High Repetition Rate mJ-Level Few-Cycle Pulse Laser Amplifier for accelerator science.

Merging advanced solid-state Laser technology with FEL sources

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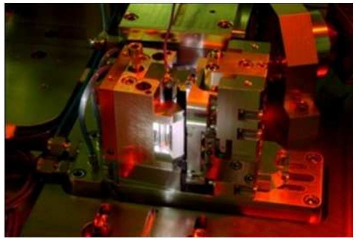
Overview.

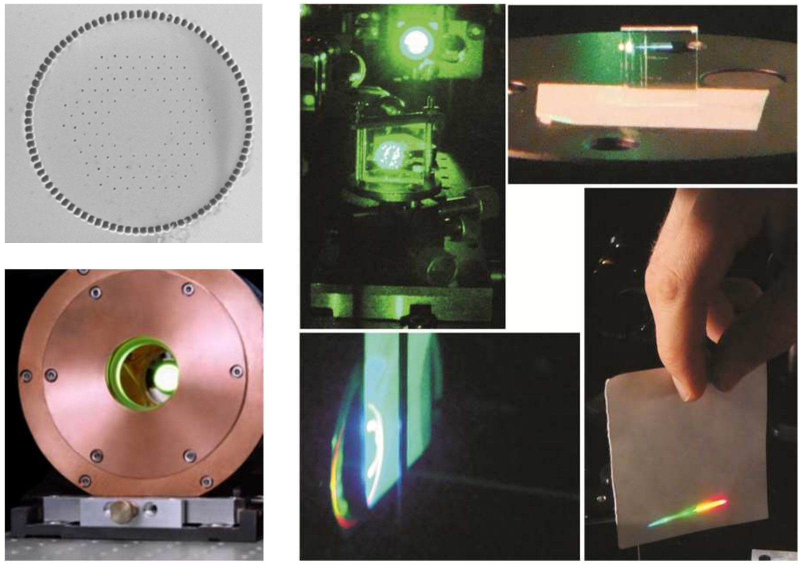
Novel HRR-HAP-FCP laser amplifiers systems at DESY

- applications
- What is needed? Input from the user community!
- methods – enabling technologies
- Laser specs … upgrades

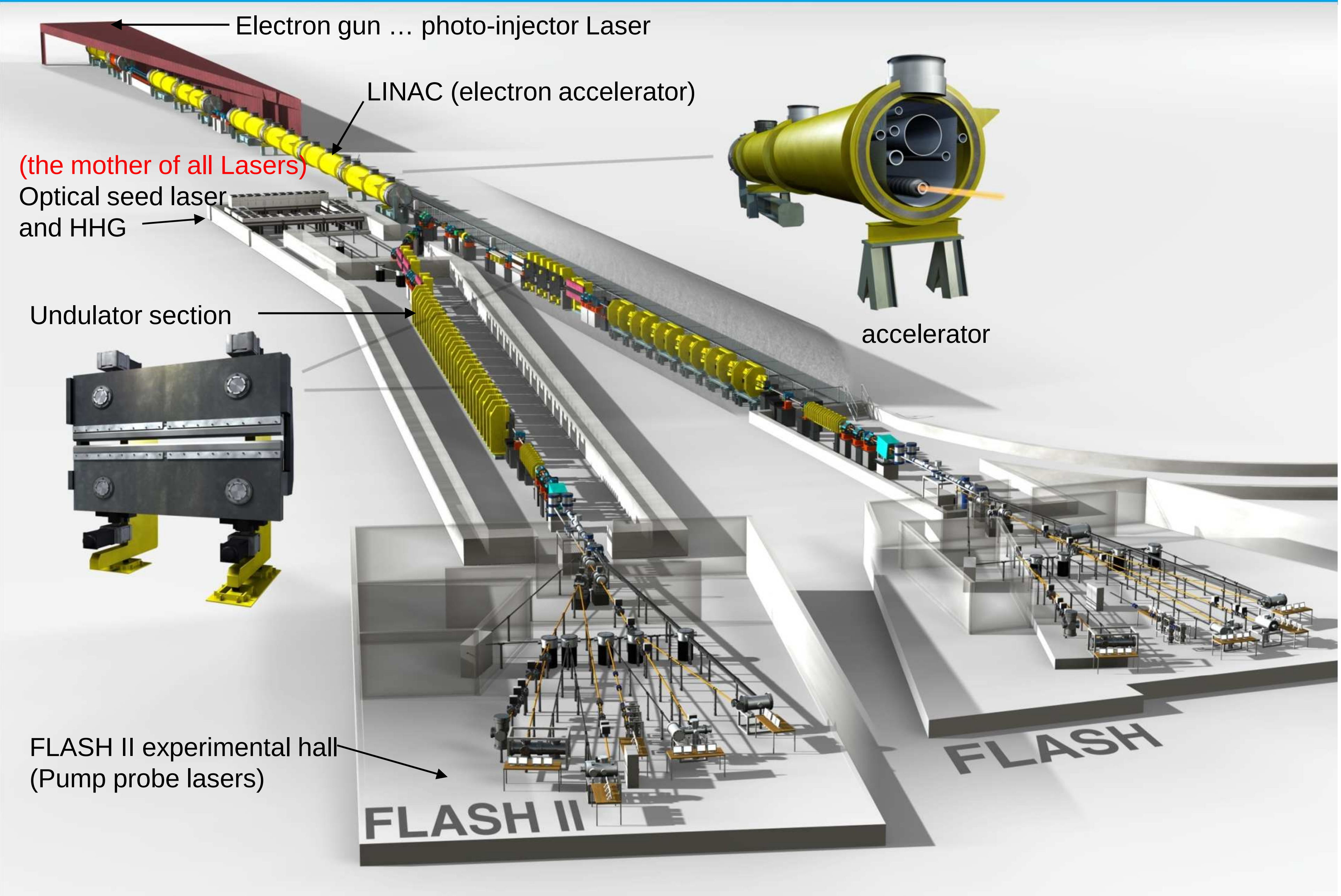


Development status

- pump amplifier system
- optical parametric chirped pulse amplifier
- (XUV seed source for FLASH-2 seeding)



Laser amplifier applications at FELs.



