26TH INTERNATIONAL
FREE ELECTRON LASER CONFERENCE
& 11TH FEL USERS WORKSHOP
FEL 2004
AUGUST 29 - SEPTEMBER 3
Trieste, Italy

LCLS

Suppression of Microbunching Instability in the LCLS

Z. Huang, M. Borland*, P. Emma, J. Wu, C. Limborg, G. Stupakov, J. Welch

SLAC, *ANL

Introduction

- FEL instability in the undulator requires a very bright electron beam (small emittance and small energy spread)

- This beam interacting with self-fields in the accelerator can be sensitive to other “undesirable” instabilities

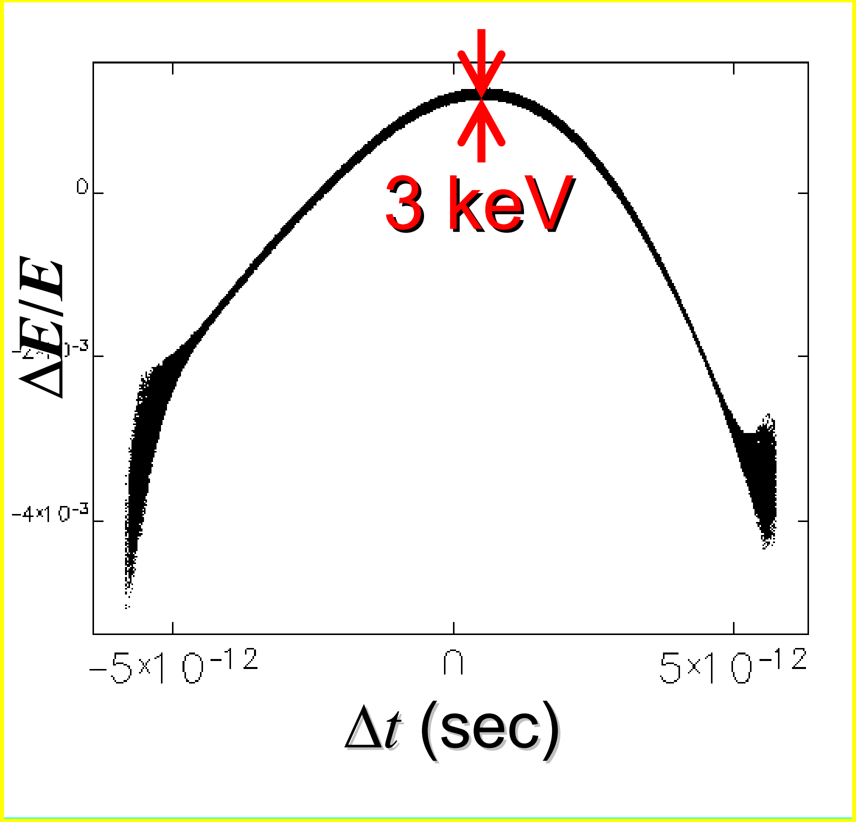
- Bunch compressors designed to increase the peak current give rise to a microbunching instability that may degrade the beam quality significantly

- In LCLS, we control the local energy spread to damp the microbunching instability without degrading the x-ray laser performance

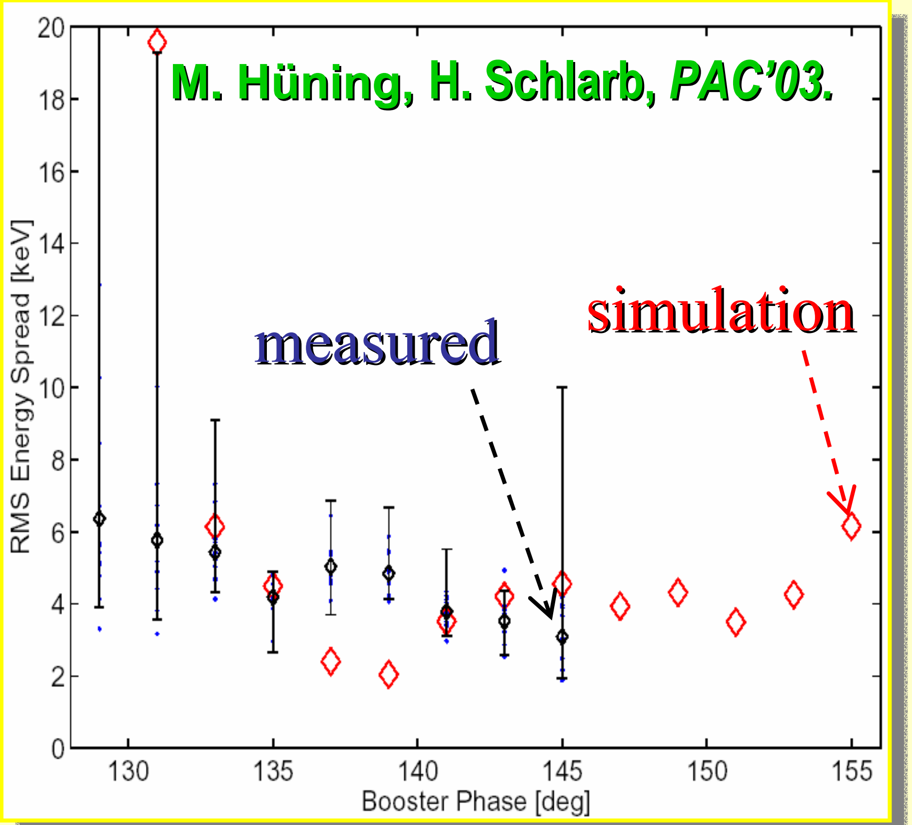
How cold is the photoinjector beam?

How cold is the photoinjector beam?

