PROCEEDINGS OF SCIENCE

Time Resolution Improvement of an Electromagnetic Calorimeter Based on Lead Tungstate Crystals

M. Ippolitov[1]
NRC „Kurchatov Institute" and NRNU MEPhI
Kurchatov sq.1, 123182, Moscow, Russian Federation
E-mail: `mikhail.ippolitov@cern.ch`

V. Lebedev, V. Manko, I. Sibiriak
NRC „Kurchatov Institute"
Kurchatov sq.1, 123182 Moscow, Russian Federation

A. Akindinov
ITEP NRC „Kurchatov Institute"
Cheremushkinskaya 25, 117218, Moscow, Russian Federation

N. Gorbunov, P. Nomokonov, I. Rufanov, A. Vodopianov, S. Zaporozhets
JINR
Joliot-Curie 6, 141980 Dubna, Moscow Region, Russian Federation

Time resolution improvement of the electromagnetic calorimeter PHOS (CERN/ALICE experiment) is discussed. The existing PHOS detection channel consists of a scintillating crystal of $PbWO_4$ viewed by an avalanche photo diode (APD) HAMAMATSU S8864-55(S8148) which is coupled to a low noise charge sensitive preamplifier. In order to improve the PHOS timing resolution of the detecting channel it is proposed to add one more photodetector - a silicon photo multiplier (SiPM) to the current APD. APD signal is used for energy measurements and SiPM provides timing information. In this study, we have investigated the properties of the detection channel with the additional SiPM MPPC Hamamatsu S12572 with different pixel size. Laboratory tests and beam test results are presented. We discuss energy and time resolutions of detection channels with two very different photodetectors.

International Conference on New Photo-detectors
PhotoDet2015
6-9 July 2015
Moscow, Troitsk, Russia

[1]Speaker

PoS(PhotoDet2015)071

1. Introduction

ALICE is a general-purpose heavy-ion experiment designed to study the physics of strongly interacting matter and the quark-gluon plasma in nucleus-nucleus collisions at the LHC [1].

The PHOton Spectrometer (PHOS [2]) is a high resolution electromagnetic spectrometer which detects electromagnetic particles in a limited acceptance domain at central rapidity and provides photon identification as well as neutral mesons identification through the two - photons decay channel. The PHOS is located inside the ALICE magnet at a distance of 4.6 m from the interaction point and covers 60^o in azimuthal angle and $|\eta|<0.12$ in pseudorapidity.

The PHOS consists of 4 independent modules. The PHOS module is divided on a warm and a cold volume. The module contains 3584 detection channels that form a 64x56 matrix. All detection channels are placed inside the cold volume at temperature -25 ^{o}C stabilized within ±0.1 ^{o}C. This arrangement allows to increase the light yield of the crystals by a factor 3 compared to room temperature and to decrease considerably the detection channel's electronics noise. A Front End Electronics Card (FEEC) reads out 2x16 detection channels. The FEEC performs shaping, digitization, generates individual high voltage for each APD and delivers information for the PHOS trigger system. To cover the necessary energy range from 5 MeV to 80 GeV each channel contains a dual gain shaper with peaking time ~2 μs and gains ratio 1/16. It allows to achieve an effective 14 bits resolution with use of 10 bit ADCs. The digitization is done with the ALTRO chip [3] which digitizes the signal profile with 10 MHz frequency. A more detailed description of the PHOS electronics can be found in [4].

The FEEC readout and trigger electronics is placed inside the warm volume at room temperature.

1.2 The PHOS detection channel upgrade

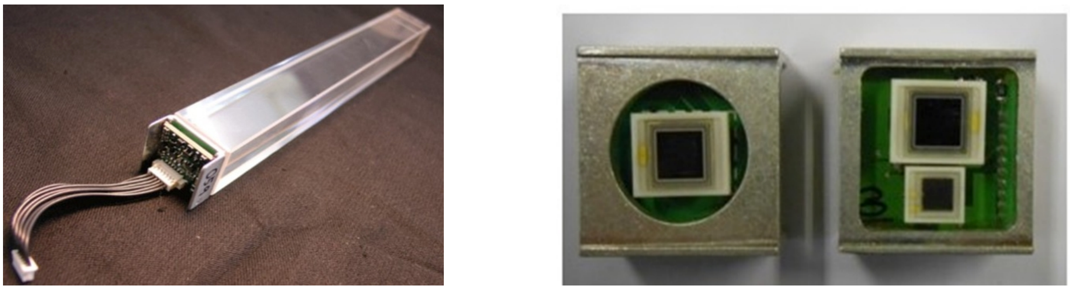
The basic part of the PHOS detection channel (see figure 1) is a 2.2x2.2x18 cm^3 $PbWO_4$ crystal. Each crystal is viewed by a single APD (Hamamatsu S1848/S8664-55) with 5x5 mm^2 sensitive area. The APD is coupled with a low noise Charge Sensitive Preamplifier (CSP) [5]. The noise equivalent of a single detection channel is ~500 e^- (RMS at room temperature).

