Terahertz Streak Camera as Arrival Time Monitor for SwissFEL

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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

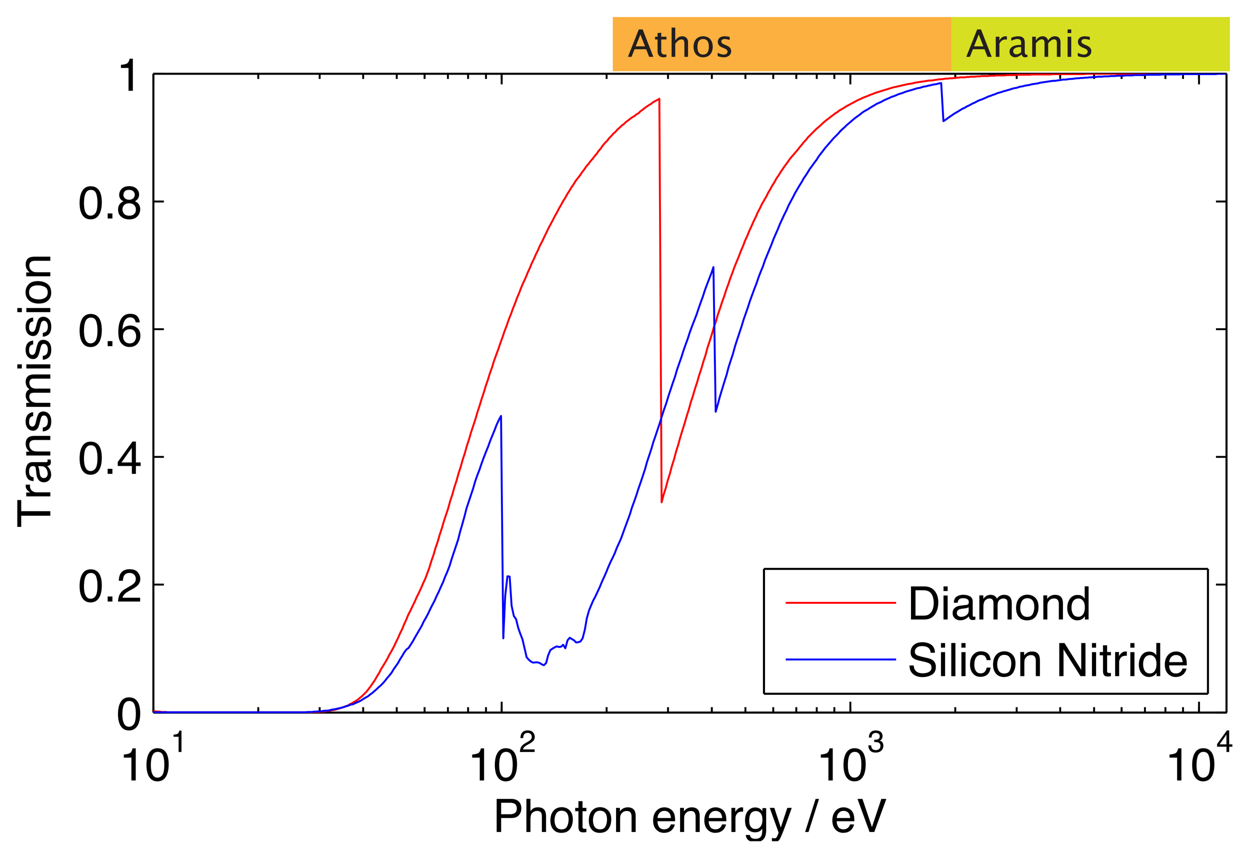
Our current options:

—> 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)

