Benefits of the laser heater at FACET-II

E-300 Collaboration Meeting

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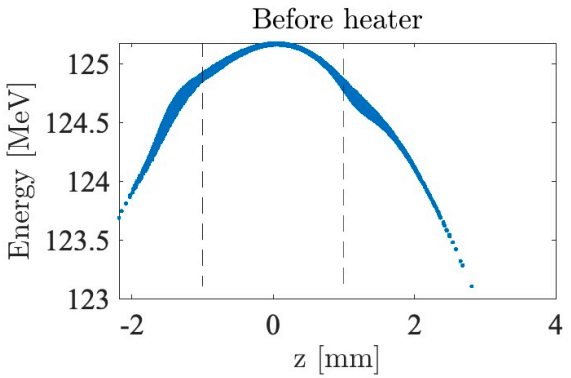
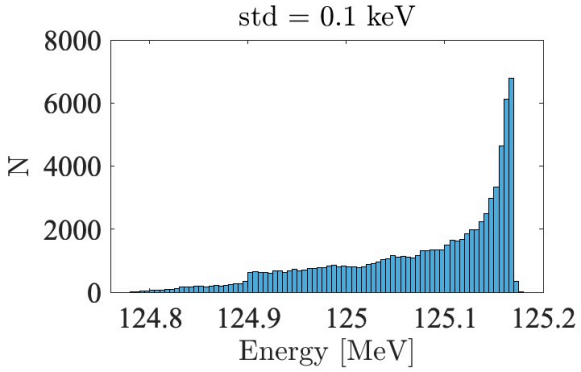
SLAC NATIONAL ACCELERATOR LABORATORY

Stanford University | U.S. DEPARTMENT OF ENERGY

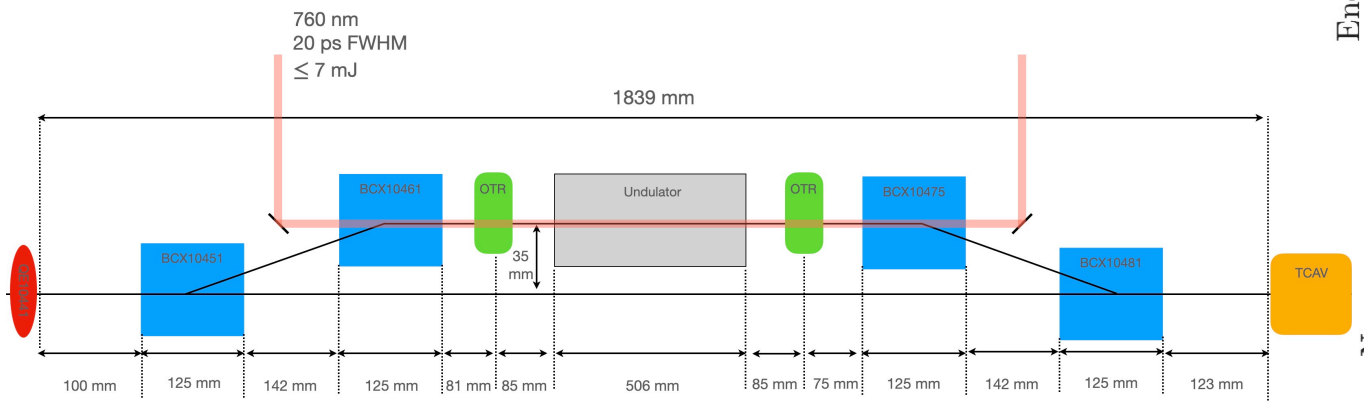
What is the laser heater and what does it do?

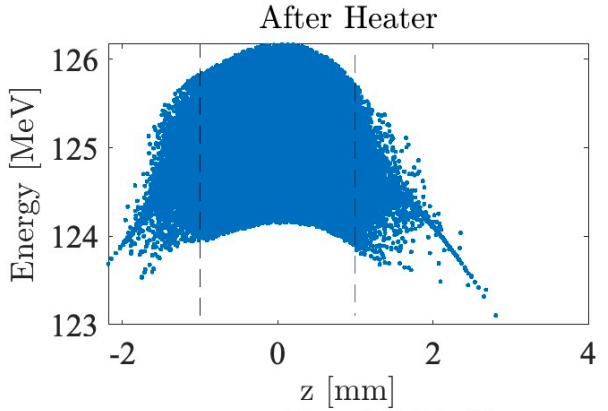


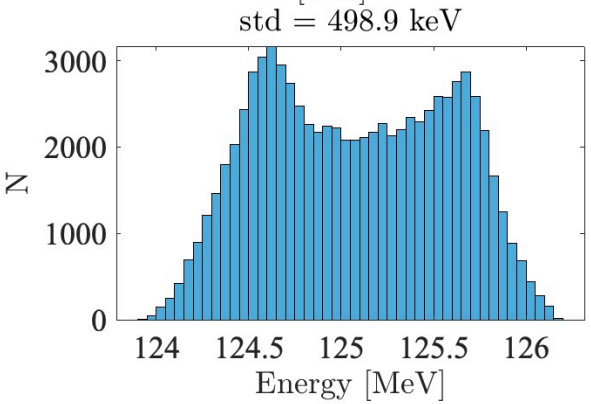


Energy modulation after the laser heater

$$\Delta\gamma(r) = \Delta\gamma_0 e^{-r^2/4\sigma_r^2} \qquad \Delta\gamma_0 mc^2[MeV] = 1.78\sqrt{\frac{E_{laser}[mJ]}{FWHM[ps]}}$$







- The laser heater is a device designed to increase the energy spread of the electron beam at the exit of the injector
- It consists of a 9 period undulator and a four dipole chicane located downstream of L0b and upstream of TCAV0
- The FACET-II laser heater closely follows the LCLS design (see [1]-[5])

Why do we want the laser heater at FACET-II?

1. Control of the peak current at the FACET Interaction Point (IP).

   1.1. Reduction of the IP emittance, achieved by reducing the peak current in the bunch compressors to limit Coherent Synchrotron Radiation (CSR).

