PNPI IN ALICE

V.M. Samsonov, V.A. Evseev, V.V. Ivanov, A.V. Khanzadeev, E.L. Kryshen, N.M. Miftakhov, V.N. Nikulin, V.V. Polyakov, E.V. Roschin, V.I. Ryazanov, O.P. Tarasenkova, M.B. Zhalov

1. Introduction

The ALICE detector is designed to study heavy ion collisions at the energies of several TeV per nucleon by detecting hadrons, electrons, photons, and muons produced in these collisions. A special feature of such collisions is high multiplicity – up to several thousand particles per event per rapidity unit. This feature demands high granularity in the detector systems. The ALICE detector consists of a central (barrel) part embedded in a large solenoid magnet (L3 magnet) and a forward muon spectrometer (Fig. 1).

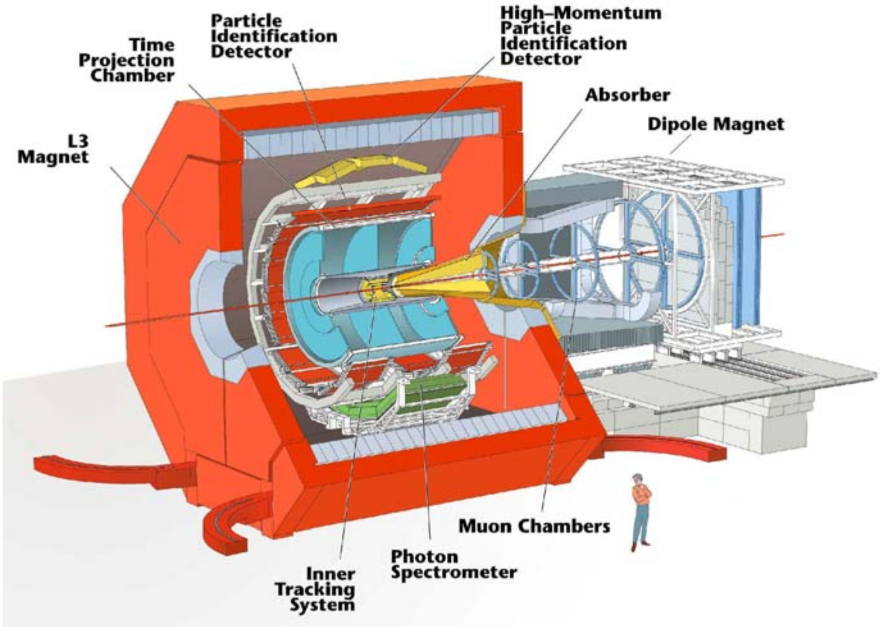

Fig. 1. The layout of the ALICE detector. The muon spectrometer arm is depicted on the right side of the figure

The barrel part comprises the Inner Tracking System (based on Si-detectors), the Time Projection Chamber, the Particle Identification System (consists of a time-of-flight detector, transition radiation detector and a ring imaging Cherenkov detector), and the Photon Spectrometer based on scintillating $PbWO_4$ crystals. There are also several small forward detectors (not shown in Fig.1): ZDC (zero degree calorimeter), EMD (forward multiplicity detector), TO (collision timing detector), and VO (centrality and collision vertex detector).

PNPI participates in design and construction of the muon spectrometer. This spectrometer consists of a large dipole magnet, absorbers, five tracking stations, the muon filter and trigger chambers. It is aimed to study the heavy quark resonances, *i.e.* J/ψ, ψ', Υ, Υ', Υ'' identified by their decay into muon pairs. The estimated mass resolution is of the order of 100 MeV at 10 GeV, sufficient to distinguish the fine structure of the ϒ resonances.

The physics interests of the PNPI team are concentrated on studies of the ultraperipheral collisions and polarization effects in production of the heavy quarkonia. We exploit the unique features of the muon spectrometer – high mass resolution and capabilities to produce various trigger signals. It has been demonstrated that minor modifications of the standard trigger algorithm may allow to obtain valuable information on gluon density behavior.

