Abstract

The theory of strong interactions, Quantum Chromodynamics, has predicted that at extreme temperature and/or energy density strongly interacting matter will undergo phase transition from a state of hadronic constituents to de-confined state of matter in which quarks and gluons are essentially free. The new state is referred to as quark-gluon plasma. The main objective of studying ultra-relativistic heavy-ion collisions is to investigate the characteristics of quark-gluon plasma in the laboratory at extreme conditions of temperature and energy density. This is possible in the collision of two heavy nuclei at ultra-relativistic energies. The resulting small and short lived droplets of the hottest and the densest medium can be studied indirectly by investigating the signals of its formation.

In heavy-ion collisions at ultra-relativistic energies, collisions between nucleons occur and nucleons lose most of their energies and consequently a region of high energy density is created. It is worthwhile mentioning that high energy deposition is envisaged to give rise to creation of a fireball of quarks and gluons in a de-confined state. However, it is not possible to observe directly the products of phase transition. The produced matter may be in the QGP phase. The particles which arise from the interactions between the constituents of the plasma will provide information regarding the state of the plasma. Various kind of signals of QGP formation have been proposed. Some of the proposed signals are discussed.

The results obtained at Super Proton Synchrotron (SPS), CERN in Pb-Pb central collisions at 158A GeV/c and Relativistic Heavy Ion Collider (RHIC), BNL in Au-Au collisions at $\sqrt{s_{NN}} = 200$ GeV have hinted that in heavy-ion collisions a transition from hadronic matter to QGP might take place. These results have motivated the high-energy physicists to investigate the characteristics of de-confined state of matter at energies, much higher in comparison to SPS and RHIC energies.

Large Hadron Collider at CERN has been commissioned and a proton beam has
been accelerated. At LHC we expect a jump of a factor 30 in the centre-of-mass energy with respect to the one available at RHIC. It will, therefore, allow a systematic study of the properties of QGP. It is believed that at LHC energies, QGP will be formed earlier than expected and it will remain thermalized for a relatively longer time; the freeze-out volume will be larger than the one observed at RHIC.

ALICE (A Large Ion Collider Experiment) is a general purpose heavy-ion experiment, designed to study the physics of strongly interacting matter and QGP in Pb-Pb collisions at $\sqrt{s_{NN}} = 5.5$ TeV and p-p collisions at $\sqrt{s} = 14$ TeV at LHC. Besides this, the physics programme includes collisions with lighter ions (N-N, O-O, Kr-Kr or Sn-Sn) at relatively lower energies.

ALICE consists of a central barrel part embedded in L3 magnet, which will measure hadrons, electrons and photons. From the inside out, the barrel contains an Inner Tracking System made of six layers of high resolution Silicon Pixel Detector, Silicon Drift Detector and Silicon Strip Detector, a cylindrical Time Projection Chamber, three particle identification arrays of Time Of Flight, Ring Imaging Čerenkov, a Transition Radiation Detector and two electromagnetic calorimeters, PHOS and EMCal. All these detectors except HMPID, PHOS and EMCal, cover the full azimuth. The ALICE detector also includes a set of forward detectors: the Photon Multiplicity Detector, the Forward Multiplicity Detector, the Zero Degree Calorimeter, a system of trigger scintillators T0 detector and quartz counters V0 detector. An array of scintillators for triggering on cosmic rays called ACORDE is placed on the top of the L3 magnet.

Forward Dimuon Spectrometer of the ALICE, covers pseudorapidity interval, -4.0 < $\eta$ < -2.4, and consists of a hadron absorber positioned very close to the interaction region, a dipole magnet with a field integral of 3 Tm and five tracking stations, an iron absorber and two trigger stations.

Heavy quarkonia suppression is believed to be one of the most important probes for examining the occurrence of phase transition to QGP. In a de-confined state and over a certain temperature they would melt through color screening. It may be inter-
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esting to mention that $J/\psi$, $\psi'$, $\Upsilon$, $\Upsilon'$ and $\Upsilon''$ production can be detected via their decays into $\mu^+\mu^-$. The invariant mass of the muon pair, which is the mass of the resonance, can be measured by FMS of the ALICE detector. FMS thus, aims to measure the production of $J/\psi$, $\psi'$, $\Upsilon$, $\Upsilon'$ and $\Upsilon''$ in different reactions like Pb - Pb, Ca - Ca, p - Pb, p - p, etc.

The tracking system of the FMS, made by ten high gain ($\sim 10^5$) Cathode Pad Chambers (CPC) grouped into five stations, is devoted for reconstruction of the tracks of Minimum Ionising Particles (MIP). The use of CPCs is to fulfil the requirement of a spatial resolution of the order of $< 100 \mu m$ in the bending plane to achieve a muon momentum resolution, $\delta p/p < 1\%$ and spatial resolution of about 2 mm in the non-bending plane to reconstruct the angles of the muons and to guarantee an efficient track-finding. Thus, the desired invariant mass resolutions of the order of 70 and 100 MeV/$c^2$ respectively in the $J/\psi$ and $\Upsilon$ mass regions can be achieved.

The CPCs have the advantage of segmentation of the cathode planes as a function of local hit density, which varies as a function of chamber radius, in order to keep the occupancy at about 5 % level. For instance, pads are small in the region where the highest multiplicity of particles is expected and larger pads are used at larger radii. Stations 1 and 2 have quadrant design, with the readout electronics distributed on their surfaces, whereas a modular structure composed of slats was chosen for Stations 3, 4 and 5. In order to get a good ionization efficiency, high gain and low detection efficiency for neutral particles, a gas mixture containing 80 % Ar and 20 % CO$_2$ is used in these detectors. The electronics chain of the tracking system is divided in three parts to read about one million channels up to a rate $\sim$ kHz: (i) front-end-boards called MA nas NU imérique (MANU), which digitize the data and performs zero suppression; (ii) the readout system called Cluster Read Out Concentrator Unit System (CROCUS), which concentrates and formats the data from the chambers and transfer them to the DAQ and (iii) interface with general ALICE trigger called Trigger Crocus Interface, which decodes the trigger signal to generate the L1 reject in the Frontal-Fan-out Trigger board and to manage busy signals of all the CROCUS crates.
The total time taken in the data readout sequence, starting from the physics trigger, i.e., particle hit in the detector to the data transfer to the Detector Data Link, is 484 μs.

The charge induced on the cathode pad by a charged particle crossing the detector is very small, ~ 10 - 200 fC and must be amplified and digitization of data should occur close to the cathode pads. Hence, a chip on board design with charge amplifiers and multiplexers in the chip to be mounted on the board was used. The VLSI chip MANAS has been selected for this purpose. It was designed at the Saha Institute of Nuclear Physics, Kolkata and fabricated at the Semiconductor Complex Limited (SCL), Chandigarh, India using 1.2 μm CMOS technology. The Indian Groups, SINP, Kolkata and AMU, Aligarh involved in the ALICE Collaboration, were responsible for its design, validation and production.

The operating principle of MANAS chip, consisting of 16 input channels and one output channel, is similar to the operating principle of Gassiplex. Each channel has a Charge Sensitive Amplifier (CSA), a Deconvolution Filter (DF), a Semi Gaussian Shaper (SGS) and a Track & Hold (T/H) stage. MANAS chip also has an Analog Multiplexer (AM) that converts 16 parallel inputs into one serial output. A set of four MANAS chips is mounted on each MANU card to collect data from 64 cathode pads.

Delivery of MANAS devices had started in August, 2005 and was completed in January, 2007. A total of 88,000 MANAS devices, tested and validated at SINP, Kolkata, with gain spread, RMS/Mean \( \leq 2.5 \% \), were delivered to the ALICE-MUON Collaboration in five gain windows with mean gain values around 3.30, 3.50, 3.60, 3.70 and 3.85 mV/fC. It may not be out of place to mention that 20,000 MANAS chips, mainly with lower mean gain values, were delivered to the ALICE-PMD Collaboration.