2. Reduction of the jitter in peak current at the IP.

3. Suppression of the micro-bunching instability and consequent emission of COTR

1. Control of the peak current and emittance at the IP

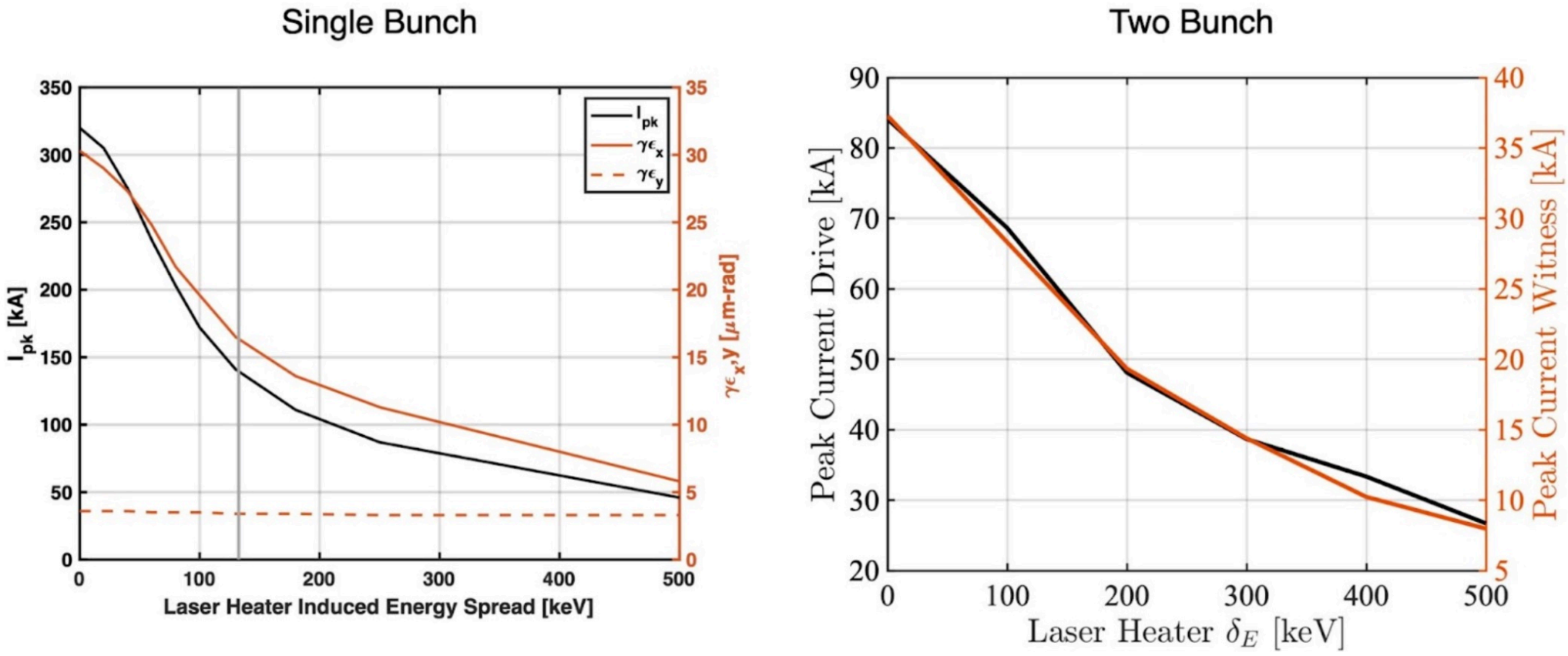
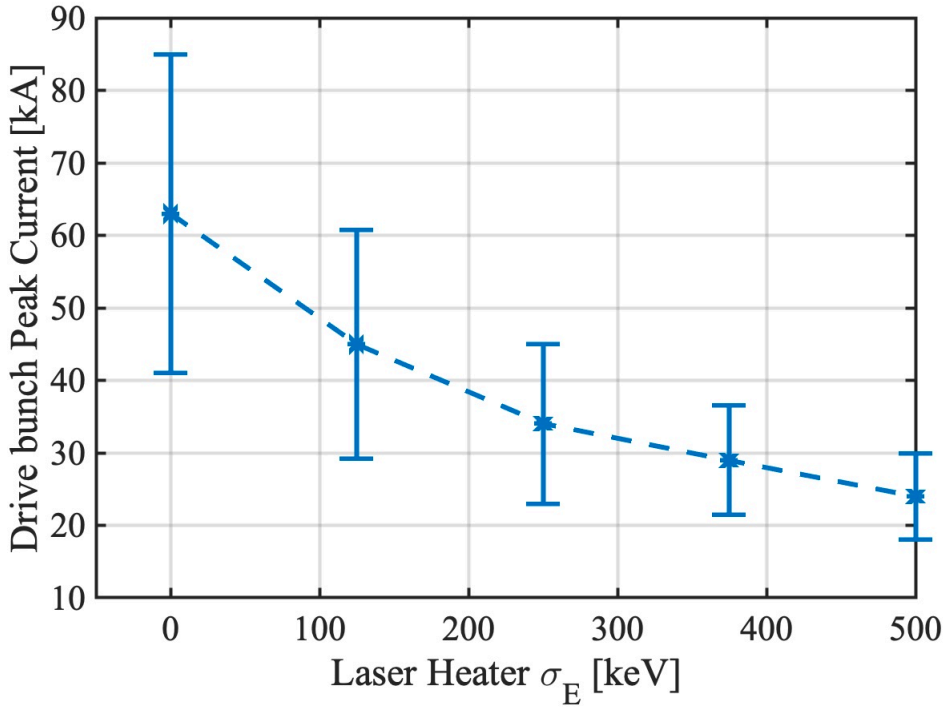
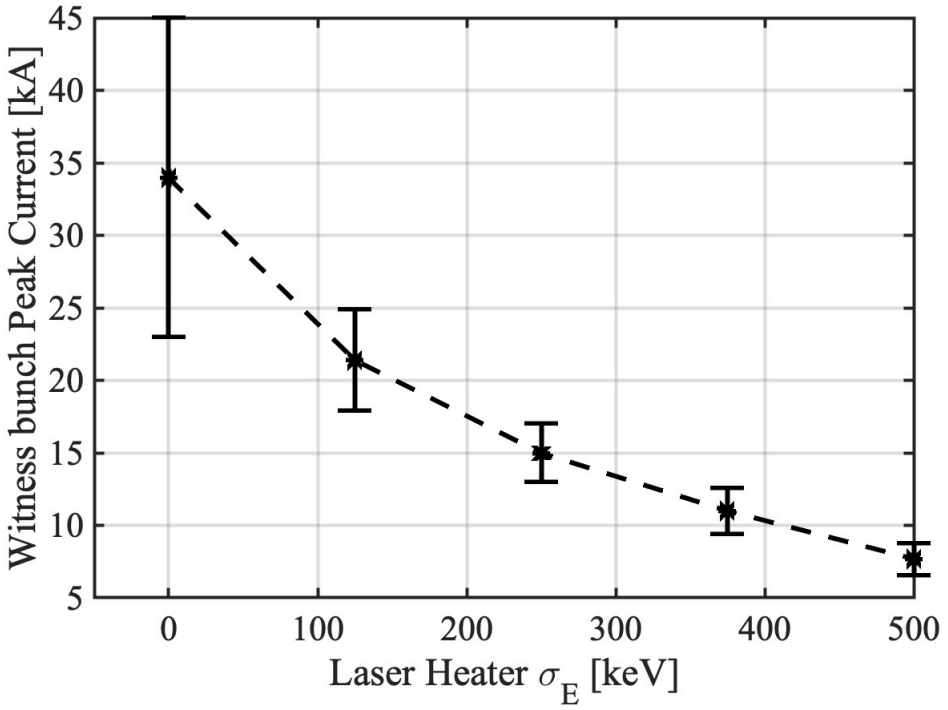


Figure 1: (left) Peak current and emittance as a function of laser heater energy for the single bunch 2nC nominal running parameters of FACET-II. (right) Peak current as a function of RMS laser heater energy modulation for the nominal two-bunch run parameters (1.5/0.5 nC for drive/witness beam).

2. Reduction of the peak current jitter at the IP (two bunch)

500 simulations per LH value Np = 1e5, 1D CSR On





	LH = 0 keV	125 keV	250 keV	375 keV	500 keV
Drive Bunch Ipk (mean+/- std) [kA]	63 ± 22	45 ± 16	34 ± 11	29 ± 7.6	24 ± 6
Witness Bunch Ipk (mean+/- std) [kA]	34 ± 11	21 ± 3.5	15 ± 2	11 ± 1.6	7.7 ± 1.1

D. Ratner et al SLAC-PUB-13392 (2008)
D. Ratner et al, PRSTAB **18**, 030704 (2015)

3. Suppression of micro bunching instability at LCLS

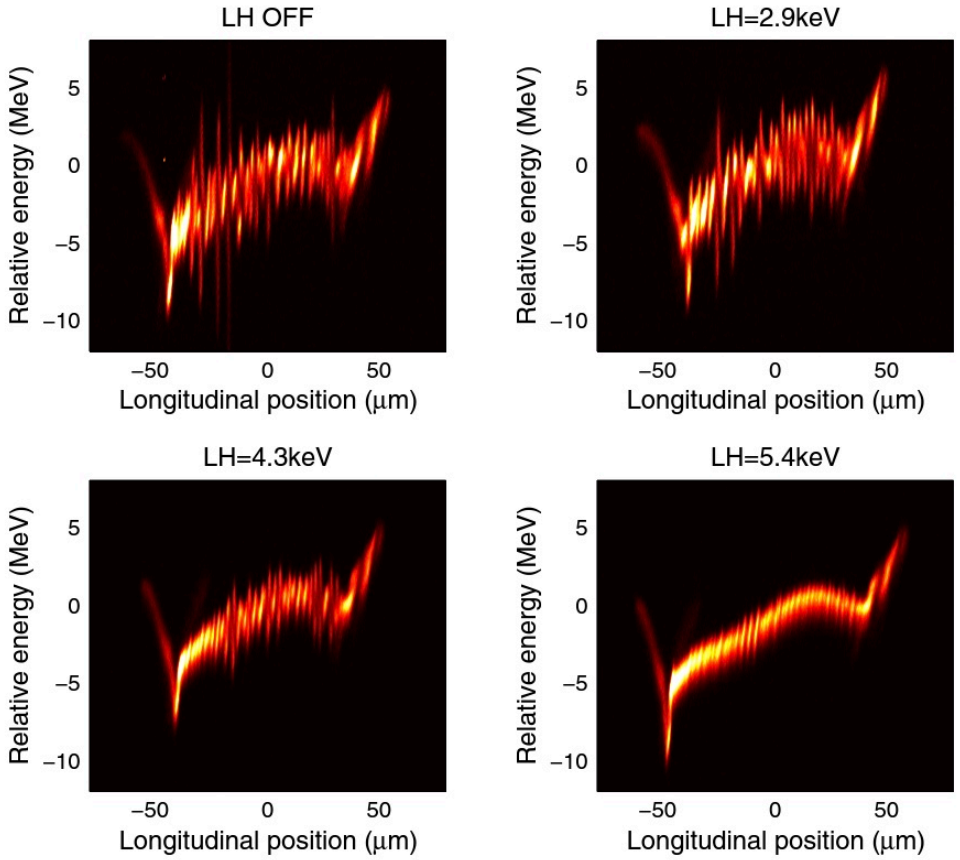
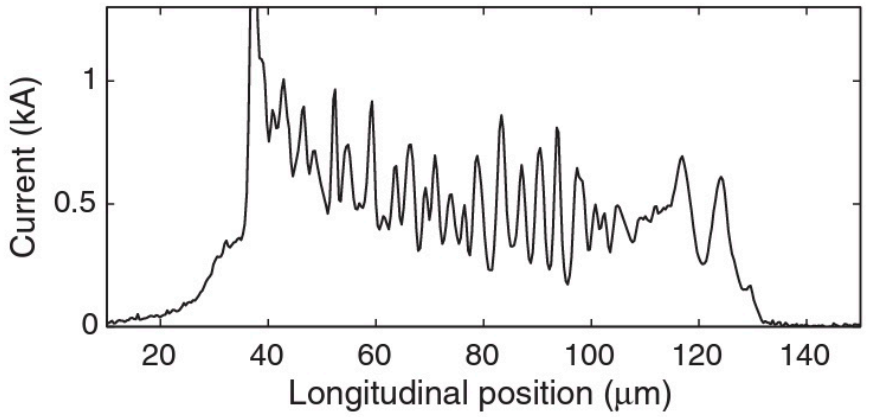
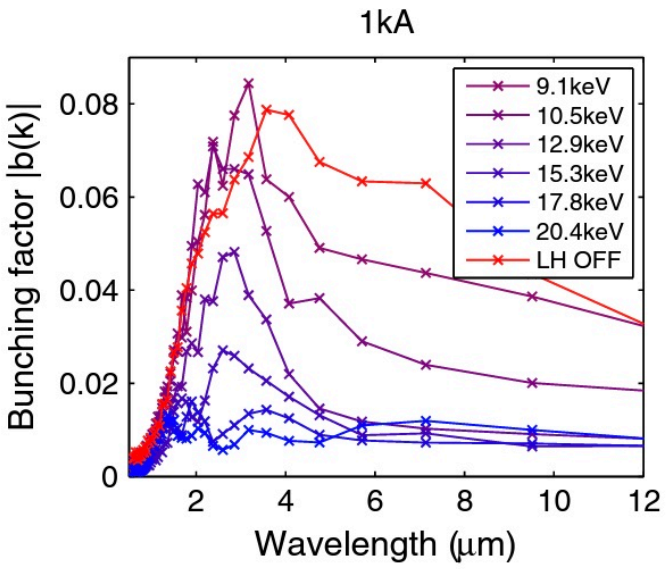


