Optimization of High Repetition-rate Laser Wakefield Accelerators Using Machine Learning Techniques

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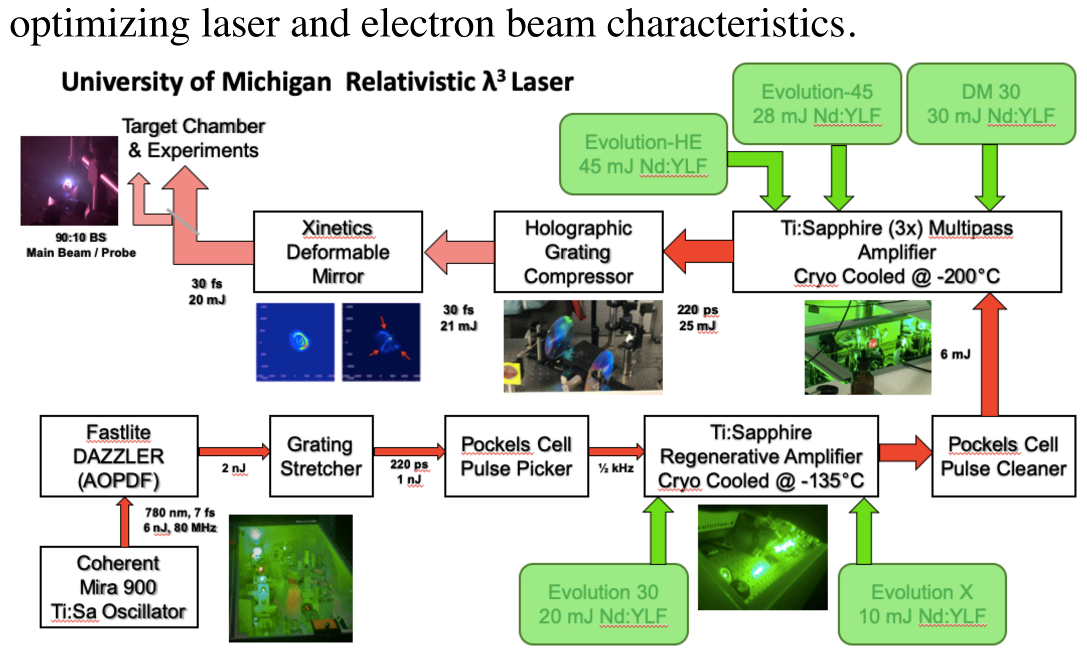
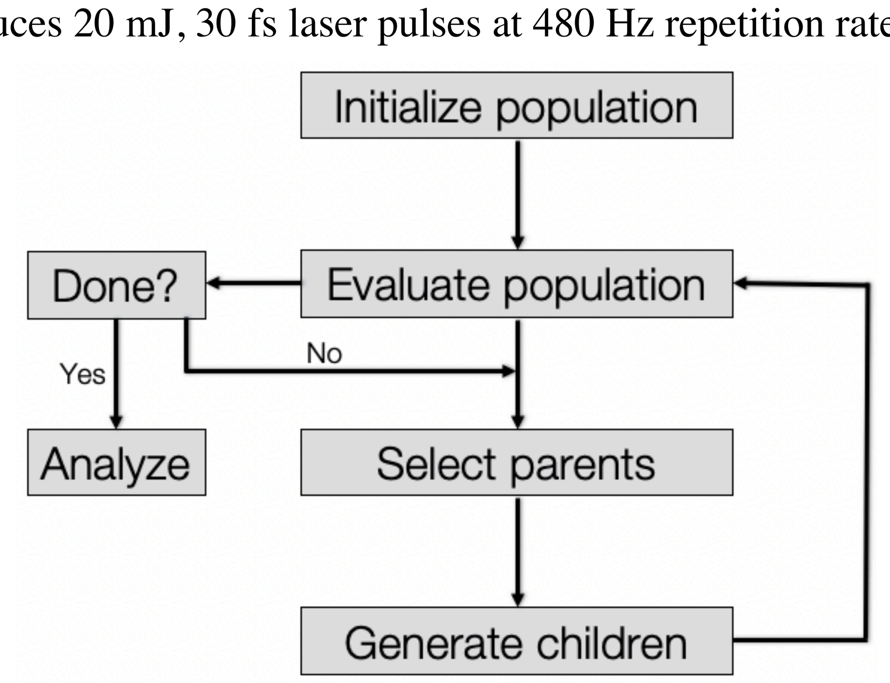
Introduction

