“Bivoj / DiPOLE” as a pump source for high repetition rate laser particle accelerators

HiLASE Center

Institute of Physics of the Czech Academy of Sciences

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SUPERLASERS FOR THE REAL WORLD

6th EAAC Workshop 2023

La Biodola Bay, Elba, Italy

Outline

Introduction:

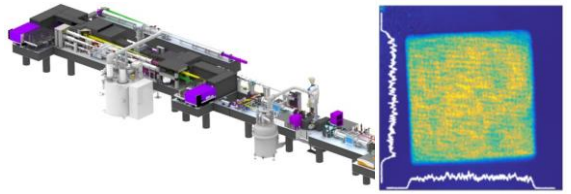
1) Hilase centre
2) ‘Bivoj’ cryogenically cooled multi-slab laser system

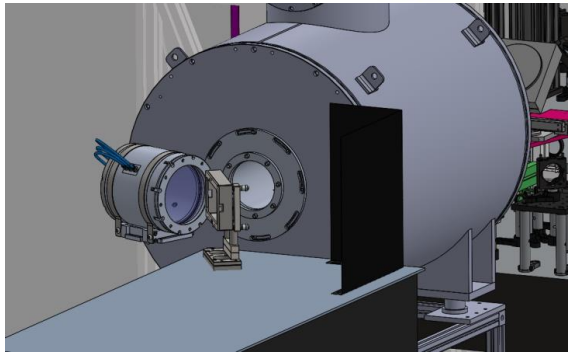
Recent upgrades:

3) 150J upgrade
4) Depolarization mitigation
5) SHG results
6) kW-class large aperture Faraday isolator
7) Beam shaping

Conclusion:

8) Summary





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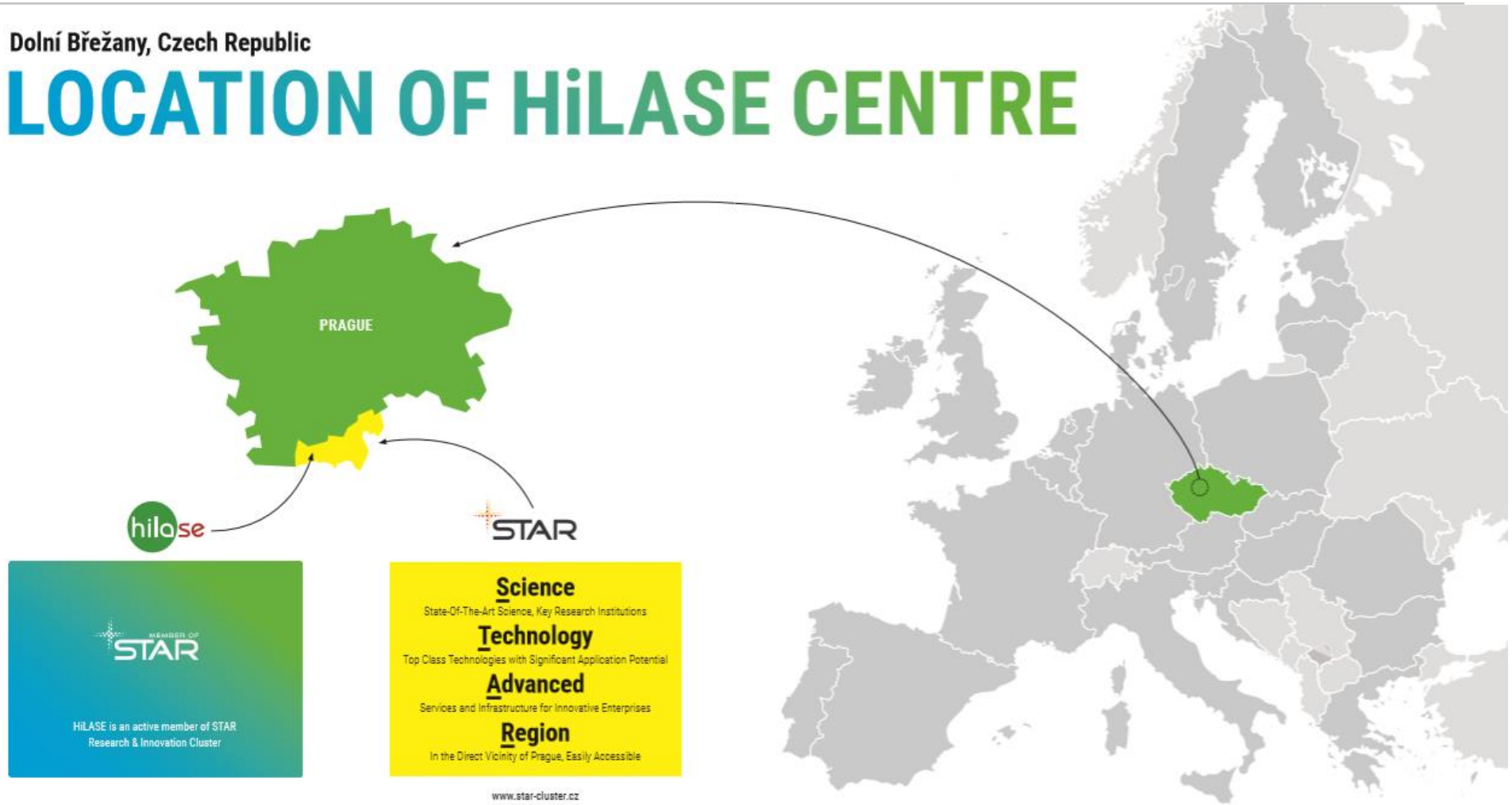
1. Hilase location



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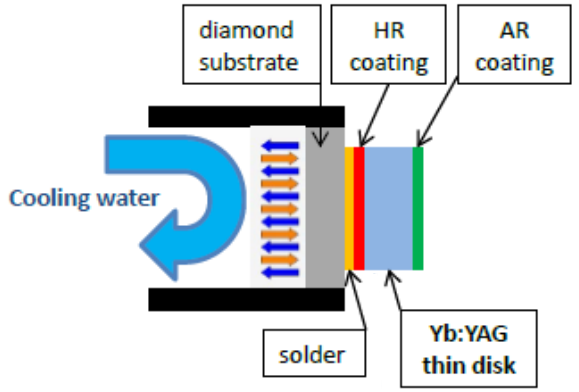
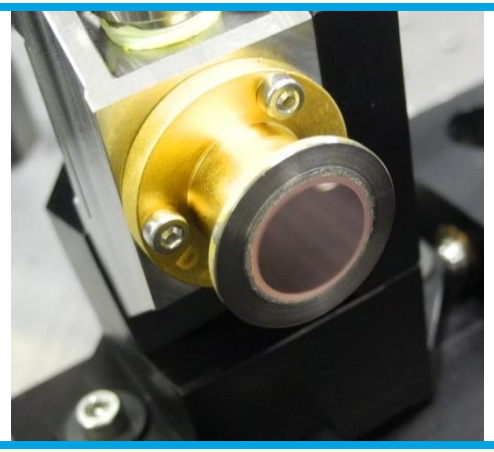
1. Hilase organization

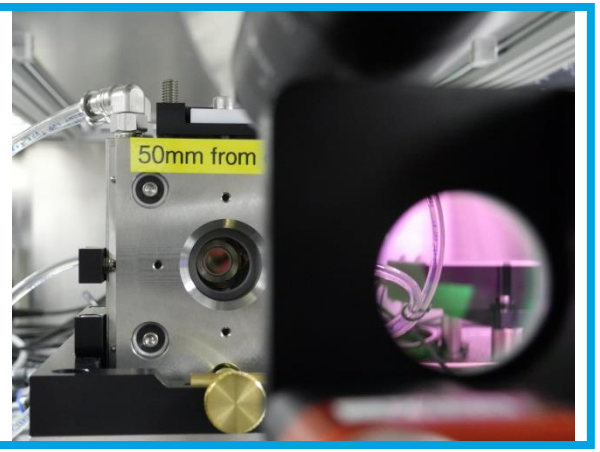
- 3 research teams
- 700 m^2 of clean labs (ISO 8) & exp. halls
- Up & running since 2016
- ~100 staff
- International team

