# Beam Based Feedback for the Linac Coherent Light Source


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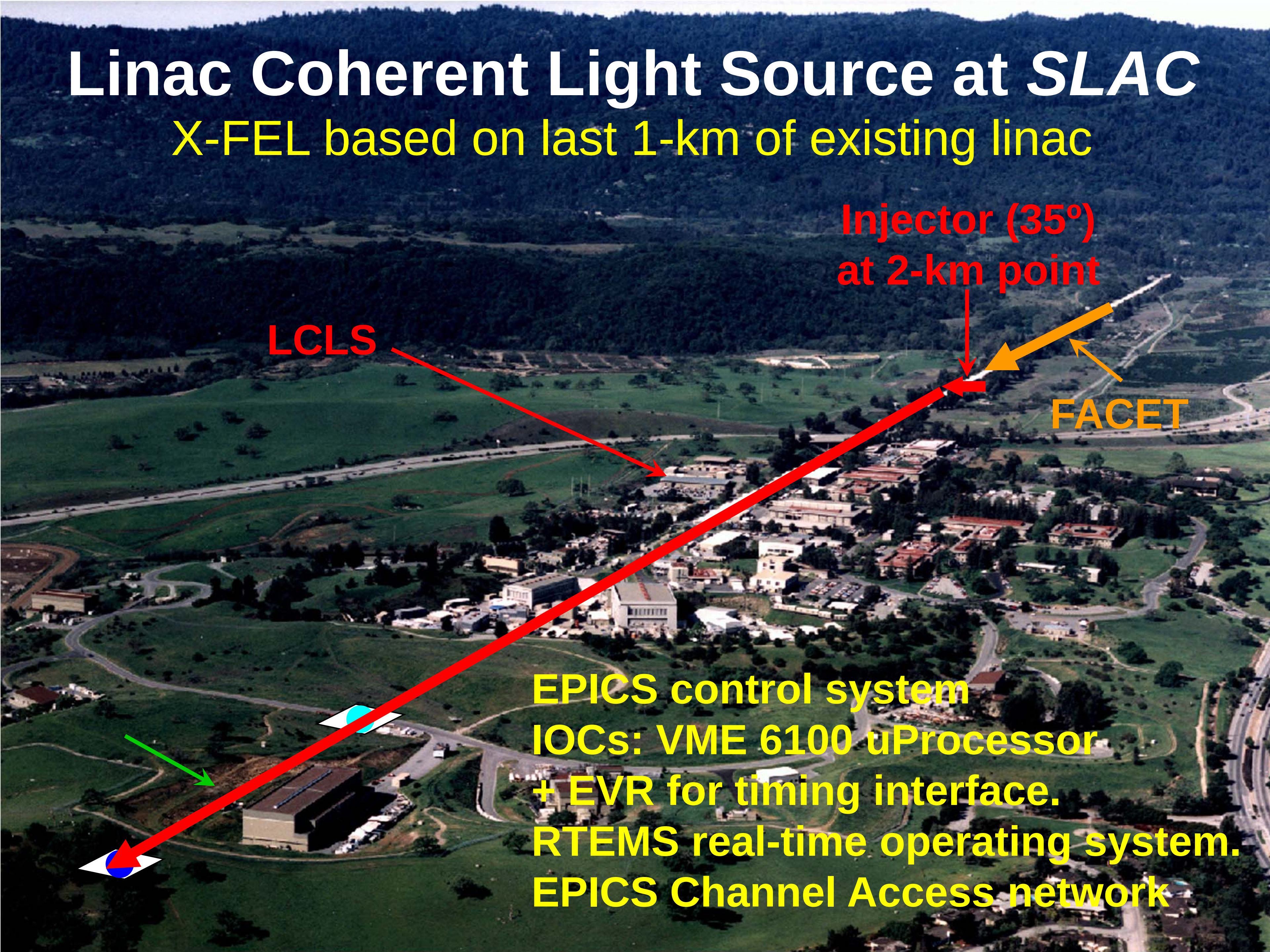
October 14, 2011

