Development of a Semi-Digital Hadronic Calorimeter Using GRPCs for Future Linear Collider Experiments

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Abstract

A new concept of high granularity hadronic calorimeter using thin Glass Resistive Plate Chambers (GRPCs) as sensitive medium with embedded semi-digital readout electronics to be used in the future linear collider experiments is under development within the CALICE collaboration. Based on this concept, a small prototype was built and tested with success at CERN PS test beam in 2008. To validate completely this new concept a prototype of 1 m^3 is being conceived. Several GRPCs as large as 1 m^2 were built with a new design reducing the dead zones and improving the gas distribution system. The GRPCs were tested with an electronics board of the same size. The board containing 144 64-channel ASICs was conceived and built for this purpose.

Key words: GlassRPC, Hadronic Calorimeter, Semi-Digital Readout

1. Introduction

Granular calorimeters are needed to successfully apply the particle flow analysis techniques (PFA)[1]. Calorimeters with gaseous detectors can provide high granularity in addition to excellent homogeneity. This high granularity implies however a tremendous amount of electronic channels. Readout electronics should be embedded on the detector to eliminate the problem of holes related to readout cables and keep the calorimeter as hermetic as possible. In addition, the huge number of electronic channels makes the electrical consumption a major issue. To overcome this difficulty, readout electronics based on power pulsing system using the ILC duty cycle[2] are proposed.

In order to face the previous challenges, the CALICE collaboration is pursuing a new development aimed at constructing a high granular gaseous hadronic calorimeter prototype based on a semi-digital readout and a transverse segmentation of 1 cm^2. According to the simulation a semi-digital readout HCAL can provide very good energy resolution in addition to tracking capability. With an appropriate choice of threshold values it can be as good as the resolution provided by an analog readout . The Semi-Digital HCAL prototype is intended to come as close as possible to the hadronic calorimeters of the future ILC experiments in terms of resolution, efficiency and compactness. Few gaseous detectors are being investigated to become the sensitive medium of such HCAL: GRPC, GEM and Micromegas. New readout electronics that meet the ILC constraints were developed and successfully tested on small GRPC detectors and more recently on a 1 m^2 detector.

2. Detector development

GRPC are well tested detectors. They have been successfully used in BELLE[3] for almost a decade and more recently in OPERA[4] and ALICE[5]. Nonetheless, GRPCs to be used as sensitive medium in the future HCAL need to be thinner than the standard ones. Thin GRPCs allow to reduce the total radius of the hadronic calorimeter and hence the cost of the magnet coil inside which the HCAL should be placed. For this reason, 3 mm thickness GRPCs were conceived and built. In addition to the thickness constraint, dead zones due to spacers used between the two glass plates of the GRPC are to be reduced in view to increase efficiency. New schemes using 1 mm radius ceramics balls were proposed leading to a negligible dead zone. Another important point is the gas consumption in such a detector. New designs of gas distribution were studied to renew the gas efficiently increasing the homogeneity and at the same time reduce the needed gas flow. Another R&D activity concerning the resistive coating of GRPC is ongoing. Different coatings were tested to reduce the number of 1 cm^2 pads associated to one mip. This number was found to go from 1.6 pads/mip in case of standard graphite coating to 1.3 pads/mip for more resistive products like the Licron and Statguard products. To guarantee the homogeneity of the painting on detectors of large surface, silk screen printing techniques were successfully used. Stability of high voltage connections were also improved thanks to new gluing materials. Although the accumulated charge on the HCAL GRPCs in the future ILC experiments is expected to be very small, a couple of GRPCs are being exposed to high irradiation in the GIF facility at CERN to discover any possible aging effect. The efficiency of the different GRPCs was found to be more than 90% when operated in the high voltage range between 7 and 8 kV (Figure 1), using either cosmic rays benches or test beams at CERN.

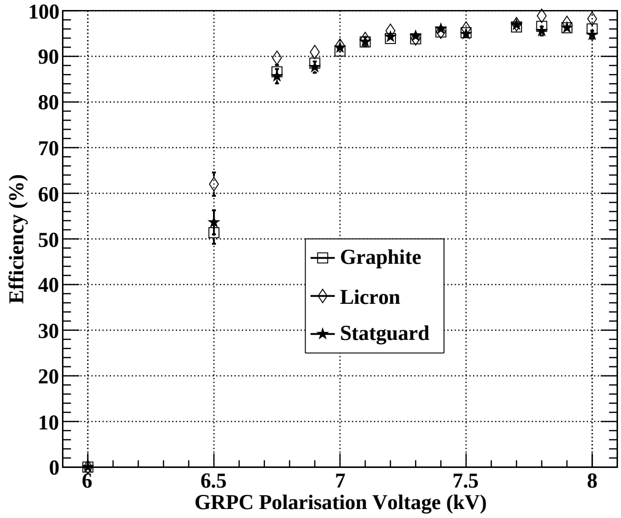

Figure 1: Comparison of efficiency versus polarisation voltage, for three kind of coating materials.

3. Electronics Development

An electronic ASIC called HARDROC[6] with a semi-digital readout was developed and successfully tested to readout the gaseous detectors mentioned above. The first version of the ASIC can provide two thresholds (2-bit readout). It contains 64 channels, each composed of :

1. A fast low impedance preamplifier with a variable gain coded over 6 bits.
2. A variable shaper (50-150 ns) and Track and Hold to provide a multiplexed analogue charge output up to 10 pC.
3. Two variable gain fast shapers (15 ns) followed by 2 low offset discriminators which allow handling wide dynamic range from 10 fC up to 10 pC. The thresholds are loaded by two internal 8-bit DACs.

Up to 128 events can be stored into the internal digital memory. An event contains the 64 discriminators output statuses, and the bunch crossing identification coded over a 24 bits counter. It is equipped with a power pulsing system which allows to reach a consumption lower than 10 μW/channel with a 0.5% duty cycle. The cross-talk among the 64 channels was measured and found to be less than 2%.

4. Prototype

A Printed Circuit Board (PCB) hosting 4 HARDROCs was conceived to validate the concept of a semi-digital hadronic calorimeter . The board provides the connection between adjacent ASICs as well as the first ASIC to the readout system. The readout system using a FPGA device was implemented on the same PCB as well as a USB device responsible for the communication between the FPGA and an external server. The PCB is an 8-layer, 800-microns thick circuit. 256 copper pads of 1x1 cm^2 were printed on one of the two PCB faces. The distance between two adjacent pads was chosen to be 500 microns. The cross-talk among adjacent pads in the absence of other electronic components on the PCB was studied by injecting a charge of 1 pC on one pad using an appropriate probe. The charges induced on the adjacent pads were then measured and found to be less than 0.3%. An acquisition software was also developed. It allows to upload the configuration parameters to the different ASICs and to collect data from these ASICs through the FPGA device. Two readout modes were implemented. The first one is ILC-like where events are recorded during the bunch crossings and the readout takes place thereafter. The other mode was conceived for cosmic rays and beam test studies. In this mode the acquisition and data taking is stopped when an external trigger occurs. The memory of the different ASICs is then read out. In both modes each event is associated with a time stamp. In the external trigger mode the time difference between the external trigger and the last recorded event is also given. This determines the time occurrence of each event with respect to the external trigger. The time precision is given by the HARDROC internal clock that runs at 5 MHz frequency. The electronics boards described above were attached to small GRPCs and assembled together to form a prototype of 5 chambers. The acquisition system was extended to deal with the data coming from each chamber and assemble them in events. A LABview-based graphical interface was developed. This allowed an easy gain correction of all the channels. The setup was exposed first to cosmic rays and then to beams at CERN. The whole system performed as expected and allowed to study the GRPC efficiency and multiplicity. Completed with 2 cm stainless steel plates, the setup was exposed to pions at PS to study the first phase of hadronic showers (Figure 2).

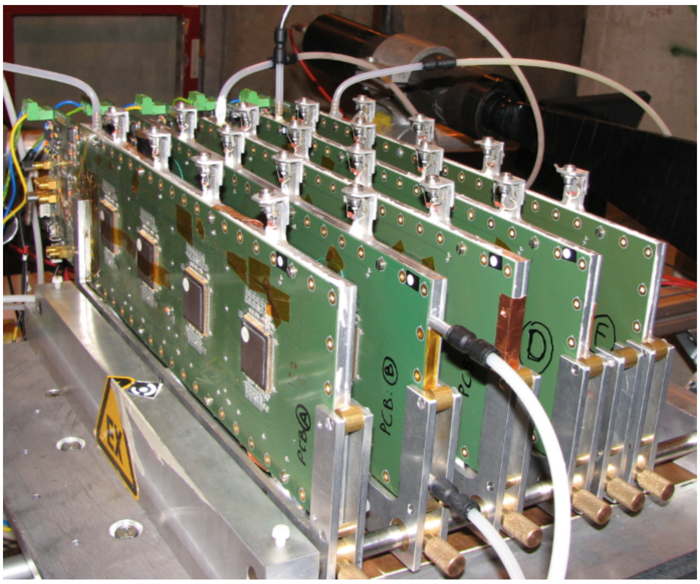

Figure 2: The small Semi-Digital Hadronic Calorimeter prototype exposed to pions beam in the PS at CERN.

5. Technological Prototype

The success of the small prototype was the first step towards the construction of the technological prototype. The second and decisive one was to build a fully equipped detector of 1 m^2. For this purpose, a new PCB hosting 24 ASICs was designed with the possibility to chain several PCBs together. An independent interface board (DIF) connecting the PCB to the acquisition system was also produced and tested. Six such PCBs were produced and equipped. Every two PCBs were chained together and connected to one DIF. The six boards were fixed to a mechanical support made of stainless steel plate and then attached to a 1 m^2 GRPC. The three DIFs connected to the PCBs are chained together and connected to a monitoring computer. An acquisition system using the Xdaq system[7] developed by the CMS collaboration is used to build events from the collected data. A cosmic ray test bench was used to study the whole system. After a debugging period, the whole system works adequately. Different GRPCs were tested using the large electronic board in test beams at CERN in June and August 2009 (Figure 3). The collected data were analysed. Synchronization among the different DIFs was successful and the data consistency demonstrated (Figure 4). The measured efficiency of the 1 m^2 GRPC was found to be in the same range as that of small GRPC chambers (>90%). This success constitutes an important milestone in the validation of the Semi-Digital Hadronic Calorimeter. To complete this study an improved electronic board equipped with the new version of the HARDROC ASICs is under construction. The board will be attached to 1 m^2 GRPC, and inserted into a cassette. This will be the first unit of the technological prototype to be built in 2010. The technological prototype will be made of 40 detectors interleaved with 2 cm stainless steel plates. The mechanical structure of the prototype is currently being conceived. The aim is to have a self-supporting structure like the one proposed in the ILD and SiD concepts. The detectors with their readout boards will be cast into cassettes that will be inserted between the Stainless Steel plates. The readout system will include data concentrators which will connect the DIF mentioned above to the general CALICE acquisition system. The development of data concentrators is almost finished and the complete readout system will soon be tested to validate the whole chain. Gas distribution system controlling both the gas flow and pressure in the different chambers is under construction in collaboration with the CERN Gas Service. High voltage power supplies using the Cockroft-Walton were designed and will be produced very soon. The construction of the technological prototype is expected to be completed by end 2010. In addition to the hardware development, a software activity is ongoing in order to properly prepare the comparison between data and the hadronic shower models used in the simulation.

6. Square meter detector results

Recent measurements have been achieved using the small GRPC chambers as a tracking device to reconstruct cosmic

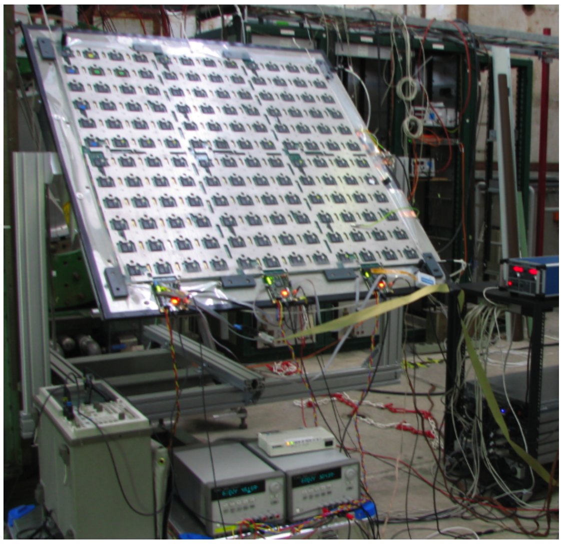

Figure 3: A fully equipped 1m^2 GRPC exposed to pions beam in the SPS at CERN.

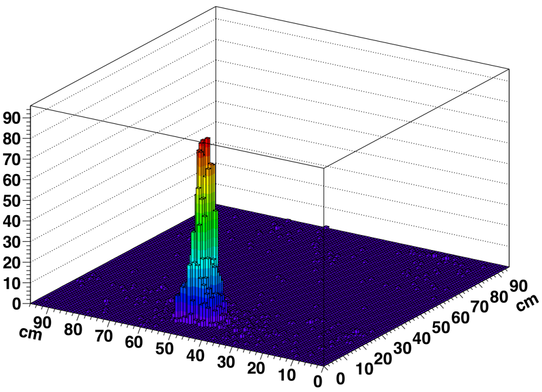

Figure 4: Profile of the pions beam as seen by the 1 m^2 equipped GRPC in SPS at CERN.

events. It allows to study local characteristics in the 1 m^2 prototype selecting only good track candidates in the small setup, and projecting them into the large prototype. The results obtained for three differents areas with this combined setup show that the efficiency is quite homogeneous across the chamber (Figure 5). We also compare the multiplicity (mean number of fired pads per MIP) in these areas (Figure 6). This good spatial homogeneity is the result of an intensive R&D activity concerning detector development:

1. Gas simulations studies allowed us to find the best channeling scheme for an efficient gas renewal in the whole detector.
2. Ceramic ball spacers lead to negligible dead zones.
3. Mechanical simulations of the glass plates deformation shown it to be less than 44 μm, ensuring a constant electric field into the whole chamber.

These measurements were the first to use a complete square meter of semi-digital electronics. Hence these results also validate the stability of the whole acqisition chain in a large scale scheme (144 ASICs taking data together).

Thanks to all of these improvements, no software compensation will be needed to correct efficiency inhomogeneity in our technical prototype. Next test beam scheduled May 2010 will allow us to scan efficency cell by cell, using the huge statistics that CERN pion beams can provide.

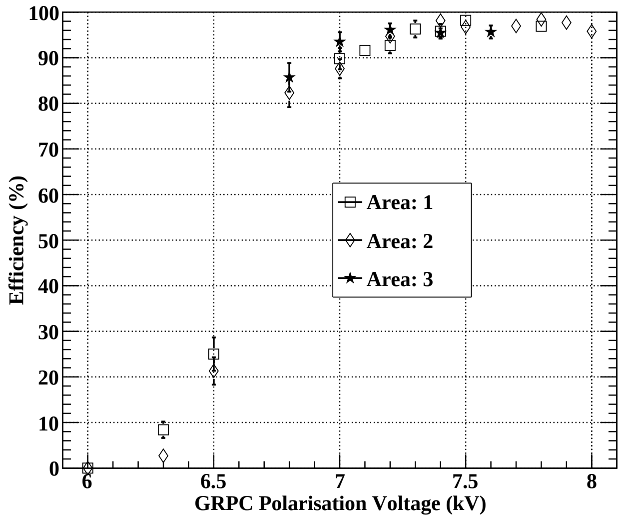

Figure 5: Efficiency of the 1 m^2 chamber in 3 different 10x10 cm^2 areas.

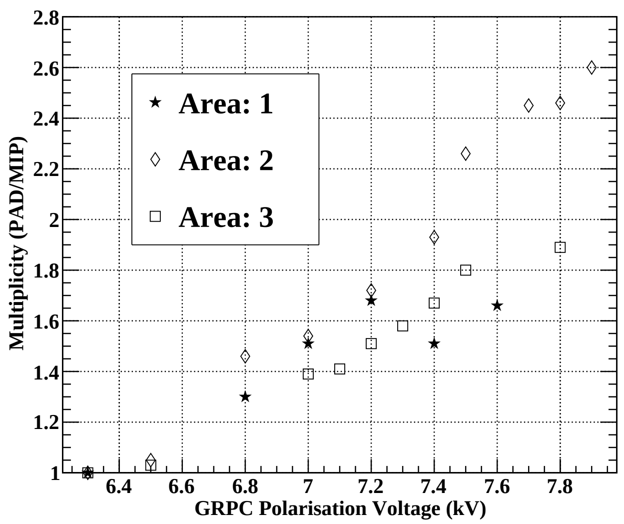

Figure 6: Multiplicity of the 1 m^2 chamber in 3 different 10x10 cm^2 areas.

7. Conclusion

A small prototype of hadronic calorimeter with semi-digital electronic readout using GRPCs was built. Tests with pion beams at CERN proved the principle of such calorimeter. A 1 m^2 GRPC fully equipped with the same electronics readout was built and successfully tested. This is the first step in building 4.5 λ_I hadronic calorimeter which is intended to be as close as possible to the one proposed for the future ILC experiments.

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