Fermilab U.S. DEPARTMENT OF ENERGY Office of Science

Mu2e DAQ and slow control systems

Antonio Gioiosa

Università di Pisa, INFN Pisa

Level 3 Manager of Trigger &

Data Acquisition System Design & Test

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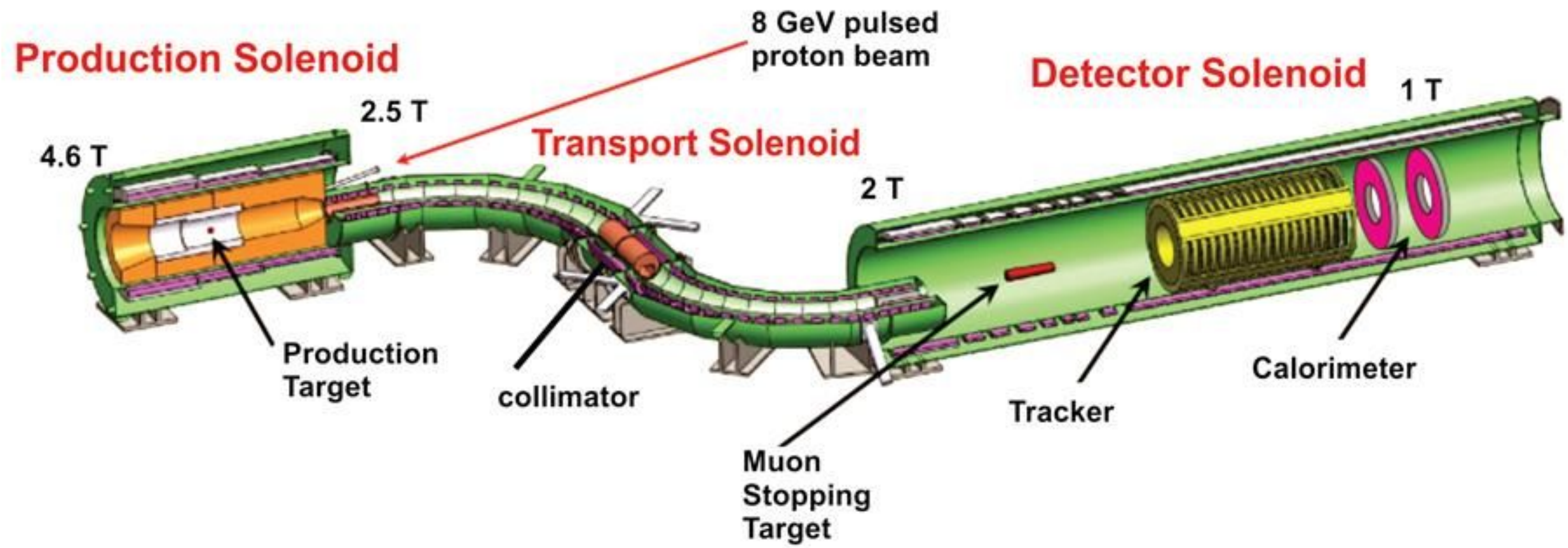
The Mu2e Experiment at Fermilab

$$(\mu^- + \mathrm{Al} \rightarrow e^- + \mathrm{Al})$$

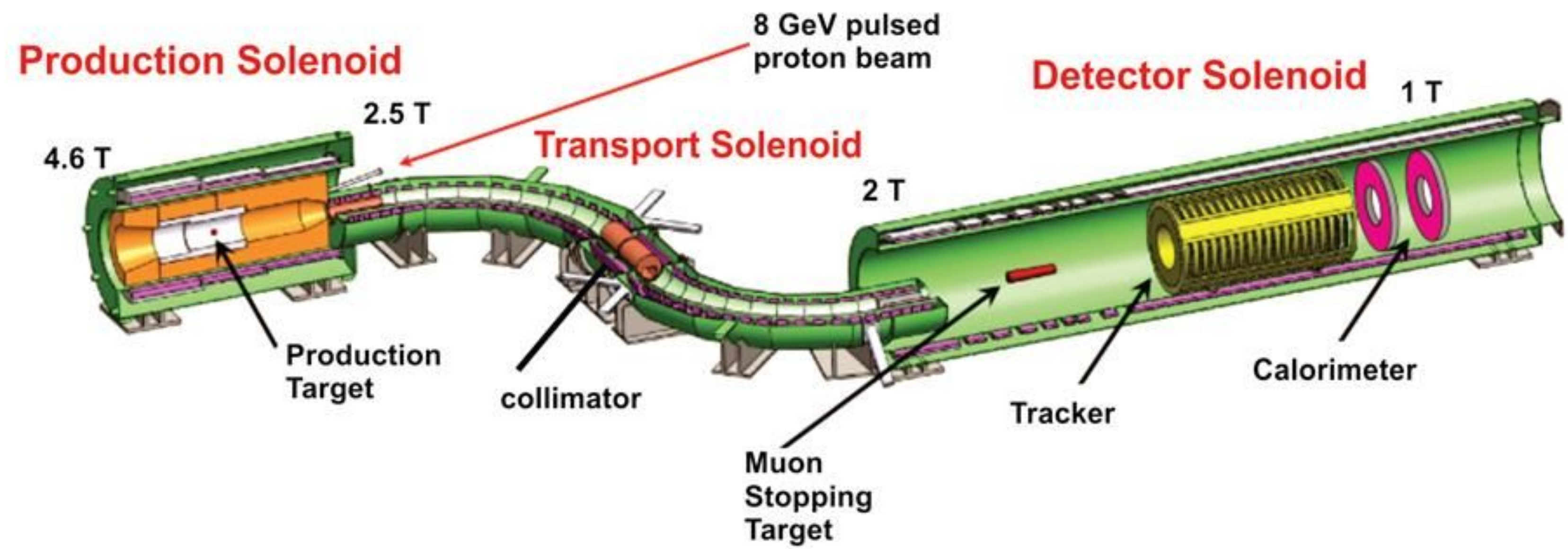
With the expected experimental sensitivity, Mu2e will improve the SINDRUM II limit ($7.0 \cdot 10^{-13}$) of four orders of magnitude

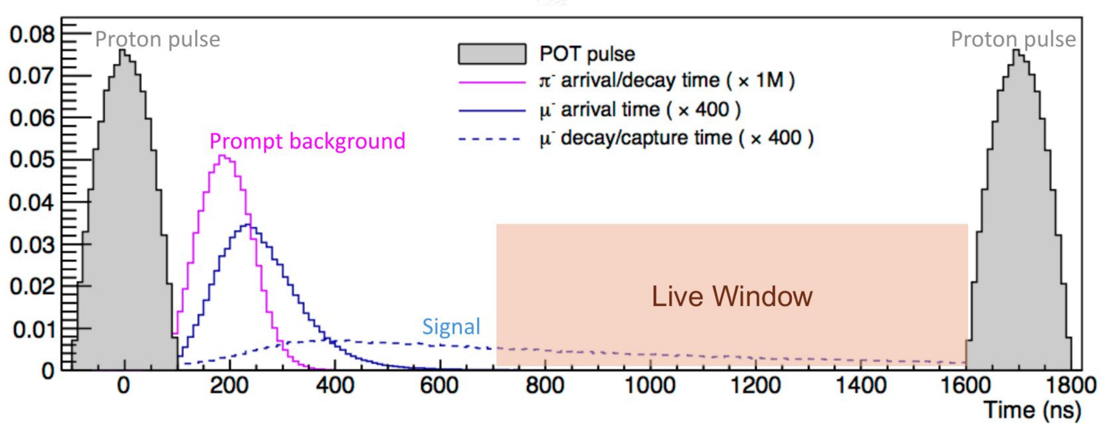
(Mu2e intends to reach a single event sensitivity of $3.0 \cdot 10^{-17}$, assuming we will run for three years, with $3.6 \cdot 10^{20}$ protons, with a run time of $6.0 \cdot 10^{7}$ s, requiring a background level below 1 event)



The Mu2e Experiment at Fermilab

The signal we are looking for is a delayed monoenergetic electron with an energy of just under 105 MeV (muon mass)



