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The ECAL precalibration in H4:

User requirements document

Version 1.0

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Abstract

This document provides elements to perform the precalibration of the Electromagnetic Calorimeter SuperModules in H4 beam line, and analyses the work to be done to build all the necessary tools to achieve this precalibration.

Table of Content

1. Introduction

The structure of the Electromagnetic Calorimeter (ECAL) is described in the Technical Design Report (TDR) [1]. In the following when the word SuperModule (SM) is used, it means endcap Quadrant as well.

The goal of the precalibration in H4 is to:

- Validate each SM. This means that each **channel** response must be consistent with the expectations computed from the parameters of the SM components.
- Calculate the calibration coefficients. The calibration coefficients give the correspondence between the ADC informations and the deposited energy in each Crystal. However, since there are several possible definitions for the meaning of these coefficients, several algorythms will be implemented, and several values will be stored. These calibration coefficients, and especially the **intercalibration coefficients**, are supposed to provide good starting values for the *in situ* calibration of the ECAL at LHC.

Each SM will be precalibrated in the H4 beam line from year 2001 to year 2004, with a frequency of one SM every two weeks (12 SM a year). In these conditions, most of the analysis will be performed in **real time**, which means practically **"online"** in the H4 control room. Delayed offline analysis will be used at the beginning to check that the online analysis works correctly, especially in year 2000 when the first SM will be brought to H4, and in case of major problems. Therefore, we have to foresee all the tools needed to achieve the precalibration as efficiently as possible. **Efficiency** means that all kinds of data (parameters, runs, etc...) must be organised in a way such that access is fast for the online user requests. **Fast** means that the response time for any request is smaller than or of the order of 5 seconds. Obviously offline users should have access to the data in order to do checks and complementary analysis. The software tools allowing access to all data from any standard analysis program (PAW, Fortran codes,...) have to be provided.

The high speed, the large data volume, and the complexity of the data organisation, require that data of all types are structured in a **database**. There are two main classes of data: **parameters** and event data. Parameters are obtained from the **Construction Database** or deduced from the analysis of **special runs**. The event data are themselves of various types; slow control, monitoring, electrons or other particles, special runs. One must have access to all these data types even if the link between them may seem complex.

Some of the points discussed in this document, like data organisation, histogramming, etc..., repesent a lot of work. The precalibration tools have to be tested gradually as soon as 99 and fully developped and debugged during year 2000.

Sections 2 and 3 of this document describe a detailed scenario of the precalibration of the SM. Then in section 4, we discuss the constraints on online software (display tools, data volume, data organisation), required to achieve the precalibration. In order to keep the text as clear as possible, several appendices gather informations about the readout system, sampling ADC signal analysis, the monitoring readout chain, calibration coefficients, histogram description, the precalibration database and a list of essential parameters which must be included in it.

2. Scenario for SuperModule calibration in H4.

In the following we will use the word run for various data taking conditions. There will be Slow Control runs, Test Pulse runs, Monitoring runs, Special runs and Beam particle runs. All these runs are parts of a **SuperModule run**. A SuperModule run is the sum of all the actions performed to validate one SuperModule and calculate the calibration coefficients attached to every channel.

In the past testbeam periods, it has been very useful to check the consistency between the measured signals and their expected values, for Test Pulse, light monitoring or electron runs. This was done only partially; we propose to do that systematically as part of the validation phase. One has to define limits outside which channels will be said anomalous. These limits have to be determined statistically and studied with the first module, then confirmed with the first SuperModule in year 2000.

Until this year, light monitoring, Test Pulse and pedestal events were recorded continuously, 50 events of each type were taken after each beam burst. From a data organisation point of view, it is much preferable for the precalibration to do these runs at regular intervals, keeping however the possibility to trigger them altogether or independently, on request. The goal of the monitoring runs is to check the stability of the whole system; therefore, in the following, a **monitoring run sequence** is the sum of pedestal runs, Test Pulse runs and light monitoring runs (one per colour). Each of these subsequences of runs may include several runs because the FPPA has 4 possible gains. This is discussed in section 3. Nevertheless during the initialization or validation phase, these runs will be performed separatly and several times.

The ultimate goal is to compute calibration coefficients, which are derived from the SADC contents. If we had used a charge ADC, the charge definition would have been simple, either one measures the ADC content for a gate spanning the whole signal in order to measure the total charge, or one uses a narrow gate to measure the signal peak height. The same principles can be used with the SADC. Appendix B explains how the height of the signal, above the pedestal, can be obtained from an optimum set of samples. In the following we will refer to the **SADC peak height** as the result of the SADC reading, although some calculations are needed to obtain it. This peak height is expressed in units of ADC channel extended to 17 bits (via the compression system) but is not necessarily an integer. In order to obtain a relative precision of $\sim 10^{-3}$ for the calibration coefficients, one needs about 400 good events in a small square of 4x4 mm^2 located at the maximum of energy deposition. Taking into account this small area and event selection efficiency (track quality cuts,...) one has to record 5000 events in order to achieve the above precision. Because of the data volume to transfer and the speed of the Data Acquisition system (see section 4), an electron run will take about 3 bursts. Therefore, taking into account a SPS efficiency of about 50 %, we will need 2 days to perform the calibration of a SuperModule at one energy.

Table. 1.

	slow control	pedestal	Test-Pulse	light monitoring	electron beam	comments
T° probes internal & external	X					SADC reading of internal SM probes
HV	X					
LV	X					
dark current	X					read via SADC
scalers + pattern unit					X	
chambers					X	
SADC	X	X	X	X	X	
TDC				X	X	
PN photodiodes		X	X	X		

In order to keep the scenario described hereafter as clear as possible, table 1 lists the **data types** which have to be measured and recorded during data taking depending on the run type, the scenario being a list of actions.

We will have to read:

- Temperature probes (including those external to the SM)
- High Voltage (HV) values
- Low voltage values
- Dark currents
- Scintillator counter pattern units and scalers. Each scintillator channel should have a pattern unit and a scaler. Scalers being reset at the end of each run.
- Drift chamber informations.
- Sampling ADC (SADC) content. Details concerning the APD readout chain are provided in appendix A.
- TDC measuring when triggers occur with respect to the 40 MHz clock of the readout system.
- Light monitoring PN photodiode informations.

Other values have also to be recorded such as the values downloaded to the electronic cards of the submodules, or the table position. These informations are part of the attributes of a run.

Before going onto the scanning table the SuperModules are cooled in garage position in the H4 zone and are supposed to reach a temperature state (in value and uniformity) very close to the one they will have once on the scanning table. Checking that necessitates some Data Acquisition means and all power supplies connected, this is discussed in section 3.2.

We now describe the different steps or actions that we have to go through in order to perform the precalibration. Appendix A provides details about the readout system and may be read before looking at the following scenario.

1. Connect cooling, supplies and fibers.

optical fiber connectors, 34 HV connectors, low voltage connectors, monitoring inputs and outputs.

2. first Slow Control run.

- Check Temperature and gradients.
- Check Low Voltages, High Voltages (HV) and dark currents (I_d)

3. SuperModule position measurement.

Calculate the table position for aiming at a reference Crystal. Reference frames and reference marks exist on the SM outside. The construction database contains the necessary informations to calculate the Crystal positions with respect to these reference marks.

4. Wait for total thermalisation?

If yes, Slow Control runs (SC) must be performed every 15 minutes, if the temperature is close enough to its assymptotic value, we could begin to check and characterise the electronics. This depends on the sensivity of the electronics to temperature. We hope there is no such significant dependance.

5. FPPA gains and calibrations using Test Pulse.

- Measure pedestal positions without any signal (baseline positions), and adjust them if not correct. There are 4 pedestals to be measured, one for each gain of the FPPA.
- Synchronisation of DAQ on Test Pulse (TP). Adjustment of the trigger latency with respect to the generation of the TP.
- Pulse shape analysis.

- Check pedestal positions with Test Pulse (only for gain 32).
- Calibration of the 4 gains: find the correspondence between Sadc peak height and the charge at the preamplifier input in electron charge units. Then compute the relative gains with high precision in order to reconstruct any Sadc signal. Comparison with Database content.
- Noise values for each of the four gains.

6. First light monitoring run.
- Check synchronisation
- Pulse shape analysis (the laser pulse shape is checked with a dedicated device).
- Compute expected APD SADC spectra from PN signals and known parameters.
- Compare with measured spectra.

7. The validation of SM functionalities is finished, wait for complete thermalisation if not yet done.

For steps 2, 5 and 6, actions must be taken in case of problems. This will be addressed in section 3.3 where the run operation is discussed.

8. Start regular Slow Control and Monitoring runs.

Slow control and monitoring runs have to be recorded every hour. See section 3.1.

9. Perform special runs.
- In situ APD gains (only in case of non understood problems).
- Non linearity runs.

10. Preparation of SuperModule scan with electrons.

Once per SuperModule run:
- Move the table to a reference Crystal.
- Check synchronisation

11. Electron data taking.
- Move table to Crystal (I,J). The table is driven by the DAQ and has to be moved between bursts.
- Pulse shape analysis
- Compute expected values from beam energy and known parameters and compare to measurements. This depends on the impact position of the particles.
- Check adjacent Crystals and compute cluster resolution.
- check that the required statistics has been effectively recorded.
- Compute calibration coefficients
- Go to next Crystal.
- Monitoring run sequences will be inserted at regular time interval.

12. Change beam energy and do point 11 again.

3. Run operation.

Each step of the preceding scenario is governed by some parameters whose values are defined by Physics or technical considerations. Conversely, these run parameters may put some constraints on the DAQ characteristics.

As seen in the scenario of section 2, each SuperModule can be calibrated in two weeks if there is no breakdown or anomaly. This rise the questions of what to do in case of problems, what can be done before going on the scanning table, shift crews and experts, documentation.

3.1. Run parameters.

In this section, we distinguish initialisation and normal or standard runs, because the parameters may be different. All parameter values written in this section are default values but one must have the possibility to change these values anytime for one run or set new default values.

3.1.1. Monitoring run sequence: pedestals.

A pedestal run sequence is, by default, the sum of four pedestal runs, one per FPPA gain. At the highest FPPA gain, one ADC channel corresponds to about 12 MeV. Assuming a maximum electronic noise of 10000 electrons and a Crystal light yield of 4 photoelectrons per MeV, 200 pedestal events would give a precision of the order of 0.1 ADC channel for the average of 16 samples.

3.1.2. Monitoring run sequence: Test Pulse.

Test Pulse runs are used to check the stability of the electronic chain response independently of other sources of variations such as APD gain changes with small HV or T fluctuations.

For standard TP run, the DAC is set to give a charge corresponding roughly to 40 GeV, that is below the switching threshold of FPPA. Assuming the same noise as previously, 200 events are enough to obtain a relative precision better than 10^{-3}. At this level the precision of stability studies will be given by the DAC reproducibility.

