Time Projection Chamber for Multi-Purpose Detector at NICA

Technical Design Report
(rev.04)


Laboratory of High Energy Physics, JINR

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Summary

This Technical Design Report describes the Time Projection Chamber (TPC) for the MPD-NICA. The TPC is the main detector for tracking in the central barrel. In following we summarize the design considerations and specifications for the TPC and its subsystems.

In Chapter 1 we briefly describe the main physics task and the Multi-Purpose Detector (MPD) barrel set-up. The main physics requirements for the TPC/MPD are pointed out.

In Chapter 2 the TPC design overview is described. The lay-out of the TPC is shown schematically. The basic design parameters of the TPC are specified.

In Chapter 3 the characteristics of the TPC filed cage and the HV electrode are described. Also the TPC deformation under gravity load is shown.

In Chapter 4 the TPC Readout Chamber (ROC) based on MWPC and pad-plane configuration are described. The chamber deformation caused by the wire tension is shown.

In Chapter 5 the TPC laser calibration configuration is described.

In Chapter 6 the common view of the TPC temperature stability and cooling system are shown. The design of outer thermo- screen and of its individual panel is shown.

In Chapter 7 the TPC gas system is shown. Its design, the main parameters and schematic view are described.

In Chapter 8 the TPC front-end electronics (FEE) configuration is declared. The basic parameters of the front-end card (FEC) and readout control unit (RCU) are described. A single channel scheme is shown. The main components of boards are given. The front-end card-prototype appearance (top and bottom views) and its characteristics are specified.

In Chapter 9 the TPC prototype testing results are presented.

In Chapter 10 the TPC detector performance is described.

In Chapter 11 the R&D for alternative readout chamber based on GEM is considered.

In Chapter 12 the material budget for TPC is summarized. Since the amount and position of material traversed by particles in the MPD inner detectors have an impact on the performance of the outer detectors the material budget of the TPC has to be kept as low as possible. The TPC thickness (less than 5% $X_0$) is acceptable.

In Chapter 13 the infrastructure, TPC implementation and safety are presented.

In Chapter 14 the organization, editorial group, participating institutions, time schedule and cost of TPC are presented.
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Chapter 1

Physics objectives

Within the framework of the JINR scientific program on study of hot and dense baryonic matter a new accelerator complex the Nuclotron-based Ion Collider Facility (NICA) \[1, 2\] is under realization. It will operate at a luminosity up to \(10^{27} \text{ cm}^{-2} \text{s}^{-1}\) for Au\(^{79+}\) ions. Two interaction points are foreseen at the NICA for two detectors which will operate simultaneously. One of these detectors, the Multi-Purpose Detector (MPD), is optimized for investigations of heavy- ion collisions \[3, 4\]. The set-up of the central barrel part of the MPD is shown in Fig. 1.1

![Figure 1.1: MPD barrel setup](image)

MPD envisaged experimental program includes simultaneous measurements of observables that are presumably sensitive to high-density effects and phase transitions. The observables measured on the event-by-event basis are particle yields, their phase-space distributions, correlations, and fluctuations.
The Time-Projection Chamber (TPC) is the main tracking detector of the MPD central barrel. It is a well-known detector for 3-dimensional tracking and particle identification for high multiplicity events. The TPC/MPD will provide:

- The overall acceptance of $\eta < 1.2$

- The momentum resolution for charge particles under 3% in the transverse momentum range $0.1 < pt < 1 \text{ GeV}/c$.

- Two-track resolution of about 1 cm.

- Hadron and lepton identification by $dE/dx$ measurements with a resolution better than 8%. These requirements must be satisfied at the NICA design luminosity, charged particle multiplicity $\sim 1000$ in central collisions and the event rate about 7 kHz.
Chapter 2

TPC design overview

The design and structure of the TPC are similar to those that were used in the STAR, ALICE and NA49 experiments [5, 6, 7].

The TPC being a large but conceptually simple detector must be constructed with very high precision to reduce nonlinear systematic effects. High stability of the mechanical structure and uniformity of the drift field, the temperature, the drift gas purity and the gas gain have to be provided to get precise track reconstruction and energy-loss measurements.

2.1 TPC operation conditions

TPC is a detector of charge particles produced by the nuclear-nuclear collisions inside the NICA collider [8, 9]. Momentum dP/P and energy dE/E resolution depend on the TPC design and the solenoid magnetic field.

The TPC body must be rigid with the minimum deformation under gravity and non sensitive to the magnetic field. The TPC material budget must be minimal for good matching the inner and the external tracking. Track reconstruction is based on drift time and R-ϕ coordinate measurement of primary clusters.

Electric field inside the TPC drift volume must be uniform and stable in time to achieve high precision of the track reconstruction. Stability of the TPC gas mixture composition is very important. The O₂ and H₂O admixture must be at level of 20 ppm and 10 ppm. The TPC drift volume temperature stability must be at the level of 0.5°C. Laser calibration system will be used for monitoring of drift velocity and for taking electric field distortion into account.

The lay-out of the TPC is shown schematically in Fig.2.1. In outline the TPC consists of hollow cylinder the axis of which is aligned with the beams from NICA and is parallel to the uniform solenoid magnetic field [15, 16, 17]. The TPC has an inner diameter of 54 cm, an outer diameter of 280 cm, and an overall length along the beam direction of 340 cm. Since the amount and position of material traversed by particles in the MPD inner detectors have an impact on the performance of the outer detectors the material budget of the TPC has to be kept as low as possible. The TPC overall thickness (less than 5% X₀) is acceptable.

The active gas volume of the TPC is bounded by coaxial field cage cylinders with a pad plane readout structure at both end-caps. The uniform electric field in the active volume required for drift electrons is created by a thin central HV electrode together
Figure 2.1: TPC schematic design

with a voltage dividing network at the surface of the outer and inner cylinders and at
the readout end-caps. Monolithic full-size plastic cylinders will be used for the TPC
field cage construction.

It has been shown that radial magnetic and electric field components have to be not
more than of order 5.2 \times 10^{-4} \text{ [4]} to reach the required value of transverse momentum
resolution. Hence, the mechanical structure and electric field defining network have to
be designed in a way to keep radial field non-uniformity at the level of \sim 10^{-4}.

TPC readout system is based on the Multi-Wire Proportional Chambers (MWPC)
with cathode pad readout. Image charges are induced on an array of pads and are
recorded as a function of time. For given drift gas mixture and fixed wire geometry the
gas gain is determined by high voltage applied to the anode wires. The electrostatic
and gravitation forces lead to variations in gas gain along the anode wires. These
variations can be controlled by calibrating the signal response with the injection of
radioactive Kr^{83} into the drift gas. This method was applied in \textbf{[6, 7]} and it was shown
the overall gas gain variation (electronics and wire amplification) of the order of 10%
can be corrected with 0.5% precision.

The gas mixture of 90% argon and 10% methane (P10) is supposed to be used in
the TPC. The gas over-pressure has to be as small as possible to reduce the multiple
scattering in the TPC gas. The TPC active volume must be sufficiently gastight to
keep the oxygen level below about 5 ppm for minimizing primary ionization loss in
the TPC drift volume. Operating on the peak of the voltage-velocity curve (for argon-
methane mixture E=140 V/cm) makes the drift velocity stable and low-sensitive to
small variations in temperature and pressure. The thermal isolation of the TPC must
guarantee the temperature stability about 0.5°C over the active gas volume \textbf{[6]}.

The TPC readout system is based on the Multi-Wire Proportional Chambers (MWPCs)
with cathode readout pads, mounted in two end-caps of the TPC cylinder and each
covering 30° in azimuth. The basic design parameters of the TPC are summarized in
Table 2.1: The basic design parameters of the TPC

<table>
<thead>
<tr>
<th>Item</th>
<th>Dimension</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length of the TPC</td>
<td>340 cm</td>
</tr>
<tr>
<td>Outer radius of vessel</td>
<td>140 cm</td>
</tr>
<tr>
<td>Inner radius of vessel</td>
<td>27 cm</td>
</tr>
<tr>
<td>Outer radius of the drift volume</td>
<td>133 cm</td>
</tr>
<tr>
<td>Inner radius of the drift volume</td>
<td>34 cm</td>
</tr>
<tr>
<td>Length of the drift volume (of each half)</td>
<td>163 cm</td>
</tr>
<tr>
<td>HV electrode</td>
<td>Membrane at the center of the TPC</td>
</tr>
<tr>
<td>Electric field strength</td>
<td>$\sim 140$ V/cm</td>
</tr>
<tr>
<td>Magnetic field strength</td>
<td>0.5 Tesla</td>
</tr>
<tr>
<td>Drift gas</td>
<td>90% Ar+10% Methane, Atmospheric pres. + 2 mbar</td>
</tr>
<tr>
<td>Gas amplification factor</td>
<td>$\sim 10^4$</td>
</tr>
<tr>
<td>Drift velocity</td>
<td>5.45 cm/$\mu$s</td>
</tr>
<tr>
<td>Drift time</td>
<td>$&lt; 30$ $\mu$s</td>
</tr>
<tr>
<td>Temperature stability</td>
<td>$&lt; 0.5$°C</td>
</tr>
<tr>
<td>Number of readout chambers</td>
<td>24 (12 per each end-plate)</td>
</tr>
<tr>
<td>Segmentation in $\phi$</td>
<td>30°</td>
</tr>
<tr>
<td>Pad size</td>
<td>5x12 mm$^2$ and 5x18 mm$^2$</td>
</tr>
<tr>
<td>Number of pads</td>
<td>95232</td>
</tr>
<tr>
<td>Pad raw numbers</td>
<td>53</td>
</tr>
<tr>
<td>Pad numbers after zero suppression</td>
<td>$&lt; 10%$</td>
</tr>
<tr>
<td>Maximal event rate</td>
<td>$&lt; 7$ kHz ( Lum. $10^{27}$ )</td>
</tr>
<tr>
<td>Electronics shaping time</td>
<td>$\sim 180$ ns (FWHM)</td>
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<tr>
<td>Signal-to-noise ratio</td>
<td>30:1</td>
</tr>
<tr>
<td>Signal dynamical range</td>
<td>10 bits</td>
</tr>
<tr>
<td>Sampling rate</td>
<td>10 MHz</td>
</tr>
<tr>
<td>Sampling depth</td>
<td>310 time buckets</td>
</tr>
</tbody>
</table>

List of the TPC main systems is presented underway. They are:

- Construction of the TPC body (includes field cage, flanges and others)
- Readout Chambers (ROC)
- FEE, Readout, DAQ
- Laser Calibration System
- Cooling System
- Gas System
- The TPC assembling hall in bld.217
2.2 TPC design units

The schematic view of the TPC is presented in Fig. 2.2. The full TPC length with electronics and heat shield is $L = 4000$ mm.

Here are:

- SSW - service support wheel with front end electronics
- C1 - C4 field cage containment cylinders
- Readout chamber (ROC) - 24 pc
- Slider - TPC & SSW support and adjust structure
Figure 2.4: Design of the cylinder C1

Figure 2.5: Design of the cylinder C2

Figure 2.6: Design of the cylinder C3
The TPC main units:

- Four cylinders C1-C4 (see Fig. 2.3 ÷ 2.7) with $L=3400$ mm, outer diameter $D_{out}=2814$ mm and inner diameter $D_{in}=540$ mm. Inside C1 a beam pipe and a Si-tracker will be installed;

- HV electrode divides the TPC into 2 equal parts. Electrode is perpendicular to the beam axis;

- Field cage: non uniformity of electric field has to be less than $10^{-4}$;

- Flanges: cylinders C1-C2 and C3-C4 are connected together by means of aluminum flanges to create gas tight gap.

### 2.3 TPC cylinders manufacture technology

The TPC body design is based on four cylinders (C1 and C2 wall thickness - 3 mm, C3 - 4 mm and C4 - 6 mm) and two end cap flanges (see Fig. 2.2). The gap between C1-C2 and C3-C4 is filled with nitrogen ($N_2$) for HV discharges protection and prevents $O_2$ and $H_2O$ diffusion into the TPC gas volume. The gap value depends on the HV electrode voltage i.e. from the TPC gas mixture $Ar+CH_4$ (90:10) and optimal drift electric field ($E=140$ V/cm). For the TPC drift distance $L=163.1$ cm the HV electrode voltage will be $U=23$ kV. The gap value between cylinders is $dL=30$ mm.

Cylinders were manufactured by Russian industry. First layer is fiberglass with thickness $h=0.5$ mm then 2 layers of 25 $\mu$m Tedlar then about 3 mm of Cevlar and again 2 layers of Tedlar. Tedlar film is used for gas tightness and Cevlar film for durability. The C1 and C4 have aluminum layer $h=50$ $\mu$m for the TPC electromagnetic shielding. The C2 and C3 have aluminum strips (width $W=30$ mm, step $S=100$ mm, aluminum thickness $h=50$ $\mu$m) for configuration electric field shape. The final material agglomeration is made at temperature $T=160^\circ C$. To protect inner surface of a cylinder
inner fiberglass layer was used and then it removed after each cylinder manufacture finished.

Typical cylinder wall cross-section is shown in Fig.2.8. Additional short fiberglass flanges on C1, C2 and C3 will be used for the TPC assembly. The flange in the middle of C2 will be used for fixation of the HV electrode. The strip to strip will be connected by resistor.

FEA calculation results were shown that C2 deformation is less than 100 µm (see Fig.2.9). The radiation thickness is about 0.4 g/cm² due to low Kevlar density. The tests have shown that C2 cylinder gas tightness for O₂ corresponds to requirements.

### 2.4 TPC assembly procedure

Since the TPC field cage containment cylinders are not differ significantly each form other in size the TPC assembling will be done at horizontal position of each elements. The special assembling tool is under design and will be produced by Russian industry.

The arrangement for TPC assembling is shown schematically in Fig.2.10. The pair
of precisely positioned rails placed on flat surface, the strong "arm" I-beam with adjustable module, a system of three travelling lodgements and a special mobile platform create mechanical structure for step-by-step assembling of the TPC field cage elements.

At the first step the pairs of cylinders C1-C2 and C3-C4 are glued by means of intermediate flanges.

For C3-C4 an additional adjustable flanges are used to prevent the cycle form of cylinders as shown in Fig.2.11.

