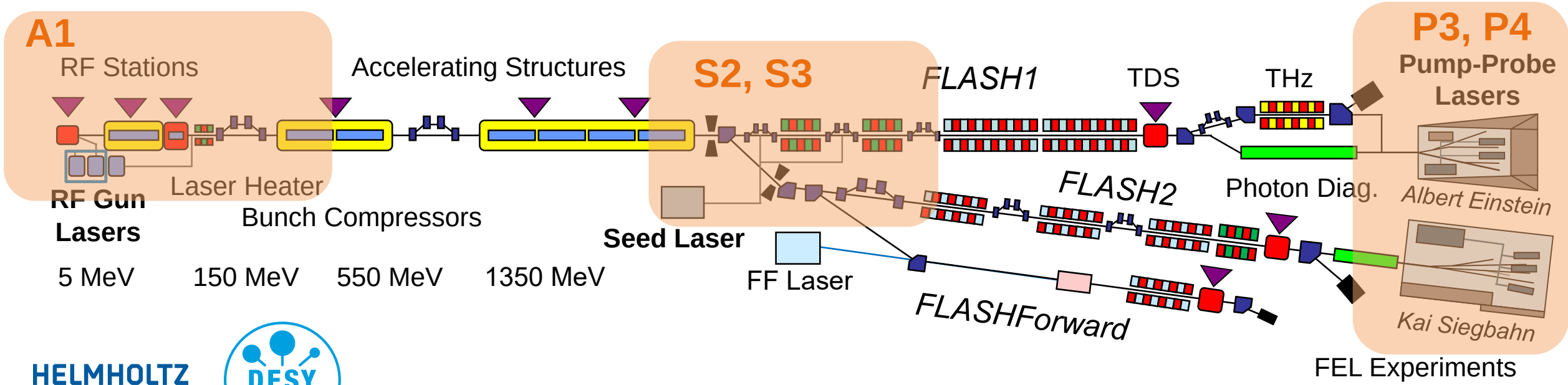
Laser Systems

Work Packages:

P3 : Pump-probe laser systems
P4: Pump-probe laser delivery
S2: Seed Laser System
S3: Seed Laser Beamline
A1: Photoinjector Lasers and Beamline (and Laser Heater Laser)

Tino Lang, on behalf of WPs P3,P4,S2,S3,A1

FLASH2020+ Progress Review Meeting, Oct. 18, 2024

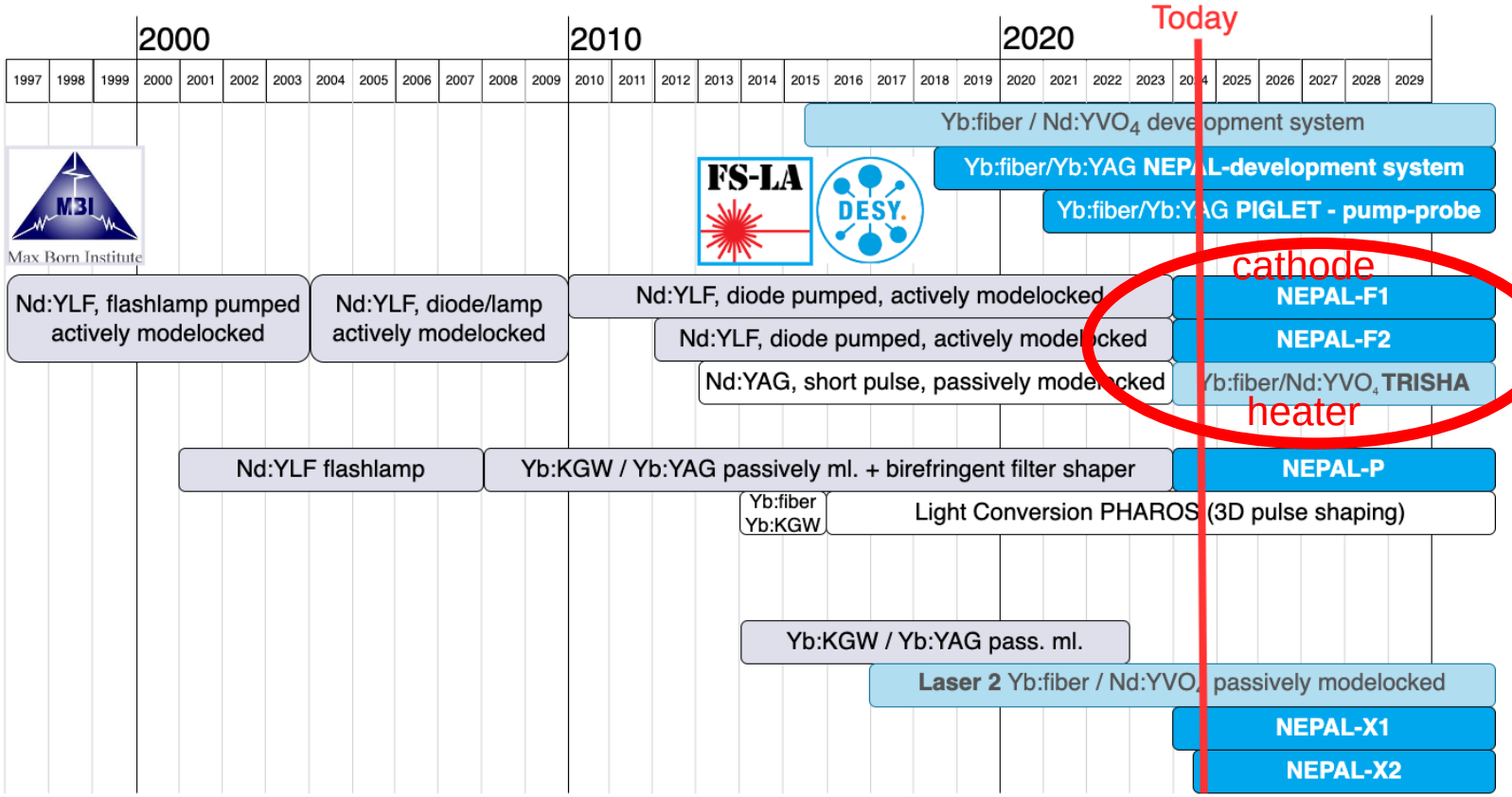


HELMHOLTZ DESY.

