Demonstration of Optical Microbunching and Net Acceleration at 0.8 microns

(almost)

E163 Collaboration, SLAC

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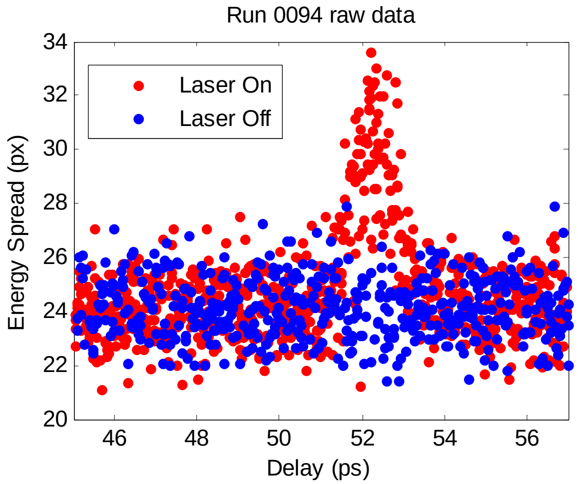
Goals

- Produce optically spaced electron microbunches
- Obtain independent verification & measure of microbunching
- Perform <u>net</u> acceleration of electrons with a laser

Recent E163 Timeline

- March 2007: First beam in hall (experimental chamber empty) beam line commissioned
- April: Experiment installed
- May 9th: Beginning of experimental run
- May 23rd: First laser-electron interaction observed at E163



Talk Outline

- Overview of E163 program, facilities, experiment hardware
- Initial results from IFEL interaction; lessons learned from first run
- Simulations of planned experiments:
  - Microbunching & COTR experiment
  - Net acceleration experiment
- The (near) future of laser electron acceleration at E163

E163 Facility and Experimental Hardware

NLCTA/E163 Facility

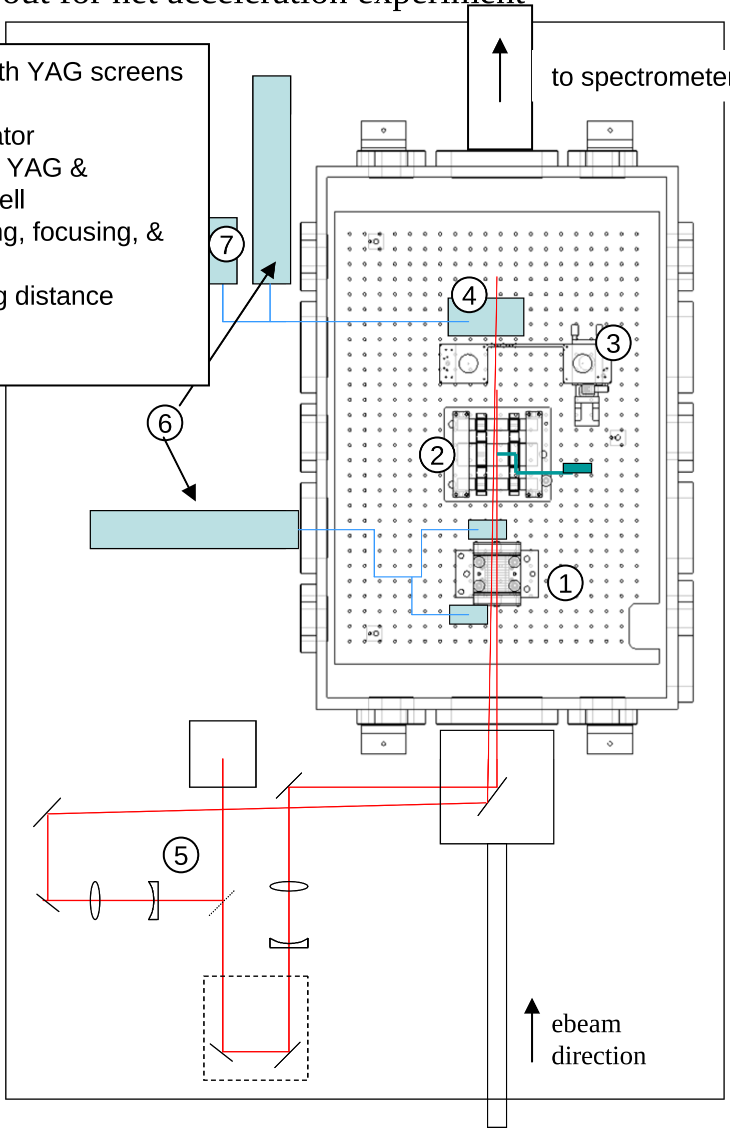
- 60 MeV xband linac w/ sband photoinjector producing 50 pC, 0.5 ps electron pulses at 10 Hz, $\delta E<0.1\%$
- Two regenerative amplifiers
  - 2 mJ/pulse regen to produce 100-150 μJ/pls UV for photoinjector
  - 1 mJ/pulse regen for light to experiment
- 2'x3' vacuum box atop a 4'x6' optical table for housing the experiment
- 90° energy spectrometer: ~2 keV resolution
- streak camera for timing

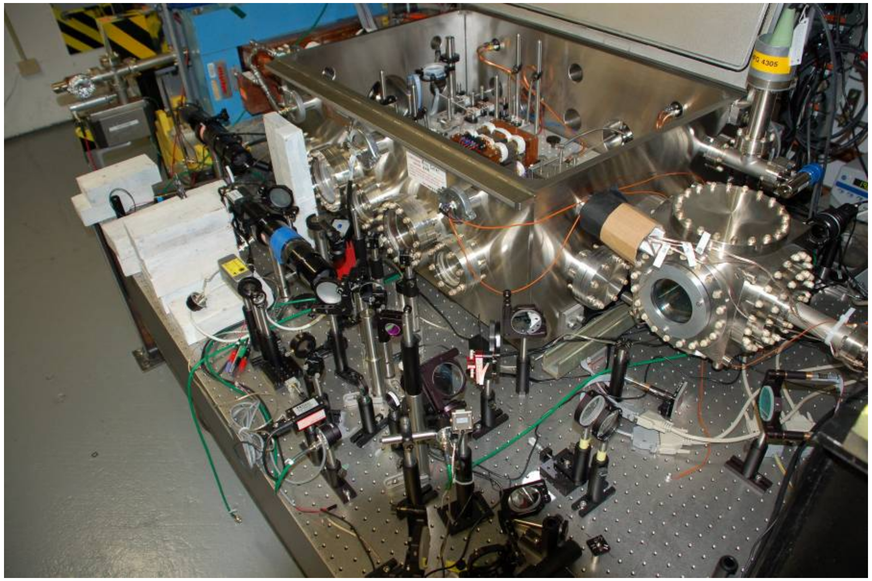
For more info, see: Poster FRPMS072 "Diagnostic and Experimental Procedures for the Laser Acceleration Experiments at SLAC", presenter Chris McGuinness

