Pump-probe laser plans for the European XFEL

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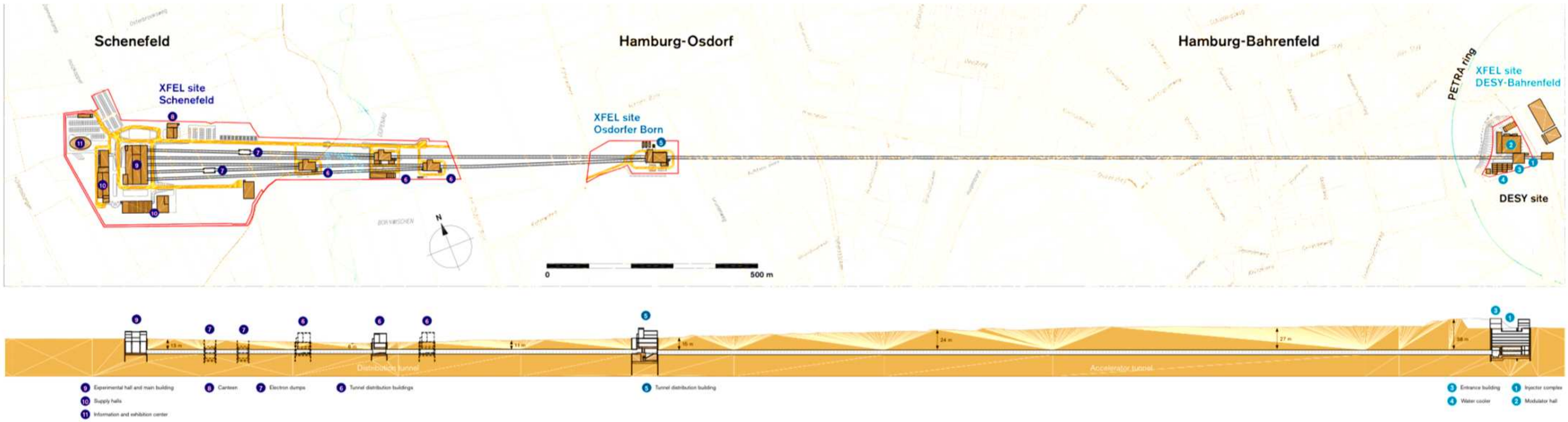
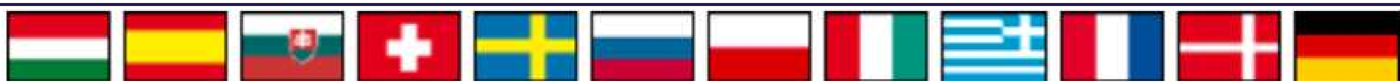




Overview

A. Project organisation, laser group

B. Experimental laser requirements at XFEL

C. Pump-probe laser development – plans and current status

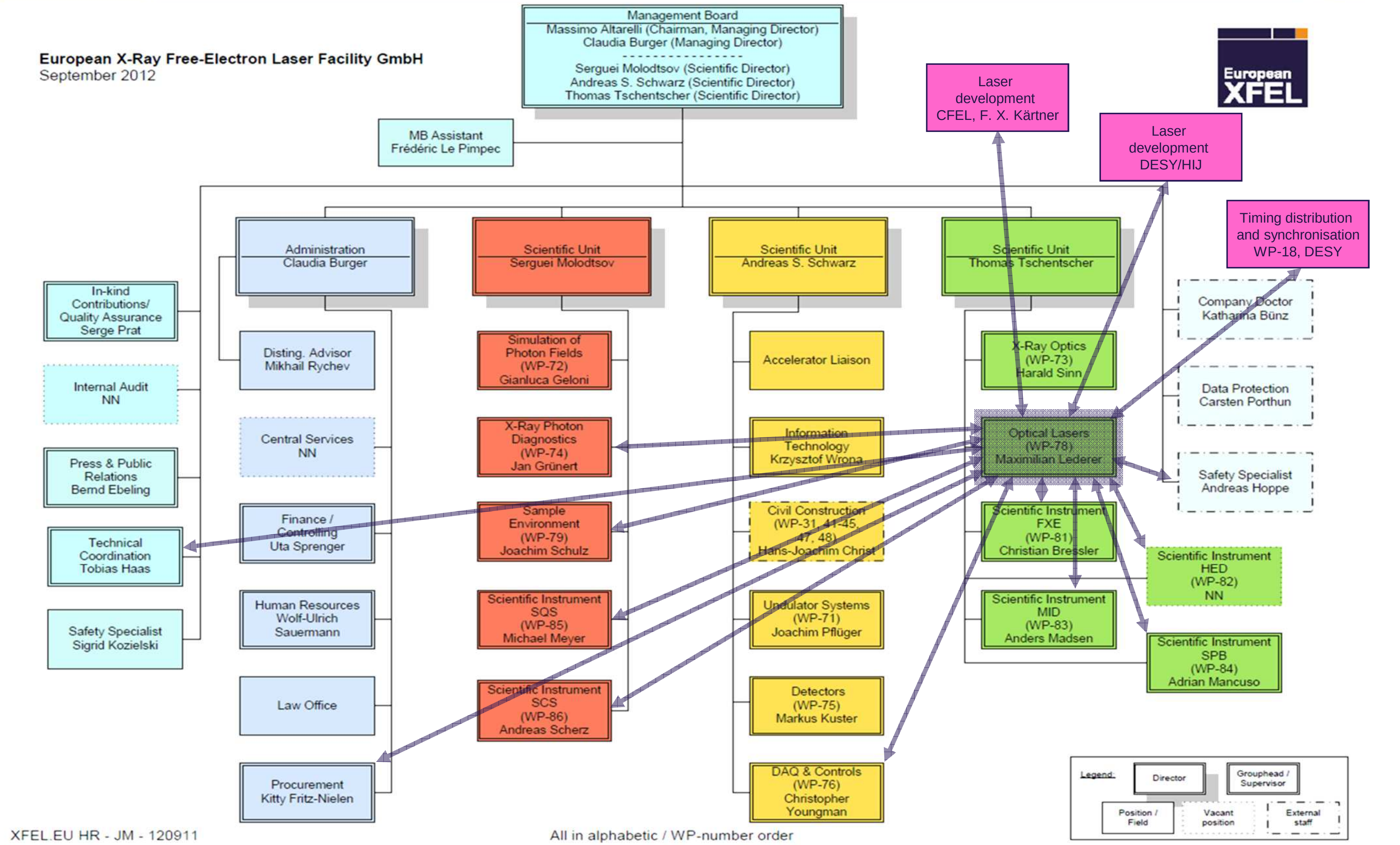
D. Facility and operational issues

A. Project organisation, laser group

General

- The **XFEL Project** is a multi-national project with currently 12 European partner countries (share holders).
  - ➢ **Goal: build worlds most brilliant X-ray free-electron laser.**
- Germany, represented by the Helmholtz Society (DESY), holds a majority of ca. 60%.
- The **XFEL GmbH** is a limited liability company with international shareholders, in charge of construction and operation of the European XFEL in Hamburg / Schenefeld.
- Responsibilities:
  - **XFEL GmbH**: **photon beam lines (undulators, experiments,…)**
  - XFEL DESY: machine (injector, accelerator, timing,…)
- **Laser group at XFEL GmbH** was founded at the end of 2010.
- Group is responsible for lasers in all photon beam lines.
- Planned development-phase group size: 10, currently : 5

Photon-Beamline Work Packages and Main Technical Interfaces in the Project



What are the main features of the European XFEL?

