LCLS Control System

Control Engineers

TOYS "R" US

Store

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For the
LCLS Controls Group

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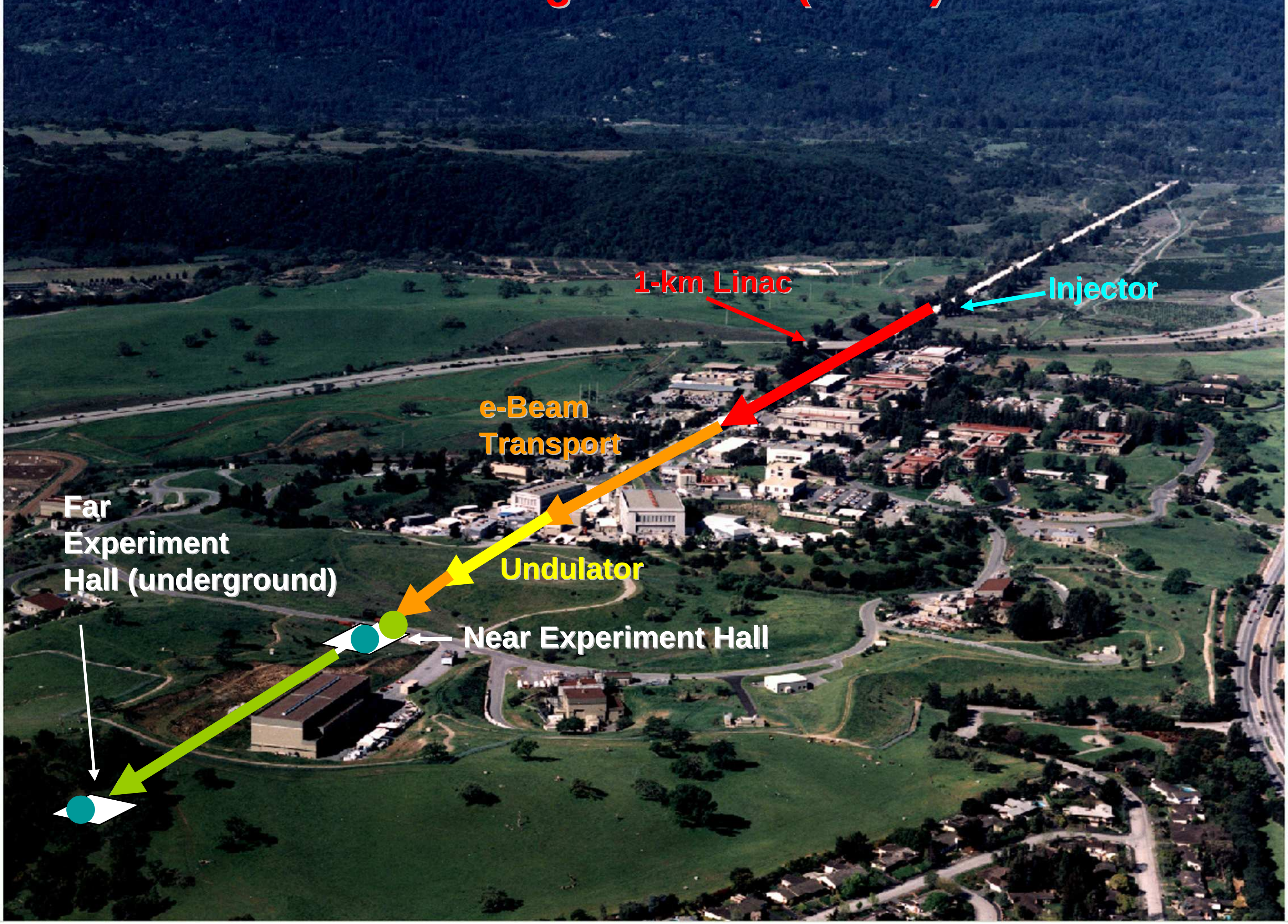
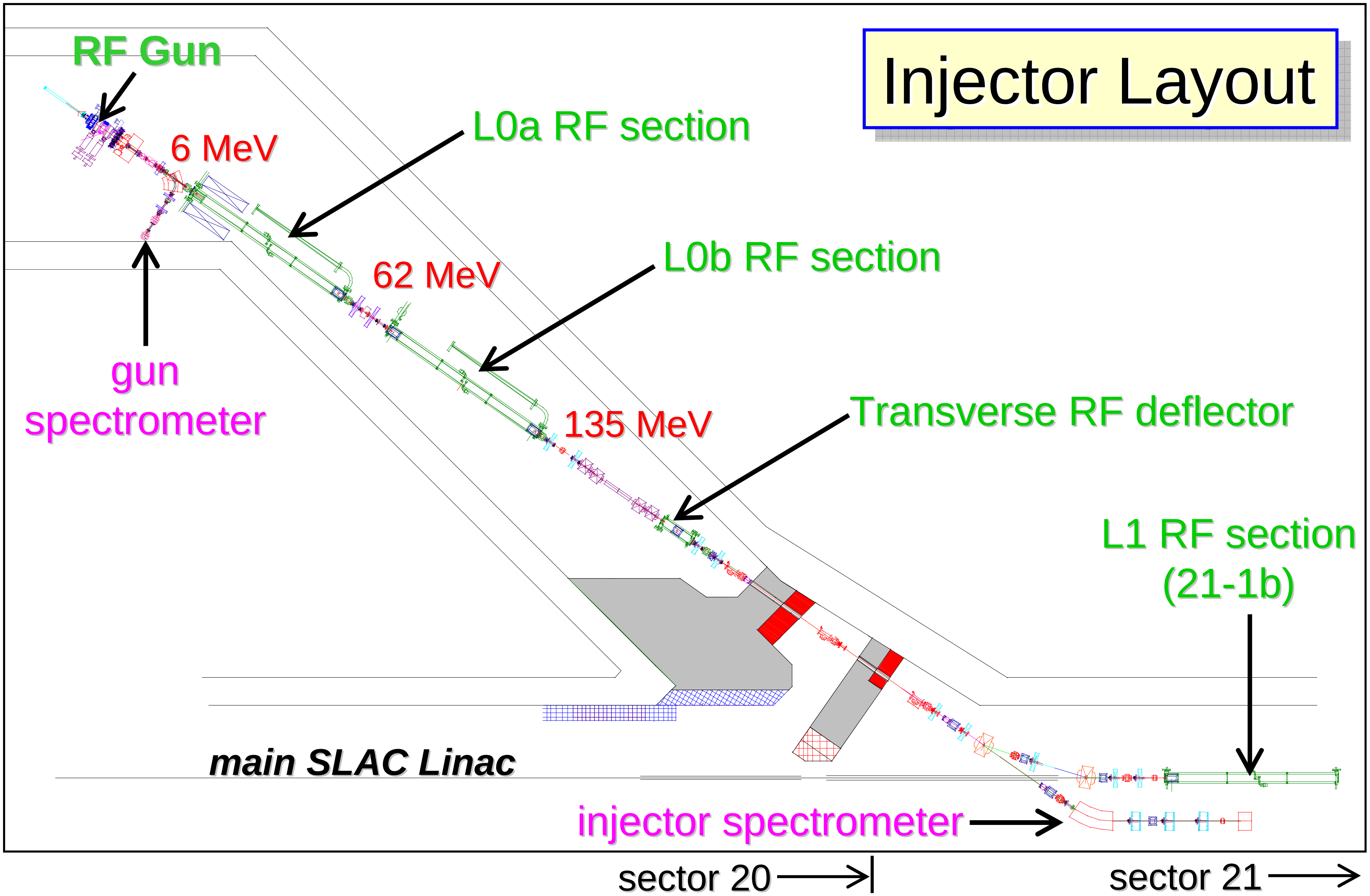
Linac Coherent Light Source (LCLS) at SLAC



Injector Layout



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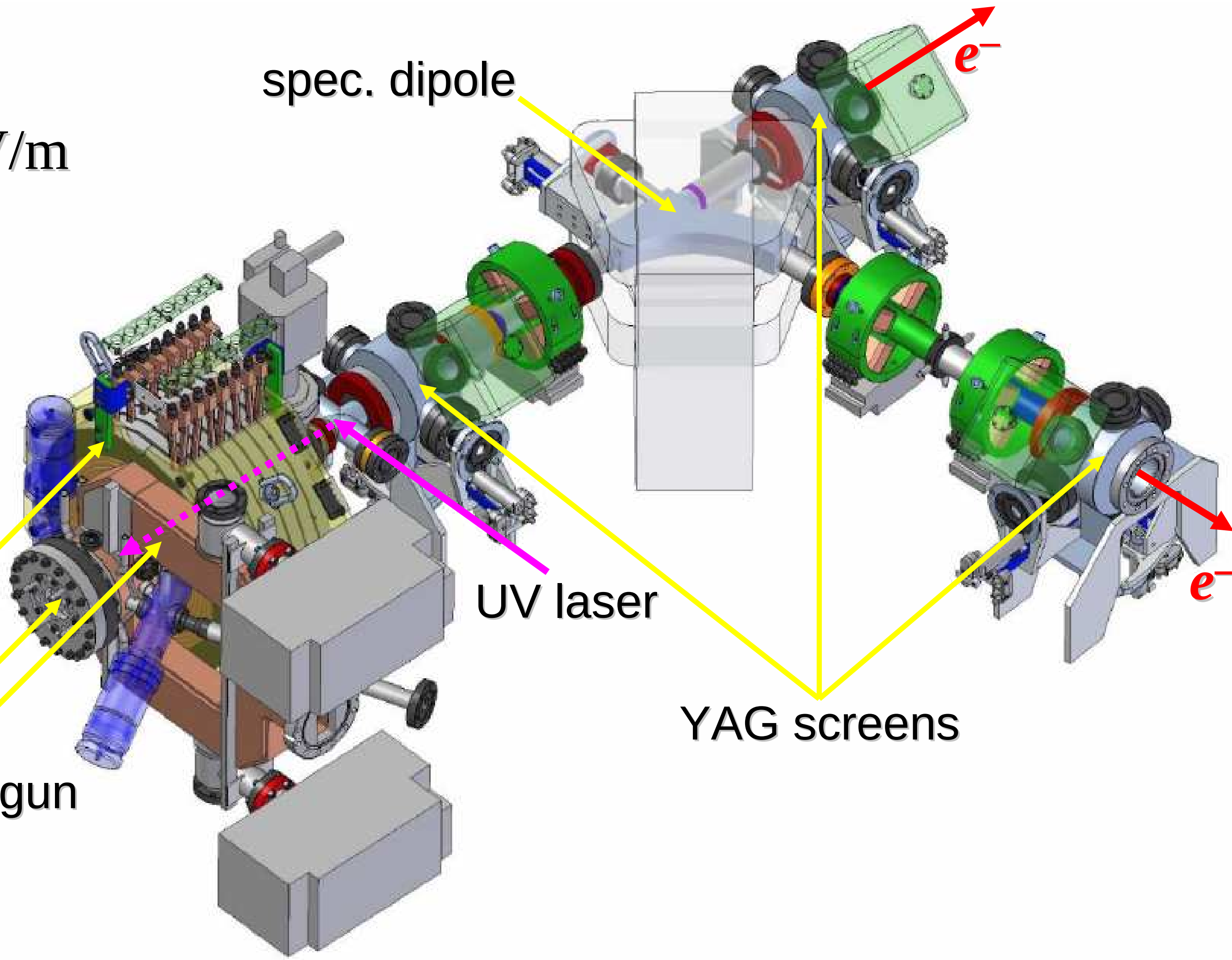
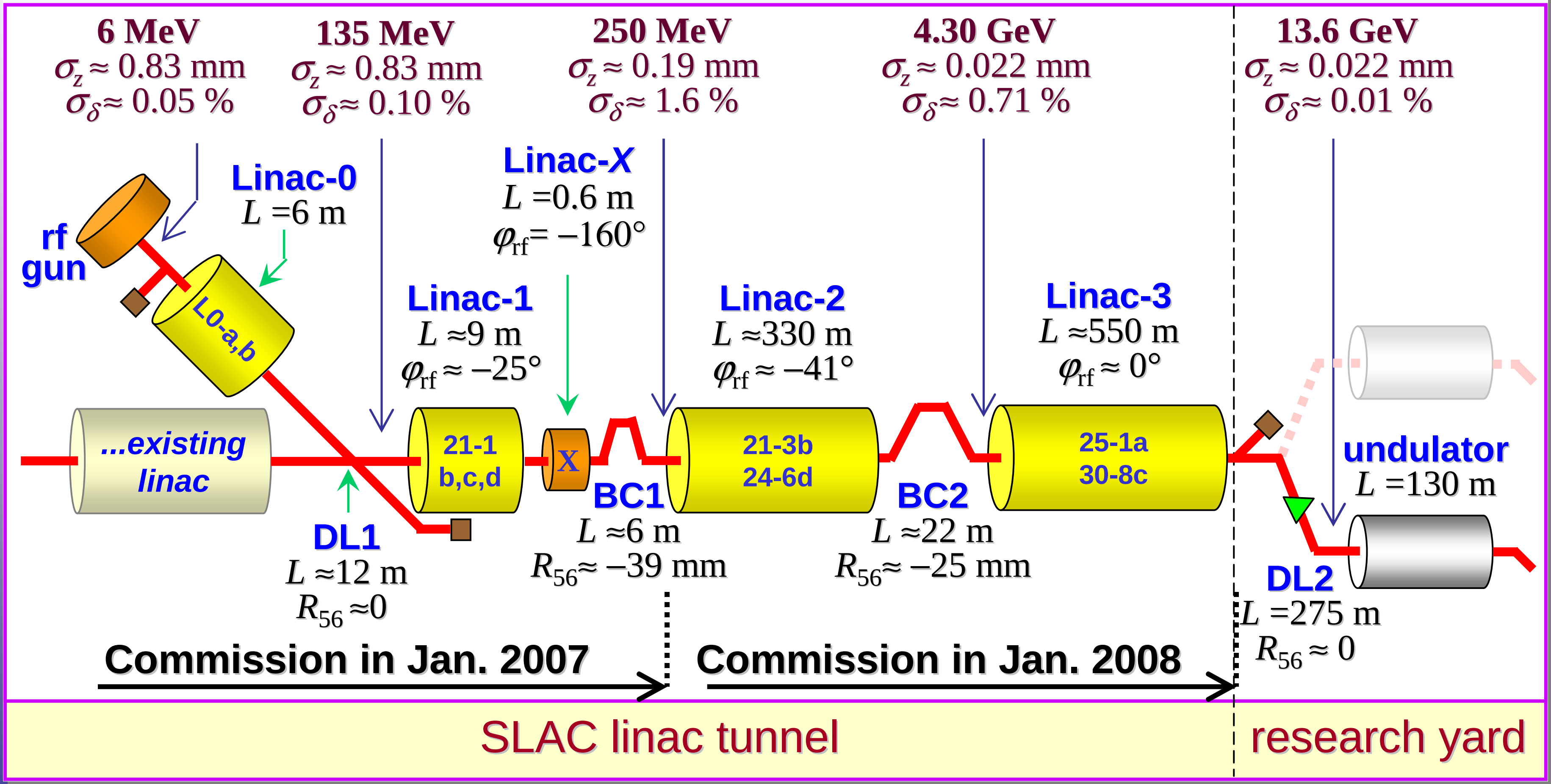
RF Photo-Cathode Gun

