Chapter 1

Introduction

1.1 ALICE experiment

ALICE (A Large Ion Collider Experiment) is a general-purpose, heavy-ion detector at the CERN LHC which focuses on QCD, the strong interaction sector of the Standard Model. It is designed to address the physics of strongly interacting matter and the quark-gluon plasma at extreme values of energy density and temperature in nucleus-nucleus collisions. It will allow a comprehensive study of hadrons, electrons, muons, and photons produced in the collision of heavy nuclei (Pb-Pb), up to the highest multiplicities anticipated at the LHC. The physics programme also includes collisions with lighter ions and at lower energy, in order to vary energy density and interaction volume, as well as dedicated proton-nucleus runs. Data taking during proton-proton runs at the top LHC energy will provide reference data for the heavy-ion programme and address a number of specific strong-interaction topics for which ALICE is complementary to the other LHC detectors.

The first conceptual ideas for a general-purpose, heavy-ion detector at the LHC were formulated in a workshop, sponsored by ECFA, at the end of 1990 [1]. The ALICE concept evolved via the Expression of Interest [2] and a Letter of Intent [3] towards the Technical Proposal [4] and its Addenda [5–7]. The experiment was approved in 1997 and the designs of the different detector systems are described in detail in a number of Technical Design Reports [8–19]. The expected detector performance and the physics reach, based on detailed simulations, are summarized in the Physics Performance Report [20, 21].[1]

The ALICE detector is built by a collaboration including currently over 1000 physicists and engineers from 105 Institutes in 30 countries. Its overall dimensions are $16\times16\times26\,\mathrm{m}^3$ with a total weight of approximately 10 000 t. ALICE consists of a central barrel part, which measures hadrons, electrons, and photons, and a forward muon spectrometer. The central part covers polar angles from 45° to 135° and is embedded in a large solenoid magnet reused from the L3 experiment at LEP. From the inside out, the barrel contains an Inner Tracking System (ITS) of six planes of high-resolution silicon pixel (SPD), drift (SDD), and strip (SSD) detectors, a cylindrical Time-Projection Chamber (TPC), three particle identification arrays of Time-of-Flight (TOF), Ring Imaging Cherenkov (HMPID) and Transition Radiation (TRD) detectors, and two electromagnetic

[1]The ALICE detector was described previously in the PPR and some figures and tables are reproduced in this article with permission from the publisher.

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calorimeters (PHOS and EMCal). All detectors except HMPID, PHOS, and EMCal cover the full azimuth. The forward muon arm (2°–9°) consists of a complex arrangement of absorbers, a large dipole magnet, and fourteen planes of tracking and triggering chambers. Several smaller detectors (ZDC, PMD, FMD, T0, V0) for global event characterization and triggering are located at small angles. An array of scintillators (ACORDE) on top of the L3 magnet is used to trigger on cosmic rays. Table 1.1 and figures 1.1, and 1.2 summarize the acceptance and location of the various detector systems.

Most detector systems will be installed and ready for data taking by mid 2008 when the LHC is scheduled to start operation, with the exception of parts of PHOS (1 out of 5 modules installed), TRD (4 out of 18), PMD, and EMCal (construction started in 2008). These detectors will be completed for the high-luminosity ion runs expected in 2010 and after.

1.2 Design considerations

1.2.1 Physics observables

As the single dedicated heavy-ion experiment at the LHC, ALICE is a general-purpose detector addressing a broad range of observables which were typically covered at previous accelerators (AGS, SPS, RHIC) by a suite of more specialized experiments. A comprehensive overview of the physics requirements as well as the expected performance of ALICE is given in the Physics Performance Reports [20, 21] and briefly summarized below according to the aspect of the collision on which they provide some information.

Global event features such as multiplicity and transverse or zero-degree energy flow define the geometry, i.e. impact parameter, shape and orientation of the collision volume, and number of interacting nucleons. Nuclear modifications to the parton distribution function can be extracted by comparing global event features and, more directly, specific hard processes (e.g. direct photons, heavy flavours in pp, pA and A-A collisions.

Heavy flavour production, and jet fragmentation will probe parton kinematics and energy loss in the plasma phase. Elliptic flow is sensitive to plasma properties like shear viscosity and equation of state. Promt photons can reveal the thermal radiation from the early phase. Quarkonia production probes deconfinement and parton recombination whereas resonance parameters (masses, branching ratios) is sensitive to chiral symmetry restoration. Particle ratios and p_{t} distributions are governed by thermodynamical properties and hydrodynamical evolution at and around the phase transition. Particle interferometry measures the space time evolution of the collision, and non-statistical fluctuations would be a sign of critical phenomena in the vicinity of a first-order phase transition.

