Performance of the ALICE Zero Degree Calorimeters (ZDC) in LHC Run 3

CALOR 2024 - Tsukuba
21-05-2024

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on behalf of the ALICE Collaboration
INFN Torino
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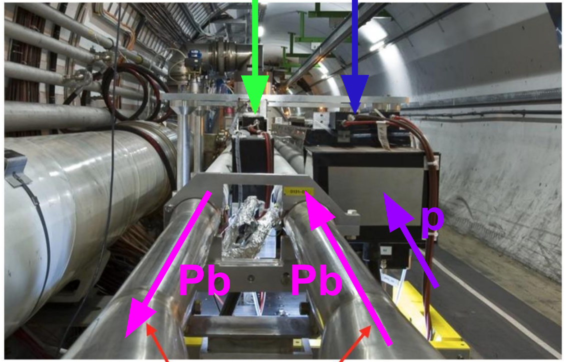
The ZDC in the ALICE experiment

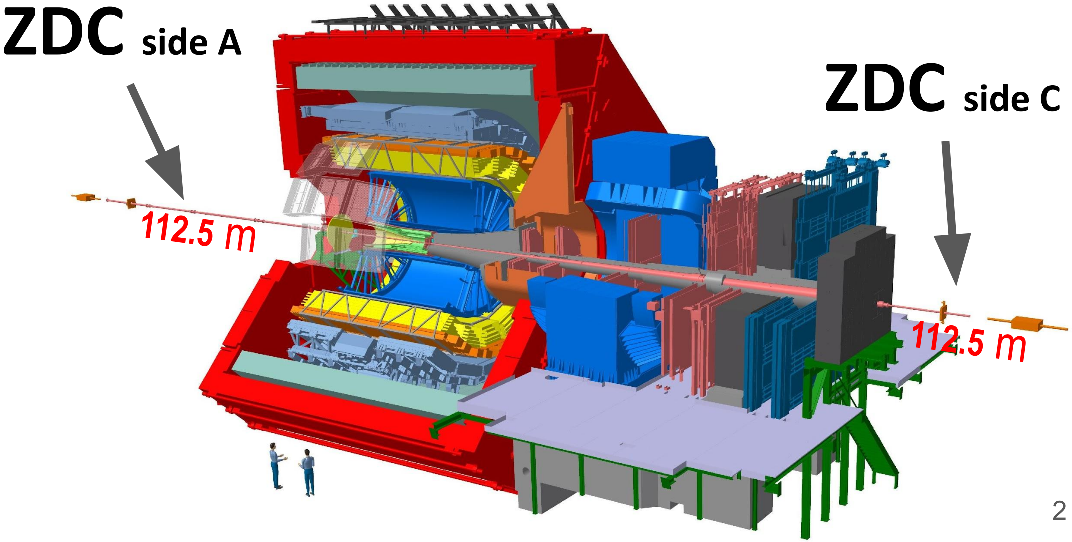
- The ZDC consists of two identical sets of calorimeters located on both sides relative to the interaction point IP2.
- Each set of detectors consists of a neutron (ZN) and a proton (ZP) calorimeter.
- Collisions may occur in fixed time slots named Bunch Crossings (BC) that are separated by ~25 ns.
-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

The ZN is placed at zero degree with respect to the LHC axis, between the two beam pipes.

The ZP is positioned externally to the outgoing beam pipe.

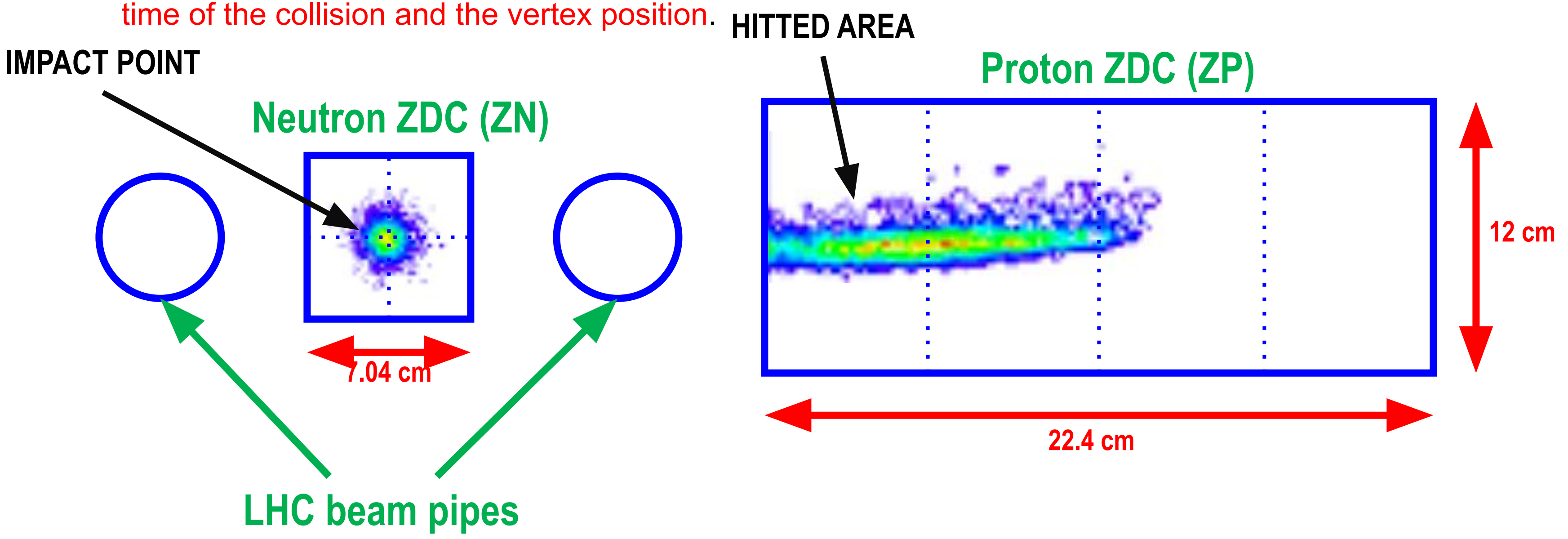


LHC beam pipes



The Zero Degree Calorimeters

- The ZDCs are quartz-fiber spaghetti calorimeters with silica optical fibers as active material embedded in a dense absorber; W alloy for ZN and brass for ZP.
- The main purpose of these calorimeters is to provide a measurement of centrality in A-A and in p-A collisions and the luminosity in A-A collisions. In addition it provides an independent measurement of the time of the collision and the vertex position.



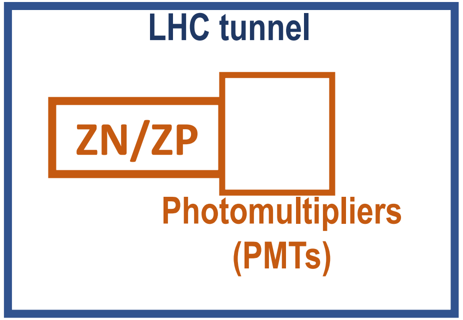
Run 3 requirements for the ZDC readout

- Operation in self-triggered mode without dead time at an average event rate up to of 2.5 MHz for the most exposed channels.
- 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.

Run 3 upgrade strategy

ALICE

In order to exploit the potential offered by the increased luminosity in Run 3, the ALICE experiment upgraded its trigger and readout system.



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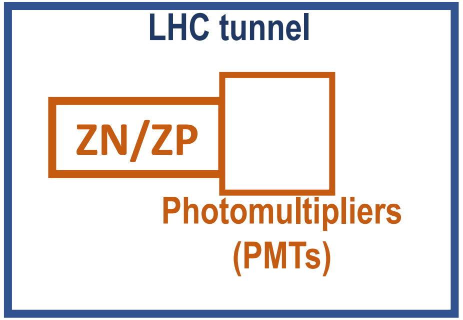
NO NEED TO REPLACE THE DETECTOR



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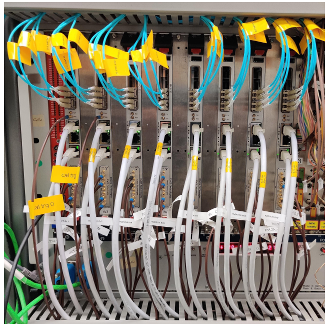

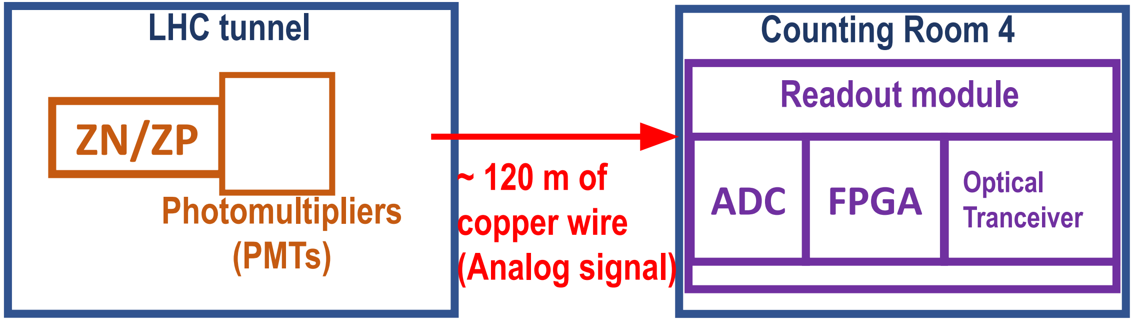

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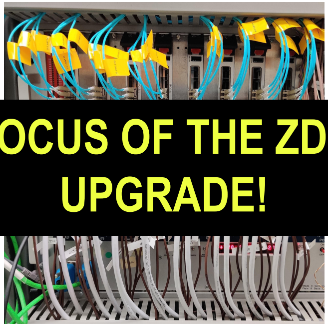
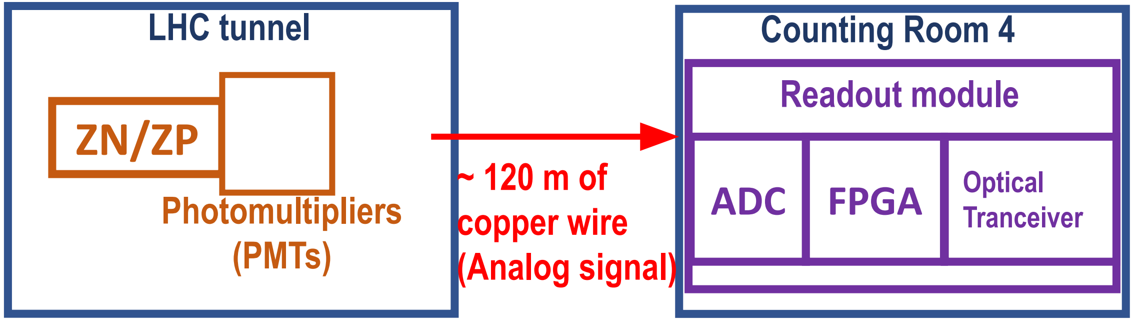


FOCUS OF THE ZDC UPGRADE!