The seeding driving laser amplifier.

synchronization to the FEL <10 fs AND 24/7 stability

	Laser	Seed	X-ray	η	Rep.-rate	P_{ave}	Comments
EEHG	0.8 µm 100 GW >10 fsec (mJ)	200 nm up to GW	2 nm	>10^{-1}conv., 10% losses	1 MHz (burst)	100s W for burst	UV and IR both required CEP (evt.)
HGHG	0.8 µm 10 GW >10 fsec (100 µJ)	200 nm 100 MW	20 nm	>10^{-1}conv., 10% losses	1 MHz (burst)	100s W for burst	CEP stabilization for ultrafast pulses
HHG+ HGHG or EEHG	0.8 µm 100 GW 10 fsec (mJ)	20 nm 100 kW	1 nm	10^{-5} conv., 10% losses	1 MHz (burst)	kW	same
HHG	0.8 µm 100 GW **10-30 fsec** **(>1 mJ)**	>10 nm 100 kW	**> 10 nm**	10^{-5} conv., 10% losses	1 MHz (burst)	**kW**	100 kHz pr. development ongoing
HHG	0.8 µm 1 TW **<10 fsec** (>10 mJ)	<10 nm 1 MW	**<10 nm**	10^{-6} conv., 10% losses	1 MHz (burst)	**10s kW**	extreme R&D necessary

Special needs…input from the future user community.

Pulse energy
few mJ

Wavelength (tunable?)
650-1000 nm

Repetition rate
100 kHz – 1 MHz

Pulse duration (tunable?)
6 fs (shortest) – 30 fs

Seeded beam parameters ??
- Bandwidth __eV ??
- FEL pulse duration __fs ??
- Tunable wavelength or fixed by laser harmonics??

CEP stabilization
Yes/ No ??

Optical Parametric Chirped Pulse Amplification (OPCPA).

Optical parametric chirped pulse amplification!

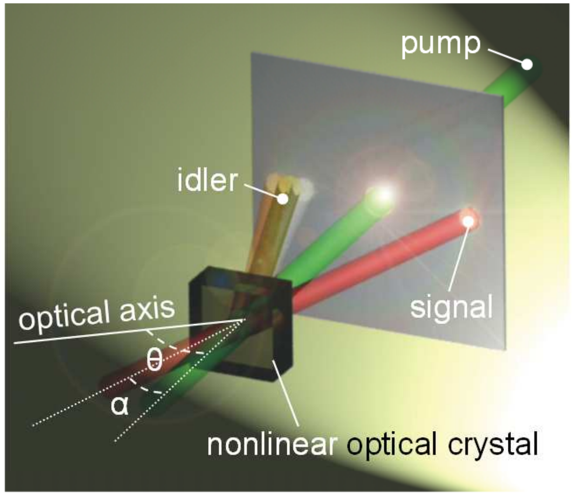
- instantaneous process → no energy storage, no inversion
- negligible absorption in transparent material
- no thermal load

→ **High repetition rates (high average power) possible**

Non-collinear broadband amplification (NOPA)

- type-I phasematching in BBO
- pump wave: extraordinary axis
- signal / idler wave: ordinary axis

→ **conversion efficiency >20% in 2-pass OPCPA**

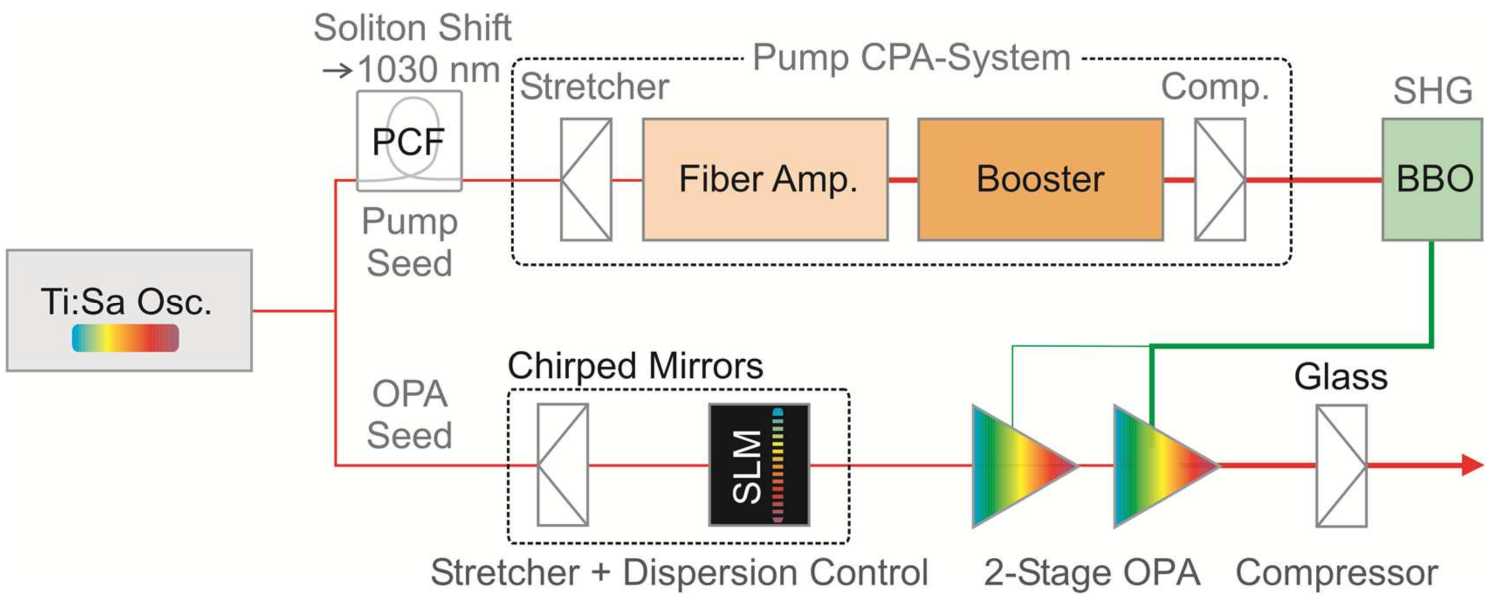


Dubietis et al., Opt. Commun., ***88****, 437 (1992).*
I. N. Ross et al., Opt. Commun., ***144****, 125 (1997).*

Optical Parametric Chirped Pulse Amplifier: Setup.