In the next stage the C1-C2 assemblage is set on the "arm" and the flanges and high voltage electrode are mounted as shown in Fig.2.12. Then they are arranged in respective to the readout chamber sectors. The HV electrode is placed on the C2 cylinder in its middle. The HV electrode has a support in its bottom part. This support gives possibility to rotate C1-C2 with the HV electrode in respect to the TPC flanges. The 3 holes on the external TPC flange diameter are used to align of the HV electrode with the TPC flanges by 3 "installation" roads.

After finishing of TPC flanges and the HV electrode adjustment the actual position of all elements, including the flatness and rotation relatively to each other, is checked by laser range meter and flange reference pins. Then 24 tubes for inner field cage are installed and all elements are fixed in its positions by epoxy as it is shown in Fig.2.13. After removing of "installation" roads the mylar tape inner field cage is mounted. Mylar tape with thickness 50 µm coated on both sides by aluminum is used. The tape cut on the "belts". Two connectors are fixed to each belt. The length of each belt with connectors is calibrated at fixed temperature and humidity.
Figure 2.11: The consecutive steps of C3-C4 field cage cylinders assembling
Figure 2.12: HV electrode and TPC end cup flange assembling procedure
Figure 2.13: Field cage assembly stage
The external TPC field cage is assembled in the same way as internal field cage. Then mirrors and prisms for laser calibration are installed and positions of laser rays inside the TPC volume are measured.

In the finish step the C3-C4 is assembled and the TPC is placed on mobile platform. All next assemble procedures are carried out in this TPC position.
Chapter 3

Field cage and HV electrode

3.1 Field cage

The main purpose of the TPC field cage is creation of uniform electrostatic field in a cylindrical high-purity gas volume to transport the primary ionization charges over long distances of $\sim 1.63$ m towards the readout end-plates. For reasons of symmetry in colliding beam experiments, two identical field cage configurations are chosen, back-to-back in common gas volume, with a common high-voltage (HV) electrode located at the axial center of the cylinder.

The basic TPC configuration is shown in Fig.3.1. Four cylinders are required to make the complete field-cage structure: two field-cage vessels (one inner and one outer) and two containment vessels (inner and outer). The outer containment vessel of the TPC is 280 cm in outer diameter, inner containment vessel is 54 cm in inner diameter and 340 cm in length. The readout end-plates spaced at 1.65 m from the central high voltage membrane. The inner and outer field-cage vessels define the active drift gas volume. They have diameters of 68 cm (inner vessel) and 266 cm (outer vessel). The active gas volume is divided by a high voltage membrane placed at the center of the outer field cage on two equal parts. High negative potential is applied to this membrane. The central electrode and two opposite axial potential degraders provide the uniform drift fields and define the drift volume with uniform electric field.

The drift field value is defined by the intrinsic properties of the drift gas affecting drift velocity and diffusion of primary ionization electrons. Thus, for the maximum drift path 1.63 m and P10 drift gas, the HV at the central electrode should be as high as 24 kV to provide the electron drift velocity of 5.5 cm/$\mu$s. For Ar+CO$_2$ gas mixture this value will be about 70 kV. In general, our design is similar to that of the TPCs used in STAR and ALICE experiments, except for the size.

The actual field cage is surrounded by insulating gas containment vessels C1 and C4 as shown in Fig.3.1(bottom). They provide personnel and operation safety with minimum material traversed by particles. The outer gas containment surface is coated with thin Al foil screen.

The main function of the outer field cage (OFC) is to retain the electric potential along one boundary of the active volume of the TPC with homogeneous electric field at one side and zero fields at the other side. The OFC vessel should be gastight to minimize drift gas contamination with oxygen and water and have minimal material budget. The Fig.3.1(top) shows the overall configuration and some details of the OFC.
Figure 3.1: Inner view of the TPC (top) and the front view of the TPC (bottom)
The primary function of the inner field cage (IFC) is defining the electrical potential along the inner radius of the active volume of the TPC; its secondary function is gas containment. Its support structure is not as substantial as that of the OFC and is required for self-support only. The space between the IFC vessel and the containment vessel is filled with dry gas N\textsubscript{2}. The IFC vessel must perform its functions and at the same time have the minimum material for particles passing through it into the TPC’s tracking volume. Therefore, minimum radiation length materials should be used to fabricate the IFC and the inner containment vessels.

As it was mentioned, our design is similar to that of the TPCs used in the STAR and ALICE experiments but, considering cylinders forming drift gas and containment volumes of the TPC, all four cylinders will be produced as monolithic Kevlar composite constructions. Such an approach allows one to minimize problems with gluing field cage parts and fragments together. Moreover, we suppose to mount field cage, central electrode and end-plates as independent precisely adjusted constructions which will be inserted between Kevlar vessels and fixed together mechanically and with epoxy.

Calculations show that walls of vessels should be rather thin (3 mm). The end cap flanges and the C\textsubscript{2} cylinder assembled together form the strong mechanical construction. It will be subjected to the maximal working load (high voltage electrode, support tubes and so on). The Fig.3.2 shows the calculation results of the deformation of the 340 cm long C\textsubscript{2} cylinder under total load of 80 kg. The deformation is not more than 100 \(\mu\text{m}\). Deformations of other cylinders will be less.

Final density of wall composite material was measured and it makes up with 1.27 g/cm\textsuperscript{3}. Kevlar composite cannot provide gastight of the envelope therefore it is laminated with two layers of Tedlar 25 \(\mu\text{m}\) film (Tedlar TUT 10BG3) at both inner and outer sides of the wall. In case of containment vessels 50 \(\mu\text{m}\) Al foil is glued over Tedlar film to form electromagnetic screen (see Fig.3.3).

The both sides of drift volume are covered with Al foil strips (pointed in the drawing) and both surfaces of outer vessels (containment envelope) are covered with continuous Al foil.
Kevlar composite laminated with Tedlar film is produced at 160°C temperature. Tedlar TUT 10BG3 film is not degraded at this temperature, on the contrary, homogenous junction between film sheets and Kevlar is obtained. The prototype of containment cylinder with length of 1 m and diameter of 90 cm was produced in this way and tested for gas tightness and mechanical hardness. In result, tests have shown that the material of prototype wall has all sufficient properties required for the TPC construction.

The vessels surrounding drift volume serves as electric field boundary. To avoid the accumulation of positive ion surface charges Al foil concentric strip rings are glued on both sides of vessel wall (30 mm wide with 100 mm pitch) as shown in 3.4(a). Corresponding outer and inner rings are connected to each other across the field cage wall via hermetic pins while inner rings are connected to low current high voltage divider (see Fig.3.4(b)).

Taking that length of the vessel is 3.4 m and diameter of the inner vessel is 60 cm into account it is a challenging task to glue rings together inside this vessel. Several
experiments were carried out and a technology was found to glue rings with high quality as shown in Fig.3.5 for 300 cm long C2 cylinder.

Figure 3.5: View of the 340 cm prototype vessel, produced to elaborate technology of aluminum foil strips gluing on inside wall of 600 mm diameter

All four cylinders C1-C4 manufactured and stored at JINR (see Fig.3.6).

Figure 3.6: TPC cylinders: C4 (top-left), C3 (top-center), C2 (top-right) and C1 (bottom-center)
3.2 HV electrode

In our design of the central membrane we used the experience of ALICE TPC team in production of the central membrane using 50 \( \mu \text{m} \) Mylar film. The membrane will be stretched over two hoops supported by the OFC cylinder and glued to the IFC cylinder as shown in Fig. 3.7.

![Figure 3.7: Scheme of the high voltage membrane assembling](image)

The potential degrading network defining the uniform electric field inside the TPC active volume will be realized in the same way as it is done in the ALICE TPC [6].

The aluminized Mylar strips will be stretched over 12 rods placed equidistantly over the outer and inner field cage circumferences in conformity with the modular structure of the readout chambers. There 112 potential 13 mm width Mylar strips along the field cage axis will be placed. They are connected electrically to the resistor high-voltage divider placed inside two rods. Rings of aluminum foil 13 mm wide and 50 \( \mu \text{m} \) thick (separated by insulating gaps of 2 mm width and 2 mm depth) are glued on the surface of rods. The supporting tube prototypes produced in industry using composite material are shown in Fig. 3.8.

![Figure 3.8: Potential degrader rods produced by industry using composite material (Kevlar + Macrolon + Al foil)](image)

The voltage on each strip corresponds to the strip center position along the field
Figure 3.9: The field distortions in the drift volume defined by Mylar strip system: (left) precisely placed strips; (right) one strip is shifted by 50 µm

Figure 3.10: The dependence of worst region size with the field distortion more than $10^{-4}$

cage axis from the central electrode. The non-uniformity of the electric field inside the sensitive TPC volume has to be not more than $10^{-4}$ relative to nominal value (140 V/cm P10 gas mixture). The numerical calculation of the electric field [24, 28] has been done using ANSYS MAXWELL software code.

The Fig.3.9(left) shows the regions of the field distortions in the drift volume defined by Mylar strip system, high voltage electrode and readout plane for the case of precisely placed strips. The Fig.3.9(right) shows how the distortion will be changed in the case where one Mylar strip is shifted by 50 µm from the nominal position.

The dependence of the size of the worst region with the field distortion more than $10^{-4}$ is shown in Fig.3.10 inward the drift space (violet line) and along the line parallel to the strip surface (orange line). The distortions are down to $10^{-4}$ at distance of about 23 mm from the strip surface inward drift space. The positioning precision of the strips into nominal place has to be not less than 50 µm.

Four outer rows of rods at any side of the HV membrane serve as a UV pipeline for laser calibration system and one is used for the voltage degrader. All rods except that for high voltage supply have 1.0 mm diameter holes (between Al strips) for drift gas inlet on inner row of rods and outlet on rods near OFC. High voltage supply for the central membrane is mounted in a rod of inner row.

The pads layout over pad plane has to be optimized to provide the required trans-
verse momentum, $dE/dx$ and multi-track resolution. To provide 3% transverse momentum resolution for 1 GeV/c charged particles we need to have at least 50 points on the particle track and 800 $\mu$m space point resolution. The pad response function depends on the readout chamber wire geometry and on the size and shape of pads.

The image charges induced on pad plane should be spread over two or three adjacent pads to allow application of an appropriate centre-of-gravity algorithm. This requirement will be met if the pad width is two times larger than the gap between the anode wires and pad plane. The energy loss resolution does not depend strongly on the pad length for constant length of measured track. For the $dE/dx$ resolution of 7% here has to be not less than 40 rows of pads with 15 mm length.
Chapter 4

Readout chambers

The TPC readout system is based on the Multi-Wire Proportional Chambers (MWPC) with cathode pad readout (ROC). The end-cap readout plane is covered by 12 trapezoidal sectors of the readout chamber with the bases of 213 mm and 642 mm and the height of 800 mm, each covering 30° in azimuth (see Fig. 4.1).

![Figure 4.1: The location of the ROC chambers](image)

The active zone length of the ROC in the radial direction is 796 mm. The dead zone between chambers is 29 mm. It includes the width of the wire framework (13 mm for every chamber) and a gap (3 mm) between chambers. The full active area of the ROC chambers is equal to 7.65 m².
4.1 Mechanical structure

The aluminum frame provides the overall mechanical stability of the ROC chamber (see Fig. 4.2). The frame thickness in beam direction is 5 mm and thickness of isolated plate and pad plane is 3 mm each. Pad plane and isolated plate glued to the aluminum frame. The frame is reinforced by stiffening rib. A series of holes across the aluminum frame are machined for the readout electronics connectors. The frame has 3 fixation holes for chamber adjustment and fixation.

![Figure 4.2: Aluminum frame of ROC chamber](image)

The chamber frame stability against deformation caused by wire stretching has to provide minimal overall deformation as possible (less than the expected wire sag caused by electrostatic force. The results of a finite element calculation of the chamber frame are shown in Fig.4.3. The deformations do not exceed 27 µm at the total wire tension \( F \sim 800 \text{ N} \) and over pressure inside the TPC up to \( dP=5 \text{ mBar} \).

![Figure 4.3: Finite element calculation of the chamber deformation caused by the wire tension \( F = 800 \text{ N} \) and overpressure 5 mBar. The maximum deformation is 27 µm](image)
The mechanical structure of the ROC chamber consists of the three wire planes, the pad plane, the insulation plate and trapezoidal aluminum frame. The cross section of the ROC chamber structure is shown in Fig.4.4.

![Figure 4.4: Cross section of the ROC chamber](image)

4.2 Wire planes and readout pads

The gap between the anode wire plane and the pad plane, as well as the gap between the anode wire and the cathode wire planes is h=3.0 mm (see Fig.4.5, left). To reduce the accumulated charge per unit length of the anode wire and thus the variation of the gas gain in high charged particle environment the anode wire pitch has to be small enough. It is matched with the pad length and is set equal to S=3 mm. Cathode wire pitch is 1.5 mm. The gating grid, with alternating wires connected together electrically, is located above the cathode-wire grid at the distance of h=3.0 mm, sufficient to trap the ions within a typical gate opening time. The anode wire grid and the gating grid are not staggered with respect to the cathode wire grid. To keep the alternating bias voltages low, the pitch between the gating grid wires is S=1.25 mm.

All wires and pad rows run in the azimuth direction. The wire length varies from ~ 190 mm at the trapezoidal pad plane bottom to ~ 620 mm at the top. To provide the gas gain of G=10^4 at moderate anode potential the gold-plated tungsten-rhenium D=20 µm diameter wire was chosen for the anode grid and mounted with F=50 g stretching force. The cathode and gating grid copper-beryllium wires have a diameter of D=75 µm and a stretching force of F=80 g.

The pad plane itself is a 3 mm thick printed circuit board with four layers of traces from the pads to the connectors. The routing of the traces has to be optimized for minimum trace length and trace-to-trace distance. The connection of the pad plane connectors with FEE cards will be made via flat flexible capton cables.

We have chosen 27 rows of pad with the size of 5x12 mm at inner area and 26 rows of pad with size of 5x18 mm at outer area of the readout plane as a compromise of
reasonable number of readout electronics channels. The pads have a rectangular shape, and the total number of pads in the TPC is 95232. The details of the pad plane are shown in Fig.4.5, right.

