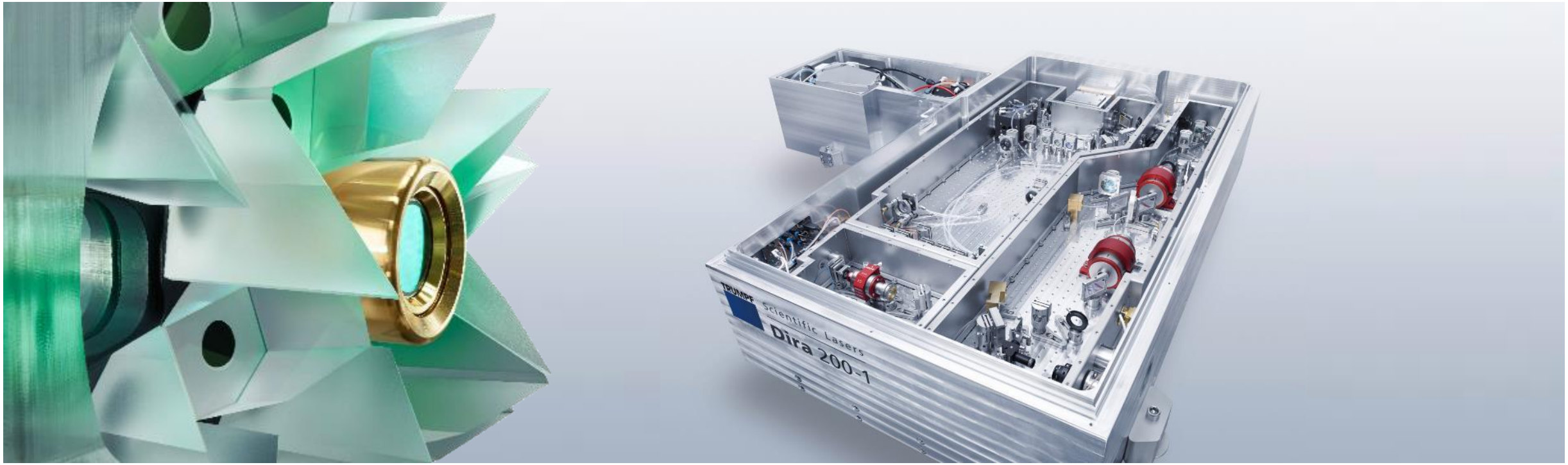


Source Workshop | November 06, 2019 | Talk S55

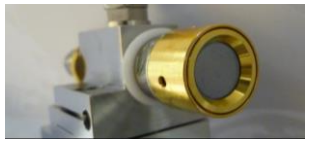
Ultrafast Thin-Disk Amplifiers

Tom Metzger | TRUMPF Scientific Lasers

TRUMPF

Content

01 Motivation



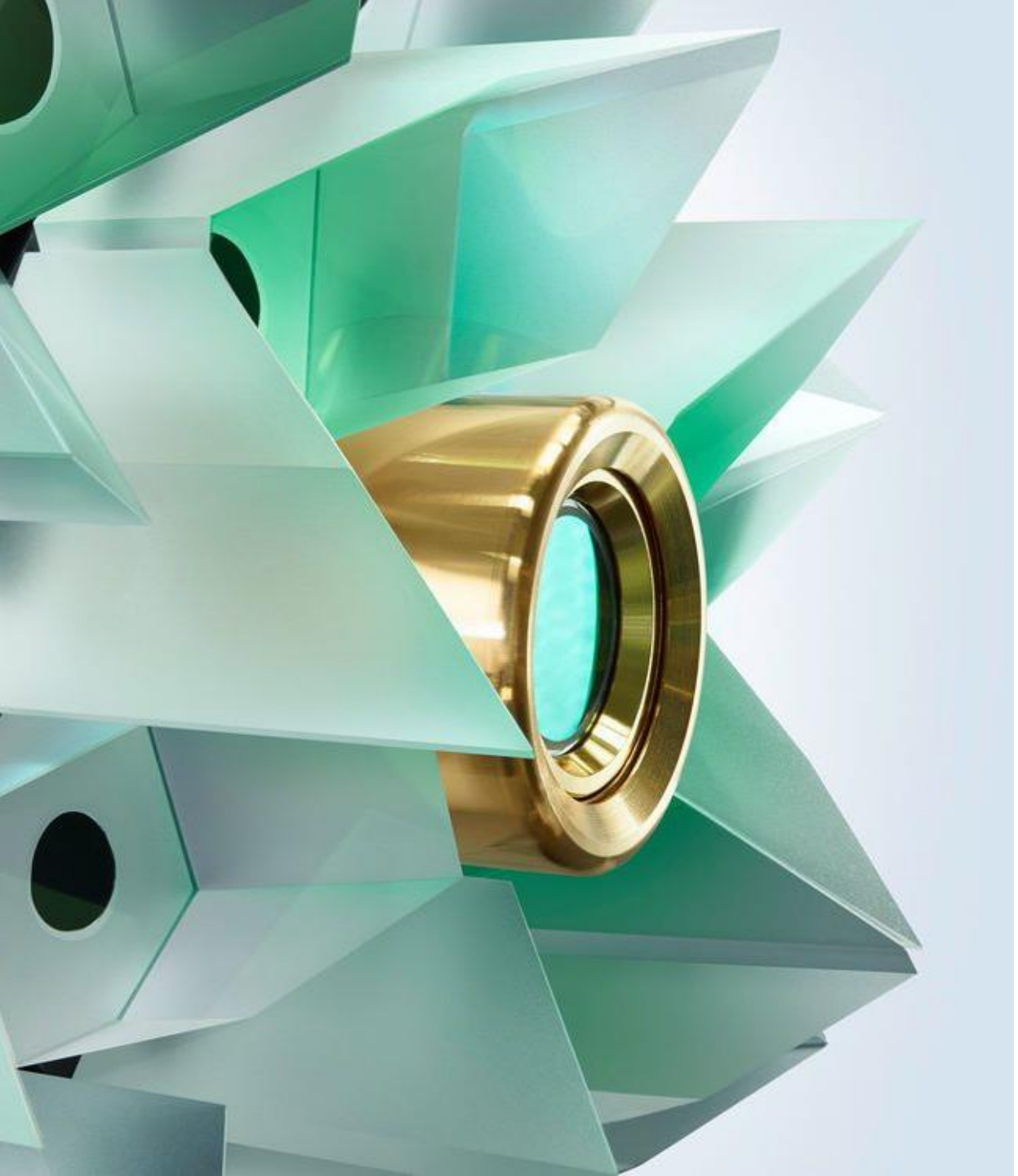
02 Thin-Disk Laser Technology

03 High Energy & High Power (Dira Series)

04 Nonlinear Compression

05 Multipass Amplifiers

06 Summary



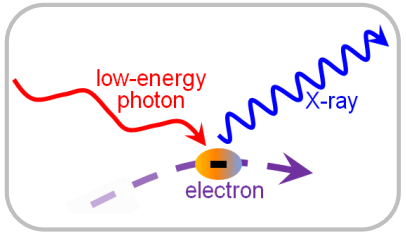
1. Motivation

Tom Metzger | TRUMPF Scientific Lasers

Motivation

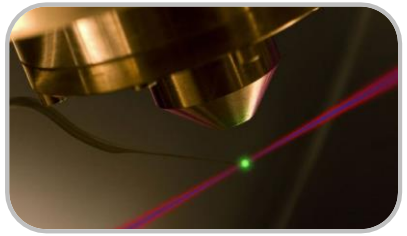
Applications

- **Inverse Compton Scattering**

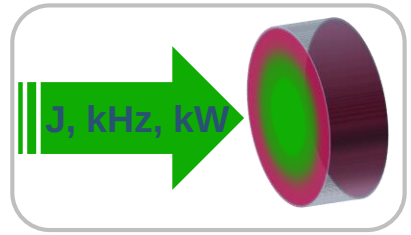


- **EUV & X-Ray Generation**

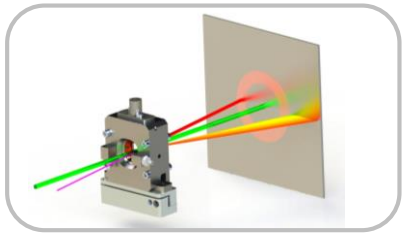
- **High Harmonic Generation**