It is not yet clear if the TP is sent to all channels or to groups of channels like, for instance, the light monitoring system. A priori, this depends on the amount of charge injected. This has to be tested with module 0 and SM1.

3.1.3. Monitoring run sequence: Light Monitoring.

The light monitoring system must provide informations about the stability with a precision of the order of 10^{-3}. This precision is limited by the fluctuations of the optical system due to the use of laser light and by photostatistics. This last term has to be negligible, that is smaller than or of the order of 0.2 10^{-3}. Then one needs about 400 events per run and colour. Taking into account the fact that only one half of a SM is lit at a time, that means a total of 800 events per colour and per SM.

3.1.4. Initialisation runs: pedestals.

3.1.5. Initialisation runs: Test Pulse.

3.1.6. Initialisation runs: Light monitoring.

3.1.7. Electron runs.

The nominal cluster size is 5x5 channels centered on the Crystal which is currently aimed at. For the Crystals bordering the SM, the cluster will be truncated or completed by adding virtual channels.

3.2. What can be done before putting the SuperModules on the scanning table.

Before arriving in the H4 zone, all SM channels have been checked so that they send some informations throughout the optical link when Crystals are illuminated with monitoring fibers. Furthermore, some steps of the precalibration scenario can be performed before a SM is put on the scanning table. Doing steps 2, 5, 6 of the previous scenario in the garage position can validate the functionnality of the SM. Depending on the thermal situation, the last two steps will have to be redone once the SM wil be on the scanning table. One can imagine a small checking system allowing to test subparts of a SM one at a time. This implies connections and deconnections, but also the presence of a specific crew. Another possibility is to connect completly a SM in garage position which presents the advantage to use the complete diagnosis facility being developped for the precalibration. The consequence is that one has to double everything, DAQ, cooling, HV and low voltage supplies, cables and optical fibers.

3.3. What in case of problems. Actions to be taken.

In case of failure inside the SuperModule, experts will decide if a reparation can be made in H4 or if the SuperModule has to be sent back to building 27.

3.4. Control of stored SuperModules.

We should also foresee the possibility to bring back some SM in H4, after their calibration, in order to have a look at ageing, if possible with electron beam, but at least with monitoring runs during winter periods.

3.5. Shift organisation.

Precalibration is at least 6 months a year full time work, therefore it is a **heavy load.** It is necessary to have several well trained teams and experts for the various hardware and software parts.

Assuming 1 week of shifts per month and per person (two persons per shift) and 3 shifts per days, about 50 persons are required for this task.

3.6. Documentation

Documentation includes check lists, run operation description, expert lists, analysis tools manual, etc.....

Somebody must be responsible for this important task.

The user documentation will also be available online. It will be presented as an hypertext package. Access to the information will be given by any browser available.

4. Online software constraints and functionalities.

As said in the introduction, the high frequency of the SuperModule precalibration implies that most of the analysis has to be performed in real time. Therefore, we need a powerful system of histogramation and data analysis. This requirement combined with the high data flow makes data organisation a key point. This section presents requirements for DAQ, analysis tools, and data organisation.

4.1. Data volume.

In the precalibration of a SuperModule, we have to deal with two types of runs : monitoring runs and electrons runs, which represent most of the data volume. According to appendix A, the significant part of the outcoming data from the SADC is composed of 16 bits which represent the sampled charge of the APD. To these 16 significant bits, we have to add some information to recognise offline which channel has been read and to eventually add a data transfer error code. We assume that a word of 32 bits is sufficient to code all these informations.

4.1.1. Electron runs.

In order to compute the amount of data to be read for each event, we have to know the modularity of the readout system. It is foreseen that each channel should be addressable individually by the acquisition system in order to only transfer relevant data. This feature will be present in the DAQ system for module 0 precalibration. Assuming a region of interest of 5x5 Crystals centered on the calibrated Crystal, we can compute the size of an event for the electron run : 25 Xtals x 16 samples x 4 bytes + DCs + scalers + ... = 2kb/event. If we consider electron runs of 5000 events (see section 2), we get 10 Mb of data per run, which gives an amount of data of 17 Gb per SuperModule and per energy, thus giving around 51 Gb of raw data per SuperModule for electron data.

4.1.2. Monitoring runs.

For the monitoring runs, the situation is slightly different : for each event, we have to read out half of a SuperModule (850 channels). This gives an event size of 54 kb. To perform a monitoring run, we have to get pedestal events for each FPPA gain (200x4), TP events (200) and laser events (400) for the 2 halves of a SuperModule. The number of light colours used depends on the available time to perform a monitoring run. For the moment we assume monitoring runs with two colours. The amount of data is thus 194 Mb per monitoring run. Assuming one monitoring run every hour during 2 weeks of data taking foreseen for calibration, we obtain 65 Gb of raw data for the monitoring tasks.

4.2. Acquisition time

Considering the transfer time measurements performed on the present hardware, we can make some estimate of the time needed to make an electron run and a monitoring run. Two hardware configurations have been tested and give similar results :

- Acquisition in 2 stages, SADCs to VME buffer on an event by event basis and then transfer to the main DAQ computer (SUN) during interspill. The first stage can transfer 5Mb/s of data and the second stage can easily follow. This is the absolute maximum rates with 100 % occupancy time.
- Direct acquisition to a VME interface located into the main DAQ computer. The transfer rate is about 16 Mb/s but the DMA protocol has to be initialised at each event. This gives penalty for electron events which require 0.5 ms to be read out, but not for monitoring events which have a biggest amount of data.

For both cases, 2 bursts are necessary to get the required number of electron events (5000). The monitoring runs could be realised in less than 2 minutes with the first scenario and in about 20 seconds with the second one. The advantage of the second scenario is clear for the monitoring runs. We emphasize that these numbers have been measured with existing hardware. Considering the number of bursts needed to get 5000 events, the necessary time to move the table from one Crystal to another, we need 24 hours of continuous beam to calibrate one SuperModule for one energy. For three electron energies with a realistic SPS efficiency, the precalibration of one SuperModule could be performed in one week once everything is working. This, obviously, does not give a lot of time to fight against any arising problem: we have to keep in mind that a SuperModule is considered as precalibrated after validation of calibration coefficients. If inconsistancies are encountered, it could be necessary to make a second pass of the SuperModule in beam after repair. This would not fit in the available two weeks.

For these reasons, further improvements are foreseen, like for instance to keep all events of one burst in the ULR cards and only transfer data to the central computer at the end of the burst, which would remove the over-head time of DMA initialisation, and then reduce the time needed to transfer the data.

With these improvements, we can come up to the ultimate scenario which is to take all events during one burst and moving the table during the inter-burst time, reducing the necessary beam time to precalibrate a SuperModule to two days. We have to try to reach this goal if we want to be able to face possible problems without delaying the calibration of the forthcoming SuperModules, and also to be able to find some room to make multiple passes of some SM all during the time foreseen for precalibration.

4.3. Online Display Tools

The display tools must be adapted to all situations, and be as much flexible as possible in order to be able to understand any problem very quickly. We will have to use different kind of histograms: **individual histograms**, that is sets of histograms per channel (note the plural to histogram, which means several histograms per view for one particular channel), **global histograms**, that is sets of histograms per group of channels, or histograms providing **history** in order to check the evolution of the system with respect to time. We will also need **maps**, for instance Temperature maps of a SM. Each type of run (Slow Control, Monitoring, Electron data taking, Special runs) will use all these types of histograms. We must foresee the possibility to combine all the informations, and have **messages** telling the online shift crew that something is wrong. Some of these messages could be generated by comparison with **reference histograms**.

Because the amount of informations to be checked is enormous, data processing should generate histograms automatically, without special request. A minimal set of histograms which should always be displayed is described in appendix E.

4.3.1. Group of channels

A large fraction of histograms present informations for group of channels in order to have a global view of the functionning. These groups are defined according to the construction criteria, but one should also foresee the possibility to define more general group as well. Here follows an non exhaustive list of group of channels which follow the construction definition. The geometry of these groups must be provided by the data stored in the Data Base.

- **Electronic boards**, there is one board for 5 channels in the z direction, that is 2 boards per submodule.
- **Submodule and their associated temperature probe**. This corresponds to one twin electronic card plus one service card.
- **Module**.
- **Common high voltage supply for APDs (HV groups)**..
- **Common low voltage supplies**.
- **Monitoring fibre-bundles and associated electronics**.
- **ULR crates and cards**.
- **Strips**. A strip is a row of 5 channels in the azymuthal direction
- **Trigger tower**. It is made of 5 adjacents strips and is a square of 5x5 Crystals. The trigger towers do not overlap.

Note that the last two groups are not directly relevant for the precalibration, but should nevertheless be included in the list of groups to let the possibility of complementary studies such as trigger studies. Concerning the ULR crate and cards, there is only one such crate plus cards (besides spare parts) which is always the same for all SM in H4, the ULR channel is not attached physically to the SM channel.

These groups are not completely independent of the others, and one must be able to know very quickly their relations to other groups, using tables or algorythms.

4.3.2. Maps

Maps are necessary to visualise all kind of groupings.

We now give two maps that one certainly wants to display and refresh after each slow control run:

- A view of a SuperModule (from the outgoing side) showing all the measured temperature. A second map with contour would allow to see temperature gradients.
- A SM map showing all the HV groups with the HV values and the associated dark currents.

More generally, it will be necessary to display all the maps corresponding to all the kind of groupings.

4.3.3. Individual histos

Individual histos are sets of histograms plus some informations attached to each channel (I,J). There are histograms specific to monitoring runs, and others to electron runs.

The (I,J) parameters must be provided by the shift person either as a couple of numbers or by clicking on some map. By default the run displayed must be the last one, but one should have the possibility to redefine the run number or even to cumulate several runs. For electron runs, by default the (I,J) parameters are those of the Crystal which is aimed at, but one should keep the possibility to display any channel.

Automatic messages must be generated if the measured values are too different from the expected ones, within some boundaries which have to be defined during the study of the first SM

4.3.4. Global histos

Global histograms summarise informations per group of channels. Default histograms should show, per module, the average of individual pedestal distribution, Test Pulse, laser, and electrons distributions, as well as noise and other spectrum widths. Besides default histograms, one should have the possibility to define any group by clicking on some regions of the maps defined in section 4.3.2. More generally, one should be able to construct global histograms dynamically, by chosing the groups, the quantity to be plotted, and the run numbers using menus. The remarks concerning run numbers for individual histograms apply also here.

Global histograms will also be used to generate warning messages. They must be used to define limits, and channels outside these limits would generate automatically warnings or alarms. These limits have to be kept in memory or could be updated, this implies some history management. One shoud be able to define some region of an histogram, for instance a few bins looking anomalous, and get back channel numbers or/and group identifiers.

