for 200mJ (project has started)**
- Multipass amplifier: **1 kHz; 1 J; ~2 ps (development - project towards multi-kW)**
- OPCPA: **µJ energies (standard)**
  mJ energies (custom design possible)



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