A LARGE ION COLLIDER EXPERIMENT (ALICE)

A.V.Khanzadeev, V.N.Nikulin, V.V.Poliakov, V.M.Samsonov

1. Introduction

High energy heavy ion physics studies the strongly interacting matter at ultra-high energy densities [1], like in the early Universe 10^{-5} s after the Big Bang or in the centre of collapsing neutron stars. The quantum chromodynamics (QCD) calculations predict at high densities of the nuclear matter dramatically new behaviour of the system: there is no longer confinement of the quarks and the gluons. That is under such conditions instead of protons, pions and other familiar particles the system behaves as it consists of the quarks and the gluons. This is essentially a collective, thermodynamical phenomenon. Such new state of the matter is called Quark Gluon Plasma (QGP).

It is well known that simple and adequate description of the thermodynamical system is possible for the equilibrium condition only. That is the high matter density is not sufficient condition to see the QGP, its properties should be studied in conditions when

i) the volume of the system is big enough and
ii) the thermolization time is much smaller than the system lifetime ($T_{\text{life}}/T_0 >> 1$).

The estimations of these parameters significantly depend on the model used. The comparison of the average results of various estimations collected by J. Schukraft[1] is presented in Table. The Table induces the obvious conclusion: only LHC allows studying the QGP. Although SPS or RHIC can give some indications to its existence and study the related non-equilibrium processes.

Table

Comparison of heavy ion colliders

Collider	*dN/dy*	Energy density, GeV/fm^3	Volume, fm^3	T_{life}/T_0
SPS	500 – 800	1.7 - 2.7 (1)	10^3 (1)	~1
RHIC	700 – 2000	2.3 - 6.8 (2)	7×10^3 (7)	~5
LHC	3000 – 8000	8 - 27 (7)	20×10^4 (200)	~30

Calculated energy density and pressure are shown in Fig. 1, together with the estimated temperature range available at different colliders. The SPS is very close to reach the hadronic phase; RHIC is ideally suited to explore the phase boundary in great detail; but only LHC will reach deep into the QGP and could approach the Stefan-Boltzman limit of an “ideal gas” of QCD quanta. The region between T_C and the SB limit is of particular interest in order to study the interactions responsible for the deviation from the ideal parton gas case.

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[1] J.Schukraft. “Heavy Ions at the HC Physics. Perspectives and Experimental Program”, ALICE-PUB-2001-09, 5 April 2001.

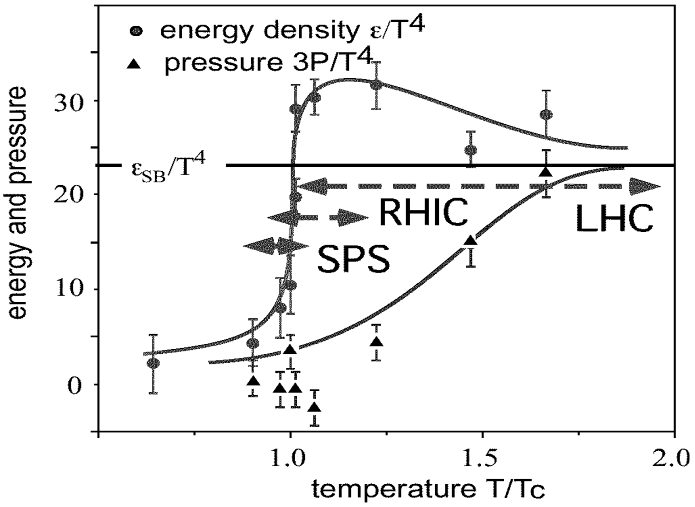

Fig. 1. Energy density and pressure as calculated[1] on the lattice as a function of temperature T in units of the critical temperature T_C. The ideal gas Stefan-Boltzman limit is labeled SB The temperature range accessible at SPS, RHIC and LHC are indicated with arrows

2. ALICE detector

ALICE is a multi-purpose detector (Fig. 2) designed to study the strongly interacting matter and quark-gluon plasma in ion collisions at the LHC. The general design allows operating with high charged particle multiplicities. At present more than 900 physicists from about 70 institutions are involved in this experiment.