2. Tracking chambers for the Muon Spectrometer

2.1. Tracking chamber design

In order to achieve the required mass resolution the tracking stations of the ALICE Dimuon arm should satisfy several main requirements:

- They must be thin enough in order to introduce negligible deterioration to the muon track (average X/X_0 of the station is less than 3%),
- They should be able to operate in high hit density environment (up to 0.01 hits per cm^2), and
- To measure the track position with the precision of about 100 μm in bending plane and about 1 mm in non-bending one.

Moreover, the stations cover large sensitive area (up to 5×5 m^2). The cathode pad chambers (CPC) were chosen for this purpose.

Following suggestions of the PNPI group [1], the rear tracking stations (stations 3, 4 and 5) have a slat structure, *i.e.* they are composed of the overlapping rectangular CPC modules (also called as slats). The length of the modules varies from 80 cm to 240 cm with the constant height of 40 cm.

Several CPC prototypes were constructed and tested, and the assembling technology was developed. The CPC body built of two carbon-fiber/honeycomb sandwiches with the PCB cathodes glued onto them. The cathode segmentation (length of the pads) varies with the behavior of the expected hit density. The signal wires (made of tungsten, diameter of 18 microns, without gold plating) are glued between the spacers made of Noryl. The materials were carefully chosen in order to minimize the detector ageing. The front-end electronics cards are plugged into connectors in the peripheral area of the slats. Special attention has been paid to perform permanent in-production quality control of the modules from the very beginning of the assembly till the final tests, to maintain the cathode planarity, uniformity of the anode-cathode distance, the stress of anode wires, to achieve the correct position of each pad. The special tooling has been developed at PNPI for this purpose.

The assembly of 38 CPC modules (a quarter of the total number) has been accomplished at PNPI. For this task, a clean assembly area was prepared and equipped with specially developed tooling and with testing setups.

2.2. Tooling for production of the tracking chambers

The PNPI team was responsible for design and construction of the tooling for production of the tracking chamber modules. The PCB trimming machine, the high voltage test bed, the β-source test bench and the devices to measure the wire tension were developed at PNPI and provided to all teams in the collaboration involved in production of the tracking chambers for stations 3-4-5 of the ALICE Muon spectrometer.

PCB trimming device

The high spatial resolution requires a precise (about ±40 microns) positioning of the cathode pads. In order to accomplish this task, the sides of the PCBs were trimmed and the fiduciary holes were punched. The typical linearity of the trim was ±15 microns, the trim line being positioned with respect to the pads within ±20 microns. The same precision was achieved in positioning of the fiduciary holes. This device (see Fig. 2, left) has been used to treat all the PCBs used in the tracking chambers for stations 3, 4, and 5.

A simplified option of the device (Fig. 2, right) has been developed and produced at PNPI for our colleagues at Saha Institute (Kolkatta, India). In this case the chamber assembling technology did not require the fiduciary holes, the cathode pads are aligned using the high quality of the PCB edge trimming. The device has been successfully used in production of the chambers for the tracking station 2.

Fig. 2. The PCB trimmers developed for preparation of the slats for stations 3, 4, 5 (left) and for station 2 (right) at PNPI

β-source test bench

Special attention was paid to monitoring the gas gain uniformity. The variations of the gas gain reflect defects of planarity of the cathode planes, resulting in degradation of the chamber spatial resolution. We controlled the gas gain by measuring the current induced in the chambers by a β-source. The constructed test bench (Fig. 3) performs movement of the collimated β-source across the sensitive area with simultaneous measurement of the current. The observed irregularities of the 2-dimensional gas gain distribution do not exceed 30% with typical dispersion around 10% [2].

