Chapter 5

ALICE Experiment

ALICE (1; 2; 3) (A Large Ion Collider Experiment) is a major experiment at the Large Hadron Collider (LHC), Geneva, which is a collider facility used for the study of QCD matter created in high-energy collisions between lead nuclei. QCD (quantum chromodynamics) calculations predict the existence of a state of deconfined quarks and gluons at energy densities above 1 GeV/fm$^3$. The transition to this state is accompanied by chiral symmetry restoration, in which the quarks assume their current masses. This state of matter occurred in the early universe after the electroweak phase transition, i.e. at the age of $10^{-12}-10^{-5}$ s (for a recent review see Ref. BraunMunzinger:2009zz.) High-energy nuclear collisions allow such energy densities to be reached, albeit in a small volume and for a limited duration. Assessing the properties of the created matter requires a sound understanding of the underlying collision dynamics. For this, the heavy-ion (AA) collision studies in the new energy regime accessible at the LHC have to be complemented by proton-proton (p+p) and proton-nucleus (pA) collision experiments. These control measurements, besides being interesting in themselves, are needed to separate the genuine QCD-matter signals from the cold-matter initial- and final-state effects. The physics goals of ALICE are described in detail in Refs. Carminati:2004fp,Alessandro:2006yt; the results obtained to date are accessible at Ref. alice pub. The ALICE apparatus (Fig. 5.1)
5.1 ALICE detectors set-up:

Figure 5.1: The ALICE experiment at the CERN LHC. The central-barrel detectors (ITS, TPC, TRD, TOF, PHOS, EMEcal, and HMPID) are embedded in a solenoid with magnetic field $B = 0.5$ T and address particle production at midrapidity. The cosmic-ray trigger detector ACORDE is positioned on top of the magnet. Forward detectors (PMD, FMD, V0, T0, and ZDC) are used for triggering, event characterization, and multiplicity studies. The MUON spectrometer covers $-4.0 < \eta < -2.5$, $\eta = -\ln \tan(\theta/2)$.

has overall dimensions of $16 \times 16 \times 26$ m$^3$ and a total weight of $\sim 10,000$ t. It was designed to cope with the particle densities expected in central collisions at the LHC. The experiment has a high detector granularity, a low transverse momentum threshold $p_T^{\text{min}} \approx 0.15$, and good particle identification capabilities up to 20. The seventeen ALICE detector systems, listed in Table 5.1, fall into three categories: central-barrel detectors, forward detectors, and the MUON
Table 5.1: The ALICE detectors: The detectors marked with an asterisk (*) are used for triggering. The central-barrel detectors – Inner Tracking System (ITS), Time Projection Chamber (TPC), Transition Radiation Detector (TRD), Time Of Flight (TOF), Photon Spectrometer (PHOS), Electromagnetic Calorimeter (EMCal), and High Momentum Particle Identification Detector (HMPID) – are embedded in the L3 solenoid magnet which has $B=0.5 \, \text{T}$.

| Detector | Acceptance Polar $|\eta|<2.0$ | Acceptance Azimuthal $|\phi|<320$ | Technology | Main purpose |
|----------|----------------|------------------|------------|-------------|
| SPD*     | $|\eta|<1.4$  | full  | Si pixel  | tracking, vertex |
|          | $|\eta|<0.9$  | full  | Si pixel  | tracking, vertex |
| SDD      | $|\eta|<1.0$  | full  | Si drift  | tracking, PID   |
| SSD      | $|\eta|<0.9$  | full  | Si drift  | tracking, PID   |
| TPC      | $|\eta|<0.9$  | full  | Si strip  | tracking, PID   |
| TRD*     | $|\eta|<0.8$  | full  | Ne drift+MWPC | tracking, PID   |
| TOF*     | $|\eta|<0.9$  | full  | TR+Xe drift+MWPC | tracking, PID   |
| PHOS*    | $|\eta|<0.12$ | $220<|\phi|<320$ | PbWO$_4$ | PID           |
| EMCal*   | $|\eta|<0.7$  | $80<|\phi|<187$ | Pb+scint. | photons and jets |
| HMPID    | $|\eta|<0.6$  | $1<|\phi|<59$ | C$_6$F$_{14}$ RICH+MWPC | PID | photons |
| ACORDE*  | $|\eta|<1.3$  | $30<|\phi|<150$ | scint. | cosmics |
| PMD      | $2.3<\eta<3.9$ | full  | Pb+PC     | charged particles |
| FMD      | $3.6<\eta<5.0$ | full  | Si strip  | charged particles |
|          | $1.7<\eta<3.7$ | full  | Si strip  | charged particles |
|          | $-3.4<\eta<-1.7$ | full  | Si strip  | charged particles |
| V0*      | $2.8<\eta<5.1$ | full  | scint.    | time, vertex |
|          | $-3.7<\eta<-1.7$ | full  | scint.    | time, vertex |
| T0*      | $4.6<\eta<4.9$ | full  | quartz   | forward neutrons |
|          | $-3.3<\eta<-3.0$ | full  | quartz   | forward protons |
| ZDC*     | $|\eta|>8.8$  | full  | W+quartz  | photons |
|          | $6.5<|\eta|<7.5$ | $|\phi|<10$ | brass+quartz | photons |
|          | $4.8<|\eta|<5.7$ | $|2\phi|<32$ | Pb+quartz | photons |
| MCH      | $-4.0<\eta<-2.5$ | full  | MWPC   | muon tracking |
| MTR*     | $-4.0<\eta<-2.5$ | full  | RPC    | muon trigger |
spectrometer. In this section, a brief outline of their features is given. Specifications and a more detailed description can be found in Ref. Aamodt:2008zz.

