MBI Studies with the LCLS X-band Transverse Deflector

6th Microbunching Instability Workshop
Trieste, Italy

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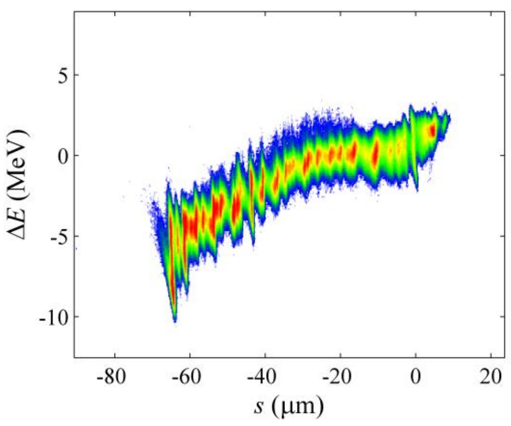
8th October, 2014



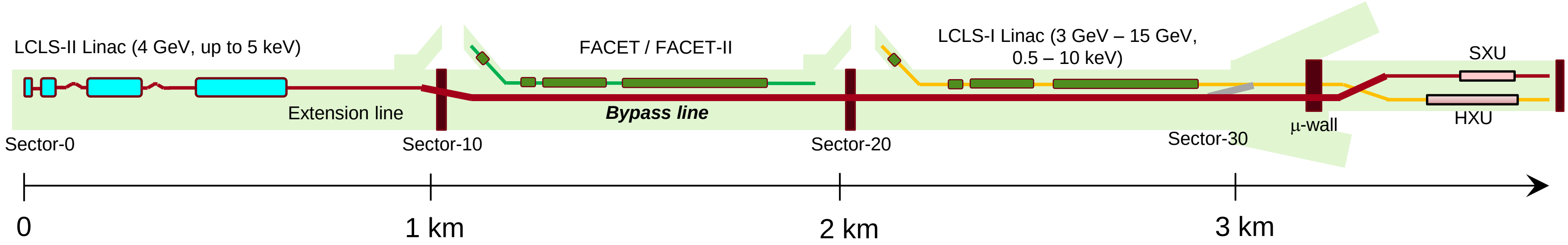
Motivation

Characterize LCLS Slice Energy Spread (SES) growth due to MBI

1. *Implications for LCLS:* Quantify/reduce SES growth for potential harmonic lasing, external seeding schemes, etc.

2. *Implications for LCLS-II*:* Additional 2 km bypass needs more careful characterization/design compared to LCLS to preserve SES

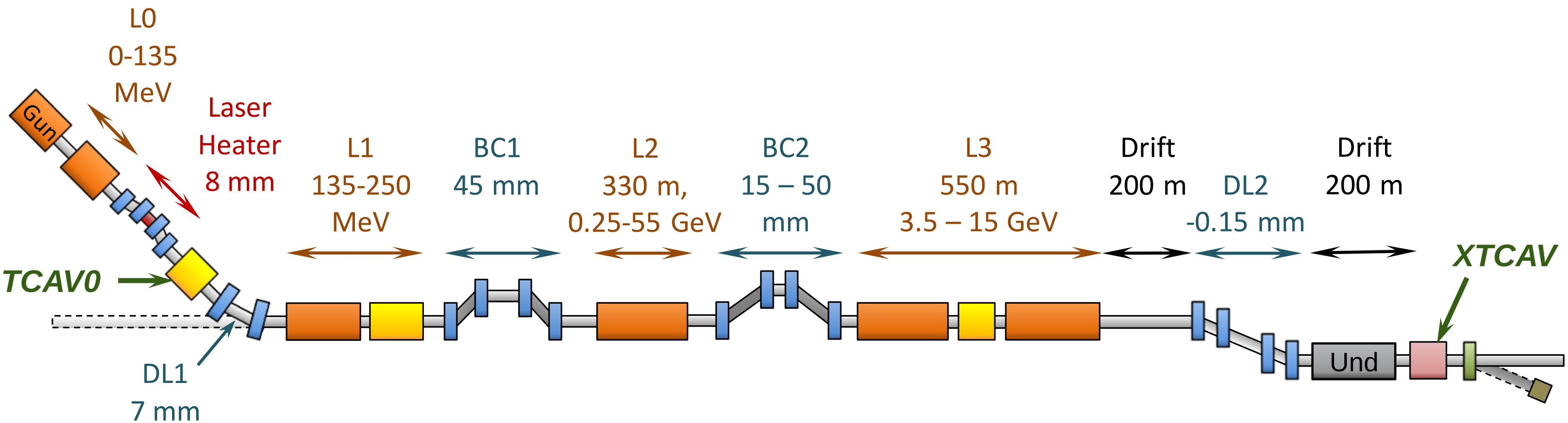
   * See M. Venturini's Monday morning talk



Outline

- Experimental setup
  - LCLS linac layout
  - Diagnostics
- Microbunching spectrum analysis
  - Analysis methodology
  - MB spectrum @ varied current and LH power
  - Effect of BC2 R_{56}
- Slice energy spread measurements
  - Systematic corrections
  - SES results @ varied current and LH power
- To-do list and summary

