The European XFEL Project – lasers for user experiments

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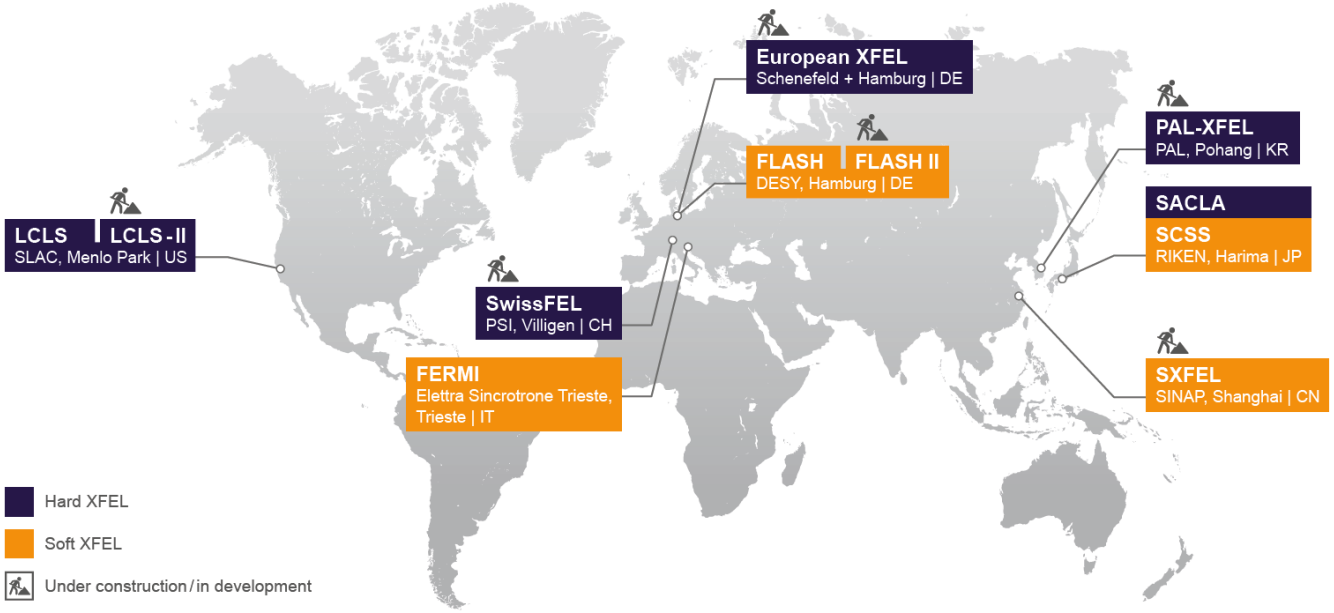
European XFEL mission

International multi-user facility for FEL research by a multi-disciplinary science community using ultrashort soft & hard X-ray FEL pulses.



- **User proposed experiments:** peer-review, invitation, support
- **Basic science:** establish the foundations for future high-tech applications
- **Multidisciplinary:** physics, chemistry, biology, materials sciences, geo-sciences, ...

European XFEL as international project

Partner countries

- GmbH under German law

Total project cost

- Construction (2009-2017) 1.15 B€(2005)
- Operation (≥2017) ~100 M€/yr
  - → **~4800 hrs/yr x-ray FEL beam delivery**

Partners & In-Kind contributions (~50%)

- About 30 different contributions
- Accelerator is biggest object
  - → **DESY: coordinator of the Accelerator Consortium**
- Responsibilities construction and operation:
  - → **DESY → Accelerator & tech. Infrastructure;**
  - → **XFEL.EU → X-ray units & scientific user program**

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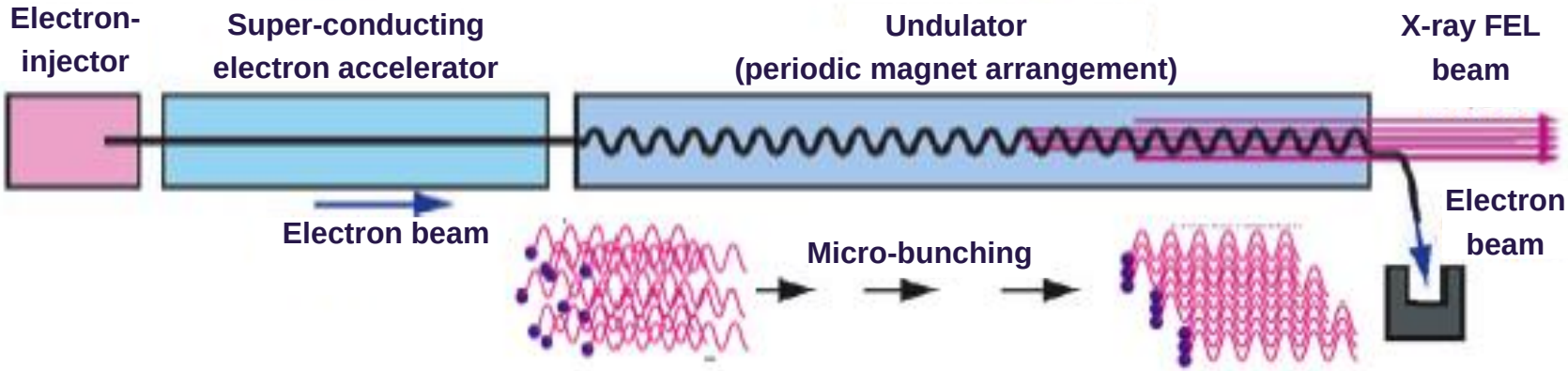
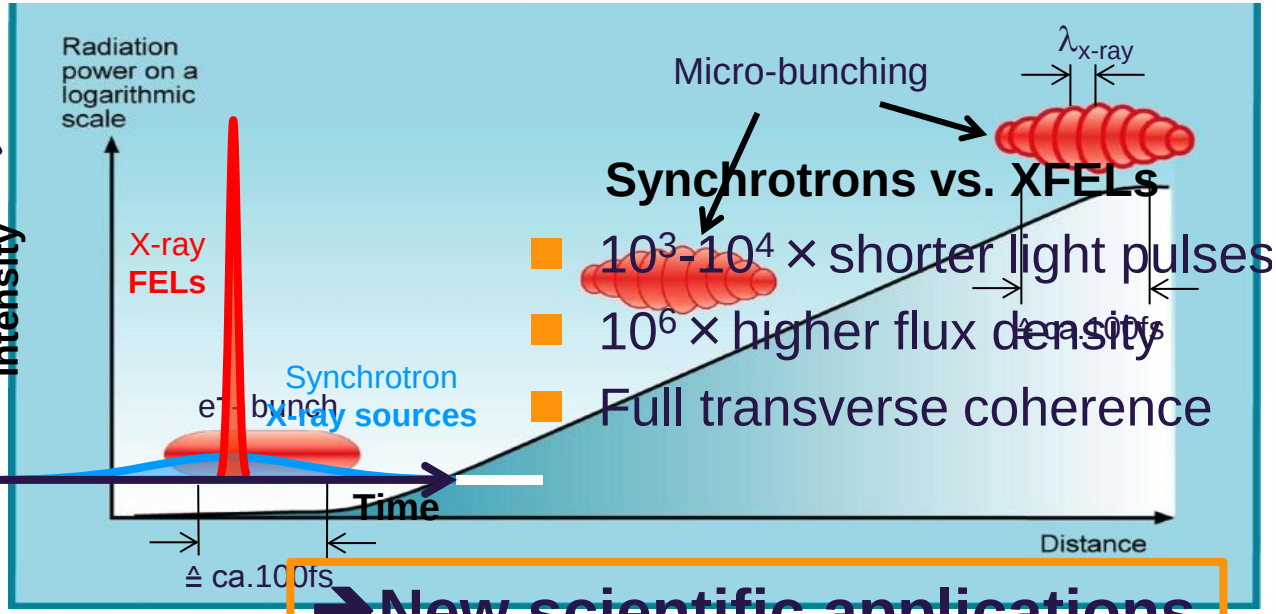
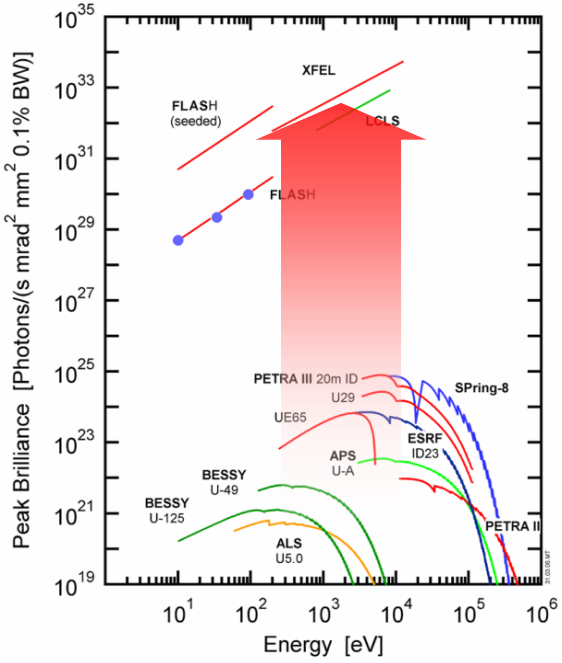
X-ray Free-Electron Laser (XFEL)





