

*Bunch compression and coherent  
radiation measurements  
experiment at UCLA-ATF chicane*

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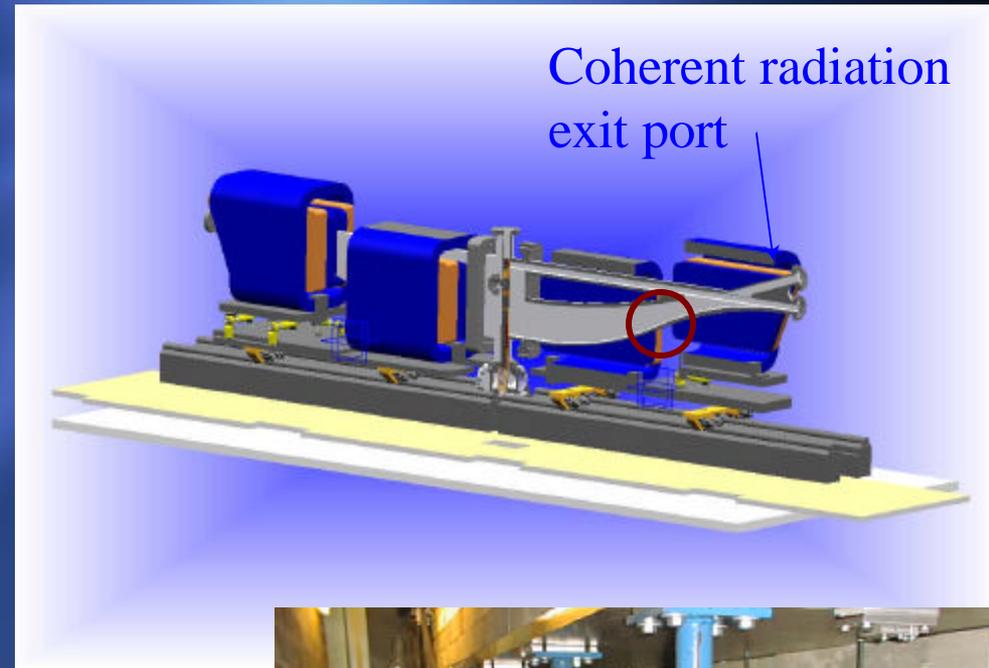
*December 5, 2005*

# *Collaborators*

- ⊕ UCLA Dept. of Physics and Astronomy: R. Agustsson, G. Andonian, M. Dunning, E. Hemsing, P. Frigola, A. Murokh, S. Reiche, J. Rosenzweig, G. Travish, F. Zhou
- ⊕ Univ. di Roma “La Sapienza”: L. Palumbo, C. Vicario
- ⊕ ENEA-Frascati: L. Giannessi, M. Quattromini
- ⊕ BNL: M. Babzien, I. Ben-zvi, V. Yakimenko

# *UCLA/ATF chicane compression experiments*

- ⊕ Extend UCLA chicane experiments to *acceleration-field regime*
- ⊕ Chicane designed, fabricated and characterized at UCLA
- ⊕ Extensive simulation work
- ⊕ Basic physics mission:
  - ⊕ Coherent radiative effects
  - ⊕ Phase space distortions
- ⊕ Add to ATF core capabilities...
  - ⊕ SASE FEL
  - ⊕ Wakefield studies



# Design Performance

## PARMELA - ELEGANT Start-to-end Simulations

- 1.5 kA peak current
- Transverse and longitudinal phase space distortions
- We don't believe ELEGANT, but it makes nice pictures

QuickTime™ and a  
TIFF (Uncompressed) decompressor  
are needed to see this picture.

### Longitudinal phase space in ATF chicane

Energy	70 MeV	Bend radius	1.2 m
Charge	300 pC	Bend angle	20 degrees
Emittance	2 mm-mrad	Initial current	55 A
RF phase	c. -20 degrees	Final current	1.5 kA

# Compression and coherent edge radiation (CER)

- ⊕ Compression from 350  $\mu\text{m}$  to  $\sim 23 \mu\text{m}$  (rms) predicted after chicane
- ⊕ CER produced on dipole 3-4 boundary region
- ⊕ Can make minimum bunch length in CER window
  - ⊕ Dispersion not cancelled
  - ⊕ Beam spread out in  $y$

QuickTime™ and a  
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# Unresolved collective physics issues in magnetic compression

