A Review of High Power OPCPA Technology for High Repetition Rate FELs

Mark J. Prandolini

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Merging advanced solid-state laser technology with FEL sources

B. Faatz, T. Tanikawa, *et al.* (FLASH-2 team)

(F. Tavella's Research Group) A. Willner, M. Schulz, R. Riedel, M. J. Prandolini, A. Hage, H. Höppner

I. Hartl, *et al.* (FS-LA team)

DESY

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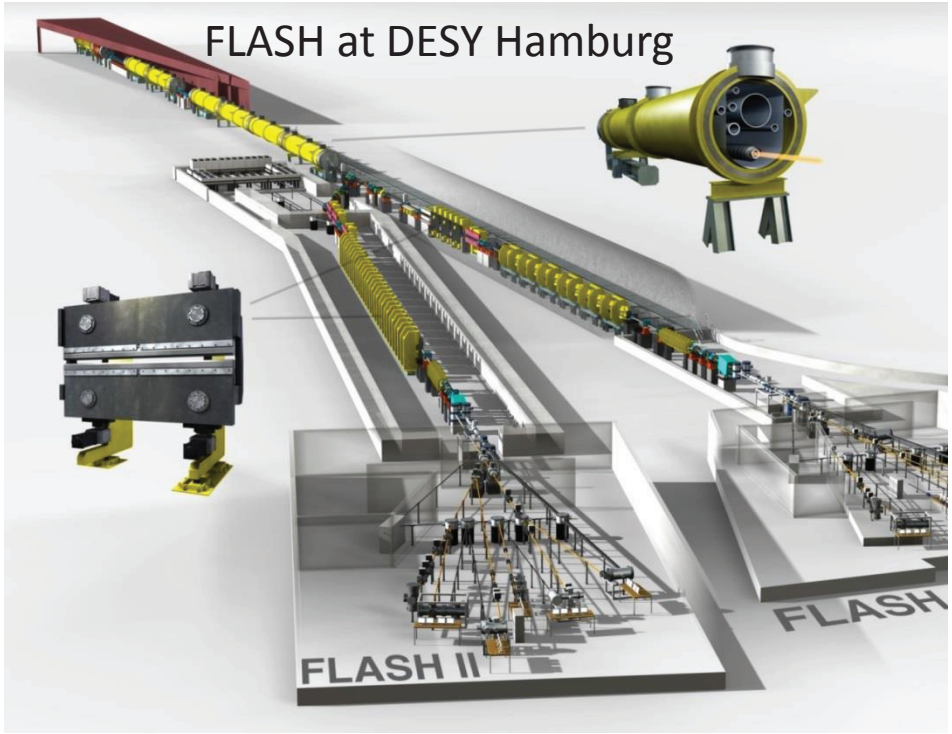
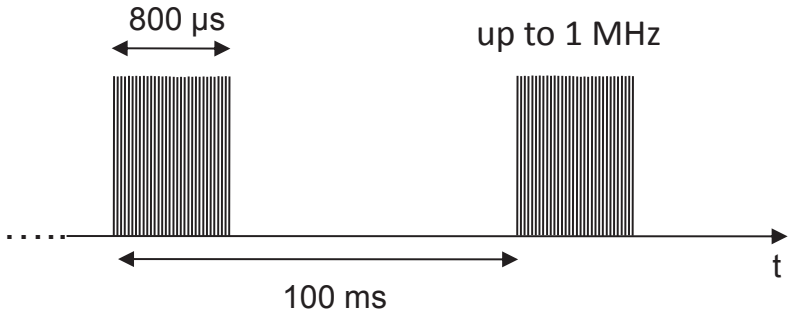
The Challenge: High Power Amplifiers





Repetition Rate:	100 kHz burst
Pulse Energy:	1mJ
Power:	**100 W**
Pulse Duration:	30 fs (<10 fs – 100 fs)
Wavelength: tunable	700 - 950 nm

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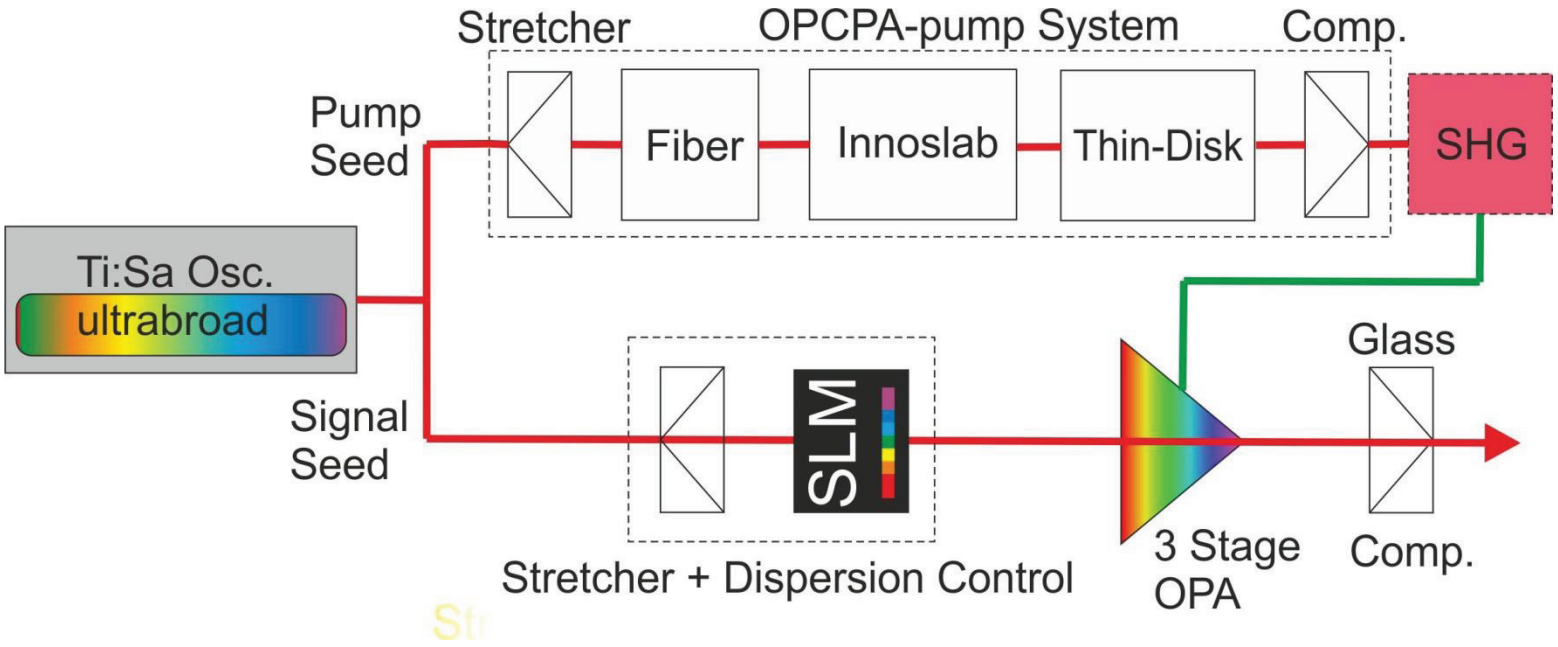
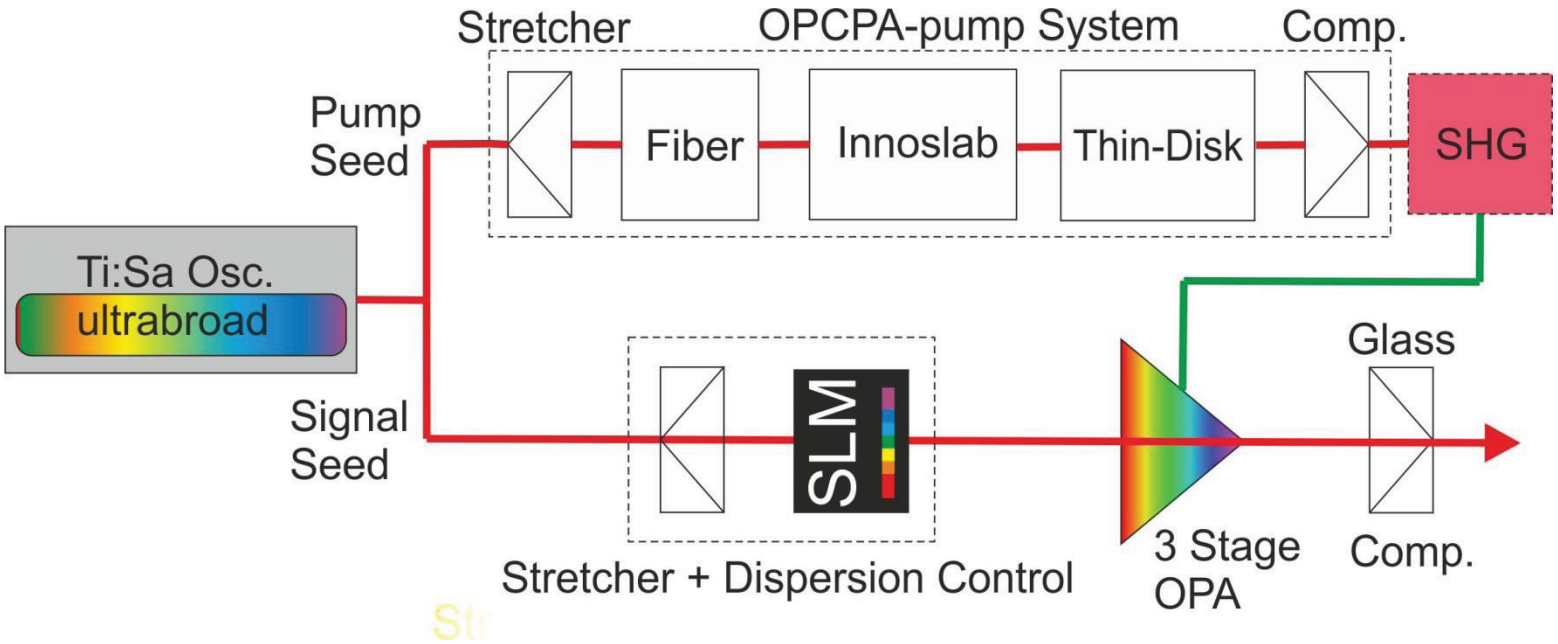
The Solution: Optical Parametric Chirped-Pulse Amplification (OPCPA)



The Solution: Optical Parametric Chirped-Pulse Amplification (OPCPA)

