Laser Heater Commissioning

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Advanced Accelerator Research Dept.

FACET-II User Meeting, October 17th, 2023

SLAC

FACET-II

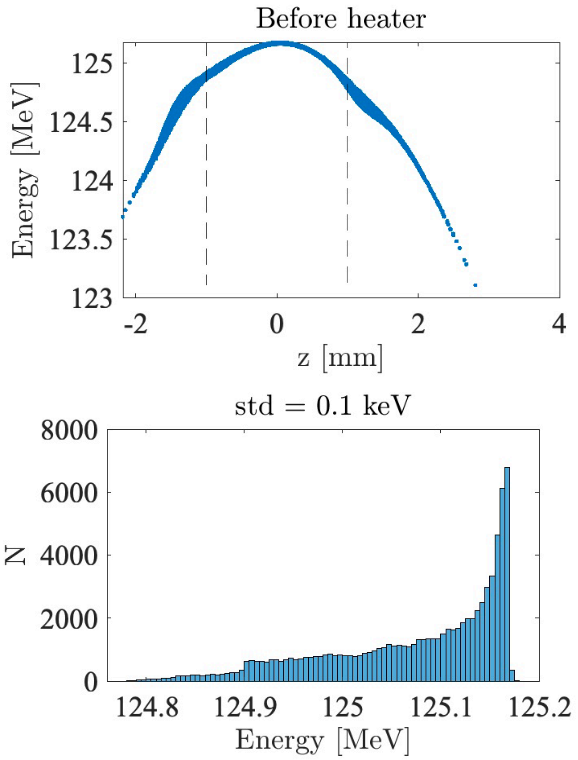
SLAC NATIONAL ACCELERATOR LABORATORY

Stanford University | U.S. DEPARTMENT OF ENERGY

Outline

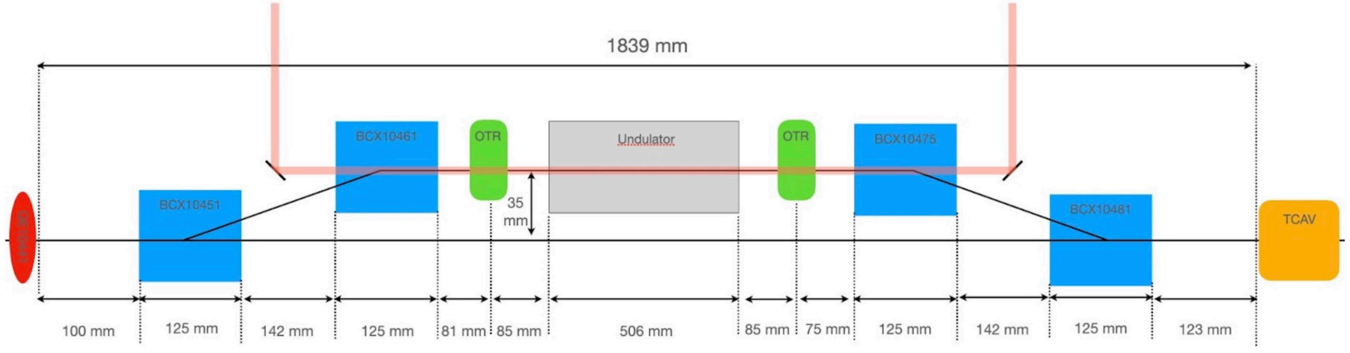
- Laser heater overview
  - What does it do?
  - Why do we want it?
  - What does it look like in practice?
- What have we measured so far?
- What's next for the laser heater?

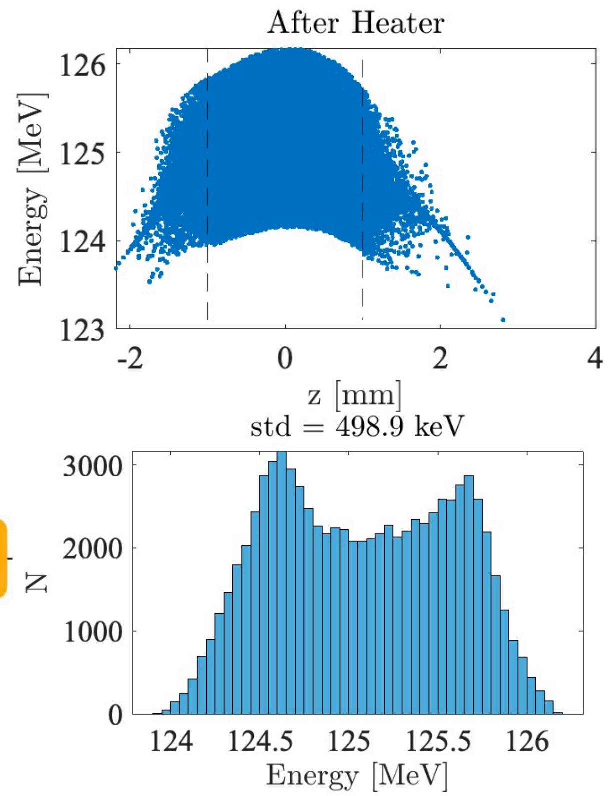
What is the laser heater and what does it do?



Energy modulation after the laser heater

$$\sigma_{\Delta E} \approx \sqrt{\frac{\sigma_r^2}{2(\sigma_x^2 + \sigma_r^2)}}\sqrt{\frac{P_L}{P_0}}\frac{K\,[\mathrm{JJ}]N_u\lambda_u mc^2}{\gamma_0\sigma_r}$$





- 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.
- Main motivations at FACET-II: damp microbunching, control current at IP, suppress CSR and emittance growth in BC20.
- The FACET-II laser heater closely follows the LCLS design.

1. Why do we want it? Control of the peak current/emittance at the IP

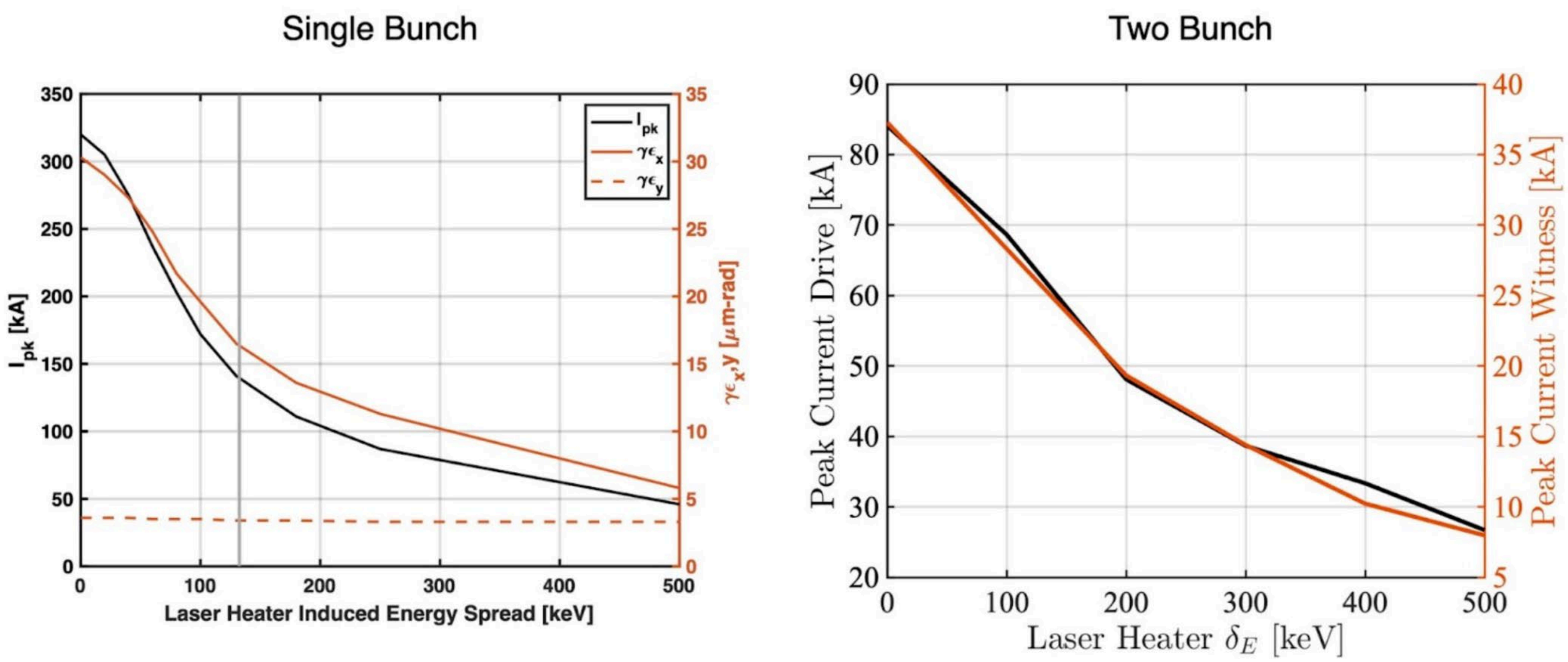
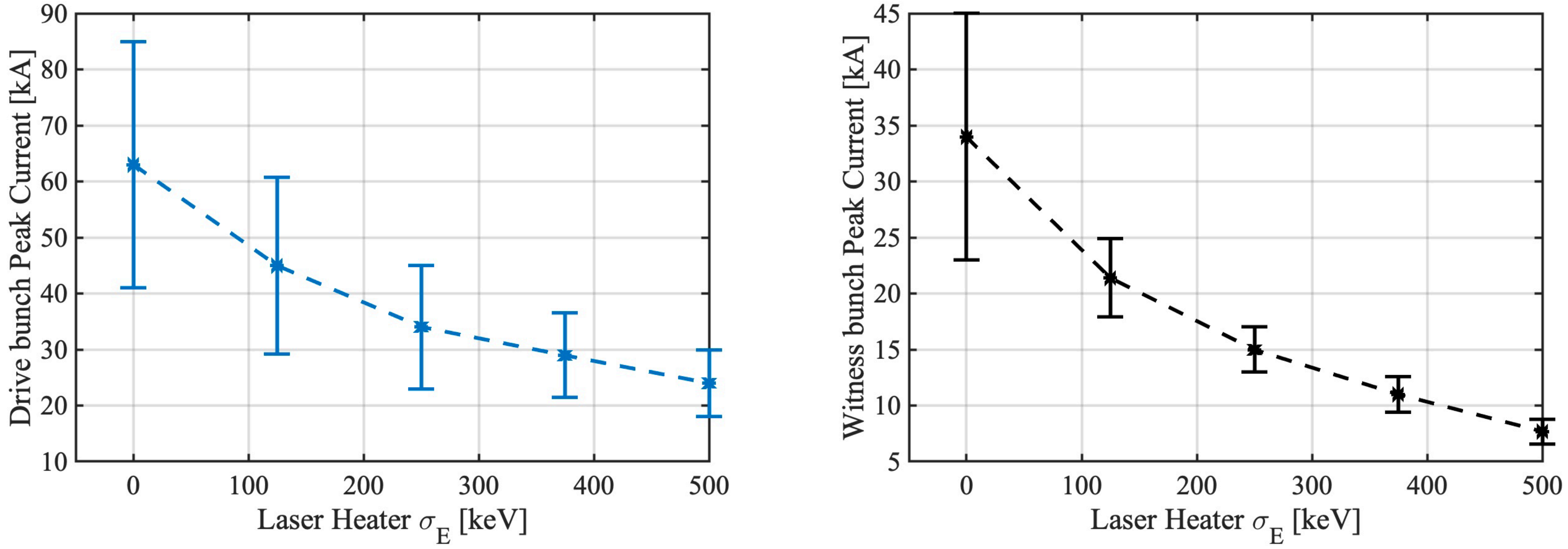


Figure 1: (left) Peak current and emittance as a function of laser heater energy for the single bunch 2nC nominal running parameters of FACET-II. (right) Peak current as a function of RMS laser heater energy modulation for the nominal two-bunch run parameters (1.5/0.5 nC for drive/witness beam).