WP A1: Photoinjector Lasers, Beamline and Laser Heater

NEPAL was developed as Next generation Photocathode Laser

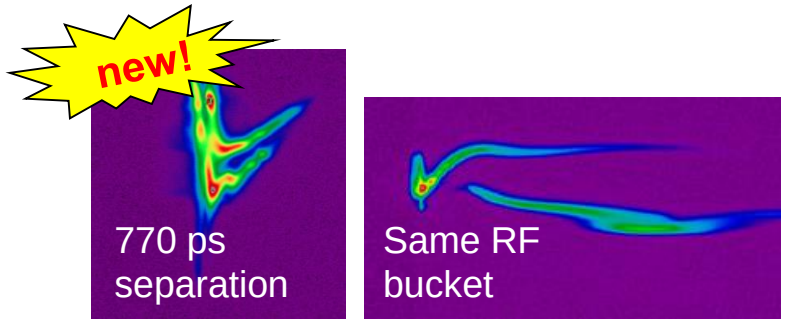
Status: NEPAL is commissioned at all three facilities (FLASH, PITZ, EuXFEL) in basic version



NEPAL:

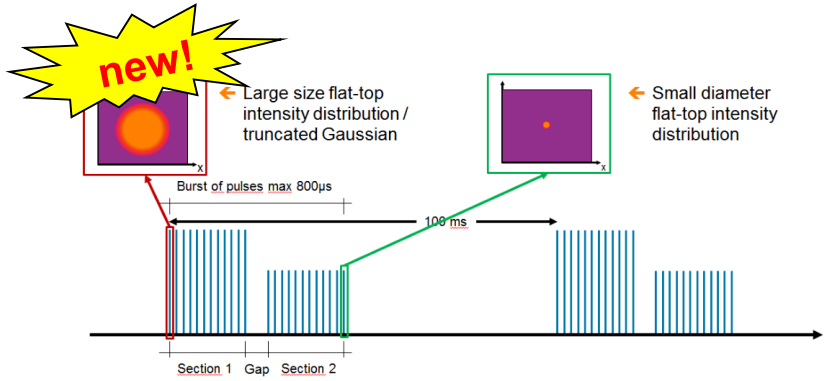
- ✓ Common laser platform across several facilities
- ✓ Common spares, operation procedures
- ✓ Fiber-laser front-end: alignment-free, low maintenance
- ✓ Remote control, ample diagnostics

NEPAL to-do: advanced feature development



- Twin-bunches (EuXFEL) / THz doubler (FLASH)
- Two laser pulses in same or close RF bucket

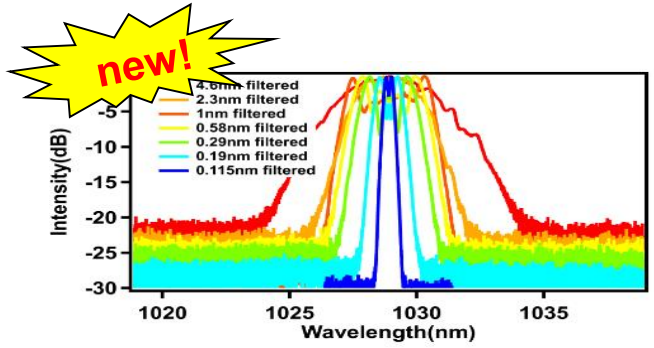
Done! (demonstrated at EuXFEL)



- Variation of charge along the bunch train using a single NEPAL laser

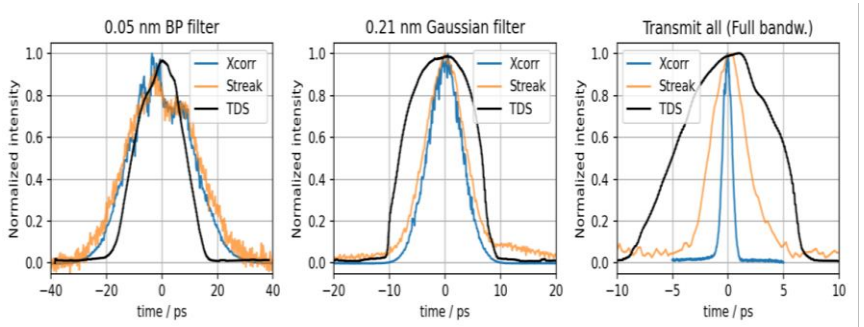
R&D version: works

currently developing production software. goal: can be used by non-expert (BKR operator)



- Variation of pulse duration
- Advanced shaping, e.g. flat-top

R&D phase ongoing
ErUM-data project: OPAL-FEL
very promising results



Results from R&D at EuXFEL

TRISHA (laser heater laser) Status / TODOs

Used for some tests (even user experiments) but not fully commissioned

- **pulse duration**
  - Autocorrelation measurement pending (equipment there, staff missing)

  → We know that the pulse duration is shorter than the specified value in the FPRD. Is this sufficient?

- **Beam transport beam stabilization system**
  - hardware complete, basic version works
  - TEM company currently finishing GUI software
    → currently running at R&D system (EuXFEL)
    → needs to be tested and verified on actual system

- **beam size control in modulator**
  - FPRD requires change beam waist size by factor of ~ 5x at LH modulator, in practice factor is limited to about 2x (due to alignment sensitivity)
  - todo: re-evaluate requirements. If 2x is not sufficient a design change is required
- **pulse energy control (different heating power for FLASH1 and FLASH2)**
  - Under development (same software as electron bunch charge variation in NEPAL
- **beamline coupling OS0 → LH Undulator**
  - not optimal (periscope too coarse, hysteresis)
    → improvements required

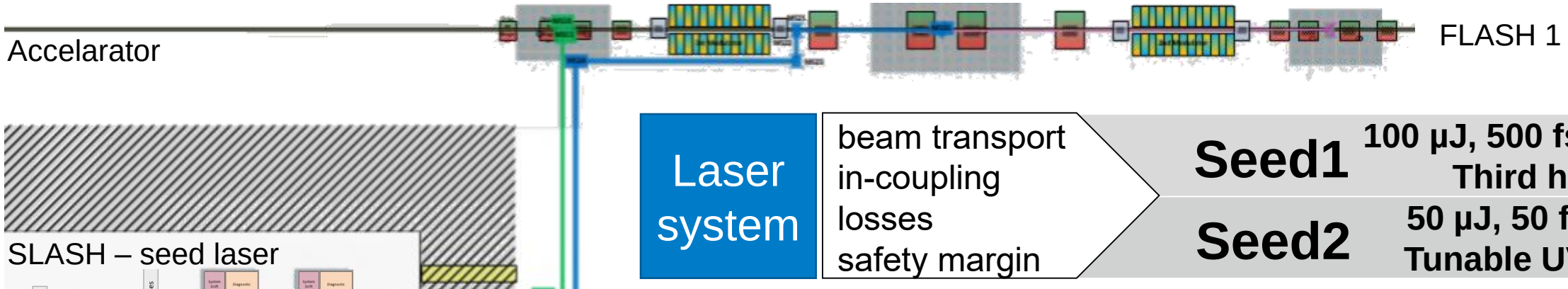
WP A1 → operation (outside FLASH2020+ project)

Currently no staff for photocathode / laser heater laser operation.
Situation needs to change for FLASH starting up after shutdown.

