SLAC-WP-127

# Shaping X-Ray Pulses at LCLS

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Office of Science, Science Undergraduate Laboratory Internship (SULI) Program

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# Abstract

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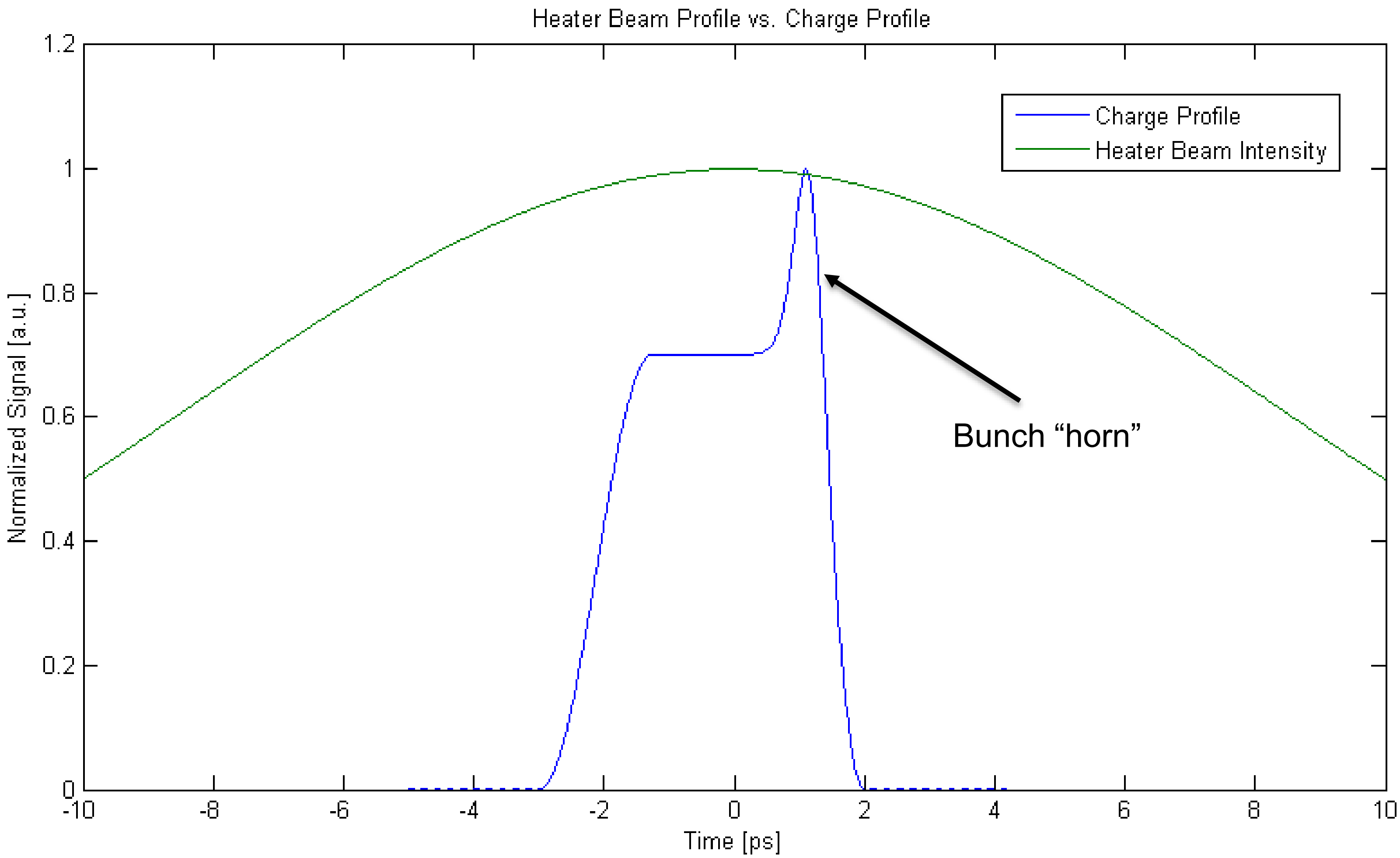
There is an inherent flexibility unique to free electron lasers (FELs) that lends well to experimental approaches normally too difficult for other light sources to accomplish. This includes the ability to optically shape the electron bunch prior to final its acceleration for the final FEL process. Optical pulse shaping of the electron bunch can enable both femtosecond and attosecond level FEL pulse control. Pulse shaping is currently implemented, not optically but mechanically, in LCLS-I with an adjustable foil slit that physically spoils the momentum phase of the electron bunch. This selectively suppresses the downstream FEL process of spoiled electrons. Such a mechanical spoiling method fails for both the soft x-ray regime as well as the high repetition rates that are planned in LCLS-II. Our proposed optical spoiling method circumvents this limitation by making use of the existing ultrafast laser beam that is typically used for adjusting the energy spread for the initial electron bunch. Using Fourier domain shaping we can nearly arbitrarily shape the laser pulses to affect the electron bunch. This can selectively spoil electrons within each bunch. Here we demonstrate the viability of this approach with a programmable acousto-optic dispersive filter. This method is not only well suited for LCLS-II but also has several advantages over mechanical spoiling, including lack of radiation concerns, experiment specific FEL pulse shapes, and real-time adjustment for applications that require high duty-cycle variation such as lock-in amplification of small signals.