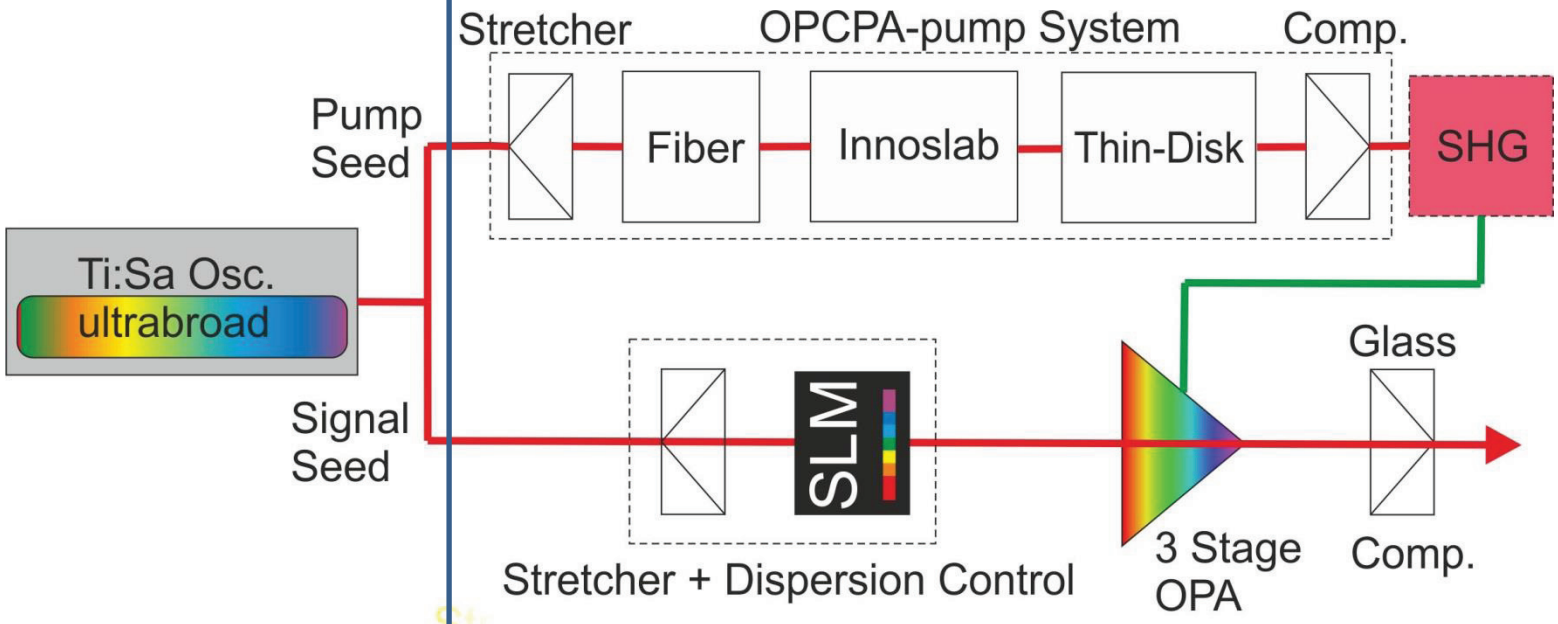
1. Introduction to OPCPA and competing technologies



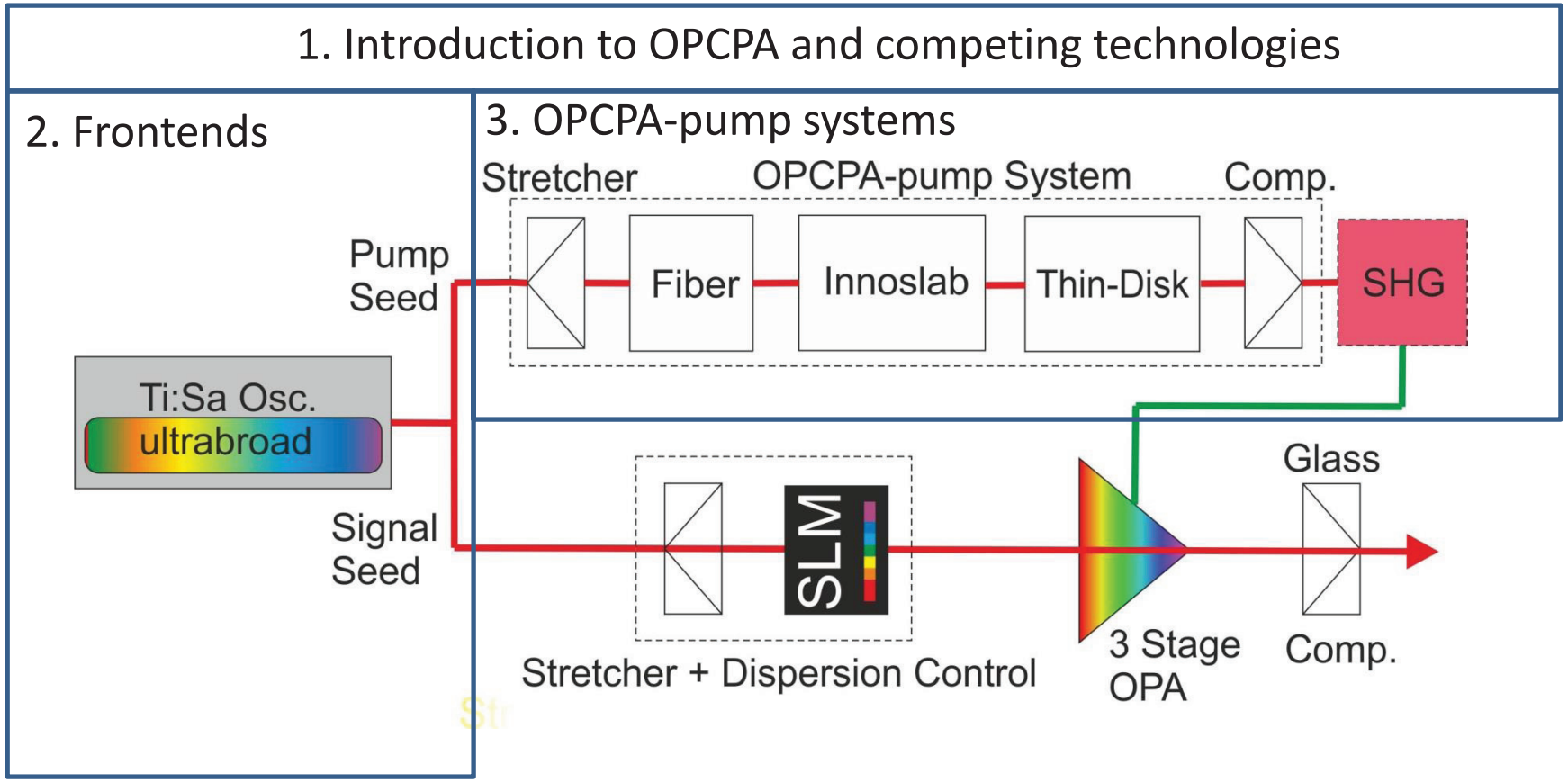
The Solution: Optical Parametric Chirped-Pulse Amplification (OPCPA)

1. Introduction to OPCPA and competing technologies

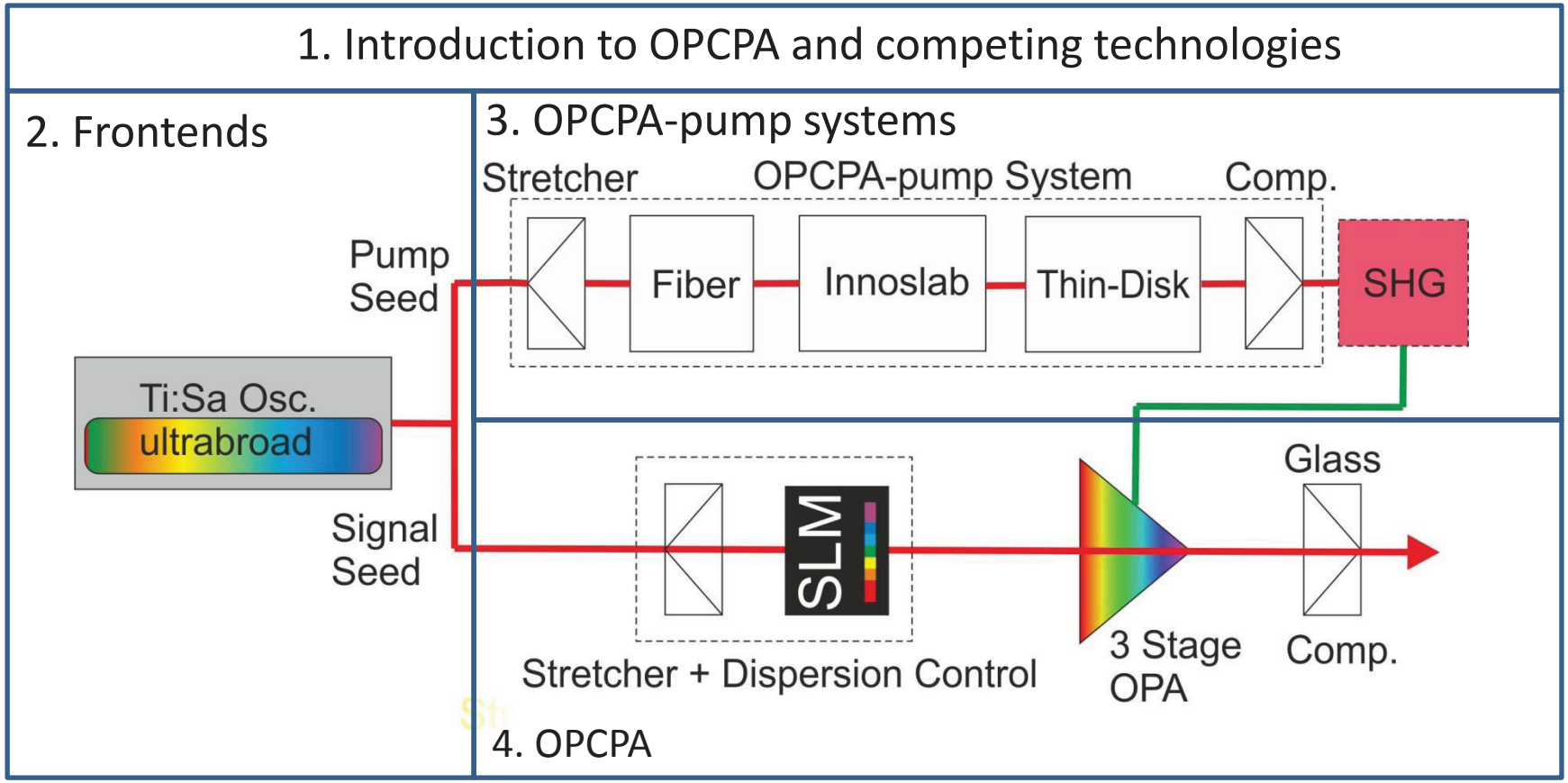
2. Frontends



The Solution: Optical Parametric Chirped-Pulse Amplification (OPCPA)



The Solution: Optical Parametric Chirped-Pulse Amplification (OPCPA)



