Bulgarian Chemical Communications, Volume 47, Special Issue B (pp. 215–221) 2015

Fast detectors for the MPD/NICA time-of-flight system

V. Babkin, S. Bazylev, O. Batenkov, P. Dulov*, V. Golovatyuk, S. Lobastov, V. Petrov, M. Rumyantsev, A. Schipunov, A. Shutov, I. Slepnyov, V. Slepnyov, A. Veschikov, S. Volgin, V. Yurevich

Laboratory of High Energy Physics, Joint Institute for Nuclear Research
6 Joliot-Qurie Str., 141980 Dubna, Russia

The Multi-Purpose Detector (MPD) [1] is being developed to study properties of hot and dense baryonic matter in collisions of light and heavy ions on the collider NICA which is under construction at JINR, Dubna [2]. Identification of charged particles in the range 0.1–2 GeV/c is carried out with Time Projection Chamber (TPC) in solenoid magnetic field and time-of-flight (TOF) system. It has been decided to use MRPCs with strip and pad readouts as a basic element of the TOF detector. Beam tests results of full scale mRPC prototypes with readout electronics are described in this article. As a start detector for the time-of-flight system we used detector based on microchannel plate photomultipliers with the time resolution of ~ 37 ps.

Key words: MPD, MRPC, particle identification, ToF, FFD, fast electronics, transmition line

INTRODUCTION

The MultiPurpose Detector (MPD) is proposed for a study of hot and dense baryonic matter in collisions of heavy ions over the atomic mass range A = 1 – 197 at a centre-of-mass energy up to $\sqrt{s_{NN}}$ = 11 GeV (for Au^{+78}) and luminosity $L = 10^{27} m^{-2} c^{-1}$. The MPD experiment is foreseen to be carried out at accelerator complex facility for heavy ions – the Nuclotron-based Ion Collider fAcility (NICA) which under construction now at JINR, Dubna.

The MPD consits of a barrel part and two end-caps located inside the magnetic field. 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 $|\ \eta\ | < 1.2$. The end-caps are aimed for precise tracking and particle identification over pseudorapidity range $(1.2 < |\ \eta\ | < 2)$. The principal tracker is the time projection chamber (TPC) supplemented by the inner tracker (IT) surrounding the interaction region. Both subdetectors (IT and TPC) has to provide precise track finding, momentum determination, vertex reconstruction and pattern recognition. The TPC and IT together with time of flight system have to provide charged particles momentum measurement.

Due to the fact that in most recent experiments in high energy physics such as Alice(LHC) and STAR(RICH) time-of-flight systems are based on multi-gap resistive plate chambers (MRPC) [3] were successfully used in the TOF systems, we decided also to use MRPCs on the base of flat glass for the time-of-flight system of the MPD. This article presents the results of the tests of MRPCs on the deuteron beam of Nuclotron at JINR of different design and readout electrode geometry [4].

DESIGN 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 readouts. 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.

The pad prototype (Fig. 1) consists of two stacks having 5 gaps each. A 210 μm gas gap is formed by a ordinary fishing line of appropriate thickness. The readout electrodes are fiberglass boards of 140×120 mm^2 with etched rectangles of 16×35 cm^2. 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 MOhm per 1 square. Signals from the pads are transferred via the twisted pair cable to the amplifier. The detector is situated in a leak-tight box in which a gas mixture (C2H2F4 – 90%/iC4H10 – 5%/SF6 – 5%) is injected.

