Journal of Instrumentation

Study of the fast calorimeter prototype for modern e^+e^- factories

To cite this article: E. Prokhorova 2020 *JINST* **15** C08023

View the article online for updates and enhancements.

IOP | ebooks™

Bringing together innovative digital publishing with leading authors from the global scientific community.

Start exploring the collection–download the first chapter of every title for free.

This content was downloaded from IP address 84.237.42.54 on 08/09/2020 at 11:15

Published by IOP Publishing for Sissa Medialab

Received: *April 24, 2020*
Accepted: *May 29, 2020*
Published: *August 27, 2020*

International Conference on Instrumentation for Colliding Beam Physics
Novosibirsk, Russia
24–28 February, 2020

2020 JINST 15 C08023

Study of the fast calorimeter prototype for modern e^+e^- factories

E. Prokhorova

Budker Institute of Nuclear Physics,
11, Acad. Lavrentieva Pr., Novosibirsk, 630090, Russia
Novosibirsk State University,
1, Pirogova str., Novosibirsk, 630090, Russia

E-mail: `e.prokhorova@g.nsu.ru`

Abstract: Modern e^+e^- factories with high luminosity require fast response of the detector subsystems to suppress severe beam background. The prototype of the electromagnetic calorimeter based on the counter with a pure CsI crystal, novel wavelength shifter with nanostructured organosilicon luminophores and avalanche photodiodes Hamamatsu S8664-55 is discussed. Results of detection of cosmic particle signals by such a prototype are reported.

Keywords: Calorimeters; Detector design and construction technologies and materials; Scintillators, scintillation and light emission processes (solid, gas and liquid scintillators)

© 2020 IOP Publishing Ltd and Sissa Medialab

https://doi.org/10.1088/1748-0221/15/08/C08023

Contents

1 Introduction 1

2 Optimisation of the WLS plate 2

3 Electronics 3

4 Counters 4

5 Conclusion 5

2020 JINST 15 C08023

1 Introduction

Modern e^+e^- factories with high luminosity like Belle II at SuperKEKB [1, 2], operating nowadays, and the future project of the Super Charm-Tau factory [3] require fast response of the detector subsystems to suppress severe beam background. A calorimeter is one of the important detector subsystems. Thus, it is preferable to use for it fast scintillation crystals.

In comparison with widely used CsI(Tl)/CsI(Na) crystals with a scintillation decay time of 1/0.6 μs [4], crystals of pure CsI (CsI(pure)), with a scintillation decay time of 30 ns, allow one to reduce substantially the pileup noise in the electromagnetic calorimeter. CsI(pure) crystals have notable light yield, high radiation hardness, handy mechanical properties, and acceptable price. Hence, these crystals are optimal for modern e^+e^- factories with ultrahigh luminosity. However, a light output (LO) of these crystals is deficient, as a result, it is necessary to use photosensitive detectors with inner gain. Recent studies [5–7] showed that silicon avalanche photodiodes (Hamamatsu S8664-55 APDs) can be applied as photosensitive elements for the calorimeter. But the quantum efficiency of the APD is low ($(20 \div 30)\%$) for the wavelength of the CsI(pure) scintillation light ($\simeq$ 320 nm). Therefore, it was proposed to use the PMMA wavelength shifting (WLS) plate ($6 \times 6 \times 0.8\,\mathrm{cm}^3$) with the novel nanostructured organosilicon luminophores (NOL-9) [8, 9] coating, which allows one to increase the signal from the counter substantially.

The prototype of the electromagnetic calorimeter based on 16 standard counters with CsI(pure) crystals, WLS plates with NOL-9, APDs coupled to the plates and custom-made charge-sensitive preamplifiers was suggested. The first tests of the standard counter with the preamplifier developed in Budker Institute of Nuclear Physics were carried out and the optimisation of the WLS plate shape has been performed to improve the signal. In this paper, we present several preparatory and check-up procedures of the prototype counters.

2 Optimisation of the WLS plate

CsI(pure) crystals emit scintillation light with the wavelength of about 320 nm in the UV region. In this regard, it was proposed to use WLS plates with NOL-9 which fast (∼ 7 ns) and efficiently (∼ 95%) re-emit the absorbed UV light with a shifted wavelength of about 588 nm in the visible range. The photosensitivity of the APD for the wavelength of 320 nm is about 5 A/W, whereas that for the shifted wavelength is already about 20 A/W. Thus, a wavelength shifter allows one to improve APD photosensitivity by a factor of 4. Moreover, the shape of the WLS plate and materials used for coupling an APD and a plate are also important, so we tried to optimise these options.

