Generation of Terahertz Radiation by Modulating the Electron Beam at the Cathode

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Overview and Motivation

Why will terahertz light be important?

• Biological Applications : DNA and other protein resonances, tissue imaging, upgraded “T-Jump” pump-probe experiments

• Chemical detection

• Short range high data rate wireless communication

Source Development is important to make these applications a reality.

Overview and Motivation

Other Terahertz Sources :

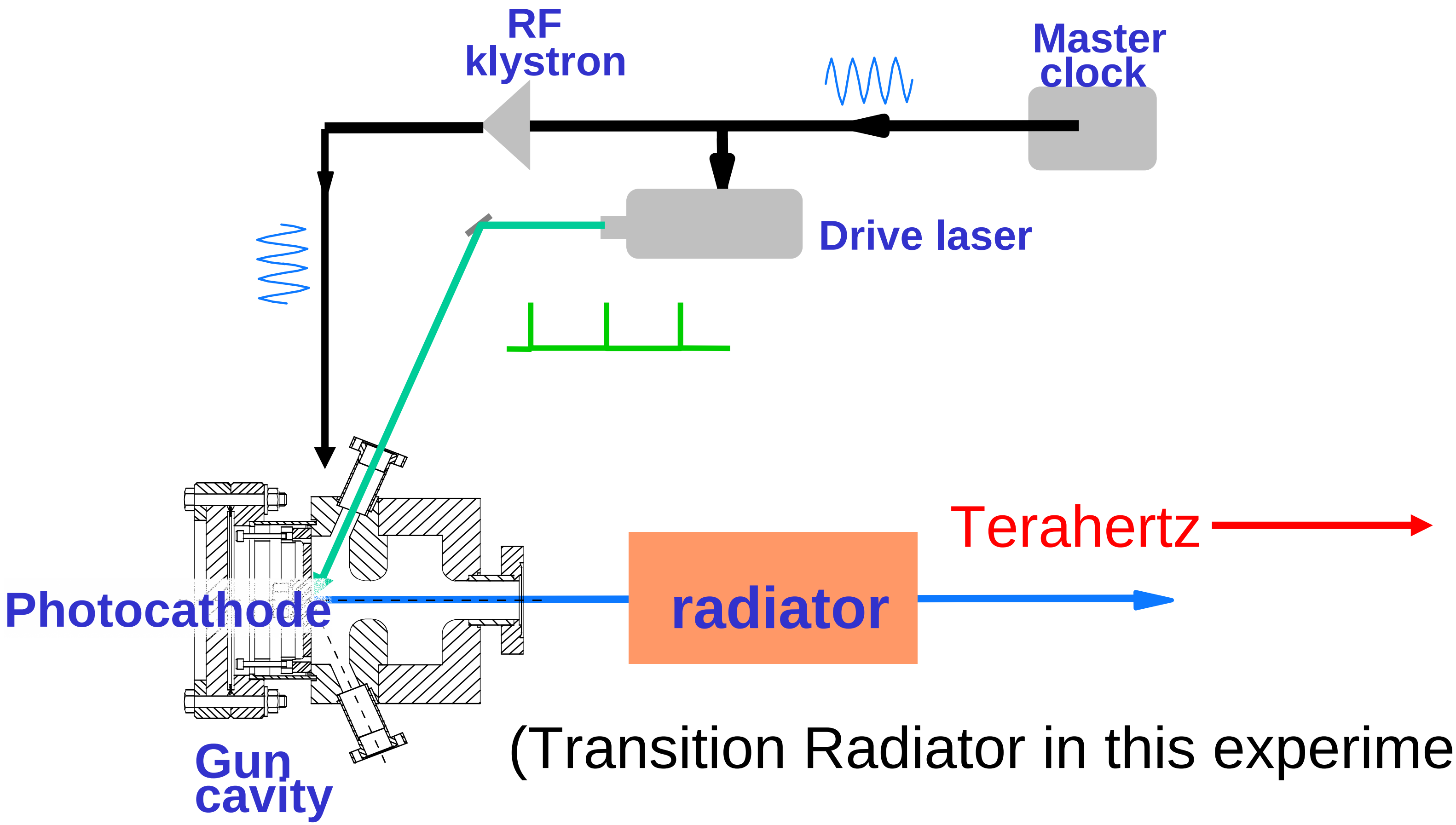
- Laser and Solid State Sources
- Short single pulse electron beam based sources
- Terahertz FELs

Questions :

- Can the electron beam be modulated at the cathode?
- Can this beam be accelerated? What happens to it?
- Can Terahertz light be seen from this beam?

Overview and Motivation

The experiment: Pre-modulate an electron beam at the photocathode of an electron accelerator using the drive laser as a switch and use this beam to generate coherent radiation.



(Transition Radiator in this experiment)

Overview and Motivation

Why should an electron beam be bunched to generate coherent radiation?

