# Implementation of the Control System for the LHCb Muon Detector

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*Abstract*

The Muon Detector of LHCb will be equipped with 1368 Multi-Wire Proportional Chambers and 24 Triple-GEM Detectors. Within the Framework of the CERN Control System Project, using PVSS as the main tool, we are developing an instrument to manage the Muon System of LHCb. Adjustment and monitoring of High and Low Voltage power supplies, on-line diagnostics and fine tuning of the Front-End read-out devices, data acquisition from the gas system and the monitoring of pressure and temperature of the experimental hall are being implemented. The system will also look after long term data archiving and alert handling. The Control System performance is currently under evaluation in a cosmic ray station. Built as a final quality control of the LHCb Multi-Wire Proportional Chambers, allowing acquisition of data from as many as 600 Front-End readout channels, the cosmic ray station is fully managed by means of a Control System prototype.

## I. THE MUON SYSTEM OF LHCB

The LHCb Muon System [1], [2] will be composed of 5 stations (for a total active surface of 435 $m^2$) equipped with 1368 Multi-Wire Proportional Chambers of 20 different sizes. The LHCb level-0 trigger, based on a 5-fold coincidence within 25 ns, requires a fast and precise measurement of the muon transverse momentum and a high efficiency in the bunch-crossing identification. This translates in the requirements for each bigap of the chambers:

1. high efficiency ($\geq$95%) in 20 ns;
2. less than 1.1 hits per chamber per track (in average);

The LHCb MWPCs were designed in order to fulfill all those requirements. Fig. 1 shows that a time resolution of about 3.8 ns (r.m.s.) is achieved [3]. The detection efficiency in a time window of 20 ns and the pad-cluster size were measured as a function of the high voltage (HV) applied to wires. The results reported in Fig. 2 show that the above conditions 1) and 2) are satisfied for

$$2530 \leq \mathrm{HV} \leq 2700\ \mathrm{V}. \qquad (1)$$

These values define the HV working region (WR) of the chamber. The ageing test was performed at the ENEA-Casaccia centre, using the Calliope gamma facility [4]. During this test a total charge of 440 mC per centimetre of wire was integrated, without any significant deterioration of the chamber gain [4].

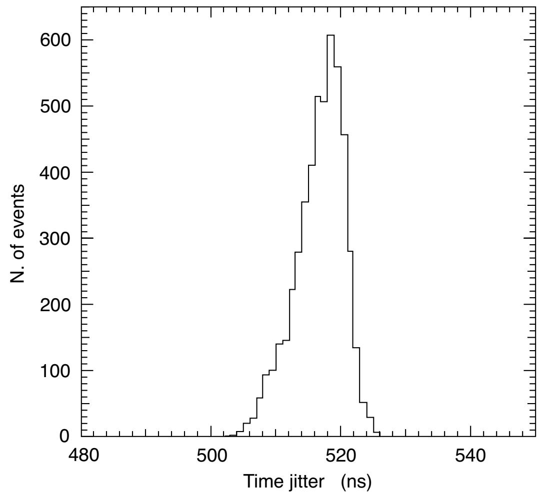



Figure 1: Typical time jitter of a four-gap chamber having a gas gain of about 5 $\times 10^4$. The zero of the time scale is arbitrary.

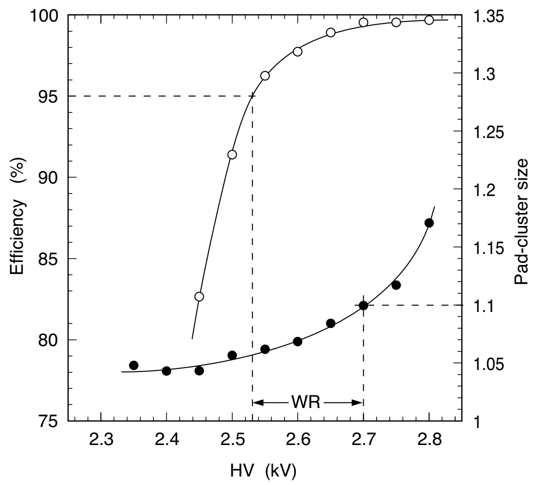



Figure 2: Efficiency (left scale and open circles) and pad-cluster size (right scale and solid circles) of a double-gap MWPC as functions of the high-voltage (HV). The working region (WR) is shown. Curves are drawn to guide the eye.