Parmela at 1 nC



TTF measurement at 4 nC



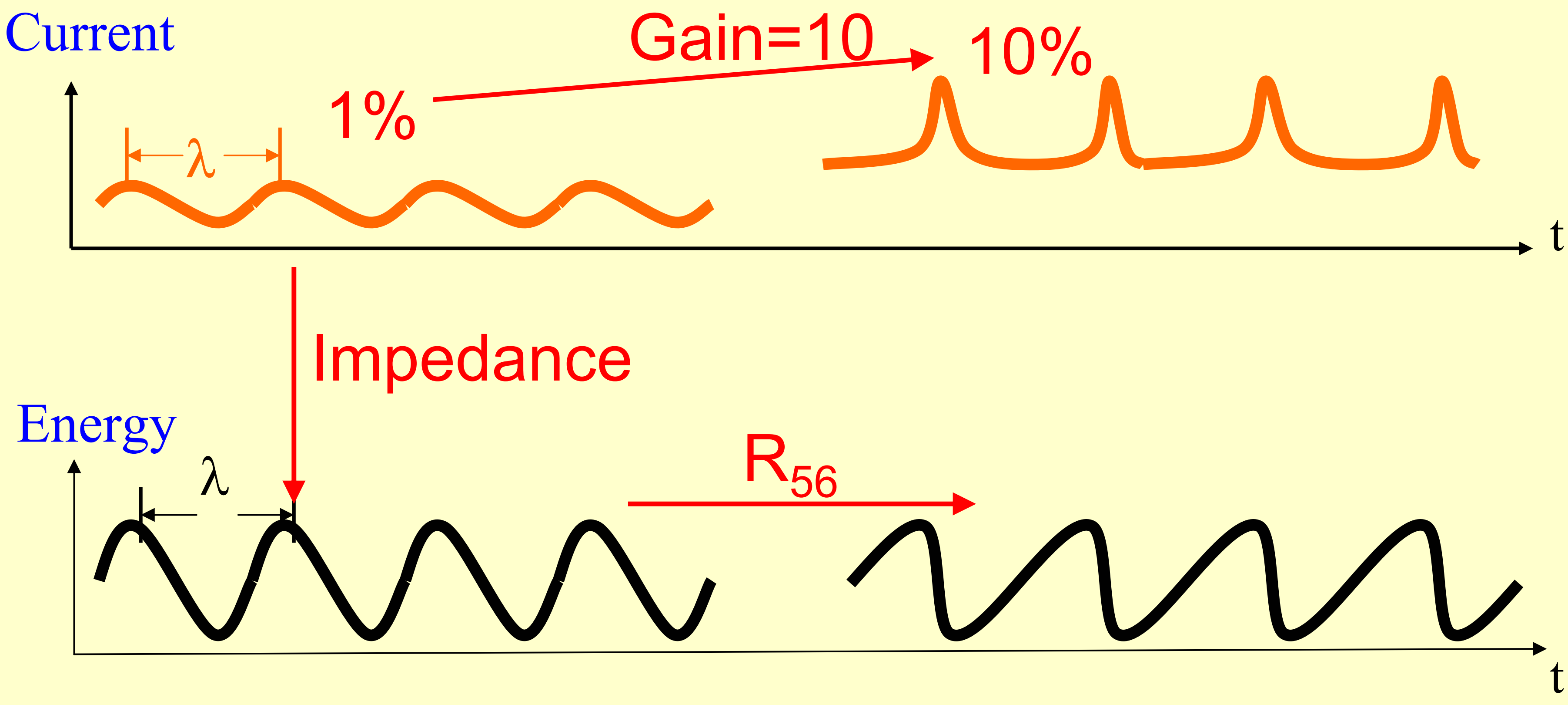
3 keV, accelerated to 14 GeV, & compressed ×32

$\Rightarrow$ 1×10^{-5} relative energy spread

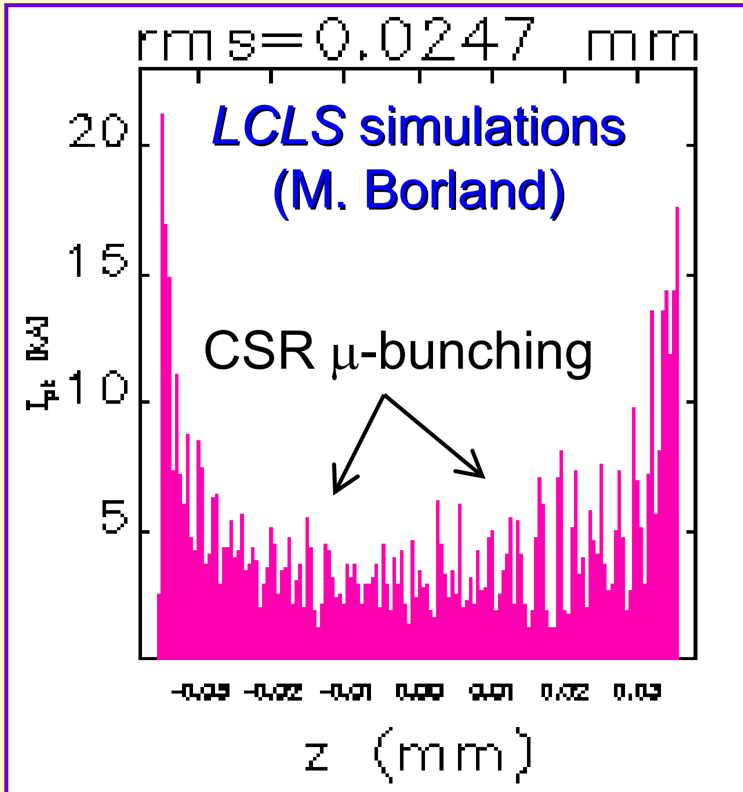
Too small to be useful in FEL (no effect on FEL gain when $<10^{-4}$)