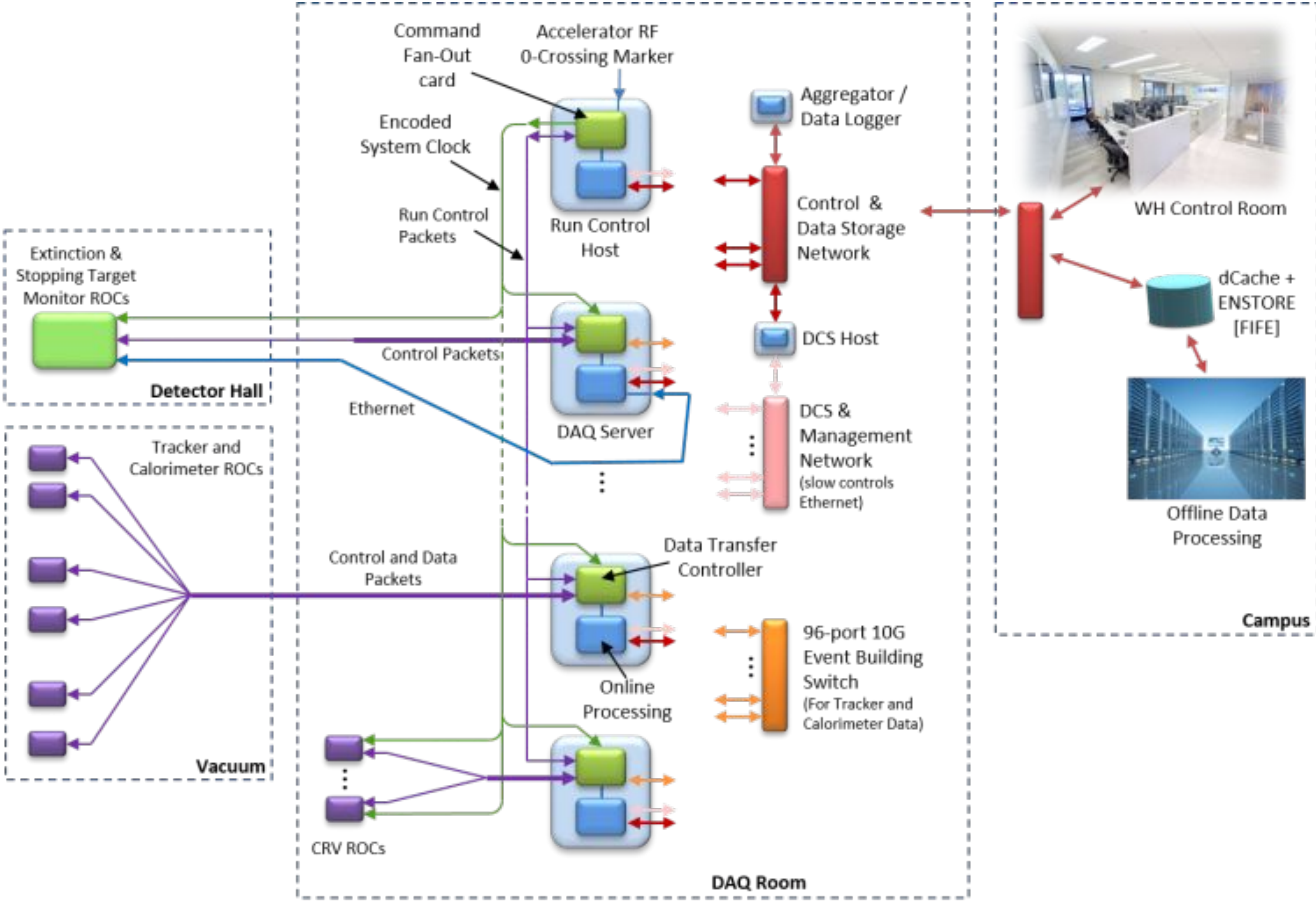


Mu2e TDAQ and Slow Control integration

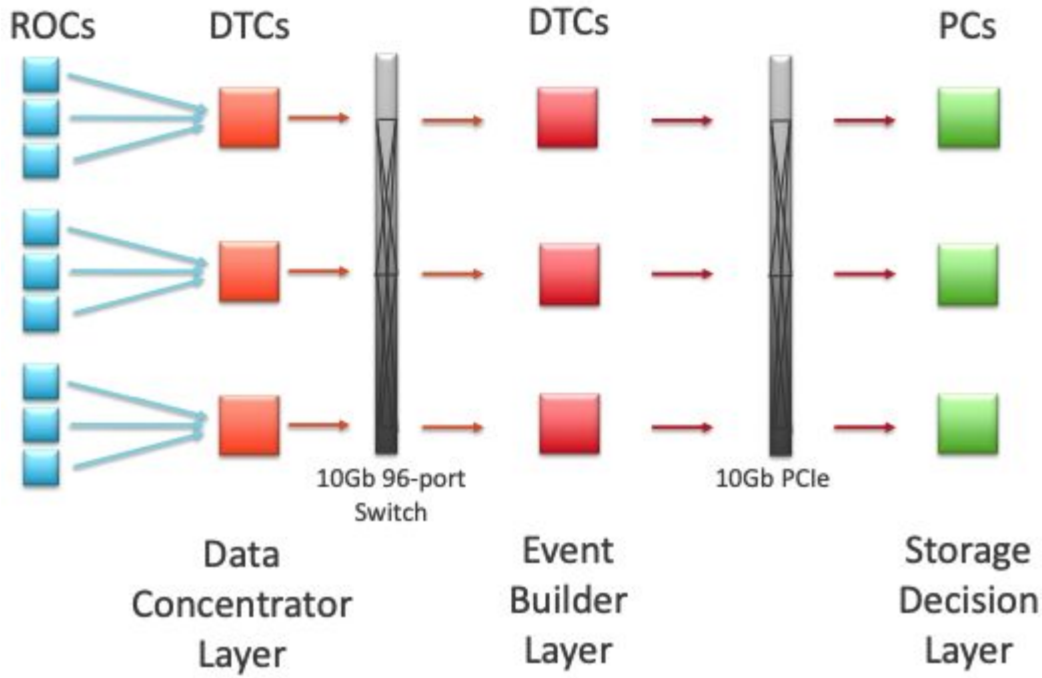
Summary:

- Mu2e TDAQ components Diagram
- Mu2e TDAQ Readout scheme
- Online DAQ (***otsdaq***) overview
- Slow control and its integration in ***otsdaq***
  - Monitoring and Slow Controls GUI
  - Slow Controls Integration with ***otsdaq*** State Machine and Alarm handling
- Conclusions

Mu2e TDAQ components Diagram



TDAQ Readout scheme



- 396 ROCs 69 DTCs (Kintex-7) for data readout and event building
- Large front end buffers to average over long off-spill time
- 800 threads on 40 nodes for HLT → ~5 ms per event
- ~40 GB/s data read out to storage decision layer, ~280 MB/s written to disk

Mu2e Online DAQ solution: *otsdaq*

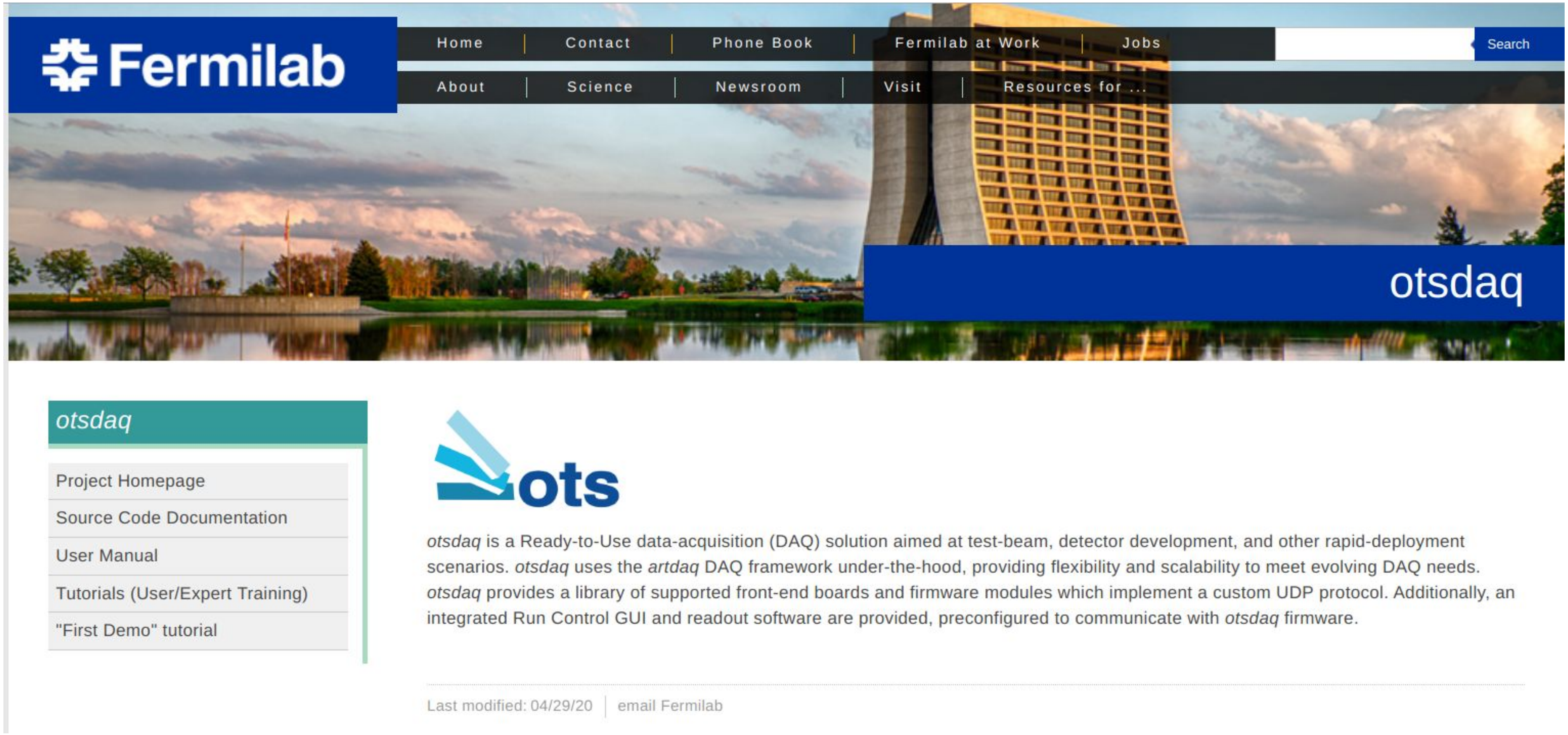
otsdaq overview

Acronym for "<u>o</u>ff-<u>t</u>he-<u>s</u>helf <u>d</u>ata <u>a</u>c<u>q</u>uisition."

- ***otsdaq*** is a Ready-to-Use data-acquisition (DAQ) solution aimed at test-beam, detector development, and other rapid-deployment scenarios
- it uses the ***artdaq*** DAQ framework under-the-hood, providing flexibility and scalability to meet evolving DAQ needs
- ***otsdaq*** provides a library of supported front-end boards and firmware modules which implement a custom UDP protocol
- Developments are in two directions: **server** side and **web** side.
- An integrated Run Control GUI and readout software are provided, preconfigured to communicate with ***otsdaq*** firmware

otsdaq overview

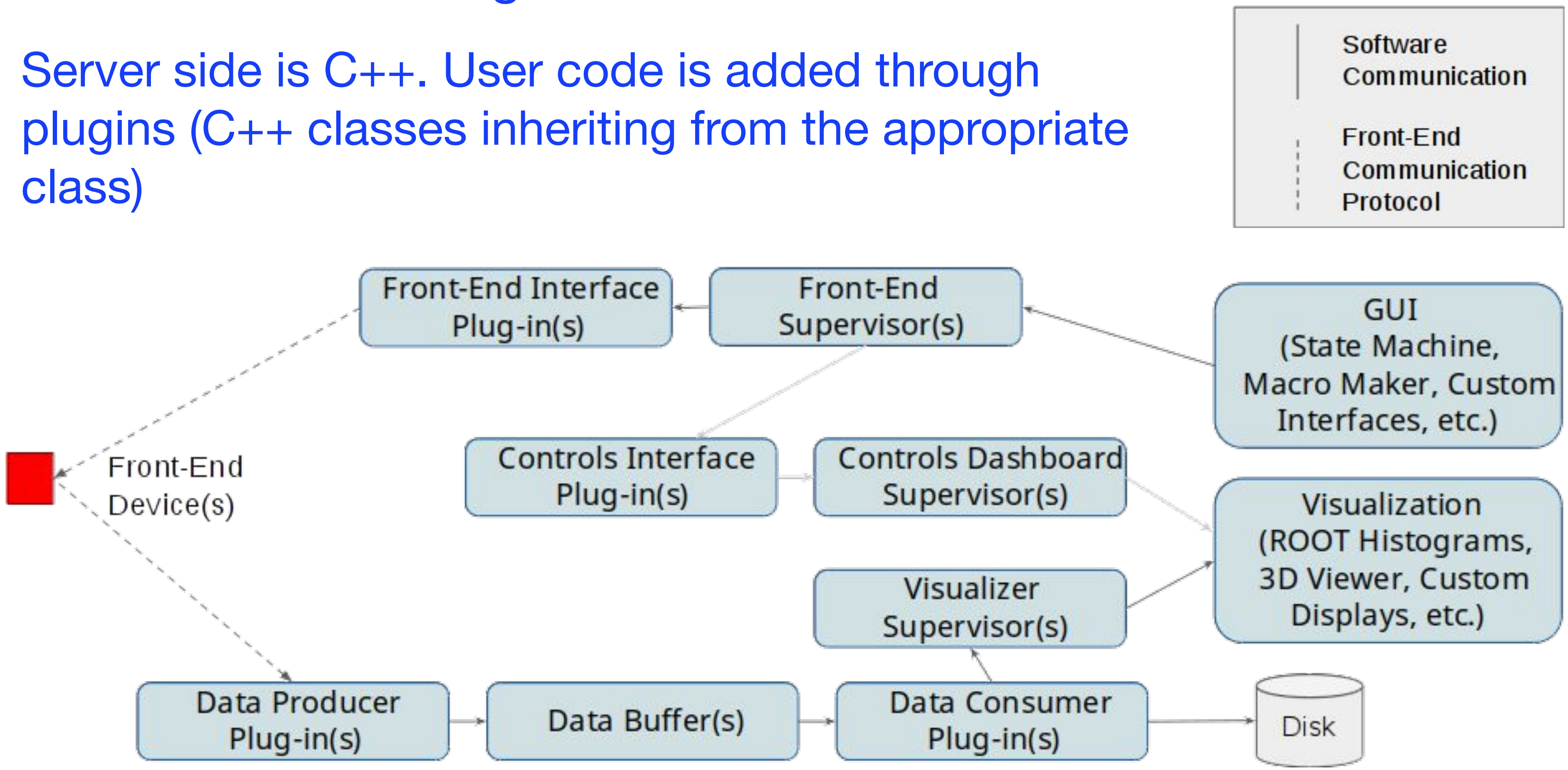
More info at ***otsdaq*** web page https://otsdaq.fnal.gov/



otsdaq overview

Data Flow Block Diagram

Server side is C++. User code is added through plugins (C++ classes inheriting from the appropriate class)

