The ATLAS and CMS experiments

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The CERN Large Hadron Collider (LHC) is currently being installed in the 27-km ring previously used for the LEP e^+e^- collider. This machine will push back the high energy frontier by one order of magnitude, providing pp collisions at a center-of-mass energy of $\sqrt{s} = 14$ TeV.

Four main experiments will benefit from this accelerator: two general-purpose detectors, ATLAS (Fig. 1) and CMS (Fig. 2), designed to explore the physics at the TeV scale; one experiment, LHCb, dedicated to the study of B-hadrons and CP violation; and one experiment, ALICE, which will study heavy ion collisions. Here only the ATLAS and CMS experiments and their physics programs are discussed in some detail.

The main goal of these experiments is the verification of the Higgs mechanism for the electroweak symmetry breaking and the study of the “new” (i.e. non-Standard Model) physics which is expected to manifest itself at the TeV scale to solve the hierarchy problem. The design luminosity of 10^{34} cm^{-2}s^{-1} of the new accelerator will also allow to collect very large samples of B hadrons, W and Z gauge bosons and top quarks, allowing stringent tests of the Standard Model predictions.

Since this program implies the sensitivity to a very broad range of signatures and since it is not known how new physics may manifest itself, the detectors have been designed to be able to detect as many particles and signatures as possible, with the best possible precision.

In both experiments the instrumentation is placed around the interaction point over the whole solid angle, except for the LHC beam pipe. As the particles leave the interaction point, they traverse the Inner Tracker, which reconstructs the trajectories of charged particles, the Electromagnetic and Hadronic calorimeters which absorb and measure the total energy of all particles except neutrinos and muons, and the Muon Spectrometer which is used to identify and measure the momentum of muons. The presence of neutrinos (and other hypothetic weakly interacting particles) is revealed as a non-zero vector sum of the particle momenta in the plane transverse to the beam axis.

Both the Inner Tracker and the Muon spectrometer need to be placed inside a magnetic field in order to measure the momenta of charged particles using the radius of curvature of their trajectories. The two experiments are very different in the layout they have chosen for the magnet system. In ATLAS, a solenoid provide the magnetic field for the Inner Tracker, while a system of air-core toroids outside the calorimeters provide the field for the Muon Spectrometer. In CMS, the magnetic field is provided by a single very large solenoid which contains both the Inner Tracker and the calorimeters; the muon chambers are embedded in the iron of the solenoid return yoke. The magnet layout determines the size, the weight (ATLAS is larger but lighter) and even the name of the two experiments.

The CMS Inner Detector consists of Silicon Pixel and Strip detectors, placed in a 4 T magnetic field. The ATLAS Inner Tracker is composed by a smaller number of Silicon Pixel and Strip detectors and a Transition Radiation detector (TRT) at larger radii, inside a 2 T magnetic field. Thanks mainly to the larger magnetic field, the CMS tracker has a better momentum resolution, but the ATLAS TRT contributes to the electron/pion identification capabilities of the detector.

The CMS electromagnetic calorimeter is composed by PbWO$_4$ with excellent intrinsic energy resolution ($\sigma(E)/E \sim 2-5\%/\sqrt{E(GeV)}$). The ATLAS electromagnetic calorimeter is a lead/liquid argon sampling calorimeter. While the energy resolution is worse ($\sigma(E)/E \sim 10\%/\sqrt{E(GeV)}$), thanks to a very fine lateral and longitudinal segmentation the ATLAS calorimeter provides more robust particle identification capabilities than the CMS calorimeter.

In both detectors the hadronic calorimetry is provided by sampling detectors with scintillator or liquid argon as the active medium. The ATLAS calorimeter has a better energy resolutions for jets