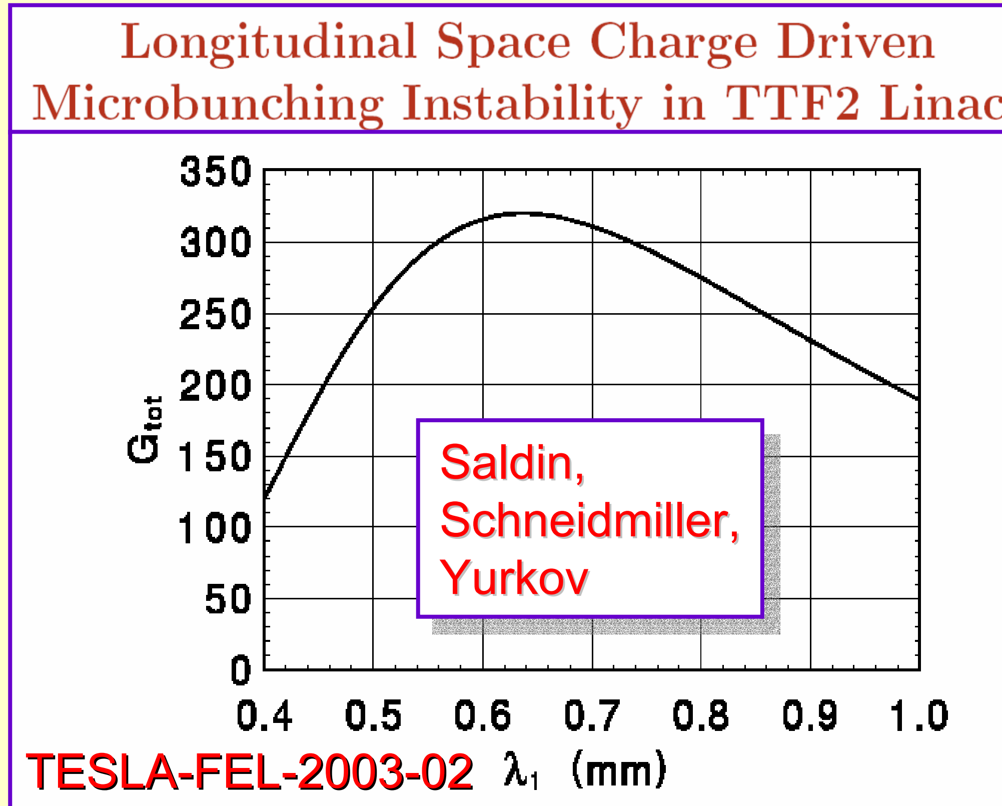
Microbunching instability

• Initial density modulation induces energy modulation through longitudinal impedance Z(k), converted to more density modulation by a compressor

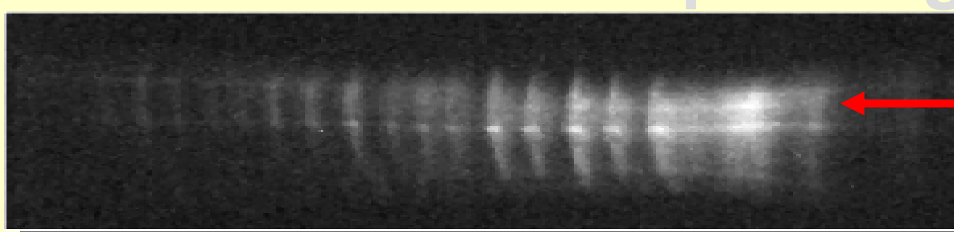


➔ growth of slice energy spread and emittance!





