LCLS Linac Technical Design Review
Diagnostics and Controls

December 12, 2003

- *Requirements for beamline instrumentation*
  - *Upgrades for conventional diagnostics*
    - *BPMs, PROFs, Wire scanners, Toroids, Collimators, Stoppers*
  - *Prototyping developments for bunch length and timing devices*
- *Definition of control system requirements*

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Beamline instrumentation

- *Conventional diagnostics and their upgrades*
  - *BPMs, Toroids, Wire scanners, Prof Monitors, Synchrotron Radiation, Beam Phase, Collimation, Loss monitors*
- *Bunch length and timing diagnostics*
  - *Fast, single-bunch relative length measurement for tuning*
    - *Linac energy wakeloss scan*
    - *THz spectral power*
      - *OTR*
      - *CSR*
  - *Absolute bunch length determination*
    - *Average bunch length from CTR autocorrelation*
    - *3-bunch measurement with transverse RF deflecting cavity*
    - *Single shot electro optic pump probe measurement*

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Controls

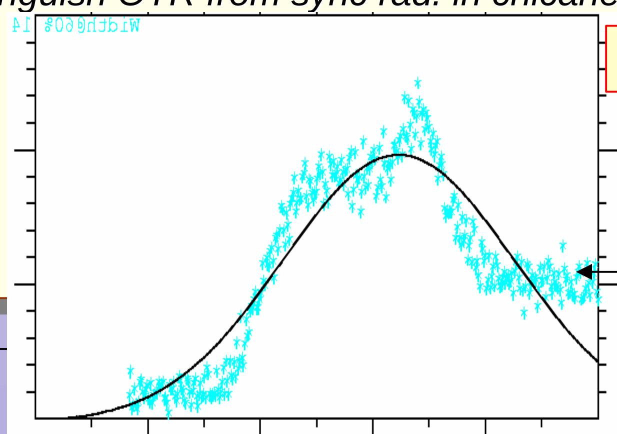
- *Modes of beam operation*
- *Control system architecture requirements*
  - *Single pulse reading and id in a shared SLC/Epics system*
- *Timing requirements*
- *Low level RF control*
- *Feedback requirements. Pulse-to-pulse control of*
  - *Orbit position & angle, energy, beam phase, bunch length*
- *MPS*
  - *Stoppers and beam dumpers*
- *PPS*
- *Control room*

Conventional diagnostics and their upgrades

- *BPMS*
  - *Linac BPM modules to be upgraded*
  - *Resolution requirements*
    - *5 um for 1 - 0.2 nC*
  - *New modules may be either camac or VME packaging*
    - *Long lead item, no resources as yet.*
  - *New stripline BPMs to be fabricated for chicanes*
    - *20 um res. for 1 - 0.2 nC in a 3 cm x 10 cm chamber*
  - *New stripline BPMs to be fabricated for the LTU in addition to existing FFTB BPM*
  - *Last 8 LTU BPMs redundant with undulator-style cavity BPMs*
    - *1 um resolution at 0.2 nC*

Conventional diagnostics and their upgrades

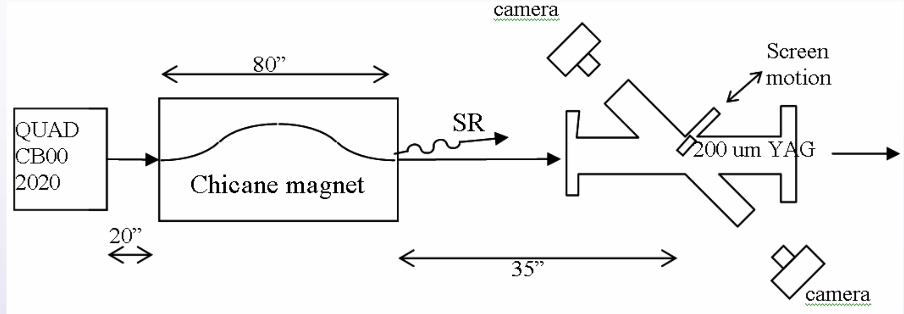
- *Wire scanners – average, projected emittance*
  - *Lattice locations optimized for phase advance*
  - *Small wire diameters for low emittance beams*
  - *Compromise between high Z for signal and low Z carbon wires in the LTU to minimize beam loss in the undulator*
- *Prof Monitors – single shot beam size, energy spread*
  - *High resolution measurement of small spots to be achieved with OTR screens (disruptive)*
    - *But requires careful, remote optics engineering layout and digital video acquisition*
    - *OTR screens require optical alignment – gaining experience at SPPS*
    - *Can distinguish OTR from sync rad. in chicane bends with polarizers*

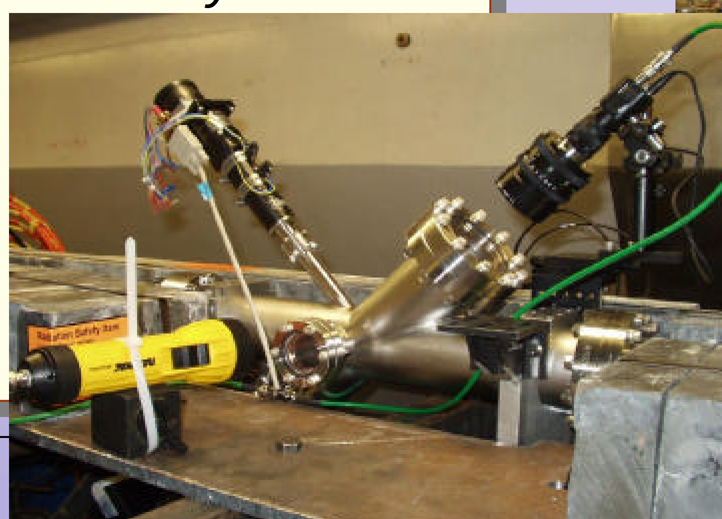


SPPS BC chicane measured energy spread

Synchrotron Radiation: single shot projected energy spread

- *Generated from vertical chicane wiggler in a horizontal dispersion region*
- *Lattice optimized for high DE resolution: low b_x, high h_x*
- *Optical resolution set by divergence of x-rays, filter out low energy x-rays with foil and use thin fluorescent crystal*





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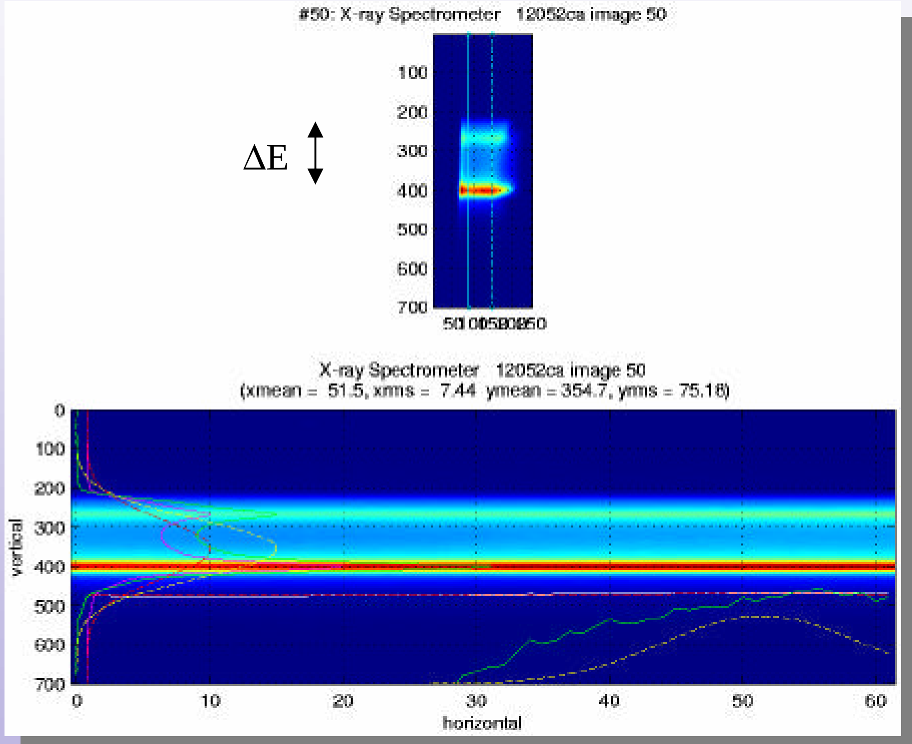
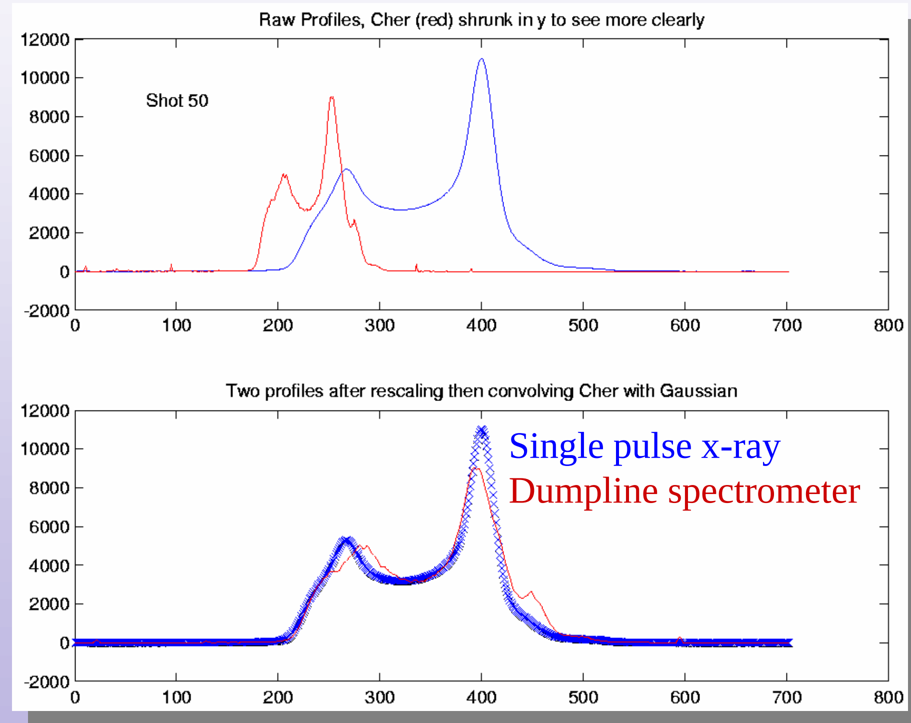
Synchrotron Radiation: single shot projected energy spread

Single shot measurement of x-ray stripe

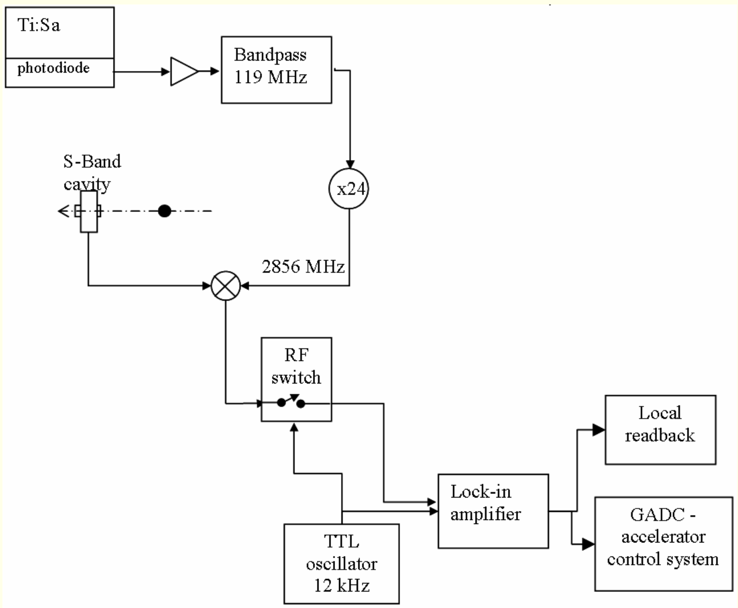


Compared to energy spread at dump spectrometer



Conventional diagnostics and their upgrades

- *Beam Phase Monitors*
  - *Use linac style S-band monitor cavities*
  - *Measure pulse-to-pulse phase jitter*
  - *Subject to thermal drift so can't use for feedback control of phase*
    - *Thermal stabilization technology (as required for the undulator) may make this possible in the future.*
  - *Beam phase can be measured w.r.t.*
    - *RF distribution*
    - *Laser from injector or at experiment*



Conventional diagnostics and their upgrades

- *Collimation*
  - *Movable energy collimator in each chicane*
    - *Diagnostic, and later for foil slits*
  - *Pair of adjustable energy collimators in the dog-leg bend of the LTU*
  - *Three x & y adjustable collimators in the matching section of the LTU*
    - *Two betatron phases and one clean-up in each plane*
- *Beam Loss Monitors*
  - *PLIC cables along the length of the machine*
  - *Protection Ion Chambers at*
    - *Injection, BC1 & BC2, dog-leg bend, collimation section*
  - *Toroid average current comparators around BC1 & BC2*
    - *Experience with SPPS*

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Bunch length and timing diagnostics

