Temporal and Spatial Characterization of Ultrafast Terahertz Near-Fields for Particle Acceleration

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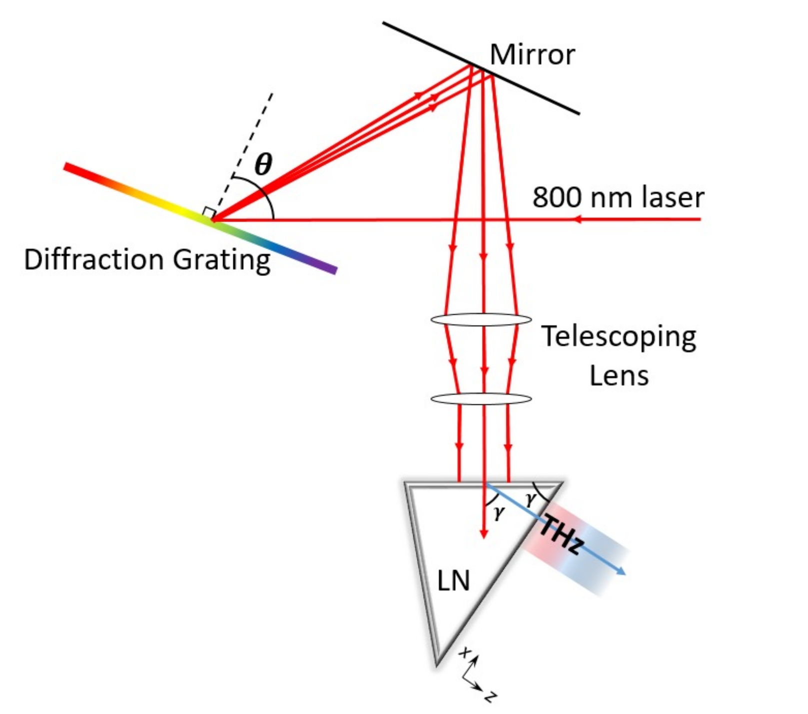
Abstract

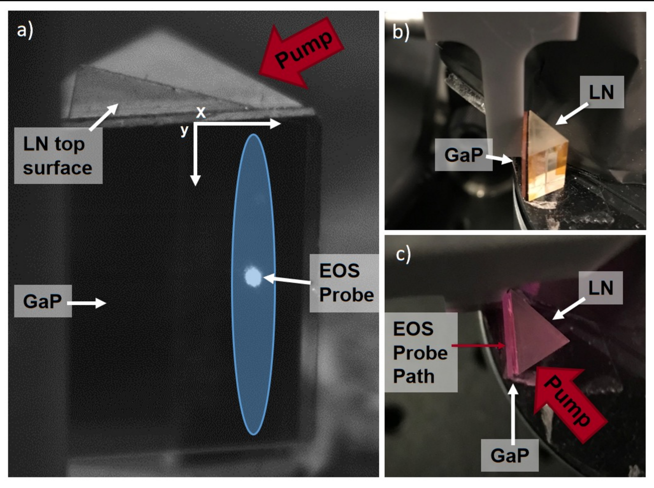
- We have measured the THz near-field in order to inform the design of improved THz-frequency accelerating structures.
- THz-frequency accelerating structures could provide the accelerating gradients needed for next generation particle accelerators with compact, GV/m-scale devices
- A better understanding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

