Progress in development of kW-class picosecond thin-disk laser systems for high-power EUV sources

Martin Smrž
Hilase centre, Dolní Břežany, Czechia

EUV source workshop, November 4 – 6 2019, Amsterdam

EVROPSKÁ UNIE
Evropské strukturální a investiční fondy
Operační program Výzkum, vývoj a vzdělávání

MINISTERSTVO ŠKOLSTVÍ, MLÁDEŽE A TĚLOVÝCHOVY

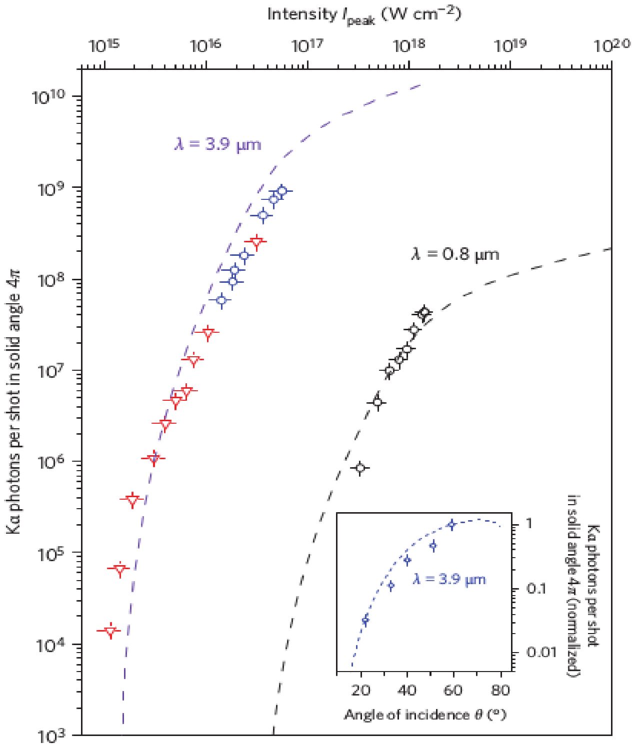
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 739573 (HiLASE CoE)

FZÚ

Outline

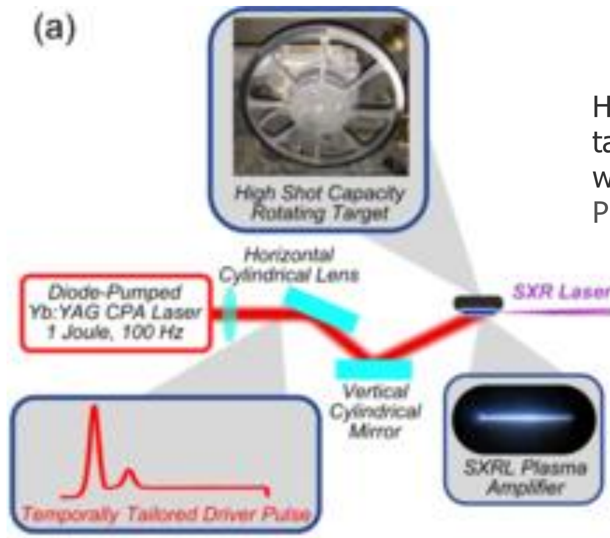
- Thin disk lasers in EUV radiation field
- Thin disk beamlines at Hilase – current status and directions
- Disk laser extensions and customized systems

High power/energy pulsed laser applicatons

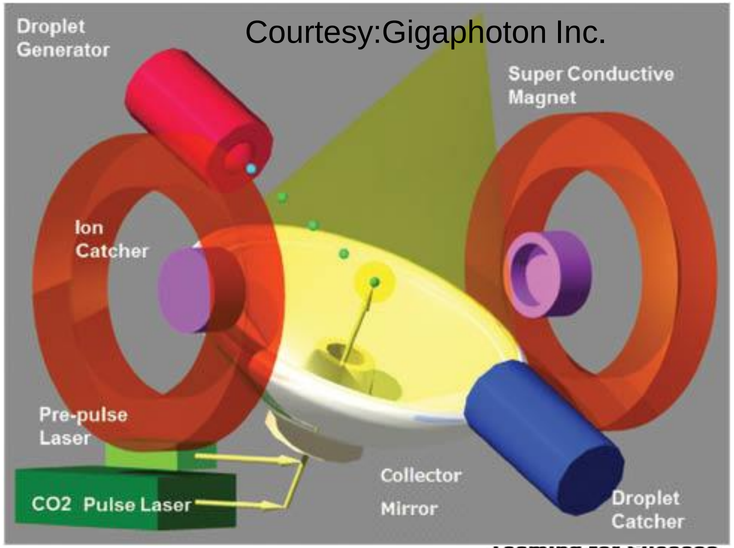


High-brightness table-top hard X-ray source driven by sub-100-femtosecond mid-infrared pulses

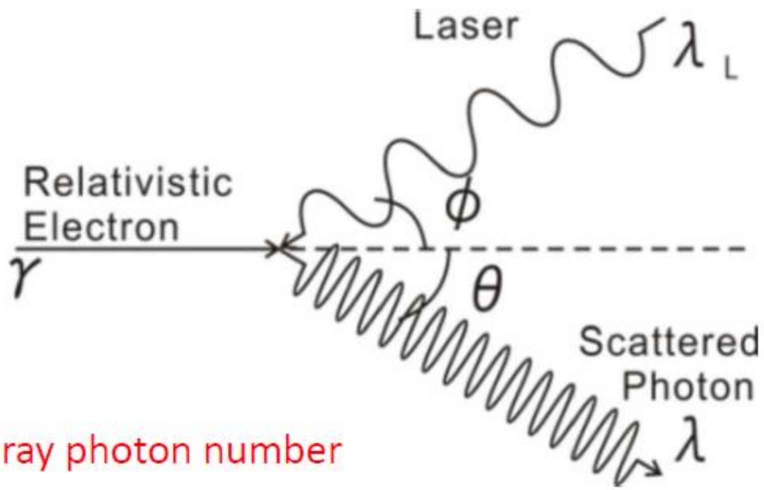
Jannick Weisshaupt[1], Vincent Juvé[1*], Marcel Holtz[1], ShinAn Ku[1], Michael Woerner[1*], Thomas Elsaesser[1], Skirmantas Ališauskas[2], Audrius Pugžlys[2] and Andrius Baltuška[2*]

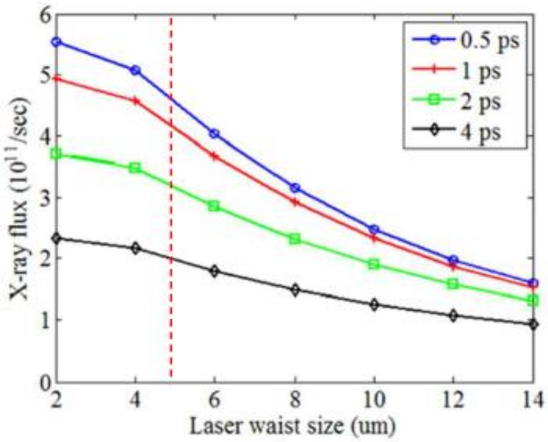


High-average-power, 100-Hz-repetition-rate, tabletop soft-x-ray lasers at sub-15-nm wavelengths; Brendan A. Reagan, et al. Phys. Rev. A **89**, 053820



Laser Compton back scattering





X ray photon number

$$N_0 \propto \frac{\sigma_c N_e N_p}{4\pi r^2}$$

λp : peak X ray wavelength

Ne : total electron number

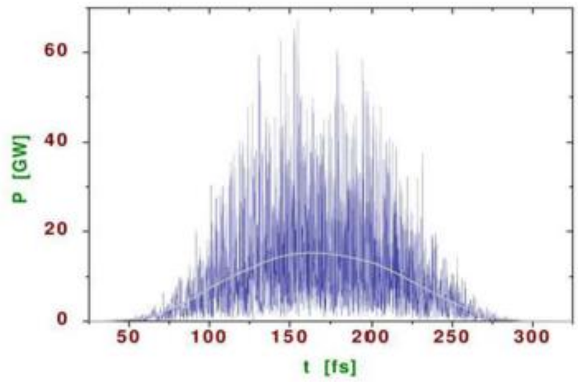
Np : total laser photon number

r : interaction cross section

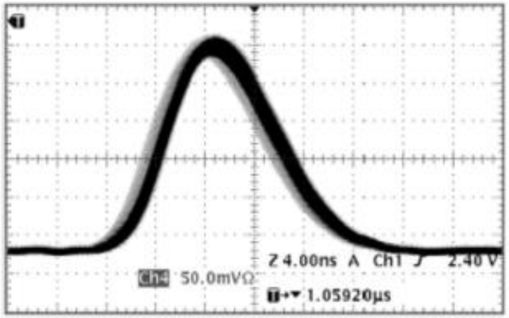
High energy, short pulse <2ps, high beam quality M2<1.5 laser beam focused down to 10µm spot size