Experimental Area Layout

layout for net acceleration experiment

1. Undulator with YAG screens
2. Chicane
3. ITR Accelerator
4. Downstream YAG & Cherenkov cell
5. Laser steering, focusing, & diagnostics
6. Long working distance microscopes
7. COTR PMT

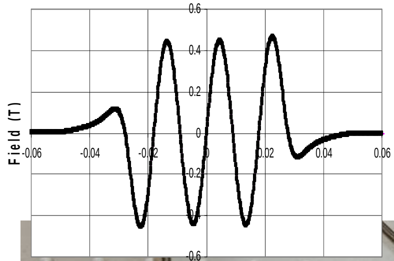


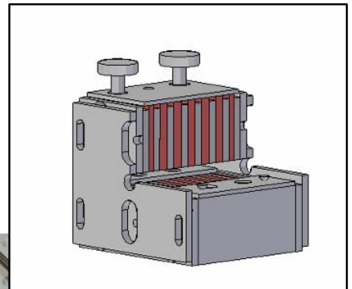


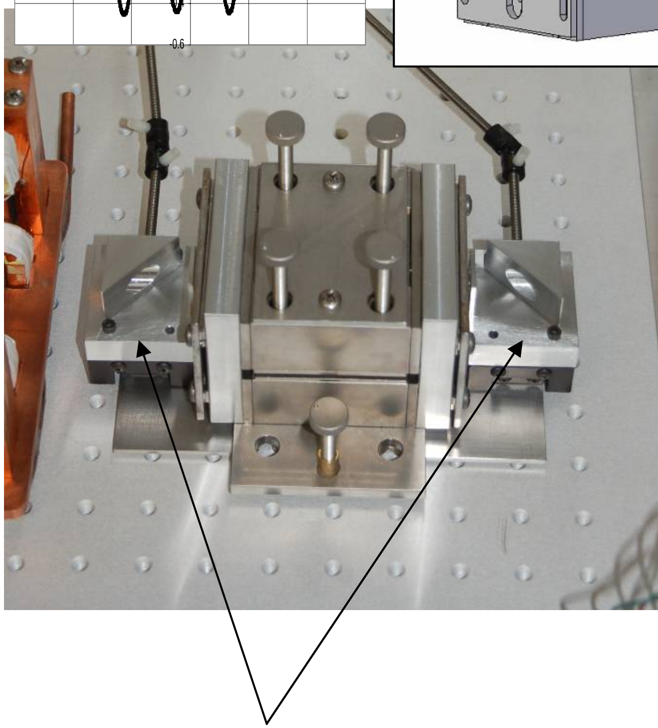
Chamber + table house...

- magnetic hardware (next few slides)
- accelerator structures, (THPMS080 & THPMS050)
- aerogel Cherenkov radiator for timing
- long working distance microscopes to view YAG screens for beam overlap and general diagnostics
- laser delay & focusing optics; photodiodes & laser position monitor

