Neutral long-living kaon and muon system of the Belle II detector

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The Belle detector operated at KEKb B-factory in 1999-2010 was one of the most remarkable experiments in the field of elementary particle physics of the last decades. The Belle successor, Belle II collaboration, is aimed to operate the Belle II detector at SuperKEKb factory at 40 times higher luminosity. Increased luminosity imposes new requirements on the detector elements: they have to survive at higher radiation levels, to operate at higher loads and at higher backgrounds. The Belle $K_L$ and muon system based on the resistive plate chambers (RPC) technology worked well during all data taking period, however at Belle II environments its performance decreases to negligible level due to increasing load and high neutron background. To sustain detector operation it will be replaced by the new system based on the scintillation strips read-out by silicon photomultipliers. The latter technology allows not only to reach time resolution at level of 1 ns but also perform the amplitude measurements. Nowadays the production of the new EKLM system’s elements are under way. The assembly at KEK is started this fall.

Keywords: Belle II, B-factory; detector; muon system; scintillator; silicon photomultiplier.

1. Belle and Belle II

In the constellation of the brilliant elementary particle experiments of the last decades, the B-factories, Belle$^1$ and BaBar$^2$, were ones of the most remarkable. Their results on CP-violation in B-mesons prove the validity of the KM mechanism, which inventors, M. Kobayashi and T. Maskawa, won the Nobel Prize in physics in 2008. Belle was successful not only in CP-violation studies. The huge amount of the data collected by the Belle detector (more than one billion $B\bar{B}$-pairs) allows to make a number of discoveries in hadron spectroscopy. More than 10 new quarkonium-like states were
discovered including puzzling X(3872) state and new charged Z-resonances which do not fit conventional quarkonium model.

The Belle successor, Belle II experiment, is aimed to collect statistics sample of $50 \text{ ab}^{-1}$ by the end of 2022. Major accelerator upgrade includes changes of the crossing angle (22 mrad to 83 mrad), introduction of the nano-beam scheme, i.e. decreasing of horizontal emittance (18 nm to 3.2 nm for positrons and 24 nm to 4.6 nm for electrons) and beta-functions at IP ($\beta_x^*/\beta_y^*$ from 1200/5.9 mm to $\approx 30/0.3$ mm), rising beam currents (from 1.64 A to 3.6 A for positrons and from 1.19 A to 2.6 A for electrons). The downside of these changes is significant rise of backgrounds. Higher luminosity delivered by the accelerator requires adequate upgrade of the detector components to sustain effective operation at new environment. New Belle II detector have 2-layer DEPFET pixel (PXD) and 4-layer DSSD silicon strip (SVD) detectors for vertexing. Tracking is done with the upgraded drift chamber (CDC) with increased size and smaller cells. Particle identification is done with time of propagation counter (TOP) combining advantages of the excellent time resolution time-of-flight system and Čerenkov ring imaging BaBar-like DIRC in barrel region and aerogel RICH (ARICH) detector with focusing radiator in endcaps. Electromagnetic calorimeter with new electronics for barrel and pure CsI crystals instead of CsI(Tl) in endcaps is able to operate at much higher backgrounds. Muon and $K_L$ system (KLM) is replaced with new one based on scintillator technique in endcaps and in two innermost barrel layers.

2. Belle KLM system

The $K_L$ and muon detector (KLM) of the Belle detector consists of an alternating sandwich of 4.7-cm thick iron plates and active detector elements located outside of the superconducting solenoid. The octagonal barrel covers the polar angle range from 45° to 125°, while the endcaps extend this coverage from 20° to 155°. There are 14 detector layers and 14 iron plates in each endcap. Each layer operates independently. The Belle KLM is based on resistive plate chambers (RPC) technology. High voltage is distributed over the two glass electrodes with bulk resistivity of $\sim 5 \times 10^{12} \Omega \cdot \text{cm}$ but transparent to the fast electric pulses. The throughgoing charged particle ionizes gas along its track and form streamer discharge in the gas-filled gap between electrodes. The signal induced on the couple of orthogonal pick-up strip electrodes is large enough to be discriminated without amplification.

In the Belle environment the performance of the most of the barrel layers was about 99% decreasing down to 91% for the innermost one. For
the endcap efficiency ranges between 95% and 76%. The lowest numbers are for the outermost layers where the background is higher and came mostly from the accelerator tunnel.

3. Belle II KLM system

Since at high background loads of Belle II experiment efficiency of the RPCs drops to zero, new Belle II endcap KLM system (EKLM) utilizes another technique based on scintillator strips read-out by wavelength shifting (WLS) fibers. The light is registered by novel devices – silicon photomultipliers (SiPM)*.

![Fig. 1. Scintillator strip with glued WLS fiber.](image)

The base element of the new system is scintillator strip of polystyrene doped with PTP (1.5%) and POPOP (0.01%) produced by extrusion technique at "Uniplast" enterprise (Vladimir, Russia). It has a cross-section of $7 \times 40 \, \text{mm}^2$ and length varying from 606 mm to 2784 mm. In total there are 41 different strip lengths. Diffusive reflective cover of the surface is produced by chemical etching. A 1.3 mm wide and 3 mm deep groove is milled in each strip to hold the WLS fiber. An optical contact between the scintillator and Kuraray Y11 WLS fiber put into the groove is provided by optical gel SL-1 by SUREL (St.-Peterburg, Russia). One WLS fiber end is connected to a photosensor while the other is mirrored using a silver-shine paint. The groove is covered by aluminized reflective tape. The schematic view of the strip is presented in Fig. 1. The photosensor is Hamamatsu SiPM (S10362-13-025CKX). It is pressed against the polished fiber end by

*Different manufacturers use different names for devices of such type, e.g. CPTA, MPPC, MRS APD.
the rubber ring in the connector. SiPMs are connected to the preamplifiers by twisted-pair cables. For the sake of efficient handling strips are glued together into segments of 15 strips. A 1.5 mm plastic plates are glued to the strips at both segment’s sides with double-sided sticky tape. The whole EKLM system consists of 112 identical modules. Each module contains 150 strips (10 segments) in two identical orthogonal planes, preamplifiers for these strips and is enclosed into aluminum box. The segments supported by aluminum I-beams that run along the segment boundaries. The I-beams supporting the $x$- and $y$-plane segments are glued into a supporting grid. The schematic view of the module is shown in Fig. 2.

![Fig. 2. EKLM sector.](image)

To control strip quality during the production process each strip is subjected to cosmic ray test, while the light yield caused by cosmic muons passing trough the strip is measured. The triggers are located at the mid-
dle of the strip and at both its ends. The results of the tests are shown in Fig. 3. The quality of the strips is found to be very good. The number of photo electrons from the end, nearest to the SiPM, is shown by solid curve. Only strips with light yield more than 33 p.e. are accepted for the further production. This number is almost 1.5 times larger than original goal.³

![Figure 3](image)

Fig. 3. Results of the cosmic tests. The filled and open circles represent light yield from the near end for short (< 2000 mm) and long (> 2000 mm) strips, respectively. The solid curve shows the results for all strips. The arrow indicates acceptance threshold value.

The mass production of the detector components have been started in ITEP in September 2012. Till the end of the September 2013 more than 75% is complete: 14075 strips are produced and tested, 13808 successfully passed the cosmic test; 875 segments are assembled. Three (out of four) batches of the detector components are sent to KEK, the last one will be sent in November.

4. Acknowledgments

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