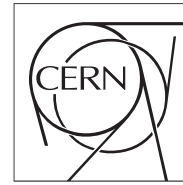


The Compact Muon Solenoid Experiment  
**Conference Report**

Mailing address: CMS CERN, CH-1211 GENEVA 23, Switzerland



3 June 2008

# Early physics with the ATLAS and CMS detectors at LHC

Andre G. Holzner

## Abstract

The Large Hadron Collider (LHC) at CERN in Geneva (Switzerland) will go into operation in the coming months and will soon enable us to analyse the highest energy collisions ever produced at an accelerator. With a design integrated luminosity of up to 100/fb per year and a centre-of-mass energy of 14 TeV it will not only allow us to probe the Standard Model beyond the TeV scale but also search for new phenomena such as the Higgs boson, supersymmetric particles, extra spatial dimensions etc. This article summarises a few selected analyses which are foreseen to be performed with the first 0.01 to 1/fb.

Presented at *HLPW08, 6.3.2008-8.3.2008, Spa, Belgium*

# Early physics with the ATLAS and CMS detectors at LHC

A.G. Holzner

*PH department, CERN, CH-1211 Geneva 23, Switzerland*

## Abstract.

The Large Hadron Collider (LHC) at CERN in Geneva (Switzerland) will go into operation in the coming months and will soon enable us to analyse the highest energy collisions ever produced at an accelerator. With a design integrated luminosity of up to  $100 \text{ fb}^{-1}$  per year and a centre-of-mass energy of 14 TeV it will not only allow us to probe the Standard Model beyond the TeV scale but also search for new phenomena such as the Higgs boson, supersymmetric particles, extra spatial dimensions etc. This article summarises a few selected analyses which are foreseen to be performed with the first  $0.01$  to  $1 \text{ fb}^{-1}$ .

**Keywords:** LHC start-up, W/Z production, underlying event, top physics

**PACS:** 13.85.Hd, 14.65.Ha, 14.70.Fm, 14.70.Hp

## 1. STATUS AND SCHEDULE

At the time of writing the LHC machine is being cooled down to the nominal operating temperature of the superconducting magnets. Two out of the eight LHC sectors are still at room temperature, three are between 20 and 200 Kelvin and the remaining three are cooled down to two Kelvin [1]. The machine should be closed end of June 2008 and should see first beams one month later. Some dipole magnets in one of the sectors unexpectedly quenched below the design current causing the need for some retraining. It was therefore decided to run LHC at  $\sqrt{s} = 10 \text{ TeV}$  in 2008 while 14 TeV is foreseen after the winter shutdown [2].

On a longer time scale, the steps towards the design performance of LHC are grouped into four phases as shown in Table 1. Assuming successful operation over three to four months (taking into account a realistic machine efficiency), a delivered integrated luminosity of  $20 \text{ pb}^{-1}$  for 2008 can be within reach.

**TABLE 1.** LHC commissioning schedule [3, 4]

| Stage | Year       | Description              | Target instantaneous luminosity<br>[ $\text{cm}^{-2}\text{s}^{-1}$ ] | Integrated luminosity per month<br>[ $\text{pb}^{-1}$ ] |
|-------|------------|--------------------------|--|---|
| A     | 2008       | pilot physics run        | $6 \cdot 10^{30}$  | $\sim 15$   |
| B     | 2009       | intermediate physics run | $1 \cdot 10^{32}$  | $\sim 300$  |
| C     | 2009       | 25 ns run I              | $1 \cdot 10^{33}$  | $\sim 3000$   |
| D     | after 2009 | 25 ns run II             | $4 \cdot 10^{33}$  | $\sim 10000$  |

Both ATLAS and CMS installations are close to complete (apart from e.g. one of



**FIGURE 1.** CMS inner tracker insertion in December 2007

the CMS electromagnetic calorimeter endcaps) and the detectors are now exercising their data acquisition and trigger systems using cosmic rays. One of the last big milestones for the CMS detector was the insertion of the inner tracking system in December 2007 (Figure 1).