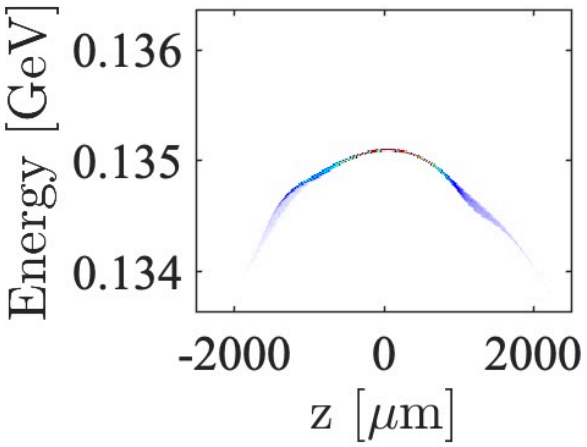
FIG. 2. Measured electron phase space with different rms energy spread induced by the laser heater (LH). Conditions are 0.5 kA peak current, 44 MV XTCAV voltage, and bunch head to the right.

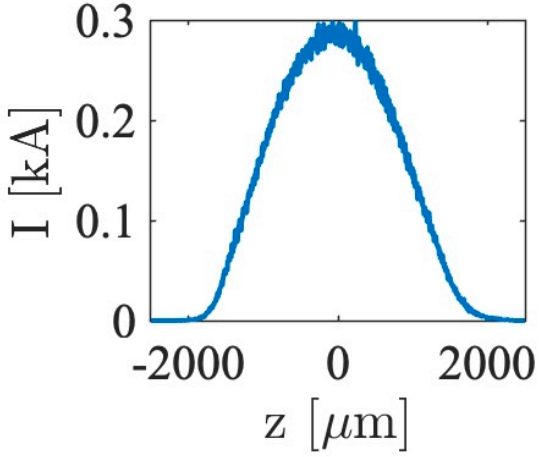




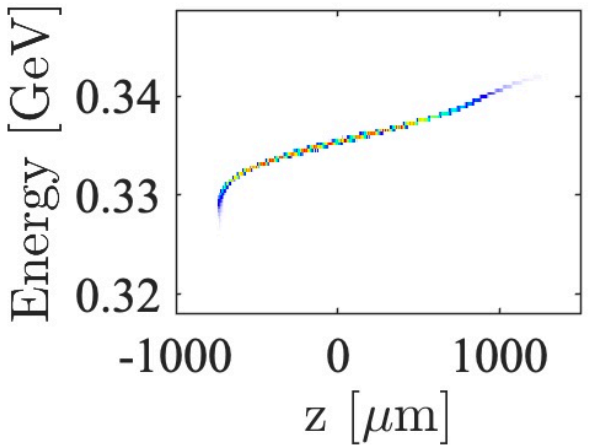
3. Microbunching simulations for FACET-II (heater off)

