Chapter 2

ALICE: experimental set up

2.1 Experiments at LHC

Availability of heavy-ion beams at LHC will open a new era in studying nucleus-nucleus collisions at ultra-relativistic energies and will greatly expand the range of conditions under which it will be possible to investigate the properties of QCD matter. With a centre-of-mass proton-proton collision energy of 14 TeV, LHC is conceived to be a discovery machine at the energy frontier of particle physics and will be the highest energy accelerator operating on the Earth. A layout of LHC structure is depicted in Fig. 2.1.

Fig. 2.1. Layout of LHC.
Four experiments will be performed at the LHC. Two, general purpose, large acceptance detectors - A Toroidal LHC ApparatuS (ATLAS) and the Compact Muon Solenoid (CMS) - are designed as state of the art detectors for new physics - Higgs boson discovery and supersymmetry, etc. A third detector, LHCb, is focused on b - physics and the fourth one, A Large Ion Collider Experiment (ALICE), is dedicated to heavy - ion physics. ALICE experiment is important for us. Hence, issues relating to ALICE are discussed.

Heavy - ion collisions at LHC are likely to access not only a quantitatively different regime of much higher energy density but also a qualitatively new regime mainly because [1]:

- LHC heavy - ion programme provides an opportunity to investigate the properties and dynamics of QCD in the classical regime. The density of the low Bjorken-x virtual gluons in the initial state will be high enough for saturation to set in so that their subsequent time evolution is governed by classical chromodynamics.

- Due to relatively higher incident energy in comparison to RHIC, semi-hard and hard processes will be the dominant feature at the LHC and gross properties of the collisions can be reliably calculated using perturbative QCD.

- Very hard strongly interacting probes, whose attenuation can be used to study the early classical chromodynamics and thermalization stages of the collisions, are produced at sufficiently higher rates for detailed measurements.

- Weakly interacting probes, such as direct photons, \( W^\pm \) and \( Z^0 \) bosons produced in hard processes, will provide information about parton distributions at very high \( Q^2 \), where \( Q^2 \) is square of the four-momentum transfer. The impact parameter dependence of their production is sensitive to the spatial dependence of shadowing and saturation effects.

- Compared to RHIC, the ratio of the life time of the QGP state to the time for
thermalization is expected to be larger by an order of magnitude so that parton
dynamics will dominate the fireball expansion and the collective features of the
hadronic final state.

2.2 ALICE experimental programme
The main aim of ALICE is to accumulate sufficient integrated luminosity of lead
beam at $\sqrt{s} = 5.5$ TeV per nucleon pair in Pb-Pb collisions, to measure rare pro-
cesses such as jet transverse - energy spectra upto $E_T \sim 200$ GeV and the pattern
of medium induced modifications of bottomonium bound states. However, interpre-
tation of these experimental data relies heavily on a systematic comparison with the
same observable measured in proton - proton and proton - nucleus collisions as well
as in collisions of lighter ions. In this way, a phenomenon which is truly indicative of
the hot equilibrating matter can be separated from other contributions.

Any successful completion of heavy - ion programme would require study of pp,
pA and lighter A-A collisions in order to establish the benchmark processes under
the same experimental conditions. Additionally, these measurements are interest-
ing in themselves. For example, study of lighter systems opens up possibilities to
study fundamental aspects of the interaction of color-neutral objects related to non-
perturbative strong phenomena, like confinement and hadronic structure. Also, due
to its excellent tracking and particle identification capabilities, the ALICE pp and
pA programmes complement those of the dedicated pp experiments.

ALICE physics goals are summarized [2] below:

- **Global event features.** Multiplicities, very forward energy flow (0 degree)
  and rapidity distribution allow to determine the centrality of the collisions, the
  number of participants in the interaction and the initial energy density.

- **The geometry and space - time evolution of the emitting source.** The
  space-time structure of the collision fireball will be studied with two - particle
  momentum correlation.
• Degrees of freedom as function of temperature. Quantities related to the dynamical evolution of the hadronic phase like $p_T$ spectra and particle ratios of identified hadrons ($\pi, \eta, \omega, \phi, p, K, \Lambda, \Xi, \Omega$) and direct photons will be measured.

• Non-statistical fluctuations and critical behaviour. These aspects will be addressed by carrying out event-by-event analysis. Distortions of $N_\pi - N_{\text{charged}}$ correlations will be suitable for the detection of disoriented chiral condensates (DCC).

• Chiral symmetry restoration. Chiral symmetry restoration will be searched by studying the decays of resonances.

• Collective effects. Elliptic and directed flows will be investigated by various sub-detectors.

• Hard probes. Open charm and open beauty, high $p_T$ spectra, jets and jet quenching will be measured. Study of spectroscopy of $J/\psi$ and $\Upsilon$ families will provide a tool particularly sensitive to de-confinement.

These physics goals imply a good particle identification capability of both hadrons and leptons over a wide acceptance and an extended $p_T$ domain.

2.3 ALICE detector

2.3.1 Introduction
ALICE is a general purpose experiment whose detectors will measure and identify mid-rapidity hadrons, leptons and photons. The unique design of ALICE has resulted from the requirements to track and identify particles from very low $p_T$ (~ 100 MeV/c) fairly high $p_T$ values (~ 100 GeV/c), to reconstruct short lived particles such as hyperons, D and B mesons and to perform these tasks in an environment involving large charged particle multiplicities, up to 8000 charged particles per rapidity unit at mid rapidity. Detection and identification of muons will be done with the help of a dedicated spectrometer, including a large warm dipole magnet and covering a domain
of large rapidities\(^2\) - 4.0 \(\leq \eta \leq -2.4\). Hadrons, electrons and photons will be detected and identified in the central rapidity region (- 0.9 \(\leq \eta \leq 0.9\)) by a complex system of detectors placed in a moderate (0.5 T) magnetic field. Tracking relies on a set of high granularity detectors: an Inner Tracking System (ITS) consisting of six layers of silicon detectors, a large volume Time Projection Chamber (TPC) and a high granularity Transition Radiation Detector (TRD). Particle identification in the central region is performed by measuring energy loss in the tracking detectors, transition radiation in the TRD, Time Of Flight (TOF) with a high resolution array, Čerenkov radiation with a High Momentum Particle Identification Detector (HMPID) and photons with a crystal PHOton Spectrometer (PHOS). Additional detectors located at large rapidities complete the central detection system to characterize the event and to provide the interaction trigger. They cover a wide acceptance (- 3.4 \(\leq \eta \leq 5.1\)) for the measurement of charged particles and triggering (Forward Multiplicity Detector-FMD, V0 and T0 detectors), a narrow domain at large rapidities (2.3 \(\leq \eta \leq 3.5\)) for photon multiplicity measurement (Photon Multiplicity Detector-PMD) and the coverage of beams rapidity to measure spectator nucleons in heavy - ion collisions (Zero Degree Calorimeter-ZDC) \([3]\).

