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K-long and muon system for the Belle II experiment

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ABSTRACT: We have studied a system based on scintillator counters with WLS fiber light collection and SiPM readout for the Belle II experiment. We have identified a few simple improvements in the strip production technology which allow significant increases in the light collection efficiency, thus increasing the efficiency and robustness of the entire detector. The new system should work efficiently at background rates and radiation doses $\sim$ 100 times larger than those observed for the Belle experiment. As demonstrated by many tests, the system has sufficient robustness to operate well in a strong magnetic field and high radiation and interaction environment with no significant degradation anticipated after many years of data taking. While this system was designed for a particular experiment, namely Belle II, our study can be applied to the construction of muon systems in many experiments.

KEYWORDS: Particle identification methods; Photon detectors for UV, visible and IR photons (solid-state) (PIN diodes, APDs, Si-PMTs, G-APDs, CCDs, EBCCDs, EMCCDs etc); Scintillators, scintillation and light emission processes (solid, gas and liquid scintillators)

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Contents

1 Introduction

Excellent work of the B-factory experiments, Belle and BaBar [1], has shown that flavor physics has a powerful potential to search for various manifestations of the New Physics. 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 the Letter of Intent in 2004 [2], followed by the Technical Design Report in 2010 [3]. The upgrade of the KEKB accelerator, SuperKEKB, is aimed to provide luminosity of 8×10^{35} cm^{-2}s^{-1}. The new installation is expected to start operation by the end of 2017 and collect 50 ab^{-1} by 2022.

The K_L^0 and muon subsystems (KLM) in the Belle experiment were 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 KLM detector is presented in this paper.

While the barrel part of the old Belle RPC KLM system does not require major upgrade (only two innermost RPC layers will be replaced with a new detectors), the entire endcap system needs to be replaced. Below throughout the paper only the Endcap KLM (EKLM) system is described.

2 Construction and tests of the Belle II Endcap KLM system

The Belle II EKLM system is based on the scintillator strips equipped with the wavelength shifting (WLS) fibers read out by the silicon photomultipliers (SiPM) [6–11] operating in the Geiger mode (Hamamatsu MPPC S10362-13-050 [12, 13]). The prospects for this technology were first suggested in [14] and later were chosen as a baseline option for the Belle II. The production and performance of the Belle II EKLM system are described in details in [15].

The entire system consists of 15600 strips assembled into 104 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.

Silicon photodetectors operating in Geiger mode were first used in particle physics for CALICE hadron calorimeter prototype (7620 channels) [16]. Hamamatsu MPPC S10362-13-050 sensor [12, 13], 1.3×1.3 mm^2 — a key element of the EKLM detector — was developed and produced

2017 JINST 12 C07035

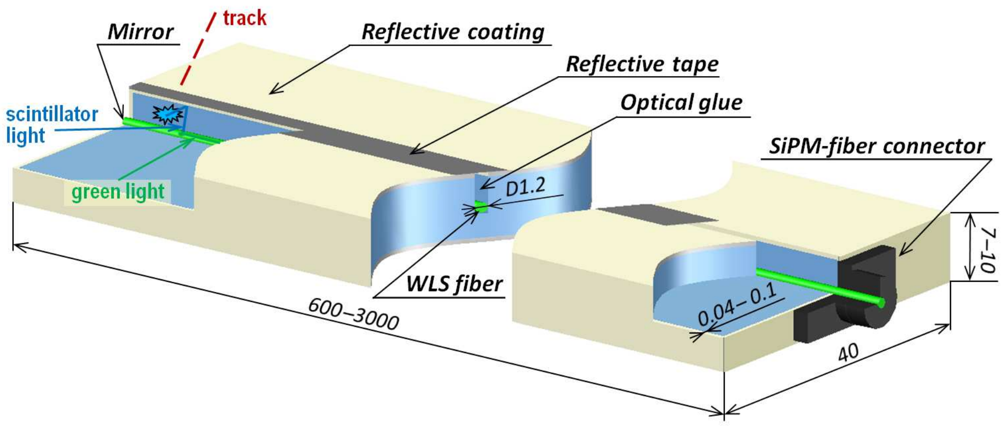

Figure 1. Schematic view of the scintillator strip. Dimensions are in mm.

in large amount (> 60000 devices) by Hamamatsu for the T2K [17] experiment. This device has 667 pixels and is based on the Hamamatsu commercial device S10362-11-050C with 400 pixels and 1×1 mm^2 sensitive area. It was the first mass usage of MPPC's in a large scale experiment.