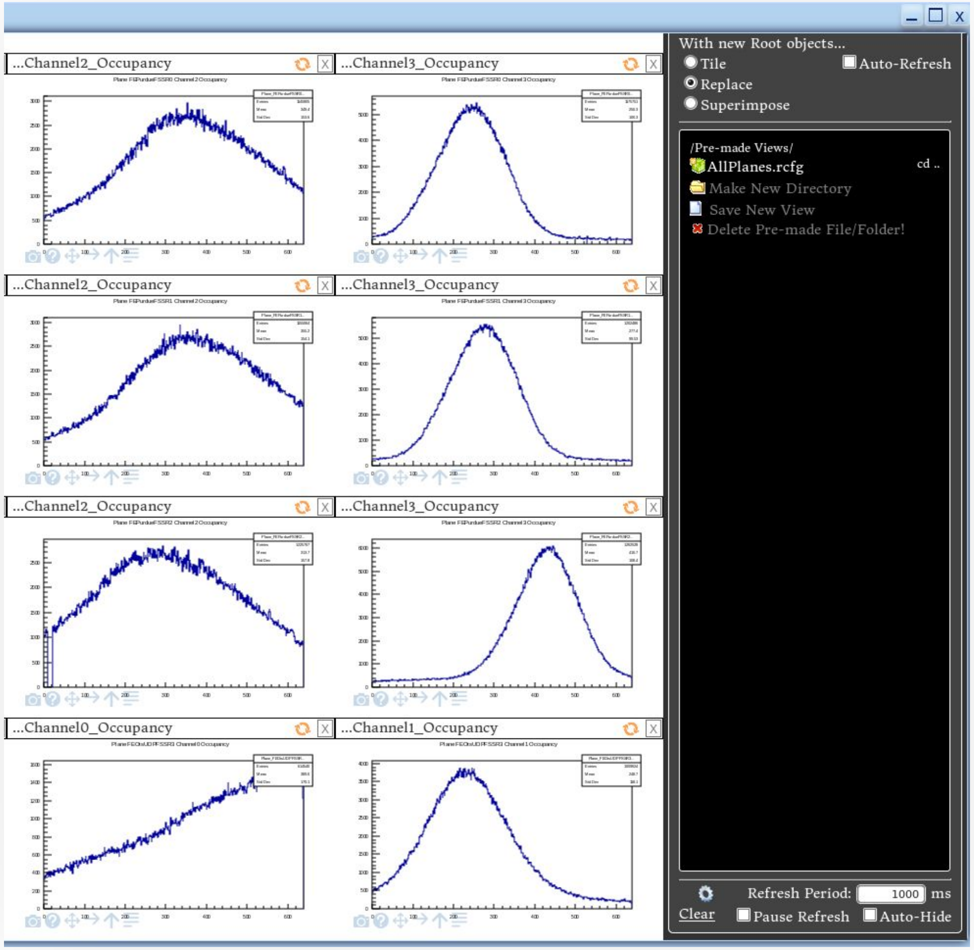


Web side is HTML and JavaScript. User code is added in the form of web-apps through .html files (including the appropriate .js and .css files)

otsdaq overview

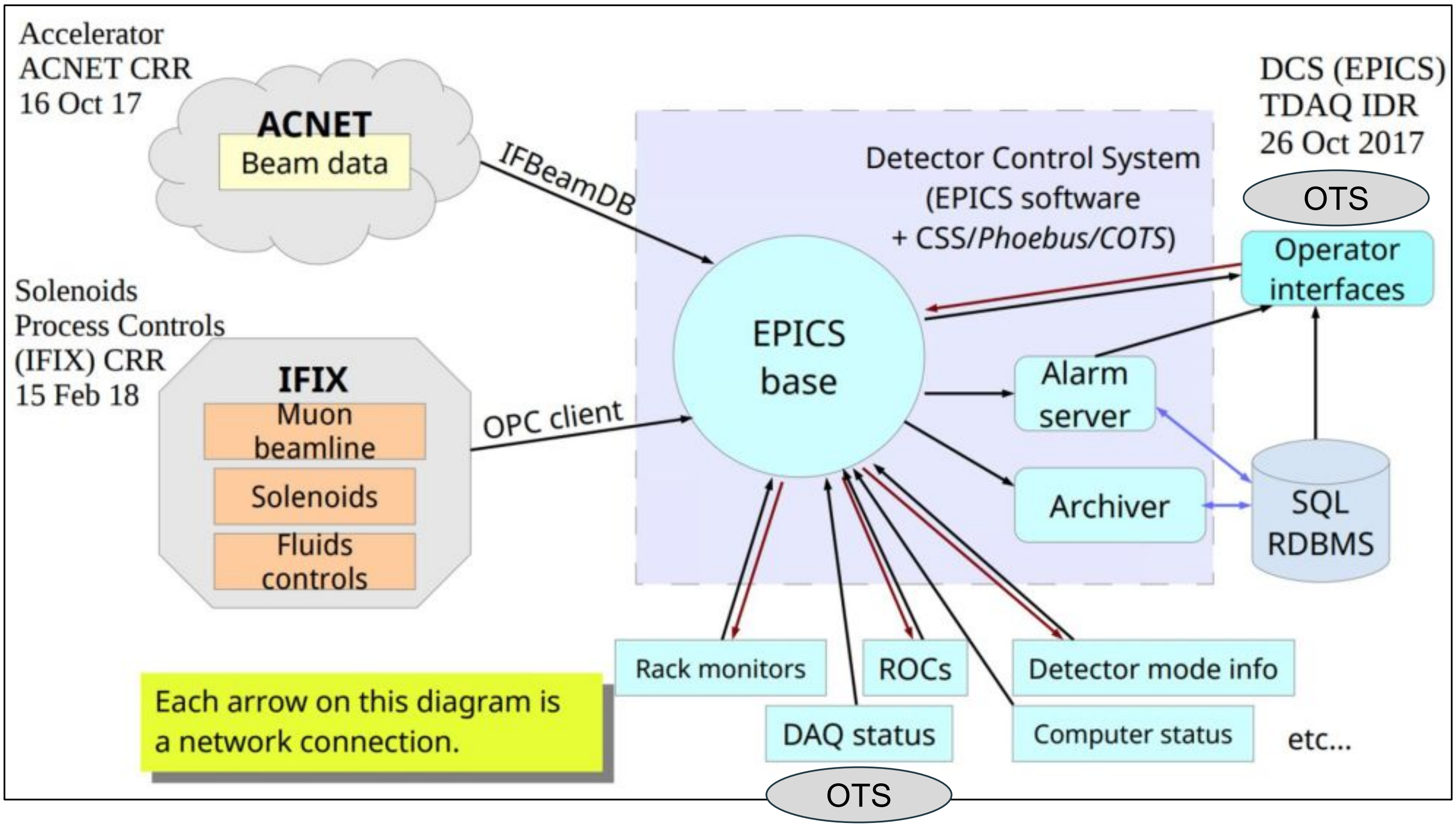
Data processing: Data Quality monitor GUI example

- Mu2e’s event window data will be processed through artdaq modules
- Data processor and Data Quality Monitor DQM plugins are provided by otsdaq core
- DQM generates data products that are sent to an artdaq Dispatcher, which aggregates DQM metrics and presents them to a visualizer application



Slow Controls connection and EPICS plugin development in otsdaq

Experimental Physics and Industrial Control System



Slow Controls connection and EPICS plugin development in otsdaq

Channel subscription to EPICS (uses Input Output Controller IOC)

- Value
- Alarm (Status, Severity)
- Settings
  - *Process Variable Unit, Lower and Upper Warning Limits, Lower and Upper Alarm Limit, Lower and Upper Control Limits, Lower and Upper Display Limits*
- Channel history and alarms retrieving from EPICS Archiver Databases
  - *dcs_archiver*
  - *dcs_alarm*
  - *dcs_log*

Slow Controls Monitoring in otsdaq

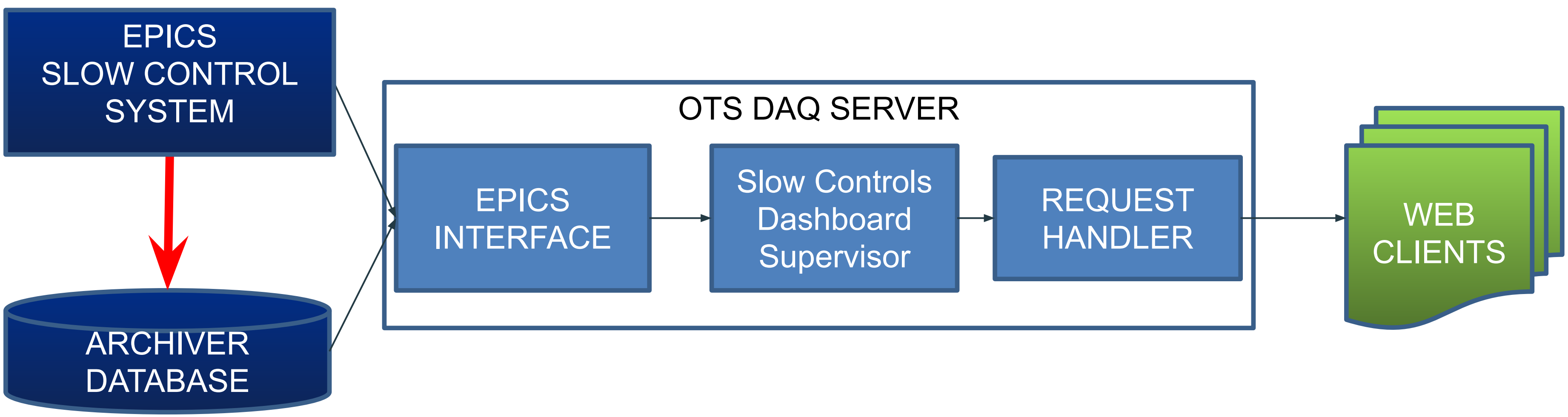
Slow Controls Software purpose

- Allow the user to monitor or interact with their own DAQ hardware. Able to see things such as:

  Alarms, Warnings, Readouts, Timestamps, Status

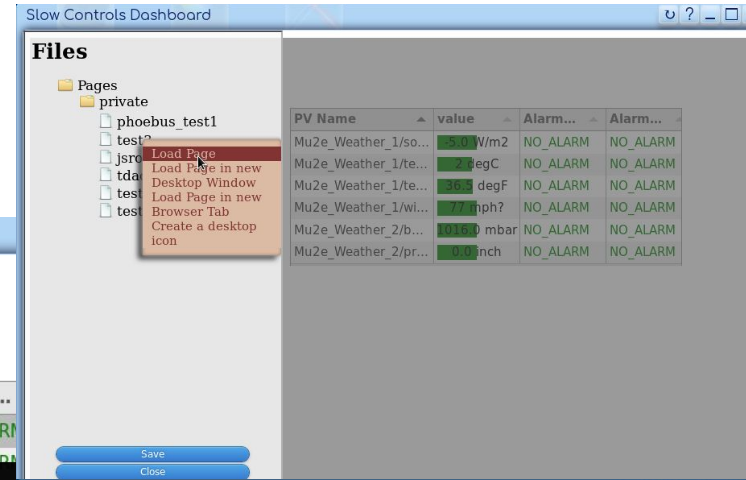
- Interact through a web interface that is:

  Lightweight, User-Friendly, Plug n' Play, Customizable



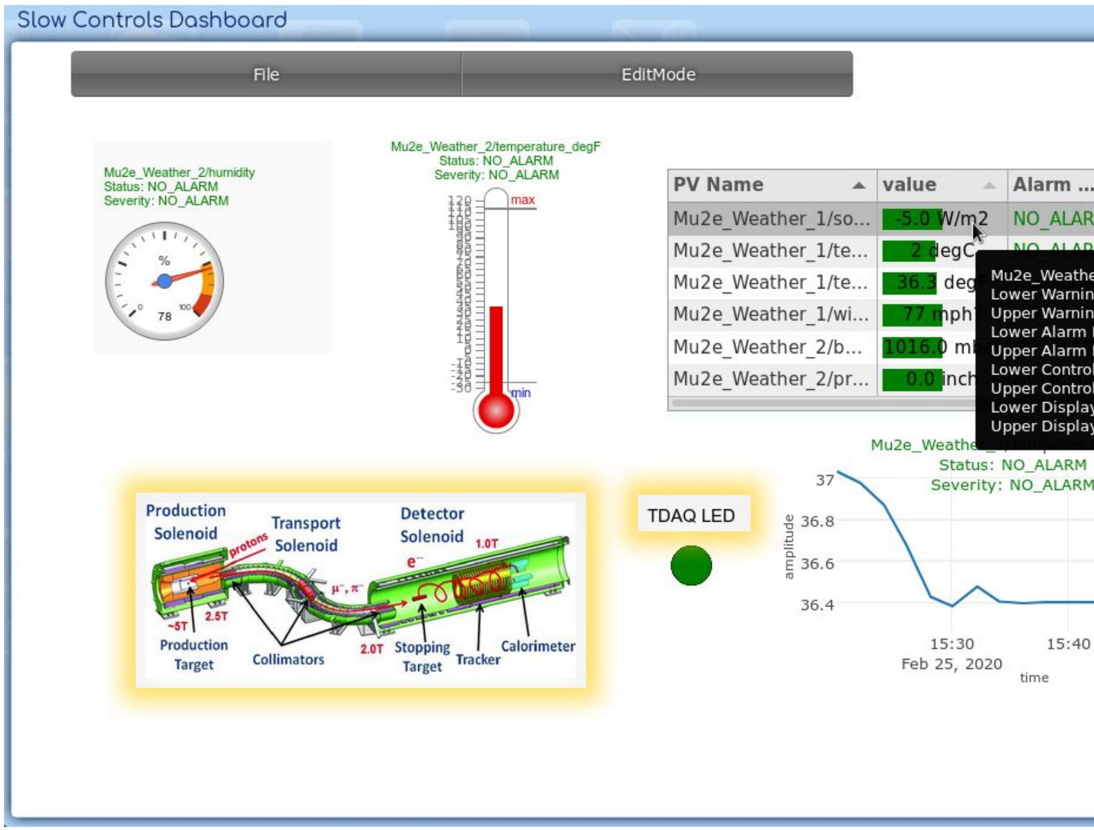
Slow Controls Monitoring GUI in otsdaq

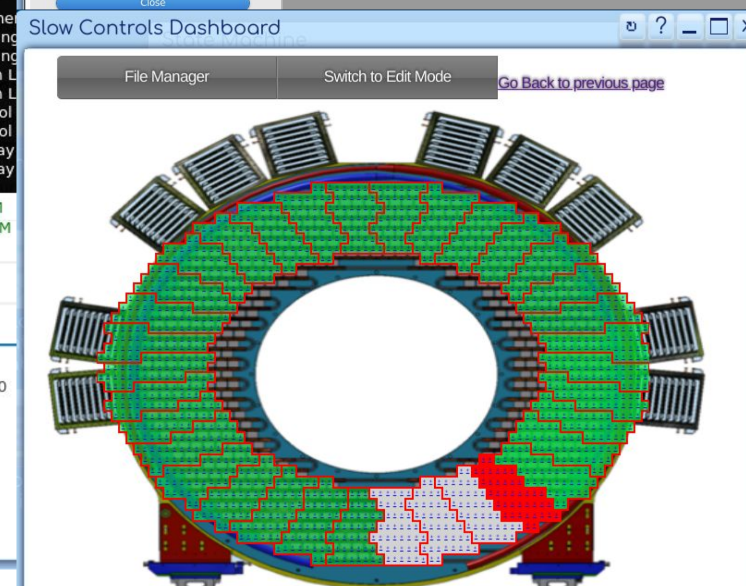
Example of page loading



Examples

Example of loaded page

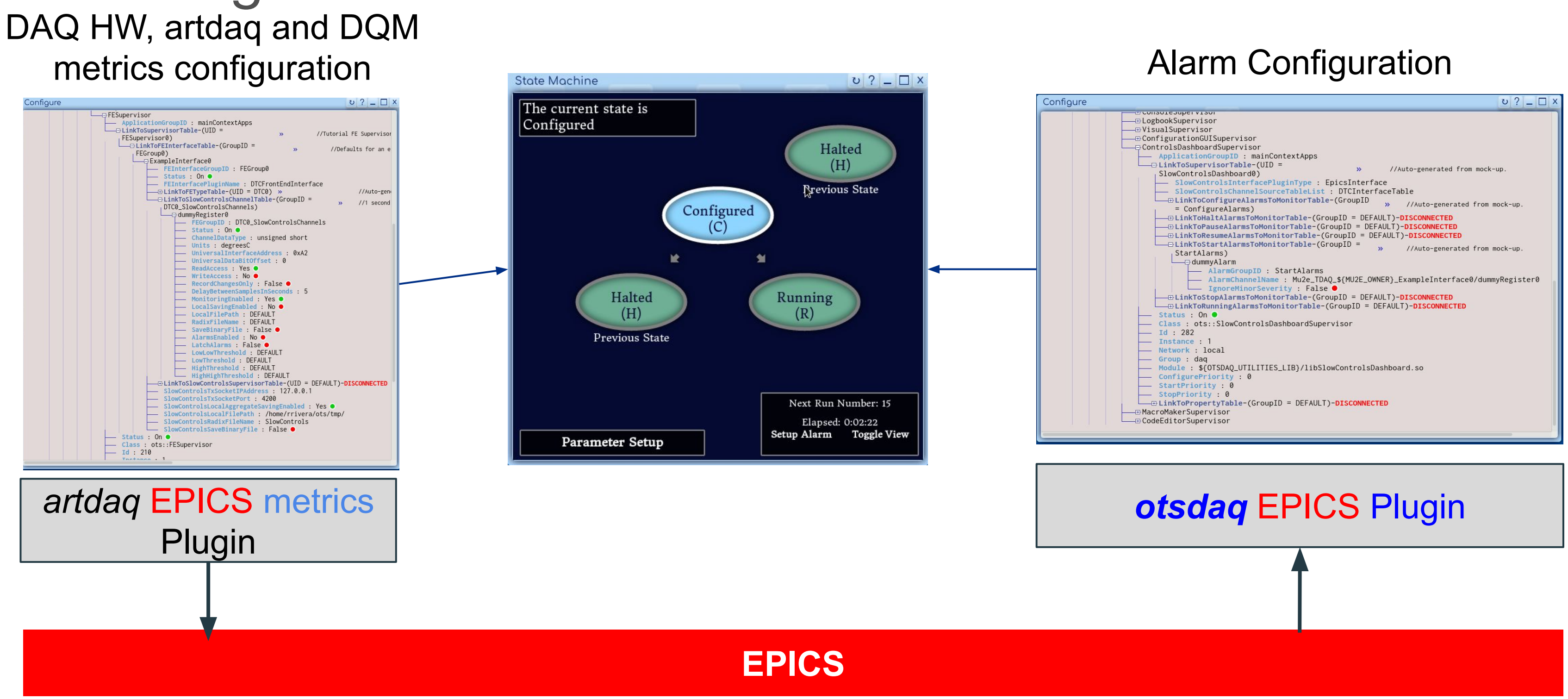




Calorimeter monitor in the slow control GUI

Integration with State Machine

- State Machine Configuration and data subscription to EPICS
- Alarm propagation (from EPICS) and *otsdaq* State Machine handling



Conclusions

- Mu2e Experiment is under construction at Fermilab and will be ready for data taking in two/three years
- Mu2e TDAQ and slow control are in large part developed according to the requirements (200K events/s for data taking) and hardware tests are going on
- Slow control integration in the online DAQ system, *otsdaq*, provides an advanced slow controls monitoring, an interface to send *otsdaq* front-end DAQ hardware, data processing, and DQM slow controls information to EPICS, and a real configuration and Integration with the *otsdaq* State Machine

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Backup Slides

Slow Controls WEB Monitoring GUI in otsdaq

developed in JavaScript and HTML (client side) and C++ (server side)

Basic Widget Mechanism

- All widgets have six required methods:

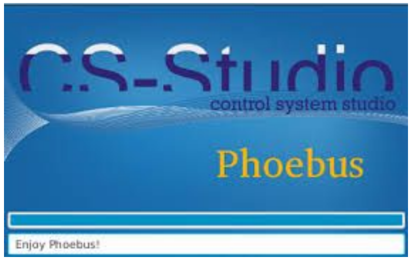
  init(), getParameters(), setParameters(), setupPVs(), newWidget(), and newValue()

Widget properties

- Dynamic sizing
- Proper handling of setups
- Value error, warning and alarm handling
- Disconnection handling

Load and save dashboard page in XML

Cs-Studio Phoebus (EPICS GUI) compatible format



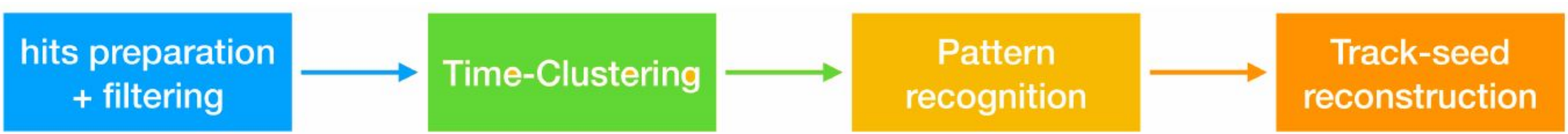
Mu2e is an experiment under construction at Fermilab to measure the charged-lepton flavour violating neutrinoless conversion of a negative muon into an electron in the field of an aluminum nucleus

Mu2e TDAQ Data Flow and High Level Trigger Software

Run Control and Data Flow summary

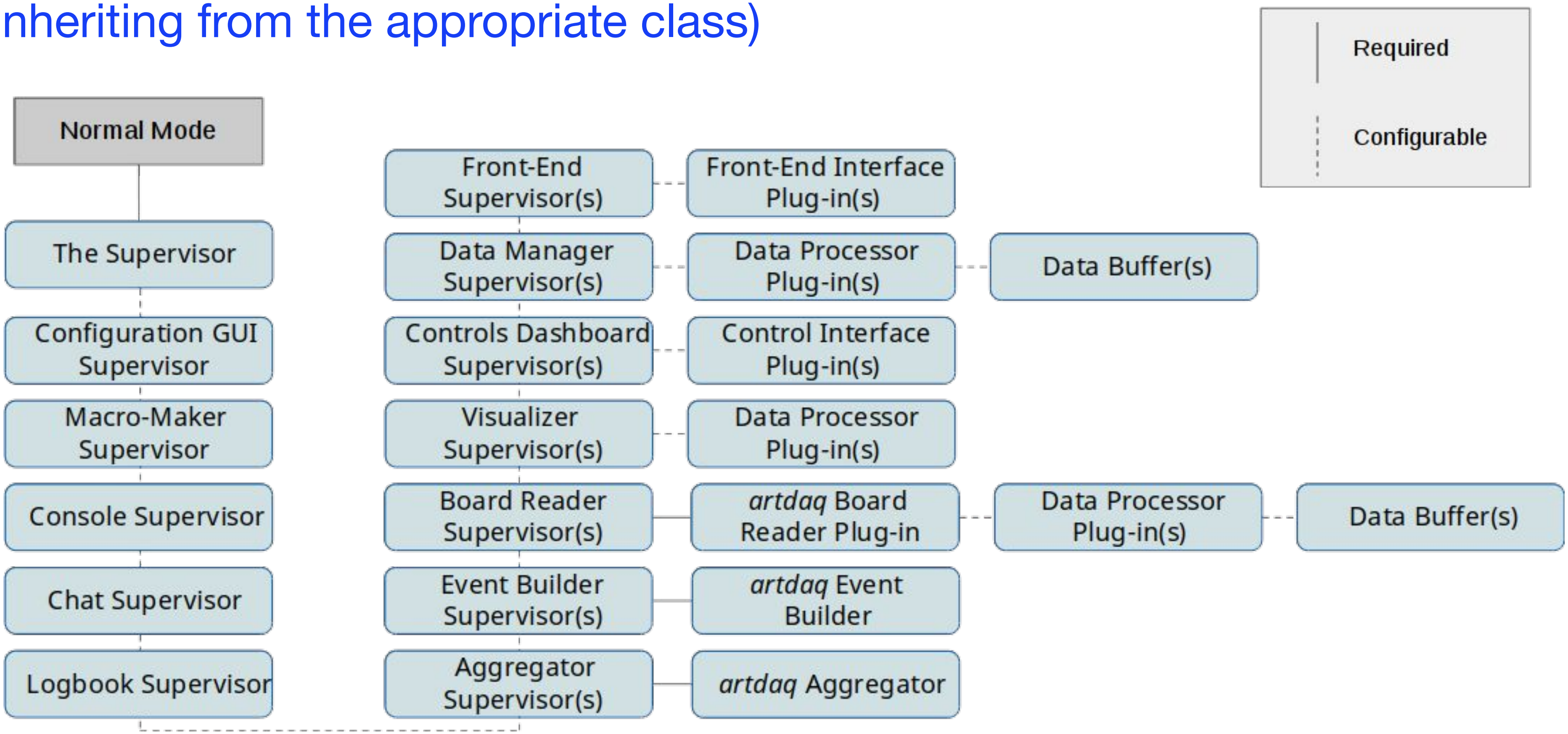
1. Experiment defined Run Plan is coordinated by CFO. The System Clock (40MHz) and Event Window markers originate at the Command Fan-Out Card (CFO) and are distributed to ROCs
2. CFO distributes System Clock and Event Windows to DTCs with fixed latency
3. DTCs distribute System Clock and Event Windows to ROCs with fixed latency
4. ROCs respond to Data Requests
5. A slice of the detector arrives at each DTC (6 ROCs for 1 DTC)
6. DTCs forward data slice through Event Building Switch to round-robin DTC destination
7. DTCs receive full events from multiple DTC sources, pre-process, and pass through PCIe to online processing
8. Trigger decision is made in online processing
9. Trigger accept causes readout of corresponding CRV data
10. Event data from all detectors are aggregated at Data Logger
11. Experiment data is transferred from Data Logger to persistent storage