The Microbunching Hardware



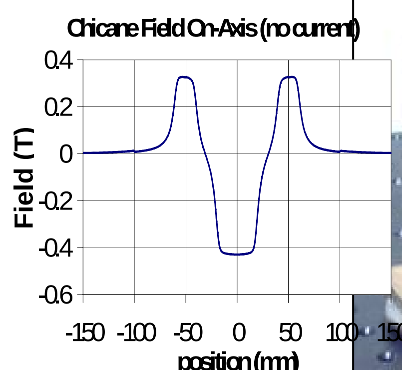


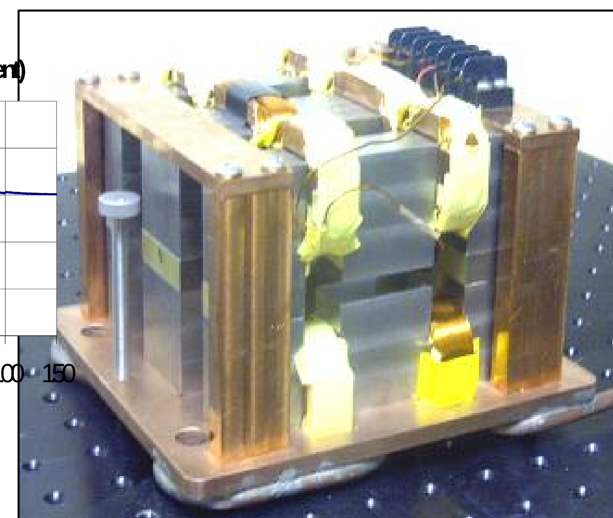


YAG screens for beam alignment inserted by pneumatic actuator

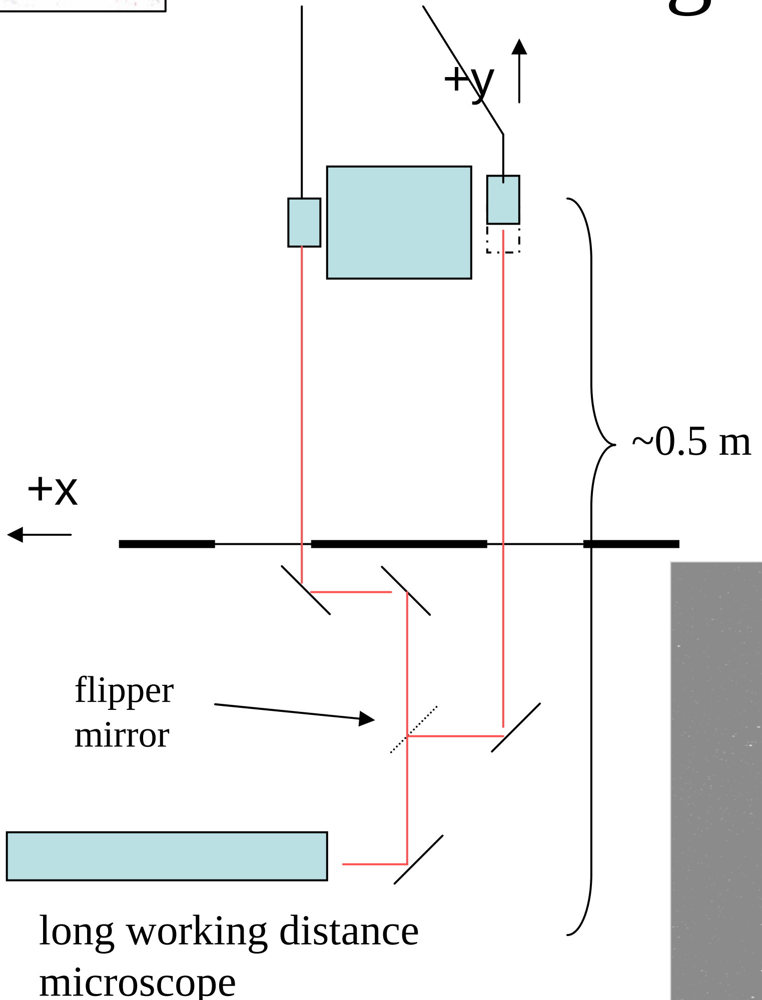
Undulator:
- 3 periods, 1.8 cm period
- Adjustable gap 4-10 mm (k_w=0.3-1.3)
- Upstream & Downstream YAG screens for alignment

Chicane:
- 3 Hybrid H-magnets (center one double thickness)
- 0.35 ±0.1 T
- Water cooling to base plate

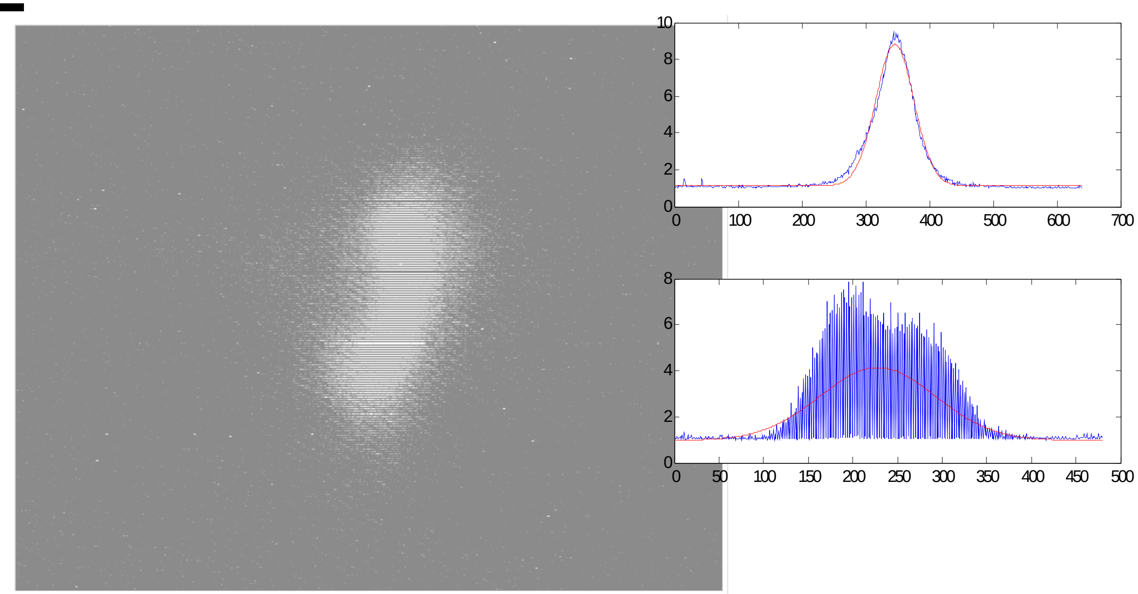




IFEL Alignment YAG screens



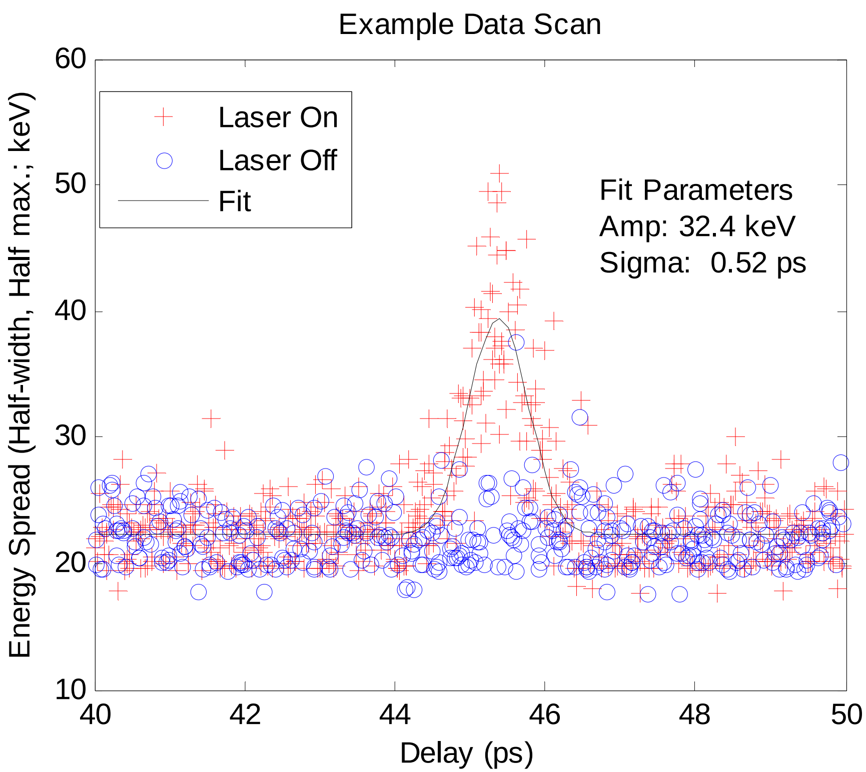
- YAG scintillator + scatterer for laser
- Fully automated screen insertion, image capture & analysis
- 7mm FOV; 25 μm resolution