4.3 Tests and prototyping

To obtain a desired spatial resolution it is necessary for the induced charge in the azimuthal direction to be distributed over 2 or 3 pads. In the case of triggering more than three pads the spatial resolution deteriorates due to the reduction of signal-to-noise ratio.

The width of the pads should be matched with the width of the distributed induced charge. The relative distribution of the signal amplitudes on adjacent pads, induced from point avalanche near anode wire, is called the response function of pads (PRF) [29]. It can be calculated by integrating the distribution of the induced charge by the square pad S:

$$PRF(x, y) = \int_S Q(x, y) dS$$

Two-dimensional distribution of the induced charge $Q(x, y)$ can be expressed by the geometrical parameters of the wire patterns [30]. In Fig.4.6 the PRF for gaps 2.5 mm and 3 mm between the pad-plane and anode grid and width of pads - 4 mm and 5 mm is shown. It is seen that a reasonable distribution of the induced charge can be achieved.

For the fabrication technique development and study of the characteristics several prototypes of the ROC were fabricated. The prototypes were tested on two gas mixtures Ar/CH$_4$ (90/10) and Ar/CO$_2$ (80/20) with radioactive sources Fe$^{55}$ and Sr$^{90}$. For both mixtures was obtained the plateau characteristic more 200 V and dark current does
not exceed several nA. The gain dependence on anode voltage for mixture Ar/CH$_4$ (90/10) is shown in Fig.4.7. The required gas gain $\sim 10^4$ is achieved by the anode voltage $\sim$1400 V. The gas gain inhomogeneity on chamber area does not exceed $\pm$9%.

When all gating grid wires are under the identical potential, the electrons from the drift volume freely pass into the zone of the gas gain. Under application of the potential difference on adjacent wires this gating grid prevents charges to penetrate in the gain zone from the drift volume and back. The main purpose of gating grid is to block the flow of ions in the drift volume from the gain zone.

The drift current dependence of the potential difference on the gating grid adjacent wires under gas gain $10^4$ is shown in Fig.4.8. According to the results of measurements the efficiency of gating grid is $\sim 10^4$ under potential difference 200 V.

The track density of charged particles overall the drift volume depends nearly 1/r. In Fig.4.9 the distribution of the ionization points per unit of the readout pad plane...
area (1 cm) is shown as a function of the radius for 2000 minimum by Au + Au collisions at 9 GeV simulated with UrQMD code. To resolve the adjacent ionization clusters the pad has to be not more than 50 mm² in the central area of the readout plane.

Figure 4.8: Drift current vs gating grid potential difference

To estimate the multi-track resolution the pad response was simulated for two close tracks. In Fig. 4.10 the distribution of pad responses is shown along the pad row in dependence of time for two tracks with the angle of 1.5° between them. The two-track resolution (∼1.2 cm) can be reached with the pads of 4 mm in width in the central area of the detector.

Figure 4.9: The distribution of the ionization points per unit area (1 cm) of readout pad plane as a function of the radius for 2000 minimum by Au+Au collisions at 9 GeV

Figure 4.10: Distribution of pad responses along the pad row for two tracks with 1.5° angle.
Figure 4.10: Distribution of pad responses along the pad row in dependence of time for two tracks with the angle of 1.5° between them.
Chapter 5

Laser calibration system

5.1 Design considerations

The aim of the laser system is to measure the response of the TPC to straight tracks at known position. Taking the experience of STAR [5] and ALICE [6] experiments into account, we suppose to use calibration system for monitoring of the TPC working regime parameters by a UV laser based. The UV laser system is a part of the test and calibration procedure designed to produce a set of the laser beam tracks at well-defined angles and positions. The accuracy of the laser beam position should be significantly better than the spatial resolution of the TPC. The system will provide on-line monitoring of the value of drift velocity which depends on the drift gas pressure changes (caused by changes of atmospheric pressure), the temperature, $E \times B$ noncollinearity and space charge effects. The laser beams follow the paths of stiff charge particle tracks emerging from the interaction region and can be used for correction of the sagitta of these tracks.

5.2 Implementation

In order to minimize the error in the absolute position measurement by the TPC, it is necessary to account for both static and time-dependent distortions in the drift path of the ionization cloud. The static distortions are the result of non-uniformities in $B$ and $E$ fields. A calibration system that provides absolute positional references is needed so that a deconvolution procedure, which determines the absolute spatial position from the row pad and time bucket information, can be developed. Time-dependent distortions can result from the changes in gas performance, in environmental variables (temperature or atmospheric pressure), or from spontaneous failures. A calibration system that can reproduce fiducial tracks is needed to monitor the TPC performance.

As shown in Fig.5.1, the initial wide beam (18 mm) is divided into two arms with a semi-transparent mirror (green box). A part of beam (25\%) is aimed into tube with bundles of micro mirrors (see Fig.5.2) while remaining 75\% are transported by set of prisms to the second semitransparent mirror splitting a part of beam (33\% of the power) into the second tube. Farther, the beam reaches the third semitransparent mirror where 50\% are aimed into tube with bundles of micro mirrors while remaining part is transported to the last mirror that 98\% of the beam reflects into tube. Small part reaches beam position detector. In every tube there are 4 bundles of 7 micro
mirrors forming 1 mm rays (see text). Thin (1 mm diameter) UV rays emitted from the 4 tubes (yellow) forms set of four planes with 28 rays in each of them. The second laser creates rays at the opposite side of the central electrode.

The technical details of a beam splitting scheme part are shown in Fig.5.3. The wide laser beam will be transported using prisms around outer perimeter because the central part over the TPC flange is filled with the readout electronics and cables.

Taking into account the experience of STAR and ALICE experiments, we suppose to use for monitoring of the TPC working regime parameters by a UV laser based calibration system. The UV laser system is a part of the test and calibration procedure designed to produce a set of laser beam tracks at well-defined angles and positions.
The accuracy of the laser beam position should be significantly better than the spatial resolution of the TPC. The system will provide on-line monitoring the value of drift velocity which depends on the drift gas pressure changes (caused by changes of atmospheric pressure), the temperature, EB non-collinearity and space charge effects. The laser beams follow the paths of stiff charge particle tracks emerging from the interaction region and can be used for correction of the sagitta of these tracks.

The system selected to perform these functions consists of two pulsed 130 mJ 5-7 ns Nd:YAG lasers NL311FH-10 or NL313FH-30 with 10 Hz repetition rate. The 18 mm wide beams from each laser are split to four beams and then, through 4 tubes placed inside the drift volume of TPC, where micro mirrors (diameter of active reflecting surface is 1.3 mm) are illuminated to form 112 narrow calibration rays at each side of HV membrane. These 112 rays are distributed into 4 equidistant quasi planes of 28 rays in each, emitted from 4 tubes (see Fig.5.1 and 5.3) within the half of active volume of the TPC (224 rays in whole TPC). Distance between planes is 300 mm. Each tube contains four bundles with 7 mirrors. Scheme of beams of a "plane" is shown in Fig.5.4. If bundles are mounted in an exact plane resolution in region of ray crossing points is distorted. Therefore, the bundles of a plane are shifted at 4 cm level respectively each to others. Therefore, we have quasi planes of narrow laser rays.

Initial beam from a laser is divided into two arms by a splitter semitransparent mirror so, that 25% of the power is transmitted inside the first tube to the bundles of micro mirrors (see Fig.5.1) while remaining part, using a system of three prisms, is transported to the second semitransparent mirror over the second tube with micro mirrors. (Really, it should be taken into account, that a part of energy is lost on the surfaces of prisms therefore reflection coefficients are calculated in dependence of prism surface covering.) This mirror reflects part of the power (33%) into second tube while other part of power is transported to the third tube. (Some details are shown in the Fig.5.1). Similarly, this semitransparent 50% mirror reflects part of beam into tube and allows a remaining part to be transported to the last mirror over the fourth tube.
with micro mirrors. The last semitransparent mirror a tiny part of light (2%) does not reflect into tube but passes to the UV beam position detector (cameras). Cameras are tuned to control laser beam position. Remote control piezoelectric pico-motor drivers will be used to adjust beam position if necessary. Cameras will be used also to control initial beam position at the front of MPD to observe position of beam profile reflected by quartz plate.

Figure 5.4: A drawing of the TPC quasi plane that showing position of four mirror blocks emitting 28 beams within one plane

The number of laser beams is of the same order as in STAR [5] and ALICE [6] TPCs and is sufficient to calibrate the TPC at different $\eta$ and $\varphi$.

To produce tracks in TPC prototype which is under testing the same type of Q-switched Nd:YAG laser model NL131/FH is used but with low power (0.2 mJ per pulse), repetition rate 10 Hz or lower, pulse duration 3-4 ns. FH notes fourth harmonic output 266 nm wavelength in the case. Two types of mirrors were tested with $1.5 \times 10^6$ high power (10-20 times more than that necessary to produce tracks) laser shots. Mirror surface degradation was controlled with microscope (see Fig.5.6 photos of two different samples). The TPC prototype is built for one of 12 readout segments therefore only two blocks of three mirrors are mounted at different distances from cathode to have a possibility to control the drift velocity. A green light laser used to adjust mirrors in the bundles and in the TPC prototype (see Fig.5.7).

A drawing of a TPC quasi plane showing position of four mirror blocks emitting 28 beams within one plane is shown in Fig.5.4. Actually, bundles of a ”plane” are shifted by 4 cm to avoid bad resolution around beam cross points. Details (tubes, field cage strips) removed. Diameter 2131 mm is inner surface of OFC wall, diameter 609 mm is outer surface of IFC. Four similar planes are placed at both sides of HV membrane. Distance between the planes - 300 mm.

Schematic view of a bundle of 7 mirrors (see Fig.5.5), 11 degree step between beams is planned.
Figure 5.5: Schematic view of a mirror bundle

Figure 5.6: Photo of the mirror surface viewed with electron microscope after $1.5 \times 10^6$ UV laser shots

Figure 5.7: Green light laser used to adjust mirrors
5.3 Testing and prototyping

Few tests of mirrors were carried out using electron microscope. It is not so easy to "see" mirror when optical microscope is used. However, we found quite effective instrument to check if mirror plane is good enough to reject mirrors with expanding beam or damaged or simply dirty surface.

We use pixel detector of high resolution (52 microns per pixel) which is sensitive to laser beam. If measured beam image is of the same size and form at 30 cm and 200 cm distance from a mirror the mirror is qualified as ready to be used for the calibration system.

Test tracks were created by UV rays reflected with few mirrors in TPC prototype and registered with readout chamber.

The first TPC prototype tests with laser beams are shown in Fig.5.8. The prototype was irradiated with UV laser to produce tracks. Beam splits into 6 narrow (⊘ =1.3 mm) rays with mirrors placed at two levels. Left - scheme of laser beam (violet) layout, right - tracks, reconstructed on base of registered signals. One of beams was situated too close to the readout chamber edge and was not reconstructed.

The tests have shown that it is rather challenging task to mount a bundle of seven tiny cylindrical glass tubes if one needs to orient all reflecting surfaces at the fixed angles. It should be taken into account that approximately 45-50 bundles should be produced because few of them are rejected due tests. Another problem is fragility of glass edges. In result we started experiments with mirrors created on ceramic base also. Considering this conception bundles are formed using three blocks with three or two mirrors in each block. Reflecting surface of each mirror is oriented at corresponding angle when ceramic prism is produced.

Thus, bundle of seven mirrors is mounted while three prisms are pressed together and glued into container. Final distribution of the laser beam angles will be measured for all bundles. However, estimates carried out at CRYTUR (Turnov, Czech Republic) have shown that such method is rather expensive. The problem is to polish faces of prisms at different angles. Therefore 40 mirror bundles were produced using mirrors on quartz glass.

While NL131/FH is used to ionize gas in the prototype TPC in the full-scale chamber two lasers of similar type but another modification NL311FH-10 or NL313FH-30 are
supposed to be used. NL311-10 can shot 10 pulses per second while maximal frequency of NL311-30 is 30 Hz. These lasers and characteristics are presented at Fig.5.9,5.10 and 5.11.

Taking proposed beam splitting scheme into account initial 130 mJ will be divided into four beams of $\varnothing = 18$ mm (maximal diameter, 20 or 24 mm options are also analyzed) or 530 mm$^2$ each beam. It means, that with pulse length of 5 ns energy density will exceed 80 $\mu$J per mm$^2$ while 20-50 $\mu$J per mm$^2$ is enough to ionize gas to simulate minimum ionization particle track. Just in case of 22 mm beam one has 40% reserve. So, the laser will provide energy high enough taking into account losses in prisms and mirrors in period of 6 month typical date of laser and optics cleaning.

In case of minimal distance (2 mm) between mirror bundles, total diameter of the system is 14 mm (see Fig.5.12). It means that laser beam of 18 mm diameter is adequate for the task. Minimal diameter of laser beam should be 14 mm to illuminate all four mirror bundles. The 18 mm beams will be used in the experiment and distance between bundles will be 4 mm to avoid accidental overlapping. The geometry will be tested using green laser beam before tubes with bundles installed in the TPC.
### SPECIFICATIONS

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<th>MODEL</th>
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<tr>
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<td>1300/1000 mJ</td>
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<td>at 532 nm</td>
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<td>Max. repetition rate</td>
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<td>Beam height</td>
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### PHYSICAL CHARACTERISTICS
- Laser head size (W×H×L): 310×230×800 mm
- Powering/cooling cabinet size (W×H×L): 550×550×600 mm
- Umbilical length: 2.5 m

### OPERATING REQUIREMENTS
- Water consumption (max 20°C): < 10 l/min
- Room temperature: 15–30°C
- Relative humidity (noncondensing): 20–80%
- Mains voltage: 208 or 240 VAC, single phase 50/60 Hz
- Power consumption: < 3.5 kVA

---

1) All specifications subject to change without notice. Parameters marked typical are not specifications. They are indications of typical performance and will vary with each unit we manufacture. Unless stated otherwise, all specifications are measured at 1064 nm.
2) 20 Hz versions.
3) Averaged from 300 shots, Std. Dev., after 5 minutes of warm-up.
4) Within 8 hours after 20 minutes of warm-up.
5) W/1000 μW.
6) In respect to Q-switch triggering pulse, Std. Dev.
7) Full angle at 1/e².
8) 20 Hz version of NL311 requires 3 phase mains.

