Microbunching Instability and Slice Energy Spread Using the XTCAV at LCLS

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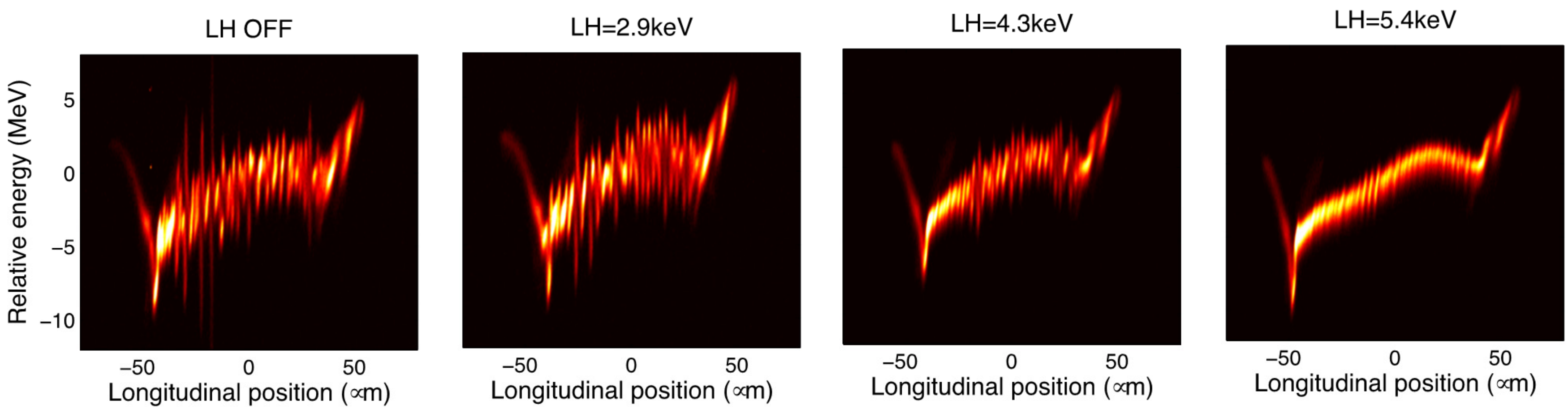
U.S. DEPARTMENT OF ENERGY
Office of Science

SLAC NATIONAL ACCELERATOR LABORATORY

Microbunching and slice energy spread

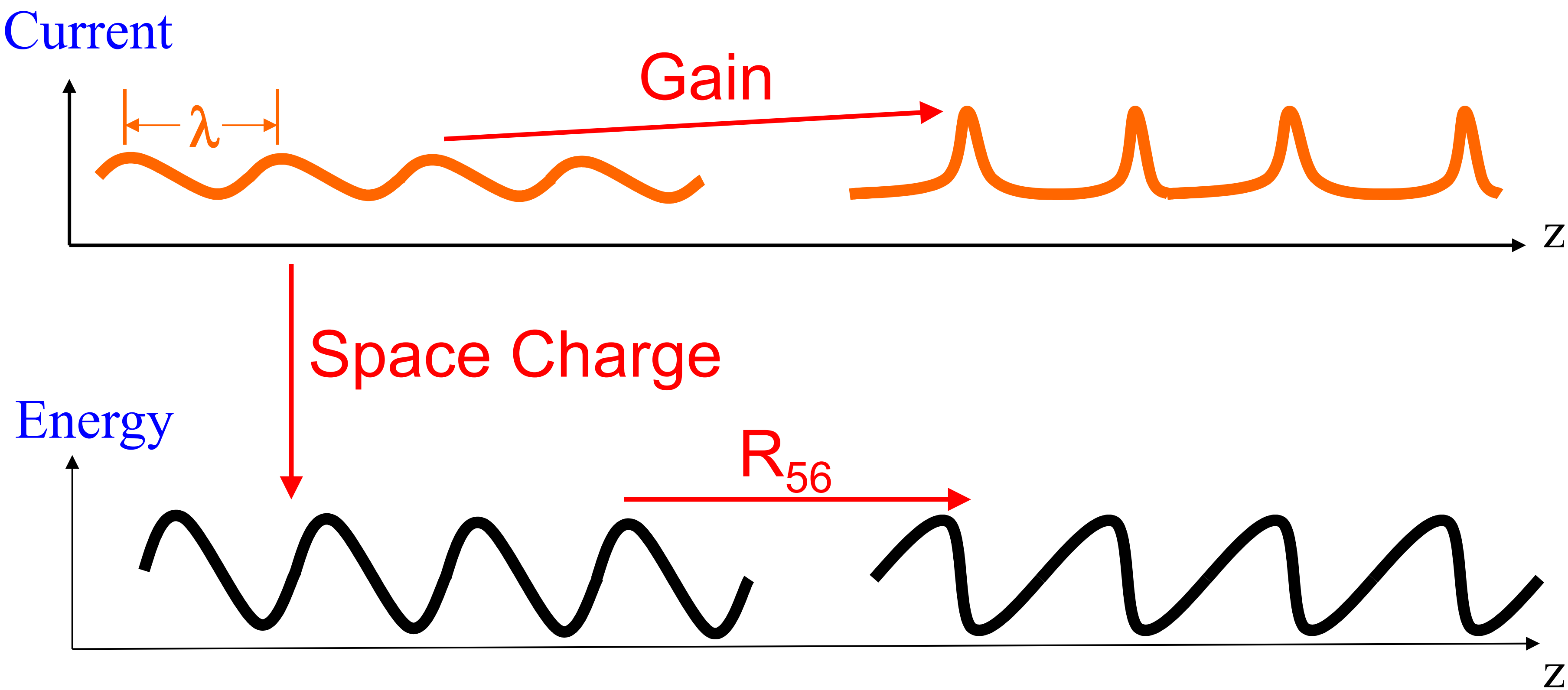
Study goals: use the XTCAV to measure

1. MBI characteristics
2. MBI dependence on laser heater
3. Final slice energy spread (SES) at the FEL



Microbunching Instability

MBI Model



Z. Huang

Microbunching Instability

Measuring MBI

Metric: $$b(k) \equiv \frac{1}{N}\left|\sum_{l=1}^{N} e^{ikz_l}\right|$$ N particles in beam

Gain: $$G(k) \approx \frac{I_0 k}{\gamma I_A}\left|R_{56}\int_0^{\ell} ds \frac{4\pi Z(k/C,s)}{Z_0}\right| \exp\left(\frac{-k^2 R_{56}^2 \delta^2}{2}\right)$$

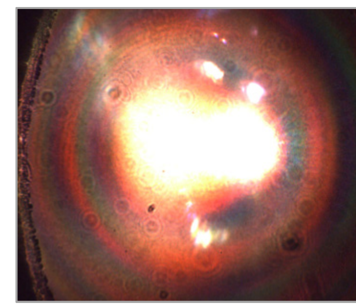
Impedance: $(k\sigma/\gamma C \ll 1)$ $$Z(k/C) \approx \frac{iZ_0 k}{4\pi\gamma^2 C}\left[1 + 2\ln(\gamma C/k\sigma_r)\right]$$

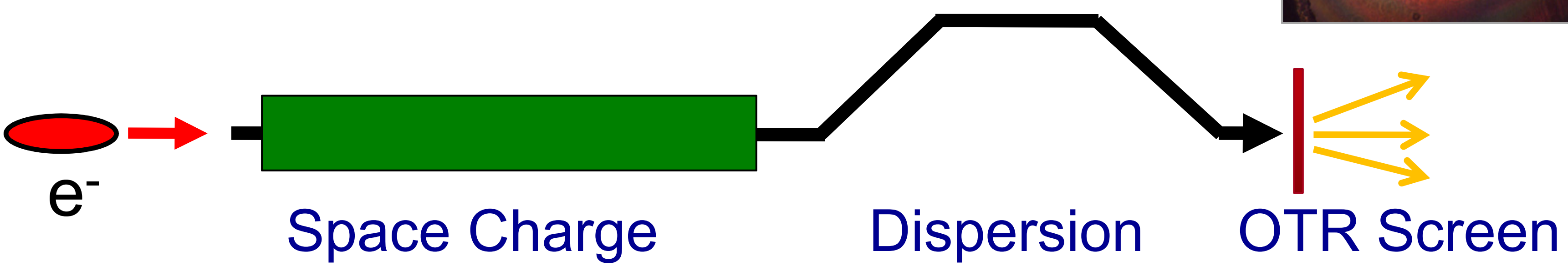
final wavenumber k, compression C, energy γ, espread δ, current I_0, beam size σ_r

