IL NUOVO CIMENTO **47 C** (2024) 299
DOI 10.1393/ncc/i2024-24299-0

Communications: SIF Congress 2023

Comparison of SiPMs and PMTs for calorimetry applications in the DUNE near detector complex

F. Alemanno(1)(2)(*)(**)

(1) *Dipartimento di Matematica e Fisica, Università del Salento - Lecce, Italy*
(2) *Istituto Nazionale di Fisica Nucleare - Lecce, Italy*

received 31 January 2024

Summary. — The KLOE electromagnetic calorimeter, selected for reuse in the DUNE experiment, has been under investigation for the potential replacement of traditional Photomultiplier Tubes (PMTs) with Silicon Photomultipliers (SiPMs). In this study, a segment of the KLOE lead-scintillating fiber calorimeter was equipped with SiPM arrays on one side and conventional PMTs on the other side. The efficiency and timing resolution of SiPMs are evaluated and compared with KLOE-PMTs. The findings contribute to determining the feasibility of substituting PMTs with SiPMs.

1. – Introduction

Silicon Photomultipliers (SiPMs) are solid-state photodetectors [1] widely used in physics instrumentation, from accelerator to astroparticle physics experiments. Their compatibility with scintillating fiber light, insensitivity to magnetic fields and low-voltage operation contribute to their appeal for calorimetry applications [2]. This study assesses the SiPMs compatibility with the KLOE electromagnetic calorimeter [3], exploring the potential for better efficiency and timing resolution compared to standard PMT readout. The evaluation is crucial as the KLOE calorimeter undergoes refurbishment for integration into SAND (System for on-Axis Neutrino Detection) within the DUNE experiment's Near Detector complex [4, 5].

2. – Experimental setup

The experimental configuration used for this study is illustrated in fig. 1 and features 4 modules of the KLOE electromagnetic calorimeter (ECAL) [3], read out by PMTs on one side and SiPMs on the opposite side. All the photosensors are coupled with the ECAL modules using light guides and additional adapters are used in the case of SiPMs. Moreover, the ECAL is equipped with 4 plastic scintillator bars read by PMTs (green

(*) For the DUNE Collaboration.
(**) E-mail: francesca.alemanno@le.infn.it

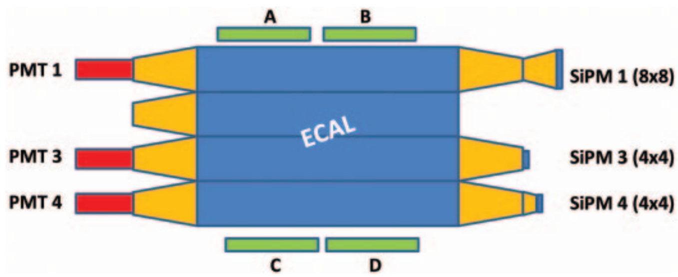

Fig. 1. – Schematic view of the experimental setup not in scale. More details are given in the text.

elements in fig. 1), providing the external trigger for cosmic rays. The ECAL is made of thick grooved lead foils and scintillating fiber layers (type Po.Hi.Tech-0046), with a composite density of 5 g/cm^3 and a peak emission wavelength $\lambda_{\text{peak}} \simeq 460\,\text{nm}$. The ECAL volume is divided into 12 cells with a $4.4 \times 4.4\,\text{cm}^2$ section and 40.0 cm length ($\simeq 2.7$ X_0 for each cell). At the ends of each cell, lucite light guides with a Winston cone shape facilitate efficient light collection and coupling with photodetectors. One side connects to Hamamatsu-R5946 1.5′ PMTs([1]), while the other side uses arrays of 8×8 or 4×4 SiPMs (Hamamatsu S13361-3050 series([2])). Various coupling solutions are adopted: a lucite adapter for the 8×8 SiPM array (SiPM 1), direct coupling for the 4×4 array on the third ECAL module (SiPM 3), and a lucite adapter for the 4×4 SiPM array on the fourth ECAL module (SiPM 4).

