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Development of the scintillation detector prototypes with SiPM readout for SPD at NICA

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Abstract. The Beam Beam Counter is a system for local polarimetry and local luminosity monitoring at the Spin Physics Detector at NICA. The main option of the Beam Beam Counter is the scintillation counters with SiPM readout. The work presents the first results on scintillation detector prototype using developed Front-end electronics based on the Time-over-Threshold technique. The procedure of the time-walk correction is discussed.

1. Introduction

The Spin Physics Detector (SPD) is a planned spin physics experiment at one of two interaction points of the Nuclotron-based Ion Collider fAcility (NICA) that is under construction at the Joint Institute for Nuclear Research. The main purpose of the experiment is the study of the nucleon spin structure in collisions of longitudinally and transversely polarized protons and deuterons at the center-of-mass energy up to 27 GeV and luminosity up to 10^{32}cm^{-2} s^{-1}.

The SPD setup is planned as a universal 4π spectrometer with advanced tracking and particle identification capabilities based on modern technologies. It will include such subsystems as a silicon vertex detector, a gaseous main tracker, a time-of-flight system, an electromagnetic calorimeter, a range system for the muon identification and instruments such as a Zero Degree calorimeter (ZDC) and a Beam Beam Counter (BBC) for the local polarimetry and luminosity control.

Currently, the R&D stage is ongoing and there are active discussions on the final technical design of the BBC, but concept of the outer part is high granularity scintillator tiles with silicon photomultipliers (SiPM) readout. Based on these considerations, the prototypes of scintillation detectors with SiPM readout have been developed. One of them is the 16-channel prototype of detector (Figure 1) with the ability to use both amplitude and time. It can be used as option for the ZDC. In another single-channel prototype of detector (Figure 3) we have the ability to measure the amplitude using developed Front-end electronics (FEE) based on the Time-over-Threshold (ToT) technique. We expect our proposed prototype to become important part of the development for the BBC as the permanent monitoring of the beam polarization using the azimuthal asymmetry of the inclusive charged particles yield. Both prototypes based on photomultipliers of Hamamatsu (S12572-010P) [1].

The paper presents tests of prototypes using the source of calibrated light pulses (LED) with the data-acquisition system (DAQ), briefly presents finding the break point of the noise characteristic for the 16-channel prototype, and describes a time-walk correction method for the single-channel prototype.

2. The prototypes and methods

2.1. The 16-channel prototype

The prototype includes a system module SM G761, a system bus, and the detector part that implemented on two PCBs with size of 78x78 mm^2. They contain power supply for sixteen SiPMs. The system module is designed as desktop device, which connects to a computer via USB, and controls the 16-channel prototype through the system bus and a microcontroller. The user sets the bias voltage with the HVsys program, which allows to set the total and the individual (range of 0 – 3.3 V) voltage. The PCBs also include photodetectors, amplifiers, and a temperature sensor. The signal from each SiPM is amplified and output to the reading electronics together with the sum of the prototype channels via the IDC34 connector. The compromise solution was to use amplifiers with a 20 ns rising edge of the signal. This choice allows receiving the amplitude of the signal along with the time information. In this way, random events that did not fall into the time peak of coincidences are discarded.

For the reason that the generally accepted method of determining the bias voltage of SiPM are difficult to implement in our case, we have proposed a method of measuring peak-to-peak amplitudes of the noise signal (V_{pp}) in dependence on bias voltage (V_{bias}). The resulting form of dependence V_{pp} versus V_{bias} (Figure 2) is very similar to the dependence I versus V. We applied a linear approximation to the regions of the plateau and the growth of the obtained noise characteristic. From the system of equations for these lines, we find their intersection point, which is the break point of the noise characteristic [2].

The average break point for sixteen channels is 73.82 V. The final bias voltage is set according to the type of SiPM and the considerations of the researchers. This method is universal for the finished multichannel detector. The advantage of this method is the opportunity to quickly find the break point of the noise characteristic and use this value as a normalizing value for determining of the operating bias voltage, as well as adjust the voltage during continuous operation in ionizing fields.