1. Hilase laser technologies

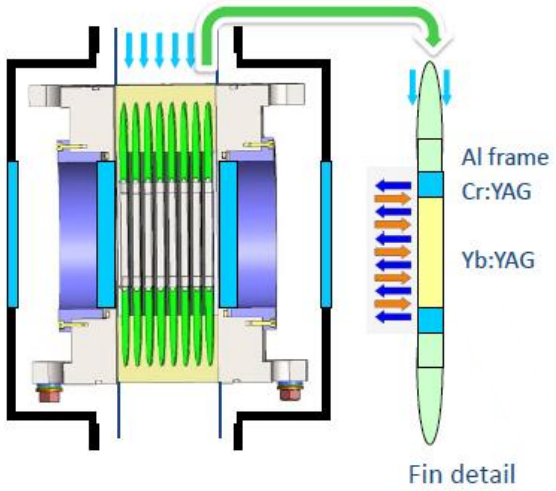
Thin-disk

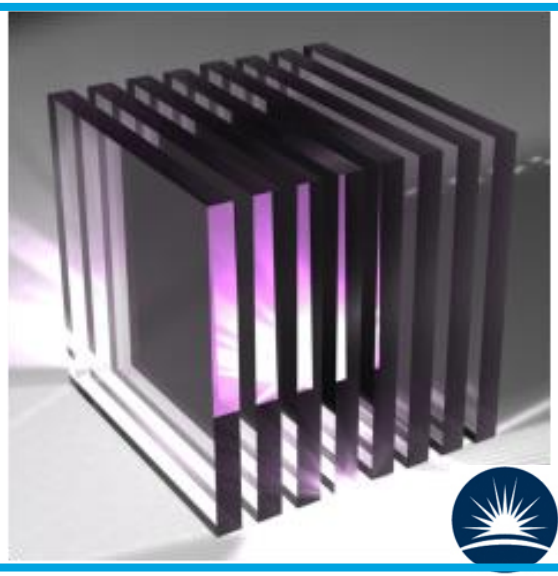






Multi-slab

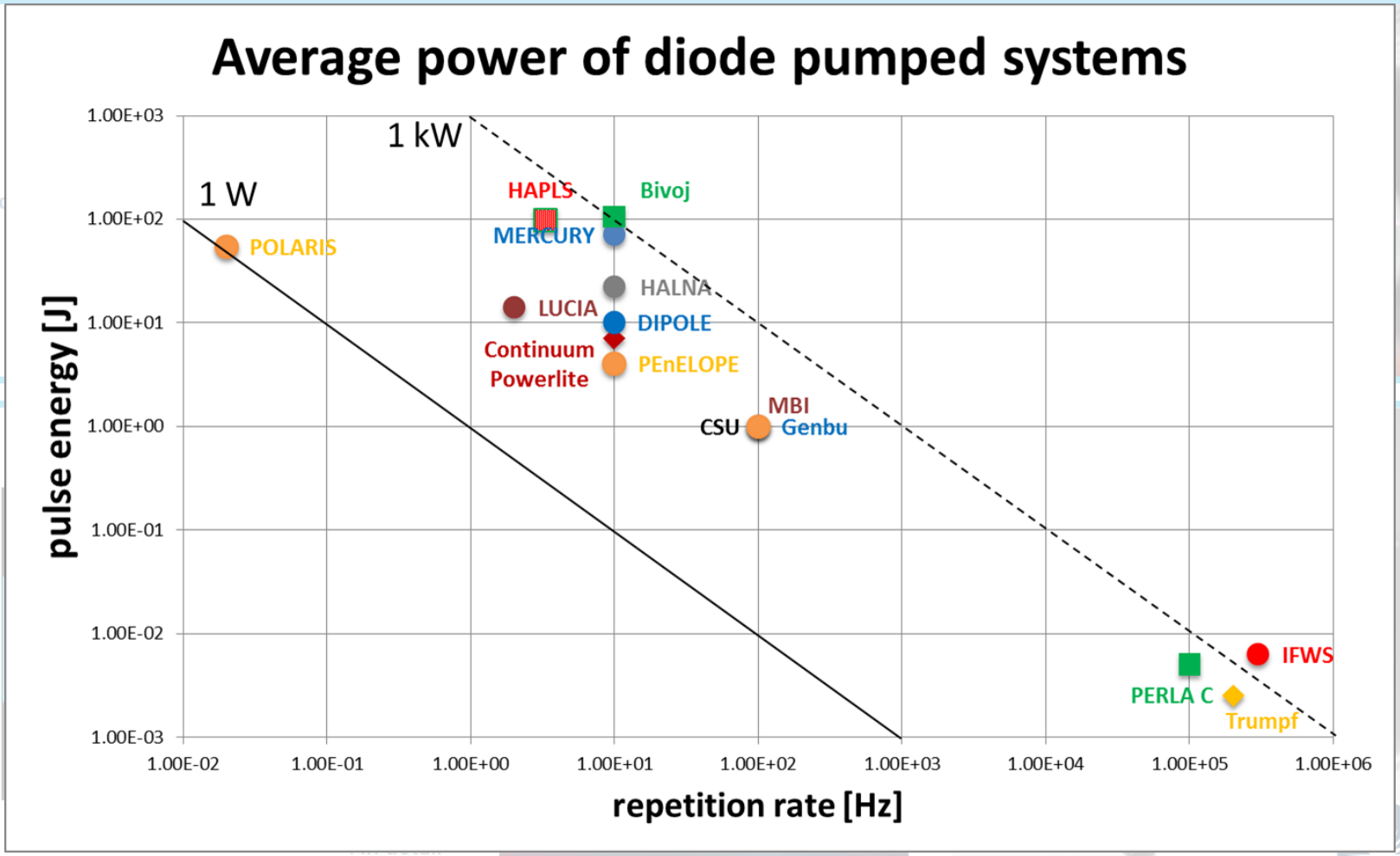




1. Hilase laser technologies

Thin-disk

Multi-slab



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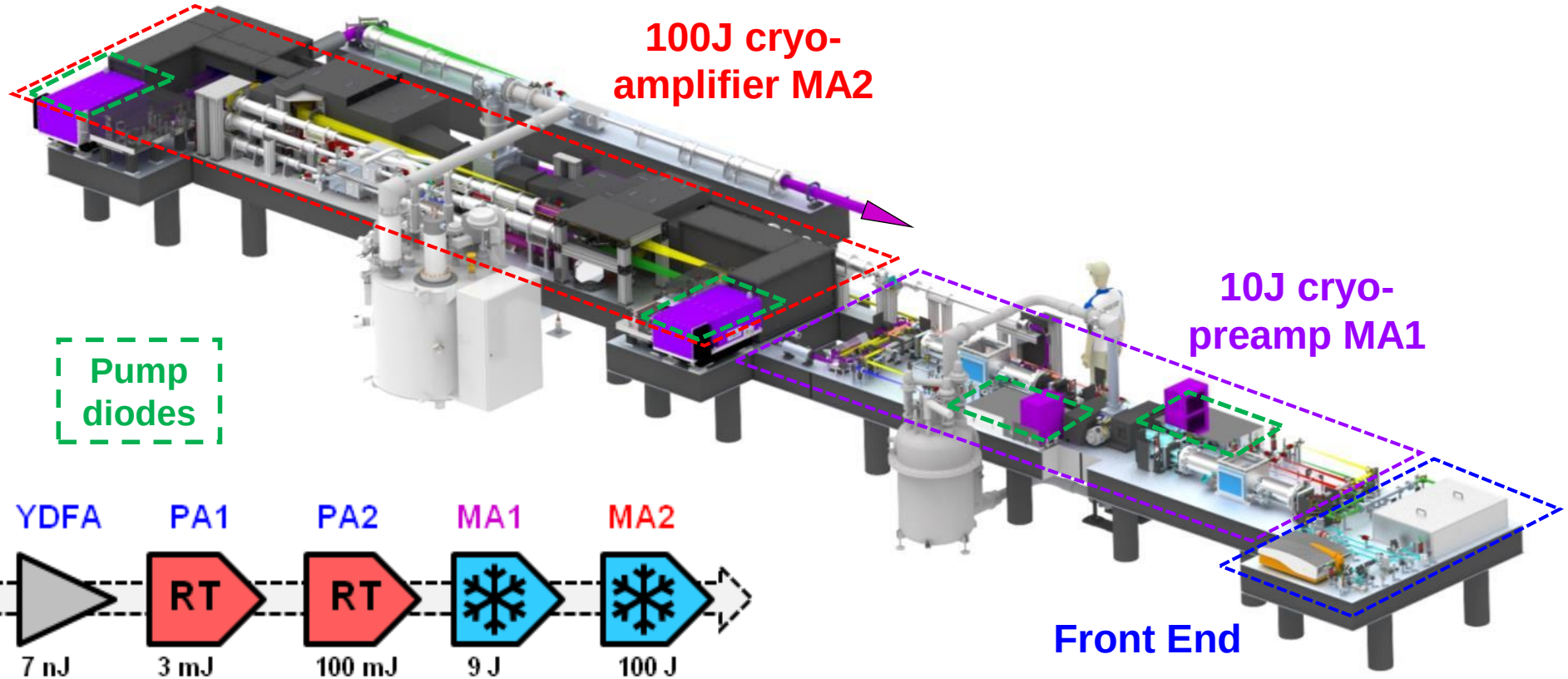
2. Bivoj layout



P. Mason et al, "Kilowatt average power 100 J-level diode pumped solid state laser," Optica 4, 438-439 (2017)