Initial Results

Goal: Oberserve COTR radiation from microbunches

- Re-established IFEL interaction at 800nm
- electron σ_t=0.4ps
- Some interactions up to 100 keV rms – matches simulation
- temporal jitter <0.2ps
- Long term stability > 5minutes (longest data scan executed)



Lessons Learned

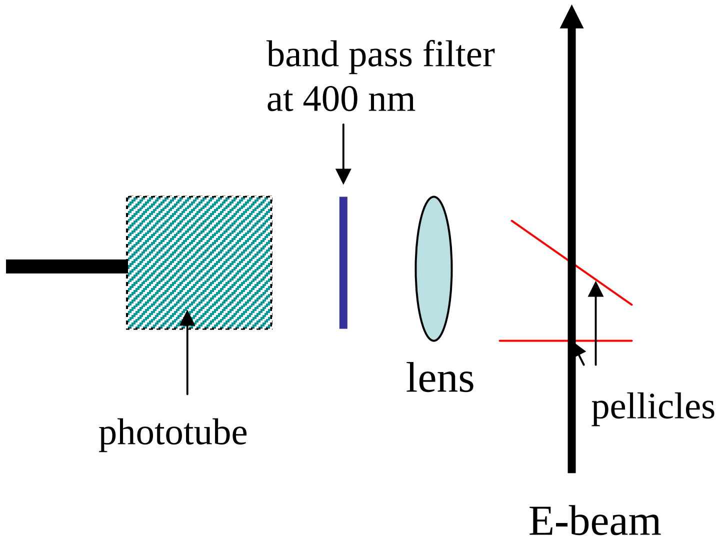
- Many challenges overcome, still learning about running NLCTA
- pellicle mirror not such a good idea; found ~factor of 10 increase in emittance
- Laser wavelength -> microbunch spacing: laser was running at 785nm, 2^{nd} harm. at 392.5nm, but using a 400±5nm bandpass filter in COTR detection (oops)
- Spot size at radiator too large: will try pinhole collimator before radiator foil

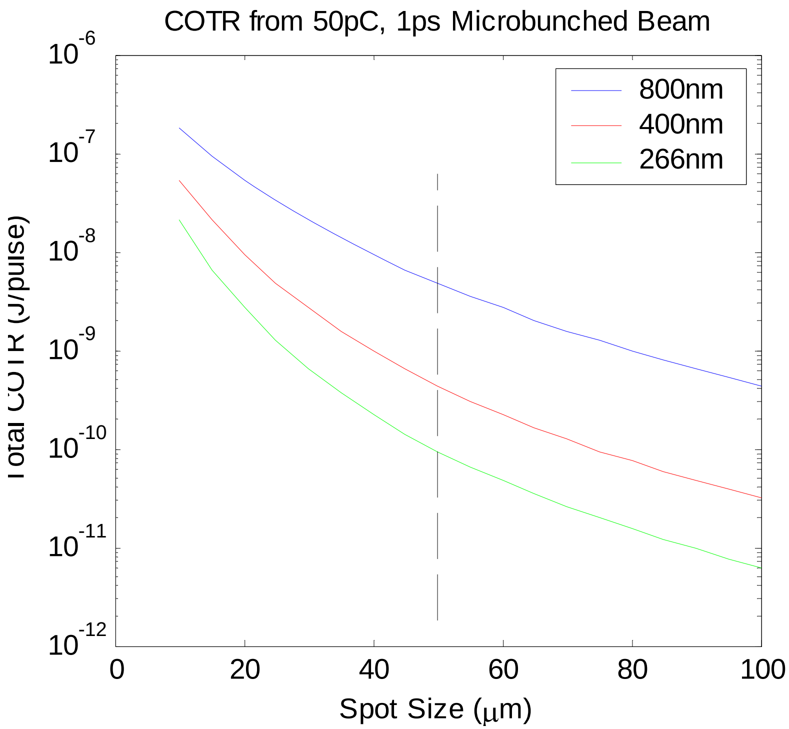
Experiment 1

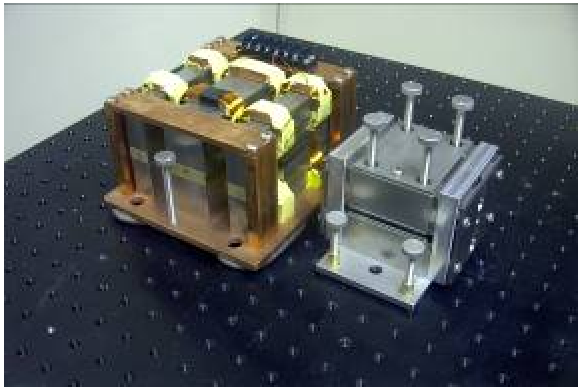
Optical Microbunching and COTR Diagnostic

Experiment 1: Coherent Optical Transition Radiation for detecting Microbunching

- independent measure of microbunching for optical acceleration experiments
- Allows optimization of bunching chicane R_{56}
- scan at 2[nd] harmonic to avoid laser background