1.2.2 Performance specification

The choice and design of ALICE is driven by the physics requirements as well as by the experimental conditions expected in nucleus-nucleus collisions at the LHC. The most stringent design constraint is the extreme particle multiplicity, which could be up to three orders of magnitude larger than in typical pp interactions at the same energy and a factor two to five still above the highest

Table 1.1: Summary of the ALICE detector subsystems. The acceptance in η is calculated from the nominal interaction point and is 360° in azimuth, unless noted otherwise. The position is the approximate distance from the interaction point to the face of the detector and corresponds to the radius for barrel detectors (inner and outer radius for the TPC and TRD) or the position along the beam (z coordinate) for the others. The dimension corresponds to the total area covered by active detector elements. 'Channels' is the total number of independent electronic readout channels. In case a detector is subdivided, the numbers refer to the individual components (e.g. pixel layers 1 and 2, muon tracking stations 1–5).

Detector	Acceptance (η, ϕ)	Position (m)	Dimension (m^2)	Channels
ITS layer 1,2 (SPD)	± 2, ± 1.4	0.039, 0.076	0.21	9.8 M
ITS layer 3,4 (SDD)	± 0.9, ± 0.9	0.150, 0.239	1.31	133 000
ITS layer 5,6 (SSD)	± 0.97, ± 0.97	0.380, 0.430	5.0	2.6 M
TPC	± 0.9 at r=2.8 m	0.848, 2.466	readout 32.5 m^2	557 568
	± 1.5 at r=1.4 m		Vol. 90 m^3	
TRD	± 0.84	2.90, 3.68	716	1.2 M
TOF	± 0.9	3.78	141	157 248
HMPID	± 0.6, $1.2° < \phi < 58.8°$	5.0	11	161 280
PHOS	± 0.12, $220° < \phi < 320°$	4.6	8.6	17 920
EMCal	± 0.7, $80° < \phi < 187°$	4.36	44	12 672
ACORDE	± 1.3, $-60° < \phi < 60°$	8.5	43	120
Muon Spectrometer				
Tracking station 1	$-2.5 < \eta < -4.0$	−5.36	4.7	1.08 M
Tracking station 2		−6.86	7.9	
Tracking station 3		−9.83	14.4	
Tracking station 4		−12.92	26.5	
Tracking station 5		−14.22	41.8	
Trigger station 1	$-2.5 < \eta < -4.0$	−16.12	64.6	21 000
Trigger station 2		−17.12	73.1	
ZDC:ZN	$\lvert\eta\rvert < 8.8$	± 116	2×0.0049	10
ZDC:ZP	$6.5 < \lvert\eta\rvert < 7.5$	± 116	2×0.027	10
	$-9.7° < \phi < 9.7°$			
ZDC:ZEM	$4.8 < \eta < 5.7$,	7.25	2×0.0049	2
	$-16° < \phi < 16°$ and			
	$164° < \phi < 196°$			
PMD	$2.3 < \eta < 3.7$	3.64	2.59	2 221 184
FMD disc 1	$3.62 < \eta < 5.03$	inner: 3.2		
FMD disc 2	$1.7 < \eta < 3.68$	inner: 0.834	0.266	51 200
		outer: 0.752		
FMD disc 3	$-3.4 < \eta < -1.7$	inner:−0.628		
		outer:−0752		
V0A	$2.8 < \eta < 5.1$	3.4	0.548	32
V0C	$-1.7 < \eta < -3.7$	−0.897	0.315	32
T0A	$4.61 < \eta < 4.92$	3.75	0.0038	12
T0C	$-3.28 < \eta < -2.97$	−0.727	0.0038	12