## **2. EARLY DATA ANALYSES**

It should be mentioned here that in the first months of data taking with beam a big effort will go into understanding the behaviour of the detector, the trigger and the data acquisition system. At the same time the calorimeters need to be calibrated and the muon and central tracking chambers need to be aligned in situ in order to achieve the best possible performance. Some of the analyses described in the following take the less-than-optimal detector performance (miscalibration and misalignment) into account.

## 2.1. Underlying event

In hadron-hadron collisions the hard scattering of the quarks and gluons is accompanied by initial and final state radiation as well as soft interactions by the beam remnants. Everything other than the hard scattering process in a collision is referred to as the *underlying event*. Soft interactions are not calculable from first principles and thus phenomenological models are used.

As the particles of the underlying event can be emitted in the vicinity of leptons a good knowledge of the underlying event properties is essential for the understanding of lepton isolation efficiencies. Furthermore, particles originating from the underlying event also contribute to the energies measured of hard jets and therefore one needs to know how much the underlying event contributes on average to each jet's energy. A nice example of how the mass spectrum of resonances decaying into hadrons can be shifted and a method to correct for this is given in [5].

The number of soft interactions per proton-proton collision is proportional to the luminosity per bunch crossing which itself depends on the instantaneous luminosity; the number of soft interactions per collision is usually larger for high luminosity than for low luminosity running and the corrections mentioned above depend on the instantaneous luminosity.

The strategy for comparing different models describing the underlying event is to select events with two back-to-back jets and count the number of charged particles in the region transverse to the jets axis. Different models – which give consistent results at Tevatron energies – then show significant differences at LHC energies when the average number of charged particles is drawn as a function of the leading charged jet transverse momentum.

CMS has performed a study using minimum bias and di-jet samples and different tracker alignment precision scenarios [6]. PYTHIA tunes DW, DWT, S0 and HERWIG were compared. With the statistics and the alignment of  $100 \text{ pb}^{-1}$  one can already see a clear difference between the DW and the DWT tunes in the distributions of the average number of charged particles (per unit detector region) and the sum of the transverse momenta of charged particles (per unit detector region) as function of the leading charged jet transverse momentum in the region transverse to the leading jet. The predictions of these two tunes (for the two variables mentioned) differ by about 20% for LHC energies while they give identical results at  $\sqrt{s} = 1.96 \text{ TeV}$  [7].

ATLAS has performed a tuning of the PYTHIA parameters to existing data (mostly from CDF, UA5 and E735) and done a comparison [8] between this tune and PHOJET. They find that the average number of charged particles and the  $p_T$  sum of charged particles in the region transverse to the leading jet differ by a factor of about two between these two generators.

## 2.2. W/Z production (leptonic decay)

These processes have several advantages: their cross section is of the order of nanobarns, they have a charged lepton in the final state which can be triggered on and their decay properties have been measured at previous colliders (e.g. at LEP) to high precision. Furthermore, there are now fully differential calculations (rapidity and transverse momentum of the boson) available at NNLO QCD [9] which reduces the theoretical scale uncertainty to less than 1%. One further advantageous feature of Z events is that backgrounds can be estimated from the off-resonance regions in the di-lepton invariant mass spectrum (sidebands).

CMS describes selections to be used for the first  $10 \text{ pb}^{-1}$  of collected data for decays of W and Z bosons into electrons [10] and muons [11].

### 2.2.1. Electron channels

These selections start from one (W) or two (Z) electron candidates with a transverse energy of at least 20 GeV. They must satisfy a track based isolation criterion and have a small ratio of hadronic to electromagnetic energy. The width of the electromagnetic shower in the direction parallel to the beam pipe must be below a given value (there is no such requirement for the shower width in the direction perpendicular to that because showers can be spread over a large range in this direction due to the emission of bremsstrahlung photons). Furthermore the track associated to the electron candidate must be close to the cluster when extrapolated to the electromagnetic calorimeter.