Epoxy resin with high transparency and the appropriate refractive index was chosen to couple reliably an APD to a PMMA plate. So, as a start of our optimisation we tested several types of epoxy resin. This optimisation procedure allows us to increase the signal due to the adjustment of the refractive indices of the PMMA plate and APD entrance window compound. The procedure of choosing the necessary optical resin is presented in [10]. For the future measurements, we decided to use the most suitable optical resin BC-600 which shows the highest light collection efficiency (LCE). Then we studied the effect of the PMMA plate shape on the light collection efficiency.

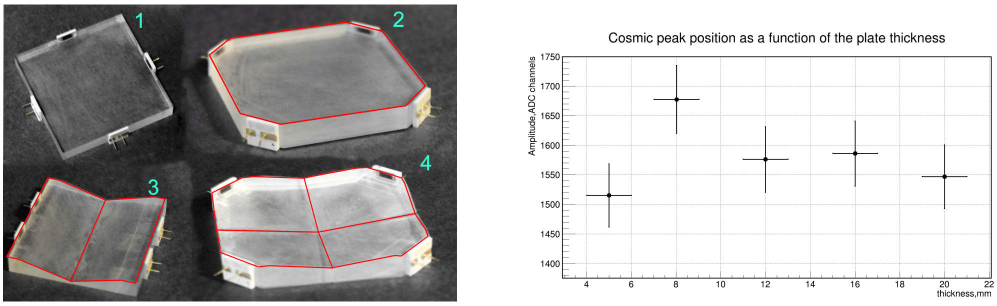

Figure 1. PMMA plates of different shapes/types. (1) flat plate, APDs is coupled to the side face of the plate, (2) flat plate, APDs are coupled to the truncated corners of the plate, (3) plate with two sloping faces, the edges of the plate are thicker than the center, APDs are coupled to the opposite edge sides of the plate, (4) plate with four sloping faces, the edges of the plate are thicker than the center,APDs are coupled to the truncated corners of the plate (left); position of the cosmic peak for the PMMA plates of type 4 with different thicknesses (right).

Table 1. Positions of the cosmic peaks for different types of the PMMA plates with a thickness of 8 mm.

Type	Peak position ADC chan.
1	1444 ± 17
2	1224 ± 14
3	1688 ± 18
4	1658 ± 19

Notable price and essential time consumption needed to cover PMMA plates of different shapes by NOL-9 luminophore forced us to study the effect of the plate shape without NOL-9 coating. For those measurements we used a CsI(Tl) crystal. It has a higher light output, and its scintillation light wavelength is more suitable for APD ($\simeq$ 550 nm) in comparison to a CsI(pure) crystal. Also these crystals have a scintillation decay time of 1000 ns, but for those measurements it is not crucial. PMMA plates of several types shown in figure 1 (left) were tested. The PMMA plate with four APDs was attached to the crystal without optical contact. The energy deposition spectrum from the cosmic particles has a distinct peak at the most probable energy deposition of about 33 MeV. It was monitored for different options of the counter. Table 1 summarises results of the measurements.

Finally, the LCE improvement of about 1.6 was observed for the PMMA plates of types 3 and 4 without NOL-9. The plate of type 4 was chosen as the main option because it provides a larger sensitive area in the shielding box of the fixed sizes. Moreover, it gives a larger LCE increase in comparison to the plate of type 2, which has the same sensitive area. The effect of the PMMA plate thickness was similarly studied with the plates of type 4 and thicknesses 5, 8, 12, 16 and 20 mm. The result of the measurements is presented in figure 1 (right). It was found that the best variant is the plate of type 4 with a thickness of 8 mm, and BC600 resin is used to couple APDs to the edge sides of the plate.

Then, 16 WLS plates of the best configuration (shape 4, thickness 8 mm and NOL-9 coating) were produced. Moreover, WLS plates with shape 4 with NOL-34 coating and shape 2 with NOL-9 (flat plate) coating were prepared as well. All these plates were tested in a counter with the same CsI(pure) crystal and positions of the cosmic peaks were monitored. The results of these measurements are shown in figure 2 (left). As it is seen from the distributions, the spread of the cosmic peak positions of 16 WLS plates with the best configurations is quite notable. It is determined mostly by the quality of the coating of the plates by NOL-9 luminophores. It turned out that the expected increase of the LCE for the plate of type 4 in comparison with the flat plate of type 2 has not been confirmed. In turn, the LCE of the flat plate is about 15% higher. The observed LCE effect is under investigation.