- ⊕ Coherent synchrotron radiation (CSR) observed at many labs
  - ⊕ What is the precise role of CSR in beam microbunching?
- ⊕ New physics effects
  - ⊕ Coherent edge radiation (CER) is focus of initial experiments
  - ⊕ CER used for beam diagnosis at longer wavelength
  - ⊕ Phase space distortions:  $z, y$ 
    - ⊕ CTR measurements of bunch length, momentum spectra
    - ⊕ Transverse phase space tomography
  - ⊕ New computational tools

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**Sample CSR spectrum calculation  
using *FieldEye* (variant of TREDI)**

# Edge Radiation Frequency Spectrum

- Edge radiation is a variant synchrotron radiation while the beam crosses the boundary of a magnet.
- Intensity is much higher than SR for wavelengths  $\lambda \gg \lambda_c$ 
  - Spectral resolution will give most information (boost to long wavelength components)
  - Flat ER spectrum good for faithful response
- *Radial polarization* allows contrast with SR

Synchrotron radiation

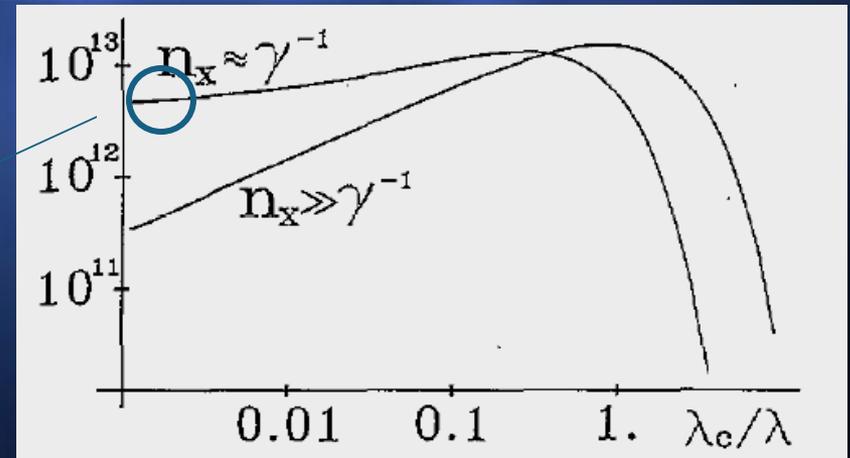
$$E_0(\omega) \sim \omega^{21/3} \quad \left( \frac{c}{R} \ll \omega \ll \omega_c \right)$$

