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Highlights of the LHC run 1 / Résultats marquants de la première période d'exploitation du GCH

The ATLAS and CMS detectors at the LHC

Les détecteurs ATLAS et CMS auprès du LHC

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ABSTRACT

The construction of the LHC detectors presented formidable challenges and, together with physics exploitation, has required the resources and talents of many thousands of scientists and engineers.

RÉSUMÉ

La construction des détecteurs auprès du LHC représentait un formidable défi et, en même temps que l'exploitation de la physique, elle a requis les compétences de plusieurs milliers de scientifiques et ingénieurs talentueux.

1. Design requirements

At the design energy of the LHC, 14 TeV in the centre of mass, the production cross-section of "new physics" is small, e.g., less than 100 pb for the long-sought Standard Model (SM) Higgs boson, while the inelastic proton–proton cross-section is close to 100 mb (see Fig. 1). Taking into account that only some rather rare decay modes with a clean signature could lead to a large enough signal to background ratio, an instantaneous luminosity of 10^{34} cm^{-2} s^{-1} was the target to be met in order to "guarantee" the discovery at the LHC of the SM Higgs boson, its mass being limited by several theoretical arguments to $\simeq$1 TeV.

The above two key numbers for energy and luminosity set the scale of the challenges to be met by the detectors: at this luminosity, and with proton bunches colliding every 25 ns, one expects an average of 20 inelastic collisions per bunch crossing (bc). These additional interactions in general produce only rather soft particles (mostly pions) and create what is called the pile-up noise. If the sensitive time of the detectors is longer than 25 ns, several bc are added up, meaning an effective increase of the pile-up. Therefore the detectors' response has to be fast, of the order of 25 ns, especially for those detectors where the particle density is highest, close to the collision point. With an average multiplicity of about six

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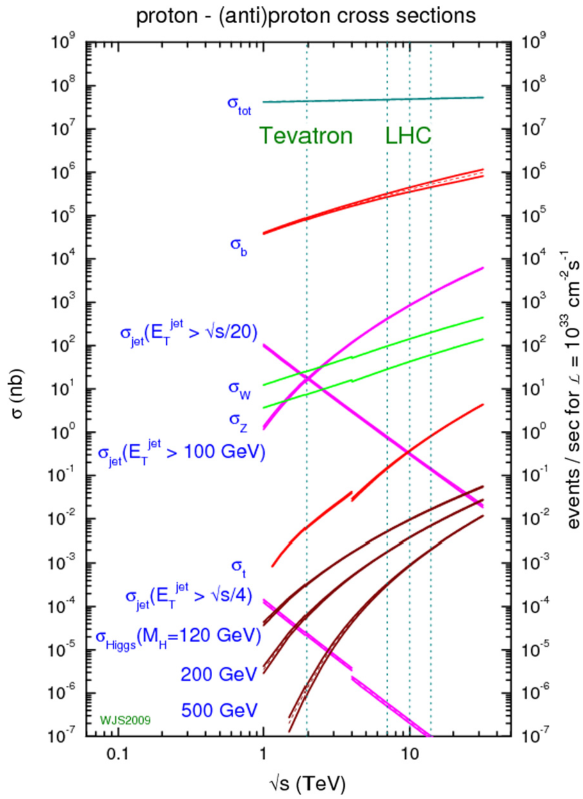

Fig. 1. (Color online.) Cross-sections for important physics processes as a function of centre of mass energy. Below 3 TeV, the cross-sections correspond to a $p\bar{p}$ initial state, as was the case for the Tevatron near Chicago (maximum energy of 2 TeV in the centre of mass).

charged particles per pseudo-rapidity[1] unit, each with an average transverse momentum of $\simeq 0.5$ GeV, and an almost equal number of photons, the soft collisions creating the pile-up noise also lead to energy deposition in the detectors, giving rise to a sizeable (ionising and non-ionising) radiation fluence. Radiation resistance was a rather new, and difficult, challenge to be met by detectors, sensors and "on-detector" electronics.

During "run I", i.e. the data taking period from 2010 to 2012, the energy was actually limited to 8 TeV (7 TeV in 2010 and 2011), and the collisions took place every 50 ns. This resulted in a maximum instantaneous luminosity of about $0.8 \cdot 10^{34}$ cm^{-2} s^{-1}, with an average number of inelastic collisions per bc of 20.7, i.e. the nominal value, and up to 40 in some cases.

1.1. General features

The LHC detectors feature a tracking and vertexing system around the collision point, immersed in a strong magnetic field, surrounded by an electromagnetic calorimeter optimised for the identification and accurate measurement of the energy of electrons and photons, which is itself surrounded by the hadronic calorimeter. The two calorimeters together contain and measure the energies of jets resulting from the materialisation of quarks and gluons. Muons are the only charged particles able to traverse the calorimeters (where they lose about 3 GeV). They are identified in the muon spectrometer behind, and measured both inside the tracker and in the spectrometer. The production of escaping particles such as neutrinos is deduced from a significant imbalance in the visible momenta of the detected particles in the plane transverse to the beam direction. See Fig. 2 for illustration.

The transverse momentum (p_T) measurement of charged particles in the tracking volume, and/or in the muon spectrometer derives from the sagitta of the corresponding curved tracks. The choice of the magnetic system to a large extent determines the geometry of the experiment. CMS uses a classical solenoid geometry, however of unprecedented size and field. ATLAS also uses a small solenoid for the tracking volume, but the choice was made to have in addition a separate large toroidal system around the calorimeters, specific to the muon spectrometer. The parameters of both magnet systems were dictated by the requirement of measuring muon p_T to better than 10% at 1 TeV, in view of understanding the behaviour of a possible Z′ (heavy partners of the Z in extended models) up to an invariant mass of a few TeV. An illustration is given in Section 2.1.

[1] Pseudorapidity is defined as $\eta = -\ln\tan\frac{\theta}{2}$ in terms of the polar angle θ measured from the z axis along the anticlockwise beam direction.