Laser systems for science instruments

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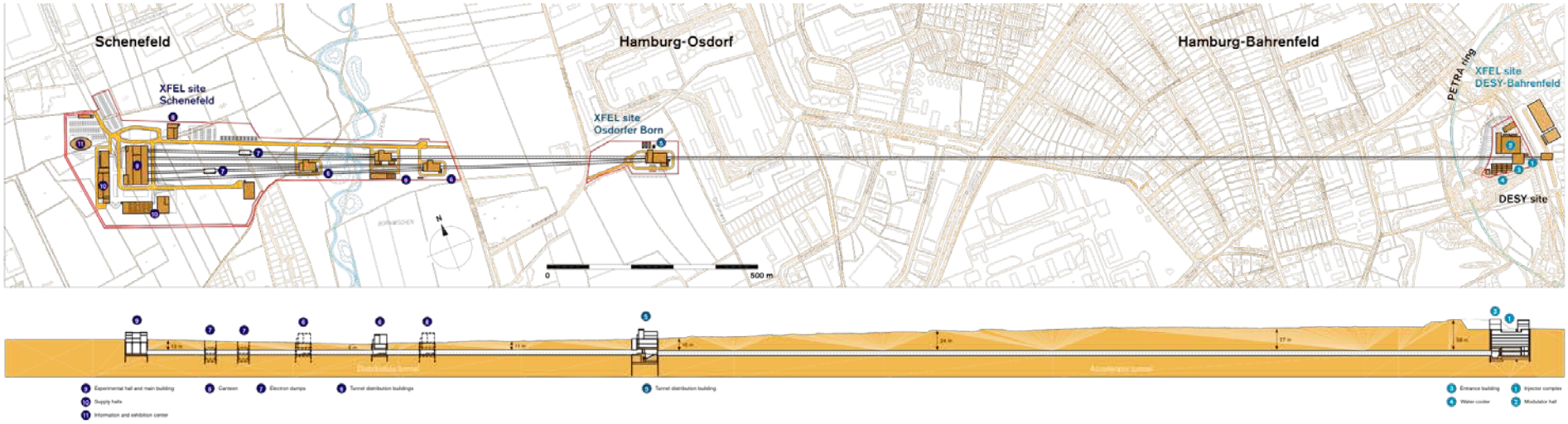
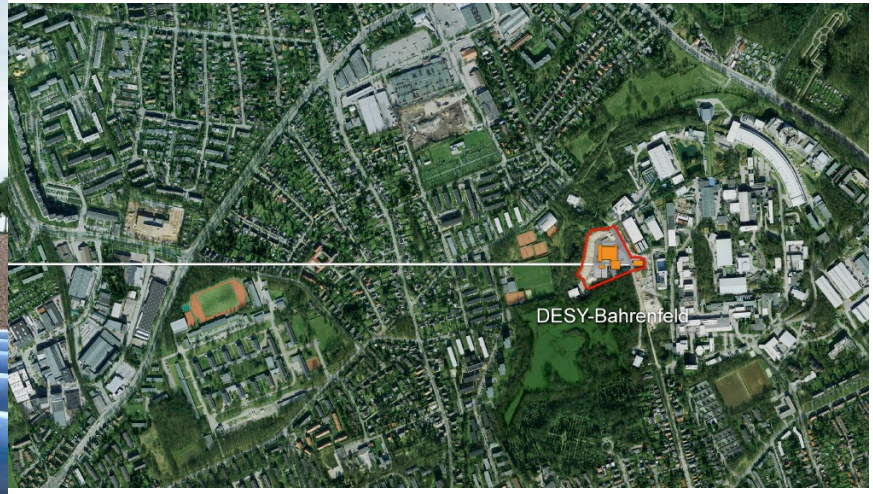


Outline

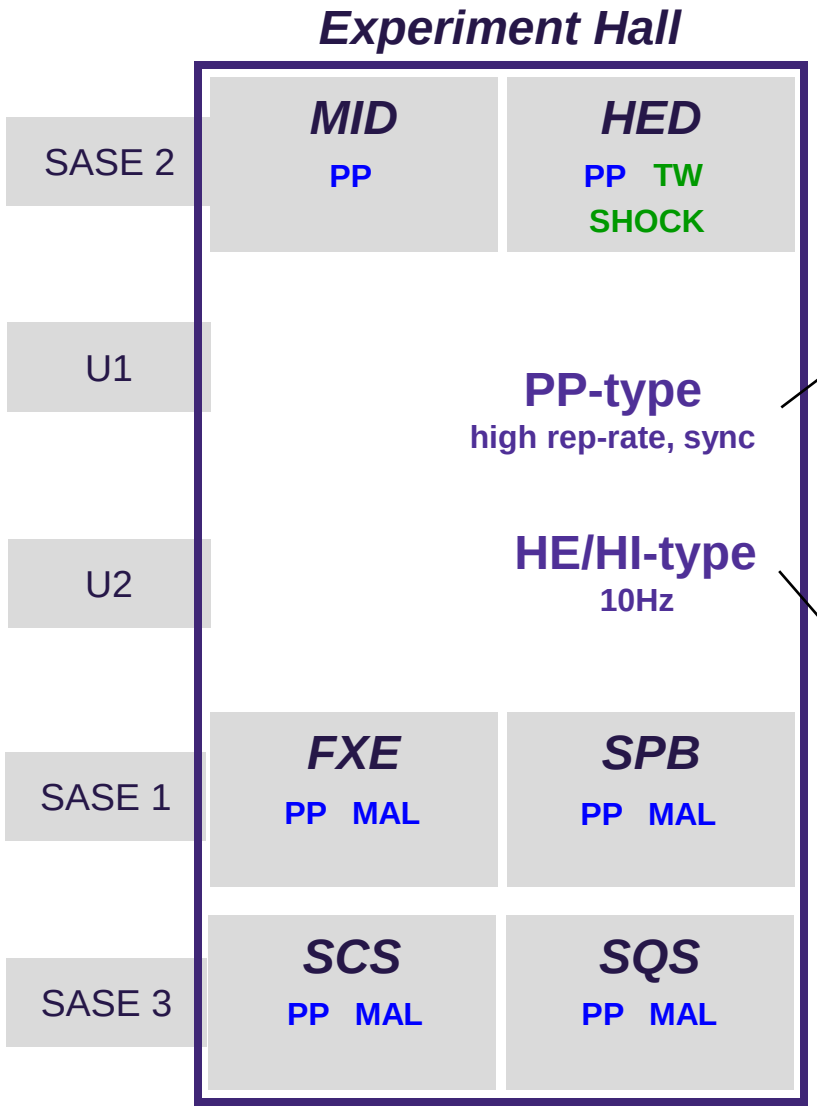
- Introduction
- Lasers for experiments at the EXFEL
- Pump-Probe laser
  - Concept, R&D results and some specs
  - Production systems and installation
- Beam delivery and day-1 conditions
- Summary and outlook

Introduction



- 3 underground experimental areas with 3 X-ray beams
- 6 experiment stations
- Up to 60% of experiments require optical lasers.

