



The ALICE Transition Radiation Detector: status and perspectives for Run II

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Abstract. The ALICE Transition Radiation Detector contributes to the tracking, particle identification, and triggering capabilities of the experiment. It is composed of six layers of multi-wire proportional chambers, each of which is preceded by a radiator and a Xe/CO₂-filled drift volume. The signal is sampled in timebins of 100 ns over the drift length which allows for the reconstruction of chamber-wise track segments, both online and offline. The particle identification is based on the specific energy loss of charged particles and additional transition radiation photons, the latter being a signature for electrons.

The detector is segmented into 18 sectors, of which 13 were installed in Run I. The TRD was included in data taking since the LHC start-up and was successfully used for electron identification and triggering. During the Long Shutdown 1, the detector was completed and now covers the full azimuthal acceptance. Furthermore, the readout and trigger components were upgraded. When data taking was started for Run II, their performance fulfilled the expectations.

INTRODUCTION

A Large Ion Collider Experiment (ALICE) is the experiment at the Large Hadron Collider (LHC) at CERN which was particularly optimized for the measurement of Pb–Pb collisions [1]. It consists of a central barrel and a forward muon spectrometer. The former is located in a warm magnet providing a solenoidal field of $B = 0.5$ T. A large cylindrical Time Projection Chamber (TPC) is used as the main tracking device. It is complemented by a silicon-based Inner Tracking System (ITS) close to the beam pipe and, towards larger radii, the Transition Radiation Detector (TRD) and the Time-Of-Flight (TOF) detectors. Part of the acceptance is covered by electromagnetic calorimetry, and further detectors are installed around the interaction point for triggering and event characterization.

Following the azimuthal segmentation of the ALICE central barrel, the TRD is organized in 18 sectors [2]. Each of them is filled with a supermodule consisting of 6 layers of Multi-Wire Proportional Chambers (MWPC). They are subdivided into five stacks to achieve manageable chamber sizes. The MWPCs are preceded by a drift volume and a fibre-foam radiator. The former allows for the detection of the ionization energy loss over a radial length of 3.7 cm. The detection includes the absorption of the transition radiation, which highly relativistic ($\gamma \gtrsim 800$) particles can emit while traversing the radiator. The transition radiation photons are predominantly in the X-ray regime, and Xenon is used as detection gas because of its high photon absorption cross section. For the central barrel, the TRD contributes tracking, triggering, and the identification of particles, in particular of electrons.

In the following, we will first discuss the setup and operation of the TRD in Run I. We will further summarize results showing the performance of the detector. Next, we will describe the consolidation and upgrade activities during the first long shutdown of the LHC, as well as the subsequent recommissioning. In the end, we will review the current situation and further plans for Run II.

RUN I

Since the beginning of Run I, the TRD was included in the data taking of ALICE with the supermodules already installed at that time [3]. By 2012, 13 out of 18 had been installed, resulting in the setup shown in Figure 1.

The central barrel tracking is based on a Kalman filtering approach [3]. Starting from seeding clusters at the outer radius of the TPC, tracks are found by inward propagation to the vertex, also attaching hits in the Inner Tracking System. In a second step, the track is propagated outwards through the TRD and TOF detectors, also attaching clusters there. In a final inward propagation, the track parameters are refitted, taking into account energy loss. The TRD clusters carry both position and charge information, the latter allowing for the particle identification.

The fundamental concept, i.e. the detection of specific energy loss and the onset of Transition Radiation (TR), could be verified using cosmic muons [4]. They can carry very large momenta and can traverse the TRD twice. In the outward direction, which corresponds to the normal scenario of particles coming from the interaction point, the radiator is traversed before the chamber and the transition radiation emitted into the drift volume. On the inward direction, however, the radiator is passed only after the chamber and the transition radiation remains undetected. This allows for the separation of the measurements with and without transition radiation. Figure 1 shows a compilation of measurements in the experiments and from previous test beams. The cosmic muons bridge the gap between data points from test beam setups with electron and pion samples and confirm the expected onset of transition radiation around $\beta\gamma \approx 800$.