2. Why do we want it? Reduce current fluctuations 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. Why do we want it? Suppress microbunching and COTR

LCLS

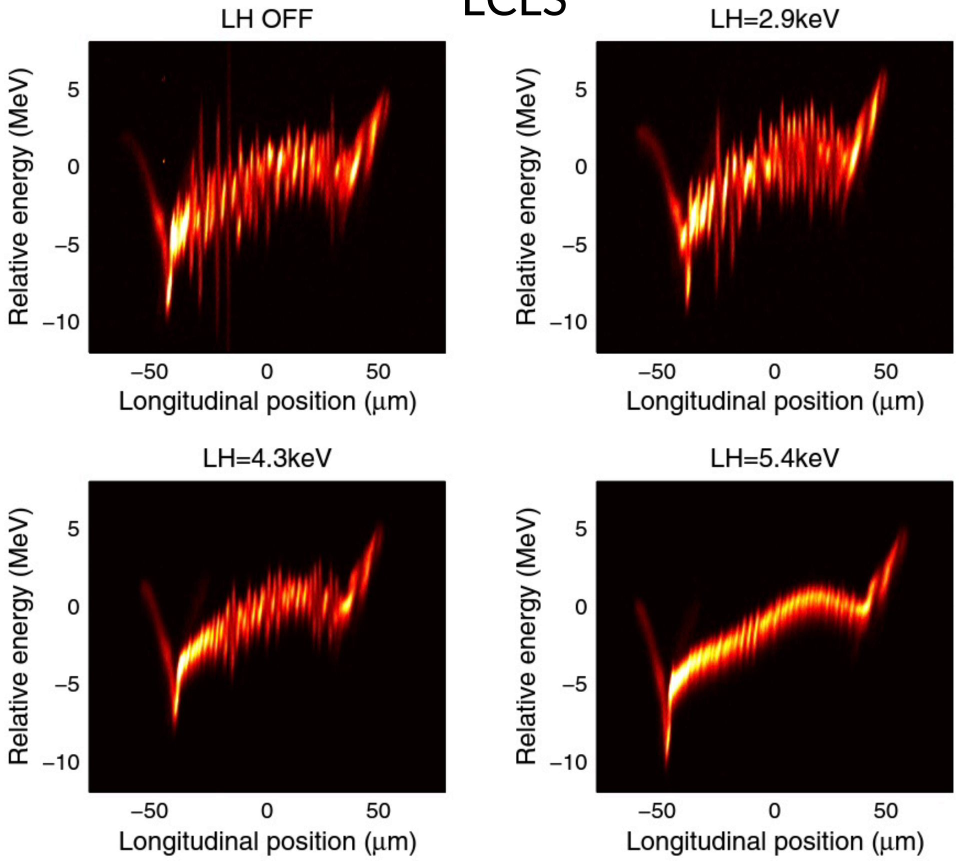
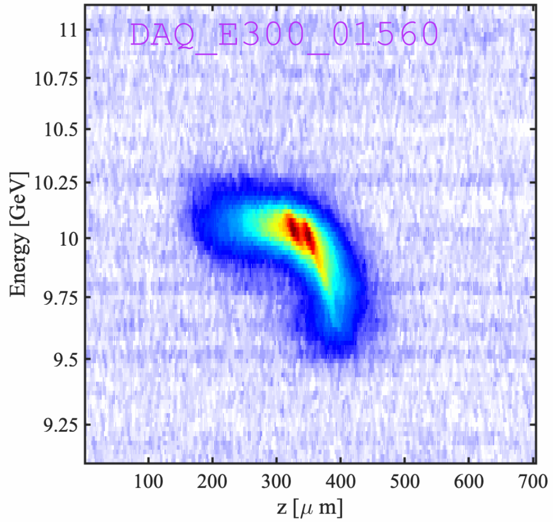
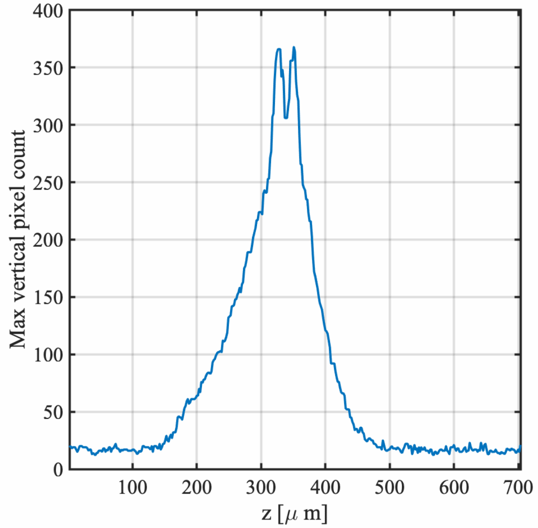


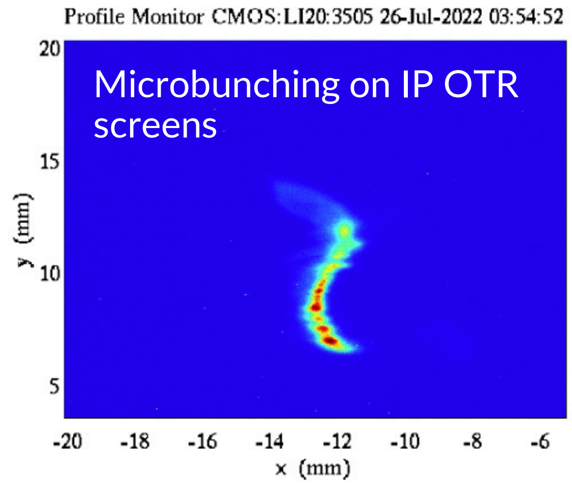
FIG. 2. Measured electron phase space with different rms energy spread induced by the laser heater (LH). Conditions are 0.5 kA peak current, 44 MV XTCAV voltage, and bunch head to the right.

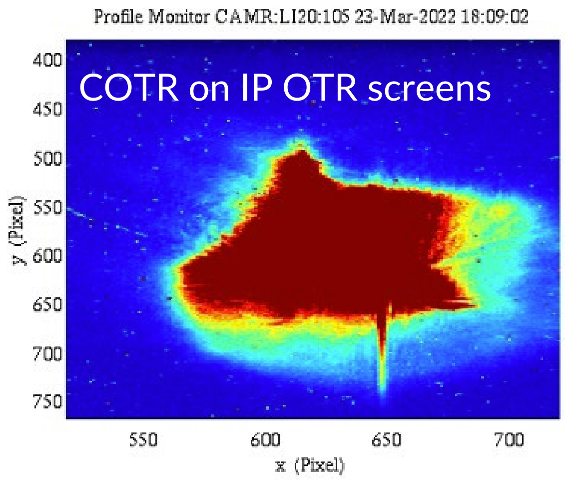
FACET-II





Microbunching on XTCAV - data from 7/12/22



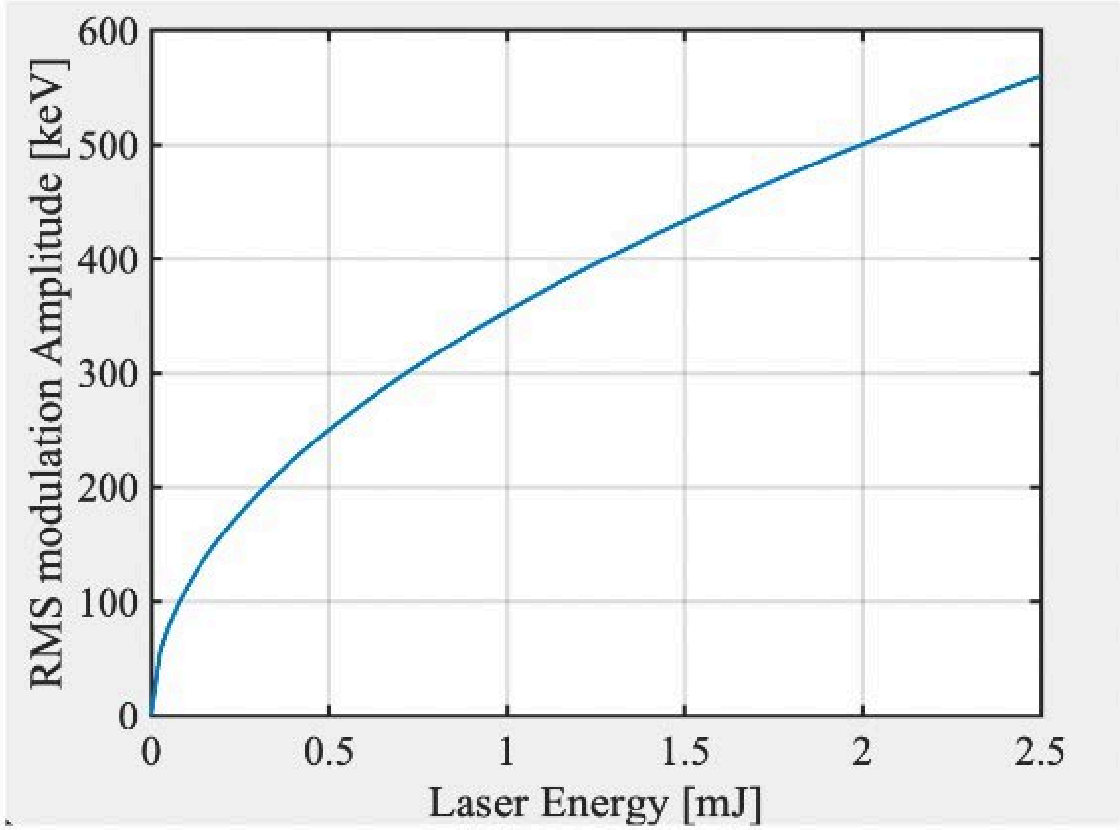


Expected heating vs laser energy

Main parameters for the FACET laser heater

Parameter	Nominal Value	Unit
Electron Energy	125	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 Pulse Energy	0 - 2.5	mJ
Laser Pulse Duration FWHM	1 - 6	ps
RMS energy spread generated	0 - 500	keV