up to 5 beam lines (3 in base line)

simultaneous operation

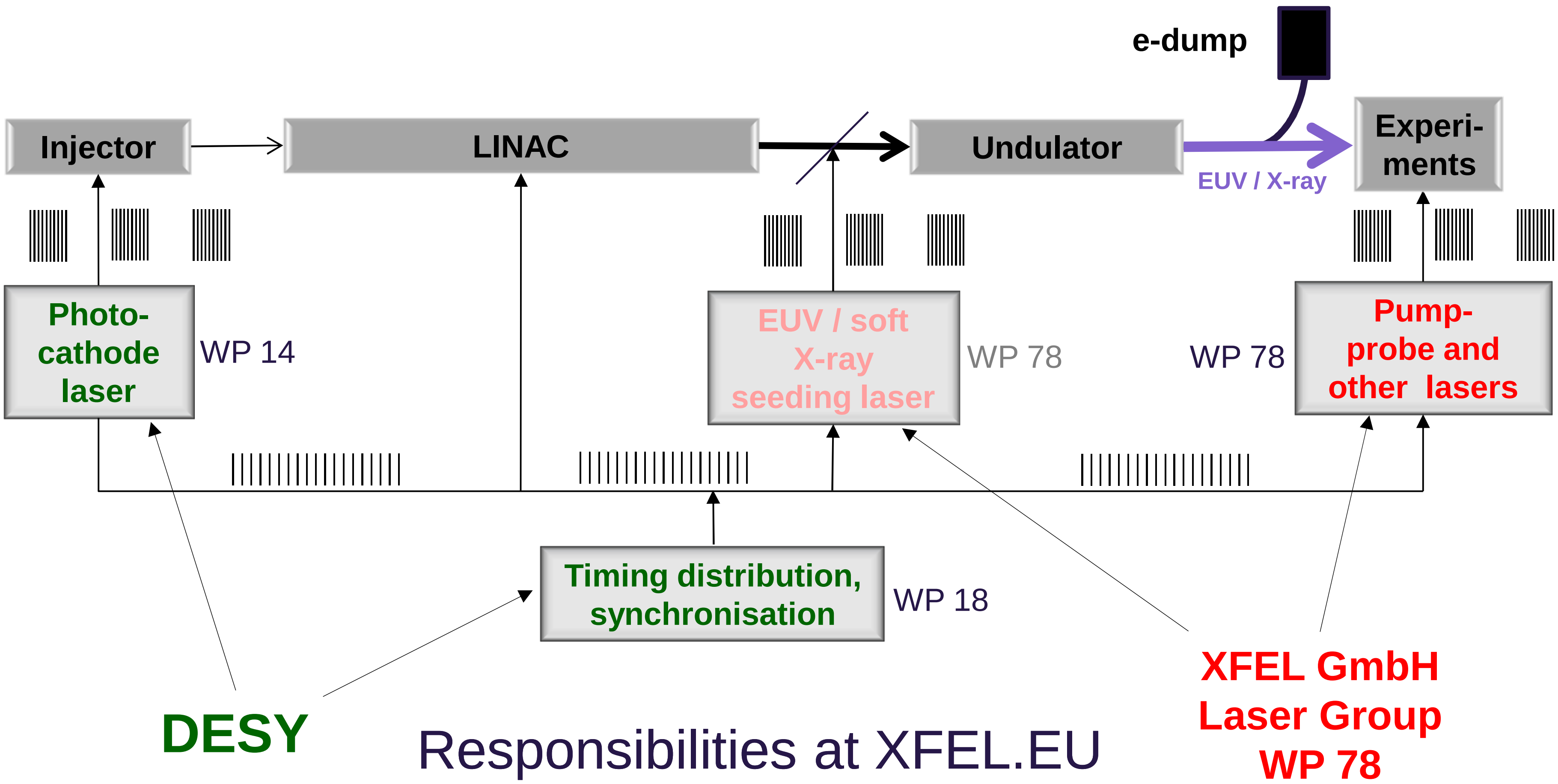
0.25 ... 24keV photon energy

Very high pulse rate: up to 27000 pulses / sec

B. Experimental laser requirements at XFEL

Ultrafast optical lasers at EUV- and X-FELs

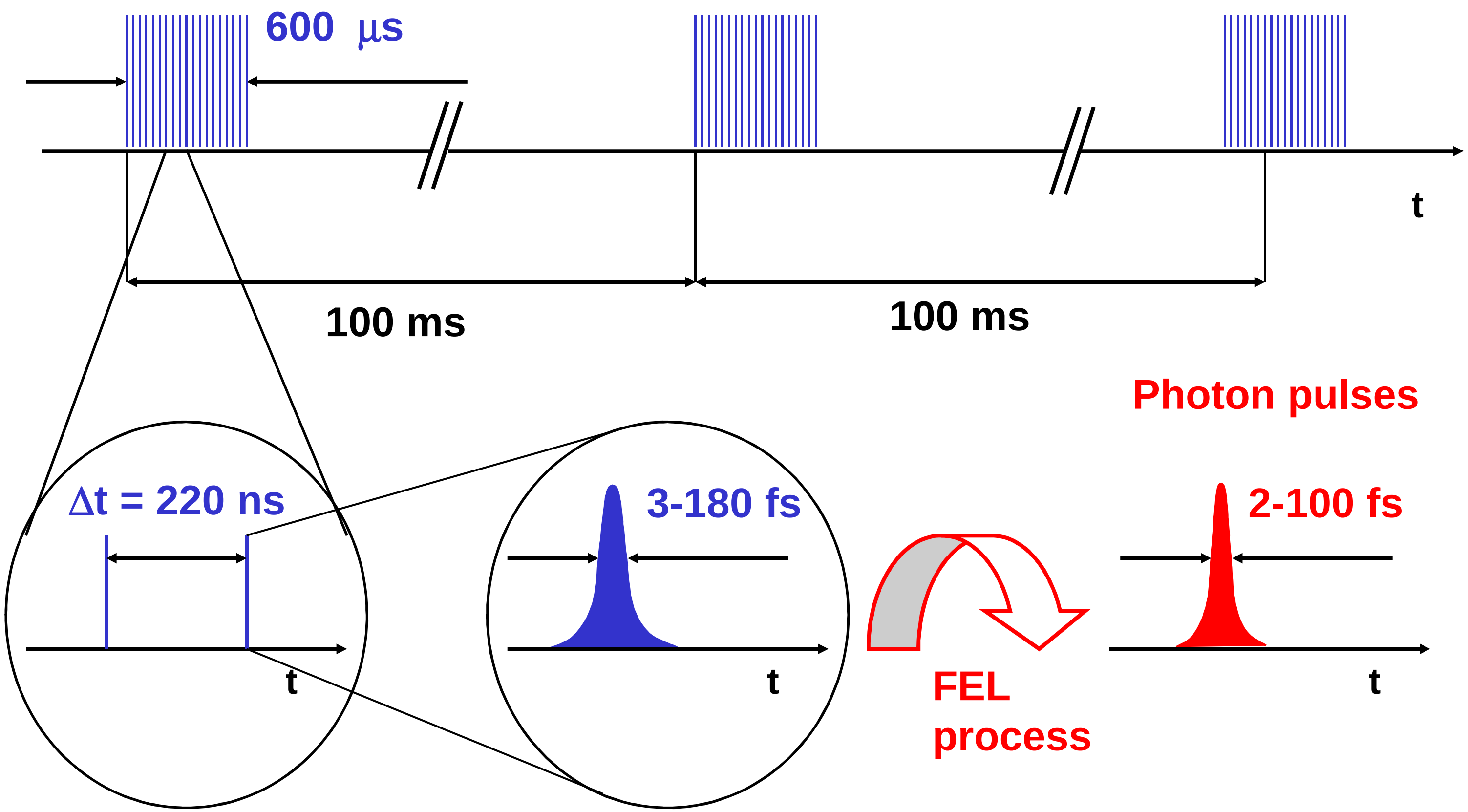
Simplified schematic of a SASE Free-Electron Laser:



Responsibilities at XFEL.EU

European XFEL pulse timing

Electron bunch trains
(with up to 2700 bunches à 20-1000 pC)



European XFEL

Experimental laser requirements analysis

Experiment Hall

SASE 2

HED + MID + NNN

Types of lasers

PP TUNE TW SHOCK PW

U1

U2

currently not in use.

SASE 1

SPB + FXE + NNN

Types of lasers:

PP MAL TUNE

SASE 3

SQS + SCS + NNN

Types of lasers:

PP MAL TUNE

Types of lasers - *a wish list*:

PP (pump-probe):

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

MAL (molecular alignment):

➔ sub-20fs, 3…10mJ, 800nm („kick“)

or

➔ 1J, 10Hz, ns („adiabatic“)

TUNE (tunability, freq. conversion):

➔ UV…mid-IR, THz (not in hutch, in coll. with instr. sci.)