2.3.2 Design criteria

As a single dedicated heavy - ion experiment at the LHC, ALICE will measure a broad range of observables, which have already been typically covered at earlier accelerators, AGS, SPS and RHIC through more sophisticated detector systems. The choice and design of these systems are driven by the physics requirements as well as experimental conditions expected in nucleus - nucleus collisions at LHC energies. The

\(^2\)In ALICE the coordinate axis system is a right handed orthogonal Cartesian system with the point of origin at the beam interaction point. The axis are defined as follows: x-axis is perpendicular to the mean beam direction, aligned with the local horizontal and pointing to the accelerator center; 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. Hence, positive z-axis points in a direction opposite to the Dimuon Spectrometer.
event rate for Pb - Pb collisions at the LHC's nominal luminosity of $10^{27} \text{ cm}^{-2}\text{sec}^{-1}$ will be about 8000 minimum-bias collisions per second, of which only about 5% correspond to the most central ones. This low interaction rate plays a crucial role in the design of the experiment, since it enables to use slow but high granularity detectors, such as the Time Projection Chamber and the Silicon Drift Detectors.

The design of the tracking system has been driven by the requirement for safe and robust track finding by using mostly three dimensional hit information with many points (upto 150) in a moderate magnetic field of 0.5 T. The field strength is a compromise between momentum resolution, acceptance at low momentum and tracking and trigger efficiency. A large dynamic range is required for momentum measurement, spanning more than three orders of magnitude from $\sim 100 \text{ MeV/c}$ (collective effects at large length scales, good acceptance for resonance decays) to $\sim 100 \text{ GeV/c}$ (jet physics). This is achieved with a combination of very low material thickness to reduce multiple scattering at low $p_T$ (13% of $X_0$ upto the end of the TPC) and a large tracking lever arm of upto 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 almost all known PID techniques: specific ionization energy loss, $\text{dE}/\text{dx}$, time of flight, transition and Čerenkov radiation, electromagnetic calorimetry, muon filters and topological decay reconstruction.

On the other hand, interaction rate with nuclear beams at LHC is likely to be low (10 kHz for Pb -Pb) and radiation doses are moderate ($< 3000 \text{ Gy}^3$), allowing the use of slow but high granularity detectors. Also, a very large acceptance, hermetic detector (For example, missing energy), is not required and, therefore, the instrumental 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 muon measurement.

The following section gives a brief overview of the central barrel and forward de-

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[^3]: Gy (gray) is the SI unit of absorbed radiation dose, 1 gray is the absorption of one joule of radiation energy by one kilogram of matter, i.e., 1 Gy = 1 Joule/Kg.
tectors of the ALICE and the observables that they will measure. Other details can be found in the ALICE Technical Proposal or Technical Design Report of each detector. The Forward Dimuon Spectrometer has been discussed in detail in the next chapter.

2.3.3 Experiment layout

The ALICE experimental set up, exhibited in Fig. 2.2, mainly consists of three parts[4]:

- The central region, housed in the L3 magnet, covering mid-rapidity (|\eta| \leq 0.9) over the full azimuth. It is dedicated to the study of hadronic signals, dielectrons and photons.

- The Forward Dimuon Spectrometer, would identify the muon pairs coming from heavy resonance decays in the rapidity range \(-4.0 \leq \eta \leq -2.4\).

- The forward detectors, covering large rapidity region up to \(\eta = 5.1\), to determine photon and charged particle multiplicities and the collision centrality.

The central system includes, from the interaction vertex to outside, six layers of high resolution silicon detectors, Inner Tracking System, the main tracking system of the experiment, Time Projection Chamber, a transition radiation detector for electron identification (Transition Radiation Detector) and a particle identification array (Time-Of-Flight). The central system is complemented by two small area detectors: an array of ring imaging Čerenkov detectors (|\eta| \leq 0.6, 57.6° azimuthal coverage) for the identification of high momentum particles (High Momentum Particle Identification Detector) and an electromagnetic calorimeter (|\eta| \leq 0.12, 100° azimuthal coverage) consisting of arrays of high density crystals (PHOton Spectrometer).

The large rapidity systems include Forward Dimuon Spectrometer (- 4.0 \leq \eta \leq - 2.4), a photon counting detector (Photon Multiplicity Detector) on the opposite side, an ensemble of multiplicity detectors (Forward Multiplicity Detector) covering the large rapidity region (upto \(\eta = 5.1\)). A system of scintillators and quartz coun-
ters (T0, V0 and Zero Degree Calorimeter) will provide fast trigger signals and two sets of neutron and hadron calorimeters, located at 0° and about 115 m away from the interaction vertex. An absorber positioned very close to the vertex shields the Dimuon Spectrometer. The Spectrometer consists of a dipole magnet, five tracking stations, an iron wall (muon filter) to absorb remaining hadrons, and two trigger stations behind the muon filter.

The acceptance and location of the various detector systems in ALICE is summarized in Table 2.1.
Table 2.1: Summary of the ALICE detector systems.