WP S2: Seed Laser System

Introduction . Seed laser system

Seeding laser specification for two color tunable EEHG x-ray FEL seeding



Laser system

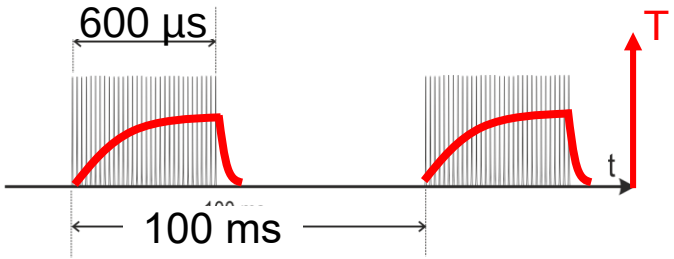
beam transport
in-coupling
losses
safety margin

Seed1 100 µJ, 500 fs, 1 MHz, Third harmonic

Seed2 50 µJ, 50 fs, 1 MHz, Tunable UV pulses

Parameter	Seed1	Seed2
Wavelength	343 nm	297 – 317 nm
Pulse duration	500 fs	50 fs
Pulse energy Peak power	50 µJ 100 MW	16 µJ 320 MW
Burst duration/ rep. rate	1 MHz	
Burst-burst | pulse-pulse instabilities	< 4% | < 2% (RMS)	
Wavelength stability	10^{-3}	$2*10^{-4}$ (0.07 nm)
Position stability	18 % of beam size (RMS)	
Pointing stability	< 50 µrad	
Timing jitter	< 50 fs	

24/7

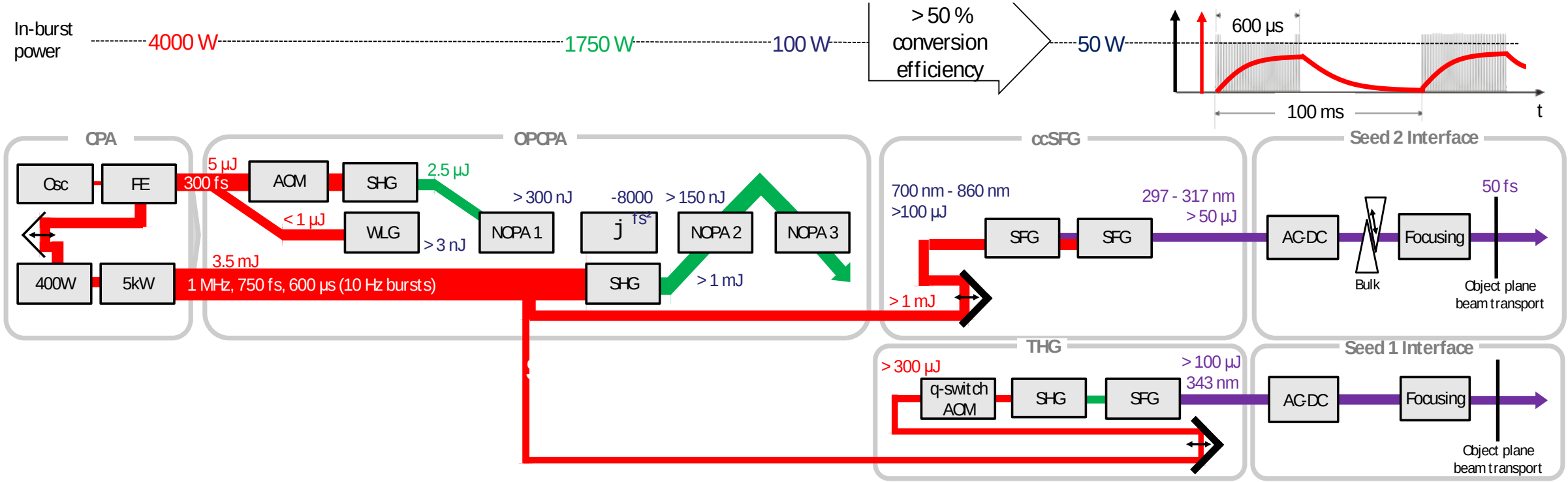


FLASH burst timing structure: Allows for high peak power but laser will nether reach thermal equilibrium

Laser System.

Overview

- Commercial pump laser
- Seed 1: Third harmonic generation
- Seed 2: Optical parametric amplifier (OPA) and cascaded UV generation
- Mode-matching and pre pulse compression before transport to the modulators



