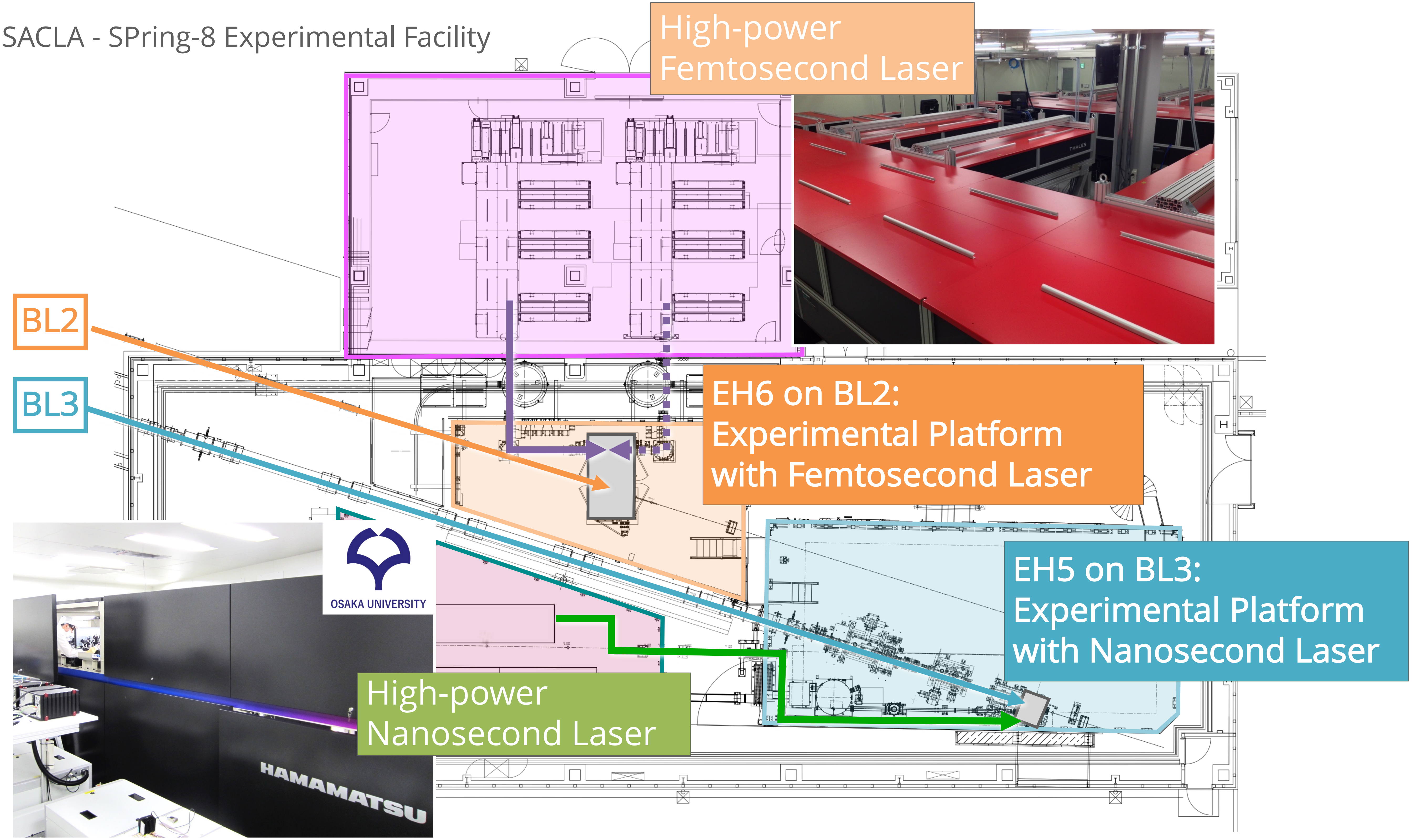
Technical Updates: High-power Optical Laser Systems

Kohei Miyanishi
on behalf of SACLA

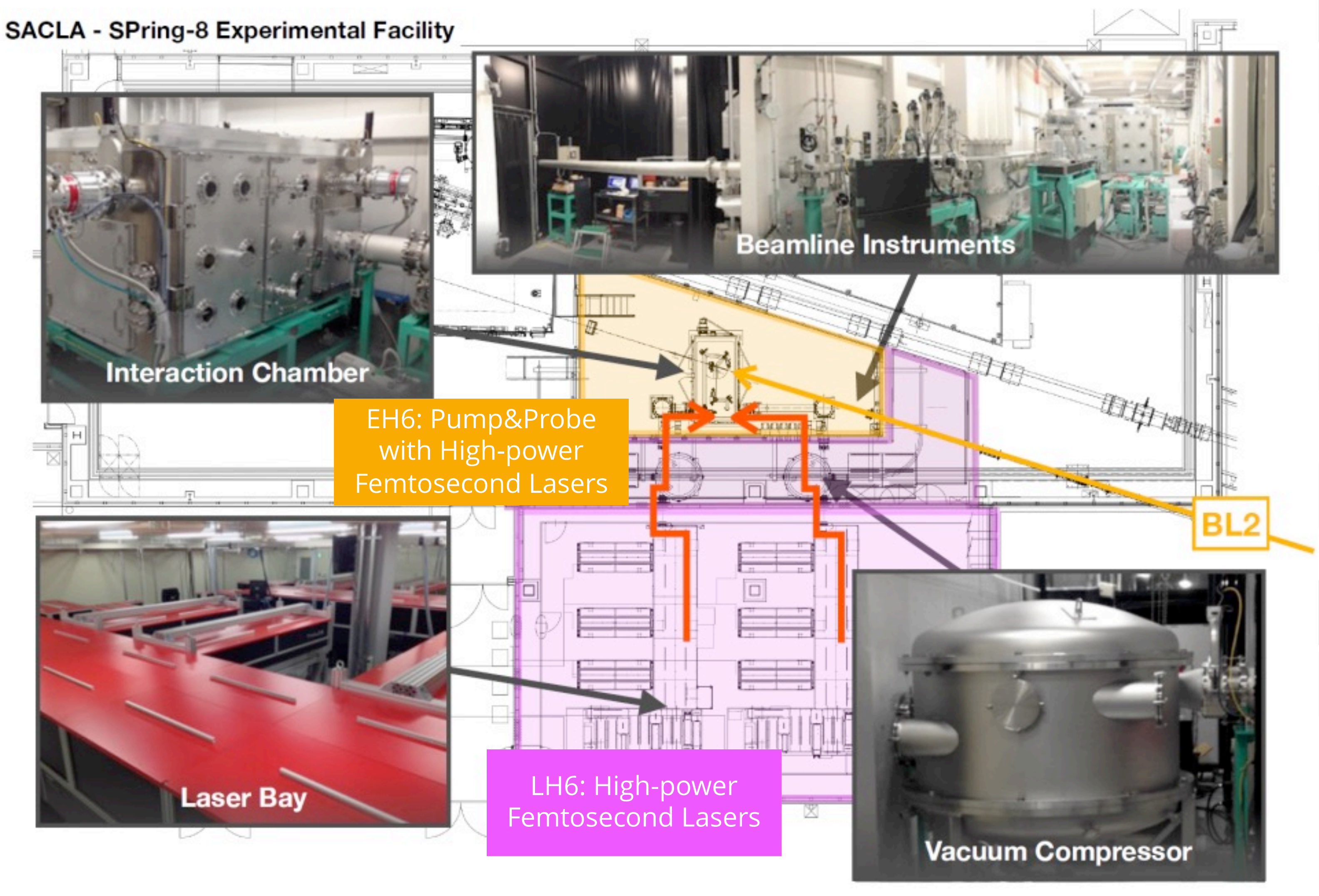
Two experimental platforms with high-power laser systems

SACLA - SPring-8 Experimental Facility



*High-power nanosecond laser was installed by Osaka University.