TW (Terawatt):

➔ <30fs, 5-10Hz, 100 Terawatt–class laser, Ti:sapphire

SHOCK (high energy):

➔ kJ-class ns-laser

PW (Petawatt):

➔ 30fs, 1Hz, Ti:sapphire

or

➔ 150fs, 1Hz, diode-pumped Yb:CaF_2

- Fixed
- Future (potential User Consortium)

Some remarks on laser requirements

- **100TW-class** laser technology is mature and commercially available from several vendors**.**
  - ➔ Plan for installation in time with start of operation phase of the XFEL.EU.
- **PW- and kJ-class** lasers are also becoming commercially available and are being installed (e. g. BELLA Ti:sapphire 1.3PW).
  - ➔ Future of these efforts at XFEL.EU depends on external user consortium.
  - ➔ Due to the size of these lasers, an additional external building will be required.
- **PP-laser will require major development effort, no commercial system is available.**
  - ➔ 10Hz burst operation with up to 4.5MHz intra-burst rep-rates.
  - ➔ mJ-class pulse energies, shorter and longer pulses.
  - ➔ Attempt to also achieve specs useful for MAL.

high flexibility
AND
high uptime

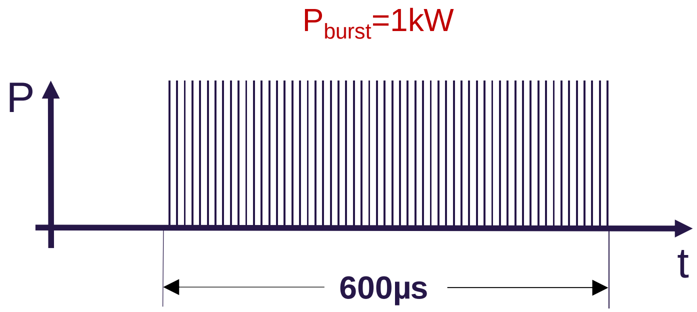
- **Tunability** will have to be derived from PP-laser and adapted to needs of instruments and users.
  - ➔ In cooperation with instruments scientists.

C. Pump-probe laser development – plans and current status

Pump-Probe laser goals

High-rep-rate operation (PP-mode):

- 10Hz ***burst***, 0.6% duty cycle,
- 15 … 100fs,
- 1 … 4.5MHz intra-burst, „PoD“,
- 1…0.2mJ per pulse, ca. 800nm

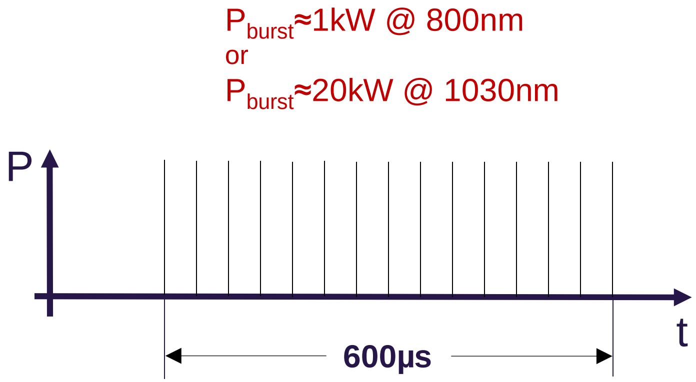


Low-rep-rate operation (MAL-mode):

- 10Hz ***burst***, 0.6% duty cycle,
- 200kHz intra-burst, „PoD“
- sub-20fs, >3mJ per pulse, 800nm.

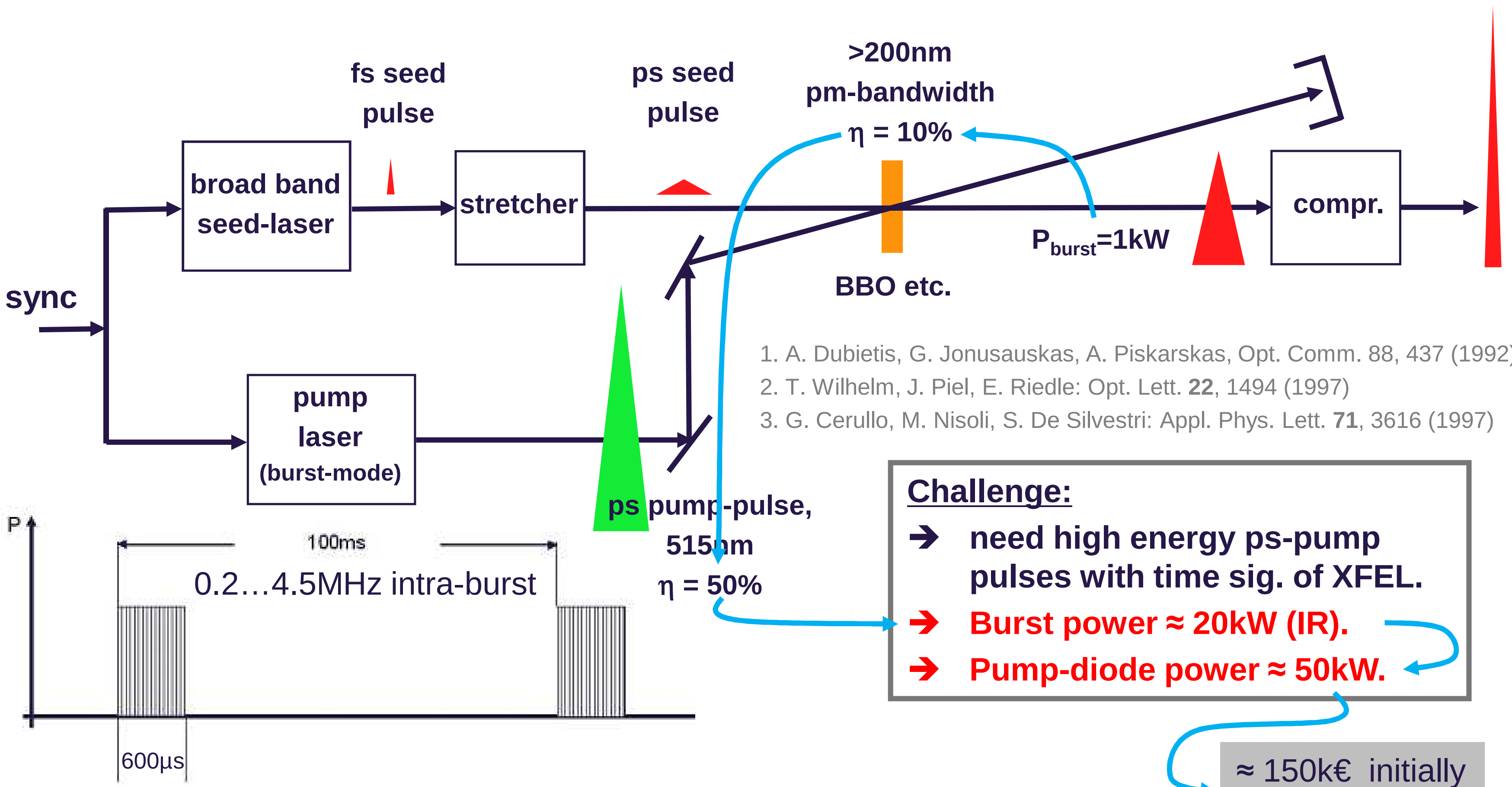
or

- ps or ns, ≈ 0.1J per pulse, 1030nm.



