Chapter 6

Forward detectors

6.1 CASTOR

The CASTOR (Centauro And Strange Object Research) detector is a quartz-tungsten sampling calorimeter [120], designed for the very forward rapidity region in heavy ion and proton-proton collisions at the LHC. Its physics motivation is to complement the nucleus-nucleus physics programme [122], developed essentially in the baryon-free mid-rapidity region, and also the diffractive and low-x physics in pp collisions [123]. CASTOR will be installed at 14.38 m from the interaction point, covering the pseudorapidity range $5.2 < |\eta| < 6.6$. Figure 6.1 shows the location of CASTOR in the CMS forward region. The calorimeter will be constructed in two halves surrounding the beam pipe when closed, as shown in figure 6.2. The calorimeter and its readout are designed in such a way as to permit the observation of the cascade development of the impinging particles as they traverse the calorimeter. The typical total and electromagnetic energies in the CASTOR acceptance range (about 180 TeV and 50 TeV, respectively, according to HIJING [121] Pb-Pb simulations at 5.5 TeV) can be measured with a resolution better than $\approx 1\%$.

The main advantages of quartz calorimeters are radiation hardness, fast response and compact detector dimensions [124], making them suitable for the experimental conditions encountered in the very forward region at the LHC. The typical visible transverse sizes of hadronic and electromagnetic showers in quartz calorimeters are 5–10 cm and about 10 mm respectively (for 95% signal containement), i.e. are a factor 3 to 4 times narrower than those in “standard” (scintillation) calorimeters [124]. A detailed description of the operation principle (including optimal geometrical specifications of the quartz and tungsten plates, and performances of light-guides, reflectors and photodetectors) can be found in references [125, 126].

Tungsten-Quartz plates

The CASTOR detector is a Cerenkov-based calorimeter, similar in concept to the HF. It is constructed from layers of tungsten (W) plates (alloy density $\approx$ 18.5 g/cm^3) as absorber and fused silica quartz (Q) plates as active medium. For the electromagnetic (EM) section, the W plates have a thickness of 5.0 mm and the Q plates 2.0 mm. For the hadronic (HAD) section, the W and Q plates have thicknesses of 10.0 mm and 4.0 mm, respectively. The W/Q plates are inclined 45° with respect to the direction of the impinging particles, in order to maximize the Cerenkov light

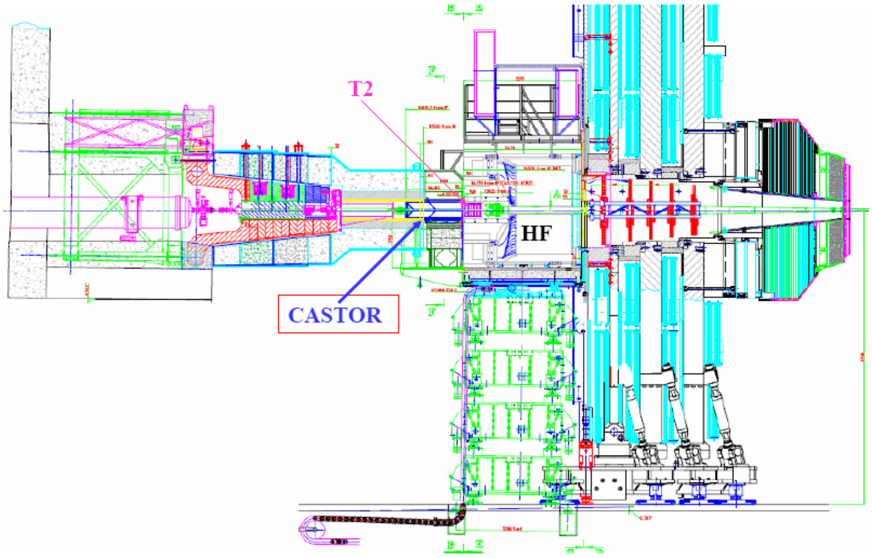

Figure 6.1: Location of CASTOR in the CMS forward region.

output in the quartz. The combination of one W and one Q plate is called a sampling unit (SU). Figure 6.3 shows the complicated geometry of the W/Q plates, due to their 45° inclination.

