PROCEEDINGS OF SCIENCE

Slow control and data acquisition systems in the Mu2e experiment

A. Gioiosa,[a,b,*] R. Bonventre,[c] S. Donati,[a,b] E. Flumerfelt,[d] G. Horton-Smith,[e] L. Morescalchi,[b] V. O'Dell,[d] E. Pedreschi,[b] G. Pezzullo,[f] F. Spinella,[b] L. Uplegger[d] and R. A. Rivera[d]

[a] *Università di Pisa, I-56127 Pisa, Italy*
[b] *INFN Sezione di Pisa, I-56127 Pisa, Italy*
[c] *Lawrence Berkeley National Laboratory, Berkeley, California 94720, USA*
[d] *Fermi National Accelerator Laboratory, Batavia, Illinois 60510, USA*
[e] *Department of Physics, Kansas State University, Manhattan, Kansas 66506, USA*
[f] *Yale University, New Haven, Connecticut, 06520, USA*

E-mail: antonio.gioiosa@df.unipi.it

The Mu2e experiment at the Fermilab Muon Campus will search for the coherent neutrinoless conversion of a muon into an electron in the field of an aluminum nucleus with a sensitivity improvement by a factor of 10,000 over existing limits. The Mu2e Trigger and Data Acquisition System (TDAQ) uses *otsdaq* as the online Data Acquisition System (DAQ) solution. Developed at Fermilab, *otsdaq* integrates both the *artdaq* DAQ and the *art* analysis frameworks for event transfer, filtering, and processing. *otsdaq* is an online DAQ software suite with a focus on flexibility and scalability and provides a multi-user, web-based, interface accessible through a web browser. The data stream from the detector subsystems is read by a software filter algorithm that selects events which are combined with the data flux coming from a Cosmic Ray Veto System. The Detector Control System (DCS) has been developed using the Experimental Physics and Industrial Control System (EPICS) open source platform for monitoring, controlling, alarming, and archiving. The DCS System has been integrated into *otsdaq*. A prototype of the TDAQ and the DCS systems has been built at Fermilab's Feynman Computing Center. In this paper, we report on the progress of the integration of this prototype in the online *otsdaq* software.

**** The European Physical Society Conference on High Energy Physics (EPS-HEP2021), ****
**** 26-30 July 2021 ****
**** Online conference, jointly organized by Universität Hamburg and the research center DESY ****

[*] Speaker

© Copyright owned by the author(s) under the terms of the Creative Commons Attribution-NonCommercial-NoDerivatives 4.0 International License (CC BY-NC-ND 4.0).

PoS(PANIC2021)082

1. Introduction

Lepton Flavor Violation (LFV) has been observed in the neutral sector in neutrino oscillations but not in the charged sector. In the Standard Model (SM), the predicted branching fractions of Charged Lepton Flavor Violating (CLFV) processes are below 10^{-50}. The observation of CLFV would thus provide unambiguous evidence for the existence of New Physics beyond the SM. The Mu2e experiment at Fermilab will search for the coherent neutrinoless muon-to-electron-conversion in the field of an aluminum nucleus ($\mu^- + {}^{13}_{27}Al \rightarrow e^- + {}^{13}_{27}Al$) [1]. The expected Mu2e single event sensitivity (SES) is:

$$R_{\mu e} \equiv \frac{\Gamma(\mu^- N(A,Z) \rightarrow e^- N(A,Z))}{\Gamma(\mu^- N(A,Z) \rightarrow \nu_\mu N(A,Z-1)^*)} = 3 \times 10^{-17}. \tag{1}$$

The current world's best limit $R_{\mu e} < 7 \times 10^{-13}$ (on gold) is from the SINDRUM II experiment at Paul Scherrer Institut [2]. In addition to Mu2e, the COMET experiment in preparation at J-PARC has an expected SES of 3×10^{-15} for Phase-I and $O(10^{-17})$ for Phase-II (on aluminum) [3], while the DeeMe experiment, also in preparation at J-PARC, has an expected SES of 10^{-14} (on carbon) [4].