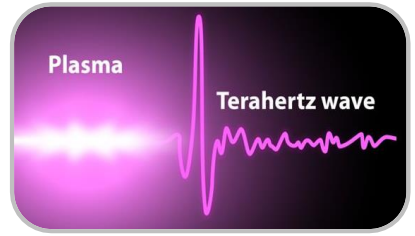
- **Pumping Ti:Sapphire**



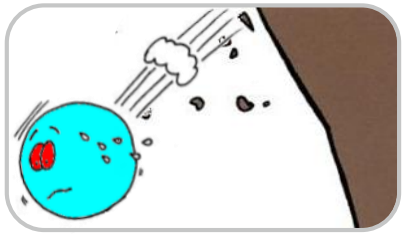
- **Optical Parametric Amplification**



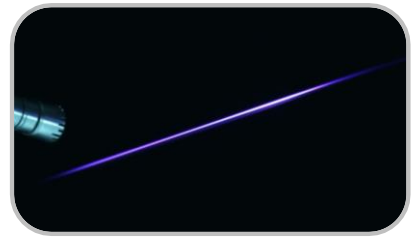
- **THz Generation**



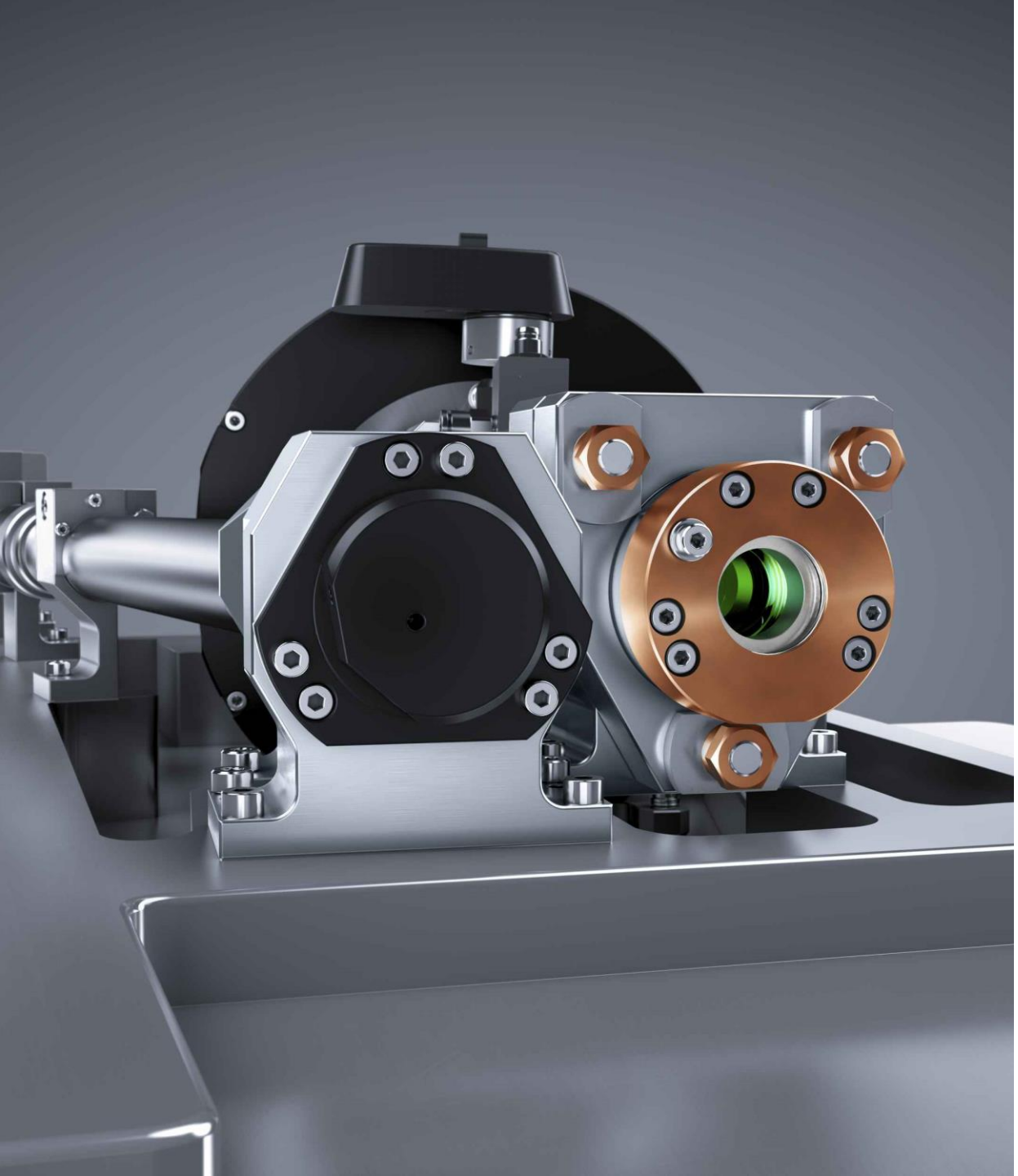
- **Electron Acceleration**



- **Filaments**



TRUMPF

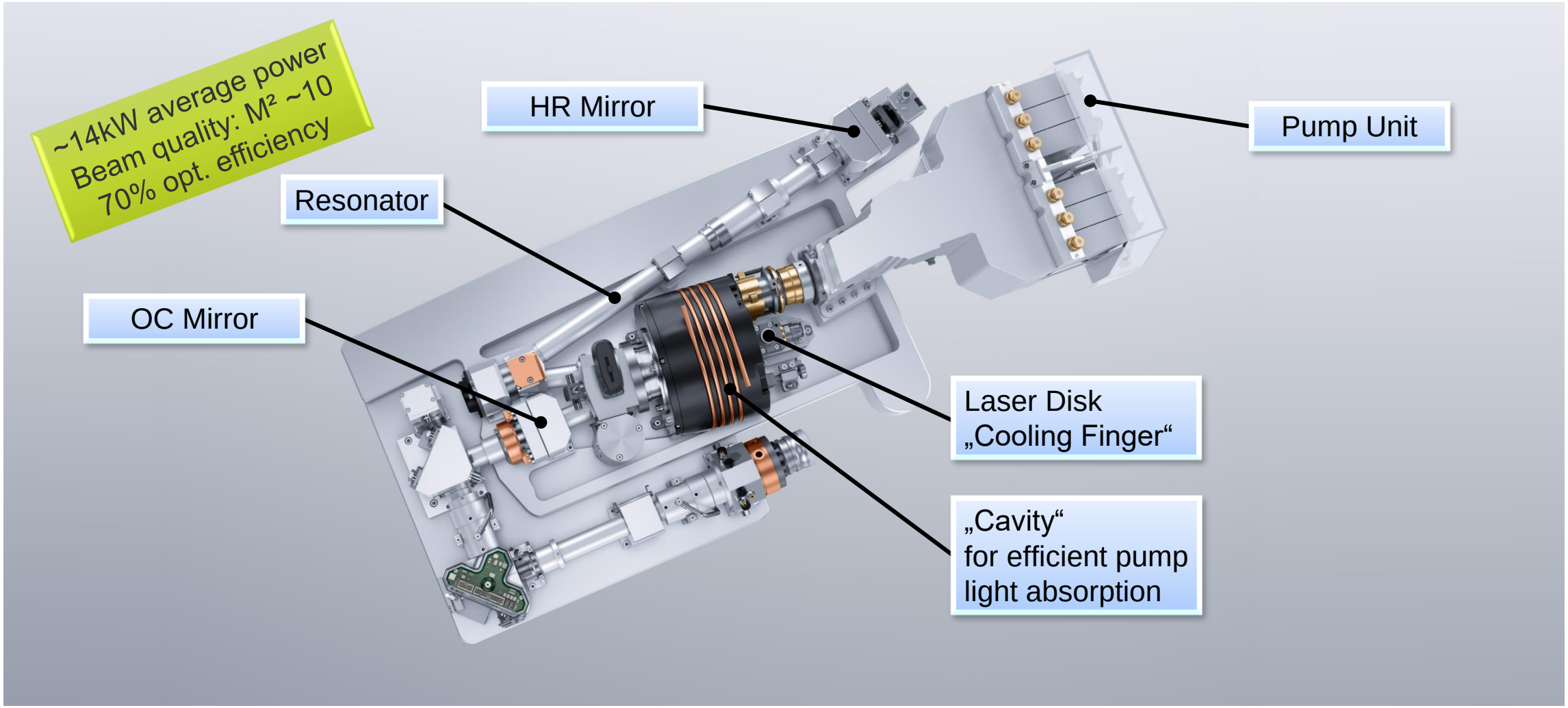


2. Thin-Disk Technology

Tom Metzger | TRUMPF Scientific Lasers

Today's State-of-the-Art High-Power Thin-Disk Oscillator

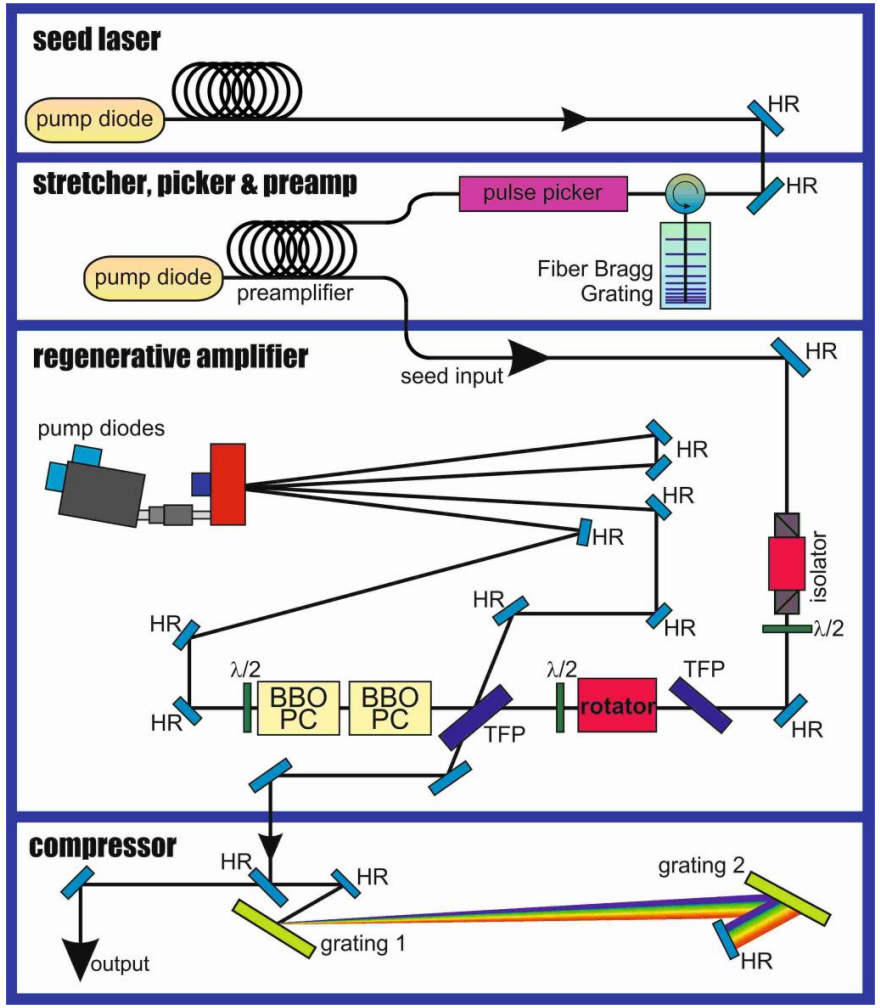
Optical setup of a high power single-disk CW laser

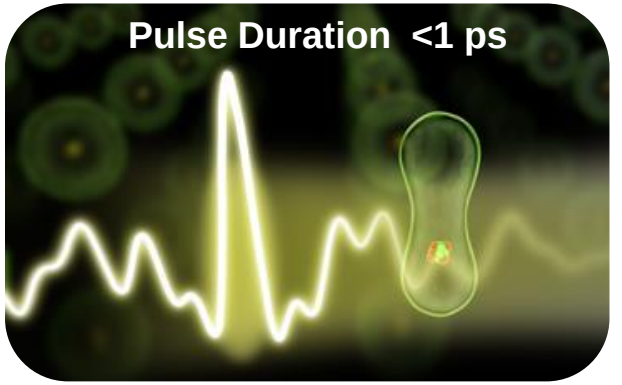


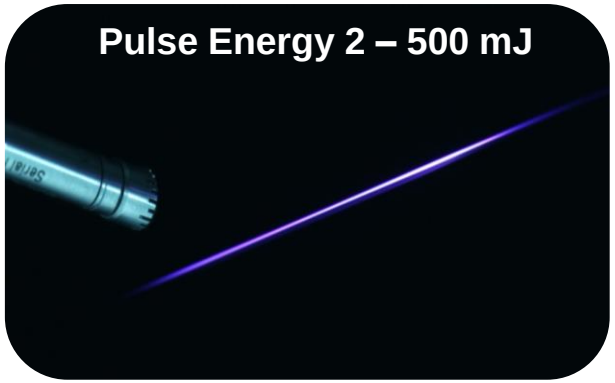
TRUMPF

Typical Ultrafast Amplifier Schematic

Regenerative thin-disk amplifier (1030 nm; <1 ps)







