Single-shot interferometer: Development and Testing

Gerard Andonian, UCLA
ATF Users' Meeting
October 6-7, 2010
Brookhaven National Laboratory

Collaboration

- UCLA PBPL
  - G. Andonian, E. Hemsing, P. Musumeci, J. Moody, J.B. Rosenzweig
- RadiaBeam Technologies
  - A. Murokh, A. Ovodenko, M. Ruelas
- Spectrum Detectors (now Gentec-EO)
  - D. Dooley, M. Stout, S. Levingston
- Univ. of Georgia
  - U. Happek
- BNL ATF
  - M. Babzien, K. Kusche, R. Malone, V. Yakimenko

Outline

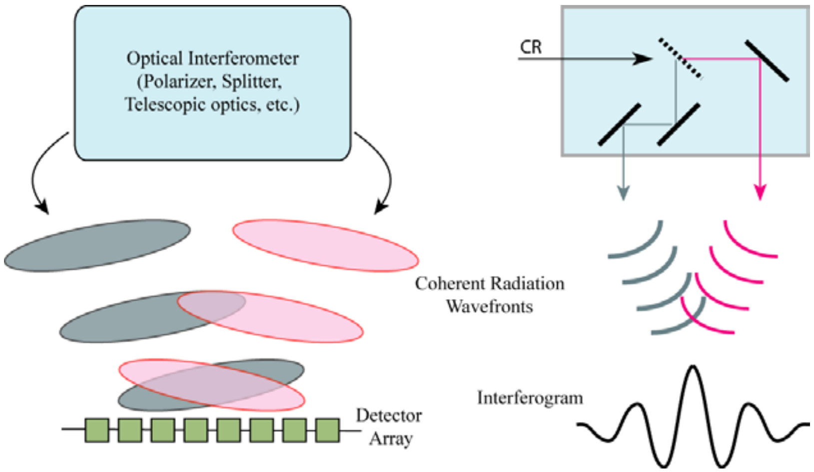
- Motivation
- Concept
  - Technical Specs
  - Detector
- Preliminary benchtop Results
- Possible sources at ATF for RTI
  - Benchmarking
- Outlook

Real-Time Interferometer

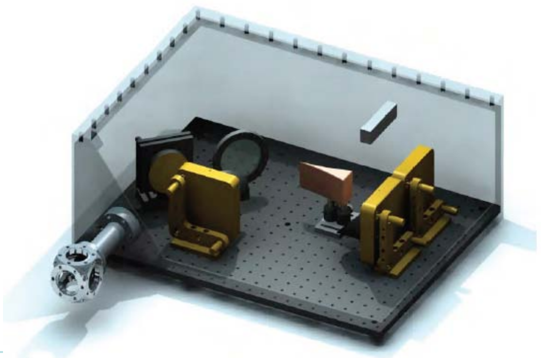
- Light sources and advanced accelerators short beams
  - Velocity bunching, chicane compressors
  - Diagnosis of compressed beams (sub-mm) on a real-time basis
- Study radiative effects (CER, CSR, CTR) from short beams
  - Bunch length correlated to emitted radiation frequency spectrum
  - Advanced reconstruction tools
- Single-shot capability
  - Characterize jitter (shot-to-shot)
- Cross calibration with existing Michelson-type interferometer
  - Wealth of data for averaging
  - Studying phase drifts
- Reconstruction algorithm refinement
- Application: Non-destructive bunch length monitor
  - CER or CDR
  - Shot-shot longitudinal beam information
  - Improve overall beam performance
  - Feedback loop

Concept

- Analogous to Michelson interferometer except time-delay transformed into spatial delay
  - Crossing angle gives range of phase delays for two linearly focused beams
  - Multi-channel detector measures the interference between two beams
  - Autocorrelation in a single-shot
- Three components
  - Interferometer
  - Detector Array
  - Reconstruction Algorithm
- Hurdles
  - THz Optics
  - Alignment
  - THz transmission
  - Detector sensitivity
  - Retrieval algorithm is radiation-dependent
    - Need assumptions or prior knowledge (extra information)