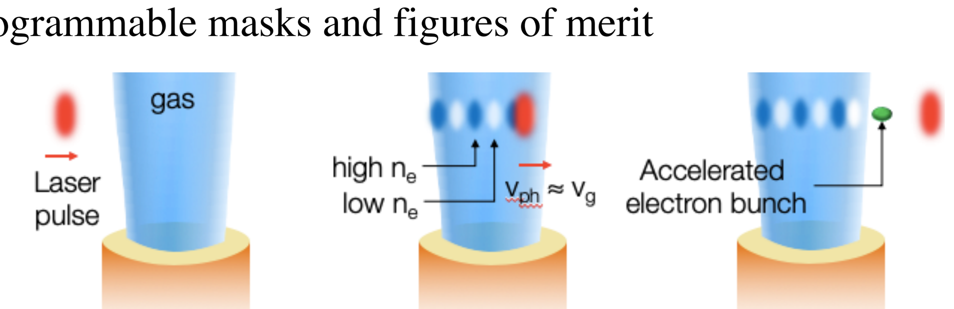
20 milliJoule pulses are generated at kilohertz repetition rate for pulse self-compression and laser wakefield acceleration experiments. A genetic algorithm is implemented using a Dazzler acousto-optic programmable dispersive filter (AOPDF) with the laser pulse characteristics from FROG measurements or wakefield electron beam characteristics optimized onto several different masks used as feedback. Additionally, the algorithm is applied to a deformable mirror for use with optimizing laser and electron beam characteristics.



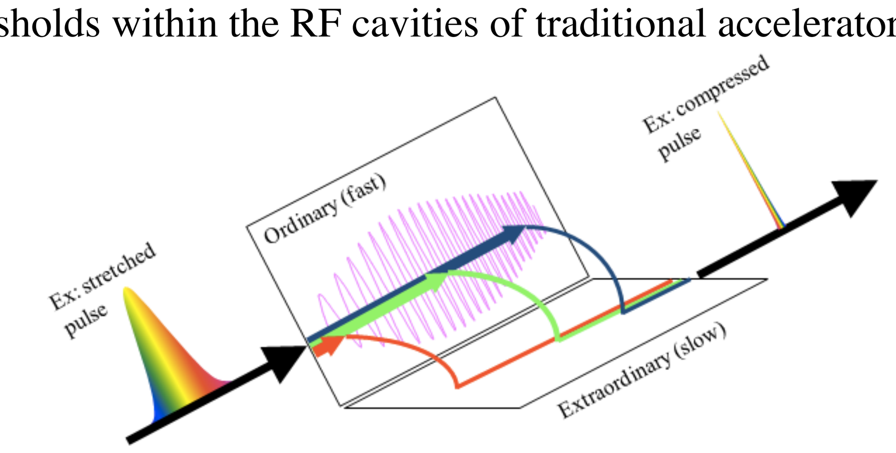
The lambda-cubed laser system at the Gérard Mourou Center for Ultrafast Optical Science at the University of Michigan produces 20 mJ, 30 fs laser pulses at 480 Hz repetition rate



The genetic algorithm is an adaptive learning method inspired by the process of biological evolution. It is administered via a python program and our deformable mirror or Dazzler to perform optimizations of a multitude of signals using different programmable masks and figures of merit

