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The Hadron Calorimeter Prototype Design and Construction

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ABSTRACT

This paper describes the design concept of the LHCb Hadron Calorimeter Prototype and it's construction experience. In total 6 modules with different internal structure have been assembled and tested on the X7 SPS beam-line during last three years.

Various optics components, PMT's and digitizing electronics have been tested with the HCAL prototype.

A calibration system with radiactive source and pulsing LED have been checked and accepted for further implementation.

Several computer controlled sub-systems were developed to make the beam-test measurements precise and reliable.

The constructed prototype showed a good performance and lead to the final design of the LHCb HCAL detector.

1 Introduction

This Note describes three year experience in construction of the HCAL Prototype. Several modification have been made in design during 1997-99, keeping unchanged the general concept. The calorimeter physical properties have been outlined in [1, 2]. The required energy resolution is quite moderate of $0.8/\sqrt{E}$. The detector has to be fast enough to mesure the particles energy at 40 MHz bunch crossing rate and provide the data for a hadron trigger.

The final design of the HCAL is substantially influenced by the chosen technology to simplify the mass production of the huge detector. Several approaches have been developed in the past for various detector construction. The hadron calorimeter design very often has the sampling iron-scintillating structure. A large progress have been made last decade with development of a casting technique for the scintillating tile production both for shashlyk-type ECAL and tile HCAL. This technology is productive and provides cheap and good quality scintillators for use in the calorimetry. Large scale hadron detector with very similar technology is currently under construction for ATLAS detector [3].

The aim of the HCAL Prototype design was to check the iron plate assembly technology, compare different tile and fiber components, measure with a test beam an intrinsic properties of the calorimeter, like the response uniformity, the signal time properties, the shower lateral dimensions. This study helps to make a decision on the final design of the full scale detector.

2 HCAL design overview

The base idea in design the hadron calorimeter was to satisfy the LHCb experiment requirements and to keep it's construction as simple as possible. As an active media the scintillating tiles have been chosen. Those are produced by a casting technology that is sufficiently productive and cost effective. There are two main possibilities to arrange steel plates in the calorimeter: the transversal to shower development direction and along it. We choose the second one as it is simply realised from mechanical point of view and requires less space for the light collection. The LHCb HCAL detector has to have a lateral dimension of $8.5 \times 7\mathrm{m}^2$ and the weigh around 500 tonn.

There are several advantages in the selected concept: the calorimeter iron parts are thin enough to be manufactured by a productive punching technology. The scintillating tiles can be produced by a casting technology. The light is collected by WLS fibers running along steel plates to the calorimeter end that requires much less space than other solutions. The design is rigid and easily can be divided on to separate modules. The aim of the protote construction is to test and simplify the assembly, to investigate the calorimeter properties at the different energies and angles, e.g. the uniformity of the responce as well as to develop the calibration procedure and to measure the light collection efficiency.

The drawing of the submodule, the basic element of prototype is shown in Fig. 1. It consist of 6 mm thick master plates of $1530 \times 159\mathrm{mm}^2$ with 4 mm thick spacer plates