# Overview

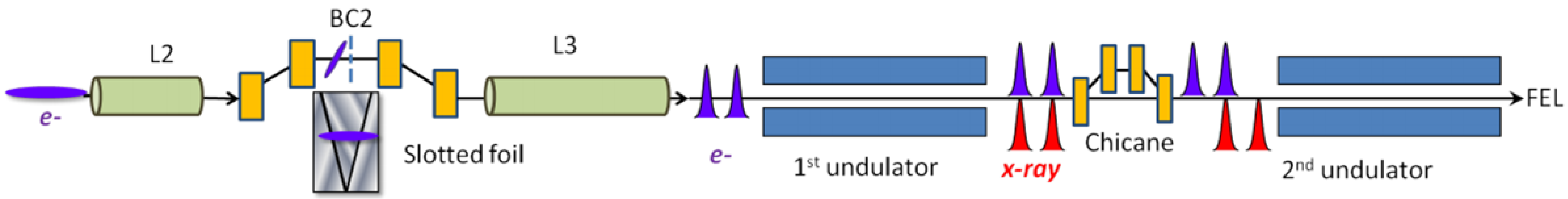
- Current LCLS-I X-Ray Pulse Characteristics
- Motivation for Non-Mechanical Pulse Shaping
- Methods of Pulse Shaping
- Dazzler Shaping System
- Implementation in LCLS
- The Future and LCLS-II

# Current LCLS Pulse Characteristics




Pre-accelerator electron bunch and laser heater characteristics

# Current LCLS Pulse Characteristics (cont'd)

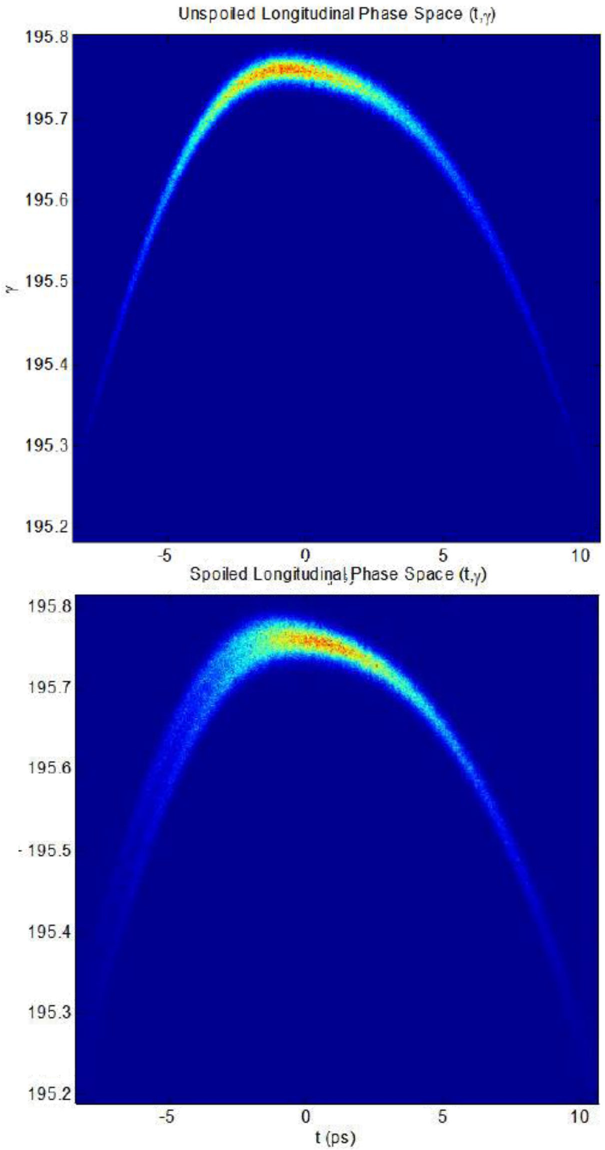



Current "shaping" method involves motor-controlled foil slots physically spoiling electrons

Ding, *et al*, *"Femtosecond x-ray pulse characterization in free-electron lasers using a cross-correlation technique"*, SLAC Publication