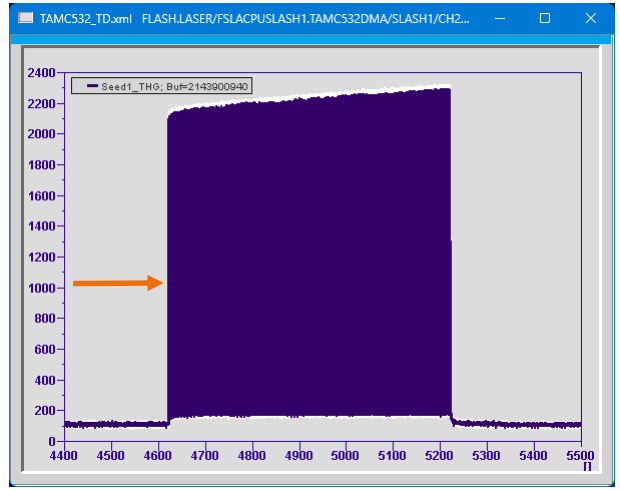
Laser System. Seed 1

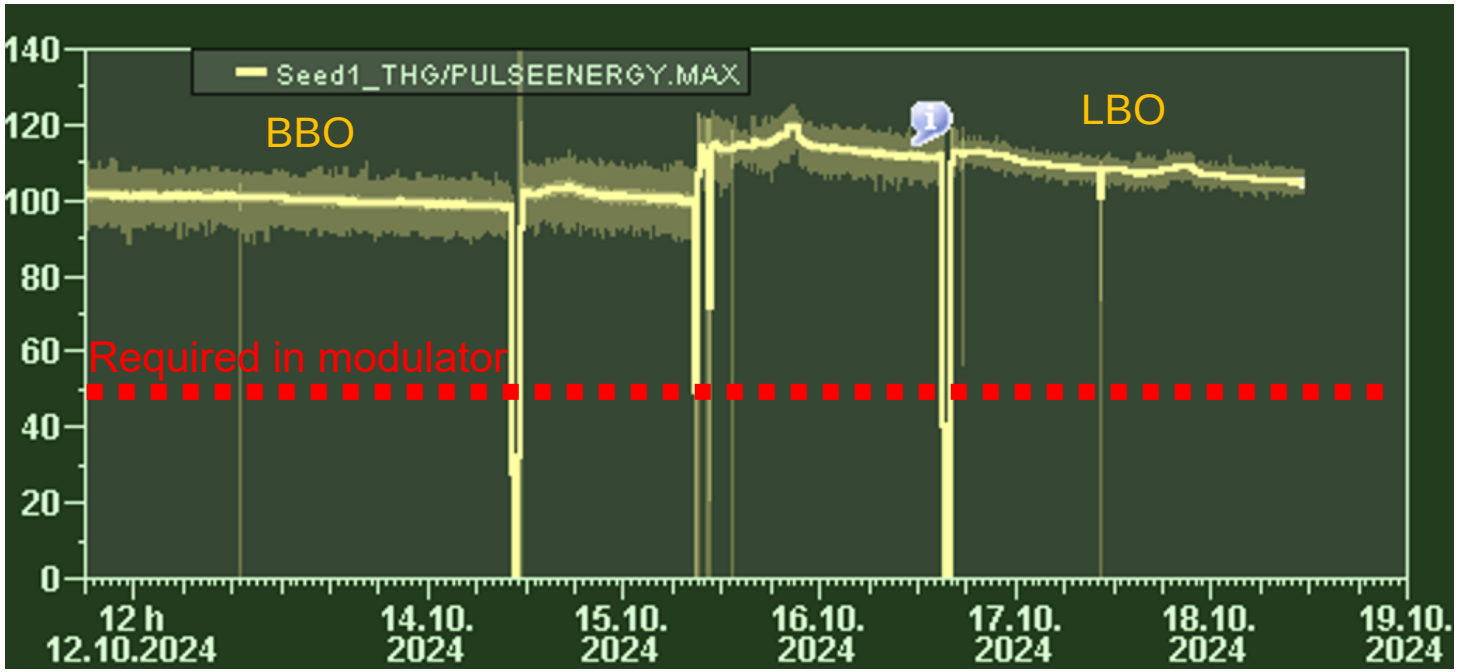
Progress

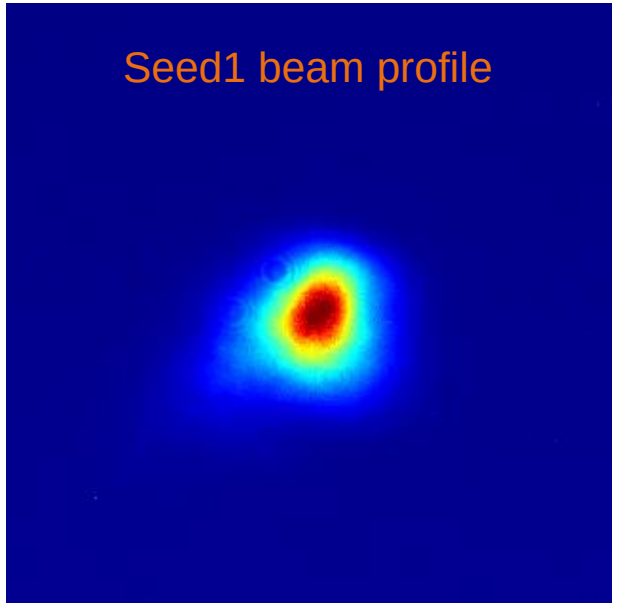
- Beam stabilization and pulse picking AOM fully operational / read for burst-flattening
- Pulse energy in specs, good beam quality (exact. specs under investigation)
- Long-term crystal degradation currently under investigation (not yet conclusive)

Next steps

- Installation of mode-matching, beam and pulse diagnostic
- Installation of vacuum chambers for beam transport







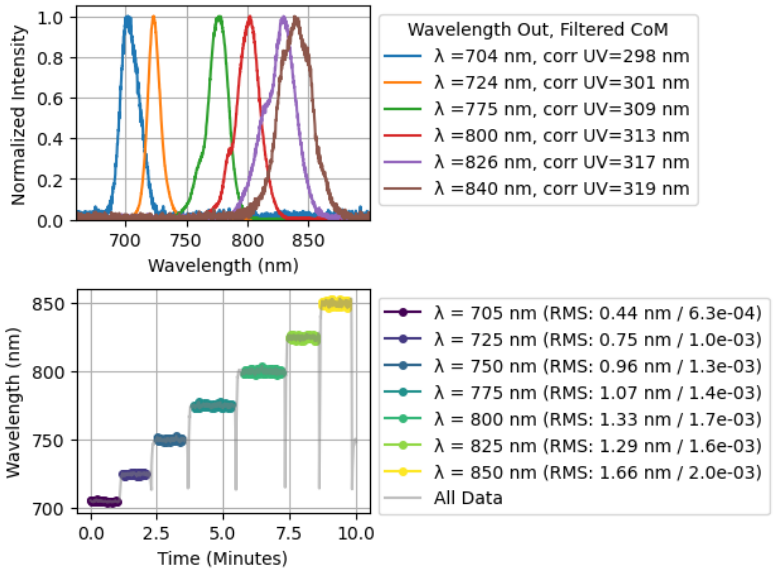
Laser System. Seed 2

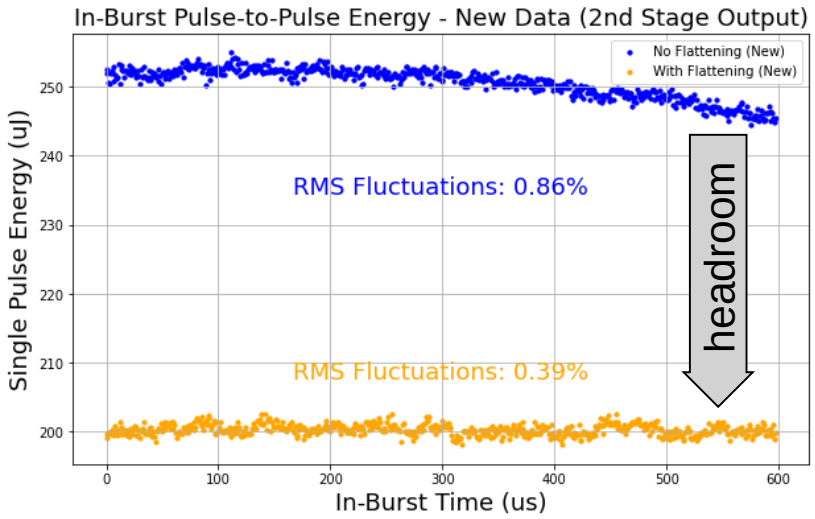
Progress

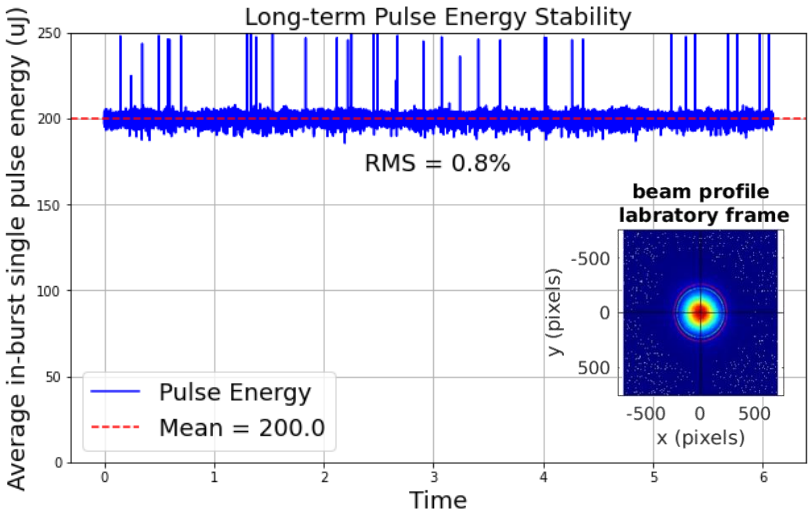
- OPCPA fully operational and in specs
- Excellent stability and long-term performance
- Detailed technical-design of Seed 2 UV conversion ready

