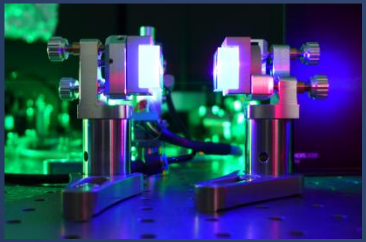
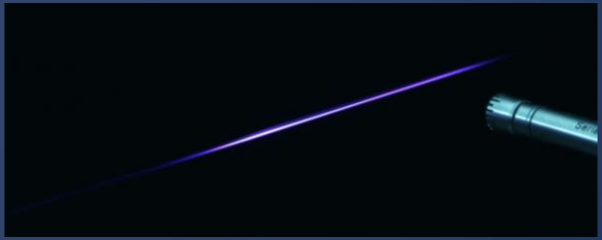
TRUMPF Scientific Lasers GmbH + Co. KG

TRUMPF LASER

TRUMPF Scientific Lasers


Tom Metzger
Feringastr. 10a

85774 Unterföhring, 19.01.2015

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1. TRUMPF GROUP

Our business divisions

World market and technology leader in production technology

Machine tools	Laser technology / Electronics	
		
Machine tools for flexible sheet metal and tube processing	Lasers for production technology	Power supplies for high technology processes

Machine tools business division

Punch and Combination Processing

2D Laser Processing

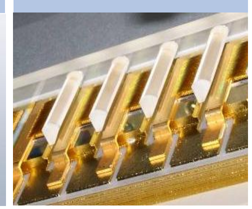
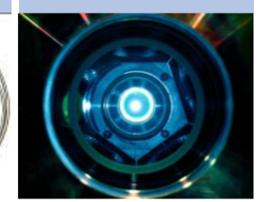
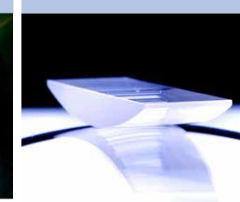
Laser Tube Cutting

Bending

TRUMPF Business Unit Laser Technology

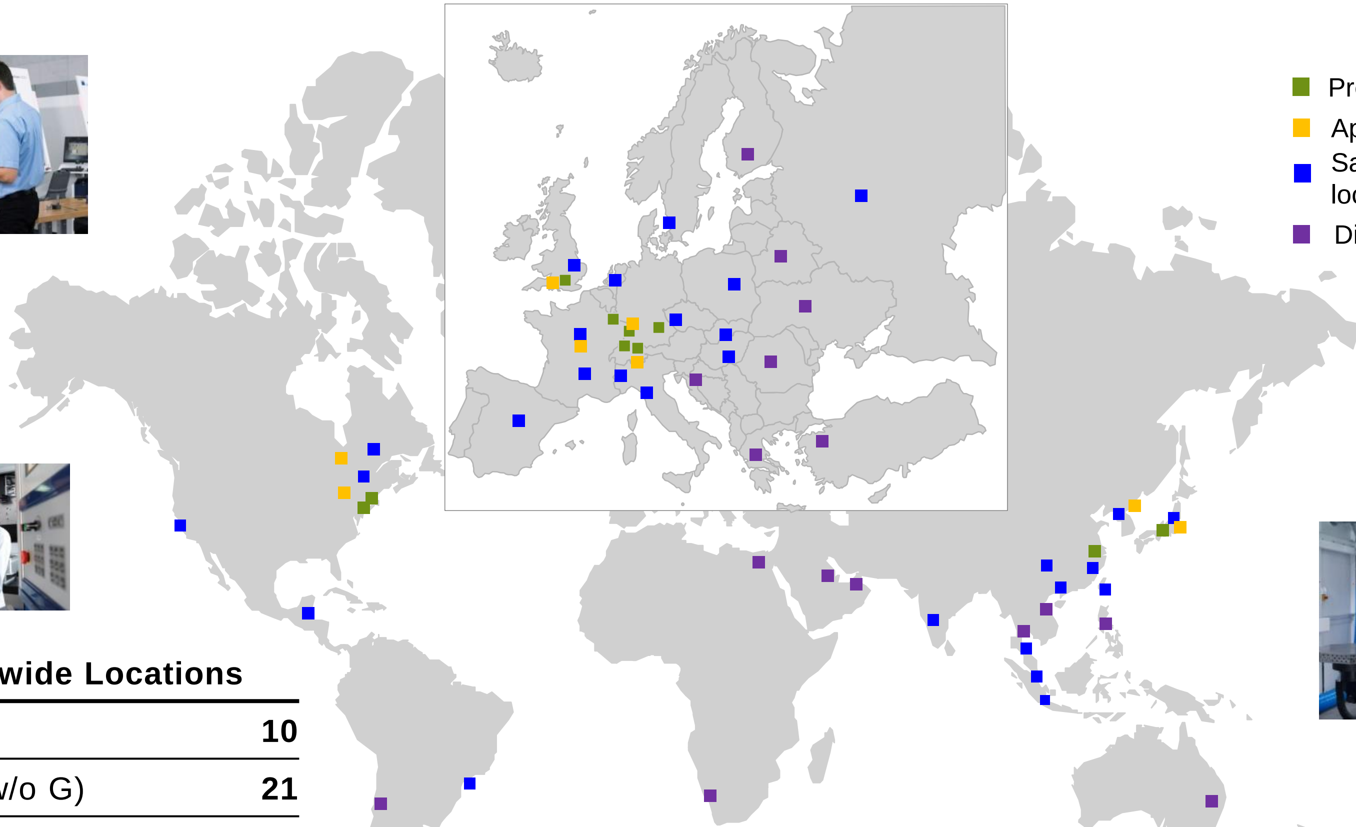
TRUMPF

Machine Tools/ Power Tools	Laser Technology	Electronics	Medical Systems
			

TRUMPF Laser- und Systemtechnik GmbH, Ditzingen	TRUMPF Laser GmbH + Co. KG, Schramberg	TRUMPF Laser Marking Systems AG, Grüsch, CH	TRUMPF Photonics, Princeton, USA	SPI Lasers, Southampton, UK	TRUMPF Scientific Lasers GmbH + Co. KG, München	Ingeneric GmbH, Aachen
						

Worldwide Support

Our Sales-, Application and Production Locations LT



- Production Location
- Application Center
- Sales- and Service location
- Distribution Partner

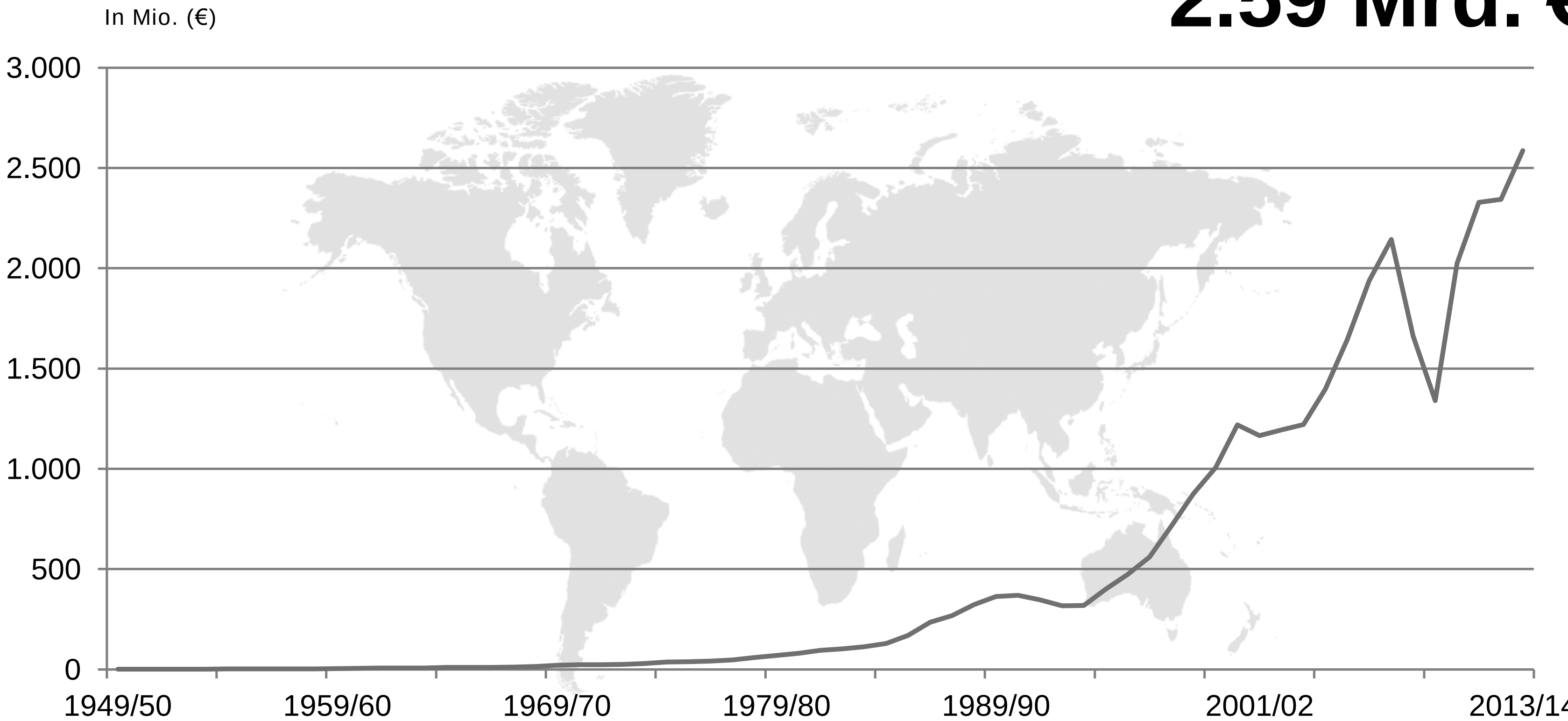
51 Worldwide Locations	
Germany	**10**
Europa (w/o G)	**21**
America	**7**
Asia/Pacific/Other	**13**

