FEL2002
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& 9TH FEL USERS WORKSHOP
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FEL Research & Development at the SLAC ***S***hort ***P***ulse ***P***hoton ***S***ource, *SPPS*

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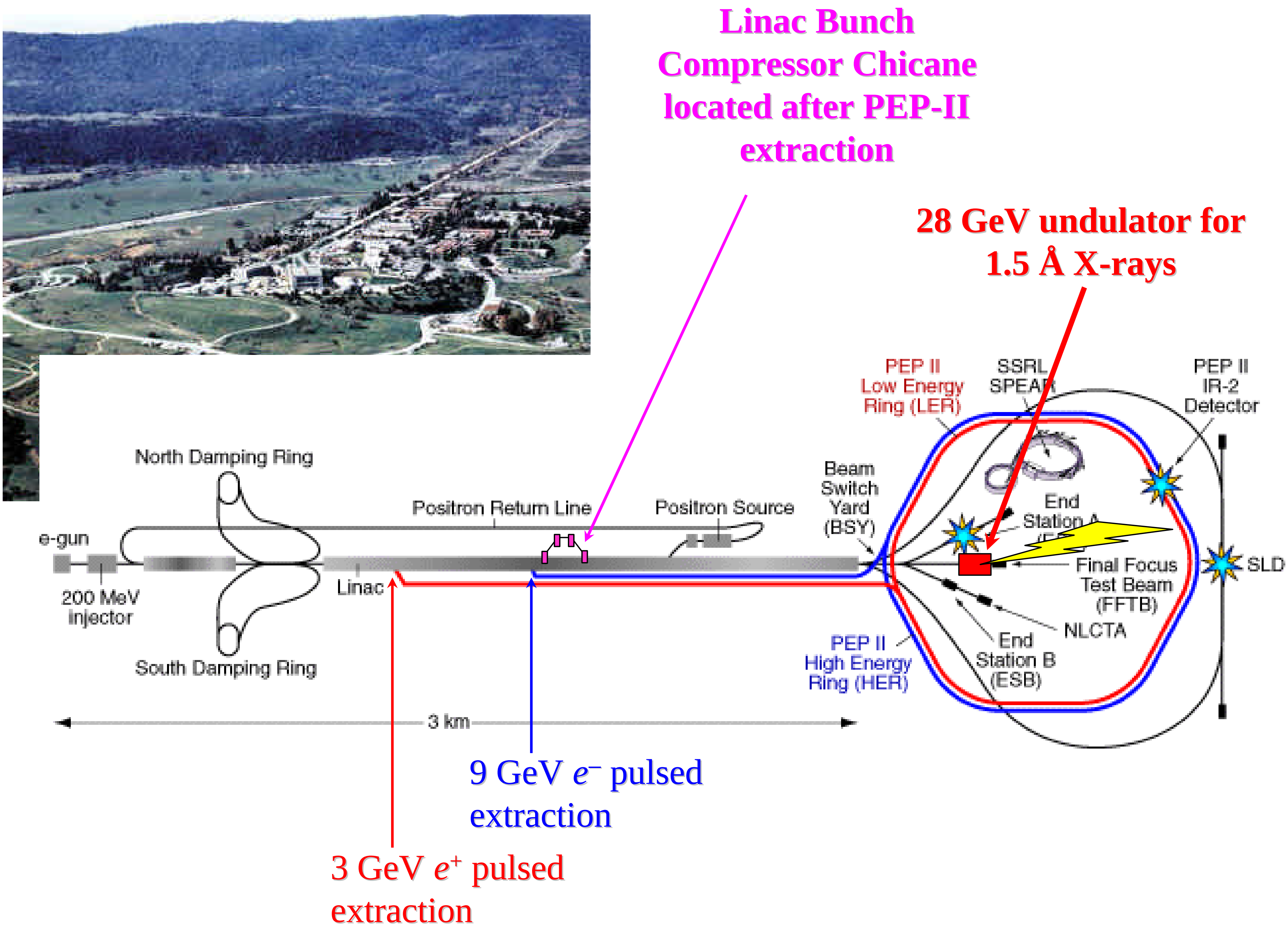


Linac Bunch Compressor Chicane located after PEP-II extraction
28 GeV undulator for 1.5 Å X-rays
PEP II Low Energy Ring (LER)
SSRL SPEAR
PEP II IR-2 Detector
North Damping Ring
Beam Switch Yard (BSY)
Positron Return Line
Positron Source
End Station A
e-gun
SLD
Final Focus Test Beam (FFTB)
200 MeV injector
Linac
NLCTA
End Station B (ESB)
PEP II High Energy Ring (HER)
South Damping Ring
3 km
9 GeV e^- pulsed extraction
3 GeV e^+ pulsed extraction

Introduction to the SPPS

Sub-Picosecond Photon Source

- ***SPPS*** is a short-term project to achieve ultra-short pulses…

- Making use of the existing damping ring and linac bunches
  - not the LCLS RF photoinjector …

- Uses a new linac bunch compressor chicane
  - compression dynamics similar to ***LCLS***

- A short undulator will be installed in a test beam line, FFTB
  - spontaneous X-ray radiation, not SASE

