PROCEEDINGS OF SCIENCE

Description of the ATLAS jet veto measurement and jet gap jet events at hadronic colliders

Christophe Royon*
CEA/IRFU/Service de physique des particules, CEA/Saclay, 91191 Gif-sur-Yvette cedex, France
E-mail: christophe.royon@cea.fr

We present a new QCD description of the ATLAS jet veto measurement, using the Banfi-Marchesini-Smye equation to constrain the inter-jet QCD radiation. This equation resums emissions of soft gluons at large angles and leads to a very good description of data. We also investigate jet gap jet events in hadron-hadron collisions, in which two jets are produced and separated by a large rapidity gap. Using a renormalisation-group improved NLL kernel implemented in the HERWIG Monte Carlo program, we show that the BFKL predictions are in good agreement with the Tevatron data, and present predictions that could be tested at the LHC.

Photon 2013,
20-24 May 2013
Paris, France

*Speaker.

Recently the ATLAS collaboration measured, in proton-proton collisions at the LHC, the fraction of di-jet events that do not contain additional hard radiation in the inter-jet rapidity range [1]. The original goal of this measurement was to look for BFKL-type effects [2], as was previously done at the Tevatron with the so-called 'jet-gap-jet' observable [3, 4, 5]. However the use of a veto scale $E_{out} \gg \Lambda_{QCD}$ by ATLAS, instead of a true rapidity gap void of any hadronic activity, drastically reduces the sensitivity to BFKL physics. In a first section of this report, we discuss the description of the ATLAS jet veto measurement and in a second section, we discuss the jet gap het events where the gap is a region of the detector devoid of any activity.

1. ATLAS measurement of the jet veto cross section

1.1 ATLAS measurement

The ATLAS collaboration chose to select events with two high p_T jets well separated by the interval in rapidity Δy. The idea is then to veto on additional jet activity between the two jets requesting the absence of reconstructed jets with $p_T > Q_0$ with $Q_0 \gg \Lambda_{QCD}$. By default, Q_0 is taken at 20 GeV. The events with such configuration are called "gapped". The observable of interest is the gapped fraction in proton-proton collisions at $\sqrt{s} = 7$ TeV. It is defined as

$$\mathscr{R}(\Delta y, p_T) \equiv \frac{d\sigma^{\text{veto}}}{d\Delta y\, d^2 p_T} \Big/ \frac{d\sigma^{\text{incl}}}{d\Delta y d^2 p_T}\,, \tag{1.1}$$

where σ^{incl} is the inclusive cross section of di-jet events and Δy is the rapidity difference of the two jets which have mean transverse momentum $p_T = (p_{T,1} + p_{T,2})/2 \geq 50$ GeV and rapidity $|y_i| < 4.4$. Jets are reconstructed using the anti-k_t algorithm [6] with the radius parameter $R = 0.6$. In defining the di-jet system in each event, ATLAS used two different selection criteria: The highest-p_T jet pair and the most forward/backward jet pair. σ^{veto} is the gapped cross section in which a veto is applied to the di-jet cross section requiring that no jet with p_T above $E_{out} = 20$ GeV is observed in the rapidity interval between the two jets.

Data are compared with the NLO MC approach using POWHEG [7] and parton shower using PYTHIA [8] or HERWIG [9] or the BFKL calculation as implemented in the HEJ [10] Monte Carlo, large discrepancies are found. Both approaches miss the resummation of soft gluons at large angles as we will see in the following.

1.2 Jet veto using the BSM formalism

The resummation of soft gluon emissions at large angle is not taken into account in usual parton shower Monte Carlo. It was computed in the e^+e^- case where one can resum the soft logarithms $\alpha_S \log p_T/E_{out}$ when the jet p_T is much larger than E_{out} while requiring that the energy flow into the region between the jets is less than E_{out}.

The e^+e^- case was extended to the pp one, and we use the Banfi Marchesini Smye equation [11] to compute the probability P_T that the total energy emitted outside the jet cone is less than E_{out}

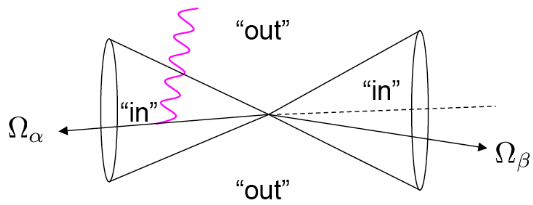

Figure 1: Geometry for the region between jets defining the "in" and "out" regions as well as the emitted soft photon.

