

Distributed Acoustic Sensing for Accelerator Stability and Environmental Diagnostics

Markus Hoffmann

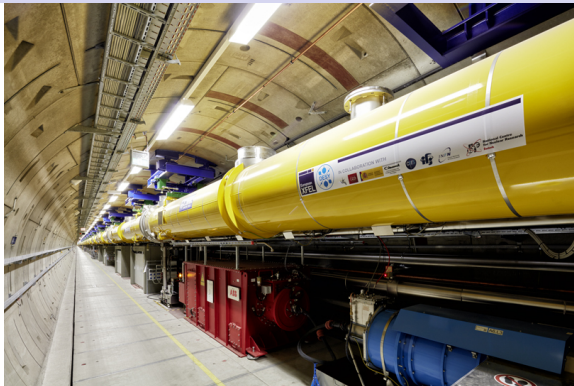
for the WAVE Collaboration

Deutsches Elektronen-Synchrotron DESY
Hamburg, Germany

IBIC 2026
Vancouver, 2026-08-30



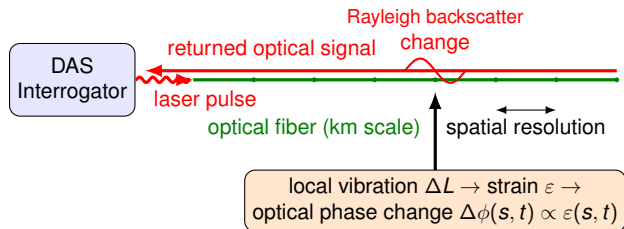
Why environmental stability matters for accelerators



Accelerator performance is affected by environmental disturbances

- Ground motion and vibrations can influence mechanical stability
- Tunnel deformations affect beam arrival time and orbit stability
- Environmental diagnostics are usually limited to discrete sensors

Turning an optical fiber into thousands of sensors



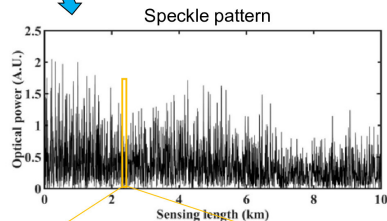
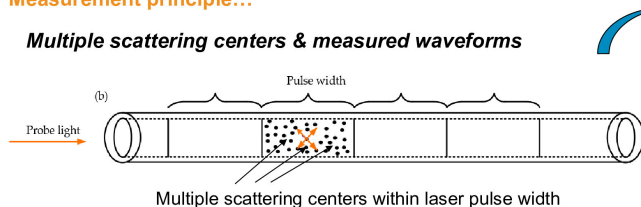
Distributed Acoustic Sensing (DAS)

- Standard telecom fiber becomes a distributed sensor array
- Continuous measurements over kilometers
- High spatial and temporal resolution

Phase-sensitive Optical Time Domain Reflectometry

Measurement principle...

Multiple scattering centers & measured waveforms



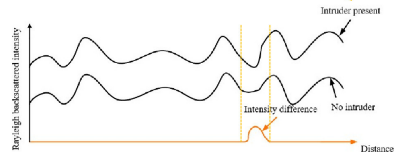
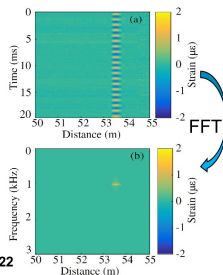
Intrinsically requires large data rates...

z: sampling of reflection $\sim 100 - 1000$ MSPS
(SNR & spatial resolution)

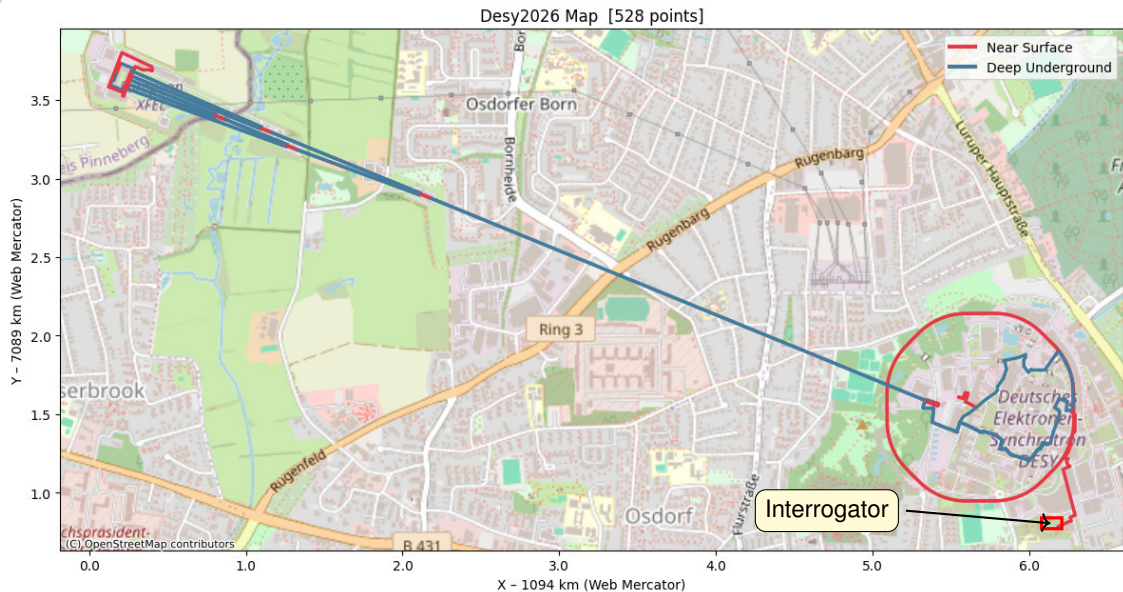
t: laser pulse rep. rate $\sim 1 - 100$ kHz
(SNR & noise frequency resolution)

