Efficient Spatiotemporal Characterization of THz Near-Fields for Particle Acceleration

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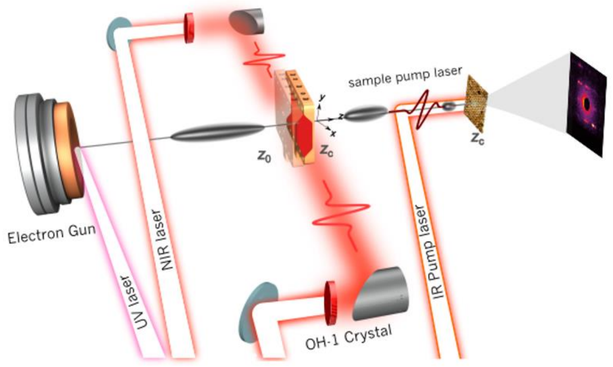
Abstract

- We have measured the THz near-field in order to inform the design of improved THz-frequency accelerating structures
- THz-frequency accelerating structures could provide the accelerating gradients needed for next generation particle accelerators with compact, GV/m-scale devices
- A better understanding of the THz near-field source properties is necessary for the optimization of THz transport and coupling into accelerator structures
- Analysis of the results from this measurement will inform designs of novel structures for use in THz particle acceleration and enable the use of the THz near field for electron streaking experiments

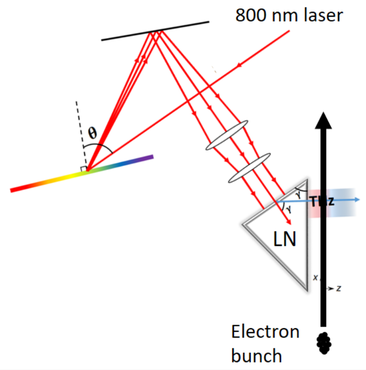
Motivation

- **Current THz accelerators:**
- ~ 100 MeV/m accelerating gradients
- Single cycle sources
- Basic dielectric and metallic accelerating structures
- Couple THz into the structure along the beam path

Mohamed A.K. Othman, **Annika E. Gabriel**, Appl. Phys. Lett. (2023)
H. Xu, *et al. Nat. Photonics* (2021).
M.T. Hibberd, *et al. Nat. Photonics* (2020).

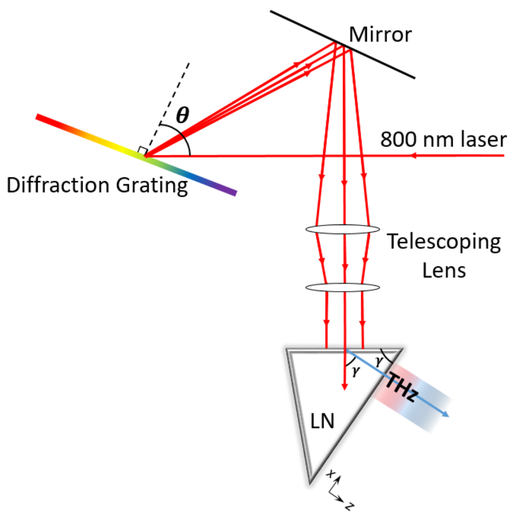


- **Electron acceleration using the THz near-field:**
  - Removes losses from beam transport and coupling
  - Allows for longer THz interaction length
  - Enables use of broadband THz pulse for acceleration
  - Allows study of effect of electron beam on THz generation

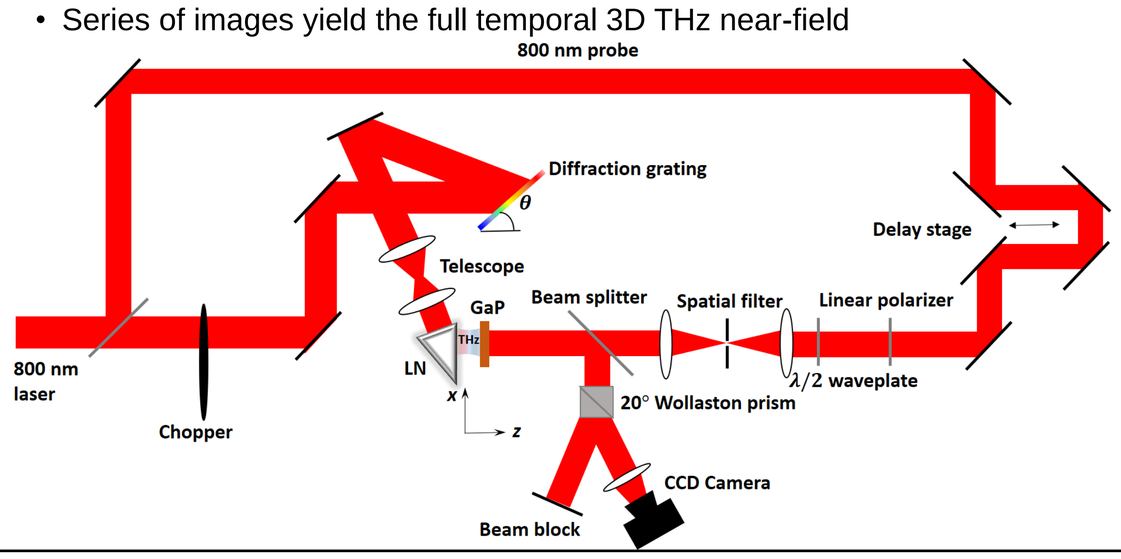


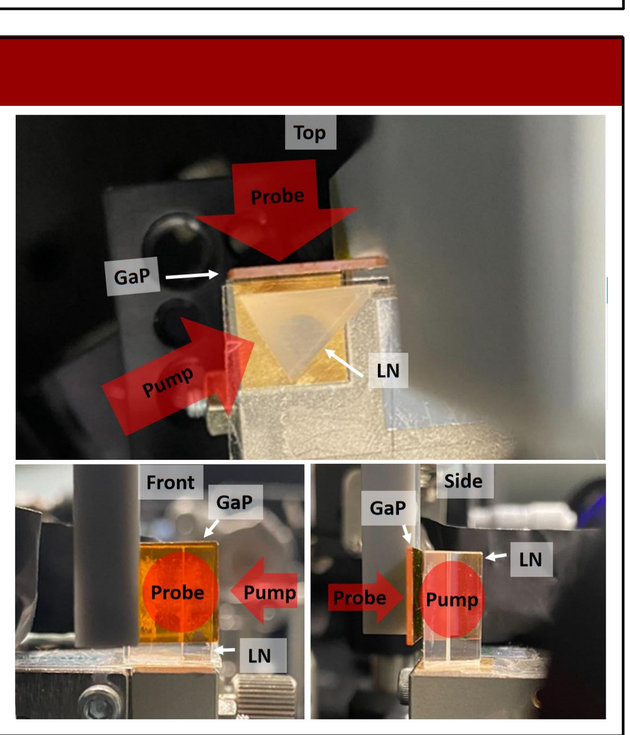
Methods

- **THz generation by optical rectification in LN:**



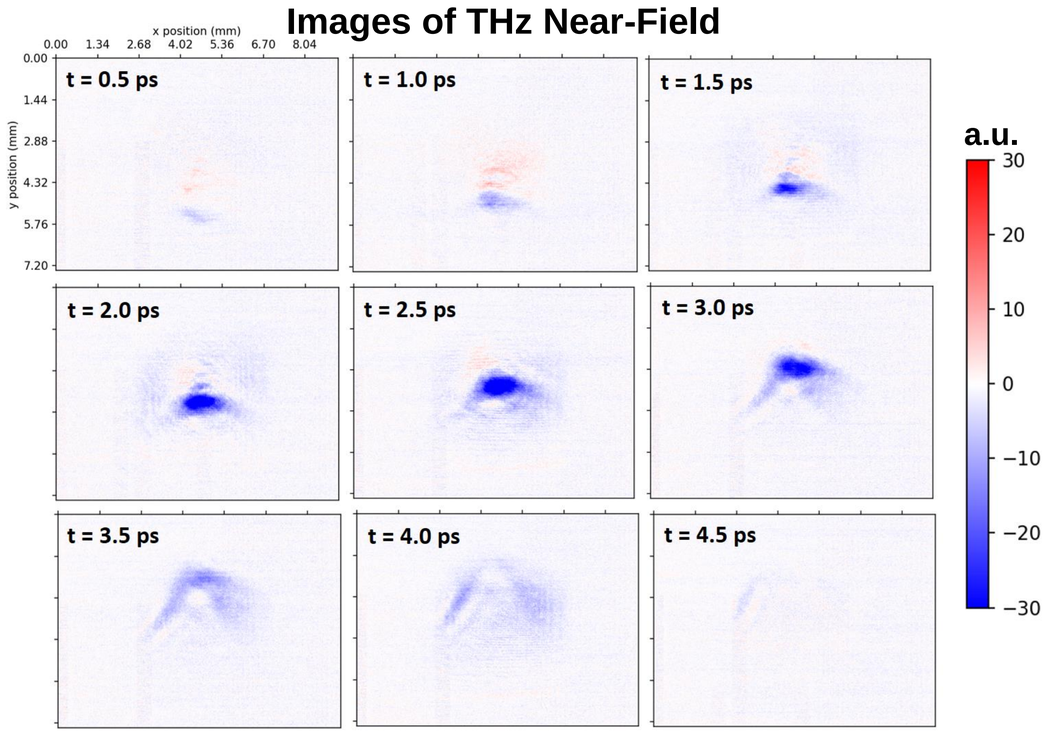
- **THz near-field detection:**
  - Electro-optic sampling in GaP
  - Series of images yield the full temporal 3D THz near-field



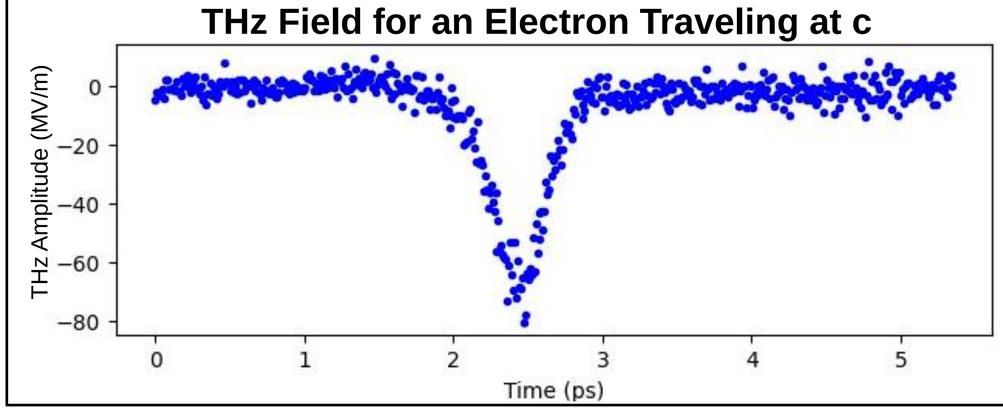


Results and Analysis

Images of THz Near-Field

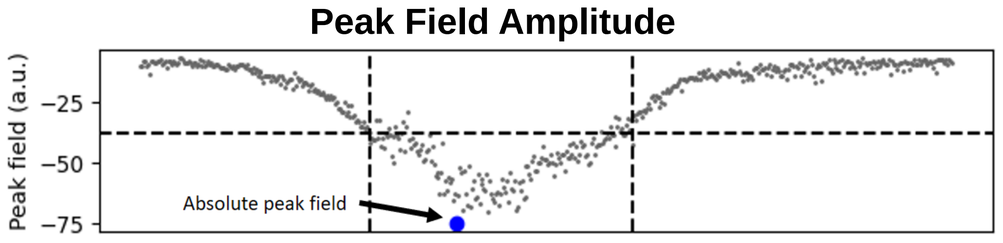


THz Field for an Electron Traveling at c



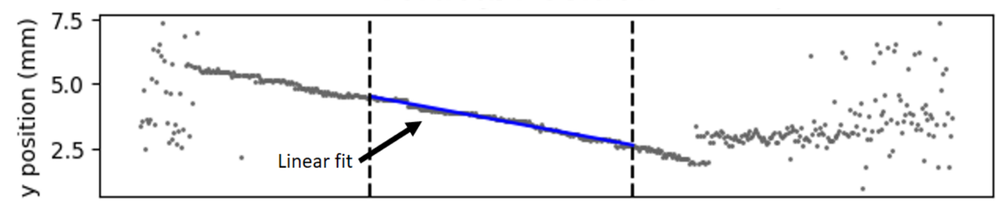
- **2D images of THz near-field:**
  - THz generation optimized for maximum THz energy
  - Images collected with THz ON and THz OFF for background subtraction
  - Scan run over over multiple ps with 10 fs step size

Peak Field Amplitude



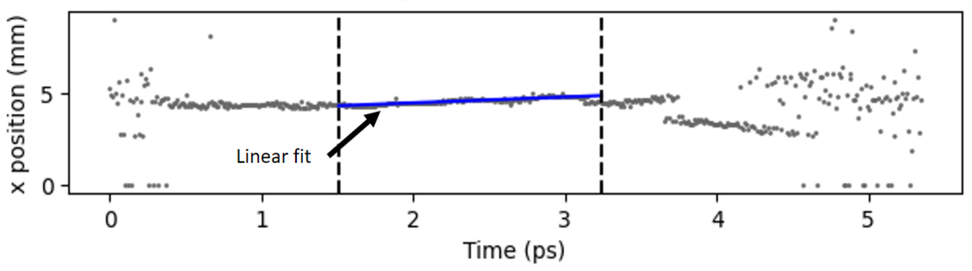
- **Calculated peak field value: 86.4 MV/m**

Vertical Position



- Vertical pulse phase front velocity: 1.08 mm/ps = 3.6c

Horizontal Position



- Horizontal pulse phase front velocity: 0.32 mm/ps = 1.1c

Conclusions

- We have measured the THz near-field generated via optical rectification in $LiNbO_3$ with excellent spatial and temporal resolution
- Measurements show a temporal delay in the emission of the pulse as a function of vertical position on the LN surface
- These measurements will inform new designs of an integrated THz generation and electron acceleration structure
- Field strengths indicate applicability for an THz near-field electron streaking experiment

Acknowledgement: This work was supported by Department of Energy contract DE-AC02-76SF00515.