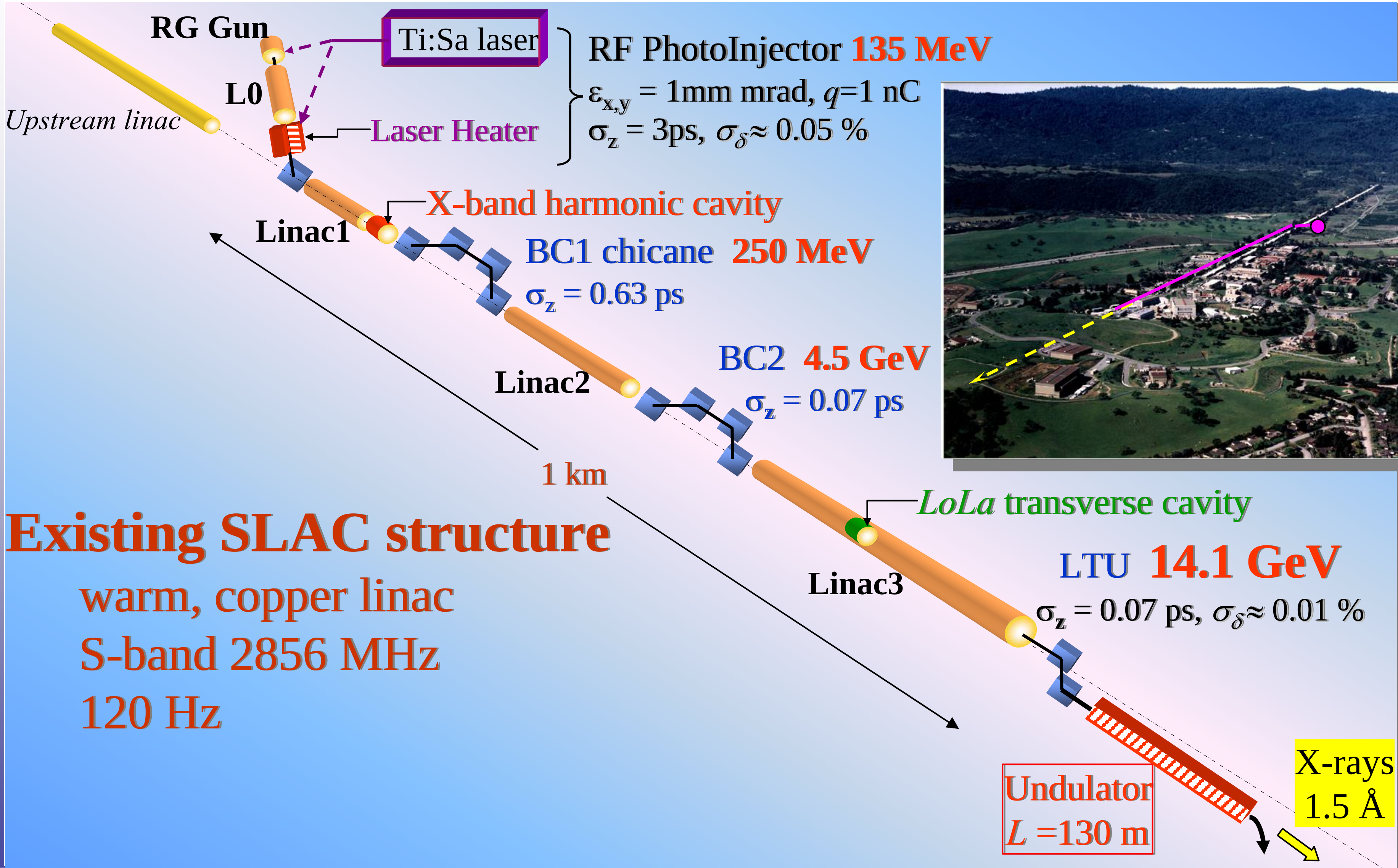
LCLS - Accelerator System Overview

Patrick Krejcik

on behalf of the LCLS Team

Stanford Linear Accelerator Center



Existing SLAC structure

warm, copper linac
S-band 2856 MHz
120 Hz

Accelerator Issues in the SLAC Design

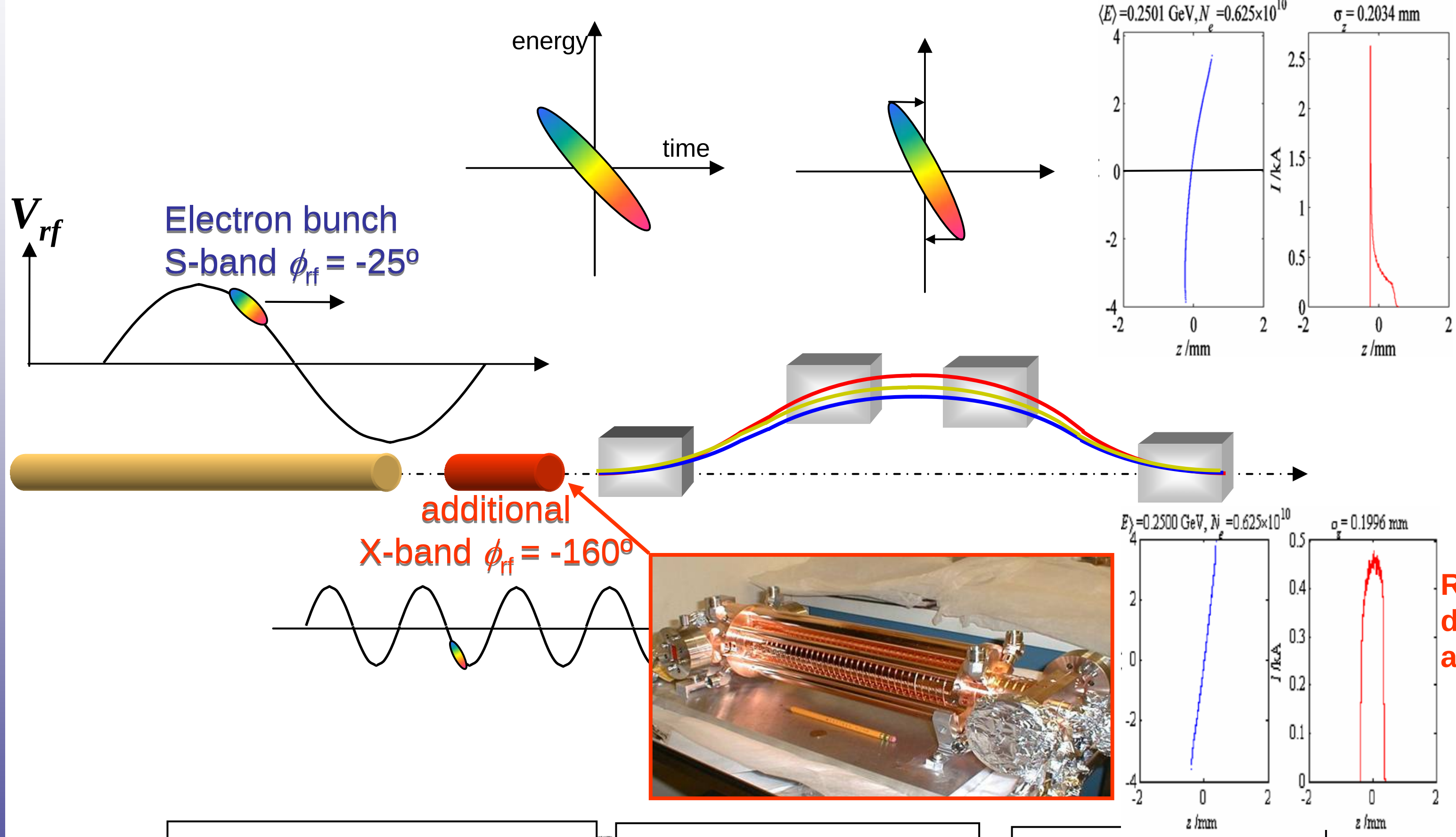
Issues

- Low emittance injector
  - Cold beam, low $\sigma_\delta \approx 0.05$ %
- Bunch compression
  - Coherent Synchrotron Radiation
  - Longitudinal space charge
- Beam stability

Design solutions

- RF photoinjector
- Laser heater
- Two magnetic chicanes
- RF linearization with higher harmonic X-band cavity
- Diagnostics
- Fast feedback

Bunch Compression Dynamics



