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Construction and commissioning of the SDHCAL technological prototype

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This proceeding presents the SDHCAL technological prototype. This prototype is a $1 \times 1 \times 1.3\,\mathrm{m}^3$ high-granularity semi-digital Hadronic calorimeter using GRPC as sensitive medium. It is one of the two HCAL options considered by the ILD collaboration to be proposed for the detector of the future International Linear Collider project. The prototype has been achieved and successfully operated within the CALICE collaboration. The prototype has all the features needed to meet the ILD requirements : power-pulsed embedded electronics, auto-triggering capability, cost-effective technology.

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1. Introduction

This article describes a hadronic calorimeter prototype. The Semi-Digital Hadronic CALorimeter (SDHCAL) is one of the two hadronic calorimeter options considered by the ILD (International Large Detector) collaboration [1] to be proposed for the detector of the future International Linear Collider (ILC). ILC detectors are designed for Particle Flow Algorithms [2] (PFA). For optimal use of PFA, calorimeters needs to be homogeneous and finely segmented.

The SDHCAL prototype meets these requirements by the combination of various technological choices. The homogeneity is achieved by the use of large Glass Resisitive Plate Chambers (GRPC) as the active medium combined with a power-pulsed embedded electronics. The power-pulsing suppresses the need of integrating a cooling circuit inside the detector by reducing the power consumption and heating. The homogeneity is further achieved by having all services (gas inflows and outflows, high voltage, readout data, etc.) to be on only one side of the GRPC and outside the HCAL.

The fine segmentation is achieved transversally by the readout electronics system. An embedded Printed Circuit Board (PCB) with a checked side made of 1 cm^2 copper pads, reads the signal created by the passage of charged particles in the GRPC detector. The other side of the PCB holds the HARDROC ASICs [3], that collect signals from the copper pads, digitalizes them and transmits them to the outside data acquisition system. The ASIC provides 2-bit readout. The choice of this semi-digital scheme rather than the binary one was motivated by simulation studies [4] and has been confirmed by results presented in this proceedings [5].

2. Mechanical structure

2.1 The Absorber

The prototype calorimeter absorber is stainless steel. The absorber has been manufactured in a self-supporting mechanical structure [4]. It consists of 51 steel squares , 1 m $\times$ 1 m, 1.5 cm thick, piled up and separated by 13 mm thick spacers put along three sides of the squared steel plates. Plates and spacers are riveted thanks to well distributed bolts.

In the 13 mm spaces, 11 mm thick cassettes [4] (see Fig. 1) are inserted. Each cassette contains one GRPC and its associated electronics. The cassette is a thin box consisting of two 2.5 mm thick stainless steel plates separated by 6 mm wide stainless steel spacers which form the walls of the box. One of the two plates is 20 cm larger than the other to hold the PCBs used for the data acquisition as well as the gas outlets and the high voltage box. Precision machined stainless steel spacers, insulated from the GRPC, are making the cassette's sides. A polycarbonate mask is added around the ASICs to ensure that once the cassette is closed, the PCB is forced to stay into contact with the GRPC anode. This cassette structure ensures a homogeneous efficiency in the GRPC signal collection by the PCB copper pads.

The SDHCAL prototype is then a sampling calorimeter with 2 cm thick absorber layers, nearly one radiation length, and 6 mm thick active detectors.

