Toward single e-bunch shape diagnostics using THz coherent radiation

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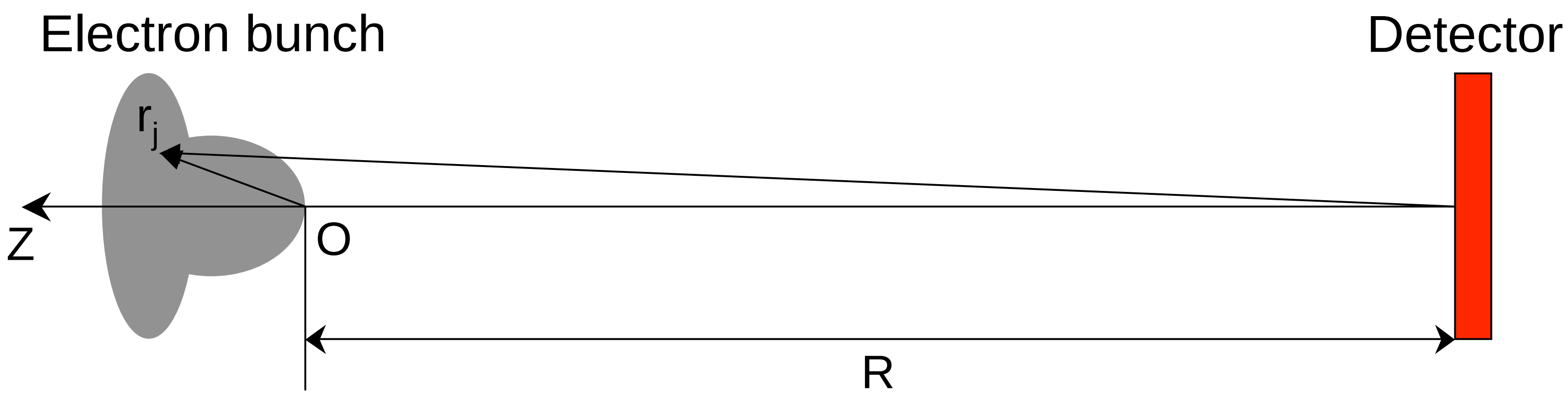
Outline

- Coherent radiation and the electron bunch shape
- Holographic spectroscopy in the THz
- Bringing measurement into the visible with EO detection
- Timeline

Coherent emission of a distant bunch



Total intensity of the bunch radiation

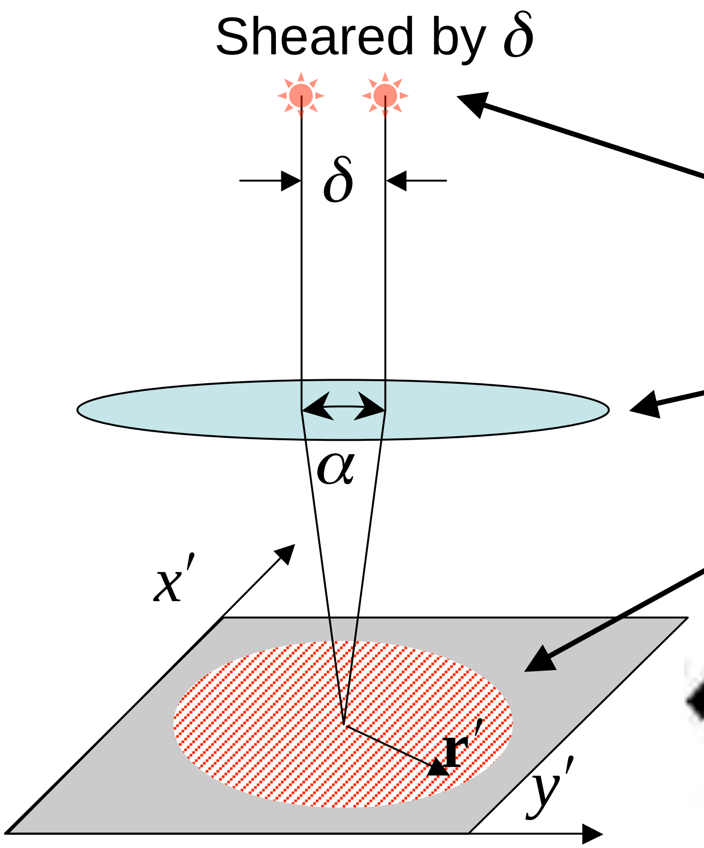
$$I_{tot}(\omega) = I(\omega)\left[N + N(N-1)F(\omega)\right]$$

Electron bunch form-factor

$$F(\omega) = \left| \int_0^\infty dz S(z) e^{i(\omega/c)z} \right|^2$$

Coherent radiation spectrum contains information about the bunch shape

Properties of ideal HFTS



Holographic FTS consists from

- shearing interferometer
- Fourier transform lens
- array detector

- No restriction on the object size – ultimate throughput!
- No need for large elements in the array

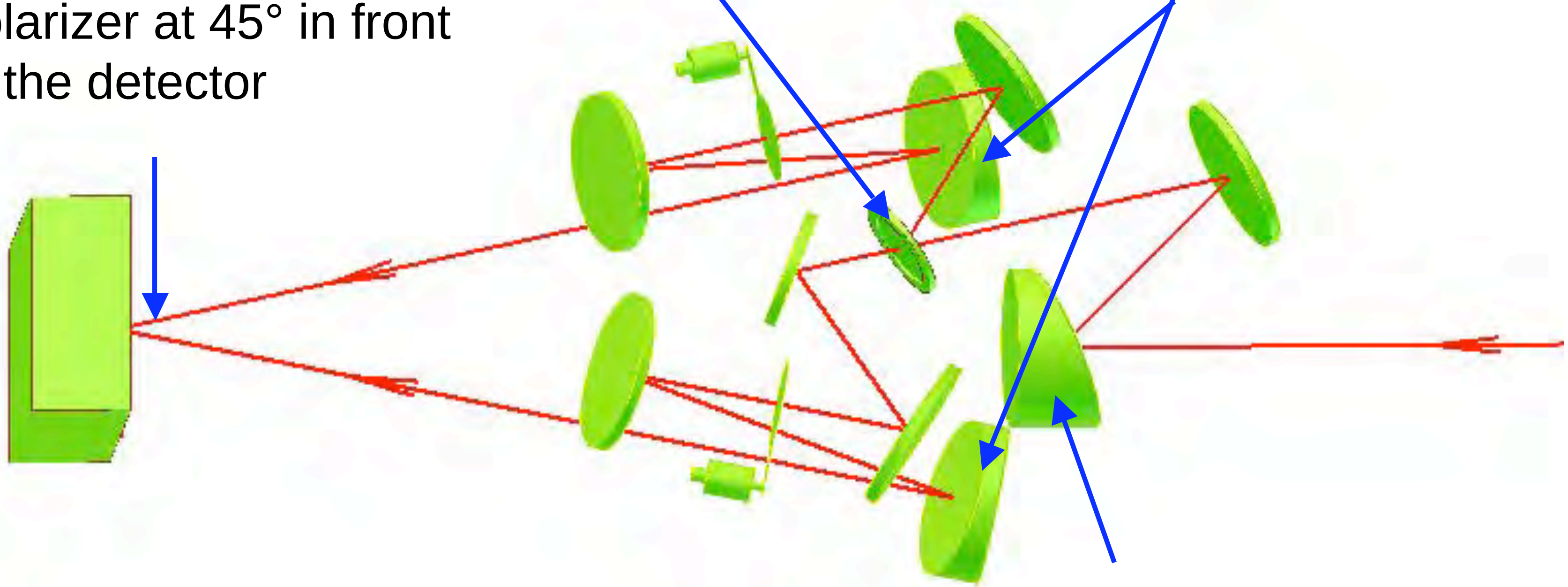
$$I(\mathbf{r}') = 1/2 \int_0^\infty d\omega \, I_0(\mathbf{r}', \omega) \left(1 + \cos \frac{\omega}{c} \frac{\delta}{f} y' \right) B(\omega)$$

