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)

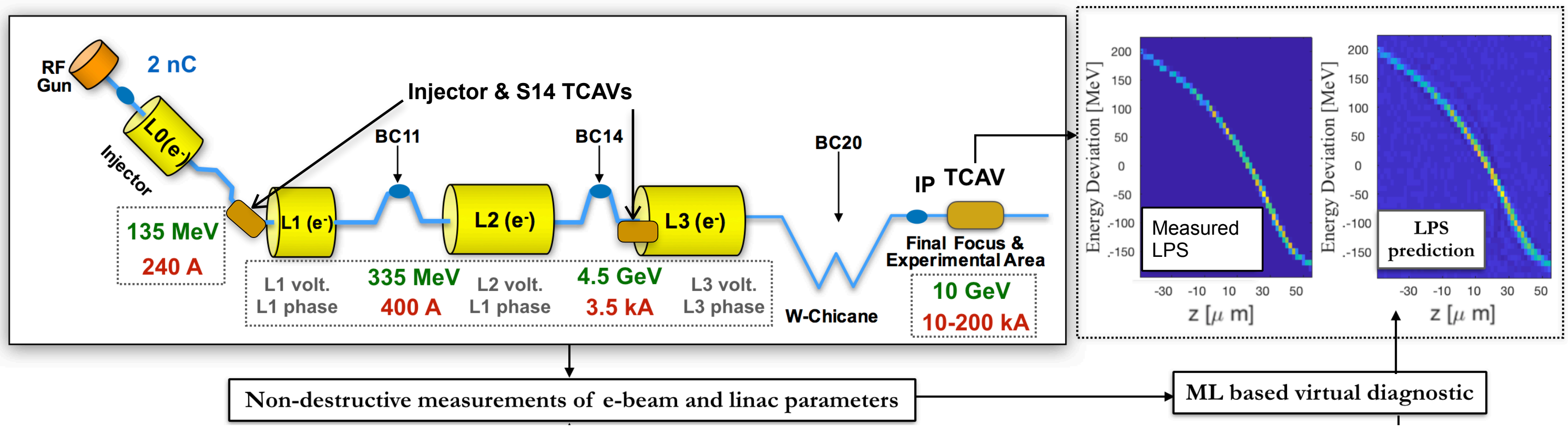
Place in the FACET-II "Pyramid of ML"

Machine Control and Understanding			
Diagnostics (Need information to make decisions)		Control (How to make decisions)	
Edge Radiation Diagnostics (E326)	Virtual TCAV Predictive Diagnostics (E327)	Adaptive Feedback (E325)	Learned Control (Reinforcement Learning, New proposal)
Non-destructive, single shot continuous monitoring of emittance of high-current beams	Longitudinal phase space diagnostics, always on, and for extremely short bunches	Stable, high-quality beams through control of unmodeled accelerator behavior	Design and control of extreme beams by learning a representative model of FACET-II

Synergistic experiments, individual success enhances all research

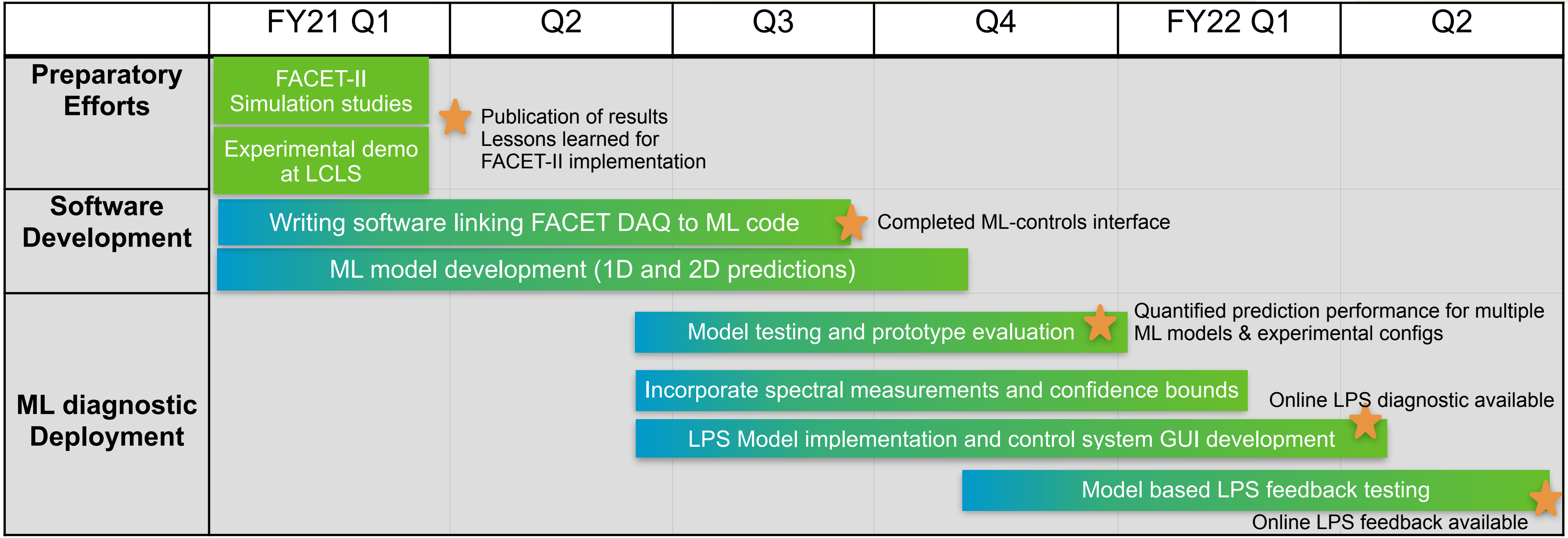
E327 Science goals: LPS virtual diagnostic