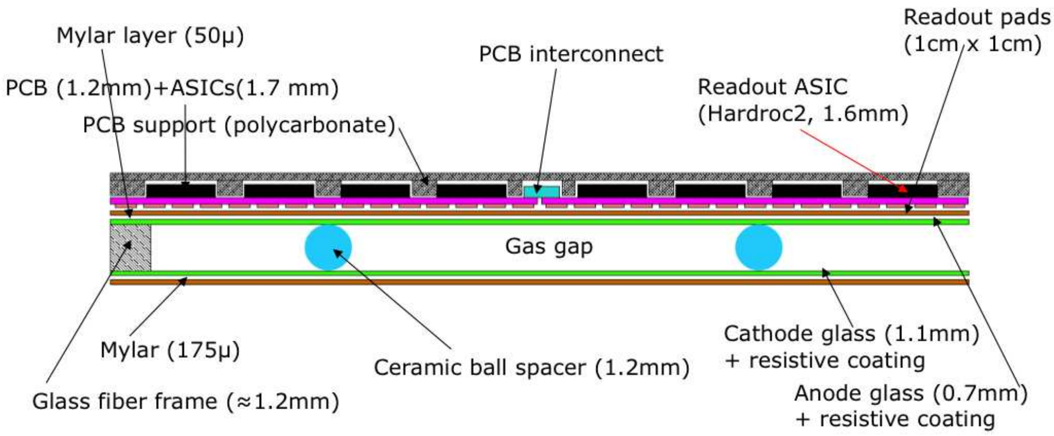

Figure 1: Schematic cross-section view of a 1 m^2 GRPC cassette.

2.2 The sensitive detector

The 6 mm thick sensitive detector is made of a 3 mm thick GRPC and a 3 mm thick PCB. The GRPC is used in saturated avalanche mode [6]: the avalanche is initiated by the crossing of the 1.2 mm thick gas gap by one or more charged particles. The gap is framed by two electrodes made of borosilicate float glass [7]. The anode and cathode thicknesses are respectively 0.7 mm and 1.1 mm. The smaller anode thickness enhances the signal in the copper pad closest to the crossing particle and lowers the relative signal seen by neighbouring pads. The high voltage used is typically 7 kV. A glass fiber frame, width 3 mm, height 1.2 mm, is used to seal the gas volume.

The gas distribution within the chamber is done with through an L-shaped channel delimited by the chamber frame and a series of PMMA fibers [7]. Gaps between the fibers allow the gas to leave the channel at regular intervals, expanding into the main chamber volume. The usual operating condition is to renew completely the chamber volume every 20 minutes. This needs a gas flow of 3.6 l/ h and an overpressure of 1 mbar in the chamber. This overpressure corresponds to a force per unit area of 100 N/ m^2, which almost balances the attractive electric force between the plates.

To maintain the gas gap over the entire chamber area, spacers in the form of 1.2 mm in diamater ceramic balls are glued on the cathode every 10 cm. A finite element analysis [7] taking into account the electric force and the glass plates weight has determined that for this distribution of balls, the maximum deflection of the anode glass is 44 μm. When the gas circulates, this deflection is reduced. To ensure the physical integrity of the chamber in case the gas circulates but the high voltage is switched off, 13 ceramic balls are replaced for each m^2 by cylindrical glass disks glued on both electrodes [8].

3. GRPC optimisation

The quality of one chamber is measured by two numbers : the efficiency and the multiplicity. The efficiency is the fraction of single crossing charged particles that induce a signal in the copper pads. The multiplicity is the mean number of pads activated by single crossing charged particles that activate at least one pad. These two numbers depend on the mechanical design of the GRPC and on the choice of the detection threshold of the readout electronics.

The operating gas is a mixture of 93% of TFE, 5% of $C0_2$ and 2% of SF_6. TFE has been chosen for its low ionisation energy enabling efficient creation of avalanche. CO_2 and SF_6 are used as UV and electron quenchers respectively. Studies of the proportion of SF_6 have been performed [8]. It can be seen on Fig 2 that adding a bit of SF_6 reduces the multiplicity without degrading too much the efficiency. This illustrates the role of the SF_6 that confines the avalanche by capturing extra electrons. If the SF_6 concentration is too high, then wanted avalanche initiating electrons will also be captured and the detector efficiency will be reduced. On Fig 2 is also shown a comparison of $C0_2$ and isobutane as UV-photon quenchers. Both gas leads to same GRPC performance and since $C0_2$ is not flammable, it has been chosen.