A CAEN FERS-DT5202 electronic board with accompanying software is used to perform the SiPM characterization and for data acquisition and efficiency measurements. A Teledyne Lecroy Waverunner 640Zi oscilloscope, along with CAEN and Lecroy modules, is employed for data acquisition and timing resolution measurements.

3. – Efficiency measurement

The SiPM and PMT efficiencies are assessed by detecting cosmic muons. Four scintillators (A, B, C, D in fig. 1) serve as an external trigger, with a surface area of $\sim 2 \times 7.5$ cm^2 each. The trigger logic involves a fired scintillator on the top (A or B) and a fired scintillator on the bottom (C or D) within a 30 ns time window. PMT and SiPM signals are counted by a CAEN Quad Scaler module and require external trigger validation. SiPM signals are managed by the CAEN FERS-DT5202 board and their signal information is collected by a desktop computer running the data acquisition program. To investigate the SiPM noise, samples collected by the DAQ with and without external trigger validation are analyzed. The ADC distribution for SiPM 3 and 4 without external trigger shows a clear peak at low ADC counts which overlaps with the externally triggered events. Based on this, a reasonable cut for the SiPMs efficiency measurement is defined. The SiPM efficiency (E_{SiPM}) calculated from scaler counts (ϵ) is adjusted by considering only events surviving the noise cut (ϵ'). The corrected SiPM efficiency is expressed as

$$E_{SiPM} = \epsilon\, \epsilon' = \frac{k_{SiPM}}{N_{SiPM}}\, \frac{k_{DAQ}}{N_{DAQ}}, \tag{1}$$

([1]) `https://www.digchip.com/datasheets/parts/datasheet/190/R5946.php`.
([2]) `https://www.hamamatsu.com/content/dam/hamamatsu-photonics/sites/documents/99_SALES_LIBRARY/ssd/s13361-3050_series_kapd1054e.pdf`.

where k_{SiPM} is the number of SiPM events on the scaler, N_{SiPM} is the number of external triggers, k_{DAQ} is the number of selected events, and N_{DAQ} is the total number of events in the sample collected by the DAQ. In contrast, the PMT efficiency (E_{PMT}) is simply calculated from scaler counts

$$E_{PMT} = \frac{k_{PMT}}{N_{PMT}}, \tag{2}$$

where k_{PMT} represents the PMT events on the scaler and N_{PMT} the externally validated events. The resulting efficiencies for SiPM 3 and 4 are $(90.82^{+0.23}_{-0.25})\%$ for SiPM 4 and $(90.70^{+0.22}_{-0.23})\%$ for SiPM 3. The PMT efficiencies are $(91.17^{+0.15}_{-0.16})\%$ for PMT 4 and $(92.06^{+0.14}_{-0.15})\%$ for PMT 3. The uncertainties are evaluated using the Clopper-Pearson method [8]. In summary, the efficiencies of PMTs and SiPMs exhibit minimal differences, with PMT efficiencies slightly surpassing those of SiPMs.

4. – Timing resolution

The photodetector timing resolution, assessed through the constant fraction method at a 50% level, was measured for PMTs and SiPMs in an experimental setup with ECAL modules 3 and 4. Cosmic ray-induced signals were acquired with a 40 GHz sampling rate, revealing that PMTs exhibit a slightly better timing resolution than SiPMs as can be seen in fig. 2, where the signal time differences for SiPMs and PMTs are reported.

For KLOE PMTs, the timing resolution energy-dependence is expressed by the formula $\sigma_t \sim 54\ \text{ps}/\sqrt{E}(\text{GeV})$ [3]. A similar pattern is observed for SiPMs and PMTs in this research, considering signal amplitude rather than deposited energy, with results fitting the formula $\sigma_{\Delta t} = \tau/\sqrt{\text{signal}}(\text{mV})$ (fig. 3). Although the τ value cannot directly compare with 54 ps due to the different nature of signal and energy, their linear relationship supports the notion that timing resolution depends on energy and signal.