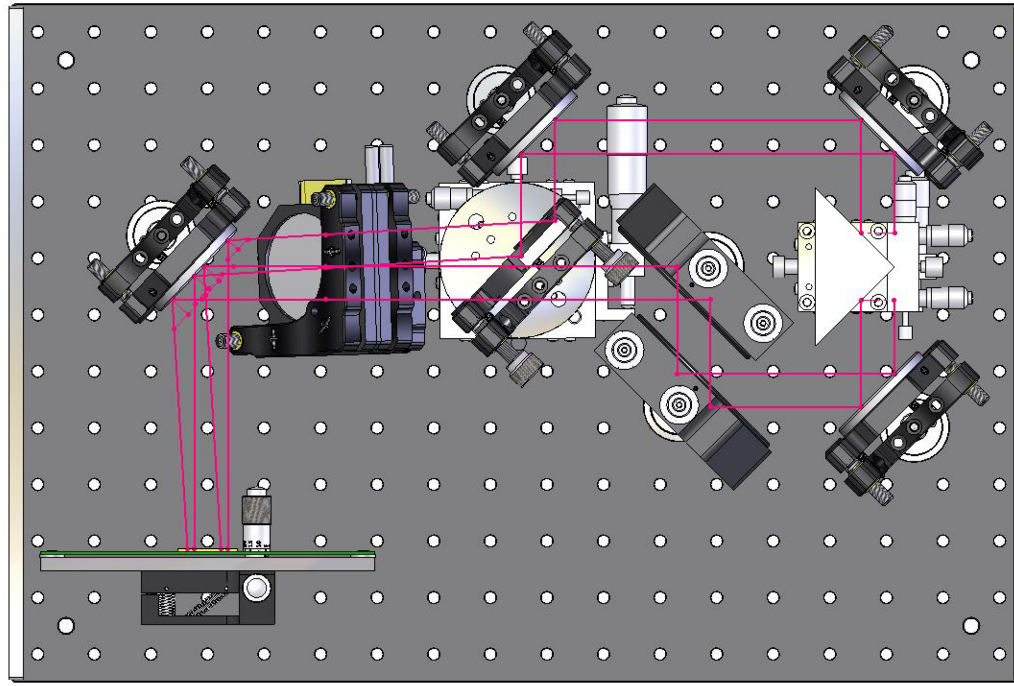


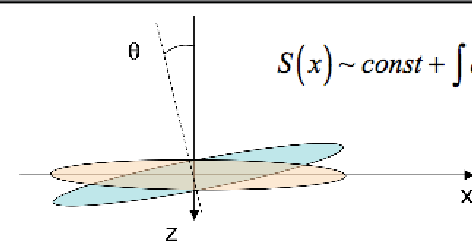
$$S(x) \sim \int dy \left[\int dt \vec{E}(x,y,t)\vec{E}(x,y,t-\theta x) + \mathrm{c.c} \right]$$



Interferometer

- All reflective optics
  - Minimize losses
- Beamsplitter for small mixing angles
  - Mirror for larger angles (3.5deg)
  - Mirror mount conflict
- Polarizer for CTR studies
- Cylindrical mirror
  - 1D focusing
- Detector Array



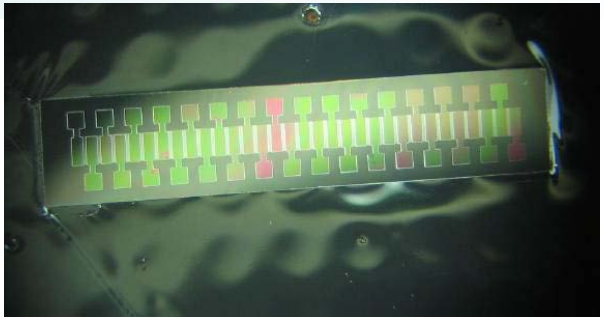


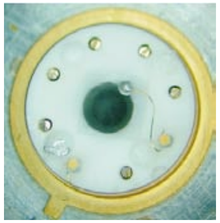
$$S(x) \sim const + \int dy \left[\int \vec{E}(x,y,t)\overline{\vec{E}(x,y,t-\theta x)}dt + c.c. \right]$$

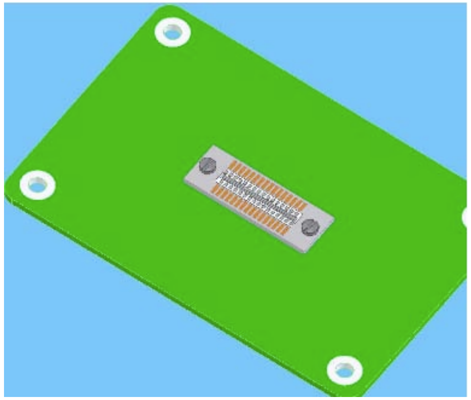
$$\tilde{S}(\omega) \approx \frac{1}{\sqrt{2\pi}} \int S(x) e^{-i\omega\frac{x\theta}{c}} dx$$

