QCD MEASUREMENTS FROM MINIMUM BIAS TO JETS*

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(Received November 15, 2006)

Recent QCD studies performed within ATLAS will be shown. QCD generators have been tuned in order to have a good description of the available minimum bias and underlying event data. Their predictions at the LHC energy and the reconstruction of events in ATLAS have also been studied. Jet physics analysis has been performed as well: to study how a measurement of the inclusive jet cross section could help on constraining parton density functions, how well dijet azimuthal decorrelations can be measured and how to use multi-jet events to calibrate the detector.

PACS numbers: 13.85.Hd, 13.87.–a

1. Introduction

At LHC, essentially all physics will come from quark and gluon interactions. Perturbative QCD has been quite successful on describing scatterings involving large amount of transverse momenta (≥ 2 GeV), known as hard interactions. However, for interactions with small transverse momenta (soft interactions) the strong coupling constant becomes too large for perturbation theory to be applied and phenomenological models have to be used instead.

High energy hadronic collisions are dominated by soft partonic interactions, usually associated to the so called Minimum Bias (MB) events. But soft interactions are also the dominant processes in the Underlying Event (UE) of the hard scattering process.

A detailed understanding of QCD is therefore important for almost all physics processes to be studied at the LHC; not only for a particular channel which might indicate interesting phenomena but also to understand the

* Presented at the "Physics at LHC" Conference, Kraków, Poland, July 3–8, 2006.

background to that channel. The LHC offers as well the possibility to test QCD precisely over a large energy range. In this note some of the latest studies done within ATLAS are presented.

2. Minimum bias and underlying event

Since soft interactions will be the dominant processes in pp collisions at the LHC, models capable of reproducing the available MB and UE data are extremely important for predicting background levels associated to many physics processes and also for understanding the complex nature of the radiation environment in which the detector will operate.

Here MB events are defined as non-single diffractive inelastic (NSD) interactions. A good description of the existing data has been accomplished by Pythia 6.214 (after some tuning) and Phojet 1.12 [1–3]. However, if one looks at their predictions at LHC energies they start to diverge, meaning that uncertainties are large (as can be seen if figure 1 for the charged particle density at $\eta = 0$). LHC data are then needed to tune these models at that energy. Due to the limited rapidity coverage of the ATLAS Inner Detector ($|\eta| < 2.5$) and to the present p_t cut-off of 0.5 GeV applied in the tracking algorithms, only a fraction of tracks are reconstructed. A special tuning of the ATLAS tracking for softer particles is being studied.

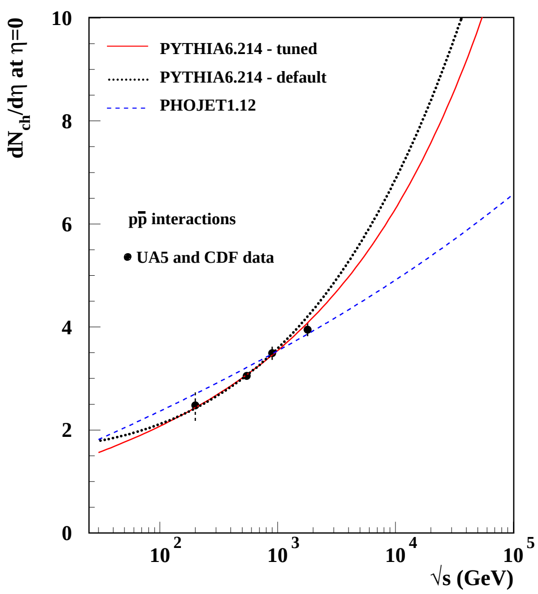

Fig. 1. Charged particle density at $\eta = 0$ as a function of $\sqrt{s}$. Monte Carlo distributions were generated with Pythia 6.214 (with default and tuned parameters) and Phojet 1.12.

In a hadronic event containing jets, the UE consists of all event activity except the two outgoing hard scattered jets. The UE contains a soft component coming from beam–beam remnants and a hard component from initial and final state radiation and secondary parton interactions. As for MB events, there are large uncertainties in the predictions given by the generators at the LHC energies [4].

Studies to measure the properties of the UE in ATLAS have been done. As an example, the average track multiplicity in the transverse region (*i.e.* in the UE), as a function of the leading jet transverse energy has been compared at reconstruction level with the Monte Carlo truth (as shown in figure 2) to conclude that detector corrections are well under control.