BNL SDL RF zero-phasing observation

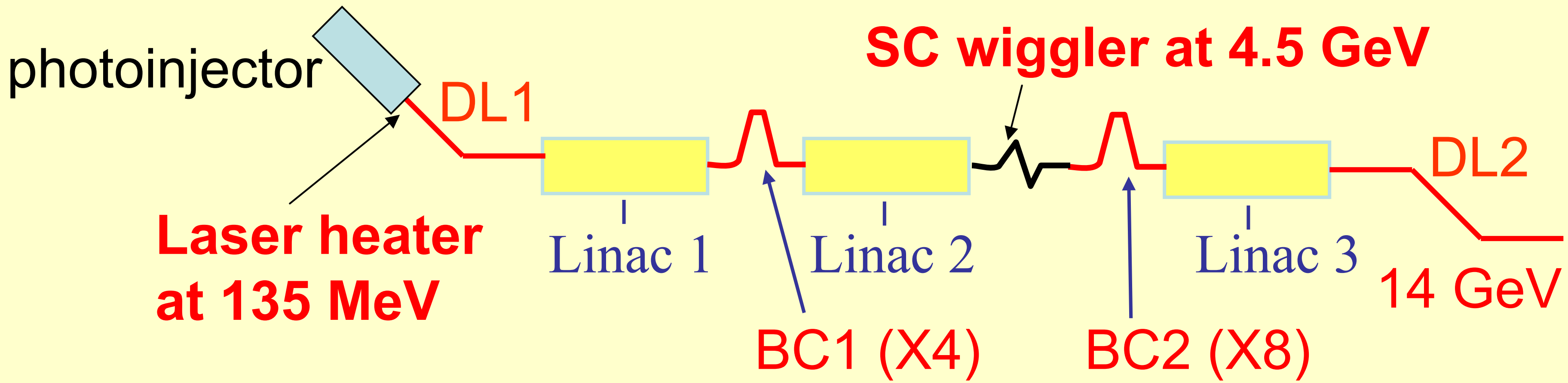


Large energy modulation induced by space charge

energy ~ time

T. Shaftan et al., *PAC'03*, PRST-AB 7, 080702 (2004)

LCLS accelerator systems

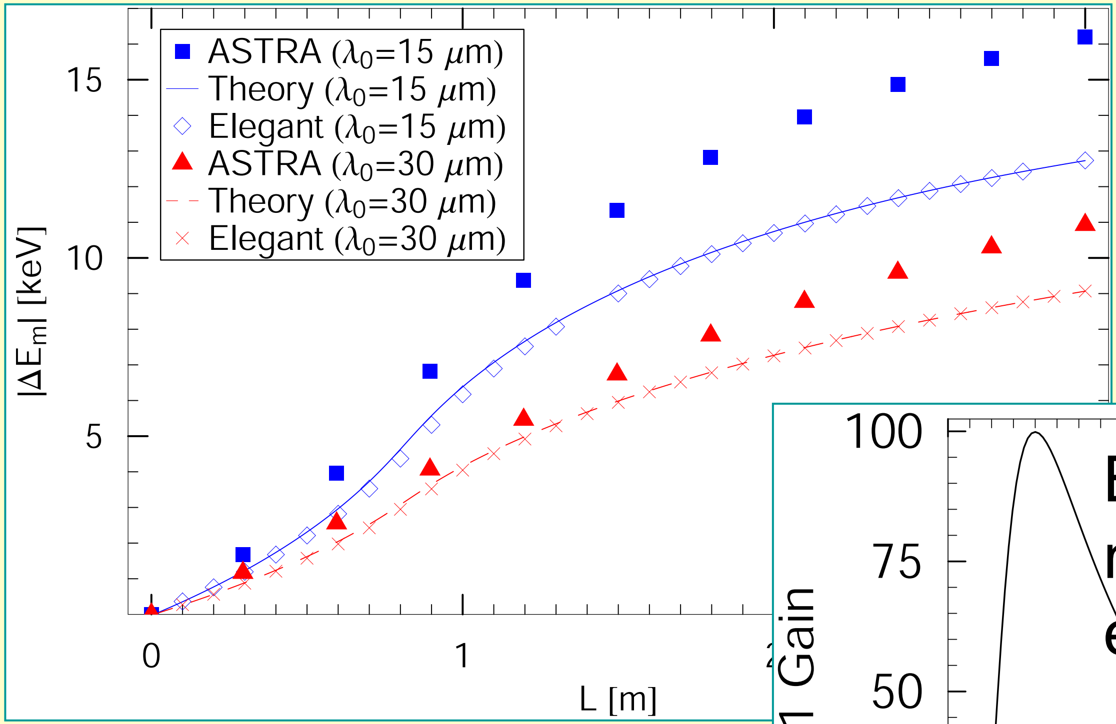


- Two bunch compressors to control jitters and linac wakefield
- Impedance sources: longitudinal space charge (LSC), coherent synchrotron radiation (CSR) and linac wakefields
- Landau damping by increasing energy spread (~10 times) with a SC wiggler before BC2 to suppress CSR microbunching or a laser heater for LSC instability (suggested by Saldin et al.)

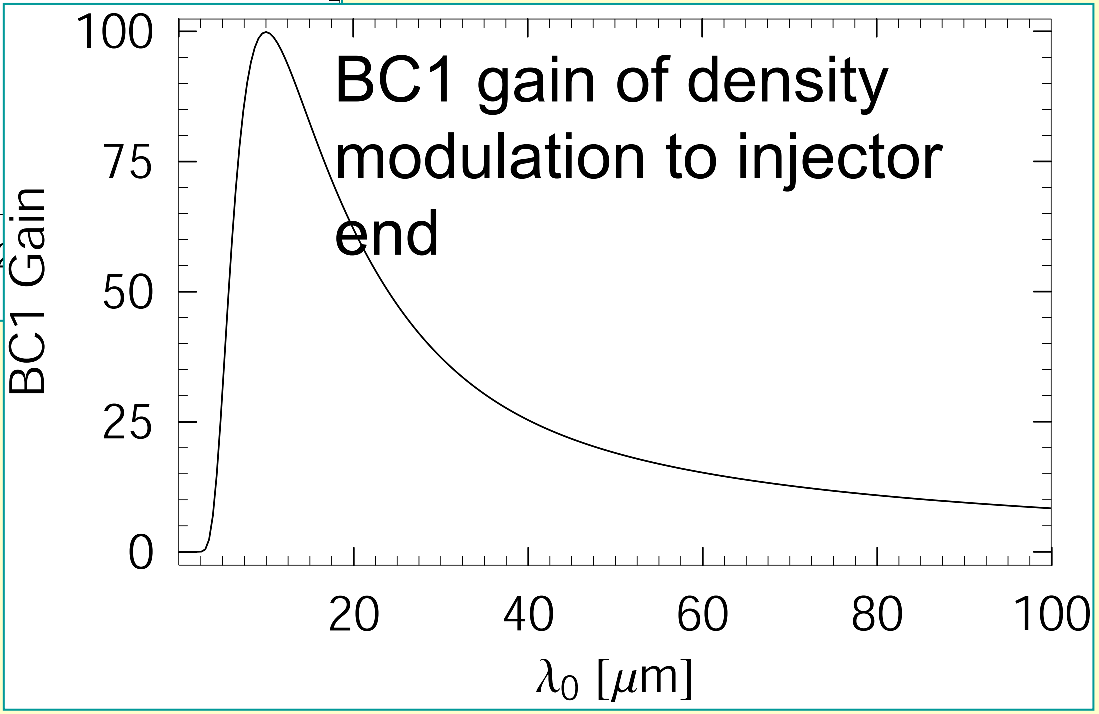
LSC in LCLS

LSC in LCLS

- LSC impedance modeled by ELEGANT after injector, reasonable agreement with ASTRA