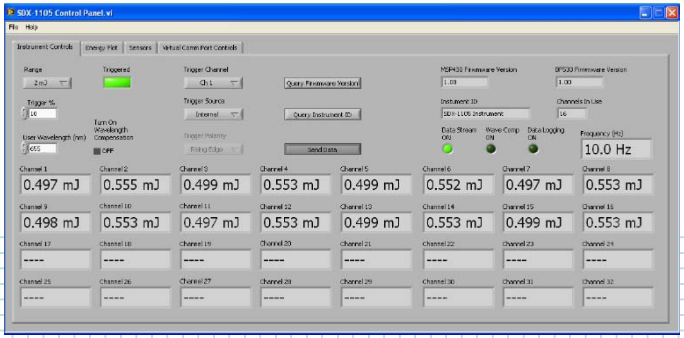
Detector Array

- Spectrum Detector
  - Formerly of Molectron
- 32 channels
  - Convenient electronics
  - 500µm center-center
  - 1mm length
  - 16mm total
  - Coated for maximum absorption
- Specified for ~1nJ sensitivity
  - 9µm thick LiTaO3 promising
    - too fragile
  - 25µm thick LiTaO3
- Integrated DAQ
  - Tested up to 10Hz operation
  - Possibility to go to 100Hz
- Portable



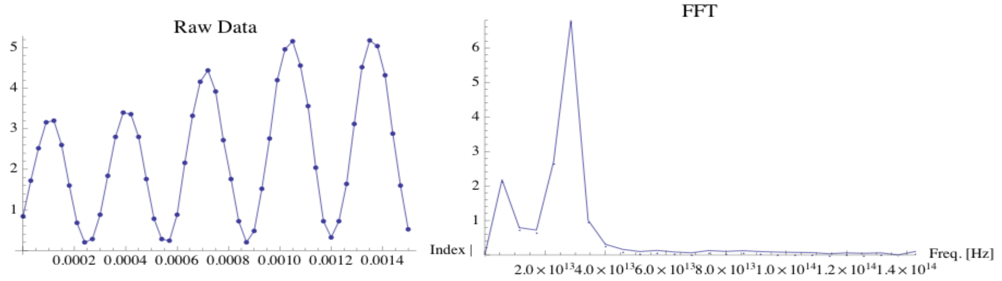




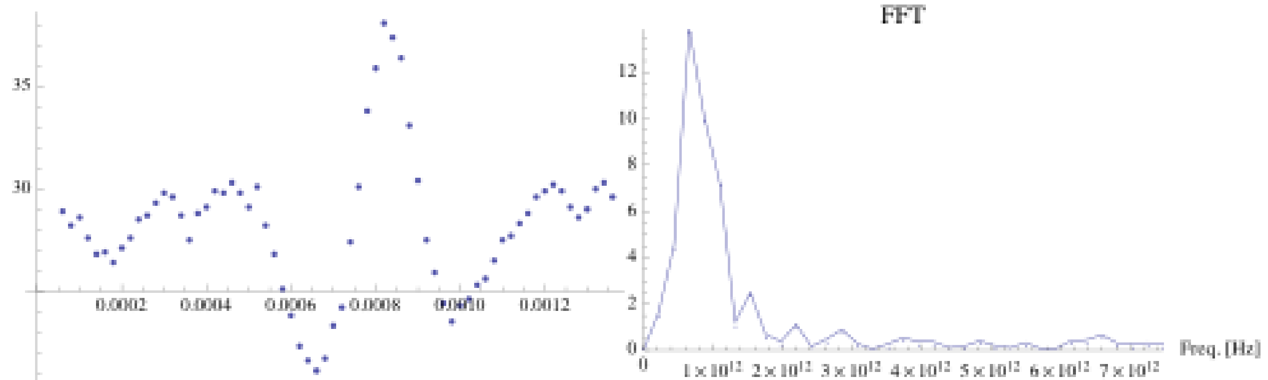


Interferometer Results

- HeNe
  - Alignment
  - Visually observed interference pattern
- Co2
  - Golay cell on translation stage
  - Benchtop, near CW
  - Fine steps
    - Sharp peak at 10.6μm
  - 500μm steps
- THz source at UCLA
  - P. Musumeci and J. Moody
  - Optical rectification
  - .75THz peak (~μJ)
  - Characterized with BLIS



