Operations Analysis Group Software for EPICS Environments

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March 18, 2004

Reporting on work of
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Outline

- Brief introduction to OAG
- Basic technologies: Tcl/Tk
  - Why and how we use it
  - PEM automation environment
- Basic technologies: SDDS
  - Why and how we use it
- Data analysis capabilities
- Data logging capabilities
- Process control capabilities

Brief Introduction to OAG

- Group of accelerator physicists and programmers formed in 1995 to “apply the lessons of commissioning to accelerator operation.”
- We automate the operation of APS accelerators.
- We manage the data logging systems.
- We also write accelerator simulation codes.
- We consistently use Tcl/Tk and SDDS.

Tcl/Tk

- Tcl/Tk is our standard scripting language
  - Free
  - Open source
  - Easy to learn
  - Extensible
  - Great for GUIs

OAG Tcl/Tk

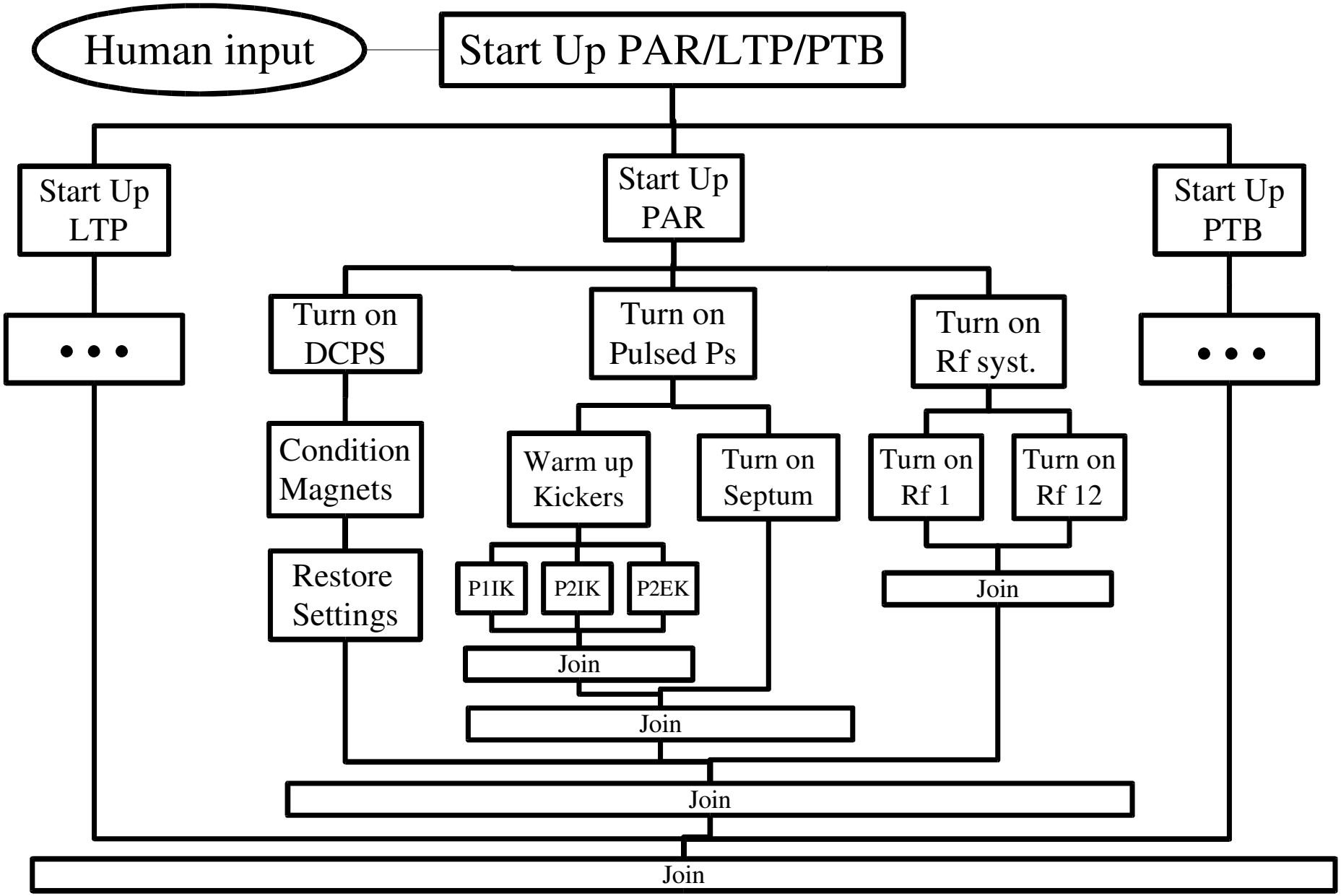
- Tag/value convention for all procedues is critical
  - Instead of
    `functionName arg1 arg2 arg3 ...`
  - We use
    `functionName -tag1 value1 -tag2 value2 ...`
  - Makes upgrades and reuse easy and robust
  - Code is far more readable
- OAG widget library for common look-and-feel
- Extensions for (among others)
  - Channel access (`et_wish`)
  - SDDS file access
- "Machine procedures" library for accelerator operations

OAG PEM Environment

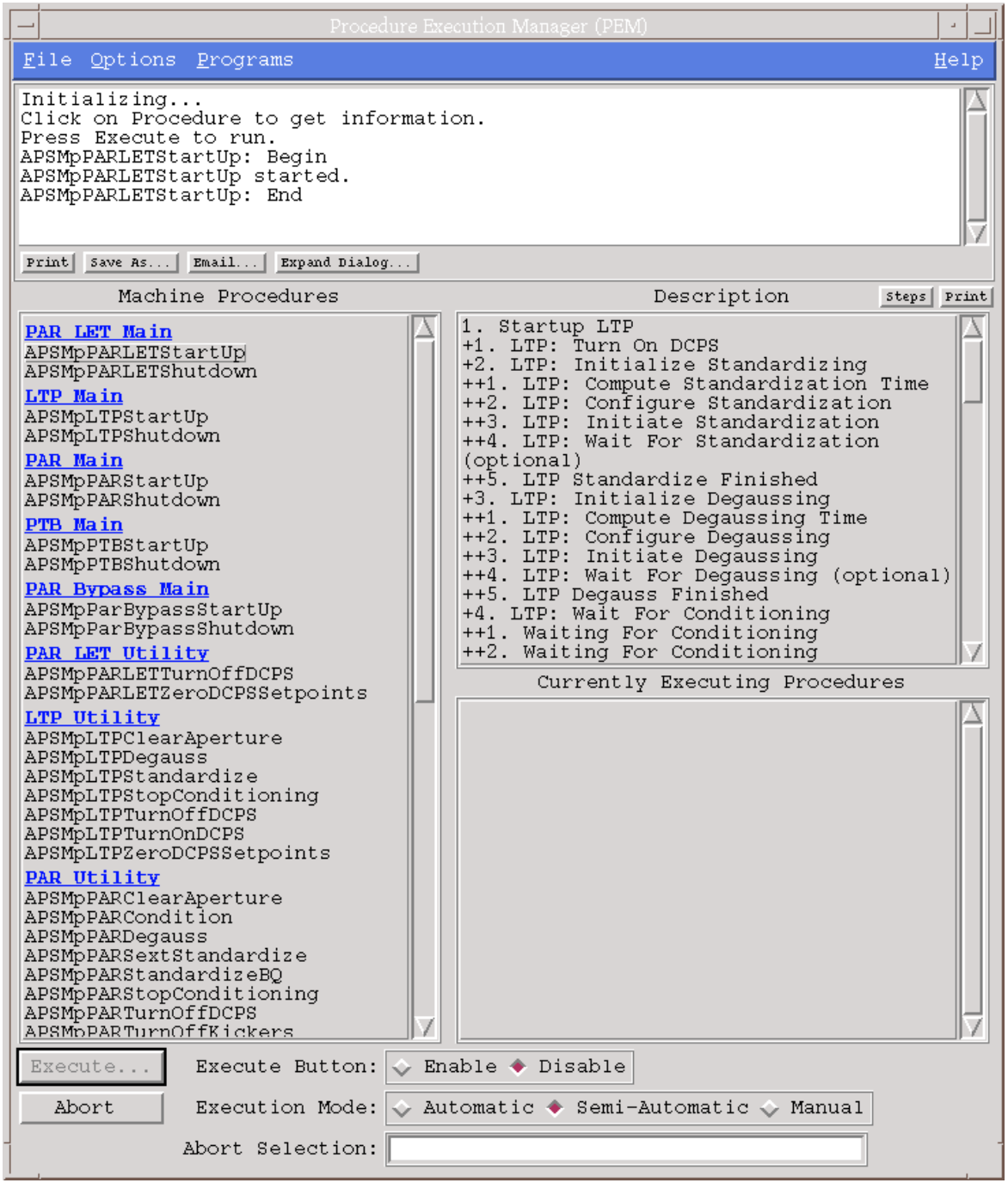
- PEM* (Procedure Execution Manager) is an Tcl/Tk environment used for automation
  - Machine procedure lists
  - Hierarchical, parallel execution
- Critical concept:
  - When a human initiates a procedure, the human must provide “arguments” through a GUI
  - When software initiates a procedure, it must provide the arguments and the GUI is suppressed