* To whom all correspondence should be sent:
dulov.bg@abv.bg

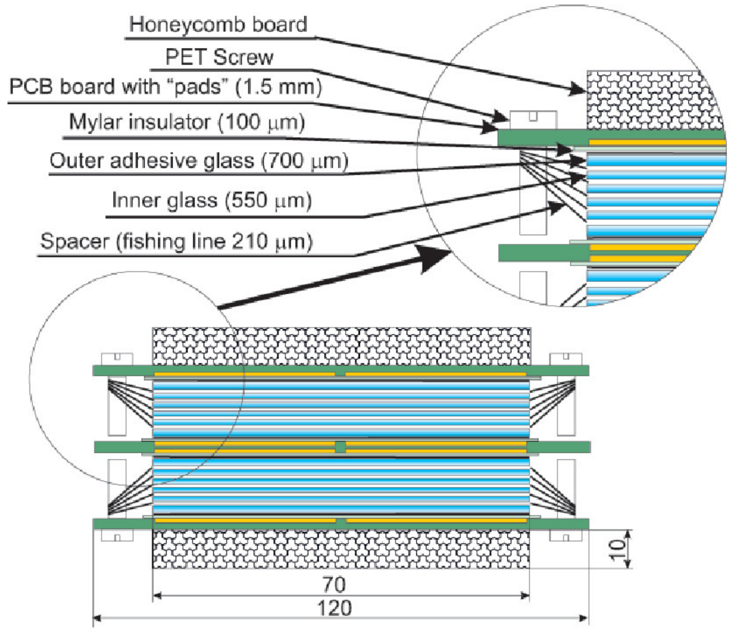


Fig. 1. Schematic view of a pad MRPC.

Full-scale strip MRPC prototypes were developed and produced for the barrel part of the time-of-flight system. The readout electrodes of these prototypes were designed as thin narrow strips. The sectional view of this prototype is shown in Fig. 2. The active region area of the MRPC was determined by the size of the glass and amounts 590×290 mm^2. The design almost completely duplicated the one of pad detectors. Three different strip MRPCs were assembled for the first test run. A single-stack MRPC prototype was assembled for the first test run at the Nuclotron beam having 5 gas gaps with the thickness of 250 μm and 24 strips with the size of 600×10 mm^2. For the second run the design of the strip detector was changed and two prototypes were assembled: a single-stack prototype having 6 gas gaps of 220 μm and 48 strips of 600×5 mm^2 and a double-stack MRPC with 12 gas gaps of 220 μm (6 per a stack) and the same strips that the single-stack prototype had. Such a design modification was fulfilled based on the first experiment's results.

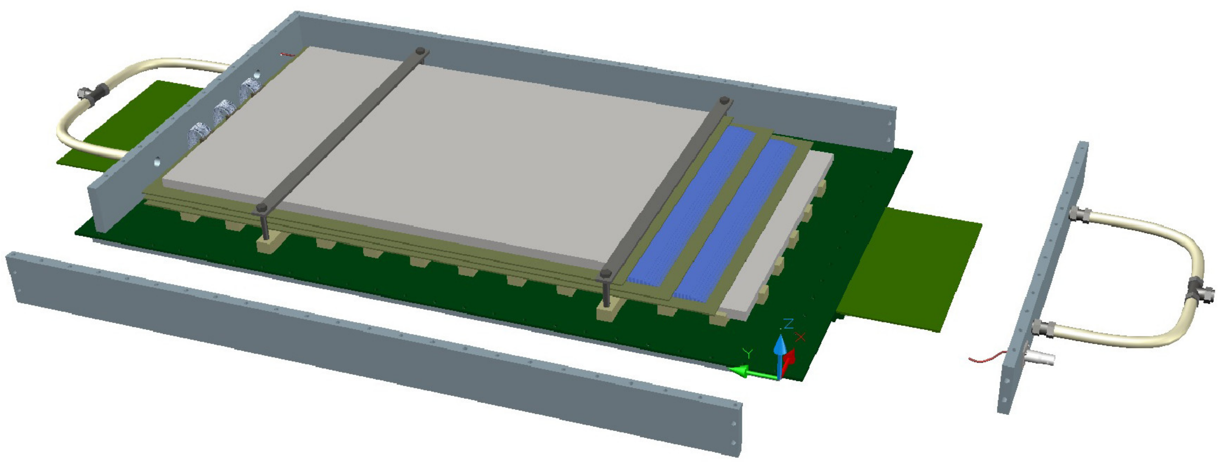


Fig. 2. Sectional view of the full-scale strip MRPC prototype.

FFD START DETECTOR

The signal from the Fast Forward Detector (FFD) will be used as a start signal for the time-of-flight system [5]. The Fast Forward Detector is a double-arm Cherenkov detector for high energy photons. Each arm of the detector consists of 12 modules laid in the shape of square around the beam pipe. The arms are placed 75 cm off the expected interaction point on both sides along the beam axis. The main functions of the detector are the following:

- generation of the fast high-precision start signal for time-of-flight measurements;
- reconstruction of the interaction point along the beam axis with the accuracy of ± 1.5 cm;
- production of signal for the L0-trigger system with selection of nuclei collisions occurring close to IP.