For the Z analysis the additional requirement that the electron-electron invariant mass be between 70 and 110 GeV is made. About 4000 events are selected (after subtraction of the very small background) for  $10 \text{ pb}^{-1}$ . This corresponds to an acceptance of 33% and an efficiency of 68%. The dominant source of uncertainty for the cross section measurement is expected to be due to the uncertainty of the collected luminosity. In light of the fact that the theoretical cross section predictions are more precise than that, one is tempted to turn this analysis into a luminosity measurement [12].

For the W analysis the electroweak background (W to  $\tau$  and Z decays) are about 5% of the size of the W signal which can be estimated from simulation. The contribution of the hadronic background (mostly di-jet events where one jet is misidentified as an electron) to the missing transverse energy distribution will be determined from the data itself. A method proposing to do this by removing one electron from Z events and by inverting the isolation criteria in di-jet events is described in [10]. Close to 68000 events are expected after background subtraction for  $10 \text{ pb}^{-1}$  at an acceptance of 52% and a selection efficiency of 65%.

ATLAS has investigated the possibility of further constraining parton density functions (PDFs) using W decays into electrons [13]. Re-fitting the ZEUS-S PDF to the  $e^+$  and  $e^-$  rapidity distributions from Monte Carlo events (leaving the absolute normalisation of the distribution free in order not to depend on any luminosity

measurement) the biggest improvement is seen in the parameter controlling the low- $x$  gluon. This is not surprising as we will have access to  $x$  values down to about  $10^{-4}$  with W and Z bosons at  $\sqrt{s} = 14$  TeV and the gluon is the dominant parton at this  $Q^2 \sim (100 \text{ GeV})^2$ .

### *2.2.2. Muon channels*

The analysis in [11] starts off with the requirement for one or two reconstructed muons (for the W or Z analysis respectively) which satisfy a track based isolation criterion. Only muons with a transverse momentum above 20 (25) GeV are accepted for the Z (W) selection. The invariant mass of the muon pair must be above 40 GeV for the Z analysis. In the case of the W selection a lower cut on the reconstructed transverse mass is applied at 50 GeV.

A procedure similar to the one used in the case of W decays to electrons is used to estimate the QCD background. It is based on inversion of the isolation cut (to determine the amount of background) and removing one muon from Z events (to estimate the shape of the transverse mass distribution of W events in the QCD-enriched background region).

### *2.2.3. Determining efficiencies from data*

The production of Z bosons is foreseen to be used to estimate lepton reconstruction efficiencies from the data using a ‘tag and probe’ method [14]. This is done by selecting events with a lepton satisfying very stringent cuts (‘tag lepton’) and then looking for a second lepton in the event which is consistent with originating from a Z decay and passing the set of cuts for which one wants to determine the efficiency (‘probe lepton’). The background passing this selection is reduced to a minimum by imposing very tight criteria on the tag lepton.

## **2.3. Top pair production**

The top pair production cross section at the LHC is 830 pb at NLO [15]. Compared to about 8 pb at the Tevatron (e.g. as measured by the D0 collaboration [16]), the top pair production cross section is more than hundred times larger at LHC. With its goal of delivering  $10 \text{ fb}^{-1}$  per year of low luminosity running, the LHC will be a top factory and should allow to study the properties of top quarks in great detail.

The final states of top pair events are determined by the fact that the decays are almost exclusively into a W and a b quark and by the branching ratios of the W boson. Three types of experimental signatures are thus distinguished as described in Table 2.

