# Measuring Ultrashort X-ray Pulses in FELs

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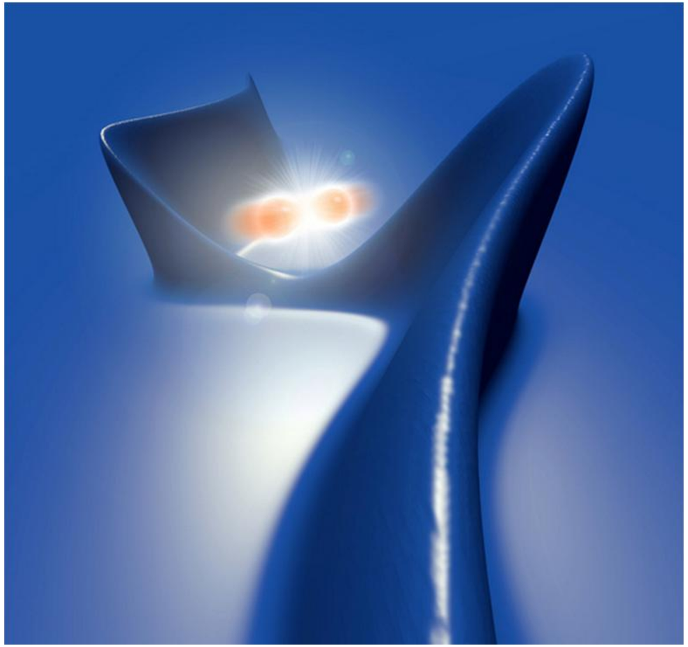


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# Outline

**@ Motivation**

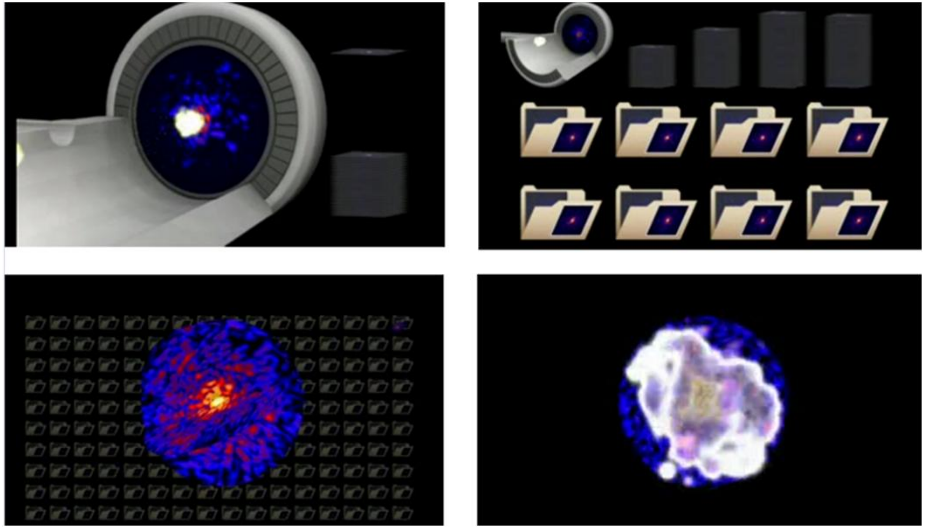
**@ Methods**

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

**@ Comparison & Summary**

# Motivation

illustration: coherent diffraction image process



- 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

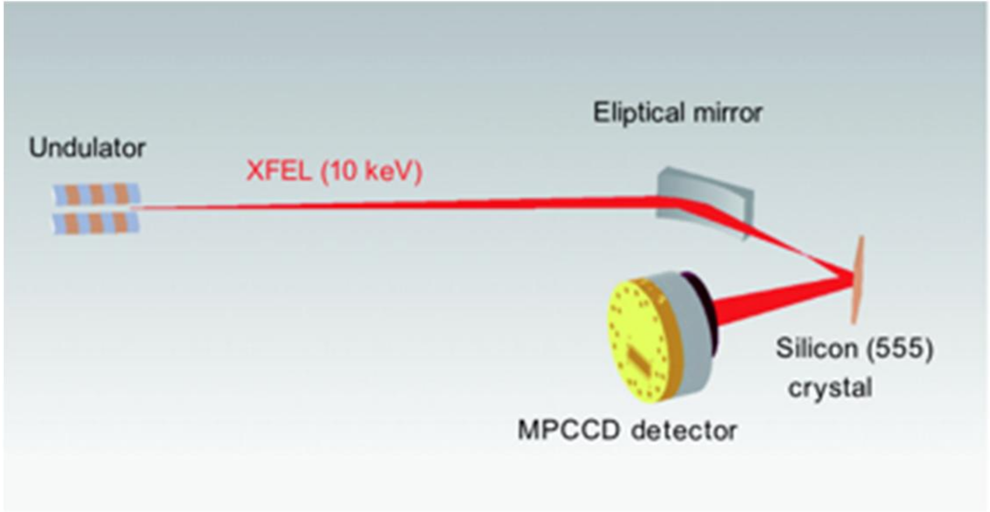
- **Principles**
  - Fourier transform.
  - Uncertainty principle.