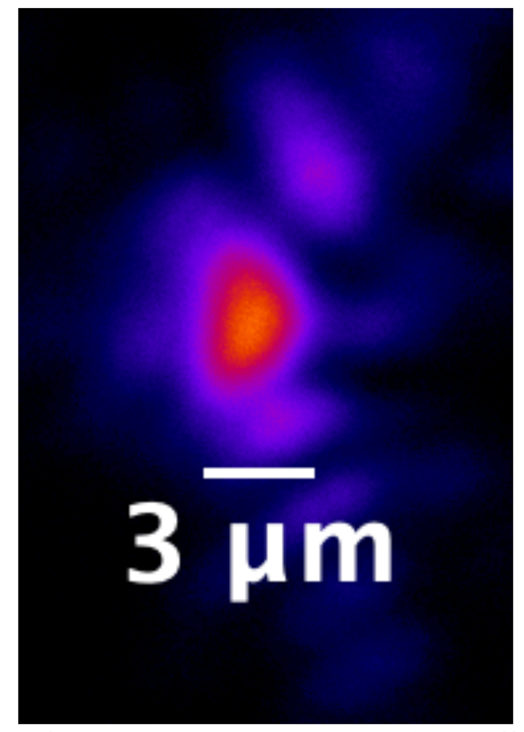


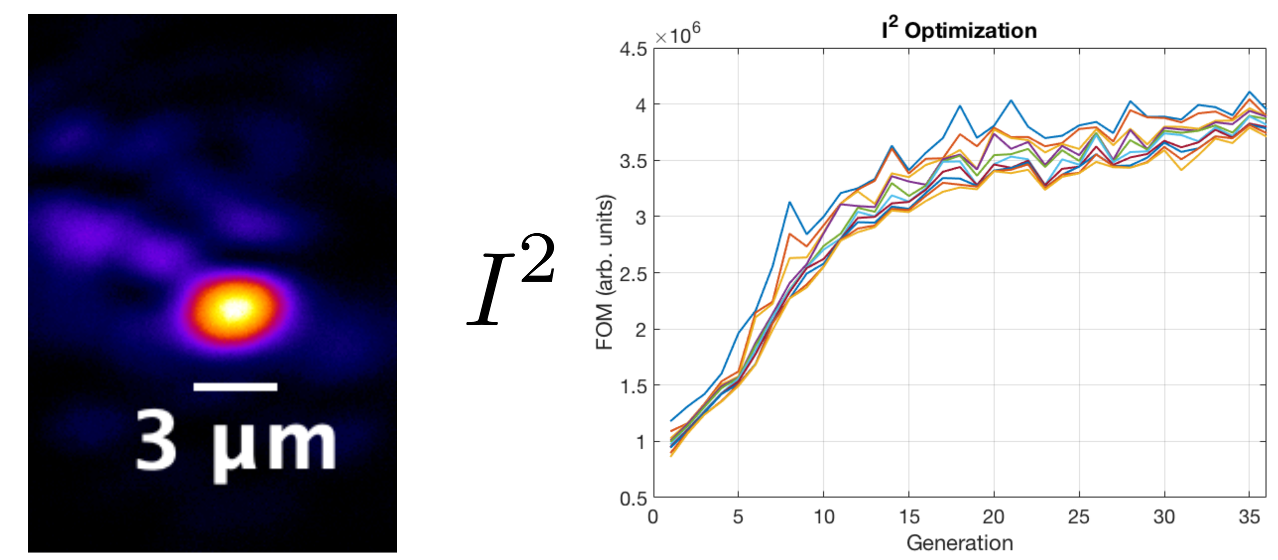
A cartoon showing the basic principle of laser wakefield acceleration. Here, plasma waves form and provide very high (100 kV/μm) accelerating fields that greatly exceed breakdown thresholds within the RF cavities of traditional accelerators.