- A test bed for electron beam and photon beam handling at

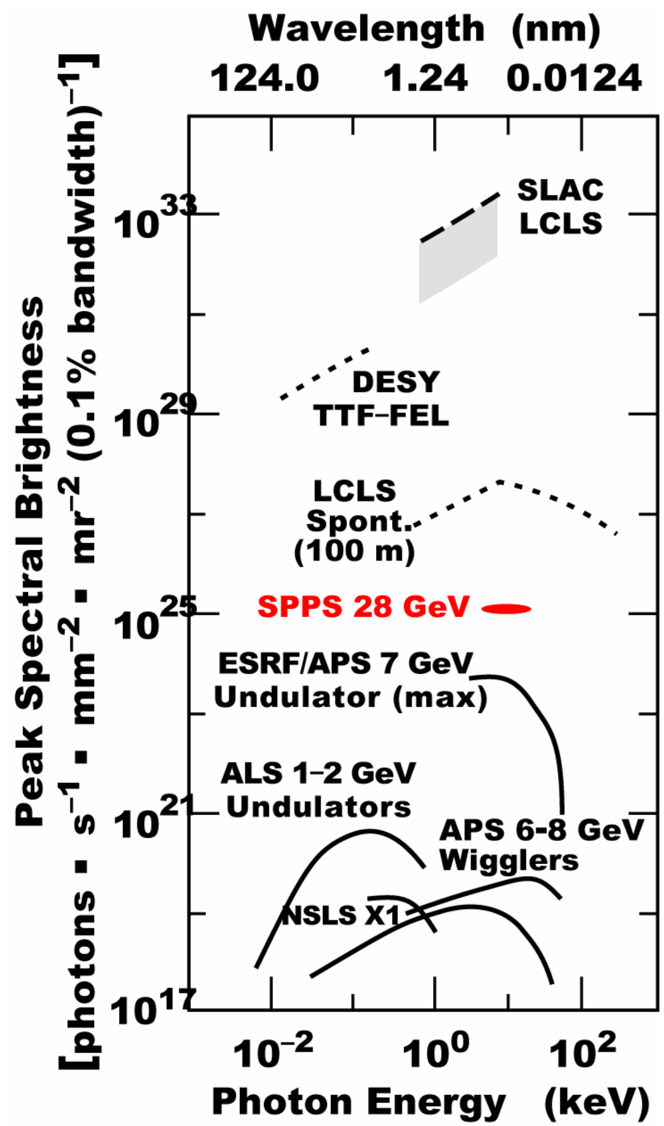
Peak Brightness

4.0×10^{24}

ph/s,mm²,mr²,0.1%bw

Ultra-short pulse

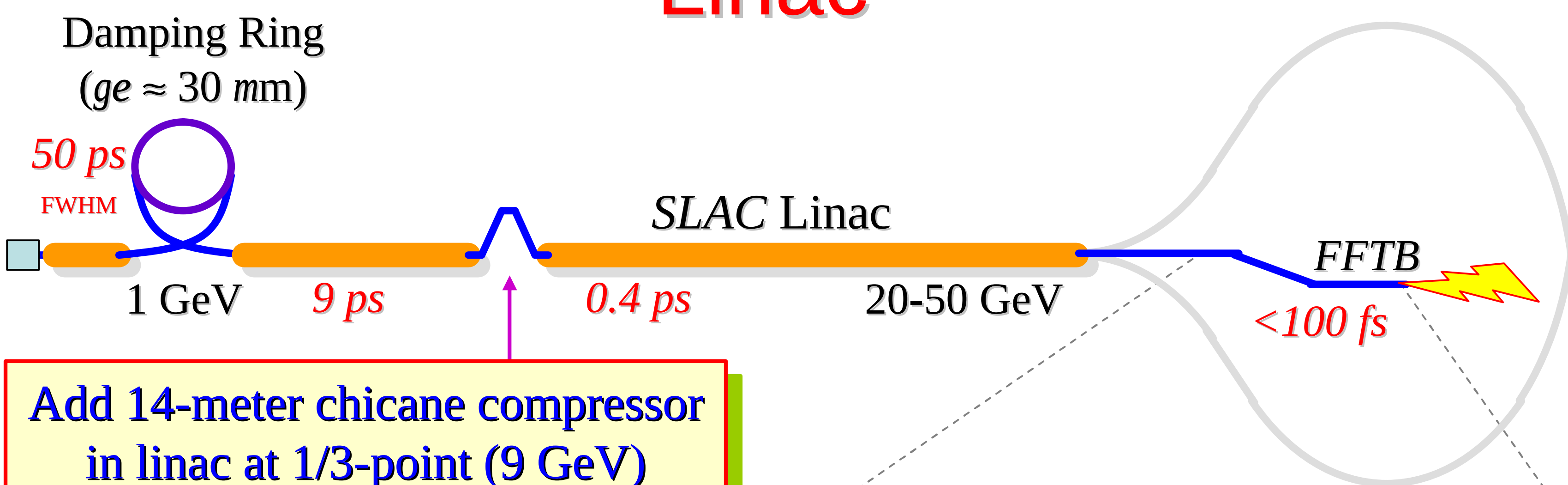
80 femtosec. fwhm



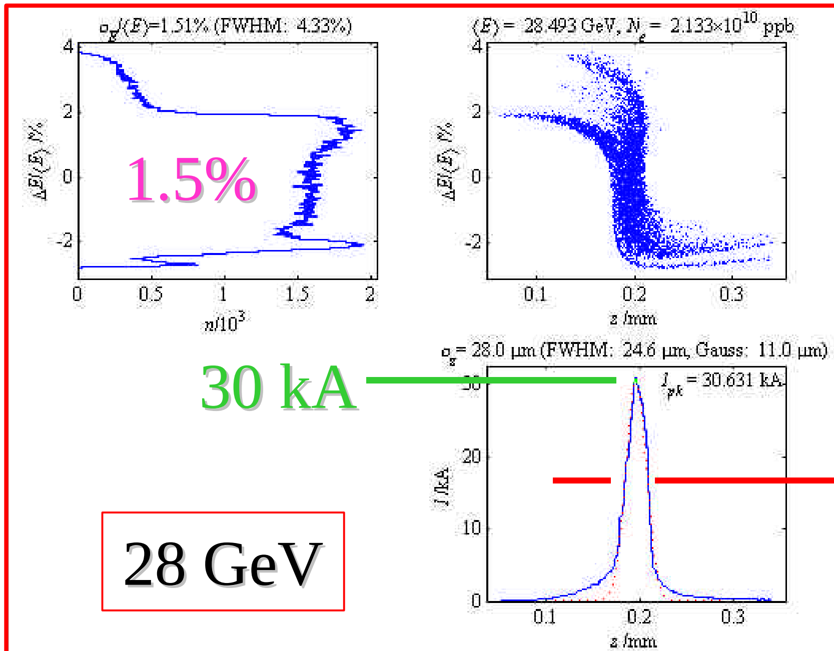
Generating ultra-short pulses…

- Bunch compression in 3 stages
  - Existing Damping Ring To Linac compressor, => 1.2 mm
  - New Linac Bunch Compressor Chicane, 1/3 along the linac
  - Comprises 4x 1.8 m long 1.7 T dipoles
  - Short, 50 μm bunch produces strong wakefields in remaining 2/3 of the high-energy linac
  - Generates a chirp (correlated energy spread) on the electron bunch
  - Final bend in the existing Test Beam line compresses => 12 μm
- 5 m undulator produces 33 femtosecond rms spontaneous radiation
  - 1.5 Å X-rays

Short Bunch Generation in the *SLAC* Linac

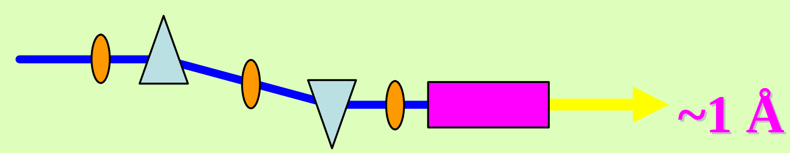


Add 14-meter chicane compressor in linac at 1/3-point (9 GeV)