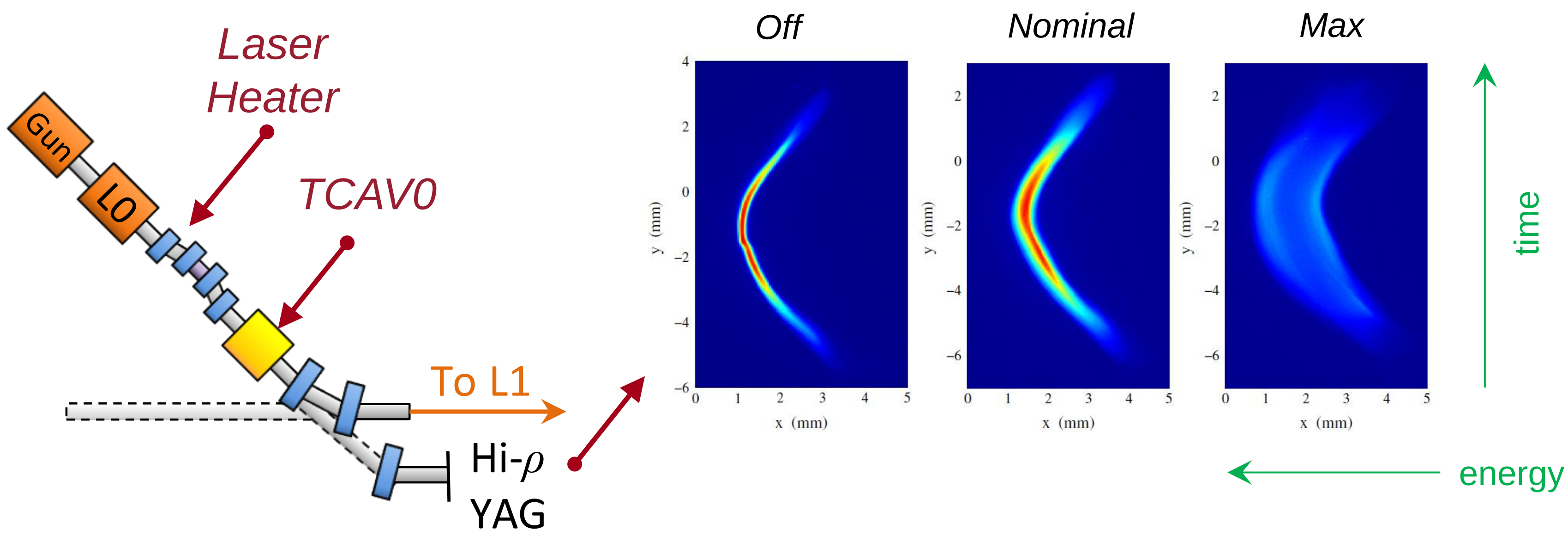
LCLS Linac Setup



- Undulator is removed (no lasing effects)
- TCAV0 to measure z-δ at LH
- XTCAV to measure final z-δ

LCLS Laser Heater & Injector Diagnostics*

- Increase *E*-spread at injector, damp growth downstream

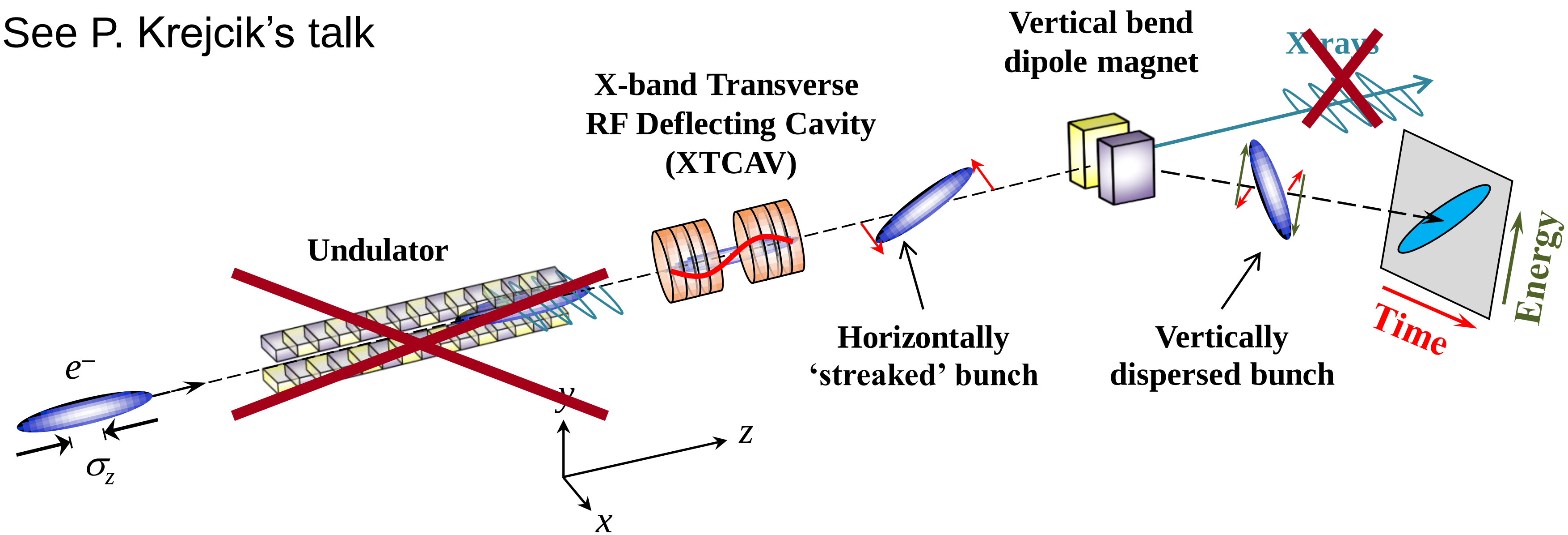


- $\Delta\sigma_{E,\,\mathrm{LH}}$ = 0 - ~100 keV
- Nominal heating improves FEL intensity ***20-100%***

* Z. Huang, *et al*, PRST-AB **7**, 074401 (2004) & Z. Huang, *et al*, PRST-AB **13**, 02073 (2010)

XTCAV

See P. Krejcik's talk



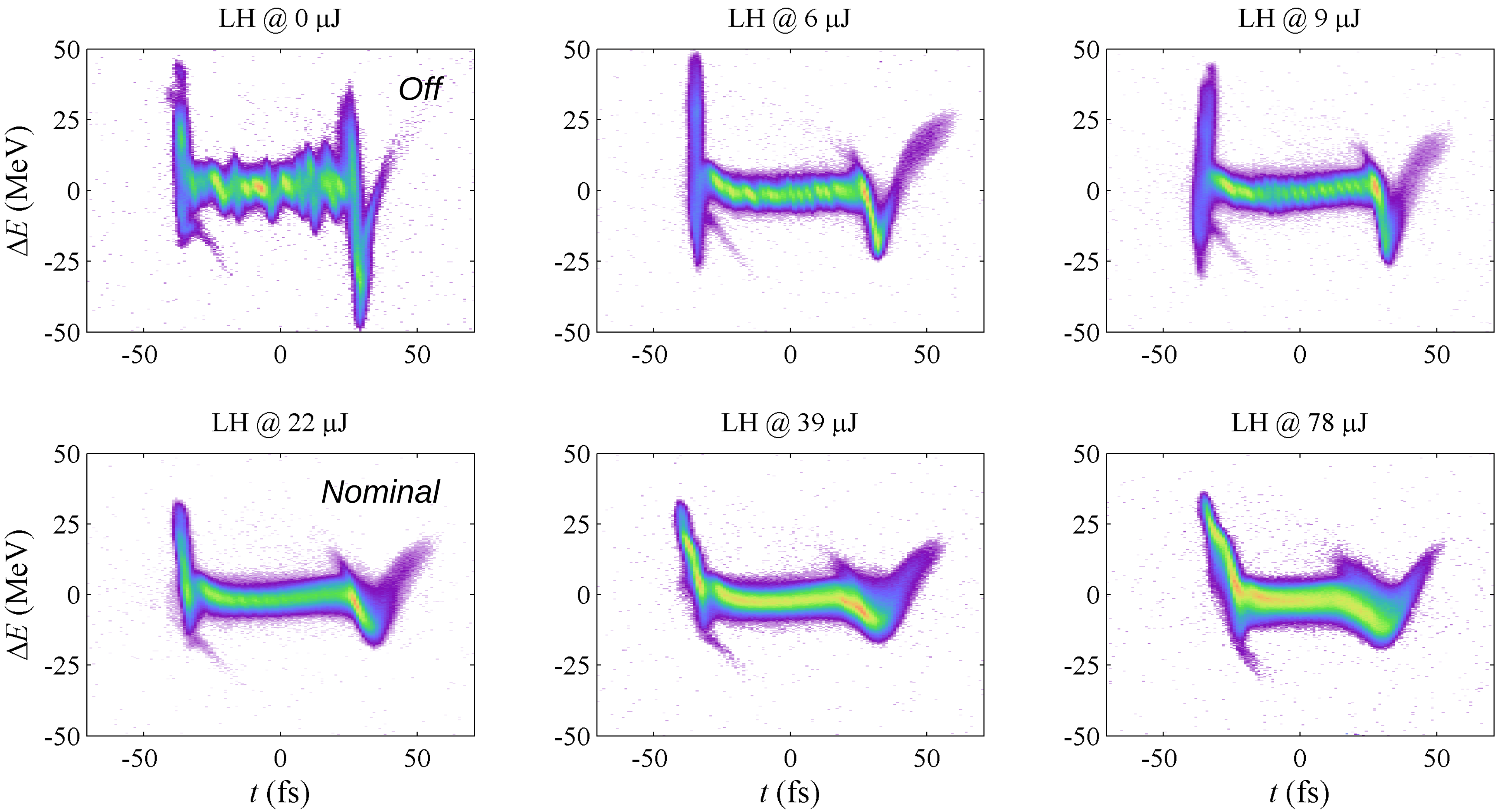
$$\sigma_z = \frac{c}{2\pi f_{\mathrm{rf}}} \frac{E_e}{eV_{\mathrm{rf}}} \sqrt{\frac{\varepsilon_x}{\gamma \beta_x}} \propto \sqrt{E_e} \propto \frac{1}{f_{\mathrm{rf}}}$$