→ Quickly ~ 1 Gbyte/sec

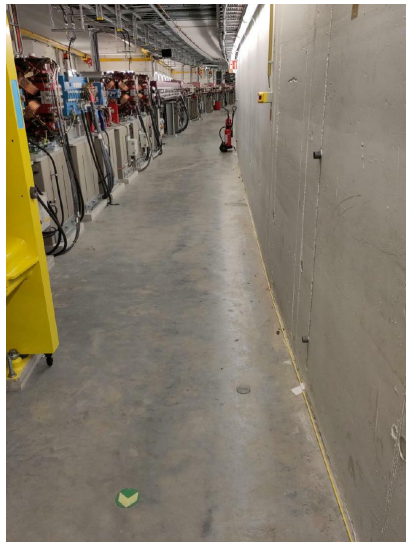
→ Data processing & analysis



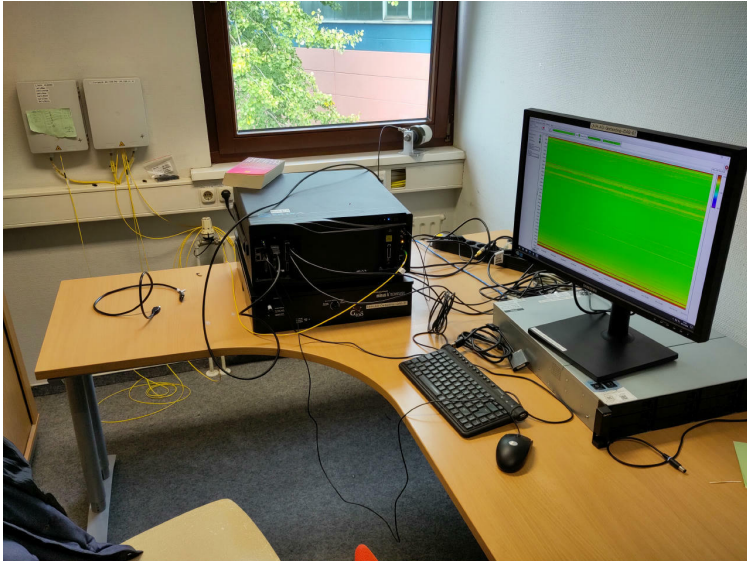
DAS sensing: DESY Campus and XFEL



Fiber cable in PETRA



The DAS interrogator



What information does DAS provide?

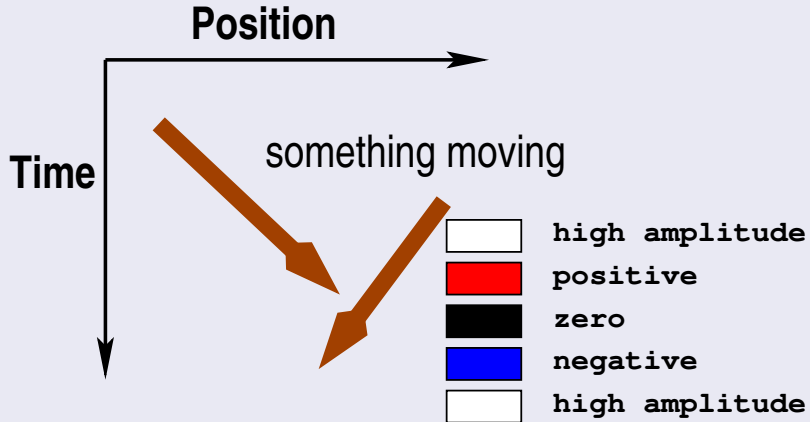
Measured quantities

- axial strain / nano strain (change in optical length)
- Strain rate
- Seismic waves
- Acoustic signals
- Slow thermal drifts