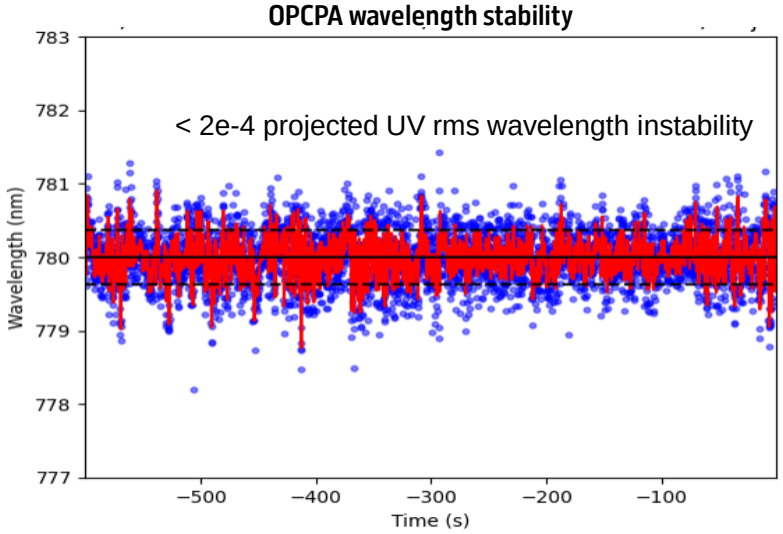
Next steps

- Installation UV conversion setup
- Installation of vacuum chambers for beam transport
- Installation of beam diagnostics and mode-matching for beam transport



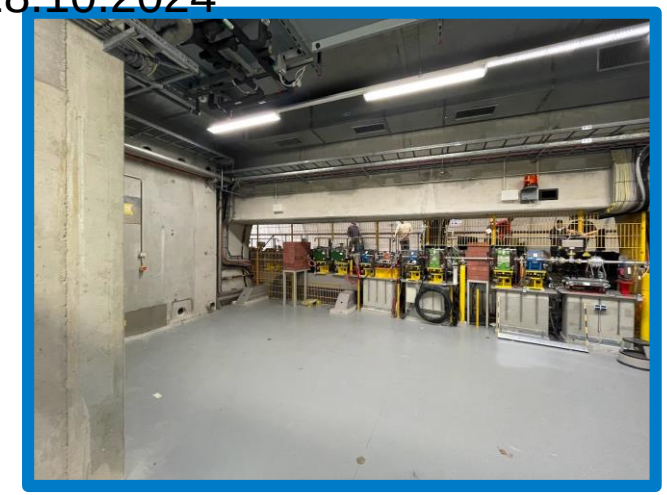


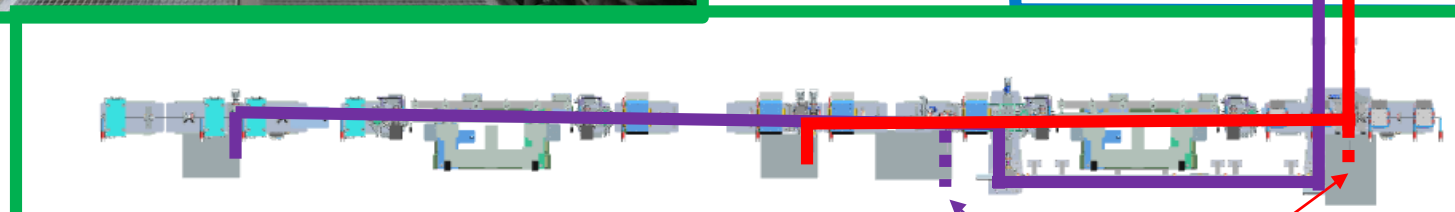




WP S3: Seed Laser Transport

Seed Laser And Transport.





