AIDA-2020-MS13

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Advanced European Infrastructures for Detectors at Accelerators

Milestone Report

Specification of systems for highly granular scintillator tests

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MILESTONE REPORT

SPECIFICATION OF SYSTEMS FOR HIGHLY GRANULAR SCINTILLATOR TESTS

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Abstract:

For precision tests of small numbers as well as for mass tests of large numbers of plastic scintillator tiles with SiPM readout and for bare SiPMs three test stands are being developed within WP14. These test stands make use of radioactive sources for precise scanning of scintillator tiles, of cosmics for tests of large numbers and larger areas of detector elements, and of a highly automated optical test system for the mass testing of SiPMs. This milestone document summarizes the specifications these systems.

For more information on AIDA-2020, its partners and contributors please see www.cern.ch/AIDA2020

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Executive summary

For the development and mass production of scintillator tiles with silicon photomultiplier readout for highly granular calorimeter systems three test stands are being constructed at participating institutes. These test stands will provide the capability for precise spatial measurements of the response of the scintillator tiles to penetrating particles, for mass characterization of SiPMs and testing of SiPMs mounted on electronics units, as well as for large area tests of detector elements with more than 100 installed tiles. Together, these systems provide crucial infrastructure for characterization and quality assurance in the development and mass production phases of highly granular scintillator-based calorimeter systems, and will be used in the production of full-scale detector prototypes that is now beginning. This document provides the detailed specifications of the three test stands, which will go into operation by the end of 2016. The documented performance and user usage of these test stands is a deliverable of WP14, due in month 40.

1. INTRODUCTION

A core part of the activities in WP14 is the development and construction of test infrastructure for calorimeter elements to support the R&D activities in the area of calorimetry for current and future collider detectors. Task 14.2 focuses on calorimeters with optical readout. Subtask 14.2.2, entitled "Test Benches for the Characterisation of highly granular Calorimeter Elements with Scintillator and SiPM Readout", develops test stands that are primarily motivated by highly granular plastic scintillator-based hadronic calorimeters for future linear colliders. Three different test stands are being developed:

- A scintillator uniformity test stand that provides detailed information about the spatial dependence of the response of scintillator tiles read out with SiPMs
- A test stand for the mass characterisation of surface-mount SiPMs
- A cosmic ray test stand for large-area tests of calorimeter active elements

Together, these three test stands provide key test infrastructure for the development and construction phases of scintillator-based imaging calorimeters. They allow the detailed characterisation of individual detector elements, the quality assurance of large quantities of photon sensors and the complete test and cell-level characterisation of larger active elements. These test stands are complemented by test infrastructure for ASICS used in the embedded electronics of the detectors, developed in WP4.

For the present milestone, these three test stands have been fully specified, and are now being constructed at the participating institutes. The detailed specifications of each test stand are discussed in the following section.

2. SCINTILLATOR TILE UNIFORMITY TEST STAND WITH RADIOACTIVE SOURCE

A test stand for the evaluation of scintillator tile designs and of the uniformity of the response of tiles with SiPM readout using a radioactive electron source will be constructed at MPG-MPP.

This test stand provides the possibility to test the performance of scintillating tiles of various designs and sizes, as well as different SiPM/scintillator combinations. The test stand also offers the possibility for detailed cross talk measurements between two neighbouring scintillator tiles.

The tile with SiPM readout under test is mounted on a two-dimensional translation stage with a precise stepping motor. By moving the tile under the collimated radioactive source its full surface can be scanned by the electron beam. Typical step sizes are on the order of 0.5 or 1 mm, providing a detailed image of the response of the tile and SiPM system. The maximum range of the translation stage is about 200 mm in both directions.

Figure 1 left shows a schematic overview of the test stand; its components are detailed in Table 1.