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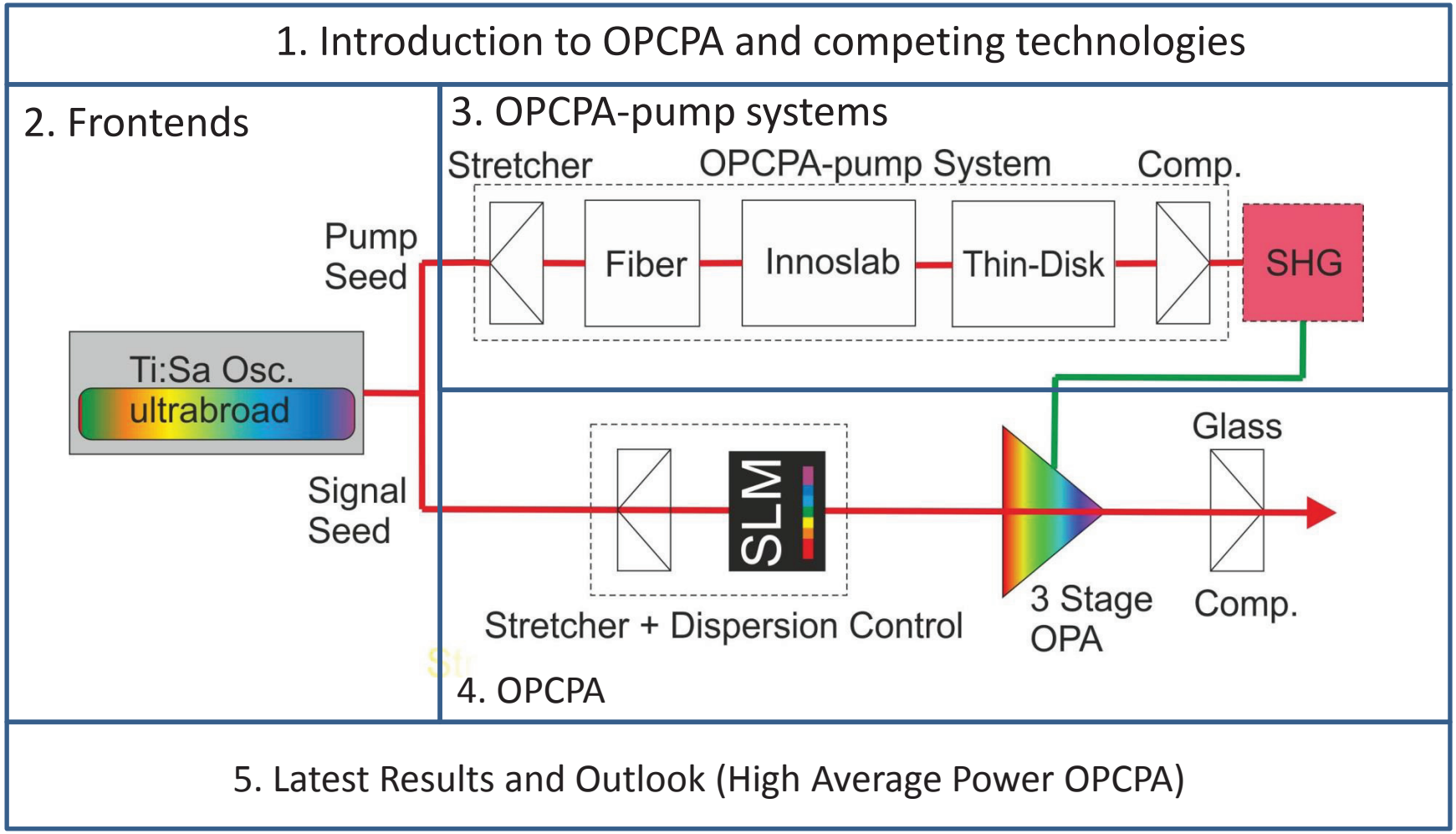
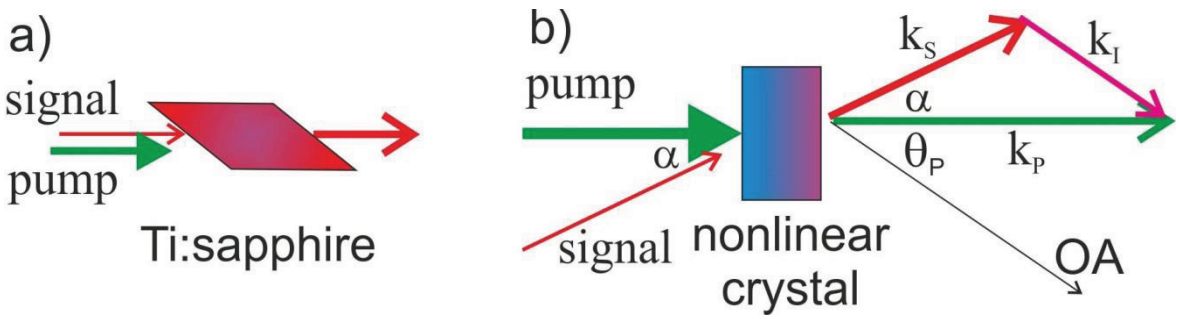


1. Introduction OPCPA



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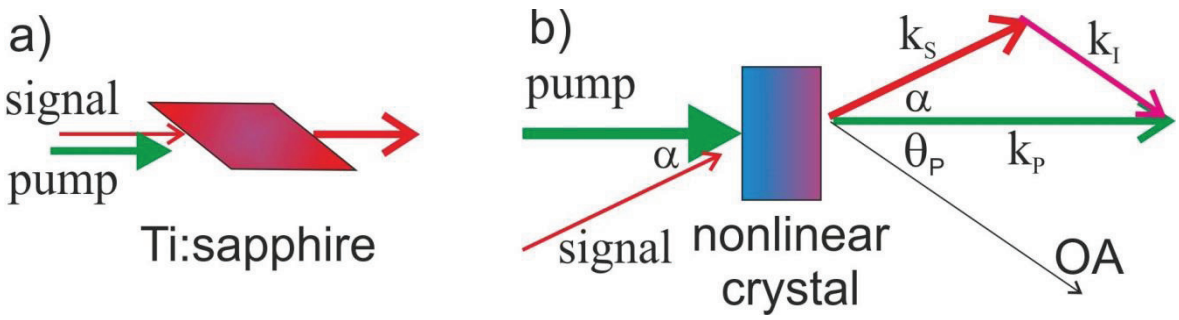
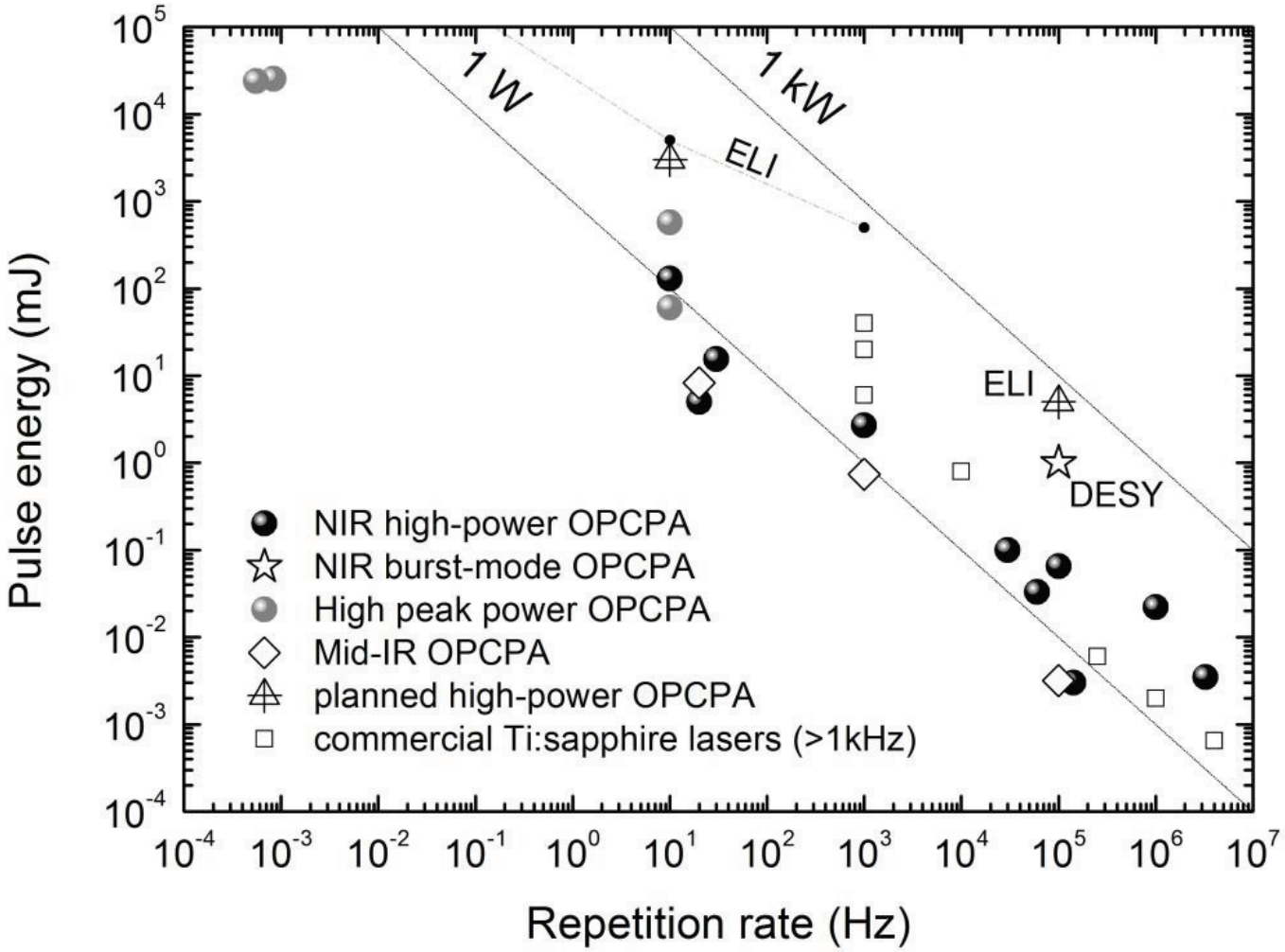


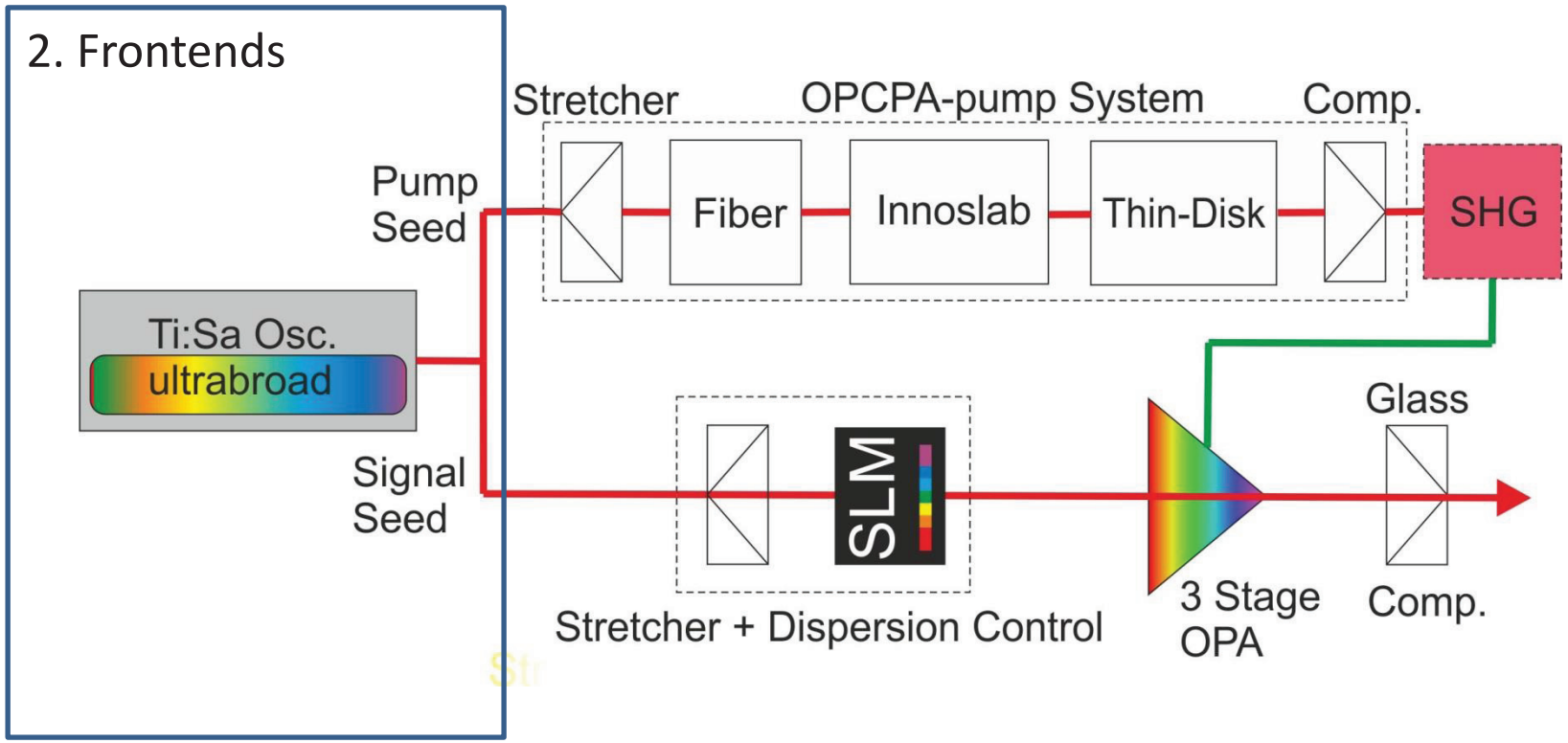
Advantages of OPCPA:

- Broadband amplification (pulses < 10 fs)
- Wavelength tunable
- Scalable to high powers

1. Introduction OPCPA



2. Frontends



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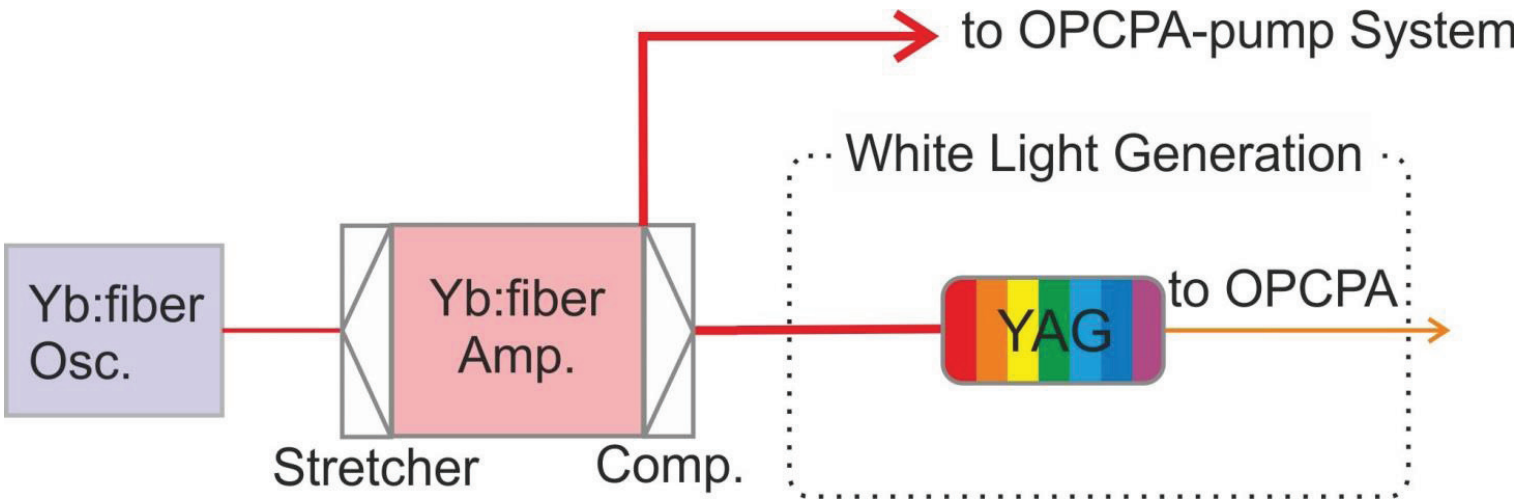

Schulz et al., Opt. Lett. **36**, 2456 (2011)
Riedel et al., Opt. Exp. **21**, 28987 (2013)
Riedel et al., Opt. Lett. **39**, 1422 (2014)

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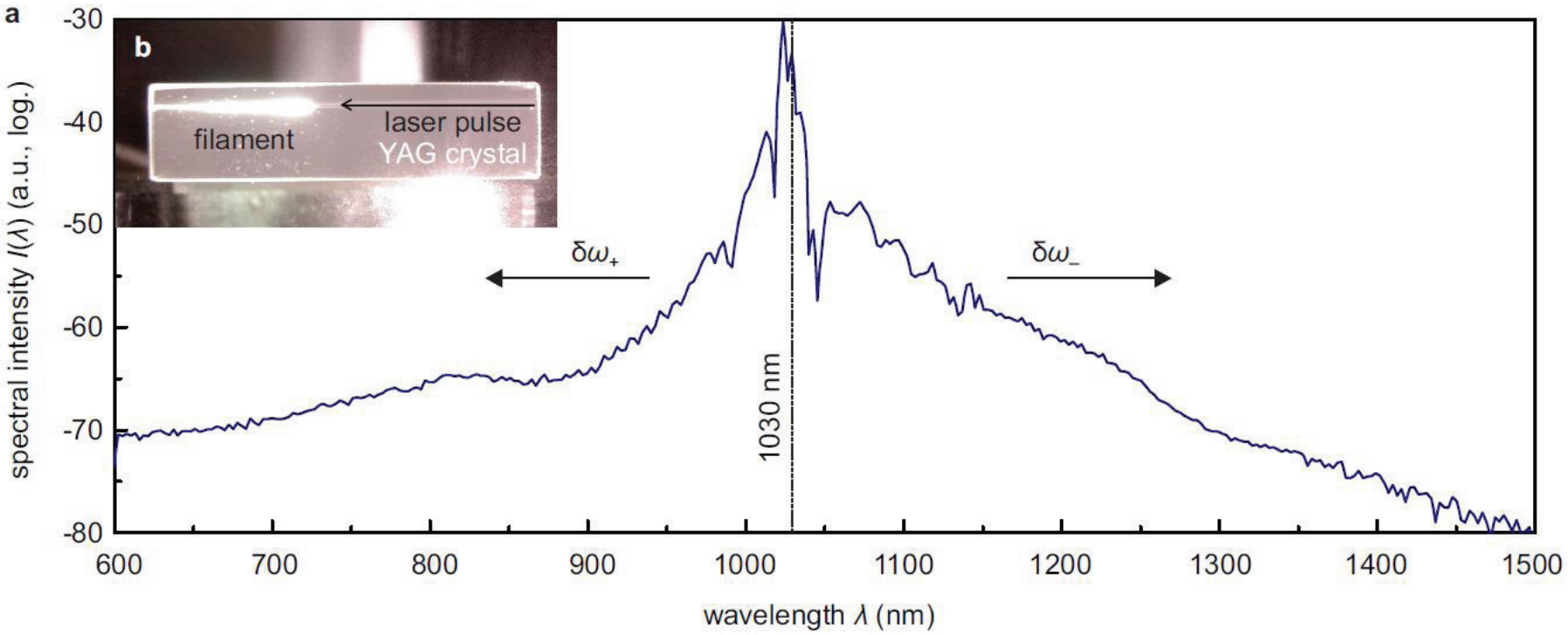

Riedel et al., Opt. Exp. **21**, 28987 (2013)

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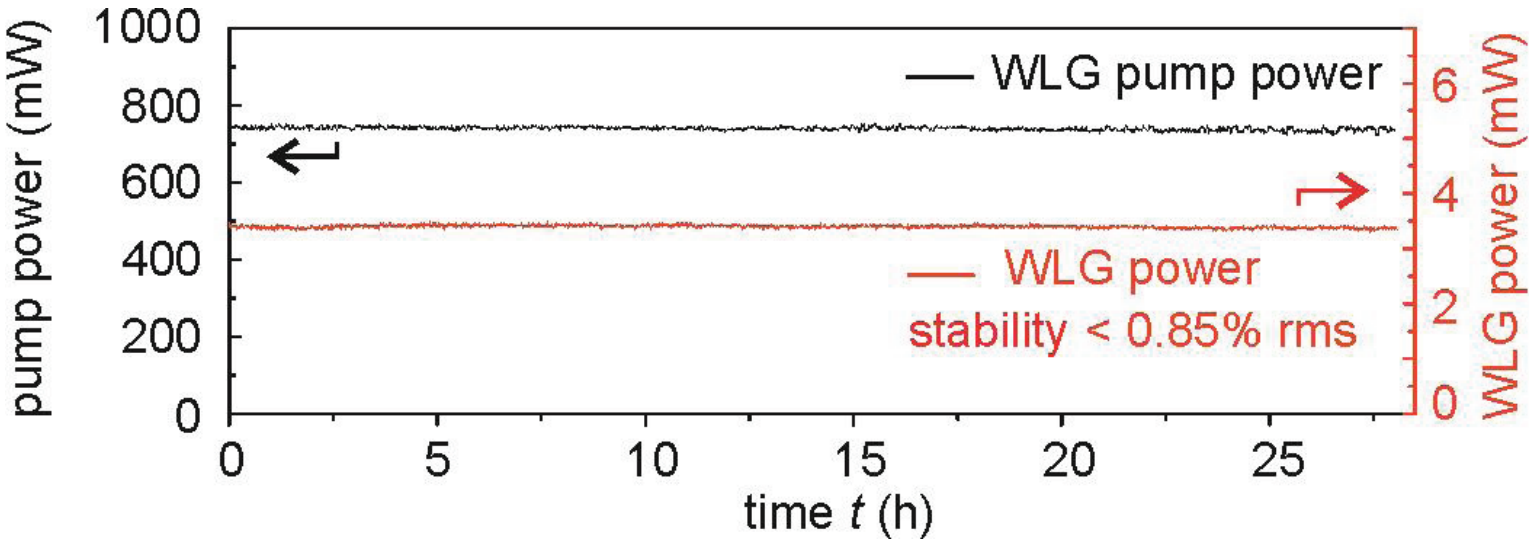
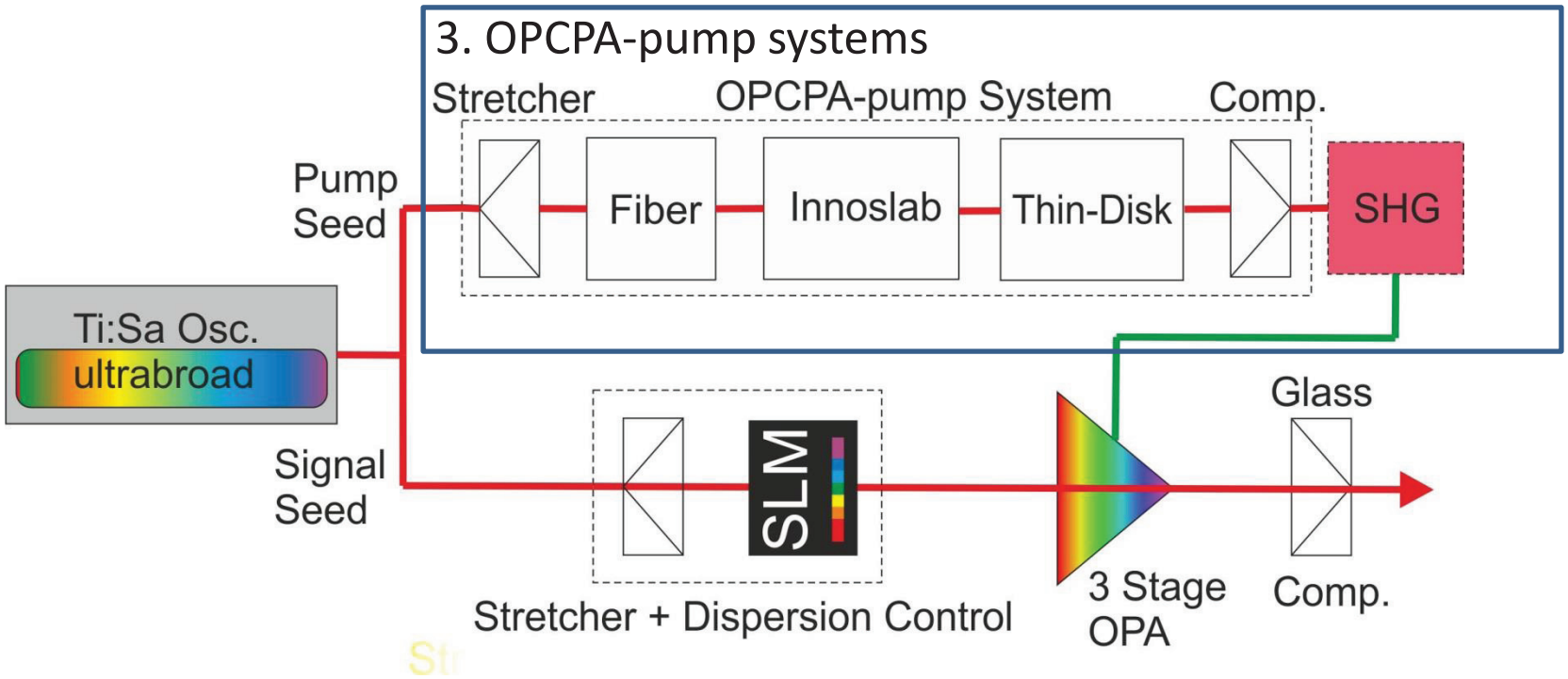