- $Q = 1$ nC
- $f = 120$ Hz
- $G = 120$ MV/m
- $\gamma\varepsilon_{x,y} = 1\ \mu$m
- $\Delta\tau = 10$ ps
- $I = 100$ A
- $E = 6$ MeV



LCLS Accelerator



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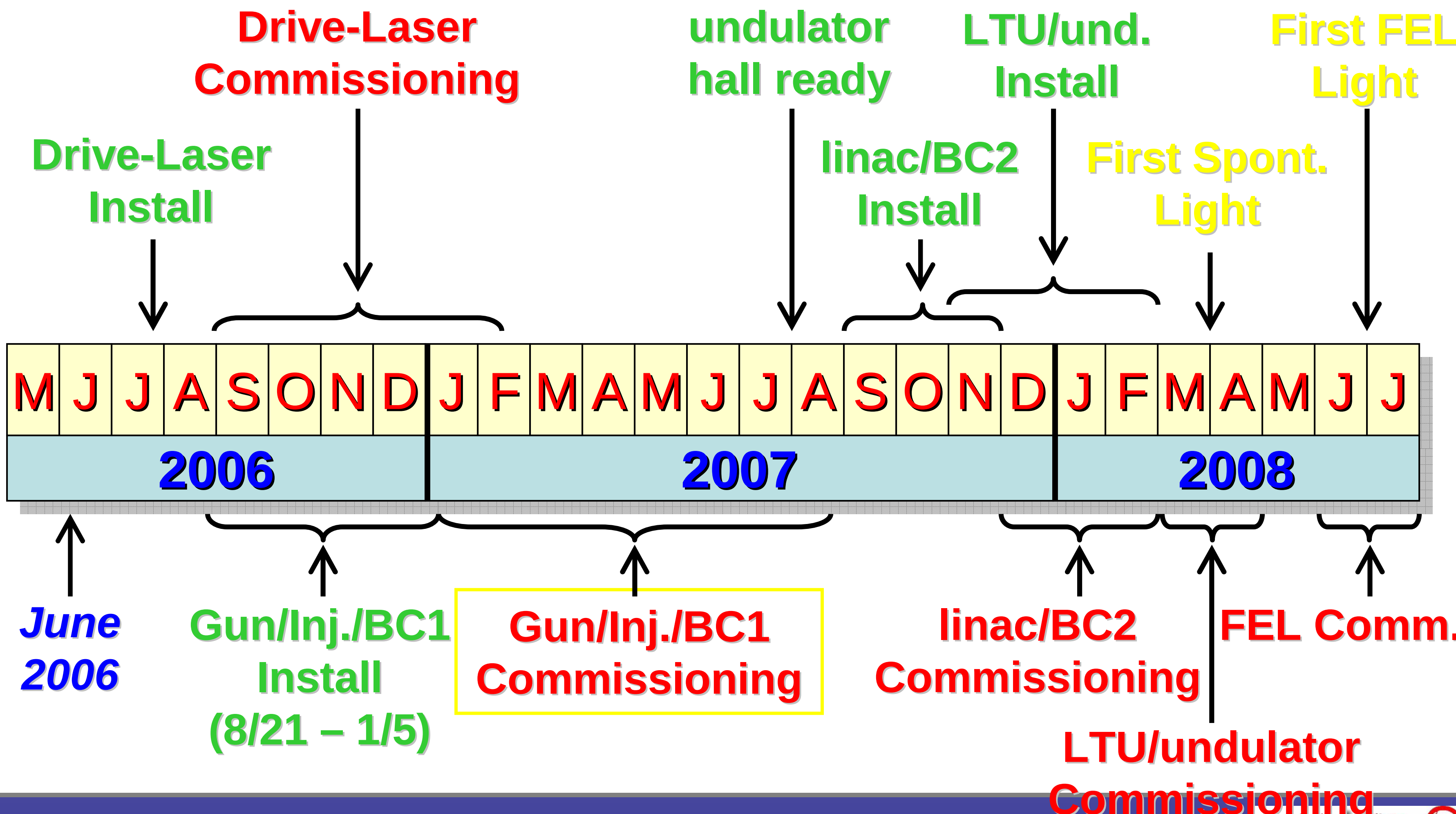
LCLS Installation and Commissioning Time-Line



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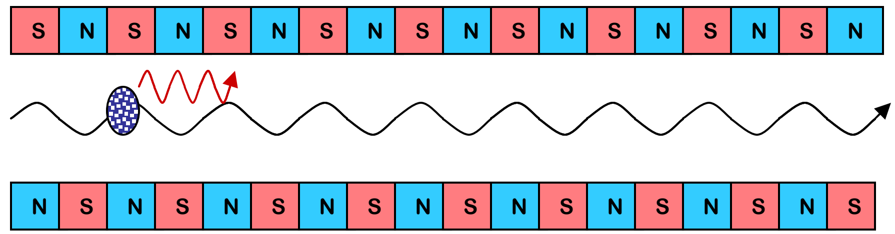
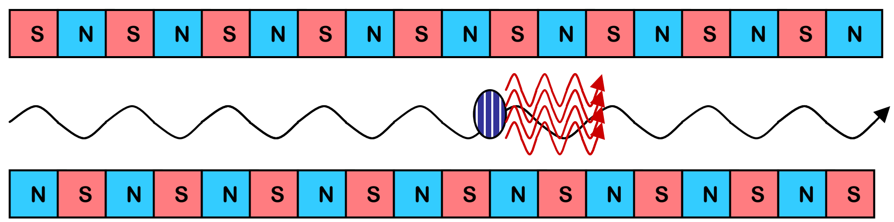
Self-Amplified Spontaneous Emission (SASE)

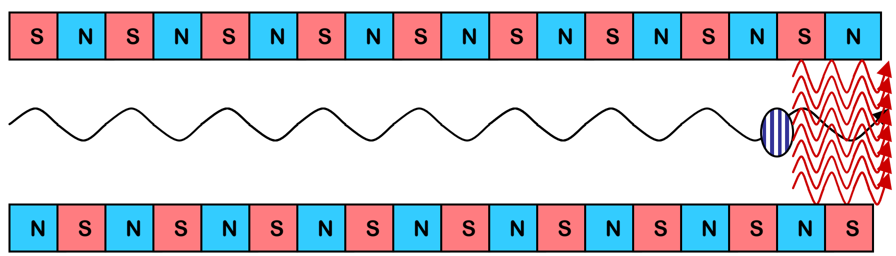
An intense, highly collimated electron beam travels through an undulator magnet. The alternating north and south Poles of the magnet force the electron beam to travel on an approximately sinusoidal trajectory, emitting synchrotron radiation as it goes.



The electron beam and its synchrotron radiation are so intense that the electron motion is modified by the electromagnetic fields of its own emitted synchrotron light. Under the influence of both the undulator and its own synchrotron radiation, the electron beam begins to form micro-bunches, separated by a distance equal to the wavelength of the emitted radiation.



These micro-bunches begin to radiate as if they were single particles with immense charge. The process reaches *saturation* when the micro-bunching has gone as far as it can go.



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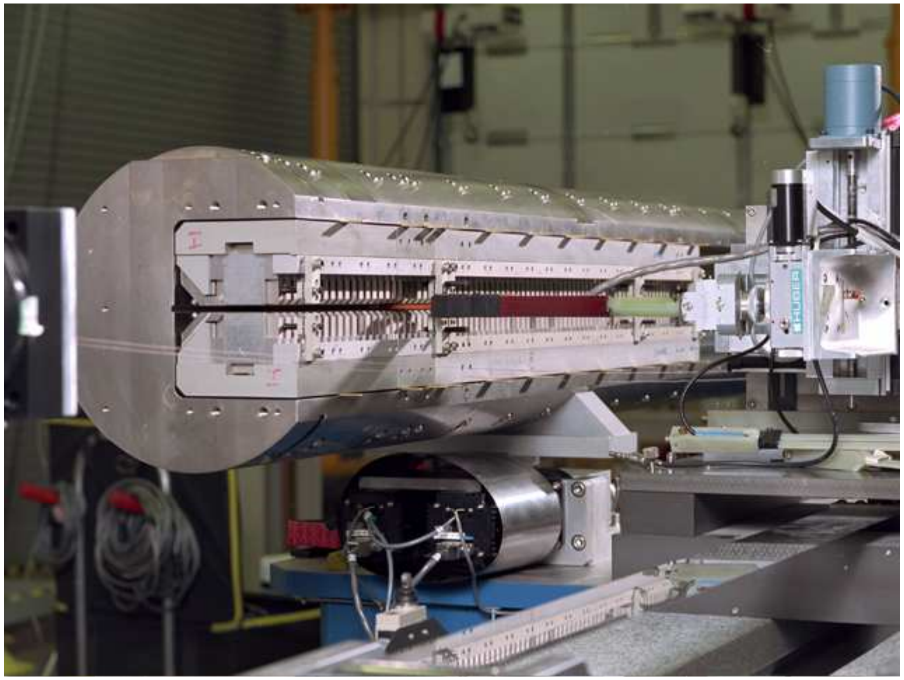
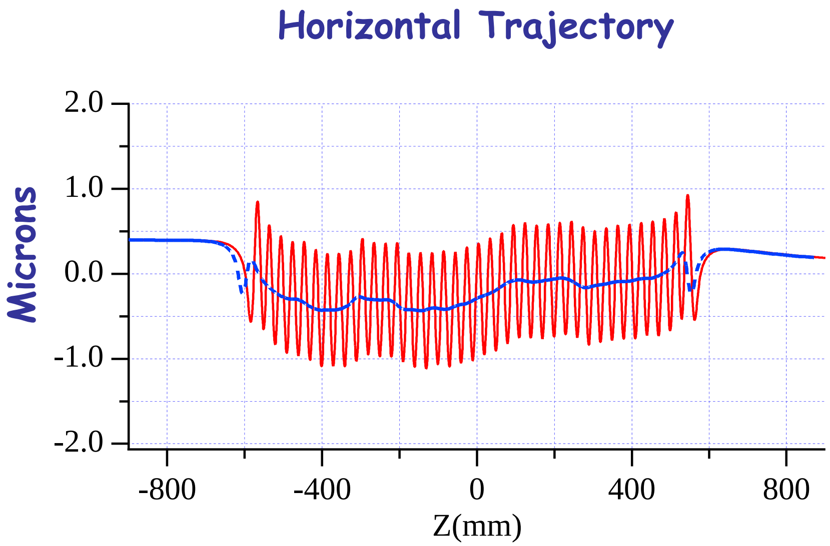
Prototype LCLS Undulator