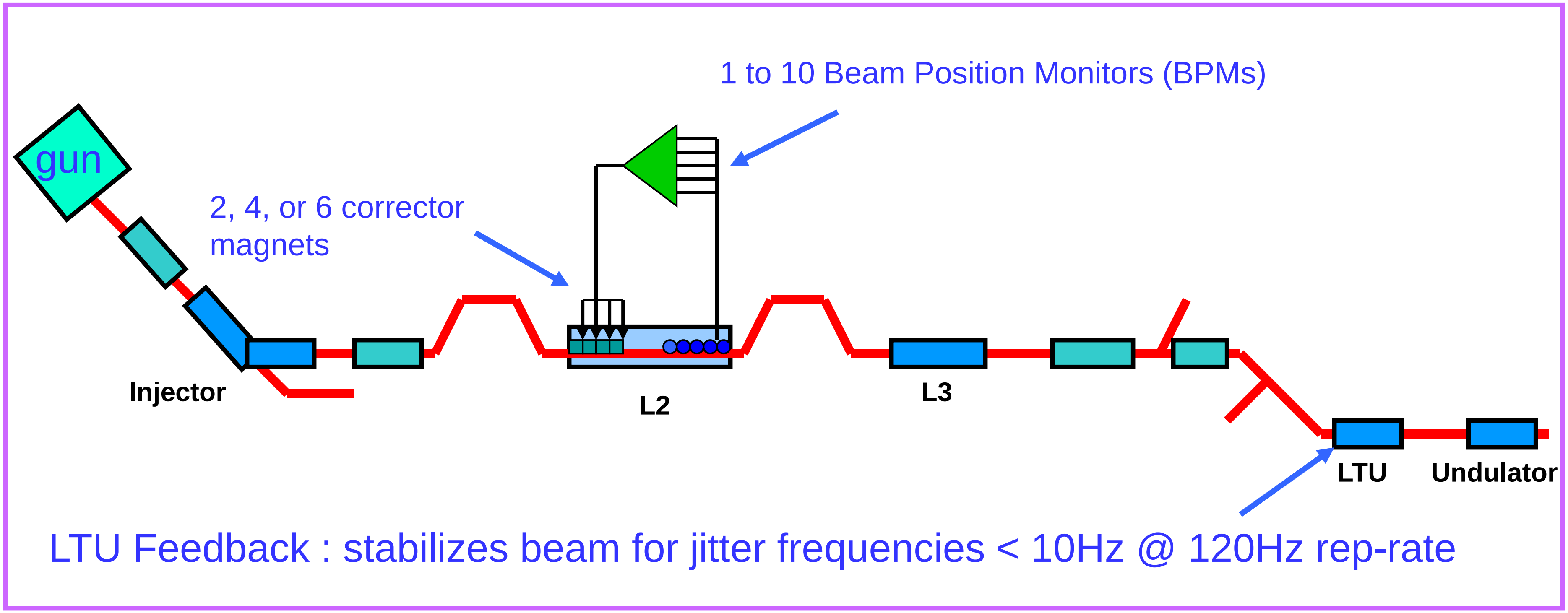

Linac Coherent Light Source at *SLAC*
X-FEL based on last 1-km of existing linac
Injector (35º)
at 2-km point
LCLS
FACET
EPICS control system
IOCs: VME 6100 uProcessor
+ EVR for timing interface.
RTEMS real-time operating system.
EPICS Channel Access network

# Outline

- Overview of LCLS Feedbacks
- Upgrades for 120Hz
- Developing the upgrades
- Commissioning on a Production Machine
- Summary - Lessons Learned

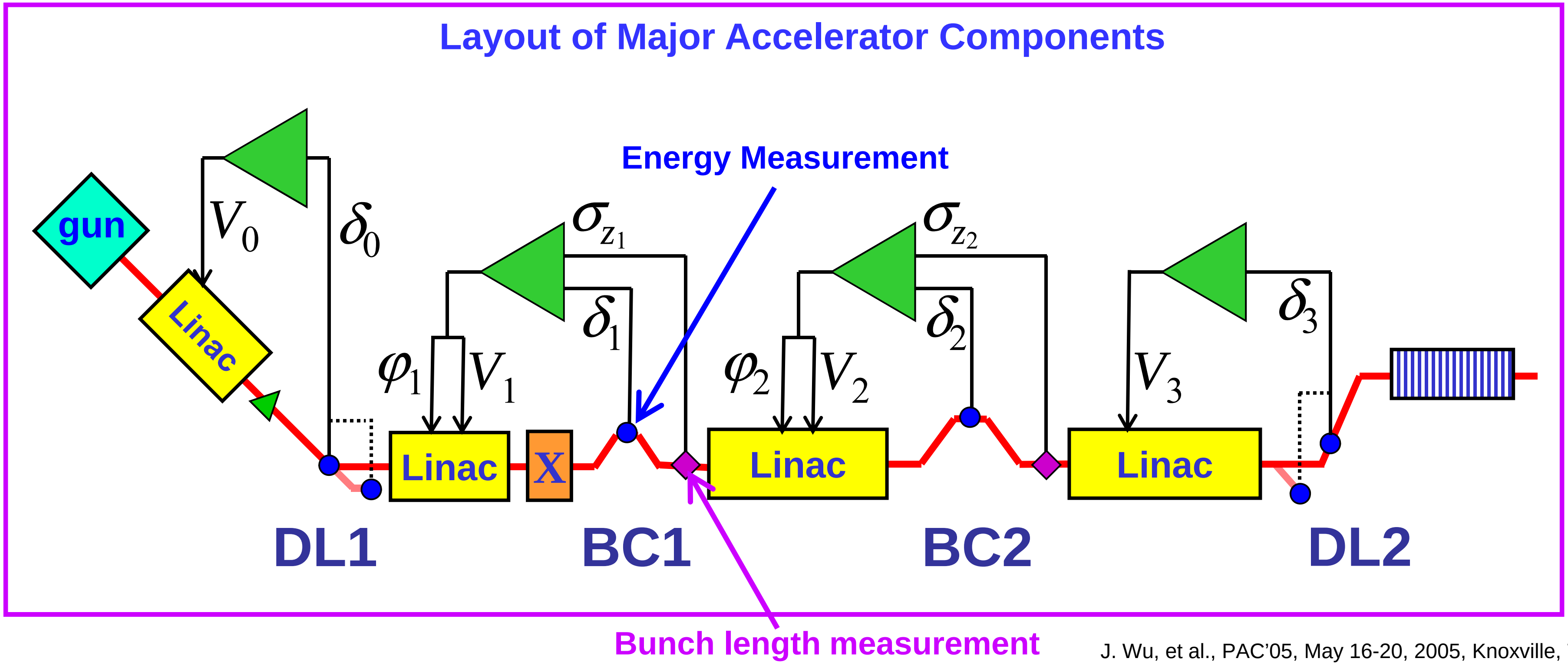
# 9 Transverse Trajectory Feedbacks

- Maintain position and angle in X and Y along the beam line



# Longitudinal Energy and Bunch length Feedback

- Maintains 6 beam parameters of energy ($\delta$) and bunch length ($\sigma$)
- Stabilizes beam for jitter frequencies < 10Hz @ 120Hz rep-rate