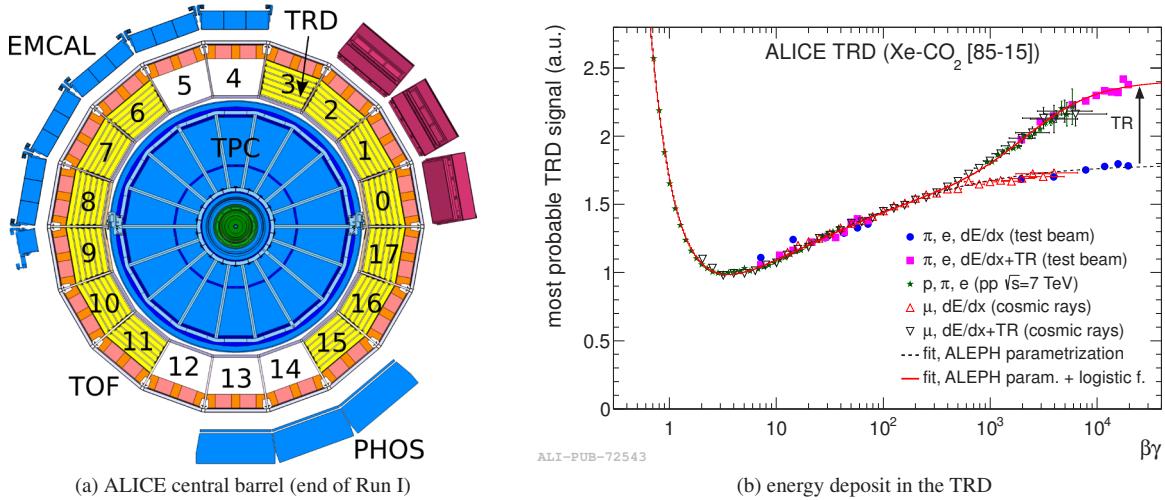


FIGURE 1: TRD in the ALICE central barrel. Left: Cross-sectional view with the installation status of 2012/13. Right: Energy deposit in the TRD with and without transition radiation.

For electron identification, a likelihood can be calculated based on the total accumulated charge, which comprises the energy loss from ionization in the active volume and, if present, the absorption of transition radiation [5]. The transition radiation is most likely absorbed close to the entrance of the active volume. Thus, the sampling in time-bins along the radial drift allows for a more refined separation of electrons and pions by exploiting this information. The simplest extension is a two-dimensional likelihood, which uses the charges in two time windows as input. As generalization, the signal is subdivided into 7 slices, which can be used for higher dimensional methods or as input for a neural network which is trained for the identification of electrons. The performance of the methods can be judged by the fraction of pions which pass the electron cuts for a given electron efficiency. Figure 2 shows a comparison of the different methods. The performance improves with each TRD layer contributing to the measurement and deteriorates with increasing momenta since the separation in specific energy loss decreases and the production of transition radiation saturates.

Besides the usage for the offline reconstruction, the data are used for the derivation of several contributions to the level-1 trigger of the experiment, which is issued $6.5 \mu\text{s}$ after the level-0 trigger [6]. The low latency poses significant challenges on the calculations and requires highly parallelized front-end electronics for local processing. On 256 chamber-mounted multi-chip modules, each of which comprises an analog pre-amplifier and shaper and a digital chip with hardware units and four CPUs, the information is combined into chamber-wise track segments (tracklets). They are shipped to the Global Tracking Unit (GTU), which combines them to tracks using an algorithm specifically designed for linear scaling with multiplicity. For the found tracks, the transverse momentum p_T and position are calculated. The online tracks serve as input for a versatile trigger logic, which allows the implementation

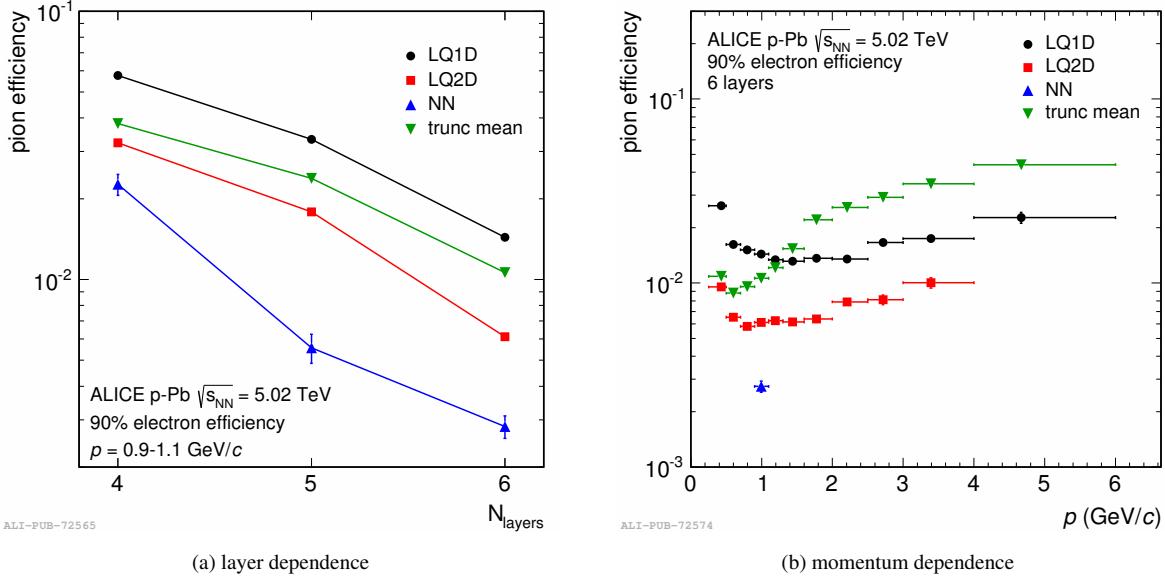


FIGURE 2: Electron identification with the TRD [3]. The efficiency (inverse of rejection) for pions at a given electron efficiency of 90% is shown.

of various signatures. Noting that the η - φ coverage of a TRD stack is comparable to the area of a typical jet cone ($R = 0.2$), a jet trigger can be derived using the condition that at least three tracks with $p_T > 3 \text{ GeV}/c$ are found in any TRD stack. Even though only charged particles enter the calculation, the trigger becomes fully efficient for charged jets with $p_T \gtrsim 100 \text{ GeV}/c$. The information on the deposited charge is also available online and was used for two electron triggers with p_T thresholds of 2 and 3 GeV/c , respectively. The identification was based on look-up tables translating the total charge to an electron likelihood. Figure 3 shows the enhancement by the TRD trigger for jets and electrons.

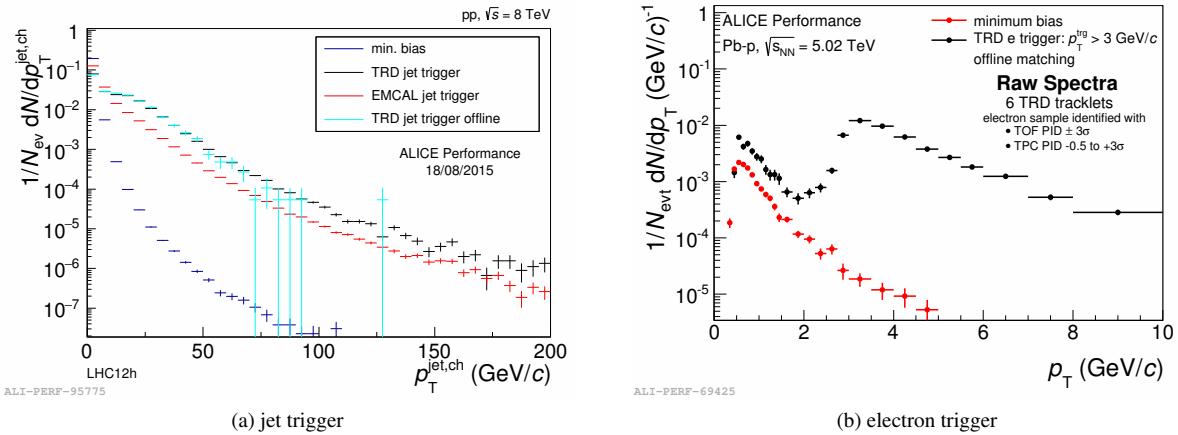


FIGURE 3: Transverse momentum spectra in TRD-triggered and minimum bias samples. Left: We compare the p_T spectra for charged jets in the triggered and minimum bias data samples. Right: We compare the p_T spectra for electrons in the triggered and minimum bias data samples.

In addition to extending the physics range by triggering, the TRD has been used for analyses requiring good and clean identification of electrons. A prime example is the dielectron decay channel of the $J/\psi \rightarrow e^+e^-$, for which the

TRD helps to improve the significance of the measurement [3]. Also for the measurement of heavy-flavour mesons through their semi-leptonic decay channel, the TRD electron identification is used [7].

LONG SHUTDOWN I

During the long shutdown of the LHC from 2013 to 2014, the production of the TRD electronics was completed. This allowed us to finish the assembly of the five remaining supermodules. They were installed at the end of 2014 before the experiment was prepared for the start of Run II. The completion of the TRD forms an important milestone in the project since it allows homogeneous usage of the TRD information in the full acceptance of the central barrel.

Besides the completion of the detector, consolidation and upgrade activities were carried out. Some low voltage connections at the supermodules had shown high resistance which resulted in increased temperatures and required short-term repairs. The affected supermodules were removed from the experiment one by one such that the connections could be reworked in the cavern before the supermodule was reinstalled. The rework resulted in stable operation of the low voltage connections for all supermodules.

Since Ethernet is used for the slow control of most detector components, failures of network components outside of the detector had resulted in the loss of control over parts of the detector during Run I. Therefore, special multiplexers were developed and manufactured to realize a redundant connection of the detector components to the upstream network. The installation for the most critical components in the supermodules had begun already in Run I. It was completed during the long shutdown such that now all connections can be remotely switched between two separate uplinks.

The front-end electronics of the TRD requires a wake-up signal prior to the experiment-wide level-0 trigger. In Run I, this signal was provided by a dedicated pretrigger system. To achieve the required low latency, it was installed inside the solenoid magnet and received direct copies of the signals from the trigger detectors. The system had some limitations in the interoperability with the central trigger processor, e.g. synchronized down-scaling was not possible. For Run II, the system has been merged with the central trigger processor to allow for a consistent trigger logic in one place.

To avoid a bottleneck in the readout, the Detector Data Links (DDL) to the data acquisition system were upgraded. The interface logic for the DDL was migrated from a dedicated mezzanine board to the fabric of the FPGAs in the GTU, using the in-FPGA multi-gigabit transceivers. This allowed for a doubling of the read-out bandwidth, resulting in a dead time similar to Run I despite the increased readout rates in Run II, see Figure 4.

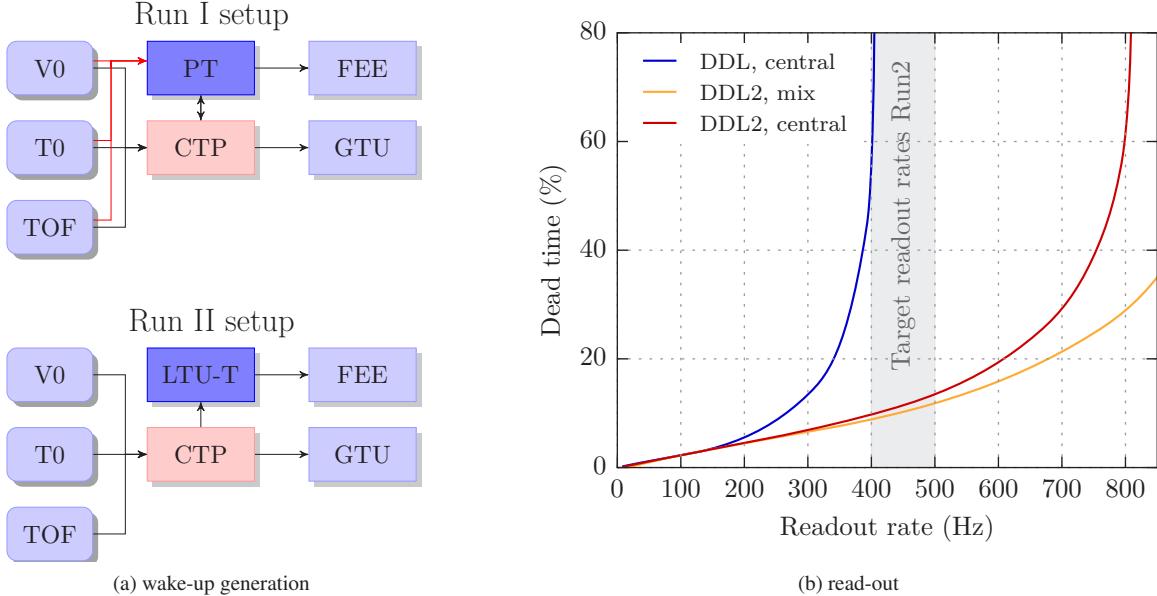


FIGURE 4: Trigger and read-out upgrade. Left: We show the setup to derive the wake-up signal for the TRD front-end electronics in Run I and Run II. Right: We show the dead time corresponding to a given read-out rate [8].

