The new readout system for the Alice Zero Degree Calorimeters in LHC Run 3

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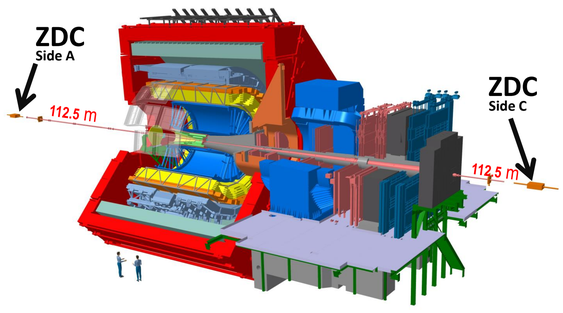
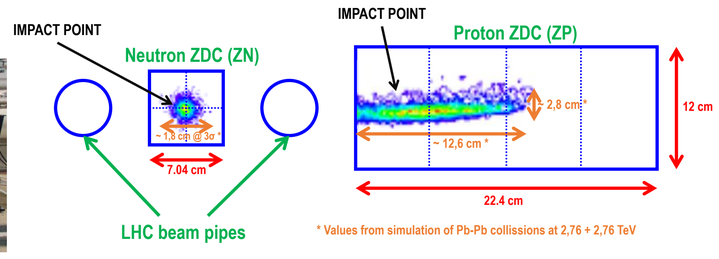
ABSTRACT

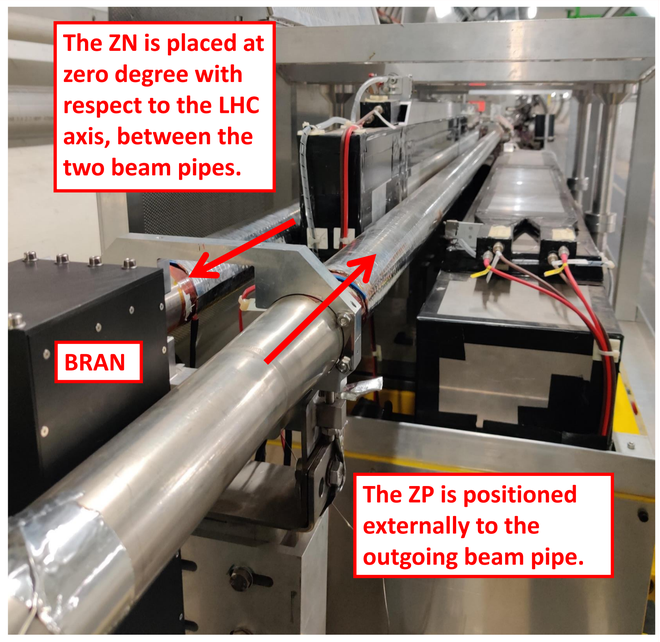
The Zero Degree Calorimeters (ZDC) were designed to provide the measurement of the event geometry and luminosity in heavy-ion operation. In order to exploit the potential offered by the LHC increased luminosity in Run 3 the ZDC upgraded its readout system to be able to acquire all collisions in self-triggered mode without dead time. The purpose of the upgrade was to enable the detector to cope with the increased event rate, while preserving its time and charge resolution performance. The ZDC operating conditions in Run 3 Pb-Pb collisions are extremely challenging due to the presence of Electro Magnetic Dissociation processes (EMD). When running in self-triggered mode the ZDC system will need to sustain a readout rate of ~ 1.4 MHz for the channels of the most exposed calorimeters that compares to the foreseen hadronic rate of 50 kHz sustained by the other detectors. The previous electronics, based on Charge-to-Digital Converters (QDCs), with a fixed dead time of ~ 10 us, and on readout through VME bus, could not cope with such a high rate. Moreover, a crucial aspect of the ZDC operation in Run 3 is acquiring the events with a reduced bunch spacing of 50 ns (lower than the length of the signal of ~ 60 ns) in the presence of a large signal dynamics (from a single neutron to ~ 60 neutrons). The new acquisition chain is based on a commercial 12 bit digitizer with a sampling rate of about 1 GSps, assembled on an FPGA Mezzanine Card. The signals produced by the ZDC channels are digitized, and samples are processed through an FPGA that, thanks to a custom trigger algorithm, flags for readout the relevant portion of the waveform and extracts information such as timing, baseline average estimation and luminosity.