Optical layout of the THz interferometer

Wire grid beamsplitter sends two polarizations along different paths

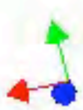
Two out-of-plane off-axis parabolic mirrors collimate beams and recombine them at the array detector

Second wire grid polarizer at 45° in front of the detector



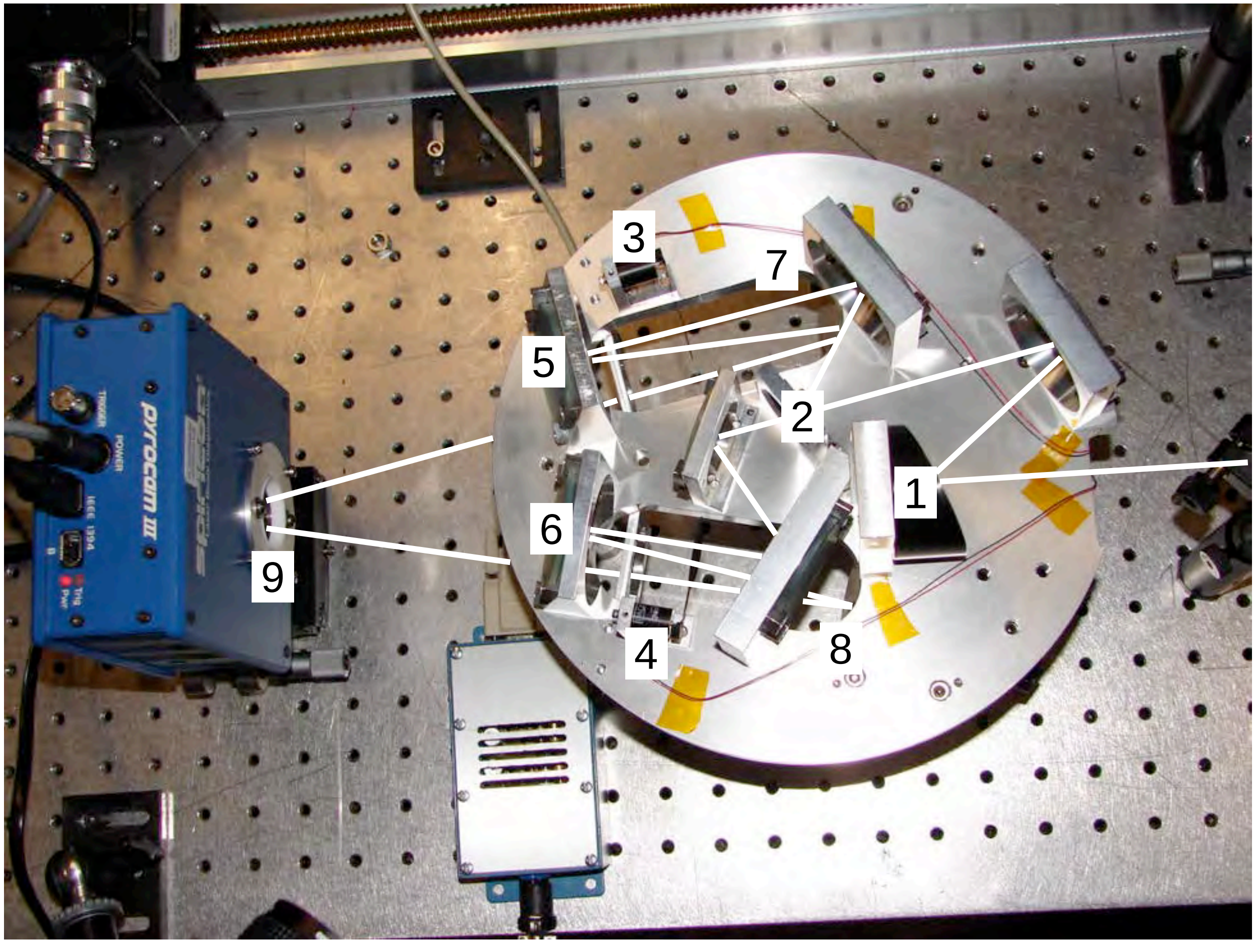
Fore-optics accepts collimated beam

Uses standard optical components



Folding mirrors for compact design