<table>
<thead>
<tr>
<th>Detector</th>
<th>Acceptance ($\eta$, $\phi$)</th>
<th>Position (m)</th>
<th>Dimensions (m$^2$)</th>
<th>Channels</th>
</tr>
</thead>
<tbody>
<tr>
<td>ITS layer 1,2 (SPD)</td>
<td>$\pm 2$, $\pm 1.4$</td>
<td>0.039, 0.076</td>
<td>0.21</td>
<td>9.8 M</td>
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<tr>
<td>ITS layer 3,4 (SDD)</td>
<td>$\pm 0.9$, $\pm 0.9$</td>
<td>0.150, 0.239</td>
<td>1.31</td>
<td>133000</td>
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<tr>
<td>ITS layer 5,6 (SDD)</td>
<td>$\pm 0.97$, $\pm 0.97$</td>
<td>0.380, 0.430</td>
<td>5.0</td>
<td>2.6 M</td>
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<tr>
<td>TPC</td>
<td>$\pm 0.9$ at $r = 2.8$ m</td>
<td>0.848, 2.466</td>
<td>readout 32.5 m$^2$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$\pm 1.5$ at $r = 1.4$ m</td>
<td></td>
<td>Vol. 90 m$^3$</td>
<td></td>
</tr>
<tr>
<td>TRD</td>
<td>$\pm 0.84$</td>
<td>2.90, 3.68</td>
<td>716</td>
<td></td>
</tr>
<tr>
<td>TOF</td>
<td>$\pm 0.9$</td>
<td>3.78</td>
<td>141</td>
<td></td>
</tr>
<tr>
<td>HMPID</td>
<td>$\pm 0.6$, $1.20 &lt; \phi &lt; 58.80$</td>
<td>5.0</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>PHOS</td>
<td>$\pm 0.12$, $220^0 &lt; \phi &lt; 320^0$</td>
<td>4.6</td>
<td>17920</td>
<td></td>
</tr>
<tr>
<td>EMCal</td>
<td>$\pm 0.7$, $80^0 &lt; \phi &lt; 187^0$</td>
<td>4.36</td>
<td>12672</td>
<td></td>
</tr>
<tr>
<td>ACORDE</td>
<td>$\pm 1.3$, $-60^0 &lt; \phi &lt; 60^0$</td>
<td>8.5</td>
<td>43</td>
<td>120</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>Muon Spectrometer</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Tracking Station 1</td>
<td>- $2.5 &lt; \eta &lt; - 4.0$</td>
<td>- 5.36</td>
<td>4.7</td>
<td>1.08 M</td>
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<tr>
<td>Tracking Station 2</td>
<td>- $2.5 &lt; \eta &lt; - 4.0$</td>
<td>- 6.86</td>
<td>7.9</td>
<td></td>
</tr>
<tr>
<td>Tracking Station 3</td>
<td>- $2.5 &lt; \eta &lt; - 4.0$</td>
<td>- 9.83</td>
<td>14.1</td>
<td></td>
</tr>
<tr>
<td>Tracking Station 4</td>
<td>- $2.5 &lt; \eta &lt; - 4.0$</td>
<td>- 12.92</td>
<td>26.5</td>
<td></td>
</tr>
<tr>
<td>Tracking Station 5</td>
<td>- $2.5 &lt; \eta &lt; - 4.0$</td>
<td>- 14.22</td>
<td>41.8</td>
<td></td>
</tr>
<tr>
<td>Trigger Station 1</td>
<td>- $2.5 &lt; \eta &lt; - 4.0$</td>
<td>- 16.12</td>
<td>64.6</td>
<td>21000</td>
</tr>
<tr>
<td>Trigger Station 2</td>
<td>- $2.5 &lt; \eta &lt; - 4.0$</td>
<td>- 17.12</td>
<td>73.1</td>
<td></td>
</tr>
<tr>
<td>ZDC:ZN</td>
<td>$</td>
<td>\eta</td>
<td>&lt; 8.8$</td>
<td>$\pm 116$</td>
</tr>
<tr>
<td>ZDC:ZP</td>
<td>$6.5 &lt;</td>
<td>\eta</td>
<td>&lt; 7.5$</td>
<td>$\pm 116$</td>
</tr>
<tr>
<td></td>
<td>$9.7^0 &lt; \phi &lt; 9.7^0$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ZDC:ZEM</td>
<td>$4.8 &lt; \eta &lt; 5.7$</td>
<td>7.25</td>
<td>$2 \times 0.0049$</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>$16^0 &lt; \phi &lt; 187^0$ and</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$164^0 &lt; \phi &lt; 196^0$ and</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PMD</td>
<td>$2.3 &lt; \eta &lt; 3.7$</td>
<td>3.64</td>
<td>2.59</td>
<td>2221184</td>
</tr>
<tr>
<td>FMD disc 1</td>
<td>$3.62 &lt; \eta &lt; 5.03$</td>
<td>inner: 3.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FMD disc 2</td>
<td>$1.7 &lt; \eta &lt; 3.68$</td>
<td>inner: 0.834</td>
<td>outer: 0.752</td>
<td>51200</td>
</tr>
<tr>
<td>FMD disc 3</td>
<td>$3.4 &lt; \eta &lt; 1.7$</td>
<td>inner: - 0.628</td>
<td>outer: - 0.752</td>
<td></td>
</tr>
<tr>
<td>V0A</td>
<td>$2.8 &lt; \eta &lt; 5.1$</td>
<td>3.4</td>
<td>0.548</td>
<td>32</td>
</tr>
<tr>
<td>VOC</td>
<td>$- 1.7 &lt; \eta &lt; - 3.7$</td>
<td>- 0.897</td>
<td>0.315</td>
<td>32</td>
</tr>
<tr>
<td>T0A</td>
<td>$4.61 &lt; \eta &lt; 4.92$</td>
<td>3.75</td>
<td>0.0038</td>
<td>12</td>
</tr>
<tr>
<td>T0C</td>
<td>$- 3.28 &lt; \eta &lt; - 2.97$</td>
<td>- 0.727</td>
<td>0.0038</td>
<td>12</td>
</tr>
</tbody>
</table>
2.3.4 Inner Tracking System

The six cylindrical layers of silicon detectors in the Inner Tracking System are located at radii \( r = 4, 7, 15, 24, 39 \) and \( 44 \) cm, as shown schematically in Fig. 2.3. The number, position and segmentation of the layers are optimized for efficient track finding and high impact parameter resolution. In particular, the outer radius is determined by the requirement to match tracks with those from the Time Projection Chamber and the inner radius is the minimum allowed by the radius of the beam pipe (3 cm). The first layer has a more extended coverage (\( | \eta | < 1.98 \)) to provide, together with Forward Multiplicity Detector, a continuous coverage in rapidity for the measurement of charged particles multiplicity [5].

![Fig. 2.3. Layout of Inner Tracking System.](image)

The pixel detectors have been chosen for the innermost two layers and silicon drift detectors for the following two layers because of the high particle density, upto 80 particle cm\(^{-2}\) and to achieve the required impact parameter resolution. The outer two layers, where the track densities are below 1 particle cm\(^{-2}\), will be equipped with double sided silicon micro strip detectors. With the exception of the two innermost pixel planes, all layers will have analogue readout for particle identification via dE/dx...
measurement.

The main tasks of ITS are to:

- localize the primary vertex with a resolution better than 100 \( \mu \text{m} \);
- reconstruct the secondary vertices from the decays of hyperons, D and B mesons;
- track and identify particles with momenta below 100 MeV/c;
- improve the momentum and angle resolutions for the high \( p_T \) particles which are also likely to traverse TPC;
- reconstruct, albeit with limited momentum resolution, particles traversing the dead region of TPC.

In addition to the improved momentum resolution, ITS provides an excellent double hit resolution enabling separation of tracks with close momenta. The silicon detectors used to measure ionization densities (drift and strips) must have a minimum thickness of approximately 300 \( \mu \text{m} \) to provide acceptable signal to noise ratio. Detectors must overlap to cover entire solid angle. Therefore, the effective thickness of the detector is approximately 0.4 \% of \( X_0 \). The thickness of additional material in the active volume, i.e., electronics, cabling, support structure and cooling system is limited to a comparable effective thickness.

The granularity required for the innermost layers is achieved with silicon micro pattern detectors with true two-dimensional readout: Silicon Pixel Detector and Silicon Drift Detector. At larger radii, the requirement in terms of granularity is less stringent, therefore, double sided Silicon Strip Detector with a small stereo angle are used. Double sided micro strips have been selected because they introduce less material in the active volume and they offer the possibility to correlate the pulse height readout from the two sides, thus help resolve ambiguities inherent in the use of detectors with projective readout. The granularity of the detectors is optimized to cope with a track density of 8000 tracks per unit rapidity at mid rapidity. Under these conditions, ITS would detect simultaneously more than 15000 particles.
2.3.5 Time Projection Chamber

The Time Projection Chamber is the main tracking detector of the central barrel and is optimised to provide, together with other central barrel detectors, charged particle momenta measurements with good two track separation, particle identification and vertex determination. Additionally, data from the central barrel detectors are used to generate a fast online High Level Trigger (HLT) for the selection of low cross section signals [6].

The phase space covered by the TPC in pseudorapidity is $|\eta| < 0.9$ for tracks with full radial track length (matches in ITS, TRD and TOF detectors); for reduced track length (at reduced momentum resolution), an acceptance up to about $|\eta| = 1.5$ is accessible. The TPC covers the full azimuth (with the exception of the dead zone). A large $p_T$ range, $p_T$ from $\sim 100$ MeV/c to $\sim 100$ GeV/c, is covered with good momentum resolution.