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Figure 5.11: The laser characteristics

![Laser characteristics diagram](image1)

Figure 5.12: The mirror bundle diameters

![Mirror bundle diameters diagram](image2)
The typical field of laser beam before expanding is shown in Fig.5.13.

![Typical field of laser beam before expanding](image)

Figure 5.13: Typical field of laser beam before expanding (beam diameter -10 mm, NL311FH)

The planned works and spending are presented in Fig.5.14.

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<th>2018</th>
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Figure 5.14: The planned works
Chapter 6

Cooling system

6.1 Temperature stabilization

The main goal of the cooling system is to provide temperature stability of the TPC gas mixture with a high precision. The temperature stability and homogeneity within the TPC drift volume have to be at the level of $\Delta T < 0.5^\circ C$. The main heat source is FE cards. Each FE card dissipates about 6.4 W, the ROC chamber - about 330 W and LV bus bar - 20 W. Another important heat source affecting the TPC gas is the power produced by the field-cage divider (resistor rods). While the power is relatively small (0.6 W per rod), but this heat is dissipated directly into the gas volume. Other heat sources are neighboring detectors.

![Common view of TPC temperature stability and cooling system](image)

Figure 6.1: Common view of TPC temperature stability and cooling system

Power consumption of 1488 FE cards is $\sim 9.5$ kW, 24 ROC chambers $\sim 8$ kW, LV buses $\sim 2$ kW. Total power consumption is about 19.5 kW.

Common view of the TPC stability and a schematic view of the cooling units are presented in Fig.6.1. It consists of the TPC outer and inner thermal screen, two end-cap screen and cooling system for FE cards, LV buses and HV divider, namely:

- 2 x 12 loops for the front-end electronic cooling
• 2 x 2 loops for the bus bar cooling and the ROC covers
• 2 x 2 loops for the ROC cooling
• 2 x 2 loops for the inner thermal screen
• 1 x 1 loops for the resistor rods

6.2 Cooling of front-end electronics

Each ROC contains 62 FE-cards. One sector dissipates \( \sim 400 \) W. The 2 x 12 sectors dissipate a total of \( \sim 9.5 \) kW. Cooling is provided individually to every sector. The schematic view of the FEE cooling and layout on the TPC is shown in Fig.6.2. We are going to use 6 mm copper tube to cool the individual card and silicon tube to connect copper tube. The FEE cooling envelope consists of two copper plates, 1 mm thick each, and the FE card inside. The copper tube is soldered to copper plate. The effective flow rate will be optimized.

![Figure 6.2: The front-end electronics cooling: left - pipe layout one individual ROC cooling, right - ROC layout for one TPC end](image)

6.3 Cooling of bus and ROC covers

This circuit cools the outer covers of the Read-Out Chambers, as shown in Fig.6.3. The heat dissipated by bus bars running along the spokes of the service support wheel need also to be removed. The one loop consists in 6 ROCs covers and 6 bus bars per supply line. Panel design and flow rate will be optimized.

The ROC readout plane circuit layout is shown in Fig.6.4.
6.4 Thermal screen

Outer thermal screen design is presented on Fig.6.5. Weight of each panel is about 3 kG. Total weight of 48 panels is 144 kG. The schematic view of the front and outer thermal screens and cooling of 62 FE-cards are shown in Fig.6.6.

A diagram representing the TPC cooling plant as well as some of the piping to the detector is shown in Fig.6.7 and based on the ALICE concept. The plant consists of a reservoir large enough to contain all the water in the set-up, a pump, heat exchanger connected to the mixed water network, one supply manifold and one return manifold. A total of 52 circuits have been connected to these manifolds. All this circuits are temperature and flow adjustable.
For monitoring the temperature distribution on the TPC the arrays of sensors are mounted both inside and outside of the gas volume of the TPC. In addition to sensors covering the outside of the inner and outer Field Cage, sensors are mounted onto each Read-Out Chamber. The Table 6.1 summarizes the location and number of the sensors. Additional temperature sensors on the front-end electronic cards complete the monitoring system.
Figure 6.7: Schematic view of the TPC cooling system
Chapter 7

Gas system

The TPC consists of an inner drift volume and two insulating volumes (gaps) enveloping it. The insulating gaps are flushed with \( \text{N}_2 \). Several hollow rods, located inside the drift volume, will be flushed with working gas mixture for resistor chain cooling. The \( \text{N}_2 \) flow rate needs to be high enough to prevent of atmospheric contaminants due diffusion into insulating gap. The \( \text{H}_2\text{O} \) concentration has to be less than a few tenths percent. A total flow of \( \sim 15 \text{ L/min} \) will allow a complete five volume change to purge insulating volumes in 1 day.

7.1 Technical requirements

The considered gas system is assigned to provide a drift volume with the gas mixture 90\% Ar + 10\% CH\(_4\) at the constant temperature and the constant overpressure. This system has to provide an inflow of the required gas flow \( \text{N}_2 \) in the insulated gaps of the TPC and of the gas mixture in the channels for the cooling of the strip system divider resistors forming a uniform electrical field in the sensitive volume.

At the regular mode the gas system operates as the closed-loop system with the regeneration of the gas mixture portion circulating through the TPC. At the same time a small amount of the fresh gas mixture is added and the same amount is removed from the system (including the leaks). In the mode of the drift volume purification this system operates as the open one.

The cross section of the TPC is shown in Fig. 7.1. The central electrode divides the active volume of the TPC into two identical parts of a length 170 cm. The drift volume of the TPC is 17640 liters, the volume of the inner and outer insulated gaps - 2380 liters.

At the modes of the purification and filling the gas flow through the TPC has to provide the five-time purify of the gas per day in the drift volume. At the regular mode the circulation rate of the gas mixture is 12000 L/hour.

The concentration of O\(_2\), CH\(_4\) and water vapor in the gas mixture is controlled by the respective analyzers in the each branch of the system. According to their readings part of the gas mixture is directed into the branch of the regeneration to remove the water vapor and oxygen. Into the system a little flow of pure gases from a reservoir for the gas mixture preparation is supplied too. The developed system has to provide the constant pressure 2.0\(\pm\)0.03 mbar (relative to atmospheric) in the active volume of the TPC.
Figure 7.1: Cross-section of
The concentration of CH₄ in Argon is retained at the level 10±0.1%. The temperature of the gas mixture is controlled at the input and output of TPC.

The operation and control of the gas system operating parameters are realized with the help of a specialized electronic system, which controls the operation of all managed elements of the system, detects the operating parameters and generates a warning signal in case of the deviation from the setting values.

The presented project is developed in accordance with the TPC gas system technical requirements. It uses the practical experience on development of the similar systems for the experiments STAR and PHENIX [31, 32, 33] at Brookhaven National Laboratory (BNL, USA) and also the last developments of the gas system [34] for the experiment CBM in Darmstadt, Germany.

### 7.2 Gas system description

The schematic circuit is presented in Fig.7.2. Its main assignment is to supply the pure gas mixture of the stable composition in the TPC at the specified temperature and differential pressure and also to provide the reliable operation of the detector during a long term experiment.

![Figure 7.2: Scheme of TPC gas system](image)

Structurally, the gas system can operate as in the closed version for a long term experiment as in the opened one for purging of the TPC. Since the distance between the TPC and the gas system location is about 70 meters, the gas scheme contains two circulating loops: outer - with the compressors C1, C2 and inner - with the blowers C3,C4. The usage of two circulating loops can significantly reduce the cost of the connecting pipelines of a large diameter, and the outer circulating loop can be used for the TPC-prototype test without the inner loop. In the mode of a long term experiment
the outer circulating loop is used for the mixture analyze at various points of the system, namely: for the fresh mixture SV4, for the mixture inside of the detector - SV5, for the mixture at the purification unit output of the outer circulate loop - SV7 and for the mixture at the purification unit output of the inner circulate loop - SV9. Also, this loop is allowed to retain the differential pressure at the level 2.0+/−0.1mbar.

7.2.1 Fresh gas mixture preparation

In this system the version of the dynamic preparation of the fresh binary mixture is used. In our case the main component is argon, which is changed into gas from liquid state by means of heat exchanger-gasifier and is blown to input SV2 of solenoid valve and then to mass-controller FM1. The flow indicator F11 and the solenoid valve SV1, opened normally, are used to increase the argon flow at the purging of the TPC. Within a long term experiment mode the rate at the F11 is set at the level of 5 L/min and the SV1 is closed. In the case of the power shutdown the SV1 and SV8 are opened and the TPC is filled by the pure argon that prevents the air diffusion into the TPC at an atmosphere pressure increasing.

The second component is the pure gaseous methane, which is supplied to the mass-controller input FM2 at the pressure of 1bar through the solenoid valve SV3 from one of the commutated collectors. The component mixing to obtain the desired composition is carried out by means of the FM1, FM2 and Mixer. In this case the FM1 controls the FM2 that is allowed to keep the fixed composition of the gas mixture independently of the pressure oscillation at the inputs of the mass-controllers. The quantitative and qualitative composition of the fresh mixture is controlled by the analyzers of CH4, H2O and O2. Additionally, the content of Methane is estimated by the flow rate relation through the FM1 and FM2 by PC of the electronic control system. The limits of the flow rate regulation are: for the FM1 - 0÷50 L/min, for the FM2 - 0÷15 L/min. The choice of these limits is due to necessity of the five-time purging of the TPC during 24 hours. The required flow rate of the gas mixture is set by PC.

Then, after Mixer, the fresh mixture is fed into the supply line (⌀ 22 × 1 mm) of the outer loop and mixed with the circulatory flow. The Mixer is a cylindrical volume with the internal diameter of 30 mm and a height of 400 mm, filled by no oxide copper shavings to promote the flow turbulization and mixing. The Mixer temperature is controlled by temperature sensor TT1.

7.2.2 Outer circulation loop

Its functional purpose was described above. The using of two diaphragm-type compressors C1, C2 are caused by a guarantee of the operation reliability within a long experiment. During the operation only one compressor is used, the second is in reserve. The capability of each compressor is 30 L/min at the pump pressure 100 mbar. The differential pressure in the input collector of the compressors is determined by the difference between the differential pressure of the TPC and the pressure loss in the pipeline (⌀ 32 mm× 1 mm) connecting the input collector with the TPC. A constancy of the differential pressure in the TPC is kept by the electro-pneumatic controller PIDC1, which controls the pneumatic bypass valve BV1. The pressure sensors PT4 (input compressor collector) or PT8 (TPC) can be used as the sensor of feedback PIDC1.
The PID controller is an autonomous, microprocessor-based and connected with PC. This gives you the possibility to set quickly the specified pressure value and the PID adjustment coefficients in order to obtain the desired process of the pressure stabilization. If the pressure in the TPC will start to decrease relative to the set value, the PIDC1 will start to open BV1. In this case a more amount of the gas mixture will bypass from the pump collector to the input collector, and the pressure in the TPC will be increased. If the pressure in the TPC will be increased relatively to the setting value, the PIDC1 will start to close BV1, the pump collector pressure will start to increase, and when it will be at the level about 100 mbar the mixture will be exhaust into the atmosphere. This level (100 mbar) is set by means of the reverse pressure regulator BPCV1 and is measured by the pressure sensor PT3 and the indicator PI4. As result of this the differential pressure in the input collector of the compressors will reduced and eventually in the TPC. It should be noted that the manual bypass gate BMV1 is adjusted in order that the PID controller tuning limits have been optimal. For the normal operation of the PID controller an air pressure (Nitrogen) 1 bar is required.

After the output collector of the compressors the circulate mixture is divided into two flows. One flow moves through the solenoid valve SV6 to the purging unit, which includes the element of oxygen removing from the gas mixture (Purifier) and the mixture dryer (Dryer). Structurally both elements have a cylinder form with the inner diameter - 40 mm and the height - 400 mm. The element Purifier is filled by an active coper and operates at the temperature - 220°C. To support this temperature the display-controller TIC1 is used. At the same temperature the element regeneration by explosion-proof mixture (Ar + 5% H2) is carried out. The Dryer is filled up by zeolite NaX and operates at room temperature. Its regeneration is performed by the purging with the dry Argon at the temperature - 350°C. This temperature is stabilized by display-controller TIC2. The manual valves MV7, MV8 and MV9 are used at the regeneration of the purging unit elements.

As noted above the solenoid valve SV7 is used for the gas sampling analyze. The content of oxygen and moisture is not above 2-3 ppm after purging unit.

The mixture flow, moving through the purging unit, is measured and regulated by the flow indicator FI7 and it can reach up to 30% of the total. For the dust removal on the output of the purging unit the filter 5 µm (F3) is installed.

The second flow passes through the pressure regulator PCV1. The pressure on the output from the PCV1is set at level about 20 mbar and is controlled by the pressure indicator PI3.

The total flow in the outer circulate loop (including the fresh mixture) is measured by the indicator FI3.

**7.2.3 Inner circulation loop**

The main purpose of this loop is a fast exchange of the TPC volume by the gas mixture with its oxygen and the moisture purging and the high-voltage resisters cooling. The loop includes two compressors of eddy type C3, C4 with the volume capability - 13 m³/hour, each at the blow pressure - 100 mbar. At the active state is only one compressor, the second is in reserve. At this capability the one TPC volume exchange will take less than 1.5 hours. The reverse valves C7 and C8 prevent the bypass of the mixture flow through the inactive compressor.
The pressure at the blower output is measured by the pressure sensor PT11 and the indicator PI5. The bypassed manual valve BMV2 regulates the overall flow of the circulate mixture. By means of the hand-operated valve MV10 and the flow indicator FI8 the mixture delivery to the purging unit is regulated.

The purging unit of this loop is similar to that described above, but it has a larger size and does not require more detailed description. The Purifier and Dryer have a cylinder form with the inner diameter - 80 mm the height - 700 mm. Up to 20% of the circulate mixture passes through the purging unit. On the output of the latest the filter 5 µm (F5) is installed. The differential pressure sensor PT12 controls the filter clogging. A mixture sample analysis is performed by means of the solenoid valve SV9. All flows are joined on the flow indicator output FI8 and then are moved into the water-cooled heat exchanger TO1. The flow sensor FT1 measures the total flow of the gas mixture circulated through the TPC. The filter 2 µm (F4) is installed at the TPC input.