Overview of Ultrafast Amplifiers (1030nm, <1ps)

TRUMPF Scientific Lasers

Low Energy

- **≤ 2mJ**
- ≤ 200W
- ≥ 100kHz

High Power: Dira 500

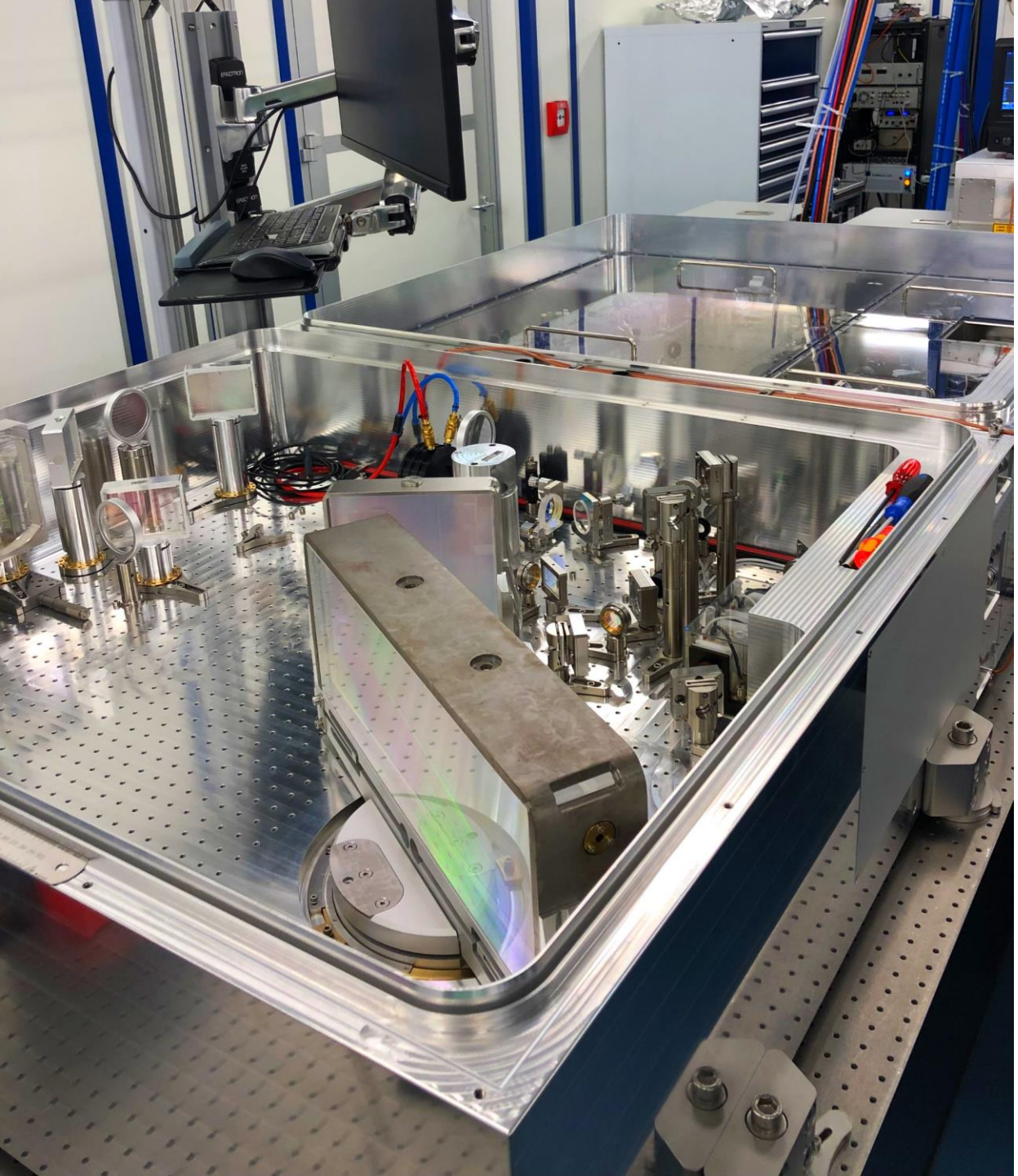
- **≤ 50mJ**
- ≤ 500W
- 1-100kHz

High Energy: Dira 200

- **≤ 200mJ**
- ≤ 200W
- 1 kHz

High Energy & High Power: Dira 1000

- **≤ 200mJ**
- ≤ 1000W
- 5-100kHz



Highest pulse energy and average power

DIRA 1000-5

Tom Metzger | TRUMPF Scientific Lasers

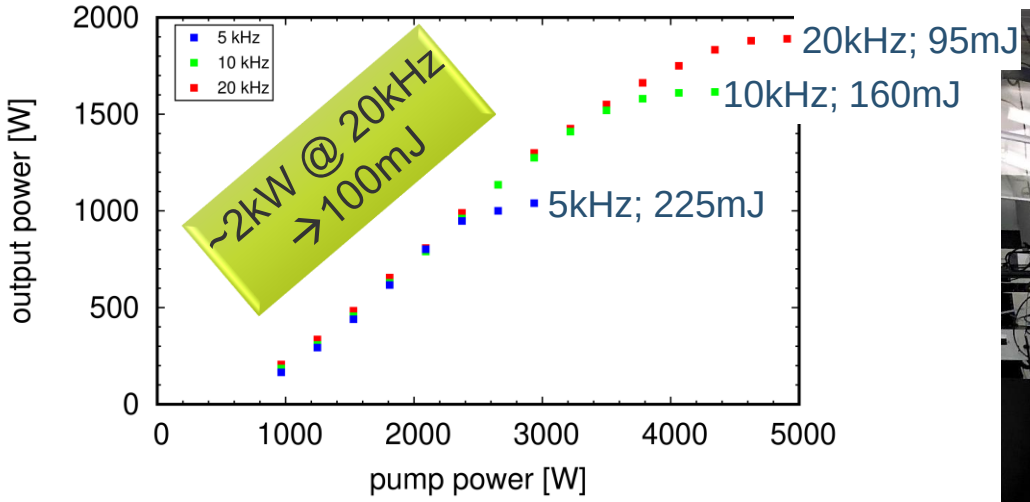
Seed Laser: TruMicro 2000

Commercial micro machining laser from TRUMPF

- Industrial solution
- Fiber laser 1030nm
- Bandwidth 8nm
- Pulse duration 300fs
- Average Power 20W
- Pulse Energy 100µJ

DIRA 1000-5 (1000W; 200mJ; 500fs; M² <1.4)

Output power, spectrum

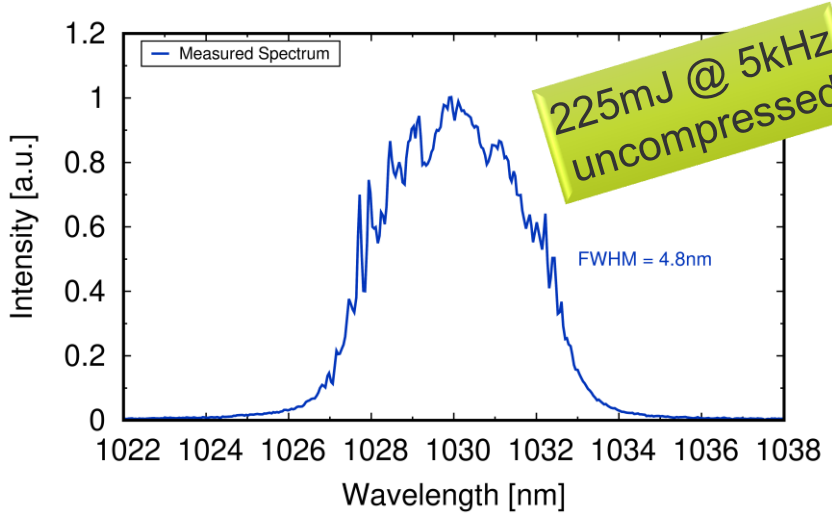


~2kW @ 20kHz
→100mJ

20kHz; 95mJ

10kHz; 160mJ

5kHz; 225mJ



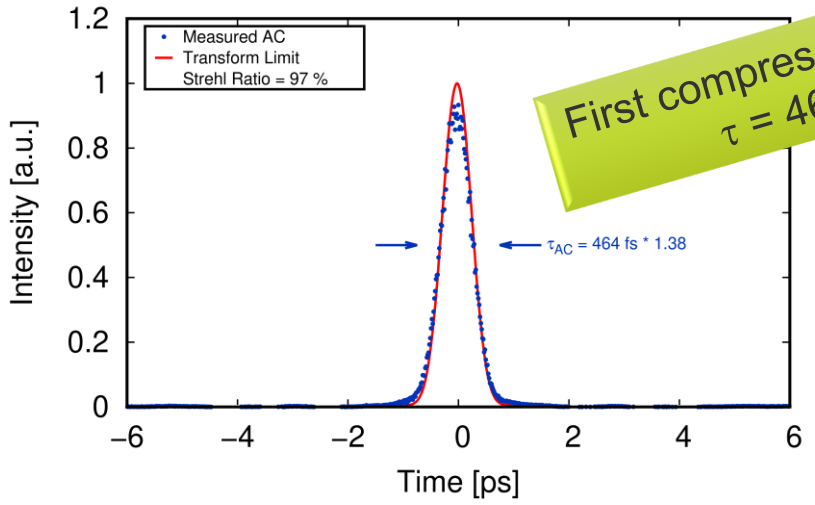
225mJ @ 5kHz
uncompressed

Now upgraded for shorter pulses

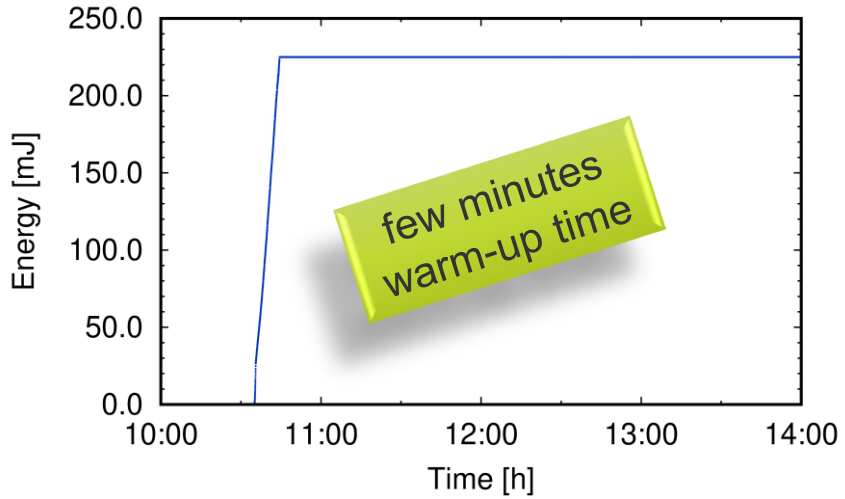
TRUMPF

DIRA 1000-5 (1000W; 200mJ; 500fs; M² <1.4)