Synchrotrons vs. XFELs

- 10^3-10^4 × shorter light pulses
- 10^6 × higher flux density
- Full transverse coherence



➔ **New scientific applications**

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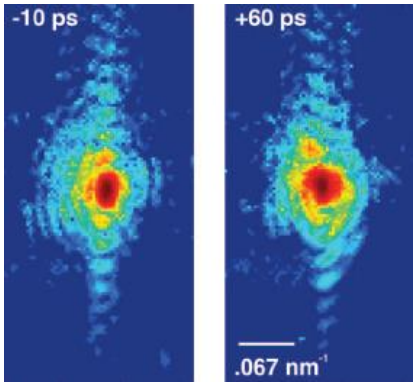
New science capabilities

Imaging and structure determination

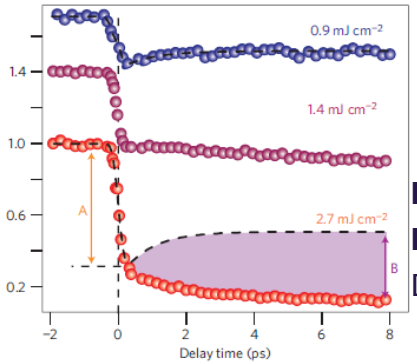
- Use high coherence & flux
- Nano-scale objects
- Single molecules or cells



Au nanocrystals
Clark et al.,
Science 341, 56 (2013)

Ultrafast processes

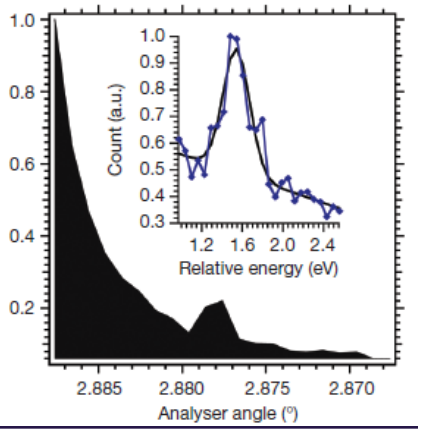
- Use extremely short x-ray pulses
- Photo- & reaction chemistry
- Condensed-matter phase transitions



Insulator-metal-transition
De Jong et al.,
DOI: 10.1038/NMAT3718

Non-linear processes and extreme states

- Higher order x-ray processes
- X-ray excitation of matter



Non-linear mixing
Glover et al.,
Nature 488, 603 (2012)

High peak & average flux applications

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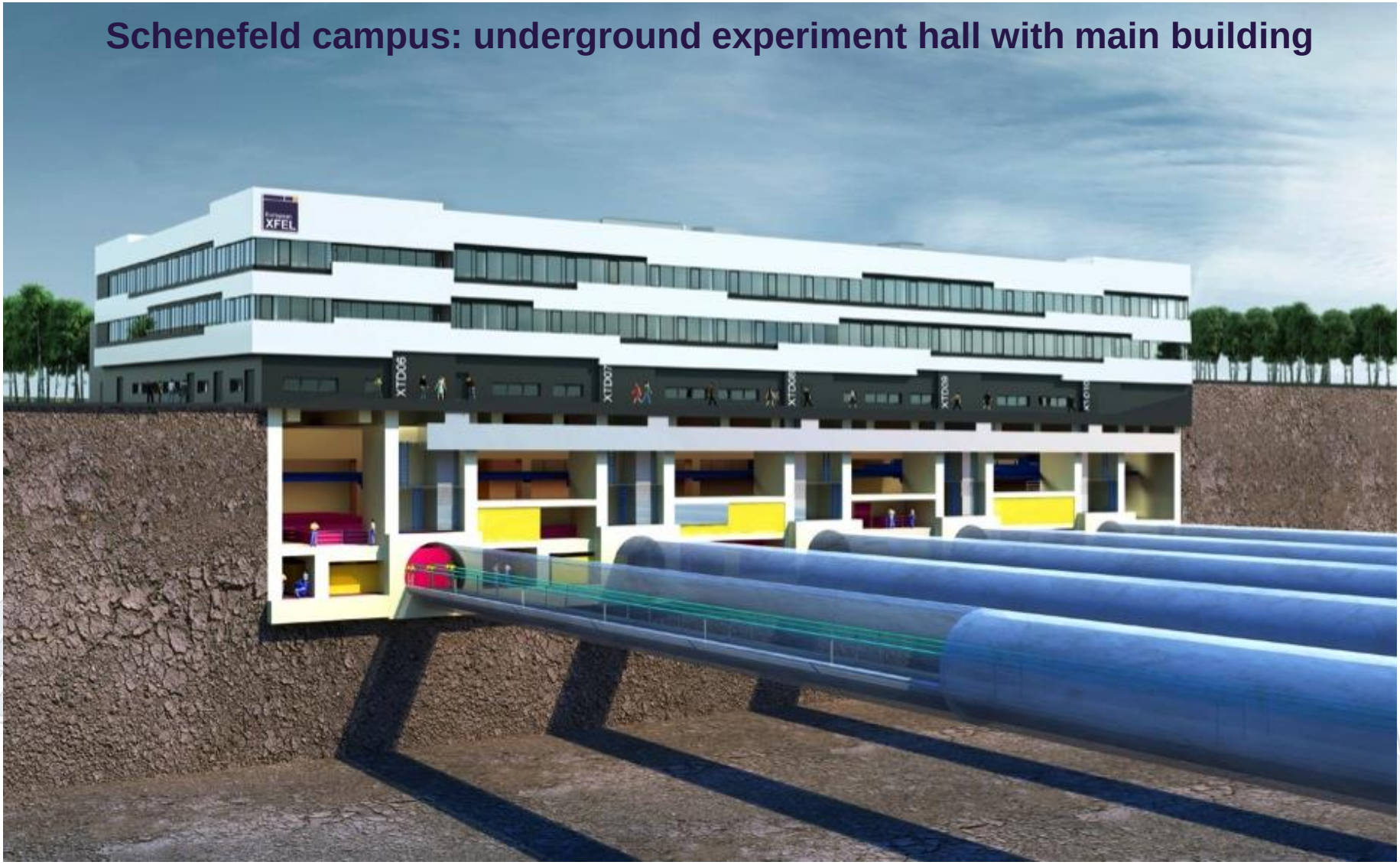
Facility overview

Schenefeld campus: underground experiment hall with main building



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LINAC-Tunnel with infrastructure

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Bird’s eye view of Schenefeld campus, Juli 2014

