E163: Laser Acceleration at the NLCTA

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Technical Roadmap

LEAP

1. Demonstrate the physics of laser acceleration in dielectric structures
2. Develop experimental techniques for handling and diagnosing picoCoulomb beams on picosecond timescales
3. Develop simple lithographic structures and test with beam

E163

Phase I. **Characterize laser/electron energy exchange in vacuum**

Phase II. **Demonstrate optical bunching and acceleration**

Phase III. **Test multicell lithographically produced structures**

Now and Future

1. Demonstrate carrier-phase lock of two ultra fast lasers [NIST, Stanford, SP]
2. Continue development of highly efficient DPSS-pumped broadband mode- and carrier-locked lasers [DARPA Proposal, SBIR Solicitation]
3. Devise power-efficient lithographic structures [CIS, SBIR Solicitation]
4. Devise stabilization and timing systems for large-scale machine [LIGO]
5. …

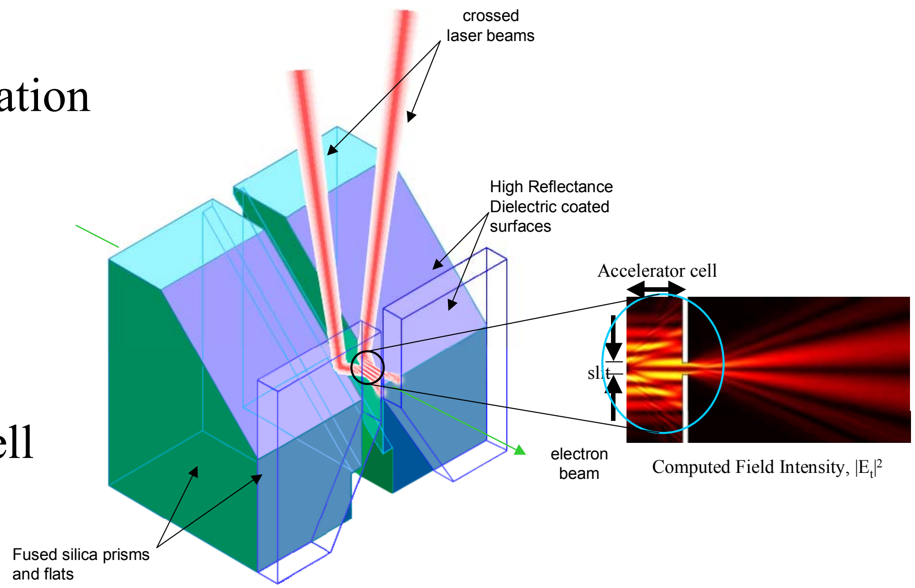
Damage Threshold Improvement →

Phase I: Laser Acceleration

Scientific Goals:

•Thoroughly characterize the dependencies of the energy modulation on:

- Interaction length
- Crossing angle
- Slit width
- Relative laser phase
- Physical tolerances of the cell

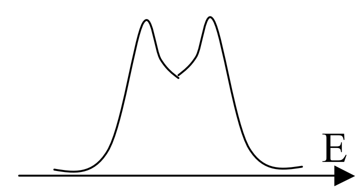


Technical Goals:

- Commission the experiment at the NLCTA

•Make progress understanding electric field breakdown issues and the attendant design implications

•Timing synchronization



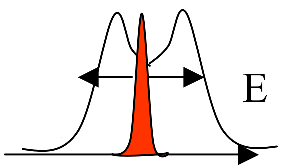
Phase II: Prebunch and Accelerate

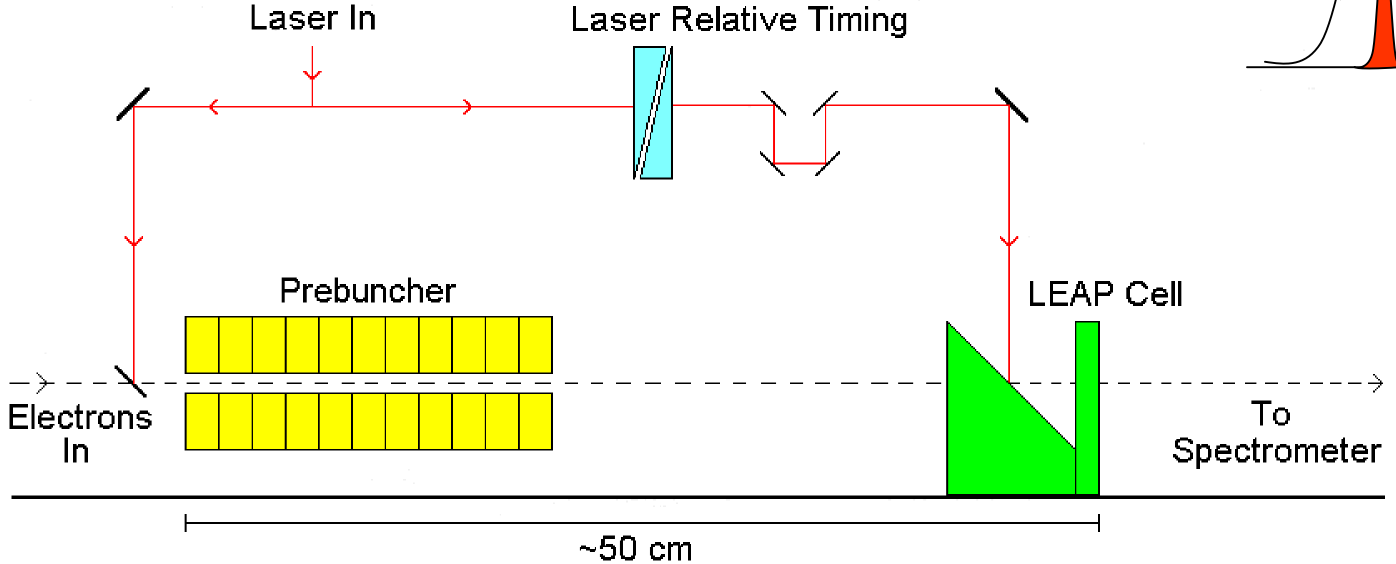
Scientific Goals:

- Demonstrate and quantify optical bunching
- Demonstrate and quantify acceleration
- Determine the impact of beam transport on bunching washout

Technical Goals:

- Commission the IFEL prebuncher
- Understand mechanical stability required to maintain attosecond-scale timing synchronism
- Implement optical bunching diagnostics





