

# The electronics of ALICE Dimuon tracking chambers

V. Chambert <sup>a</sup>

For Alice Collaboration

<sup>a</sup> Institut de Physique Nucléaire d'Orsay, 15 rue Georges Clémenceau F-91406 ORSAY FRANCE

[chambert@ipno.in2p3.fr](mailto:chambert@ipno.in2p3.fr)

## Abstract

The muon spectrometer is one of the main detection system of ALICE, the dedicated heavy-ion experiment at CERN LHC. The muon tracking system consists of five cathode-pad chamber station (ST) with two detection planes each. The readout architecture, based on dedicated FE boards, embedded digital crates and a trigger dispatcher crate and the process to reach the electronics final design will be described, as well as the production and the tests of the 19.600 FE boards. Finally, the integration of ST1 at CERN (including EMC issues and commissioning) will be highlighted.

## I. INTRODUCTION

The Quark-Gluon Plasma is expected to be formed in heavy-ion collisions at LHC energies. Several signatures of this new state of the matter will be studied by Alice [1]. The Dimuon spectrometer will be especially devoted to the measurement of the quarkonia,  $J/\psi$  and  $\Upsilon$ , and heavy flavours which decay in muons. Because of very close mass of the  $\Upsilon$  states, a very good mass resolution, better than  $100\text{MeV}/c^2$  is required [2, 3]. It is directly correlated to a very good spatial resolution of the chambers with many consequences on the electronics requirements.

The ALICE Dimuon spectrometer is composed of several absorbers, a trigger system, a dipole and a tracking system. The muon tracking system consists of five cathode-pad chamber (CPC) stations with two detection planes each. The stations 1 and 2 are built with quadrants. The stations 3, 4 and 5 are composed of slats. The total chamber surface is about  $100\text{ m}^2$  [4].

The main responsibilities are the following : IPN Orsay is in charge of the electronics design and production for the whole tracking system. It is also responsible for the first tracking station (ST1) design and building, and for the Dimuon tracking readout software. SAHA institute (Kolkata India) is responsible for the second tracking station (ST2) design and building. IRFU-CEA Saclay, Subatech Nantes, INFN Cagliari, PNPI Gatchina laboratories jointly are responsible for the stations 3, 4 and 5 (ST345) design and building. Two ASIC were designed and produced for the experiment. The front-end readout ASIC called Multiplexed Analogue Signal (MANAS) was designed by Semiconductor Complex Limited (SCL Chandigar India) CMOS N-well  $1.2\mu\text{m}$ , while the digital front-end ASIC so called Muon Arm Readout Chip (MARC) was design by INFN Cagliari team in  $0.6\mu\text{m}$  AMS CMOS technology [5].

## II. READOUT ARCHITECTURE

### A. Specifications and environment

The main constraint is the chamber resolution which must be better than  $100\text{ }\mu\text{m}$  to achieve the required mass resolution. The amount of channels is about 1.1 million. The noise must be lower than 2 ADC channels for a 12 bits conversion. With such a requested noise level the front-end electronics must be very close to the detection pads. In a CPC, the detection pads cover all the chamber surface and the front-end electronics must be plugged directly on the chambers, in the detector acceptance. Consequently, special care was taken in the design of the front-end boards to keep their thickness as small as possible in term of radiation length. In addition, in the detector area, the magnetic field value is up to 7000 Gauss, the radiation level is of the order of 500 Rad for the total dose, and the equivalent of 27 neutrons  $/\text{cm}^2/\text{s}$  ( $E > 2\text{MeV}$ ) [6].