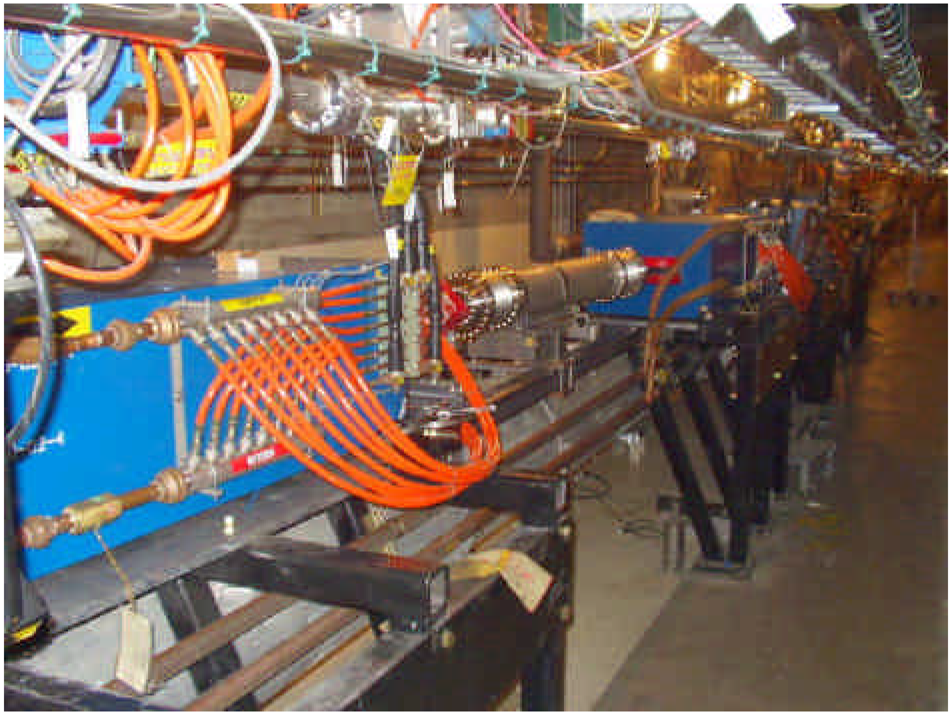


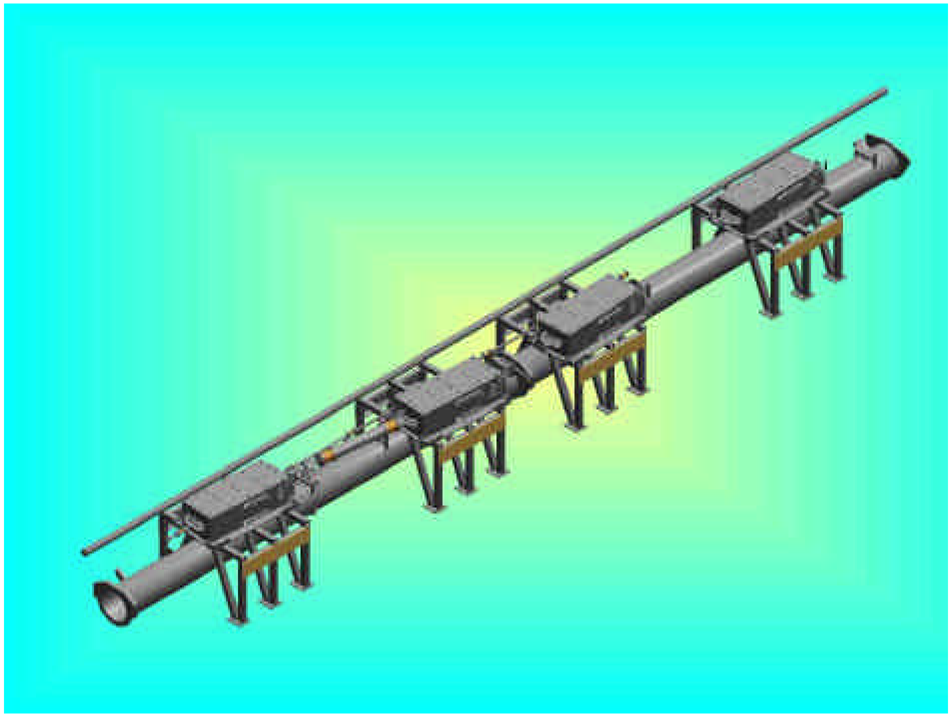
80 fsec FWHM

Existing bends compress to **<100 fsec**

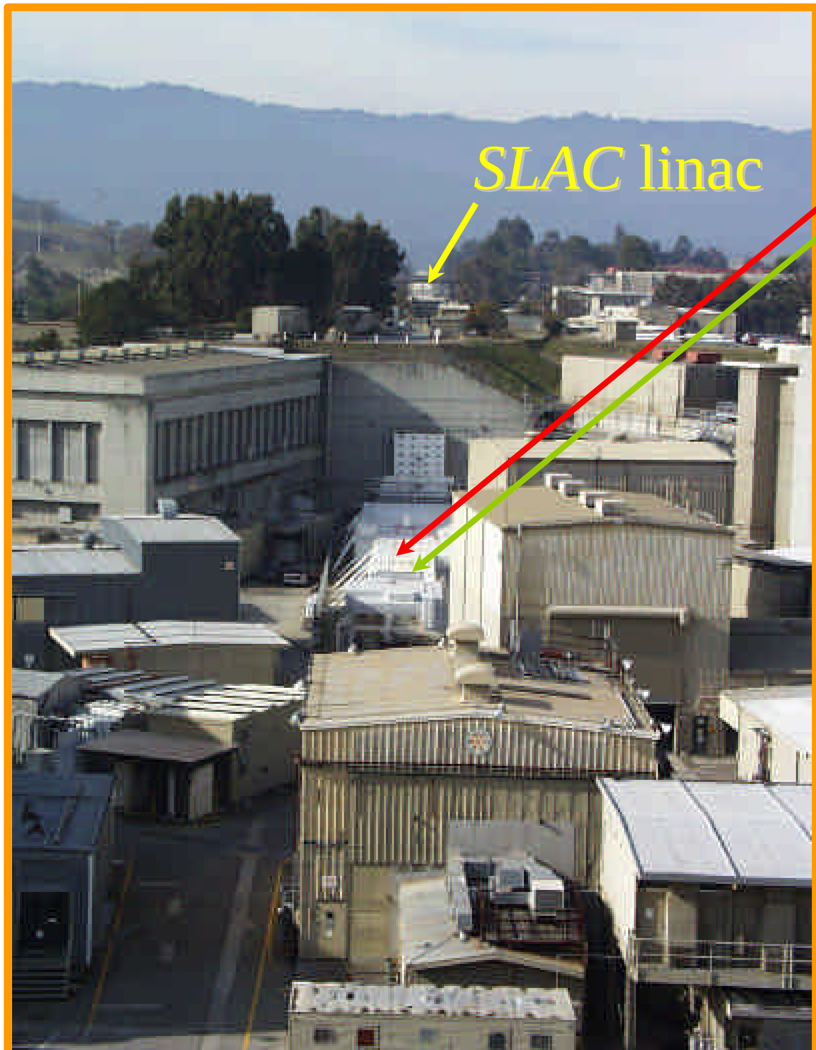


Linac Bunch Compressor Chicane Installation

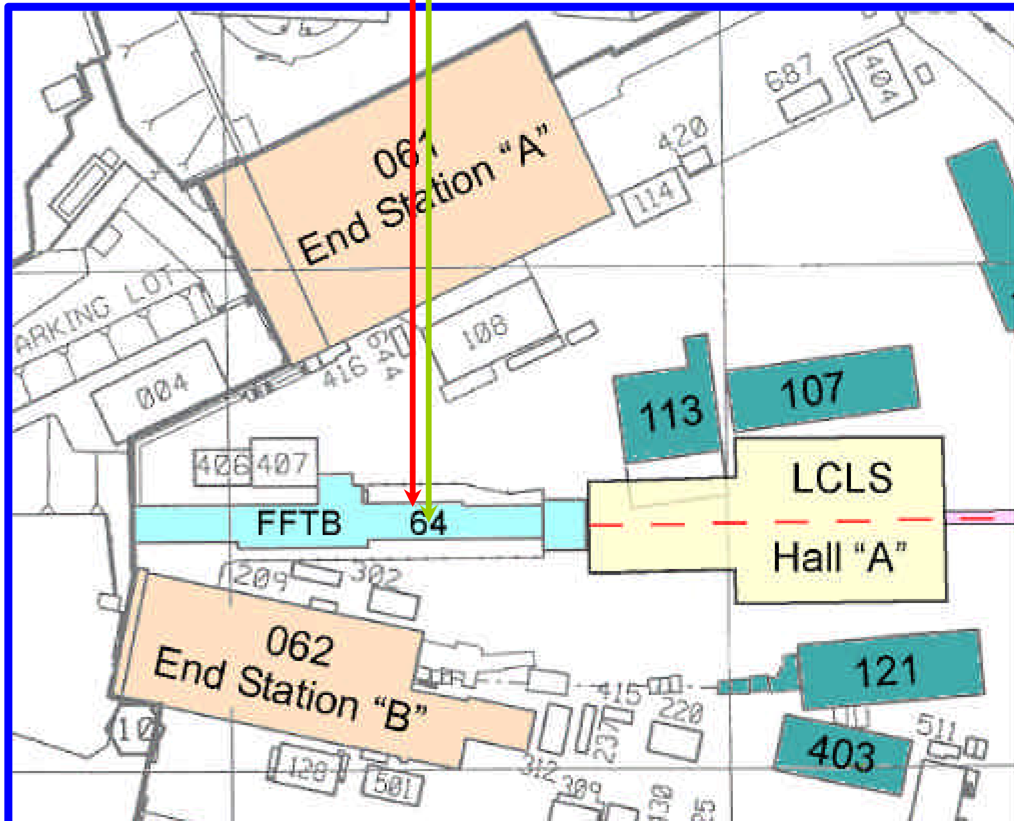




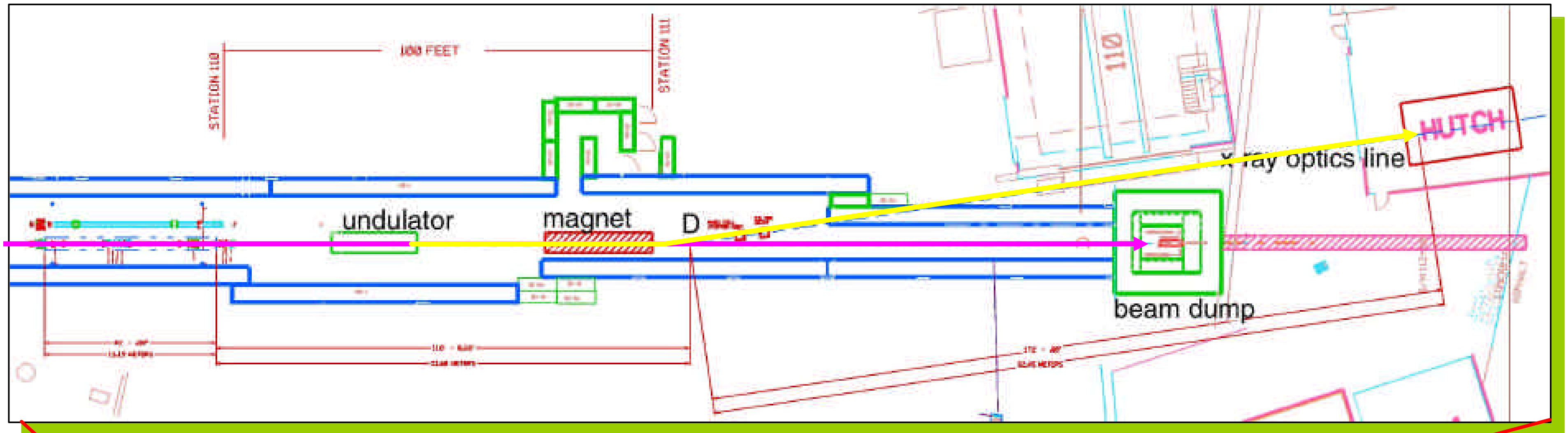
Linac and *FFTB* Hall

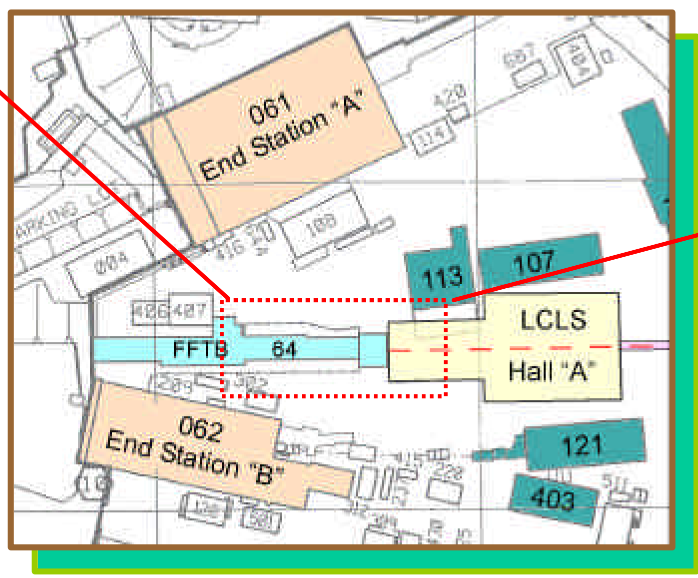


add undulator to *FFTB* hall at end of linac



Layout of the *x*-ray optics transport system and experimental hutch



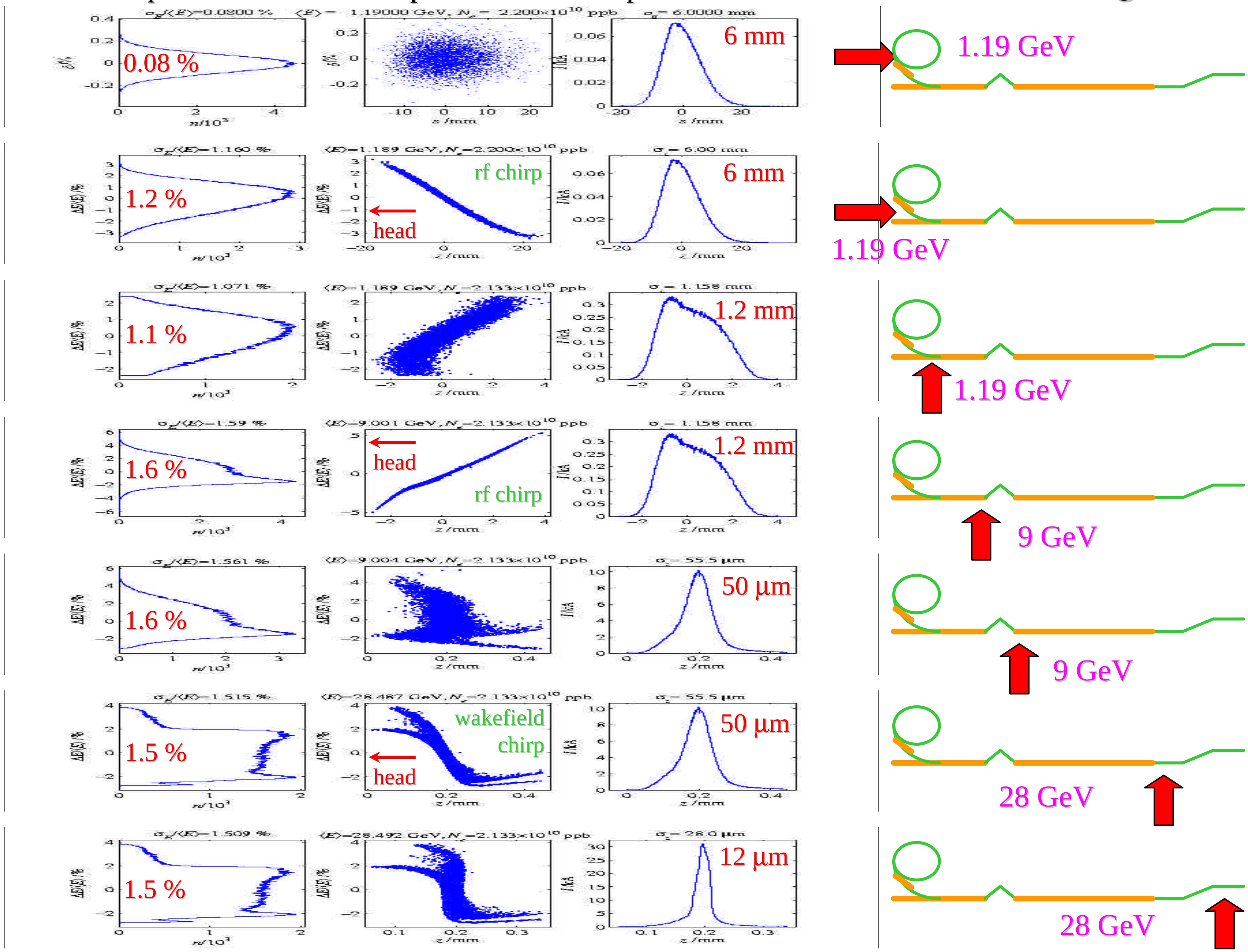


R & D Issues

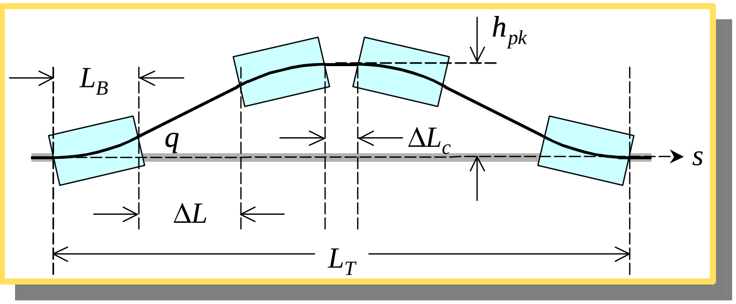
- For electron accelerators
  - Dynamics and tuning of bunch compressor
