STI OPTRONICS

W. D. Kimura

ATF Users' Meeting, Jan. 8, 2004

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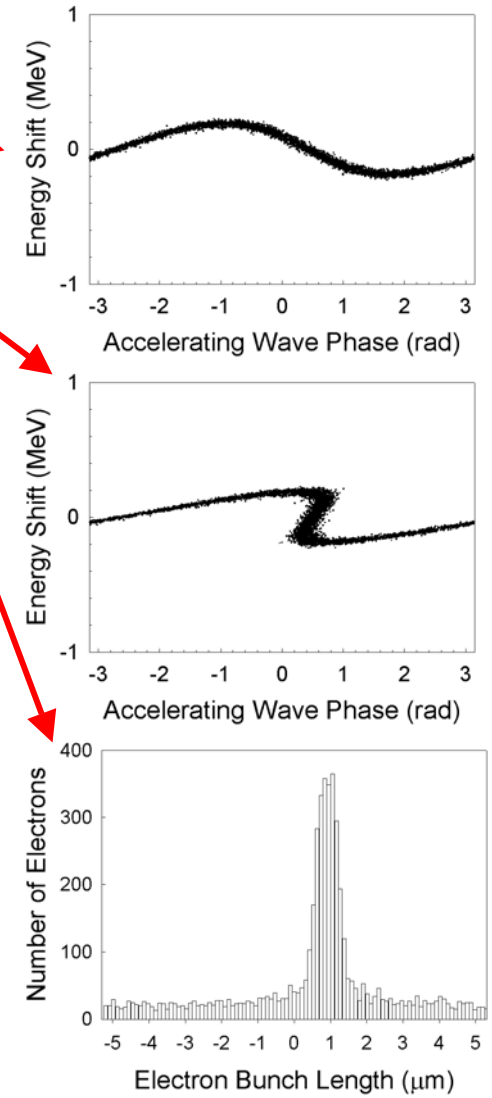
Motivation

- Laser-driven electron linear accelerators (laser linacs) offer potential for more compact, less costly accelerators with very high acceleration gradients
- A useful laser linac must have the following characteristics
  - Efficient trapping of electrons into ponderomotive potential well (“bucket”) of accelerating wave
  - Preserving narrow energy spread of trapped electrons during acceleration
  - These are critical for efficient staging of the acceleration process, which is is needed to achieve high net energy gain
- Most laser acceleration research has not focused on this issue
- Staged Electron Laser Acceleration (STELLA) experiment is first to demonstrate these important characteristics

Experimental Approach

- Basic approach is to first create microbunches
  - Modulate *e*-beam energy using laser light
  - Allow modulated electrons to drift or pass through chicane to create microbunches
  - Trap and accelerate microbunches in second laser accelerator
- Can apply basic approach to different laser acceleration methods
  - For convenience, chose to use inverse free electron laser (IFEL) as method
  - First IFEL modulates *e*-beam; second IFEL traps and accelerates microbunches
- Precursor STELLA experiment demonstrated microbunch formation and staging using IFELs [see W. D. Kimura, *et al.*, Phys. Rev. Lett. **86**, 4041-4043 (2001)]



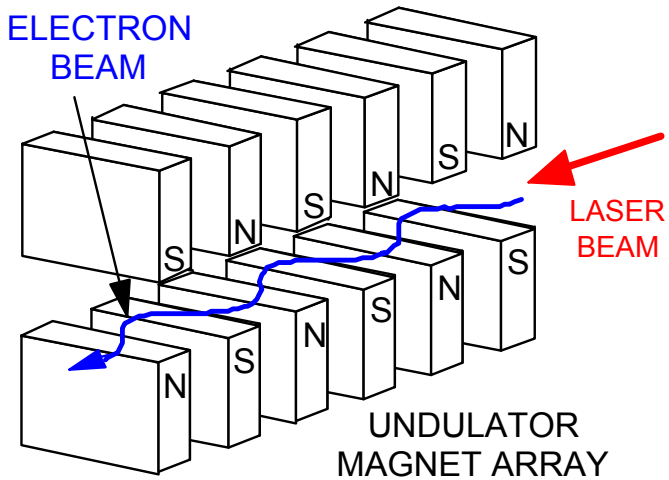
Inverse Free Electron Laser (IFEL)