Longitudinal tracking with *litrack* – P. Emma

Remove spike in distribution with addition of X-band

Electron bunch with higher energy tail

…tail begins to catch up

…fully compressed

Diagnostic challenges

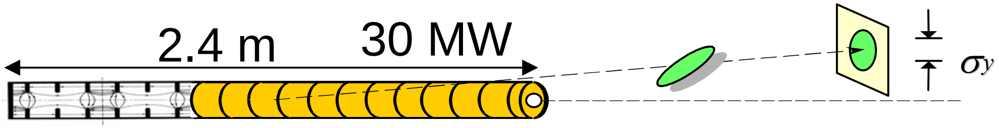
Measurement

- Measurement of ultra-short bunch profiles
- Shot-by-shot measurement of bunch length
- Bunch timing measurement

Devices

- RF transverse deflecting cavity "LOLA"
- Terahertz coherent spectral power measurement
- Coherent radiation autocorrelation
- Electro-optic bunch profiling

Bunch Length Measurements with the RF Transverse Deflecting Cavity



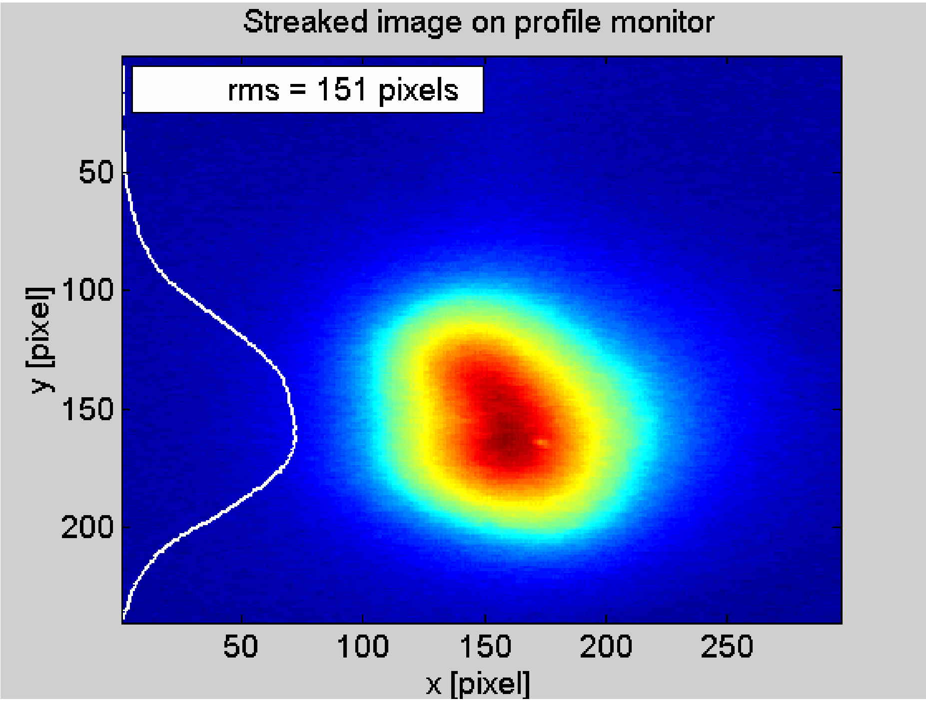
Bunch length reconstruction
Measure streak at 3 different phases