$$I_c \sim 50 \text{ nm}$$

Edge radiation

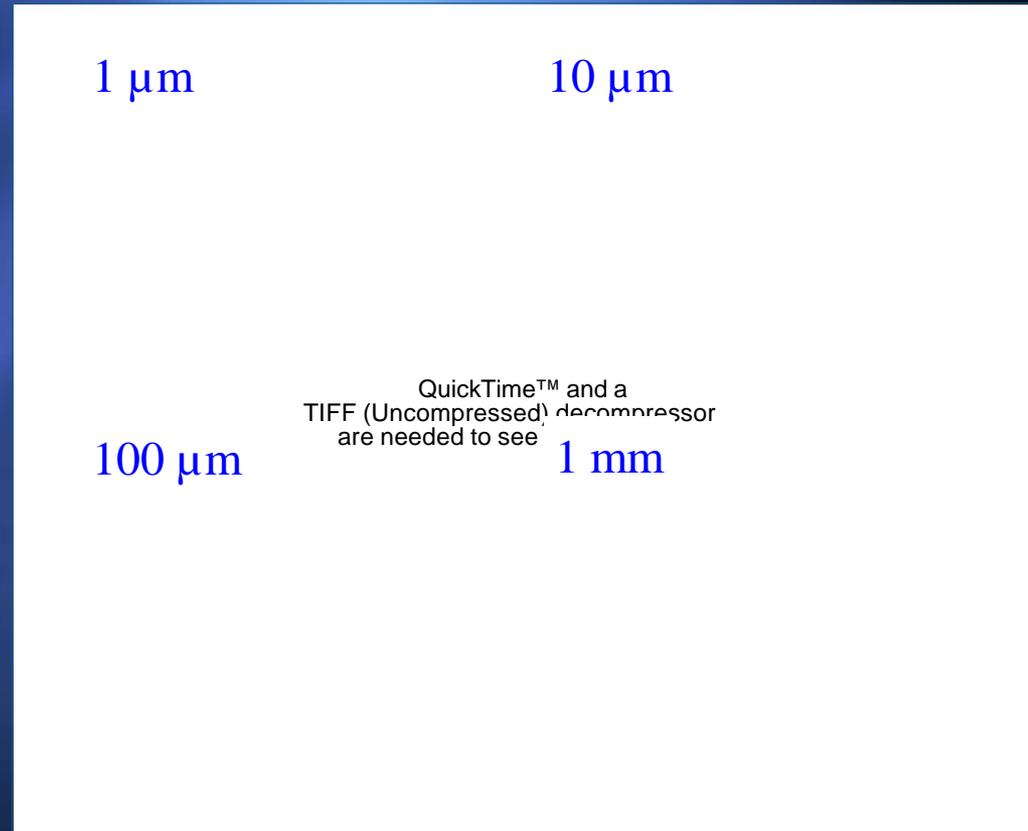
CER

$$E_c(\omega) \sim |I_b(\omega)|^2$$



# CER Angular Spectrum?

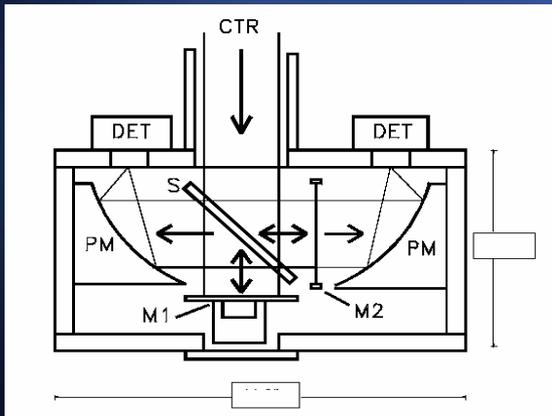
- ❖ Semi-analytical model (S. Reiche)
- ❖ Shows transition from:
  - ❖ synchrotron radiation-like, to
  - ❖ Transition-like (edge) radiation
- ❖ Idealized calculation
- ❖ How to measure?
- ❖ Detailed differential spectra from QUINDI



Spectrally resolved spatial resolution of  
CER far-field intensity at FIR output port

# Coherent transition radiation diagnosis of rms bunch length

- ⊠ Coherent transition radiation (CTR) interferometer downstream of chicane for independent determination of bunch length
  - ⊠ New model desined by U. Happek, built by RadiaBeam



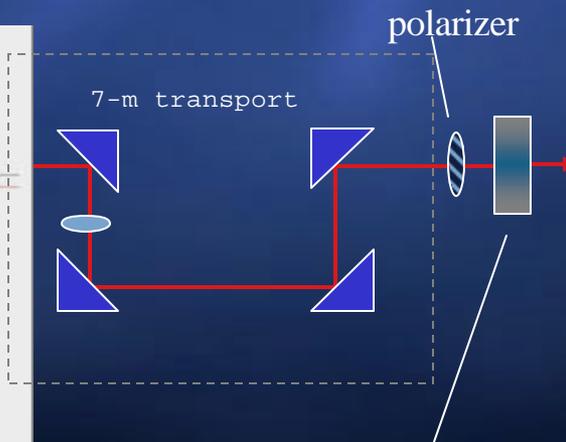
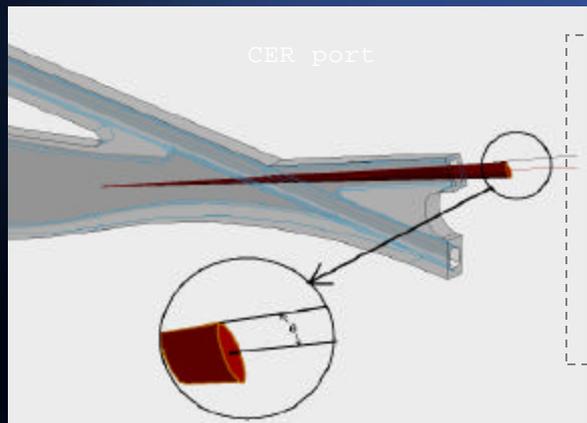
Hi-res Michelson for CTR



RadiaBeam commercial model

# CER Measurement System

- ⊕ Radiation port gives CER emitted between dipoles 3 and 4
- ⊕ Quartz window (clear polycarbonate for FIR response?)
- ⊕ Difficult transport with coherent, diffracting light, mirrors at angle. Picarin collecting lens used
- ⊕ Si bolometer (4.2°K) from IR labs measure CER spectrum
  - ⊕ Low pass filters at 13, 27, 45, 130, 285 microns



