Introduction

The aims of this work are the characterization of the ATLAS hadronic calorimeter prototypes at the CERN SPS collider during the years 1997 - 1998 at several beam energies and the search for Higgs boson using the data sample from the Monte Carlo simulations of proton-proton collisions in the ATLAS detector at the LHC collider, during three years at low luminosity ($10^{34}\ cm^{-2}\ s^{-1}$) and a centre-of-mass energie of $E_{cm} = 14$ TeV.

Beam crossings are 25 ns apart and at design luminosity there are 23 interactions per crossing. The ATLAS experiment has now entered in the construction phase for many of its detector components, with a strict schedule to meet the first collisions at LHC in summer 2005. The ATLAS experiment has several subdetectors: Inner Detector, Electromagnetic and Hadron Calorimeters and the Muon system. The ATLAS hadronic calorimeters cover the range $|\eta| <4.9$. Over the range $|\eta| <1.7$, the iron scintillating-tile technique is used for the barrel and extended barrel tile calorimeters and for partially instrumenting the gap between them and the intermediate tile calorimeter (ITC). This gap provides space for cables and services from the innermost detectors. Over the range $1.5< |\eta| <4.9$, Liquid Argon calorimeters were chosen: the hadronic end-cap calorimeter (HEC) extends to $|\eta| <3.2$, while the range $3.1< |\eta| <4.9$ is covered by the high-density forward calorimeter (FCAL).

The tile calorimeter (Tile - Cal) is a sampling calorimeter using iron as the absorber and scintillating tiles as the active material. The tiles are placed radially and staggered in depth. The structure is periodic along z. The tile calorimeter is composed of one barrel of 5.46 m and two extended barrels of 2.65 m each one. Radially the tile calorimeter extends from an inner radius of 2.28 m to an outer radius of 4.32 m. Azimutally (ϕ), the barrel and extended barrels are divided into 64 modules. The new feature of its design is the orientation of the scintillating tiles which are placed in planes perpendiculars to the colliding beams and are staggered in depth. A good sampling homogeneity is obtained when the calorimeter is placed behind an electromagnetic compartment and a coil equivalent to a total of about two interaction lengths of material. This has been verified with Monte Carlo simulation and has been proven by the test beam results.

In the framework of the RD34 project, the Valencia team works in an extensive program of test beams demostrating the good performance of the calorimeter that fulfils the requirements for the ATLAS hadronic barrel calorimetry. The Tile Calorimeter test beam program was started in 1993 using three 1 m prototype modules. Between 1994 and 1995, the test beam was categorized to take data with a prototype stack of five 1 m modules. A first test of the electromagnetic and the five hadronic calorimeter prototypes in a combined setup was performed in 1994. Another run was performed in 1996. In September 1996 a full scale barrel sector (Module 0) was tested. In October 1997 two Extended Barrel Module 0 were exposed to the calibration beams. The five originale one meter prototype modules were placed on either sides of the Extended Barrel Modules 0, three on one side and two on the other. In July 1998 the Barrel Module 0 was tested with five one meter prototypes placed on either sides of module 0. The main goal of the test beam programs is the optimization of the design in order to reach the desired physics and mechanics requirements, for example:

- measurement of the energy and jets direction,
- measurement of the missing transverse momentum of the event (E_T^{miss}),
- accurate measurement of the energy and position of electrons and photons.

The single particle hadronic energy resolution of $\frac{\sigma}{E} = \frac{50\%}{\sqrt{E}} \oplus 3\%$, and a granularity $\Delta\eta \times \Delta\phi = 0.1 \times 0.1$ is needed to reach the physics goals.

The Standard Model of Elementary Particle Physics (SM) describes with a very high precision the matter and its interactions at the energies reached by the present accelerators. However, several questions remain still unanswered and there is a consensus among physicists that this model cannot be considered a final theory. One of the most promising extensions of the Standard Model is Supersymmetry (SUSY). It assumes a symmetry between fermions and bosons which leads to the prediction of new supersymmetric particles, partners of all known particles.

