The status of the ALICE TRD project

The ALICE TRD collaboration*

During the year 2008 the Transition Radiation Detector project of the ALICE experiment at LHC has accomplished important milestones and has progressed towards readiness for data taking. We will review the status of the project and the various ongoing activities.

The chamber production was completed in 2008, so that now all 540 individual readout chambers (ROC) of TRD are ready. The chambers are equipped with front-end electronics (manufactured in industry based on our own design and tested in Heidelberg) and the readout functionality tested in Frankfurt and at GSI (on a newly setup test stand). The chambers are then shipped to Münster, where they are assembled in supermodules (each containing 30 chambers). Extensive measurements with cosmic-rays are undertaken at this stage. As the individual readout chambers are no longer accessible once the super-module is assembled, rigorous testing is necessary at this stage. For this purpose, all necessary infrastructure for the operation of super-modules has to be available in Münster and as similar as possible to the conditions found in the final installation in the ALICE pit. This includes low- and high-voltage power supplies, gas and cooling as well as computers for slow control and data aquisition. In addition, a trigger system for cosmic rays has been developed to acquire data for a first calibration pass.

The assembly of a supermodule starts with the assembly of the supermodule hull including distribution of low voltage and cooling water. Afterwards, the readout chambers are installed layer by layer. Each layer undergoes tests of electronics, gas tightness, high-voltage distribution and cooling. The integration of a supermodule is concluded by several days of cosmics data taking to produce a calibration data set.

The tightness of the gas volume is tested by flushing the ROCs of one layer with a mixture of argon and carbon dioxide while the pressure is regulated by a fan. The oxygen content at the outlet of the layer is a measure for the leaks in the layer. Separate tests at over- and underpressure of 1 mbar allow for the distinction of diffusive and high resistity viscous leaks. The average leak conductance per chamber is less than 1 Nl/bar·h[1], consistent with single ROC tests performed at GSI and well below the limit of 3 Nl/bar·h set by the cost of xenon.

A large acceptance trigger for cosmic rays is used to acquire data for supermodule testing and calibration. The trigger consists of two arrays of scintillators above (40 scintillators, 220×173 cm) and below (50 scintillators, 550×66 cm) the supermodule. The setup is shown in Fig. 1. While the lower layer covers the full length, the upper layer limits the acceptance to about one third of a supermodule and has to be moved along it. The scintillator signals are discriminated and the logical OR of the upper and lower layers are generated. A coincidence of signals from the upper and lower layers triggers the readout of the super-module. Depending on the positioning of the upper layer, between 60 and 90 events are triggered per second.

Figure 1: Cosmic ray setup in Münster .

To overcome the limited acceptance of the upper layer, the trigger logic was modified to take advantage of the trigger capabilities of the TRD: the logical OR from the scintillators in the lower layer is provided as a pretrigger to start the read-out, store the raw data in the event buffer and calculate the tracklets for the Global Trigger Unit (GTU). The GTU generates a L1 trigger if it finds tracklets in four layers of one stack, otherwise the event is rejected. In this configuration, eleven hundred pretriggers per second yield three hundred events recorded on disk. Apart from reducing the time to collect calibration data, this setup also provides a more realistic test for the front-end-electronics.

The reconstructed point resolution in pad direction has been determined by applying a straight line fit to the clus-

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[1] 1 Nl/bar·h corresponds to a leakage of 1 ml of gas under normal conditions per hour at a differential pressure of 1 mbar

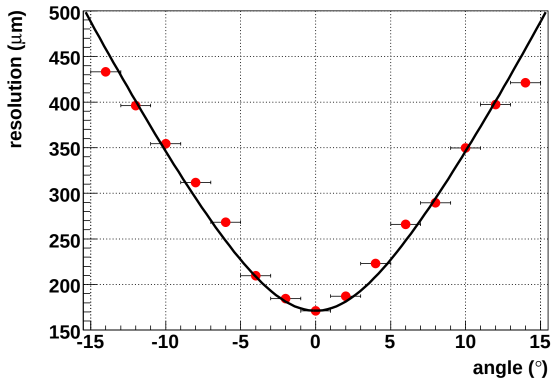

Figure 2: Residuals of cluster with respect to a straight line fit within one chamber.

ters in one chamber, constituting the so-called tracklet. For tracks perpendicular to the pad plane, the residuals of the clusters with respect to the tracklet determine the detector resolution. Inclination of the tracks leads to a contribution of the resolution in drift direction according to $\sigma = \sqrt{\sigma_{pad}^2 + \sigma_{drift}^2 \tan^2 \alpha}$ and widens these residuals. The residuals are shown in figure 2 and indicate a resolution in pad direction of 170 μm.