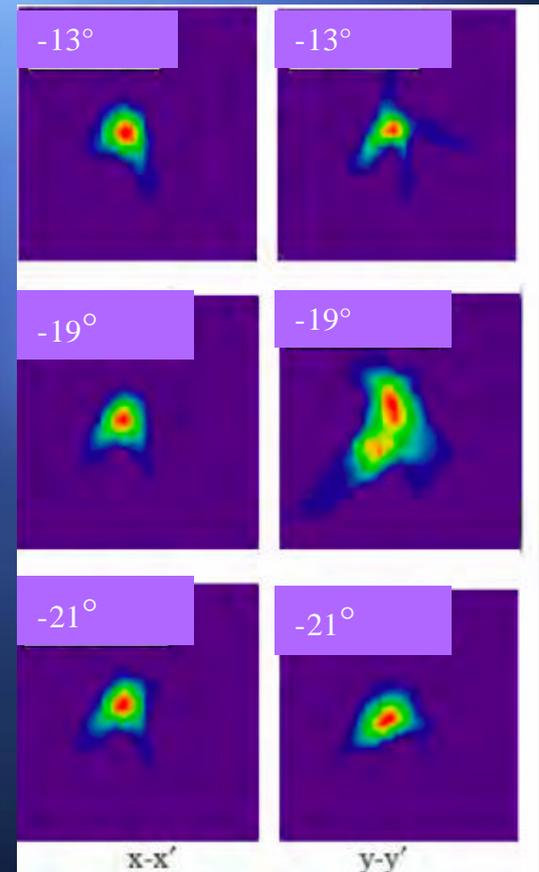
Cold filter wheel (low pass ): 13, 27, 45, 103, 285  $\mu$ m

# *Data set taken for cross-correlation of physics; benchmarking*

- ⊕ CTR autocorrelations v. RF phase
- ⊕ Momentum spectra v. RF phase (front and back of crest)
- ⊕ Transverse phase space reconstruction v. RF phase
- ⊕ CER power measured in parameter matrix:
  - ⊕ v. RF phase
  - ⊕ v. polarization
  - ⊕ v. spectral filter
  - ⊕ autocorrelated

# *Bifurcation of transverse phase space*

- ⊕ Tomography used to measure transverse phase space (Yakimenko, Zhou)
- ⊕ Bifurcation not as severe as in Neptune 13 MeV experiments
- ⊕ Due to energy spread, dispersion mismatch?

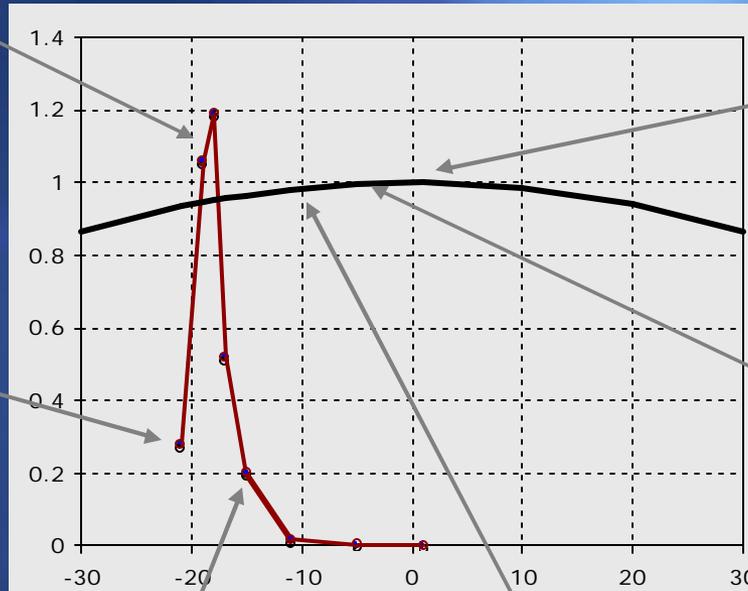


Bend plane is along vertical axis.  
Reconstructed phase space plots for under-, full-, and over- compression