In region R3 of station M3 a charge of 3.5 (6.0) mC/cm is expected to be integrated in 10 years by a chamber operating at the centre (upper bound) of its HV working region and at an average collider luminosity of $2 \times 10^{32}$ cm$^{-2}$s$^{-1}$. This ageing test proved that, for HV within the working region, the MWPC can operate safely in the LHCb experiment and that the HV upper limit is determined only by the upper limit on the pad-cluster size (Fig. 2).

## II. The Muon Detector Control System

In order to manage and monitor the LHCb Muon Detector a Control System is now being developed and tested. A Finite State Machine architecture has been adopted, following the CERN Joint Controls Project (JCOP) recommendation: "*The experiment control systems are modelized as a hierarchy of Finite State Machines (FSM). In this model there is a state/command interface between a parent and its children. Commands are passed from a parent to its children and the states/alarms of the children are passed to the parent who derives its state from those of its children.*" Each item (Device Unit) is thought of as having a set of stable states. Items can move between their allowed states by making transitions triggered either by commands or state changes of a dependent FSM. After a change of state the Device Unit generates a signal to inform the Control Unit about its state. For the Muon System, the hierarchy in Fig. 3 is being implemented.

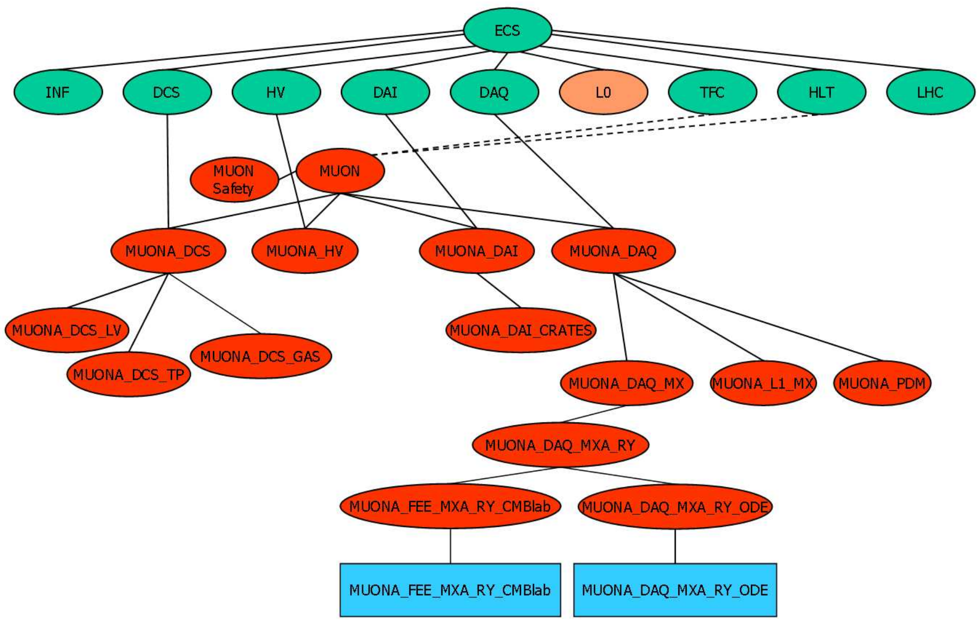



Figure 3: Hierarchy tree for the Muon Detector Control System.