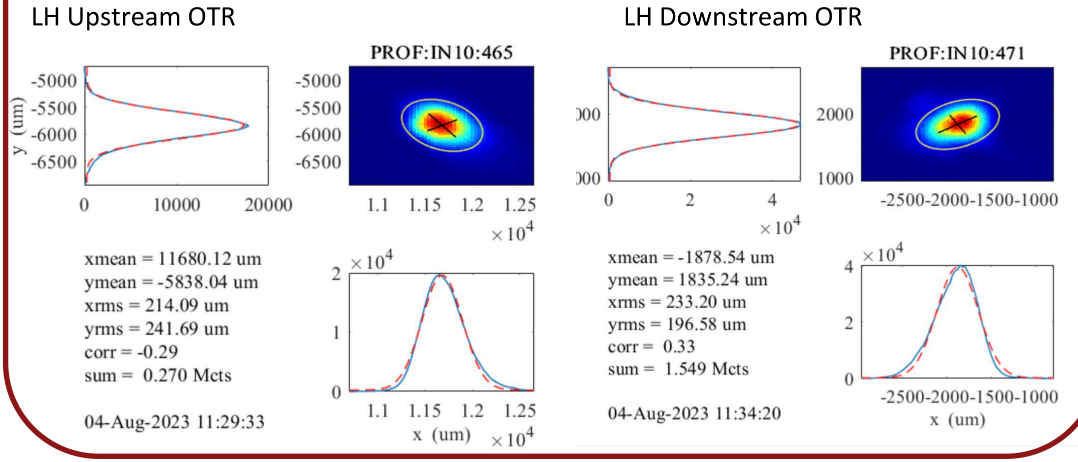
Assuming Gaussian e-beam and laser of equal 200 um spot size and Gaussian IR profile of 6ps FWHM



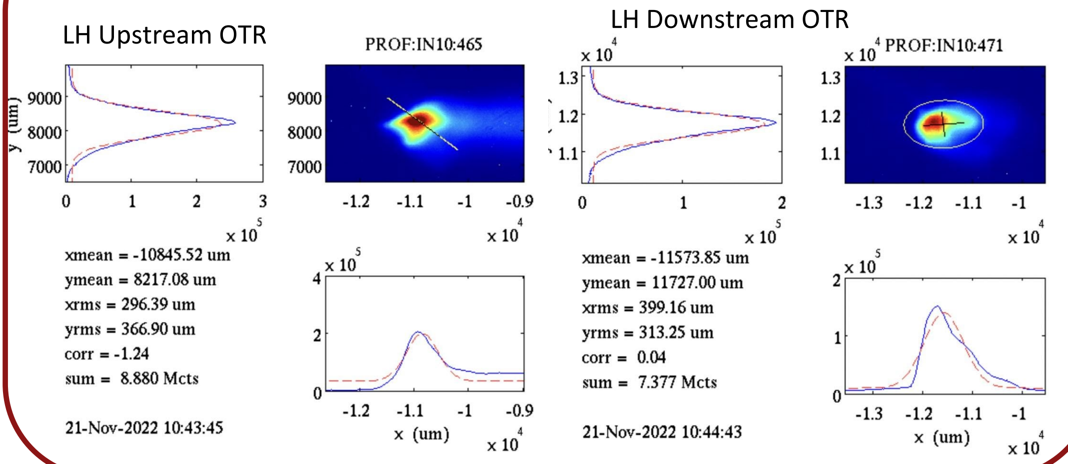
Laser heater designed to deliver up to 500 keV RMS heating

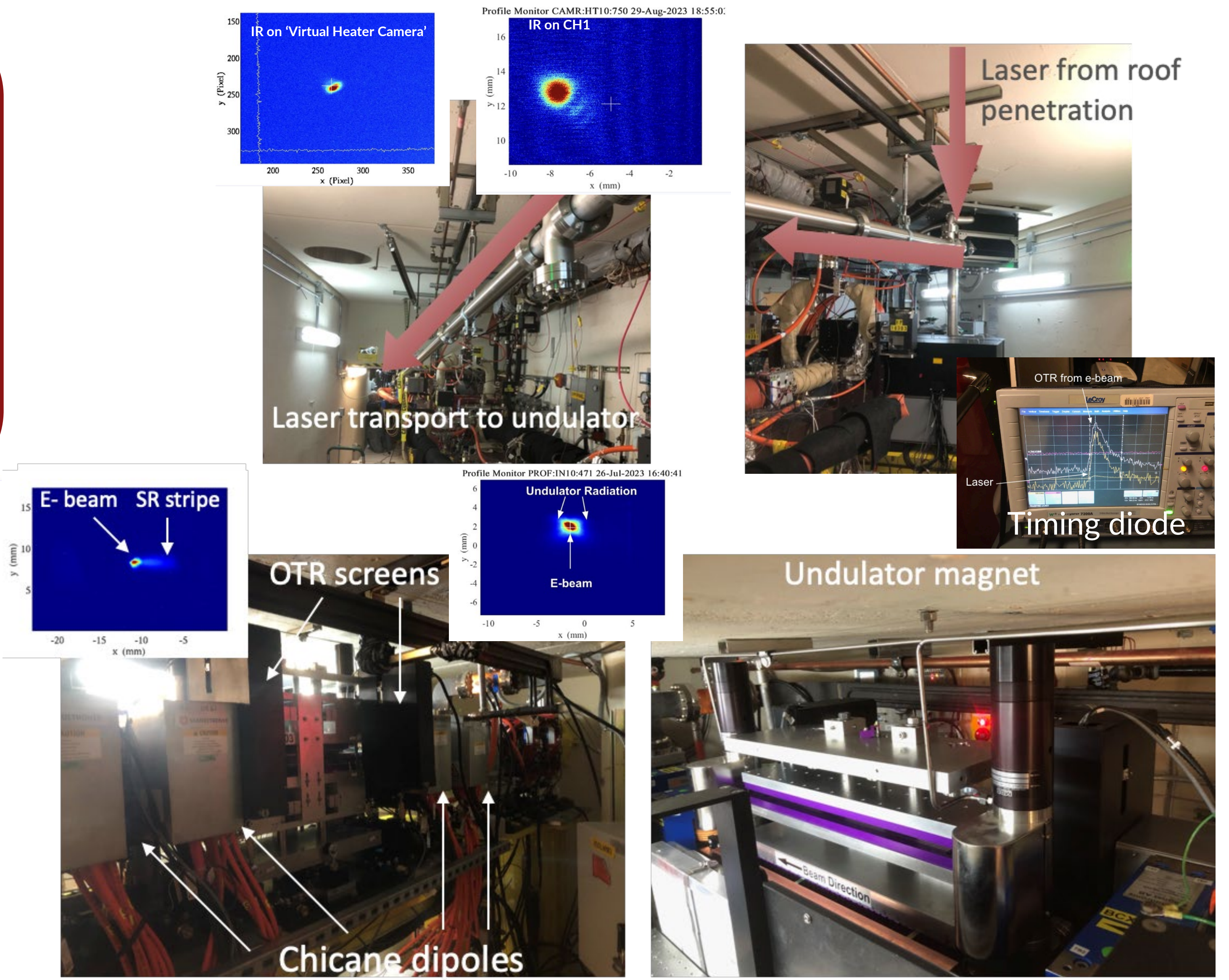
What does it look like in practice

Laser (200-240um RMS) ***Spot size measurements***



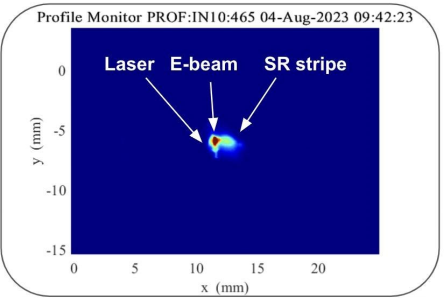
E-beam (300-400um RMS)

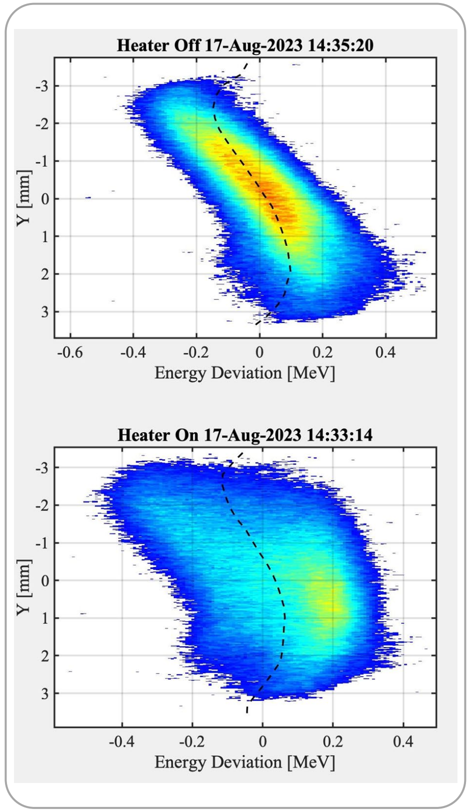


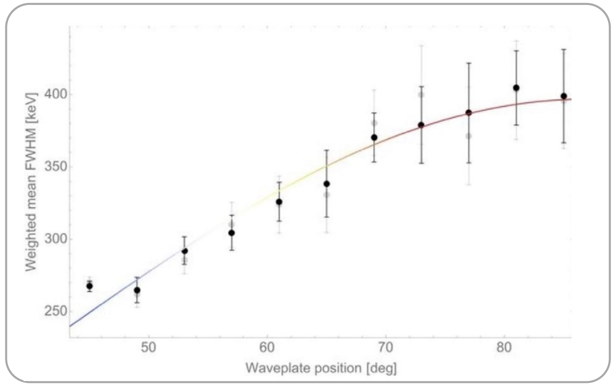


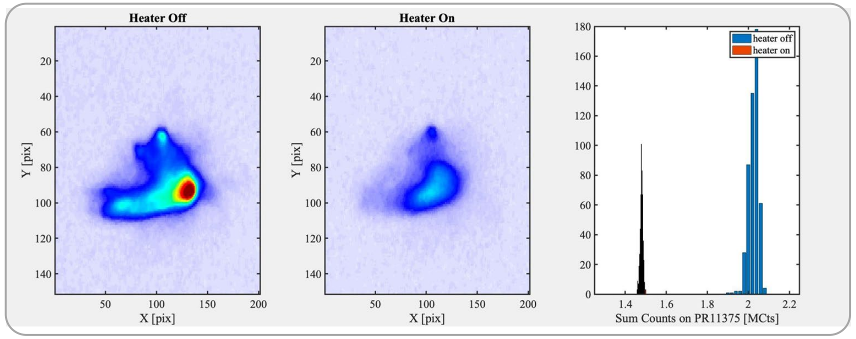
What have we measured so far?