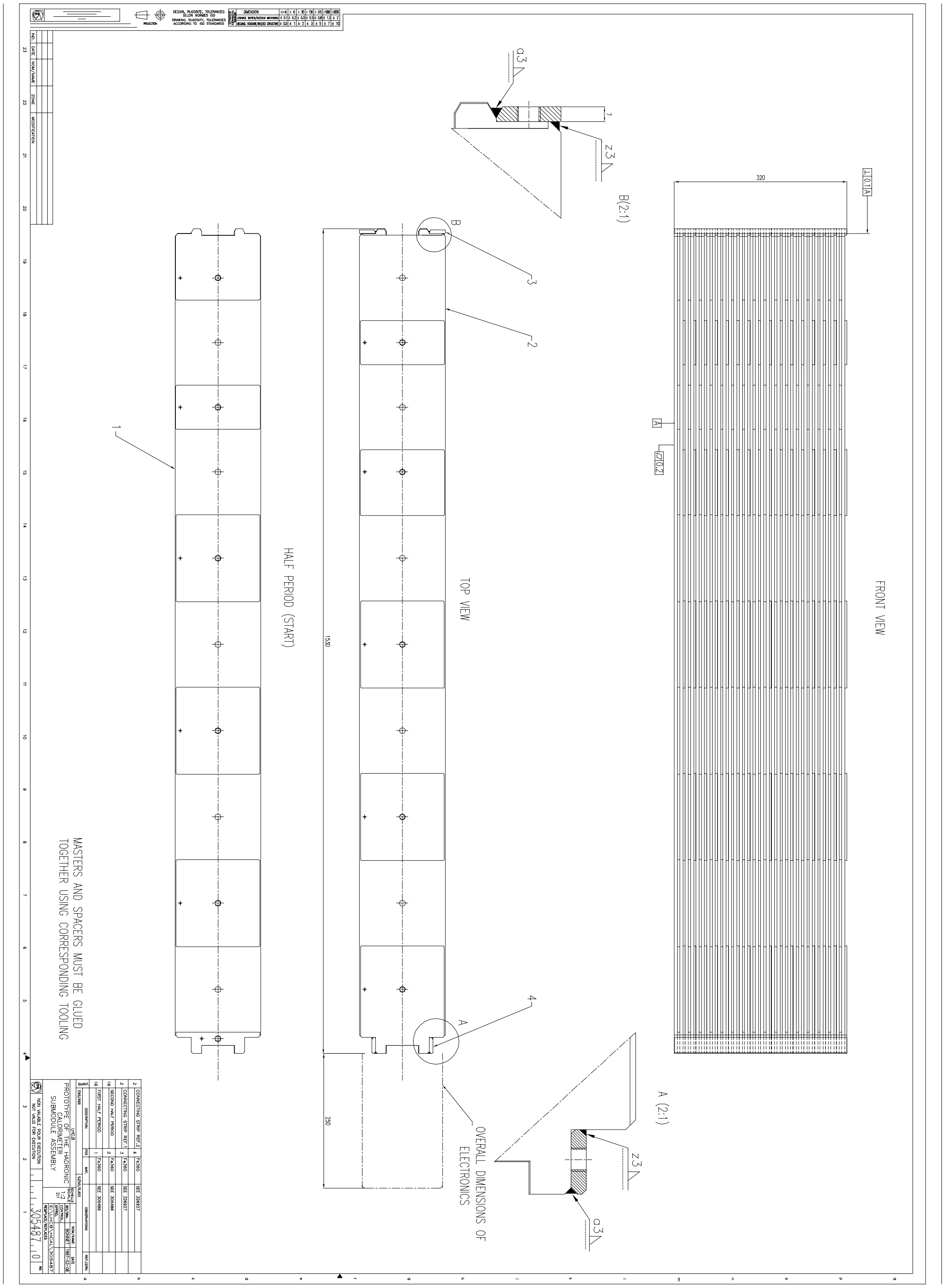

Figure 1: The HCAL submodule assembly drawing. Spacer layout on the master plate is shown separately.

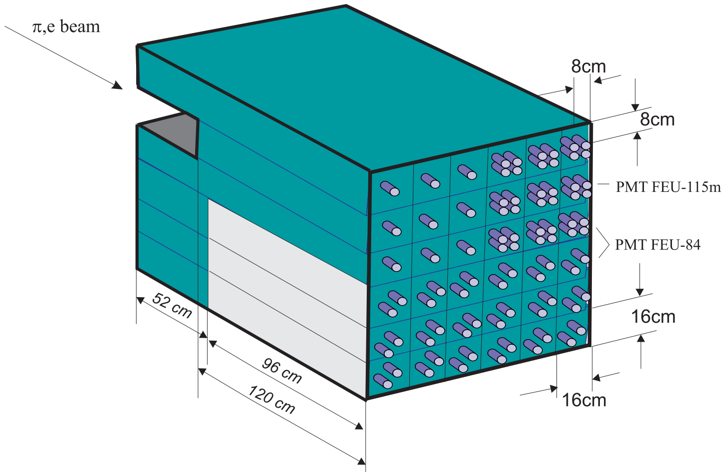

Figure 2: The HCAL Prototype general view. Three bottom modules have two segment in depth. Three top modules have single segmentation in depth, instead have a four times smaller cell size. A different PMT types were used for light detection.