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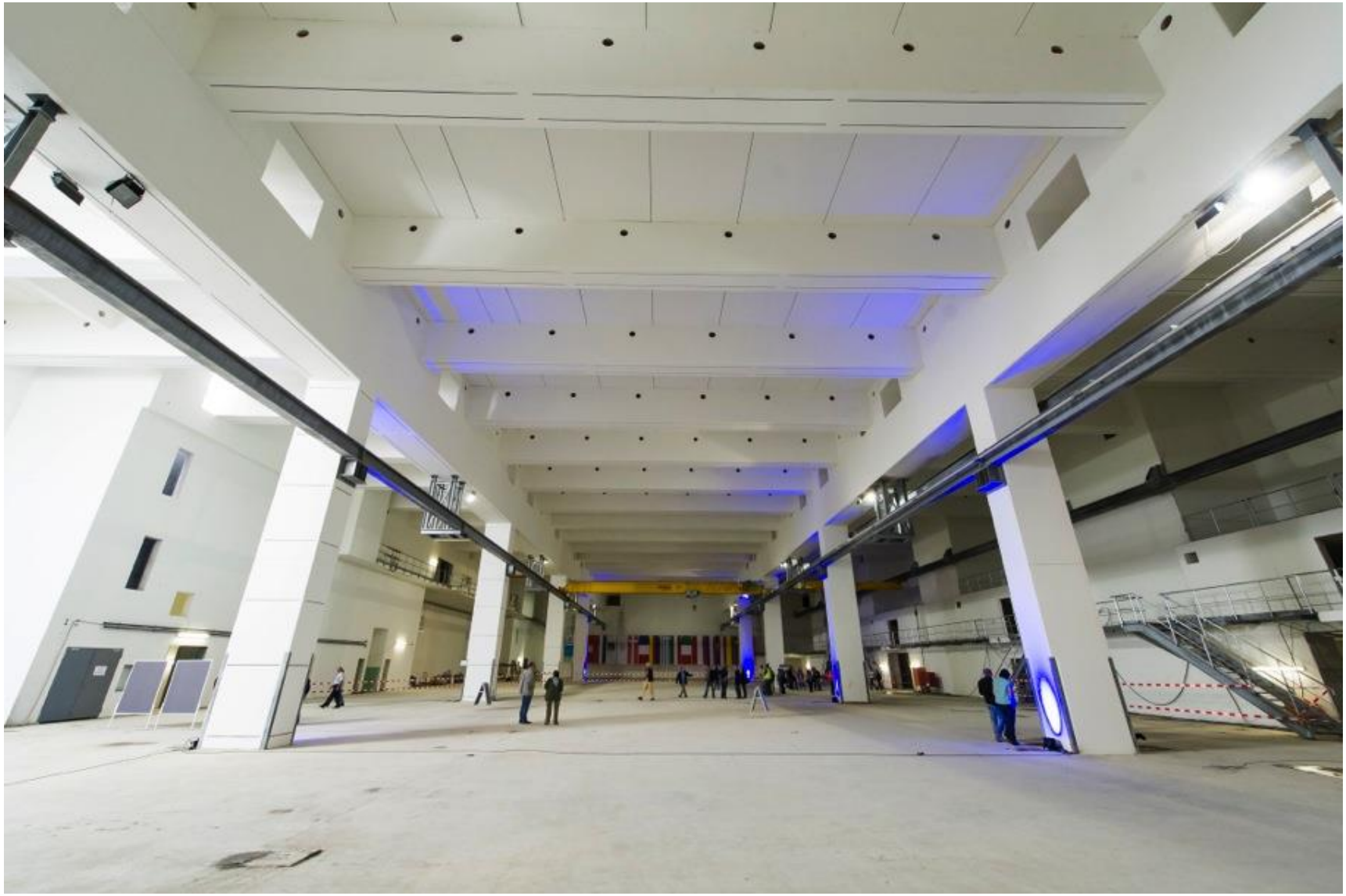
Experiment hall, June 2013



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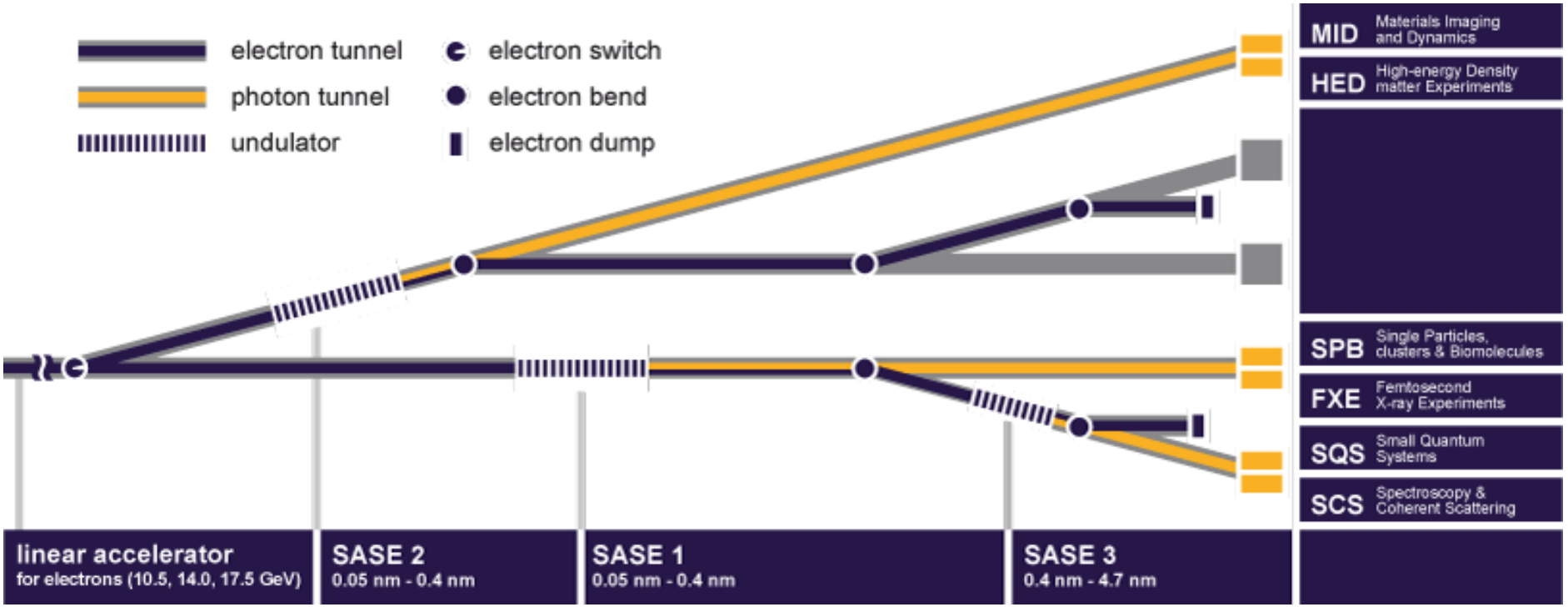
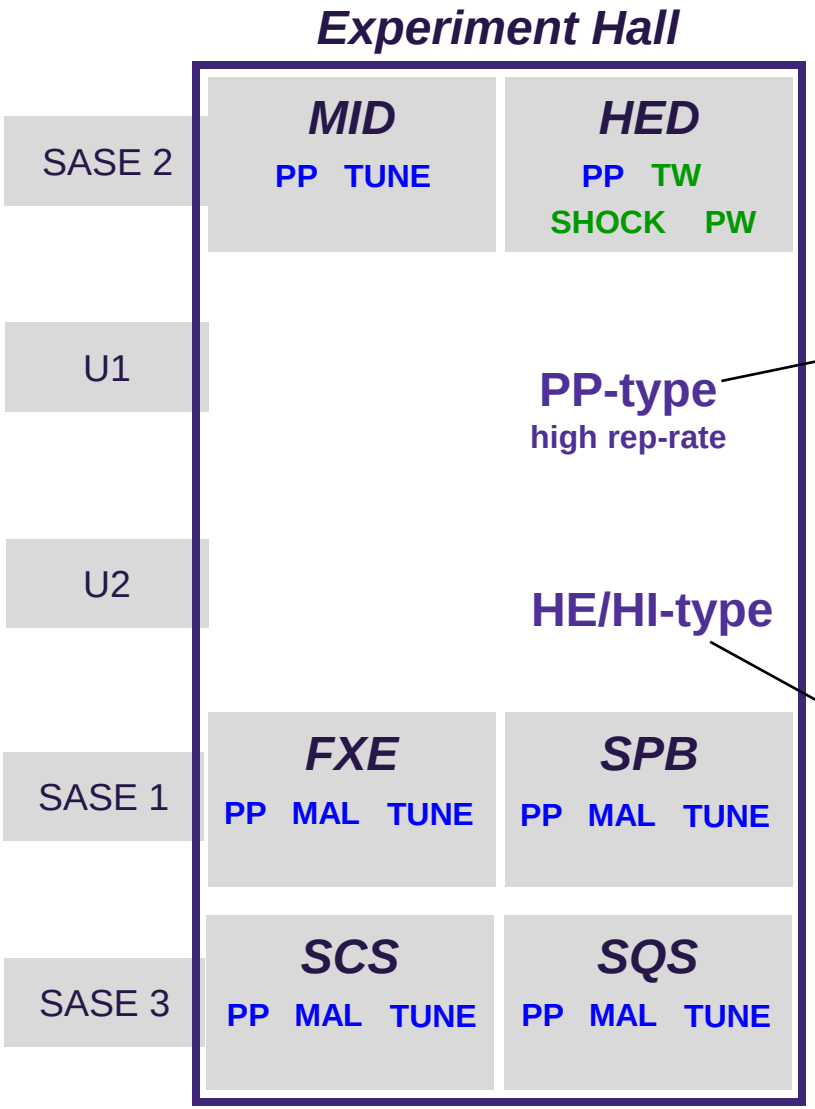
X-ray FEL delivery to 6 science instruments