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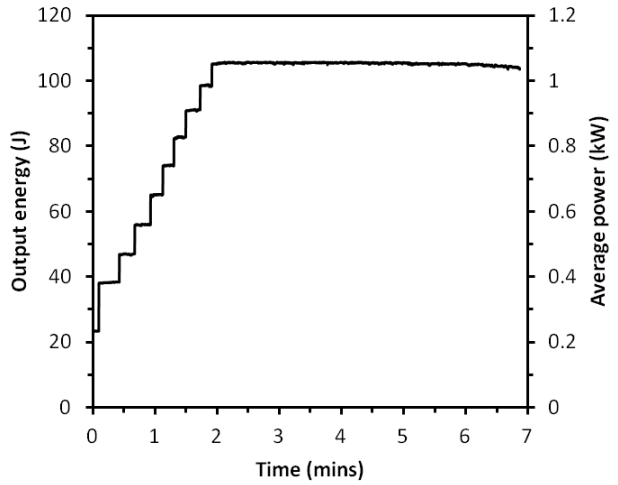
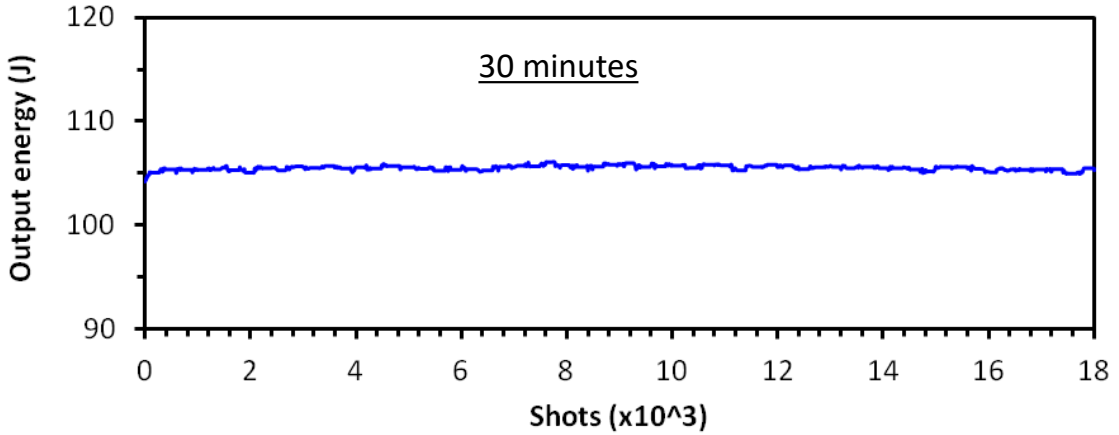
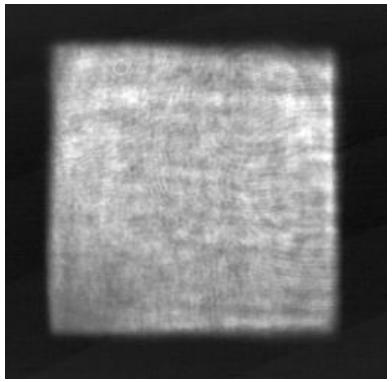
2. 1st world record in 2016

- BIVOJ achieved 105 J @ 10 Hz for 6 J input
- Joint effort of STFC and HiLASE

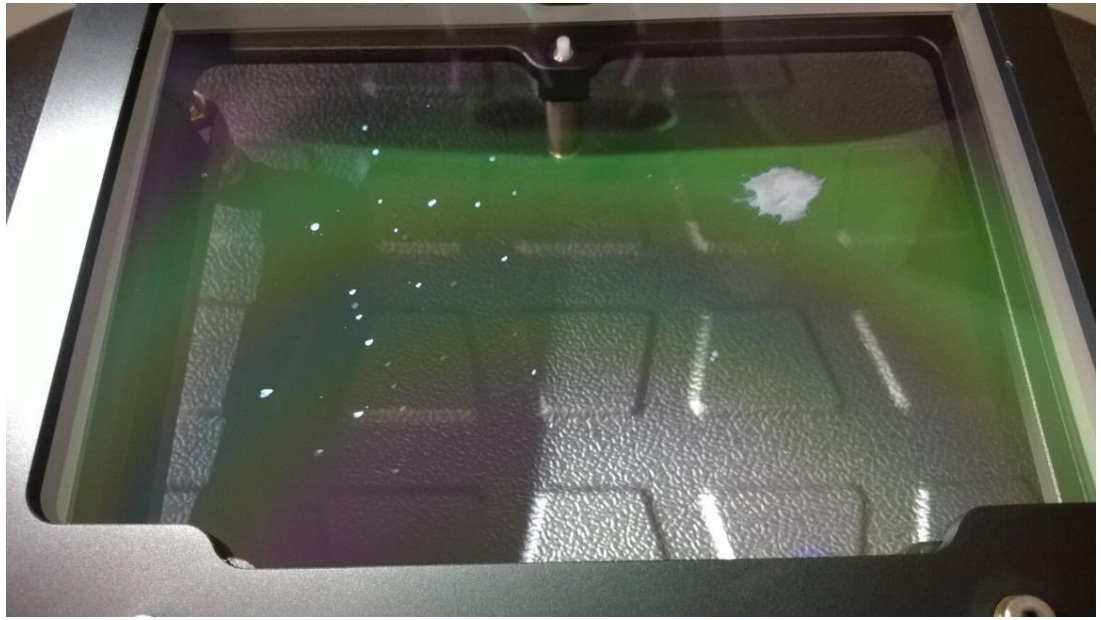






2. LIDT in 2016

- Optics rated to 20 J/cm^2 failed at 1.5 J/cm^2
- 1030 nm, 10 ns pulses, 10 Hz repetition rate