The construction of the strip is shown in figure 1. The 7 mm thick polystyrene strips are produced by Uniplast (Vladimir, Russia) [18] 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 [19] are glued using SL-1 glue produced at SUREL (St. Petersburg, Russia) [20]. 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 increases the glue transparency. Lab tests demonstrate an increase in the average detected light yield by $(25 \pm 5)\%$ 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 figure 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 the 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 (figure 2, b), which results in $(37 \pm 5)\%$ 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 two times larger, than it was expected by the TDR [3], and only a few strips were rejected. The measured time resolution of 0.7 ns allows to use Belle II EKLM system as a time-of-flight detector for K_L^0's.

A EKLM module shown in figure 3 is constructed of two placed in othogonal directions equal planes of 75 strips each, covered by 1.5 mm thick polystyrene substrate from both sides and supported by the net of aluminum I-profile beams. The supporting net is fixed inside the frames,

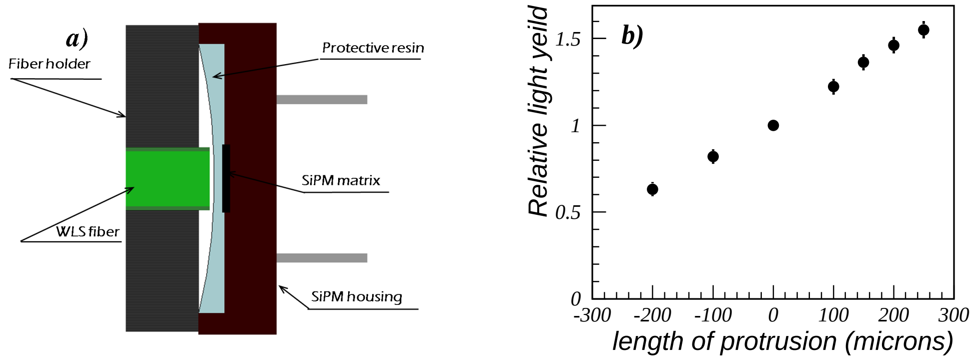

Figure 2. a) Schematic view of the optical connection of the WLS fiber end and SiPM (Hamamatsu MPPC S10362-13-050); b) relative light yield dependence on the length of the protrusion (normalized to zero protrusion).

previously used for KLM RPC chambers. 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 and are now being equipped with readout electronics and tested.

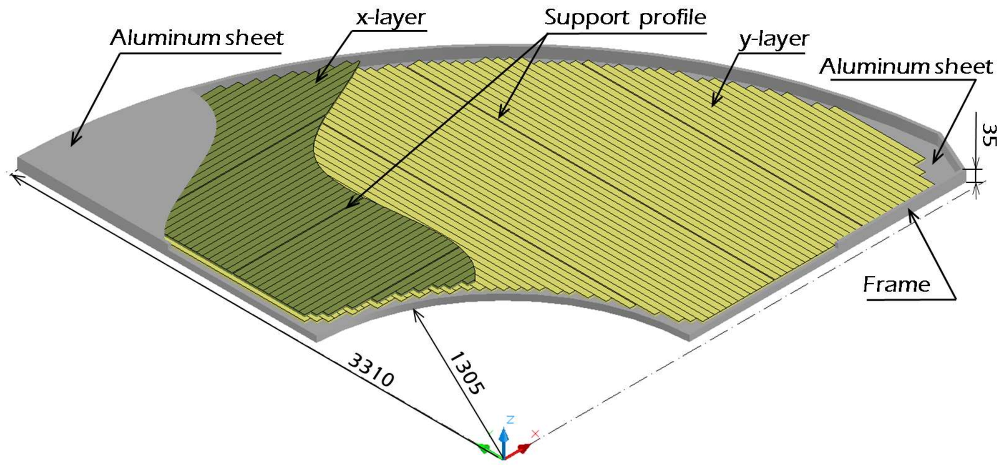

Figure 3. Schematic view of a EKLM module formed by scintillator strips. Sizes are given in mm.