E-modulation (λ_0=15 μm and λ_0=30 μm) for 5% density modulation in a 3-m drift at 120 MeV

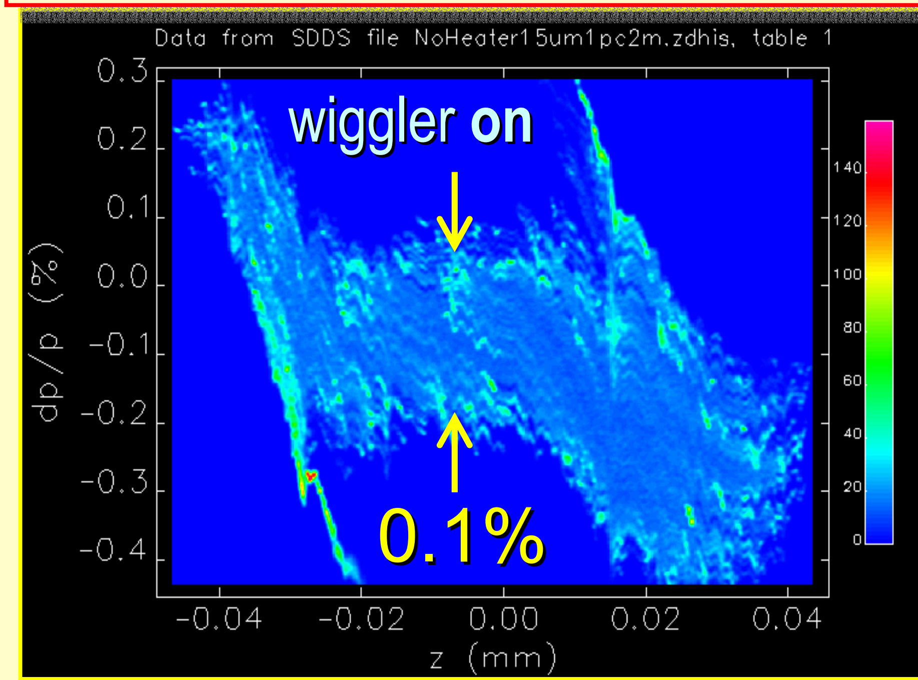


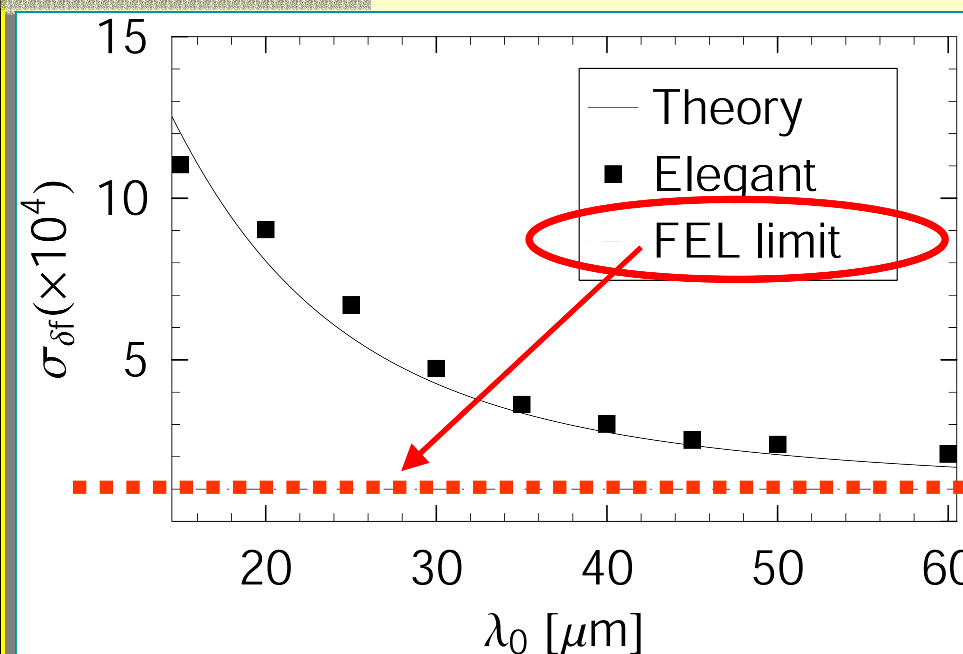
- **If no Landau damping at BC1, accumulated E-modulation turns into large density modulation**

Growth of slice energy spread

• High BC1 gain ➔ significant energy modulation in Linac-2 ➔ temporally smearing in BC2 to become effective slice energy spread (➔ SC wiggler too late)