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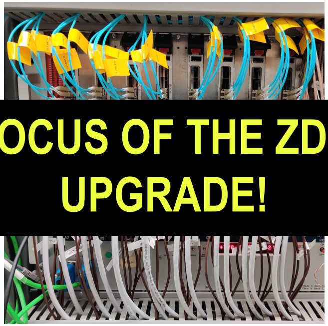

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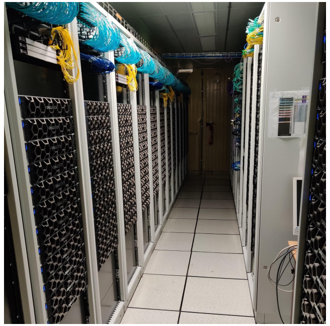

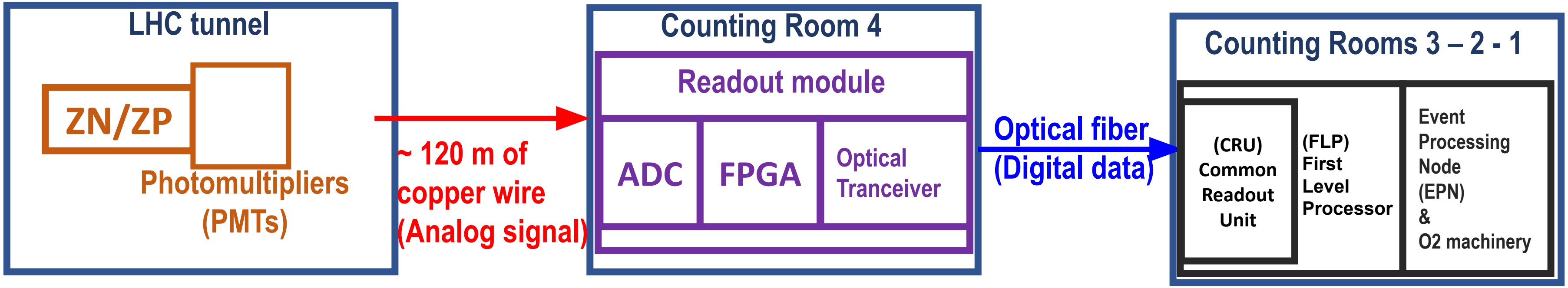

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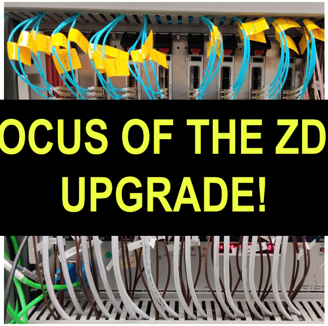
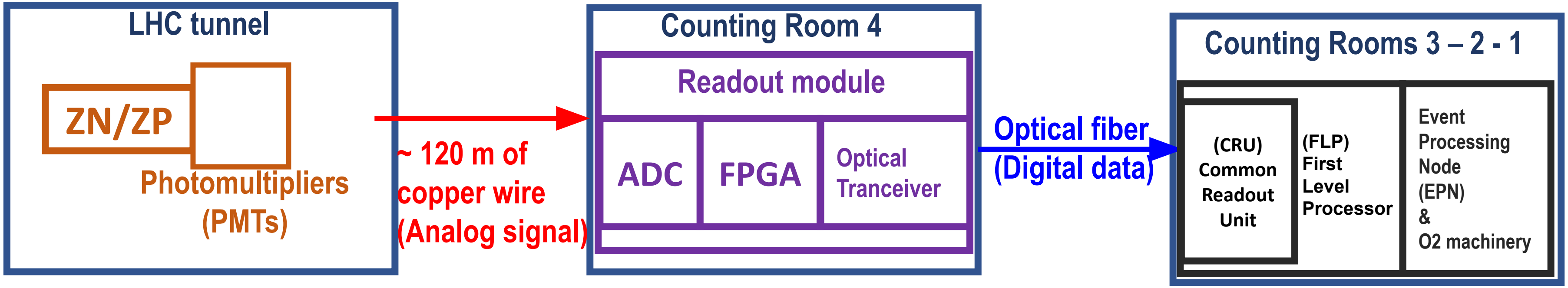


FOCUS OF THE ZDC UPGRADE!

UPGRADED BY THE ALICE COLLABORATION



The digitizer & FPGA carrier selected for the upgrade

ALICE

IOxOS FMC digitizer ADC 3112, mounting a TI ADS5409 digitizer.

- Maximum sampling rate of 1 Gsps
- 1 Vpp dynamics
- 12-bit resolution with ENOB of 10-bit
- 4 channels per module
- DC coupling
- working with digital filtering and decimation by 2.

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The triggering is performed on digitized data!!

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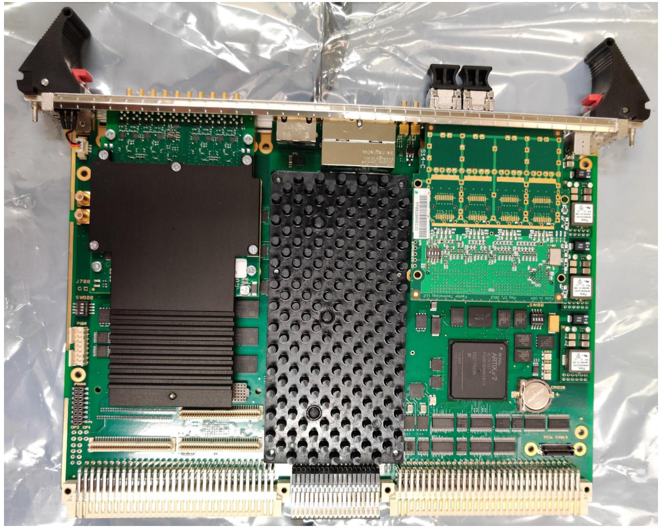
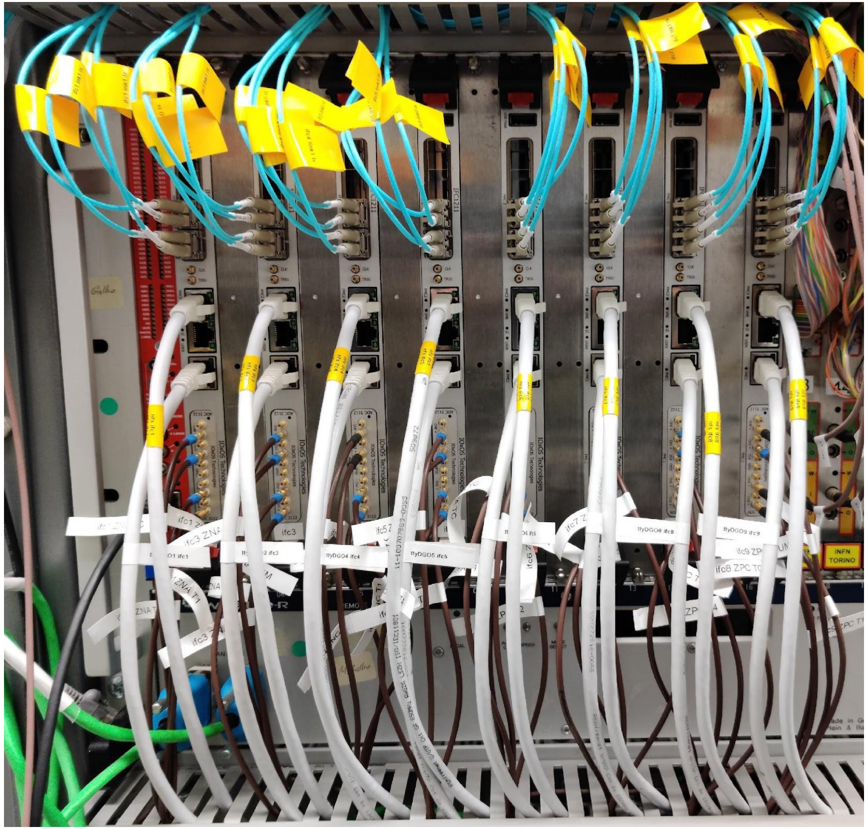
IOxOS ifc1211 carrier equipped with two FMC ports, a Xilinx FPGA Kintex Ultrascale xcku040-1ffva1156 and a PowerPC processor.



The system installed at Point 2



8 carriers are currently deployed in ALICE CR4 for a total of 32 usable channels.