$$\Delta E \, \Delta t \geq \frac{\hbar}{2}$$

- **Measurements** at SACLA in different bunch compression modes.
- **SIMPLEX simulation** applied to measurements to characterize pulse duration.

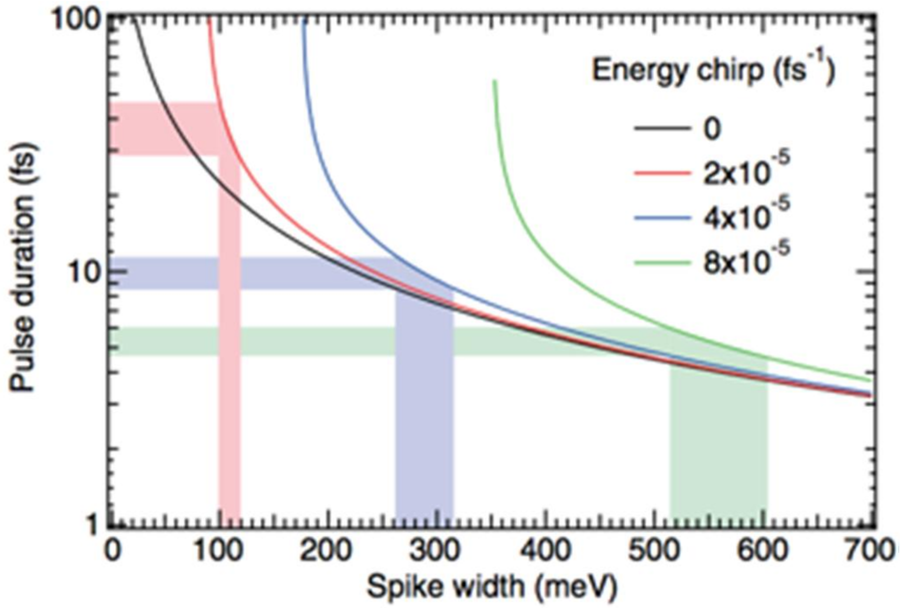
# High Resolution X-ray Spectrometer

- Spectral **resolution** 14meV at 10keV.
- Applicable to a **wide EM range** (VUV, soft x-rays, hard x-rays).