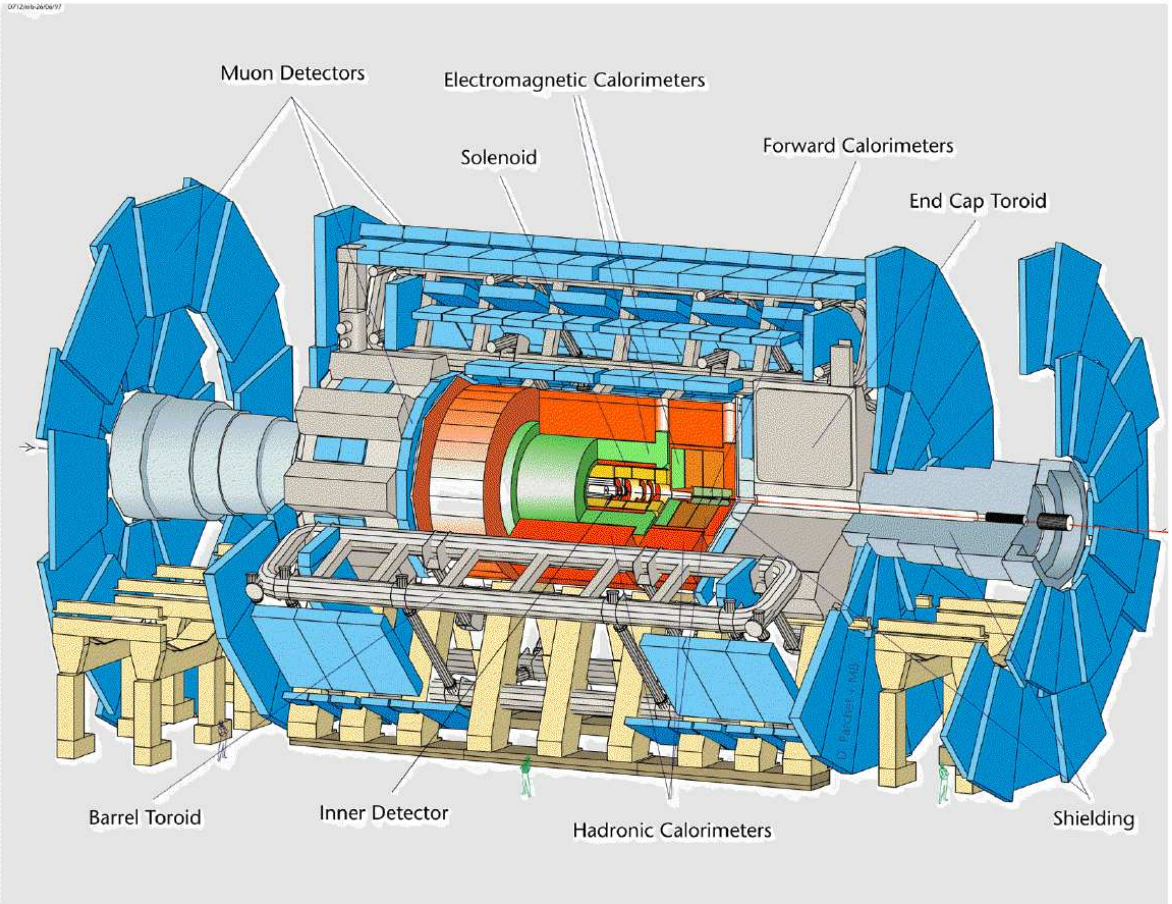

Fig. 1: An exploded view of the ATLAS detector.

