Stability tests of a GEM-based Inner Read-Out Chamber for the upgrade of the ALICE TPC

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The ALICE experiment at CERN is planning a major upgrade of its main central tracking device, the Time Projection Chamber (TPC), for the upcoming RUN 3 at LHC, beyond 2019. The present TPC uses gated Multi-Wire Proportional Chambers (MWPCs) with pad readout to amplify and read out the signal. The gate consist of a grid of wires that collects the ions produced in the amplification process, to prevent them from drifting back in the drift volume, which would eventually lead to deviations of the electrons trajectories and thus to distortions of the reconstructed tracks (*space-charge effect*). The gating grid also blocks the electrons from the ionization tracks, which in turn involves a dead time in the TPC corresponding to the collection time of the ions. Due to their low velocity ($v_{ion} \sim 10^{-3}\, v_{electron}$), the maximum read-out rate of the TPC is currently $\sim$ 300 Hz in Pb-Pb collisions, much lower than the maximum collision rate envisaged for RUN 3 (50 kHz)[1]. To fully exploit the capabilities of LHC, it has been planned to substitute the MWPCs with *Gas Electron Multiplier* (GEM) detectors, which combine a comparable spatial and momentum resolution with an intrinsic suppression of the back-drifting ions, allowing to operate in a continuous, trigger-less readout mode. A first prototype of a GEM-based TPC Inner Read-Out Chamber (IROC) has been built and commissioned at TU-München. One of the most problematic requirements associated to the LHC environment, especially in the high-multiplicity scenario of Pb-Pb collisions, is the stability against sparks, that are thought to be triggered by high charge-densities on the GEM-foils. During the first test of the IROC at the LHC, in the ALICE cavern during RUN 1 (p-Pb collisions), it was indeed observed a relatively high rate of discharges ($\sim$ 1/day). It was thus necessary to properly test and improve the IROC's stability. These dedicated tests were performed at the Maier-Leibnitz-Laboratorium (MLL) with a beam of low energy, highly-ionizing protons. According to a detailed Geant4 simulation of the experiment, it was possible to reproduce and even overtake the LHC RUN 3 conditions in terms of ionization density across the detector and, conversely, current density flowing across the GEM-foils ($\sim$ 10 nA/cm^2), which is thought to be the crucial quantity determining sparks. During the tests we used 2 different HV-settings (voltage distributions across the GEMs and electric fields in between), which were thought to optimise the two crucial characteristics of the detector: stability ("standard" HV-settings) and ion back-flow ("IBF" HV-settings).

[1]ALICE TPC collaboration, *Technical Design Report of the ALICE TPC Upgrade*, 2013

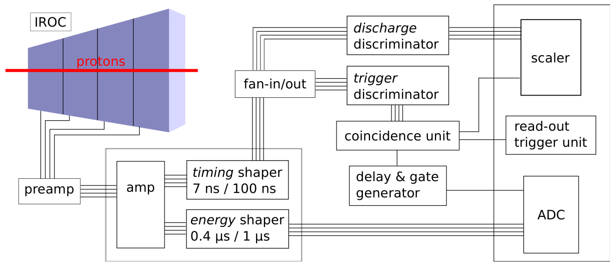

Figure 1: Sketch of the read-out scheme.

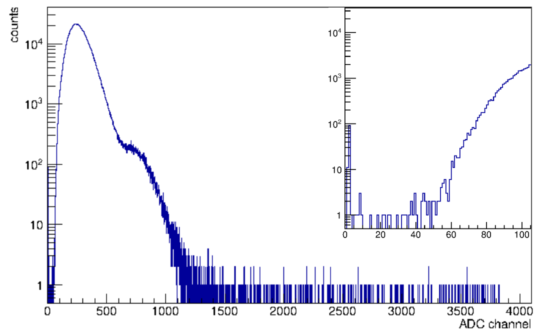

Figure 2: ADC spectrum of protons. Beam rate 10 kHz, "IBF" HV-settings, gain 2000.

For the first test (15/07/2013-17/07/2013) we used the gas mixture currently employed in the ALICE TPC, Ne/CO_2 (90/10), with a beam current of $\sim$ 2 nA, chopped in slices of 500 ns, at a rate of 50 kHz. The discharges were monitored through the currents across the GEM-foils. While with "standard" HV-settings we didn't observed any discharges, the "IBF" ones, which are planned to be used in the ALICE TPC, were on the contrary extremely unstable, already at the nominal gain of 2000. During a second test (22/11/2013-26/11/2013) a new gas mixture was used, $Ne/CO_2/N_2$ (90/10/5), which was expected to improve the detector's stability. The proton beam was in DC at rates of 10-250 kHz. A dedicated read-out was developed to measure sparks in the detector and correlate them to the beam conditions, allowing a precise study of its stability (fig.1). We recorded *event-by-event* both the signals on the pick-up electrode and the currents across the GEM-foils.

We first performed a long term measurement in conditions comparable to LHC RUN 3 (gain 2000, current density 40.5 nA/cm^2), allowing us to set an upper limit on discharge probability ($< 2.5 \times 10^{-8}$), both for "standard" and

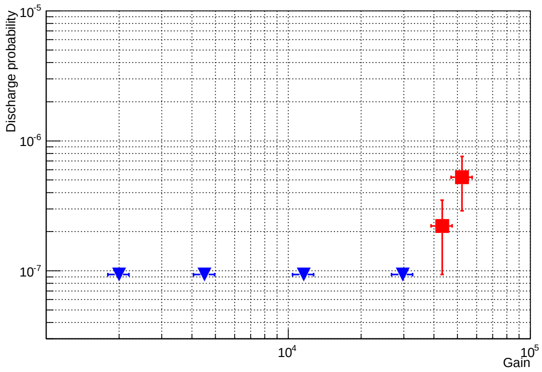

Figure 3: Discharge probability as a function of gain. Beam rate 10 kHz, ”IBF” HV-settings. Blue points are lower limits, red points established values.

”IBF” HV-settings. In fig.2 a typical spectrum of the proton signal on one sector of the pick-up electrode is shown: a single energy peak, followed by a small amount of tail pile-up.

We then performed a scan on the detector’s gain, at a constant beam rate (10 kHz). While with ”standard” settings we didn’t observed any discharge up to gains of $\sim 10^5$ (above which the IROC was discharging even without the beam), we indeed observed them with ”IBF” settings, which confirm that these settings have a negative influence on detector’s stability. Anyway, we were able to set a safety margin with respect to the values foreseen for TPC operations (gain 2000), see fig.3.

In conclusion, we were able to test the IROC stability in an extremely harsh environment, which is expected to be comparable to the LHC one with respect to the crucial quantity, the current density through the GEM-foils. Thanks to a new gas mixtures, Ne/CO_2/N_2 (90/10/5), the detector showed to satisfy the ALICE TPC requirements in terms of discharge probability, also with the more problematic ”IBF” HV-settings. We were also able to set safety margins in detector’s gain.

These tests constituted an important benchmark for the GEM-IROC prototype, that militates in favour of the possibility to sustain the ALICE TPC scenario during RUN 3. Further tests at LHC are nevertheless required to unambiguously prove the reliability of the detector.