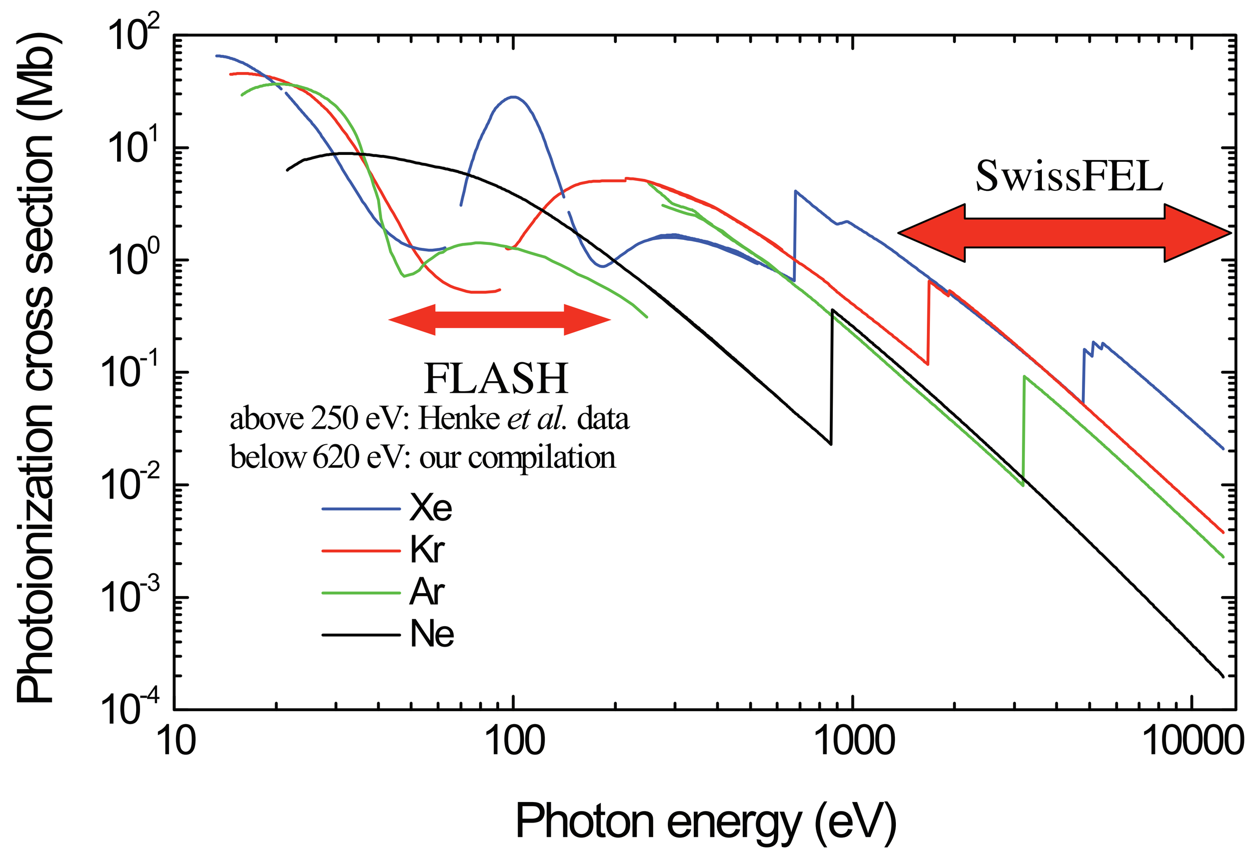
Challenges for Soft X-Rays

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

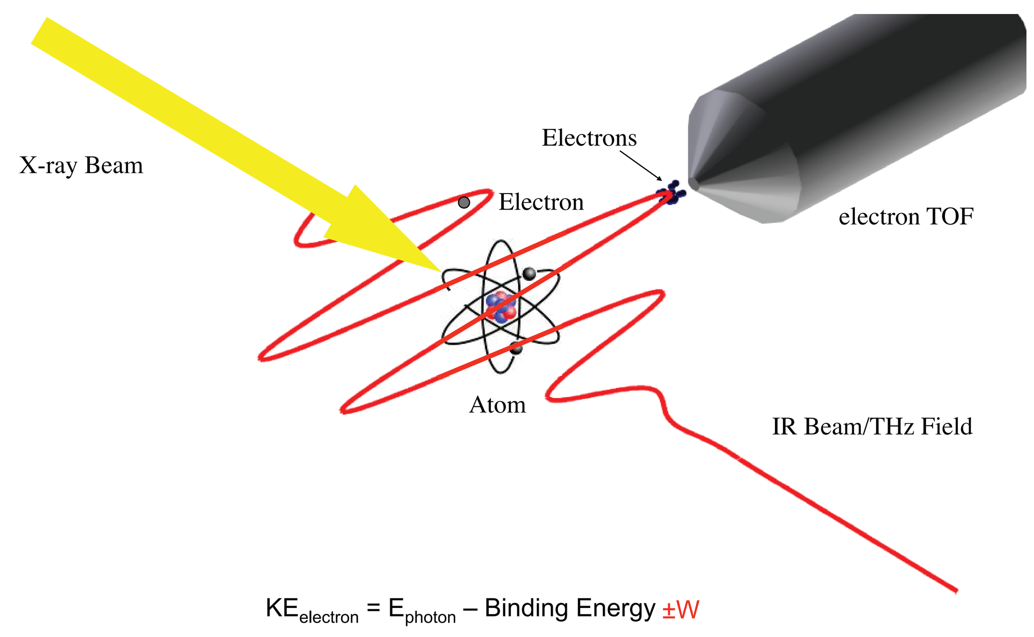


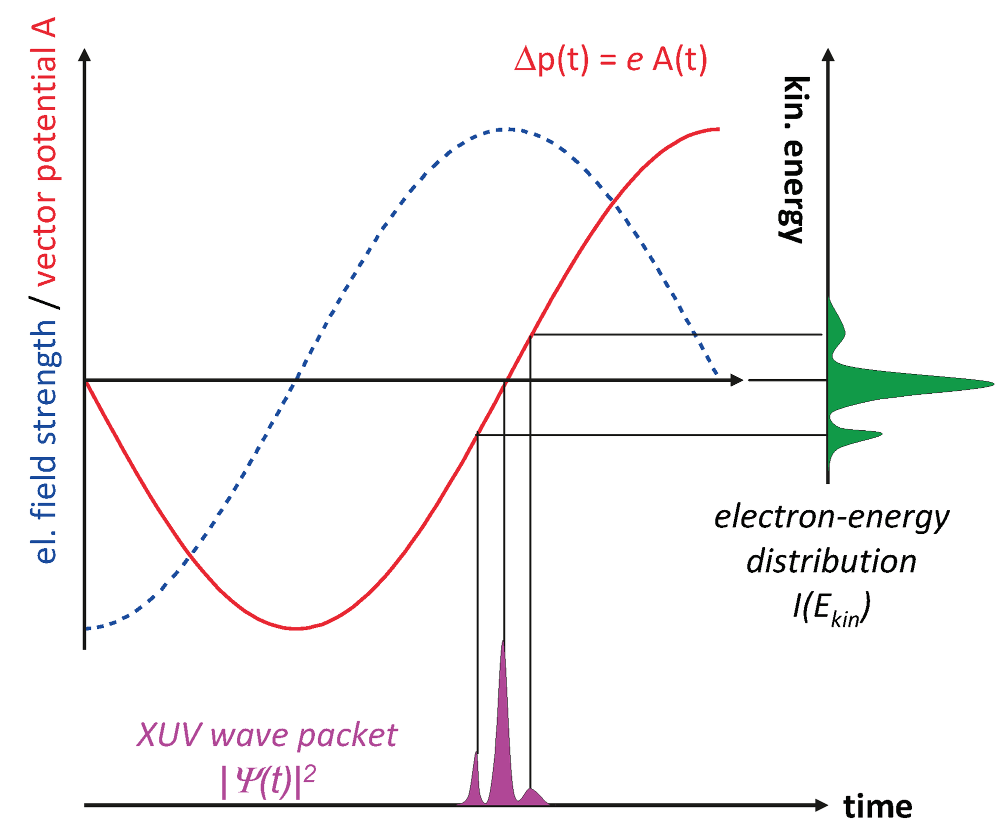
Challenges for Hard X-Rays

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