*Written by OAG emeritus C. Saunders

Simplified Particle Accumulator Ring PEM Diagram



PAR PEM Panel



SDDS

- SDDS = Self-Describing Data Sets
  - A stable, general-purpose file protocol
  - Generic tools that operate on SDDS files
  - EPICS tools that are configured by SDDS files
  - Libraries for working with such files
- Multiplatform and open-source
  - Solaris, Linux, Windows, OS-X, VxWorks
- Supported languages
  - Shell commandline
  - C/C++, Tcl/Tk, Python, Java, IDL, MATLAB, FORTRAN

Why Use Self-Describing Data?

- Programs that use it are much more robust and flexible
  - Check existence, data-type, units of data instead of crashing or doing something inappropriate
  - Respond appropriately to the data that is provided
    - Exit and warn user, or
    - Use defaults for missing data
  - Data doesn't become obsolete when the program is upgraded
- Data sets can evolve without breaking applications
- Multiple uses for one data set are possible
  - Helps maintain consistent configuration of multiple applications

SDDS File Protocol

- Data model
  - File has a sequence of instances of a structure
  - Structure contains
    - Parameters (scalar values)
    - Table
    - Arbitrarily-dimensioned arrays (little-used)
- All elements are named.
- Meta-data includes units, description, data type
- Options for binary, ASCII, and compressed storage

SDDS Toolkits

- Without the Toolkits, SDDS would be just another boring file format
- Toolkit is UNIX-inspired

- UNIX
  - Everything is a file
  - Programs are “filters” operating on ASCII streams
  - Pipes allow sequencing filters arbitrarily
- SDDS
  - Everything is a self-describing file
  - Programs are operators that transform datasets
  - Pipes allow sequencing operators arbitrarily

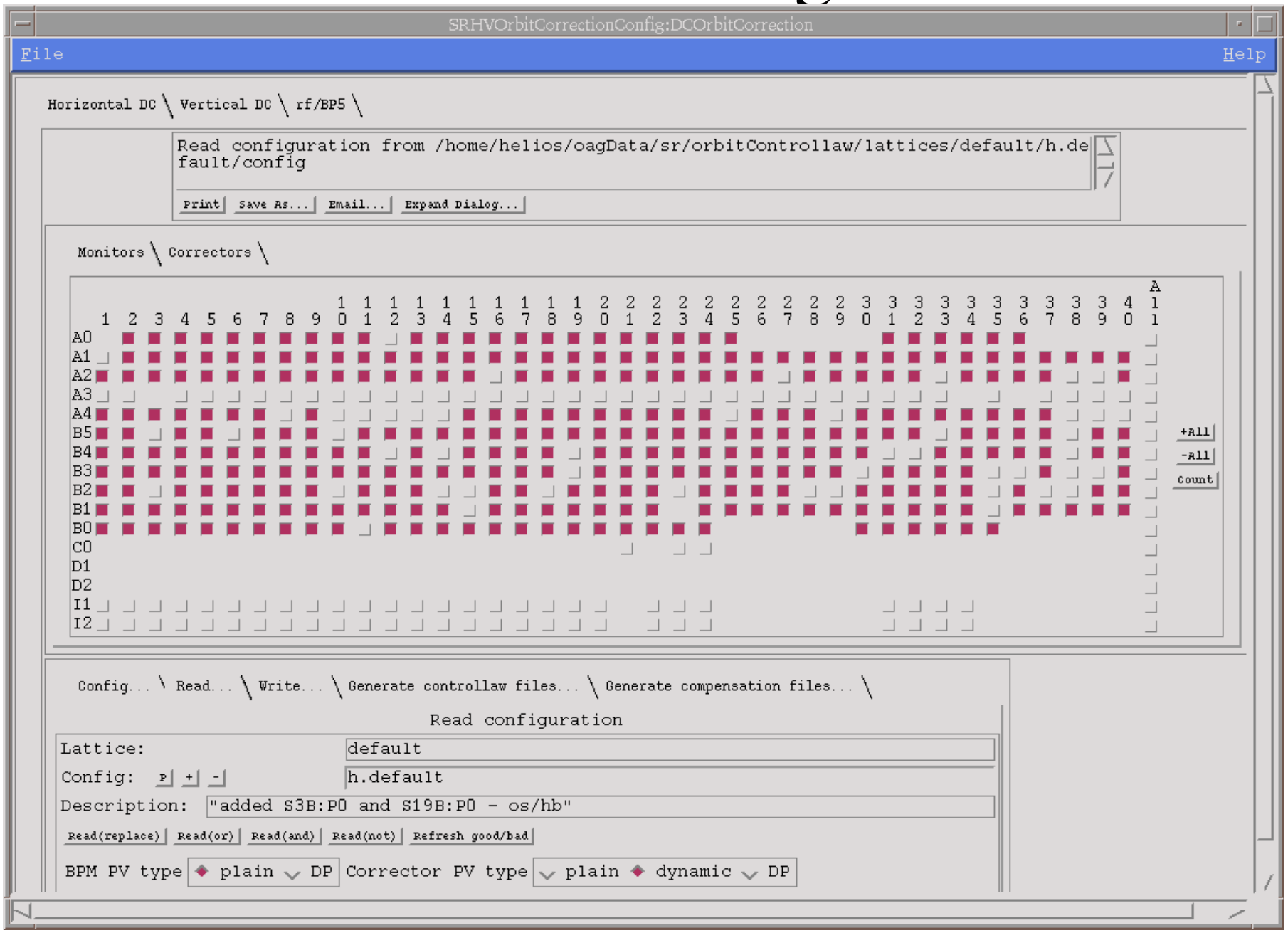
SDDS and Tcl/Tk

- SDDS and Tcl/Tk complement each other
- Tcl/Tk is a good language for GUIs, but
  - Lacks data management capabilities
  - Not great for computation
- SDDS offers data management, analysis, and computation, but
  - Is not a programming language
  - Has commandline user interface

