Recent results from the ATLAS experiment at the CERN Large Hadron Collider are presented. The experiment operates with high data taking efficiency since the first collision. The results show an excellent detector performance and rapid achievement of the ATLAS physics program. This paper provides a brief overview of the highlights of physics results.

§1. Introduction

Since the first collision at Large Hadron Collider (LHC)\(^1\) last December 2009, the ATLAS detector\(^2\) has successfully recorded the data for the proton-proton collision at the center of mass energies of 900 GeV, 2.36 TeV and 7 TeV. The data samples at 900 GeV and 2.36 TeV correspond to the integrated luminosities of 9 \(\mu\text{b}^{-1}\) and 0.7 \(\mu\text{b}^{-1}\), respectively, while the accumulated data reached about 330 \(\text{nb}^{-1}\) with 7 TeV collisions in the end of July 2010 and the peak luminosity was \(2 \times 10^{30} \text{cm}^{-2}\text{s}^{-1}\). The data taking efficiency was more than 95% and almost all detectors were fully operated. The uncertainty on the absolute luminosity determination is under control by 11%\(^3\).

Many physics analyses are started at the 7 TeV data just arrived. In this paper, only selected topics are presented. The first measurement of the \(W\) and \(Z\) bosons, di-jet resonance search and test of the QCD events are summarized in brief.

§2. The ATLAS detector

The ATLAS detector comprises a thin superconducting solenoid surrounding the inner detector and three large superconducting toroids arranged with an eight-fold azimuthal coil symmetry placed around the calorimeters, forming the basis of the muon spectrometer. The Inner-Detector (ID) system consists of the pixel and silicon tracking detectors surrounded by the wire-based straw tube tracking detector which allows to identify electrons through their radiation. They are immersed in a 2 T axial magnetic field and provides tracking information for charged particles in a pseudorapidity range \(|\eta| < 2.5\). The calorimeter system covers the pseudorapidity range \(|\eta| < 4.9\). It is based on two different detector technologies, with liquid argon (LAr) and scintillator-tiles as active media. The electromagnetic (EM) calorimeter consists of lead absorbers and liquid argon as the active material, and the hadronic tile calorimeter is placed directly outside the EM calorimeter envelope. This steel/scintillating-tile detector is used in the barrel region, while the LAr-based calorimeter is used in the endcap region. The muon spectrometer is based on the magnetic deflection of muon tracks in the large superconducting air-core toroid magnets, instrumented with separate trigger and high-precision tracking chambers, cov-
Fig. 1. (a) Reconstructed transverse mass of the muon plus missing transverse energy system. (b) The invariant mass $m_{ll}$ of $Z$ candidates in the electron channels.


ering the pseudorapidity range $|\eta| < 2.7$. The first-level (L1) trigger system uses a subset of the total detector information to make a decision on whether or not to record each event, reducing the data rate to a design value of approximately 75 kHz. The subsequent two levels, collectively known as the high-level trigger, are the Level-2 (L2) trigger and the event filter (EF). They provide the reduction to a final data-taking rate designed to be approximately 200 Hz. Since the recording rate on this data taking period was low, most of analyses however do not use the higher level triggers, L2 and EF.

§3. Physics highlights

3.1. $W$ and $Z$ production cross section measurement

One of the highlights is the re-discovery of the $W$, $Z$ bosons and top quark at LHC. The $W$ boson was first observed in June 2010, then the observation of the first top candidate events are reported. The ATLAS has performed studies of various aspects of the weak boson properties. The $W$ and $Z$ bosons are cleanly identified with their decays to leptons (mostly electrons or muons). The $W$ boson transverse mass and the $Z$ boson invariant mass distributions are demonstrated in Figs. 1(a) and (b), respectively. This large excess of the events gives us a confidence of our understanding of the data.

The measurements of the inclusive production cross sections of the $W$ and $Z$ bosons is an important test of the Standard Model. The theoretical calculations involve parton distribution functions (PDF) with different couplings of the partons to the weak bosons. They are affected by significant higher-order QCD corrections.
The Latest Results from the ATLAS Experiment

Fig. 2. The measured values of $\sigma_W \times Br(W \to l\nu)$ for $W^+$, $W^-$ (a) and of $\sigma_{Z/\gamma^*} \times Br(Z/\gamma^* \to ll)$ (b). Results are shown for the combined electron-muon results. The theoretical predictions are based on NNLO QCD calculations. The predictions are shown for both proton-proton and proton-antiproton colliders as a function of $\sqrt{s}$. In addition, previous measurements at proton-antiproton colliders are shown. The CDF and D0 measurements are shown for both Tevatron collider energies, $\sqrt{s} = 1.8$ TeV and $\sqrt{s} = 1.96$ TeV. All data points are displayed with their total uncertainty. The theoretical uncertainties are not shown.