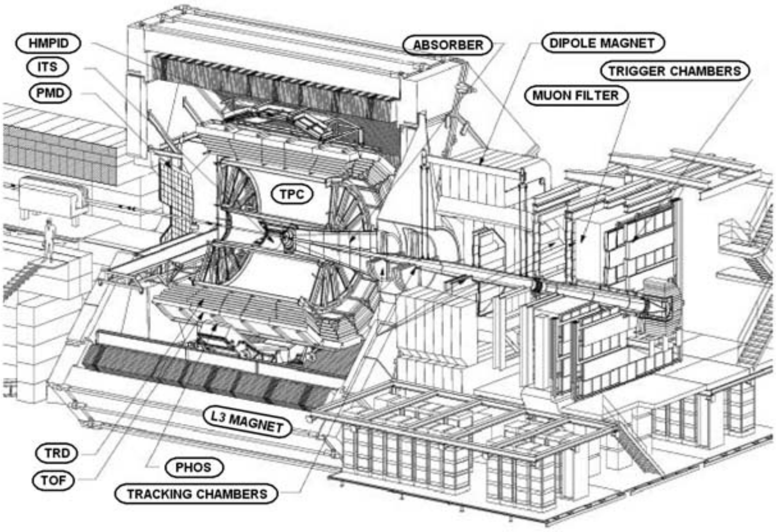

Fig. 2. The general view of the ALICE detector

ALICE consists of a central part, which measures hadrons, electrons and photons, and a forward spectrometer to measure muons. The central part covering polar angles from 45° to 135° over the full azimuth (pseudorapidity range $-0.9 < \eta < 0.9$), is embedded in the large solenoidal magnet L3. It consists of an inner tracking system (ITS) of high-resolution silicon tracking detectors, a cylindrical TPC, three particle identification arrays of time-of-flight (TOF), Ring Imaging Cherenkov (HMPID) and Transition Radiation (TRD) detectors, and a high resolution electromagnetic calorimeter (PHOS). The addition of a large solid angle electromagnetic calorimeter (EMCal) is under serious study now. The forward muon arm consists of a complex arrangement of absorbers, a large dipole magnet, and fourteen stations of tracking and triggering chambers. Several smaller detectors (ZDC, FMD, V0, T0) are located at very forward angles.

2.1. Magnet

The optimal field strength and its volume is the compromise between momentum resolution, momentum acceptance, and tracking efficiency. The magnet of the finished L3 experiment satisfies all requirements to such magnet. Low field about 0.2 T allows full tracking and particle identification down to p_t of ~100 MeV/c. Lower momenta are resolved by the inner tracking system. The inner radius of the magnet is sufficient to place a high resolution electromagnetic calorimeter for prompt photon detection.

2.2. Inner Tracking System (ITS)

The main goals of the ITS are: the primary and secondary vertices reconstruction (required for the analysis of charm and hyperon decays), tracking of low-momentum particles, the particle identification, and the improvement of the momentum resolution. This function is implemented by six barrels of high-resolution detectors. Due to high particle density, the innermost four layers are required to be two-dimensional devices, *i.e.* silicon pixel and silicon drift detectors. The outer layers, at $r \approx 50$ cm, will be equipped with double-sided silicon micro-strip detectors. Four of the layers will have analog readout for independent particle identification via dE/dx in the non-relativistic region, which will give the inner tracking system a stand-alone capability as a low p_t particle spectrometer.

2.3. Time Projection Chamber (TPC)

The tasks of the TPC are the track finding, momentum measurement and particle identification by dE/dx. TPC enables the efficient and reliable tracking of up to 12000 charged particles within the acceptance. The inner radius of the TPC ($r \approx 90$ cm) is given by the maximum acceptable hit density (0.1 cm^{-2}). The outer radius of 250 cm by the length required for a dE/dx resolution of <10%. The large granularity (about 5×10^8 pixels) together with the optimal gas choice ensures a good double-track resolution.

2.4. Particle Identification System (PID)

Ability to identify a large number of particles in Pb-Pb event (protons, pions, kaons) is the strongest feature of the ALICE detector. It provides a possibility to perform an event-by-event study of the transverse momentum spectra. The PID employs a number of different techniques. A large time-of-flight (TOF) array (140 m^2, 160000 channels) at a radius of about 3.5 m is made of novel multigap resistive plate chambers (MRPC) with an intrinsic time resolution of order 100 ps. The Ring Imaging Cherenkov detector HMPID (covering ~15% of the acceptance) is optimized for the detection of high p_t particles and will extend the accessible momentum range for inclusive particle spectra into the semi-hard region. The six-layer Transition Radiation Detector (TRD) will identify electrons with momenta above 1 GeV/c to study quarkonia suppression and heavy quark production (charm, beauty) in the central acceptance.

2.5. Photon Spectrometer (PHOS)

Prompt photons, π^0's η's are measured by a single arm high-resolution electromagnetic colorimeter. The electromagnetic calorimeter will be located below the interaction region at 4.6 m from the vertex and cover 8 m^2 with 17 k channels of scintillating $PbWO_4$ crystals to measure direct photons and high p_t neutral mesons. These very dense crystals are needed to cope with the large particle density and to have sufficient light output to allow readout with silicon photodiodes.

2.6. Photon Multiplicity Detector (PMD)

The Photon Multiplicity Detector (PMD) will search for non-statistical fluctuations in the ratio of photons to charged particles, measure collective flow and transverse energy of neutral particles, and in addition determine the reaction plane. It is a pre-shower detector (a lead converter placed between two planes of cellular honeycomb gas detector). The PMD covers the pseudorapidity range $1.8 < \eta < 2.6$.

2.7. Forward Muon Spectrometer

The forward muon spectrometer will study the production the heavy quark resonances, *i.e.* J/Ψ, Ψ', Υ, Υ', and Υ''. These resonances, both in proton-proton and in heavy-ion collisions, will be identified by their decay into muon pair. The angular acceptance of the muon spectrometer is from 2° to 9°, it covers the pseudorapidity range $2.5 < \eta < 4.0$. The expected mass resolution is of order 100 MeV at 10 GeV, sufficient to distinguish the fine structure of the Υ resonance.

The muon spectrometer consists of a composite absorber, made of layers of both high- and low-*Z* materials, located 90 cm behind the interaction point, a large dipole magnet with a 3 T·m field integral, 10 planes of thin, high-granularity tracking chambers (Cathode Strip and Cathode Pad Chambers), a muon filter made of a 1.2 m iron at the end of the spectrometer, and four trigger chambers. The spectrometer is shielded throughout its length by a dense conical absorber tube, which surrounds the beam pipe.

2.8. Forward Detectors

ALICE uses a number of smaller detector systems (ZDC, FMD, V0, and T0) positioned at small angles to define and trigger on global event characteristics, *e.g.* impact parameter, event reaction plane, multiplicity of charged secondary particles, and precise time of the event.

Four small and very dense calorimeters (Zero Degree Calorimeters, ZDC) are located in the machine tunnels at about 100 m on both sides of the interaction point. They measure the signal from the spectator nucleons (both neutrons and protons) produced in the collision. As they are located after the LHC dipole, the spectator nucleons go out of the beam and detected by the calorimeters. This signal will define the impact parameter of the collision. The detected pseudorapidity range is $8.6 < \eta < 8.75$.

The Forward Multiplicity Detector (FMD) is the silicon strip ring counter with about 25000 channels. It measures charge particle production in the pseudorapidity range $-5.1 < \eta < -1.7$ and $1.7 < \eta < 3.4$.

The T0 (Beam-Beam) detector consists of the two arrays 12 Cherenkov radiators coupled with PM tubes. It will produce the fast timing ($\sigma \sim 50$ ps) allowing the on-line main vertex reconstruction.

The V0 (Centrality and collision vertex) detector consists of the 2 arrays of plastic scintillators covering the pseudorapidity range $-5.1 < \eta < -1.5$ and $1.7 < \eta < 3.8$.

2.9. Trigger, Data Acquisition and Off-line

Special attention is paid to the ALICE trigger: the huge event size causes severe acquisition and storage problems. Thus the trigger should suppress the background as much as possible, keeping the useful events. The ALICE features a complex and flexible Central Trigger Processor. Several detectors provide input to the different trigger levels to select *e.g.* for centrality, high p_t electrons, muons, or photons. Three trigger levels are foreseen:

- L0 – the fast minimum bias interaction pre-trigger (issued after < 1 μs) to strobe some of the front-end electronics;

- L1 – the additional decisions of relatively slow detectors;

- HLT (high level trigger) – is essentially the on-line computing farm of several hundred PC's providing further event selection and event compression.

The relatively short heavy-ion running period and the very large event sizes (up to 80 Mbyte even after zero suppression) determine the main features of the DAQ. In order to collect a sufficient number of events for physics analysis, the DAQ system has to be designed with a very large bandwidth up to 1.25 GByte/s on mass-storage. The DAQ architecture is based on a network of high-speed links linking all the data sources and the data destinations through a switch. This architecture provides the required flexibility and scalability to run in very different modes.

A new Off-line framework (AliRoot) has been developed since 1998 based on all new C++ code and the OO paradigm. The ROOT framework was adopted as a base for this development, integrating currently the GEANT 3 and later also the GEANT 4 simulation package. At the moment a complete OO simulation of ALICE exists and the OO reconstruction code is being developed in this framework. The enormous amount of the data to be collected (petabytes) requires principally new off-line analysis approach. The global computing which is combining the power of the computing clusters in various centers is the only possibility for the data mining. The integration in the projects like Data Grid / Globus is mandatory if one would like to have an access to physics.

3. PNPI in ALICE

The PNPI activity in ALICE is concentrated in the Forward Muon Spectrometer. As mentioned above, the ALICE muon spectrometer consists of the front and the small-angle absorbers, 10 tracking chambers TC1–TC10 (grouped into 5 stations TS1–TS5), the dipole magnet, the muon filter, and the trigger.

The muon 3-momentum is determined from the track deviation in the magnetic field of the dipole magnet. In order to achieve the desired mass resolution, the tracking chambers should satisfy the following principle requirements:

- Spatial resolution better than 100 µm in the bending plane;
- Average material thickness of each chamber less than 3% of radiation length;
- Capability to cope with high occupancies and to cover the whole acceptance zone (up to 5.6 m in diameter).

The spatial resolution requirement and hit density condition pushes to use the segmented cathode strip chambers (SCSC). The hit position is defined by the charge induced onto the neighbor strips. The strips are cut in relatively short pieces (pads). The individual readout channel services each pad, so the distant hits are invisible for a given group of the pads. The strip width of 5 mm enables to achieve the spatial resolution of about 80 µm in bending plane for incidence minimal ionizing particle. Fig. 3 shows the actual space resolution achieved in the test run.

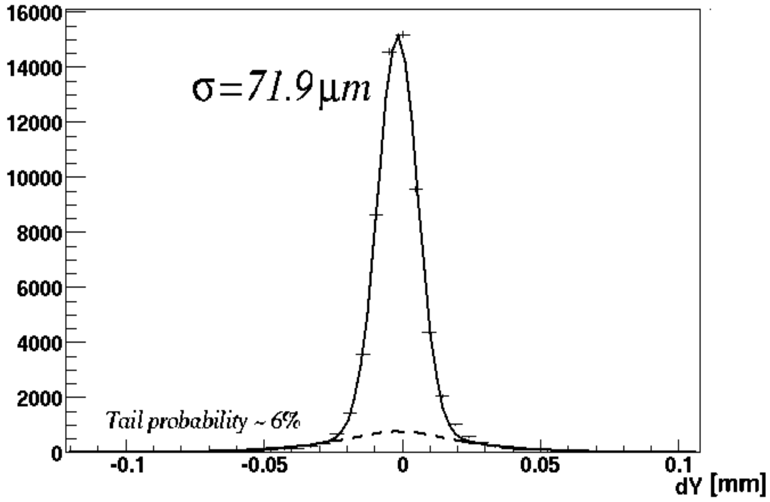

Fig. 3. Spatial resolution of the slat prototype (experiment). Resolution ~ 72 µm, tails ~ 4%, efficiency ~ 96%

In order to have a high spatial resolution in SCSC, one should keep stable gas gain along the SCSC area; otherwise the front-end electronics will be either overloaded or will have signals with insufficient amplitude. The gas gain is defined by the chamber geometry, namely the anode-cathode separation. It is very difficult technically to maintain the stability of the large chamber gap. The long wires, inherent to the large chamber, require supports, where the chamber efficiency will be degraded. These were the main reasons why PNPI proposed to abandon the large chamber conception and replace it with combination of the overlapping long SCSC modules (so-called *slats*) [2, 3].

Mechanically each tracking chamber is composed of two movable frames with an overlapping set of slats attached to them. The height of the sensitive zone of each slat is 40 cm; the length should be sufficient to cover the required acceptance (from the vertical which passes through the beam up to the distance, corresponding to an angle 9 degrees). In particular, the longest slat will be up to 2.4 m long, the length of the shortest one is 1.2 meter. The slats are made of the lightweight composite materials, so the requirement of small thickness is satisfied. The relatively small height (40 cm) minimizes possibilities of the cathode distortion and allows using the wires without support.

The slat design and assembling technology has been developed at SUBATECH (Nantes, France). The cathode is made of Printed Circuit Boards (PCB) glued with the composite sandwich. The technology foresees positioning of the cathode PCBs (size of 400×600 mm^2) using the reference holes positioned with high precision (of order 10 microns) with respect to the pad pattern etched on the PCB surface. The PCB edges should be also trimmed with the precision of better than 100 microns with respect to the axis of the pad pattern.

PNPI actively participated in the development of the slat assembling tooling. A special device for the precise PCB machining (Figs. 4, 5) has been built [4]. It has been successfully tested with real PCBs at INFN, Cagliari (Italy-Sardinia).