Lasers for experiments at the EXFEL



Types of experimental lasers:

PP **pump-probe:**

- sub-15…300fs, mJ-class, 0…4.5MHz, 800nm
- UV…mid-IR, THz

MAL **molecular alignment:**

- sub-20fs, 1…10mJ, 800nm („kick“)

or

- 1J-class, 10Hz ns („adiabatic“)

In-house R&D

100TW **high intensity (HI):**

- <30fs, 10Hz, 100 TW–class laser, Tisa

100J **high energy (HE):**

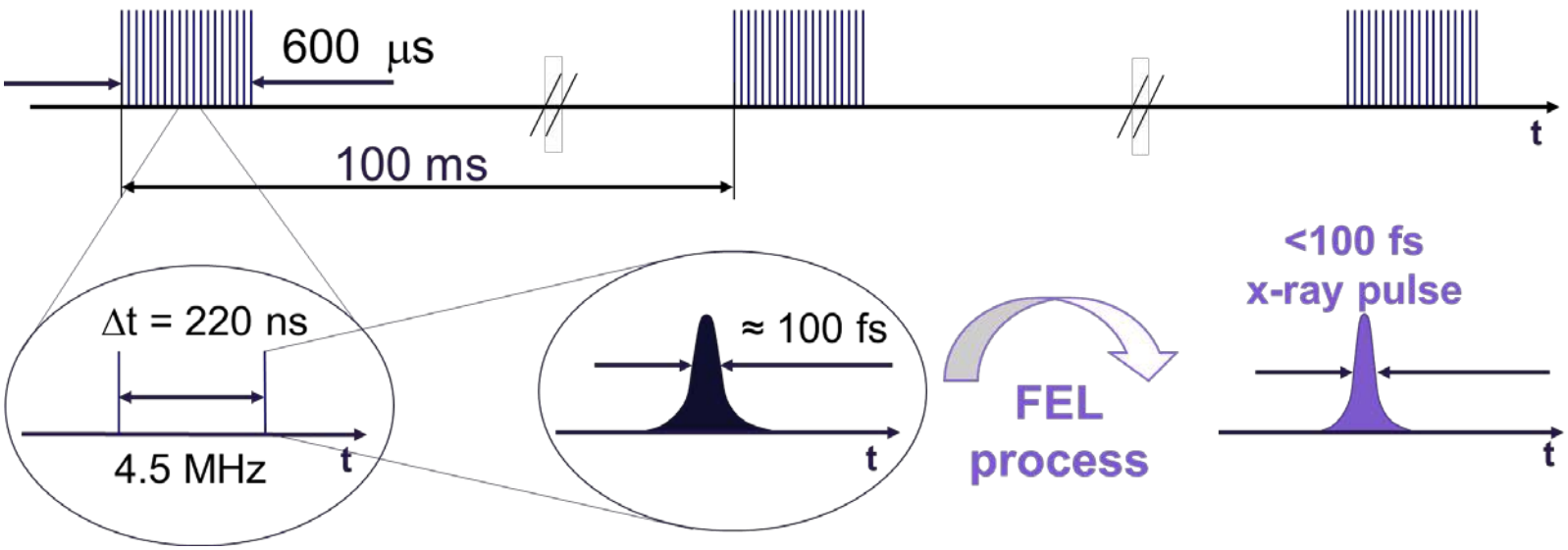
- 100J … kJ-class ns-laser, 10Hz, green, exp. ramp

UC „HiBEF“

Pump-Probe laser

The European XFEL mode of operation: 10Hz Burst

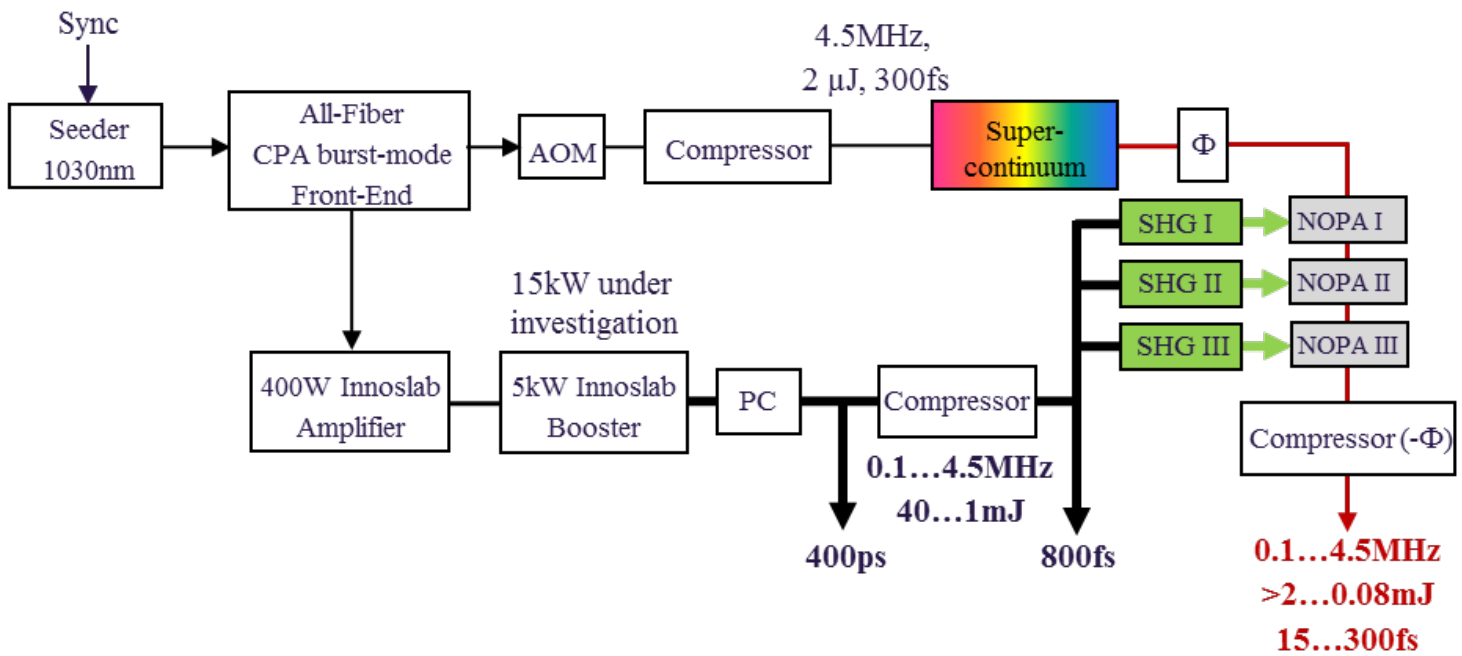
up to 2700 „e⁻ bunches“ à 0.1…1 nC => eff. rep-rate: 27000 Hz



Pump-probe laser goals

- ⇨ **Match XFEL: 10Hz burst, 0 – 4.5MHz**
- ⇨ **800nm: 15 - 300fs, mJ**
- ⇨ **Arbitrary pulse pattern selection**
- ⇨ **Frequency conversion**

Pump-Probe laser concept: *fs-pumped NOPA*

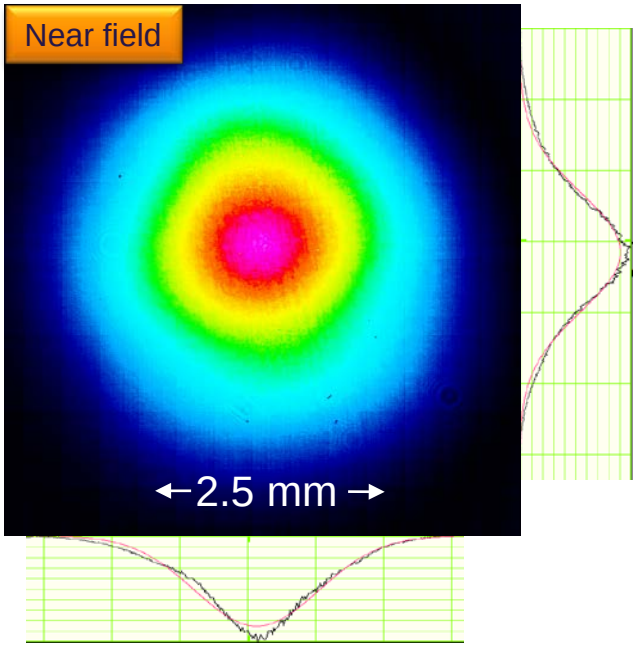


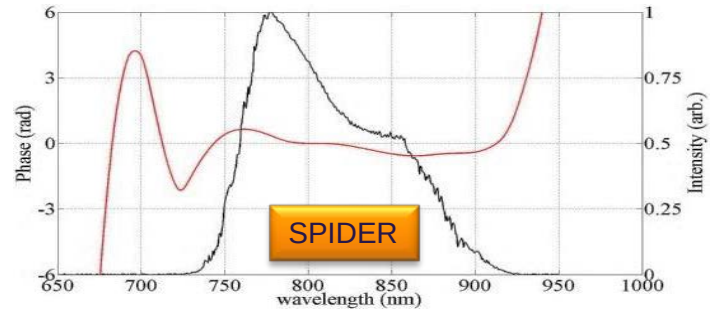
Working points:

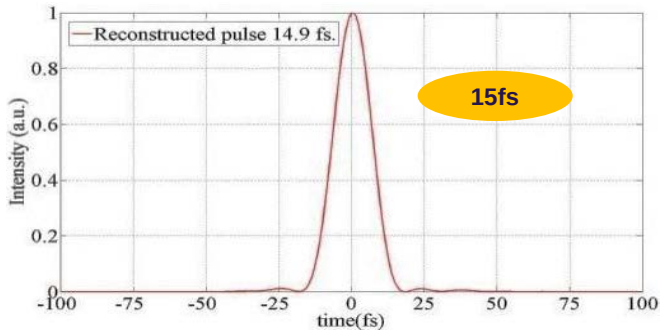
- 4.5MHz and 1MHz: NOPA I + II (BBO)
- 200kHz and 100kHz: NOPA I + II + III (BBO)

1. A. Dubietis, G. Jonusauskas, and A. Piskarskas, "Powerful femtosecond pulse generation by chirped and stretched pulse parametric amplification in BBO crystal," Opt. Commun. 88, 437–440 (1992)
2. G. Cerullo and S. De Silvestri, "Ultrafast optical parametric amplifiers," Rev. Sci. Instrum. **74**, No. 1 (2003)
3. M.J. Lederer, M. Pergament, M. Kellert, and C. Mendez, "Pump–probe laser development for the European X-Ray Free-Electron Laser Facility," Paper 8594-20, SPIE Conference on Optics and Photonics 2012, 12-16 August 2012, San Diego, Invited talk.
4. M. Pergament, M. Kellert, K. Kruse, J. Wang, G. Palmer, L. Wissmann, U. Wegner, and M. Lederer, "High power burst-mode optical parametric amplifier with arbitrary pulse selection," Optics Express, Vol. 22, Issue 18, pp. 22202-22210 (2014)
5. M. Pergament, M. Kellert, K. Kruse, J. Wang, G. Palmer, L. Wissmann, U. Wegner, M. Emons, M. J. Lederer, "340W Femtosecond Burst-mode Non-collinear Optical Parametric Amplifier for the European XFEL Pump-probe-laser," Advanced Solid State Lasers, 04-09. October 2015, Berlin, Germany, ATu4A.4

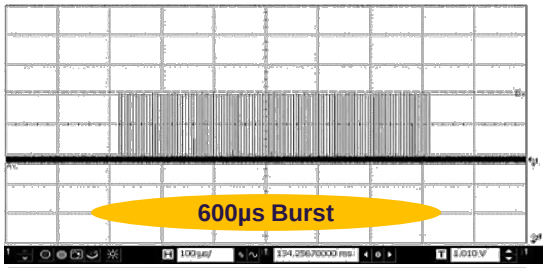
NOPA I + II

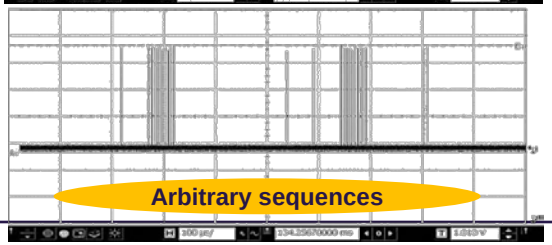






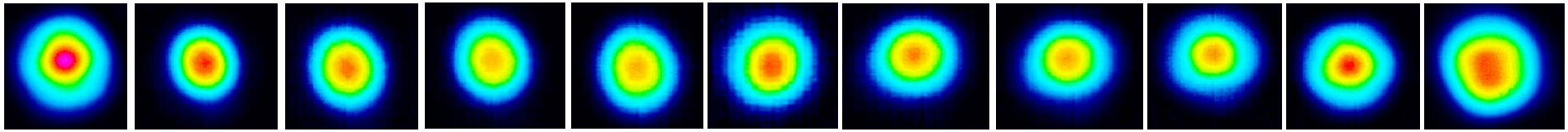
- **Pulse energies:**
  - ⇨ 80 µJ @ 4.5MHz
  - ⇨ 330 µJ @ 1.1MHz
- **Burst power:** 360W (600 µs)
- **Pulsewidth:** 15fs
- **Spectrum:** 13.8 fs Fourier-limited pulse
- **Burst-noise:** 2.5 % rms (scope, high air flow conditions)
- **Burst shape:** clean, arbitrary sequences possible