Experimental platform with high-power femtosecond lasers



High-power femtosecond laser	
Pulse energy	~8 J
Pulse duration	~30–40 fs (typ.)
Wavelength	800 nm
Rep. rate	1Hz
Shot rate	~ 1 shot / 3 min.
Timing jitter	~20 fs (rms) / 3 min.
Timing drift	+/- 500 fs / day

XFEL	
Beamline	BL2
Focusing optics	CRLs for focus (~a few μm) Mirror for 1D focus (~a few um in vertical)

Combination of high-power fs laser and XFEL allows for studying transient, high-energy density states on fs-ps time scales; however, spatial and temporal controls are challenging due to the extreme scales (μm and fs)

Key features

- High power (>200 TW)
- Short pulse duration (~30 fs)
- Small spot size (~20 μm, typical minimum)
- High intensity (up to ~ 10^{19} W/cm^2)

➡ Spatial and temporal controls are key but challenging

Application example

Talk by M. Nakatsutsumi at Scientific Talks A

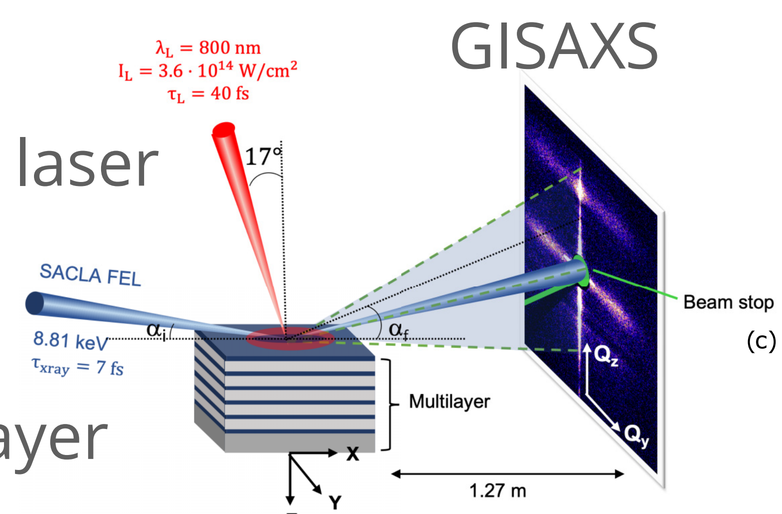
- Nanoscale subsurface dynamics of solids upon high-intensity femtosecond laser irradiation