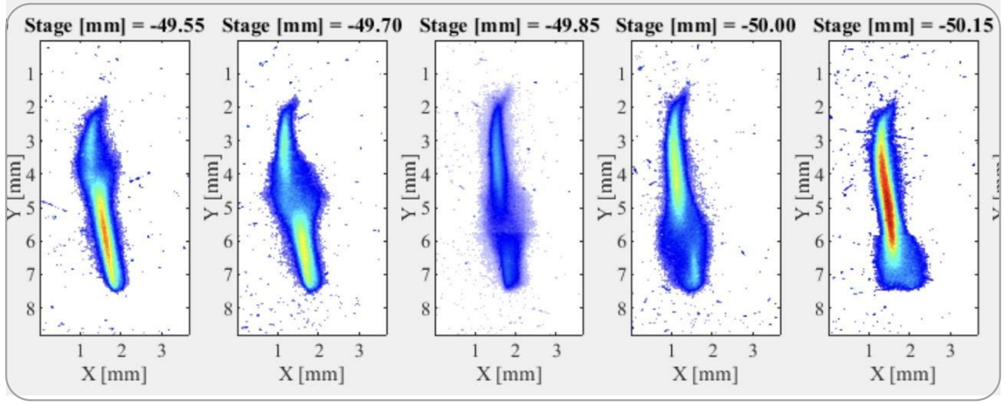
7/25/23	8/4/23	8/17/23	8/23/23	8/30/23	9/1/23	9/1/23
Beam back on	Spatial Overlap achieved	Temporal Overlap achieved	Quantified heating vs laser energy	Quantified heating vs delay (short pulse operation)	Observed COTR suppression	Measured uniform heating with adjusted IR pulse length

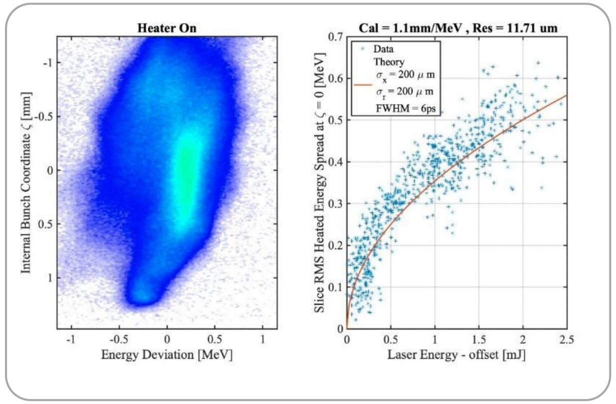




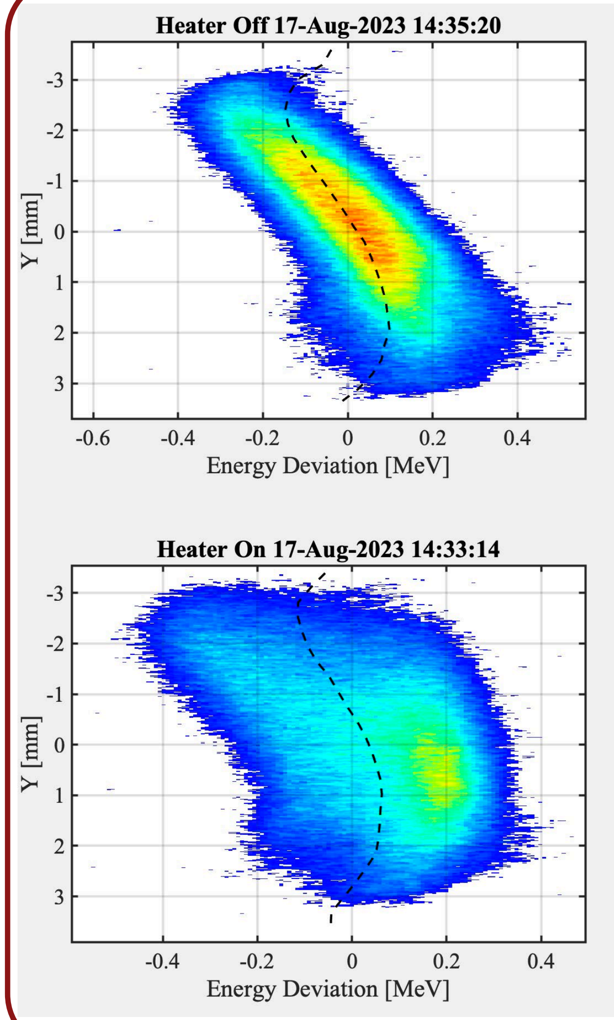




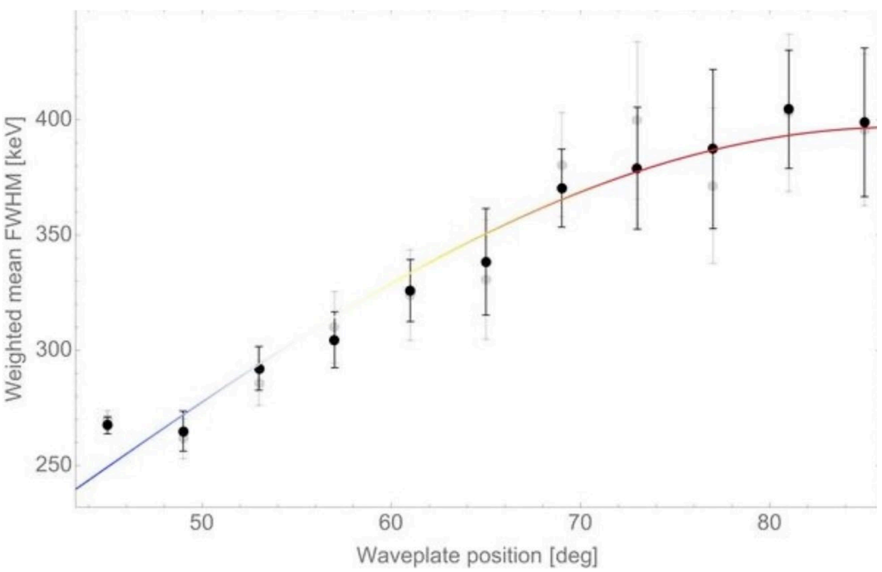




First heating - quantified heating vs laser energy and delay

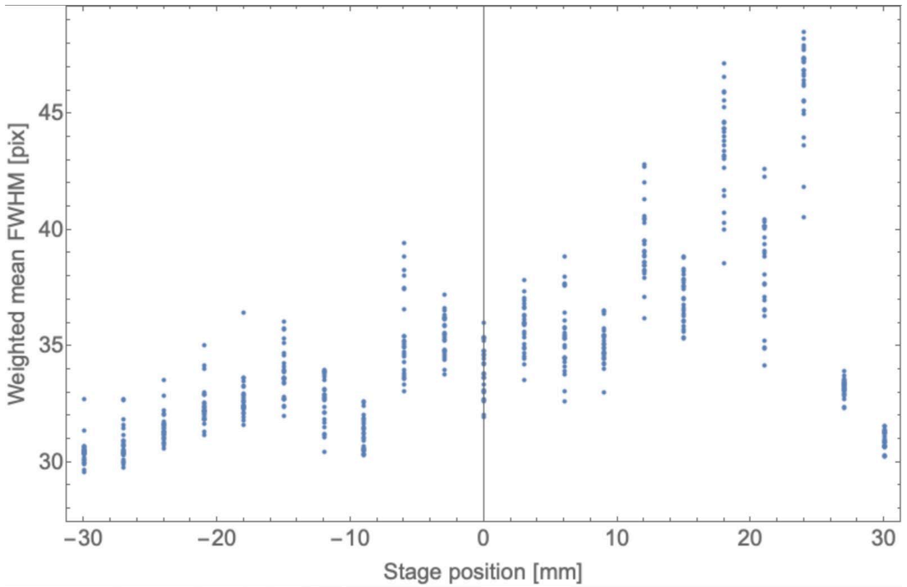


Heating vs laser heater waveplate



Dependence of heating on laser energy matches sqrt(energy) scaling expected from theory