  - Diagnostics and instrumentation for ultra-short bunches
  - Feedback control of bunch length
  - Wakefield effects for ultra-short bunches
  - Coherent Synchrotron Radiation effects for ultra-short bunches
  - Bunch stability and timing

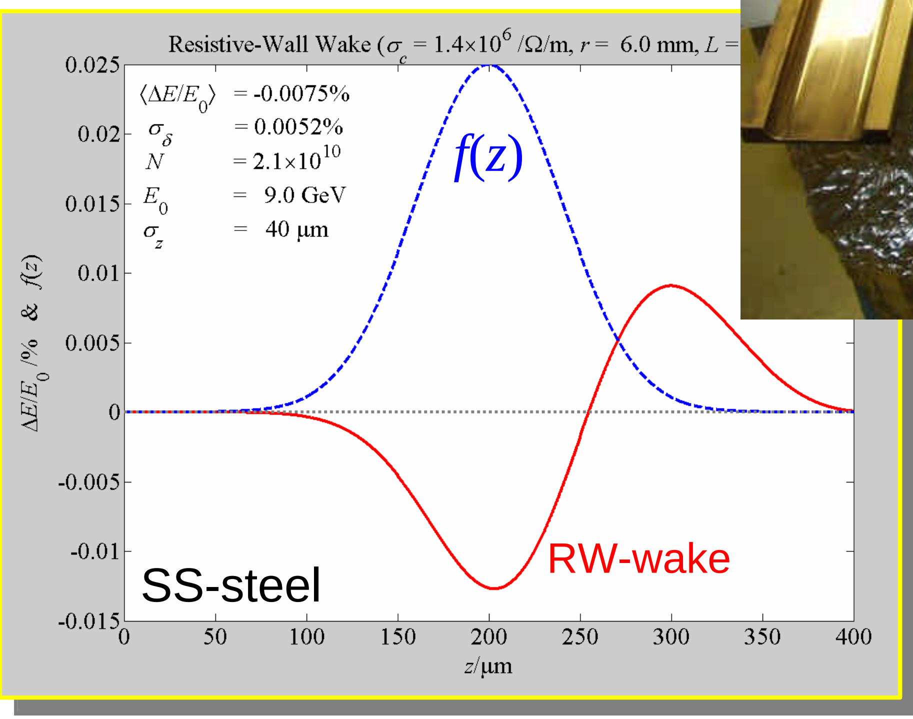
Particle tracking in 2D…

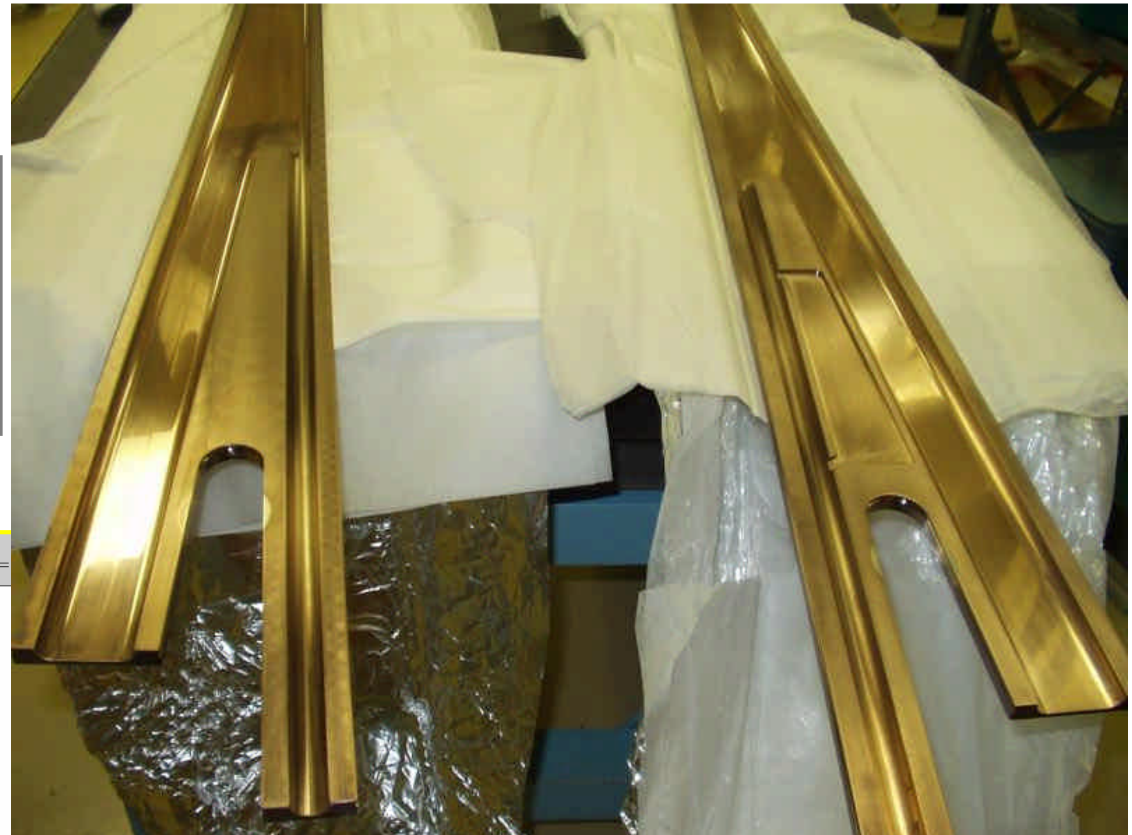
energy profile | phase space | temporal profile



Copper coated dipole chamber







x-emittance growth due to RW-wake in final bend

$$\frac{\Delta\varepsilon_x}{\varepsilon_{x0}} \approx 0.024\left[\frac{e^2cNL_B}{2\pi^2 aE}\right]^2 \frac{Z_0}{\sigma_c}\frac{1}{\sigma_z^3}\theta^2\frac{\beta_x}{\varepsilon_{x0}} << 1$$