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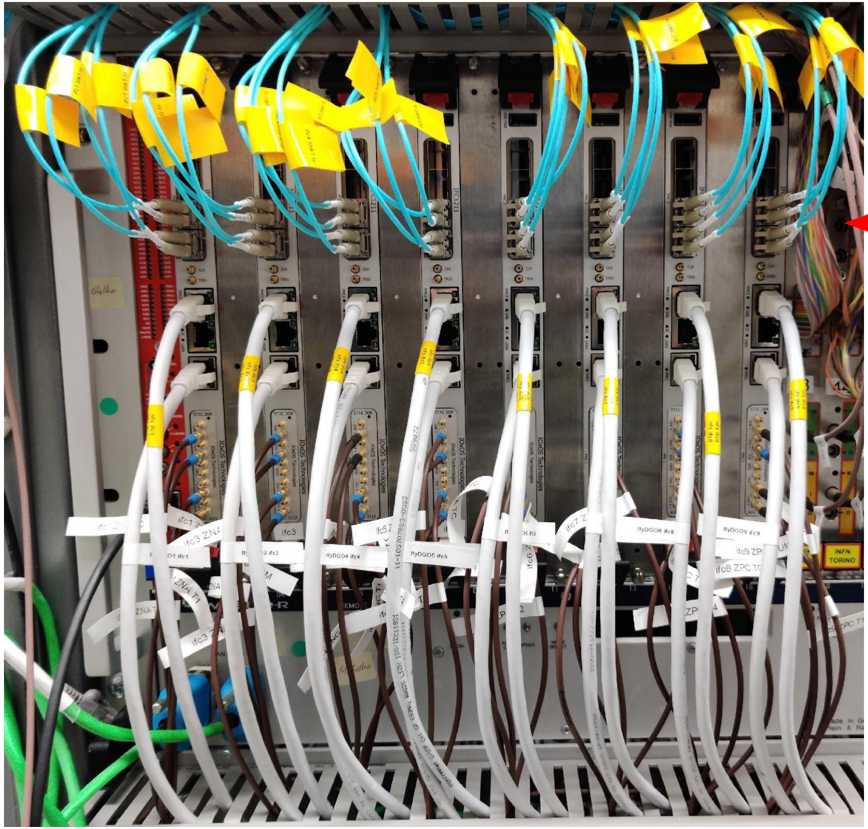

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Optical Fiber TX/RX

TAS-A2NH1-P11, multimode, 850 nm, SFP+ optical transceivers.

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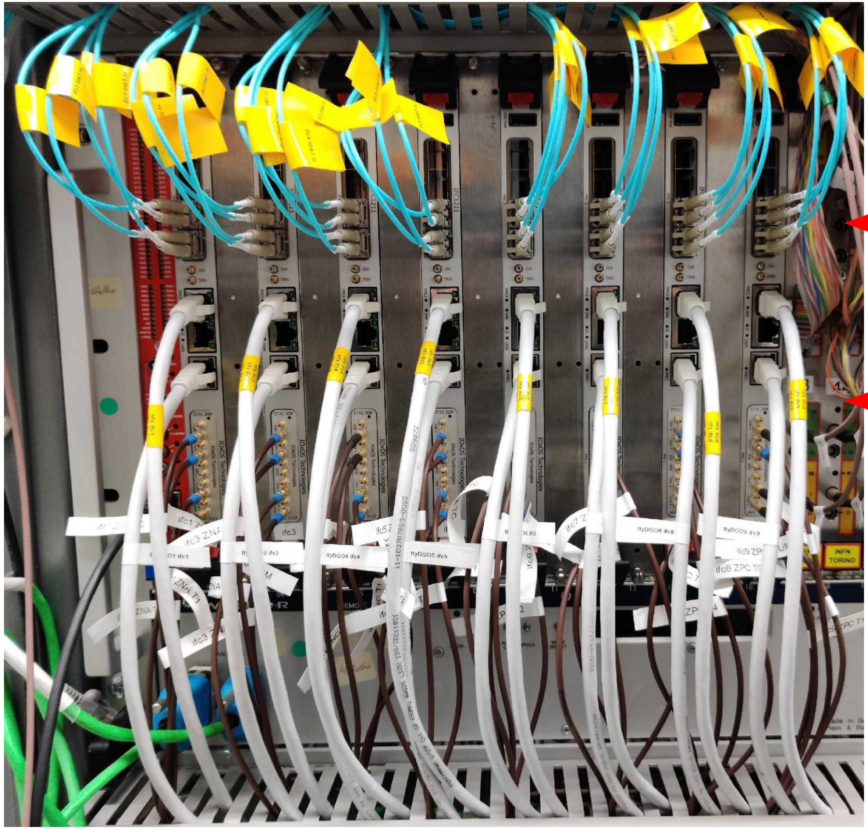

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Network File System (NFS) boot system for the PowerPC Processor

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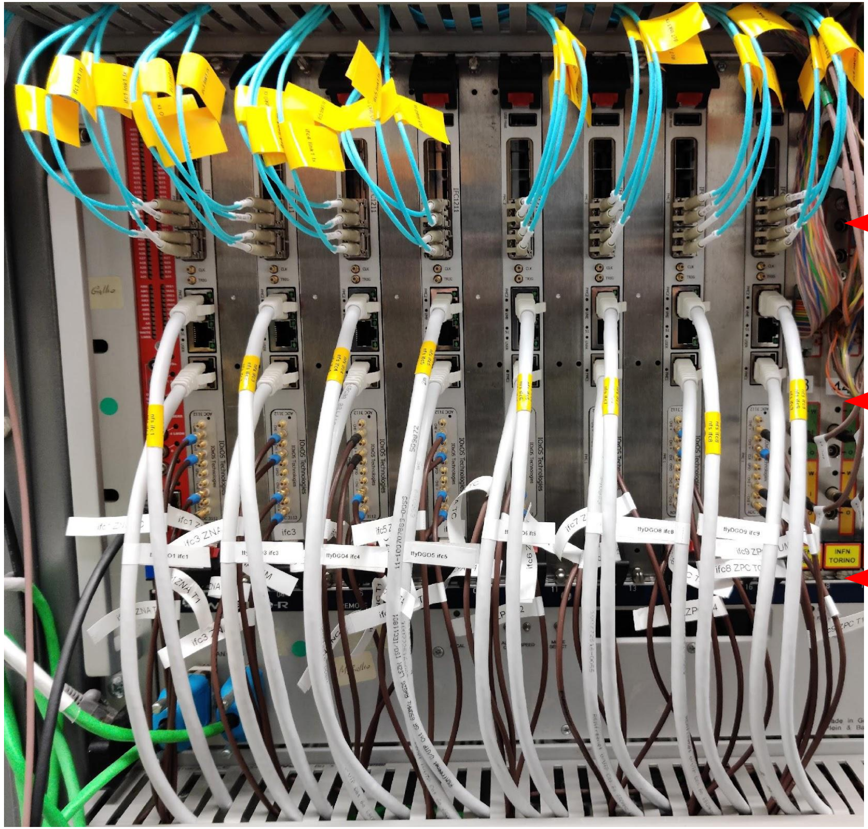

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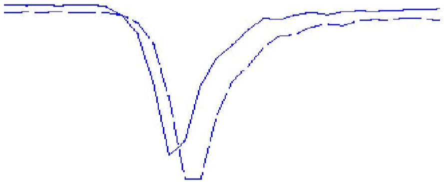
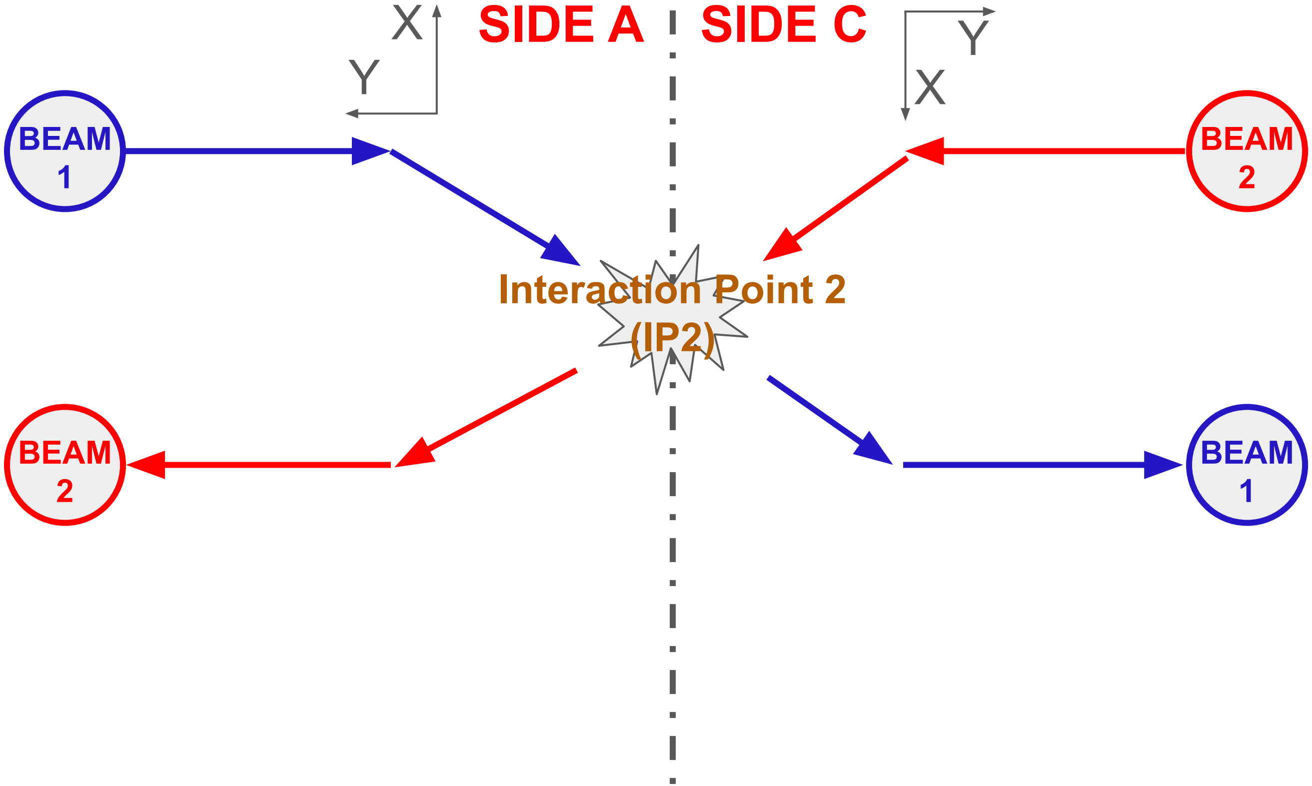
Analog signal IN