Typical performance

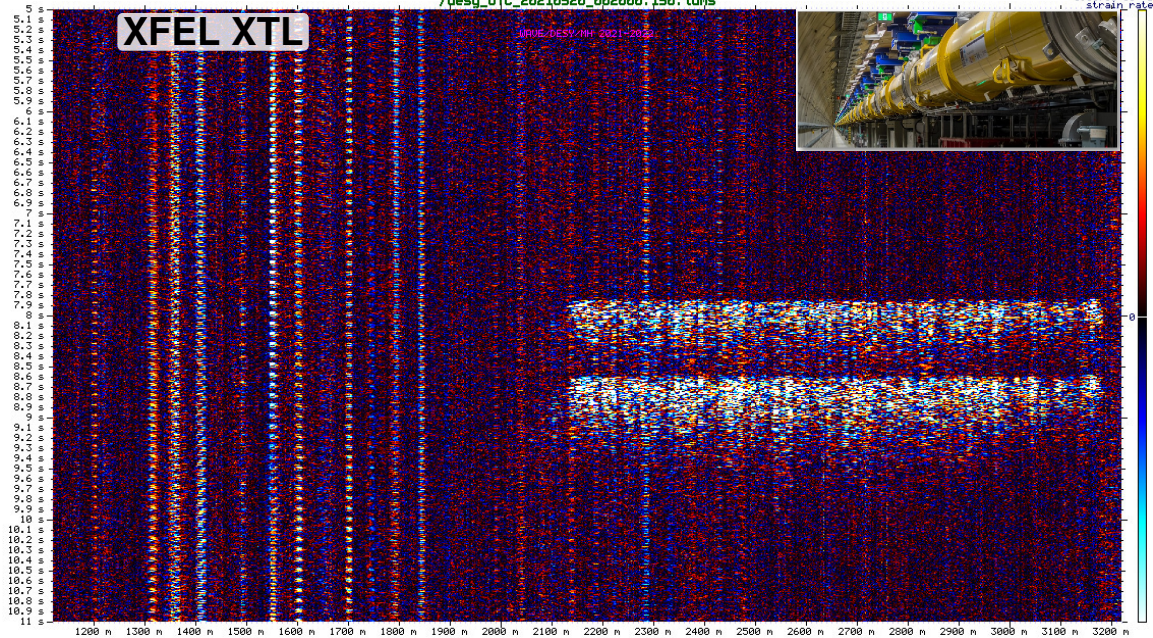
- 20 km fiber
- 1 m sampling
- 10 m gauge length
- 1000 Hz sampling rate
- near DC ... 500 Hz bandwidth

Space-Time (waterfall) diagrams

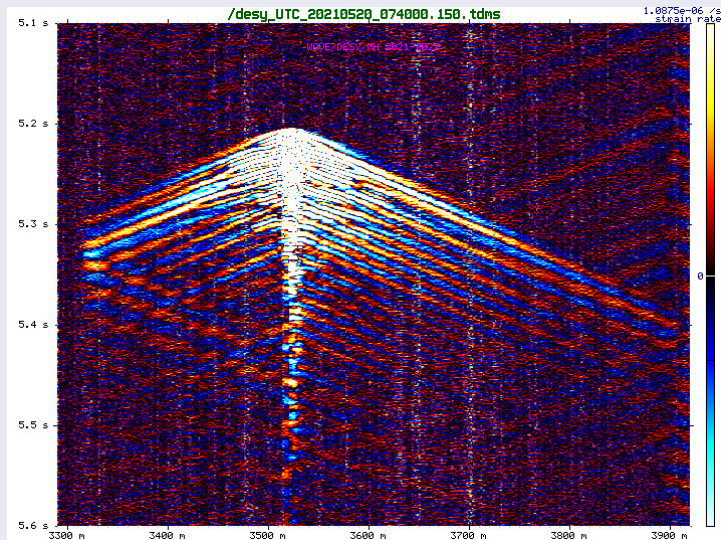


XFEL XTL

WAVE/DESY/MT 2021-2022

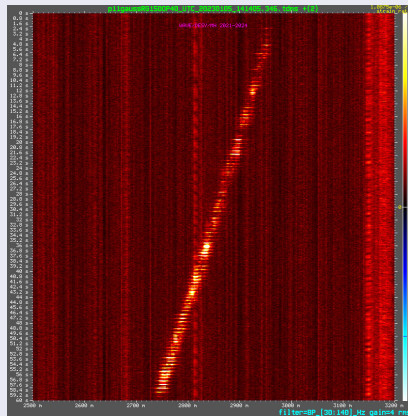
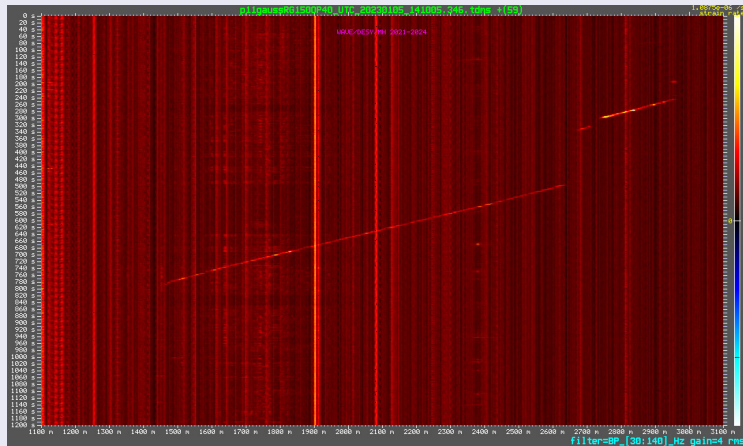


