Update on Start-to-End Modeling Efforts at SLAC

E300 Collaboration Meeting

6/24/2024

SLAC NATIONAL ACCELERATOR LABORATORY

Stanford University | U.S. DEPARTMENT OF ENERGY

Outline

1. S2E simulation framework.

2. Single bunch simulations
   a. Injector sims vs machine measurements.
   b. Comparison of Bmad vs Lucretia in the linac.

3. Two bunch simulations

4. Next steps:
   a. Updated Jitter numbers
   b. Add PIC code in the workflow (QPAD, QuickPIC etc) to simulate plasma

S2E simulation framework

We have transitioned from GPT + Lucretia -> IMPACT + Bmad

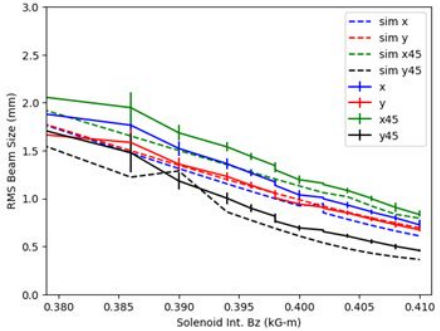
- Advantages - open source codes with active development/support, work on HPC, easy beam file I/O via openPMD

We can run S2E sims on single SLAC HPC system

- How to run S2E sim on S3DF:
  - Uses pre built conda environment in a container setup for IMPACT + Bmad
  - Automatically copies Jupyter notebooks and Facet-II Lattice to user's directory for reliable predefined paths
  - Instructions for how to start container in 5 clicks on web interface here
  - More info in FACET-II S3DF Onboarding youtube videos.
  - E. Cropp's S2E IMPACT + Bmad example notebook (~5 mins on 119 cores, Np = 2e5, w wakes, **speedup possible and is work-in-progress**)

We have a framework in place for users to run S2E sims on SLAC HPC

Injector sims vs machine measurements



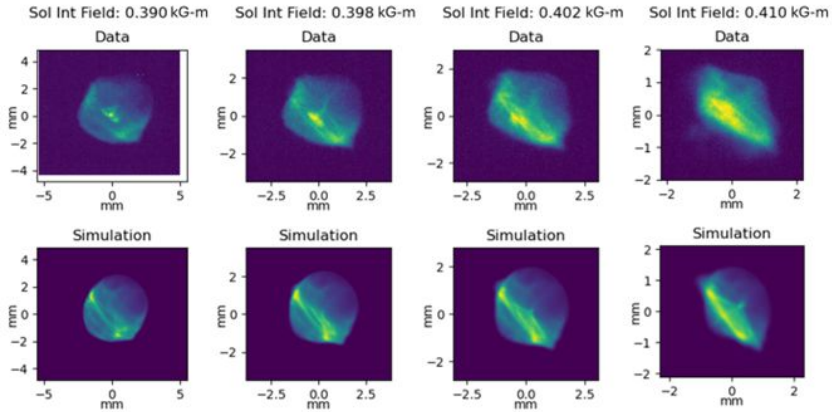
Second-order moments from solenoid scan on PR10241

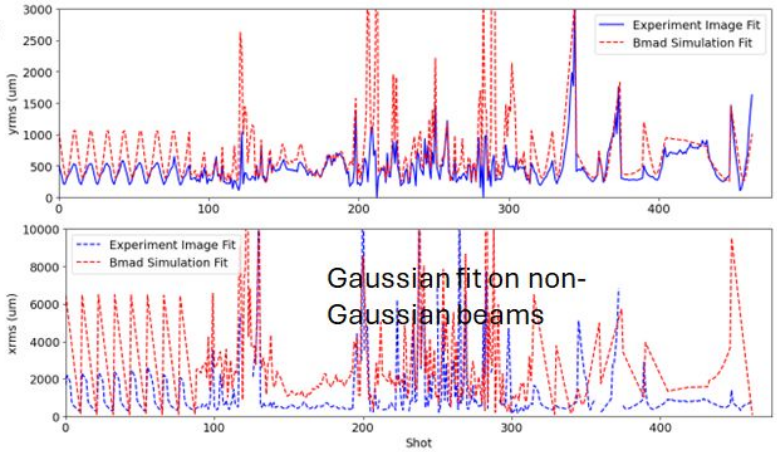
Selected images from PR10241 same solenoid scan (below)

Work in progress: fitting simulations to data at PR10571

Below: before picture – nominal model predictions (Impact to Bmad) compared to image fits from Bayesian exploration of beamline parameters

Up next: Multifidelity Bayesian fitting using **direct comparison of images** at PR10571

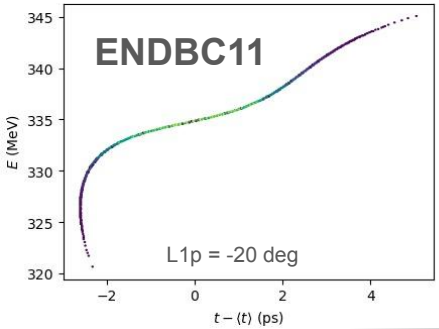


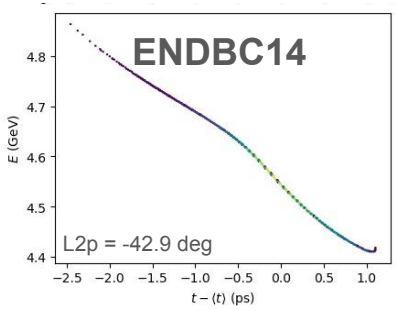


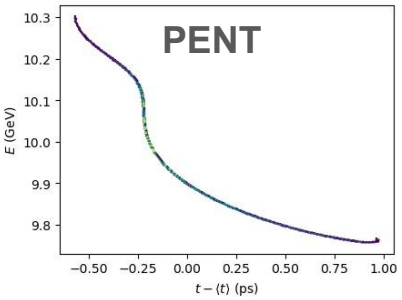
Good qualitative agreement between injector sims and machine; better quantitative agreement is work in progress