The energy emitted by a group of particles is given by

$$\frac{dW}{d\omega d\Omega} = \frac{dW_1}{d\omega d\Omega}\left[N_e + N_e\left(N_e - 1\right)F\left(\omega,\theta\right)\right]$$

N_e = number of particles
ω = angular frequency of emitted radiation

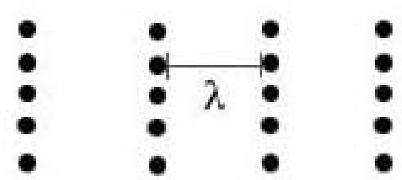
$$\frac{d^2W_1}{d\omega d\Omega} =$$ Single Particle TR from finite metal disk

Overview and Motivation

$$F(\omega,\theta)=e^{-\frac{1}{2}\sigma_r^2\sin^2\theta\left(\frac{\omega}{c}\right)^2}\left|\int dzS_z(z)e^{i\frac{\omega}{c}z\cos\theta}\right|^2$$

- S_z is the longitudinal electron beam density profile.
- The transverse profile is assumed to be gaussian.
- θ is the angle of deviation from the z-axis (direction of beam propagation)

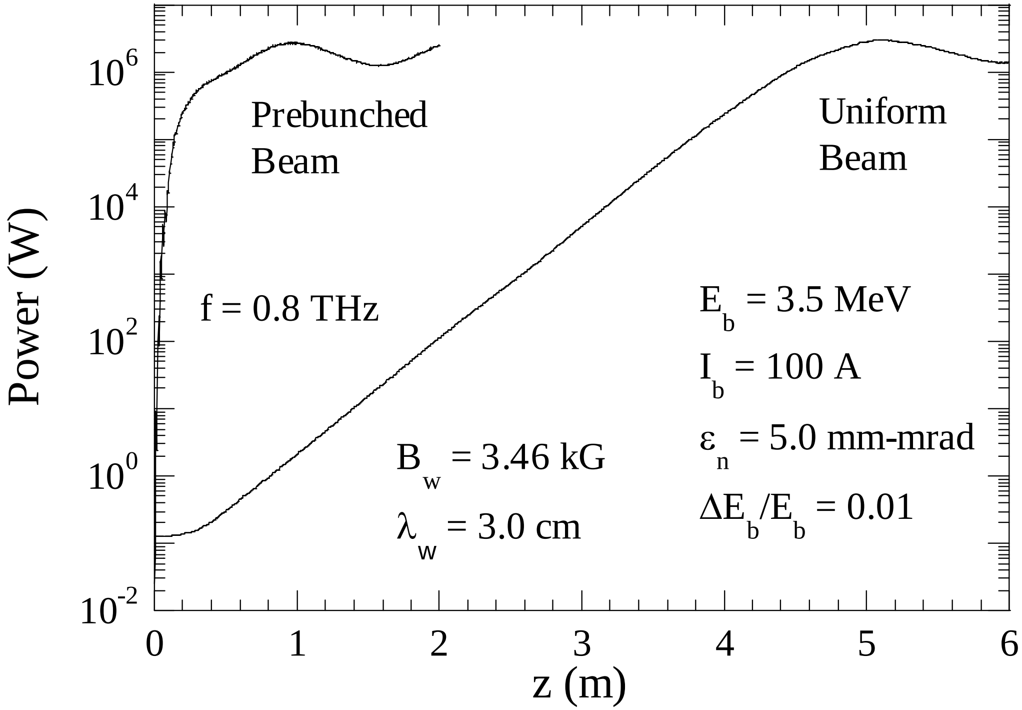
If bunch size is << λ, f(ω)→ 1, $W \propto N_e^2$
If bunch size is >> λ, f(ω)→ 0, $W \propto N_e$



Since N_e is very large in a typical electron beam (10^8-10^{10} electrons) even slight longitudinal structure (bunching) of the electron beam can lead to significant coherent radiation emission because $W \propto N_e^2$