Laser system Setup: combining OPCPA with ultra-short pump amplifiers

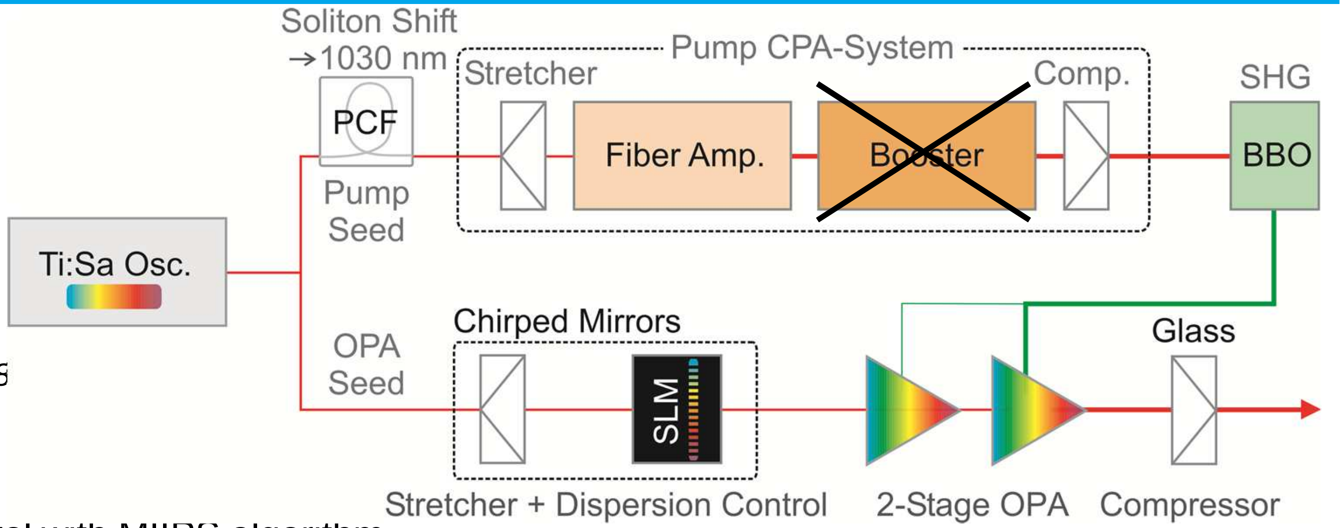
- Ti:Sa oscillator frontend
  → split for signal and pump seed
- adaptive dispersion control for signal (4-f SLM)
- Yb based CPA with high repetition rate
- sub-ps pump pulses from CPA



Results: OPCPA with fiber pump laser.

1-Stage OPCPA
60 kHz, 20 µJ, 6.9 fs
(F. Tavella et al, Opt. Exp. 18 4689-4694 (2010)

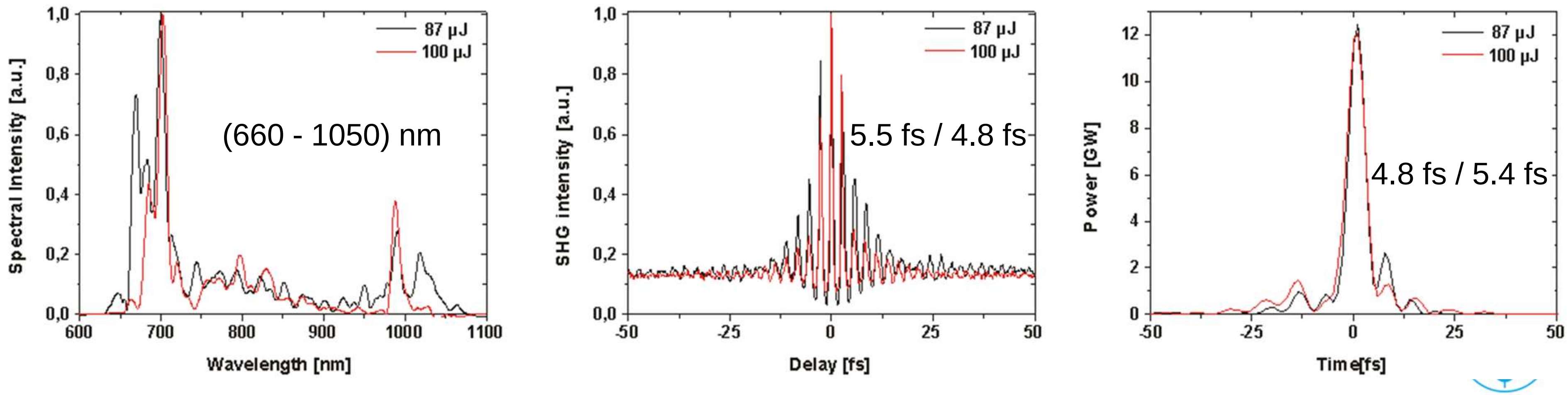
2-Stage OPCPA
96 kHz, 70 µJ, 8.0 fs
J. Rothhardt et al, Opt. Exp. 18 12719-12726 (2010)



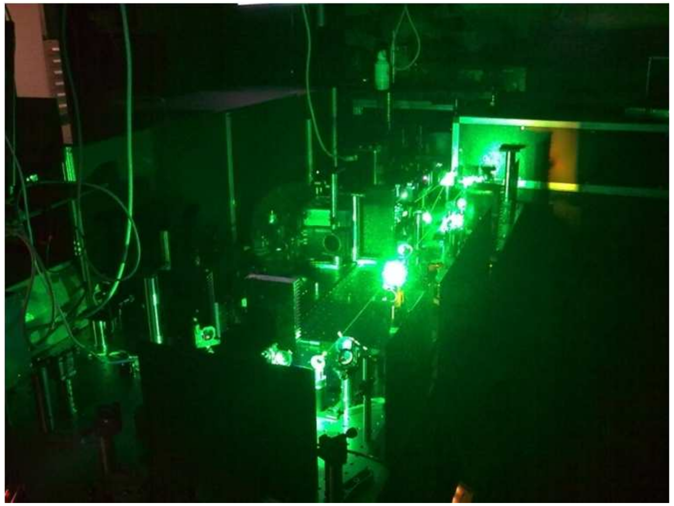
2-stage OPCPA
adaptive dispersion control with MIIPS algorithm

