Study of the fast calorimeter prototype for the Super Charm-Tau Factory

Ekaterina Prokhorova[1,2,*,**]

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

Abstract. Modern e^+e^- factories with high luminosity require fast response time of the detector subsystems to collect the data efficiently and suppress severe beam background. The prototype of the electromagnetic calorimeter based on the counter made of pure CsI crystal, novel wavelength shifter with nanostructured organosilicon luminophores and avalanche photodiodes Hamamatsu S8664-55 is discussed. Results of the measurement of the basic characteristics of the counter are presented.

1 Introduction

Nowadays the project of the Super-Charm Tau Factory (SCTF) [1] is actively discussed in Budker Institute of Nuclear Physics. SCTF is a double ring electron-positron collider with the crab waist scheme. This collider makes it possible to reach the record luminosity up to the the 10^{35} 1/cm^2/s at the beam energy of 2 GeV. The energy range of the collider will be from 2 to 6 GeV in the center-of-mass system. The main goal of experiments at SCTF is a precise study of processes with c-quarks and τ leptons. Such physics program requires good energy and momentum resolution of the detector and a particle identification system with the best parameters among the detectors already existing or under construction. Moreover, high luminosity of the Super-Charm Tau factory requires a fast response time of the detector subsystems to cope with high trigger rate and suppress severe beam background. Electromagnetic calorimeter is one of the important subsystems of the detector, it serves for high efficiency γ detection with good energy and coordinate resolution. The information from the calorimeter is also crucial for particle identification and luminosity measurement. Crystals of pure CsI (CsI(pure)), with a scintillation decay time of 30 ns, allow one to reduce substantially pileup noise in the electromagnetic calorimeter. These crystals have notable light yield, high radiation hardness, handy mechanical properties, and acceptable price. Thus, the CsI(pure) crystals are an optimal variant for calorimeter of the Super-Charm Tau Factory. However, a light output of these crystals is deficient, as a result, it is necessary to use photosensitive detectors with inner gain. Recent studies [2–4] showed that silicon avalanche photodiodes (APD) can be applied as a photosensitive element for the calorimeter. Although the quantum efficiency of the APD is low ($(20 \div 30)\%$) for the wavelength of the CsI(pure) scintillation light, the wavelength shifting (WLS) plate ($6 \times 6 \times 0.8$ cm^3) with the novel nanostructured

*e-mail: e.prokhorova@g.nsu.ru
**on behalf of the Super Charm-Tau calorimeter group

organosilicon luminophores (NOL-9) [5, 6] allows one to increase the signal from the counter substantially.

The prototype of the electromagnetic calorimeter based on the standard counters with the CsI(pure) crystals, WLS plates coated 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, the optimisation of the WLS plate shape has been done to improve the signal. In this paper we present several solutions to improve the characteristics of the standard counter.

2 Optimisation of the WLS plate

CsI(pure) crystal emits the scintillation light with the wavelength of about 320 nm in the UV region. While NOL-9 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 the photosensitivity for the shifted wavelength is already about 20 A/W. This wavelength shifter allows one to improve APD photosensitivity by a factor of 4.

To optimize the coupling of the APDs to the PMMA plate covered by NOL-9, several types of epoxy resin were tested: PEO-210KE, PEO-610KE-20/0, PEO-510KE-20/0, BC600, Polytec. 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. Counter based on CsI(Tl) crystal with matted PMMA plate of type 1 without wavelength shifter was assembled for selection the optimal optical cement. This counter was used to monitor the energy deposition spectrum from the cosmic particles. It has a distinct peak of the most probable energy deposition of about 33 MeV. First, APDs were coupled to the plate by optical grease BC630. Position of the cosmic peak in this case served as a reference. Then, the same plate and APDs were coupled with the optical cement BC600 or Polytec, and positions of the cosmic peaks were compared with the reference. In these experiments, BC600 gives an improvement by a factor of 1.36. Table 1 summarises results of measurement. Then, another

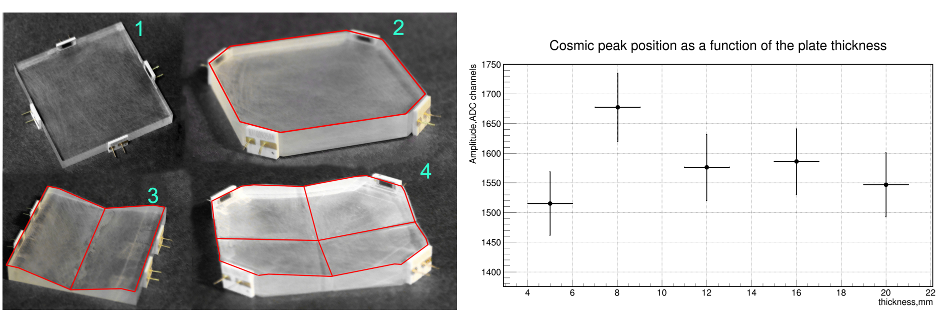

Figure 1. PMMA plates of different shapes/types (left); position of the cosmic peak for the PMMA plates of type 4 with different thicknesses (right).