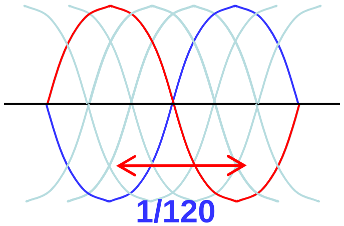



J. Wu, et al., PAC'05, May 16-20, 2005, Knoxville, TN.

# 120Hz and Power Phases

- 120 Hz beam operation draws power from two interleaved 60 Hz power line phases. Beam generated on different 60 Hz power line phases have differing noise characteristics. The new program, FACET, introduces further disturbance by drawing additional power at 30Hz from a third power phase.

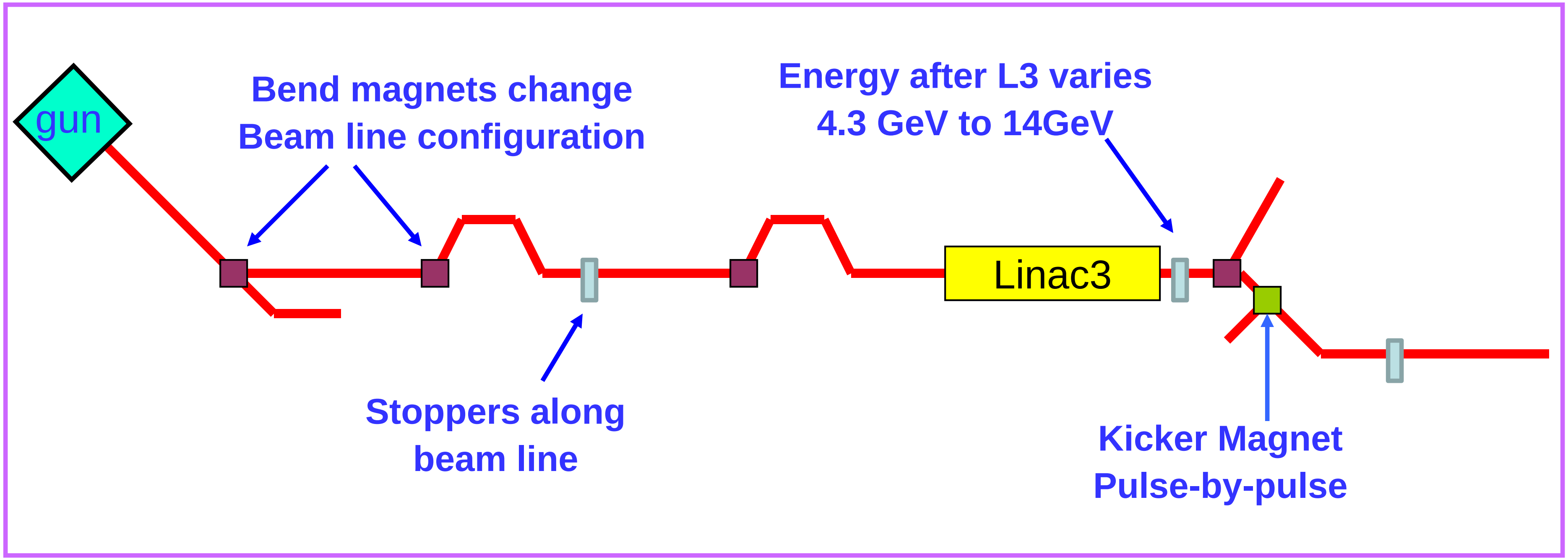
3-phase power




- The LCLS timing system generates a fiducial interrupt at 360 Hz, dividing the LCLS timeline into 6 “timeslots”. The timing system labels each timeslot with a “pattern” describing features of the beam at that timeslot.
- The Fast Feedback system must use the timing system “patterns” to help correct for these high frequency differences on different timeslots.
- These noise differences have a large DC component which can be corrected by an offset between the timeslots – so it was determined that the actuators should be made “pattern-aware” as well as the feedback, so that the timeslot differences could be reduced even when the feedbacks are off.

# Additional Requirements for LCLS

- Automatic energy, charge, and bunch length changes
- Beam line configuration changes: pulse-by-pulse
- Beam rate changes: 120Hz, 30Hz, 10Hz, 1Hz
- User controls, and interactions with tuning scripts