RUN II

After the completion of the detector, the recommissioning started in the beginning of 2015. The upgraded read-out systems performed as expected. At first, the full detector was calibrated using Krypton injected to the gas system [9]. The detector was fully aligned using early data. After further tweaking of the detectors used for the wake-up trigger, the upgraded system was confirmed to fulfill the latency requirements.

With the full azimuthal coverage of the central barrel acceptance, the TRD information shall be used to update the track parametrization during the Kalman propagation. This leads to a significantly improved p_T resolution, see Figure 5.

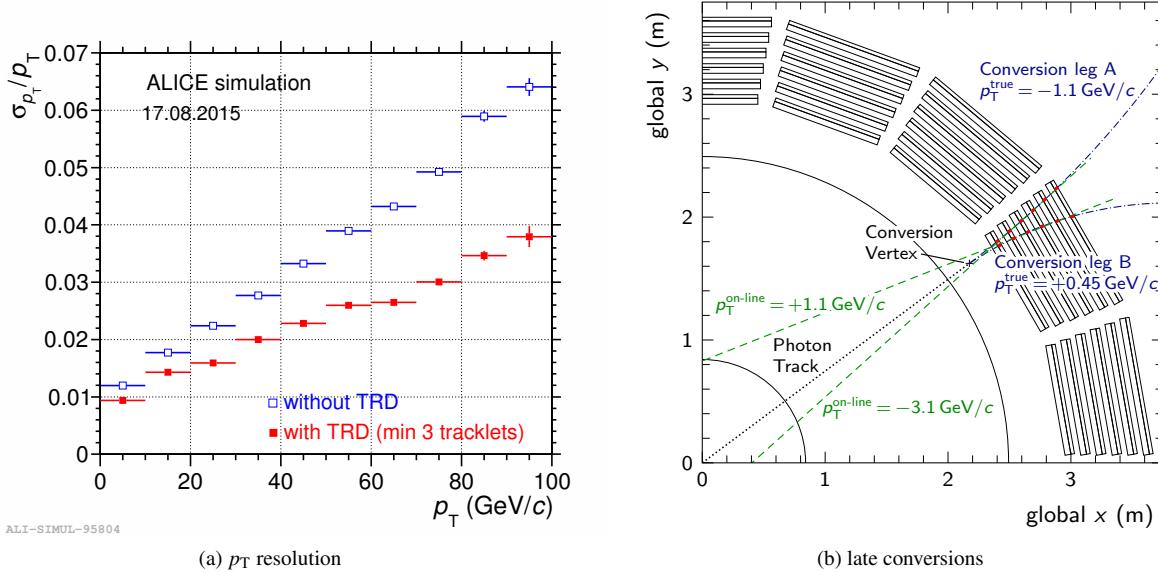


FIGURE 5: TRD tracking. Left: Transverse momentum resolution without and with the TRD used for updating the global track parameters. Right: Event display of an exemplary late conversion which wrongly fires the trigger.

The dominant background for the single electron triggers was caused by photon conversions at large radii, close to or in the TRD, see Figure 5. For the online tracking, the resulting tracks resemble those with large transverse momenta. For Run II, a rejection of these late conversions has been included in the FPGA-based online tracking. It compares the p_T^{-1} estimated from the sagitta and from the global fit and rejects those with a large discrepancy.

In addition to the electron identification, the TRD can also be used for hadron identification. For this purpose, the truncated mean is calculated based on the TRD clusters attached to the track. For the identification, the deviation from the expectation for a given species is used after normalization to the resolution expected for the track under study.

SUMMARY AND OUTLOOK

The TRD has been completed in time for the start of Run II and performs well now. It shall contribute to the physics output of the experiment in various areas. The trigger helps to extend the p_T reach for jets and heavy-flavour electrons. The particle identification is used for analyses of heavy-flavour electrons with respect to their nuclear suppression factor and the second harmonic v_2 .

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