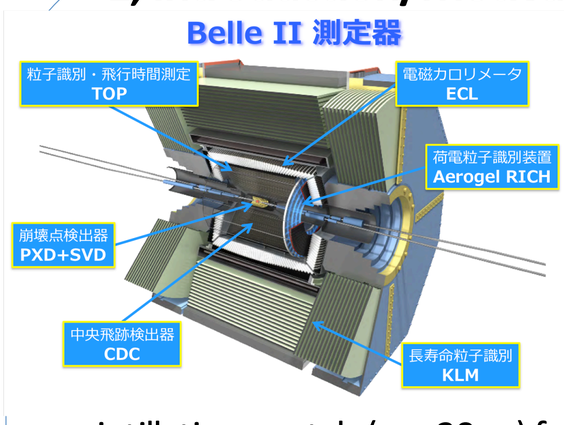
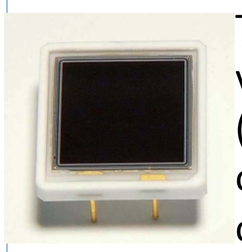
Research of pure CsI crystal readout by APD for ECL end cap of BELLE II

Yi-Fan Jin (on behalf of BELLE II ECL group)
The University of Tokyo
jin@hep.phys.s.u-tokyo.ac.jp

1, Introduction/Motivation:



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

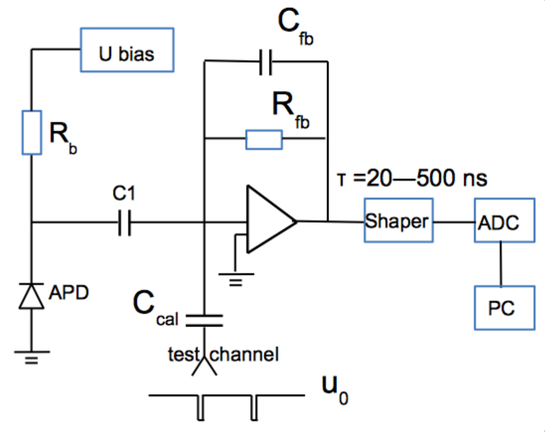
2, Study of Equivalent Noise Charge (ENC):

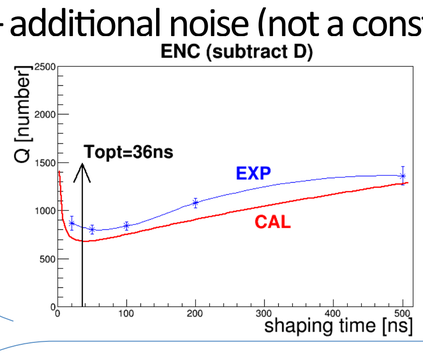
Low electronic noise is crucial for the scheme with APD. High quality charge sensitive preamplifier optimized for the work with short shaping time is needed. Correlated noises should be studied and suppressed as well. The readout electronics include a CAEN A1422B045F3 preamplifier, a CP 4467A shaper and a Hoshin C008 ADC. In order to optimize the noise at shaping time 30 ns, the shot noise, thermal noise and additional noise were studied.

$$ENC^2 = (2eI_d + \frac{4k_bT}{R_b} + i_{na}^2)K_iT_s + (4k_bTR_s + e_{na}^2)K_\nu\frac{C^2}{T_s} + K_{\nu f}A_fC^2$$

$$ENC^2 = \frac{2I_dKgF\tau}{e} + (\frac{B^2}{\tau} + E^2)C^2 + D^2$$

e – electron charge; F – excess noise factor;
I_d – dark current; C – APD's capacitance
g – APD gain; B – thermal noise coefficient;
τ – shaping time; K – shaper factor;
D – additional noise (not a constant)

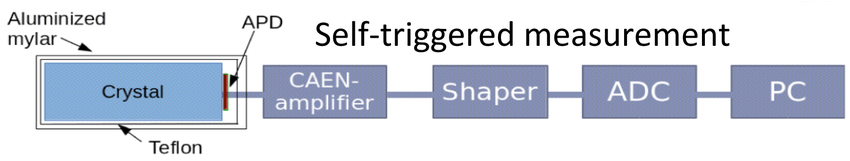




The measured total noise agrees well with the calculated result.

The best commercially available FETs (BF862 and 2SK932-23) with the largest transconductance were tested in preamplifier, they showed similar results.

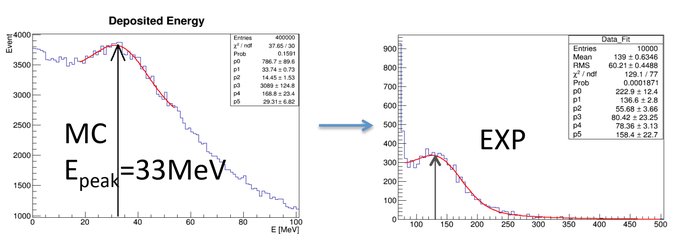
3, Measurement of Equivalent Noise Energy (ENE):



Self-triggered measurement

The counter consists of pure CsI crystal (covered by Gore-Tex Teflon and aluminized mylar film) and APD (Hamamatsu S8664-55 and S8664-1010 type) coupling with optical grease (OKEN-6262A). With help of cosmic muons, the ENE of the counter with one or two or four APDs have been measured.