Overview and Motivation : What might be possible

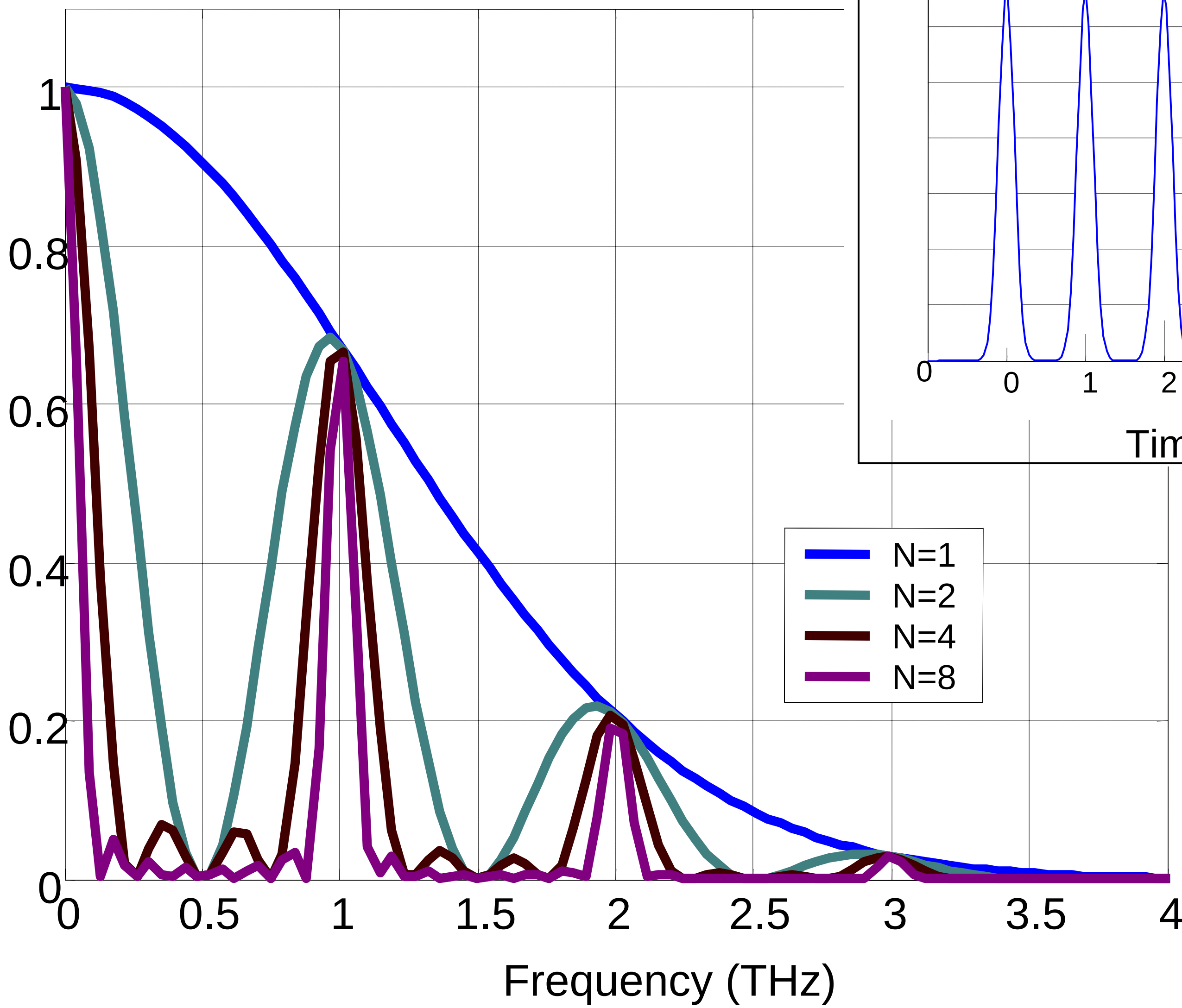
Any radiator can be used,but in a Free Electron Laser, the device reaches saturation in a wiggler much more quickly when the beam is prebunched.

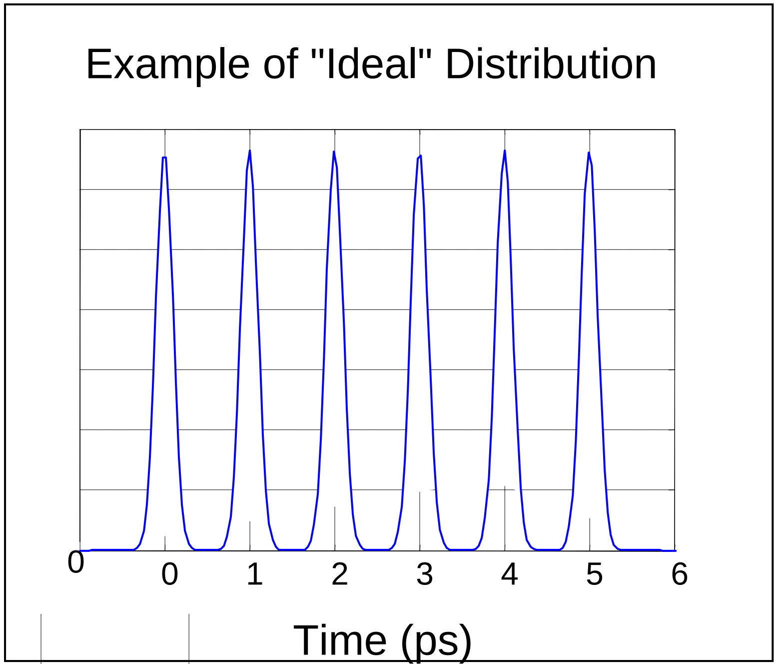


WIGGLIN simulation courtesy of Henry Freund (SAIC).