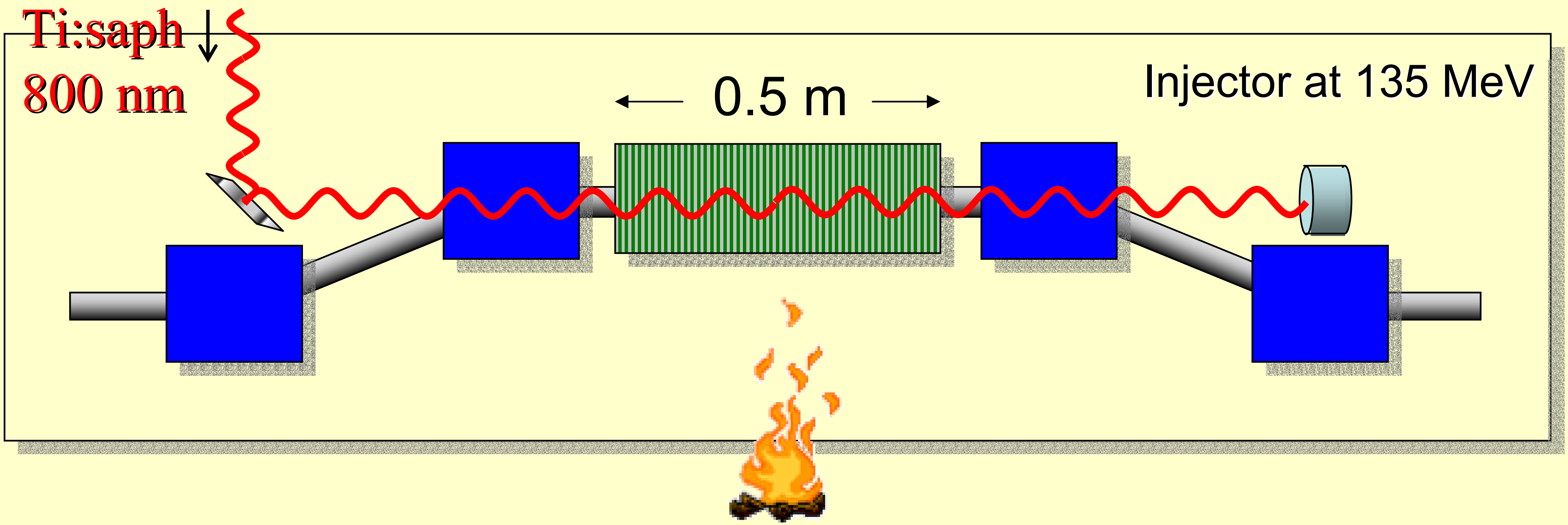
Final long. phase space at 14 GeV for MeV





Need **~0.1%** initial density modulation at injector end or suppress BC1 gain effectively

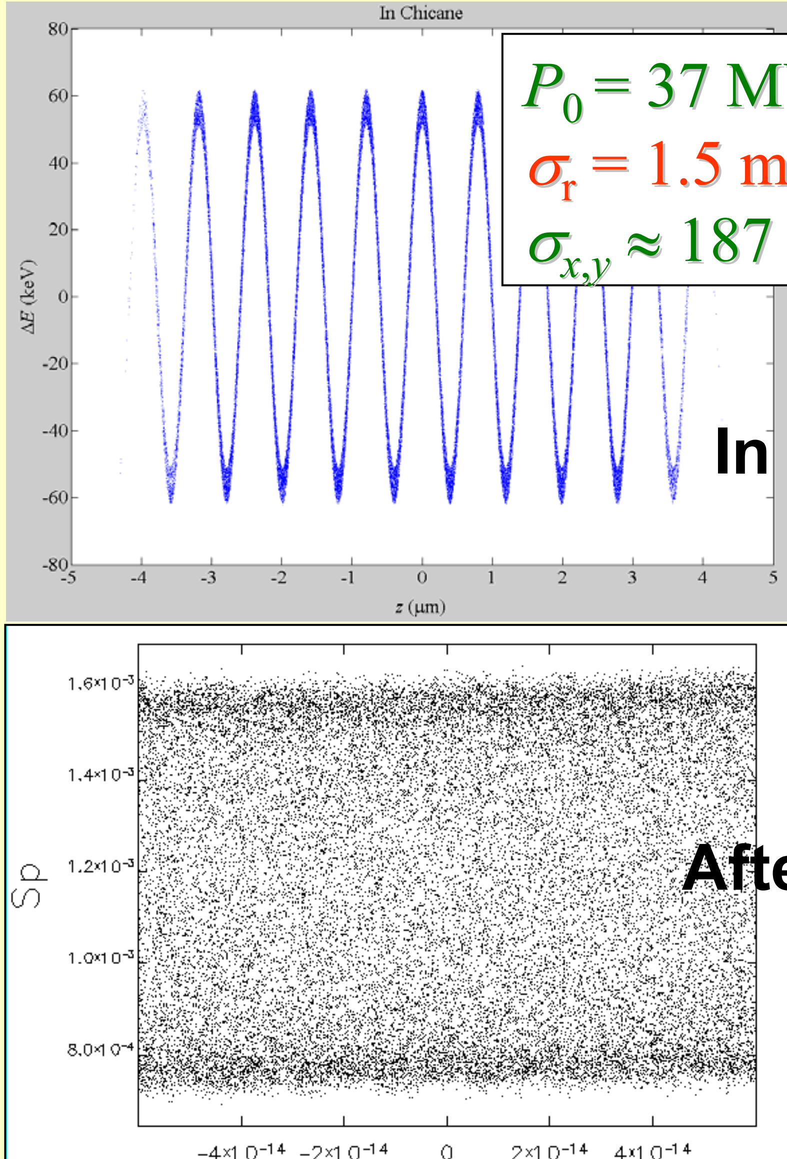
LCLS Laser Heater



• Laser-electron interaction in an undulator induces rapid energy modulation (at 800 nm), to be used as effective energy spread before BC1 (3 keV➔ 40 keV rms)