Hammer tap on cable tray in XFEL

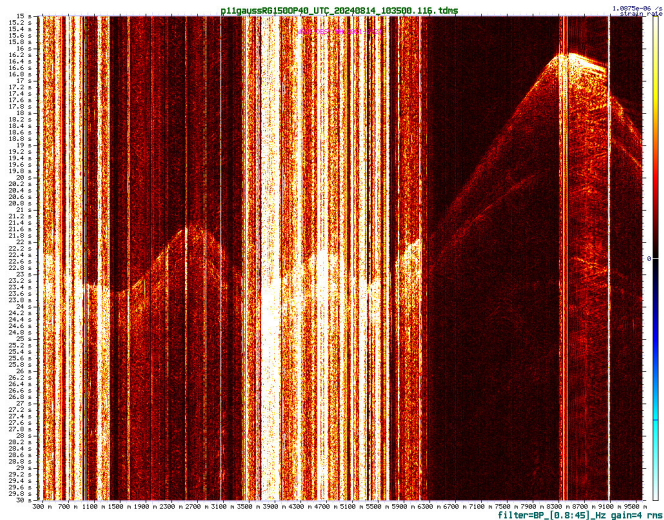


used for geo-referencing. See eigenfrequency, group-velocity, phase-velocity, reflexion.

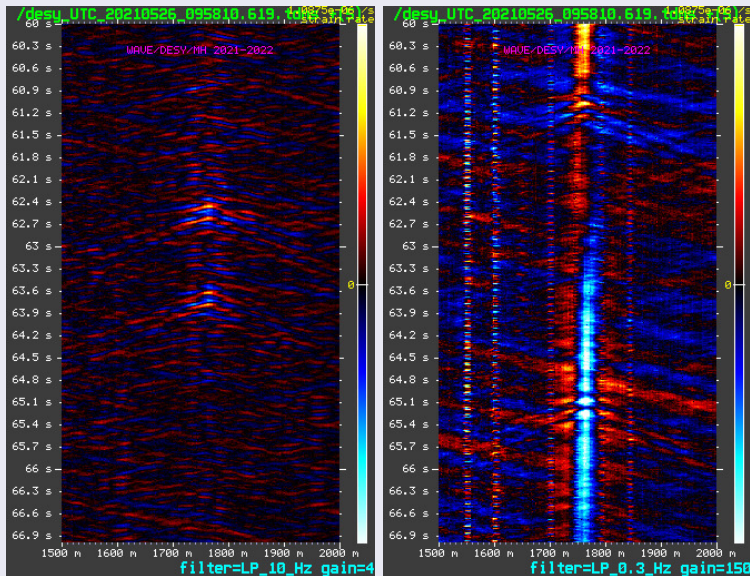
People in the XFEL tunnel



Thunderstorms



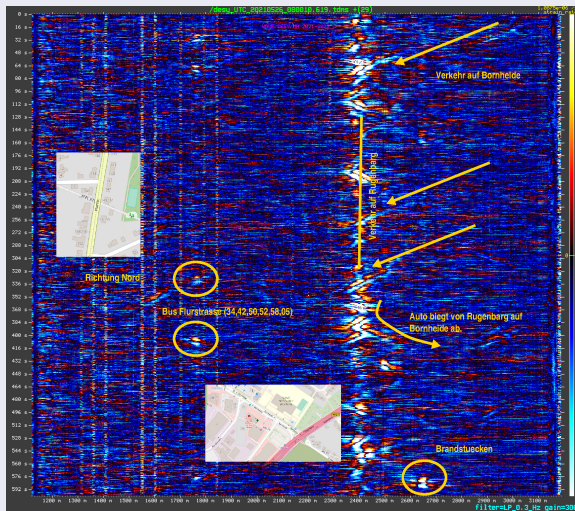
What is this? (seen inside the XTL tunnel)