Overview and Motivation

Longitudinal Form Factor

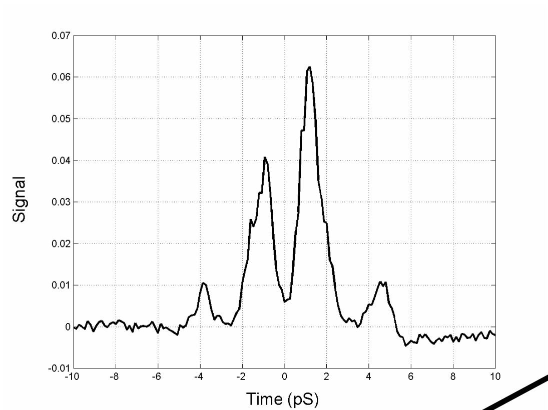


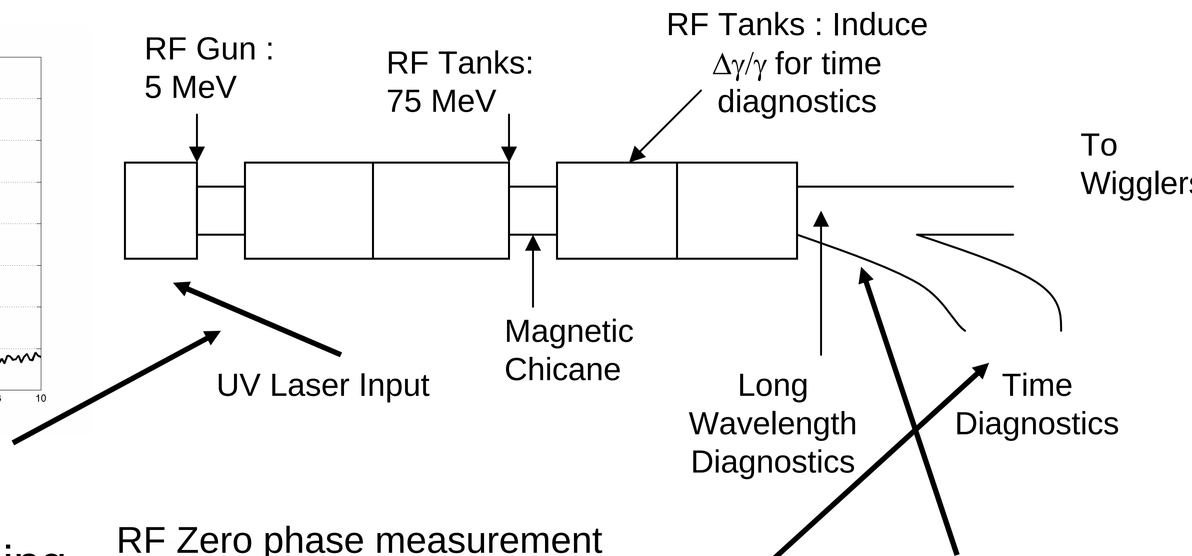


Approx 4*10^10 enhancement vs. unmodulated long pulse w/1nC @ 1 THz

Experimental Apparatus and Techniques

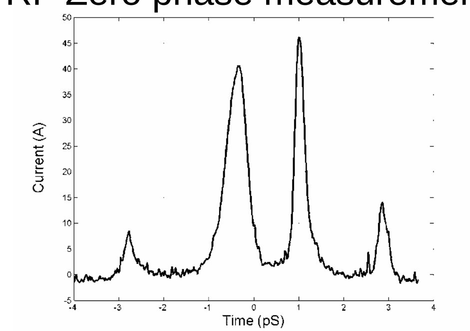
Cross-Correlation Trace

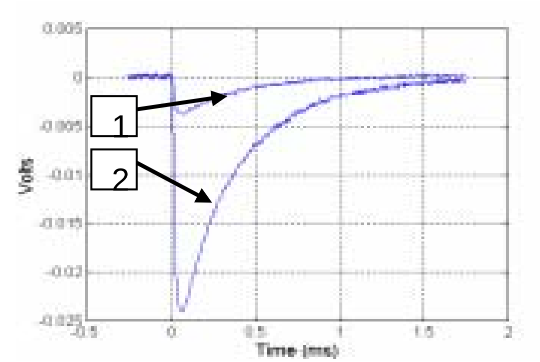