Experimental setup at J-Lab



1 - fore-optics

2 - beamsplitter

3,4 - shutters

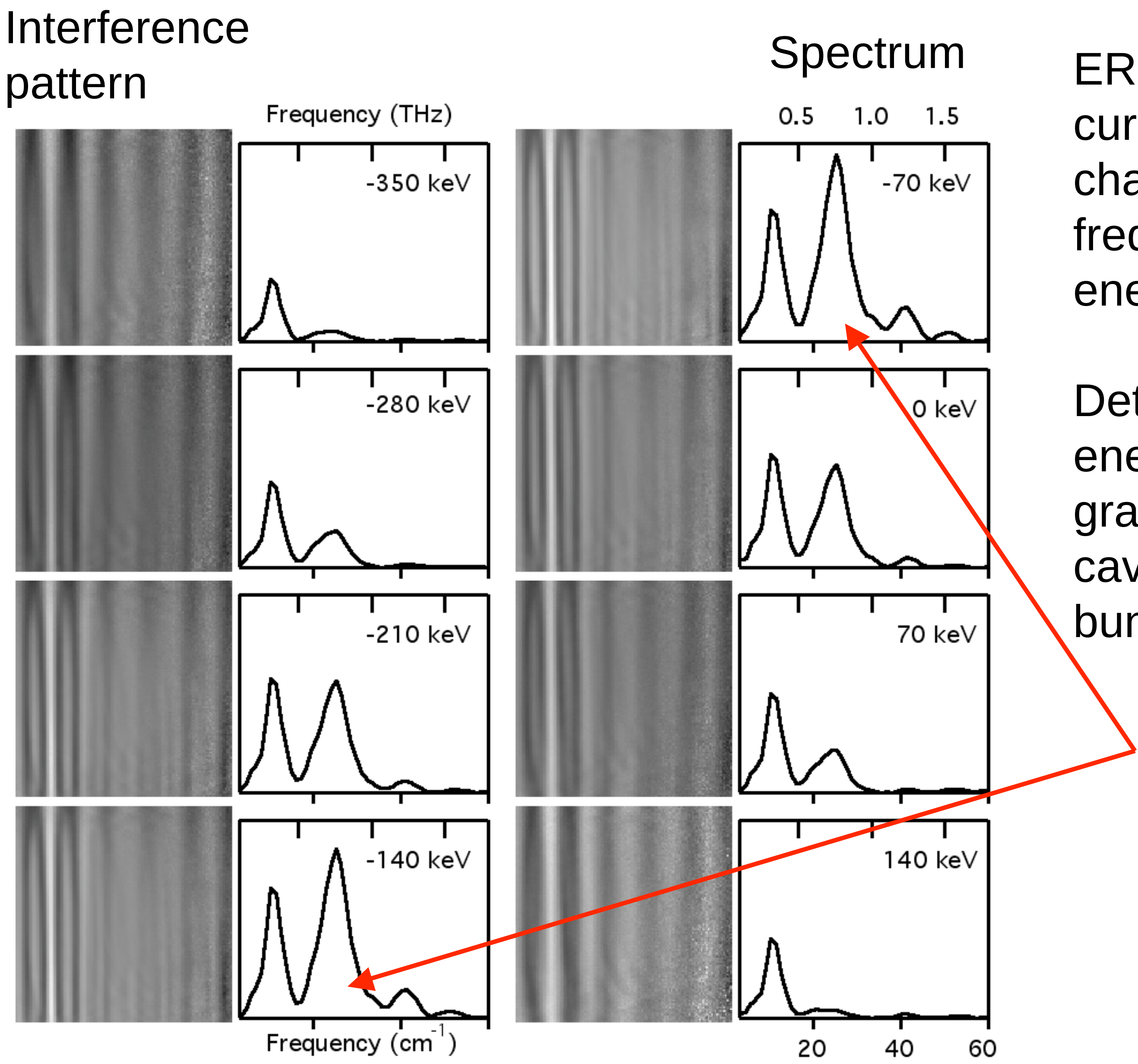
5,6 - tilted folding mirrors

7,8 - off-axis parabolic mirrors

9 - polarizer

Experiments conducted in air since only a few water lines occur below 40 cm^{-1}

Coherent SR measurements at JLab

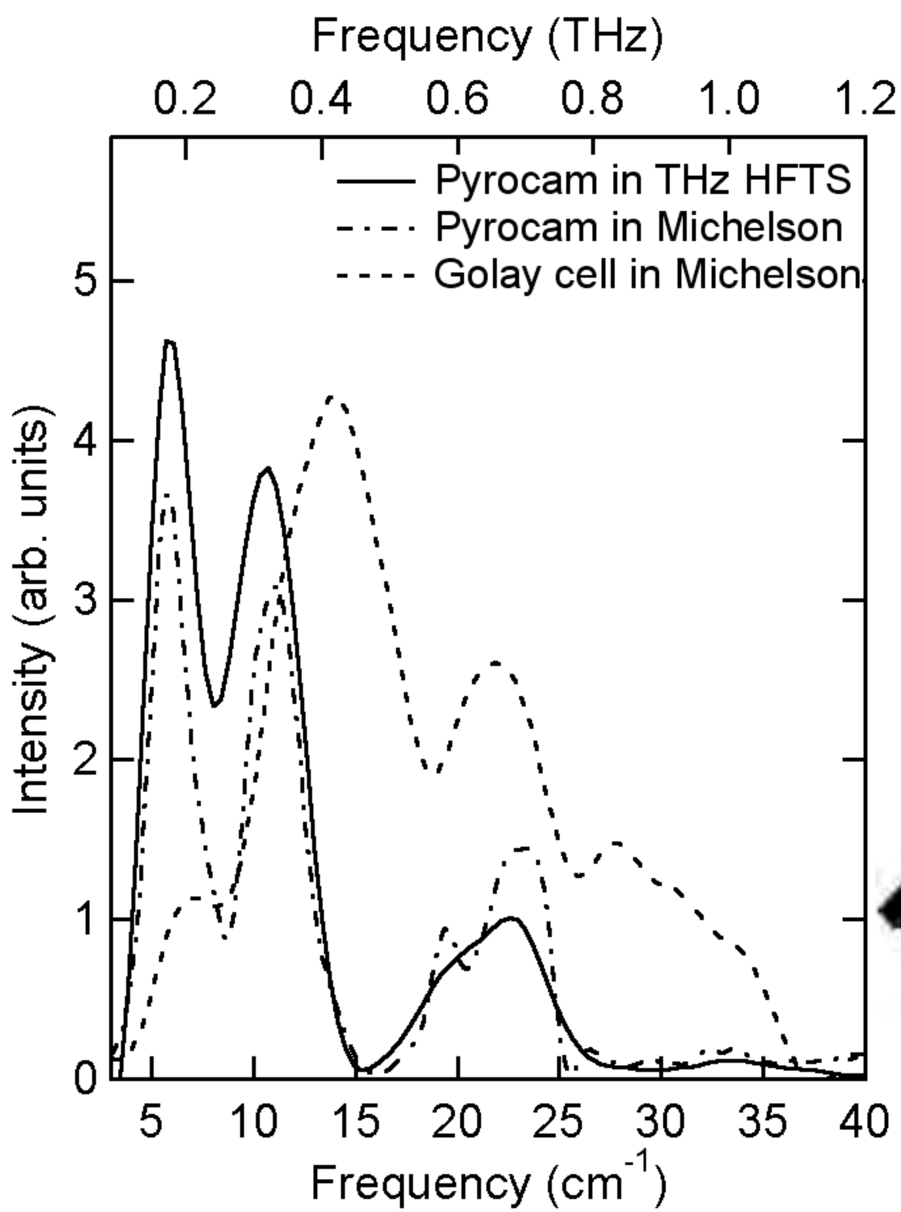


ERL parameters:
current - 1 mA
charge - 100 pC
frequency - 9.36 MHz
energy - 114.65 MeV

