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The Compact Muon Solenoid (CMS) Hadron Calorimeter

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Abstract

The Hadron Calorimeter of the CMS detector for the CERN LHC accelerator is designed to measure hadron jets as well as single hadrons. It has six segments. The central barrel made of brass and scintillators covers the $|\eta|$ range of about 0 to 1.3. Two End Caps, also made of brass and scintillators extends the $|\eta|$ range to 3.0. Two Forward calorimeters made of iron and quartz fibers cover the range 3.0 to 5.0. Since the barrel portion of the calorimeter is only 6.5 interaction lengths, the outer barrel will sample, by scintillators, outside the magnet coil and cryostat. Progress has been made on all subsystems and prototypes have been built. We now have a better understanding of magnetic field effects on calorimeters.

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THE COMPACT MUON SOLENOID (CMS) HADRON CALORIMETER

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The Hadron Calorimeter of the CMS detector for the CERN LHC accelerator is designed to measure hadron jets as well as single hadrons. It has six segments. The central barrel made of brass and scintillators covers the $|\eta|$ range of about 0 to 1.3. Two End Caps, also made of brass and scintillators extends the $|\eta|$ range to 3.0. Two Forward calorimeters made of iron and quartz fibers cover the range 3.0 to 5.0. Since the barrel portion of the calorimeter is only 6.5 interaction lengths, the outer barrel will sample, by scintillators, outside the magnet coil and cryostat. Progress has been made on all subsystems and prototypes have been built. We now have a better understanding of magnetic field effects on calorimeters.

1. INTRODUCTION

The Hadron Calorimeter (HCAL) barrel and end caps are inside the magnetic solenoidal coil and cryostat that will produce a field of 4 tesla. The barrel rests inside the cryostat. The forward portion of the calorimeter is far away (over 10 meters) from the interaction point where the magnetic field is low, but the radiation levels are very high. This calorimeter has been designed to minimize the dead regions in order to improve the missing energy determination. The engineering design is complete and work is progressing at the detail design level of the active components.

The Central Barrel (HB) consisting of 36 wedges of about 30 tons each. The HB is 9 meters long and between 2 and 3 meters in diameter. The η - ϕ segmentation is 0.087×0.087 . There are 16 scintillator megatile layers where the tiles are arranged in a tower structure pointing to the interaction center. The barrel portion is attached to the cryostat on two horizontal rails. Figure 1 shows a 20° wedge segment with the electromagnetic calorimeter (ECAL) attached. The HB is the responsibility of the US CMS collaboration.

The End Caps (HE) are attached to the muon end caps and have about 10 interaction lengths. It is about 1.8 meter thick, with an inner radius of 40 cm and an outer radius of about 3 meters. The η - ϕ

Figure 1. A 20 degree hadron and electromagnetic calorimeter barrel wedge.

segmentation matches the central barrel, except near the $\eta = 3$ region, where the segment size is 0.17×0.17 . There are 19 layers of scintillator megatiles. Radiation damage is non-negligible near $\eta = 3$, so the tower structure is sampled more often longitudinally to be able to correct for the loss of light yield due to radiation damage. The HE mechanics is the responsibility of the CMS Russian groups, while the readout is a US responsibility.

The Forward Calorimeter (HF) made of iron and quartz fibers, is in a very high radiation area and will use quartz fibers as the active media. Quartz is much more radiation hard than plastic and is insensitive to the radioactivity that will be induced in the iron

absorber. This venture includes many groups from Europe and the US.

The Outer Calorimeter (HO-B) is one layer (two layers near $\eta = 0$) of scintillators outside the superconducting magnetic coil and cryostat to sample the energy leakage from the barrel calorimeter. HO-B is needed as the HB plus electromagnetic calorimeter (ECAL) is only about 6.5 interaction lengths. The HO-B is the responsibility of the Indian groups.

HB, HE and HO-B are inside the magnetic field and will use hybrid (HPD) photodetectors to measure the light yield. The HPD is a single stage photodetector with a high voltage of about 10kV. When the electric axis is aligned with the magnetic field, the HPD will operate without degradation, even in 4 tesla field. The HF will use conventional photomultiplier tubes.

The tower structure of the calorimeter modules are created optically in optical decoder boxes that will be mounted on the edge of the calorimeter modules. The optical decoder box has inputs for laser and LED signals for calibration and monitoring. The HPD's and the ADC electronics are also mounted in the decoder boxes. The HPD's/PMT's and Optical Decoder Boxes, including electronics are the responsibility of US CMS for all of the HCAL subsystems.

2. THE CALORIMETER

Most of the design of the calorimeter has been completed. The basic design was reported two years ago at this conference [1] and will not be repeated here. The original brass alloy was changed to "cartridge" brass that reduced the cost substantially. This reduced the interaction length by 3%, but was judged a good compromise to save substantial amount of funds. Otherwise the tower structure and depth segmentation stays the same. The brass segments are 5 cm thick in the barrel section and 8 cm thick in the end caps. The active region is made of 3.75 mm thick segmented scintillators with a wavelength shifting fiber embedded inside the scintillator tiles and the light signal carried out to the optical decoder box by means of clear optical fibers cables. The scintillator tiles are grooved from long scintillators, so that the relative position of the tiles do not change. Most of the advances in the design

and construction have occurred in the details that improve the performance of the detector.