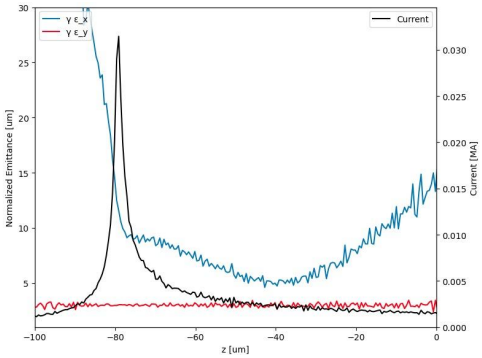
Comparison of Bmad vs Lucretia in the linac

Bmad

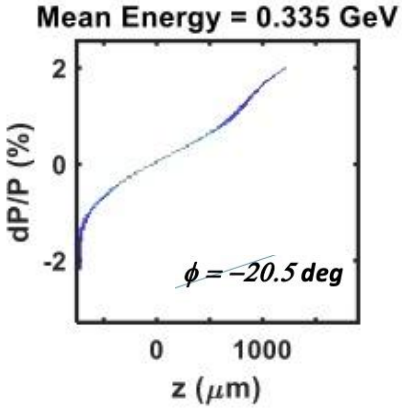


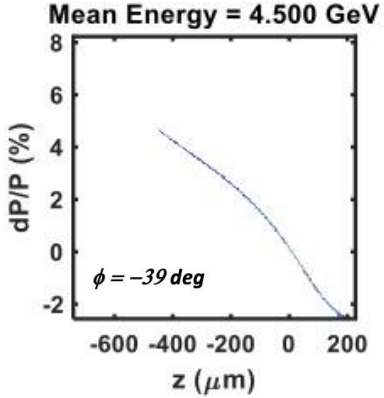


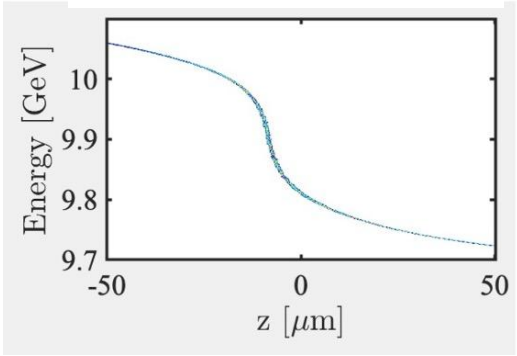


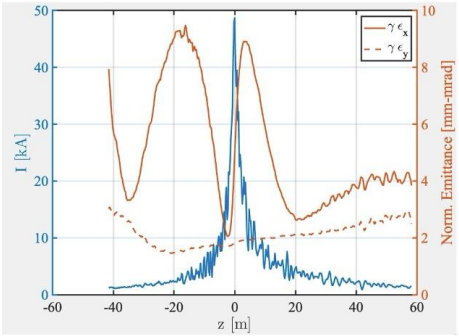


Lucretia







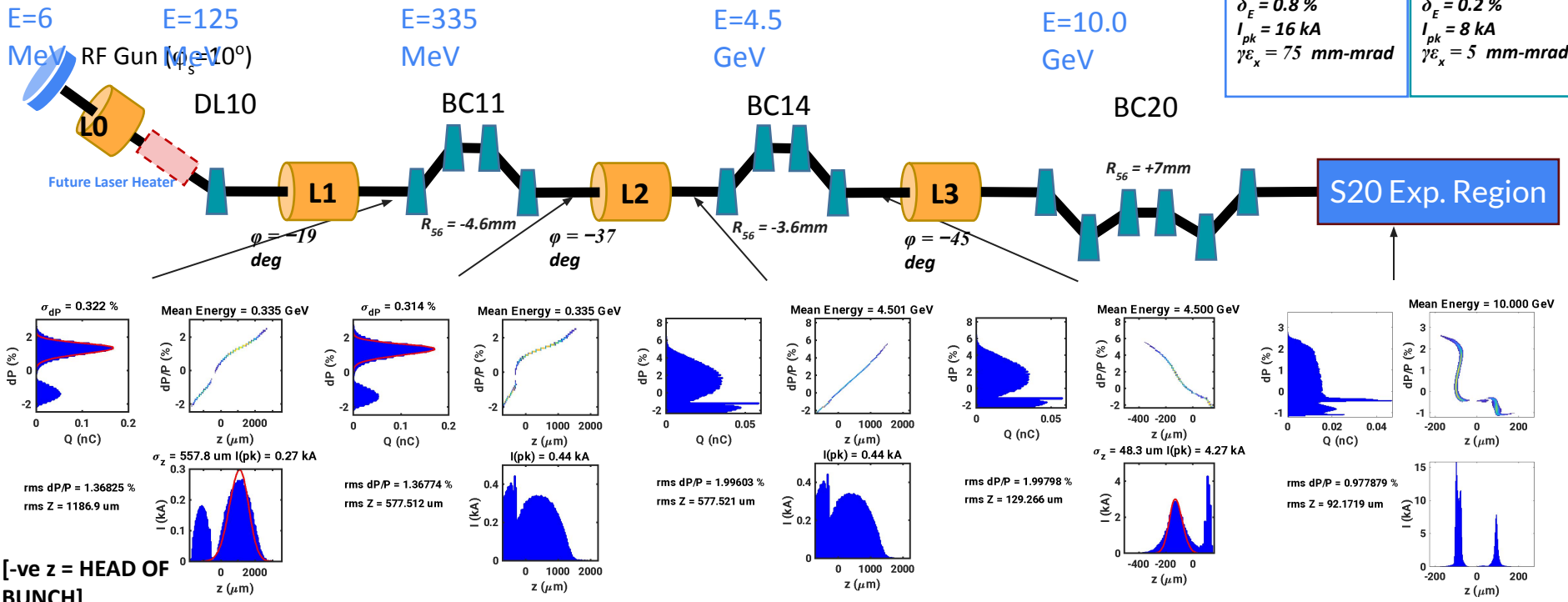


Good qualitative Lucretia <-> Bmad agreement; quantitative agreement between Bmad and machine is work in progress

