Terahertz Streak Camera as Arrival Time Monitor for SwissFEL

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Goals for the SwissFEL photon pulse length and timing stability:

<table>
<thead>
<tr>
<th>Operating Mode</th>
<th>X-Ray Pulse length</th>
<th>Arrival Time Stability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard</td>
<td>20 fs rms</td>
<td>20 fs rms</td>
</tr>
<tr>
<td>Short-Pulse</td>
<td>1.5 fs rms</td>
<td>5 fs rms</td>
</tr>
<tr>
<td>Attosecond</td>
<td>60 as rms</td>
<td>5 fs rms</td>
</tr>
<tr>
<td>Wide Bandwidth</td>
<td>20 fs rms</td>
<td>20 fs rms</td>
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</tbody>
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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 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)


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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.