# CER power, correlation with linac phase/momentum spectrum

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Detected power v. RF phase

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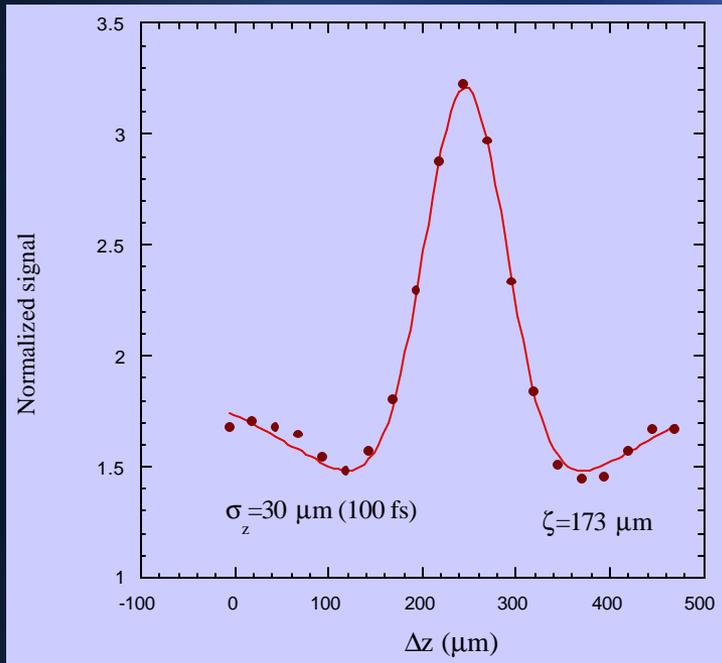
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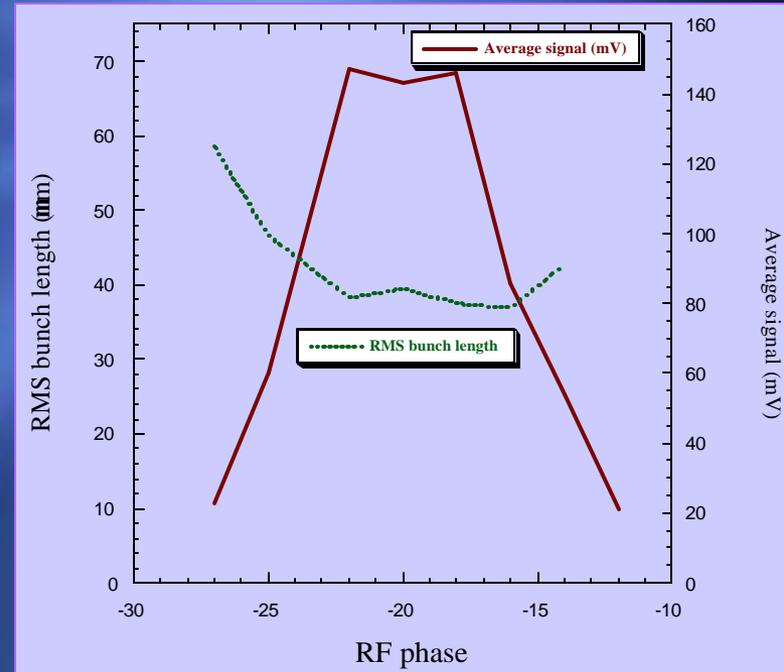
QuickTime™ and a TIFF (LZW) decompressor are needed to see this picture.

Beam images are post-bend analyzer

# CTR measurements



Sample autocorrelation



Bunch length, CTR energy v. RF phase

- ⊕ Bunch lengths observed  $< 30$  micron rms
- ⊕ Bunch is short over large range of RF phases
  - ⊕ *A part of the beam always compresses*
  - ⊕ More CTR power when center of beam compresses

