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A scintillation counter consisting of a pure CsI crystal, WLS and APD for Belle II

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Belle II

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1, Introduction

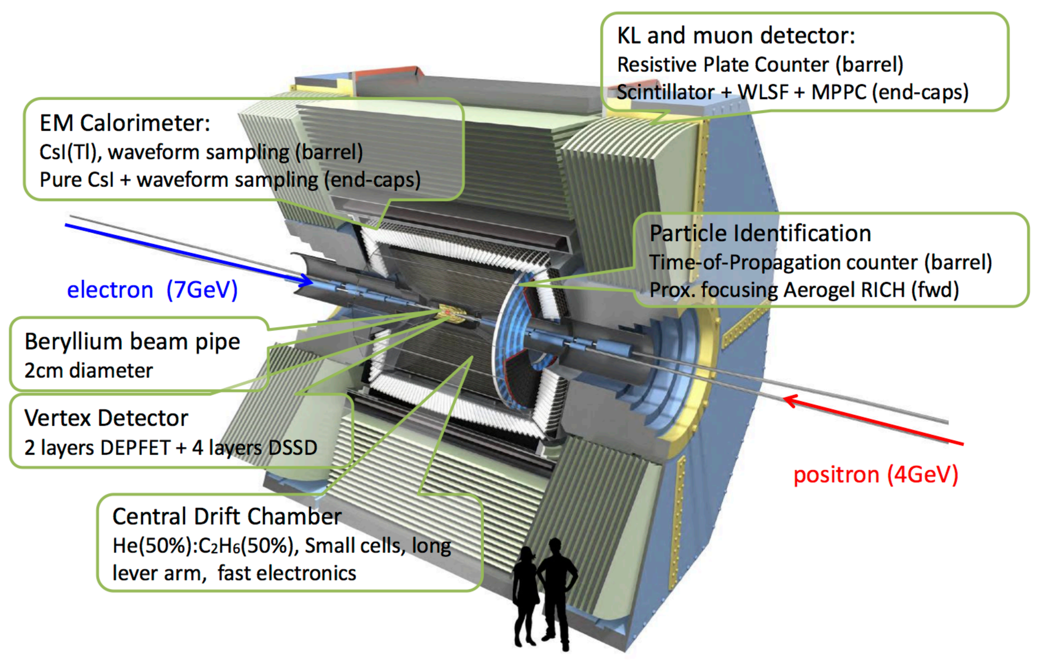
BELLE experiment, operated at KEKB accelerator, was the world's highest luminosity $e^+ e^-$ collider, investigating CP-violation effects in B meson decays. BELLE II, as an upgrade of its predecessor, aims at searching for New Physics with 40 times higher luminosity. In order to cope with higher luminosity, fast pure CsI scintillation crystals (τ_{CsI} = 30 ns) for the ECL end-caps have been proposed.

Two options are considered for the photosensitive elements: vacuum photopentodes and silicon avalanche photodiodes (APD). APD (Hamamatsu S8664-1010 and S8664-55), which is compact, only demanding 400 V bias voltage with a low dark current (~nA) and insensitive to magnetic field is studied here.