between them. The typical spacer dimension was $162 \times 156.5\text{mm}^2$. The gaps in the iron are filled by a scintillating tiles. The volume ratio of the iron to scintillator was $\mathbf{Fe} : \mathbf{Sci} = \mathbf{5.35} : \mathbf{1}$. This ratio is slightly larger than used for ATLAS TileCal design (4.18:1) but is adequate to the resolution requirements of the LHCb and allows to have a shorter calorimeter with the same thickness, measured in an absorption length. To study the HCAL performance on it's thickness, the prototype modules of $7.3\,\lambda_{int}$ and $5.6\,\lambda_{int}$ have been assembled. The beam test results that compare properties for both types of modules are given in [4].

The constructed HCAL Prototype is incorporating a several different type of the structure. Along with mentioned shorter module the inner optics have been organised in a different way as follows:

- first three modules have two segmentation in depth ($2.4\lambda_I$ as a first partition and $4.9\lambda_I$ in the rest) with the separate PMT read-out;
- upper three modules have single partition in depth, but one half of those modules has cell size of $16 \times 16\text{cm}^2$ and the second half has smaller cell size of $8 \times 8\text{cm}^2$;

It is worth to mention that the iron structure is identical for small cells and for big cells. The scintillating tile for smaller cells have been cut in the middle and separated by a Tyvek to exclude the light mixing.

The general view of the HCAL Prototype is shown in Fig. 2.

Figure 3: The submodule assembly tool. Stack of glued plates are being pressed by thick cover.

3 Iron plate assembly

Iron plates, masters and spacers, have been produced in a different countries (Great Britain, Romania and Ukraine). Submodule assembly was done at CERN workshop with a slightly modified assembling tool, available there. The iron for this prototype was produced with an ordinary mill machine. No attempt has been taken to construct a punching die because the cell size and the HCAL depth have been chosen after the beam-tests with a prototype [5].

The sub-module assembly chain started with cleaning of the plates. They were washed in white-spirit vessel and dried. After that and just before glueing they were degreased by the cloth wet in an acetone. The Araldite 2011 two-component glue was used that has of the order of 10 hours hardening time in the ambient environment. Glue was applied manually by a pistole type mixing tool. A 32 layer of master plates and spacers have been stacked in assembly tool between two vertical keys that define the alignment between layers. The spacers position on the master plate has been fixed by a set of iron pins and elastic rings, inserted in the holes.

The stack of iron plates have been stressed by a thick flat steel cover between the height-defining gauge bars (see Fig. 3) and left pressed during the night. The submodule assembly was completed after welding of four steel bars at the each corner of pre-pressed submodule.

Three submodules joint together with two welded steel beam have the weight of 1.2

tonn and dimensions of $96 \times 16 \times 153 \mathrm{cm}^3$. The last check have been performed to remove the blob of glue from the gaps in the iron for further tile insertion.

In total 18 submodules have been assembled without considerable problem. People from different institutes that participate in assembly got an experience in this procedure within several days.

4 Optics preparation and assembly

4.1 Scintillating tiles

Scintillating tiles have been produced in Vladimir, Russia using the modern casting technique. The base component of plastic was the granulated polystyrene PSM-115. It was recognized as having the best transparency [3]. The dopants were 1.5% paraterphenyl (PTP) and 0.03% POPOP.

Dopants have been mixed with polystyrene granules (8-10 kg per batch) in the rotating barrel for several hours to get an uniform paint powder spread in the volume.