Provision to add 2 more FEL sources and additional scientific instruments

Lasers for European XFEL user experiments

European XFEL experimental laser plans



Types of experimental lasers:

PP (pump-probe):

➔ sub-15…100fs, 0.2mJ, 10Hz ***burst***, 0…4.5MHz, 800nm

MAL (molecular alignment):

➔ sub-20fs, 3…10mJ, 10Hz ***burst,*** 800nm („kick“)
or

➔ 1J-class, 10Hz or burst, ns („adiabatic“)

TUNE (tuning, freq. conversion):

➔ UV…mid-IR, THz

TW (Terawatt):

➔ <30fs, >1Hz, 100 Terawatt–class laser, Ti:sapphire

SHOCK (high energy):

➔ 100J … kJ-class ns-laser, exponential ramp

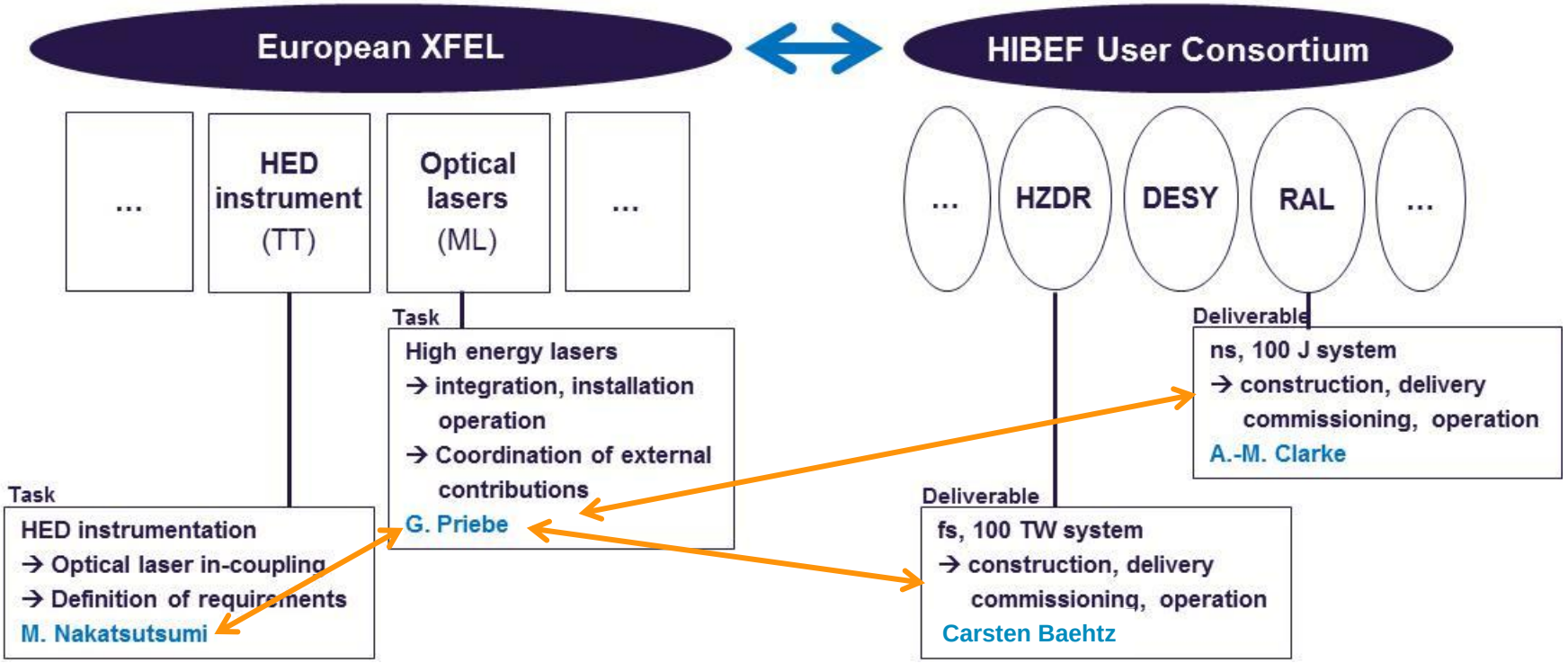
PW (Petawatt):

➔ 30fs, 1Hz, Ti:sapphire

- Baseline
- HIBEF User Consortium

HE / HI – type lasers

Helmholtz international Beam-line for Extreme Fields (HiBEF)



HiBEF contributions:

- **HI-laser:** 100 TW / 10 Hz laser system (industry, Ti:sapphire)
- **HE (ramped compression):** 100 J / 10 Hz laser system (RAL, DiPOLE 100-X)
- External laser building, chamber, spectrometers, diagnostics, etc.