→ 30 kHz, 87 µJ, 4.8 fs
S. Hädrich et al, Opt. Letters 36, No. 3 (2011)

broad amplification spectrum | interferometric autocorralation | retrieved from spectral phase



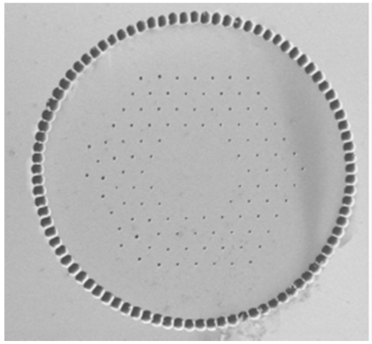
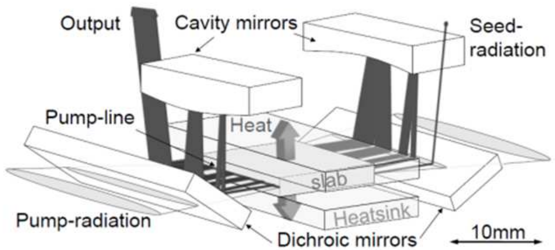
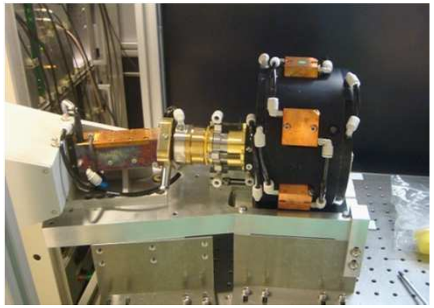
High-power sub-1ps OPCPA pumping system.



The challenge: OPCPA pump laser

- central wavelength: **1030 nm** (SHG @ 515 nm used for OPCPA)
- pulse energy: **20 mJ** → 10 mJ @ 515 nm
- repetition rate: **100 kHz cw** / burst (1 MHz final version)
- pulse duration: **sub-1 ps**

→ 2 – 20 kW High-Average-Power Laser Amplifier!

Fiber amplifier (IAP Jena)	Booster amplifier	
	Innoslab amplifier (ILT Aachen)	Thin disk multipass (DESY)
		
T. Eidam, et al, Opt. Lett. ***35****, 94-96, (2010).* <1 kW	*P. Rußbüldt et al., Opt. Letters, Accepted, Doc. ID: 131645 (2010)* >kW	*Trumpf Laser GmbH* >kW

The fiber amplifier.

Yb:glass rod type PCF amplifier

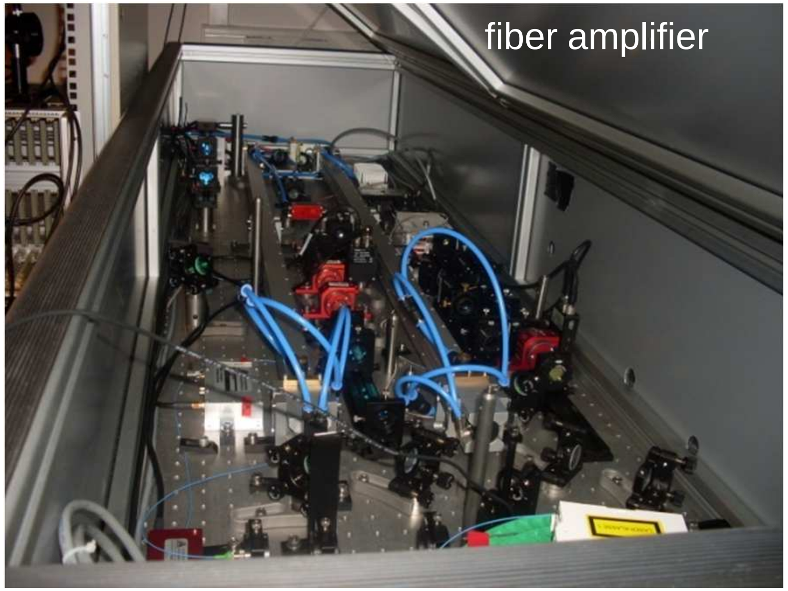
- developement: IAP Jena
- fiber pre-amplification (1.9 mW @ 2 MHz)
- pulse picking with acousto optic modulators
- grating stretcher / compressor (2.27 ns / <1 ps)

1st Main amplifier

- LMA core diameter: 40 µm
- pulse energy: 20 µJ @ 100 kHz

2nd Main amplifier

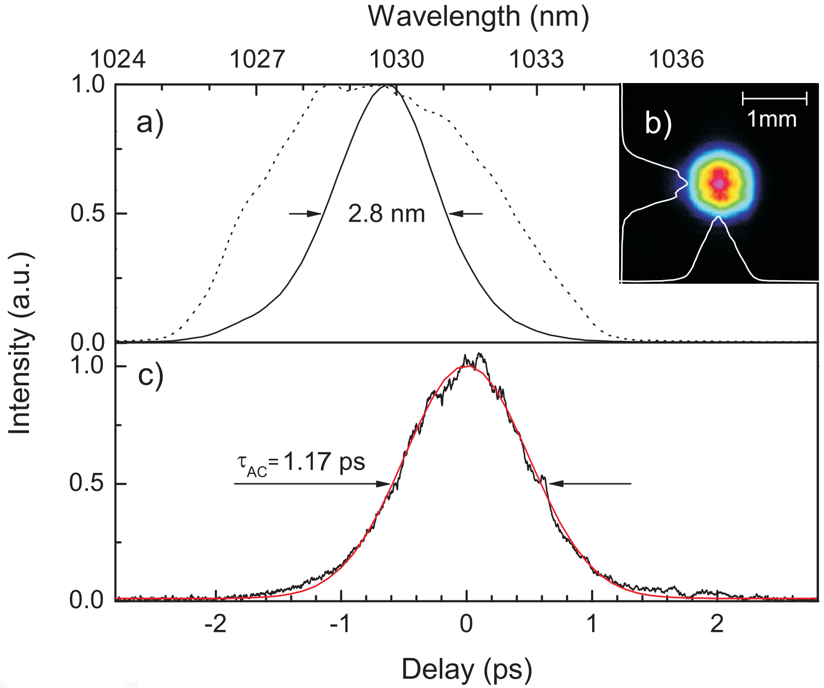
- LMA core diameter: 80 µm
- pulse energy: **0.5 mJ** @ 100 kHz
- spectral width: **6.8 nm** FWHM
- compressed pulse duration: **850 fs** FWHM
- burst mode operational