For tile production the casting machine KuASY 170/55D-ASPW have been used with thermostabiliezed molding tool. Melted polystyrene-dopant mixture has been injected in the mold. The cycle for an optical surface quality tile production lasts less than two minute. Aftar the tile pass the visual quality check and have been wrapped in a Tyvek envelope. The production rate was about $300 \div 400$ tiles per day. All batch of 4000 tiles have been produced in a two week.

Later on three tiles from each batch (of 80-90 tiles) have been checked for the uniformity of response using a beta-source scan through the tile surface. The schematics of that system is described in [6]. The typical tile responce measured in this test is shown in Fig. 4.

It represents the PMT current dependence on the beta-source position between two fibers, collecting the light from the both side of the tile. The uniformity within ±5% in response is clearly seen.

During the production precess several tiles didn't pass the visual quality check, mainly at the beginning and at the end of batch.

4.2 Fibers

In the prototype we use a Pol.Hi.Tech.(S250) single clad wave-length shifting fibers of 1 mm in diameter with a polished and aluminized mirror at one end. Several fibers have been measured for an attenuation length, that was found to be $\lambda_{att} = 2.8 \div 3.5\,\mathrm{m}$ at a distances to the PMT exceeding 35 cm.

The decay time of this type of fiber are found to be $\sim 7\,\mathrm{ns}$, almost the same as for Kuraray Y-11 [8].

Recently, the faster fiber of type Bicron BCF-92 (single clad, $\tau_d \sim 3\,\mathrm{ns}$) have been instrumented and tested on the beam. The results are presented in [4, 8]. During the preparation of this type of fiber we used the aluminization facility, available in the IHEP

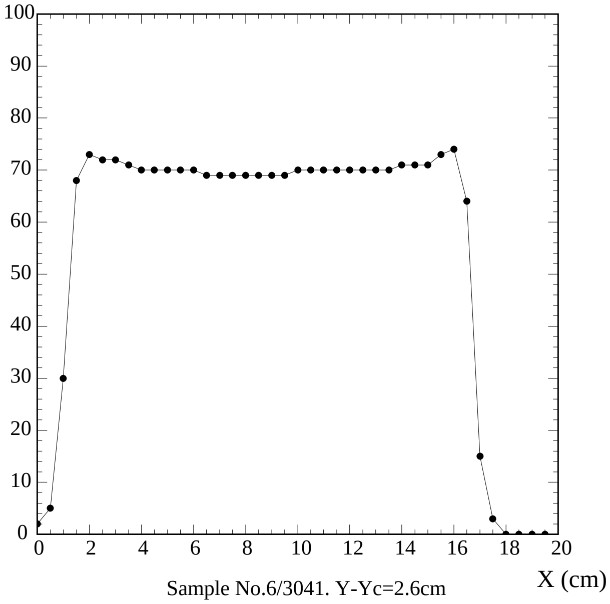

Figure 4: The typical tile response to a β-source scanned between two readout fibers.

workshop to apply the reflecting mirror at the fiber end. In average the reflecting factor of 85 % have been achieved.

4.3 Optics assembly

Wrapped tiles and fibers have been transported to the CERN workshop for incersion into the iron module. A part of the tiles (720) have been cut on two equal pieces by a specially designed 4-teeth, 100 mm diameter, 0.5 mm thick mill. In principle those pieces can be produced by a casting. Later on during tha mass production we are going to design the modified mold, able to produce both types of the tile with the same tooling. For our small amount of tiles the cut took several days. No special treatment have been applied to the surface after cut. Each half was wrapped in a Tyvek envelope to separate them.

The tiles were inserted in the iron slits and the fibers were fed under the Tyvek in the tile envelope.The tile and the fiber insertion procedure needed some training and have been rather quickly possessed.