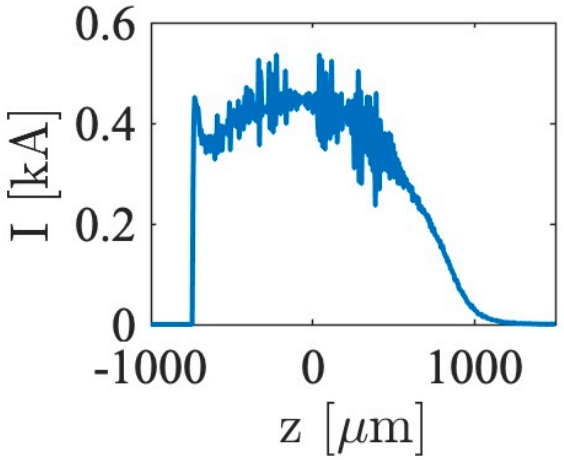
After injector



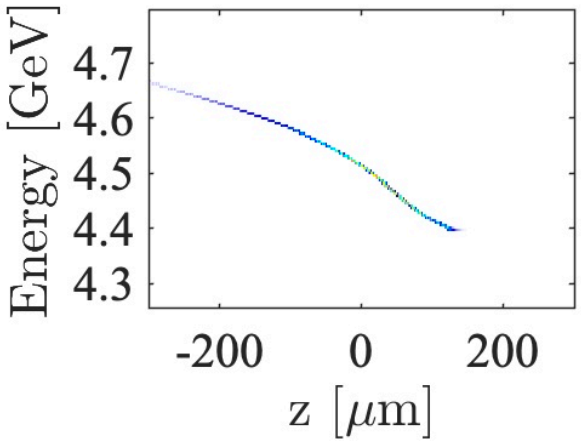


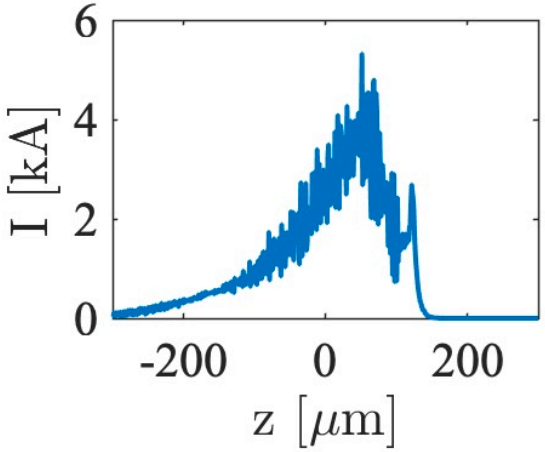
After BC11



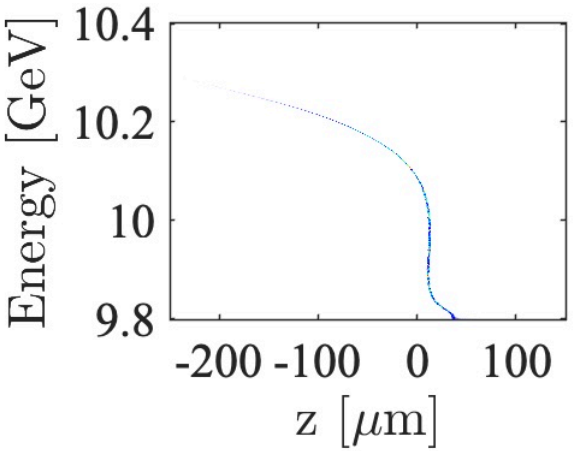


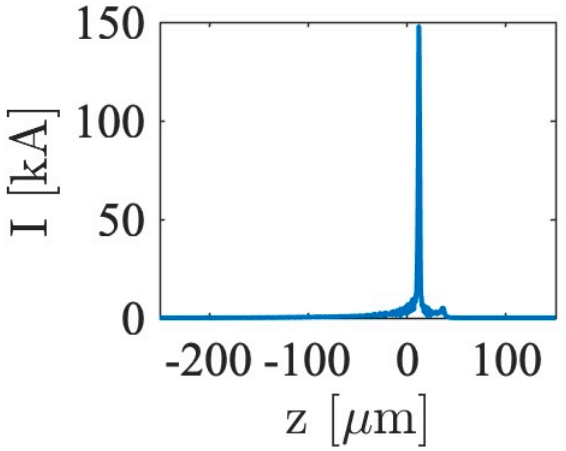
After BC14



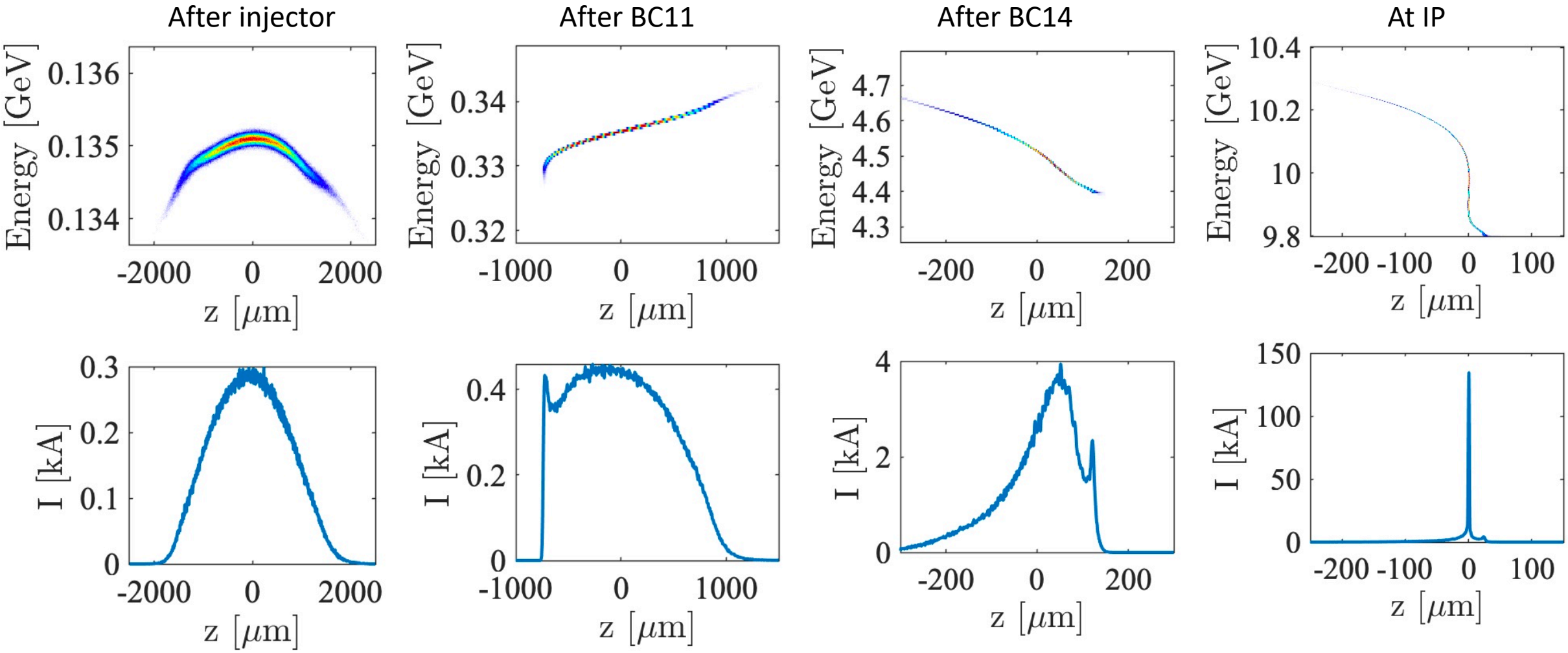


At IP





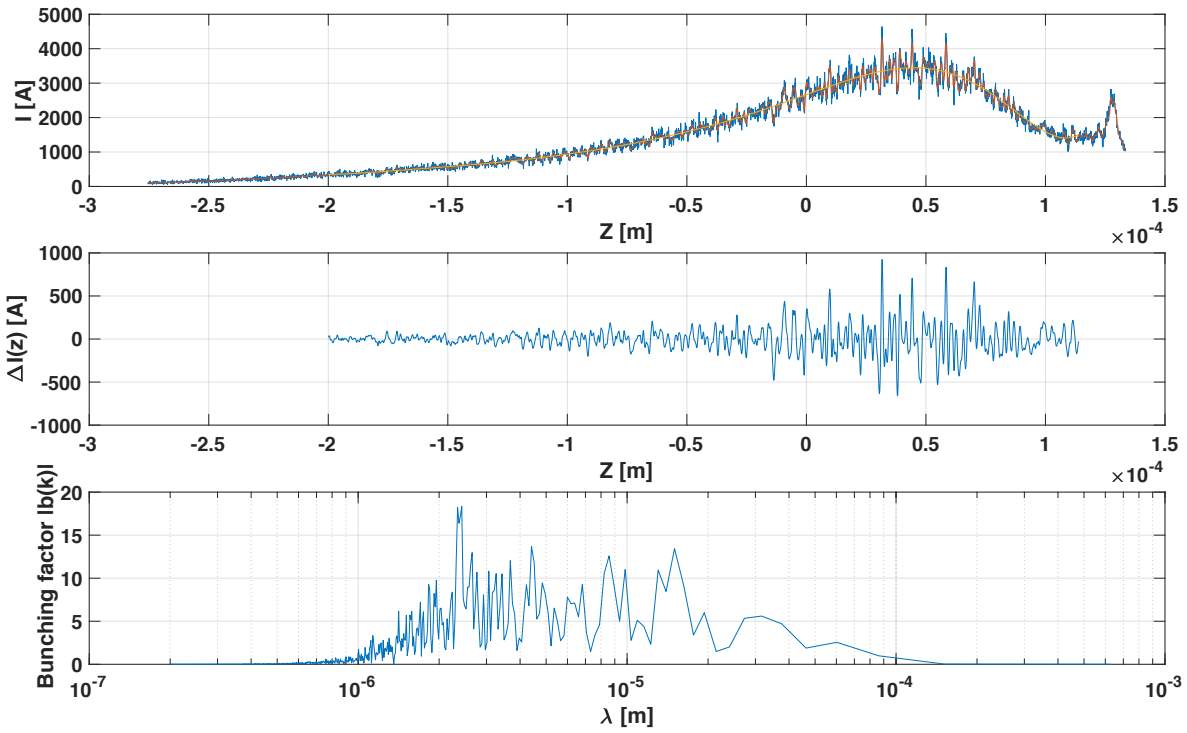
3. Microbunching simulations for FACET-II (heater on 50 keV)



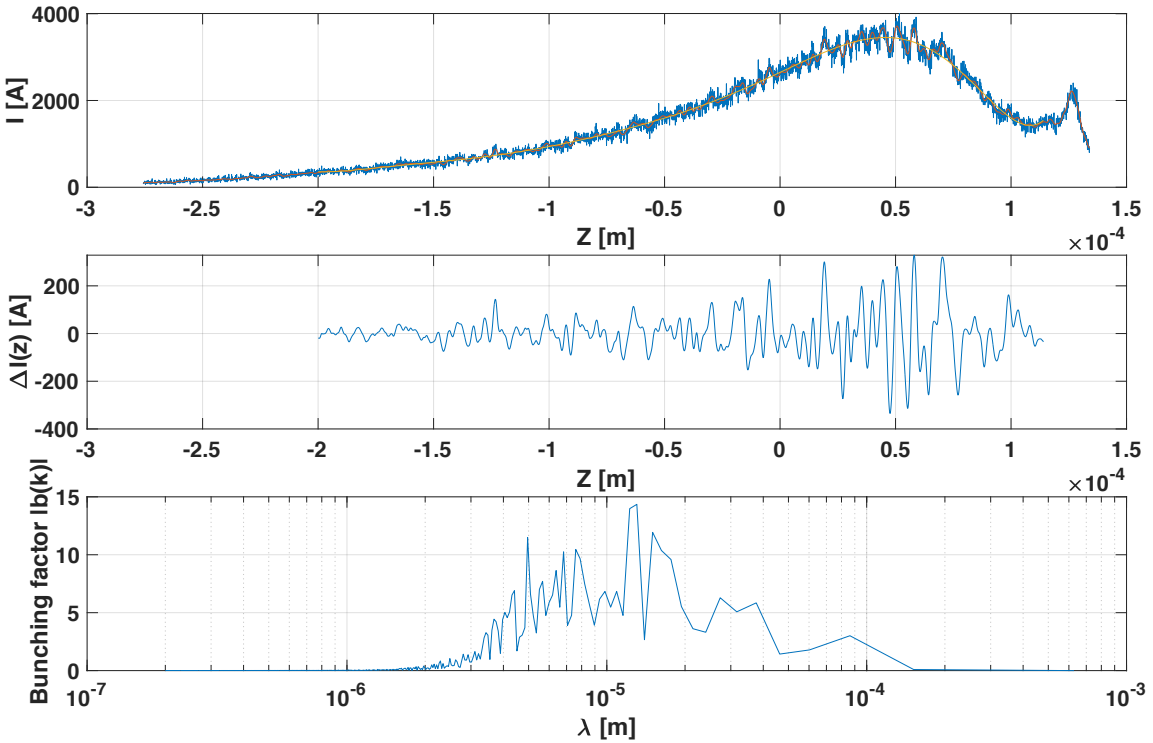
Laser heater smooths out longitudinal current modulations

Heater on vs heater off bunching factors

Heater Off



Heater On (50 keV)



Beam tracker to the end of BC14 with 1M macro-particles

Status and timeline for the LH installation

Operations Progress:

- Single bunch 2nC commissioning to continue until summer downtime
- Two bunch commissioning to start after summer downtime

Chicane Dipole Installation:

- Dipoles arrived at SLAC 03/2022. Currently with magnetic measurements group. Targeted installation in the vault before summer downtime

Undulator Installation:

- Undulator magnets to arrive at SLAC 07/2022. Construction and assembly by magnetic measurements during summer downtime. Targeted installation by 09/2022 before fall restart.