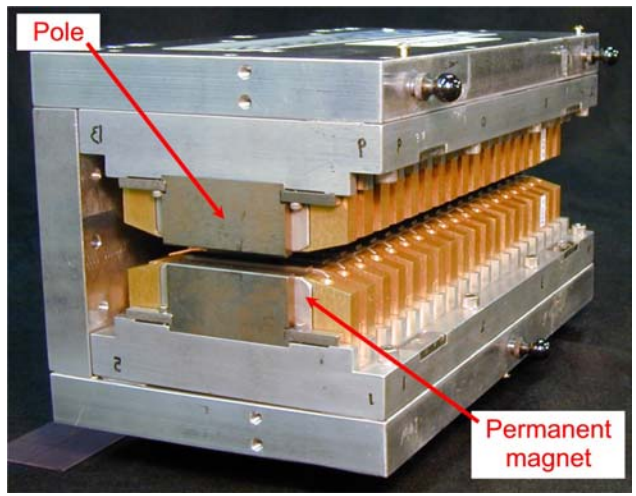
- Use periodic magnet array (wiggler/undulator) to cause electron trajectory to oscillate while traveling through array
- Net energy exchange between electrons and laser beam possible if resonance condition is satisfied

$$\gamma^2 = \frac{\lambda_w}{2\lambda_L}\left(1+\frac{K^2}{2}\right)$$

where λ_L = laser wavelength
λ_w = wiggler wavelength
γ = Lorentz factor
$K = eB_o\lambda_w/2\pi mc$
B_o = peak magnetic field