7.2.4 Temperature measurement

The temperature of the circulating mixture is measured at a few points, mostly in close of the TPC. As the temperature sensors the platinum thermometers 100 Ω placed in the mixture flow are used. It is provided the 5 temperature sensors for installation. The TT1 is located on the Mixer of the TPC gas system main frame, the TT2 - at input of water-cooled heat exchanger TO1, TT3 is placed at the TPC input, the TT4 - directly in the TPC gas volume and the TT5 - at output from the TPC.

7.2.5 Insulating volume purging

The pure dry Nitrogen is used for the purging of the TPC insulating gap. It is obtained by the gasification of the liquid Nitrogen in air heat exchanger gasifier at a pressure 1bar which is measured by the pressure sensor PT10 and the indicator PI6. Then the pure and dry Nitrogen is injected to the flow indicator FI9. By means of this indicator the required flow rate within the limits 5÷10 L/min is set. The differential pressure sensor PT7 is installed at the insulating volume input. It controls the pressure difference between the pressures in the active and the insulating volumes of the TPC. This difference must be positive. At the negative difference the electronic scheme will warn by sound and the light signals.

The sensor of the minimal Methane concentration LLT1 is installed at the insulating gap output. It measures a minimal amount of Methane in the flow relatively to the minimal acceptable level of an explosive risk. At occurrence of the signal above the predetermined level from the sensor LLT1 the electronic system will warn by sound and the light signals. The pressure liquid limiter Bubbler 2, configured to 1mbar, is used for the insulating volume protection.

7.2.6 Protection level for high and low pressure

The electronic and electromechanical protection levels for the high and low pressure in the active TPC volume, which can lead to detector failure, are foreseen at the gas system. These levels duplicate each other and differ by capability (response time of
an electronic protection is 10-20 ms and of an electromechanical is no more 1 s). All sensors, including the pressure, temperature, gas consumption and the analyzer output signals, are connected to electronic system. The pressure in the TPC is controlled by the differential pressure sensor PT9 in relation to the atmospheric pressure measured by the barometer BP1. The electronic system will warn by the sound and the light signal if the pressure value will exceed the first preset limit - 2.2 mbar. Upon the reaching of the second acceptable limit the electronic system will close the fresh mixture supply (SV2 and SV3 will be closed) and will open the alarm solenoid valve SV8 to eject the excess mixture into atmosphere. When the operating pressure inside the TPC will be 2 mbar, all valves will return to the initial state.

If the pressure is reduced below the operating value to 1.8 mbar, the electronic system will increase the fresh mixture flow by 30% of the initial one. Upon the reaching of the operative pressure in the TPC the fresh mixture flow will be returned to the starting state. The pressure decreasing to 1.8 mbar can only happen at the sharp barometric pressure increment (rate > 0.5 mbar/min), that is not typical for Moscow region, or at the alarm loss of the pressure in the TPC.

An electromechanical protection system is based on the pressure liquid limiter Bubbler 1 and the electro-contact manometer PIS1, in which are the adjustable limiters of low and high pressure levels.

The pressure liquid limiter Bubbler 1 is filled up by vacuum oil and is tuned to the maximal permissible pressure 3 mbar in the TPC.

A low pressure threshold determined at the electro-contact manometer PIS1 will not exceed 0.8 mbar and high one not above 2 mbar. If the pressure will be below 0.8 mbar, the PIS1 will open SV1, and the pure Argon will be added to the fresh mixture. At the exceeding of 0.8 mbar the PIS1 will close the SV1. An addition of pure Argon will not cause a significant variation of the mixture composition in the TPC. The estimates show that this variation will not exceed 0.01% on Methane. This value is below the Methane analyzer error. If the pressure will be above 2 mbar, the PIS1 will open SV8 and will close it at the pressure decrease below 2 mbar.

The main technical features of the gas system are shown in Table 7.1.

<table>
<thead>
<tr>
<th>Feature</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating mixture</td>
<td>Argon + 10.0 ± 0.1% Methane</td>
</tr>
<tr>
<td>Consumption range control of fresh mixture</td>
<td>0 - 50 L/min</td>
</tr>
<tr>
<td>Operating pressure in TPC</td>
<td>2.0 ± 0.1 mbar</td>
</tr>
<tr>
<td>Recirculation rate of outer loop</td>
<td>30 L/min</td>
</tr>
<tr>
<td>Recirculation rate of inner loop</td>
<td>200 L/min</td>
</tr>
<tr>
<td>Oxygen content</td>
<td>20 ppm</td>
</tr>
<tr>
<td>Moisture content</td>
<td>10 ppm</td>
</tr>
<tr>
<td>Gas purging of TPC insulating volume</td>
<td>nitrogen</td>
</tr>
<tr>
<td>Purging rate of insulating volume</td>
<td>5 - 20 L/min</td>
</tr>
</tbody>
</table>
7.3 Gas consumption

The suggested data on a consumption of gases per day and month in view of the TPC initial purging, the volume of which is accepted to 18 m$^3$, are presented in Table 7.2. The initial purging of the TPC is implemented by Nitrogen two-times exchange of the TPC volume, by Argon two-times exchange and by the mixture (Argon+10%Methane) three-times exchange. The fresh mixture rate is accepted to 6 liter/min within a long term experiment.

<table>
<thead>
<tr>
<th>Mode</th>
<th>Argon, m$^3$</th>
<th>Methan, m$^3$</th>
<th>Nitrogen, m$^3$</th>
</tr>
</thead>
<tbody>
<tr>
<td>TPC purging</td>
<td>84</td>
<td>5.4</td>
<td>36</td>
</tr>
<tr>
<td>Experiment</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Per day</td>
<td>7.8</td>
<td>0.86</td>
<td>8.6</td>
</tr>
<tr>
<td>Per month</td>
<td>234</td>
<td>25.9</td>
<td>259</td>
</tr>
</tbody>
</table>

7.3.1 Pipelines pressure losses

The estimate of the pressure losses is performed for the direct and inverse pipelines of the outer circulating loop and also for feed line of Nitrogen into the insulating gap, as each of them has a length about 70 m.

The purging mode pressure losses for the direct pipeline with the inner diameter - 20 mm and the rate - 50 L/min are shown in Table 7.3.

<table>
<thead>
<tr>
<th>Gas</th>
<th>Pressure losses, mbar</th>
</tr>
</thead>
<tbody>
<tr>
<td>Argon</td>
<td>8.5</td>
</tr>
<tr>
<td>Argon + 10% Methane</td>
<td>8.1</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>5.6</td>
</tr>
</tbody>
</table>

The experiment mode pressure losses for the direct and inverse pipelines for mixture (Argon + 10% Methane) with rate 36 liter/min are shown in Table 7.4.

<table>
<thead>
<tr>
<th>Pipeline name</th>
<th>Inner diameter, mm</th>
<th>Pressure losses, mbar</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct</td>
<td>20</td>
<td>3.6</td>
</tr>
<tr>
<td>Inverse</td>
<td>30</td>
<td>0.5</td>
</tr>
</tbody>
</table>
7.4 Gas system assembly and slow control subsystem

Structurally the gas system is divided into 3 parts. The main part of the gas system is mounted in the standard frame of the electronics (600×800×2058 mm³). It is located about 70m from the detector. The second part of the system is mounted in a smaller frame with dimensions - 600×800×1258 mm³ and is located in close to detector to provide the minimum length of the inner circulating loop. Some of the gas system equipment is assembled at the area for gases reservoir.

The major part of the control subsystem is mounted on the sidebar of the gas system main frame. The computer is installed there too.

The schemes for gas system and slow control subsystem are shown in Fig.7.3–Fig.7.7.

7.4.1 Slow control software

It is assumed that for the gas system slow control of the TPC/MPD the software [35], which has been developed at the experiments STAR and PHENIX at BNL (USA) and RICH CBM [36], will be used. Developed on the windows platform this software includes a manual control by the gas system, data readout from all sensors, visualization and saving of all requirement parameters and the detector protection from differential alarms too.

This software consists of three separate program modules:

- The module ”Gas system control” is provided the data acquisition, its storage and the control by the gas system

- The DBViewer [37] performs the functions of the data visualization, event logging and data transfer from the database to the text file or MS Excel table for the successive analysis

- The module ”Charts” [38] is used for an imaging of the time-dependent parameters in real time. It is possibility to set the alarming levels for each table parameter in the tabular style. Additionally, this program module supports a protocol TCP/IP for the data transfer that provides the remote system control
Figure 7.4: Connection scheme of gas system main frame

Figure 7.5: Cable scheme of control module
Figure 7.6: Connection scheme of power supply modules and heaters

Figure 7.7: Connection scheme of sensors and devices in close to detector
The database MS Access is used for the data and system events storage.

7.4.2 Main control module

The main control module consists of two threads. The first is provided the graphical user interface (GUI) and event log, and the second is for data acquisition from the system sensors, a hardware control and an error handling. The second thread has a highest priority to provide a stable system operation at the high loads.

The software basic window has the following menu options:

- **Main control** - the basic graphical interface window
- **System parameters** - the parameter tuning, electronics connection, sensor readout period et al.
- **Alarms** - the system diagnostic configuration of failed and alarm states
- **Database** - the sensor calibrated modification of coefficients and database edition
- **DAQ32** - an expert fine tuning of the controller DAQ32

The software interface is described by the RICH CBM gas system example.

7.4.3 GUI items

Main control item

The **Main control** item is to control manually by the gas system (see Fig.7.8). In this window is displayed a simplified scheme of the gas system. All controllable discrete elements of the gas system are shown by the active icons on the scheme. The red color of an icon indicates the closed valves or disconnected devices, the green the opened valves or enabled hardware. A part of hardware and valves are controlled by the electro-contact manometer PIS1, which can disable a software manual control.

All readout sensor names and values are shown at right as the tree-type structure. Below are located the control buttons of the gas system modes and diagnostics (at right) and event log contents (at left). On default button Alarms Disable is ON and error processing is OFF before start.

System parameters item

The **System parameters** item contains the tuning of all communication parameters and the pressure sensors PT4 (input compressor collector) (see Fig.7.9).

The button Connect is used for connection to the controller by serial port. The buttons Data poll interval and Database interval are significant. The first determined readout period of sensor values from controller and the second the readout period of the parameter storage in the database (is recommended 10 – 20 s). In case of an alarm the parameters values will be immediately written into database regardless of storage period.
A flag [Ask valves control confirmation] prevents casual touches on the valve icons in the main window by any action confirmation if it is ON.

**Alarm item**

At an alarm the all system parameters will be automatically processed (see Fig. 7.10). For each parameter user (Alarm name/Enable) can set the next values:

- Active sensor 'Sensor'
- Actuation level 'Level'
• Recovery level ‘Recovery’ - the system diagnostic configuration of failed and alarm states

• Alarm message

• Status indicators of the valves and the configuration of all devices

---

Figure 7.10: Alarm configuration

The alarm processing procedure is analogized with an algorithm of the hardware alarm lockout developed for experiments STAR and PHENIX [39]. In each readout cycle the DAQ thread compares the actuation levels with the sensors values. If the sensor value exceeds the actuation level, the alarm message is written in the event log and the valve/device state is changed relate to the response template (red - OFF, green - ON, grey - prior state). A map of the changed state devices is stored in the memory. A recovery procedure after an alarm situation refers to the map devices. The alarm processing has the highest priority in relation to the recovery procedure.

At the each cycle beginning of alarm processing the current state of all active devices as initial map of hardware states is used. Also is possibility to load defaults.

The alarm configuration is saved in ini-file. There are two configuration files: an operation configuration and default. The operation configuration is read at every run and used at normal operation.

The control buttons for alarm situations are shown in Fig.7.11.

Database item

The Database enables item to tune the system parameters and calibrating coefficients for its writing into database (see Fig.7.12). All channels are divided into 3 groups: Fast, Slow and Control. For gas system is used only groups Fast and Control. The first 32 channels correspond to sensors connected to 32 analog inputs of controller. The channels from 33 to 36 fit to four analog outputs. The physical values for these
channels are calculated by formula:

\[ S = (V + KA) \cdot KB \]

The each channel has the following properties for an edition:

- **Name** - channel name
- **KA, KB** - calibrating coefficients
- **AVG** - average coefficient
- **Units** - sensor measurement unit
- **Branch** - branch of channel
- **Comment** - user comment

The name, units and comment are character strings. Coefficient of averaging AVG is used for sensor value smoothing by formula:

\[ \langle S_i \rangle = AVG \cdot S_i + (1 - AVG) \cdot \langle S_{i-1} \rangle \]

Thus, if AVG=1 average is off, if AVG=0.1 average is performed by 10 samples.

The branches are used as channel groups for program modules Charts and DBViewer. For systems with 100 parameters and more to classify channels on subsystems. For simple systems with low count of channels are used two branches: the first for all system parameters, the second for controller (tuning coefficients, readout period et al.).
Besides there is special branch for unused channels (Disabled branch). In this case unused channels are not shown at visualisation.

The tool bar in the upper right corner enables to write and read channel configuration to/from ini-file.

The database size should not exceed 800 MB otherwise a new database with the file name (date+time) will be automatically created.

7.5 Multichannel controller DAQ32

7.5.1 Controller purpose and facility

The controller DAQ32 is intended for the sensor signal measurement at the slow control system [40]. Up to 32 sensors can be connected to it. Its accuracy is 0.004% of measurement range, which can be switched at limits +4 V, ±5 V, +10 V, ±10 V. The used at industry analog sensors, as rule, have the voltage and current outputs. An accuracy of these sensors is not better than hundredth of a percent and therefore a resolution of 16 bits is enough for such sensors.

The DAQ32 is based on MCU-on-chip SiLabs C8051F064 and can independently control experimental setup without PC. All main control algorithms are programmed inside the microcontroller. All signals are practically outputted to the single backside connector (96-pin DIN41612) excepting the interfaces USB and RS-232. Besides the 16 digital control signals are outputted to this connector. These are buffered outputs by type open collector for relay control by other devices of experimental setup, for example as valves, compressors et al. Maximal current through the each output - 500 µA.