Laser Optics Installation:

- LSS modified and certified to allow laser heater operation 04/28/2022.
- Laser heater compressor and transport hardware currently being installed. Remaining work involves adding transport pipe in the vault and installing the laser heater optics table. Laser Optics scheduled to be installed before summer downtime to allow initial commissioning of laser transverse + temporal overlap with e-beam.

LH system scheduled to start commissioning in Fall 2022

References

[1] P. Emma LCLS PRD 1.2-004, Revision 2,
[2] P. Emma LCLS PRD 1.2-007, Revision 1
[3] R. Carr LCLS ESD 1.2.124
[4] Z. Huang et al., Measurements of the linac coherent light source laser heater and its impact on the x-ray free electron laser performance, Phys. Rev. STAccel. Beams 13, 020703 (2010).
[5] Z. Huang et al., Suppression of microbunching instability in the linac coherent light source, PRSTAB **7**, 074401 (2004)
[6] FACET laser heater requirements document (in progress) https://docs.google.com/document/d/1Xku2n1apbFHsdBRUckTMy6oqUhX3a_rWKNEXd4DCwIM/edit#heading=h.wvsg22f2zl5u

Extra Slides

Two bunch example with max RMS energy spread

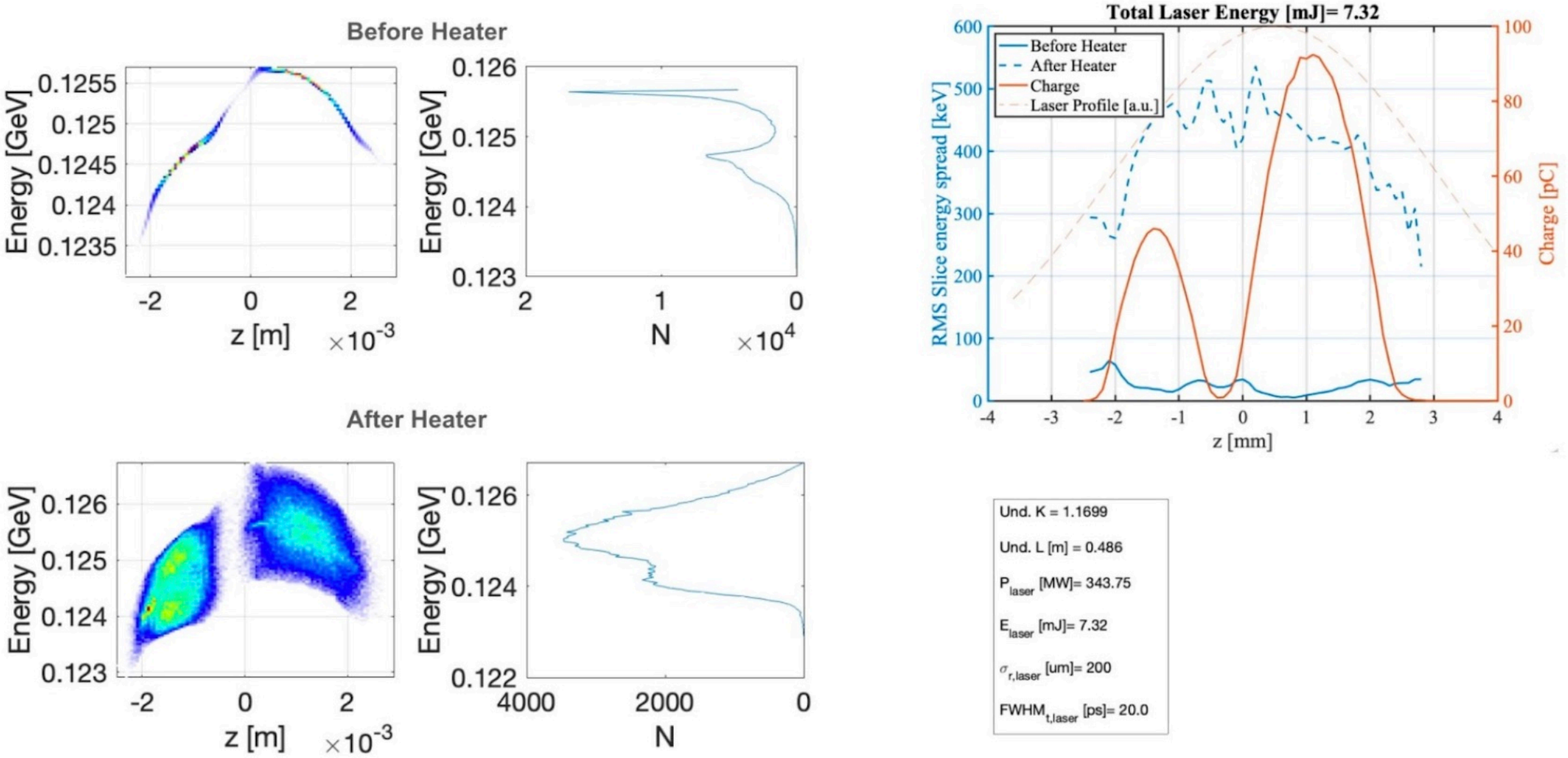
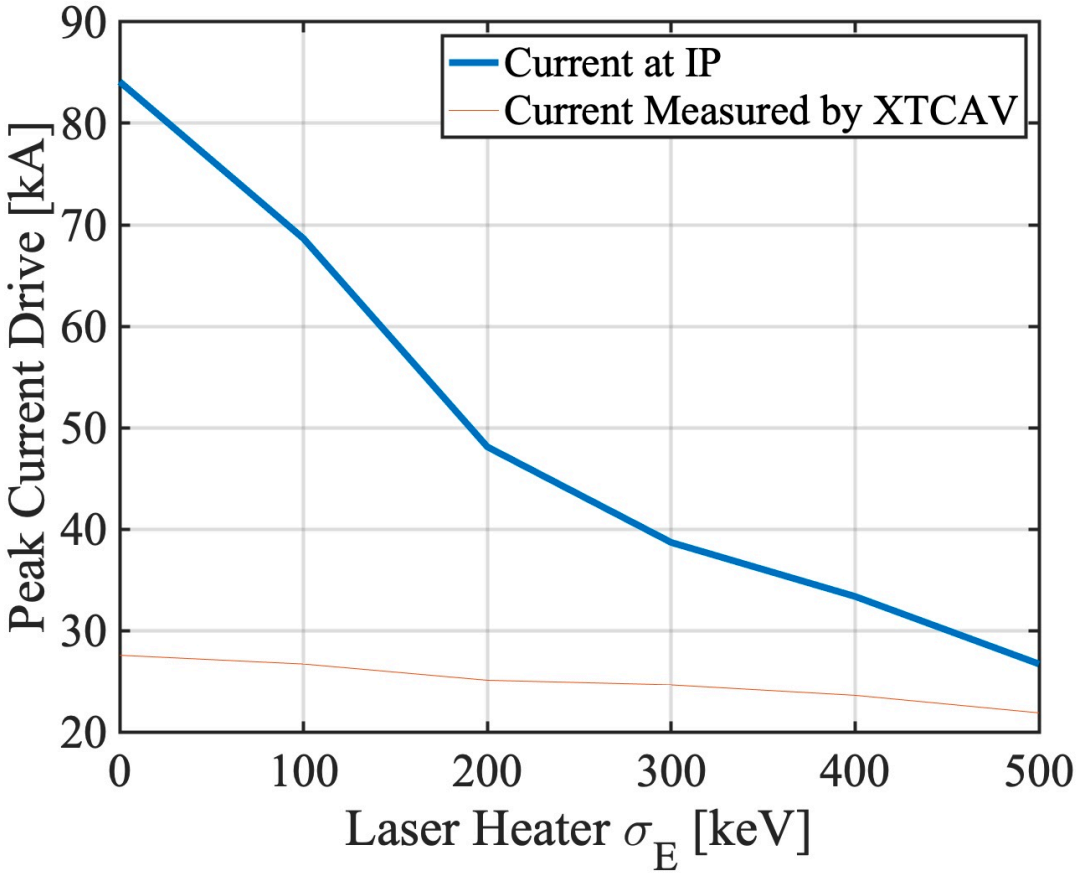


Figure 5: Longitudinal phase space before and after the laser heater for a 1.5/0.5 nC two bunch run configuration with a max RMS