High Level Trigger Software



otsdaq overview

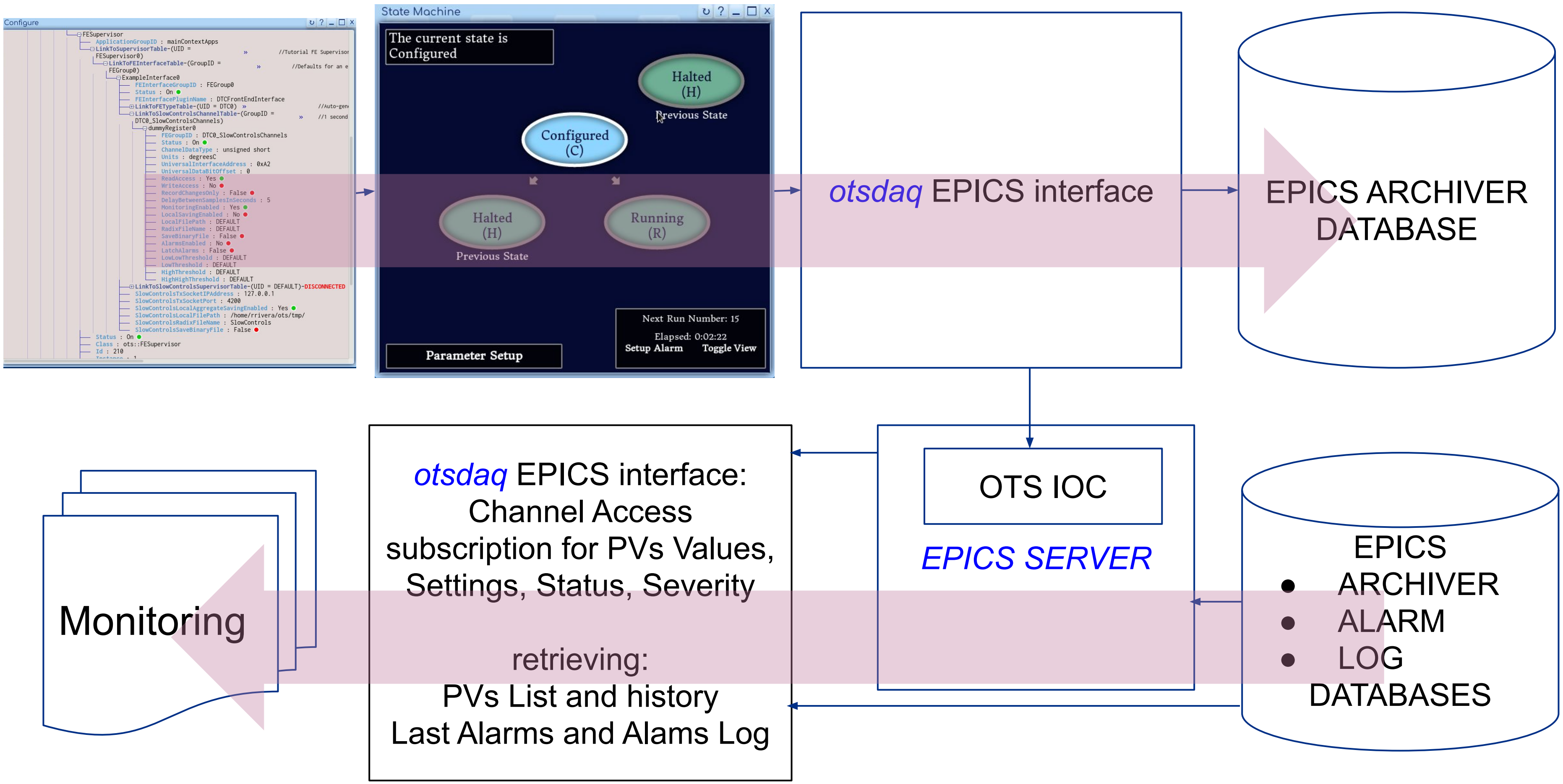
Server side is C++. User code is added through plugins (C++ classes inheriting from the appropriate class)



Web side is HTML and JavaScript. User code is added in the form of web-apps through .html files (including the appropriate .js and .css files)

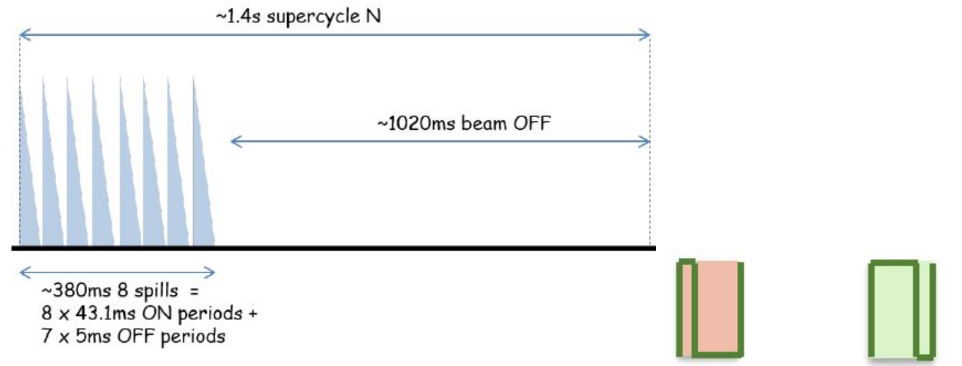
Integration with State Machine

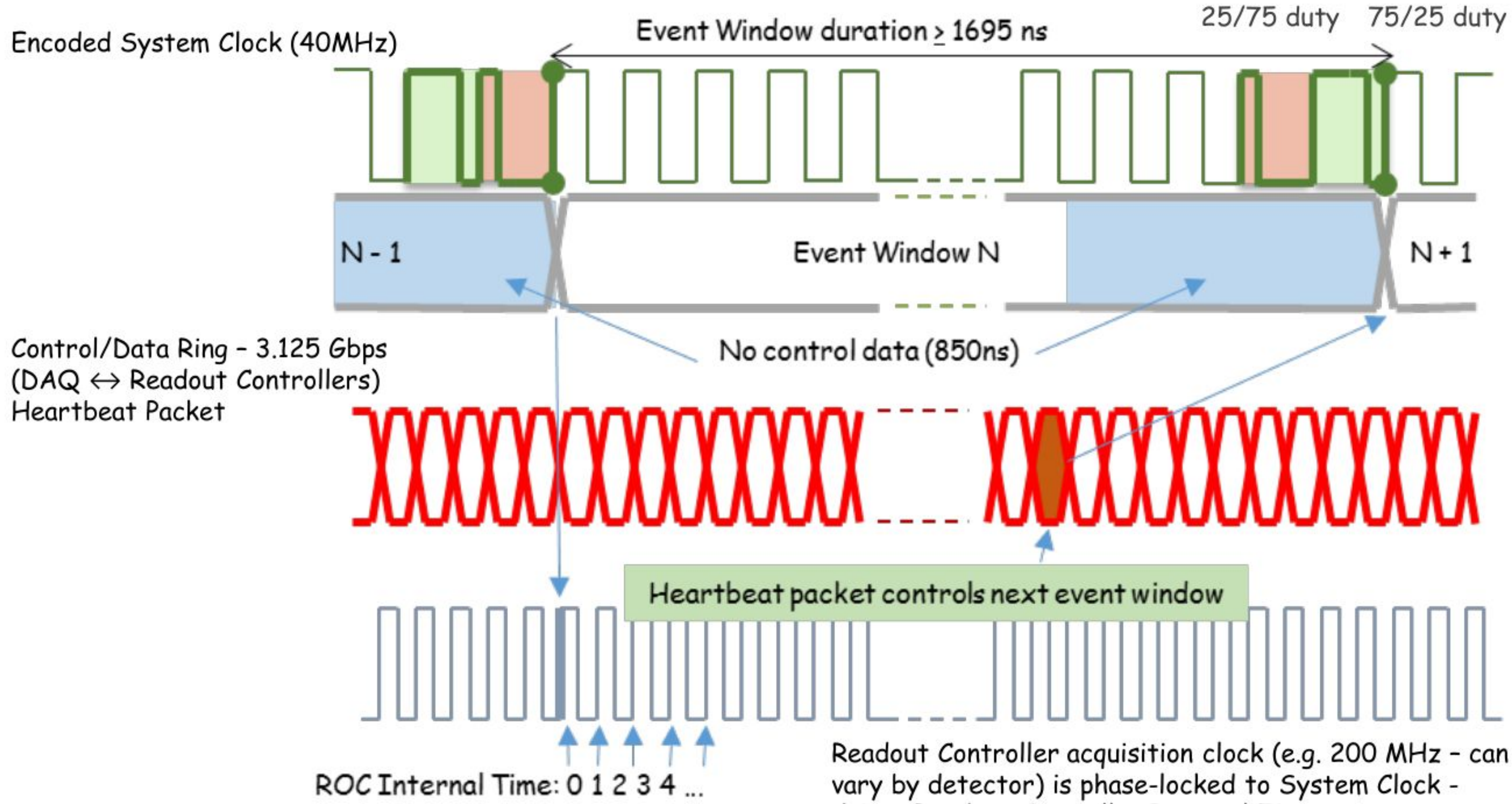
- *otsdaq FE (DTC/ROC/CFO) / artdaq metric new channel or new slow control setting → configuring State Machine → EPICS DBs and IOC* configuration
- *otsdaq Interface→ otsdaq* CA subscription and DBs select → Monitoring