4.3.5. History histograms

History histograms are very important to understand the stability of SuperModules by looking at the correlations between signals and temperatures or high voltage variations, etc... The quantities to be compared may come from individual histograms or they may be averaged quantities deduced from global histograms. As for global histograms one has to foresee the possibility to build pictures with the help of menus.

4.3.6. Error messages and warnings.

Because the shift people can not look at every histograms, it is very important that each class of histograms is able to generate warnings and messages. These messages can be issued by comparison with **reference histograms** or directly by comparing the measured to the expected values after having defined meaningful boundaries.

Reference histograms will be obtained after the analysis of the first SuperModule. The histograms belonging to the minimal set will be used to generate these reference histograms, but one should be able to create other reference histograms. Since obviously these histograms will be updated from time to time, this rises the problem of keeping track of their history.

A log file of error messages and warnings should be recorded.

4.4. Data organisation.

The description of the online tools shows how the organisation of data is important for good performances. For this reason, it is necessary to build a Precalibration Data Base (PDB) which contains the important parameters, converted data, calibration coefficients, and some summary of histogramation (see appendix G). Since different algorithms could be used to convert raw data to precalibration coefficients, the results of all the algorythms used must be written into the PDB. The converted data should contain enough informations to allow fast analysis and partial reprocessing, for instance if one wants to implement new calculations of calibration coefficients. The Raw Data are saved and stored elsewhere in a way allowing full reprocessing. This PDB will be used as a source for a more general Calibration Data Base including several detector informations. It has been chosen to use an Object Oriented Data Base Management System (OODBMS). This organisation leads to the following requirements:

- The system will be used by the physicists in charge of the precalibration process. Even if most of them are familiar with computers and softwares, no special knowledge of software engineering has to be required to set up and update the basic configuration of the system and to use it during a measurement phase. First installation and maintenance will be carried out by persons having specific skills.
- Whatever the way raw data are stored, their access should be easy for any physicist using standard analysis tools (PAW, Fortran codes,etc...).
- All the interfaces necessary to access the PDB from standard codes or other means have to be delivered and tested before filling the PDB. The content of the database (text and histograms) can be visualized.
- PDB of the SuperModule under test must be fastly and easily accessible for analysis by several users (at least 10 concurrent users). In order to avoid degradation of the performance, the online system has priority over all other users.

At the begining of the operations for a new SuperModule, the precalibration software populates the PDB with the necessary data found in the Construction Data Base (CDB). A list of parameters is given in appendix G. Some of them are attached to each channel (e.g. APD gain versus HV), others are global parameters (e.g. fibre-bundle number). Some parameters are obtained or updated in the initialisation phase or during special runs. The organisation of the PDB is necessarily different from the one of the CDB:

- PDB must be organized into readout channels since we perform analysis (Calibration, histogramming......) by considering one channel or groups of channels.
- PDB must take into account the concepts of run, event and time.

The concept of run is important, because the PDB must accomodate to various types of runs and their relations to time: electron runs, slow control runs, monitoring runs, special runs (in situ APD gain measurement, non linearity,...).

In case of problems it may be necessary to retrieve data stored in the CDB. These access must be provided to the people doing the analysis.

4.5. Software requirements.

The precalibration software must be fully debugged and operational for 2001. The building of this software needs a huge amount of work and we must protect this large investment against possible evolution of software products (database, graphics) and hardware... In addition we must **reuse** part of it (histogramming tools,...) during LHC operation because a local Data Acquisition System for ECAL will be devoted to control **simultaneously** the 36 SuperModules and the 8 Quadrants.

The software written for precalibration must be **portable, scalable, fast** and **easy to use**.

As said in the previous subsection, an OODBMS has been chosen, as a consequence we have several requirements in order to fulfill scalability, portability and delivery of the code for 2001:

- The design goal of the database interface must be to make it applicable to one SuperModule or one Quadrant as well as 36 SuperModules and 8 Quadrants.
- The developper must make the applications independent from the underlying database system as well as make it possible to port the application programs between platforms and from a database system to another.
- The choice made for the DBMS will stay transparent for the future customers of the precalibration

data.
• A perfect collaboration between old and new software technology must be possible even within the same application. We need a software fully debugged and operational for 2001 but we have to move gradually to object orientation.
• Precalibration of ECAL SM will certainly undergo big evolution during the development phase and in addition, it is intended to **reuse part of the control software at LHC**. Therefore, documentation is crucial for maintenance, portability and further reuse. Softwares must be accompanied by a full documentation.
• In order to maintain the software and to correct easily the errors in case of problems, a simple but efficient diagnostics system will be implemented.
• The software will be installed on the computers devoted to the experiment. Other instance of the software will be installed on other hardware if necessary.

More details will be provided in a forthcoming Software Requirement System document.

It must be stressed that during the testing and set-up period, an efficient collaboration between software experts and physicists will be needed to face unexpected evolution.

5. Online hardware.

How many computers? what computation power? network capacity, disk size, etc..... .

The shift crew must have easy access to all data as we already stressed, and because of the high rate of runs, basic informations must be displayed automatically, that is without operator intervention. Therefore we suggest to have several dedicated screens for:

- maps refreshed after each slow control runs, displaying also histories.
- Test Pulse and monitoring global histograms.
- electron data taking
- construction and display of ‘interactive’ histograms
- general informations. Run status, run number, table position, etc...

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7. Appendix A, readout description

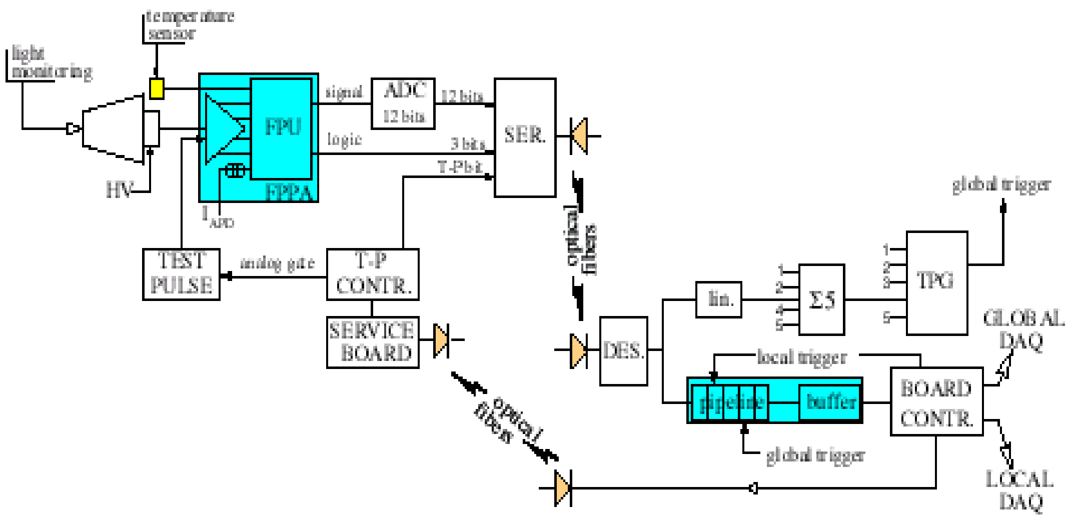
7.1. Introduction

The readout of electromagnetic calorimeter PbWO4 Crystals is composed with :
• a mould piece of plastic (medium to be defined) glued on the rear face of Crystal and named Capsule. Each Capsule contains two 5x5mm^2 avalanche photodiodes (APD) from Hamamatsu. A temperature sensor is added inside one Capsule of each submodule of 10 channels.
• a Floating Point PreAmplifier (FPPA) [2], for amplification, conversion into voltage with a shaping time (peaking time) of 40ns and compression of signal. The aim of this chip is to accomodate the 16 bits dynamic range of expected signals in the 12 bits of the Analog to Digital Converter (ADC). Measurements of temperature and leakage current of APD are performed via the FPPA logic.

- a 12 bits, 40MHz sampling ADC from Analog Device (ref. AD9042),
- a high-speed fiber-optic link : a 20 bits serializer, a light driver and an emitter VCSEL (Vertical Cavity Surface Emitting Laser [4]) and about 80 meters of 62.5µm multimode optical fibers ribbon. To limit the power consumption at about 100mW per channel, bits are serialized at 40MHz with a delay loop and only the transmission is made at 800Mbits/s.

These elements constitute the inner detector part of the readout. In consequence, they have to be designed in radiation hard technologies. The FPPA will be built in DMILL 0.8µ BiCMOS or Harris UHF1x technology and the serializer is a Honeywell CHFET process in AsGa.

Fig. 1. The Readout Chain



In the upper level readout (ULR), bits are firstly deserialized and then splitted in order to :

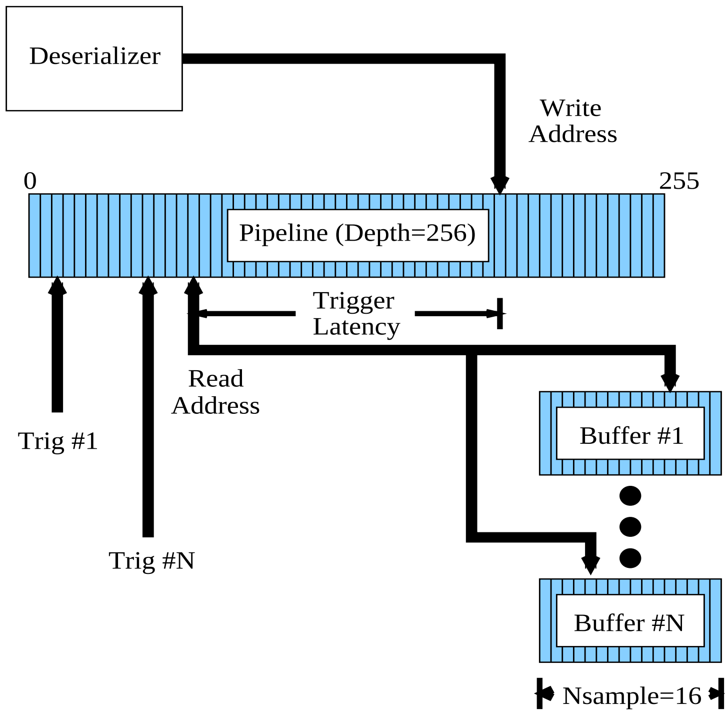
- store data : Data are pipelined and buffered waiting for trigger decision. For selected events, the bunch crossing is identified and data are sent in a local DAQ (of a size of one SuperModule) and the global DAQ.
- built the trigger decision. This part is not relevant for precalibration. After linearization, the channels of a trigger tower are summed and the result is sent in the trigger primitive generator (TPG). The output signal (for example, in the barel channels are summed according to a strip 1x5 in $\eta x\varphi$ and then the five strips signals corresponding to a trigger tower are sent in the trigger primitive generator).