From Glen's 2022 PAC slides, "BeamConfigs_gwhite.pptx"

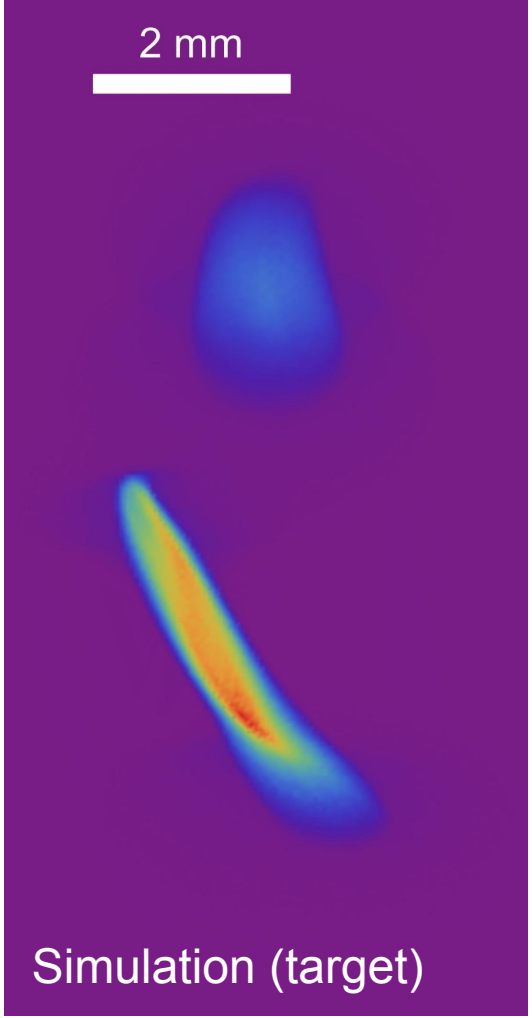
3) Two-Bunch Design Configuration

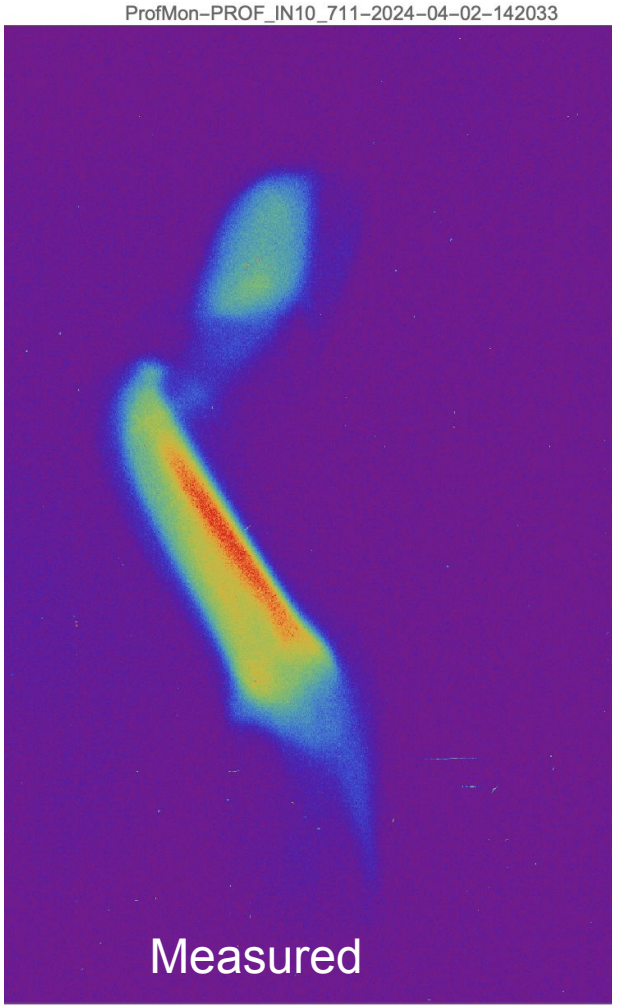
	Drive bunch	Witness bunch
	$Q = 1.4$ nC	$Q = 0.5$ nC
	$\beta^* = 5$ cm	$\beta^* = 5$ cm
	$\sigma_z = 11\ \mu$m	$\sigma_z = 7\ \mu$m
	$\delta_E = 0.8\ \%$	$\delta_E = 0.2\ \%$
	$I_{pk} = 16$ kA	$I_{pk} = 8$ kA
	$\gamma\varepsilon_x = 75$ mm-mrad	$\gamma\varepsilon_x = 5$ mm-mrad