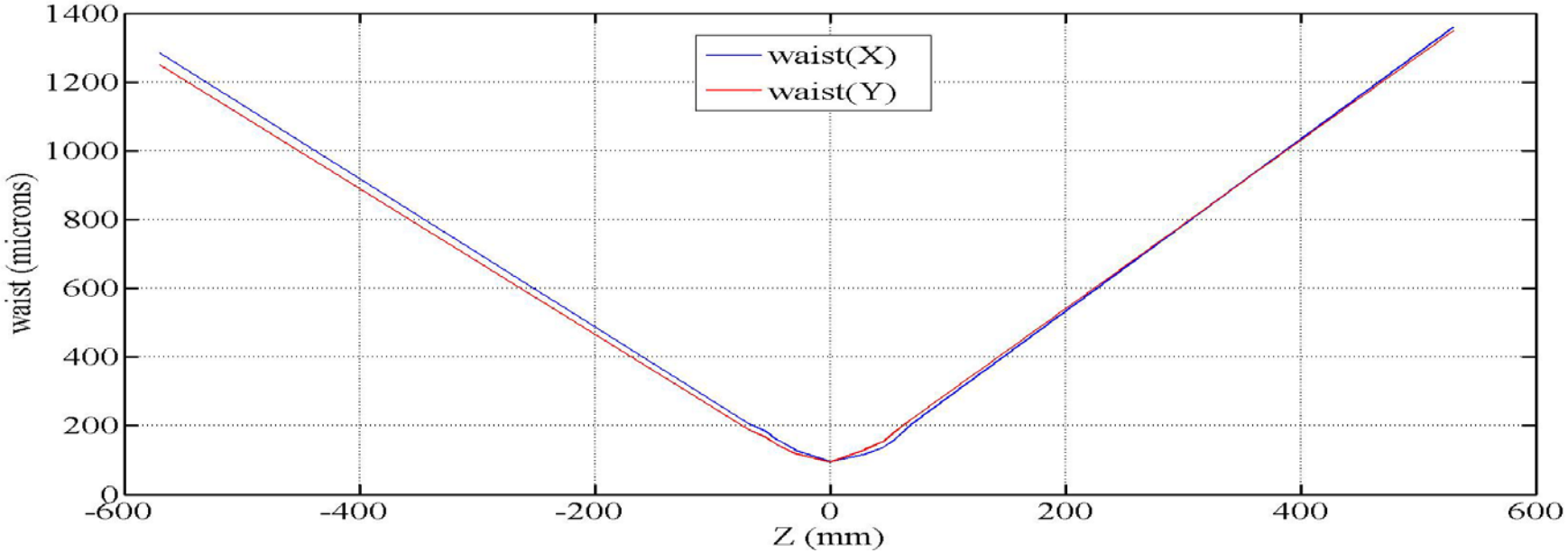




Beam quality NOPA I + II

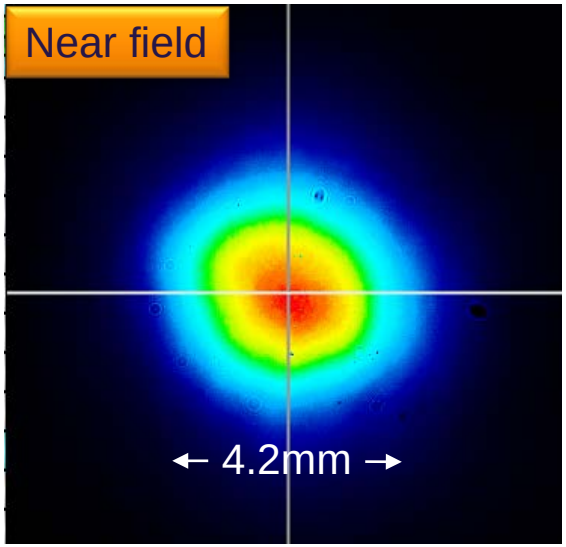
Waist Scan

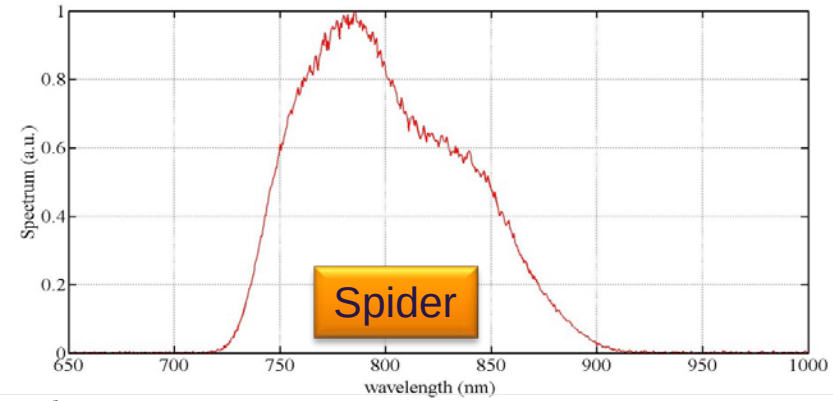


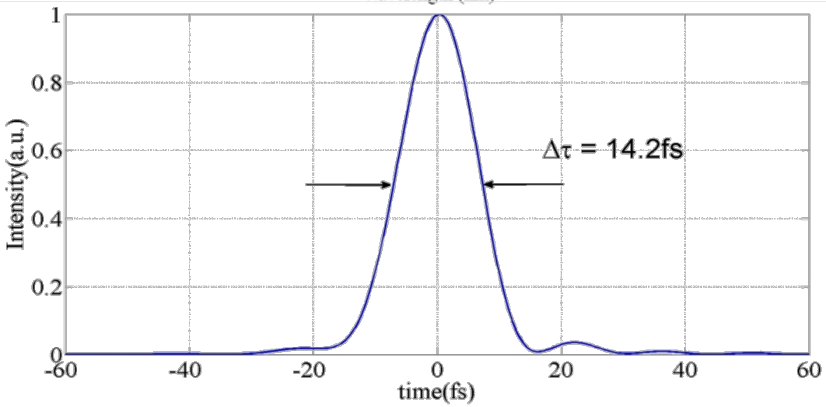


- Gaussian fit >94% for 15 Rayleigh ranges
- Close to diffraction limited Gaussian beam: $M^2<1.1$

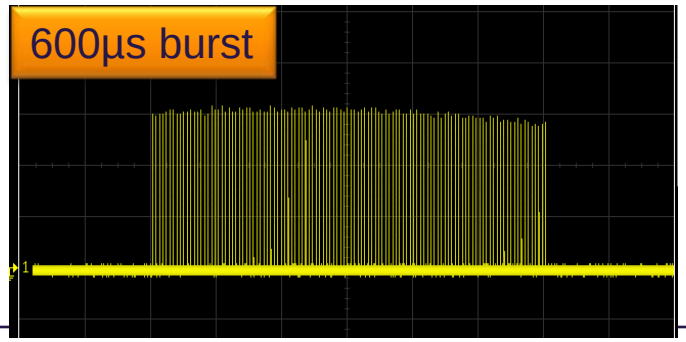
NOPA I + II + III





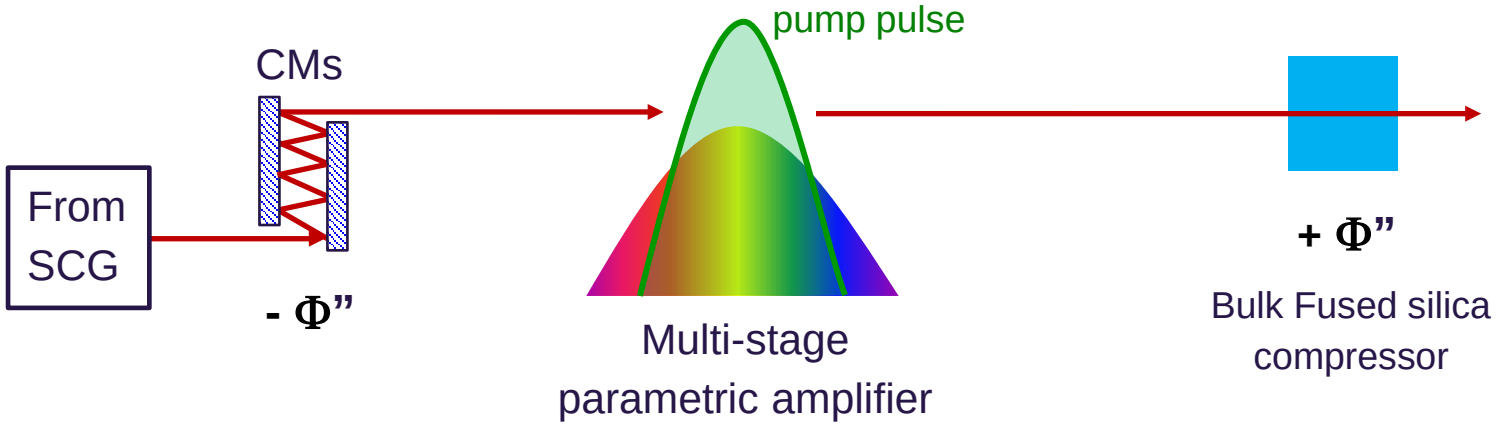


- **Pulse energy:** 1.7mJ @ 188kHz
  2.5mJ @ 100kHz
- **Burst power:** >250W (600 µs)
- **Pulsewidth:** <15fs
- **Beam quality:** similar to NOPA I + II