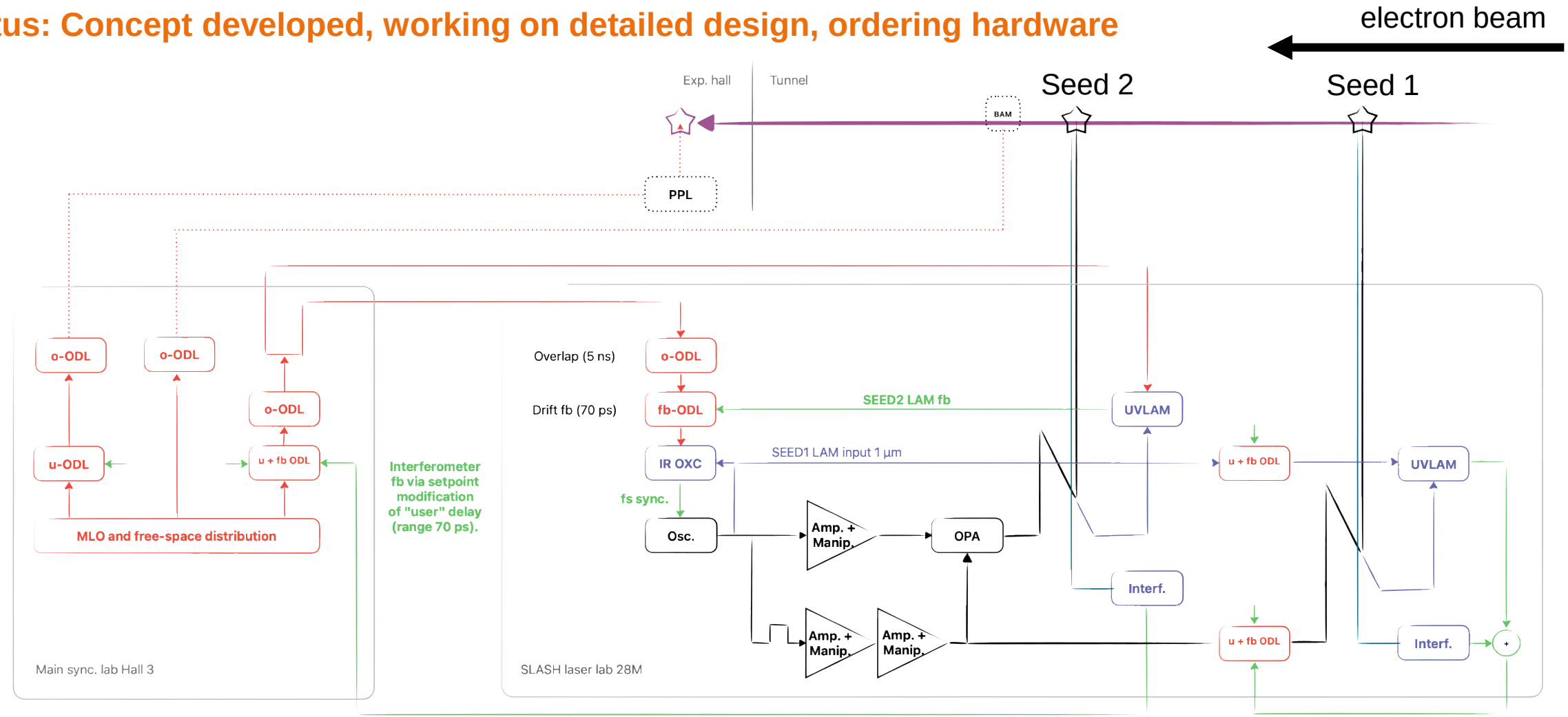
Status – Beam transport

- **Beam Transport Optics**
  several review meetings (Sept/ Oct. 2024)
  → design frozen
  → UV coatings ordered, damage tests in Dec. 2024
- **Vacuum System / Optomechanics**
  Laser lab: design frozen
  → install vacuum system Nov. 2024
  !!! Needed: arrival of ordered components ASAP
  – one key component (force-balancing-bellow) sits in Denmark for pick up
  → working with V4 to solve situation
  Extraction/ tunnel: finalizing design (last touches)
  → expect to freeze design end of next week
  → drill holes / mount base plates in November
- **Diagnostics**
  Diagnostics in laser lab
  → conceptual design finished,
  → currently working on detailed design
  → ordering components
  Diagnostics extraction / tunnel
  → conceptual design finished
  expect to start detailed design end of year

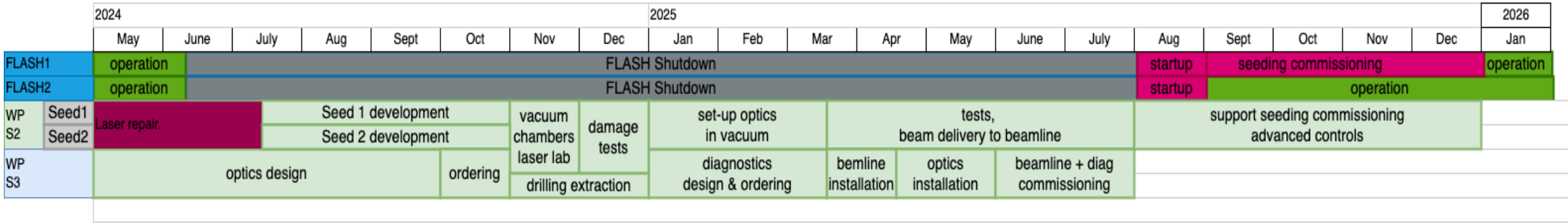
Synchronization / Timing to Electron Bunch

WP T5 (LbSync)

Status: Concept developed, working on detailed design, ordering hardware



Coarse Timeline….



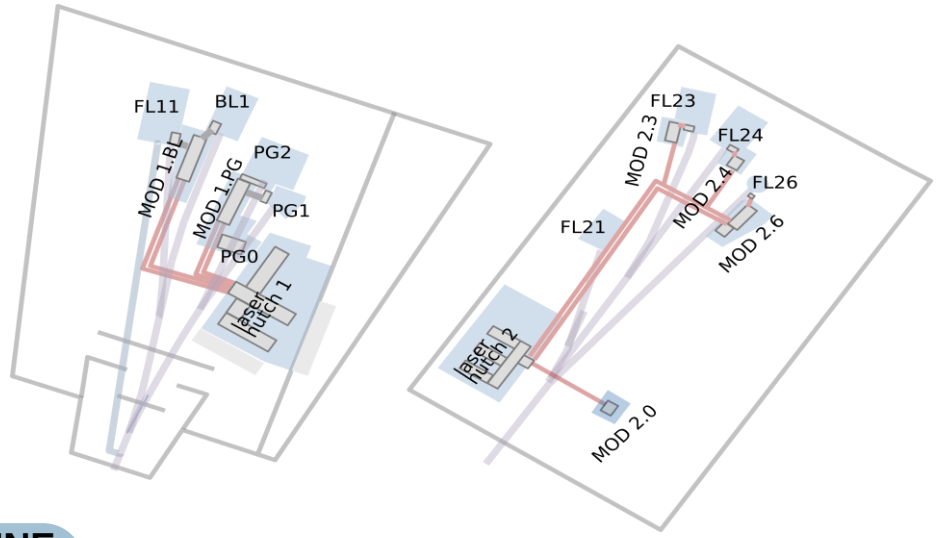
- Till end of the year:
  - Seed laser ready for beamline installation (initial reduce feature set)
  - Conclusive study about long-term performance of Seed1 and Seed2 (damage tests)
  - Installation the vacuum components in the laser lab
  - Drilling and installation of beamline mounting in the extraction
- Till next year Aug.:
  - Installation diagnostic beamline in-coupling in the laser lab
  - Beamline installation including optics and commissioning
- Till end of next year
  - Seeding commissioning
  - Implementing advanced laser controls (extend the laser feature set)

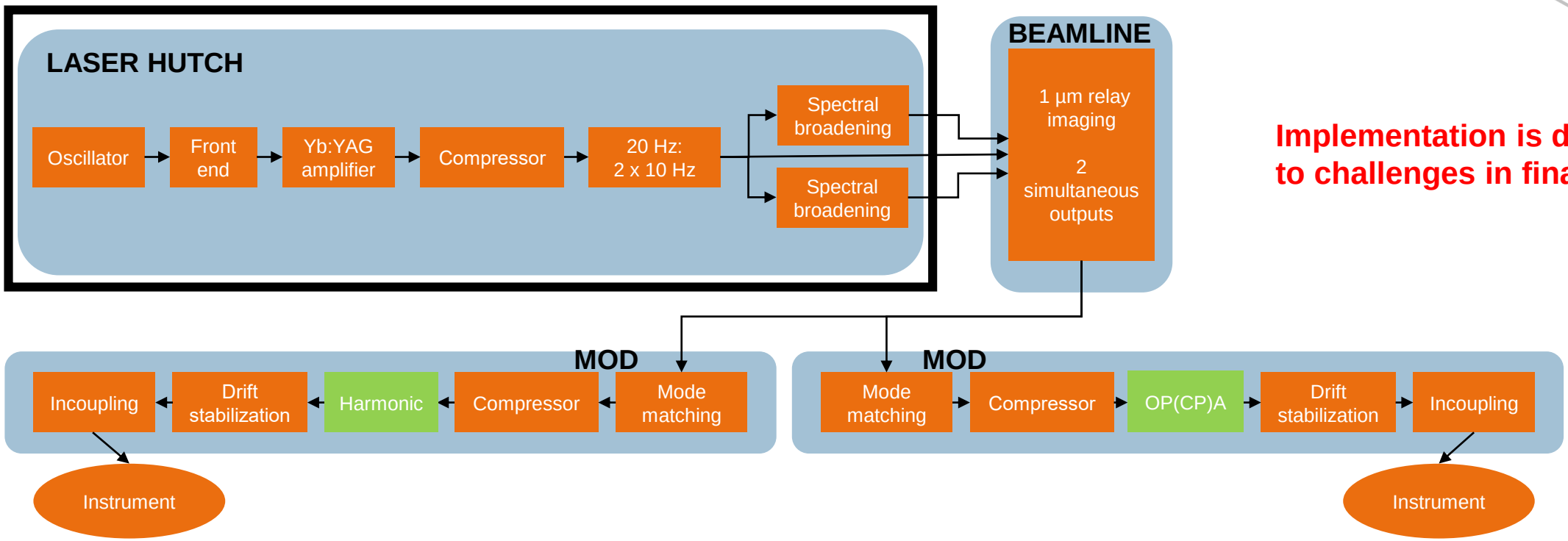
WP P3:
Pump-probe laser systems

WP P4:
Pump-probe laser delivery

FLASH2020+ laser delivery concepts

Delivering beams simultaneously to two instruments!
Concurrent pump-probe experiment and preparation for the next experiment (applicable to both FLASH1 and FLASH2 FEL's).