NOPA principle

NOPA ⇨Non-collinear Optical Parametric Amplifier



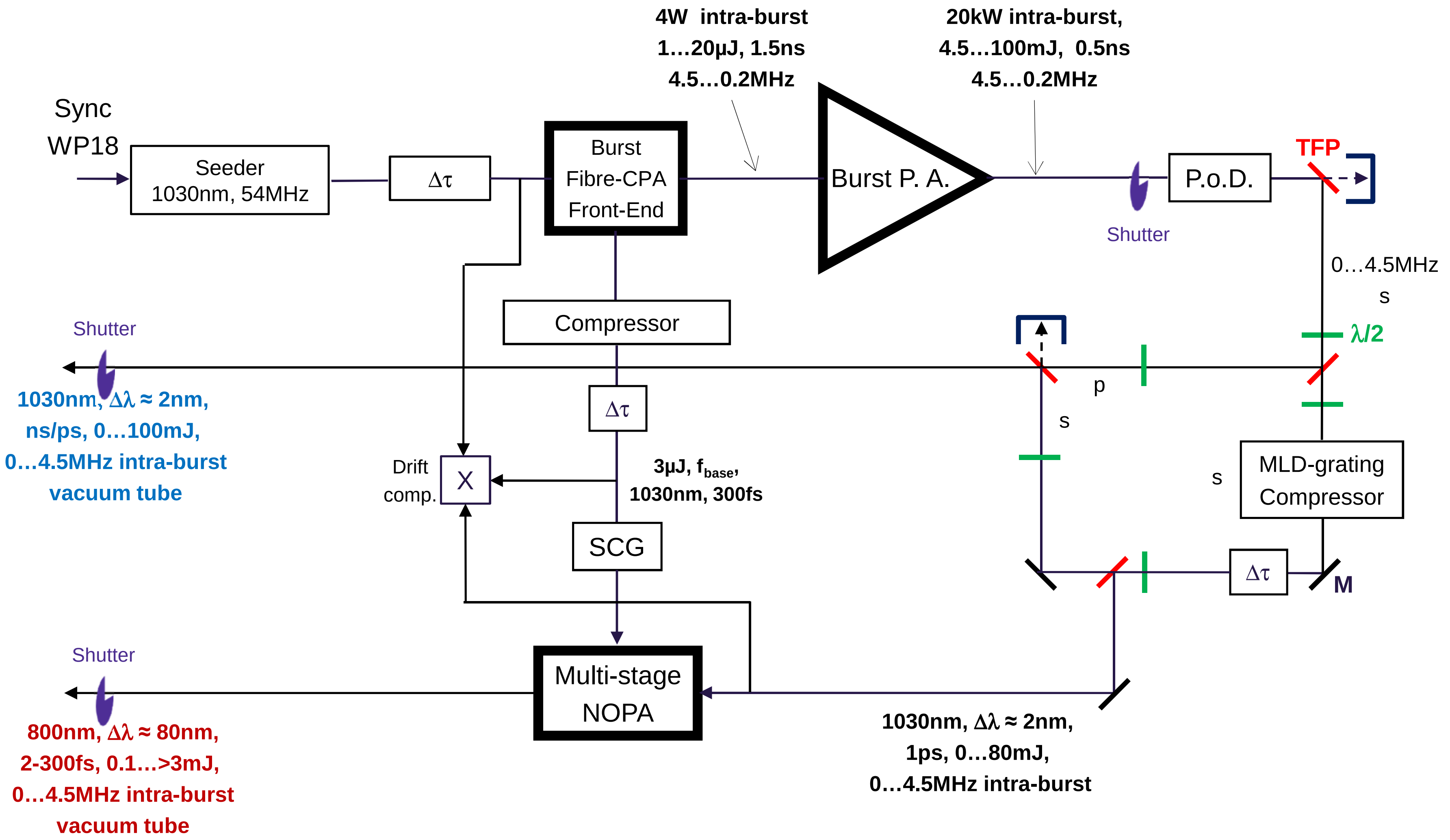
1. A. Dubietis, G. Jonusauskas, A. Piskarskas, Opt. Comm. 88, 437 (1992)
2. T. Wilhelm, J. Piel, E. Riedle: Opt. Lett. **22**, 1494 (1997)
3. G. Cerullo, M. Nisoli, S. De Silvestri: Appl. Phys. Lett. **71**, 3616 (1997)

Challenge:

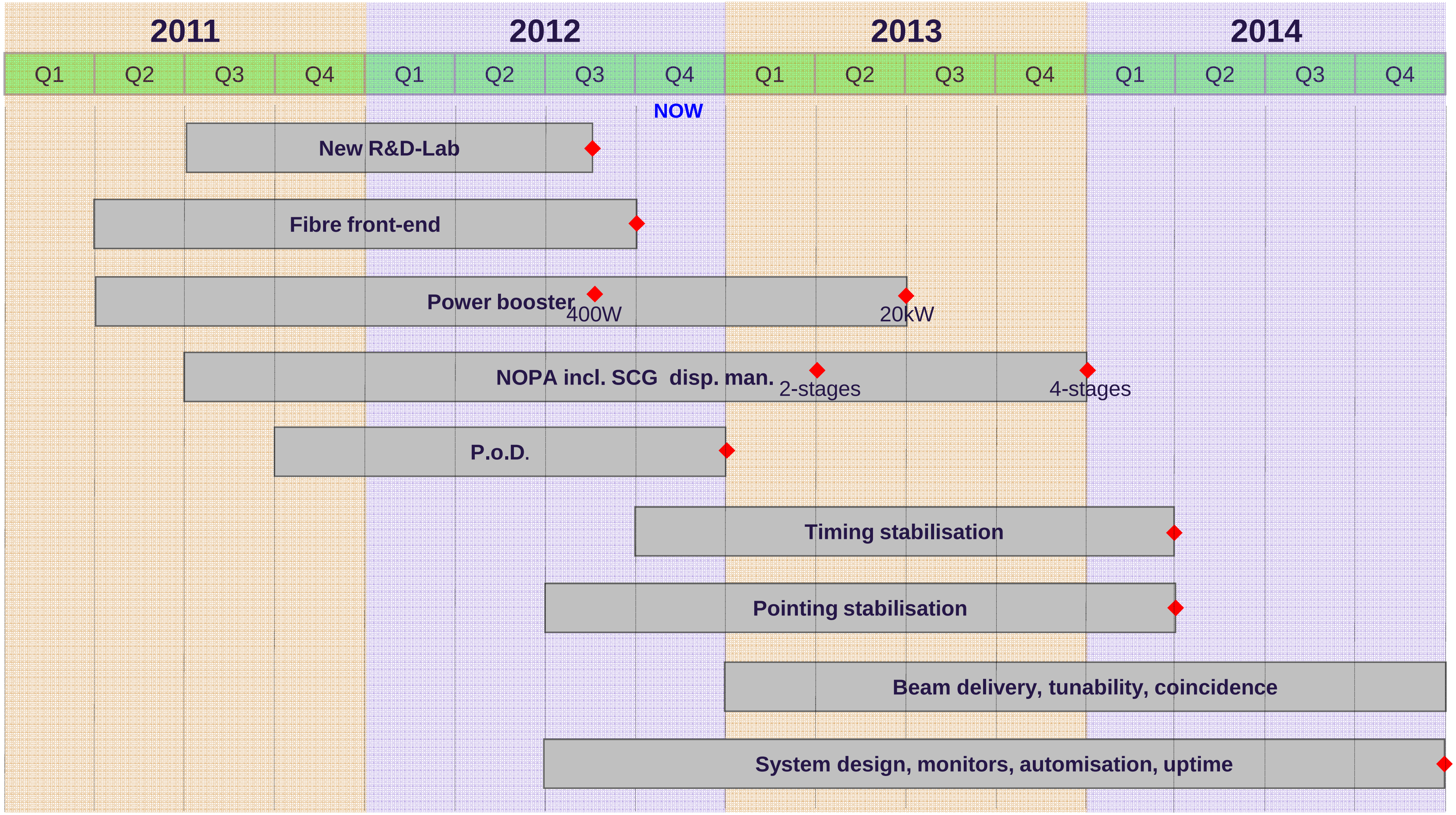
- ➔ need high energy ps-pump pulses with time sig. of XFEL.
- ➔ Burst power ≈ 20kW (IR).
- ➔ Pump-diode power ≈ 50kW.

≈ 150k€ initially
≈ 50k€ p. a.

Pump-Probe laser conceptual layout



Major mile stones in pump-probe laser R&D

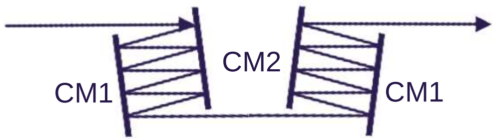


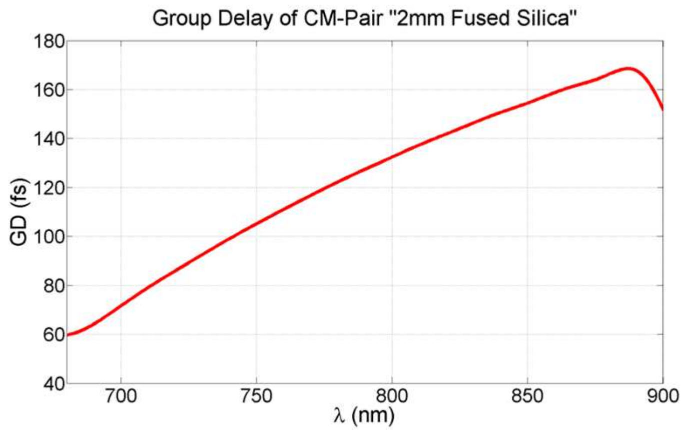
D. Facility and operational issues

Beam delivery

Dispersion and bandwidth management

- Use passive dispersion management : chirped mirrors (CMs)
- Limit amplified signal bandwidth to 15fs (transform limited)
- Pre-chirp continuum before amplification
  - ➔ Stretcher is made from compensated CM-pair.
  - ➔ Amount of chirp is chosen to amplify ≈ 80nm by the ≈ 800fs pump pulse.
- Compressor: bulk fused silica at experiment.
  - ➔ Fused silica is dominating element.
  - ➔ GDD / TOD ratio of BBO is similar to that of fused silica.
  - ➔ Use CM-design optimised for GDD and TOD to be conjugate to fused silica.