**TABLE 2.** Experimental signatures for  $t\bar{t}$  events. For the sake of simplicity the assumption was made in the third column that one quark will produce one jet which is however not the case for all events.

| $t\bar{t}$ final state | $t\bar{t}$ Branching Ratio | Experimental signature   |
|------------------------|----------------------------|--|
| Hadronic               | 46%                        | Two b-jets and four light jets   |
| Semi-leptonic          | 44% (29 % to $e/\mu$ )     | Two b-jets, two light jets, one charged lepton and missing transverse energy |
| di-lepton              | 10% (5% to $e/\mu$ )       | Two b-jets, two charged leptons and missing transverse energy                |

Due to the fact that top pair events have all kinds of objects in the final state (electrons, muons, light and b jets and missing transverse energy), they will help to understand a large variety of reconstruction aspects. Furthermore, they are a background to many searches for new physics and therefore must be understood before a signal can be claimed in these search channels.

With  $20 \text{ pb}^{-1}$ , about 800 di-lepton and about 4700 semi-leptonic ( $e/\mu$ ) events are produced which should allow the observation of top pair events [17]. With ten times more data, background rates can be estimated from data, the production cross section can be measured, measurements of the top mass will become feasible and distributions of several quantities (such as the reconstructed top mass, the reconstructed transverse top mass, the top transverse momentum) can be looked at in more detail. At the same stage events involving decays to taus can be observed.

### *2.3.1. Di-lepton channel*

The analysis described in [18] starts from events triggered by the single or di-lepton trigger. At least two jets and two reconstructed isolated leptons with opposite charge must be present in the event. All four objects must have a transverse momentum above 20 GeV. To exploit the presence of the two neutrinos from the W decays, a requirement that the missing transverse energy be above 40 GeV is made. A b-tag criterion is applied to select two b jets in the event. Then, a kinematic fit imposing W mass constraints is imposed which allows to reconstruct a clear top mass peak. At 1.2% the efficiency is quite low but still 657 signal events are expected for  $1 \text{ fb}^{-1}$ . The signal to background ratio of 12:1 makes this analysis robust with respect to background uncertainties.

### *2.3.2. Semi-leptonic channel*

The following describes the CMS analysis in the muon channel [19]. Events triggered by the single muon trigger are selected if they have at least for jets with transverse energy above 30 GeV. The muon is required to be isolated and must have

a transverse momentum of at least 20 GeV. Two jets need to be likely to originate from a b quark. A kinematic fit imposing a W mass constraint is applied. At the final stage of the selection the efficiency is 6.3%. Using leading order cross sections and under the assumption of an integrated luminosity of  $1\text{fb}^{-1}$ , 5211 semi-leptonic  $t\bar{t}$  (muon channel only) are expected compared to 1084 from other  $t\bar{t}$  decays, 104 from W + jets, 82 from Wbb + 2 jets and 50 from Wbb + 3 jets.

ATLAS has studied the scenario of an integrated luminosity of  $150\text{pb}^{-1}$  and the absence of b-tagging [20]. In this analysis, an isolated lepton above 20 GeV transverse momentum and missing transverse energy above the same value is required. Only events with exactly four jets above 40 GeV transverse momentum pass the selection. This selection has an efficiency of 4.5%. There are four possibilities to assign three of the four jets to the top decay in which the W decays hadronically. In order to select the ‘best’ jets assignment the combination where the three jets system has the highest transverse momentum is chosen. Using this procedure, a peak at 167 GeV can be obtained clearly visible above the W + jets background.

### 3. CONCLUSIONS

The LHC is foreseen to deliver the first proton-proton collisions in 2008. Several interesting physics topics which can be pursued with the two omni-purpose detectors ATLAS and CMS with integrated luminosities between 10 and  $1000\text{pb}^{-1}$  have shortly been described. We all look forward to seeing the first data at energies never accessible before at a collider !

### ACKNOWLEDGMENTS

I would like to thank the conference organisers for the invitation to give this talk. And I certainly enjoyed the friendly and inspiring atmosphere during the conference.