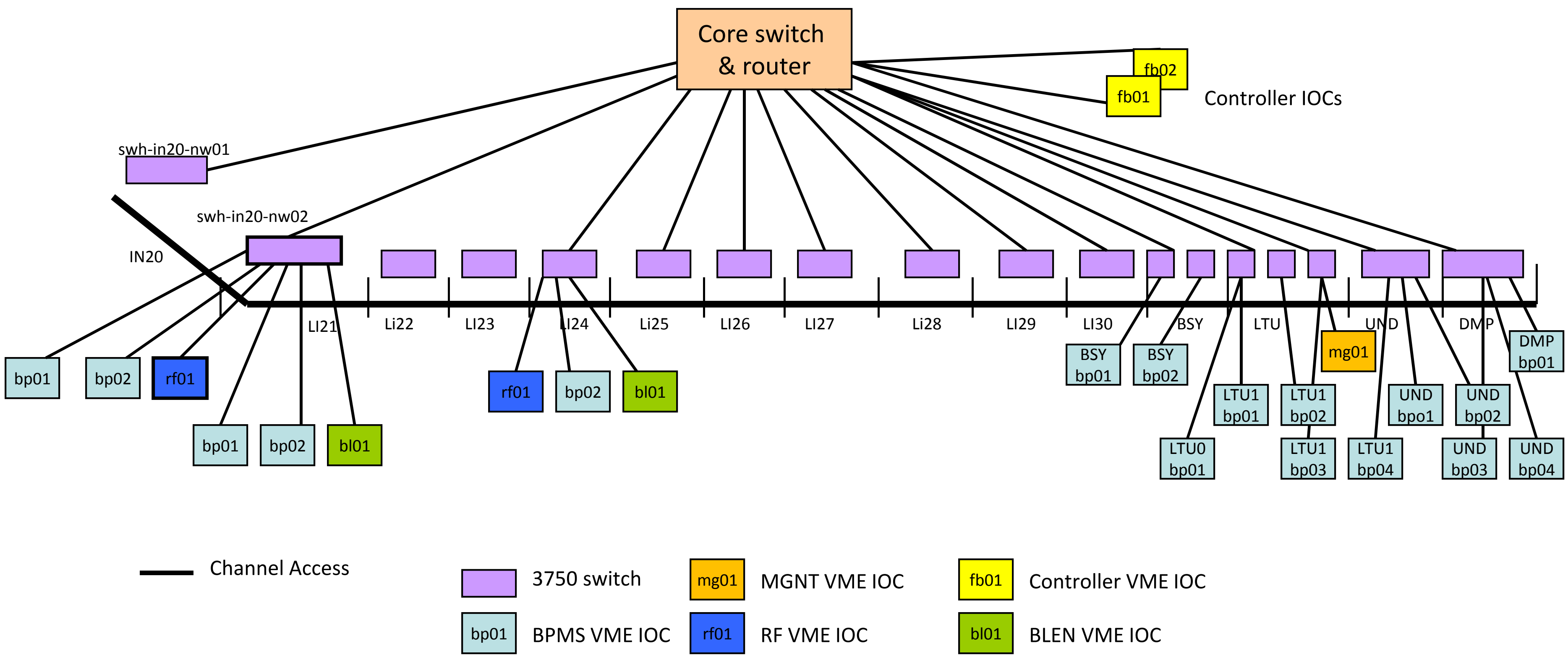


# Upgrades for LCLS Fast Feedback

- 8.33ms between beam pulses – 6ms settling time for magnets = ~2ms for all feedback processing
  - Goal: Sensors collect, process, and send data <1ms
  - Goal: Feedback IOCs process, send actuator commands < 1ms
- Move feedback communications to an isolated multicast network.
- New communications protocol and software module, FCOM.
  - Similar to a ‘reflective memory’ network.
  - integrated into all devices used by feedback.
- Faster feedback processing with Feedback Controller IOCs

# The Feedback Network and FCOM

- Installed dedicated network uplinks and connections to $2^{nd}$ NIC on ~150 IOCs
- Sensors multicast, feedback loop controllers listen & multicast, actuators listen



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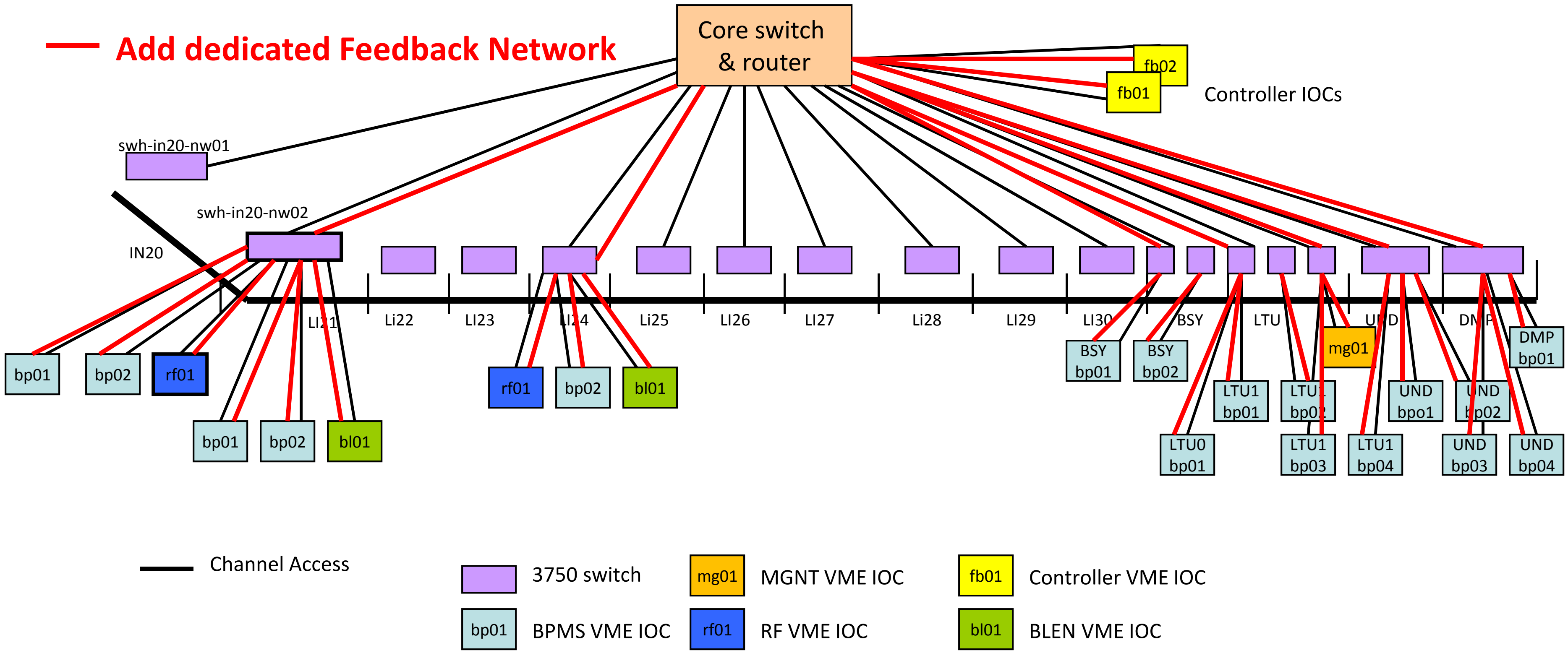