Measuring MBI

Metric: $$b(k) \equiv \frac{1}{N}\left|\sum_{l=1}^{N} e^{ikz_l}\right|$$

COTR: $$\left|b(k)\right|^2 \propto I(k)$$





Measuring MBI

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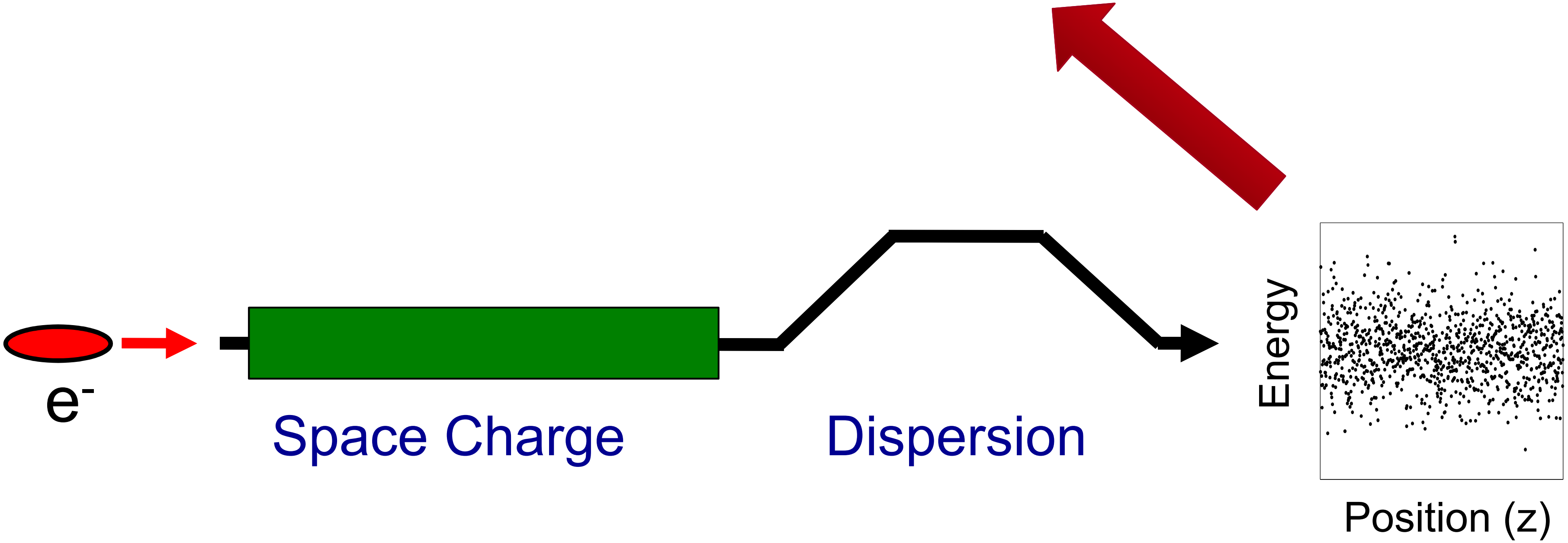
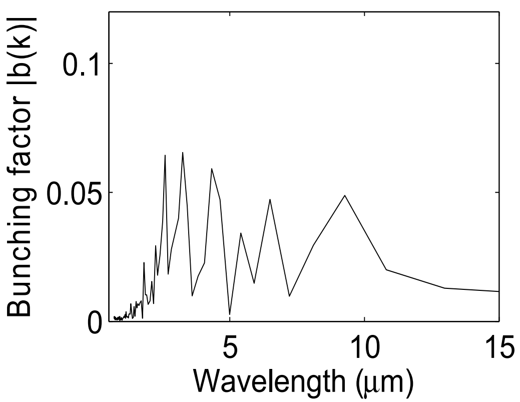
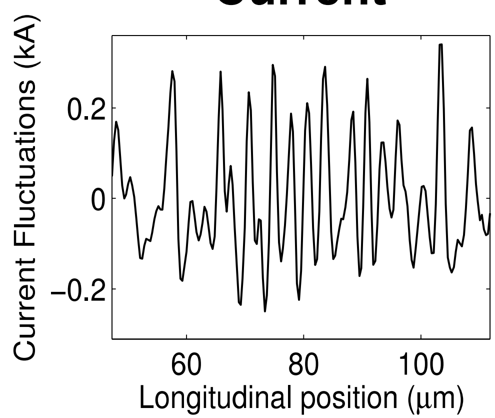