Detector description

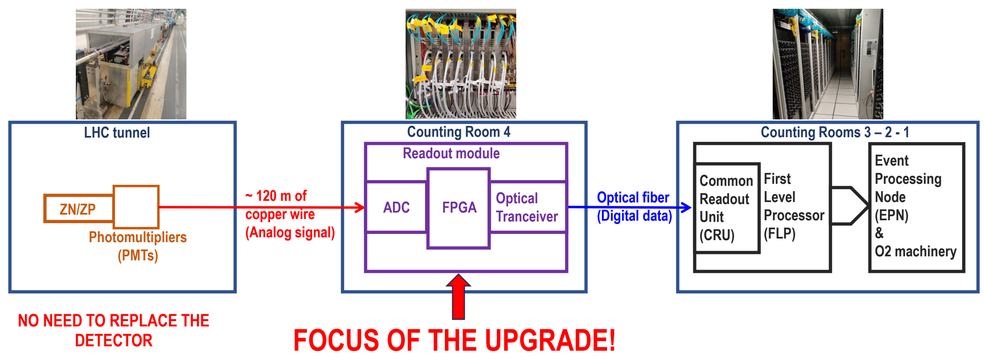
- The ZDC consists in two identical sets of calorimeters located on both sides relative to the interaction point IP2.
- Each set of detectors consists of a neutron (ZN) and a proton (ZP) calorimeter.
- Collisions may occur in fixed time slots named bunch crossings (BC) that are separated by ~25 ns.
- In A-A collisions, ZDC is mainly sensitive to spectator nucleons.
- The ZDC detector is completed by 2 forward EM calorimeters (ZEM) placed at about 7.35 m from IP2, on side A.