1) Laser Pulse Shaping

RF Zero phase measurement





2) Electron Beam Dynamics

3) Radiation Measurements

Experimental Apparatus and Techniques

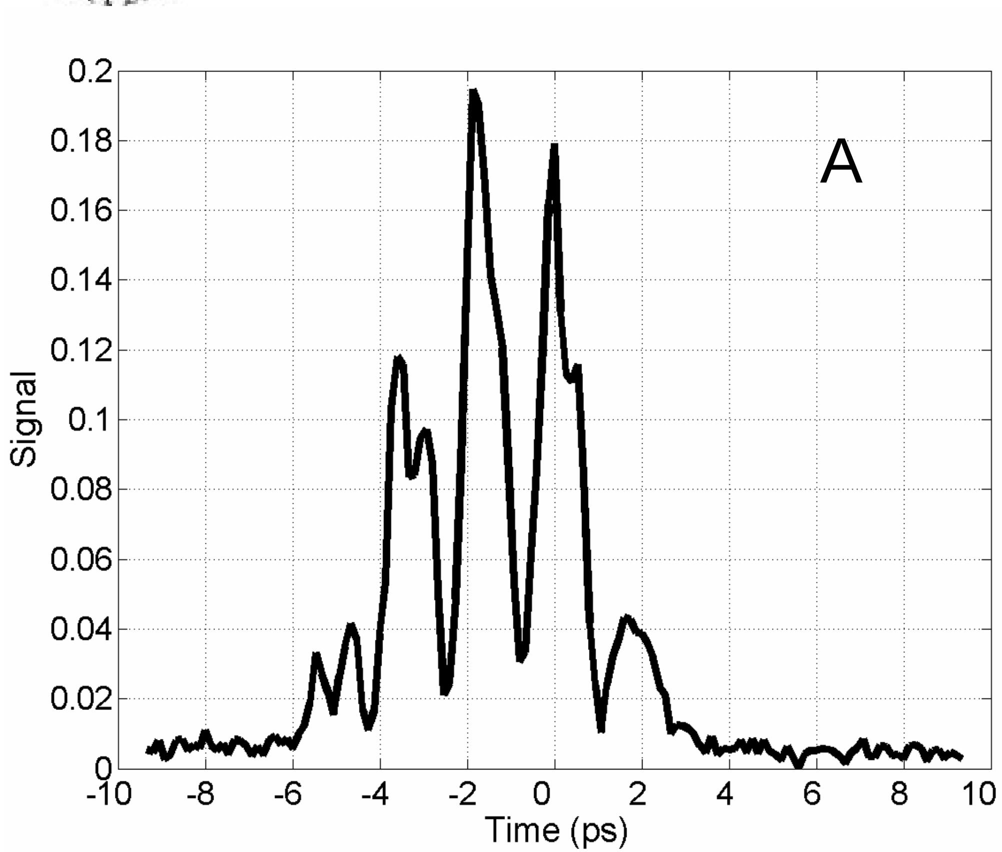
Accelerator Control

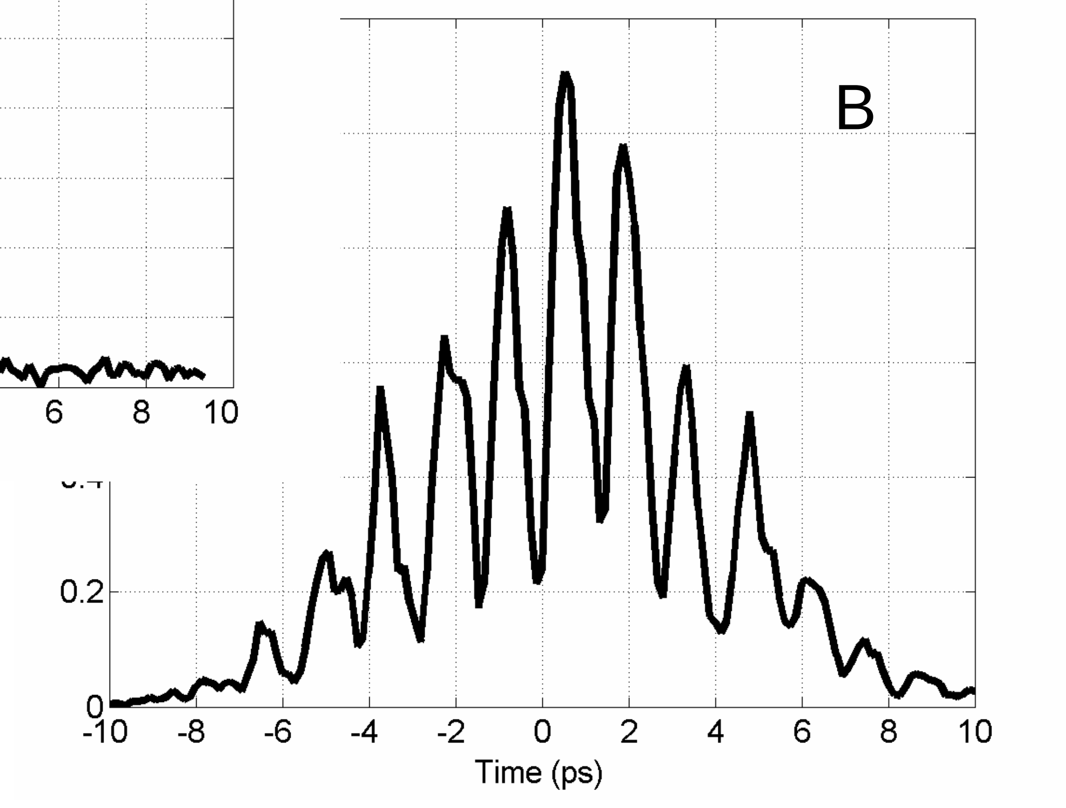
Beamline

The Source Development Laboratory at Brookhaven National Laboratory is an ideal testbed for this experiment.