The production cross sections are measured to be\(^6\)

\[
\sigma_W \times Br(W \to l\nu) = 9.96 \pm 0.23 \text{ (stat)} \pm 0.50 \text{ (syst)} \pm 1.10 \text{ (lumi)} \text{ nb},
\]

\[
\sigma_{Z/\gamma^*} \times Br(Z/\gamma^* \to ll) = 0.82 \pm 0.06 \text{ (stat)} \pm 0.05 \text{ (syst)} \pm 0.09 \text{ (lumi)} \text{ nb},
\]

where the $Z/\gamma^*$ invariant mass window is $66 < m_{ll} < 116$ GeV. The used data is corresponding to the integrated luminosity of approximately 320 nb\(^{-1}\). In Figs. 2 (a) and (b), we summarize the single boson production cross sections as a function of the center-of-mass energy starting from earlier measurement at CERN together with previous measurements. The theoretical prediction is based on the NNLO calculation\(^7\) and they are a good agreement with the measurements.

3.2. Search for di-jet resonance

A search for the di-jet resonance is one of the goal of the early physics program at ATLAS. Several extensions beyond the SM predict new heavy particles, accessible at LHC energies, that decay into two energetic partons. The excited composite quark $q^*$ model is one of major target of the di-jet resonance search.\(^8\) The analysis was performed with the data for the integrated luminosity of 315 nb\(^{-1}\).

We present the di-jet mass distribution in Fig. 3(a). The error bars indicate the statistical uncertainty on the measurement. The predicted $q^*$ signals\(^9\) for excited-quark masses of 500, 800, and 1200 GeV are overlaid, and the bin-by-bin significance of the data-background difference is shown in the bottom of the figure. There was no resonance found. Thus, the upper limits were set on the product of cross section and signal acceptance for excited-quark production as a function of $q^*$ mass. These
exclude at the 95% CL the $q^*$ mass interval $0.30 < m_{q^*} < 1.26$ TeV. This exclusion limits are shown in Fig. 3(b). The black dotted curve shows the expected 95% CL upper limit and the light and dark yellow shaded bands represent the 68% and 95% credibility intervals of the expected limit, respectively. There is an additional overall uncertainty of 11% due to the luminosity measurement that is not shown. The dashed curves represent excited-quark $\sigma \cdot A$ predictions for different MC tunes, each using a different PDF set. In addition, the overall theory uncertainty shown in red is the quadratic sum of uncertainties from the choice of renormalisation and factorisation scales, parton distribution functions, $\alpha_s(M_Z)$, and the modelling of soft QCD effects. The results are already extending the reach of Tevatron experiments.

3.3. Test of QCD event model

Since the first collision, the detector was thoroughly commissioned and calibrated using QCD events. The initial performance studies were done using 900 GeV and 2.36 TeV collision data.\textsuperscript{10} Although there are so many studies to test the event properties arised by the QCD event model, one consequence is the inclusive jet cross section measurement.\textsuperscript{11} The measurement uses the data set of an integrated luminosity of 17 nb$^{-1}$. The anti-$k_t$ algorithm\textsuperscript{12} is used to identify jets, with two jet resolution parameters, $R = 0.4$ and 0.6. The uncertainty in the jet energy scale is determined to within 9% over the whole kinematic range of the measurement, and to within 6% for central jets above 60 GeV transverse energy, leading to systematic uncertainties in the cross section of around 40%. In Fig. 4, the inclusive jet double-differential cross section as a function of jet $p_T$ in different regions of $|y|$ for jets identified using the
Fig. 4. Inclusive jet double-differential cross section as a function of jet $p_T$ in different regions of $|y|$ for jets identified using the anti-$k_t$ algorithm with $R = 0.4$ (a), and the inclusive jet multiplicity spectrum (b). The data are compared to NLO pQCD calculations, Alpgen+Herwig/Jimmy and Pythia. The Pythia Monte Carlo simulation has been normalized to data to compare the shapes.