A simulation of deposited energy of cosmic muons in crystal was developed, and the peak position was found to be about 33 MeV.

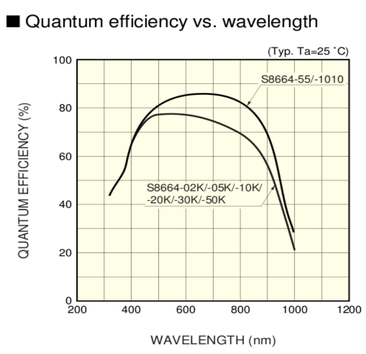


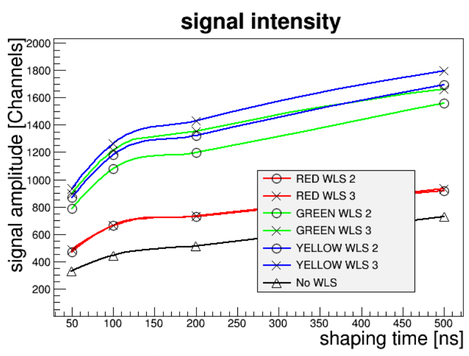
2 S8664-1010 APDs-> 1.1 MeV;
4 S8664-1010 APDs-> 0.8 MeV;
2 S8664-55 APDs -> 1.7 MeV;
4 S8664-55 APDs -> 1.2 MeV

Further improvement is needed. The only way to improve ENE is to increase signal.

4, Improvement of signal:

Several optical greases, OKEN-6262A, TSF451-50M and BC-630 have been studied. OKEN-6262A is the best. Different types of reflectors have been tested to enhance the light collection efficiency. Porous Gore-Tex Teflon is the best. The emission light of pure CsI is in ultraviolet range, where quantum efficiency the APD is about 30%[2]. With wavelength shifting (WLS) plates specially developed by LumInnoTech LLC[3], the ultraviolet scintillation light of pure CsI is shifted to visible range where APD has maximal quantum efficiency of about 85%.



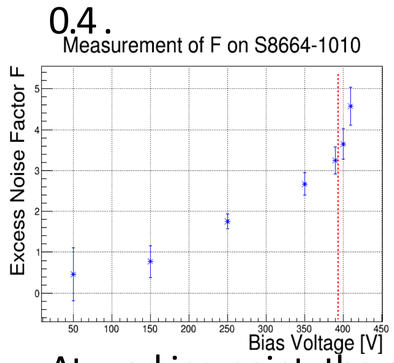


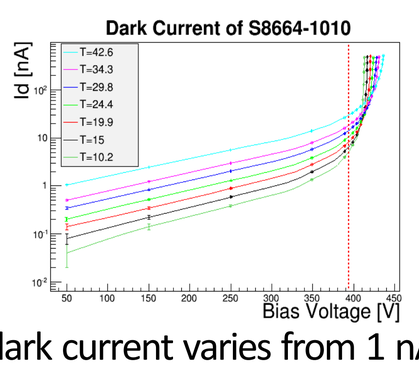
With help of innovative WLS plates signal from APD is increased by a factor 3. The WLS NOL9 provides largest signal and makes the ENE of *2 S8664-1010 ->0.55MeV, 4 S8664-55 -> 0.45MeV*.

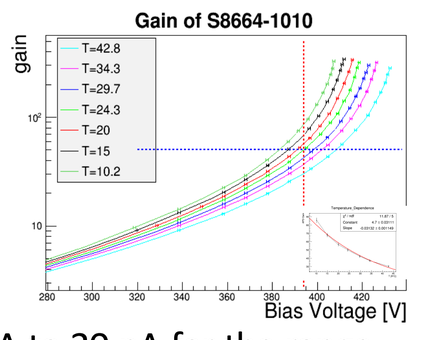
5, Characteristic of APD:

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

The excess noise factor F, as an important parameter of the APD was also measured. At working point of APD (gain=50, bias voltage=394 V), F = 3.4 ± 0.4 .







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

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

6, Conclusion:

APD, which is compact, insensitive to magnetic field and only demanding 400 V bias voltage with a low dark current provides a promising option for BELLE II ECL end caps upgrade.

- Optimal wrapping material (Gore-Tex Teflon) and optical grease (OKEN-6262A) were established.
- WLS plates with innovative luminophores were applied to improve signal.
- Several APDs were used for the further decrease of ENE.
- The required electronic noise was achieved for the counter with 2 S8664-1010 APDs (ENE=0.55MeV) and with 4 S8664-55 APDs (ENE=0.45MeV).

The work is going on to elaborate the final design of the BELLE II end cap ECL channel.

Acknowledgments:

I am grateful to Prof.H.Aihara, D.Epifanov (The University of Tokyo) for their instructions and K.Miyabayashi (Nara Women university), S.A.Ponomarenko, O.V.Borshchev (EISPM of RAS, LumInnoTech LLC) for cooperation.

Reference:
1: T.Abe, et al. Belle II Technical Design Report, arXiv:1011.0352.
2: http://www.hamamatsu.com
3: http://www.luminnotech.com/