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Slow control and TDAQ systems installation and tests in the Mu2e experiment

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The Mu2e experiment at Fermilab will attempt to detect a coherent neutrinoless conversion of a muon into an electron in the field of an aluminum nucleus, with a sensitivity that is 10,000 times greater than existing limits. The Mu2e trigger and data acquisition system (TDAQ) uses the *otsdaq* framework as its online Data Acquisition System (DAQ) solution. Developed at Fermilab, *otsdaq* integrates several components, such as an *artdaq*-based DAQ, an *art*-based event processing, and an EPICS-based detector control system (DCS), and provides a uniform multi-user interface to its components through a web browser. The data streams from the Mu2e tracker and calorimeter are handled by the *artdaq*-based DAQ and processed by a one-level software trigger implemented within the *art* framework. Events accepted by the trigger have their data combined, post-trigger, with the separately read-out data from the Mu2e Cosmic Ray Veto system. The foundation of Mu2e DCS, EPICS, an Experimental Physics and Industrial Control System, is an open-source platform for monitoring, controlling, alarming, and archiving. Over the last three years, a prototype of the TDAQ and DCS systems has been built and tested at Fermilab's Feynman Computing Center. Currently, the production system installation is underway. At the end, this work presents a brief update on the installation of racks and DAQ hardware.

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1. Introduction

The Mu2e experiment at Fermilab will search for neutrino-less charged-lepton flavor violating (CLFV) conversion of a negative muon into an electron in the field of an aluminum nucleus ($\mu^- + ^{27}_{13}\mathrm{Al} \rightarrow e^- + ^{27}_{13}\mathrm{Al}$) [1].

In the Standard Model (SM), the predicted branching fractions of CLFV processes are below 10^{-50}. The expected Mu2e single event sensitivity (SES) is 3×10^{-17} respect to the current world's best limit $R_{\mu e} < 7 \times 10^{-13}$ (on gold) has been set by the SINDRUM II experiment at PSI [2]. In addition to Mu2e, the COMET and DeeMe experiments in preparation at J-PARC have an expected SES less than or comparable [3, 4].

The Mu2e apparatus includes three consecutive superconducting solenoids: The Production Solenoid contains a radiatively cooled tungsten production target hitted by an 8 GeV pulsed proton beam (period of 1.7 μs) that produces mostly pions; The Transport Solenoid, where the pions decay-producing the low-momentum μ^- beam; The Detector Solenoid, which houses the aluminum stopping target, where the muons get stopped and form the muonic atoms, then decay to 105 MeV/c^2 electrons, which are detected by state-of-the-art detectors for tracking and energy reconstruction, in the 1 T solenoidal magnetic field.

The Mu2e Trigger and Data Acquisition System (TDAQ) is a streaming system with a software-only trigger. In this paper, we present the Mu2e Trigger and Data Acquisition System (TDAQ), the online DAQ software suite *otsdaq* designed and developed at Fermilab, and the built detection control system (DCS). Finally, we report on the integration of the DCS system with *otsdaq* and the status of installation for racks and DAQ hardware.

2. The TDAQ System

The Mu2e Trigger and Data Acquisition System (TDAQ) is designed to meet the following requirements [5][6]:

Provide efficiency better than 90% for the conversion electron signal; Keep the total trigger rate below a few kHz - equivalent to approximately 7 PB/year of total data rate (to keep the collected data less than 21 PB in 3 years of running); Keep the processing time below 5 ms/event.

The Mu2e Data Acquisition System (DAQ) is designed to meet certain objectives, and it is based on a streaming readout with a higher off-detector data rate (which is enabled by a "software-only" trigger architecture). The detector data from the tracker, calorimeter, and cosmic ray veto are digitized, zero-suppressed in the front-end electronics, and then transmitted off the detector to the DAQ. This system uses 36 dual-CPU servers to handle a rate of approximately 152,800 proton pulses per second and an average of 4,240 events per second per server. Each Mu2e event data includes all data read out between two consecutive proton pulses, which is approximately 120 kB of zero-suppressed data per event, resulting in an average total data rate of about 20 GB/s when the beam is present [5].

The Run Control Host obtains beam status and timing information from the Accelerator Control network, and its Control Fanout (CFO) module then produces and synchronizes readout requests. The detector front-end electronics are read out by the ReadOut Controllers (ROCs), which stream out the zero-suppressed data collected from the detectors to the Data Transfer Controllers (DTCs) between two proton pulses. A total of 374 ROCs and 69 DTCs will be employed. The Mu2e trigger is implemented as a series of software filters applied after the reconstruction of online events [6], and the total trigger rate is expected not to exceed 700 Hz [6].

TDAQ employs *otsdaq* as a software solution. Developed at Fermilab, it uses *artdaq* [7, 8] and *art* [9] software as event filtering (data transfer, event building, and event reconstruction) and processing frameworks. *otsdaq* includes a run control system using the XDAQ [10] data acquisition software XDAQ [10] implemented for the development and calibration mode runs in CMS.

With the *artdaq* framework, it is possible to limit the offline data storage to less than 7 PB/year with a reduction factor of about 100 at the event building level [11].

3. The Detector Control System

The Detector Control System (DCS) monitors the detectors' status and operational conditions. The DCS provides the display of the real-time event and detector data via Graphical User Interfaces (GUIs) for each subsystem and archives the monitoring data to disk.

It uses EPICS (Experimental Physics and Industrial Control System) framework, used in several experiments [12]. The total number of slow control quantities should be of the order of thirty thousand. On average, these quantities will be updated approximately twice per minute, for a resulting generated data rate of 10 kB/s. EPICS supplies an Input Output Controller (IOC), running for each subsystem on a central DAQ server, will provide channels for all data [13].

As part of the DCS, *otsdaq* delivers slow control data from the DTCs and ROCs to EPICS. The *otsdaq* allows the user to monitor and interact with the DAQ hardware and the other devices managed by EPICS.

C++ programming and web-app applications are used in the *otsdaq* to include the Mu2e slow control monitoring and alarm handling. It permits also online daq slow control entities writing in EPICS.

The C++ interface, developed to connect *otsdaq* to EPICS, uses the EPICS Channel Access Client Library functions and Postgres database connections to read/write the data.

4. The DAQ room installation

The Trigger and Data Acquisition system is located in the DAQ room of the Mu2e Detector Hall. The racks, cabling, networking, and controls are installed first, followed by the DAQ servers. The cables and fibers that connect the TDAQ to the various detector elements will be pulled before installing the Detector Train. In the last two years, vertical and horizontal slice tests have focused on the characterization of synchronization and jitter, testing of the DTC-ROC interface, and benchmarking of triggers.

Currently installed in the DAQ room are 12 DAQ servers and a general-purpose networking that includes separate private networks for Data/Run Control and DCS/Management. System integration tests are ongoing.

5. Conclusions

In this work, we have presented the Trigger and Data Acquisition System (TDAQ) and Detector Control System (DCS) developed for the Mu2e experiment at Fermilab. The TDAQ system uses the online DAQ software suite *otsdaq* developed at Fermilab to provide a high level of flexibility and scalability. The Detector Control System (DCS) system uses the open source framework EPICS developed at Argonne and Fermilab and widely employed in a number of experiments, including CMS. The *otsdaq* system includes a part of DCS that communicates with EPICS.

A test-stand equipped with the *otsdaq* web-based GUI was set up at Fermilab to test TDAQ and its timing performance. First level results of tests show that the requirement to achieve a total processing time/event below 5 ms is fulfilled. Installation of the production system and preparations to the integration tests are underway.

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