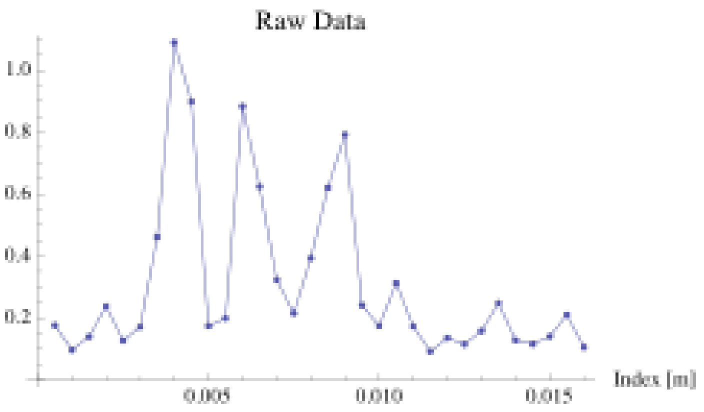
CO2 interferogram and FT (10.5μm peak)



THz interferogram and FT (~.7THz peak)

Full RTI Results

- Detector array test
  - CO2 laser
  - spot size ~17mm
- Peaks separated by ~2.3mm
  - Mixing angle~0.26deg
- FT shows peak at 10.4µm
- Better results if array is flooded (bigger beam)
- Is detector sensitive enough for RTI application?
  - Currently being studied at UCLA THz lab
  - Continue at ATF to characterize coherent radiation sources

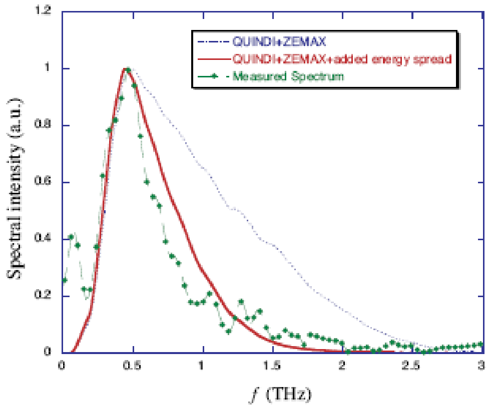


CO2 interferogram with full array

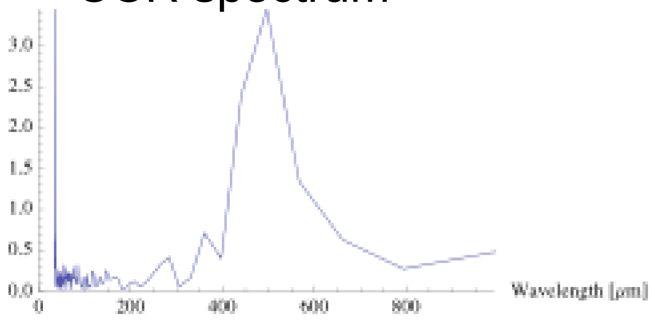
Characterization of Coherent Radiation Sources at ATF

- ATF offers many sources
  - Different properties (advantages/disadvantages)
- Compressor and pulse train mask allow many THz radiation sources
- CTR
  - Broadband
  - Higher energy (~10µJ)
  - Cross-calibrate with BLIS
- CER
  - Broadband
  - Lower energy (~1µJ) due to transport
  - Outside interlocked hall
    - Manual manipulations
  - Nondestructive (run parallel with other expt)
- CCR
  - Cerenkov radiation from DWA
  - Narrowband, tunable
  - Setup is already in place
  - Energy 1-10µJ
- Need to expand beam to fill detector array
  - THz optical telescope using OAP lenses