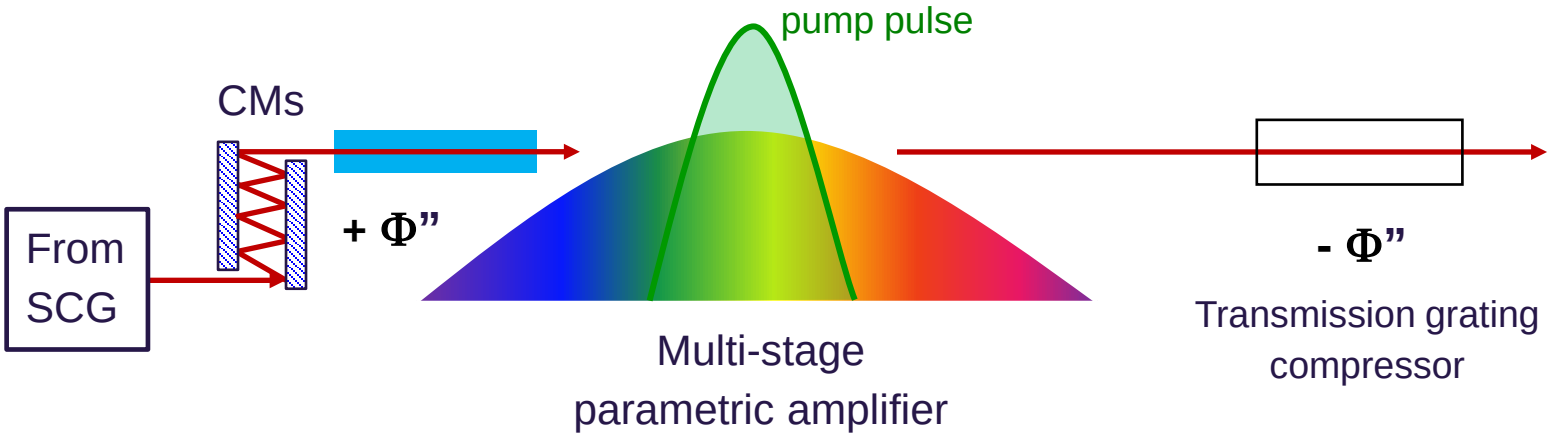


Dispersion management

Short pulse dispersion management: 15fs pulse duration

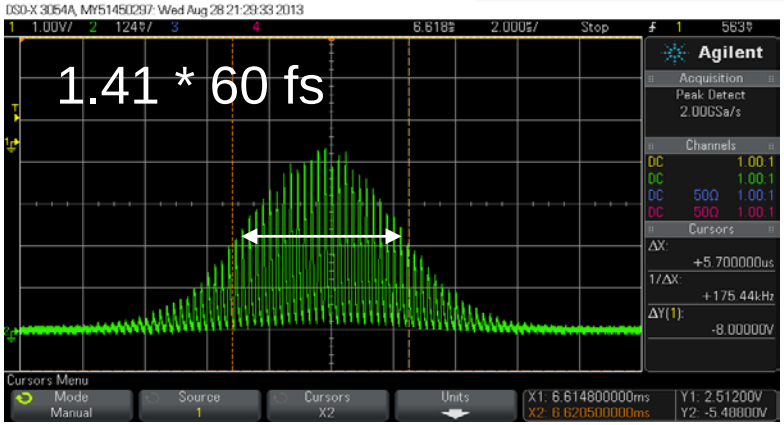


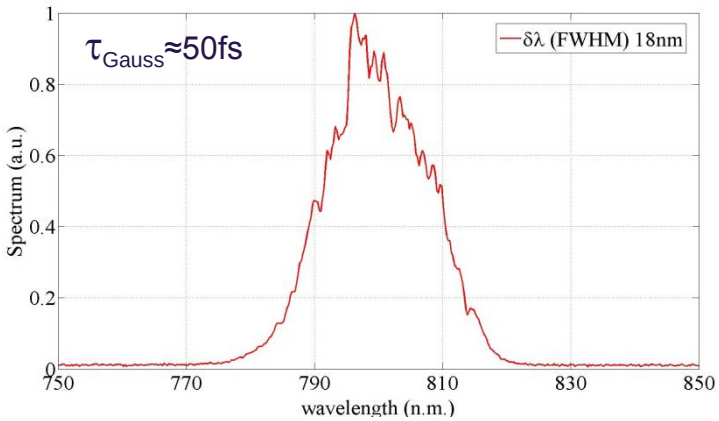
Long pulse dispersion management: 25-300fs pulse duration



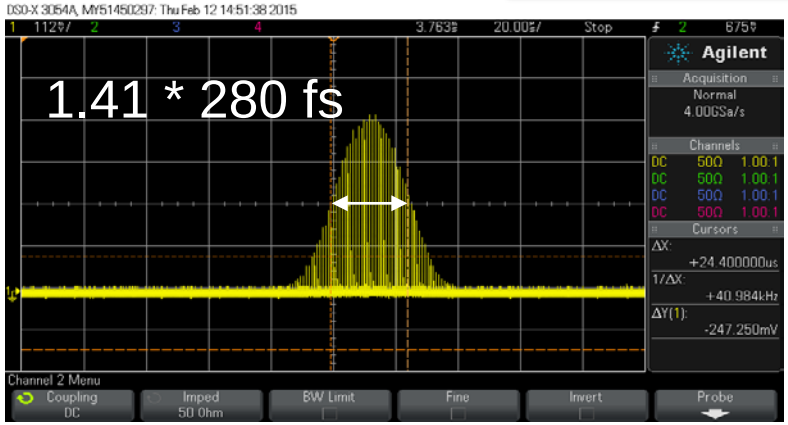
Long pulses from the NOPA

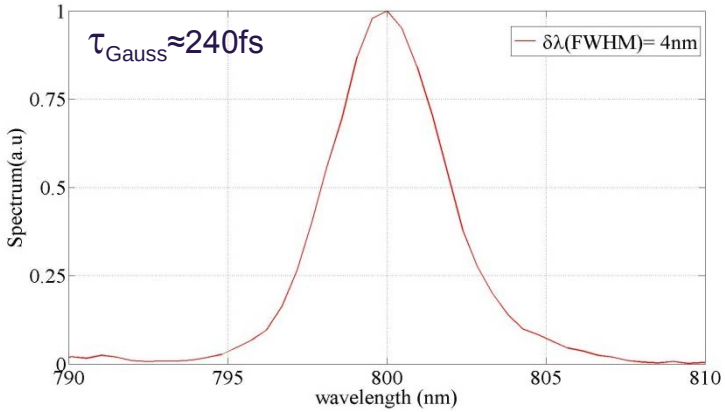
60 fs pulse (Treacy compressor)