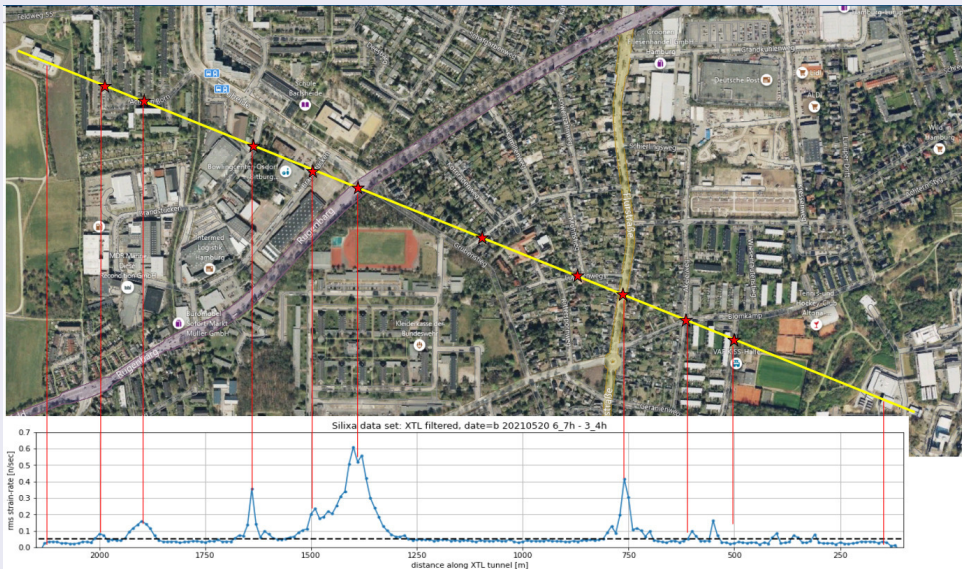
Traffic on Flurstrasse



Traffic above XTL



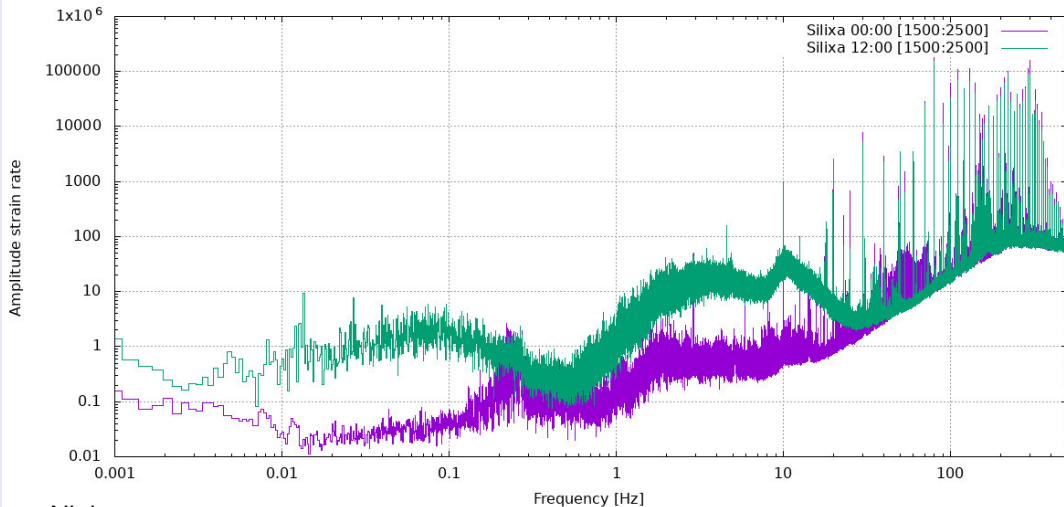
Noise from Traffic above XFEL tunnel



(courtesy: Holger Schlarb)