In the EM section, each sampling unit corresponds to 2.01 X_0 (0.077 λ_I). Each readout unit (RU) consists of 5 SUs and is 10.05 X_0 (0.385 λ_I) deep. The EM section is divided in two successive RUs and has a total of 20.1 X_0 (0.77 λ_I). In the hadronic section, a sampling unit corresponds to 0.154 λ_I. Each readout unit consists of 5 SUs and is 0.77 λ_I deep. The HAD section has 12 RUs, corresponding to 9.24 λ_I. In total, the calorimeter has 10 λ_I. The total number of channels is 224.

Light-guides and photodetectors

The Cerenkov light, produced by the passage of relativistic charged particles through the quartz medium, is collected in sections (RUs) along the length of the calorimeters and focused by air-core light guides onto the photomultiplier (PMT), as shown in figure 6.3. The inside surfaces of the light guides are covered with Dupont [AlO+ SiO_2+TiO_2] reflective foil. The light guide is made out of a 0.8 mm stainless steel sheet. Each light guide subtends 5 SUs in both the EM and HAD sections. The PMT is located in the aluminium housing on the top. Two types of PMTs are currently under consideration: (i) a Hamamatsu R7899 PMT, and (ii) a radiation-hard multi-mesh, small-size PMT FEU-187 produced by Research Institute Electron (RIE, St. Petersburg), with cathode area ≈2 cm^2. Both PMTs allow the muon MIP peak to be separated from the pedestal, an important feature for calibration purposes.

Beam tests results

The energy linearity and resolution as well as the spatial resolution of two CASTOR prototypes have been studied at CERN/SPS tests in 2003 [125] and 2004 [126] (as well as in tests end-of-summer 2007, for the final prototype). The response of the calorimeter to electromagnetic and

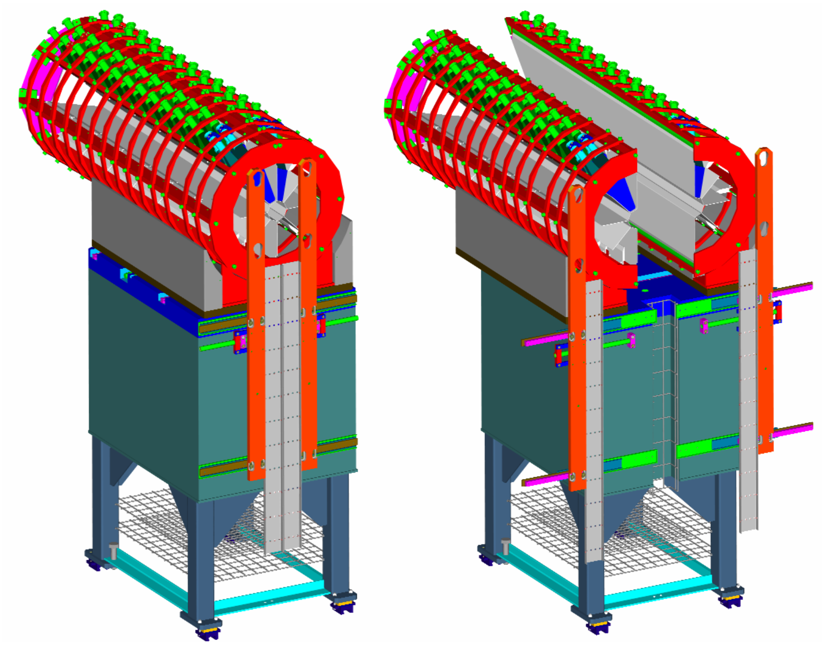

Figure 6.2: CASTOR calorimeter and support.

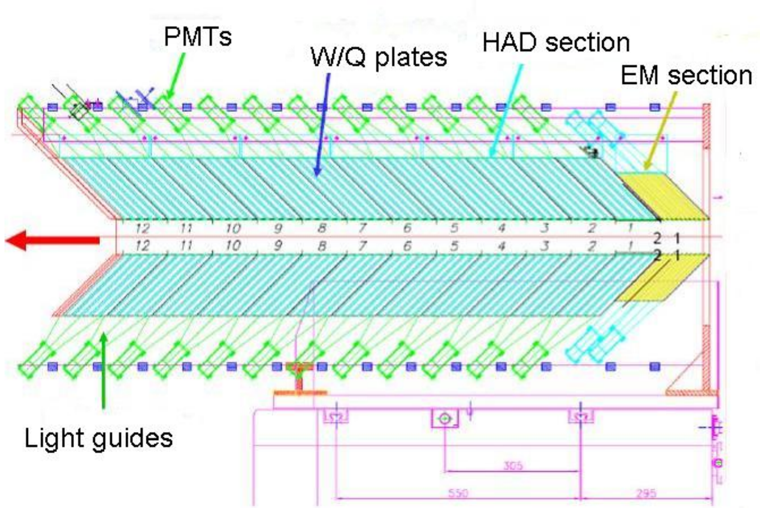

Figure 6.3: Details of the components and geometry of the CASTOR calorimeter.