# Upgrades for LCLS Fast Feedback

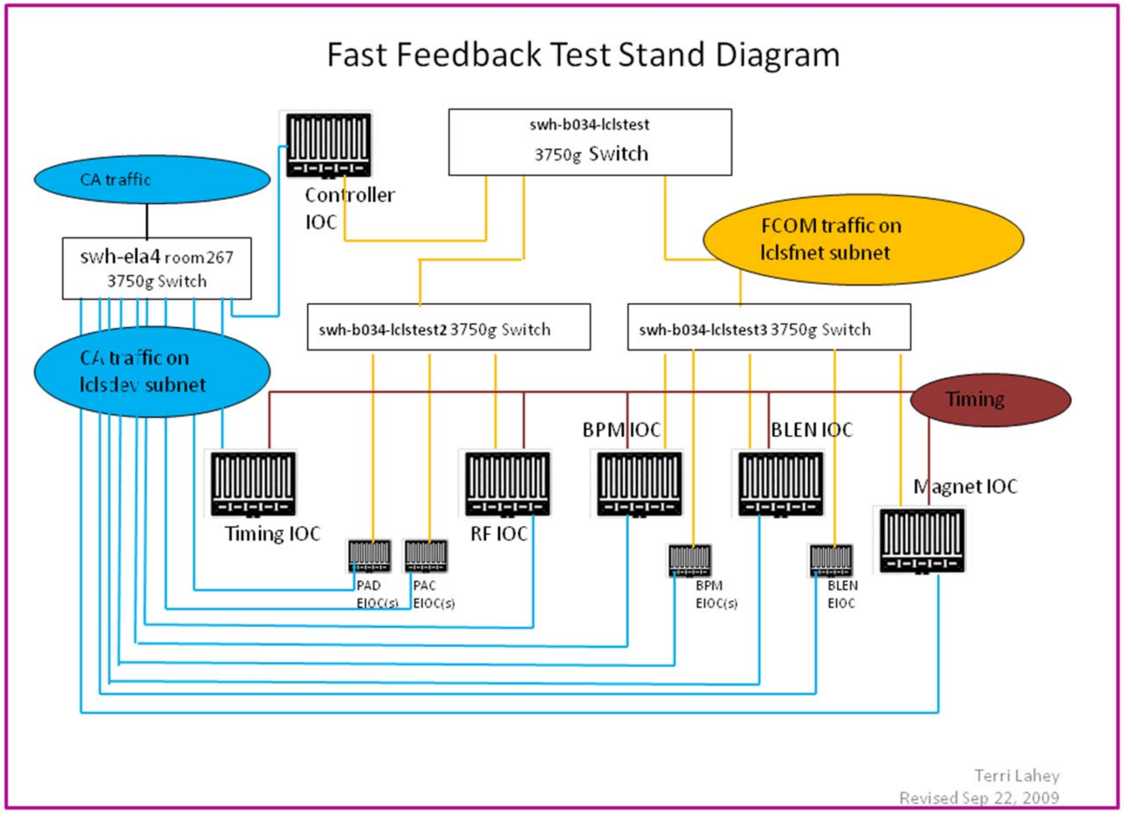
- Feedback loops and actuators require access to the timing system ‘patterns’ to correct for high frequency noise differences in power line phases.
  - New interface to the timing system for actuators, the Pattern-aware Unit (PAU) software module. It is integrated into magnets and RF stations.
    - [WEPMN032] Development of Pattern Awareness Unit (PAU) for LCLS
  - New Feedback Controller IOCs include timing system interface software and an EVR.

# Develop Upgrades

- LCLS Machine Schedule
  - January to April 2010 - downtime
  - May 2010 to March 2011 – 30 Hz user operation
  - April to May 2011 – downtime
  - June 2011 to present – 120Hz user operation
- Opportunities for beam time
  - during 1 week recovery after downtime, or
  - machine development days - competing with many other tasks
- How can we commission beam-base feedbacks without beam time??

# Development Test Stand

- Included all major components
  - Dedicated Network
  - Timing System
  - Actuators and Sensors
  - Feedback Controller
  - Development server for Configuration Tool and Runtime Display and Control development
  - Read-only gateway to access production machine data.