XFEL groups:

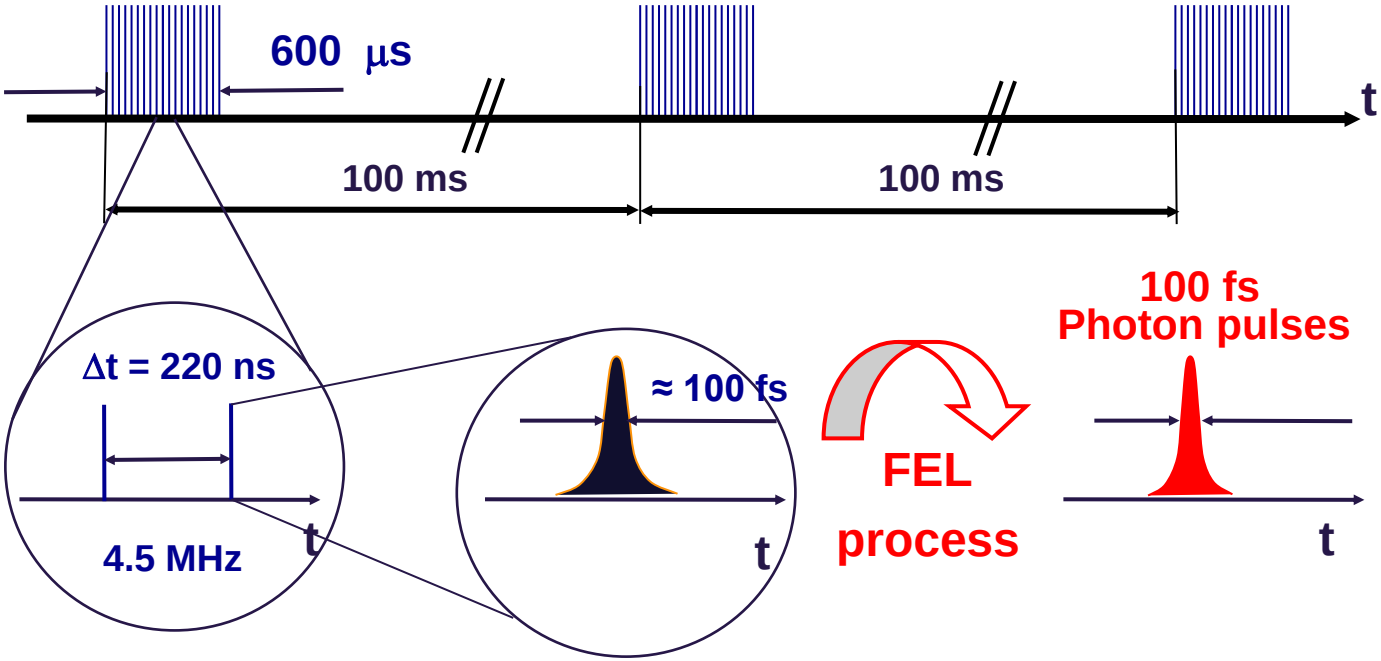
- **Integration effort**

Pump-probe laser

European XFEL pulse timing

10Hz electron bunch trains

(with up to 2700 bunches à 0.1…1 nC) => eff. rep-rate: 27kHz

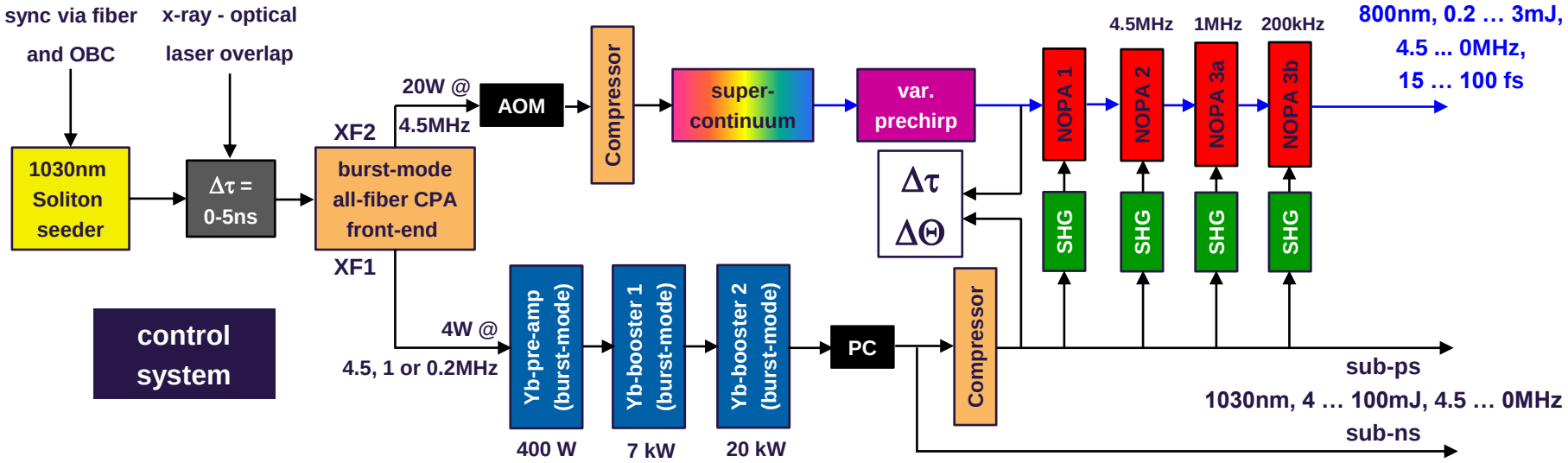


Pump-probe laser development goals as set in 2010:

- Synchronized few-cycle laser pulses with energy up to the few mJ-level
- 10 Hz bursts (600µs) with intra-burst rep. rate up to 4.5MHz

What is the development strategy with highest likelihood for success?

European XFEL pump-probe laser concept: NOPA

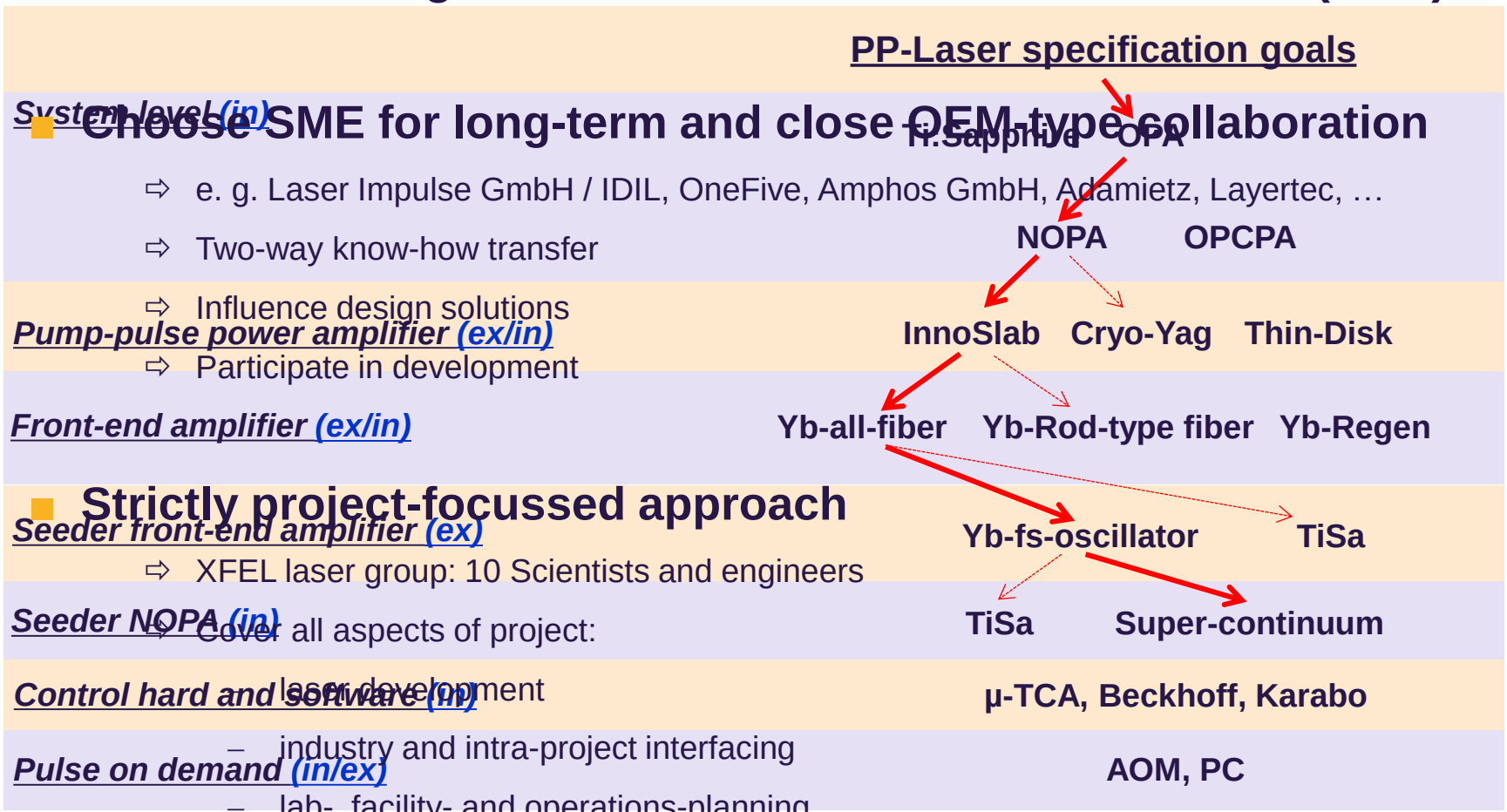


- Complex (sub-)systems with challenging requirements
- Scientific user facility: ideally combine high flexibility with high up-time
- System aspects: integrated control system, reliability
- No commercial off-the-shelf solutions, high risk, highly customized
- Project constraints (time line, resources, …)
- Multiple installations

