Coherent-transition-radiation-based emittance diagnostics

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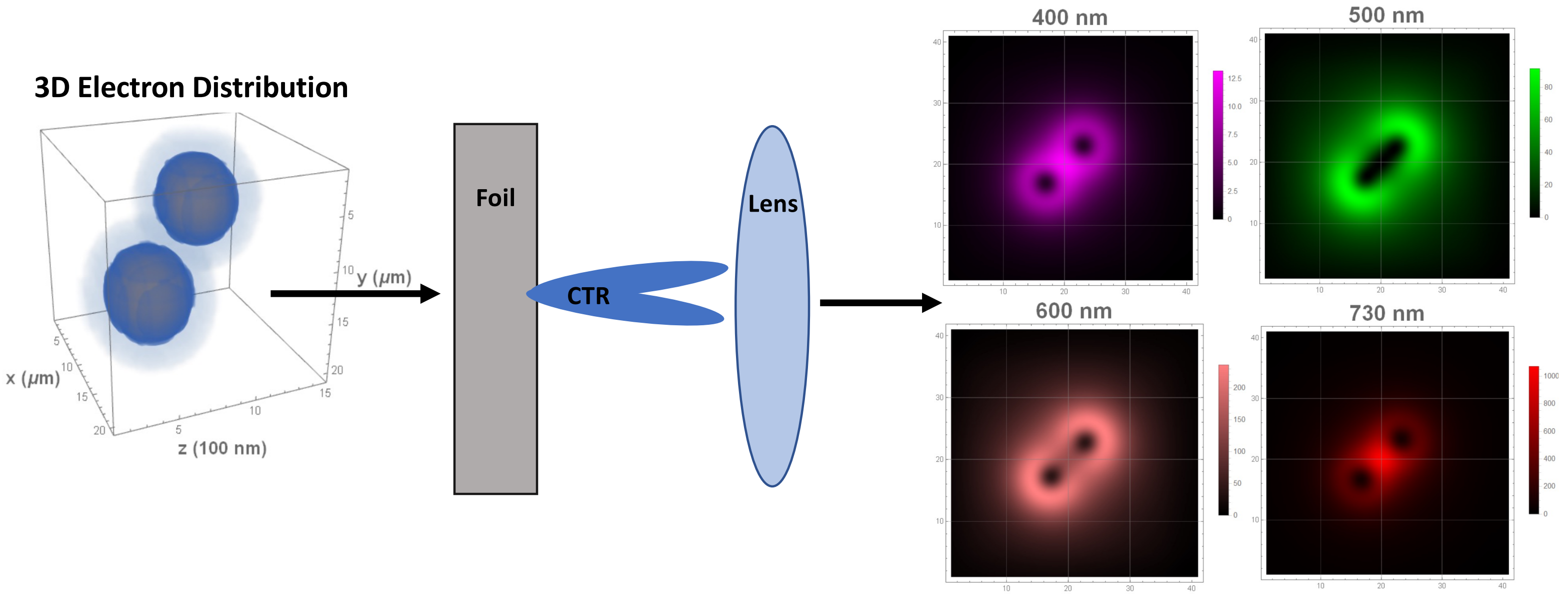
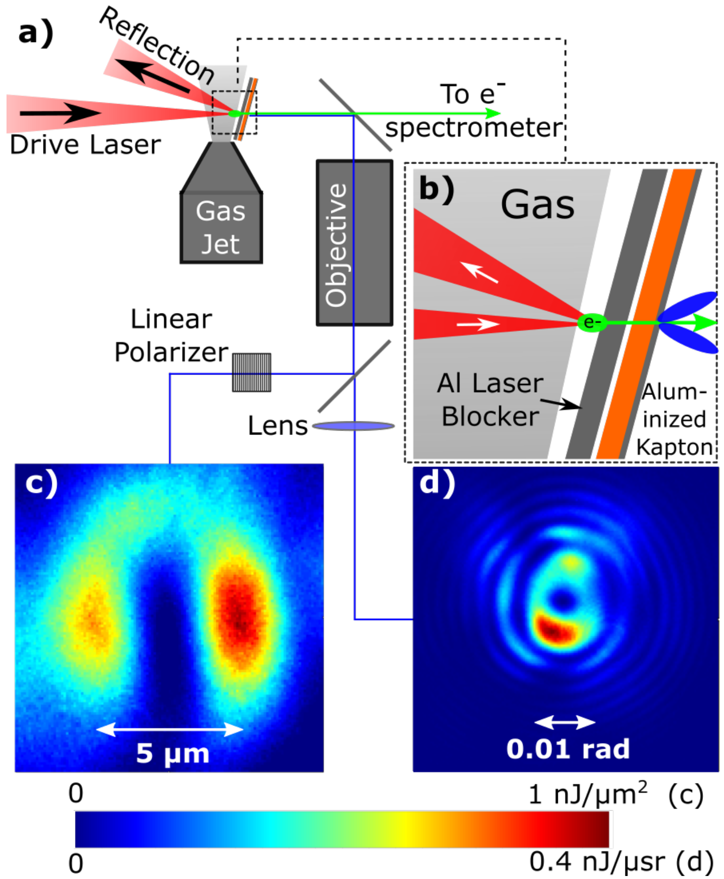
Transition radiation results from charged particles crossing a boundary between two different media