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

Smoothing of FEL pulses by UV picosecond laser seeding

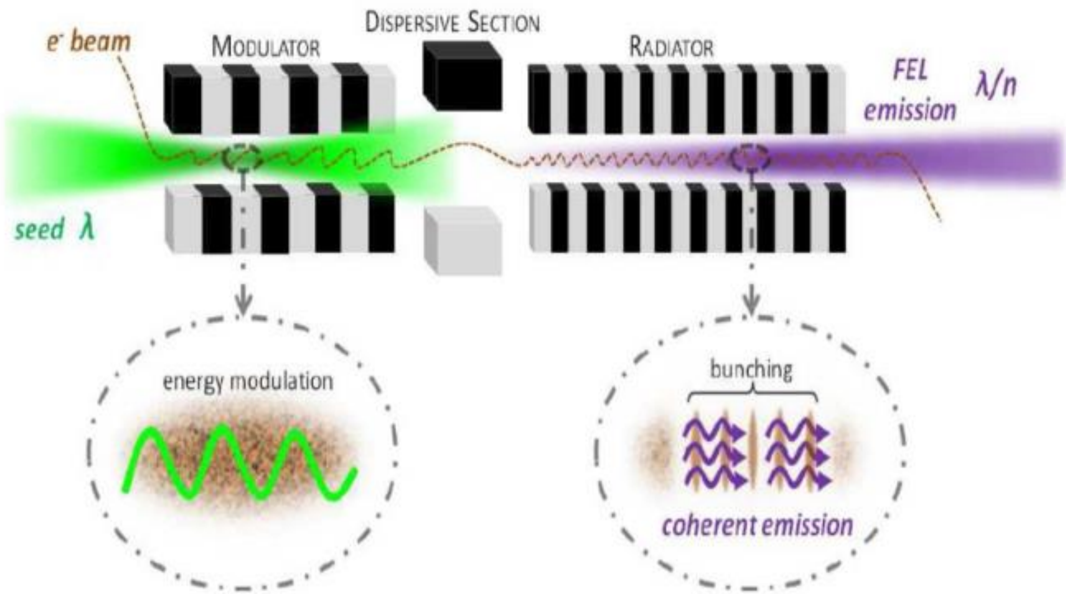


SASE FEL pulse shape



Smoothed pulse shape

100µJ x 10MHz = kW, 1ps, 4HG

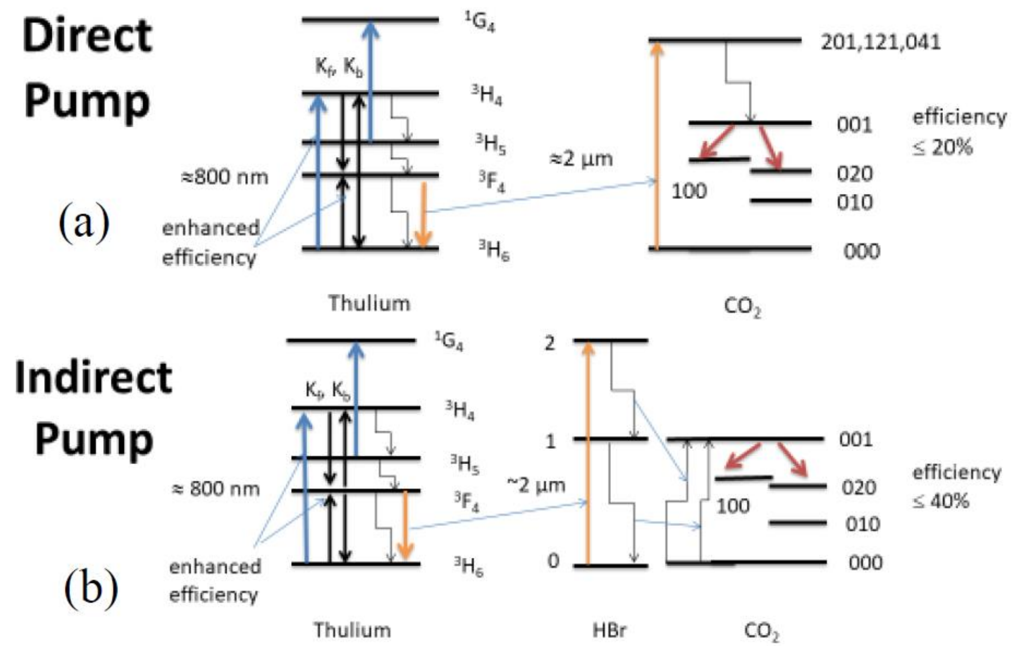


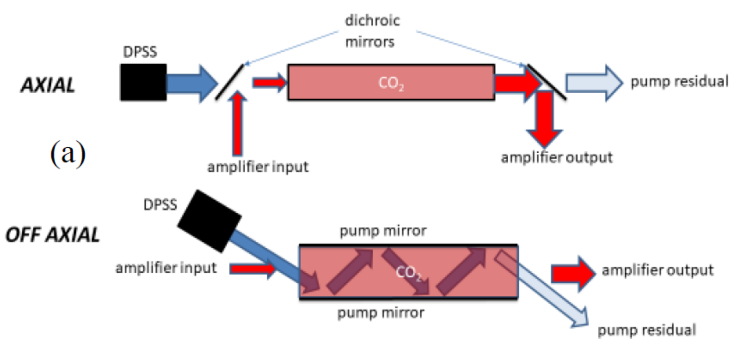
Schematic of the working principle of a HGHG free-electron laser.

Chirped pulse amplification in X-ray free electron lasers
Hugo Ducasa et.al. SPIE 9585-15, San Diego 2015

Optical pumping of CO_2 lasers

- High pressure CO_2 amplifier
- MOPA design – tens of kW
- Small signal gain 5-10%/cm
- High efficency and small size
- Ultrashort pulses <1ps feasible



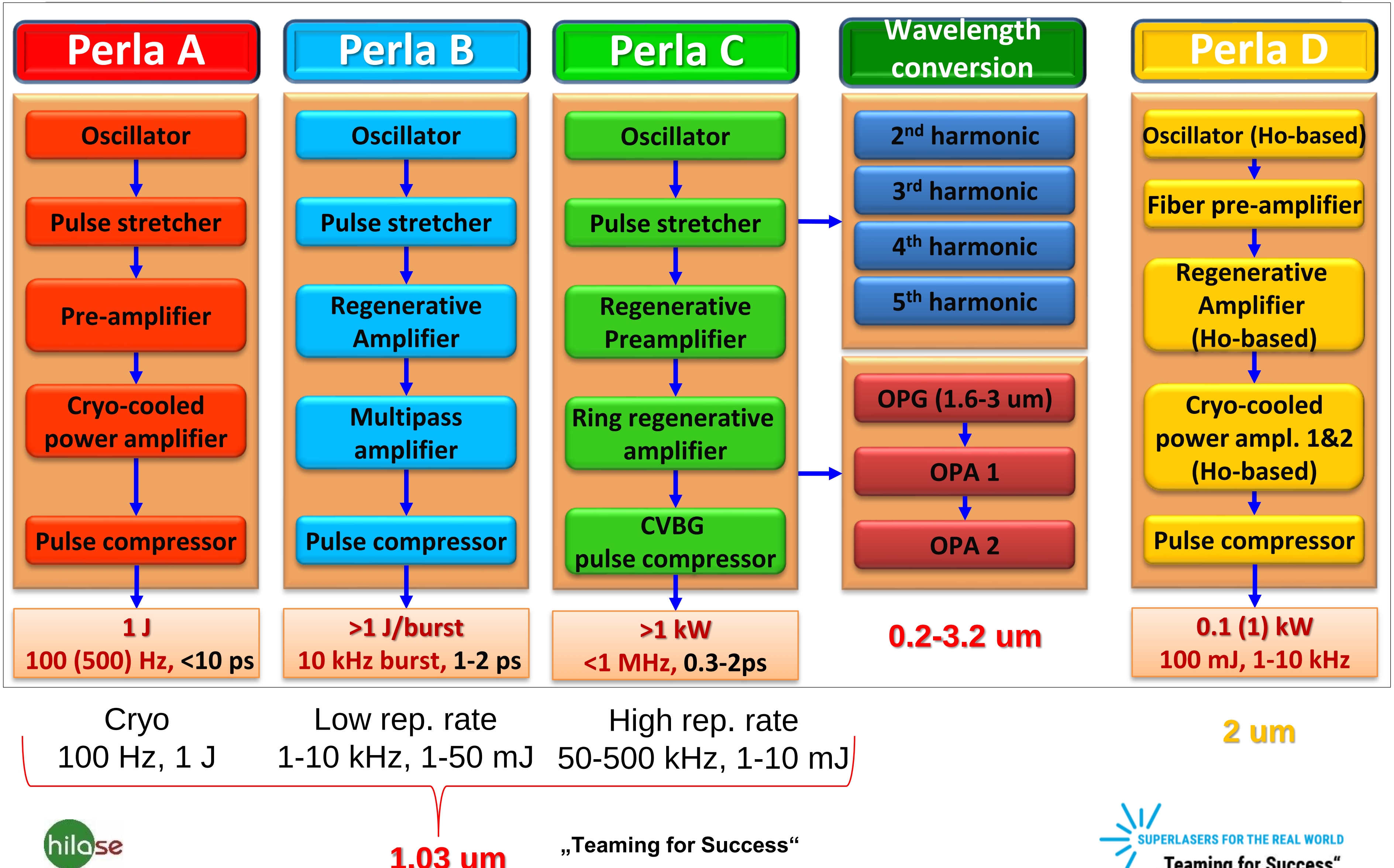


Optical pumped ultra-short pulse CO₂ lasers as drivers of laser-plasma accelerators and other applications