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Free-Electron Lasers

- 1977- First operation of a free-electron laser at Stanford University
  - Deacon, et al. PRL v. 38, no.16, pp. 892-894
  - http://accelconf.web.cern.ch/accelconf/p73/PDF/PAC1973_0980.PDF
- Today
  - 22 free-electron lasers operating worldwide
  - 19 FELs proposed or in construction
  - http://sbfel3.ucsb.edu/www/vl_fel.html

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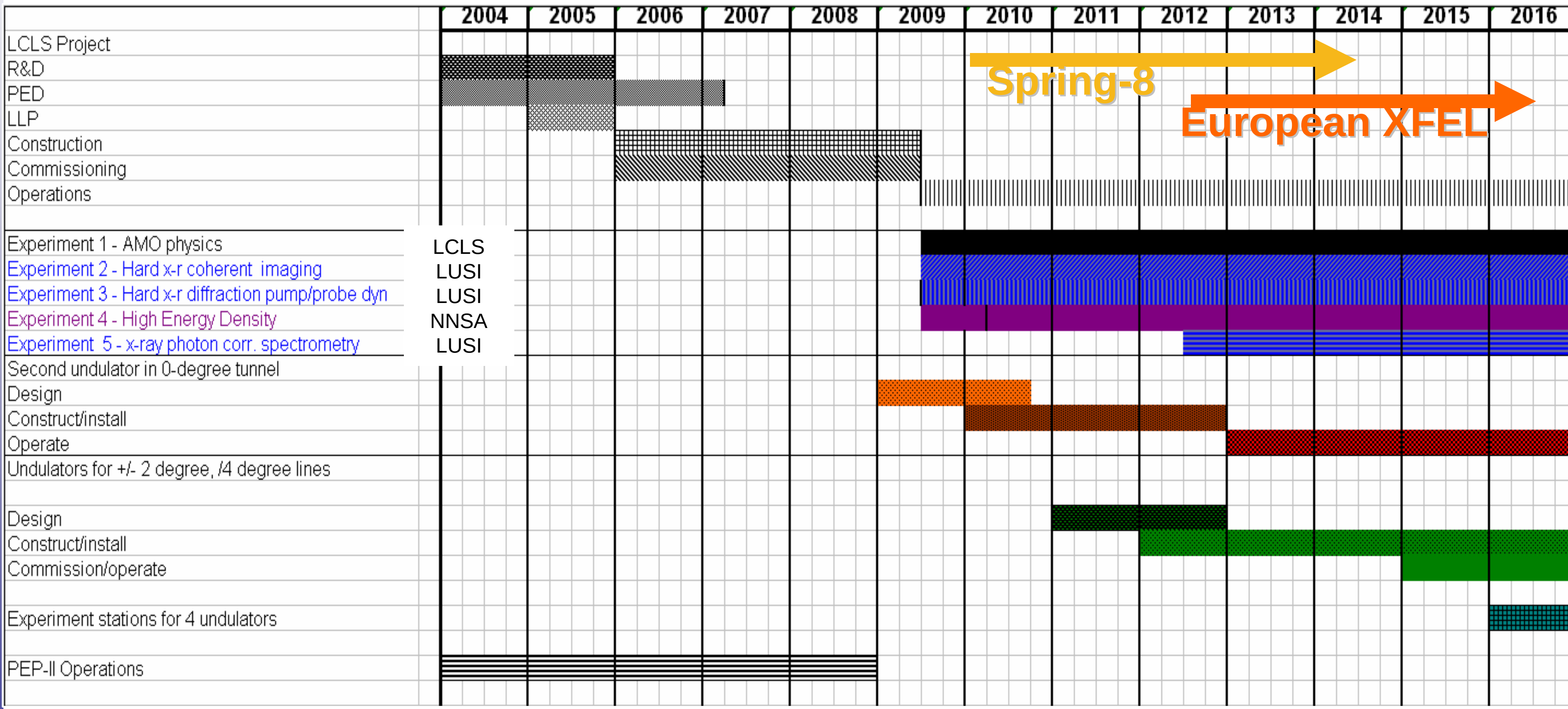
Looking Ahead – LCLS development



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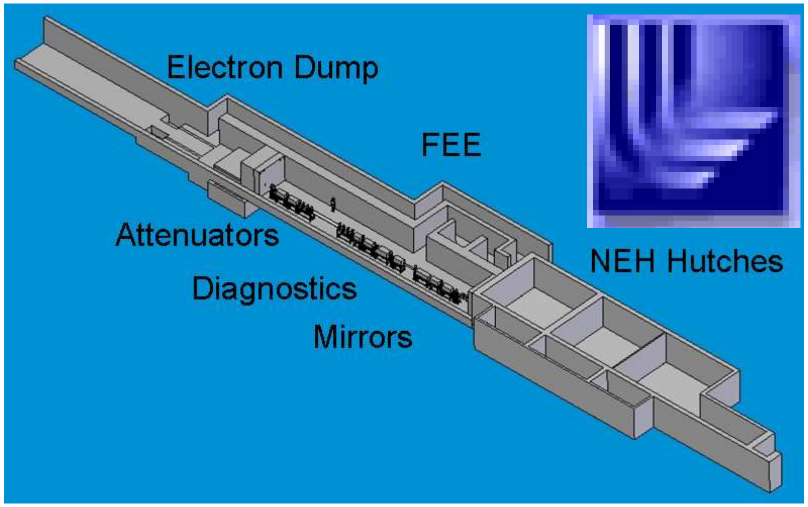
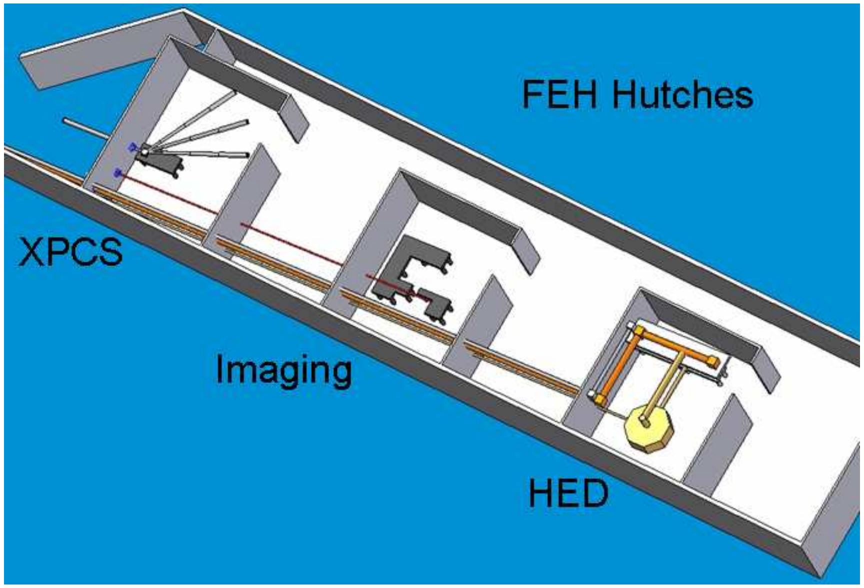
Photon Beam Systems



1.5 X-Ray Transport/Optics/Diagnostics



1.6 End Station Systems

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Controls responsibilities cover a large range of activities

- The group's responsibilities range from cable trays to end station detector control and DAQ
- Cable plant design
- Global control infrastructure
- A rich set of beam diagnostics and instrumentation
- Operations software and control room tools
- High level applications
- Feedback systems
- Safety systems
- Experimental end station control and data management

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Injector Tunnel Installation

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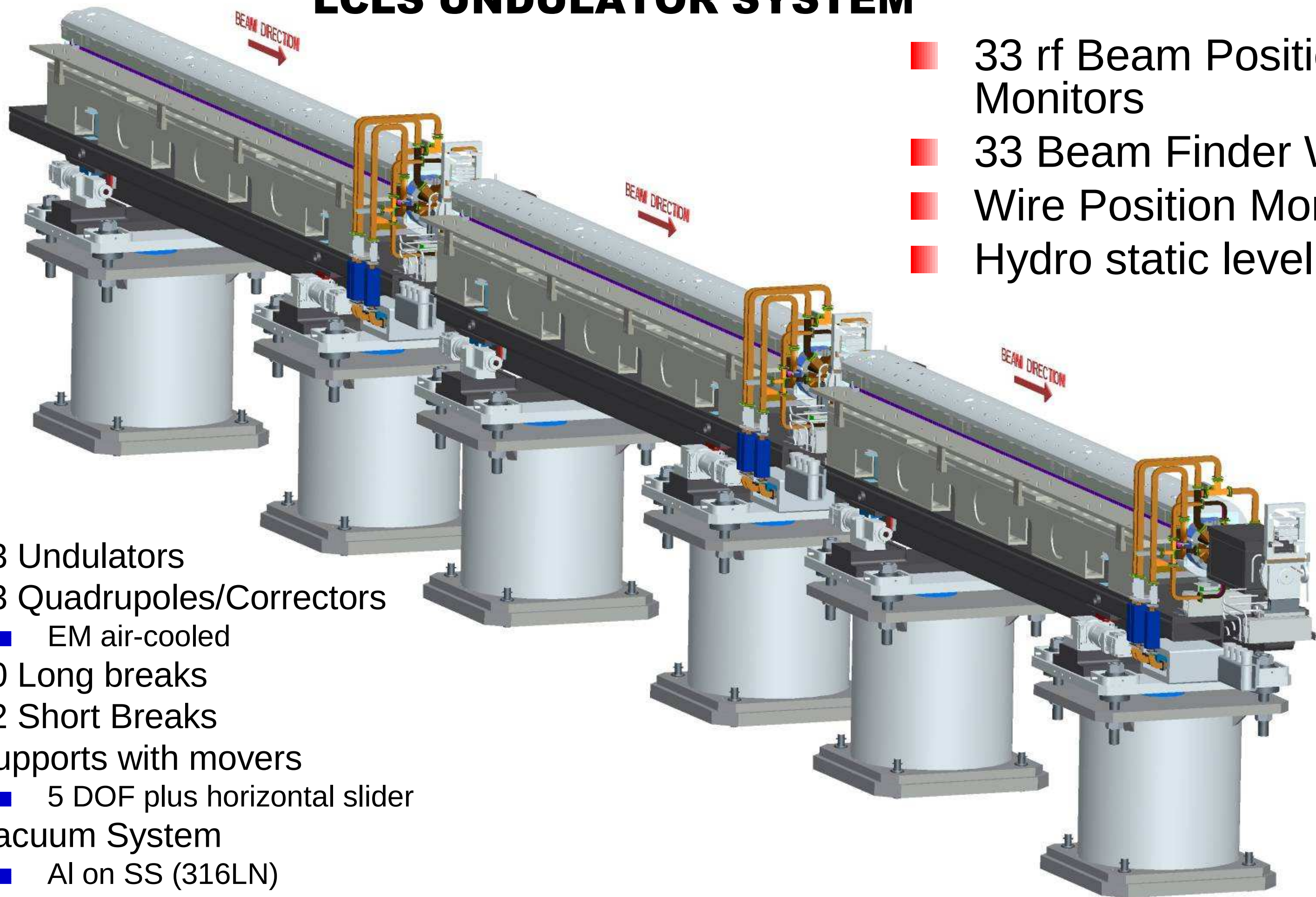
LCLS UNDULATOR SYSTEM