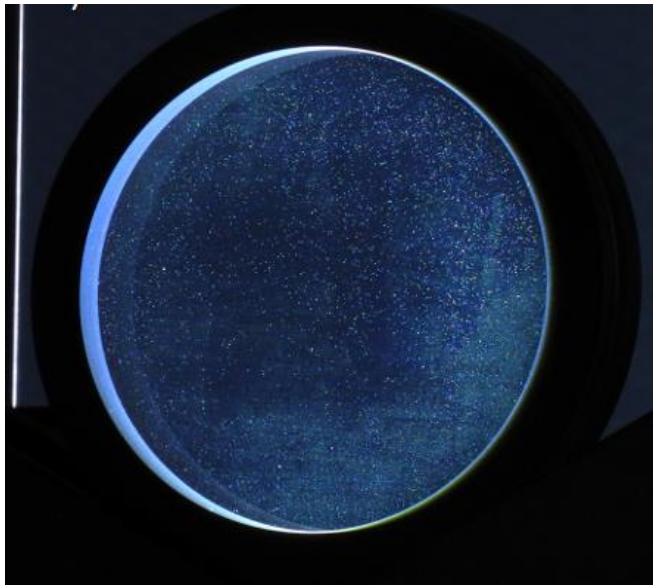


3. After 4 years of research

- HfO_2 optical coatings with new method of surface preparation
- Qualified for 5 J/cm^2 for 2”sample
- Tested at >3 J/cm^2 on 6” sample

- Crytur s.r.o. (AR)
- Manx Precision Optics Ltd. (HR)

- More manufacturers validated for 5 J/cm^2 since then



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3. 2nd world record in 2021

- 40% increase of energy compare to maximum from 2016
- BIVOJ reached its full potential

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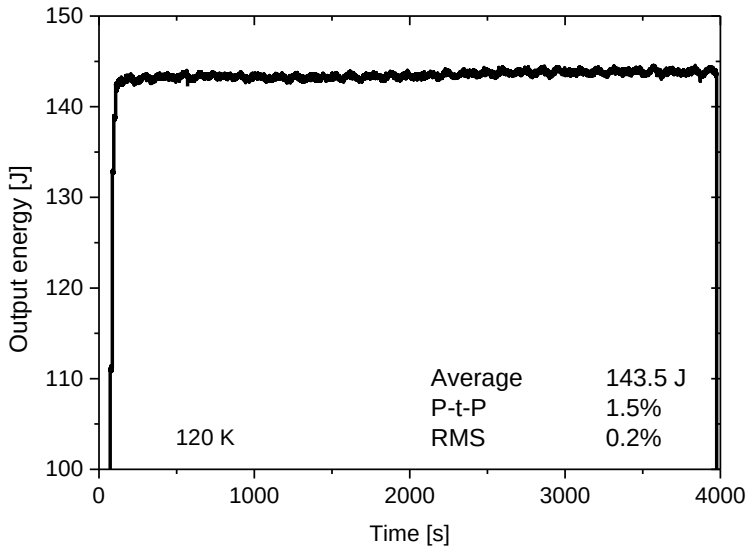
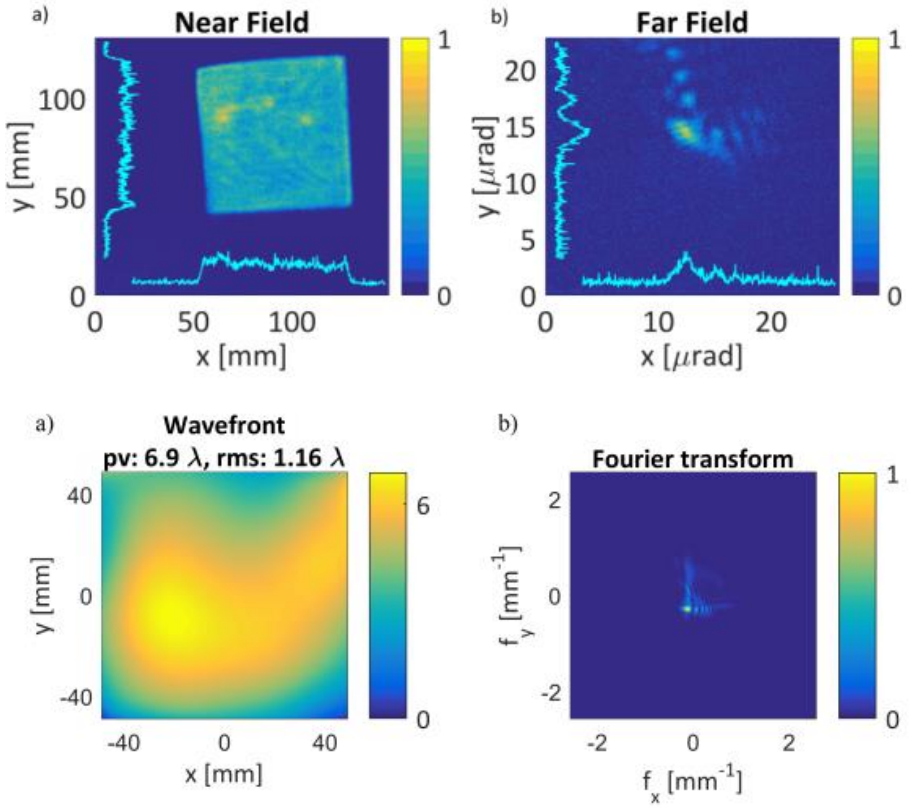
3. 143 J @ 10 Hz for 60 mins

- 143 J for 60 mins
- without deformable mirror
- No damage, no power drop





Martin Divoký, et al., "150 J DPSSL operating at 1.5 kW level," Opt. Lett. 46, 5771-5773 (2021)

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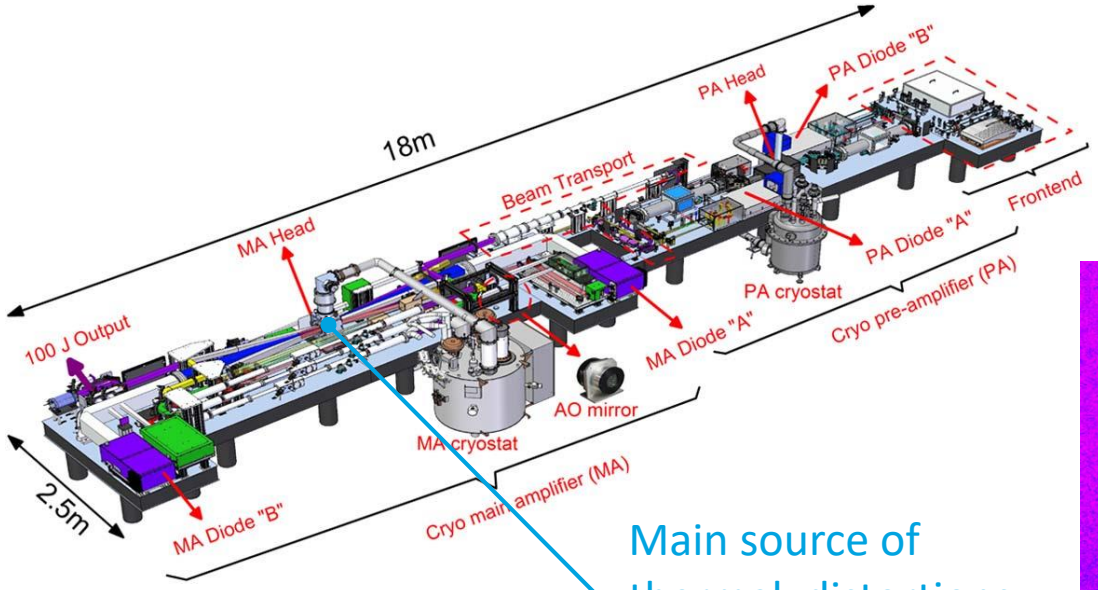
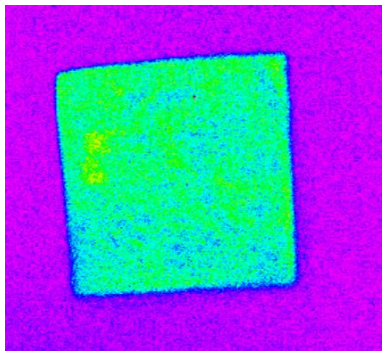
4. Depolarization in Bivoj in 2016