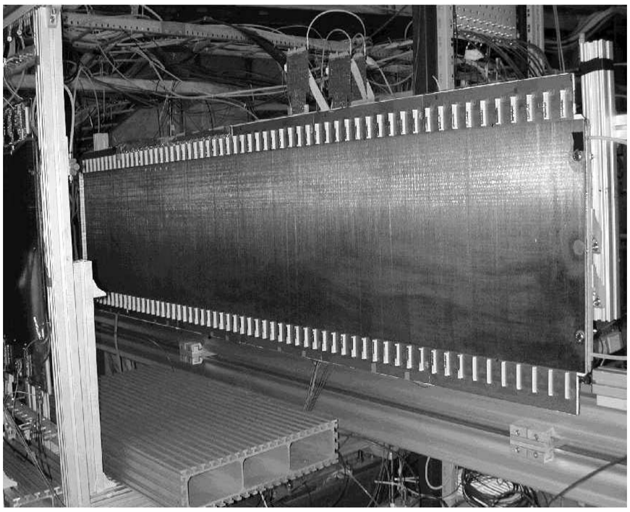

Fig. 4. Full size slat prototype

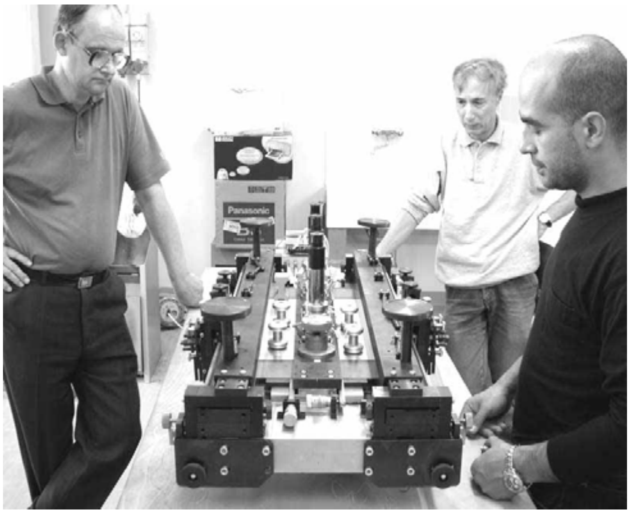

Fig. 5. General view of the PCB machining device

The quality control is essential part of the production process. The slat is composed of two cathodes connected together with spacers. One of the cathodes is equipped with the anode wires glued to the spacer. The PNPI team proposed [5] to put it into a special box with transparent top. The top has electrodes and spacers attached to it. The box has positioning device enabling to put the half-slat to the box top, reproducing the HV conditions as it is in a real chamber. The box is filled by nitrogen. This gas is spark-safe, it provokes the corona discharge at the locations with strong electric field: at dusts, sharp defects of the wires etc. The chamber defects could be immediately localized, the small motes are burnt away in the corona discharge. The device is designed. The prototype is manufactured and will be testing soon in real conditions.

The PNPI has prepared a clean room for the slat assembling. A 60 m^2 room is equipped according to the requirements to the slat assembling ($T = (20 \pm 2)$°C), controlled humidity in the range 55 ± 5%, no more than 35000 dusts with diameter of 0.5 μm per liter).

The winding machine has been designed, manufactured and tuned; the wire tension is constant within ± 3 g.

The PNPI participates in design and production of the chambers for stations TS3–TS5, the largest ones in the spectrometer. It is responsible for the production of a quarter of total amount of the slats.

The first full-scale slat prototype (2400 mm length) has been produced at SUBATECH Nantes and successfully tested on the CERN PS beam. These achievements are summarized in the slat chamber Production Readiness Review held in December 2001.

The members of the PNPI team together with the CERN integration team developed the engineering design of the muon filter and the superstructure for the support of the tracking (stations 4 and 5) and trigger chambers. The production readiness review has been held in December 2001. The market survey is under way, it is supposed that the PNPI team will also supervising the manufacturing of the system.

Substantial efforts were also applied in the software domain. One direction is the analysis of the beam test data. Currently the highly flexible program *AliDate* is fully functional. The plans are the integration of the code in general ALICE software framework *AliRoot* in order to validate the analysis code and refine the detector simulation assumptions. The by-product of this activity is general-purpose histogramming tool *hparse*.

The simulation activity is also under way: the justification of the sizes and tolerances chosen for the Muon Filter has been done.

PNPI would like to find its own "ecological niche" in ALICE physics program. Our attention has been attracted by the theoretical studies of coherent J/Ψ production in ultra-peripheral collisions [5]. Though the topic is rather far from the ALICE baseline (studies of the QGP), it is rather important as it allows studying the nuclear shadowing effects in heavy ion collisions. This knowledge is essential for understanding of the QGP formation process. Dependence on the gluon density has been also demonstrated. The recent simulations demonstrated the feasibility of such measurements in ALICE. More precise simulations are currently in progress.

List of PNPI participants in the ALICE experiment:
Yu.A.Berdnikov, V.A.Evseev, A.V.Khanzadeev, N.M.Miftakhov, V.N.Nikulin, V.V.Poliakov, V.I.Riazanov, G.V.Rybakov, E.V.Rostchin, V.M.Samsonov, G.P.Solodov, V.I.Tarakanov, O.P.Tarassenkova, M.B.Zhalov.

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