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.



ML diagnostic learns mapping of non-destructive measurements of beam/linac parameters to the beam LPS

E327: Experimental design, timeline, milestones



LPS diagnostic will leverage available software (FACET DAQ) and hardware with limited installation

Experimental design follows successful demonstration, safety review is underway

E325 Automatic tuning for high gain, low energy spread, and low variance PWFA - A. Scheinker, S. Gessner, C. Emma

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

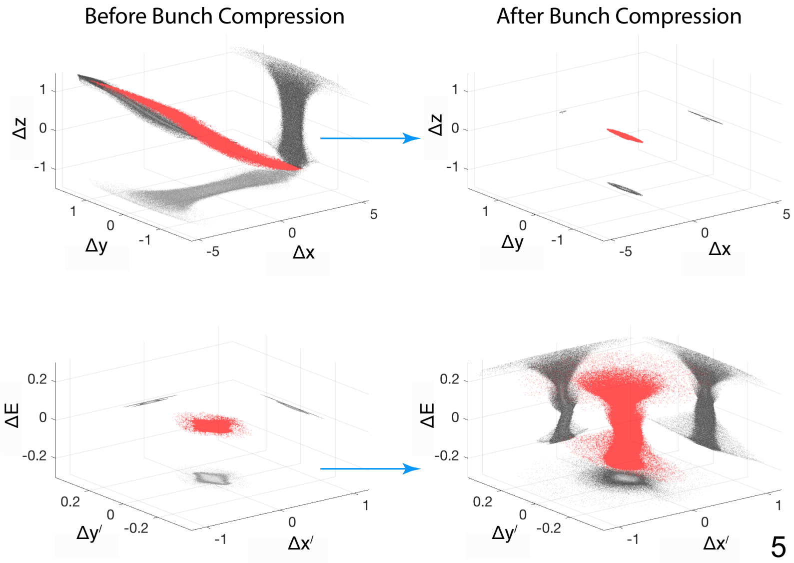
Quickly and automatically control longitudinal current profile.

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.



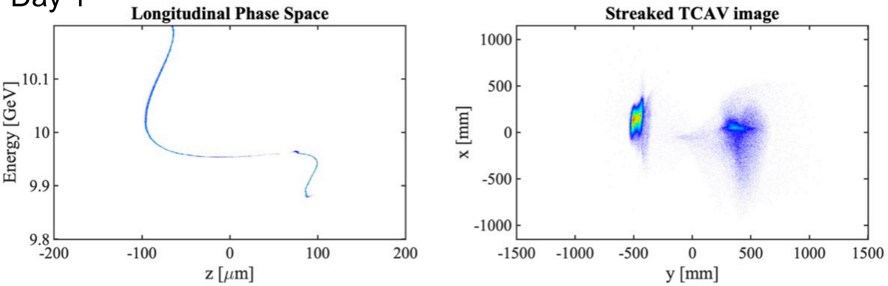
Progress: This experiment is on track and ready for beam

Preliminary simulation studies completed, code design has started.

