

## ACORDE, a cosmic ray detector for ALICE

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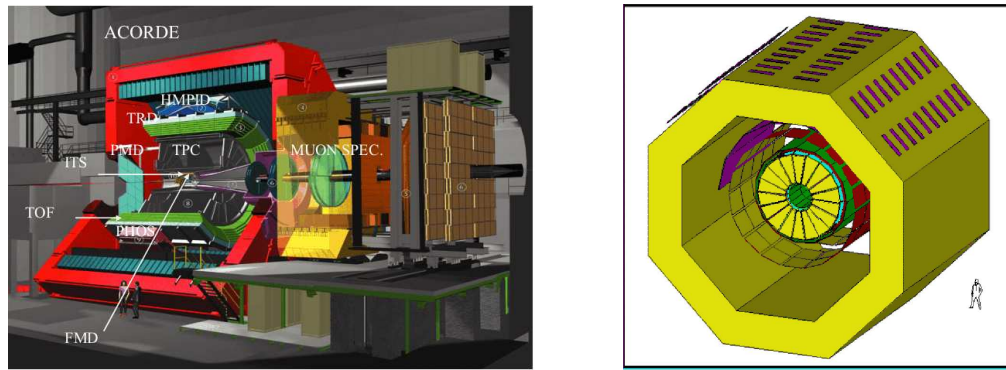
ALICE is an experiment devoted to heavy ion physics at LHC. The underground location of the apparatus with 30 m of overburden can be exploited for studying cosmic rays through the muons reaching the experiment. The ALICE setup includes a cosmic ray trigger system (ACORDE), a big TPC designed to track large densities of charged particles, a TRD and a TOF all of which can be used for the detection of atmospheric muons. These instruments open new possibilities on the study of cosmic ray physics, mainly in the range of primary energies around  $10^{15-17}$  eV. Here we discuss the design of ACORDE, including the performance of the plastic scintillator material available to build the ACORDE counter array, the simulated response of this array to atmospheric muons arriving at the ALICE hall, as well as the proposed electronics design for this cosmic ray trigger. We also discuss the integration of the ACORDE scintillator array into the ALICE detector.

### 1. Introduction

ALICE is an experiment designed to detect the products of heavy nuclei collisions at the LHC at CERN in order to study the physics of strongly interacting matter and the possible formation of quark-gluon plasma [1]. It will be located in the same place in which the L3 experiment was installed. The underground site of the ALICE apparatus with 30 m of overburden composed of subalpine molasse is ideal for muon based experiments.

The ALICE cosmic ray trigger, shown in Figure 1, is based on the ACORDE sub-detector, an array of 60 plastic scintillator modules placed on the top sides of the central magnet. The central part of the ALICE apparatus consists of an Inner Tracking System (ITS), unuseful for our purposes due to its small size, a large volume Time Projection Chamber (TPC), a high granularity Transition Radiation Detector (TRD) and a Time Of Flight (TOF) detector with a high resolution array (Particle Identification Detector). Additional detectors do not cover the whole azimuth angle. The ACORDE array and the TPC are the main detectors for atmospheric muons, while the TRD and TOF can improve the tracking performance. The molasse above imposes an average energy threshold for atmospheric muons reaching the experiment of  $E_{\mu_{th}} \simeq 15$  GeV cutting all the hadronic and electromagnetic components, while the upper energy limit for reconstructed muons will be less than 2 TeV, depending of the magnetic field intensity (up to 0.5 T).

ACORDE will provide a fast L0 trigger signal, to the central trigger processor, when atmospheric muons impinge upon the ALICE detector. The signal will be useful for calibration, alignment and performance of several ALICE tracking detectors, mainly the TPC and the ITS. The cosmic ray trigger will be capable to deliver signals before and during the operation of the LHC beam. The typical rate for single atmospheric muons crossing the ALICE cavern will be less than 3-4 Hz/m<sup>2</sup> [2]. The rate for multi-muon events will be lower (less than 0.04 Hz/m<sup>2</sup> [3]) but sufficient for the study of these events provided that one can trigger and store tracking information from cosmic muons in parallel to ALICE normal collider data taking.



**Figure 1.** Left: General view of the ALICE setup. Right: ACORDE array, TPC, TOF and TRD detectors, used to detect atmospheric muons.