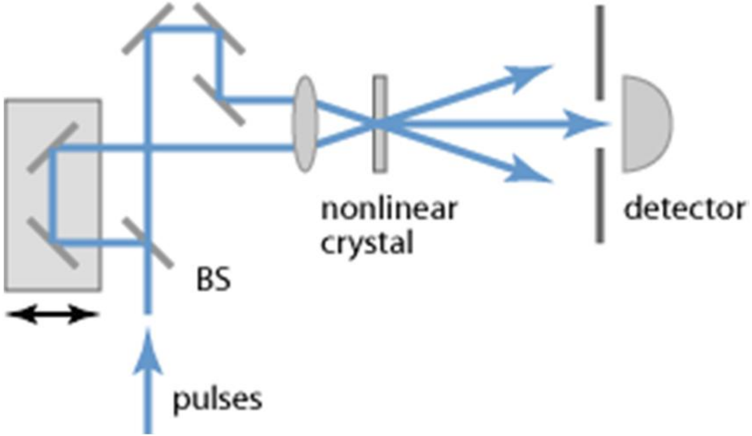
# High Resolution X-ray Spectrometer

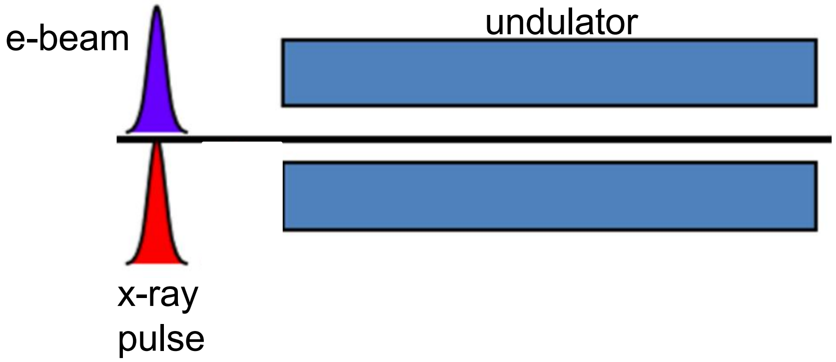
- Steps
  - **Measure** spectra ~> **fit** rms deviations to spikes ~> use values in **simulation** ~> **construct** temporal profile



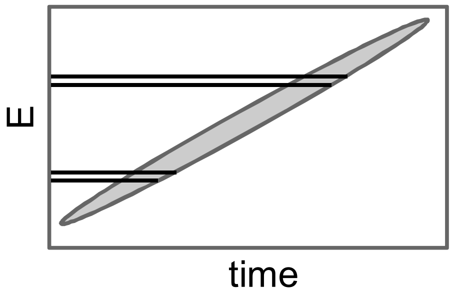
# Cross-Correlation

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

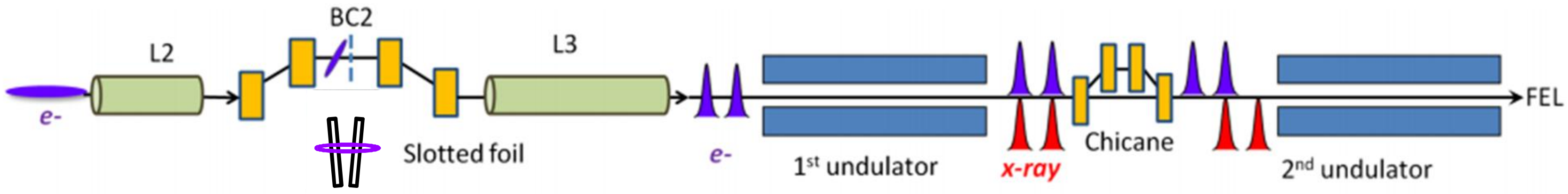


# Cross-Correlation

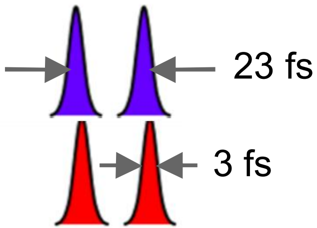


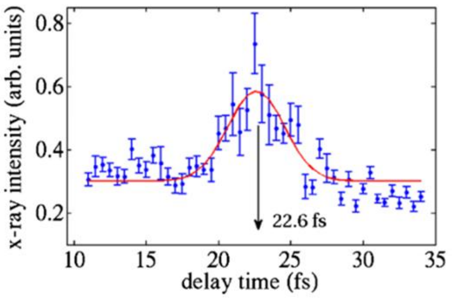

1. Chirp electron beam
2. Chicane 1: slice beam in chicane
3. Undulator 1: generate 2 x-ray pulses
4. Chicane 2: delay e-beam
5. Undulator 2: amplification of x-ray pulse 2



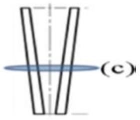
# Cross-Correlation

## Results:




(c)