3 Summary

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 (~ 48 photoelectrons for the near end of the 3 meter strips) is twice as large as it was planned in the TDR [3]. The resulting efficiency of the whole system is estimated as > 99% for MIP in the acceptance region.

2017 JINST 12 C07035

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References

[1] Belle, BaBar collaborations, A.J. Bevan et al., *The Physics of the B Factories*, *Eur. Phys. J.* **C 74** (2014) 3026 [`arXiv:1406.6311`].

[2] S. Hashimoto et al., *Letter of Intent for KEK Super B Factory (Part-II, Detector)*, KEK Report 04-4 (2004).

[3] Belle-II collaboration, T. Abe et al., *Belle II Technical Design Report*, KEK Report 2010-1 (2010) [`arXiv:1011.0352`].

[4] A. Abashian et al., *The Belle Detector*, *Nucl. Instrum. Meth.* **A 479** (2002) 117.

[5] Belle collaboration, A. Abashian et al., *The K(L)/mu detector subsystem for the BELLE experiment at the KEK B factory*, *Nucl. Instrum. Meth.* **A 449** (2000) 112.

[6] A.V. Akindinov, A.N. Martemyanov, P.A. Polozov, E.A. Grigorev and V.M. Golovin, *New results on MRS APDs*, *Nucl. Instrum. Meth.* **A 387** (1997) 231.

[7] G. Bondarenko, B. Dolgoshein, A. Ilyin, E. Popova, V. Golovin and R. Klanner, *Limited Geiger-mode silicon photodiode with very high gain*, *Nucl. Phys. Proc. Suppl.* **B 61** (1998) 347.

[8] V. Saveliev and V. Golovin, *Silicon avalanche photodiodes on the base of metal-resistor-semiconductor (MRS) structures*, *Nucl. Instrum. Meth.* **A 442** (2000) 223.

[9] G. Bondarenko et al., *Limited Geiger-mode microcell silicon photodiode: New results*, *Nucl. Instrum. Meth.* **A 442** (2000) 187.

[10] Z. Sadygov et al., *Super-sensitive avalanche silicon photodiode with surface transfer of charge carriers*, *Nucl. Instrum. Meth.* **A 504** (2003) 301.

[11] V. Golovin and V. Savelev, *Novel type of avalanche photodetector with Geiger mode operation*, *Nucl. Instrum. Meth.* **A 518** (2004) 560.

[12] M. Yokoyama et al., *Application of Hamamatsu MPPC to T2K Neutrino Detectors*, *Nucl. Instrum. Meth.* **A 610** (2009) 128 [`arXiv:0807.3145`].

[13] A. Vacheret et al., *Characterization and Simulation of the Response of Multi Pixel Photon Counters to Low Light Levels*, *Nucl. Instrum. Meth.* **A 656** (2011) 69 [`arXiv:1101.1996`].

[14] V. Balagura et al., *Study of scintillator strip with wavelength shifting fiber and silicon photomultiplier*, *Nucl. Instrum. Meth.* **A 564** (2006) 590 [`physics/0504194`].

[15] T. Aushev et al., *A scintillator based endcap K_L and muon detector for the Belle II experiment*, *Nucl. Instrum. Meth.* **A 789** (2015) 134 [`arXiv:1406.3267`].

[16] CALICE SiPM collaboration, B. Dolgoshein et al., *Status report on silicon photomultiplier development and its applications*, *Nucl. Instrum. Meth.* **A 563** (2006) 368.

[17] T2K collaboration, K. Abe et al., *The T2K Experiment*, *Nucl. Instrum. Meth.* **A 659** (2011) 106 [`arXiv:1106.1238`].

[18] Research and production enterprise UNIPLAST, Russia, http://uniplast-vladimir.com/index.php?page=scint (in Russian).

[19] Kuraray, Ltd., Japan, http://kuraraypsf.jp/psf/ws.html.

[20] Research and production enterprise SUREL, Ltd., Russia, http://www.surel.ru/silicone/76/ (in Russian).