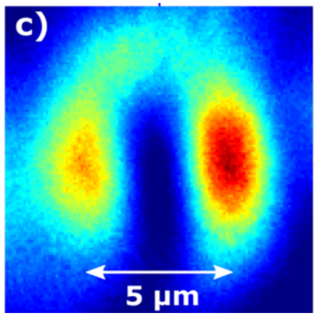
- **Coherent transition radiation (CTR) from charge distributions manifests differently at different wavelengths**
- **Near field (NF) CTR is a result of the superposition of the transverse fields from every electron with temporal phase delay**

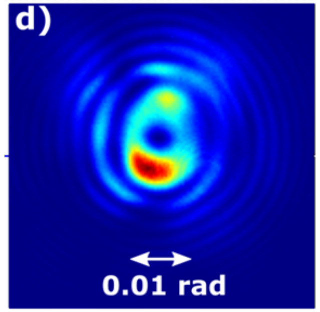
We measure the far field and near field CTR simultaneously on shot

- Blocking foil reflects ~2.5 J Draco pulse
- Aluminized Kapton foil is first CTR source
- Si wafer is second CTR source
- Linearly polarized near field CTR imaged with microscope objective
  - Only sees CTR from first source
  - 600 nm image
- Focus of objective imaged using second lens to create far field (FF) image on camera
  - Sees interference from both sources
- Microbunching fraction $f_b \approx 0.013$
- A. Lumpkin, M. LaBerge et al., "Coherent Optical Signatures of Electron Microbunching in Laser-Driven Plasma Accelerators," PRL 2020

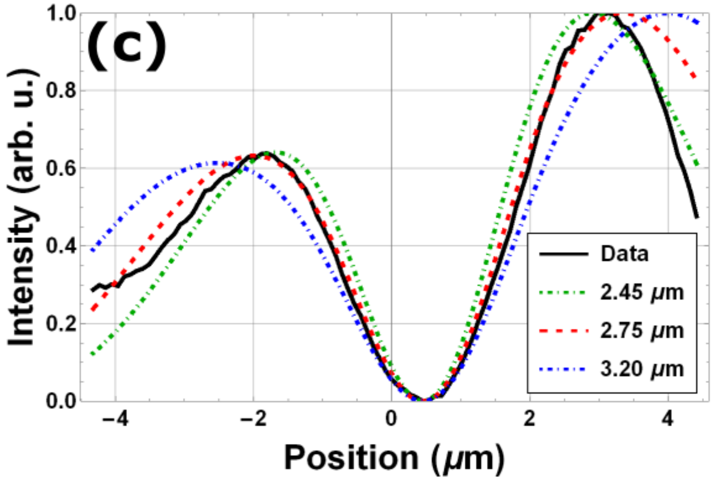


Using both the near field and far field CTR, we can determine an upper limit on the microbunched emittance

