TIME PROJECTION CHAMBER FOR MULTI-PURPOSE DETECTOR AT NICA*

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The time-projection chamber (TPC) is the main tracking detector in the MPD at NICA. Information on charge particle tracks is registered by the multi-wire proportional chamber with cathode pad readout. The main parameters and some details of the TPC design and readout electronics are presented.

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1. Introduction

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} cm^{-2}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.

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.

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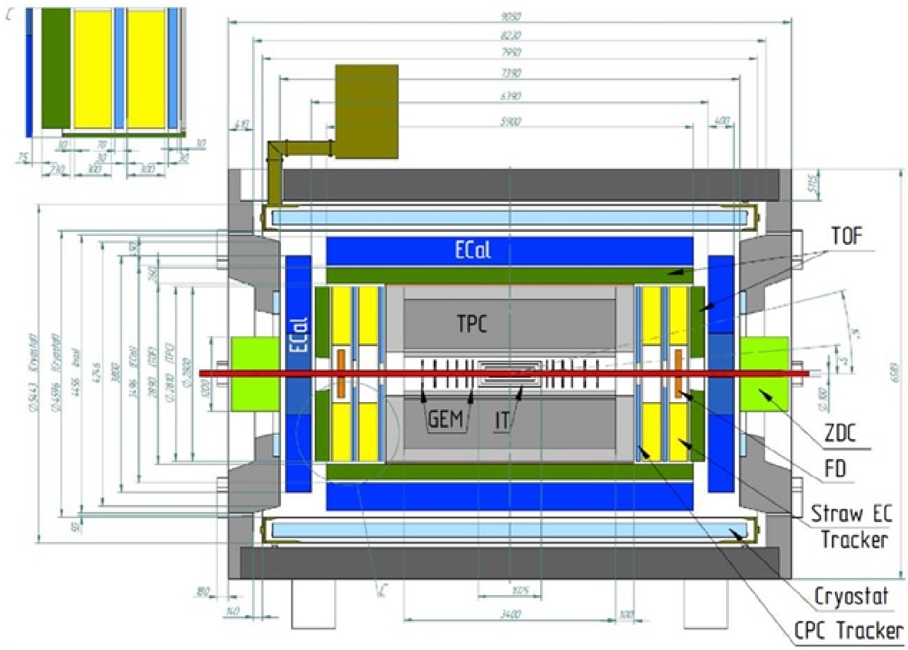

Fig. 1. MPD barrel setup.

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 of $0.1 < p_{\rm t} < 1$ GeV/c;

— Two-track resolution of about 1 cm;

— Hadron and lepton identification by $\mathrm{d}E/\mathrm{d}x$ measurements with a resolution better than 8%. These requirements must be satisfied at the NICA design luminosity, charged particle multiplicity ~ 1000 in central collisions and the event rate about 7 kHz.

2. TPC design

The basic design parameters of the TPC are summarized in Table I.

TABLE I

The basic design parameters of the TPC.

Item	Dimension
Length of the TPC	340 cm
Outer radius of vessel	140 cm
Inner radius of vessel	27 cm
Outer radius of the drift volume	133 cm
Inner radius of the drift volume	34 cm
Length of the drift volume	163 cm (of each half)
HV electrode	Membrane at the centre of the TPC
Electric field strength	~ 140 V/cm
Magnetic field strength	0.5 Tesla
Drift gas	90% Ar+10% methane Atmospheric pres. + 2 mbar
Gas amplification factor	$\sim 10^4$
Drift velocity	5.45 cm/μs
Drift time	< 30 μs
Temperature stability	$< 0.5°$C
Number of readout chambers	24 (12 per each end-plate)
Segmentation in φ	30°
Pad size	5×12 mm^2 and 5×18 mm^2
Number of pads	95232
Pad raw numbers	53
Pad numbers after zero suppression	$< 10\%$
Maximal event rate	< 7 kHz (Lum. 10^{27})
Electronics shaping time	~ 180 ns (FWHM)
Signal-to-noise ratio	30:1
Signal dynamical range	10 bits
Sampling rate	10 MHz
Sampling depth	310 time buckets

The MPD TPC is a detector of charge particles produced by the nuclear–nuclear collisions at the NICA collider. Momentum $\mathrm{d}P/P$ and energy $\mathrm{d}E/E$ resolution depends on the TPC design and uniformity of solenoid magnetic field.

The MPD TPC design and structure are similar to those of the TPCs used in the STAR, ALICE and NA49 experiments [5–7]. 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.

The lay-out of the TPC is shown schematically in Fig. 2. 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. 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% X_0) is acceptable.

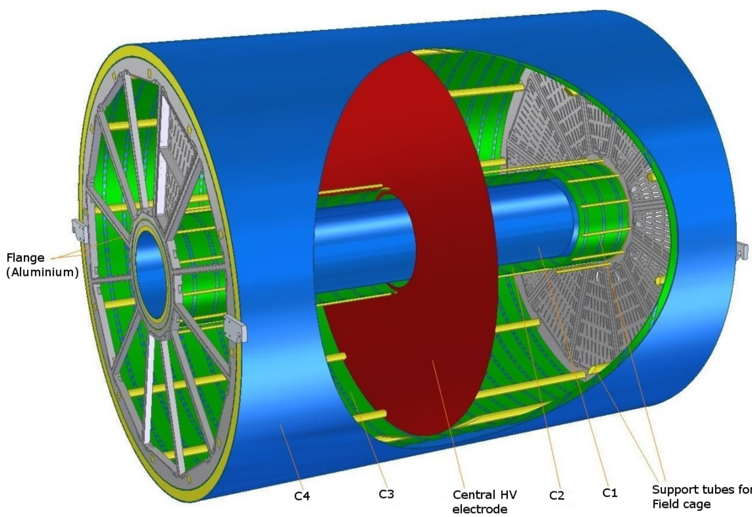

Fig. 2. TPC schematic design.

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 of electrons from ionization is created by a thin central HV electrode together with a voltage dividing network at the surface of the outer and inner cylinders and at the read-out end-caps. Monolithic full-size composite material cylinders produced by Russian industry are used for the TPC field cage construction.

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 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 [6].

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. 3, 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 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 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 1.25 mm.

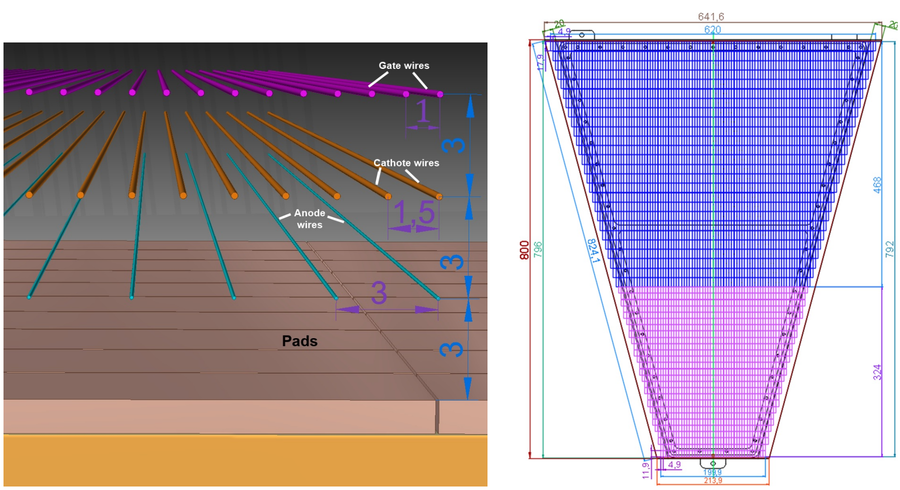

Fig. 3. Schematic view of readout chamber (left) and pad plane electrode (right).

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 20 μm diameter wire was chosen for the anode grid and mounted with 50 g stretching force. The cathode and gating grid copper–beryllium wires have a diameter of 75 μm and a stretching force of 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 are 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 kapton cables.

We have chosen 27 rows of pad with the size of 5×12 mm at inner area and 26 rows of pad with size of 5×18 mm at outer area of the readout plane as a compromise of reasonable number of readout electronics channels and two track resolution. 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. 3, right.

3. Laser calibration system

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.

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 the TPC working regime parameters by an 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 the value of drift velocity which depends on the drift gas pressure changes (caused by changes of atmospheric pressure), the temperature, EB

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.

As shown in Fig. 4, 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 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. A small part reaches the beam position detector. In every tube, there are 4 bundles of 7 micro mirrors forming 1 mm rays (see the text). Thin (1 mm diameter) UV rays emitted from the 4 tubes (yellow) form set of four planes with 28 rays in each of them. The second laser creates rays at the opposite side of the central electrode.

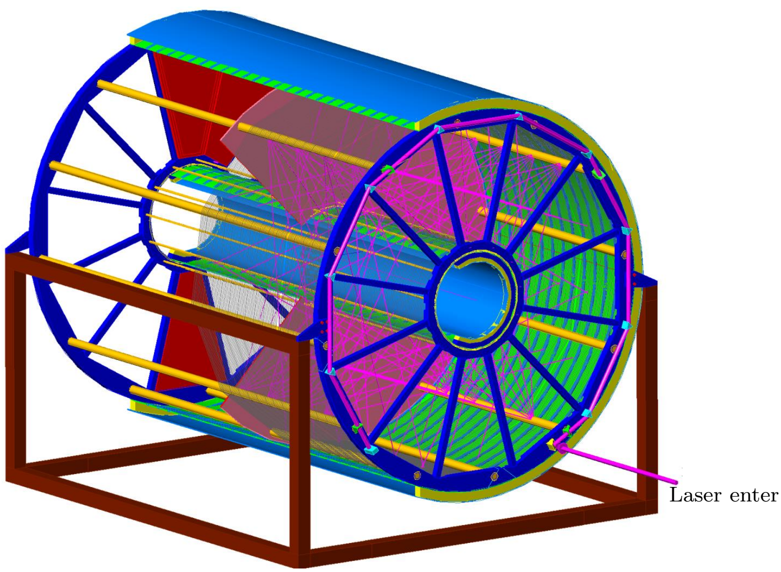

Fig. 4. (Colour on-line) Schematic view of high-power laser beam into 112 "tracks" of 1 mm in diameter.

4. Gas system

The schematic circuit of gas system is presented in Fig. 5. 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.

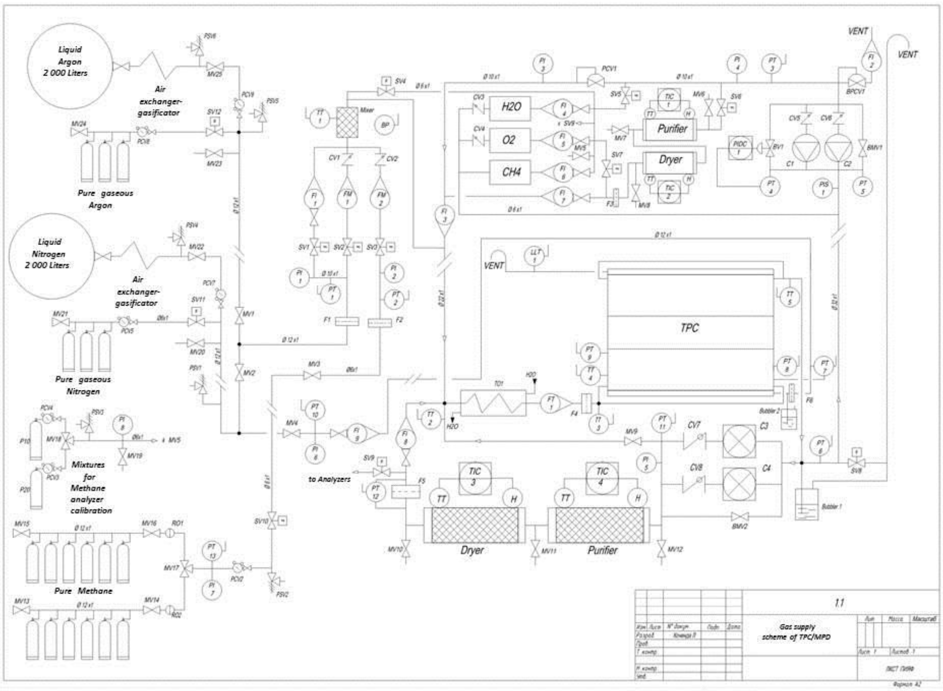

Fig. 5. Gas system scheme.

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 system 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 analyse 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 of $2.0 + / - 0.1$ mbar.

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

TABLE II

The technical features of the gas system.

Feature	Value
Operating mixture	Argon + $10.0 \pm 0.1\%$ metane
Consumption range control of fresh mixture	0–50 L/min
Operating pressure in TPC	2.0 ± 0.1 mbar
Recirculation rate of outer loop	30 L/min
Recirculation rate of inner loop	200 L/min
Oxygen content	20 ppm
Moisture content	10 ppm
Gas purging of TPC insolating volume	Nitrogen
Purging rate of insolating volume	5–20 L/min

5. Front-end electronics

The Front-End Electronics (FEE) has to read out charge the 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 III.

FEE for the MPD TPC is based on two ASICs:

— 16-channel charge sensitive shaping amplifier (PASA) [8];

— 16-channel analog–digital ALICE TPC Readout chip (ALTRO) [9].

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.

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. Data from 24 Readout chambers are collected by 64-chs front-end cards (about 4000 electronic channels per sector).

TABLE III

Main parameters of FEE.

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

6. Conclusion

The main design parameters and construction units of Time Projection Chamber for MPD detector to be built for the heavy-ion experimental program at future collider NICA at JINR (Dubna) are overviewed. The TPC will be an adequate device of MPD for tracking and identification of charge particles in ion–ion collisions at the NICA collider.

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