$$\partial_T P_T(\Omega_\alpha,\Omega_\beta) = -\int_{C_{out}} \frac{d^2\Omega_\gamma}{4\pi}\frac{1-cos\theta_{\alpha\beta}}{(1-cos\theta_{\alpha\gamma})(1-cos\theta_{\gamma\beta})}P_T(\Omega_\alpha,\Omega_\beta)+$$
$$\int_{C_{in}} \frac{d^2\Omega_\gamma}{4\pi}\frac{1-cos\theta_{\alpha\beta}}{(1-cos\theta_{\alpha\gamma})(1-cos\theta_{\gamma\beta})}\left(P_T(\Omega_\alpha,\Omega_\gamma)P_T(\Omega_\gamma,\Omega_\beta)-P_T(\Omega_\alpha,\Omega_\beta)\right) \quad (1.2)$$

where the Sudakov and the non-global logarithms are resummed. Numerical solutions of this equation are available [12] and we used them for our calculation.

1.3 Comparison with ATLAS measurement

The comparison with ATLAS data is given in Figs. 2 and 3 as a function of the rapidity interval between the jets for E_{out} =20 GeV and as a function of E_{out}. The description of the Δy dependence is very good [13] showing that the discrepancy between the ATLAS data and the NLO calculation was indeed due to the lack of resummation of the soft gluons at large angles. The E_{out} dependence is poorly described when the jet p_T are of similar values as E_{out} as expected. It is clear that the jet veto cross section measurement is not a good test of the BFKL resummation effect and other obsevables such as gap devoid of any energy between jets are needed.

2. Jet gap jet cross section measurements at the LHC

In a hadron-hadron collision, a jet-gap-jet event features a large rapidity gap with a high$-E_T$ jet on each side ($E_T \gg \Lambda_{QCD}$). Across the gap, the object exchanged in the $t-channel$ is color singlet and carries a large momentum transfer, and when the rapidity gap is sufficiently large the natural candidate in perturbative QCD is the Balitsky-Fadin-Kuraev-Lipatov (BFKL) Pomeron [2]. Of course the total energy of the collision $\sqrt{s}$ should be big ($\sqrt{s} \gg E_T$) in order to get jets and a large rapidity gap.

Following the success of the forward jet and Mueller Navelet jet BFKL NLL studies [14], we use the implementation of the BFKL NLL kernel inside the HERWIG [9] Monte Carlo to compute the jet gap jet cross section, compare our results with the Tevatron measurement and make predictions at the LHC [5].