The residuals with respect to tracks crossing several ROCs, which are shown with the red data points in Fig. 3, are wider than in the case of a tracklet within one chamber mainly because the ROCs are not perfectly aligned. When the chamber misalignment is accounted for, employing the ALICE Alignment Framework, the resolution becomes comparable with that obtained with respect to tracklets (green points in Fig. 3). Fig. 4 shows the alignment values, which are typically below 1 mm.

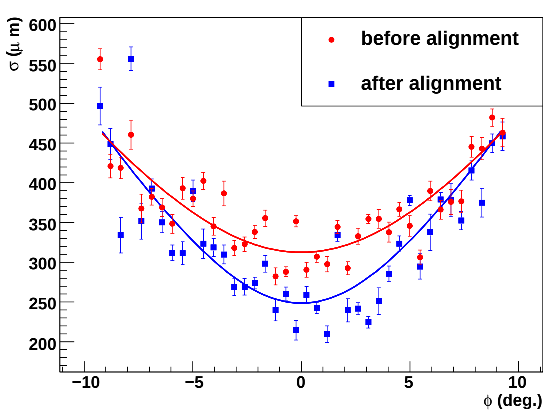

Figure 3: Residuals of clusters with respect to a track before (red) and after (green) alignment.

After delivery to CERN, each supermodule undergoes functionality and gas tightness tests on the surface, before being inserted in the ALICE setup. The delicate procedure of insertion lasts about one day and is followed by several

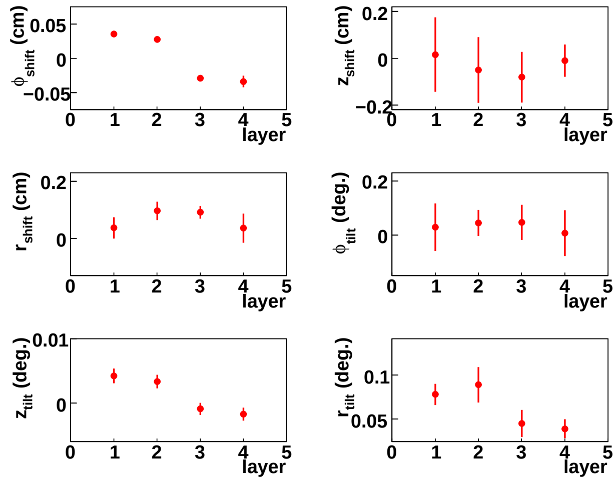

Figure 4: Alignment parameters of the inner four chambers in stack 2 of super-module III.

days of connecting all the cables. Four supermodules were present in the ALICE setup in 2008 with the full data read-out chain and participated in the cosmic-ray data taking. A display of a cosmic-ray event is shown in Fig. 5. During the cosmic-ray data taking, the TRD was operated with an Ar-CO_2 [82-18] gas mixture to replace the more expensive nominal (Xe-based) mixture.

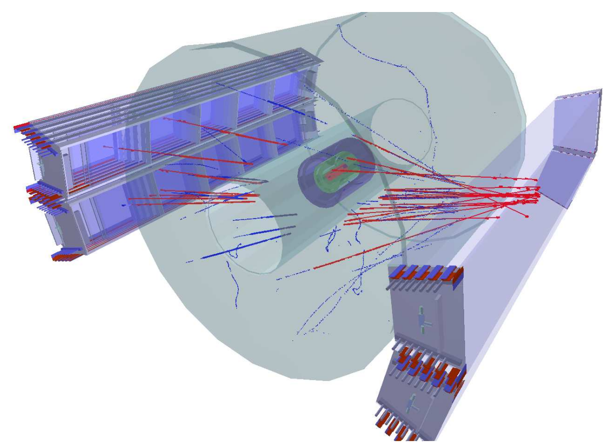

Figure 5: A cosmic-ray event display with the TPC and the 4 supermodules of the TRD.

During data taking, the Transition Radiation Detector requires a trigger signal within 500 ns after the interaction. This is 1 μs before the first trigger decision by the ALICE experiment is made. The design of the TRD pretrigger, using 88 analogue inputs from the V0 and T0 detector and interfacing an additional 576 digital input from TOF via an external unit, has been developed and is now installed in the L3-magnet of the ALICE experiment. All input information from the fast V0 and T0 detectors is processed by 27 FPGAs, which are mounted at a distance of 1.5 m to

4.5 m around the interaction point. The pretrigger system was successfully commissioned during several data taking periods with ALICE using cosmic events and a first circulating proton beam at LHC injection energy in September 2008. Trigger signals have been provided to the Central Trigger Processor of ALICE. The system is highly flexible to account for different physics conditions in $p+p$ and Pb + Pb collisions. A sophisticated client-server software which implements a finite state machine and provides a graphical interface for user friendly operation is under development.