Measuring MBI

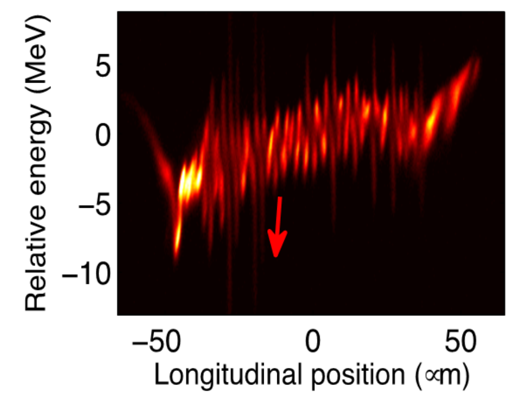
Bunching

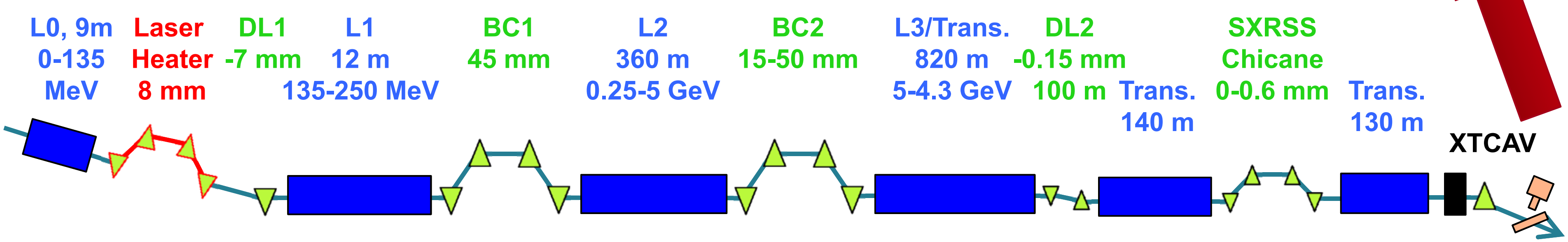


Current



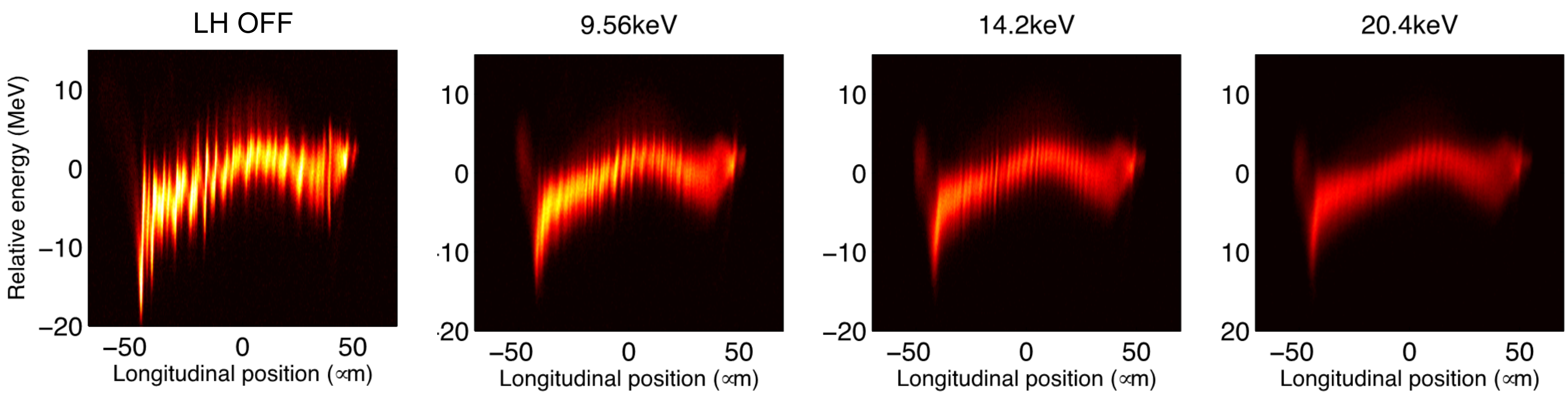
Phase space

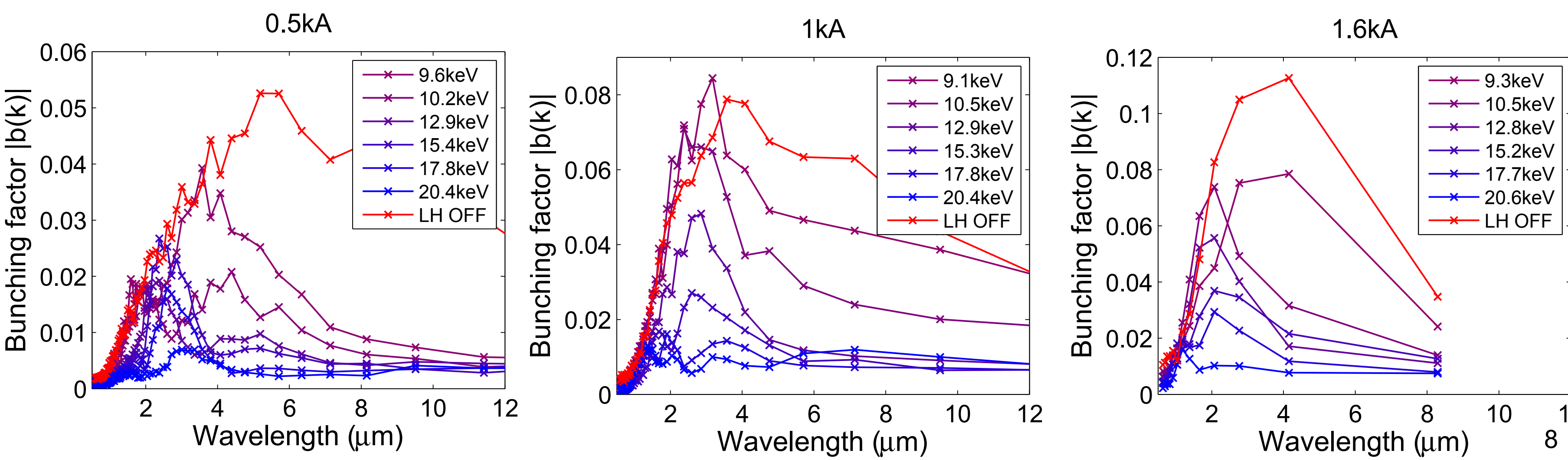




Microbunching Instability

MBI vs. Laser Heater





Benchmarking for LCLS II: Simulations vs. Measurements

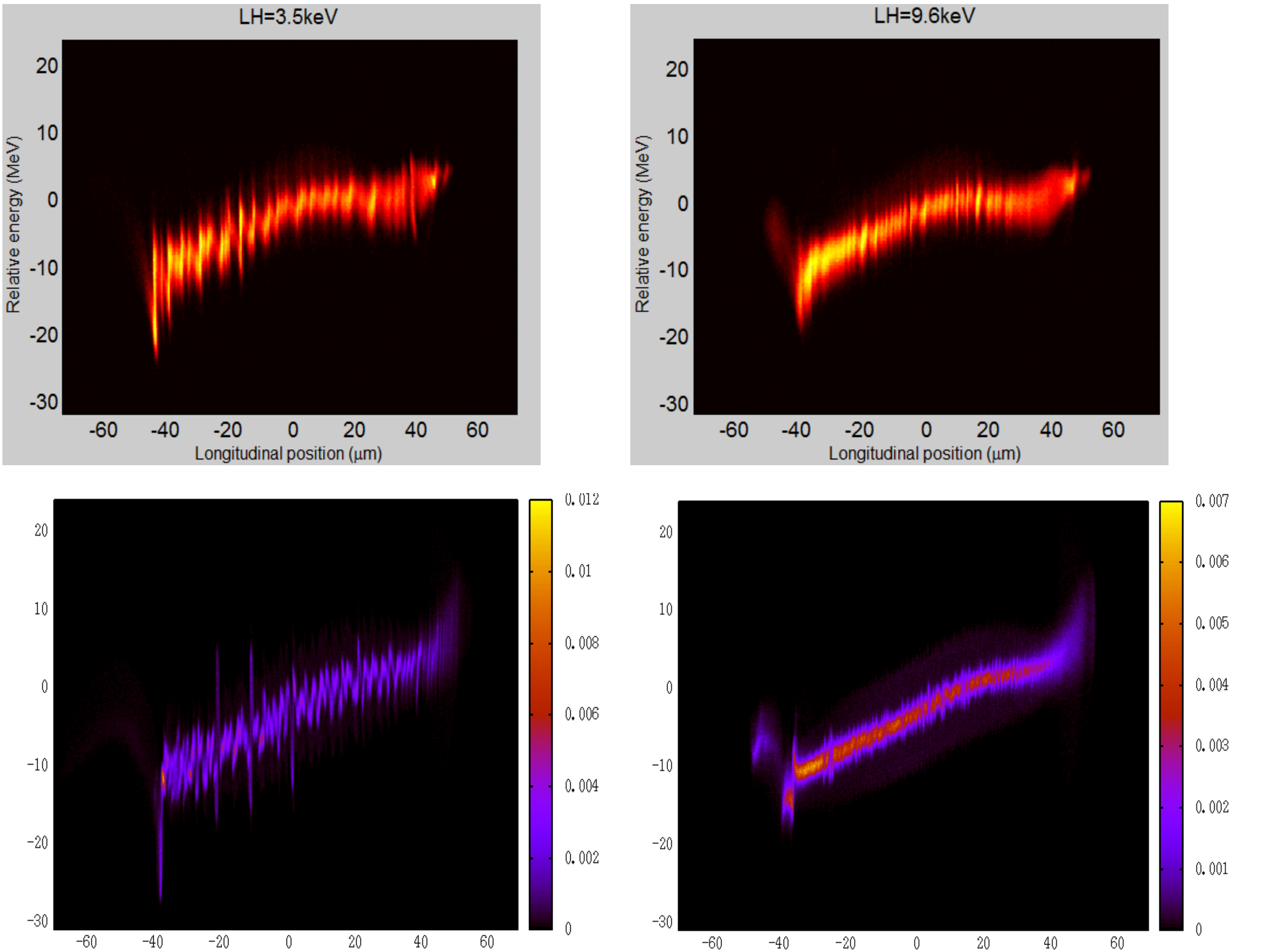
June 18 **500 A** data, with XTCAV

Images courtesy
J. Qiang

LH OFF | LH=9 keV

Measurement

Simulation



Benchmarking for LCLS II: Simulations vs. Measurements
June 18 **500 A** data, with XTCAV