- 33 rf Beam Position Monitors
- 33 Beam Finder Wires
- Wire Position Monitor
- Hydro static level system

- 33 Undulators
- 33 Quadrupoles/Correctors
  - EM air-cooled
- 10 Long breaks
- 22 Short Breaks
- Supports with movers
  - 5 DOF plus horizontal slider
- Vacuum System
  - Al on SS (316LN)
  - "Rectangular" Cross Section

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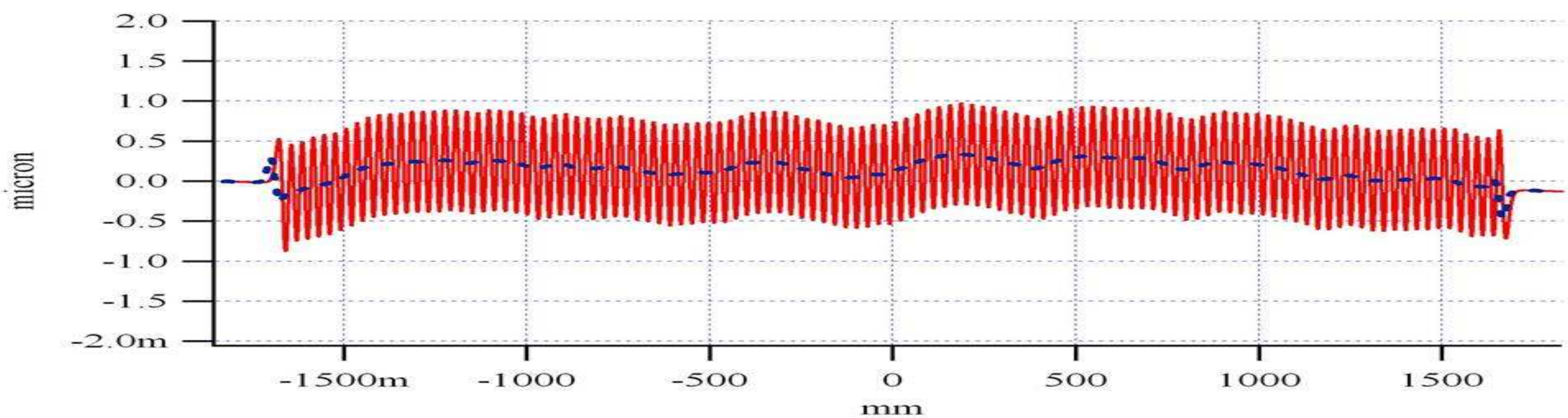
1st Article Undulator Received

- One each received from the two vendors
- Initial Measurements and Tuning
  - *x* & *y* trajectories well under the 2-micron limit
  - RMS phase error well under the 10-deg. limit



RF BPM for Undulator

- First Prototype Completed
- Bench Measurements
  - No surprises
- Installation for Beam Test
  - Planned to install in ITS by end of month
- 3 BPM Test
  - Planned installation mid to late summer
- Schedule
  - Still considered an undulator system critical path item

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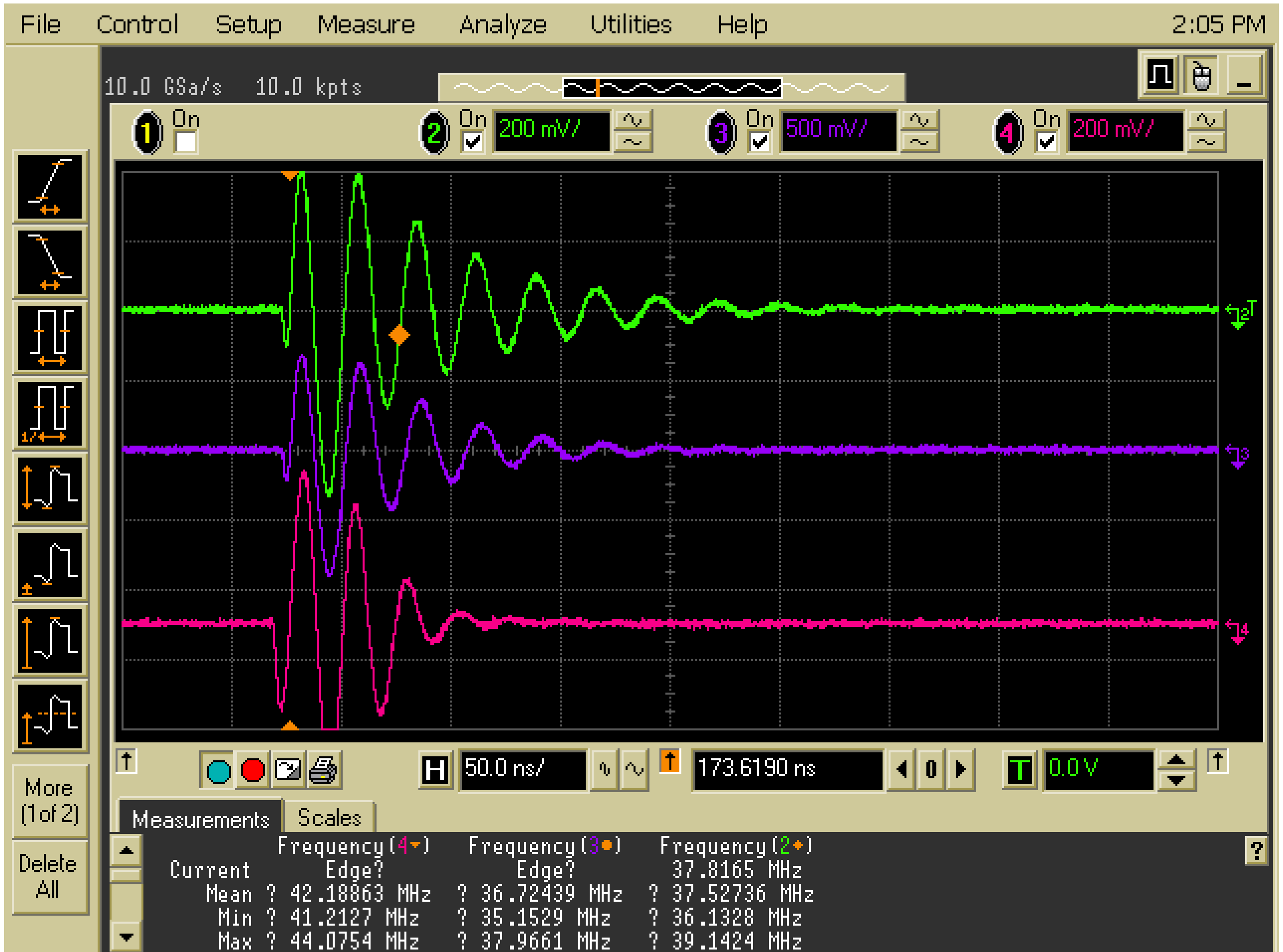
First Beam Observed in Undulator Cavity BPM



LCLS Presentations at this Meeting

■ LCLS Timing and LLRF on RTEMS	*Dale Kotturi*
■ LCLS Timing	*Stephanie Allison*
■ LCLS Magnet Support	*Debbie Rogind*
■ LCLS network and support planning	*Terri Lahey*
■ LCLS Undulator Positioning Control System	*Shifu Xu*
■ Experience installing and getting started with XAL	*Sergei Chevtsov*

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Vacuum System Controls Hardware

Hardware	*Function*
Allen-Bradley ControlLogix Programmable Logic Controller (PLC)	Valve control, interlock logic, interface to global control system
MKS 937A gauge controller	Cold cathode and Pirani gauges
Granville-Phillips 307 gauge controller	Hot filament and Convectron gauges
Gamma Digitel Multiple Pump Controller (MPC)	Ion pumps
Digi PortServer TS 16	Terminal server: RS232 connections to vacuum controllers

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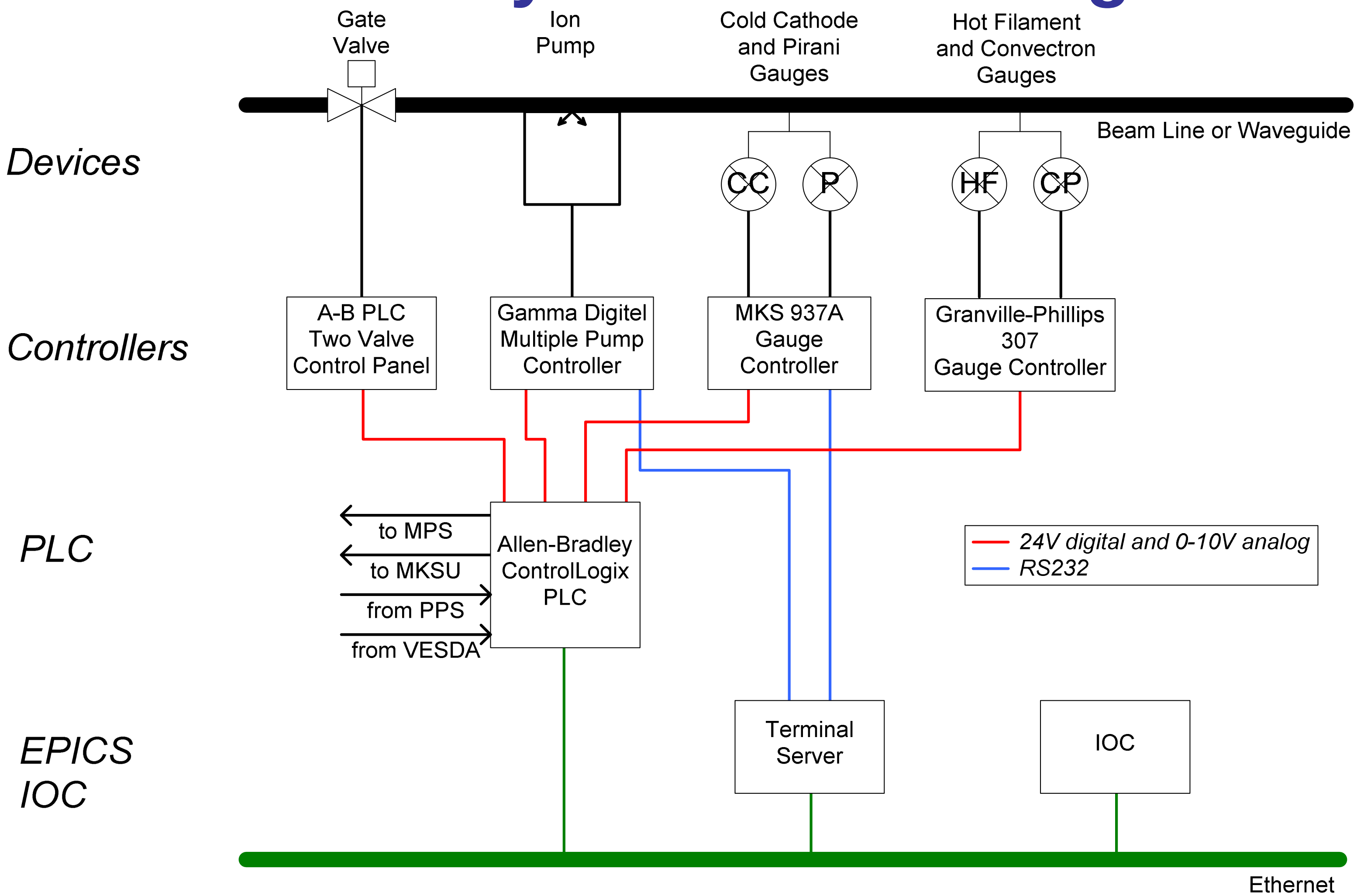
Vacuum System Block Diagram



