Physics potential of the CMS CASTOR forward calorimeter

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The CASTOR calorimeter is a detector covering the very forward region of the CMS experiment at the LHC. It surrounds the beam pipe with 14 longitudinal modules each of which consisting of 16 azimuthal sectors and allows to reconstruct shower profiles, separate electrons and photons from hadrons and search for phenomena with anomalous hadronic energy depositions. The physics program that can be performed with this detector includes a large variety of different QCD topics. In particular, the calorimeter is supposed to contribute to studies of low-x parton dynamics, diffractive scattering, multi-parton interactions and cosmic ray related physics in proton-proton and heavy-ion collisions. The physics capabilities of this detector are briefly summarized in this paper.

1 Detector overview

The CASTOR (Centauro And STrange Object Reseacrh) detector is located at a distance of 14.4 m from the CMS interaction point right behind the Hadronic Forward (HF) calorimeter and the T2, a tracking station of the TOTEM experiment, covering the pseudorapidity region $-6.6 < \eta < -5.2$. This is a quartz-tungsten Cerenkov sampling calorimeter. That is, it is made of repeating layers (arranged in a sandwich structure) of quartz and tungsten plates. The former is used as the active material because of its radiation hardness, while the latter serves as the absorber medium providing the smallest possible shower size. The signal in CASTOR is produced when charged shower particles pass through the quartz plates with the energy above the Cerenkov threshold (190 keV for electrons). The generated Cerenkov light is then collected by air-code light guides, which are transmitting it further to photo-multipliers tubes PMTs. These devices produce signals proportional to the amount of light collected. As can be seen in Figure 1, the detector plates are tilted at 45° w.r.t. the beam axis to maximaize the Cerenkov light output in the quartz. The CASTOR detector is a compact calorimeter with the physical size of

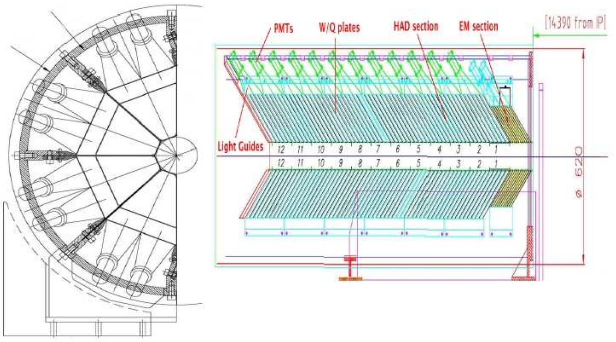

Figure 1: *Sketch of the CASTOR calorimeter: front view (left) and longitudinal cross section (right).*

about 65 cm × 36 cm × 150 cm and having no segmentation in η. It is embedded into a skeleton, which is made of stainless steel. The detector consists of 14 longitudinal modules, each of which comprises 16 azimuthal sectors that are mechanically organized in two half calorimeters. First 2 longitudinal modules form the electromagnetic section, while the other 12 modules form the hadronic section. In the electromagnetic section, the thicknesses of the tungsten and quartz plates are 5.0 and 2.0 mm, respectively. The corresponding thicknesses in the hadronic section are twice as large as in the electromagnetic section. With this design, the diameter of the showers of electrons and positrons produced by hadrons is about one cm, which is an order of magnitude smaller than in other types of calorimeters. The detector has a total depth of 10.3 interaction lengths and includes 224 readout channels. It should be noted that the final CASTOR design is the result of three test beam campaigns and numerous Monte Carlo simulations. After the completion of the detector construction in the spring of 2009, the calorimeter has been successfully installed and commissioned in the summer of 2009.

2 The CASTOR physics capabilities

Because of its pseudorapidity coverage, CASTOR significantly expands the CMS capability to investigate physics processes occurring at very low polar angles and so, providing a valuable tool to study low-x QCD, diffractive scattering, multi-parton interactions and underlying event structure. Another CASTOR objective is to search for exotic objects with unusual longitudinal shower profile, several of which have been observed in cosmic ray experiments.