With the Pb - Pb design luminosity of the LHC, an interaction rate of 8 kHz is expected, of which 10 % are considered to be central collisions. In the TPC design phase, an extreme charged particle multiplicity density of $dN_{ch}/d\eta = 8000$ was assumed which would result in 20000 charged primary and secondary tracks in the TPC acceptance.

The TPC design is conventional in overall structure but innovative in many ways. The TPC layout is depicted in Fig. 2.4. It is cylindrical in shape and has an inner radius of about 85 cm, an outer radius of about 250 cm and an overall length along the beam direction of 500 cm. The detector is made up of a large cylindrical field cage, filled with 88 m$^3$ of Ne and CO$_2$ gases in 90 % and 10 % ratio, which is needed to transport the primary electrons over a distance of up to 2.5 m on either side of the central electrode to the end plates. Multiwire Proportional Chambers with cathode pad readout are mounted into 18 trapezoidal sectors of each end plate.

The data rate capabilities of the TPC readout are designed to allow transfer of 200 central or 400 minimum bias Pb - Pb events per second for $dN_{ch}/d\eta = 8000$ [1]. The recorded data volume can be reduced using the ‘region of interest’ option of the
trigger, reading out only a few sectors of the TPC.

The total number of readout pads used to keep the occupancy as low as possible and to ensure the necessary dE/dx and position resolution is 560,000. The sizes of the pads are: 4 x 7.5 mm² in the inner chamber, 6 x 10 mm² and 6 x 15 mm² in the outer chambers.

After zero suppression and data encoding the event size from TPC for a central Pb - Pb collision at the expected charged multiplicity of dN_{ch}/dη = 2500 will be about 50 MB. In order to increase the physics potential of ALICE, especially on jets and electron physics, rare signals like dielectron pair candidates have to be enriched to readout rates of 100 - 200 Hz. Therefore, an intelligent readout is available via a HLT processor farm, which will operate on the raw data shipped via optical links to the ALICE counting house. The HLT will allow lossfree data compression, selective readout of electron candidates identified by the TRD (the 'region of interest' option of the trigger), as well as online track finding and tracking of the whole TPC.

2.3.6 Transition Radiation Detector
The main aim of the Transition Radiation Detector (TRD) of the ALICE is to carry out electron identification in the central barrel for momenta greater than 1 GeV/c. This is because of the reason that pion rejection capability through energy loss measurement in the TPC is no longer substantial [7]. In conjunction with the data from TPC and ITS it is possible to study production of light and heavy vector meson resonances and the dilepton continuum in Pb - Pb as well as p-p collisions. It can be used to derive a fast trigger for charged particles with comparatively higher momenta. It is a part of Level 1 trigger and can significantly enhance the recorded T yield in the high mass part of the dilepton continuum, J/\psi having high p_T as well as jets. The coverage in the pseudorapidity matches the coverage of the other central detectors, |\eta| \leq 0.9. The TRD fills the radial space between TPC and TOF detectors.

The final design of TRD is exhibited in Fig. 2.5, which consists of six individual layers to improve the quality of electron identification. There are 18 sectors to match the azimuthal segmentation of TPC and there is a 5-fold segmentation along beam direction, z. In total, there are 540 (18 x 5 x 6 = 540) individual readout detector modules arranged into 18 super modules, each containing 30 modules arranged in 5 stacks and 6 layers. The active length in longitudinal direction is 7 m, the overall length of the entire super module is 7.8 m and its total weight is about 1700 Kg. Each detector element consists of a Carbon fibre laminated Rohacell/polypropylene fibre sandwich radiator of 48 mm thickness, a drift section of 30 mm thickness, and a Multiwire Proportional Chamber section (7 mm) with pad readout. The entire readout electronics is directly mounted on the back panel of the detector, including the water cooling system. The total thickness of a single detector layer is 125 mm. To achieve 80 % tracking efficiency (single track) and to cover a total area of about 736 m^2 the cathode planes are segmented into pads with a \sim 6 - 7 cm^2 area. The total number of readout channels is 1.16 x 10^6.

The gas mixture in the readout chambers is Xe/CO_2 (85 %/15 %). Each readout chamber consists of a drift region of 3.0 cm separated by cathode wires from an amplification region of 0.7 cm. The drift time is 2.0 \mu s, requiring a drift velocity of
1.5 cm $\mu$s$^{-1}$. At extreme multiplicity ($dN_{ch}/d\eta = 8000$) the pixel occupancy will be 34%. A space point resolution in the bending direction of 400 $\mu$m can be achieved for low multiplicity ($dN_{ch}/d\eta = 2000$) at $p_T = 1$ GeV/c. For full multiplicity, this resolution is degraded to 600 $\mu$m after unfolding.

![Diagram of TRD layout](image)

Fig. 2.5. Left panel: schematic drawing of the TRD layout in the ALICE space frame. 18 super modules (light blue face side), each containing 30 readout chambers (red) arranged in five stacks of six layers. The TRD is surrounded by TOF detector (dark blue) from the outside. The heat shield (yellow) towards the TPC is shown on inside. Right panel: supermodule during assembly with the first three layers installed.

### 2.3.7 Time Of Flight detector

The Time Of Flight detector is a large area array that covers the central pseudorapidity region ($|\eta| \leq 0.9$) for Particle IDentification (PID) in the intermediate momentum range. It detects pions and kaons of momenta below 2.5 GeV/c and protons of momenta up to 4 GeV/c, with $\pi$/K and K/p separations better than 3$\sigma$. The measurement and identification of charged particles in the intermediate momentum range will provide observables which can be used to probe the nature and dynamical evolution of the system produced in ultra-relativistic heavy-ion collisions at LHC energies. The TOF detector, coupled with the ITS and TPC detectors for track and
vertex reconstruction and for dE/dx measurements in the low momentum range, will provide event-by-event identification of large samples of pions, kaons and protons [8].

A large coverage TOF detector should have an excellent intrinsic response and an overall occupancy not exceeding 10 - 15 % level at the highest predicted charged particle density \( (dN_{ch}/d\eta = 8000) \). This led to the current design with more than \( 10^5 \) independent TOF channels. Since a large area had to be covered, a gaseous detector was chosen and the best solution for TOF detectors was the Multi-gap Resistive-Plate Chamber (MRPC).

The key aspect of these chambers is that the electric field is high and uniform over the full sensitive gaseous volume of the detector. The main advantages of the MRPC technology with respect to other parallel plate chamber designs are:

- chamber operates at atmospheric pressure;
- signal is the analogue sum of the signals from many gaps, so there is no late tail and the charge spectrum is not of an exponential shape—it has a peak well separated from zero;
- resistive plates quench the streamers and there are no sparks, thus high gain operation becomes possible;
- construction technique is in general simple and makes use of commercially available materials.