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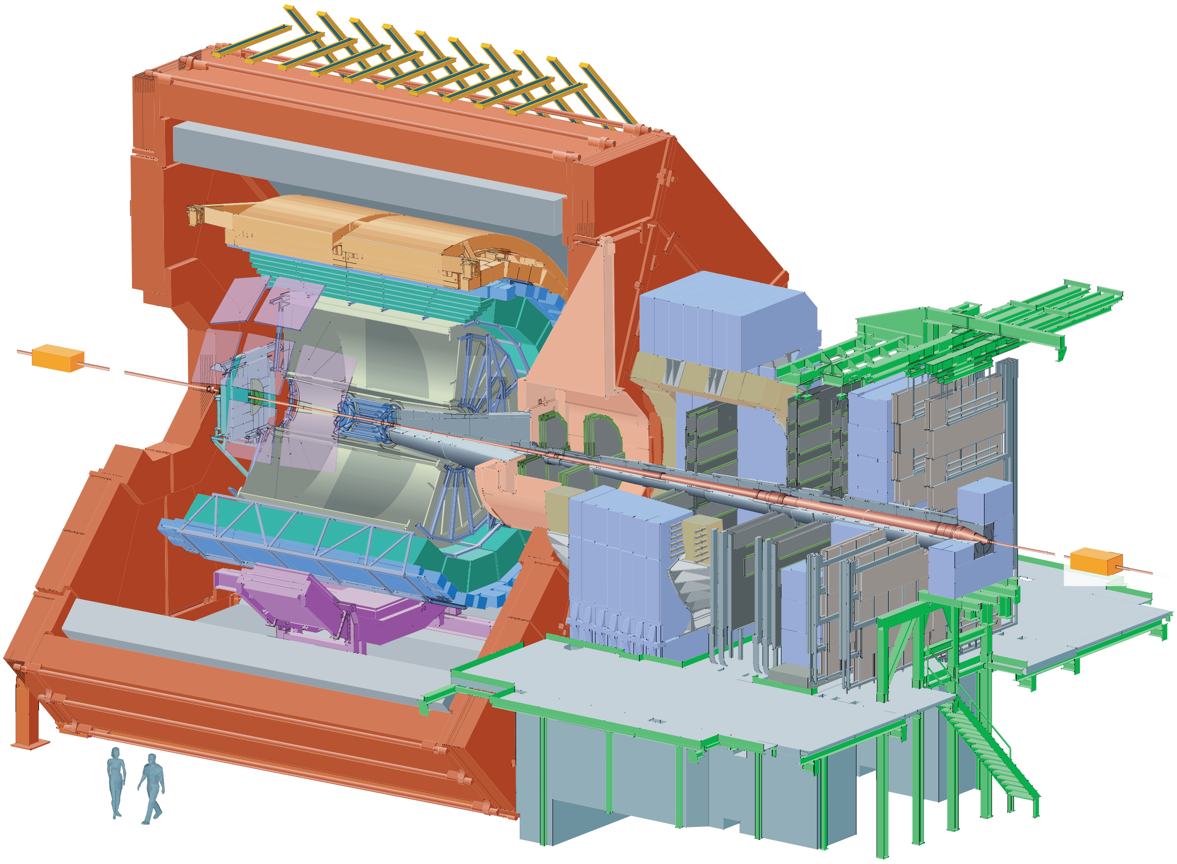

Figure 1.1: ALICE schematic layout.

multiplicities measured at RHIC. Originally, estimates for the charged particle multiplicity density at mid-rapidity in central Pb–Pb collisions spanned the range from $\mathrm{d}N/\mathrm{d}\eta$ = 2000 up to almost $\mathrm{d}N/\mathrm{d}\eta$ = 8000. More recent extrapolations from RHIC measurements point to significantly lower values of $\mathrm{d}N/\mathrm{d}\eta$ = 1500–4000. The design of ALICE was optimized for a value of about $\mathrm{d}N/\mathrm{d}\eta$ = 4000, but tested with simulations up to twice that amount. The tracking was made particularly safe and robust by using mostly three-dimensional hit information with many points (up to 150) in a moderate field of 0.5 T. A large dynamic range is required for momentum measurement, spanning more than three orders of magnitude from tens of MeV/c (collective effects at large length scales, good acceptance for resonance decays) to well over 100 GeV/c (jet physics). This is achieved with a combination of very low material thickness to reduce multiple scattering at low p_t (13% X_0 up to the end of the TPC) and a large tracking lever arm of up to 3.5 m to guarantee a good resolution at high p_t. Particle Identification (PID) over much of this momentum range is essential, as many observables are either mass or flavour dependent. ALICE employs essentially all known PID techniques: specific ionization energy loss $\mathrm{d}E/\mathrm{d}x$, time-of-flight, transition and Cherenkov radiation, electromagnetic calorimetry, muon filters, and topological decay reconstruction.

ALICE will concentrate on physics at or close to midrapidity, i.e. the region of lowest baryon density and maximum energy density. The acceptance has to be sufficient to cover particle decays even at low momentum, jet fragmentation, and to study some variables on an event-by-event basis,

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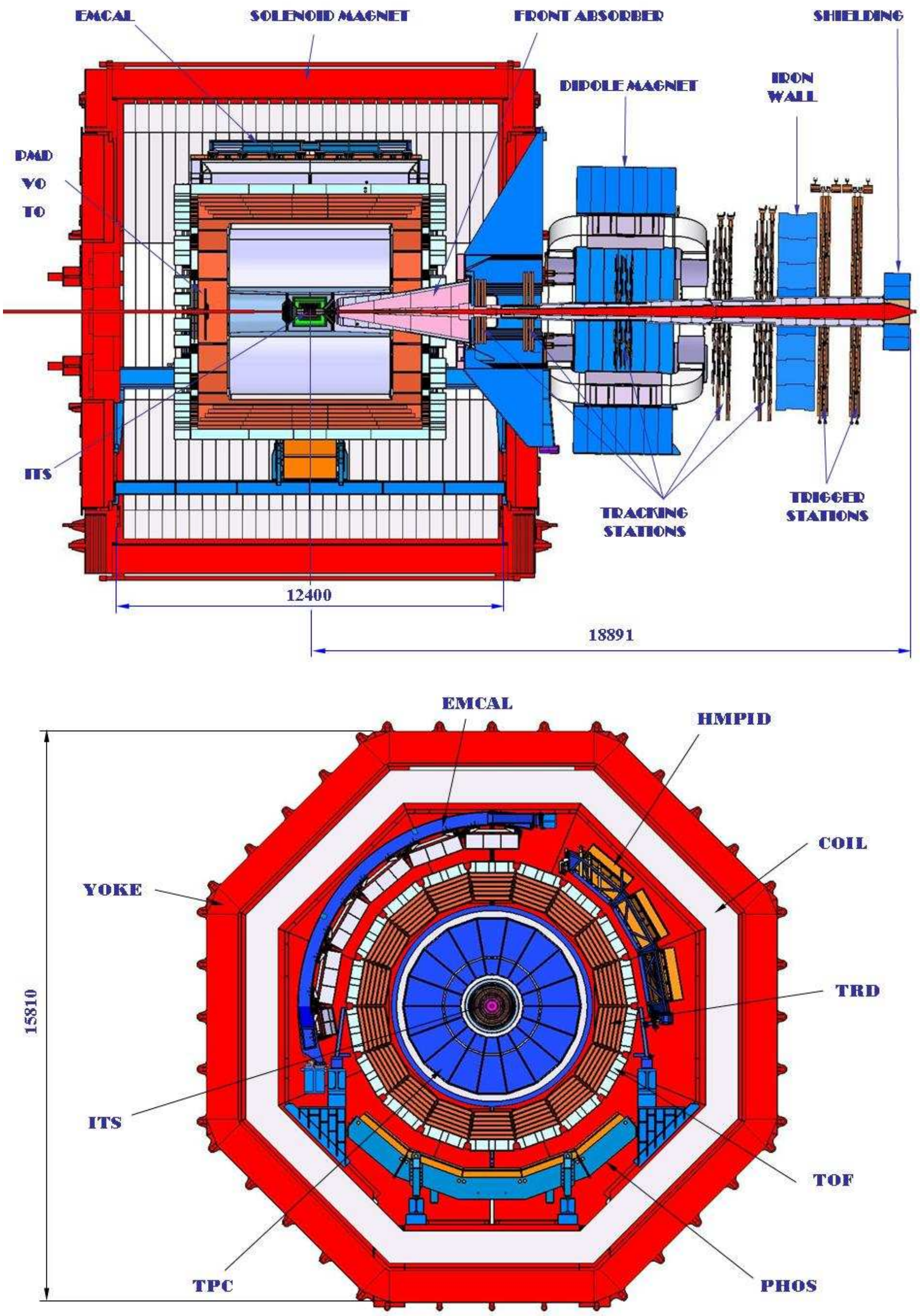

Figure 1.2: ALICE 2D cut views along the *yz* direction (upper part) and along the *xy* direction (lower part). The ALICE coordinate system is defined as follows: *x*-axis is perpendicular to the mean beam direction, aligned with the local horizontal and pointing to the accelerator centre; *y* axis is perpendicular to the *x*-axis and to the mean beam direction, pointing upward; *z*-axis is parallel to the mean beam direction. The positive *z*-axis is pointing in the direction opposite to the muon spectrometer; see [22].

requiring typically several thousand reconstructed particles per event. Therefore the instrumented part is concentrated over 2 units in rapidity around mid-rapidity for the barrel detectors and covers 1.5 units in rapidity at small angles for the muon measurement. The interaction rate with nuclear beams at LHC is low (10 kHz for Pb–Pb) and radiation doses are moderate (< 3000 Gy), allowing the use of slow but high-granularity detectors like TPC and SDD. Rare signals are enriched with selective triggers operating at several levels wherever possible (jets, high p_t electrons, muons, photons). With the expected integrated Pb–Pb luminosity of 0.5 nb^{-1} per year, the kinematic reach for example for jets within the acceptance of the EMCAL will exceed 200 GeV and the muon arm will collect some 10 000 Υ decays. A number of rare signals like heavy flavour decays are however very difficult to select at the trigger level in heavy ion reactions; these require then a large sample of minimum bias or central collisions and a high bandwidth Data Acquisition system (1.3 GB/s to permanent storage) to collect of the order of a few 10^7 events in the few weeks of LHC operation dedicated to ions each year.

1.3 Detector layout

1.3.1 Tracking detectors

Tracking in the central barrel is divided into the Inner Tracking System (ITS), a six-layer, silicon vertex detector, and the Time-Projection Chamber (TPC). The Transition Radiation Detector (TRD) will also be used for tracking in the central region improving the p_t resolution at high momentum.

The basic functions of the inner tracker are: i) secondary vertex reconstruction of heavy flavour and strange particle decays, ii) particle identification and tracking of low-momentum particles, and iii) improvement of the impact parameter and momentum resolution. Because of the high particle density, the innermost four layers need to be truly two-dimensional devices, i.e. silicon pixel and silicon drift detectors. The outer layers are equipped with double-sided silicon micro-strip detectors. The four outer layers have analog readout for independent particle identification via dE/dx in the non-relativistic region, which provides the ITS with stand-alone capability as a low-p_t particle spectrometer.

The need for efficient and robust tracking has led to the choice of a TPC as the main tracking detector. In spite of its drawbacks concerning speed and data volume, only such a conservative and redundant tracking device can guarantee reliable performance at order 10 000 charged particles within the acceptance. The inner radius of the TPC is determined by the maximum acceptable hit density, the outer radius of 2.5 m by the length required for achieving dE/dx resolution of better than 5–7%. With this resolution the TPC can serve, in addition to tracking, as a detector for particle identification in the region of the relativistic rise, up to momenta of order 50 GeV/c. The designs of the readout chambers and electronics, as well as the choice of the operating gas, are optimized for good double-track resolution and minimal space charge induced distortions.

1.3.2 Particle identification

Particle identification over a large part of the phase space and for many different particles is an important design feature of ALICE with several detector systems dedicated to PID: the TOF array is optimized for large acceptance and average momenta; it covers the central barrel over an area of 140 m^2 with 160 000 individual cells at a radius of close to 4 m. The requirement for an affordable system with a large number of channels, needed to keep the occupancy at or below 10%, as well as state-of-the-art time resolution of better than 100 ps, was solved with the development of a novel type of gas detector, the Multigap Resistive Plate Chamber. The HMPID detector is a single-arm, 10 m^2 array of proximity focusing ring imaging Cherenkov counters with liquid radiator and solid CsI photocathode evaporated on the segmented cathode of multiwire proportional chambers. It extends the hadron identification capabilities toward higher momenta in about 10% of the barrel acceptance. The Transition Radiation Detector will identify electrons above 1 GeV/c to study production rates of quarkonia and heavy quarks near mid-rapidity. It consists of six layers of Xe/CO_2-filled time expansion wire chambers following a composite foam and fibre radiator and includes a distributed tracklet processor in the front-end electronics for triggering purposes. A hadron rejection of order 100 in central collisions is required to bring the background from misidentified hadrons below the level of real electrons.

1.3.3 Electromagnetic calorimeters

Photons, spanning the range from thermal emission to hard QCD processes, as well as neutral mesons are measured in the small single-arm, high-resolution and high-granularity PHOS electromagnetic calorimeter. It is located far from the vertex (4.6 m) and made of dense scintillating crystals ($PbW0_4$) in order to cope with the large particle density. $PbW0_4$ has both a small Moliere radius and sufficient light output to measure the lowest energies of interest with good resolution. A set of multiwire chambers in front of PHOS acts as a charged particle veto (CPV). The interaction and energy loss of high-energy partons in dense matter will play an essential role in the study of nuclear collisions at the LHC. In order to enhance the capabilities for measuring jet properties, a second electromagnetic calorimeter (EMCal) will be installed in ALICE starting in 2008. The EMCal is a Pb-scintillator sampling calorimeter with longitudinal wavelength-shifting fibres, read out via avalanche photo diodes. Much larger than PHOS, but with lower granularity and energy resolution, it is optimized to measure jet production rates and fragmentation functions in conjunction with the charged particle tracking in the other barrel detectors.

1.3.4 Muon spectrometer

The forward muon arm is primarily designed to measure the production of heavy-quark resonances (J/Ψ, ψ', Υ, Υ', Υ'') with a mass resolution sufficient to separate all states. It is located at small angles (2°–9°, $-4 < \eta < -2.4$) to provide good acceptance down to zero transverse momentum and a manageable background from hadron decays. It consists of a composite absorber ($\approx 10\lambda_{\rm int}$), made with layers of both high- and low-Z materials starting 90 cm from the vertex, a large dipole magnet with a 3 Tm field integral placed outside the L3 magnet, and ten planes of very thin, high-granularity, cathode strip tracking stations. A second muon filter ($\approx 7\lambda_{\rm int}$ of iron) at the end of the spectrometer and four planes of Resistive Plate Chambers are used for muon identification and triggering. The spectrometer is shielded by a dense conical absorber tube, of about 60 cm outer diameter, which protects the chambers from secondary particles created in the beam pipe.

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1.3.5 Forward and trigger detectors

A number of small and specialized detector systems are used for triggering or to measure global event characteristics. The event time is measured with very good precision (< 25 ps) by the T0 detector; two sets of 12 Cherenkov counters (fine mesh photomultipliers with fused silicon radiator) mounted around the beam pipe. Two arrays of segmented scintillator counters, called V0 detector, are used as minimum bias trigger and for rejection of beam-gas background. An array of 60 large scintillators (ACORDE) on top of the L3 magnet will trigger on cosmic rays for calibration and alignment purposes, as well as for cosmic ray physics. The Forward Multiplicity Detector (FMD) provides multiplicity information over a large fraction of the solid angle ($-3.4 < \eta < -1.7$ and $1.7 < \eta < 5$). Charged particles are counted in rings of silicon strip detectors located at three different positions along the beam pipe. The Photon Multiplicity Detector (PMD) measures the multiplicity and spatial distribution of photons event-by-event in the region $2.3 < \eta < 3.7$. It consists of two planes of gas proportional counters with cellular honeycomb structure, preceded by two lead converter plates of 3 radiation lengths each. Two sets of two compact calorimeters each will be used to measure and trigger on the impact parameter of the collision (Zero Degree Calorimeter ZDC). They are made of tungsten (neutron calorimeters, ZN) and brass (proton calorimeters, ZP) with embedded quartz fibres, and located on both sides in the machine tunnel, about 116 m from the interaction region. In addition, two small electromagnetic calorimeters (ZEM) are installed on one side, 7 m from the vertex, to improve the centrality selection.

1.3.6 Trigger and data acquisition

The hardware trigger in ALICE combines the input from detectors with fast trigger capability (T0, V0, ZDC, SPD, TOF, TRD, PHOS, EMCal, Muons, ACORDE). It operates at several levels to satisfy the individual timing requirements of the different detectors, as the ALICE electronics is in general not pipelined: a pretrigger activates the TRD electronics shortly after each interaction ($<$ 900 ns) while two further levels (L0 at 1.2 μs and L1 at 6.5 μs) reduce the event rate depending on the trigger inputs. A final trigger (L2 at about 100 μs) is issued after the end of the drift time in the TPC, the slowest detector in ALICE.

The trigger includes a flexible protection against pile-up and an event priority scheme which optimises both the acceptance of rare triggers and the overall throughput of accepted events. The software-based High-Level Trigger (HLT) is a farm of up to 1000 multiprocessor PCs which will subject essentially complete events to a detailed on-line analysis. Its main task is to select or reject events and to reduce the event size by either selecting only a fraction of the data for readout (region of interest) or by compressing the complete event information. The relatively short LHC heavy-ion runs determine the main feature of the data acquisition system, i.e. , the very large bandwidth of 1.25 GB/s to permanent storage which is required to collect a sufficient number of events. It combines a custom optical data link, used throughout the experiment, with commodity equipment (PCs and network switches) in a highly parallel and scalable architecture.

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