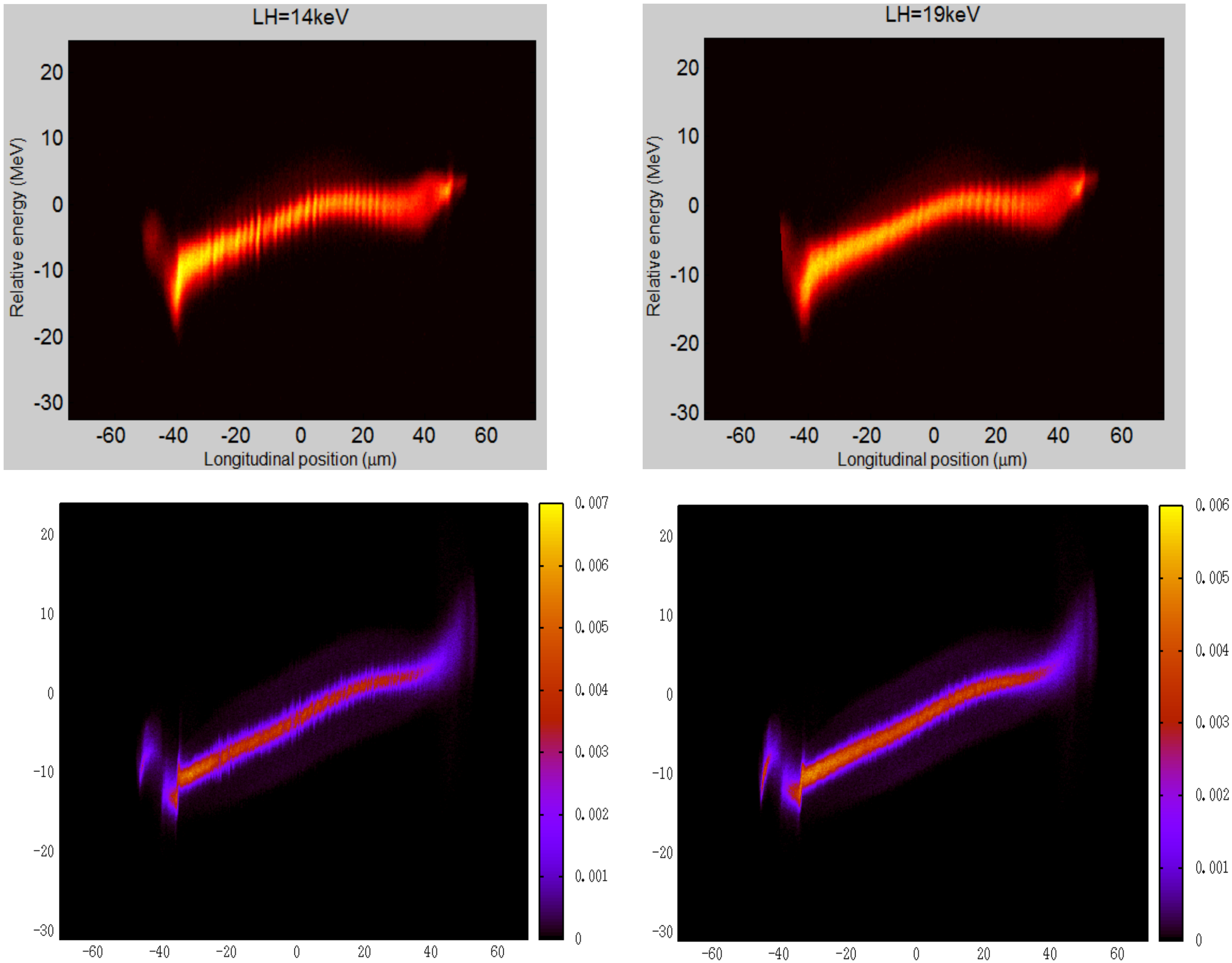
Images courtesy J. Qiang

LH=14 keV

LH=19 keV

Measurement

Simulation



Benchmarking for LCLS II: Simulations vs. Measurements

June 18 **1 kA** data, with XTCAV

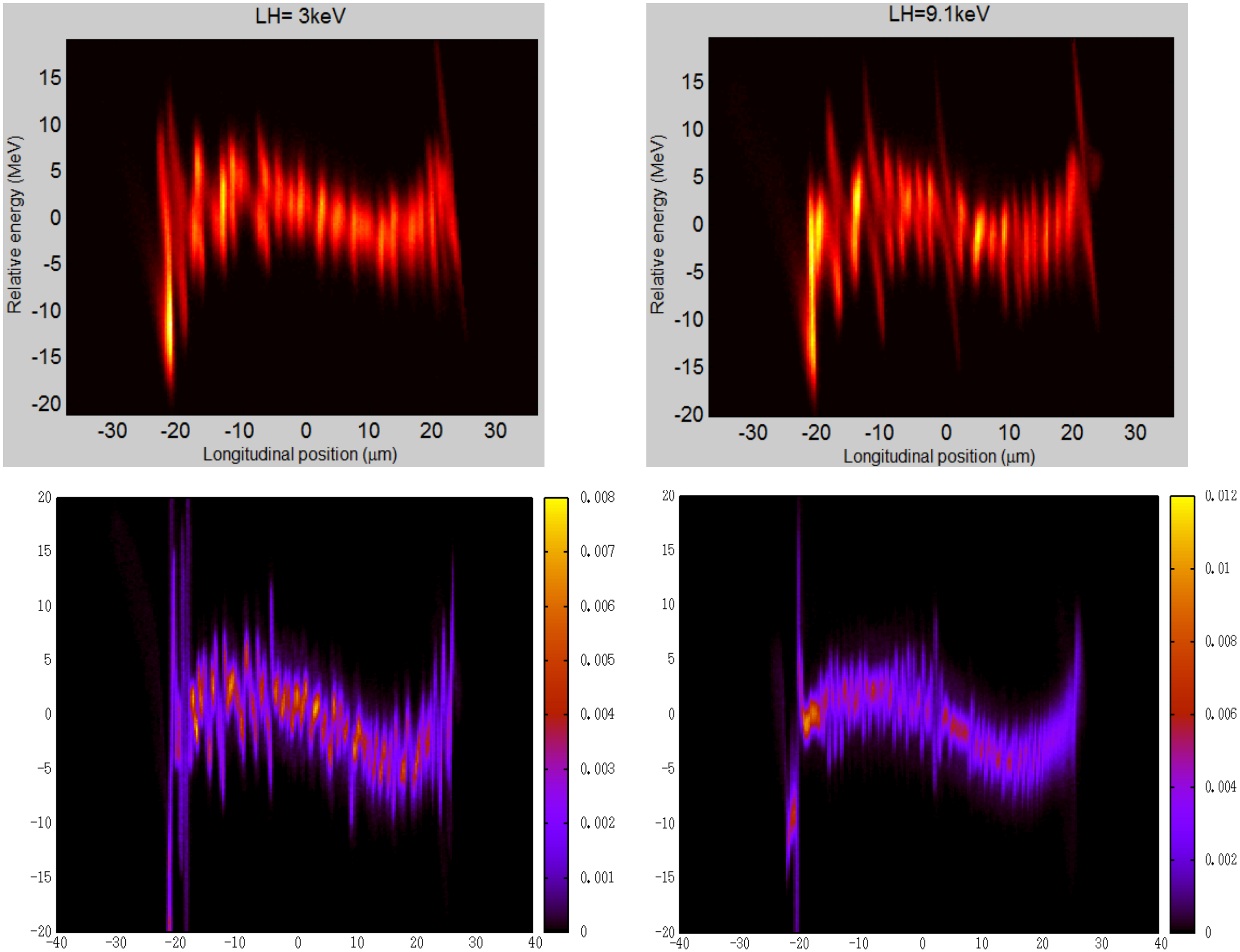
Images courtesy J. Qiang

LH OFF

LH=9 keV

Measurement

Simulation



Benchmarking for LCLS II: Simulations vs. Measurements

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LH=14 keV

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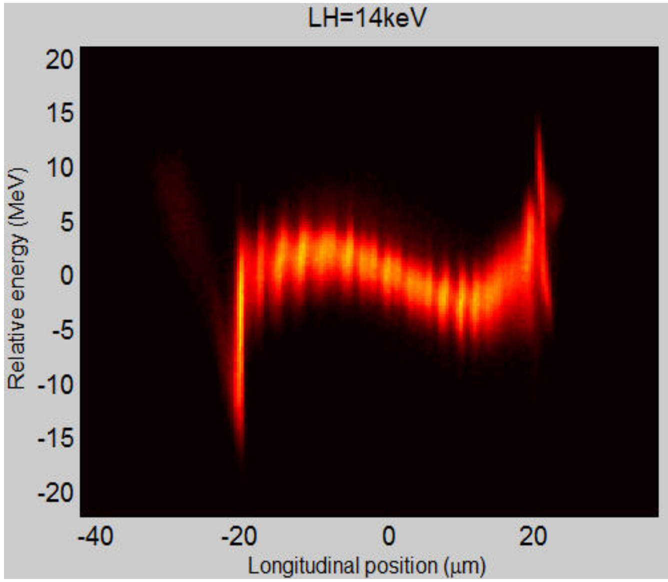
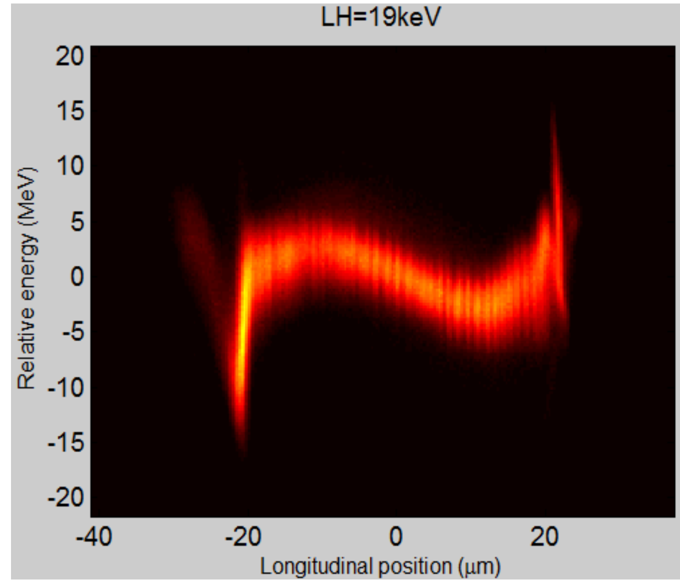
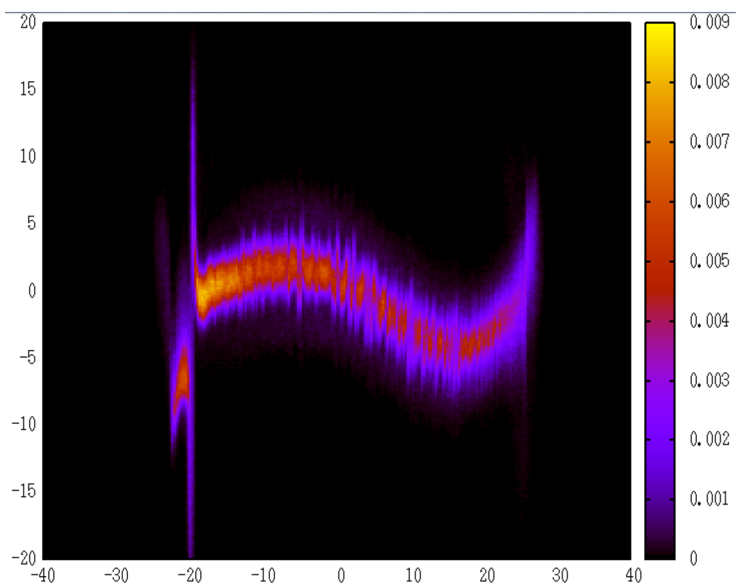
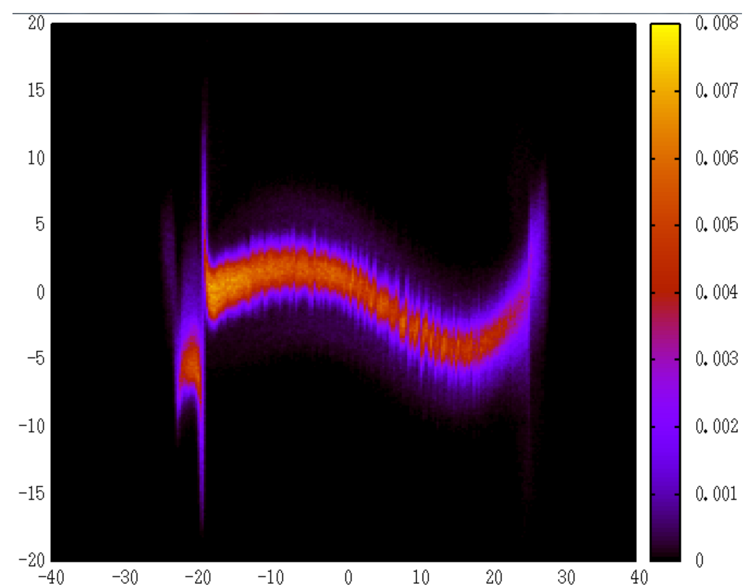




Simulation

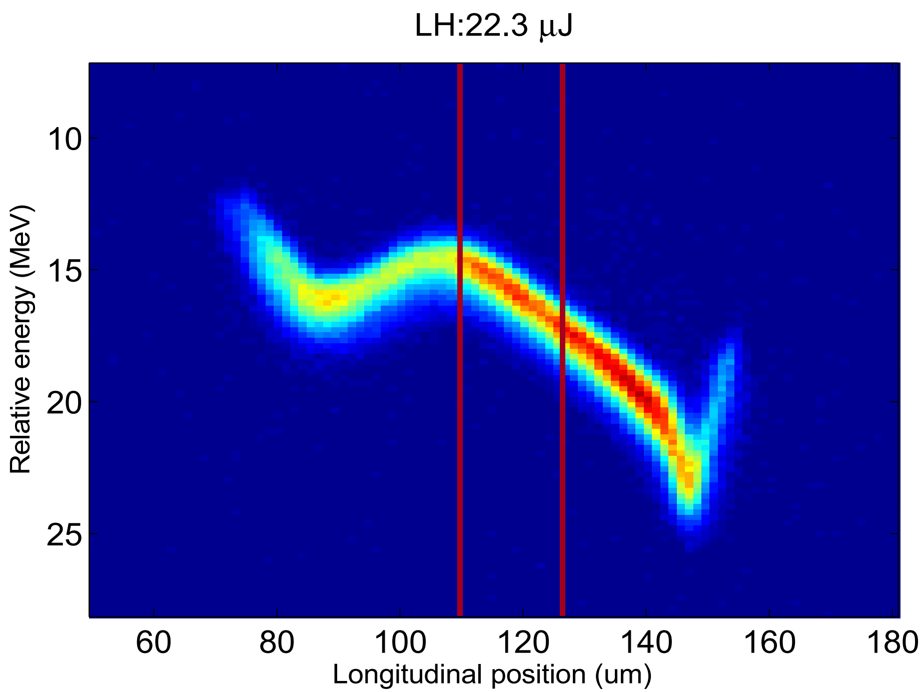




SLAC

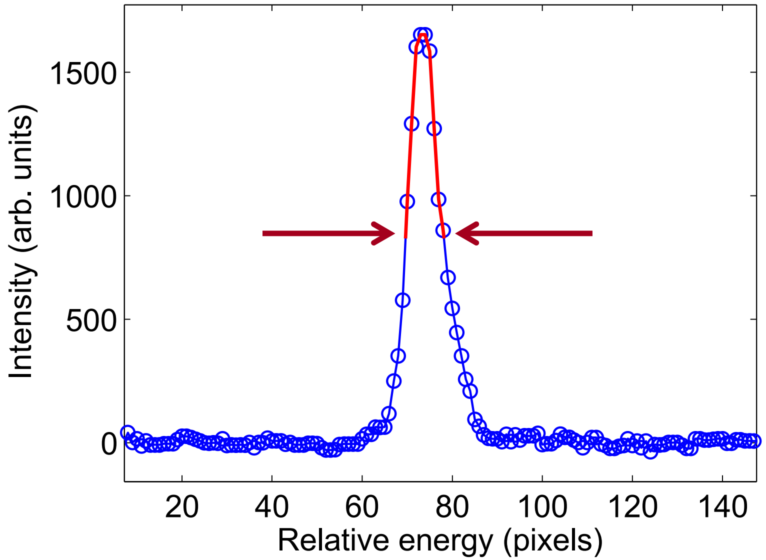
Measuring "slice" energy spread

Select middle of beam



Calculate slice energy spread

(linear interpolation because few pixels)