Long. resolution **High-E FEL** **SLAC X-band @ 11.4 GHz**

Result: *< 1 μm rms @ 4 GeV, can now directly investigate final MBI impact*

XTCAV vs. Laser Heater

Direct & quantitative LH study



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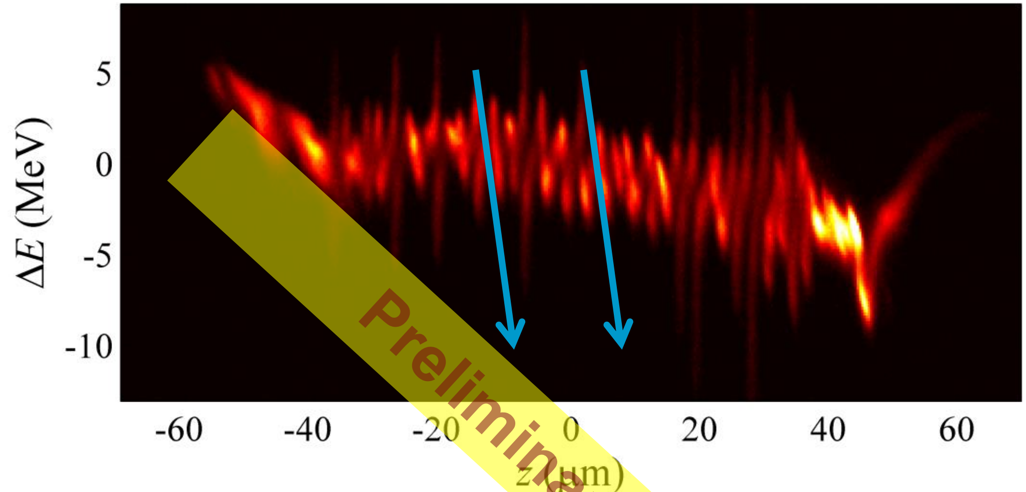
Analysis Methodology

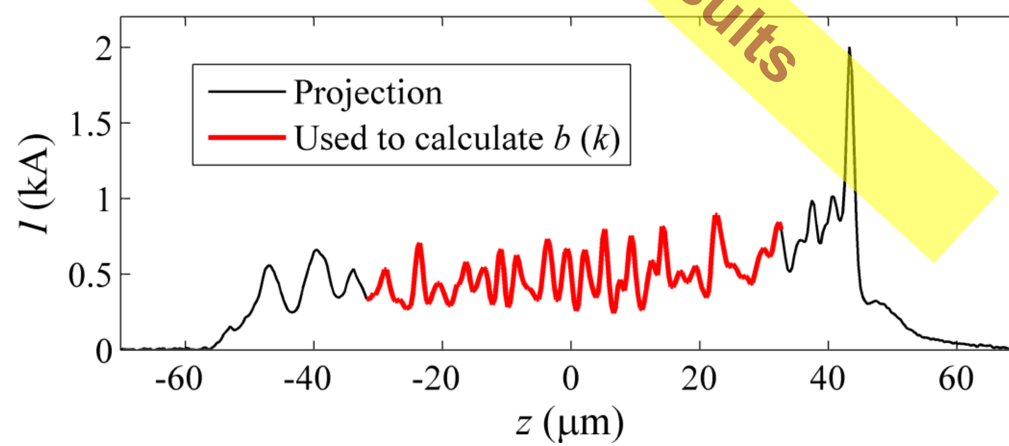
Getting $b(k)$ from images

1. Project $I(z)$ along direction that maximizes density modulation



Correction for suspected small error in β_x / β_y phase advance from XTCAV to screen, same direction used in all images