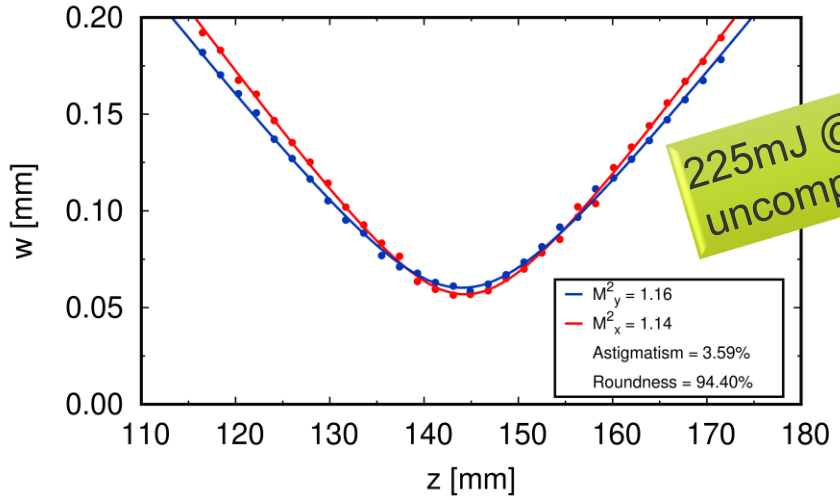
Performance before compression



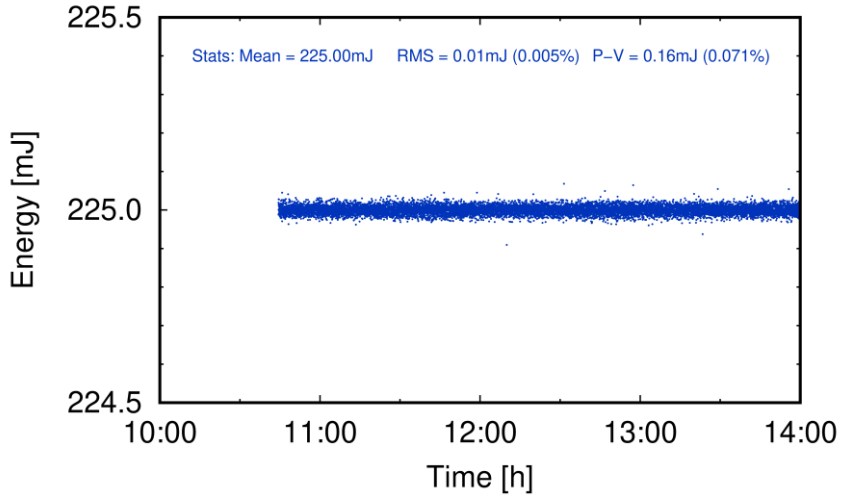
First compression results
τ = 464fs!



few minutes
warm-up time

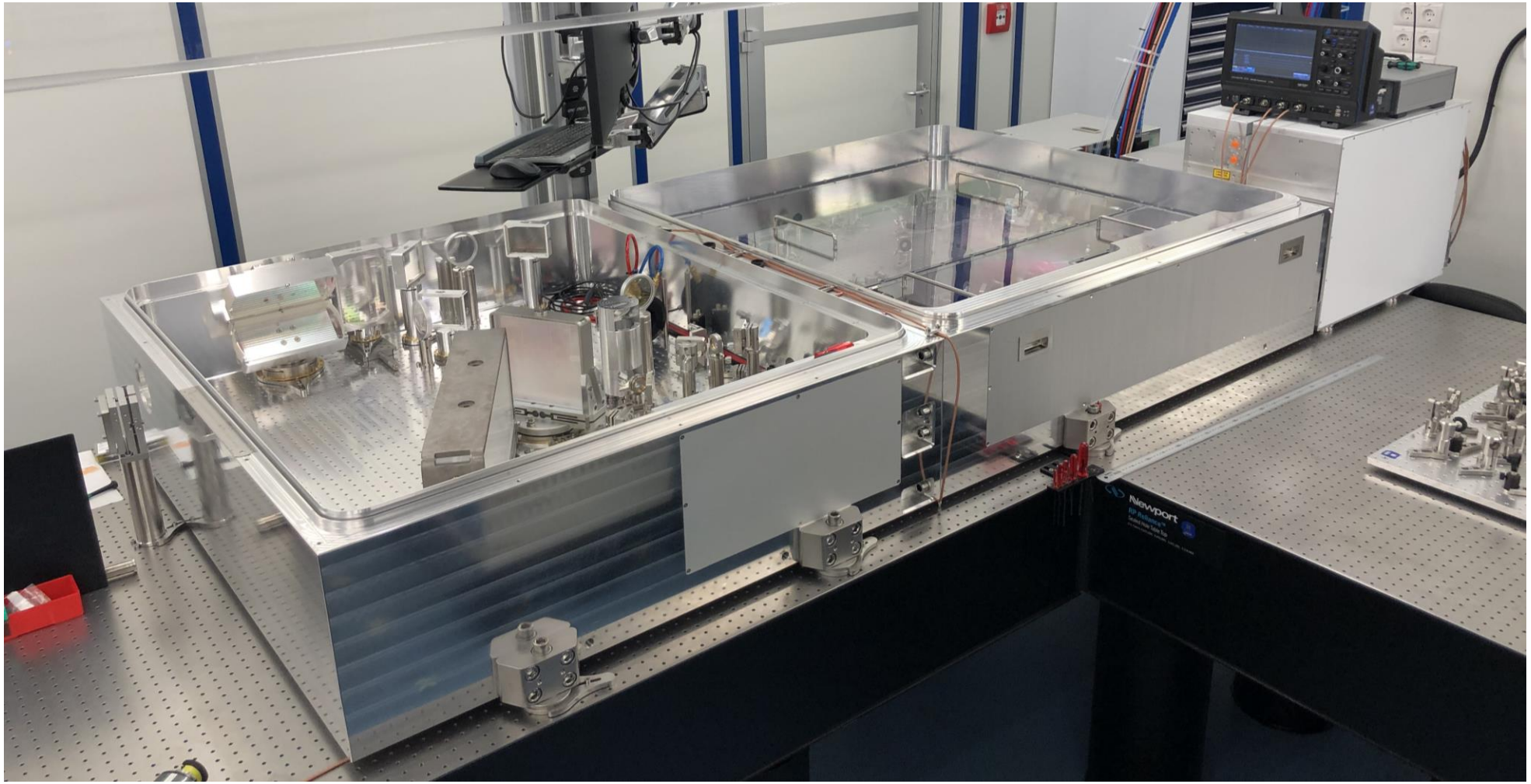


225mJ @ 5kHz
uncompressed



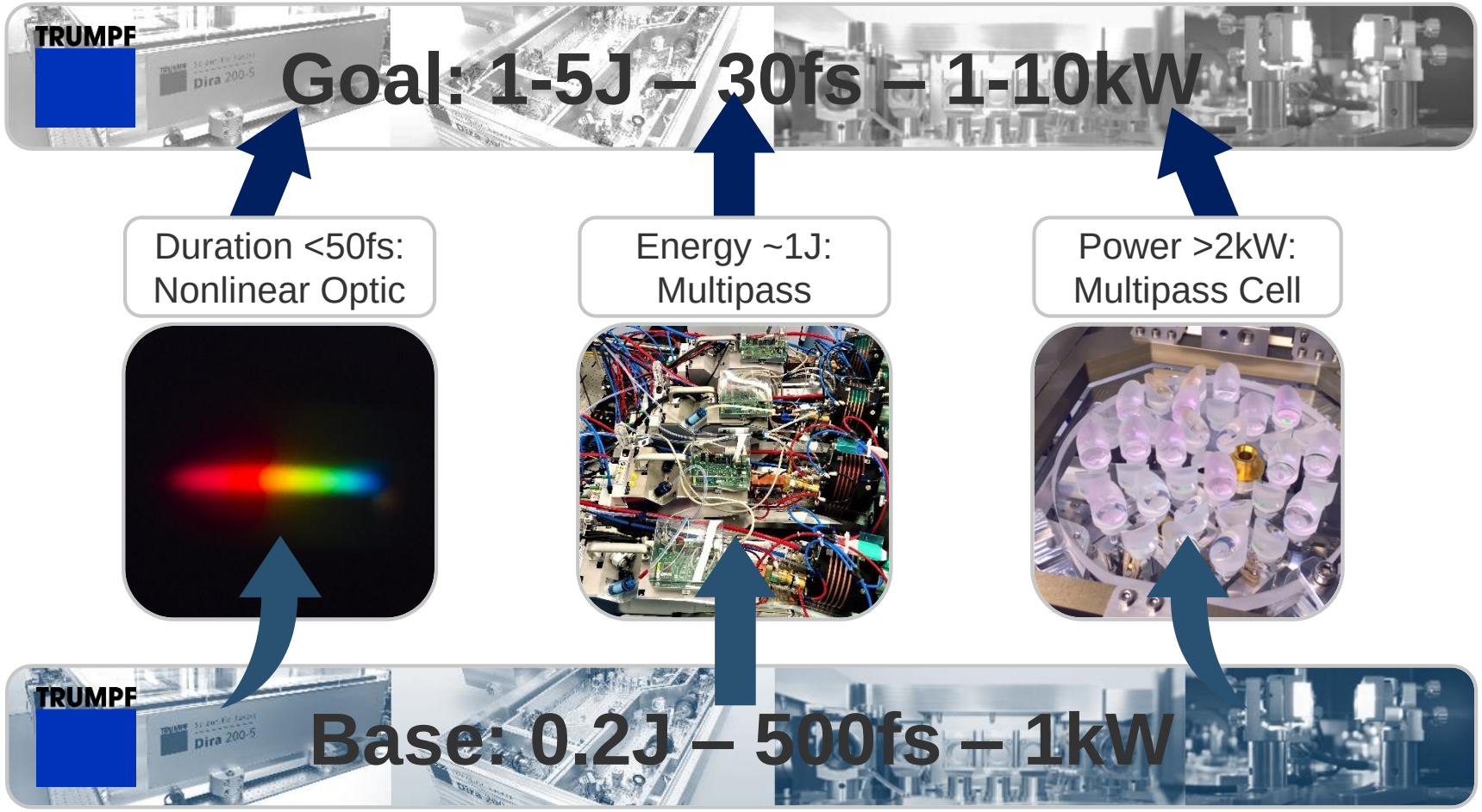
DIRA 1000-5 (1000W; 200mJ; 500fs; M^2 <1.4)