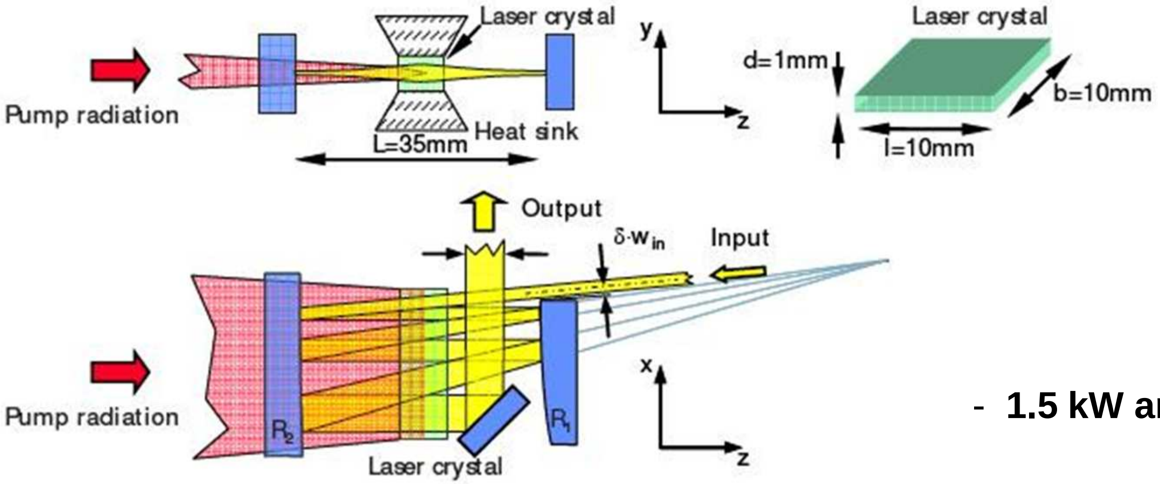


Tested booster amplifiers.

Yb:YAG Innoslab multipass amplifier

- provided by ILT Aachen, Amphos GmbH
- diode pump power: 600 W
- average power: 250 W
- spectral width: **2.8 nm** FWHM
- pulse duration: **830 fs** FWHM
- pulse energy: 2 mJ @ 100 kHz
- beam quality: $M^2 < 1.4$





→ 20 mJ @ 12.5 kHz

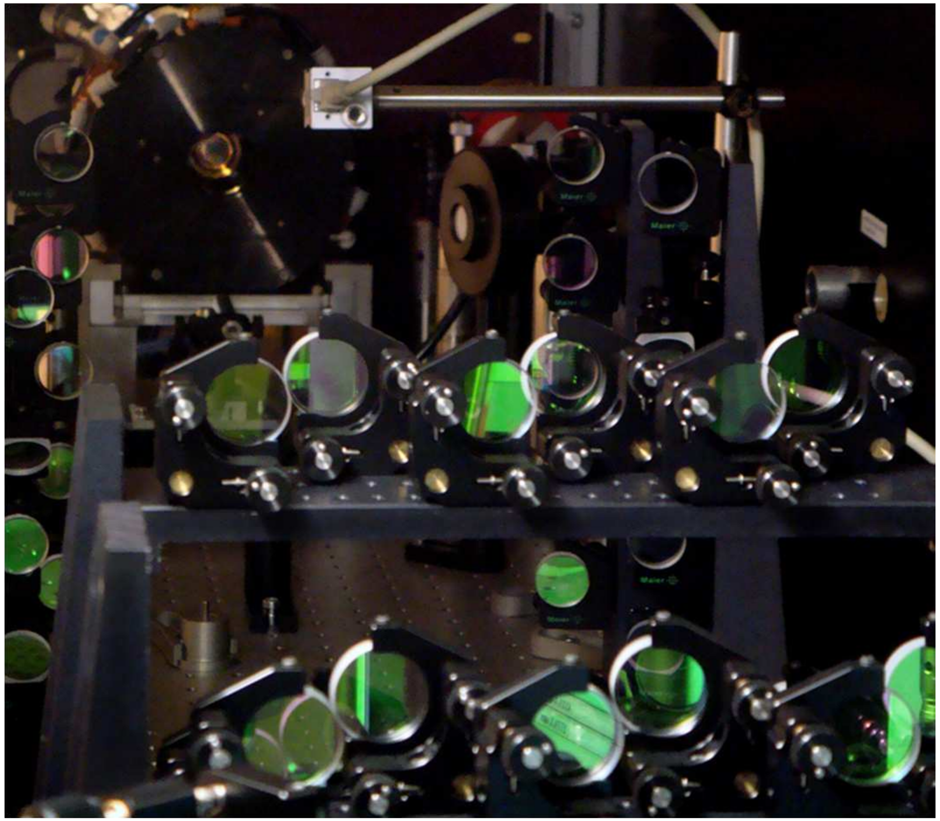
M. Schulz et al.,
Opt. Lett. 36 2456-2458 (2011)

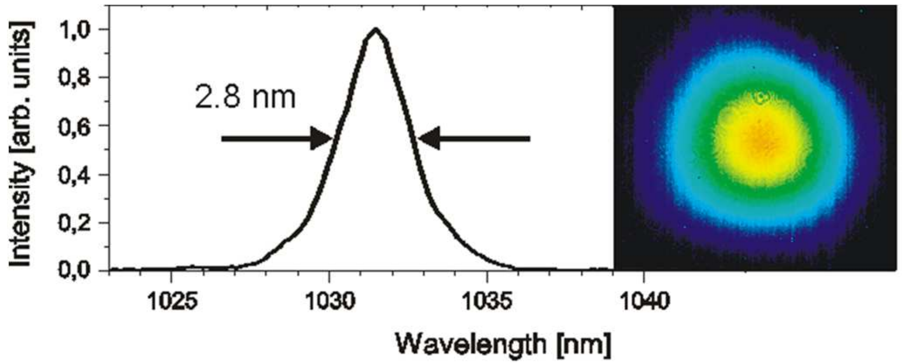
- **1.5 kW amplifier** being installed !