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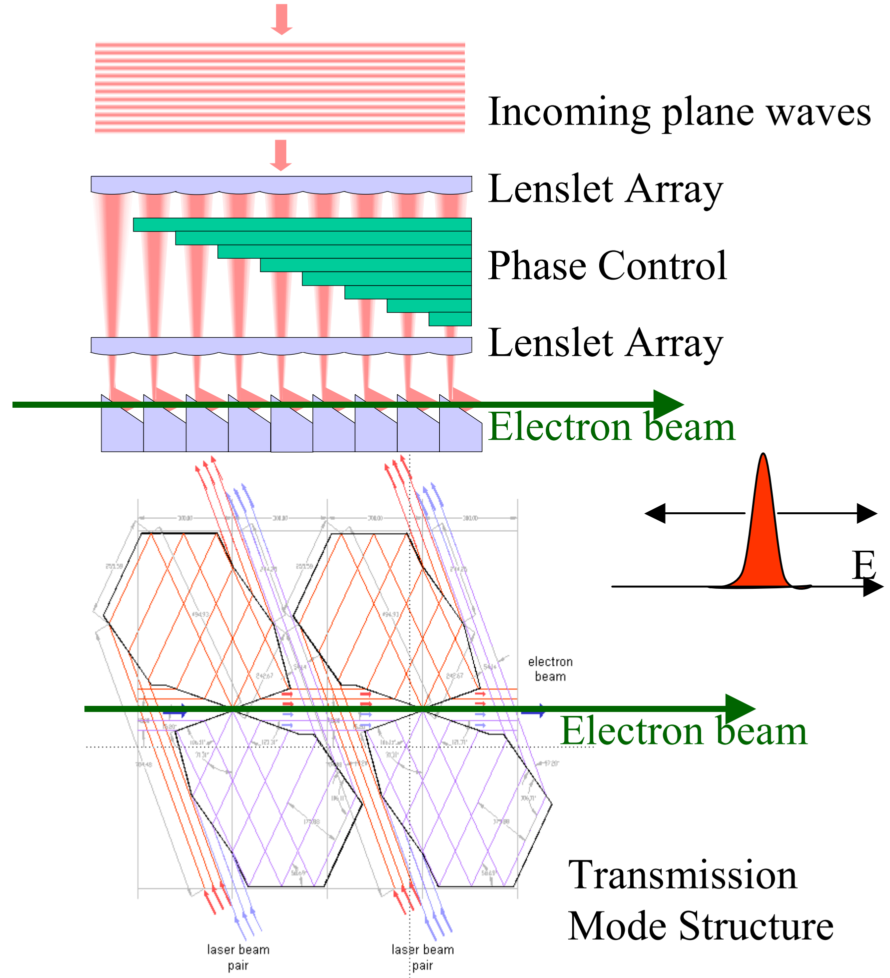
Phase III: Multicell Structures

Scientific Goals:

- Demonstrate multi-stage acceleration of optically bunched beam
- Quantify micropulse wakefields



Technical Goals:

- Master lithographic production techniques for silica or silicon microstructures
- Make progress understanding damage threshold issues
- Fabricate integrated accelerator components
- Devise and test methods of beam focussing

Experimental Requirements

Parameter	**Value**	**Comment**	**Present Values at HEPL**
Electron Beam Properties			
Bunch Charge	50 pC		**5 pC**
Beam Energy	60 MeV		**28 MeV**
Transverse Emittance	< 2.5 π mm-mr	Normalized	**10 π mm-mr**
Bunch Length	< 5 ps	FWHM	**~5 ps**
Energy Spread	< 20 keV	FWHM	**~20 keV**
Pulse Repetition Rate	10 Hz		**10 Hz**
Laser Beam Properties (for experiment)			
Pulse Energy	1 mJ		**1 mJ**
Pulse Wavelength	800 nm		**800 nm**
Pulse Length	0.1-10 ps	FWHM, variable	**1.0-10 ps**
Pulse Repetition Rate	10 Hz		**10 Hz**
Timing jitter w.r.t. electron beam	< 1 ps		**<3 ps**

EPAC Comments

October 4, 2001 Experimental Program Advisory Committee

Lynn Comminsky, Lance Dixon, Eckard Elsen, Emlyn Hughes, Joseph Lykken, Daniel Marlow, Hugh Montgomery, Matthias Neubert, Tor Raubenheimer, Jeffrey Richman, Aaron Roodman, Hitoshi Yamamoto, Ilan Ben-Zvi, David Rice.

1) We consider this work, with the combination of short (about 1 micron) wavelength that offers the potential for using highly efficient lasers and lithographic techniques in constructing structures to be very important.

2) The experiment would also be important as a first step towards Orion (which we also consider to be an important initiative).

3) As the first experiment in the Orion series, it is especially important that it have a high probability of success.

4) E163 will rely on a new rf gun to deliver a very high quality beam to the laser accelerator experiment. Specifically, the goal is to have a beam, which can be focused through slits with a width of 10 um or less, which also has a very small longitudinal energy spread of less than 0.03%.

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EPAC Comments

5) Developing the rf gun and delivering the high quality beam will take an extensive R&D effort. The proposal does not indicate how this will be achieved.

6) The proposal discusses bunch lengths less than 5ps but to keep the energy spread small in the x-band linac the bunch length must be the order of 250 fs. The studies to support the generation and propagation of such a beam are not presented.

7) The modifications to the NLC Test Accelerator are extensive. It would seem appropriate to detail these changes in much greater detail.

8) The expected acceleration as proposed is small and may easily be masked by jitter and drifts. A start to end calculation of all jitter and drift sources and comparisons to the signal are essential.

9) The 2nd phase experiment, using IFEL bunched beams, requires also a calculation of the survival of the bunching through the beam transport system.

Based on the above, we feel that the proposal, as presented, does not give the appropriate level of assurance of success, either by directly addressing key issues of jitter and beam optics, or by performing a consistent set of simulations using the parameters foreseen for the experiment.

Response: Changes to the NLCTA

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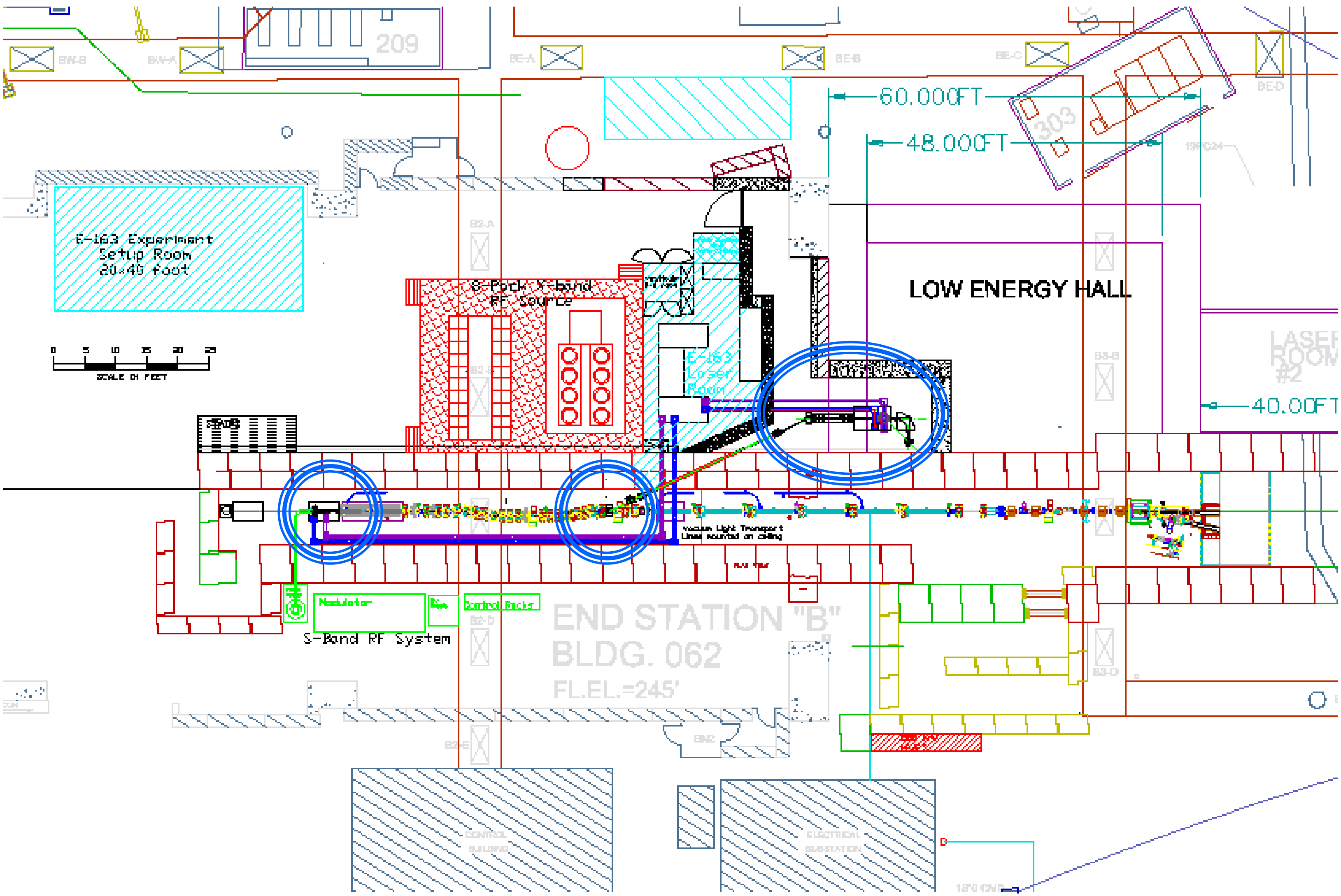