The Mu2e apparatus includes three superconducting solenoids: The Production Solenoid, the Transport Solenoid and the Detector Solenoid [5].

The Mu2e Trigger and Data Acquisition System (TDAQ) is a streaming system with a software-only trigger designed to satisfy 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; Keep the processing time below 5 ms/event. To achieve these goals and allow for a higher off-detector data rate, the Mu2e Data Acquisition System (DAQ) is based on a streaming readout. This means that all detector data are digitized, zero-suppressed in the front-end electronics and then transmitted off the detector to the DAQ. In this paper, we present the Mu2e Trigger and Data Acquisition System (TDAQ) and the Detector Control System (DCS) prototypes built at Fermilab's Feynman Computing Center. We also present the Mu2e online DAQ software suite *otsdaq* designed and developed at Fermilab. We report at end the integration of the DCS system into the online *otsdaq* software.

2. The TDAQ System

The Mu2e Trigger and Data Acquisition System (TDAQ) provides the necessary infrastructure to collect digitized data from the tracker, calorimeter, cosmic ray veto and monitor the beam status. The TDAQ employs 36 dual-CPU servers to handle a total rate of 192,000 proton pulses per second and an average of 5,400 events per second per server. According to preliminary estimates, the detectors generate approximately 120 kB of zero-suppressed data per proton pulse for a resulting average total data rate of about 20 GB/s when beam is present [5]. Figure 1 shows the global TDAQ architecture.

Each Read Out Controller (ROC) continuously streams out the zero-suppressed data collected between two proton pulses from the detectors to the DTCs (Data Transfer Controller). The data of a given time-frame are then collected in a single server using a 10 Gb/s switch. Then, the online reconstruction starts and a trigger decision is made. If an event gets triggered, the data from the cosmic ray veto (CRV) are pulled and aggregated into a single data stream. The DAQ servers filter these events (aggregator/data logger) and forward a small subset of them to the offline storage.

PoS(PANIC2021)082

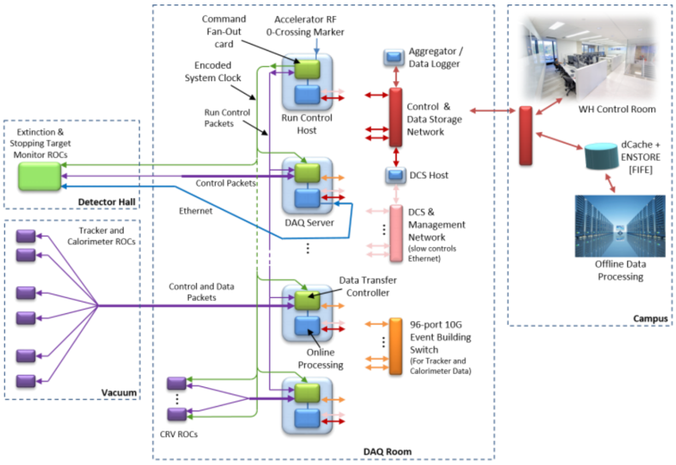

Figure 1: Mu2e TDAQ architecture and components diagram.

The TDAQ employes *otsdaq* as a software solution. Developed at Fermilab, it uses the *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 data acquisition software XDAQ [10] implemented for the development and calibration-mode runs at CMS.

The Mu2e physics triggers identify signal event candidates [6]. It is implemented as a series of software filters applied after each step of track reconstruction. The total trigger rate is expected not to exceed 700 Hz [6]. 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

Mu2e selected EPICS (Experimental Physics and Industrial Control System) for the Detector Control System (DCS) slow control and monitoring software[12]. EPICS, with the Control System Studio (CSS) GUI software, is an open source framework originally developed at Argonne and Fermilab and now used in numerous experiments [13]. An Input Output Controller (IOC), running for each subsystem on a central DAQ server, will provide channels for all data [14]. The total number of slow control quantities is expected to 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.