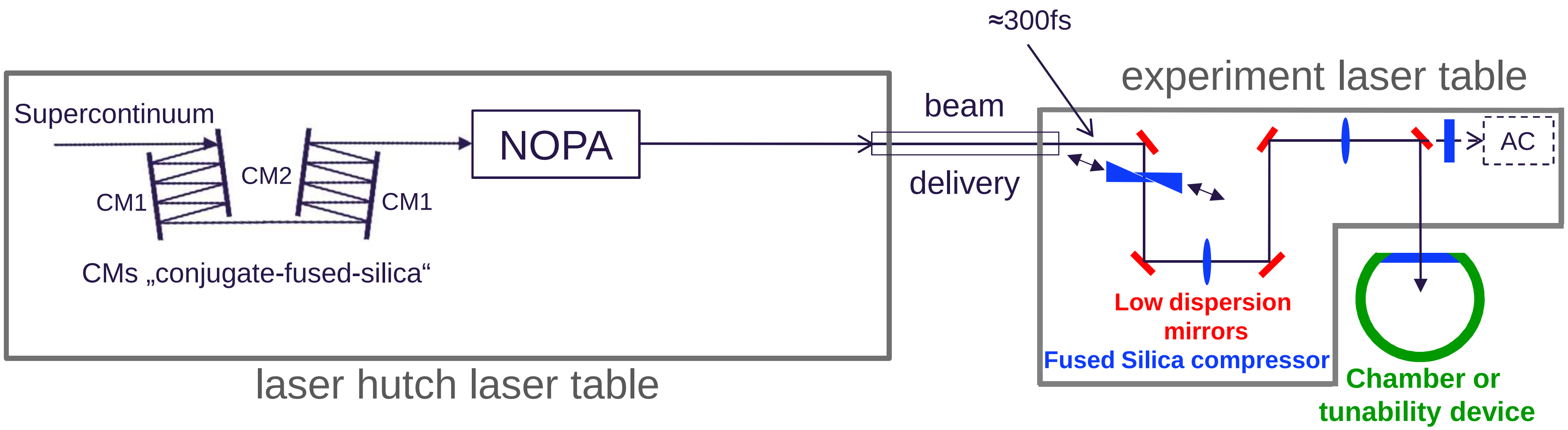


- Flexibility of scheme:
  - ➔ Bandwidth of CM-pair might support shorter pulses ⇨ reduce input chirp.
  - ➔ For longer pulses ⇨ increase input chirp (≈ 15nm, i. e. 50fs compressed) .

Pulse and beam delivery

Dispersion management 15fs pulses:

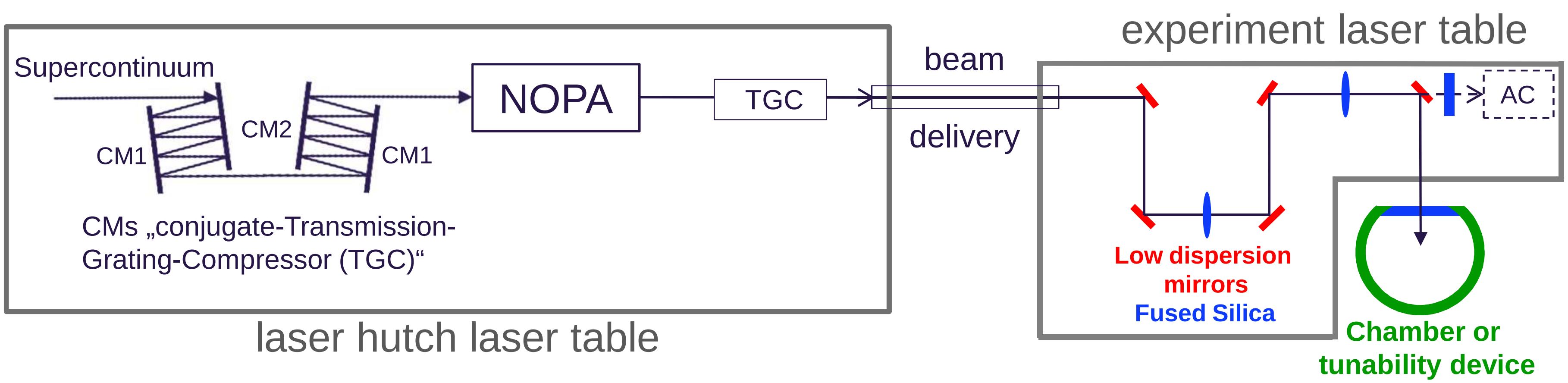
- Pulses have negative chirp: ≈300fs pulsewidth at delivery point.
- Fused Silica elements are compressor: lenses, windows, wedges for fine tuning (FS-budget: ca. 30mm).
- Turning mirrors : dispersion free or low disperion.
- Pulsewidth monitor before chamber.



Pulse and beam delivery

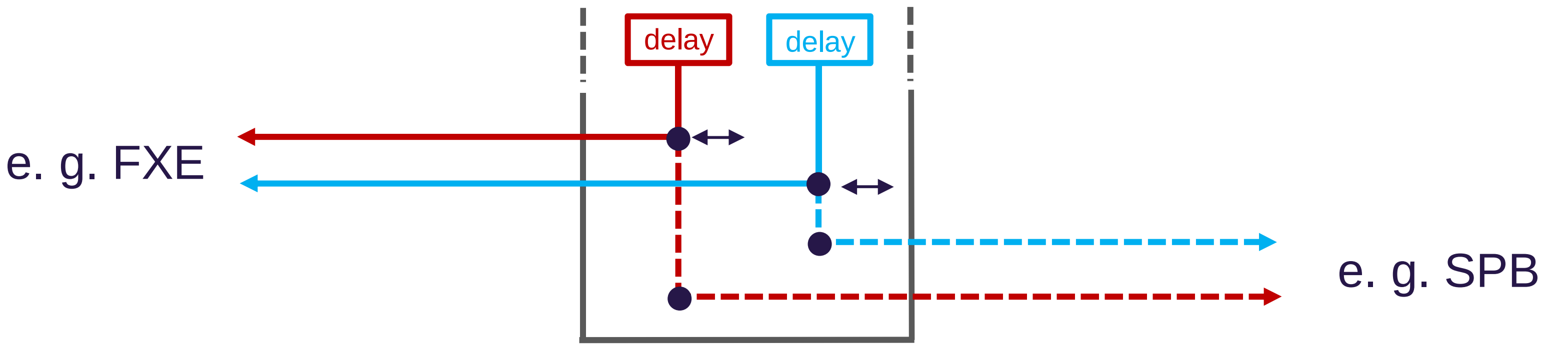
Dispersion management >50fs pulses:

- ➔ Pulses have positive chirp: pulsewidth optimised through TGM.
- ➔ Transmission grating compressor: lenses, windows, wedges for fine tuning (FS-budget: larger…).
- ➔ Turning mirrors : dispersion free or low disperion.
- ➔ Pulsewidth monitor before chamber.