Closing the gap between the actual current and what XTCAV can measure



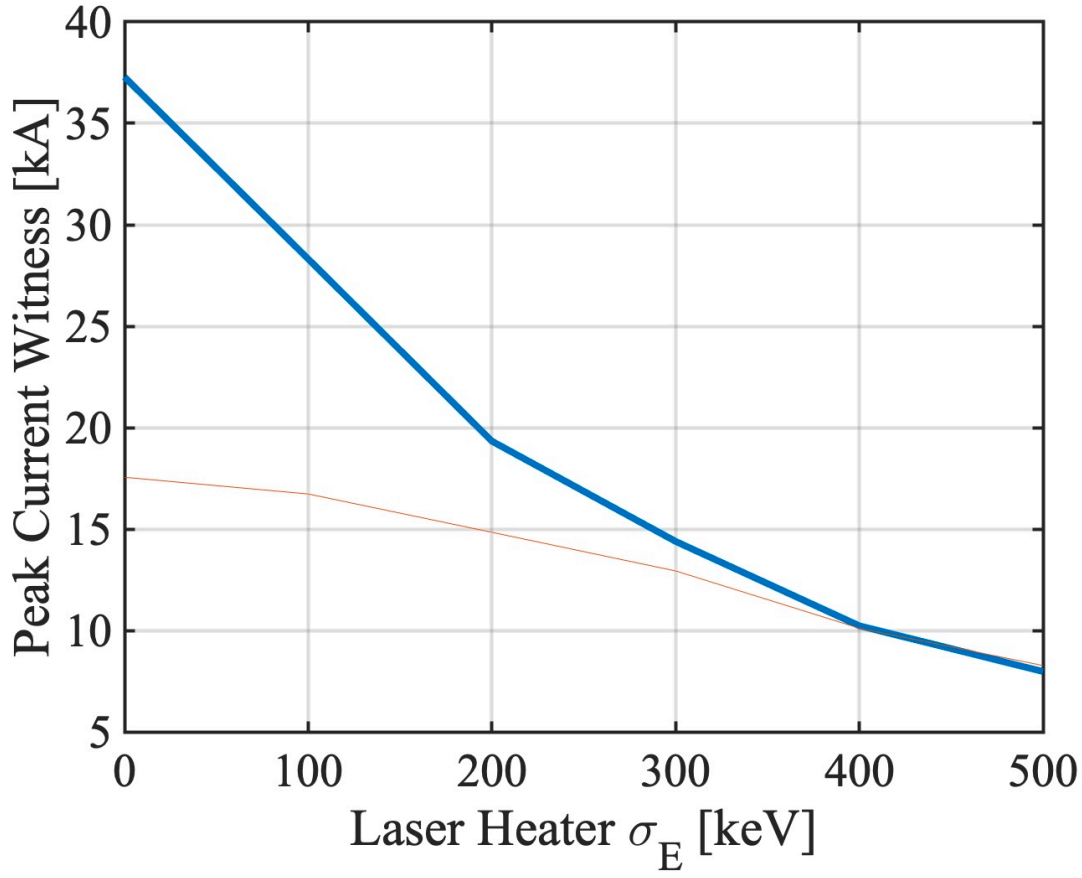


Table 1: Main parameters for the FACET-II laser heater.

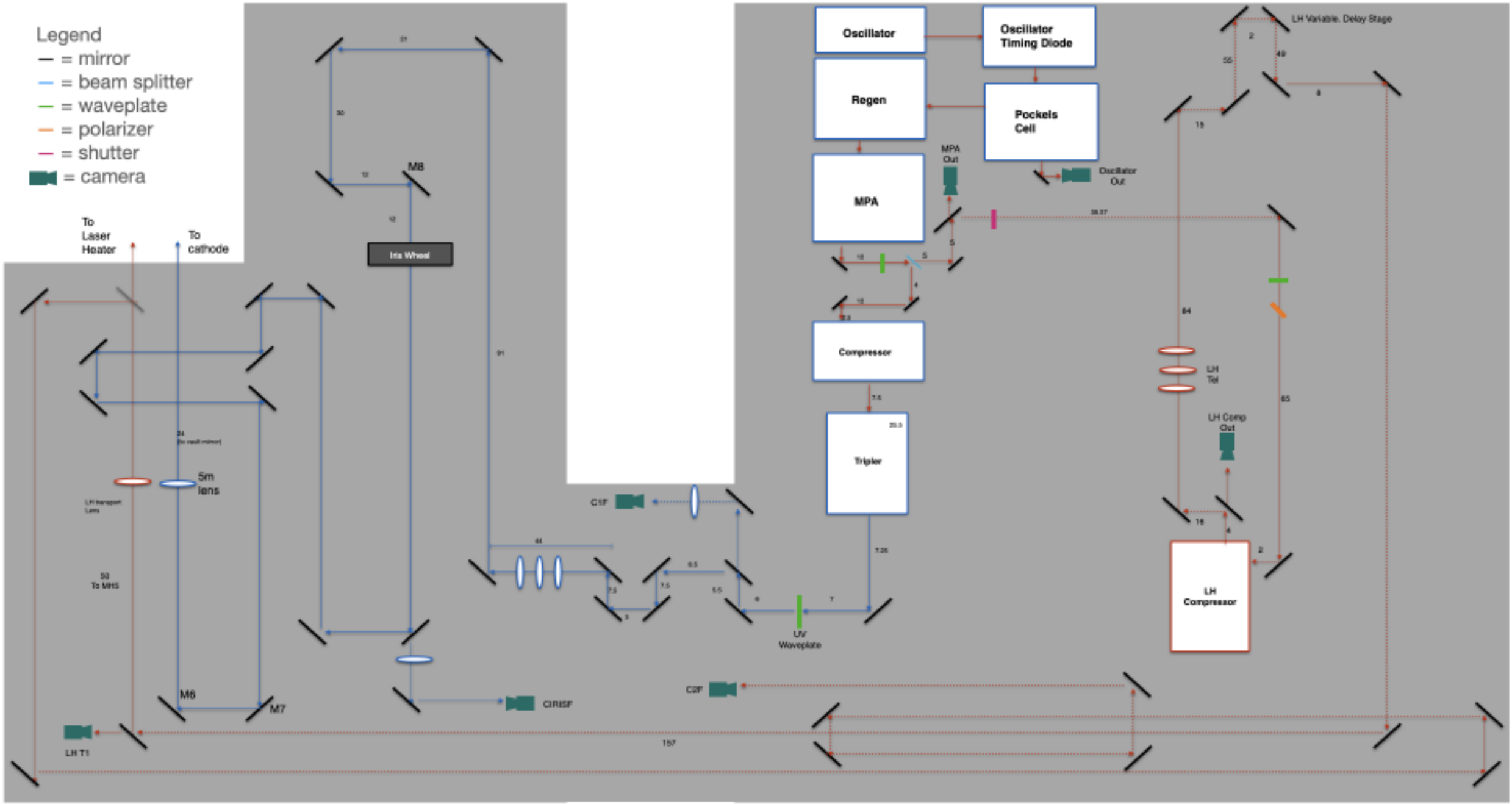
Parameter	Nominal Value	Range	Unit
Electron Energy	125	125-135	MeV
Transverse RMS e-beam size	200	-	μm
Undulator Period	5.4	-	cm
Peak Undulator Field	0.232	-	T
Peak Undulator Parameter	1.17	-	-
Undulator Length	48.6	-	cm
Number of undulator periods	9	-	-
Laser Wavelength	760	-	nm
Laser RMS spot size	200	-	μm
Laser Peak Power	175	0-700	MW
Laser Pulse Energy	4	0-6.7	mJ
Laser Pulse Duration FWHM	20	-	ps
RMS energy spread generated	250	0-500	keV

Cathode UV, LH IR and e-beam simulation parameters for single and two-bunch operating modes

Parameter	Single Bunch	Drive Beam	Witness Beam	Unit
Charge at laser heater [nC]	2	1.5	0.5	nC
FWHM UV laser pulse length on cathode	7 (4)	5.25 (4)	2 (4)	ps
Radius of Cut Gaussian UV pulse on cathode	2.68	2.68	2.68	mm
E-beam FWHM pulse length at laser heater	6.8	5.43	3.9	ps

Table 2: UV laser parameters at the cathode and corresponding electron beam parameters at the laser heater for the single and two-bunch injector simulations. The FWHM UV laser pulse length on the cathode shows the original values specified in the FACET-II TDR and the value in brackets of 4ps representing the current laser configuration.

Sketch of Sector 10 Laser Transport. Distances in inches unless otherwise specified 1/31/2022