Mu2e Timing Distribution

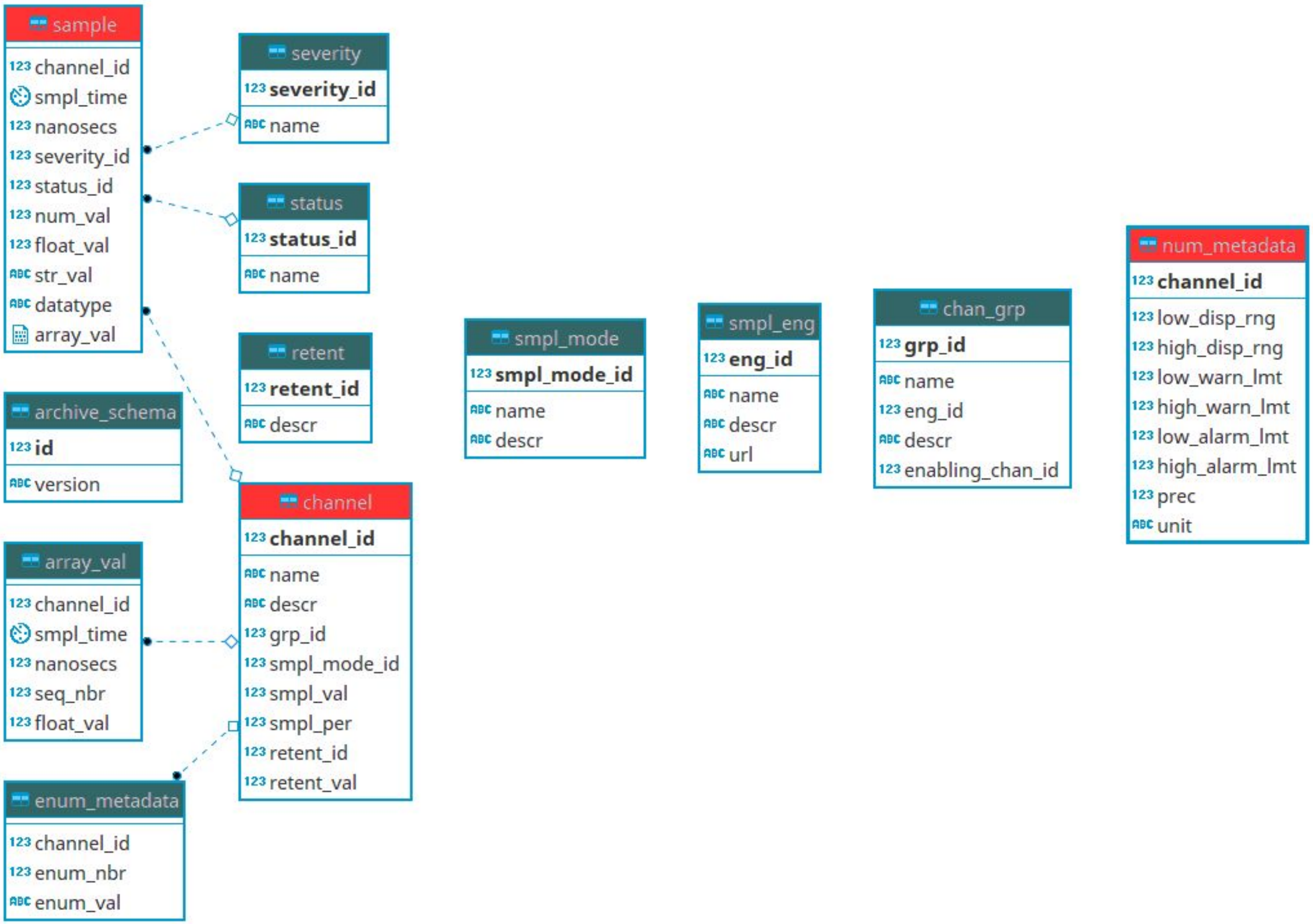
Requirement is to process 200K events/s





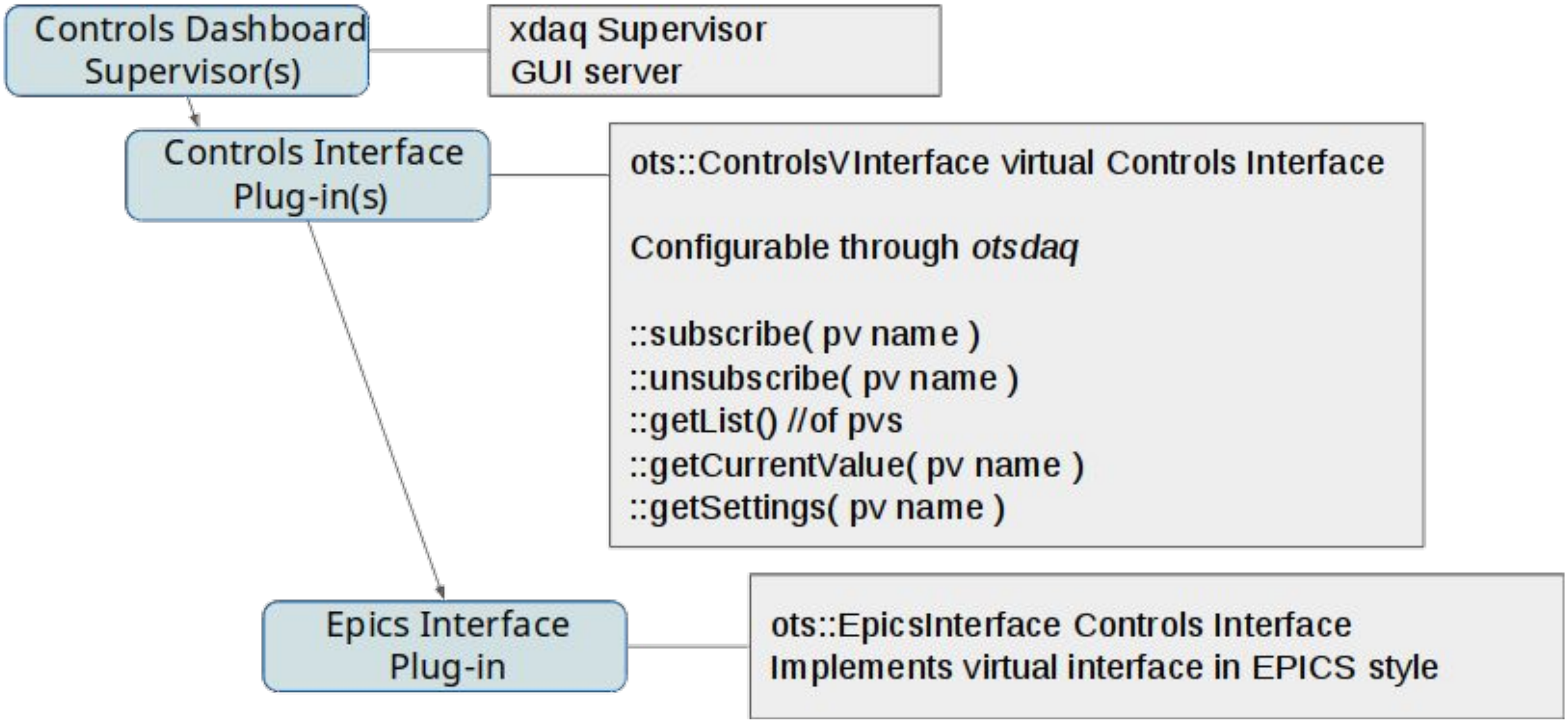
EPICS Database

- Postgres DBMS



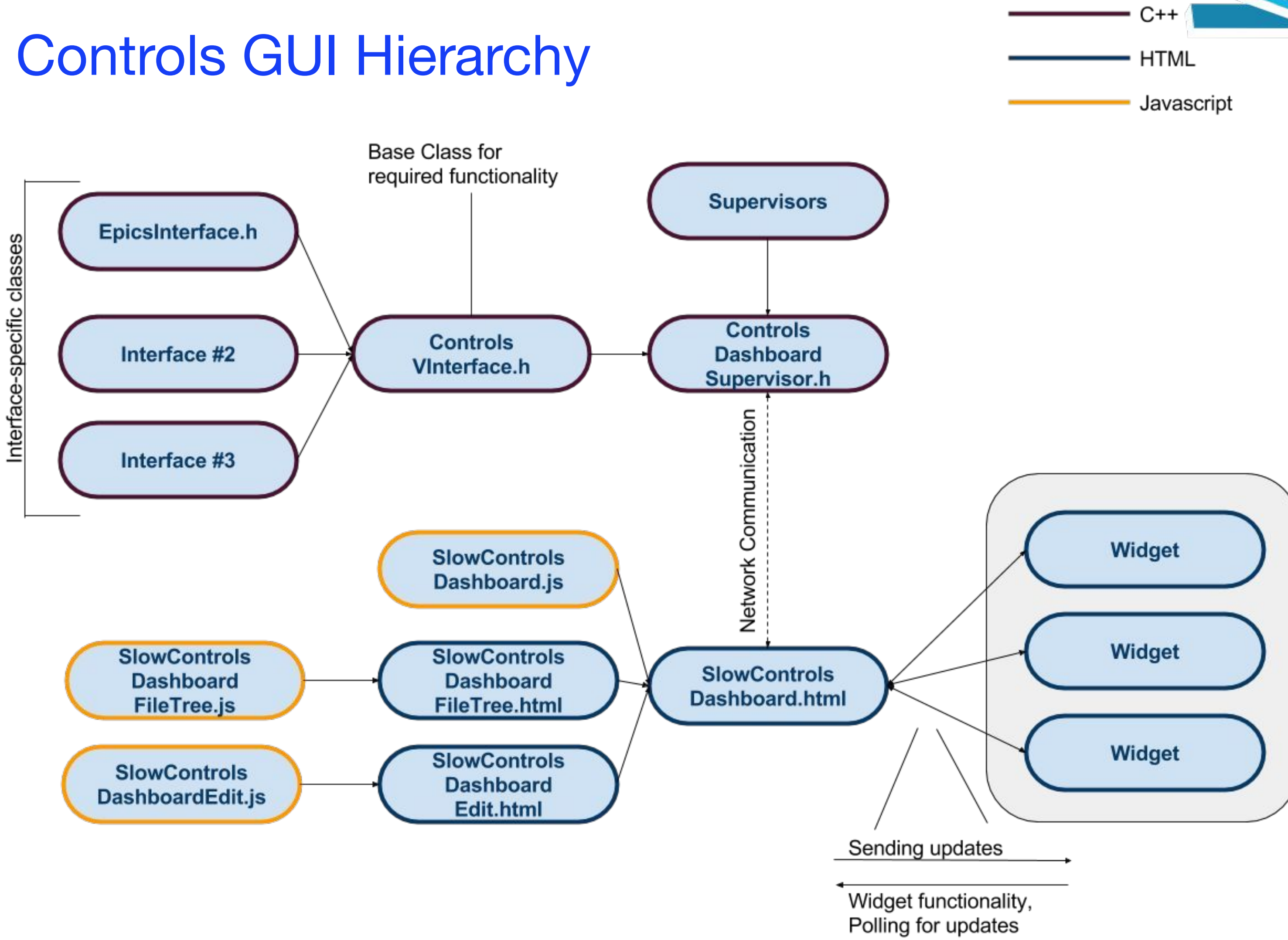
Slow Controls Monitoring in otsdaq

Slow Controls C++ Hierarchy



Slow Controls Monitoring in otsdaq

Slow Controls GUI Hierarchy

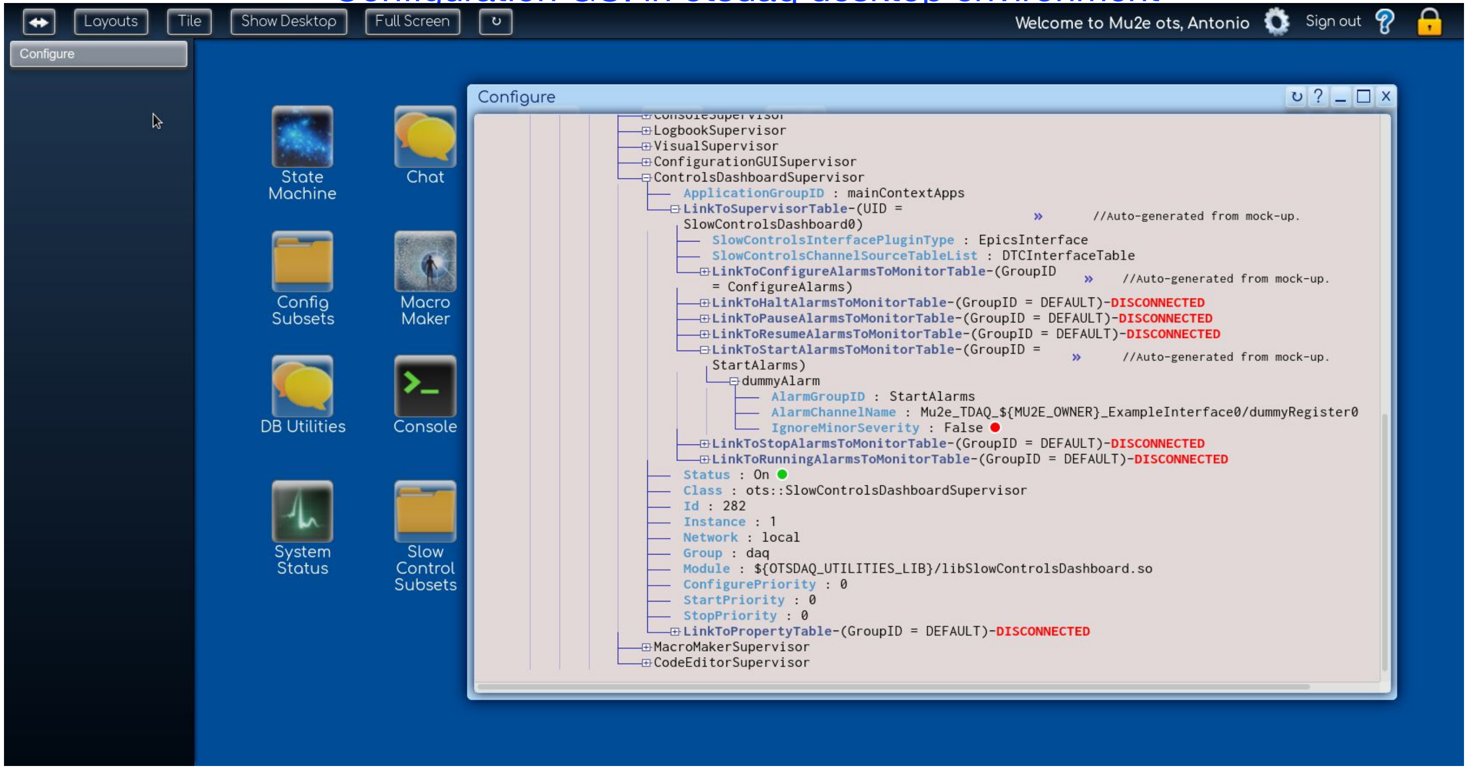


Slow Controls Monitoring in otsdaq

Configuring by specific tables in otsdaq

DesktopIconTable, XDAQApplicationPropertyTable, XDAQApplicationTable, XDAQContextTable

Configuration GUI in otsdaq desktop environment



Integration of otsdaq front-end DAQ hardware and artdaq metrics with EPICS

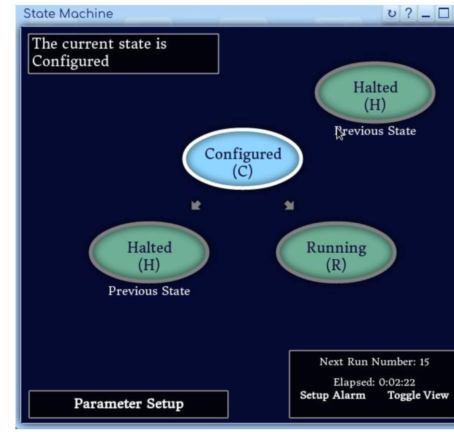
Actions designed and developed in *otsdaq*

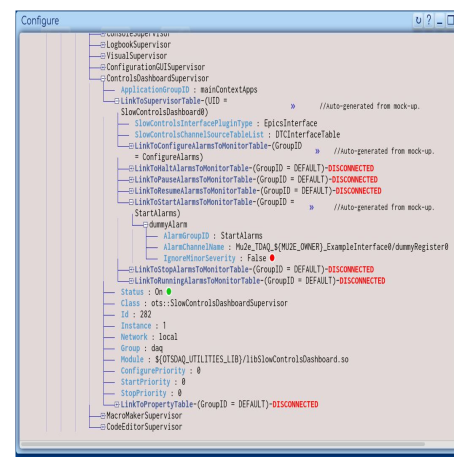
1. *otsdaq* DCS channels Front End and tables configuration
2. *otsdaq* State Machine configuration implementation
3. add/update channels info for IOC and Archiver DB
4. software IOC restarting
5. EPICS Archiver restarting