- Higher energy exchange possible using tapered wiggler/undulator

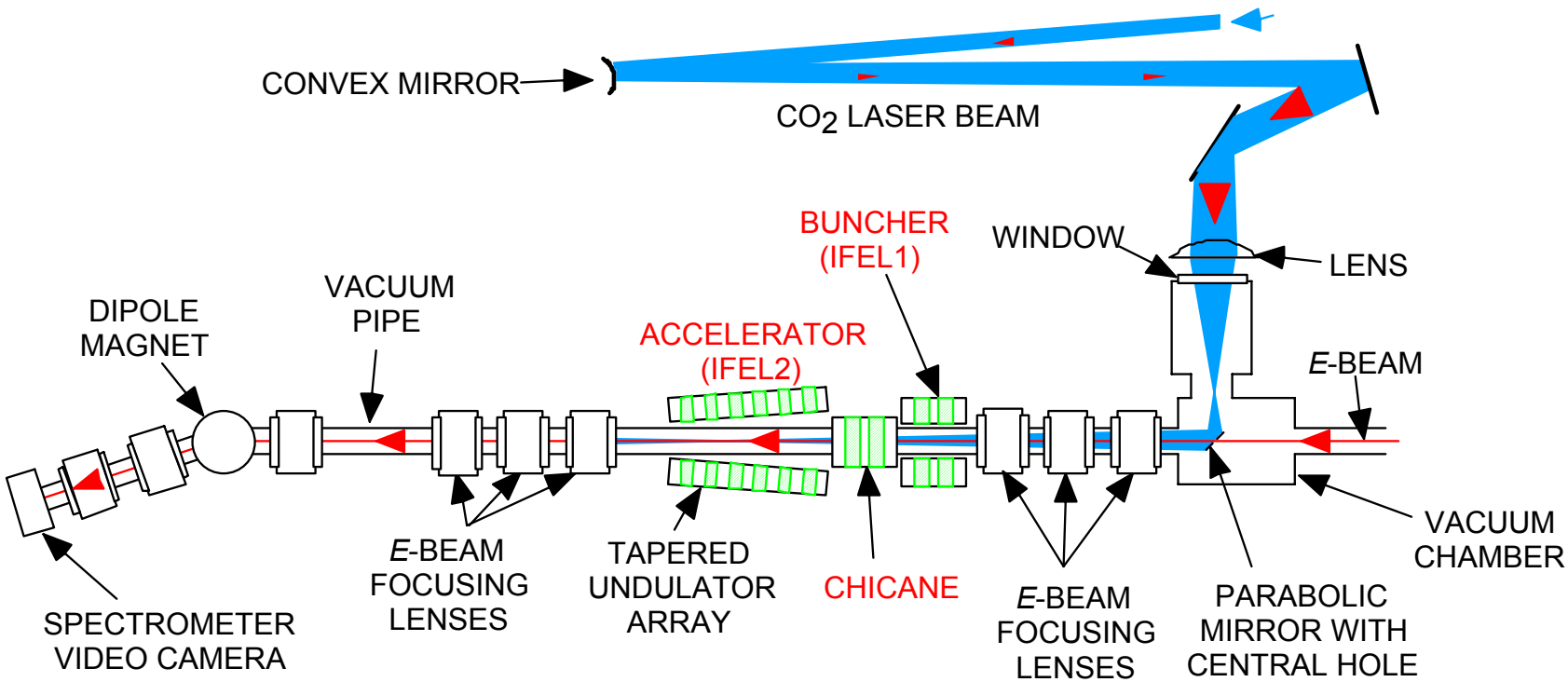




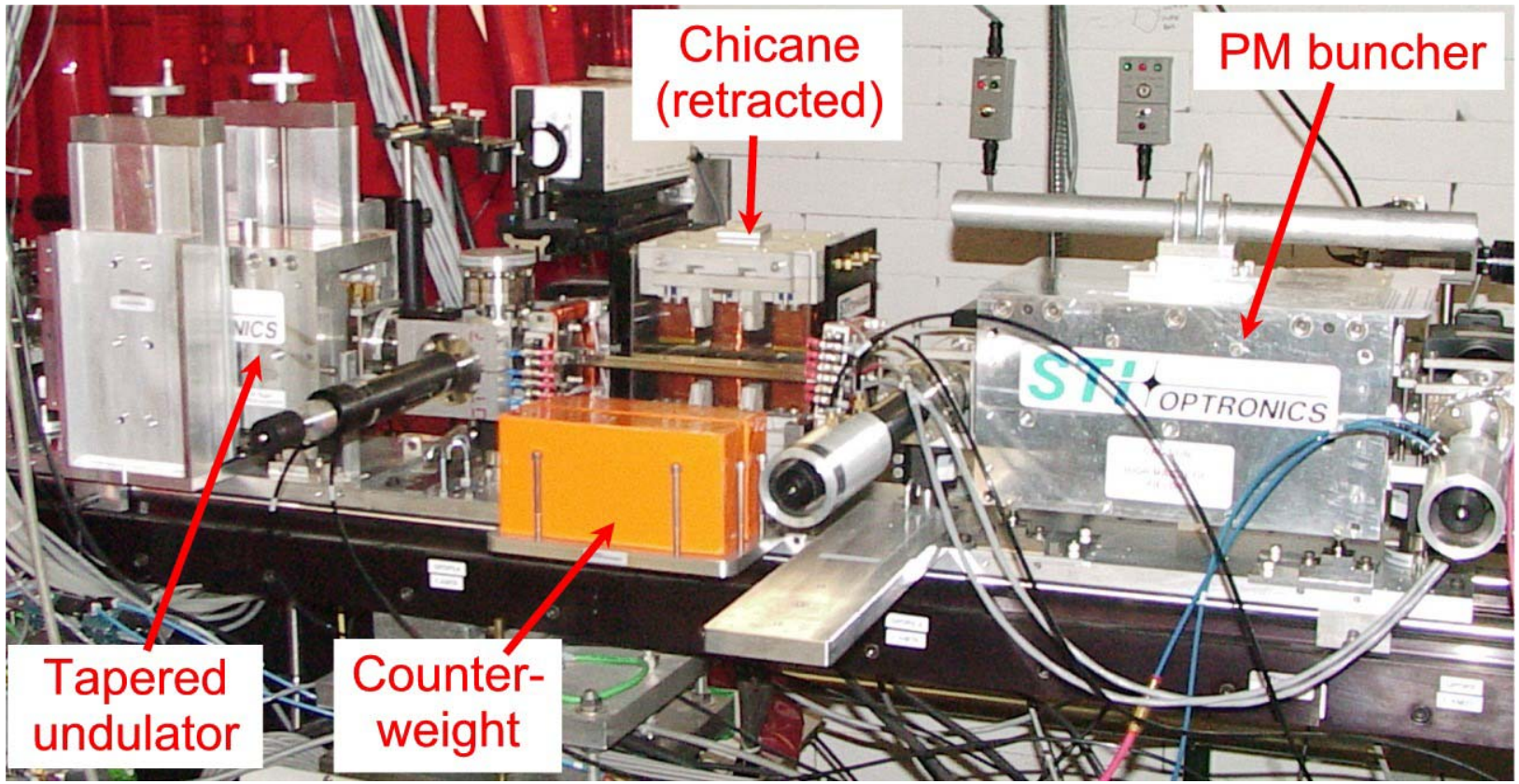
Description of STELLA Experiment

- Experiment located on Beamline #1 of ATF
  - Use 45.6-MeV *e*-beam, which is resonant energy for IFEL undulators
  - Use single 180-ps long ATF CO_2 laser beam to drive both IFELs
- First IFEL (IFEL1) is buncher
  - Designed to cause ~$\pm$0.5% energy modulation
  - Has large gap between magnet arrays to permit passage of wide laser beam
- Send modulated *e*-beam through hybrid permanent magnet (PM)-electromagnet (EM) chicane
  - Static PM field chosen to form microbunches at second IFEL (IFEL2)
  - Variable EM field used to adjust phase of microbunches entering IFEL2 with respect to the laser field inside IFEL2
- Second IFEL (IFEL2) is accelerator
  - Features 11% gap taper (12% energy taper)
  - Tapering important for efficient trapping and acceleration of microbunches