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. R. Riedel, A. Stephanides, M. J. Prandolini, B. Gronloh, B. Jungbluth, T. Mans, and F. Tavella "Power scaling of supercontinuum seeded megahertz-repetition-rate optical parametric chirped pulse amplifiers," Opt. Lett. 39, 1422-1424 (2014)
4. M. Lederer, M. Bergmann, M. Kellert, and C. Mendez, "Pump-probe laser development for the European X-Ray Free-Electron Laser Facility," Paper 8504-20, SPIE Conference on Optics and Photonics 2012, 12–16 August 2012, San Diego, invited talk.

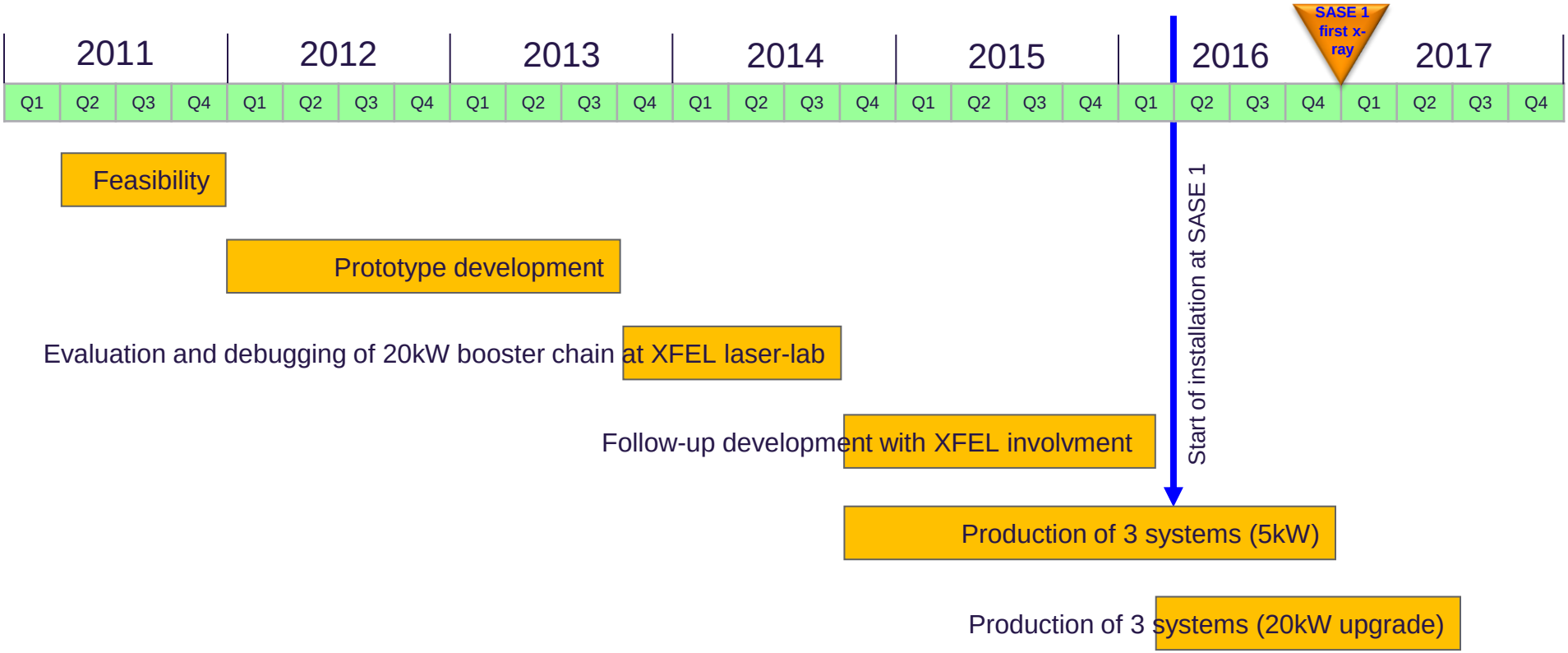
XFEL PP-laser development strategy

- **Select technologies and define in- and ex-house efforts (2011)**
- **Choose SME for long-term and close OEM-type collaboration**
  - ⇨ e. g. Laser Impulse GmbH / IDIL, OneFive, Amphos GmbH, Adamietz, Layertec, …
  - ⇨ Two-way know-how transfer
  - ⇨ Influence design solutions
  - ⇨ Participate in development
- **Strictly project-focussed approach**
  - ⇨ XEFL laser group: 10 Scientists and engineers
  - ⇨ Cover all aspects of project:
    - laser development
    - industry and intra-project interfacing
    - lab-, facility- and operations-planning
    - Installation, commissioning, operation, experiment facilitation



Example: InnoSlab high power burst-mode amplifiers

- **Goal: 20kW burst power, 10Hz (20Hz), 600µs, 0.1…4.5MHz**
- **SME: Amphos GmbH**