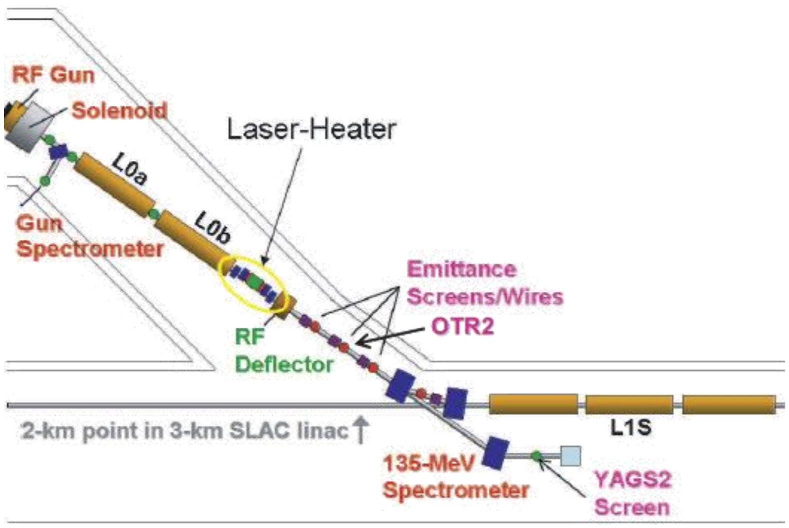
# Motivation for Non-Mechanical Pulse Shaping

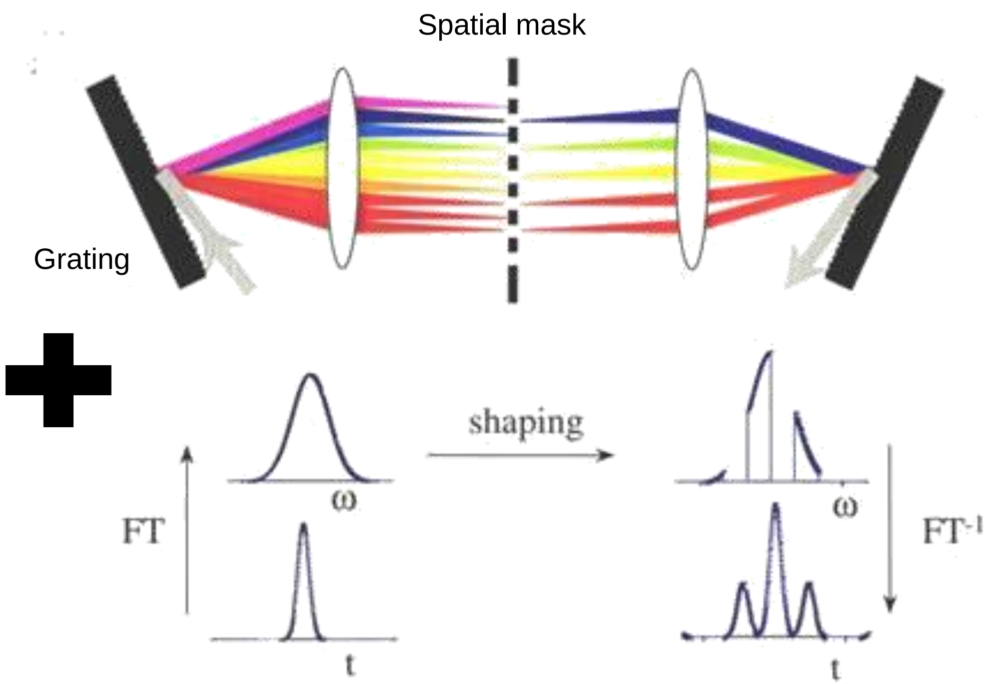
- Radiation limitations of foil method responsible for shut down of Mangaros' (LF-62) carbon experiment and prohibit foil use in LCLS-II
- Elimination of bunch horn reduces wake field aberration
- Allows lock-in amplification for small signal nonlinear experiments done in high noise environments
- Allows higher degree of freedom in output pulse shapes and faster shape adjustments




Ryan Coffee, Agostino Marinelli, "*Optical Tailoring of Electron beams for LCLS-I and II*", SLAC Internal Presentation