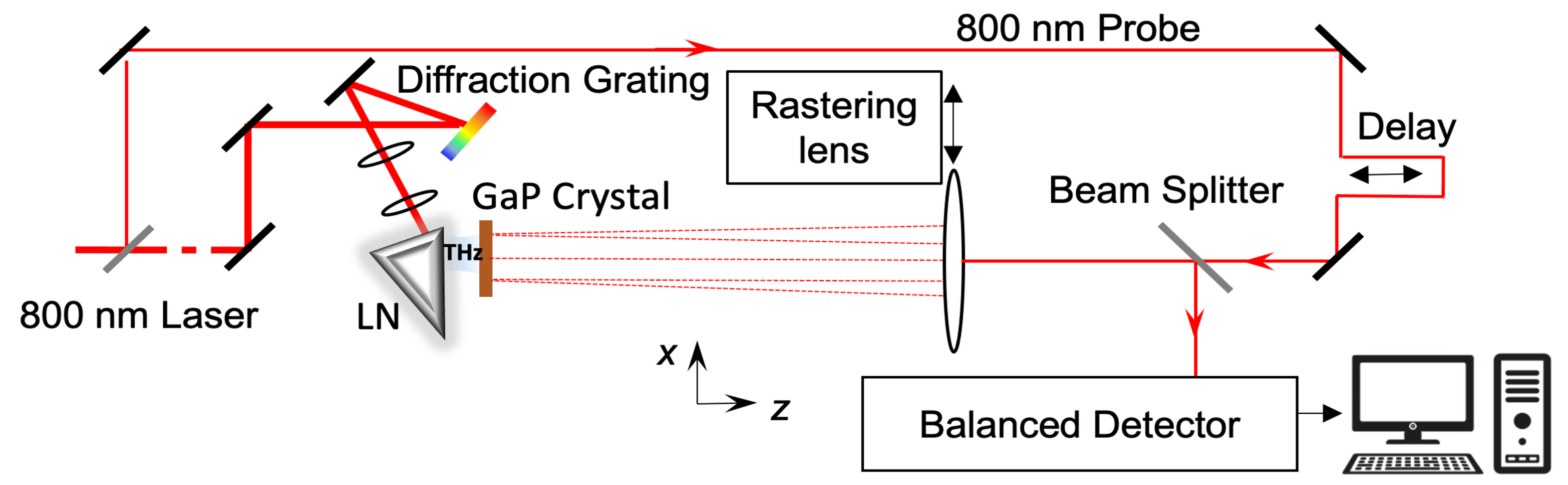
Methods

- **THz generation by optical rectification in LN:**
  - Requires tilted pulse front to achieve velocity matching



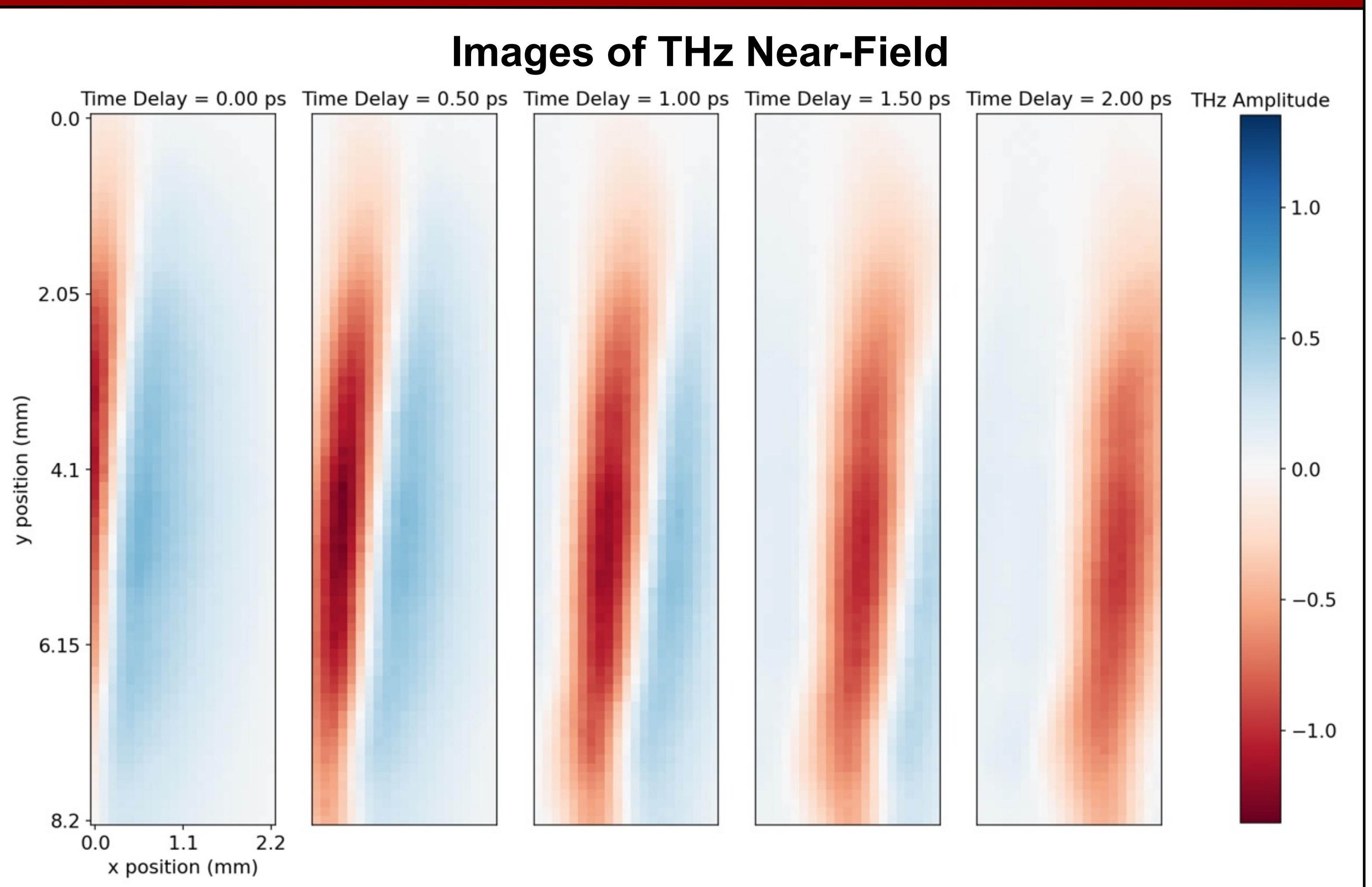
- **THz detection:**
  - Electro-optic sampling in GaP and balanced diode detection
  - Series of images yield the full temporal 3D THz near-field