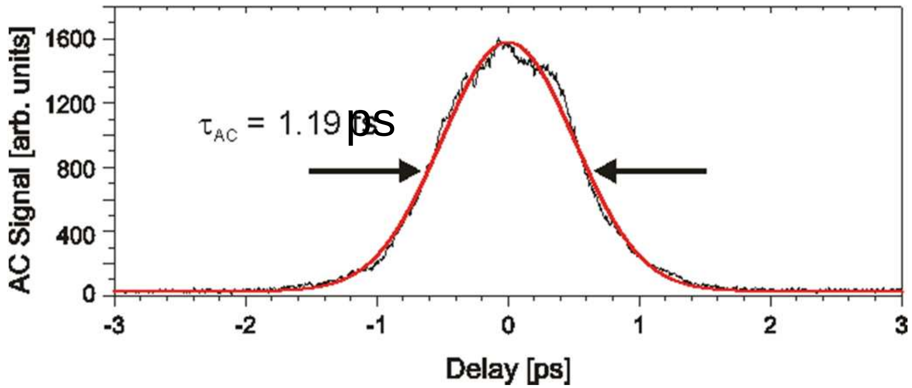
Tested booster amplifiers.

Yb:YAG thin disk multipass amplifier

- number of passes: 30
- diode pump power: 10 kW available
- spectral width: **2.8 nm** FWHM
- pulse duration: **843 fs** FWHM
- pulse energy: >25 mJ @ 100 kHz







- ASE reduced using smaller pump spot:

  → **25 mJ @ 100 kHz (burst)**
  design goal was 20 mJ!

- optimize ASE reduction by different disk geometries

→ **enable full pump power of 10kW!!**

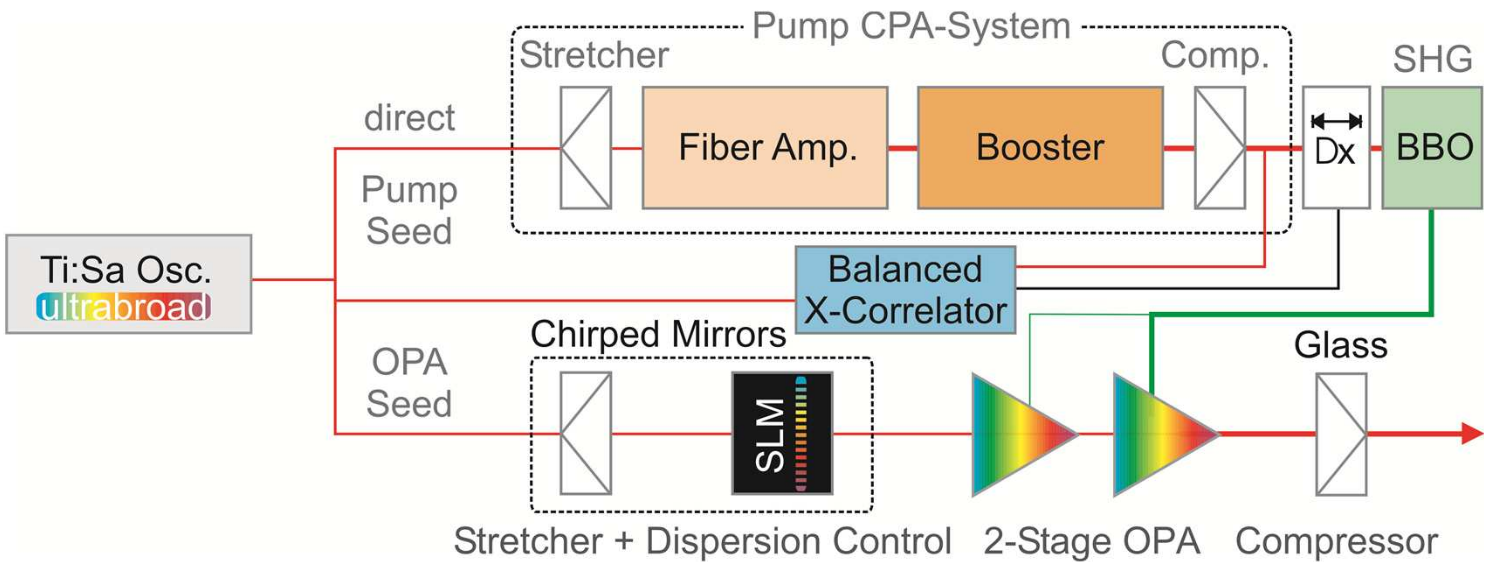
Stability improvements.

The Challenge: make it stable…

temporal pump-seed drift → opto-electronic measurement & control (based on cross correlation)

spatial drifts → beam pointing stabilization systems

pump energy stability → direct seeding of pump amplifier (no PCF required)



Stability improvements.