# Pulse Shaping with Heater Beam



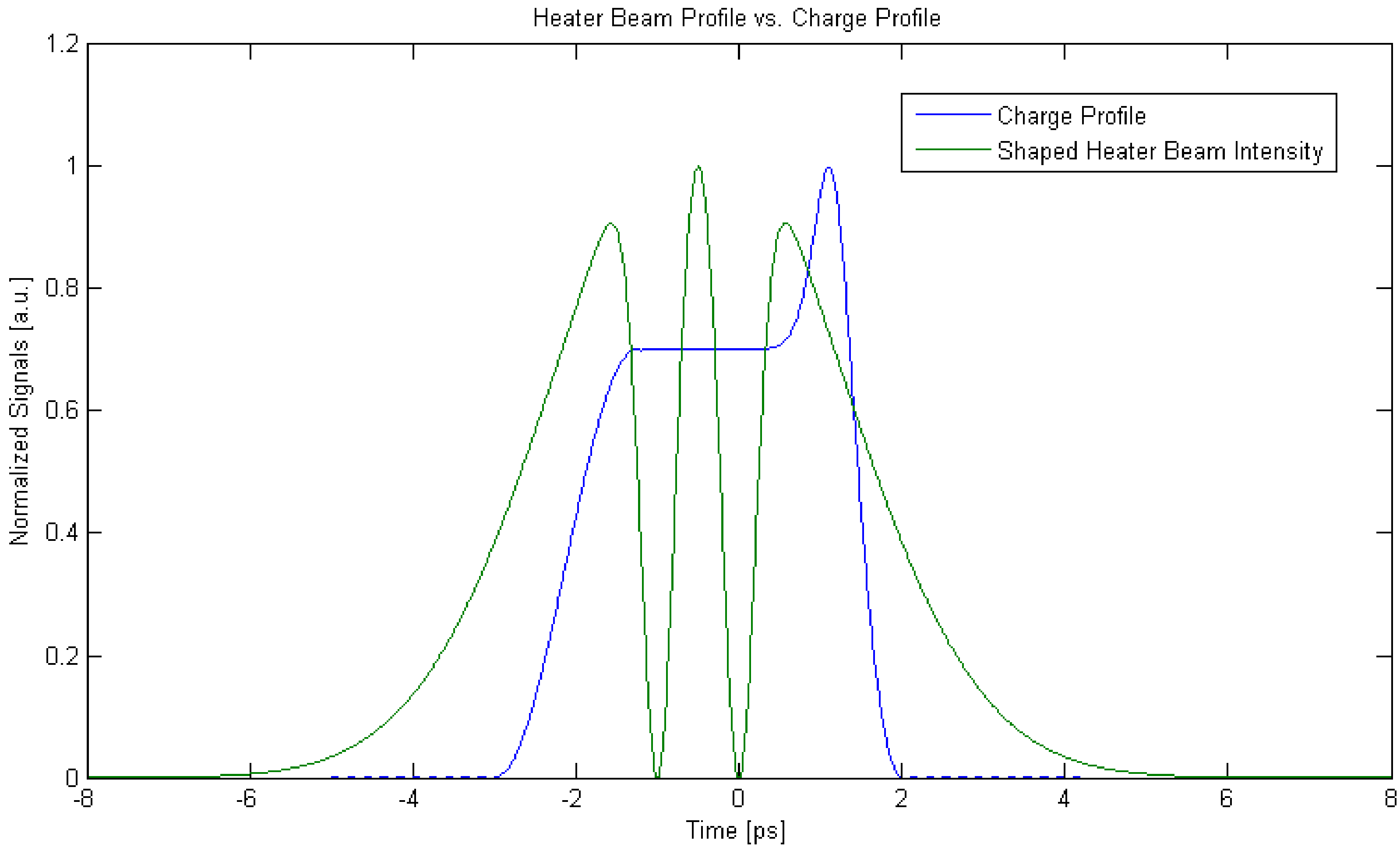




Heater laser outputs 100fs transform-limited pulses, stabilizing electron energy distribution

Spectral amplitude shaping also shapes temporal profile

Huang, *et al*, "*Measurements of the LCLS laser heater and its impact on x-ray FEL performance*", SLAC Publication