5.2 ALICE Coordinate Systems and detectors classifications:

The collision systems and energies inspected by ALICE are summarized in Table 5.1 in Section ???. In the following, we start from a description of the running conditions, data taking and calibration, and then review the performance of the experiment in terms of various physics observables.

The ALICE Coordinate System, used in Table 5.1 and throughout the paper, is a right-handed orthogonal Cartesian system defined as follows (7).

![Figure 5.2: schematic diagram of ALICE coordinate system](image)

The origin is at the LHC Interaction Point 2 (IP2). The $z$ axis is parallel to the mean beam direction at IP2 and points along the LHC Beam 2 (i.e., LHC anticlockwise). The $x$ axis is horizontal and points approximately towards the center of the LHC. The $y$ axis, consequently, is approximately vertical and points upwards.

- **The central-barrel detectors** – Inner Tracking System (ITS), Time Projection Cham-
5.2. ALICE COORDINATE SYSTEMS AND DETECTORS CLASSIFICATIONS:

ber (TPC), Transition Radiation Detector (TRD), Time Of Flight (TOF), Photon Spectrometer (PHOS), Electromagnetic Calorimeter (EMCal), and High Momentum Particle Identification Detector (HMPID) – are embedded in the L3 solenoid magnet which has \( B=0.5 \) T. The first four cover the full azimuth, with a segmentation of 20, at midrapidity \( (|\eta| \lesssim 0.9) \). The ITS and the TPC are the main charged-particle tracking detectors of ALICE.

- **The forward detectors** – Include the preshower/gas-counter Photon Multiplicity Detector (PMD) and the silicon Forward Multiplicity Detector (FMD), which are dedicated to the measurement of photons and charged particles around \( |\eta| \approx 3 \), respectively. The quartz Cherenkov detector T0 delivers the time and the longitudinal position of the interaction. The plastic scintillator detector VZERO measures charged particles at \(-3.7 < \eta < -1.7\) and \(2.8 < \eta < 5.1\), and is mainly used for triggering and for the determination of centrality and event plane angle in collisions (6). The centrality can also be measured with the Zero Degree Calorimeter (ZDC).

- **The MUON spectrometer** – With a hadron absorber of \( \sim 10 \lambda_{\text{int}} \), a dipole magnet of 3 Tm, and five tracking stations with two pad chambers each (Muon Chambers, MCH), is used to measure quarkonium and light vector meson production in a region of \(-4.0 < y < -2.5\). The measurement of high-\( p_T \) muons, which predominantly come from the decay of charm and beauty, also falls within the scope of the spectrometer. Single-muon and muon-pair triggers with an adjustable transverse-momentum threshold are provided by two further stations (Muon Trigger, MTR) placed behind an additional \( 7 \lambda_{\text{int}} \) absorber.

Below we discuss few main detectors which is most important for this analysis in detailed. It can also be classified in terms of:

- (a) **Hadron identification detectors** (e.g. ITS, TPC etc.)

- (b) **Tracking and vertexing detectors** (e.g. ITS, V0 etc.)
5.2. ALICE COORDINATE SYSTEMS AND DETECTORS CLASSIFICATIONS:

- (c) centrality estimator detectors (e.g. V0, ZNA etc.)
- (d) Special purpose detectors (e.g. PMD, Muon spectrometer etc.)