Schematic Layout of STELLA Experiment



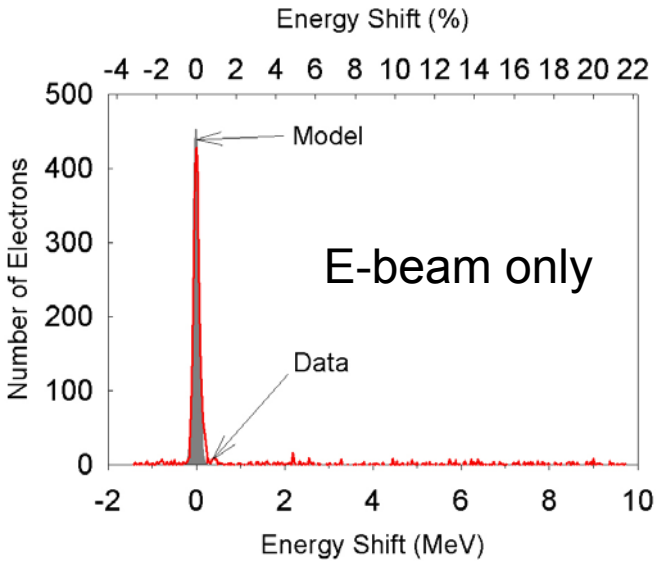
STELLA Experiment on Beamline #1

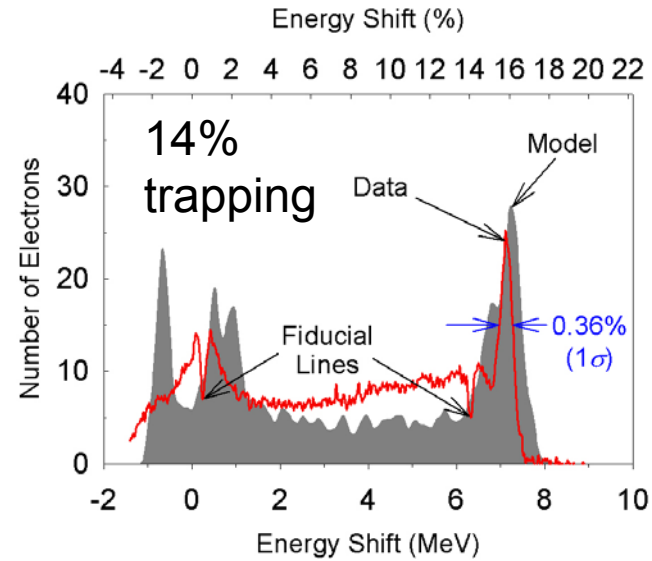


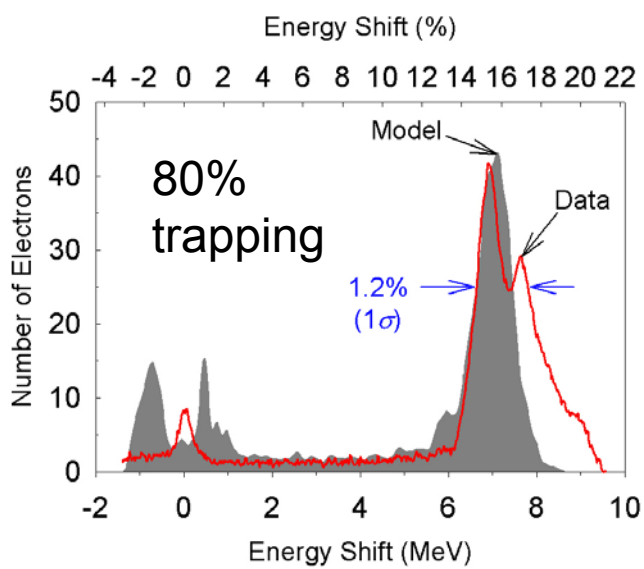
Successfully Demonstrated Monoenergetic Acceleration With High Trapping Efficiency

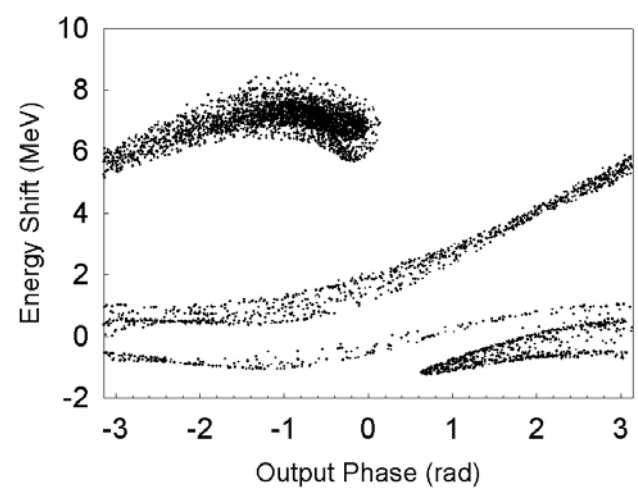
- ATF CO_2 laser delivered 1.7-2.7 TW/cm^2 intensity at center of IFEL2
  - Sufficient intensity to drive 11% gap-tapered undulator
  - Intensity lower in IFEL1 and sufficient to achieve $\approx\pm$0.5% modulation
- Measured *e*-beam energy spectrum using energy spectrometer at end of Beamline #1
  - Spectrometer able to capture entire modulated energy spectrum
  - Resolution of spectrometer is 0.14%
- Data spectrums show clean separation of accelerated microbunches from background electrons
  - Varying chicane EM field causes shift in microbunch energy gain
  - Peak energy gain of >20% is highest yet observed for IFEL
  - For 33-cm long undulator, represents acceleration gradient of >27 MeV/m