Detuning of the bunch energy by changing the gradient field in the RF cavities varied the electron bunch length

The stronger and broader spectra are observed for shorter bunches

Non-uniform sensitivity of Pyrocam array

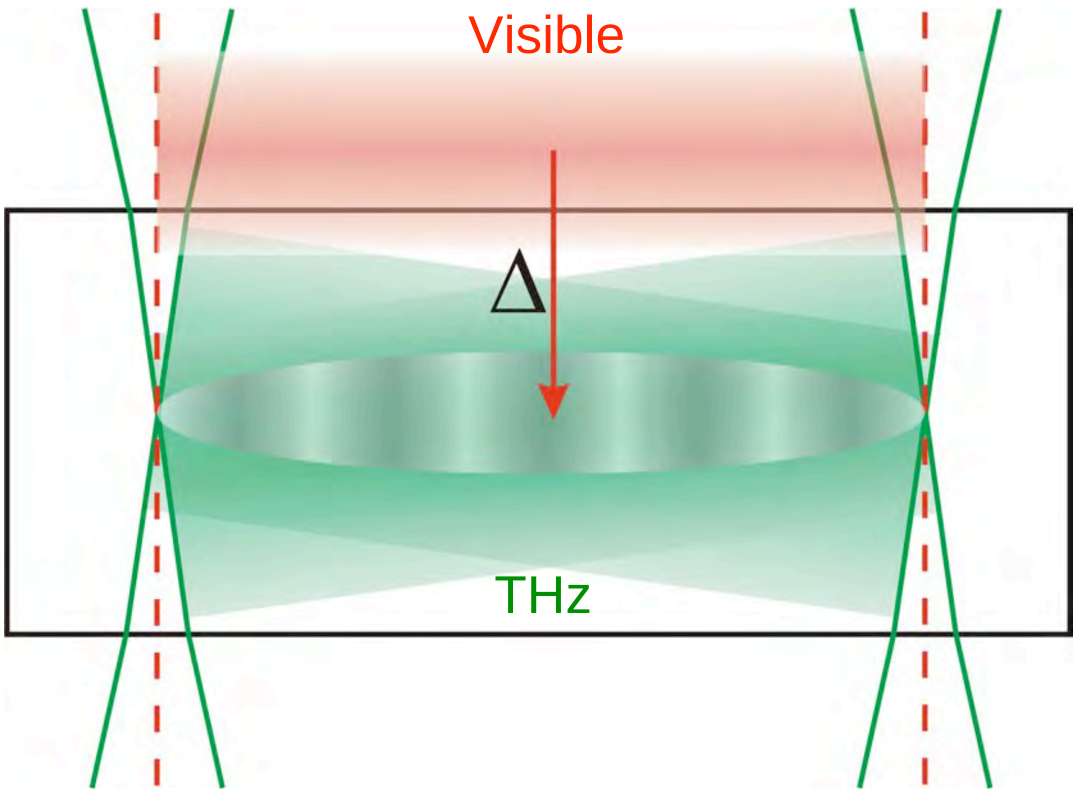


Three measurements were performed at JLab

1. THz HFTS with Pyrocam array
2. Scanning Michelson FTS with the Pyrocam
3. Scanning Michelson FTS with the Golay cell

Dips in the spectra are due to the Pyrocam array non-uniform sensitivity

Electro-optic detection of the THz interference



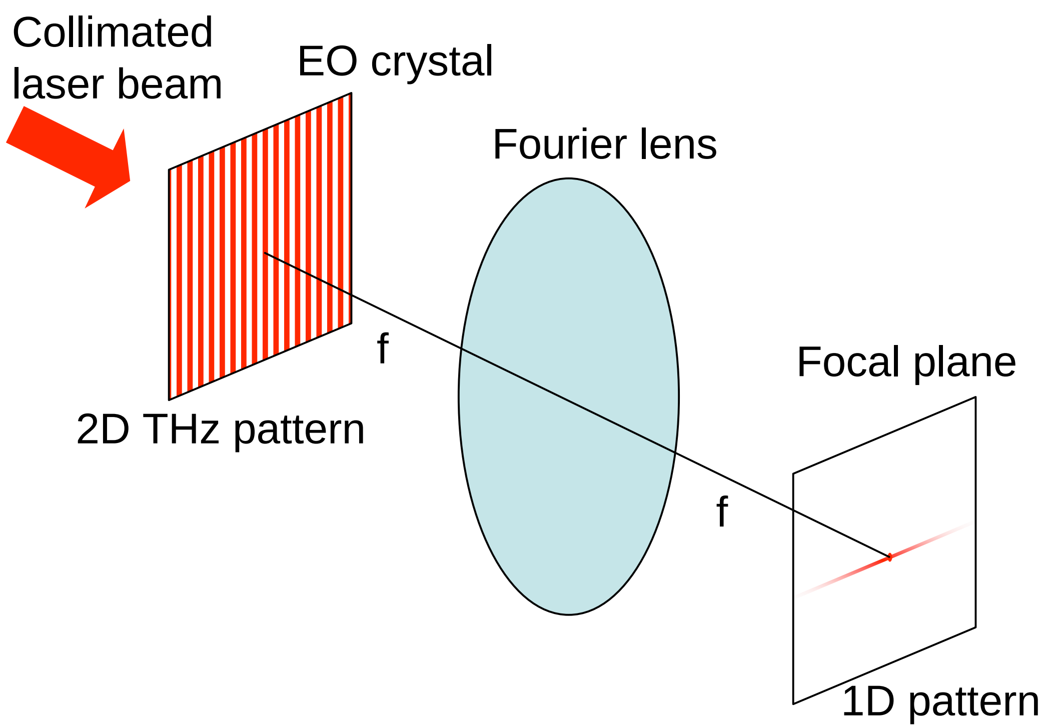
Delay Δ between THz and visible pulses is variable