As part of the DCS, *otsdaq* delivers slow control data from the DTCs and ROCs to EPICS.

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

4. Conclusions

In this article, we have presented the Trigger and Data Acquisition System (TDAQ) and Detector Control System (DCS) currently being 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. We have reported on the preliminary results of the system performance. The Detector Control System (DCS) system uses the open source framework EPICS developed

PoS(PANIC2021)082

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 run control GUI has been developed and integrated in *otsdaq* to provide a multi-user, web-based control and monitoring dashboard.

Acknowledgements

We are grateful for the vital contributions of the Fermilab staff and the technical staff of the participating institutions. This work was supported by the US Department of Energy; the Istituto Nazionale di Fisica Nucleare, Italy; the Science and Technology Facilities Council, UK; the Ministry of Education and Science, Russian Federation; the National Science Foundation, USA; the Thousand Talents Plan, China; the Helmholtz Association, Germany; and the EU Horizon 2020 Research and Innovation Program under the Marie Sklodowska-Curie Grant Agreement No. 690835, 734303, 822185, 858199, 101003460. This document was prepared by members of the Mu2e Collaboration using the resources of the Fermi National Accelerator Laboratory (Fermilab), a U.S. Department of Energy, Office of Science, HEP User Facility. Fermilab is managed by Fermi Research Alliance, LLC (FRA), acting under Contract No. DE-AC02-07CH11359.

References

[1] R.H. Bernstein *et al*, "Charged Lepton Flavor Violation: An Experimenter's Guide," Phys. Rep., 532, 2, 27-64, 2013.

[2] W.H. Bertl *et al*, "A Search for muon to electron conversion in muonic gold," Eur. Phys. J., C47 p. 337-346, 2006. doi:10.1140/epjc/s2006-02582-x.

[3] M. Lee, "Comet Muon conversion experiment in J-PARC," Frontiers in Physics, v. 6 p. 133, 2018. doi:10.3389/fphy.2018.00133.

[4] N. Teshima, "Status of the DeeMe Experiment, an Experimental Search for μ-e Conversion at J-PARC MLF," PoS, v. NuFact2019 p. 082, 2020. doi:10.22323/1.369.0082.

[5] L. Bartoszek *et al*, "Mu2e Technical Design Report", 1501.05241, arXiv, physics.ins-det, 2015.

[6] D. Brown, G. Pezzullo, P. Murat, "The Track finder algorithm for the Trigger system of the Mu2e experiment at Fermilab," Connecting The Dots, Princeton, 2020.

[7] K. Biery, E. Flumerfelt, J. Freeman, W. Ketchum, G. Lukhanin, A. Lyon, R. Rechenmacher, R. Rivera, L. Uplegger and M. Votava, "Flexible and Scalable Data-Acquisition Using the artdaq Toolkit," [arXiv:1806.07250 [physics.ins-det]], 2018.

[8] K. Biery, C. Green, J. Kowalkowski, M. Paterno and R. Rechenmacher, "artdaq: An event filtering framework for Fermilab experiments," doi:10.1109/RTC.2012.6418358, 2012.

[9] C. Green, J. Kowalkowski, M. Paterno, M. Fischler, L. Garren and Q. Lu, "The Art Framework," J. Phys. Conf. Ser. 396, 022020 (2012) doi:10.1088/1742-6596/396/2/022020.

[10] G. Bauer et al., "The CMS data acquisition system software," J. Phys. Conf. Ser., vol. 219, p. 022011, 2010.

[11] Kurt Biery et al 2017 J. Phys.: Conf. Ser. 898 032013.

[12] https://epics-controls.org/, 2020.

[13] https://epics-controls.org/epics-users/projects/, 2020.

[14] "EPICS Record Reference Manual" http://www.ing.iac.es/ docs/external/epics/recordref.pdf.

PoS(PANIC2021)082