PMMA plate of type 1 was used in the counter. Each of 4 APDs was coupled to the plate with particular type of resin. Thus, signals from APDs coupled by PEO-210KE, PEO-510KE-20/0, PEO-610KE-20/0, and BC600 optical resins were registered independently. Position of the peak of the most probable energy deposition registered by APD with cement BC600 was used as a reference, and the other 3 positions of the cosmic peak corresponding to the

Table 1. Positions of the cosmic peak for the optical grease BC630 and optical resins BC600 and Polytec (left); ratios of the positions of the cosmic peak for PEO-210KE, PEO-510KE-20/0, PEO-610KE-20/0 optical resins and BC600 (right).

resin/grease	peak position
BC630 (grease)	1058 ± 14
BC600 (resin)	1444 ± 17
BC630 (grease)	974 ± 11
Polytec (resin)	1159 ± 15

resin	ratio of peaks
PEO-210KE	1.01 ± 0.02
PEO-510KE-20/0	0.98 ± 0.02
PEO-610KE-20/0	0.912 ± 0.013

Table 2. Positions of the cosmic peaks for different types of the PMMA plates with the thickness of 8 mm.

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

remaining 3 types of optical cement were compared with the reference. Ratios of the positions of the cosmic peak to that with BC600 are presented in Table 1 The PEO-210KE, PEO-510KE-20/0, and BC600 showed the highest close to each other light collection efficiencies (LCE).

The effect of the shape of the PMMA plate on the light collection efficiency was studied with CsI(Tl) crystal and PMMA plate without NOL-9. Plates of several types shown in Fig. 1 were tested. APDs were coupled with PMMA plate with BC600 epoxy resin. The PMMA plate with 4 APDs was attached to the crystal without optical contact. Position of the cosmic peak was monitored for different options of the counter. Table 2 summarises result of the measurements.

Finally, the LCE improvement of about 1.6 was observed for the plates of types 3 and 4. The plate of the type 4 was chosen as the main option once it provides larger sensitive area in the shielding box of the fixed sizes. The effect of the PMMA plate thickness was checked with the plates of type 4 and thicknesses 5, 8, 12, 16 and 20 mm. The result of the measurements is presented in Fig. 1(right). It was found that the best variant is the plate of type 4 with the thickness of 8 mm, and BC600 resin is used to couple APDs to the edge sides of the plate.

3 Electronics

The custom-made four-channel charge sensitive preamplifier board with dimensions of 53x55 mm^2 was designed for the counter. The circuit design of each preamplifier channel is similar to that of the preamplifier [7] designed for Electromagnetic Calorimeter of the COMET experiment, but the new circuit design features 2 input FETs 2SK932, special output stage which derives differential current output signal, and test pulse input. The HV bias rectifier for each channel is also housed on the board. The procedure to assemble mechanics and electronics of the counter has been elaborated. The readout of the signals from the counter is performed by four-channel Shaper-ADC board, each channel includes CR-RC^4 filter (τ=30ns), 40MSps, 12-bit ADC and 256-word circular buffer for storing the sampled waveforms.

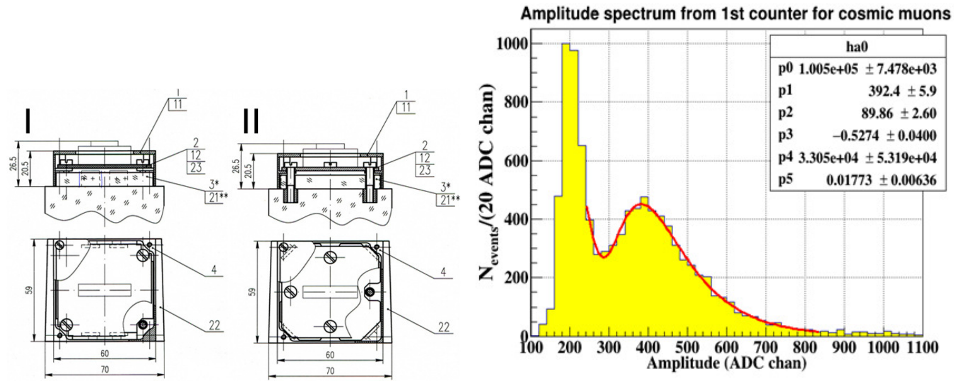

Figure 2. Two variants of the counter: (I) - two pairs of APDs are coupled to the opposite edge sides of the plate of type 1 or 3, (II) - four APDs are coupled to the truncated corners of the plate of type 2 or 4 (left); amplitude spectrum from cosmic particles for the reference counter (right).

4 Counter

Two types of mechanical construction of the counter were tested, see Fig. 2. The first variant is optimised for the usage of the WLS plate of type 1 or 3, while the second variant - for the usage of WLS plate of type 2 and 4. In the aluminium shielding box with fixed sizes, the plate of type 2 or 4 has notably larger sensitive area, hence the signal from the counter (II) is larger, we chose this design as a reference. The procedure of the electric mounting of the counter was elaborated. The WLS plate of type 2 was used for the reference counter. Amplitude spectrum from cosmic particles for the reference counter is shown in Fig. 2. Light output was measured to be LO = (80 ± 20) photoelectrons/MeV.

5 Conclusion

CsI(pure) inorganic scintillation crystal is 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. An essential increase (×6) of the light output of the CsI(pure)+4APDs counter was achieved with the WLS plate of type 4 made of PMMA and NOL-9. The calorimeter prototype of 16 counters based on CsI(pure) crystals, WLS(NOL-9) plates and Hamamatsu S8664-55 APDs is under construction. All necessary electronics (preamplifiers, Shaper-ADC boards) have been developed and produced. The prototype will be studied on the ROKK [8] test beam facility in 2019 in Budker Institute of Nuclear Physics.

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