Long-term success

Development of sales

Sales fiscal year 2013/14

2.59 Mrd. €



At a glance-fiscal year 2013/14

Company figures

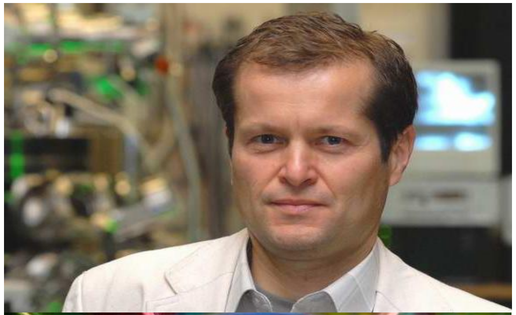
	Fiscal Year 2013/14	Change in %
Sales (in Mio. €)	2.586,8	+ 10,4
Income before taxes (in Mio. €)	248,4	+ 61,2
Investments (in Mio. €)	124,8	- 8,4
Expenditure for research and development (in Mio. €)	243,3	+ 15,3
Employees (as of 06/30/2014)	10.914	+ 10,0

2. TRUMPF SCIENTIFIC LASERS

TRUMPF Scientific Lasers

Introduction

- Joint Venture between the TRUMPF Group and Prof. Ferenc Krausz founded in May 2012
- Strong benefits due to TRUMPF network:
  - Extensive expertise in thin-disk technology
  - High-quality product engineering and highest reliability
  - Worldwide service and spare part availability
- Strong cross link into the scientific community especially by Professor F. Krausz
- Product portfolio:
  - Picosecond Thin Disk Lasers
  - Optical Parametric Amplifiers (OPA)
  - Synchronization units



TRUMPF Scientific Lasers

Location

TRUMPF Scientific Lasers

Team

- Stephan Prinz (PhD student)
- Robert Bessing (Mechanical Engineering)
- Matthias Häfner (Electronics)
- Catherine Teisset (Physicist)
- Marcel Schultze (Physicist)
- Sandro Klingebiel (Physicist)
- Christoph Wandt (Physicist)
- Tom Metzger (CTO)
- Knut Michel (CEO)









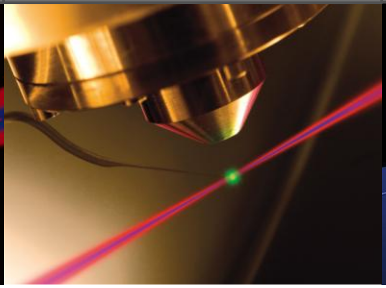
Product Portfolio

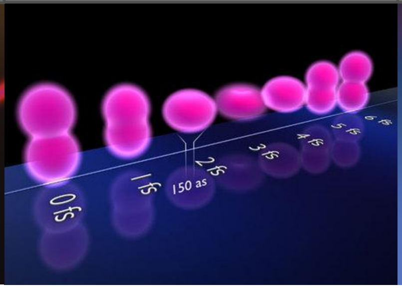
Picosecond thin disk lasers: mJ – J; 100W - 1kW

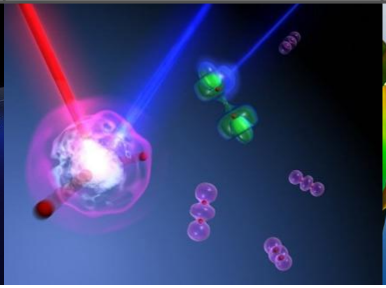
OPA based femtosecond and few-cycle laser systems

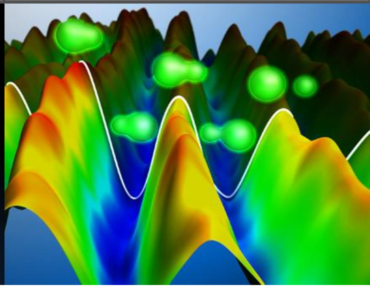
➔ for attosecond spectroscopy, EUV/XUV generation, LIDAR applications, …

Attosecond pulse generation via HHG	as streaking and spectroscopy	Observation of Electron dynamics	Manipulation of molecules	Intramolecular charge migration









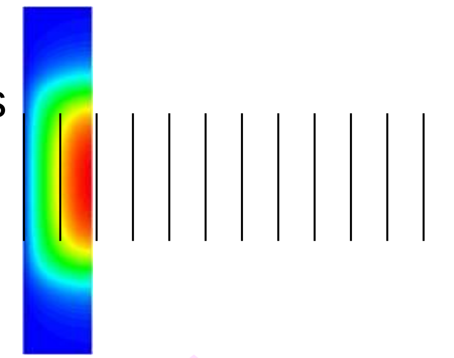
4. THIN DISK LASER DEVELOPMENT

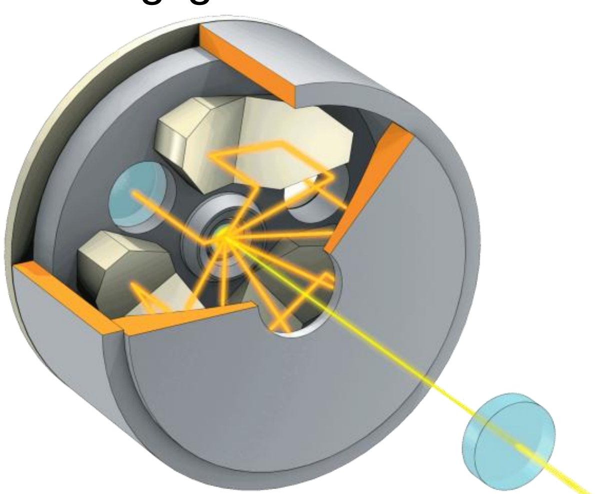
Disk Laser Principles

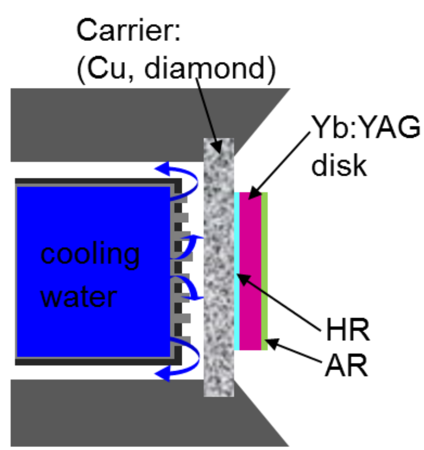
Diameter of pumped area >> disk thickness

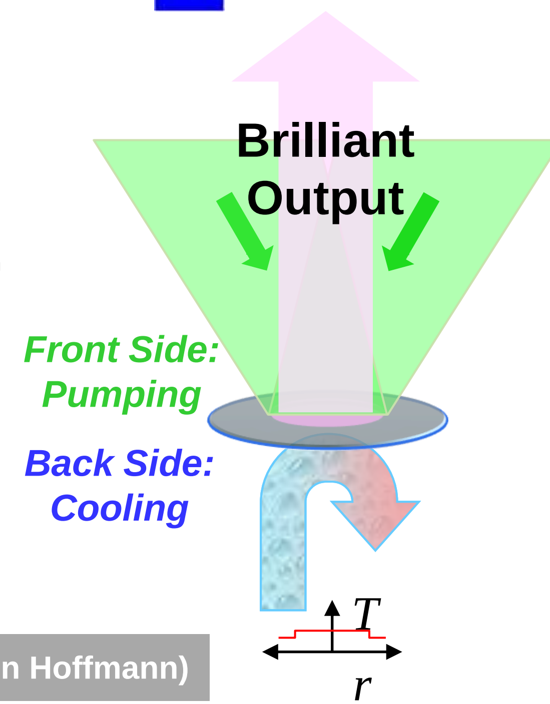
+ uniaxial heat flux: Low thermal lensing → High brightness
+ Low brightness constraints for pump diodes
+ High gain saturation: Insensitive to back reflections
+ Scalability by increase of beam cross section
+ Negligible nonlinearities at high peak powers

