Terahertz Streak Camera as Arrival Time Monitor for SwissFEL

Pavle Juranić, Christoph Hauri, Rasmus Ischebeck, Peter Peier, Volker Schlott

Goals for the SwissFEL photon pulse length and timing stability:

Operating Mode	X-Ray Pulse length	Arrival Time Stability
Standard	20 fs rms	20 fs rms
Short-Pulse	1.5 fs rms	5 fs rms
Attosecond	60 as rms	5 fs rms
Wide Bandwidth	20 fs rms	20 fs rms

Detector requirements
> Transparent (non-destructive to intensity and wavefront)
> On-line
> Resolution sufficient to validate SwissFEL photon beam stability goals

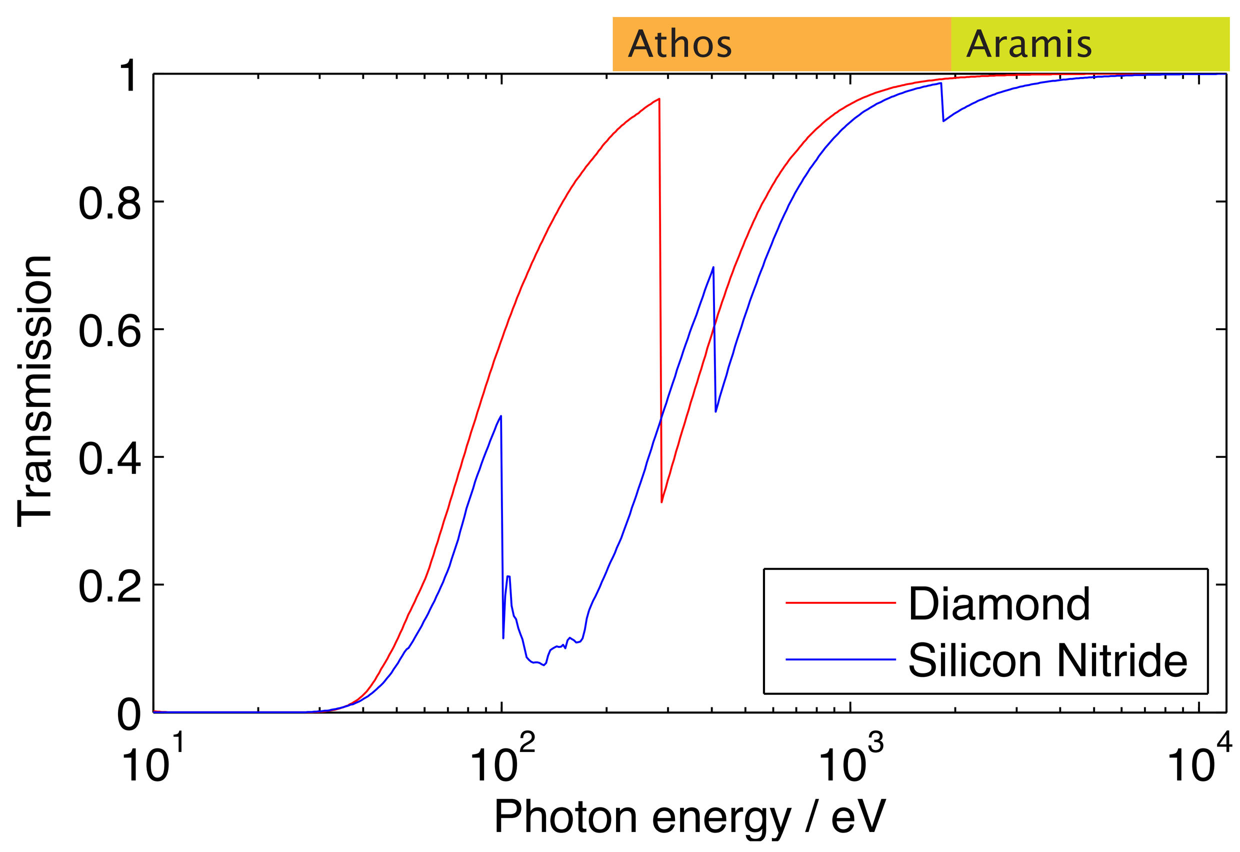
Our current options:

—> X-ray induced reflectivity change
Has been used at SLAC

—> Terahertz streak camera
Pioneered by ultra-short laser groups [1]
Has been used at FLASH [2] to measure
> 15 fs pulse length
> 5 fs arrival time (using THz and X-rays from the same electron beam)

