The commissioning of ALICE's TPC

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ALICE exploits a large volume time projection chamber (TPC) as its main tracking detector. After ten years of construction it was installed in its final location in 2008 and has been continuously running with cosmic data ever since. This extensive data collection led to a well calibrated detector at "day zero".

As soon as the LHC collided beams for the first time at $\sqrt{s} = 900\,\mathrm{GeV}$ in November 2009, the TPC was a key sub-detector in the ALICE data taking stream. During the following period of $\sqrt{s} = 7\,\mathrm{TeV}$ collisions in April 2010 it recorded more than 30 million *pp* events within the first 5 days of integrated running time. Excellent performance and a thorough understanding of the detector were achieved.

1 Introduction and system overview

After having been completely assembled in 2006, installed in the cavern in 2007 and commissioned with cosmic rays in 2008 the ALICE Time Projection Chamber (TPC) took its first *pp* collision data on December, 6th 2009 at $\sqrt{s} = 900\,\mathrm{GeV}$ shortly after the first collisions were delivered by the LHC. With the confidence gained from the first days of operation, the $\sqrt{s} = 7\,\mathrm{TeV}$ data taking started directly on March, 30th 2010 and is continuing since.

The ALICE-TPC [1] is built out of a huge gas filled hollow cylinder with active radial and transverse dimensions of $848 < r < 2466\,\mathrm{mm}$ and $|z| < 2497\,\mathrm{mm}$, respectively (see Fig. 1). The electric field is orientated along the z-axis, aligned with the beams and the magnetic field. It is defined by a high voltage electrode at $100\,\mathrm{kV}$ in the $z = 0$ plane as well as a field cage made of aluminised Mylar strips that are held at the correct potential by a voltage divider network.

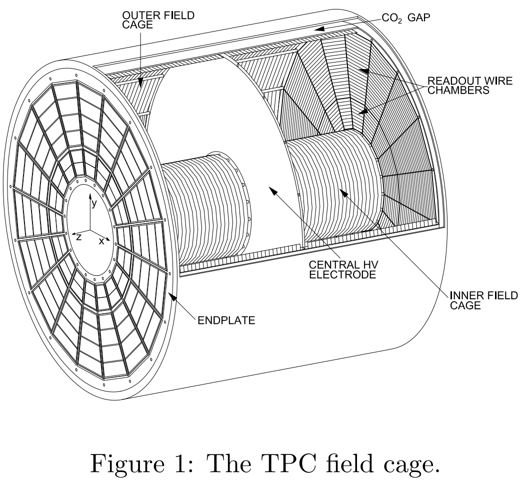

Figure 1: The TPC field cage.

The gas used is a Ne–CO_2–N_2 mixture in a ratio of [85.7–9.5–4.8], which is highly purified, cleaned from Oxygen (down to 1 ppm), and kept at a fixed humidity ($50 - 60$ ppm of H_2O) to avoid the drying-out of glue. In addition radioactive Krypton may be injected into the gas for calibration purposes. At nominal conditions this gas mixture yields a drift velocity of $2.6\,\mathrm{cm}/\mu\mathrm{s}$ and thereby defines the TPC acquisition time to be around $96\,\mu\mathrm{s}$. 72

multi-wire proportional read-out chambers (18 inner and 18 outer on each side) provide the necessary gas amplification and signal read-out.

The read-out is performed by 557,568 pads connected to custom made electronics, which samples the signal with 10 MSPS resulting in 960 units in drift direction at nominal conditions. The channels are distributed over 4,536 front-end cards (FECs) housing 128 complete analog and digital data acquisition chains each. The FECs are grouped into 216 read-out partitions (two on each inner and four on each outer read-out chamber), which provide the interfaces to the ALICE Trigger, detector control system (DCS) and data acquisition (DAQ). Custom made chips "PASA" (Pre-Amplifier and Shaping Amplifier) and "ALTRO" (ALICE TPC Read-Out, digitisation, signal processing and multiple-event buffering) housing 16 channels each are used to acquire and process the signals on-detector in order to achieve a good noise figure and the necessary data reduction (without zero-suppression an event has a size of about 700 MByte) to fit a high event rate into the available bandwidth.