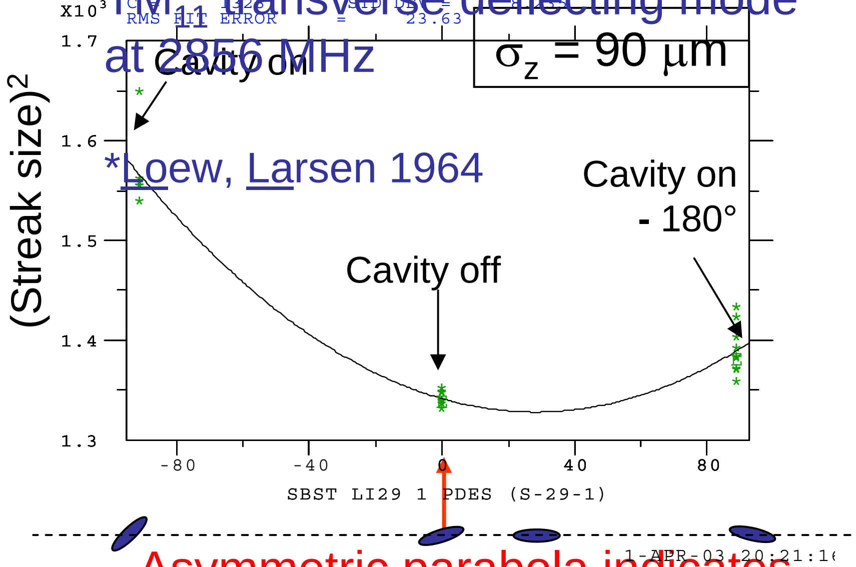
LoLa*

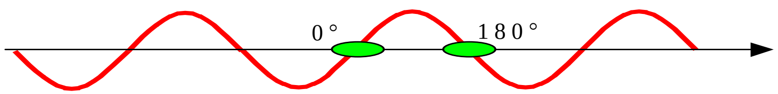
$$\sigma_y^2 = A\phi_{rf}^2 + B, \quad \sigma_z = \frac{\lambda_{rf}\sqrt{A}}{4C}$$

An S-band DLW structure with a TM_{11} transverse deflecting mode at 2856 MHz

*Loew, Larsen 1964







Asymmetric parabola indicates incoming tilt to beam

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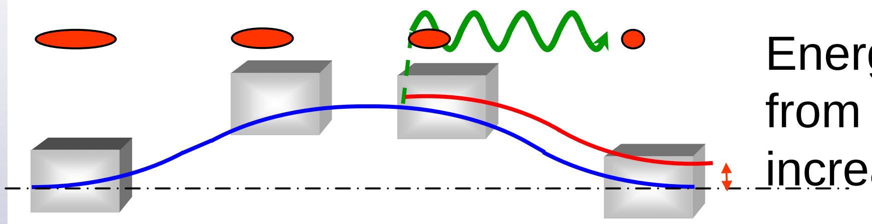
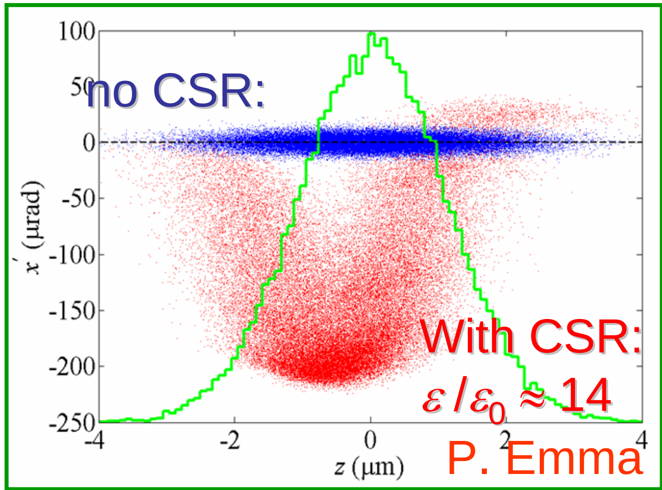
Limitation from Coherent Synchrotron Radiation