Final tests of several MRPC multicell strips from mass production have confirmed that these devices indeed reach an intrinsic time resolution better than about 40 ps and an efficiency close to 100 %. The detector covers a cylindrical surface of polar acceptance \( |\theta - 90^0| < 45^0 \). It has a modular structure corresponding to 18 sectors in \( \phi \) and to five segments in \( z \) direction. The whole device is inscribed in a cylindrical shell with an internal radius of 370 cm and an external one of 399 cm. The whole device thickness corresponds to 30 % of the radiation length.

The basic unit of the TOF system is a 10 gap double stack MRPC strip (Fig. 2.6)
122 cm long and 13 cm wide, with an active area of 120 x 7.4 cm² subdivided into two rows of 48 pads of dimensions 3.5 x 2.5 cm². The strips are placed inside gas tight module and are positioned transversely to the beam direction.

They all have the same structure and width (128 cm) but differ in length. The length of the central module is 117 cm, the intermediate one has a length of 137 cm and the external module is 177 cm long. The overall TOF barrel length is 741 cm (active region). Detailed simulation studies have shown that with the chosen pad size 3.5 x 2.5 cm² and the tilted strip geometry the occupancy of the detector is ~ 14 % at the highest charged particle density, including secondary particles, with a magnetic field of 0.5 T. Lower values of particle density result in lower occupancy.

The readout electronics, located in custom crates at both ends of a supermodule,
consists of the TRM (TDC Readout Module) and DRM (Data Readout Module) cards. The TRM card houses the HPTDC (High Performance TDC) 8-channel chips that are used in the very high resolution mode (24.4 ps bin width). Each TRM card contains 30 HPTDC chips, i.e., 240 channels, corresponding to the readout pads of 2.5 MRPC strips. The DRM card is the TOF interface with the ALICE DAQ system, it reads and encodes the data from the TRM cards and sends them to the DAQ via the DDL optical link. The DRM card receives the trigger information from the CTP via the TTCrx (Timing Trigger and Control receiver) chip and performs a slow control function with a dedicated FPGA.

### 2.3.8 High Momentum Particle Identification Detector

High Momentum Particle Identification Detector is dedicated to inclusive measurements of identified hadrons of $p_T > 1$ GeV/c [9]. The aim is to enhance the PID capabilities of ALICE by enabling identification of charged hadrons beyond the momentum interval attainable through energy losses in ITS and TPC and time of flight measurements. The detector was optimized to extend the useful range for $\pi$/$K$ and $K/p$ discrimination, on a track-by-track basis, upto 3 and 5 GeV/c, respectively. The HMPID was designed as a single arm array with an acceptance of 5% of the central barrel phase space. The geometry of the detector was optimized with respect to the particle yields in pp and heavy-ion collisions at LHC energies, and with respect to the large opening angle required for two particle correlation measurements. In addition, identification of light nuclei ($d, t, ^3He$) and anti-nuclei ($\bar{d}, \bar{t}, \bar{^3He}$) at high transverse momenta in the central rapidity region can also be performed with the HMPID.

The HMPID is based on proximity-focusing Ring Imaging Čerenkov (RICH) counters and consists of seven modules of about 1.5 x 1.5 m$^2$ each, mounted in an independent support cradle (Fig. 2.7) [10]. The cradle is fixed to the spaceframe at the 2 O’clock position.

The radiator, which defines the momentum range covered by the HMPID, is a 15
mm thick layer of low chromaticity C$_6$F$_{14}$ (perfluorohexane) liquid with an index of refraction of $n = 1.2989$ at $\lambda = 175$ nm corresponding to $\beta_{\text{min}} = 0.77$. Čerenkov photons, emitted when a fast charged particle traverses the radiator, are detected by a photon counter as shown in Fig. 2.8, which exploits the novel technology of a thin layer of CsI deposited onto the cathode of a Multi-Wire Pad Chamber (MWPC). The HMPID with a surface area of 11 m$^2$ represents the largest scale application of this technique [11, 12]. The photo detector filled with pure methane and operated at ambient temperature and pressure is closed on one side by an end-flange, which supports six independent CsI photocathode panels, of size $64 \times 40$ cm$^2$, segmented into pads of $8 \times 8.4$ mm$^2$. On the opposite side, a honeycomb panel supports three C$_6$F$_{14}$ radiator vessels placed at a distance of 80 mm from the anode wire plane.

A low gain can be used in ion - ion collisions, minimizing the photons feedback and MIPs contribution to the occupancy, while in proton - proton runs, where much lower track density eases the pattern recognition, higher gain can be used to improve the efficiency. A positive voltage of 2050 V is applied to the anodes, while cathodes are grounded, providing an overall gas gain of $4 \times 10^4$. 
Fig. 2.8. Working principle of a RICH detector employing CsI thin films deposited onto the cathode plane of a MWPC. The Čerenkov cone refracts out of the liquid radiator of C6F14 and expands in the proximity volume of CH4 before reaching the MWPC photon detector. Electrons released by ionizing particles in the proximity gap are prevented to enter the MWPC volume by a positive polarization of the collection electrode close to the radiator.

The front-end electronics is based on two dedicated ASIC chips, GASSIPLEX [13] and DILOGIC [14]. In the HMPID application the GASSIPLEX analogue output is presented to the input of a 12-bit ADC. The multiplexing level is 3 chips (48 channels) per ADC at a maximum frequency of 10 MHz. The DILOGIC chip is a sparse data scan readout processor providing zero suppression and pedestal subtraction with individual threshold and pedestal values for upto 64 channels. Data are readout via the standard ALICE Detector Data Link (DDL). The readout time after L2 arrival is of the order of 300 μsecs. Since momentum information is vital to exploit the HMPID detector, only events for which the TPC information is available are of interest and the HMPID can perfectly cope with the readout rates foreseen for the TPC.
2.3.9 PHOton Spectrometer

The PHOton Spectrometer (PHOS) \[15\] is a high resolution electromagnetic spectrometer covering a limited acceptance domain at central rapidity. The main physics objectives are: test of thermal and dynamical properties of the initial phase of the collision extracted from low $p_T$ direct photon measurements and the study of jet quenching through the measurement of high $p_T \pi^0$ and $\gamma$ - jet correlations.

Identification of photons requires high discrimination power against charged hadrons, neutrons and anti-neutrons. Topology analysis of the shower developing in the electromagnetic calorimeter, time of flight measurement and charged particle identification provide the discriminating criteria \[16\]. The required performances are met through high granularity of the electromagnetic calorimeter, timing resolution of the individual detector cells of the order of a few nanosec and a charged particle detector in front of the calorimeter. The high resolution is provided by using scintillator material of 20$X_0$ with high photo-electron yield.

The required time resolution is achieved by using a fast scintillator and a dedicated preamplifier. The timing resolution, which can be reached with PHOS, is at energies above 1.5 GeV of about 0.5 nanosecond.

PHOS includes a highly segmented Electromagnetic Calorimeter (EMC) and a Charged Particle Veto (CPV) detector. It is subdivided into five independent EMC + CPV units, named PHOS modules. It is positioned on the bottom of the ALICE setup at a distance of 460 cm from the IP. After its final installation it will cover approximately a quarter of a unit in pseudorapidity, 0.12 $\leq \eta \leq$ 0.12, and 100° in azimuthal angle. Its total area is $\sim$ 8 m$^2$.

