# SPPS: The SLAC Linac Bunch Compressor and Its Relevance to LCLS

Patrick Krejcik

# LCLS Technical Advisory Committee Report 1: July 14-15, 1999

"… The collaboration should explore the possibility of using the low vertical emittance of the electron beam from the SLC damping ring for early tests of dynamics and emittance preservation issues."

# Linac Bunch Compressor Chicane

- Funding approved in October 2001
- Design and fabrication of components has begun
- Installation in Sector 10 scheduled June-September 2002
  - Beam Dynamics: P. Emma
  - Mech. Eng.: L. Bentson
  - Magnet Design: C. Spencer, C. Rago
  - ...

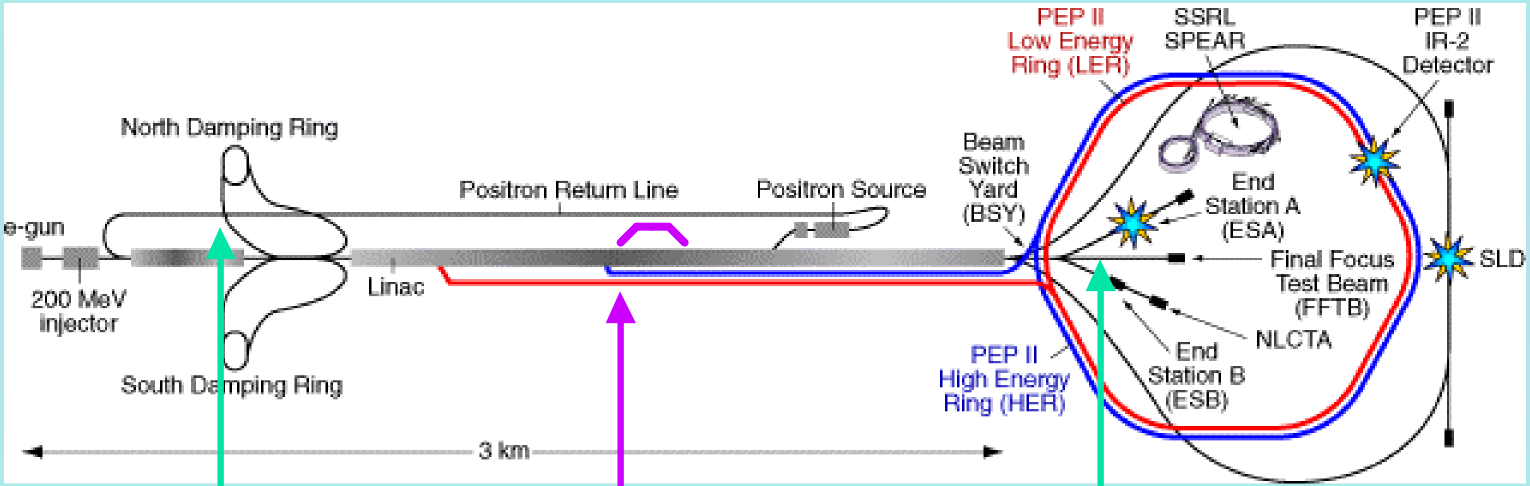
# Briefly,

- A chicane bunch compressor is being added to sector 10 of the SLAC linac
- It uses beam from the damping rings interleaved with PEP II operation
- Bunch transported to FFTB and compressed in 3 stages
  - 80 fs fwhm with 3.5 nC => 30 kAmp peak
- R & D for LCLS
- Numerous scientific applications in its own right

# SPPS

- **S**ub-**P**icosend **P**ulsed **S**ource
  - White Paper describing a proposal to use sub-picosecond spontaneous X-rays generated by an undulator in the FFTB beamline
    - LCLS-TN-01-7 M. Cornacchia, J. Arthur, L. Bentson, R. Carr, P. Emma, J. Galayda, P. Krejcik, I. Lindau, J. Safranek, J. Schmerge, J. Stohr, R. Tatchyn, A. Wooton, **"A Sub-Picosond Photon Pulse Facility for SLAC."** SLAC-PUB-8950 (August 16, 2001)
- Plus numerous applications for plasma wakefield acceleration and laboratory astrophysics