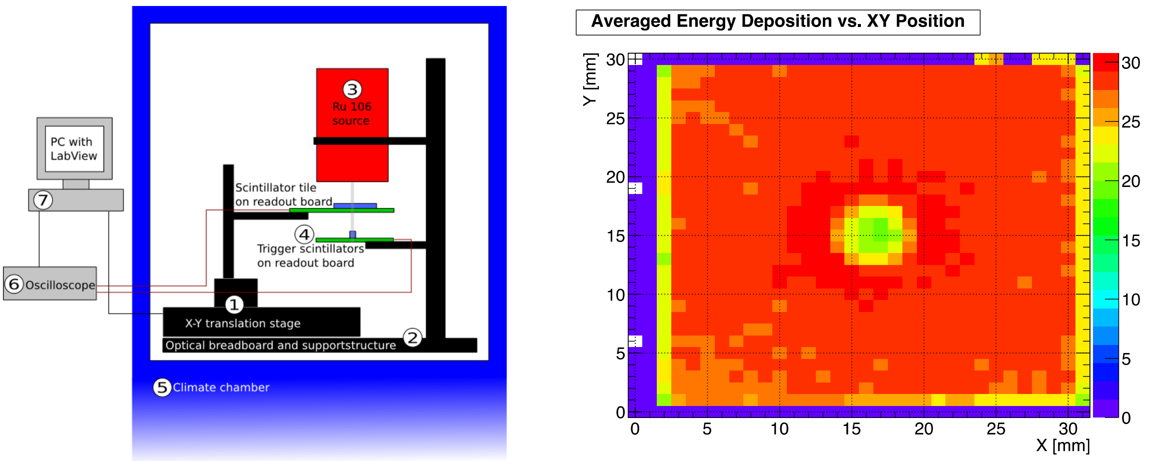


Figure 1 Left:Schematic overview of the MPG-MPP test stand with radioactive source for the evaluation of the response uniformity of SiPM/scintillator tile systems. The numbers on the components correspond to the component numbers listed in Table 1. Right: Example of the response of a SiPM/Scintillator system to a scan over the full tile surface in a previous MPG-MPP test stand. The tile is readout by a SiPM placed in a cavity (dimple) in the middle of the bottom surface of the scintillator tile.

A computer-controlled USB oscilloscope reads out the signal from the SiPM. The data acquisiton is triggered by a coincidence system, positioned under the tile under test, aligned with the source. This system consists of two small pieces of scintillator stacked on top of each other and both read out by the low noise SiPMs. A signal above threshold in both these trigger scintillators guarantees that an electron has traversed the scintillator tile under test.

The radioactive source used in the setup is a ^{106}Ru source with an initial activity of 37 MBq, which emits electrons with an energy spectrum up to 3.5 MeV. These electrons will be able to penetrate the scintillating tile and supporting material and create a signal in the trigger scintillators, motivating the choice of the source over the ^{90}Sr source used in a previous setup at MPG-MPP.

The scanning setup is placed inside a climate chamber to provide precise temperature control, stable measurement conditions during a full scan, and repeatable measurement conditions.

Data acquisition and analysis of the SiPM signal is combined into one LabView steered program that controls the motors of the translation stages, the readout of the oscilloscope and the evaluation of the signal. A previous test stand at MPG-MPP has been used for similar measurements, which were however limited in spatial range, readout and online analysis and particle energy of the radioactive source. Figure 1 right shows an example of the result of a scan with the previous setup over the surface of a 3x3 cm scintillating tile that is readout by a SiPM in the middle of the bottom of the tile. The new setup now under construction will be capable of providing such measurements, with the addition of an extended spatial range crucial for cross-talk measurements, higher electron energy to support scintillator tiles mounted directly on PCBs and an improved user interface and better analysis capabilities. Depending on the covered area and the granularity, a full scan takes between 1 hour and 24 hours of running time.

Table 1 Components of the MPG-MPP test stand. The component numbers correspond to the labeling in Fig. 1 left.

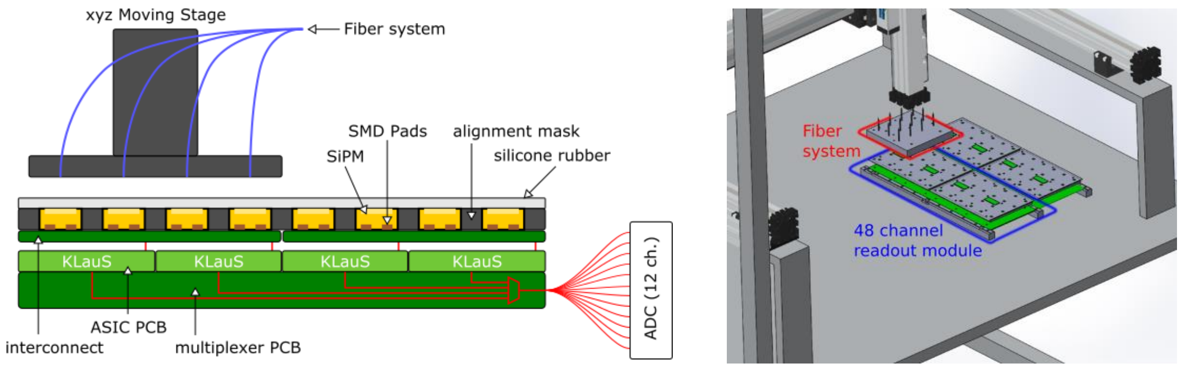
	Component	**Model/Description**	**Characteristics**
1	Translation stages	OWIS LTM 80-200-HSM	Range 195 mm in x and y Precision < 25 µm/100 mm
2	Optical breadboard and mounting system	Thorlabs solid aluminium optical breadboard	Size 45x45 cm^2
3	Collimated radioactive source	^{106}Ru	Electrons with energy <= 3.5 MeV, initial activity 37 MBq
4	Trigger scintillators	Scintillator: BC-408 SiPM: Hamamatsu MPPC 13360 series	Key SiPM characteristics: Low cross-talk, permitting low trigger thresholds without incurring random noise triggers
5	Climate chamber	Vötsch VT4021	Temperature range [-35 °C, 100 °C]
6	Oscilloscope	Picoscope 6404D	4 readout channels Bandwidth 500 MHz 8 bit resolution Sampling rate 1.25 GS/s Buffer memory 2 GS
7	PC with LabView	LabView2015	LabView Full Development System
8	Powersupply	Keysight N6700B mainframe Keysight N6736B powersupply Keysight N6733B powersupply	