hadronic showers has been analysed with $E = 20$–200 GeV electrons, $E = 20$–350 GeV pions, and $E = 50$, 150 GeV muons. Good energy linearity for electrons and pions in the full range tested is observed. For the EM section, the constant term of the energy resolution, that limits performance at high energies, is less than 1%, whereas the stochastic term is $\approx 50\%$. The measured spatial resolution of the electron (pion) showers is $\sigma_{\text{EM(HAD)}} = 1.7$ (6.4) mm.

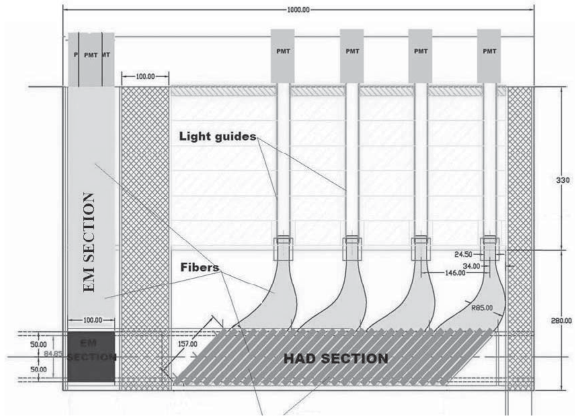

Figure 6.4: The side view of the ZDC showing the EM and HAD sections.

Figure 6.5: Photograph of the ZDC HAD section.

6.2 Zero degree calorimeter (ZDC)

A set of two zero degree calorimeters [127, 128], with pseudorapidity coverage of $|\eta| \geq 8.3$ for neutral particles, are designed to complement the CMS very forward region, especially for heavy ion and pp diffractive studies. Each ZDC has two independent parts: the electromagnetic (EM) and hadronic (HAD) sections. Two identical ZDCs will be located between the two LHC beam pipes at $\approx$140 m on each side of the CMS interaction region at the detector slot of 1 m length, 96 mm width and 607 mm height inside the neutral particle absorber TAN [129]. The TAN is located in front of the D2 separation dipole. It was designed to protect magnets and detectors against debris generated in the pp collisions, and against beam halo and beam losses. During heavy ion running the combined (EM + HAD) calorimeter should allow the reconstruction of the energy of 2.75 TeV spectator neutrons with a resolution of 10–15%. Sampling calorimeters using tungsten and quartz fibers have been chosen for the detection of the energy in the ZDCs with a design similar to HF and CASTOR. The quartz-quartz fibers [127] can withstand up to 30 GRad with only a few percent loss in transparency in the wavelength range 300–425 nm. During the low-luminosity pp (10^{33} cm^{-2}s^{-1}) and design-luminosity Pb-Pb (10^{27} cm^{-2}s^{-1}) runs, the expected average absorbed radiation doses is about 180 MGy and 300 kGy, respectively, per data-taking year.

Figure 6.4 shows a side view of the ZDC with the EM section in front and the HAD section behind. A photo of the HAD section is shown in figure 6.5. The total depth of the combined system is $\approx$7.5 hadronic interaction lengths (λ_I). The configuration includes 9 mm Cu plates in the front and back of each section. For the TAN's final detector configuration an LHC real-time luminosity monitor (BRAN, Beam RAte of Neutrals [130]) will be mounted in the 120 mm space between the ZDC's calorimetric sections. The HAD section consists of 24 layers of 15.5 mm thick tungsten plates and 24 layers of 0.7 mm diameter quartz fibers (6.5 λ_I). The tungsten plates are tilted by 45° to optimize Cerenkov-light output. The EM section is made of 33 layers of 2-mm-thick tungsten plates and 33 layers of 0.7-mm-diameter quartz fibers (19 X_0). The tungsten plates are oriented vertically. The fibers are laid in ribbons. The hadronic section of each ZDC requires 24 fiber ribbons. After exiting the tungsten plates the fibers from 6 individual ribbons are grouped together to form a readout bundle. This bundle is compressed and glued with epoxy into a tube. From there, an optical air-core light guide will carry the light through radiation shielding to the photomultiplier tube. The full hadronic section will consist of four identical towers divided in the longitudinal direction. For the electromagnetic section, fibers from all 33 fiber ribbons will be divided in the horizontal direction into five identical fiber bundles. These 5 bundles will form five horizontal towers and each fiber bundle will be mounted with a 0.5 mm air gap from the photocathode of a phototube. The EM and HAD sections will be instrumented with the same type of phototube as the HF: Hamamatsu R7525 phototubes with a bi-alkali photocathode, resulting in an average quantum efficiency for Cerenkov light of about 10%.