$\lambda_r > \sigma_z$ radiation coherent

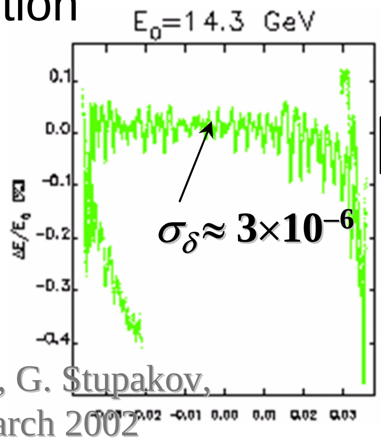


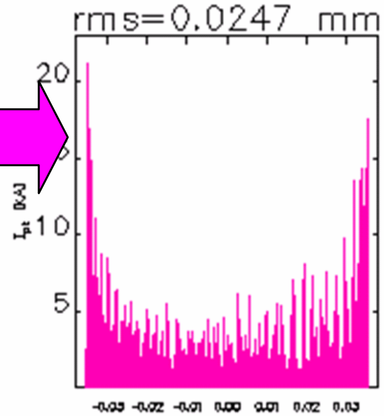
Energy spread from CSR increases ε_x

Limits compression hypothetical 1 μm bunch



CSR instability amplifies noise in initial charge distribution





S. Heifets, S. Krinsky, G. Stupakov, SLAC-PUB-9165, March 2002

Microbunching*

and further emittance growth

* First observed by M. Borland (ANL) in LCLS *Elegant* tracking

Two-stage bunch compression approach – P. Emma

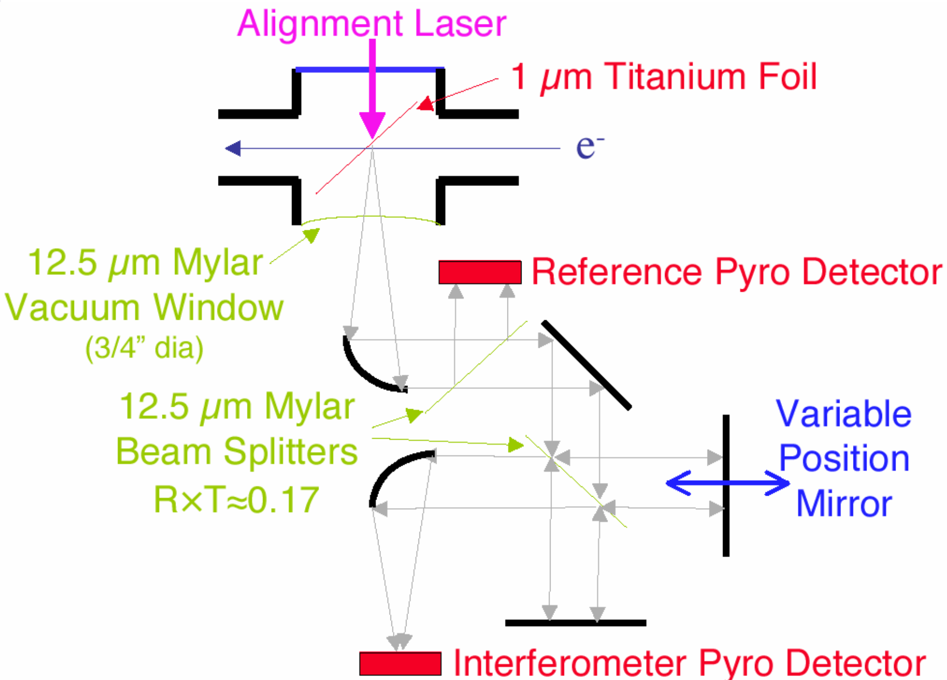
Issues

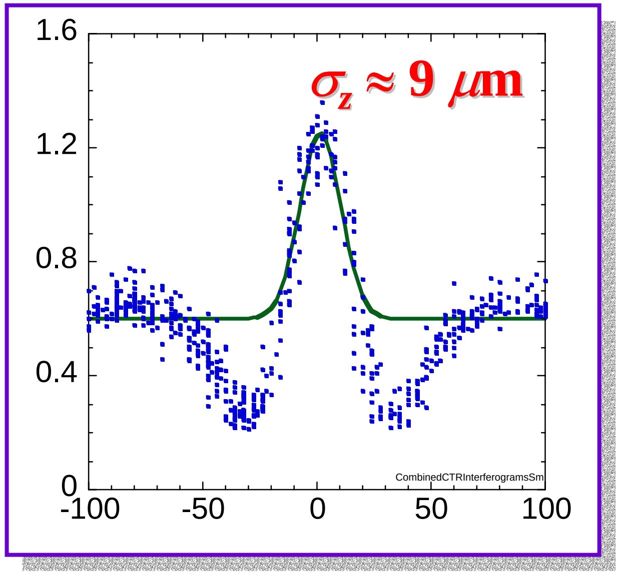
- At low energies if bunch is compressed too much space charge spoils emittance
- At high energies if bunch is compressed too hard synchrotron radiation adds large energy spread

Design solutions

- Compress in two stages
- Limit low energy compression so space charge not a limit
- Second compression to final bunch length at higher energy, but with weaker bends to limit synchrotron radiation.