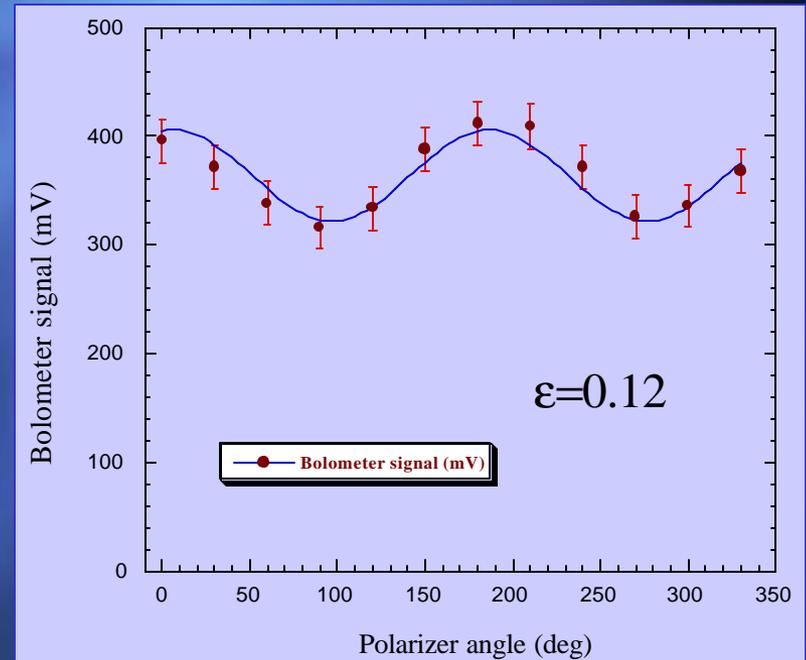
# *CER strongly radially polarized*

- ⊕ Edge radiation process enhances radial polarization
- ⊕ Polarizer placed in front of bolometer
- ⊕ Between 12-25% variation in “ellipticity”

$$e \equiv \frac{V_{\max} - V_{\min}}{V_{\max} + V_{\min}}$$

⊕ Measure of CSR/CER

- ⊕ No strong dependence on RF phase



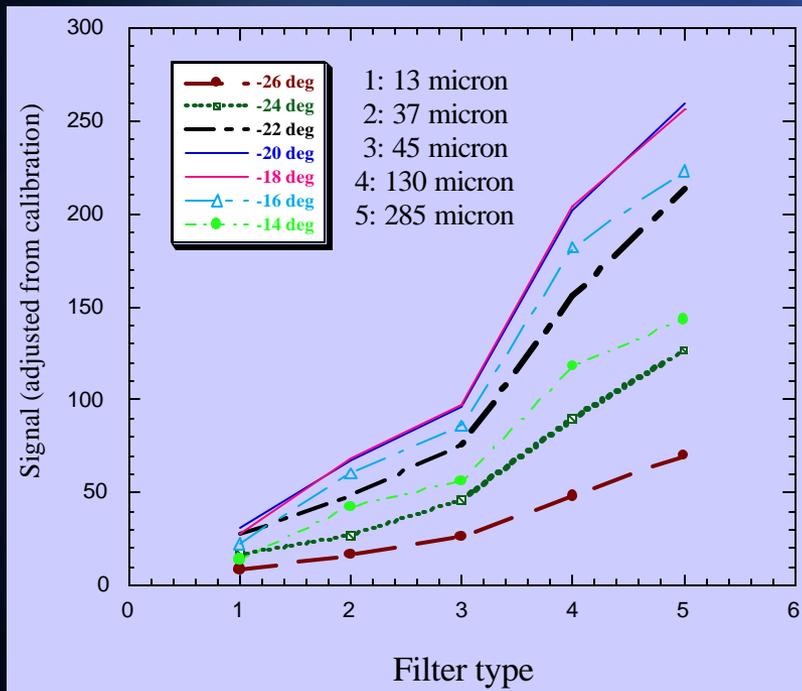
Polarizer varied at phase of maximum power

# *Far-field angular distribution*

- ⊕ Distribution is function of polarization
- ⊕ Compare to simulation
  - ⊕ QUINDI
- ⊕ Quantify by position of:
  - ⊕ Maximum intensity
  - ⊕ Center of "mass"

QuickTime™ and a  
TIFF (Uncompressed) decompressor  
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# CER Spectrum from filters



- ⊕ Signal adjusted from BB calibration response for each filter
  - ⊕ Preliminary analysis
- ⊕ All compressed beams have similar frequency breakdown
  - ⊕ Same reason as for observing little bunch length dependence on phase