Slice Energy Spread

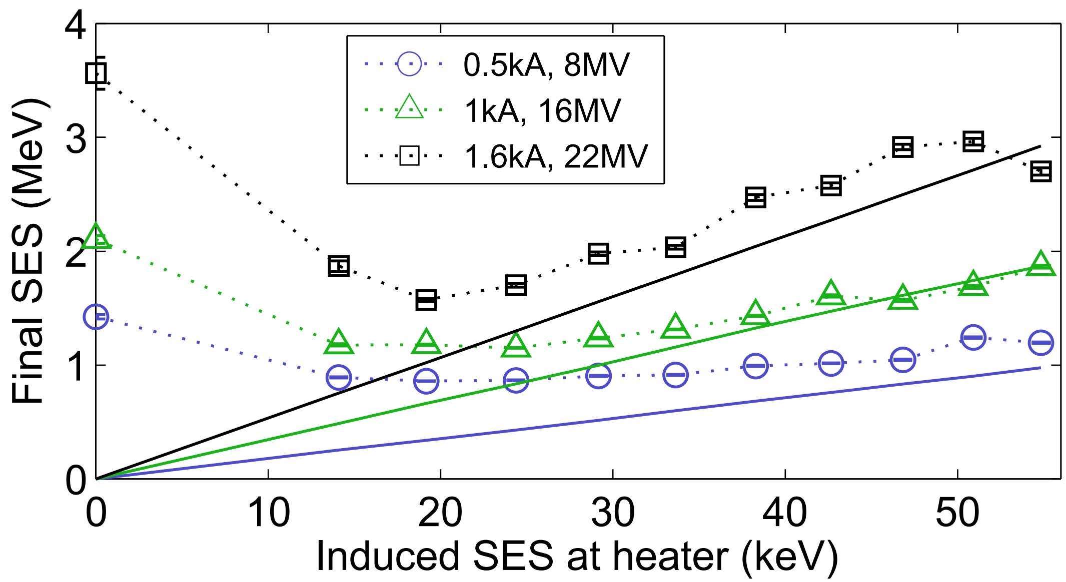
SES vs. Laser Heater

Solid lines show contribution from laser heater

Minimum SES:

Peak current (kA)	0.5	1	1.6
SES (MeV)	0.9	1.2	1.6

Dominated by MBI

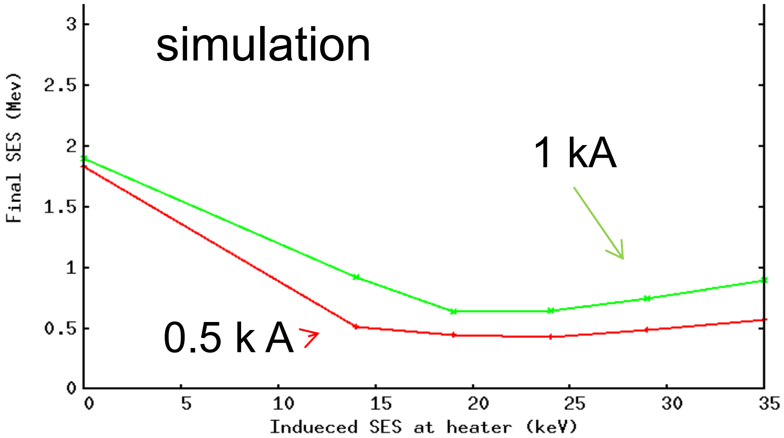


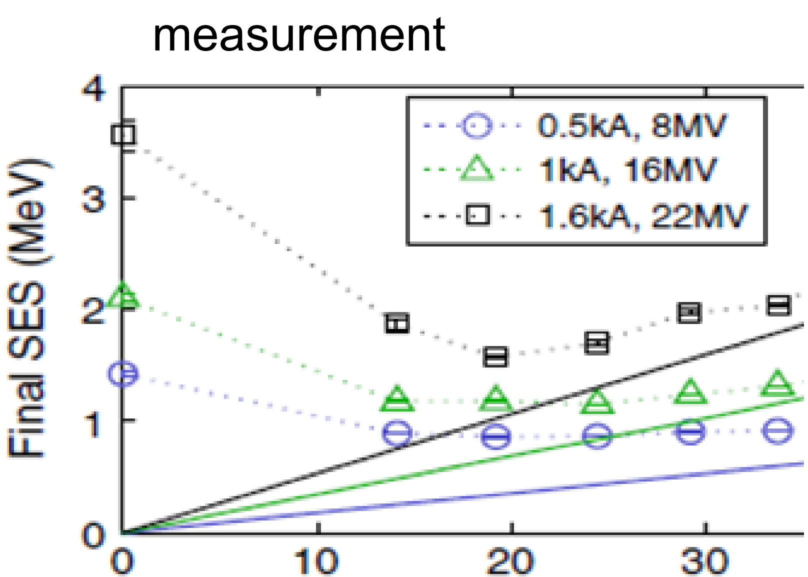
Dominated by heater

Slice Energy Spread

Slide courtesy J. Qiang

SES vs. Laser Heater

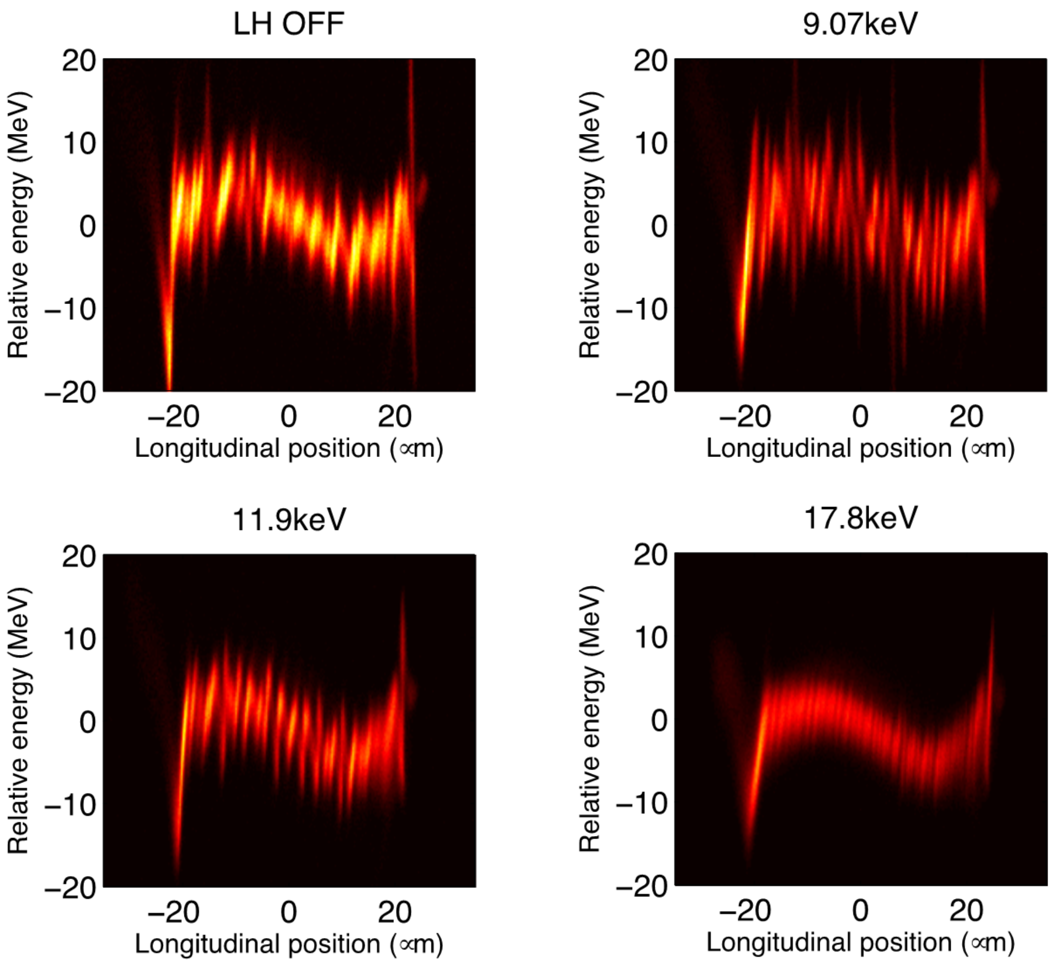




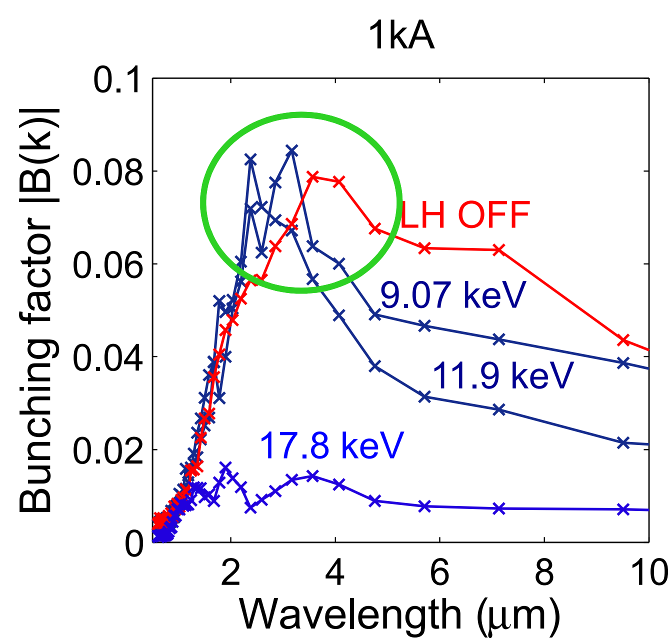
- Good agreement in minimum location of the LH induced energy spread
- Good agreement in general trend of the final SES vs. LH induced SES
- Final SES vs. LH induced SES agrees with measurements with 50%
- General agreement of final SES vs. final current

Self-heating

MBI vs. laser heater

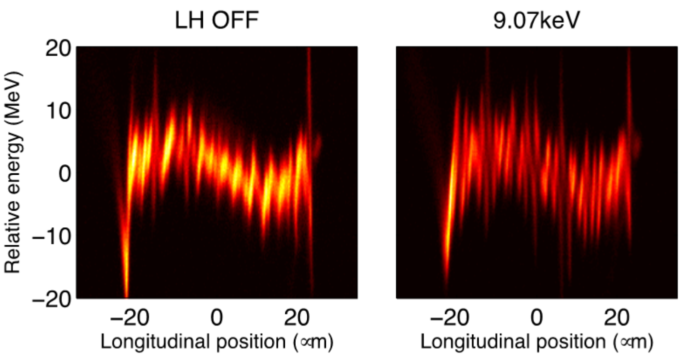


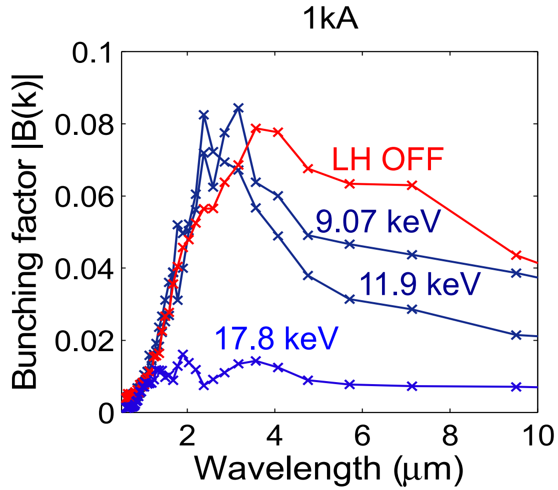
$$\Delta\gamma(k) \propto Z(k) \propto k$$