Examples of Experimental Results

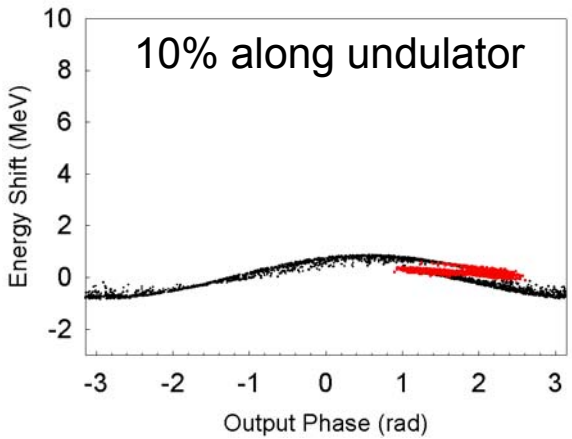


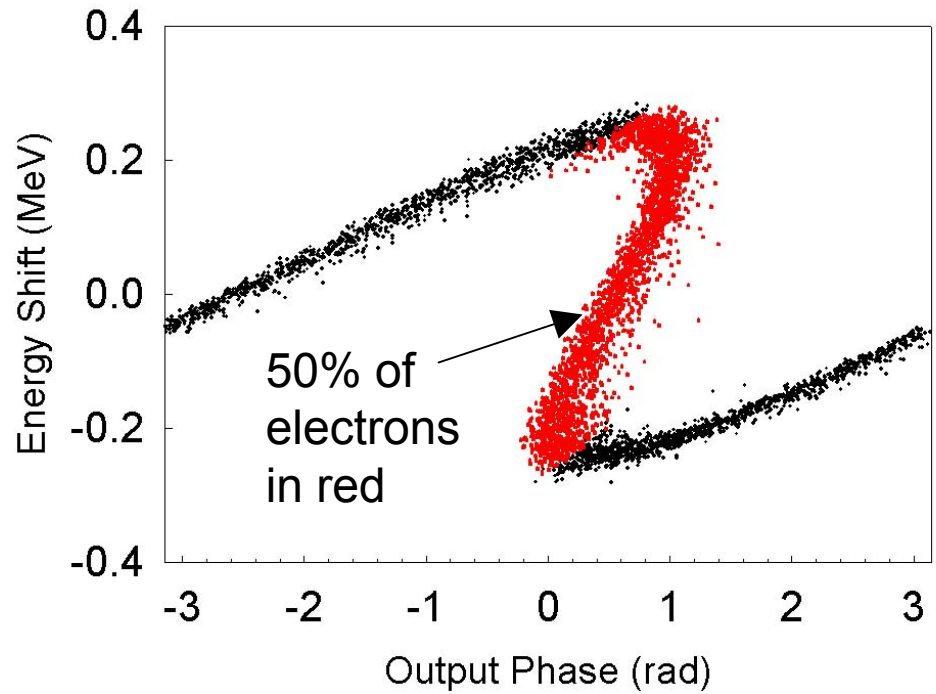






Model Simulation of Trapping Process





