Early QCD measurements with ATLAS

Craig Buttar[1] on behalf of the ATLAS collaboration

1- University of Glasgow - Dept of Physics and Astronomy
Glasgow, G12 8QQ - United Kingdom

This paper describes some of the QCD measurements that ATLAS will make using data from the large hadron collider (LHC). Studies of minimum bias events and the underlying event that can made with the first LHC data are presented. The determination of the jet energy scale of high P_T jets is discussed.

1 Introduction

This note describes some of the early QCD analyses that will be carried out by the ATLAS experiment [2] [3] with the first LHC data: measurement of characteristics of inelastic pp collisions through studies of minimum bias events, modelling and characterising the underlying event and the uncertainties on the jet energy scale (JES) of high-P_T jets, which is the principal uncertainty on the inclusive jet cross-section and will limit the constraints that can be placed on the high-x gluon pdf.

2 Minimum bias

The copious production of inelastic pp collisions means that some of the first studies at the LHC will be measurements of properties of minimum bias events: central pseudorapidity distribution of charged particles and the transverse momentum spectrum. Although measurements have been made at many low energy hadron colliders, there is no clear theoretical way to extrapolate the properties of the inelastic collisions from lower energies to LHC energies. Comparing predictions of the these quantities using PYTHIA [4] and PHOJET [5] simulation programs show that there large uncertainties in them [6]. Therefore there is much interest in measuring these events to provide a deeper understanding of low momentum transfer interactions and to understand the connection to the underlying event, which is discussed in the next section. Measurements based on charged tracks will be discussed in this note.

A description of the analysis of minimum bias events with ATLAS can be found in [7]. Inelastic events are dominated by events with low momentum particles in the geometric acceptance of ATLAS. This requires a trigger capable of selecting events without a bias for high momentum events and reconstruction of low momentum particles [8].

A critical element of the analysis is understanding the trigger efficiencies so that relative fractionss of the different inelastic processes: non-diffractive, single-diffractive and double diffractive accepted by the trigger can be determined,which allows comparison with other measurements and theoretical predictions. Central diffraction is not discussed here as it is only around 1% of the total inelastic cross-section [7].

The minimum bias trigger in ATLAS consists of several elements. The simplest minimum bias trigger is a random trigger selecting filled LHC bunches. However, during startup the protons will interact in only 10% or less of events.

ATL-PHYS-PROC-2009-075
03 August 2009

Therefore a high level trigger based on the number of spacepoints or tracks found in the silicon tracking detectors, which cover $|\eta| < 2.5$, has been implemented to reduce the number of noise events selected by the random trigger.

A hardware based level 1 trigger using a fast signal from the minimum bias trigger scintillators (MBTS) covering $2.1 < |\eta| < 3.8$ is also used.

	MBTS_1_1	MBTS_2	SP
ND	0.99	1.0	1.0
SD	0.45	0.69	0.57
DD	0.54	0.83	0.65

Table 1: Trigger efficiencies for MBTS and track trigger

The MBTS signals are combined to give two different triggers: MBTS_1_1 requires at least one hit above a given threshold in both the forward and backward MBTS and MBTS_2 requires at least two hits above threshold anywhere. The efficiencies of these triggers have been studied for each of the physics processes: non-diffractive (ND), single-diffractive (SD) and double-diffractive (DD), and are given in table 1.