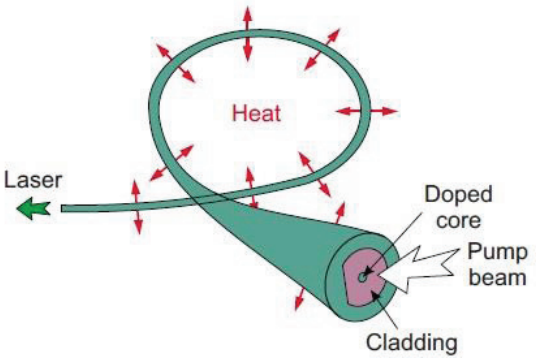
Riedel et al., Opt. Exp. **21**, 28987 (2013)

3. OPCPA-Pump Systems



3. Pump Laser Systems

1. Fiber Amplifiers

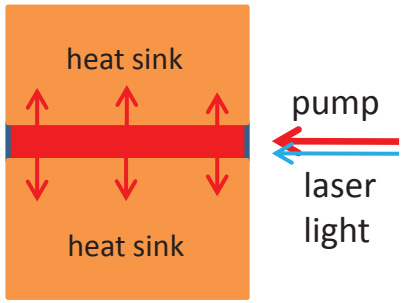


G. Huber et al., J. Opt. Soc. Am. B,

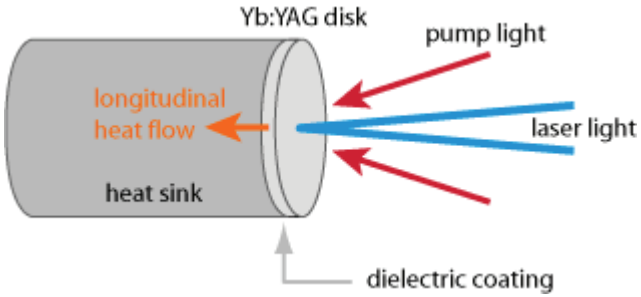
27, B93 (2010)

High Surface-to-Volume Ratio

2. Slab Amplifiers



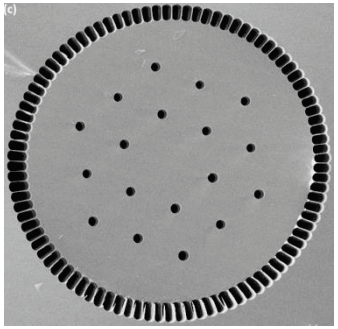
3. Thin-Disk Amplifiers



Encyclopedia of Laser Physics and Technology

3. OPCPA-Pump Systems

1. Fiber Amplifiers



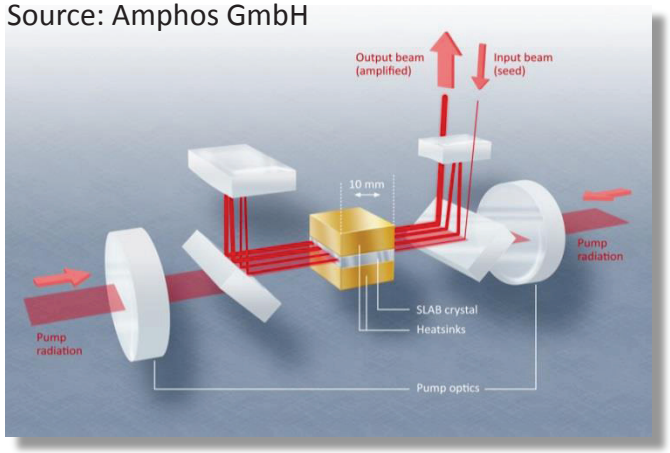
Output powers > 800 W

Eidam et al., Opt. Lett. 35, 94 (2010)
(pulse energy ~ 10 µJ)

Stutzki et al., Opt. Lett. 37, No. 6 (2012)

2. Innoslab Amplifiers

Source: Amphos GmbH

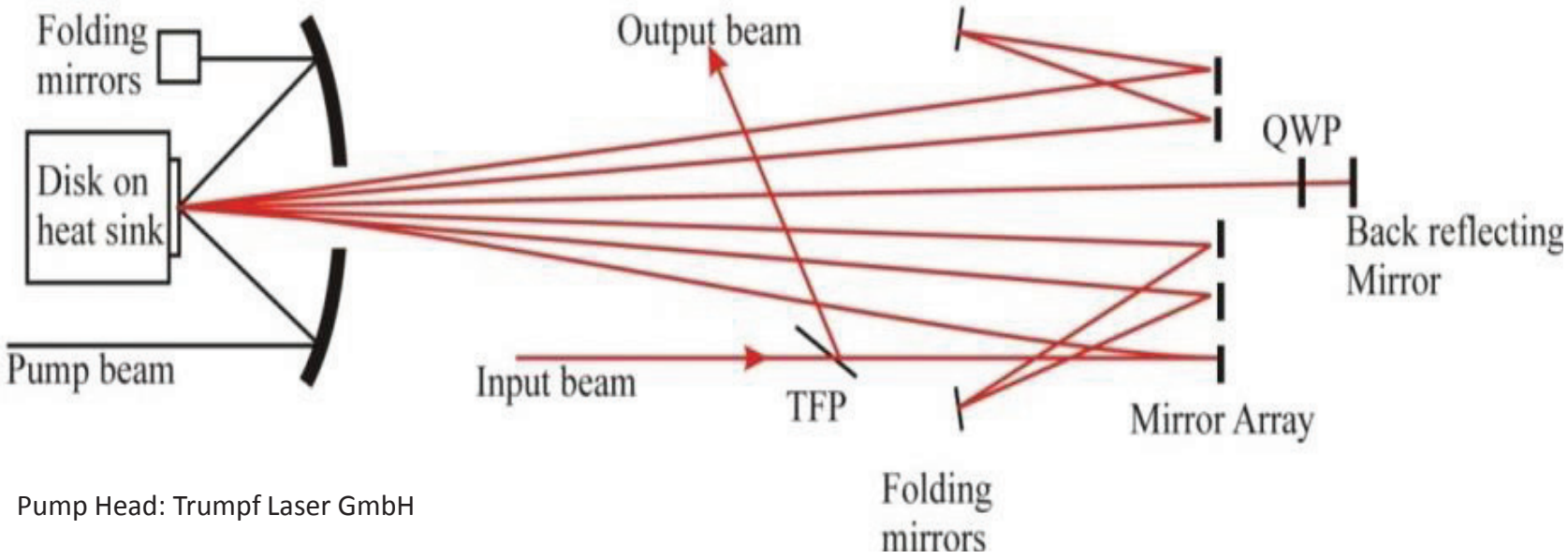


Yb:YAG Innoslab amplifier (AMPHOS GmbH)

250 W (2010) → **500 W** (2011) → **1.5 kW** (2012)

Schulz *et al.*, Opt. Lett. **36**, 2456-2458 (2011)

3. Thin-Disk Multipass Amplifier Development

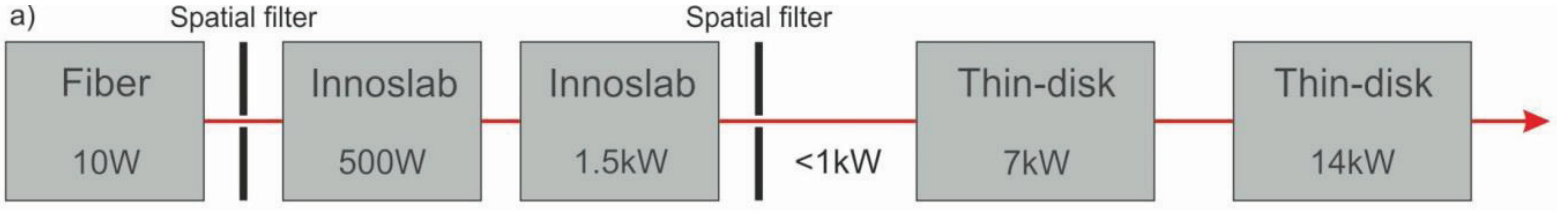


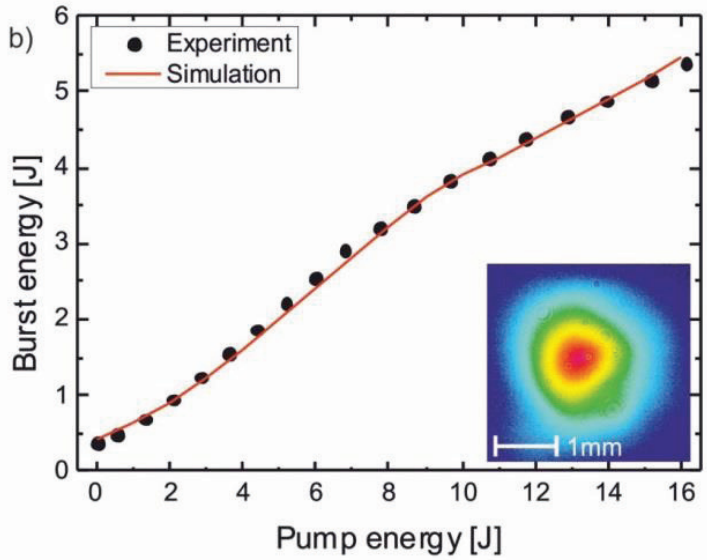
Pump Head: Trumpf Laser GmbH

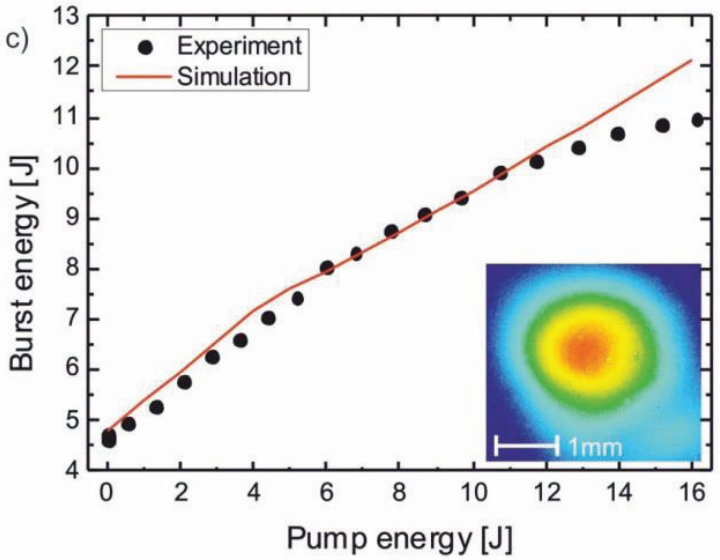
M. Schulz *et al.*, Opt. Exp. **20**, 5038-5043 (2012)

3. Pump Systems: Thin-Disk (World Record)

Schulz *et al.*, FTu4A.2 (2013)







Average Power:	14 kW (in burst)
Pulse Energy:	**140 mJ**
Repetition Rate:	**100 kHz (10 Hz burst)**
Stability:	2% rms