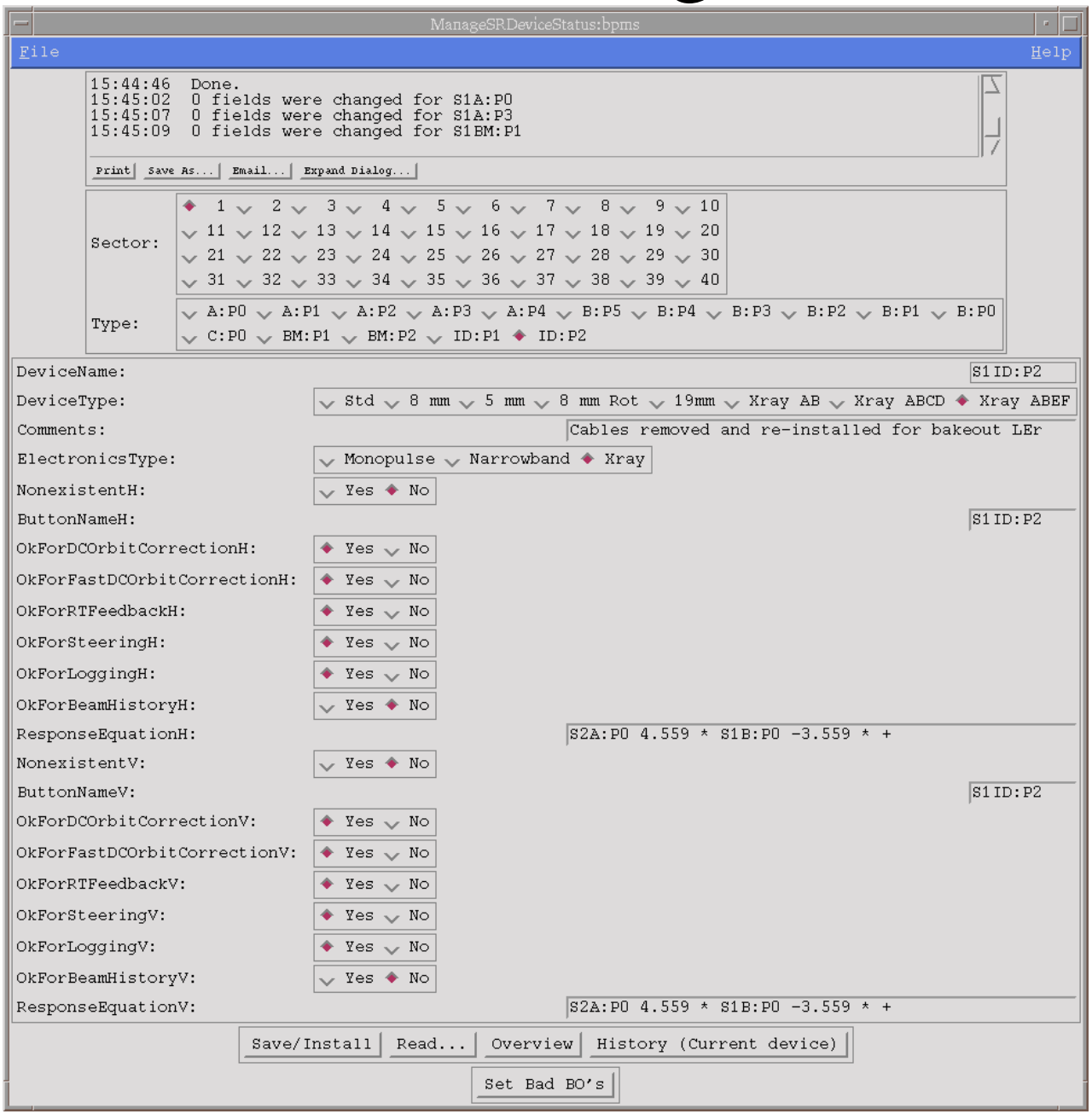
Examples: Orbit Correction

- SDDS-linked Tcl/Tk GUIs for
  - Component status tracking (e.g., “bad BPMs”)
  - Correction configuration management
  - Starting and monitoring processes
- SDDS-configured processes include
  - In-IOC or workstation-based feedback algorithm
  - Permission-to-run testers
  - Feedforward for x-ray BPM correction and fault tolerance
- All data storage and preparation uses SDDS, including
  - Simulation data (response matrix)
  - Measurements (feedforward data)
  - Configurations and configuration history

Orbit Correction Configuration GUI



BPM Status Management GUI

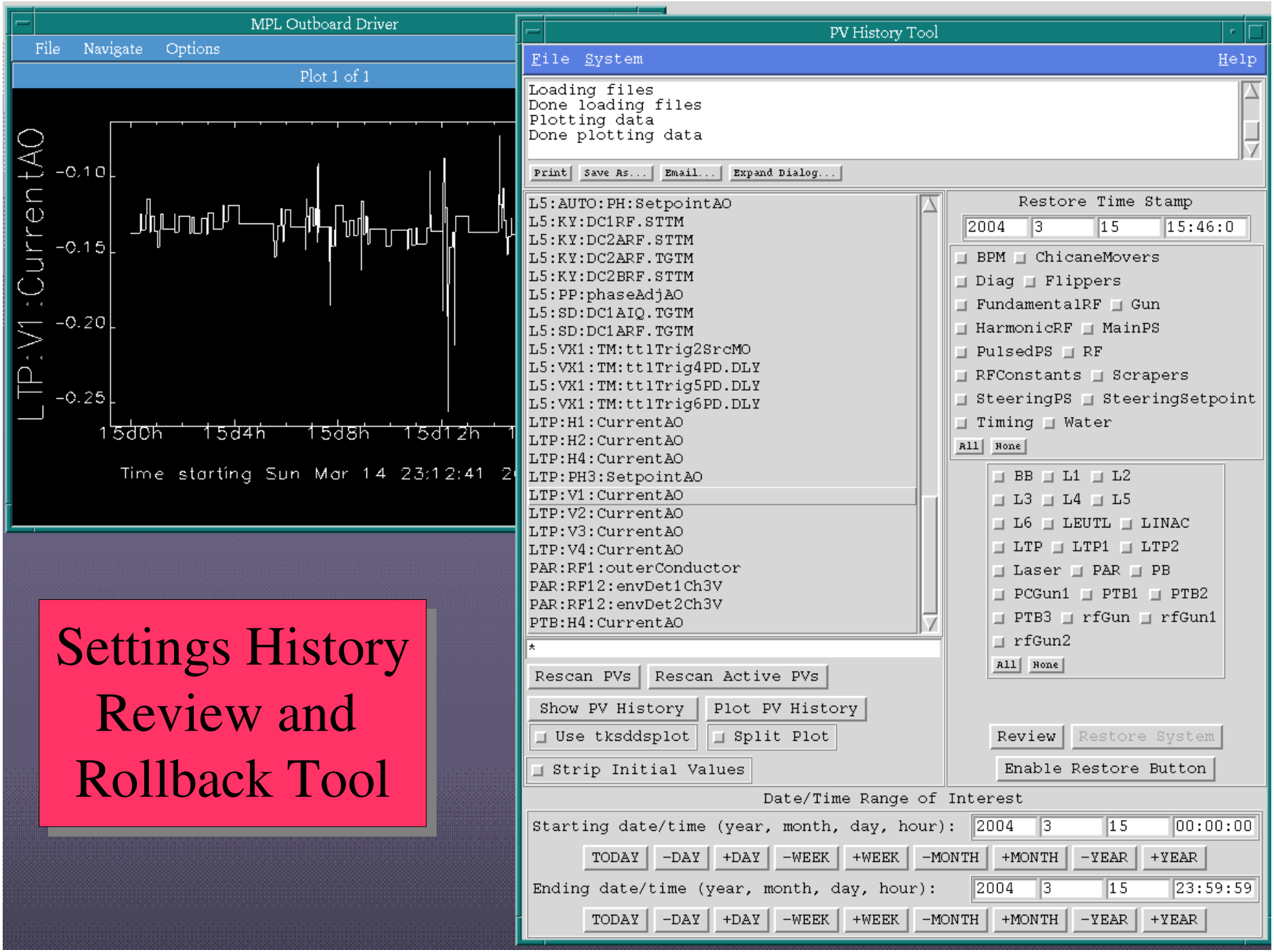


Examples: Save/Compare/Restore System

- SDDS request and snapshot files have PV meta-data
  - System, subsystem
  - Data type (numerical, enumerated)
  - Access mode (read-only, protected, manual-only)
  - Tolerance
- Tag configurations as “preferred” or “reference”
- Compare configurations, or saved state to present state
- Review all or part of a configuration
- Restore/ramp to all or part of a configuration
- 60k process variables are tracked for APS machines

Examples: Setpoint Tracking

- S/C/R only manages discrete configurations stored on demand
- We also monitor changes to “all” setpoints (with deadbands)
- The PVHistory application allows
  - Plot or print history of setpoints
  - Rolling back to any point in the past