Double-pulsed laser on RF Gun generates drive+witness pulse with 3:1 charge ratio, 2:1 I_{pk}

PR10711 (streaked)

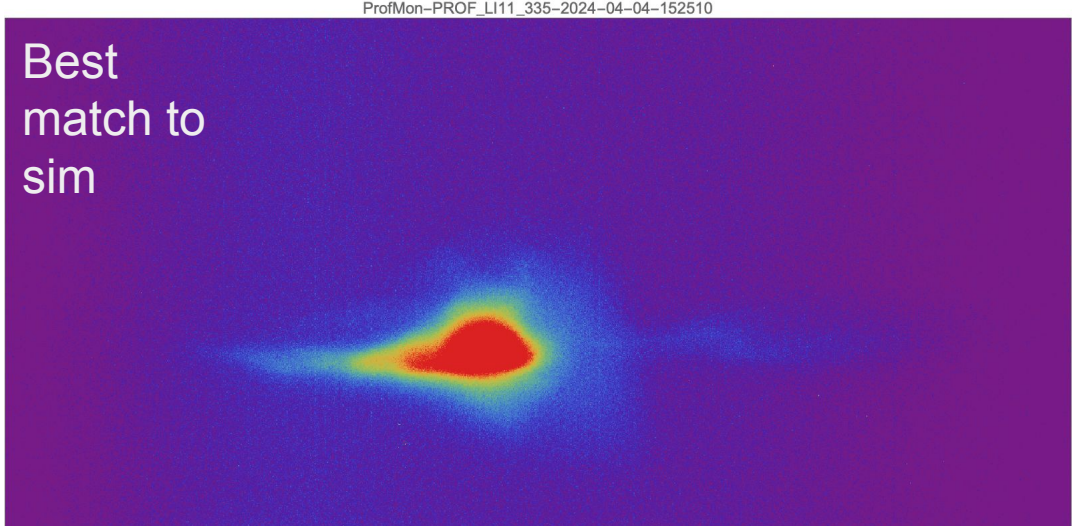


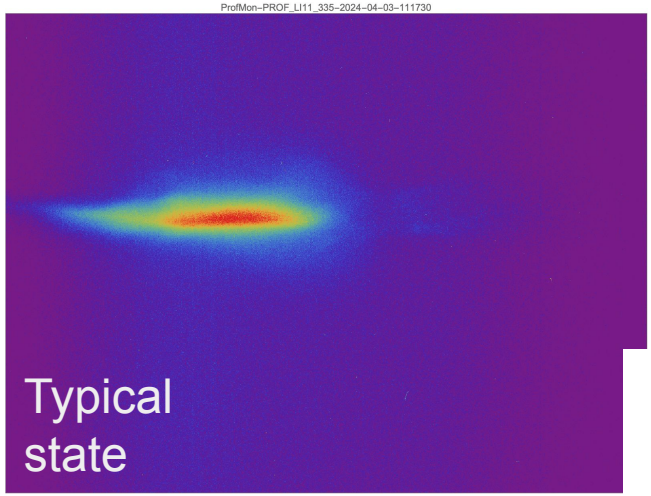


PR11335

Despite lots and lots of tuning, unable to get good agreement on this screen between simulation and reality. Unclear what's going on between 10711 and here (or if there are hidden issues in the beam already that we just can't see on 241, 571, or 711)

[Phase scan]





Nominal sim

Next steps

- Repeat TDR jitter scans with updated numbers and with/without laser heater.
- Update expectation of beam parameter variation vs machine sensitivities.
- Include plasma code (QPAD, QuickPIC) in jitter study.
- Continue simulation-machine measurement comparison beyond the injector.