- **Timeline: consistent with facility plans**

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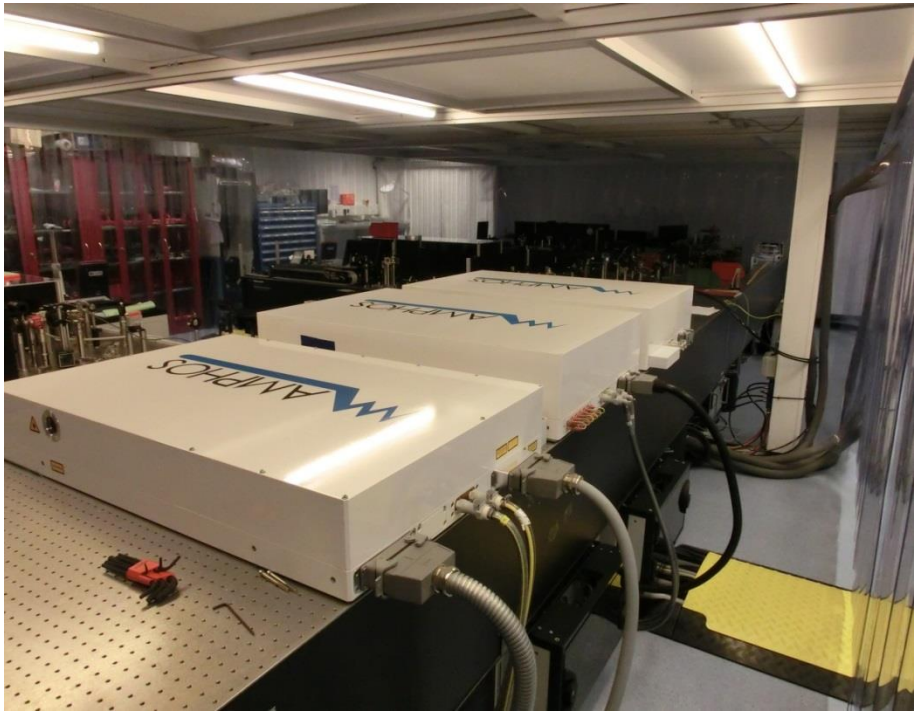
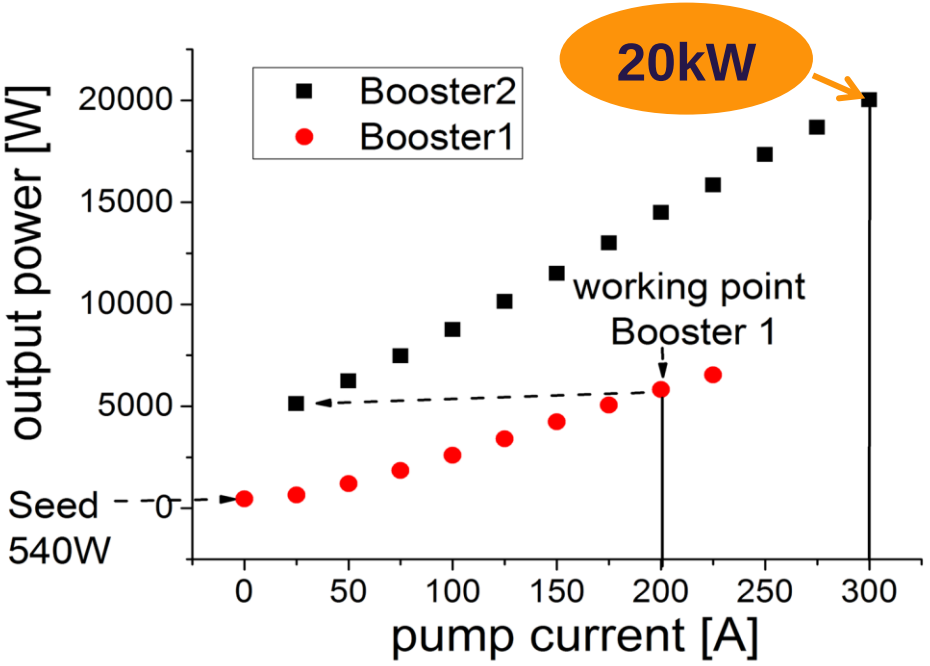
Example: InnoSlab high power burst-mode amplifiers



Measured slope of booster stages 1 and 2



- ✓ **System installed**
- ✓ **20kW (during burst) is reached**

Remaining issues: mainly beam quality => require follow-up development.

Mitigation: NOPA experiments continue with 5kW beam from booster 1.

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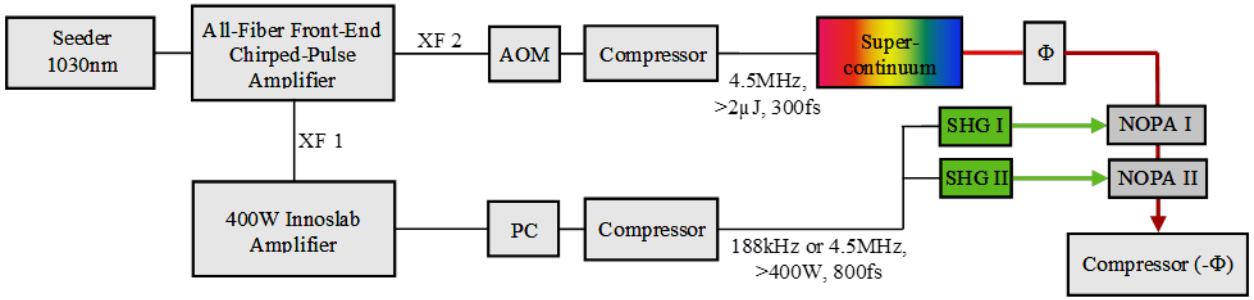
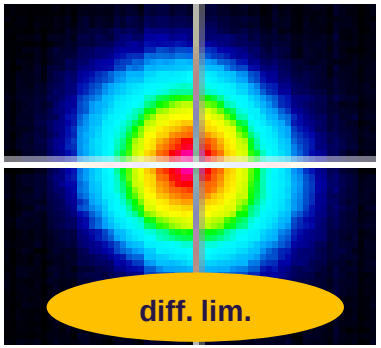
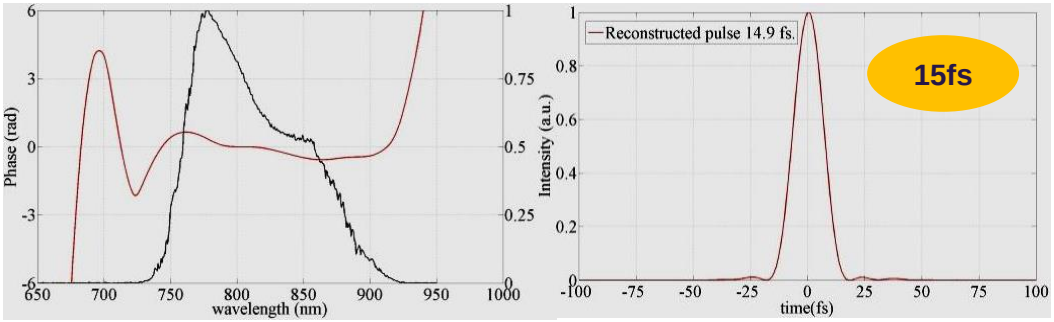
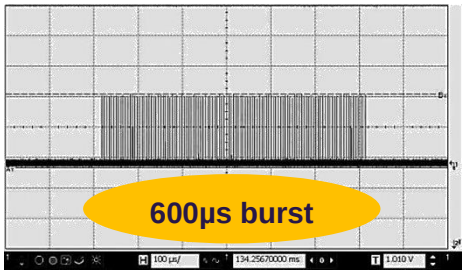
Status of pump-probe laser NOPA R&D



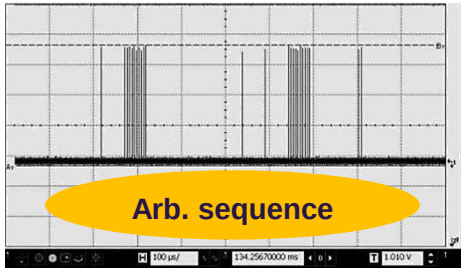






Some features:

- ✓ **180µJ per pulse, 34W average power during burst**
- ✓ **Nearly transform limited pulses: 15fs … 75fs**
- ✓ **100nm tuning for longer pulses**
- ✓ **200kHz and 4.5MHz intra-burst operation**
- ✓ **Identical performance from BBO and LBO**



High power burst-mode optical parametric amplifier with arbitrary pulse selection
Optics Express, Vol. 22, Issue 18, pp. 22202-22210 (2014)