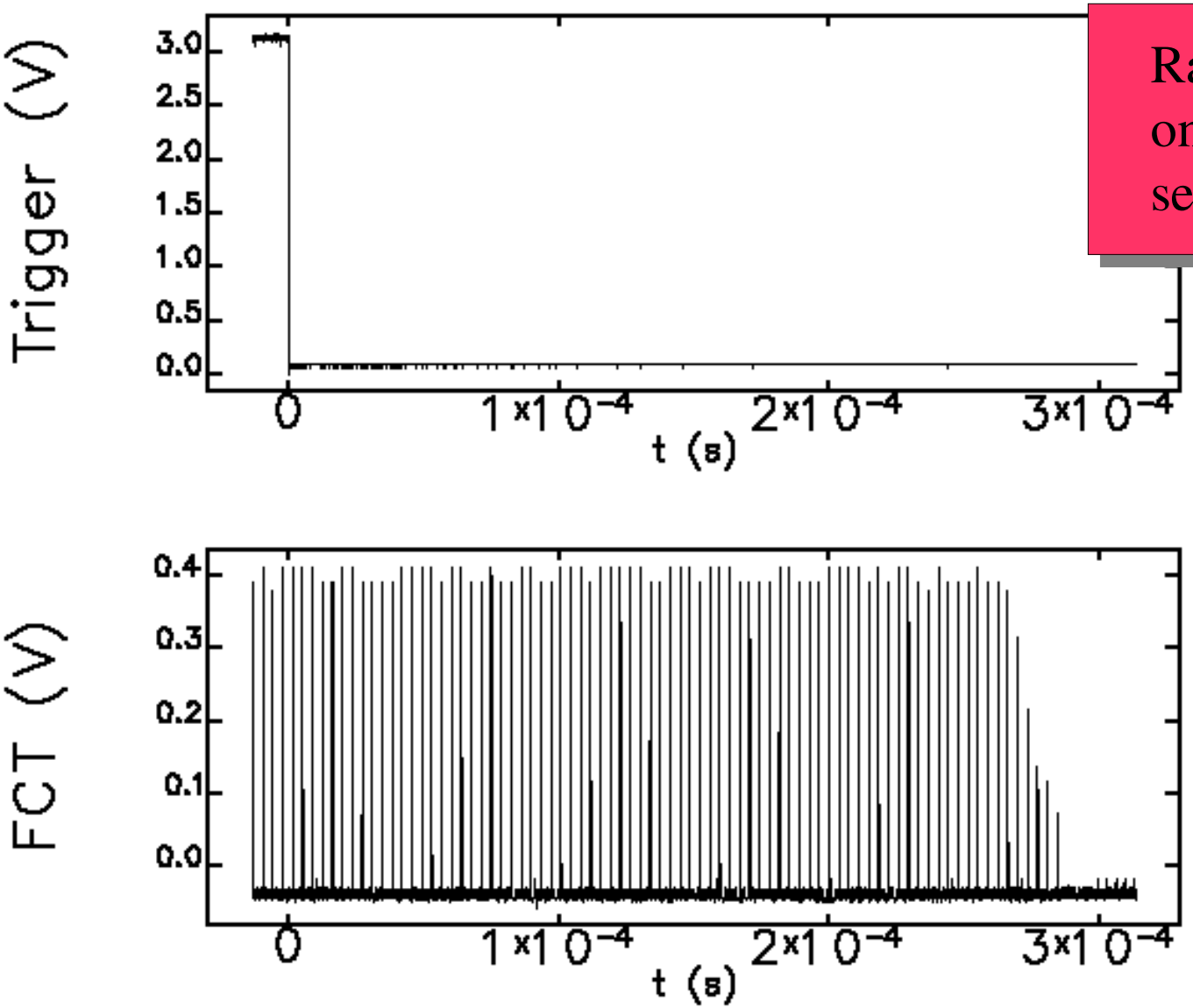


Settings History Review and Rollback Tool

SDDS Toolkit Capabilities

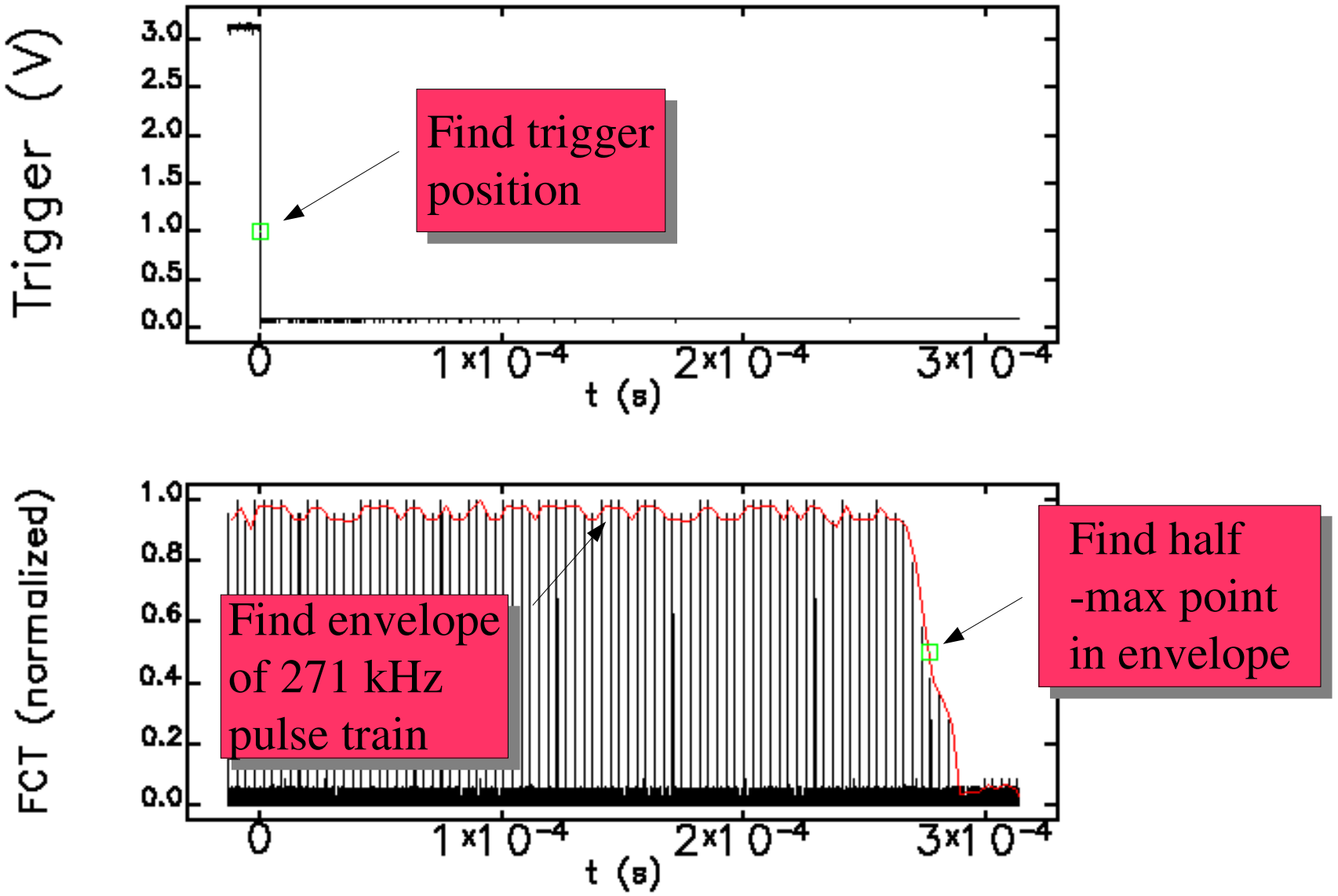
- Display: graphical and text output
- Math: integrate, differentiate, interpolate, normalize, smooth, peakfind, zerofind, evaluate equations, remove baseline
- Matrix: pseudoinverse, transpose, arithmetic operations
- Statistics: correlate, histogram, outlier removal, envelopes, column statistics, running statistics
- DSP: (de)convolution, filtering, FFT, NAFF
- Fitting: exponential, polynomial, gaussian, user-defined
- Manipulation: filter, match, sort, merge, collapse/expand tables, cross-reference/select
- Similar to MATLAB or IDL, but free and open-source