2.1 Low-x QCD

A study of QCD processes at a very low parton momentum fraction $x = p_{\mathrm{parton}}/p_{\mathrm{hadron}}$ is a key to understand the structure of the proton, whose gluon density is poorly known at very low values of x. At the LHC the minimum accessible x in proton-proton (pp) collisions decreases by a factor of about 10 for each 2 units of rapidity. This implies that a process with a hard scale of $Q \sim 10$ GeV and within the CASTOR acceptance can probe quark densities down $x \sim 10^{-6}$ [1], that has never been achieved before. Such processes include the production of forward jets and Drell-Yan electron pairs. The latter occurs via the $qq \rightarrow \gamma^* \rightarrow e^+e^-$ reaction within the acceptance of CASTOR and TOTEM-T2 station, whose usage is essential for detecting these events. Measurements of Drell-Yan events can also be used to study QCD saturation effects – the effects of rising of the gluon density in the proton with decreasing values of x, that have been firstly observed at HERA. It was found that the Drell-Yan production cross section is suppressed roughly by a factor of 2 when using a PDF with saturation effects compared to one without. Another way to constrain the parton distribution function (PDF) of the proton at low x is provided by measuring forward jets in CASTOR that will enable to probe the parton densities down 10^{-6}. Moreover, this allows to gain information on the full QCD evolution to study high order QCD reactions. Apart from that, it has been found that a BFKL like simulation, for which the gluon ladder is ordered in x, predicts more hard jets in the CASTOR acceptance than the DGLAP model that assumes strong ordering in the transverse momentum k_{T} and random walk in x. Therefore, measurements of forward jets in CASTOR can be used as a good tool to distinguish between DGLAP and non-DGLAP type of QCD evolution. Furthermore, CASTOR in combination with HF can be used to measure Mueller-Navalet dijet events, which are characterized by two jets with similar p_{T} but large rapidity separation. By measuring Mueller-Navalet dijets in CASTOR one can probe BFKL-like dynamics and small-x evolution.

2.2 Diffraction

A good way to study the perturbative QCD and the hadron structure is provided by diffractive pp interactions (where one or both the colliding protons stay intact) via measurements of the cross sections for diffractive W, Z, jet or heavy quark productions. The CASTOR calorimeter is, in particular, a very useful tool to measure the single-diffractive productions of W and dijets in pp collisions ($pp \to pX$ reaction, where X is either a W boson or a dijet system). These are hard diffractive processes that are sensitive to the quark and gluon content of the low-x proton PDFs, correspondingly. A selection of such events can be performed using the multiplicity distributions of tracks in the central tracker and calorimeter towers in HF plus CASTOR exploiting the fact that diffractive events on average have lower multiplicity in the central region and in the "gap side" than non-difractive ones. Feasibility studies to detect the single-diffractive productions of W [2] and dijets [3] have shown that the diffractive events peak in the regions of no activity in HF and CASTOR.

2.3 Multi-parton interactions and underlying event structure

Measurements of energy deposits in the CASTOR acceptance should significantly improve our understanding of the multi-parton interactions (MPI) and underlying event (UE) structure. The latter is an unavoidable background to most collider observables, whose understanding is essential for precise measurements at the LHC. It consists of particles arising from the beam-beam remnants and from MPI. The MPI arise in the region of small-x where parton densities are large so that the likelihood of more than one parton interaction per event is high. According to all QCD models, the larger the collision energy the greater the contribution from MPI to the hard scattering process. However, this dependence is currently weakly known. Measurements of the forward energy flow by means of CASTOR will allow to discriminate between different MPI models, which vary quite a lot. Furthermore, measurements of forward particle production in pp and Pb-Pb collisions at LHC energies with CASTOR should help to significantly improve the existing constraints on ultra-high energy cosmic ray models.

3 Conclusion

The CASTOR calorimeter is a valuable CMS subcomponent allowing to perform a very rich physics program. The detector is fully integrated in the CMS readout and currently take collision data. Its first physics results are currently under preparation.

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References

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