E327: Virtual diagnostic for phase space prediction and customization at FACET-II
E325: Automatic tuning for high gain, low energy spread, and low variance PWFA
C. Emma, A. Edelen, S. Gessner, A. Hanuka, B. O'Shea, A. Scheinker, G. White

FACET-II PAC Meeting
October 2020
(Virtual)
<table>
<thead>
<tr>
<th>Diagnostics</th>
<th>Control</th>
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<tr>
<td>(Need information to make decisions)</td>
<td>(How to make decisions)</td>
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<tr>
<td>Edge Radiation Diagnostics (E326)</td>
<td>Adaptive Feedback (E325)</td>
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<td>Virtual TCAV Predictive Diagnostics (E327)</td>
<td>Learned Control (Reinforcement Learning, New proposal)</td>
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<tr>
<td>Non-destructive, single shot continuous monitoring of emittance of high-current beams</td>
<td>Stable, high-quality beams through control of unmodeled accelerator behavior</td>
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<td>Longitudinal phase space diagnostics, always on, and for extremely short bunches</td>
<td>Design and control of extreme beams by learning a representative model of FACET-II</td>
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Synergistic experiments, individual success enhances all research
E327 Science goals: LPS virtual diagnostic

1. Implement a single-shot non-destructive ML diagnostic to predict the e-beam LPS along the linac.

2. Use the ML-diagnostic to customize/control the LPS for different experiments.
## E327: Experimental design, timeline, milestones

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<tr>
<th></th>
<th>FY21 Q1</th>
<th>Q2</th>
<th>Q3</th>
<th>Q4</th>
<th>FY22 Q1</th>
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<td><strong>Preparatory Efforts</strong></td>
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<td>FACET-II Simulation studies</td>
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<td>Experimental demo at LCLS</td>
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<td><strong>Software Development</strong></td>
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<td>Writing software linking FACET DAQ to ML code</td>
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<td>ML model development (1D and 2D predictions)</td>
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<td><strong>ML diagnostic Deployment</strong></td>
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<td>Model testing and prototype evaluation</td>
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<td>Incorporate spectral measurements and confidence bounds</td>
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<td>LPS Model implementation and control system GUI development</td>
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<td>Quantified prediction performance for multiple ML models &amp; experimental configs</td>
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<td>Online LPS diagnostic available</td>
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<td>Model based LPS feedback testing</td>
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- **LPS diagnostic** will leverage available software (FACET DAQ) and hardware with limited installation.
- **Experimental design** follows successful demonstration, safety review is underway.
Motivation

Impossible to predict results of the PWFA process in real time based on models because there is too much uncertainty: PWFA is sensitive to the detailed 6D phase space distribution which is time varying and dominated by complex collective effects.

Existing non-invasive diagnostics cannot image extremely short (1 fs) and intense (100 kA) bunches.

Goals for Adaptive Tuning at FACET-II

- Quickly and automatically control longitudinal current profile.
- Stabilize beam to minimize variance of peak current.
- Minimize variance of the PWFA process (energy gain, emittance growth).
- Maximize energy gain while minimizing emittance growth of PWFA.
- Study the results to extract physics from adaptive feedback guided tuning.

Progress: This experiment is on track and ready for beam

Preliminary simulation studies completed, code design has started.
E327: Evolution of the experiment

**2D LPS with sector 20 chicane upgrade**

Day 1

*Longitudinal Phase Space*

*Streaked TCAV image*

Only 1D projection available with current W-chicane

With S20 upgrade

**Spectral data for flagging high current shots**

Figure A. Hanuka

Spectral data will provide additional confidence in flagging high current shots

2D LPS will be available after S20 upgrade
Desired facility upgrades

• S20 chicane
• Laser Heater
• Upgrading critical legacy control subsystems
• E325/E327 experiments are on track and ready for beam
• Preparatory work for E327 has included simulation studies and proof of concept experiment at LCLS.
• The diagnostic will predict the LPS along the linac and provide: bunch separation, charge ratio, current ratio and energy difference/energy chirp in drive-witness beams for PWFA experiments.
• Desired upgrades: laser heater will reduce the jitter of current profile and S20 upgrade will allow full LPS (energy-time) prediction.

• **Next steps:** deploy ML diagnostic code on control system. Test on FACET-II machine data. Automate (re)training and develop models for different configurations. Incorporate uncertainty quantification & mitigation measures.
Collaboration


• LANL: A. Scheinker


• First experiments aim to demonstrate LPS reconstruction and one/multiple TCAV locations along FACET-II linac.

• Further experiments will explore on model sensitivities to inputs, prediction accuracy for different configurations, model architecture tuning and automating (re) training.

FACET-II ML experiments will address key issues for transition between demonstration and use in regular operation.
Spectral data for flagging high current shots