Emittance Growth

- Due to resistive wakes in the chicane
  - 10% emittance growth for stainless steel
  - Reduced by order of magnitude with Cu
  - Similar contribution from roughness wakes before polishing
- Coherent Synchrotron Radiation in the chicane
  - Damping ring beam emittance is 10x larger in the chicane bend plane than in the vertical plane
  - only10% to 20% growth expected
- CSR microbunching instability
  - Not expected due to large incoherent energy spread on damping ring beam

Ultra-Short
Bunch Length Diagnostics

- Single-shot measurement of rms bunch length
  - TeraHertz power monitors
    - CSR from bends
    - Coherent diffraction radiation

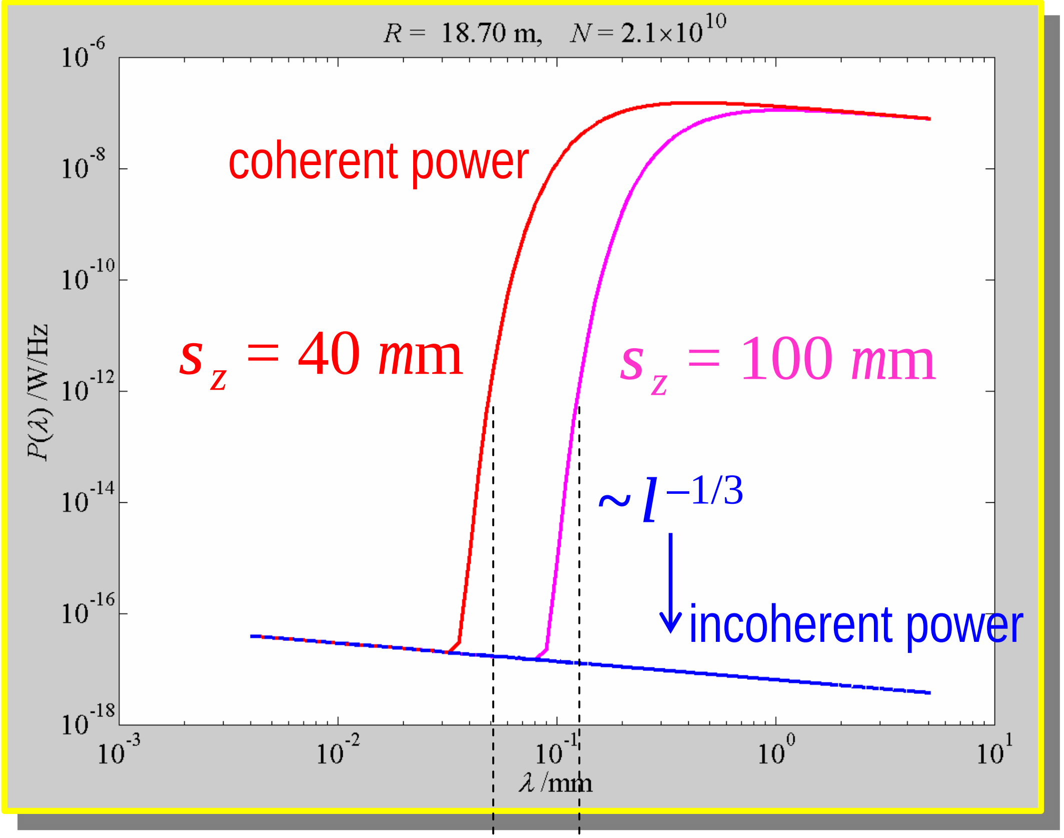
CSR power spectrum in chicane bend

Incoherent power proportional to no. of electrons

Coherent power proportional to N^2

$$P(\lambda) = P_0 N \{1 + N F(\lambda)\}$$

$$F(\lambda) = \left| \int_{-\infty}^{+\infty} dz S(z) e^{2\pi i/\lambda} \right|^2$$

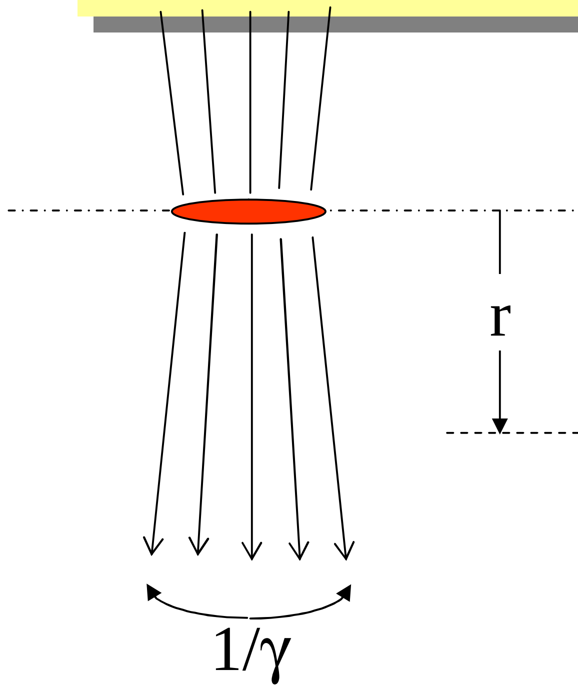


THz Bandpass Filter

Diagnostic

THz power ∝ 1/ bunch length

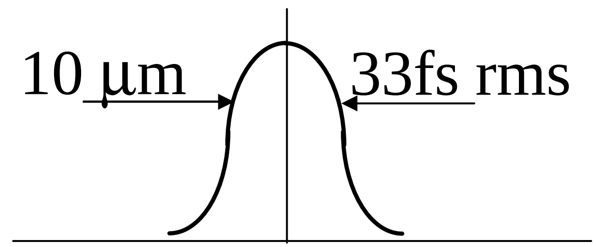
Electric Field from a Relativistic Bunch



$$E \approx \frac{\gamma N_e e}{4\pi\varepsilon_0 r^2}$$

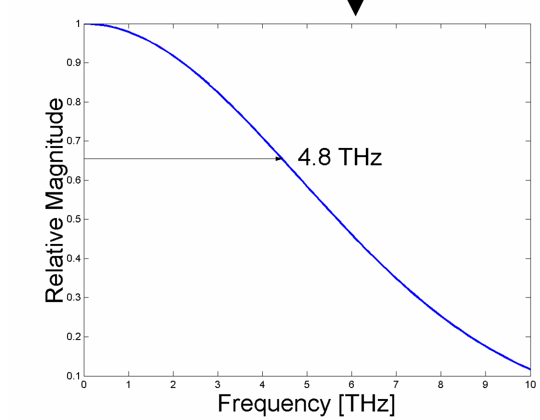
1 nC 30 GeV 1 cm away

E = 5 GVm^{-1}



Frequency components

$$F(\omega) = e^{-\frac{\omega^2 \sigma^2}{2}}$$



Wakefield bandwidth

Ultra-Short Bunch Length Diagnostics

- Single-shot measurement of longitudinal profile
  - Invasive, pulse-stealing methods
    - Transverse RF deflecting cavities
  - Non-invasive
    - Electro-optic detection with chirped laser pulse
      - Pump probe measures timing

RF deflecting cavities

Beam size RF off

Bunch Length

Beta fn at cavity & screen

Cavity voltage and beam energy

Phase adv cavity to screen

Beam size on screen

RF phase

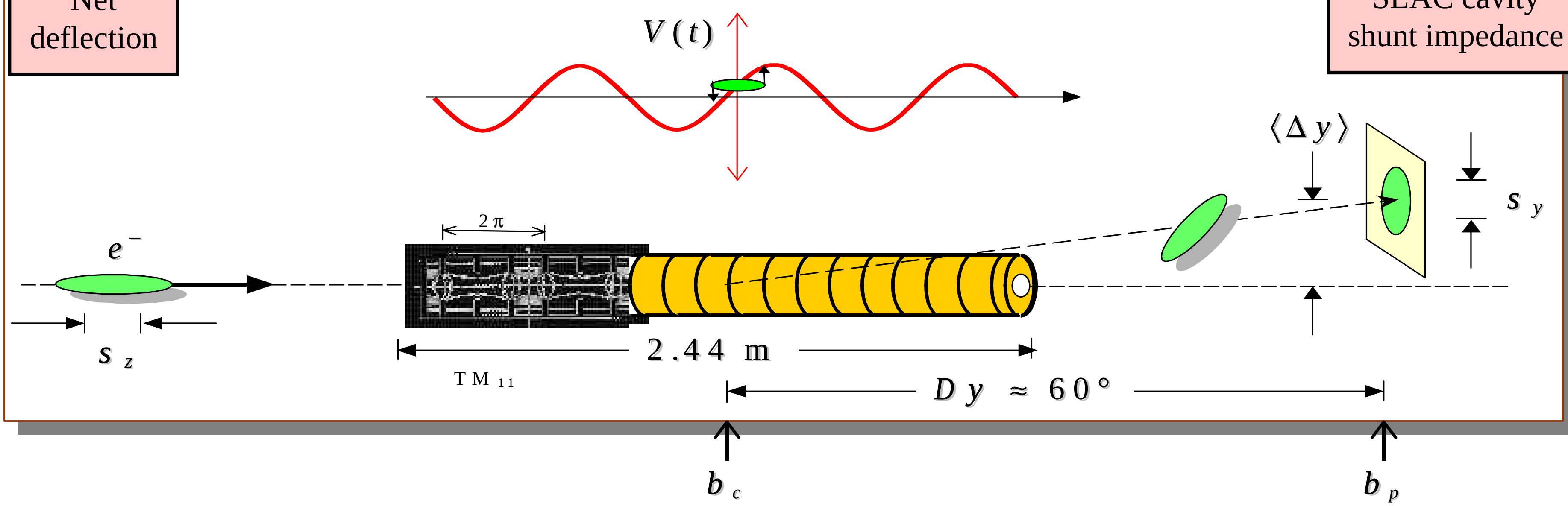
$$\sigma_y = \sqrt{\sigma_{y0}^2 + \sigma_z^2 \beta_c \beta_p \left(\frac{2\pi eV_0}{\lambda E_0} \sin \Delta\psi \; \cos\varphi \right)^2}$$

$$\langle \Delta y \rangle = \frac{eV}{E_0} \sqrt{\beta_c \beta_p} \sin \Delta\psi \; \sin\varphi \; , \qquad V_0 \approx \left(1.6 \text{ MV/m/MW}^{1/2}\right) L \sqrt{P_0}$$

