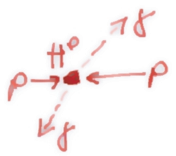
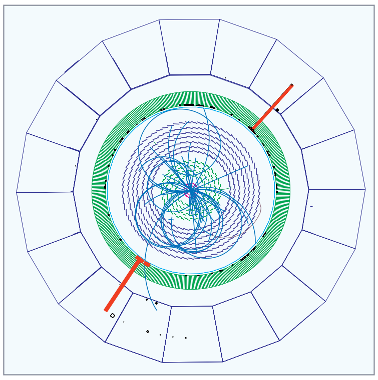
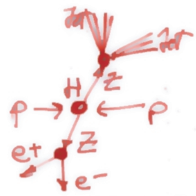
Calorimetry

CERN LHC

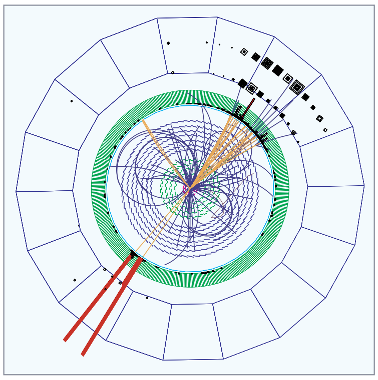


p p → H^0
↳ γ γ





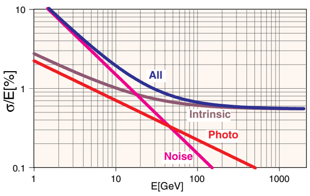
p p → H^0 → Z Z
↳ jet jet
↳ $e^+ e^-$



Electrons, photons and hadrons will be stopped by the calorimeters allowing their energy to be measured. The first calorimeter layer is designed to measure the energies of electrons and photons with high precision. Since these particles interact electromagnetically, it is called an electromagnetic calorimeter (ECAL). Particles which interact via the strong interaction, hadrons, deposit most of their energy in the next layer, the hadronic calorimeter (HCAL). Neutrinos escape direct detection but their presence can be inferred as an apparent energy imbalance in a collision

Electromagnetic Showers

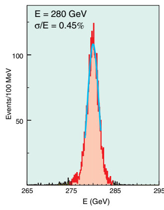
The physics channel that imposes the strictest performance requirement for the electromagnetic calorimeter (ECAL) is the decay of the Higgs boson with mass in the range 100-140 GeV into two photons. All the terms making up the energy resolution (i.e. stochastic, constant and noise) have to be kept small and should be roughly equal at photon energies corresponding to approximately half the Higgs mass.

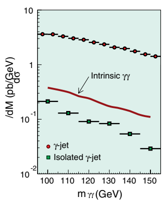


The resolution of the energy measurement of the electromagnetic calorimeter is driven by three major parameters:
- The shower containment and photostatictics
- The electronic noise and pileup energy
- The constant term

The full energy resolution is the sum of these terms and is shown in the figure on the left.

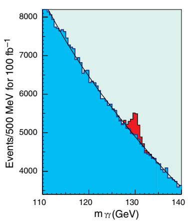
The resolution of the two-photon mass depends on the energy resolution and on the uncertainty on the angle between the two photons. If the vertex position is known, the angular error is negligible. However, if the only information available is the average spread of the interaction vertices, there is an additional 1.5 GeV contributing to the diphoton mass resolution.
At low luminosity the longitudinal position of the Higgs production vertex can be localized using high transverse momentum tracks found in the tracking system. Studies indicate that even at high luminosity the correct vertex can be located for a large fraction of the events using the same method.

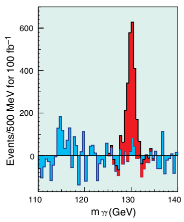




The ECAL must also have good two-shower separation capability to reject a sufficient number of π^0's carrying moderate transverse energy (20-40 GeV). The non-identification of these π^0's results in a very large background from photon+jet events, as shown on the left.
The last requirement on the ECAL is that of a large rapidity coverage. This is also true for the channel in which the Higgs boson decays to four charged leptons via one real and one virtual Z boson or via two real Z bosons.

The expected signal from the decay $H^0 \to \gamma\gamma$ for M_H=130 GeV, after 100 fb^{-1} collected at high luminosity.
On the left is the total diphoton mass spectrum, and on the right is the Higgs excess after background subtraction.

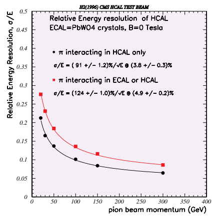




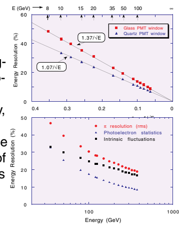
Hadronic Showers

The performance required from a hadron calorimeter (HCAL) is less constrained by the physics processes. The jet energy resolution is compromised by effects such as the jet-finding algorithm, the fragmentation process, the magnetic field and energy pile-up when running at high luminosity. The important characteristics are the transverse granularity and the η coverage.

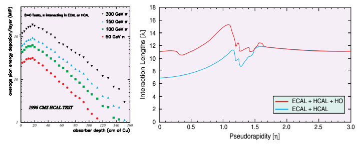
The energy resolution in the Barrel HCAL for pions as a function of beam momentum is displayed for interactions in the HCAL only and in ECAL or HCAL. The absolute energy scale was set using 50 GeV pions interacting only in the HCAL.



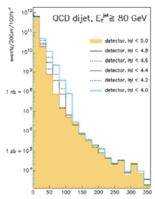
Measured energy resolution for electrons (upper figure) and pions (lower figure) for the HF calorimeter. In the hadronic energy study, the intrinsic resolution is found to scale with the logarithm of the energy (squares in the lower figure).



Emphasis is laid on hermeticity to ensure a good missing transverse energy measurement. Coverage up to |η|=5 is necessary for several reactions, e.g. a heavy Higgs decaying into two Z bosons which in turn give a lepton pair and jet pair. Adequate depth is also needed to contain high-energy jets and also to filter out the hadrons in jets for a cleaner muon measurement and trigger. A relatively fine transverse granularity is important in measuring the jet direction and also to separate two-jet combinations.



Left: shower profiles for pions of various momenta as a function of absorber depth in the calorimeter, as measured in beam tests. Right: depth of the calorimetry in absorption lengths. The full depth corresponds to approximately 11 absorption lengths of material.



Distribution of missing energy associated with QCD dijets for different detector coverage; the figure justifies an HCAL coverage over the range |η| < 5, particularly for missing transverse energy in the range 25 < E_T < 125 GeV.

The reconstruction of jets and dijet masses are keys to searches for high mass Higgs bosons. It is also very important in searching for Higgs bosons predicted by supersymmetry.

Possible signal from the production of a low mass supersymmetric Higgs boson (h) decaying into two b-jets. To identify this final state requires use of both the tracking detectors, to identify displaced vertices, and of the calorimetry, to measure and reconstruct the b-jet energies, over the full kinematic region.