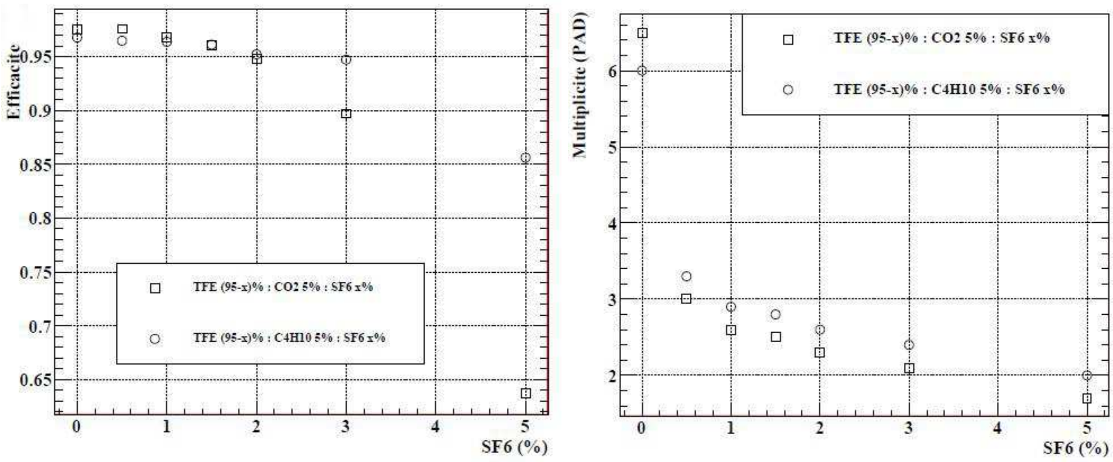

Figure 2: GRPC efficiency (*left*) and multiplicity (*right*) as a function of the proportion of SF_6 electron quencher. Measurements have been done with 7.1 kV high voltage and 135 fC signal threshold detection. Two UV-photon quenchers have been tested : isobutane and $C0_2$.

The glass electrodes are covered with resistive coatings to provide uniform spread of the high voltage over the 1 m^2 electrodes. Three coatings were tested [7, 8]. There characteristics are listed in Table 1

Coating	surface resistivity ($M\Omega/\square$)	Best application method
Licron©	~ 20	Spray
Statguard©	1 to 10	Brush
Colloidal graphite	Depends on mix ratio; choose ~ 0.7	Silkscreen painting

Table 1: Characteristics of the three tested coatings.

The Figure 3 shows the GRPC performance for the different coatings. The efficiencies are similar for the three cases but the multiplicity is reduced by higher resistivity coatings. Based on the performance, Licron is the best choice. However after few months of operation, the Licron painting migrates away from the HV connectors. Statguard has similar performance as Licron. However, Statguard can only be applied with a brush, leading to too big coating thickness inhomogeneity. Moreover, it needs a month for complete drying and stabilisation of the resistivity value. Finally, the GRPC electrodes were coated with a bicomponent painting based on colloidal graphite. This painting can be silkscreen printed for a very good coating uniformity. In addition, the resistivity is adjustable by varying the proportion of the two components and it is the less expensive of the three coatings.

