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SiPM application for K_L/μ detector at Belle II

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We report on a new K_L and muon detector based on scintillators to be used for the endcap and inner barrel regions in the Belle II experiment. The increased luminosity of the e^+e^- SuperKEKB collider entails challenging detector requirements. We demonstrate that relatively inexpensive polystyrene scintillator strips with wavelength shifting fibers ensure a sufficient light yield at the Silicon PhotoMultiplier (SiPM) photodetector, are robust and provide improved physics performance for the Belle II experiment. We also describe the simple technological methods used in the mass production for K_L and muon detector modules, that allowed to increase significantly the light collection efficiency at SiPM, and the first experience of multichannel SiPM adjustment.

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Excellent work of the B-factory experiments, Belle and BaBar [1], has shown that flavor physics has the powerful potential to search for various manifestations of New Physics. The construction of the new generation devices, operating at an order of magnitude higher luminosity allows to exceed 1 TeV energy threshold in the hunt for the New Physics. The idea of an upgraded Belle experiment was first presented in a Letter of Intent in 2004 [2], followed by a Technical Design Report in 2010 [3]. The upgrade of KEKB accelerator, SuperKEKB, is aimed to provide luminosity of 8×10^{35} cm^{-2}s^{-1}. The new installation is expected to start operation in 2016 and collect 50 ab^{-1} by 2022.

The K_L^0 and muon subsystems (KLM) in the Belle experiment was based on the resistive plate chambers technique (RPC) [4, 5]. Though it worked successfully over the entire lifetime of Belle (1999-2010), its performance is expected to decrease to unacceptable level in higher backgrounds of the Belle II experiment. This requires development of a new detection technique, which should be robust, inexpensive and capable of coping with high backgrounds. A scintillator-based solution for the Belle II endcap KLM (EKLM) detector is presented in this paper.

The Belle II KLM system is based on the scintillator strips equipped with the wave-length-shifting (WLS) fibers read out by the silicon photomultipliers (SiPM) [6] operating in the Geiger mode (Hamamatsu MPPC S10362-13-050 [7]). The prospects for this technology were first suggested in [8] and later were chosen as baseline option for the Belle II. The production and performance of the Belle II EKLM system are described in details in [9].

The entire system consists of 15600 strips assembled to 110 sectors and installed into the gaps in the segments of the Belle solenoid flux return. In the forward part of the detector all 14 gaps are filled with EKLM modules, while the backward part contains 12 layers only.

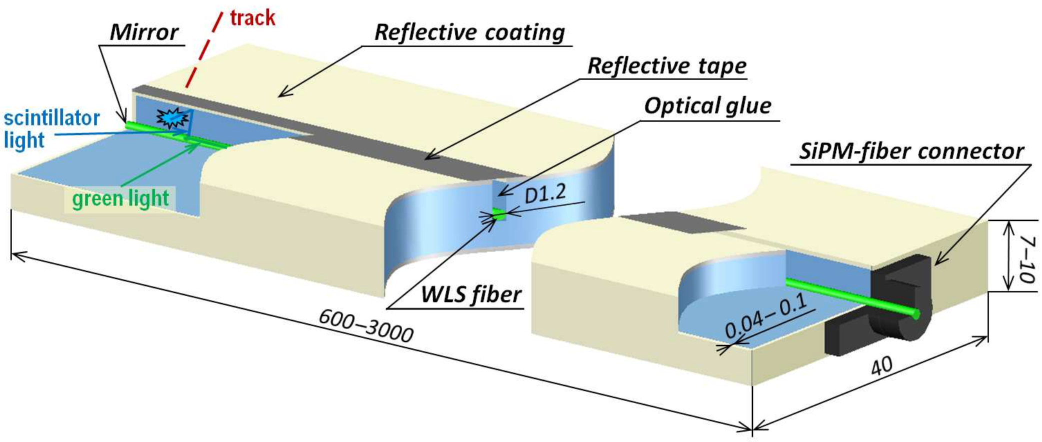

Figure 1: Schematic view of the scintillator strip. Dimensions are in mm.

Silicon photodetectors operating in Geiger mode were first used in particle physics for CALICE hadron calorimeter prototype (7620 channels) [10]. Hamamatsu MPPC S10362-13-050 sensor [7], 1.3×1.3 mm^2 — a key element of the EKLM detector — was developed and produced in large amount (>60000 devices) by Hamamatsu for the T2K [11] experiment. This device has 667 pixels and based on the Hamamatsu commercial device S10362-11-050C with 400 pixels and 1×1 mm^2 sensitive area. It was first mass usage of MPPC's in a large scale experiment.

PoS(PhotoDet2015)065

The construction of the strip is shown in Fig. 1. The 7 mm thick polystyrene strips are produced by Uniplast (Vladimir, Russia) [12] by extrusion which allows to manufacture long strips. The scintillation is provided by PTP (p-terphenil) and POPOP (1,4-bis-2-(5-phenyloxazolyl)-benzene) dopes. Being extruded, strip is cut to the proper width (4 cm) and length, its surface is covered with diffusion reflective coating by chemical etching. A groove is milled along the strip. Kuraray WLS Y-11(200)MSJ multi-cladding 1.2 mm diameter fibers [13] were glued using SL-1 glue produced at SUREL (St. Petersburg, Russia) [14]. To improve the efficiency of the light collection by the WLS fiber a groove of the rounded shape is milled. This allows to avoid small residual air bubbles at the groove corners and thus increase the glue transparency. Lab tests demonstrate an increase in the average detected light yield by $(25\pm5)\%$ relative to the “standard” rectangular-shaped grooves. One of the ends of the fiber (’far end’) is mirrored with silver-shine dye. Another one (’near end’) is connected to the SiPM as shown in Fig. 2, a). The better optical contact between the WLS fiber and SiPM corresponds to the minimal air gap between the fiber end and SiPM surface. The surface of the SiPM is covered with protective resin having concave shape due to surface tension effects during the hardening of the resin. As a result, the light from the fiber is defocused at the SiPM matrix. The optimal length of WLS protrusion inside the meniscus is found to be 150 micron (Fig. 2, b), which results in $(37\pm5)\%$ increase of the number of photoelectrons, collected by SiPM, and still ensures no mechanical contact of the fiber end to the resin surface.

All produced strips were tested with cosmic ray stand to determine the quality of the strip assembly. The measured light yield appears to be almost twice large than it was expected by TDR [3] and only a few strips were rejected. The measured time resolution of $\sigma_t \approx 0.7$ ns allows to use Belle II EKLM system as time-of-flight detector for K_L^0s.

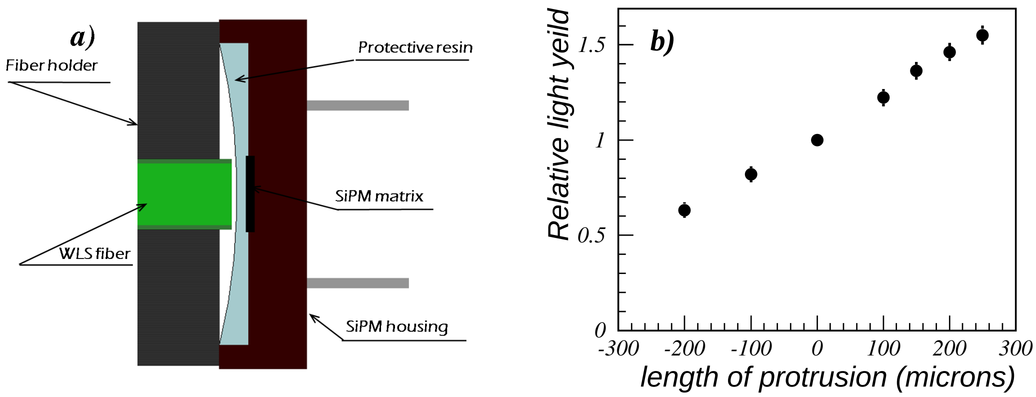

Figure 2: a) schematic view of the optical connection of the WLS fiber end and SiPM (Hamamatsu MPPC S10362-13-050); b) relative light yield dependence on the length of the protrusion (normalized to zero protrusion).

A EKLM module 3 is constructed of two equal planes of 75 strips each, covered by 1.5 mm thick polystyrene substrate from both sides, placed in orthogonal directions and supported by the net of aluminum I-profile beams. The supporting net is fixed inside the existing RPC frames. In the middle part of the sector, unavoidable small dead zones (0.8%) are due to the presence of support structures. The total insensitive area between strips due to the reflective cover is only 0.3%. In total, the geometrical acceptance of the new system is slightly better than that of the Belle RPC EKLM. All 104 produced modules were successfully installed in the flux return gaps in 2014 and are now being equipped with read out electronics and tested.

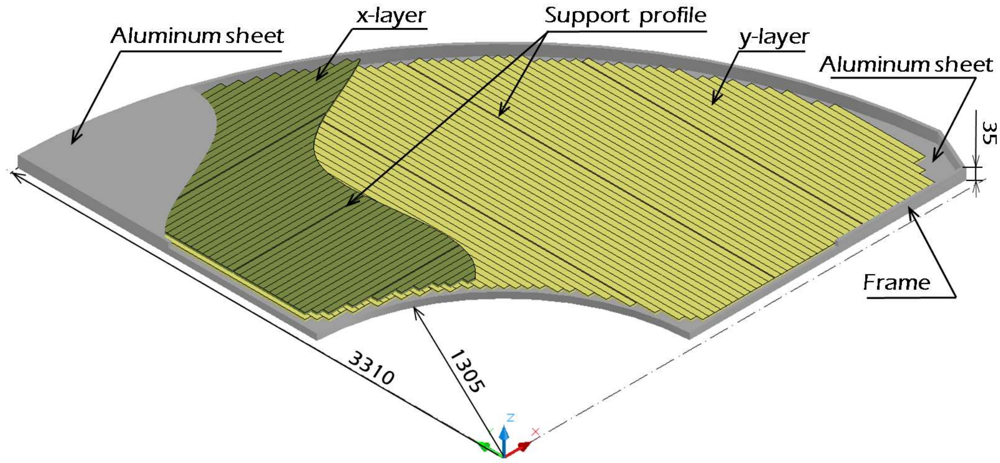

Figure 3: Schematic view of one KLM module formed by scintillator strips. Sizes are given in mm.

In summary, a scintillator-based endcap K_L^0 and muon system of the Belle II detector was designed. Elements of the EKLM system were produced, tested, and assembled. A number of simple methods were elaborated to increase light yield. The achieved light yield ($\sim$ 48 photoelectrons for the near end of the 3 meter strips) is twice as large as it was planned in TDR [3]. The resulting efficiency of the whole system is estimated as $> 99\%$ for MIP in the acceptance region.

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