# Three-Stage Bunch Compression in the SPPS




**RTL Compressor**

**1.2 mm rms**

**Sector 10 Chicane**

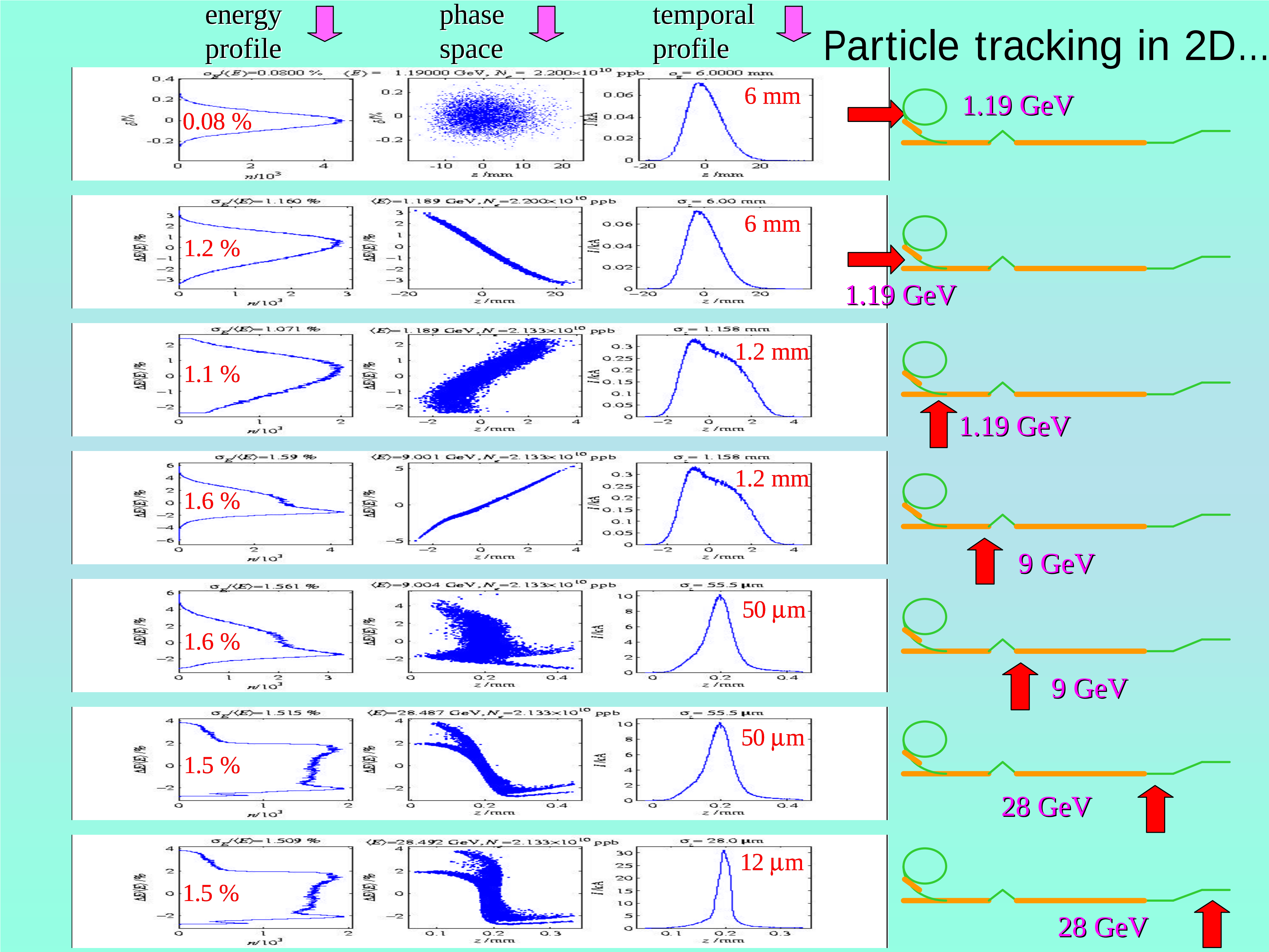
**50 mm rms**

**FFTB Beamline**

**12 mm rms**

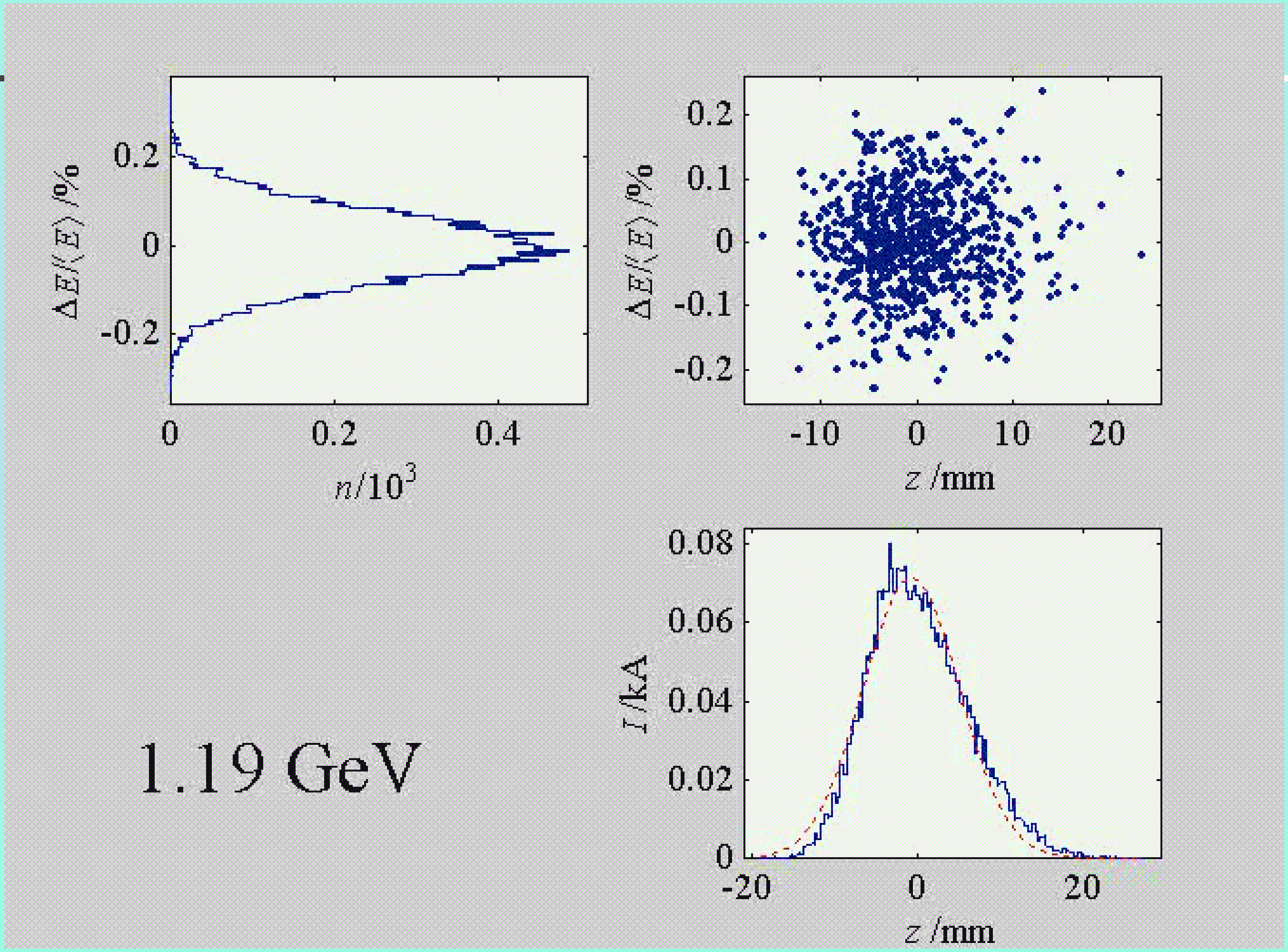
# LCLS Accelerator R & D

- Test bunch compression dynamics and tuning
  - Phase, energy setup, beam diagnostics using SLAC control system
- Will greatly shorten LCLS commissioning time
- Measurement of emittance growth mechanisms
  - Set upper limits on CSR effects
- Direct measurement of short-bunch wakefields in SLAC S-band structure



energy profile
phase space
temporal profile
Particle tracking in 2D...
0.08 %
6 mm
1.19 GeV
1.2 %
6 mm
1.19 GeV
1.1 %
1.2 mm
1.19 GeV
1.6 %
1.2 mm
9 GeV
1.6 %
50 µm
9 GeV
1.5 %
50 µm
28 GeV
1.5 %
12 µm
28 GeV

# Beam Dynamics of Compression

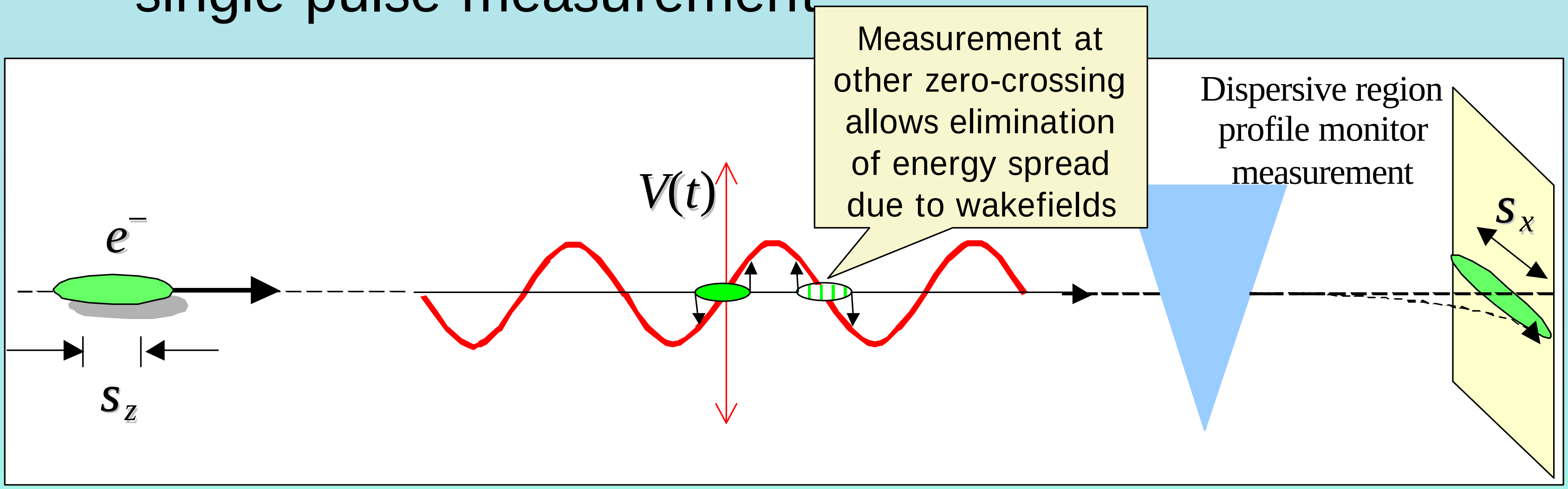


# LCLS Accelerator Performance

- Beam observation of bunch phase and energy stability
- Test bed for
  - bunch length **diagnostics**
  - bunch length **feedback systems**
- Demonstration of linac compatibility for multiple beam program (PEP II, FFTB II)

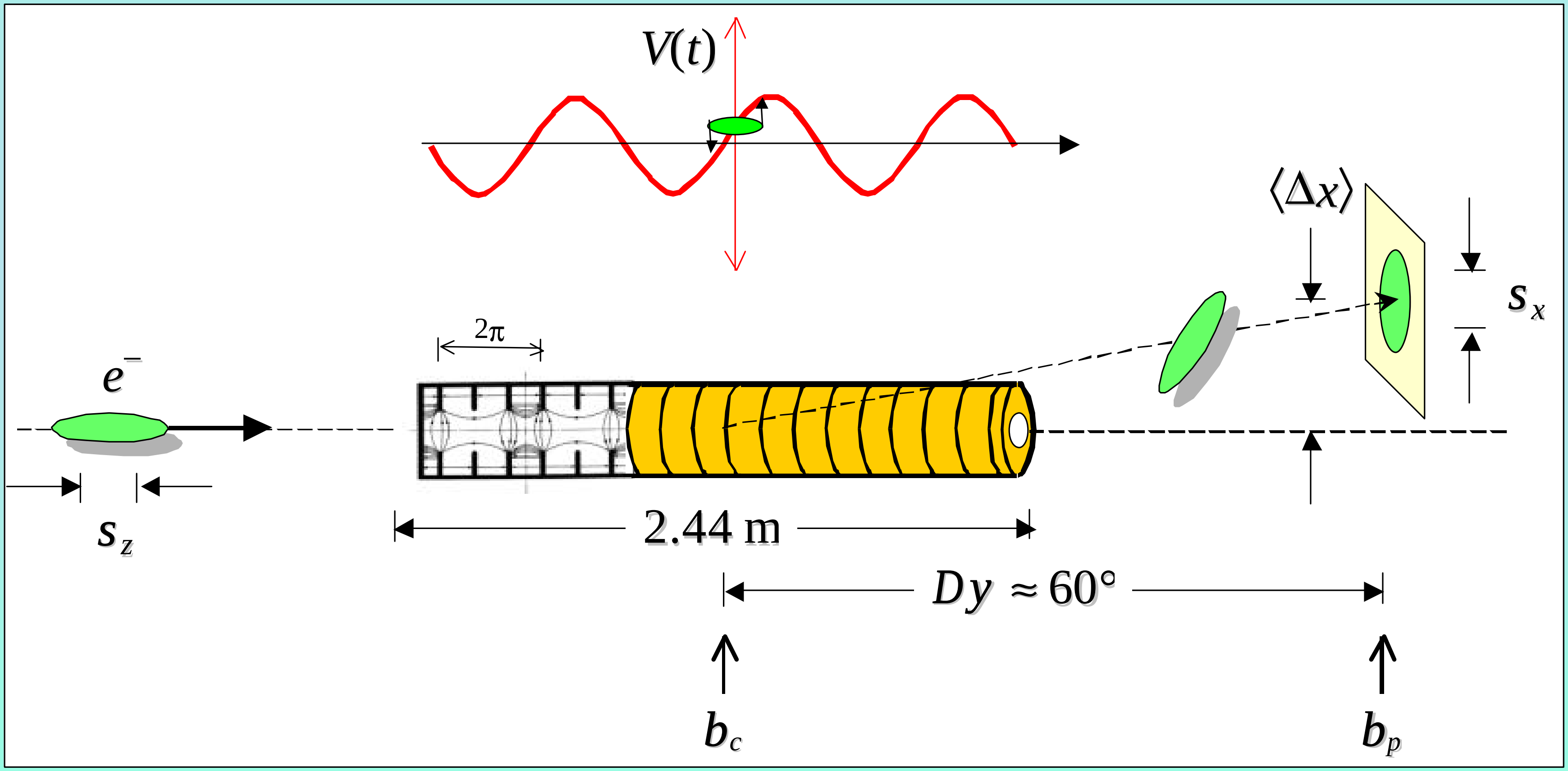
# Bunch Length Measurement With RF Zero-Crossing Technique

- translates bunch length into energy spread measurement
  - single pulse measurement




- routinely used at Damping Rings RTL bunch compressor to measure Damping Ring bunch length