25 MW

Net deflection

SLAC cavity shunt impedance

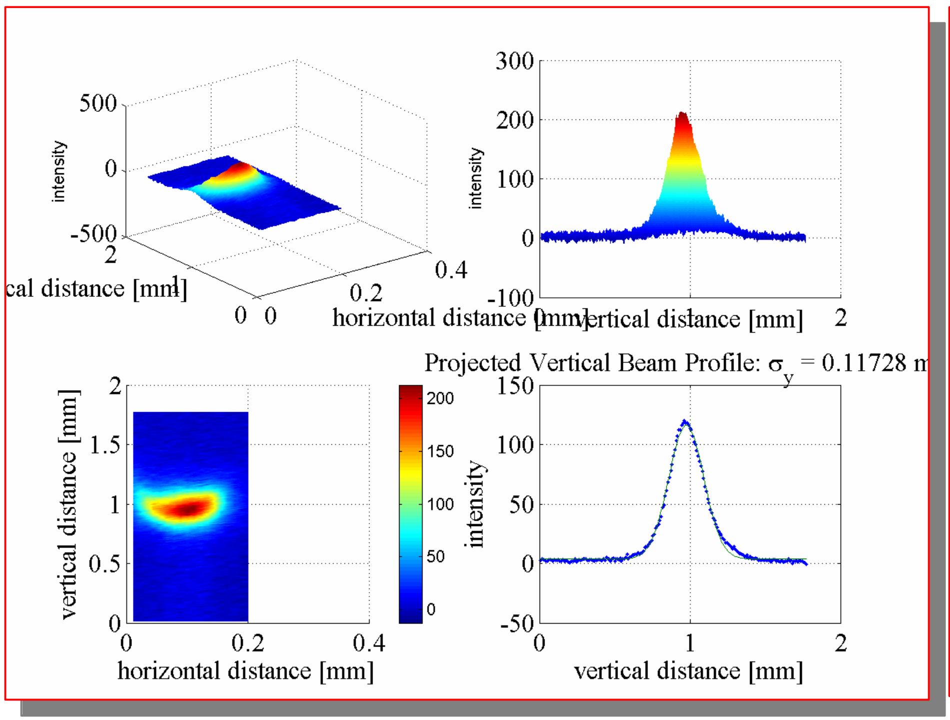


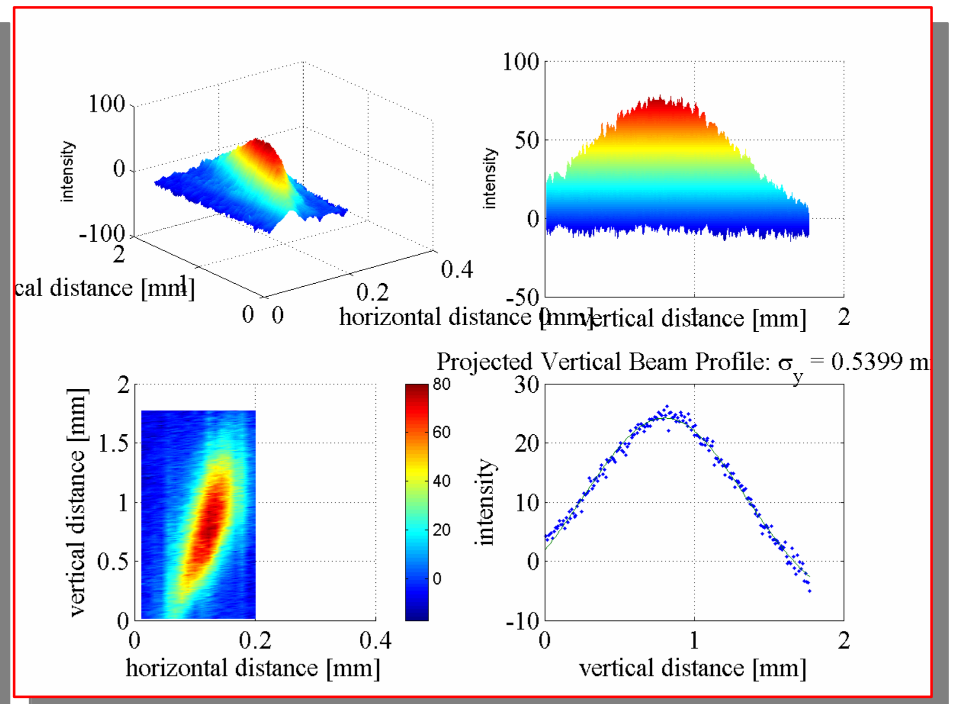
Measurements at the SLAC Linac

Profile Monitor Images of Damped, scavenger bunch at end of linac

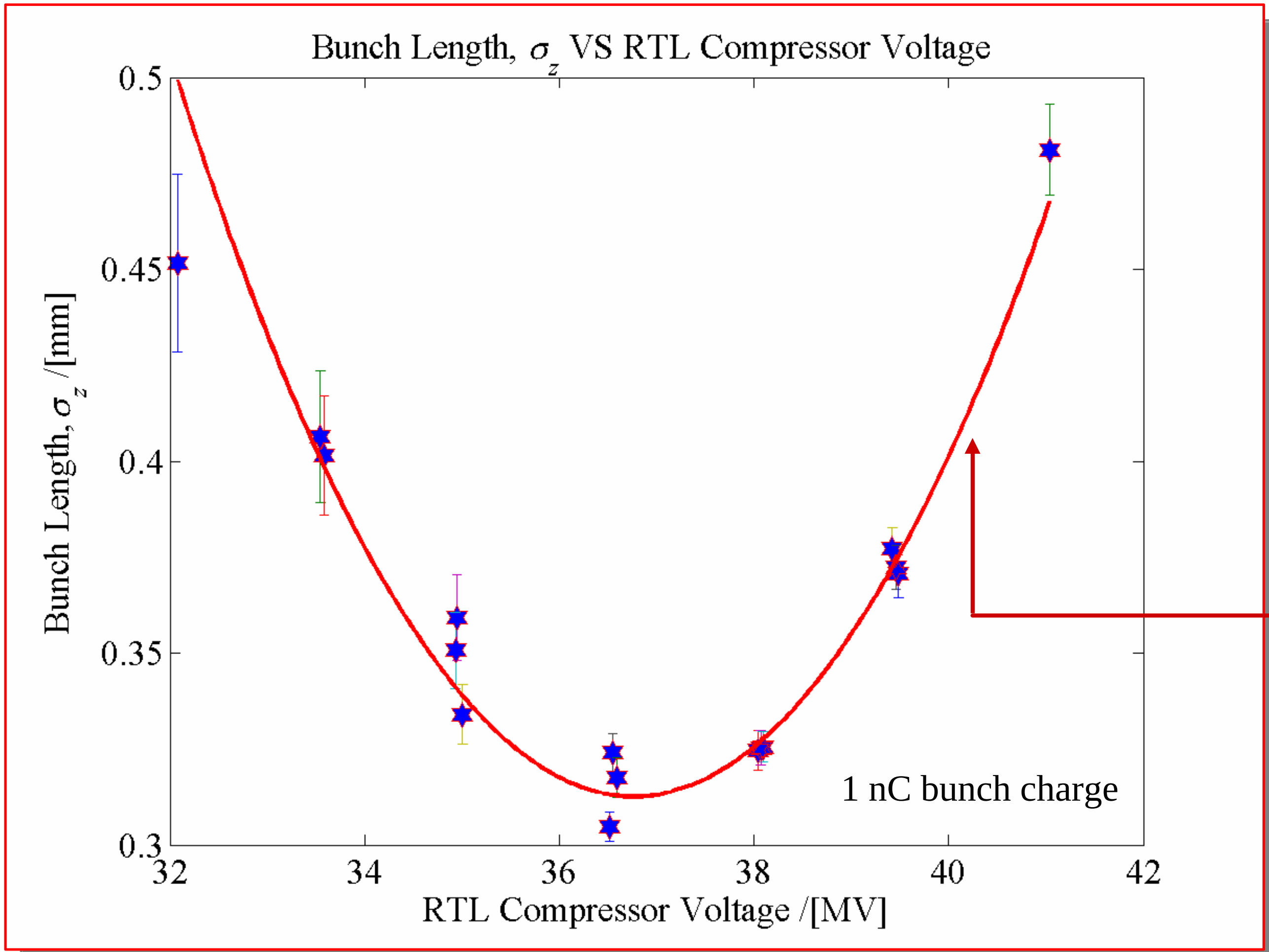
Transverse Cavity OFF

Transverse Cavity ON





Bunch Length Measurement at a fixed RF Deflector Voltage as the Compressor is Varied

