Conclusions

In this work we have presented the analyses made and the results obtained for the hadronic calorimeter prototypes of the ATLAS detector, carried out with the data taken during 1997 - 1998, with extensive tests of pions and electrons. The search for Higgs boson using the data sample of Monte Carlo simulations for the ATLAS detector at energies E_{cm} = 14 TeV have been studied and also presented in this thesis. Total integrated luminosities of 30 fb^{-1} (3 years at low luminosity) and 100 fb^{-1} (1 year at high luminosity) were analysed in this work.

The Tile Calorimeter (Tile - Cal) test beam program was supported by the CERN program RD34. Two calorimeter prototypes were analysed: a full scale barrel sector (Module 0) and two Extended Barrel modules 0. Early measurements were performed in the H8 beam line at the SPS at CERN. Data were taken with pions and electrons between 20 and 400 GeV. A full simulation package has been developed, based on the GEANT program, which describes in full detail the barrel detector prototype that was used for the 1998 test beam runs in order to compare the data and Monte Carlo events.

Before going into the energy reconstruction of the pion and electron data, a crucial phenomenom for understanting the different used techniques has been discussed. This concept is the so-called *non-compensation* in hadron calorimetry and is the main physical motivation for the algorithms applied in the reconstruction of the Extended Barrel and Barrel pion data. The energy released by electrons and the signal released by pions of equal incident energy has been compared; this ratio is usually named e/π and allows us to introduce the concept of non-compensation: $e/\pi \neq 1$. In most sampling calorimetes $e/\pi > 1$; this is mostly caused by the energy loss to overcome the binding energy of the excited nucleus in the hadronic shower development. The binding energy to boil off these nucleons is *robbed* from the energy of the cascade ($\sim$ 20%) and in most cases will not contribute to a measurable (*visible*) energy. For hadrons the resolution and linearity of a non-compensated calorimeter ($e/\pi \neq 1$) are degraded by the different response to the electromagnetic and hadronic components of the hadronic shower.

Nevertheless, it is possible to achieve compensation and improve the linearity and resolution. Two different strategies have been adopted, which may result in $e/\pi \sim 1$:

- designing an intrisically compensated calorimeter (U, Pb, etc...).

- achieving compensation in off-line analysis using different weights for the electromagnetic and hadronic components of the shower.

The approaches applied in this work use the latest method for trying to achieve compensation.

In order to estimate the energy from pions, several reconstruction methods have been studied. A new approach inspired in the H1 collaboration to correct the data has been developed and compared with previous methods.

The linearity and resolution parameters in the data reconstruction have been studied in three steps, from "Raw data" to "H1" weighting method going through the "benchmark" approach. The "Raw data" analysis has studied the direct data taken in the detector without to apply any weighting method. In the "Benchmark" algorithm the energy of the particles is obtained as the sum of several terms, where the involved parameters, constants with the beam energy, are optimized by minimizing the fractional energy resolution and correcting the energy losses due to the longitudinal and transversal leakage. The "H1" weighting technique is based in correcting *upwards* the energy of the cells instead of *downwards* improving the linearity and the resolution detector.

The results obtained in the test beam of the Tile - Cal prototypes are the following:

- The linearity and resolution of the Tile Calorimeter prototypes improve using the "H1" method as are summarised in table C.1 and C.2. Also these results are compatible for the two prototypes used in the 1997 and 1998 test beam at different values of η. In the ATLAS environment, the aim will be to develop an effective jet reconstruction algorithm. The "H1" method described here may be flexible and powerful enough to suit this purpose.

Respect to the linearity, the "Benchmark" approach gives aproximately the same results than the "Raw data", improving a little at high energies due to the leakage corrections. Using the "H1" approach we found a good linear response inside of the ATLAS colaboration requirements. The linearity obtained with Monte Carlo simulation is better than for the test beam data but at high energies the hadronic shower simulation is insufficent and the shower descriptions became quite far away from reality.

The "H1" method improves significantly the resolution with respect to the "Raw data" or the "Benchmark" algortihm. The statistical and the constant terms for the resolution are very similar for Monte Carlo simulation and test beam data.

- A scan over η has been made in order to obtain the e/h ratio. The e/h ratio of a sampling calorimeter with an iron-scintillator structure is expected to be > 1 as is

Table C.1: *Resolution parameters for the different approaches, prototypes and η values.*