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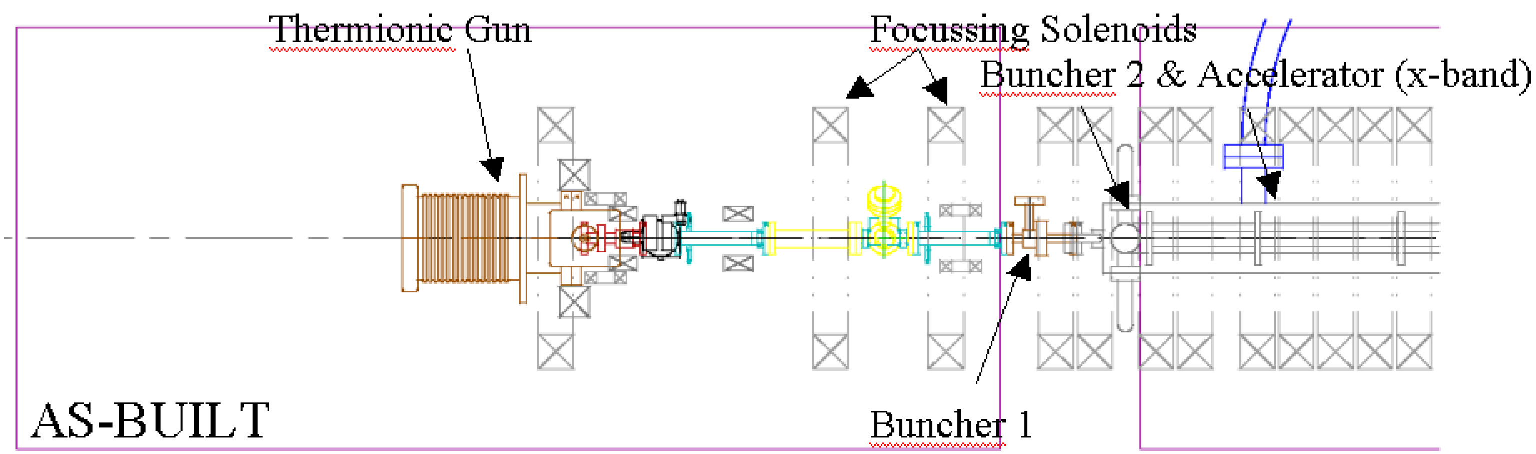
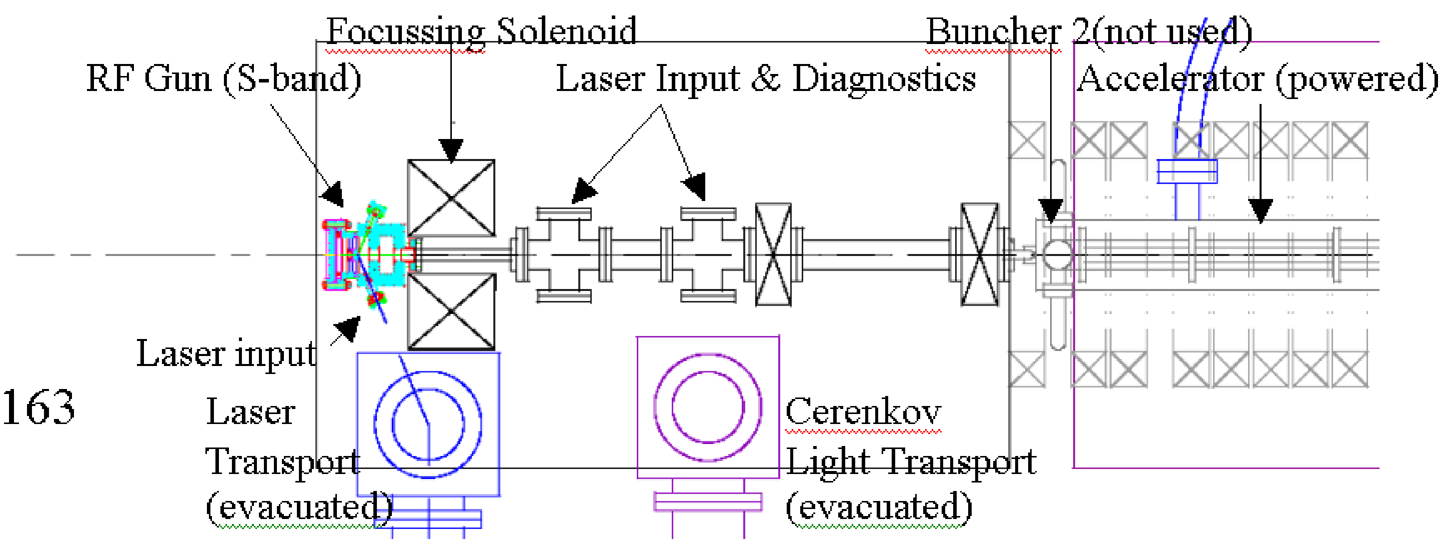
Response: Changes to the NLCTA