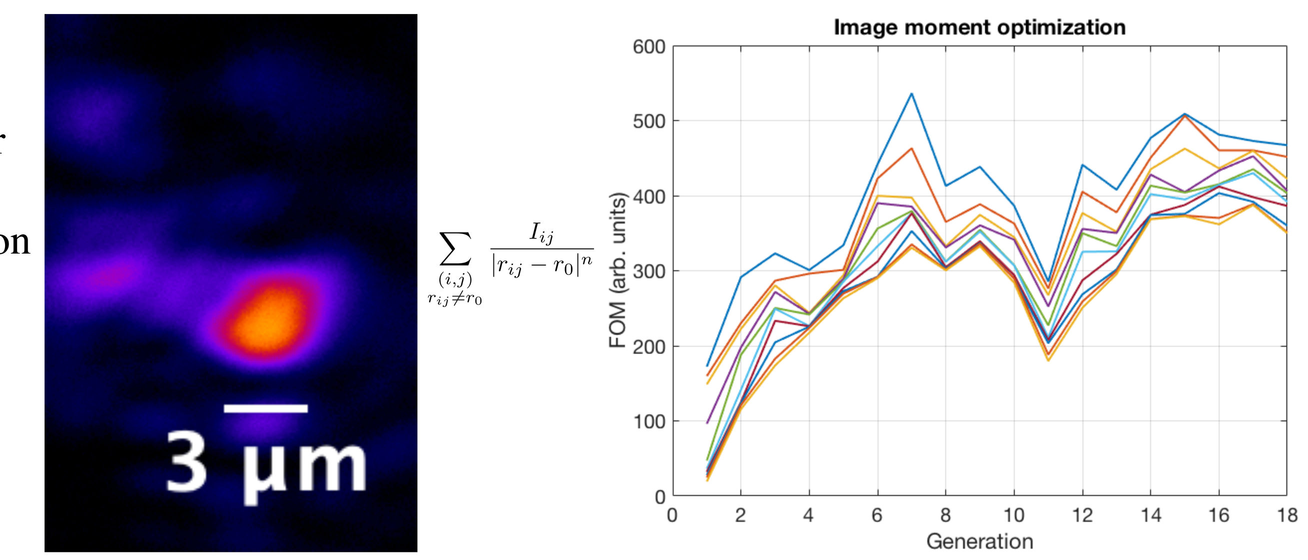


Schematic of the Dazzler AOPDF's operation [1]