From Electron Energy to Arrival Time

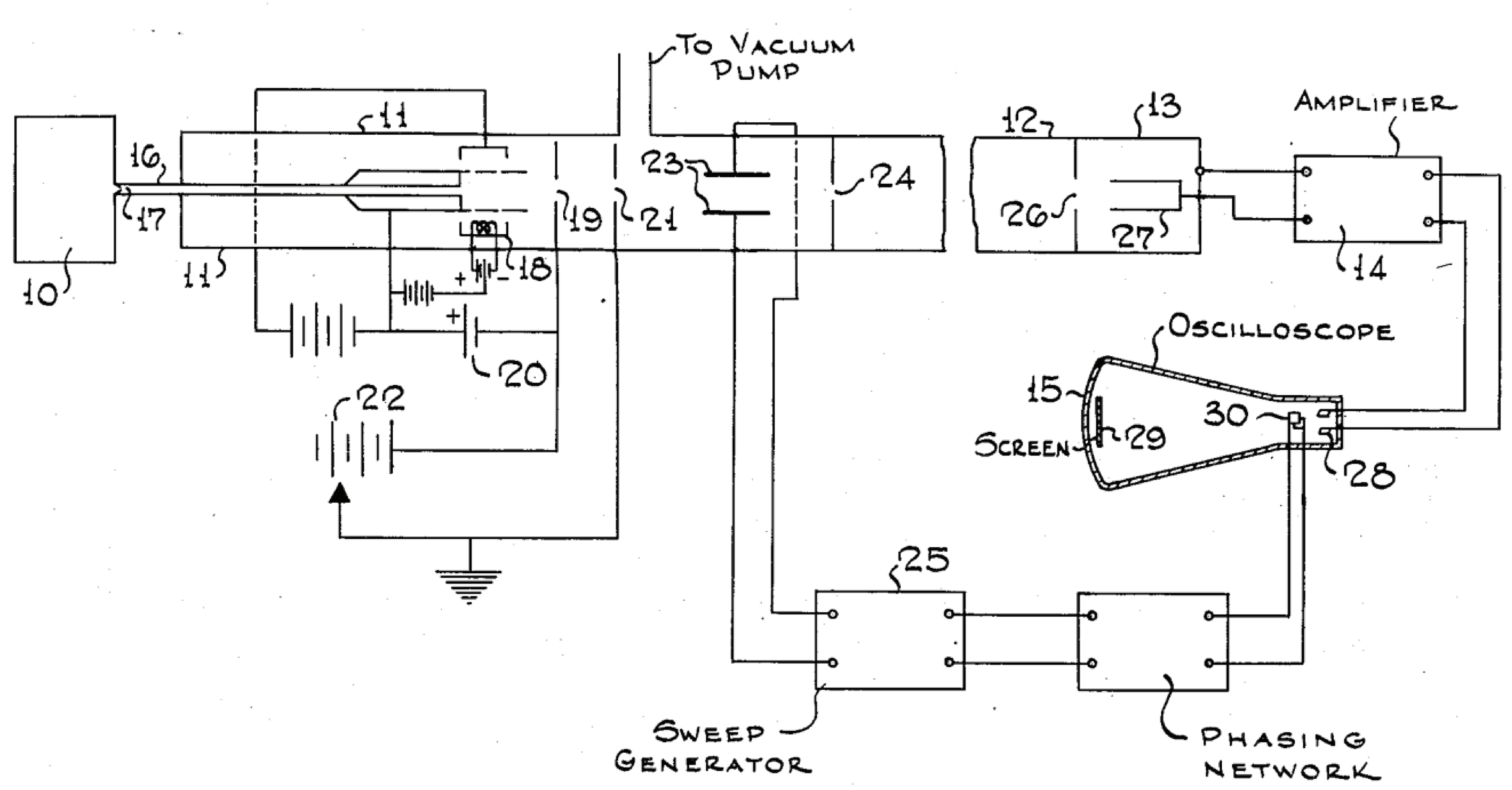




The X-ray pulses from the FEL generate photoions in a gas. The photoelectron energy is thus the X-ray energy minus the binding energy.
By introducing an additional electromagnetic terahertz field derived from the pump laser, the photo-electrons "born" inside this field acquire additional energy proportional 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)

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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.

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