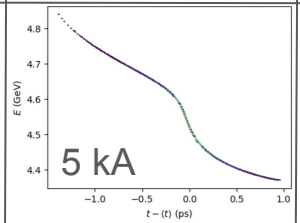
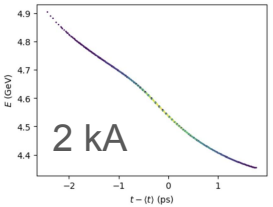
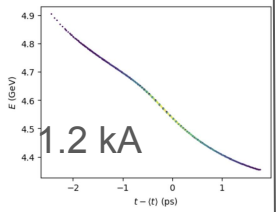
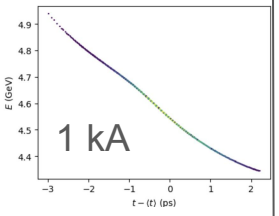
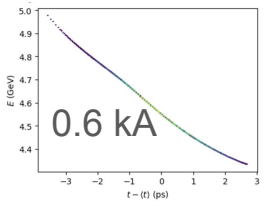
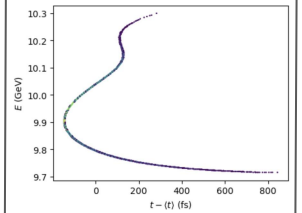
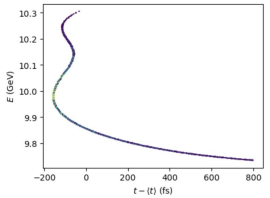
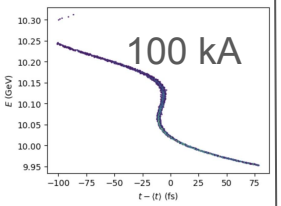
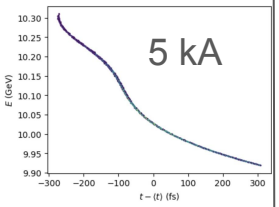
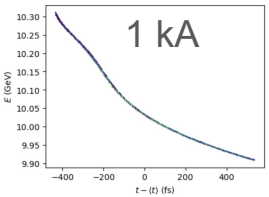
Jitter location	units	TDR table 6.2	2024 run	2025 exp
source Q	%	1	2.3	
source position	%	3		
laser time	fs	200	50	
Gun phase	degS	0.1	0.15	
Gun amp	%	0.25	0.25	
L0A Phase	degS	0.1	0.1	
L0A Amp	%	0.25	0.06	
L0B P	degS	0.1	0.1	
L0B A	%	0.25	0.5	
L1A P	degS	0.1	0.7	
L1A A	%	0.1	0.6	0.25
L1B P	degS	0.1	0.5	
L1B A	%	0.1	0.7	0.25
L2 P	degS	0.25	0.4	
L2 A	%	0.25	0.3	
L3 P	degS	0.25	0.4	
L3 A	%	0.25	0.3	
LH mag	dB/B		3.20E-04	
DL10 mag	dB/B	1.00E-05	8.00E-05	
BC11 mag	dB/B	1.00E-05	7.00E-05	
BC14 mag	dB/B	1.00E-04	6.40E-05	
BC20 mag	dB/B	1.00E-04	2.50E-04	
linac mag vibration	um	1.5/0.5		2.0/2.0
inj mag vibration	um	1.00E-01		1.0/1.0
Color legend				
yellow = this number was optimistic				

Human Resources

Project	People	Start/end dates
Machine/plasma jitter sims	Robin Hwang, Alex Short **(summer students)**	6/24/24 - 15/8/24
Laser heater MBI/jitter sims	Anna Giribono, Claudio Emma	Now - mid September
Simulation <-> machine model calibration	Eric Cropp	ongoing
Two bunch simulations	Nathan Majernik	ongoing
Live modeling	Zack Buschmann	ongoing

Bonus slides

What can we expect to see in experiment as we scan the L2 phase?

L2 phase [deg]	-37.5	-39.5	-41.5	-43.5	-45.5
LPS @ BC14END					
LPS @ PENT					

As we get closer to full compression in BC14, the LPS becomes more nonlinear in BC14 and BC20. This can result in high current spikes which will affect the BC14 BLEN and BC20 BLEN.

We need an independent way of controlling the L2 chirp that does not rely on BC14 BLEN. Currently we use the L2 phase multiknob but this is slow (energy feedback needs to catch up after each move) and not repeatable.

Notes

Matched gaussian beam at L0Aend.

L1 phase = -17 deg

ISR,LSC on

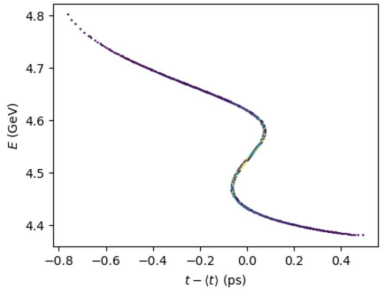
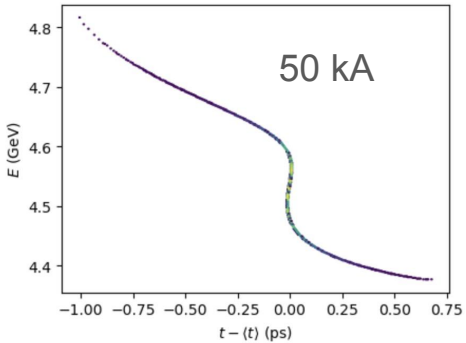
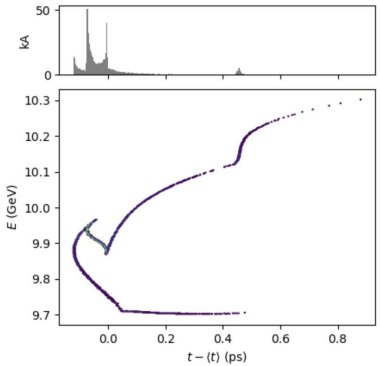
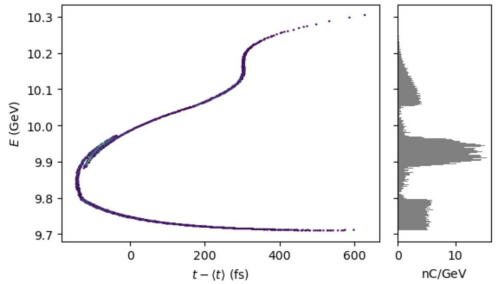
CSR off

Head of the beam is on the left

L2 voltage adjusted to get same energy at BC14

L2 phase is defined as deg from crest

What can we expect to see in experiment as we scan the L2 phase?