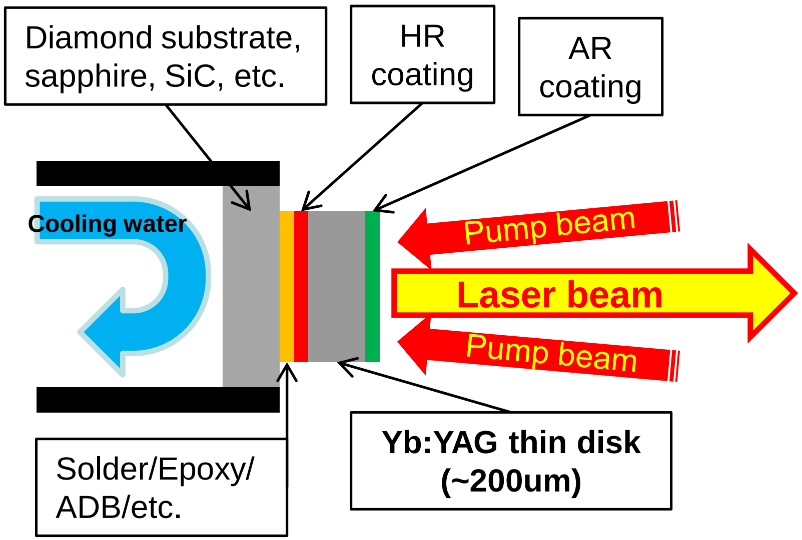
D. A. Jaroszynski[1,*], R. N. Campbell[2], E. Brunetti[1] and S. R. Yoffe[1]

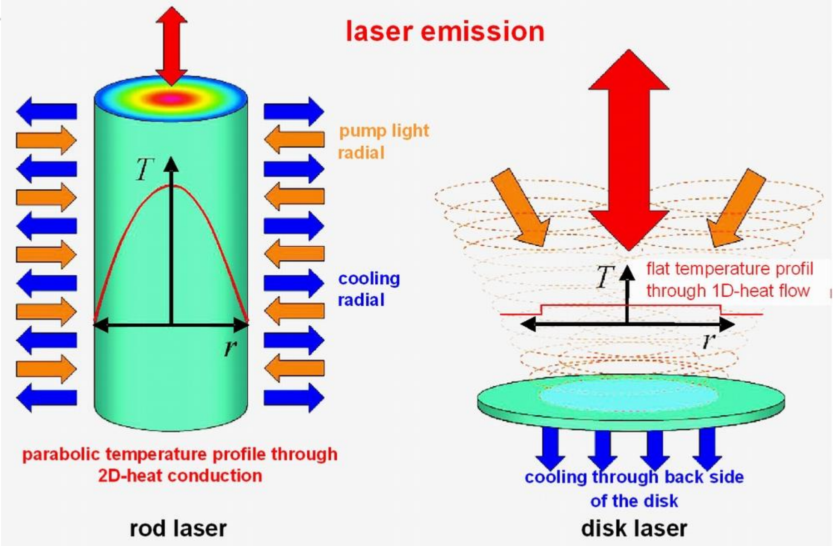
[1]University of Strathclyde, Physics Department, Glasgow G4 0NG, Scotland, UK;
[2] IRP TECHNOLOGY, Camino de la Tierra, Corrales, NM 87048, USA,

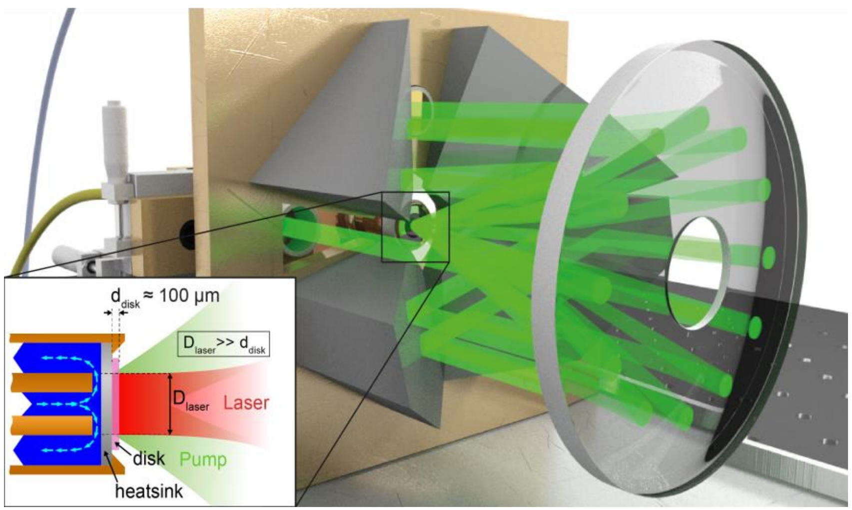
PERLA thin-disk laser systems



Thin-disk geometry for high-power lasers







Thin-disk pros and cons:

+ Efficient cooling

+ Low thermal lensing

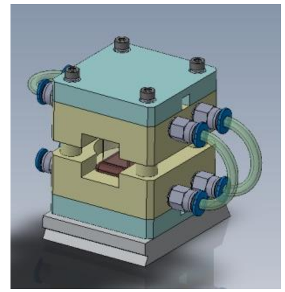
+ Axial heat flow

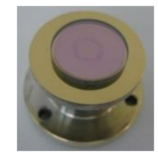
+ Low nonlinearities (B-integral,SPM)

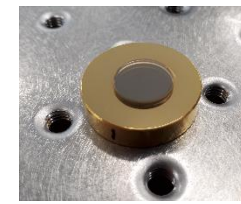
- Low single pass gain

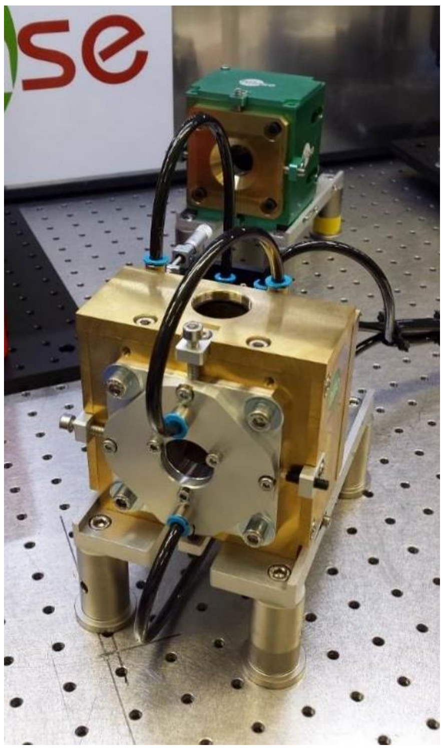
Core technology development

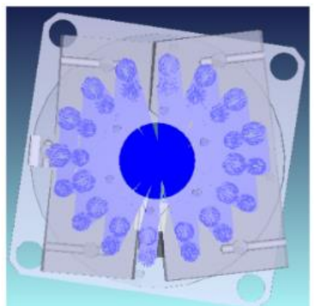
- **Laser heads**
- **Thin-disk modules**
- **High power Pockels cells**