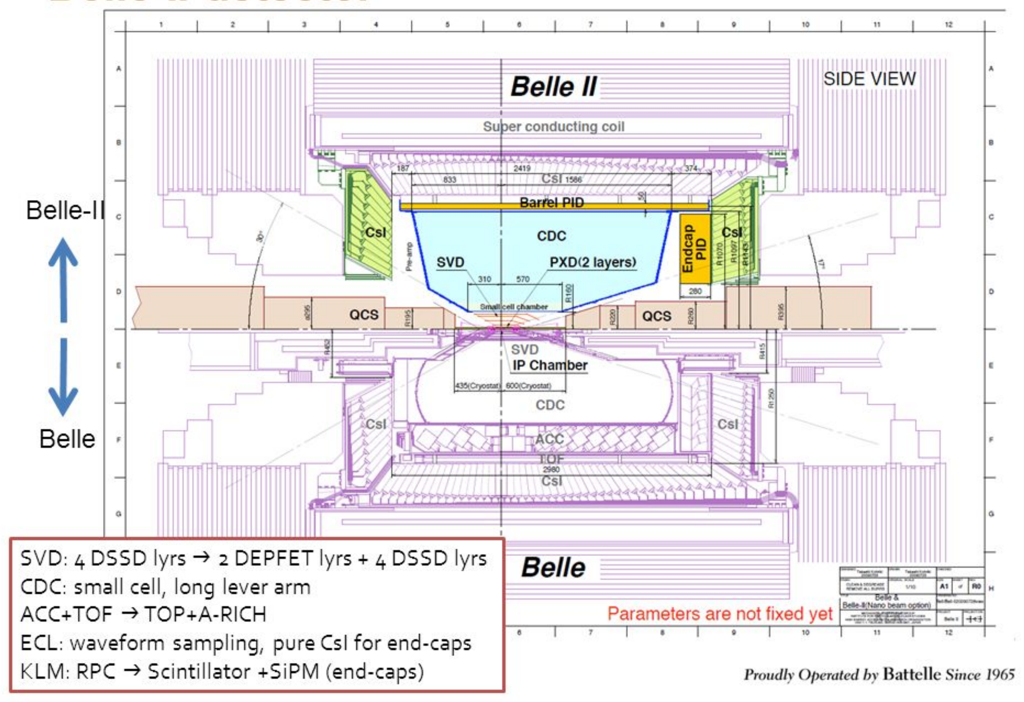
The high electronic noise due to short shaping time (30 ns) and large junction capacitance of APD, along with the small light yield of pure CsI (1 order of magnitude smaller than that of doped CsI(Tl)) result in large equivalent noise energy (ENE). In the scheme with one actual size crystal (6x6x30 cm^3) and one APD (S8664-1010), we obtain ENE about 2 MeV, which is 4 times the acceptable level (0.5 MeV)[1].

Therefore, Wavelength shifting plate, developed by LumInnoTech LLC, is applied to the scheme, which matches the emission spectrum of pure CsI and quantum efficiency spectrum of APD perfectly. The signal is enhanced and ENE suppressed[2].