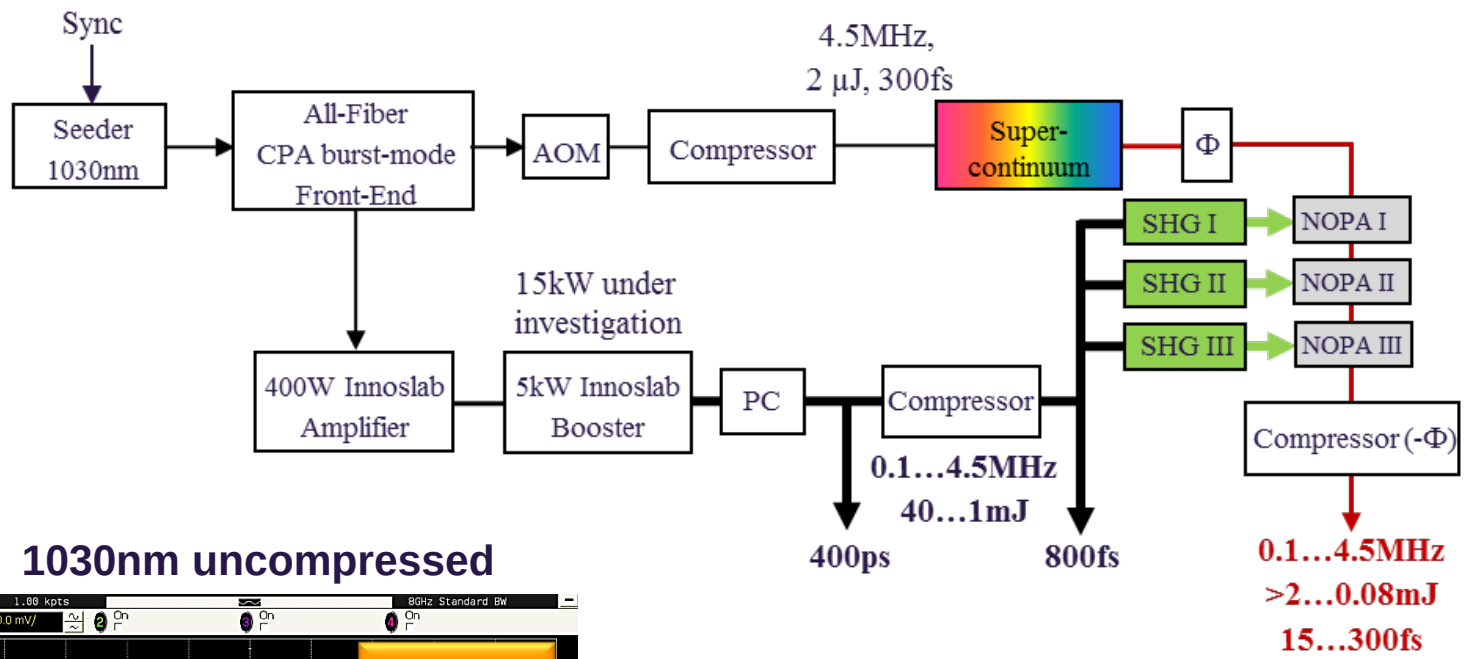


280 fs pulse (No compressor)