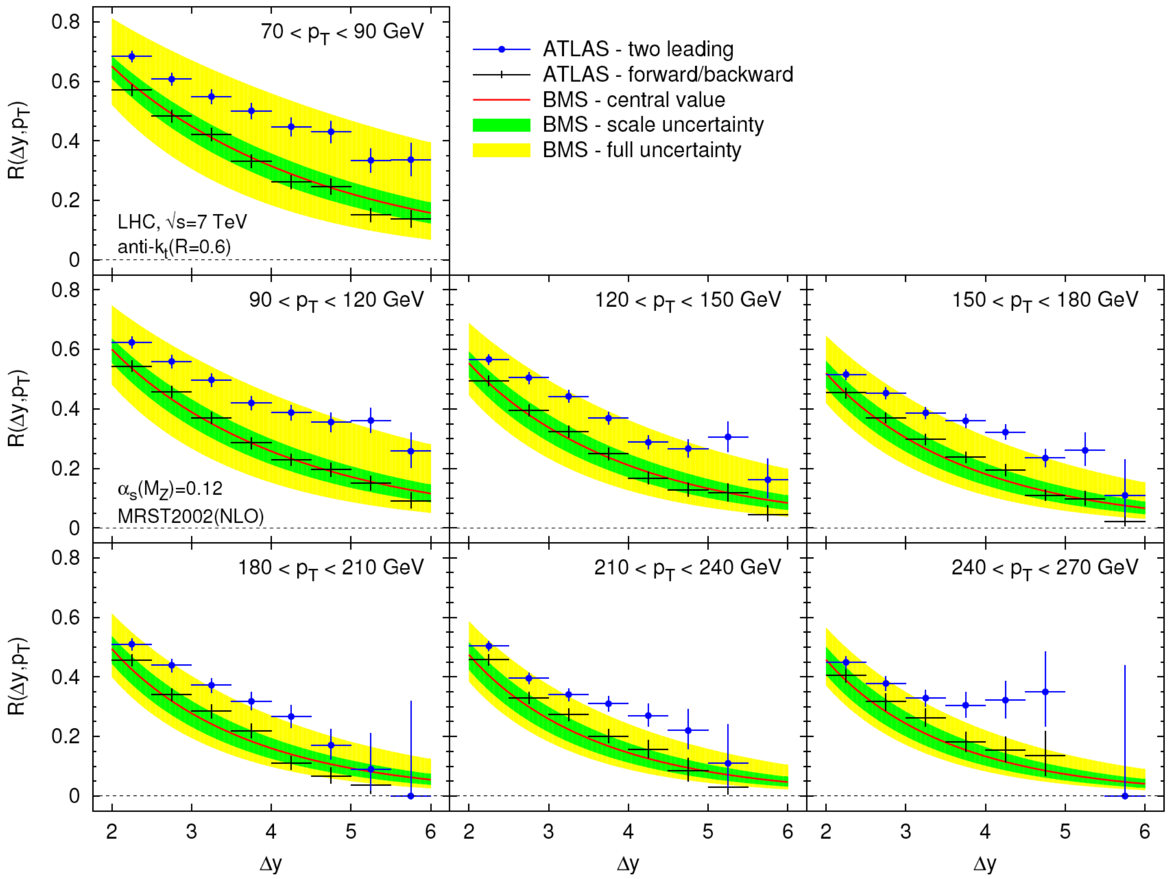

Figure 2: Comparison of the resummed veto fraction with the ATLAS measurement, for a fixed veto energy of $E_{out} = 20$ GeV, in different bins of p_T. The inner (green) uncertainty band is obtained taking into account only the renormalization and factorization scale uncertainties, while the outer (yellow) band also includes the subleading logarithmic uncertainty. For the ATLAS data, circles represent the case where the two leading jets are selected while the one where the most forward and backward jets are selected are represented by crosses.

2.1 BFKL NLL formalism

The production cross section of two jets with a gap in rapidity between them reads

$$\frac{d\sigma^{pp\to XJJY}}{dx_1 dx_2 dE_T^2} = \mathscr{S} f_{eff}(x_1, E_T^2) f_{eff}(x_2, E_T^2) \frac{d\sigma^{gg\to gg}}{dE_T^2}, \tag{2.1}$$

where $\sqrt{s}$ is the total energy of the collision, E_T the transverse momentum of the two jets, x_1 and x_2 their longitudinal fraction of momentum with respect to the incident hadrons, S the survival probability, and f the effective parton density functions [5]. The rapidity gap between the two jets is $\Delta\eta = \ln(x_1 x_2 s/p_T^2)$.

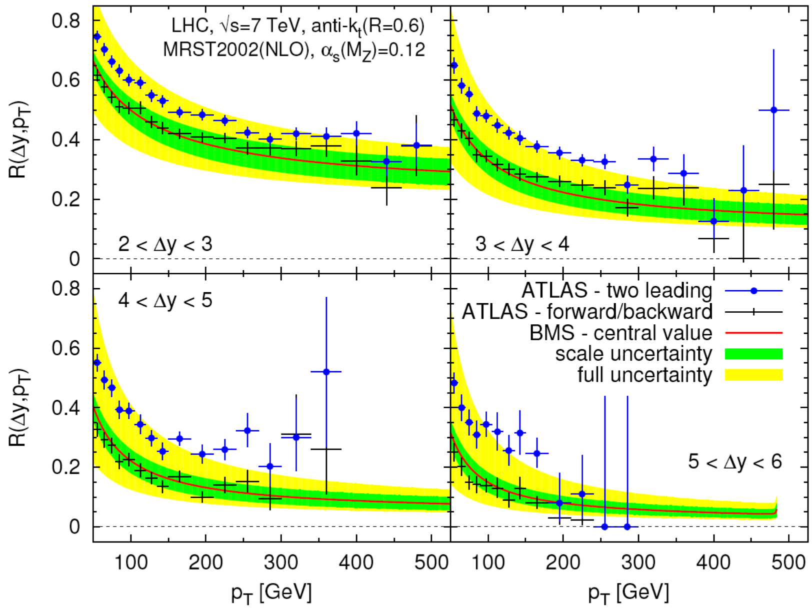

Figure 3: Comparison of the resummed veto fraction with the ATLAS measurement, for different kinematic bins, as a function of the veto threshold E_{out}.

The cross section is given by

$$\frac{d\sigma^{gg\to gg}}{dE_T^2} = \frac{1}{16\pi}\left|A(\Delta\eta, E_T^2)\right|^2 \tag{2.2}$$

in terms of the $gg \to gg$ scattering amplitude $A(\Delta\eta, p_T^2)$.