3. TEST STAND FOR MASS CHARACTERIZATION OF SURFACE MOUNTABLE SIPMS

A test stand for the characterization of unsoldered silicon photomultipliers in surface mounted (SMD) package will be constructed at KIP, Heidelberg University. The test stand allows to characterize the spread of SiPM parameters before soldering the devices e.g. to the HBUs (**H**CAL **b**ase **u**nits) of the CALICE analog hadronic calorimeter and serves as a pre-qualification test of SiPM batches based on sub-samples. Depending on the user's needs, the test can be performed also after soldering of the components to the read-out board and in combination with a scintillator tile. To gain sufficient statistics on the spread of sensor characteristics, the test stand is designed to automatically characterize medium-sized quantities in the order of 50-150 SiPM devices with high speed.

To achieve this goal, the system relies on the parallelized measurement of 12 sensors using a pulsed laser source. The characterization speed depends on the number of voltage steps to be measured and is typically below 2 minutes for a set of 12 SiPMs measured in parallel. From the analysis of the resulting single photon spectra, the sensor gain is evaluated as a function of the applied bias voltage in order to measure the SiPM breakdown voltage. From the measurement of charge spectra with the laser source disabled, the dark-count rate can be estimated.

Since the test stand requires the SiPMs to be unpacked from the tape compatible with automatic placement machines, the predominant purpose for the system is to test and characterize medium-sized subsamples of sensor batches being held for replacement.



a) b)

Figure 2: a) Schematic sketch of the KIP setup. b) CAD drawing of the fiber system mounted to the translation stage and two of the readout modules..

A schematic view of the sensor related part of the test stand is shown in Figure 2a. The SiPMs under test are aligned to an interconnection board to provide connection to the readout electronics and high voltage supply. To assure good electrical contact between the interconnection board and SiPM pads, soft pressure is applied on the sensors by a sheet of transparent silicone rubber. The sensor signals are first processed by a custom 12-channel analogue integrated circuit (ASIC) "KLauS", which integrates and shapes the signals from the SiPMs. A peak-sensing ADC VME module digitizes the generated output voltage signals.

To increase the automation level, the ADC input signals are multiplexed from modules of 4 ASICs, providing in total 48 channels per module.

A picosecond laser source generates light pulses, which are distributed to a bundle of 12 fibers. The fibers are mounted to a 3-dimensional moving stage, allowing the simultaneous illumination and characterization of 12 SiPMs.

To ensure system stability, a PIN diode and a digital temperature sensor close to the SiPMs monitor the light output of the laser and the SiPM temperature, respectively.

The SiPM bias voltage is supplied from a high voltage source common to all SiPMs. During the measurement, the bias voltage is typically swept in 15 steps from the SiPM breakdown voltage to ≈ 4-5V above.

By multiplexing the ASICs output signals and moving the fiber head to the corresponding positions, the setup allows characterizing 48 SiPMs without human interference. It is further designed to be scalable to host several modules as shown in Figure 2b. The characterization of a single module of 48 SiPMs is expected to take less than 8 minutes.

All measurement data are collected on a DAQ PC, which stores the data and provides online analysis and data basing functionality.

The distances of the individual fibers on the moving head are designed to coincide with the CALICE AHCAL tile size, allowing also for testing fully equipped HBUs with mounted SiPMs with their dedicated readout system prior to the installation of the scintillator tiles on the readout board. In addition, using the laser system for tests with tiles installed will also be possible.

The single characterization modules are designed to fit into a temperature-controlled chamber to allow for measurements of SiPM parameters as a function of the temperature. Without the presence of a translation stage in this configuration, only 12 SiPMs can be characterized automatically.

Table 2 Components of the KIP/Uni Heidelberg test stand.

	Component	**Model/Description**	**Characteristics**
1	Translation stages	Xemo Driveset KiS M3P-M1-V1LNK053 with controller R362	Working range (x,y,z) 63cm x 40cm x 16cm Programming accuracy 100µm
2	Laser source	ALDS Picosecond laser system with controller EIG1000D	Pulse width 30ps Max repetition range 1MHz Wavelengths 400nm & 378nm
3	HV Source	Keithley 6487	Voltage source up to 500V pA current measurement
4	ADC	CAEN V785N	16 channels VME module 12 bit resolution on 4V range
5	Climate chamber	Binder MK53	Temperature range [-40°C, 180°C]

4. LARGE SCALE COSMIC RAY TEST STAND

A cosmic ray test stand will be built to characterize the light yield of detection units (scintillator + SiPM) on fully assembled boards. The test stand is capable of triggering all channels on this boards at once while resolving the channels along the particle trajectory.

The resolution is achieved with a strip design of in total 24 scintillator strips read out by classical photomultipliers with a triggering area of 365 mm x 30.07 mm and a thickness of 1.2 mm. The scintillators are arranged in 2 triggering layers, each with a total area of 365 mm x 361.8 mm. The layers are rotated by 90° to achieve a separation within the dimensions of a scintillator tile of the CALICE AHCAL design. The total height between the two triggering layers is adjustable. The usable height is 50 cm. Several boards can be stacked in between these two layers and can be read out in parallel to significantly speed up the systematic test of large number of detection units. Within the available height, the distance between the devices under test and the trigger scintillators can be varied to include cosmic rays with different incident angles. The setup is in a dark box and temperature monitoring is provided.

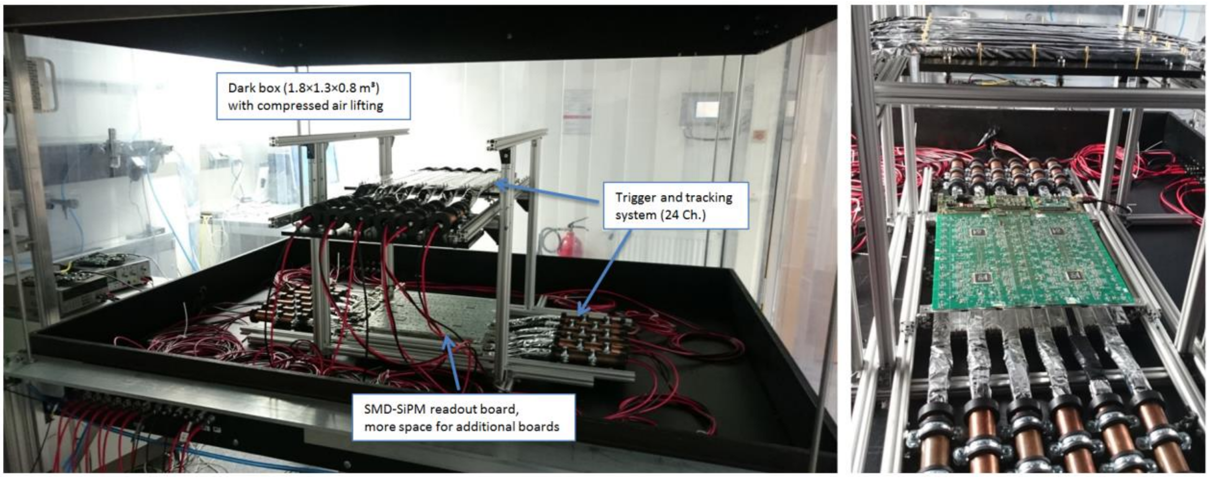


Figure 3: Pictures of the mechanical holding structure of the cosmic ray test stand

The trigger logic shown in Figure 4 will be implemented in an FPGA and the recorded data are sent out via Ethernet to a connected PC. For general use, a smaller number of scintillator triggers per layer can be chosen, so that the triggered area can be reduced and smaller boards can be triggered as well.

The tested boards have to be synchronized offline with the trigger unit data. A counter programmed in the FPGA is synchronizing the time stamp with the triggered events of the boards. The signal defining the data acquisition window will be sent by the DAQ system to the FPGA and to the boards under test. In total the FPGA evaluation board (equipped with an adapter board designed by Mainz University) can cope with 3 single ended I/O signals (for example TTL) and can receive 28 differential signals (for example LVDS, upgradable to 36 if needed). Due to the flexibility of the FPGA and its programming an adaption to different logics is possible. The data acquisition is controlled by a Labview PC.

With a distance between the scintillators and the device under test of 20 cm, the rate of events triggered by cosmic rays over the whole area is about 11 Hz.

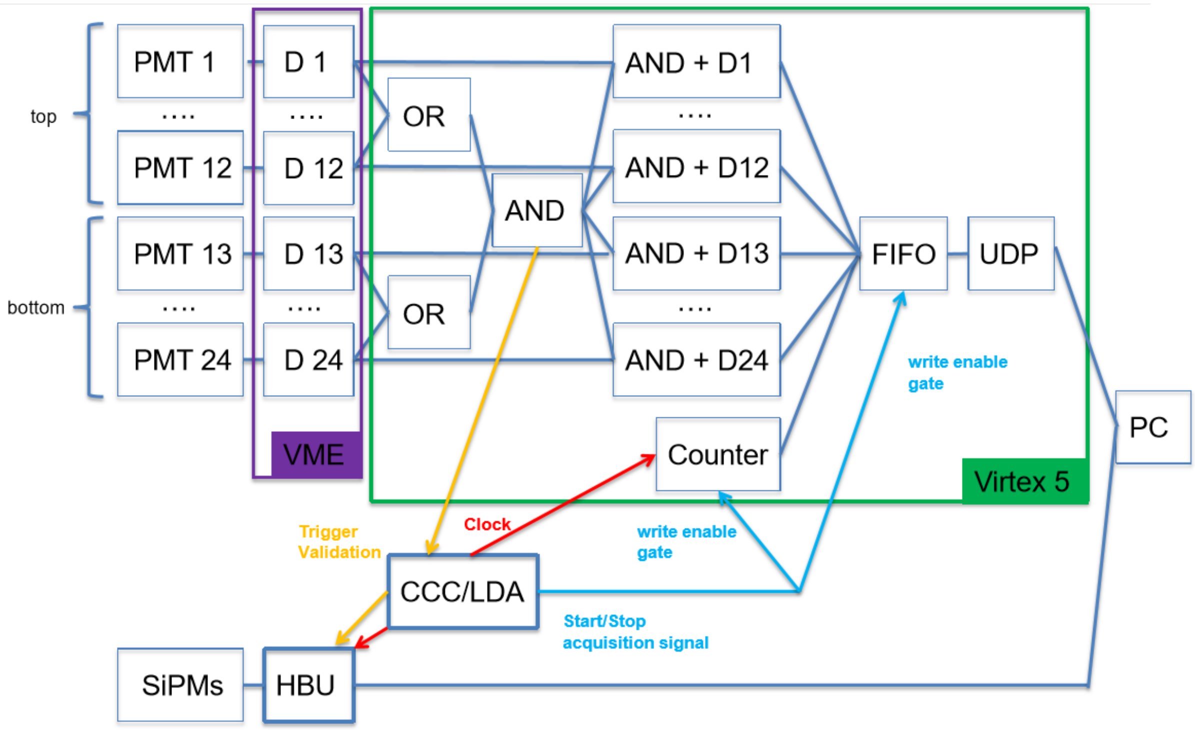


Figure 4: Trigger logic of the large scale cosmic ray test stand

Table 3 Components of the Mainz cosmic ray test stand.

	Component	**Model/Description**	**Characteristics**
1	Temperature measurement	T&D TR-701NW	Range: -40 bis 110 °C Precision: 0.3 °C 2 channels
2	Scintillator	NA62 custom scintillator	365 mm x 30.07 mm x 1.2 mm
3	Photomultiplier	Hamamatsu R6095	Head-On PMT, Bialkali photocathode, spectral response 300 - 650 nm
4	Power Supply	CAEN AG 535SN	24 Channel HV power supply, max values: -3.5 kV, 3 mA
5	Discriminator	CAEN V895b	24 channel leading edge VME discriminator, ECL output
6	FPGA evaluation board	Xilinx ML-506	Virtex-5 FPGA
7	Level Translator ECL – LVDS	NA62 custom level translator board	32 channel ECL-LVDS level translator
8	PC with Labview	Labview	LabView Full Development System

ANNEX: GLOSSARY

Acronym	Definition
SiPM	Silicon Photomultiplier, a silicon-based photon sensor
CALICE AHCAL	The CALICE Analog Hadron Calorimeter