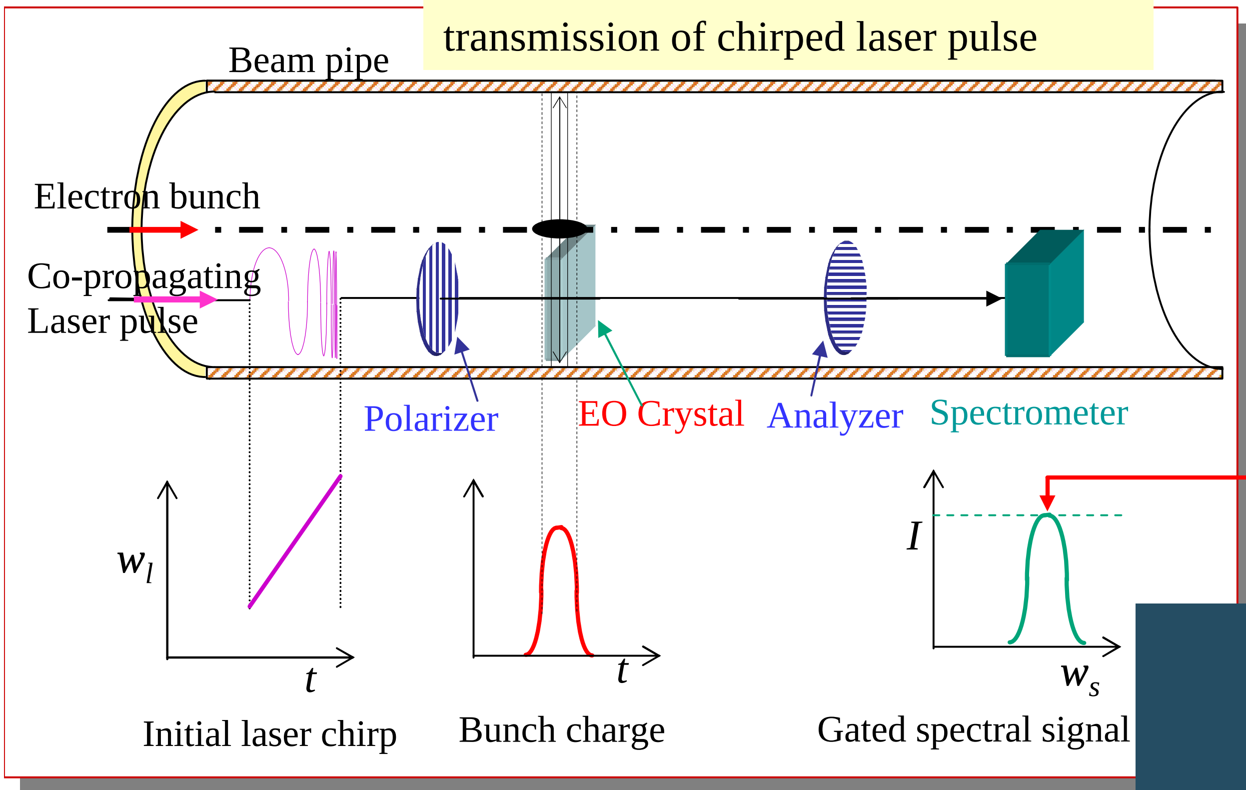


Practical example of tuning of a bunch compressor in the SLAC linac

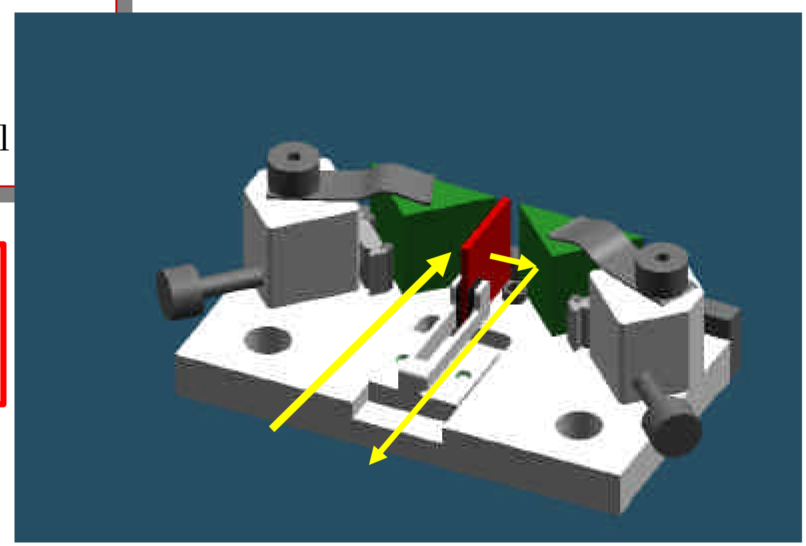
Over compression case examine bunch distribution

Principal of Electro Optic Detection

• Electric field from bunch modulates transmission of chirped laser pulse



Centroid position also yields timing between laser and electrons



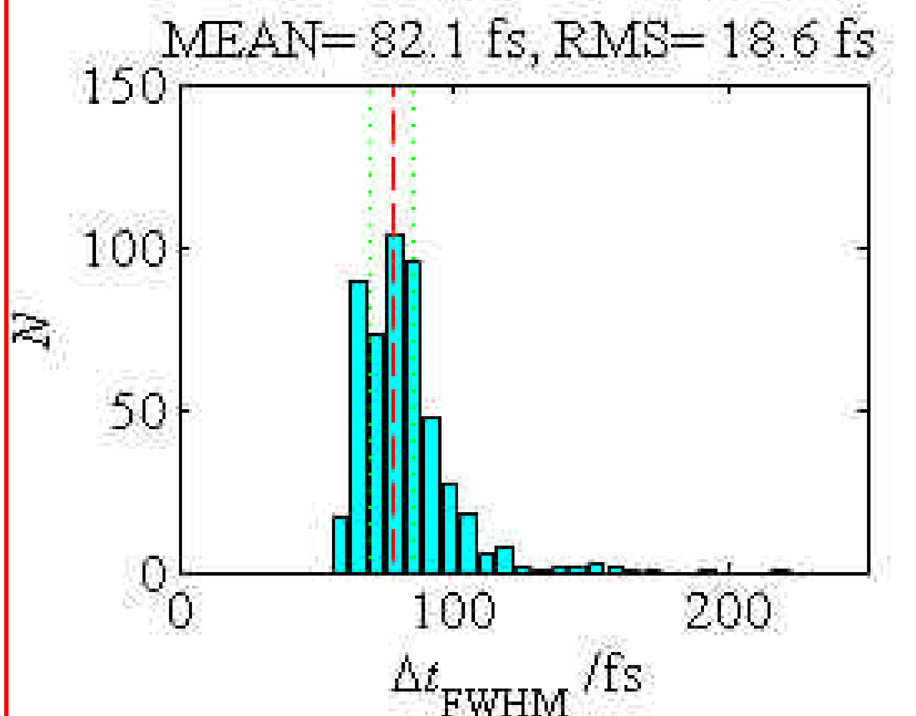
$$P = \varepsilon_0 \left[\chi_1 E + \chi_2 E^2 + \chi_3 E^3 + \ldots \right]$$

2nd order, Pockels term

Pulse-to-pulse jitter estimates based on machine stability…

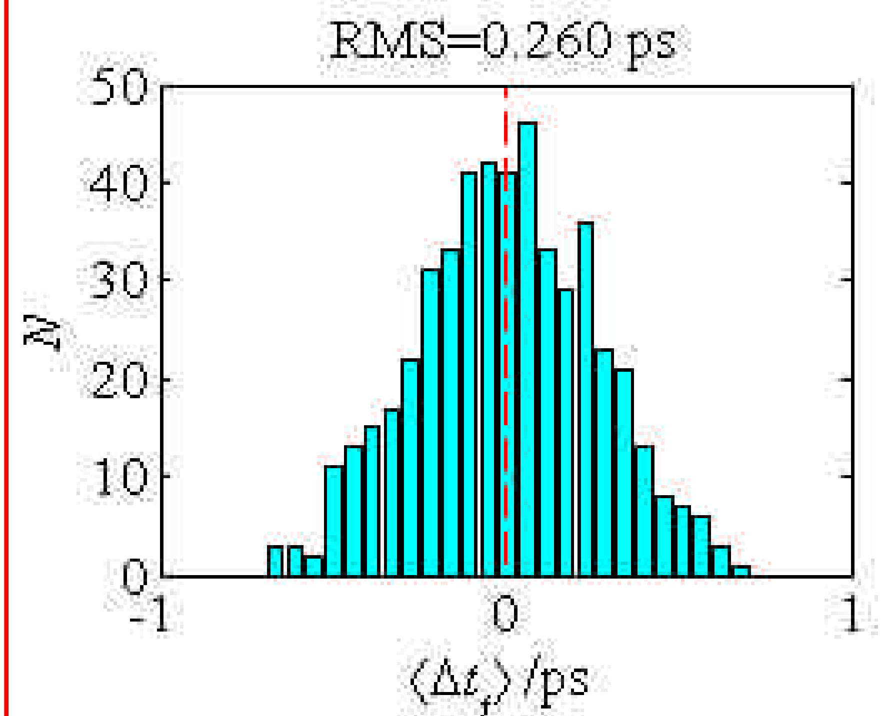
- linac ⟨phase⟩ 0.1 deg-S rms
- linac ⟨voltage⟩ 0.1% rms
- DR phase 0.5 deg-S rms
- Charge jitter of 2% rms