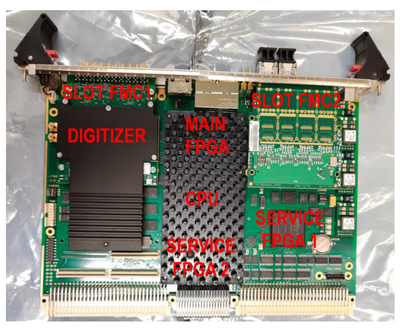


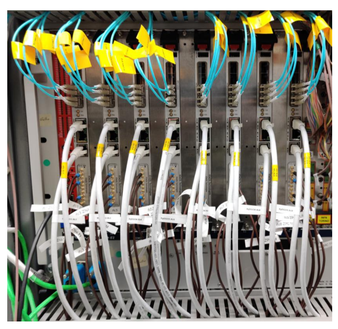


Readout upgrade for Run 3



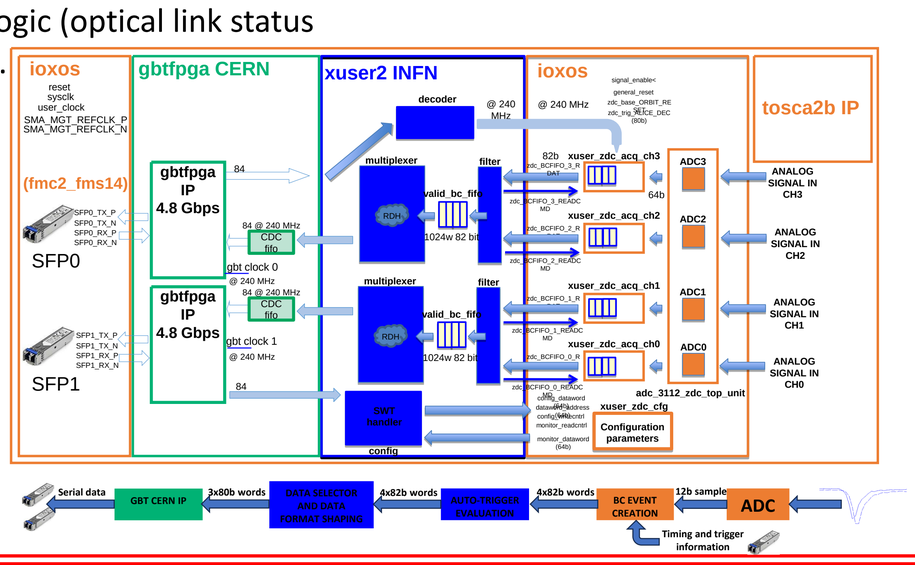
- Operation in self-triggered mode without dead time at an average event rate in Pb-Pb collisions of 2.5 MHz (almost 2 safety factor).
- Preserve time and charge resolution performance of Run 2 (~20 % resolution for the single neutron peak and ~0.35 ns time resolution w.r.t. ALICE L0 trigger).
- Efficient triggering in the presence of a large signal dynamics (from a single neutron signal to ~60 neutrons for Pb-Pb collisions).
- Data acquisition with a bunch spacing of 50 ns (lower than the length of the signal of 60 ns).
- Firmware that evaluates the average baseline for each orbit in events where no collision takes place.
- Real time monitoring of the collision rate.



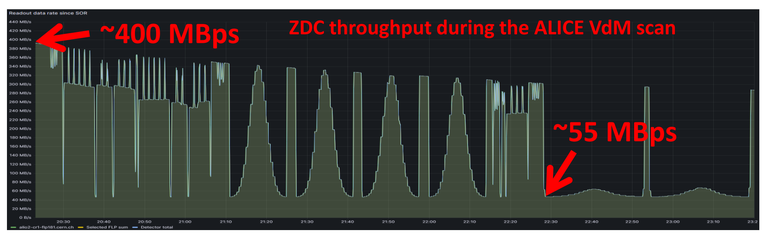


Key firmware features:

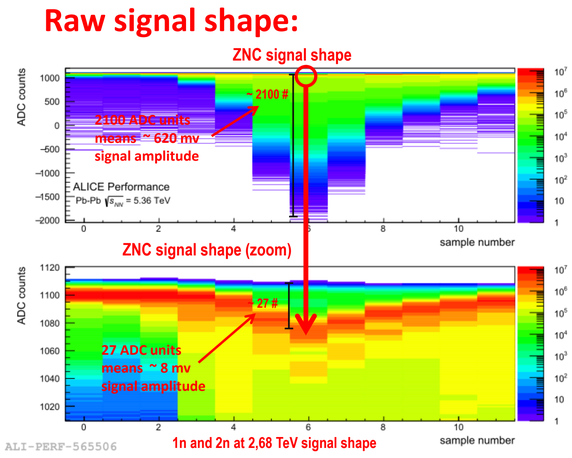
- Auto trigger algorithm.
- Automatic baseline evaluation.
- Rate measurement capabilities.
- Auto calibration system.
- Auto reset logic (optical link status monitoring).
- Fiber controlled slow control.
- Backpressure detection and protection.
- Configuration of channel role (triggering/readout).



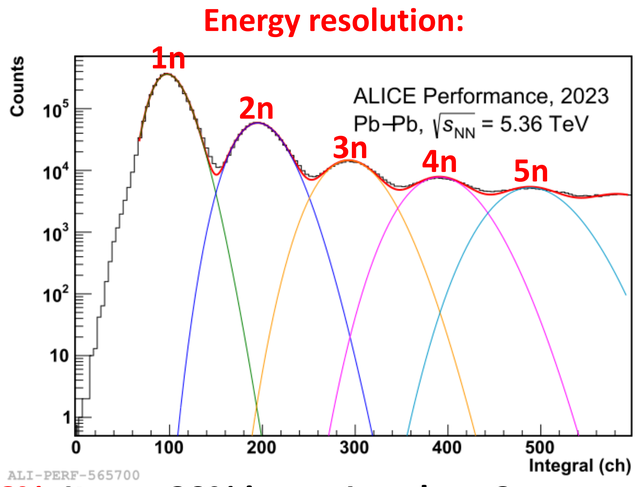
Performance during Run 3



Raw signal shape:



Energy resolution:

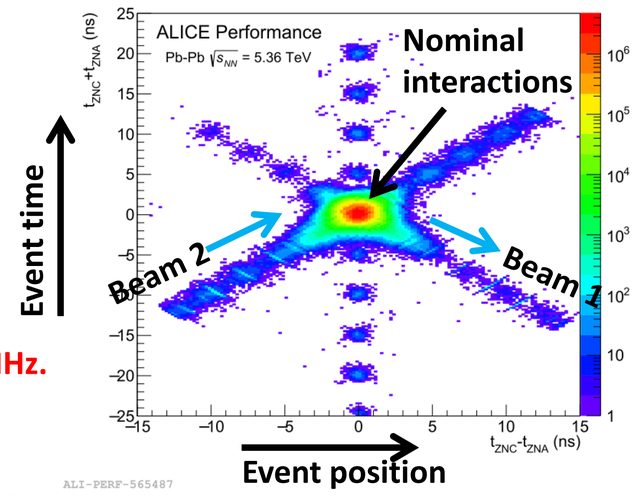


1n peak resolution ~ 15%-16%. It was 20% in run1 and run2.

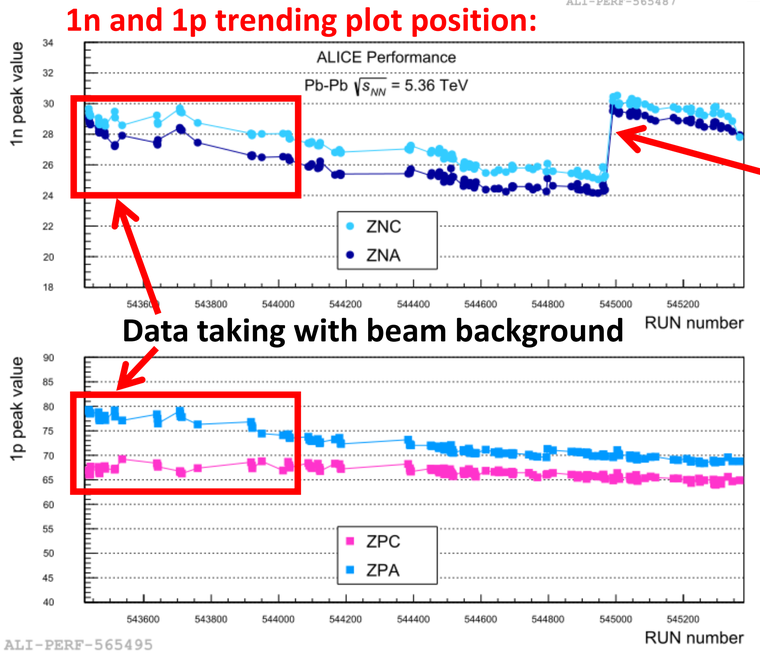
Time resolution and rejection of satellites:

ZNs can be used to identify displaced collisions.

LHC RF cavities frequency = 400 MHz.



1n and 1p trending plot position:



Increased High Voltage to the photomultiplier

A decrease in the peak value is compatible with an aging effect of the photomultiplier. This can be corrected by increasing the HV.

Outlook: The new readout system is fully compliant with the different acquiring modes foreseen in ALICE and was fully and successfully commissioned during the 2023 Pb-Pb Run 3 data taking. The addition of new features and standard firmware maintenance will be performed during 2024. The detector with the new readout system allows for an energy resolution of 15 % for the amplitude for the single neutron peak, better than Run 2.