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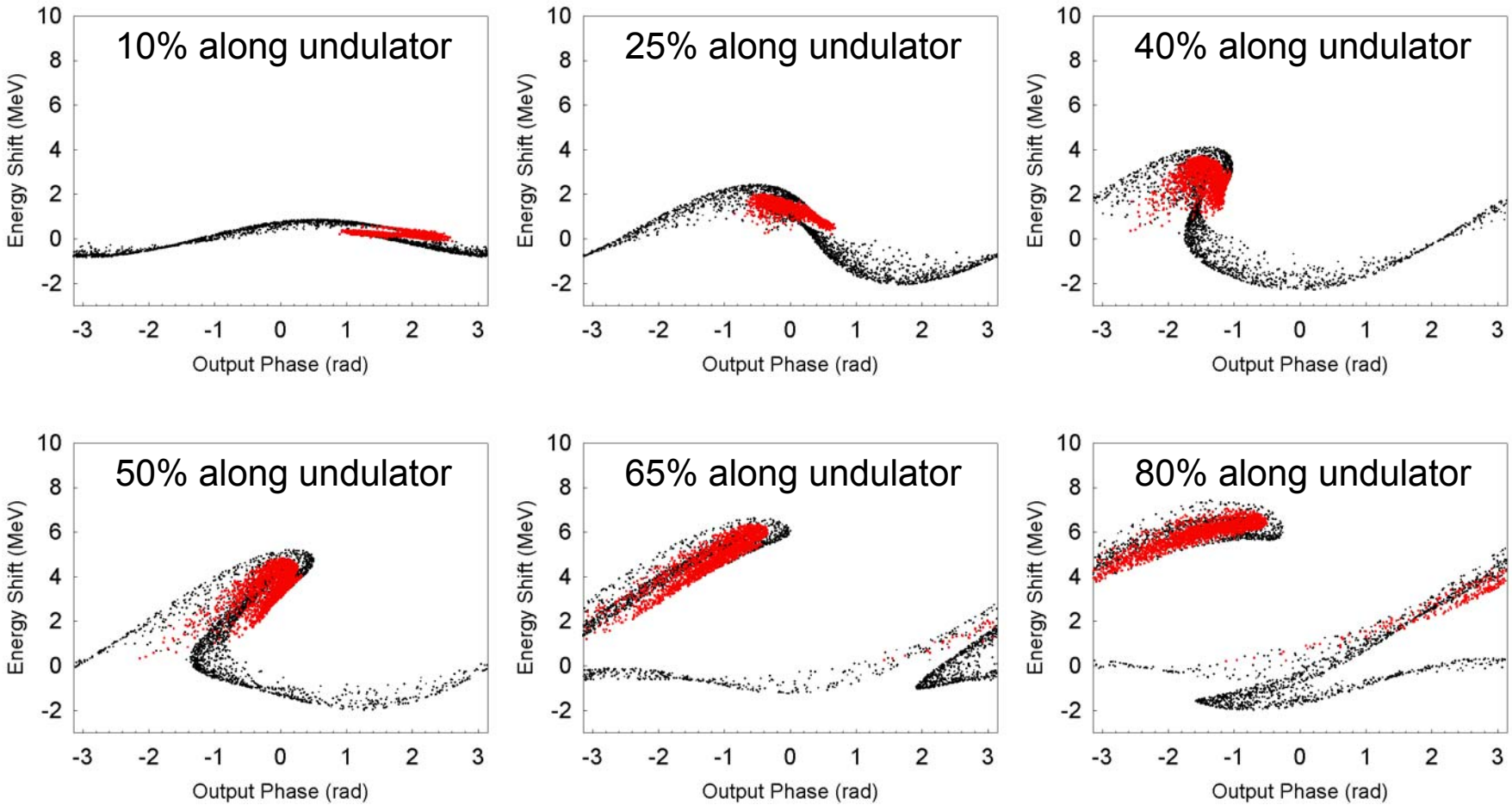
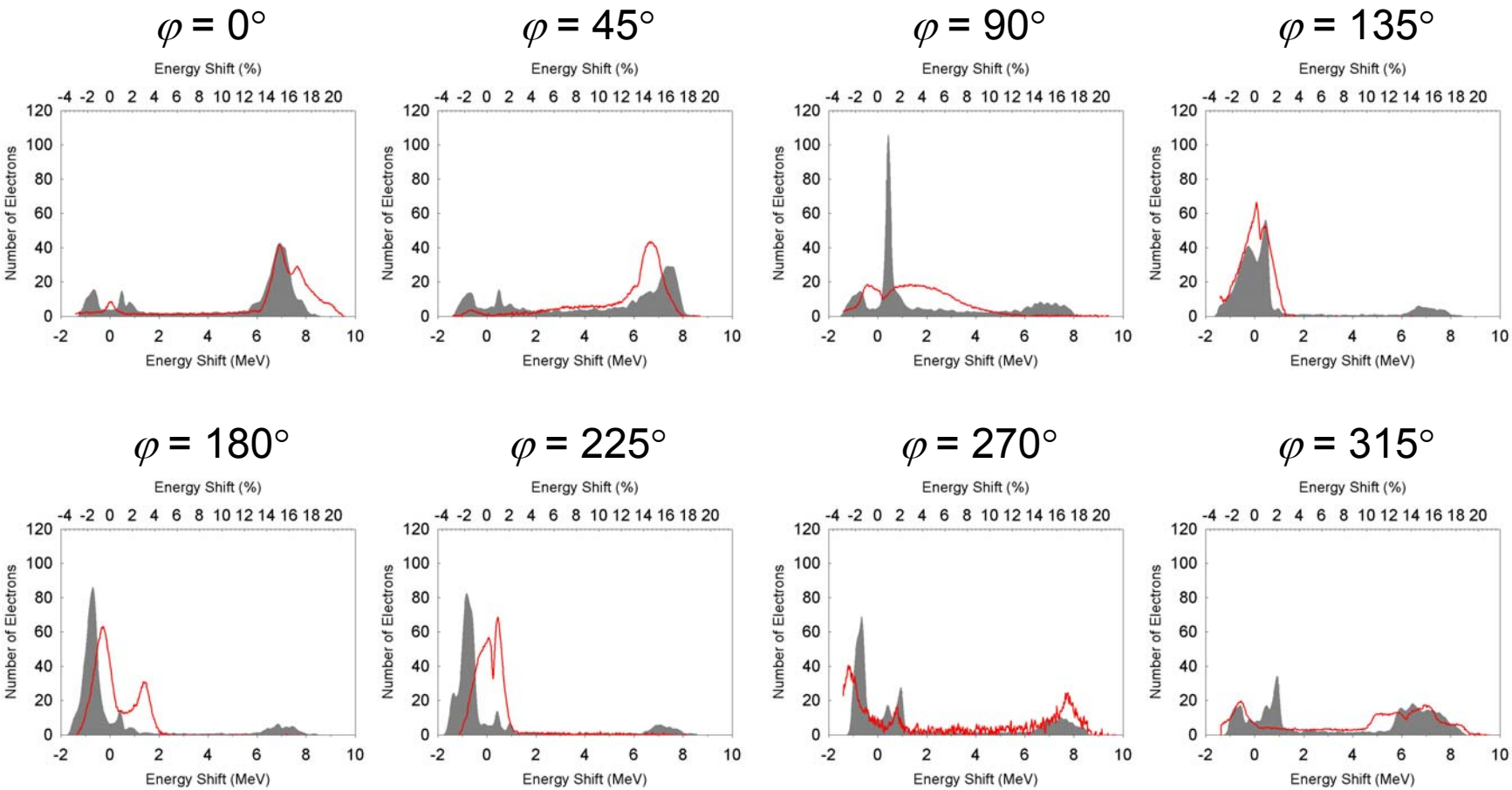