The anti-$k_t$ algorithm with $R = 0.4$ (a), and the inclusive jet multiplicity spectrum (b) are presented. The data are compared to NLO pQCD calculations, Alpgen+Herwig/Jimmy and Pythia. The Pythia Monte Carlo simulation has been normalized to data to compare the shapes. The overall theoretical predictions are well agreed with the measurements.

For further detail structure of the jets, the distributions are also compared with various Monte Carlo simulations with different underlying event and fragmentation tunings, where the MC simulations are normalized to the measured cross sections. Figures 5(a) and (b) show the jet width and its correlation with the jet $p_T$ within $|y_{jet}| < 2.8$ for all jets with $p_T > 20$ GeV, respectively. The jet width is defined as the transverse jet profile of the weighted average distance of the jet constituents to the jet direction. As we can see, the observed data is wider than the MC simulations. And their jet $p_T$ dependence is also different even at high $p_T$ jets. These studies will help the Monte Carlo tuning effort and provide the first steps towards the successful commissioning of jet calibration in ATLAS.

3.4. Underlying event tuning

The first underlying event measurements with the ATLAS detector at the LHC are presented. Used data is from the minimum-bias trigger collected in December 2009 and March 2010 during proton-proton collisions at center of mass energies of 900 GeV and 7 TeV respectively. Various event properties are compared with the different MC underlying tunings. The charged particle density and the charged transverse momentum sum are measured as function of the leading track transverse momentum. The track with the largest transverse momentum is chosen as the direction of the hard
scattering. Then, the angular distribution of the charged tracks with respect to the leading track is sensitive to the underlying event activity. The event is categorized in three regions according to the direction with respect to the azimuthal angle between charged particles and the leading track. The transverse regions, defined as $60 < |\Delta \phi| < 120$ degree between the tracks and the leading track, are most sensitive to the underlying event, since they are perpendicular to the axis of hardest scattering.

The parameter sets for the MC underlying event tunings are so called, AMBT1 (MC09), DW, Perugia0 and PHOJET. The AMBT1 (MC09)\textsuperscript{19} is the default parameter sets used in the ATLAS for the physics analyses at this time, which uses the $p_T$-ordered parton shower algorithm interfaced by PYTHIA. The initial state radiation and multi-parton interaction are treated as the separate cutoff scales. The MRST LO\textsuperscript{20} is used as the PDF set. The DW tune is to fit the D0 di-jet $\Delta \phi$ distribution\textsuperscript{21} based upon the virtuality-ordered shower interfaced by PYTHIA. The initial state radiation is maximized their virtuality. It uses the CTEQ5L1 PDF set. The Perugia0 is similar with DW tune but it uses the $p_T$-ordered parton shower. Then, finally, the PHOJET\textsuperscript{22} is the dual parton model based tune, which uses the pomeron exchange for soft and leading order perturbative QCD for hard interactions. It incorporates a model for high-mass diffraction dissociation including multiple jet production and recursive insertions of enhanced pomeron graphs.

As one typical example, in Fig. 6, we present the scalar sum $p_T$ density (a) and its standard deviation (b) of charged particles with $p_T > 0.5$ GeV and $|\eta| < 2.5$ as a function of the leading track $p_T$ in the transverse region. Phojet predictions are only shown in the region where sufficient statistics are available. The error bars show the statistical uncertainty while the shaded area shows the combined statistical and systematic uncertainty. In the scalar sum $p_T$ density distribution, the DW tune describes data better than the other tunes. This is mostly due to the larger forward
Fig. 6. Scalar sum $p_T$ density (a) and its standard deviation (b) of charged particles with $p_T > 0.5$ GeV and $|\eta| < 2.5$ as a function of the leading track $p_T$, for the transverse region defined by the leading track and compared with Pythia ATLAS MC09, DW and Perugia0 tunes and Phojet predictions. Phojet predictions are only shown in the region where sufficient statistics are available. The error bars show the statistical uncertainty while the shaded area shows the combined statistical and systematic uncertainty.

particle activity with $|\eta| \gtrsim 3$ than the other tunes. In fact, the data has larger activity in the forward region. On the other hand, none of tunes describe data for the standard deviation. As shown in Fig. 5, the internal jet structure is not so well described to the data.

§4. Summary

First physics results from the ATLAS detector at the LHC have been presented. The results show an excellent detector performance and rapid achievement of the ATLAS physics program. In this paper, only selected topics are presented, but many physics results are already available in the official ATLAS documentation page. An excellent agreement is obtained between data and theoretical predictions. While the level of the agreement already gives us confidence, the details studies for the underlying event model tuning is on-going.

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