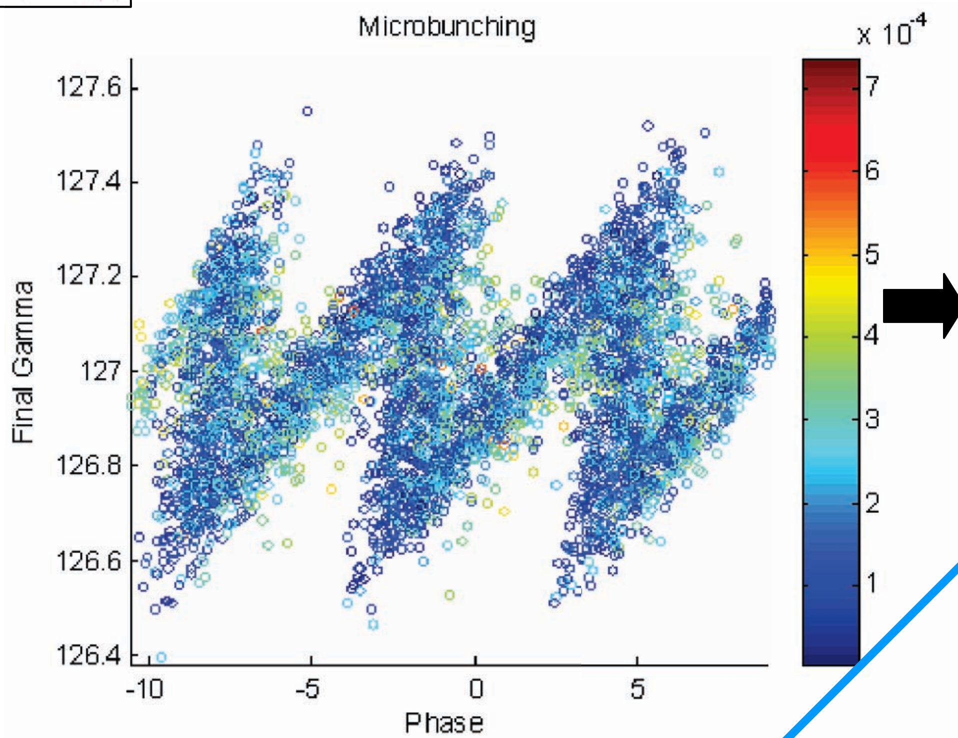


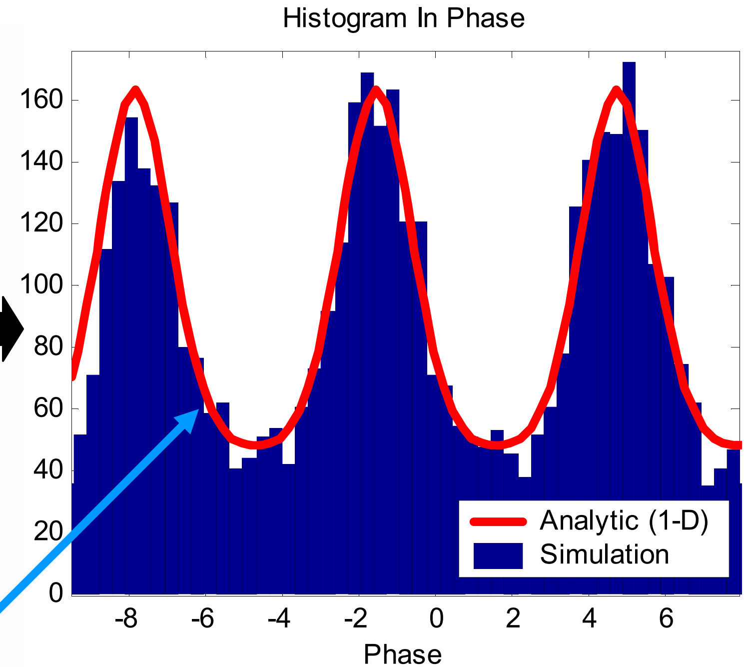




IFEL and Chicane together.

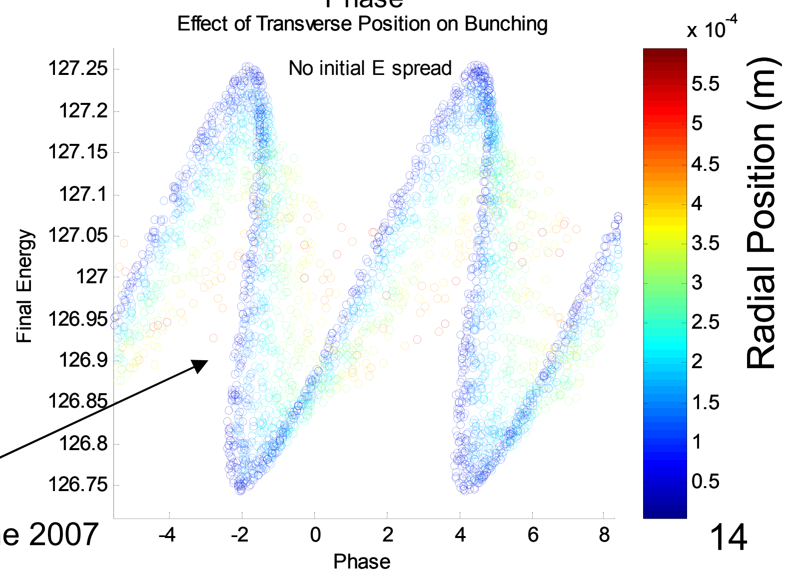
Experiment 1: Microbunching Characteristics





Analytic form is for plane wave and beam with no divergence/focusing (i.e. 1-D)

From comparison, bunch quality clearly dominated by initial Energy spread...