### REFERENCES

1. See the LHC page at <http://cern.ch/lhc>.
2. “A word from the DG: The home straight,” *CERN Bulletin* **14/15** (2008) .
3. See the LHC commissioning procedures page at [http://cern.ch/lhccwg/overview\\_index.htm](http://cern.ch/lhccwg/overview_index.htm).
4. R.Bailey, “LHC status and commissioning plans”, presentation given at “Physics at the Terascale”, DESY, Hamburg, December 2007.
5. M. Cacciari and G. P. Salam, “Pileup subtraction using jet areas,” *Phys. Lett.* **B659** (2008) 119–126, [arXiv:0707.1378](https://arxiv.org/abs/0707.1378) [hep-ph].
6. CMS Collaboration, “Measurement of the Underlying Event in Jet Topologies using Charged Particle and Momentum Densities,” CMS Physics Analysis Summary QCD-07-003.
7. CDF Collaboration, R. D. Field, “Studying the underlying event at CDF,” Presented at 33rd International Conference on High Energy Physics (ICHEP 06), Moscow, Russia, 26 Jul - 2 Aug 2006, FERMILAB-CONF-06-409-E.



8. A. Moraes, C. Buttar, and I. Dawson, "Prediction for Minimum Bias and the Underlying Event at LHC Energies," ATL-PHYS-PUB-2005-007, ATL-COM-PHYS-2005-010.
9. K. Melnikov and F. Petriello, "Electroweak gauge boson production at hadron colliders through  $O(\alpha(s)^2)$ ," *Phys. Rev.* **D74** (2006) 114017, [arXiv:hep-ph/0609070](#).
10. CMS Collaboration, "Towards a Measurement of the Inclusive  $W \rightarrow e\nu$  and  $\gamma^*/Z \rightarrow e^+e^-$  Cross Sections in pp collisions at  $\sqrt{s} = 14$  TeV," CMS Physics Analysis Summary EWK-07-001.
11. CMS Collaboration, "Towards a Measurement of the inclusive  $W \rightarrow \mu\nu$  and  $Z \rightarrow \mu^+\mu^-$  cross sections in pp collisions at  $\sqrt{s} = 14$  TeV," CMS Physics Analysis Summary 2007/002.
12. M. Dittmar, F. Pauss, and D. Zurcher, "Towards a precise parton luminosity determination at the CERN LHC," *Phys. Rev.* **D56** (1997) 7284–7290, [arXiv:hep-ex/9705004](#).
13. A. Tricoli, A. Cooper-Sarkar, and C. Gwenlan, "Uncertainties on W and Z production at the LHC," ATL-PHYS-CONF-2005-008, ATL-COM-PHYS-2005-045, CERN-ATL-COM-PHYS-2005-045, CERN, Geneva, 2005. Contribution to the proceedings : HERA-LHC workshop 2005.
14. CMS Collaboration, "Measuring Electron Efficiencies at CMS with Early Data," CMS Physics Analysis Summary EGM-07-001.
15. R. Bonciani, S. Catani, M. L. Mangano, and P. Nason, "NLL resummation of the heavy-quark hadroproduction cross-section," *Nucl. Phys.* **B529** (1998) 424–450, [arXiv:hep-ph/9801375](#).
16. D0 Collaboration, V. M. Abazov *et al.*, "Measurement of the  $t\bar{t}$  production cross section in  $p\bar{p}$  collisions at  $\sqrt{s} = 1.96$  TeV," [arXiv:0803.2779 \[hep-ex\]](#).
17. CMS Collaboration, G. L. Bayatian *et al.*, "CMS technical design report, volume II: Physics performance," *J. Phys.* **G34** (2007) 995–1579.
18. M. Davids *et al.*, "Measurement of top-pair cross section and top-quark mass in the di-lepton and full-hadronic channels with CMS," CMS NOTE-2006-077.
19. J. D'Hondt, J. Heyninck, and S. Lowette, "Measurement of the cross section of single leptonic  $t$  anti- $t$  events," CMS NOTE-2006-064.
20. S. C. M. Bentvelsen and M. Cöbal, "Top studies for the Atlas detector commissioning," ATL-PHYS-PUB-2005-024, ATL-COM-PHYS-2005-039, CERN, Geneva, 2005.