ALICE FIT data processing and performance during LHC Run 3

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During the upcoming Run 3 and Run 4 at the LHC the upgraded ALICE (A Large Ion Collider Experiment) will operate at a significantly higher luminosity and will collect two orders of magnitude more events than in Run 1 and Run 2. A part of the ALICE upgrade is the new Fast Interaction Trigger (FIT). This thoroughly redesigned detector combines, in one system, the functionality of the four forward detectors used by ALICE during the LHC Run 2: T0, V0, FMD and AD. The FIT will monitor luminosity and background, provide feedback to the LHC, and generate minimum bias, vertex and centrality triggers, in real time. During the offline analysis FIT data will be used to extract the precise collision time needed for time-of-flight (TOF) particle identification. During the heavy-ion collisions, FIT will also determine multiplicity, centrality, and event plane. The FIT electronics designed to function both in the continuous and the triggered readout mode. In these proceedings the FIT simulation, software, and raw data processing are briefly described. However, the main focus is on the detector performance, trigger efficiencies, collision time, and centrality resolution.

1. INTRODUCTION

ALICE (A Large Ion Collider Experiment) is the dedicated heavy ion experiment at the CERN Large Hadron Collider (LHC) [1]. The main goals of ALICE are: physics of the strongly interacting matter at extreme energy densities and the formation of the Quark-Gluon Plasma (QGP) — a new phase of matter. The ALICE detector is undergoing a major upgrade during the Long Shutdown 2 (2019-2021). The main reason for the upgrade is the increased luminosity and interaction rate. The LHC will deliver Pb–Pb collisions at up to luminosity $6 \cdot 10^{27} cm^{-2}s^{-1}$, corresponding to an interaction rate of 50 kHz. The goal of

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ALICE is to integrate a luminosity of 13 nb$^{-1}$ for Pb–Pb collisions at $\sqrt{s_{NN}} = 5.5$ TeV, together with dedicated p–Pb and pp reference runs. Data from pp collisions will also be collected at the nominal LHC energy $\sqrt{s} = 14$ TeV [2]. Run 3 at the CERN LHC is scheduled to start in 2022.

The ALICE upgrade includes:

• A new, high-resolution, low material Inner Tracking System (ITS)
• An upgrade of the Time Projection Chamber (TPC)
• New Muon Forward Tracker (MFT)
• New Central Trigger Processor (CTP)
• New Fast Interaction Trigger (FIT) detector
• New readout and trigger systems allowing for continuous data taking.

2. FIT DETECTOR

2.1. General description

The new Fast Interaction Trigger [3] replaces four Run 2 detectors (T0, VZERO, FMD and AD [4]) with three new subdetectors: FV0, FT0 and FDD. These three subdetectors, each utilizing a different technology, are placed at both sides of the interaction point, in the forward and backward rapidity regions, as shown in Fig. 1. The online functionality of FIT includes luminosity monitoring and the lowest-latency (< 425 ns) minimum bias, vertex, and centrality triggers. Offline, FIT provides the precise collision time for the TOF-based particle identification, determines the centrality and event plane, and measures the cross section of diffractive processes. In addition, FIT can reject beam-gas events and provide vetoes for ultra-peripheral collisions.

2.2. Construction of FIT subdetectors

The FT0 subdetector has two modular arrays, FT0A and FT0C, placed at opposite sides of the interaction point. The FT0A array consists of 24 modules, and the FT0C array,
of 28 modules. Each module has four, optically separated, 2 cm-thick quartz Cherenkov radiators, coupled to a customized PLANACON MCP-PMT. The anodes of the MCP-PMT are grouped into four outputs providing an independent readout channel from each individual radiator segment. As a result, FT0A delivers 96 readout channels and FT0C, 112 channels. The FT0C, being located close to the interaction point, has a concave shape to equalize the flightpath of primary particles and assure their perpendicular entry to the radiators. The intrinsic time resolution of each section of a module is $\approx 13$ ps. The FT0 contributes to the minimum bias trigger, luminosity monitoring, and background rejection.

The FV0 is a large scintillator disk, assembled from 40 optically insulated elements, arranged in 8 sectors and 5 rings with progressing radii. Clear optical fibers deliver light from each element to a Hamamatsu R5924-70 PMT. Owing to its much larger size, each sector of the outermost ring is read by two PMTs. In total there are 48 FV0 readout channels. Time resolution is $\approx 200$ ps. The FV0 provides inputs for minimum bias and multiplicity triggers at LM (Level Minus one) level and, because of its large acceptance, delivers data for centrality and event plane determination.

The FDD consists of two stations, FDDA and FDDC, covering very forward rapidity region at the opposite sides of interaction point. The stations are made of two layers of plastic scintillators, divided into four quadrants. Each quadrant has two wavelengths shifting (WLS) bars connected to individual PMTs via a bundle of clear optical fibers. Benefiting from the forward pseudorapidity coverage, the FDD will contribute to cross section measurements of diffractive processes [5] and studies of ultra-peripheral collisions, and participate in beam monitoring and beam-gas rejection.

2.3. FIT electronics

The FT0, FV0, and FDD utilize the same electronics scheme based on two custom-designed modules: the processing Module (PM) and the Trigger and Clock Module (TCM). The PM processes and digitizes input signals, packs the data for readout (in continuous or triggered mode), and makes the first stage calculations for trigger decision. The TCM processes data from PMs, makes the final trigger decisions, provides accurate clock reference, and serves as the slow control interface to the connected PMs.
3. FIT DATA PROCESSING

All ALICE detectors are integrated into a common Detector Control System and Online and Offline Computing system called O$^2$ [6].

The functional flow of the O$^2$ system includes a succession of steps. Data arrive at the First Level Processors (FLP) from the detectors. The first data compression is performed inside of an FPGA-based readout card (Common Readout Unit). The data is transferred from the detectors either in a triggered or in a continuous mode. Temporary simulated raw data were used for system preparation and performance studies. Heart-Beat triggers from Central Trigger Processor (CTP) are used to chop data in Sub-Time Frames (STF). The STF are assembled into Time Frames (TF) in the Event Processing Nodes (EPN). One TF packet includes 128 or 256 orbits. A second step of data aggregation is performed to assemble the data from all detector inputs. A global calibration, the first reconstruction and data compression using Graphics Processing Unit (GPU) is performed synchronously with the data taking. Compressed Time Frames (CTF) are stored permanently on tapes. Results of each step are monitored within the Quality Control (QC) framework.

In the asynchronous stage, a second (and possibly third) reconstruction with final calibration is run on the O$^2$ EPN farm and on the GRID. The final Analysis Object Data (AOD) is produced and stored permanently.

4. FIT FT0 PERFORMANCE

4.1. FIT FT0 performance in pp collisions at $\sqrt{s} = 14$ TeV

The FT0 can produce trigger signals every 25 ns that is for each LHC bunch crossing. However, due to the limited acceptance, the efficiency has to be verified by simulations. Pythia8 [7] was used to simulate particles from pp collisions. Twenty thousand pp collisions were generated and transported through the ALICE setup. Cherenkov photons from relativistic charged particles traversing quartz radiators were utilized to produce digitized signals taking into account the detector response and possible pile-up. The signals were used to evaluate the efficiency of the following FT0 triggers:

- FT0A – signal only from the A side;
- FT0C – signal only from the C;
Vertex – signals from both sides and vertex within given range.

Fig. 2 shows FT0 trigger efficiencies as a function of event multiplicity. Total vertex trigger efficiency is approximately 77%, fraction of triggered events with only FT0A trigger signal is 9%, FT0C – 6%.

Collision time is half of the sum of the average arrival times at FT0A and FT0C and does not depend on the position of the primary vertex. The resolution can be estimated as a sigma parameter of a Gaussian fit of the distribution of differences between the average arrival times on each side, corrected with the primary vertex. As shown in Fig. 3, the resolution of the collision time is below 20 ps for pp collisions at \( \sqrt{s} = 14 \) TeV. If the collision time measured can not be obtained due to the limited acceptance of FT0, the individual times measured by FT0A and FT0C, corrected for the primary vertex position, could be used.

4.2. FT0 performance for Pb-Pb collisions

When the impact parameter of two colliding ions is larger than the sum their radii, hadron collisions are replaced by electromagnetic interactions corresponding to photon-photon and photon-nuclear collisions. The main source of background comes from pair production \((e^+e^-)\), having orders of magnitude larger cross section than the hadronic processes. For instance, according to PYTHIA8, the Pb-Pb hadronic cross-section at \( \sqrt{s_{NN}} = 5.5 \) TeV is 8 b while the cross section for electromagnetic collisions, used by the QED generator, developed especially for ALICE, is around 180 kb. Fortunately, QED events have a very low charged particle multiplicity. They can be rejected by setting a threshold value for the sum of the FT0A and FT0C amplitudes.

Fig. 4 shows the efficiency of the minimum bias trigger (coincidence between FT0A and FT0C) as a function of the impact parameter for hadron collisions. The squares (dots) show the results with (without) the selection on the amplitude. It is clear that, for events with an impact parameter below 12 fm, the amplitude cut does not affect the efficiency of the minimum bias trigger. The total efficiency of the FT0A and FT0C trigger is \( \approx 92\% \). The vertex trigger (coincidence between FT0A and FT0C together with the requirement for the position of the z-vertex lie to within 10 cm around interaction point) efficiency is 83%. For central and semi-central events the efficiency of the vertex trigger is 100%.

Centrality determination with a good resolution is an important functionality of
the FIT detector. Fig. 5 shows the centrality resolution for Pb-Pb collision at $\sqrt{s_{NN}} = 5.5$ TeV calculated for FT0A, FT0C, and FV0 separately, and the combined resolution (FT0A+FT0C+FV0).

5. CONCLUSIONS

Our analysis has demonstrated that the simulated performance of the FT0 subdetector of FIT satisfies the design requirements of the ALICE experiment:

- The minimum bias trigger efficiency matches that of the VZERO detector operated during the Run 1 and 2 of the LHC;
- The collision time resolution is better than that of the T0 during the Run 1 and Run 2;
- The vertex trigger has a 100% efficiency for semi-central and central events.

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**Figure 1.** FIT detector layout.
Figure 2. Efficiency of FT0 triggers: vertex trigger (triangles), trigger only from A side (circles); trigger only from C side (squares).
Figure 3. Distribution of a difference between average arrival times on each side corrected with the primary vertex for pp collisions at $\sqrt{s} = 14$ TeV. The bold line is a Gaussian fit, with the sigma of the fit being the resolution on the collision time.
Figure 4. Minimum bias trigger efficiency as a function of impact parameter. Red squares show efficiency of minimum bias trigger, green circles are efficiency of both minimum bias trigger and cut of the sum of the amplitude at 30 ADC channels.
Figure 5. Centrality resolution for measurements with different parts of the FIT detector. FT0A (up triangles), FT0C (down triangles), FV0 (squares), combination of all 3 (dots).