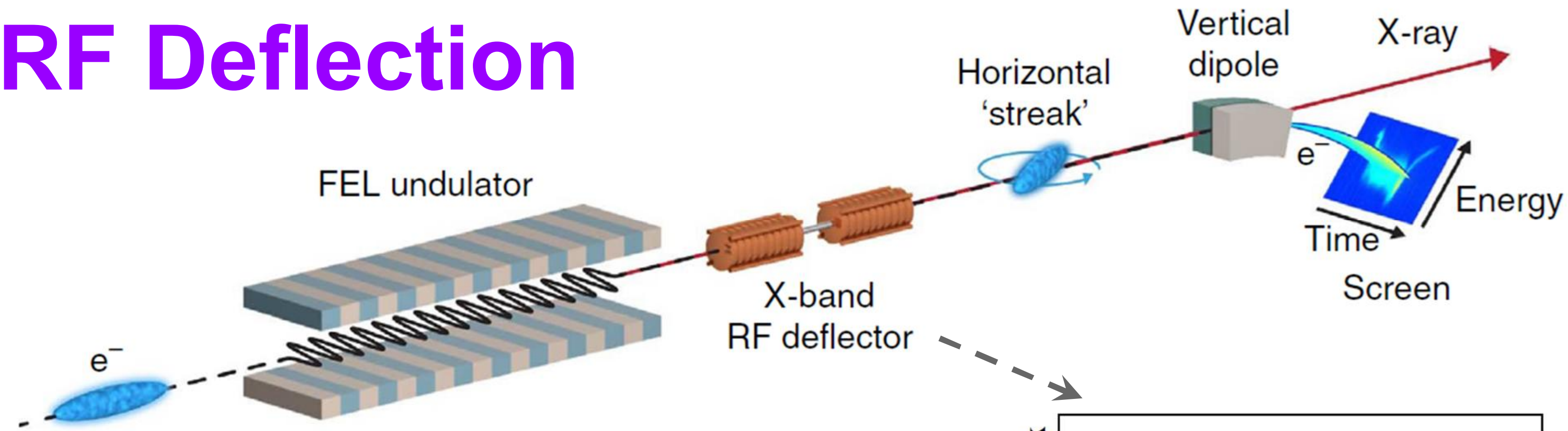

**Advantages:**

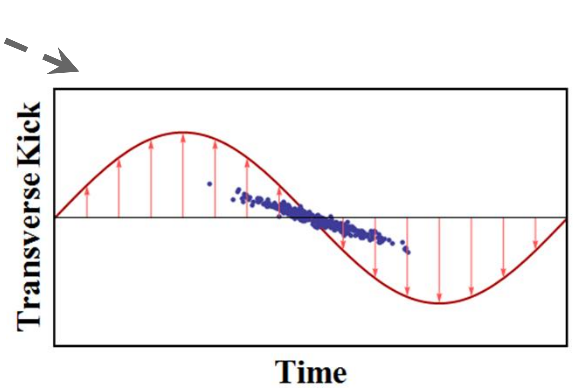
- no additional equipment

## 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

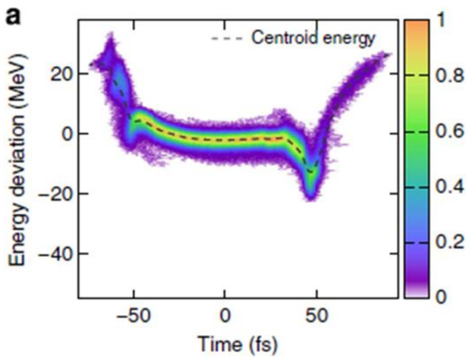
# RF Deflection

Energy loss measurement

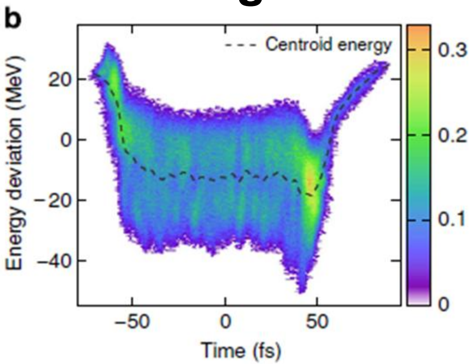
- X-ray power, $P(t_i) = \Delta E(t_i) \times I(t_i)/e$