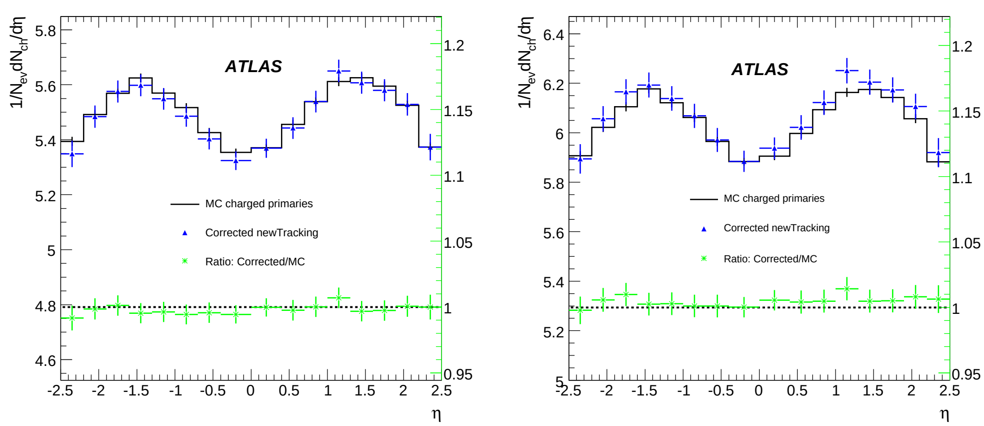

Figure 1: Charged particle pseudorapidity distributions, the left plot shows events selected using the MBTS_2 trigger and tracks with $p_t > 150\ \frac{MeV}{c}$ and the right plot shows the non-single diffractive pseudorapidity distribution

This shows that both the MBTS and track triggers are highly efficient for non-diffractive events but the efficiency for diffractive events is less. The MBTS_2 provides a less biased trigger compared to MBTS_1_1 as it accepts asymmetric events and therefore accepts more diffractive events. However, the MBTS_1_1 trigger is included to provide a trigger that is robust against beam-gas background. Which trigger is best will only be known when LHC collisions begin. In addition to MBTS and track trigger, both LUCID and ZDC [2] will provide triggers covering $5.6 < |\eta| < 5.9$ and $|\eta| > 8,3$ these will provide complementary triggers to the central trigger provided by MBTS and the track trigger, and improve the acceptance of diffractive events.

The charged particle pseudorapidity distribution of events selected using the MBTS_2 trigger and the distribution corresponding to non-single diffractive (NSD) events are shown in Figure 1 for $p_T > 150\ \frac{MeV}{c}$. The results are based on 75,000 simulated events and so the statistical errors are negligible. The principal systematic arising from the experiment is the uncertainty on the mis-alignment of the tracker, which is estimated to be 6%. However, the cosmic ray data taken has allowed the central barrel region of the tracker to be aligned [3]. Therefore it is expected that this error will be substantially reduced. The correction of the rapidity distribution to remove the SD events requires the relative cross-sections of the inelastic processes to be well understood. However, PYTHIA and PHOJET give large differences and a systematic uncertainty of 4% was therefore assigned. The results show that a measurement of the NSD charged particle rapidity distribution can be made with systematic uncertainties at the level of 8%. This will allow the models of inelastic events to be tuned using the first LHC data.

3 Underlying event

The underlying event (UE) is the structure of the event not associated with the hard scattering process. This includes: the beam remnants and the connection of the hard scatter to them, radiation and parton distribution functions (pdfs). It can affect a range of physical quantities: for example, lepton isolation, the top mass and jet energies at low P_T. The UE has been extensively studied at the Tevatron. As the soft component related to the beam