2. Select uniform current core away from horns



Analysis Methodology

Getting $b(k)$ from images

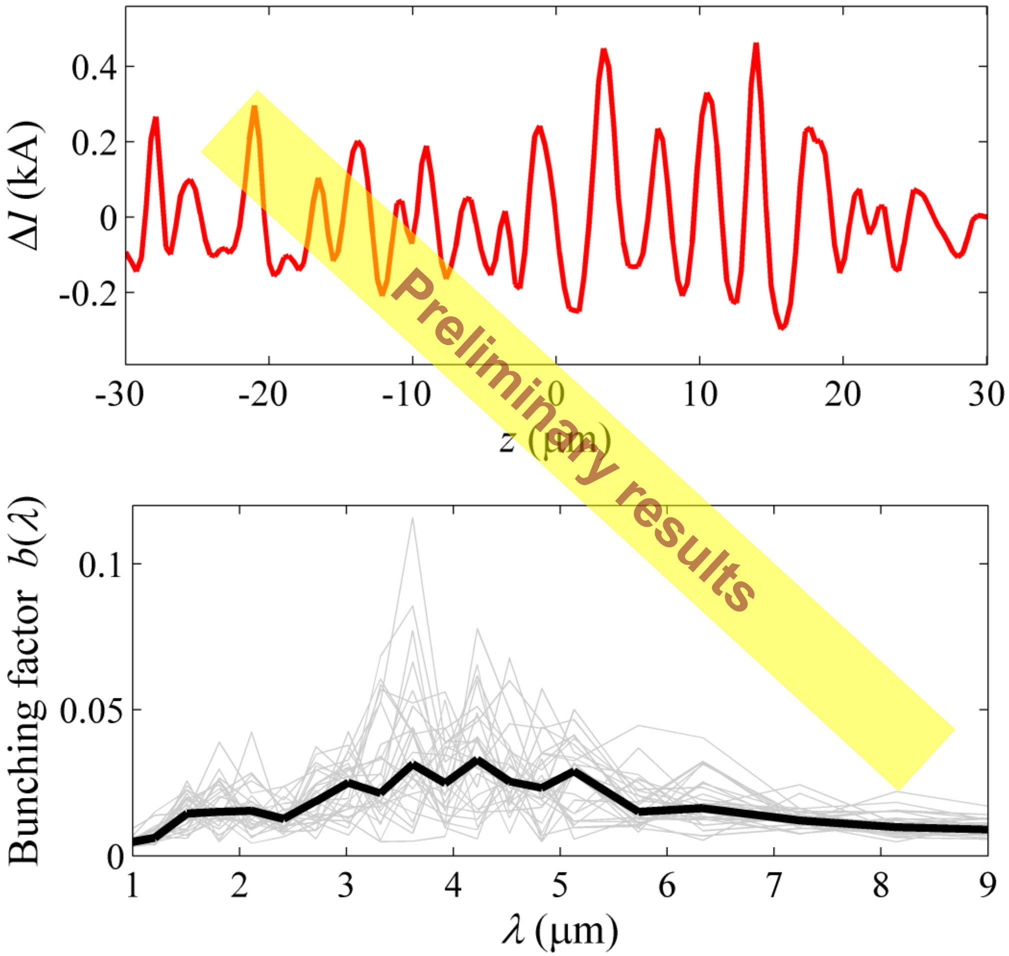
3. Remove $\langle I(z) \rangle$ and first order current corr.