Lab situation



Strategy & Current Laser Development of TLS

Pulse Duration, Energy, Average Power



4. Nonlin. Compression

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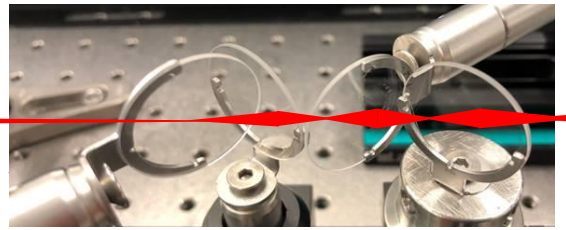
Spectral Broadening in Glass Plates

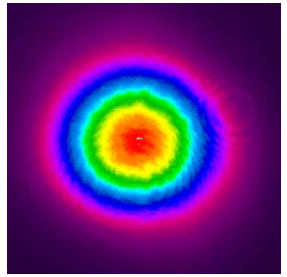
First results with a TruMicro 2000

Input:
89 µJ // 324fs



Chirped mirrors

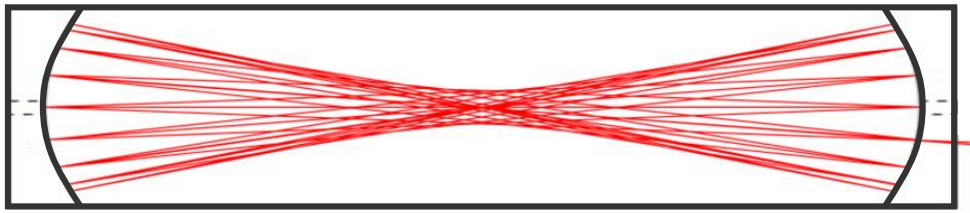
Output:
80 µJ // 114fs

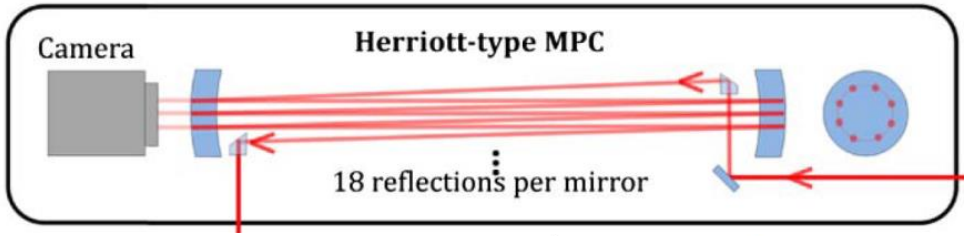


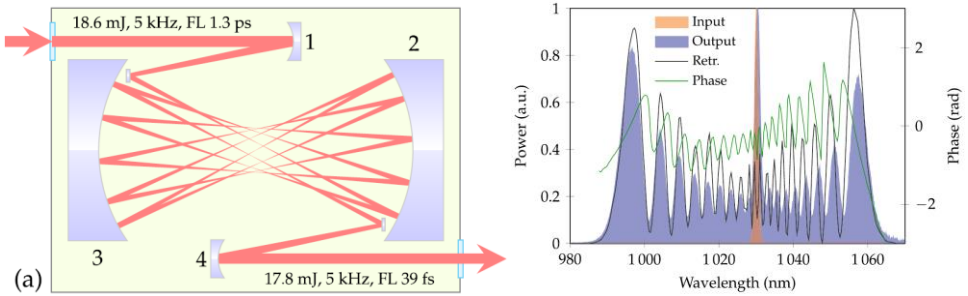
- Optical efficiency ~90%
- Beam quality maintained M^2 ~ 1.4
- Second stage planned, goal ~ 30fs

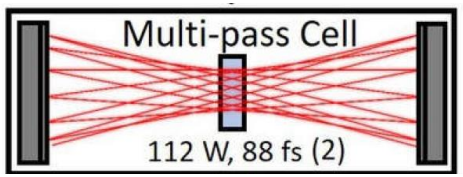
Spectral Broadening in a Herriott Cell

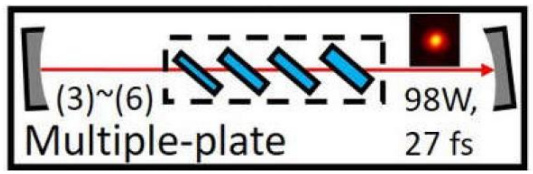
Idea & Literature











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

Fraunhofer ILT

Opt. Lett. 41, 4511 (2016)
0.9ps → 170fs
375W, 10MHz, 37.5µJ

LMU LUDWIG-MAXIMILIANS-UNIVERSITÄT MÜNCHEN

Opt. Lett. 43, 5878 (2018)
1.3ps → 41fs
90W, 5kHz, 18mJ, M^2 <1.2

RUHR UNIVERSITÄT BOCHUM RUB

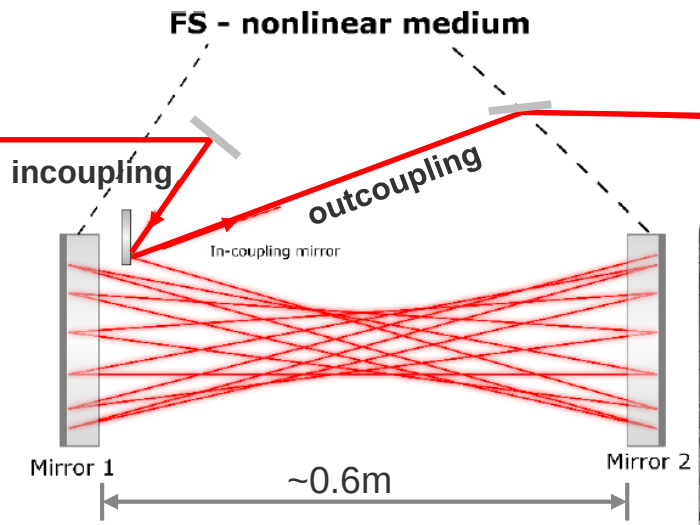
Opt. Lett. 44, 4115 (2019)
0.53ps → 27fs
99W, 13.4MHz, 4.5µJ

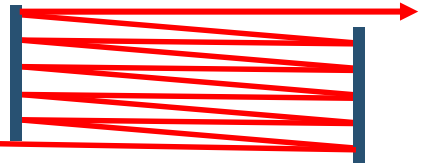
TRUMPF

Spectral Broadening in a Multipass Cell

First results with a TruMicro 2000 (36 passes)

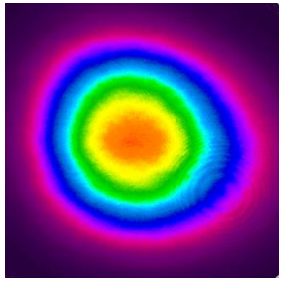
Input:
40 µJ // 324fs

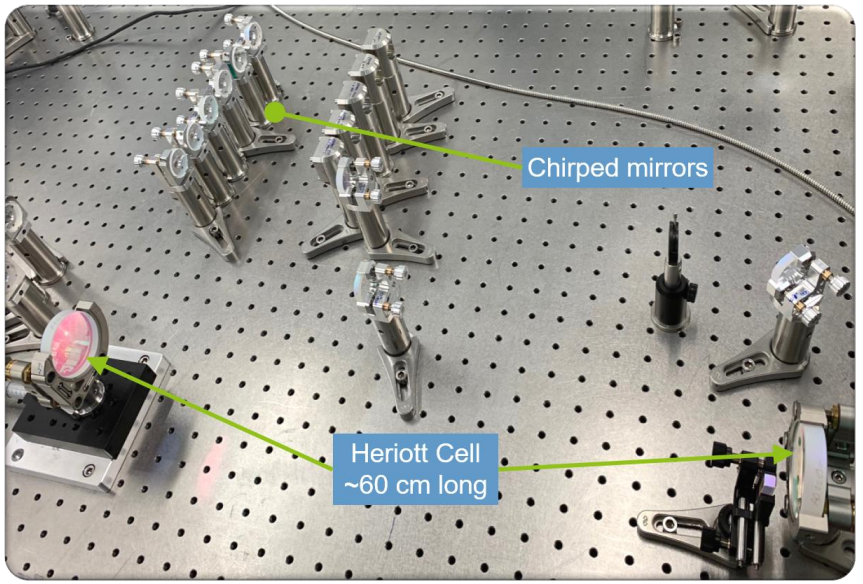




Chirped mirrors

Output:
36 µJ // 70fs





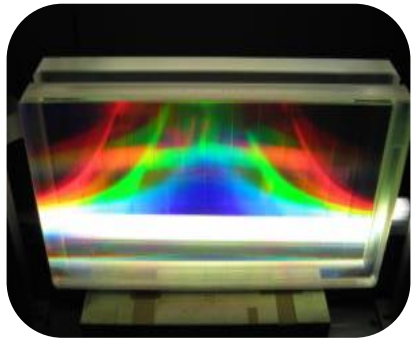
- Optical efficiency ~90%
- Beam quality maintained $M^2 \sim 1.3$

Current development

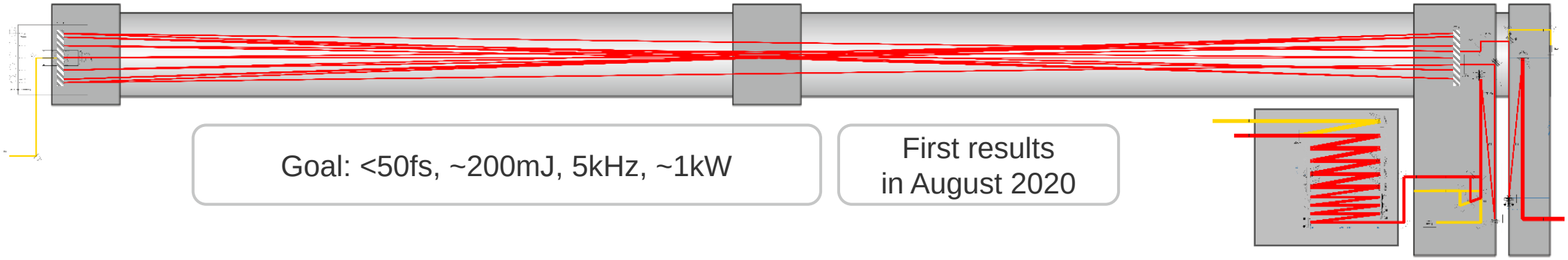
Nonlinear Compression of a Dira 1000-5 (200mJ, 5kHz, 500fs)