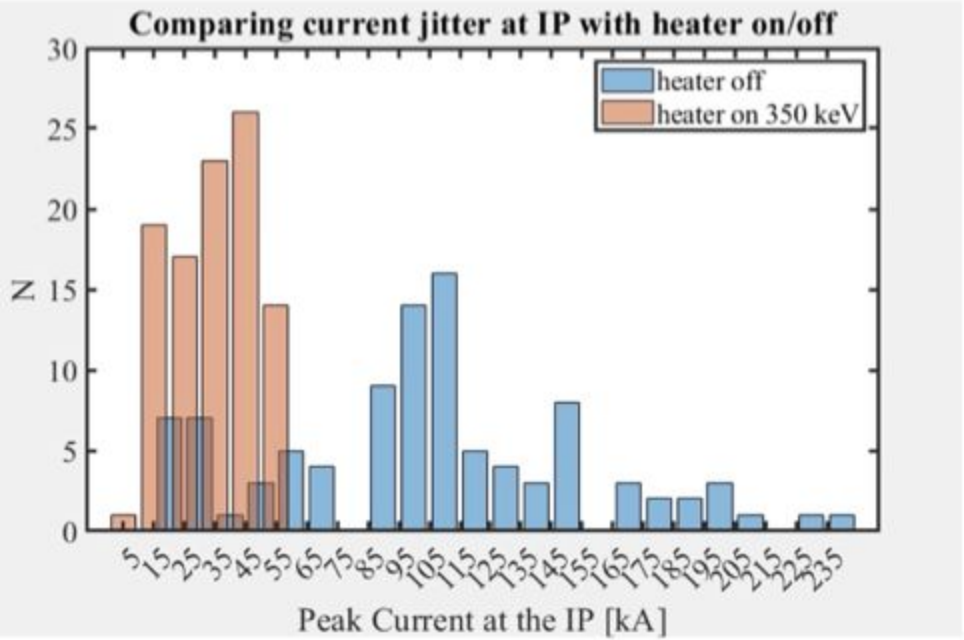
L2 phase [deg]	-35 Under comp in BC14	-36 Full comp in BC14	Notes
LPS @ BC14END			**Matched gaussian beam at L0Aend.** **L1 phase = -17 deg** **ISR,LSC on** **CSR off** **Head of the beam is on the left** **L2 voltage adjusted to get same energy at BC14**
LPS @ PENT			**L2 phase is defined as deg from crest**

The folds in the LPS at PENT have 50 kA of peak current. What is the effect of the heater on these ‘way off compression’ distributions? Could they be responsible for the remnant COTR we still see on DTOTR cameras even when the LH is on full energy? To be quantified with A. Giribono’s upcoming simulation work.

From 10/023 FACET-II User Meeting

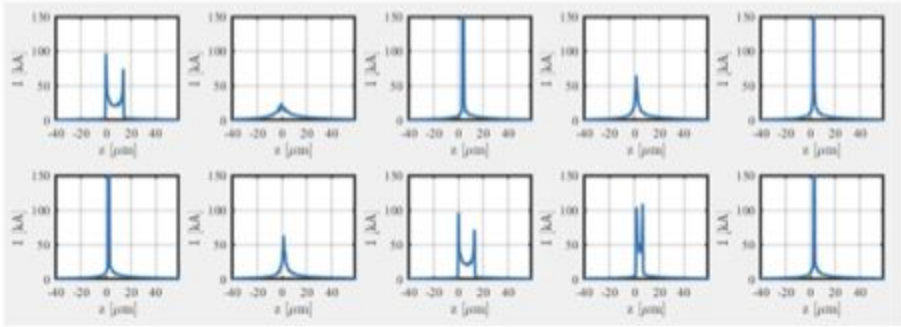
Starting point for the jitter scans is the 2nC single bunch simulation shown in the slides.
Jitter parameters are L1 and L2 RF phase (±0.25 deg) and amplitude (±0.1 %)