The codes obtained during digitization are stored by DAQ and used off-line for the signal shape reconstruction. An amplitude and an arrival time of the signal are determined from the signal shape. This digital processing provides good two gammas invariant mass resolution ~5-6 MeV/C^2 [6]. Nevertheless, it does not allow to have time resolution $\boldsymbol{\sigma_t}$ better than 3-4 ns at deposit energy in single channel ~ 1 GeV [7]. To improve the time resolution of the detecting channel it is proposed to enter additional fast photodetector SiPM (see figure 1) and use conventional start-stop method for time-of-flight (TOF) measurements. Therefore electronics have to contain two channels: current PHOS "slow" channel with Hamamatsu S1848/S8664-55 APD and CSP only for energy measurement and "fast" with SiPM with simple electronic schema only for time measurements. Upgrade of the PHOS with goal of improvement of time resolution to value $\boldsymbol{\sigma_t} \leq 0.5$ ns can be carried out in 2018-2019 during LS2 of LHC or later. Such time resolution is necessary for improvement of neutron and antineutron rejection power of the PHOS.

In this paper option of an arrangement of SiPM and APD at one end face of a crystal is considered. Both photodetectors are sealed on one 19 x 19 mm^2 printed-circuit board (PCB).

On the PCB the existing CSP for APD and electronic schema for SiPM are located. In this study Hamamatsu S12572 family MPPC with pixel size 25, 50 and 100 μm and sensitive area 3 x 3 mm^2 were used.

For the test two types of detection channel electronics for MPPC were designed and produced – fast current preamplifier and simple electronics schema based on AD CMP604 comparator [8].



A **B**

Figure 1: From the left – PHOS detection channel, from the right –front view of photodetectors, situated on the PCB **A**- current PHOS design , **B** – proposed design of detection channel.

1.3 Beam test results

Before beam test all MPPCs were checked in laboratory. To find operating conditions of MPPCs dependencies of gains on voltage and on dark current were measured both at the room temperature and at -20 °C. As example curves for MPPC with 50 μm pixel are shown on figure 2.

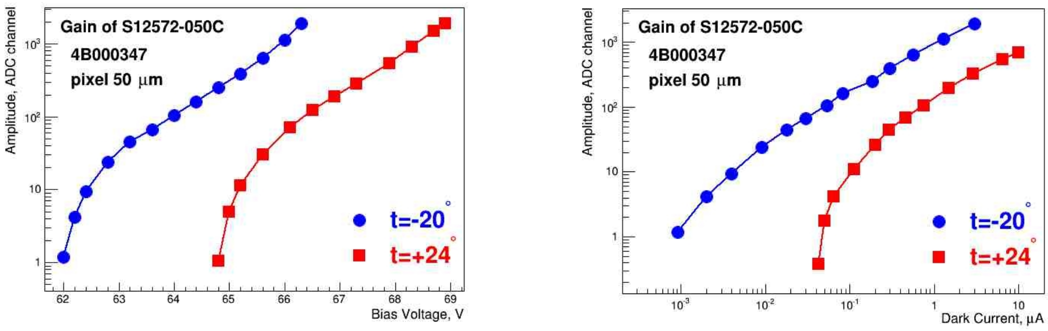


Figure 2: From the left - gain vs voltage, from the right – gain vs dark current for Hamamatsu MPPC S12572 -050 C with serial number 4B000347.

For beam-test 3x3 prototype with new design of detectors was prepared (see figure 3). Beam tests with beam momentum 1.5 GeV/C were carried out at the T10 secondary beam line of CERN PS in 2014. Set of scintillation counters and gas Cherenkov's counter were used for trigger and electrons identification. Common start signal was delivered with 60 ps resolution. The prototype was cooled down to -25 °C. The detailed description of the experiment is given in [7].

In figure 3 dependence of time resolution on deposited in detector energy for MPPC S12572-100C and electronics on base of AD CMP604 comparator is shown. All results of time resolution measurements are presented in table 1.

It has been studied the influence of timing channel on spectrometric channel. For the case with the current detector preamplifier observed a decrease in the signal from the APD. The effect increases with increasing voltage on the MPPC. In the case of electronic comparator of this behavior was not observed.

Energy resolution of 3x3 matrix was defined taking into account APD signals. The energy resolution was determined by fitting the histograms of the sum of the amplitudes of all detectors by Gaussian distribution. For comparison 3x3 matrix with current PHOS detectors was also tested. Results of energy resolution are presented in table 2.