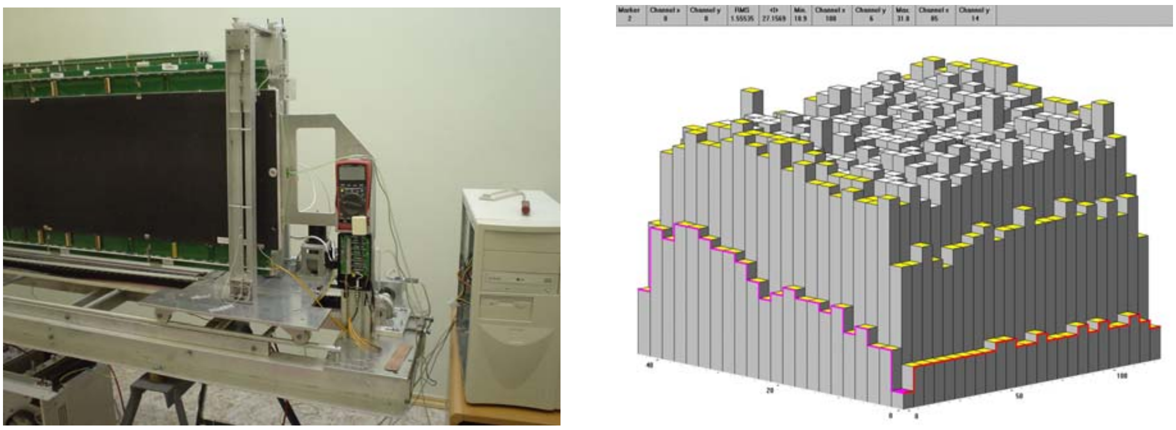

Fig. 3. β-source test bench and an example of gas gain homogeneity distribution in a tracking chamber

High voltage test bed

The High Voltage Test Bed (HVTB) was build to check the quality of assembled chamber wire planes [3]. The HVTB is a leak-proof box with a transparent cover (see Fig. 4). The cover has a translucent cathode grid and spacers attached to it. The HVTB is equipped with a pneumatic system which lifts up the wire plane and presses it to the cover spacers to reproduce the HV geometry close to that of the real slat chamber. The HVTB is filled with nitrogen – a spark-resistant gas. The applied HV induces corona discharge around the anode wires. The glow is brighter near locations with abnormally strong electric field, as motes, sharp burrs, loose wires etc. This makes the chamber defects visible. The small motes and burrs can be burnt out after 6–7 hours of the corona discharge. Such devices were shipped to all teams which produced chambers for tracking stations 3-4-5.

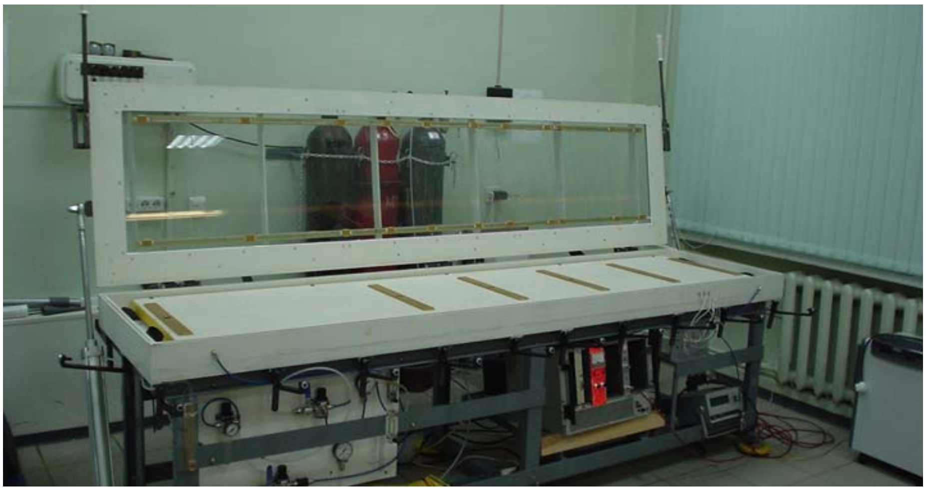

Fig. 4. A view of the high voltage test bed

Measurement of wire tension in tracking chambers

The total number of wires in the tracking system is of the order of 100,000. All wires must be stressed; otherwise the system would be mechanically unstable due to electrostatic repulsion (so-called staggering effect). For the chosen wire parameters the minimal tension (staggering limit) is estimated to be 17 grams, while the wire elasticity limit is about 70 grams. The nominal wire tension was chosen to be 40 grams. In order to guarantee the quality of the wiring, it was foreseen that each individual wire tension should be measured during the chamber production. Two kinds of devices for measurements of the wire tension have been built. The first one (see Fig. 5) is designed for use during the chamber production and the other one to check the fully assembled chambers. Both devices use the relation between the wire tension and its resonance frequency. Capacitive sensors are used to catch the free wire oscillations, and the Fourier procedure is used to find the resonance frequency. The difference between the setups is the wire excitation method: while the in-production procedure uses electrostatic pulses, the assembled chambers are checked using the mechanical tap.