2.3.9.1 ElectroMagnetic Calorimeter (EMC)

Each EMC module is segmented into 3584 detection cells arranged in 56 rows of 64 cells. The detection cell consists of a 22 x 22 x 180 mm$^3$ lead-tungstate crystal, PbWO$_4$ (PWO), coupled to a 5 x 5 mm$^2$ Avalanche Photo Diode (APD) in which signal is processed by a low noise preamplifier \[17\]. The APD and the preamplifier are
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integrated in a common body glued onto the end face of the crystal. The crystals are assembled in strip units of two rows of eight detection cells, as exhibited in Fig. 2.9. The 16 analog signals from one strip unit are fed into a T-shaped connector connected to the shaper/digitizer/trigger electronics.

Fig. 2.9. Left top: crystal detector unit with glued photo detector, APD mounted on the preamplifier substrate; Right top: strip unit containing 8 x 2 crystal detector units; Left bottom: PHOS modules with strip units installed onto cooling plates; Right bottom: 5 PHOS modules.

To increase the light yield of the PWO crystals, the EMC module is operated at a temperature of -25 °C stabilized with a precision of 0.3 °C. The crystal strips are
located in a cold enclosure, whereas the readout electronics are located outside this enclosure.

2.3.9.2 Charged Particle Veto detector

The Charged Particle Veto detector is a Multi-Wire Proportional Chamber with cathode pad readout [18, 19]. Its charged particle detection efficiency is better than 99%. The spatial precision of the reconstructed impact point is about 1.54 mm along the beam direction and 1.38 mm across the beam.

The CPV is placed on top of the EMC modules at a distance of about 5 mm. The active volume of 14 mm thickness is filled with a gas mixture of 80 % Ar and 20 % CO₂ at a pressure (1 mbar⁴) slightly above atmospheric pressure. The cathode plane is segmented into 7168 pads of 22 x 10.5 mm² size with an inner pad distance of 0.6 mm. The larger dimension is aligned along the wires. The total sensitive area of the CPV module is equal to about 1.8 m².

With the good intrinsic resolution of PbWO₄, care must be taken to minimize the electronics contribution to the noise. This can be done by a judicious choice of the shaping time of the amplifier. For a detector capacitance of 100 pF as for the Hamamatsu S8664-55 APD, the results indicated an electronic noise minimum of about 300e⁻ for a shaping time of about 2 μsec.

A readout controller unit (RCU) on the detector transfers formatted event data over the ALICE digital data link (DDL) to the ALICE DAQ system. The RCU operations are executed by means of firmware in the on-board FPGA. The firmware includes a processor core for handling the Ethernet connection to the ALICE detector control system. The data and control interfaces between the RCU and trigger units of the front-end electronics are implemented by means of the GTL cable bus.

2.3.10 ElectroMagnetic Calorimeter

Construction of a large ElectroMagnetic Calorimeter (EMCal) [20], started in early 2008 with an aim to enable ALICE to explore in detail the physics of jet quenching,
interaction of energetic partons with dense matter, over a large kinematic range provided in heavy-ion collisions at the LHC [1].

The scope and basic design parameters of the calorimeter were chosen to match the physics performance requirements of high $p_T$ physics goals [16]. The EMCal is a large lead scintillator sampling calorimeter with cylindrical geometry, located adjacent to the ALICE magnet coil at a radius of $\sim 4.5$ m from the beam line. It covers $|\eta| \leq 0.7$ and $\Delta \phi = 107^\circ$, and positioned approximately opposite in azimuth to the high precision ALICE PHOS calorimeter.

Fig. 2.10 shows a schematic integration drawing of the end view of the ALICE central barrel. The EMC will be located inside the large L3 magnet within a cylindrical integration volume 112 cm deep sandwiched between the ALICE central detectors space frame (housing the TPC, TRD and TOF apparatus) and the magnet coils.

![Fig. 2.10. Integration drawing of the end view of the ALICE central barrel.](image)

In Fig. 2.11, a perspective view of the EMC in its dedicated support structure is shown. The chosen technology is a layered lead scintillator sampling calorimeter with a longitudinal pitch of 1.44 mm Pb and 1.76 mm scintillator with longitudinal wave length shifting fibre light collection. The detector is segmented into 12672 towers,
each of which is approximately projected in $\eta$ and $\phi$ to the interaction vertex. The towers are grouped into supermodules of two types: 'full size' which span $\Delta \eta = 0.7$ and $\Delta \phi = 20^\circ$, and 'half size' which span $\Delta \eta = 0.7$ and $\Delta \phi = 7^\circ$. There are 10 full size and 2 half size super modules in the full detector acceptance.

![Figure 2.11](image)

**Fig. 2.11.** The calorimeter is a section of a circular cylinder with inner radius $\sim 4.2$ metres and an active length along the beam direction of $\sim 6.8$ metres.

The light yield, per unit of energy, deposited in the EMC is similar to that of the PHOS [15, 21]. Since the electronic noise performance requirements of the EMC are less stringent than those for PHOS due to the larger intrinsic energy resolution of the EMC, the PHOS readout electronics were adopted for the EMC readout, with only minor modification. The only significant difference with the PHOS readout is the difference in the FEE amplifier due to the chosen dynamic range and the amplifier shaping time.

### 2.3.11 ALICE COsmic Ray DEtector

The ALICE COsmic Ray DEtector is an array of plastic scintillator counters placed on the upper surface of L3 magnet. It plays two-fold role in ALICE:

- the first task is to provide a fast (Level 0) trigger signal, for the commissioning, calibration and alignment procedures of some of the ALICE tracking detectors;
• it will also detect, in combination with the TPC and TRD, atmospheric muons and multimuon events, thus allowing us to study high energy cosmic rays.

A feasibility and performance study is given in detail in references [1, 16, 22, 23]. An ACORDE module consisting of two scintillator counters, each with 190 x 20 cm$^2$ effective area, arranged in a doublet configuration as shown in Fig. 2.12.

![Fig. 2.12. The ACORDE scintillator module array on the upper faces of the magnet yoke.](image)

With this set up a uniform efficiency higher than 90% along the whole length of the test module is achieved. The typical rate for single atmospheric muons reaching the ALICE detector is relatively low (4.5 Hz/m$^2$), the rate for multi muon events is expected to be much lower (less than $10^{-3}$ Hz/m$^2$). However, this is statistically sufficient for studying these types of events, provided we can trigger and store tracking information from cosmic ray muons parallel to the ALICE data taking with colliding beams. Atmospheric muons need an energy of at least 17 GeV to reach the ALICE hall, while the upper energy limit for reconstructed muons in the TPC will be nearly 2 TeV at a magnetic field intensity of 0.5 T. This allows us to measure and analyze the atmospheric muon momentum spectra in a wide range (0.1 - 2 TeV).

The ACORDE electronics is formed by:
(i) 60 FEE cards, one per ACORDE module;
(ii) 'ACORDEOR' card to generate the TRD wake up signal which receives the 60 coincidence LVDS signals coming from the FEE cards;
(iii) Main cards, which contain the electronics to receive the 120 LVDS signals coming from 120 scintillators. This card produces the single and the multi-coincidence trigger signals and provides connectivity to the ALICE trigger and DAQ systems.