Each module of the FFD is a sequential assembly of the following elements: a 7–10-mm thick lead plate; a 15-mm thick quartz radiator; a micro-channel XP85012Q photomultiplier by Photonis; front-end electronics and a high voltage divider. High energy photons are converted into relativistic electrons in the lead plate. These electrons entering the quartz radiator emit Cherenkov light which is registered by the photomultiplier. The active area of the photocathode of the XP85012Q photomultiplier, which is sensitive to the visible and ultraviolet regions of wave lengths (170–670 nm), is 53×53 mm^2 and covers 81% of the front area of the photomultiplier. The photomultiplier has multi-anode structure of 8×8 anodes; its gain of the order of $\sim 10^5$–10^6 depends on the applied high voltage value, good linearity of the output signal with the leading edge of 0.6 ns and the transit time spred of $\sigma \sim 37$ ps [6].

Each module has 4 quartz radiators of 3×3 cm^2 which are light-isolated from each other. There are 4×4 anodes of the photomultiplier per each quartz radiator; signals from them are added together and transferred to the front-end electronics. The front-end electronics produce analog and digital LVDS signals and its width informs of the pulse height. Thus, each module has 4 independent channels.

READOUT ELECTRONICS

In order to increase the differential signal accepted up from the MRPC's pads and strips, a 24-channel amplifier on the base of a NINO chip was used [7], which was specially designed for the time-of-flight system of ALICE and now is the most common amplifier for time-of-flight MRPCs. This amplifier has a highly rapid output signal (<1 ns) and small jitter of the output signal (< 10 ps), which is provided by the low noise level of the amplifier. Another characteristic feature of the NINO chip is the possibility to change input resistance in order to match it with the readout electrodes. A discriminator with the minimal triggering threshold of about 25 fC is imbedded into the NINO chip. The discrimination threshold was set at 75 fC for all the conducted experiments. The output signal from the discriminator is LVDS-standard differential signal. The leading edge of the pulse corresponds to the time of its passing through the threshold, and its width corresponds to the amplitude of the input pulse, which allows one to make time-amplitude correction with the use of only one TDC.

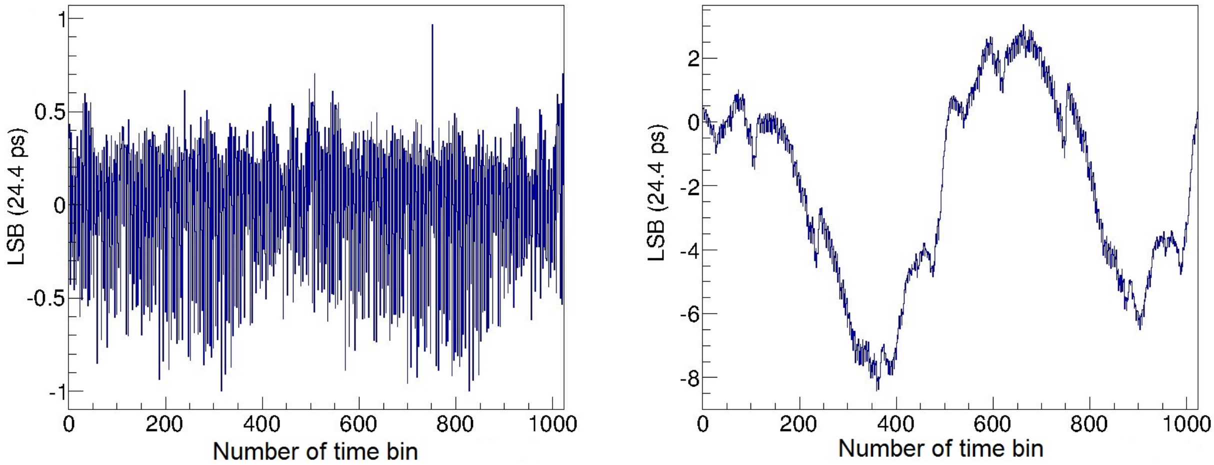
32-channel time-to-digital converters (TDC32VL) based on HPTDC chip were developed and produced for digitization of LVDS signals and data acquisition [8].

Experiments on the MRPC time resolution evaluation conducted in March of 2011 showed that integral nonlinearity occurs with TDC operating in the mode of 24.4 ps per bin as a result of cross talk to channels of the signals from clock speed generators in 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 [9] as well as in other publications [10, 11].