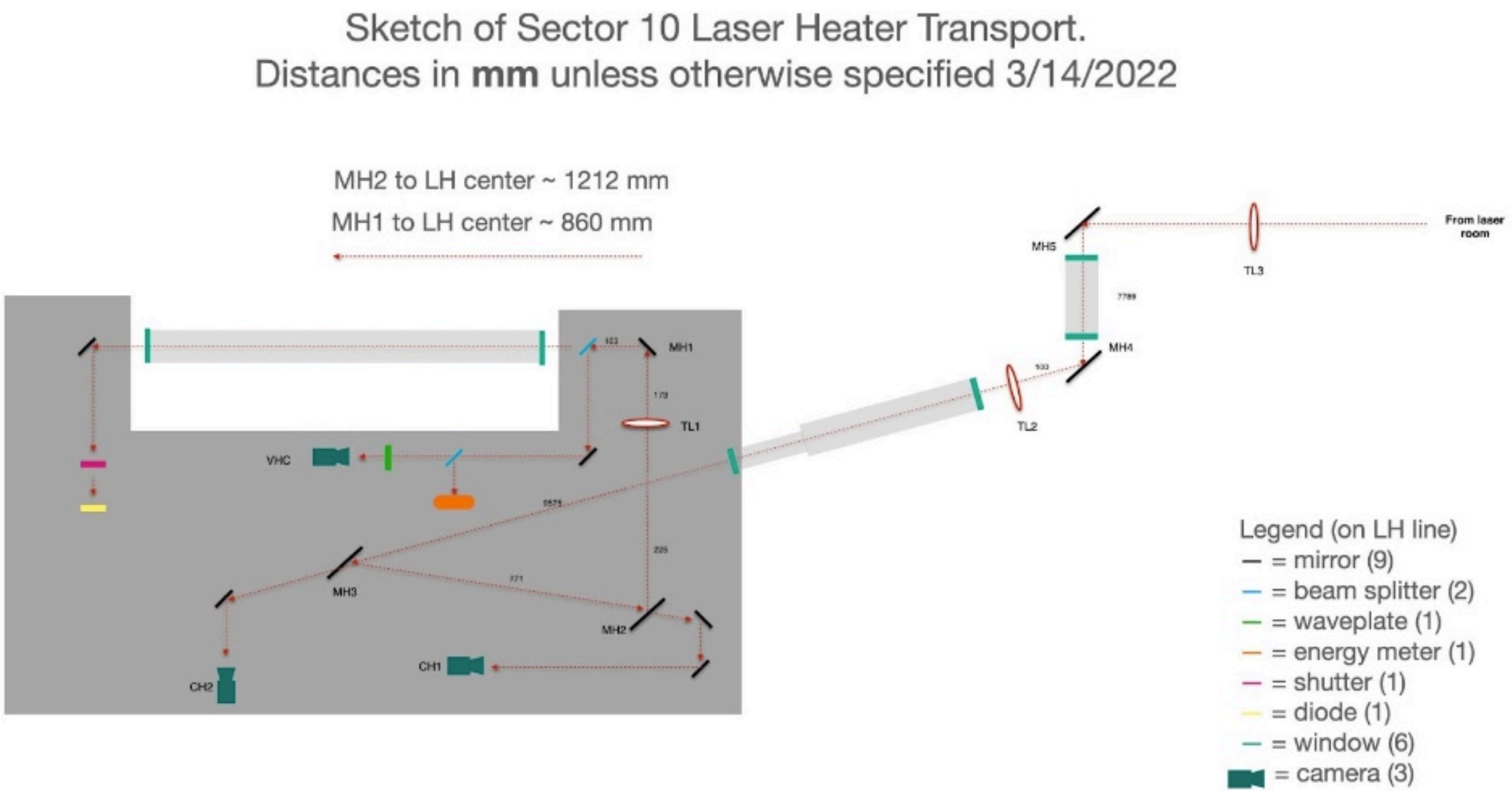
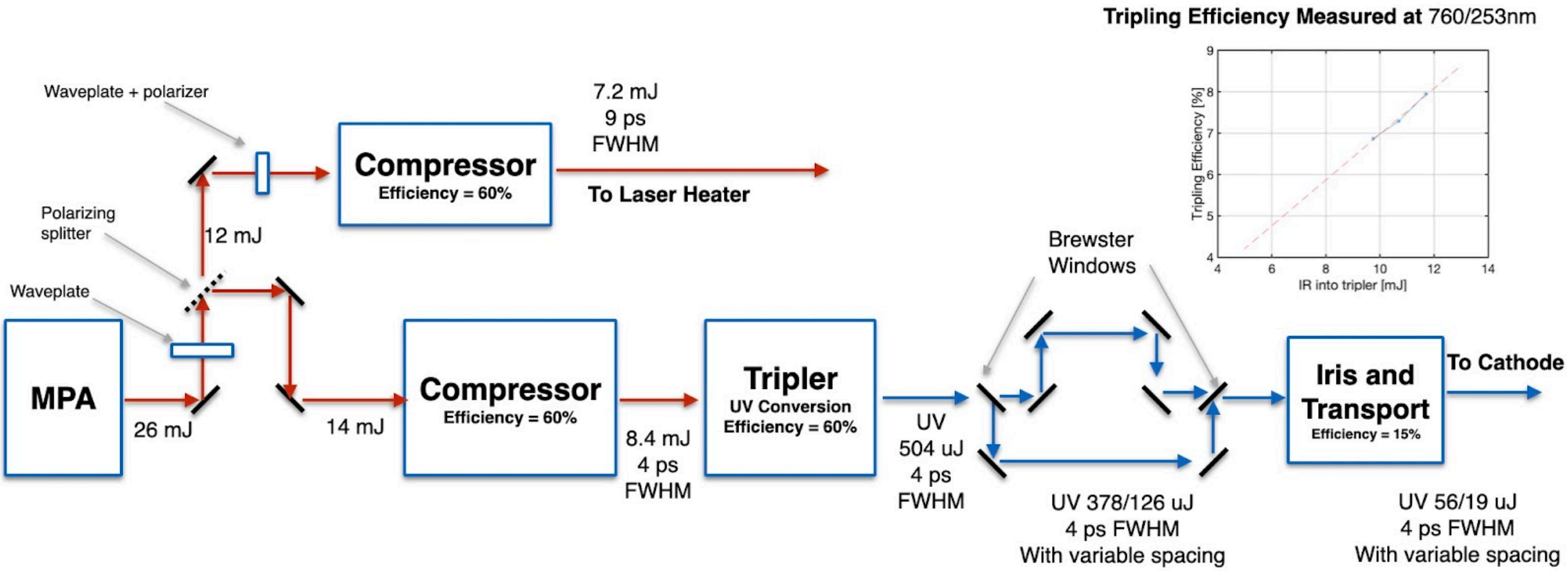
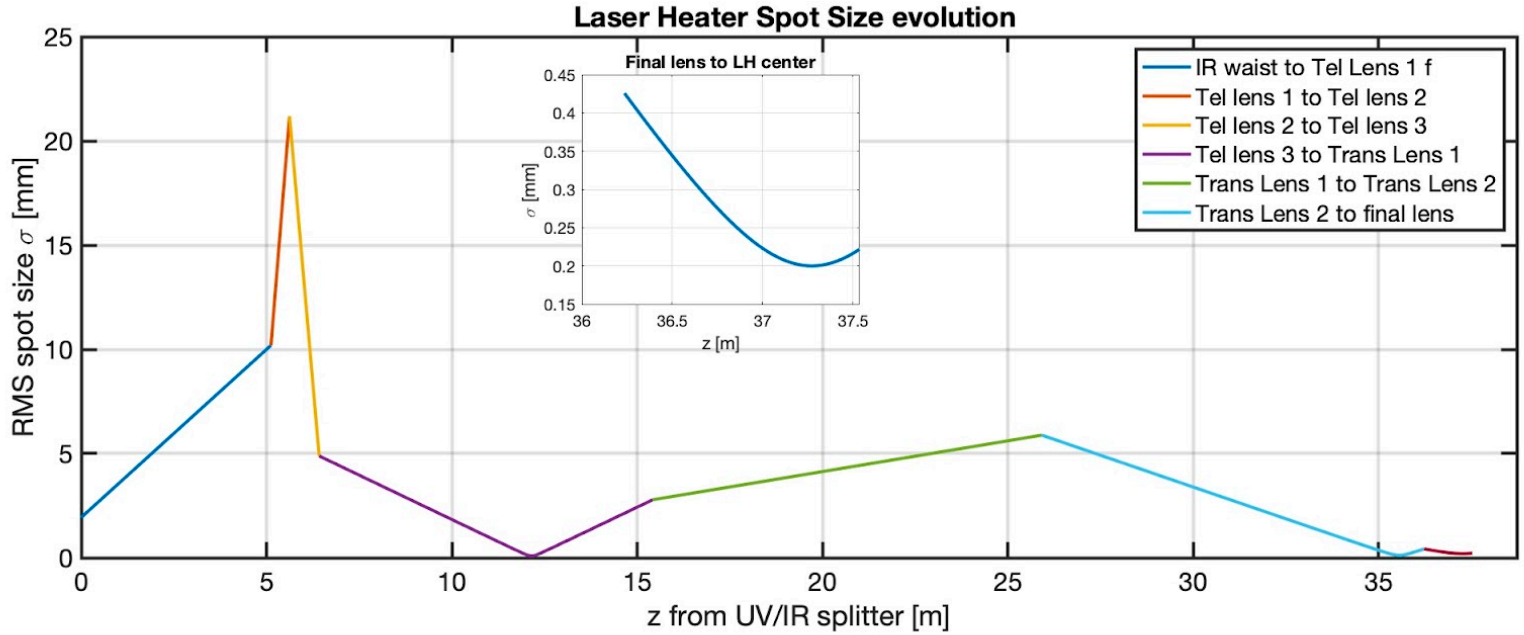
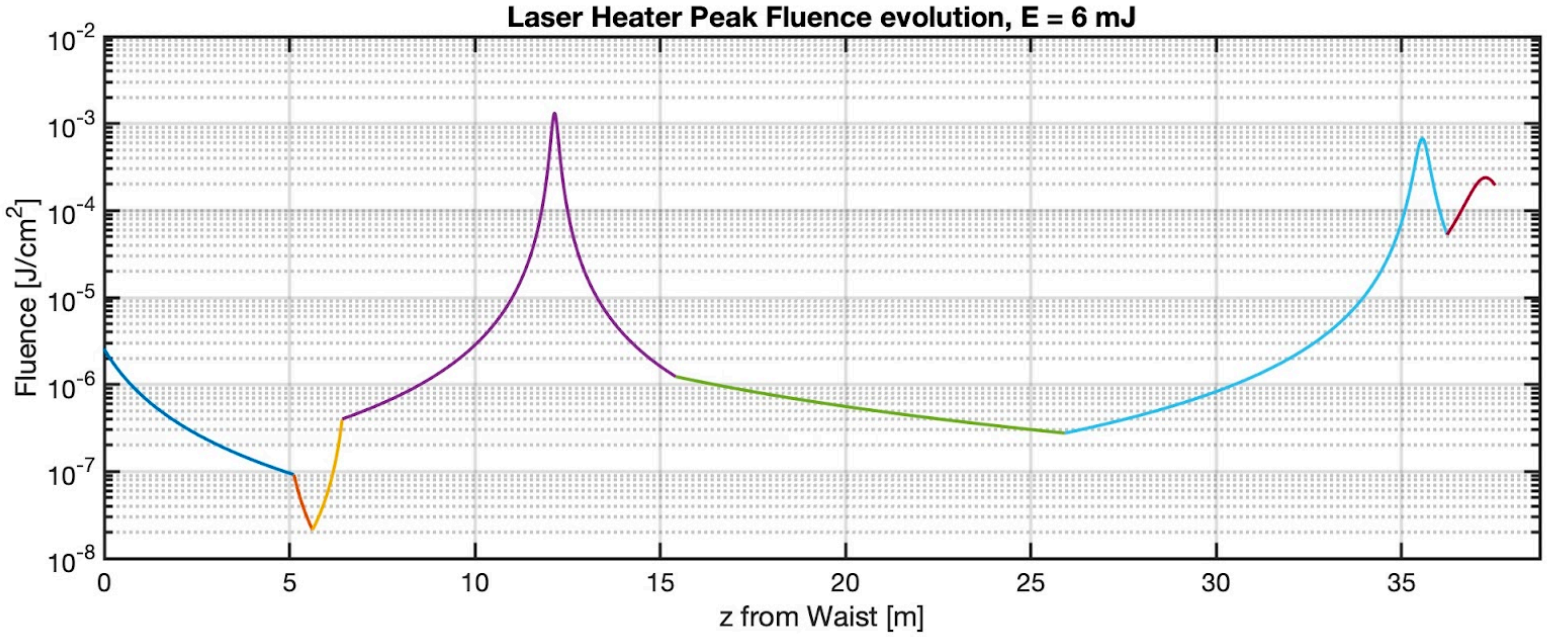