4. Compute (amplitude)

$$|b(k)| = \left| \int dz \, \Delta I(z) \, e^{ikz} \right|,$$

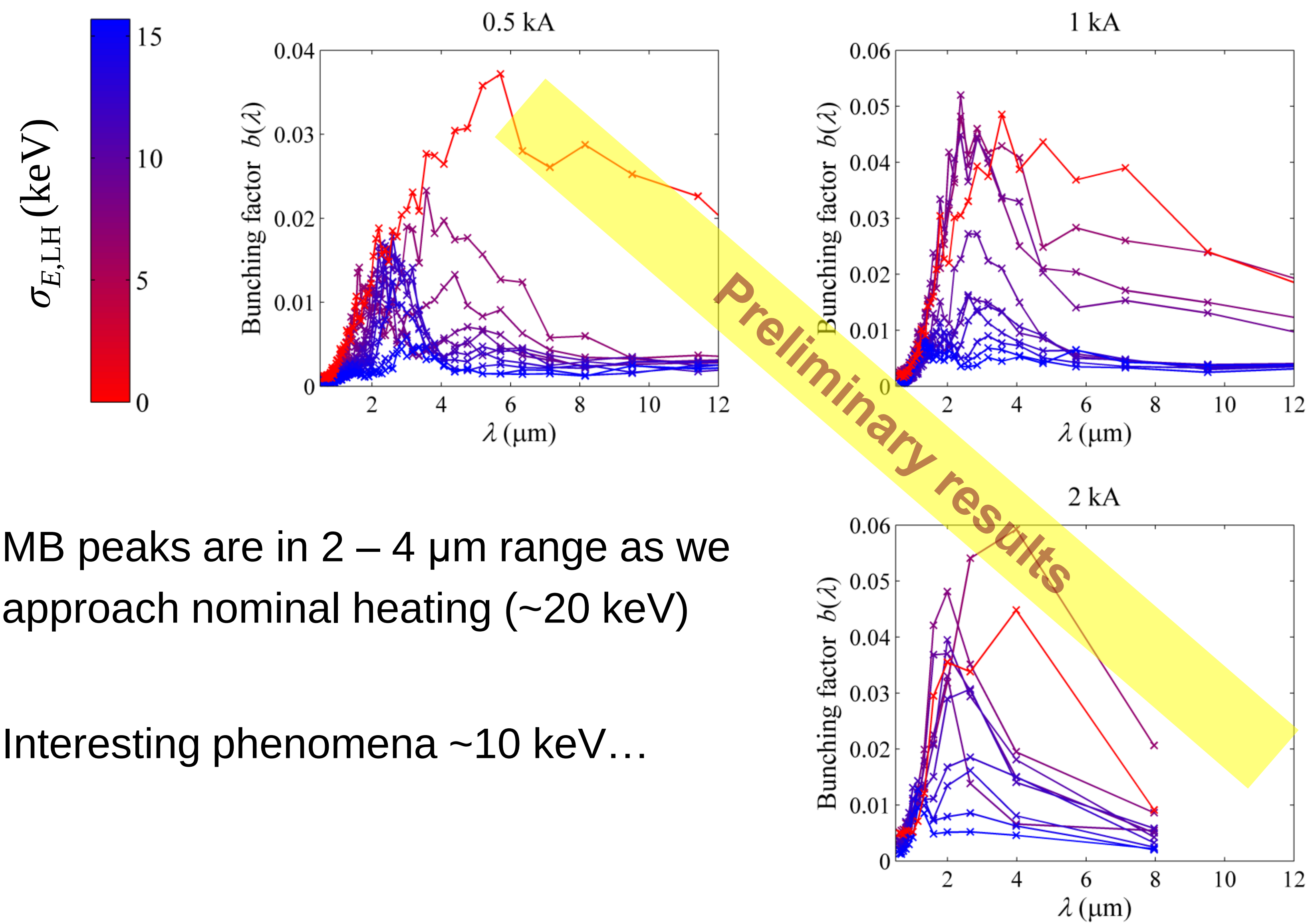
average many shots

Up to 50% modulation @ 500 A



Strong shot-noise fluctuations

Final MB Spectra vs. LH



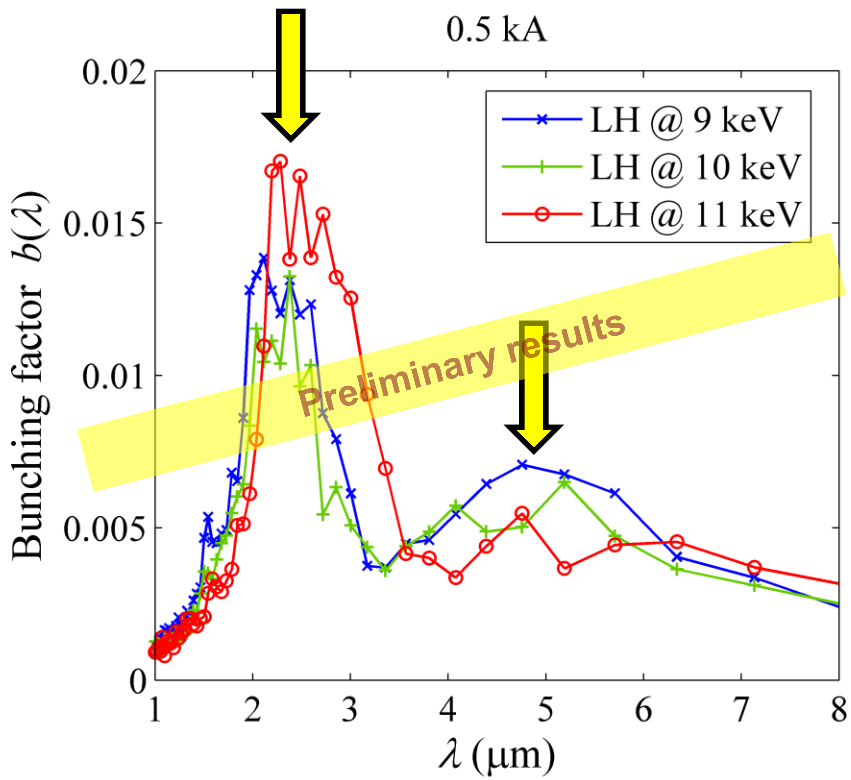
MB peaks are in 2 – 4 μm range as we approach nominal heating (~20 keV)

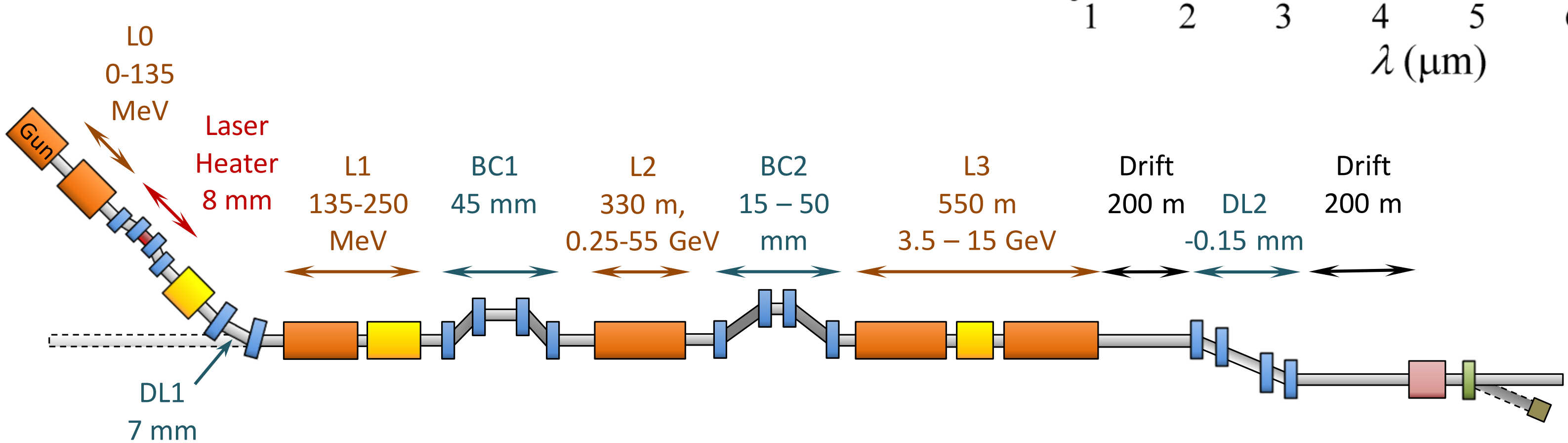
Interesting phenomena ~10 keV…

Finer Structure

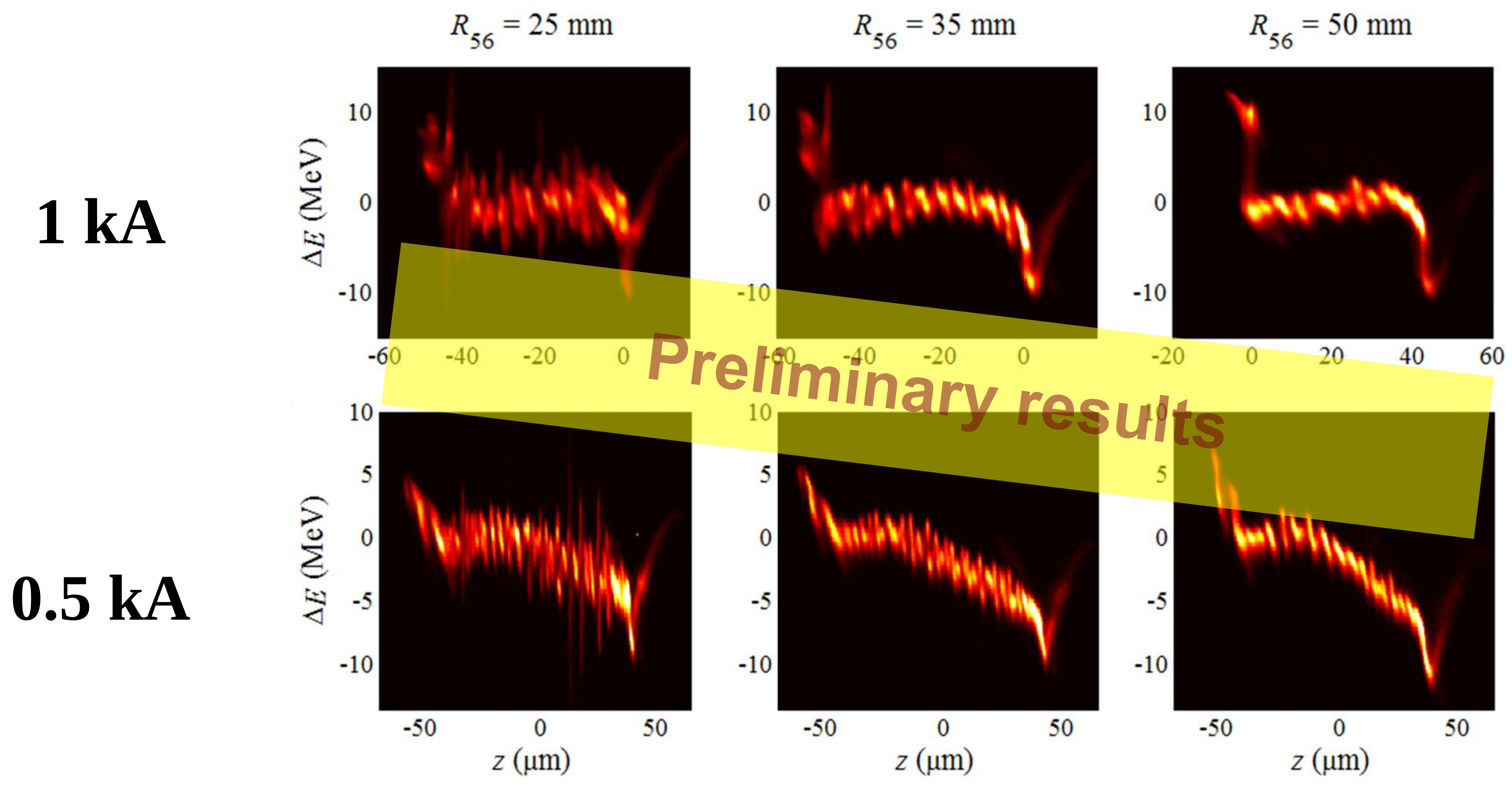
Sub-nominal heating, observe apparent bimodal distribution