disk





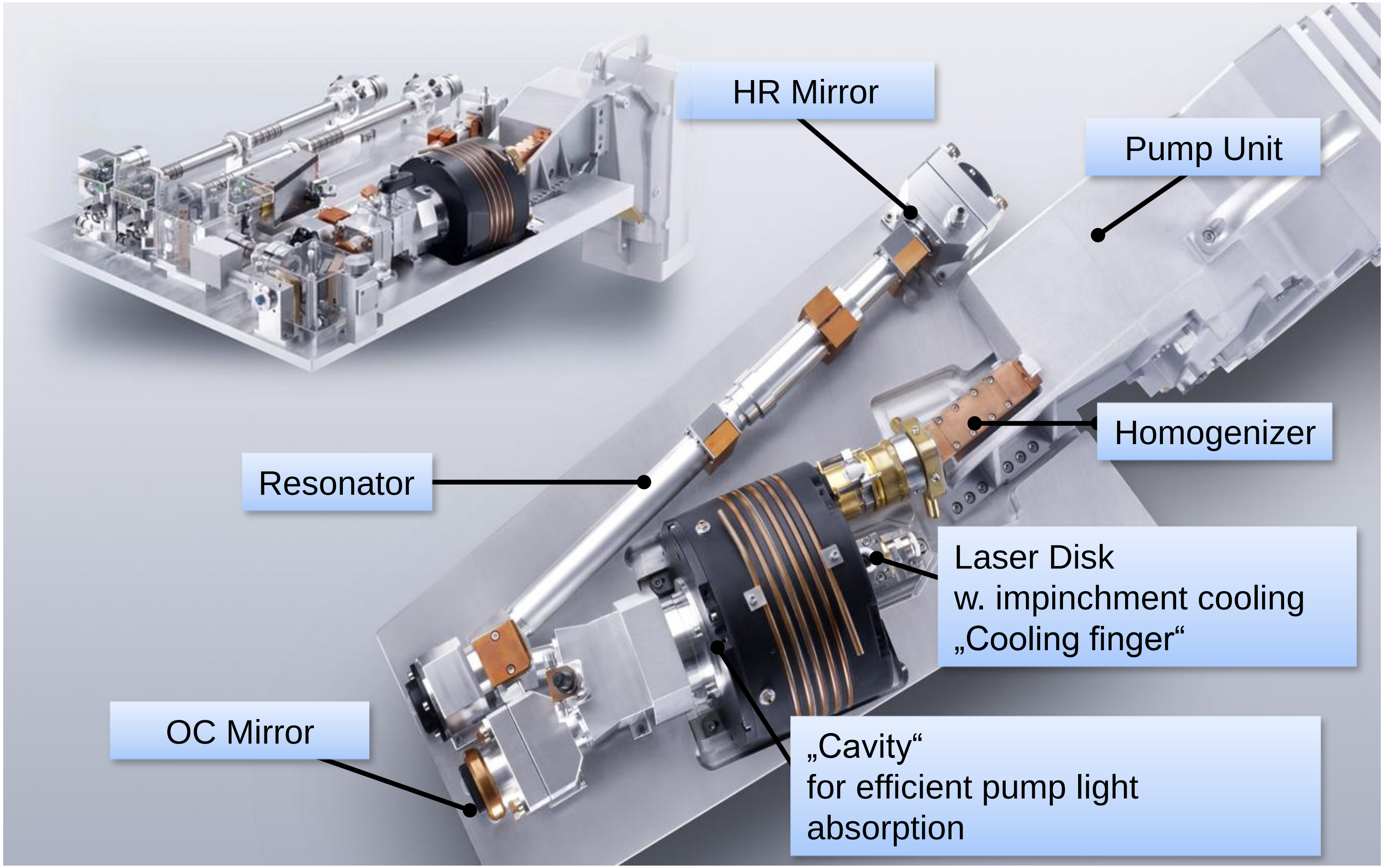




http://www.rp-photonics.com/thin_disk_lasers.html (animation from Martin Hoffmann)

Optical setup of cw disk laser

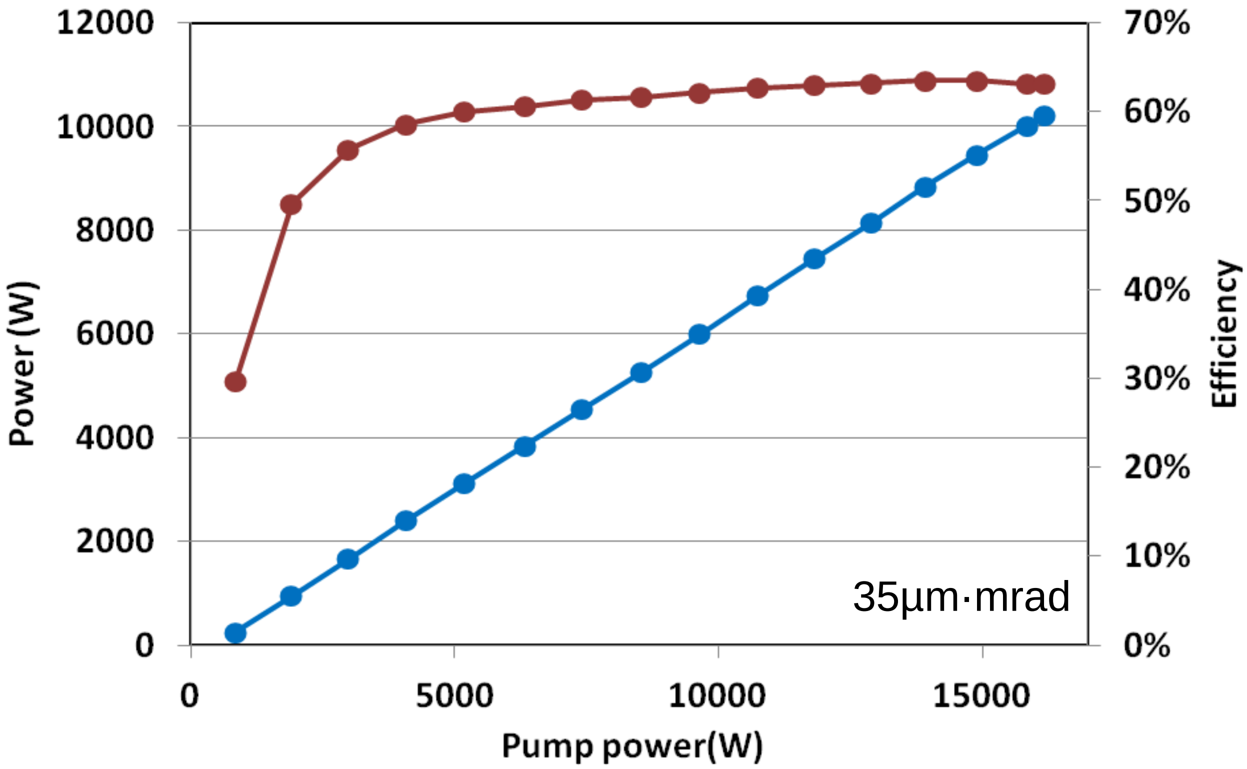
TRUMPF



Record performance: 10 kW per Disk / 62 % optical efficiency

TRUMPF

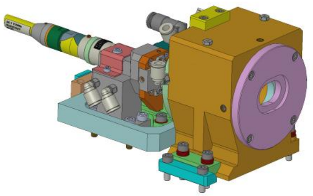
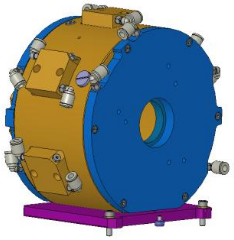
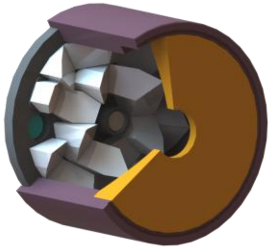
→There are no barriers to scale power/disk beyond current power levels
→ Up to 32kW commercially available



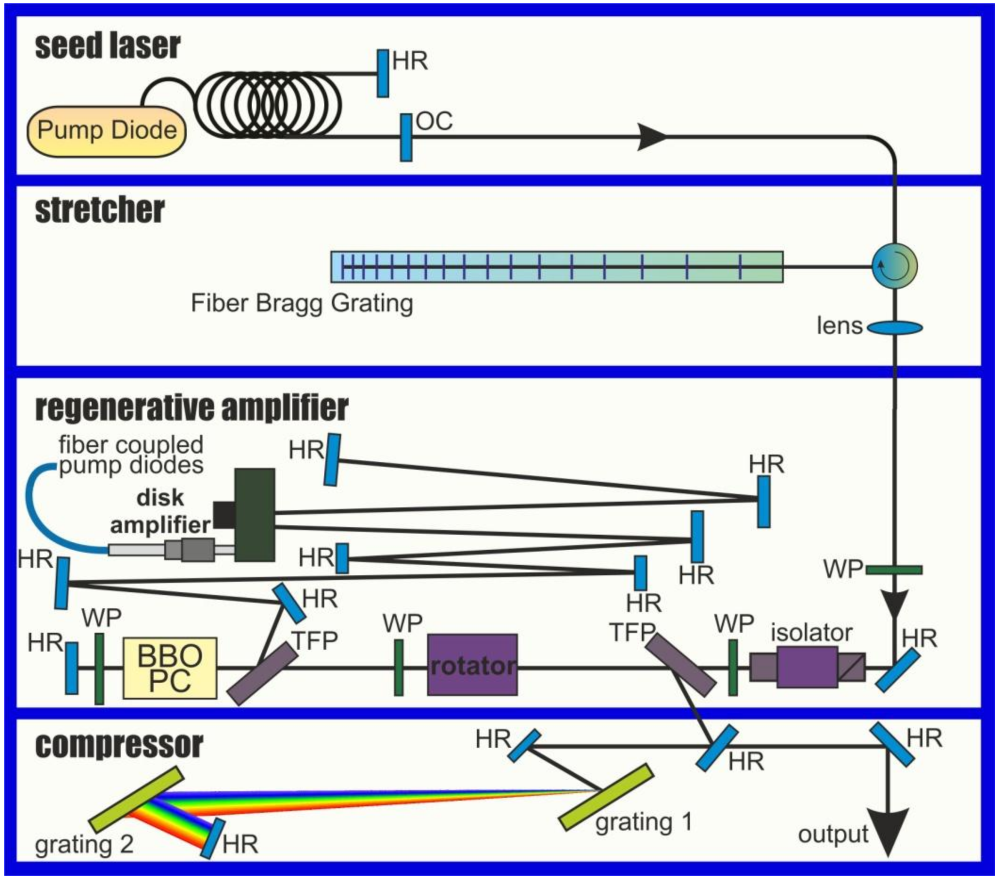
Tina Gottwald et al. "Recent disk laser development at TRUMPF",
Proc. SPIE 8547, High-Power Lasers 2012: Technology and Systems, 85470C (November 8, 2012)