E327: Evolution of the experiment

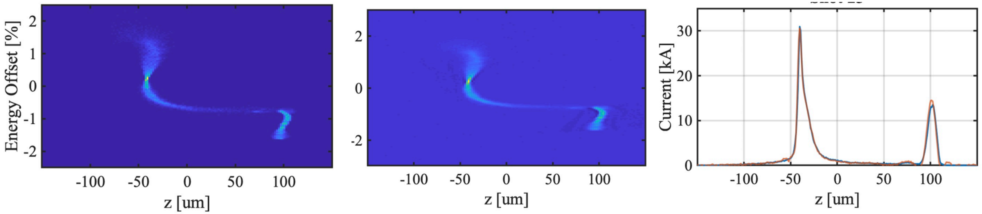
2D LPS with sector 20 chicane upgrade

Day 1



Only 1D projection available with current W-chicane

With S20 upgrade



2D LPS will be available after S20 upgrade

Spectral data for flagging high current shots

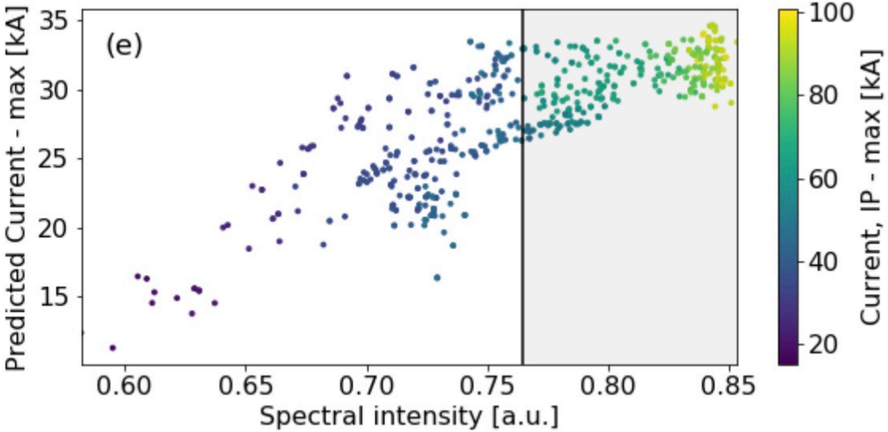


Figure A. Hanuka

Spectral data will provide additional confidence in flagging high current shots

Desired facility upgrades

- S20 chicane
- Laser Heater
- Upgrading critical legacy control subsystems

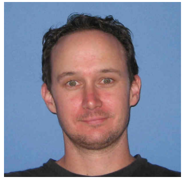
Summary

- 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.

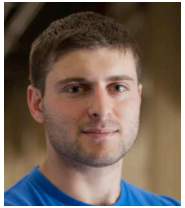
- **Next steps:** deploy ML diagnostic code on control system. Test on FACET-II machine data. Automate (re)training and develop models for different configurations. Incorporate uncertainty quantification & mitigation measures.

Collaboration

- SLAC: C. Emma, B. O’Shea, A. Hanuka, A. Edelen, G. White, S. Gessner, L. Gupta
- LANL: A. Scheinker



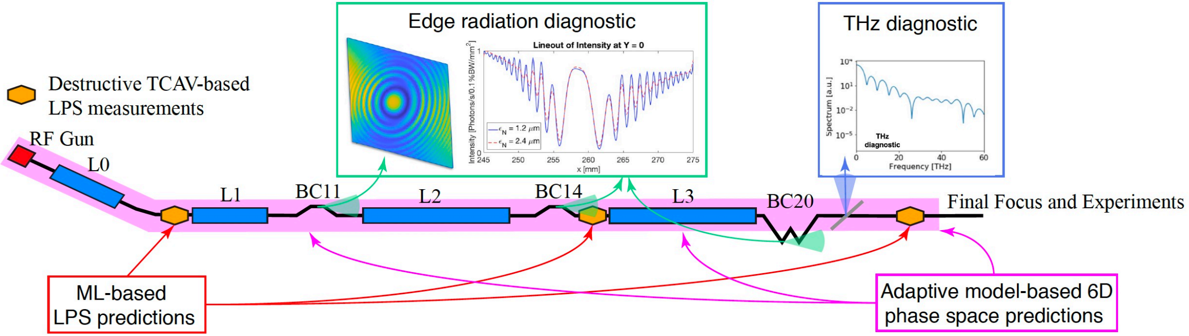


Backup slides

Publications

1. C. Emma and A. Edelen, et al., “Machine learning based longitudinal phase space prediction of particle accelerators”, PRAB **21**, 112802 (2018)
2. A. Scheinker, A. Edelen, D. Bohler, C. Emma, and A. Lutman, “Demonstration of Model-Independent Control of the Longitudinal Phase Space of Electron Beams in the Linac-Coherent Light Source with Femtosecond Resolution”, Phys. Rev. Lett. 121, 044801 (2018).
3. Scheinker, A., Emma, C., Edelen, A., and Gessner, S.. Mon . "Advanced Control Methods for Particle Accelerators (ACM4PA) 2019". LANL Workshop Report, United States. doi: 10.2172/1579684. https://www.osti.gov/servlets/purl/1579684.
4. A. Hanuka, C. Emma et. al., “Accurate and confident prediction of electron beam longitudinal properties using spectral virtual diagnostics” *under review,* https://arxiv.org/abs/2009.12835
5. C. Emma, A. Edelen, A. Hanuka, B. O’Shea, A. Scheinker, “Virtual diagnostic suite for electron beam prediction and control at FACET-II” *to appear in Information*, Nov 2020
6. A.L. Edelen, F. Cropp, C. Emma, A. Hanuka et al., “Machine Learning-Based Tuning of the Round-to-Flat Beam Transform at the UCLA Pegasus Photoinjector” *in preparation*

Experimental layout, diagnostics, observables



First experiments

Scan machine parameters:
L0,L1,L2,L3 RF phase & amplitude
BC11, BC14,BC20 peak current set points

Inputs to ML model:
L0,L1,L2,L3 voltage & phase readbacks,
BC11,BC14, BC20 current monitor
SYAG, EOS, Edge radiation, THz spectrum

- 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