Suspect competing MB from different linac sections



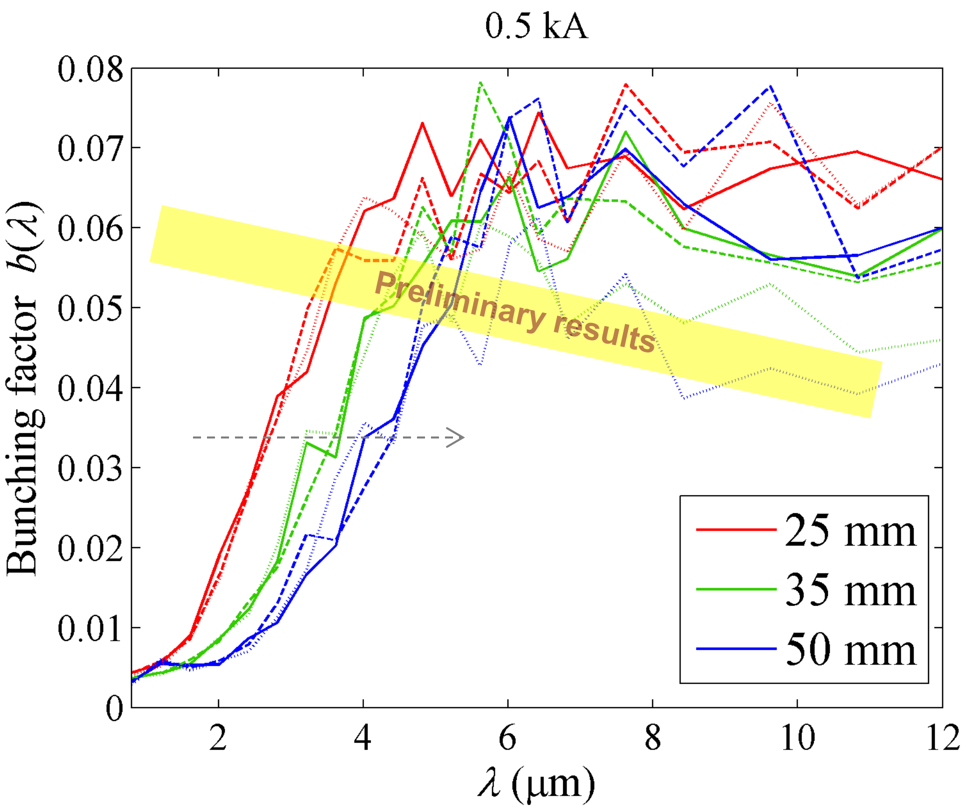


BC2 R_{56} Effect (~no LH)



L2 chirp is DOF to feedback for constant peak currents

BC2 R_{56} Effect (~no LH)



Average MB spectra from multiple runs, observe MB b.w. receding with BC2 R_{56}

Infer that strong BC2 R_{56} damps incoming $b(k)$

Gain dominated by BC2 b.w.

$$\sigma_{k,\mathrm{MBI}} = \frac{1}{R_{56}\sigma_\delta}$$

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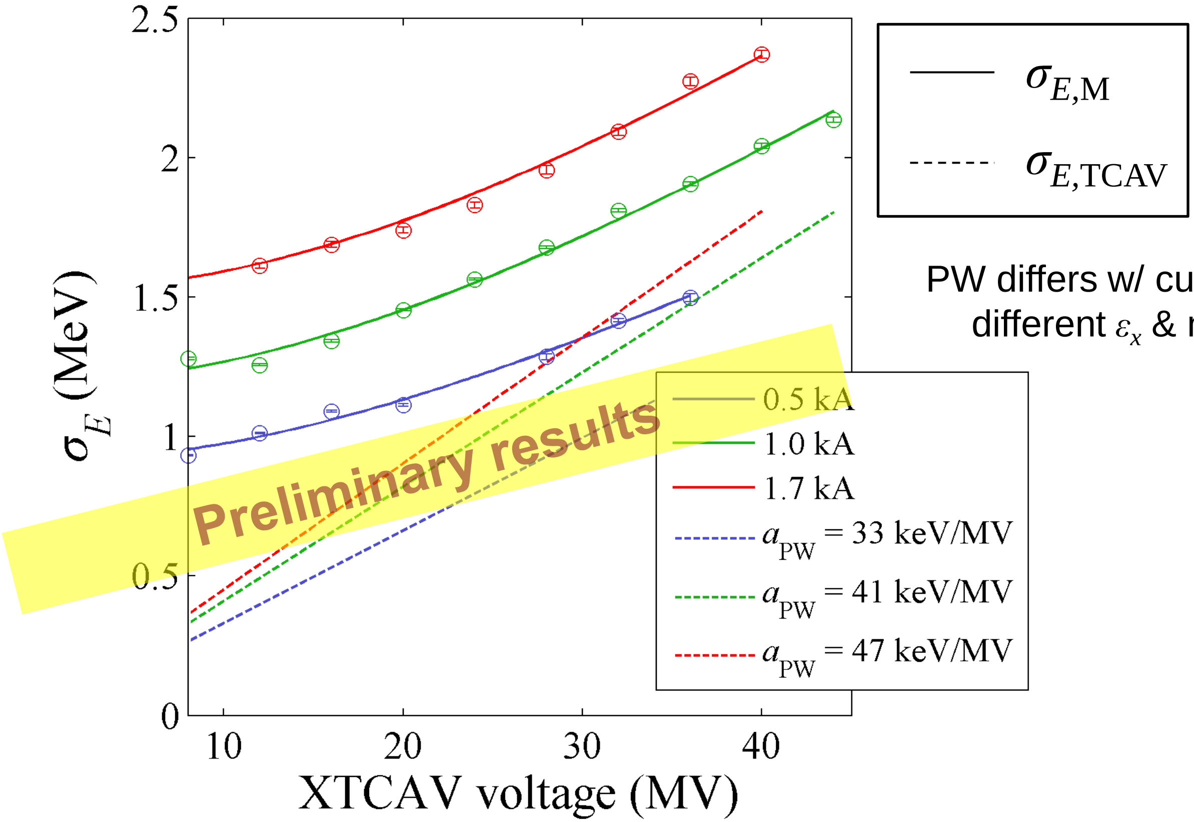
Panofsky-Wenzel Effect