Industrial Yb:YAG Thin-Disk Laser Heads

Disk diameter between 9 mm and 23 mm

Pump Power:	Laser Head:
~ 1 kW	
~ 10 kW	
~ 16 kW	

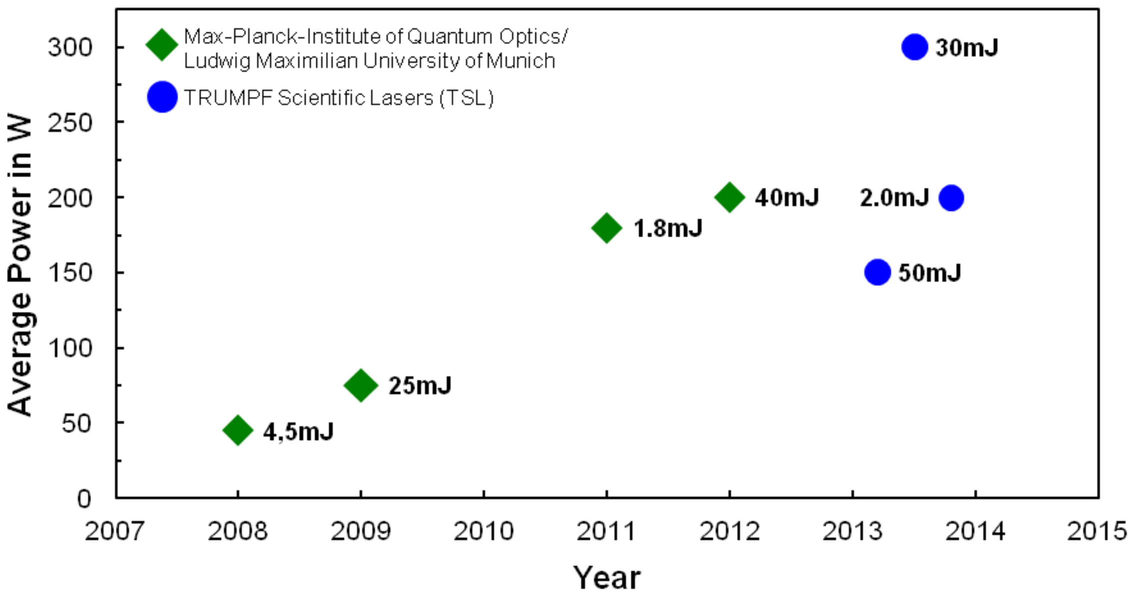
Ultrafast Regenerative Amplifiers from TRUMPF



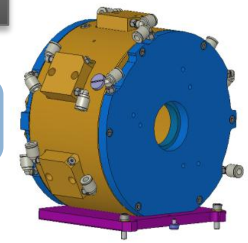
Metzger et al., Opt. Lett. **34**, 2123-2125 (2009)
Sutter et al., Photonics West 8235-27 (2012)

History of Ultrafast Thin-Disk regenerative Amplifiers (<2ps; mJ)

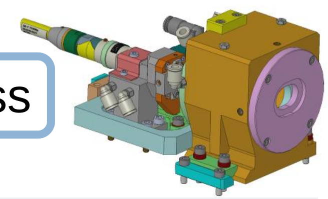
First thin-disk based regenerative amplifier at ETH: Clemens Hönninger et al. Appl. Phys. B **65** 423 (1997)



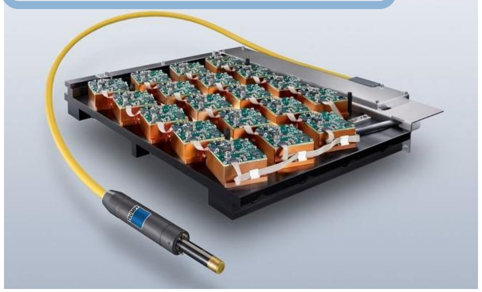
24 pass



36 pass



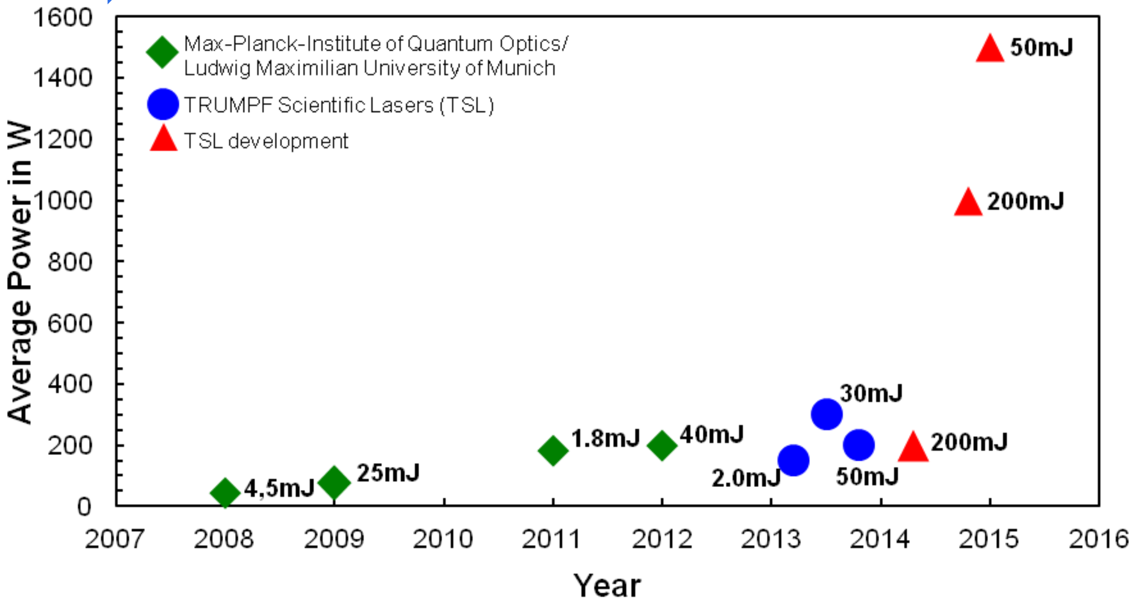
969nm pumping



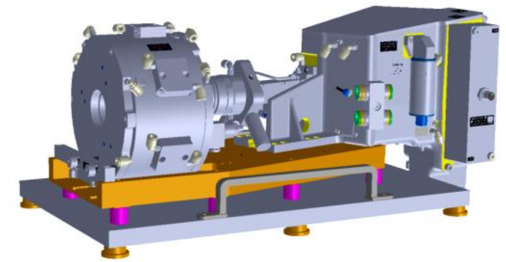
- C. Teisset, et al., “Picosecond Thin-Disk Regenerative Amplifier with High Average Power for Pumping Optical Parametric Amplifiers,” in CLEO: 2013, OSA Technical Digest (online) (Optical Society of America, 2013), paper CTh5C.6.
- C. Teisset, et al., “300 W Picosecond Thin-Disk Regenerative Amplifier at 10 kHz Repetition Rate ,” in *Advanced Solid-State Lasers Congress Postdeadline*, G. Huber and P. Moulton, eds., OSA Postdeadline Paper Digest (online) (Optical Society of America, 2013), paper JTh5A.1.
- T. Metzger, et al., “High-repetition-rate picosecond pump laser based on a Yb:YAG disk amplifier for optical parametric amplification,” Opt. Lett. 34, 2123-2125 (2009).

Current Thin-Disk Laser Development

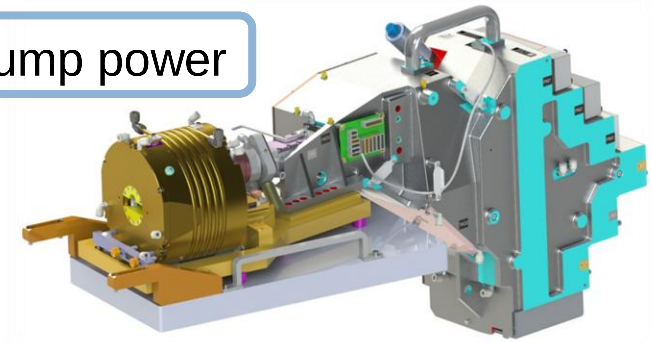
Massive increase of pump power.