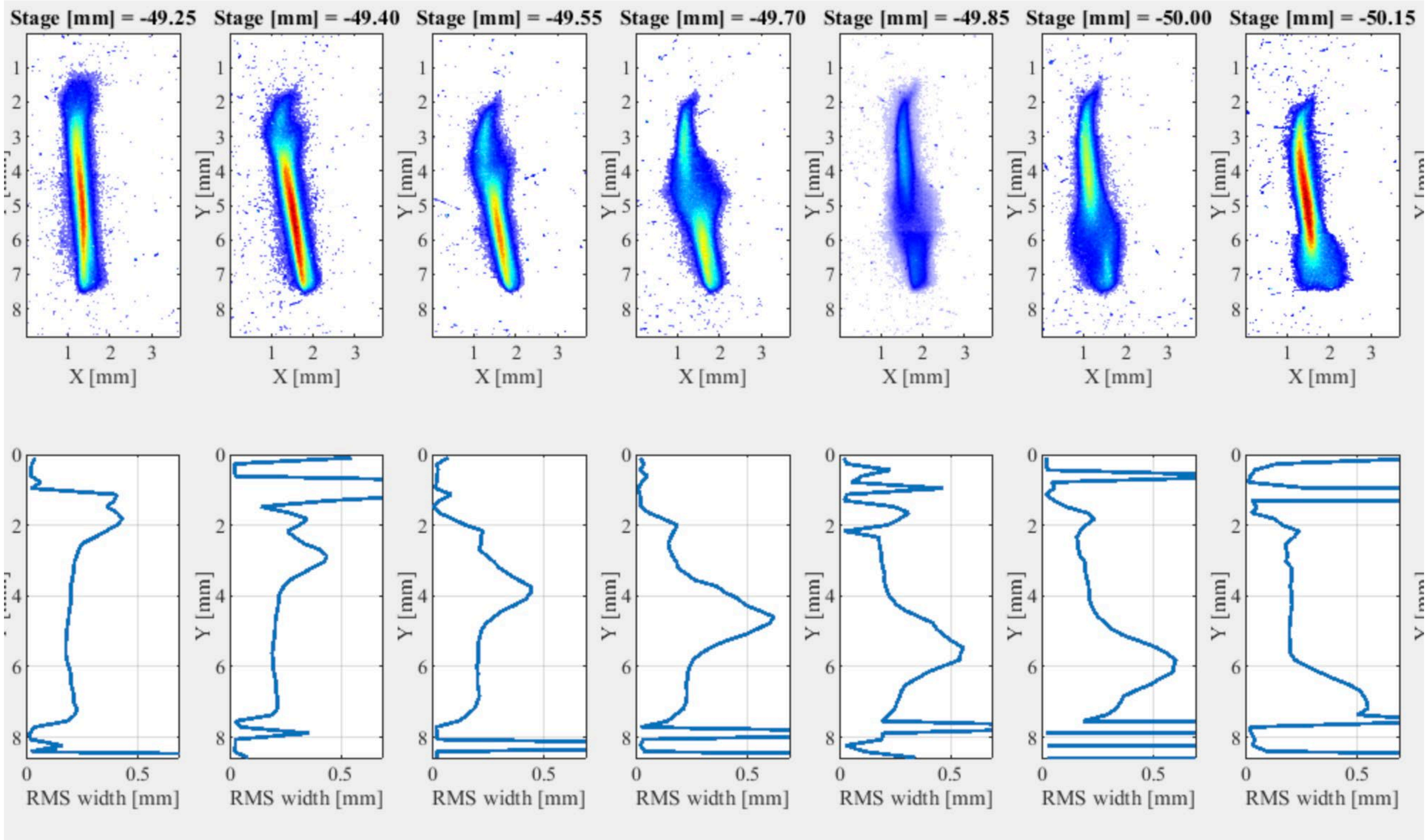
Heating vs laser heater delay stage

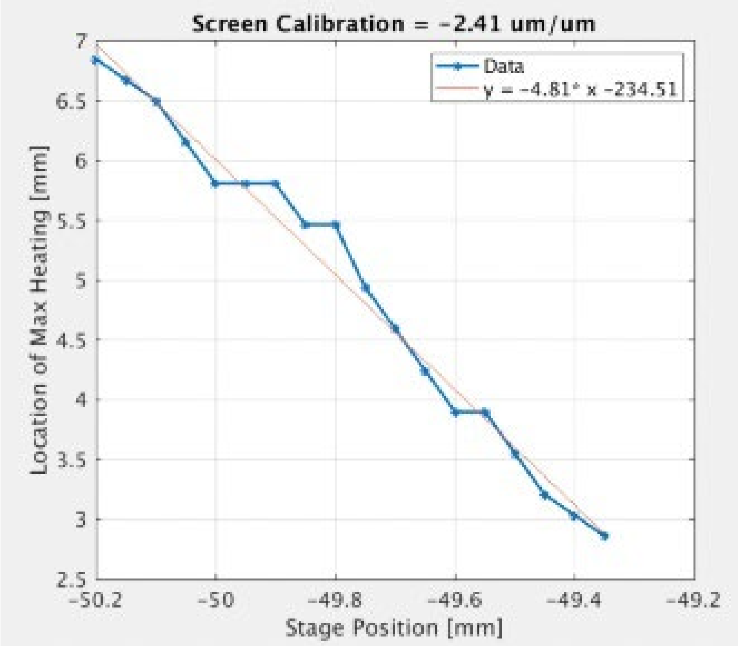


Asymmetric behavior. Heating observed over a very large (60 mm) delay stage position. Much larger than expected laser pulse length

Energy scaling understood from first heating measurements but not delay -> move to shorter IR pulse

Short pulse heating - delay stage scans

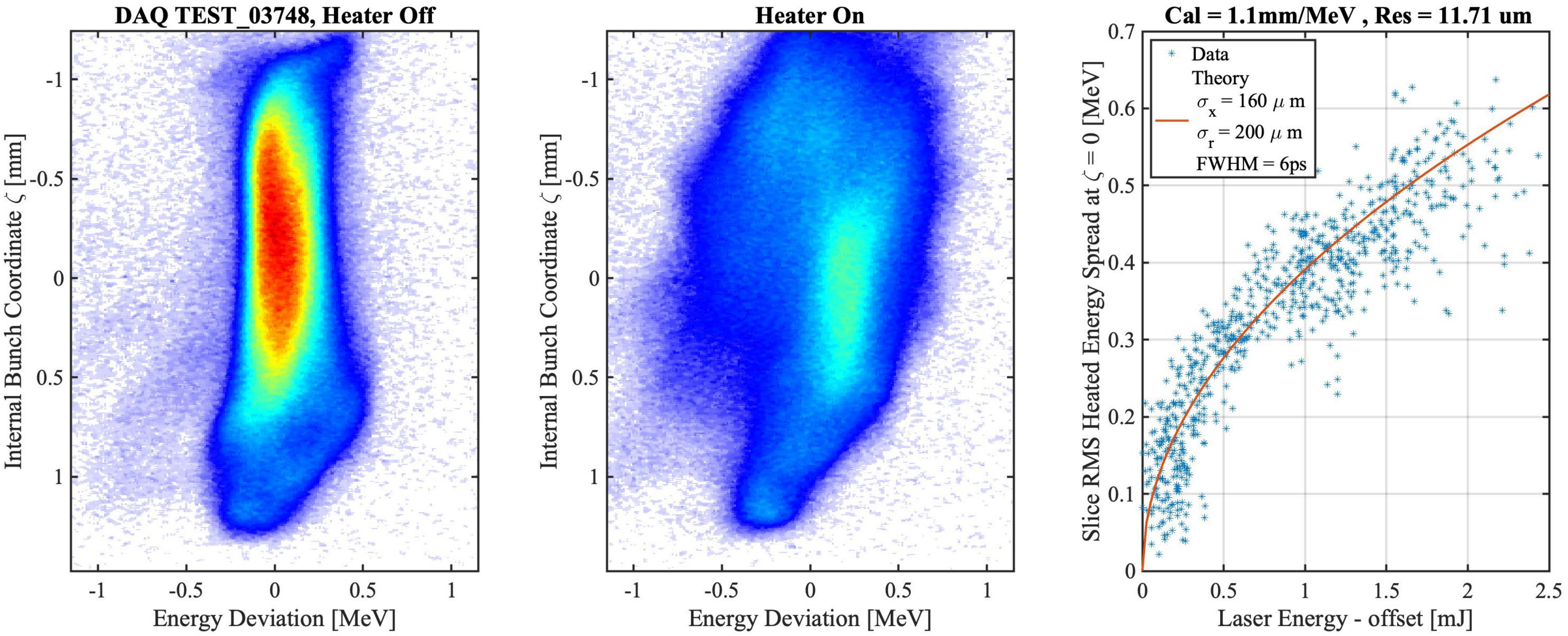




Screen calibration consistent with TCAV data

Heating vs delay understood with short IR pulse. Short pulse mode opens opportunities for beam shaping

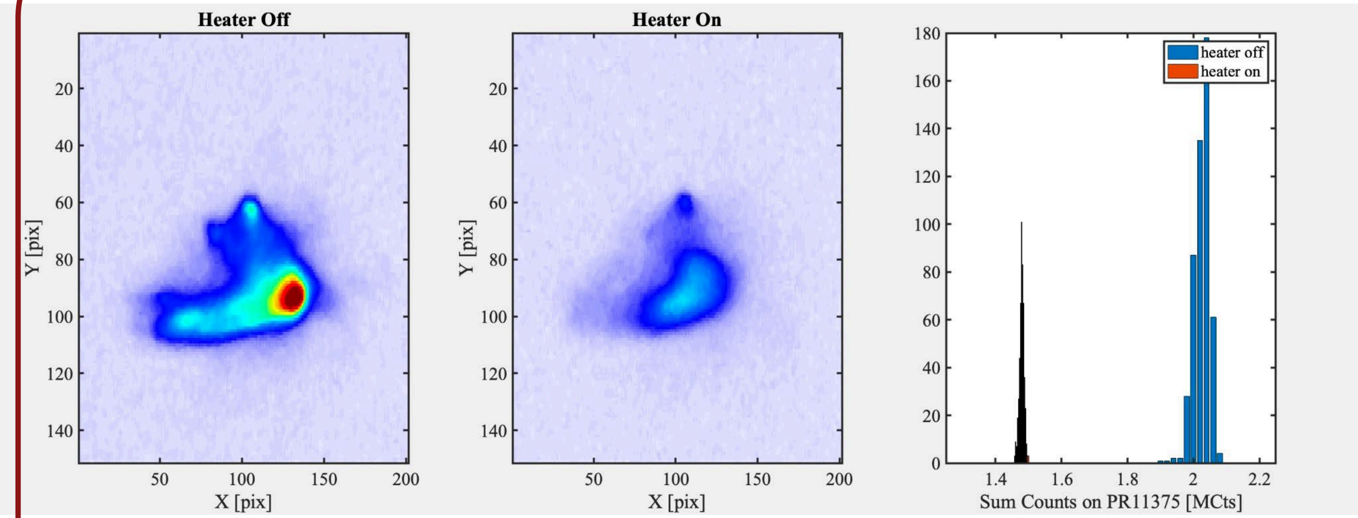
Heating vs laser energy with a 6ps FWHM laser pulse



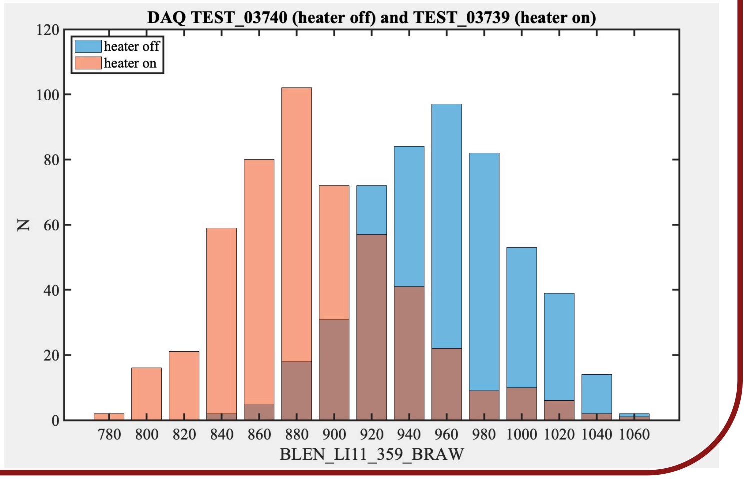
IR pulse stretched to overlap entire electron bunch. Heating matches expected behavior from theory.