DESY

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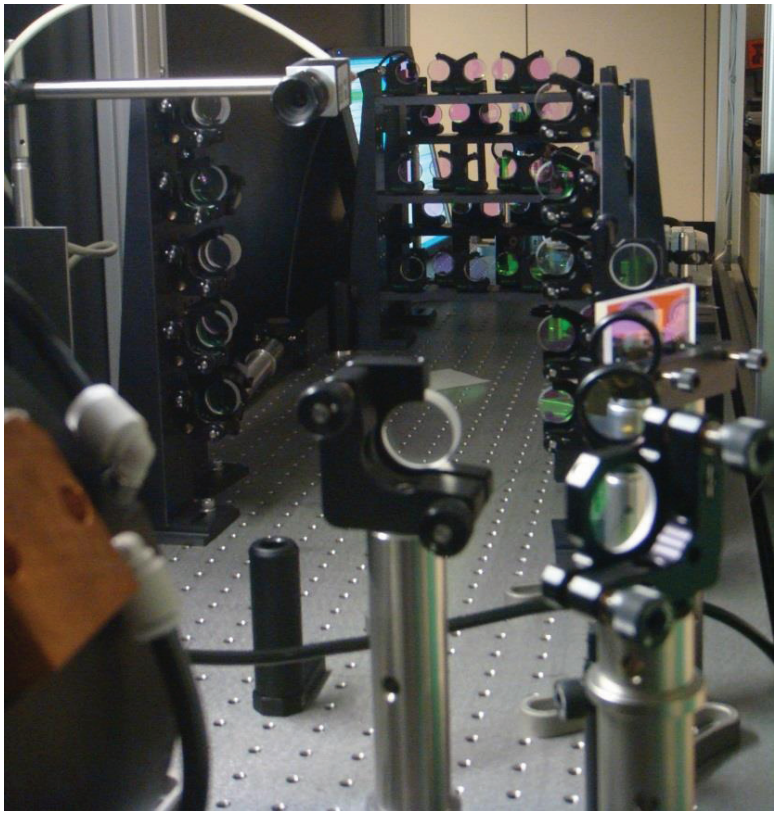
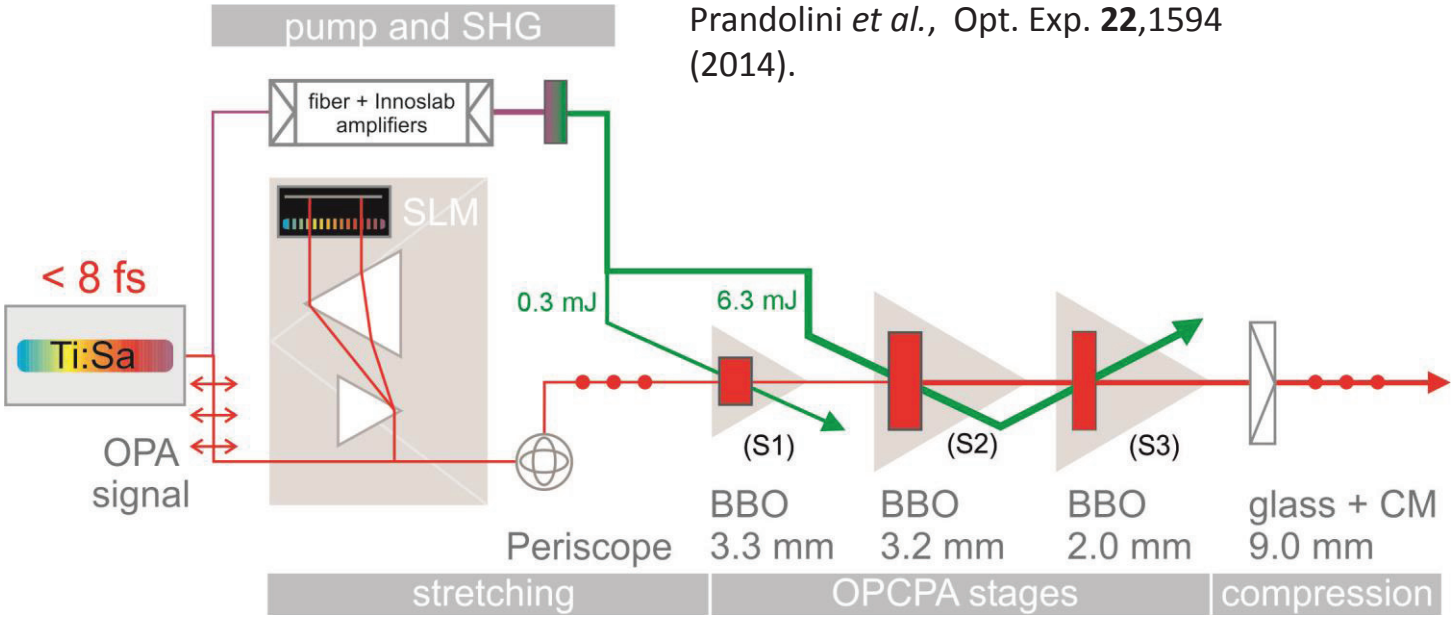
3. OPCPA-Pump Systems

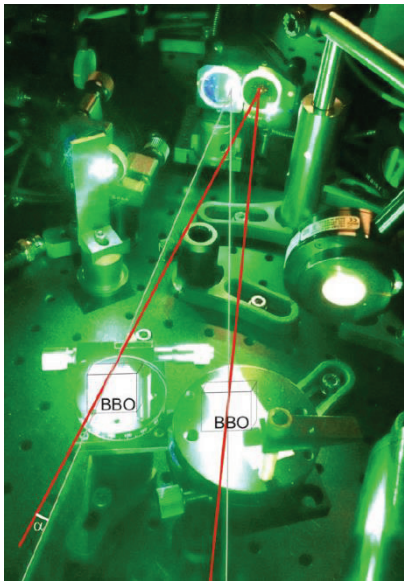
	Fiber	Innoslab	Thin-Disk
Average Power	o	++	++
Pulse Energy	o	+	++
Single Pass Gain	++	+	--
Pointing Stability	++	+	-
Energy Scaling	--	+	++

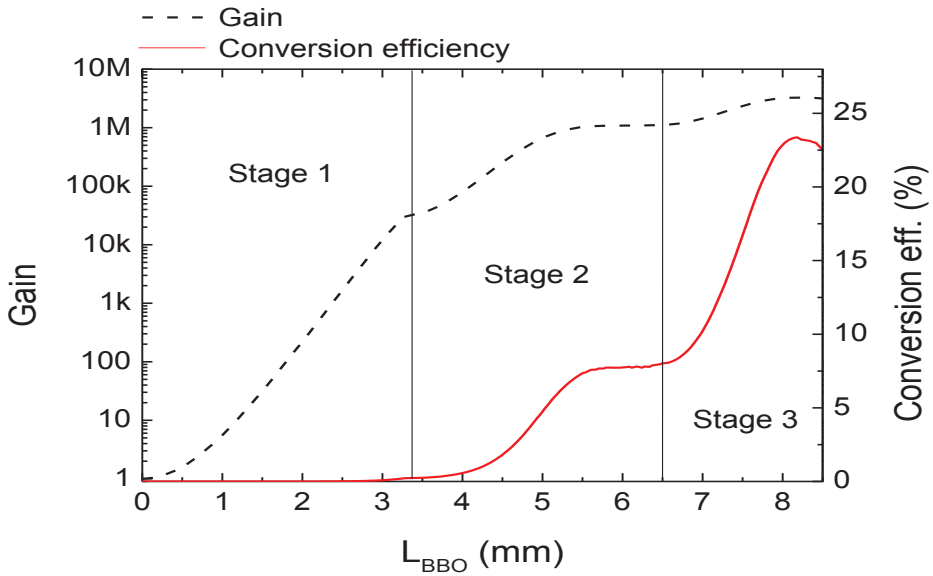


4. OPCPA setup



Prandolini *et al.*, Opt. Exp. **22**,1594 (2014).





DESY

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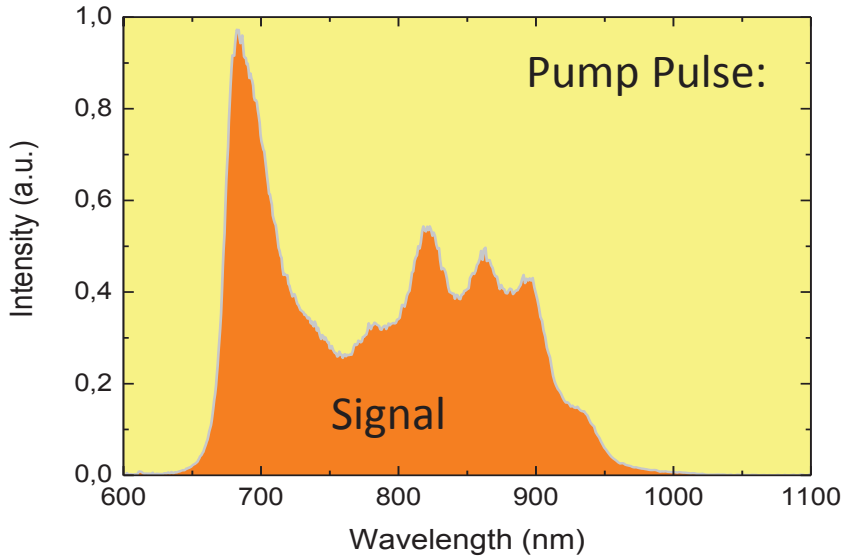
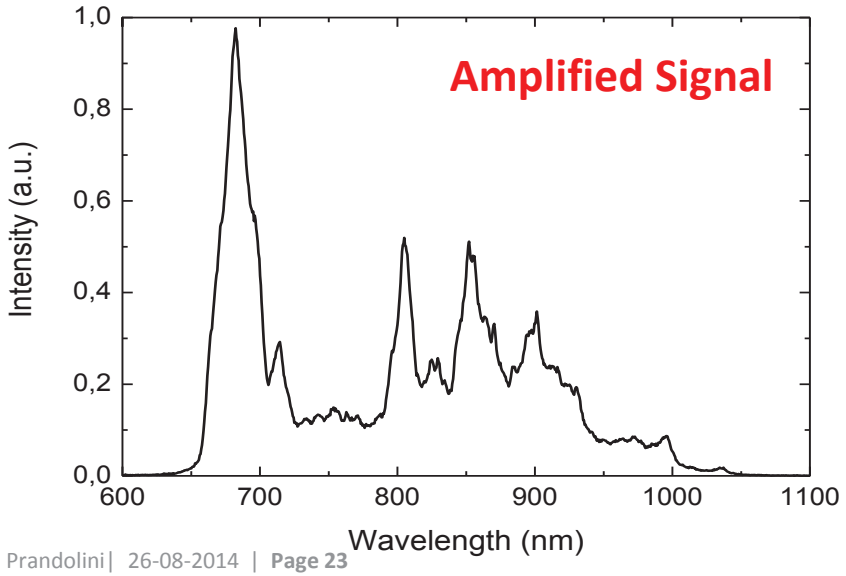
4. OPCPA: short pulse



Pump Pulse: 1 ps



3-STAGE OPCPA
Pulse Energy: 1.39 mJ
Pulse Duration: 6.4 fs (Fourier Limit)

Riedel et al., Opt. Exp. **21**, 28987 (2013)