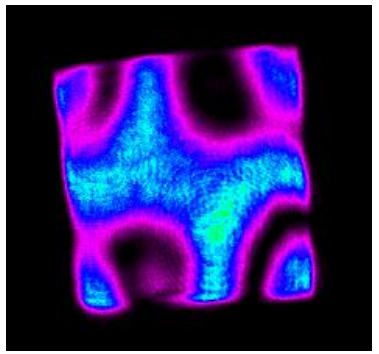
- Power loss ~ 30 %
- Beam shape ruined
- Polarization state useless for polarization sensitive experiments



Main source of thermal distortions



looking through the polarizer



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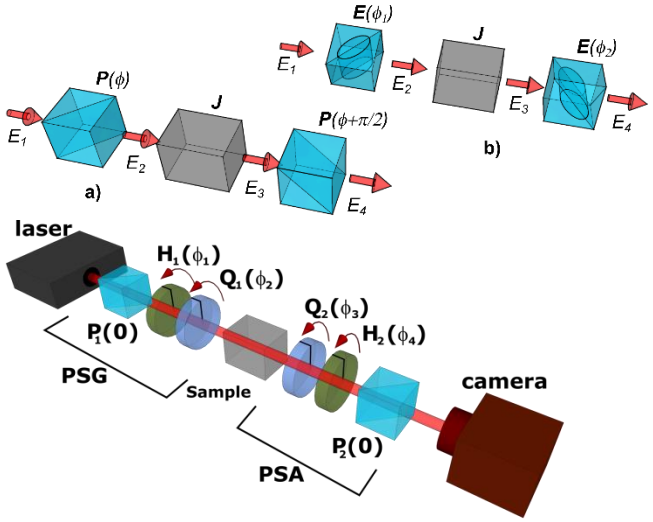
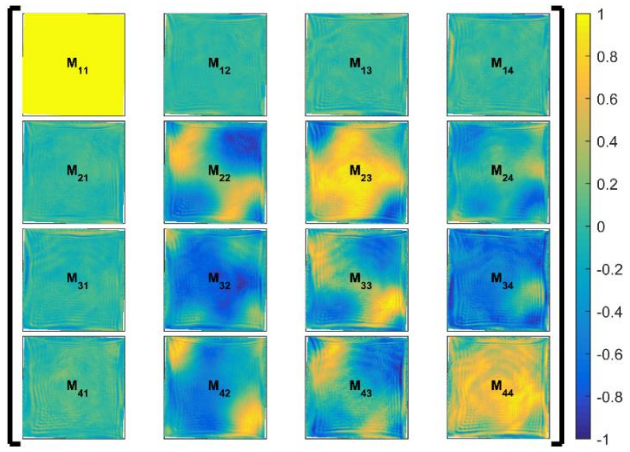
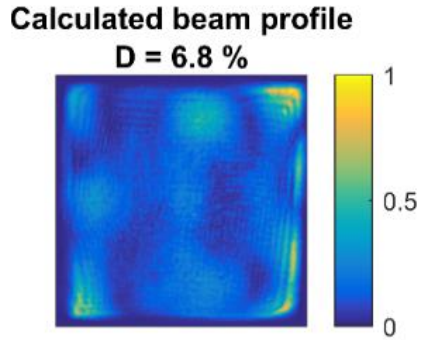
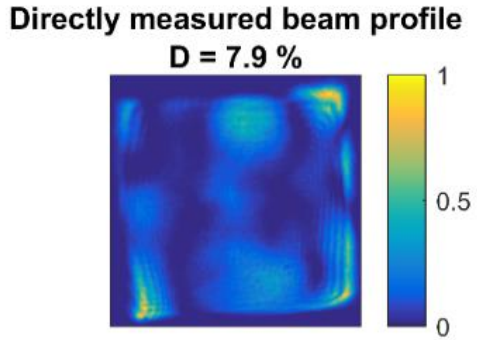
4. Depolarization characterization

- Polarimetric measurement acquire full information about polarization properties of the system
- From measured polarization response, optimization of input and output polarization is possible
- Optimized method described by Lu and Chipman in 1996 (*)









* Lu, S. and Chipman, R.A., JOSA A 13(5), 1106-1113 (1996).

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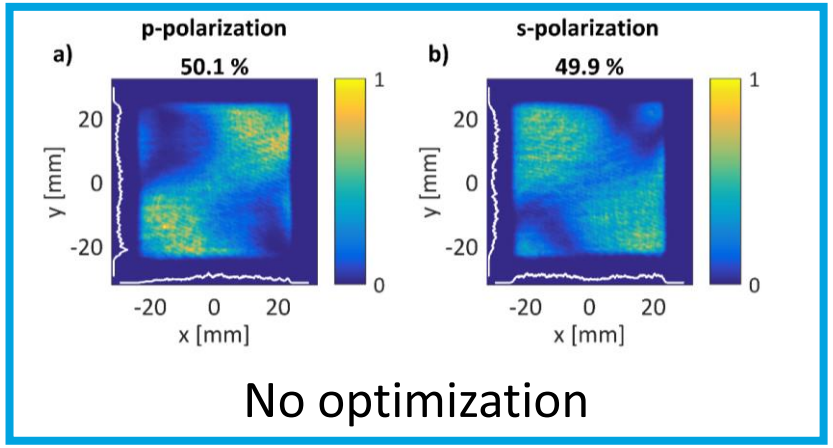
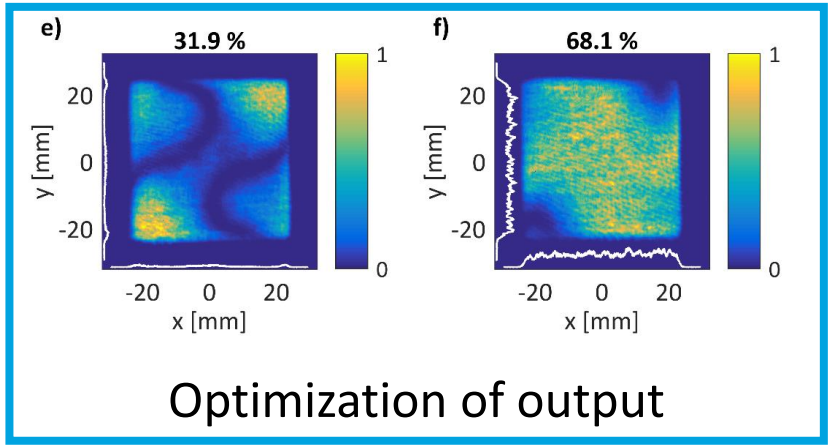
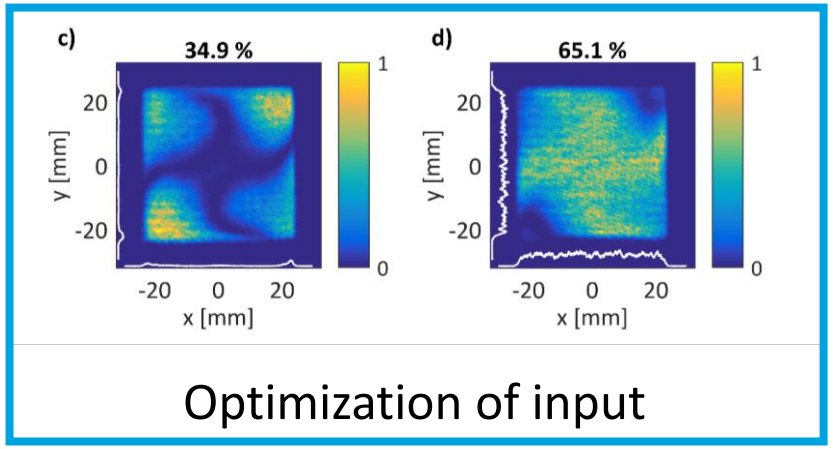
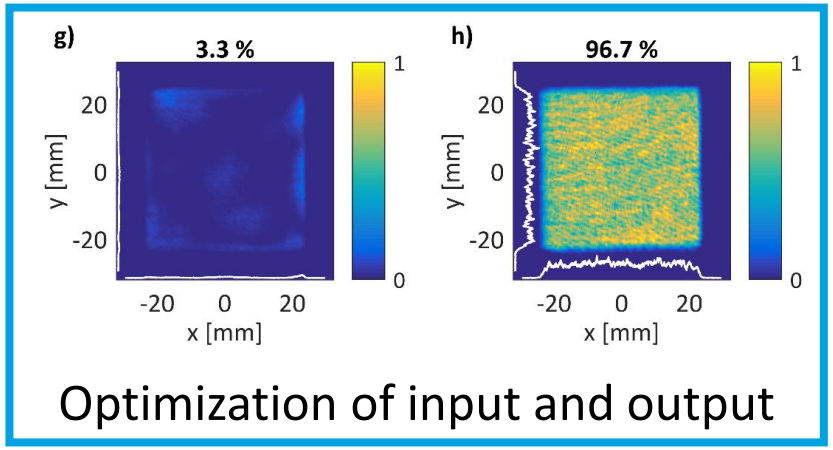
4. Depolarization mitigation

- From 50% losses
- To 3% losses









Slezak, O., *et al.*, "Thermal-stress-induced birefringence management of complex laser systems by means of polarimetry," *Sci Rep* 12, 18334 (2022).

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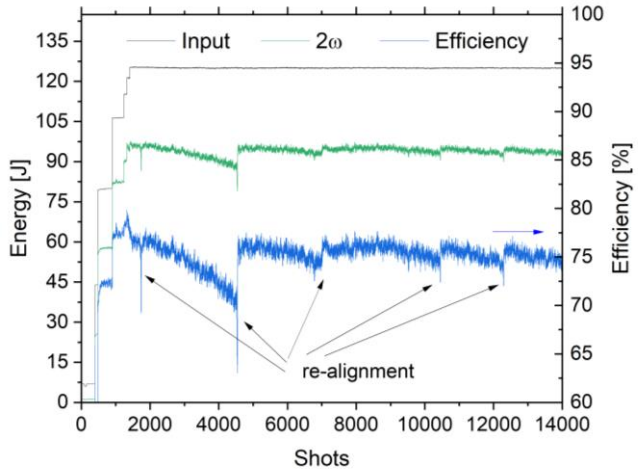
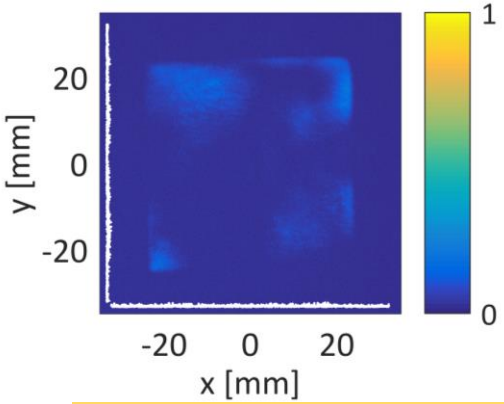
5. SHG results

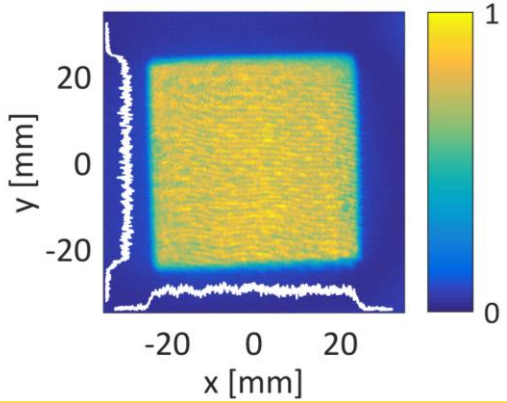
- SHG 515 nm
- Input 120 J (115 J in vertical polarization)
- Output 95 J @ 10 Hz
- LBO Type I
- Efficiency 79% (82% without depolarization)



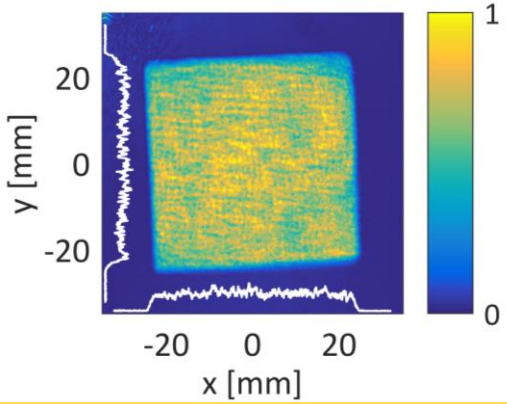
1ω (1030nm) vertical polarization

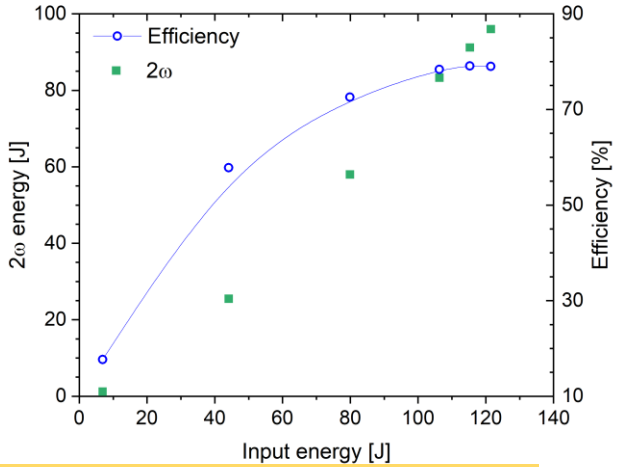


1ω (1030nm) horizontal polarization



2ω (515nm) vertical polarization





Divoky et al., "Kilowatt-class high energy frequency conversion to 95 J at 10 Hz at 515 nm." HPLSE, pp. 1-15., doi:10.1017/hpl.2023.60

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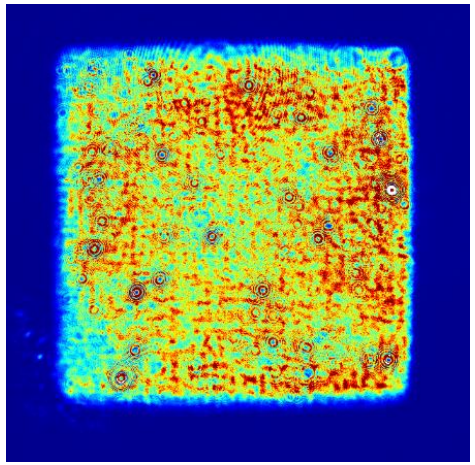
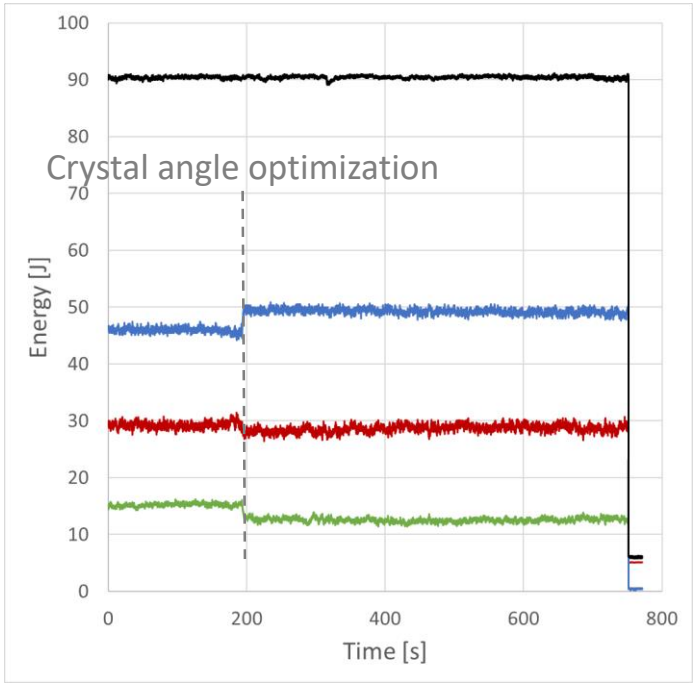
5. High energy THG

- After stabilization
- **45 J @ 10 Hz several hours**
- 55 J @ 10 Hz peak energy in the beginning of the run (several minutes)
- 49.5 J @ 10 Hz for several minutes, stable, lacked time for longer run
- Damaged diagnostic sampler





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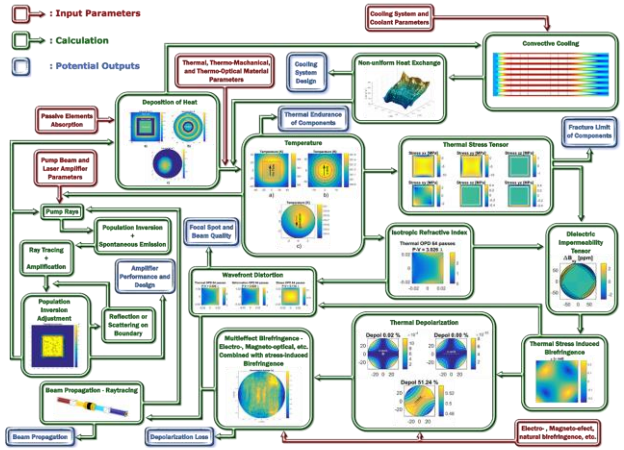
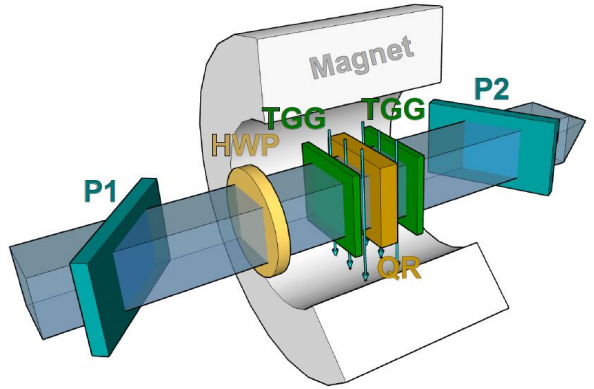
5. SHG & THG summary

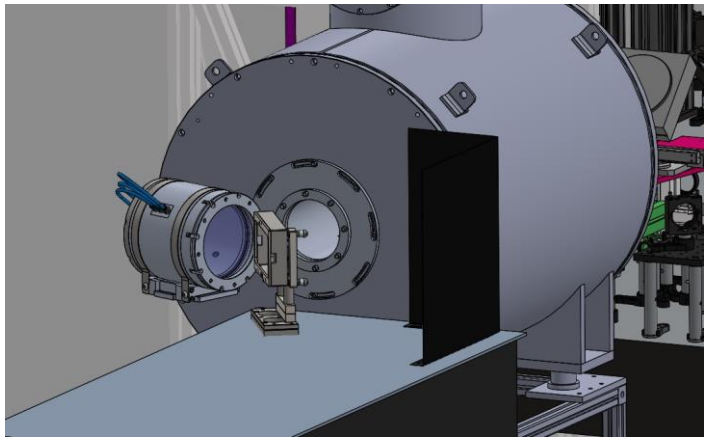
- **145 J / 10 Hz** / 10 ns @ 1030 nm (2021)
- **95 J / 10 Hz** / 10 ns @ 515 nm (2022)
- **55 J / 10 Hz / 10 ns @ 343 nm (2022)**
- **Benchmarking with complex model**

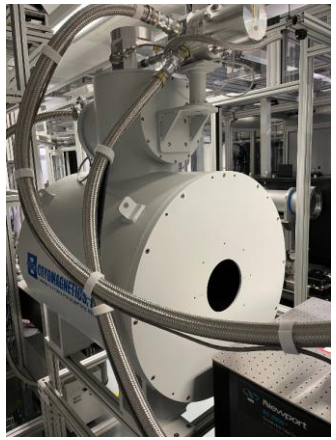


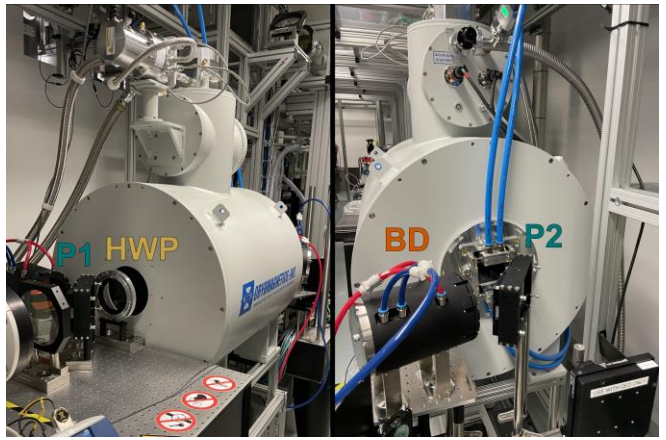
6. Faraday isolator for Bivoj 100 J

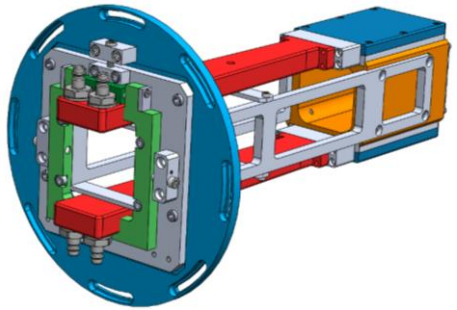
- Cryogenically-cooled supraconductive magnet 3.5 T
- Farady rotator for 100 J / 1 kW / ns pulse isolation
- 1030 nm
- TGG magneto-optic crystals 69 x 69 x 3.6 mm^3











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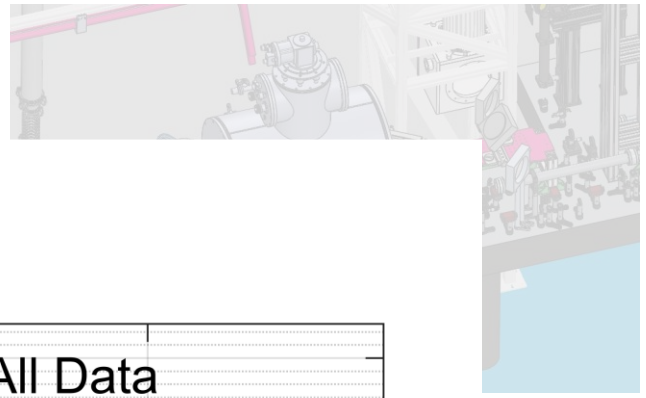

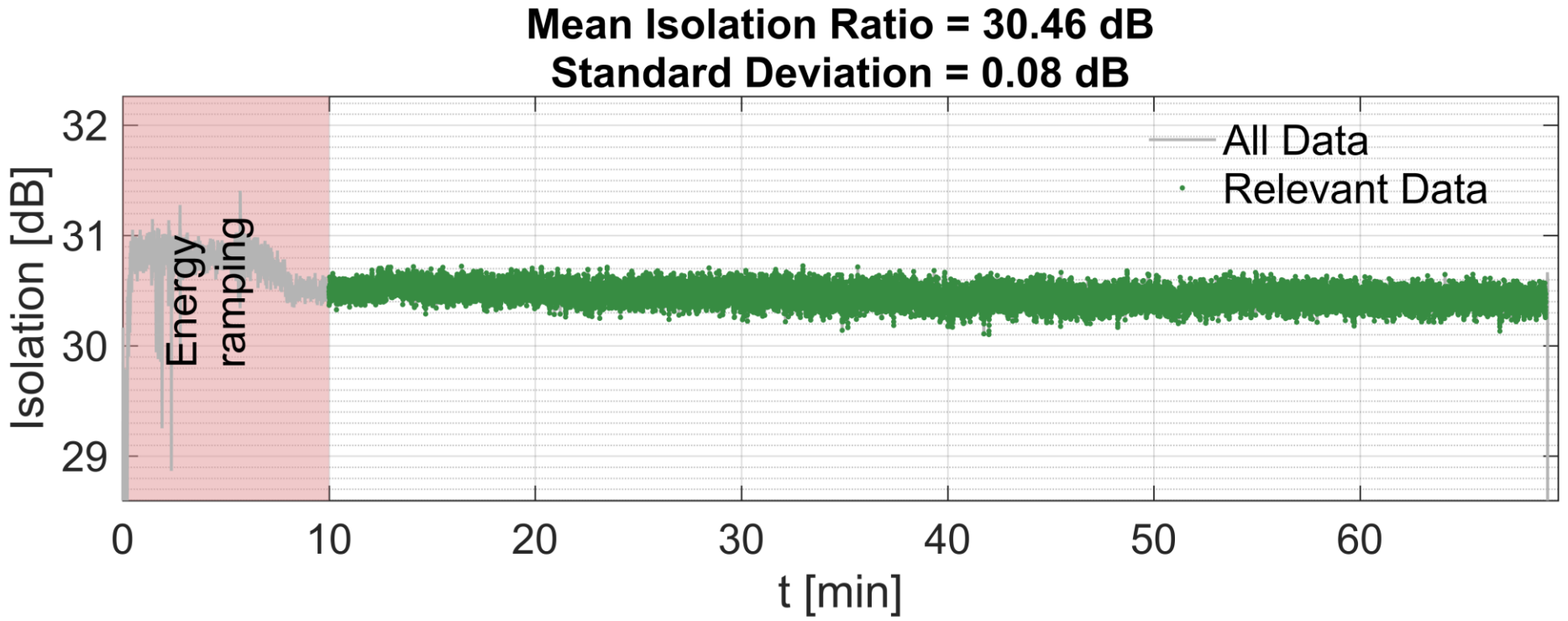

"Faraday isolator for a 100 J/10 Hz pulsed laser," Opt. Lett. 48, 3471-3474 (2023)

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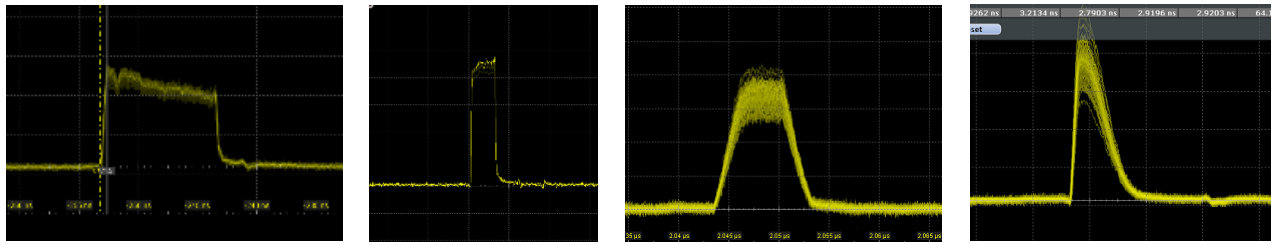
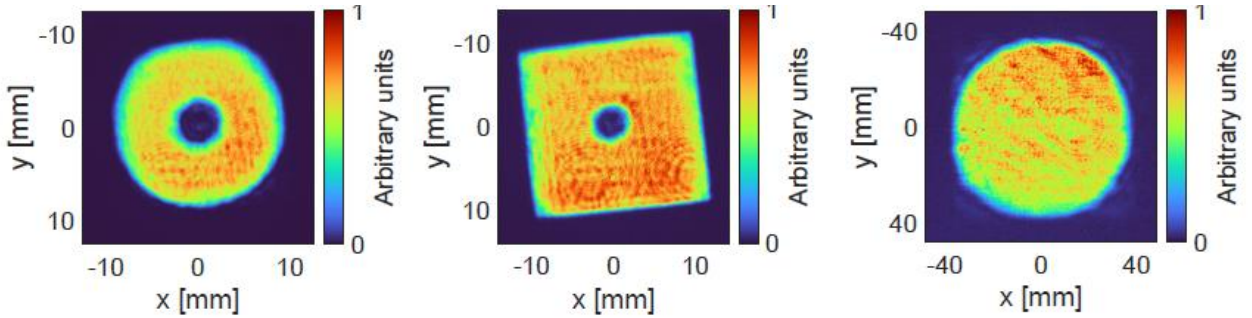
7. Beam shaping

- Possibility to shape beam in time domain by pre-shaping the FFE pulse
  - Top head
  - Ramp
  - Gaussian
  - Half-gaussian



- Possibility to shape the beam trace in spatial domain by SLM in FE part
  - Square (different sizes)
  - Circle
  - Half-circle
  - Imprint a ‘hole’



PALIESEK, T. et al., “Beam shaping in high-energy kW-class laser system Bivoj at HiLASE facility”, HPLSE [accepted] (2023), ISSN 2052-3289

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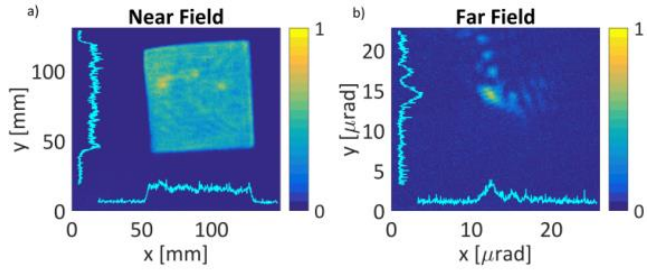
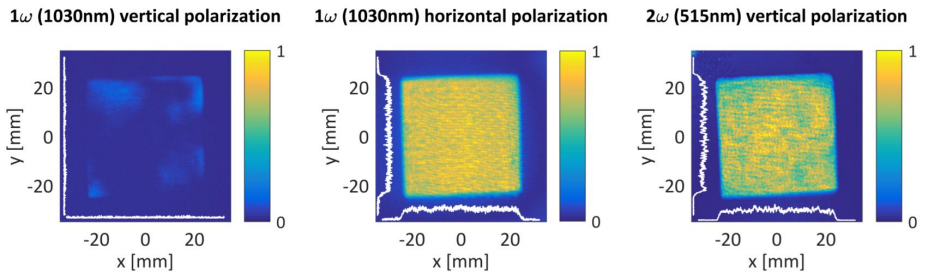
8. Summary

- Bivoj laser – a unique tool
- Depolarization mitigation
- Complex numerical model of the laser
- Faraday isolator allows direct usage of 1030nm beam
- Beam-time available via Open access





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