SDDS Processing Example: Beam Dump Analysis

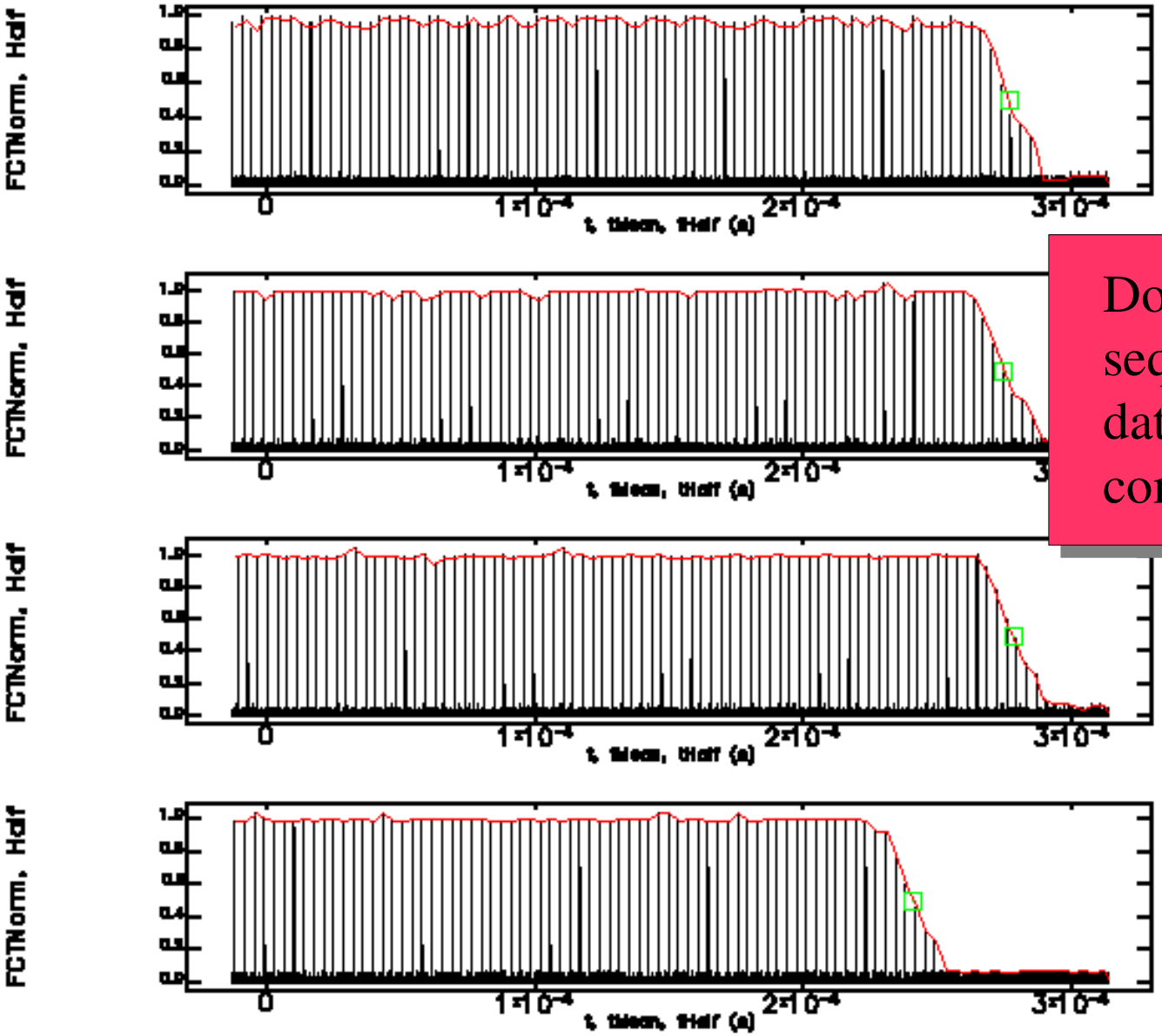


Raw data for one scraper setting

SDDS Processing Example: Beam Dump Analysis

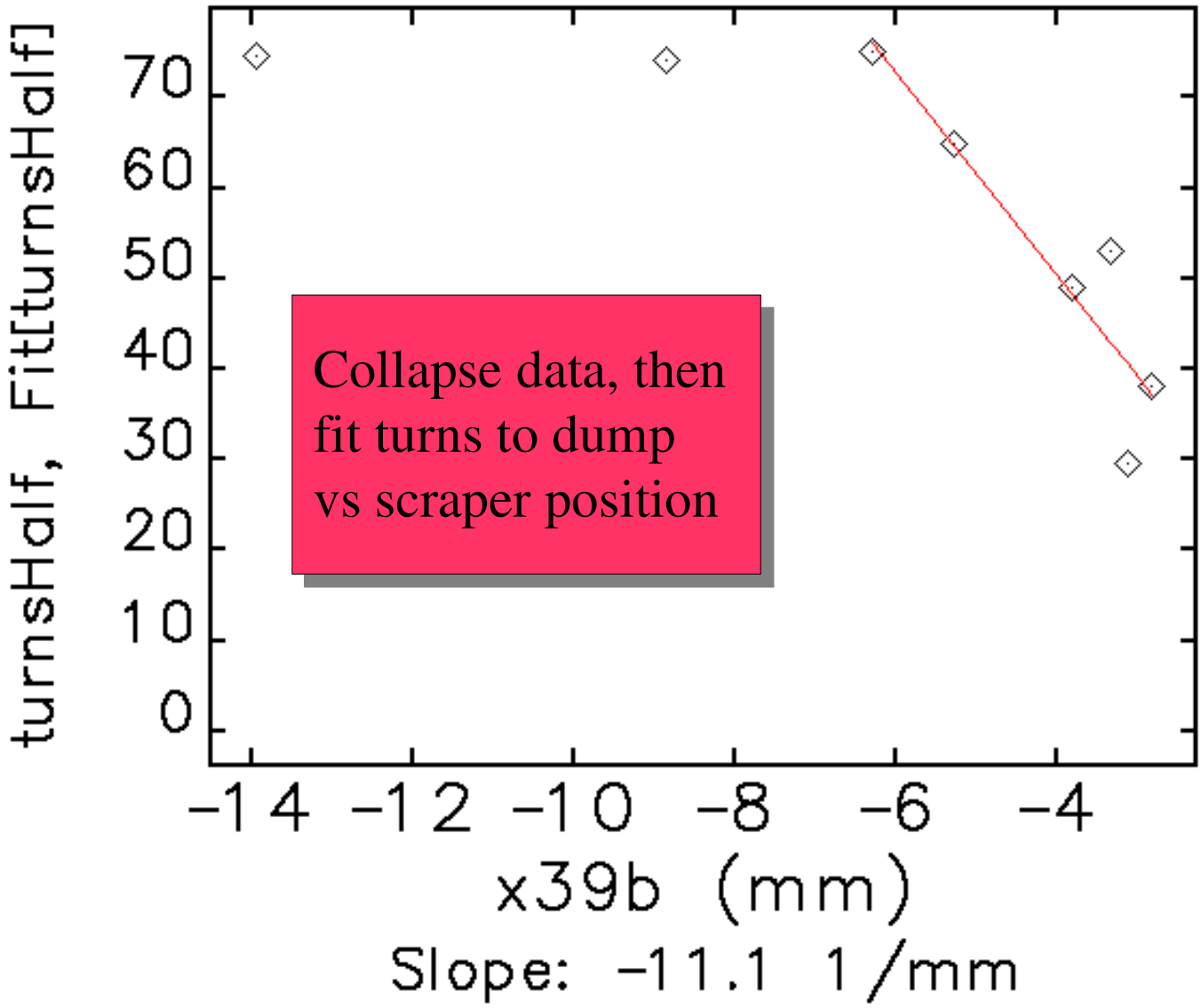


SDDS Processing Example: Beam Dump Analysis



Do for a whole sequence of data sets (just combine files)

SDDS Processing Example: Beam Dump Analysis



SDDS/EPICS Toolkit Capabilities

- Scalar data collection
  - Time-series (`sddslogger`)
  - Time-series statistics (`sddsstatmon`)
  - Glitch- or alarm-triggered with pre- and post-trigger data (`sddsglitchlogger`)
  - Log-on-change (`sddslogonchange`)
  - Conditional logging supported
- These tools are used for most OAG data logging