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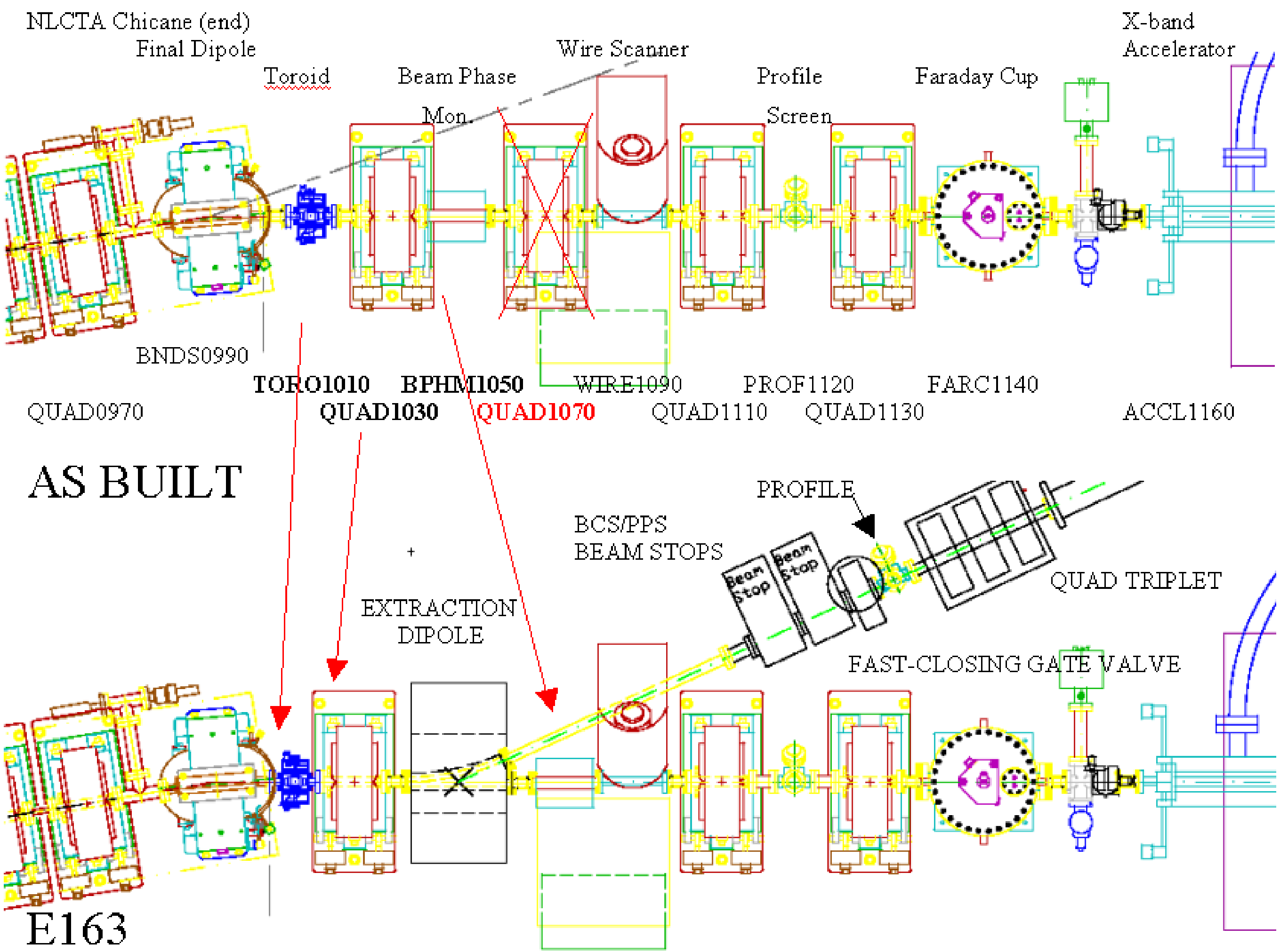

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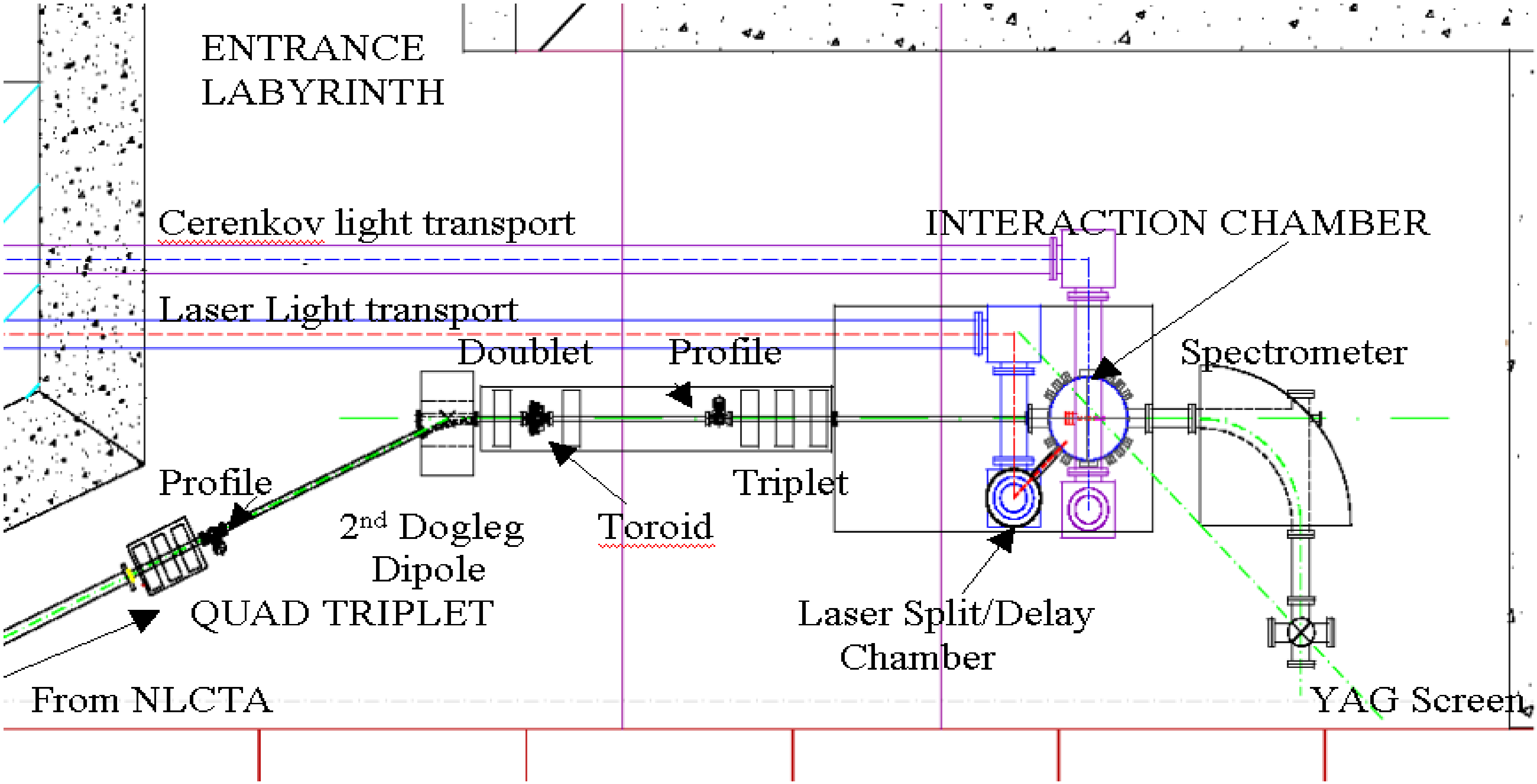