As this thesis is mainly dealing with precise measurement of particle identification and their transverse momentum spectrum, so mainly (a) Hadron identification detectors are useful, keeping in mind their identification range capabilities which is listed below.

The ALICE detector has a number of different subsystems for identifying charged hadrons and electrons. The following subsystems are used for hadron identification:

- **ITS:** The outer four layers of the Inner Tracking System have an analog readout to measure the deposited charge, thereby providing a measurement. This is mainly useful for low-\(p_T\) tracks (\(p_T \lesssim 0.7\)), specifically at very low \(p_T\), where the ITS is used for standalone tracking.

- **TPC:** The Time Projection Chamber measures the charge deposited on up to 159 padrows. A truncated mean (40% highest-charge clusters discarded) is calculated and used for a wide range of momenta. The largest separation is achieved at low \(p_T\) (\(p_T \lesssim 0.7\)) but a good separation is also present in the relativistic rise region (\(p_T \gtrsim 2\)) up to \(\sim 20\).

- **TOF:** The Time-Of-Flight detector is a dedicated detector for particle identification that measures the arrival time of particles with a resolution of \(\sim 80\) ps. This provides a good separation of kaons and protons up to \(p_T \gtrsim 4\).

- **HMPID:** The High Momentum Particle Identification Detector is a ring-imaging Cherenkov detector that covers \(|\eta| < 0.6\) in pseudorapidity and 57.6 in azimuth, corresponding to 5% acceptance of the central barrel, and provides proton/kaon separation up to \(p_T \gtrsim 5\).

The measurements in the different particle identification detector systems are then combined to further improve the separation between particle species. This is discussed in details below.

The particle identification (PID) capabilities of these detectors are used for a wide range of physics analyses, including transverse momentum spectra for pions, kaons, and protons (9;
10), (11); heavy-flavor decays (8); Bose-Einstein correlations for pions (12; 13? ) and kaons (14; 15); and resonance studies (16). The hadron identification systems is also used to identify electrons. In addition, the calorimeters (PHOS and EMCal) and the Transition Radiation Detector (TRD) provide dedicated electron identification.

5.3 Inner Tracking System -ITS

Location-wise being the closest detector to the beam pipe, the Inner Tracking System (ITS) (17) is used for the determination of the primary interaction vertex. Along with precise vertex measurement, ITS is also used for the tracking and particle identification of low momentum tracks that fail to reach TPC. Consisting of six concentric layers of silicon detectors around the beam-pipe, it cover 0.9 units in pseudorapidity and $2\pi$ in azimuth. As shown in the Fig. 5.3, moving radially outward from the interaction point, the six layered ITS has 2 layers each of SPD, SSD and SDD respectively.

![A schematic view of ALICE-Inner Tracking Chamber. Also shown different sub-layers: SPD, SDD and SSD.](image)

**Silicon Pixel Detector** : The two inner-most layers of ITS consist pixel based silicon detectors, the SPD. Made of 2-dimensional array of $256 \times 160$ finely segmented silicon pixels. Fine granularity of SPD detectors allow them to localize tracks in the z-direction. SPD con-
tributes significantly towards precise vertex measurement and impact-parameter measurement.

**Silicon Drift Detector:** The two intermediate layers of the ITS are SDDs, are particularly used for particle identification using specific energy loss (dE/dx) of the tracks passing through the active volume of the detectors. These are finely granulated in one direction and coarse along the other. The position of the track hits in the transverse direction is obtained from the drift-time of electrons to the electrode with respect trigger-time and the z-position of the hits are determined from the centroid of the charge accumulated in the anodes. A precise knowledge of drift-time is extremely necessary for the accurate reconstruction of the tracks in SDD.

**Silicon Strip Detectors:** The last two (fifth and sixth) layers of ITS are made of double-sided silicon strips. Like SDD, SPDs are also used for low momentum particle identification exploiting the energy loss (dE/dx) information in the detector volume. The outer two layer are also crucial for ITS-TPC track matching.

Overall, ITS can improve tracking and angular resolution of the tracks. Most of the low momentum tracks (tracklets) that fail to reach TPC are reconstructed in ITS thereby allowing physics measurements at low $p_T$ below 200 MeV. Use of silicon based detectors also facilitates maintaining a low material budget.