Existing THz arrays insensitive and not optimized for spectral measurements

The way forward: use electro-optic detection

- EO effect is fast
- No pixel size restriction
- Flexibility and expandability

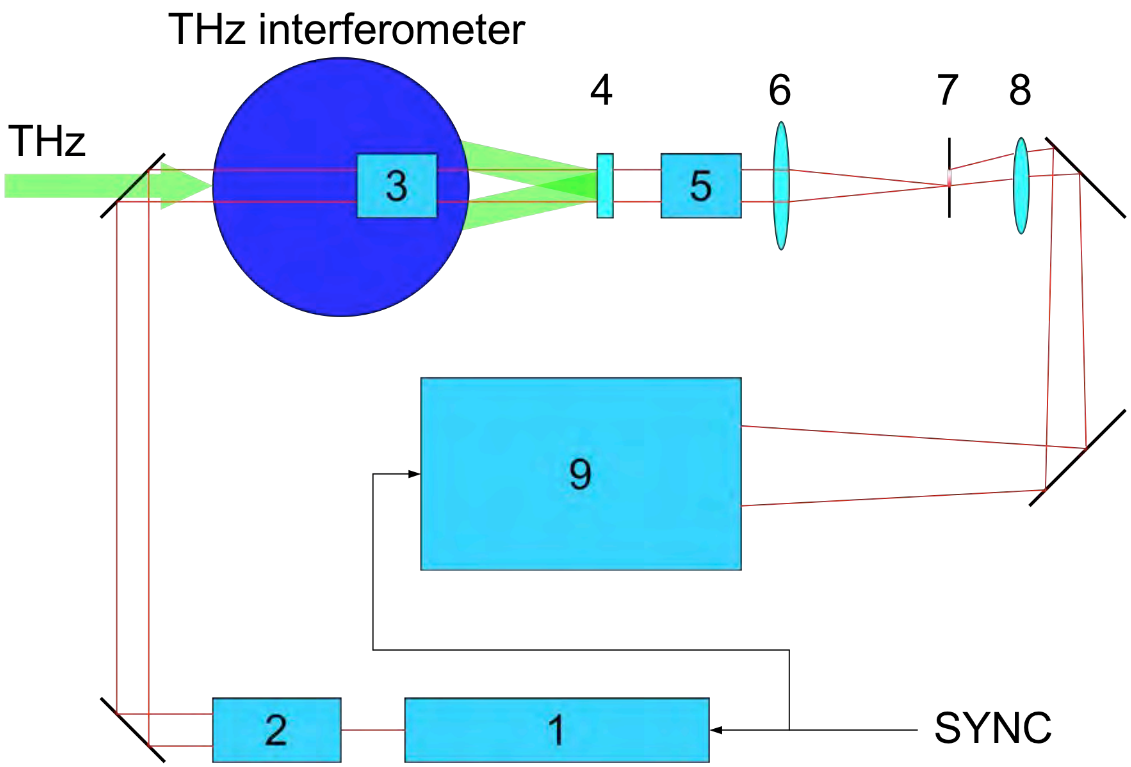
Optical FT of the THz interference pattern



Optical FT advantages

- Signal concentrated in a 1D pattern increasing the signal-to-noise ratio
- No signal in the absence of THz radiation - no need to use ultrafast laser pulses
- Rejection of the DC component - decreased background

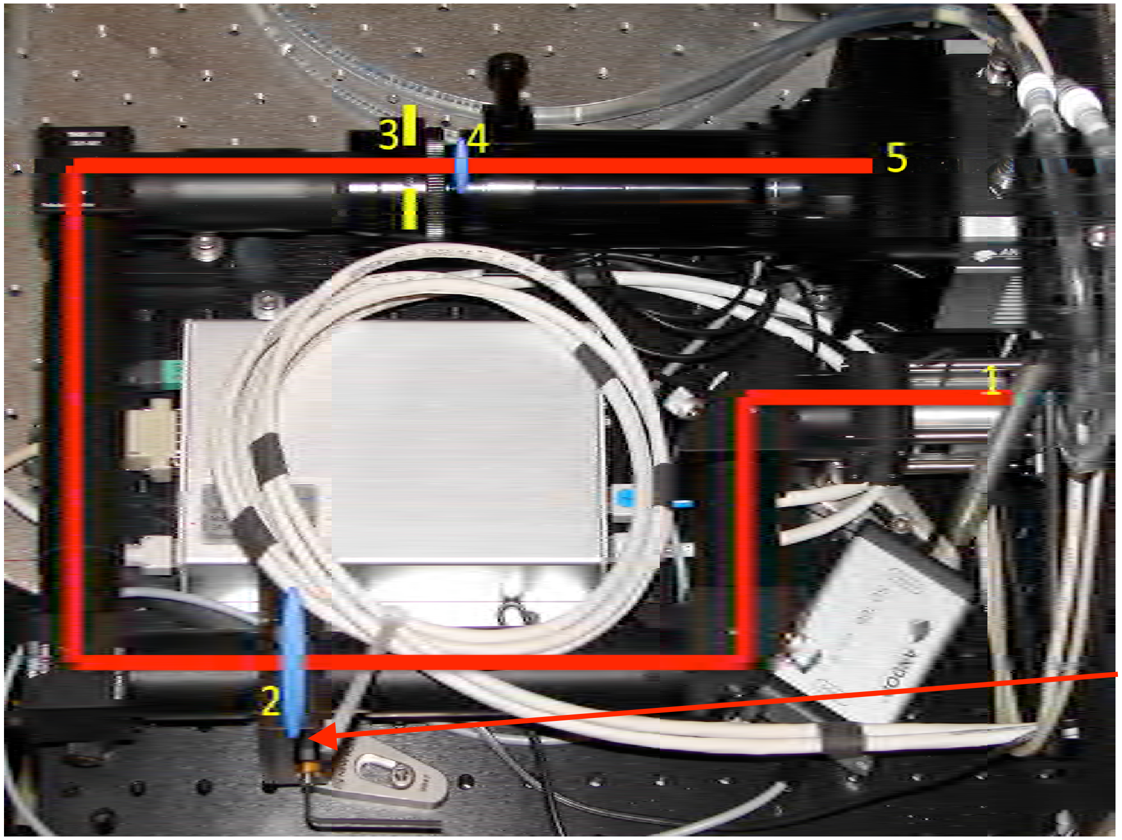
Schematic of the THz HFTS with optical FT



1. Pulsed laser
2. Beam expander
3. Polarizer
4. EO crystal
5. Analyzer
6. Fourier transform lens
7. Aperture
8. Magnifying lens
9. CCD camera

