# ALICE TPC control and read-out system

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*Abstract*

ALICE is a dedicated heavy-ion experiment at CERN LHC aiming to study the properties of the quark–gluon plasma. A lead–lead collision might produce several ten thousand new particles. Detailed study of the event requires precise measurements of the particle tracks. A 90 m$^3$ Time Projection Chamber (TPC) with more than 500 000 read-out pads was built as the main central barrel tracker. Collisions can be recorded at a rate of up to about 1 kHz. The front-end electronics, designed from FPGAs and custom ASICs, performs shaping, amplification, digitisation and digital filtering of the signals. The data is forwarded to DAQ via 216 1.25 Gb/s fibre-optical links. Configuration, control and monitoring is done by an embedded Linux system on the front-end electronics.

First results on the performance of the front-end electronics and the distributed detector control system are presented.

## I. Time Projection Chamber (TPC)

The A Large Ion Collider Experiment (ALICE) [1] is using a TPC [2] as the main track-finding detector. A TPC is a gaseous detector. It is shaped like an horizontal barrel and positioned in the same direction as the beam pipe, which is passing through the centre of the barrel. The overall length is 500 cm, divided by a 100 kV Central Electrode (CE) into two identical drift volume. The diameter is 494 cm, though the innermost 170 cm is not part of the TPC to make room for the beam pipe and inner tracking detectors. A schematic view of the TPC can be seen in Figure 1.

Collisions will take place in the beam pipe in the centre of the TPC, allowing the particles produced to traverse the TPC and leave tracks of ionised gas along their paths. A strong electric field of from the CE will make the electrons drift towards the end planes, where data read-out is performed.

Each end plane is divided into 18 azimuthal sectors, which again are divided into two Multi-Wire Proportional Chambers (MWPC), the Outer and Inner Read-Out Chamber (OROC/IROC). The OROC has four Read-out Partitions (RPs); the IROC two. A RP is an electronic entity for reading out data from read-out pads. The ionistic signal will be amplified by the space charge around the wires of the MWPC. The induced charge on the read-out pads is forwarded to the read-out electronics. In total for both sides there are 557568 pads.

The drift volume is filled with counting gas composed of 85.7 % Ne, 9.5 % $CO_2$ and 4.8 % $N_2$. A cold, light gas is used to assure low diffusion and low multiple scattering. Field distortions are minimised because of the high ion mobility and few ionisation electrons per unit length. The electronics design noise figure is 1000 RMS e$^-$ (700 actually achieved); not limiting the position resolution will require a signal/noise ratio of at least 20.

Apart from tracking—measuring the charged particle momentum and having a good two-track separation—it also provides Particle IDentification (PID). The TPC is expected to perform well at multiplicities as high as $dN_{ch}/d\eta$=8000 in the particle momentum range [0.1, 100] GeV/c and within $|\eta|$ <0.9. Tracking efficiency is required to be >90 %, and the dE/dx resolution better than 10 %. Further, the TPC alone will have a momentum resolution of about 1 % at 2 GeV/c and 10 % at 50 GeV/c. For p–p collisions a read-out rate of ≈1 kHz is expected, while for central Pb–Pb collisions ≈0.2 kHz.

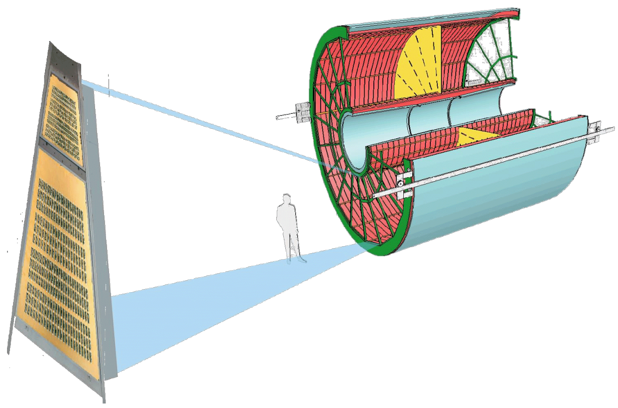

Figure 1: Schematic view of the TPC. To the left a singe Read-out Partition (RP) is enlarged for visibility. The support for the sectors is shown on the two end planes. Between them is the Central Electrode (CE). The TPC allows space around the centre of the length axis for beam pipe and inner silicon detectors.

## II. Data read-out design

As already mentioned, each sector has six RPs. A RP consists of a Read-out Control Unit (RCU) with up to 25 Front-End Cards (FEC), depending on the radial location. The innermost RPs have the highest number of FECs, as a smaller size for the readout-pads is used to increase the resolution to take into account the higher track density close to the collisions. The electronics for one RP, as well as its connection to the central systems is shown as a block diagram in Figure 2.