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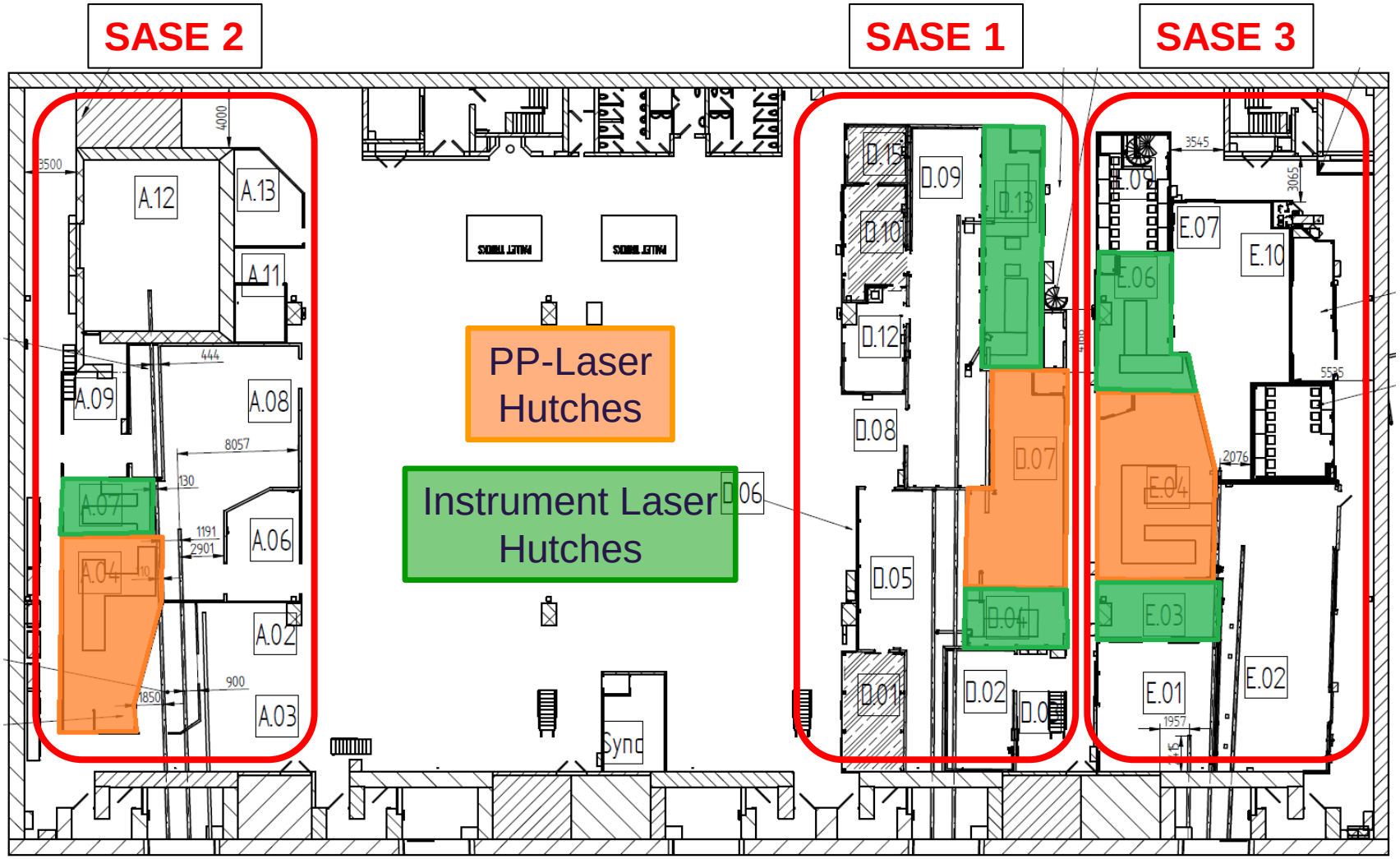
Laser locations in Experimental Hall



SASE 1: Laser area (PP, FXE, SPB)

SFX instrument

SFX - laser hutch

SPB instrument

SPB - laser hutch

FXE instrument

PP - laser hutch

FXE - laser hutch

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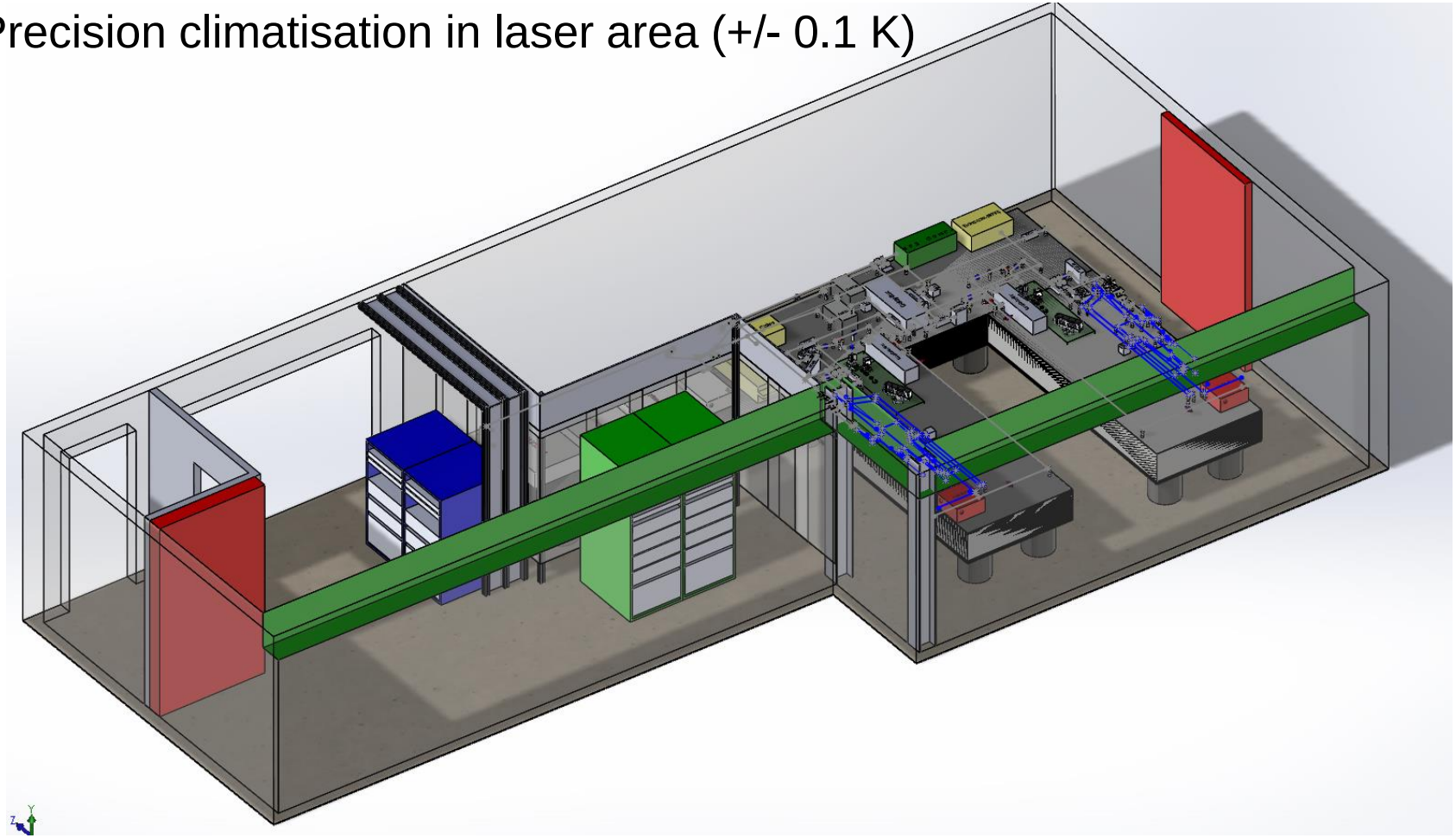
Laser hutch for SASE 1

- Different climate zones:
  - Air-condition in preparation/rack area (+/- 0.5 K)
  - Precision climatisation in laser area (+/- 0.1 K)



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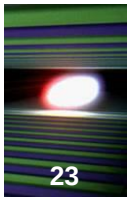
Summary I



Start-up of European XFEL is in full swing

- Civil construction completed
- Installation of accelerator started
- First x-rays: end of 2016
- Early users: 2017
- Ramp-up x-ray delivery to ~4.800 hrs per annum
- Dedicated instruments and trained staff support users in complex FEL exp.

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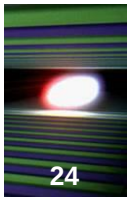
Summary II



Lasers for European XFEL user experiments

- Pump-probe laser highly specialized => development at European XFEL
- Strategy: mixed in- and ex-house developments, involving suitable SMEs and OEM-style collaborations
- Development and installation schedule in agreement with current facility plans
- HE/HI lasers planned to be contributed by user consortium „HIBEF“

➔ Laser group to coordinate integration into HED-instrument

➔ RAL: DiPOLE 100-X (10Hz, 100J, ns-laser for ramped compression)

➔ Industry: 100TW, 10Hz, Ti:sapphire

Thank you!!