### B. Readout architecture

For the 5 stations, the readout principle is the same (See Figure 1). The wire chamber pad signals are processed by front-end MANAS ASIC which insure the signals amplification, their shaping with a  $1.2\mu\text{s}$  peaking time and multiplexing of the 16 channels. These circuits are embedded on MANAS Numérique (MANU) boards. These boards insure the digital conversion and the data transmission through a MARC ASIC. Sets of MANU boards are connected together on a data bus transmission line called Protocol for Alice Tracking Chamber (PATCH) Bus. Then they go through Translator boards to a digital Concentrator Read-Out Cluster Unit System (CROCUS) Crate. These CROCUS crates are directly connected to ALICE DAQ with an optical link. They receive the Trigger signals through a Trigger Crocus Interface (TCI) Crate. The system represents a large amount of various boards. There are more than 19.000 MANU boards to process about 1.1 million channels. The CROCUS read out crates (22 crates) which include FRonTal boards (120 CROCUS-FRT), ConcentRaTor boards (22 CROCUS-CRT) and 22 BACK-Panels. The trigger dispatching crates (two Trigger Crocus Interface (TCI) crates which include two types of boards: Frontal Fan-out Trigger (FFT) and Frontal Trigger Dispatching (FTD)) and the related software were designed at Orsay and were produced for the whole Dimuon spectrometer collaboration [4].

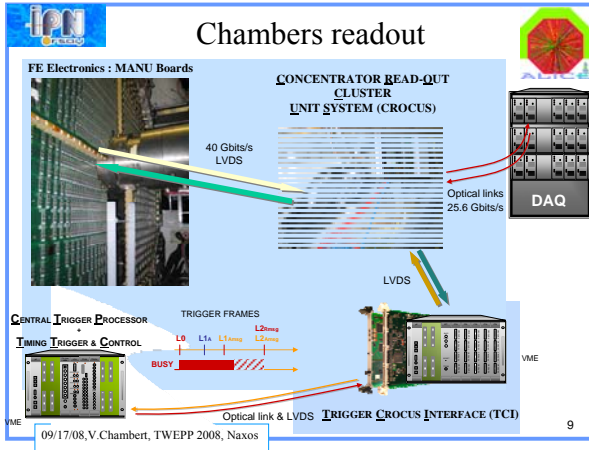


Figure 1: Readout architecture

### C. Bus lines principle

A key point on the detectors is the data transmission. It is performed thanks to lines called Bus Patch. They were designed at Orsay but each laboratory adapted the system for its station. Each MANU board is connected on the line and the impedance matching is calculated for the board located in the middle of the line. All the other boards are not impedance matched. The line impedance is settled with a resistor impedance terminal at the end of the line. This is an acute problem especially for ST1 which density is quite high as seen on horizontal lines in Figure 2 (the black rectangles are MANU boards).

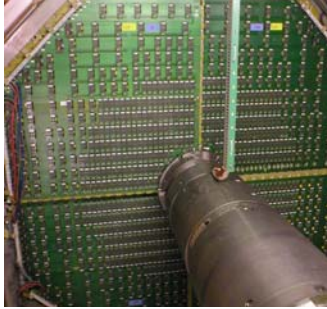


Figure 2: One chamber of the first tracking station with all its MANU boards plugged on the PATCH bus

During the detectors debugging phase, we had to tune the current in some Bus Patch to be able to read them or to increase the safety margin to read them. The data edges are detected High or Low with to corresponding thresholds on comparators. This detection is made on a terminal board called Translator board. The lines currents were increased so that these thresholds can shift up to  $\pm 30\text{mV}$  without data loss. Moreover, on very long buses, boards called Bridges are implemented to bufferize the signals. The readout of the buses is performed thanks to a token which is sent to one MANU board which keeps it while it

sends its data on the bus and then sends the token to the next MANU board.

### D. MANU boards functionalities

Each MANU board deals with 64 channels. The front-end MANAS circuit includes the data processing functions and a calibration capacitor, for online detector calibration. The main issue is the gain dispersion between the electronic channels which gives a wrong charge measurement on these channels. Without charge correction, especially gain correction, the impact point is not correctly determined leading to a bad spatial resolution. The MARC circuit drives all the detectors configurations parameters, the data transfers from detectors to DAQ, and the data transfers from DAQ to the MANU boards. The system is designed so that it can read any types of bus lines. The operator can describe the detector that he wants to read (number of buses, number of MANU boards on each bus) and the DAQ send an address to each MARC. Due to the fact that we just want to read hit pads an important function of the MARC circuit is zero suppression. For this purpose, pedestals measurements are performed and thresholds are computed and stored into MARC circuits. Online, MARC circuit is also able to switch off one MANAS of its board or to switch off the full MANU board if it is requested by the shifter.