Eight ALICE TPC Read-Out (ALTRO) [3] chips are mounted on a FEC, each capable of reading out 16 read-out pads. The FECs are attached to the RCU via buses; one for data transfer and one for control/monitoring. Once on the RCU, the data is forwarded to Data Acquisition system (DAQ) and the High Level Trigger (HLT) via a 1.25 Gb/s optical fibre. A Detector Control System (DCS) board equipped with an embedded

ARM processor running Linux is attached to the RCU for control and monitoring. The board is equipped with a standard Ethernet network interface. Radiation tolerant electronics is needed to sustain the radiation from the collisions.

On the FECs, the pad signal passes through a shaping amplifier before it is forwarded to the ALTRO, which will digitise and digitally filter it. The ALTRO is using a 10-bit Analogue-Digital-Converter (ADC) capable of 10 million samples per second. The digital filtering is performed in four stages. First, systematic effects and low frequency perturbations are removed as part of a base-line correction. Tail cancellation removes the tail of the pulses within 1 $\mu$s of the peak. Fully programmable filter coefficients allow for removal of a wide range of tail shapes. Next, non-systematic perturbations of the base-line superimposed on the signal is removed by applying a base-line correction moving average filter.

The RPs will read out data from a collision when they receive an external trigger. Before a new trigger is issued, it must be ascertained that all RPs have finished reading out data associated with the previous trigger. This is handled by a BUSY system. The Busy Box has a direct link to each of the DAQ computer nodes receiving data from a RP. Once the node has received all data from a certain RP, it will flag this to the Busy Box. When the Busy Box detects that the read-out is done, it will inform the central trigger system, which can now issue a new trigger to the RPs.

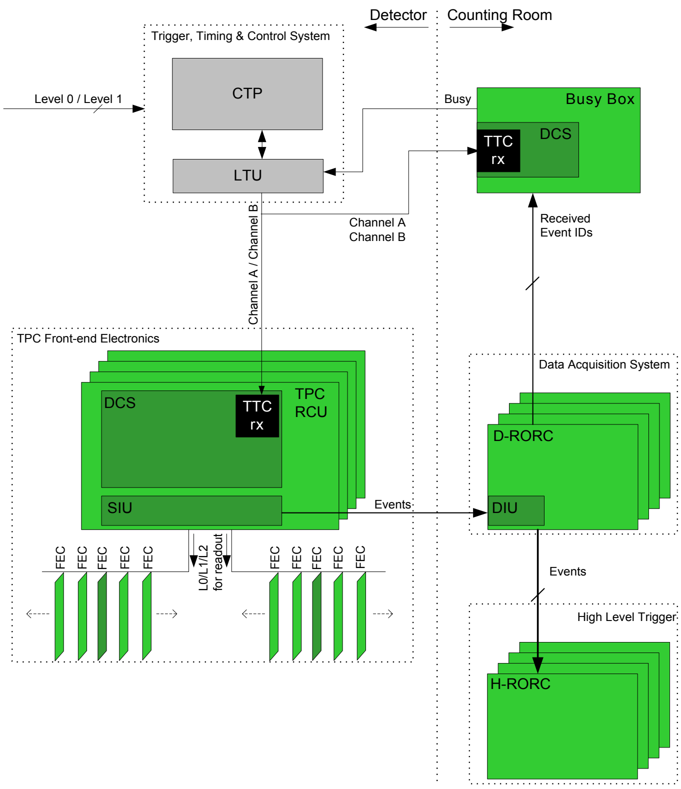


Figure 2: Block diagram of TPC read-out and control electronics. Left side is embedded on the detector, right external system in the counting room. Data is collected from FECs, forward to DAQ/HLT via the RCU. Control is achieved via the associated DCS board. The Busy Box indicates when read-out is finished, and a new trigger may be fired.

## III. Detector Control System (DCS)

Control and monitoring of the RPs is mainly done via a special software, the FeeServer (FS), running on the embedded Linux system on the DCS board. Communication is via standard IP/TCP network. Functionally, the FeeServer has two main functionalities: monitoring and command handling. Monitoring will publish the values of important hardware registers to external clients. Command handling allows an instruction set to be built for configuring the Front-End Electronics (FEE). The handling of the fundamental network interface and infrastructure for monitoring and command handling is implemented in FeeServer Core, whereas the specific implementation for of hardware access for monitoring and command handling is done in a module called Control Engine (CE).

The InterComLayer (ICL) acts as a hub in the system. It maintains contact with the FS' of all 216 RP, as well as the PVSS-based GUI for the operator and a configuration database containing pre-defined configurations for the FEE.