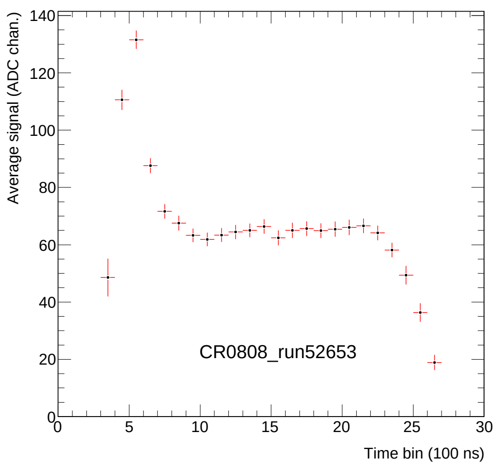

Figure 6: Average signal as a function of time.

The completion of the pretrigger system, realized in summer 2008, allowed for a readout of the complete detector signal and enabled for the first time the track reconstruction in real operation. The signal as a function of time averaged over all detectors is shown in Fig. 6. During the cosmic-ray data taking in ALICE in the fall of 2008 a total of about 50k tracks were recorded in the TRD. This was made possible due to the successful operation of the TRD Level 1 trigger, allowing a fast and efficient track decision at the GTU level.

The tracking and PID algorithms of the TRD rely on the knowledge of several calibration constants depending on temperature and pressure, the gas composition and the chamber geometry. These are the drift velocity of the electrons, the time-offset of the signal, the gas gain and the width of the Pad Response Function. They will be calibrated using the raw signal of the detector or the signal from reconstructed tracks in $p+p$ and Pb+Pb collisions. During the data taking, a first calibration is performed on the online systems, the Data Acquisition (DAQ) and High Level Trigger (HLT). The software was tested on DAQ with so-called "black events" and with cosmic-ray events taken in the ALICE setup. With the assumption that the cosmic rays are uniformly distributed over the detector, a gas gain variation of about 16 % was found over the chambers. Fig. 7 shows the gain factors as function of the detector number for the four supermodules operated in ALICE in 2008.

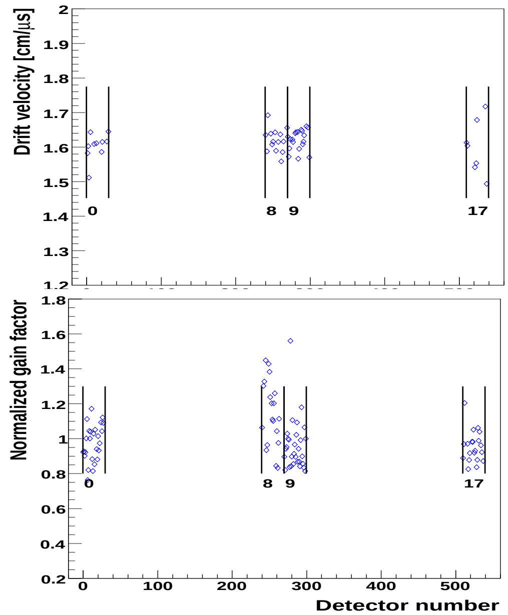

Figure 7: Drift velocity and normalized gain factor as a function the detector number.

The drift velocity and time offset are determined with the average signal as function of time shown in Fig. 6. The results obtained online were consistent with those obtained offline after the tracking in a second pass calibration. The extracted drift velocity values had a variation of 3.3% over the chambers.

Figure 8: Screenshot of the DCS system for TRD. This example shows the status of the front-end electronics of all 30 chambers within one TRD supermodule.

The running of a complex system as the TRD is facilitated by an efficient and user-friendly detector control system (DCS) which ensures safe and stable operation and monitoring of the detector. It is built on a SCADA system, allowing modelling, supervising and operating the detector via finite state machines, which also provide easy scalability. It models and realizes the complex TRD FEE communication architecture in the supervisory control layer. The TRD DCS is realized as a large distributed system scattered over ten computers. It integrates about a quarter million embedded processors mounted on the detector chambers that implement complex on-detector controls with massive use of ethernet for both interprocess communication and device control. The DCS monitors about three thousand parameters read out by the FEE. The TRD low- and high-voltage systems implement all together more than twelve hundred channels that are controlled and monitored independently. All parameters relevant to off-line analysis are archived by means of dedicated mechanisms implemented in the TRD DCS. The data read from the detector is archived on an ORACLE datbase cluster. A special emphasis has been put on making the TRD DCS graphical user interfaces intuitive and user-friendly for non-expert operation. An example is shown in Fig. 8. The TRD DCS has been commissioned during runs within the ALICE experiment in the cosmic-ray data taking in 2008.