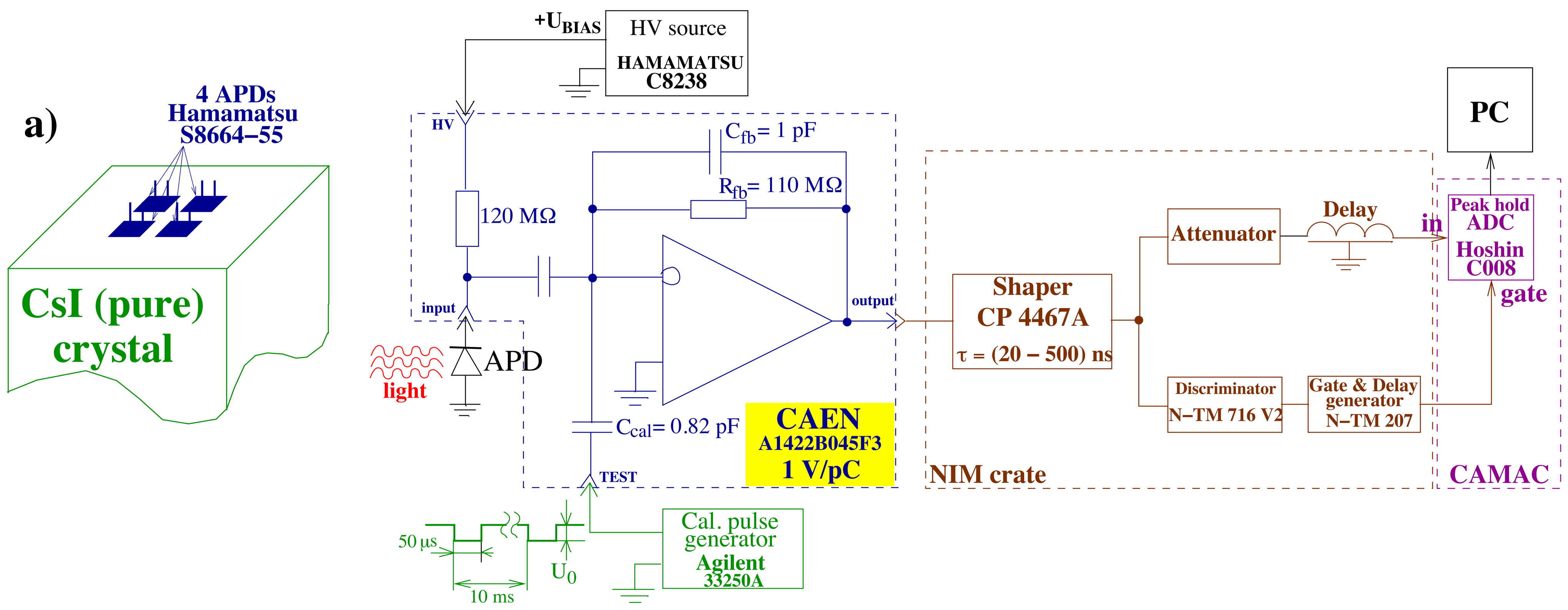
Belle II Detector



Belle-II detector



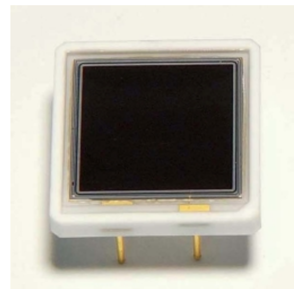
2, Scheme of the counter



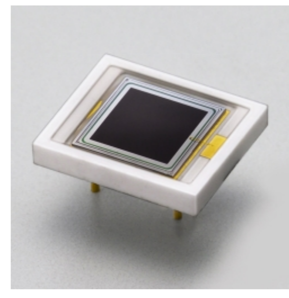
Schematic diagram of the experimental setup[3]

In the previous study [2], the counter consisted of a pure CsI crystal (6x6x30 cm^3, covered by Gore-Tex Teflon and aluminized mylar film) and APD (Hamamatsu S8664-55 and S8664-1010 type) coupling with optical grease (OKEN-6262A). The readout electronics[3] included a CAEN A1422B045F3 preamplifier, a CP 4467A shaper and a Hoshin C008 ADC. With the help of cosmic muons, the ENE of the counter system has been measured. By attaching several APD's per crystal, lower ENE's were obtained, 1.1 MeV in the case of 2 S8664-1010, 0.8 MeV in the case of 4 S8664-1010, 1.7 MeV in the case of 2 S8664-55 and 1.2 MeV in the case of 4 S8664-55.

The electronic noise of the counter system was studied and proved to be suppressed very well. The most feasible way to further reduce ENE is to increase the signal from APD.

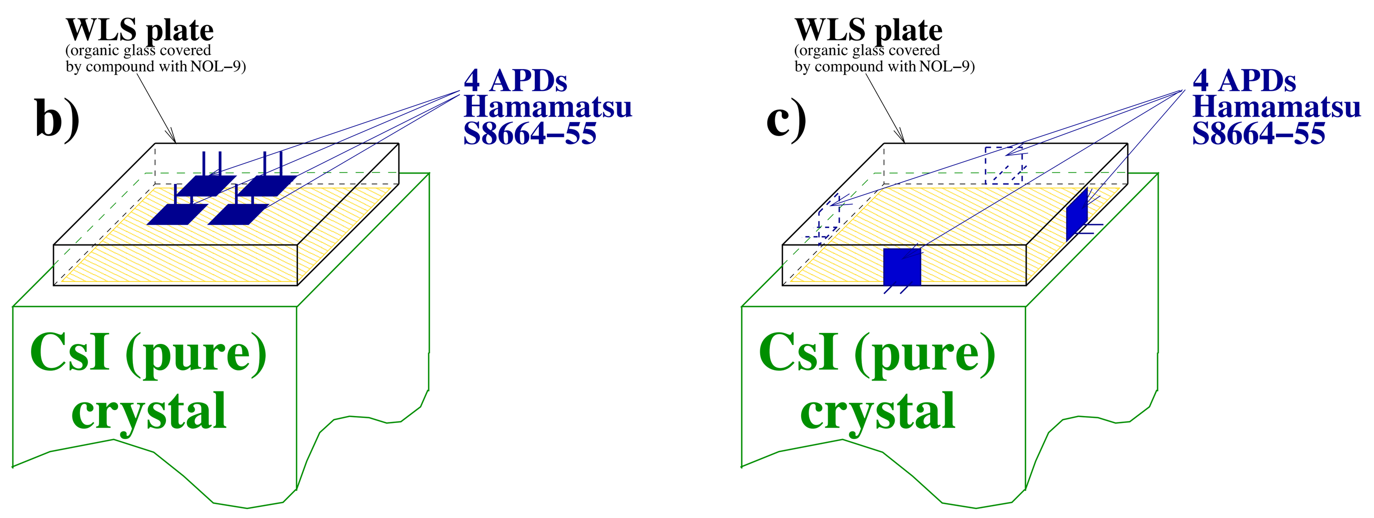


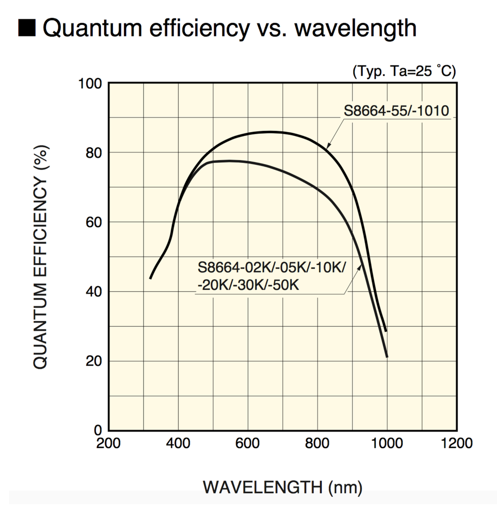
S8664-1010



S8664-55

3, Improvement on light output by WLS

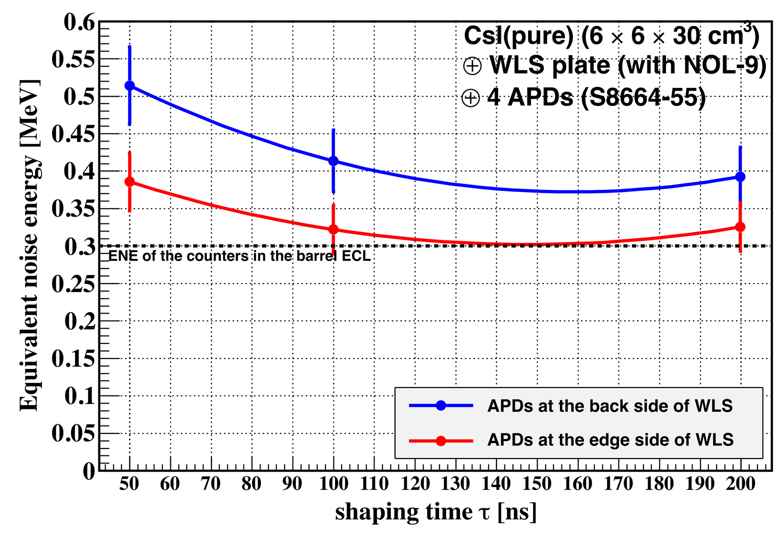




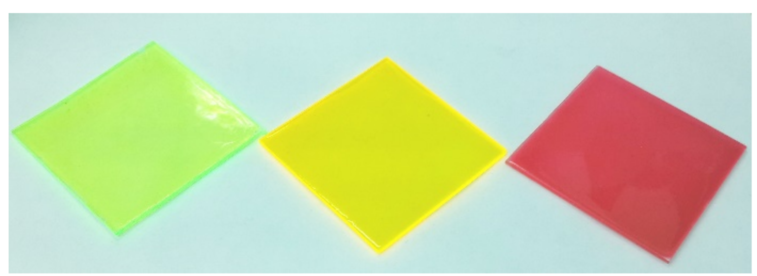
The emission light of pure CsI is in ultraviolet range (peak at 315 nm), where the quantum efficiency of APD is only about 30%[4]. With wavelength shifting (WLS) plates specially developed by LumInnoTech LLC[5], inserting it between the crystal and APD, the ultraviolet scintillation light of pure CsI is shifted to visible range where APD has maximal quantum efficiency of about 85%.