Energy spread confirmation

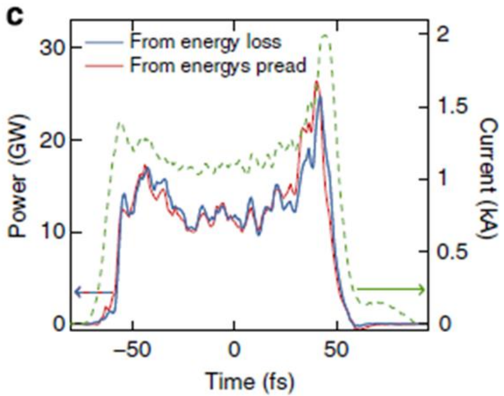
**“Lasing OFF”**




**“Lasing ON”**




**Extracted X-ray profile**



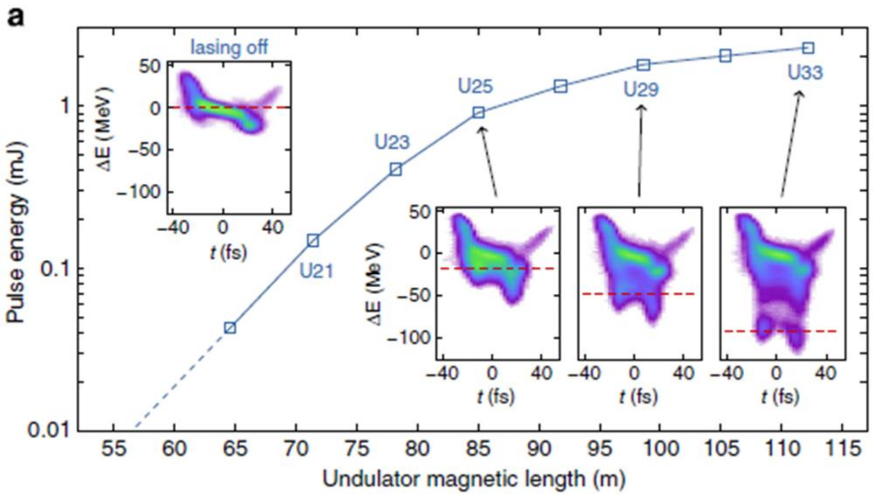
# RF Deflection

**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



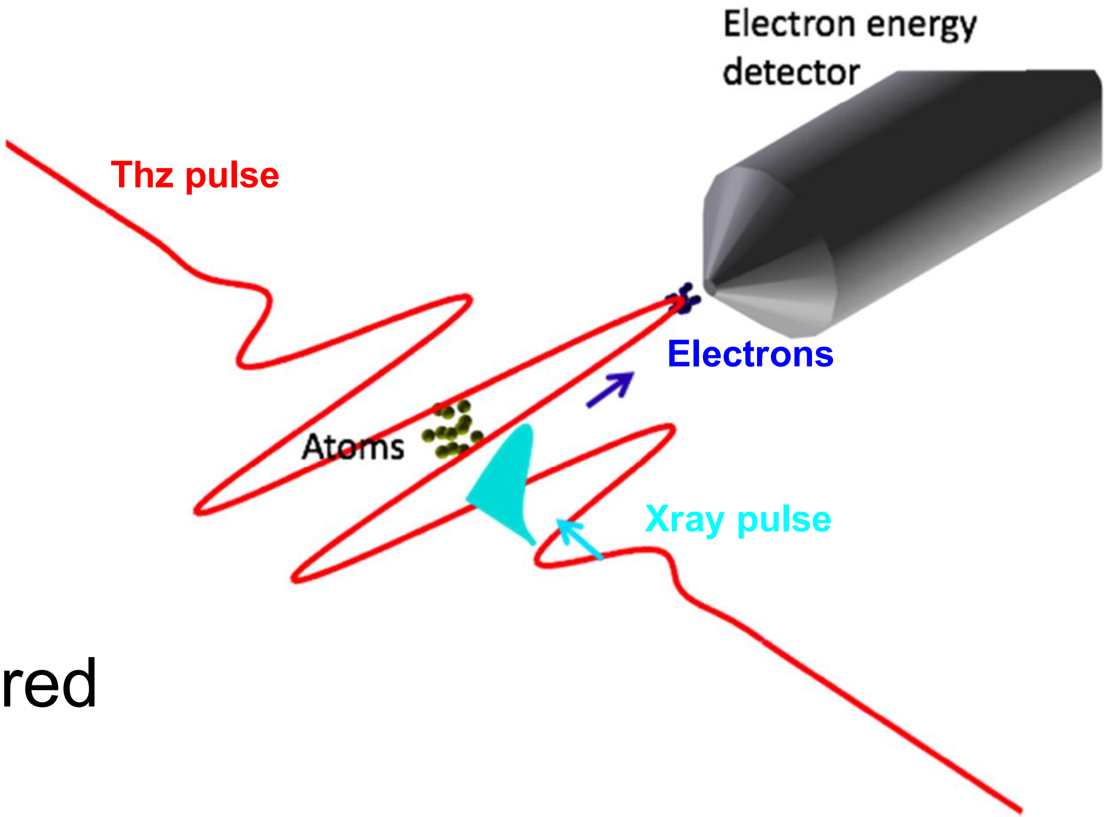
# THz streaking

FEL pulse ionizes gas

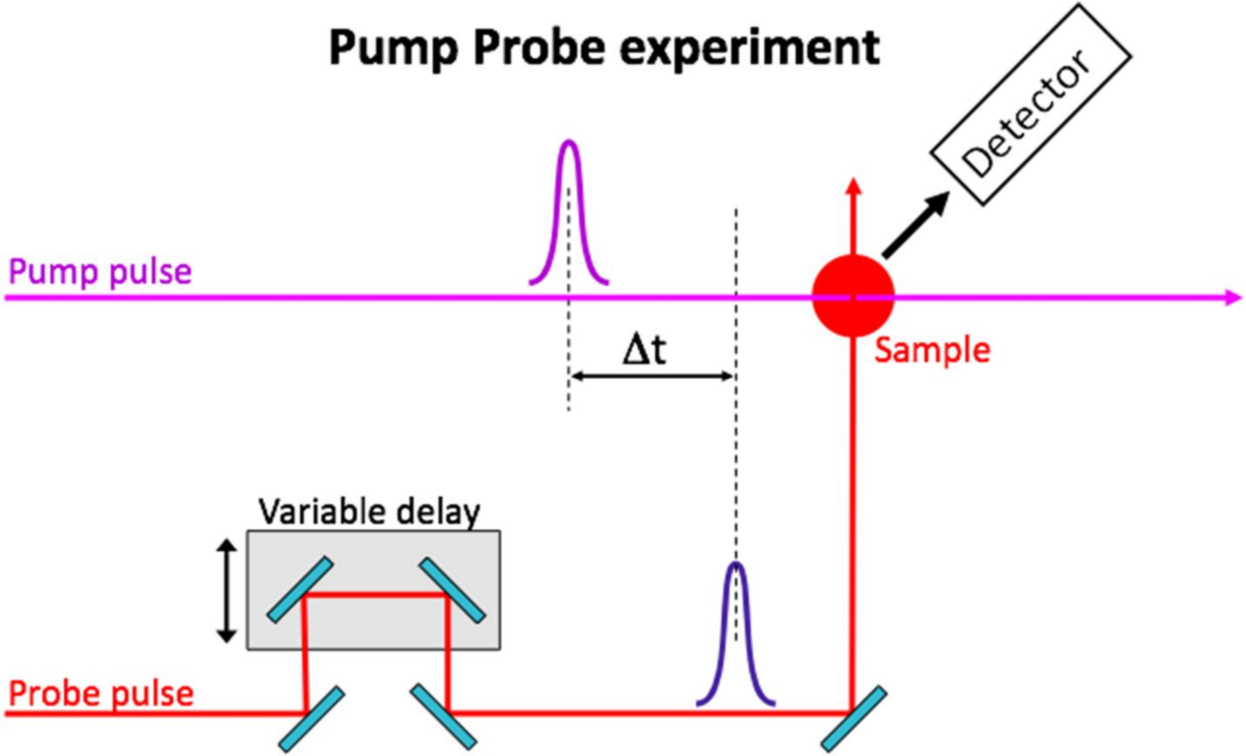
Free electrons