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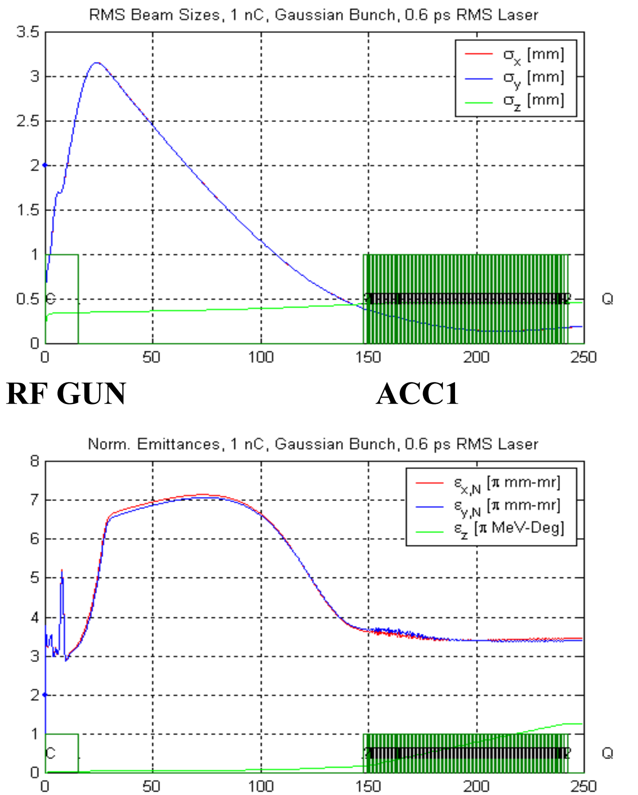
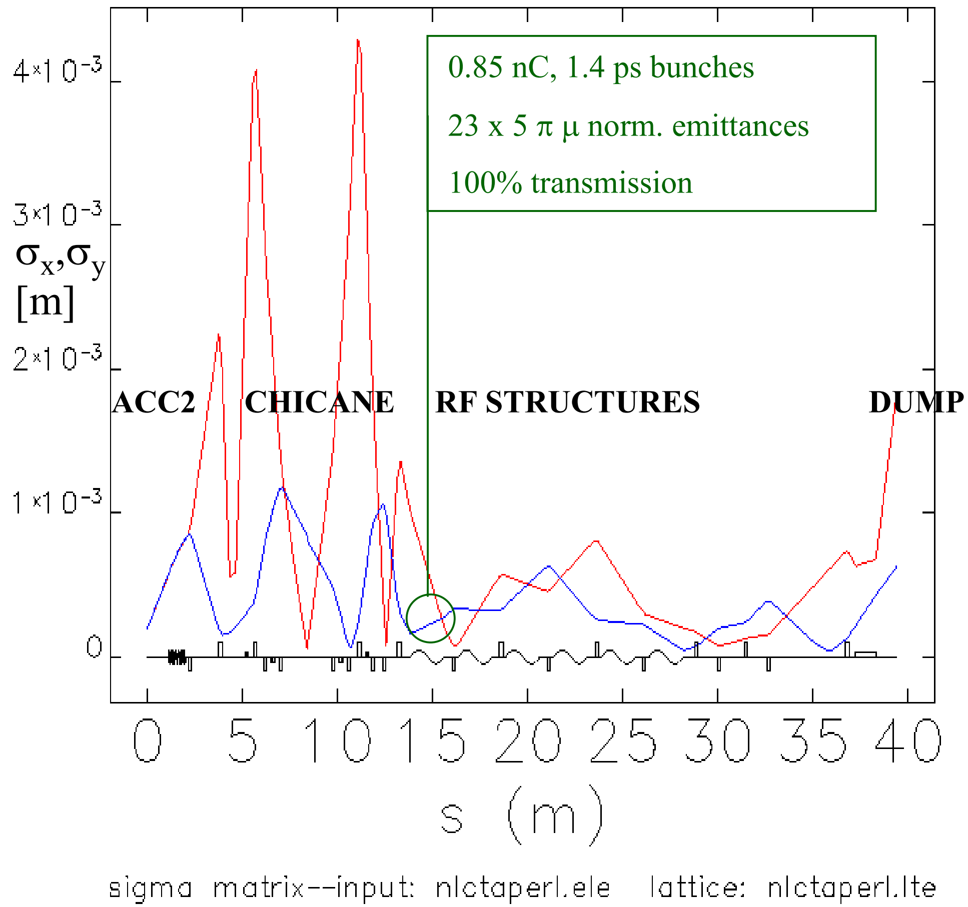
NLCTA 1nC Operation