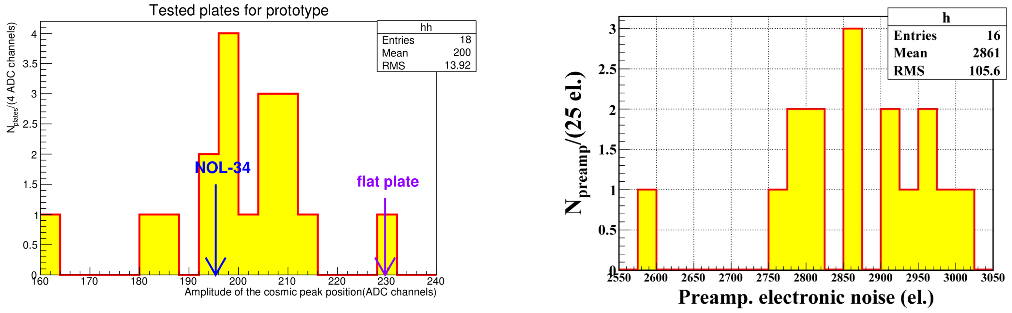

Figure 2. Cosmic peak positions for a counter with different plates used in the prototype (left); measured noises of a custom-made charge-sensitive preamplifier (right).

3 Electronics

The custom-made four-channel charge-sensitive preamplifier board with dimensions of 53×55 mm^2 was designed for the counter. The circuit design of each preamplifier channel is similar to that of the preamplifier [11] designed for electromagnetic calorimeter of the COMET experiment, but the new circuit design features two input FETs 2SK932, special output stage which derives a differential

2020 JINST 15 C08023

current output signal, and test pulse input. The HV bias rectifier for each channel is also housed on the board. The readout of the signals from the counter is performed with a four-channel shaper-ADC board, each channel includes CR-RC^4 filter (τ = 30 ns), 40 MSps, 12-bit ADC and 256-word circular buffer for storing the sampled waveforms. Four output signals from each preamplifier are transferred via twisted pairs to the input of the shaper-ADC board, where they are summed in the newly developed differential receiver and summator circuit. Sixteen custom-made charge sensitive preamplifiers were produced and the electronic noise for each preamplifier was measured (see figure 2 (right)).

4 Counters

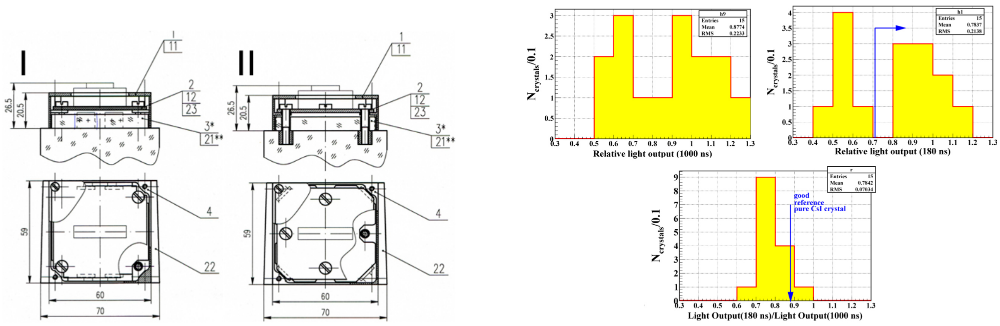

Figure 3. Two variants of the counter: (I) — two pairs of APDs are coupled to the opposite edge sides of the plate of type 1 or 3, (II) — four APDs are coupled to the truncated corners of the plate of type 2 or 4 (left); relative LO with the scintillation light integrated within 1 µs (TOTAL), relative LO with the scintillation light integrated within 180 ns (FAST), FAST/TOTAL ratio of the LO components for the crystals used in the prototype (right).

Two types of mechanical construction of the counter were tested, see figure 3 (left). The second variant has been chosen for the prototype. It is optimised for the usage of the plates of type 2 and 4 which have larger sensitive areas, hence the signal from the counter (II) is larger. The procedure of the electric mounting of the counter was elaborated. One counter with the WLS plate of type 2 with NOL-9 coating, CsI(pure) crystal and custom-made charge-sensitive preamplifier was assembled. To study experimental environment, data acquisition system, and sources of electromagnetic interference, beam tests with one counter have been carried out at the BINP ROKK facility [12]. The electron beam with the energies of 0.8, 1.5, 2.0, 2.5 and 3.0 GeV hit the center of the front transversal facet of the counter. Signals from the counter were recorded with the trigger from the external plastic scintillation detector and from CsI counter itself. In total, about 1.2 million events were recorded, got expected energy deposition spectra from the counter (see figure 4 (left)).

Sixteen CsI(pure) crystals required for the prototype were studied. The relative LO and the ratio of fast to total LO components of available crystals have been measured (see figure 3 (right)). Then crystals with the best characteristics and suitable sizes were chosen for a prototype.