Implementation is delayed due to challenges in financing

A-L. Viotti, S. Alisauskas, M. Seidel, A. Tajalli, B. Manschwetus, H. Cankaya, K. Jurkus, V. Sinkus, I. Hartl, Review of Scientific Instruments, 2023, 94: p 023002.

FLASH Pump-Probe Laser Upgrade (Fit-to-Budget Proposal)

Realization of pump-probe lasers under tight budget constraints

Beamline	Fundamental	Harmonics	MIR	UV/VIS
BL1-3 & FL11	0.5 mJ (200kHz), <50 fs	> 10µJ (200kHz) in UV-Vis, <100 fs		
PG1	50 µJ, 1.03µm, 60 fs, 1MHz,	5 µJ, VIS, (1MHz) <0.5 µJ, UV (1MHz)		
PG2				
FL23	2 mJ (100kHz), <50 fs	> 10µJ (200kHz) in UV-Vis, <100 fs		
FL24	200 µJ (1MHz), λ=1030 nm <50 fs	8 µJ (1MHz) VIS,	0.8 µJ (1MHz), λ=2-5 µm <150 fs **Burst**	Tunable 8 µJ (200kHz), 0.8 µJ (1MHz), λ=200-500 nm <40 fs **Burst**
FL26		15 µJ (200kHz), 0.8 µJ (1MHz) UV		

- FLASH1: PG1/2 – keep interims laser (PIGLET)
- FLASH2: Hybrid Operation
  - FL24 & FL26: Existing 800 nm OPCPA at 100 kHz and harmonics
  - FL23 (New beamline): 1 µm technology at 100 kHz, 1 mJ at 1 µm and harmonics (2nd, 3rd and 4th) at target
- FLASH1: 1 µm operation for FL11:
  - FL11 (New beamline): 1 µm technology at 200 kHz, 0.5 mJ at 1 µm and harmonics (2nd, 3rd and 4th) at target
  - **Budget is available since June 2024 for minimum version**
    - currently starting to setup-up the laser (detailed planning on-going)

Conclusions

- WP A1:
  Photocathode laser NEPAL: commissioned – developing advanced features
  Laser heater laser TRISHA: set-up tested (limited controls) needs to be finalized
  ISSUE: No operations staff
- WP S2/S3
  Set-up ongoing, on target but timeline critical
- WP P3/P4
  Received funding for fit-to-budget proposal
  → starting developing FLASH1 pump-probe laser DALGA
  → keep FLASH1 PG laser (PIGLET) and FLASH2 pump-probe laser (ULGAN-F2) as is.

Thank you

Ingmar Hartl (WPS3)
Ayhan Tajalli (P3)
Hüseyin Cankaya (P4)
Sebastian Schultz (P5)

Areeb Ahmed, Oender Akcaalan, Skirmantas Alisauskas, Nelvin Blanken, Andreas Bremer, Frank Brinker, Anne-Laure Calendron, Ye Chen, Giovanni Cirmi, Massimo de, Matthias Felber, Christopher Gerth, James Good, Uwe Große-Wortmann, Arne Grünhagen, Marc Guetg, Nhat-Phi Hoang, Denis Ilia, Yujiao Jiang, Mehdi Kazemi, Tomasz Kozak, Nick Kschuev, Thorsten Lamb, Changxiu Li, Chen Li, Christoph Mahnke, Frederik Mey, Christian Mohr, Harsha Panuganti, Dirk Pieper, Federico Pressacco, Hamid Rashtabadi, Maike Roehlin, Sarper Salman, Matthias Schacht, Martin Schäfer, Lucas Schaper, Sebastian Schulz, Maximilian Schütte, David Schwickert, Marcus Seidel, Angad Swiderski, Peter Talkovski, Hamed Tavakol, Henrik Tünnermann, Caterina Vidoli, Anne-Lise Vittoli, Lutz Winkelmann, Jiaan Zheng, Falco Zummack, et al.

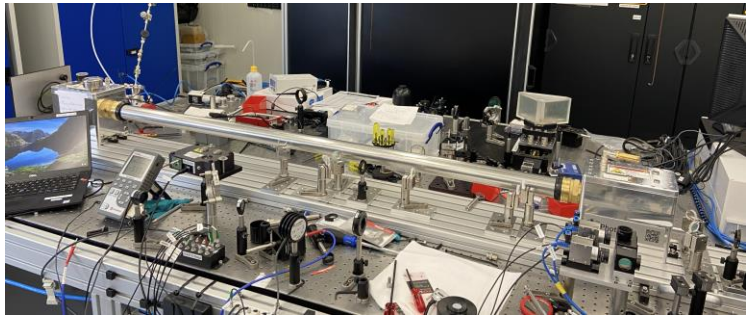
Realization: MPC for FLASH2 Pump-Probe laser

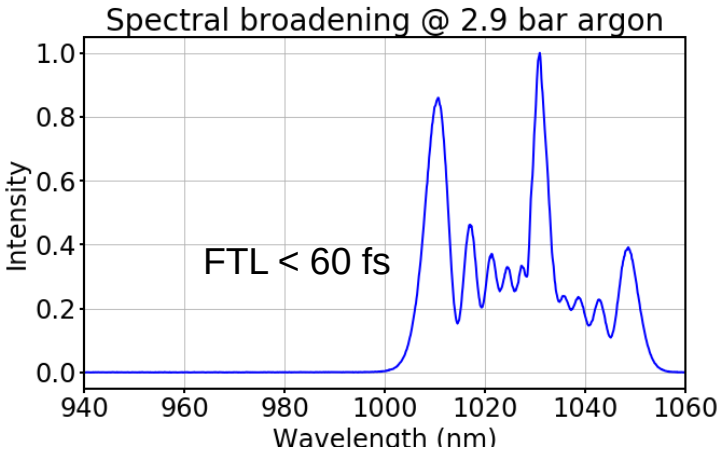
Commercial system: cost-effective & less complexity with German safety Regulations (less gas volume) → n_2 Photonics