Pulse and beam delivery

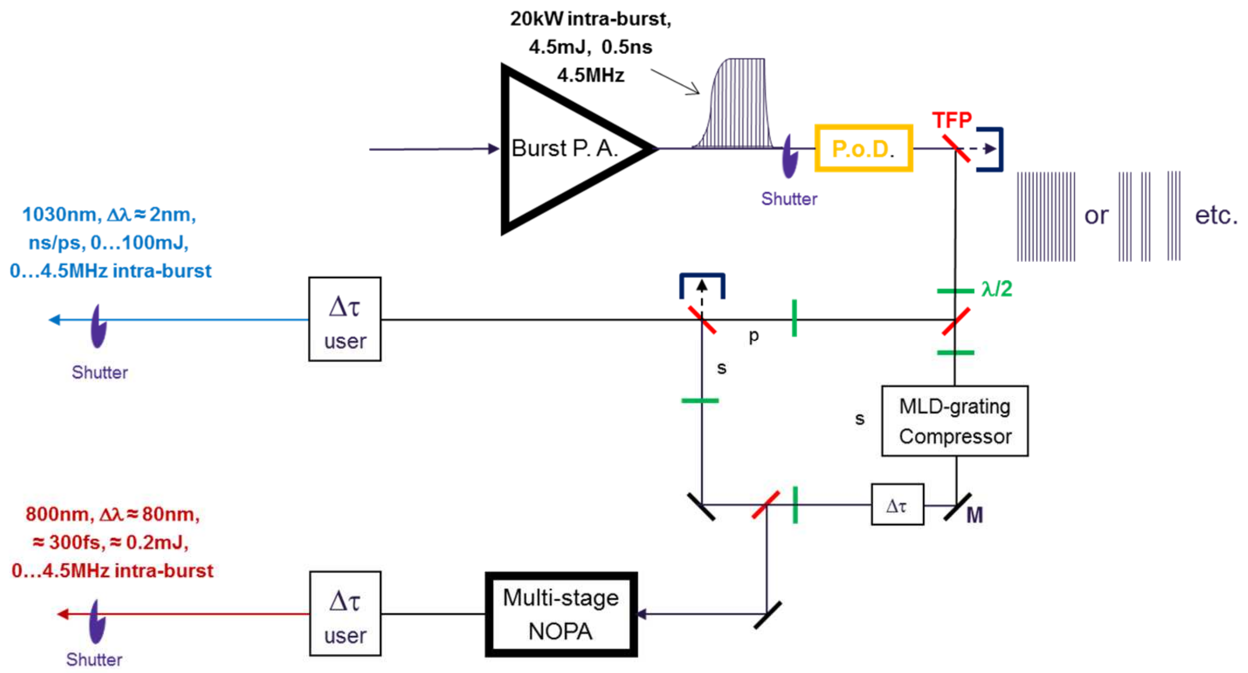
- **Beam delivery:**
  - ➔ if at all possible:
    - SHORT and STRAIGHT
    - „laser table to laser table“
    - no turning on the way
  - ➔ Two separate beam lines: 800nm and 1030nm.
    - For 800nm: evacuated (1-10 mbar) 2-Inch pipes, beam diameter: ≈1cm.
    - For 1030nm: evacuated (1-10 mbar) pot. up to 6-Inch pipes, up to 3cm beam.
  - ➔ Beam diameters in air and through compressor (Fused Silica elements):
    - 1cm ok for 200µJ / 800nm operation.
    - Up to 3cm for >3mJ / 800nm and/or 100mJ / ps / 1030nm operation.
  - ➔ Simultaneous operation of different experiments in one SASE ***is not*** possible:
    - e. g. $\overline{SQS \cdot SCS}$.
  - ➔ Simultaneous operation of 800nm and 1030nm ***is*** possible.



Laser table in laser hutch

Pulse and beam delivery

- **Pulse-on-demand (PoD):**
  - ➔ Pulse-picker after 1030nm high power booster.
    - Clean up the burst.
    - Select single pulses and arbitrary sequences from base rep-rate.
    - Expect little dynamic effects due to very low absorption in NOPA and other components following PoD.



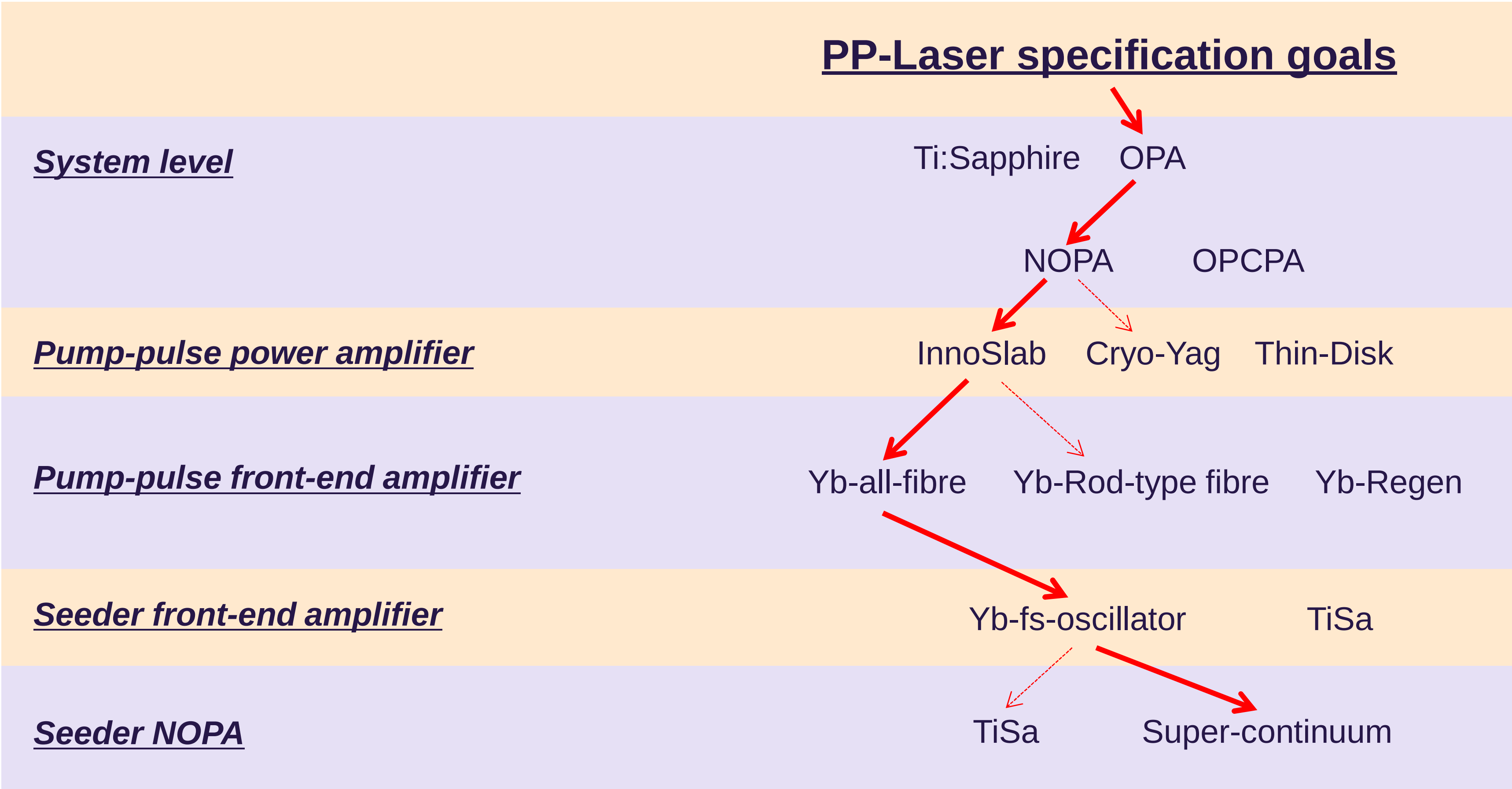
- **Mixed-mode 800nm / 1030nm (ns/ps):**
  - ➔ Through polarisation management using TFPs and λ/2.

Operation and up time

- ***Design measures***
  - Choice of laser design and sub-systems
  - Passive stability
  - Active stability
- ***Preventive measures***
  - Maintenance and spare parts management
  - Monitoring, logging, remote-access
- ***Operative measures***
  - Choice of operation-point and -specifications
  - Personnel

Design: Choice of laser design and sub-systems

- Choice can be limited, depending on specification goals.
- For the XFEL PP-Laser development, major choices are as follows. Detailed reasons and motivations are given elsewhere.
- Second choice / fall-back options are indicated by dashed arrows.



Design: Some specific points regarding sub-systems

- **NOPA, system level and beam delivery:**
  - timing and pointing critical.
    - ⇨ require passive and active stabilisation measures.
- **InnoSlab power amplifier:**
  - industrial design based on extensive experience of Fraunhofer-ILT
    - ⇨ highly stable optomechanics
    - ⇨ substantial monitoring built in.
- **Yb-all-fibre front-end:**
  - thermo-mechanical stability through all-in-fibre design.
    - ⇨ substantial monitoring built in.
- **Yb-fs-oscillator:**
  - turn-key and expected long-term stability (10k hours).
    - ⇨ requires care with fibre coupling.
- **SCG NOPA-seed:**
  - longterm performance t. b. d.
    - ⇨ reqires means of preventive maintenance, if critical.

Design: Passive stability

General considerations:

- Laser as close as possible to experiment.
  - ⇨ shortest possible beam delivery
  - ⇨ if possible, no turning elements between laser-hutch and experiment laser-tables.
- Laser on ultra-stable floor (HEXP1) instead of raised platforms or other level in building.

Opto-mechanical components:

- Implement selected industrial components where available
- Draw on external experience for custom mounts and components.

Laser tables:

- State of the art vibration control in all tables.
- Thermo-mechanically sensitive sub-sections (NOPA) on Super-Invar skins.

Design: Active stability

Operational environment stabilisation

- Temperature control to < +/- 0.1 ° C above laser tables in laser hutch
- Humidity control to 45 +/-2.5% above laser tables in laser hutch

Control of temporal overlap between pump and seed pulses at input of NOPA

- balanced cross-correlation right before NOPA.

Control of pointing, where necessary.