The electromagnetic calorimeter readout chain is schematized on figure 1.

Several parameters of the pipeline-derandomizer chip are programmable. The depth of the pipeline is set to the nominal value of 256 front-end readings. The trigger delay called trigger latency is the number of address registers between the write address of incoming data and the read address for data to be written to a buffer. The value of the trigger latency is programmable, but, as discussed in section 8.1, should adjusted so pulses begin in the 7th time sample of a buffer. The number of time samples stored in a buffer is set to a nominal value of 16. If multiple triggers occur before the buffers are readout, then a new buffer will be filled. The maximum trigger latency to 255*25ns.

The pipeline-derandomizer chip runs synchronously at 40 MHz. This means that the write address and the read address change every 25ns, and as the write address wraps from position 255 to position 0, the memory position in the pipeline is overwritten with new data. Similarly, a trigger begins the writing of data into a buffer from the read address. Data is written to each successive address in the buffer until a total of 16 time samples are written. The next trigger, which is allowed to occur while a buffer is being filled, will cause a new buffer to be loaded. The parameters of the pipeline-derandomizer are shown in figure 2.

Fig. 2. Parameters of the Pipeline-Derandomizer

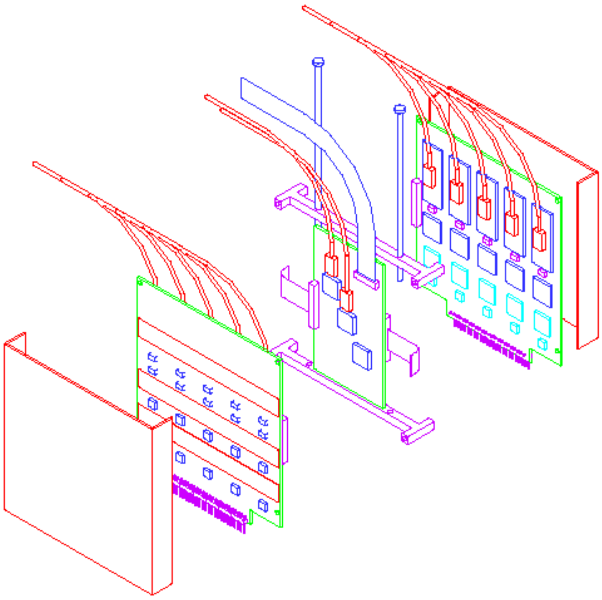


The trigger which extracts the Test Pulse signal from the pipeline is generated locally on the ULR board by the board controller after a programmable delay, initiated by the detection of the TP bit in the SADC data (described in Section 7.2). The ULR board controller runs synchronously with the pipeline and VFE. This

guarantees that the Test Pulse will always arrive in the same position within the event buffer and that a VME initiated Test Pulse request need only to wait for the ULR to have one buffer trigger in waiting before reading out the Test Pulse data. A similar technique is used to generate the local trigger for temperature and leakage current events.

7.2. Very front end readout

Fig. 3. Schematic Drawing of the Electronic Box



At the scale of a submodule (10 read-out-channels), the front-end electronic is grouped in a unique electronic box, constituted of two cards containning 5 electronic chain each (FPPA, ADC and optical link). and one service card. Figure 3 [3] gives a schematic representation of an electronic box.

Two input-fibers are dedicated to the clock transmission and serial download (there are connected to the service card). Ten output-fibers bring the digital signal to the Upper Level Readout.

The 40MHz-clock signal has to be synchronized with the LHC bunch-crossing. It is distributed with appropriate delay to the FPPA, the sampling ADC, the serializer and the board controller (with phase adjustment for each of them).

The signal send via the serial download fiber specifies the readout mode of the FPPA. Two major modes are available :

- *Dynamic mode* : the FPPA logic determine which of the four gains (x1, x4, x8, x32) is the highest below a programmable *threshold*,
- *Force mode* : the FPPA can be forced to read 1 of 6 possible inputs :

1. x32-gain
2. x8-gain
3. x4-gain
4. x1-gain
5. temperature or other
6. leakage current

In definitive, output data consists of a 16-bit representation in the form :

| TP | G3 | G2 | G1 | A12 | A11 | A10 | A9 | A8 | A7 | A6 | A5 | A4 | A3 | A2 | A1 |

where TP is the Test Pulse trigger bit generated by the TP controller, G3 is a data type flag, G1 and G2 is a 2-bit code representing the gain range used (x1, x4, x8 and x32) and A1, A2, ..., A12 is the 12-bit ADC mantissa. 4 bits (not represented here) are used for data transfer error code.

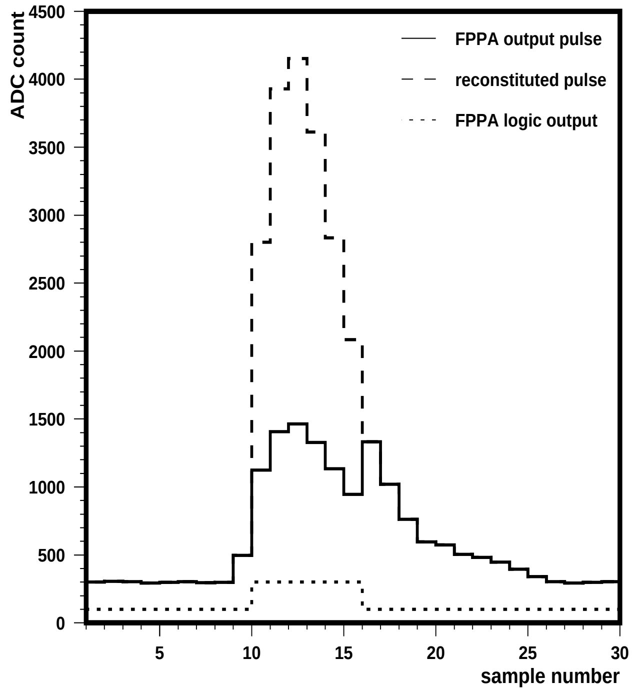
As an exemple :

- G3=0 can be used to read gain (G1+G2) and output data (A1+...+A12)
- G3=1 and G1=1 is used to read leakage current of Capsule with A1 to A12
- G3=1 and G1=0 allow to read temperature from A1 to A12

The last point (temperature measurement) refers only to one readout-channel over a submodule. The other nine readout-channels may be used for other measurements.

For energy reconstruction, we have to reconstitute the original pulse shape from the 12+2-bit word. The figure 4 shows a pulse reconstitution (shaded line) from the 12-bit ADC samples (full line) and the 2 bits representing the used-gain (visualized by the dotted line).

Fig. 4. Pulse reconstitution from FPPA data



7.2.1. Pedestal setting

The nominal level of the pedestal is adjusted by the setting of a single DAC for each channel. The pedestal adjustment occurs at the output of the preamplifier and is, therefore, a common adjustment for all input signals. However, the value of the pedestal will, in general, not be equal for all input signals because of additional offsets.

7.2.2. Threshold setting

The threshold at which gains are switched in dynamic mode readout mode is set with a DAC for each channel. The transition thresholds are approximately 50 GeV, 200 GeV and 400 GeV with a maximum reading of 2 TeV on the lowest gain channel.

7.2.3. Charge injection

There is a DAC setting for groups of 10 channels to set the amplitude of the Test Pulse signal. A trigger command follows the setting of the amplitude. The timing of the Test Pulse trigger command with the ULR board for the pipeline is discussed in Section 8.1.

7.2.4. Synchronization

Testing of digital optical link forces groups of 5 or 10 channels to send synchronization frames. The synchronization frames cause the deserializers to actively search and find the 20-bit word alignment with the serializers, and, therefore, is a method for resynchronizing the link after power loss in the VFE.

7.2.5. Serial Protocol

Consists of 32-bit instruction words. An instruction word is decoded by the VFE once the VFE detects the header. Following the header are the mode, DAC, sync and Test Pulse information. The instruction word format is:

| HEADER | CK | LD | D | ED | M | F0 | F1 | F2 | TCK | TLD | b0 | b1 | b2 | b3 | TED | TH |

Header - Specific pattern to identify the beginning of an instruction word. During data-taking, only zeros are sent over the optical fiber. A possible startup header has leading zeros and ends in 11101.

1. Readout Mode. The bit M tells the FPPA to run in dynamic mode (0) or in force mode (1). The bits F0, F1, F2 set the FPPA to one of the 6 force mode input signals.

2. DAC setting. The bits TCK, TLD, TH are used to slowly clock-in the pedestal and threshold DAC values for all 10 channels in series. Once the values are moved into each of the channel registers, the load line is set to update the settings.

3. Synchronization. The bit ED is used to initiate the fill-frame command from the serializers.

4. Test Pulse. The Test Pulse DAC is loaded with the TCK, TLD, b0, b1, b2, b3 bits. A 12-bit amplitude requires 3 instructions words to be clocked-in. The TED signal provides the trigger command and simultaneouly marks the channel data with the 16th bit of the serializer inputs for each channel.

7.3. Calibration data

7.3.1. Pedestals and pseudo-slow control

Computed from force mode trigger several times per SM run :

1. x32 pedestal and noise
2. x8 pedestal and noise
3. x4 pedestal and noise
4. x1 pedestal and noise

7.3.2. FPPA gains

Computed in force mode with Test Pulse triggers at least once per SM run:

1. x32 gain
2. x8 gain
3. x4 gain
4. x1 gain

7.3.3. Pulse shapes

The format is not yet specified. We can have :

1. electron beams (several energies),

2. light monitoring signals,

3. Test Pulse.

8. Appendix B, Sampling ADC signal analysis

(In this draft, the SADC data is assumed to be taken with a single gain of the FPPA. The multi-gain technique preferably needs benchmarking with testbeam data from proto99.)

The form of the SADC data will be a buffer of 16 time samples for each channel being readout.

8.1. Timing Information

The trigger latency will be adjusted so that pulses begin in the 7th time sample, thereby giving 6 pre-samples and 10 signal samples. A TDC will measure the time difference between the trigger and the next 40MHz clock transition with an LSB ~50ps. This is necessary for both beam and software generated triggers. The latencies of all pulsed signals need to be timed in to within 1ns as measured by the SADC data.