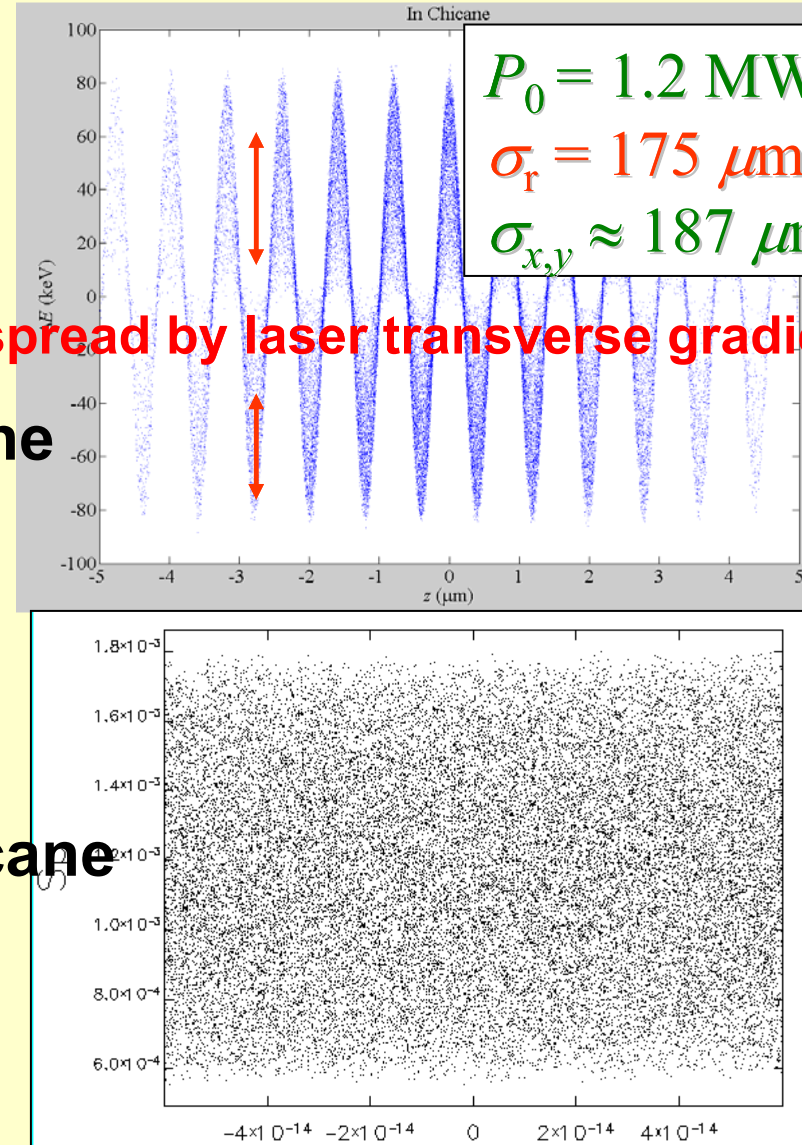
•Inside a weak chicane for easy laser access, time-coordinate smearing (Emittance growth is negligible)

Large laser spot size



Non-uniform heating

Matched laser spot size



more uniform heating

In Chicane

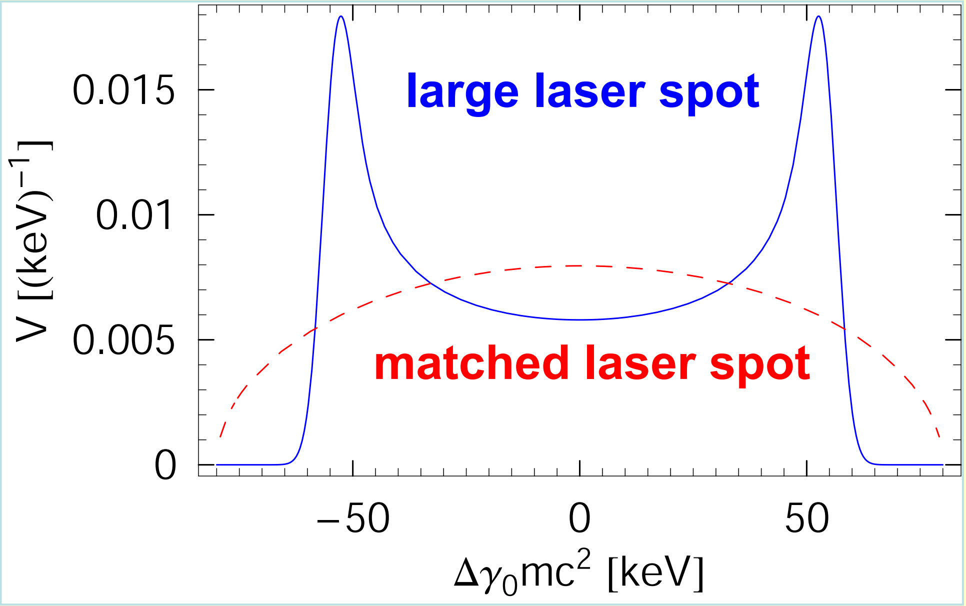
After Chicane

Gain suppression depends on laser spot size

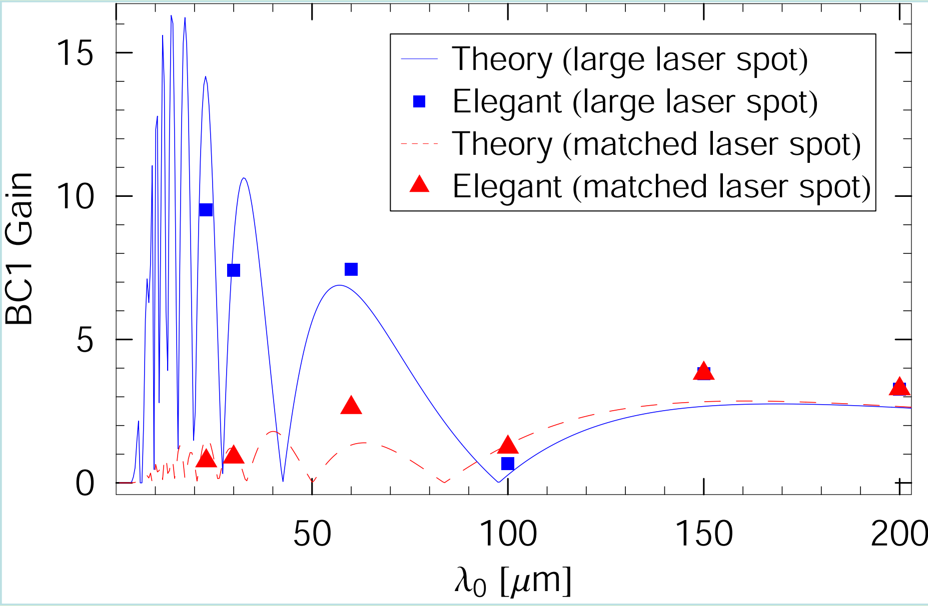
- Large laser spot generates "double-horn" energy distribution, ineffective at suppressing short wavelength microbunching