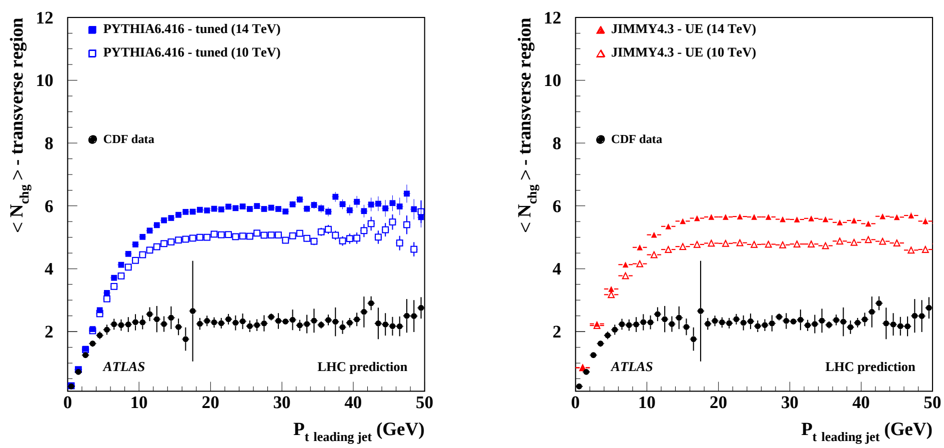

Figure 2: The predicted charged particle flow in the transverse region as function of the leading jet P_T in jet events for PYTHIA (left plot) and HERWIG with JIMMY (right plot).

remnants is a significant component of the underlying event it is difficult to extrapolate to LHC energies. However for studies of LHC physics it has been important to tune current event generators capable for simulating the underlying event: PYTHIA and HERWIG [9] with JIMMY [10], with CDF data and use this to evaluate the uncertainty on the underlying event at the LHC.

The PYTHIA 6.4 UE model, which uses the new PYTHIA multi-parton interaction model, has been tuned to CDF data by varying the string length and matter distributions

Similarly HERWIG and JIMMY were tuned and details can also be found in [11]. These have been used to make predictions of the particle and p_T-flow in the transverse region in jet events for 14 and 10 TeV, as shown in Figure 2, and show that the plateau values at 10 TeV are reduced by around 16% compared to 14 TeV.

These studies show that the UE can be evaluated for leading jets of p_T up to 50 GeV using the minimum bias trigger with around 10 pb^{-1}. Further studies probing the properties of the UE can be made by, for example, splitting the transverse region into maximum and minimum regions [11].

The effect of the underlying event in Z+jet events is demonstrated in Figure 3, which shows the ratio of jet P_T in Z+jet events to that of jets generated without fragmentation and the underlying event where the jets were reconstructed with the ATLAS cone algorithm with R=0.4 . This shows that fragmentation reduces the jet energy. Figure 3 shows the

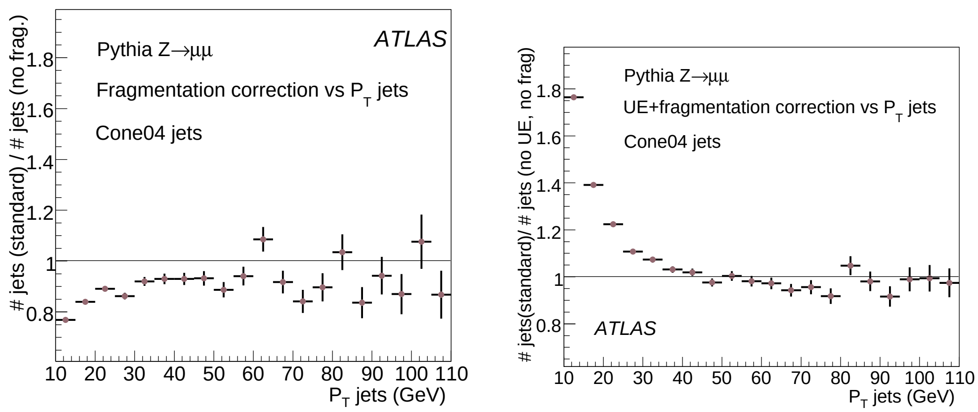

Figure 3: Ratio of leading jet P_T for jets in Z+jet events reconstructed with R=0.4 with and without fragmentation corrections (left plot) and with and without corrections for fragmentation and the UE (right plot)

same ratio but including fragmentation and the UE. The UE adds energy to the jet and this compensates the energy loss from fragmentation. The precise balancing of fragmentation and underlying event in the jet energy is dependent on the jet reconstruction algorithm used. Nonetheless it is clear that an understanding of the UE is required in order to accurately reproduce jet P_T in simulated events to allow theoretical predictions to be compared to data.

4 Determination of the jet energy scale for high-P_T jets

Previous studies have shown [12] that measurements of the inclusive jet cross-section at the LHC has the potential to constrain the high-x gluon pdf. However the prinicpal experimental uncertainty is the uncertainty on the jet energy scale (JES) for high P_T jets ($P_T \gtrsim 500$ GeV), which needs to be at the level of a few per cent to allow a constraint to placed on the pdfs.

The JES can be determined using P_T-balance in Z+jet and γ+jet events covering the ranges $10 < P_T < 100 - 200$ GeV and $100 - 200 < P_T < 500$ GeV, respectively. The statistical errors lead to a 1-2% uncertainty on the JES for luminosities around 100pb^{-1}. However, the uncertainty in the modelling of the initial and final-state radiation (ISR/FSR) and the underlying event lead to uncertainties on the JES of 5-10% for $P_T < 100$ GeV and of 1-2% for $P_T >$100-500 GeV [7].

The JES uncertainty for P_T is measured by balancing a high P_T jet against several low P_T jets. The statistical errors lead to an uncertainty on the JES of around 2% for 1fb^{-1}. However, the uncertainty on the JES is dominated by the uncertainty in the JES of the balancing jets with P_T in the range 40-100 GeV due to uncertainties in ISR/FSR and UE as discussed above. The uncertainty on the JES is therefore around 8% for P_T in the range 400-1100 GeV [7]. This would preclude a measurement of the high-x gluon pdf from the inclusive jet cross-section. However, it should be noted the uncertainties arise from uncertainties in the modelling of ISR/FSR and the UE. With data, ATLAS will be able to tune models of the UE to data as described above and ISR/FSR to measurements such as the azimuthal decorrelation [13].

5 Summary and Conclusions

A study of the measurement of the $\frac{1}{N_{ev}}\frac{dN_{ch}}{d\eta}$ in minimum bias events was presented and demonstrates that this measurement can be made with sufficient accuracy to distinguish between models. Studies of measurements of the underlying event show that it can be measured sufficiently well to distinguish between models, and the effect it has on the simulation of jet P_T. A method for determining the JES of high-P_T jets was discussed but is found to be affected by systematic uncertainties of the JES of low-energy P_T jets arising from uncertainties in the UE and ISR/FSR.

6 Acknowledgments

I am grateful to my ATLAS colleagues for many useful discussions,particularly Arthur Moraes, Will Bell and Alessandro Tricoli. I am grateful to the UK Science and Technology Facilities Council for support.

References

[1] Slides of this talk can be found at: `http://indico.cern.ch/contributionDisplay.py?contribId=24&sessionId=38&confId=53294`

[2] G. Aad *et al.*, JINST. **3** S08003 (2008).

[3] A. Watson, The Status of ATLAS, these proceedings

[4] T. Sjostrand, S. Mrenna and P. Skands, JHEP **05** 26 (2006).

[5] R. Engel, Z. Phys. C. **66** 203 (1995).

[6] A. Moraes, C. Buttar and I. Dawson, Eur. J. Phys. **C50** 435 (2007).

[7] G. Aad *et al.*, arXiv:0901.0512, (2009).

[8] W. Bell, ATL-PHYS-PROC-2009-051,(2009).

[9] G. Corcella *et al.*, JHEP **01** 10 (2001).

[10] J.M. Butterworth, J.R. Forshaw and M.H. Seymour, Z. Phys. C. **72** 637 (1996).

[11] A.Moraes, ATL-PHYS-PROC-2009-045, (2009).

[12] D. Clements, Prospects for inclusive jet cross-section measurement with early data at ATLAS, XV International Workshop on Deep Inelastic Scattering and Related Subjects, Munich, Germany (2007).

[13] A. Moraes *et al.*, ATL-PHYS-PUB-2006-013 (2006).