The controller DAQ32 is a euro-mechanics unit with the high - 3U (100 mm×160 mm, see Fig.7.13). It can control other units of a crate. The each signal from the sensor is moved through the analog filter and then to the multiplexer. After that signal is digitized by 16-bit ADC and buffered. At analog filter (see Fig.7.14) a shunt installation for the sensor current signals is provided. The rated current shunt should be chosen in compliance with ADC dynamic range. The simplified structural scheme of controller
DAQ32 is shown in Fig.7.15.

For the purpose of the MCU from hanging the specialized scheme watch-dog, which restarts it through 47 ms, is used. In this case, the counter of the restarts is incremented.

The software for DAQ32 is realized on the C/C++ and supported the main functions: the readout of the input analog channels, the control by the output channels and the data transfer. In the controller firmware the 4-channel PID-regulator for tuning of analog outputs is realized.
7.5.2 Accuracy and measurement time

The controller software provides an averaging of the analog signal amplitudes on the ADC sampling tuning number. This procedure (average) permits to suppress a noise but to increase the time of the measurement for 32 channels. The 32-channel scanning time dependence of the averaging factor is shown in Table 7.5.

<table>
<thead>
<tr>
<th>Sampling number for averaging</th>
<th>Scanning time, ms</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>8</td>
</tr>
<tr>
<td>8</td>
<td>16</td>
</tr>
<tr>
<td>16</td>
<td>25</td>
</tr>
<tr>
<td>32</td>
<td>45</td>
</tr>
<tr>
<td>64</td>
<td>78</td>
</tr>
<tr>
<td>128</td>
<td>150</td>
</tr>
<tr>
<td>255</td>
<td>280</td>
</tr>
</tbody>
</table>

The measurement results are saved in RAM and can be read and processed by PC. The time resolution is $\leq 35$ μs.

Figure 7.16: Voltage-Time characteristic for one channel without averaging

The typical voltage-time characteristic for channel 31 at measuring path after a multiplexer switching to channel 1 is shown in Fig.7.16. The external source voltage is 2.5 V. The transient processes at multiplexer switching are faster ADC sampling. The maximal total current for 32 channels is 640 mA. For a crosstalk research three channels (1, 3 and 5) were connected to external voltage source (2.5 V). Even channels are equipped by the current shunts and are connected to 5 V. The 11 odd channels are equipped by current shunts 301 Ω and are connected to zero potential or 5 V by turns.
Thus, there were studied the crosstalk of total current 183 mA on the measurement stability of the external reference voltage.

The distribution of the reference voltage measuring values for 3 channels is shown in Fig. 7.17. Measurement mode is averaging on 16 samplings, the total scanning time of 32 channels - 25 ms, ADC sampling range - 0 to 10 V. From the distribution is seen that sigma (180 $\mu$V) approximately equals ADC least bit value (153 $\mu$V).

The switching current crosstalk on the reference voltage for the neighbor analog channels is shown in Fig. 7.18. The switching current in the odd channels is represented by 7th channel plot (ADC7). As you can see on the chart the current crosstalk 183 mA essentially smaller of the ADC resolution and has no effect on the measurement stability.
7.5.3 Calibration

The controller calibration is carried out by means of the multimeter Keithley 2700. The measurement differential between the DAQ32 and the Keithley 2700 is shown in Fig. 7.19. Evidently that the calibration error is not exceeded $\pm 0.2 \text{ mV}$. It corresponds to 0.004% of the full scale at the ADC using range from 0 to 10 V. Also, this error corresponds to the proper error of the multimeter Keithley 2700, which equals 0.2 mV at the 10V-range.

![Figure 7.19: The DAQ32 calibration error](image)

Thus, the errors of the DAQ32 and the Keithley 2700 are comparable. The error 0.004% of the full scale satisfies quite the requirements of the measuring systems overwhelming majority, because the sensor calibration error as rule is not better of 0.01%.
Chapter 8

Front-end electronics

8.1 General requirements

The Front-End Electronics (FEE) has to read out charge detected by pads of the readout chamber located at the TPC end-caps. These pads deliver a current signal with a fast rise time and a long tail due to the motion of the positive ions. The induced on the pad plane signal is usually over 3 neighbouring pads. Total number of the FEE channels is - 95 232. They should have high reliability and accuracy, high throughput and electronics density, and low power consumption. The main parameters of the FEE are specified in Table 8.1.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total number of channels</td>
<td>95 232</td>
</tr>
<tr>
<td>Signal to noise ratio, S/N</td>
<td>&gt; 30:1 @ MIP ( (\sigma_{\text{noise}} &lt; 1000 \text{ e}^-) )</td>
</tr>
<tr>
<td>Dynamic Range</td>
<td>1000 (10-bit sampling ADC)</td>
</tr>
<tr>
<td>Shaping time</td>
<td>190 ns</td>
</tr>
<tr>
<td>Sampling</td>
<td>10 MHz</td>
</tr>
<tr>
<td>Tail cancellation</td>
<td>&lt; 1% (after 1 ( \mu \text{s} ))</td>
</tr>
<tr>
<td>Zero-suppression</td>
<td>up to 90%</td>
</tr>
<tr>
<td>Bandwidth</td>
<td>up to 5 GB/s @ TPC</td>
</tr>
<tr>
<td>Power consumption</td>
<td>100 mW/ch</td>
</tr>
</tbody>
</table>

FEE for the MPD TPC is based on two ASICs:

- 16 channel charge sensitive shaping amplifier (PASA) [12]
- 16 channel analog-digital ALICE TPC Readout chip (ALTRO) [13]

On the FE card, as was FE-prototype, there are 4 PASAs and 4 ALTROs supporting altogether 64 channels per board and one FPGA Altera in the capacity of board controller.
8.2 Front-end cards

8.2.1 Single channel overview

A single readout channel consists of three basic units: a charge-sensitive amplifier/shaper, a 10-bit low-power sampling ADC and a digital circuit that contains a shortening digital filter for the tail cancellation, the baseline subtraction, zero-suppression circuits and a multi-event buffer (see Fig.8.1). Data from 24 Readout chambers are collected by 64-chs front-end cards (about 4000 electronic channels per sector).

The electronics has to take several samples for each ionization cluster reaching the pad and then a fit can be used to localize the hit. Estimations show that the contribution of the electronics noise to the space resolution is comparable to the chamber resolution when the signal-to-noise ratio (S/N) is about 30:1 for mean of MIP (ENC < 1000 electrons).

The dynamic range is determined by the energy loss $dE/dx$ of the produced particles. Taking that the maximum ionization of a 200 MeV/c into account proton is 10 times higher than ionization of MIP, the path length is longer at non-zero dip angle, signal-to-noise ratio is $\sim 30$ and Landau fluctuations dynamic range value is about 1000. Therefore a 10-bit sampling ADC is required.

Drift velocity, drift length and diffusion of primary electrons determine timing constants of the FEE. The average longitudinal diffusion determines peaking time and the electronics is best matched to the signal of cluster if the shaping time is comparable to the width of this signal (about 190 ns for the TPC MPD).

The PASA provides reliable operation, low noise, optimal shaping and small power consumption. The outputs of PASA fed the input of ALTRO, which digitizes and processes signals. After digitization, a baseline correction unit removes systematic perturbations of the baseline by subtracting a pattern (stored in a memory). The tail cancellation filter removes the long complex tail of the detector signal, thus narrowing (up to 2 times) the clusters to improve identification. It can also remove undershoot that typically distorts the amplitude of the clusters when pile-up occurs.

The second correction of the baseline is performed based on the moving average of
the samples that fall within a certain acceptance window. This procedure can remove non-systematic perturbations of the baseline. At the end the zero-suppression scheme removes all data that is below a certain threshold.

After the digital processing data flow to the several-event (4-8) deep buffer memory to eliminate loosing of data due to DAQ dead time.

Control functions and the so-called ”spars” mode of operation on the FEC are fulfilled with FPGA. Data from all ALTRO chips are preliminary readout and kept in the special memory buffer organized on the card and then transferred to RCU under the FEC FPGA control. Since safety of data is a question of the highest priority this FPGA should be of radiation hard type preferably.

The power consumption is expected to be less than 100 mW per channel. Such small power dissipation is required to keep gas volume of the TPC at stable ($A_{e} \sim 0.5^\circ$C) temperature using appropriate cooling system. Each card will be wrapped in copper envelope with water-cooling tube, there a common airflow cooling will be organized as well.

The FEC provides measurements of temperature, digital and analogue voltage and current which can be read out by slow control system.

### 8.2.2 Prototype of front-end card

The first phase of the FEE development was to create front-end card prototype (FEC64) for the ALTRO features study and the FPGA logic debugging. This card has interface USB 2.0 that allows you to operate with it without readout controller (RCU).

![FE-card prototype view and features](image)

**Figure 8.2:** FE-card prototype view and features

A view of FE-card prototype and its block-diagram are shown in **Fig.8.2 and 8.3**. The FPGA architecture is shown in **Fig.8.4**.
The main tasks of FPGA are:

- Clock control
- Power supply control
- Trigger signal control
- Interface with 40-bit bidirection bus of ALTRO chip
- Interface with SPI-bus
- Interface with FT232H (USB 2.0)

8.2.3 Front-end card

The 64-channel front-end card FEC64S is developed on the base of card-prototype FEC64. The main parameters of this card are shown in Table 8.2.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Channel number</td>
<td>64</td>
</tr>
<tr>
<td>ASIC ALTRO number</td>
<td>4</td>
</tr>
<tr>
<td>ASIC PASA number</td>
<td>4</td>
</tr>
<tr>
<td>FPGA</td>
<td>1</td>
</tr>
<tr>
<td>Temperature sensor</td>
<td>1</td>
</tr>
<tr>
<td>12-bit ADC</td>
<td>1</td>
</tr>
<tr>
<td>Gigabit data interface</td>
<td>1</td>
</tr>
<tr>
<td>Dimension</td>
<td>95 mm × 167 mm</td>
</tr>
<tr>
<td>Layer number</td>
<td>8</td>
</tr>
</tbody>
</table>

The card FEC64S view, its features and structural scheme are shown in Fig. 8.5 and 8.6.

![Card FEC64S view](image_url)
The major components of card FEC64S are the next:

- 16-channel ASICs PASA [12] and ALTRO [13]

- FPGA Altera Cyclone III

- Temperature sensor MAX6608 with a measurement range of -20°C ÷ +85°C and accuracy from 0.6°C to 1.5°C

- Fast-speed and low-current consumption 12-bit ADC - AD7490 (for slow control)

- Gigabit interface Data Link with date transfer rate from 1.6 Gbps to 2.7 Gbps - TLK 2711

- Power control

### 8.2.4 Parameters monitoring for card FEC64S

Besides the function of control and configuration of FECs the ROC has to perform the parameters monitoring. The list of these parameters is presented in Table 8.3.
Table 8.3: FEC64S monitoring parameters

<table>
<thead>
<tr>
<th>N</th>
<th>Parameter</th>
<th>Symbol</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>ALTRO 1 Analog Voltage</td>
<td>altro1av</td>
<td>The ALTRO first pair analog voltage</td>
</tr>
<tr>
<td>2</td>
<td>ALTRO 2 Analog Voltage</td>
<td>altro2av</td>
<td>The ALTRO second pair analog voltage</td>
</tr>
<tr>
<td>3</td>
<td>ALTRO 1 Digital Voltage</td>
<td>altro1dv</td>
<td>The ALTRO first pair digital voltage</td>
</tr>
<tr>
<td>4</td>
<td>ALTRO 2 Digital Voltage</td>
<td>altro2dv</td>
<td>The ALTRO second pair digital voltage</td>
</tr>
<tr>
<td>5</td>
<td>ALTRO 1 Analog Current</td>
<td>altro1ac</td>
<td>The ALTRO first pair analog current</td>
</tr>
<tr>
<td>6</td>
<td>ALTRO 2 Analog Current</td>
<td>altro2ac</td>
<td>The ALTRO second pair analog current</td>
</tr>
<tr>
<td>7</td>
<td>ALTRO 1 Digital Current</td>
<td>altro1dc</td>
<td>The ALTRO first pair digital current</td>
</tr>
<tr>
<td>8</td>
<td>ALTRO 2 Digital Current</td>
<td>altro2dc</td>
<td>The ALTRO second pair digital current</td>
</tr>
<tr>
<td>9</td>
<td>PASA 1 Voltage</td>
<td>pasa1v</td>
<td>The PASA first pair power voltage</td>
</tr>
<tr>
<td>10</td>
<td>PASA 2 Voltage</td>
<td>pasa2v</td>
<td>The PASA second pair power voltage</td>
</tr>
<tr>
<td>11</td>
<td>PASA 1 Current</td>
<td>pasa1c</td>
<td>The PASA first pair current</td>
</tr>
<tr>
<td>12</td>
<td>PASA 2 Current</td>
<td>pasa2c</td>
<td>The PASA second pair current</td>
</tr>
<tr>
<td>13</td>
<td>FPGA IO Voltage</td>
<td>fpgaiov</td>
<td>The FPGA supply voltage</td>
</tr>
<tr>
<td>14</td>
<td>Temperature</td>
<td>tempvout</td>
<td>The FEC Temperature in mV</td>
</tr>
<tr>
<td>15</td>
<td>3V0</td>
<td>3v0</td>
<td>Input supply voltage 3.0 V</td>
</tr>
<tr>
<td>16</td>
<td>3V8</td>
<td>3V8</td>
<td>Input supply voltage 3.8 V</td>
</tr>
</tbody>
</table>

8.2.5 Testing of FEC64S cards

The first version of the testing system for the front-end cards FEC64S is based on the development kit Cyclone-5 SoC. The KIT-board view is shown in (see Fig. 8.7).

![KIT Cyclone-5 SoC view](image)

Figure 8.7: KIT Cyclone-5 SoC view (left KIT, right FEC64S)

This system is allowed to test up to 4 cards.
8.3 Readout controller RCU

The readout electronics of each ROC is an independent system. The TPC electronics consists of a set of front-end cards (FEC) that receive analogue data from the detector sensors. The FECs amplifies and shapes the analogue input signal, performs analogue to digital conversion and digital filtering of the data. The FECs can be connected to one Readout Control Unit (RCU) up to 64 via fast serial interface (2.5 Gbps). Such an approach allows one to provide high data throughput with flexibility. We are also considering other ways to optimize these features.