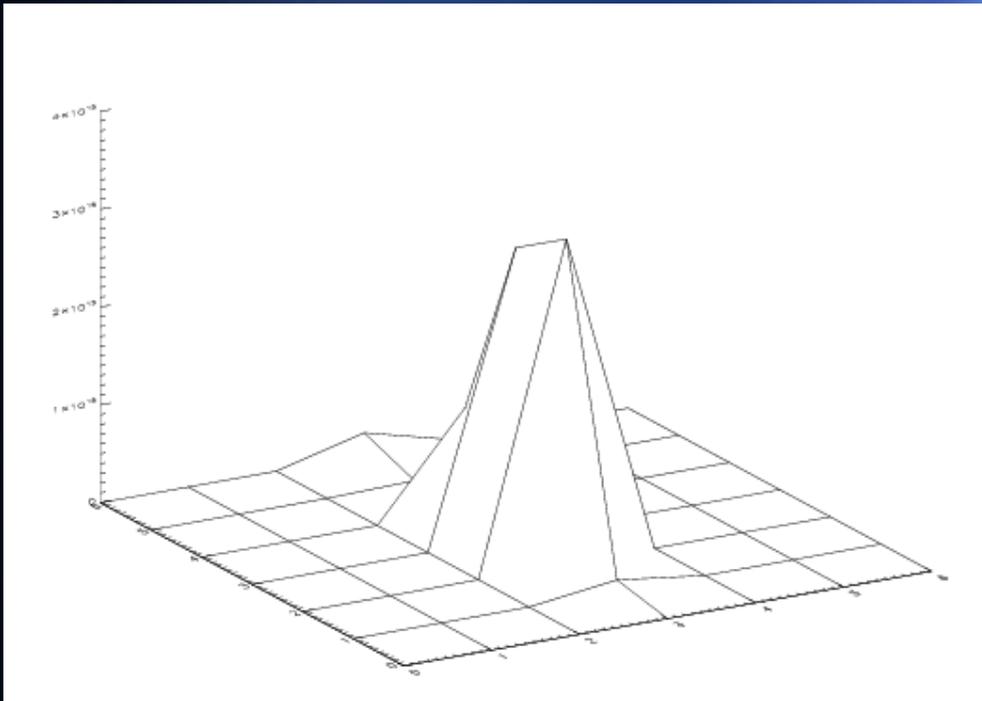
# *CER autocorrelation*

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- ⊕ Autocorrelation using BLIS (Michelson interferometer)
- ⊕ Dispersion causes lengthening of pulse
- ⊕ Fourier analysis indicates absorption due to
  - ⊕ Fused silica window
  - ⊕ H<sub>2</sub>O in transport...

# *QUINDI development*



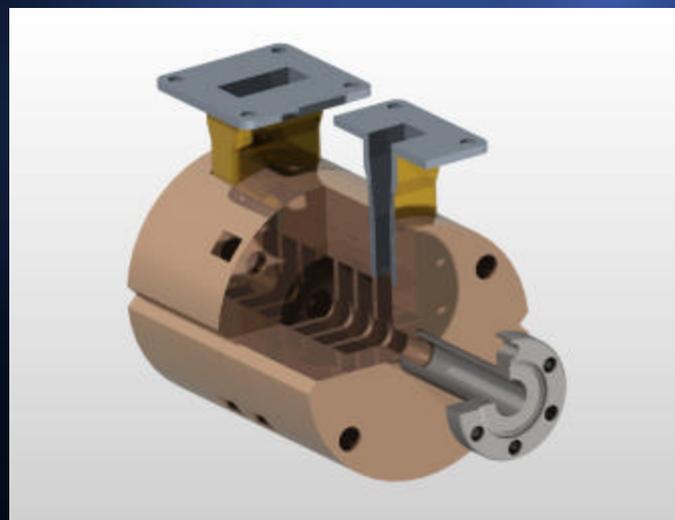
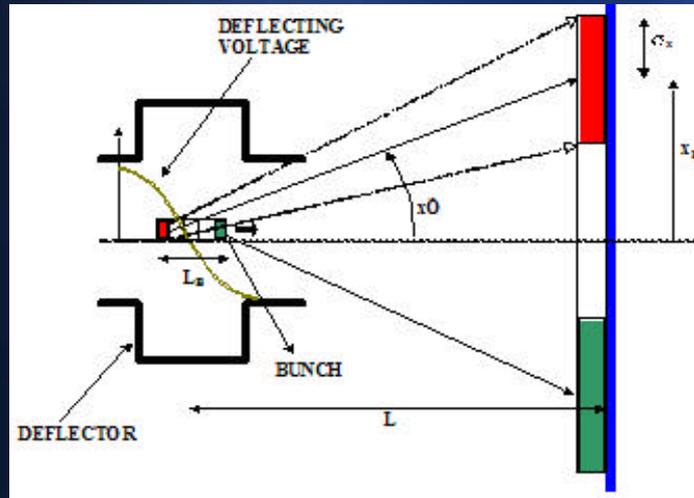
QUINDI far-field intensity profiles  
(0.15-0.85 THz)