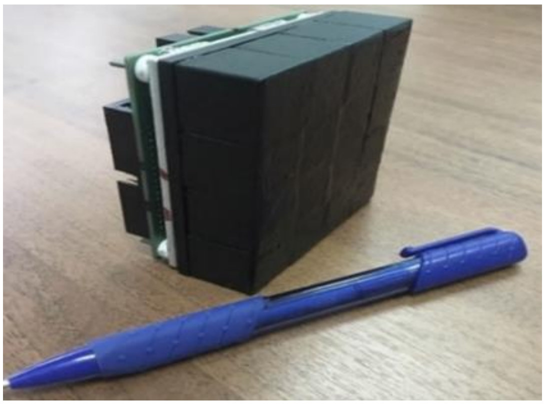

Figure 1. The 16-channel prototype view.

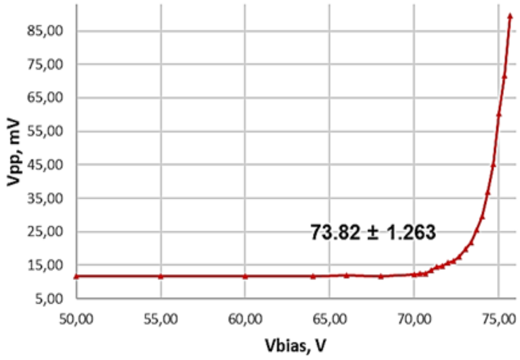

Figure 2. V_{pp} as a function of V_{bias}.

2.2. The prototype of detector based on the ToT technique

At single-channel prototype of detector we have the possibility to measure the amplitude using developed FEE based on the ToT technique. This technique is a well-known method that allows us to measure the energy deposited in the material by reconstructing a given property of the output current pulse – the total charge collected, the pulse amplitude, etc. The ToT method converts the signal pulse height into a digital value in the early stage of the FEE, which greatly simplifies the system in comparison to analog detectors with serial readout through ADCs. The measurement of the ToT

(Figure 4) is composed of two measurements of time for the signal going above (leading) and returning below (trailing) a given threshold [3].

Figure 3. The single-channel prototype view.

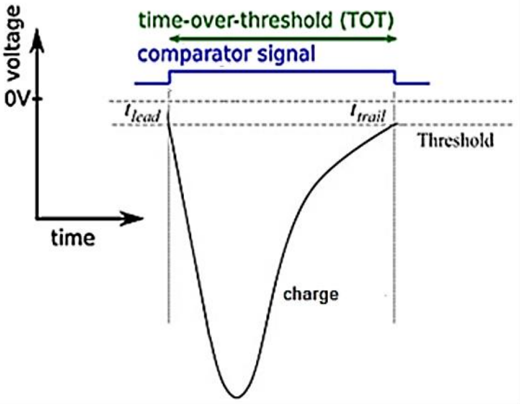

Figure 4. The ToT technique.

The first version of the prototype includes a power supply and the electronics (Figure 5) made on a separate PCB. This PCB used for each cell of the SiPM. Power supply for SiPM with the total (65 V) and individual (range of 0 to +10 V) voltage, built-in voltmeter, and manual interface for voltage supply. It is possible to connect eight cells simultaneously. The amplifiers are used that do not change the leading edge of the signal. This allows to get the time stamp of the event. Then the signal is integrated and transmitted to the comparator.

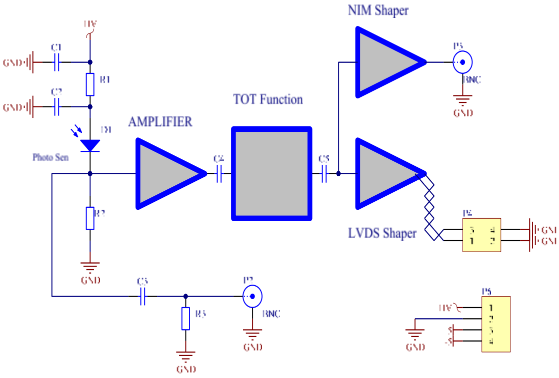

Figure 5. The schematic view of electronics.

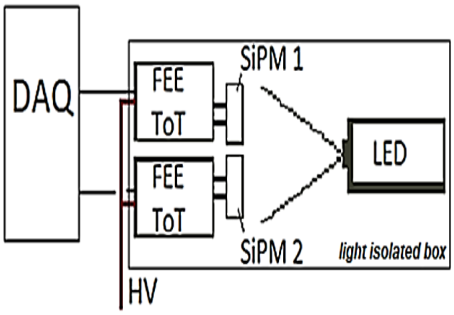

Figure 6. The schematic view of setup.