Diagnosing Coherent Radiation
1. autocorrelation





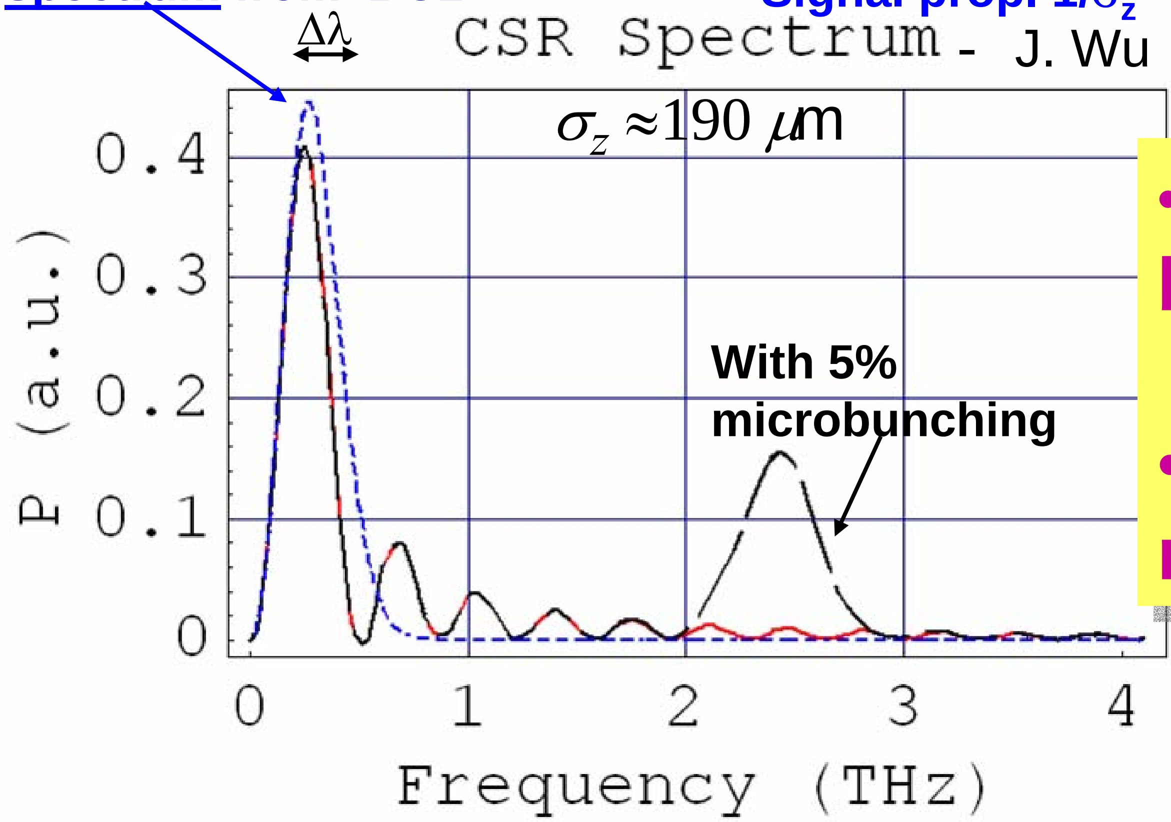
Transition radiation is coherent at wavelengths longer than the bunch length, $\lambda > (2\pi)^{1/2}\,\sigma_z$

Limited by long wavelength cutoff and absorption resonances

SLAC **SPPS** measurement:
P. Muggli, M. Hogan

Diagnosing Coherent Radiation
2. spectral power

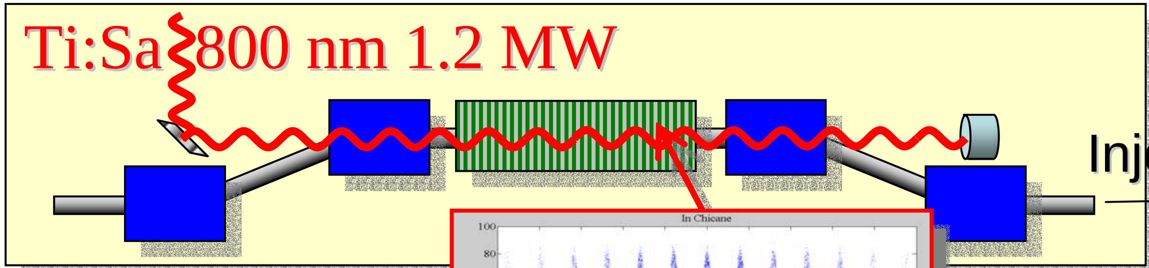
Smooth Gaussian bunch spectrum from BC1 → **Fixed BW detector Signal prop. 1/σ_z** → **Bunch length signal for RF feedback**



- **Measure bunch length**
- **Detect microbunching**

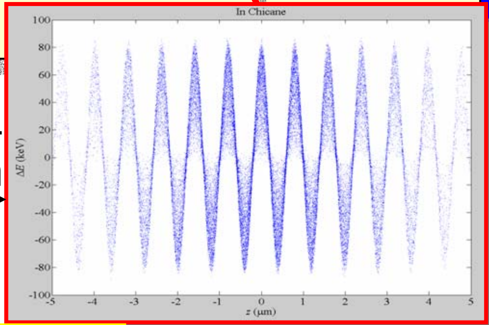
'Laser Heater' for Landau Damping

'Laser heater' suggested by Saldin et al.