THz field streaks them

Kinetic energy is measured



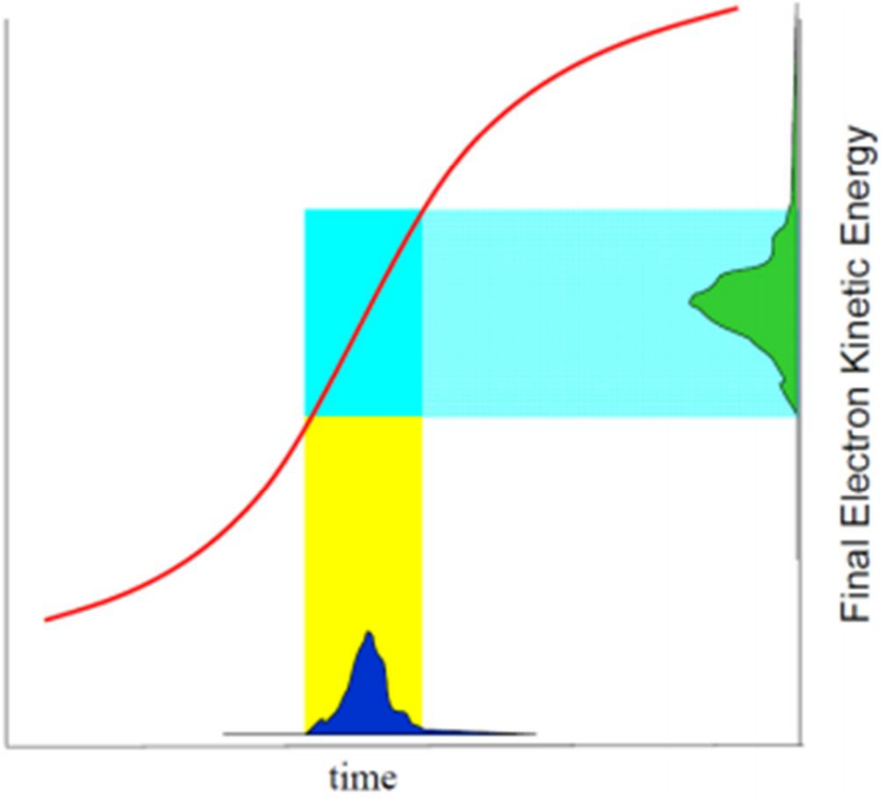
# THz streaking

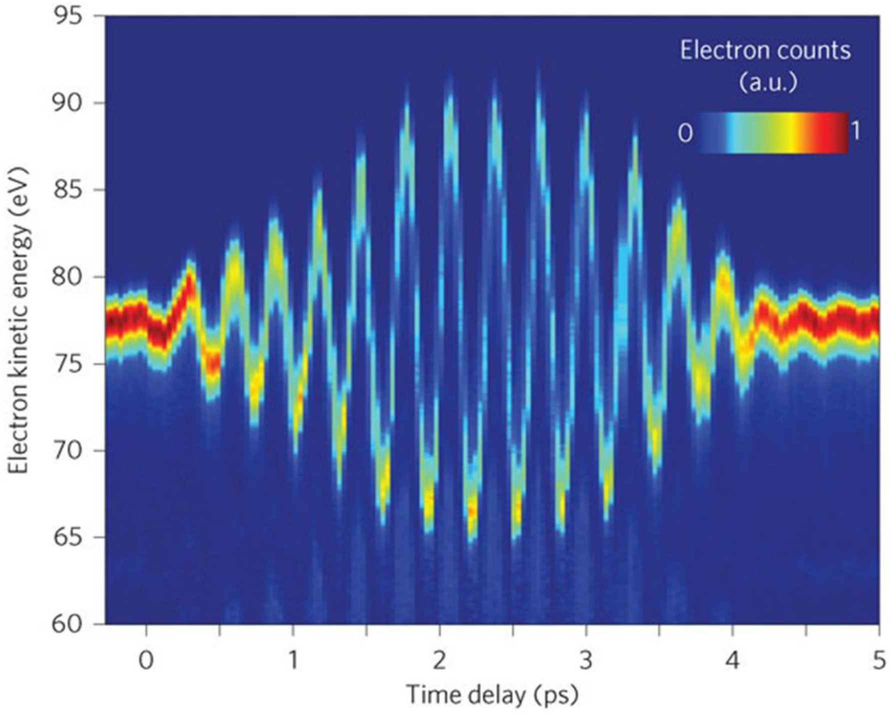



Final electron energy is a function of **relative arrival time** between the X-ray & THz

# THz streaking

$I_X(t) \rightarrow I_e(p) \rightarrow I_e(E)$




$t_{Xray}$= 15 ± 3 fs

# Take away


| | | |
|---|---|---|
| **Spectrometer** | OK | still relies on simulation |
| **Cross-correlation** | Good | temporal and energy info, but low power operation required |
| **RF deflection** | Better | temporal and energy info, non-destructive |
| **Thz streaking camera** | Best | temporal and energy info, direct measurement (potential for phase info), non-destructive??? |

## References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# Thanks for the attention!