2.3. *The equipment for the tests*

The response of SiPM to the LED has been studied. The light source is designed as a separate board with synchro pulse [4]. The electrical signal from a lemo output of the LED was used as a trigger. Light was transmitted to the multichannel prototype by uniform homogeneous illumination (uniform light) and by single channel illumination with optic fiber with the core diameter of 50 μm (fiber). The charge histograms for each channel of the prototype were built at different voltages. In the case of a single-channel prototype, illumination was performed only by uniform light (Figure 6). All measurements were performed in light isolated box.

In both cases, the data were accumulated by a VME based DAQ [5]. The DAQ included FVME-V2.0 controller, TDC32, CAEN V976 module, TMWR module, and two 16-channel TQDC16 modules (time and charge-to-digital converter). Data processing was performed by the ROOT package.

3. Experimental results

3.1. The 16-channel prototype

We obtain time resolution of the SiPM. We used the time difference (dT) between the prototype channel response (T_{SiPM}) and the trigger signal (T_{Tr}) with the uniform light or the fiber. The distributions were approximated by the Gaussian function, and the time resolution was defined as the Sigma (σ) parameter of the Gaussian function. The operating temperature of prototype was 26 °C during the measurements. The time resolution was approximately 1.0 ns for the uniform light (Figure 7) and about 0.4 ns for fiber (Figure 8) at the voltage of 71.2 V.

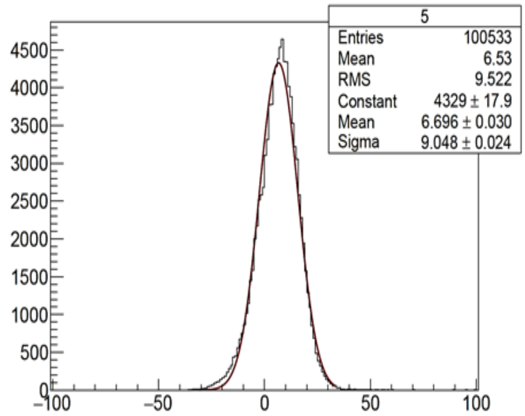

Figure 7. The dT (T_{tr} - T_{SiPM}) in case of the uniform light.

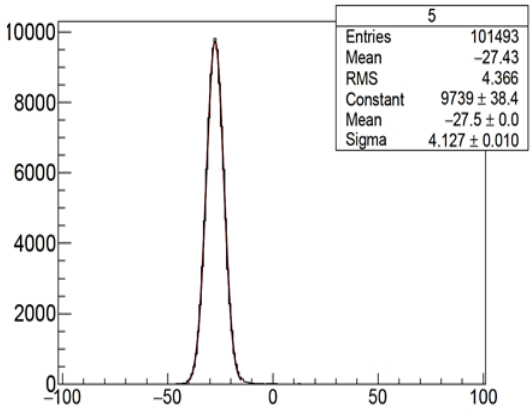

Figure 8. The dT (T_{tr} - T_{SiPM}) in case of the fiber light.

3.2. The prototype of detector based on the ToT technique

In addition to the ToT information (Figure 9) the time stamp of the event for each SiPM cell was investigated. The distribution (Figure 10) shows the correlation of these values and that the signal in the region of small amplitudes comes later in time. This is due to signal latency, often referred to as the "time-walking" effect. This delay occurs due to the difference between the time when a photon or charged particle passes through the detecting element and the time when the electronics register this signal. This leads to deterioration in the time resolution.

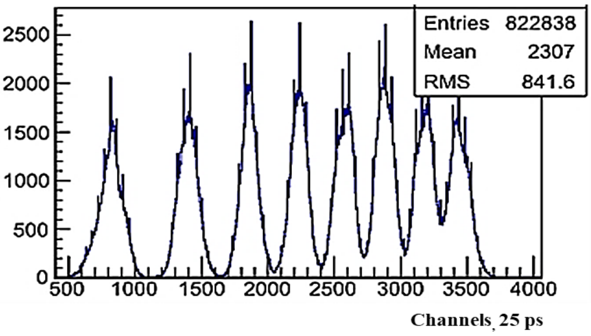

Figure 9. The distribution of the ToT.