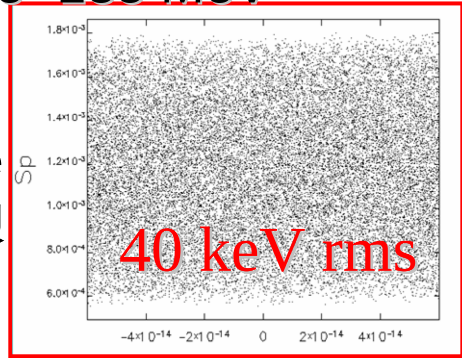


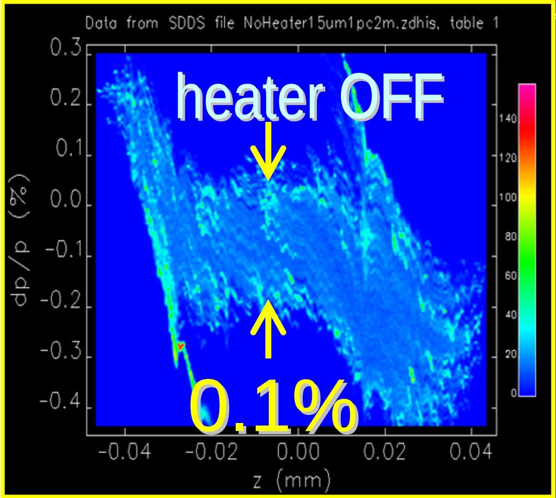
Injector e- 135 MeV

IFEL
energy modulation



chicane
energy mixing

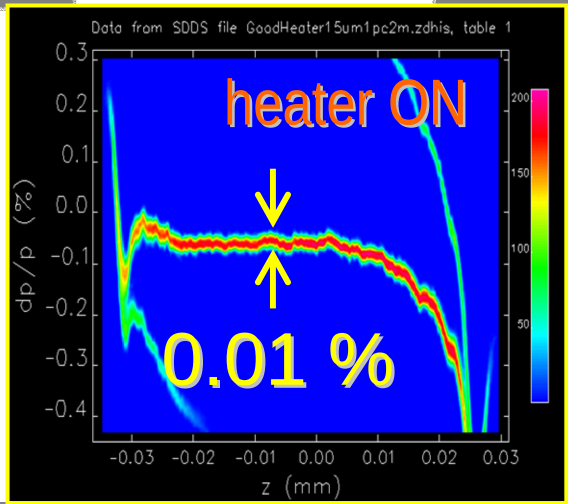




Final energy distribution:

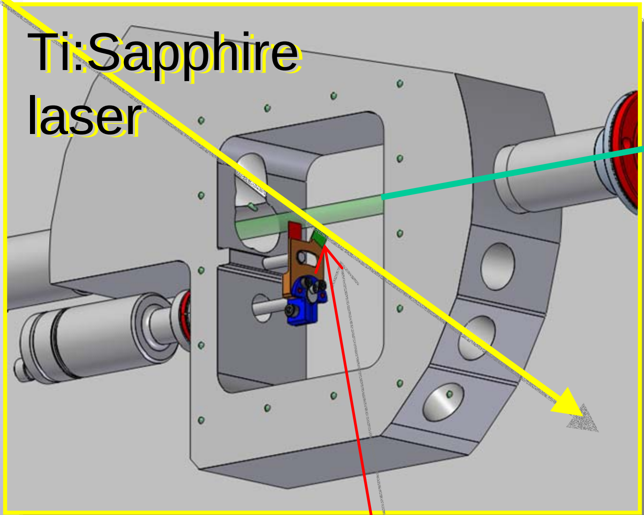
Microbunch instability

Damped

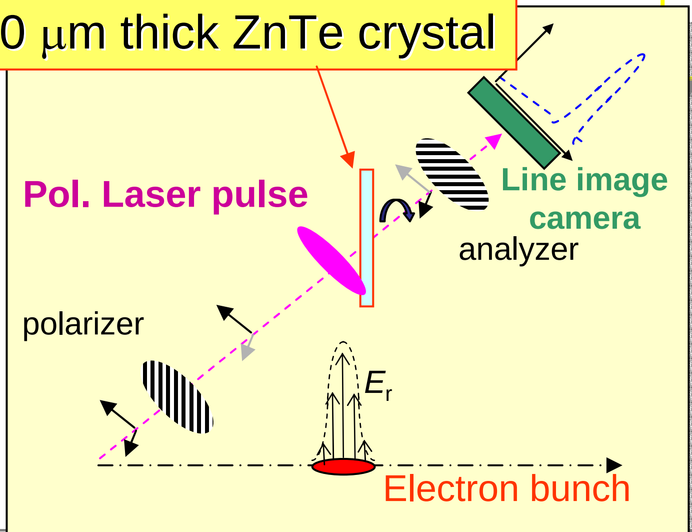


Z. Huang et al.
PR ST AB, June 2004

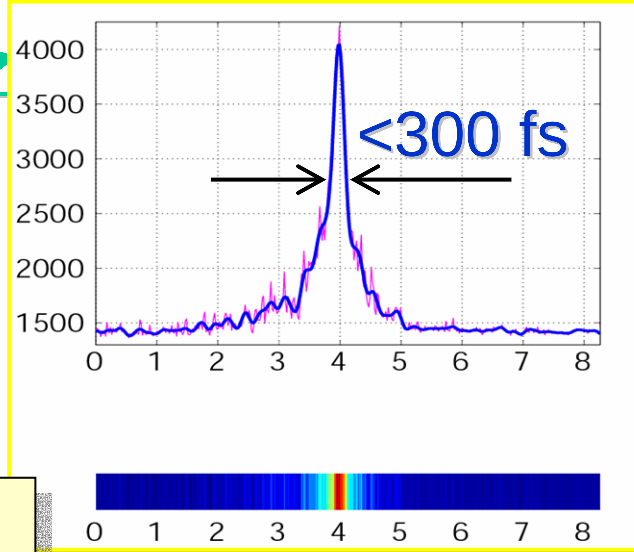
Electro-Optical Sampling at SPPS – A. Cavalieri et al.