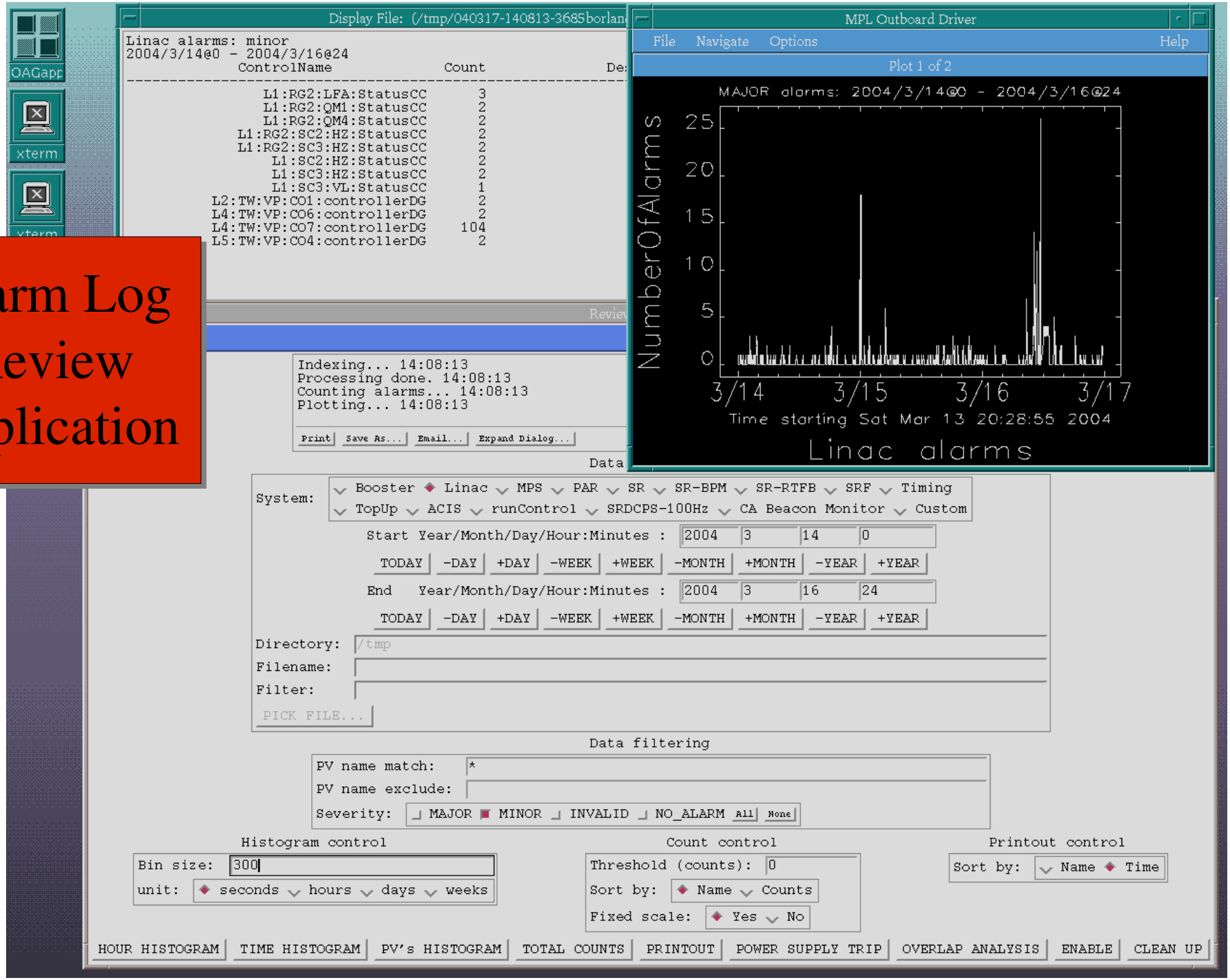
SDDS/EPICS Toolkit Capabilities

- Synchronized collection (`sddssynchlog`)
  - Does timestamp alignment of high-rate data
  - Optionally collects related, unsynchronized data
  - Supports scalars and waveforms
- Used for on-demand investigation of correlations

SDDS/EPICS Toolkit Capabilities

- Alarm data collection (`sddsalarmlog`)
  - Space-efficient binary files with coded PV names
  - Optional “related PV” logging (e.g., status bits)
- GUI applications for alarm analysis and review, including
  - Alarm rate vs time
  - Alarm counts per PV
  - Alarm overlap
  - Decoding status bits

Alarm Log Review Application



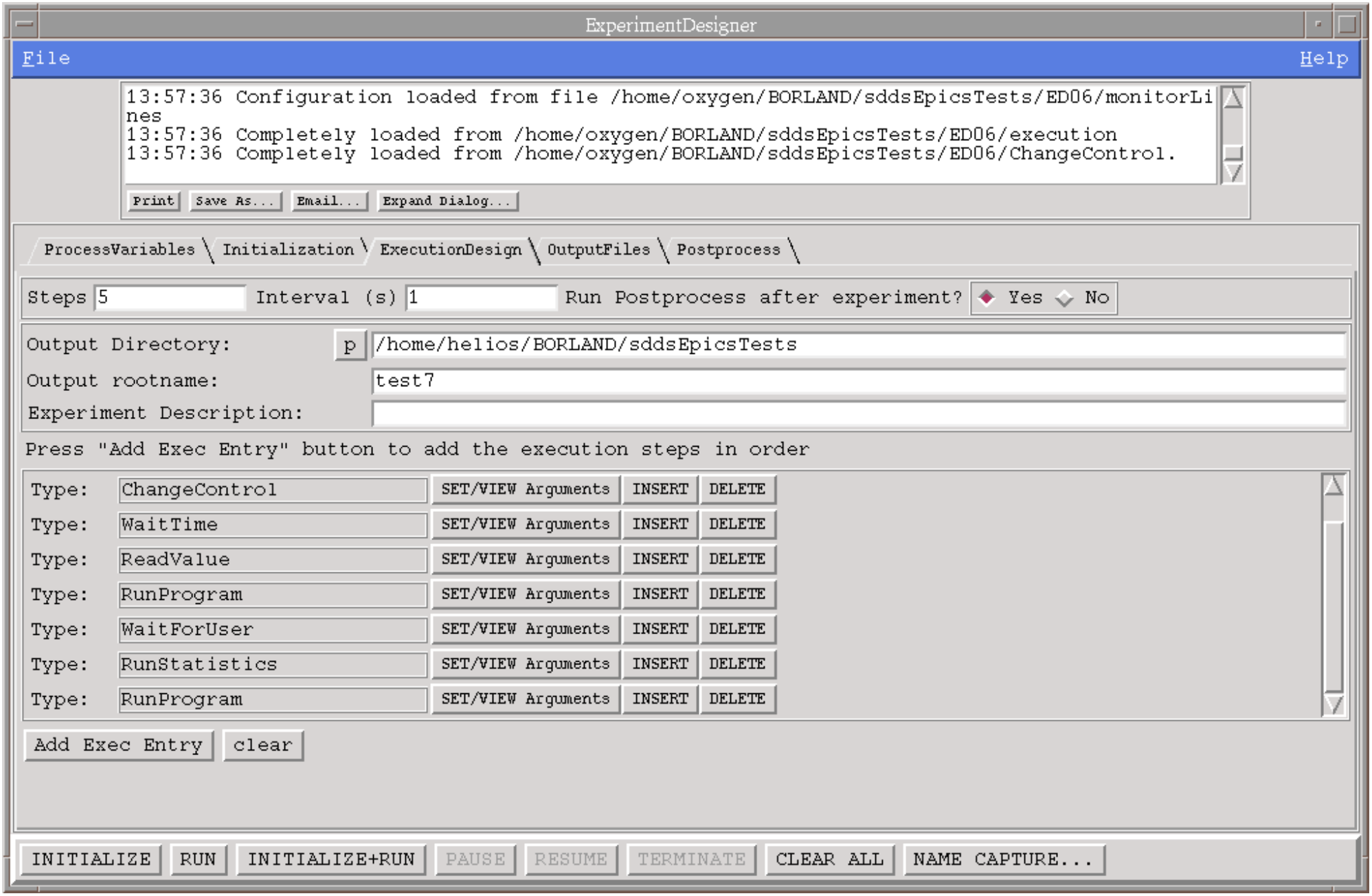
SDDS/EPICS Toolkit Capabilities

- Waveforms collection:
  - At intervals, or when changed (`sddswmonitor`)
  - Simultaneous collection of related scalars
  - Get/put to/from SDDS files (`sddswget/sddswput`)
- Used for
  - Beam profile and image capture
  - BPM fast history capture
  - Feedback history capture
  - IOC orbit correction configuration