A self contained instrument without external synchronized lasers

EO detection module for optical FT

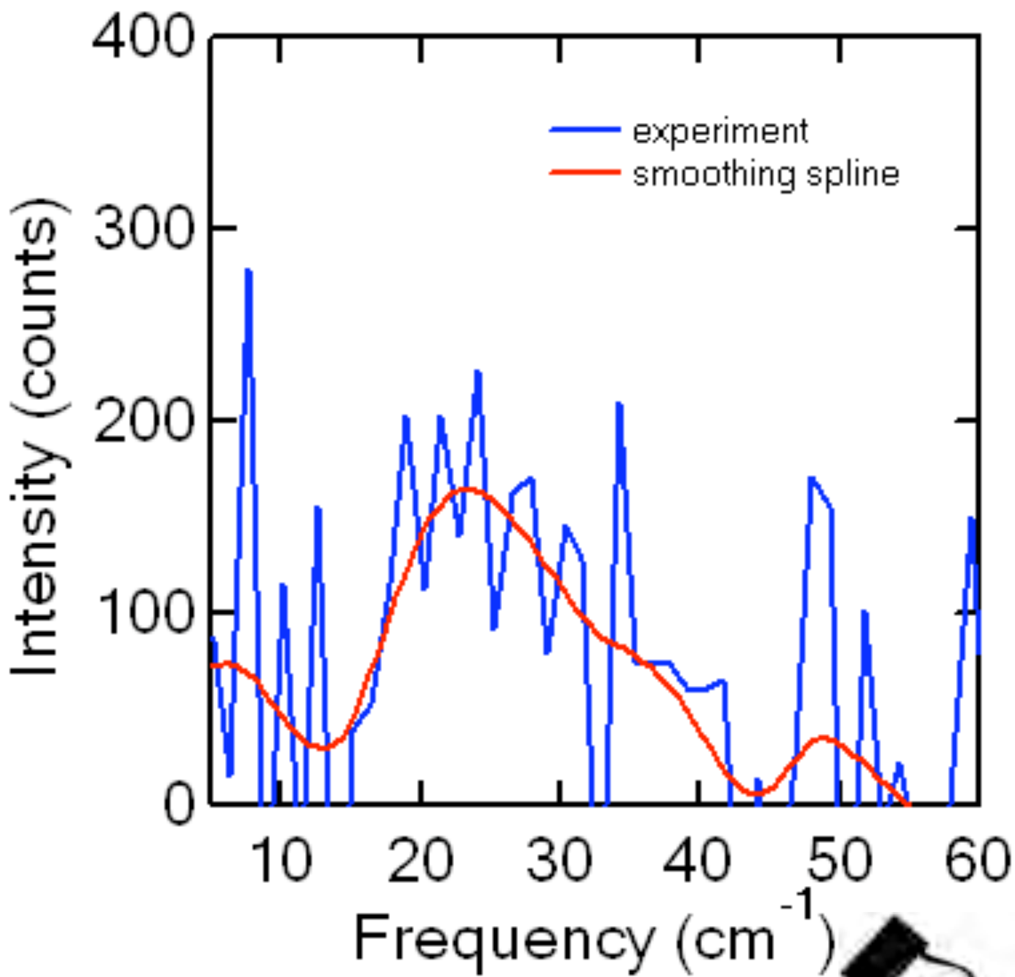


1. Analyzer
2. FT lens
3. Aperture
4. Magnifying lens
5. CCD camera

The FT lens is mounted on the XY stage in order to move the DC component outside of the aperture (3)

Complete instrument including the diode laser, THz interferometer, and the EO detection module fits on the 12" X 36" optical board

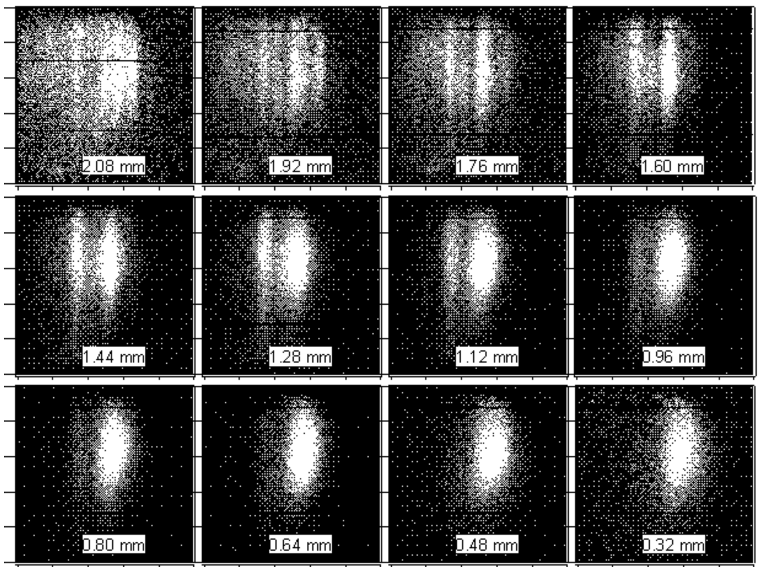
Experimental results for HFTS with optical FT at DESY

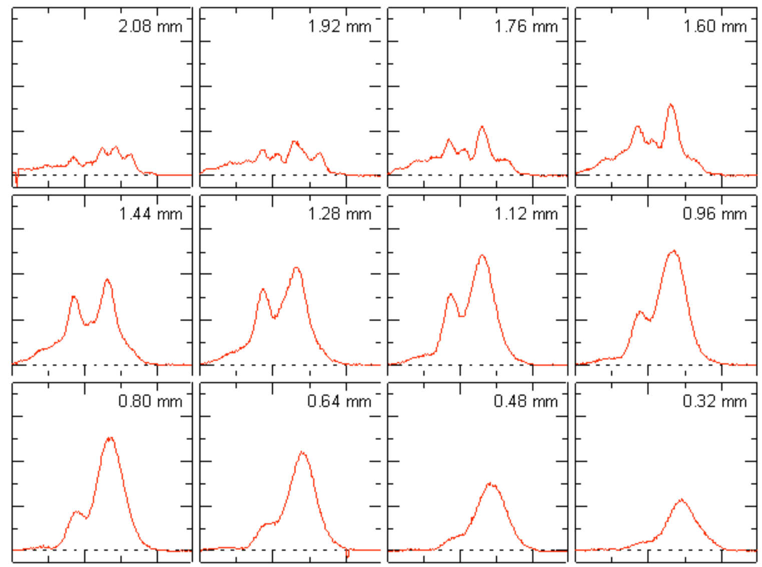


- Operation of the THz interferometer in the imaging mode
- Large background due to the long diode laser pulse and the EO crystal inhomogeneity
- Weak signal for the crossed polarizers geometry
- Accumulation of multiple shots