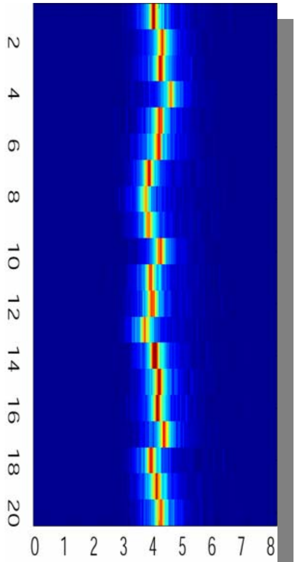


200 μm thick ZnTe crystal

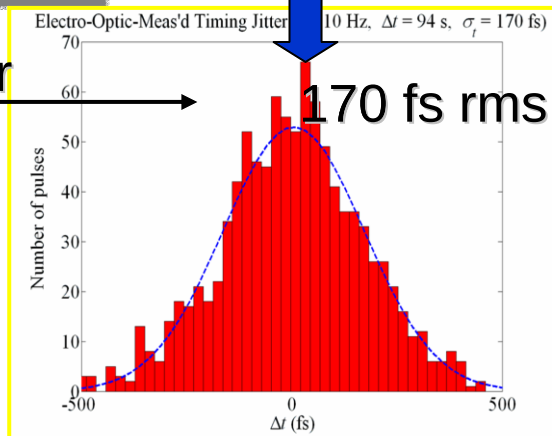


Single-Shot





Timing Jitter



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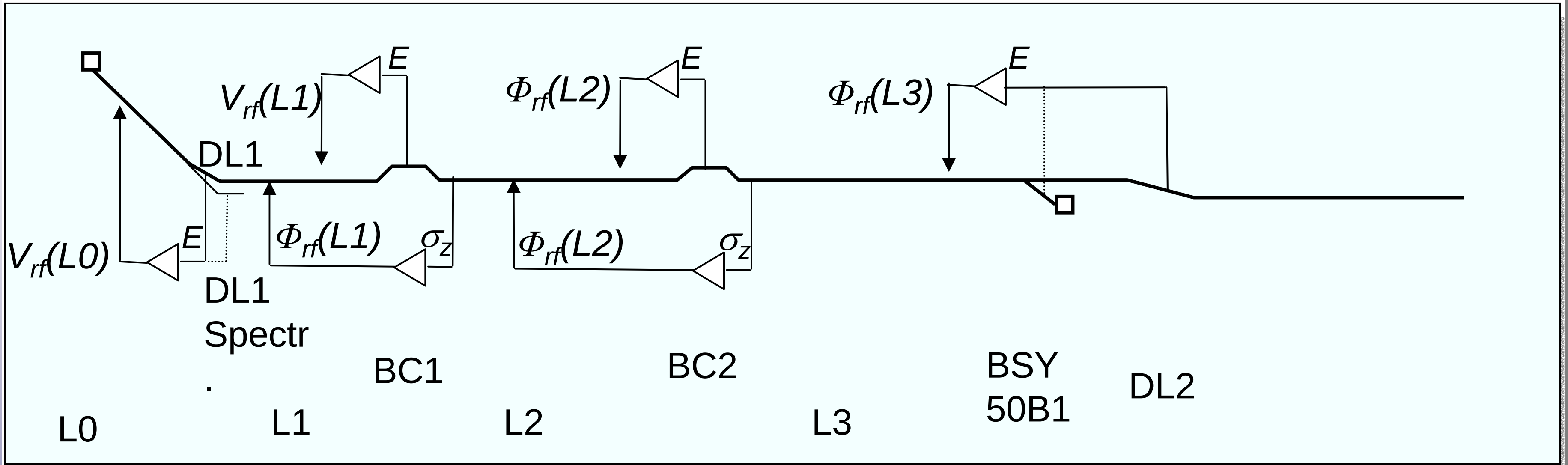
Energy and Bunch Length Feedback Loops



- *4 energy feedback loops*
- *2 bunch length feedback loops*
- *120 Hz nominal operation, <1 pulse delay*