6. new *otsdaq* epics_plugin channels subscriptions to EPICS
7. Sending configured channels values to EPICS:

   otsdaq DCS channels new values → artdaq Metric Manager → software IOC → EPICS → otsdaq DCS GUI

Integration with State Machine

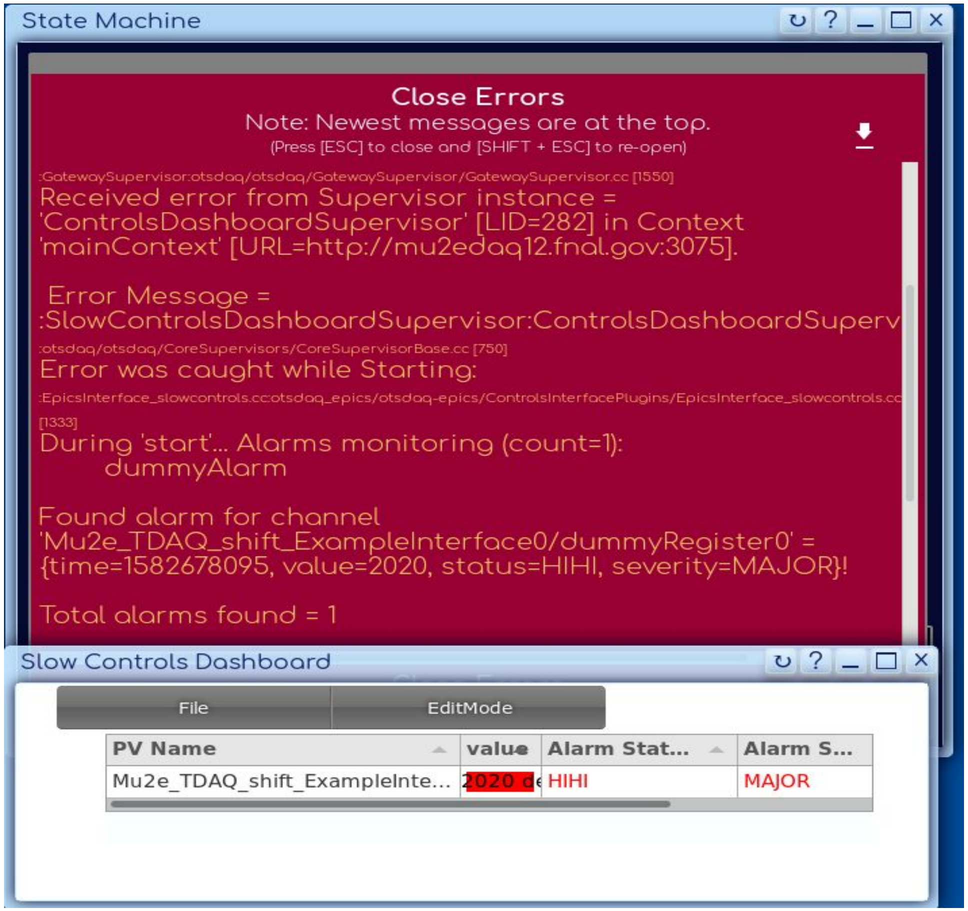
- Alarm propagation (from EPICS) and *otsdaq* state machine handling is available: needs just to identify which PV alarms, *status* and *severity* will be propagated
- *Tables and parameters designed for configuration*
  - SupervisorTable parameters:
    - *Slow Controls Interface Plugin Type*
    - *Slow Controls Channel Source Table List (HW list i.e. DTC Interface, CFO Interface)*
  - Alarms To Monitor Tables for transition to states:
    - *Configure*
    - *Halt*
    - *Pause*
    - *Resume*
    - *Start*
    - *Running*

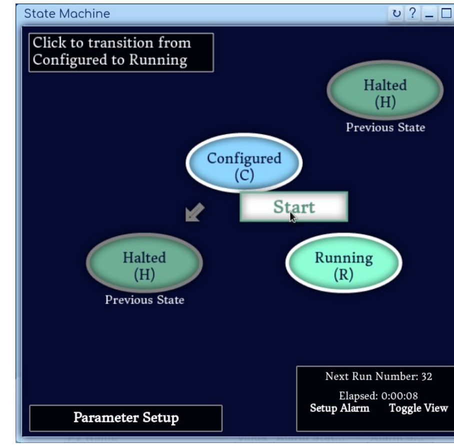


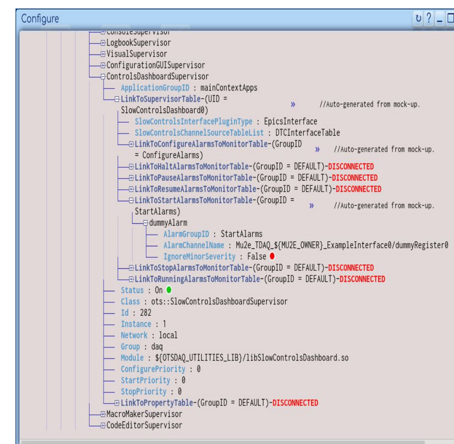


Integration with State Machine

- Alarm propagation (from EPICS) and *otsdaq* state machine handling: Example on “Start” transition