The method of uniform filling the time gap with random events (code density test) was used for calibration (consideration of nonlinearity) of VME TDC32VL module. Minor differential (Fig. 3 (a)) and strong integral (Fig. 3 (b) nonlinearity in terms of time were observed distracting the measured value for 8 bins ($\sim$ 200 ps) from the real time, which deteriorated significantly the time resolution of the electronics. Calibration matrices were developed for further data processing for each channel of the TDC allowing for elimination of the integral nonlinearity contribution. Native time resolution of a TDC32VL channel made up about 25 ps after applying the calibrations.

TESTING THE PROTOTYPES AT THE ACCELERATOR BEAM

Tests of the prototypes were carried out at the Nuclotron deuteron beam at LHEP JINR in December 2012 and March 2013. The deuteron beam with the



(a) (b)

Fig. 3. Differential (a) and integral (b) nonlinearity of HPTDC.

energy of 1 GeV/n and spill duration of 2 s was injected into Building 205 and with the use of magnet optics was sent to the experimental setup (Fig. 4). A scintillation telescope made up of C1-C5 counters was used for trigger signal obtaining. At that, C5 counter corresponded in size to the FFD prototype's effective surface and was placed immediately before FFD-1. The following MRPC prototypes were tested: two identical double-stack pad prototypes (PRPC) and three full-sized strip prototypes (SRPC).

Two identical FFD prototypes were studied in the experiments. The detectors were placed one after another along the beam line with the minimal gap between them. The signal from one of the detectors was considered as "start", and the signal from another – as "stop".

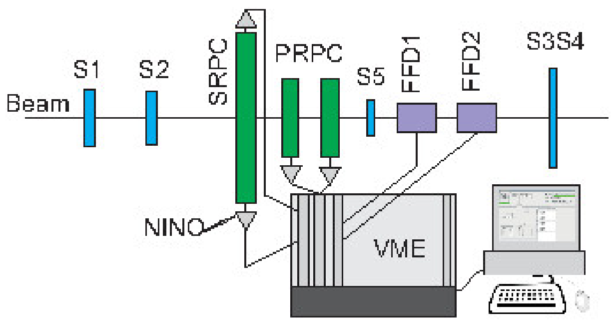
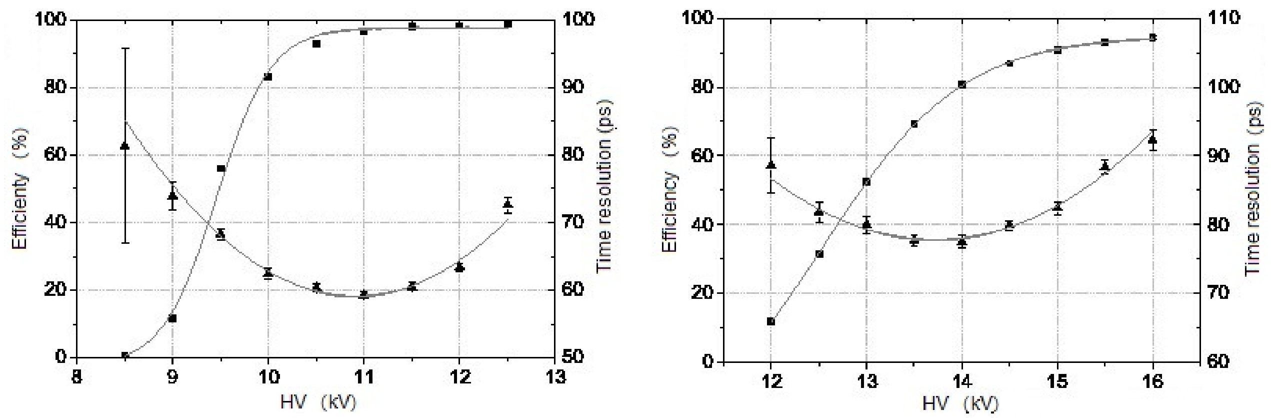


Fig. 4. Layout of the experimental setup. S1–S5 – a scintillation counters; FFD-1, FFD-2 – start detectors (FFD prototypes); PRPC – pad prototypes; SRPC – strip prototypes, VME – a crate with the readout electronics.

The detectors FFD1 and FFD2 was used as a start detector T0 in all the experiments and had the time resolution of 37 ps with TDC32VL, as it was measured early [5]. This value was used later on for calculation of the time resolution of MRPCs.

The dependencies of efficiency and time resolution on voltage for pad chambers and a single-stack chamber with a 10 mm-wide strip were measured in the experiment in December 2012. Time difference between the T0 detector and PRPC was measured without any corrections. Time distribution for PRPC is worse than 120 ps in this case. The LVDS pulse width corresponds to the height of the signal. Therefore the time-over-threshold method of correction was used. Approximation of the distribution of time depending on the width of the signal allows one to obtain the ratio for correction. When the time-over-threshold dependence was taken into consideration, time resolution improved significantly. The same procedure was done for the SRPC. The best time resolution came to 60 ps for PRPC and 80 ps for the SRPC in December 2012 experiment was achived.

Fig. 5 demonstrate the dependencies of the efficiency and time resolution of the first prototypes versus voltage. The detector operated in the optimal mode as the maximal resolution could be achieved at the efficiency of about 98%. In contrast to the pad MRPC, the efficiency of the first prototype of the strip MRPC made up 80% at the best time resolution and it didn't exceed 93% even at the voltage increased up to 16 kV. Such degradation of the time resolution at the low efficiency was associated with the contri-



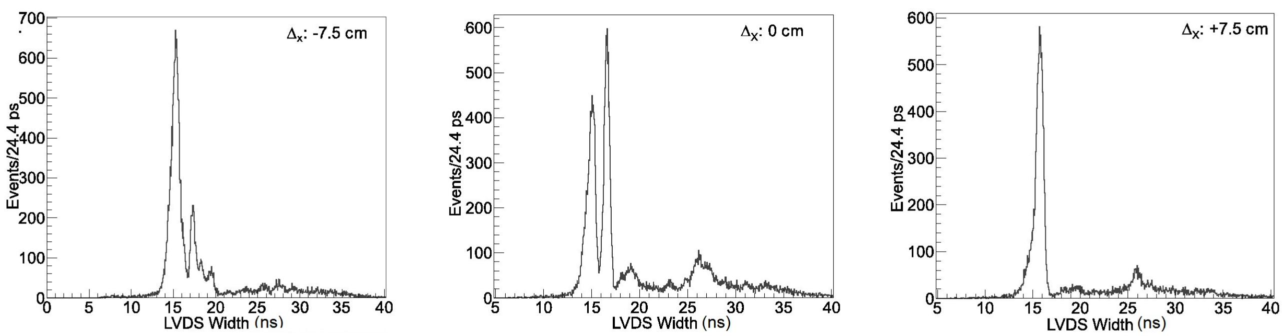
(a) (b)

Fig. 5. Time resolution and efficiency for PRPC (a) and SRPC (b) in first experiment.

bution of the signal reflection from the edge of the strip. The reflection was caused by bad matching of the strip (which impedance is about 75 Ohm, according to the calculations and measurements) with cable and amplifier. An 8-cm long ribbon twisted pair cable with the impedance of 110 Ohm was used. For this reason splitting was observed of the width spectrum of the output LVDS signal. As a consequence, the information on the actual pulse height was distorted. Such splitting may be caused by interference of the reflected signal with the trailing edge of the main pulse. It is supported by the fact that the position of the second width peak and its value depends on the coordinate of the particle passing the detector along the strip (Fig. 6).

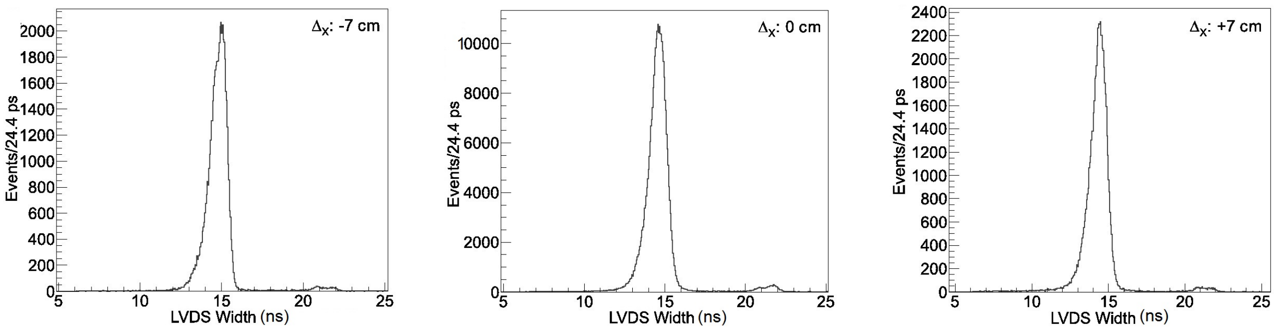
A similar problem arose during the work with the MRPC with a long strip [12]. In order to avoid splitting of the width spectrum, the strip is matched with the amplifier by adjusting the input impedance of the amplifier. According to the manual, the input impedance of the amplifier can be changed within the range of 20 – 100 Ohm. In our case, such a method hardly influenced the width spectrum and it was decided to change the design of the detector and the way of accepting the signal because the main reflection take place in the point of strip-cable.

Two new MRPC prototypes with strip readouts were assembled for the experiment at the Nuclotron beam in March 2013. The first prototype represented a single-stack six-gap chamber with the gap width of 220 μm and a 5-mm wide and 600-mm long readout strip. The active area of the detector remained of the same size of 290×590 mm^2, however the number of channels per one detector increased twice. As pulse generator tests demonstrated, this construction was well matched with the signal transmission line.



(a) (b) (c)

Fig. 6. Splitting of the width spectrum of the SRPC (10 mm) LVDS signal as a function of the coordinate. (a) shifted by 7.5 cm from the strip center; (b) in the center of the strip; (c) shifted by +7.5 cm from the center.



(a) (b) (c)

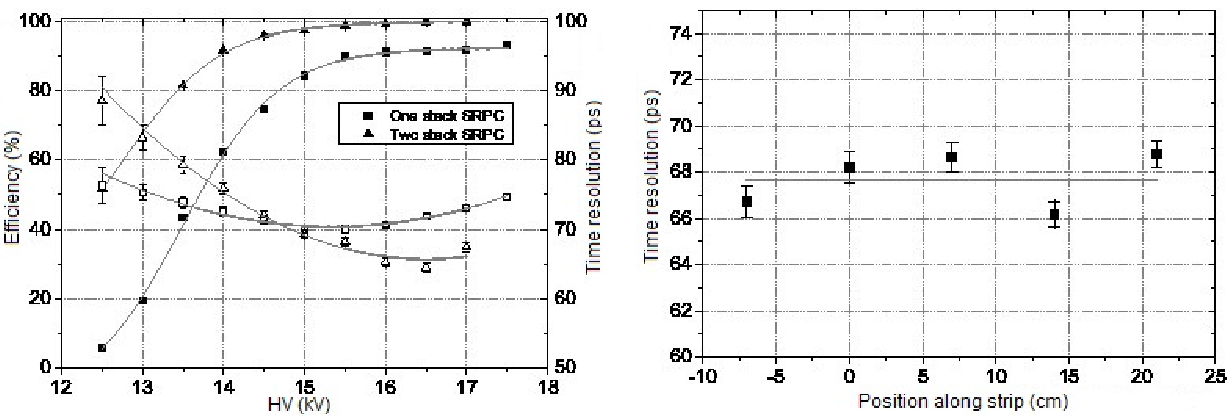
Fig. 7. Spectra of the single-stack MRPC (5 mm) prototype with the strip readout and a matched strip for particles passed through different points of the strip: (a) shifted by 7 cm from the strip center; (b) in the center strip; (c) shifted by +7 cm from the strip center.

It was discovered in the course of the experiment that the width spectrum splitting was almost absent with such a configuration (Fig. 7).

Calculations predicted the efficiency of the single-stack chamber will not exceed 90%. Therefore, a double-stack MRPC was assembled with the same stacks as the described single-stack one. The results on the efficiency and time resolution of the single- and double-stack strip MRPC prototypes obtained from March's run are shown in Fig. 8 (a).

As it was expected, the efficiency of the single-stack prototype made up 92%. In this case the best time resolution was in the limit of 70 ps. The efficiency of 99.9% and time resolution of about 65 ps were achieved for the double-stack version. An important feature of the two-ends strip readout is possibility to position quite precisely the particle passing along the strip. Using the time difference between arrivals of signals from the left and the right ends of the strip, it is possible to reconstruct the point of the particle transit. The position resolution in this case is about 5 mm.

It was suggested that due to non-symmetric location of strips in the double-stack SRPC, degradation of the pulse front edge might occur and, as a result, the time resolution might decrease. In order to prove this effect, the dependence was measured of the time resolution on the point of the particle transit through the strip (Fig. 8(b)). It is shown that the time resolution remains almost the same with the coordinate being changed. I.e. dispersion has little impact on the signal.



(a) (b)

Fig. 8. (a) test results for the MRPC prototype with a 5-mm wide strip. (b) time resolution of the double-stack SRPC as a function of the coordinate of a particle's flight.

CONCLUSIONS

The optimization of the full-sized MRPC prototype design was fulfilled for the time-of-flight system of the MPD. The two experiments at the Nuclotron beams allowed us to reveal imperfections of the detectors' design and to develop the MRPCs optimal for these conditions.

The results obtained for the double-stack MRPC with the strip readout and for the double-stack MRPC with the pad readout meet the requirements to the time-of-flight system of the MPD. Further investigations will be aimed at the optimization of the readout and front-end electronics. The matching will be performed for strips of various configurations, which will allow for reduction of the total number of the electronics channels.

REFERENCES

[1] Kh. U. Abraamyan, et al., *Nucl. Instrum. Methods Phys. Res., Sect. A* **628**, 99 (2011).

[2] A. N. Sissakian and A.S. Sorin, *J. Phys. G: Nucl. Part. Phys.* **36**, 064069 (2009).

[3] A. Akindinov, et al., *Nucl. Instrum. Methods Phys. Res., Sect. A* **456**, 16 (2000).

[4] V.A. Babkin, et al., *Bulletin of the Russian Academy of Sciences: Physics* **75**, 1277 (2011).

[5] V.I. Yurevich, et al., *Physics of Elementary Particles and Atomic Nuclei, Letters* **10**, 414 (2013).

[6] J. Va'vra, et al., Report SLAC-PUB-14279 (2010).

[7] F. Anghinolfi, et al., *Nucl. Instrum. Methods Phys. Res., Sect. A* **533**, 183 (2004).

[8] Internet site: http://afi.jinr.ru/TDC32VL

[9] J. Christiansen. *High performance time to digital converter (HPTDC)*, Digital Microelec. Group, CERN, *HPTDC manual version 2.2 for HPTDC version 1.3*.

[10] Daniel McDonald, *Calibration of the STAR Time-of-Flight Detector for Particle Identication*, MS degree thesis, Houston, Texas, December 2010.

[11] P. Antonioli, S. Meneghini, *9th Workshop on Electronics for LHC Experiments*, Amsterdam, The Netherlands, 29 Sep - 3 Oct 2003, 311.

[12] K. Doroud, et al., *Nucl. Instrum. Methods Phys. Res., Sect. A* **660**, 73 (2011).

ВРЕМЕ-ПРЕЛИТНА СИСТЕМА (TOF) НА ДЕТЕКТОРА MPD (NICA)

П. Дулов[1], В. Бабкин[1], М. Румянцев[1], В. Галватюк[1], В. Чолаков[2]

[1] *Лаборатория по високи енергии, Обединен институт за ядрени изследвания, ул. "Академик Балдин" № 4, 141980 Дубна, Московски регион, Русия*

[2] *Физически факултет, Пловдивски университет "Паисий Хилендарски", ул. "Цар Асен" №24, 4000 Пловдив, България*

(Резюме)

Концептуалният дизайн на многоцелевия детектор MPD (Multi-Porpose Detector) е създаден за изучаването на горещата и плътна барионна материя от сблъсъците на тежки йони с атомна маса в диапазона $A = 1–197$ с максимална енергия 11 GeV за Au79+.

MPD експеримента ще се извърши в Обединения институт за ядрени изследвания, Дубна в новостроящия се колайдер NICA (Nuclotron-based Ion Collider fAcility) при средна яркост $L = 10^{27}$ cm^{-2}s^{-1}.

Идентификацията на заредените адрони с междинни импулси (0,1-2) GeV се постига с измерване на времето за прелитане от TOF детектора. Основен елемент на TOF е mRPC (Multi-gap Resistive Plate Chambers) – многопроцепна