The Higgs supersymmetric sector requires two Higgs doublets and five physical states of the Higgs boson. The SM predicts one Higgs doublet and the existence of a Higgs boson. The physical states of the Higgs boson are two charged ($H^{\pm}$) and three neutral (h, H, A) physcial states. The h and H are the CP-odd scalars and A is the CP-even scalar. One of the main goals of this high energy (14 TeV) regime is the search for new particles, in particular, the search for the lightest Higgs boson and supersymmetric particles.

The search for the five physical states of the Higgs boson has been carried out in the framework of the Minimal Supersymmetric Standard Model (MSSM). At the tree level, all Higgs-boson masses and couplings can be expressed in terms of only two parameters. They are usually chosen to be m_A, and tanβ, the ratio of the vacuum expectation values of the Higgs doublets. It is assumed that SUSY particles are suficiently heavy that they do not play an important role in the phenomenology of MSSM Higgs-boson decays. The interest was focused on the discovery potential of various decay modes accesible also in the case of the SM Higgs boson: h $\rightarrow$ b$\bar{\text{b}}$, H $\rightarrow$ ZZ $\rightarrow$ 4l , and of modes strongly enhanced at large tanβ: H/A $\rightarrow$ $\tau\tau$, H/A $\rightarrow$ $\mu\mu$. Much attention was given also to other potentially interesting channels such as: H/A $\rightarrow$ t$\bar{\text{t}}$, A $\rightarrow$ Zh, H $\rightarrow$ hh.

In proton-proton collisions the complete region of parameter space, m_A = 50-500 GeV and tanβ = 1-50, should be accesible for Higgs-boson discovery by the ATLAS experiment. Over a large fraction of this parameter space, more than one Higgs boson and/or more than one decay mode would be accesible.

The work is presented in five chapters. In the first chapter a brief introduction of the Supersymmetry concepts is given and mention is made of several of the open questions in the Standard Model wich suggest that it is necessary to look for more general theories beyond this model. Later on in the chapter, the motivations of Supersymmetry and the basic concepts of the Minimal Supersymmetry Standard Model are discussed. The main supersymmetry breaking mechanisms and its phenomenological consequences are also summarised.

The experimental setup is described in the second chapter. A general description of the LHC accelerator system is given and its operation is summarised. On the other hand, the ATLAS detector and the main characteristics of its subdetectors are treated.

The third chapter is devoted to the main features of electromagnetic and hadronic showers and its differences. There is discussed how the e/h ratio affects the calorimeter performance and energy resolution. Finally, a description of the Tile Calorimeter as one of the ATLAS sub-detectors is given. All the requirements on the detector specifications to reach the ambitious physics goals of the LHC are gathered at the end of the chapter.

The fourth chapter describes the test beam performances of the barrel and extended barrel Tile Calorimeter prototypes. In October 1997 two extended barrel modules 0 were built for the test, one in Barcelona (Spain), and the other at Argonne (USA). The modules were tested at CERN together with the five 1 meter old modules. In order to improve the transverse leakage for both, the two extended barrel modules were sandwiched between the 1 m prototype modules. In July 1998 the barrel module 0 was tested in the beam area using the same five 1 meter modules as for the test beam in 1997.

The analysis carried out in this work has as goal to study the resolution, linearity and e/h ratio of the barrel and extended barrel to demonstrate the good performance of the calorimeter, which fulfils the requirements for the ATLAS barrel calorimetry. Test beam pion energies from 20 to 400 GeV along different values of η, from η = -1.4 to η = -0.25 have been used in this analysis. The cuts used to select the events are also described. The methods followed in the pion energy reconstruction (Raw Data, Benchmark, and H1) are also mentioned. The evolution of the linearity and resolution parameters in the data reconstruction, from Raw Data to H1 weighting method going through the benchmark method is studied. Then, a comparison between the test beam data of the Tile Calorimeter prototype modules and the GCALOR full simulation Monte Carlo program has been done for the 1998 test beam. The linearity and resolution of the Tile Calorimeter prototypes improve using the H1 method. Also these results are compatible for the different modules and η values. Respect to the linearity, the benchmark approach gives aproximately the same results than the raw data, improving a little at high energies. The response obtained for electron and pions gives the possibility to extract the e/h value, that is the ratio of the calorimeter responses to the electromagnetic and non-electromagnetic (purely hadronic) components of hadron showers. An e/h value different from 1 causes deviation from linearity in the hadronic response versus energy, besides broadening the energy resolution and introducing tails in the energy distribution. In the case of the Tile Calorimeter this ratio is expected to be greater than 1 for the conventional orientation of tiles perpendicular to incident hadrons. Finally, a comparative study between the barrel and extended barrel prototypes is provided, showing the good agreement obtained with the ATLAS calorimetry requirements about resolution, linearity and e/h value.