~ 4 kW pump power

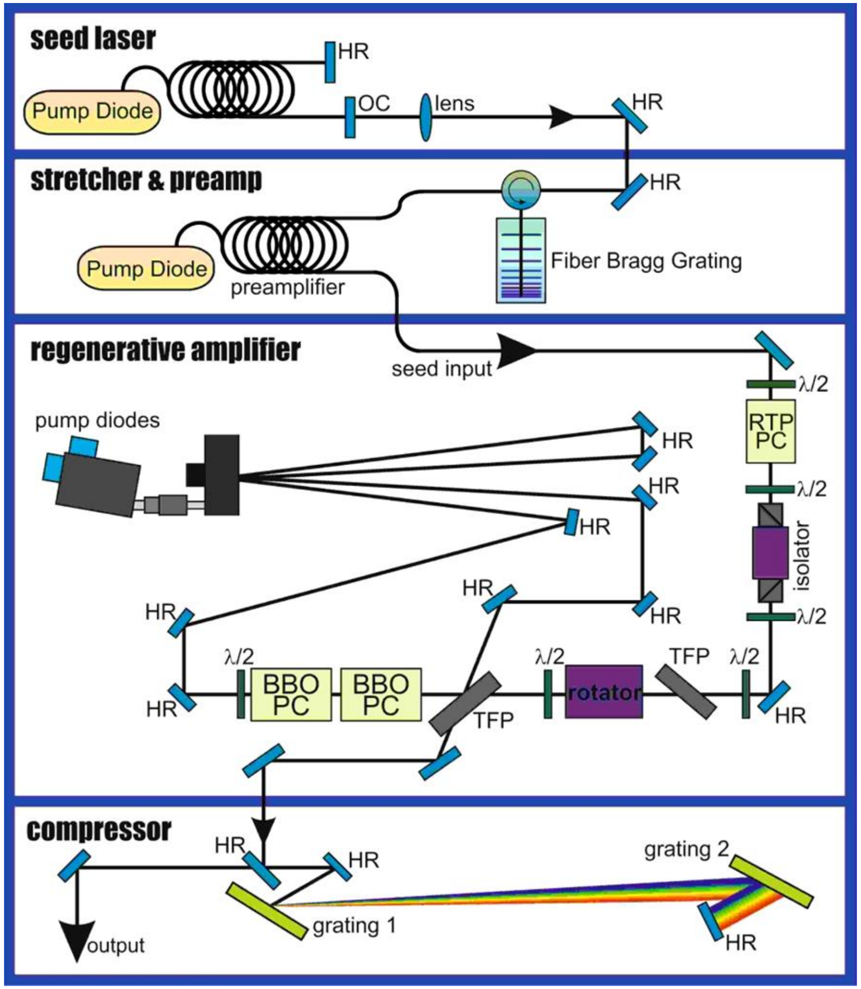


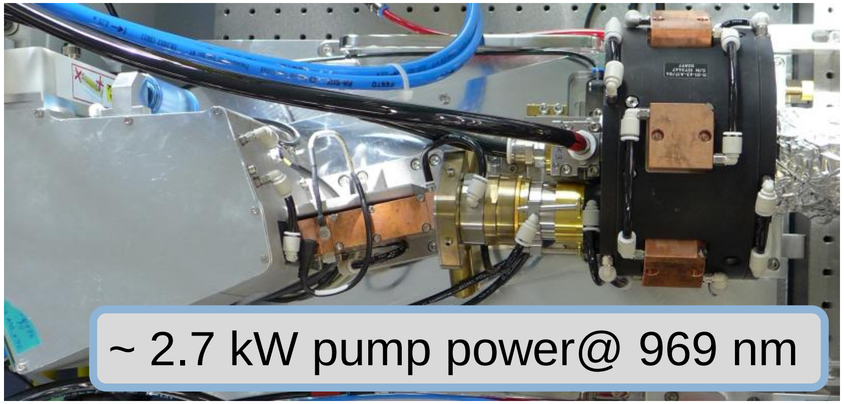
~ 12 kW pump power



Regenerative Amplifier with High Average Power (100kHz)

Ring type cavity with double pass through the disk



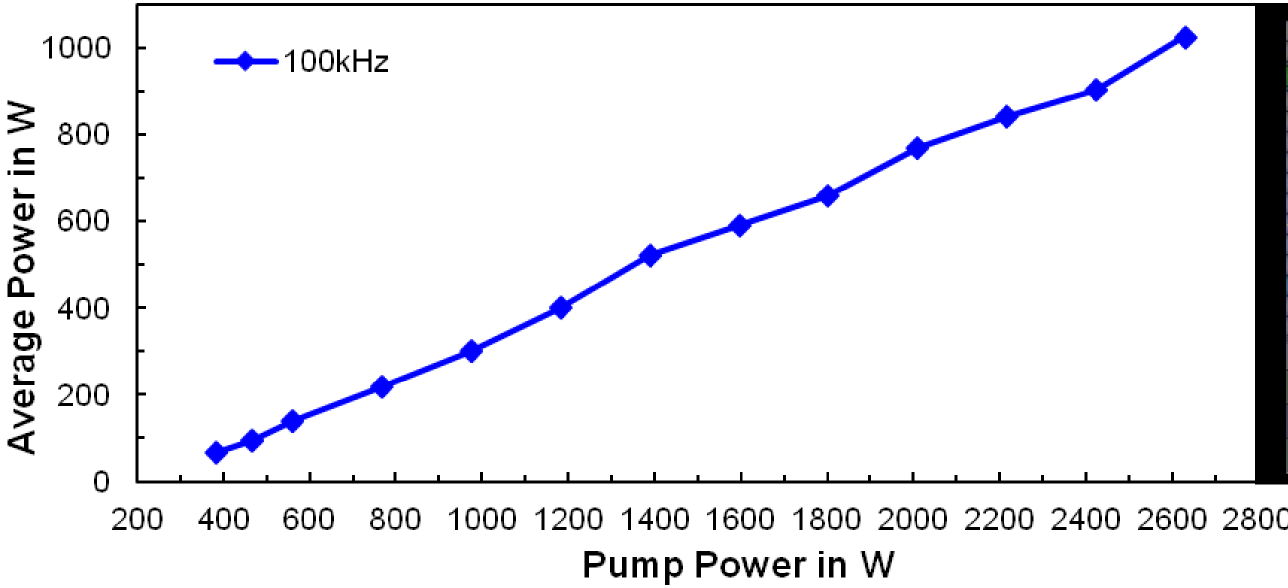


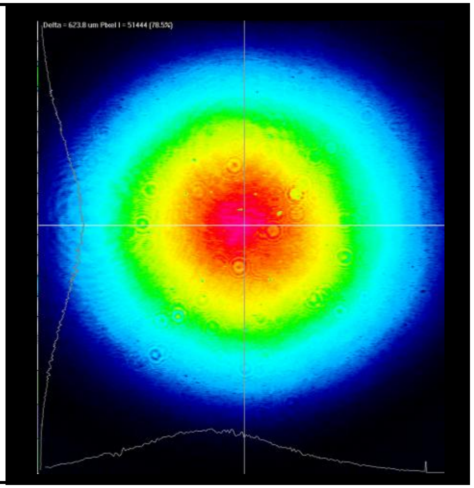
Rotators:

- Max. 300W
- thermal lensing
- no identical behavior
  low repeatability
- beam parameter change
  with average power

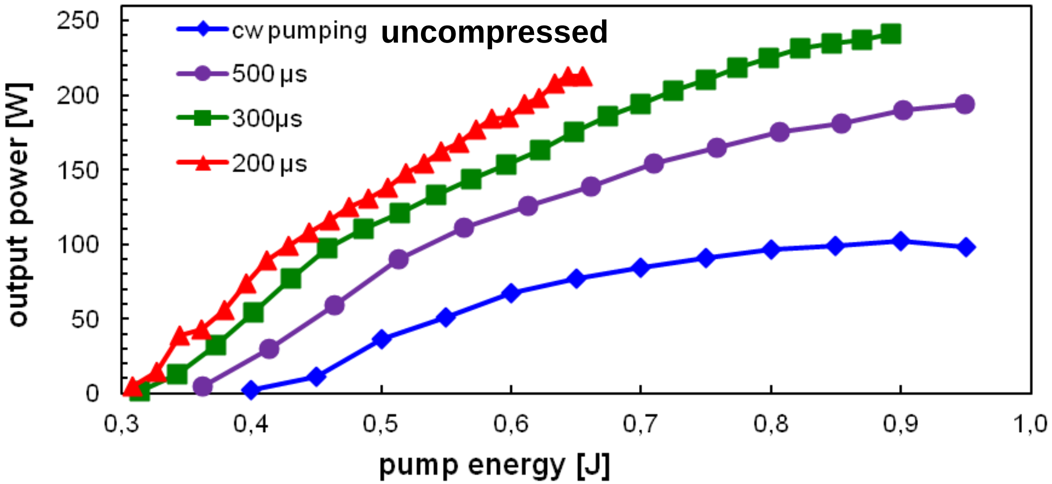
First Test at 100 kHz

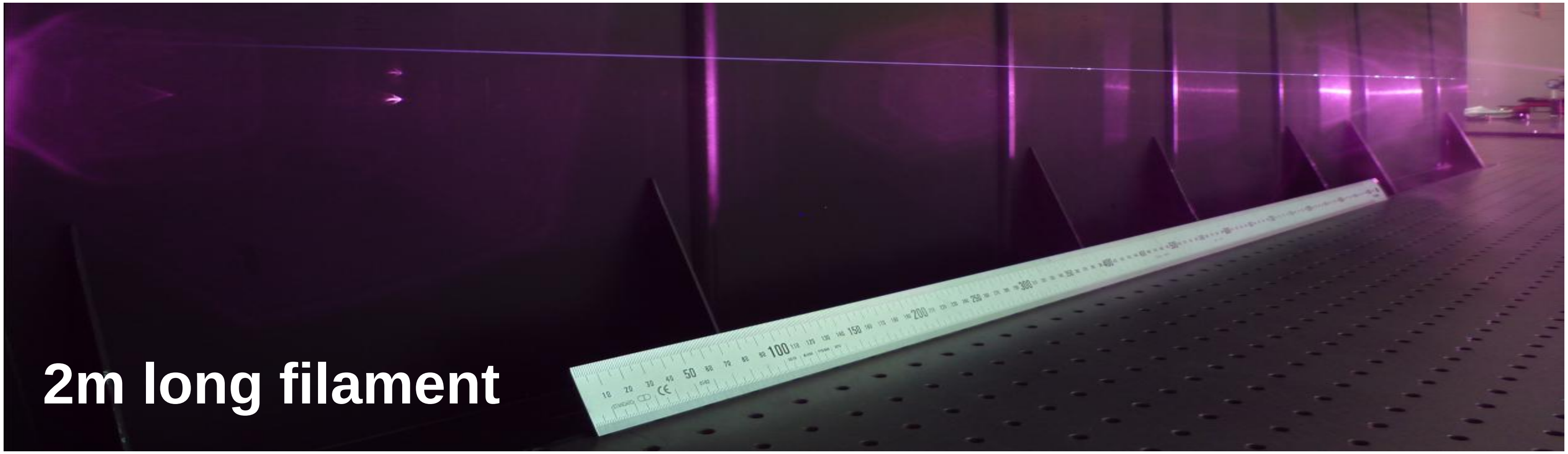
Output power for uncompressed pulses: 1050 W
Pump power limited (2.7 kW @ 969 nm)
Ring type cavity with double pass through the disk