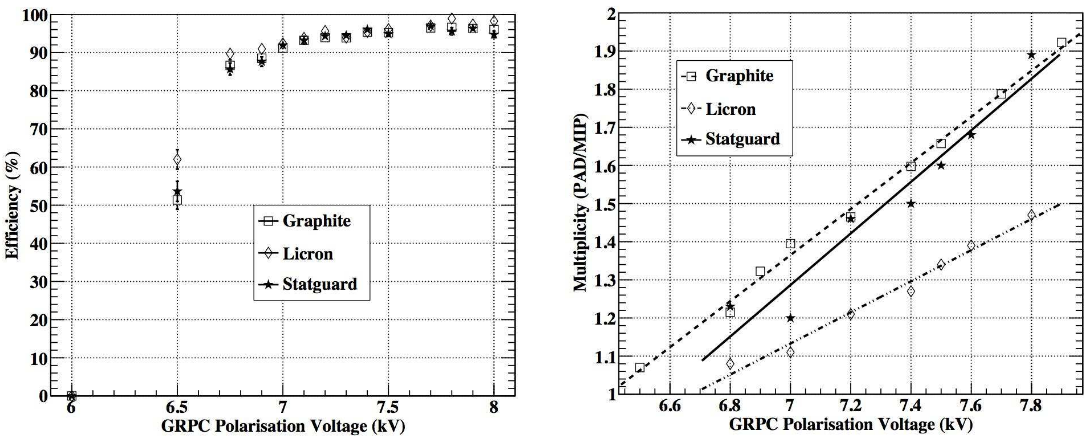

Figure 3: GRPC efficiency (*left*) and multiplicity (*right*) as a function of the applied High Voltage for the three studied coatings.

4. Electronics

4.1 Design

A 1 m^2 GRPC is tiled with 6 PCB, $\frac{1}{3} \times \frac{1}{2}$ m^2. The PCBs have eight layers. On one external face, 1536 copper pads of 1 cm^2 are printed. Copper pads are separated by 406 μm. On the opposite face, 24 HARDROC2 ASICs [3] are soldered. Each ASIC is connected to 8×8 pads through the PCB. The electronic channel cross-talk between two adjacent pads is less than 2% [9].

Each of the 64 channels of an ASIC is made of a fast low-input-impedance current-preamplifier. The gain of each preamplifier can be varied over 6 bits to correct for the non-uniformity between channels. The 2-bit readout is done by 3 variable fast shapers (15-25 ns), each one followed by a low-offset discriminator. Each fast shaper covers a different dynamic range leading to a total channel dynamic range ranging from 10 fC to 15 pC.

When the ASIC is in acquisition mode, the 192 discriminator outputs are checked each 200 ns. If one is fired, an event is stored in an integrated digital memory. This “auto-triggering” mechanism enables the operation of the calorimeter without external triggers. An ASIC event consists of the ASIC identification number, a 3-byte clock counter and the output state of the 192 discriminators. The HARDROC2 can store up to 127 ASIC events. Once the memory is full, the ASIC raises a signal and waits for instruction from the external Data Acquisition (DAQ) system.

The ASICs are daisy chained on the PCB. Configuration data (the 64 preamplifier gain, the 192 discriminator thresholds, etc.) and the readout data are transfered through the chain of ASICs. The $\frac{1}{3} \times \frac{1}{2}$ m^2 PCBs can be chained themselves. On a 1 m^2 GRPC, the 6 PCBs are paired and connected to 3 DAQ interface boards (DIF) located on the larger cassette plate. This daisy-chaining reduces the amount of cables needed between the cassette and the external DAQ

4.2 Power-pulsing

An important feature of the ASIC is the possibility to be power-pulsed. It is possible to switch on/off the power-hungry parts of the ASICs by sending external control signal. The portion of the ASICs that should be power-pulsed is configurable before the acquisition starts. With everything on, the power consumption is 1.425 mW per copper pads. When most of the ASICs is switched off, it reduces to less than 0.2 μW. The ILC operating cycle [10], is planed to have a 200 ms period in which collisions will occur only during 0.95 ms. By switching on the HARDROC2 only 0.5% of the time, the SDHCAL power consumption is below 10 μW per channel and sufficiently low to avoid the need of an internal cooling system.

After the switch on, the ASIC is ready for data taking after a 25 μs latency [11]. This time is needed to stabilise the digital to analog converters that set the 192 discriminators thresholds. A first test was to inject a known charge into an ASIC channel and measure the fraction of charge injection that have fired the output discriminator. The Figure 4 (*left*) shows this fraction as a function of the delay between the ASIC switching on and the discriminator output reading. The response efficiency is independant of the delay in the measured range. A test of a GRPC efficiency to detect a charge particle has been done on the CERN H2 beamline. The GRPCs has been tested inside a 3 T magnetic field to be closer to the future ILD operating conditions. The measured efficiency is shown on Figure 4 (*right*) and no significant difference is seen with and without power pulsing. The power-pulsing technique has been fully validated.