Spectral capabilities of DAS

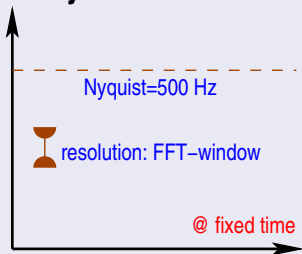
XTL avg spectrum 2021-05-25



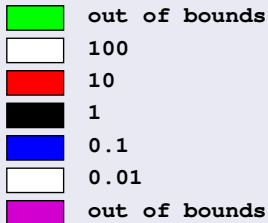
Day – Night

Spectral diagrams

Frequency

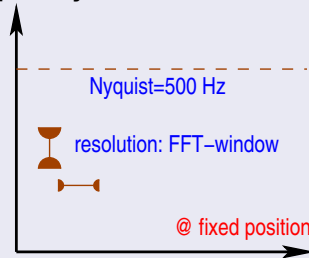


Position



and

Frequency



Time

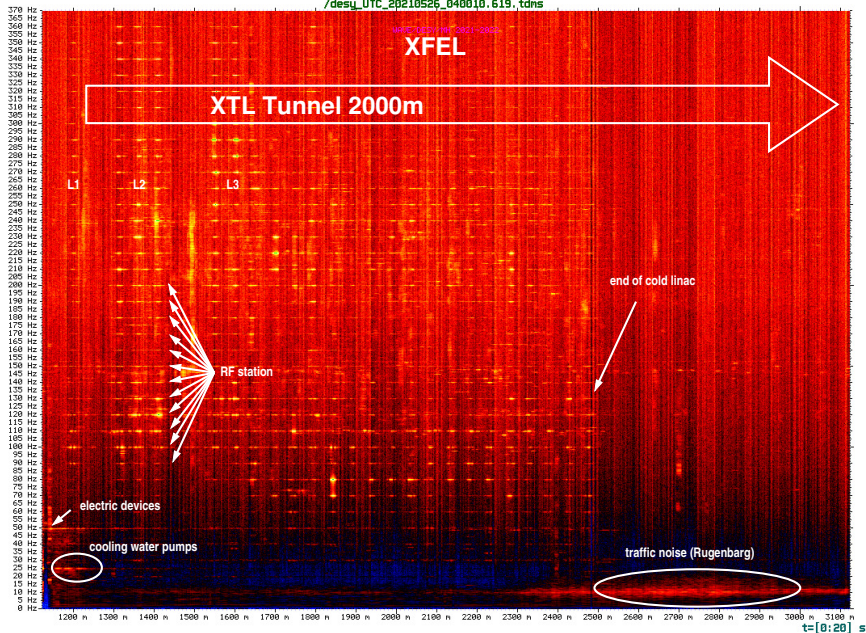
Examples:

- fingerprints of technical devices
- earthquakes
- microseismics: ocean waves

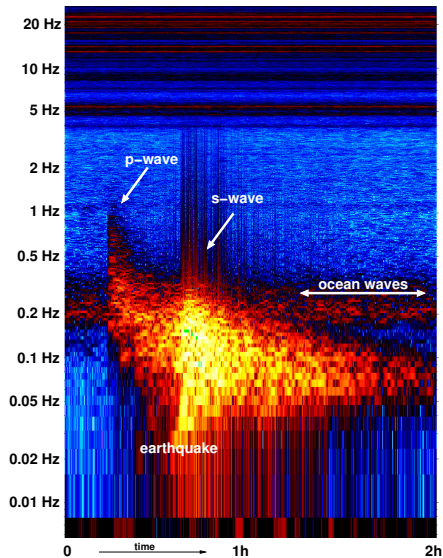
WAVE_OES/MI_2021-2022

XFEL

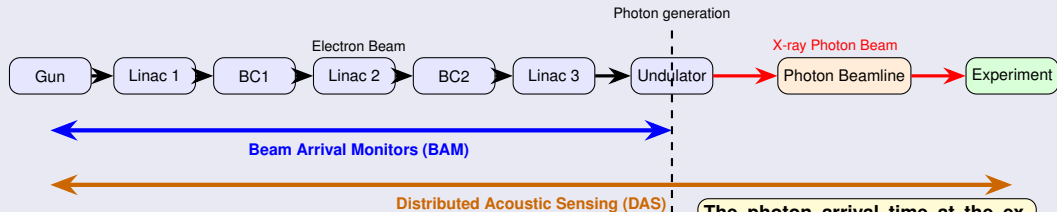
XTL Tunnel 2000m



Earthquake
in China,
magnitude 7.2



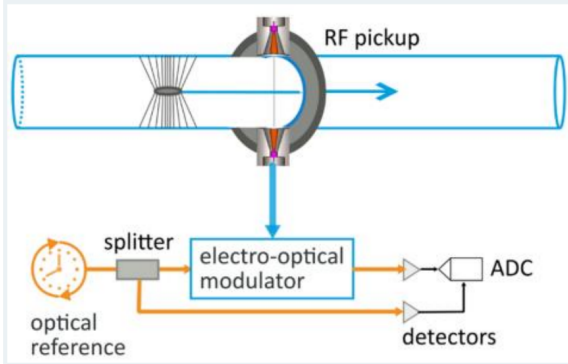
Spacial Arrival Time Budget



The photon arrival time at the experiment defines the ultimate timing performance for pump-probe experiments. Mechanical path-length variations downstream of the undulator directly contribute to the timing jitter but cannot be observed by BAM systems.

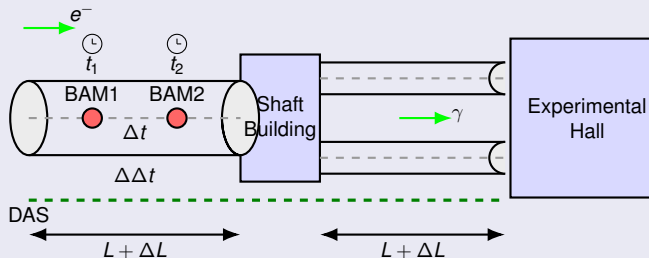
BAM

Bunch arrival-time monitor

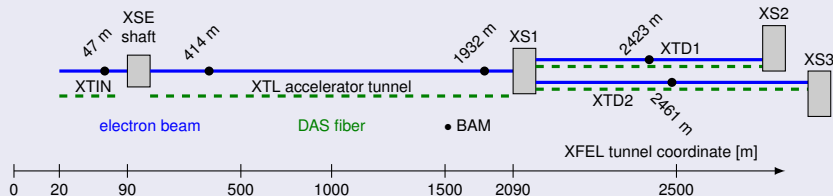


(courtesy: M.-K. Czwalińska)