- fibre input coupling
- NOPA input pointing

Preventive: Maintenance and spare parts

- **<u>Regular maintenance cycles:</u>**
  - All relevant consumables such as closed cycle chiller water, etc.
  - Known pot. degradation spots such as e. g. supercontinuum crystal, etc.
  - Check on state of all relevant system constituents.

- **<u>Spare parts:</u>**
  - Set of long lead time components, such as pump diodes, as spare.
  - Cost-issue: ca. 200k€ for all high power amplifier pump diodes of one pump-probe laser. Expected life time: 3y under continuous operation.
    - ➔ Longterm commitment on average 200k€ p. a. for 3 pump-probe lasers (rather conservative worst case).

Preventive: Monitoring, logging, remote-access

Parameters for constant monitoring and logging:

- System-level
  - ⇨ temperatures, humidity, power levels, spectra, pump/seed timing-lock, pump-AC, beam profiles, delay, etc.
  - ⇨ Error logging of sub-systems and below (e.g. front-end pump diodes, beam pointing, etc.). Definition of errors required and implemented in laser control GUI
- Sub-system-level
  - ⇨ these monitors are built–in in the case of seeder, front-end and power amplifiers, but need to be provided in the case of the NOPA.
    - temperatures, power levels, spectra, beam profiles, rep-rates, PD-signal levels, etc.

Control-Software with remote-access:

- All relevant live- and history-data can be accessed and displayed locally and remotely.
- Control of all relevant laser parameters both locally and remotely.
- Trend-analysis of parameters.
  - ⇨ prompt maintenance in case of alarming trends.

Operative: Operating-point and -specs

Laser operating point:

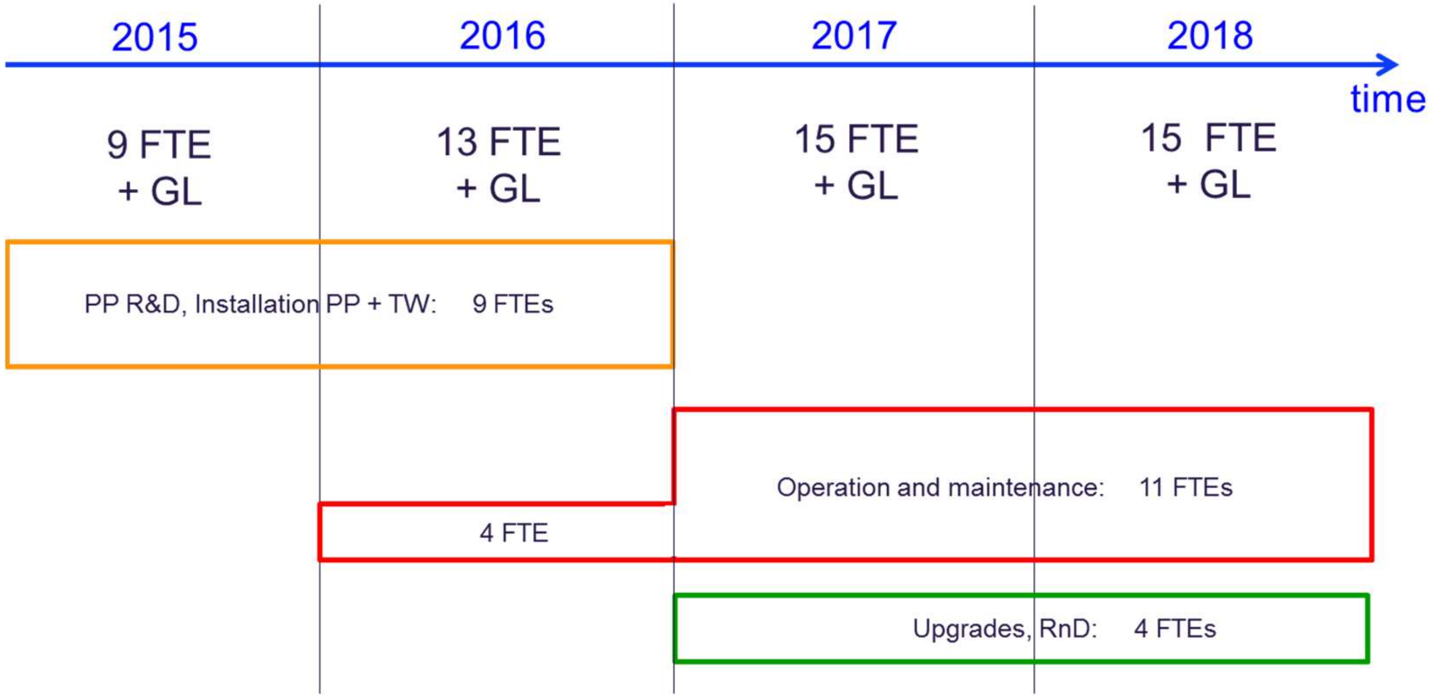
- Stable working point.
  - ⇨ reasonable margin to „hero-specs“.
- „Minimally invasive“ parameter change during experiments. I. e. Change rep-rate through P.o.D. rather than laser itself, in case pulse energy is OK, etc.

Laser spec:

- Specify to user what is definitely possible. Refrain from „hero-specs“ unless explicitely communicated.
- Advertise conservative time spans for parameter changes.

Personnel

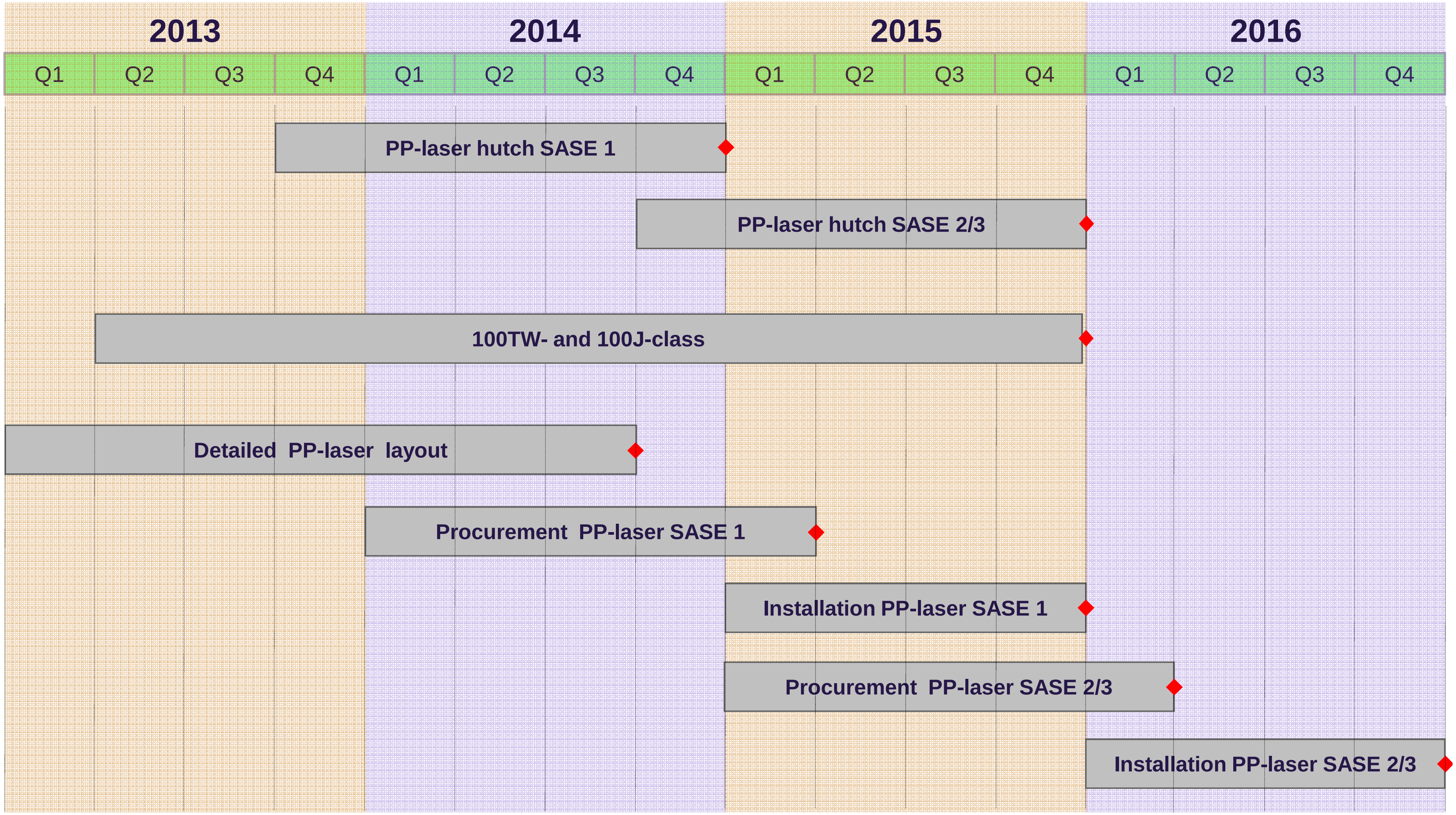
- **Possible personnel development into operative phase:**
  - Assumptions:
    - 2 shifts
    - 2 Laser Eng. + 1 Laser Sci. per shift on experiment floor.
    - At least 1 laser trained instrument Sci./Eng. is present per instrument and shift.



