The Semi-Digital Hadronic Calorimeter Calibration and its Follow-up

The semi-digital hadronic calorimeter proposed in the ILD letter of intent uses a gaseous detector (Glass RPC) as a sensitive medium. The Glass RPC is a very stable and, most importantly, a homogeneous detector [1]. This is an important feature which distinguishes the semi-digital option and makes its calibration rather simple. Despite this asset, in the case of semi-digital option the number of electronics channels is a real challenge and should be addressed properly.

This document explains the procedure we intend to apply to calibrate the electronic channels (a total of about 70 million channels) and the gaseous detectors (a total of 2302) before and after the installation. It addresses also the SDHCAL follow up in the different phases.

Electronics calibration:

Each readout board of those we intend to use in the case of the SDHCAL hosts a large number of ASICs (up to 500). The precise number depends on the associated GRPC detector size. Each ASIC handles 64 channels. The boards are connected to the acquisition system through Detector InterFace (DIF) boards. More details concerning the SDHCAL readout system can be found in the related section of the LOI. The procedure described here after was successfully applied to the small SDHCAL prototype and are currently optimized to be used in the case of a 1 m^2fully equipped GRPC detector and then generalized to the case of in situ calibration.

Calibration procedure:

The calibration procedure includes the noise level determination, the gain correction and the DAC/charge conversion for each of the electronic channel.

- **Noise curve:** The noise level of each electronic channel is studied by varying step by step the lowest threshold expressed in DAC units (the comparator level coded with 10 bits). The typical response obtained by this scan takes the shape of a S-Curve which describes the channel efficiency in terms of the threshold value. The inflection point indicates the average noise level. The slope of the S-Curve around the inflection point determines the electronics intrinsic spread.
  For a pure Gaussian noise, the S-Curve can be fitted by an error function to extract the previous information, but is also properly described for the prototypes by a a sigmoid function (the same used to describe the Fermi-Dirac statistics)..
  The Noise level S-Curve can be obtained for all the channels belonging to the same electronic board at the same time.

- **Gain Correction procedure for the lowest threshold:**
  The HARDROC ASIC that we propose for the SDHCAL readout provides the possibility to apply a gain correction to each of the 64 channels independently. The aim of this correction is to reduce the discrepancy that may exist among the different channels of one ASIC and also among the channels of different ASICs.

  To estimate the gain correction for each channel adequately the cross-talk effect should be eliminated when possible. For this reason each of the 64 channels belonging to one ASIC is addressed individually by injecting a known amount of charge through a test capacitor.

  Here after the different steps we perform to obtain the gain correction:

  1- A charge corresponding to the desired lowest threshold (say 100 fC) is injected 100 times in one specific channel for some or all of the 1024 possible threshold values. The S-Curve is then determined for this channel

2- The same procedure is repeated for all the channels belonging to the same board and the average value of the inflection point is determined.

3- The same S-Curve determination for each channel is performed with different gains values around the natural one (1 in the case of GRPC)

4- The relation between the inflection point value and the gain value is determined. This relation is a linear one in the conditions mentioned before. This relation is then used to choose the gain to be applied so that the inflection point of one channel comes as close as possible to the average value.

- **Gain Correction procedure for the higher thresholds:**

  The gain correction applied to the first (usually the lowest) threshold is automatically applied to the two additional thresholds of the HARDROC ASIC. The dispersion correction of these two thresholds is not as optimal as the one obtained for the first threshold. This is due to slight no-linearity behaviour of the ASIC. Still the applied correction reduces the dispersion of the channels response when the higher thresholds are used.

- **DAC/Charge correction ratio:**

  By injecting different charge values in the same electronic channel and by determining the associated S-Curve one can deduce the conversion factor relating the DAC and charges values. This is indeed obtained by measuring the distance separating the inflection points of two S-Curves associated to two known charges.

Electronics control after installation:

The calibration of the SDHCAL electronics described above is intended to be performed before the installation. A strategy to control the electronics evolution is under study. The aim is to reduce the calibration time and its effect on the data collection.

Based on the results obtained with a fully equipped 1 m^2 detector we estimate the needed time to perform the noise curve to be 10-20 minutes for all the channels. For the gain correction procedure our preliminary estimate is about 200 minutes.

The frequency of the electronics calibration will be determined by the stability test we are performing on our electronics.

Detector Calibration:

Although the homogeneity of the GRPC response is well established, each of the SDHCAL detectors equipped with the calibrated electronics board will be tested using cosmic bench. The homogeneity will be tested by means of the local efficiency measurement.

In order to reduce the time needed to test all the detectors each cosmic bench will host few GRPC detectors (5–10). Tracking algorithms based on information obtained by the detectors (1 cm resolution) will be used to estimate the local efficiency of each of the detectors.