**Particle identification in the ITS**

The inner tracking system (ITS) of ALICE consists of six layers of silicon detectors. The outer four layers provide a measurement of the ionization energy loss of particles as they pass through the detector. The measured cluster charge is normalized to the path length, which is calculated from the reconstructed track parameters to obtain a value for each layer. For each track, the is calculated using a truncated mean: the average of the lowest two points if four points are measured, or a weighted sum of the lowest (weight 1) and the second-lowest points (weight 1/2), if only three points are measured. An example distribution of measured truncated mean energy loss values as a function of momentum in the ITS is shown in Fig. 5.3.
Figure 5.3: Distribution of the energy-loss signal in the ITS as a function of momentum. Both the energy loss and momentum were measured by the ITS alone.

5.3.1 Time Projection Chamber -TPC

The Time Projection Chamber or TPC (18) is a gas detector and at the center of ALICE central-barrel detectors, dedicated towards tracking and particle identification. It is most important detector in the ALICE, placed coaxially with beam-pipe and ITS, whose inner radius located at 80 cm and the outer radius at approx 250 cm from the beam pipe. The length of the chamber is about 510 cm along the beam pipe. The TPC covers a phase space of $|\eta| < 0.9$ and full range of azimuth. Till 2010 June, TPC was used with Ne:CO$_2$:N$_2 = 85.7\%:9.5\%:4.8\%$ gas mixture but later(2011), a new gas-mixture Ne:CO$_2 = 90\%:10\%$ was introduced to decrease the gas-gain and prevent frequent detector-breakdown during high luminosity runs. The choice of this gas mixtures and detector configuration has been optimised further to minimize low electron diffusion, small space charge effect and low material budget in order to ensure good momentum resolution, high rate handling capacity, minimal re-scattering and secondary particle generation.
Particle identification in the TPC

The TPC (20) is the main tracking detector in ALICE. In addition it provides information for particle identification over a wide momentum range. Particle identification is performed by simultaneously measuring the specific energy loss $\lambda$, charge, and momentum of each particle traversing the detector gas. The energy loss, described by the Bethe-Bloch formula, is parametrized by a function originally proposed by the ALEPH collaboration (21),

$$f(\beta\gamma) = \frac{P_1}{\beta P_3} \left( P_2 - \beta P_3 - \ln(P_3 + \frac{1}{(\beta\gamma)^{P_3}}) \right),$$

(5.1)

where $\beta$ is the particle velocity, $\gamma$ is the Lorentz factor, and $P_{1-5}$ are fit parameters. Figure 5.4 shows the measured vs. particle momentum in the TPC, demonstrating the clear separation between the different particle species. The lines correspond to the parametrization. While at low momenta ($p < 1$) particles can be identified on a track-by-track basis, at higher momenta particles can still be separated on a statistical basis via multi-Gaussian fits. Indeed, with long tracks ($\geq 130$ samples) and with the truncated-mean method the resulting peak shape is Gaussian down to at least 3 orders of magnitude.

In the relativistic rise region, the exhibits a nearly constant separation for the different particle species over a wide momentum range. Due to a resolution of about 5.2% in collisions and 6.5% in the 0–5% most central collisions\(^5\), particle ratios can be measured at a $p_T$ of up to 20 (22). The main limitation at the moment is statistical precision, so it is expected that the measurement can be extended up to $\sim 50$ in the future.

As an example, distributions for charged particles with $p_T \approx 10$ are shown in Fig. 5.5 for and the 0–5% most central collisions. Note that, for this analysis, a specific $\eta$ range was selected in order to achieve the best possible resolution. The curves show Gaussian fits where the mean and width were fixed to the values obtained using clean samples of identified pions and protons from, respectively, and $\Lambda$ decays, and assuming that the response at high $p_T$ depends only on

\(^5\)The deterioration of the energy-loss resolution in high-multiplicity events is caused by clusters overlapping in $z$ and/or sitting on top of a signal tail from an earlier cluster.
Figure 5.4: Specific energy loss (\(dE/dx\)) in the TPC vs. particle momentum in collisions at = 2.76 TeV. The lines show the parametrizations of the expected mean energy loss.

\(\beta\gamma\).