TruMicro 2000
100µJ; 20W

Dira 1000-5
220mJ; 1.1kW



Compressor
200mJ; 1kW; <0.6ps



Goal: <50fs, ~200mJ, 5kHz, ~1kW

First results
in August 2020

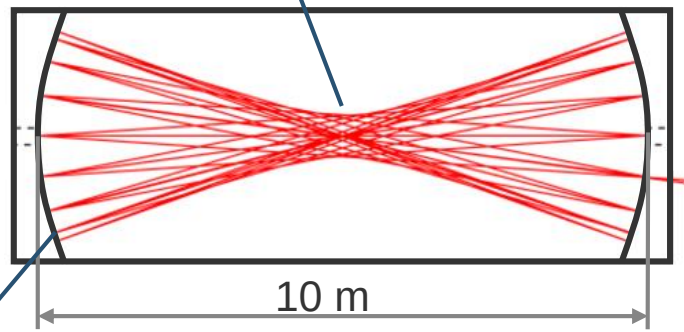
Simulations for 200mJ-Herriott Cell

Simulations from Jonathan Brons (TRUMPF Laser)

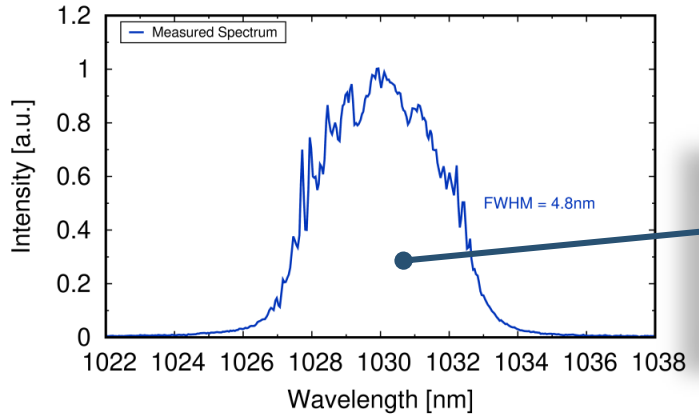
Helium **175 mbar**
200mJ
520fs
54 passes

$I=2\cdot10^{14}W/cm^2$

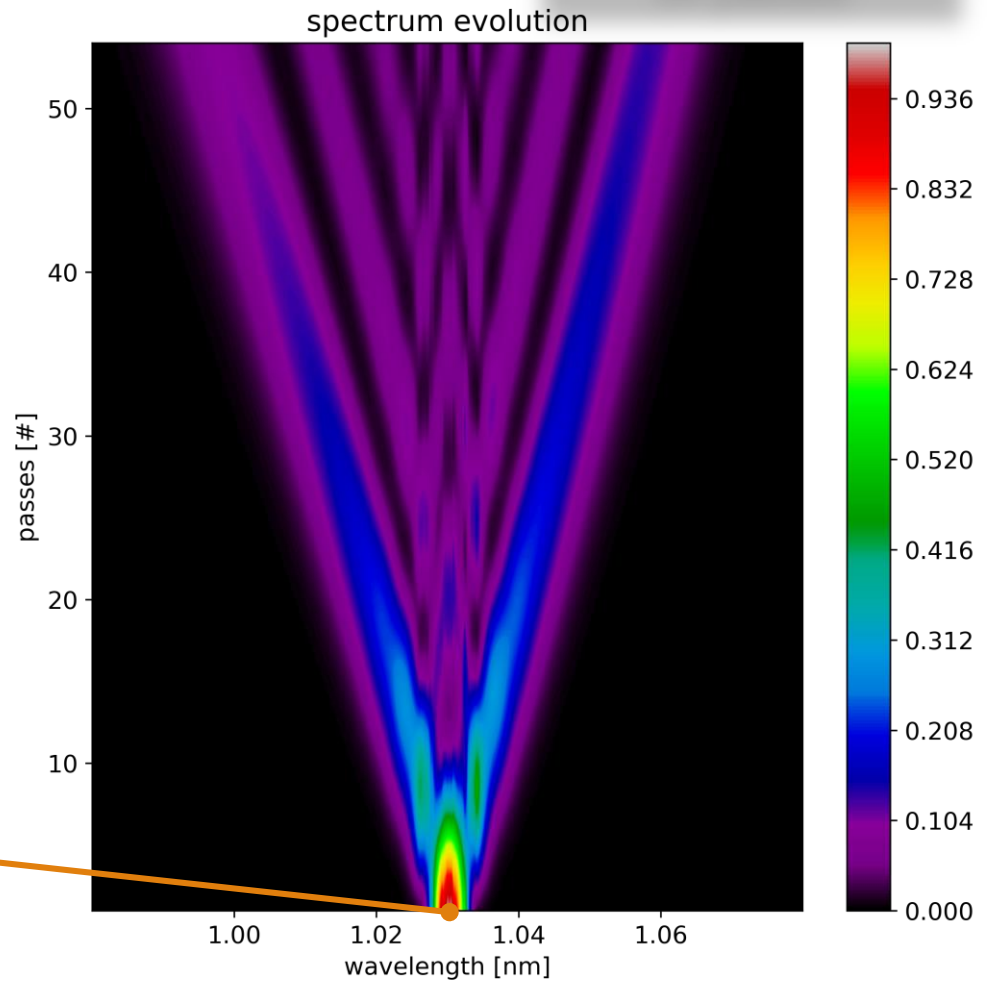
Ionization of Helium:
$I=3.4\cdot10^{14}W/cm^2$