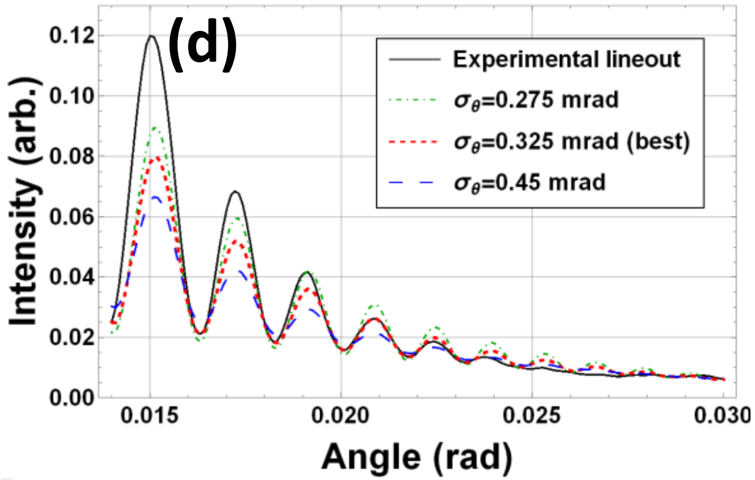




COTR from various microbunched sizes

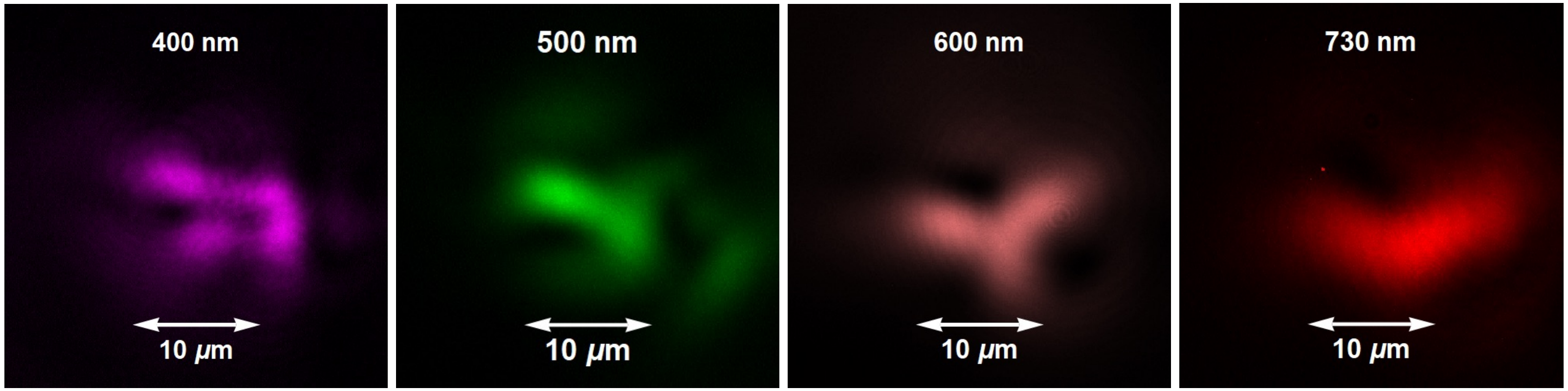


COTR interferometry from various microbunched divergences

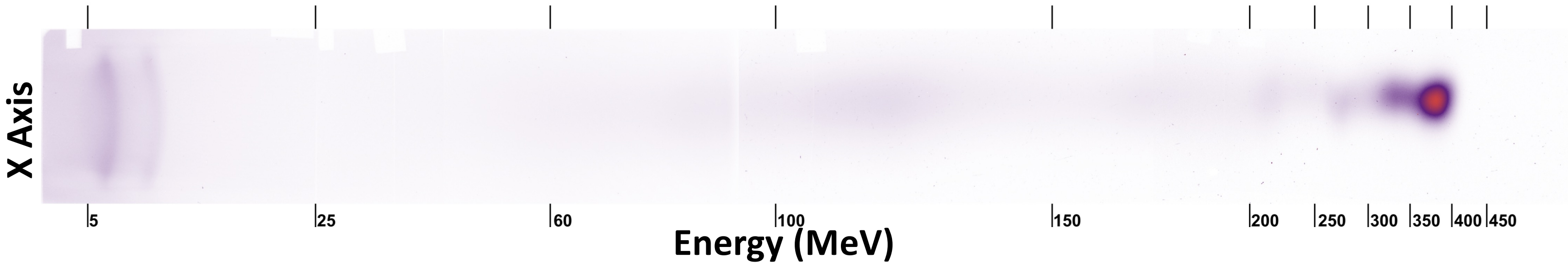


- **Microbunched size measured to be $\sigma_x = 2.75^{+0.45}_{-0.30}$ μm**
- **CTR interferometry outer fringe visibility is most sensitive to microbunched divergence**
- **Microbunched divergence measured to be $0.33^{+0.12}_{-0.05}$ mrad**
- **Microbunched normalized emittance upper limit: $\varepsilon_n = 0.36^{+0.19}_{-0.09}$ μm**

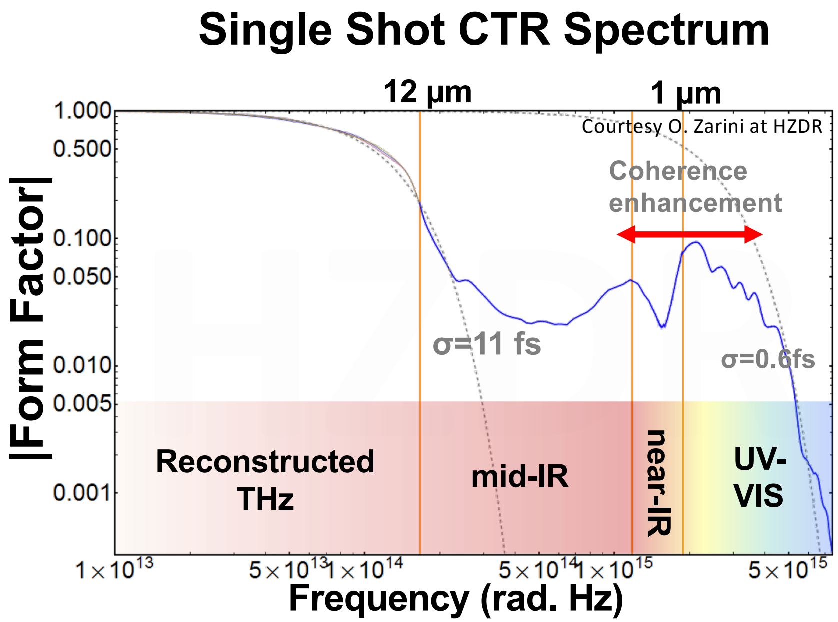
Our CTR imaging diagnostic reveals transversely-longitudinally correlated structures in our electron beams

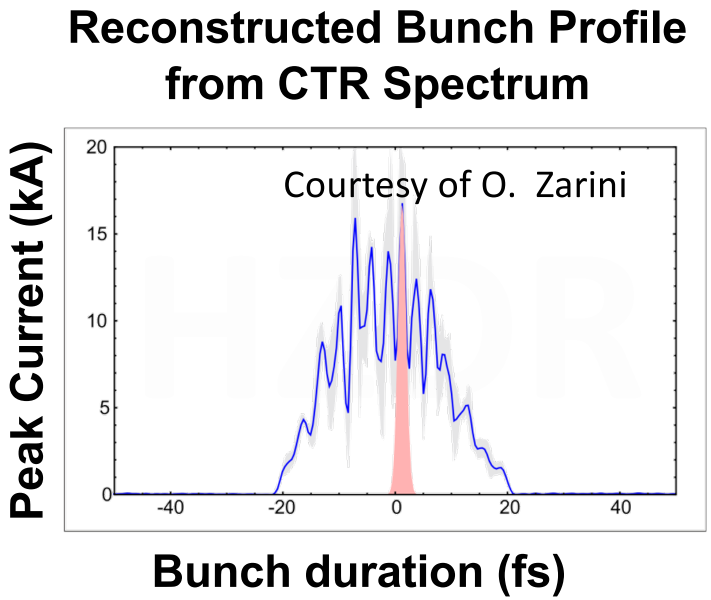


- No clear annular pattern
- Significant variation in structure across wavelengths
- There is no indication of this structure on the spectrometer
- Must have coupled transverse and longitudinal substructure



We have performed longitudinal bunch reconstructions using CTR

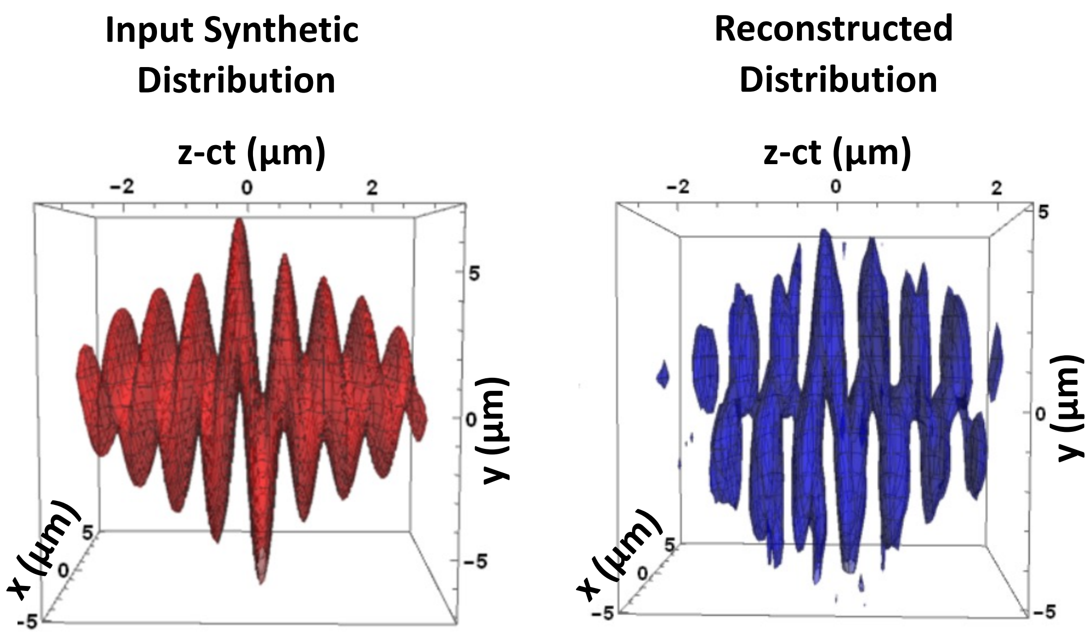




- **We employ a 5.9 octave CTR spectrometer (in preparation)**
- **The visible region of the spectrum reveals significant substructure**
- **We use a phase reconstruction to determine longitudinal profile**
  - O. Zarini et al., "Advanced Methods for Temporal Reconstruction of Modulated Electron Bunches," 2018 IEEE

We are benchmarking our spatial reconstruction algorithm using synthetic data

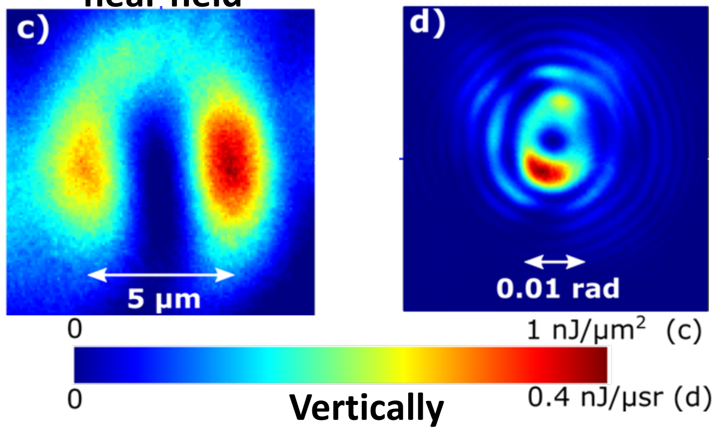
- Reconstruction based on
  - CTR spectra
  - Electron spectra
    - including total charge
  - CTR images
- Findings from synthetic reconstructions
  - CTR images must be bright enough to constrain problem
  - Reconstructions with experimental data currently in progress



CTR near and far field imaging can be used as high resolution monitors of next generation beams

Horizontally polarized near field

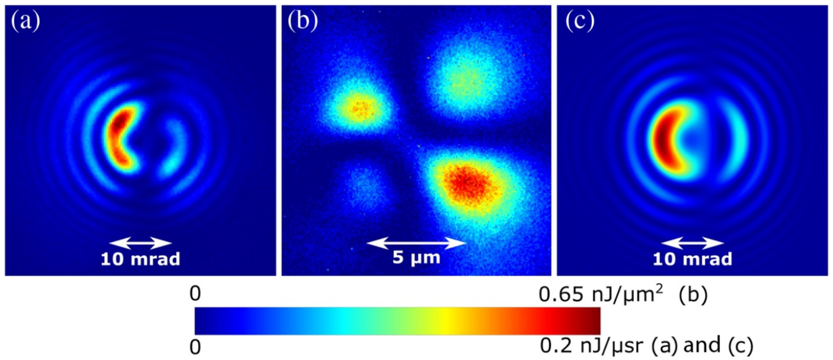
Far field



Far field

Vertically polarized near field

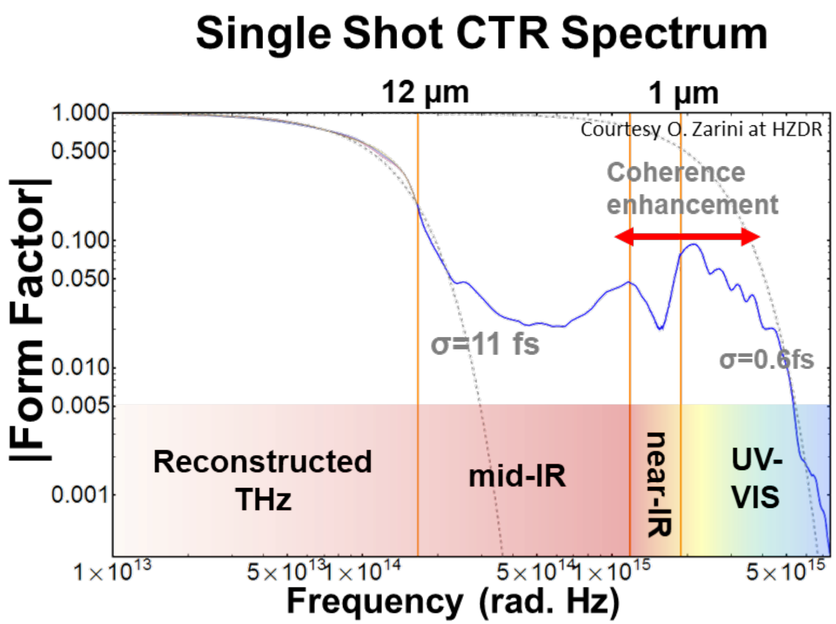
Synthetic Far field



- Transverse shape and divergence monitors for 10+ GeV beams
  - Transverse field size of $\gamma\lambda$ approaches size of foil
  - NF pattern and FF fringes not sensitive to bunch energy
  - Important for multistage acceleration and storage ring injection

CTR spectra can guide us towards high energy, peak brightness beams

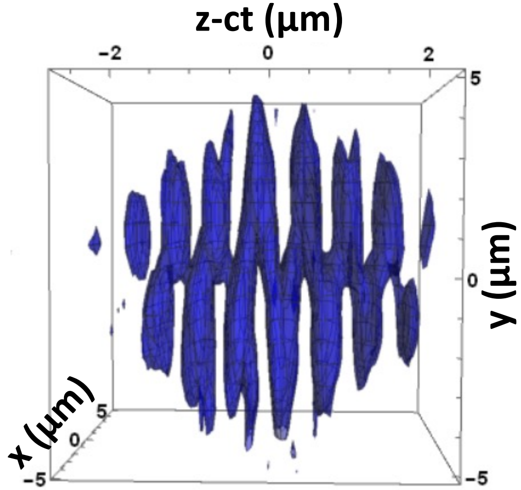
- **Longitudinal distribution measurements for 10+ GeV beams**
  - **Transverse field size of $\gamma\lambda$ approaches size of foil**
    - **2 cm size for 10 Gev, $\lambda = 1\ \mu m$**
    - **10% cutoff for 0.1 TeV electron beam on a 2 cm CTR foil is $\lambda \approx 4\ \mu m$**
      - M. Castellano el al. Nucl. Instrum. Methods Phys. Res. A (1999)
  - **Compact compared to transverse deflection structures**



As our beams improve, CTR techniques will be more informative and easier to implement

- **As bunch durations approach visible wavelengths, CTR diagnostics become simpler**
  - **CTR spectrometers do not need to reach so far into the IR**
  - **NF, FF imaging capture larger portion of the beam**
  - **Possible to use NF, FF and spectra for a 5D reconstruction**

Reconstructed Distribution



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