8.2. Pulse Shape Histogram Data

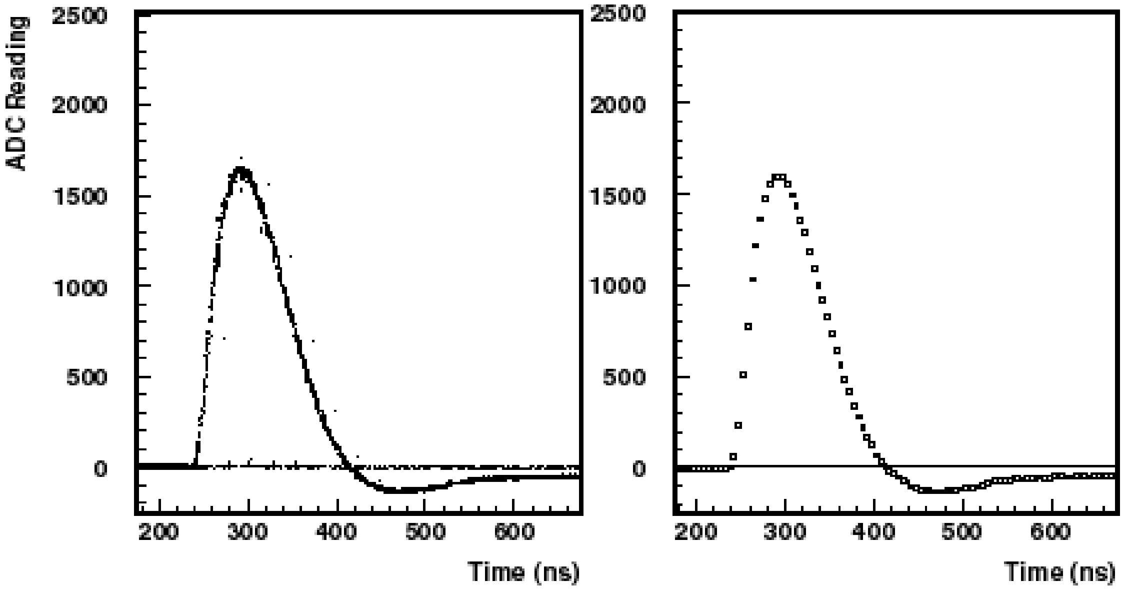
The pulses used for the shape determination should have nearly equal height on top of a stable pedestal baseline. In the case of electrons, low beam-dispersion settings and chamber cuts can be applied. Otherwise, the data can be made suitable for pulse shape analysis by the following two steps.

1. Take the average of the first 5 pre-samples. If the average is within a prescribed range of the nominal value, then subtract this value from all 16 time samples, otherwise, reject the pulse.(The average should be histogramed, and a count of the number of pulses rejected versus accepted can be used to look for channel problems.)

2. Take the average of the first 8 signal samples. If the average is within a prescribed range of the nominal value, then rescale all 16 time samples by the ratio of the nominal average to the average, otherwise, reject the pulse.

The pulses selected for the shape determination are loaded into a histogram storage. A histogram record of the raw pulse shape data is extremely valuable. Distortions and digital problems not seen by a normal analysis are preserved in the histogram record. On the timing index of the histogram, a total of 16x5 entries are used. Each of the 16 time samples account for 25ns of time, and then 5ns steps are kept within each time sample (5 phases). The pulse variation is fast enough to warrant 5ns steps. The ADC index of the histogram is the raw 12-bit ADC reading (or in the case of pedestal subtraction, an offset and nearest integer rounding is used). A histogram with double index (time index, ADC index) is incremented for the time sample data of each pulse. An example of a histogram record is shown in figure 5.

Fig. 5. An example of pulse shape histogram data on the left and shape analysis on the right



8.3. Pulse Shape Analysis

From the pulse shape histogram data, the median position for each timing index is computed. Based on the median position for each timing index, a window size is computed. The windowing technique removes spurious data and improves the accuracy of the pulse shape determination. The window size is the quadrature summation of the baseline noise, the difference between neighboring medians and a term dependent on the distance of the median from the nominal pedestal. The medians are recomputed within these windows and the process is iterated. The final medians are the best estimates for the pulse shape position for each timing index and the spread and number of entries in each window is used to estimate the error on the measurement.

For the purpose of pulse shape comparisons and for interpolation, the pulse shape data is fit with a parameterized curve. For strictly positive-valued pulses, the following signal shape using 4 parameters can be used:

$$A_0\left[1 + \frac{(t - t_m)}{\alpha \cdot \beta}\right]^{\alpha} \times \exp\left[-\left(\frac{t - t_m}{\beta}\right)\right]$$

where t_m is the time at which the signal is maximum. However, for the data taken so far, an undershoot exists in the pulse, and, therefore, a more general parameterization with 7 parameters is required:

with, for t_0 being the beginning of the pulse:

$$x_f = \frac{t - t_0}{\tau}$$

$$A_0\left(x_f + c_2 \cdot [x_f]^2 + c_3 \cdot [x_f]^3\right) \times \exp\left[-x_f + d_2 \cdot [x_f]^2 + d_3 \cdot [x_f]^3\right]$$

Since no curve is perfect (so far), the mean shift of the pulse shape data with respect to the parameterized curve is stored for each timing index. (The shifts are assumed to scale with pulse height.)

8.4. Pulse Shape Weights and SADC Energy Measurements

In order to accurately convert voltage sampling data into a charge measurement, the voltage correlations between time samples must be measured. The inverse of the correlation matrix is used as a weight matrix for an analytic χ^2 minimization for the pedestal and the uncalibrated pulse height. The correlation matrix is measured with the same class of pulses selected for the pulse shape determination.

Conversion of Voltage Samples into a Charge Measurement
Voltage Sample Fluctuations are Correlated

The weight matrix of sample correlation is the following:

$$W = \begin{bmatrix} s_{11} & s_{12} & \dots & \dots & s_{1M} \\ \dots & s_{22} & \dots & \dots & s_{2M} \\ \dots & \dots & \dots & \dots & \dots \\ \dots & \dots & \dots & \dots & \dots \\ \dots & \dots & \dots & \dots & s_{MM} \end{bmatrix}^{-1}$$

with

$$s_{ij} = \left(\frac{1}{N}\right)\sum_{k=1}^{N} [s_i - \bar{s}_i] \times [s_j - \bar{s}_j]$$

The vectors

are respectively the **Measured Time Samples**, the **Unit Pulse Shape** and the **Unit pedestal**. The parameter ϕ is the 40 Mhz Clock Phase. The goodness-of-fit is given by

$$\chi^2 = (\vec{y} - a \cdot \vec{p} - b \cdot \vec{f}(\phi))^T W (\vec{y} - a \cdot \vec{p} - b \cdot \vec{f}(\phi))$$

$$\vec{y} = \begin{bmatrix} y_1 \\ \dots \\ \dots \\ y_M \end{bmatrix} \qquad \vec{f}(\phi) = \begin{bmatrix} f_1(\phi) \\ \dots \\ \dots \\ f_M(\phi) \end{bmatrix} \qquad \vec{p} = \begin{bmatrix} 1 \\ \dots \\ \dots \\ 1 \end{bmatrix}$$

where

$$a = \frac{1}{\Delta}\left(\vec{f}(\phi)^T W \vec{f}(\phi)[\vec{p}^T W] - \vec{p}^T W \vec{f}(\phi)\left[\vec{f}(\phi)^T W\right]\right)\vec{y} \equiv pedestal$$

$$b = \frac{1}{\Delta}\left(\vec{p}^T W \vec{p}\left[\vec{f}(\phi)^T W\right] - \vec{f}(\phi)^T W \vec{p}[\vec{p}^T W]\right)\vec{y} \equiv SADC - peak - height$$

$$\Delta = \vec{f}(\phi)^T W \vec{f}(\phi)[\vec{p}^T W \vec{p}] - \vec{p}^T W \vec{f}(\phi)\left[\vec{f}(\phi)^T W \vec{p}\right]$$

and

$$P = prob(\chi^2, M - 2)$$

The distribution of the probability *P* is flat when the weight matrix *W* is an accurate representation the voltage correlations between time samples. Based on a comparison of charge ADC readings versus computed sampling ADC energies, it was found that a minimum of *M*=8 was needed to achieve the required ECAL energy resolution.

Minimum number of Time Samples
$= 3_{Pre\text{-}samples} + 5_{Signal}$

for the Required ECAL Energy Resolution

The SADC peak height is the closest equivalent to an uncalibrated charge measurement, and, therefore, can be followed by to normal Crystal calibration techniques.

9. Appendix C, the monitoring readout chain.

The basic modularity of the monitoring system is 200 Crystals, that is to say that half a module of type 2, 3, or 4 receives the light of a common fibre-bundle called Level-1. These Level-1 fanouts receive the light from upper level distributors called Level-2. There are two Level-2 fanouts per SuperModule which work one at a time. Each distribution system is monitored by two PN photodiodes.

The readout chain of the PN photodiodes looks like the one of figure 1, except that instead of the FPPA there is a charge preamplifier and a shaper amplifier (in a single radiation hard chip). The preamplifier has two gains. The gain is chosen externally, it has to be set by the DAQ. The PN electronic impulse is much wider than the one of the APDs, the front edge reaching its maximum after 750 ns. Since the same kind of ULR as for the APDs will be used this has two important consequences. First the latency (see appendix A) will not be the same, and a separate synchronisation will have to be done, and secondly, special pedestal runs will be needed because it will be impossible to get the pedestal position and the maximum of the signal in the same sample frame.

10. Appendix D, calibration coefficients

For a given channel, the physically significant data is the charge at the preamplifier input, because this quantity is proportionnal to the deposited energy in the Crystal, the APD response being perfectly linear in the domain of use (2 TeV represents only 4 10^6 photoelectrons). Let S_i be the charge at the preamplifier input and $E_{0\,i}$ the deposited energy in the Crystal number i. The deposited energies are related to the incident particle energy **p** through:

$$\sum_{CrystalsInCluster} E_{0i} = H(p)$$

where H is a function which depends on the finite size of the Crystals, the cluster size, the matter in front of Ecal, the particle energy and type, particle superimpositions, etc...

The charge and the deposited energy are proportional up to a convolution term [5] :

$$S = E_0[CristalTransmissionAndAcceptance \otimes ApdGain \otimes LightYields \otimes EnergyDepositionProfile]$$

and one can introduce calibration coefficients c_i such that:

$$E_{0i} = c_i \cdot S_i$$

Such a definition of calibration coefficients does not involve any hypothesis on the source of the energy clusters (electrons, electrons+photons,...), at least at first order.

It would be quite nice if the coefficients c_i were independent on external parameters such as impact position or particle angle, or particle energy. There are two possibilities in order to fulfil this condition. If the Crystal uniformisation plays completly its role, the convolution term is independent of the profile of the deposited energy, and the c_i are constants. More generally, one can calculate an approximate deposited energy by evaluating the above convolution term [5] and then define calibration coefficients with respect to this approximate deposited energy, the calibration coefficients being close to 1.

The difficulty is to determine the charges S_i from the Sadc informations. This is explained in Appendix B. Figure 5 represents a signal at the FPPA output,before it enters the Sadc. If the electronic chain is linear, the height of the peak (the maximum) and the integral of the signal are proportionnal to the input charge S_i . If the electronic chain is not quite linear, we have to know the relationship between the input charge and the height or integral of the output signal.