In order to obtain optimal light collection efficiency, the coupling of WLS to APD and crystal has also been studied in detail. It is proved that applying optical grease between WLS and APD and attaching WLS to CsI crystal without optical grease provides the largest signal intensity.

Furthermore, different configurations of attaching APD have also been tested, APD on the backside of the WLS, as shown in fig.b, and APD on the edge of WLS, as shown in fig.c. The ENE of the former scheme (blue line) is reduced to 0.52 MeV at 50 ns and 0.41 MeV for the latter scheme (red line), as plotted below[3]. Therefore the required noise level is achieved.

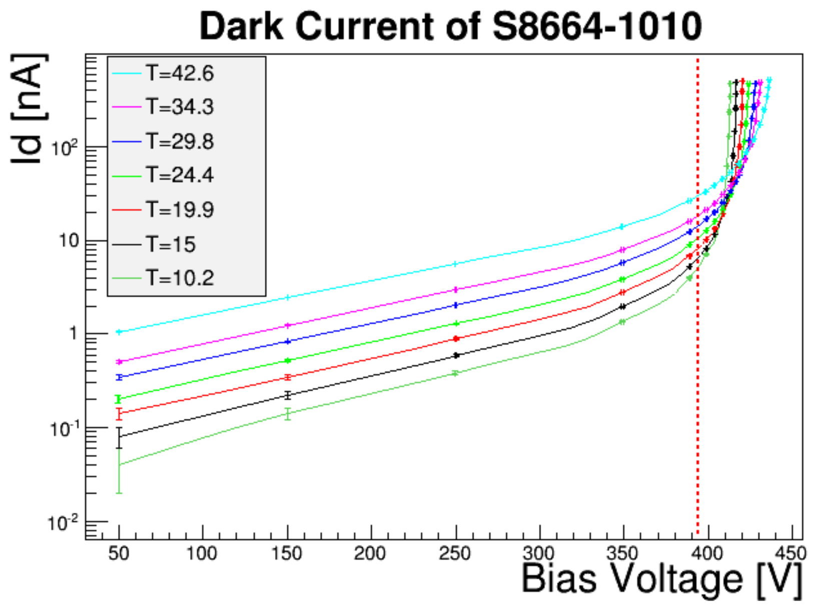


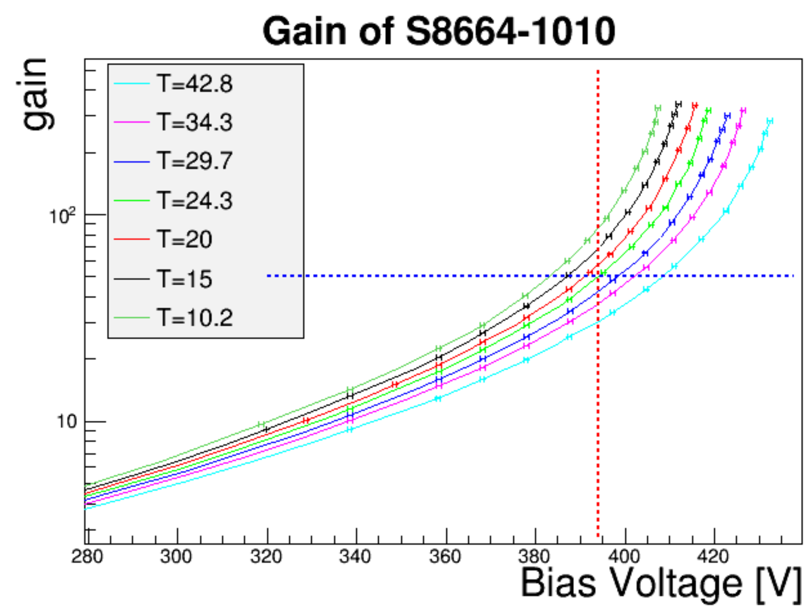
ENE of the counter with WLS[3] .