Jitter scans - single bunch current variation with LH on/off at 350 keV

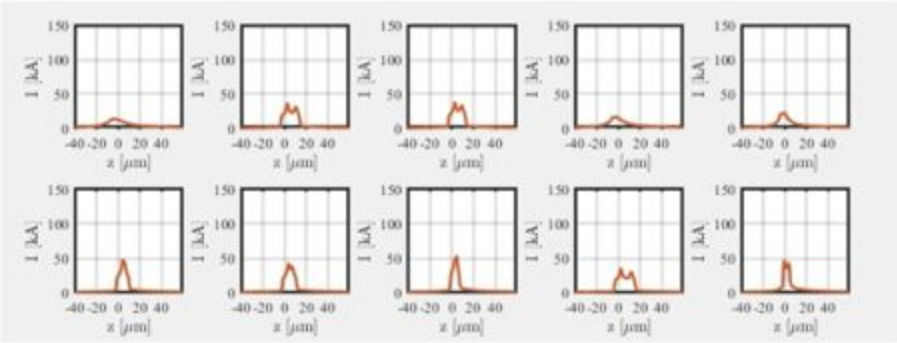


The laser heater reduces fluctuations of the peak current at the IP

Current profile examples heater off

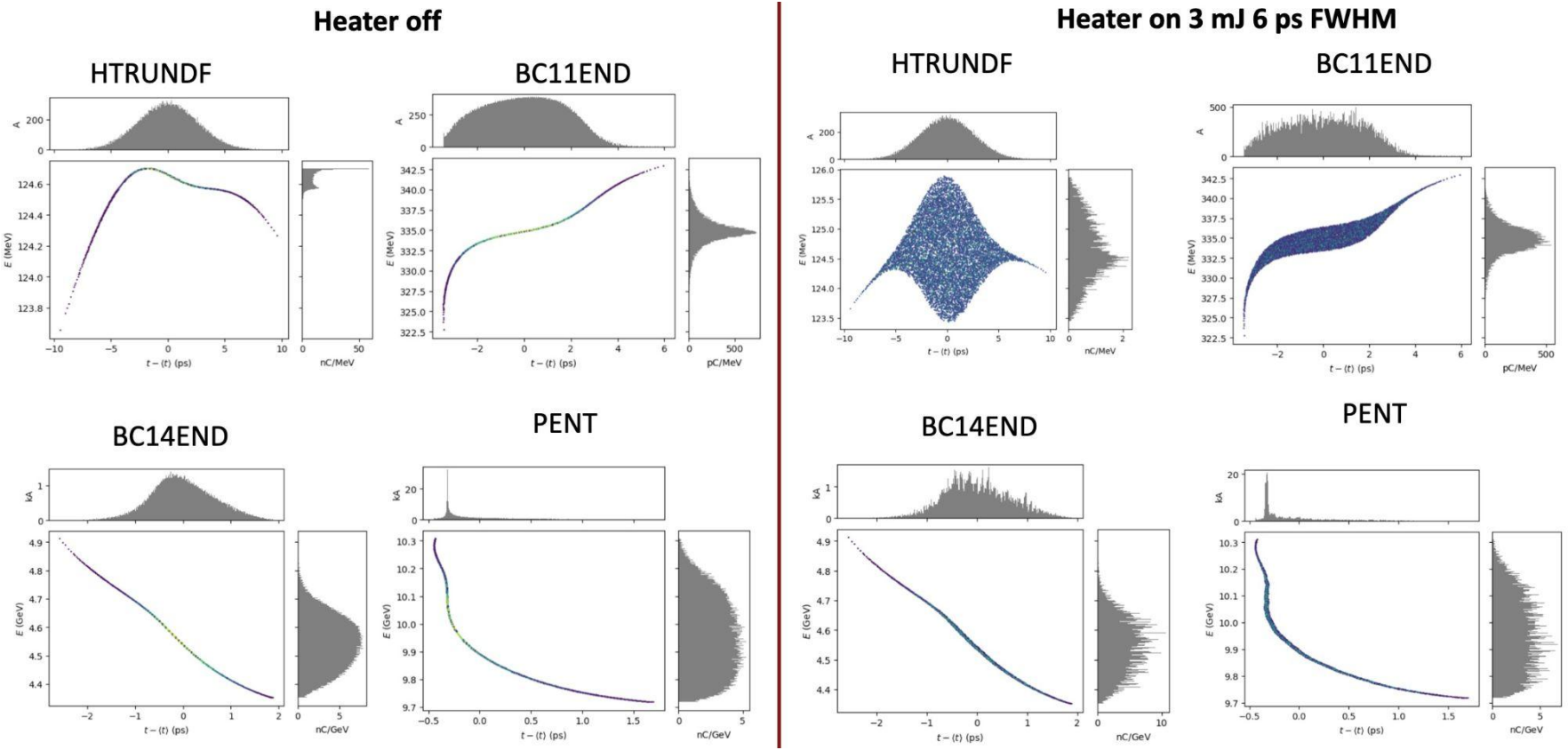


Current profile examples heater on



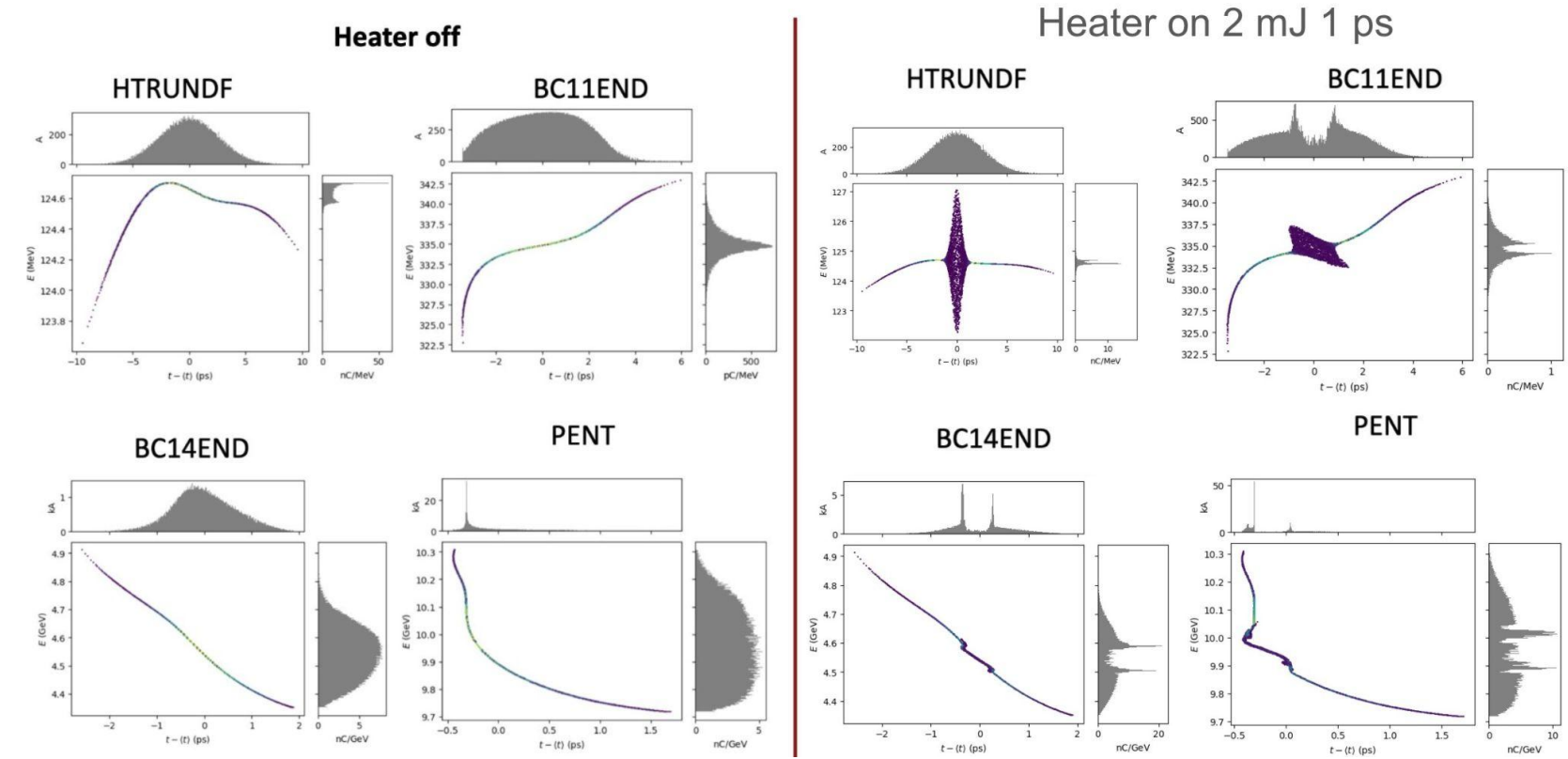
SLAC

Laser heater simulation with Bmad