DESY
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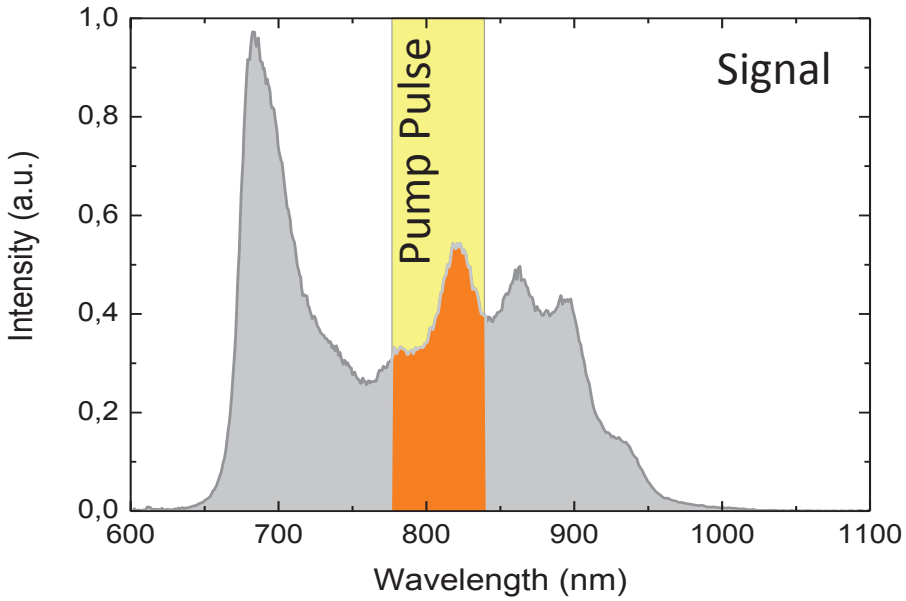
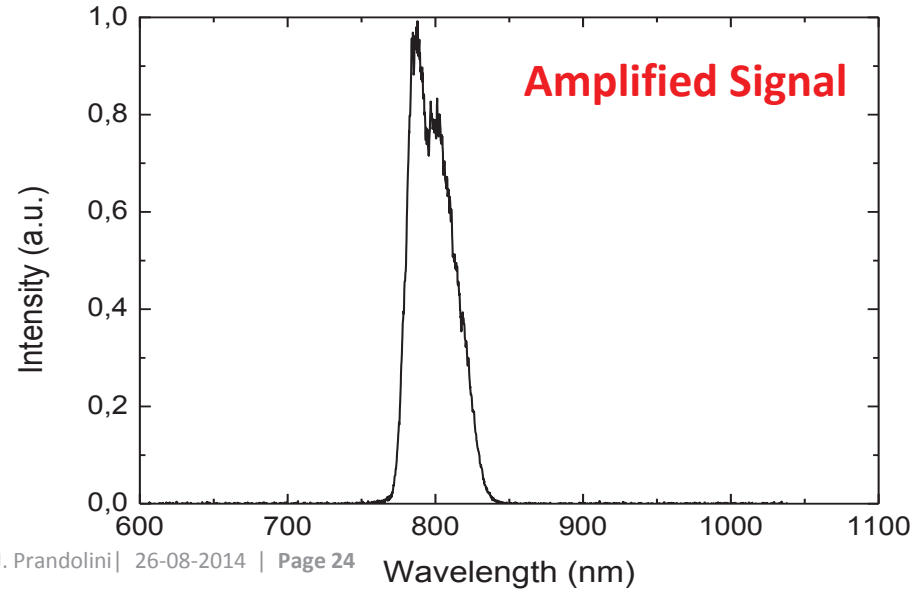
4. OPCPA: wavelength tunable (long pulse)



Pump Pulse: 1 ps



3-STAGE OPCPA

Pulse Energy: > 1 mJ

Pulse Duration: 30 fs (Fourier Limit)

DESY

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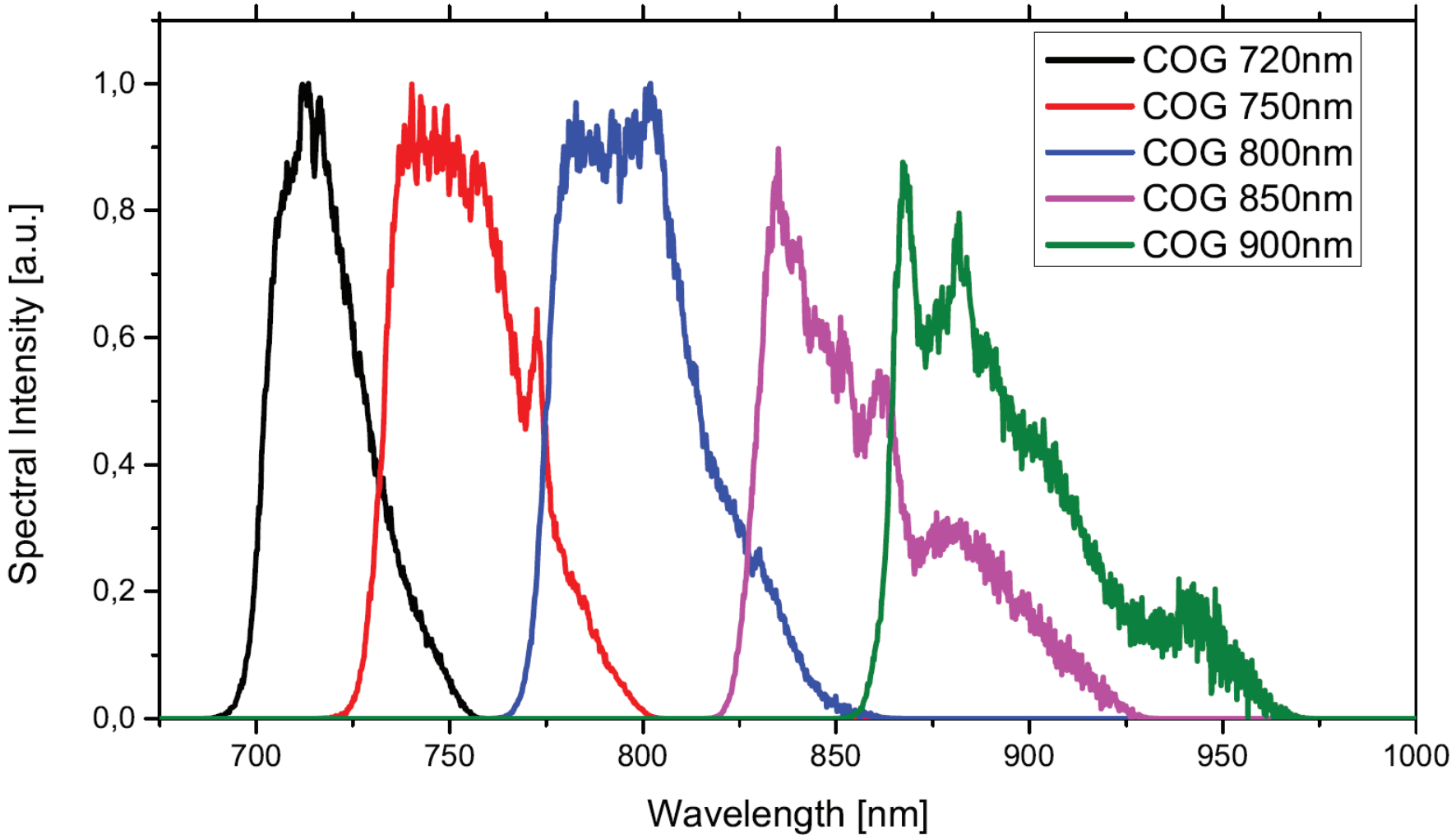
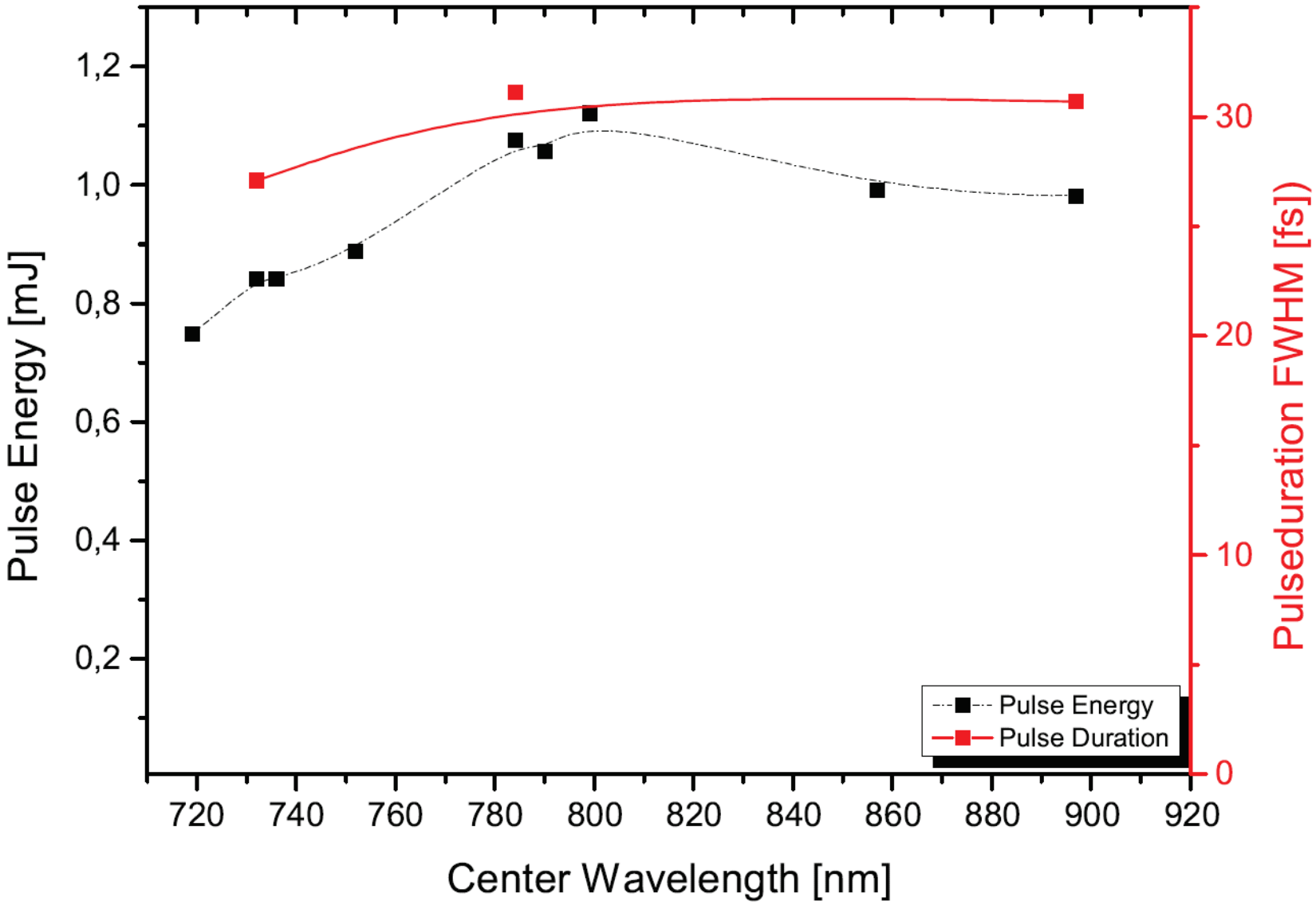
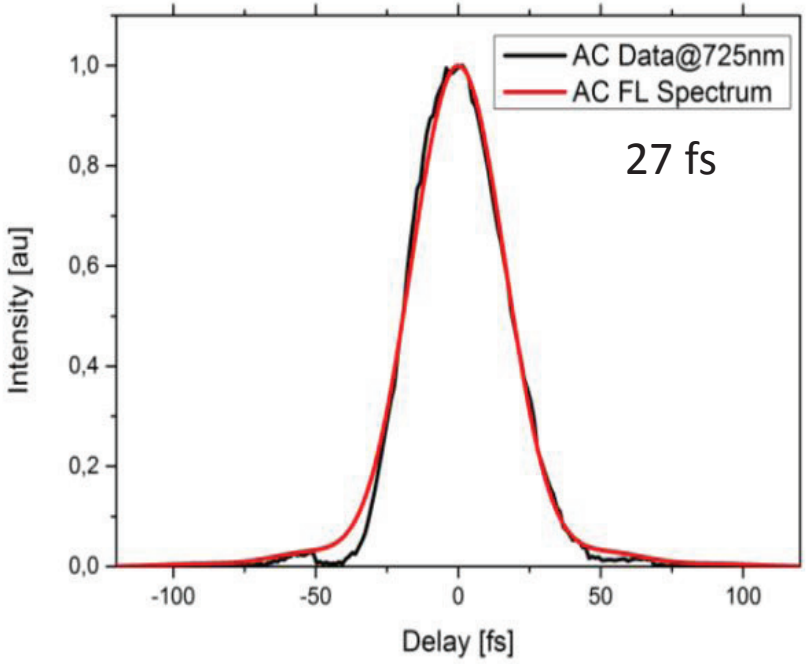
4. OPCPA: long pulse/flexible λ_c