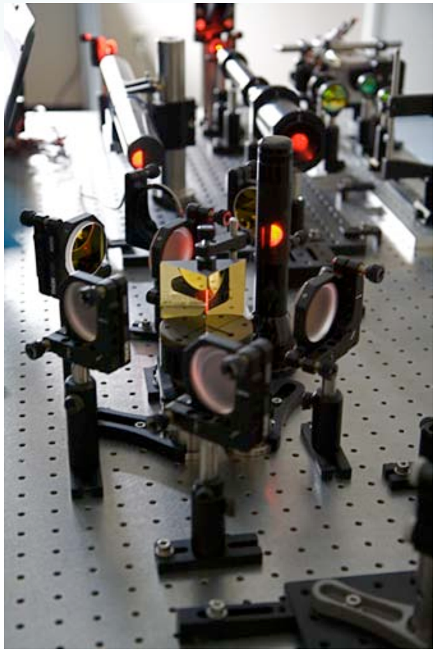
CER spectrum



CCR spectrum



Conclusions

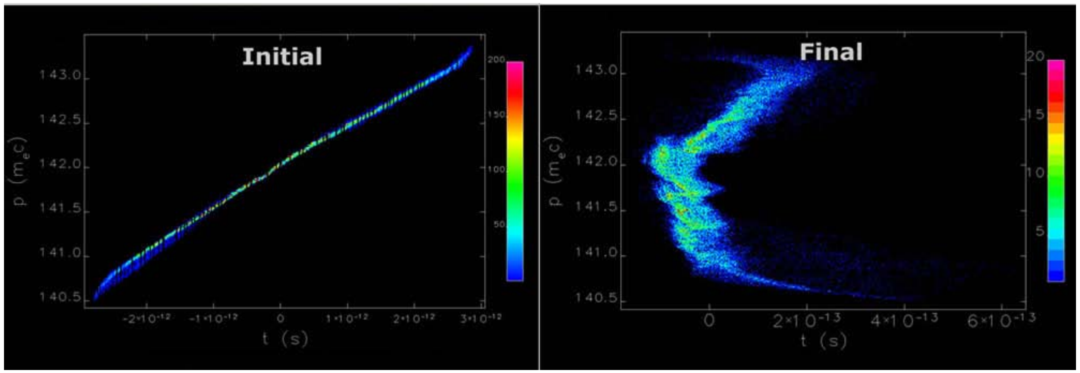


- RTI has demonstrated operations at CO2 and THz regimes
- Bunch length monitor
  - Calibrate against other methods
  - Online feedback tool
  - Benchmarking simulations in real time
- Reconstruction algorithms
  - Assumptions needed to fill in gaps in spectra
  - Low and high frequency components
  - Correction factors
- Testing at ATF using multitude of CR sources

Backup slides

Motivation

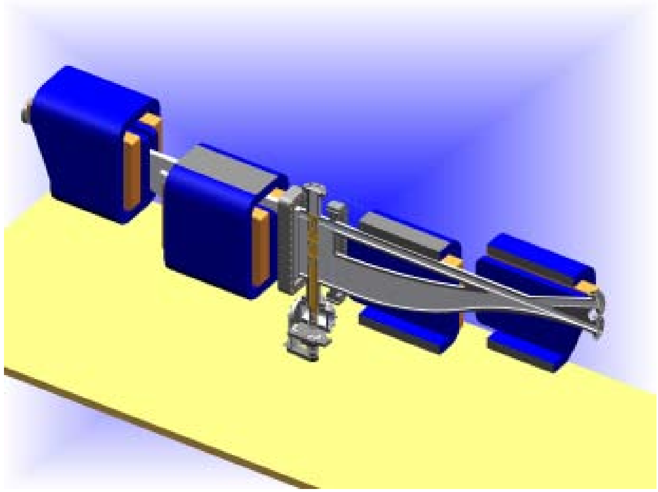
- Generation of compressed sub-micron beams
  - Study radiative effects (CSR, CER) emitted from short beams
  - Continue UCLA Neptune compressor physics studies in acceleration field dominated regime (space charge -> coherent radiation)
  - May greatly impact performance of future compressors and FELs (e.g. microbunching instability)
  - Use CER as non-destructive bunch length monitor



Parmela-Elegant simulation longitudinal phase space of beam, with compression from 50A to 1.5 kA.

Chicane Compressor

- Designed and Constructed at UCLA
  - Modeled with Amperes
  - Engineering, safety concerns addressed by ATF
- Installed and operational at BNL ATF
  - Add to ATF core capabilities
    - SASE FEL, wake field studies
    - Other experiments
- Field = 0.2 T ; Bend Radius = 1.2m
- Extensive Simulation work
  - TREDI, Field-Eye, Parmela, Elegant, Quindi
  - Compress from 350 μm – 30 μm
- Study basic beam physics
  - X-ray FEL, linear collider, etc.
    - bunch diagnostic, phase space degradation



Chicane Radiation Results

- Polarization
  - sigma and pi polarizations
    - radial polarization
    - CER + CSR
- THz spectrum
  - Zemax transport calculations include water absorption
  - Data (green dots)
  - added energy spread used as “fitting parameter”
    - 0.36% sliced energy spread in sims