- *Fast, single-bunch relative length measurement*
  - *Linac energy wakeloss scan*
    - *Shorter bunches lose more energy from longitudinal wakes in the linac*
    - *Use energy feedback in LTU dog-leg bend*
    - *Plus energy feedback in BC2 to maintain fixed energy while scanning L2 phase*
    - *Demonstrated at SPPS as tuning tool*
    - *Confirmation of model for longitudinal wakes in S-band linac for short bunches*

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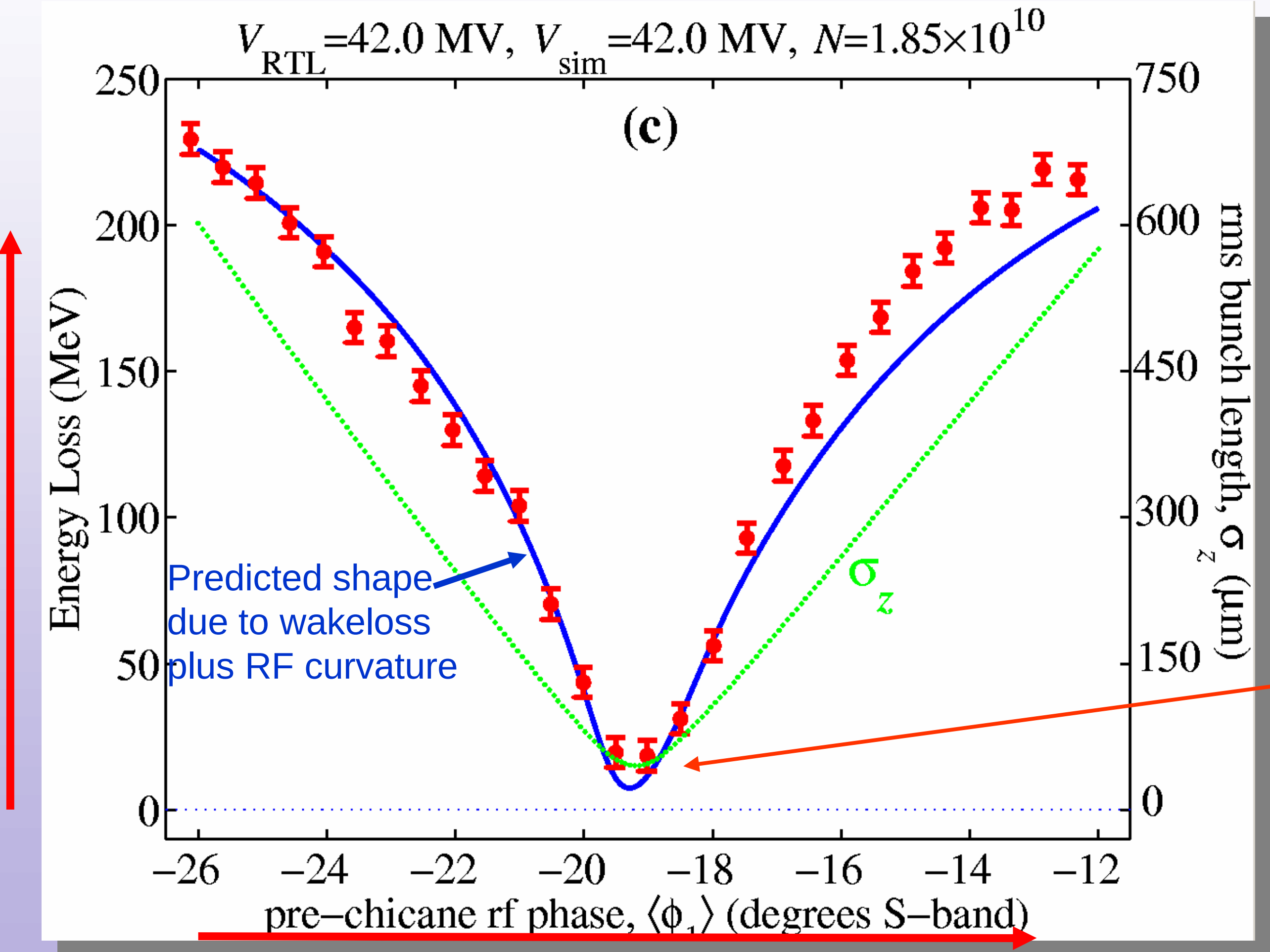
Relative bunch length measurement at SPPS based on wakefield energy loss scan



Energy change measured at the end of the linac

as a function of the linac phase (chirp) upstream of the compressor chicane

Shortest bunch has greatest energy loss

Predicted wakeloss___ (EMMA)
For bunch length s z___

Bunch length and timing diagnostics

- *Fast, single-bunch relative length measurement*
  - *THz spectral power*
    - *Coherent radiation from the bunch increases in power at shorter wavelengths as bunch length is reduced*
    - *Coherent radiation detected as either*
      - *OTR from a thin foil – demonstrated at SLAC/SPPS*
      - *CSR from a bend field – demonstrated at TJNAF*
    - *Difficult to calibrate as an absolute bunch length measurement*
      - *But relative changes in signal clearly show minimum bunch length in tuning scans*
    - *Simple spectral analysis showing power at different wavelengths can be used to tune to arbitrary wavelengths – under test DESY/SPPS*

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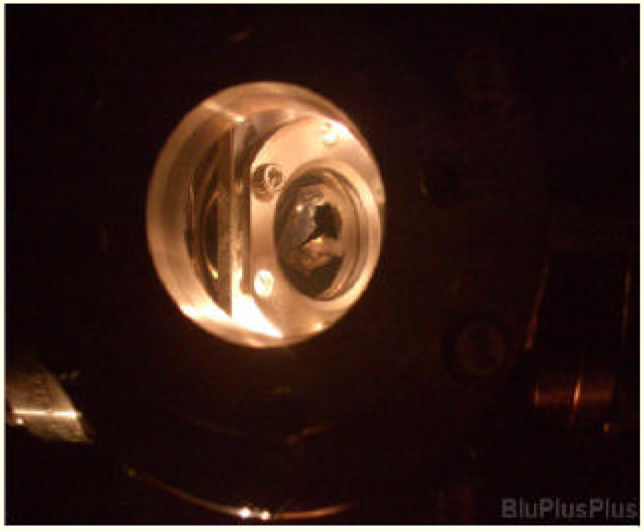
Bunch length and timing diagnostics

- *THz spectral power*
  - *OTR issues studied at SPPS*
    - *Intercepting thin foil (OTR) versus foil with hole (ODR)*
    - *Wavelength response of vacuum window*
      - *Fused silica*
      - *Mylar foil vacuum window*
      - *Window diameter*
    - *Wavelength response of water vapor*
      - *Dry nitrogen blanket*



Hole experiment!

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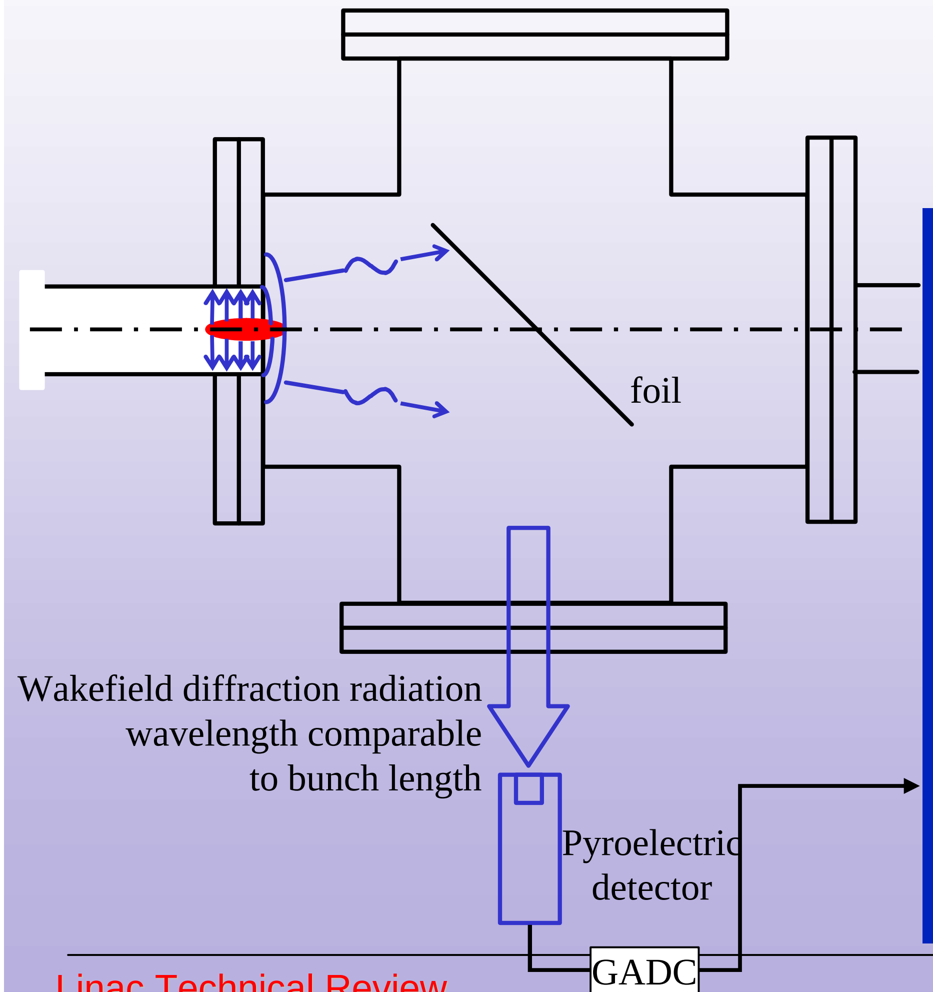
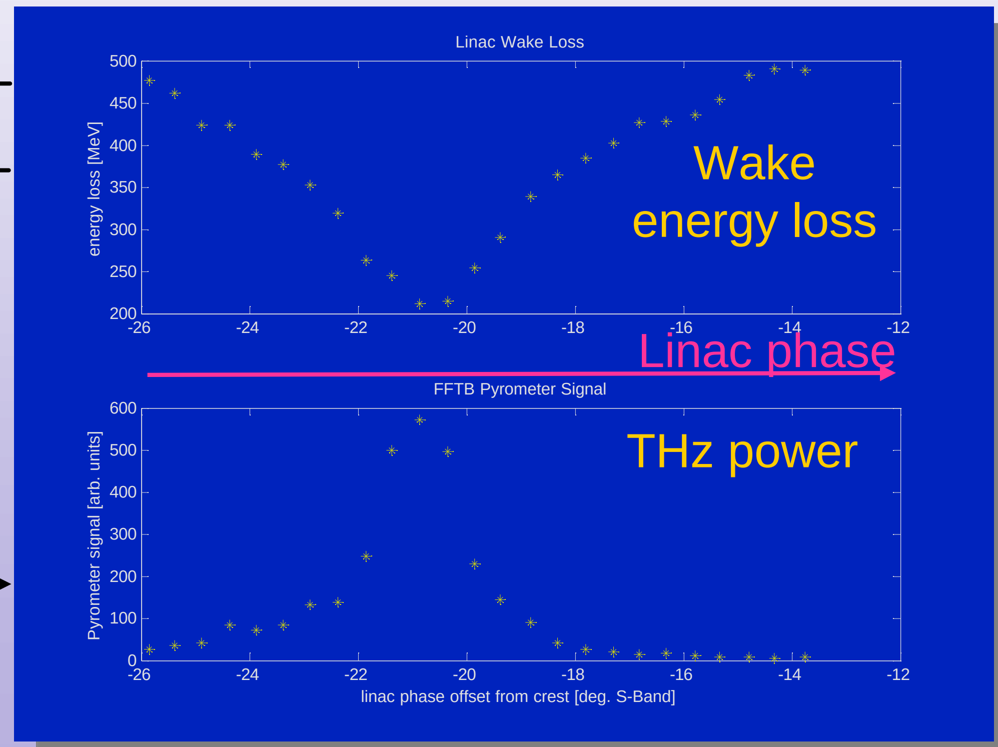
Far-Infrared Detection of Wakefields from Ultra-Short Bunches



