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A compact light readout system for longitudinally segmented shashlik calorimeters

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ABSTRACT

The longitudinal segmentation of shashlik calorimeters is challenged by dead zones and non-uniformities introduced by the light collection and readout system. This limitation can be overcome by direct fiber–photosensor coupling, avoiding routing and bundling of the wavelength shifter fibers and embedding ultra-compact photosensors (SiPMs) in the bulk of the calorimeter. We present the first experimental test of this readout scheme performed at the CERN PS-T9 beamline in 2015 with negative particles in the 1–5 GeV energy range. In this paper, we demonstrate that the scheme does not compromise the energy resolution and linearity compared with standard light collection and readout systems. In addition, we study the performance of the calorimeter for partially contained charged hadrons to assess the e/π separation capability and the response of the photosensors to direct ionization.

1. Introduction

The "shashlik" readout technology [1] for sampling calorimeters has been successfully employed in particle physics for more than twenty years [2–8]. Shashlik calorimeters are sampling calorimeters in which the scintillation light is readout via wavelength shifting (WLS) fibers running perpendicular to the converter/absorber plates. This technique offers flexibility in the calorimeter design combined with ease of assembly, good hermeticity and fast time response. In most applications, it represents a cost effective solution compared to crystals or cryogenic liquid calorimeters. The main drawback of this technique is the limitation imposed on the longitudinal segmentation by the optical fiber readout. For each segment, fibers must be bundled and routed toward the photosensors, introducing non-uniform response or the presence of dead zones. As a consequence, shashlik calorimeters allow for high flexibility in the choice of parameters except for the granularity of the longitudinal sampling [9].

The current generation of shashlik calorimeters [10–12] is readout by compact solid-state photosensors. In particular, the INFN FACTOR Collaboration has demonstrated that Silicon PhotoMultipliers (SiPMs) can be used very effectively for the light readout of these detectors [13,14]. The compactness of SiPMs and the possibility to use these devices embedded in the bulk of the calorimeters [15] open new possibilities to implement longitudinal segmentation in shashlik devices.

In particular, the INFN SCENTT Collaboration is developing an ultra-compact module (Fig. 1) where every single fiber segment is directly connected to a SiPM and the SiPMs array is hosted on a PCB (Printed Circuit Board) holder that integrates both the passive components and the signal routing toward the front-end electronics (fast digitizers). This setup offers maximum flexibility in the choice of the longitudinal sampling (length of the fiber crossing the scintillator/absorber tiles) and transverse granularity (tile size and number of summed SiPM channels). Applications range from high granularity devices for collider physics employing particle flow algorithms for hadrons [15], up to beam dump [16] and non-

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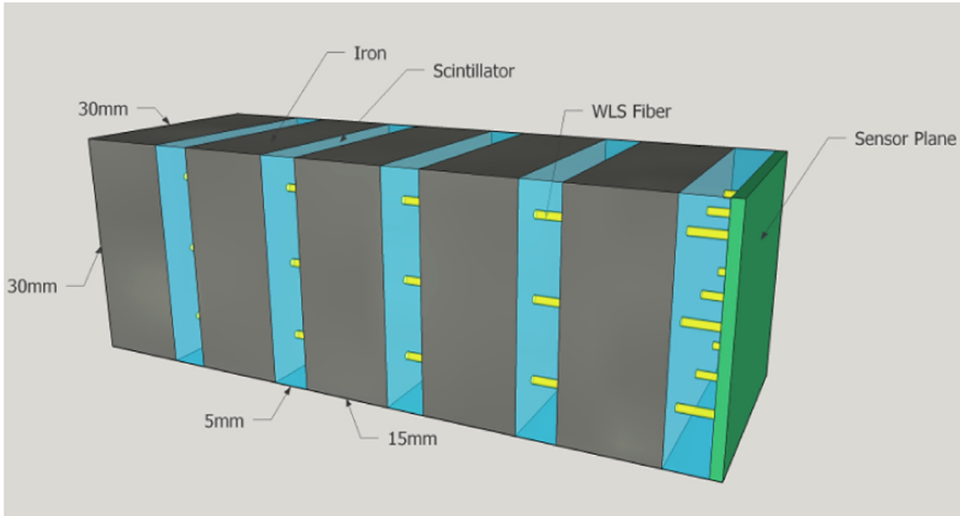


Fig. 1. Schematic of the ultra-compact module that is being developed by SCENTT. The module corresponds to a 4 X_0 sampling and a transverse granularity of 3 $\times$ 3 cm^2 (9 fibers per module).

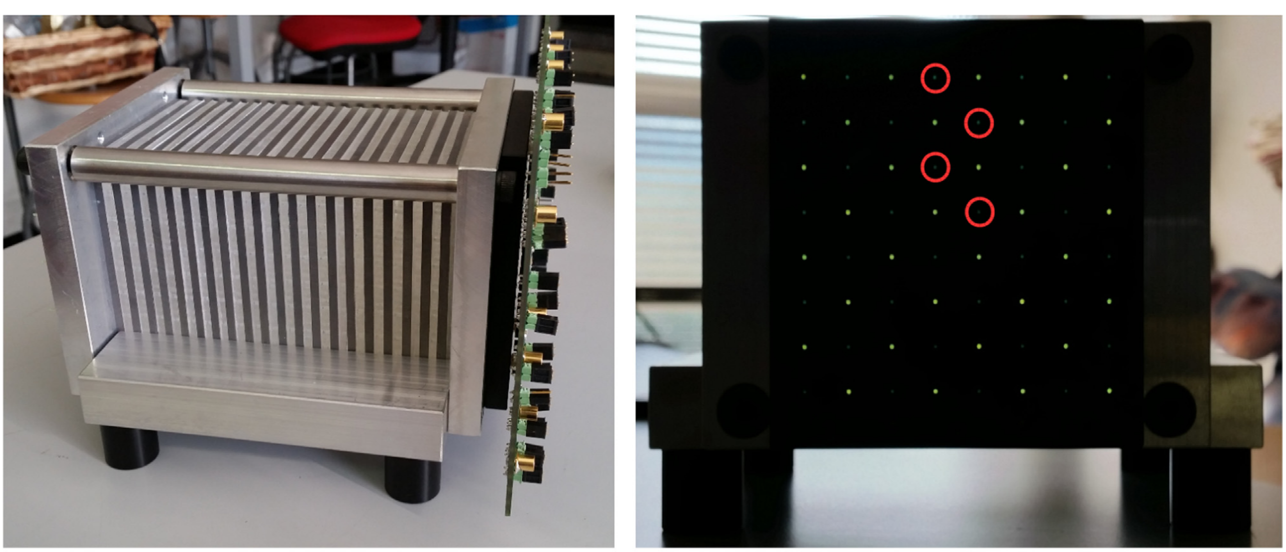
conventional neutrino facilities [17–19], where the large sizes of the detectors pose stringent requirements on the cost.

In view of the SCENTT R&D, one of the FACTOR calorimeters was modified to allow for direct fiber-SiPM coupling without bundling and tested with negative charged particles at the CERN PS-T9 beamline. The goals of the test were to demonstrate that direct fiber coupling to SiPMs and summing up of the SiPMs output signal without pre-amplification can replace fiber bundling to a single large area photosensor. In particular, the tests were aimed at checking that direct coupling does not compromise the energy response and linearity achieved in FACTOR. During the test, e/π separation, nuclear counter effects (NCEs) and the performance of the readout electronics were also investigated.

Sections 2 and 3 of this paper are devoted to the description of the shashlik prototype and the experimental setup. Section 4 presents the GEANT4 simulation of the calorimeter under test. Linearity and energy resolution for electrons are discussed in Section 5.1, while studies with partially contained hadrons for e/π separation, NCE and readout electronics are reported in Sections 5.2, 5.3 and 5.4, respectively.

2. The test calorimeter

The shashlik calorimeter prototype employed in this study is a modified version of the calorimeter tested by FACTOR in 2009 [13]. It is composed of two modules: each module consists of 8 $\times$ 8 cm^2 tiles of lead interleaved with plastic scintillator. The thickness of both the lead and scintillator tiles is 3.3 mm and each module groups 20 (lead) + 20 (scint.) tiles. The depth of the module corresponds to $\sim 12 X_0$ (Fig. 2a). Due to the limited amount of SiPMs available for the test only one module per run could be readout: the longitudinal containment of a 1(5) GeV electromagnetic (EM) shower in a module is 88% (83%) (see Section 4). Given the beam energy range (1–5 GeV) and the number of available radiation lengths, a single module with different fiber lengths (see below)



(a) (b)

Fig. 2. Picture of the first module of the calorimeter prototype (a); close-up on the WLS fibers (b) and the long/short alternated pattern: short fibers (some of them highlighted with red circles) are less bright than long ones due to the different ambient light collection efficiency. (For interpretation of the references to color in this figure caption, the reader is referred to the web version of this paper.)