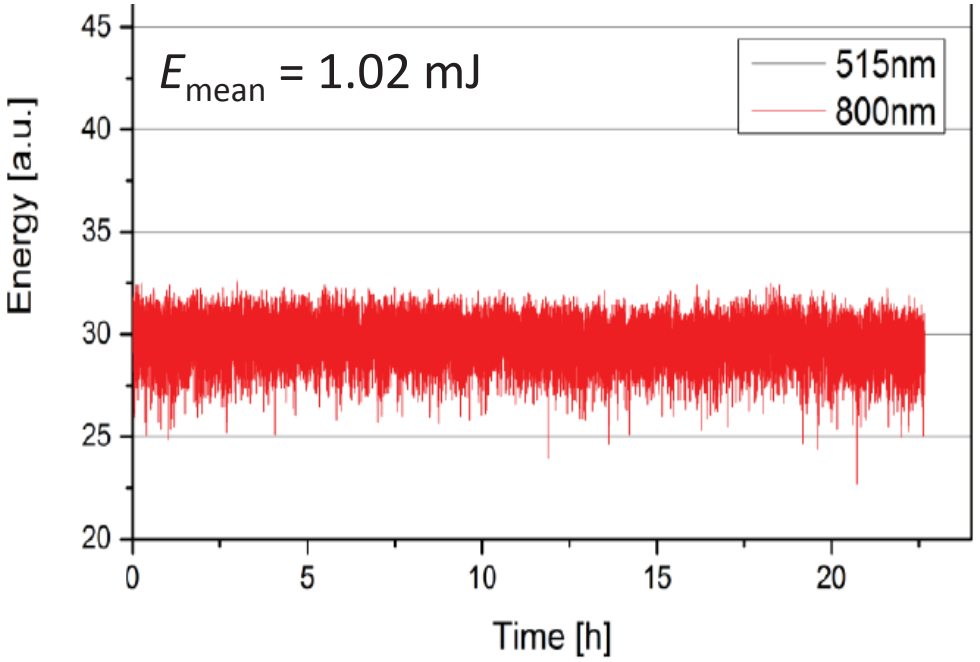


4. OPCPA: (1 mJ x 100 kHz =) 100 W burst (World Record)



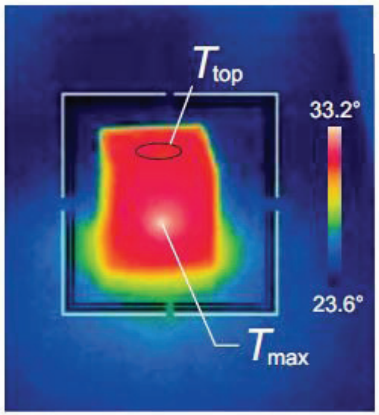
4. OPCPA: 100 W (~30 fs)OPCPA

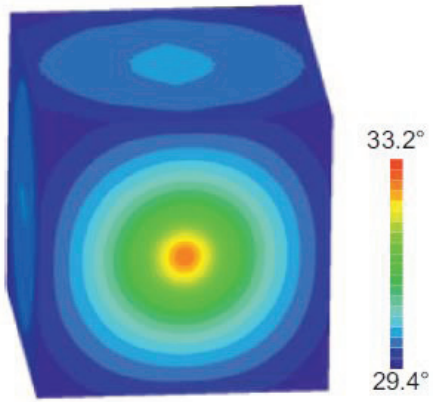




5. Latest Results

Thermal Imaging

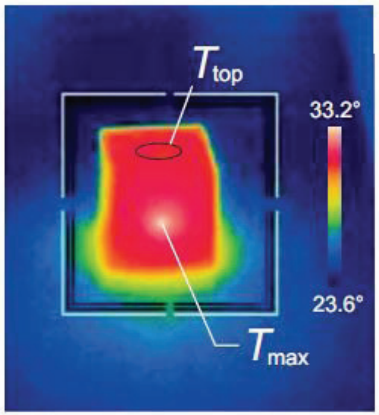


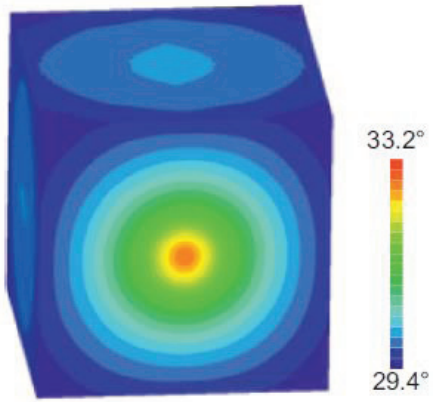


BBO	127 ppm/cm
LBO	86 ppm/cm

5. Latest Results

Thermal Imaging





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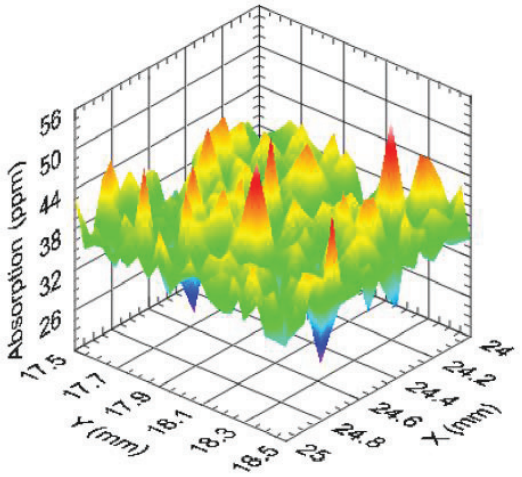
Common-Path Interferometry



BBO	43 ppm/cm
LBO	37 ppm/cm

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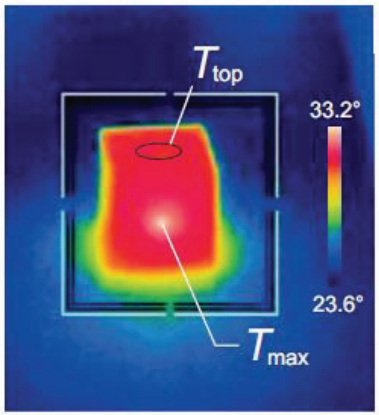

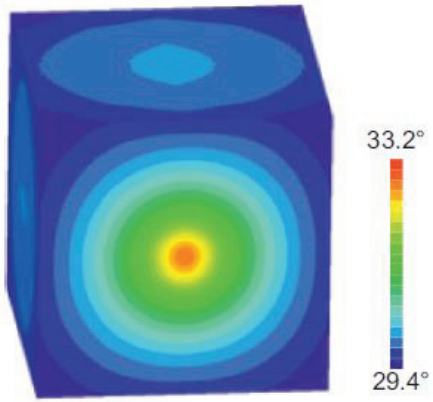

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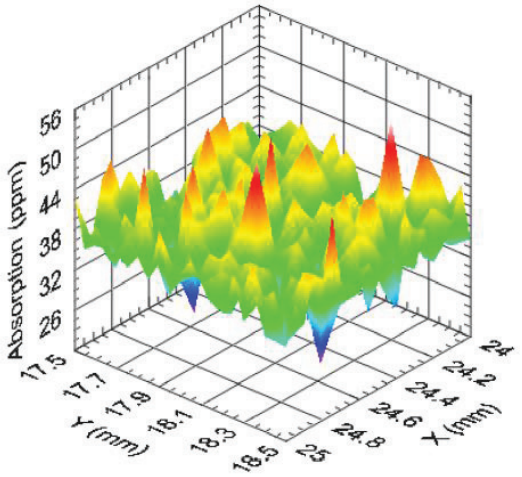

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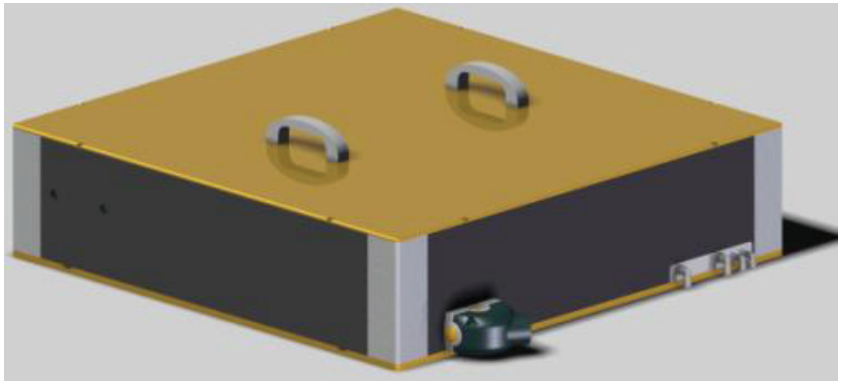
> 10 kW pump → **> 1 kW OPCPA** →

Riedel et al., Opt. Exp. **22**, 17607 (2014)

5. Outlook

Riedel et al., “Power Scaling of supercontinuum seeded MHz repetition rate OPCPA”, Opt. Lett. **39**, 1422 (2014)



Pulse Duration: < 30 fs
Pulse Energy = 3.5 µJ
f_{rep} = 3.25 MHz
Power = **11.4 W**

OPCPA Advantages

- Scalable to high powers
- Large Bandwidth
- Wavelength tunable
- Compact Design

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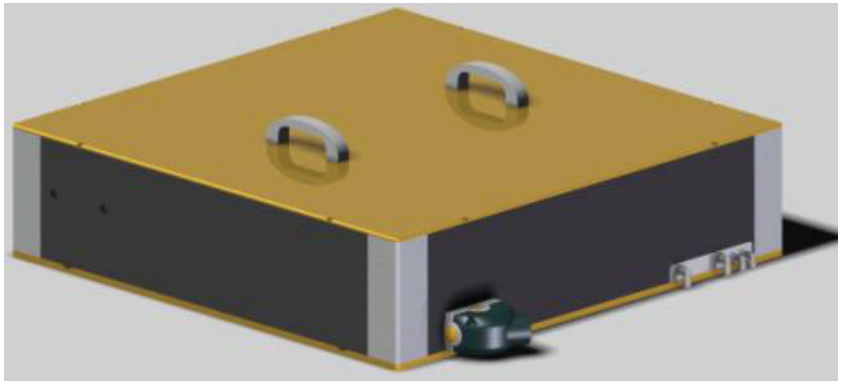

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CLASS **5** photonics

flexible high average power laser sources
http://class5photonics.com

Optical Parametric Chirped-Pulse Amplifiers

DESY

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Thanks for your Attention

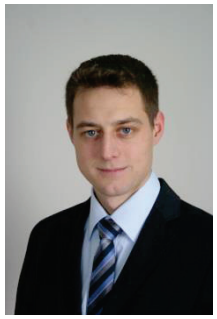
Tavella´s Young Investigator Group

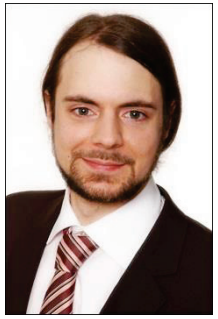

F. Tavella


R. Riedel


M. Schulz


M.J. Prandolini


A. Hage


H. Höppner