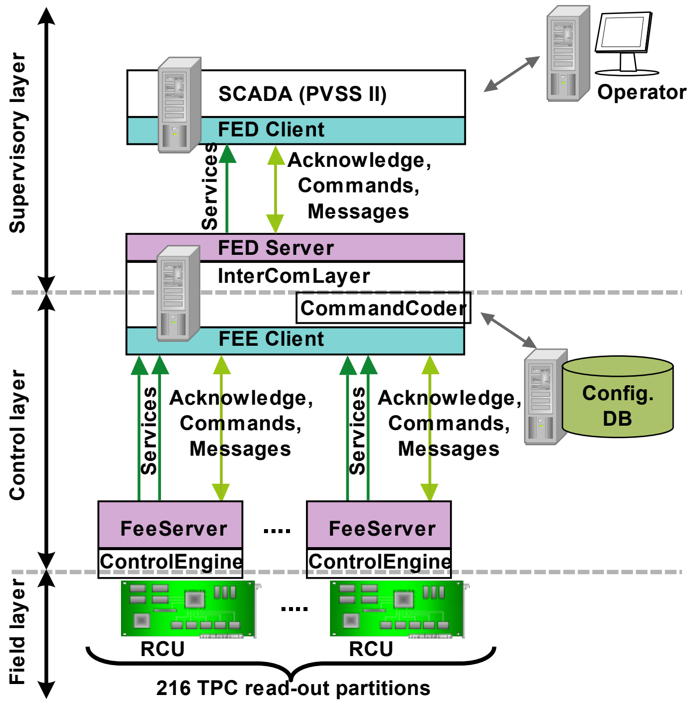


Figure 3: Structure of the control hierarchy for the Detector Control System (DCS). From bottom: "field layer" (FEE); "control layer" (FS and lower part of ICL); "supervisory layer" (upper part of PVSS and GUI).

A three-layer hierarchy is defined for the DCS: "field layer" is the FEE itself; "control layer" is the FS on each RP, as well as the lower part of the InterComLayer (ICL); "supervisory layer" is the upper part of the ICL and the GUI the shifter is operating. This structure is shown in Figure 3.

Configuration of the FEE is accomplished by sending binary configuration data blocks to the FS. Values of registers of special importance, such as FEC temperatures, voltages and currents, as well as states of the state machine, are being published. Upon receiving a high-level configuration command from the GUI, ICL assembles configuration blocks for the FS by retrieving configuration parameters from the DB. ICL also collects data points published by FS, and forward them to the GUI. There is a full integration with the Experiment Control System (ECS), enabling operation of the TPC by the ALICE shifter.

## IV. Noise level

The background noise level is obtained regularly from pedestal runs. Figure 4 shows the distribution for pairs of ROCs for one of the end planes. The IROC constitutes one pair, while the four chambers of the OROC is divided into two pairs. In Figure 5 the same data is plotted on the corresponding read-out pad.

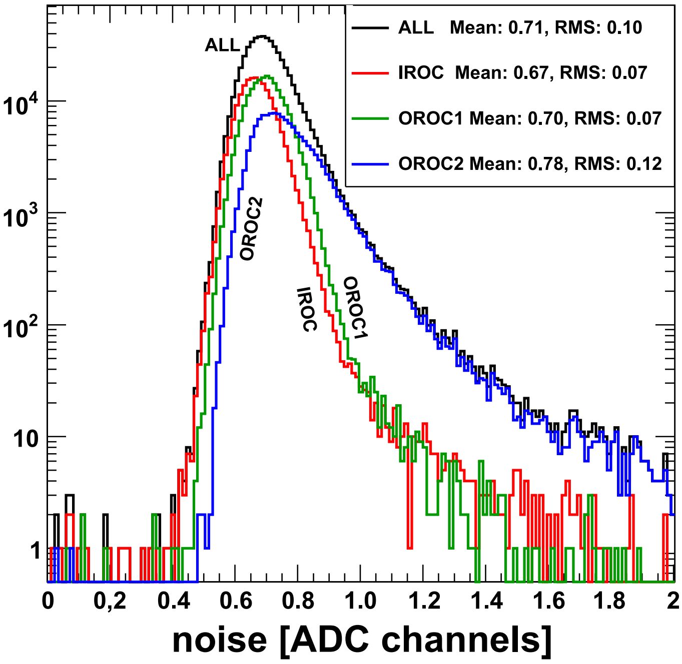


Figure 4: Noise distribution from pairs of ROCs: IROC and two OROC. The peak is around 0.7 ADC counts.