THz Near-Field Results

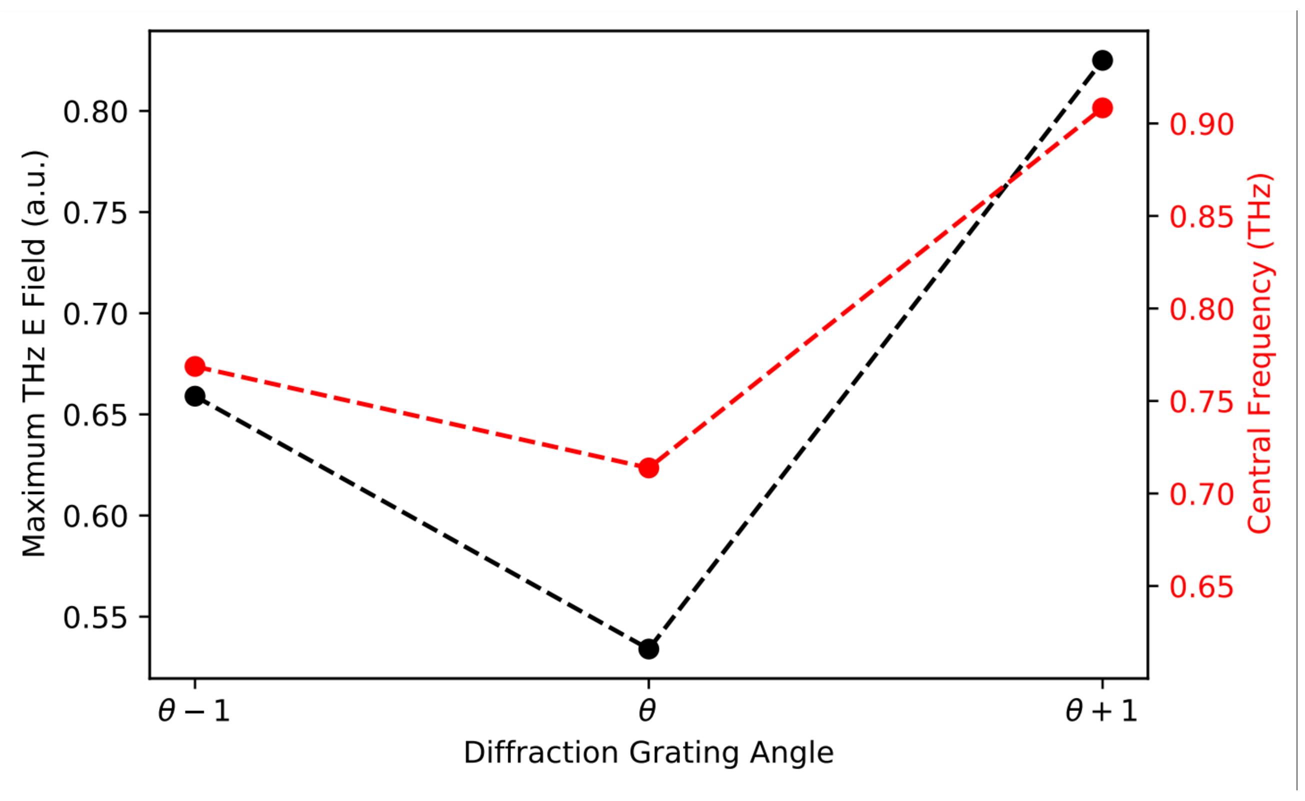
- **2D images of THz near-field**:
  - A series of 2D images of the THz near-field were reconstructed from grid scans of the GaP crystal
    - 5 representative images are shown at right
    - Our results show a temporal delay in the emission of the pulse as a function of lateral delay on the LN surface
    - Temporal delay can be seen as movement of the THz pulse peak in the *x* direction