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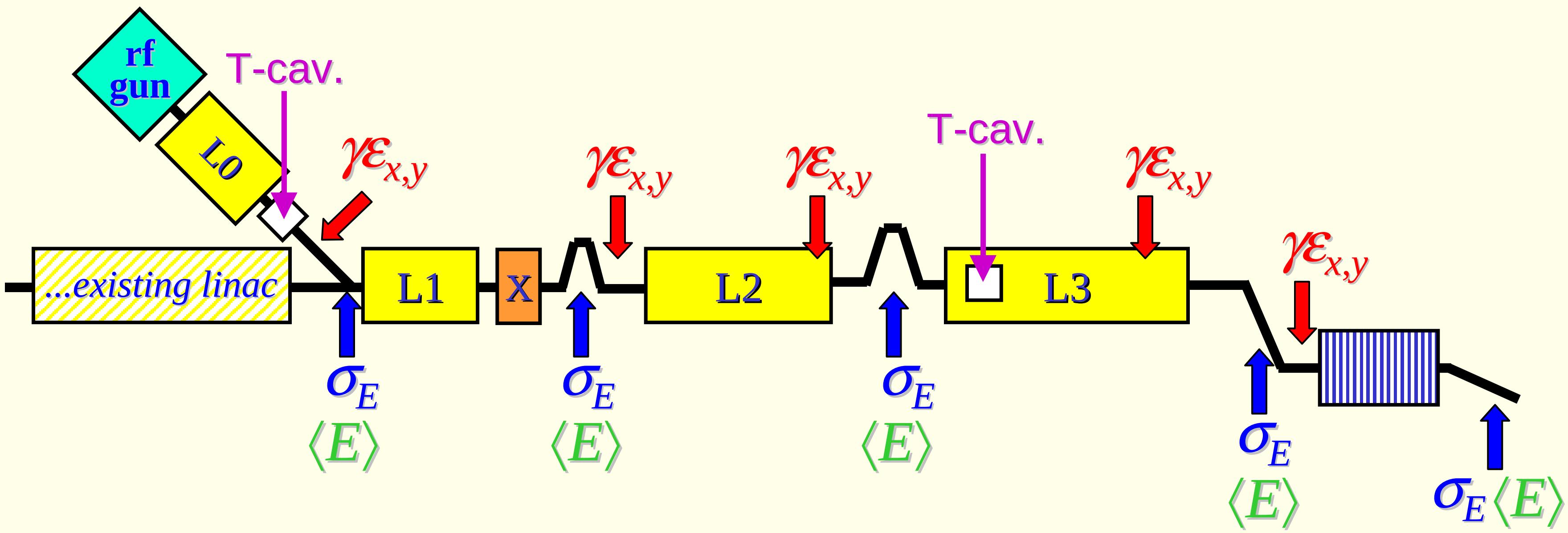
Location of Main Linac Diagnostics

- *5+ energy spread meas. stations (optimized with small β)*
- *5+ emittance meas. stations designed into optics ($\Delta\psi_{x,y}$)*
- *BPMs at or near most quadrupoles and in each bend syst.*
- *RF deflectors for slice ε and σ_E measurements (L0 & L3)*



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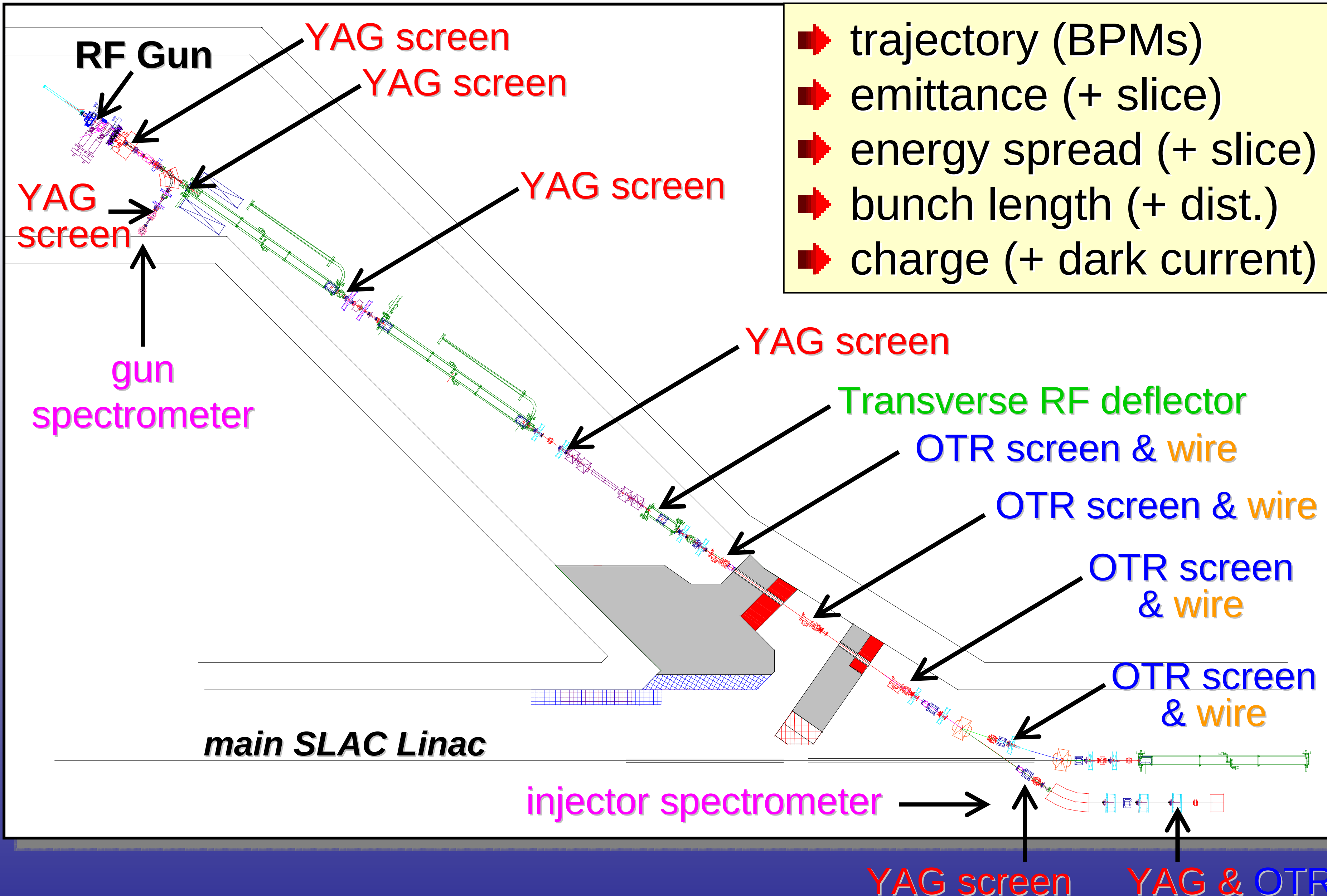
Gun/Injector Diagnostics

- trajectory (BPMs)
- emittance (+ slice)
- energy spread (+ slice)
- bunch length (+ dist.)
- charge (+ dark current)



LCLS Timing System

- The LCLS timing system is used to transmit a fiducial 360 Hz signal to all triggered devices in LCLS
- System requirements include
  - receiving 128 bit PNET data at 360 Hz;
  - appending additional information;
  - operate at 120 Hz
- The component parts are known: PNET VME receiver, EVG-200 and EVR-200
- The interfaces are being defined

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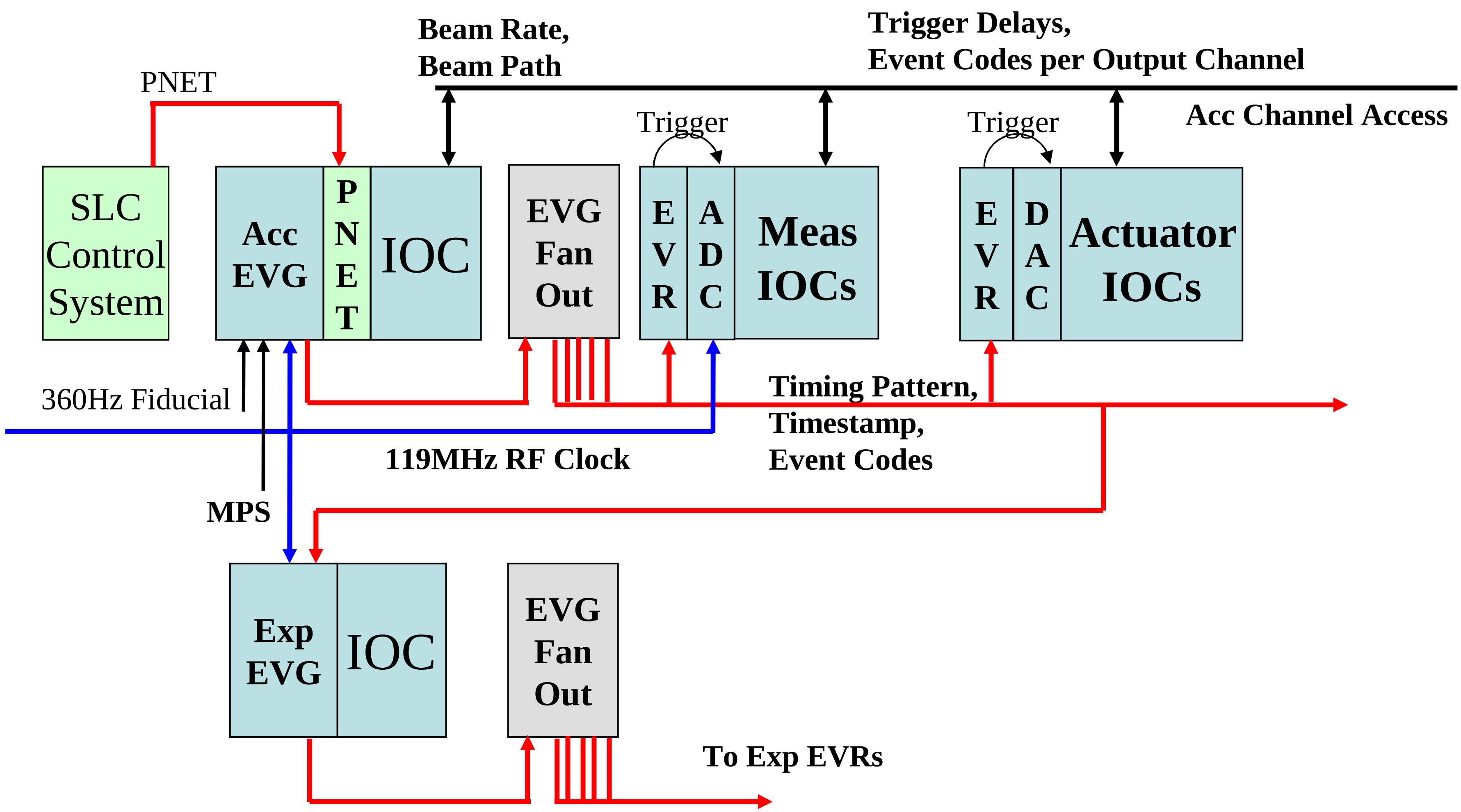
Timing System



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Timing Requirements

Maximum trigger rate	360 Hz
Clock frequency	119 MHz
Clock precision	20 ps
Coarse step size	8.4 ns ± 20 ps
Delay range	>1 sec
Fine step size	20 ps
Max timing jitter w.r.t. clock	2 ps rms
Differential error, location to location	8 ns
Long term stability	20 ps

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Event/Timing System Status

- Status
  - Testing with new EVG/EVR 200 series VME and PMC modules
  - Adapted EVG/EVR driver/device support to send data buffers and run on RTEMS
  - Stephanie Allison and Mark Crane coming up to speed
  - Test stands for HW folks not yet ready
  - PMC-EVR driver not yet ready
  - Rack/cable design for injector/BC1 and procurement well underway
  - Tight schedule
- Tasks:
  - Finish PMC-EVR driver and test
  - EVG sequence RAM programming at 360 Hz
  - EVG rules and algorithm definition for January commissioning
  - Add support for EVR timing pattern data records
  - Jitter testing
  - Interface with other subsystems needs review
  - Commissioning test plan

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Motion control & Image acquisition

- The injection laser stabilization control system includes up to 3 feedback loops. Each loop includes 2 mirrors. Each mirror has two actuators and one camera.
- The IOC should read back the image from camera, figure out centroid, multiple pre-calculated matrix and apply the correction to the actuators.
- Whole loop should be about 1 Hz. Camera should be synced to 120Hz.