SDDS/EPICS Toolkit Capabilities

- N-dimensional experiment execution (`sddsexperiment`)
  - Data and statistics collection
  - Validity testing
  - Subprocess execution
- Used for accelerator and hardware characterization
  - Feedback matrix measurement
  - X-ray BPM feedforward data collection
  - BPM offset measurement
- For direct-user interaction, we prefer the new `ExperimentDesigner` script

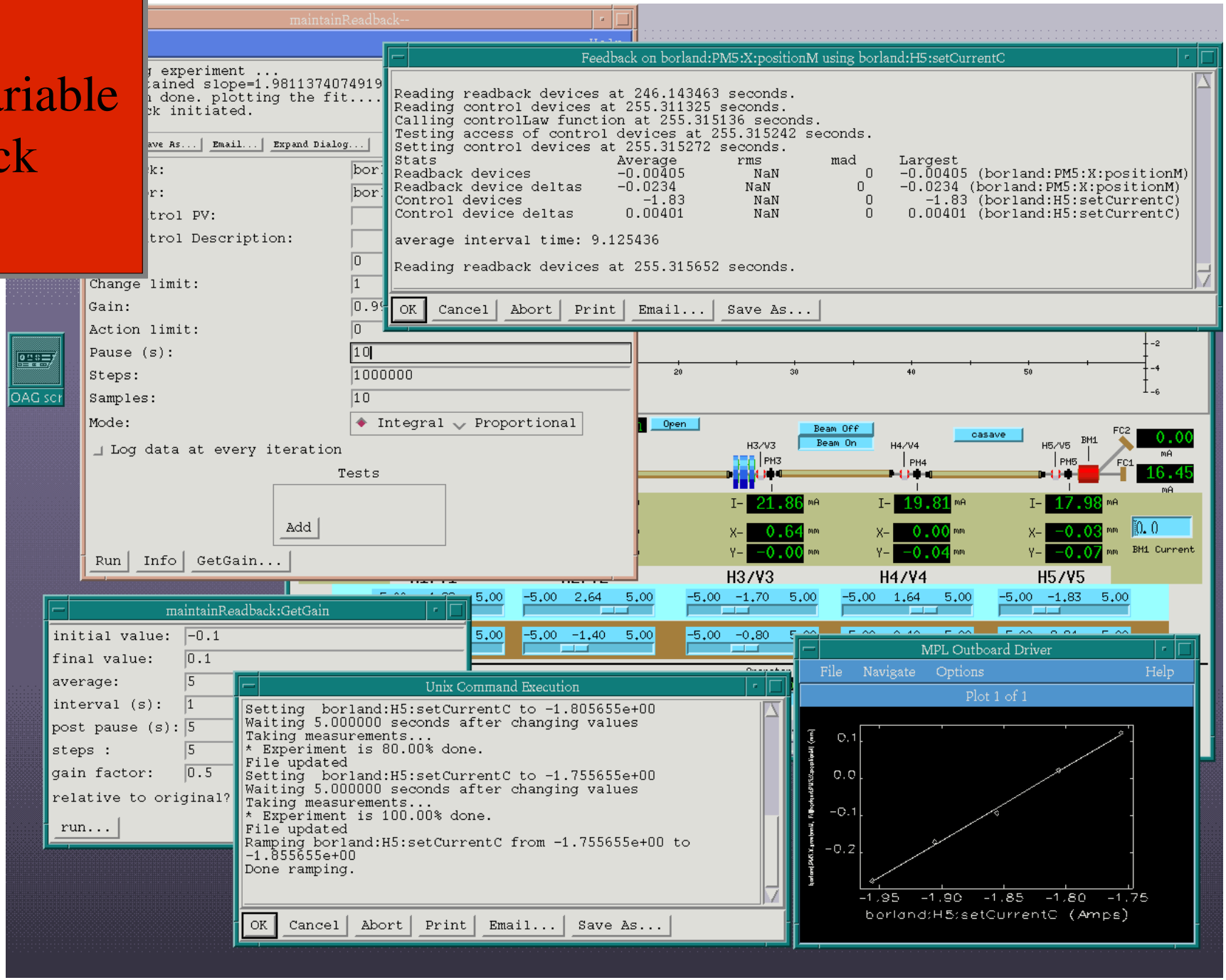
Experiment Designer



SDDS/EPICS Toolkit Capabilities

- Feedback (`sddscontrollaw`)
  - Proportional or integral mode
  - Validity testing, change limits, deadbands, logging
  - PV controls include locking semaphores
  - Will run under VxWorks
- Applications include
  - Storage ring orbit control
  - Beamline steering
  - Linac energy and trajectory control