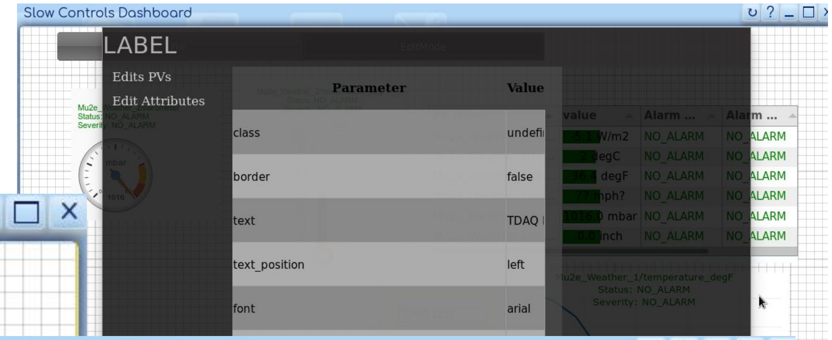




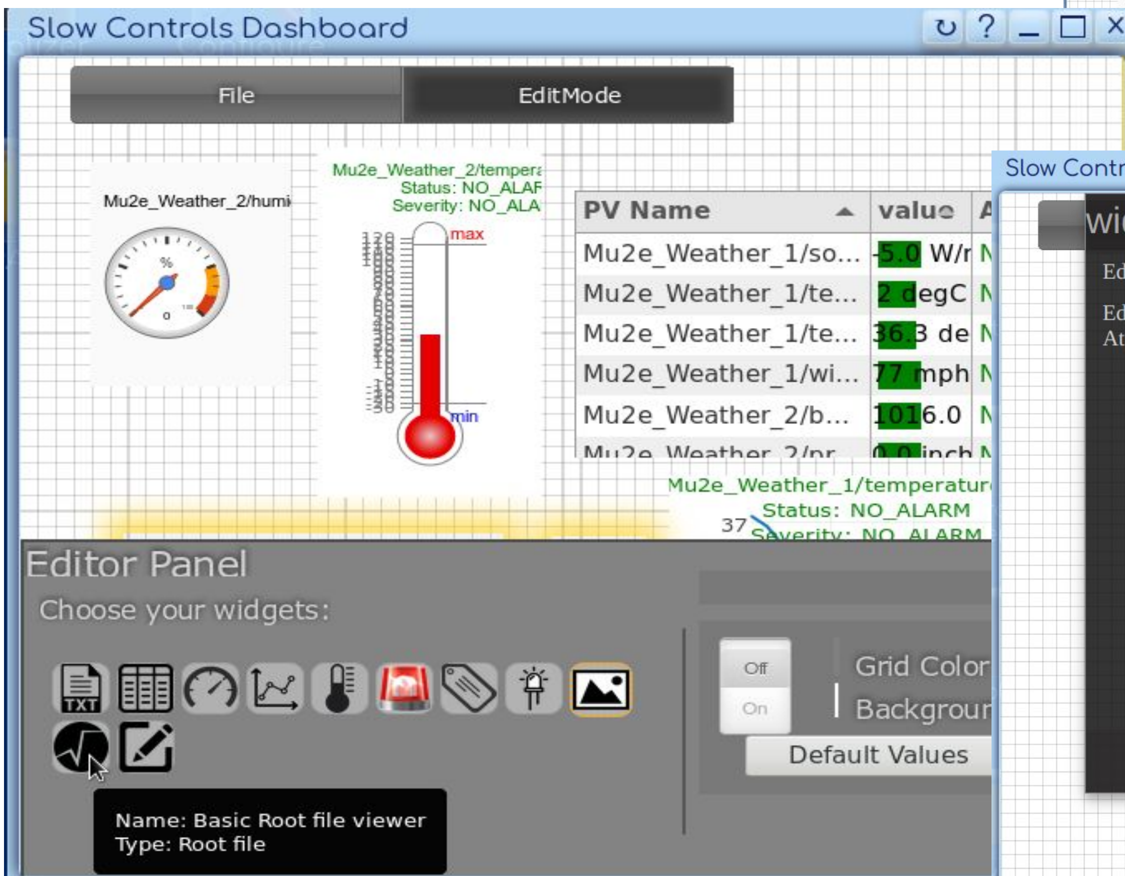
Slow Controls Monitoring in otsdaq

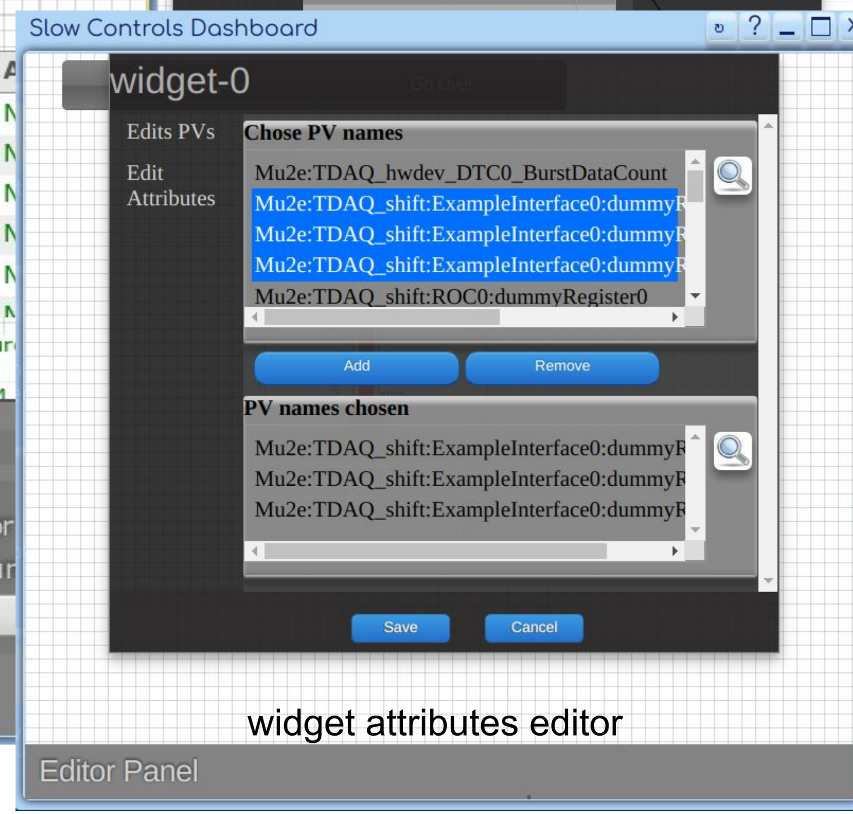
Examples

Example of widget settings window



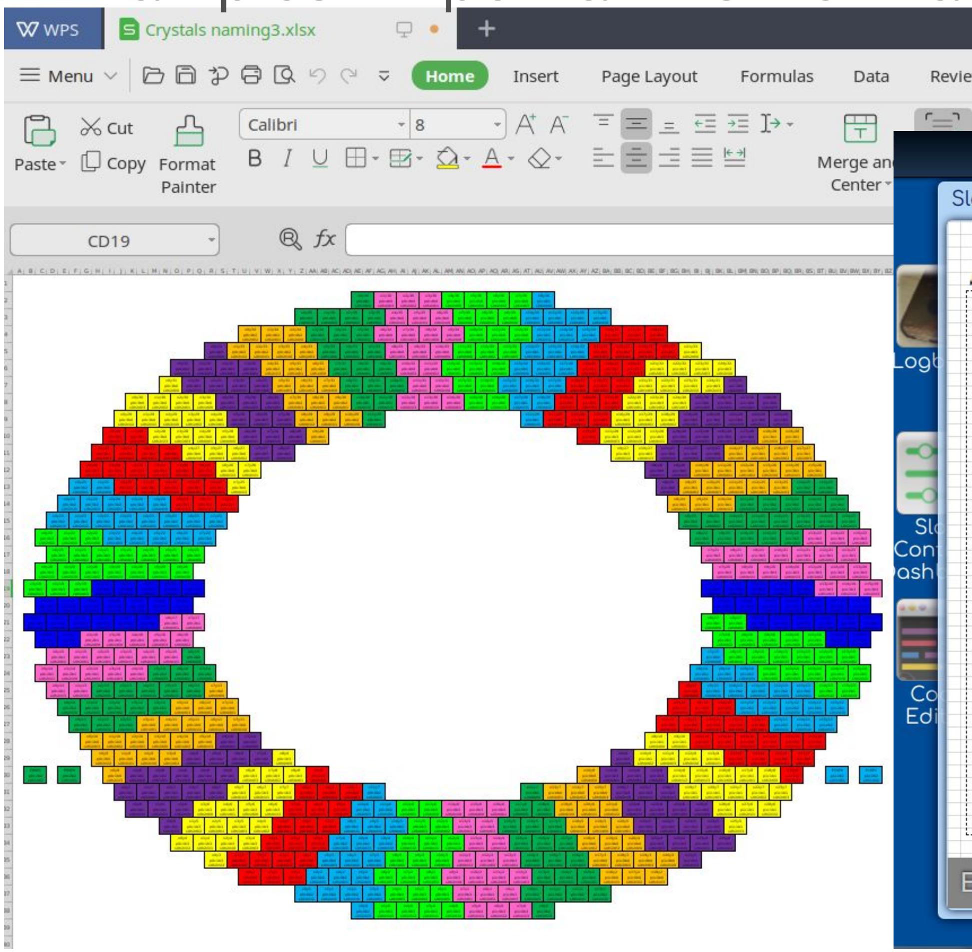
Editor

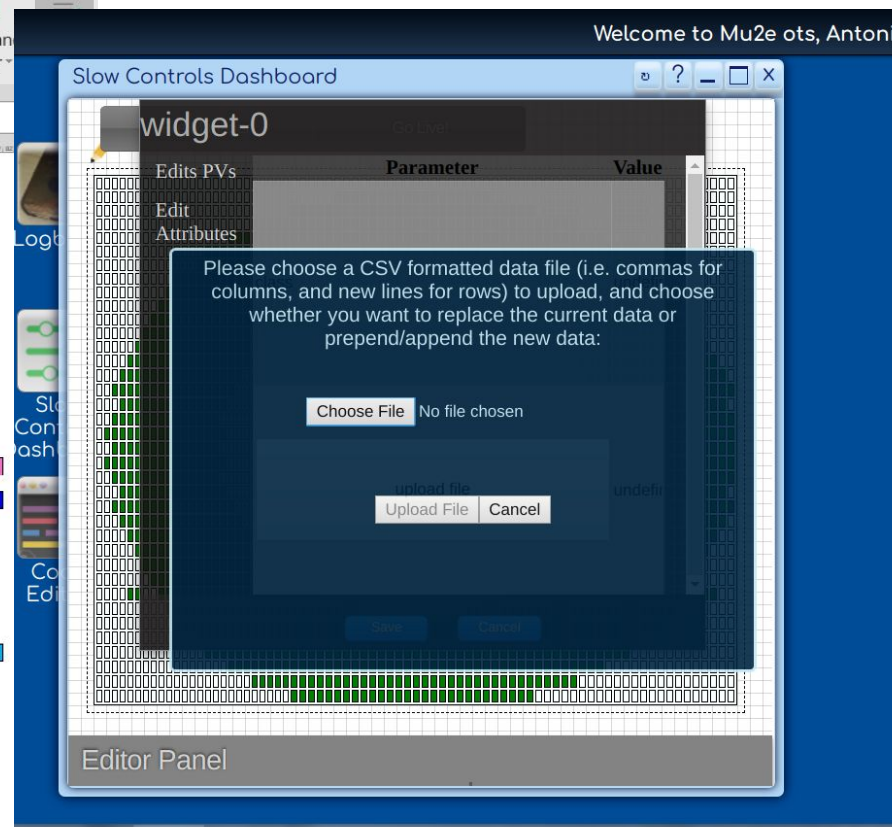




Calorimeter monitoring and the Slow Controls GUI

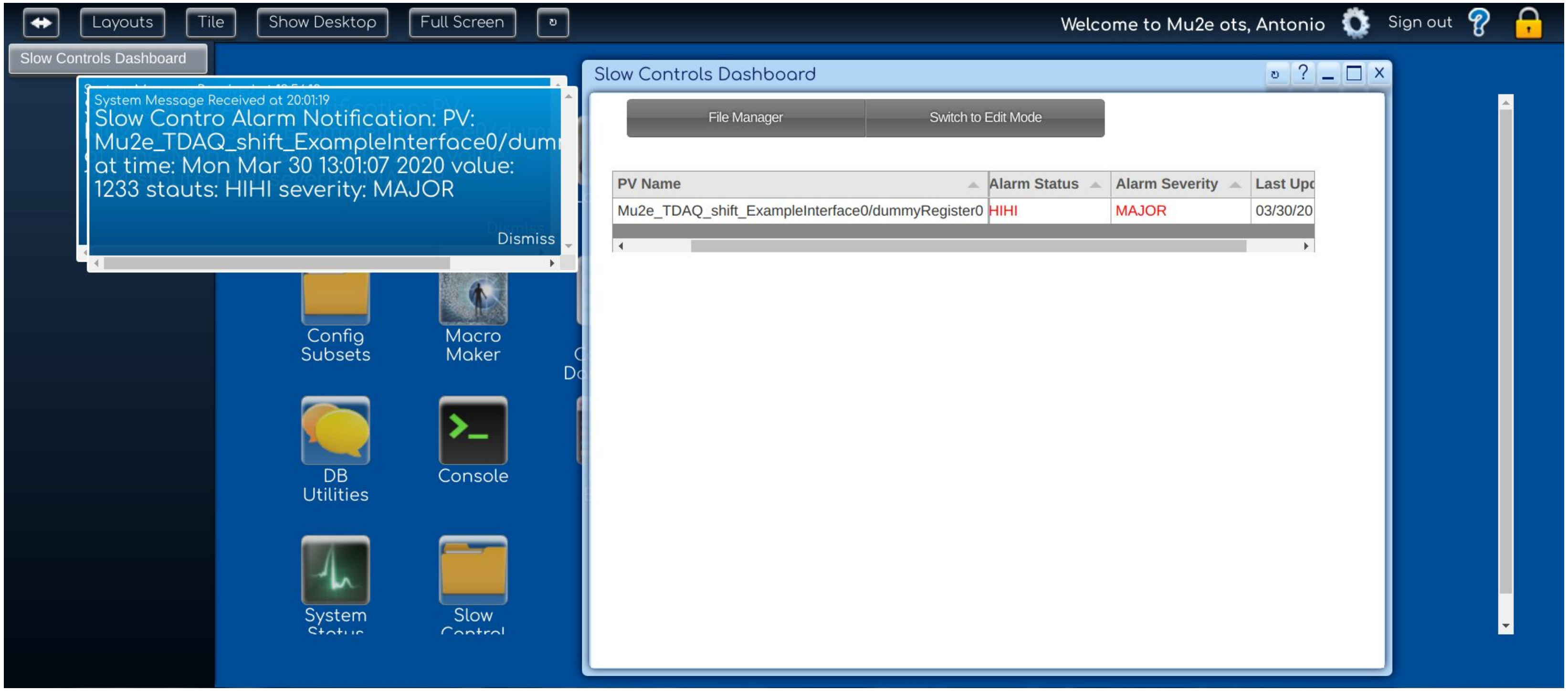
Examples: Import an xls file in a 2D-stop light widget





Slow Controls alarm notification by System Message

System message alarm notification example



Slow Controls alarm notification by System Message

Configured by specific table in otsdaq: