Tile detector configurations testing for the SPD Beam-Beam Counter prototype

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The Spin Physics Detector is an experiment at NICA designed to study the spin structure of the proton and deuteron and other spin-related phenomena using polarized beams. Two Beam-Beam Counters (BBCs) will be installed symmetrically aside from the interaction point in the end-cups of SPD setup and will serve as a tool for beam diagnostics including local polarimetry. The outer part of the BBC wheel is based on fast scintillator tiles and cover the polar angels between 60 and 500 mrad.

Different material configurations for the BBC prototype based on scintillator tiles were tested. The light collection depends on material combinations - fiber (Saint Gobain BCF91AS, BCF92S, and Kuraray Y-11), tile surface cover (Matted and double covered with Tyvek sheets tiles), and optical cement (CKTN mark E, OK-72). SensL 1×1 mm^2 and 3×3 mm^2 SiPMs were used as photosensors in the prototype tiles. The studies were performed with a cosmic rays test setup equipped with CAEN FERS-5200 readout system.

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Introduction

The Spin Physics Detector will be installed in the second interaction point of the NICA collider (JINR, Dubna) to study the spin structure of the proton and deuteron and other spin-related phenomena using polarized beams at a collision energy up to 27 GeV and a luminosity up to 10^{32} cm^{-2} s^{-1} [1].

The SPD is planned to be in operation in 2028. The starting configuration should consist of the Range System, solenoidal superconducting magnet, Straw tube-based Tracker, a pair of Zero Degree Calorimeters, and a pair of Beam-Beam Counters. Two BBCs will be installed symmetrically aside from the interaction point in the end-cups of the SPD setup and will serve as a tool for beam diagnostics including local polarimetry (Fig. 1a).

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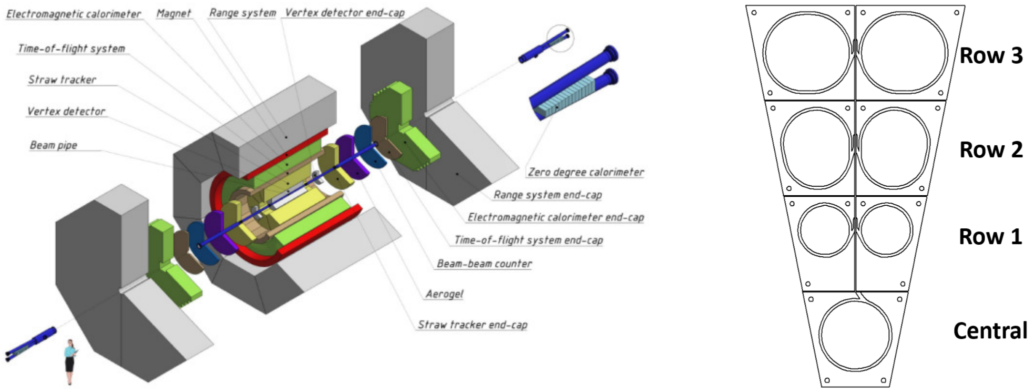


(a) (b)

Fig. 1: (a) General layout of the SPD setup; b) Geometry of seven tile prototype

Detector prototype and test setup

The SPD BBC is designed to have 16 sectors with 25 tiles in each sector, for a total of 800 tiles per two wheels. Scintillator light is collected from the tiles by wavelength shifting (WLS) fibers and guided to silicon photomultipliers (SiPM). In order to cover such a large number of individual electronic channels, there are FEE designed specifically for large detector arrays , such as CAEN FERS-5200 readout system. FERS includes 64 channels for a single board, a large number of integrated electonic curcuits, such as analog-to-digital converter (ADC), coincidence curcuit (CC), trigger logic, etc. For a cosmic ray test setup, prepared for studies of the prototype tile configurations, we used external trigger system, based on two 10×10 cm^2 scintillators with Hamamatsu H10720-110 PMTs readout and time resolution ∼650 ps. For each study we placed a small group of tiles between the trigger scintillators on top of each other. For the study we used four innermost rows of BBC sector prototype (Fig. 1b) with the total height of 224.3 mm (about 55 mm each with 1 mm gaps) and a thickness of 10 mm. Several samples of scintillator tiles (by Uniplast Vladimir [2], [3]) were covered two times with Tyvek, others - with white acrylic paint (from now and on we call them matted tiles) to prevent light migration from scintillator volume. Both ends of the fiber are polished and the one inside the scintillator is covered with white acrilyc paint too. The amplitude spectra obtained with FERS-5200 were fitted offline using the convoluted Landau and Gaussian function [4] so that we could estimate the mean and the width parameters of a distribution peak. In order to improve light collection efficiency by WLS fiber, the surface of tile is covered with material that can reflect or scatter the light. Fibers are glued inside the tile with optical cement. Light collection may depend not only on the properties of fibers and cover material, but also on spectral characteristics of the optical cement.

Tests of prototype tile configurations

Table 1: Test results for two types of tile cover material and two types of optical cements

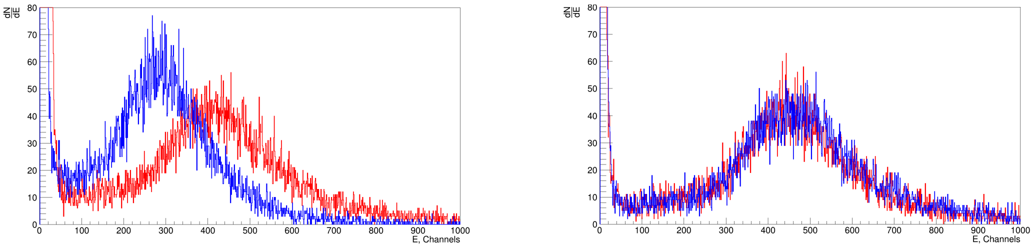
Tile	Matted VS Tyvek				CKTN MED mark E VS OK-72			
	Row 1 Matted	Row 1 Tyvek	Row 3 Matted	Row 3 Tyvek	Row 1 CKTN	Row 1 OK-72	Row 3 CKTN	Row 3 OK-72
Mean, Channels	372.9	346.7	406.9	348.3	372.9	254.4	406.9	412.3
Width, Channels	28.5	30.0	30.3	27.5	28.5	17.6	30. 3	36.2

Comparison of tile cover materials. We compared two types of scintillator covers: Tyvek and a white acrylic paint. For the test we used tiles from the first and the third rows of the sector, CKTN MED mark E [5] optical cement, Saint-Gobain BCF92 fibers, and 3×3 mm^2 SiPMs. The CKTN was mixed according to the composition specified in the data sheet - 100 of A to 3.2 of B.

Tyvek covers were made of two layers according to geometry of the tiles and looked like tight double-covered cases. For the study we used SensL 3×3 mm^2 SiPMs.

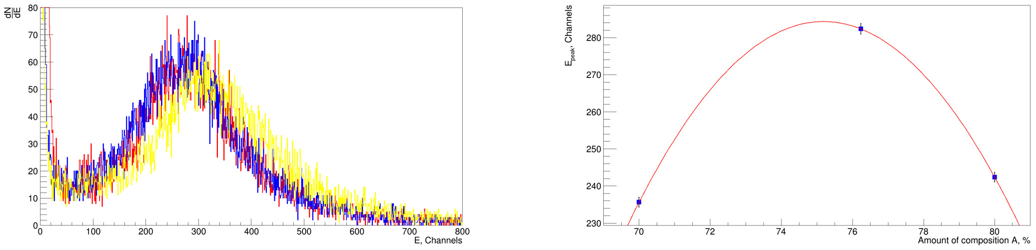
Results for comparison of cover materials made of Tyvek and acrylic paint (named as matted) are presented in Table 1 (left part). The study showed that matted tiles proved to be more efficient in terms of light collection. This type of tile cover is also more suitable for mass production which is important as well.

Comaprison of optical cements. The dependence of light collection efficiency on the choice of the optical cement was tested with CKTN MED mark E and OK-72 [6] (Table 1, right part). The cements are made of A and B compounds, which, according to the data sheet for OK-72, should be mixed in proportions 76.24% of A to 23.66% of B (from now on, short form of the A/B ratio is used, i.e. 76.24/23.66). In view of the fact that a slight difference in ratio of the cement compositions might affects on light collection (Fig. 2), we also tested 70/30 and 80/20 compositions of the OK-72. These tests were performed with Saint-Gobain BCF92 fibers and SensL 1×1 mm^2 SiPMs.



(a) (b)

Fig. 2: Comparison of CKTN (red) and OK-72 (blue) optical compounds in tiles of row 1, 76.24/23.66 (a) and row 3, 70/30 of A to B ratio (b)



(a) (b)

Fig. 3: a) Comparison of OK-72 A/B compositions: 70/30 (blue), 76.24/23.66 (yellow) and 80/20 (red); b) Dependence of mean amplitude on the percentage of A component

Table 2: Test results for different A/B components ratio of the OK-72 optical cement

Fit Parameters	80/20	70/30	76.24/23.66
Mean, Channels	242.7	237.8	284.4
Width, Channels	20.4	22.1	26.0

Figure 3a shows distributions corresponding to row 2 tiles with 70/30 (blue), 76.24/23.66 (yellow) and 80/20 of OK-72 (red). Figure 3b demonstrates the peak of light collection dependence on the composition of A for OK-72, the data points are fitted with a second-degree polinomial function as a guide to the eye. Fit parameters for light collection distributions are presented in Table 2.

As can be seen, among the tested OK-72 mixtures, the best result corresponds to the 76.24/23.66 composition (in agreement with the data sheet), however, the ratio of components does not affect light collection dramatically.

Comparison of WLS fiber types. In the next set of tests we compared Saint Gobain BCF92 and Kuraray Y-11 fibers using rows 2 and 3 tiles and 1×1 mm^2 SensL SiPMs. The study also includes comparison with OK-72 and CKTN optical cements. Results are presented in Table 3.

Table 3: Test results for comparison of Saint-Gobain BCF92 and Kuraray Y-11 fibers

Fit Parameters	SG BCF92 CKTN Row 3	Kuraray Y-11 CKTN Row 3	SG BCF92 OK-72 Row 2	Kuraray Y-11 OK-72 Row 2
Mean, Channels	402.2	596.7	284.4	293.0
Width, Channels	24.7	43.7	26.0	23.0

In both cases Kuraray Y-11 showed better results in terms of light collection.

Conclusion

BBC detector prototype configurations for the SPD Beam-Beam Counter were tested with cosmic rays using the CAEN FERS-5200 readout system. Various studies using 3×3 and 1×1 mm^2 SensL SiPMs were performed. The matted coating proved to be more preferable compared to Tyvek wrapping in two important aspects: the amount of collected light and mass production convenience. The study of optical cements, in particular, comparison of compositions for OK-72 showed that difference in A to B ratio weakly affects light collection and proved that 76.24/23.66 ratio, speciffied in the datasheet, is the most efficient one. Saint Gobain BCF92 and Kuraray Y-11 WLS fibers were compared. Kuraray Y-11 fibers collect more light than BCF92 in both tested cases using different optical cements and proved to be more suitable for our purposes.

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