Nominal LH operation reduces peak current at the IP

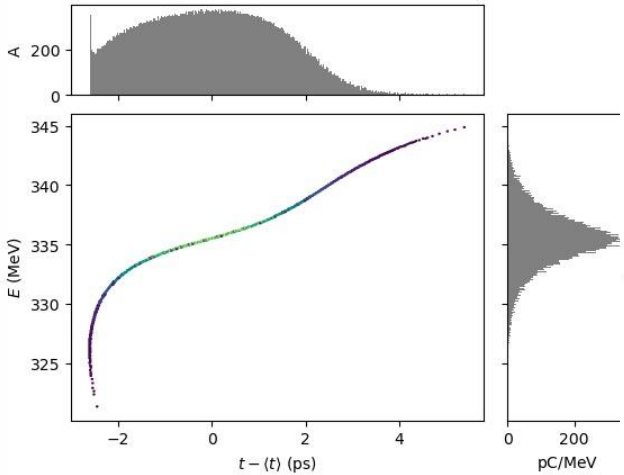
Laser heater simulation with Bmad - short heater



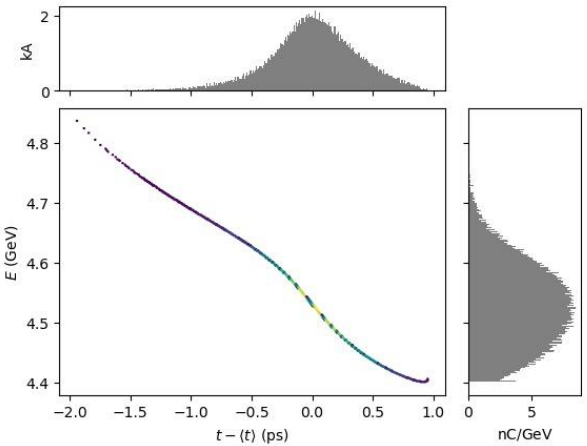
Short (or modulated) LH profile can be used to seed current spikes at the IP

1.6 nC Bmad sim starting from ideal injector beam

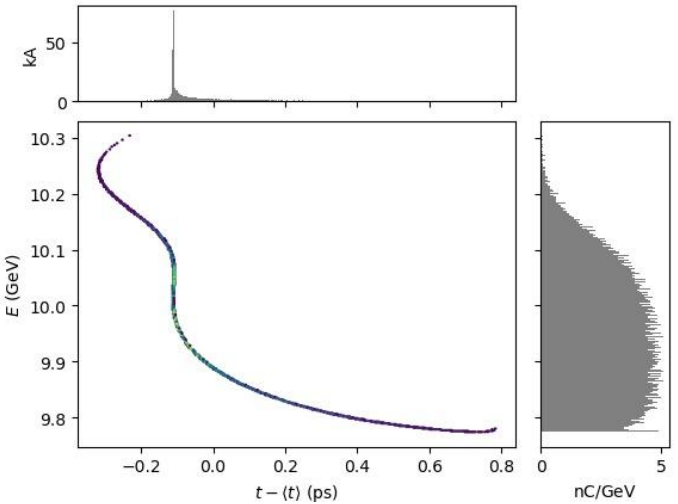
BC11CEND



BC14CEND



PENT



L1 p = -19 deg

L2 p = -39.5 deg

CSR LSC OFF