Comparison of bunch length minimized according to wakefield loss and THz power



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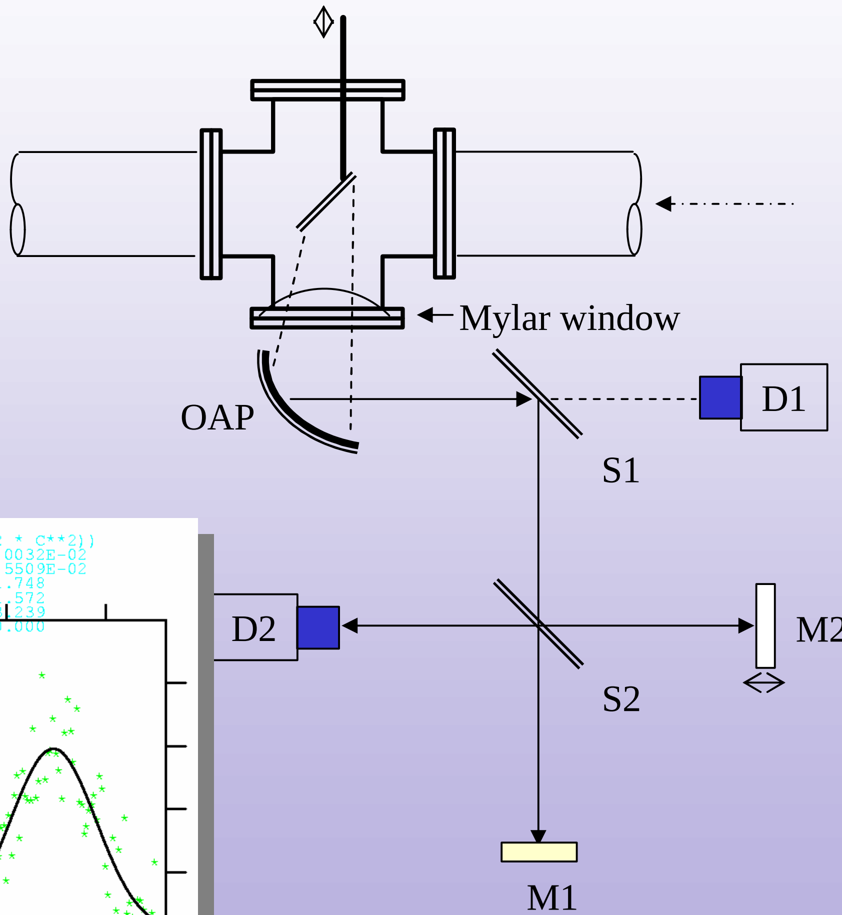
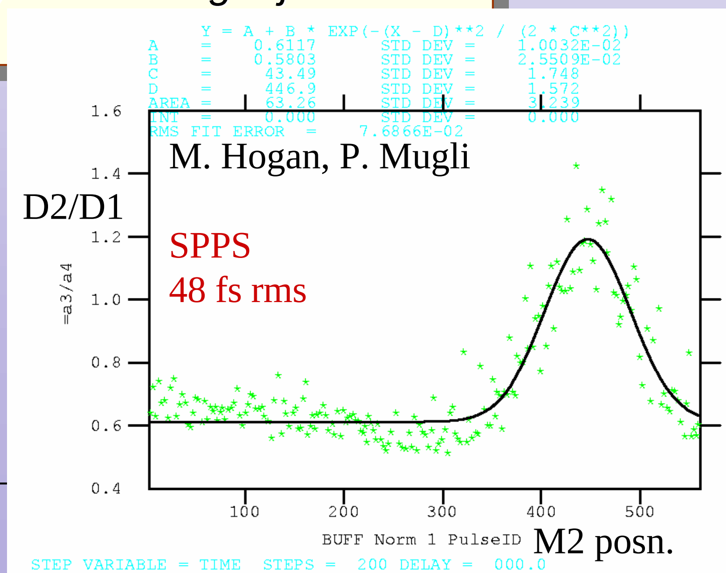
Absolute bunch length determination

- *Average bunch length from CTR autocorrelation*
  - *Radiation from the OTR screen is focused into an interferometer*
  - *One arm of interferometer is movable, so two profiles are swept through each other*
  - *Measured bunch length is calibrated in microns of arm motion*
  - *Averaged over many pulses, so integrates any bunch length jitter*





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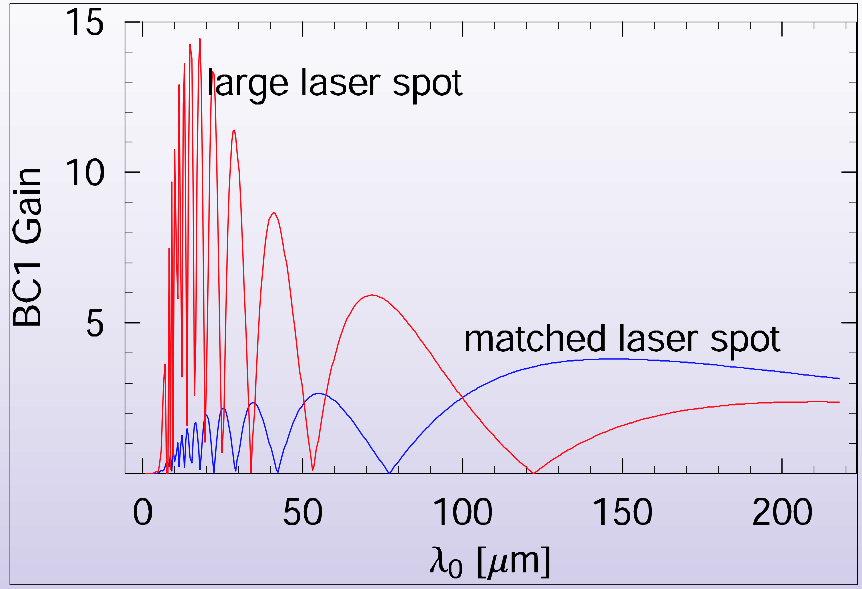
LCLS

Bunch length and timing diagnostics

- *Microbunching diagnostics*
  - *At exit of BC1 & BC2*
    - *Coherent transition radiation*
    - *Spectral power measurements*
    - *measurements can resolve micron-sized substructure in the bunch, demonstrated at LEUTL at 0.5 um scale (Lumpkin)*
    - *Coherent synchrotron monitor from final BC bend*
    - *Spectral power measurements*
    - *Analyze as radiation from an edge*

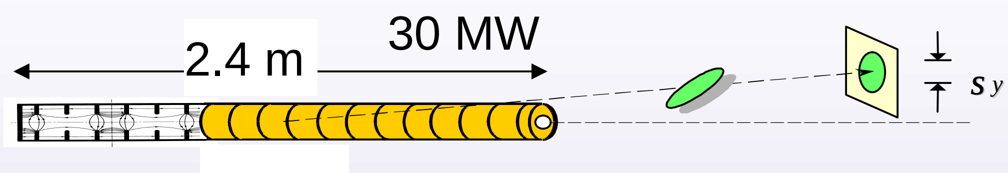


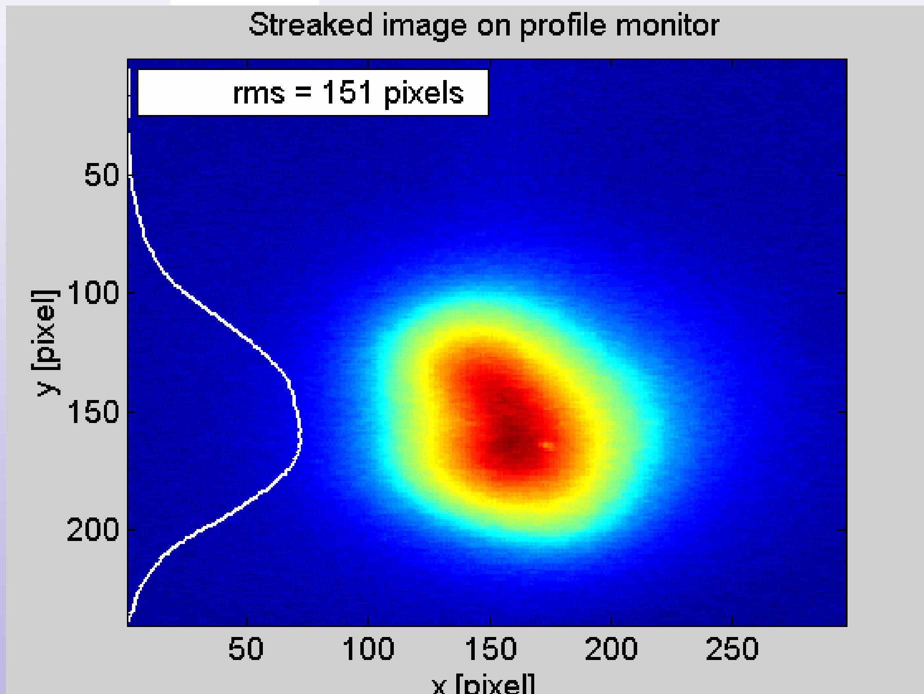
Z. Huang:
expect to observe microstructure at l_0/comp.fact

Bunch length and timing diagnostics

- *Absolute bunch length determination*
  - *3-bunch measurement with transverse RF deflecting cavity*
    - *Tested at SPPS*
    - *Initial transverse tilt to the bunch from transverse wakes requires measuring at both zero phase crossings*
    - *Absolute calibration of bunch length*
      - *in units of screen dimensions versus deg. S-band*
    - *Resolution determined by ratio of RF vertical kick to vertical beam size*
      - *Achieved 50 um resolution in SPPS at 28.5 GeV with 5 um emittance*
  - *1 Hz pulse stealing mode of operation*
    - *(new) pulsed magnet deflects beam onto off-axis screen*
  - *Future option is an x-band Tcav. in the LTU*

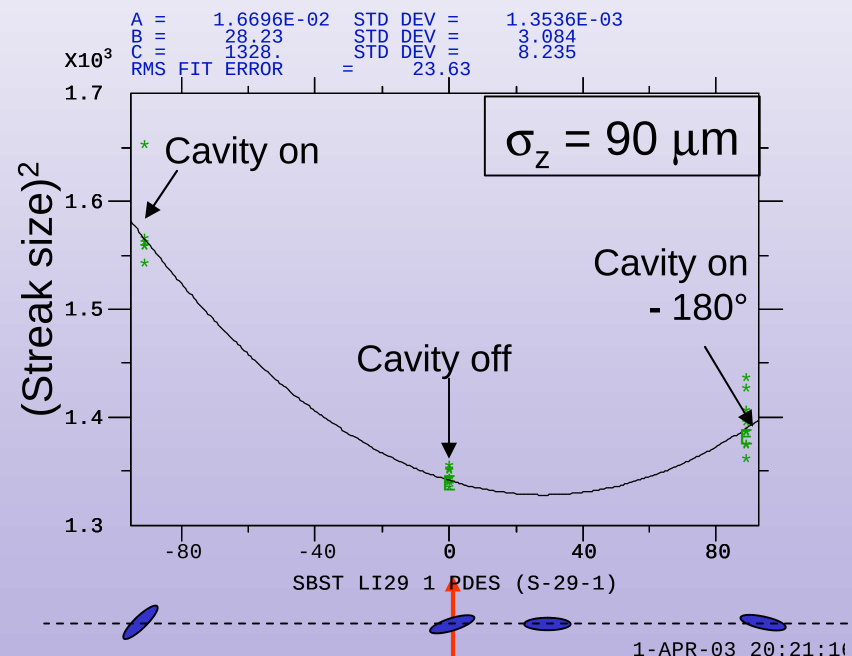
Bunch Length Measurements with the RF Transverse Deflecting Cavity

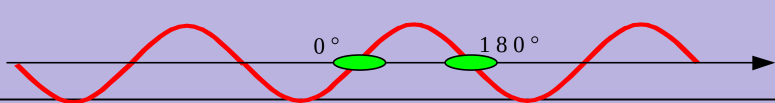




Bunch length reconstruction
Measure streak at 3 different phases

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





Asymmetric parabola indicates incoming tilt to beam

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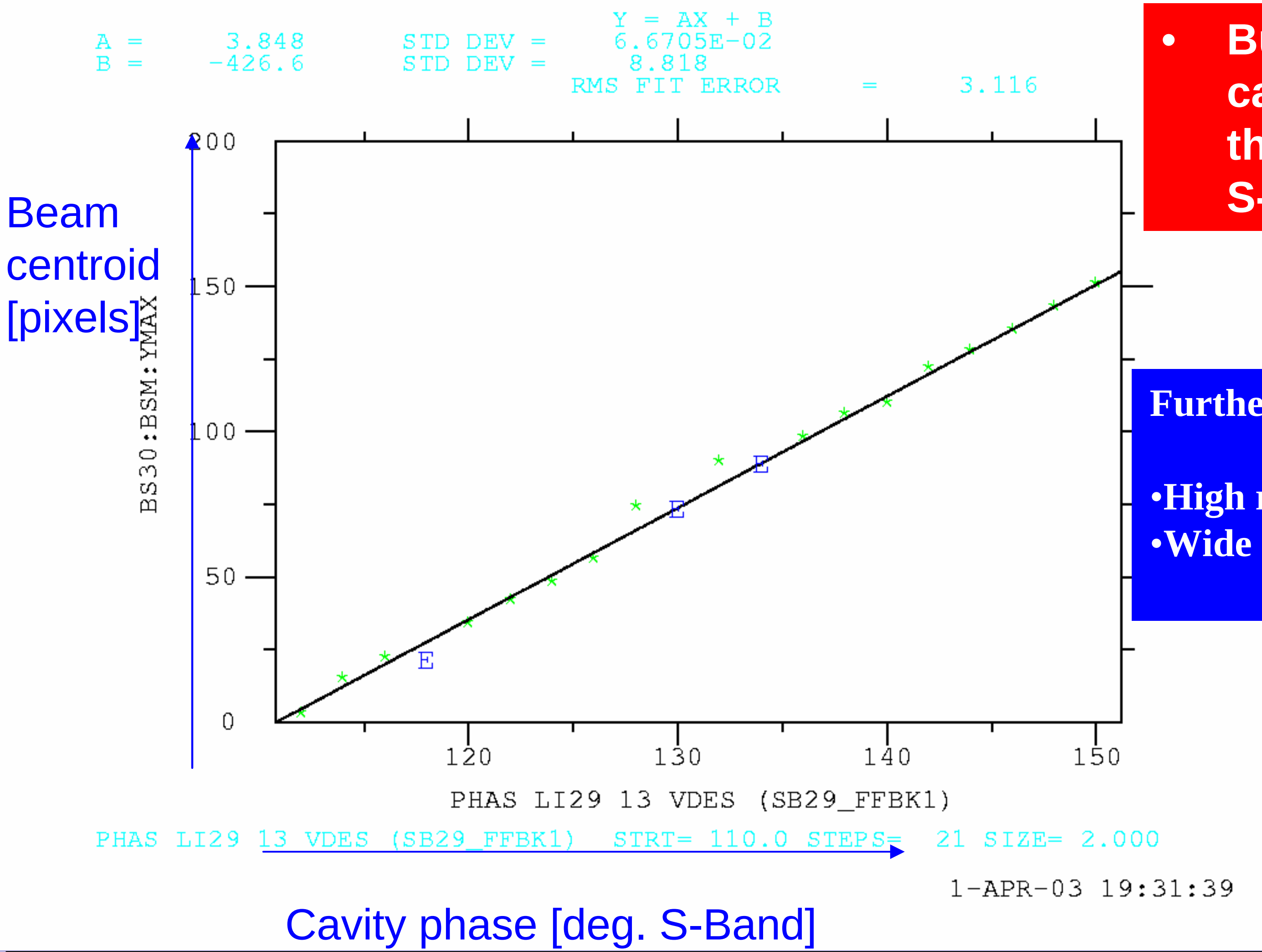
Calibration scan for RF transverse deflecting cavity