Varying Diffraction Grating

- Series of 1D scans varying the diffraction grating angle within the tilted pulse front setup by $\pm 1°$ from the ideal angle θ
- Results were analyzed to yield the maximum THz E-field amplitude, central frequency, and change in lateral motion of the pulse.

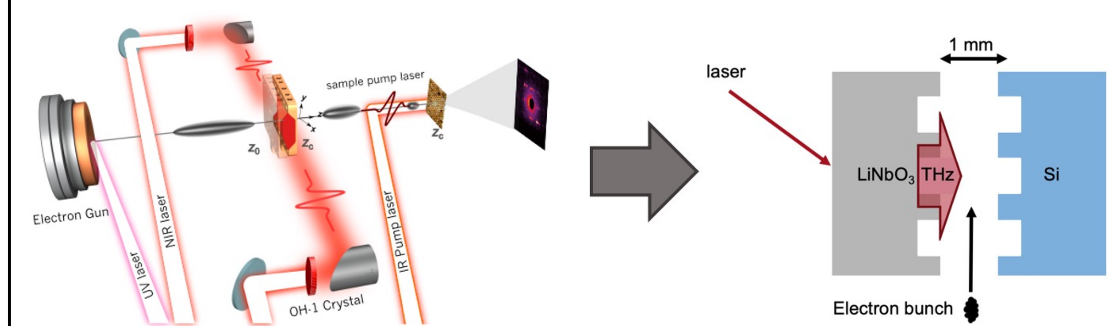
Diffraction Gating Angle	Lateral Motion (mm/ps)
θ-1°	0.73± 0.06
θ	0.85±0.04
θ+1°	0.99± 0.05



- **THz near-field results show that:**
  - Lateral delay of the pulse can be tuned by varying the diffraction grating angle
  - Could allow for synchronous motion with an electron bunch for particle acceleration
  - THz pulse amplitude and central frequency can be changed for different beam manipulation applications

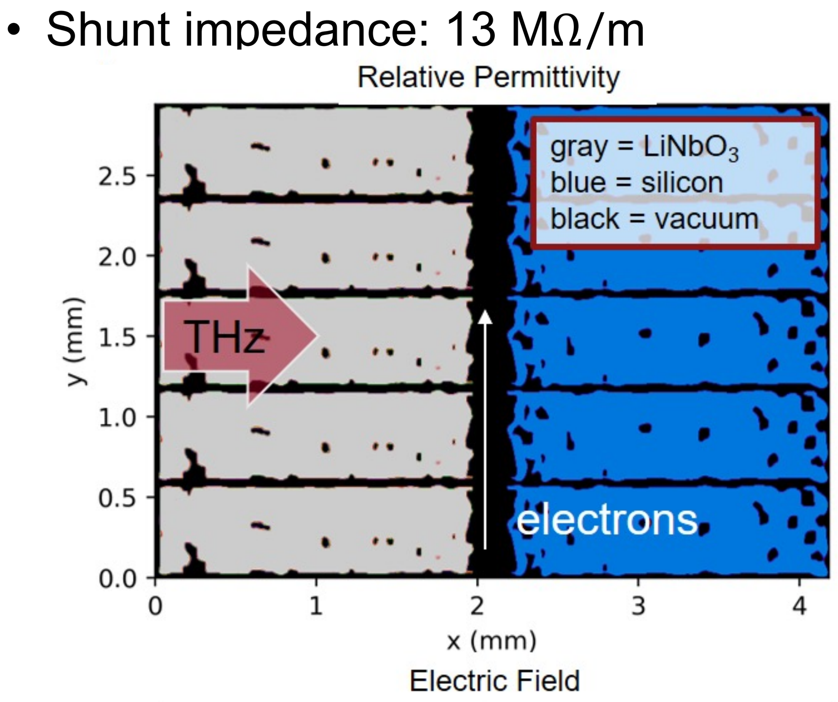
Integrated THz Generation and Electron Acceleration

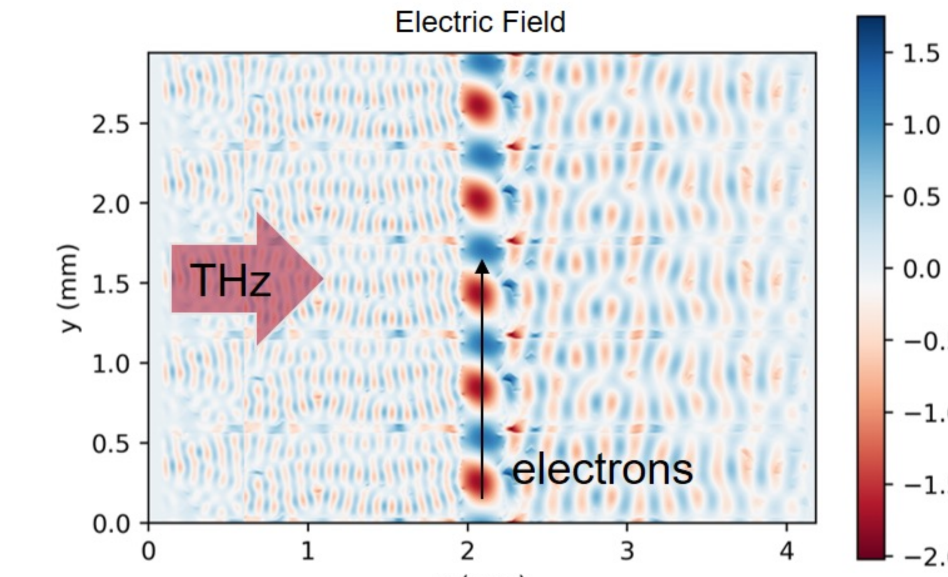
- **THz generation and acceleration within one structure:**
  - Removes losses from beam transport and coupling
  - Allows for longer THz interaction length



M. A.K. Othman, E. C. Snively, A. E. Gabriel, *et al.* arXiv:2104.05691 (2021).

- **Preliminary simulations of THz generation and electron acceleration structure:**
  - 0.5 THz CW incident from left side
  - Shunt impedance: 13 MΩ/m





A. E. Gabriel, *et al.* IPAC'21.

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 lateral position on the LN surface
- The temporal delay could be tuned by varying the diffraction grating angle
- We also show a change in maximum THz amplitude and central frequency with change in diffraction grating angle
- These measurements will inform new designs of an integrated THz generation and electron acceleration structures

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