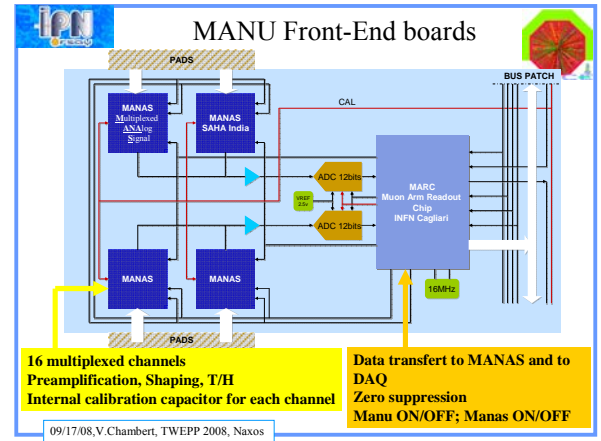


Figure 3: MANU board principle

### E. CROCUS crates

All the data readout is driven by the CROCUS crate. The CROCUS crate receives data from a maximum of 50 Patch Buses spread on 5 CROCUS\_FRT boards. 10 Patch Buses are connected to 1 CROCUS\_FRT, more precisely 5 Patch Buses are connected to 1 frontal Data Signal Processor (DSP), so there are 2 frontal DSP per CROCUS\_FRT board. The data speed transmission between the Patch Buses and the CROCUS\_FRT is 40 Gbits/s via LVDS links. Each CROCUS\_FRT\_DSP is connected with one link port to one CROCUS\_CRT concentrator DSP (Figure 4). There are 10 link ports for the 10 CROCUS\_FRT frontal DSP connected via the Back Panel to 2 CROCUS\_CRT

concentrator DSP. The data transmission speed on these link ports is 200 Mbyte/s. Then a CROCUS\_CRT Master DSP concentrates the 2 DSP data via a 320 Mbyte/s parallel bus. This Master DSP sends the data via a Xilinx FPGA to a Single Interface Unit (SIU) board (designed at CERN) which send the data via an optical link to Alice DAQ. All these transmissions are driven by some FPGA.

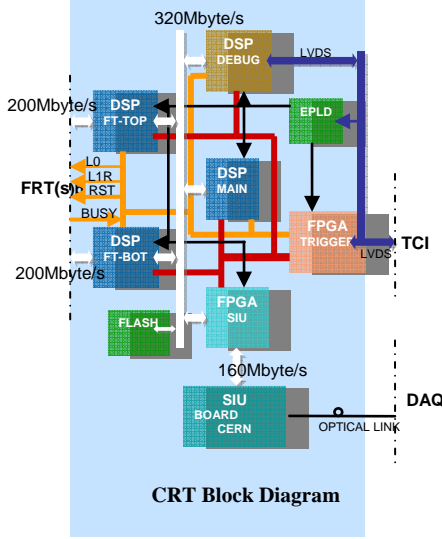


Figure 4: CROCUS CRT Diagram

All the readout sequence was tested on quadrants and slats to tune the whole timing managements. A Jtag chain is implemented on the boards so that all the CROCUS FPGA programs can be modified and reloaded from the Alice control room. Another point is the detector calibration, which is an important concern for the tracking. A dedicated piggy-back board was designed to be embedded on CROCUS-FRT boards. A signal is sent to all the MANU boards thanks to a DAC and some switches.

#### F. Trigger CROCUS Interface

This crate insures the dispatching of the trigger signals to the 20 CROCUS crates. Two different boards were designed: FFT board and FTD board. FFT board receives the trigger signal from the Central Trigger Processor and dispatches it to 5 FTD boards (one per station). The crate receives the trigger signal through a Clock distribution board called TTCrX and designed at CERN. Many tests were necessary to control the delivered trigger sequences and to deal with the data errors. The TCI crate also has a function of CROCUS crate checking.