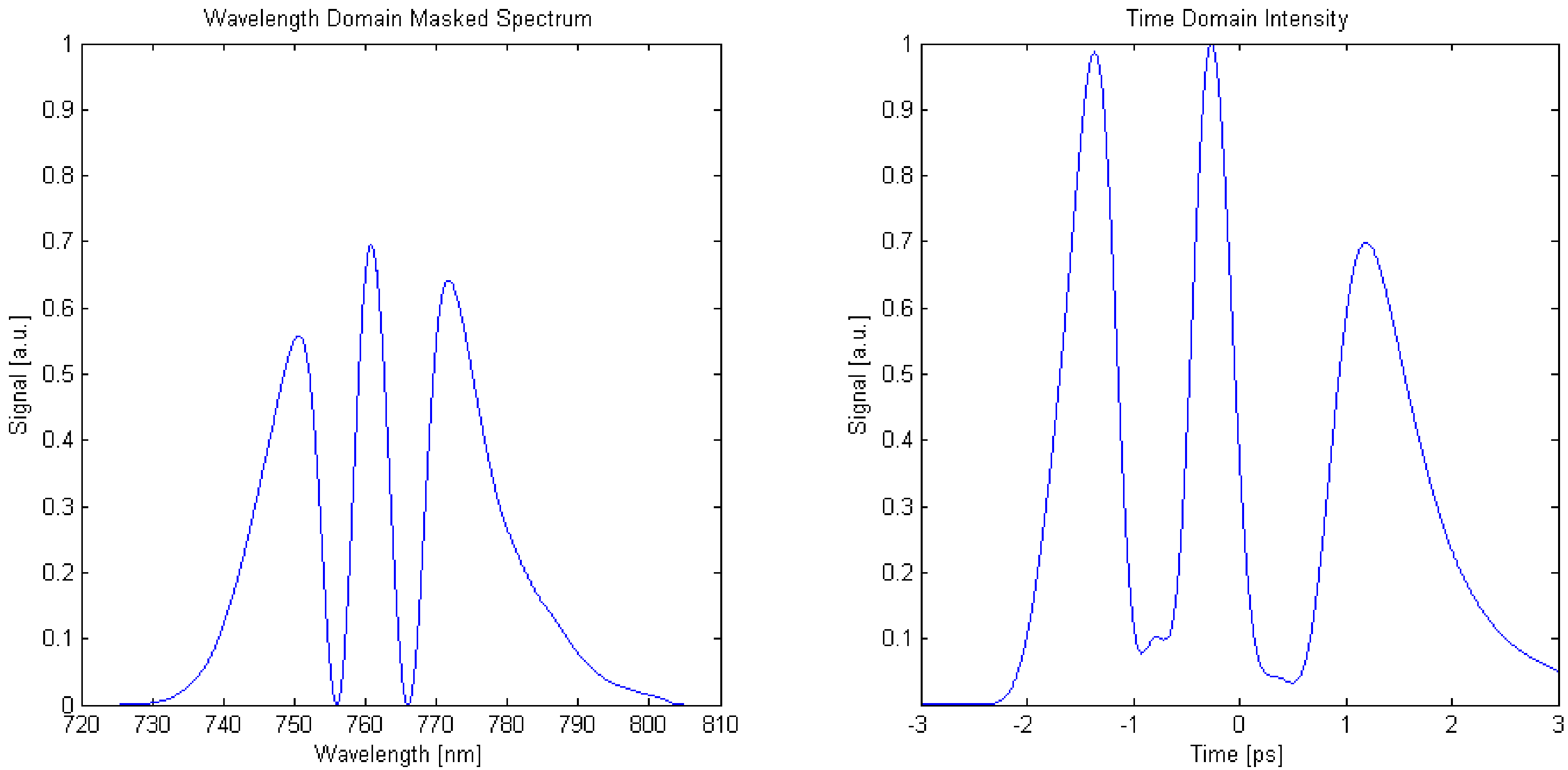
# Pulse Shaping with Heater Beam (cont'd)



# LCLS-I Feasibility Demonstration

Phase and Amplitude control with "Dazzler" RF Acousto-Optic Modulator


# Dazzler Capabilities




Predicted temporal shape from actual Dazzler transmission

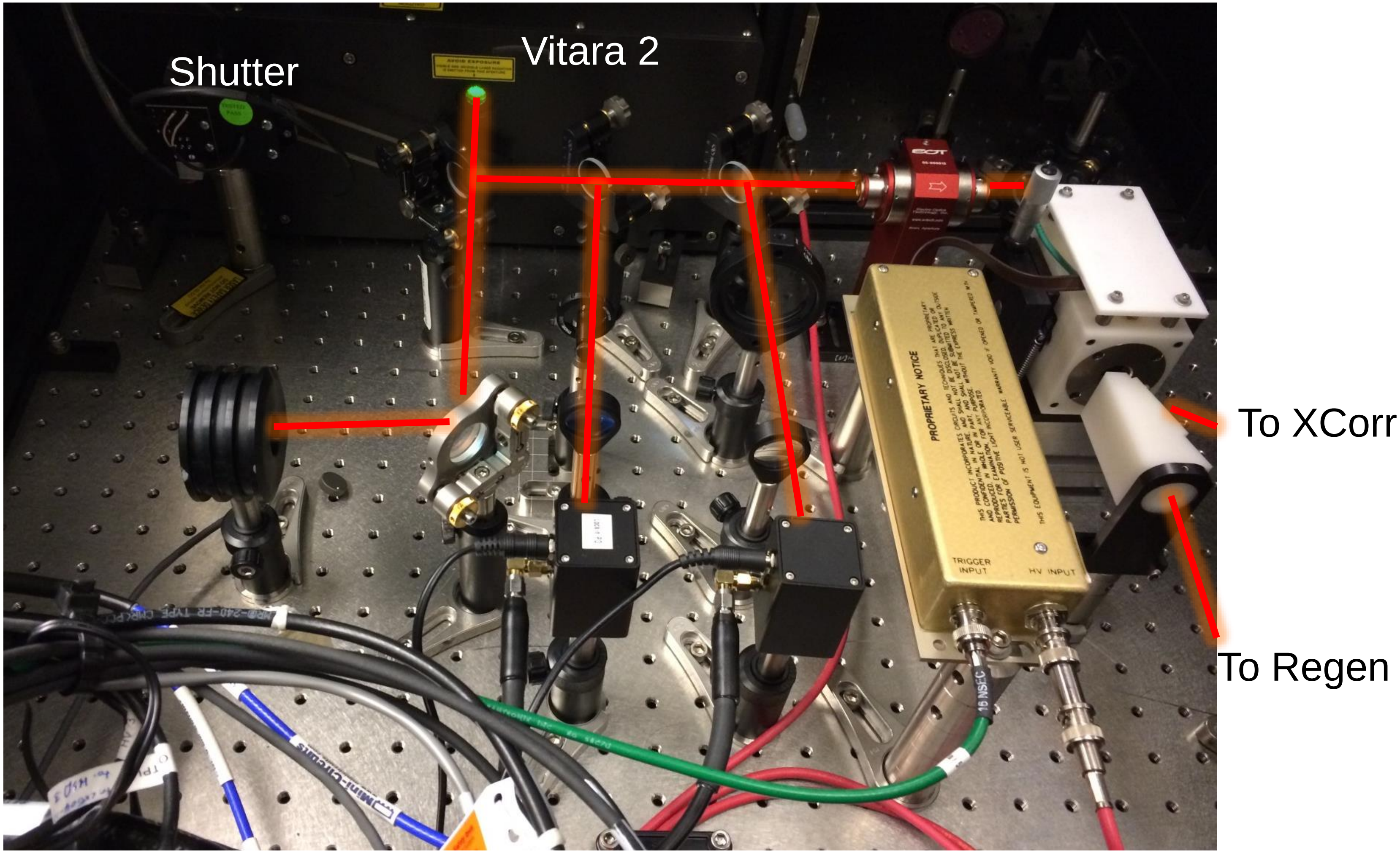
# Next Steps (LCLS Downtime and Restart)