- KEY to successful commissioning

# Test techniques

- Use timing system without beam
  - Trigger sensors at 120Hz to collect  and send ‘noise’ data packets
  - Install a test controller IOC on production with diagnostic application
  - Receives sensor packets, sends actuator commands, collects statistics
- Keep all original functionality in feedback devices
  - Turn Off new functionality instead of back out
- Automate switchover between new and old software
  - Scripts to automatically switch control/alarms between MATLAB and fast feedbacks.
  - Scripts to automatically program/reprogram network switches/vlans
  - Backout of LLRF includes reprogramming switches

# Development on Test Stand

- Proof of concept and complete development of network protocol, sensors and magnets
- Complete development of configuration GUI and runtime displays.
- Partial development of LLRF upgrades
  - Too costly to include control HW for ~ 6 unique RF stations at one time
- Partial development of feedback controller
  - Could not duplicate all required interfaces to other subsystems
  - Could not ‘close-the-loop’ for final algorithm checkout, no ‘virtual machine’
    - This was not critical since algorithms were working in MATLAB already
- Could not duplicate full machine network loads (FCOM and CA)
- Could not duplicate the range of operating conditions of the real machine.

# Commissioning in Two Phases

- Phase I started April 2010 (infrastructure)
  - FCOM network
  - BPMS and BLENs
  - RF and Magnets
- Phase II started Dec 2010 (feedbacks)
  - Feedback Controller IOCs
  - Each feedback loop
  - Feedback Configuration application
  - Feedback displays

# Commissioning: Phase I April 2010

- March 2010 Downtime (no beam)
  - Installed and configured the dedicated multicast network
  - Upgraded sensors: ~100 BPMs and 2 BLENs
  - Upgraded actuators: 14 LLRF stations and 4 corrector magnets
  - Using a test ‘controller’ and timing system verified FCOM communications and feedback timing.
- April recovery before user run 2010 (30Hz Operation)
  - Allotted three 8-hour shifts to commission with beam
  - Must test that devices work as usual, plus test new features.
  - Required to back out untested changes at the end of each shift, until fully commissioned (1 hour effort for LLRF system)
  - After 3 shifts, remaining work done on MD days, ~once per week during the user run.

# Phase 1 2010 Commissioning results

- BPMs capable of collecting, processing and sending measurements in <1ms, meeting the requirement
- Bunch length monitors did not meet requirement (~3ms) but can still be used by longitudinal feedback since RF actuators do not require settling time.
- Needed only one MD day beyond tune-up time to fully commission the sensors, magnets, and LLRF
- There have been bug fixes since that time…
- LLRF enhancements began in June of 2010.

# Commissioning: Phase II Oct. 2010

- Commissioned  4 feedbacks, configuration GUI, and runtime displays with 30Hz beam
- Installed 4 more feedback controller IOCs downtime in April 2011
- June 2011 user run till present (120Hz Operation)
  - Allotted 1 to 3 hour shifts on a few machine development days since May.
  - commissioned feedback loops one at a time
  - Load balanced feedback loops across four IOCs.
  - One IOC for test/staging.
  - Set up LLRF PAUs to correct for 60Hz, 30Hz noise using offsets

# Phase II Commissioning Results

- Feedback loops process one iteration in <400ms on average, easily meeting requirement.
- Beginning July 2011, added several features to the longitudinal feedback that were conceived of during the Phase I commissioning and the following user run
- Still testing some of these new features….
- Used <45 hours beam time total since October 2010, 18 hours at 120Hz, 10 of those on longitudinal feedback enhancements, so far….
- ~2.5 hours downtime assigned to Fast Feedbacks