Figure 8: Sketch of the FACET Laser heater transport from the laser room to the vault. Focal lengths for the transport lenses f = 5m,6.5m,0.5m.

Sketch of LH and UV energy and pulse length evolution along the laser transport



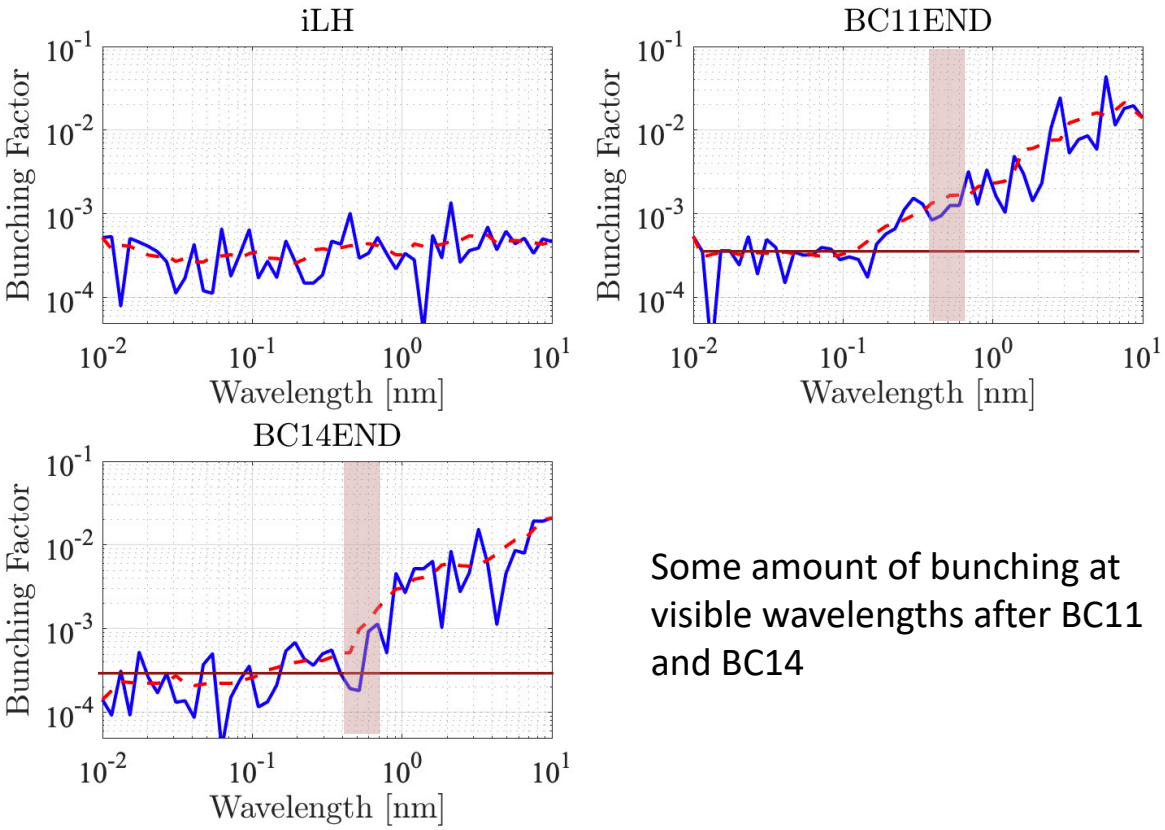

Laser Heater Spot Size evolution
Final lens to LH center
σ [mm]
z [m]
RMS spot size σ [mm]
z from UV/IR splitter [m]
IR waist to Tel Lens 1 f
Tel lens 1 to Tel lens 2
Tel lens 2 to Tel lens 3
Tel lens 3 to Trans Lens 1
Trans Lens 1 to Trans Lens 2
Trans Lens 2 to final lens


Laser Heater Peak Fluence evolution, E = 6 mJ
Fluence [J/cm^2]
z from Waist [m]

3. Tracking simulations with micro bunching for FACET-II (heater on vs off)

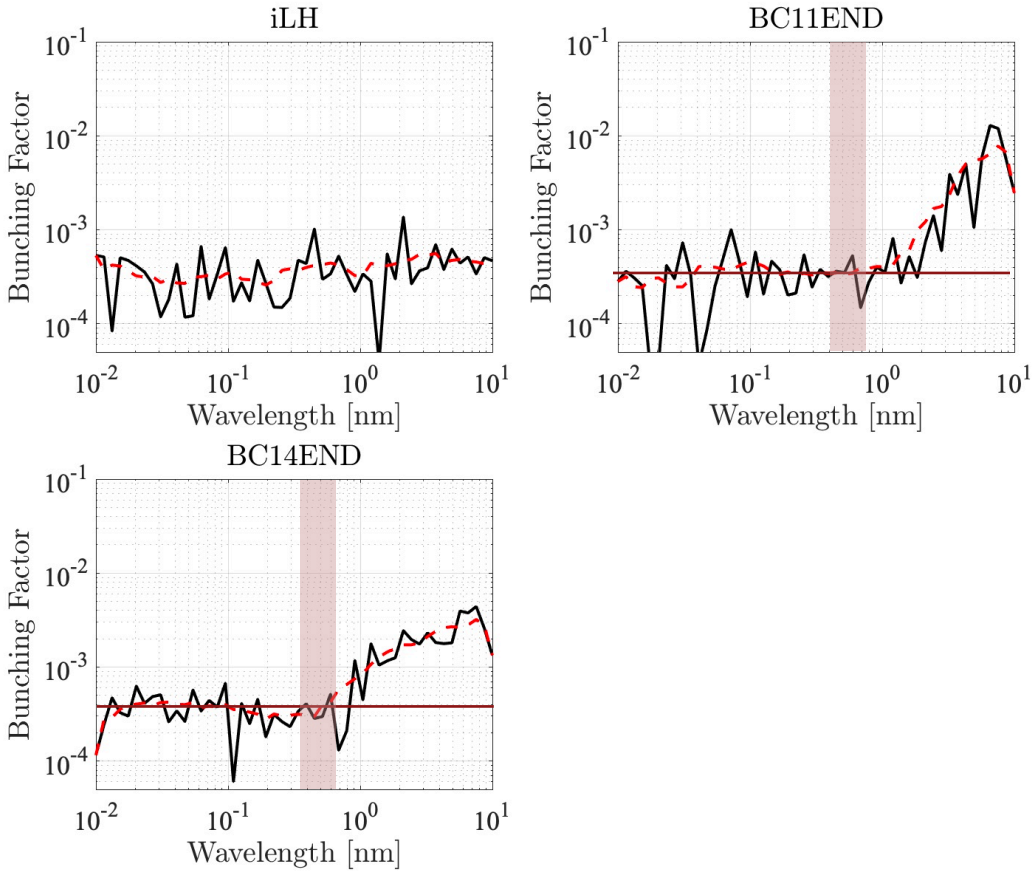
Np = 7e6, CSR off

Heater Off



Some amount of bunching at visible wavelengths after BC11 and BC14

Heater On (50 keV)



Bunching suppressed to shot noise level 1/sqrt(Np) = 4e-4 by 50 keV of laser heater modulation

More particles + finer binning of LSC needed to resolve sub-um bunching after BC20