- LCLS shuts down 10 August
- Dazzler will be installed between 17 August and 28 August
- LCLS restarts 9 September
- Beam time for Dazzler test to be determined during LCLS downtime

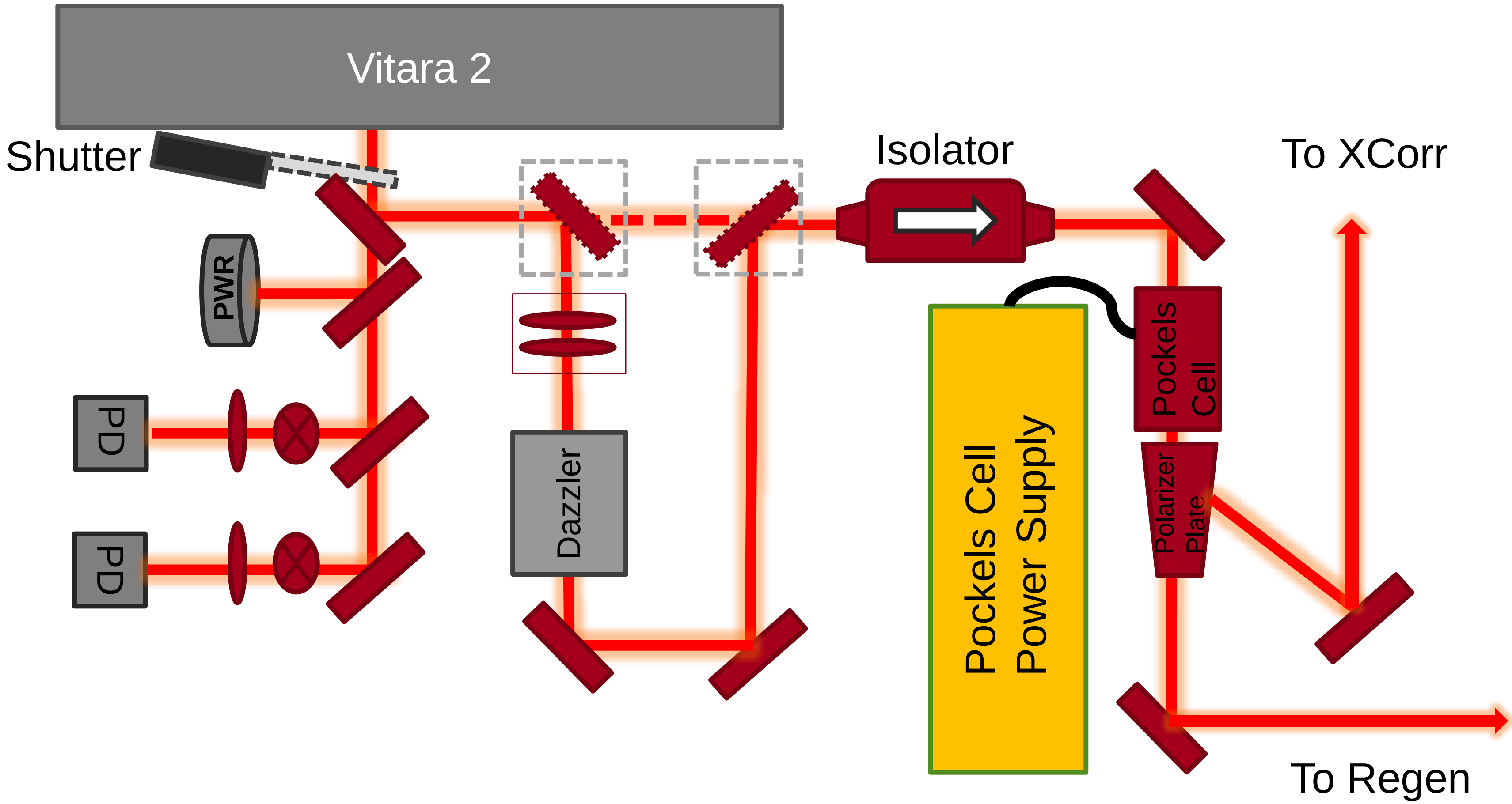
**Downtime LCLS Injector Detailed Schedule**