Beam-Ø
~10mm



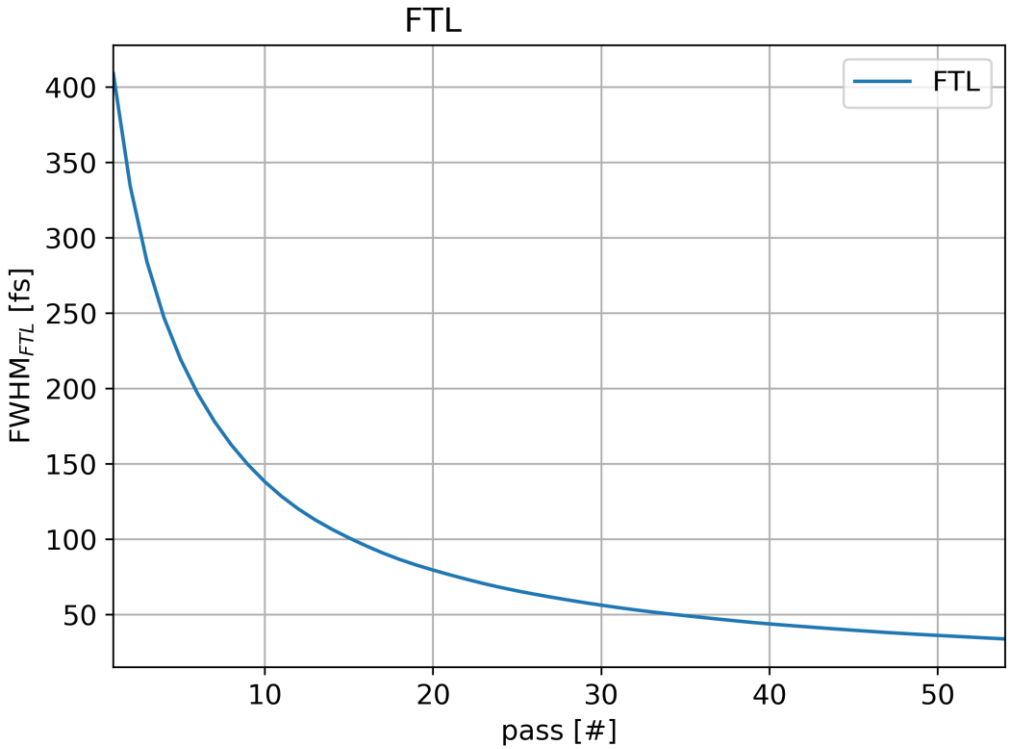
Measured amplifier output spectrum

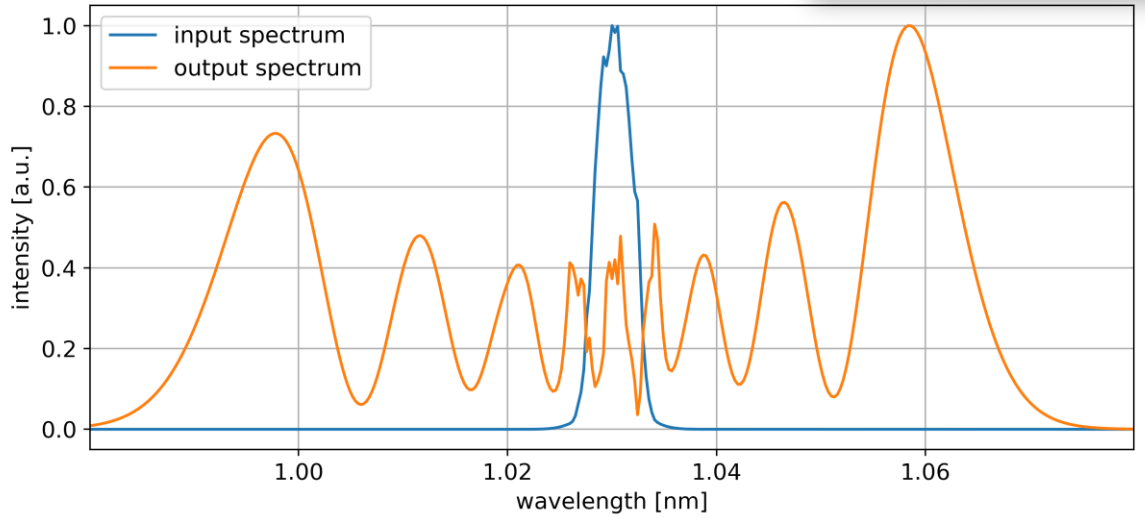


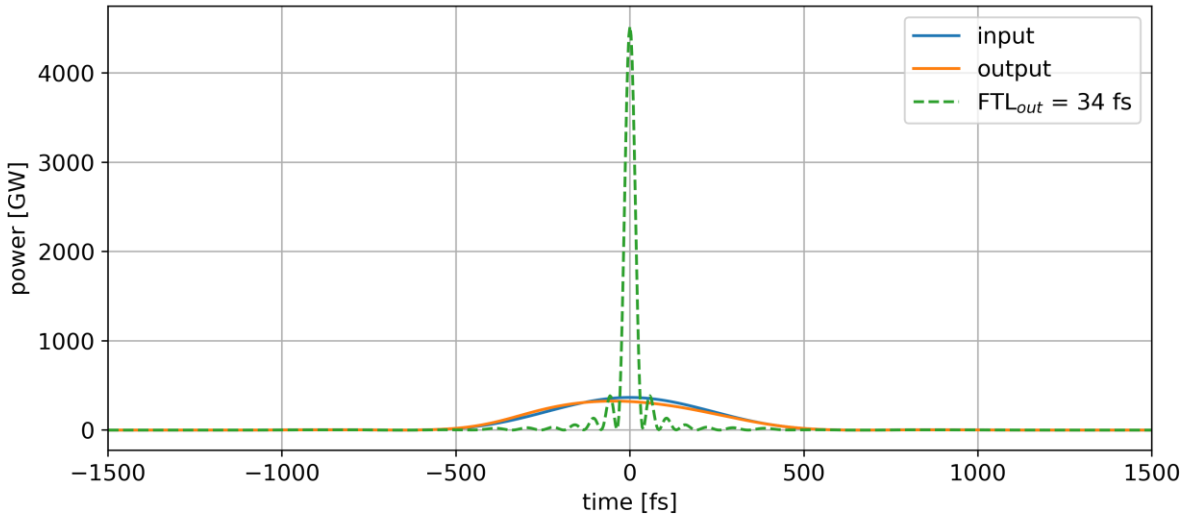
Nonlinear Compression of a Dira 1000-5

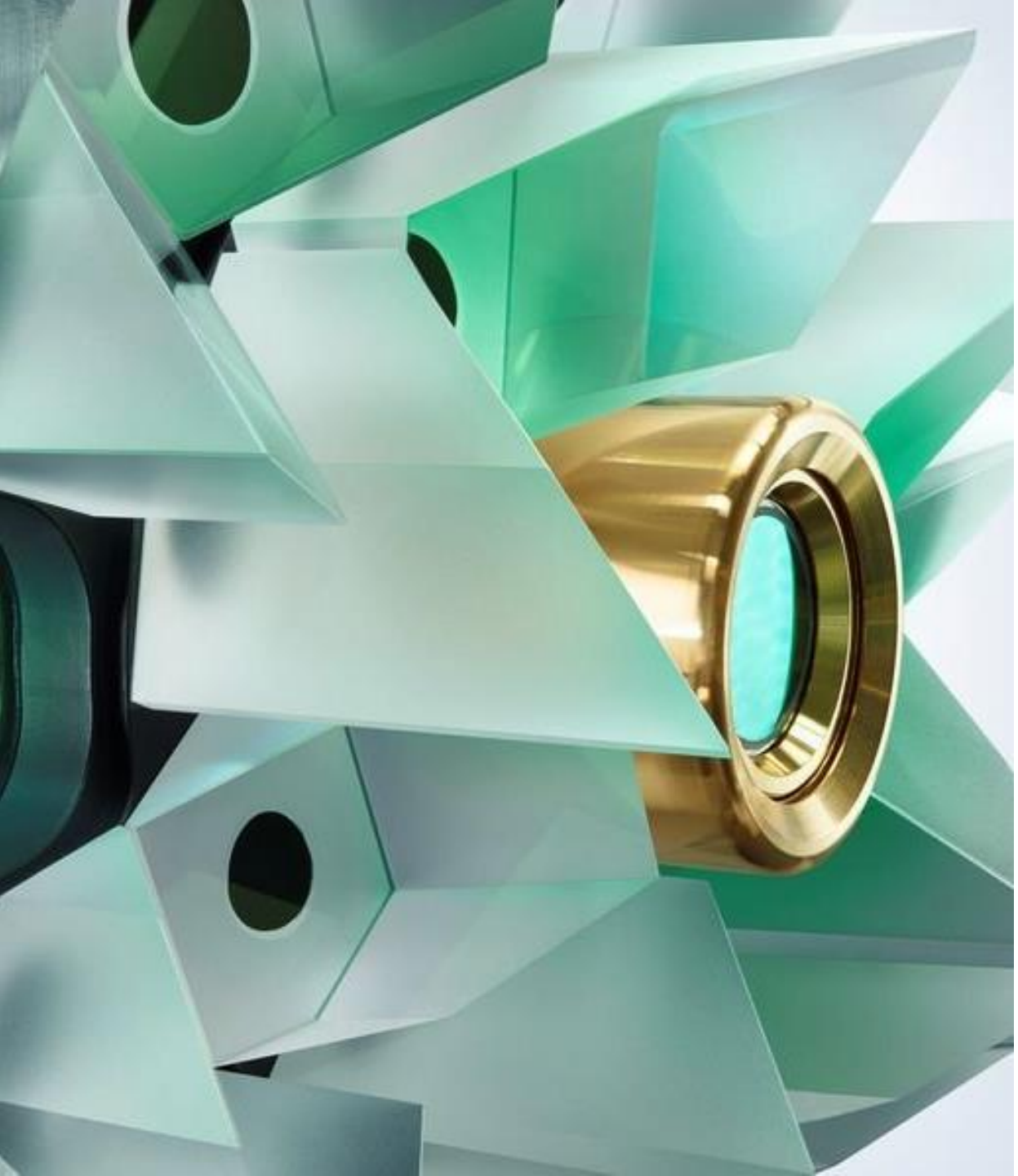
Simulation Results for 200mJ; 500fs

Helium **175 mbar**
200mJ
520fs
54 passes







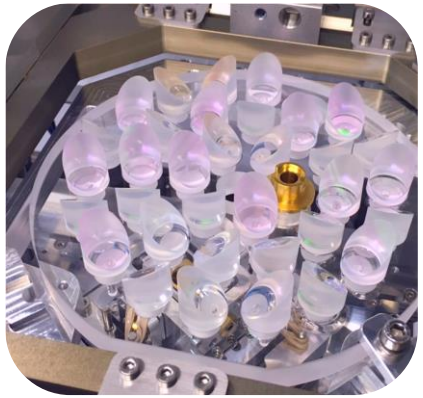


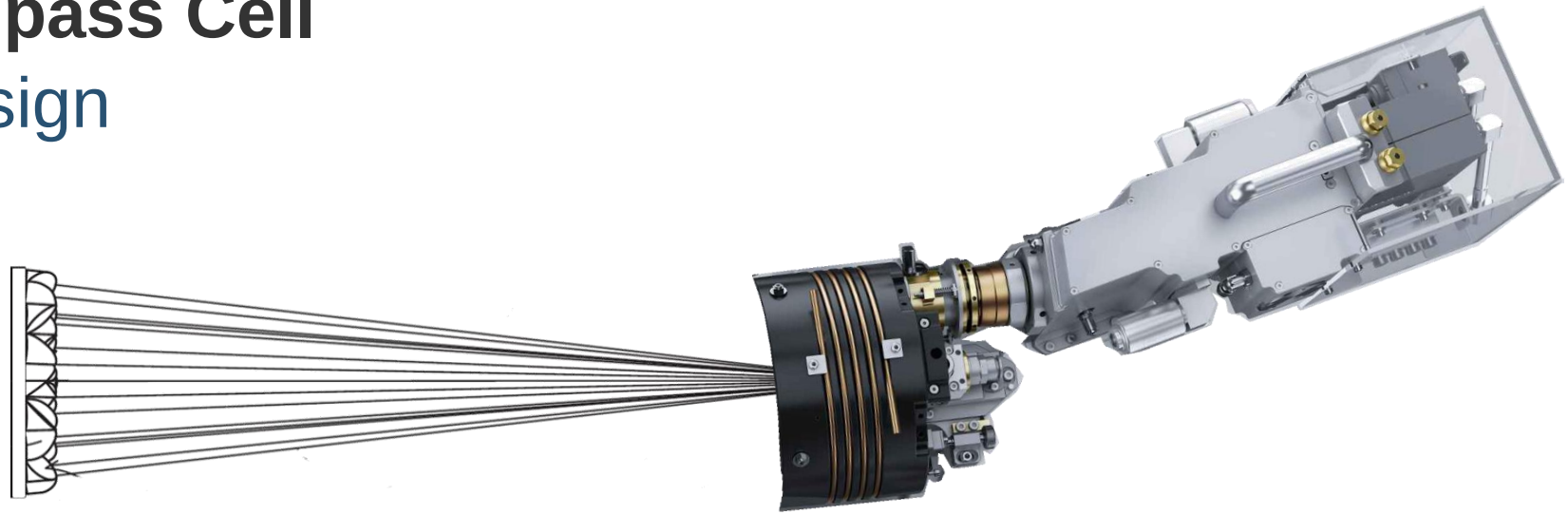
5. Multipass Amplifier

Tom Metzger | TRUMPF Scientific Lasers

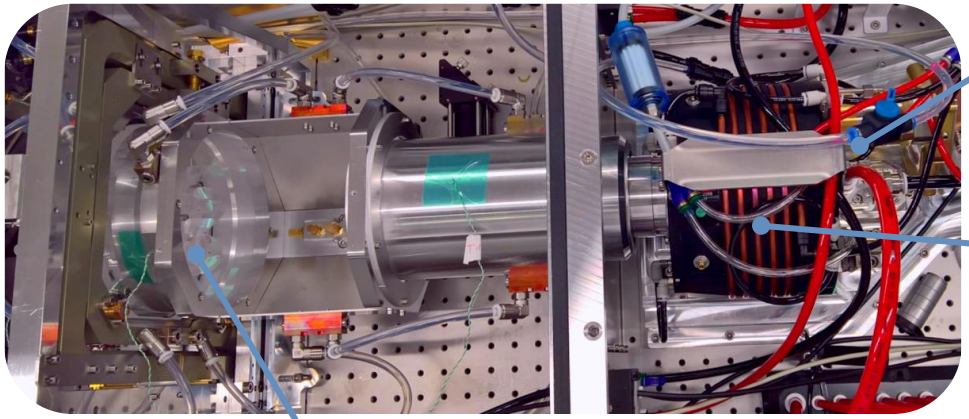
Thin-Disk Multipass Cell

Monolithical Design





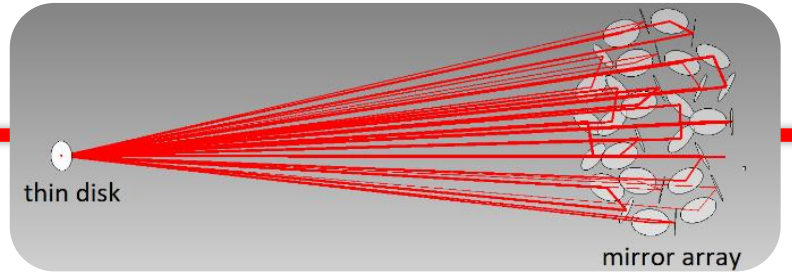
1m

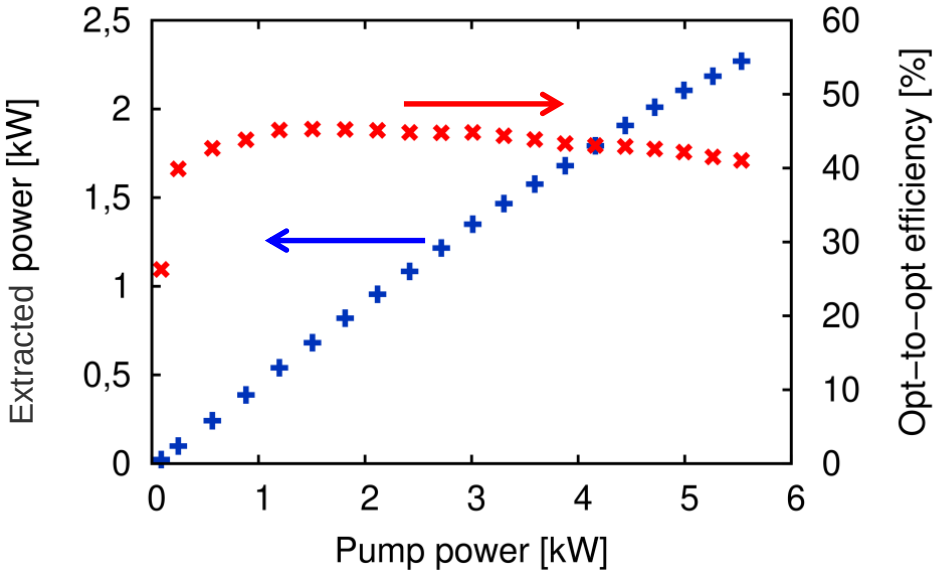


TRUMPF

Multipass Cell

Seeding with 1kW of average power (TruMicro 7000)



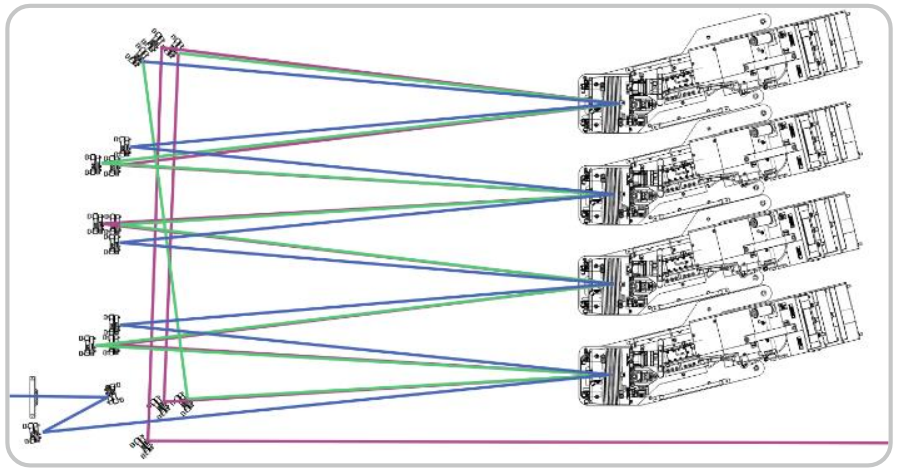


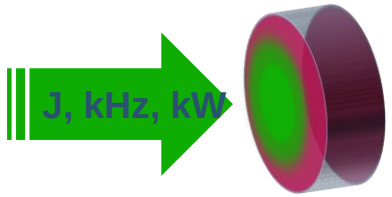
3kW output power @ 10kHz
Pulse duration ~10ns
Beam quality M^2 ~ 11

7kW Seed:
20kW output power in cw
Multimode

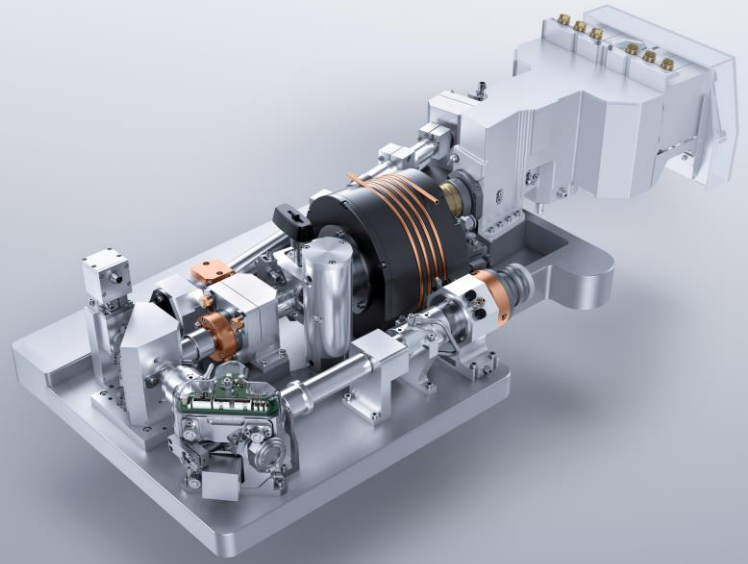
Pump Laser for Ti:Sapphire (Goal: 1J, 1kW, 515nm)