Method	MODULE	η	a %	b %
Raw Data	BCN	-1.1	46.7± 0.9	5.34±0.08
	BCN	-1.2	43.7± 1.2	4.80±0.08
	ANL	-1.1	51.7± 0.8	5.09±0.08
	ANL	-1.2	49.9± 1.4	6.04±0.08
	M0	-0.25	59.1± 1.9	5.40±0.08
	M0	-0.35	56.3± 1.5	6.88±0.10
	M0	-0.45	56.5± 1.5	5.35±0.08
	M0	-0.55	55.2± 1.4	5.10±0.11
Benchmark	BCN	-1.1	50.1±1.4	3.10±0.10
	BCN	-1.2	52.2±1.5	4.21±0.12
	ANL	-1.1	51.5±1.5	4.87±0.12
	ANL	-1.2	59.1±1.9	3.71±0.16
H1	BCN	-1.1	45.6± 0.7	2.71±0.07
	BCN	-1.2	47.8± 0.6	2.25±0.06
	ANL	-1.1	45.2± 0.7	3.10±0.07
	ANL	-1.2	43.7± 1.0	3.91±0.07
	M0	-0.25	41.1± 1.3	5.68±0.08
	M0	-0.35	40.7± 1.2	5.33±0.08
	M0	-0.45	45.9± 1.0	4.22±0.08
	M0	-0.55	43.2± 1.0	4.87±0.10

shown in table C.3 and the values are in good agreement with the results obtained from previous precise studies.

• A comparison between the barrel and extended barrel prototypes has been made. The resolution, linearity and e/h ratio for both prototypes are inside of the Hadronic Calorimeter requirements. The statistical resolution term and e/h ratio are very similars in the two cases. However, the constant resolution term is less in the Extended Barrel than in the Barrel. As this term is related with the leakage, we can say that the Barrel Module 0 has more leakage than the Extended Barrel Module 0. Respect to the linearity, the RMS for the Barrel is better than for the Extended Barrel due to the poor quality of data from 1997 test beam.

The search for a Higgs boson via its decay to $t\bar{t}$ in a possible extension of the Standard Model, the MSSM, has been explained in detail. It is assumed that SUSY particle masses are large, so the Higgs-boson decay to SUSY particles are kinematicaly forbidden. The physical states of the Higgs boson are two charged ($H^{\pm}$) and three neutral (h, H, A) physical states. The Higgs particle is copiously produced at hadron colliders through gluon-gluon collisions, via virtual top quark loop. However at a hadron collider there is a large irreducible background from the QCD production of top quarks.

Table C.2: *RMS for the different approaches, prototypes and η values.*

Method	MODULE	η	RMS (%)
Raw Data	BCN	-1.1	4.3
	BCN	-1.2	4.3
	ANL	-1.1	4.3
	ANL	-1.2	4.3
	M0	-0.25	2.0
	M0	-0.35	2.5
	M0	-0.45	2.0
	M0	-0.55	2.5
Benchmark	BCN	-1.1	4.5
	BCN	-1.2	4.5
	ANL	-1.1	4.5
	ANL	-1.2	4.5
H1	BCN	-1.1	1.2
	BCN	-1.2	2.5
	ANL	-1.1	1.8
	ANL	-1.2	2.9
	M0	-0.25	1.4
	M0	-0.35	1.8
	M0	-0.45	0.8
	M0	-0.55	2.0

Due to the strong coupling of the SM Higgs boson to gauge-boson pairs, the H $\rightarrow$ t$\bar{\text{t}}$ branching ratio is too small ($\sim$ 10%) for this channel to be observable in the SM case. In the MSSM case, however, the H $\rightarrow$ t$\bar{\text{t}}$ and A $\rightarrow$ t$\bar{\text{t}}$ branching ratios are close to 100% for $m_{H,A} > 2m_t$ and for tan$\beta \sim 1$. The signal from H/A $\rightarrow$ t$\bar{\text{t}}$ decays appears as a peak in the t$\bar{\text{t}}$ invariant mass spectrum above the t$\bar{\text{t}}$ continuum background for values of m_H smaller than 500 GeV. There is an interferance between the signal and background amplitudes which causes a strong suppresion of the observability of the signal at higher masses. This suppresion of the total H+A rates is estimated to be roughly 30%, 50% and 70% for m_H = 370 GeV, 400 GeV and 450 GeV. These factors are taken into account in the analysis presented in this thesis.

The study presented has been performed using the data sample of the Monte Carlo simulation for the ATLAS detector at the LHC collider. Two programs has been used, ATLFAST, a fast simulation of signal and background and, SLUG-DICE-ATRECON for a sophisticated full detector simulation. In order to be able to cross-check the results obtained with ATLFAST a comparison between fast and full simulation has been performed.

The signal is extracted by searching for WWb$\bar{\text{b}}$ final states, with one W $\rightarrow$lν and one W $\rightarrow$ jj decay. This final topology consists of one isolated lepton and four reconstructed

Table C.3: *The values of e/h ratio for different prototypes and η values.*

MODULE	η	e/h
BCN	-1.1	1.38 $\pm$ 0.013
BCN	-1.2	1.48 $\pm$ 0.014
BCN	-1.3	1.52 $\pm$ 0.015
BCN	-1.4	1.60 $\pm$ 0.016
M0	-0.35	1.61 $\pm$ 0.015
M0	-0.45	1.39 $\pm$ 0.012
M0	-0.55	1.41 $\pm$ 0.012

jets, the lepton is required for the trigger and has to have $p_T > 20$ GeV and $|\eta| < 2.5$. For all jets, those from W-decay and the two b-jets, $p_T > 40$ GeV and $|\eta| < 2.5$ were required. The assumed efficiency for b-jets identification is $\epsilon_b = 60\%$ (50%) at low (high) luminosity.