- **Bunch lenght calibrated in units of the wavelength of the S-band RF**

Further requirements for LCLS:

- **High resolution OTR screen**
- **Wide angle, linear view optics**

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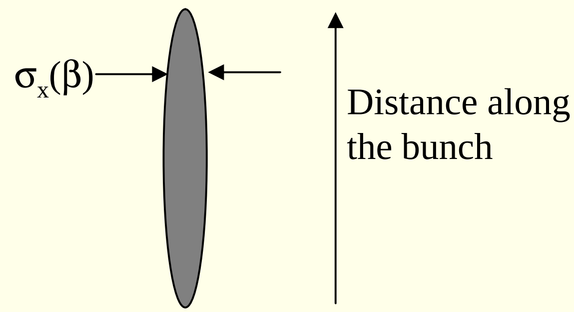
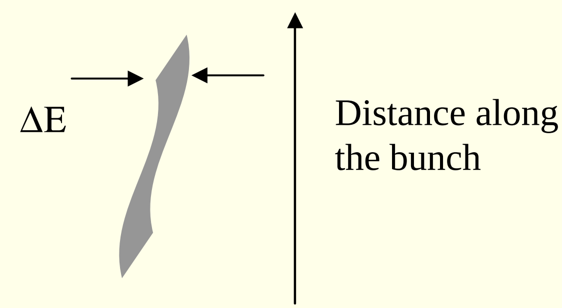
Slice parameters from transverse RF deflecting cavity

- *OTR screen down stream of the Tcav. can be used in conjunction with a quadrupole scan to measure horizontal slice emittance*



- *OTR screen down stream of the Tcav. At a horizontal dispersion location, large h_x, small b_x, can measure slice energy spread*



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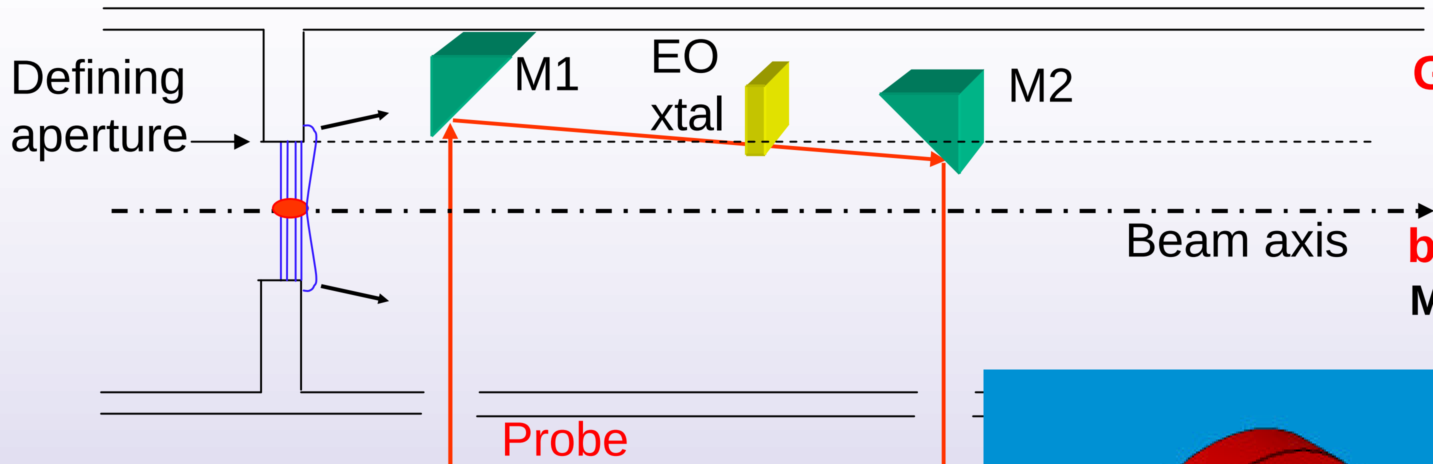
Bunch length and timing diagnostics

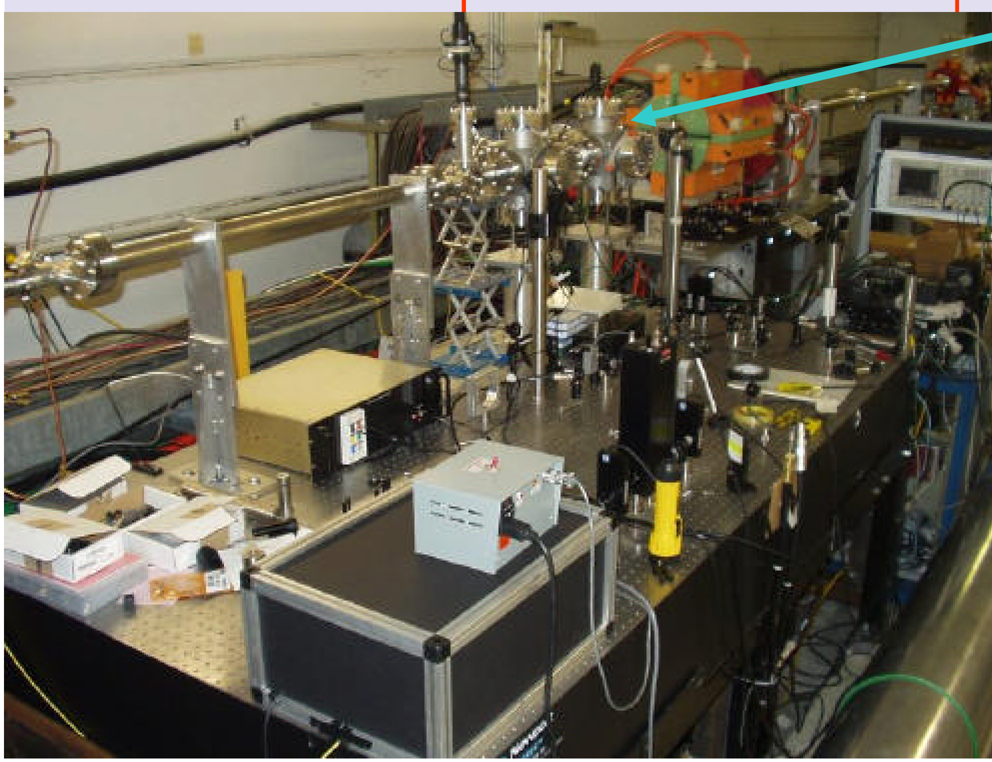
- *Absolute bunch length determination*
  - *Single shot electro optic pump probe measurement*
    - *Transforms the problem of measuring short electron bunch length to measuring a short pulse of laser light.*
    - *Electro-optic process is inherently fast, < 2 fs*
    - *Time resolution is dependant on crystal geometry and laser BW*
    - *Investigating two geometries at SPPS*
    - *Femtosecond laser systems are complex*
    - *Innovation at SPPS is transport a compressed beam to the e- beamline with a long fiber*

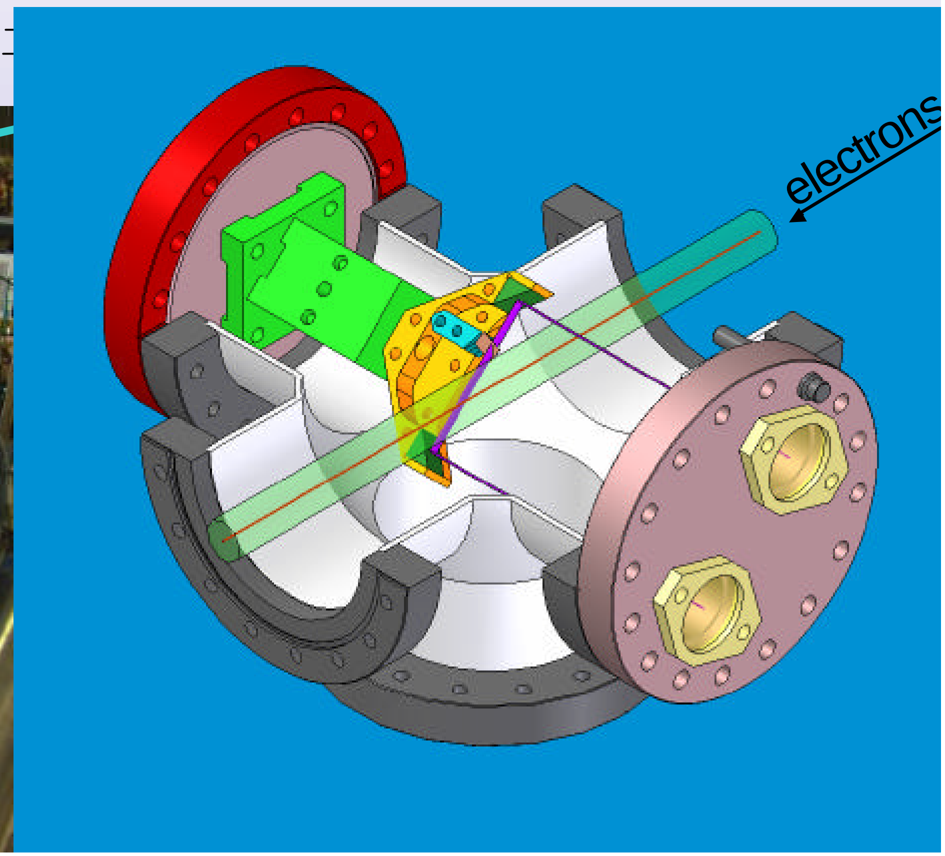
Electro Optic Bunch Length Measurement



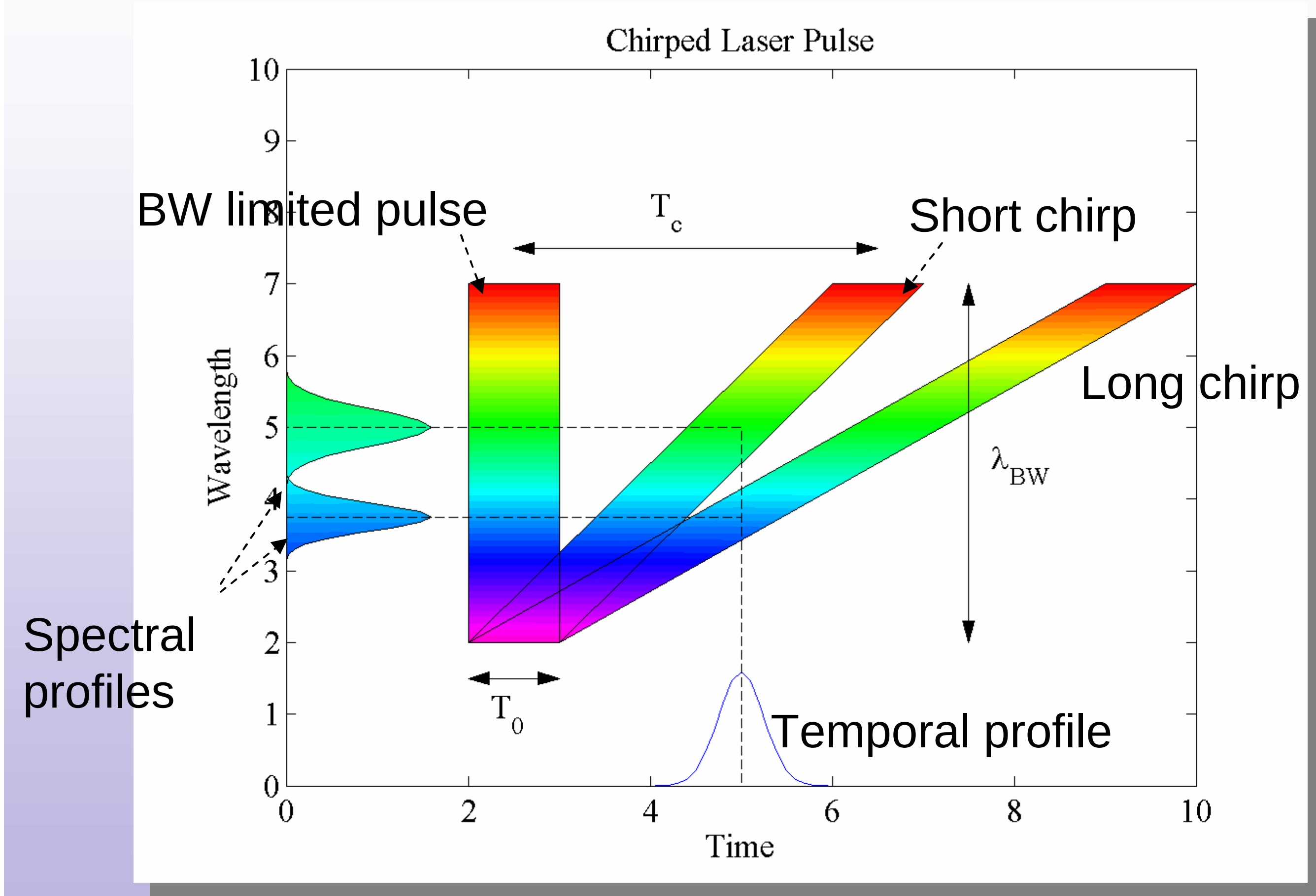
Geometry chosen to measure direct electric field from bunch, not wakefield