No initial energy spread

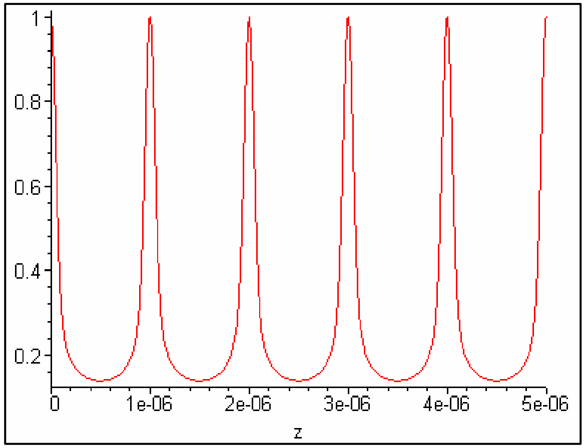
Experiment 1: Possible Extension

Multi-color COTR & determining longitudinal profile

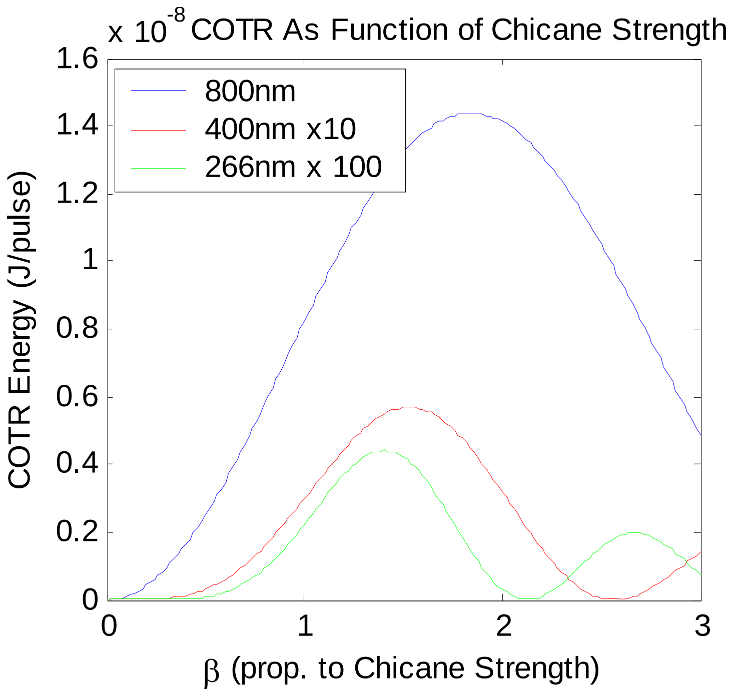
Microbunching density should be given by:

$$\rho_{IFEL}(z) = \rho_0 \left[1 + 2\sum_{n=1}^{\infty} J_n(n\beta) \exp\left[-\left(\frac{n\sigma_\gamma}{2\eta} \right)^2 \right] \cos(n k_B z) \right]$$

$$\beta = k_l R_{56} \eta$$

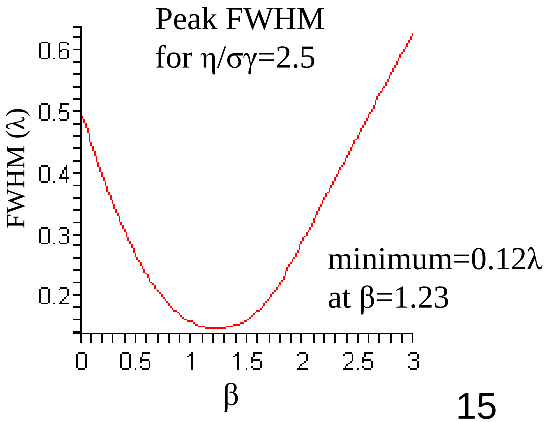


Longitudinal distribution for β=1, η/σ_γ=2.5, 5 optical cycles shown.



scanning chicane strength and finding max's for each color will inform on longitudinal profile

Note: peak harmonic content ≠ densest bunch →



Experiment 2

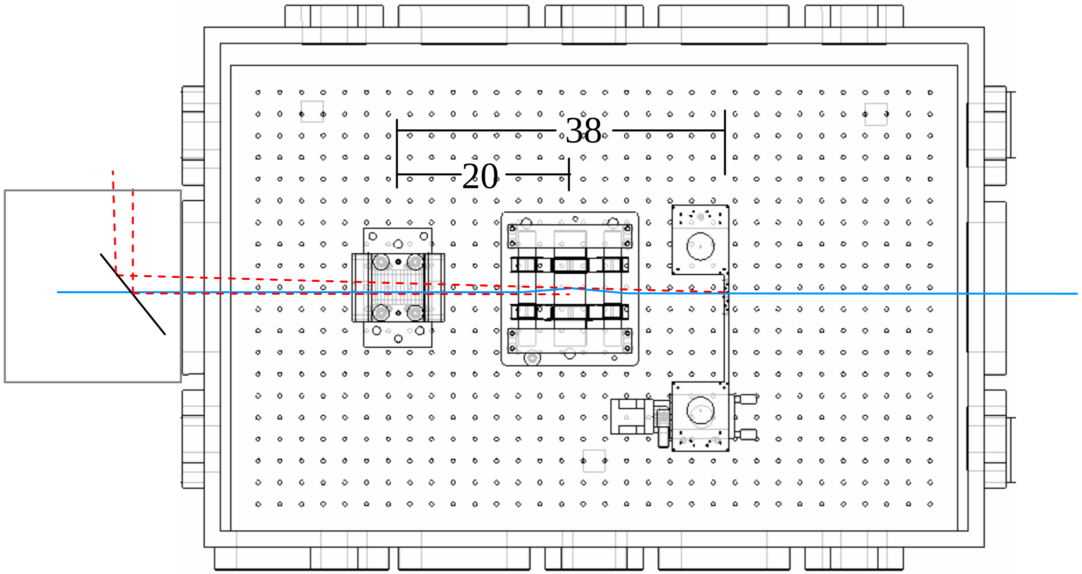
Net Acceleration of Electrons with Light

- Combine microbunching hardware with ITR accelerator to obtain net acceleration
- laser power split between IFEL and ITR
- Careful beam control and electron filtering to avoid interference and obtain signal