The developed RCU, which is physically a part of the on-detector electronics (one RCU per ROC), implements the interfaces to the Data Acquisition (DAQ), the Trigger and Timing Circuit and the Detector Control System (DCS). It broadcasts the trigger and clock information to the FECs, performs the initialization and readout via a high-bandwidth bus, and implements monitoring and safety control functions. A readout sequence of the TPC is initiated by the common TPC/MPD trigger-signal. The trigger is sent to the RCU by the central trigger processor. The RCU has two mezzanine cards, one performs handling trigger signals and the other provides Slow Control functions. The RCU performs the following tasks:

- Collection of event data from all FECs, reformation and sending of the packed data to the Data Acquisition Data Link (DDL)
- Control and initialization of all FECs. The supervision includes event readout for monitoring purposes, statistics (number of data and number of triggers received), temperature variation monitoring, current measurement and power consumption monitoring for hardware fault detection, which will be achieved via a separate slow-control bus

The RCU has two mezzanine cards, one performs handling trigger signal and the other provides Slow Control functions. The structural scheme of the RCU is shown in Fig.8.8.

8.4 ROC readout concept

The TPC MPD has totally 24 RCUs connected to ~1500 FECs, e.g. 62 cards per ROC. Taking relatively high number of the cards with regards to the pad plane size into account a serial link topology was used there. Each FEC is connected to the RCU via fast serial interface. Communication between RCU and DAQ (see Fig.8.9) is fulfilled with 4 Gbps optical fibers.
Figure 8.8: The structural scheme of RCU

Figure 8.9: ROC readout structural scheme
Chapter 9

TPC prototyping

For testing of the TPC drift volume gas leak the cylindrical tube for technological prototype is 950 mm in diameter and 900 mm long and has a mass of about 10 kg. The prototype cylinder was covered at both bases by flat plate and blown through with clean argon gas. A test of the tube showed that Kevlar laminated by Tedlar film as the wall material satisfies the requirements for the gas tightness. The oxygen admixture to the output gas was controlled in time and it has been found oxygen content is below 10 ppm.

![Image of test setup](image-url)

**Figure 9.1:** Test of 3 FE cards with small prototype of ROC chamber

Test set up for study FE cards and DAQ is shown in **Fig.9.1**. Small proportional chamber with pad cathode was built. The signal shape is presented in **Fig.9.2**.

To test the ROC chamber prototype the small gastight box with Mylar foil cover was constructed. The tests were performed with Fe$^{55}$ radioactive source. The drift gap for Fe$^{55}$ gamma-rays was about 5 cm. The anode of the chamber is segmented into five independent parts across high voltage power. The chamber cathode pad plane was manufactured by multilayer printed-board technology. It contains two sets of pad: 16 layers of 4x10 mm$^2$ pads and 32 layers of 6x12 mm$^2$ pads.

Gas mixture Ar/CH$_4$ (90/10) was used in for testing. The test results are shown in **Fig.9.3 and 9.4**. The expected gas gain $G \sim 10^4$ is reached at the anode voltage of 1450 V for the case of Ar/CH$_4$ (90/10) gas mixture.
Figure 9.2: Digitized signal from the single pad

Figure 9.3: Count plateau and gas gain versus anode voltage for Ar/CH\textsubscript{4} (90/10) gas mixture

Figure 9.4: The TPC drift current value versus U\text{gate}
The ”Prototype 1” (see Fig.9.5-9.7) was built using the monolithic containment vessel 90 cm in diameter and 95 cm long cylinder produced by Industry. The wire chamber is used for readout. The Field Cage is constructed from aluminized 13 mm wide Mylar strips with 15 mm pitch. The drift volume is about 75 cm long. The quartz windows are mounted into Prototype for ultraviolet laser beam input-output.

![Figure 9.5: Prototyping of the TPC with Industry (Material: Kevlar laminated by Tedlar film)](image1)

The TPC prototype tests with UV-laser beam and cosmic rays have been carried out. Low-power light pulse from Q-switched Nd:YAG laser model NL131/FH (0-2 mJ per pulse) with repetition rate 10 Hz or lower and duration 3-4 ns got into the TPC prototype field cage through sapphire window to produce tracks in the TPC prototype and have been synchronized with the readout electronics.

![Figure 9.6: Assembly of readout chamber prototype](image2)
In the cosmic ray tests the trigger signal for the readout electronics was generated by coincidence of signals from three scintillation counters. Two scintillation counters were positioned above the prototype field cage and one counter below.
One of the goals of the TPC prototyping is the determination of the space point resolution. The laser and cosmic ray tests data of track coordinates are fitted by straight line and the space point resolution is determined from the residuals of the fit to the track coordinates. The residual distributions for laser beam are shown in Fig.9.8.

![Figure 9.9: Pad Response Function (Prototype 1)](image)

The Pad Response Function (PRF) for 4x10mm pads determined using 0.8mm diameter collimated Fe\textsuperscript{55} source is presented in Fig.9.9. The PRF dispersion (1.9 mm for 4x10 mm\textsuperscript{2} pads) is consistent with the simulation results.

The Prototype was equipped with the Field Cage and high voltage degrader. Field Cage consisting of set of aluminized Mylar strips. UV laser used for generate 5 "tracks" inside the TPC prototype drift volume. The five reconstructed laser "tracks" are shown in Fig.5.8 (section 5.3). In the drift velocity measurement (time difference between signals from any two laser beams) the electric field created in this way was found to be sufficiently uniform over the active area of the pad plane.

The main obtained results for the period of 2012-2014 were presented on many conferences and presentations see reference [15] - [29].
Chapter 10

Detector performance

The TPC is the main tracking device of the MPD. To evaluate its capabilities for heavy ion collision investigations a series of a simulation have been carried out.

The analysis [41] was performed with the help of the MPDROOT framework and event samples produced with the UrQMD and the DSM_QGSM (Dubna Cascade Model Quark-Gluon String Model) generators for Au+Au collisions at the NICA energies.

The track finding efficiency in the TPC (entering the TPC acceptance rapidity region $|\eta|<1.3$) for primary and secondary charge particles is shown in Fig.10.1 as a function of particle transverse momentum. The Kalman filter track reconstruction method is used for the track finding with requirement the number of TPC points per track is more than 10.

The relative transverse momentum resolution for the primary particles within the TPC is shown in Fig.10.2 (left) versus transverse momentum (the particle energy losses in lateral TPC material is taking into account in track fitting procedure). The result was obtained with the assumption the TPC coordinate resolution is 0.5 mm and 1.0 mm in transverse and longitudinal directions, respectively.

The Fig.10.2 (right) shows the transverse momentum resolution dependence on particle pseudorapidity. The resolution degrades sharply out of the TPC acceptance.
Figure 10.2: The relative transverse momentum resolution as a function of transverse momentum $p_t$ (left) and pseudorapidity $|\eta|$ (right).

Figure 10.3: The primary vertex position resolution along transverse and longitudinal directions as a function of primary track multiplicity.

Figure 10.4: Specific energy loss vs magnetic rigidity for electrons, hadrons and light nuclei.

A precise knowing of the primary events vertex position essentially improves the momentum resolution and the secondary vertices finding efficiency. The primary vertex
is found by the extrapolating all primary tracks reconstructed in the TPC back to the origin. The primary vertex resolution is found as the RMS of the distribution of the primary tracks extrapolation at the origin.

The Fig.10.3 shows the primary vertex resolution along the beam direction as a function of the reconstructed primary tracks multiplicity.

Figure 10.5: The reconstructed invariant mass of $\pi^+$ and $\pi^-$ spectrum

![Invariant mass: $K^0_s \rightarrow \pi^+ + \pi^-$](image1)

Figure 10.6: The reconstructed invariant mass of protons and $\pi^-$ spectrum

![Invariant mass: $\Lambda \rightarrow p + \pi^-$](image2)

The TPC will provide $dE/dx$ resolution at the level of 8%. Hadrons ($\pi$, K, p) and light nuclei can be identified using the energy loss information from the TPC only. For every track reconstructed in the TPC the specific energy loss $dE/dx$ is calculated as a truncated mean of charges of the TPC hits assigned to the track. The truncation level of 70% was chosen.

As shown in Fig.10.4 kaons can be discriminate from pions up to momenta of 0.7 GeV/c and protons discriminate from $\pi$ and K mesons up to momenta 1.3 GeV/c. The charge particles are selected if their energy loss measured lies within $3\sigma$ interval around the predicted value which is taken from Bethe-Bloch parameterization for the mean energy loss.

In Fig.10.5 reconstructed invariant mass of $\pi^+$ and $\pi^-$ spectrum obtained for $10^4$ central Au+Au collisions is shown. One can see the reconstruction quality and
efficiency are high enough for using of $K^0$ two pions decay mode as a convenient tool to monitor tracking detector and track reconstruction performance.

The reconstructed invariant mass of protons and $\pi^-$ spectrum obtained for $10^4$ central UrQMD generator events is shown in Fig.10.6.
Chapter 11

R&D for alternative readout

The track registration of charge particles in the pseudorapidity region above 1.2 will provide by the system of MPD end cap tracking detectors. In order to reach required momentum resolution and particle identification capability in this pseudorapidity region the TPC end caps have to be "transparent" in material.

One of a way to minimize the material in the end caps is the use of low material gaseous detector such as GEM for TPC readout, by either to use more up-to-day ASIC chips for front-end electronics.

11.1 GEM-based readout chamber

In our studies we are based on wide experience in the development of GEM for ALICE time projective chamber [Christian Lippmann "A continuous read-out TPC for the ALICE upgrade", Frontier Detectors for frontier physics, 13th Pisa Meeting on advanced detectors, 24-30 May 2015, La Biodola, Isola d’Elba, Italy].

In collaboration with CERN a few GEM detectors were produced and tested in BM&N experiment with the NUCLOTRON beams at JINR. The detector design was done at JINR. All detector components were manufactured at CERN facility and detector assembly and technological test was done at CERN by CERN and JINR engineers. The complete technological chain of GEM detector production is studied at CERN by JINR engineers for the last years and an infrastructure for the GEM chamber assembling is created at JINR.
The strip readout electrode, drift electrode, GEM frame, GEM gap bars and GEM foil are shown in Fig.11.1. Gas inlet and outlet are installed into GEM frame. HV spring connectors (6 pc) for GEMs are soldered on drift electrode.

All components are cleaning by compressed air and are washing by deionization water before assembling. The components are heating up to T=160°C inside thermo-box. GEM frame and gap bars are coating by urethane.

GEM detector assembly is carried out in clean room. The special tool with reference pins is used for GEM gap bars installation and GEM-foil positioning. GEM-foil is fixed on temporary frame and is pretension by scotch. The anti-dust role and napkins are used for dust cleaning. All 3 pc GEM-foils are installed on gap bars one by one (see Fig.11.2, left) and then bars-foils package is compressed by screws (see Fig.11.2, right). HV test is applied to check current leakage each GEM. If current leakage is acceptable GEM foils are cutting around frame perimeter.

The detector gas tightness is checked with gas leak detector. HV divider is soldered
Figure 11.4: Detector gas gain non uniformity test with radioactive source Fe\textsuperscript{55} (see Fig.11.4, left) to strip electrode and grounding connectors plug - to strip electrode connectors. The detector is flashed by gas mixture Ar/CO\textsubscript{2} (70:30).

HV is apply to detector up to HV = -4 kV with step 50-100 V. The HV current must be less than 100 nA. The detector gas gain non uniformity is tested with radioactive source Fe\textsuperscript{55} (see Fig.11.4, right).

11.2 SAMPA-based front-end electronics

The SAMPA project was started at the CERN in 2014 aiming to develop new ASIC chip for an Alice TPC/MCH frontend electronics upgrade for operating after 2018 when a luminosity of LHC accelerator will significantly increase. There are a number of institutes from Europe, America and US involved in this project.

The main SAMPA features are presented in Table 11.1.

<table>
<thead>
<tr>
<th>Specification</th>
<th>SAMPA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage supply</td>
<td>2.5 V, 1.25 V</td>
</tr>
<tr>
<td>Polarity</td>
<td>Positive/Negative</td>
</tr>
<tr>
<td>Linear Range</td>
<td>100 fC, 500 fC</td>
</tr>
<tr>
<td>Sensitivity</td>
<td>4 mV/fC, 20 mV/fC, 30 mV/fC</td>
</tr>
<tr>
<td>Non-Linearity</td>
<td>&lt; 1%</td>
</tr>
<tr>
<td>Crosstalk</td>
<td>&lt; 0.2%</td>
</tr>
<tr>
<td>ADC resolution</td>
<td>10-bit</td>
</tr>
<tr>
<td>Sampling Frequency</td>
<td>10 MSps</td>
</tr>
<tr>
<td>Read-out Bandwidth</td>
<td>1.28 Gbps</td>
</tr>
<tr>
<td>Power consumption (per ch.)</td>
<td>30 mW</td>
</tr>
<tr>
<td>Channels per chip</td>
<td>32</td>
</tr>
</tbody>
</table>

The first version of SAMPA chip with full functionality expected to be manufactured at the beginning of 2016. SAMPA is considered as main component for the frontend electronics upgrade in the ALICE experiment at CERN, in TPC/STAR at RHIC and in TPC/NICA (JINR).
There are several features, which SAMPA attractive for an application in the TPC/NICA frontend electronics are making.

The first of all is a small size of chip, which comprising both analog and digital parts. This significantly decreases a size of the frontend electronics board that, in turn, provides the essential step toward the TPC end caps transparency.

The second, chip possibility of operating as well positive as negative input signal gives such opportunity for smooth upgrade TPC readout system when MWPC chambers will be substitute for GEM chambers.

The SAMPA chip will integrate 32 analog-digital channels. Each channel includes charge sensitive amplifier shaper (PASA), digital signal processor (DSP) and event buffer. It supports continuous and triggered read-out. In fact, this chip is an evolution of two 16-channels PASA and ALTRO chips, which are presently used in ALICE.