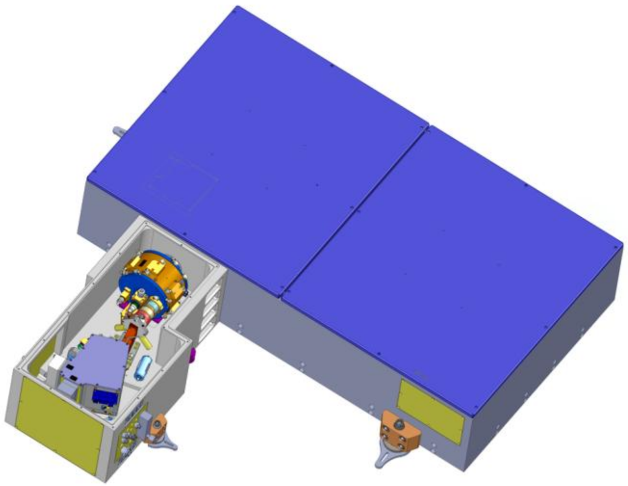


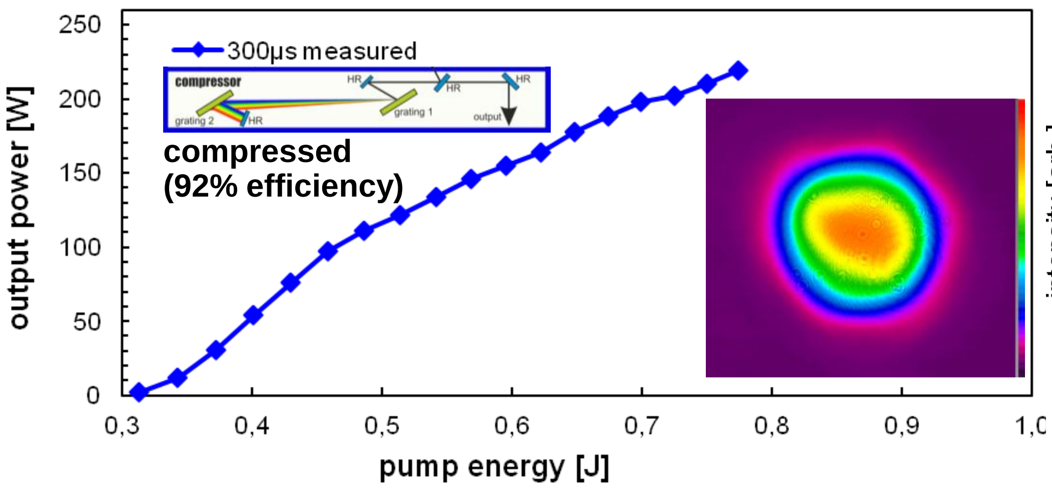
High Energy <2ps Disk Amplifier @ 1kHz: 220mJ

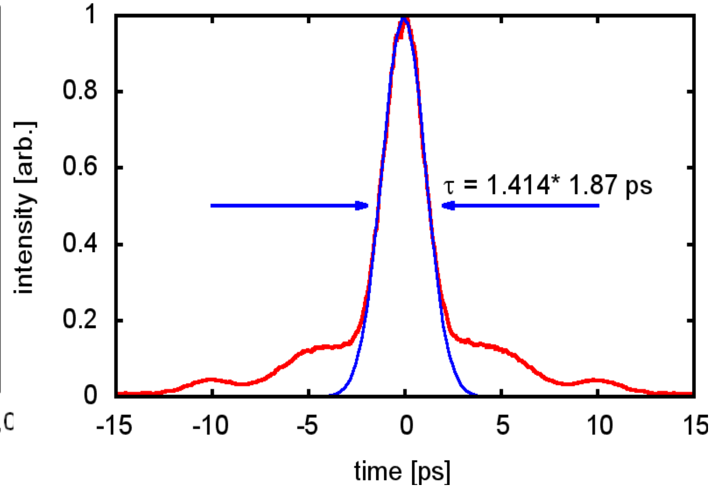




High Energy <2ps Disk Amplifier @ 1kHz: 220mJ

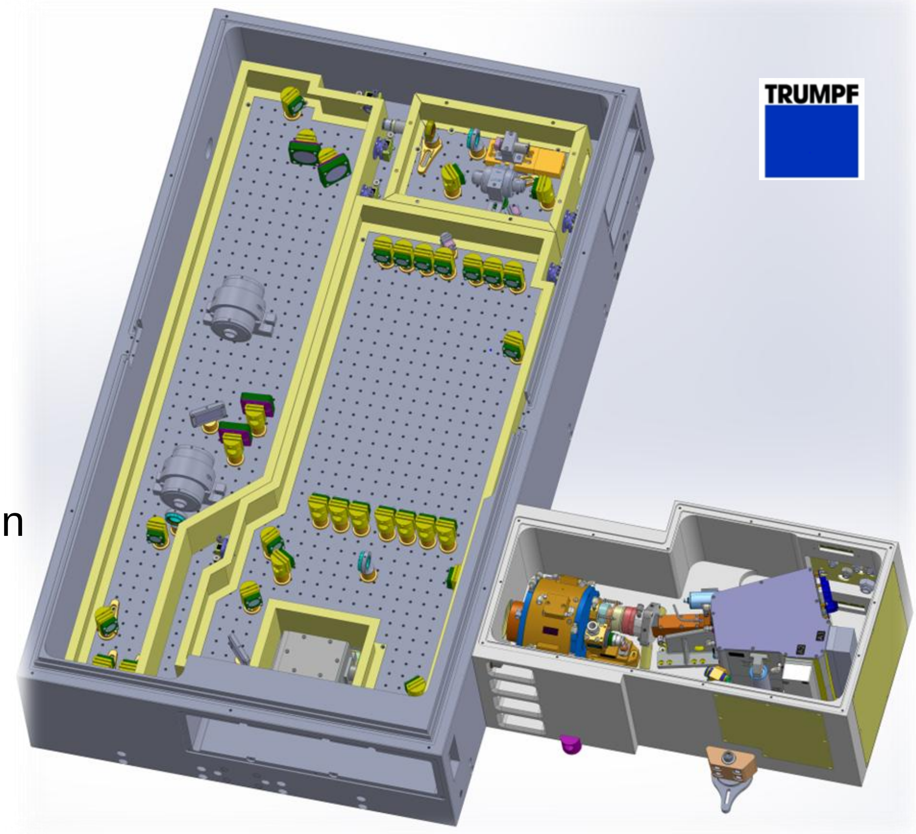




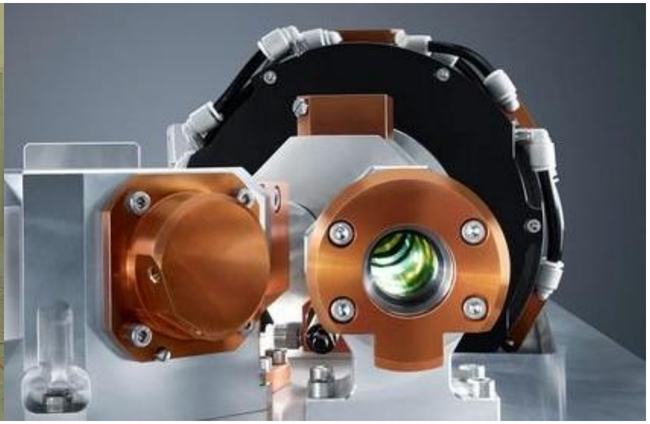


submitted to CLEO US 2015: Sandro Klingebiel et al. “220mJ Ultrafast Thin-Disk Regenerative Amplifier”

200 mJ Amplifier SDL H0.1-200

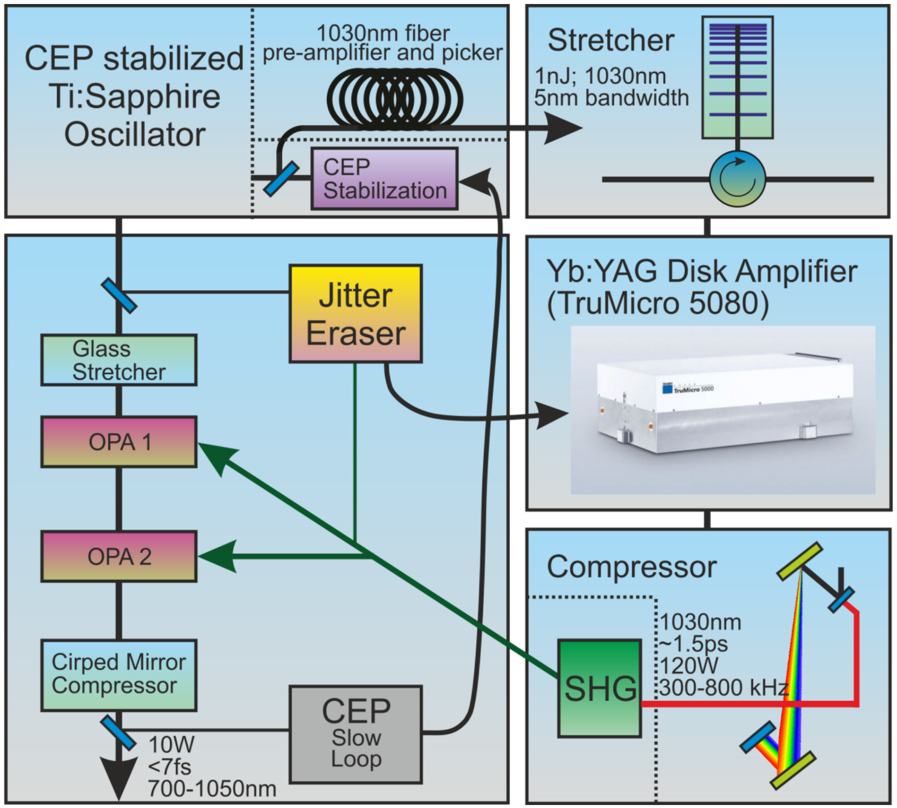


- Massive & temperature controlled housing (double air sealed)
- Implemented electronics
- User friendly operation and software
- Fully computer controlled and safe operation
- System will be introduced and exhibited at CLEO Europe in June 2015