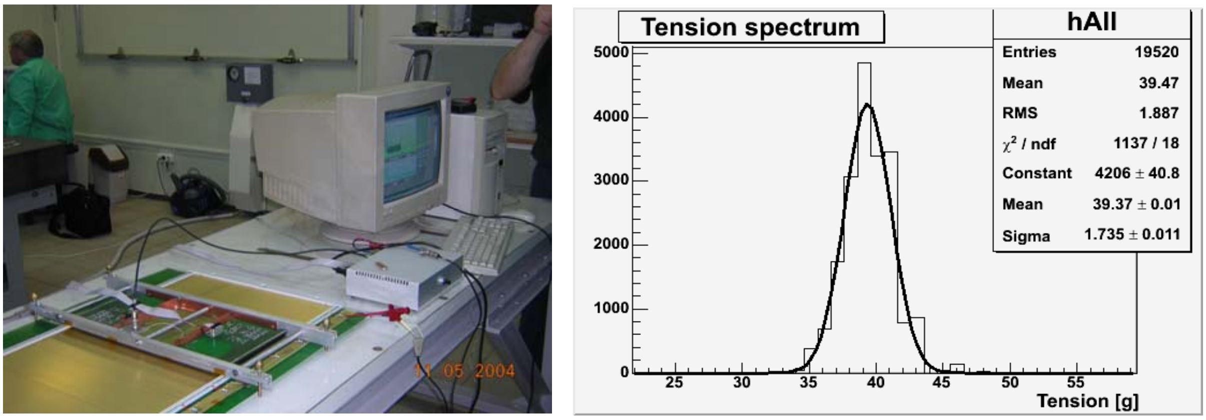

Fig. 5. The equipment for wire tension measurement and the wire tension distribution measured for about 20,000 wires in the chambers produced at PNPI

Both devices can measure the wire tension with the tolerance of ±0.5 g within reasonable time (about 20 minutes per 80 wires) [4]. The results of the measurements with the first device are filled in the production database. The second device is used during the chamber commissioning and in periodical checks during the LHC shutdowns.

Beam tests results

The prototypes of the tracking chambers were tested at CERN using the pion beam at PS with the momentum of 7 GeV/c and the muon beam at SPS with the momentum of 120 GeV/c. An array of 10 silicon strip detectors (pitch of 50 microns) has been used to reconstruct the track parameters. The beam test data has been analyzed by several teams. The analyses gave consistent results: the spatial resolution had a narrow component with sigma of about 70 microns at PS and about 50 microns at SPS (the difference is caused by the multiple scattering) at the efficiency of 96% (inefficiency is caused by the distribution tails). The PNPI analysis [5] featured a readout/decoding subroutine, several new methods for the position reconstruction, wide-range parameterization of the realistic residual distribution (see Fig. 6), and parameterization of the resolution angular dependence.

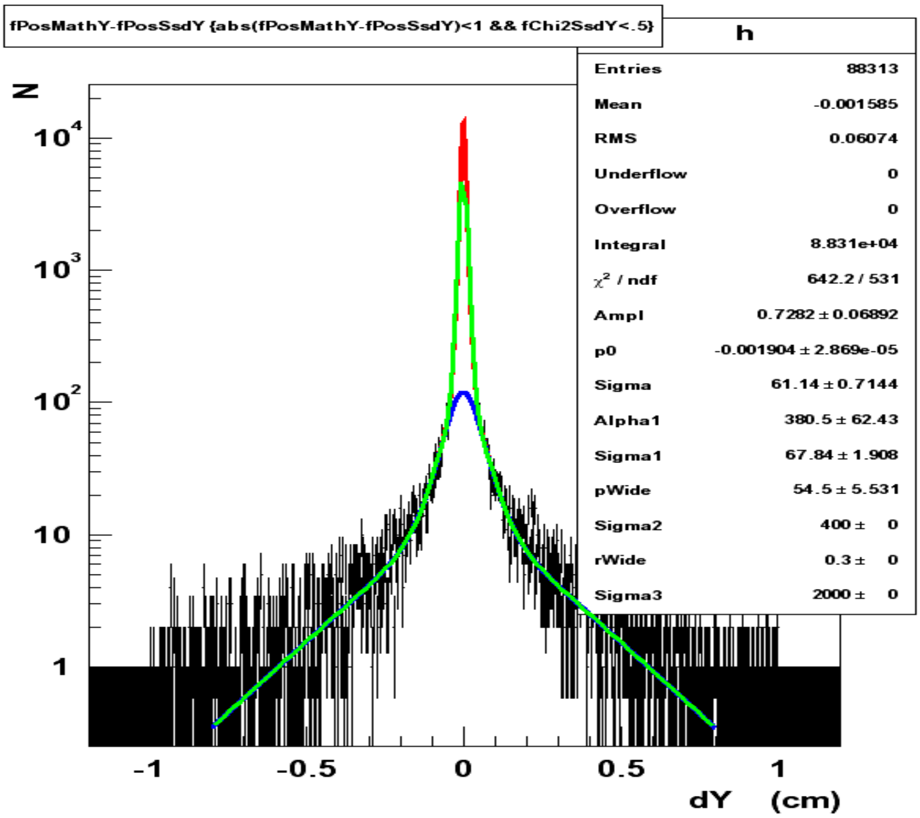

Fig. 6. Parameterization of the residual distribution measured at PS, one can see narrow (~70 microns) and wide (~300 microns) components of the distribution

2.3. Assembling, tests and commissioning of the tracking chambers

To perform the slat production of the tracking chambers, a dedicated assembling site was organized at PNPI (Fig. 7). It includes a clean room (equipped with necessary tooling with a climate control) and several auxiliary rooms.

The final assembling of the tracking stations took place at CERN; the PNPI representatives participated in this activity (see Fig. 8). During the chamber assembling, the slats were tested for gas tightness and high voltage, they were equipped with electronics; the electronics was burned and the readout has been tested. By mid of 2007 the Muon Spectrometer assembling is nearly completed, most of the chambers are equipped with electronics and installed in the ALICE cave. The time before the run will be devoted to the commissioning: final installation of the services, tests of the readout, *etc.*

(a) (b) (c) (d)

Fig. 7. A view of clean assembling room (a), gluing of the PCB to the composite sandwiches (b), wiring machine (d), and installation of the signal wires on a wire plane (c)

Fig. 8. Tests of tracking chambers at CERN (left) and the assembled half of the tracking station (right) at CERN

3. Mechanical design of the setup

The PNPI team contributed to mechanical design of the muon spectrometer parts: the muon filter and the superstructure. The design includes a complete set of the engineering drawings and the finite element analysis (stress and buckling analysis, simulation of the earthquake). The design was adapted to the capabilities and features of Russian plants. Unfortunately the price tag proposed by Russian industry was too high, so the muon filter has been redesigned in order to build elsewhere. The design of the superstructure did not affected significant changes; it was built at CERN (Fig. 9).

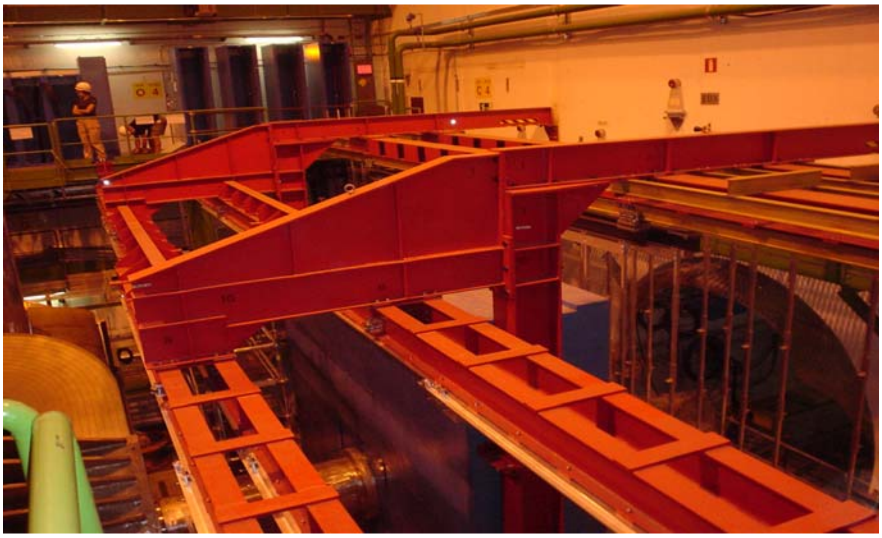

Fig. 9. Superstructure for support of the tracking and trigger chambers designed by the PNPI group

It has also been demonstrated that the requirements to the quality of the gaps between the elements of the muon filter could be rather loose [6].