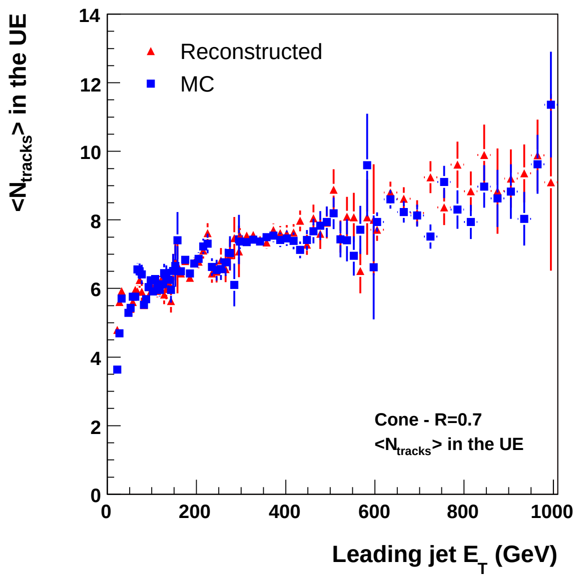

Fig. 2. Average track multiplicity in the transverse region, as a function of the leading jet transverse energy at reconstruction and Monte Carlo truth level.

3. Jet physics

3.1. Inclusive jet cross section

A measurement of the inclusive jet cross section can be used to constrain parton density functions (PDFs) and to look for new physics (*e.g.* quark compositeness). Due to the huge cross section, the measurement will be fully dominated by systematics, as the knowledge of the jet energy scale (at 1 TeV leading jet a change of 1% on the jet energy implies an uncertainty of 6% on the inclusive jet cross section).

On the theoretical side, at next-to-leading order (NLO), typical residual renormalization and factorization scale uncertainties are about 5–10% and should hopefully be reduced once calculations at higher order are available. On the other hand, the impact of PDF uncertainties can be substantially larger in some regions, specially at large p_t, and dominate the overall uncertainty ($\sim$10–15% at 1 TeV).

In order to study how much ATLAS data could help on constraining PDFs, pseudo-data equivalent to one year of data taking was generated and used in a global PDF fit [5]. Figure 3 shows the gluon fractional uncertainty as a function of x before and after including the ATLAS pseudo-data (assuming 10% systematic uncertainty). A significant improvement is observed at high x. Improving statistics from 1 fb^{-1} to 10 fb^{-1} has little effect on improving the constraining of PDF, while a better understanding of systematics (from 10% to 5%) does.

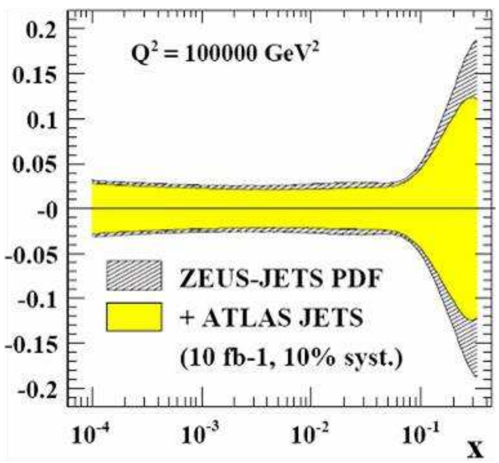

Fig. 3. Gluon fractional uncertainty as a function of x without and with the inclusion of the ATLAS pseudo-data.

Concerning the low x region, it has been shown that it can be significantly constrained by measuring W rapidity distributions. The low x gluon parameter λ uncertainty can be reduced by $\sim 35\%$ after including 1 million of ATLAS pseudo-data into global PDF fits (assuming 4% uncertainty) [6].

3.2. Dijet azimuthal decorrelations

A clean way to study QCD radiative processes is to examine their impact on the angular distributions of jets. In the most simple case, a *pp* collision will produce two jets with equal energies transverse to the beam direction and correlated azimuthal angle such that the azimuthal difference $\Delta\phi_{\rm dijet}$ is equal to π. As additional particles or additional jets are produced in the same event $\Delta\phi_{\text{dijet}}$ becomes less than π. The production of a small number of low energetic additional particles leads to small deviations from π. On the other hand, small values of $\Delta\phi_{\text{dijet}}$ are an indication that additional high energy jets have been produced in the event due to hard radiative emissions or even multiparton interactions. The azimuthal difference provides then an ideal testing ground to study the transition between soft and hard QCD processes based on a single observable.

Figure 4 shows the prediction given by Pythia 6.226 for two different values of the parameter controlling the amount of ISR (Initial State Radiation) and Herwig 6.506 for the azimuthal decorrelation at LHC for two leading jet p_t regions [7]. The two Pythia predictions show significant changes in the low $\Delta\phi_{\text{dijet}}$ region, meaning that this measurement is sensitive to the modeling of ISR. The distributions generated by Herwig are fairly similar to those generated by Pythia with increased ISR.