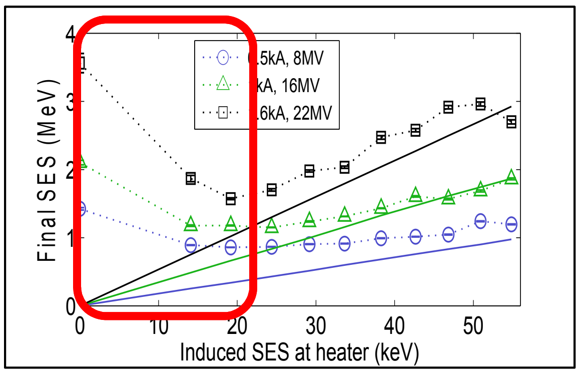


Self-heating

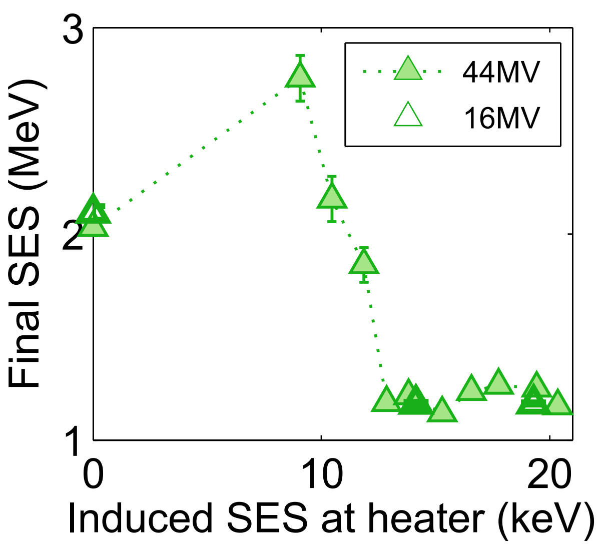
SES vs. Laser Heater



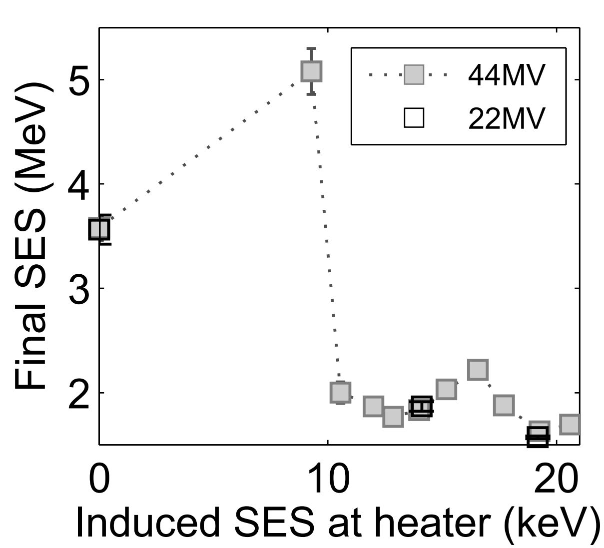




1kA



1.6kA



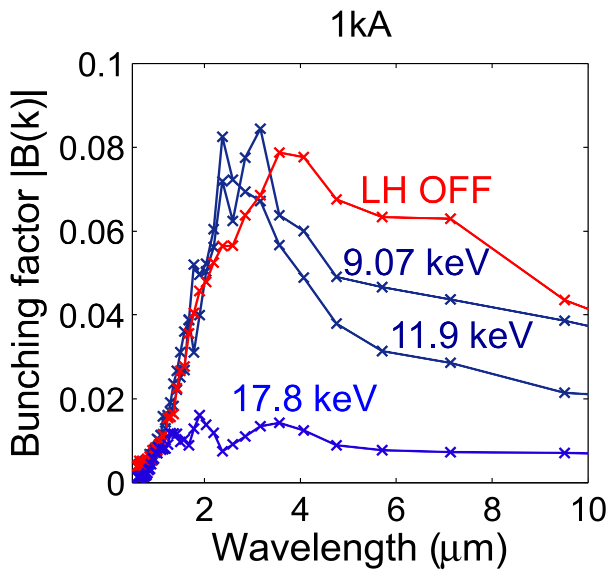
Microbunching Instability

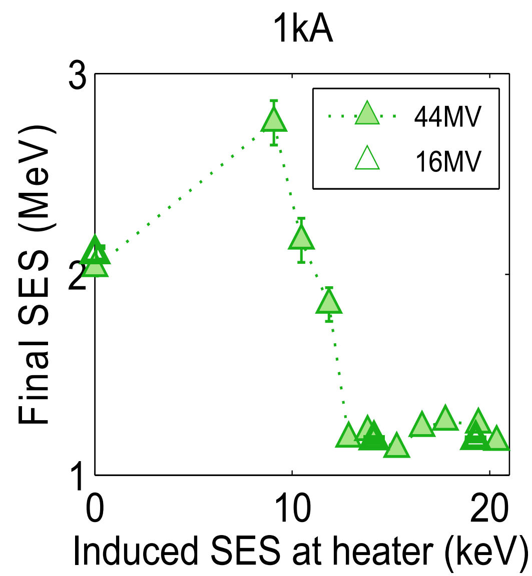
Peak MBI gain vs. Laser Heater

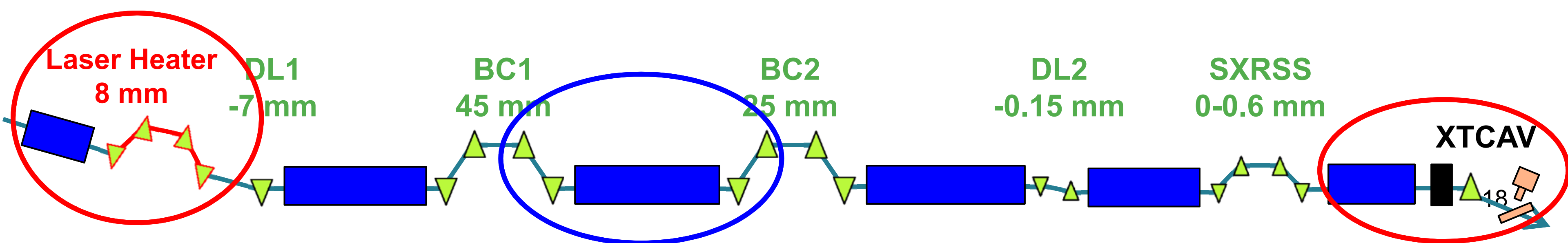
Landau damping

$$b(k) \propto e^{-k^2 R_{56}^2 \delta^2 / 2}$$

$$\delta^2 = \delta_0^2 + \delta_{LH}^2 + \delta_{MBI}^2$$





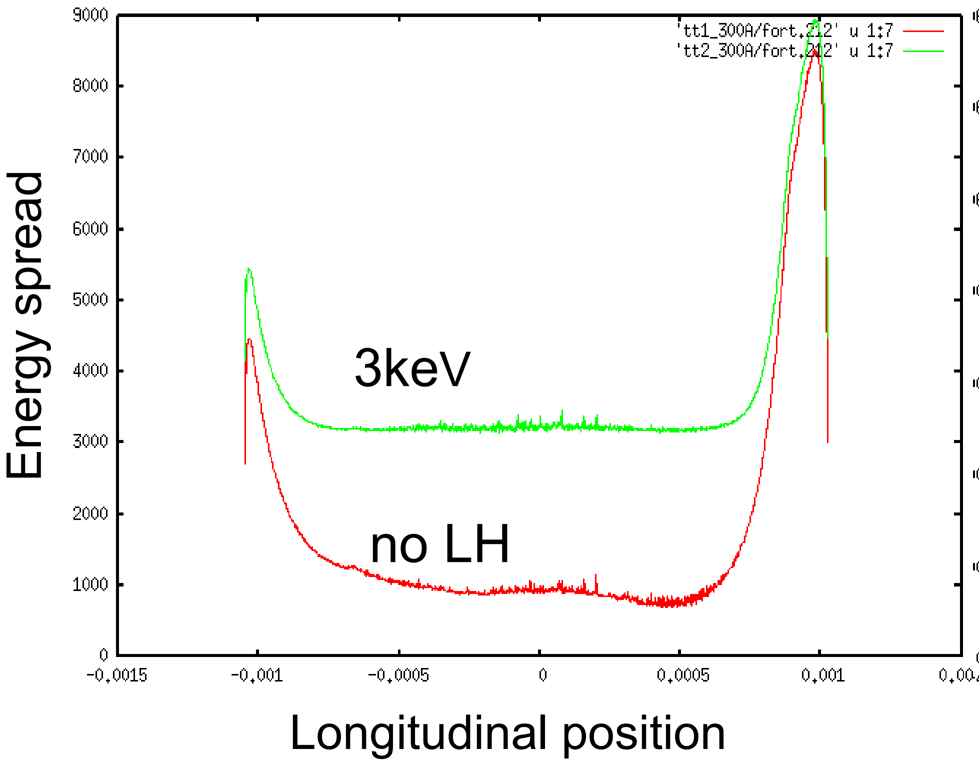


Microbunch Self Heating Effects (1kA)