- TCAVs increase measured $\sigma_{E,\mathrm{M}}$ in quad. by $\sigma_{E,\mathrm{TCAV}} = a_{\mathrm{PW}} V_{\mathrm{TCAV}}$
- Scan V_{TCAV} fit $\sigma_{E,\mathrm{M}} = \sqrt{\sigma_E^2 + \sigma_{E,\mathrm{TCAV}}^2}$ with fixed σ_E



PW differs w/ current due to different ε_x & matching

Then can correct SES measurements:

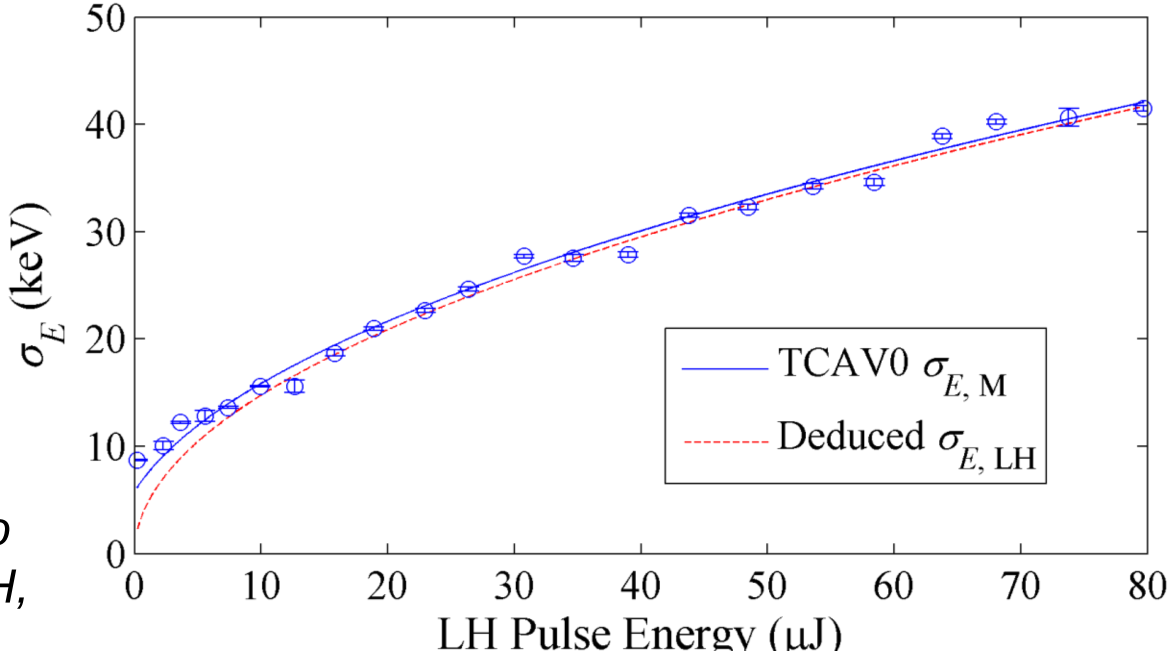
$$\sigma_E = \sqrt{\sigma_{E,\mathrm{M}}^2 - \sigma_{E,\mathrm{TCAV}}^2}$$

Preliminary results

Heater Scan

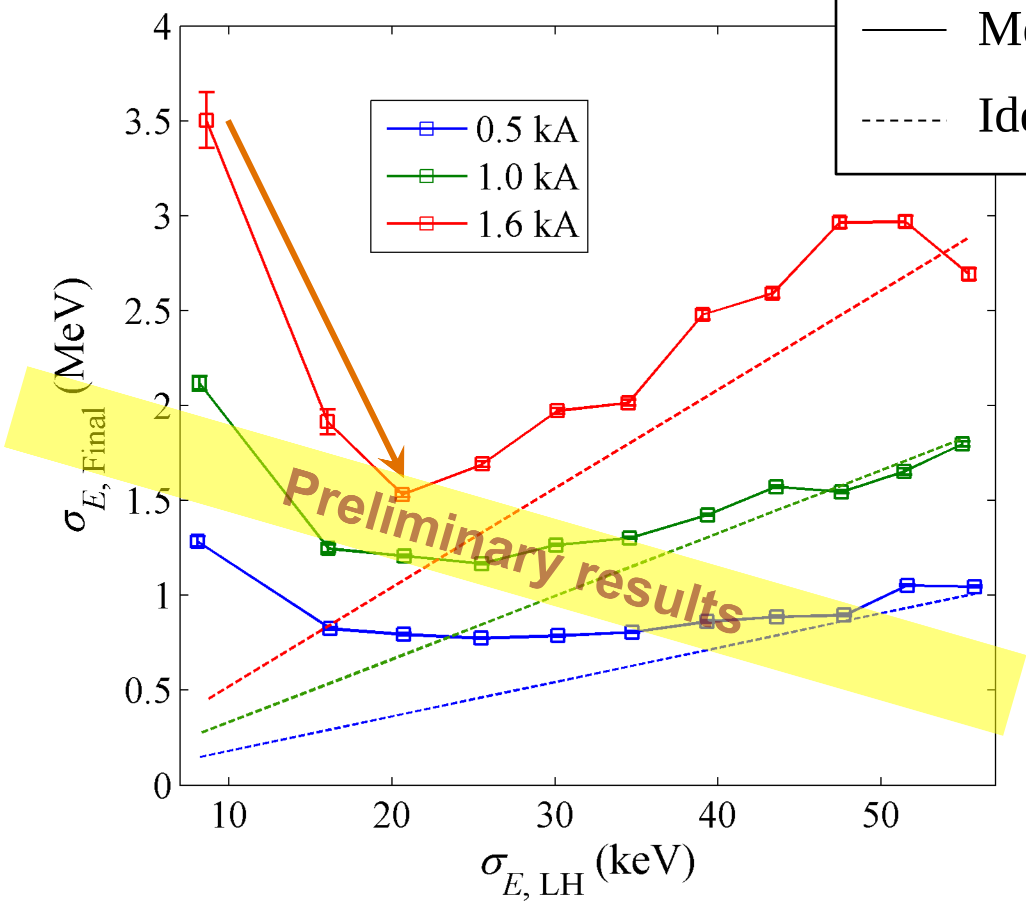
LH calibration similar:

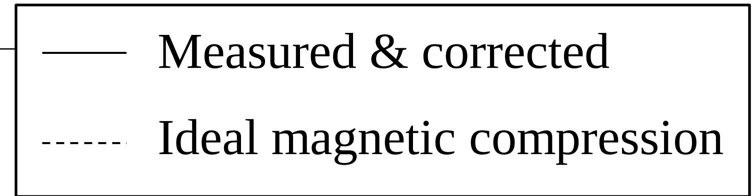
- $\sigma_{E,\mathrm{LH}} \propto \sqrt{U_{\mathrm{LH}}}$
- $\sigma_{E,\mathrm{M}} = \sqrt{\sigma_E^2 + \sigma_{E,\mathrm{TCAV0}}^2 + \sigma_{E,\mathrm{LH}}^2}$
- From fit, compute LH contribution

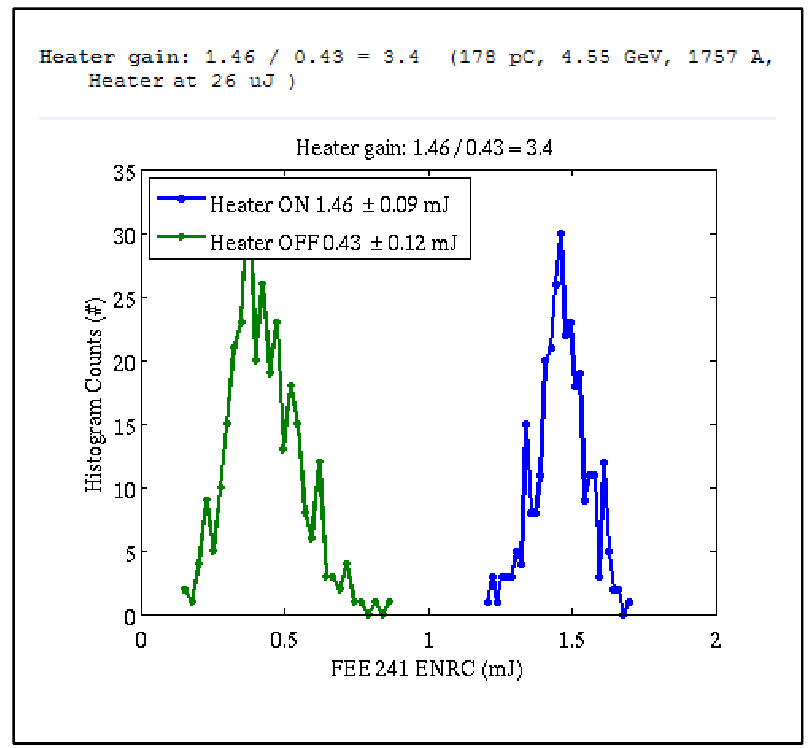


Lack of trickle heating due to alternative match through LH, later confirmed by Y. Ding

Heater Efficacy





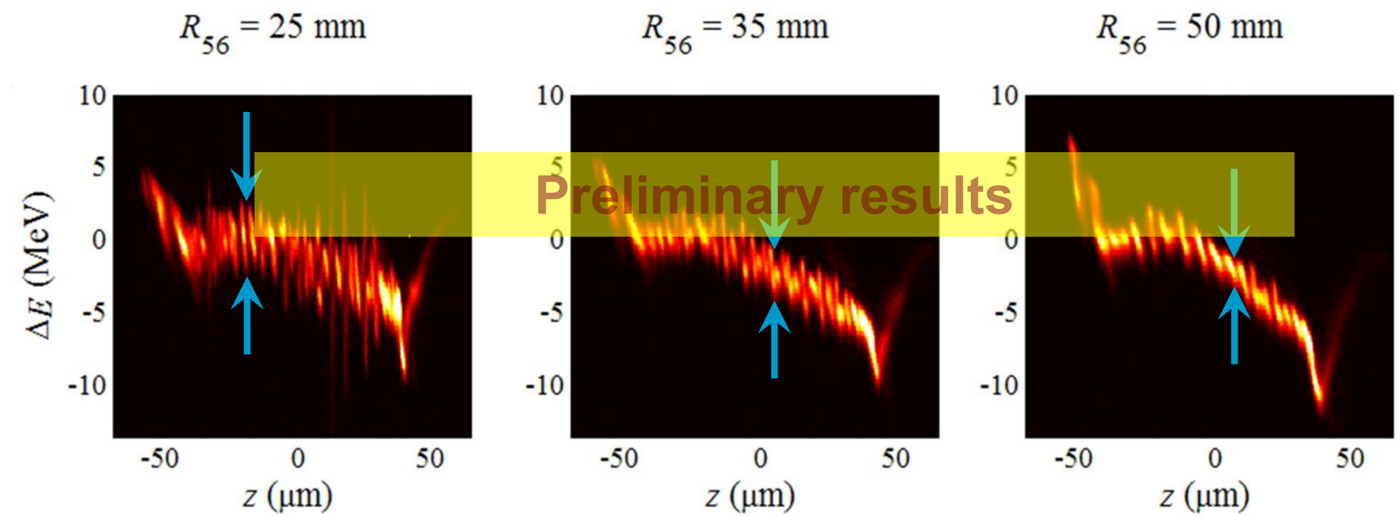


Still appears high, but LH doing its job.

BC2 R_{56} Effect (~no LH)

- Images suggest SES reduction at higher R56
- Could be explained by significant BC2 damping of incoming MB competing with higher BC2 MB gain
- *Insufficient PW data to verify*

0.5 kA



To-do List

- Careful investigation of fine LCLS dump optics matching (energy & trans.) impact on phase space images
- Revisit with alternate, “trickly” LH matching
- Modeling of MB competition between sections
- *With* laser heater, further explore adjusting/increasing BC2 R_{56} to reduce nominal SES (+ corrections)

Summary

- Full compliment of S2E diagnostics are completing the empirical picture of MBI dynamics at the LCLS
- Evidence of MB competition between sections for specific LH settings
- Potential MB point of optimization found in final transport
- Direct observation of LH-induced SES reduction at linac end (though the FEL already told us that)

Thank you!