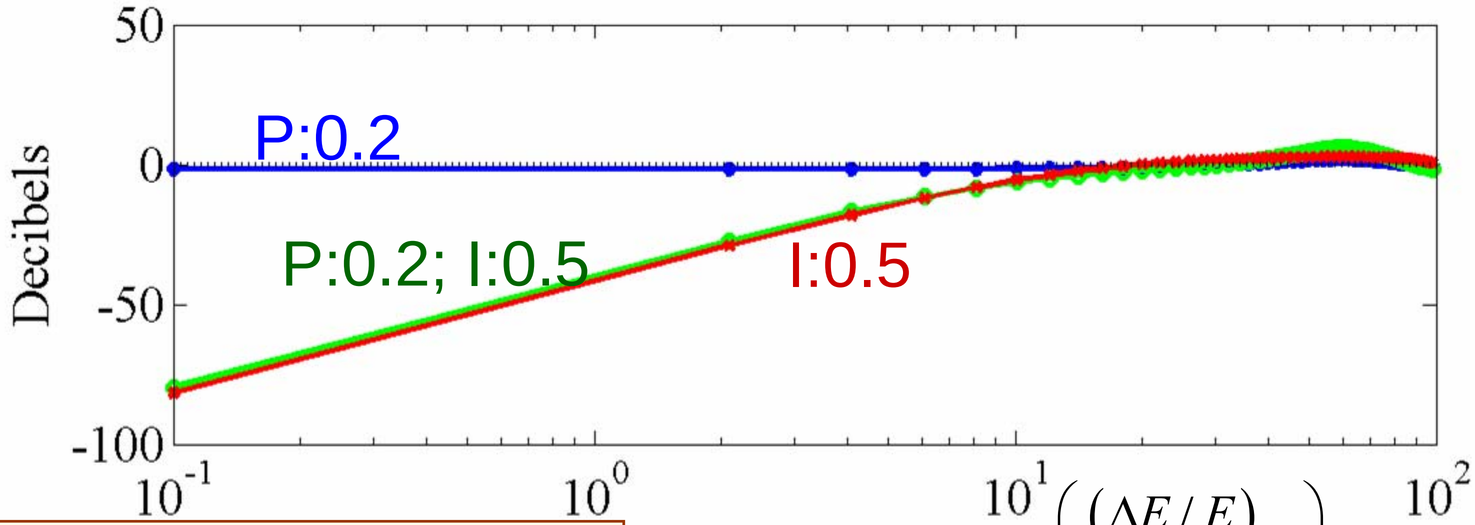
- *Feedback model (J. Wu)*
- *PID controller (proportional, integral, derivative)*
- *Cascade control for sequential loops (off-diagonal matrix elements)*

Energy feedback loop response -

J. Wu
P. Emma

$$20\log_{10}\left(\left|\frac{(\Delta E/E)_{\mathrm{on}}}{(\Delta E/E)_{\mathrm{off}}}\right|\right)$$

Bode Plot (ΔE/E)



$$\arg\left(\frac{(\Delta E/E)_{\mathrm{on}}}{(\Delta E/E)_{\mathrm{off}}}\right) = 0.0$$

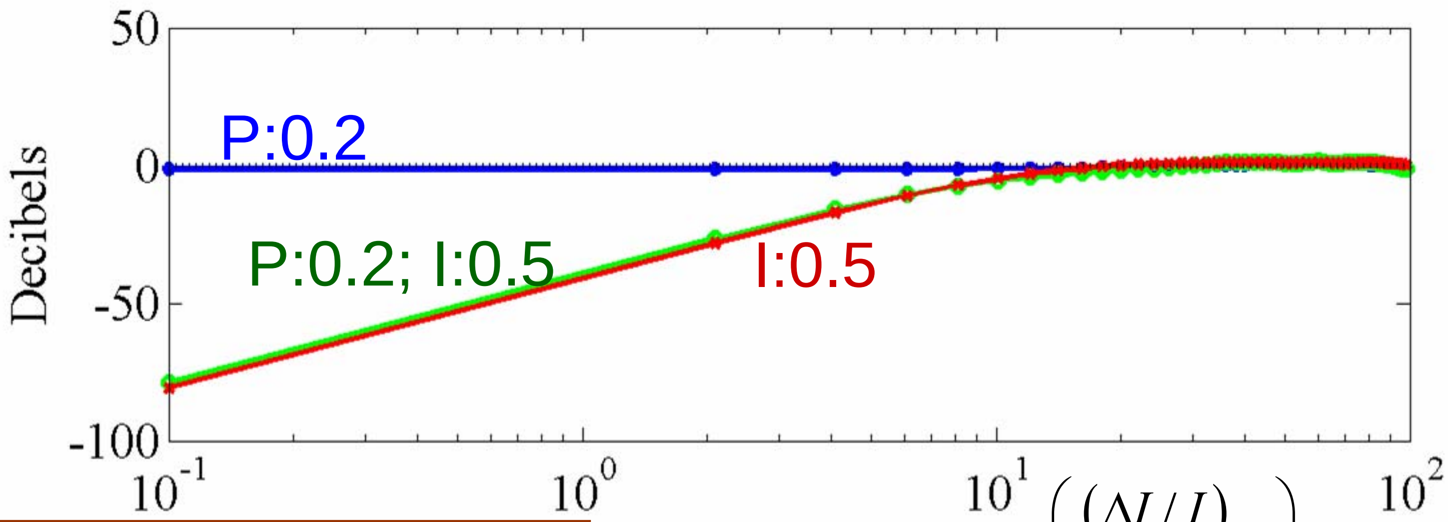
- 3 different settings of the PID controller
- Integral term dominant

Bunch length feedback loop response -

J. Wu
P. Emma

$$20\log_{10}\left(\left|\frac{(\Delta I/I)_{\text{on}}}{(\Delta I/I)_{\text{off}}}\right|\right)$$

Bode Plot (ΔI/I)



$$\arg\left(\frac{(\Delta I/I)_{\text{on}}}{(\Delta I/I)_{\text{off}}}\right) = 0.0$$

- 3 different settings of the PID controller
- Integral term dominant

Summary

- Design optimized for emittance preservation
- Minimize disruption from strong self-fields of the bunch
- Two-stage compression
- Laser heater reduces instabilities
- Diagnostics and feedback integral part of design
- Future expansion to multiple *sase* beamlines
- New possibilities include enhanced *sase* and ultra-short bunches!

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