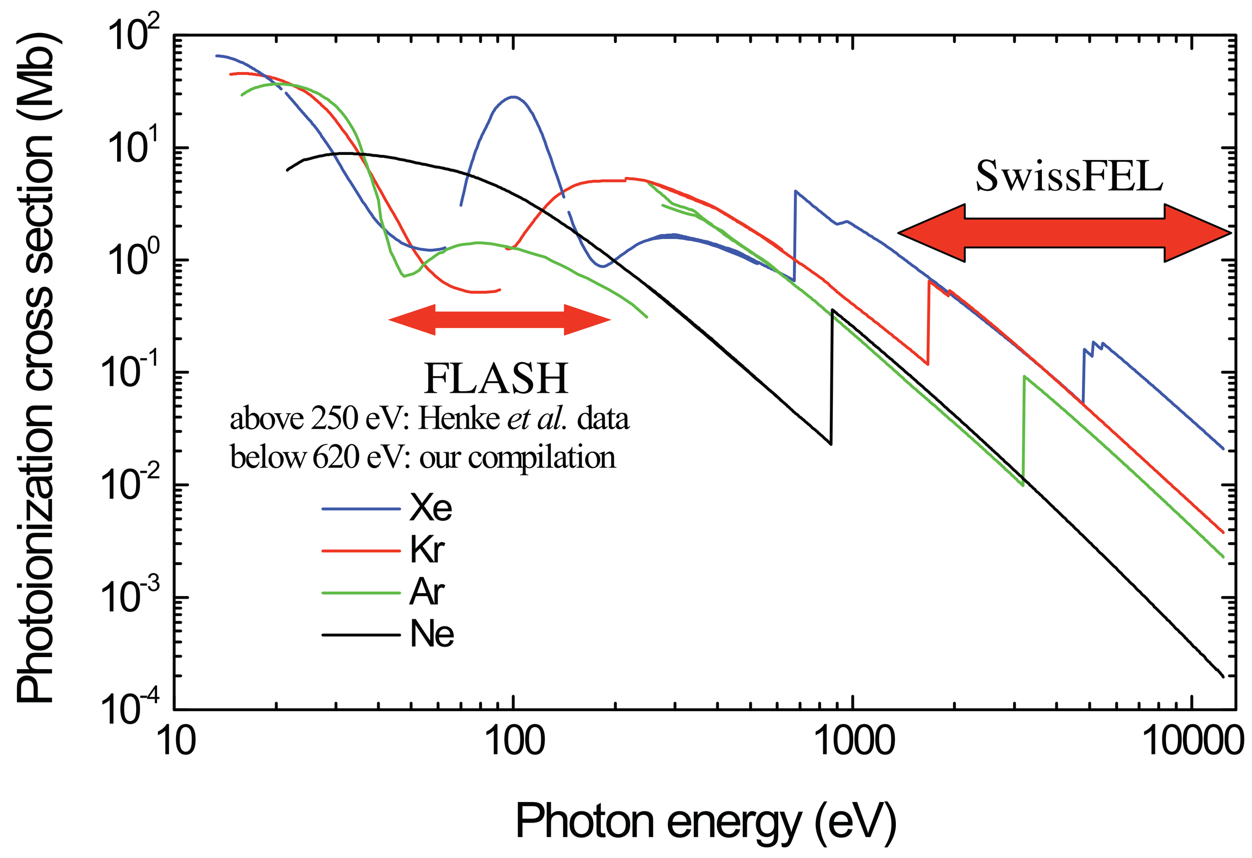
Challenges for Soft X-Rays

Absorption in solids for soft X-rays
—> Use gas-based detectors

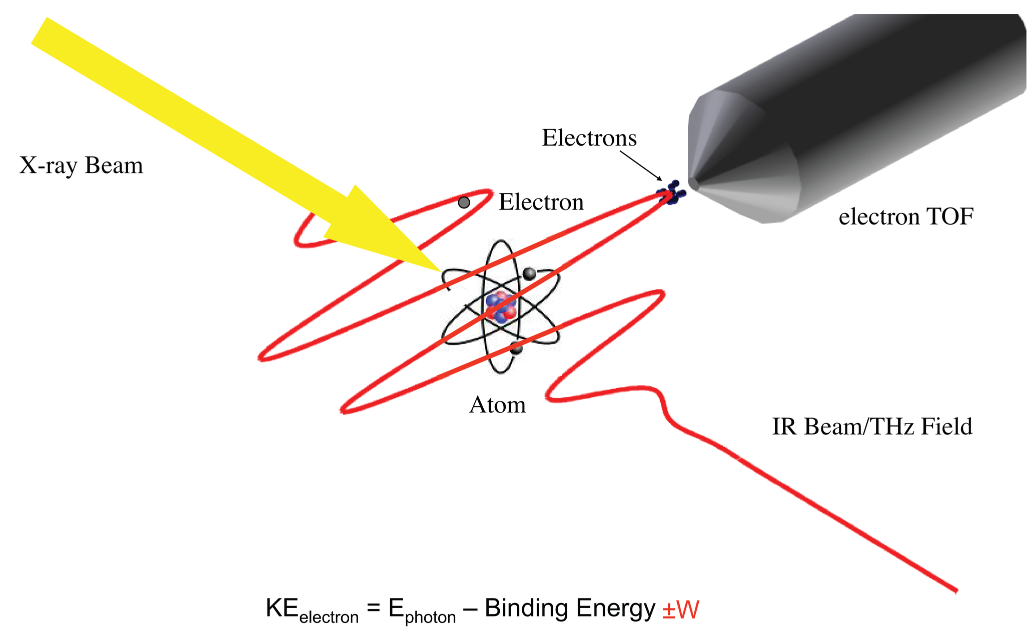


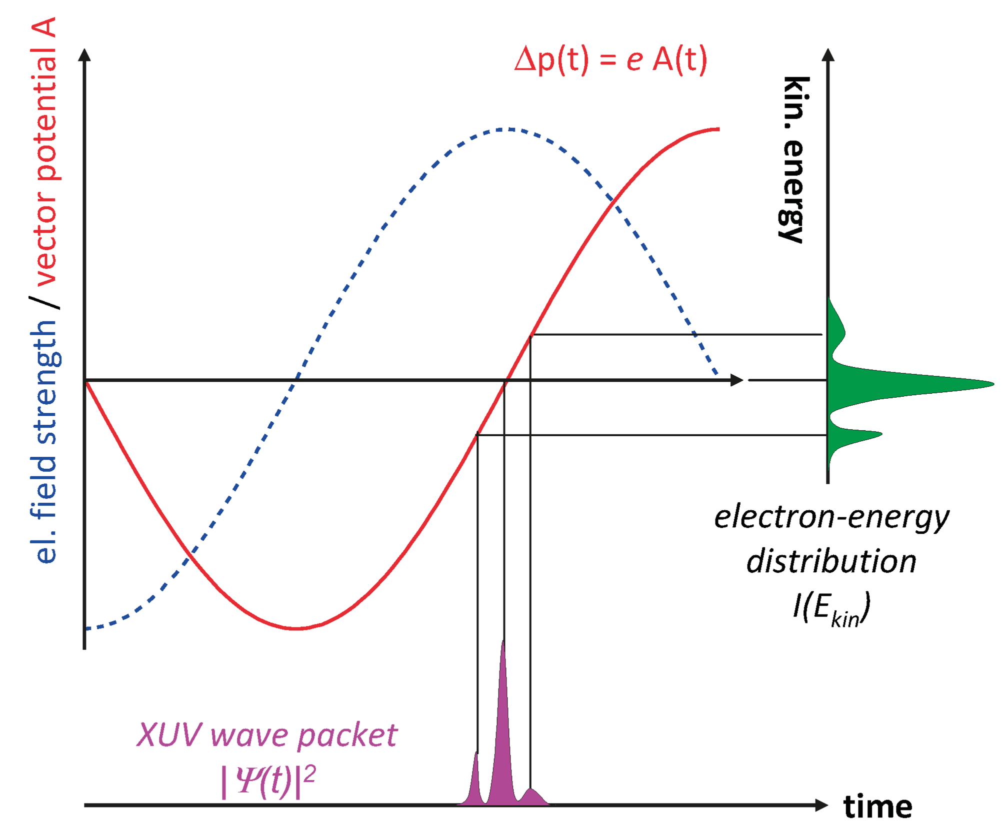
Challenges for Hard X-Rays

Low cross section in gases
—> Use Xenon
—> Pulsed gas jet for high pressures



From Electron Energy to Arrival Time

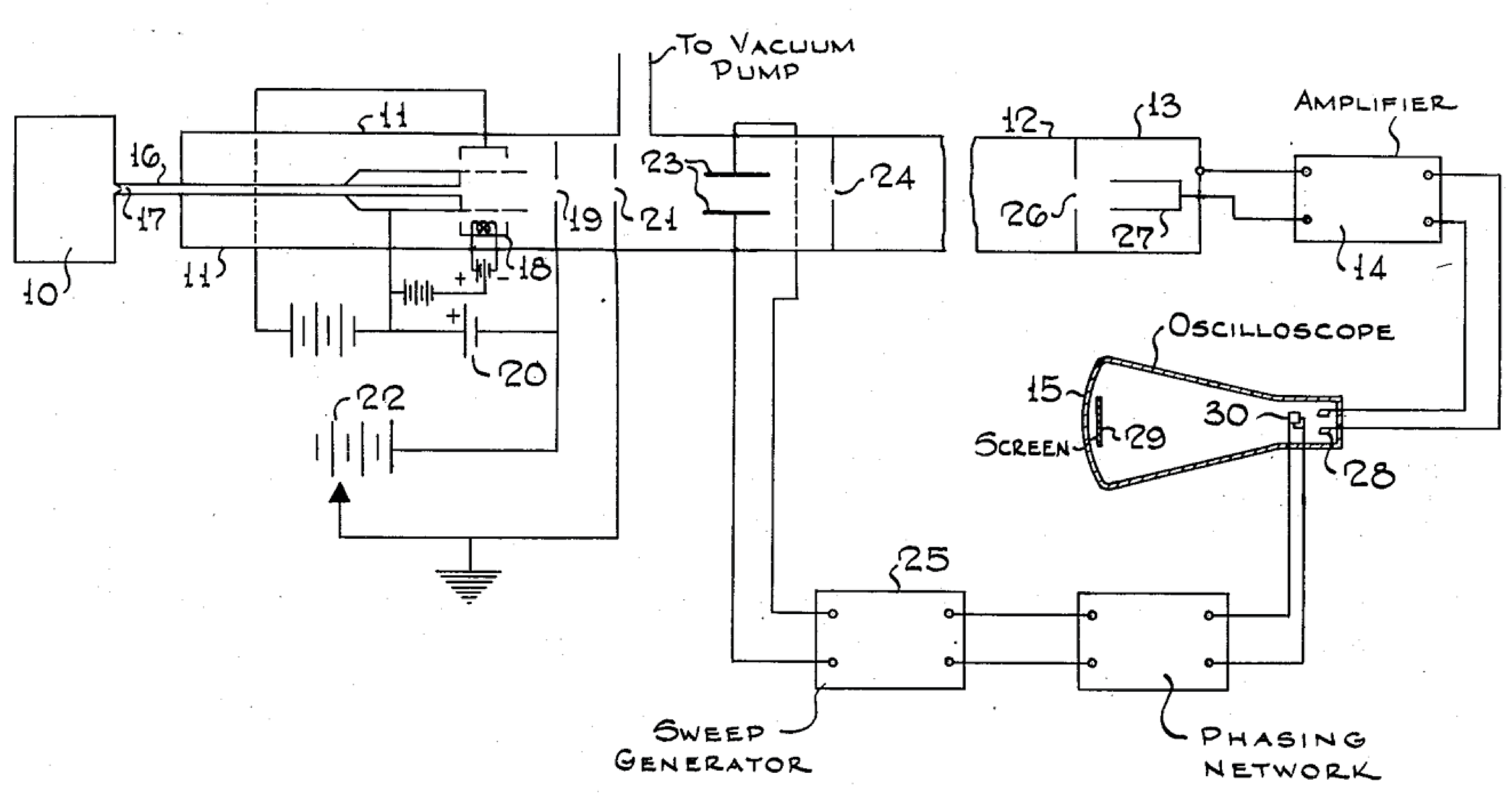




The X-ray pulses from the FEL generate photoions in a gas. The photo-electron energy is thus the X-ray energy minus the binding energy.
By introducing an additional electro-magnetic terahertz field derived from the pump laser, the photo-electrons "born" inside this field acquire additional energy proportional 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.