There are a total of 18 readout channels for the two ZDCs. The signals from the ZDCs are transmitted through a long (210 m) coaxial cable to the front-end HCAL VME crates in the underground counting room (USC55). The signal from each channel will be split, with 90% going to the QIE (Charge Integrator and Encoder) while 10% will be used for making trigger signals. An analog sum, proportional to the total energy deposition in each detector, will provide the basic Level 1 trigger in the heavy-ion running mode: the coincidence of (neutron) signals from both sides of the interaction point is sensitive to most of the nuclear and electromagnetic cross section. A left-right timing coincidence will also be used as a fast vertex trigger, to suppress beam-gas events in the heavy ion runs. Information from scalers will be used for tuning the interaction of beams and for defining the real-time luminosity. Finally it may be possible to improve the overall energy resolution of the system by looking at the correlation between the ZDC and the BRAN detector, which sits between the electromagnetic and hadronic sections, near the shower maximum.

The response of the ZDC EM and HAD sections has been studied in beam tests at the CERN/SPS in 2006 [131] and 2007. The calorimeter is found to be linear within 2% in the range from 20 GeV to 100 GeV. The energy resolution obtained for the different positron energies can be parametrized as

$$\left(\frac{\sigma}{E}\right)^2 = \left(\frac{70\%}{\sqrt{E}}\right)^2 + (8\%)^2 \tag{6.1}$$

where E is in GeV. Positive pions with energies of 150 GeV and 300 GeV were used to measure the response of the combined EM+HAD system. The pion energy resolution, obtained by a Landau fit, can be parametrized as

$$\frac{\sigma}{E} = \frac{138\%}{\sqrt{E}} + 13\% \tag{6.2}$$

where E, again, is in GeV. The width of EM showers is ≈5 mm. Such a good position resolution will allow measurement of the beam crossing angle with a resolution of ≈10 mrad.

The performance of both the left and right ZDCs has been studied with electron, pion and muon beams in 2007. Figure 6.6 shows online plots for positrons entering the electromagnetic section of one calorimeter.

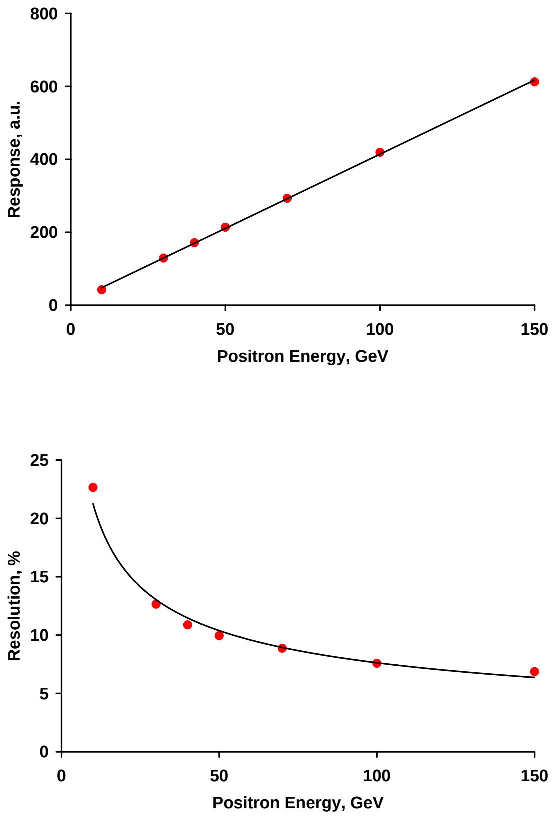

Figure 6.6: Online results for positrons from the 2007 test beam. The top panel shows the response linearity, while the bottom panel gives the energy resolution as a function of the incoming positron beam energy.