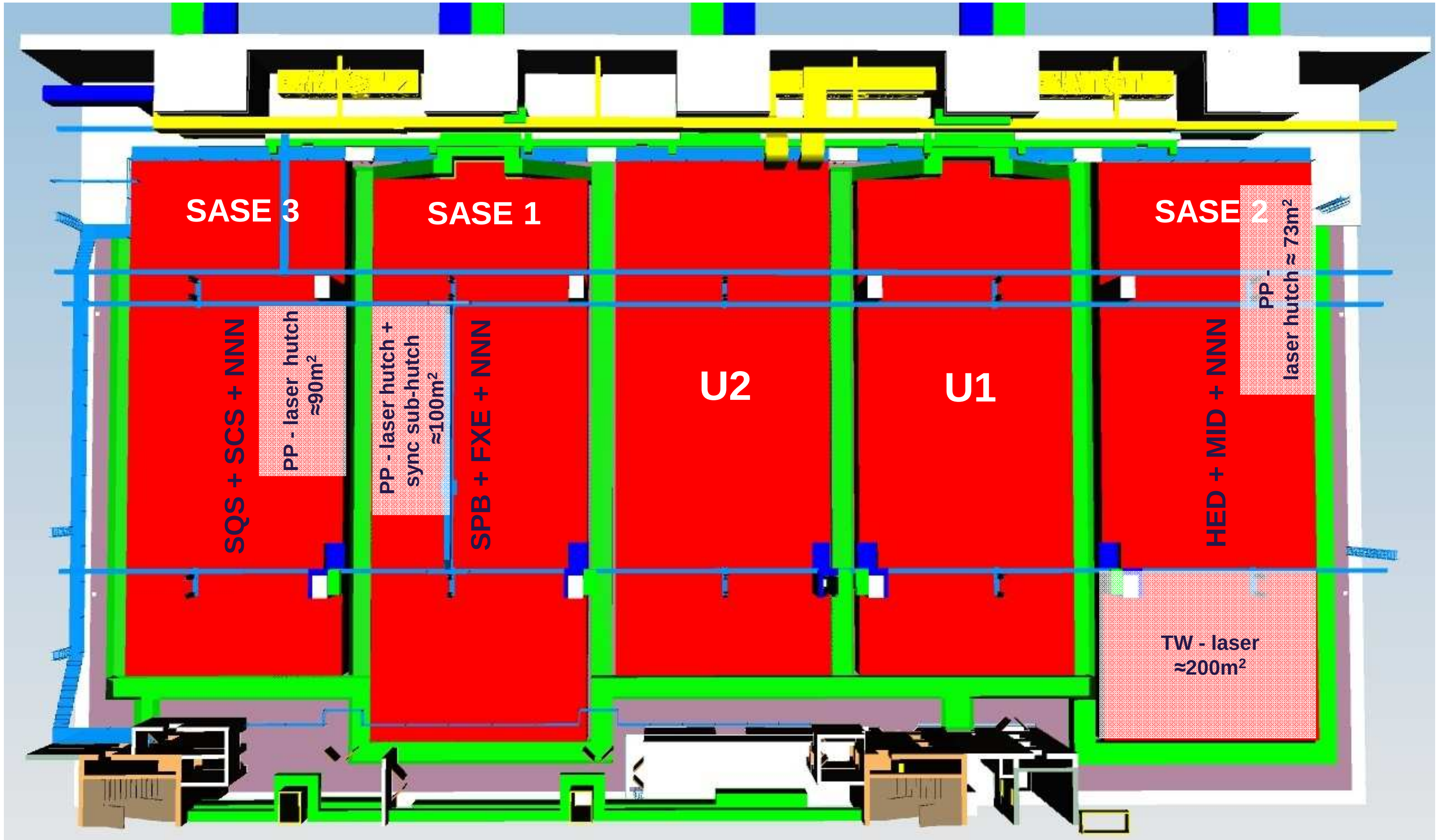
Note: Operation conditions at European XFEL are not yet determined (shifts, etc.)

Planning and current status

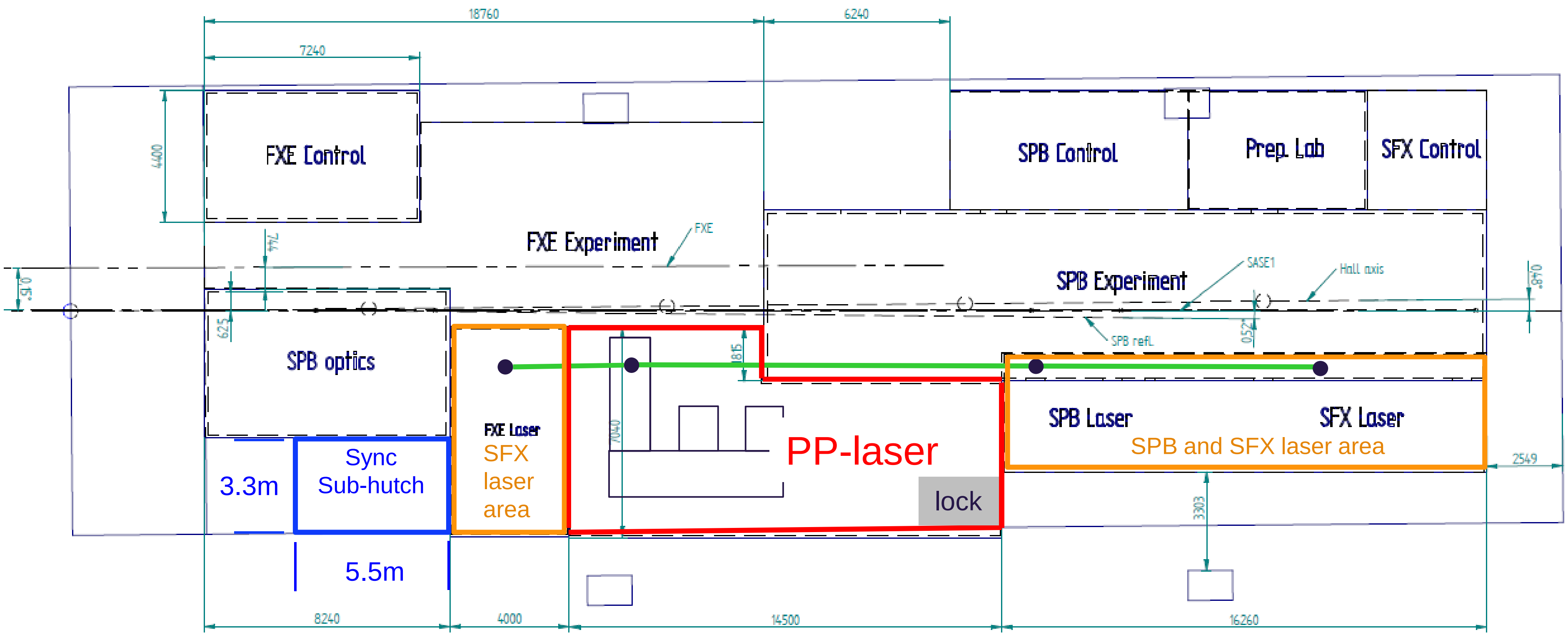
Pump-probe laser installation plan



90m x 50m experiment hall (current plans).



Example: laser hutch integration SASE 1.



Conclusions

Due to the burst-mode emission pattern of the European XFEL and the pulse requirements, the pump-probe laser development faces unique challenges, both technological as well as time line.

♦

Close collaboration with industry is necessary in order to achieve our goals in time.

♦

After a 1 ½ year planning and design phase, lab work has started in August 2012. First results on super continuum seed generation, all-fibre front-end and first stage power amplifiers are encouraging and turn out to be as planned.

♦

Design, preventiv-maintenance and operative measures have been identified to maximise up time of the pump-probe and other laser systems at the European XFEL.

Thank You!