### III. CONSTRAINTS IMPOSED BY THE ENVIRONMENT

The front-end electronics is plugged directly within the detector acceptance (MANU boards) or very close to the detectors (CROCUS crates) with consequences on the design.

To decrease the matter thickness in front of the detectors, the MANU PCB are to the upper limit of today technology

in term of thickness, they are very thin (0.5mm, 6 layers) and the component density is quite high, so the manufacturer had to face many problems in the fabrication process. In addition, the ground layers in these PCB are wire meshed. The other power supplies are carried with wires instead of layers, which is not recommended to deal with such low noise levels, but it was sufficient for us.

All the metallic structures as Crocus crate are amagnetic ones because of the high level magnetic field. The crocus crate was especially designed to be embedded close to the detectors.

Many Radiation tests were performed. The total dose should be 500 Rad for 10 LHC years. The MANAS were tested up to 13 kRad [6] with no changes in noise and gain up to 12.8 kRad. A decrease of pedestals value was observed after a 1 kRad dose. However, this does not represent a problem since, as previously mentioned, pedestals measurements are regularly foreseen to perform zero suppression. It should correct their decrease, if they decrease.

MARC circuits were tested for SEU hardness for a  $5.6 \times 10^{11} \text{ cm}^{-2}$  equivalent hadrons fluence which is expected for the Dimuon spectrometer. For the whole detector, the SEU rate will be 56 per day. With a pedestal reload every 6 hours, the error rate will be negligible compared to the total number of channels (1.1M).

FPGA and DSP also were SEU hardness tested with an equivalent rate of 27 ( $E > 2 \text{ MeV}$ ) neutrons per  $\text{cm}^{-2}/\text{s}$ . The results were 1 SEU every 5 hours for the Stations 1 and 2 and no SEU for the stations 3, 4 and 5.

The stations 1 and 2 are mounted in a confined environment. So, an air cooling system was carefully designed. During the commissioning period the measured temperature was lower than 30 °C.

### IV. ELECTRONICS PRODUCTION

We produced 19600 Manu boards, 22 CROCUS read out crates including 110 CROCUS-FRT boards, 210 calibration boards, 22 CROCUS-CRT boards and 22 back-panels. We also produced and tested about 450 Translators boards for ST1 and ST2, 150 special board for ST2 called bridges, about 675 translator boards and about 350 bridges for Stations 3, 4 and 5. Two TCI crates with 10 FTD boards and 2 FFT boards were produced.

#### A. Front-end boards production

After production, the 19600 boards were numbered and were tested in industry from 2005 to 2007. For tests purpose, a dedicated test bench was developed and transferred to industry (Figure 5).

The test bench has a go/no go function and a diagnostic option to help for the boards repairing. Each MANU board wears a barcode with its number. The test bench produces a test sequence for the power supplies short circuits, for the MARC circuit test (i.e. all the transmission protocol), for the MANAS specifications (i.e. pedestal, noise, gain, value of the internal calibration capacitor). A data file was produced and delivered to Dimuon Spectrometer





Figure 5: FE boards test bench

collaboration with the data of each Manu boards. The test bench deals with two MANU boards at the same time. It sends the calibration signals through the same calibration generator as on the CROCUS-FRT boards. The program was written in Visual C++ language.

## V. INTEGRATION AT CERN

### A. Detectors mapping

Because of the channels gain dispersion, the detector must be fully mapped. The average channel gain is about 3.3mV/fC and we sorted gains from 3.1mV/fC to 3.45mV/fC. All the other values were rejected. As said before, the Front-end boards are numbered with a bar code. All the detector locations are also numbered with a bar code. So, we have a channel/gain corresponding file for the whole detector, and corrections can be implemented to reach a resolution better than 100  $\mu$ m.

### B. EMC questions

We were extremely careful concerning the EMC questions. The boards design included power supply layers and guard rings between analogue and digital parts.