Wavelength shifting plates from LumInnoTech[5].

4, Characteristics of APD





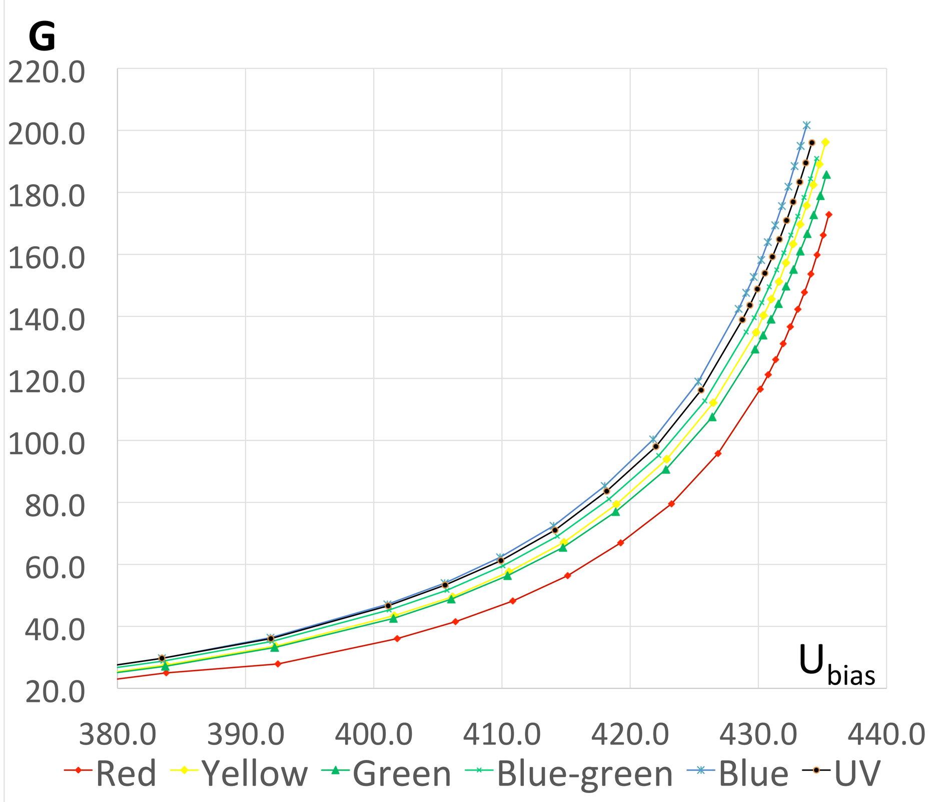
For the sake of the stability of the counter, it is necessary to design a temperature compensation circuit in the bias voltage supply for APD. For that purpose, the dependence of APD's dark current and gain on temperature were measured in range 10°C -> 43°C.

Relative temperature gain variation (1/G)·(dG/dT) is calculated at gain 30, 50 and 100 respectively.

(1/G)·(dG/dT) = 2.261% (@G=30);
(1/G)·(dG/dT) = 3.132% (@G=50);
(1/G)·(dG/dT) = 4.903% (@G=100).

At working point (G=50), the dark current varies from 1 nA to 30 nA for the range 10°C->43°C.

Meanwhile, the response of the gain of S8664-1010 to lights of different wavelength has been measured, as plotted below.



Gain VS bias voltage, irradiated by different color

Reference:
[1] T.Abe, et al. Belle II Technical Design Report, arXiv: 1011.0352.
[2] Y.Jin, H.Aihara, O.V.Borshchev, D.A.Epifanov, S.A.Ponomarenko, N.M.Surin, Nucl. Instrum. Methods A, 2016, 824: 691-692.
[3] D. Epifanov, H. Aihara, O. Borshchev, Y. Jin, S.A. Ponomarenko and N.M. Surin, PoS(PhotoDet2015) 052.
[4] http://www.hamamatsu.com
[5] http://www.luminnotech.com