Arrival Time Jitter from time of flight and from ΔL

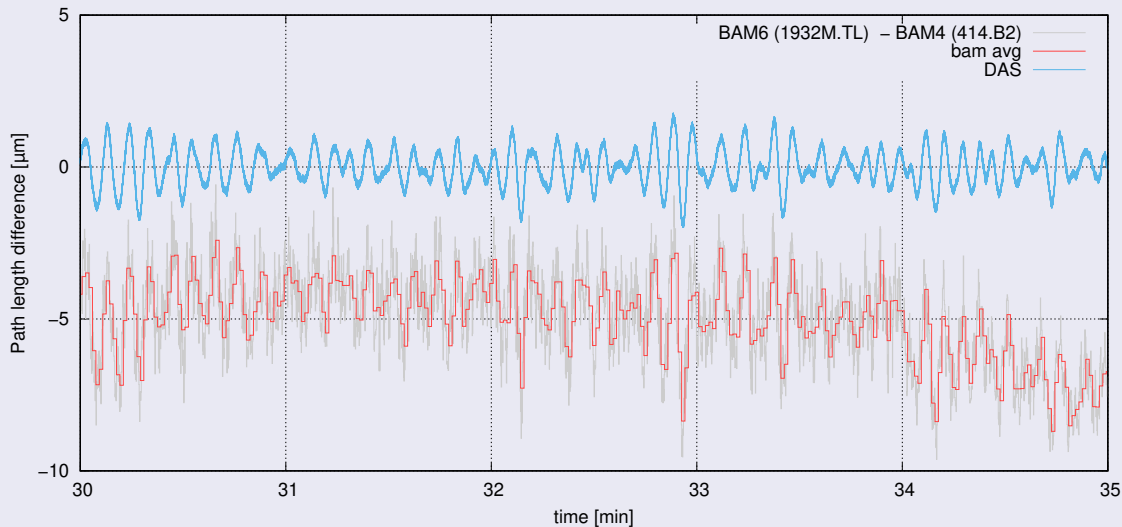


BAM & DAS in XFEL

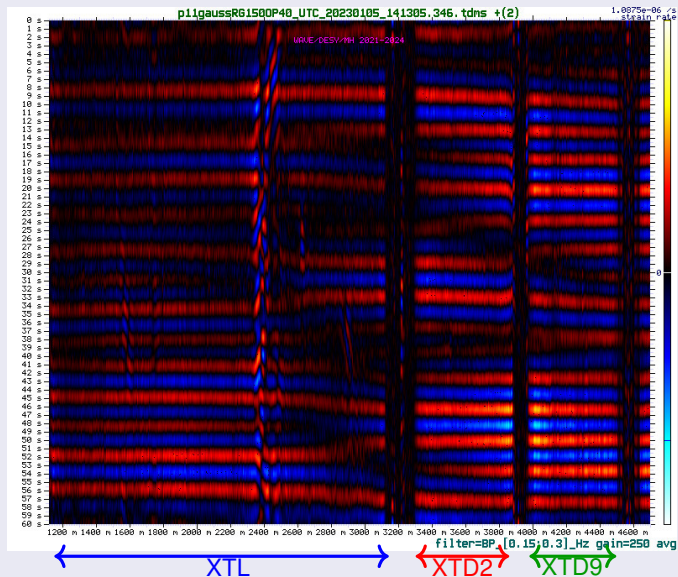


0.2 Hz ocean waves (time domain)

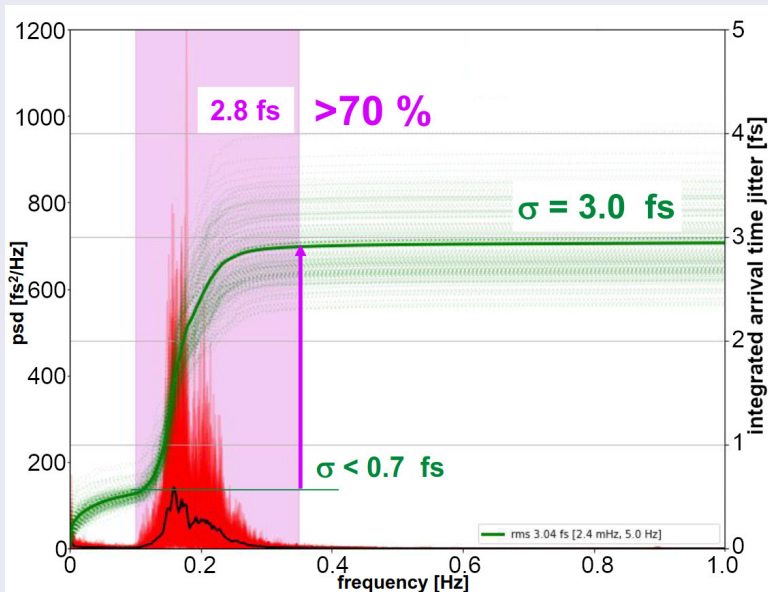
XFEL BAM1932 – BAM414 [350:1200] – DAS [6614:8132] 2026-03-23 21h UTC