Modelled by H. Schlarb





Resolution limit in temporal-to-spectral translation



$$T_{res} = \sqrt{T_0 T_C}$$

However, recent work shows this limit can be overcome with noncollinear cross correlation of the light before and after the EO crystal

S.P. Jamison,
Optics Letters, 28, 1710, 2003

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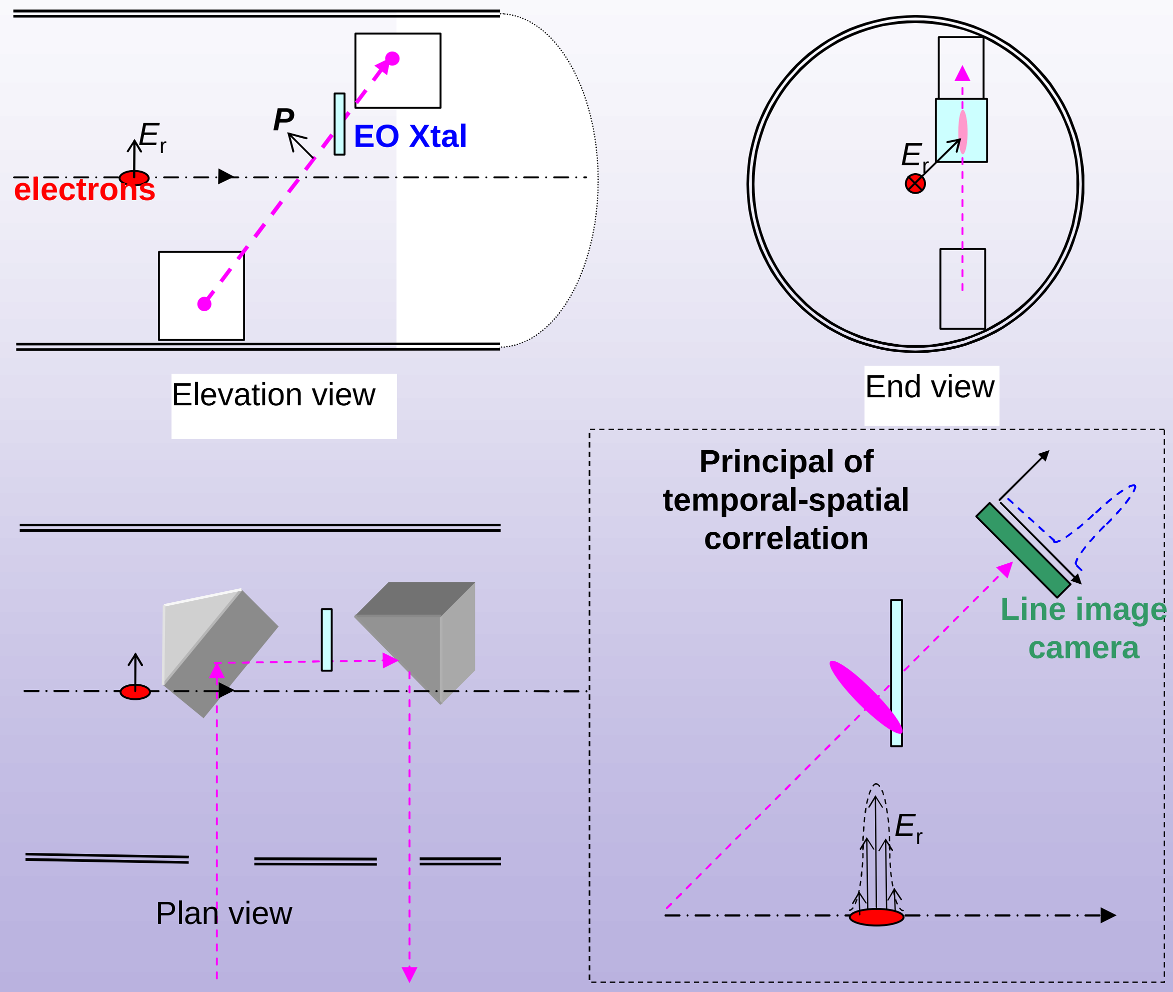
Temporal to spatial geometry under test at SPPS



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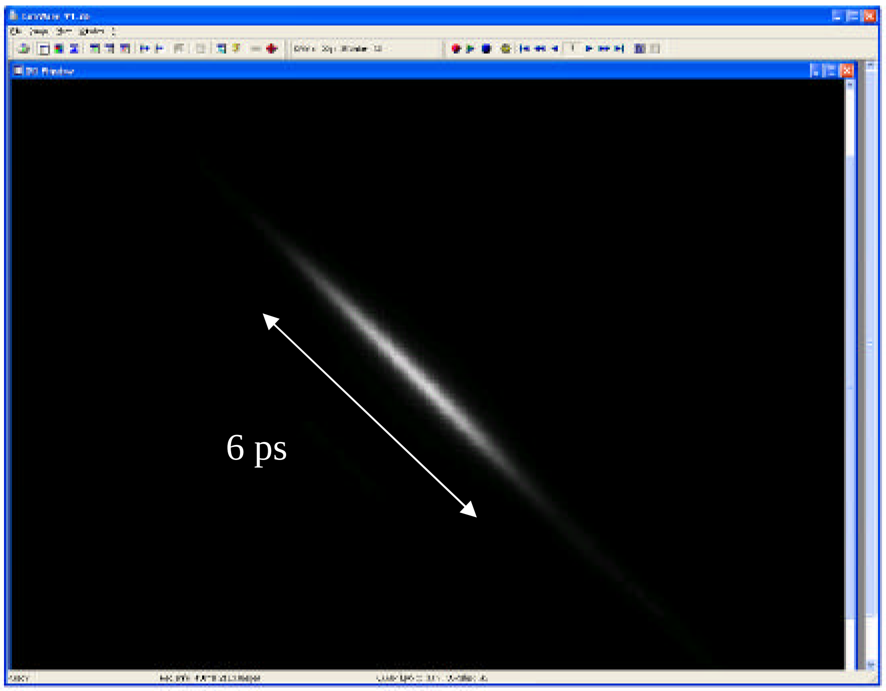
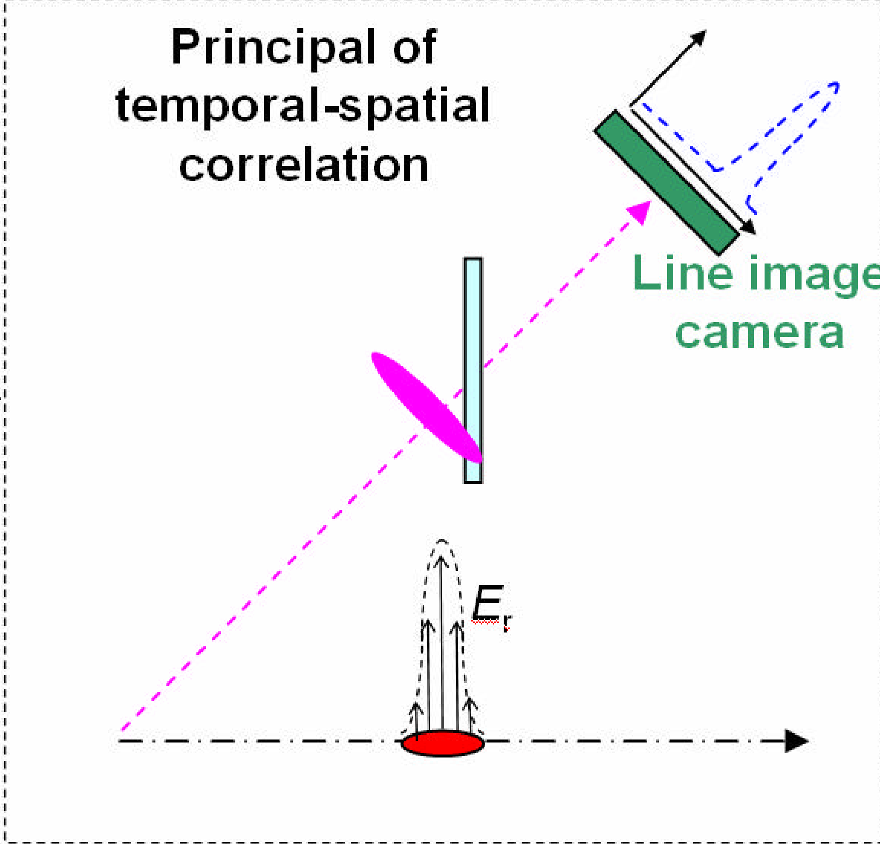
SPPS Electro Optic bunch length measurements – Adrian Cavalieri et al

Spatial profile of beam focused along time axis, total sweep only several picoseconds





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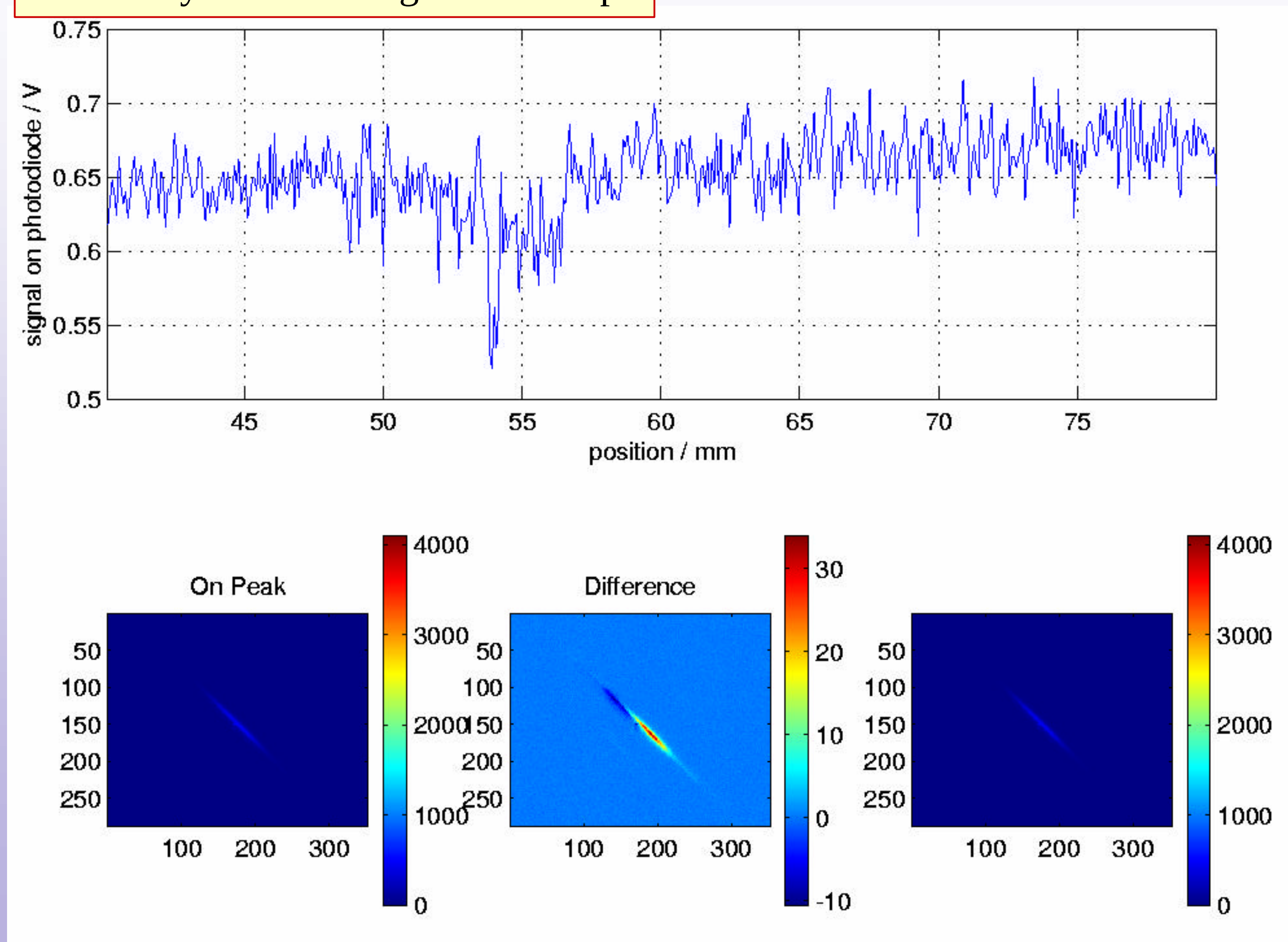
SPPS - EO signal vs time and single bunch