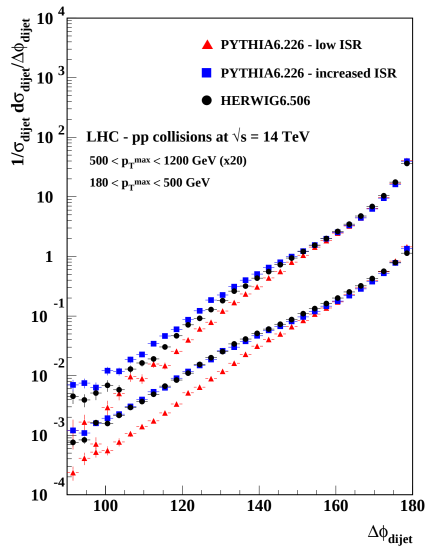

Fig. 4. Azimuthal decorrelation at the LHC predicted by Herwig 6.506 and Pythia 6.229 for two different values of the parton virtuality parameter (PAR(67) = 1 (low) and 4 (increased) ISR).

QCD jet events were generated by Pythia 6.226, passed though the initial ATLAS layout geometry and reconstructed by the ATLAS software. The dijet azimuthal decorrelations distributions were then computed at generator and reconstruction level. As can be seen in figure 5 the reconstructed distribution reproduces reasonable well the Monte Carlo truth distributions.

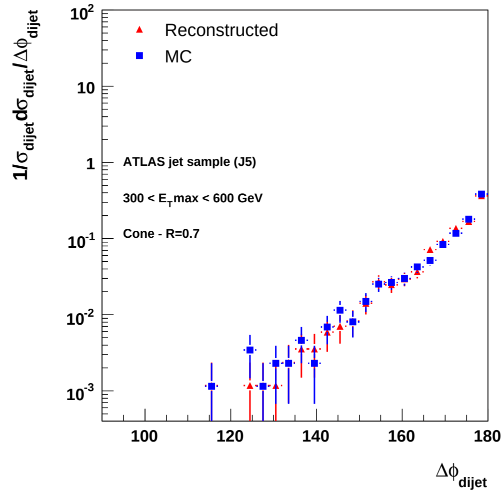

Fig. 5. Dijet azimuthal decorrelation distribution at Monte Carlo truth and reconstructed level. Jets are defined using a cone jet algorithm with a cone radius R set to 0.7. Leading jets with $300 < E_{\mathrm{T}} < 600$ GeV have been required.

3.3. Multi-jet production

If one looks at the jet cross section for different jet multiplicities (see figure 6) one observes that, compared to Tevatron where the cross section decreases steeply with increase jet transverse energy, the cross section is

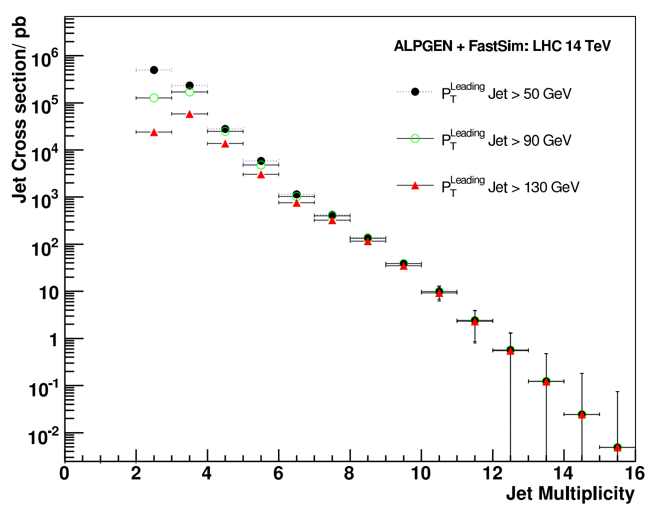

Fig. 6. Jet cross section for different jet multiplicities and different leading jet transverse momentum cuts.

still huge for $E_{\mathrm{T}} > 130$ GeV. That means that they are not a negligible background in many searches for new physics or top studies for instance. But also that they can be used for calibration purposes, as jet energy scale calibration. As an example, from the p_t balance in γ+jets using special techniques to take into account the multi-jet environment or by reconstructing the invariant mass of the two jets coming from the W in $t\bar{t}$ events.

4. Summary

A good understanding of QCD is essential for physics at the LHC. Since soft interactions are the dominant process, it is crucial to have a good description of MB and UE events. Monte Carlo event generators have been tuned in order to provide a good description of the available data but uncertainties are large at the LHC energy.

The jet cross section at the LHC will be huge ($\sim 10^5$ nb) which will allow to probe the smallest distance scales. A measurement of the inclusive cross section can help on constraining the gluon PDF at high x substantially. The low x region can be improved by measuring the W rapidity distribution.

Studies of dijet azimuthal decorrelations have been done in ATLAS showing that the measurement is quite robust. It has also been shown to be sensitive to the amount of ISR modeled in the generators.

I am specially grateful to M. Boonekamp, C. Buttar, T. Carli, D.R. Clements, A. Cooper-Sarkar, I. Dawson, C. Gwenlan, A. Moraes, S. Padhi, M. Sutton and A. Tricoli for their input to this note and for all the useful discussions.

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