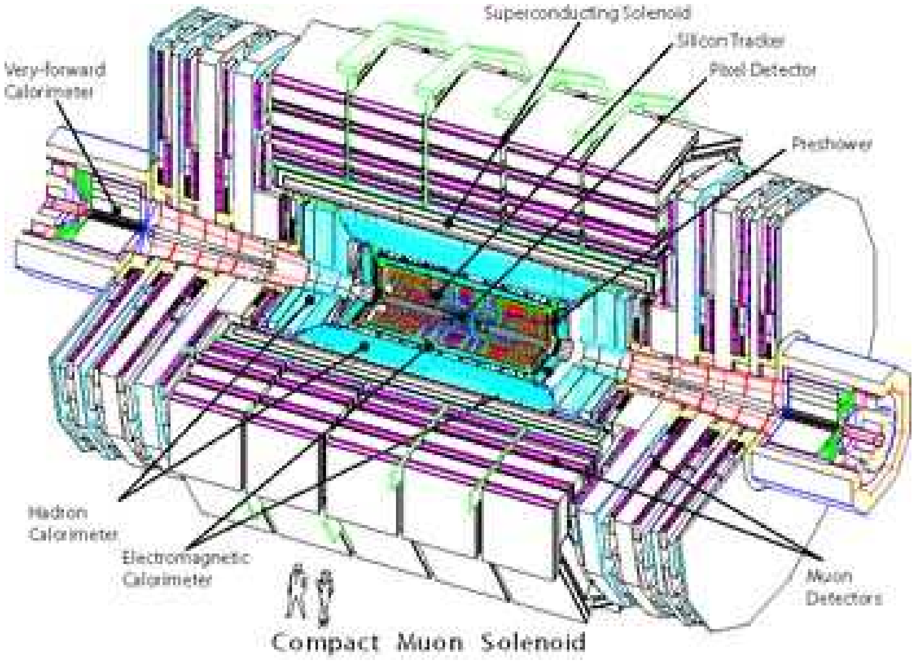

Fig. 2: An exploded view of the CMS detector.

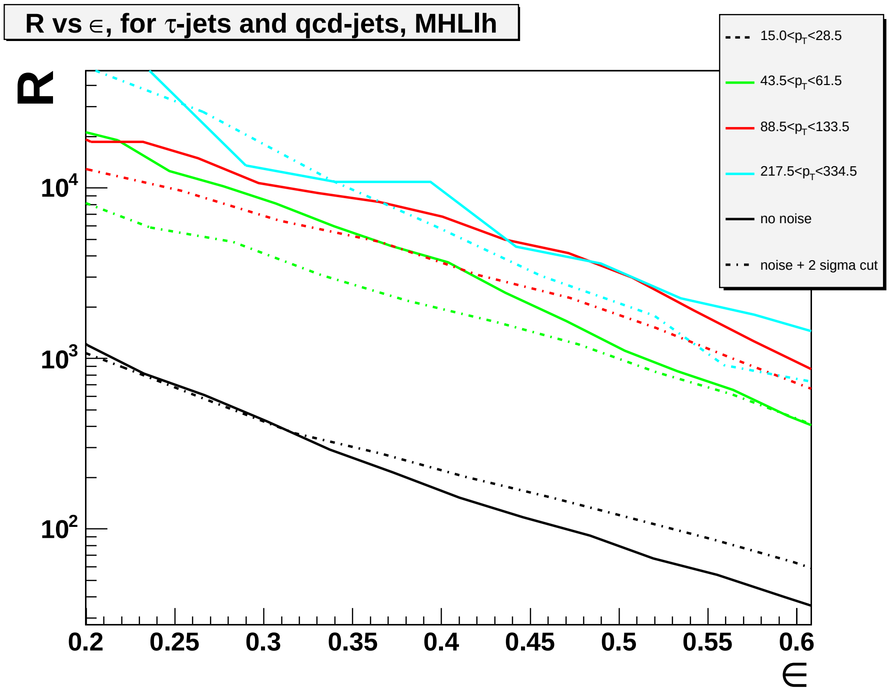

Fig. 3: The QCD jet rejection (inverse of mistagging efficiency) as a function of τ tagging efficiency is reported for the ATLAS detector for different jet transverse momentum ranges. The full and dashed curves correspond to simulation without and with electronic noise in the calorimeters respectively [2].

($\sigma(E)/E \sim 50\%/\sqrt{E(GeV)} \oplus 0.03$) than CMS ($\sigma(E)/E \sim 100\%/\sqrt{E(GeV)} \oplus 0.05$) because it is thicker and has a finer sampling frequency.

The chamber stations of the CMS muon spectrometer are embedded into the iron of the solenoid return yoke, while those of ATLAS are in air. Because of multiple scattering in the spectrometer, and the larger field in the Inner Tracker the CMS muon reconstruction relies on the combination of the informations from the two systems; the ATLAS muon spectrometer can instead reconstruct the muons in standalone mode, though combination with the Inner detector improves the momentum resolution at low momenta. The momentum resolution for 1 TeV muons is about 7% for ATLAS and 5% for CMS.