Readout strategy and cabling



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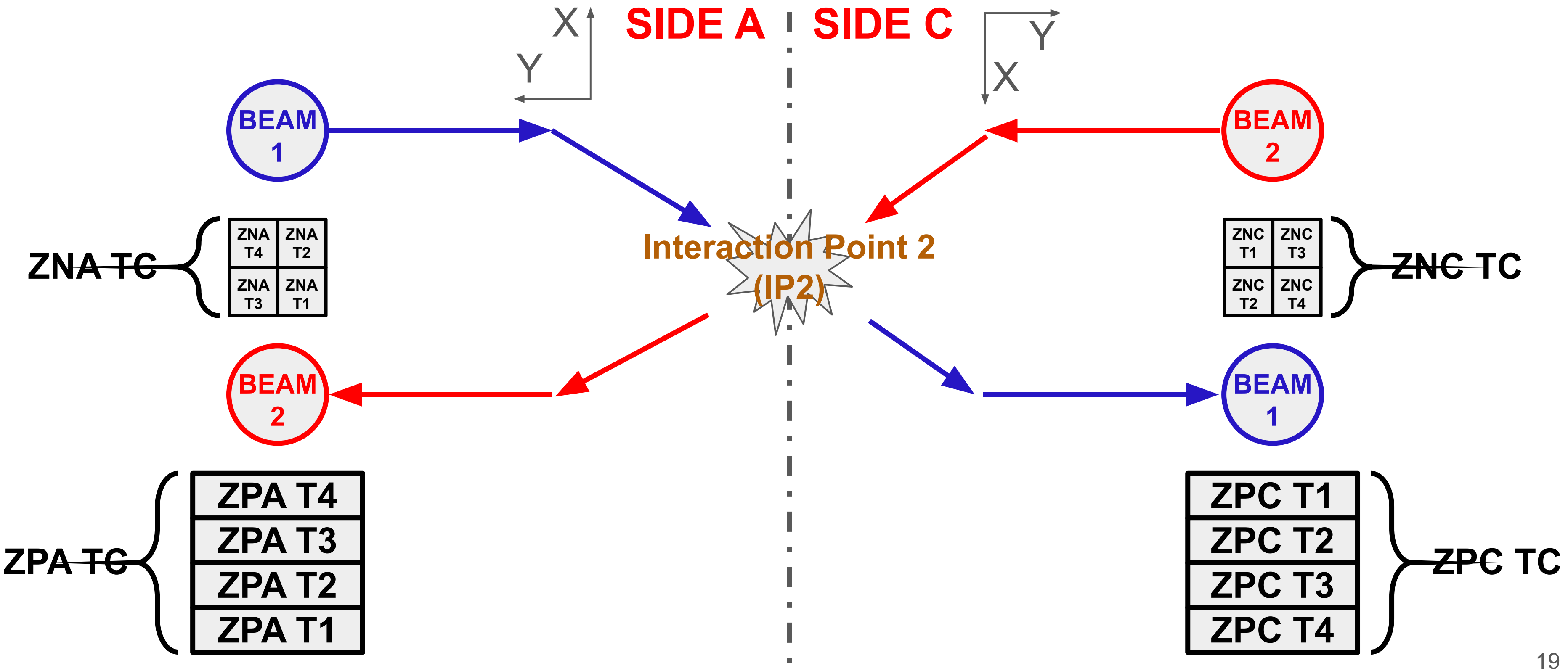

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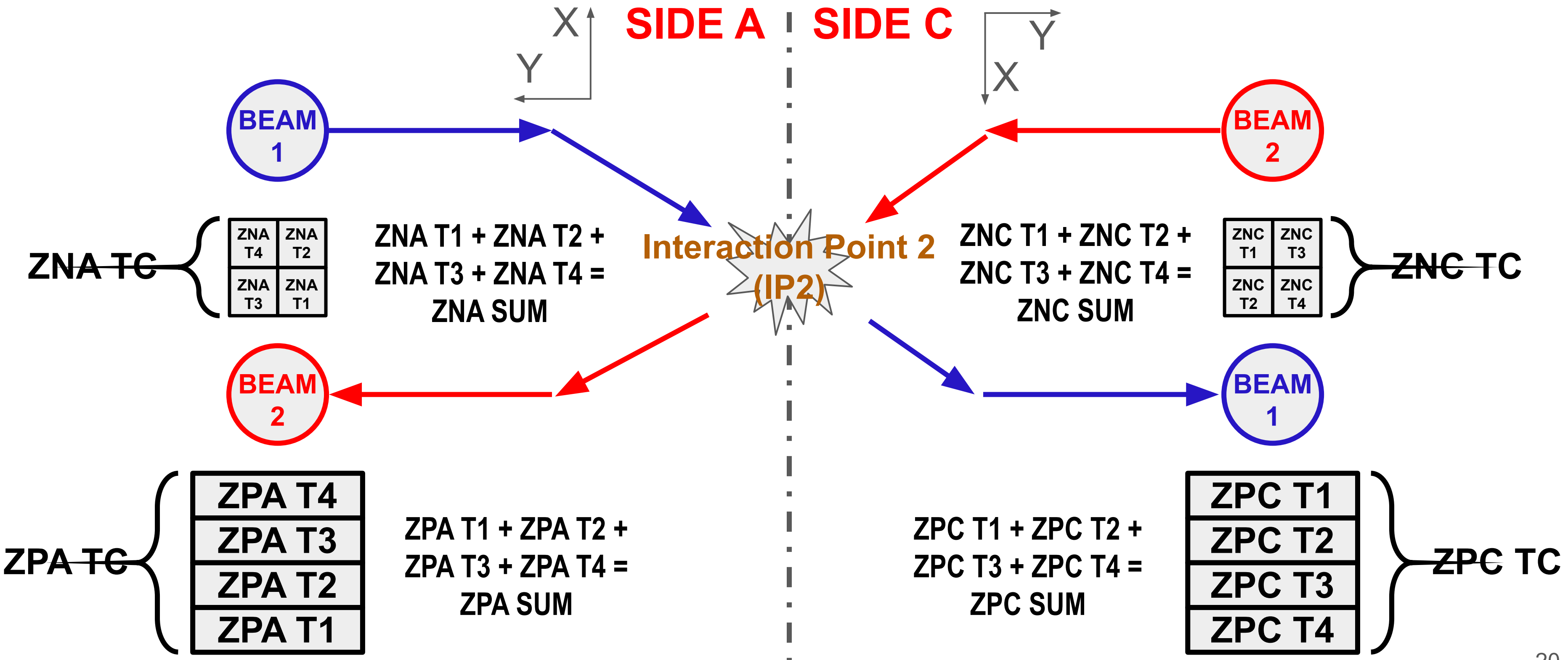
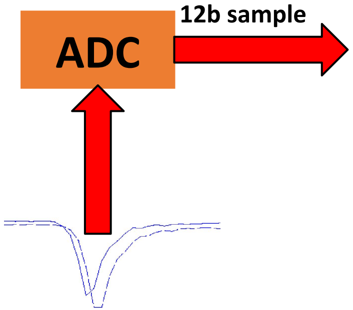


The firmware of the ZDC readout module



Digitization of the signal

The part of the firmware that interfaces with the hardware was developed by a Swiss company, IOxOS, under detailed INFN specifications.

12 samples per BC (25 ns) -> 2.08 ns/sample

color coded in ORANGE

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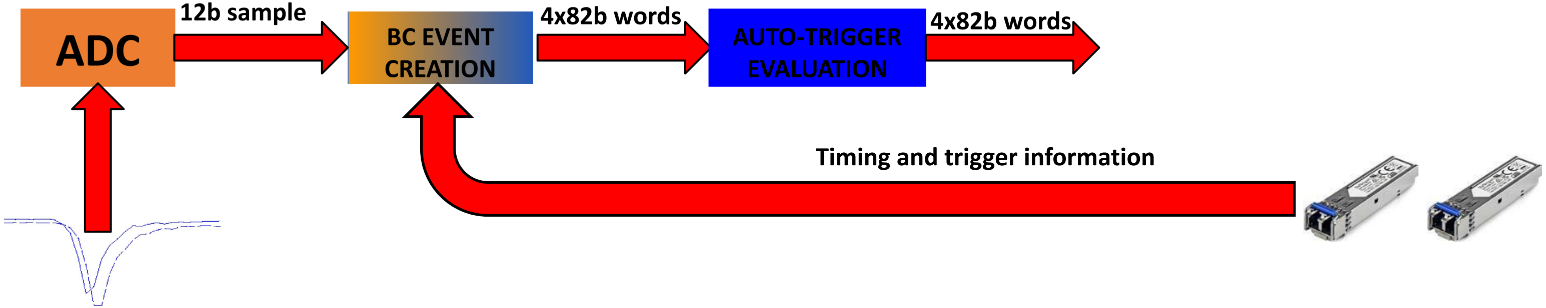


Event packet creation and auto trigger algorithm

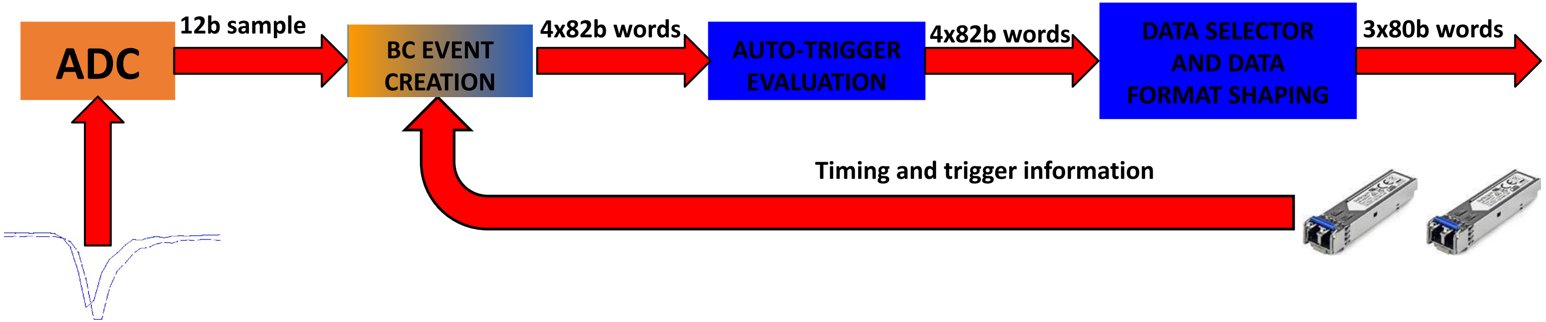
An algorithm evaluating the differences between samples has been developed by INFN Torino. This behaves like a differential threshold, thus a threshold (t) on the derivative of the signal. Indicating with y_i the ith ADC sample and considering that the signal has negative polarity.