Multipass Amplifier Chain





4 compact multipass cells can boost the pulse energy to
2.5J at 1kHz and 1030nm
(Flat-top beam profile, ~30ns)
After SHG: 1J, 1kHz at 515nm



6. Summary

Tom Metzger | TRUMPF Scientific Lasers

High-Power Ultrafast Industrial Thin-Disk Lasers

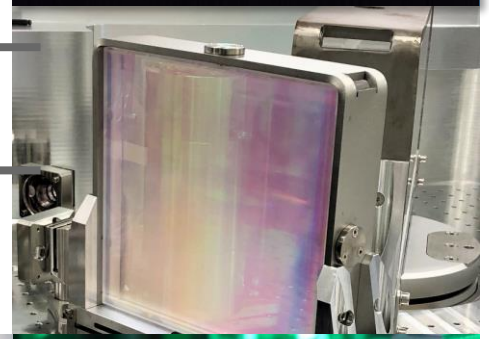
Summary

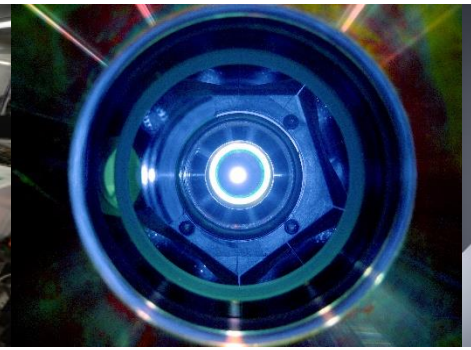
- Dira Series: **200mJ; 1kHz; <1ps (standard)**
  Regen. amplifier **500W ; 6-100kHz; <1ps (standard)**
  1-2kW; 5-100 kHz; <1ps (standard – new: 500fs)

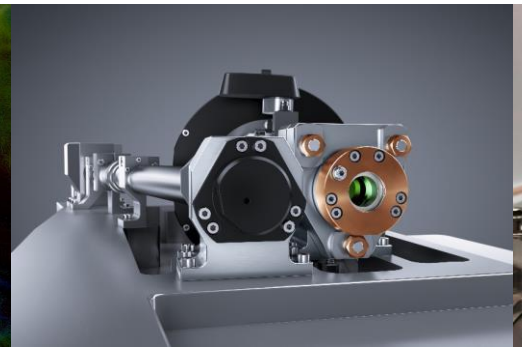
- Nonlin. Compression: **Ongoing for 200mJ; 5kHz; <30fs (project has started)**
  Small Herriott Cells & Multiplates (1st tests with TruMicro 2000)

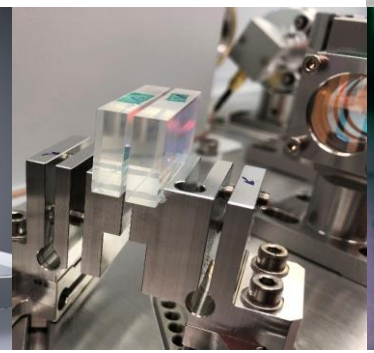
- Multipass amplifier: **1kHz; 1J; ~2ps (development - project towards multi-kW)**

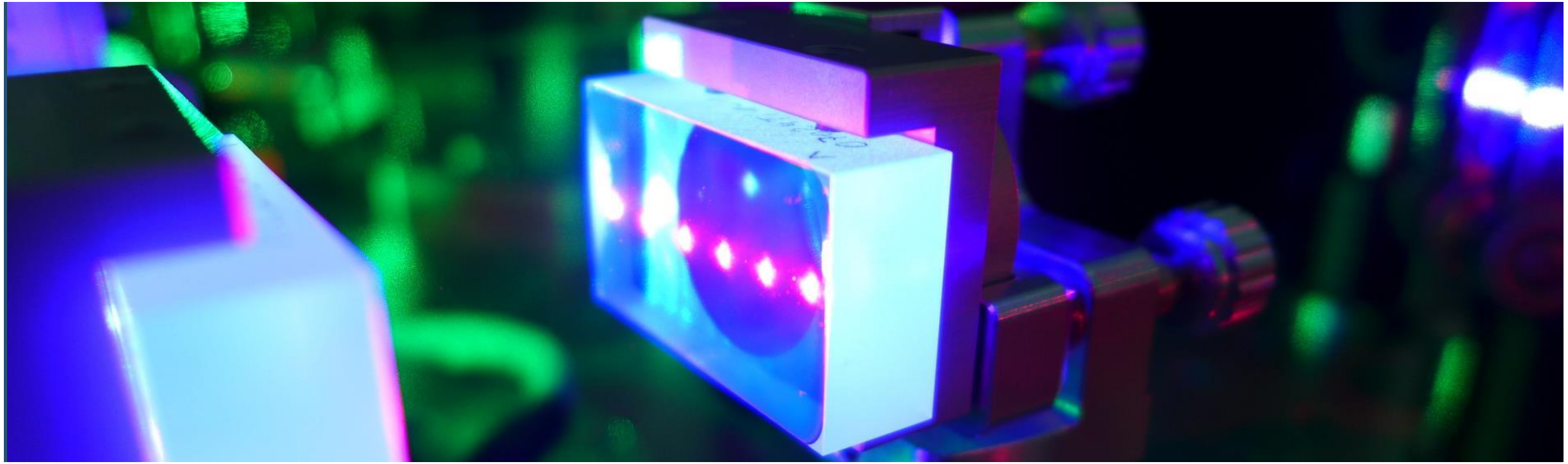
- OPCPA: **µJ energies (standard)**
  mJ energies (custom design possible)











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