Note that the shape of the signal at the FPPA output depends on the shape of the input charge distribution with respect to time, and that the exact relationship could be slightly different for Test Pulse, laser signals, and scintillation light. This is not a problem if the shape of S(t) does not change with time, but this is not guaranteed in case of laser or Test Pulse problems.

The role of the Sadc analysis is to provide a value of the height of the signal or an equivalent charge (a charge equivalent to the charge one would measure with a charge ADC). This charge will be expressed in electron charge units at the preamplifier input.

The absolute value of the coefficients c_i defined above depends on an estimation of the deposited energy in the Crystal number i, therefore it depends on some Monte Carlo simulation. The relative values of the c_i can be determined with high precision and do not depend on simulation. These relative values are what we call **intercalibration coefficients**.

At LHC the SM will be inside the magnetic field, therefore the absolute values of the calibration coefficients will be changed. However the intercalibration coefficients should remain the same. This last statement assumes that between precalibration and LHC, when SM are stored, the ageing is uniform. If intercalibration coefficients are constant the reference[5] explains how the absolute value of the calibration coefficients can be obtained with physical events. Ageing must be studied by putting some SM back un H4 for measurements with monitoring but preferably with beam.

11. Appendix E. Description of minimum online histograms.

The histograms described in this section **are not** only examples. They are part of the minimal set of histograms that should be automatically displayed. Obviously, in these pictures some details like labels, comments, etc... are just examples; what is important is the underlying idea and not the presentation details.

11.1. Individual histograms.

11.1.1. Monitoring runs

Figure 6 shows a picture displaying 6 histograms for one (I,J) channels and some informations.

The histograms show pedestal, Test Pulse, and laser distributions. It is also important to display systematically the APD response versus the PN photodiode response, and the ratio APD signal/PN signal vs PN signal. The pedestal histogram should show both pedestal distributions obtained from pedestal runs and pedestal distributions obtained from presamples. The information content of the view has two parts. One with relevant measured values: noise, calibration values, average of laser distributions. The other containing expected values: noise, expected laser signal computed from the channel parameters, and from the PN photodiodes informations. The information part must also tell if the run was performed at fixed FPPA gain or normal mode. It is also important to visualise pulse shapes for TP or light monitoring runs, for the various gain conditions.

11.1.2. Electrons runs

The electron run individual histograms are the same as those we used to see in H4 testBeam. Figure 7 represents the ADC contents (SADC peak height value) of the 3x3 submatrix centered on the Crystal under calibration. Figure 8 shows the sum of the ADC value of these 9 channels. One must foresee histograms showing pedestal distributions obtained from presamples and informations concerning the FPPA functionning such as frequency of gain changes or gain used, etc... this has yet to be defined. Pulse shape pictures are necessary, both before and after FPPA gain corrections.

11.2. Global histograms.

Figure 9 shows an exemple taken from proto97 june 98 analysis. These four histograms represent the mean value of the green laser distributions obtained during monitoring runs. There is one entry per channel and each histogram correspond to different groups of channels.

Similar set of histograms must exist for pedestal, Test Pulse and electron runs. Some information block must tell the FPPA gain condition in the case of monitoring runs. One should be able to superimpose easily reference histograms to the one under study.

11.3. History Histograms.

History histograms are very important to check the stability of the whole system. Figure 10 shows the evo-

Fig. 6. Individuals Histograms

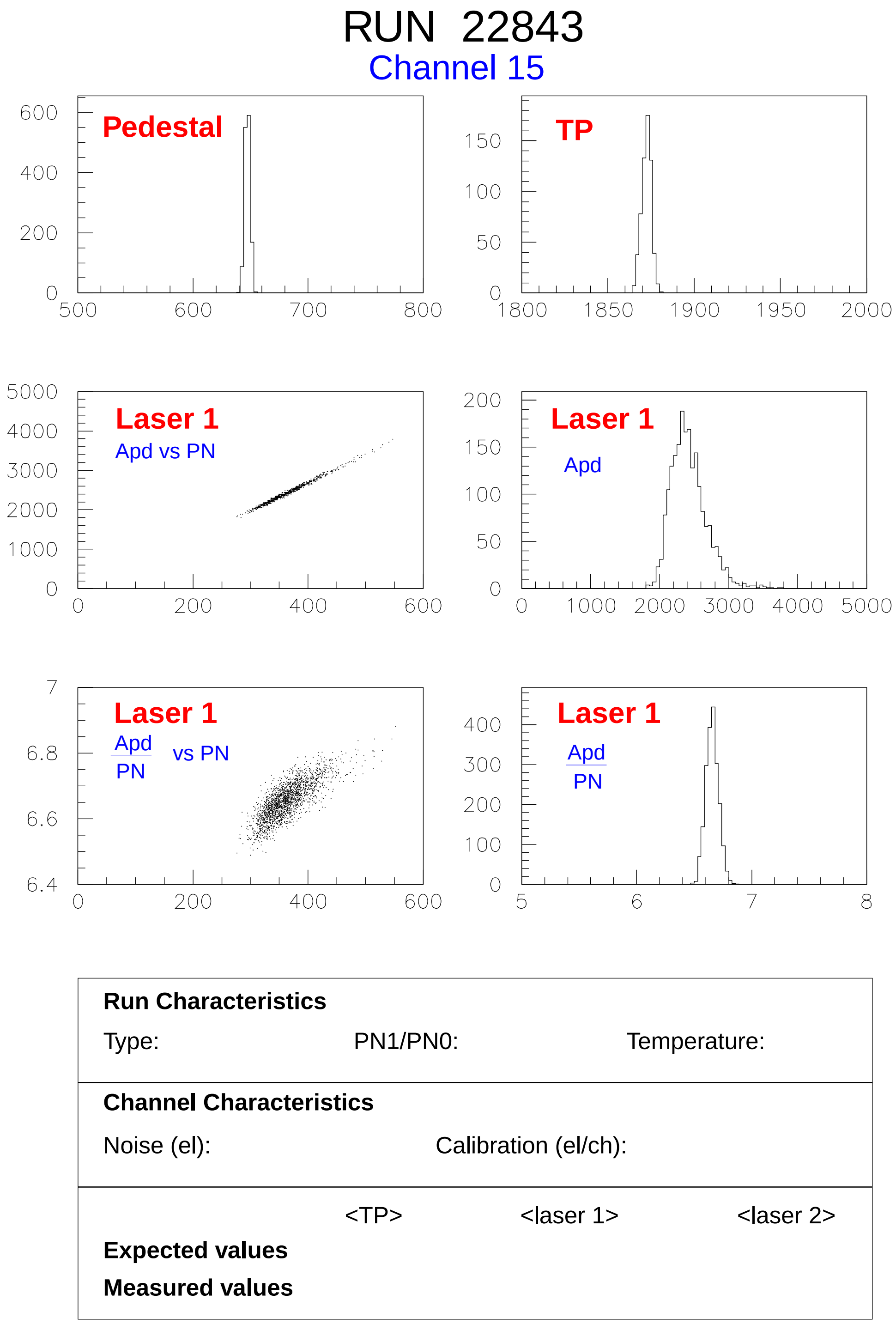
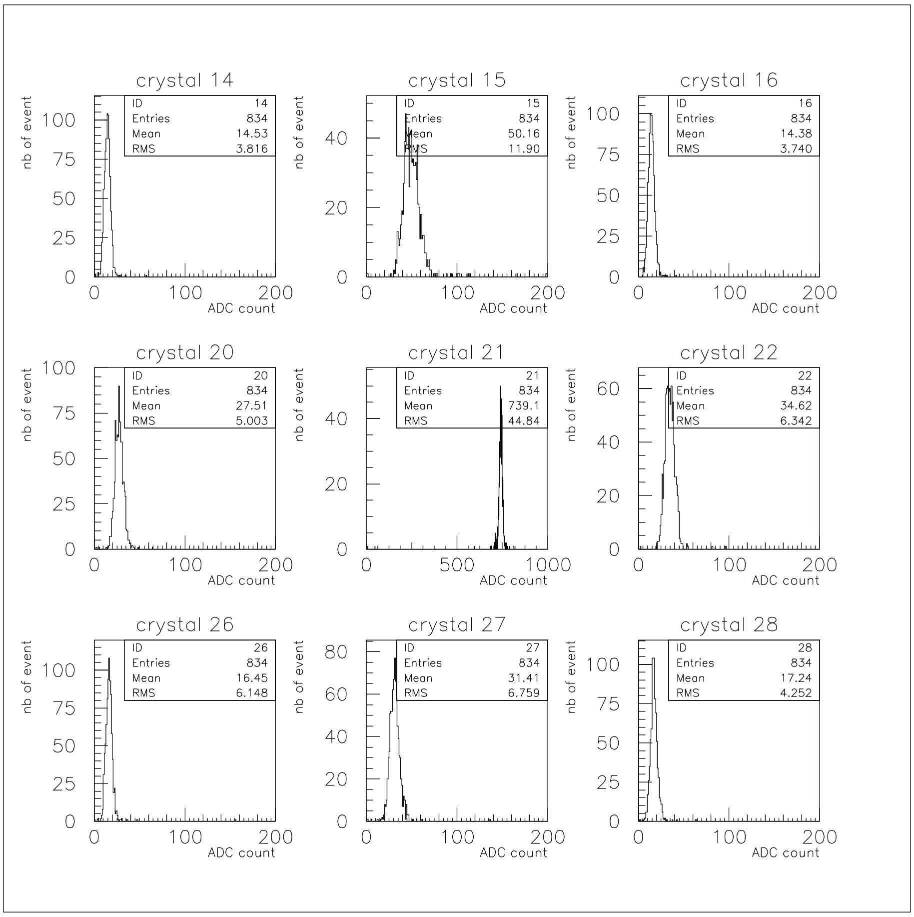


Fig. 7. Electron Run



lution with respect to time of the ratio of the APD signal over the PN photodiode one for three different channels, compared with temperature. This figure is only one example, and one must have a lot of flexibility to define these picture dynamically as stressed in section 4.1.5. For instance one may want to see the time evolution of the noise for different groups of channels, almost all the quantities discussed in the previous sections are interesting to consider from a history point of view. Some pulse shape parameters or χ^2 must also be plotted versus time.

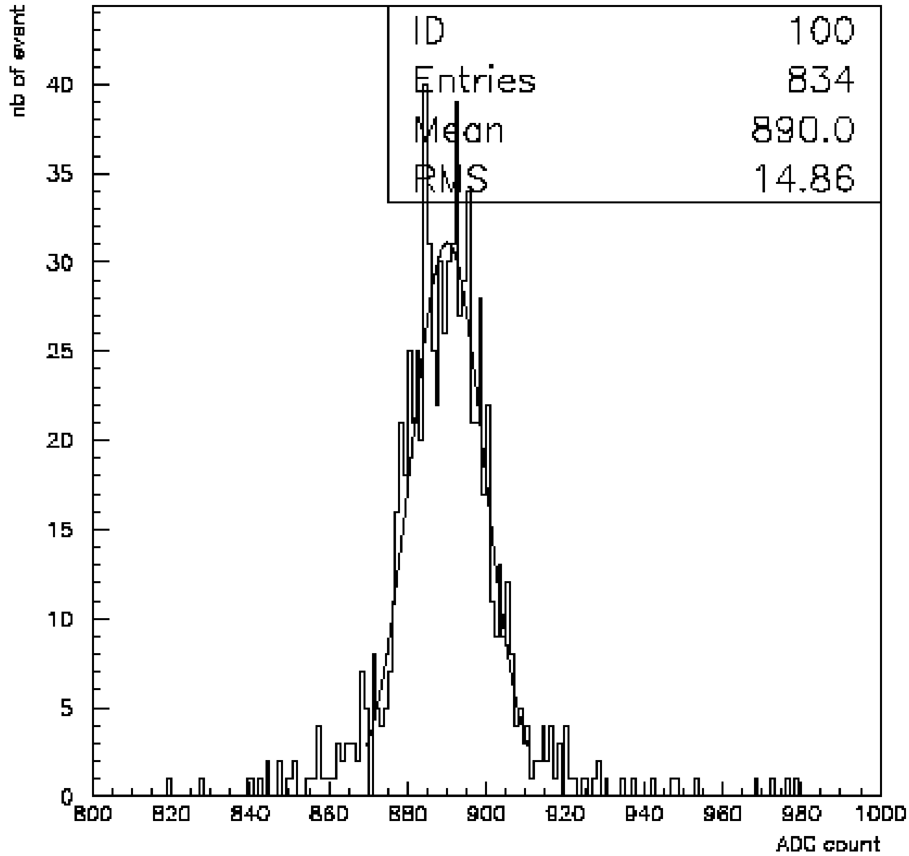
12. Appendix F: the Precalibration Data Base.

12.1. The H4 Precalibration Database

During 1999 an ECAL Barrel module (referred to as module0 of type 2) will be built to validate the construction and assembly procedures of Crystals, Capsules, sub-units etc. This module will be exposed to the H4 testbeam early in 2000 for precalibration tests. Soon after the first production SuperModule will be constructed using the knowledge accumulated from building module0 and it will also require precalibration. These H4 tests will need access to the ECAL construction database (described in [6] and [7]) to extract characteristics for each Crystal, Capsule, electronics unit etc.

Following assembly of CMS it is essential for calibration programs to have access to detector characteristics, stored in the ECAL construction database, in order to calculate calibration coefficients on a readout

Fig. 8. Electron Run



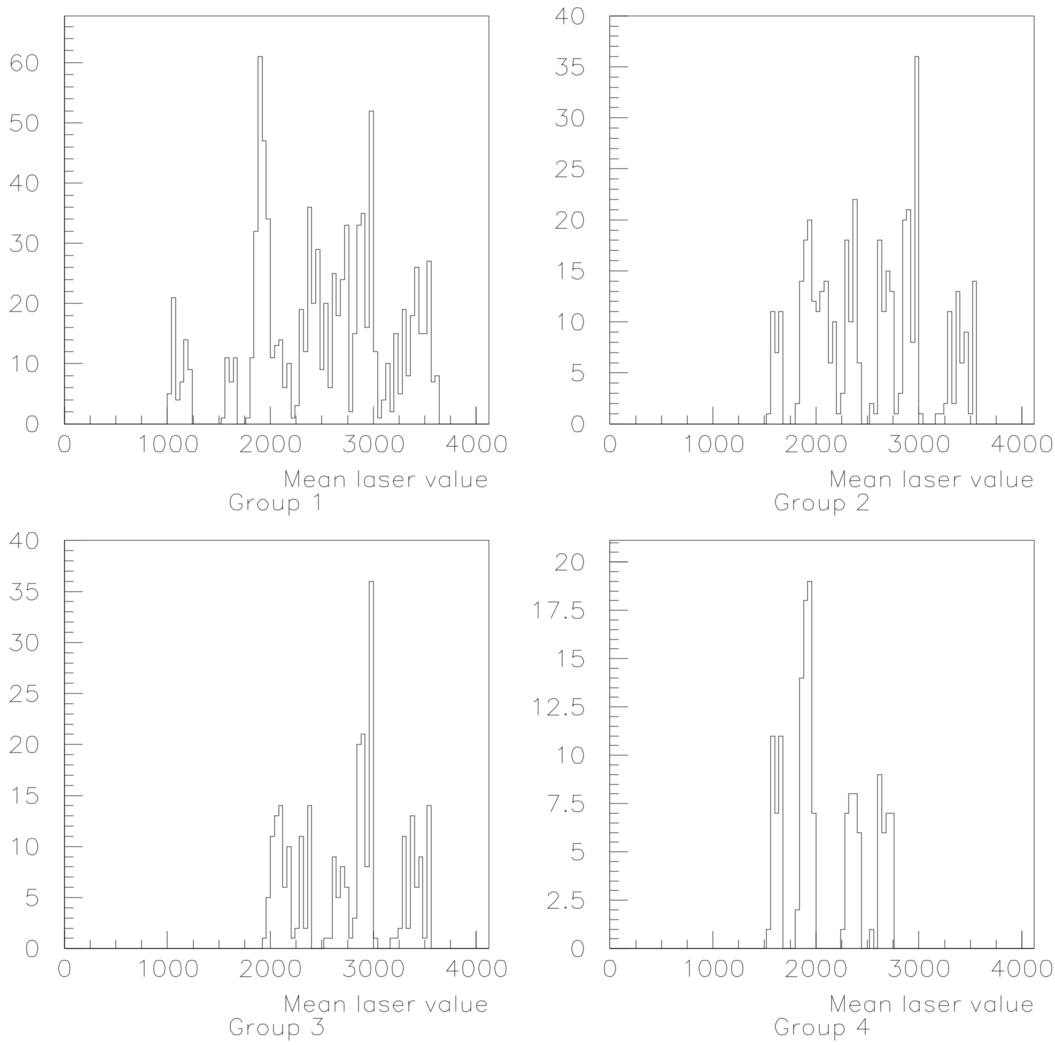
channel-by-channel basis. The information required by the ECAL Barrel for calibration includes data for Crystals, Capsules, SuperModules and electronics. All of this information will be captured in the construction database as the detector is constructed step-wise from individual Crystals to sub-units, modules and SuperModules.

The physics data collected during the assembly phase must be presented to calibration physicists in a manner that facilitates population of the precalibration database. However, the step-wise construction procedure leads to a data organisation which is necessarily different from that required for calibration: the structure of the construction database follows the assembly ordering of the calorimeter, while the structure of the calibration database must follow the ECAL readout structure, where the unit of detector that is normally considered is the readout channel. Calibration constants need to be determined for each readout channel (e.g. a Crystal plus its Capsule, electronics (ADC etc.) and optical fibres) so that ADC counts can be translated into energy deposited in a single readout channel. In essence, the calibration system must be able to *extract* subsets of physics characteristics from the construction database for the calibration of particular physics elements (or sets of detector components) even if these elements are specified in a manner which is different to that in which structures are defined in the ECAL construction database. For example in the Upper Level Readout of ECAL Barrel, so-called Trigger Towers are defined as units of 5 readout strips (each of 5 Crystals) – this 5 by 5 representation exists nowhere in the construction database.

To build a complete picture of the conditions under which calibration data is taken, information from test beam slow controls, data acquisition and monitoring is added to the physics data extracted from the construction database and, on completion of the calibration runs, these data are copied back into secure central storage. The central storage then accumulates this pre-calibration data for each SuperModule and acts as the source of calibration data for all 36 final SuperModules. The static calibration constants for the complete ECAL are finally extracted from the central storage into a final calibration database.

Physicists will need to associate specific events recorded in the testbeam to their appropriate structures (and potentially their associated characteristics) extracted from the construction database. For example,

Fig. 9. Global Histograms



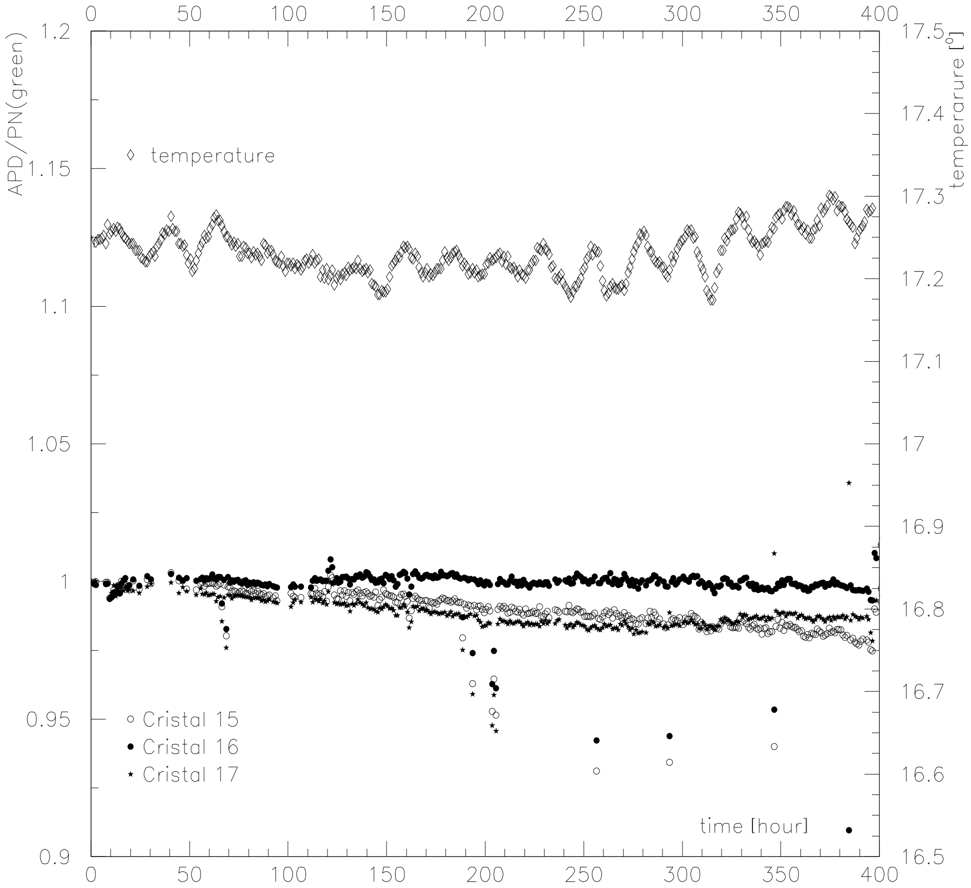
temperature monitoring events will need to be associated with the detector elements defined for monitoring. These detector elements will thereby constitute the temperature monitoring *viewpoint* and will be defined in terms of a set of detector components (as in figure 11). Similarly, high voltage events must be associated with slow control elements (the slow control viewpoint) and the extraction of physics characteristics from the construction database is then carried out at a level appropriate for slow control. One member of the high voltage map (or one detector element for high voltage) will control a physical area of the ECAL Barrel detector.

