Measurements with the X-Ray Pulse Arrival and Length Monitor (PALM) at SACLA

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Abstract

The development of FEL facilities all over the world necessitates the development of temporal diagnostics for the photon pulses these facilities provide. SwissFEL is the upcoming X-ray FEL facility at PSI that will provide short pulsed radiation in hard X-ray region. In order to face the challenge of measuring the temporal properties of such pulses, a pulse arrival time and length monitor (PALM) is currently being developed at PSI [1]. The concept of THz-streak camera is used to measure the arrival time relative to a beamline laser and the length of a photon pulse [2]. A prototype version of the device was used for measurements at SACLA in order to show the feasibility of the device for photon pulses in hard X-ray region and test the reliability of the measurements. The first results from the beamtime at SACLA are presented here. The plans for further development of the system are discussed.

Goals for the SwissFEL photon pulses:

Operating Mode	X-Ray Pulse length	Arrival Time Stability	
Standard	20 fs rms	20 fs rms	Standard mode
Short-Pulse	2 fs rms	5 fs rms	
Attosecond	60 as rms	5 fs rms	Upgrade mode
Wide Bandwidth	15 fs rms	20 fs rms	

Wavelength 1 Å - 7 Å

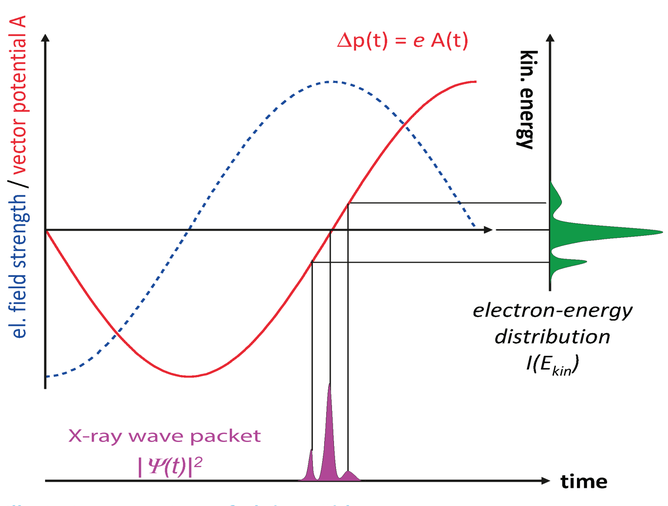
Challenges for temporal diagnostics:

- Performance for high-energy photons (up to 12.4 keV)
- High resolution for SwissFEL short pulses and arrival time stability monitoring
- Online monitor on shot-to-shot basis
- Non-invasive measurements

PALM, based on streak camera concept, is developed at PSI to face these challenges

The concept of the streak camera

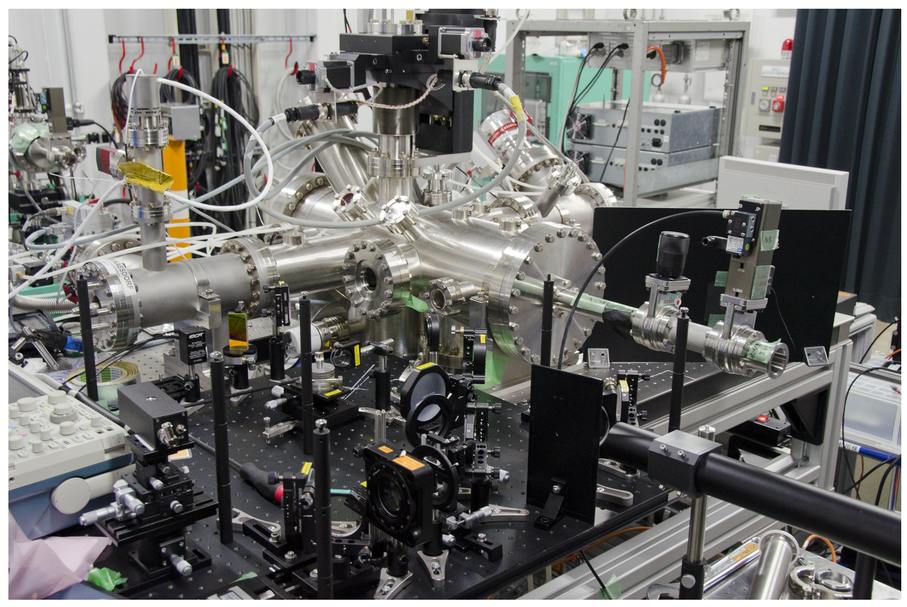
- The X-ray pulses from the FEL ionize the atoms of the gas. In absence of any external field, the spectrum of the generated photoelectrons represents the spectrum of the ionizing FEL pulse minus the binding energy.
- After introducing an additional electromagnetic terahertz field derived from the pump laser, the photoelectrons "born" inside this field acquire additional energy proportional to the vector potential of the terahertz wave.
  The final electron energy is thus a function of relative arrival time between the X-ray pulse and the terahertz pulse.
- Therefore, in presence of an external time-dependent field, the spectrum of photoelectrons contains information both about the FEL pulse energy spectrum and its temporal properties.