COTR suppression observed with heater on

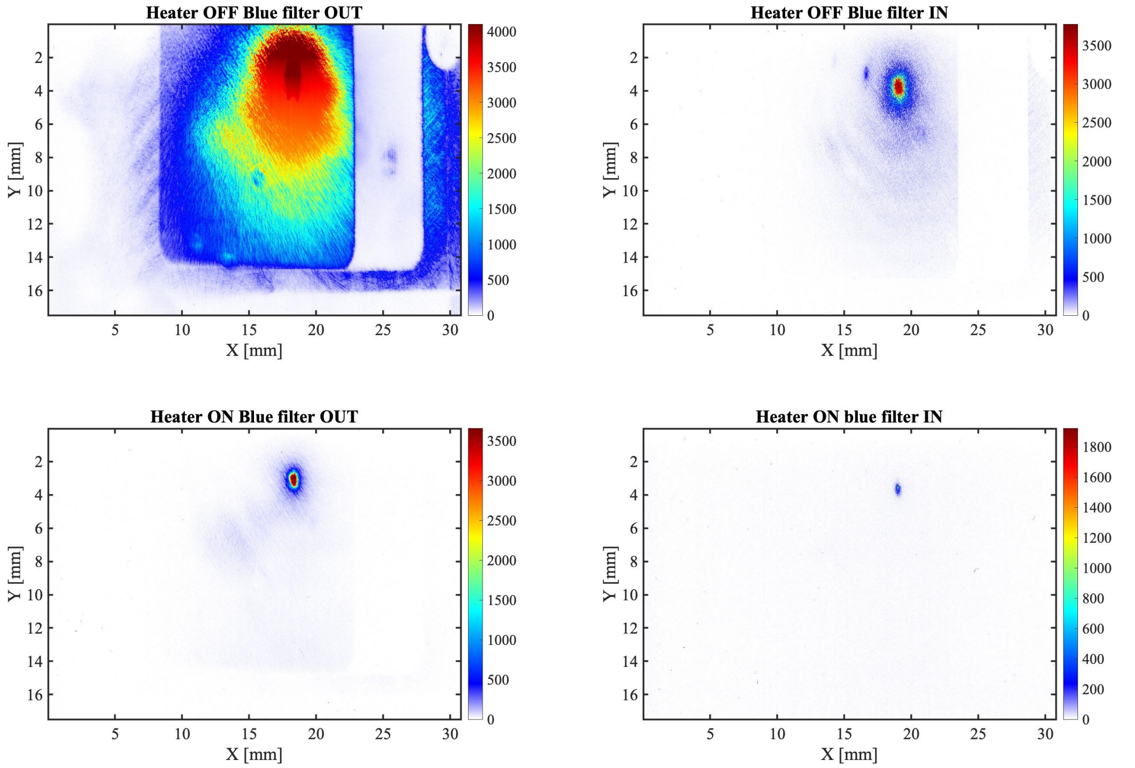
Transverse Profile at BC11 exit (335 MeV)



Reduced signal on BC11 bunch length monitor. COTR suppression evident at lowest laser energy.



Transverse Profile at IP (10 GeV)

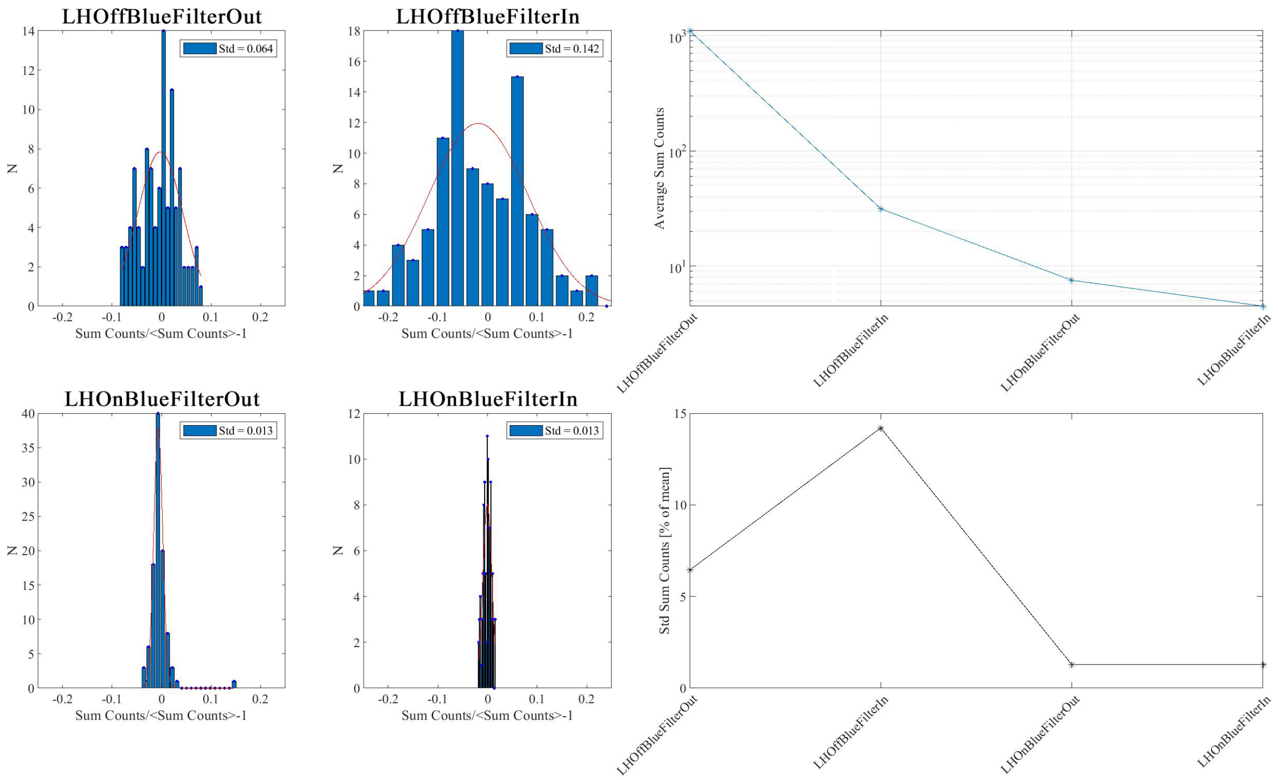


Heater on + blue filter reduces counts & fluctuations, renders IP screens usable for beam measurements

COTR suppression observed after BC11 and at IP. Signal reduction also visible on bunch length monitors.

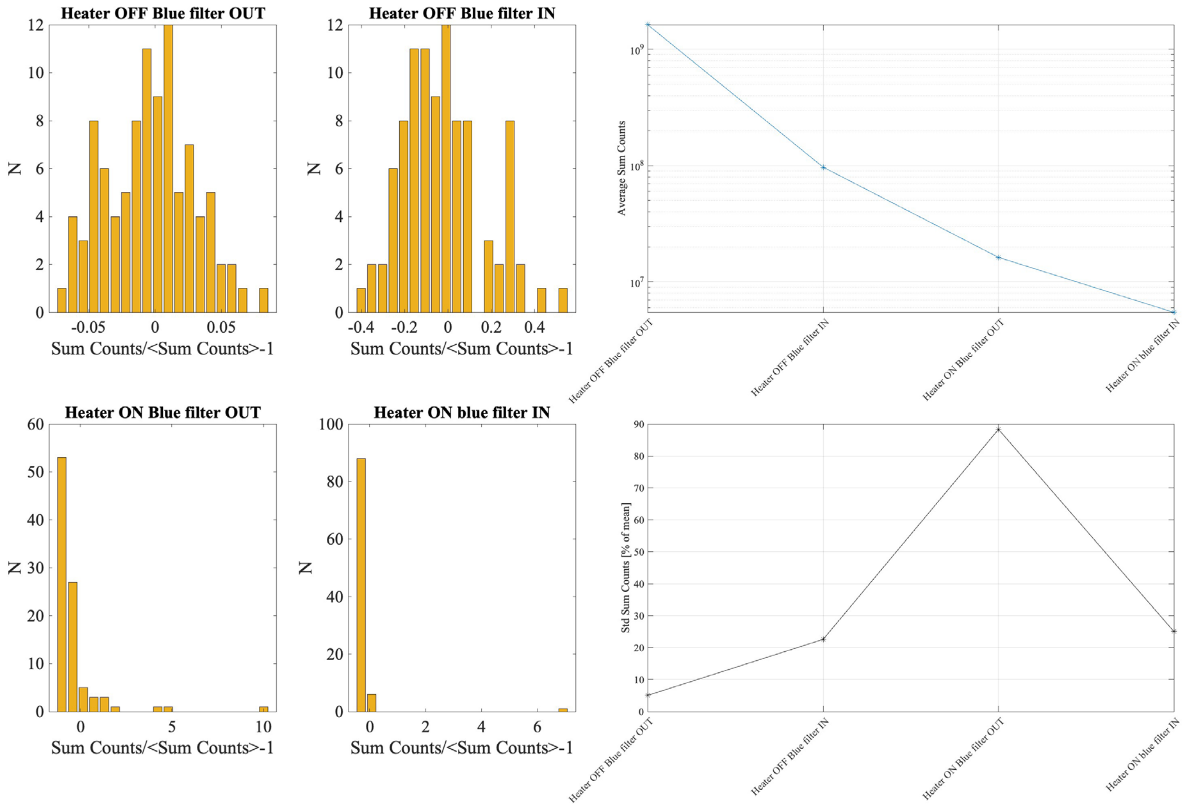
COTR suppression measurements at the IP

OTR camera counts with 'long bunch' in S20



Order of magnitude suppression in sum counts and fluctuations with laser heater on

OTR camera counts with 'shorter bunch' in S20



With more compression, some shots with significant COTR still observed with laser heater on and blue filter in

COTR completely suppressed in long bunch mode. Some shots with COTR persist with more compression

Conclusion and next steps for the laser heater

- The FACET-II laser heater has been installed, commissioned and is currently operational.
- Measured heating performance agrees with theoretical expectations.
- The laser heater will be a useful tool, available to users and machine physicists, for increasing machine stability, providing tunable peak current at the IP and suppressing COTR and microbunching.
- **Next steps**
  - Quantify reduction of COTR at IP. Initial studies at 1nC show promising results, will be repeated at 2nC and at full compression.
  - Quantify reduction in peak current and peak current jitter in S20 as a function of RMS heating with XTCAV.
  - Fine tune heater operation for different beam configurations e.g. two bunch heating (next year).
  - Improve ease of set up, heating stability and repeatability.