5. OPCPA DEVELOPMENT

Optical Parametric Chirped Pulse Amplifier (300kHz; 15W; <6fs)



Seed source:

Venteon: Pulse One OPCPA

- **CEP-stabilized**
- **>2 nJ seed energy in 350 nm bandwidth**
- **fiber pre-amplifier → >1 nJ@1030 nm**

Pump Amplifier:

- **fiber based stretcher**
- **regen amp; TRUMPF disk technology**
- **grating compressor + SHG**

→>140W (100 – 300 kHz) @ 515 nm; ~ 1 ps

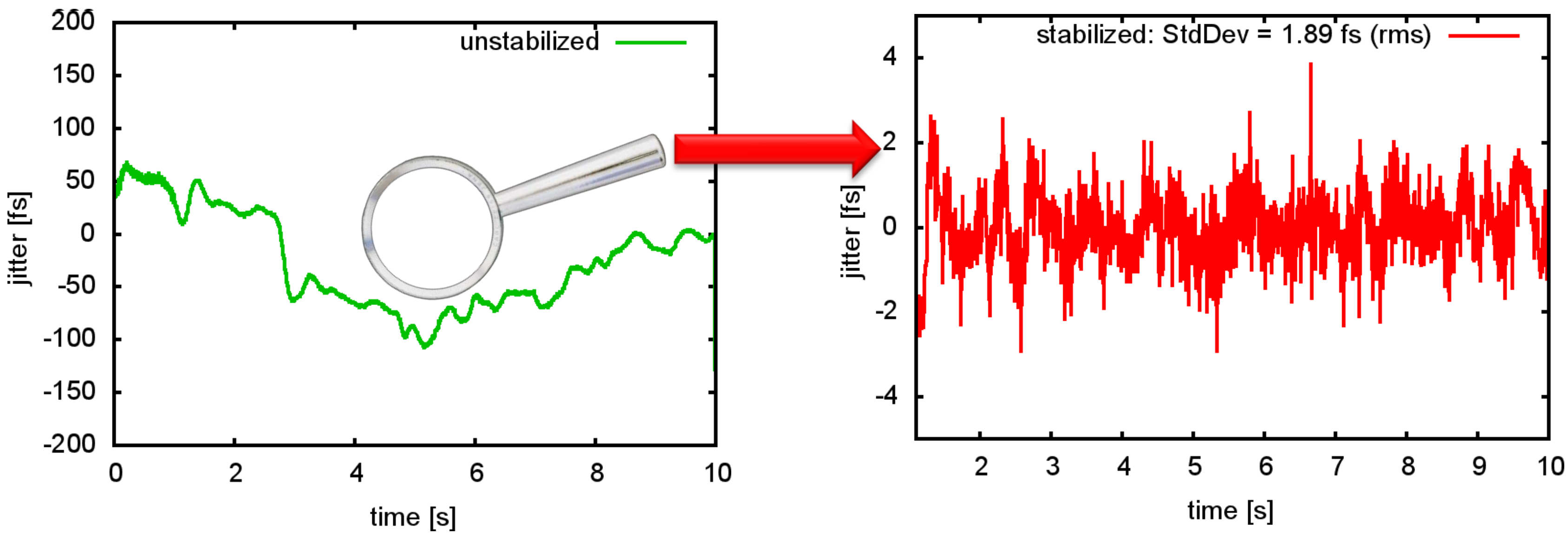
OPA amplifier:

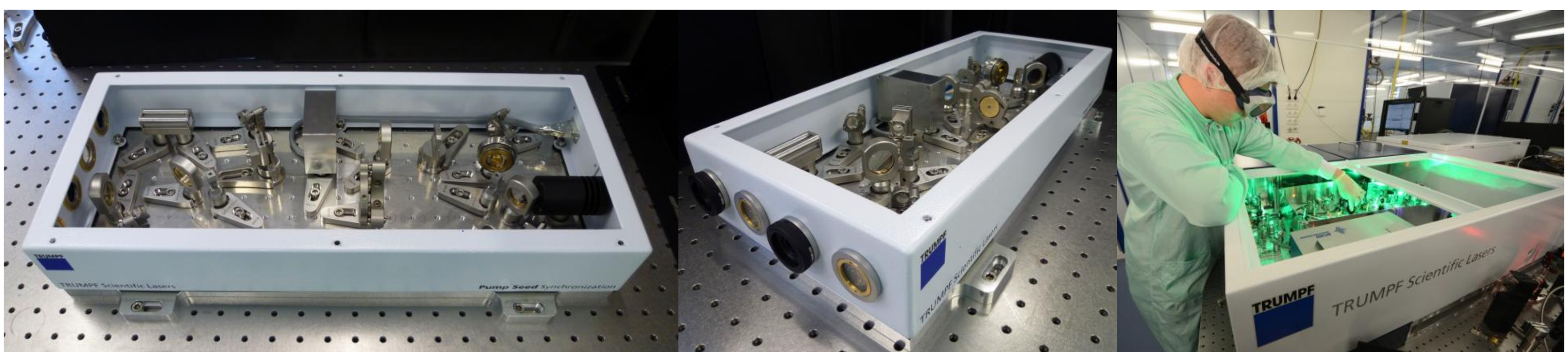
- **two amplification stages**
- **chirped mirror compressor**
- **slow loop CEP feedback**

→ 5.5 fs, > 15 W (@300 kHz)

Submitted to Opt. Express and accepted Jan. 2015:
Stephan Prinz et al. "CEP-stable, sub-6 fs, 300-kHz OPCPA system with more than 15 W of average power"