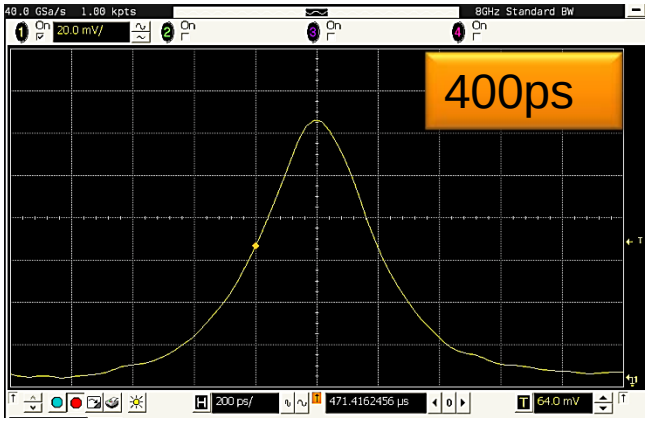




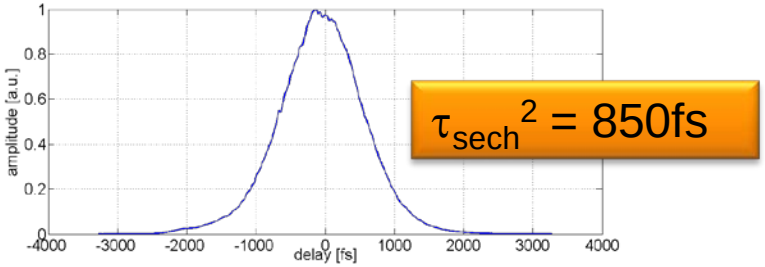
1030nm pump beam and mixed-mode



1030nm uncompressed

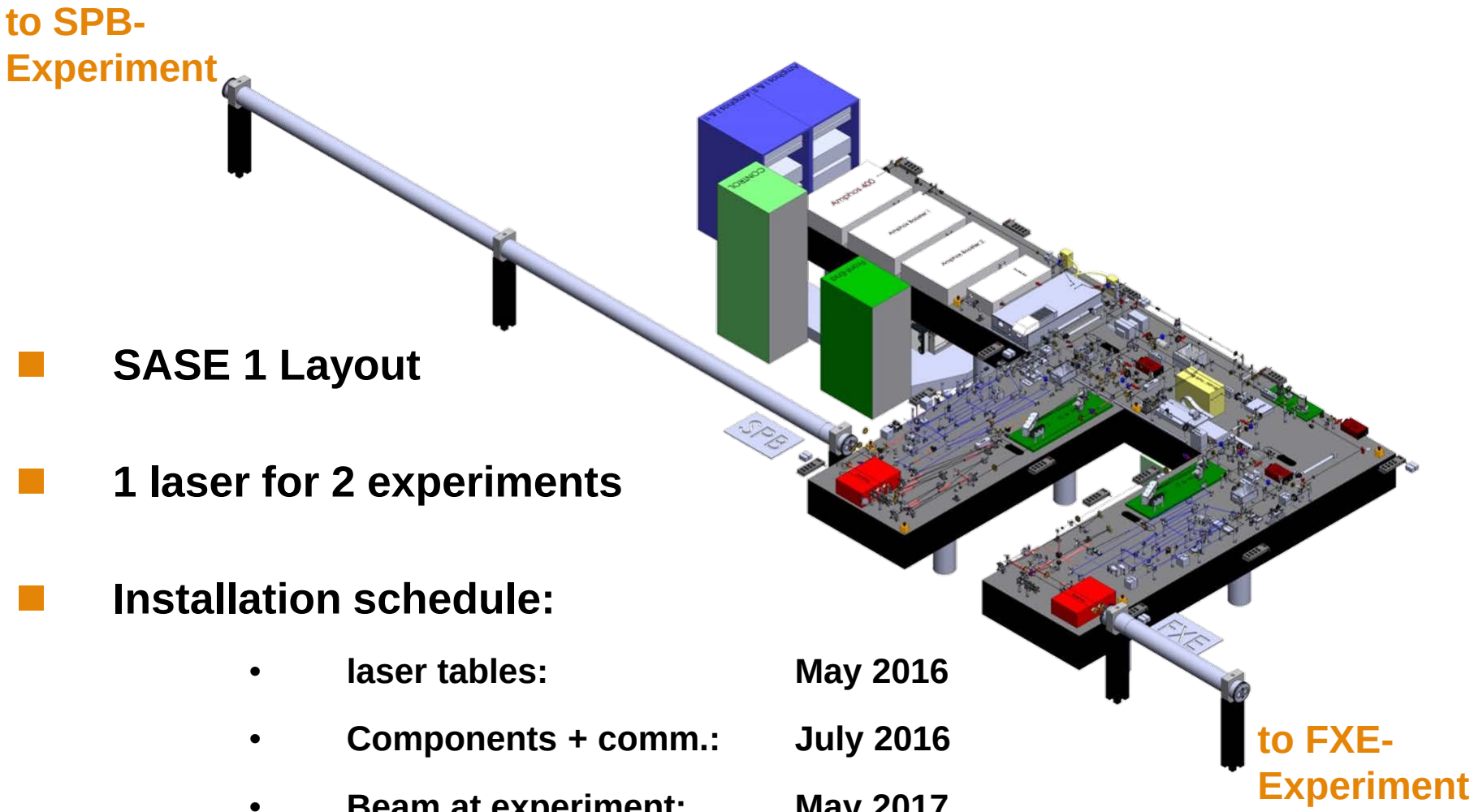


1030nm compressed



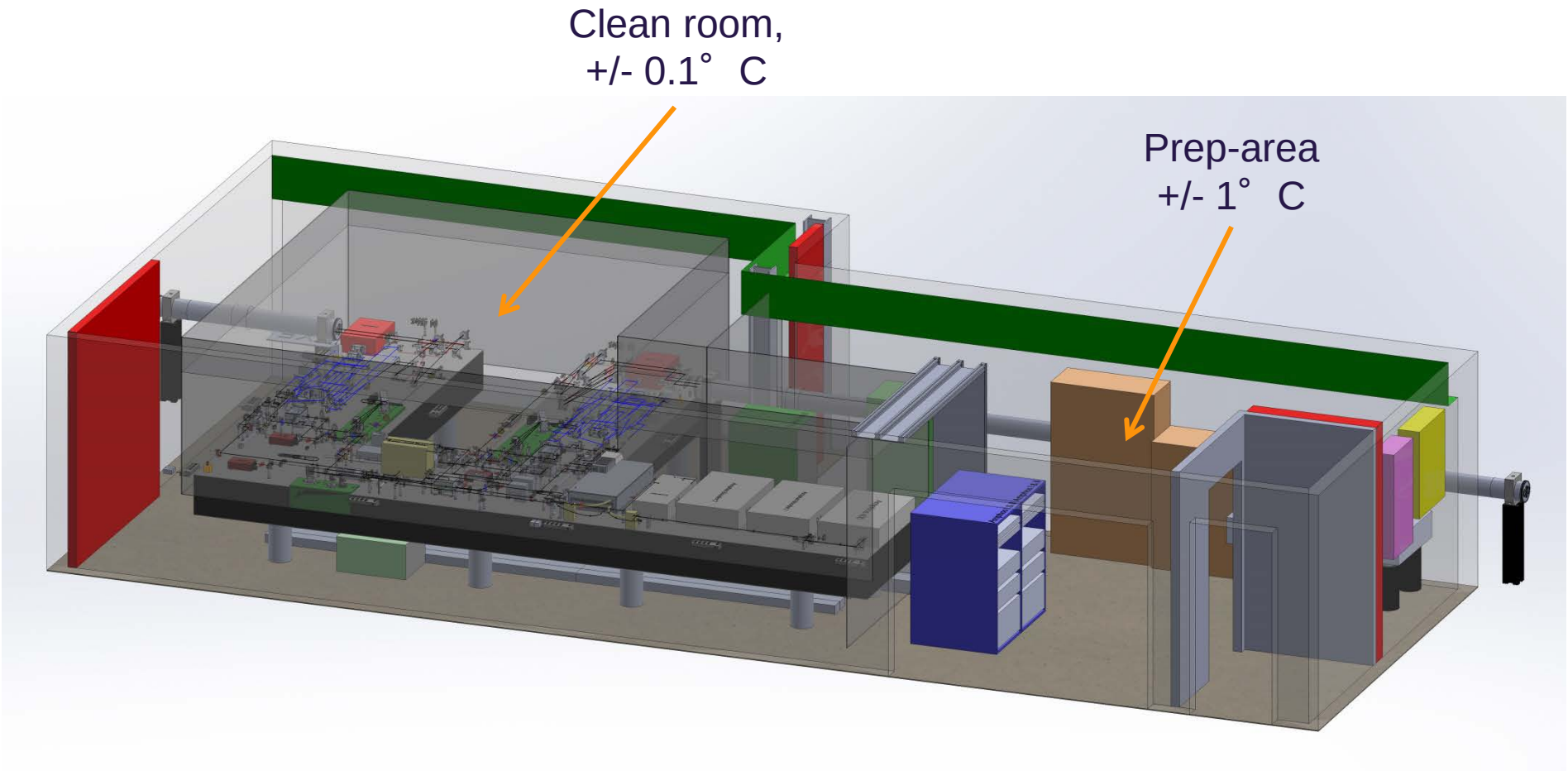
Mixed-mode: e. g. 100kHz, 1mJ / 15fs / 800nm and 10mJ / 400ps / 1030nm

Production system SASE 1

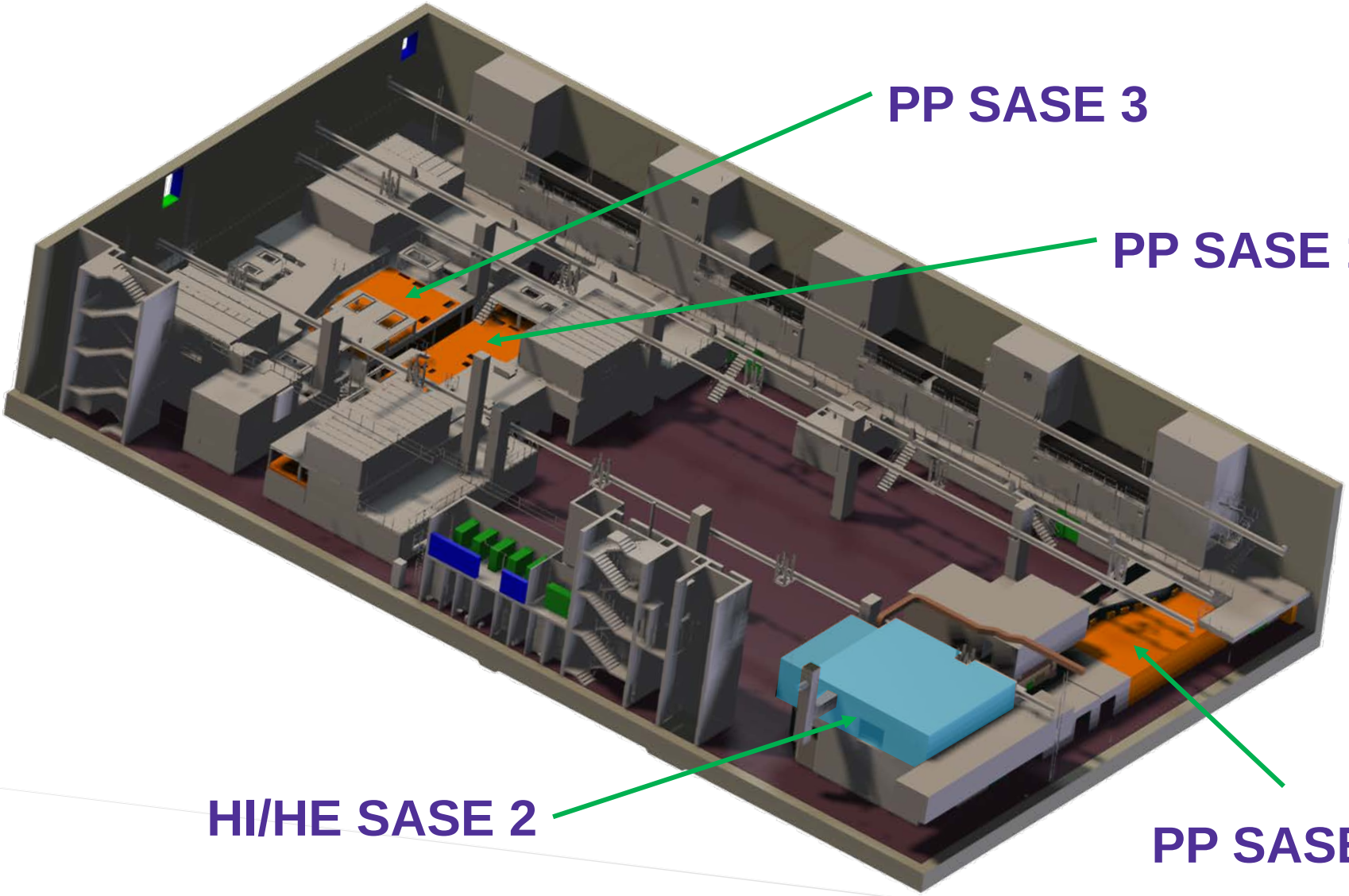


- **SASE 1 Layout**
- **1 laser for 2 experiments**
- **Installation schedule:**
  - **laser tables: May 2016**
  - **Components + comm.: July 2016**
  - **Beam at experiment: May 2017**