For single shot capability needed laser with < 100 ps pulses, > 1 W peak power

THz interference readout with incoherent radiation at JLab

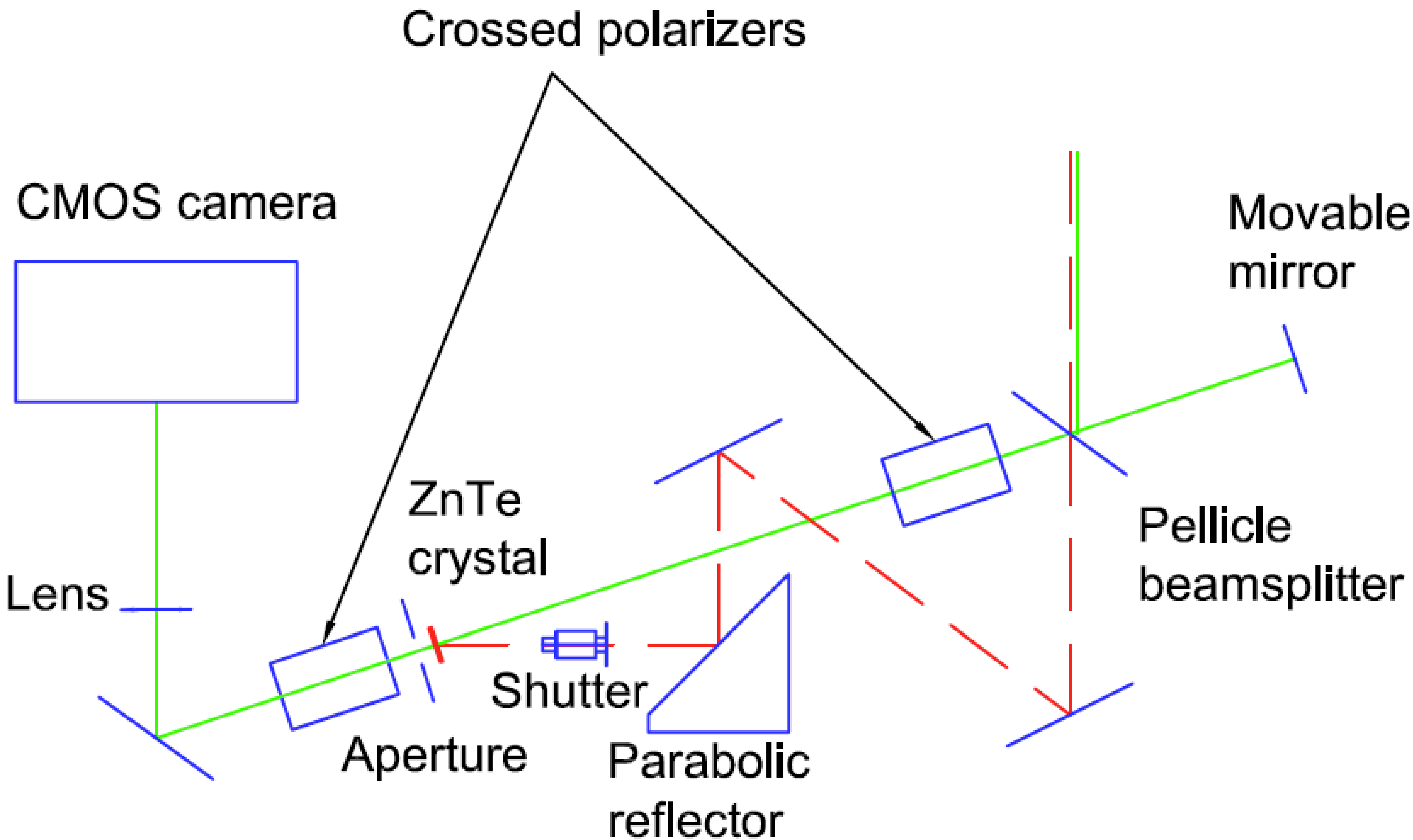




Frames (left) and corresponding profiles (right) reflect change in the THz interference pattern with the varying delay Δ between the incoherent and coherent pulses

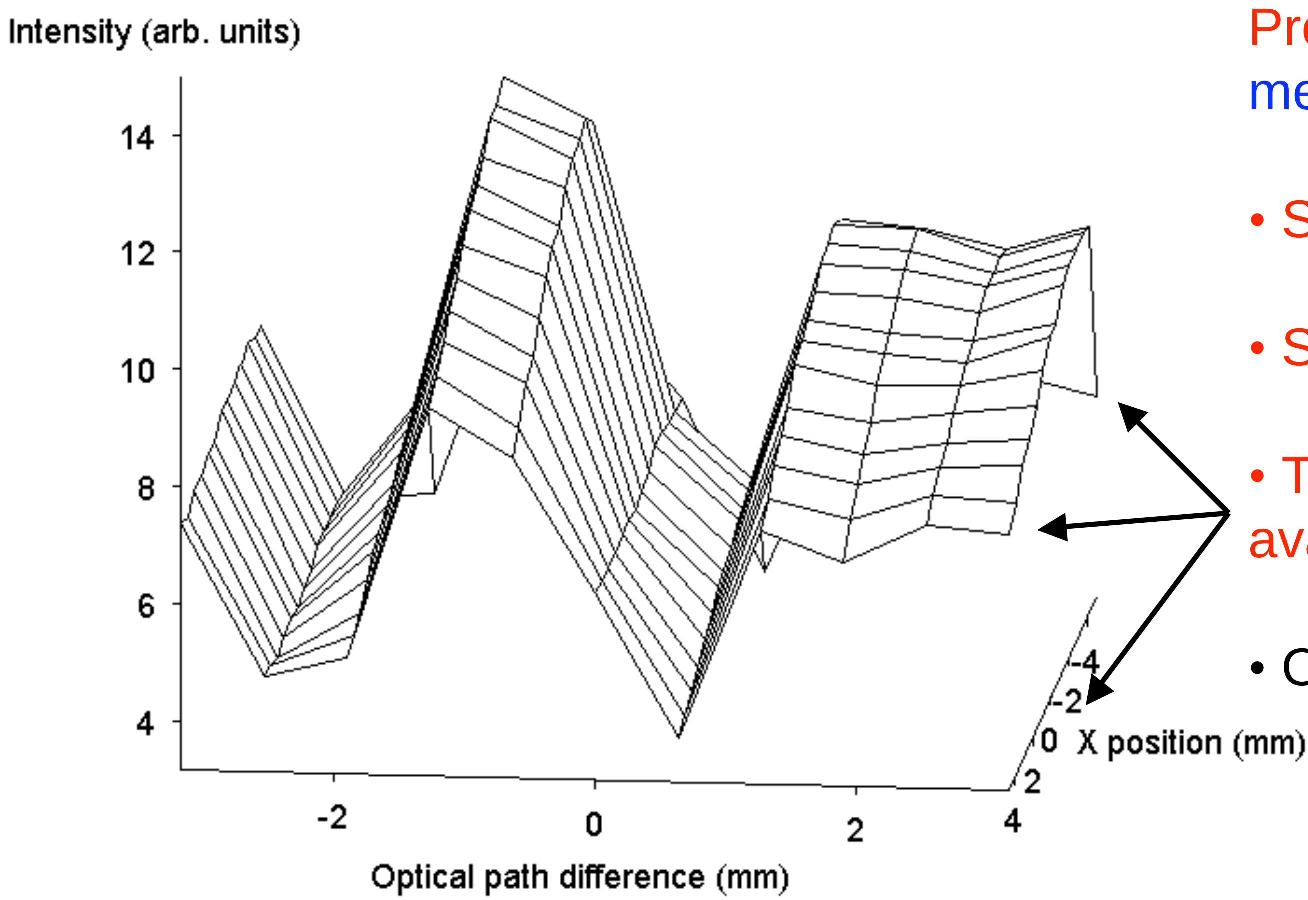
- Self-contained, no external laser
- Single shot capable
- Asymmetry capable

Cross-correlation of incoherent and coherent radiation



Simple, compact and self-contained system

Cross-correlation results at JLab

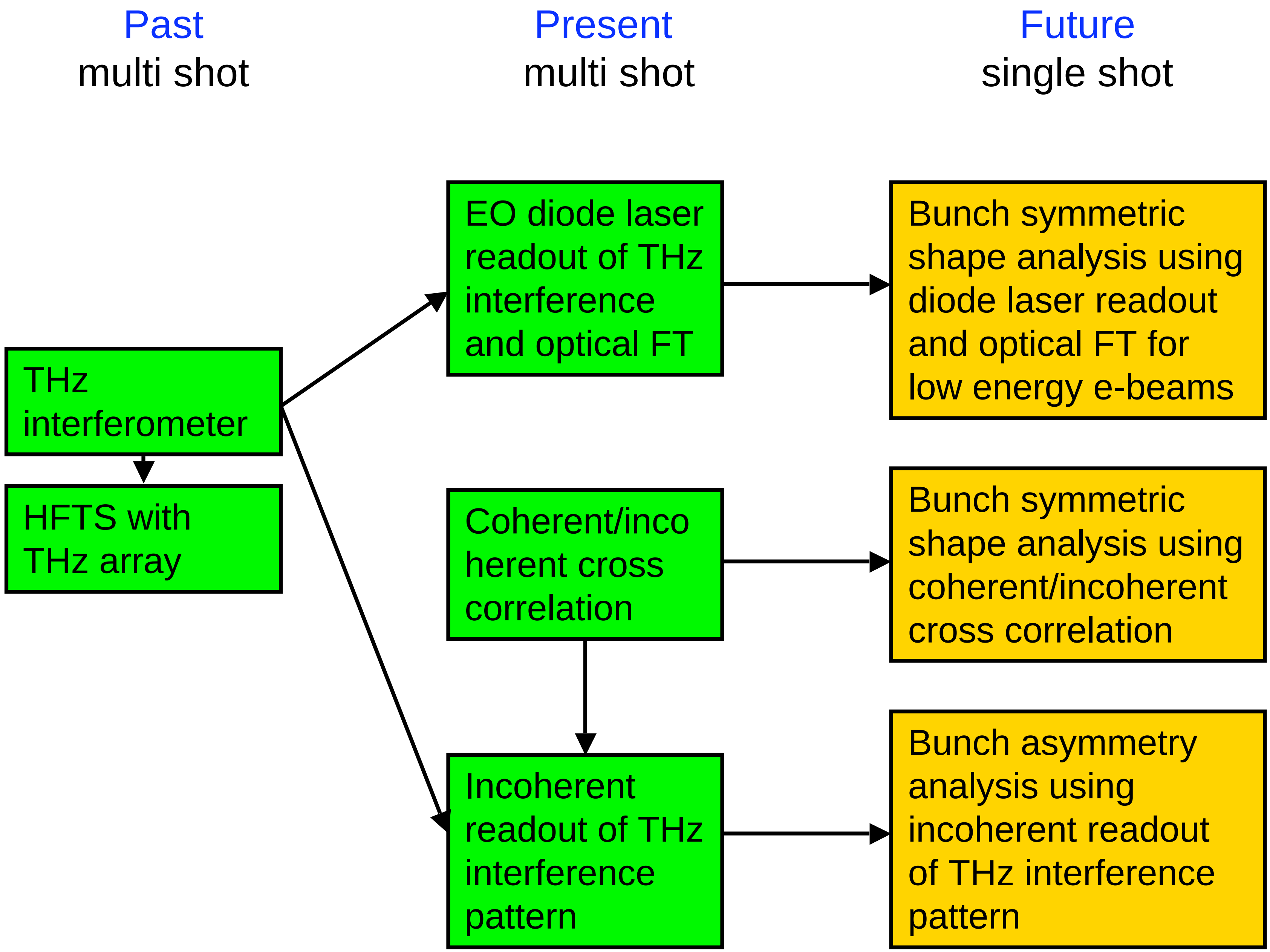


Pros and cons of the method

- Simple, self-contained
- Single shot capable
- Transverse dimension available as well
- Only symmetric shape

- Preliminary results confirm the idea
- Effects of crystal dispersion on the EO response function should be investigated

Timeline


Past
multi shot
Present
multi shot
Future
single shot
THz interferometer
HFTS with THz array
EO diode laser readout of THz interference and optical FT
Coherent/incoherent cross correlation
Incoherent readout of THz interference pattern
Bunch symmetric shape analysis using diode laser readout and optical FT for low energy e-beams
Bunch symmetric shape analysis using coherent/incoherent cross correlation
Bunch asymmetry analysis using incoherent readout of THz interference pattern