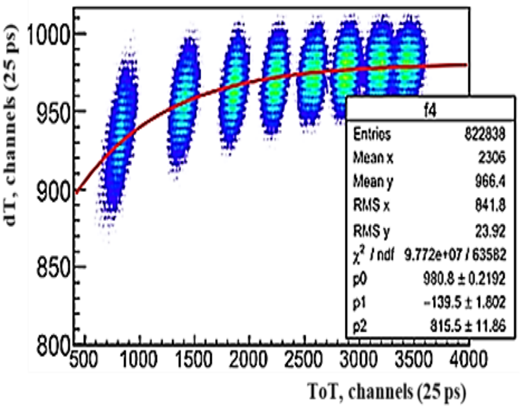

Figure 10. The dT (T_{SiPM1} - T_{SiPM2}) correlation on the ToT

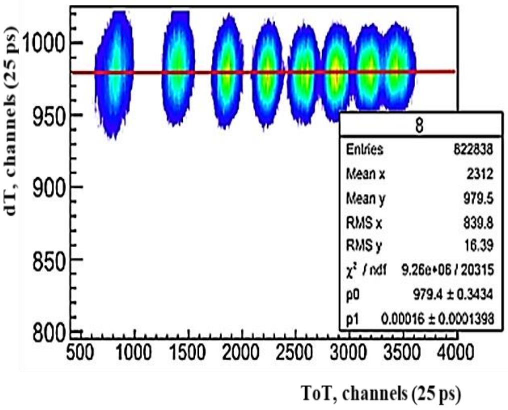

Figure 11. The result after the time-walk correction for the dT (T_{SiPM1} - T_{SiPM2}) correlation on the ToT.

The time resolution was defined as the RMS and was approximately 600ps. Taking into account the non-Gaussian waveform (Figure 12) and the fact that the time resolution is not the maximum allowed for this type of detector, we made the time-walk correction.

We construct the correlation of the dT (T_{tr} - T_{SiPM}) versus the ToT for this SiPM and the same correlation for second SiPM. We approximate the obtained dependencies with function (1), extract the parameters of these functions, and then we apply these parameters.

$$f(x) = a + b \cdot e^{\frac{-x}{c}} \quad (1)$$

Thus after performing the correction (Figure 11), the "time-walking" effect is removed. The main and important result of the correction was a time resolution of approximately 400ps (Figure 13), which is 1.5 times better before the correction.

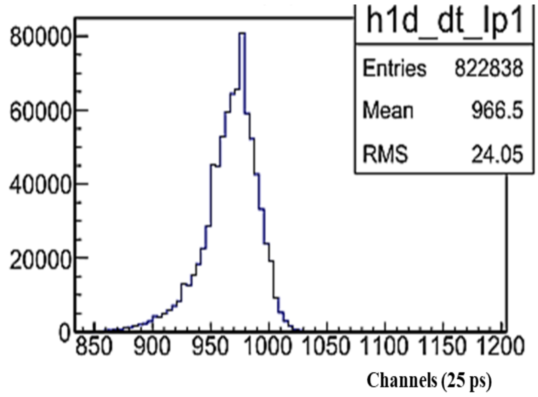

Figure 12. The dT (T_{SiPM1} - T_{SiPM2}).

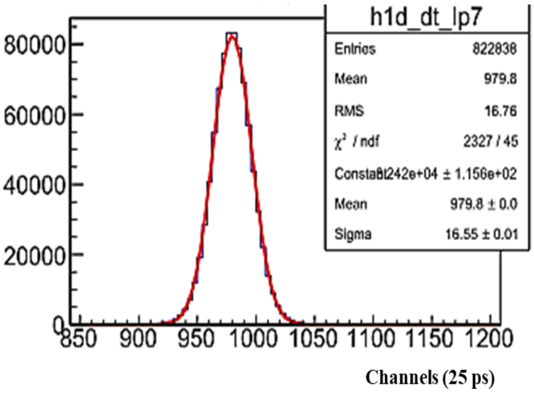

Figure 13. The result after the time-walk correction for the dT (T_{SiPM1} - T_{SiPM2}).

4. Conclusions

The scintillation detector prototypes for the future Spin Physics Detector at NICA with Hamamatsu (S12572-010P) SiPM readout have been developed and tested.

The proposed method of the bias voltage determining according to noise characteristics is useful also for adjusting the voltage during continuous operation in ionizing fields.

The first version of the prototype using developed Front-end electronics based on the Time-over-Threshold method was tested. After the time-walk correction, the time resolution improved to 400 ps. Taking into account the SiPM suboptimal for precise time measurements the result is promising.

Acknowledgments

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