Muons can be unambiguously identified as they are the only particles which are capable to reach the detectors outside the calorimeters. Both detectors have also an excellent capability to identify electrons that are isolated (that is, they are outside hadronic jets). For example, ATLAS expects an electron identification efficiency of about 70% with a probability to misidentify a jet as an electron of the order of 10^{-5} [1]. The tau identification relies on the hadronic decay modes, since leptonically decaying taus cannot be separated from electrons and muons. The jets produced by hadronically decaying taus are separated from those produced by quark and gluons since they produce narrower jets with a smaller number of tracks. The capability of the ATLAS detector to separate τ-jets from QCD jets is shown in Fig. 3.

The identification of the flavour of a jet produced by a quark is more difficult and it is practically limited to the identification of b jets, which are tagged by the vertex detectors using the relatively long lifetime of B mesons; the presence of soft electron and muon inside a jet is also used to improve the b-tagging performances. In Fig. 4 the probability of mis-tagging a light jet as a b jet is plotted as a function of the b-tagging efficiency for the CMS detector [3]; comparable performances are expected for ATLAS.

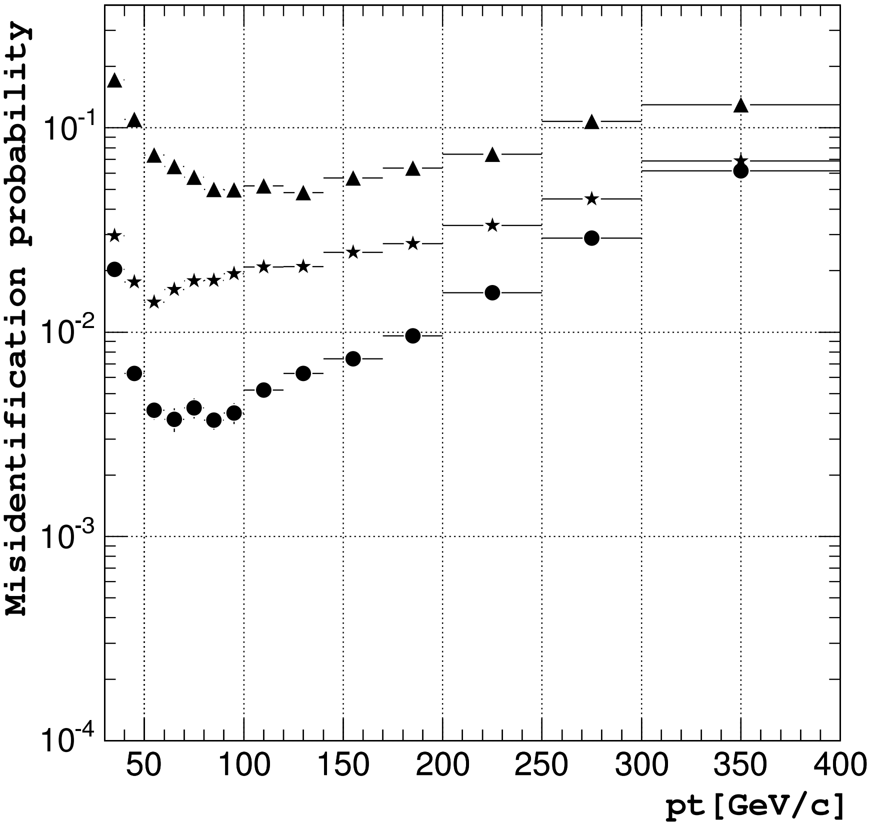

Fig. 4: The non-b jet mistagging efficiencies for a fixed b-tagging efficiency of 0.5 as a function of jet transverse momentum for c-jets (triangles), uds jets (circles) and gluon jets (stars) obtained for the CMS detector with an event sample of QCD jets and the secondary vertex tagging algorithm [3].

References

[1] The ATLAS Collaboration, ”ATLAS detector and physics performance Technical Design Report, vol. 1”, CERN/LHCC 99-14 (1999)

[2] M. Heldmann and D. Cavalli, “An improved τ-identification for the ATLAS experiment”, ATLAS note ATL-PHYS-PUB-2006-008 (2006).

[3] Della Negra M. et al., ”CMS Physics Technical Design Report, vol. 1”, CERN/LHCC 2006-001 (2006).