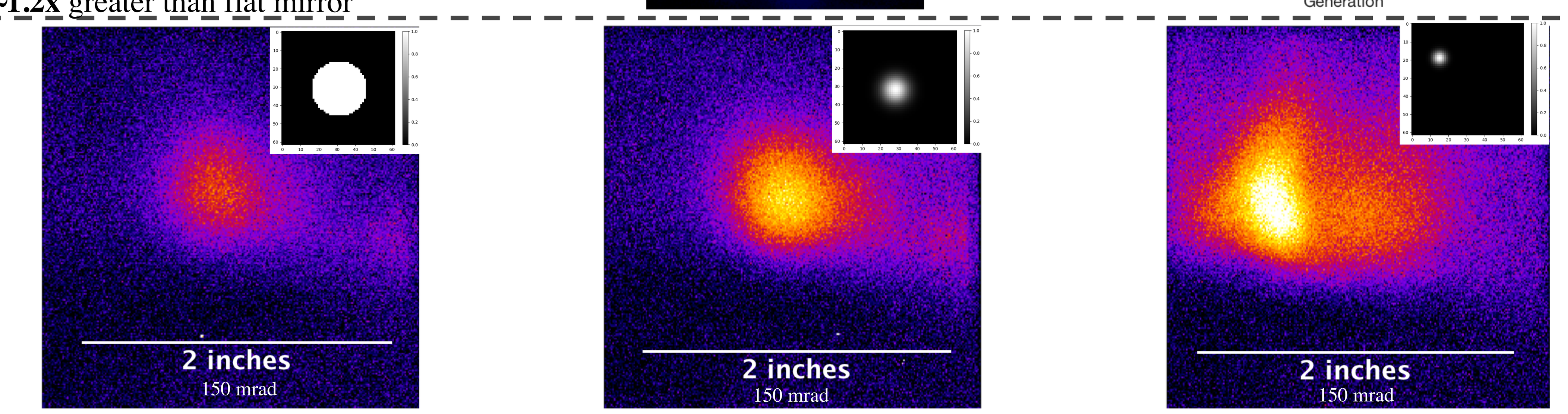
Figure of Merit Choice







Above: Focal spot measurement with a flat mirror (0 V on all DM actuators)
Right, top: Focal spot measurement and generation chart for optimization using I² fitness function, peak pixel brightness **~2x** greater than flat mirror
Right, bottom: Focal spot measurement and generation chart for optimization using image moment fitness function, peak pixel brightness **~1.2x** greater than flat mirror



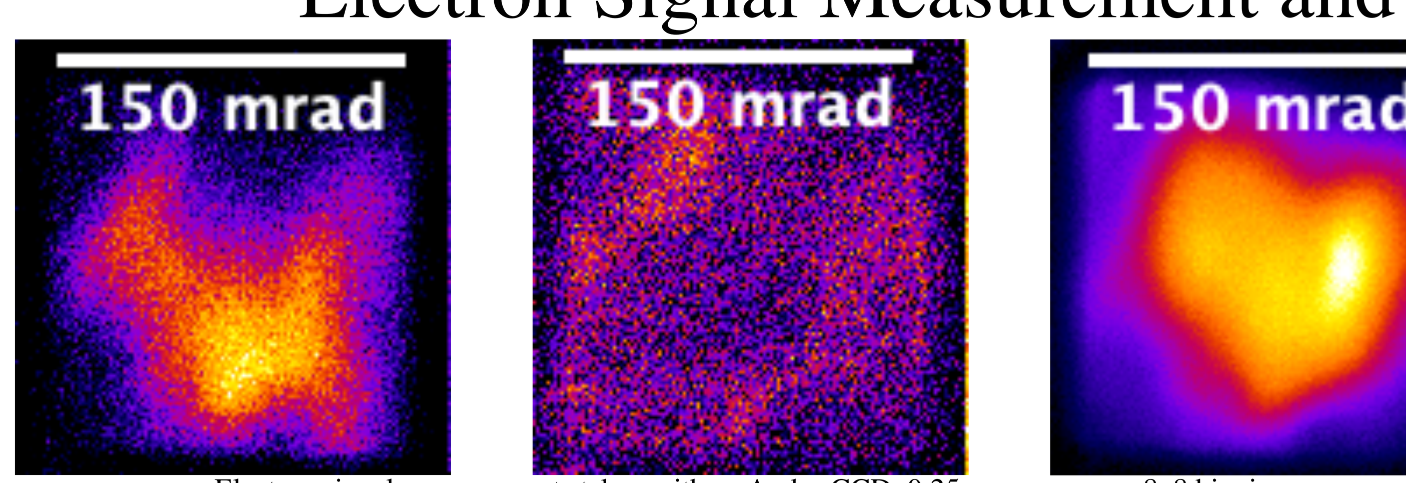
Binary Mask Electron optimization using binary mask near center

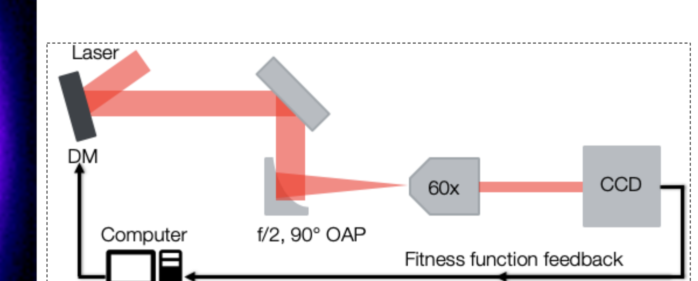
Gaussian Mask Electron optimization using Gaussian mask near center