Pump-probe laser hutch SASE 1



XHEXP 1 with laser installations



Beam delivery concept and responsibilities

PP-laser hutch ➔ Instument laser hutch ➔ Experiment

WP78

- Laser configuration
- 800nm /1030nm / f / τ
- Burst and pulse selection
- Overlap delay
- Limited tuning

Instruments, WP78

- Beam routing
- Dispersion management
- Various controls
  - Attenuation
  - Pulse selection
  - Overlap delay
  - Shutter
  - Limited tuning
- Harmonics ?
- TOPAS ?
- …

Instruments, WP78

- Pump-probe delay
- Various controls
  - Attenuation
  - Pulse selection
  - Overlap delay
  - Shutter
  - Limited tuning
- Coupling to experiment
- Timing tool
- Harmonics ?
- TOPAS ?
- …

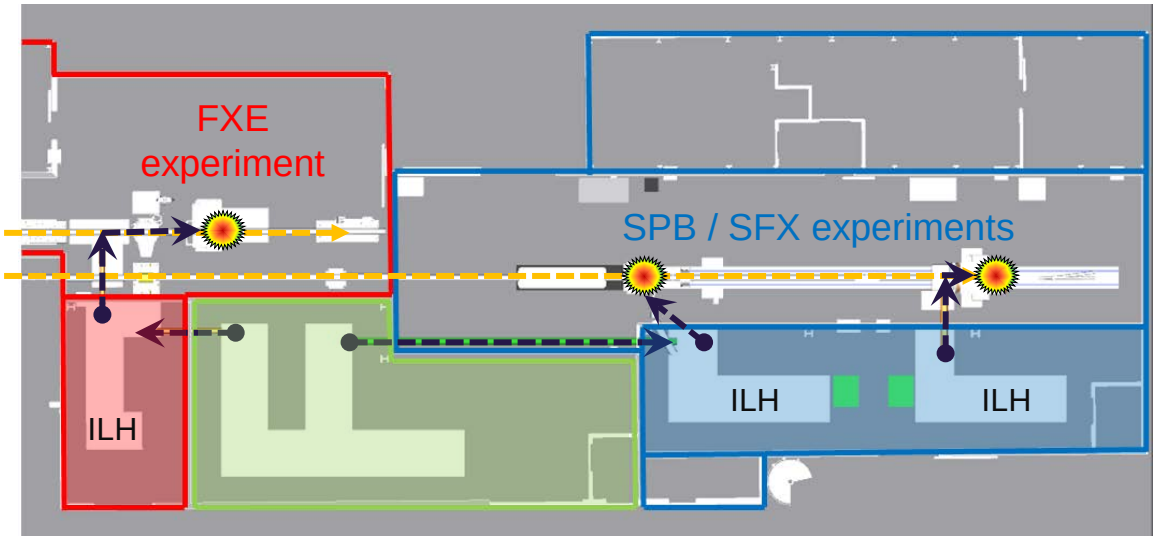
Beam delivery concept and responsibilities

SASE 1

FXE: x-ray

SPB: x-ray

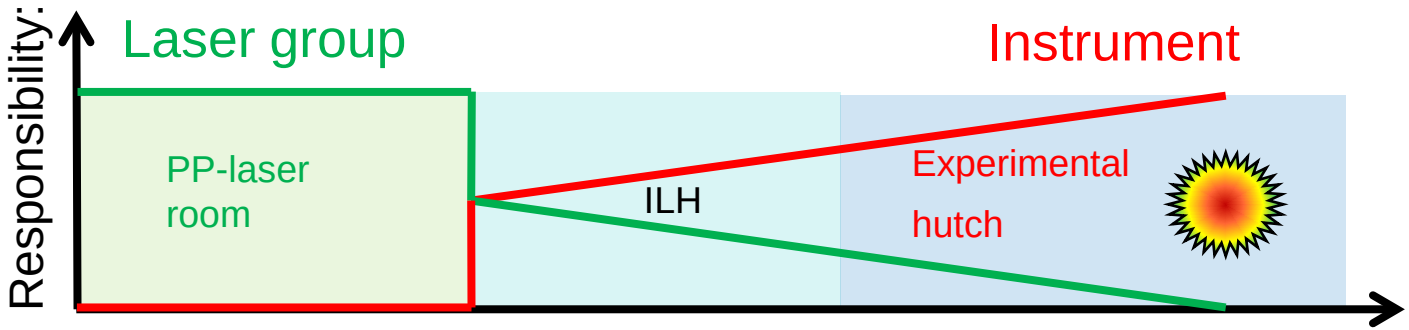
sample interaction



FXE instrument laser hutch

PP-laser hutch

SPB/SFX instrument laser hutch



Some day-1 requirements at SASE 1

Example SPB-SFX:

1) From PP-Laser hutch:

- **800 nm**, ~ 300fsec (chirped, compressible to 15fs when passing correct length of UV-grade fused silica)
- Pulse energy: **~ 50 µJ**
- Polarisation: Linear, vertical
- Rep-rate: **100 kHz**
- Alignment laser: 787 nm and 1055 nm (collimated laser diodes)
- Remote operation of alignment laser and shutter.

2) Laser Specs at SPB experiment:

- **400 nm** – *SHG provided by WP78*
- Beam diameter: **50 µm on target**
- Pulse duration: ~ **15 fsec**
- Pulse energy: **1 µJ**
- Polarisation: Linear
- Repetition Rate: 100 kHz
- Delay time: -2, -1, 0, 1, 2, 3….100 ps. -100, -90, …. 100, 110, 120…. 1000 fs 100 – 200 time point

Schedules

General PP-laser installation schedule:

Task 1:	Laser tables and infrastructure in PP and ILH-hutches	**month 1-3**
Task 2:	Components + commissioning in PP and ILH-hutches	**month 4-11**
Task 3:	Beam at experiment for day-1	**month 12**

SASE-specific milestones:

SASE 1	Milestone	Date
	„sensitive equipment (start **Task 1**)	26.04.2016
	„infrastructure complete“ (start **Task 2**)	19.07.2016
SASE 3		
	„sensitive equipment (start **Task 1**)	29.10.2016
	„infrastructure complete“ (start **Task 2**)	23.12.2016
SASE 2		
	„sensitive equipment (start **Task 1**)	14.01.2017
	„infrastructure complete“ (start **Task 2**)	10.03.2017

Summary PP-laser for science instruments

- **800nm** burst-mode NOPA:
  - burst average power of >300W
  - up to >2mJ single pulse energy
  - <15fs … 300fs, close to transform limited
  - nearly diffraction limited beam quality
  - 4.5MHz, 1.1MHz, 200kHz, 100kHz, arbitrary pulse sequences
- **1030nm** burst-mode:
  - Burst average power of >4kW
  - up to 40mJ single pulse energy
  - 800fs or 400ps
  - $M^2 < 1.5$
  - 4.5MHz, 1.1MHz, 200kHz, 100kHz, arbitrary pulse sequences
- **Installation of production systems starts in May 2015 at SASE 1**

Thank you!

WP78:

Mikhail Pergament
Martin Kellert
Kai Kruse
Jin Wang
Guido Palmer
Gerd Priebe
Laurens Wissmann
Ulrike Wegner
Moritz Emons
Daniel Kane
Max Lederer