Exp 2: IFEL-ITR Experiment Simulation

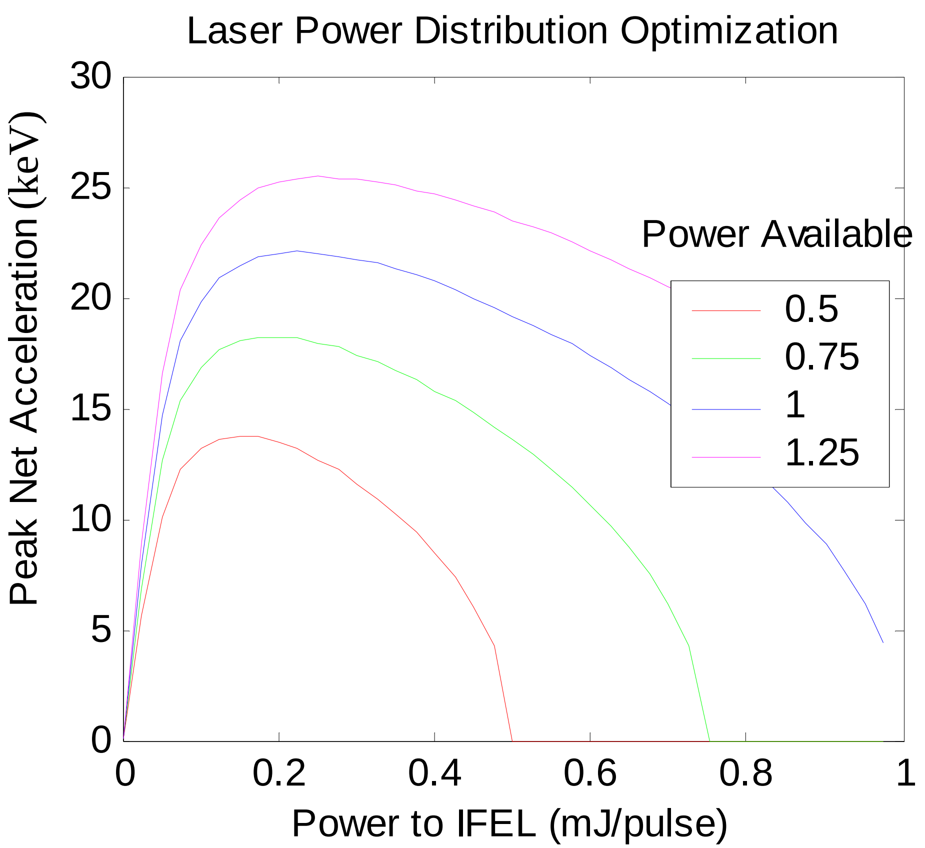
Code Overview:

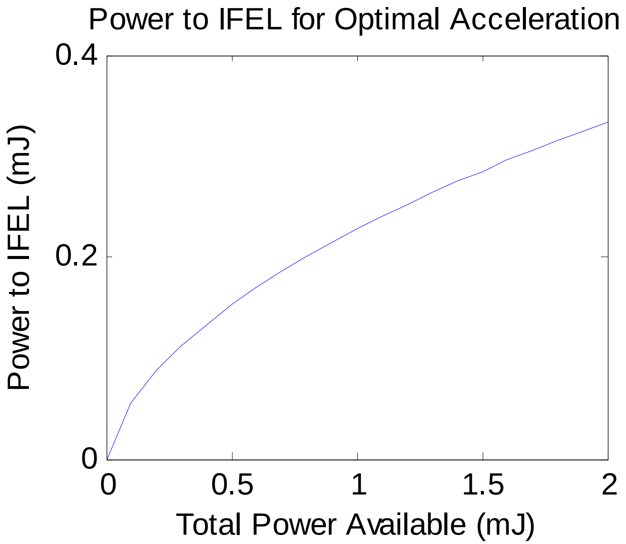
- Euler method Integration of Lorentz eqs. No emission/absorption
- 1-D field profiles of undulator & chicane from magnetostatic code Radia
    - ignores focusing & edge effects of magnets; previous studies found these to be negligible
- Analytic form for full TEM_{00} laser field for both lasers



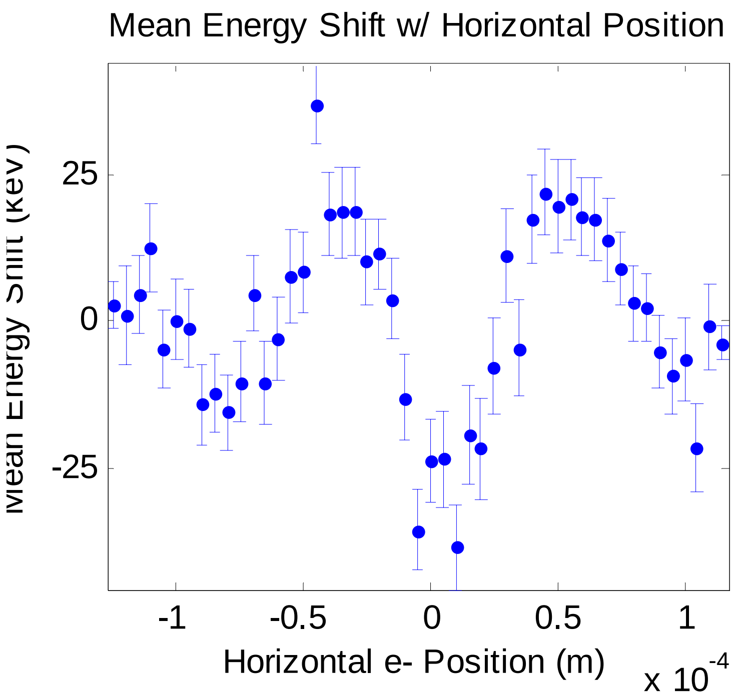
Parameter	Value
E-beam	
Beam Energy	60 MeV
Spread	0.1%
Emittance	1.5 π-mm-mrad
Focused Size	50 μm (rms)
IFEL Laser	
Energy	0.4 mJ/pulse
Focused Size	100 μm (rms)
Focus Location	10 cm after und.
ITR Laser	
Energy	0.6 mJ/pulse
Focused Size	50 μm (rms)
Angle	7 mrad