Two algorithms for reconstructing the invariant mass of the $t\bar{t}$ pair have been studied. The second algorithm improves substantially the signal resolution, the signal-to-background ratio and the statistical significance with respect to the first one. However, the first algorithm is interesting as it reproduces in more unbiased way the shape and magnitude of the combinatorial background to the hadronic ($t \rightarrow jjb$) and the semileptonic ($t \rightarrow bl\nu$) channels.

After to reconstruct the invariant mass of the top quarks a study in order to subtract the signal peak from the background has been performed for a $m_A = 370$, 400 and 450 GeV. The statistical error, the systematic error from overall normalisation and from the shape of the background have been taken into account.

The results obtained are the following:

• The expected mass resolution on m_{tt} increases from 14 to 20 GeV as m_H increases from 370 to 450 GeV. This implies that a typical mass window to observe most of the signal would be between 25 and 80 GeV. After both top quarks have been reconstructed, the background from continuum $t\bar{t}$ production is larger than all other backgrounds (such as W + jets).

• The signal-to-background ratio varies between 9% and 1% over the mass range from 370 to 450 GeV. For an integrated luminosity of 30 fb^{-1} (3 years at low luminosity) and tan$\beta = 1.5$ about 2120 signal events and 40000 background events are expected inside a mass window of $\pm 2\sigma_m$ around $m_A = 400$ GeV, see table C.4. For high luminosity operation and an integrated luminosity of 100 fb^{-1} (1 year at high luminosity) one expects for Higgs mass of 400 GeV about 4900 signal and 90000 background events.

• The extraction of the signal would only be possible for Higgs masses above the kinematic peak of the background distribution which is around $m_{tt} = 400$ GeV. Such

Table C.4: *Observability of the $H/A \rightarrow t\bar{t}$ channel for an integrated luminosity of 30 fb^{-1} and 100 fb^{-1}, for tanβ = 1.5. The rough estimation of the effect of the negative interference with continuum production has been included.*

m_H (GeV)	370	400	450
$\sigma \times$ BR (pb) (no supresion)	11.8	8.4	4.8
$\sigma \times$ BR (pb) (with supresion)	8.3	4.2	1.4
Signal # (Low Lum.) (Hig. Lum.)	 3190 7380	 2120 4900	 980 2270
Backgr. # (Low Lum.) (Hig. Lum.)	 34200 79100	 39500 91400	 52900 122400
Significan. (Low Lum.) =S/$\sqrt{B}$ =S/0.01B (Hig. Lum.) =S/$\sqrt{B}$ =S/0.01B	 17.3 26.2 	 5.4 5.4	 4.3 6.5

an extraction assumes that the uncertainty on the shape of the continuum background is small and that it can be fitted from events outside the assumed Higgs mass window. This leads to the significance levels given in table C.4.

• For masses close to 400 GeV only an excess of events above the continuum background would be observed. This excess would be statistically significant, but this significance would only be meaningful if the theoretical uncertainties on the continuum background shape were not larger than about a percent.

• For the optimistic scenario assuming that the differential spectrum of m_{tt} would be known to better than 1% a limited region in parameter space has been found. This limit corresponds to $2m_t < m_A <$ 470 GeV for tan$\beta \sim 1$.

• The results obtained for the mass resolution in the H/A $\rightarrow$ t$\bar{\text{t}}$ decay channel for a m_A = 400 GeV and using ATLFAST have been compared with a full detector simulation. The two simulation packages are in good agreement for the kinematic cuts acceptance, the quantities involved in the analysis and the top and Higgs mass resolutions, as is shown in tables C.5. and C.6. The two simulations can be used in a complementary way to study physics channels: full simulation has to be used to check in detail the detector performance, fast simulation can be used as a croos-check for full simulation reconstruction code and the algorithms used there and also for the production of large statistics samples of events for the physics analysis.

Table C.5: *Acceptances for each cut selections (leptons, jets, bjets).*

Ac.	electrons	muons	leptons	*jets*	*bjets*
Fast	0.90	0.77	0.88	0.41	0.62
Full	0.89	0.74	0.85	0.49	0.59

Table C.6: *Invariant mass resolution obtained for the top and Higgs with a fast and full detector simulation of ATLAS at LHC .*

Resolution	*Fast simulation*	*Full simulation*
	σ (GeV)	σ (GeV)
$t \rightarrow bjj$	13.93	21.11
$t \rightarrow bl\nu$	11.92	12.67
m_{tt}	19.39	17.5