2.3.12 Zero Degree Calorimeter

The number of participant nucleons is the observable most directly related to the geometry of A - A collisions. It can be estimated by measuring the energy carried in the forward direction at $0^\circ$ relative to the beam direction by non-interacting spectator nucleons. In ALICE, spectator nucleons are detected by means of Zero Degree Calorimeters. If all the spectators are detected, the number of participants may be calculated [1] from:

$$E_{ZDC} \, (\text{TeV}) = 2.76 \times N_{\text{spectators}}$$
$$N_{\text{participants}} = A - N_{\text{spectators}}$$

where 2.76 TeV is the energy per nucleon of the Pb beam at LHC energy. However, such a simple estimate can not be used at a collider since not all the spectator nucleons can be detected. The centrality information provided by the ZDC is also used for triggering at Level 1 (L1). Finally, the ZDC being also a sensitive detector, can give an estimate of the reaction plane in nuclear collisions.

In ALICE two sets of hadronic ZDCs are located at 116 m on either side of the Interaction Point (IP). Additionally, two small zero degree electromagnetic calorimeters (ZEM) are placed at about 7 m from the IP, on both sides of the LHC beam pipes, opposite to the muon arm as exhibited in Fig. 2.13.

Spectator protons are spatially separated from neutrons by the magnetic elements of the LHC beam line. Therefore, each ZDC set is made by two distinct detectors: one for the spectator neutrons, placed between the beam pipes at $0^\circ$ relative to the
LHC axis, and one for spectator protons, placed externally to the outgoing beam pipe on the side where positive particles are deflected. A front view of the positions of ZN and ZP are displayed in Fig. 2.14.

**Fig. 2.13.** Schematic top view of the ALICE beam line opposite to the Muon Arm. The locations of the neutron (ZN), proton (ZP) and forward electromagnetic (ZEM) calorimeters are shown.

**Fig. 2.14.** Front view of one ZDC set placed on the lifting platform in data taking position.

The quartz fibre calorimetry [24] technique has been adopted for the ZDC of the ALICE. The shower generated by incident particles in a dense absorber, called 'passive' material, produces Čerenkov radiation in quartz fibre ('active' material) interspersed with the absorber. Due to the small amount of space available (particularly
for the neutron calorimeter), the detectors are very compact. For this reason a very dense W-alloy was used as passive material for ZN, to maximize the containment of the showers. For the proton calorimeter (ZP), there are no such stringent space constraints. Moreover, the spectator proton’s spot has a wide spatial distribution. Therefore, a larger detector made up of brass was constructed. The ZDC will operate in a very high radiation environment upto $10^4$ Gy/day at a luminosity of $10^{27}$ cm$^{-2}$sec$^{-1}$. For this reason, quartz fibres were chosen due to their intrinsic radiation hardness.

The energy resolution of ZEMs were estimated by carrying out Monte Carlo simulation within the AliRoot offline framework and using HIJING event generator [25]. The results show that in central collisions ($b < 2$ fm) the total incident energy on the two electromagnetic calorimeters is about 7 TeV, while in the peripheral interactions ($b \sim 10$ fm) it is of the order of 1.5 TeV. A resolution:

$$\sigma/E = 0.69/\sqrt{E(\text{GeV})}$$

has been obtained with a detector prototype tested at SPS. Extrapolating this resolution to the LHC energy, we expect an energy resolution < 1% for central collisions, increasing upto 1.8 % for the peripheral events.

For the readout, each analogue signal from the photomultipliers will be sent to commercial ADC modules housed in a VME crate. When a Level 0 (L0) trigger is received, the ZDC readout electronics will start to convert the signals and make them available for the ALICE DAQ if the L1 trigger is available.

2.3.13 Photon Multiplicity Detector

The multiplicity and spatial ($\eta - \phi$) distribution of photons in the forward pseudorapidity region of $2.3 \leq \eta \leq 3.7$ are measured by the Photon Multiplicity Detector (PMD) [26]. These measurements also provide estimates of transverse electromagnetic energy and the reaction plane on an event-by-event basis. The measurement of photon multiplicity gives vital information in terms of limiting fragmentation, order of phase transition, the equation of state of matter and the formation of disoriented
chiral condensates.

The PMD uses the preshower method, where a $3X_0$ ($\sim 1.5$ cm) thick lead converter with 0.5 cm thick stainless steel backing is sandwiched between two planes of high granular gas proportional counters. The sensitive element of the detector consists of a large arrays of gas proportional counters in a honeycomb cellular structure. The basic cell is a honeycomb shaped cathode which has a 20 $\mu$m thick gold plated tungsten wire kept at a ground potential at the centre of each cell. The schematic diagram of the unit cell is shown in Fig. 2.15.

![Schematic diagram of the cross section of a unit cell of the PMD.](image)

The granularity of the PMD was optimized given the requirements of low occupancy, high efficiency and purity of photon detection at the maximum predicted charge particle multiplicity density ($dN_{ch}/d\eta = 8000$). The cell cross section and depth are 0.22 cm$^2$ and 0.5 cm, respectively. The insulation circle diameter is 2 mm and the diameter of wire support is 0.3 mm. The optimal operating voltage for the detector is - 1400 Volts. The efficiency is about 96 % for the charged pions at this voltage.

The PMD chambers are fabricated in the form of module consisting of 4608 honeycomb cells. Each plane of PMD is made up of 24 modules as shown in Fig. 2.16. Two different types of modules (A - type and B - type) were employed, consisting of an array of 48 x 96 honeycomb cells configured in two different arrangements. Each
module is served by separate high voltage and low voltage supplies. In total, 48 high voltage channels are used for 48 modules.

![Diagram of PMD](image)

**Fig. 2.16.** The PMD position and layout in the ALICE shown with respect to ITS.

The schematics of FEE for the PMD is similar to the set up for the tracking chambers of the Forward Dimuon Spectrometer of the ALICE. The signals from the anode wire for a group of 64 cells within a matrix of 4 rows and 16 columns are connected to two 32 pin FRC connectors by a flexible cable which connects to the FEE board at the other end. The signals are processed using MANAS chips, which handle 16 channels providing multiplexed analog outputs. Each FEE board consists of four MANAS chips, two 12-bit ADCs and a custom built ASIC called MARC chip which controls all 64 channels and performs zero suppression of the data. A set of FEE boards are readout using Digital Signal Processors (DSP). The DSPs are handled through a cluster readout system (CROCUS). The main objective of the CROCUS is to gather and concentrate information coded on the FEE and pass to the DAQ, drive the FEEs via patch bus controllers, receive and distribute the trigger
signals and perform the calibration of the detector. Each CROCUS crate can handle 50 patch buses. Each patch bus handles one chain of FEE boards.

### 2.3.14 Forward Multiplicity Detector

The main function of Forward Multiplicity Detector is to provide charged particle multiplicity information in the pseudorapidity range \(-3.4 < \eta < -1.7\) for FMD1 and \(1.7 < \eta < 5.0\) for FMD2 and FMD3. Fig. 2.17 shows the location of each FMD ring in ALICE as well as the basic layout of the silicon sensors that are located on either side of the ITS detector.