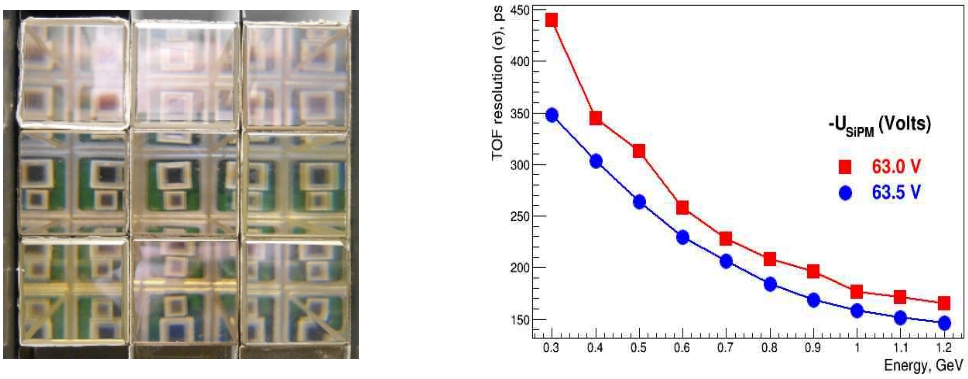


Figure 3: From the left – front view of 3x3 matrix, from the right – time resolution of detection channel vs deposited energy.

Table 1: Time resolution measured with different MPPC and with and different electronics at 1 GeV deposited energy.

-U(V)	σ_t (ps)	-U(V)	σ_t (ps)	-U(V)	σ_t (ps)	-U(V)	σ_t (ps)
25 µm pixel with current preamp		50 µm pixel with current preamp		100 µm pixel with current preamp		100 µm pixel with comparator	
63.0	552 ± 4	62.5	396 ± 24	62.0	651 ± 18	63.0	167 ± 3
63.5	332 ± 10	63.0	267 ± 10	62.4	423 ± 5	63.5	149 ± 1
64.2	240 ± 5	64.0	175 ± 12	63.5	183 ± 2		
65.0	218 ± 4	65.0	140 ± 2				
67.0	182 ± 3	66.0	113 ± 3				
68.0	150 ± 3						

Table 2: Relative energy resolution σ(E)/E at 1.5 GeV/c

APD only array	APD+100 µm+comparator
0.035 ±0.002	0.037 ±0.001

1.4 Conclusions

Results of measurements of time and energy resolutions of 3x3 assemblies from the detecting elements based on lead tungstate crystals are presented. It is shown that introduction of the additional channel with the SiPM MPPC S12572(Hamamatsu) allows to improve significantly timing resolution of the PHOS for 1 GeV energy from the existing 3-4 ns to 0.15-0.2 ns without considerable deterioration of energy resolution.

We are grateful to the team of the accelerator complex at CERN for the possibility of carrying out the experiments on the PS accelerator beams and for the excellent performance of the accelerator, as well as to our colleagues from the ALICE experiment and the PHOS collaboration for their help in preparing and carrying out the experiments. This work was supported by the Ministry of Education and Science of the Russian Federation, contract no. 14.610.21.0003 of October 20, 2014.

References

[1] ALICE Collaboration,ALICE: *Physics Performance Report Volume I*, J.Phys.G: Nucl.Part.Phys. 30 (2004)1517-1763.

[2] ALICE Collaboration, *Technical Design Report of the Photon Spectrometer (PHOS),* CERN/LHCC 99-4 ,ALICE TDR 2, 5 March 1999.

[3] W R.Esteve Bosch et al.,*The Altro Chip: A16 Channel A/D Converter and Digital Preprocessor for Gas Detectors*, IEEE Trans. on Nucl. Sci., V.50, No.6, December 2003, p.2460-2469.

[4] H.Muller et al., *Front-end Electronics for PWO based PHOS Calorimeter of ALICE ,* Nucl.Instrum.Meth.A567(2006)264-267.

[5] D.V.Aleksandrov et al., *A High Resolution Electromagnetic Calorimeter Based on Lead-Tunstate Crystals*, Nucl.Instrum.Meth. A550(2005)169-184.

[6] The ALICE Collaboration, *Neutral pion production at midrapidity in pp and Pb–Pb collisions at* $\sqrt{sNN} = 2.76$ *TeV,* Eur. Phys. J. C (2014) 74:3108.

[7] D.V.Aleksandrov et al., *Improving the Timing Resolution of an Electromagnetic Calorimeter Based on Lead Tungstate Crystals*, Instruments and Experimental Techniques, 2014, Vol. 57, No. 3, pp. 233–247.

[8] M.Ippolitov et al., *International Conference on New Photo-detectors PhotoDet2015 Web site*, https://indico.inr.ru/event/4/session/3/contribution/56/material/poster/0.pdf