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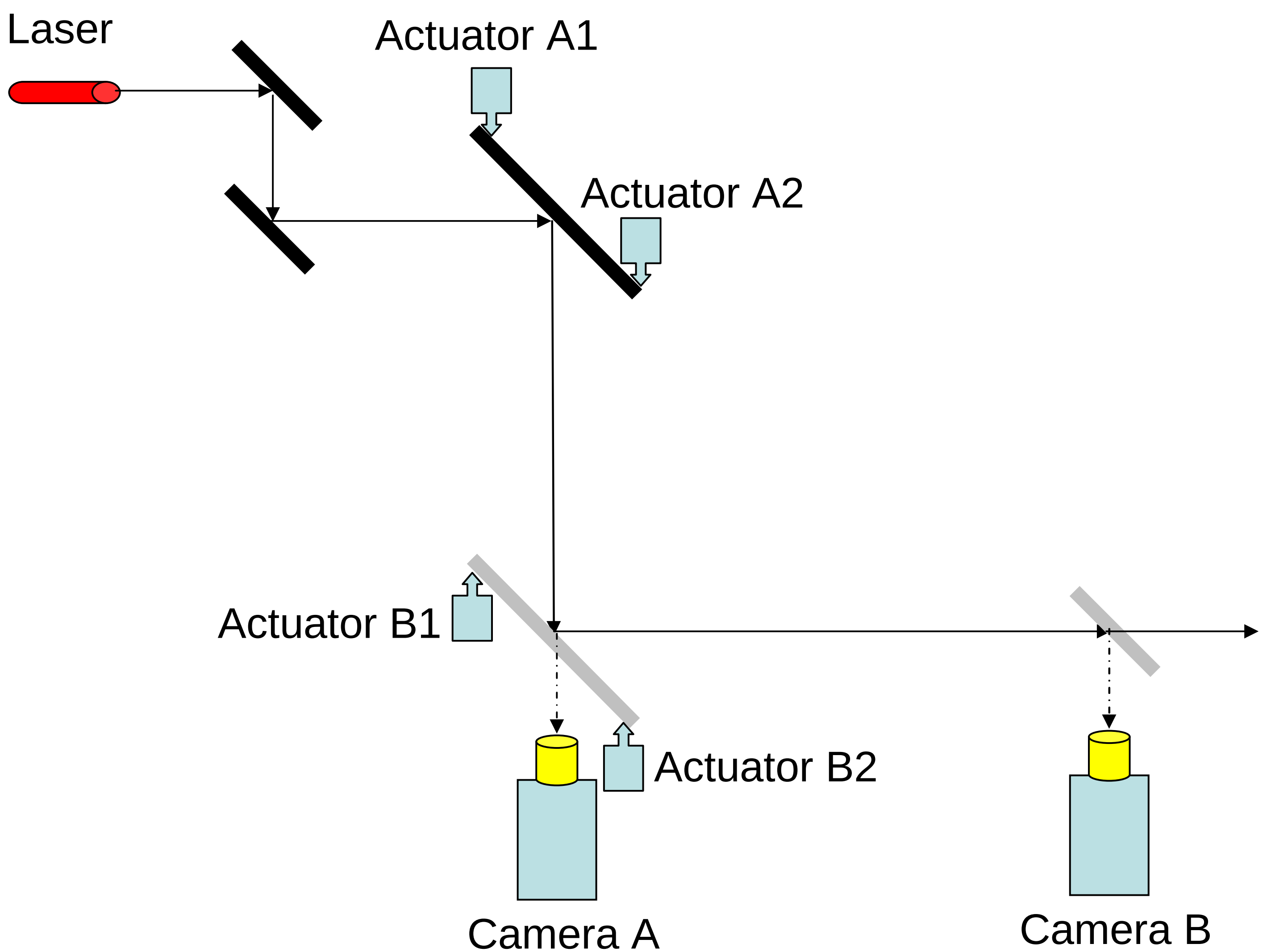
Introduction



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Motion: Newport XPSC8 Motion Controller

- Pentium 4 PC based
- vxWorks powered
- Support up to eight motors
- Ethernet control interface
- Mark Rivers has pioneered the use of this system

Motion: Newport CMA-12CCCL actuator

- Travel range: 12.5 mm
- Resolution: 0.2µm
- Encoder: Yes
- Bi-Direction repeatability: 3µm
- Speed: 50~400 µm/S
- Load Capacity: 90N
- Compatible with XPSC8

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Image Acquisition: PULNiX TM-6710CL camera

- CCD: 1/2”
- Shutter: Full Frame
- UV option: Yes
- Resolution: 648x484
- Progressive: Yes
- External Trigger: Yes
- Full scan: 120Hz
- Analog Output: Yes
- Cameralink: Yes

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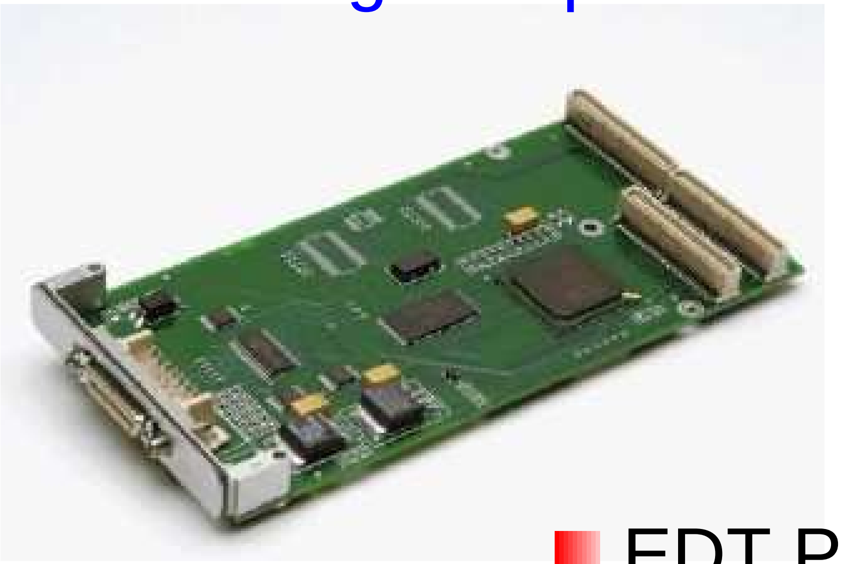
Image Acquisition: Cameralink interface



- EDT PMC DV C-Link
  - Cameralink compatible
  - 32bit/66MHz PCI
  - Support up to 80MHz pixel clock
  - One base channel per card

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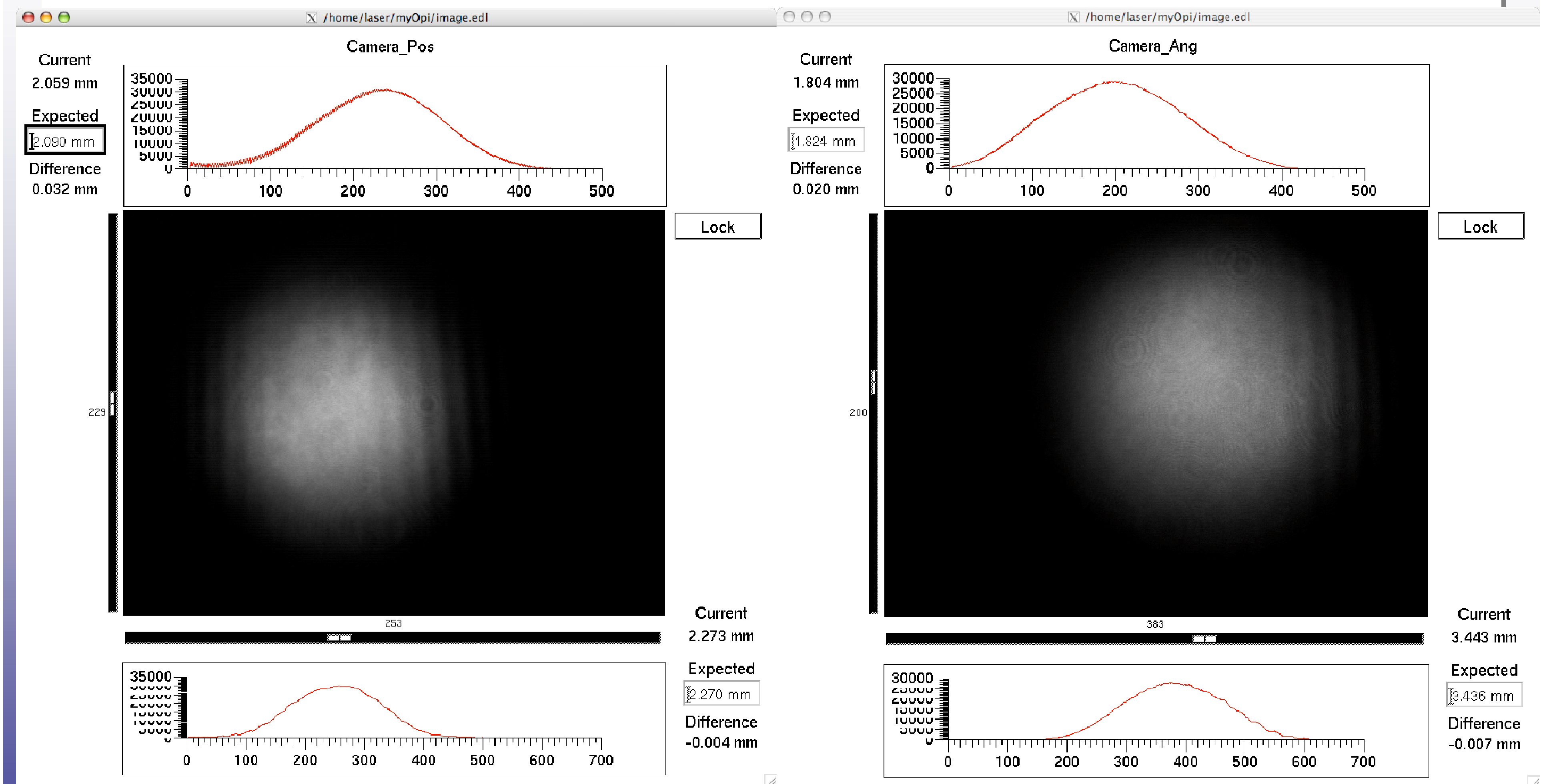
EDM screen of two cameras