# Bunch Length Measurement With a $TM_{11}$ Mode RF Transverse Deflecting Structure



# RF Deflector Installation

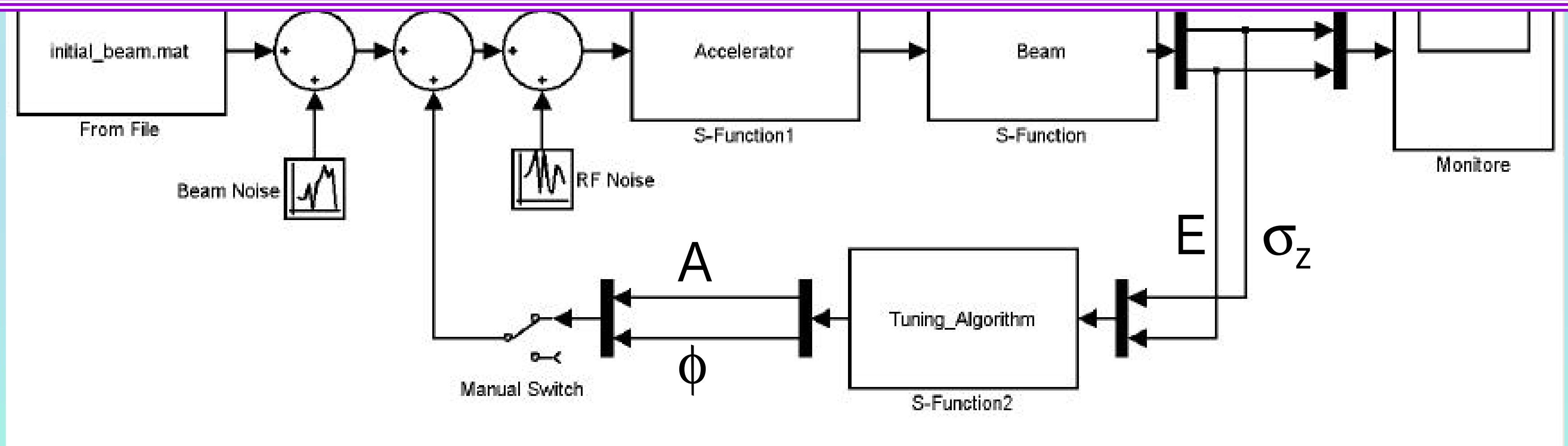
- Installed in the linac at Sector 29-4
- Klystron and waveguide now also under vacuum.
- Problem in getting access to linac during PEP II operation
  - Will likely continue to be an issue throughout LCLS
- Final linking of two vacuum systems scheduled January 3, 2002.
- Devising commissioning tests during End-Station A long-pulse operation using witness bunch.

# Feedback Control of Linac Phase and Amplitude Using Bunch Length and Energy

**Beam function**

**[zpos,dE_E,Ebar,dFWpct,ZFWmm,z_bar,Ebarcuts,fcut,sigzG,sigEG]**

**= LITRACK(fn,seed,z0in,dQ_Q,param,blnew)**




- Simulation usingMatlab-Simulink tools
- Incorporates 2D tracking (Litrack)
  - Experience with Damping Ring and PEP II RF feedback systems

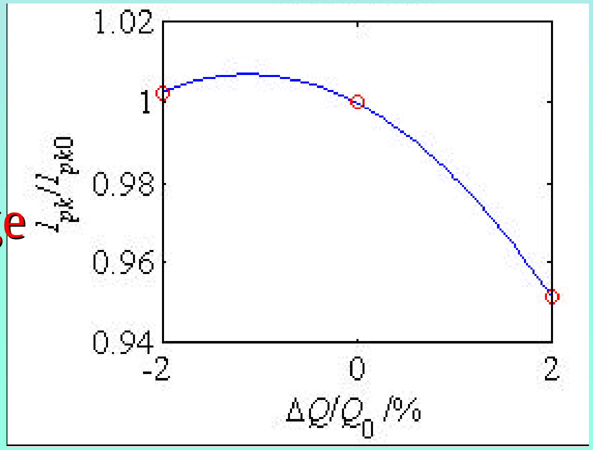
# Machine stability affects energy, bunch length, and arrival time...

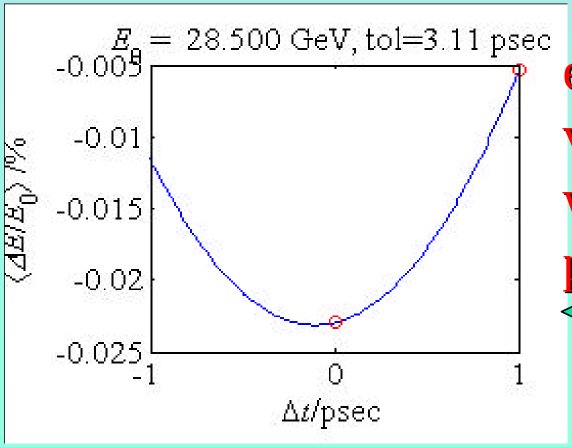
Paul Emma

| SPPS Parameter | Similar LCLS Parameter | SPPS Sensitivity* |
|---|---|---|
| Bunch Charge | Bunch Charge | 7.7 % |
| Damping Ring Extraction Phase | Gun laser phase | 0.9 °S-band |
| RTL Compressor phase | L1 phase | 0.3 °S-band |
| Linac Sectors 2 – 10 mean phase | L2 mean phase | 0.25 °S-band |
| Linac Sectors 2 – 10 mean RF voltage | L2 mean RF voltage | 0.79 % |
| Sect 10 chicane R56 | BC2 chicane R56 | 1.8 % |

* for 0.2 % energy and 20 % bunch length stability

peak current variation with charge




energy variation with ring phase

# Bunch Timing Jitter

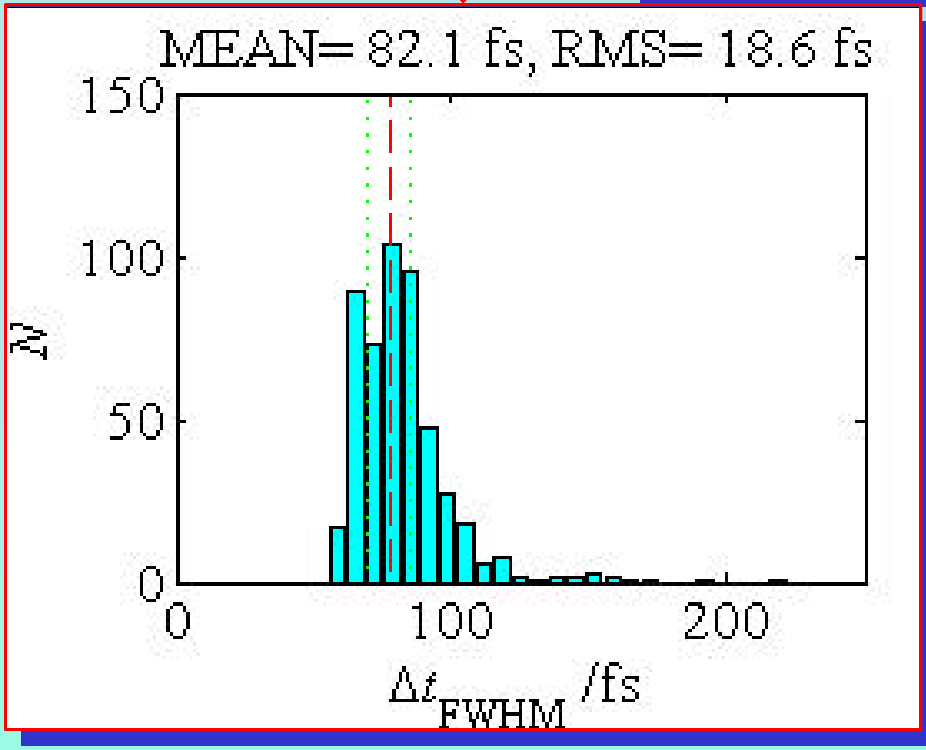
- Energy jitter in the Bunch Compressor chicanes translates into path length
- Result is jitter in the bunch arrival time that is significantly larger than the bunch width ...

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

**Paul Emma**

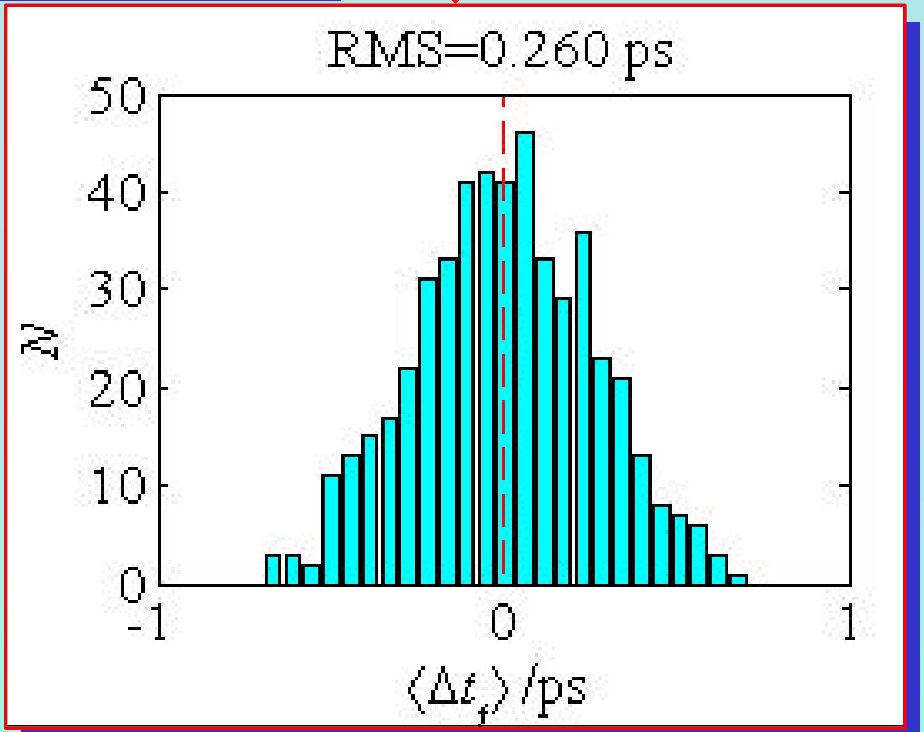
- linac ⟨phase⟩ 0.1 deg-S rms
- linac ⟨voltage⟩ 0.1% rms
- DR phase 0.5 deg-S rms
- Charge jitter of 2% rms