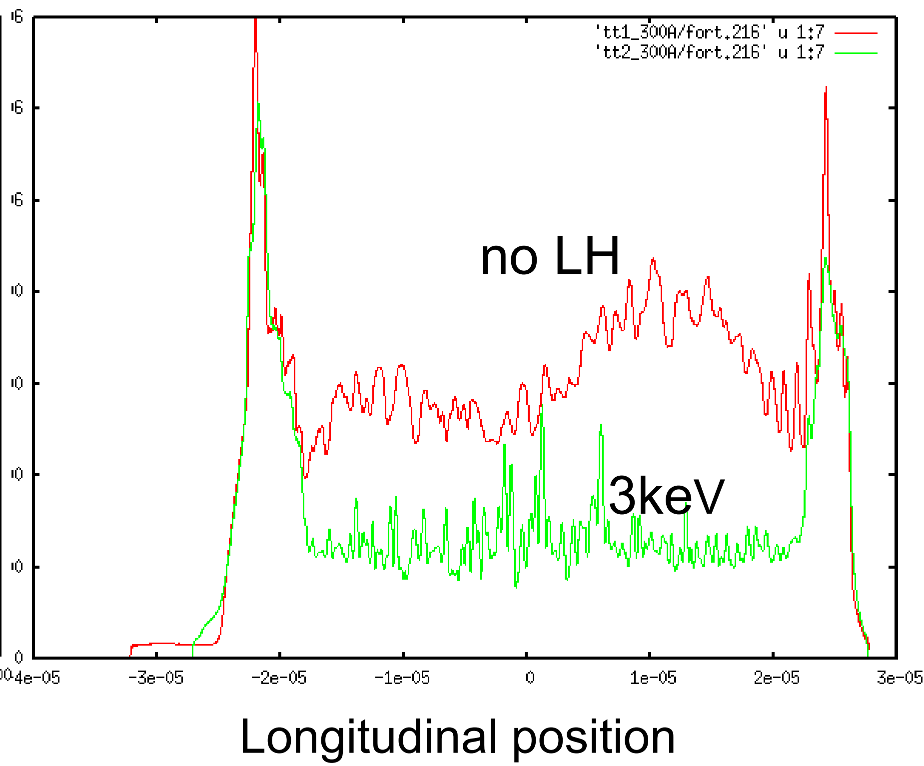
Images courtesy J. Qiang

Slice uncorrelated energy spread after LH and before BC2

After Laser Heater



Before BC2

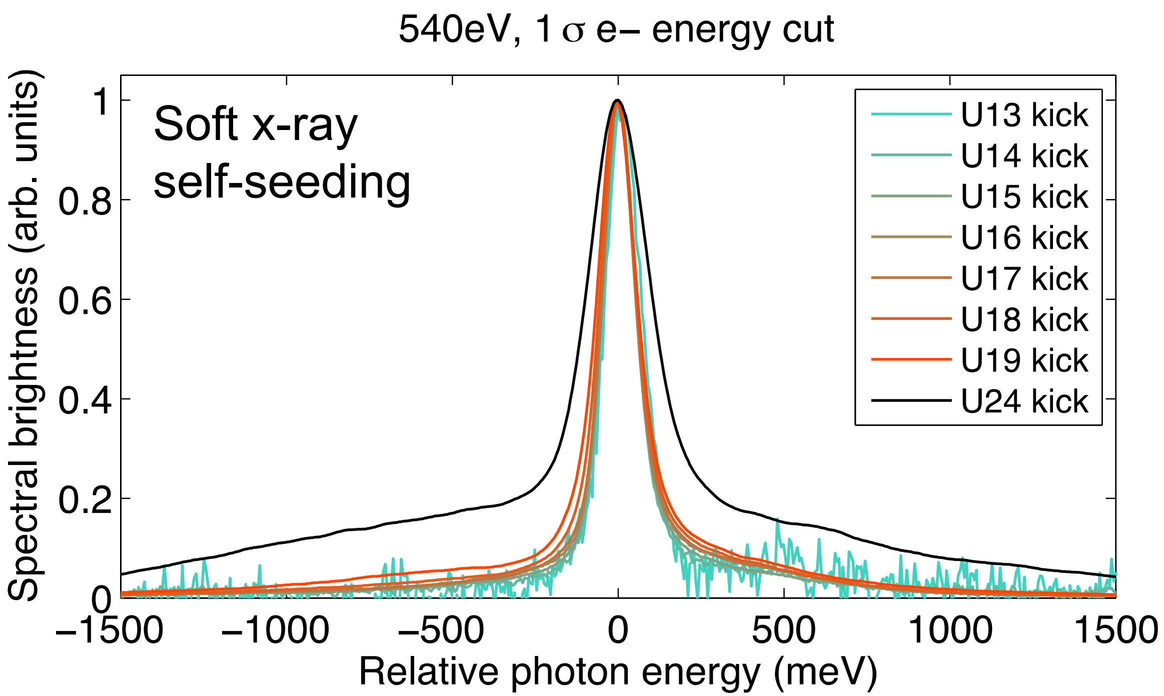


MBI Control

SLAC

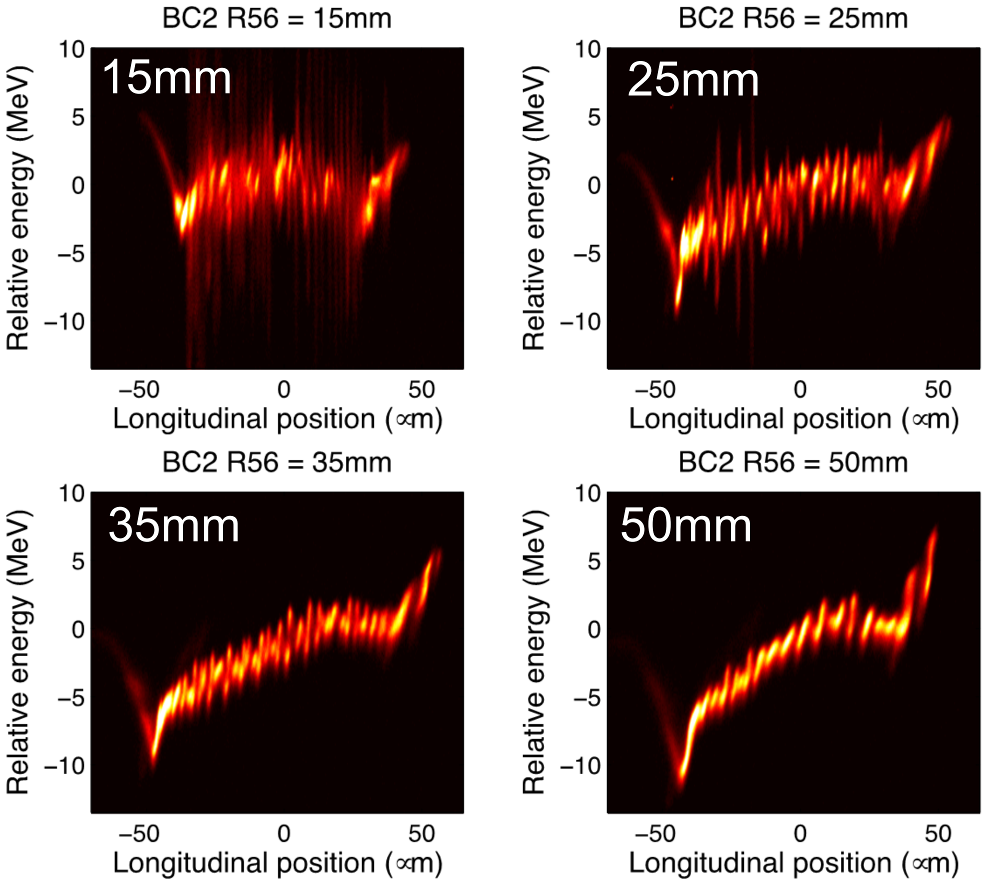
Can we improve MBI Suppression?

Motivation: improve advanced schemes (seeding, noise suppression, harmonic lasing, etc.)

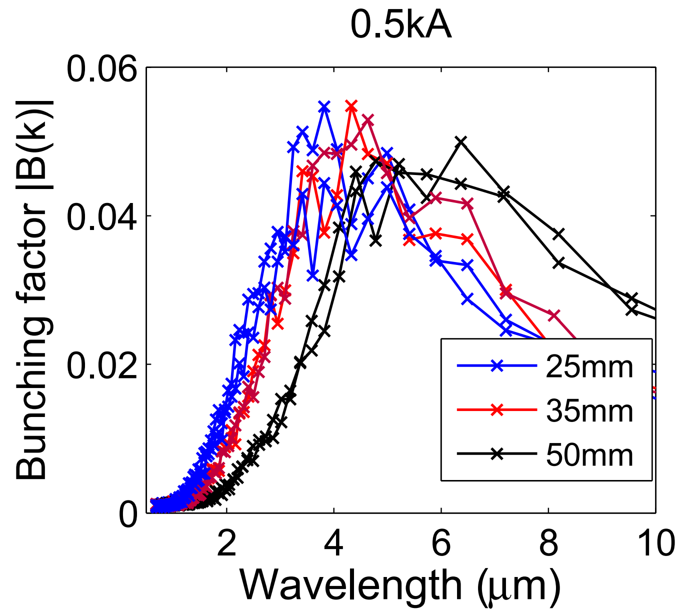


MBI Control

Bunch compressors (phase mixing)



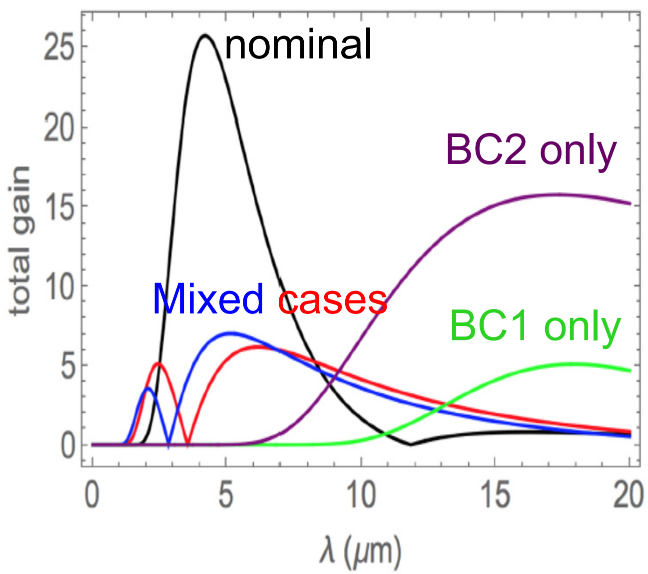
$$G(k) \propto R_{56} k^2 e^{-k^2 R_{56}^2 \delta^2 / 2}$$