$$T = (y_i - y_{i+k} > t) \wedge (y_{i+1} - y_{i+k+1} > t)$$ ← **DOUBLE CONDITION**

$$T = (y_i - y_{i+k} > t) \wedge (y_{i+1} - y_{i+k+1} > t) \wedge (y_{i+2} - y_{i+k+2} > t)$$ ← **TRIPLE CONDITION**

color coded in ORANGE and BLUE

The firmware of the ZDC readout module

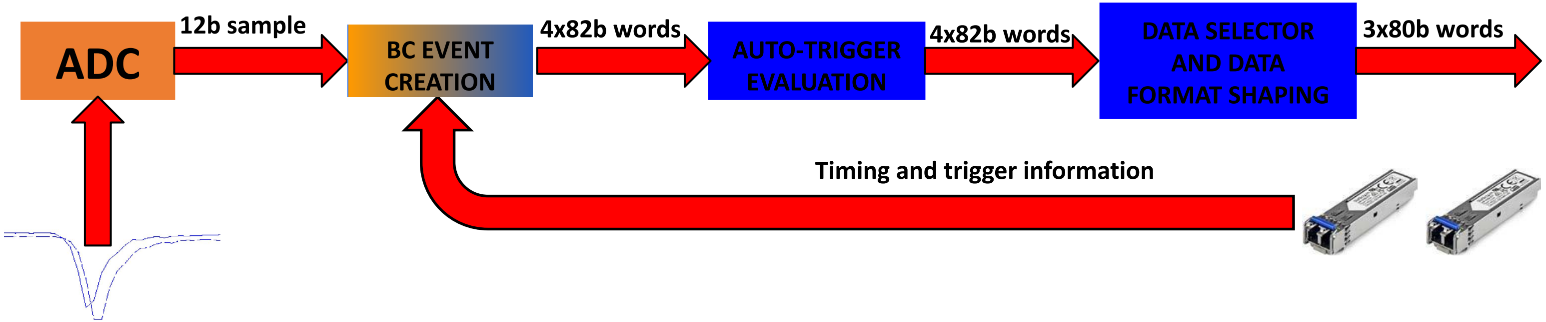


Main firmware features

- 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).

color coded in BLUE

The firmware of the ZDC readout module



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Each readout channel is completely independent and can have different readout and auto-trigger configuration to respect to its neighbors!!!

color coded in BLUE

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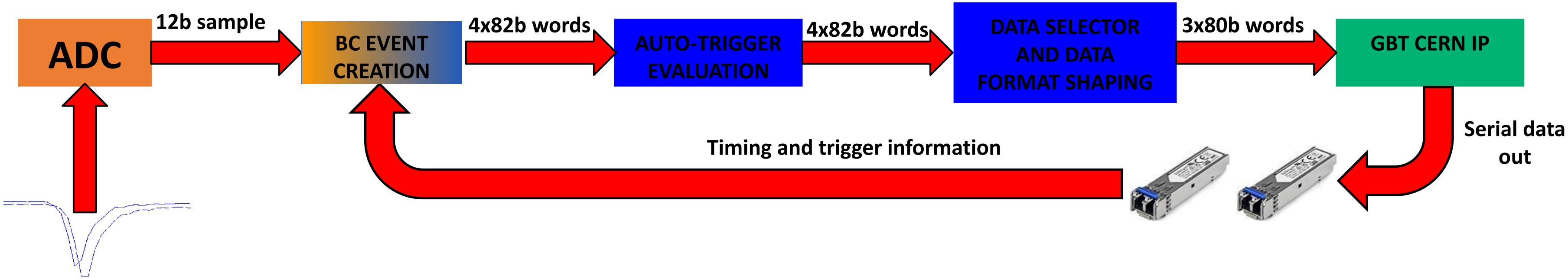
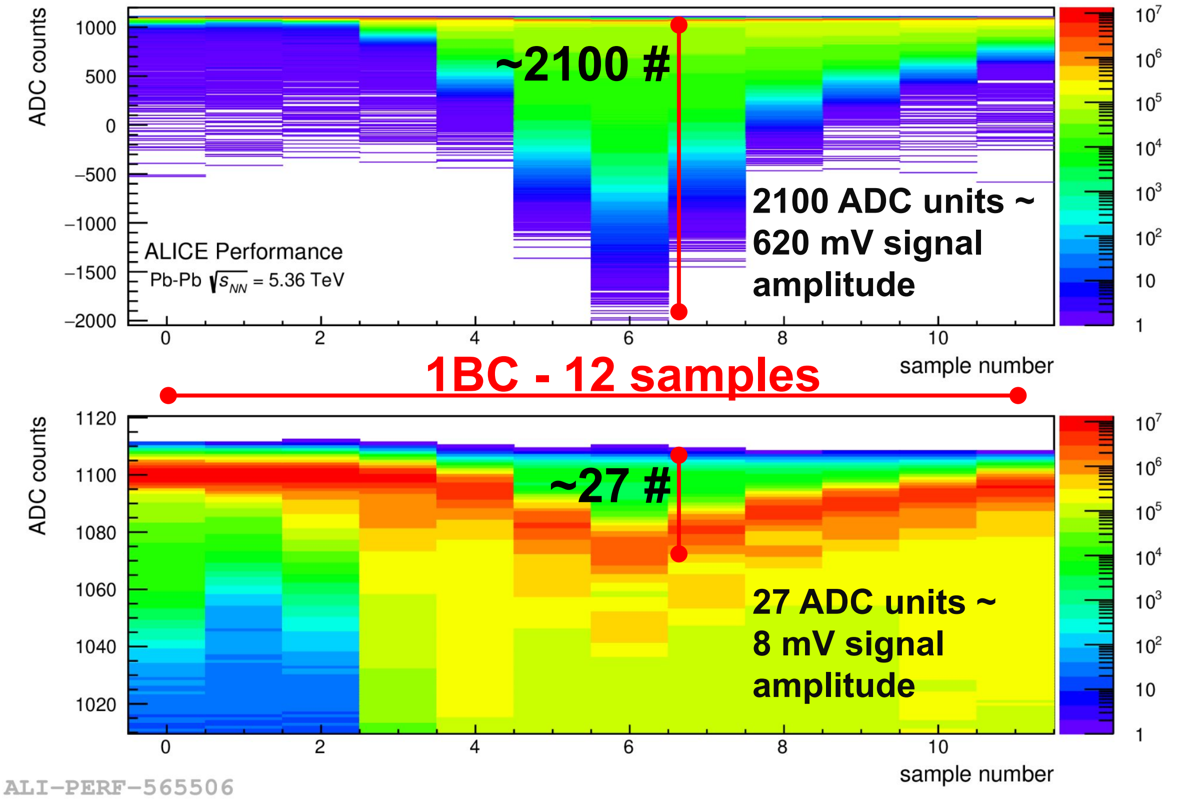


CERN GigaBit Transceiver

For the fiber optic communication, a CERN IP was used, the GigaBit Transceiver (GBT) 4.8 Gbps.
Each module has two links.
The channels with the highest event rate are located on different links in order to spread the load.

color coded in GREEN

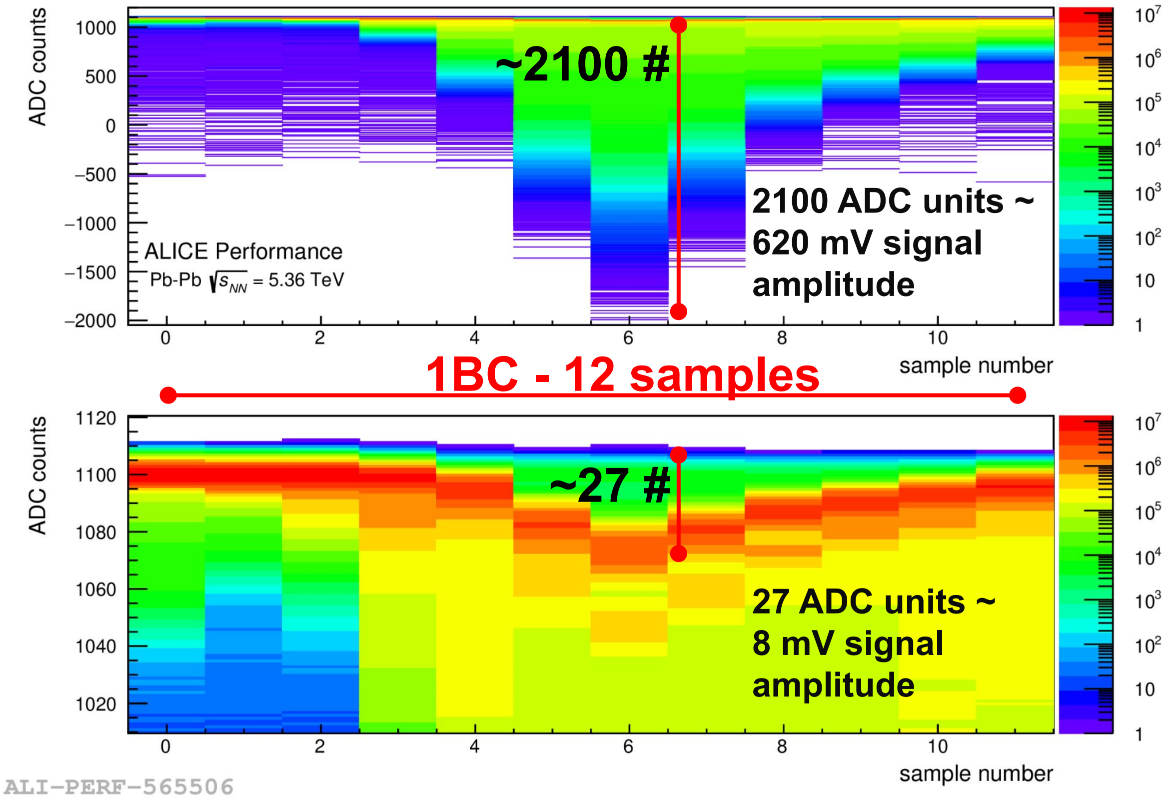
ZDC performance in PbPb - Signal dynamics



ZNC signal shape at 2,68 TeV

1n and 2n at 2,68 TeV signal shapes

ZDC performance in PbPb - Signal dynamics



ZNC signal shape at

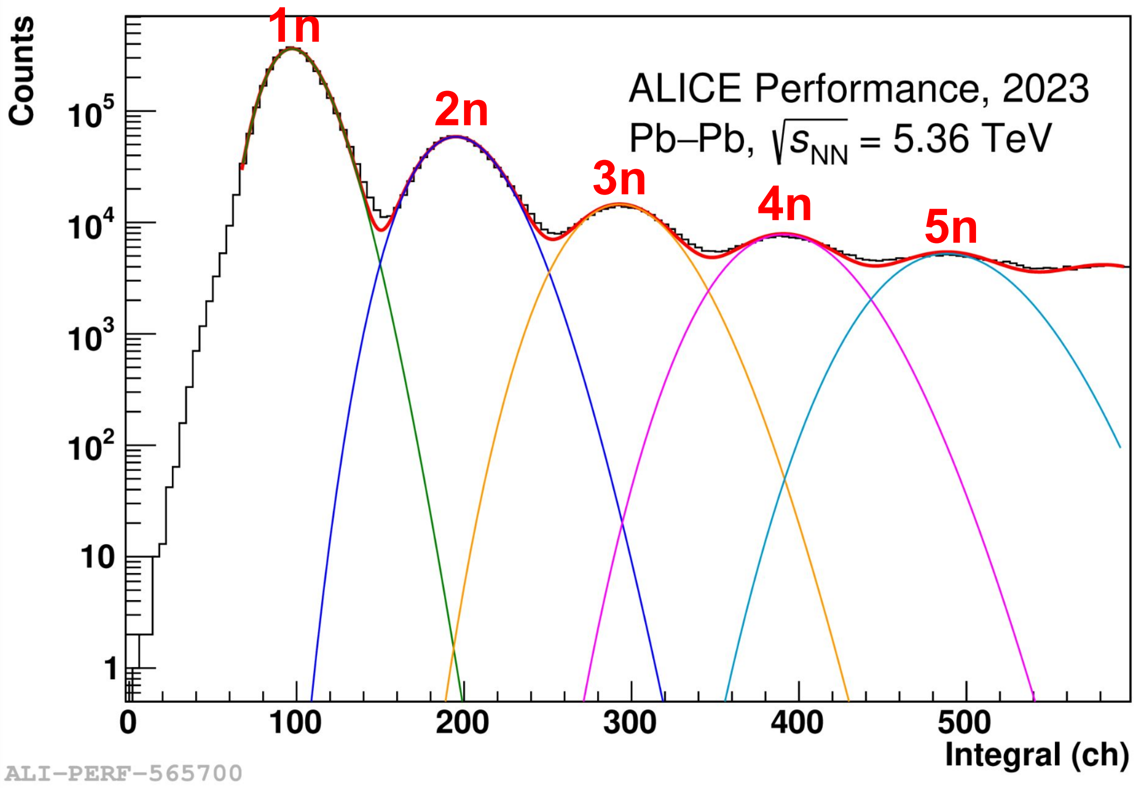
2,

1r

signal shapes

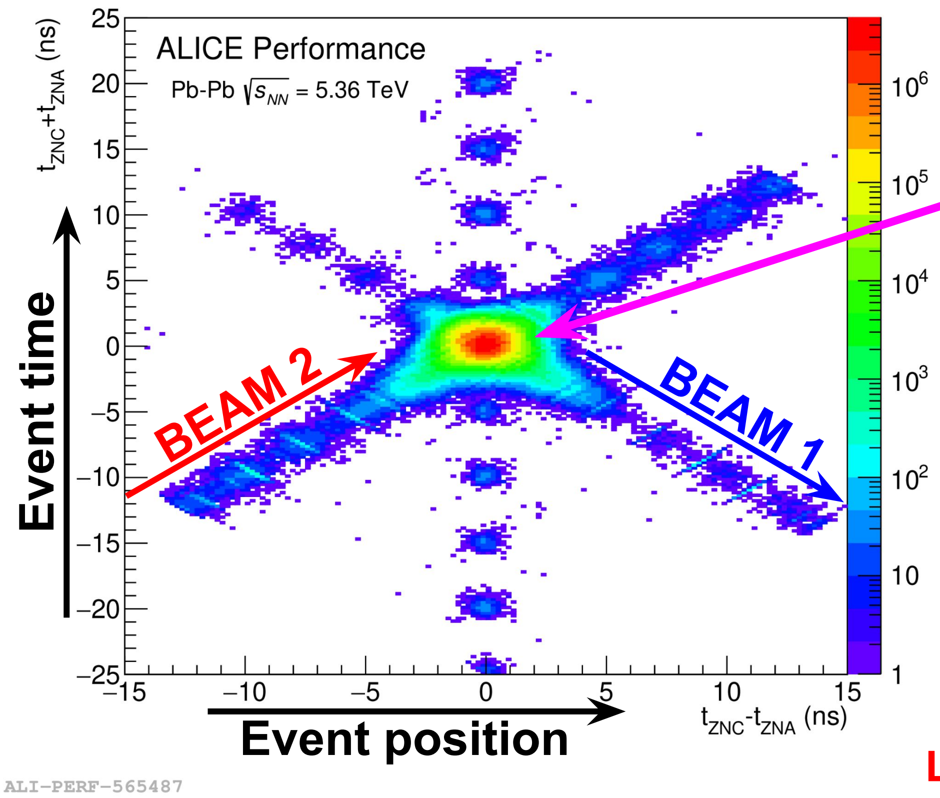
At 50 KHz of nominal hadronic interaction ZNC and ZNA see an event rate of 1.5 MHz due to Electromagnetic Dissociation Processes (EMD)

ZDC performance in PbPb - Energy resolution



1n peak resolution ~ 15% - 16%.
It was 20% in Run 1 and Run 2.

ZDC performance in PbPb - Time resolution

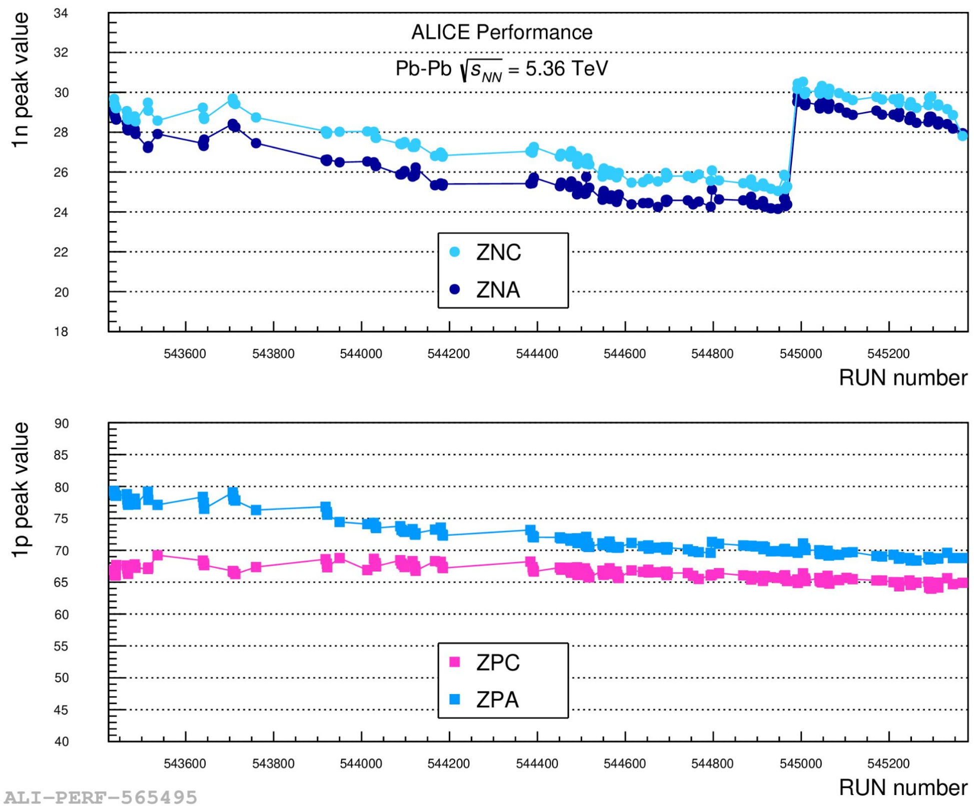


Nominal interactions

Time resolution and rejection of satellites: ZNs can be used to identify displaced collisions.

LHC RF cavities frequency = 400 MHz.

ZDC performance in PbPb - Peak position



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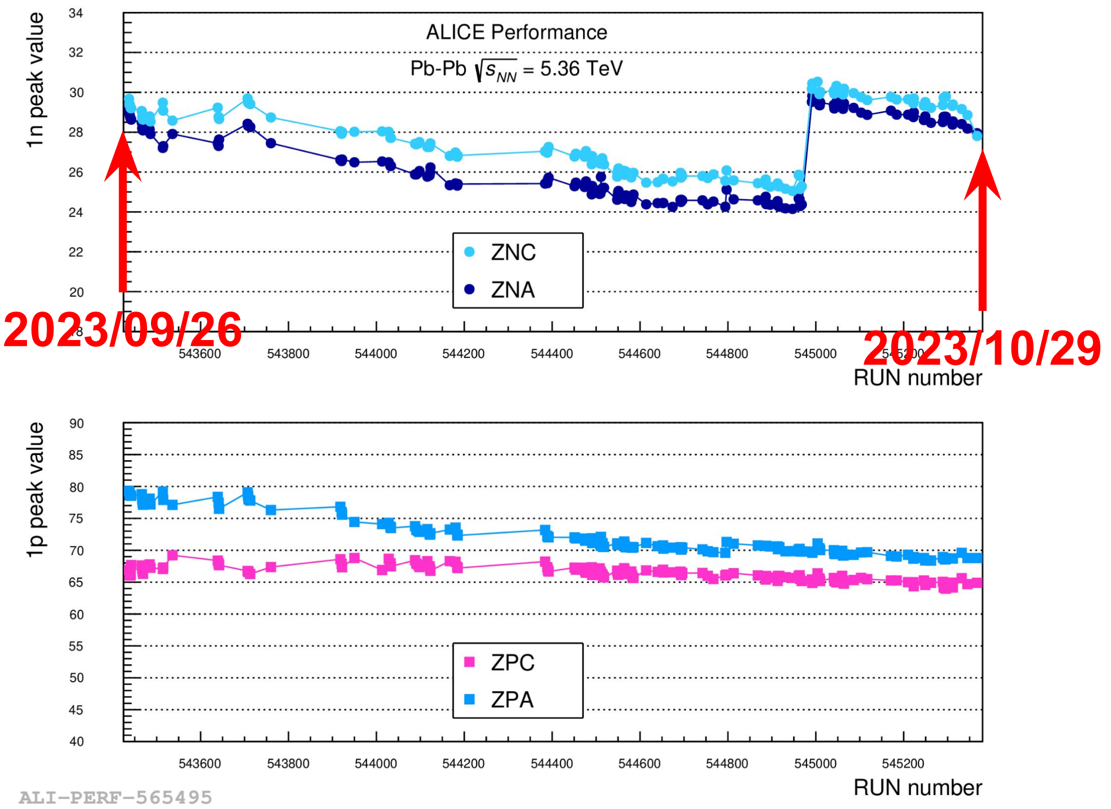
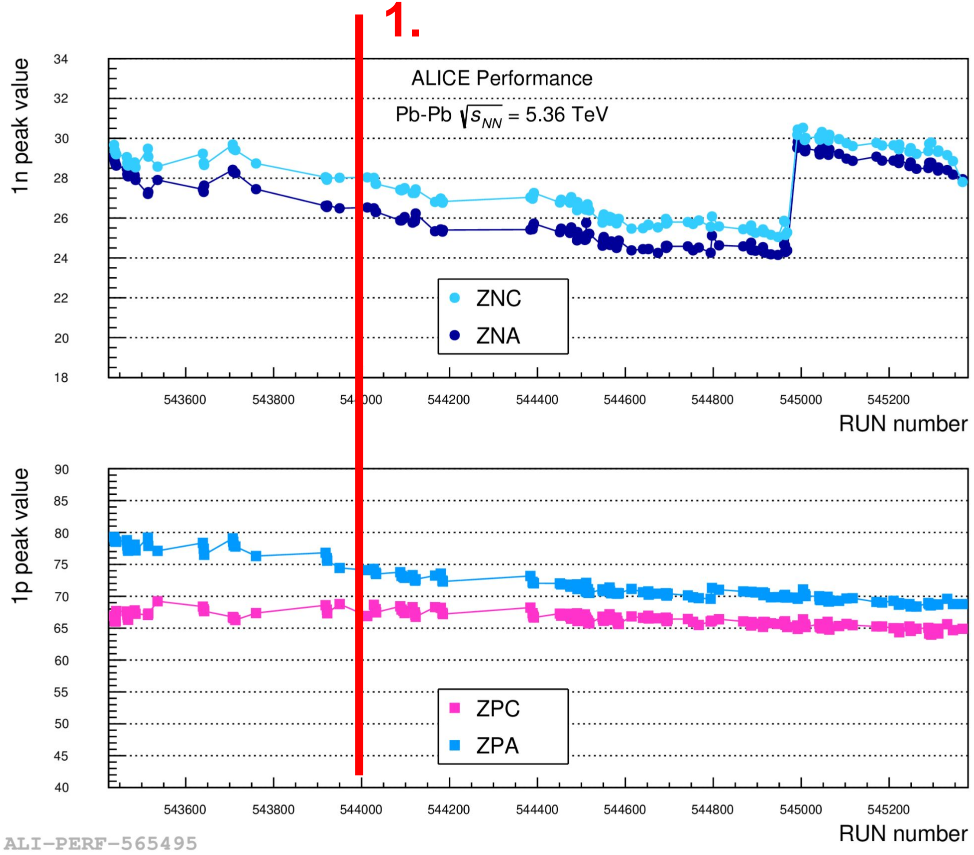
ZDC performance in PbPb - Peak position

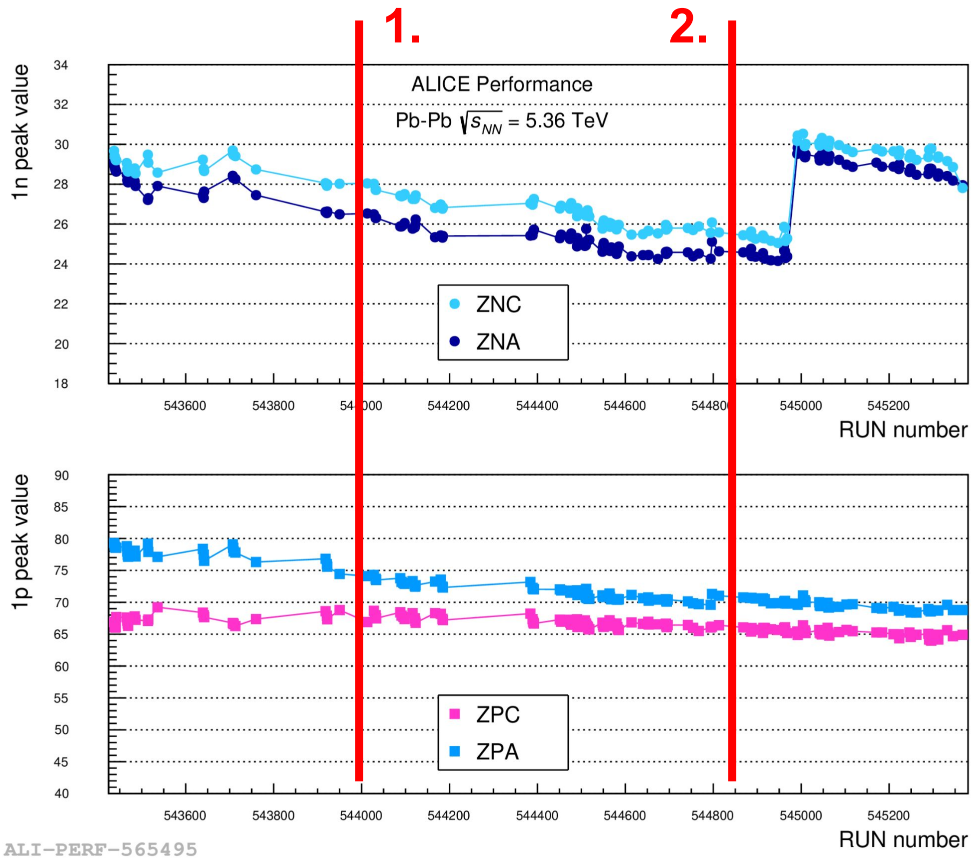


ZDC performance in PbPb - Peak position



1. **Change in the LHC optics & reduction in the background**

ZDC performance in PbPb - Peak position



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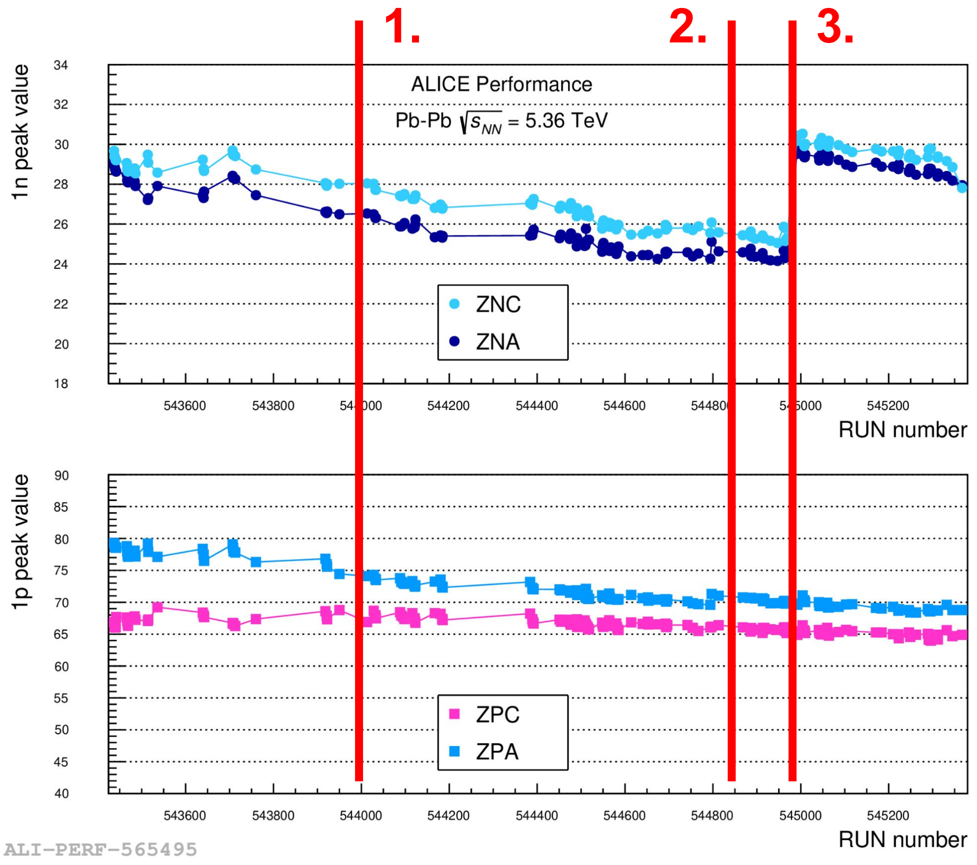
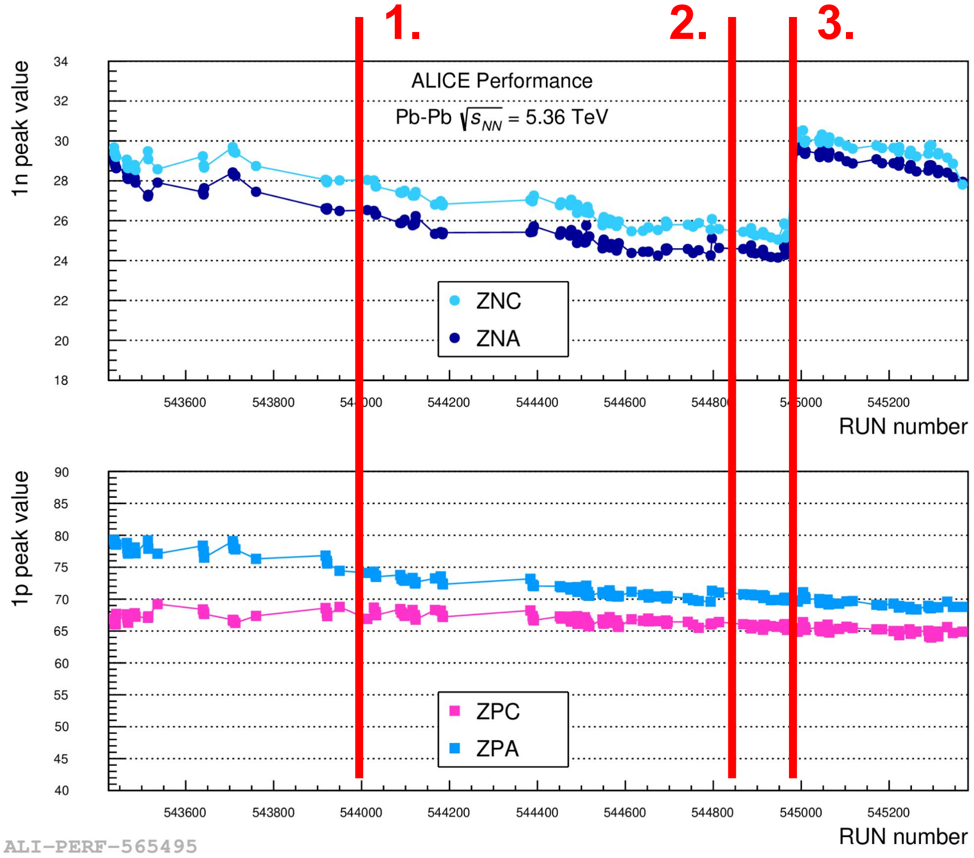
2. Inversion of the alice bipole from +/+ to -/-

ZDC performance in PbPb - Peak position



1. **Change in the LHC optics & reduction in the background**
2. **Inversion of the alice bipole from +/+ to -/-**
3. **Increased HV on ZN photomultipliers**

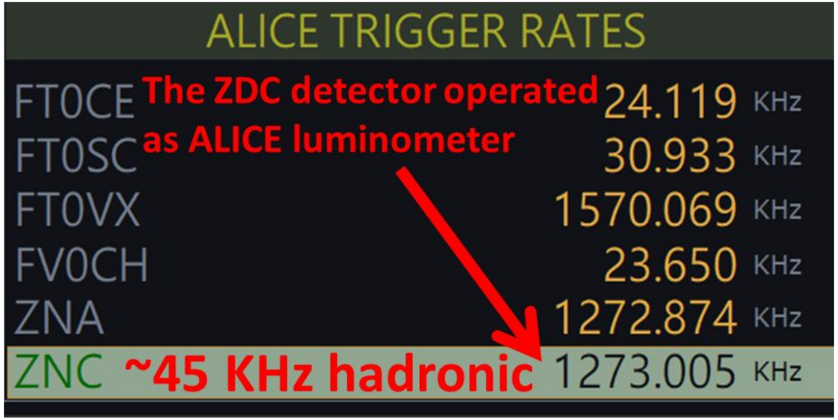
ZDC performance in PbPb - Peak position



1. Change in the LHC optics & re… und
2. In… ble fr…
3. In… photomultipliers

THE SLOPE IN THE 1n PEAK VALUE IS DUE TO THE Pm AGING EFFECT. THIS IS COMPLETELY UNDER CONTROL AND CAN BE COUNTERACTED BY INCREASING SLIGHTLY THE VOLTAGE.

The ZDC as luminometer

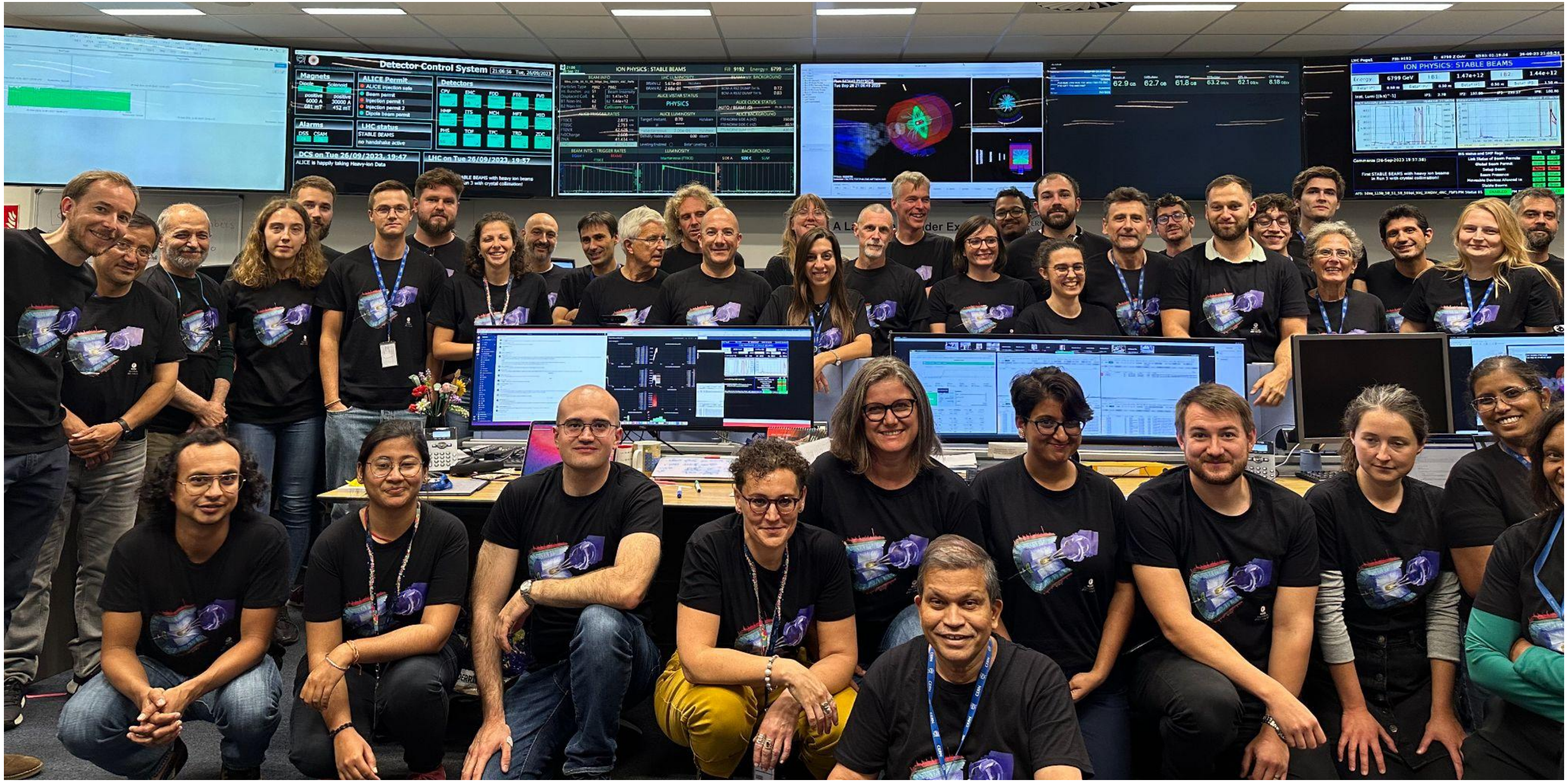


ZDC data throughput during the ALICE VdM scan

Summary and outlook

- A new FPGA based readout system for the ALICE ZDC detector has been developed for Run 3 which is able to operate in self–triggered mode without dead time at a rate of 2.5 Mevent/s.
- The commercial 12 bit 1 GSps digitizers from IOxOS allow an energy resolution of 15 % for the amplitude for the single neutron peak, better than RUN 2.
- The new readout system is fully compliant with the different acquiring modes of the ALICE experiment and was successfully commissioned in October 2023 in Pb-Pb collisions at nominal luminosity.
- The ZDC took data during the October 2023 Pb period at nominal rate without issues.

Thank you for your attention!



BACKUP

The 2023 RUN 3 data taking

Readout strategy and cabling

	MODULE 0	MODULE 1	MODULE 2	MODULE 3
ch 0	ZNA_TC(T)	ZNA_TC (OT)	ZNC_TC(T)	ZNC_TC(OT)
ch 1	ZNA_SUM(OT)	ZNA_SUM(T)	ZNC_SUM(OT)	ZNC_SUM(T)
ch 2	ZNA_T1	ZNA_T3	ZNC_T1	ZNC_T3
ch 3	ZNA_T2	ZNA_T4	ZNC_T2	ZNC_T4

	MODULE 4	MODULE 5	MODULE 6	MODULE 7
ch 0	ZPA_TC(T)	ZPA_TC (OT)	ZPC_TC(T)	ZPC_TC(OT)
ch 1	ZEM1(T)	ZPA_SUM(T)	ZEM2(T)	ZPC_SUM(T)
ch 2	ZPA_T1	ZPA_T3	ZPC_T3	ZPC_T1
ch 3	ZPA_T2	ZPA_T4	ZPC_T4	ZPC_T2

Cabling of each IFC1211 module of the upgraded ZDC readout system.
T = Trigger. OT = Only Trigger. S = Spare.