| Monday | Tuesday | Wednesday | Thursday | Friday |
|---|---|---|---|---|
| 8/10/2015 | 8/11/2015 | 8/12/2015 | 8/13/2015 | 8/14/2015 |
| Machine Characterization Before Shutdown | "NO TIMING<br>CATER124734 - Inspect Optics and Replace Damaged, check temporal shape<br>"ALL LASERS OFF AT END OF DAY" | "POWER OUTAGE"<br>"NO TIMING"<br>CATER124771- LSS Recertification | "NO TIMING"<br>CATER124771- LSS Recertification<br>CATER124356 - Replace damaged cameras<br>CATER124732- Replace Damaged Transport Window<br>CATER124298- Reorganize optics/PDs after Osc as prep for | "NO TIMING"<br>CATER124356 - Replace damaged cameras<br>CATER124298- Reorganize optics/PDs after Osc as prep for<br>"ALL LASERS OFF AT END OF DAY" |
| 8/17/2015 | 8/18/2015 | 8/19/2015 | 8/20/2015 | 8/21/2015 |
| "NO TIMING"<br>" HVAC ON 6:30AM"<br>CATER124859 - Shelf Support Brackets install<br>CATER125433- Remove redundant hardware in the Inj Vault<br>CATER125859- Remove Old BSOIC | CATER124859 - Shelf Support Brackets install<br>CATER125859- Remove Old BSOIC | "NO TIMING"<br>CATER124859 - Shelf Support Brackets install<br>CATER125859- Remove Old BSOIC<br>"ALL LASERS OFF AT END OF DAY | "NO TIMING"<br>"POWER OUTAGE"<br>CATER124859 - Shelf Support Brackets install<br>CATER125859- Remove Old BSOIC | CATER124859 - Shelf Support Brackets install<br>CATER125859- Remove Old BSOIC |
| 8/24/2015 | 8/25/2015 | 8/26/2015 | 8/27/2015 | 8/28/2015 |
| "NO TIMING"<br>CATER124300 - DMD Installation<br>CATER124298-Dazzler Installation<br>CATER125704- Removal of long cables<br>"ALL LASERS OFF AT END OF DAY | "POWER OUTAGE"<br>"NO TIMING"<br>CATER124300 - DMD Installation<br>CATER124298-Dazzler Installation | CATER124300 - DMD Installation<br>CATER124298-Dazzler Installation<br>CATER125705- Coherent 2 SDG Replacement | CATER124300 - DMD Installation<br>CATER124298-Dazzler Installation | "NO TIMING"<br>CATER124300 - DMD Installation<br>CATER124298-Dazzler Installation<br>"ALL LASERS OFF AT END OF DAY |
| 8/31/2015 | 9/1/2015 | 9/2/2015 | 9/3/2015 | 9/4/2015 |
| "NO TIMING"<br>" HVAC ON 6:30AM"<br>CATER124300 - DMD Installation/Testing<br>CATER125704- Removal of long cables<br>CATER114908-LH Stabilization System<br>CATER123225-Mirror feedback Improvements/Testing | CATER124300 - DMD Installation/Testing<br>CATER114908-LH Stabilization System Testing<br>CATER123225-Mirror feedback Improvements/Testing | CATER124300 - DMD Installation/Testing<br>CATER114908-LH Stabilization System Testing<br>CATER123225-Mirror feedback Improvements/Testing | CATER124300 - DMD Installation/Testing<br>CATER114908-LH Stabilization System Testing<br>CATER123225-Mirror feedback Improvements/Testing | CATER124300 - DMD Installation/Testing<br>CATER114908-LH Stabilization System Testing<br>CATER123225-Mirror feedback Improvements/Testing |
| 9/7/2015 | 9/8/2015 | 9/9/2015 | 9/10/2015 | 9/11/2015 |
| CATER124300 - DMD Installation/Testing<br>CATER114908-LH Stabilization System Testing | CATER124300 - DMD Installation/Testing<br>CATER114908-LH Stabilization System<br>CATER 125018 - Flush all chillers | MACHINE START UP | | |