The main Control Unit is called Muon and is subdivided in two Control Units for the A(ccess) and the C(ryogenics) sides. They sends commands and receives States and Alarms to and from a set of subdomains:

- *Detector Control System (DCS)* that controls the Low Voltage, Gas System and enviromental parameters (such as the temperature and the pressure);
- *High Voltage* that manages the high voltage system of the apparatus;
- *DAQ Infrastructure* that controls infrastructures needed for DAQ (such as crates and vans)
- *DAQ* that manages all the data acquisition tools. The DAQ domains is divided in subdomains controlling the electronics of each Station (M1–M5) and Region (R1–R4) of the Muon System. Different domains are foreseen for the frontend (FEE) and off detector electronics (ODE and PDM) and Level-1 boards (Tell1).

## III. Detector Control System

### A. Low Voltage

An array of low voltage supplies, used to provide power to the front end readout devices, will also need supervision, because of the high radiation levels in the experimental hall, and their main parameters, such as current, voltage as well as their overall status will be will be acquired.

## B. Gas System

The data coming from the gas distribution system, regarding the supply of the gas mixtures to the detectors will be monitored and acquired.

## C. Temperature and Pressure Sensors

Performance of the chambers in the Muon System will strongly depend on the temperature (T) and pressure (P) of the gas. For little T and P variations the dependence of the gas gain can be linearized:

$$\frac{\Delta G}{G_0} = \alpha \left( \frac{\Delta T}{T_0} - \frac{\Delta G}{G_0} \right)$$

The value of $\alpha$ was measured ([8] and [9]) to be 5.34 as shown in Fig.4.

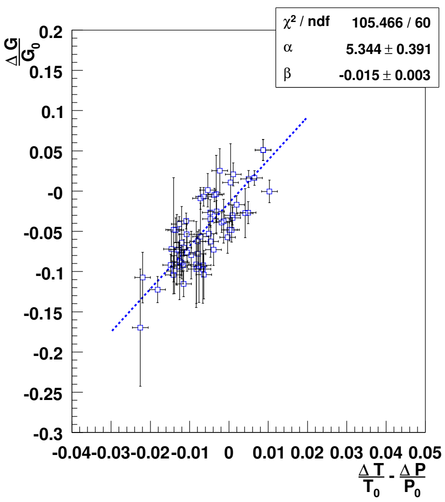



Figure 4: Dependence of the gas gain variations as a function of little temperature and pressure variations.

While the temperature inside the experimental hall will be controled and constant within 1 K, variations in of the atmospheric pressure of $\pm30$ mbar are expected. Consequently, the chamber gain can vary up to $\pm$ 15%. Therefore it will be mandatory to monitor and acquire the environmetal parameters.

# IV. High Voltage

The MWPC will be supplied with 2 or 4 (depending on the region) HV channels, while the triple-GEM detectors will need 4 HV channels each. Therefore that there will be more than 4000 HV channels. The high perfomance required and the high particle flux foreseen in the Muon System, suggest to have all the chambers working at the same gain value in the middle of the efficiency plateau. An equalization and a stabilization of the gain will be achieved by tuning the high voltage supplies on a case by case basis.

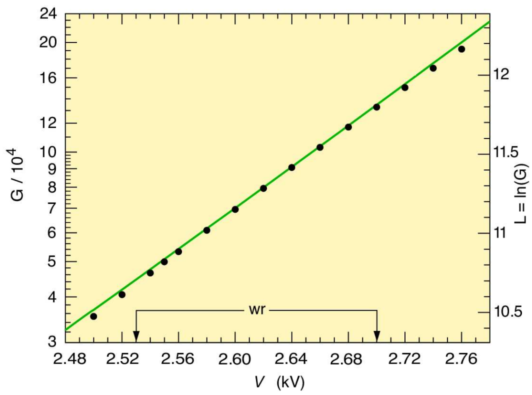



Figure 5: Dependence of the gas gain as a function of the voltage applied to the wires in the LHCb working region.

As shown in Fig. 5 the gas gain doubles each 100 V. The Control System will also manage the ramp-up and ramp-down phases of the entire high voltage system, monitoring of the current drawn at the same time.