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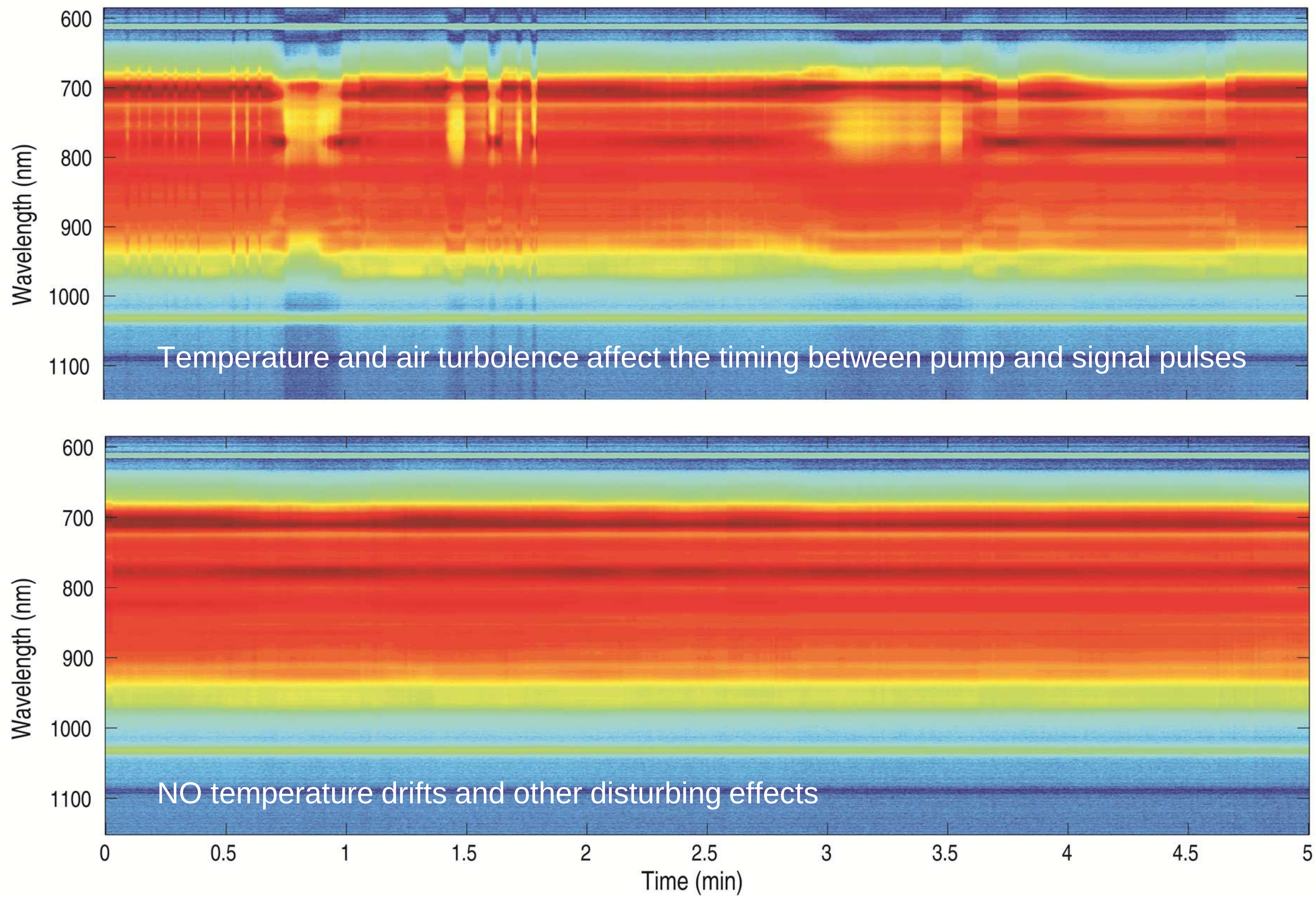
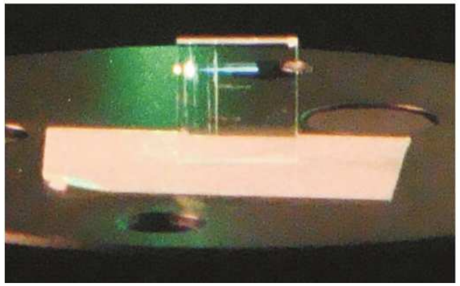
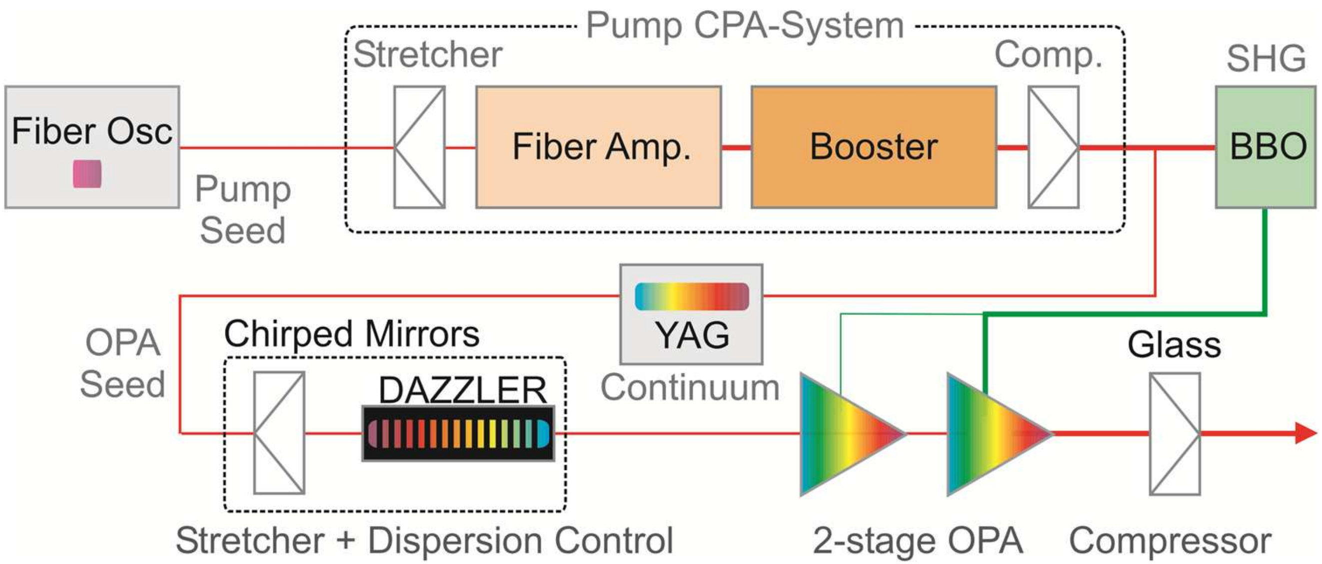


Continuum-seeded OPCPA: Setup.

Generate seed directly with fraction of pump laser

- continuum generation in YAG
- temporal pump-seed drift negligible (short optical paths)
- Yb:glass fiber frontend … no Ti:Sapphire technology in the system !!!!!!





