Measuring Ultrashort X-ray Pulses in FELs

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Outline

@ Motivation

@ Methods
1. Spectrometer
2. Cross-correlation
3. RF deflection
4. Thz streaking camera

@ Comparison & Summary
Motivation

- Utilization of ultrashort X-ray pulses
  - molecular biology
  - chemical dynamics
  - material science
- Analysis of femtosecond pulses required
- Typical nonlinear optical techniques have not been extended to x-rays.
High Resolution X-ray Spectrometer

- **Principles**
  - Fourier transform.
  - Uncertainty principle.

- **Measurements** at SACLA in different bunch compression modes.

- **SIMPLEX simulation** applied to measurements to characterize pulse duration.
High Resolution X-ray Spectrometer

- Spectral resolution 14meV at 10keV.
- Applicable to a wide EM range (VUV, soft x-rays, hard x-rays).
High Resolution X-ray Spectrometer

- Steps
  - Measure spectra
  - \( \rightarrow \) fit rms deviations to spikes
  - \( \rightarrow \) use values in simulation
  - \( \rightarrow \) construct temporal profile
**Cross-Correlation**

- **Intensity autocorrelation:** useful for lasers
- **Problem:** not for x-rays!
- **Solution:** cross-correlate x-rays with e-beam
Cross-Correlation

1. Chirp electron beam
2. Chicane 1: slice beam in chicane
3. Undulator 1: generate 2 x-ray pulses
4. Chicane 2: delay e-beam
5. Undulator 2: amplification of x-ray pulse 2
Cross-Correlation

Results:

Advantages:
- no additional equipment

Disadvantages:
- Requires dedicated setup (low power)
- Must assume gaussian (or similar) profile
RF Deflection

Energy profile:
- Vertical bend dipole magnet

Temporal profile:
- Horizontal streaking from two X-band deflector cavities
- Better time resolution than S-band
RF Deflection

Energy loss measurement
- X-ray power, \( P(t_i) = \Delta E(t_i) \times I(t_i)/e \)

Energy spread confirmation

Extracted X-ray profile

“Lasing OFF”

“Lasing ON”
RF Deflection

Temporal resolution: soft X-ray 1 fs, hard X-ray 4 fs

Advantages: Non-destructive measurement

Applications: tapering optimization
- kick beam to “lasing-off” trajectory
- study resulting temporal and energy profile
**THz streaking**

FEL pulse ionizes gas

Free electrons

THz field streaks them

Kinetic energy is measured
Final electron energy is a function of relative arrival time between the X-ray & THz.
THz streaking

\[ I_X(t) \rightarrow I_e(p) \rightarrow I_e(E) \]

\( t_{\text{Xray}} = 15 \pm 3 \text{ fs} \)
## Take away

<table>
<thead>
<tr>
<th>Method</th>
<th>Score</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spectrometer</td>
<td>OK</td>
<td>still relies on simulation</td>
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<tr>
<td>Cross-correlation</td>
<td>Good</td>
<td>temporal and energy info, but low power operation required</td>
</tr>
<tr>
<td>RF deflection</td>
<td>Better</td>
<td>temporal and energy info, non-destructive</td>
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</tbody>
</table>
| Thz streaking camera    | Best  | temporal and energy info, direct measurement (potential for phase info), non-destructive??
References

C. Behrens et al., Nature communications, (2014)
Thanks for the attention!