The Indian Groups have been responsible for the design, fabrication, installation and commissioning of Station 2 of FMS. Station 2 is situated at 6860 mm along the z direction from the Interaction Point and has a circular design. There are two planes
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of the tracking chambers, TC3 and TC4, in Station 2 with an inner mechanical radius of 232 mm and an outer mechanical radius of 1172 mm. Each tracking chamber consists of four quadrants, which are identical and fully interchangeable. These are the largest area CPCs ever made. Each quadrant consists of two cathode planes in order to obtain position resolution both in the bending and non-bending planes. Cathode planes are sandwiched by using 25 mm Rohacell for providing the required rigidity to the 0.4 mm thick PCB boards.

The first quadrant of Station 2, constructed during January - April, 2005, was tested for gas leakage, high voltage limits and dark current and gain uniformity over the active surface. It was found that the quadrant has a leak rate ~ 50 ml/hr. The dark currents in the quadrant were observed to be ~ 6 - 8 nA and ~ 20 - 24 nA for High Voltages of 1700 and 1750 V respectively. The X-ray Fluorescence Technique using $^{241}$Am was used for measuring the gain uniformity. A RMS/Mean of about 10 %, which is within the acceptable limits, was obtained.

10 quadrants were fabricated following the same procedure of fabrication, quality controls and tests and shipped to CERN in October, 2006. The anode wires in these quadrants are not supported although the longest wire length is 120 cm. Hence, strip support of G10 material of dimensions: 950 mm x 2 mm x 2.4 mm and 990 mm x 2 mm x 2.4 mm was provided at 76 cm on five quadrants and at 72 cm on remaining five quadrants for a long time High Voltage stability. Each CPC quadrant of Station 2 has two electronics readout planes, that is, bending and non-bending. Full plane electronics readout boards with 12 buses were tested using CROCUS set up during April - May, 2007 at CERN. The five point calibration data taken for individual bus patches showed a linearity and the bias voltage over the whole bus patch was uniform for both bending and non-bending plane sides. The analysis of the data set for both bending and non-bending readout planes showed pedestal distribution within 200 mV and noise around 1000e⁻ with a gain dispersion ~ 3.3 %.

The chambers were successfully installed at the experimental site, Point 2 of the LHC, during May - June, 2007.
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All the channels of Station 2 were tested and found to function well before the Cosmic Ray Run (CRR) during January - February, 2008. The average noise and pedestal spread were $\sim 0.7$ mV and $\sim 180$ mV respectively. A mean pedestal of 209 ADC $\approx 125$ mV and an average noise of 1.148 ADC $\approx 0.7$ mV was found from the analysis of the data set. Moreover, probability of measuring the vertical tracks has turned out to be quite high after the observation of the first Cosmic Ray track in CRR during January - February, 2008 with the ACORDE trigger. The Cosmic Ray tracks with tracker and trigger (MRK + MTRG) together were also observed during the same CRR.

Performance of FMS of the ALICE is studied in the AliRoot framework as well. The full chain of simulation and analysis in AliRoot framework provides track reconstruction, which gives transverse momentum of every track. The $p_T$ and mass resolutions of FMS are studied with 10000 single muon events generated in the chosen momentum range, from 2 to 20 GeV/c, using BOX event generator. The $p_T$ and mass resolutions are found to be 48.72 MeV/$E$ and 90.66 MeV/c$^2$ respectively. Furthermore, study of mass resolution as a function of background level shows that for one nominal background event the mass resolution is 111.12 MeV/c$^2$.

In order to address some of the issues relating to QGP formation and to unravel the mystery of the Universe and verify the Big Bang theory, the Large Hadron Collider was triggered on September 10, 2008. The Project Coordinator, Professor Lyn Evans, rightly said on the occasion: "it is a fantastic moment and we can look forward to a new era".