Thank you to everyone who contributed to the design, installation and commissioning of the laser heater

Design, Simulations, Project Management: Glen White, Mark Hogan, Carsten Hast, Brendan O'Shea

Laser: Brendan O'Shea, Nathan Majernik

Installations: Doug McCormick, Juan Cruz, Carl Hudspeth

Beam operation: Jerry Yocky, Beam Physics & Operations Group

Undulator: Yurii Levashov, Magnetic Measurements Group

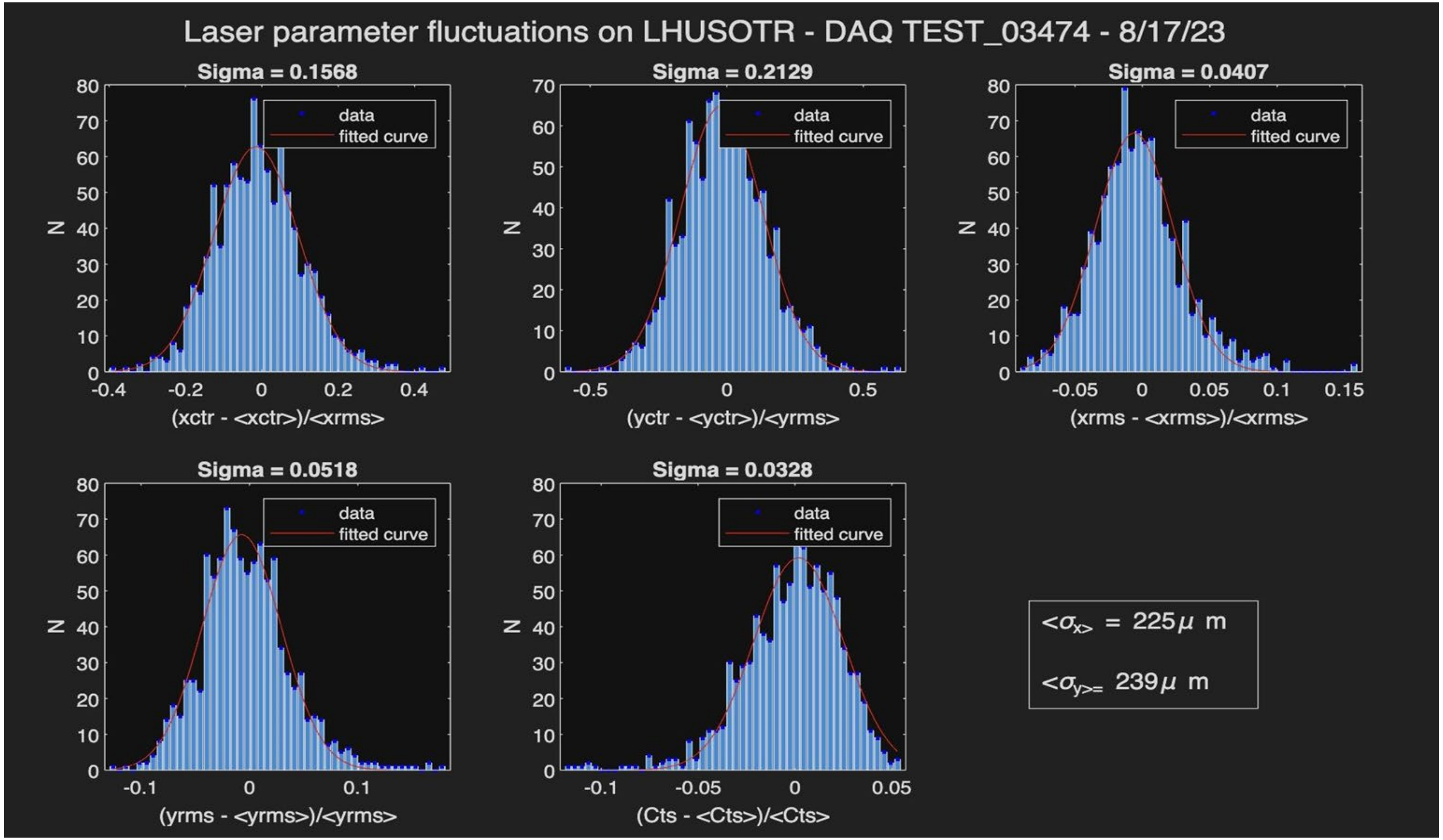
Diagnostics/Controls: Spencer Gessner, Courtney Curtis, Shawn Alverson, Janos Vamosi, Janez Govednik

Questions?

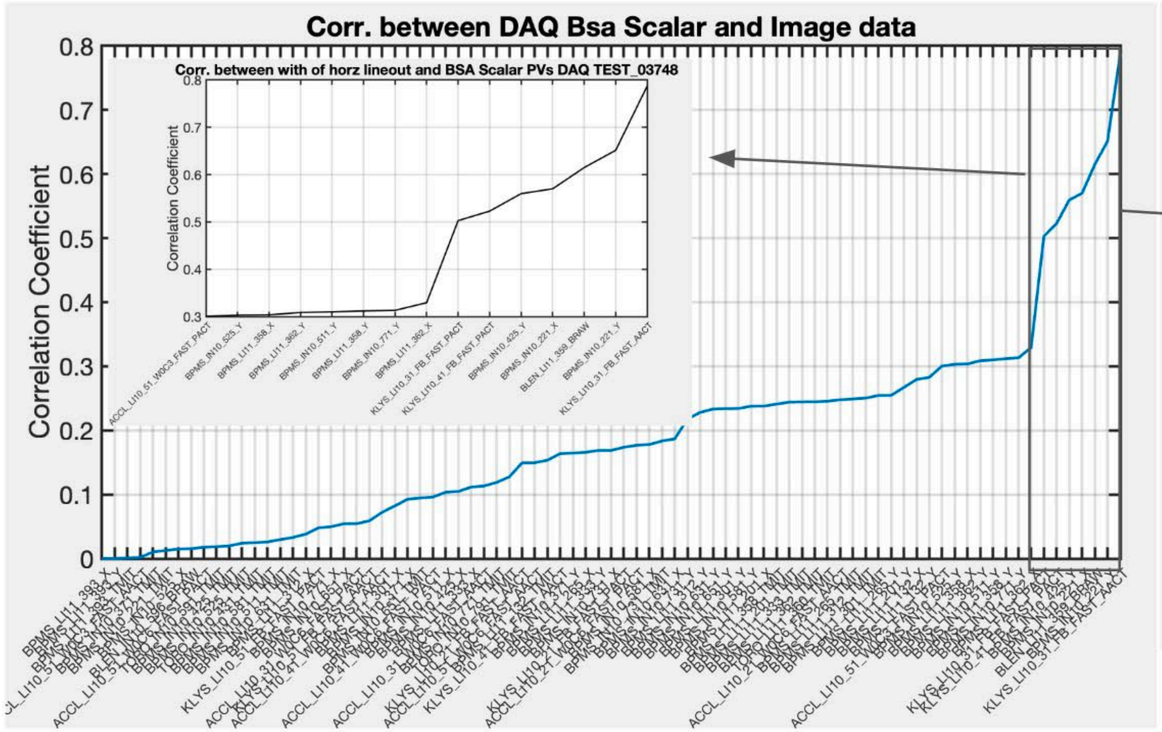
Extra Slides

Measurement of laser fluctuation on LHUSOTR

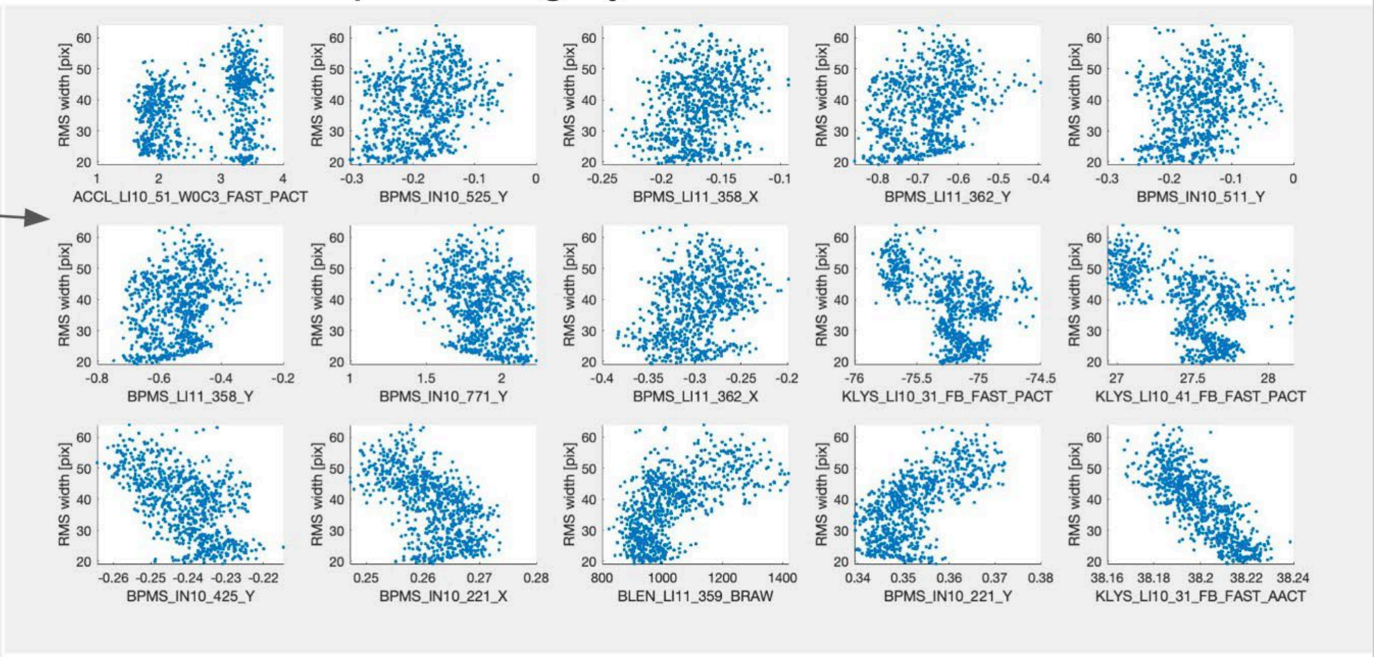
- Note this measurement was done at a long laser pulse before we moved to 1ps short pulse and before moving to 6ps which we definitively settled on
- Fluctuations in laser centroid position, rms size and energy (measured at ~10%) affect shot-to-shot heating of the beam.



