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Vitalii Burtsev ✉; Temur Enik; Bogdan Topko; Evgenii Martovitsky; Alexandr Makankin; Sergey Khabarov; Oleg Tarasov; Kirill Salamatin; Elina Kasyanova; Artem Ivanov; Nikolay Zamyatin; Yuri Kopylov

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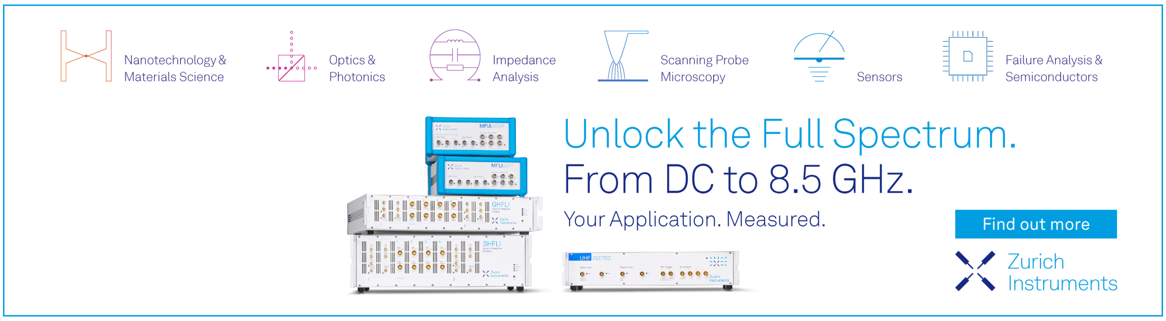

MiniSPD Testing Facility

Vitalii Burtsev,[a] Temur Enik,[b] Bogdan Topko,[c] Evgenii Martovitsky,[d] Alexandr Makankin, Sergey Khabarov, Oleg Tarasov, Kirill Salamatin, Elina Kasyanova, Artem Ivanov, Nikolay Zamyatin, and Yuri Kopylov

Joint Institute for Nuclear Research, 6 Joliot-Curie, 141980, Dubna, Moscow region, Russia

[a]*Corresponding author: burtsev@jinr.ru*
[b]*temuren@mail.ru*
[c]*bogdantopko@gmail.com*
[d]*3plix@mail.ru*

Abstract. MiniSPD is an installation for cosmic muon tests of all types of detectors to be used in the Spin Physics Detector (SPD) setup. The detectors and readout electronics for the NA64 experiment were used for testing. The MiniSPD setup includes the scintillator-based trigger system, straw, silicon, and Gas Electron Multiplier (GEM) tracking detectors, electromagnetic calorimeter, and the lead filter to remove the low-energy component of cosmic rays. The MiniSPD setup was used to measure such important parameters of detector prototypes and subsystems as the spatial and time resolution, efficiency, drift characteristics, amplification, data acquisition parameters, slow control implementation, and online monitoring systems features.

MINISPD MOTIVATION AND CONSTRUCTION

For almost three years (2018-2021), there is no extracted beam from the NUCLOTRON at Veksler and Baldin Laboratory of High Energy Physics (JINR) for any beam tests. With this in mind, the MiniSPD testing facility has been created to use cosmic muons for testing the detectors and subsystems for SPD. The initial task was to get a working framework in which pieces of equipment could be added or removed for testing. This task includes the implementation of a data acquisition system similar to that used in the COMPASS (NA58) and NA64 experiments at CERN. An essential point of the program is obtaining cosmic ray data and using prototype SPD detectors for track reconstruction. The next step is construction of the Monte Carlo (MC) model of the installation and comparison of the MC results with data. One more goal is to measure characteristics of the detectors and subsystems in order to prepare them for an upcoming experiment. An additional task is the time stability check of the detectors and components of the system over a long period, using all the prototypes of the SPD detectors or elements of these detectors in the facility.

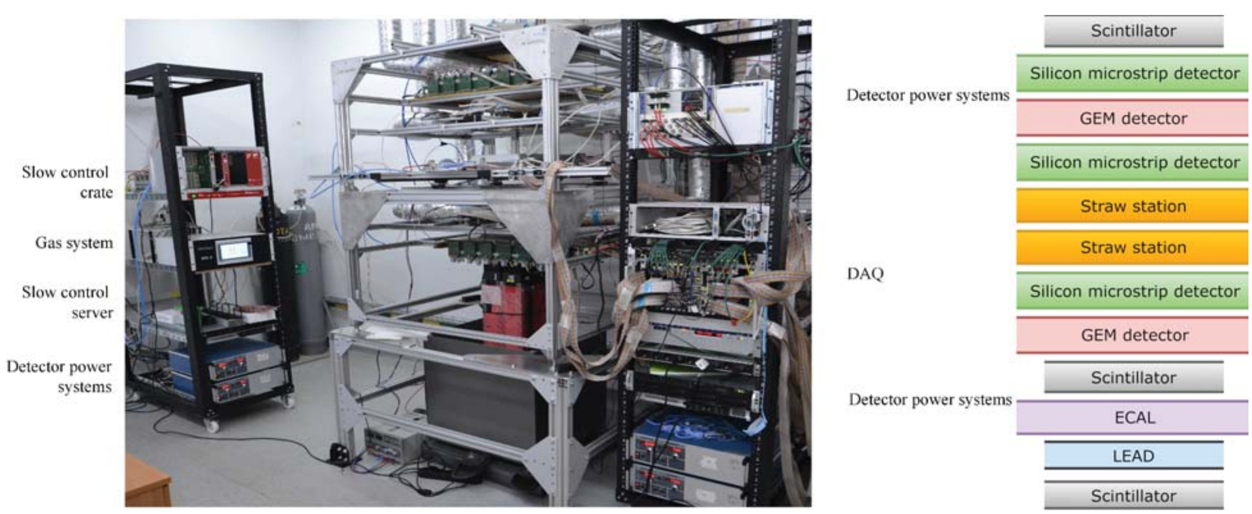

FIGURE 1. Layout (left) and scheme (right) of the MiniSPD facility.

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Main subsystems of the MiniSPD testing facility

Mechanical construction

The mechanical support of the MiniSPD is assembled from BOSCH Rexroth aluminum profiles that makes easy the maintaining of detectors, modification, and upgrade of the mechanical part with sufficient rigidity parameters. The three-dimensional model of the installation was built with the Autodesk Inventor toolkit to facilitate the alignment procedure for the reference points of the detector bodies. Their coordinates were determined using the Leica absolute tracker AT402.

Trigger system

The trigger system is based on the set of three plastic scintillators. The upper and middle ones have 150x150mm^2 of sensitive area and are equipped with a symmetrical readout of the volume using silicon photomultipliers. The sensitive area of the lower scintillator has size of 400x400mm^2 and is read by one high-voltage vacuum photomultiplier tube.

The readout system, combining transistor-based amplifier and digitizing electronics, is represented by the AFI Electronics TQDC module. It it includes a 16 channel 125 MS/s ADC with the time-stamping TDC 25 ps bin size and implemented controllable on-board coincidence logic with individual discrimination thresholds.

Silicon microstrip detectors

The BM@N silicon detector is used as a high resolution tracker, that allows to detect coordinate and amplitude of minimum ionizing particle (MIP) signals. The silicon detectors are manufactured basing on the double-sided planar technology (RIMST, Zelenograd). They have size of 63x63x0.3 mm^3. The pitch for the p+ side is 95 μm while for the n+ side it is 103 μm. The number of strips is 640 and 614, respectively. The stereo angle between strips is 2.5 degrees. An integral dark current of the detector is less than 1 μA at 150 V of bias voltage and a temperature of $+20^oC$. The MiniSPD includes three such silicon stations.

Front-end electronics of the module is based on the application-specific integrated circuit (ASIC) VATAGP7.1 (IDEAS, Norway). It has 128 channels. Each channel is equipped with low-noise and low-power preamplifiers (power dissipation per channel is 2.2 mW) as well as shapers with T_p=500 ns with a sample and hold and multiplexed analogue output. The chip dynamic range is $\pm 30 fC$. The ASIC electronic input wires are bonded to PA-640 pins. Two readout cards contain 5 encapsulated ASICs per each side of the silicon module [1].

The ADC and U40VE modules operate as a sequencer and a waveform digitizer. The U40VE module sends a sequence of pulses that are received by the VATAGP ASICs. The chip sends multiplexed data with signal values to each detector strip. Each ADC channel digitizes 128 channels or strips of the detector. The cooling system is responsible for temperature stability. The first version with a compact air cooler demonstrated low reliability and is replaced by an industrial cooler (AmeriCool Weltem WPC-4000). It operated within acceptable temperature limits, but there were significant problems with electromagnetic compatibility and interference with detector signals. Currently a closed-loop cooling system with channel-ducted air conditioning and thermal insulation of the cooling system from environment is used.

GEM detectors

Gas Electron Multiplier (GEM) detectors are used at high beam intensities and large multiplicity of charged particles with rates up to 10^6 hits per second. Each detector consists of three GEM foils with the following gaps between the electrodes: the drift gap of 3 mm, the first transfer gap of 2.5 mm, the second transfer gap of 2 mm, and the induction gap of 1.5 mm. One GEM foil is made of a 50 μm kapton foil clad on both sides with 5 μm copper electrodes. The foil is optically semi-transparent due to chemical perforation by a large number of holes with a diameter of 70 μm, separated by a distance of 140 μm. It is manufactured by the CERN PH Detector Technologies and Micro-Pattern Technologies workshop [2]. When the foil is placed between a drift cathode and a readout anode plates under a potential applied between the two sides of the foil, it behaves like a charge amplifier. It is possible to use several GEM foils to achieve gains appropriate for efficient detection of MIPs [3]. The front-end electronics used for GEMs is close to the silicon microstrip detector readout: IDEAS VA162 ASICs - 32 channel, 500 *ns* shaping time - read by ADC and uses U40VE as a sequencer.

Straw tube-based detectors

Straw tubes are planned to be used as a main tracking elements at SPD. They are used also as a low material budget detectors in the NA64 [4] experiment. The system of straw detectors include two stations. The station has 64 channels in two layers of tubes with an inner diameter of $6.02^{+0.025}_{-0}$ mm and a wall thickness of 62 μm. Each individual tube is bounded from two kapton ribbons. The internal ribbon is made of kapton (XC160) with resistivity of 370 Ohm/mm and has thickness of 40 μm. The outer ribbon made of kapton mark 100HN 12.5 μm thick with 500 Å-aluminization of the inner surface. The anode is made of gold-plated tungsten wire with a diameter of 30 μm. The gas mixture is Ar (80%) and CO_2 (20%).

The readout board for straw detector includes a charge-sensitive amplifiers based on the AST-1-1 chip [5]. These chips are specially designed to read signals from straw detectors. Each AST-1-1 chip processes signals from eight straw tubes providing eight LVDS (low voltage differential signal) outputs to the TDC [6]. They have the following parameters: input impedance is 50-560 *Ohm*, the adjustment range of the threshold of operation is 1-23 fC, duration of LVDS output signals is 70 *ns*, delay of the output signal is 6 *ns*, and supply voltage is 2.5-3.3 V. The VME64x, a 64-channel 100*ps* multihit timestamping TDC, allows one to perform precision drift time measurement.

Calorimeter

The electromagnetic calorimeter (ECAL) module consists of 16 rectangular cells with a size of $75 \times 75 mm^2$ made of fiber-riddled alternating layers of polystyrene scintillator and lead with a thickness of 1.5 *mm* and 0.3 *mm*, respectively. The construction is placed into the light-protective box. The readout uses silicon photo-multipliers manufactured by Hammamatsu. High voltage sources for Multi-Pixel Photon Counter are produced by HVSYS.

The ADC board quantize an analogue input signal with a fixed sampling time interval. The zero suppression logic is based on a baseline estimation and a threshold value. Signal shaping is performed in a digital form by the FIR filters. They allow one to reduce the number of waveform points required for a digital signal representation with a minimum loss of accuracy. The ring-type memory allows to read back of last 30 μs of a waveform. This value is the limit of the trigger latency [7].

Data acquisition system

The data acquisition system of the MiniSPD is taken from the BM@N experiment. It includes 5 64-channel ADC, 2 64-channel TDC and 1 TQDC module, a crate controller, a trigger module, a run-control, and a trigger splitter, combined in a single VME64X crate. The requirements for performance of the data acquisition (DAQ) system are quite soft because of the low rate of cosmic muons. Data from the readout electronics are collected to the main server. After receiving the trigger signal, the run control system starts the new event by propagating the trigger signal to every module. Modules set the "busy" signal until all data are transferred. The event builder receives data, waits for signal from the multiplexing VATAGP-based readout system, and writes the full event to the storage. Run control waits for every readout module drops the "busy" signal and becomes ready to receive a new trigger signal.

Slow control system

The MiniSPD slow control system includes the gas gain monitor and the power supply monitoring. The gas gain monitor is based on the straw tube detector and signal amplifier from the NA62 experiment. Gas gain is monitored via the position of the signal peak from the FE_{55} in the amplitude spectrum from the straw tubes.

TQDC16VE, a self-triggering ADC+TDC, is used for the readout. Then data are transmitted via the ZeroMQ socket from the TQDC2 control software to a visualization program, which logs the data and writes them to the Tango database. The data are visualized within the Graphana system. The same approach is used for monitoring of the power supply, based on Weiner MPOD modules, FUG low-voltage and ISEG high-voltage power supplies. The temperature and humidity measurement is based on block-ready modules.

Gas mixing system

Gas detectors previously used pre-mixed gas mixtures in cylinders. A new gas system was developed, installed, and calibrated to enhance the testing capabilities of the detectors. Manual calibration is done by the bubble method. The gas flows from the outputs were calibrated and the gas mixtures of Ar and CO_2 in proportion 70% to 30% and 80% to 20% were prepared, for Straw and GEM detectors, respectively. Development of the gas supply system aims to create a universal system for testing the parameters of detectors based on gas amplification. According to the current design the inlet pressure is 2.5 *bar* while the maximal value is 3 *bar*. The GEM and straw tube detectors are connected in parallel. It is possible to switch on the gas gain monitor manually using a system of valves to control the mixture in the detectors. Each detector is equipped with oil bubblers that show the flow rate of the mixture on the level of about 3.2 l/h per channel. It allows you to mix gases in arbitrary proportions to change the gas amplification parameters.

Run monitoring system

This system, that allows to monitor data from detectors during the data taking, was developed basing on the LABView framework. The following parameters from the detectors are controlled and visualized:

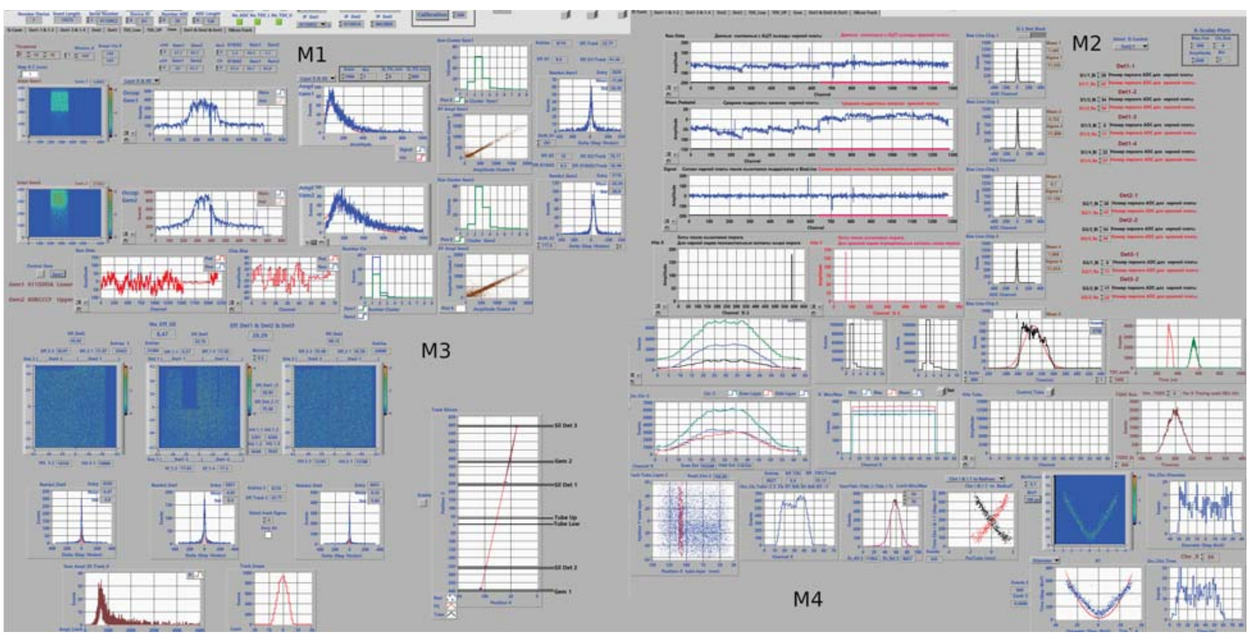

FIGURE 2. Monitoring data from the detectors.

- for GEM detectors (block M1): hit areas (projection from the scintillator), hits by channels (X-axis), amplitude spectra (the ratio of ADC bins of one channel to the number of such events), cluster size distribution (how many strips are triggered in one event), detector-averaged residuals;
- for silicon detectors (blocks M2 and M3): the raw data from the ADC, the pedestals averaged over 100 events, the result of pedestal subtraction, channels with signals above the threshold and noise characteristics of the readout ASIC chips, hit positions, residuals and amplitude spectra;

- for straw detectors (block M4): number of tubes triggered is event, hit distributions for each layer, raw timing data, the drift time and the *R-t* dependence.

Monte Carlo simulation

Passing through the materials of detectors, the low-energy particles experience multiple scattering in the material, which causes deviation of particle tracks from a straight line. Such tracks cannot be used for determination of characteristics of the straw detectors. To remove soft component of the cosmic rays a lead filter was installed. The thickness of the filter was optimized based on the results of the Geant4-based Monte Carlo simulation.

CONCLUSION

The MiniSPD facility based on the external BM@N tracking system was developed and implemented within the framework of the SPD project for calibration and testing of the strow detectors and studying the front-end electronics, slow control, and the DAQ systems with cosmic muons. Till the moment we performed the mechanical alignment of the detectors, implemented the slow control system, and obtained first results for *R-t* distributions for straw tubes for different pressure.

As the next steps we plan to develop and implement the software alignment procedure, add to the MiniSPD new elements, such as the module of the Muon (range) system and additional coordinate detectors in order to increase the tracking accuracy, implement the calorimeter with a higher sensitivity range to perform the energy scan, introduce the DAQ system, based on AFI Electronics and COMPASS DAQ, and perform the Garfield-based simulation of the straw-tube response.

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