• thick crystal with long bunch > 1 ps



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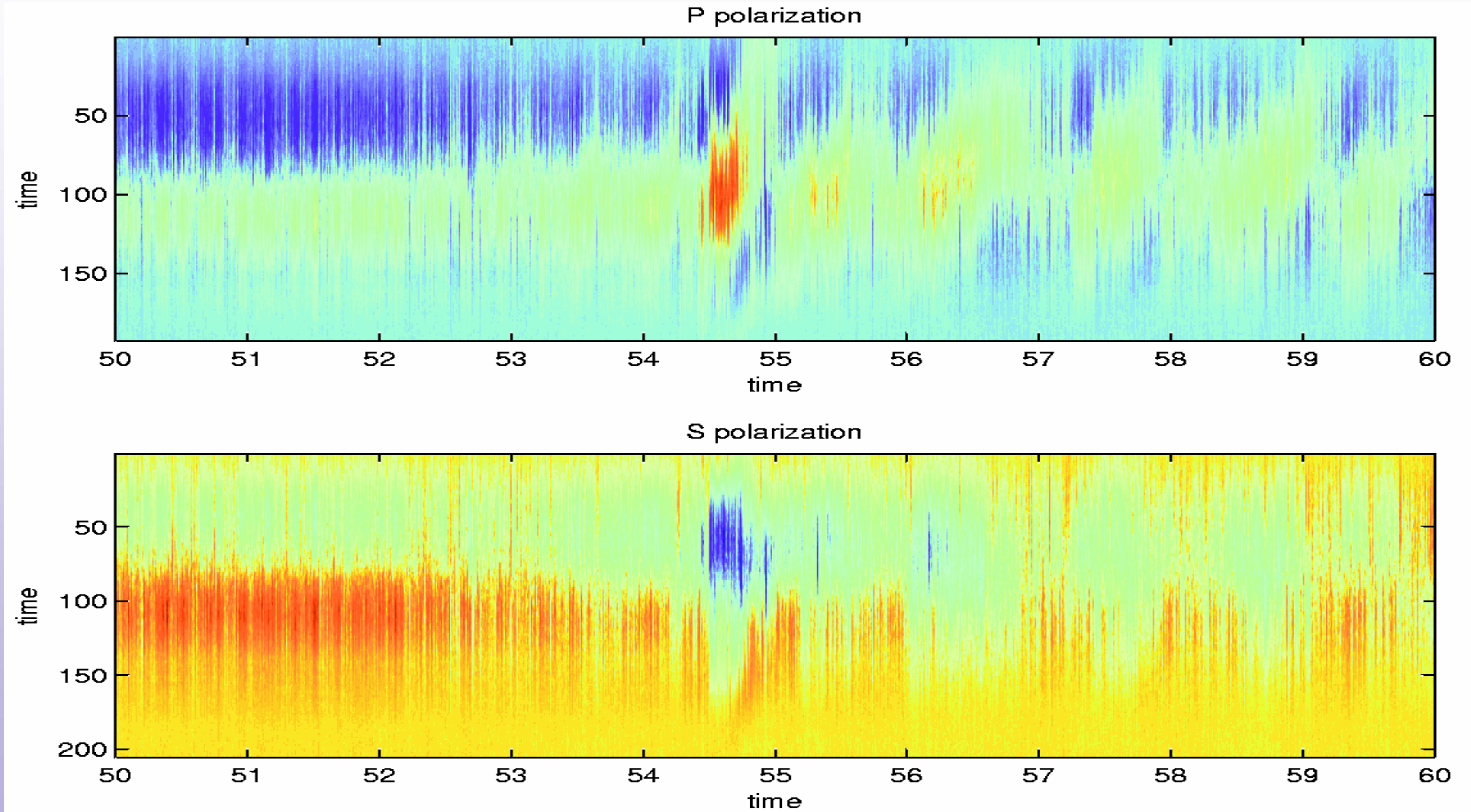
SPPS - time sequence of multiple EO images



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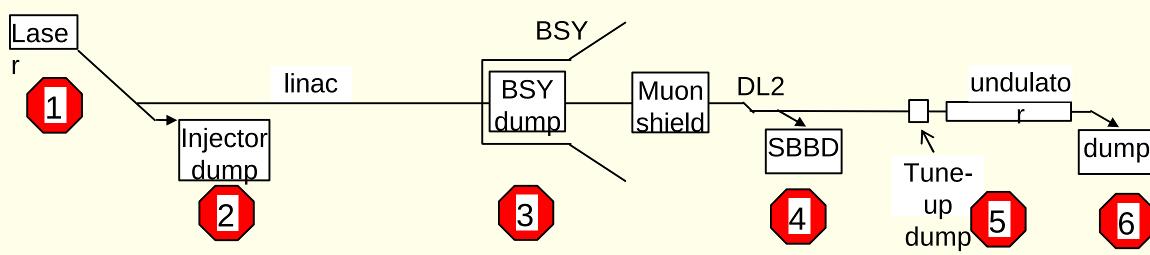
Controls

- *Modes of beam operation*
    1. *No beam, injector in controlled access*
        - *laser to cathode permissive, but no high-power RF permissive*
    2. *Injector operation with beam to the sector 21 dump in the linac housing*
        - *1 nC at 120 Hz maximum*
    3. *Beam to the BSY, stopped in the BSY*
        - *1 nC at 120 Hz maximum*
    4. *Beam to the LTU (linac to undulator) single bunch beam dump*
        - *1 nC at 120 Hz maximum*
    5. *Beam to the undulator entrance tune-up dump*
        - *1 nC at 10 Hz maximum*
    6. *Beam to the final beam dump*
        - *1 nC at 120 Hz maximum*



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Controls

- *Timing requirements*
  - *Choice of frequencies*
    - *The linac RF operates at 2856 MHz*
    - *The laser for the RF photoinjector will be synchronized to the 24th subharmonic at 119 MHz*
  - *The timing system counts cycles of 119 MHz and can be adjusted in inter periods of this frequency, giving a timing step size of 8.4 ns.*
  - *Time slots chosen to avoid PEP II phase shifts on the MDL*
    - *Preferable solution is if PEP II phase shifts are removed from MDL*
  - *Trigger resolution of 8.4 ns and stability of 10 ps adequate*
    - *Although doesn't provide absolute RF bucket determination*
  - *Pulse identification, buffering and feedback*
  - *RF phase locking and stability*

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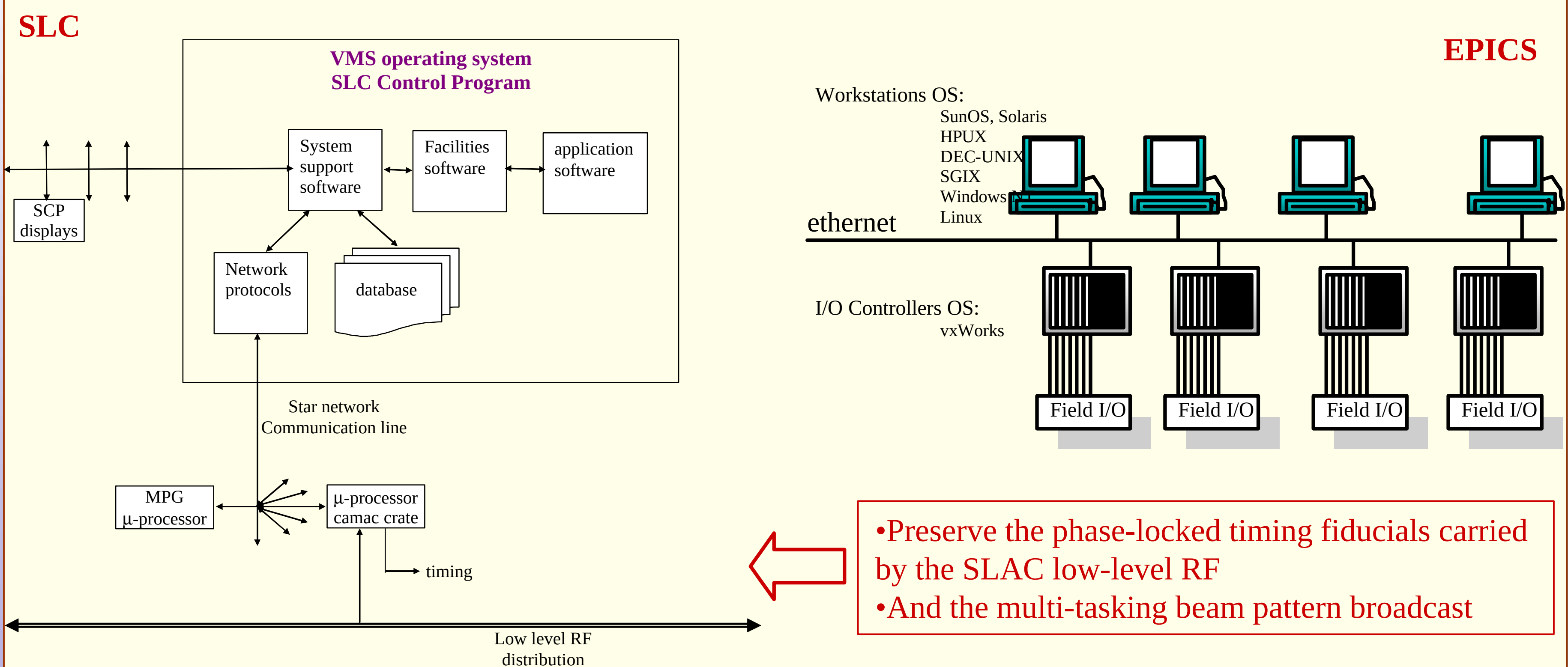
Controls - system architecture requirements

- *How to preserve single pulse reading and id in a shared SLC/Epics system*



•Preserve the phase-locked timing fiducials carried by the SLAC low-level RF
•And the multi-tasking beam pattern broadcast

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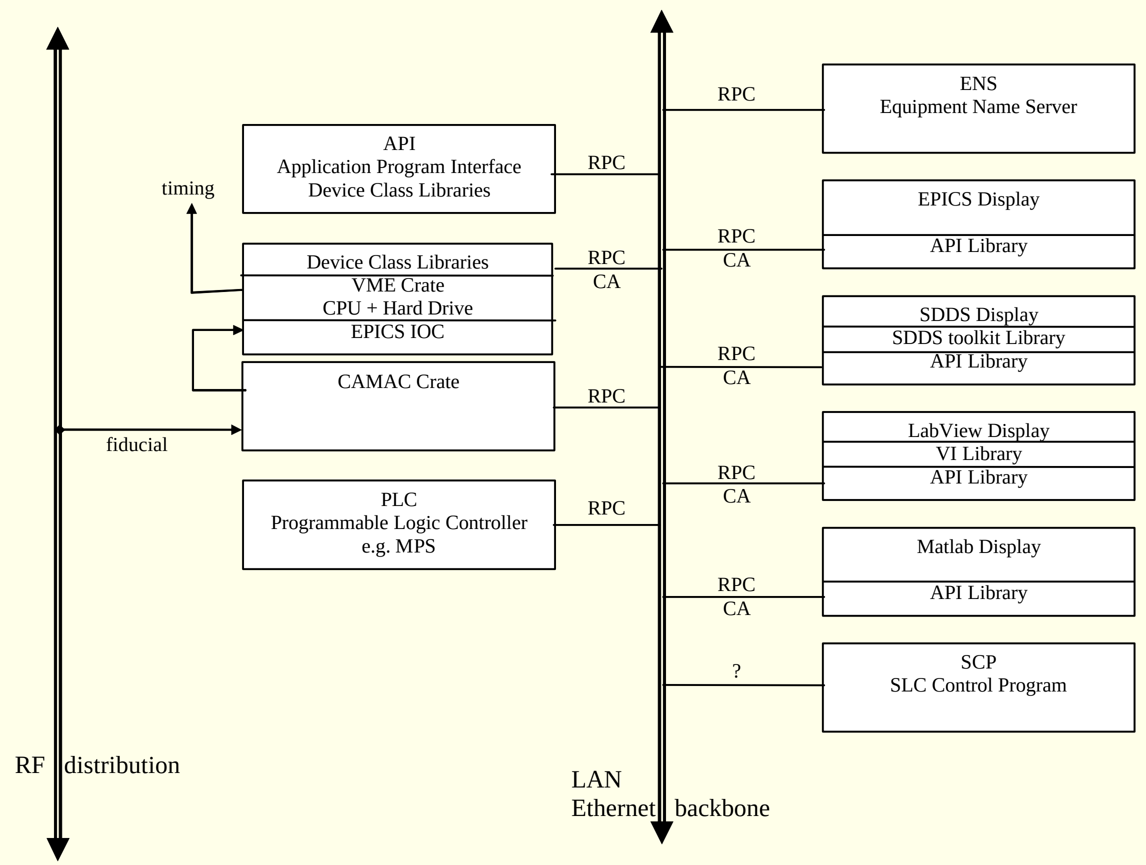
Control system hybrid