The power supplies are filtered with devoted SHAFFNER FN7562-32-M4 100 nF capacitors. They provide an attenuation of 65 dB for 100 MHz signals and 40 dB for 10 MHz signals. Three capacitors, one for each power supply, are implemented in dedicated filtering boxes (figure 6). The global electronics grounding was studied and implemented on the detectors. The data transmission cables are flat shielded cables, and all the data are driven with LVDS level differential lines. There is a large mechanical grounding for these cables both on the Crocus crates and on the detectors. Inside the Crocus crate, the EMC problems are solved with individual boards shields. Concerning this matter, Station 1 and Station 2 are in a favourable configuration: all



Figure 6: Filtering boxes

the metallic parts (filtering boxes, Crocus crates, detector supports) are screwed on the grounded Alice structure as seen on figure 6.

### C. Tests summary

Many beam tests were performed to validate the detectors and the electronics design. During these beam tests the spatial resolution was measured to 50  $\mu$ m [7]. Each board (a global amount of 21.000 boards including 19600 MANU) was individually tested and the FPGA and DSP programs were downloaded. ST1 and ST2 assembly began, and each bus line was validated with a CROCUS-FRT board readout. Concerning Station 345 all the slats were validated with a Crocus crate. For station 1 each quadrant was tested with a cosmic-ray test bench which included a full readout Crocus system and the final water cooled Wiener PS512 power supply.

#### 1) Pedestals run

The first tests were pedestals runs, without high voltage, with a 2.5 kHz random external trigger. They show quite uniform values (about 300 ADC channels) of the pedestals for all the tested channels. The corresponding noise is 1.2 ADC channel corresponding to 0.73 mV or 1300 e<sup>-</sup> for a full readout channel including the MANAS circuit, an amplifier and the ADC AD7476 (figure 7). The MANAS calibration test showed a 1.8 V linearity (2.5 V power supply). So the electronic dynamic range is about 11 bits, which is quite good.

#### 2) Cosmic run at Orsay

With a 1600 V High Voltage applied to the detector, we observed many correlated spots between the two cathode planes of each quadrant. These events are due to cosmic rays and confirmed the functionality of the zero suppression system (Figure 8).

#### 3) Installation at CERN

All the detectors were tested again after their shipping in a surface building at CERN (pedestals tests). Then, they were mounted in the cavern and electrically connected.

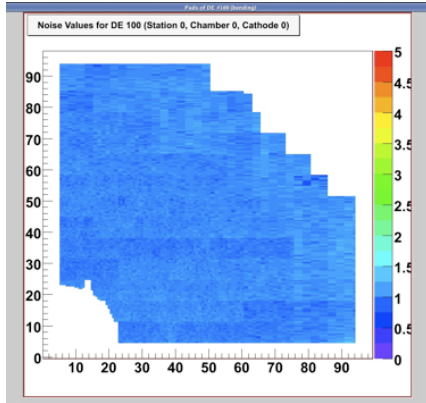


Figure 7: Display of the electronic noise in ADC channels of a full cathode plane of ST1