Gaussian Mask Electron optimization using smaller sigma-valued Gaussian mask moved to a corner

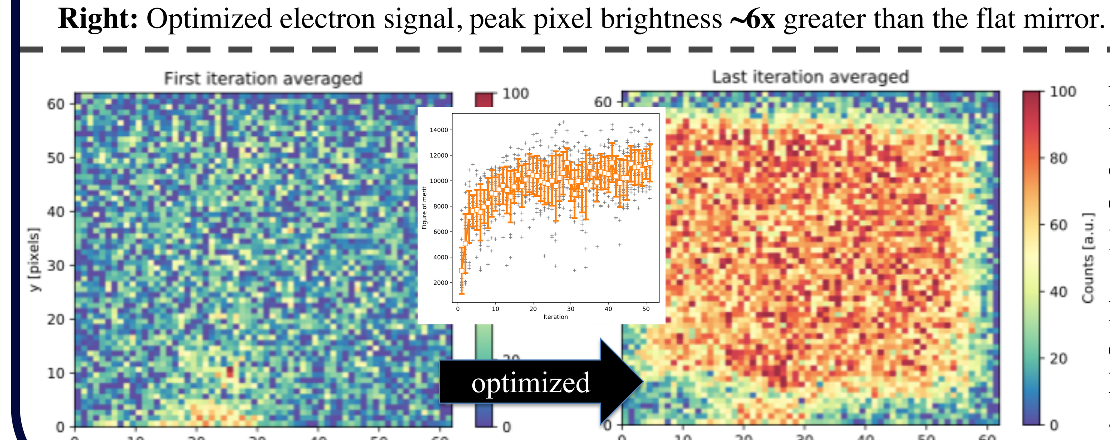
The optimized electron signal also shows interesting behavior given different masks to be optimized onto. The inset on each image shows the location of the mask, where white pixels indicate those pixels that are part of the FOM calculation, and for the two Gaussian masks in the center and on the right, the pixel brightness indicates how heavily they are weighted in that calculation

Electron Signal Measurement and Optimization





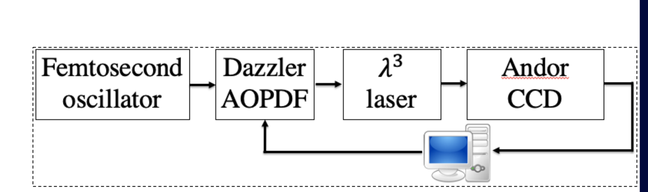
Electron signal measurements taken with an Andor CCD: 0.25 sec. exposure, 8x8 binning
Left: Signal taken with flat mirror (0V on all DM actuators)
Middle: Signal taken with optimal focal spot mirror, peak pixel brightness *less* than flat mirror peak pixel brightness.
Right: Optimized electron signal, peak pixel brightness **~6x** greater than the flat mirror.



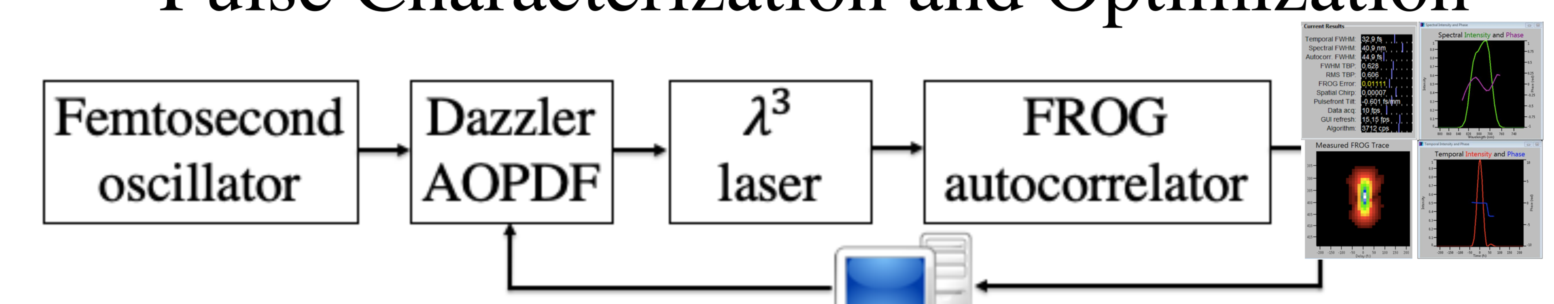
Electron signal measurements taken with Andor CCD during Dazzler optimization experiment using a Gaussian mask and a constant flat DM