Exp 2: Laser Power Optimization





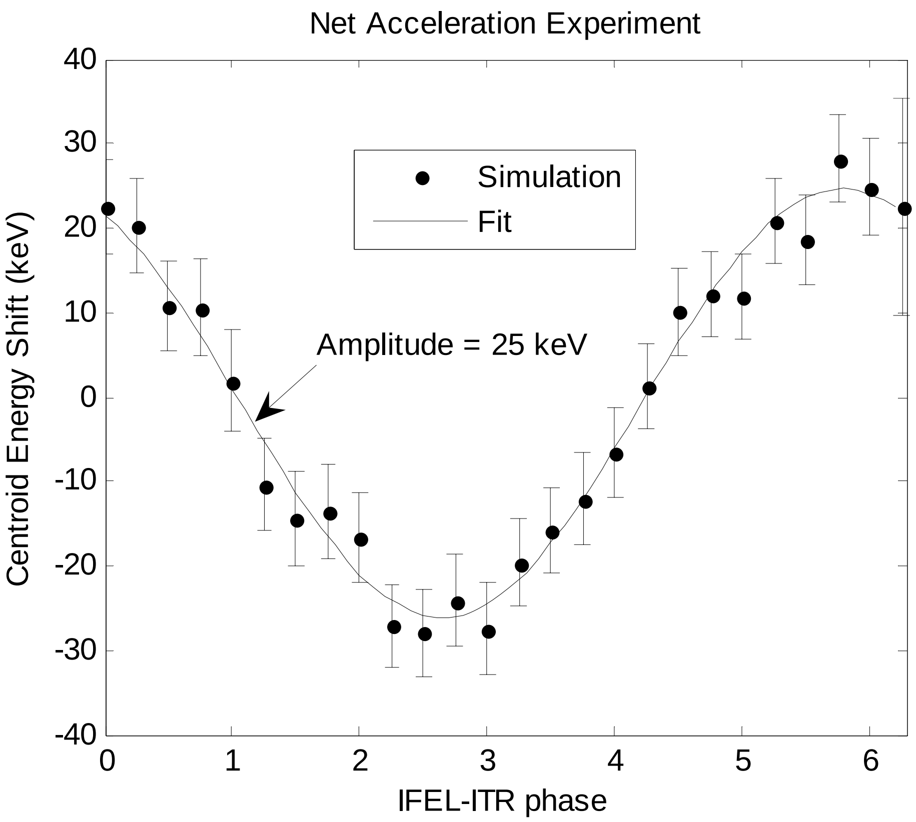
Exp 2: Interaction at Tape & effect of e- beam spot size



Compare to Wavelength/sin(angle)=96 μm

So, need to collimate e-beam or focus very tightly to see net acceleration

Experiment 2:
Full Net Acceleration Experiment Simulation



Exp Parameters:

- Ebeam
  - γ=117, $\Delta\gamma$=0.1%
  - 50 micron focus (on tape)
  - ε_N=4e-6 m
- IFEL:
  - 0.4 mJ/pulse
  - 100 micron focus
  - z_0=10 cm (after center of und.)
  - 0.5 ps FWHM
  - Gap 8mm
- Chicane 20 cm after undulator
- ITR:
  - 38 cm after undulator
  - 0.6 mJ/pulse
  - 50 micron focus
  - 0.5 ps FWHM

Collimation of ±25μm about center (38% acceptance)

Total Energy Spread After Tape ~180 keV FWHM.

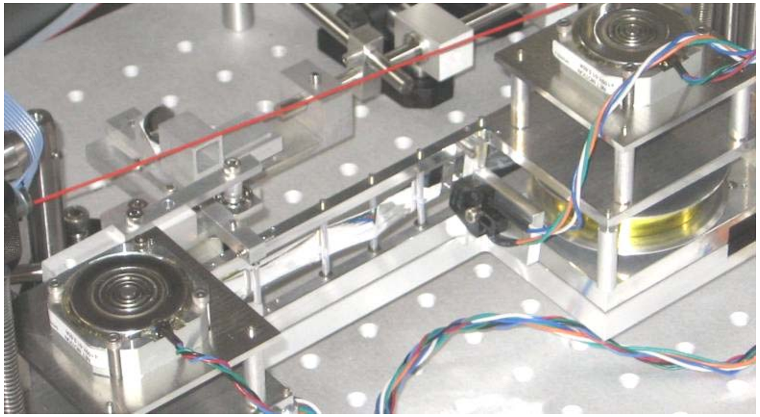
The Near Future of E163

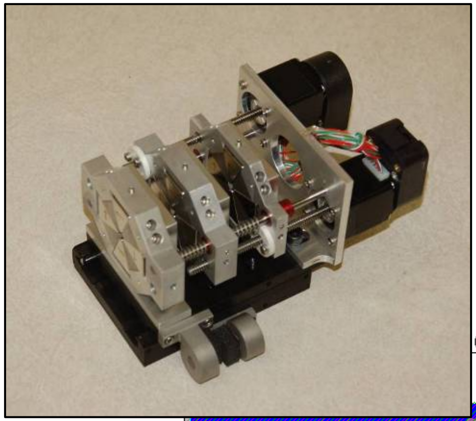
- Observe COTR/perform net acceleration experiment

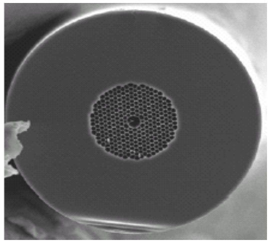
- Inverse Transition Radiation (ITR) studies – T. Plettner, THPMS080

- Ultra strong focusing & wakefield from PBG fibers – C. Sears, THPMS052

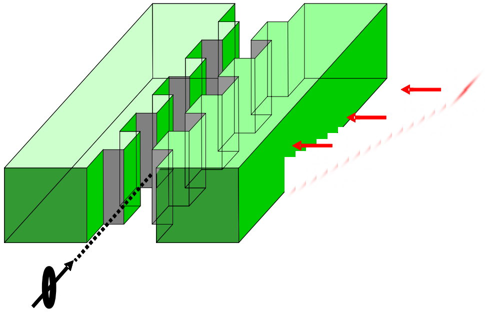
- First optical scale acceleration - THPMS050

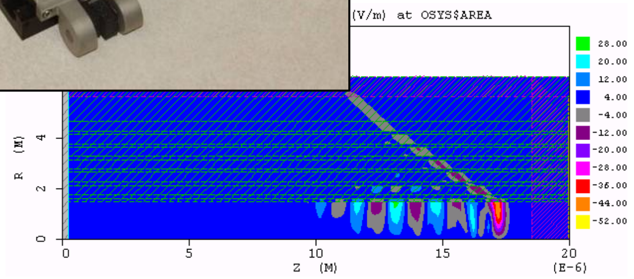






Thorlabs HC-1550-02 Photonic Crystal Fiber





Many Thanks

The E-163 Collaboration

Chris McGuinness | Bob Siemann | Bob Byer | Eric Colby | Chris Sears

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Not in photo Bob Noble, Dieter Walz

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- Janice Nelson, Doug McCormick, Justin May, Tonee Smith, Keith Jobe, and Richard Swent
- Zach Wolf & rest of magnetic measurement group
- Denise Larsen
- Roger Carr