- Laser spot matched to e-beam size generates Gaussian-like energy distribution for effective Landau damping

energy distribution (rms 40 keV)



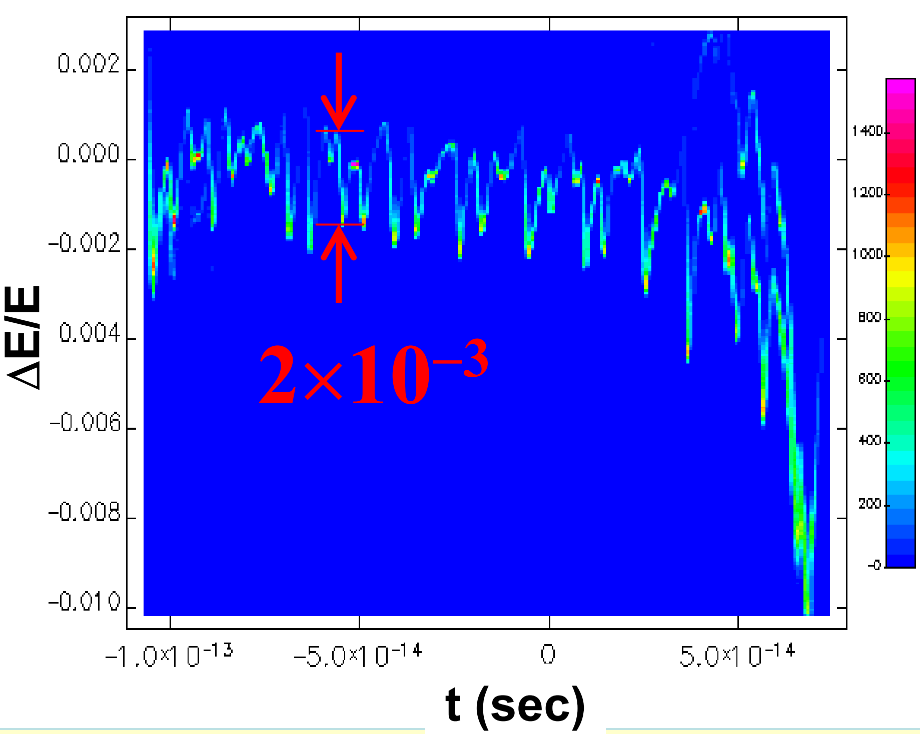
BC 1 gain with heater



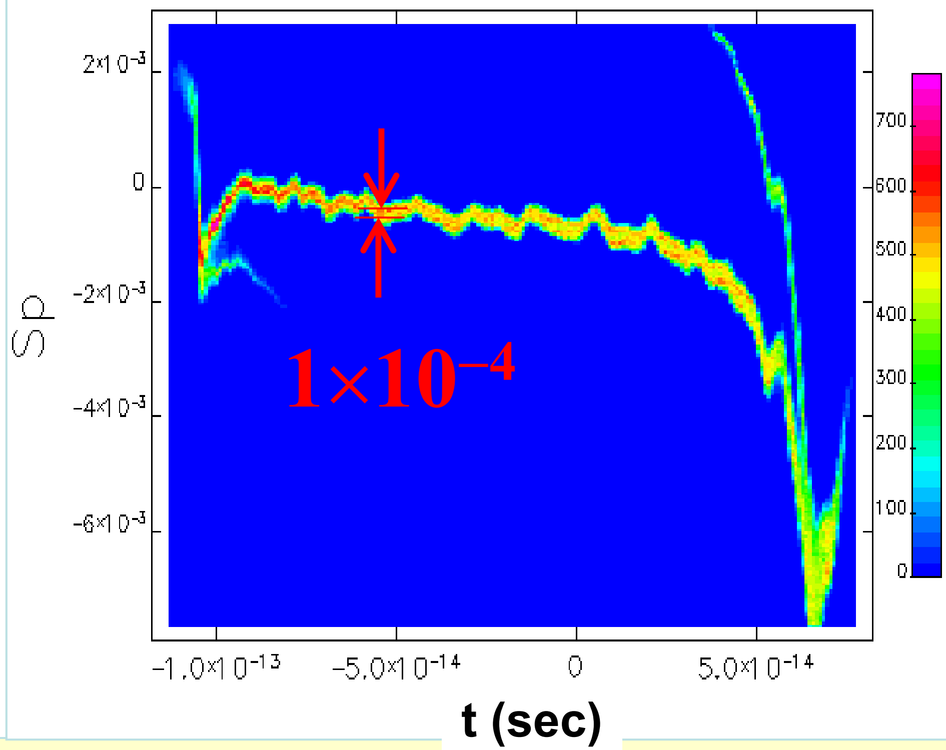
S2E Microbunching simulation

- Injector space charge dynamics is modeled by ASTRA, Linac by ELEGANT with LSC/CSR/machine impedances

Example: final long. phase space at 14 GeV for initial 8% uv laser intensity modulation at λ=150 μm



No Laser-Heater



Matched Laser-Heater

Summary

- Microbunching instability driven by LSC, CSR and machine impedance is a serious concern for x-ray FEL

- Photoinjector beam is too “cold” in energy spread, “heating” within FEL tolerance (~10X) to control the instability

- A laser heater with a laser spot matched to the transverse e-beam size is most effective in suppressing microbunching and is designed for LCLS

- It gives flexible control of slice energy spread to manipulate FEL radiation