To estimate the efficiency for each square cm within 1 percent uncertainty the time exposure is estimated to be ten hours in case of a stack of 5 GRPCs with a mean efficiency of 95%. This means that in average we need about 100 hours/module and hence 4000 hours for the Barrel modules and about 1000 hours for those of the Endcaps, resulting in a total of 200 days if a unique bench must be used.

The detector calibration procedure before installation can be shared by the different groups participating in the DHCAL efforts to reduce the tests duration. Increasing the number of detectors per stack will also reduce the needed time.

In addition to the cosmic bench tests some of the detectors will be tested using muon beam to confirm the obtained results in higher density conditions.

Detectors control after the installation

As mentioned before, one of the interests of using gaseous detector as a sensitive medium resides in its homogeneity over large surfaces. Once the homogeneity is controlled before installation only the detector efficiency will be followed up during the data taking. Indeed in experiments using GRPCs (like the Belle experiment) only global evolution was observed (essentially due to gas contamination). This propriety of gaseous detectors presents a big advantage in terms of detector follow-up since it reduces the number of tracks needed to control the detector behaviour. As a consequence, the number of needed tracks will be determined by the surface of the smallest detector used in the DHCAL which is about 1800 cm^2.

The tracks we can use to control the detector efficiency can be provided by different sources:

- **Cosmic Rays:** The number of those particles will depend on the depth of the ILD detector. At the sea level one expects a rate of $1/min/cm^2$. On the contrary to the pre-installation phase, the needed number here is much lower since we would like to control the global efficiency. For horizontal GRPCs in the upper part of the detector (just under the Yoke) 20 seconds will be sufficient to control the efficiency. However, in the power pulsing regime, with a duty cycle of 0.5%, this time will increase by a factor of 200 leading to about one hour. For the horizontal GRPCs of the detector lower part few hours will be necessary due to the flux reduction (Iron and Tungsten presence above them).

  For the non-horizontal detectors the needed time will depend on their inclination.

- It is clear that the cosmic rays are of big importance. However in the case the future detector is situated deep underground the reduction factor will increase the needed time for calibration.

- **Beam Halo Muons:** the number of muons will ultimately depend on the protection system that will be used to prevent them from reaching the detector: a BDS [2] background study predict, in the absence of shielding, a constant rate of ~2 muons/s/cm² up to a radius of ~4 m. These muons, in time with the beam, do not suffer from the power pulsing system. Even with halo shielding, there will be enough muons to calibrate the detector Endcaps: with 660 muons/seconds only few seconds are needed to control the global efficiency of the Endcaps GRPCs (each layer is made of 4 GRPCs).

- **Hadronic Shower:** in each hadronic shower few long tracks are produced. In order to separate them from the hadronic environment, different methods can be used. One of the methods is based on the Hough Transform. This method that was applied to reduce noise and select tracks in bubbles chambers can be used here because of the high resolution of the proposed SDHCAL.

  At the Z^0 peak, for an instantaneous luminosity of $10^{33}cm^{-2}s^{-1}$, one roughly expects 2000 mip hits/s.

- **Muon tracks** produced by Z^0 and W boson decays. This source becomes the essential one in the case of ILC running at the Z^0 pole with about 7 tracks/s in the so-called GigaZ scenario (2.1 nb). Less than 5 hours is needed to control all the GRPC detectors.

In addition to the efficiency, the leakage current is another control element. It is stability is an important indication of the detector one.

Additional controls

The use of semi-digital readout in the SDHCAL proposed for ILD makes its control more difficult than the simple binary one. The way we envisage to control the relation between the detector response and the hadronic energy is to use the average ratios between pads with one, two and three thresholds. The evolution of those ratios with time will indicate a change of the detector behaviour with respect to the deposited energy.

Optional control:

Although the gaseous detector homogeneity will be controlled before the installation, a homogeneity test can be envisaged if efficiency measurements presented in the previous section show some discrepancy among different zones of the detector (this of course could only be seen after accumulating significant statistics). The test we envisage is based on adding a small percentage of radioactive gases to the gas mixture, like ^{133}Xe (ß decay) and/or ^{222}Rd (α decay); the final choice of the nuclide should take all the chemical aspects of the daughter elements. The decay products will induce signal in homogeneous way in the detector. The hits frequency distribution should be the same everywhere in the detector. Deviation can then be a signal of homogeneity problem in our detector.

Quick response checks could also be performed using short lived medical nuclide (^{36}Cl or ^{18}F for example).

Alignment:

The alignment quality is determined by the mechanical structure. Less than few millimetres resolution is expected. The cosmic rays as well as halo beam muons will be used to check the relative alignment of the different detectors.

References:

[1] BELLE collaboration: NIM A 508 (2003) 56-6, NIM A 449 (2000) 112-124

[2] N.V. Mokhov WG-D meeting, Aug 15, 2007, http://ilcagenda.linearcollider.org/materialDisplay.py?contribId=4&materialId=slides&confId=2114