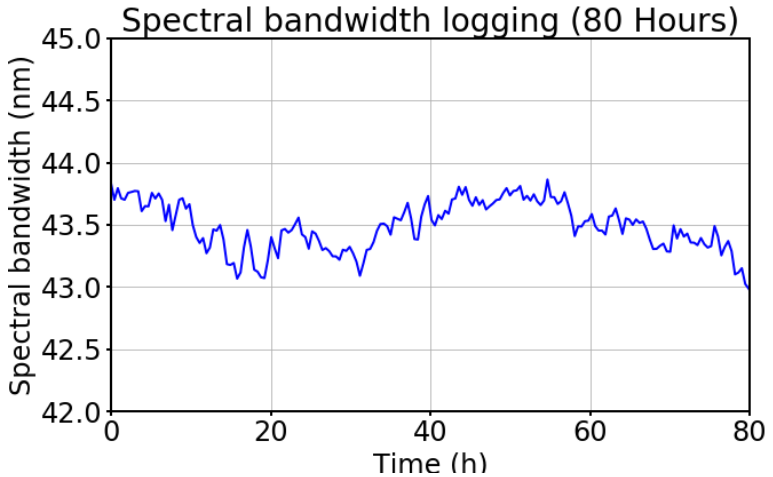
Installed in Sep. 2023 & Debugged until Jan. 2024

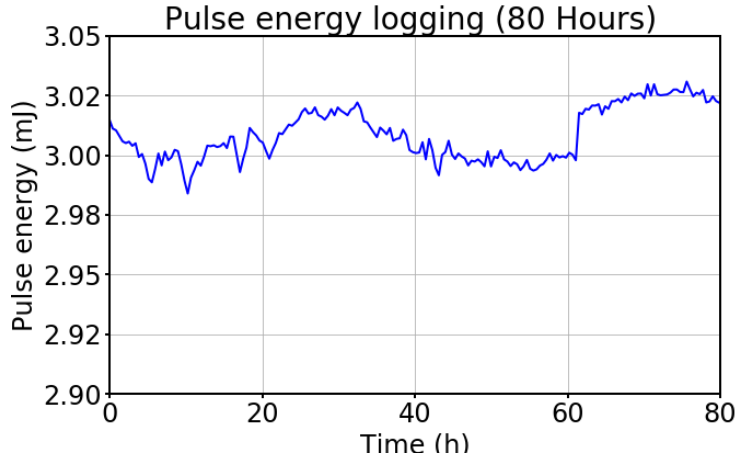
Input: 3.5 mJ ,100 kHz, 1030 nm, 1 ps

Output: FTL < 60 fs, Transmission >90%



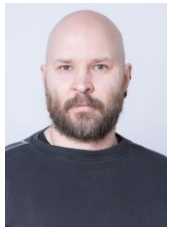




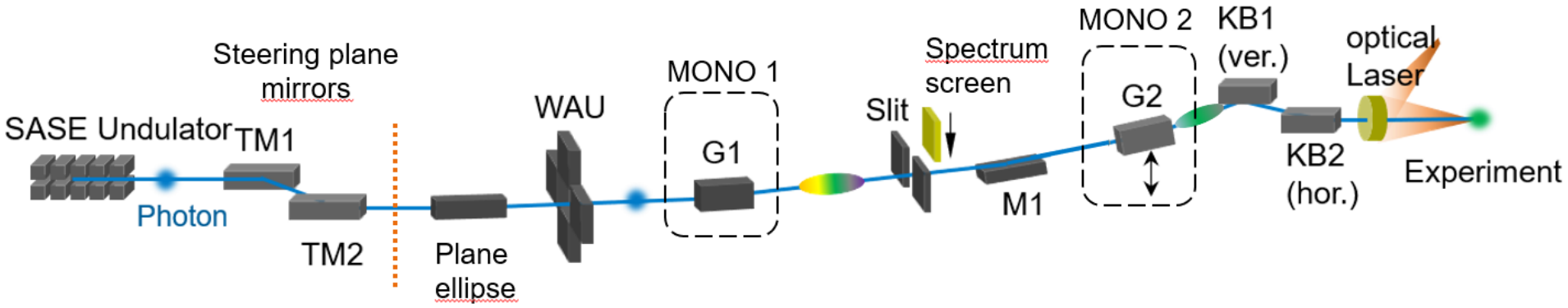


FL23/MOD2.3: First Experiment

Spectral Encoding

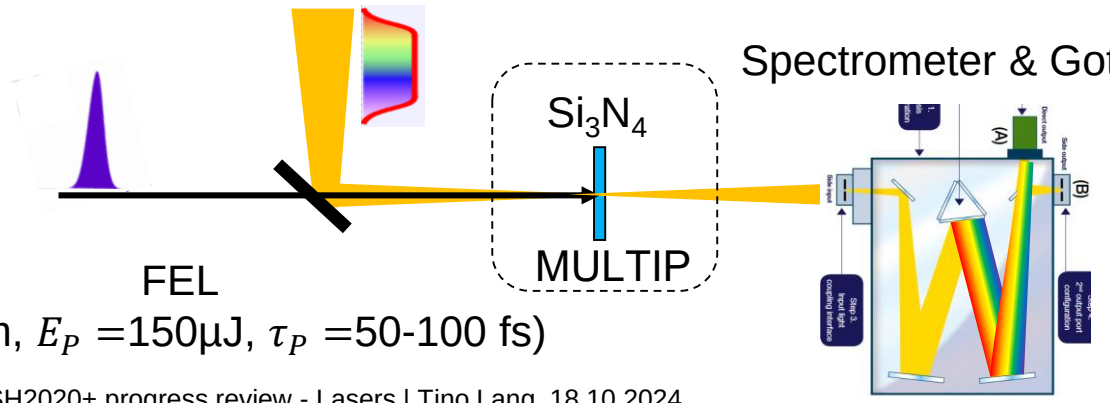



& FLASH Team



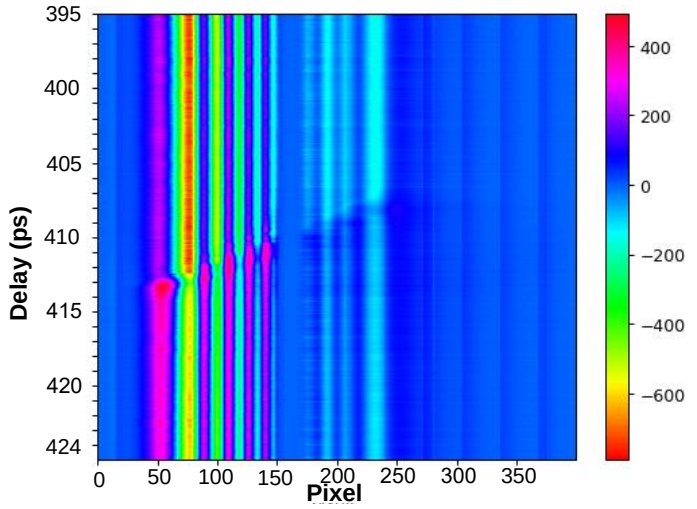
Chirped pump-probe laser pulse:

(λ =1030nm, $\Delta\lambda$ =45nm@ -10 dB, τ_{TL}=70 fs (FWHM), τ_P=2-4ps (FWHM))



(λ =15nm, E_P =150µJ, τ_P =50-100 fs)

Change of transmitted laser spectrum



Manuscript in preparation