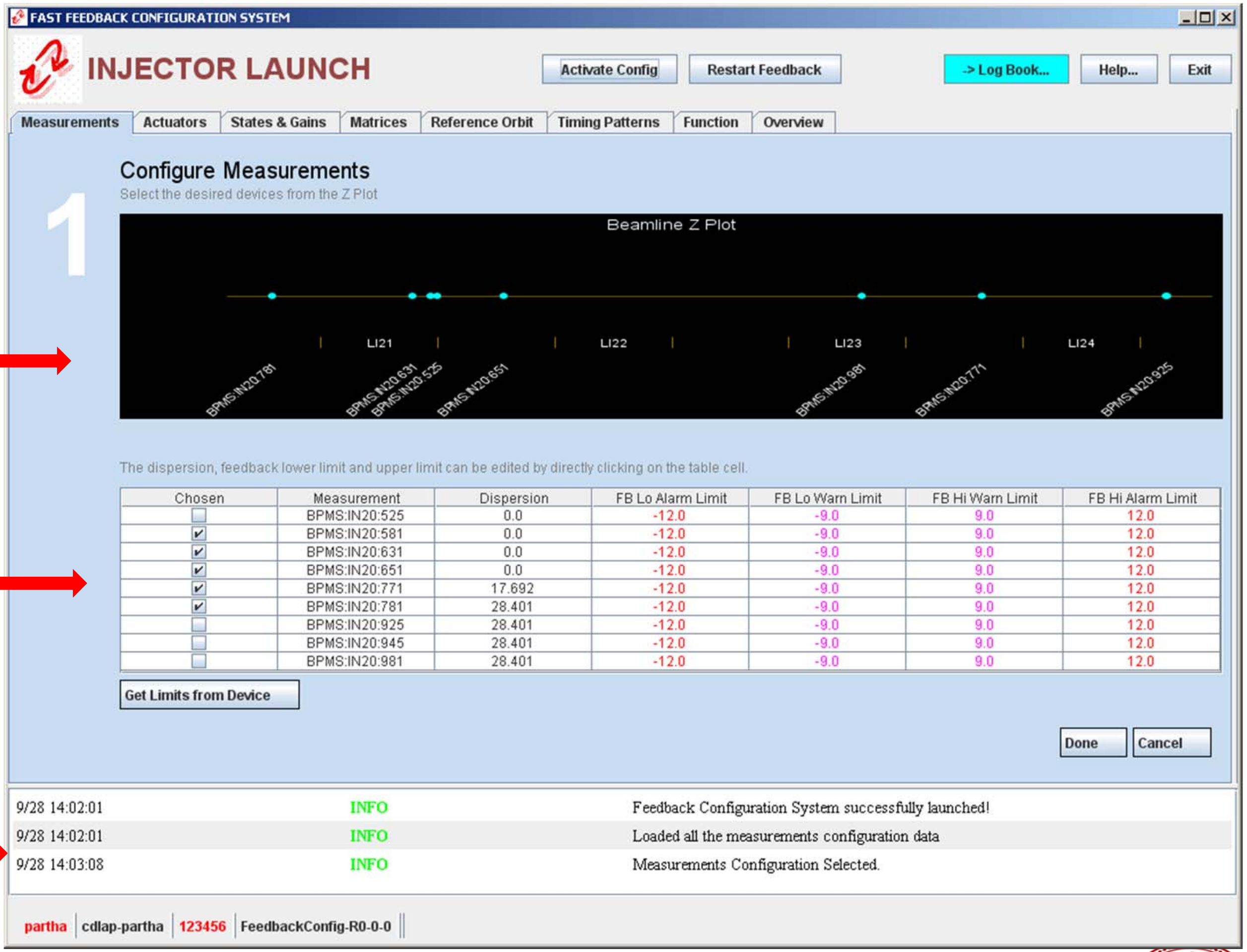
# Configuration Tool

- Java application: allows user to create / configure feedbacks off-line.