2 Calibration

The TPC is equipped with three dedicated calibration sub-systems:

- a calibration pulser that injects electrical pulses onto the cathode wires of the read-out chambers,
- a radioactive Krypton source that can be attached to the gas system, and
- a laser system that shoots 336 narrow, intense (40 μJ in 10 ns), 266 nm wavelength beams into the TPC volume (see Fig. 2).

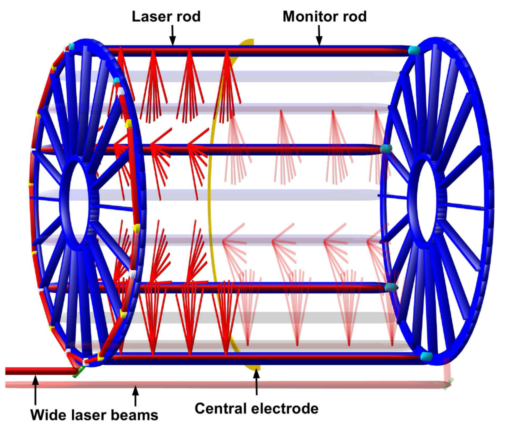

Figure 2: The laser calibration system.

The laser system is activated interleaved with collision data taking in order to capture time (and space) dependent variations of the drift velocity, while the Krypton calibration is repeated only once a year in a dedicated session.

Moreover data from cosmic rays and collisions are used to calibrate the detector. This led to a well calibrated detector in advance of the first collisions [1, 2, 3]. The complementary topology (in particular important for alignment) of collision events and their high abundance further improved the calibration.

Noise. The detector RMS noise stabilised at an average level of 700 electrons (0.7 LSB). It has a smooth spacial variation throughout the pad plane with only a few hot spots next to the high voltage feed-throughs. It is very stable in time, which allows us to adjust the zero-suppression scheme in the on-detector electronics accordingly and leads to an average empty event (no tracks) size of only 30 kByte.

Gain. The gain of the TPC read-out chambers and electronics is precisely measured by using decays from injected radioactive Krypton gas and the calibration pulser, respectively, and shows fluctuations of the order of 20%. No attempt was made to equalise the gain by adjusting the high voltage of the gas amplification, but the different gains are taken into account in the offline reconstruction.

The Krypton measurement was repeated at different gain levels to choose the best trade-off between chamber stability and loss of signal.

$\boldsymbol{E} \times \boldsymbol{B}$. The inhomogeneities of the magnetic field (about 1%) lead to a spacial distorition of up to 7 mm in the transverse plane for maximum drift. Before the detectors were inserted into the magnet the magnetic field had been carefully measured, which allowed us to correct for the $E \times B$ effect due to B-field inhomogeneities.

In addition to the B-field inhomogeneity also the E-field is not perfectly homogeneous, which is mostly caused by slightly misaligned read-out chambers and not precisely tuned reference voltages at the chambers. Recent calculations helped to tune the voltages and to apply mechanical forces to reshape the field cage. Moreover the B- and E-fields' principle axes are not perfectly aligned which gives an additional contribution to the $E \times B$ effect.

Recent analysis taking into account the E-field inhomogeneities and the angle between the fields allows to correct for the distortions down to 1 mm. Additional refinements of the models and methods to obtain their parameters indicate that this can be improved further in the near future.

3 Performance results

3.1 Operation

Stability. The detector runs in a fully automated way and is remotely operated by the ALICE-wide DCS. The TPC has proven to work in a very stable fashion. However, occasionally the field cage and read-out chambers trip. While the precise reason is still under investigation there is a clear correlation with LHC beam losses.