The search for a Higgs boson via its decay to $\mathrm{t\bar{t}}$ in a possible extension of the Standard Model, the MSSM, is explained in detail in chapter five. It is assumed that SUSY particle masses are large, so that Higgs-boson decays to SUSY particles are kinematicaly forbidden. Due to the strong coupling of the SM Higgs boson to gauge-boson pairs, the $\mathrm{H \to t\bar{t}}$ branching ratio for this channel is too small to be observable in the SM case. In the MSSM case, however, the $\mathrm{H \to t\bar{t}}$ and $\mathrm{A \to t\bar{t}}$ branching ratios are close to 100% for m_H, $m_A > 2m_t$ and for $\tan\beta \sim 1$. The $\mathrm{H \to t\bar{t}}$ and $\mathrm{A \to t\bar{t}}$ decays cannot be distinguished experimentally from each other, since the H and A bosons are almost degenerate in mass in the relevant region of parameter space. Then, some details about the ATLAS simulation and the two Monte Carlo programs used to generate events are given. The first program, ATLFAST, is an intermediate step between a simple parton-level analysis and a very sophisticated full detector simulation. It can be used for fast simulation of signal and background processes, including the most crucial detector aspects: jet reconstruction in the calorimeters, momentum/energy smearing for leptons and photons, magnetic field effects and missing transverse energy evaluation. The second program, SLUG-DICE-ATRECON, is a sophisticated and high CPU-time intensive full detector simulation. It is always needed to study effects due to noise, calibration and intercalibration of calorimeters, detailed showers development, pile-up, cracks, and to provide parametrisation for fast simulation.

The strategy used to identify $\mathrm{t\bar{t}}$ decays from H/A consists in searching for $\mathrm{WWb\bar{b}}$ finale states. One top decay, $\mathrm{t \to Wb}$, is required to be followed by the semileptonic decay of the W-boson, $\mathrm{W \to l\nu}$, giving an isolated lepton to trigger the experiment. The second W boson is required to decay hadronically, $\mathrm{W \to jj}$. This final topology consists of one isolated lepton and four reconstructed jets. The initial selection cuts used to reject events coming from the reducible (W + jets) and from the irreducible background ($\mathrm{t\bar{t} \to bl\nu bjj}$) are explained. Then, several algorithms for reconstructing the invariant mass of the $t\bar{t}$ pair have been studied in order to obtain the signal resolution, the signal-to-background ratio and the statistical significance for m_A = 370, 400 and 450 GeV. The shape and magnitude of the combinatorial background to the ($t \rightarrow bjj$) hadronic channel, and the ($t \rightarrow bl\nu$) semileptonic channel is reproduced. Later on in the chapter, the signal is extracted by fitting the mass distribution with a superposition of a polynomial reproducing the background and a Gaussian, taking into account the statistical error, the systematic error from overall normalisation and from the shape of the background. This is not posible for a mass of 400 GeV, since also the background peaks around this value. For masses close to 400 GeV only an excess of events above the continuum background would be observed. This excess would be statistically significant if the theoretical uncertainties on the continuum background shape were not larger than about a percent. Then, a comparison between full and fast simulation is described. A good agreement between the two simulation packages is found for the acceptance of the kinematic cuts and the top and Higgs mass resolutions. The performance of the ATLAS detector in order to search for a Standard Model or a Minimal Supersymmetric Standard Model Higgs boson is reviewed at the end of the chapter.

To end up, the most important conclusions extracted from this work are summarised.