# V. DAQ

The Muon System will be made up of 120,000 readout channels. The front-end readout devices performance will require appropriate supervision. In the PVSS framework there will be one DataPoint Type for each type of chamber (20 in total). An example of a DataPoint Type for an M5R4 chamber is showed in Fig. 6. Each DataPoint is a Folder containing as many subfolders as the number of Front End Boards of the chamber. Each FEB folder contains 11 DataPoint Element: 9 dynamic arrays of integers and 2 integers. Each DataPoint element is directly linked to an equivalent SDO.

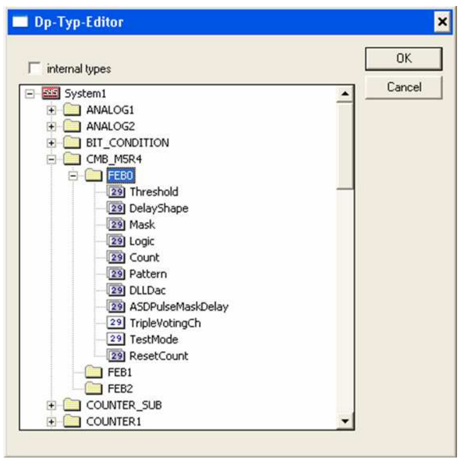



Figure 6: Example of a DataPoint type for M5R4 Muon Chamber

In this way it will be possible to exploit all the PVSS tools for data Control, Archiving and Alarm. The CANBus communication is based on the segmented SDO transfer. For each chamber on the apparatus a DataPoint will be created (for a total of 1380 DataPoints). Electronic channels will need a constat monitoring of their parameter in order to single out dead or noisy channels and adjust the channel settings, such as thresholds and masks. A set of states and procedures is being developed (Fig.7).

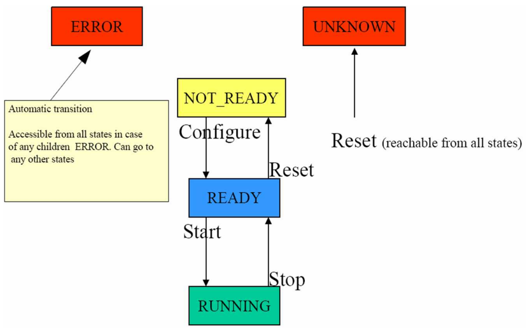



Figure 7: States and procedures of the DAQ domains

Following the general guidelines [6] of LHCb the states foreseen for the Font End Domain are:

| State | Meaning |
|---|---|
| NOT-READY | The FEE boards are working and communicating properly,but they need a heavy configuration (i.e. the CONFIGURE procedure) before they can be used |
| READY | The FEE is correctly CONFIGUREd but it needs a light configuration (i.e. the START) procedure before acquiring. Only from this state it is possible to run the CALIBRATION procedures |
| RUNNING | The FEE is taking data and its configuration cannot be changed. |
| ERROR | An important fraction of the Front End boards has published an ERROR state and is not able to take valid data. |
| UNKNOWN | It is not possible to communicate with part of the system. |

They can be divided into two main groups: INTERNAL (only the FEE domain is involved).

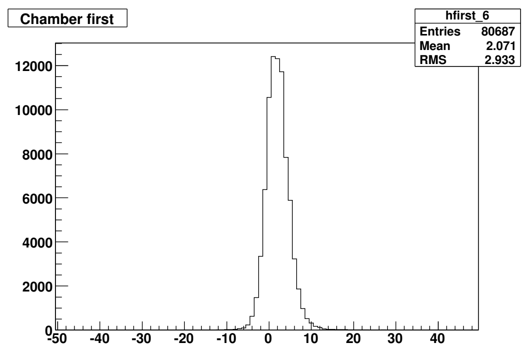
- CONFIGURE: loading of all default values from the Configuration DB or from some preloaded memory in the Service Board;
- START: fine tuning of main parameters (threshold, logic, masks) according to different possible acquisition runs;
- STOP: reset the value of FE channels to the default ones;
- MONITORING: during the runs we'll be interested in a continuous monitoring of the FE channels (mainly the noise levels);
- CALIBRATION: threshold scan, measurements of noise level, DLL calibration;

EXTERNAL (other system are involved)