This method, originally pioneered for infrared pulses, has been used at terahertz frequencies to measure X-ray pulse length at FLASH. In this case, both X-rays and terahertz field were derived from the same electron pulse and were thus intrinsically synchronized to 5 fs. [2]
For the SwissFEL arrival time monitor, we plan to derive the terahertz field from the pump laser.

Illustrations courtesy of Ulrike Frühling

Electron Time-of-Flight Spectrometer



Invented by William Stephens (1952)

[1] Drescher, M. et al. X-ray pulses approaching the attosecond frontier. Science 291, 1923-1927 (2001)

[2] Frühling, U. et al. Single-shot terahertz-field-driven X-ray streak camera. Nature photonics 3, 523-528 (2009)

The authors would like to thank Rafael Abela, Ulrike Frühling, Luc Pathey, Kai Tiedtke, and Jens Viefhaus for fruitful discussions.

Next Steps

Need to extend the method to the hard x-ray region and compensate for the smaller atomic cross section by using pulsed gas jet valves.

Need to build a dedicated photon arrival time chamber as on-line instrumentation for the SwissFEL photon beam front end—such a thing currently does not yet exist in other FEL facilities around the world.

Prototyping for extensive testing and parameter optimization in 2012.

Final engineering for SwissFEL from 2014 on.