Simulate bunch length variations…




82 ± 20 fsec rms

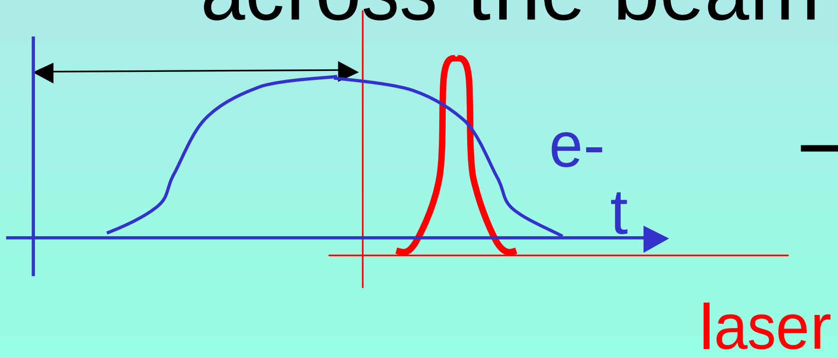
…and bunch arrival time variations…




0 ± 0.26 psec rms

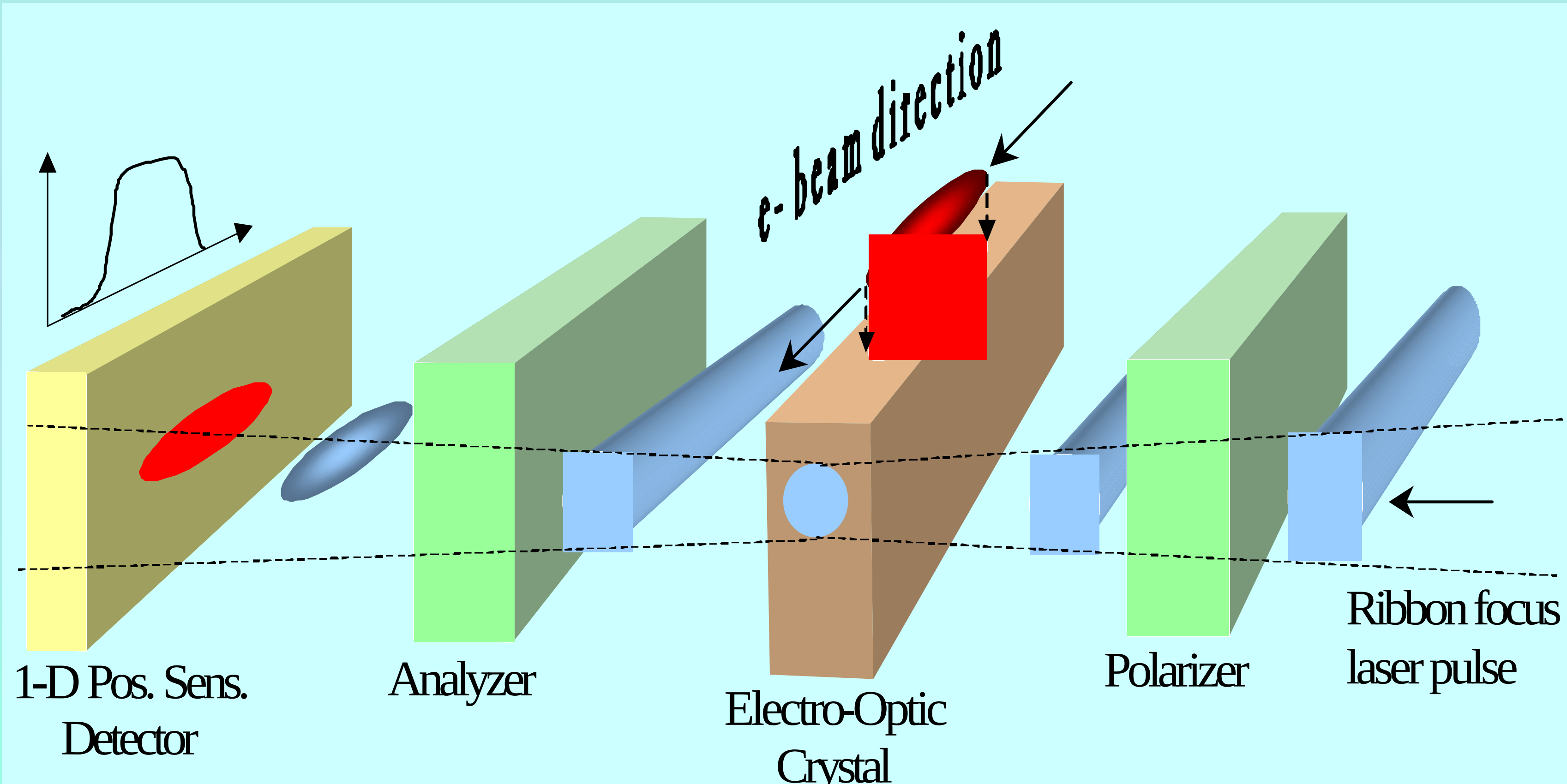
# Final Bunch Length Diagnostic is a Challenge

- Exploit fast (~20 fs) visible lasers.
- Must be a single shot technique
  - Transform time into spatial coordinate or frequency domain
- Scanning a narrow probe pulse in time across the beam succumbs to jitter




e.g. While observing Compton X-rays

# Timing and bunch length measurement with a probe laser beam



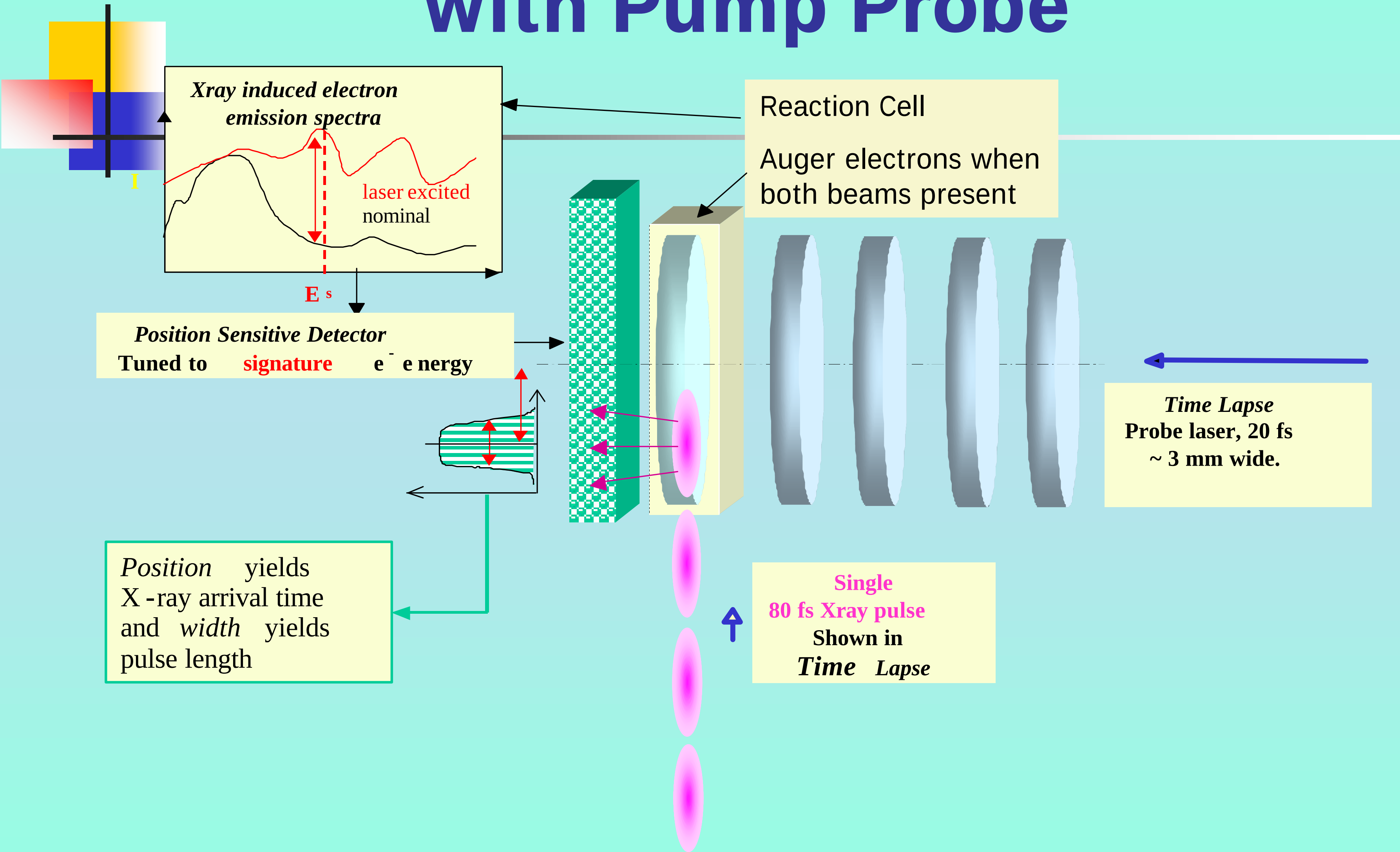
# LCLS X-Ray R & D

- Spontaneous X-ray radiation from a short (5 m) undulator
  - 1.5 Å, $10^8$ photons/pulse, $10^{25}$ peak brightness
- Development of
  - X-ray monochromator and optics
  - X-ray timing and synchronization
  - Pump-probe techniques
  - Characterization of temporal structure of photon beam
- Not yet funded

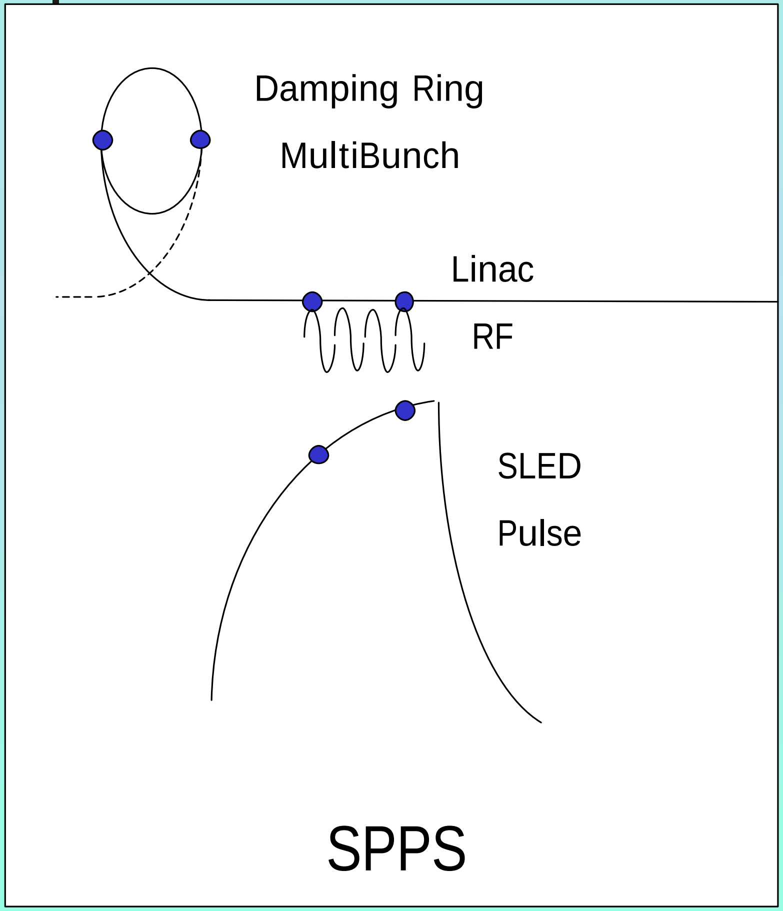
# At the SSRL Workshop on Metrology with Sub-Picosecond X-ray Pulses, Oct. 17 2001

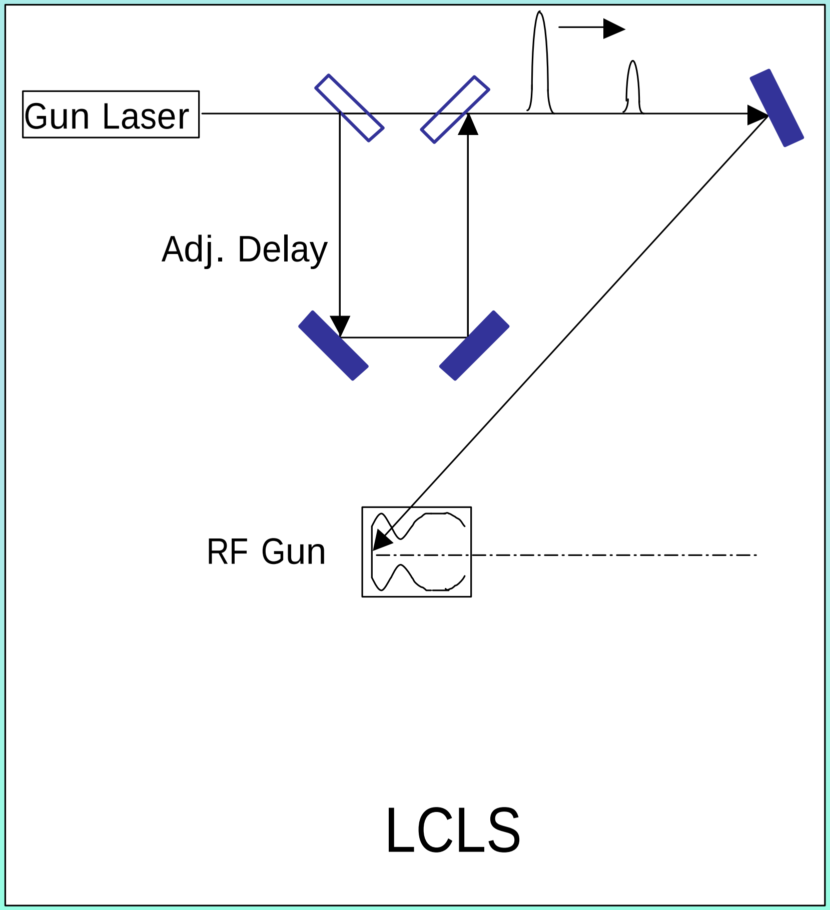
- Emphasized the need for R&D on precise timing of the photon bunch
- And measurement of the temporal distribution of the photon pulse
  - Which will differ from the electron bunch.

# Temporal to spatial translation with Pump Probe



# Two bunches on the same klystron pulse will preserve a fixed phase relationship



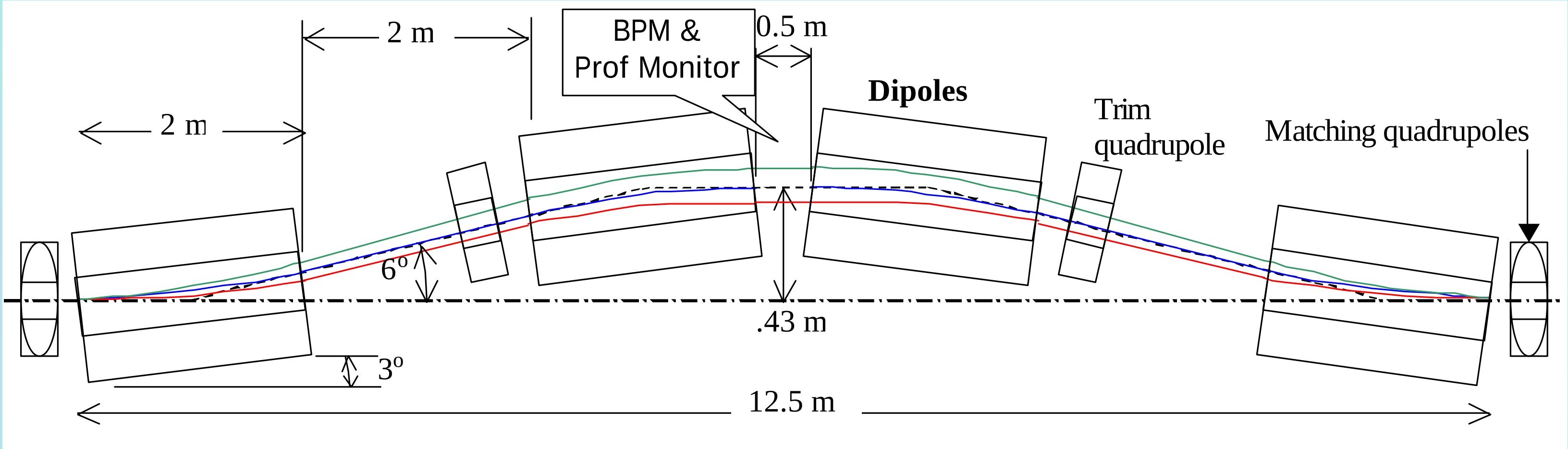



# LCLS Engineering R & D

- We are designing and currently building
  - Magnets
  - Vacuum chambers
  - Diagnostics: BPMs, Prof Monitors
  - Machine protection systems

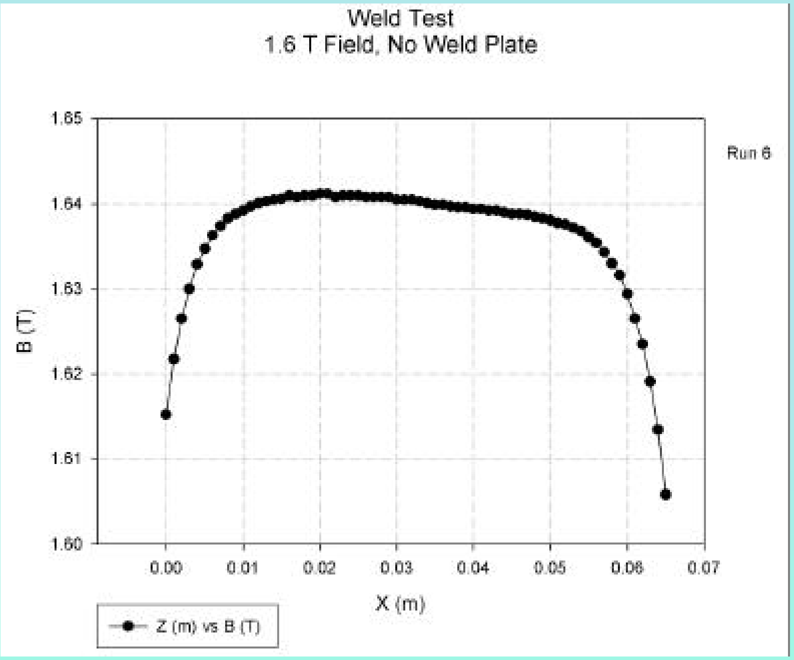
  For LCLS style bunch compressors

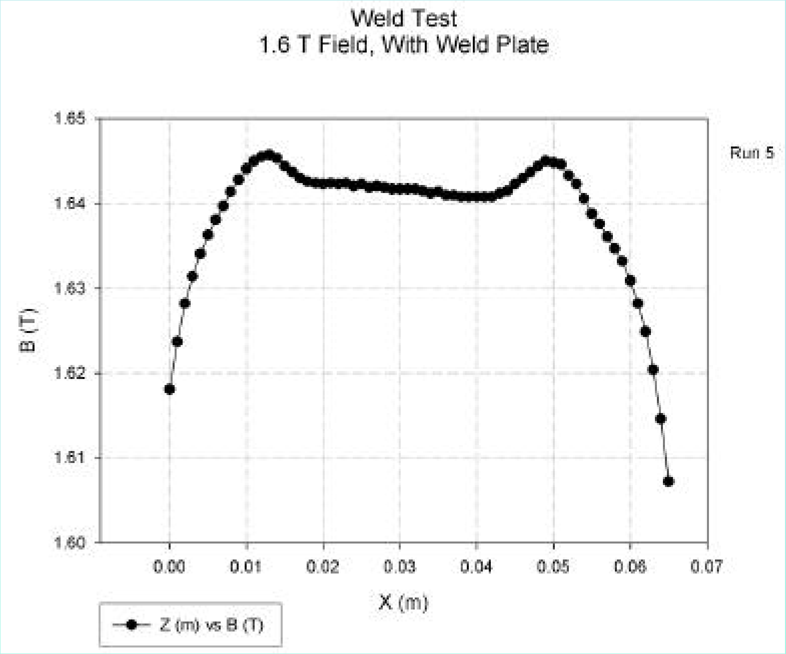
# Sector 10 Bunch Compressor Chicane Layout




- Dipole 1.6 T, 4.5” wide good field region
  - Field quality, sextupole component < 0.25%

# Dipole Field Perturbations Due to stainless Vacuum Chamber Welds – Zachary Wolfe



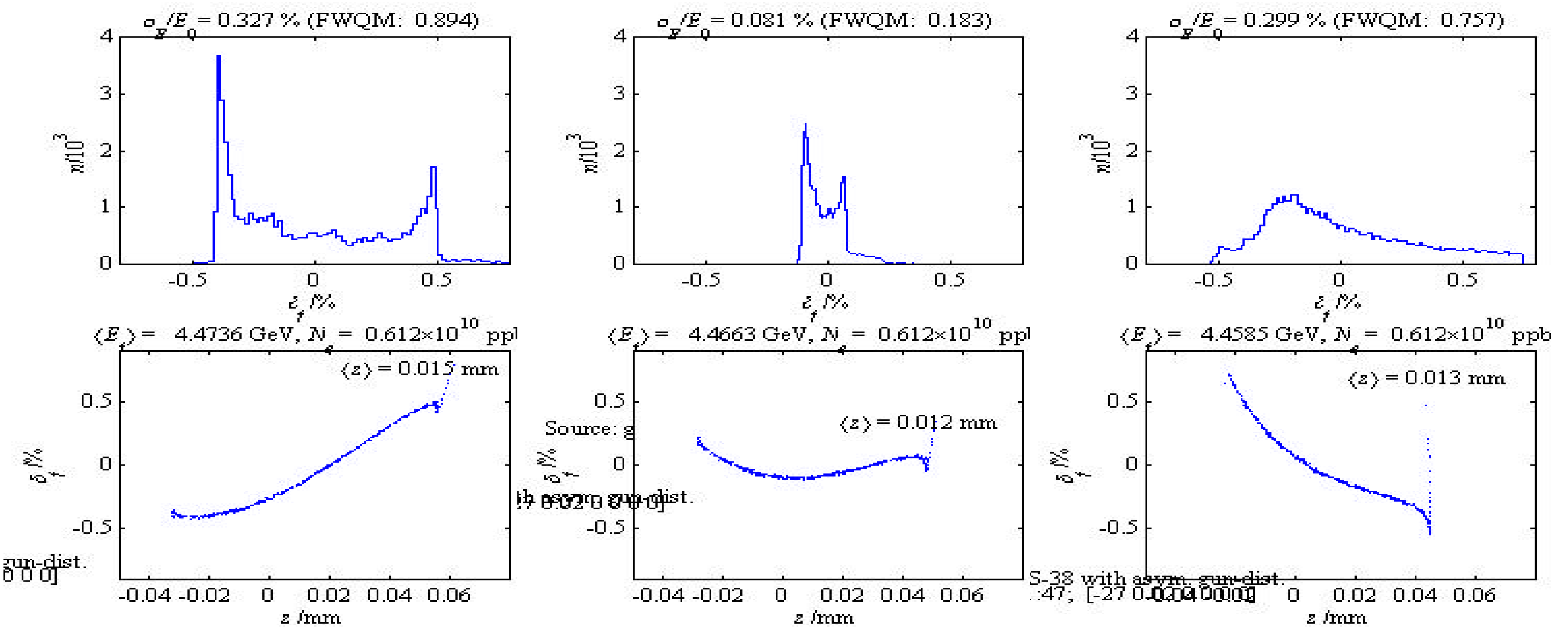



# Supplementary Slides

# RF Zero-Phasing Applied to LCLS

Paul Emma

| $f_{rf} = -90°$ | RF off | $f_{rf} = +90°$ |
| --- | --- | --- |
| $s_d = 0.33$ % | $s_d = 0.08$ % | $s_d = 0.30$ % |




$E_i = 4.5$ GeV

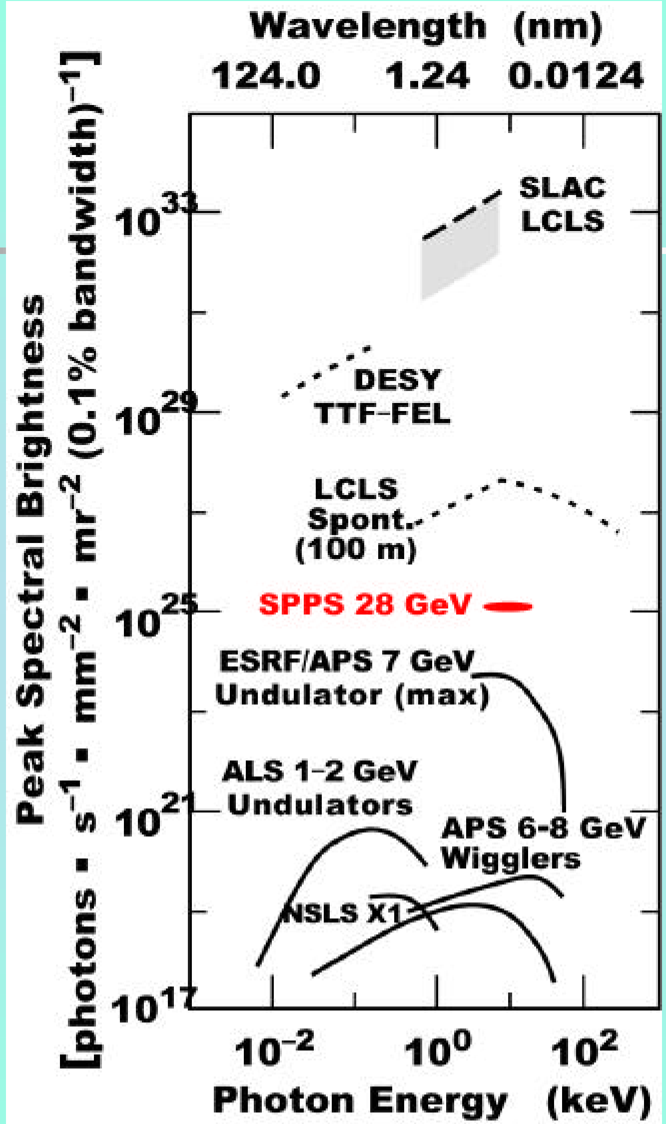
$E_f = 14.4$ GeV

$l_{rf} = 105$ mm

$$s_z \approx \frac{l_{rf}}{4p}\,\frac{E_i}{E_f - E_i}\left[s_{d(-90)} + s_{d(+90)}\right]$$

→ 24 mm

# Peak Brightness



# Minimum bunch length achievable...

Damping ring energy (1.2 GeV)

Damping ring energy spread (0.08%)

$$s_{z_{\min}} \approx \frac{E_{\mathrm{DR}}}{E} \frac{s_{d_{\mathrm{DR}}}}{s_{d}} s_{z_{\mathrm{DR}}}$$

energy in FFTB (28 GeV)

energy spread in FFTB (1.5%)

Damping ring bunch length (6 mm)

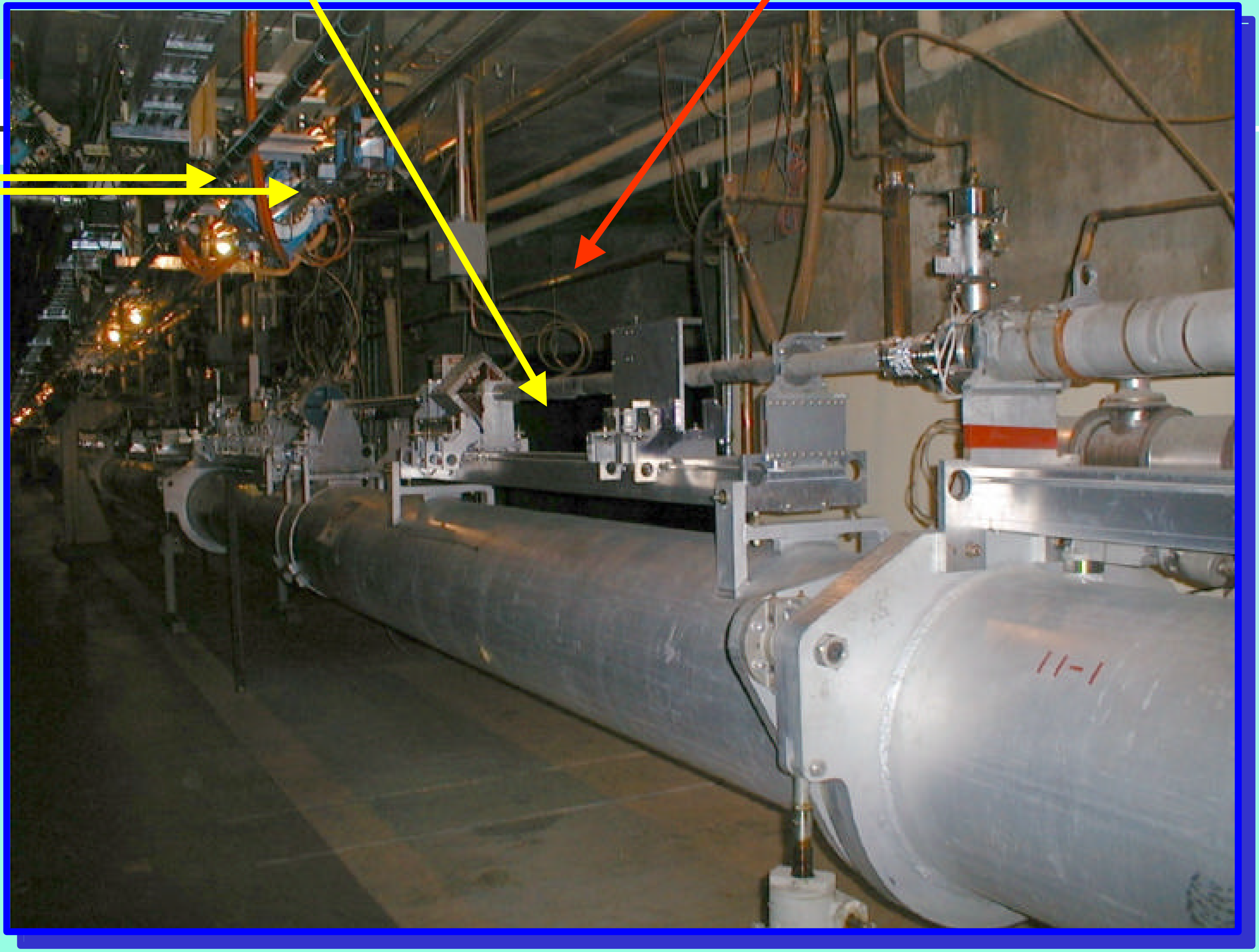
$$s_{z_{\min}} \approx 12\ m\mathrm{m}$$

preservation of longitudinal emittance

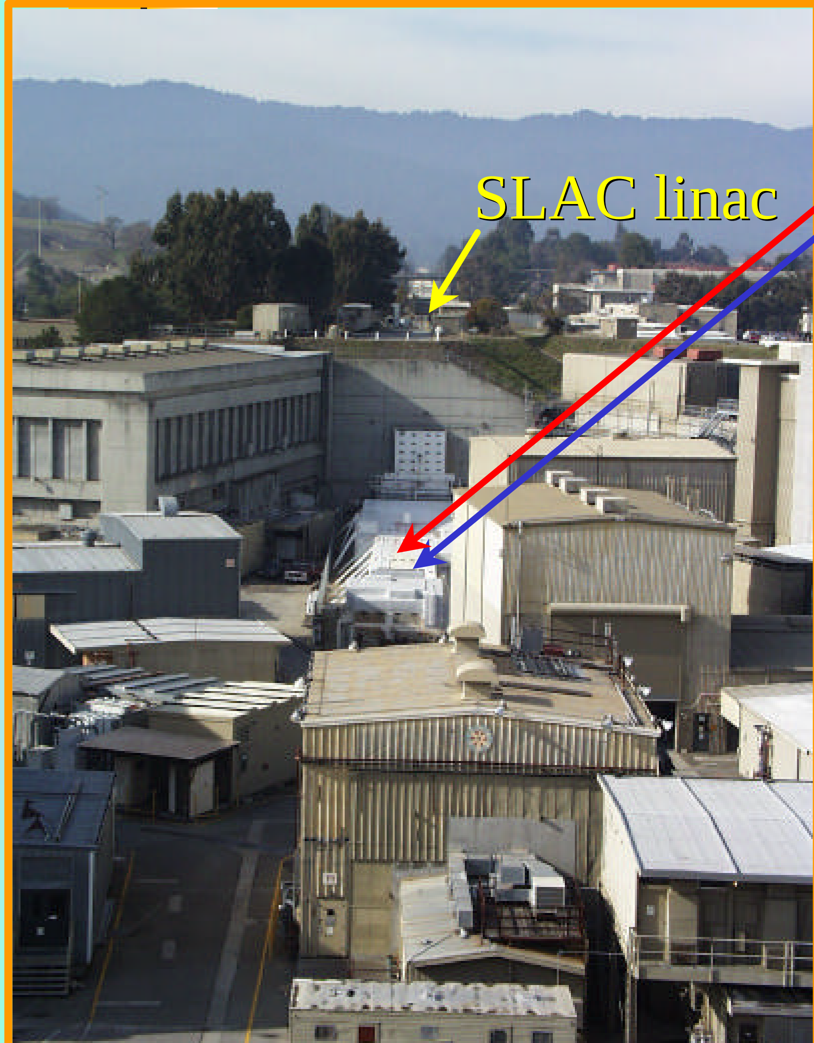
# Open Location in the Linac Sector 10

Long drift section at girder 10-9 opposite the Sector 10 off-axis tunnel.

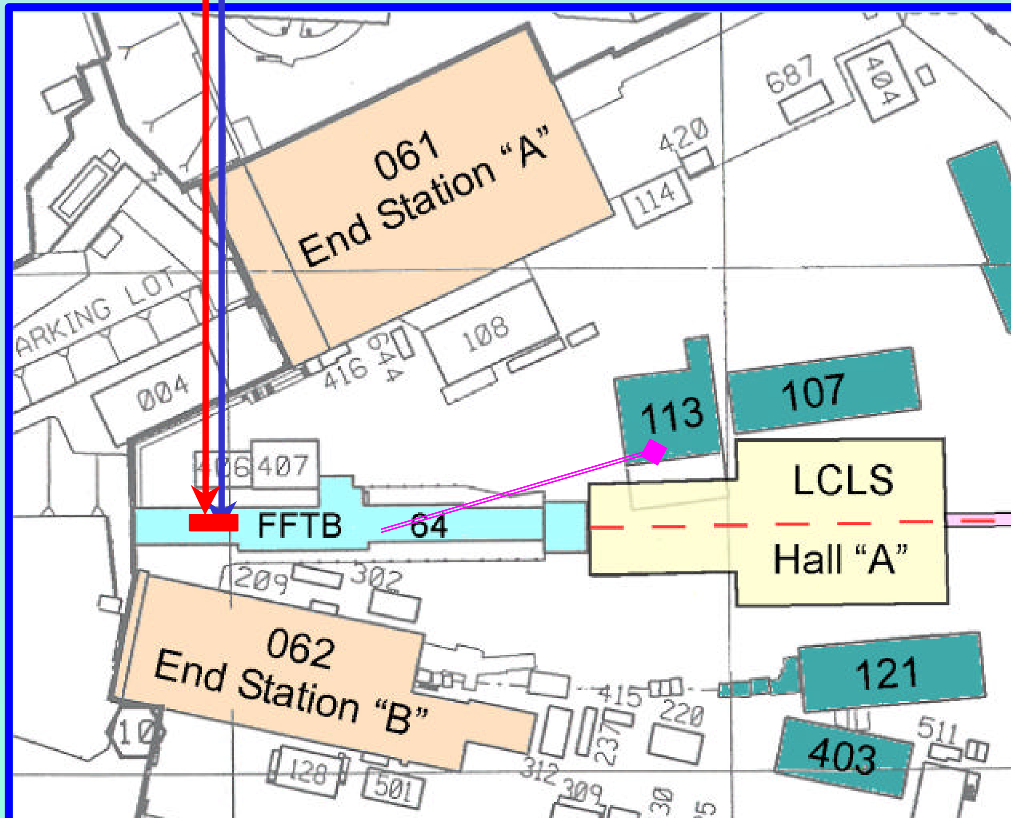
PEP II bypass lines



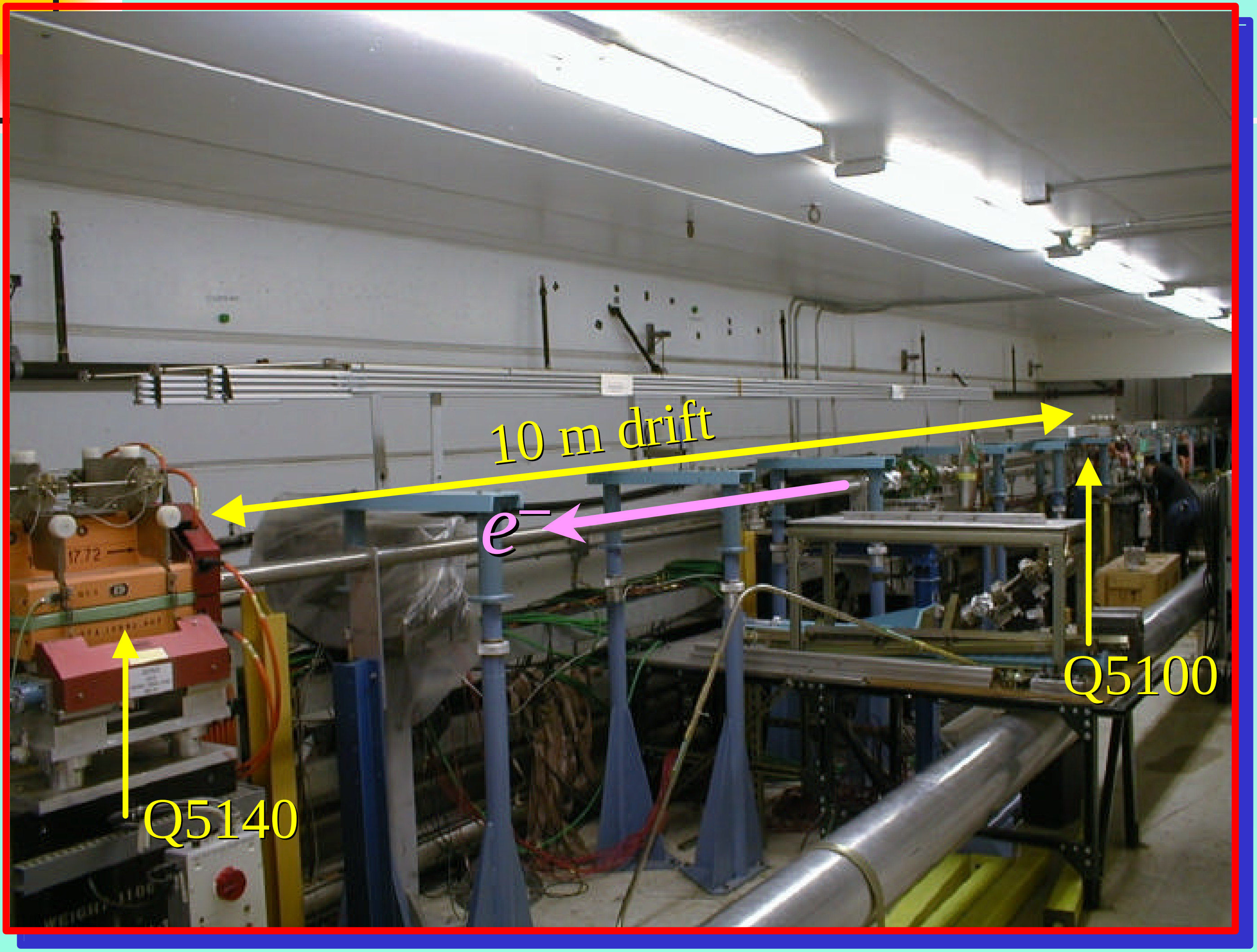
# Linac and FFTB Hall




add undulator to FFTB hall at end of linac

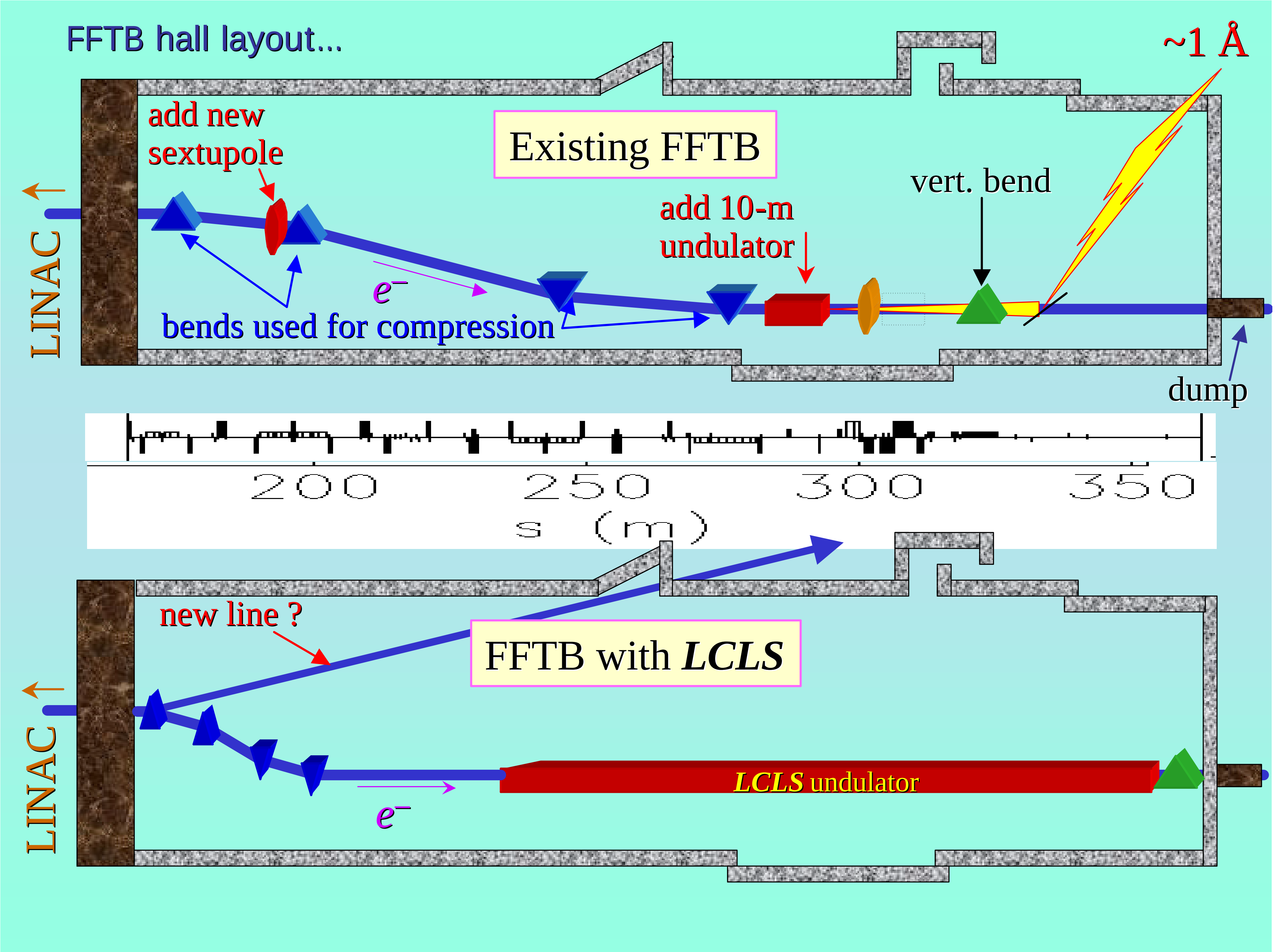


# FFTB Location for SPPS Undulator




Undulator parameters

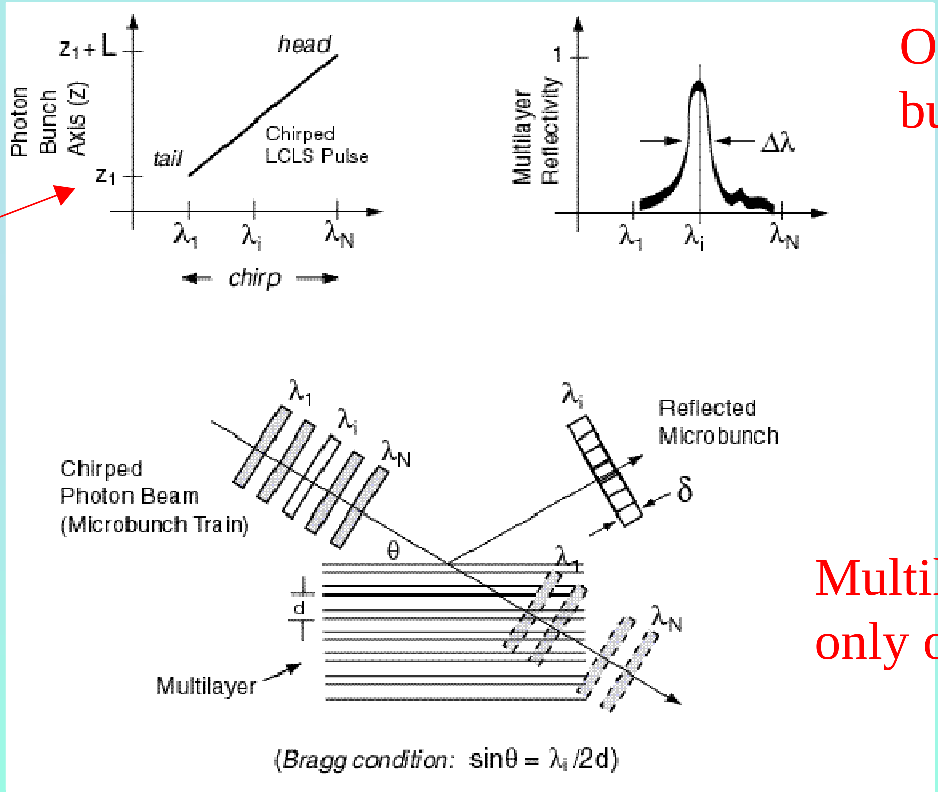
$L_u \approx 10$ m
$l_u \approx 4.5$ cm
$K \approx 6.2$
$B \approx 1.5$ T
$N_p \approx 220$



FFTB hall layout...
~1 Å
add new
sextupole
Existing FFTB
vert. bend
LINAC
add 10-m
undulator
e⁻
bends used for compression
dump
200
250
300
350
s (m)
new line ?
FFTB with LCLS
LINAC
e⁻
LCLS undulator

# Temporal slicing of photon beam

Chirp produces changing wavelength along bunch




One “slice” of the bunch is selected

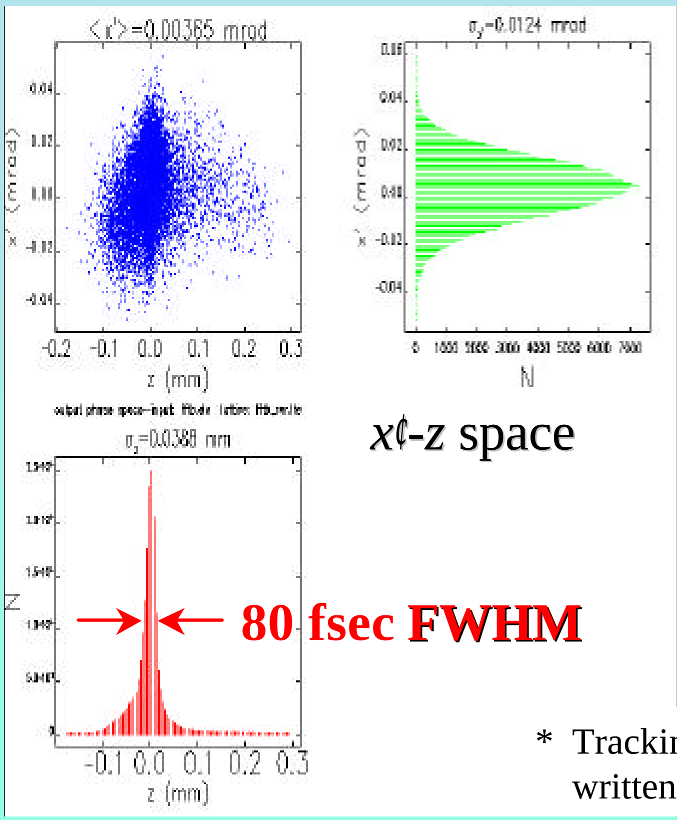
Multilayer reflects only one wavelength

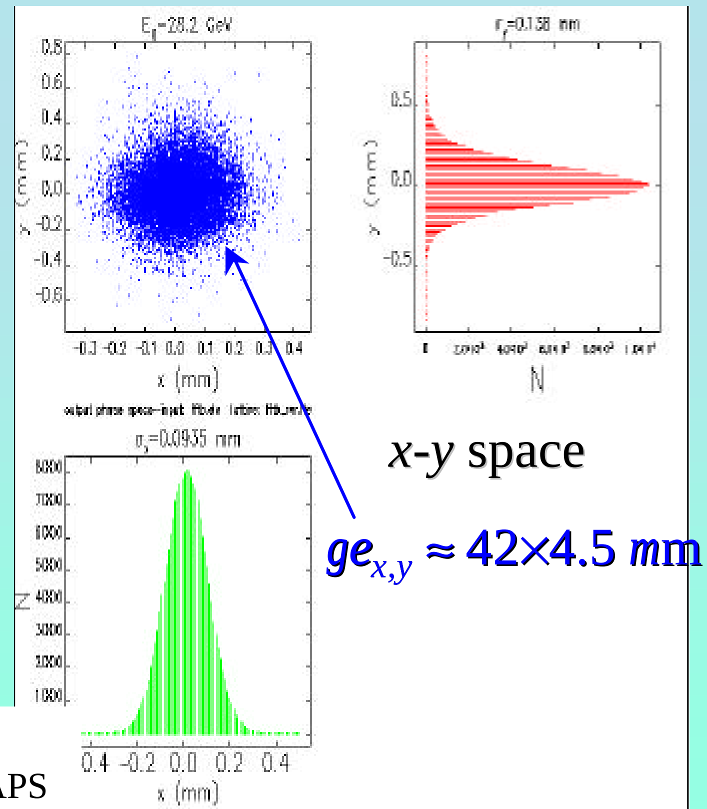
# Particle tracking* in 6D done and includes...

- >4000 beamline elements: *ring to undulator*
- 200k macro-particles
- Wakefields (geometric, resistive)
- Synchrotron radiation (coherent, incoherent)
- 2nd order aberrations
- Bunch compression with non-linear effects

Ring: $ge_{x_0} \approx 30\ mm$, $ge_{y_0} \approx 3\ mm$

No RF structure misalignments included yet, but ***SPPS*** is more tolerant than ***SLC***




* Tracking performed using ***Elegant*** written by Michael Borland at ANL/APS

# Profile Monitor Images with Transverse Deflecting Cavity