Correlation between heating measurements and BSA PVs



Scatter plot of highly correlated PVs

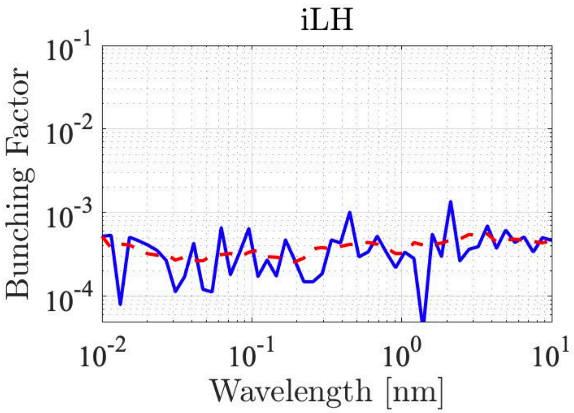


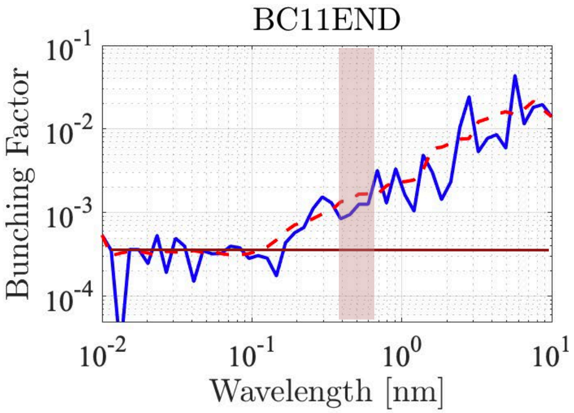
Correlate heated width in central slice with 81 BSA scalars. Both vertical and horizontal BPMs and Klystron phase and amplitude feedbacks correlate strongly with heating.

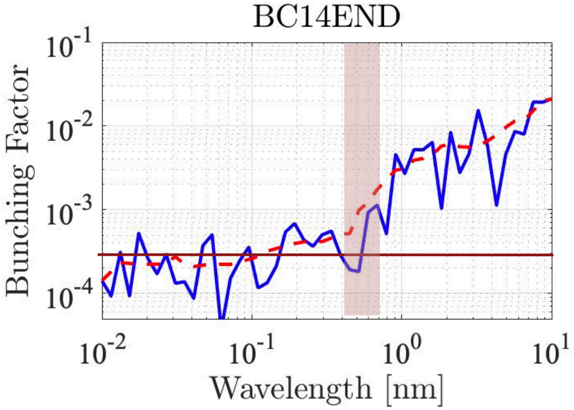
Tracking simulations with micro bunching for FACET-II (heater on vs off)

Np = 7e6, CSR off

Heater Off

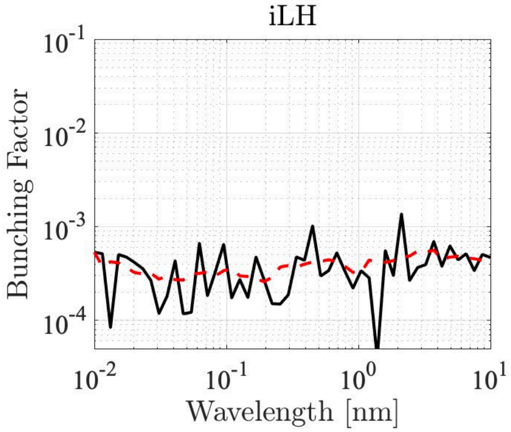


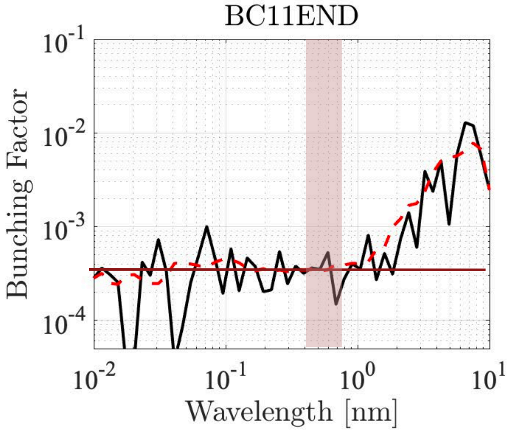


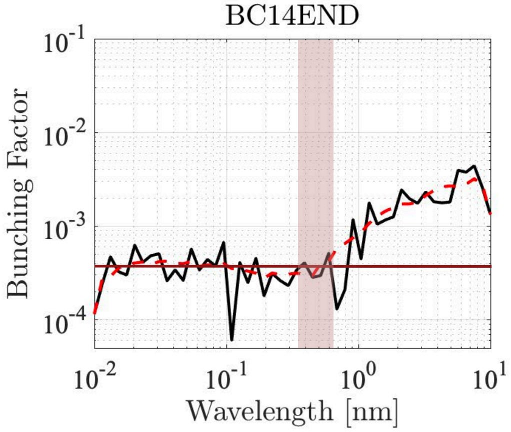


Some amount of bunching at visible wavelengths after BC11 and BC14

Heater On (50 keV)



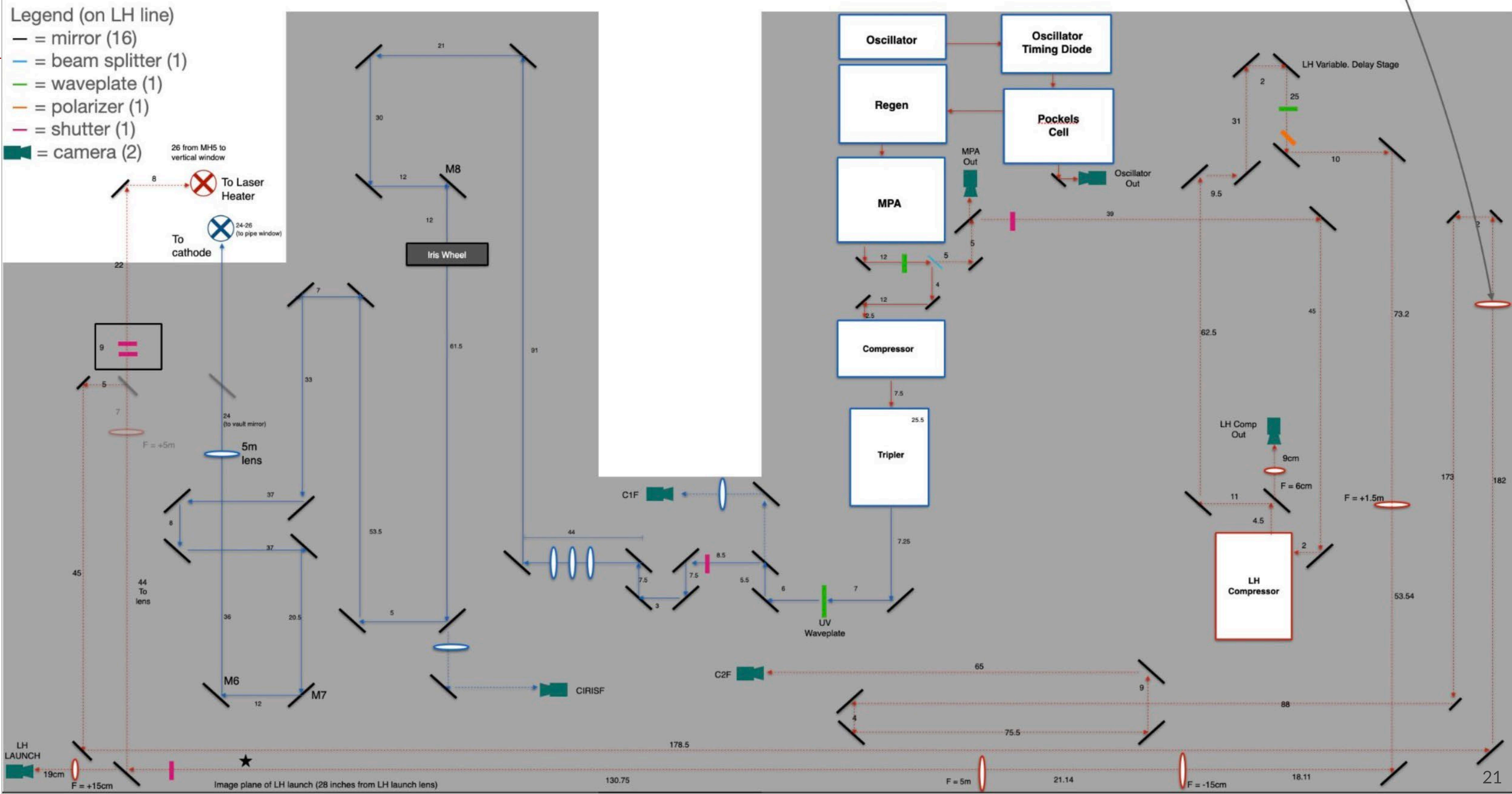




Bunching suppressed to shot noise level 1/sqrt(Np) = 4e-4 by 50 keV of laser heater modulation

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

Sketch of Sector 10 Laser Transport. Distances in inches unless otherwise specified 3/15/2023



Sketch of transport in the vault (distances in mm)