## 2. Performance of the ACORDE scintillator counters

An ACORDE module consists of two plastic scintillator paddles with  $188 \times 20 \text{ cm}^2$  effective area, arranged in a doublet configuration. Each doublet consists of two superimposed scintillator counters with their corresponding photomultipliers active faces looking back to back, see Figure 2. A coincidence signal (in a time window of 40 ns) from this two scintillator paddles will be the useful information from each module. We developed a PCI BUS electronics card to measure the plateau and efficiency of the ACORDE counters. The PMT signals were discriminated with a threshold of 15 mV. In average, a plateau voltage is reached at 1450-1550 V with a measured rate of 73.4 Hz (at 2,200 m above the sea level). In order to measure the efficiency of the modules we took data at three positions along the doublet. We triggered on vertical muons by using a scintillation hodoscope consisting of two plastic scintillation paddles with an active area of  $20 \times 20 \text{ cm}^2$ , one placed above the module and the other below it; the vertical separation between these paddles was 30 cm. In order to harden the muon spectrum and to get rid of low energy muons, we used a 1" steel slab just above the lower paddle. The trigger was given by the coincidence between the PMT signals from the two scintillation paddles within a time window of 100 ns. The trigger signal was obtained at a rate of around 0.17 Hz using the same NIM electronics described above for the plateau measurement. As mentioned above, the longitudinal overlap between the two plastics, named A and B respectively, is 188 cm. The first position where we positioned our scintillation hodoscope was 15 cm away from the start of the overlap, at the end closest to PMT A, the second position was at the center of the overlap (i.e. 79 cm away from the first position) and the third at 15 cm away from the start of the overlap at the end closest to PMT B (i.e. 158 cm away from the first position). From now on we call these positions 15 cm from A, central and 15 cm from B, respectively. These data were saved in a PC and analyzed off-line. We measured the distributions for the voltage amplitude, integrated charge, rise times from 10% to 50% and from 10% to 90%, as well as the arrival time of the pulses from PMT A and PMT B at a threshold of 10% of their amplitudes for a number of modules chosen arbitrarily. In order to get the efficiencies we divided the number of events with amplitudes  $V_A$  and  $V_B$  above 15 mV and  $V_A$  and  $V_B$  below 350 mV by the number of events with amplitudes  $V_A$  and  $V_B$  below 350 mV, for each of the three positions of each module tested. The efficiencies calculated this way for a typical module were 93.1%, 97.7% and 92.6% for each of the three positions, respectively.



**Figure 2.** ACORDE module. This scintillator counter module consists of two superimposed scintillator counters with their corresponding photomultipliers active faces looking back to back. The active area is  $188 \times 20 \text{ cm}^2$ .

In order to gain further understanding of the operational state of the scintillation plastics we are using, we made a rough estimate of the attenuation length of light along the analyzed plastics. Given that we measured the amplitude and charge distribution of PMT A and B for three test positions, we obtained the ratio of the charge collected by PMT A in the position 15 cm from A to the charge collected in the central position. The most probable value (MPV) of the charge distribution, for PMT A at first position is 33 pC and the MPV for the same PMT A at the central position is 13 pC. This gives a charge ratio of 2.54 for plastic A. Likewise, the MPV for PMT B at last position is 41 pC, whereas the MPV for PMT B at the central position is 17 pC. This gives a charge ratio of 2.41 pC for plastic B. Given that the distance between the extreme positions and the central one is 79 cm, and assuming an exponential attenuation of light along the plastics, we get attenuation lengths of 84.7 cm and 89.8 cm for plastic scintillator A and B of module 1, respectively. We repeated these measurements for a number of modules obtaining similar values for the efficiencies and the attenuation lengths.

### 3. Electronics and Detector Control System

The signal of each ACORDE scintillator channel will be applied to a leading edge discriminator. The discriminators should convert the negative low signal coming from each PMT to a digital signal. These signals will be analyzed to generate the single muon and the multi-coincidence trigger signals. In both cases we will use a tracking system to identify which ACORDE modules were hit. This information will be stored in a FIFO memory before being sent to the DAQ system through the Detectors Data Link (DDL). The proposed system will contain a TTCrx chip in order to receive and decode the LHC clock signal and the trigger messages coming from the ALICE trigger system through the TTC partition. This TTCrx chip will be connected to a Data header generator. This generator will produce the data header using the trigger messages. This will supply the data header and the hit information to the DAQ system. This interface will be used to receive and supply the data to the Source Interface Unit (SIU). The SIU is part of the DAQ system and has two optical links, one can be used to send data from the DAQ to ACORDE and the other can be used to send data from ACORDE to the DAQ system. One requirement is to set the multi-coincidence number remotely. The ACORDE electronics can receive data from the DAQ system through one of the optical links of the DDL. We can use this optical link to transmit the calibration signal and the multi-coincidence data from the DAQ system to the ACORDE electronics. See Figure 3.