5. – Conclusions

A section of the KLOE calorimeter was assembled with SiPMs and PMTs to assess their suitability for the DUNE experiment's near detector. While PMT coupling was

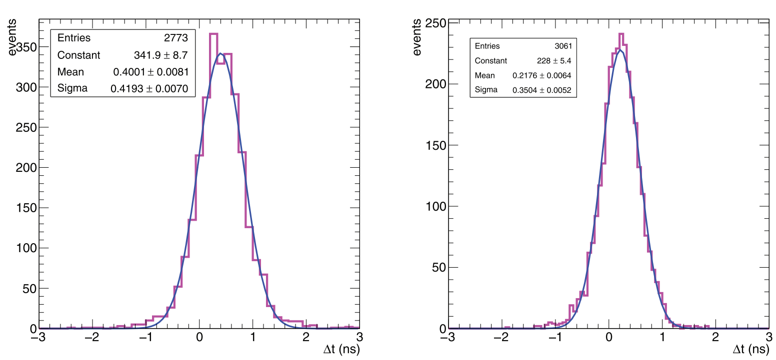

Fig. 2. – Time difference for SiPM 3 and SiPM 4 (left) and for PMT 3 and PMT 4 (right) fitted with a Gaussian function (in red).

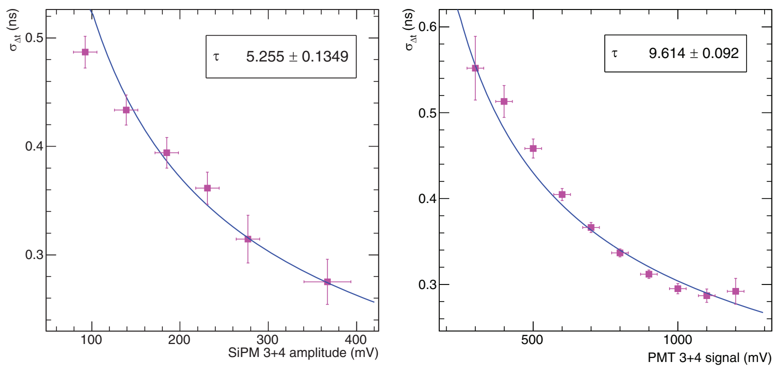

Fig. 3. – Timing resolution as a function of the signal for SiPMs (left) and PMTs (right). The red curve represents the fit function reported in the text.

already optimized, various optical couplings were tested for SiPMs with KLOE light guides. Efficiency and timing resolution were measured, revealing that SiPM noise impacts efficiency, lowering it by a few percent compared to PMTs. Despite a slightly lower timing resolution, challenges in SiPM coupling, lack of strong improvements, cost considerations, and commissioning time discourage their substitution of already tested PMTs in the KLOE calorimeter. However, this study does not rule out potential SiPM use in other calorimetry applications.

* * *

The author acknowledges the laboratory staff of the Department of Mathematics and Physics at the University of Salento and INFN-Lecce for their technical support.

REFERENCES

[1] Acerbi F. and Gundacker S., *Nucl. Instrum. Methods A*, **926** (2019) 16.
[2] Gundacker S. and Heering A., *Phys. Med. Biol.*, **65** (2020) TR01.
[3] Adinolfi M. *et al.*, *Nucl. Instrum. Methods A*, **482** (2002) 364.
[4] DUNE Collaboration (Abed Abud A. *et al.*), *Instruments*, **5** (2021) 31.
[5] DUNE Collaboration (Abi B. *et al.*), *Eur. Phys. J. C*, **80** (2020) 978.
[6] Mazzitelli G. *et al.*, *Nucl. Instrum. Methods A*, **515** (2003) 524.
[7] Puill V. *et al.*, *Nucl. Instrum. Methods A*, **695** (2012) 354.
[8] Clopper C. J. and Pearson E. S., *Biometrika*, **26** (1934) 404.