- ⊕ Lenard-Wiechert code
- ⊕ Analytical or mapped fields
- ⊕ Non-self-consistent particle trajectory
- ⊕ First results in last weeks

# *Future plans*

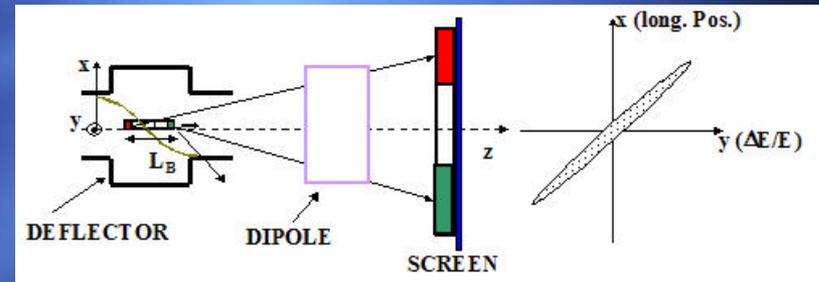
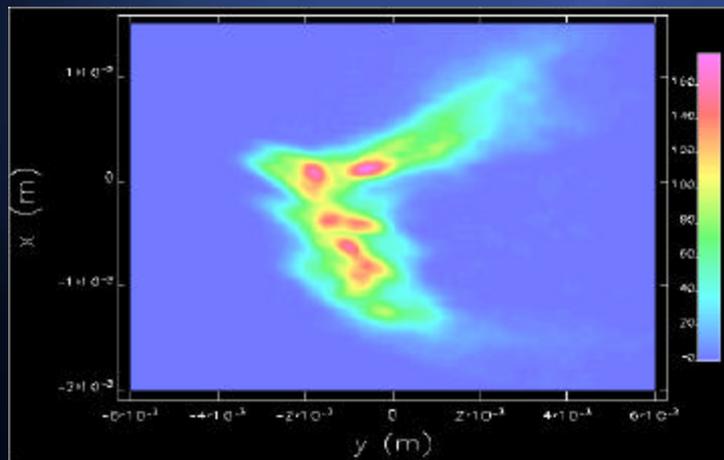
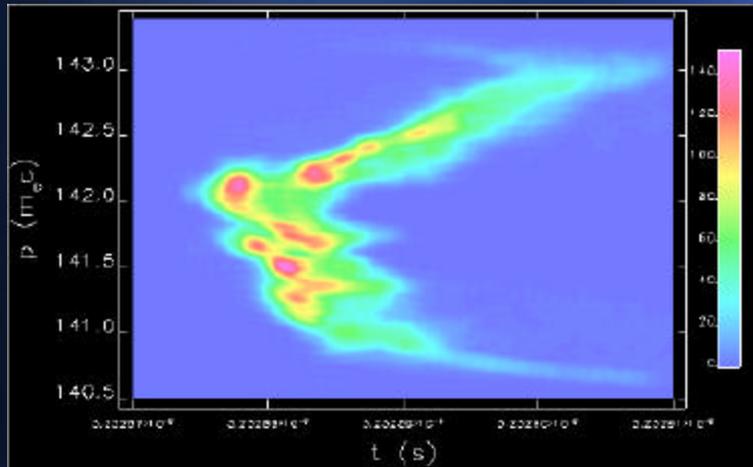
- ⊕ First publication underway on CER
  - ⊕ First short wavelength CER observation
- ⊕ Start-to-end with PARMELA-QUINDI
- ⊕ Improved CER spectral diagnostics
  - ⊕ Dry N<sub>2</sub> transport
  - ⊕ Diamond window
  - ⊕ Grating-based system
- ⊕ Worry about self-consistent effects in simulations
  - ⊕ TREDI
  - ⊕ Trafic4
- ⊕ Better diagnosis using RF deflector...

# *X-band traveling wave RF deflector*



- ⊕ “Relativistic streak camera”
- ⊕ Extension of UCLA-Roma work
- ⊕ RadiaBeam, UCLA, BNL collaboration
- ⊕ X-band for fast sweeping
- ⊕ Traveling wave for length
- ⊕ ~3 fsec resolution

# Single shot longitudinal phase space



- ⊕ Dipole after deflector
- ⊕ Image at betatron waist
- ⊕ Excellent reconstruction
  - ⊕ Some distortion due to CSR!