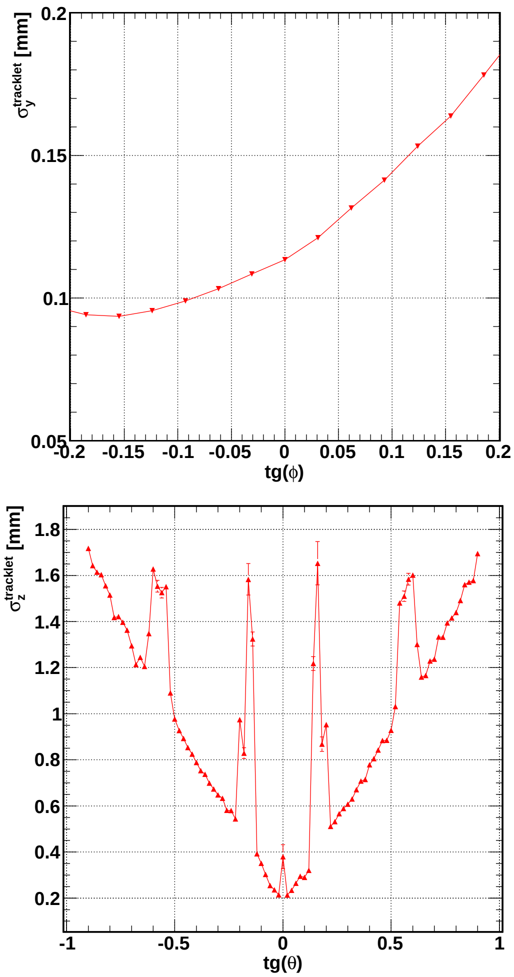

Figure 9: The spatial resolution in the transverse (bending) plane (upper panel) and in the beam direction for tracks crossing pad rows (lower panel).

To achieve the ambitious design values for the TRD performance [1] we continuously develop the algorithms to reach the theoretical limit for spatial resolution as well as those for particle identification. We briefly describe the status of the reconstruction within the TRD. The TRD reconstruction comprises the steps of point and tracklet reconstruction as welll as track prolongation. The first two steps are applied independently from the other barrel detectors while the third is highly correlated with the reconstruction in the TPC. Besides the quality of the reconstructed values like spatial, momentum and charge resolution, the reconstruction code has to fullfill also criteria of flexibility, speed and low memory usage (in particular for usage in the High Level Trigger, HLT).

The code had been developed as a modular structure with two main components: the ”Clusterizer” for point reconstruction and the ”Tracker” for tracklet construction and track prolongation. Additionally, all algorithms used for data reconstruction have been made parametric and the corresponding set of parameters have been calibrated and saved to a database. Sets of parameters have been thus obtained which can provide dynamical response of the reconstruction algorithms to the particularities of the data (for instance track multiplicity).

The results for the spatial resolution obtained with the present algorithms on simulated data are summarized in Fig. 9. Shown is the tracklet resolution with respect to the Monte Carlo information. A minimum of approx 90 μm is obtained in the transverse plane for the azimuthal angle corresponding to the Lorentz angle (the angle under which the electrons are drifting due to $\mathbf{E}\times\mathbf{B}$ coupling). The expected linear dependence of the resolution on the tangent of the dip (polar) angle is seen, together with the 5-fold TRD segmentation in the beam direction. The best resolution of about 200 μm is reached around θ=0. Only about half of all tracks do cross the pad rows of the detectors and are characterized by such a good resolution.

The complexity of the TRD project did lead to several challenging issues. We have fortunately discovered in time a leak problem in our detectors and we were able to rectify this for all the chambers, in a concerted effort of our teams at CERN and in particular in the detector laboratory of GSI. Unexpected complications with the manufacturing in industry of our front-end electronics boards, occuring after successful preseries, have caused a delay in the supermodule assembly. Despite this, eight out of the total 18 supermodules of the TRD will be ready in the ALICE setup when cosmic-ray data taking resumes in June 2009 and will contribute to physics results with beams expected to start in fall 2009. The TRD will be completed during the next shutdown period.

References

[1] ALICE Transition Radiation Detector Technical Design Report, ALICE TDR 9, CERN/LHCC 2001-021.