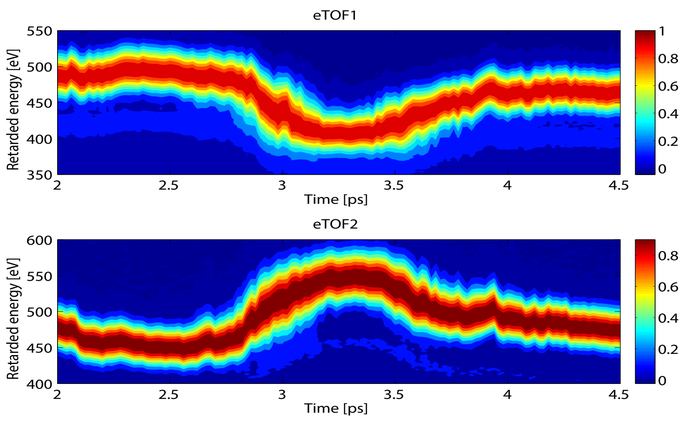
Illustrations courtesy of Ulrike Frühling

- By measuring the spectrum of the electrons by Electron Time-of-Flight Spectrometers (eTOFs), one can extract the arrival time of the FEL pulse with respect to the experimental laser and the pulse length.

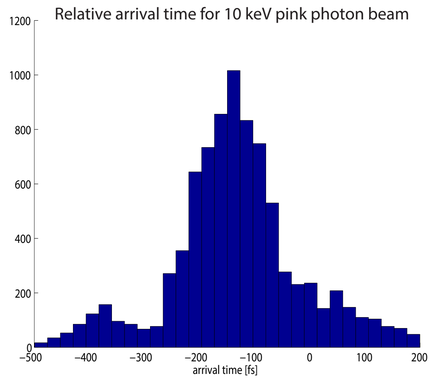
Prototype setup at SACLA

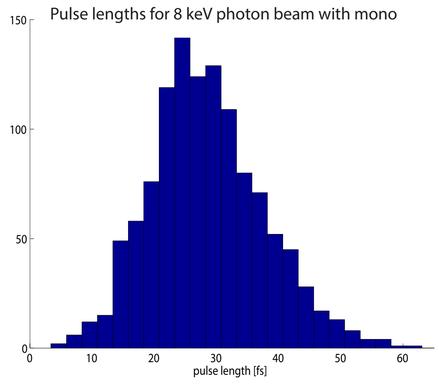


The first results from measurements



- The normalized signal from the THz scan for 10 keV photon beam. The spectrum of the photoelectrons changes during the scan in accordance to the shape of the vector potential.
- Measuring 10000 shots for streaked and non-streaked pulses we calculate the average photon pulse length and the arrival time jitter.





DATA TO BE PUBLISHED

Details about the measurements

- Single THz pulse from $LiNbO_3$ with a field strength of 5MV/m
- Pulsed Xe gas jet for higher signal
- Measurements with photon energies of 5-12.5 keV
- Using mainly electrons from L_3 shell and Auger electrons
- Measurements with a Double Crystal Monochromator (DCM)

Discussions and outlook

- ✓ Successful measurements at SACLA
- ✓ Measurement of the arrival time with small errors
- ✓ Measurement of the pulse length at high photon energies
- ✓ Concept of the setup proved to be working

- ♦ Improvement of the THz field strength and stability
- ♦ Designing a new setup for online measurements on shot-to-shot basis
- ♦ Applying to a new beamtime to test the new design of PALM and (preferably) cross-check it with other techniques

[1] Juranić P. et al. A scheme for a shot-to-shot, femtosecond-resolved pulse length and arrival time measurement of free electron laser x-ray pulses that overcomes the time jitter problem between the FEL and the laser, Jinst 2014
[2] Frühling, U. et al. Single-shot terahertz-field-driven X-ray streak camera. Nature photonics 3, 523–528 (2009)

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