- TIME ALIGNEMENT: when detector is switched ON after long time we'll need to synchronize the response of the chambers. This procedure requires a tight communication between OffDetectorElectronics and FrontEndElectronics;

## VI. The Cosmic Ray Test Station for the LHCb Muon Chamber

A first down scaled implementation of the Control System is now being used and tested to fully manage a cosmic ray station built for the studies of the LHCb MultiWire Proportional Chambers. The cosmic ray stand is able to house 6 MWP chambers and allows the acquisition of as much as 600 Front-End channels. The CS controls high and low voltage supplies as well as the front-end readout devices, stores data regarding the system status and manages the alert and the alarm situations. The CS test is giving a unique possibility to study in details their different features and is an usefull tool to test the robustness of the Muon Detector CS. In the Fig. 8 some of the results of the cosmic ray measurements are reported: a typical time jitter (top) and the time resolution of three chambers as a function of the voltage applied (bottom).



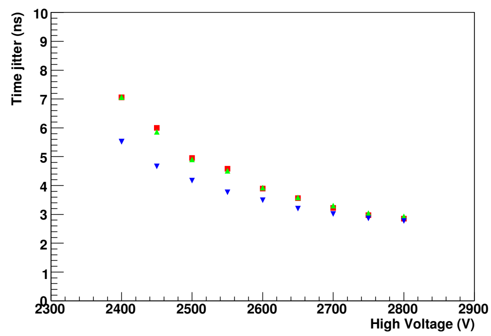




Figure 8: Top: Typical time jitter of a four-gap chamber studied with the cosmic rays. Bottom: Time resolution as a function of the high voltage applied for three types of MWP Chambers

## VII. Conclusion

Management of the LHCb Muon Detector requires the monitor and set of many different parameters. Following the recommendation of the CERN Joint Controls Project group, the Finite State Machine architecture was adopted. A Control System in the PVSS FrameWork is being developed. Control Units are created to manage the main System aspects. Usage of the tools developed to manage a Cosmic Ray Station, already in use for tests and performance evaluation of the LHCb Muon Chambers, makes possible to have a fast feedback on the usefullness of the implemented features and to test for robustness of the Control System itself. Routines for calibration and diagnostics of the front-end electronics and for high voltage setting and monitoring have already shown to work very well and result of great importance for the automation of the Muon Detector Control System.

## References


[1] LHCb Collaboration, "LHCb Muon System Technical Design Report", CERN/LHCC 2001-010 (2001).

[2] LHCb Collaboration, "Addendum to the Muon System Technical Design Report", CERN/LHCC 2003-002 (2003).

[3] M. Anelli *et al.* "Test of MWPC Prototypes for Region 3 of Station 3 of the LHCb Muon System"; LHCb-Muon 2004-074 (2004). CERN-JCOP 2000-008

[4] M. Anelli *et al.* "Ageing test of a prototype of quadrigap MWPC for the region 3 of the LHCb muon system", LHCB-MUON 2003-040, 2003.

[5] JCOP Framework Team "Joint controls project framework sub-project guidelines and convenctions", CERN-JCOP 2000-008.

[6] P. Duval "Guide for ECS FSM design in LHCb detectors" LHCb Public Note avelaible at https://edms.cern.ch/document/655828/2.

[7] V. M. Filimov, "Description of the CANopen OPC server" CERN, Geneva, Switzerland.

[8] D. Pinci and A. Sarti, "Study of the behaviour of the LHCb Muon System MWPC as a function of the gas pressure and temperature" CERN-LHCb-2005-079.

[9] E. Dané, D. Pinci and A. Sarti, "Report on the quality of the LHCb-Muon four-gap MWPC produced at LNF" CERN-LHCb-2006-056.

[10] W. Bonivento *et al.* "Development of the CARIOCA front-end chip for the LHCb muon detector", *Nucl. Instrum. Methods A* vol. 491 pp. 233-243, 2002.

[11] V. Bocci *et al.* "Service board datasheet, v1.0", INFN sezione di Roma, Italy.