![Diagram of FMD rings in ALICE experiment](image)

**Fig. 2.17.** Layout of the FMD rings in the ALICE experiment.

The FMD1 ring is placed further from the interaction point to extend the charged particle multiplicity coverage. An outer ring is not necessary on FMD1 because it would have added additional material in front of the PMD. FMD2 and FMD3 each consist of both an inner and an outer ring of silicon sensors and are located on either side of the ITS detector. FMD2 and FMD3 are positioned to have approximately
the same acceptance. However, the presence of T0 detector necessitated a different placement for the FMD3 inner ring.

Each detector ring consists of 10 and 20 silicon sensors for inner and outer rings. The radial span, distance from inner radius to outer radius, is limited by the 15 cm diameter by wafers from which the silicon sensors are made. Two types of silicon sensors were fabricated. Inner sensors consist of two azimuthal sectors each with 512 silicon strips. The radii of inner strip range from 4.2 cm to 17.2 cm. Outer sensors also consist of two azimuthal sectors each with 256 silicon strips with radii ranging from 15.4 cm to 28.4 cm. Each ring (inner and outer) contains 10240 silicon strips giving the full FMD a total of 51,200 silicon strips to be readout. An assembled FMD ring system (FMD3) is shown in Fig. 2.18.

Fig. 2.18. Assembled FMD3 detector. Two outer digitizer boards can be seen while the two inner digitizer boards are partially covered. Each of the green cables connects a silicon module mounted on the other side of the support plate of its respective digitizer board.
To achieve the best signal resolution, amplification of the signal must be done as close as possible to the detector element. A VA preamplifier chip [27] is placed directly on the hybrid PC card to amplify and shape of the detected signal. This preamplifier chip has low noise (250 - 350 ENC for the FMD detector load) and a gain allowing for signals up to 20 MIPs to be readout before saturating. Each VA chip has input lines for individual amplification and shaping of 128 signals. An inner silicon module, therefore, requires eight VA chips, while an outer silicon module requires four.

Further, electronics is needed to digitize the signals and to control readout. Short readout cables connect five inner modules to an inner digitizer card or 10 outer modules to an outer digitizer card. The main components of a digitizer card are the ALTRO chip [28] (three per digitizer card), each used for digitizing the signal from one or two silicon modules, and an FPGA chip, which controls the readout of the silicon modules as well as controlling monitoring services for temperature, voltage and current. Transfer of data from the ALTRO buffers to the DAQ system is controlled by the RCU and done serially for all data in all ALTRO buffers for that event on a 40 MHz bus that can transfer data nominally at 160 MB/s and maximally at 200 MB/s.

2.3.15 V0 Detector

The V0 detector [29] is a small angle detector which provides minimum bias triggers for the central barrel detectors in pp and A-A collisions. The V0 serves as an indicator of the centrality of the collision via the multiplicity recorded in the event. Cuts on the number of fired counters and on the total charge can be applied to achieve rough centrality triggers. It provides a validation signal for the muon trigger [30] to filter background in pp mode. Finally, the V0 detector participates in the measurement of luminosity in pp collisions with a good precision of about 10%.

The V0 detector is made of two arrays of scintillator counters called V0A and V0C which are installed on either side of the ALICE interaction point. The V0A is located 340 cm from the Interaction Point on the side opposite to the Dimuon Spectrometer. The V0C is fixed at the front face of the hadronic absorber, 90 cm from the vertex.
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They cover the pseudorapidity ranges $2.8 < \eta < 5.1$ (V0A) and $-3.7 < \eta < -1.7$ (V0C) for collision vertex at the central position. A picture of each array is shown in Fig. 2.19.

![Fig. 2.19. Front view of V0A (left) and V0C (right) arrays.](image)

The Channel Concentrator Interface Unit (CCIU) board distributes the clock to elements of FEE, generates the calibration triggers, the five final trigger and busy signals, collects and organizes the data from CIU boards, provides several interfaces with some elements of ALICE ECS (Experimental Control System). The three main blocks of CCIU board are: (i) the FPGA for the data handling, (ii) the SIU mezzanine, interface between DAQ and FEE and (iii) the DCS mezzanine, interface between FEE and DCS for the V0 slow control and between FEE and TTC partition.

2.3.16 T0 Detector

The T0 detector [29, 31] was designed with the following objectives:

**First**, to generate a T0 signal from the TOF detector. This timing signal corresponds to the real time of the collision (plus a fixed delay) and is independent of the position of the vertex. The required precision of the T0 signal is about 50 ps (r.m.s.).

**Second**, to measure the vertex position (with a precision of $\pm 1.5$ cm) for each interaction and to provide L0 trigger when the position is within the preset values. This will discriminate against beam - gas interactions.

**Third**, to provide an early 'wake-up' signal to TRD, prior to L0.
Fourth, to measure the particle multiplicity and generate one of the two possible trigger signals: $T_{0\text{semi-central}}$ or $T_{0\text{central}}$.

The detector consists of two arrays of Čerenkov counters, 12 counters per array, namely: $T_0A$ and $T_0C$. Each Čerenkov counter is 30 mm in diameter and 45 mm long optically coupled to a quartz radiator 20 mm in diameter and 20 mm thick. The $T_0C$ array is placed 72.7 cm from the nominal vertex. The pseudorapidity range of $T_0C$ is $-3.28 \leq \eta \leq -2.97$. The $T_0A$ array is about 375 cm from the central region on the opposite side of the Interaction Point (IP) as shown in Fig. 2.20. The $T_0A$ is grouped together with the other forward detectors (FMD, V0 and PMD) and covers pseudorapidity range of $4.61 \leq \eta \leq 4.92$.

![Fig. 2.20. The layout of $T_0$ detector arrays inside ALICE.](image)

The $T_0$ timing signal is generated online by mean timer. The position of the $T_0$ signal on the time axis is equal to $(T_0A + T_0C)/2 + T_{\text{delay}}$, where $T_{\text{delay}}$ is the fixed delay of the analogue mean timer. The position of the vertex is measured as $T_0A - T_0C$ and this value is fed to a digital discriminator with preset upper and lower limits, thus providing the $T_0\text{vertex}$ trigger signal. $T_{0\text{semi-central}}$ and $T_{0\text{central}}$ multiplicity trigger signals are generated by 2 discriminator levels applied to the
linear sum of the amplitudes from all the detectors in the array.

The readout electronics consists of the CPDM (Clock and Pulse Distribution Module), TRM (TDC Readout Module) and DRM (Data Readout Module) cards. The CPDM card is used to distribute 40 MHz low-jitter LHC clock to TRM, DRM and to main T0 electronics. The TRM card houses the HPTDC chips, used by T0 in very high resolution mode (24.4 ps bin width). Each TRM card contains 30 HPTDC chips. The DRM card is the T0 interface to the ALICE DAQ system, it reads and encodes the data from the TRM cards and sends them to the ALICE DAQ via the DDL optical link. The DRM card receives the trigger information from the CTP via the TTCrx chip and performs a slow control function with a dedicated CPU.
References: