**MPD NICA**

**Technical Design Report**

**of the**

**Time of Flight System (TOF)**

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# Introduction

## The MPD experiment

The MPD is designed as a 4π-spectrometer capable of detecting charged hadrons, electrons and photons in heavy-ion collisions in the energy range of the NICA collider [1, 2]. To reach this goal, the detector will include a precise 3-D tracking system and a high-performance particle identification system based on time-of-flight measurements and calorimetry. At the design luminosity, the event rate in the MPD interaction region is about 6 kHz; the total charged particle multiplicity exceeds 1000 in the most central Au+Au collisions at  GeV. As the average transverse momentum of the particles produced in a collision at NICA energies is below 500 MeV/c, the detector design requires a very low material budget. The general layout of the MPD apparatus is shown in Fig. 1.1.

The Central Detector (CD) consists of a barrel part and two endcaps located inside the magnetic field (Fig.1). The barrel part is a shell-like set of various detector systems surrounding the interaction point and aimed to reconstruct and identify both charged and neutral particles in the pseudorapidity region of |η| ≤ 1.3. The endcaps are aimed for precise tracking over pseudo rapidity range (1.3 < |η| < 2). The ion beams interact inside the beam pipe located along the z axis with the central interaction point at *z* = 0 in the centre of the detector. The interaction region covers an interval of |*z*| ≤ 25 cm.

The barrel part shown in Fig. 1.1 consists of tracker and particle identification system. The principal tracker is the time projection chamber (TPC) supplemented by the inner tracker (IT) surrounding the interaction region. Both subdetectors (IT and TPC) have to provide precise track finding, momentum determination, vertex reconstruction and pattern recognition.

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| **Figure 1.1:** Cutaway side and cross views of the Central Detector of MPD with dimensions. |

## Particles identification in MPD

The event-by-event (E-by-E) hadron identification will provide us with the opportunity to measure, with high statistics, on a single event basis the yields of pions, kaons and protons, their ratios, thus giving a possibility of comprehensive study as many as possible event-by-event dynamical fluctuations and correlations. Consequently, it will provide information on possible instabilities during phase transitions, on the degree of thermal equilibrium, on collective flow phenomena and on expansion dynamics.

Physics goals of MPD require particle identification over as large as possible phase space volume. The MPD has two main identification subsystems. The first subsystem is high performance time-of-flight (TOF) detector. TOF together with TPC must be able to identify charged hadrons and nuclear clusters in the broad rapidity range and up to total momentum of 3 GeV/c. The fast forward detectors (FD) will provide the TOF system with the start signal. The second PID system is the electromagnetic calorimeter. Its main goal is to identify electrons, photons and measure their energy with high precision.

## Requirements to the TOF system

### The basic requirements

Ambitious physics goals of MPD require excellent particle identification capabilities over as large as possible phase coverage. Identification of charged hadrons (PID) at inter-mediate momenta (0.1 – 2 GeV/c) is achieved by the time-of-flight (TOF) measurements which are complemented by the energy loss (*dE/dx*) information from the TPC and IT detector systems.

The basic requirements to the TOF system are:

* large phase space coverage;
* high granularity to keep the overall system occupancy below 15%;
* good position resolution to provide effective matching of TOF hits with TPC tracks;
* high geometrical efficiency (better than 95%);
* identification of pions and kaons with up to *pt* < 1.5 GeV/c;
* identification of (anti)protons with up to *pt* < 3 GeV/c;
* TOF detector elements must function in a 0.5 T magnetic field.

### Required time resolution of the TOF system of MPD

For charge particle identification (mass reconstruction) one need to measure the follow parameters: momentum of the particle, its track length and time of flight from interaction point to TOF detector:

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where *m* is mass of the particle, *p* – the momentum, *l* – track length and t is the time of flight. There are three sources of the error in the mass reconstruction of particle:

At the relatively high momenta of particles the errors in time of flight measurement and track length definition have higher weight than the error of momentum determination. The momentum spectra of secondary particles at the NICA colliding energies produced in the regions of pseudorapidity |*η*| < 1.2 and 1.2 < |*η*| < 2 for minimum (4 GeV) and maximum (11 GeV) colliding energies are presented on the Fig. 1.5. The average momentum of pions for energy 4 GeV is about 300 MeV/c and for 11 GeV is about 400 MeV/c.

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| **Figure 1.5:** Momentum spectra of pions, kaons and protons in two regions of pseudorapidity: |η| < 1.2 (left) and 1.2 < |η| < 2 (right) and for two center of mass energy: 4 GeV (top) and 11 GeV (bottom). | |

The smallest track length for time of flight measurement at MPD is 1.5 m. We expect to have overall time resolution better than 100 ps. It allows us reliable separation of pions, kaons and protons in the entire interval of momenta for produced particles for NICA energies (Fig. 1.6a, 1.6b).

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| **Figure 1.6a:** Calculation of the separation of pion and kaons in units of standard deviation as a function of TOF base for TOF resolutions: 80ps and 100 ps. | **Figure 1.6b:** Separation of pions and kaons as a function of secondary particles momenta for different fixed bases (time resolution is 100 ps). |

In Fig. 1.7 we present the fraction (in percent) of pions and kaons below a particular momentum as a function of momentum. These distributions are obtained for the particle spectra from Fig. 1.2. One may conclude that TOF system can separate pions on the level of 99 % and kaons – almost 98 % up to the total momentum of 1.5 GeV/c.

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| **Figure 1.7:** Part of the pions and kaons below a particular momentum ( GeV). |

### Occupancy and counting rate estimation

For simulation we used Au-Au interactions with total energy 4.5 + 4.5 GeV/n from the UrQMD generator and GEANT4 for tracing particles in the detector. Impact parameter range for minimum bias: b = 0 – 15.8 fm, for central collision: b = 0 – 3 fm.

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| **Figure 1.8:** Estimated occupancy of the TOF system as a function of pseudorapidity. | **Figure 1.9:** Charged particles multiplicity per one minimum bias interaction as a function of (θ-π/2). |

Simulated occupancy for the proposed TOF system is shown in Fig .1.8. There are occupancies for the endcup and barrel parts of the TOF in this figure. Barrel occupancy is shown for two cases: for a rotated and flat arrangement of detectors. Maximum occupancy does not exceed 0.25 % per cm2 for both cases of location of detectors in the barrel.

For particles rate estimation the anticipated luminosity for Au + Au collisions *L*= 1027 cm-2s-1 was used. The collision rate for minimum bias events was taken as:

The interaction rate for central collisions is bellow 1 kHz. From Fig. 1.9 one can see that in one event there are 0.005 charged particles that cross the surface of 2.6 cm2. Number of charge particles per second crossed the 1 cm2 surface of TOF is only *N*= 6000 Hz x 0.005 / 2.6 = 11.5 Hz/cm2. The experience of ALICE [3] demonstrated a good timing performance of MRPC and its efficient work at particle fluxes up to 103 cm-2s-1 (Fig. 1.10).

So, the TOF MPD system based on MRPC has to demonstrate reliable work at particle flux bellow 12 Hz/cm2.

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| **Figure 1.10:** Efficiency and time resolution versus counting rate for double stack MRPCs [3]. |

# Development and study of MRPC for TOF

## Motivation of choosing MRPC for ToF system

Our choice for the TOF system is the Multigap Resistive Plate Chambers (MRPC), which were widely used in such heavy-ion experiments as ALICE [3, 4], PHENIX [5], STAR [6], HADES [7] and is planning TOF CBM [8]. Such widespread use of this detector caused by that the multigap resistive plate chamber has good timing characteristics. At the same time MRPC is quite easy to manufacture and it is relatively inexpensive. Its production requires materials that are commercially available.

The multigap resistive plate chamber consists of a stack of resistive plates separated one from the other with equal size spacers creating a series of gas gaps [9]. High voltage coating is made on the outer surfaces of the outer resistive electrodes. Internal plates are left electrically floating. The voltage of the internal plates appears due to the flow of electrons and ions created in the gas gap. The resistive electrodes quench the streamer and prevent a spark breakdown. The MRPC operates at high gain in avalanche mode. Float glass plates are used as resistive plate electrodes.

## Designs of MRPC prototypes

Two types of MRPCs were considered: with the pad signal readout and with the strip readout. Both options have their special traits in terms of assembling and operation. But at low multiplicity of events, it makes sense to use a strip electrode for readout. It reduces the number of channels making the system more cost-effective. Therefore, strip MRPCs have been chosen for the barrel part of the MPD. At the end cup parts of the detector, there will be combined pad and strip readouts.

### Pad prototype

The first prototype of a multigap resistive plate chamber (MRPC) for TOF MPD (Fig. 2.1) was made small with pad readout [10]. A 208 µm gas gap is formed by a monofilament fishing line of appropriate thickness. The readout electrodes are PCB of 140×120 cm2 with copper rectangles of 16×35 cm2. They make up in total two rows of 8 pads in each. In order to supply high voltage to glasses closest to the readout electrodes, they are coated with a graphite conductive layer with a surface resistance of 2 – 10 MΩ per square. Signals from the pads are transferred via the twisted pair cable to the amplifier. The detector is situated in a leak-tight box (Fig. 2.2) in which a gas mixture is injected.

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| **Figure 2.1:** Pad MRPC scheme. | **Figure 2.2:** Pad MRPC prototype in gas box. |

### MRPC prototype with strip readout electrodes

Expected multiplicity of particles in the central Au + Au collisions at  GeV allows using readout electrode area of 100 cm2 with maximum occupancy about 25 %. On the other hand, increasing the size of the electrode can lead to time resolution worsening due to signal deterioration (front drops). In case of using readout electrode as a long narrow strip and reading signal from both sides, it avoids the need to take into account the time dependence of the position of the flight of the particle. This method significantly reduces the number of channels of readout electronics without degrading the time resolution.

The first strip prototype has been designed with active area of 600x300 mm2 (Fig. 2.3). The main feature of this MRPC is readout electrode. 24 readout strips with dimensions of 600x10 mm2 were etched on the glass fiber (FR4) plate with overall dimensions of 610x360 mm2. Distance between strips is 1.25 mm. The signal is readout from both sides of the electrode. 12 gas gaps with width of 220 μm formed by sheets of glass with thickness of 400 μm. To improve the efficiency of the gas detector 12 gaps was divided to two stacks of 6 gaps in each stack like in pad MRPC. Stacks are divided by 5-millimeter plate of honeycomb panel to align the electrical wave properties of the inner and outer strip. Signal is taken separately from each stack by twisted pair cable (Fig. 2.4) and combined at the input of the amplifier.

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| **Figure 2.3:** Layout of the strip MRPC. | **Figure 2.4:** Readout from two stacks of the MRPC. |

## Beam setup and cosmic stand for testing detectors

The principal goal of the R&D is to investigate the problems associated with scaling up from a small to a full size MRPC with strip readout electrodes. Various issues were addressed, such as: (a) material and thickness of resistive plates (b) definition of the edge of the active area (c) connection between readout pads and electronics (d) assembly problems and (e) front-end electronics. The tests were performed in both cosmic rays and proton beam of the Nuclotron.

Laboratory with cosmic test setup was organized (Fig. 2.5) for testing detectors in the intervals between runs of the Nuclotron. Cosmic stand includes (Fig. 2.6): scintillation telescope (S1-S8) which cover the entire active area of the tested detectors; 4-channel gas system with MKS-Instruments controllers; fast readout electronics based on VME (TDC, TQDC ...); high-voltage and low-voltage power supplies; the oscilloscope LeCroy Wave Runner with a bandwidth of 4 GHz; x-ray tube; fast start detector (FFD); slow control system (temperature, gas flow, currents and voltages of the high and low voltage power supply).

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| **Figure 2.5:** Appearance of the cosmic test setup. | **Figure 2.6:** Diagram of the cosmic test setup. |

“Test beam MPD” facility is a complete system of equipment and devices for studying detectors on the beams of particles (deuterons) from Nuclotron with energy range 1 – 4 GeV/n.

It includes (Fig. 2.7):

* two platforms made of aluminum profile for fixing and adjustment detectors along a beam axis;
* the precision positioning device for movement and turn of the tested detector concerning a beam axis operated by remote control;
* three proportional chambers (MWPC 1, 2, 3) with 6 coordinate planes for tracking and definition of the profile of the beam with an accuracy of determination of coordinate about 1 mm;
* five scintillation counters for trigger and to determine the intensity of the beam;
* gas system consisting of two independent control panels, allowing to prepare the gas mixture to blowing various gas-filled detectors with different gas mixtures (MRPC, GEM, DC etc.);
* data acquisition system (DAQ) based on the standard VME and Ethernet, allowing to control operation of the detector "on-line", as well as to record data files for further processing.

The beam room and control room are provided with temperature stabilization system.

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| D:\babkin\NIKA-MPD\ToF_RPC\documents_15\Отчет_2010-2015\2015-02-26 08-36-01.JPG  **Scint. coucnter**  **MWPC 1**  **MWPC 2**  **Positioning device**  **Fast start detector**  **Tested detector** |
| **Figure 2.7:** General view of the “Test beam MPD” setup during working in the 51 Nuclotron run. |

## Test results

The detector was tested on deuteron beam of the Nuclotron with energy of 2 GeV/nucleon. Start signal to define the time of flight was generated by the fast Cherenkov detector with Photonis micro-channel XP85012Q photomultiplier. The time resolution of the start detector was about 37 ps. The total time resolution of the system was approximately 70 ps (Fig. 2.8). Thus, the time resolution of the pad MRPC prototype was in the region of 60 ps (including the "jitter" of electronics) with particle detection efficiency of about 99% (Fig. 2.9).

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| **Figure 2.8:** The distribution of the difference between the start detector and the "pad" MRPC. | **Figure 2.9:** Efficiency and time resolution of the "pad" MRPC in dependence of high voltage. |

This full-scale detector has been tested on cosmic rays and deuteron beam of the Nuclotron. Dependence of the efficiency and time resolution for strip MRPC from applied high voltage are shown in Figure 2.10. Efficiency, due to the large number of gas gaps, quickly reaches a plateau of 99.8 %. The best time resolution (~ 65 ps) is observed at approximately 16.5 kV [11]. Upon further increasing of the high voltage the number of streamers rises sharply and the resolution degrades. The time resolution of the detector does not change due the position of the particles tracks along the strip (Fig. 2.11). All time resolution results include jitter of electronics which is about 20 ps.

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| **Figure 2.10:** Efficiency and time resolution of the strip MRPC from high voltage. | **Figure 2.11:** Time resolution in dependence from position along strip. |

## Study of rate capabilities of a MRPC

In order to use MRPCs in endcap TOF one need to keet in mind tht high multiplicity of particles (up to 3000 particles/cm2·s) expected in the regions close to the beam axis for the peripheral events. It is known that MRPC made of ordinary glass with thickness of 550 microns are effective at particles rates up to 1 kHz/cm2. Therefore it is necessary to have detectors operating at high particles intensities. Two case of solving the problem were chosen: reducing the thickness of the glass and reducing its conductivity.

High rate MRPCs were tested on the beam of high intensity in the 47 run of Nuclotron with a group of physicists from the Tsinghua University (Beijing). Two types of detectors were studied: detector made of low-resistance "Chinese" glass with a volume resistivity about 1010 Ohm·cm [12] and detectors with different thicknesses of glass [13]. The test results are shown in the figures below.

Prototypes with different thin ordinary glass could be used in area where the particle flux will be less than 3 kHz/cm2. Very strong dependence of rate capabilities from the thickness of ordinary glass resistive electrodes was found. The best result was achieved with a prototype of a 350 μm glass. Its efficiency was 90 % and time resolution was in the region of 70 ps (Fig. 2.12).

Prototype with a low resistance glass showed excellent rate capability, as expected. Its efficiency was higher than 90 % at particles rates up to 100 kHz/cm2. At the same time resolution was better than 80 ps. The time resolution of this MRPC reached 52 ps (Fig. 2.13) at low fluxes of particles.

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| **Figure 2.1****2:** Efficiencies and time resolution of MRPCs with different glasses from the beam intensity. | **Figure 2.13:** Efficiency and time resolution of MRPC with low-resistance glass from the beam intensity. |

# TOF Detector Design

## Development of the Multigap Resistive Plate Chamber

After analyzing the results of testing of prototypes we have fixed the design and geometry of the MRPC for barrel TOF. It will be double stack MRPC with strip readout.

### Detail layout of the MRPC for MPD time-of-flight system

A scheme of the MPD TOF detector is presented in Fig. 3.1. The detector consists of two stacks of 5 gas gaps each. As resistive electrodes we use common float glass. The outer glass electrodes have thickness 0.55 mm. The internal glass electrodes have thickness 0.4 mm. The fishing line as a spacer defines the 220 μm gap between all resistive electrodes. The outer part of external glass electrodes is covered by conductive paint with surface resistivity about 2 – 10 MΩ/□ to apply high voltage. All internal glasses are floating. The pickup electrodes look like strips and made on the PCB board (Fig. 3.2). An important feature of the double-stack “strip” prototype is that the internal strips of two different stacks are separated by 5-mm panel of Honeycomb. This ensures the symmetry between two stacks, and provides the equal speed of signals on the anode and cathode strips and as result prevent the dispersion of the signal.

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| **Figure 3.1:** Sectional view of the proposed double stack strip MRPC for TOF MPD. |

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| **Figure 3.2:** PCB board with 10 mm wide strips. |

Dimension of active area of one MRPC is 300 x 735 mm2. It has 24 readout strips, 10 mm wide and 735 mm long. To reduce crosstalk the gap between strips is 2.5 mm. Thus the pitch of electrodes in this case is 12.5 mm. Active surface of one strip is about 90 cm2. Mean occupancy for this area (see Fig. 1.8) not exceed 17 % for central Au-Au collisions with energy .

Differential analog signal is transferred from PCB by twisted pair cable to front-end electronics. Signal is reading out from both ends of the strip. It provides better time resolution and determination of the coordinate of a particle along strip. For stiffening structure we glue aramid fiber honeycomb panel with a thickness of 8 mm on outer part of the external PCBs.

## Front-end electronics and data acquisition system

Very important part of the high performance time-of-flight system is readout electronics. For the full exploitation of the excellent timing properties of the Multigap Resistive Plate Chamber, front-end electronics with special characteristics are needed. The signals from MRPCs must be amplified and discriminated as fast as possible without lossless.

Leading and trailing times of the discriminated signal must be digitized and measured with accuracy much better than the time resolution of the detector.

Readout electronics for the MPD-TOF will consist of the front-end electronics (FEE) and data acquisition system (DAQ).

### Preamplifiers for TOF MRPC

For the front-end electronics we decided to use electronics like used in TOF ALICE. Such electronics is very convenient for our TOF system. Since each detector has a 24 strip it was decided to create a 24-channel amplifier on the example of the FEA of the TOF ALICE.

NINO application-specific integrated circuit (ASIC) (Fig. 3.3) developed in 0.25 micron CMOS technology recently by the CERN LAA project, which combines a fast amplifier, discriminator and stretcher. The NINO ASIC had to satisfy the following requirements [14]: differential input; optimized to operate with 30-100 pF input capacitance; LVDS differential output; output pulse width dependent on the charge of the input signal; fast amplifier to minimize time jitter (a peaking time less than 1 ns); threshold of discriminator adjustable in the range 10 –100 fC; eight channels per ASIC. Main features of the NINO ASIC are shown in Table 3.1.

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| http://knowledgetransfer.web.cern.ch/sites/knowledgetransfer.web.cern.ch/files/images/technology/69_0.jpg |
| **Figure. 3.3:** The NINO ASIC (8 channels) directly bonded on the PC board (no packaging). |

**Table 3.1:** NINO ASIC specifications table.

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| **Parameter** | **Value** |
| Number of channels | 8 |
| Peaking time | 1 ns |
| Supply voltage | 2.5 V |
| Power consumption | 27 mW/ch |
| Input signal range | 30 fC – 2 pC |
| Noise (with detector) | < (2.5 – 5)×103 e- rms |
| Discriminator threshold | 10 fC to 100 fC |
| Differential input impedance | 40 Ω < Zin < 75 Ω |
| Timing precision | < 10ps jitter |
| Output interface | LVDS |

A block diagram of the NINO is shown in Fig. 3.4. The input stage is followed by 4 stages of low-gain, high-bandwidth differential amplifier. A slow feedback circuit supplies current to ensure that the input stages remain correctly biased. In addition an offset is added at this point that acts as a threshold adjustment. There is a stretcher just before the LVDS output driver. The pulse width before stretching varies between 2 ns and 7ns; the digitizing electronics based on HPTDC chip [15] that will be used in data acquisition system of the TOF MPD can only measure both leading and trailing edges of an input pulse for widths greater than 6 ns; thus the pulse stretcher will increase the pulse width by 10 ns.

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| **Figure 3.4:** Block diagram of the NINO ASIC. |

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| **Figure 3.5:** Simplified schematic of NINO FE board for MPD TOF system. |

Two types of 24-channel and 8-channel preamplifiers-discriminators based on NINO v2 were developed especially for installation on the TOF MPD modules. These amplifiers had to adapt under strip MRPC for the MPD experiment.

Features of MPD TOF preamplifier-discriminator board:

* stabilization of the supplied voltage;
* differential input and output;
* overload protection of input channels;
* capacitors on the inputs for double-end strip readout;
* the possibility to use for a trigger (parallel “or” output);
* monitoring and control of the sensitivity threshold.

Block-scheme of the front-end board presented at the Fig. 3.5. The amplifier is specially adapted to the used type of MRPC to align tract preamplifier - chamber, preventing reflections. The presence of protective resistors on each channel allows changing the preamplifier when the high voltage applied to the detector. The output preamplifier signal is in the LVDS standard. Overall dimensions of the 24-channel preamplifier is 200x120 mm2, 8-channel is 42x47 mm2. 24-channel preamplifier is made in two versions: with output connector’s type of VHDCI (Fig. 3.6) and CXP (InfiniBand) (Fig. 3.7). Voltage stabilizer is installed on the preamplifier that eliminates the additional measurement error and the voltage drop on the cable. The preamplifier can be powered with voltage of 3 V to 6 V. Measured jitter between two channels of the amplifier about 6 ps.

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|  |  |
| **Figure. 3.****6:** 24-channel amplifier based on NINO with VHDCI output connector. | **Figure 3.7:** 24-channel amplifier based on NINO with CXP (InfiniBand) output connector. |

LDO regulator allows avoid jitter of controlling stages and improve more accurate measurement. Differential pair input designed to reach 55 ohm impedance from MRPC output. VHDCI and Molex’s CXP 12x connectors used as output. Capacitors must be removed from the cable connector for using Molex’s CXP cable (Fig. 3.8).

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| **Figure. 3.8:** View of the Molex CXP cable with connector. |

Fig. 3.9a and Fig. 3.9b are shown the difference of transmitting output signal from the NINO front-end board in two types of cables. Molex's CXP cable provide a precision 100 Ω transmission line with better electrical characteristics, although it is two times longer than Amphenol cable and more available.

|  |  |
| --- | --- |
| blue 3m | inf no cc |
| **Figure 3.9a:** LVDS signal after passing through 2.5 m length Amphenol cable with VHDCI connectors. | **Figure 3.9b:** LVDS signal after passing through 5 m length Molex cable with CXP connectors. |

### Time-Over-Threshold method

Signal amplitude must be taken into account in time measurements. Time-amplitude correction can significantly improve the time resolution. The NINO pulse width is somewhat dependent on the MRPC pulse height. Thus the integral of the pulse (charge) can be obtained by measuring the pulse width. Time correction using LVDS pulse width called the “Time-Over-Threshold” [14]. Because this method requires only time information it can simplify and reduce the cost of readout electronics.

The dependence of the width of the LVDS pulse from the charge at the input of the NINO preamplifier shown in Fig. 3.10. A wide range of width for small amplitudes allows making corrections more accurate in the areas with the highest jitter of the input signal. Example of the correction curve for strip readout MRPC shown in Fig. 3.11. This correction improves the time resolution of the detector is almost twice.

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| **Figure 3.10:** Charge dependence of the width of output LVDS impulse from NINO preamplifier. | **Figure 3.11:** Example of “time-over-threshold” curve with time-width distribution. |

### Time-to-digital converter TDC72VHL

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| **Figure 3.12:** Time-to-digital converter TDC72VHL with VHDCI input connector. | **Figure 3.13:** Electronics for data acquisition system in the VME rack. |

A special 72-channel VME64x time-to-digital converter TDC72VHL (Fig. 3.12) based on a High Performance TDC ASIC (HPTDC) chip developed at CERN. TDC72VHL was designed and produced in the LHEP NEOAFI department. It used for digitizing LVDS signals, coming from the output of the NINO amplifier. Time-sampling of the TDC72VHL is less than 25 ps. This time-to-digital converter was produced under both types of connectors, like the amplifiers. Three amplifiers can be connected to one such module of the VME TDC. One VME rack can hold up to 19 of the TDC72VHL (Fig. 3.13).

The HPTDC chip has a very strong integral nonlinearity (INL). First experiments on the MRPC time resolution evaluation showed that integral nonlinearity occurs with TDC operating in the very high resolution mode (24.4 ps per bin) as a result of cross talk from clock signal inside the HPTDC chip. This nonlinearity causes strong degradation of time distribution. The contribution of this nonlinearity and the method to eliminate it has already been shown in the HPTDC Manual [15] as well as in other publications [16], [17].

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| **Figure 3.14:** Differential nonlinearity of HPTDC. | **Figure 3.15:** Integral nonlinearity of HPTDC. |
| dt_vs_Delay_Corr_graph | |
| **Figure 3.16:** Time resolution of HPTDC without correction (black) and with INL corrections (red). | |

The code density test was used for calibration (consideration of nonlinearity) of VME TDC72VHL modules. It is a method of uniform filling the time gap with random events. A scintillation counter irradiated by a 137Cs radioactive source was used as a source of random signals. A random signal is supplied to the test input of the NINO amplifier in order to calibrate up to 24 channels of the TDC at once. This is essential for accelerating the process of calibration as there must be not less than 10000 events in each time “bin” in order to achieve good precision of calibration factors. Ideally the time gap should be filled uniformly. In this experiment, minor differential (Fig. 3.14) and strong integral (Fig. 3.15) nonlinearity in terms of time were observed distracting the measured value for 8 bins (~200 ps) from the real time, which deteriorated significantly the time resolution of the DAQ electronics. Calibration tables were developed for further data processing for each channel of the TDC allowing for elimination of the integral nonlinearity contribution. Native time resolution of one channel of electronics (including NINO resolution) made up better 20 ps after applying the calibrations (Fig. 3.16).

The main estimated parameters of the TOF DAQ are in Table 3.2. Data rate calculated from average occupancy (~17%) and mean trigger rate (~6000 Hz). Average number of fired channels in one interaction is 6912 × 0.17 ≈ 1200. Event size in this case calculated as 1200 × 2 × 12 = 28 kBytes. Data rate is 28kB × 6000 Hz ≈ 165 MB/s ≈ 1.3 Gb/s.

**Table 3.2:** TOF DAQ estimation parameters.

|  |  |
| --- | --- |
| **Parameter** | **Value** |
| Raw data information type | Lead+trail time, 25 ps/bin |
| Channel size | 12 Bytes |
| Average event size | 28 kBytes |
| Maximum data rate | < 1.5 Gb/s |
| Number of TDC72VHL | 192 |
| Total power | 3500 W |

## Mechanical design of the TOF barrel

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| **Figure 3.17:** The main sizes of TOF barrel in φ direction. |

The cylindrical part of ToF MPD located in the barrel between the time-projection chamber (TPC) and the electromagnetic calorimeter (ECal). The TOF system internal diameter is 2.89 m from the beam axis and outer diameter is 3.41 m (Fig. 3.17). The MPD ToF covers the pseudorapidity range |η| ≤ 1.2 and full coverage in φ. The total surface of the barrel TOF system is about 53 m2. The TOF detector system is organized in a modular way in order to minimize the number of components and cost.

The detector is segmented in φ into 12 sectors of ~5.7 m length.The maximum distance between sectors does not exceed 15 mm. Each sector carries 4 individual modules (Fig. 3.18). Each module contents 6 MRPCs arranged in 2 layers. The special shape of module minimizes the dead area inside the sector. The dead area between sectors is due to the limited space along the radius of barrel. This fact is not allows to put modules with overlap azimuthally dire.

Each ToF module consists of a two separate volumes: inner gas region which contains the six MRPCs and an outer one containing the Front End Electronic (FEE) cards, cables, high voltage and gas plugs. The MRPCs have been described in detail in Chapter 2. The inner gas tight box containing the MRPCs is made of the polypropylene trough 5 mm thick and the polypropylene cover same thick with the holes to bring the MRPCs signals to the Interface Cards (IC), where the FEEs will be plugged into and the FEEs themselves. Holes for gas connectors and HV connectors are also provided on the top cover. The MRPCs are positioned inside the box as shown in Fig. 3.18.

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| **Figure 3.18:** Modules along beam direction. |

Adjacent MRPCs will be positioned inside the module in such a way as to create an overlap of 4 readout strips between two adjacent MRPCs, at the edge of the active area: this will ensure the inter-calibration of the MRPCs via tracks traversing both of them. The signals from the pick-up strips on the MRPCs are brought to the FEE via Interface Cards (ICs). The ICs are made of small PCBs and will be glued and fixed to the top cover of the box closing in this way the gas volume. Each IC will have on one side the connectors facing the MRPC, and, on the other side, the connectors for the FEEs. To add safety to the system the perimeter of the IC is poured silicone.

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| **Figure 3.19:** Pair of modules on one aluminum frame. |

Two modules are combined in pairs on one aluminum frame (Fig. 3.19). A lid of aluminum honeycomb closing in this way the volume for the electronics and the cables covers the frame. Two pair of modules are inserted into the frame of barrel from each side of the barrel forming one sector. The cables taking the signals from FEE to the TDC readout modules will be routed to the center of the module and from there to the readout crates placed at both ends of each sector. At the present time two sample TOF modules are made for tests (Fig. 3.20; Fig. 3.21). We use it for optimization of the overall design of the all TOF system.

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| **Figure 3.20:** MRPCs inside the gas volume of the module. | **Figure 3.21:** TOF module on the cosmic stand. |

Main parameters of the TOF system parts are listed in Table 3.3. Calculated total sensitive area of the TOF system is about 50.3 m2. The inner radius of the barrel is about 1.45 m. The total area of a dodecahedron with this inner radius and length of 5.7 m is about 53 m. It means estimated geometrical efficiency must be about 95%.

**Table 3.3** Main parameters of the TOF system.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | **Number of detectors** | **Number of readout strips** | **Sensitive area, m2** | **Number of FEE cards** | **Number of FEE channels** |
| MRPC | 1 | 24 | 0.2205 | 2 | 48 |
| Module | 6 | 144 | 1.08 | 12 | 288 |
| Sector | 24 | 576 | 4.19 | 48 | 1152 |
| Barrel | 288 | 6912 | 50.3 | 576 | 13824  (1728 chips) |

## TOF system geometric efficiency and acceptance estimation

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| **Figure 3.22:** TOF detector layout in MPDROOT (TOF system with gas box, electronics and covers). |

Monte Carlo simulations have been performed using the MPDROOT framework based on the ROOT software. The MPDROOT framework has interfaces to several event generators (UrQMD, LAQGSM, HIJING, etc.) and includes all algorithms for MPD reconstruction and analysis, thus providing a complete set of instruments to simulate ion-ion collisions.

The barrel of the MPD TOF system is a cylinder covering the region of polar angles |θ – 90°| < 60° (|η| < 1.3). The structure of the TOF, the inner structure of each module and MRPC detectors have been described in the GEANT 4 package. All simulations have been done for geometry shown in Fig. 3.22.

Obviously, there are inactive areas at the junctions of TOF sectors. In Fig. 3.23 the TOF geometric efficiency is shown versus azimuthal angle. Fig. 3.24 that for the detectors in the outer layer the acceptance is lower than for those in the inner layer. The resulting TOF overall geometrical efficiency is approximately 95%.

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| **Figure 3.23:** Distribution of geometric efficiency along *φ* angle. | **Figure 3.24:** Distribution of geometric efficiency along *Z* direction integrated over azimuthal angle. |  | |

Pt versus rapidity distributions of the primary hadrons reaching the TOF barrel are presented on Fig. 3.25. The events were simulated by UrQMD at energy 11 GeV. The produced particles were traced with the GEANT at the magnetic field *B*= 0.5 T, particle decays are also taken into account. The distributions are for the region |η| < 1.3. Different empty regions for pions, kaons and protons are due to magnetic field and polar angle acceptance. In Table 1 are tabulated the absolute numbers and the fractions of different particle specie (per event) registered by the TOF detector. Due to decay only 63% of kaons and 78 % of charged pions from Au-Au interactions 11 GeV reach the barrel TOF (within).

**Table 3.4:** Particles losses in the region |η|<1.3 for central Au-Au collision with 11 GeV/n.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | **π±** | | **K±** | | **p** | |
| Produced in 4π | 844.2 | | 82.9 | | 161.1 | |
| |η| < 1.3 | 530.5 | 1.0 | 48.8 | 1.0 | 67.3 | 1.0 |
| Reached TOF (*B* = 0.5 T) +decay, interaction losses | 412.6 | 0.78 | 30.8 | 0.63 | 63.4 | 0.94 |
| TOF matching and registration efficiency ~0.95 | 392.0 | 0.74 | 29.7 | 0.60 | 60.2 | 0.89 |

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| **Figure 3.25:** MPD TOF phase-space for charged hadrons (from top to bottom): pions, kaons and protons. (2000 UrQMD central events, *B* = 0.5 T). |

## Time-of-Flight particles identification performance

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| --- | --- |
|  | dL_tpc_1[1] |
| **Figure 3.26:** Particle momentum and track length reconstruction accuracy with TPC in magnetic field *B* = 0.5 T. | |

As mentioned in chapter 1.3.2 the uncertainties in the time of flight measurement and track length determination have the highest weight in the error of the reconstructed particle mass. In Fig.3.26 are shown estimated accuracy of the reconstructed particle momentum and track length at several values of particle’s momentum. Track reconstruction in TPC was performed using the Kalman filter. As can be seen from figure, at η = 1.1 the momentum resolution of 1 GeV/с particle is about 2.5 % and track length accuracy measurement is less than 3 mm. Then particle's mass can be calculated using the information about the reconstructed momentum, track length and time-of-flight from the collision vertex to the TOF hit. Detector response was simulated in accordance with the processes taking place inside the TOF-module when a charged particle passing through it, the overall time resolution of the TOF system (including the resolution of the start counter) was estimated to be below 100 ps.

In Fig. 3.27 an example of mass separation capabilities of the TOF MPD system is presented. The green lines show a suggested way to select particles, i.e. particles of given type which get outside of the boundary were counted as a loss of efficiency while those in other area are counted as a contamination.

The MPD PID performance can be considerable enhanced using a combination of ionization loss (*dE/dx*) from TPC and time-of-flight measurements. An example PID plot for the momentum interval of 0.5 < p < 1.0 GeV/c is shown in Fig. 3.28.

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| **Figure 3.27:** Mass separation with TOF (100 ps resolution). The green lines show boundaries for efficiency and contamination estimation. | **Figure 3.28:** Combined *dE/dx* and TOF particles identification for 0.5 < *p* < 1 GeV/c region. |

As the results of simulation demonstrate for a typical track length of about 1.6 m the pion/kaon separation will be achieved up to the total momentum of 1.5 GeV/c; one can select protons from other species up to *p*= 3 GeV/c.

## Weight and material budget of the TOF MPD modules

Details of the evaluation of the module weight are given in Table 3.5. The total weight of the full TOF (48 modules) is thus 5540 Kg. Considering in addition weight for the read-out crates placed at the end of each sector and other service devices and communications, the total TOF weight on the space frame will about 6000 kg.

**Table 3.5:** Weights of the TOF module components.

|  |  |
| --- | --- |
| **Part** | **Weight, kg** |
| MRPC | 6.7 |
| Box (module) | 42 |
| FEE and cables per module | 18.2 |
| Aluminum frame on two module | 30 |
| Total per sector | 461.6 |
| Total per barrel | **5539.2** |

Calculated contributions of all parts of the TOF to the radiation length of one average Module are listed in Table 3.6.  In overlap region (about 25 % of all effective surfaces) of the MRPC radiation length is up to *X/X0* = 19.6%. Work to optimize the design of the detector is underway in order to reduce its radiation length.

**Table 3.6:** MPD TOF material budget.

|  |  |
| --- | --- |
| **Material** | **Radiation Length *X/X0* (%)** |
| Gas box | 2.0 |
| 12 MRPC glass plates | 4.3 |
| 3 plates Honeycomb | 0.17 |
| 4 PC board | 2.3 |
| 4 Copper layer | 0.37 |
| Electronics | 1.68 |
| Top Cover | 1.24 |
| Gas | 0.19 |
| Cables | 0.4 |
| Total | **12.65** |

## Area for mass-production of the TOF MRPC

Since 2014 area (Fig 3.29) for the mass production of detectors is created in the laboratory. The workshop consists of the several areas (Figs. 3.30 – 3.33):

* ultrasonic cleaning glass;
* drying the glass;
* assembly of MRPC;
* assembly the modules;
* test of the assembled modules on cosmic.

The cleaning of the glass is carried out in two stages. First, the glasses are cleaned in the ultrasonic bath with a special surfactant, and washed with deionized water, which is purified by reverse osmosis filter in a special cleaning system. After washing, the glass is dried in special drying oven, then it comes to the area for assembly detectors. MRPC assembly take place on the tables made of massive granite slabs to avoid detector deformation during gluing and assembly. Detailed description of the assembly procedure is given below.

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| **Figure 3.29:** Scheme of the MRPC mass production workshop. |

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| **Figure 3.30:** The areas of ultrasonic cleaning glass. | **Figure 3.31:** The area of drying the glass. |
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| **Figure 3.32:** Clean room for detectors assembly. | **Figure 3.33:** The area of assembling and testing of supermodules. |

## Step-by-step MRPC assembling procedure

The materials for the assembly of the MRPC are commercially available. The list of the materials to produce one detector is shown in Table 3.7.

**Table 3.7:** Components and materials for the production of one MRPC detector.

|  |  |  |
| --- | --- | --- |
| **Name of material or component** | **Dimensions** | **Quantity** |
| Aramide honeycomb panel with 0.5 mm fiberglass coating | 735x300x8 mm3  735x300x5 mm3 | 2 pcs  1 pcs |
| Fiberglass PCB with strips | 745x330 mm3 | 4 pcs |
| Float glass (inner)  (outer) | 735x300x0.4 mm3  735x300x0.55 mm3 | 8 pcs  4 pcs |
| Monofilament fishing line | ∅ 0.22 mm | 100 meters |
| PET screws with nuts | M5 x 25 mm | 40 pcs |
| Mylar sheets | 735x300x0.1 mm3 | 4 pcs |
| Kapton adhesive tape | 10 mm width | 8 m |
| Copper adhesive tape | 10 mm width | 10 cm |
| Double-sided adhesive tape | 20-30 mm width | 10 cm |
| Special conductive paint | - | 100 ml |

There are four main areas (rooms) in the workshop (see Fig. 3.29):

1. Clean rooms for washing and drying glass.
2. Room for applying the conductive paint to the glass.
3. Clean room for MRPC detectors assembling.
4. Hall for modules assembling and testing.

**Procedures to do in the area 1 (washing and drying):**

1. The required number of glasses is checked for defects (splits, cracks and dirty) and measured their thickness.
2. Glasses rinsed ordinary water to wash away particles of glass dust.
3. Container with glasses is placed into the ultrasonic bath with special detergent where the glasses are washed for 10 minutes at the temperature of about 50 ºC.
4. Glass after cleaning in the ultrasonic bath thoroughly washed under a shower of deionized water to wash away the detergent residues.
5. Container with washed glasses is placed in a drying oven for 1 hour at the temperature of 70 ºC.
6. Glasses in container after drying are moved from the oven to the closed shelves in the same room.
7. Container with clean glasses is transferred to the assembly room.

**Procedures to do in the area 2 (painting conductive layer):**

1. Container with cleaned outer glasses brought to the room for applying conductive layer.
2. Preparation of glass for coating by conductive layer:
   1. Each glass is taken out from the container and is blown by “ionizer” for preventing the adhesion of dust.
   2. Glasses are placed on the painting surface so that the paint consumption was minimal.
   3. The high-voltage contact is glued on the glass to the side for painting.
   4. Glass fixed on the edges by adhesive tape (3-5 mm from the edge of the glass).
3. Prepared glasses are placed in a fume hood.
4. The first layer of paint applied on the glass and dried by blow-dryer for 5 minutes.
5. The second layer is applied and also dried for 5 minutes.
6. The glasses are placed in a drying oven for 12 hours at a temperature of 90 °C.
7. Painted and dried glasses removed from the oven.
8. The adhesive tape removed carefully (so as not to damage the edge of the paint and glass).
9. Surface resistance is measured at the 6 – 10 points of the conductive layer. It must be within 5 – 20 MΩ/□.
10. Ready-to-assemble glasses transferred to the assembling room.

**Procedures to do in the area 3 (MRPC assembling):**

1. Honeycomb panels are glued to the PCB:
   1. In the special place outside clean room the surface of the honeycomb panel treated sandpaper and wiped with isopropyl alcohol.
   2. Clean PCB's are transferred on the granite table for gluing with honeycomb panels.
   3. The surface of the PCB with strips wiped with isopropyl alcohol.
   4. Epoxy adhesive applied on the surface of the honeycomb panel.
   5. Honeycomb panel is pressed to the PCB on the side with strips and pressed down by the load (for example lead bricks).
   6. The adhesive completely dries within 24 hours.
   7. Surface is checked for flatness by mechanical method.
   8. Boards with glued panels are ready for assembly.
2. Preparation of external PCB for assembling:
   1. External PCB with honeycomb panel placed on the granite table.
   2. The external glass sheet is put to the PCB, the surface painted with the resistive paint facing the PCB.
   3. Wire soldered to high voltage contact and insulated by polyimide tape.
   4. Glass is glued on the edges to the board by 10 mm polyimide (Kapton) adhesive tape.
   5. Plastic screws (M5 x 25) are installed to the holes at the edges of the PCB.
   6. Board immovably fixed to the table.
3. Monofilament diameter of 0.2 mm binds to the first screw.
4. Monofilament is wound on the screws in the form of a triangle.
5. Mylar strips (5 mm width) are glued to the both short edges of the inner thin glass.
6. Inner thin glass (with) placed on the monofilament fishing line.
7. Steps 4 – 6 are repeated until the five layers of monofilament fishing line will lie in the stack.
8. Preparation of the internal readout electrode:
   1. The inner electrode consists of two identical boards with strips separated by a honeycomb panel (5 mm width).
   2. Second glass with conductive coating is put conductive paint down on the one PCB of internal electrode. The high-voltage contact must be positioned on the PCB so that the anode and cathode contacts located on the diagonal.
   3. Wire soldered to inner high voltage contact and insulated by polyimide tape.
   4. Glass glued around the perimeter of a polyimide tape 10 mm (3-5 mm from the edge).
   5. Internal electrode is laid glass side down to the 5th layer of the monofilament line. Before lying the both surfaces are blown ionizer.
   6. The PCB is pressed tightly to the line.
9. Third glass with conductive coating put conductive paint down on the other side of internal electrode in accordance with items 8.2 – 8.4. High voltage contact must be at the same position that on the other side of internal electrode.
10. Second stack assembled like the first in order of 3 – 7.
11. The upper outer board prepared in accordance with step 2 and placed on the last fishing line layer in the second stack.
12. Assembled detector carefully pressed down by lead brick and stacks fixed by PET nut.
13. Two twisted pair cable soldered to each strip (one pair to one stack) and combined at the amplifier input.
14. Ready detector checked for defects on the special stand:
15. Cracks searched by laser.
16. Glass plates integrity in assembled MRPC are controlled with video camera.
17. The readout differential line checked for the absence of reflections and the quality of the electrical contacts with generator and oscilloscope.

**Procedures to do in the area 4 (TOF module assembling):**

1. The module box is placed on the table.
2. The first detector is fixed to the box in the recess.
3. The remained detectors are stacked and fixed in a box.
4. After the installation of the detectors the lid fixed above the box.
5. Connect all the connectors inside.
6. Close lid and fix it by screws.
7. Test module on gas tightness.

## Modules installation procedure

The four TOF modules located inside each of the 12 sectors will be kept in position by two rails fixed to the space frame. The space frame is a supporting structure inside the barrel which located between TOF and ECal. Four bushes are attached to the aluminum frame of pair modules; they allow the sliding of modules along the rails suspended from the space frame. The bushes are located along the edges of aluminum frame, parallel to the beam axis, two of them on one side and two on the other side. The mounting of the sliding system to the module has been studied in such a way as to allow the compensation of the changing distances and orientation induced onto the supporting rails by the progressive deformation of the space frame under the loads applied by the installation of different detectors. To allow this every bush will be attached to the module by means of a system having the appropriate degrees of freedom, translational and rotational. The system will allow to compensate for a maximum difference of 5 mm and a few degrees.

The installation will be done once the space frame will be inside the barrel. Two pairs of modules will be inserted in their position on both sides of the frame. This will be done by means of a rigid support structure. The structure is equipped with a pair of adjustable rails of the same kind used inside the space frame. To insert a module inside the space frame it is enough to suspend the structure with the hall crane in front of the chosen services sector and connect the rails together to form a unique sliding line that will allow to push the module in the right position. The supporting structure is designed in such a way as to allow the positioning of the module at the different angles corresponding to the ones of the sectors. The requested positioning precision is not high (of the order of a millimeter), so a simple mechanical reference is sufficient to deﬁne the position.

In the future, as a consequence of discussions with the Collaboration, it is possible to envisage, if required, a different installation procedure.

# Service

## Gas system

TOF detectors will be operated with a non-flammable Freon rich gas mixture containing 90% C2H2F4 + 5% i-C4H10 + 5% SF6. A total gas volume of barrel is approximately 3000 liters. Volumes of all elements of the TOF system are presented in the Table 4.1.

**Table 4.1:** Volumes of the elements of the MPD TOF.

|  |  |  |  |
| --- | --- | --- | --- |
|  | **Number of detectors** | **Gas volume without MRPC detectors, liters** | **Gas volume with detectors, liters** |
| Detector | 1 |  | 8 |
| Module | 6 | 111 | 63 |
| Supermodule | 24 | 444 | 252 |
| TOF Barrel | 288 | 5328, ~5.3 м3 | 3024, ~3 м3 |

### Simple gas system for testing elements of the TOF

Now we use for MRPC tests simple gas systems without reflow. Gas systems almost identical both at the cosmic stand and at the MPD Test setup (see chapter 2.3). This system based on MKS 1479A controller. The flows of component gases will be metered by MKS mass flow meters, which have an absolute precision of 0.3% under constant conditions. Flows will be monitored by a process control computer, which continuously calculates and adjusts the mixture percentages supplied to the system. The flow of gas mixture can to be adjusted in range from 3 l/hour up to 20 l/hour but running flows will be typically about 30% of full-scale flow on the mass flow controllers. Gas will successively blow modules and go out to atmosphere through oil bubbler.

**Table 4.2:** Parameters of the existed “Test beam MPD” gas system.

|  |  |
| --- | --- |
| **Parameter** | **Value** |
| Gases | C2H2F4, i-C4H10, SF6 |
| Number of channels | 4 |
| Maximum flow rate | 20 l/hour |
| Reflow system | No |
| Working pressure | < 2 bar |

|  |  |
| --- | --- |
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| **Figure 4.1:** The scheme of the MRPC gas system at the MPD Test area: 1 – gas bottles; 2 – gas pressure regulator; 3 – safety gas pressure regulator; 4 – control manometer; 5 – MKS1479A flow meter; 6 – MKS647C gas controller; 7 – interface cables; 8 – gas mixer; 9 – detector; 10 – oil flap. | |

### A closed loop circulation gas system

Although the gas volume of the detector is relatively big, the high cost of the gas mixture makes a closed loop circulation system necessary in the future.

Principal scheme of the closed loop gas distribution system is shown in Fig. 4.2. The mixing unit and purifier will be located in the special room. Gas supplies should be located in a separate building (gas storage). Circulating rack can be situated near the MPD detector.

In the same way as in the simple system primary gases through the main pipelines come under pressure into the mixing system room. Here the pressure is reduced with gas pressure regulators. The gas components are mix in a certain proportion in the gas mixing. From the mixer unit the mixture is sent to the purification system where oxygen and water filtered out directly within the gas loop by cartridges filled with activated copper. From the purification system mixture is transmitted to the MPD zone into the recirculation system to be distributed into the 12 TOF supermodules. With the help of the pump module the return gas from the detector is compressed and pumped back to the gas mixing room where it is recycled with the help of the purifiers. The loop pressure regulation is performed by acting on the suction speed of the compressor; this reaction mechanism is driven by the pressure sensor located at the detector.

|  |
| --- |
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| **Figure 4.2:** Schematic of the proposed TOF closed loop gas distribution system. |

## High Voltage supplies

The detector element of the TOF system, the MRPC, will be operated with a differential voltage of about ±6 kV, i.e. ∼12 kV across each of the two 5 gap stacks. The maximum expected rate at the MPD experiment will be of the order of 50 Hz/cm2 and assuming that the average charge produced in by minimum ionizing particle ∼3 pC [18], the current and the power consumption of the TOF detector can be evaluated as shown in Table 4.3. The measured power consumption and the values quoted in Table 4.3 confirm that the MRPCs are low power devices.