We have developed a Detector control System (DCS) for ACORDE. The main tasks of this system are the monitoring and control of the necessary electrical and physical parameters to operate our detector. These include the high voltage (HV) and low voltage (LV) power supplies, the front-end electronics (FEE) configuration parameters, alarm handling, and parameter archiving. A general view of our DCS is shown in Figure 3. We plan to use the SY1527 and the EASY [4] (*Embedded Assembly SYstem*) power supply systems from CAEN as the HV and LV supplies respectively. The latter is a radiation- and high-magnetic-field tolerant power supply

system to be installed in the cavern racks to supply the LV for ACORDE. The SY1527 crate can hold up to 16 boards. Ten of its slots will be filled with 12-channel HV boards (A1733N) to feed the 120 PMTs. We will also install the EASY Branch Controller (A1676A) board that can control up to 6 EASY crates. We will need two full EASY 3000 crates each with five 12-channel 2–8 V boards (A3009) for the discriminators. The remaining four channels for the ACORDE Electronics Card and the shoebox producing the TRD wake up signal will be hosted by a third EASY 3000 crate with an additional A3009 board. The intrinsic grouping of the scintillators into modules (each with a couple of scintillators and PMTs) and the fact that the FEE cards will be mounted on the modules make it natural to select a detector-oriented hierarchy for our DCS. This hierarchy will allow us to independently control a single module in a simple way which can be useful for purposes of isolating, testing or calibrating it. There will be a total of 183 Control Units (CU) in the DCS; the parent ACORDE DCS with 61 module CUs (M0 through M60). M1 to M60 will control each one of the modules respectively, including its associated FEE card. Module 0 will take care of the LV supply to the electronics and TRD shoebox cards.

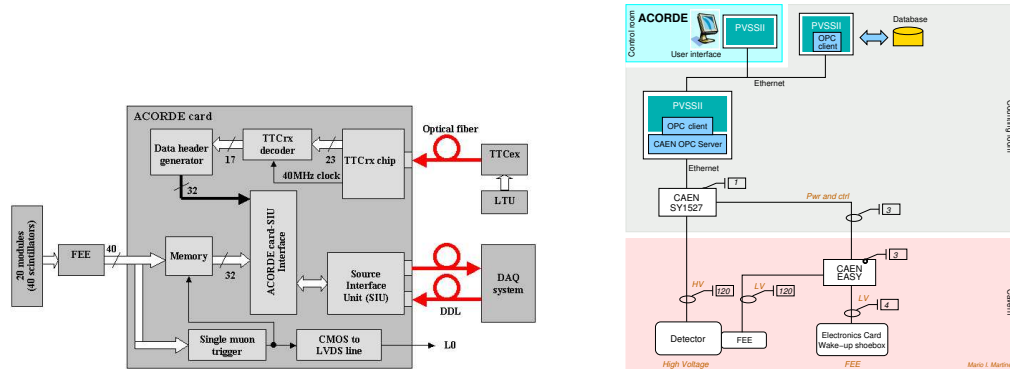


Figure 3. Left: Scheme of the ACORDE electronics. Right: General view of the ACORDE-DCS.

#### 4. Physics topics of interest

An accurate measurement of the energy spectrum and charge ratio of atmospheric muons in the energy range 20–2000 GeV can be performed in one year of data taking by ALICE, provided that a dedicated scintillator trigger system (ACORDE) is added to the apparatus. ALICE will be also able to measure the atmospheric muon flux and charge ratio at different zenith angles, giving information on hadrons created in the air shower and constraining the hadronic interaction models. Given the high spatial resolution of the ALICE TPC, we will be able to resolve muon bundles with densities higher than 20 muons/m<sup>2</sup>, and analyze the momentum and the charge of each muon of the bundle. This will bring the opportunity to study cosmic ray composition in the range of primary energies around the knee of the spectrum.

#### References

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