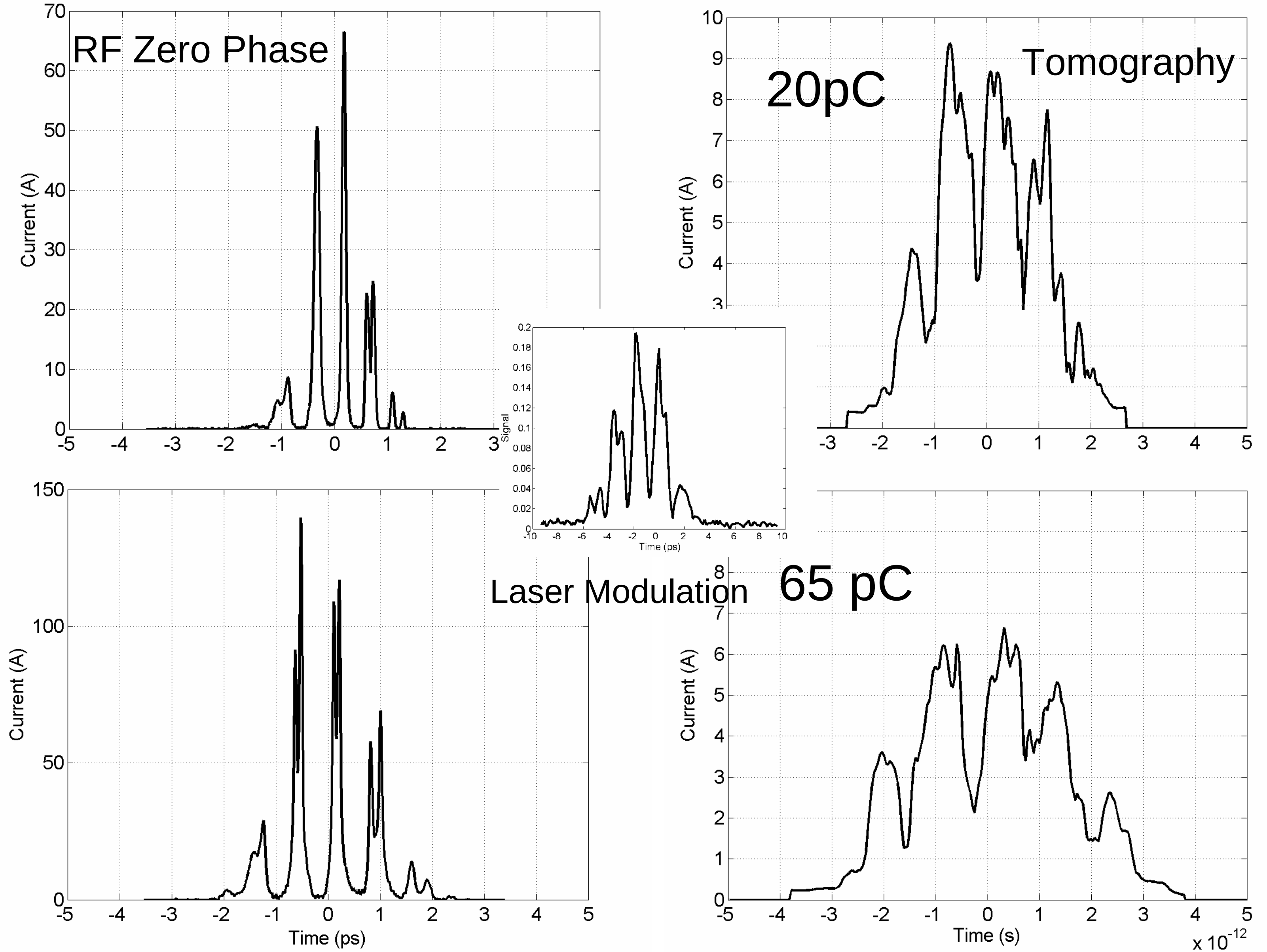
Laser Modulation

UV Drive Laser : 266 nm
Sample Cross-Correlation Measurements

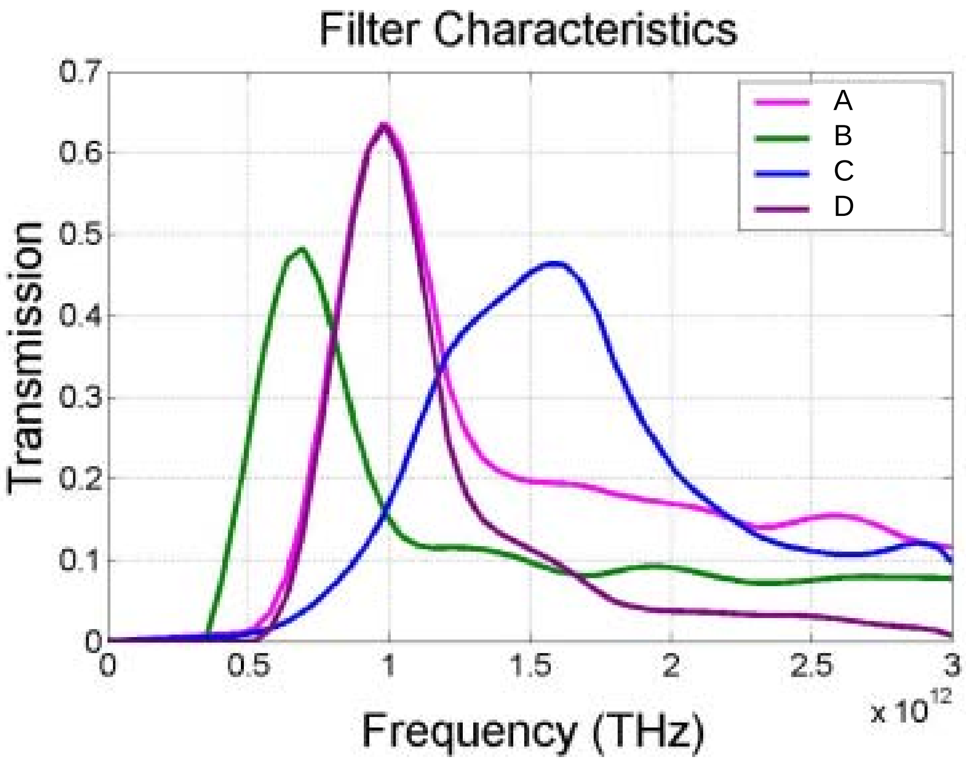


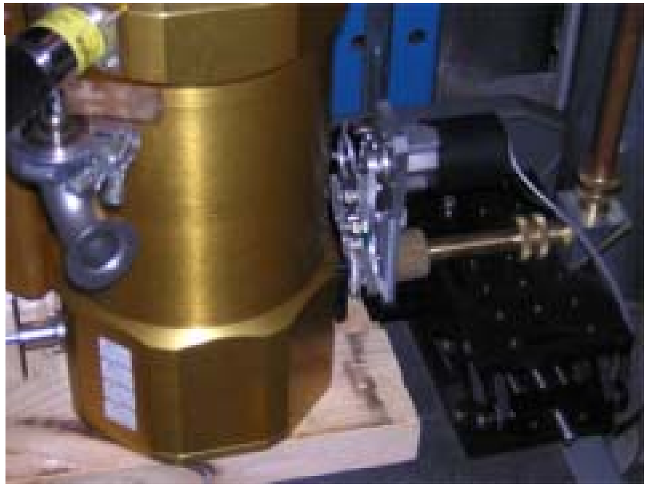


Electron Beam Modulation : RF Zero Phase vs. Tomographic Reconstruction (From Laser Profile A)