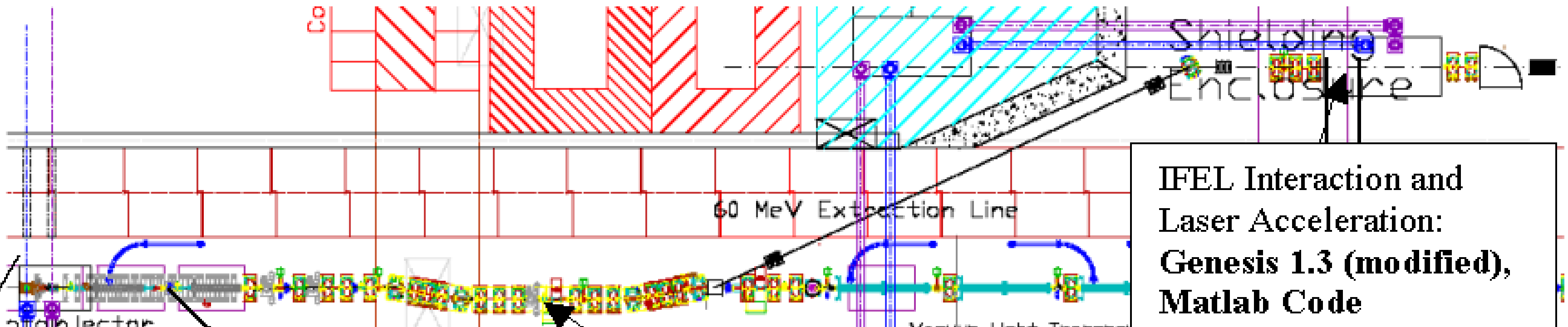


Parmela simulation of Gun+linac



Elegant simulation of remainder of NLCTA

E163 End-to-end Simulation



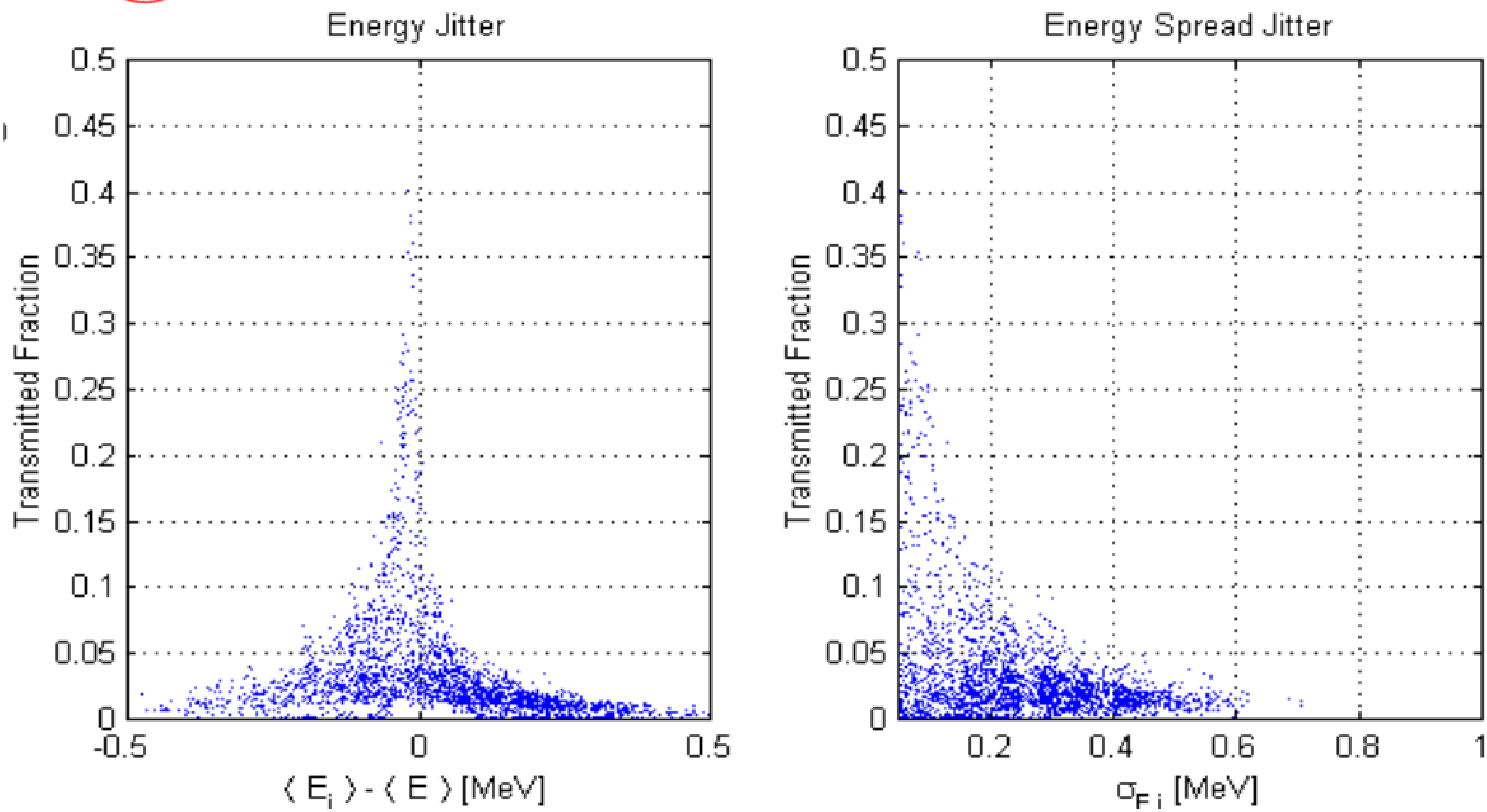
IFEL Interaction and Laser Acceleration: **Genesis 1.3 (modified), Matlab Code**

Electron generation and acceleration to 32.5 MeV: **Parmela** (UCLA/SLAC)

Electron transport through 2nd accelerator, chicane, dogleg, energy scraper: **Elegant 14.6β2**, with accelerator structure and collimator wakefields from analytic treatment in the NLC-ZDR, and initial magnet settings from 2nd-Order **Transport** optimization.

Remainder of Transport: **Elegant 14.6β2**

Collimation of Jitter



Mean energy and energy spread of bunches transmitted by the collimator. Measured NLCTA jitters of 1 ps RMS timing, 1% voltage and a 5% laser intensity are included.

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Simulated Null Interaction Data Sets

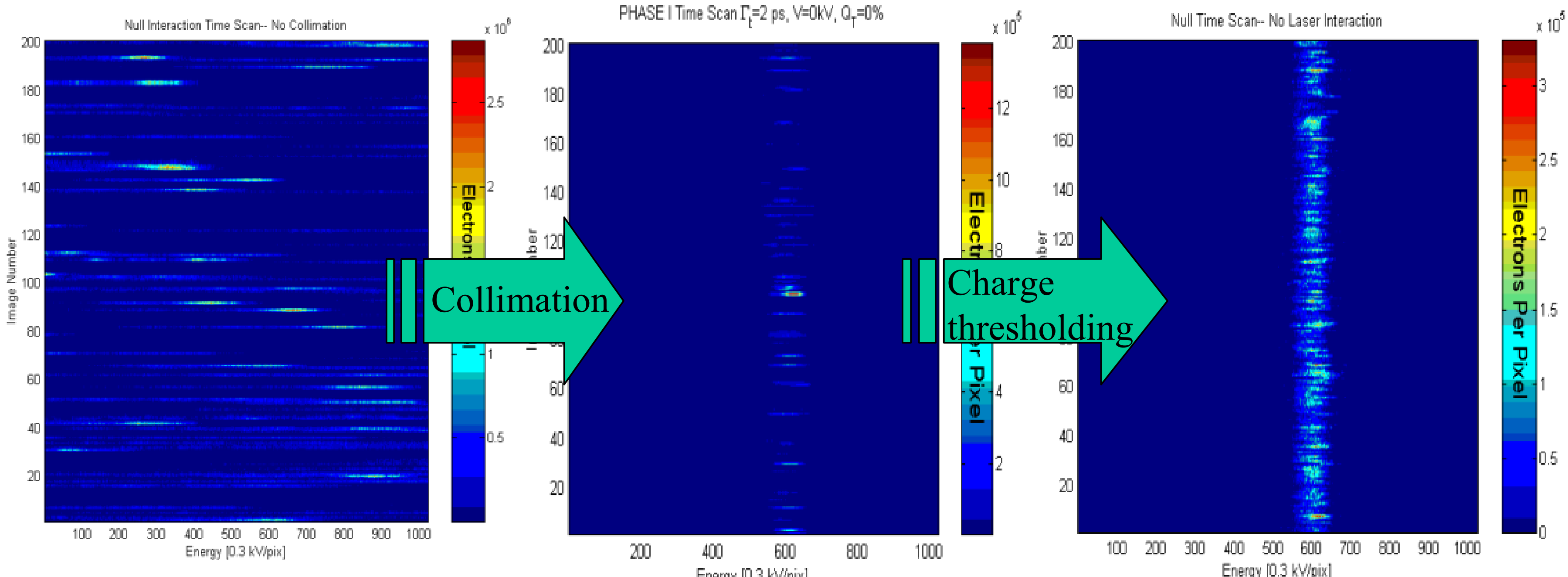

FIGURE 14. Null interaction time scan data sets: (left) with no collimation or charge thresholding, (center) with collimation only, and (right) with collimation and thresholding. Note that intensity per pixel has decreased an order of magnitude, but probe electron bunch has well defined energy characteristics. Bunch parameters and jitter are as in figures 12 and 13 above, but no laser interaction is present.

JITTER: (Meas. NLCTA) 5% Charge, 1% RF amplitude, 1 psec RF phase. (RMS).

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Simulated Optical Modulation Experiment (Phase I)

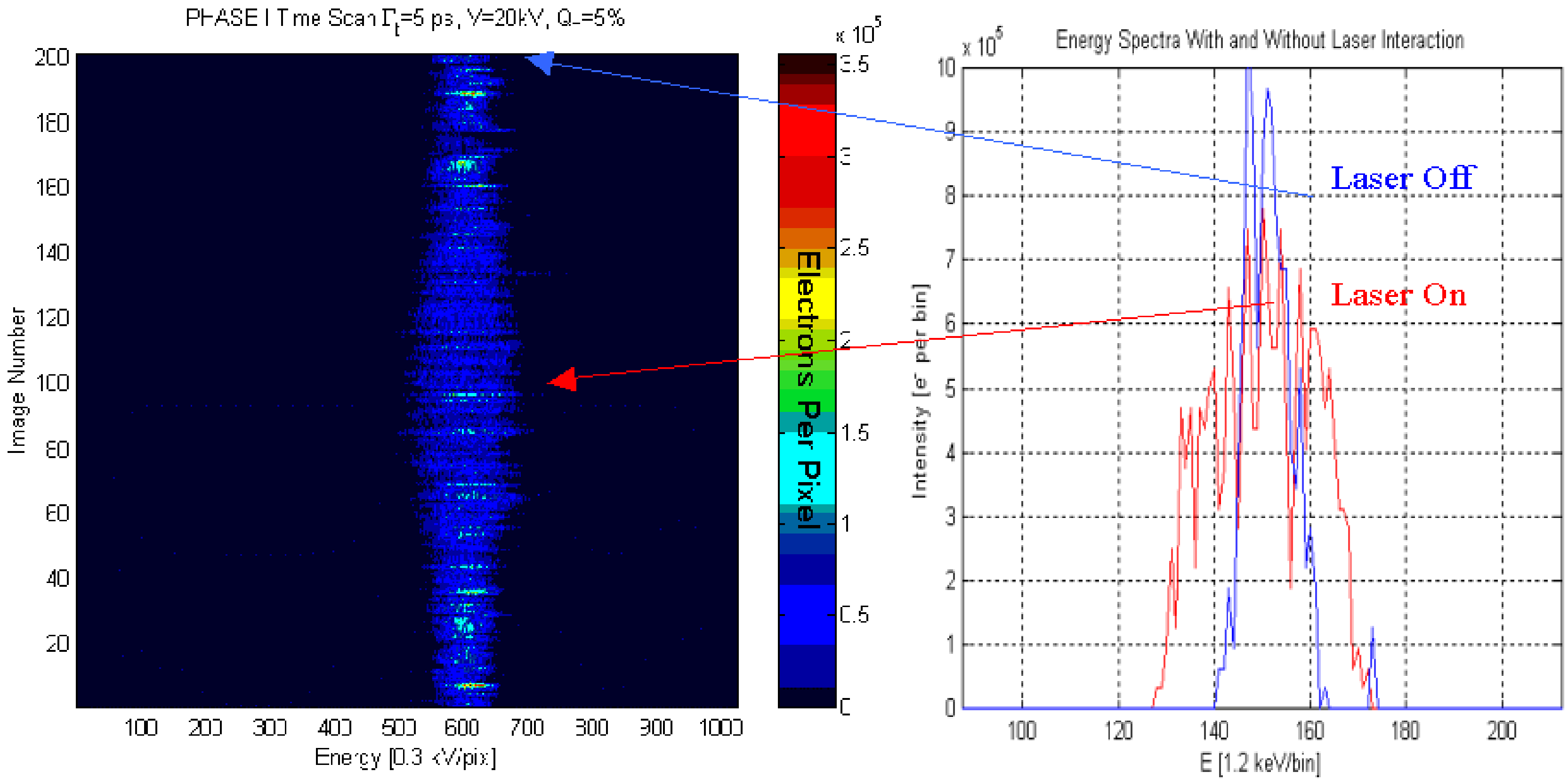

FIGURE 12. Simulated time scan data set (left), and comparison energy profiles for laser at full overlap (red) and out of time (blue), on an expanded scale. The relative timing between laser and electron bunch is swept from –5 psec to +5psec, with optimum overlap occurring at 0 psec (image #101). The laser pulse length is 5.0 ps FWHM, the laser-induced energy modulation amplitude is ±20 kV.

JITTER: (Meas. NLCTA) 5% Charge, 1% RF amplitude, 1 psec RF phase. (RMS).