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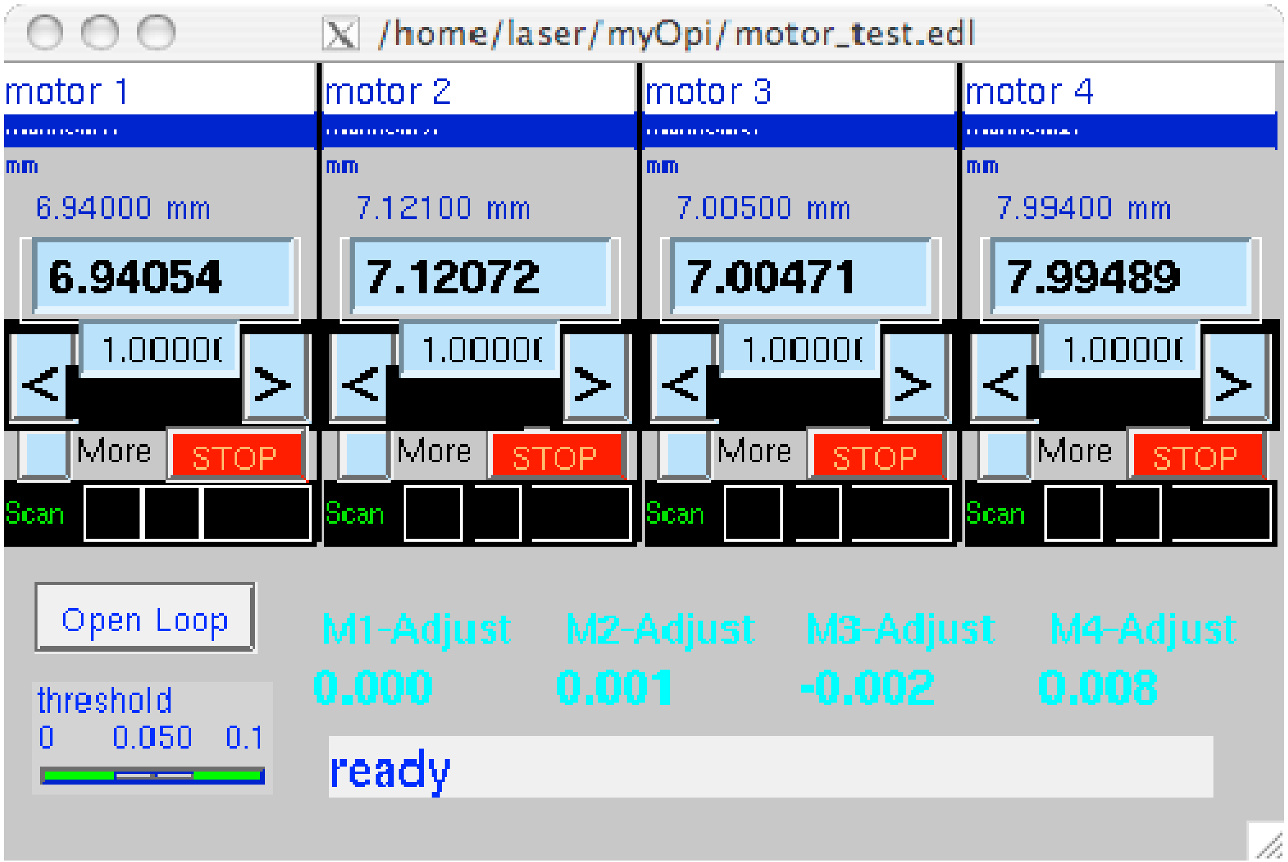
EDM screen of motion control



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OTR/YAG system

- OTR/YAG system share the PMC CameraLink interface but use different camera
- UniqVision UP900CL-12B
  - ½" CCD progressive scan
  - 1392 x 1040
  - 12 bits per pixel
  - 15 Frames per second
  - Full frame shutter
  - Cameralink® interface
- Cameralink® interface
  - EDT PMC DC C-Link

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Applications Software

- The challenge is to integrate the existing control system (CAMAC) with the new equipment (VME)
- High Level Applications
- Fast Feedback Applications

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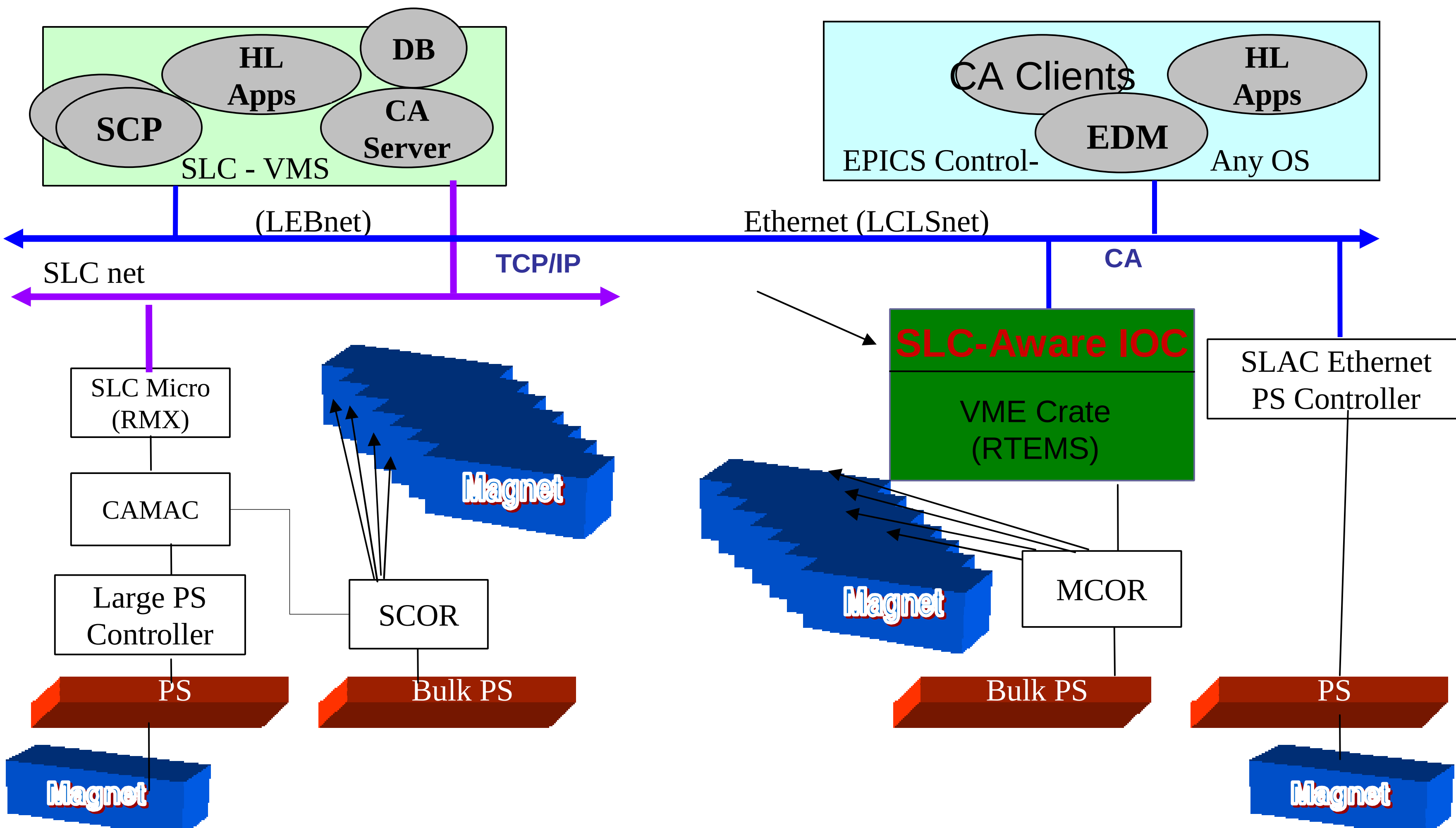
Solution: SLC-Aware IOC

- Mimics RMX micro; communicates via SLC message protocol; receives/updates SLC DB
- Minimal changes to SLC



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High Level Applications

- The Legacy system will provide most High Level Applications required for Injector Commissioning
  - Orbit applications: such as orbit display, orbit fitting, orbit correction, bump calculations, etc
  - Supporting applications: such as buffered acquisition, correlation plots, configuration, on-line model
  - The LCLS on-line model and configuration are being entered into the Legacy system now.
  - The slc-aware IOC, which provides the interface between the Legacy system and the new EPICS based control, is ready for system integration.

High Level Applications

- Applications that the Legacy system cannot provide are being prototyped in Matlab for commissioning
  - Emittance application
  - Energy Spread application
  - Bunch Length Measurement
  - Fast Feedback
- LabCA, a Matlab CA interface (Till Straumann:SLAC/SSRL), will be used to interface to IOCs
- AIDA, a multi-platform distributed data access server (Greg White:SLAC), will be used retrieve model parameters from the Legacy on-line model
- The long term goal is
  - to adopt the XAL package
  - to develop a comprehensive fast feedback facility

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Fast Feedback

- Fast Feedbacks for Commissioning 2006 - 2007
  - Bunch Charge
  - Injector Launch
  - DL1 Energy
  - DL1 Energy + BC1 Energy + Bunch Length
  - Transverse Deflecting Cavity (to support Bunch Length Measurement)
- Prototype in Matlab limits rate to ~1Hz.
- An 'LCLS machine simulation' IOC is being used to support the Matlab feedback prototyping
- The Injector Launch Feedback will be prototyped in an EPICS IOC to support development of a long-term general feedback system design in EPICS.

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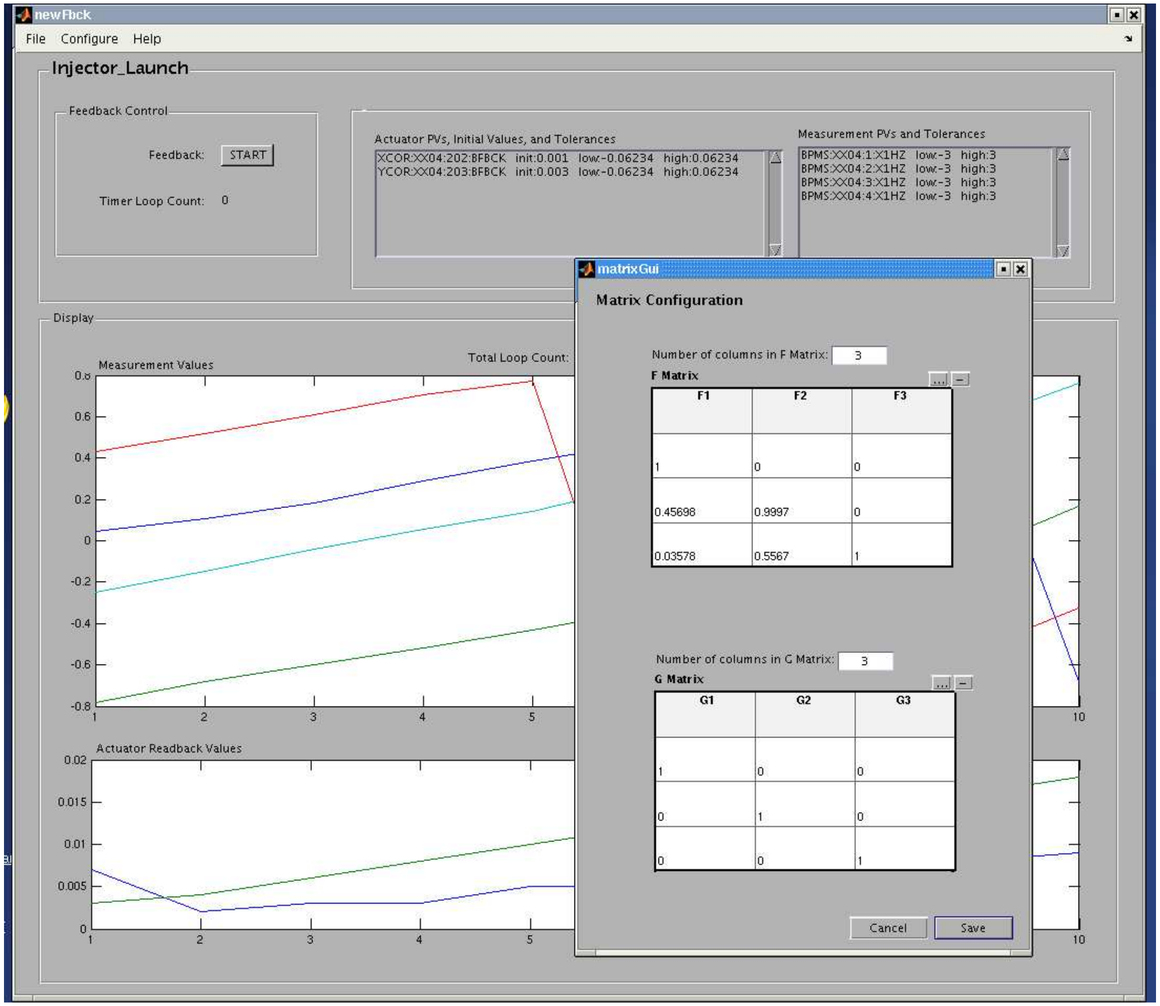
Matlab Feedback Application