Interactive beamline map

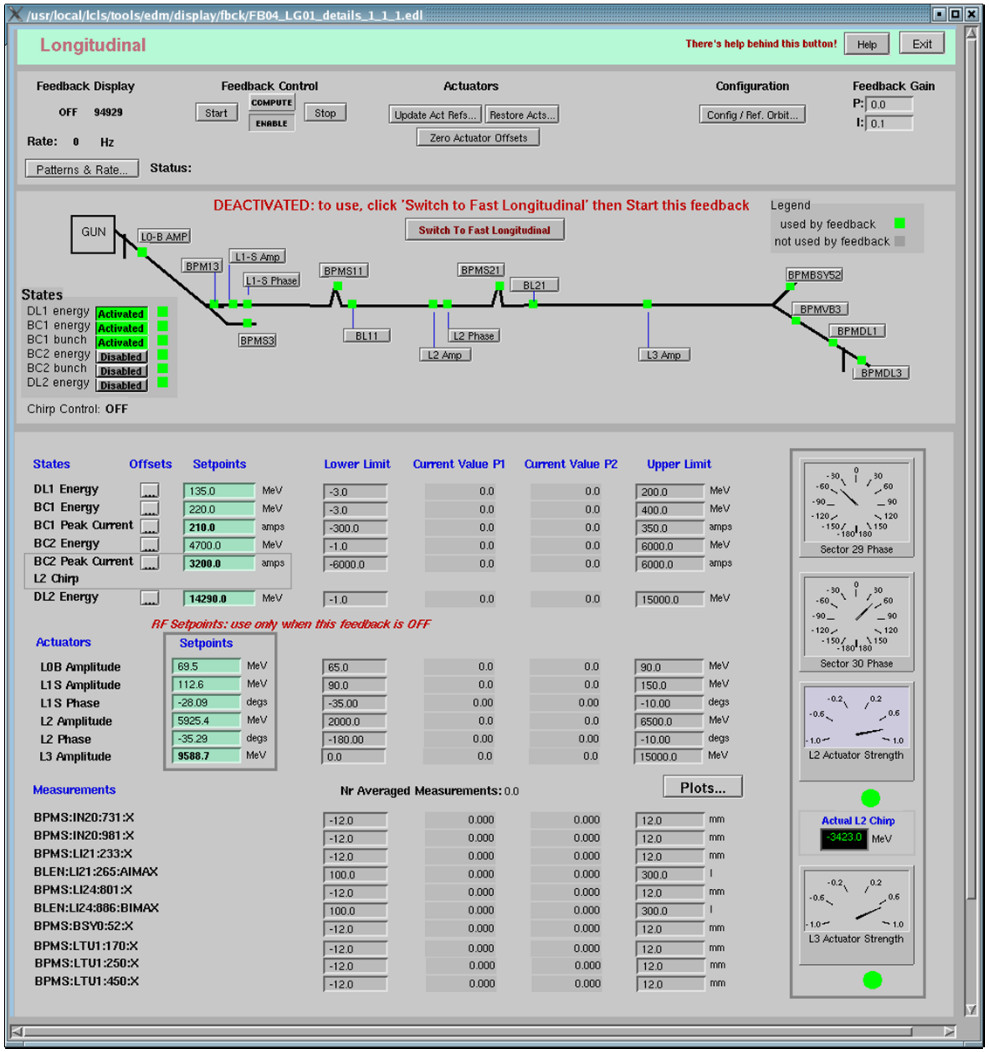
User editable fields

Message window

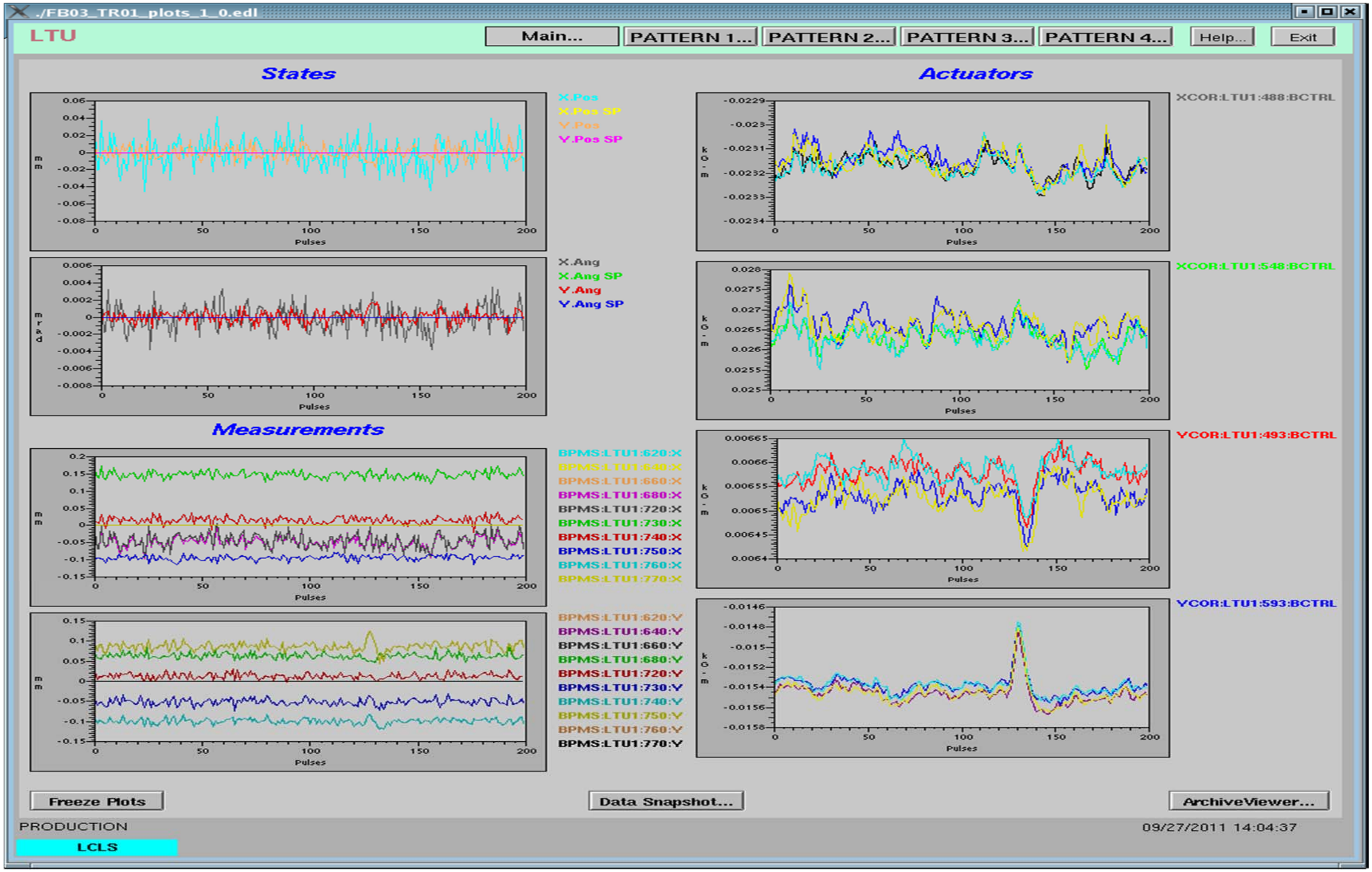


# Runtime Control

- •EDM displays allow changes while feedback is running.
- •start, stop, disable
- •choose which parameters to stabilize
- •setpoints, limits, gains.
- •Scan parameters for correlations



# Runtime Display



# Summary – things we did right

- Prototyping the feedbacks in MATLAB
- Extensive test stand
- Developing with Test in mind
- Commissioning in two phases
  - network and timeslot aware actuators available for 120Hz before full feedback installation. We were able to adequately correct for 60 and 30Hz noise during the 120Hz user run.
  - This allowed us to 'shake out' the bugs for half of this complex upgrade before moving on to the final feedback installation.

# Summary – things we'd do differently

- Feedbacks need test time in a variety of machine conditions, some of which are very invasive and take time to set up.  For efficient testing, we should have negotiated for longer  blocks of dedicated time before the user run started.
- Commissioning in two phases
  - network and timeslot aware actuators to use at 120Hz before full feedback installation - meant that commissioning feedbacks was a lower-priority job on development days so final commissioning has dragged on significantly.
- New features for the longitudinal feedback have taken over %50 of the 120Hz beam time . An additional review of 'Use Cases' for the longitudinal feedback might have caught these desired features earlier in the development process.
- Scope Creep: adding in 'simple' new features is never simple. Review additional features as carefully as the original design. Complete the original design first – declare victory before considering add-ons!

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