**Table 4.3**: Estimates of the current and power for the HV system.

|  |  |  |
| --- | --- | --- |
|  | **Current** | **Power** |
| MRPC | 330 nA | 3.4 mW |
| Module (6 MRPCs) | 2 µA | 24 mW |
| Supermodule (4 modules) | 8 µA | 96 mW |
| Whole TOF system (12 sectors) | 96 µA | 1.16 W |

High performance and high reliability High Voltage power supplies need for stable operation of the TOF system. The CAEN N471A power supply used for all tests of MRPCs. This device has a good performance, but at the same time it cannot be used in the MPD experiment because of the impossibility of remote control, large size and high cost of a single channel.

A multi-channel high voltage system with remote control and a relatively small cost needed. The “HVSys” [19] high voltage power supplies meet these requirements. Sample HV source with all necessary characteristics especially for the TOF system were ordered. Device is housed in the crate Euromechanics-6U (Fig. 4.3). It consists of a controller, the main power supply, and several high voltage cells. Main characteristics of the “HVSys” high-voltage source are given in Table 4.4.

Remote control of the source is carried out by the RS-232 or USB interface. It is possible to use Ethernet control and integration of the high voltage source to the Slow Control System database. Control program in TCL has user friendly graphical interface (Fig. 4.4) and can be run in Linux or Windows operation systems.

In the case of supplying of one TOF module from one differential channel of this power supply we need only 3 such devices.

|  |
| --- |
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| **Figure 4.3:** Example of 420-channel HV source in the "Euromechanics" format (TRT ATLAS). |

|  |
| --- |
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| **Figure 4.4:** HVSys power supply remote control user interface. |

**Table 4.4:**  TOF power supply “HVSys” main parameters.

|  |  |
| --- | --- |
| **Parameter** | **Value** |
| Number of channels (pair of ±) | 40 (20) |
| Minimum voltage per channel, V | ±1200 (ramp up: 2 – 4 sec) |
| Maximum voltage per channel, V | ±12000 |
| Output voltage ripple at Imax (pick-to-pick) | ~ 10E-4 (10Е-5) |
| Voltage ramp up speed, V/sec | 0.5 – 125 |
| Maximum current per channel, μA | 60 |
| Precision of the voltage monitoring | 3V (12 bit) |
| Precision of the current monitoring | 12 bit (I ≤ 8 μA: 2 nA)  (8 < I < 60: 15 nA) |
| Output connector | Radiall SHV (RG58/U) |
| Remote control interface | USB, RS232, Ethernet |

## Low Voltage power distribution

The power consumption of one FE card is 1.35 W. The total power consumption of the TOF is less than 800 W. Such a small power allows using a simple and cheap power supply scheme. Two options are considered to supply LV power to the electronics:

1. Power supplies located immediately outside the MPD magnet, in the experimental hall, delivering the needed voltage and current directly to the load.
2. DC-to-DC converter placed inside the magnet as close as possible to the load. Such converters must operate in a high magnetic field (possibly up to 0.5 T) and substantial radiation environment.

In both options the main low voltage power supplies will be located as close to the detector as possible, but outside the magnetic field region.

We consider now the first of the two LV system options mentioned above. The closest location for the power supplies is at ∼15 m on each side of the barrel. The detector is subdivided in 12 + 12 half sectors. Each half sector needs ∼33 W at 3.3 V for the analogue electronics. We will then use four cable lines for the analogue circuitry of half a sector (one cable for six FE cards). Each cable line will draw a current of only 2.5 A. Allowing about 0.5 V voltage drop through the 15 m line, the cross section of each bus bar order of 2 mm2. The power dissipation on one cable less than 1W. The location of power supplies outside the MPD magnet allow to use simple and chip AC-to-DC supplies. For example Mean Well DR-4505 DIN rail power supply (one 25 W output channel).

The second option of LV system is based on delivering the power at higher voltage (48 V or more), using LV power supplies located outside the MPD magnet and converting it, using DC-to-DC converters, to the required voltages in a region very close to the electronic cards. The main concern in this choice is that the region where the DC-to-DC converters should be located is irradiated and with a significant magnetic field (up to 0.5 T). Commercially available DC-to-DC converters are not able to operate in magnetic field higher than 0.05 T. Several companies are developing DC-to-DC converters with characteristics that would be suitable to the MPD environment. Among them, CAEN has a solution based on the use of toroidal coils.  
Discussion on the choice of the LV system continues.

## Slow control for the TOF system

Slow control system (SCS) refers to a computer system that monitors and/or controls one or more systems for failure prevention, monitoring, direct control by the user or automated control.

User interaction with SCS is based on a toolkit named TANGO control system, which also has been used at the Nuclotron in JINR. TANGO is software for building control systems, which need to provide network access to hardware. Hardware can range from single bits of digital input/output up to sophisticated detector systems.

All connections with devices are based on Ethernet. For devices without network access, like temperature sensors with RS-485 interface, Serial-to-Ethernet MOXA NPort convertors are applied. Acquired data from devices is being archived into database for further analysis and handling. TANGO control system provides handy tools for browsing data history.

An example of the temperature and gas flow monitoring which is carried on the cosmic test stand is shown in Fig. 4.5.

Time-of-Flight system of MPD is necessary to monitor several parameters of different subsystems such as temperature monitoring, voltage monitoring, gas flow monitoring and so on. In Table 4.5 are listed subsystems with controlled parameters and control devices. At present, most of the slow control system has been developed and continues to develop. In the right column of the table indicated the planned additions and changes of the system.

**Table 4.5:** Status of the TOF slow-control system.

|  |  |  |  |
| --- | --- | --- | --- |
| **TOF Subsystem** | **Monitored value** | **Devices for monitoring,**  **realized** | **Planed** |
| Detector | Temperature, pressure | Up to 255 on single line DS1624-based temperature sensors. | Honeywell HSCDRRN005PD2A5 pressure sensors. |
| Gas system | Flow, pressure | 4-channel MKS 647C and MKS 247C gas flow controllers. readout. | Readout and control directly from the MKS 1479A flow controller. |
| Low Voltage | Voltage, current | 10-channel ICP DAS PET-7017-10 voltage monitoring. | Integrated voltage and current control. |
| High Voltage | Voltage, current | CAEN N471A source current monitoring by 10-channel ICP DAS PET-7017-10. | Integrated voltage and current control and monitoring. |
| Front-End Electronics | Voltage, threshold | ICP DAS PET-7017-10 voltage monitoring. | Threshold control and monitoring. |
| DAQ, Readout Elecronics | Temperature, voltage, current | --- | Read values to the database. |

|  |
| --- |
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| **Figure 4.5:**TANGO example of the temperature and gas flow monitors. |

## Power consumption and cooling

The power consumption foreseen for the TOF subsystems is 5.5 kW (see Table 4.6). There are two separate volumes inside the Barrel which power dissipation of 4.3 kW.  The first volume is Front-End Electronics space over the gas box, where 15 W/m2 of the thermal power is dissipated. The second volume which contents the Readout Electronics (TDC) is located on both ends of the every sector where about 150 W of the thermal power is dissipated in small space (80x20x16 cm3). To keep the temperature within the MPD specifications an air cooling system is envisaged. A rack with equipment which power consumption about 1.2 kW will be located in the experimental hall.

**Table 4.6:** TOF subsystems power consumption.

|  |  |
| --- | --- |
| **Part** | **Power, W** |
| Power of FEEs, W | 800 |
| Power of Readout Electronics (TDC), W | 3500 |
| LV system | 500 |
| HV system | 200 |
| Power of slow control devices | 500 |
| **Total** | **5500** |

# Timetable and cost estimation



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