5.4 Time of Flight -TOF

The Time-Of-Flight (TOF) detector (23) of ALICE is a large area array of Multigap Resistive Plate Chambers (MRPC), positioned at 370–399 cm from the beam axis and covering the full azimuth and the pseudorapidity range \(|\eta| < 0.9\). In collisions, in the centrality range 0–70% the overall TOF resolution is 80 ps for pions with a momentum around 1. This value includes the intrinsic detector resolution, the contribution from electronics and calibration, the uncertainty on the start time of the event, and the tracking and momentum resolution (24).

The active area of the detector is filled with a gas mixture of Freon:SF\(_6\):Iso-butane=90%:5%:5%. These MRPCs achieve an efficiency of 99.9% and time resolution better than 40 ps. The start time for the TOF measurement is provided by the T0 detector, which consists of two arrays of Cherenkov counters T0C and T0A, positioned at opposite sides of the interaction point (IP) at \(-3.28 < \eta < -2.97\) and \(4.61 < \eta < 4.92\), respectively. Each array has 12 cylindrical counters.
5.4. TIME OF FLIGHT -TOF

![Graphs showing ionization energy loss distributions in the TPC in (left) and collisions (right) at $\gamma = 2.76$ TeV. The lines represent Gaussian fits as described in the main text.](image)

Figure 5.5: Ionization energy loss (ΔE) distributions in the TPC in (left) and collisions (right) at $\gamma = 2.76$ TeV. The lines represent Gaussian fits as described in the main text.

Equipped with a quartz radiator and photomultiplier tube (?). Thus the overall time resolution of ALICE-TOF is given by: $\sigma_{TOF} = \sqrt{\sigma^2_{intrinsic} + \sigma^2_{0}}$

In Pb-Pb collisions, $\sigma_{TOF}$ was found to be 86 ps. Hence a maximum separation of 2σ between protons and kaons could be reached at a momentum of 5 GeV/c. Combined with TPC and ITS, TOF can facilitate event by event identification of pure samples of $\pi^{\pm}, K$ and protons up to a momentum range of 4 GeV/c (31). TOF provides PID in the intermediate momentum range, up to 2.5 for pions and kaons, and up to 4 for protons.

5.4.1 Particle identification in TOF

The start time (interaction time of the collision) as measured by the sum of the time signals from the T0A and T0C detectors in collisions at $\gamma = 2.76$ TeV with respect to the nominal LHC clock value. The width of the distribution is indicative of how much the collision time can jitter with respect to its nominal value (the LHC clock edge). This is due to the finite size of the bunches and the clock-phase shift during a fill. The time resolution of the detector, estimated by the time difference registered in T0A and T0C, is 20–25 ps in collisions and ~40 ps in collisions. The efficiency of T0 is 100% for the 60% most central collisions at $\gamma = 2.76$ TeV, dropping to about
50% for events with centrality around 90%. For collisions at \(7\) TeV, the efficiency is about 50% for a T0 coincidence signal (T0A-AND-T0C) and 70% if only one of the T0 detectors is requested (T0A-OR-T0C).

The start time of the event \(t_{ev}\) is also estimated using the particle arrival times at the TOF detector. A combinatorial algorithm based on a \(\chi^2\) minimization between all the possible mass hypotheses is used in the latter case. It can be invoked when at least three particles reach the TOF detector, to provide increased resolution and efficiency at larger multiplicity. With 30 tracks, the resolution on \(t_{ev}\) reaches 30 ps (24). This method is particularly useful for events in which the T0 signal is not present. If neither of these two methods is available, an average TOF start time for the run is used instead.

At \(p_T < 0.7 GeV/c\), the matching efficiency is dominated by energy loss and the rigidity cutoff generated by the magnetic field. At higher transverse momenta it reflects the geometrical acceptance (dead space between sectors), the inactive modules, and the finite efficiency of the MRPCs (98.5% on average).

Figure 5.6 illustrates the performance of the TOF detector by showing the measured velocity \(\beta\) distribution as a function of momentum (measured by the TPC). The background is due to tracks that are incorrectly matched to TOF hits in high-multiplicity collisions. The distribution is cleaner in collisions (Fig. ??), showing that the background is not related to the resolution of
the TOF detector, but is rather an effect of track density and the fraction of mismatched tracks.

Fig. 5.7 shows, for tracks with $1.5 < p_T < 1.6$ GeV/c, the difference between the measured time of flight and the expectation for kaons, together with a template fit to the pion, kaon, and proton peaks and the combinatorial background from mismatched tracks.

![Graph showing TOF measurements](image)

Figure 5.7: TOF measured in collisions at $\sqrt{s_{NN}} = 2.76$ TeV. The expected time of flight for kaons is subtracted and the result is divided by the expected resolution.