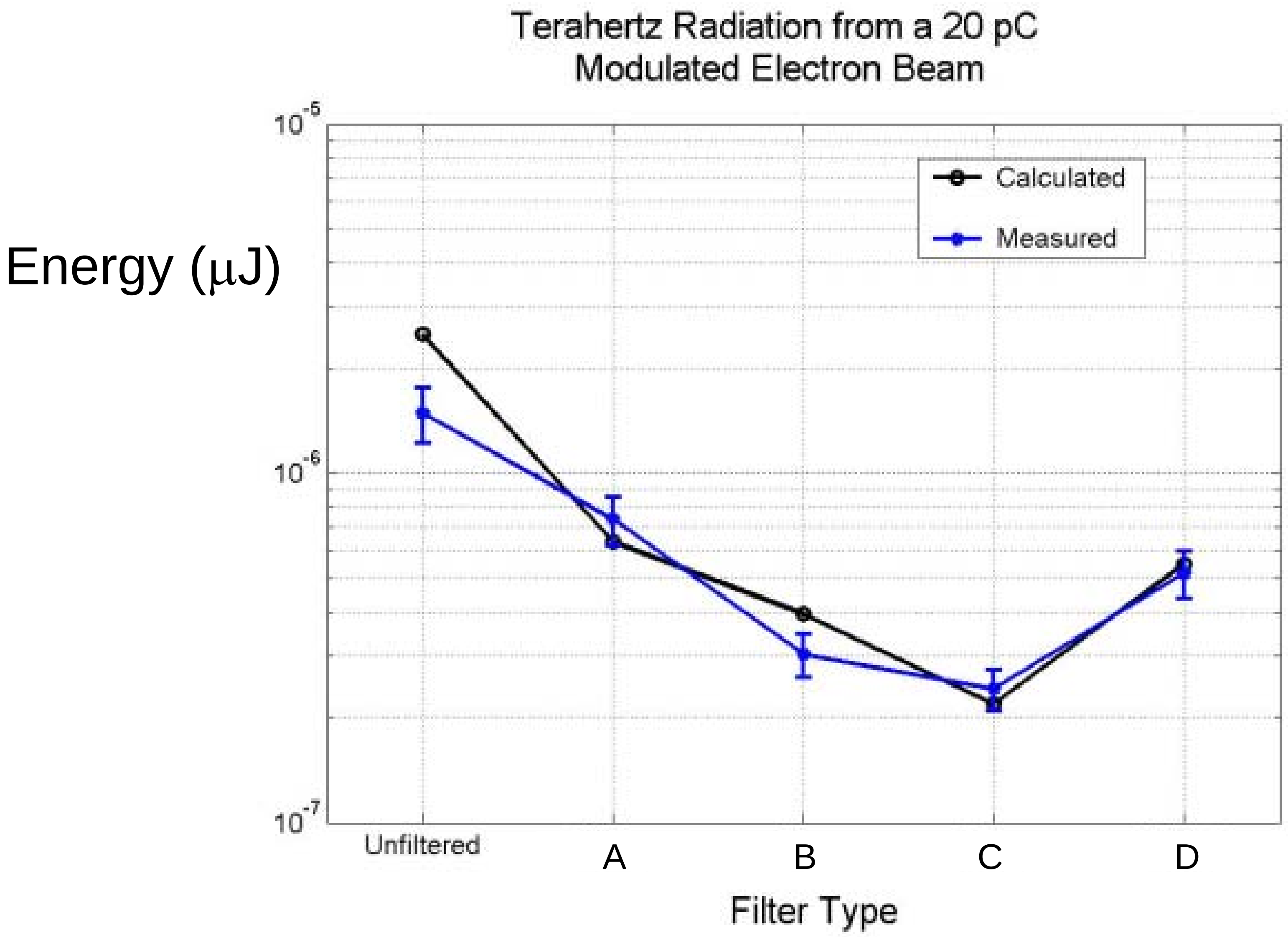
Terahertz Measurements



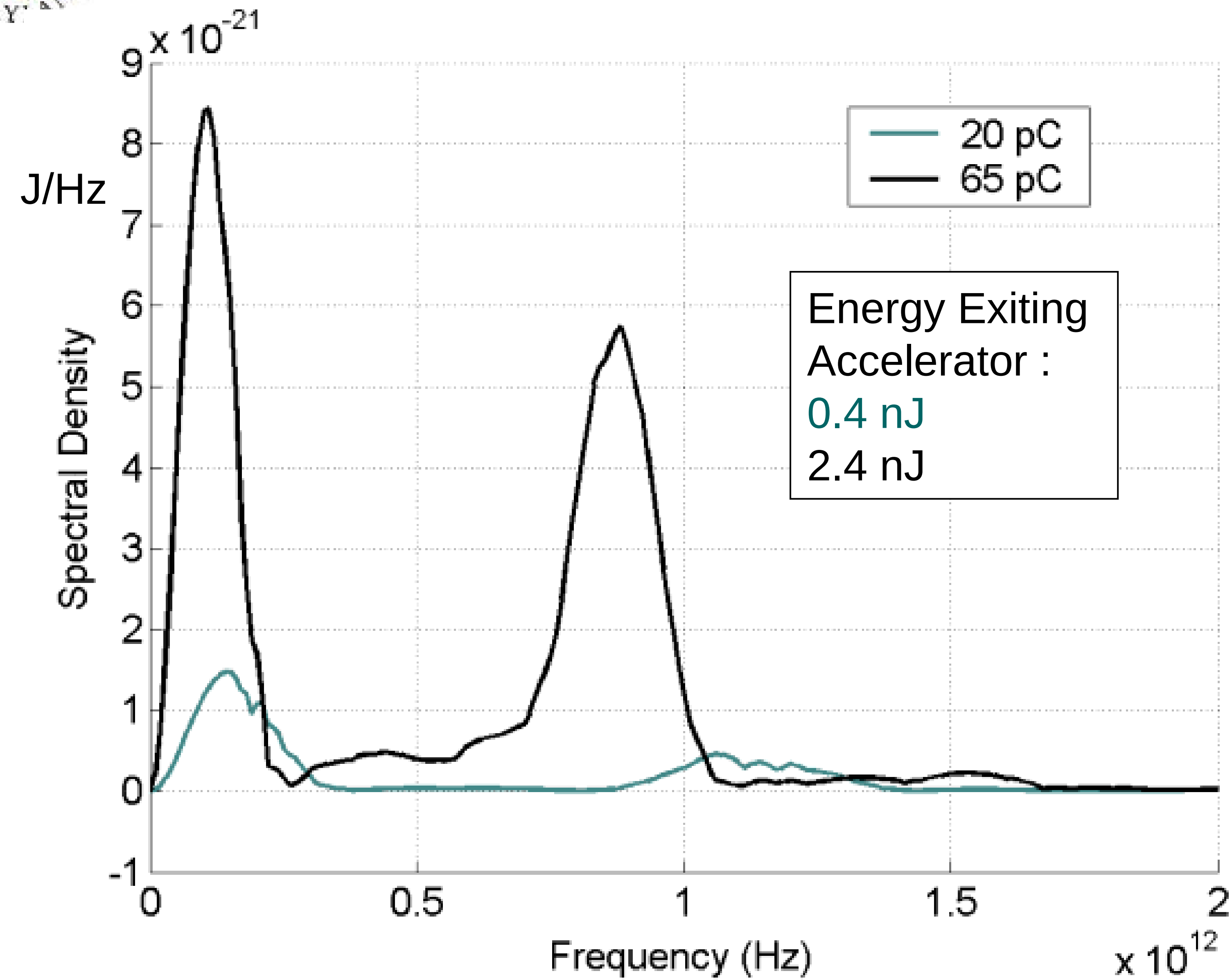


Bolometric Detector with Filter Wheel

Terahertz Measurements



Calculated Terahertz Spectrum



Conclusions

- Modulation information from drive laser is carried to electron beam
- “Ideal case” yields powerful narrowband terahertz source
- Low energy measured experimentally, but there may be ways to improve performance
- Spectral density for terahertz radiation inferred from comparison to filter measurements
- Even if density modulation washes out, there is still evidence of modulation in Energy-Time phase space.

Conclusions

- As modulated beam travels down accelerator it could radiate and affect beam structure – we are also conducting experiments on the University of Maryland Electron Ring (UMER) with a pre-modulated bunch train of electrons – this device will not be able to radiate, and so are looking at purely space-charge induced effects.

Acknowledgements

UMD Team

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