As a result of these works, all WLS plates, APD, preamplifiers and crystals were sorted and sixteen counters were fully assembled. Light output and electronic noises of all counters were

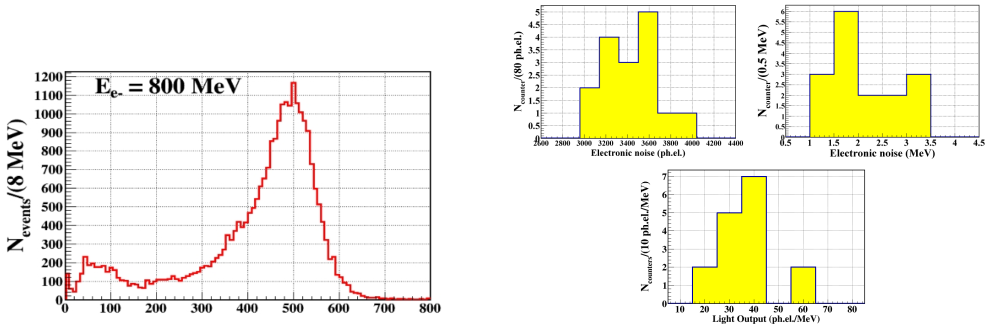

Figure 4. Energy deposition from the counter with the NOL-9 plate of type 2 (left); distributions of the Equivalent Noise Charge (ENC), Equivalent Noise Energy (ENE) and Light Output (LO) for 16 counters of the prototype (right). The spread of the counter light outputs is determined by the spread of the light yields of the utilized crystals (about factor of 2) and the remaining spread of the light collection efficiencies due to the partial coverage of the crystal facets by the WLS plates in some counters.

measured (see figure 4 (right)). This prototype is being studied now using cosmic muons. The energy resolution of the prototype will soon be measured at the photon test beam.

5 Conclusion

CsI(pure) inorganic scintillation crystals are an appropriate material for the electromagnetic calorimeter of the modern e^+e^- factories. Compact, insensitive to magnetic field and modest price Hamamatsu APD S8664-55 is an appropriate photosensitive element, several APDs in one counter provide signal readout redundancy. The calorimeter prototype of 16 counters based on CsI(pure) crystals, WLS (NOL-9) plates and Hamamatsu S8664-55 APDs has been constructed. All necessary components (crystals, plates, preamplifiers and shaper-ADC boards) have been developed, produced and studied. The prototype is being studied with cosmic particles now. Then, energy resolution of the prototype will be measured at the ROKK test beam facility in 2020 in Budker Institute of Nuclear Physics.

2020 JINST 15 C08023

References

[1] Belle-II collaboration, *Belle II Technical Design Report*, `arXiv:1011.0352`.

[2] Belle-II collaboration, *The Belle II Physics Book*, *PTEP* **2019** (2019) 123C01 [*Erratum ibid.* **2020** (2020) 029201] [`arXiv:1808.10567`].

[3] A.E. Bondar, *Project of a Super Charm-Tau factory at the Budker Institute of Nuclear Physics in Novosibirsk*, *Phys. Atom. Nucl.* **76** (2013) 1072 [*Yad. Fiz.* **76** (2013) 1132].

[4] B.A. Shwartz, *Crystal calorimeters*, *Nucl. Instrum. Meth. A* **494** (2002) 288.

[5] H. Aihara, O. Borshchev, D. Epifanov, Y. Jin, S.A. Ponomarenko and N.M. Surin, *Study of scintillation counter consisting of a pure CsI crystal and avalanche photodiodes*, *PoS* **PhotoDet2015** (2016) 052.

[6] H. Aihara, D. Epifanov, Y. Jin and K. Wan, *A scintillation counter consisting of a pure CsI crystal, WLS and APD for Belle II*, *PoS* **ICHEP2016** (2016) 703.

[7] Y. Jin, H. Aihara, O.V. Borshchev, D.A. Epifanov, S.A. Ponomarenko and N.M. Surin, *Study of a pure CsI crystal readout by APD for Belle II end cap ECL upgrade*, *Nucl. Instrum. Meth. A* **824** (2016) 691.

[8] S.A. Ponomarenko, N.M. Surin, O.V. Borshchev, Y.N. Luponosov, D.Y. Akimov, I.S. Alexandrov et al., *Nanostructured organosilicon luminophores and their application in highly efficient plastic scintillators*, *Sci. Rep.* **4** (2014) 6549.

[9] http://www.luminnotech.com/.

[10] E. Prokhorova, *Study of the fast calorimeter prototype for the Super Charm-Tau Factory*, *EPJ Web Conf.* **212** (2019) 01007.

[11] Y.V. Yudin, D.N. Grigor'ev and L.B. Epshtein, *Amplification channel for avalanche photodiode signals purposed for spectrometric measurements under high peak rates*, *Optoelectron. Instrument. Proc.* **54** (2018) 203.

[12] G. Kezerashvili, A.M. Milov, N. Muchnoi and A.P. Usov, *A Compton source of high-energy polarized tagged gamma-ray beams. The ROKK-1M facility*, *Nucl. Instrum. Meth. B* **145** (1998) 40.