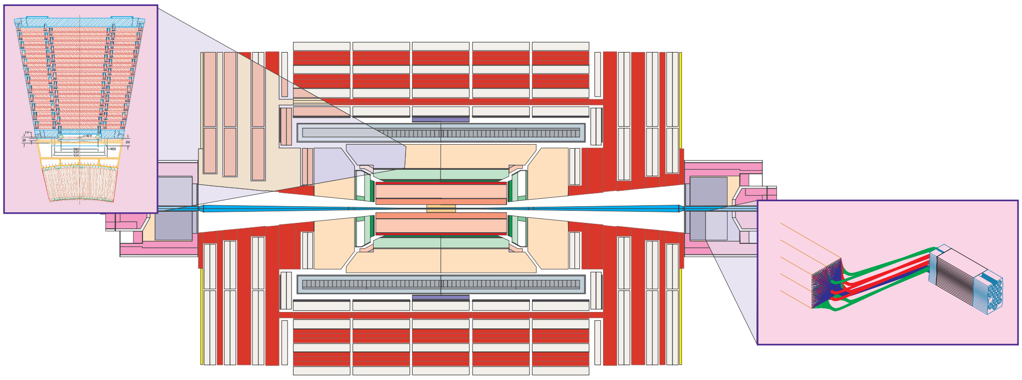
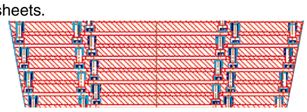
Hadronic calorimeter



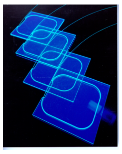
The Hadronic Calorimeter (HCAL), plays an essential role in the identification and measurement of quarks, gluons, and neutrinos by measuring the energy and direction of jets and of missing transverse energy flow in events. Missing energy forms a crucial signature of new particles, like the supersymmetric partners of quarks and gluons. For good missing energy resolution, a hermetic calorimetry coverage to $|\eta|=5$ is required. The HCAL will also aid in the identification of electrons, photons and muons in conjunction with the tracker, electromagnetic calorimeter, and muon systems

Barrel & Endcap

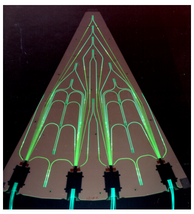
The hadron barrel (HB) and hadron endcap (HE) calorimetesr are sampling calorimeters with 50 mm thick copper absorber plates which are interleaved with 4 mm thick scintillator sheets.



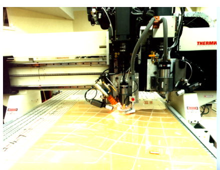
Copper has been selected as the absorber material because of its density. The HB is constructed of two half-barrels each of 4.3 meter length. The HE consists of two large structures, situated at each end of the barrel detector and within the region of high magnetic field. Because the barrel HCAL inside the coil is not sufficiently thick to contain all the energy of high energy showers, additional scintillation layers (HOB) are placed just outside the magnet coil. The full depth of the combined HB and HOB detectors is approximately 11 absorption lengths.



Light emission from the tiles is in the blue-violet, with wavelength in the range λ = 410-425 nm. This light is absorbed by the waveshifting fibers which fluoresce in the green at λ = 490 nm. The green, waveshifted light is conveyed via clear fiber waveguides to connectors at the ends of the megatiles.



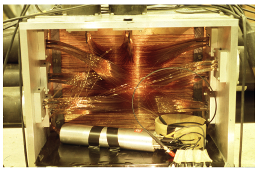
Megatiles are large sheets of plastic scintillator which are subdivided into component scintillator tiles, of size $\Delta\eta \times \Delta\phi = 0.87 \times 0.87$ to provide for reconstruction of hadronic showers. Scintillation signals from the megatiles are detected using waveshifting fibers. The fiber diameter is just under 1 mm.



Megatiles are cut out on a special milling machine called a Thermwood. The Thermwood is programmed to cut tiles of varying dimension and also to machine keyhole grooves in the plastic into which the waveshifting fibers are inserted. The gaps between adjacent tiles are filled with diffuse reflective paint to provide optical isolation.

Forward

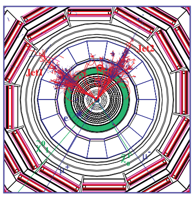
There are two hadronic forward (HF) calorimeters, one located at each end of the CMS detector, which complete the HCAL coverage to $|\eta| = 5$. The HF detectors are situated in a harsh radiation field and cannot be constructed of conventional scintillator and waveshifter materials. Instead, the HF is built of steel absorber plates; steel suffers less activation under irradiation than copper. Hadronic showers are sampled at various depths by radiation-resistant quartz fibers, of selected lengths, which are inserted into the absorber plates.



Quartz fibers of 300 µm diameter are shown threaded into an early prototype HF test module which utilized copper absorber. This view is looking directly into the beam.

The energy of jets is measured from the Cerenkov light signals produced as charged particles pass through the quartz fibers. These signals result principally from the electromagnetic component of showers, which results in excellent directional information for jet reconstruction. Fiber optics convey the Cerenkov signals to photomultiplier tubes which are located in radiation shielded zones to the side and behind each calorimeter.

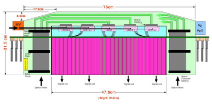
Spectral analysis of data taken during intense radiation exposure of an HF prototype, underway at LIL. Quartz fibers with various claddings were tested.



Supersymmetric particles may reveal themselves in some spectacular events involving leptons, jets and missing energy.
In this simulated event, jets are observed in the HB calorimeter. The hermeticity of the HCAL (the HB, HE and HF detectors working together) is used to identify the substantial missing energy in the event.

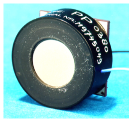
Readout

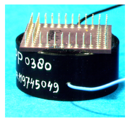
Light from waveshifting fibers is "piped" via clear optical waveguide fibers to readout boxes located at the ends of the barrel and endcap detectors at large radii relative to the beam, yet within the region of high magnetic field. For HCAL detector elements in the barrel region located beyond the magnet coil, the readout boxes are positioned on the iron flux return outside the muon system.



Within the readout boxes, the optical signals from the megatile layers are grouped into "towers" according to $\Delta\eta \times \Delta\varphi$ interval. These tower signals are detected and converted into fast electronic signals by photosensors.

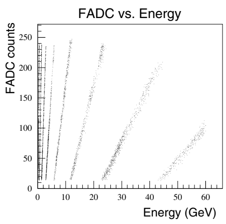
For the barrel and endcap detectors, the photosensors are hybrid photodiodes (HPDs). For the forward detectors, conventional photomultiplier tubes are used.





The HPDs are new devices consisting of a fiber-optic entrance window onto which a multi-alkali photocathode is deposited, followed by a gap of several millimeters over which a large applied electric field accelerates photoelectrons onto a silicon diode target. The target is subdivided into individual readout elements called pixels. For CMS, 19-channel and 73-channel HPDs will be used.

The gain of HPDs is typically 2000-3000 for applied voltages of 10-15 kV. HPDs are capable of operating in high axial magnetic fields and provide a linear response over a large dynamic range from minimum ionizing particles (muons) up to 3 TeV hadron showers. The electronic signals from the HPDs are processed and digitized using special front end integrated circuits called QIE chips. QIE is an acronym for charge (Q) integration (I) and encode (E).



The demand of large dynamic range in the energy measurement is accomplished through a multi-range technique. The encoded output signals are then sent via fiber-optic links to the trigger and data acquisition systems.