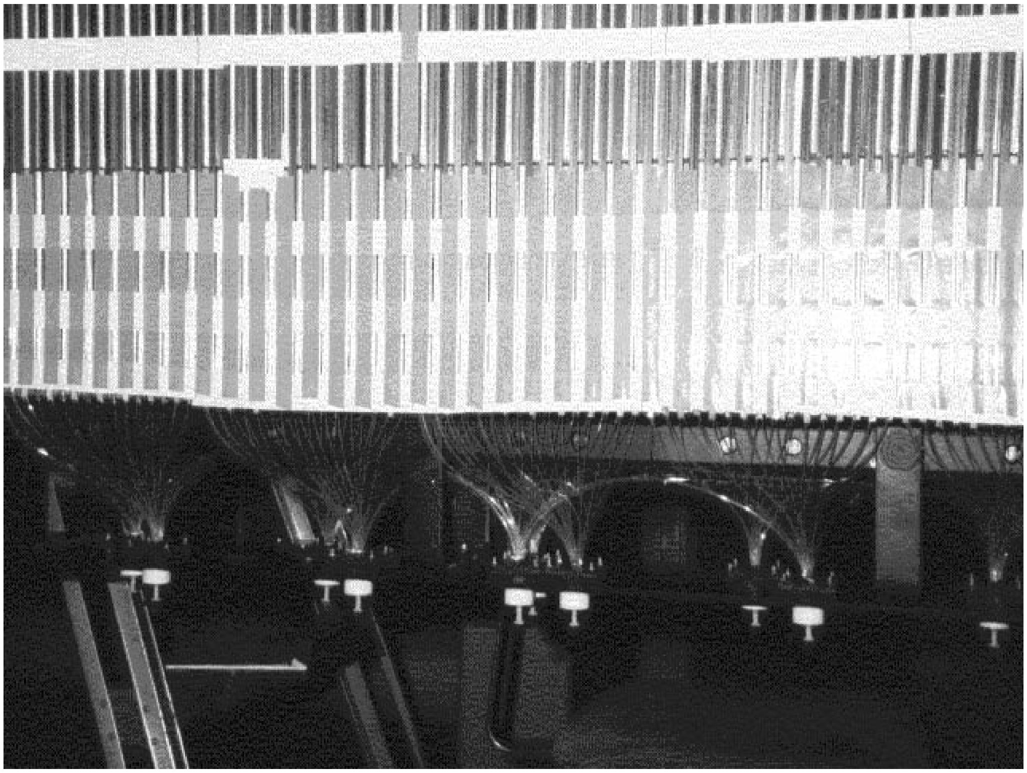

Figure 5: The module outlook after optics assembly. White cup's on the bottom contain glued fiber end's.

Fibers were grouped into the bundles according to the cell structure and have been glued together. For that a removable teflon cup was attached to the bundle and filled with a glue as shown in Fig. 5. This procedure was needed to obtain a good quality for the fiber surface after being cut and polished. For the prototype this procedure was done manually, but for the mass production a handy milling tool is currently under development.

A bundle include both the signal fibers and two additional fibers used to deliver a LED light-pulse to each PMT. A fast blue LED with computer controlled LED-driver used to monitor a short term stability of the PMT gain.

The most time-consuming item in optics assembly is fiber insertion. In average one fiber have been installed in $5 \div 8$ min by the experienced person. The assembly of the module with ~ 200 fibers have been completed within one working day by a group of $3 \div 4$ person.

At the last stage of the assembly, the fibers and tiles have been covered with a transparent maylar foil and with a rigid black paper for a light protection.

5 Photomultipliers and electronics

Two type of russian photomultipliers were used in the HCAL Prototype beam-tests: FEU-84-3 and FEU-115M.

The first type is rather cheap and widely used in the calorimetry at the moderate particle rates (up to 1 MHz). A typical signal responce to the short light pulse for this PMT is about 40 ns FWHM.

The second PMT type has a shorter responce time ($\sim$ 7 ns FWHM) and designed for the improved linearity [9] up to 50 mA in the pulse with 2 % tolerance. All studies of a signal shape have been performed with this photomultiplier.

The standard CAMAC based 11-bit LeCroy 2249W charge integrating ADC's were connected through a 50 m coaxial cable to the detector with a typical gate of 120 ns.

All PMT's reside in a common black-box attached to the module. The leucite light mixer was inserted between PMT window and the fiber bundle to randomize the possible photo-cathode non-uniformity. It was 1cm^2 and 42 mm long.

All PMT's passed quality check in advance. The photocathode sensitivity and gain at the same high voltage have been recorded. Then the high voltage was adjusted at the test bench to get an equal response to the same light pulse. This allow to distribute the PMT's in the several groupes with with an almost equal properties. In total 150 PMT FEU-84-3 and 15 FEU-115M have been checked.

A set of compact resistive 0.5 mA dividers have been developed and assembled in the IHEP electronics workshop.

6 Radiactive source calibration

The reliable and stable calibration methode has been developed and tested withf HCAL Prototype. It's aim is to monitor the detector properties like ageing in plastic and fibers, give an absolute reference for the cell calibration.

We use the radioactive ^{137}Cs gamma-source that has 30 year half-decay time, could be made compact and intensive enough. Under the R&D program three ^{137}Cs sources encapsulated in the stainless steel pipe were obtained with activity of 5, 8 and 10 mCi. In the current Prototype the first of them was in use and others are left for use in the LHCb detector.

The HCAL calibration system incorporates the following parts:

- continuous 8 mm diameter stainless steel pipe that is fed through the middle of all scintillating tiles and filled with a distilled water;
- a computer controlled hydraulic pump and valves that create a reversible water flow in the pipe and therefore move the capsule with a radioactive source throughout the detector;
- an automated garage with a 5 cm thick lead wall, to safekeep the source between calibration run;

- integrating on-detector electronics to measure the PMT current when the source is moved from cell to cell across the HCAL.

A schematic view of the system is shown in Fig. 6.

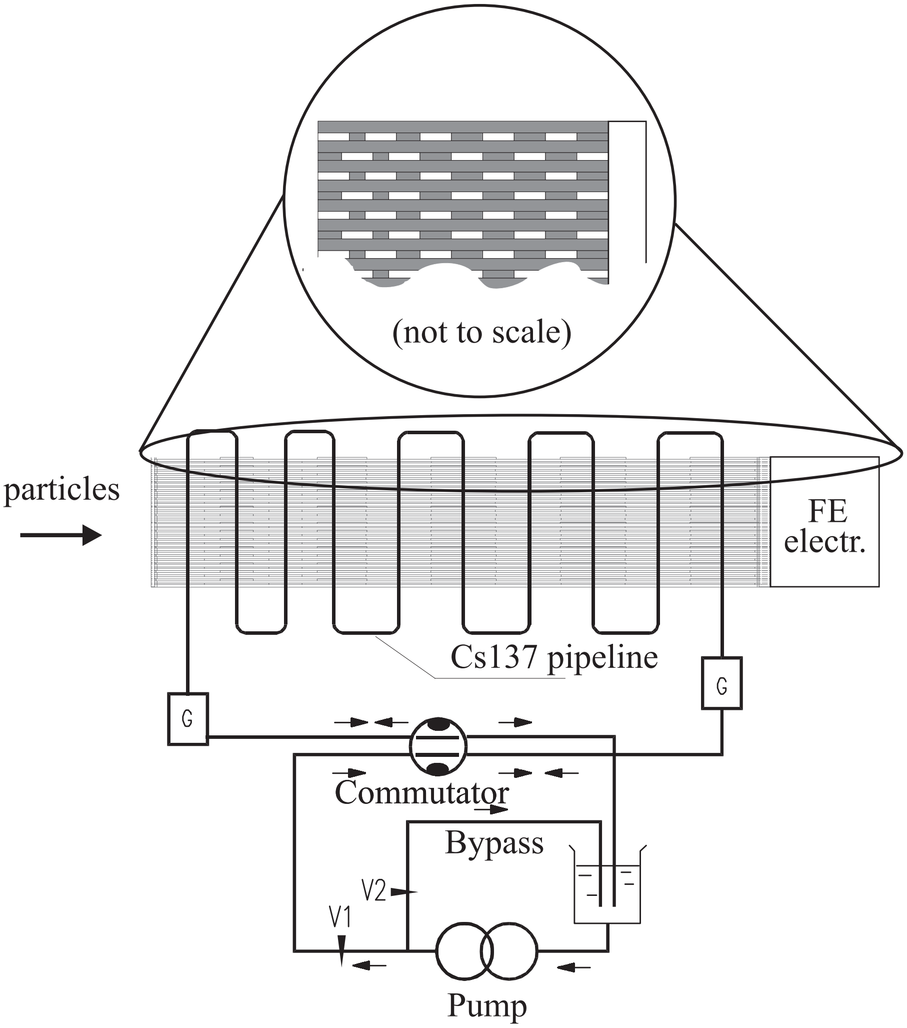

Figure 6: The schematics of the radioactive source calibration system.

7 Test-beam environment

7.1 Computer driven platform

Beam tests with the HCAL Prototype has been done at the X7 beam-line of the West Area experimental hall at CERN. To exploit a variaty of the Prototype internal structure, it was moved by a 15 tonn capacity platform, that has a lateral and an up-down displacement range of 2 m. A rotating table on the platform allows to turn the detector on up to 180_0 around the vertical axis . The control electronics have been designed to move the platform with a personal computer. The friendly software interface allows to visualize the calorimeter position with respect to beam spot and set the detector position with precision of better than 1 mm. This automatics was used for both the ECAL and the Preshower detectors during their beam tests.

7.2 High voltage power supply system

The second development concern to the computer controlled High Voltage distribution system, specially designed for the HCAL prototype. The aim was to allow individual setting of the HV on each PMT for the gain adjustment with a minimal amount of cables. Only three HV cables were used for 45 PMT's. The system consists of three parts:

- the control box which includes the low voltage power supply, the RS232 interface to a PC and three modules of the high voltage power supply: two with $V_{max} = 2000\,\mathrm{V}$, $I_{max} = 10\,\mathrm{mA}$ and one with $V_{max} = 2500\,\mathrm{V}$, $I_{max} = 20\,\mathrm{mA}$;
- two types of the multichannel HV distributors with an individual voltage setting within 512 V range;
- a software package to control all settings and refresh them periodically.

The HV system show the stable and reliable performance. This system have been used for the most of data collected during the beam-tests with HCAL Prototype.

7.3 Data Acquisition System

The data acquisition system used for the beam-test is based on the CASCADE package developed at CERN. It consists of two-processor data readout system. The low-level processor and interface modules reside in the VME crate and the front-end electronics in two CAMAC crates. The high-level processor controls the data recording and user interface. We use the LeCroy-2249A/W ADC modules for all calorimeter detectors, e.g. for Preshower, ECAL and HCAL. Later on one VME crate with 40 MHz front-end electronics board [7] have been incorporated in the common readout system. This feature allow to perform a direct comparison of the digitized data on the event-by-event basis.

In total more than 10K runs with different data types have been recorded in thee years.

8 Summary

In summary several HCAL configurations have been tested under current R& D study. The assembly technology has been checked and accepted as a simple and reliable.

Two types of the HCAL modules with a different depth have been constructed. Their comparison in the beam-tests bacame an important step in the HCAL detector cell size and length optimization.

The different optics assembly scheme have been used with the same internal iron structure, that makes the final design flexible and easy. Two HCAL modules have been re-assembled with new faster fibers and irradiated components in a several days that gives an experience for the future.

Two types of the PMT have been checked that allows to establish the essential PMT parameters for the final choise.

The radiactive source and LED calibration procedures have been well defined and checked. The PC controlled hydraulic system have been tested and accepted for further impplementation.

A new HV distribution scheme was realized and tested on the HCAL Prototype. The next design that satisfy the LHC requirements is in progress.

The flexible DAQ system have been developed that incorporates a different electronics type read-out. The hardware and software developments in the beam-test experimental environment allowed to increase the efficiency of the beam time usage.

The design of the full scale detector have been started and is currently in progress.

References

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