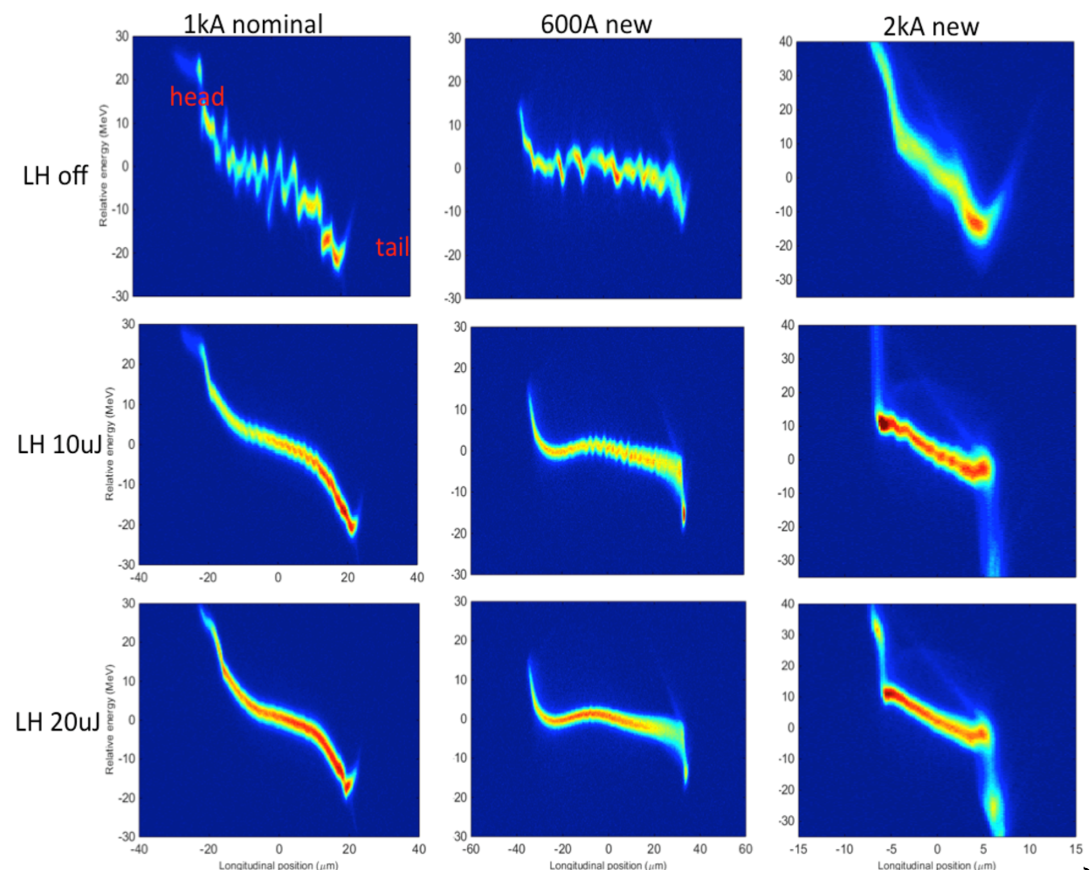


MBI Control

Even better: lower BC2 energy (more damping)
lower BC1 compression (less gain)

MBI gain models



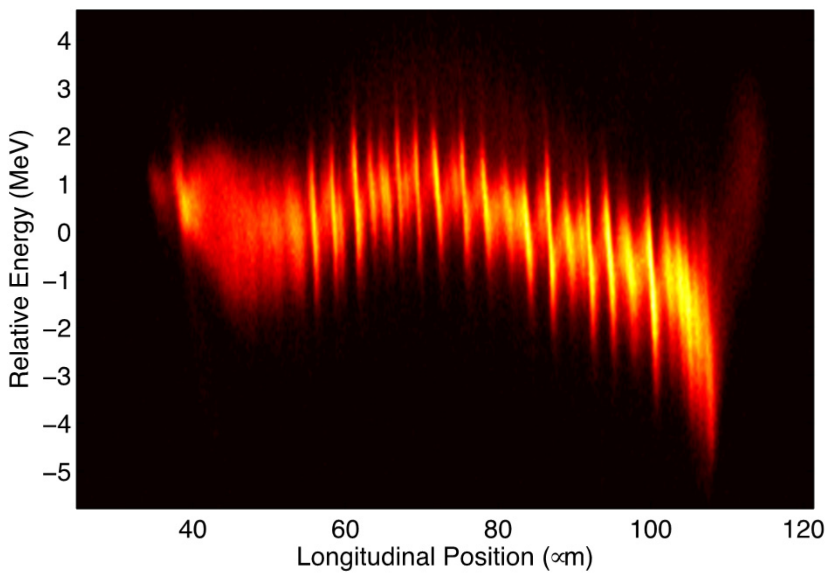


Images from S. Li

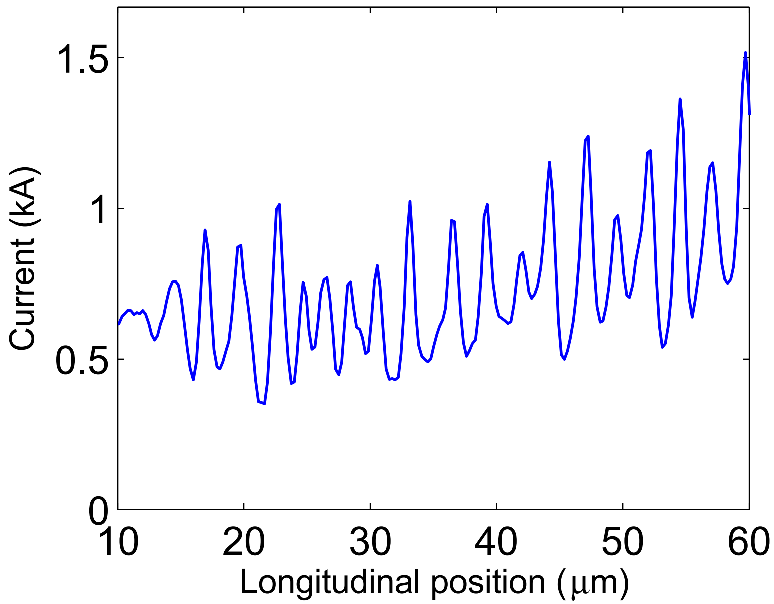
MBI Correlations

Source of MBI

Sample shot, 500 A



Projected current



Looks a bit like longitudinal correlations…

MBI Correlations

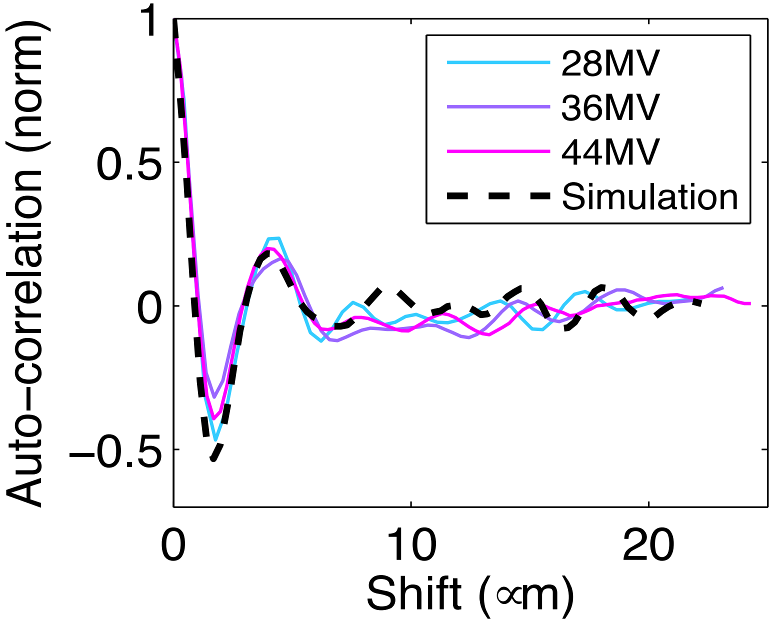
SLAC

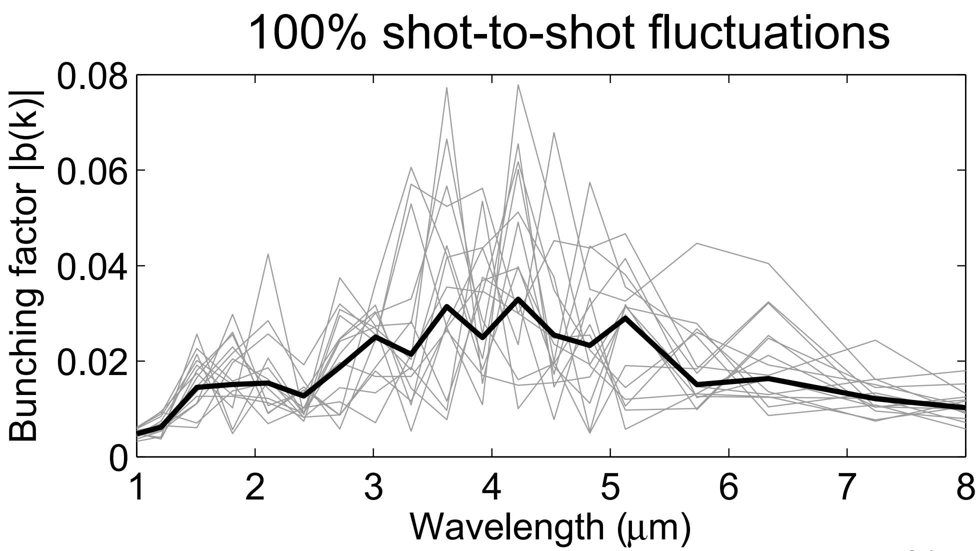
Source of MBI

Define autocorrelation: $$C(s) = \frac{1}{C_0} \int dz \Delta I(z) \Delta I(z-s)$$

$$C_0 \equiv \int dz \Delta I(z)^2$$

Upshot: MBI is consistent with shot-noise origins





SLAC

Conclusions

MBI:

1. Direct time domain measurements with XTCAV
2. Good benchmark for LCLS-II simulations
3. Change bunch compressors to reduce MBI
4. Detailed MBI behavior is complicated!

SES:

1. Even at optimal LH setting, MBI dominates SES
2. Need more effective way of suppressing MBI!

Peak current (kA)	0.5	1	1.6
SES (MeV)	0.9	1.2	1.6

Thank you!