5.5 The Forward Detectors

The Forward detectors in ALICE comprise of pre-shower Photon Multiplicity Detector (PMD), silicon-based Forward Multiplicity Detector (FMD) quartz Cherenkov detector T0, plastic scintillitor based V0 and Zero Degree Calorimeter (ZDC).

The main objective of the ALICE Forward Multiplicity Detector or FMD (33) is to allow determination of charged particle multiplicity at forward rapidity. The FMD consists of 5 rings of silicon strip detectors placed around the beam-pipe. 3 inner rings (FMD1i, FMD2i and FMD3i) contain 10 hexagonal silicon cells while, 2 outer rings (FMD2o and FMD3o) have 20
such silicon sensors segmented into 2 sectors. Each sector is further cut into strips at constant radius. Beside extending multiplicity measurement at large forward rapidity, it also caters the need for independent and reliable measurement of event plane inclination. The pseudorapidity coverage of the detector on either side of the interaction point is \(-3.4 \leq \eta \leq -1.7\) and \(-1.7 \leq \eta \leq 5.0\), respectively. Combination of FMD and ITS allow charged particle counting over an extraordinarily large pseudorapidity range \((-3.4 \leq \eta \leq 5.0)\).

The Photon Multiplicity Detector or PMD (35; 36) was installed with an aim to measure photons at the forward rapidity. Located at \(3.67\) m from the interaction point towards the A side of the ALICE it covers pseudorapidity \(2.3 < \eta < 3.9\) and full azimuth. It consists of two planes, Charged Particle Veto (CPV) and Pre-Shower (PRE). A Pb-converter is sandwiched between these two planes. The thickness of the Pb-converter has been optimised to deliver high photon-conversion efficiency but low transverse shower spread. The working principle of the detector is similar to a proportional counter. The active volume of the detector is filled with Ar-CO\(_2\) gas mixture in a proportion of 70:30 by weight. Each PMD plane has 24 modules and each module has 4608 honeycomb cells.

The T0 (33) detector consists of two arrays (T0A and T0C) of Cherenkov counter placed assymmetrically with respect to the interaction point (IP). The T0A is positioned \(3.75\) m from the IP on the A-side of the ALICE and T0C is located \(7.27\) m from the IP towards the C-side of the ALICE. T0 detectors provide the start time of the collision with a precision of 25 ps. This time is also used as a start time by the TOF detector for the time-of-flight measurement of the particles.

**VZERO (V0)**

Similar to T0, plastic scintillator based two arrays of VZERO(V0) detectors (V0A nd V0C) (33; 40) (see Fig. 5.8) are also placed assymmetrically on the either side of the IP. Located at a distance of 340 cm towards the A side of the IP, V0A measures the charged particles in the pseudo-rapidity window of \(2.8 \leq \eta \leq 5.1\). This detector is particularly used for triggering,
5.5. THE FORWARD DETECTORS

![Diagram of forward detectors]

Figure 5.8: V0 detector modules (34)

centrality estimation and backgrounds rejection. Triggering logics are designed using the timing information from V0A and V0C detectors to reject backgrounds originating from the interactions other than beam-beam. Furthermore, the energy deposited in the V0 scintillators can be used to extract charged particle multiplicity in the detector coverage. The V0C is located on the other side of IP at a distance of 90 cm and measures charged particle multiplicity in $-3.7 \leq \eta \leq -1.7$. Each detector has 4 rings and each ring is segmented into 8 sectors, making an overall 32 segmented counters. The information from The calibrated V0 signal amplitudes (V0A + V0C) has been used for centrality estimation. It allows centrality estimation with a resolution of $\approx 0.5\%$ and $2\%$ (32) in most central and peripheral event classes, respectively.

Another important detector is Zero Degree Calorimeter (ZDC) (37), located at 114m on either side of the interaction point IP, measures the energy deposited by the spectator nucleons. Amount of energy deposited in ZDCs is directly related to the spectator nucleon number which are not involved in the interaction. This information can also be utilized for centrality estimation in nuclear collisions (32). Since the spectator protons are deflected by the magnetic elements along the beam-line, ZP is placed outside the beam-line on the side where positive particles are deflected.
5.6. EVENT SIMULATION AND RECONSTRUCTION

5.5.1 The Muon Spectrometers

The purpose of the MUON spectrometer is a RPC based detector used to measure all states of quarkonia and φ-mesons in forward rapidity. The spectrometer is located on the C side of the IP and designed to track muons in the pseudorapidity range $-4 < \eta < -2.5$ with full azimuthal acceptance.