Speed. Designed for high multiplicity heavy-ion collisions, looking at single *pp* events the TPC is essentially empty. This has a crucial impact on its performance as protocol overhead of empty channels become an issue. A special mode of operation "sparse read-out" was employed to partly overcome these restrictions but required us to waive the derandomising multiple event buffering feature. The mean event size of 300 kByte for minimum bias 7 TeV *pp* collisions leads to a read-out time of about 500 μs, which is defined by the slowest read-out partition. The latter is one housing a track, and is about ten times slower than the average partition. A summary is given in Tab. 1 together with an estimate for *PbPb* based on the real *pp*-rates.

event type	size	read-out time
empty	30 kByte	280 μs
7 TeV min. bias	300 kByte	500 μs
PbPb central	70 MByte (est.)	2.3 ms (est.)

Table 1: Event sizes and read-out times.

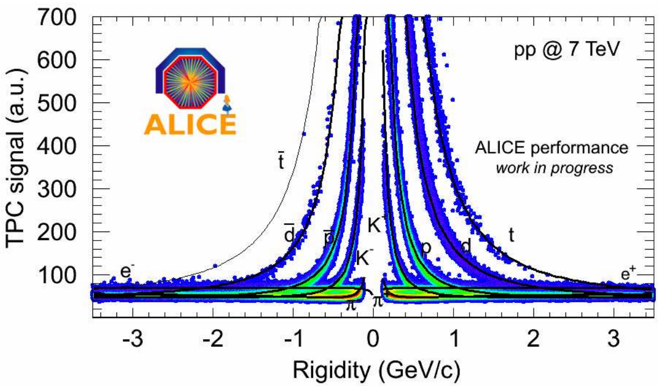

Figure 3: The $\mathrm{d}E/\mathrm{d}x$-spectrum for 7 TeV data.

3.2 Observables

$p_\perp$ resolution. The transverse momentum resolution of the TPC is obtained by looking at cosmic rays that cross the whole TPC and go through the inner tracking system. These tracks have a topology similar to two back-to-back particles emerging from a collision and are tracked as such. Their mismatch in reconstructed momentum yields the $p_\perp$ resolution, which can be expressed as: $(\sigma_{p_\perp}/p_\perp)^2 = (0.01)^2 + (0.007\,\mathrm{GeV}^{-1} \cdot p_\perp)^2$.

$\mathrm{d}E/\mathrm{d}x$ resolution. The PID information collected by the TPC is based on the specific ionisation loss of the traversing particles. Trained by extensive cosmic ray studies, the spectrum obtained shortly after the first collisions clearly shows the good PID properties of the detector. Figure 3 depicts the obtained 7 TeV spectrum. The current resolution for minimum ionising pions is 5%.

Tomography. Photon in e^+e^- conversions are used to identify the material content of the inner detectors. This includes the inner tracking system as well as the inner field cage of the TPC. Figure 4 shows the comparison to Monte-Carlo estimations based on the material distribution given by the technical drawings. The study shows both, the accuracy of the tracking, and the understanding of the material budget, which is in radial direction: 1.367% (inner field cage), 0.607% (gas) and 2.153% (outer field cage).

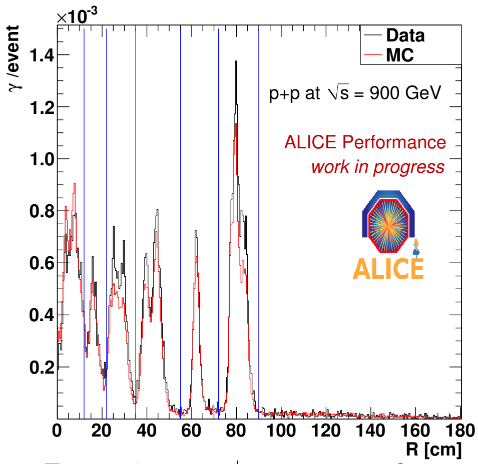

Figure 4: $\gamma \rightarrow e^+e^-$ tomography.

References

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