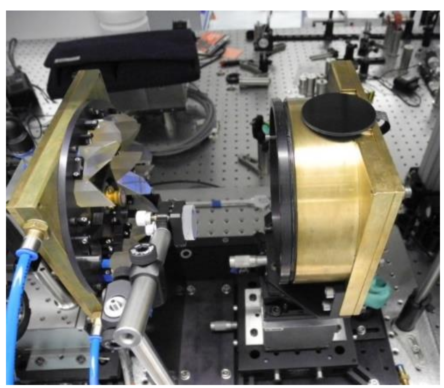


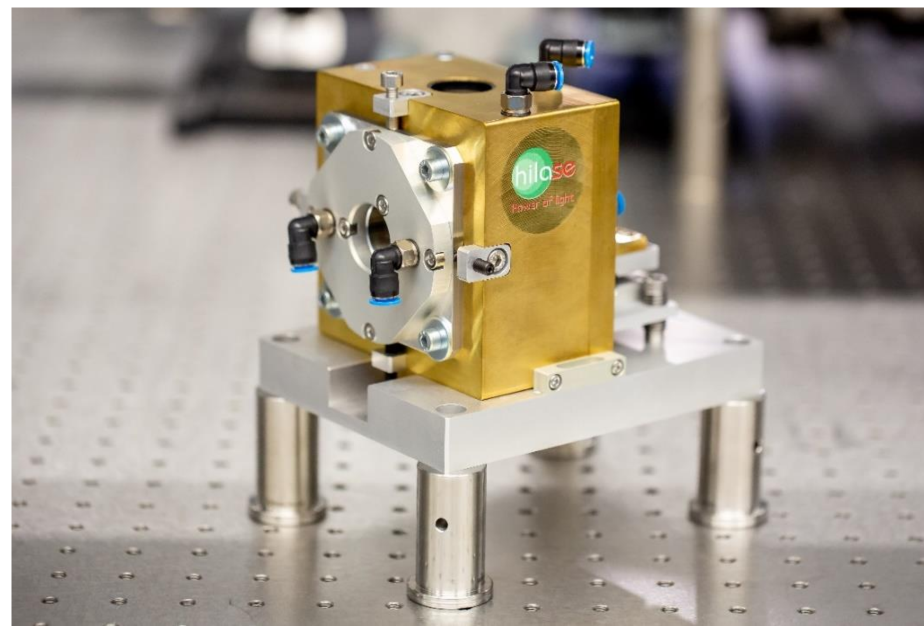




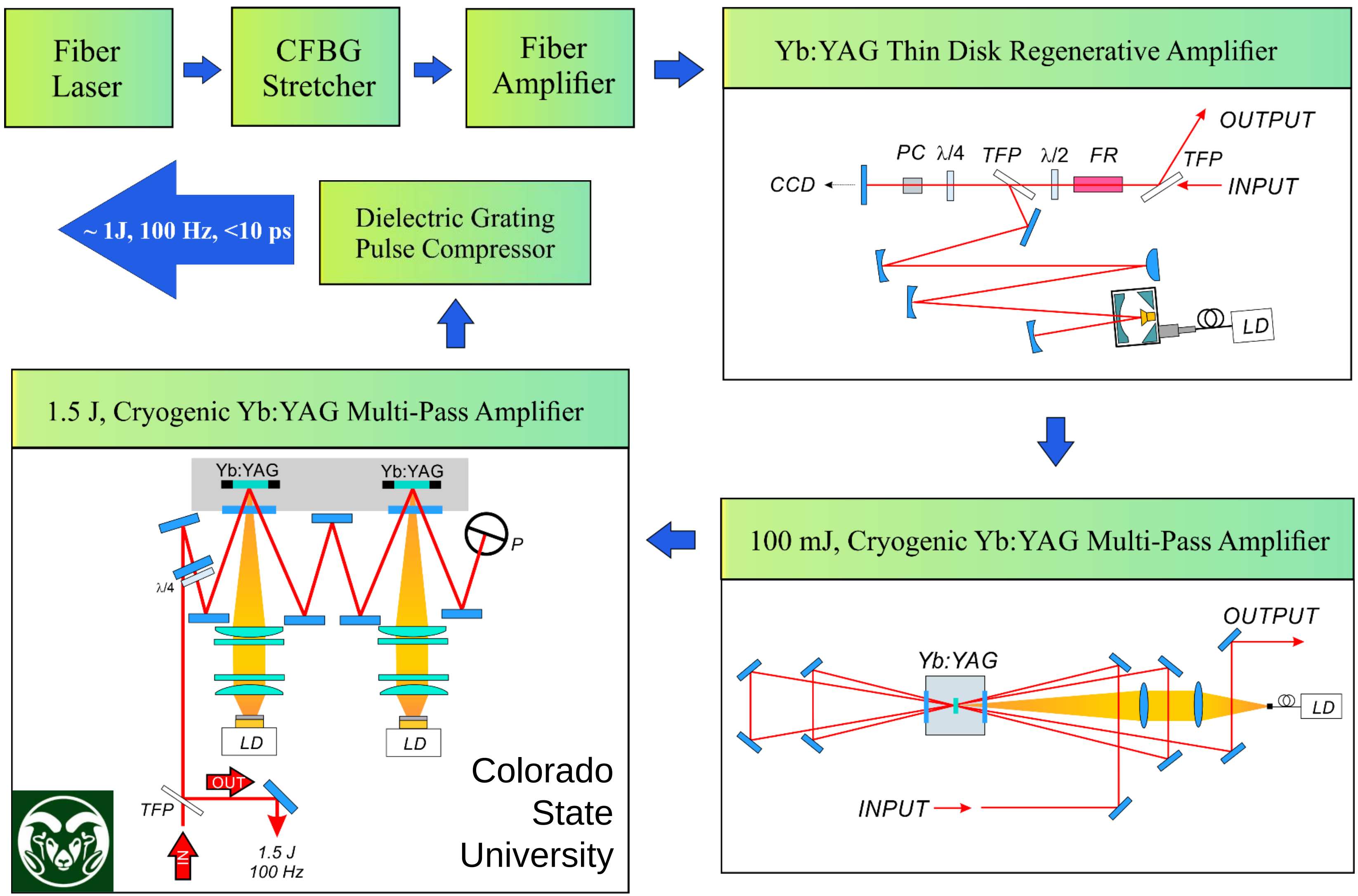






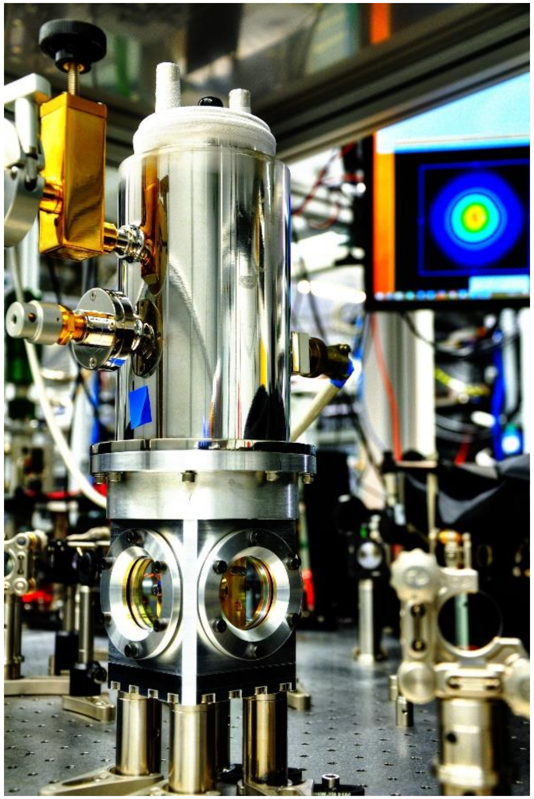


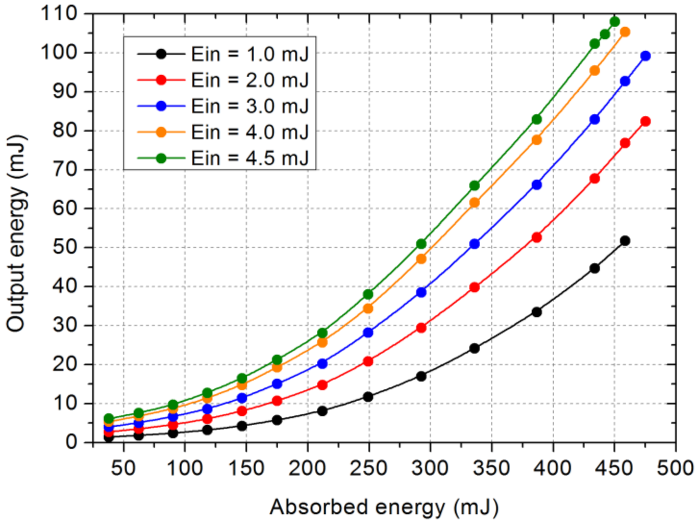
PERLA A- cryo-cooled thick disk laser

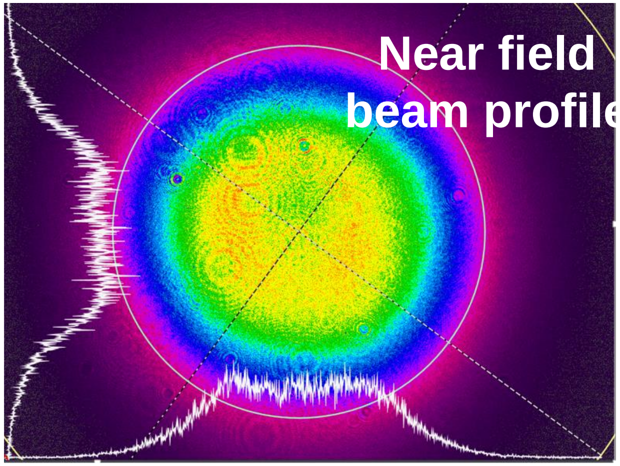


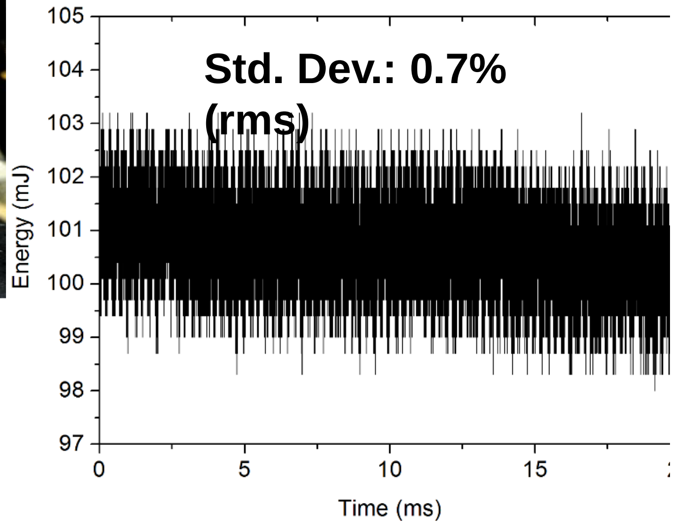
Power of light

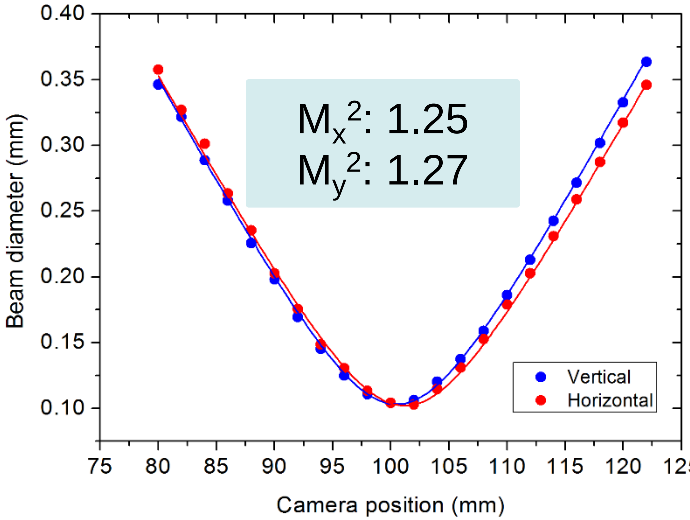
PERLA A100 cryo-cooled thick disk amplifier