5. Prototype testing

The GRPCs have been tested on CERN beamlines. A particle beam has been shoot on a chamber at various location. The measured efficiency and multiplicity are very stable along the GRPC surface. The only places a little less efficient are the 13 reinforcing disks where the detection efficiency is only around 80% instead of 95%. The goal of building homogeneous efficient large GRPC has been achieved. Tests of the full prototype with the absorber and up to 50 chambers inserted has been performed with pion beams. For these tests, the power-pulsing was used to switch on the ASICs only when beam were delivered to the experimental area. The Data Acquisition has been performed with the XDAQ software[12]. The ASICs configuration and clock synchronisation was sent to the DIFs by HDMI cables and the readout data was retrieved from the DIFs through USB cables. On a total of more than 460000 channels, around one per mil were dead or dysfunctioning. The rate noise has been estimated to be of the order of 1 Hz/cm^2. First preliminary estimates of the prototype calorimetric performances are presented in [5]

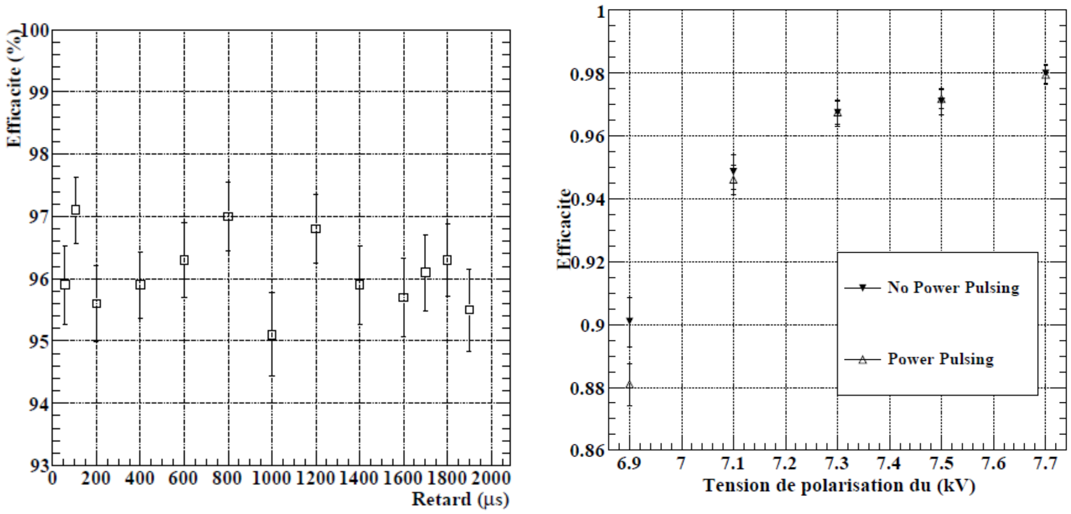

Figure 4: (*left*) Response efficiency of an ASIC channel to the injection of a 0.54 pC charge with a discriminator threshold at 140 DAC as a function of the delay between the switch on and the acquisition. (*right*) GRPC efficiency as a function of the applied voltage with and without power pulsing. A 3 T magnetic field was applied. The discriminator threshold was at 140 DAC. The power-pulsing frequency was 100 Hz.

6. Conclusion

A technological prototype for a Semi-Digital Hadronic CALorimeter has been achieved and successfully operated. The calorimeter is finely segmented as needed for Particle Flow Algorithm. It has an embedded readout electronics that has successfully taken data with power-pulsing. It has been demonstrated that cost-effective GRPCs can operate with high efficiency and uniform response on large area. The homogeneity of the prototype and its operational stability are very good. Preliminary physics results show encouraging performance [5]. In the future, test beam combining the SDHCAL with some electomagnetic calorimeter will be performed to assess the PFA performance with the SDHCAL.

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