- *Requires multi-protocol support on the LAN*



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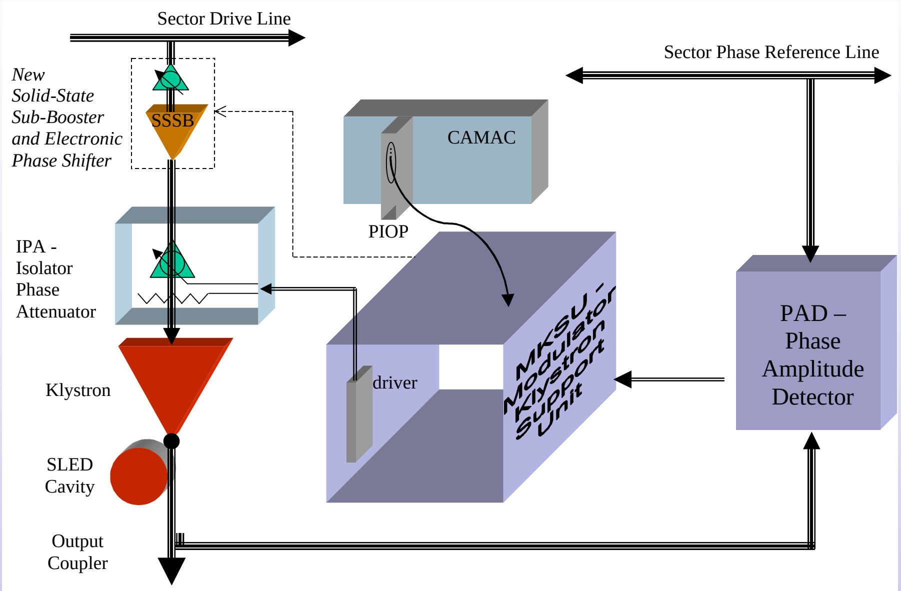
Controls - Low level RF

- *Present parallel input-output processor (PIOP) control of phase and amplitude does not meet LCLS specs*
- *Feasibility study to packaging of new module in either camac or VME/epics*
  - *Long lead item, but no resources allocated so far*
- *Some klystrons will run unsaturated with individual phase and amplitude control using solid state subboosters*



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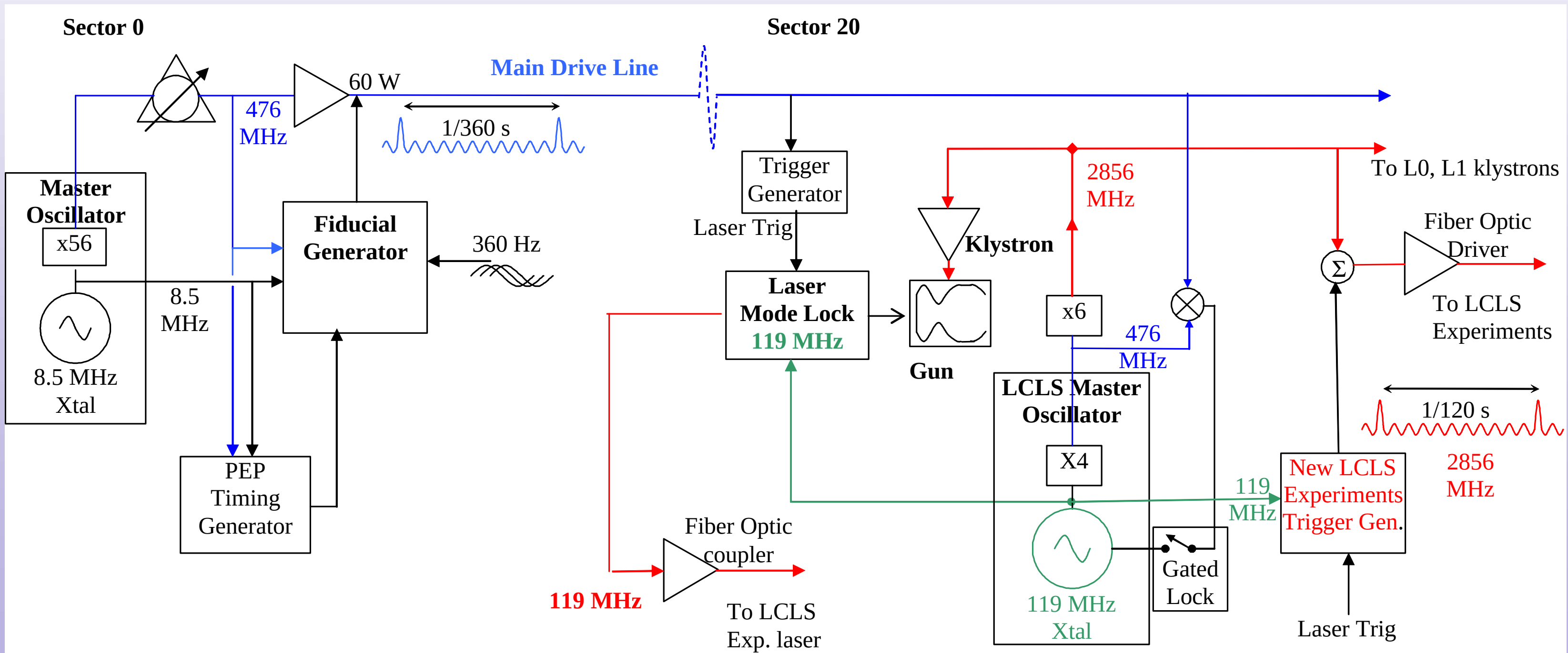
Controls - Low level RF

- *Low-noise, low-drift RF source in sect 20*
  - *Change from CDR, now lock at 119 MHz*



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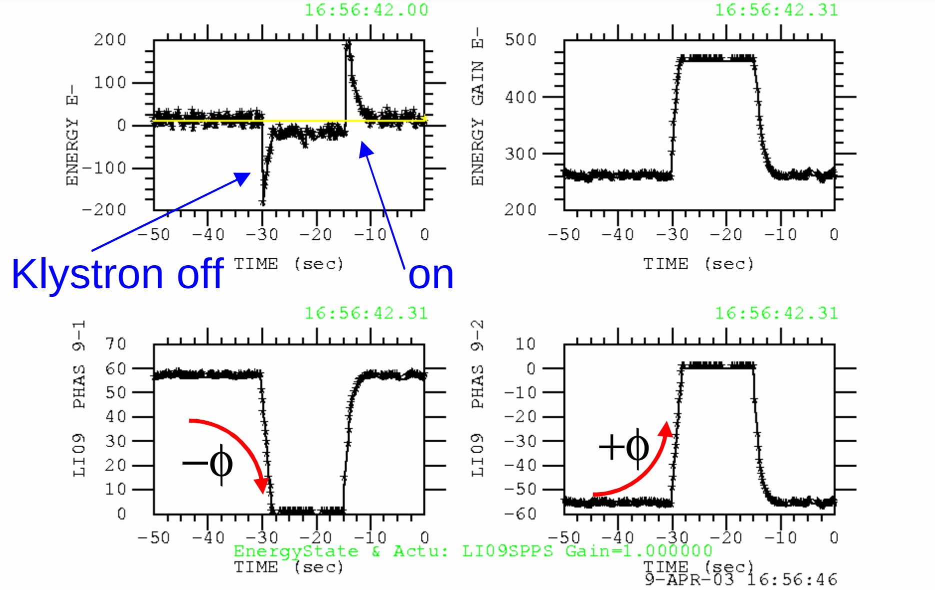
Controls - Low level RF

- *Low-noise, low-drift RF oscillator issues*
  - *Oscillator and distribution housed in thermally stabilized enclosure*
    - *In spite of this there will be some drift requiring beam-based feedback*
  - *Advances in technology have allowed us to choose 119 MHz over previous 79.33 MHz*
    - *Greatly simplifies timing system as we are now in synchronization with existing timing fiducials*
    - *Big advantage for experimenters who can mode lock their lasers to photoinjector laser with 119 MHz optical pulses and always be in the same RF bucket*
    - *Lesson learned from SPPS that exp laser is susceptible to bucket jumps*
  - *LCLS will operate on a different time slot from PEP II*
    - *Avoid phase jumps on MDL during PEP injection*
    - *Feasibility study to reconfigure phase shifters and avoid MDL phase jumps*

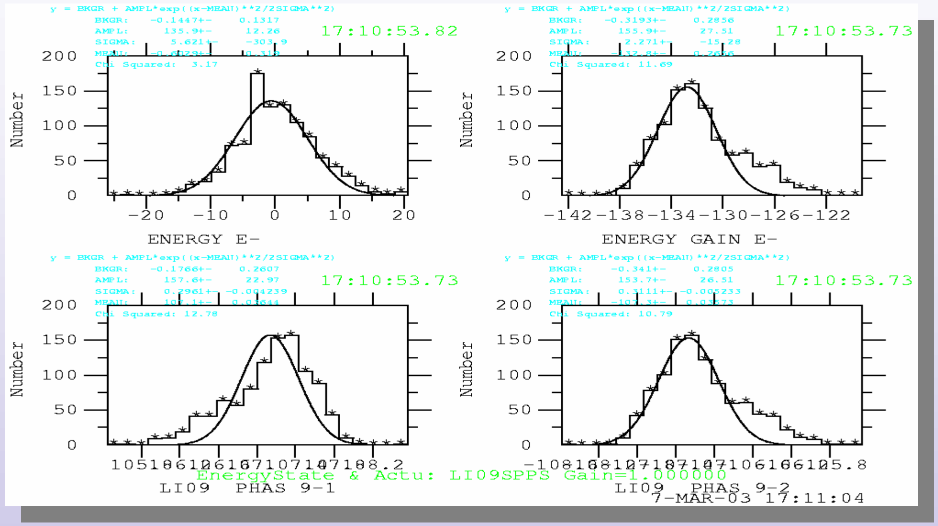
Controls

- *Feedback requirements.*
  - *Pulse-to-pulse control of*
    - *Orbit position & angle, energy*
      - *as in SLC*
    - *beam phase,*
      - *Necessary, for example, to measure orbit after RF deflecting cavity to maintain cavity at zero phase crossing*
    - *bunch length*
      - *Use relative signal strength from OTR THz spectral power measurement*
      - *Demonstrated at SPPS with dither feedback to minimize bunch length*
      - *Needs power measurement at several THz wavelengths to tune to arbitrary bunch lengths*
      - *Decouple longitudinal feedback requirements*
        - *Energy feedback maintains constant energy at the BC chicane*
        - *Bunch length feedback controls the linac phase (energy chirp)*

