The AIDA-2020 Advanced European Infrastructures for Detectors at Accelerators project has received funding from the European Union’s Horizon 2020 Research and Innovation programme under Grant Agreement no. 654168.

This work is part of AIDA-2020 Work Package 14: Infrastructure for advanced calorimeters.

The electronic version of this AIDA-2020 Publication is available via the AIDA-2020 web site <http://aida2020.web.cern.ch> or on the CERN Document Server at the following URL: <http://cds.cern.ch/search?p=AIDA-2020-D14.5>

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Abstract:
Key performance parameters of calorimeters depend crucially on the complete calorimeter system and the interplay of its components. Therefore, in order to characterise the performance of calorimeter prototypes in beam tests, it is important to test a complete calorimeter system, typically consisting of an electromagnetic and a hadronic section, sometimes complemented by a tail catcher and often in conjunction with a tracking device or telescope. Within AIDA-2020 WP5 (Data acquisition system for beam tests) standards for common beam tests have been defined, and a DAQ software and run control framework (EUDAQ) has been developed. This deliverable reports on common beam tests of calorimeter prototypes based on this framework.
AIDA-2020 Consortium, 2018

For more information on AIDA-2020, its partners and contributors please see [www.cern.ch/AIDA2020](http://www.cern.ch/AIDA2020)

The Advanced European Infrastructures for Detectors at Accelerators (AIDA-2020) project has received funding from the European Union’s Horizon 2020 Research and Innovation programme under Grant Agreement no. 654168. AIDA-2020 began in May 2015 and will run for 4 years.

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Executive summary

The common running of several calorimeter prototypes in beam tests is important to evaluate the relevant performance parameters for particle physics experiments. These prototypes often differ in their data acquisition (DAQ) systems, making the synchronisation of the prototypes challenging. Within AIDA-2020 WP5 (Data acquisition system for beam tests) standards for synchronisation have been defined, and a modular framework for DAQ systems has been developed. This deliverable reports on the application and use of these in the common running of the CMS HGCAL calorimeter prototype and the CALICE AHCAL calorimeter prototype. It also reports on the common running of the CALICE AHCAL calorimeter prototype with a EUDET-style beam telescope, which was an essential step in the synchronisation of two detectors with very different triggering and DAQ concepts. Further beam tests with the common running of several calorimeter prototypes in this framework are planned, indicating the success of the chosen approach.

1. INTRODUCTION

Calorimeters form an essential part of modern particle physics detectors, providing energy measurements for electrically charged and neutral particles by fully stopping them. Relevant performance parameters for calorimeters are the linearity and resolution of the energy measurement. In recent years the power to separate close-by showers of two impinging particles became more and more important, leading to high granularity calorimeters with small cells and a large number of readout channels. Quantifying the performance of calorimeters in beam tests requires prototypes large enough for stopping the beam particles, which leads to relatively complex DAQ systems for test beam prototypes of highly granular calorimeters with channel counts of several thousand up to a few hundred thousand. The calorimeter systems of most particle physics detectors consist of several sections which are optimised for the measurement of various particle species, usually an electromagnetic calorimeter (ECAL), a hadronic calorimeter (HCAL) and a tail catcher. Since they can be based on different detection techniques, prototypes are often developed separately for each section, leading to the need to run several calorimeter prototypes in combined beam tests. Within AIDA-2020 WP5 (Data acquisition system for beam tests) standards for common beam tests have been defined. They cover the synchronisation of different detectors by standardising the interfaces to a common timing and control system [1] as well as the development of a data acquisition (DAQ) software and run control framework, EUDAQ. A new version with improved modularity and better support for detectors with different timing and triggering concepts, EUDAQ2, has been released end of 2017 [2].

This report describes the common running of calorimeter prototypes which are being developed within the context of WP14 of AIDA-2020, based on the EUDAQ framework. Beam tests with other detectors, which were essential to develop and test the common running and synchronisation of detectors with different timing and triggering concepts, will also be presented.
2. COMMON TESTBEAMS OF DETECTORS WITH DIFFERENT TIMING AND TRIGGERING CONCEPTS

2.1. THE DETECTORS AND THEIR TIMING AND TRIGGERING CONCEPTS

Several beam tests at the DESY test beam facility [3] have been performed to develop and test the synchronisation of detector prototypes with different timing and triggering concepts. Here the common running of a beam telescope and a prototype of the CALICE analogue hadronic calorimeter (AHCAL) will be described, which have very different triggering concepts. The tests were done in February 2017 and used a pre-release version of EUDAQ2.

The DATURA beam telescope in beamline TB21 at DESY is a EUDET-type telescope [4], consisting of 6 layers of MIMOSA silicon pixel sensors providing a high precision beam tracking (~2 μm) at an event rate of several kHz. It includes trigger scintillators which provide the signal to read out the MIMOSA sensors (externally triggered mode). The synchronisation with other detectors is usually done by counting the trigger number.

The CALICE AHCAL is a highly granular hadronic calorimeter based on 3x3 cm² scintillator tiles individually read out by Silicon Photomultipliers (SiPMs). Its read-out electronics is optimised for operation at a linear electron-positron collider, where the expected occupancy is low. Within AIDA-2020 WP14, a new Detector Interface (DIF) card, optimised in size and power consumption, has been designed [5]. For each detector cell the energy and time information is stored in analogue memory if the signal crosses a predefined trigger threshold (auto-trigger mode). An external trigger signal is not needed but can be provided to suppress noise and to record a reference time stamp with ~25 ns accuracy. The data taking is divided into phases where the detector is ready to store information (data acquisition), and phases where the data is digitised and sent out (readout). The synchronisation of events with other detectors can only be done by the hit time which is stored relative to the beginning of a data acquisition phase.

Fig. 1: Setup of the DATURA beam telescope (right) and five active layers of the CALICE AHCAL prototype (left) in beamline TB21 of the DESY testbeam facility in February 2017.
A EUDET Trigger and Logic Unit (TLU) was used to distribute the signal of the trigger scintillators to the AHCAL and to veto triggers during the readout phases of the AHCAL. A photo of the setup in beamline TB21 of the DESY test beam facility is shown in figure 1. It consisted of the DATURA beam telescope and 6 active layers of the AHCAL prototype (without absorber layers). The combined setup was tested with electrons of beam energies between 2.0 and 5.4 GeV.

### 2.2. COMMON RUNNING: SYNCHRONISATION AND RESULTS

The synchronisation of the DATURA beam telescope and the CALICE AHCAL prototype is based on the standard and interfaces defined within AIDA-2020 WP5 [1]. It is a mixed scheme, based on trigger numbers and time stamps of hits as well as trigger signals. A schematic sketch is shown in figure 2. The information from different readout ASICs of the AHCAL is independent, such that in a first step this information is combined and sorted by time stamp (TS). The time stamp of the external trigger signal is then used to keep only AHCAL hits which are consistent with the trigger signal. This can be refined by using the Beam InterFace (BIF), which can store the trigger time with a much better time resolution (~1 ns) than the AHCAL itself. In the last step the telescope information is added to the event, based on the trigger number, and the complete event with trigger number, time stamp, AHCAL and telescope information is stored.

![Schematic sketch of the synchronisation of the information from the CALICE AHCAL and the DATURA beam telescope.](image)

If the synchronisation between beam telescope and AHCAL succeeded, a stored event should contain signals of the same beam particle recorded in the two detectors. This should result in a correlation of the time and space information between the two detectors. Since the time stamps are already used in the event building, only the spatial information can be used for a cross check. The position information from the AHCAL is very coarse compared to the beam telescope, but by aiming the beam at the edge of two AHCAL tiles the correlation between the hit position in the telescope and the AHCAL can be clearly observed for properly synchronised events. It can be easily distinguished from the non-synchronised case (figure 3).
3. COMMON CALORIMETER TESTBEAM

3.1. THE DETECTORS: CMS HGCAL AND CALICE AHCAL

For the high-luminosity upgrade of the LHC accelerator at CERN, which is planned to start in 2025, also the detectors need to be upgraded for the higher data rates, the larger radiation levels and the higher number of simultaneous events (pile-up). The CMS experiment plans to replace its calorimeter endcap with a high-granularity calorimeter, the HGCAL, consisting of a front part with silicon sensors, and a rear part with scintillator tiles read out by SiPMs as active medium, in a design very similar to the CALICE AHCAL.

CMS has built a test beam prototype for the silicon part of the HGCAL, based on hexagonal 6 inch silicon sensors with about 1 cm² large cells. It records 13 time samples with 25ns distance, and the readout is triggered by external signals. Similar to the AHCAL, the HGCAL prototype cannot record new events during the readout phase.

The design of the active layers of the scintillator part of the CMS HGCAL is similar to the CALICE AHCAL. Therefore, the AHCAL test beam prototype can be used together with the HGCAL silicon prototype to study the performance of the combined calorimeter system. For this purpose, a dedicated AHCAL absorber stack with 74 mm thick steel absorbers was produced.

The combined setup of the HGCAL silicon prototype and the AHCAL prototype was tested in several periods in 2017 in the H2 and the H6 beam lines at the CERN SPS beam test facility. A photograph of the setup in July 2017 in H2 is shown in figure 4. It consists of the ECAL part of the HGCAL prototype with lead absorber (left), the HCAL part of the HGCAL prototype with steel absorber (middle) and the AHCAL prototype (right). During the tests the number of active layers in the HGCAL varied, with a final configuration of 5 layers in the ECAL part and 7 layers in the HCAL part with ~2400 readout channels in total. The AHCAL prototype had 12 layers, with ~1700 readout channels in total. In addition, wire chambers that are available in the SPS beam lines were read out. Like the HGCAL prototype they are triggered by an external signal. The readout of all detectors was based on EUDAQ 1.6.
3.2. COMMON RUNNING

The synchronisation of the CMS HGCAL silicon prototype and the CALICE AHCAL prototype is very similar to the scheme used for the synchronisation of the AHCAL prototype with the DATURA beam telescope described in the previous chapter. The external trigger signal was provided by trigger scintillators in the H2 beamline. Their signal was fed into the SYNC board of the HGCAL prototype which distributed it to the HGCAL layers, the AHCAL and the wire chambers. The SYNC board also handled the vetoing of triggers during the readout times of the two calorimeter prototypes. After solving some problems with data integrity, all 3 detectors recorded the same number of triggers. The detailed analysis of the data is still ongoing, but the first results of the combined test beam form an important contribution to the Technical Design Report (TDR) of the CMS HGCAL [6] (figure 5).
4. RELATION TO OTHER AIDA-2020 WORK AND FUTURE PLANS

Within AIDA-2020 WP5 (Data acquisition system for beam tests) a new version of the common DAQ framework, EUDAQ2, has been released at the end of 2017. In order to fully profit from the improvements, future combined calorimeter beam tests should use EUDAQ2.

For 2018, two beam tests of combined calorimeter prototypes are planned at the CERN SPS. In October 2018, another period of common running of the CMS HGCAL silicon prototype and the CALICE AHCAL is foreseen in beamline H2. More HGCAL modules, allowing a nearly fully equipped prototype with 40 active layers, are in production. A similar synchronisation scheme as in 2017 is planned. In September 2018, a common running of the CALICE SiWECAL prototype and the CALICE SDHCAL prototype is planned in beamline H2. Both prototypes are based on highly granular calorimeter concepts developed for a linear electron-positron collider. The SiWECAL uses silicon sensors as active material, while the SDHCAL employs glass RPCs. Both prototypes are auto-triggered, but differ in their DAQ schemes such that synchronisation is necessary for common running. In 2016 already a first common beam test of those two detectors has been carried out as a proof of principle, with a small number of silicon sensors. This was before AIDA-2020 standards on common running were defined and before corresponding synchronisation hardware became available. The full demonstration of common data taking and analysis will be enabled by the synchronisation available for the tests planned for September 2018. Future common running will further benefit from the development of DIF cards for the SiWECAL and the SDHCAL, in addition to the new AHCAL DIF, which is already in use. The two additional interfaces will be ready by the end of 2018 (AIDA-2020 Deliverable 14.6).
5. REFERENCES


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