Simulate bunch length variations…



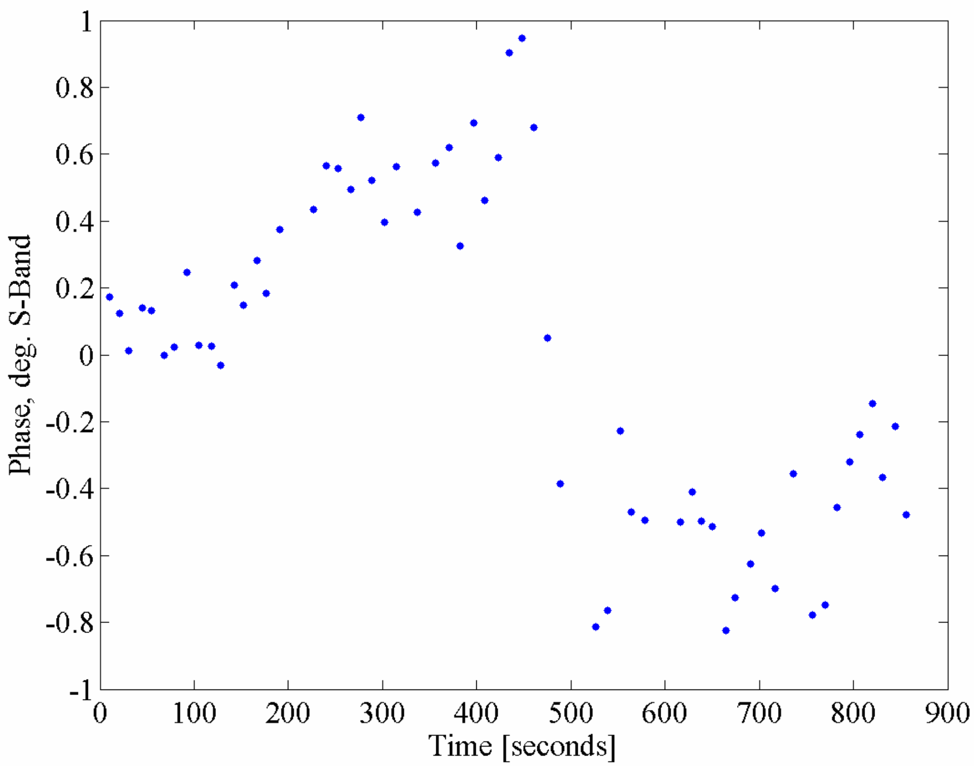
fwhm 82 ± 20 fsec rms

…and bunch arrival time variations…



0 ± 0.26 psec rms

Actual Beam Based Measurement of Relative Phase Jitter Between Bunch and the Transverse Deflecting Cavity



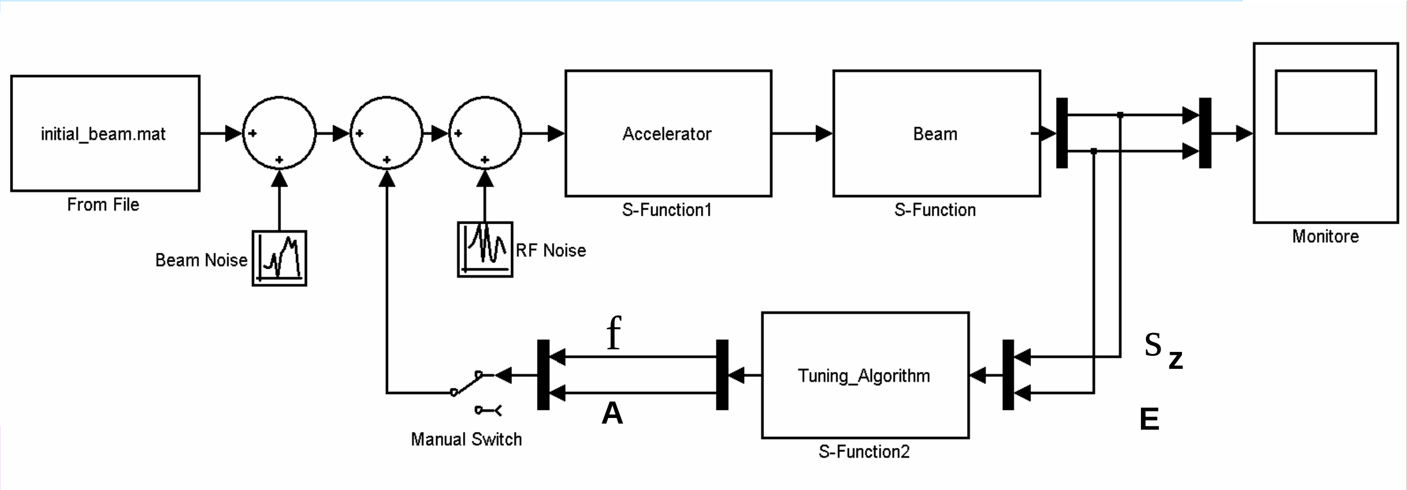
Phase deviations calculated from transverse kick measured by fitting BPM orbit downstream of cavity

~0.1° rms short term (~100 fs)

~ 1 ° rms longer term (~1 ps)

Feedback control of RF phase and amplitude

- RF feedback relies on beam-based measurement of:
  - Energy
  - plus bunch length
  - plus (a less precise) phase measurement at each compressor



•Simulation using

Matlab-Simulink tools

•Incorporates 2D tracking (Litrack)

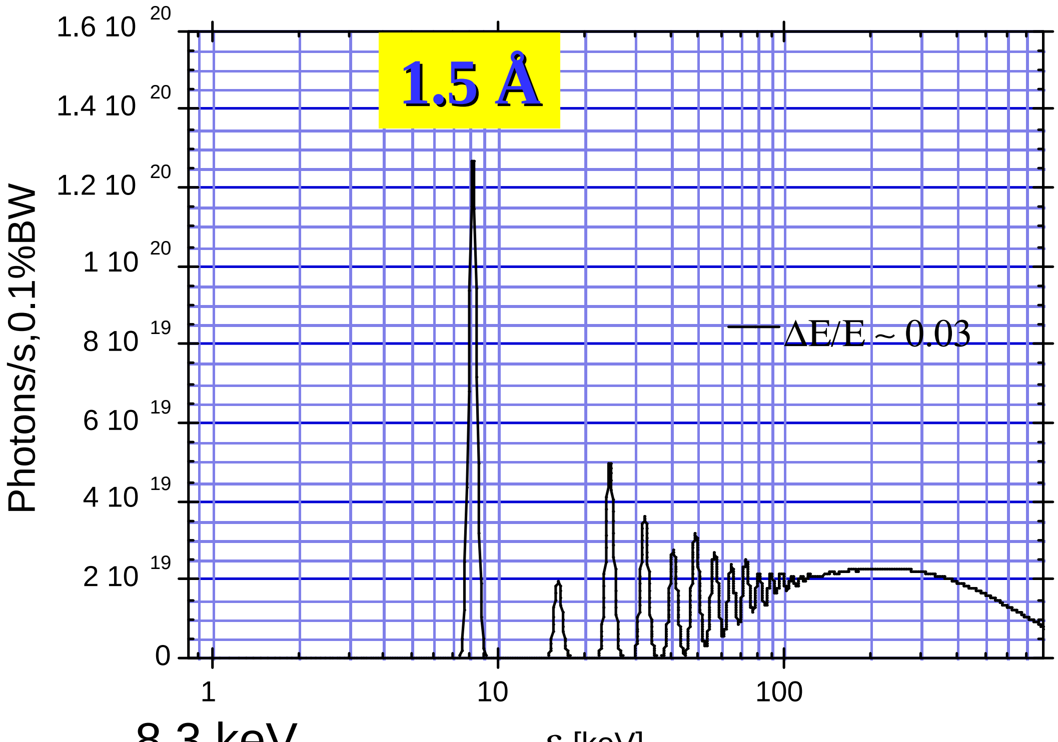
•Experience with Damping Ring and PEP II RF feedback systems

R & D Issues

- For short pulse X-ray radiation
  - Timing and stability issues
  - Pump probe measurements with 1.5 Å X-rays
  - Optics and transport for high-brightness x-rays

APS Wiggler "A" as Undulator at SLAC

K = 4.45



Fundamental photon energy	8.3 keV
Peak Brightness	4.0×10^{24} ph/s,mm^2,mr^2,0.1%bw
Output photons per pulse	2.9×10^{7}ph/0.1% bw, all angles

Conclusion

- SPPS is a scientific enterprise in its own right
- Tests many of the fundamental physics issues for the LCLS FEL project
  - Short bunch beam dynamics and tuning
  - Diagnostics and instrumentation
  - Stability and feedback control
- Implemented on the linac to be used for LCLS
      - .