The light from the scintillator tiles is absorbed by wavelength shifting green fibers. The green fibers are fused to clear fibers and the light signal brought to the end of the megatile. Two layers of each barrel wedge and all layers of the end caps have quartz fibers that illuminate each scintillator tile for calibration and monitoring. All the fibers, with the exception of the quartz fibers, have a core diameter of 940 microns.

The optical decoder boxes are in the final design stage. This is the place where the light signals from the optical fibers are arranged into tower structure by means of clear optical fibers and fed to the HPD's. Each tower, with the exception of $\eta = 3$ region, will have two samples. The first sample is the innermost layer that samples the interactions in the region between the ECAL and HCAL. The second sample are layers 2 to 17 added together. The optical boxes also contain the HPD's and the ADC counters, called QIE's that are a modified version of the QIE's for KTeV at Fermilab. On the side of the decoder box will be mounted a calibration box that has a K27 wavelength shifting bar, to be excited by a single laser or two independent LED's. The normalization of the calibration and monitoring is by means of pin diodes. In addition, the laser signal splitting for the megatile layers will also be done inside the calibration box unit. A total of 160 decoder boxes will be used for HB, HE and HO-B. Each decoder box will contain between 3 and 5 HPD's with either 19 or 73 pixels. In general towers with over 10 layers will use the 19 pixel HPD while the single or two layer scintillators will use the 73 pixel HPDs.

Prototypes of all the subsystems were built during 1998 and some were tested in the H2 test beam at CERN during 1998. Based on our experience with the test beam the optical decoder box is being refined to make it more modular.

3. PROGRESS SO FAR

The first 20 degree HB wedge prototype has been built and assembled with the scintillator megatiles and will be tested during the 1999 test beam. A second prototype is under construction. A 30 degree segment of the HE calorimeter prototype is also ready to be tested during 1999. A single Optical

Figure 2. Hybrid Photodetector (HPD) performance at the photo cathode surface.

Decoder Box was constructed for the summer of 1998 test beam. A single module of the double layer HO-B (at $\eta = 0$) and another single layer HO-B prototypes were also tested with muons.

About 10 HPD's made by DEP, were tested and some non-negligible fraction failed at the high voltage connection. The gain of each pixel within a HPD is the same. More work is required to reduce the failure rate. Figure 2 shows a typical sensitivity across a 19 pixel HPD and figure 3 shows a typical gain of an HPD as a function of high voltage. The HPD's have linear gain curves with high voltage, reaching a gain value of about 2,500 at about 10kV.

A 5 channel high voltage supply system was constructed by our Bulgarian colleagues and improvements will be done that will provide a PC controlled, noise free 12 kV, with 100 V bias potential system. The plan is to use independent high voltage channels for each HPD.

4. MAGNETIC FIELD EFFECTS

It has been known for some time[2] that scintillators brighten in magnetic fields by about 6% to 8%, depending on the plastic. It was also known that in calorimeters with scintillator active elements, the light yield sometimes increases more than 10%

Figure 3. Gain curve of a HPD.

and other times, it was just the scintillator brightening. This confusion was finally understood by Monte Carlo simulation of showers in magnetic field and verified by test beam results. The same Monte Carlo simulation also pointed out how to construct a calorimeter, where this increase of light yield beyond scintillator brightening is kept to a minimum.

The increased light yield is dependent on the direction of the magnetic field relative to the scintillator planes. When the field is perpendicular to the scintillator plane, then the only increase is due to the scintillator brightening. If the field is parallel to the scintillator plane, then there is an extra light yield increase due to the curling of electron and positrons and is very dependent on the exact geometry of the scintillator in the absorber gap. This is due to the competing effects of increased path length of electrons in the scintillator due to the curved trajectory and the reduced energy deposit due to an electron energy cutoff if there is a gap between the absorber back face and the scintillator front face.

In the CMS HCAL calorimeter, the scintillator package is 7 mm thick and the gap is 9 mm. Figure 4 shows the Monte Carlo calculations and test beam results[3] from 1996 where we can reproduce the light yield increase of up to 20% when the magnetic field was parallel to the scintillator plates and perpendicular to the beam. Figure 5 is a plot of the light yield increase as a function of the gap size for

Figure 4. B field effect on calorimeter module. Test beam results and MC

the system described in figure 4. This gap distance can be changed from 0 to 2 mm to effectively eliminate this extra light yield.

5. CONCLUSIONS

The CMS Hadron Calorimeter mechanical design is complete and prototypes have been built. Radiation damage is manageable and the magnetic field effects are understood. We are ready to start construction of the calorimeter.

6. ACKNOWLEDGMENT

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Figure 5. MC computation of light yield increase as a function of the front air gap for the system described in figure 4.