The schematic diagram of SAMPA channel is shown in Fig.11.5. The input signal of positive/negative polarity is amplified and integrated by charge sensitive amplifier...
(CSA) and Shaper and then is digitized by 10-bit 10 MHz ADC.

The SAMPA higher integration 9x9.5 mm$^2$ BGA chip instead of 80x80 mm$^2$ for 2x(ALTRO+PASA) chips and reduced power consumption will enable to design a more compact readout card. The test boards for the nicked and BGA package chips are under design (see Fig.11.6).

The first iteration of SAMPA chip (MPW1) studied together with ALICE collaboration at JINR. The second iteration MPW2 will be available in April 2016.
Chapter 12

Material budget

The MPD Time Projection Chamber is the main tracking detector of the central barrel and, together with inner tracking system, time of flight system and electromagnetic calorimeter, has to provide the requirements following from physics objectives at pseudorapidities $|\eta|<1.2$. Since the amount and position of material traversed by particles in the MPD inner detectors has an impact on the performance of outer detectors it has to be optimized for minimal multiple scattering and secondary particles production.

The list of TPC materials traversed by particle moving from interaction point is presented in Table 12.1 (without central electrode).

<table>
<thead>
<tr>
<th>Material</th>
<th>Thickness, cm</th>
<th>X0, cm</th>
<th>X/X0,% for $\eta = 0$</th>
<th>X/X0,% for $\eta = 1.31$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tedlar</td>
<td>0.040</td>
<td>26.18</td>
<td>0.08</td>
<td>0.16</td>
</tr>
<tr>
<td>Kevlar C1 h=0.3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nitrogen N$_2$ gap C1-C2 h=6.5</td>
<td></td>
<td></td>
<td>0.020</td>
<td>0.040</td>
</tr>
<tr>
<td>Kevlar C2 h=0.3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>90%Ar+10%CH$_4$ h=98.9</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kevlar C3 h=0.4</td>
<td></td>
<td></td>
<td>1.29</td>
<td>2.58</td>
</tr>
<tr>
<td>Nitrogen N$_2$ gap C3-C4 h=6.7</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kevlar C4 h=0.64</td>
<td></td>
<td></td>
<td>30.94</td>
<td>2.07</td>
</tr>
<tr>
<td>Al TPC shielding h=0.01</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>8.9</td>
<td>6.243</td>
<td>12.486</td>
</tr>
</tbody>
</table>

In the azimuth the field cage material is not homogeneously distributed. We have 24 Kevlar support rods (1.8cm) here, as shown in Fig.2.2, and for each $30^\circ$ there will be singularity in material distribution.

The track reconstruction in the region of pseudorapidity beyond 1.2 is provided by both TPC and endcap tracker. In order to have required momentum resolution and particle identification capability in this region the TPC end plate elements and readout electronics which is mounted on them have to be minimized for material budget.
Table 12.2: Material distribution in TPC end cap for wire chamber and GEM-based chamber readout

<table>
<thead>
<tr>
<th>Wire Chamber</th>
<th>Base line option</th>
<th>Upgrade</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Wires + Gas</td>
<td>0.08 X/X0, %</td>
<td>1.4 GEM foils Cu, 8x5 µm = 40 µm</td>
</tr>
<tr>
<td>2. Pad plane h = 3 mm</td>
<td>2.00</td>
<td>2. Pad plane h = 1.5 mm</td>
</tr>
<tr>
<td>3. Insulating plate h = 3 mm</td>
<td>1.55</td>
<td>3. Insulating plate h = 1.5 mm</td>
</tr>
<tr>
<td>4. Al frame h = 5 mm</td>
<td>5.62</td>
<td>4. Carbon panel h = 25 mm</td>
</tr>
<tr>
<td>5. Epoxy glue (2x0.1 mm)</td>
<td>0.056</td>
<td>5. Epoxy glue (2x0.1 mm)</td>
</tr>
<tr>
<td>Air gap L = 10 cm</td>
<td>0.03</td>
<td>Air gap L = 10 cm</td>
</tr>
<tr>
<td>Total:</td>
<td>9.34</td>
<td>Total:</td>
</tr>
<tr>
<td>FE (62 FE boards)</td>
<td></td>
<td>FE (based on SAMPA chip)</td>
</tr>
<tr>
<td>PCB + components</td>
<td>21.13</td>
<td>FE single layer</td>
</tr>
<tr>
<td></td>
<td></td>
<td>FE - 4 layers</td>
</tr>
<tr>
<td>FE Cooling</td>
<td></td>
<td>FE Cooling</td>
</tr>
<tr>
<td>Cu radiators + H₂O</td>
<td>49.9</td>
<td>Al pipes + plates on chips</td>
</tr>
<tr>
<td>TPC thermo-screen</td>
<td>1.69</td>
<td>TPC thermos-screen</td>
</tr>
<tr>
<td>Total:</td>
<td>~86.1</td>
<td>Total:</td>
</tr>
</tbody>
</table>

The TPC with proportional chamber readout it is suppose will be used for first stage of MPD setup. In future to minimize the material in the TPC end cap the proportional chamber will be replaced by GEM-based readout chamber equipped with front end electronics based on SAMPA chip. The readout electronics will be mounted on the pad plane directly or on a few printed boards placed in stack parallel to pad plane. The fractional radiation lengths of the different constructional elements in the TPC end plate are shown in Table 12.2.
Chapter 13

Infrastructure, implementation and safety

13.1 Infrastructure

13.1.1 TPC assembly hall

As was mentioned above the main TPC construction elements were produced by industry. A new TPC assembly hall will be built for the TPC assembly and testing. The common view of Bld.217 and general layout of the TPC assembly hall are shown in Figs. 13.1 and 13.2. The hall has the area about 7 m x 12 m = 84 m² for the TPC assembling and two rooms for experimental equipment such as gas supply and regeneration system, cooling system, high voltage and the LV power supplies and so on.

![Figure 13.1: Building 217 common view](image)

All handling of the TPC will be done using a special transportation frame which will allow moving the TPC from Bld.217 to the MPD detector hall. It will also be used during the installation of the TPC into the MPD detector.
13.2 Implementation

(...in progress)

13.3 Safety

(...in progress)
Chapter 14

Organization

14.1 TPC organization

The TPC organization is constituted by project leader, a deputy leader and sections as is shown in Fig.14.1

![Figure 14.1: TPC organization](image)

14.2 TPC TDR editorial group

The TPC TDR editorial group was composed of the following persons: S.A.Movchan, S.V.Razin and G.A.Cheremuhina.

14.3 Participants

*(in progress...)*
14.4 Time schedule and cost book

The TPC assembly and test time schedule is presented in Table 14.1 for the period of 2015-2019.

<table>
<thead>
<tr>
<th>N</th>
<th>Item</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Assembly TPC cylinders C1+C2</td>
<td>December 2015</td>
</tr>
<tr>
<td>2</td>
<td>TPC assembly hall ready</td>
<td>January 2016</td>
</tr>
<tr>
<td>3</td>
<td>TPC assembly (C1-C4 + 2 flanges)</td>
<td>December 2017</td>
</tr>
<tr>
<td>4</td>
<td>ROC chamber manufacture (27 pc)</td>
<td>2016 2017</td>
</tr>
<tr>
<td>5</td>
<td>Assembly ROC chamber (24pc)to</td>
<td>January - June 2018</td>
</tr>
<tr>
<td>6</td>
<td>TPC electronics manufacture (~1650pc FEC64S and 24pc RCU)</td>
<td>May 2018</td>
</tr>
<tr>
<td>7</td>
<td>1488pc FE cards assembly to ROC chamber</td>
<td>September December 2018</td>
</tr>
<tr>
<td>8</td>
<td>TPC test with cosmic and laser calibration system</td>
<td>2018  July 2019</td>
</tr>
<tr>
<td>9</td>
<td>TPC transportation from Bld.217 to the MPD hall</td>
<td>August 2019</td>
</tr>
<tr>
<td>10</td>
<td>Installation to MPD</td>
<td>September 2019</td>
</tr>
<tr>
<td>11</td>
<td>TPC gas and cooling systems assembly in the MPD hall</td>
<td>January  September 2019</td>
</tr>
<tr>
<td>12</td>
<td>test inside MPD</td>
<td>October December 2019</td>
</tr>
</tbody>
</table>

TPC total cost is 8 000 000$. The TPC cylinders C1-C4, the TPC prototypes and FE electronic prototype were manufactured for the period of 2010-2014. Total expenses for this period are about 2.1M$.

The TPC cost book is presented in Fig.14.2.
Figure 14.2: TPC financial costs 2010 -2019
References


[4] The Multipurpose Detector (MPD), Conceptual Design Report The MPD detector at the NICA heavy-ion collider at JINR.


[24] Yu.V.Zanevsky, S.V.Razin, A.G.Bazhazhin et al. Time-projection chamber (TPC) of detector MPD at NICA collider, Time-Projection Chamber of detector MPD at the collider NICA, XVIII International Conference of Young Scientists and Specialists (AYSS’14) Dedicated to the 105-th Anniversary of


[34] L. Kochenda et al., CBM Progress report 2010, Darmstadt.


### Abbreviation

<table>
<thead>
<tr>
<th>A-C</th>
<th>Description</th>
</tr>
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<tbody>
<tr>
<td>ADC</td>
<td>Analog-to-Digital Converter</td>
</tr>
<tr>
<td>ALICE</td>
<td>A Large Ion Collider Experiment</td>
</tr>
<tr>
<td>ALTRO</td>
<td>ALICE TPC ReadOut chip</td>
</tr>
<tr>
<td>ASIC</td>
<td>Application-Specific Integrated Circuit</td>
</tr>
<tr>
<td>BM&amp;N</td>
<td>Baryonic Matter Nuclotron</td>
</tr>
<tr>
<td>Cyclone III</td>
<td>Altera FPGA Family</td>
</tr>
<tr>
<td>CTP</td>
<td>Central Trigger Processor</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>D-G</td>
<td>Description</td>
</tr>
<tr>
<td>DAQ</td>
<td>Data AcQuisition</td>
</tr>
<tr>
<td>DCS</td>
<td>Detector Control System</td>
</tr>
<tr>
<td>FEE</td>
<td>Front-End Electronics</td>
</tr>
<tr>
<td>FEC</td>
<td>Front-End Card</td>
</tr>
<tr>
<td>FIFO</td>
<td>First Input First Output</td>
</tr>
<tr>
<td>FPGA</td>
<td>Field Programmable Gate Array</td>
</tr>
<tr>
<td>FTDI</td>
<td>Future Technology Devices International</td>
</tr>
<tr>
<td>FT232H</td>
<td>Single Channel Hi-Speed USB to</td>
</tr>
<tr>
<td></td>
<td>Multipurpose UART/FIFO IC</td>
</tr>
<tr>
<td>GUI</td>
<td>Graphical User Interface</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>H-L</td>
<td>Description</td>
</tr>
<tr>
<td>HV</td>
<td>High Voltage</td>
</tr>
<tr>
<td>IFC</td>
<td>Inner Field Cage</td>
</tr>
<tr>
<td>IIR</td>
<td>Infinite Impulse Response</td>
</tr>
<tr>
<td>LHC</td>
<td>Large Hadron Collider</td>
</tr>
<tr>
<td>LV</td>
<td>Low Voltage</td>
</tr>
<tr>
<td>LUT</td>
<td>Look Up Table</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>M-O</td>
<td>Description</td>
</tr>
<tr>
<td>MEB</td>
<td>Multi-Event Buffer</td>
</tr>
<tr>
<td>MPD</td>
<td>Multi - Purpose Detector</td>
</tr>
<tr>
<td>MSps</td>
<td>Mega Samples per second</td>
</tr>
<tr>
<td>Mbps</td>
<td>Mega bit per second</td>
</tr>
<tr>
<td>MBps</td>
<td>Mega Bytes per second</td>
</tr>
<tr>
<td>MWPC</td>
<td>Multi-Wire Proportional Chamber</td>
</tr>
<tr>
<td>NICA</td>
<td>Nuclotron-based Ion Collider fAcility</td>
</tr>
<tr>
<td>OFC</td>
<td>Outer Field Cage</td>
</tr>
<tr>
<td>P-R</td>
<td></td>
</tr>
<tr>
<td>-----</td>
<td>--------</td>
</tr>
<tr>
<td>PASA</td>
<td>Pre-Amplifier Shaping Amplifier</td>
</tr>
<tr>
<td>RCU</td>
<td>Readout Control Unit</td>
</tr>
<tr>
<td>ROC</td>
<td>Read-Out Chamber</td>
</tr>
<tr>
<td>TPC</td>
<td>Time Projection Chamber</td>
</tr>
<tr>
<td>TDR</td>
<td>Technical Design Report</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>S-U</td>
<td></td>
</tr>
<tr>
<td>USB</td>
<td>Universal Serial Bus</td>
</tr>
<tr>
<td>UART</td>
<td>Universal Asynchronous Receiver Transmitter</td>
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<td>4</td>
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<td>7</td>
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<td>7</td>
</tr>
<tr>
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<td>Design of the cylinder C3</td>
<td>7</td>
</tr>
<tr>
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<td>Design of the cylinder C4</td>
<td>8</td>
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<td>2.8</td>
<td>C2 cylinder wall cross-section (non in scale). Yellow - 3 mm of Cevlar, violet - 50 µm of Tedlar, blue - aluminum strips h=50 µm. Opposite strips connected by wire (black) and strip to strip - by resistor (red)</td>
<td>9</td>
</tr>
<tr>
<td>2.9</td>
<td>FEA calculation result for cylinder C2 with L=3000 mm, wall thickness h=3 mm, load F=80 kG in the middle (from the HV electrode) and fixed flanges. (Deformation is less than 100 µm and deformation of rest cylinders is less than for C2)</td>
<td>9</td>
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<td>10</td>
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<td>The consecutive steps of C3-C4 field cage cylinders assembling</td>
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<td>17</td>
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<td>18</td>
</tr>
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<td>View of the 340 cm prototype vessel, produced to elaborate technology of aluminum foil strips gluing on inside wall of 600 mm diameter</td>
<td>19</td>
</tr>
<tr>
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<td>19</td>
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<tr>
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<td>20</td>
</tr>
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<td>Potential degrader rods produced by industry using composite material (Kevlar + Macrolon + Al foil)</td>
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