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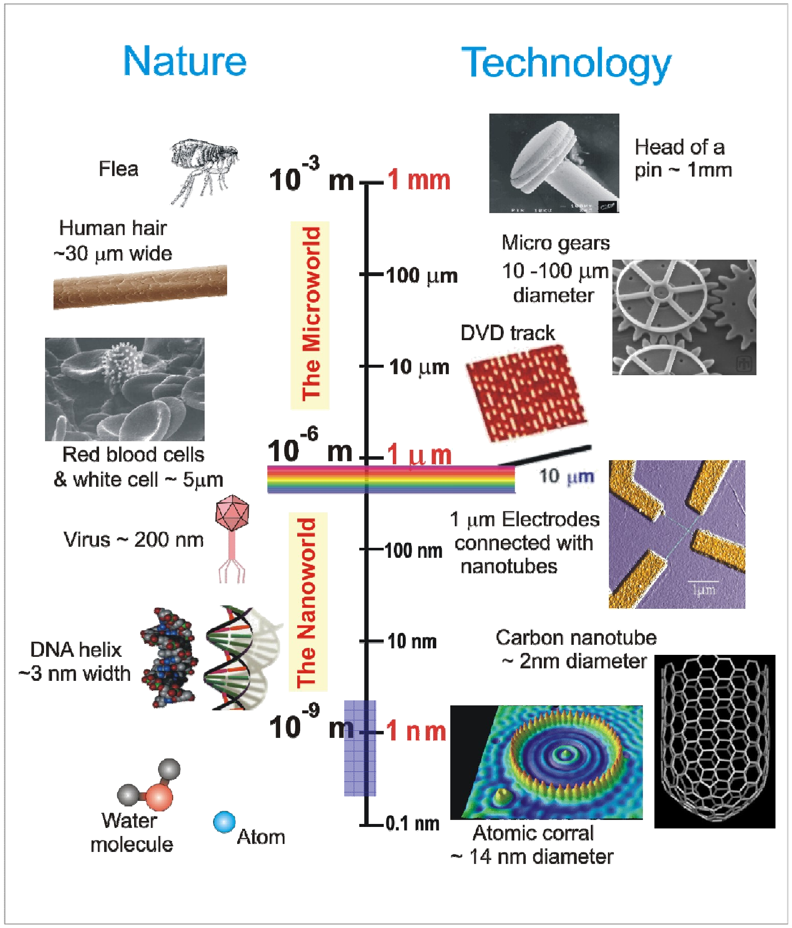
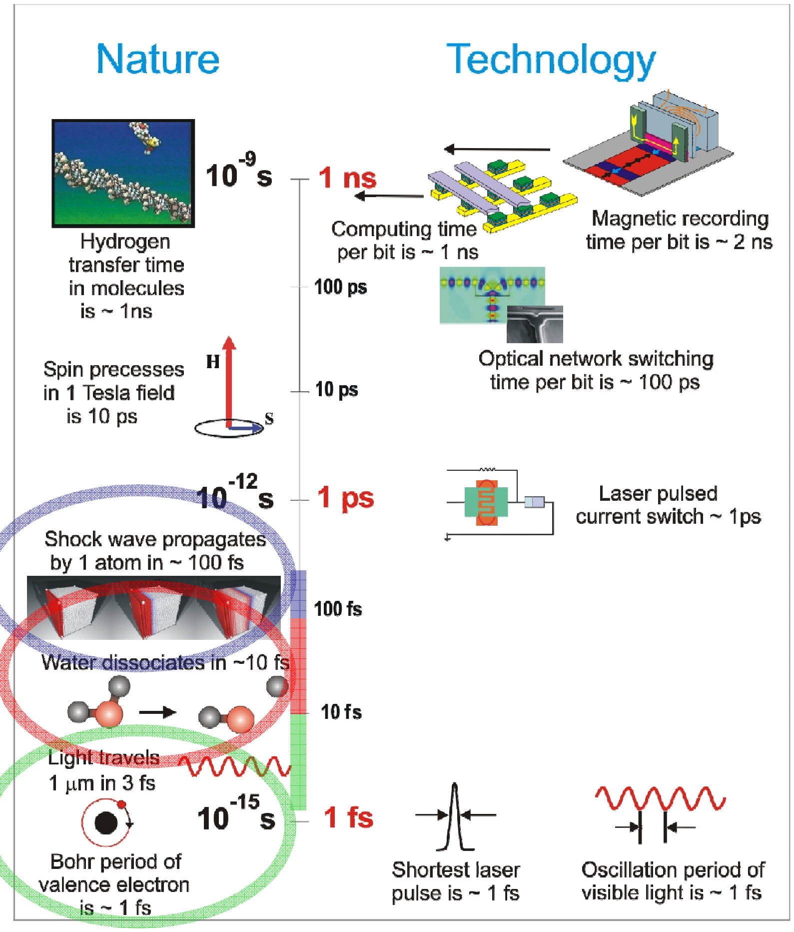
LCLS - The World's First Hard X-ray Laser

Ultra-Small



Ultra-Fast



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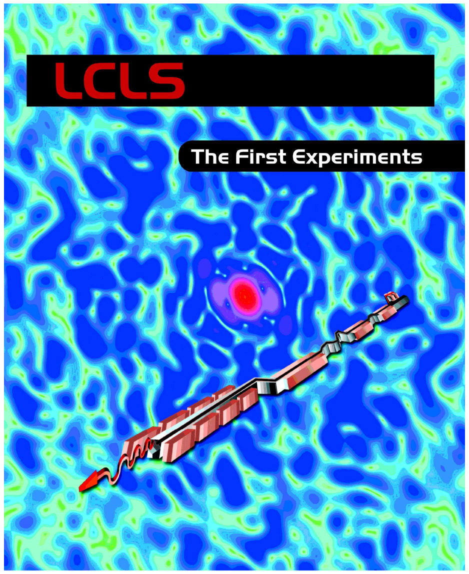
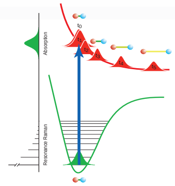
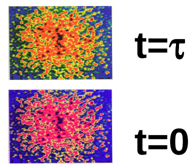
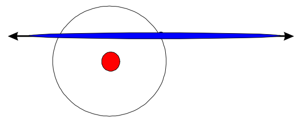




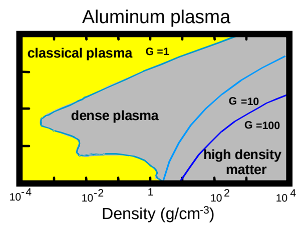
Femtochemistry



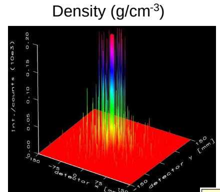
Nanoscale Dynamics in Condensed matter



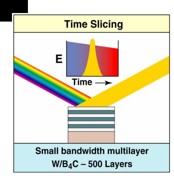
Atomic Physics



Plasma and Warm Dense Matter



Structural Studies on Single Particles and Biomolecules



FEL Science/Technology

- SLAC-R-611
- http://www.slac.stanford.edu/cgi-wrap/getdoc/slac-r-611.pdf

The Atomic, Molecular & Optical Science (AMOS) Instrument @ LCLS

- study of atoms & molecules, the basic building blocks of matter
- Useful for understanding fundamental interactions of energy and matter
- The people that brought you the laser
- Recommendation of the 1994 National Research Council: “develop techniques to better control atoms, molecules, ions and light”

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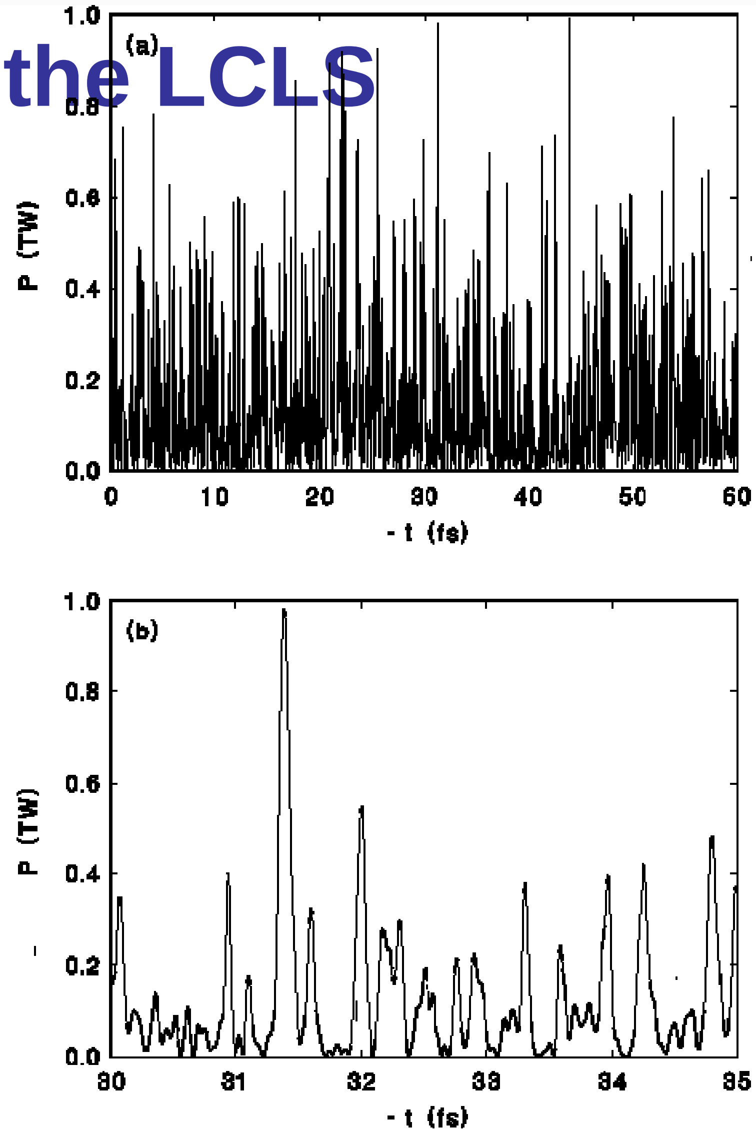
AMO Science at the LCLS

- LCLS pulses:
  - 120 Hz
  - Photon energy 800 – 8000 eV
  - Bandwidth ~0.07 – 0.03%
  - ~200 fs duration
  - 10^{13} – 10^{12} photons/pulse
  - ~1.9 mJ/pulse – up to 10^{18} W/cm^2 (with a 1 μm^2 focus)



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AMO Instrument – temporally resolving

- Initiate a process with an external laser & follow temporal evolution with LCLS pulse
  - Utilize site specificity of inner-shell probes to explore evolution of temporal sensitivity
  - Can also use laser to impulsively align molecule(s) and investigate body-frame ionization information
  - Forms basis of “clock” for overlap of two pulses
  - Use of lasers to create non-equilibrium samples (laser ablation, coulomb explosion of cluster…)

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AMO Instrument – temporally resolving

- Requirements:
  - Need timing signal before LCLS pulse with ~100fs resolution – i.e. want to explore temporal envelope *before* & after LCLS pulse
  - Need high field laser – 20mJ sufficient
  - Want capability to create other colors:
    - Harmonic generators to double & triple Ti:Sapp
    - OPA to shift wavelength to anything in between
    - Will need to control lasers/alignment optics

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AMO Instrument - Layout

- Instrument control issues:
  - Many stepper motors (50-100) to align chambers, position detectors, etc
  - High voltage (dozens) controlled through 0-10V analog signals (and similarly monitored)
  - Valves & pumps etc for vacuum system
  - Valves & pumps for gas handling system
  - Hoping whole control system architecture can live in hutch (no long cable pulls)

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Summary

- LCLS is a rich ground for developing a comprehensive control system
- The challenges (aside from the usual time constraints) include, the breadth of responsibilities, development of new technologies, and integration of the old and the new…

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Toys available… ☺

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