For the ULR, the viewpoint needed must reflect the structure of the trigger readout where individual readout channels are grouped into strips (of 5 Crystals), trigger towers (of 5 strips), ULR boards (of 4 trigger towers) and ULR crates (of 17 boards). Each viewpoint is extracted for a specific purpose (e.g for beam events, for slow control events) and are necessarily different in structure since they are associated with detector elements defined at different levels in the detector (for further detail on viewpoints consult reference [8]).

12.2. Data Types Required for Precalibration

For the calibration of module0, an electron beam of measured energies will be incident on a 2-dimensional

Fig. 10. History Histograms



array of 400 Crystals (+ Capsules + electronics) and beam data will be collected. Two data types will need to be stored: **parameters** and **data**. Parameters for each readout channel include references to construction data for its Crystal, APD, electronics and Upper Level Readout (ULR), its channel number, relevant run numbers etc. Global parameters such as fibre-bundle numbers also require recording. Data (in the form of **events**) are collected for electron beam **runs** (differing beam energy, table positions etc.), for slow control runs (differing temperatures, high voltages etc.), for monitoring runs (response to standard laser pulse heights), for ADC pedestal measurement run, for runs in which events come from multiple sources and for other, non-standard, runs. A run is the recording of a set of events of various types over a specific period of time and events are collections of data read from a subset of the calibration readout channels. This accumulated data is used together with the physics characteristics extracted from the construction database to calculate calibration coefficients for the readout channels.

The precalibration database is used to hold data derived from multiple event types:

1 Beam events (electrons, pions)

2 Laser events (generated by differently coloured laser pulses)

3 Test Pulse events

4 Pedestal events (4 types off)

5 CapsuleTemperature events

6 LeakCurrent events

7 ChamberEvents (Beam position from Chamber)

8 TriggerEvents (TDC data)v) Viewpoint Definitions and Physics Element Definition

9 HV events

10 LowVoltage events

11 CoolingCircuitTemperature events

12 TableEvents (Table position at time t)

For each kind of events the database must be able to handle the following data types:

i) Run Information:

- Run Type definitions (Beam runs, Monitoring runs, Laser runs, Test Pulse runs, Temperature runs, HV runs, LeakageCurrent runs, Pedestal runs) and individual instances of runs

ii) Parameters:

- Individual channel parameters e.g Crystals, Capsules, channel number, no of runs, run nos
- Global partameters e.g fibre-bundle number, PN photodiode number etc.
- Other non-specific parameters

iii) Data:

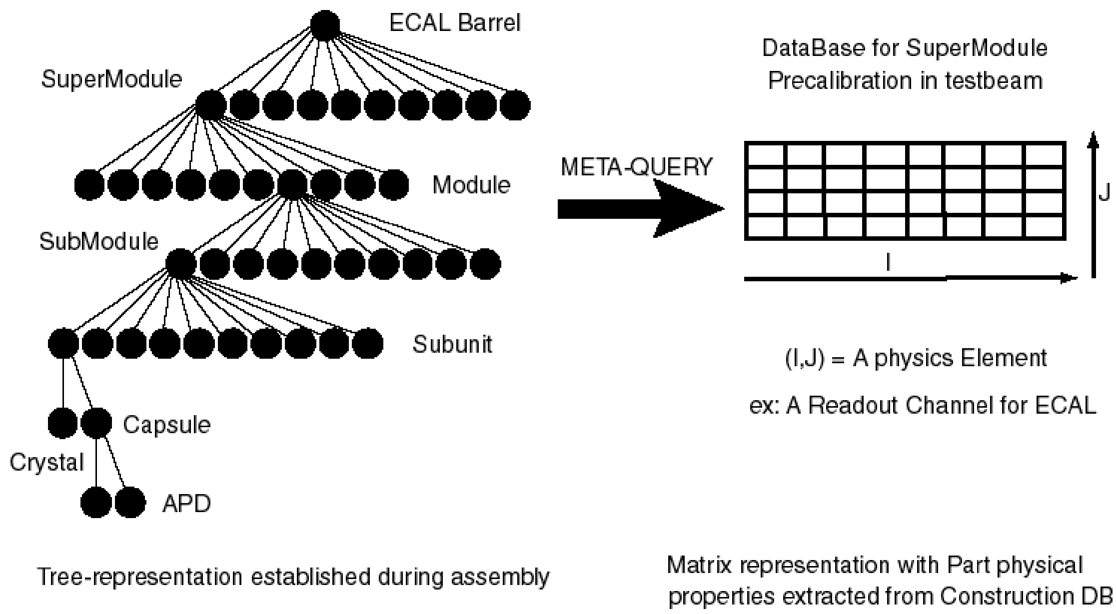
- Standard beam data e.g converted data, Theta, Phi, table positions, beam energy
- Slow Control data e.g Temperature, High Voltage, Low voltage etc.
- Monitoring data e.g. blue/green laser data
- Pedestal & FPPA gains
- Other non-standard information e.g non-linearities, APD gain fluctuations

iv) Histograms

- For validation purposes histograms must be stored so that measured data (so-called ‘photos’) can be compared to a saved nominal set of histograms.

v) Viewpoint Definitions and Physics Element Definition

Fig. 11. Deriving the calibration viewpoint (matrix of ‘physics elements’) from the Construction database



13. Appendix G: List of parameters contained in the precalibration database and converted data.

13.1. Parameter list.

The parameters needed in the precalibration database are listed hereafter. This list does not suggest any data organisation, it is presented according to the physical components of channels.

The parameters will be used to perform validation and consistency checks. Measured values of pedestal positions, calibration values with Test Pulse have to be consistent with what is measured with the Lyon machine designed to characterise the electronic cards. For light monitoring runs, the signals obtained for each channel can be evaluated from the signals delivered by the monitoring PN photodiodes and the above parameters [5], and compared to the measurements.

13.1.1. general informations about the channel.

- Crystal geometry description
- geometrical position in SM
- where to find more informations in the CDB

13.1.2. Parameters related to Crystals

- Attenuation length versus wavelength
- Light yields

13.1.3. Parameters related to Capsules (and a similar list for VPTs).

- Gain versus high voltage
- 1/M (dM/dT) at gain M=50 and 40 (obtained from subsample measurements)
- Nominal bias at gain M=50 and 40
- Temperature during the measurements
- An approximate value of the Excess Noise Factor at gain M=50 (from subsamples)
- Quantum efficiency of APDs (1 value per APD at 420 nm).

13.1.4. Parameters related to the monitoring

- Quantum efficiency of the PN photodiodes versus wavelength (for 3 wavelengths)
- Values of the preamlplifier injection capacitances
- linearity (to be defined)
- initial calibration (number of electrons per ADC channel)

13.1.5. Parameters related to electronics

- Level of pedestals of the 4 outputs
- Noise evaluated in electrons (one per each FPPA gain)
- Values of the electronic charge injection capacitance
- Relative gains of the 4 outputs
- Linearity , to be defined
- initial calibration in electrons per ADC channel.
- pulse shape informations (to be defined)

13.1.6. Parameters related to the temperature probes

To be defined

13.1.7. Geometrical structure of groups.

13.2. Converted Data.

13.2.1. Electron runs.

For each event the converted data must contain:

- track parameters
- trigger TDC value
- 10 SADC samples (as at LHC) x 25 Crystals. Samples are gain corrected, truncated to 16 bits and packed to form a 32-bit-word.
- peak height value and pedestal position obtained from SADC analysis. As many times as there are algorythms.
- data quality word.

Scaler contents are written in an end-of-run block.

13.2.2. Monitoring runs.

For each event:

SADC peak height values and pedestal positions for APD and PN photodiodes.

14. Glossary

- **Channel** A channel is one Crystal + Capsule (twin APDs) + associated electronics (preamplifier, multislope, Sampling ADC (SADC), serializer) + optical link + corresponding electronic channel in the Upper Level Readout (ULR).A SuperModule (SM) is made of 1700 channels Each channel has some coordinates in a SM, which can be defined as coordinates with respect to some predefined frame attached to the mechanical structure, or by its position numbers (I,J) respectively in the z and phi directions.
- **Event** An event is the set of data from the relevant detectors (beam chambers and counters, ecal readout channels, TDC, laser informations, etc...) corresponding to a particular trigger. There are Test Pulse events, Monitoring events, Beam particle events.
- **F.P.P.A.** (Floating Point PreAmplifier) It is one single chip containing the four output-gain preamplifier with shaping time and the digital logic to determine which of the four voltage samples is the largest (corresponding to the highest gain) below a certain threshold. There are two outputs from the FPPA, the selected analogic signal to be digitized and a 3-bit word from digital logic.
- **Group** A group is a set of channels which may correspond to some construction criteria (for instance to a monitoring fibre-bundle or an ULR card), or more generally, which may be defined by the users in order to do global analysis, or comparisons between differeent sets of channels. A list of groups is given in section III.1.
- **Intercalibration coefficients** relative values of the calibration coefficients inside a group of channels (see Appendix D).
- **Module** A module or basket is made of 400 or 500 channels. There are 4 modules per SM.
- **Monitoring run**. A monitoring run is the sum of pedestal runs, Test Pulse runs, and light monitoring runs.
- **Parameters** are data which characterize the components of the channels or group of channels. Component characteristics are for instance the attenuation length versus wavelength or APD gain vs HV. Group parameters describe the relations or the hierarchy between groups or between groups and channels. Some of the parameters are obtained from the Construction Data Base; others are obtained or simply updated by doing special runs in the initialisation phase (pedestal position,etc...). See appendix G.
- **Pulse shape**. see 8.2.
- **SADC peak height**. see section 8.4.
- **Scanning table**. The scanning table has been designed so that each Crystal can be precisely positionned on the beam line, respecting the same tilt of the Crystal with respect to the particles as at LHC. Its movements are driven directly from the Data Acquisition System.
- **Submodule** This is the basic mechanical element. It consists of 2x5 alveolas plus one twin electronic cards. For the endcap a submodule correspond to a SuperCrystal.
- **SuperModule run** A SuperModule run is the sum of all the actions performed to validate one SuperModule and calculate the calibration coefficients attached to every channel.

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