The members of the PNPI team (Fig. 10) also participated in magnetic field mapping, geometry survey of the detectors and pulling of the cables (together with colleagues from JINR, Dubna).

Fig. 10. Geometrical survey (left) and cabling activity (right) at ALICE

4. Physics activities

Heavy quarkonia photoproduction

In their pioneering article [7], L. Frankfurt, M. Strikman and M. Zhalov demonstrated that the coherent photoproduction of heavy quarkonia in Pb-Pb collisions at LHC has considerable total cross section and is sensitive to the small-x behavior of the gluon density. We found that the Level-0 trigger in the muon spectrometer, with minor modifications, could be used to study the coherent quarkonia photoproduction (Fig. 11). The two cases were considered: when both muons are detected by the muon spectrometer, and also when one muon hits the muon arm while another one is detected in the barrel. In the first case the standard muon trigger could be used with T0 and V0 decisions excluded. In the second case an additional pre-selection of the events of interest could be achieved including a veto from the Photon Spectrometer. Later, more sophisticated L0 triggers from the pixel Inner Tracking System and from the Time-of flight detectors could be implemented. The additional clean-up could be done at Level-1 analyzing the (ZDC) information. The off-line quarkonia p_t analysis will make a final selection of the coherent events. The estimated counting rates are order of 20,000 events in both cases for J/ψ and few hundreds for the case of Upsilon per heavy ion running year [8].

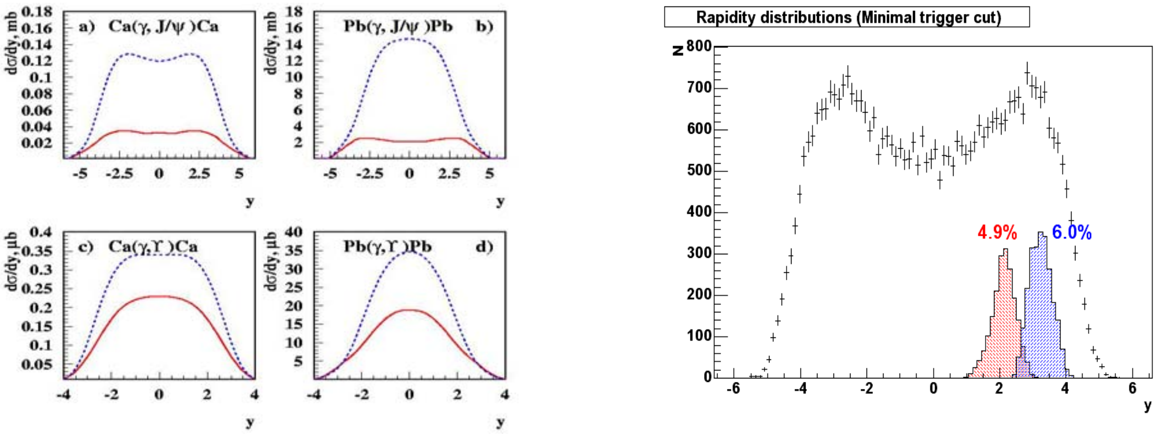

Fig. 11. The theoretical predictions (left) and the AliRoot simulation of the coherent *J/ψ* photoproduction (right) in function of rapidity; the blue peak corresponds to the case when both muons are detected in the muon arm, the red peak corresponds to the case when one muon is detected in the muon arm, and another one is detected in the barrel

Heavy quarkonia polarization

We considered the possibility of the J/ψ polarization measurements in the barrel part of ALICE [9]. The quarkonium polarization is an important test for understanding the quarkonium production mechanisms and heavy ion collision dynamics. The simulations were carried out within the *AliRoot* framework. An event generator has been developed; the 3D acceptance analysis (p_t, y, $\cos\theta$) has been carried out. It has been demonstrated that the polarization parameter can be extracted in five p_t bins, with the statistical uncertainties on the reconstructed parameter ranging from 0.02 to 0.13.

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