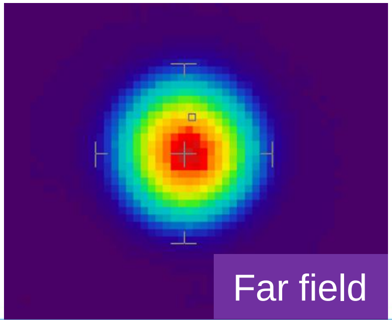








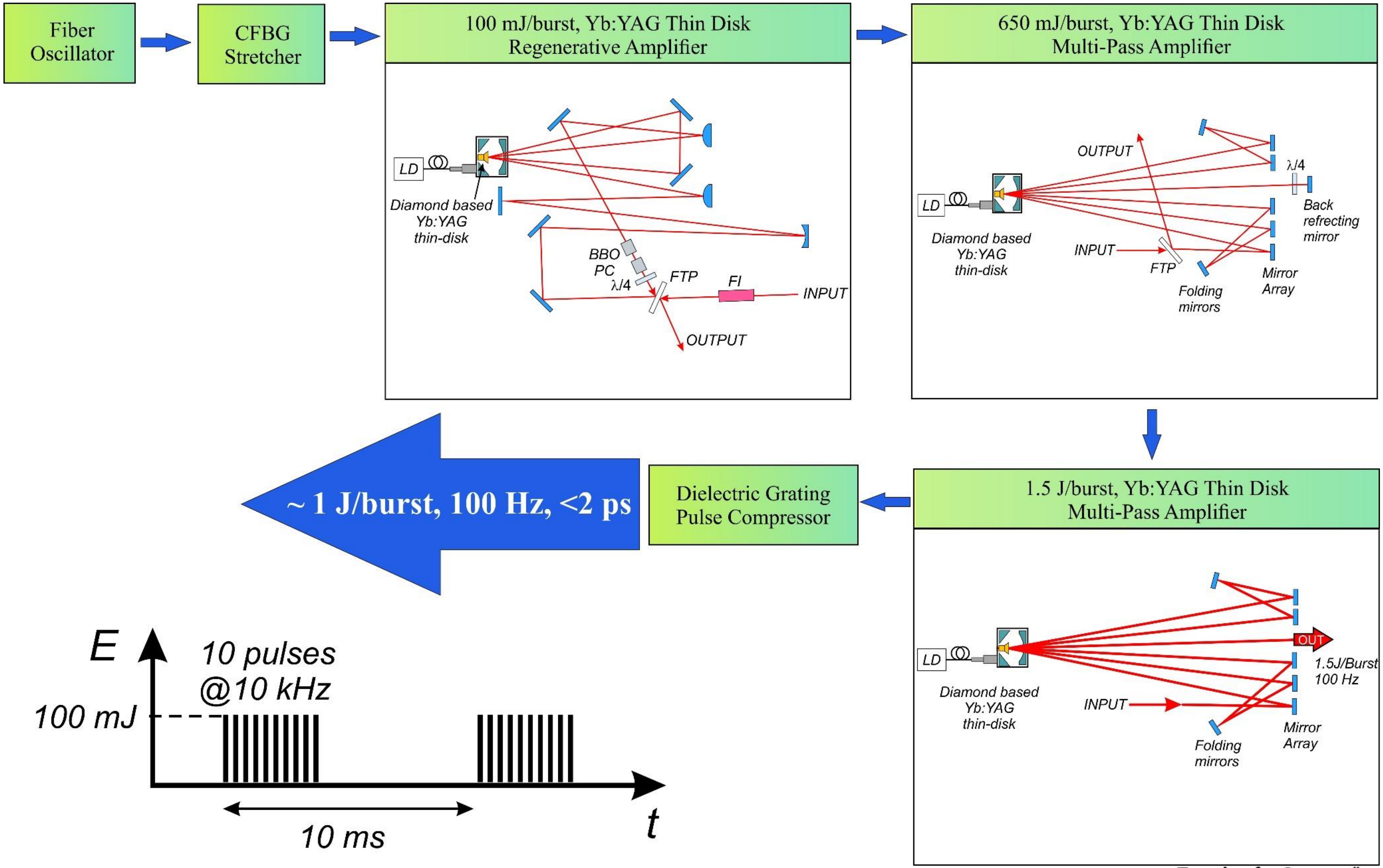




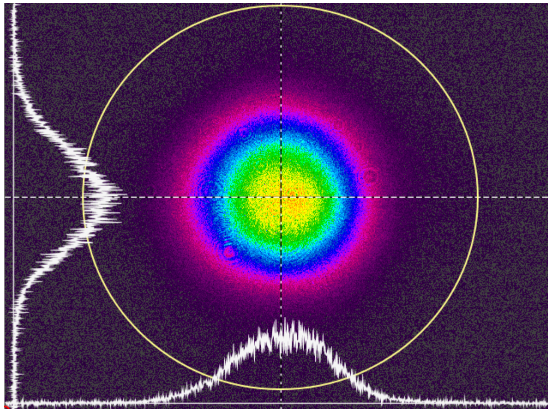
10 W, 100 Hz, 100 mJ, 1.5 ns (FTL 4 ps)

„Teaming for Success“

PERLA B- room temperature thin-disk beamline



PERLA B20



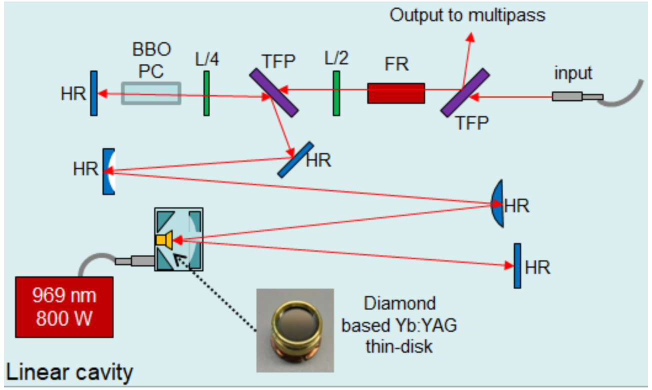
Output pulse energy **20 mJ @ 1 kHz** (10 mJ compressed)

Pulse duration **1.7 ps** ($sech^2$)

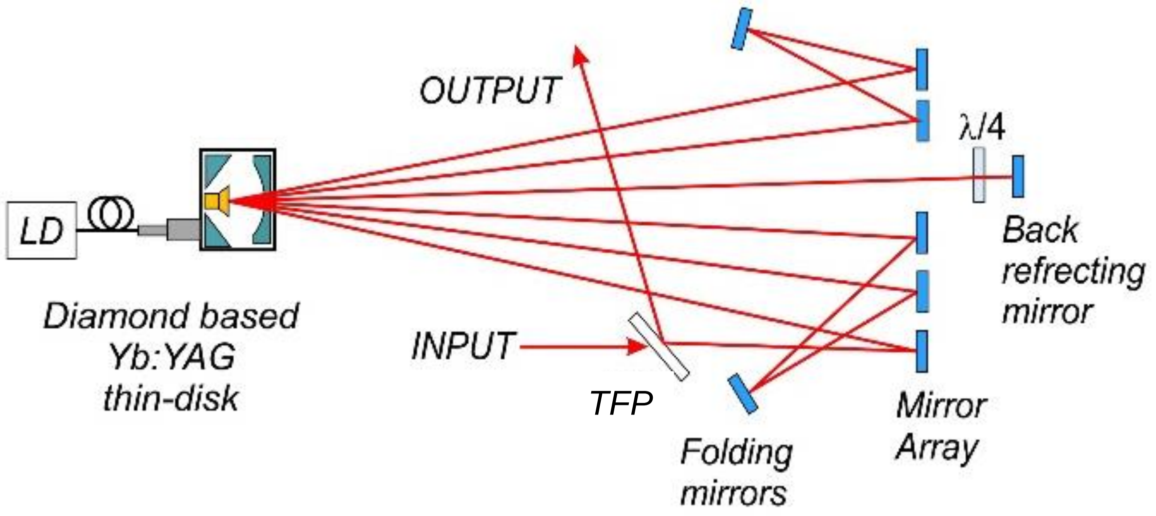
Power stability **0.5% RMS**

Pulse-to-pulse energy stability **0.6% RMS**

M^2 1.22/1.23 (after compressor)



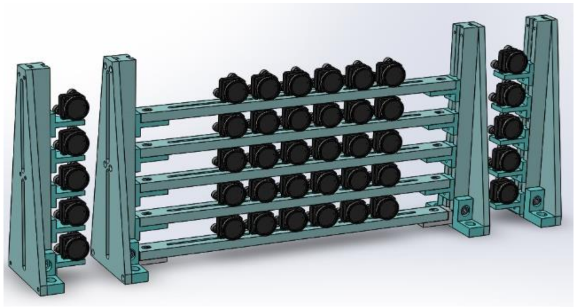
PERLA B500- thin-disk Multipass amplifier

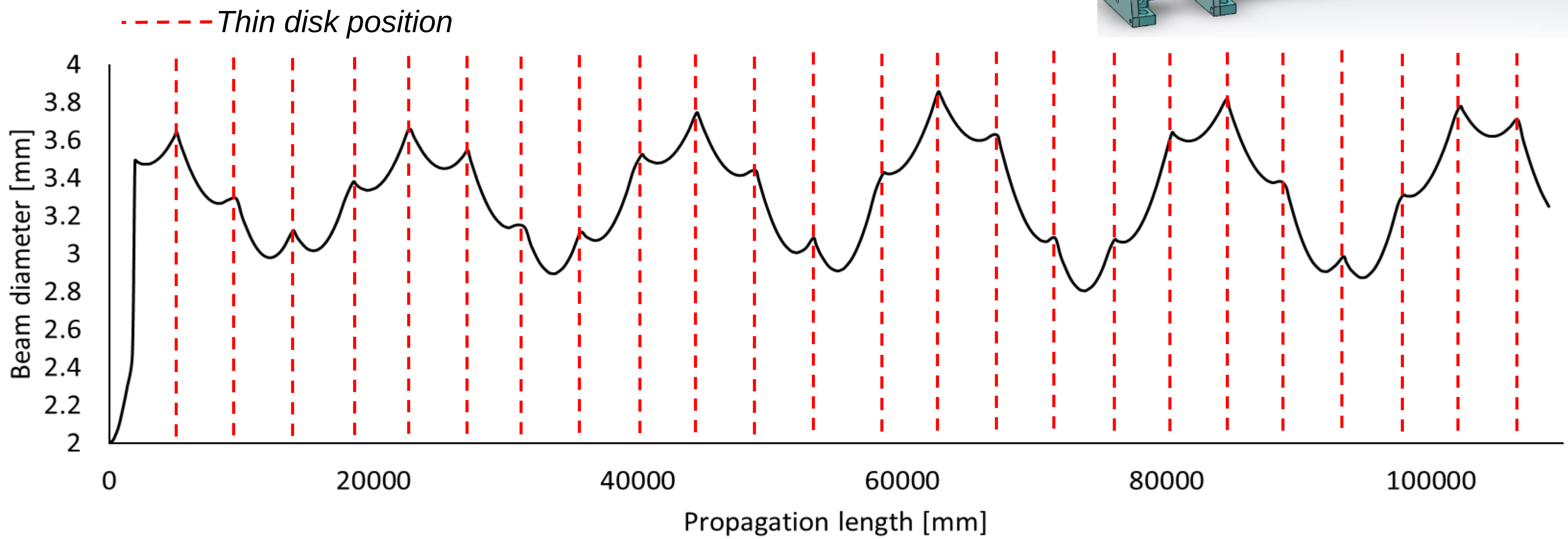


4x3 array -12 passes (with λ/4 plate)

12	11	7	5	1	6
	13	17	16	14	15
3	2	4	8	10	9

Thin disk   Mirror with λ/4 plate



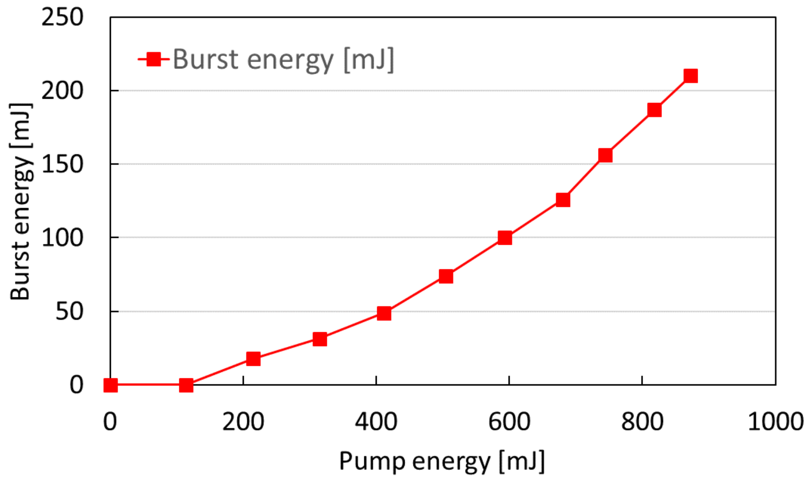


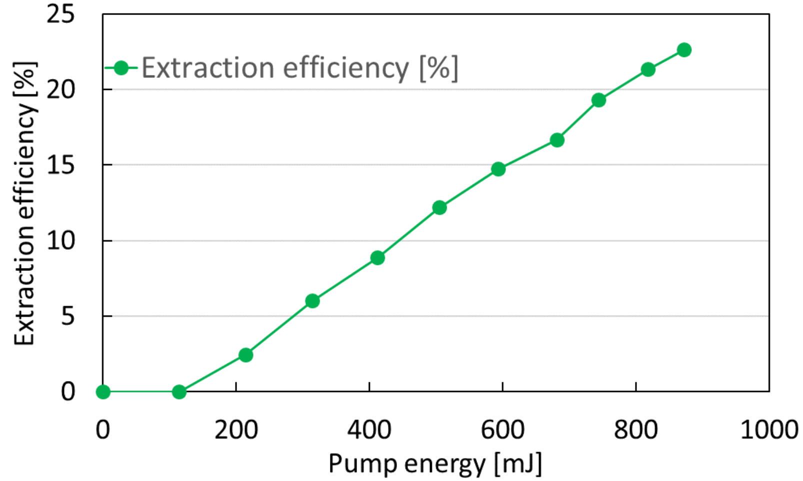
Nearly collimated seed beam propagation within the multipass amplifier with 24 reflections on thin disk TD

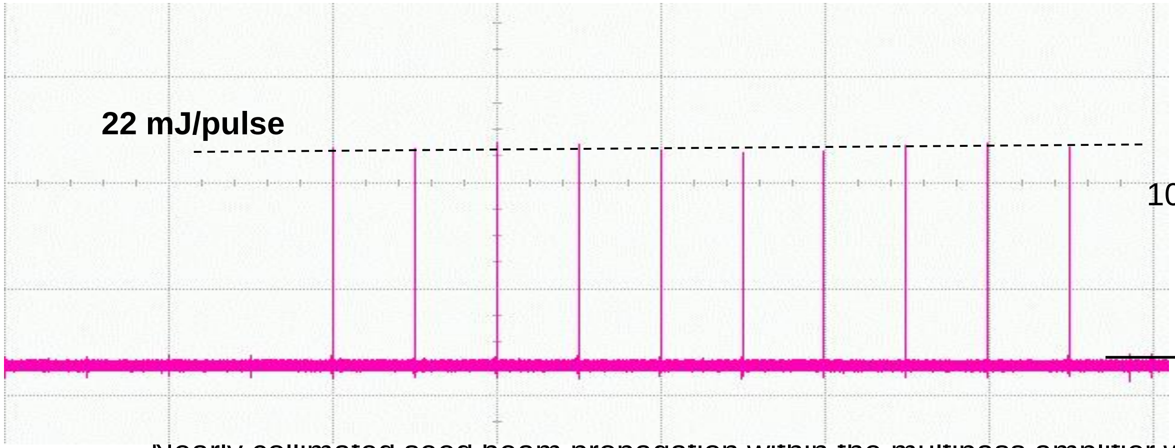
PERLA B500- Burst-mode amplification

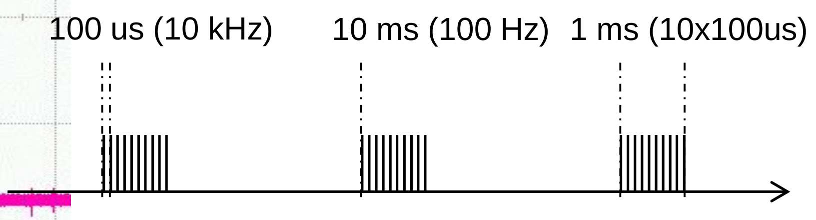
Pump 940 nm
Pulse width1.5 msec at 100 Hz
Delay between pump and first pulse in burst-550 µs

Seed
1.2 mJ/pulse at 10 kHz
10 pulses/burst at 100 Hz
12 mJ/burst









Nearly collimated seed beam propagation within the multipass amplifier with 24 reflections on thin disk TD

PERLA C- room temperature thin-disk beamline

high-repetition rates (50-500 kHz)

PERLA C100

Regenerative amplifier
1 mJ (100 W @100 kHz)

PERLA C500

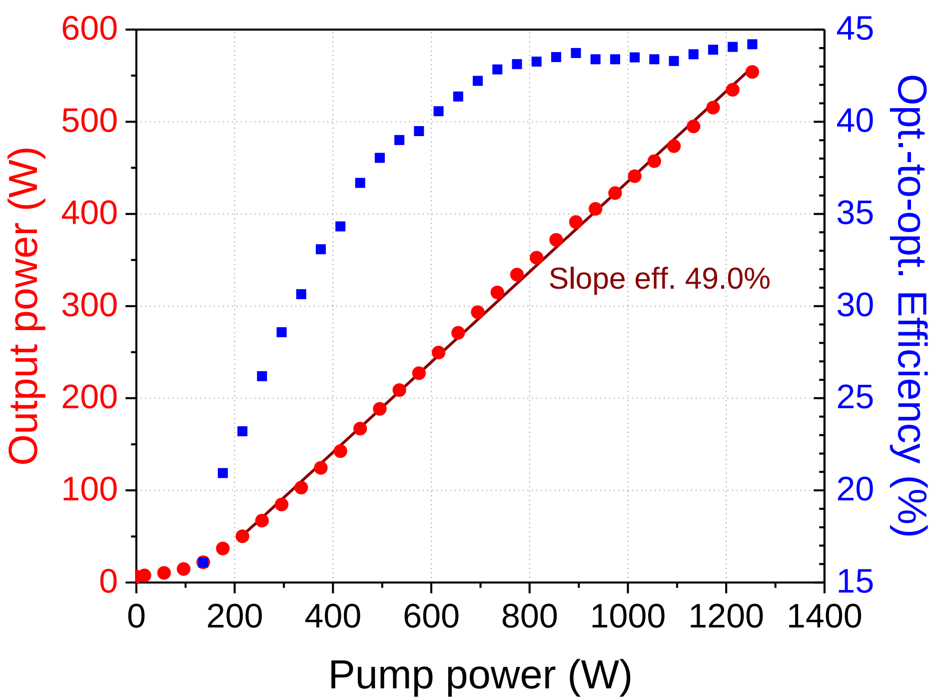
Regenerative amplifier
6 mJ (550 W @92 kHz)

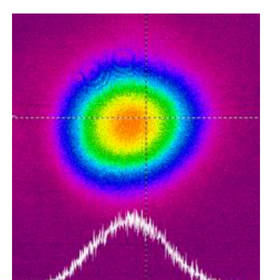
PERLA C1000

Regenerative amplifier
20 mJ (1000 W @50 kHz)

RLA C500

- Single-disk ring regenerative amplifier
- Compact size (1.2×0.8 m^2 footprint)
- Maximum achieved output power 550 W @92kHz (pulse energy 6 mJ)
- High efficiency (>40%)
- Long-term stable operation
- Up to 9-mJ pulse energy @50kHz
- Good beam quality ($M^2 \approx 1.4$)





6 mJ @ 92 kHz
550 W

„Teaming for Success“

PERLA 100

Standard PERLA 100 configuration:

- 100 W, 100 kHz, 1 mJ, 1030 nm
- Pulse compressor for <2 ps
- Integrated all-in-one control system
- Active beam stabilization system
- Thermally-stabilized robust housing

Options:

- Integrated pulse-picker
- Motorized and automated attenuator
- Laser safety output shutter
- Air or water cooling possible
- Stand-alone amplifier
- 2^{nd}, 3^{rd}, 4^{th} harmonics or Mid-IR OPA stage on the output of the laser in a form of additional module with thermally-stabilized robust housing and control system integration

KEY SPECIFICATIONS

– Wavelength 1030 nm
– Output power 100 W
– Repetition rate 100 kHz
– Pulse duration <2 ps
– Robust design
– Stable and reliable laser source

APPLICATIONS

– Laser source for drilling and cutting of composites, ceramics, plastics, metals, and alloys
– Laser source for surface micro structuring
– Pump source for mid-IR optical parametric amplifiers (OPAs)
– Driving laser for high harmonics generation
– LIDT testing with picosecond pulses

OPTION FEATURES

– Stand-alone regenerative amplifier
– Pulse picker
– Repetition rate 1-200 kHz
– 2^{nd}, 3^{rd} or 4^{th} harmonics stage
– Mid-IR OPA stage

PERLA 100

1030 nm THIN-DISK LASER SYSTEM

PERLA 100 is a compact laser system based on a thin-disk regenerative amplifier delivering picosecond pulses at 100 kHz repetition rate with pulse energy of 1 mJ. It incorporates a fiber front-end seeding the amplifier and a versatile control system allowing precise control and monitoring of the laser. Robust design guarantees excellent stability and maintenance free operation. PERLA laser platform design allows flexible modification of output parameters. User customized solutions are available upon request.

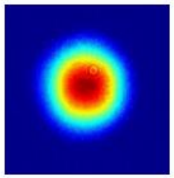


FIG.1 TYPICAL NEAR FIELD BEAM PROFILE AT 1030 NM

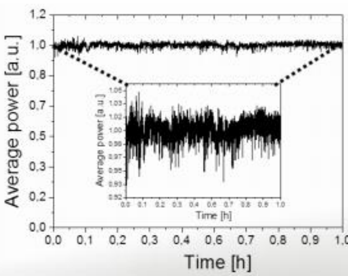


FIG.2 POWER STABILITY (<1% RMS OVER 1 HOUR AT AMBIENT TEMPERATURE OF 23°C)

KEY SPECIFICATIONS

- Wavelength 1030 nm
- Output power 100 W
- Repetition rate 100 kHz
- Pulse duration <2 ps
- Robust design
- Stable and reliable laser source

APPLICATIONS

- Laser source for drilling and cutting of composites, ceramics, plastics, metals, and alloys
- Laser source for surface micro structuring
- Pump source for mid-IR optical parametric amplifiers (OPAs)
- Driving laser for high harmonics generation
- LIDT testing with picosecond pulses

OPTION FEATURES

- Stand-alone regenerative amplifier
- Pulse picker
- Repetition rate 1-200 kHz
- 2nd, 3rd or 4th harmonics stage
- Mid-IR OPA stage

FZU

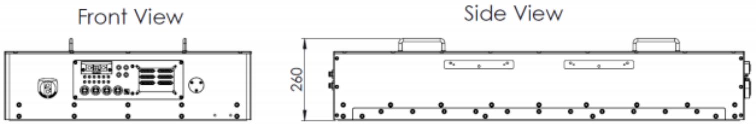
EVROPSKÁ UNIE
Evropské strukturální a investiční fondy
Operační program Výzkum, vývoj a vzdělávání

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 739573 (HiLASE CoE)

Czech Academy of Sciences

PERLA 100

1030 nm THIN-DISK LASER SYSTEM



Top View

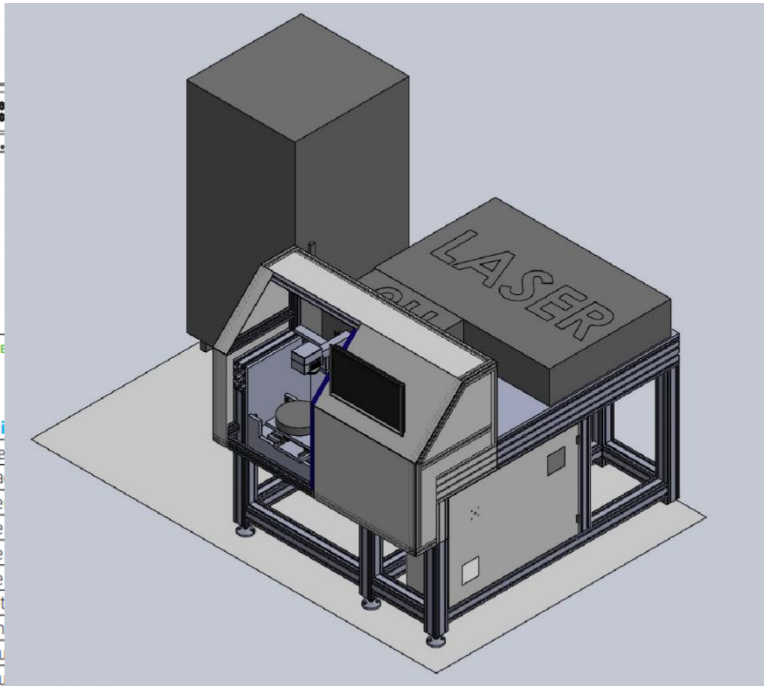


FIG.3 TE

Speci
Cente
Avera
Powe
Pulse
Pulse
Pulse
Repet
Beam
Outpu
Outpu

densing)
m³

ORDERING INFORMATION

solutions@hilase.cz

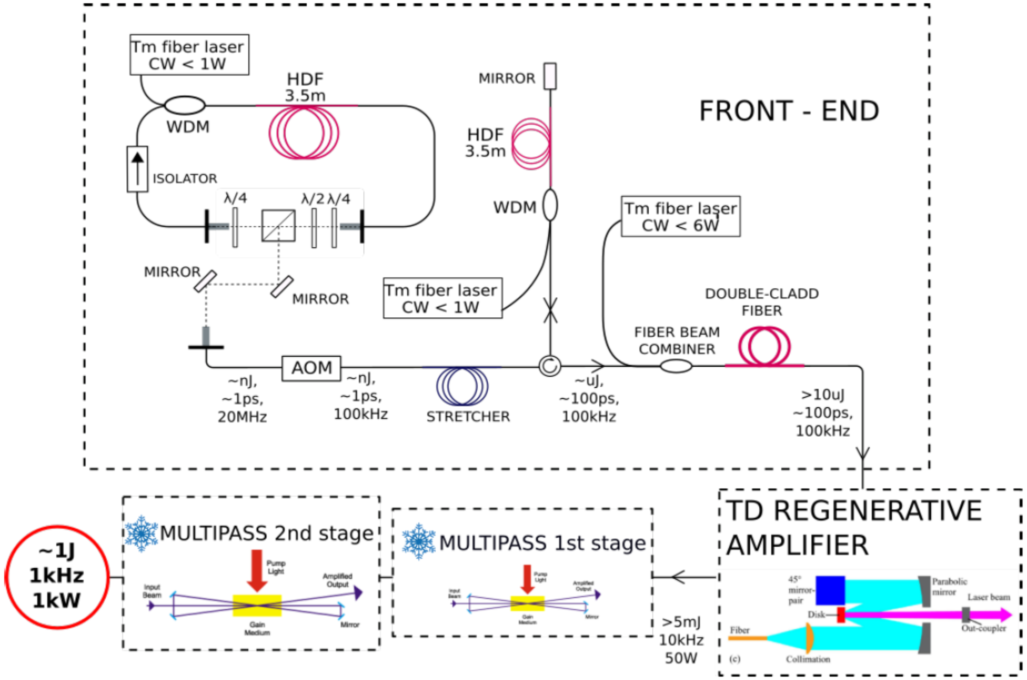
HiLASE Centre
Institute of Physics ASCR, v.v.i.
Za Radnicí 828, 25241 Dolní Břežany, Czech Republic

Please, send email for pricing information.
Specifications are subject to change without notice.
Custom modifications are available upon request.

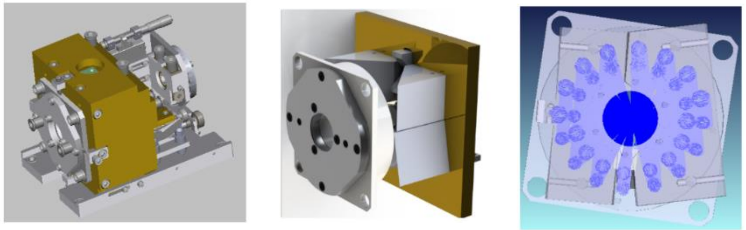
RMS average power stability for 1 hour: **0.22%**

s"

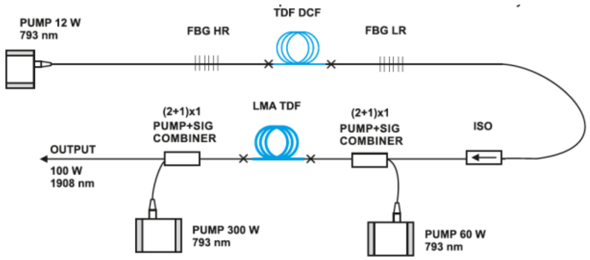
PERLA D- 2um laser system

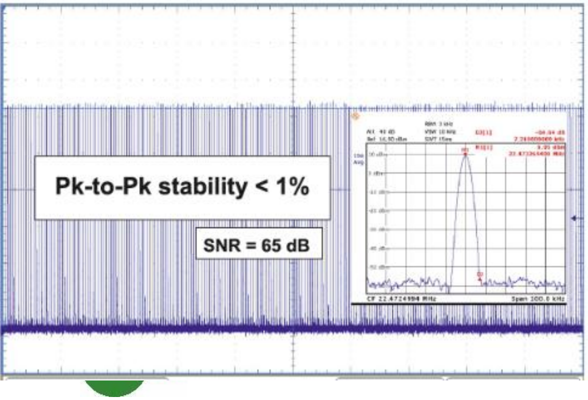


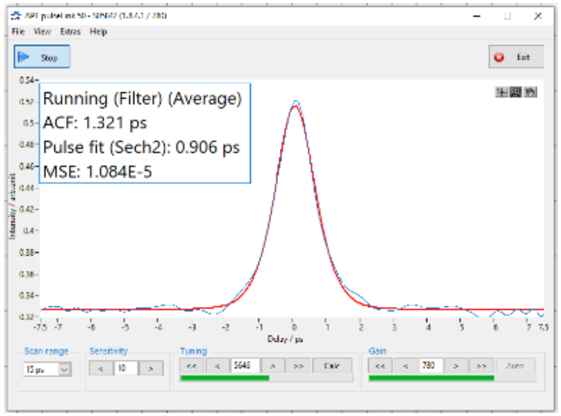
2 um TD laser head



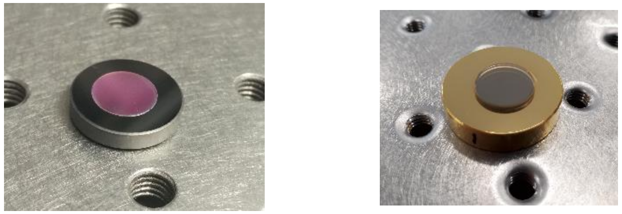
High power Tm fiber pump laser (100W)







Comparison of Ho:YAG TD



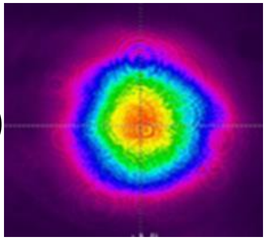
SUPERLASERS FOR THE REAL WORLD
„Teaming for Success“

Harmonics generation

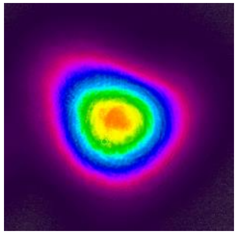
Harmonic	Wavelength (nm)	Crystal	Power (W)	Efficiency
2ω	515	LBO	90	~50% from 1ω
3ω = 1ω + 2ω	343	LBO	40	~40% from 2ω
4ω = 2ω + 2ω	258	CLBO/BBO	20	~20% from 2ω
5ω = 1ω + 4ω	206	CLBO	1	~20% from 4ω

Application of the harmonics for our users is in cutting, microprocessing and surface phase modification of different materials.

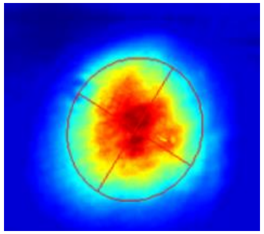
1ω (100 W)



2ω (30 W)



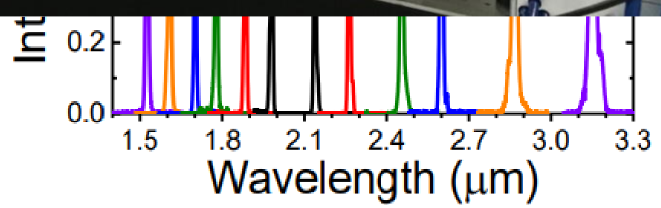
4ω (3W)

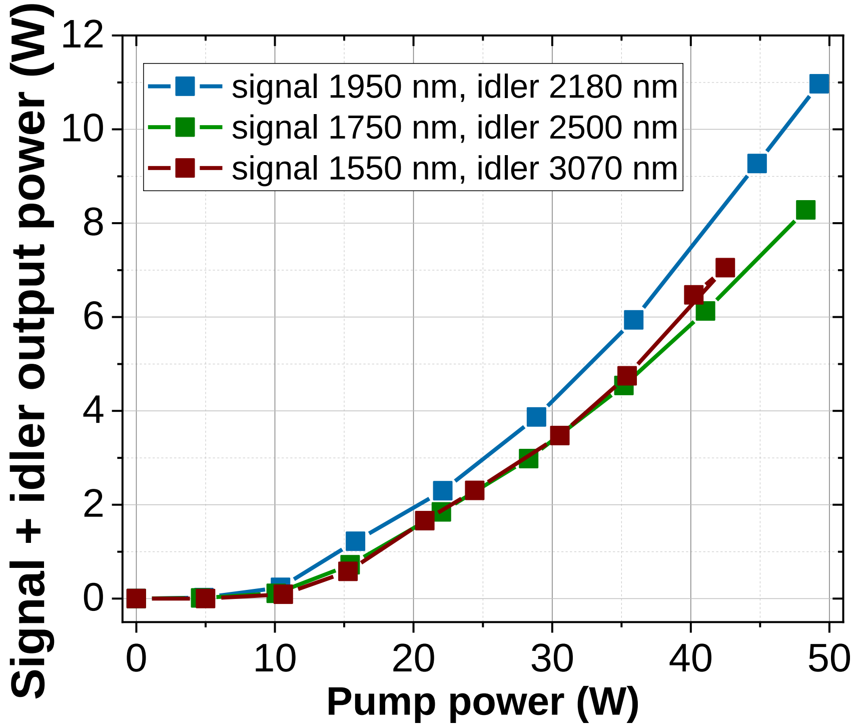


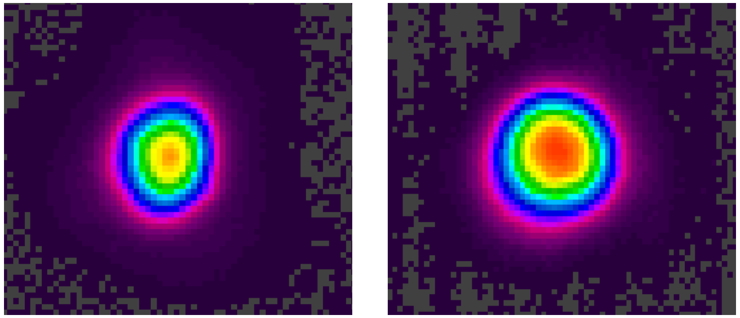
PERLA B (20 W, 1 kHz, 1.5 ps):
2ω (515 nm): LBO crystal, 4 W at 515 nm from 7W at 1030 nm (60% efficiency)

Broadly tunable, high-power mid-IR OPA

- Optical parametric amplifier s – PPLN, KTA NL
- **1.5 to 3.2 (3.5) µm** wavelength tunability
- 11 W output power KTA (1950 nm signal + 218
- 15 W output power KTP crystal
- 1.3 ps pulse duration, fs amplification possible
- repetition rate 88.9 kHz
- Pulse picker available







Fluence profiles of the OPA output beams
1750 nm signal (left) and 2500 nm idler (right)

Summary

- <u>Rich experience in thin-disk lasers</u>

  10 W, 100 Hz, 100 mJ, 1.5 ns (FTL 4 ps)
  20 W, 1 kHz, 20 mJ, 1.8 ps
  100 W, 100 kHz, 1 mJ, 1.4 ps
  550 W, 92 kHz, 6 mJ, <2ps
  >1 kW available soon

  Wavelengths from 206 nm up to 3.2 um

- <u>Commercial Laser Development</u>
  - PERLA 100 platform with wide range of option features
  - GOseries mode-locked oscillators available in different configurations

- <u>Core technology development</u>

  Thin-disks, thin-disk laser heads, oscillators, regenerative amplifiers

- <u>Perla applications</u>

  Multi-beam processing, surface treatment, processing by difractive optical elements, precise micromaching, EUV and soft x-ray generation (plasma)