Controls – Energy feedback



Klystron 1 Klystron 2



Energy feedback at SPPS chicane responding to a step energy change

Energy measured at a dispersive BPM,
Actuator is a klystron phase shifter

Energy jitter measured from chicane feedback system 5.6 MeV rms 0.06%

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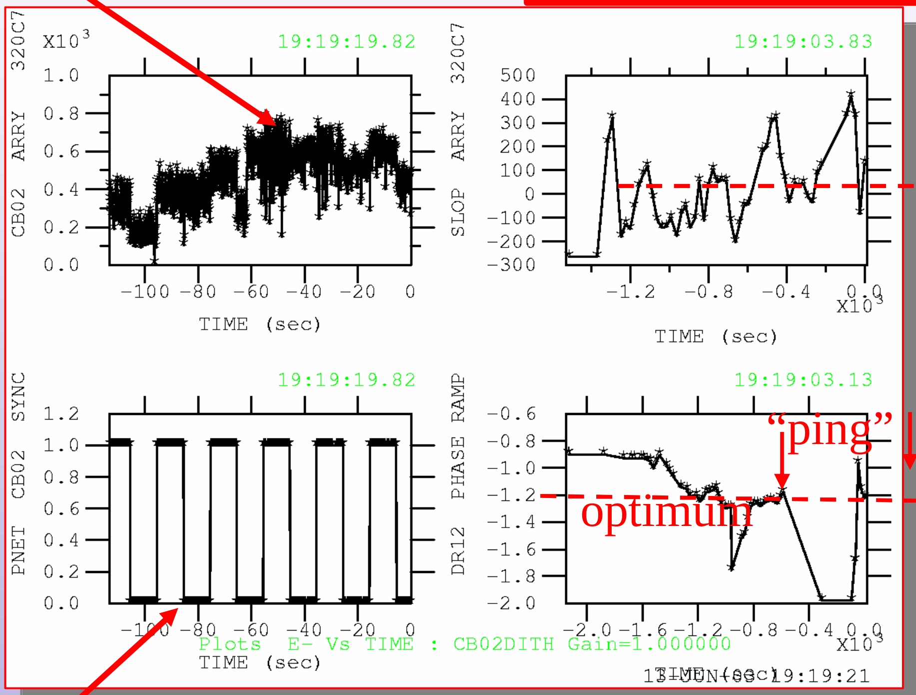
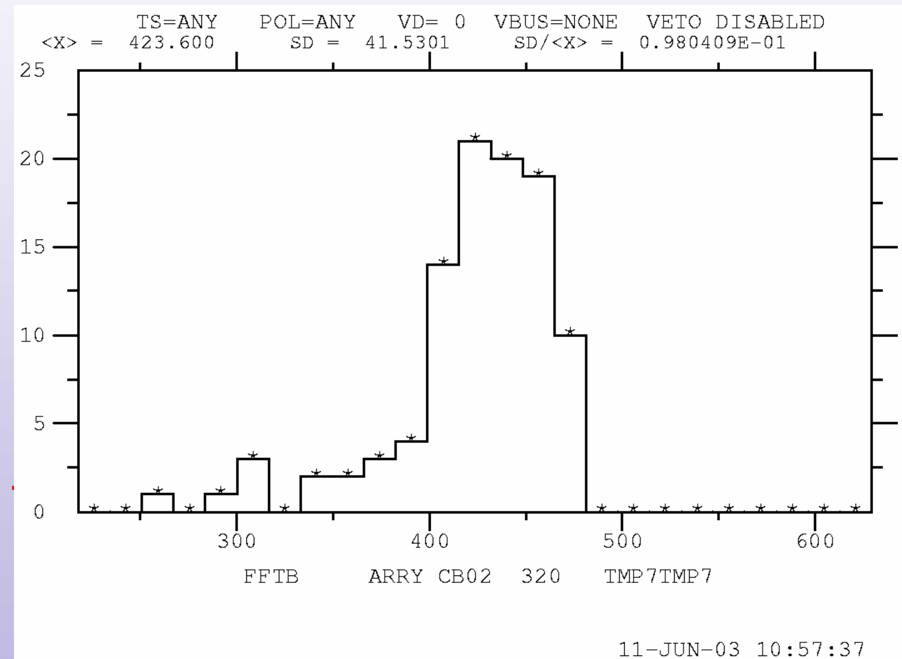
Dither feedback control of bunch length minimization - L. Hendrickson

Bunch length monitor response

Feedback correction signal





Dither time steps of 10 seconds

Linac phase

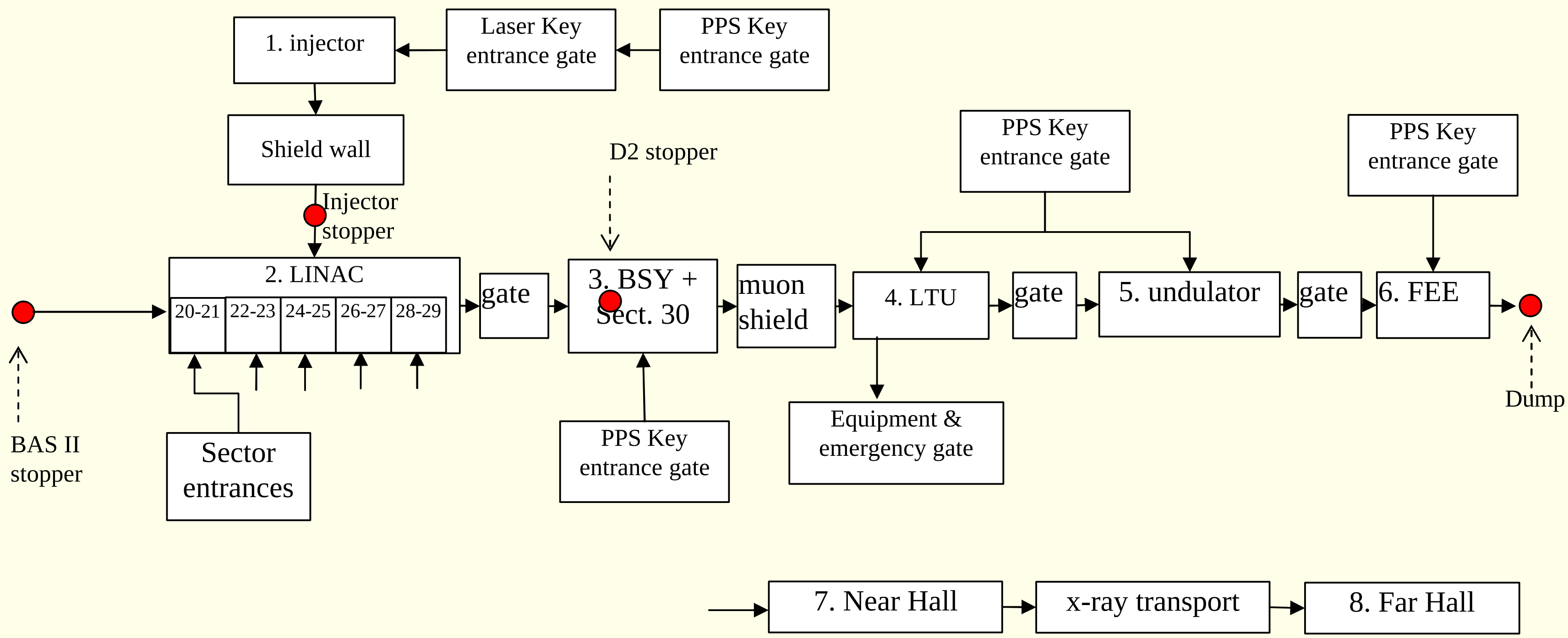
Jitter in bunch length signal over 10 seconds ~10% rms

Controls

- *MPS*
  - *Stoppers and beam dumpers (tune-up dumps)*
    - *Injector energy spectrometer (full rate)*
    - *BSY, D2 (full rate)*
    - *Exit of muon shield, formerly known as ST61 (10 Hz)*
    - *Single bunch beam dumper (SBBD) after LTU dogleg (full rate)*
      - *SLC design*
    - *End of LTU (10 Hz)*
  - *Bunch compressor MPS*
    - *PLIC, PICs, Av. Current monitor comparator interlocked to gun rate control*
  - *LTU Collimator MPS*
    - *PLIC, PICs interlocked to SBBD*
    - *Allows full rate in the linac and arbitrary rate to the undulator*

Controls

- *PPS zones*



Controls - PPS

Zone	PPS entry	Second egress	Access conditions	Search requirement
1. injector vault	Gate key and laser key (new)	None	No RF, elec. hazards off, inj. stopper in.	Vault only
2. linac	Individual sector manways (existing)	Gate to adjacent sector (existing)	No beam in linac, or LCLS injector, elec. hazards off	Accessed sectors only
3. BSY and sector 30	Gate key (existing)	Numerous (existing)	linac in BAS II mode, elec. hazards off, or linac off	Entire BSY
4. LTU	Gate key (new)	Equipment and emergency gate (new)	Beam stopped in BSY, elec. hazards off	LTU only if gate to undulator has not been opened
5. Undulator hall	Gate key (shared with LTU)	gate to FEE	Beam stopped in BSY, elec. hazards off	undulator only if gate to LTU has not been opened
6. Front End Enclosure	Gate key (new)	gate to undulator hall	Beam stopped in BSY, elec. hazards off	FEE only if gate to undulator has not been opened
7. Near Hall	Independent access to hutches		x-ray shutters in	Hutch only
8. Far Hall	Independent access to hutches		x-ray shutters in	Hutch only

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Controls - PPS

- *Changes to linac PPS*
  - *Following preliminary discussions with Saleski, Rokni*
  - *Upgrade linac entries for controlled access*
    - *Keybanks, video*
  - *Possibly combine 5 sectors instead of 2 into one PPS zone*
    - *Fewer systems to certify*
    - *Each zone contains an equipment hatch*
  - *Interlock sect 20 modulators individually*
    - *sect. 19-20 VVS not turned off for injector vault entries while PEP II running*
  - *Sect.19 BAS II beam stopper to become a backward beam stopper*
    - *Allows access to the linac upstream of sect. 18 while LCLS running*
- *System upgrades*
  - *Migrate to PLC instead of relay logic*
  - *Try and do this in the BSY before LCLS starts*

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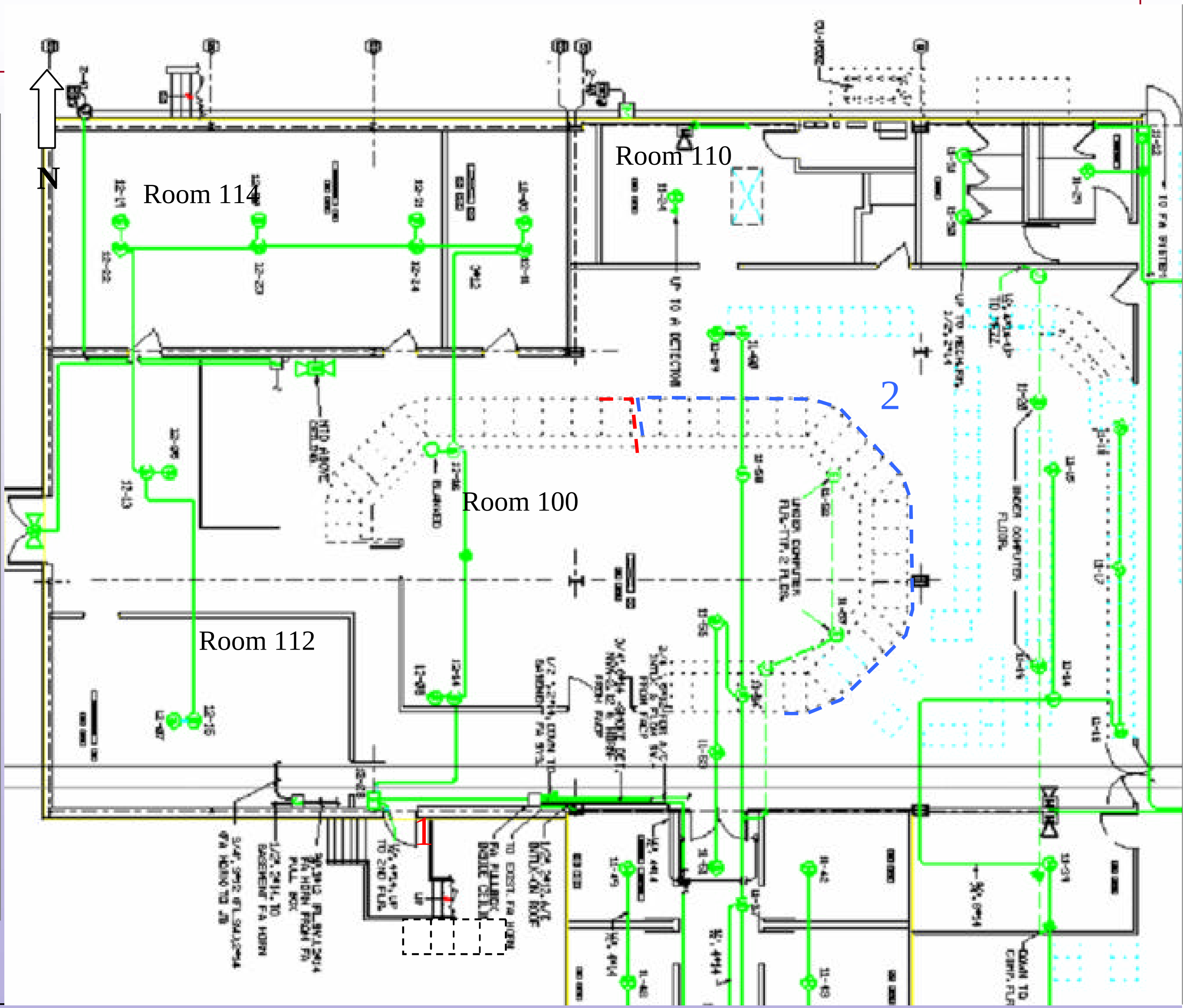
Control Room

- *LCLS will double present occupancy and number of consoles*
- *Feasibility study to expand space by removing old racks and replacing with modular consoles*



Conclusion

- *Upgrades to conventional diagnostic instrumentation have been listed*
- *Linac relies heavily on several new and complex bunch length and timing diagnostics*
  - *Development work on these has started at SPPS*
- *Control system faces challenge of compatibility with existing systems and integrating new, multi-protocol systems*
  - *Have defined the constraints this system faces, plus the requirements for LCLS, particularly the timing stability*
  - *Some conceptual designs discussed for SLC/EPICS hybrid (Bob Dalaseio) but now needs engineering design*

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