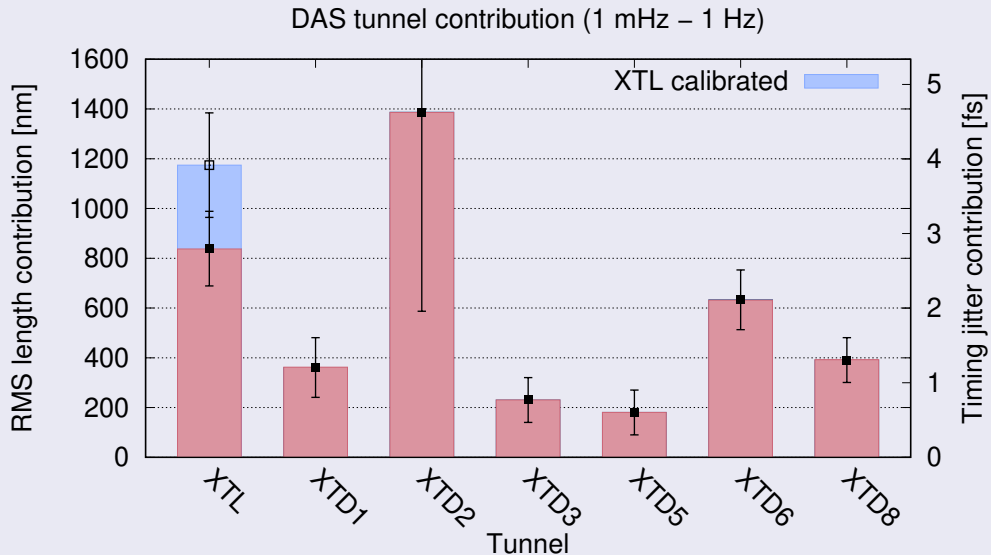
0.2 Hz ocean waves seen in space-time domain in XFEL



XFEL Performance Measure: Arrival Time Jitter



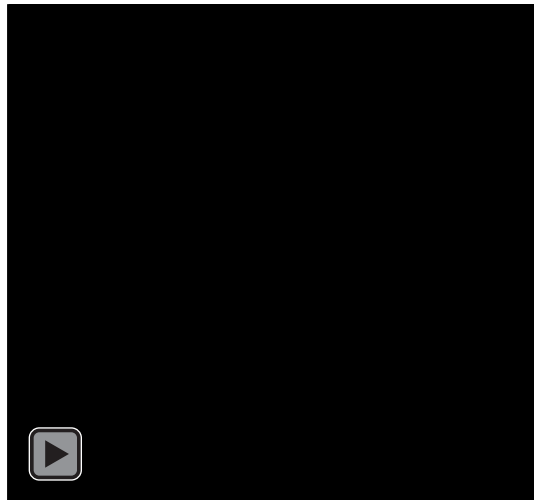
XFEL Arrival Time Jitter Budget

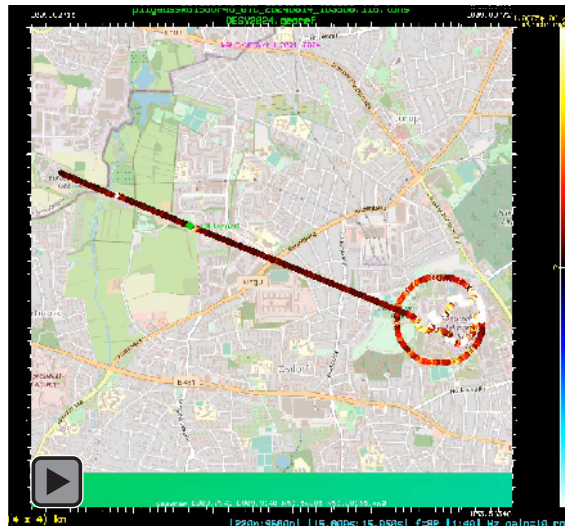


The Movies

- Swift-Waves
- A Swift-Concert (Rainbow-Blobs)







Towards a permanent

Seismic Network for Accelerators

- Continuous monitoring of DESY and XFEL
- Automatic localization of disturbances
- Prediction of ground motion
- Integration into accelerator operation
- Condition monitoring using existing fiber infrastructure