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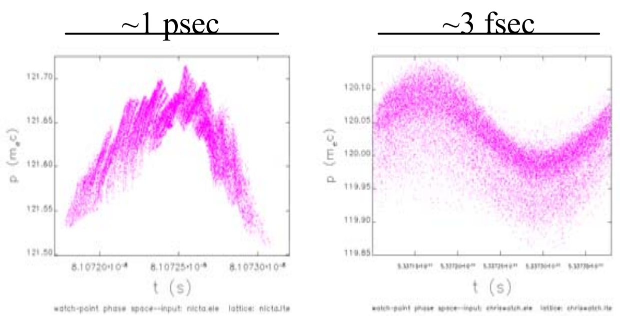
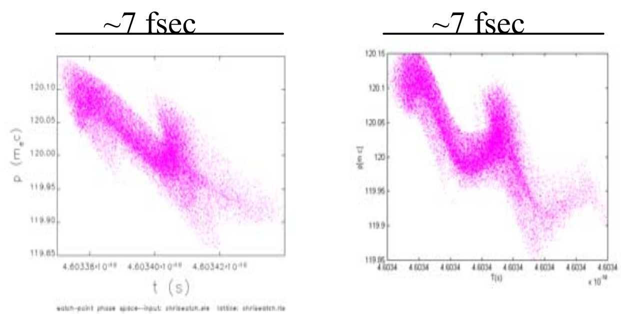
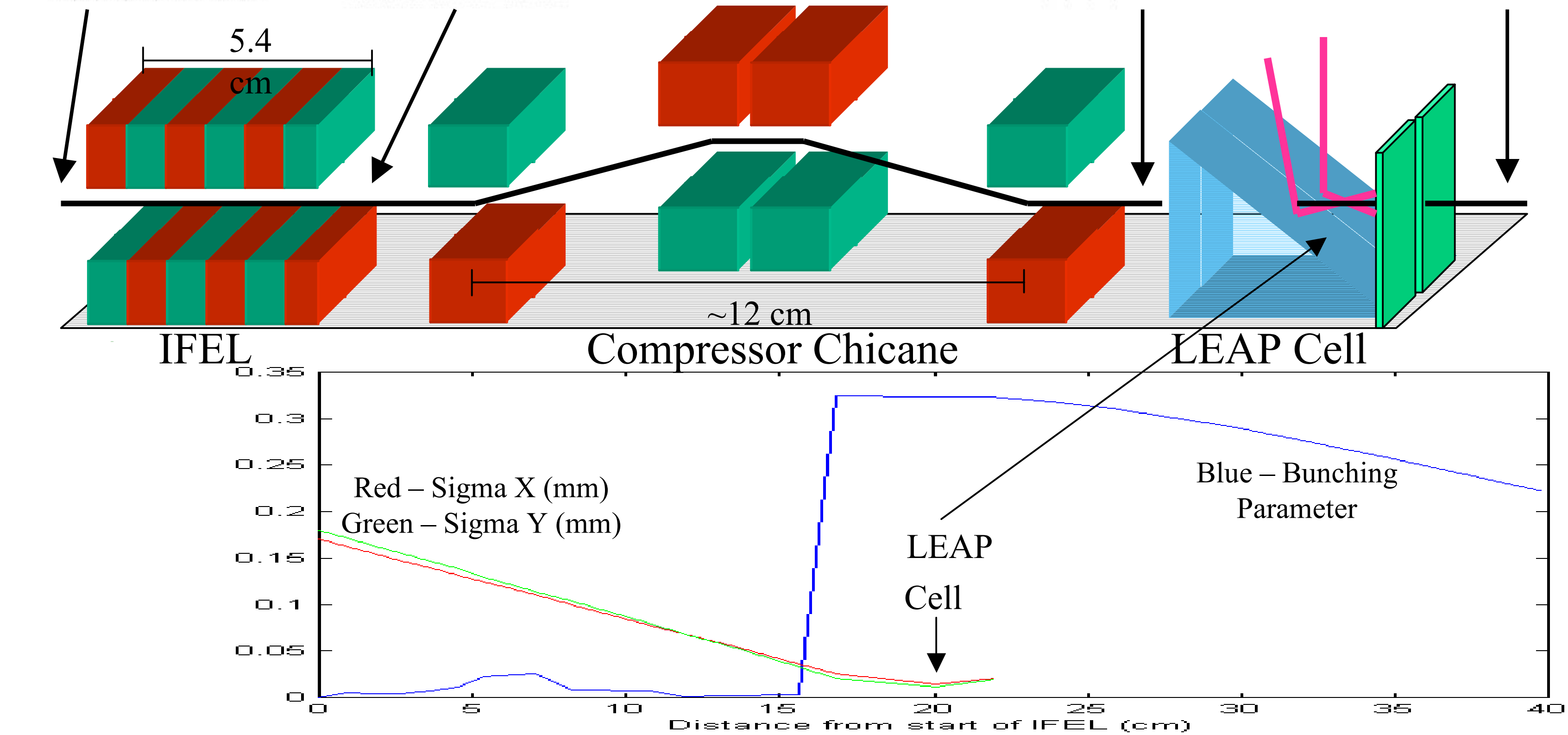


Christopher Barnes

8 February 2002





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Simulated Optical Bunching and Acceleration Experiment (Phase II)

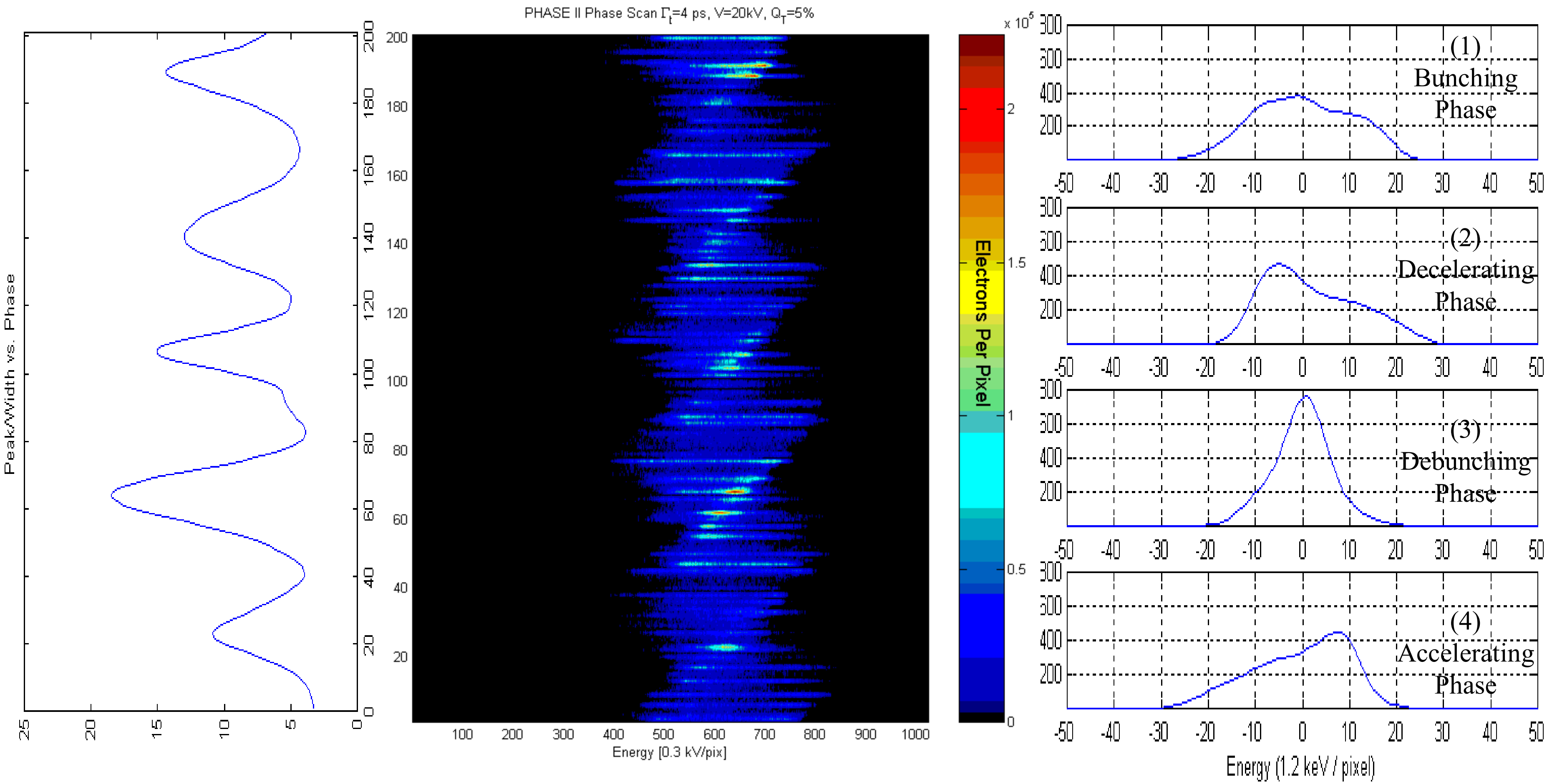

FIGURE 16. Charge density (left), simulated phase scan with jitter added (center), covering 10 π of variation in the relative phase between IFEL and laser accelerator, and averaged spectra (right) at (1) bunching, (2) decelerating, (3) debunching, and (4) accelerating phase.

JITTER: (Meas. NLCTA) 1% RF amplitude, 1 psec RF phase, 5% Charge. (RMS).

Summary

We have addressed the EPAC comments:

1. By detailing the changes to the NLCTA

2. By constructing a detailed numerical model of the entire beamline and experiment

Simulations have shown that the experiment is feasible