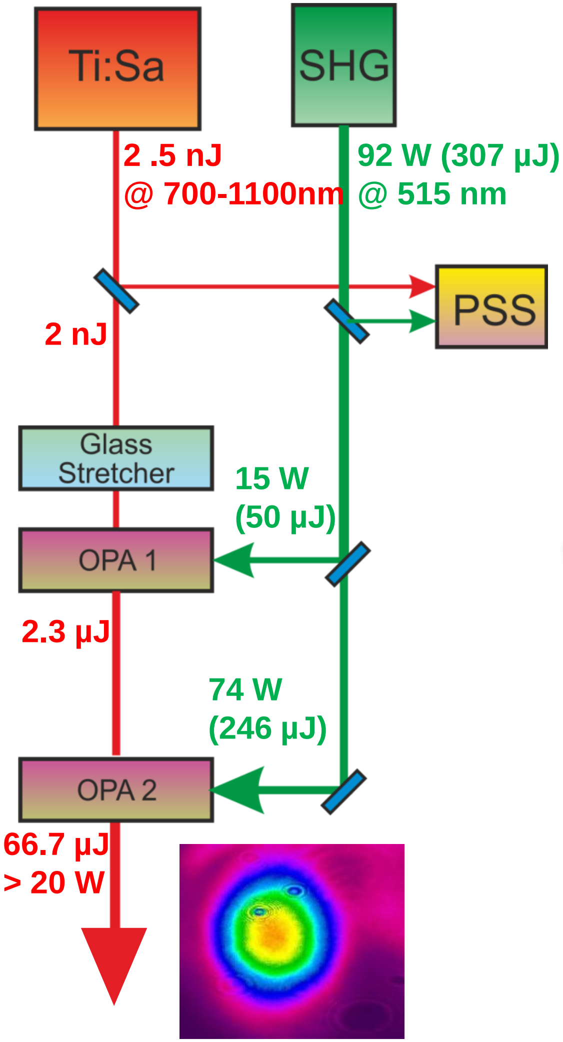
Pump-Seed Synchronization

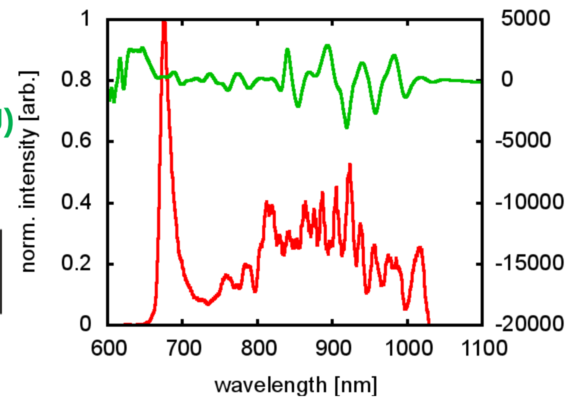


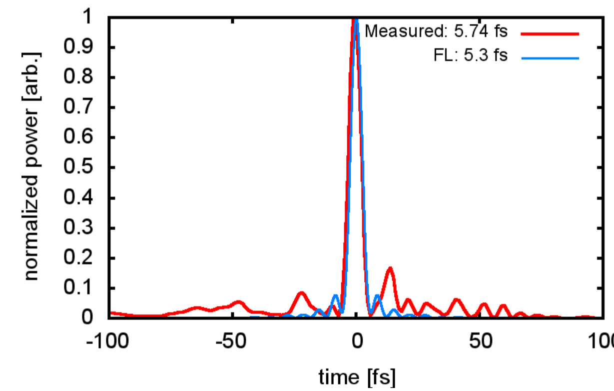


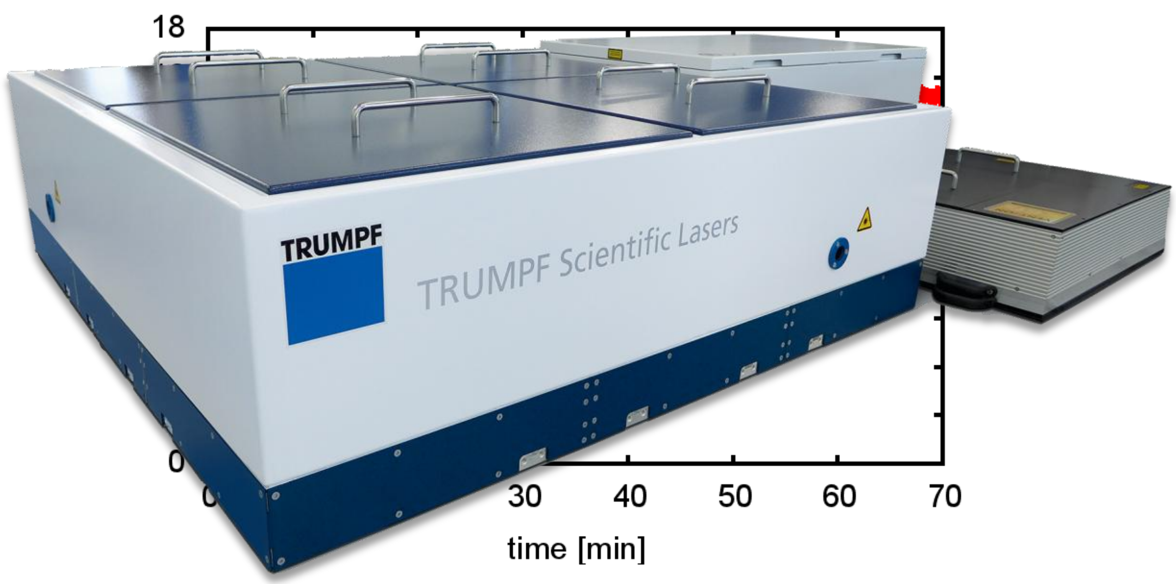
S. Prinz, M. Häfner, M. Schultze, C. Y. Teisset, R. Bessing, K. Michel, R. Kienberger, and T. Metzger, "Active pump-seed-pulse synchronization for OPCPA with sub-2-fs residual timing jitter," Opt. Express **22**, 31050-31056 (2014)

CEP-stable OPCPA (300kHz; 15W; <6fs)

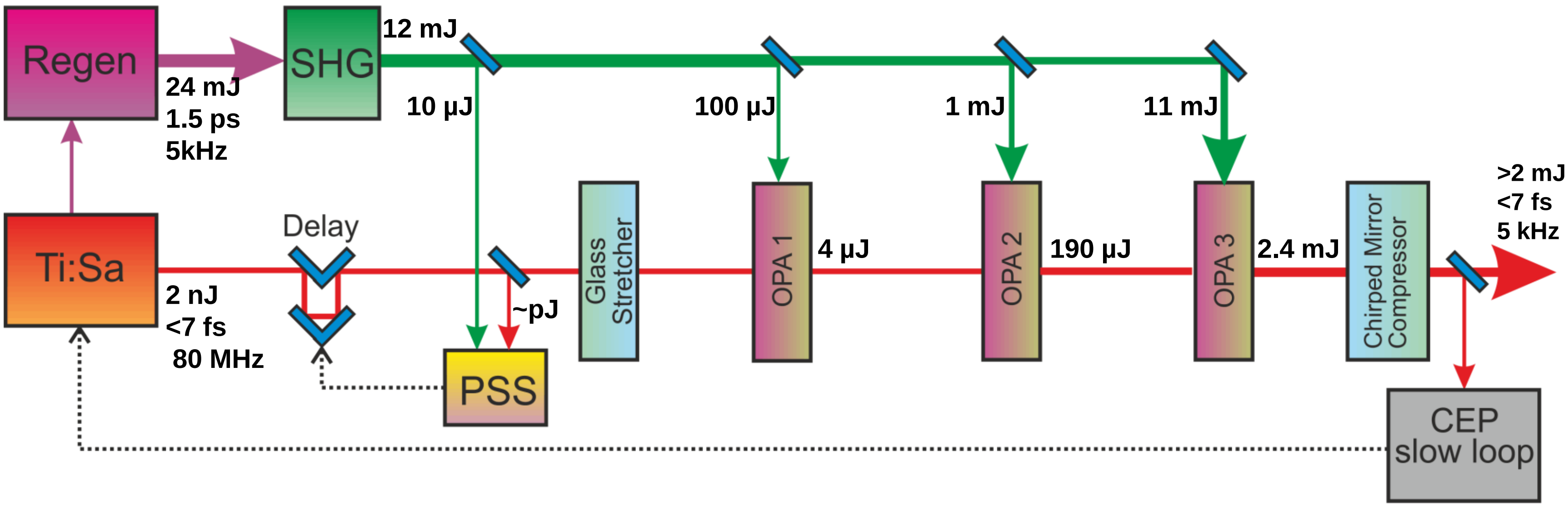




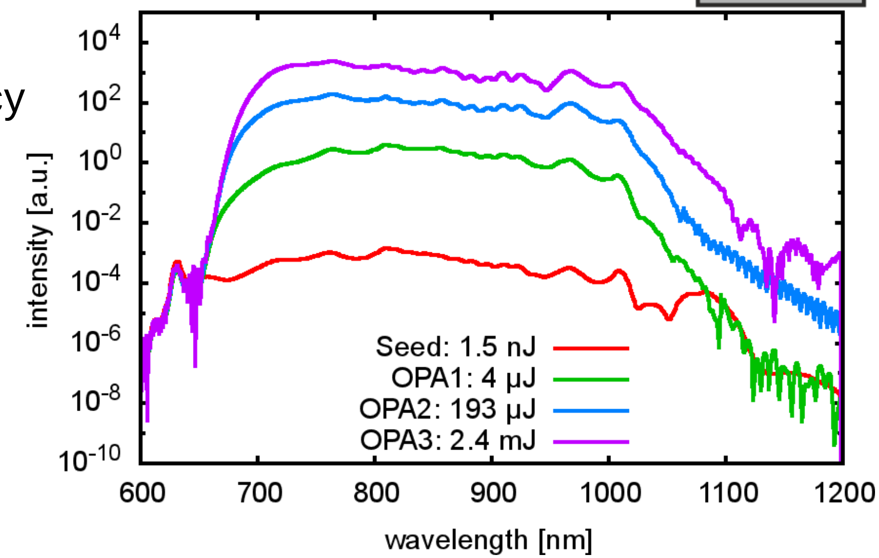




Current Development: CEP-stable OPCPA (5kHz; 12W; <7fs)



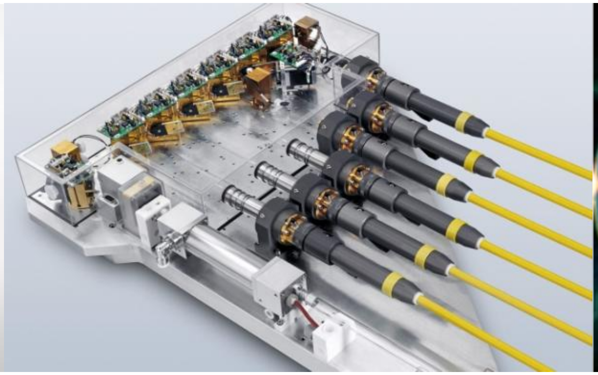
- SHG in 1.5 mm LBO with ~50% efficiency
- Pump-Seed Synchronization
  for stable temporal pulse overlap
- Goal: >2 mJ, 5 kHz; <8 fs, CEP-stable
  (Fourier Limit: 6.2 fs)



5. SUMMARY

Summary

- cw disk lasers: **Commodity for cutting and welding**
  commercially up to 32 kW (no upper limit); 4 kW single mode
- Regen amplifiers: **100 kHz; >1050 W** (demonstrated and potential for multi kW)
  1 kHz; 220 mJ; < 2 ps (product)
  3 kHz - 20 kHz; 100 mJ - 25 mJ; 300 – 500 W; < 2 ps;
- Multipass amplifier: **300 kHz; > 1.400 W; ~8 ps** (IFSW, Stuttgart)
  100 Hz; 500 mJ; <2 ps (MBI, Berlin)
  multi kHz; 2 J; ~2 ps (supported by TRUMPF technology)
- OPCPA: **300 kHz, ~15 W, < 6 fs** based on TruMicro 5000 (product)
  2-20 kHz, ~12 W, < 7 fs based on TSL pump source (developing)

TRUMPF Scientific Lasers GmbH + Co. KG

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TRUMPF