It is a conical shaped front end absorber made of carbon, concrete and steel to stop hadrons and photons and allow muon with momentum $> 4$ GeV/c to pass through. A large dipole magnet (magnetic field of 3Tm) installed perpendicular to beam-pipe outside the L3 magnet, that allows tracking and momentum reconstruction of the muon candidates.

Figure 5.9: A schematic diagram of Muon Spectrometer & its position in ALICE detector system(38; 39)

5.6 Event simulation and reconstruction

The ALICE off-line analysis framework, AliRoot (46), is described in detail in Ref. (47). This framework, based on the Object Oriented / C++ environment of ROOT (48), allows to reconstruct and analyze physics data coming from simulations and real interactions. The role of the framework can be graphically represented as shown in Fig. 5.10. Events are generated via Monte Carlo simulation programs, generators and detector simulation, and are then trans-
formed into the format produced by the detector (raw data). Here we have a minimum of the physics information. At this point, the reconstruction and analysis chain is used to evaluate the detector and the physics performance, and most of the initial information on the generated event can be retrieved (e.g. particle ID and kinematics, event topology). In the next paragraphs we will follow from the left to the right the parabola in Fig. 5.10 and detail the aspects which are relevant to the studies reported in this thesis. The Monte Carlo event generators that were used for the simulation of $Pb - Pb$ collisions (HIJING) at LHC energies, is mainly HIJING (26) (Heavy Ion Jet INteraction Generator) combines a QCD-inspired model of jet production with the Lund string model (?) for jet fragmentation. Binary scaling with Glauber geometry is used to extrapolate to proton–nucleus and nucleus–nucleus collisions.

sectionTrack reconstruction

The event reconstruction procedure includes:

1. cluster finding;

![Diagram](image.png)

Figure 5.10: Schematic representation of the data processing chain.
2. track reconstruction;

3. reconstruction of the position of the interaction vertex.

Next part is on the cluster finding, reconstruction of the interaction (or primary) vertex determination and track reconstruction.

**Cluster finding**

During cluster finding, the information given by the detector electronics \textit{(digits)} is converted to space points, interpreted as (a) the crossing points between the tracks and the centres of the pad rows in the readout chambers, in the case of the TPC, and (b) the crossing points between the tracks and the silicon sensitive volumes, in the case of the ITS. Another important piece of information provided by the cluster finder, is the estimate of the errors of the reconstructed space points. At present, a procedure for parallel clustering and tracking in the TPC is being tested. In the high-multiplicity scenario of $Pb - Pb$ collisions clusters from different tracks may overlap and a preliminary knowledge of the track parameters is very helpful in the cluster deconvolution.

The possibility to use a fast simulation of the detector response is implemented for many sub-systems of ALICE. The clusters are obtained directly from the hits via a parameterization of the response, in terms of efficiency and spatial resolution. The dramatic reduction in computing time (e.g. a factor $\simeq 25$ in the case of the ITS) allows the use of very high statistics in simulation studies. The clusters obtained via the fast simulation are called \textit{fast points}, while those obtained from the detailed detector response are called \textit{slow points}.

**Track reconstruction in TPC–ITS**

Due to the expected charged particle multiplicity, track finding in ALICE is a very challenging task. In the most pessimistic case, the occupancy (defined as the ratio of the number of read-out channels over threshold to the total number of channels) in the inner part of the TPC may reach 40%.
The track finding procedure developed for the barrel (ITS, TPC, TRD, TOF) is based on the Kalman filtering algorithm (43), widely used in high-energy physics experiments. The Kalman filter is a method for simultaneous track recognition and reconstruction (or, in other words, track finding and fitting) and its main property is that, being a local method, at any given point along the track it provides the optimal estimate of the track geometrical parameters at that point. For this reason it is a natural way to find the extrapolation of a track from a detector to another (for example from the TPC to the ITS or TRD). As we will explain, in the Kalman filter energy loss and multiple scattering are accounted for in a direct and simple way.

The first step in tracking starts with clustering of the in each of the detectors. Each cluster is loaded with information regarding its spatial location with respect to a pre-defined origin, signal strength, signal time and their corresponding errors. The clusters from first two layer in ITS are used to determine the location of preliminary priminary vertex followed by tracking in TPC using Kalman Filter (52) technique and track-matching with other central-barrel detectors.

- **Vertex Determination** After applying a three-level trigger system, the primary vertex determination in ALICE is performed by using the cluster information from first two layers in ITS (SPD). Each tracklet, ( pair of space points in first two layers are connected by a line) is propagated to the nominal interaction point (IP) and made to converge. A primary vertex is defined as a point close to IP where most of the tracklets converge. In case of pile-up, this process is repeated and at each iteration, clusters which have been already assigned to a vertex are discarded. However, for final vertexing, global tracks from ITS and TPC after final reconstruction instead of tracklets are extrapolated and made to converge around the IP.

- **Tracking** ALICE tracking strategy based on inward-outward-inward scheme (44; 45). Tracking starts from the two outer-layers of TPC and the parameters from the outer most space-points are considered as seeds for the track-finding algorithm. Seeds are now propagated in-ward and at each step, nearest clusters are assigned depending on their
proximity with the previous seed prolonged to the recent layer. Whenever such clusters are found track parameters and covariance matrices are updated. Tracks with less than 20 clusters are rejected. Accepted tracks are then propagated to the inner radius of TPC. Tracks reconstructed in the TPC are then extrapolated to the outer layer of the ITS which tries to extend the tracks close to the primary vertex. Once the track reconstruction in TPC-ITS is performed, a stand-alone track reconstruction in the ITS is carried out for those tracks (tracklets) which fail to reach TPC.

In the second tracking stage, tracks are refitted using Kalmann Filter in the outward direction (vertex to TPC) taking the clusters obtained in the previous stage. At this stage, track-length integrals and expected flight-time of different particles are calculated and updated for particle identification with TOF. Tracks that could reach TOF are matched with TOF-clusters and propagated further for track matching in EMCAL, PHOS and HMPID.

At the final stage, again Kalman fitting is done in outward-inward approach, starting from the TRD. Position, direction, track-curvature and their respective covariance matrices are re-evaluated and updated.

**ALICE Offline Analysis**

The Offline analysis procedure mainly of two ways:

- Common User Analysis Task
- Analysis Train

In both ways, Event Summary Data (ESD) or Analysis Object Data (AOD) format.

Reconstructed events are stored as ESD or AOD which contain all information about an event both at event and track level like: trigger type, vertex information, centrality/multiplicity and track by track preliminary PID from various detectors. However, ESD files are bulky and not efficient to handle. The data files can be compressed to Analysis Object Data (AOD). AODs
are derived from ESD through re-filtering. Tracks satisfying some pre-defined sets of cuts are kept, rest are deleted. AOD may contain some advanced level information like reconstructed jets from different algorithms. Thus, running on AODs reduce the I/O overhead. Analysis can be performed on both AODs and ESDs, while ESDs are flexible, AODs are computationally efficient.

![The overall picture](image)

**Figure 5.11:** A schematic diagram of offline analysis procedure

Analyses are generally performed on a distributed computing facility called GRID. The ALICE environment software AliEn acts as an interface with the GRID. The job scheduler in AliEn divides a job into multiple sub-jobs and process them parallely in short time. ALICE has also developed Light weight Environment for Grid Operation (LEGO) framework which allows simultaneous execution of jobs from different users intending to run their analyses on same sets of events. Thus data from the storage devices are read just once. This increases CPU efficiency as multiple users can run their jobs using the same computing resources. Additionally, end users are not exposed to grid complexity and hassles of job submission, resubmission, end-of run report, as these are done automatically and designated support personnels handle issues related to bug fixing of the grid environment.

In Analysis Train same procedure has been followed with a common analysis manager as engine
and different analysis task as wagon. The analysis train is the way to run analysis in the most efficient way over a large part or the full dataset. It is using the AliAnalysisManager framework to optimize CPU/IO ratio, accessing data via a common interface and making use of PROOF and GRID infrastructures. The train is assembled from a list of modules that are sequentially executed by the common AliAnalysisManager object. All tasks will process the same dataset of input events, share the same event loop and possibly extend the same output AOD with their own information produced in the event loop.
Bibliography


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R. Frühwirth, Application of the Filter Methods to the Reconstruction of Tracks and Vertices in Events of Experimental High Energy Physics, HEPHY-PUB 516/88, Vienna (1988);  


The code can be found in http://www-nsdth.lbl.gov/~xnwang/hijing/