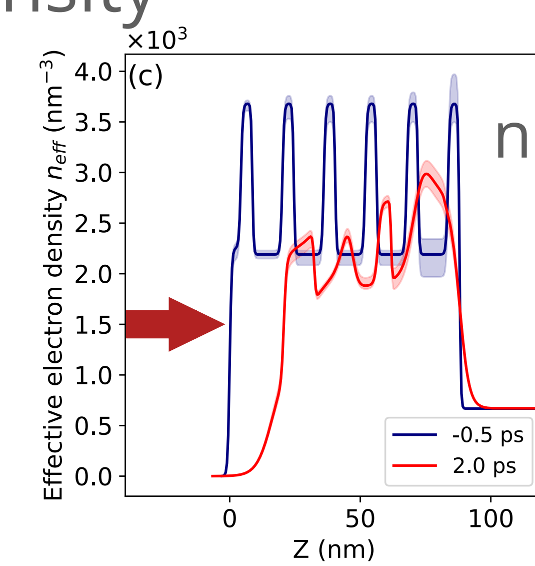
GISAXS

fs laser

XFEL

nm multilayer



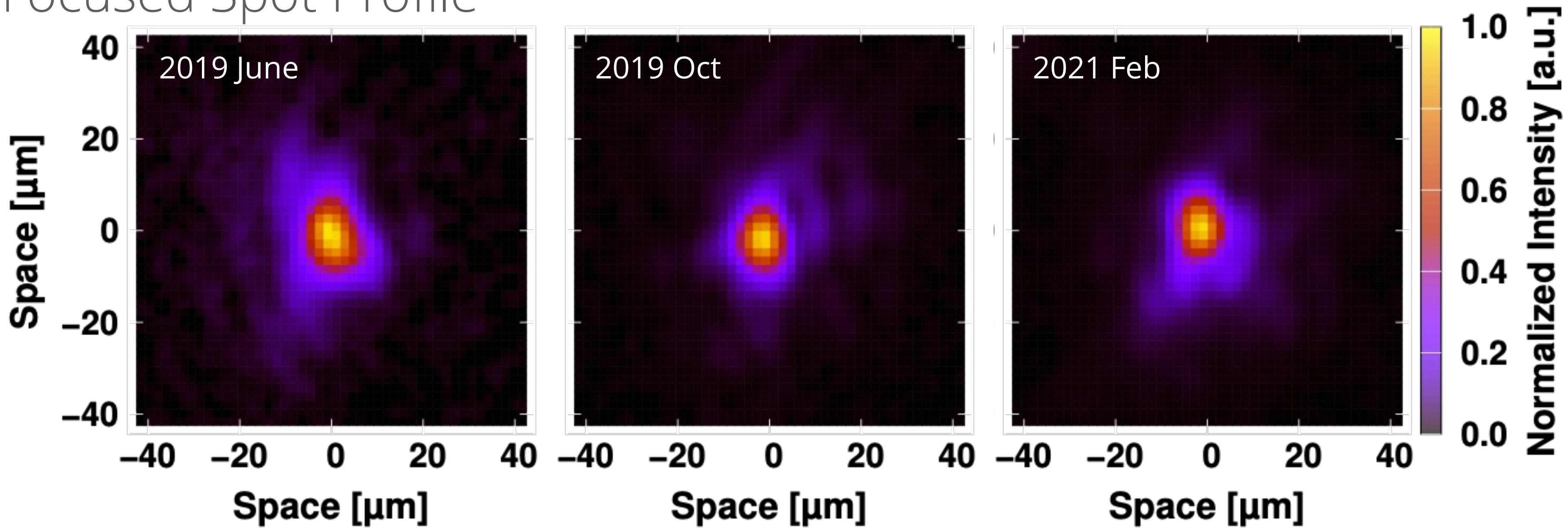


nm, ps

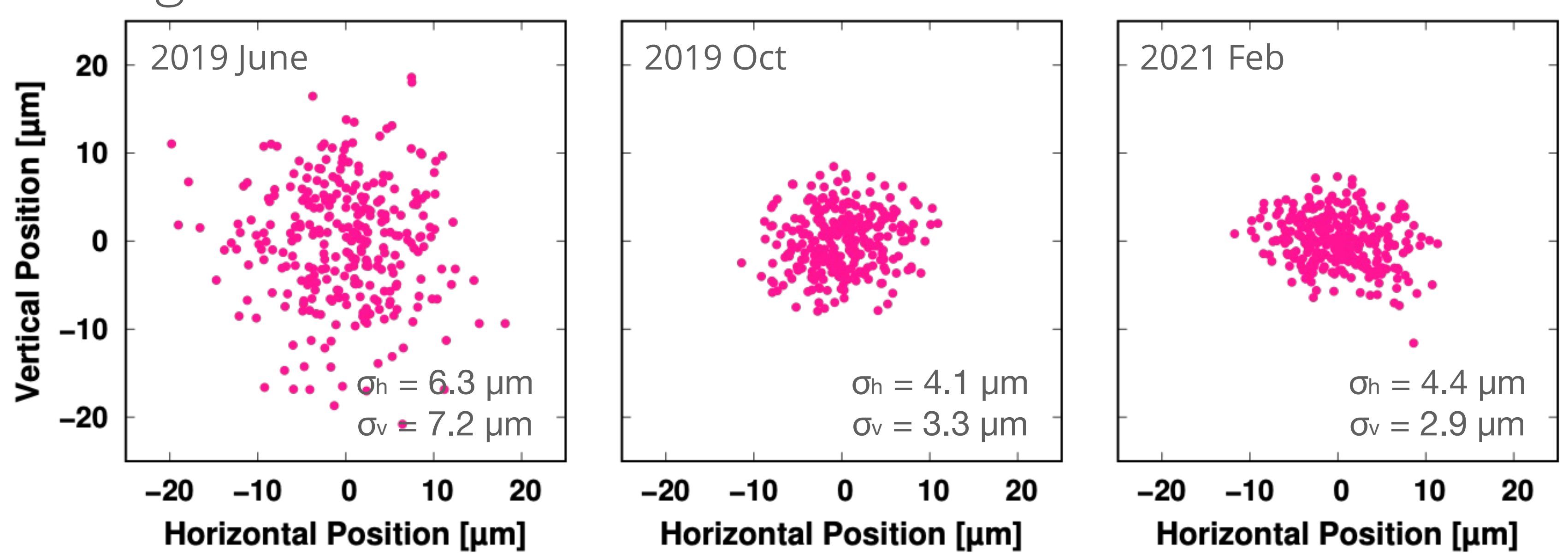
Randolph et al., *Physical Review Research*, *4* (3), 033038 (2022).

Spot profile and pointing fluctuation have been improved

Focused Spot Profile



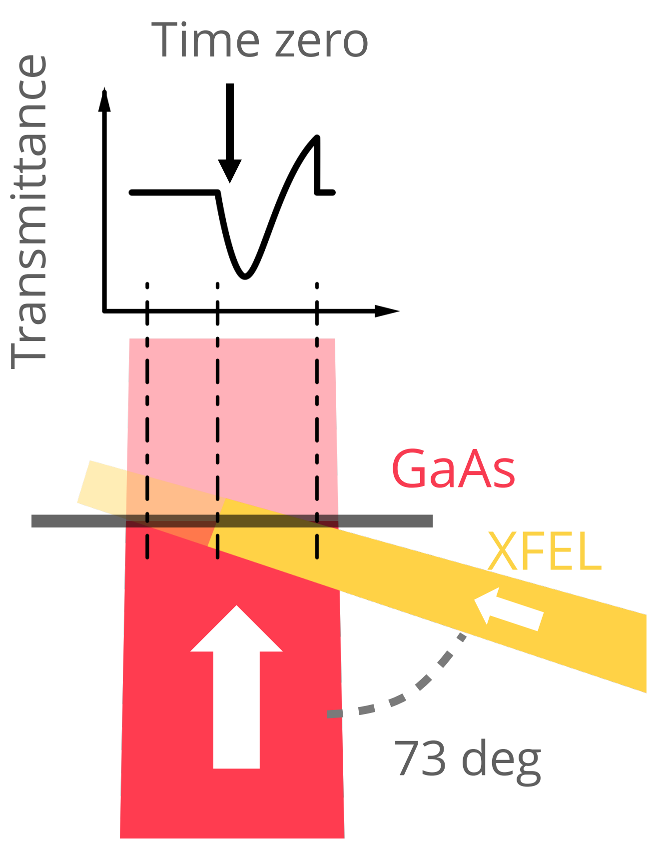
Pointing Fluctuation

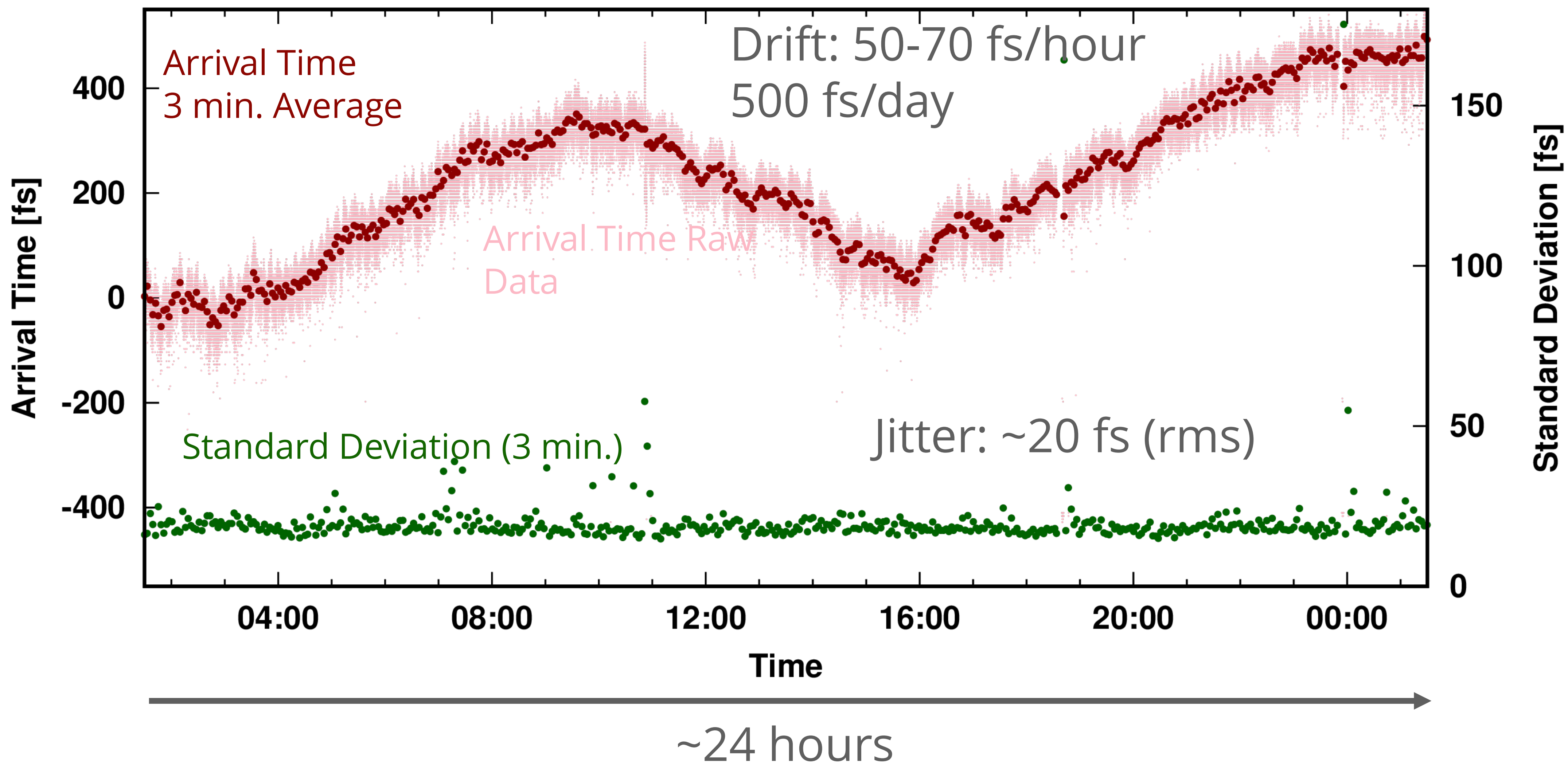


- ✓ Effective wavefront correction of amplified laser pulses made possible by an attenuator results in focused spot profile improvement.
- ✓ Pointing stabilities have also been improved mainly due to the beam stabilization at the XPW (Cross Polarized Wave) system.

High-power femtosecond laser is well synchronized to XFEL with a timing jitter of 20 fs (rms); however, a timing drift of 50-70 fs/hour may be an issue

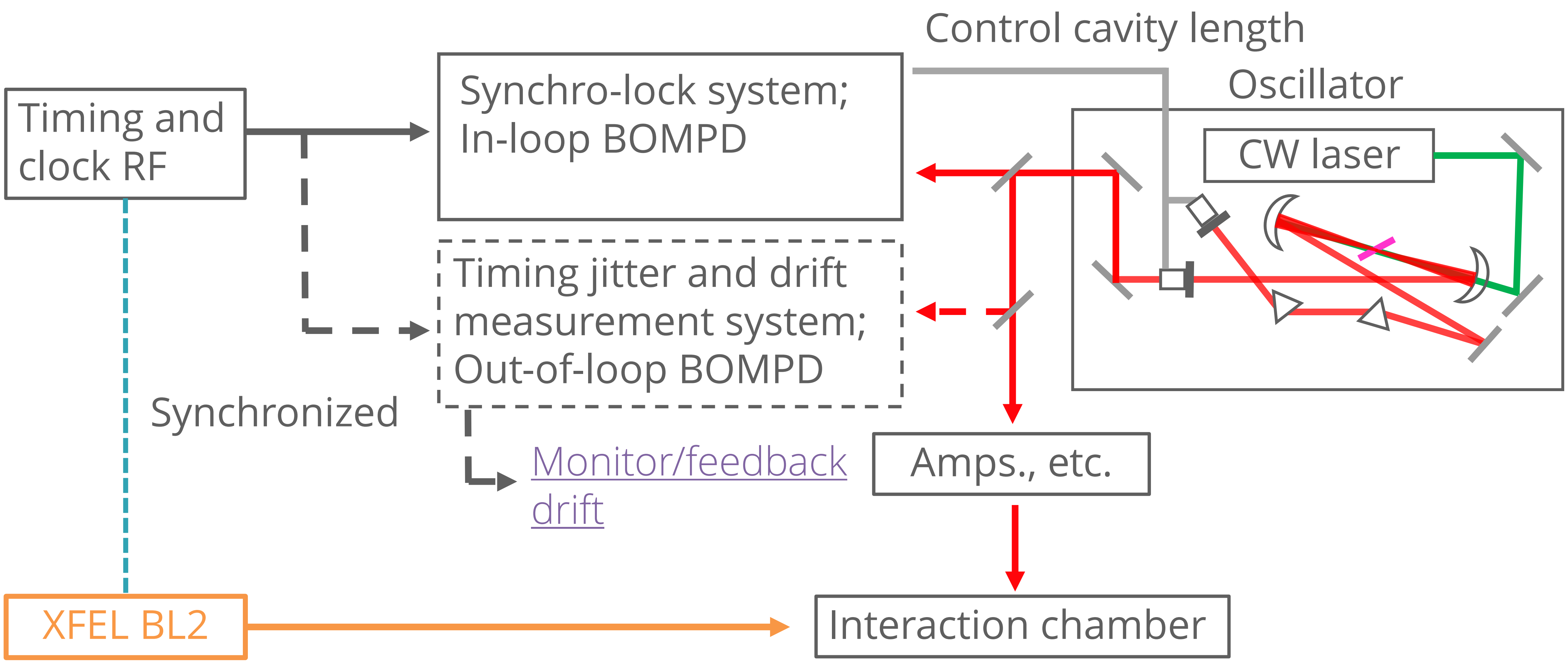
Spatial decoding





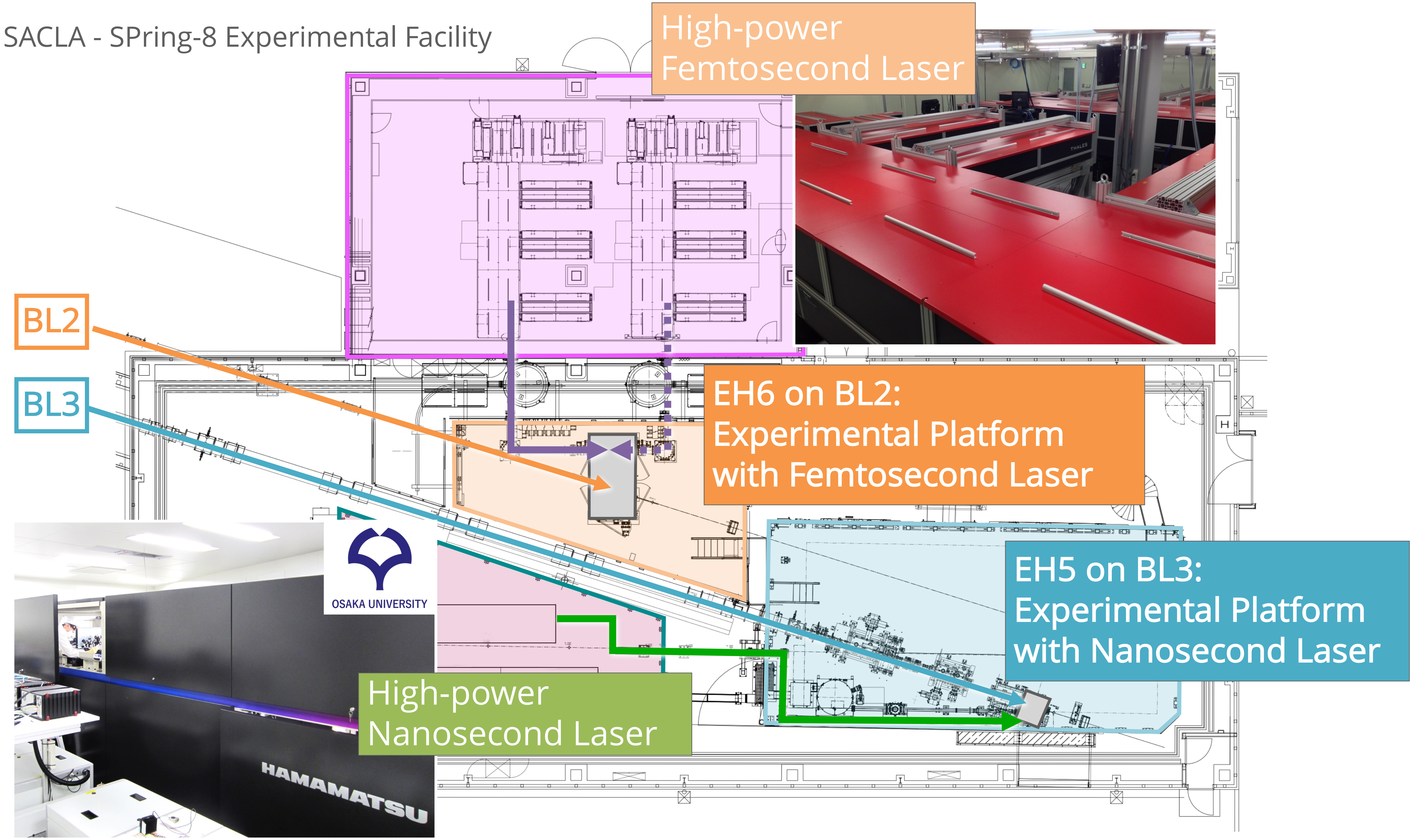
A timing monitor is unavailable on this platform to provide the “on-shot” arrival timing. We are developing a system to minimize and monitor the drift.

Development of timing drift monitor/feedback control with Out-of-loop BOMPD is in progress



BOM-PD: Balanced Optical-Microwave Phase Detector

Two experimental platforms with high-power laser systems



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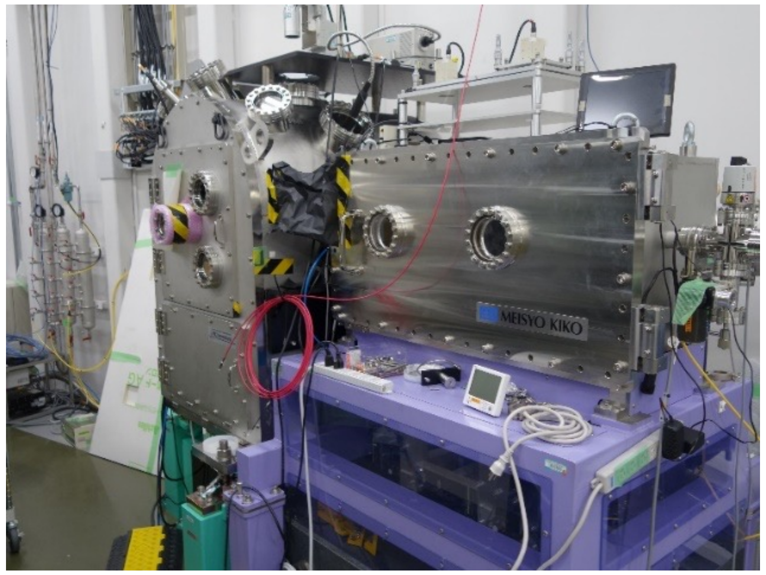
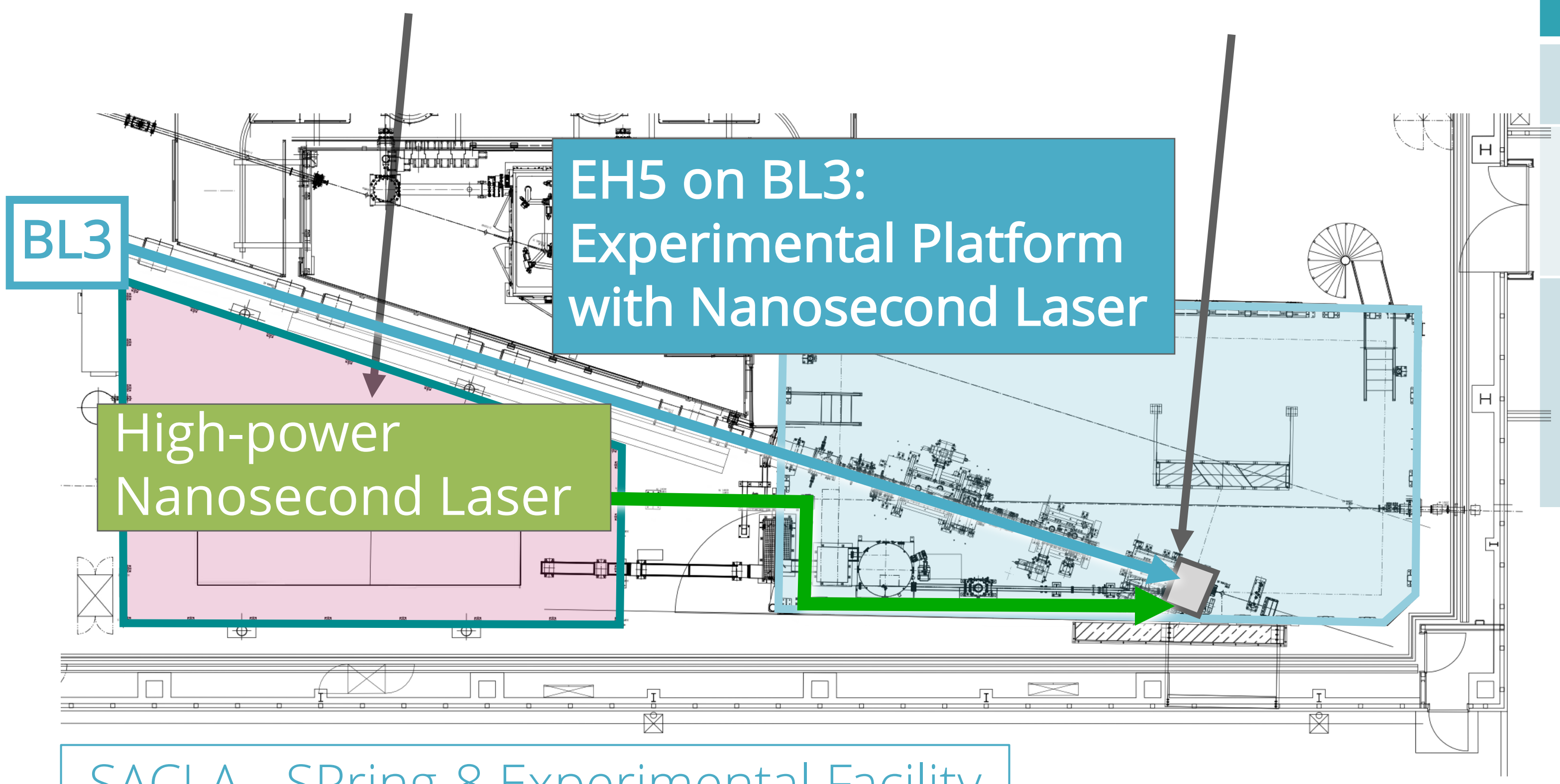
Experimental platform with high-power nanosecond laser

Laser Bay

Experimental Chamber





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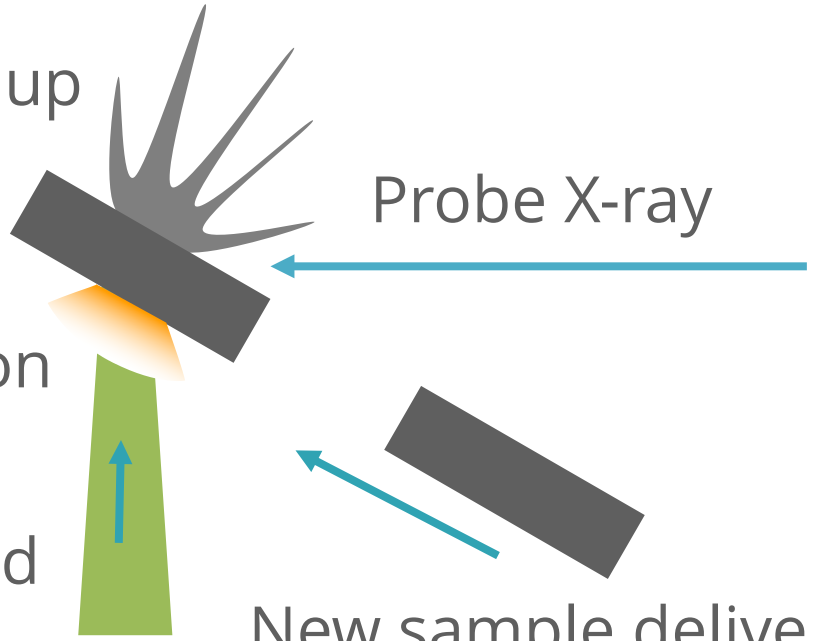
High-power nanosecond laser	
Pulse energy and duration	15 J on sample in 5 ns quasi square
Wavelength	532 nm
Rep. rate	0.1Hz
Shot rate	1 shot / 3-10 min.

XFEL	
Beamline	BL3
Focusing optics	KB mirror for focusing (down to 0.5 μm, 1D or 2D)
Advanced operation	Self-seeding Two color Split-and-delay optics

High-power nanosecond laser system was installed by Osaka University

Stabilities in the laser's pulse shape and pulse energy are essential to precise and efficient experiments exploring high-pressure phenomena

Reproduce high-pressure phenomena



- The laser-induced high-pressure state depends significantly on the laser's power.
- A limited number of data due to the destructive, single-shot experimental style may make sorting or picking data after data acquisition impractical.
- The laser's stability is essential for precise pump and probe experiments.

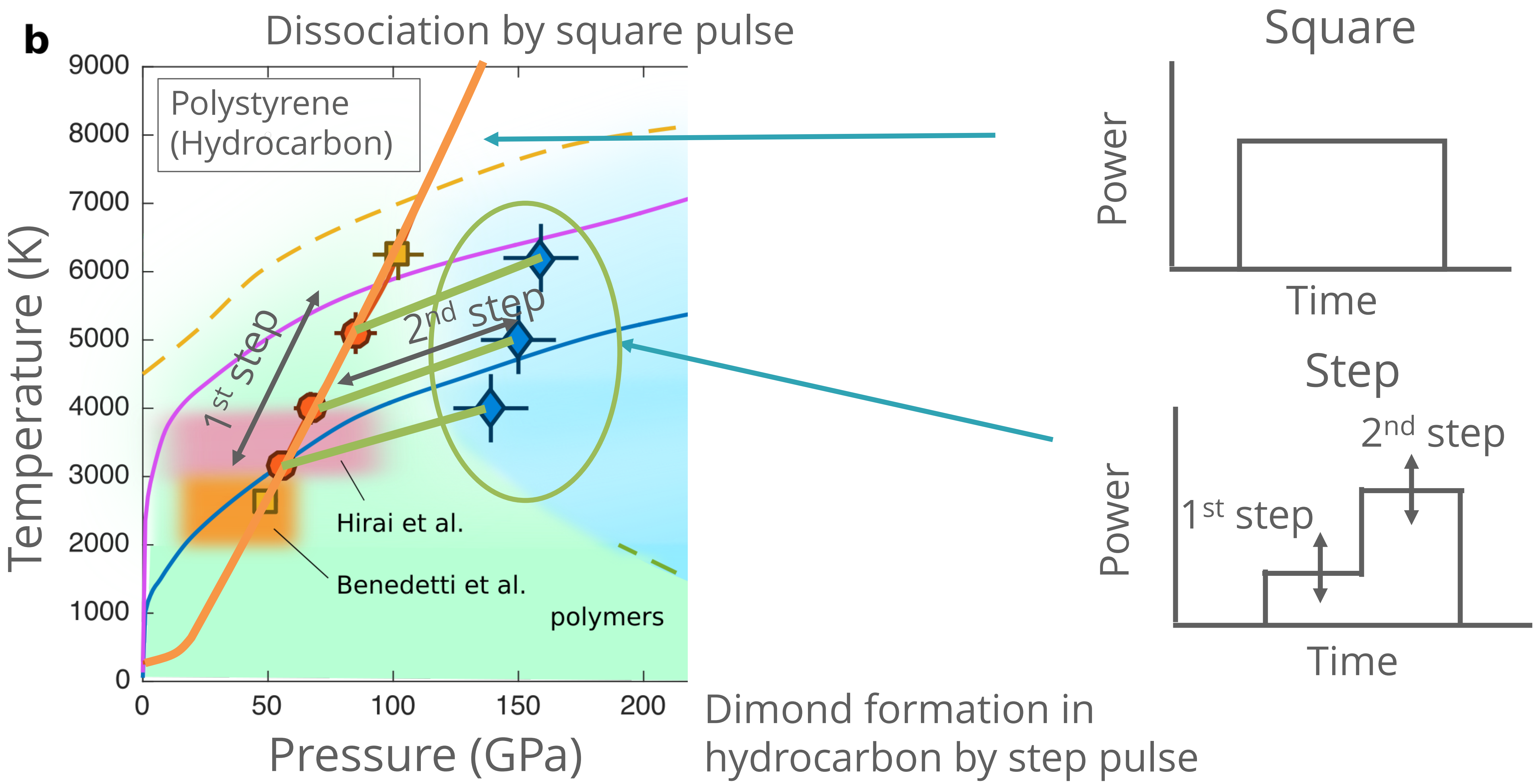
https://www.lpi.usra.edu/publications/slidesets/craters/slide_10.html

Pulse shape stability is also mandatory for arbitrary pulse shaping to extend the thermodynamic region to be explored

Thermodynamic region

Laser pulse shape

Dissociation by square pulse



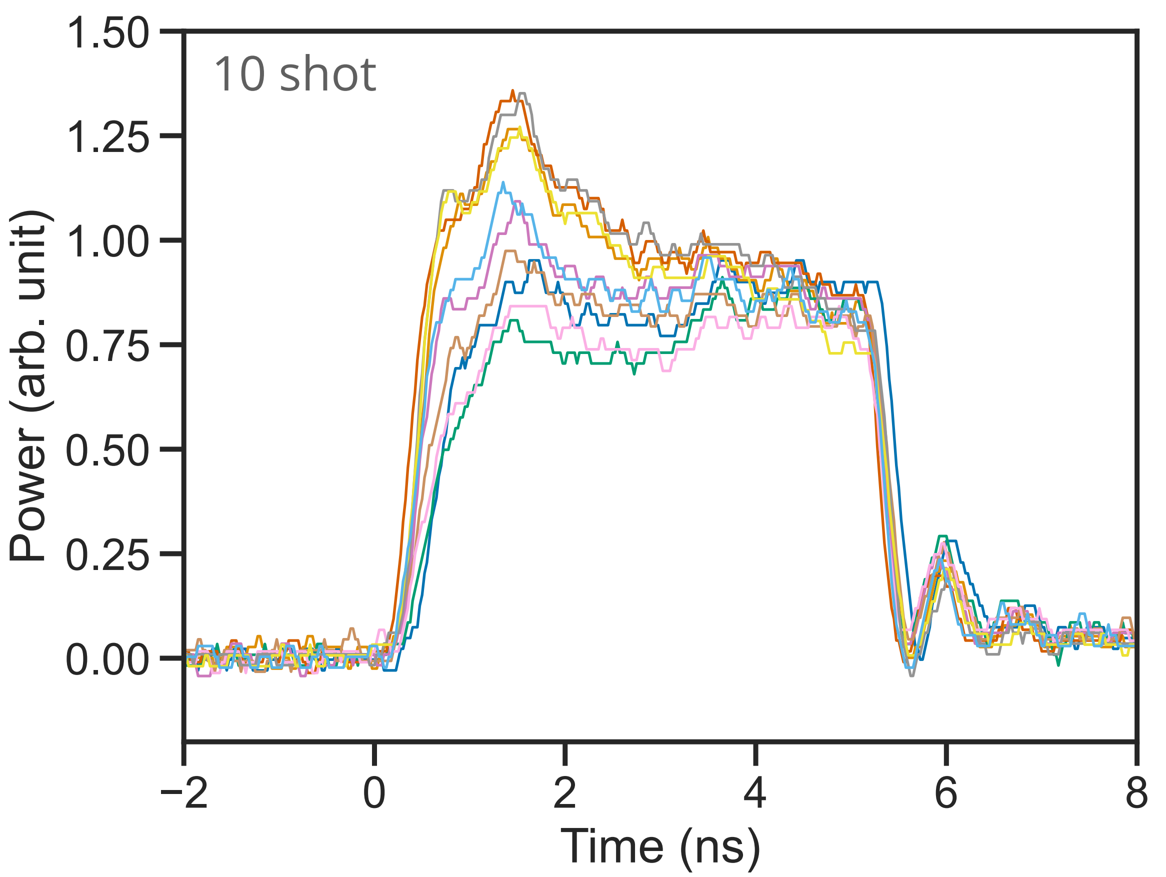
Dimond formation in hydrocarbon by step pulse

We are working on the improvement of laser's stability with Osaka University.

D. Kraus et al., *Nature Astronomy*, *1*(9), 606–611 (2017).

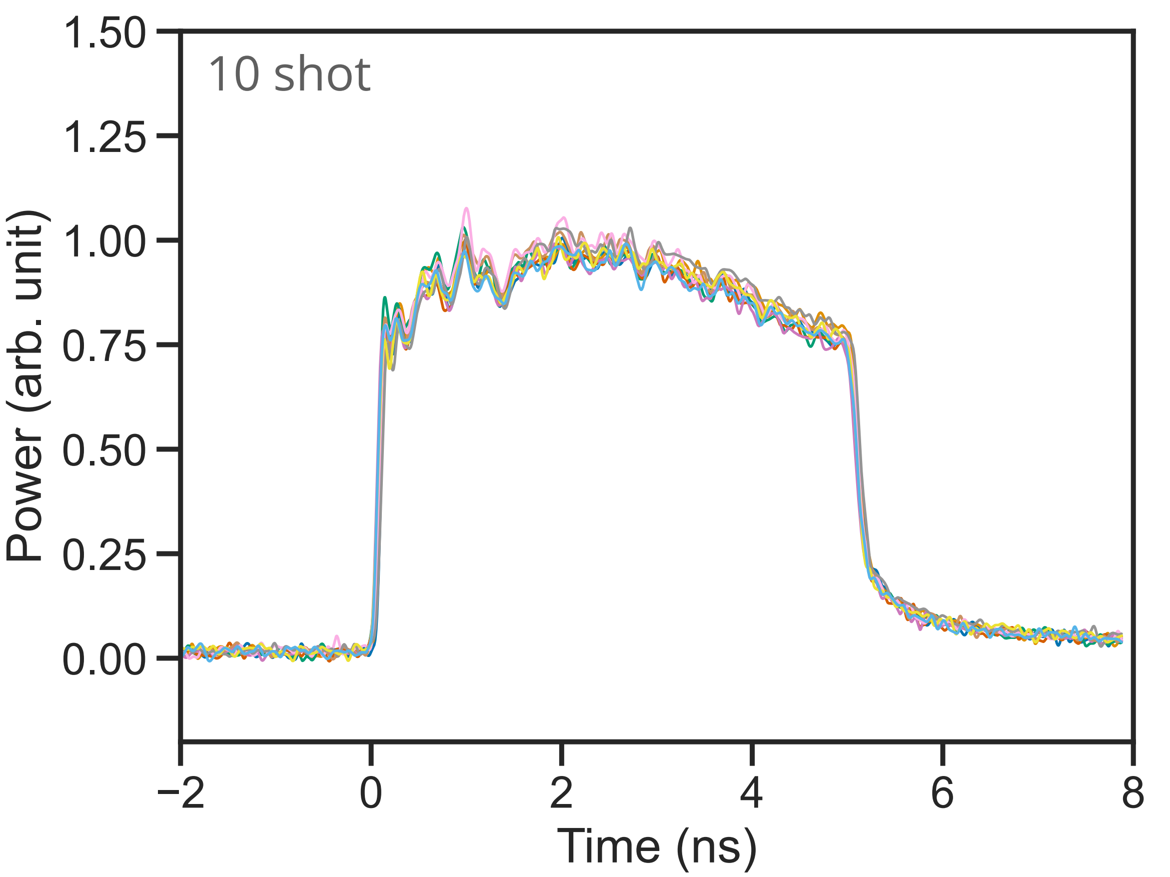
Improvement of shot-to-shot stabilities in pulse shape and pulse energy is ongoing

Previous



- 16 % (std. dev.) in peak power
- 10 % (std. dev.) in pulse energy

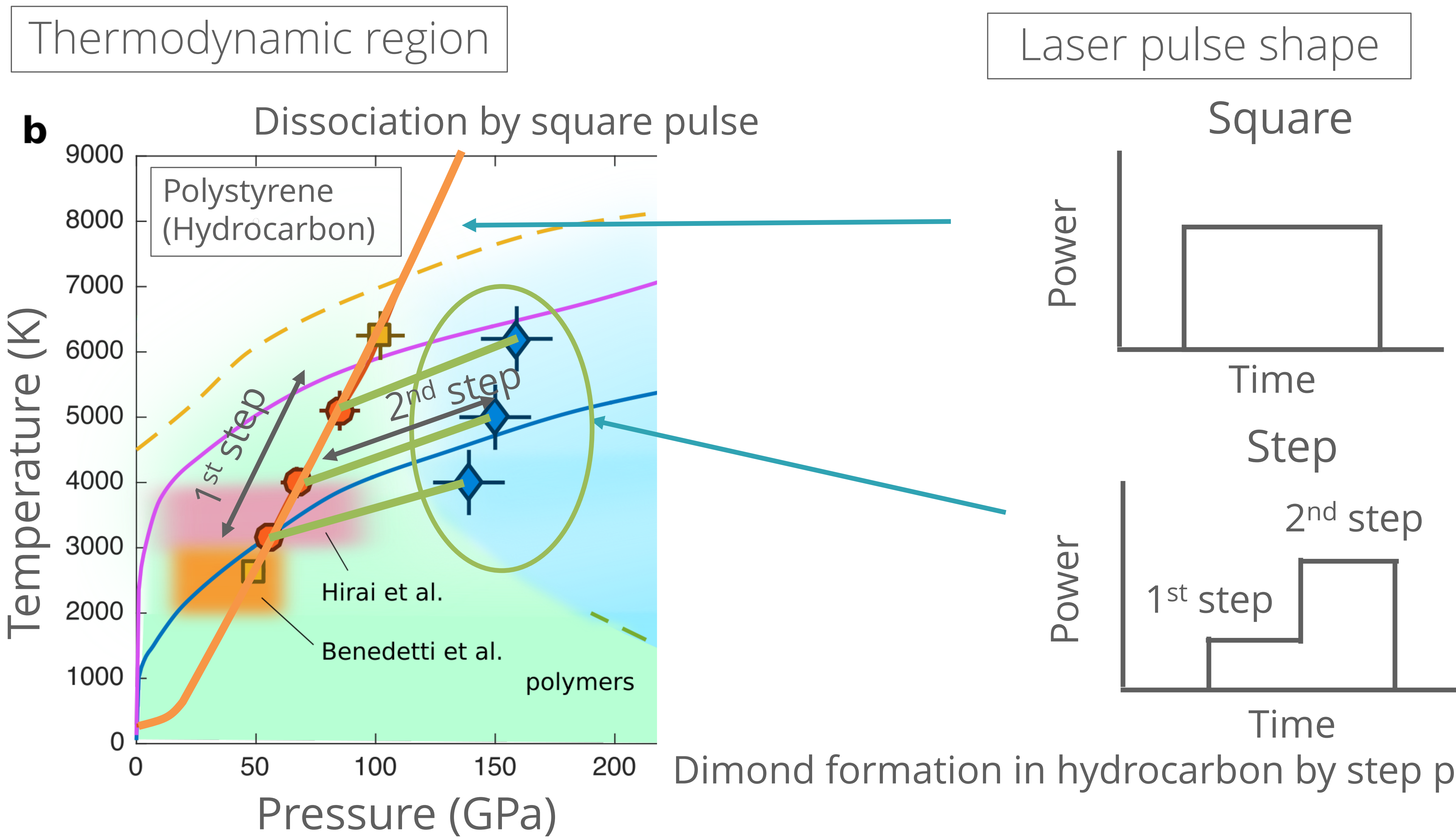
Ongoing



- 3 % (std. dev.) in peak power incl. measurement error
- 1.3 % (std. dev.) in pulse energy

Improved system is expected to be available to users in 2023A with 5 ns quasi-square shape

Improved pulse-shape stability allows providing arbitrary pulse shapes to extend the thermodynamic region to be explored.



Dimond formation in hydrocarbon by step pulse

We plan to provide arbitrary pulse shaping in 2023B on a trial basis

D. Kraus et al., *Nature Astronomy*, *1*(9), 606–611 (2017).

Summary

- Two experimental platforms with high-power fs and ns lasers are available at SACLA

Femtosecond Laser

- Spatial and temporal controls are key but challenging to studying transient, high-energy density states on ultrafast time scales with fs laser and XFEL
- ✓ Spot profile and pointing fluctuation have been improved with better wavefront correction and XPW stabilization
- ☐ Development of timing drift monitor/feedback control with Out-of-loop BOMPD is in progress

Nanosecond Laser

- Stabilities in the laser's pulse shape and pulse energy are essential to precise and efficient experiments exploring high-pressure phenomena
- ☐ Improvement of shot-to-shot stabilities in pulse shape and pulse energy is ongoing
- ☐ We plan to provide arbitrary pulse shapes with stability improvement to extend the thermodynamic region to be explored