Quick One-Variable Feedback GUI



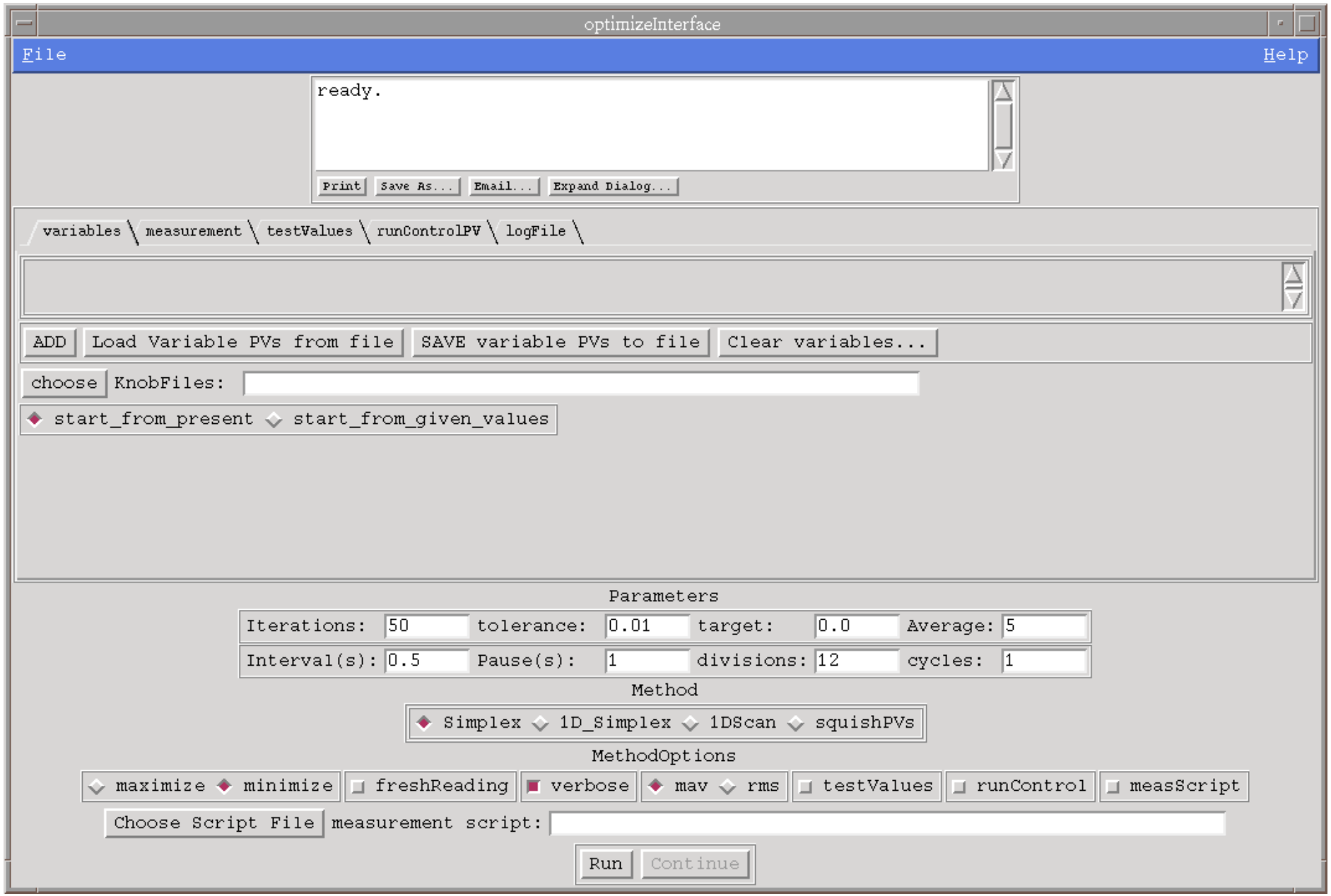
SDDS/EPICS Toolkit Capabilities

- Feedforward (`sddsfeedforward`)
  - Multiple inputs and outputs
  - Locking semaphores
  - Will run under VxWorks
- Applications
  - X-ray BPM gap-dependence compensation
  - Rf BPM intensity-dependence compensation
  - EMW switching correction
  - Septum magnet temperature drift compensation

SDDS/EPICS Toolkit Capabilities

- Generic optimization (`sddsoptimize`)
  - Simplex or successive 1D scan methods
  - Validity testing
  - Script option for setting conditions
  - Script option for computing penalty function
- Applications include
  - Kicker bump matching
  - Coupling optimization
  - Injector efficiency optimization
  - Optimization of simulation results

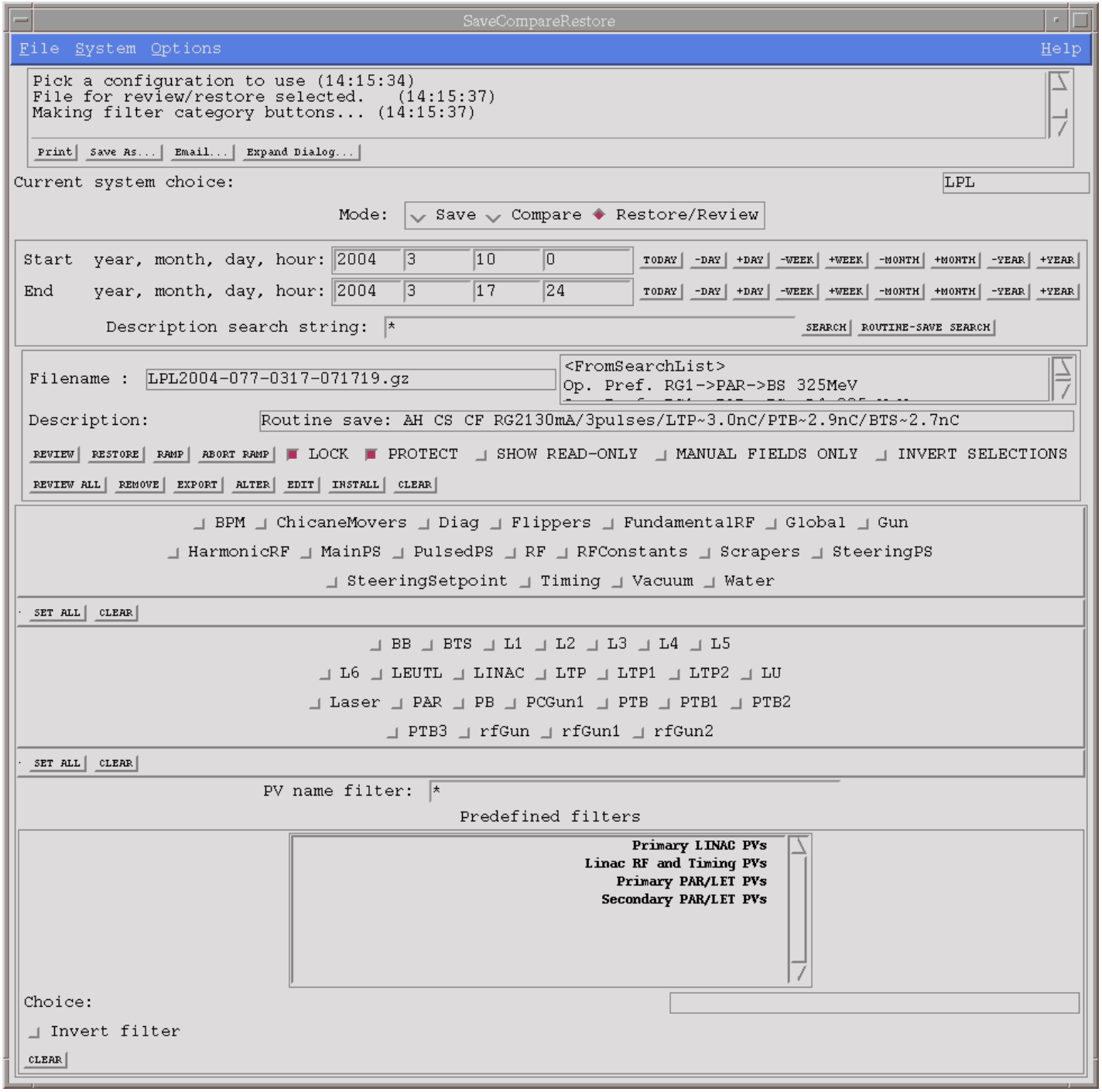
Generic EPICS Optimization Interface



SDDS/EPICS Toolkit Capabilities

- Save/restore
  - Venerable `burtrb`/`burtwb` pair are (mostly) SDDS-compliant
  - New `sddscasr` program is completely compliant
    - Faster than `burtrb`/`burtwb`
    - Server mode with PV controls is faster yet
    - Waveform save/restore
  - Program `sddscaramp` ramps through a sequence of snapshots

Save/ Compare/ Restore GUI



SDDS/EPICS Toolkit Capabilities

- PV creation
  - PVs can be created on-the-fly with `sddspcas`
  - SDDS-configured by a file that can also double as
    - Data logger input file
    - Save/restore input file
  - Creates scalar and waveform PVs
  - Checks for existence of PVs before continuing
  - Handy for development work

OAG Data Logging System

- For time-series logging, master (SDDS) configuration file is read by a script on each workstation
  - Identifies the logger, its rate, inputs, triggers, etc
  - Identifies workstations to use for logging, postprocessing
  - Defines how long to keep the data
  - Defines how to postprocess the data.
- Script is run periodically to ensure that all loggers are active
- About 36k PVs are time-series logged
- Intervals from 0.25s to 2 minutes

OAG Data Logging System

- Most loggers use `sddslogger`
  - Multiple input and output file pairs
    - Economize TCP connections
    - Reduce multiple connections to a PV
  - Jobs run forever, creating a new file for each day
  - Supports conditional logging
  - Honors “inhibit PV” that prevents logging and restarts during emergencies (e.g., power outage recovery)
  - Supports use of “data strobe PVs” for quasi-synchronous logging across many loggers and workstations
- Data reviewed through a Tcl/Tk interface or Web 

OAG Data Logging: Unique Features

- OAG data logging tools offer more than simple time-series or monitor-based logging
  - Conditional logging
  - Glitch logging
  - Statistics logging
  - Synchronized logging of fast data
  - Alarm logging with related data
- Loggers are SDDS-configured
  - Generate configurations with scripts
  - Process configurations like any other SDDS data
- Custom post-processing and display is easy to develop with SDDS tools

Conclusion

- OAG has a powerful set of EPICS tools based on
  - Tcl/Tk scripting language
  - SDDS file protocol and program toolkits
- This software is used to
  - Automate APS accelerator operations
  - Automate accelerator physics measurements
  - Perform data logging, analysis, and display
  - Perform feedback, feedforward, and optimization
  - Pre- and post-process simulation data
- Software is generic and configurable to diverse applications