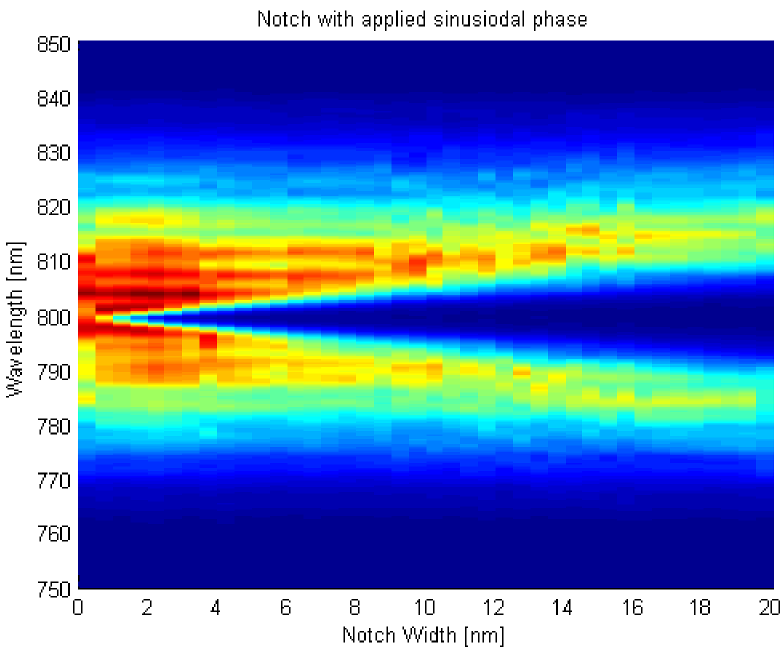
# Implementation in Injector—Current Setup



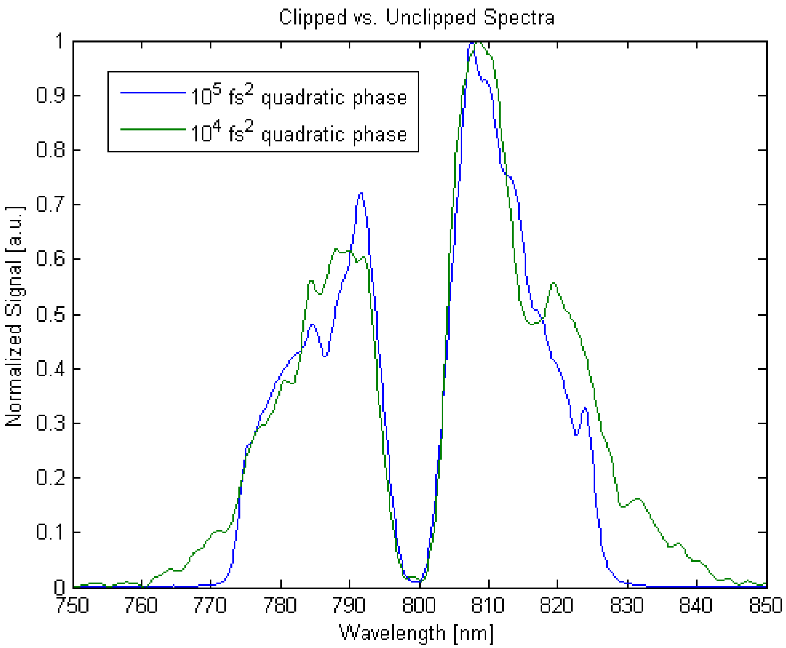
# Implementation in Injector—Proposed Setup



# Dazzler Limitations




Phase-Amplitude crosstalk




Spectral Clipping with high polynomial phase

# Dazzler alternatives and LCLS-II

Full control for LCLS-II requires higher resolution amplitude and phase masking and faster repetition rate


Transmissive SLM: 1x640 pixels at 30Hz refresh rate

Reflective SLM: 1x12,228 pixels (supersampled 10x-20x) at 200 Hz refresh rate

# Conclusions

- Non-Mechanical pulse shaping system is desirable
- Demonstrated ability to achieve desired waveforms
- Dazzler AOM can be used as feasibility test
- Defined roadmap for LCLS-II Implementation

# Acknowledgements

Ryan Coffee, Sharon Vetter, and Phillippe Herring

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