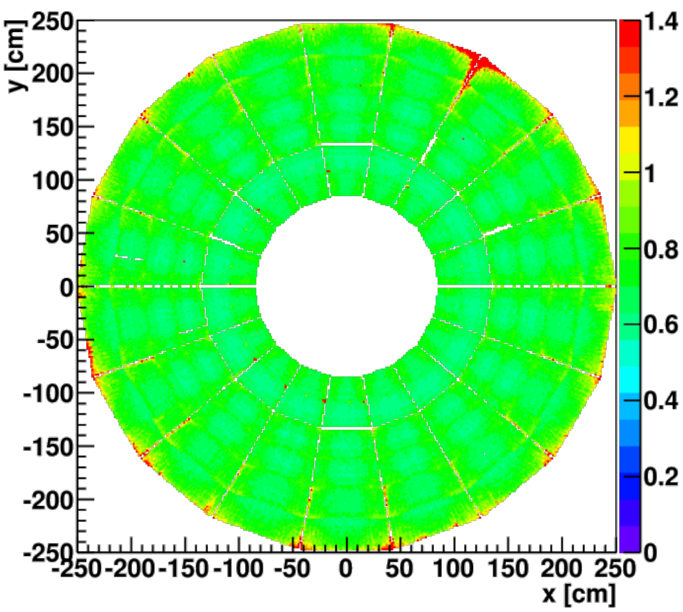


Figure 5: Typical noise level (in ADC counts) for the TPC from a recent pedestal run. As in previous figure, the noise level is around 0.7 ADC.

The noise figure is required to be less than 1000 $e^-$ RMS of base-line, corresponding to 1 ADC count. The noise levels from the pedestal runs, showing that the noise figure is ≈0.7 ADC count (700 $e^-$), well within the requirement. This is close to the natural limit, and do not change much with time. Also, it allows for zero-suppressed empty events less than 70 kB (noise); without zero-suppression 10 000 times larger.

## V. Data read-out performance

RPs have a varying number of FECs depending on radial position in the sector, from 25 (innermost) to 18 (outermost). Reserving the same amount of bandwidth for each FEC regardless of radial location implies only RPs with 25 FECs can utilise the full bandwidth of the optical fibre, hence effective read-out rate per 6-RP sector is limited to 770 MB/s. Benchmark tests (Figure 6) show that this is indeed achievable for high-occupancy events where zero-suppression has been applied. Considering the case of low-occupancy events, read-out is possible at an event rate of 595 Hz (0 % occupancy) using full readout. The electronics also supports sparse read-out, in which case empty channels are entirely stripped, including headers. Applying this technique, the read-out rate increases to 1386 Hz. The respective data rates are 70 MB/s and 927 kB/s.

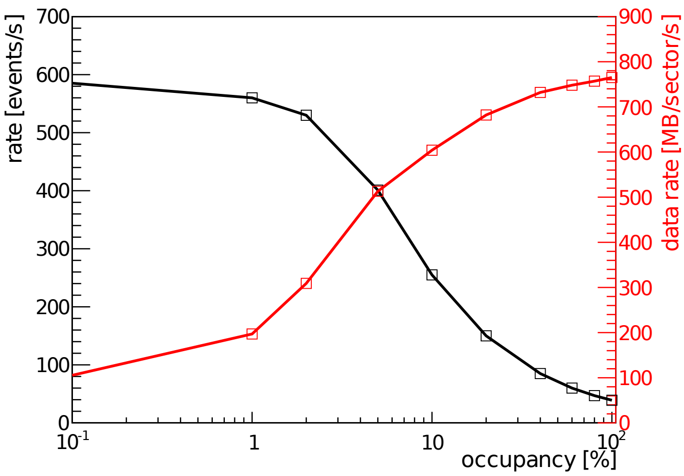


Figure 6: Event rate (black, left scale) and data rate (red, right scale) as function of occupancy, for full read-out. At 100 % occupancy the theoretical maximal data rate of 770 MB/s is reached. At 0 % occupancy the data rate is 595 Hz, however applying sparse read-out increases this to 1386 Hz (not shown, as it only significantly departs at low occupancy).

## References


[1] The ALICE Collaboration, K. Aamodt et al., "The ALICE Experiment at the CERN LHC", JINST 3 (2008) S08002.

[2] The ALICE Collaboration, "ALICE TPC Technical Design Report", CERN/LHCC 2000-001, ALICE TDR 7, 7 January 2000.

[3] L. Musa et al., "The ALTRO chip: a 16-channel A/D converter and digital processor for gas detectors", IEEE Trans. Nucl. Sci., November 2003.