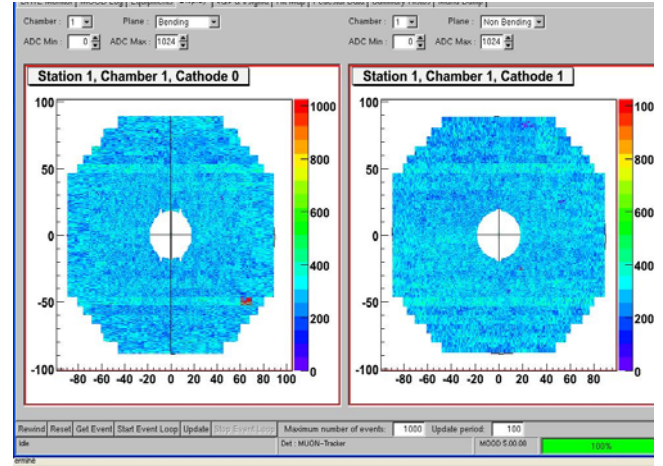


Figure 9: Pedestals for 115.200 channels

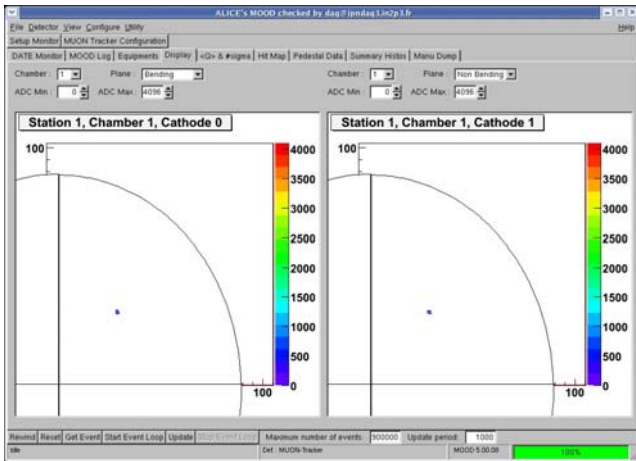


Figure 8: Cosmic signals

At the end of their integration, the CROCUS crates were connected to ALICE DAQ and the CROCUS software was integrated in the ALICE Data Acquisition system.

In September 2007, the first chambers readouts were performed. 115.200 channels were read (figure 9). The results showed the same levels of pedestals and noises as in the laboratory tests or in the surface tests. It shows that the EMC choices implemented on the detectors are correct. Then a first Cosmic test was performed in December 2007 with zero suppression. The first track crossing Station 1 and Station 2 as well as the muon trigger was observed in March 2008 (figure 10).

## VI. CONCLUSIONS

In September 2008, half of the Dimuon spectrometer was successfully commissioned. The CROCUS software is integrated in ALICE DAQ system, so the Dimuon spectrometer can participate to ALICE runs. The electronics functionalities were tested: pedestals runs, zero suppression mode data taking. The average pedestal is around 300 ADC channel, it is uniform and stable. The noise is 1.2 ADC channel, and it is stable. The conditions are good so that a less than 100  $\mu\text{m}$  chamber resolution can

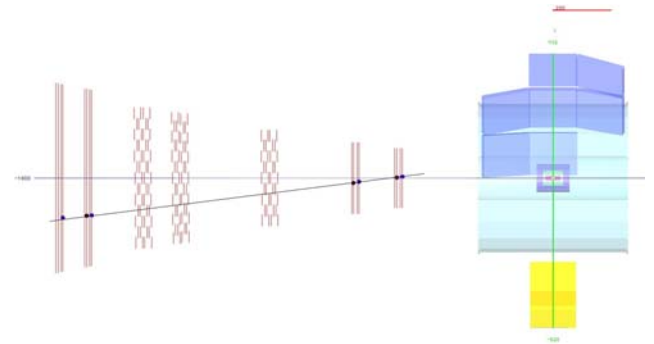


Figure 10: A reconstructed track in ST1, ST2 and Dimuon trigger planes (left)

be reached. The commissioning of Dimuon spectrometer is being completed.

## VII. REFERENCES

- [1] ALICE collaboration, ALICE Physics Performance Report Vol I, J. Phys G 30 (2004) 1517
- [2] ALICE collaboration, Technical Design Report DIMUON FORWARD SPECTROMETER, CERN/LHCC 99-22, ALICE TDR 5, 13<sup>th</sup> August 1999
- [3] ALICE collaboration, Addendum Technical Design Report DIMUON, CERN/LHCC/2000-046
- [4] ALICE collaboration, The ALICE experiment at the CERN LHC, 2008\_JINST\_3\_S08002
- [5] P. COURTAT et al., The electronics of the Alice Dimuon Tracking Chambers, ALICE-INT-2004-026
- [6] C. SUIRE et al. Radiations studies for the Readout Electronic of the Alice dimuon forward spectrometer; ALICE-INT-2005-008
- [7] A. CHARPY et al. Test of the tracking readout electronics of the dimuon forward spectrometer; INTERNAL NOTE ; ALICE-INT-2006-008

I thank all the people involved in the experiment, specially the electronics team, the detector people and the software people together with the Dimuon physicists.