THE SPD BEAM-BEAM COUNTER SCINTILLATION DETECTOR PROTOTYPE TESTS WITH FERS-5200 FRONT-END READOUT SYSTEM

A. V. Tishevsky [a,*] , F. A. Dubinin [b] , A. Yu. Isupov [a] , V. P. Ladygin [a] ,

G. A. Nigmatkulov [b], S. G. Reznikov [a] ,

P. E. Teterin [b] , I. S. Volkov [a] , and A. M. Zakharov [b]

[a]*Joint Institute for Nuclear Research, Dubna, Moscow region, 141980, Russia*

[b]*National Research Nuclear University MEPhI, Moscow, 115409, Russia*

[*]*e-mail: tishevskiy@jinr.ru*

Abstract – The Spin Physics Detector is a collider experiment at NICA designed to study the spin structure of the proton and deuteron and other spin-related phenomena using polarized beams. The collision energy is up to 27 GeV and the luminosity is up to 10^{32} cm^{-2} s^{-1} in pp mode.

Two scintillator-based detectors, Beam-Beam Counters (BBC), will be installed upstream and downstream the interaction point and will serve as a tool for beam diagnostics including local polarimetry. The BBCs will be designed as high granularity scintillation detectors.

In this paper we present the tests of a BBC prototype based on the tiles with the green wavelength shifter and silicon photomultiplier (SiPM) readout. The prototype was tested with 1x1 mm^2 and 3x3 mm^2 SensL SiPM using CAEN FERS-5200 front-end readout system. Amplitude and time response to cosmic rays was compared for different tile configurations.

INTRODUCTION

One of the subsystems of the Spin Physics Detector (SPD) is the Beam-Beam counters (BBC). Two scintillator-based BBC detectors will be installed symmetrically upstream and downstream the interaction point. The main purpose of the BBC is the permanent monitoring of the beam polarization using the azimuthal asymmetry of the inclusive charged particles yield, as well as the monitoring of the beam collisions. Details of the BBC experimental setup is described in the SPD Conceptual Design Report (CDR) [1].

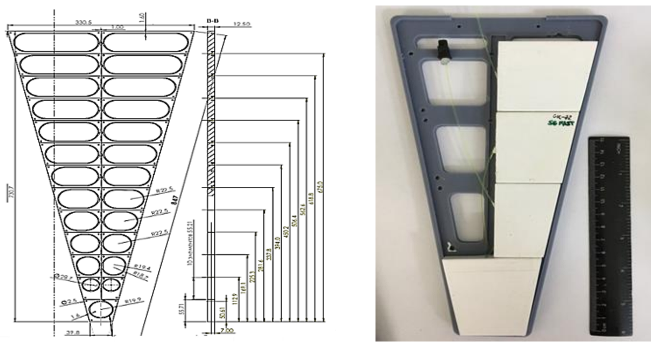

Fig. 1. Schematic view of a BBC sector with 25 tiles (left). The 7-tiles sector of BBC detector prototype (right).

After publication of the CDR, an update to the BBC design was proposed to increase radial and azimuthal granularity of the detector. Schematic view of one of the 16 sectors each having 25 scintillator tiles is presented in Fig.1, left.

In order to maximize the BBC efficiency, extended studies with several detector prototypes are ongoing. Potential points for optimization include the geometry and material of the scintillation tiles, the choice of the wavelength shifter (WLS) and optical cement, as well as the type of silicon photomultipliers (SiPM).

EXPERIMENTAL SETUP AND TEST EQUIPMENT

The BBC prototype used for the studies reported in this paper represents the inner part of one BBC sector (Fig.1, right). We label the most inner tile as central, and others by their position relative to the central tile: first, second, and third rows correspondingly. The BCF92 fast fiber from Saint-Gobain Cristals was chosen as WLS for the prototype tiles. The fiber is glued into the plastic using optical cement CKTN-MED mark E produced by SUREL (St.Peterburg, Russia). The glued end of the fiber is painted with silver reflective paint. The other end is placed in the connector for coupling with SiPM. The gap between the fiber and the SiPM is filled with optical grease.

We performed studies of different configurations including comparison of the central and third row tiles equipped with 1x1 mm^2 or 3x3 mm^2 SensL SiPMs. The bases of the central tile have length of 40 and 60 mm. Third raw tiles (right-angled trapezoids) have bases 53 and 65 mm long. All tiles are 10 mm thick and 55 mm high. In addition to different tile geometry, two options for SiPM connection form factors were compared: the SensL SMTPA board (the PCB board with soldered contacts) and SMT (see Fig.2, right).

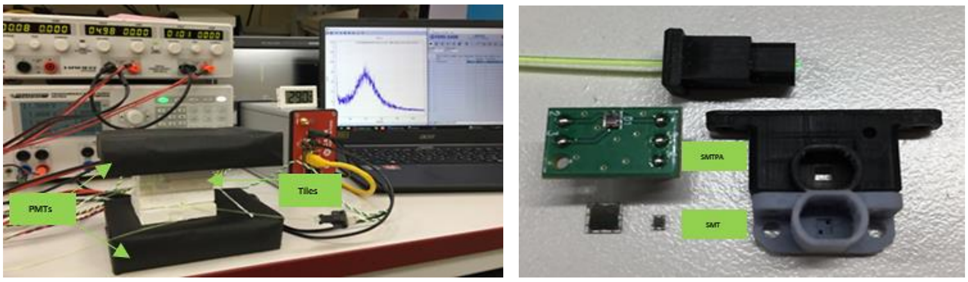

Fig. 2. The setup for studies (left). The SMTPA board and SMT form factors (right).

Measurement conditions

The BBC prototype tiles were tested using cosmic rays. The SiPMs bias voltage was 27.95 V. The detector prototype tiles were tested at 25 ± 1 ºC temperature.

Two external trigger counters (ETC), each of them based on a 100×100×10 mm^3 scintillator viewed by Hamamatsu H10720-110 photomultiplier tubes have been assembled for the setup. The ETC were positioned 20 mm vertically apart from each other, and the prototype tiles were placed between them. Tiles with the same geometry were stacked together and tested in one group as shown in Fig.2 (left). The coincidence of ETC with time resolution ~650 ps was used as the time reference signal for the readout system CAEN FERS-5200.

CAEN FERS-5200

CAEN FERS-5200 is an extendable front-end readout system allowing the possibility to expand the number of channels up to 8192. An important advantage is the ability to work with trigger-less data streaming, which is extremely promising both for future testbeam measurements and "phase zero" experiments at BBC SPD. The 64-channel DT5202 based on two 32-channel Citiroc-1A ASICs specifically designed for the readout of SiPMs was used for the prototype research.

Each readout channel is composed of two charge measurement (PHA) lines with different gain (1 to 10 ratio), which are working in parallel in order to maximize the dynamic range. The readout channel is also equipped with a fast shaper followed by a discriminator. The 64 outputs of the discriminators, which can be operated in a self-triggering mode, are used in the FPGA both to feed the trigger logic (OR, Majority, etc.) and to acquire the timing information Time of Arrival (ToA) and Time over Threshold (ToT). The ToT pulse duration is strongly correlated with the pulse amplitude and can be used in combination with the PHA or even as an alternative.

Citiroc-1A outputs the 32-channel triggers with a high time resolution (< 100 ps RMS), even though it does not have an internal TDC to acquire the timing measurement. However, the FPGA of the DT5202 is programmed for this purpose and a low resolution TDC (0.5 ns) was added to calculate the time interval between the reference signal and input pulses.

“Janus” software for Windows® and Linux® provided by CAEN was used to manage the DT5202 module and the data acquisition, as well as to save output file in ASCII and/or Binary formats.

Output data and data analysis tool

The DT5202 data that are saved in the output file depend on the selected acquisition mode, which can be: Spectroscopy, Counting, Timing, and Spectroscopy+Timing (Hybrid). The output files can contain the PHA, ToT and ToA information for each event, where ToA and ToT are expressed in ns or LSB (least significant bit).

The “FersRun” framework has been designed by us to work with both output data formats. The framework has a wide functionality, which allows user to automatically determine the data format depending on the conditions of the data run; to implement a logical trigger, both for all channels (global) and for particular one (local); and to apply cuts to select the useful events. It is useful to be able to build correlations of the obtained values in Hybrid Mode. One significant example is the correlation of PHA versus ToT for further determination of the time walk effect. The “FersRun” also uses ROOT framework to visualize obtained distributions.

RESULTS OF TILES TEST

The results of amplitude and time spectra measurements using cosmic rays for the central and third rows prototype tiles are presented in Fig.3 and Fig.4. The important result is that less than 5% difference in signal amplitude is observed when one compares measurements performed with the SMTPA board and SMT form factors of SiPMs. Table 1 summarizes the number of events accumulated in the tests as well as values of mean and RMS in the obtained amplitude distributions.