Experimental Results vs. Phase Delay



Discussion of Experimental Results

- Model agrees with data within accuracy of known parameters
  - Good agreement in gross features
  - Some disagreement in fine details
    - Fine details affected by precise overlap of *e*-beam and laser beam, etc.
    - Can only estimate values of certain parameters
- Intentionally operated near threshold for driving tapered undulator
  - Provides narrowest energy spread of trapped electrons
  - Also meant spectrums varied greatly due to natural shot-to-shot variations in laser beam pulse energy
    - Below threshold tapered undulator performs poorly
    - Hence, many laser shots collected during experiment

Basic STELLA Approach Can be Applied to Other Schemes

- IFEL chosen for convenience, has inherent scaling limitations
- STELLA-LW (short for STELLA Laser Wakefield) would apply basic STELLA approach to laser wakefield acceleration (LWFA)
  - First phase of STELLA-LW program recently approved by DOE
  - Will present STELLA-LW program for approval by ATF Program Committee
- First phase of STELLA-LW would:
  - Build upon past ATF capillary discharge (CD) work for plasma source
  - Diagnose CD using coherent Thomson scattering (CTS) for first time
  - Demonstrate LWFA at 10.6 μm for first time
- Ultimately in future phases would like to:
  - Demonstrate CO_2-laser-driven LWFA buncher
  - Combine with CO_2-laser-driven LWFA accelerator

Conclusions

- First demonstration of monoenergetic laser acceleration and high trapping efficiency
  - Observed >20% energy gain
  - Observed up to 80% trapping efficiency
  - Observed energy width of accelerated electrons as low as 0.36% (1σ)
  - Demonstrated ability to control microbunch phase using chicane
  - Model agrees well with data
- STELLA-LW experiment will apply the STELLA basic approach to laser wakefield acceleration
  - STELLA-LW team of collaborators includes LWFA and capillary discharge experts
  - ATF has already demonstrated key components of experiment
- STELLA success brings us closer to someday realizing a practical laser linac