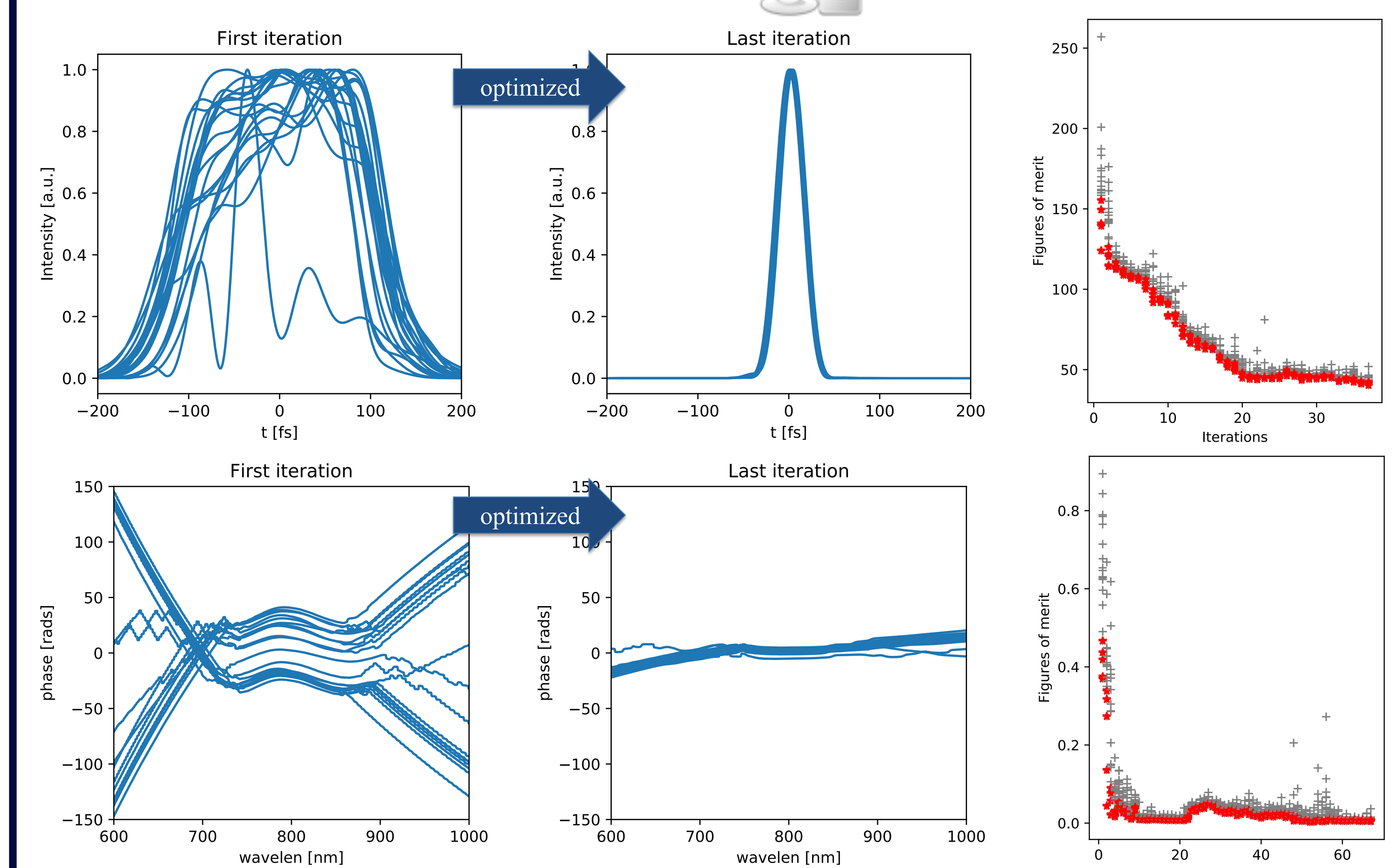
Left: Lack of distinguishable electron signal
Right: Diffuse electron signal achieved after Dazzler optimization