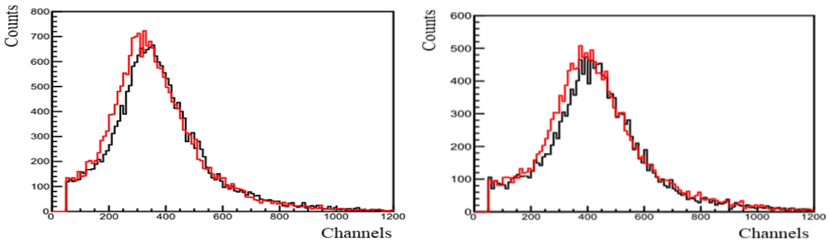

Fig. 3. The amplitude spectra from third (left) and central (right) row tiles. Black and red lines correspond to the measurements with SMT and SMTPA board, respectively.

Peak position difference for both geometries are due to the difference in fiber bending radii in the central and row three tiles. The effect of fiber bending losses is currently under investigation.

Table 1: Mean, RMS and Events values for tiles of two rows and several options of SiPM

	1x1 mm^2				**3x3 mm^2**	**1x1 mm^2**
	third row tile		central row tile		central row tile	
	SMT	SMTPA board	SMT	SMTPA board	SMT	SMTPA board
Mean	332.8	319.5	411.6	404.5	377.7	396.2
RMS	124.6	118.7	129.4	137.1	125.2	145.5
Events	20840		15650		20550	

The results of time information analysis are presented in Fig.4. One can notice minimal difference between the ToT spectra obtained with two SiPMs form factors. However, more attention for small amplitudes region is needed, when the signal arrives later in time, due to the signal delay often called the “time-walking” effect. In this regard, a method for correcting time spectra was proposed [2].

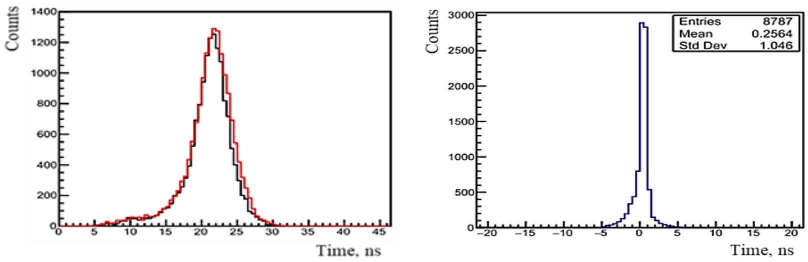

Fig. 4. Left: Time-over-Threshold spectra measured with SMT (black) and SMTPA board (red). Right: time spectrum obtained with signals from two third row tiles.

In addition, a raw estimation of the time resolution (ToA) for two SMT SiPM coupled with two third row tile was carried out (Fig.4, right). It was estimated by the RMS of the distribution divided by the √2 and as about 0.8 ns.

CONCLUSION

The tests of SPD BBC scintillation detector prototype with CAEN FERS-5200 front-end readout system have been started. The obtained data were processed with “FersRun” framework.

The 1x1 mm^2 and 3x3 mm^2 SensL SiPMs have been compared. The latter was used as a starting option and has a large geometric inefficiency if one takes into account large difference in the sensitive area of the SiPM and the WLS fiber cross section. Considering the results obtained with the two options for the SiPM mount form factor, the SMTPA board is a ready-made solution, but requires additional space. Because the results are similar, SMT SiPM has a higher priority as the final option for the BBC. This option involves the development of a PCB for a higher SiPM density. However, in this case, the final cost is still about 3 times cheaper, which affects the final cost of the BBC detector.

First results of ToT spectra measurements, obtained with 1x1 mm^2 SiPM for two form factors, showed minimal visible difference. The ToT function served for estimation of the signal amplitude is available in combination with the amplitude information (Hybrid Mode) or without it (Timing Modes). Further correction procedure is under consideration, but results with ToT have become the first step on the way to a full implementation of the Timing Mode, which is the only option for trigger-less data streaming.

The first result of time resolution of a single tile was estimated to be approximately 0.8 ns. Given the suboptimal timing capabilities of the FPGA in the DT5202 with a low resolution TDC (0.5 ns), the result is promising. We are waiting for the DT5203 board that uses the picoTDC chip produced by CERN for high-resolution time measurements.

The future step is to assembly and test the optimized complete 7-tiles sector of BBC detector prototype.

REFERENCES

1. Abazov V.M., et al. Conceptual design of the Spin Physics Detector. - 2022. - arXiv:2102.00442.
2. Tishevskiy A.V., Gurchin Yu.V., Isupov A.Yu., Khrenov A.N., Kulevoy T.V., Ladygin V.P., Polozov P.A., Reznikov S.G., Terekhin A.A., Volkov I.S., Development of the scintillation detector prototypes with SiPM readout for SPD at NICA //J. Phys.: Conf. Ser. 2020. V. 1690. P. 012051