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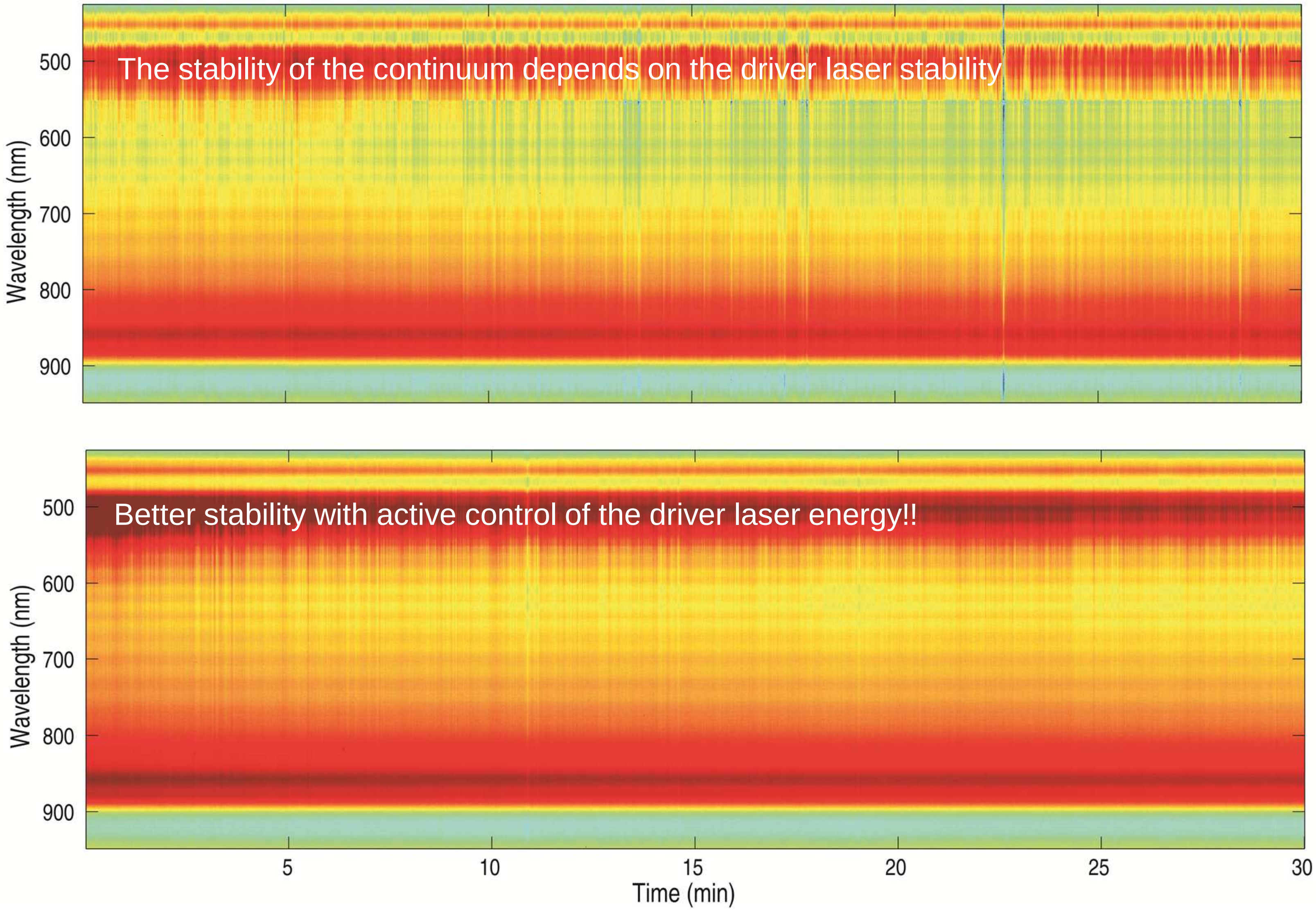


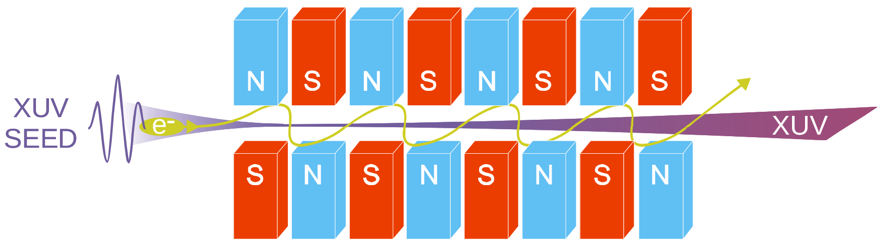
The „Laser-Express“.

HRR-HAP-FCP OPCPA

- mJ level, few-cycle pulses
- kilowatt-level pump amplifier
- active and passive stabilization concepts
- Ready to be used beginning 2012

Highly efficient QPM HHG source

- developement & characterization
- dual gas jet target
- FLASH-II seeding planned in 2015



Seeding FLASH II.

development of high repeptition rate, mJ-level, sub-10 fs laser amplifiers
-enabling technologies-

Collaboration partners:

- Helmholtz Institut Jena
- Institut of Applied Physics Jena (IAP)
  group of A.Tünnermann
- Institut für Lasertechnik Aachen (ILT)
  H. Hoffmann group
- ILT-spinoff Amphos
  T. Mans, C. Schnitzler
- European XFEL
  M. Lederer

development of a laser-driven XUV source
with high conversion efficiency
(QPM-schemes)

Collaboration partners:

- Queens University of Belfast (QUB)
  group of M. Zepf
- Technical University of Crete (TEI)
  group of M. Tatarakis and N. Papadogiannis

Laser Development... F. Tavella, A. Willner, M. Schulz, R. Riedel, A,Hage, M. Prandolini (HI-Jena/DESY/Hamburg University)
DESY-Hamburg University… S. Düsterer, J. Rossbach, M. Drescher, H. Schlarb, J. Feldhaus

FLASH-II team (DESY-Helmholtz Zentrum Berlin)... B. Faatz, A. Meseck, R. Mitzner, F. Tavella, A. Willner, M. Schulz, R. Riedel M. Abo-Bakr, N. Baboi, J. Bahrdt, V. Balandin, W. Decking, S. Düsterer, R. Follath, A. Gamp, K. Holldack, K. Honkavaara, T. Limberg, K. Tiedtke, R. Treusch, K. Wittenburg, S. Schreiber, M.V. Yurkov, E. Schneidmiller