Work is ongoing



Pulse Characterization and Optimization

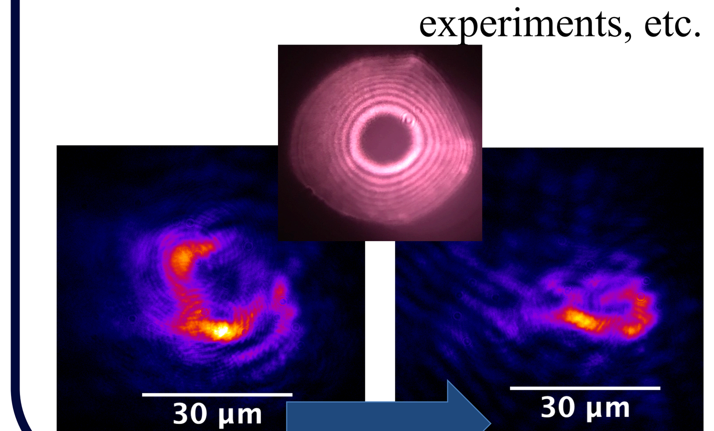


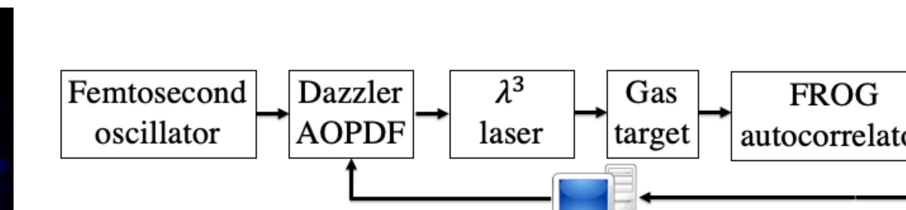


Measurements of various laser pulse parameters pre- and post-optimization via the genetic algorithm coupled with the Dazzler AOPDF, shown with respective optimization curves showing convergence
Top - Figure of merit: *minimization* of (kurtosis*FWHM pulse duration) to achieve a normally distributed, short pulse
Bottom – Figure of merit: *minimization* of slope of spectral phase to achieve a flat phase profile

Ongoing and Future Works

- Shaping of the longitudinal profile of a laser pulse interacting with a plasma has a great effect on the dynamics of the interaction [2][3][4]
  - Continued optimization of electron beam properties using the Dazzler/coupled with the DM and genetic algorithm
  - Optimization of injection mechanisms via genetic algorithm
- Investigating the optimization of laser pulse self-compression experiments using the Dazzler
  - Coupling self-compression experiments with laser wakefield experiments
- Exotic beams: Use of a spiral phase plate to create an approximate Laguerre-Gaussian$_{01}$ laser beam with optical angular momentum
  - Use this optical beam in focus optimizations, laser wakefield acceleration experiments, etc.





References

[1] https://en.wikipedia.org/wiki/Acousto-optic_programmable_dispersive_filter
[2] P. Chen, A. Spitkovsky, T. Katsouleas, W.B. Mori, Nucl.Instrum. Methods 410, 488 (1998)
[3] Leemans W. P. et al. Phys. Rev. Lett. 89, 174802 (2002)
[4] Pathak, V. B., Vieira, J. & Fonseca, R. a. & Silva, L. O. New J. Phys. 14, 23057 (2012)

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