New readout electronics for ATLAS ZDC detector in LHC Run3

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1. Introduction

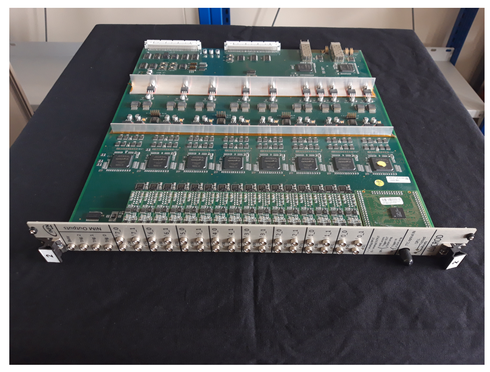
The Zero Degree Calorimeter (ZDC) detectors are located in the LHC tunnel on both sides of ATLAS Interaction Point (IP) and designed for detecting far-forward neutrons and photons from interactions during lead-lead and proton-proton collisions. Significant backgrounds in hadron colliders are created by beam-gas and beam-halo effects and can greatly be reduced by a tight coincidence from the two arms of ZDCs located symmetrically with respect to the IP at distance of 140 m. From each side ZDC detectors send 4 analogue signals by the 200 m air-core cables to the ATLAS counting room.The signals arrive at ZDC-adapted Lucrod modules where they are digitized and processed to generate a trigger.

2. Detectors

Within each ZDC detector there are three different sections (counting from IP) - electromagnetic, reaction plane detector and hadronic (3 modules) with detection based on Cherenkov light emission in high purity, ultra radiation-hard fused silica materials. The light produced in layers of fused-silica rods by the charged components of showers is transported to the top of the rods, where it is emitted into air light-guides directing light to the PMT windows.

3. ZDC-adapted LUCROD module

The new ZDC-LUCROD readout module, originally designed for the LUCID detector [1], is a 9U VME board capable of processing signals from 8 channels with a FADC sampling rate of 320 MHz. To allow for a larger amplitude's dynamic range the signals from both sides enter one board (LowGainThresholds) and after programmable amplification are fed into inputs of another board (HighGainThresholds). The first 4 channels of the board are assigned to side A and the remaining 4 to C. The ZDC-LUCROD modules were also modified to produce ZDC digital triggers. To efficiently identify a peak in the signal as a candidate for a trigger the module has been equipped with online calculation of the 2^{nd} derivative. The calculation, based on FPGA pipelined oepration, uses 12 bit FADC samples with subtracted baseline values (the first sample from the programmable time window).

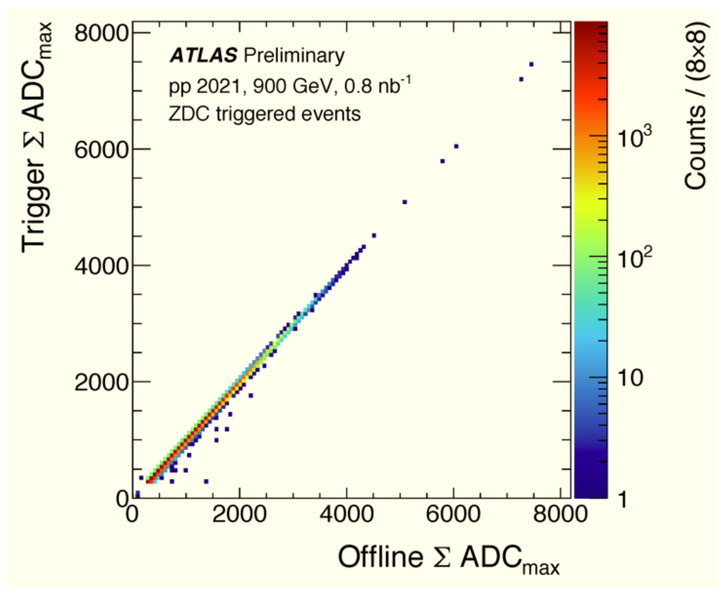


The 2^{nd} derivative going above a programmable threshold indicates a pulse. Presence of a pulse starts a search in the time window for a maximal ADC value. The further processing calculates arithmetic average of the 4 channels from each side. This average is then used in first level of LUTs to produce a 4-bit output. In the final step the 4-bit outputs from both sides are used as 8-bit address in another level of LUT to produce 3-bit final trigger code sent to CTP. The thresholds used to classify pulses when accessing the first level LUTs and the contents of all LUT are programmable.

[1] Avoni G., Bruschi M., Cabras G., Caforio D., Dehghanian N., Floderus A., Giacobbe B., Giannuzzi F., Giorgi F., Grafström P., et al., Journal of Instrumentation, 2018, **13**, No. 07, P07017–P07017.

4. Improvements in trigger

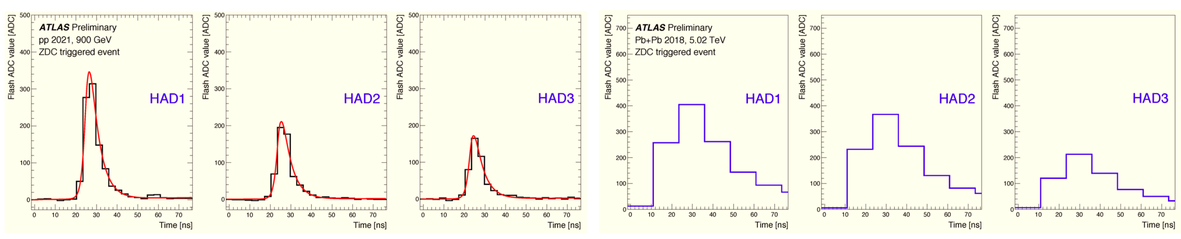
Comparison of the sum of amplitudes obtained in the trigger (ZDC-LUCROD) and in the offline analysis for the three installed ZDC modules (HAD1-HAD3) during 2021 pilot run operation by ATLAS. A total of 175 thousand events have a pulse in one or more of the modules. Here, for both the trigger and the offline analysis, the pulse amplitude in a single module is represented by the maximum flash ADC sample.



The agreement between the trigger sum, which enters the lookup tables used for the ultimate trigger decision, and the offline sum is generally excellent. The outliers mainly result from events with two significant pulses falling in the same bunch crossing.

5. Improvements in pulse shape acquisition

Flash ADC (320 Mz) samples read out from a ZDC-LUCROD FEE board for the three installed ZDC calorimeter modules for a single event recorded during the 2021 pilot run operation of ATLAS. The samples are plotted (left part of the figure) as a function of time expressed relative to the start of the readout window. The baseline is measured in the first sample and subtracted from the other samples. The red curves show fits to the pulses that are performed as part of the standard ZDC offline analysis.



The pulses have shorter rise and fall times, compared to those during Run 2 (right part of the figure), thanks to the installation during LS2 of air-core cables that carry the signals from the tunnel to USA15.

6. Integration with ATLAS TDAQ system

The full integration with the ATLAS TDAQ required s-link interface and firmware to handle Level-1 Accept requests. The ZDC-LUCRODs send data to ATLAS Readout System (ROS) via the s-link fiber with ATLAS formatting (ROD headers). The modules can also generate a BUSY to avoid data loss in case the s-link throughput is saturated by bursts of triggers. The module is also equipped with trigger Level-1 Accept pipeline where samples await a decision. In case of module's desynchronization the TTCrestart procedure can be executed to reintegrate the module into a running ATLAS TDAQ system.