In the following, we consider the high energy limit in which the rapidity gap $\Delta\eta$ is assumed to be very large. The BFKL framework allows to compute the $gg \to gg$ amplitude in this regime, and the result is known up to NLL accuracy

$$A(\Delta\eta, E_T^2) = \frac{16N_c\pi\alpha_s^2}{C_F E_T^2}\sum_{p=-\infty}^{\infty}\int\frac{d\gamma}{2i\pi}\frac{[p^2-(\gamma-1/2)^2]\exp\left\{\bar{\alpha}(E_T^2)\chi_{eff}[2p,\gamma,\bar{\alpha}(E_T^2)]\Delta\eta\right\}}{[(\gamma-1/2)^2-(p-1/2)^2][(\gamma-1/2)^2-(p+1/2)^2]} \tag{2.3}$$

with the complex integral running along the imaginary axis from $1/2-i\infty$ to $1/2+i\infty$, and with only even conformal spins contributing to the sum, and $\bar{\alpha} = \alpha_S N_C/\pi$ the running coupling.

Let us give some more details on formula 2.3. The NLL-BFKL effects are phenomenologically taken into account by the effective kernels $\chi_{eff}(p,\gamma,\bar{\alpha})$. The NLL kernels obey a *consistency condition* which allows to reformulate the problem in terms of $\chi_{eff}(\gamma,\bar{\alpha})$. The effective kernel $\chi_{eff}(\gamma,\bar{\alpha})$ is obtained from the NLL kernel $\chi_{NLL}(\gamma,\omega)$ by solving the implicit equation $\chi_{eff} = \chi_{NLL}(\gamma,\bar{\alpha}\ \chi_{eff})$ as a solution of the consistency condition.

In this study, we performed a parametrised distribution of $d\sigma^{gg\to gg}/dE_T^2$ so that it can be easily implemented in the Herwig Monte Carlo since performing the integral over γ in particular would be too much time consuming in a Monte Carlo. The implementation of the BFKL cross section in

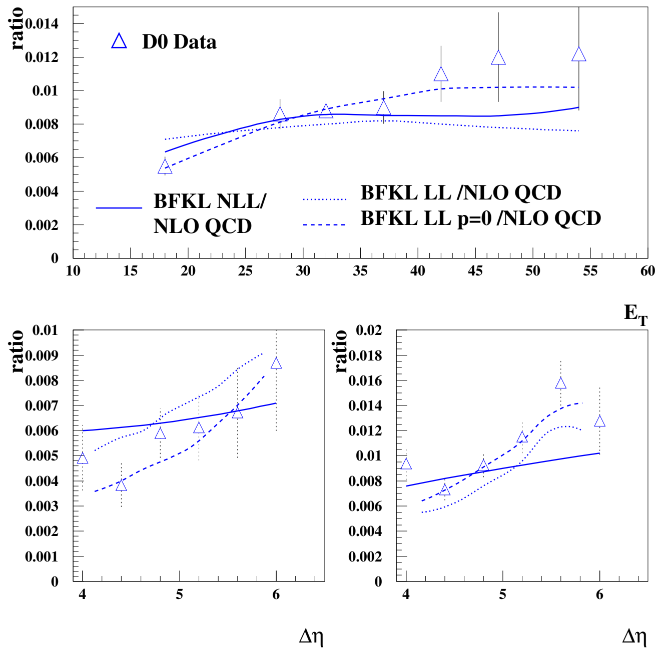

Figure 4: Comparisons between the D0 measurements of the jet-gap-jet event ratio with the NLL- and LL-BFKL calculations. For reference, the comparison with the LL BFKL with only the conformal spin component $p = 0$ is also given.

a Monte Carlo is absolutely necessary to make a direct comparison with data. Namely, the measurements are sensititive to the jet size (for instance, experimentally the gap size is different from the rapidity interval between the jets which is not the case by definition in the analytic calculation).

2.2 Comparison with Tevatron measurements

Let us first notice that the sum over all conformal spins is absolutely necessary. Considering only $p = 0$ in the sum of Equation 2.3 leads to a wrong normalisation and a wrong jet E_T dependence, and the effect is more pronounced as $\Delta\eta$ diminishes.

The D0 collaboration measured the jet gap jet cross section ratio with respect to the total dijet cross section, requesting for a gap between -1 and 1 in rapidity, as a function of the second leading jet E_T, and $\Delta\eta$ between the two leading jets for two different low and high E_T samples (15< E_T <20 GeV and E_T >30 GeV). To compare with theory, we compute the following quantity

$$Ratio = \frac{BFKL\ NLL\ HERWIG}{Dijet\ Herwig} \times \frac{LO\ QCD}{NLO\ QCD} \tag{2.4}$$

in order to take into account the NLO corrections on the dijet cross sections, where *BFKL NLL HERWIG* and *Dijet Herwig* denote the BFKL NLL and the dijet cross section implemented in HERWIG. The NLO QCD cross section was computed using the NLOJet++ program [16].

The comparison with D0 data [17] is shown in Fig. 4. We find a good agreement between the data and the BFKL calculation. It is worth noticing that the BFKL NLL calculation leads

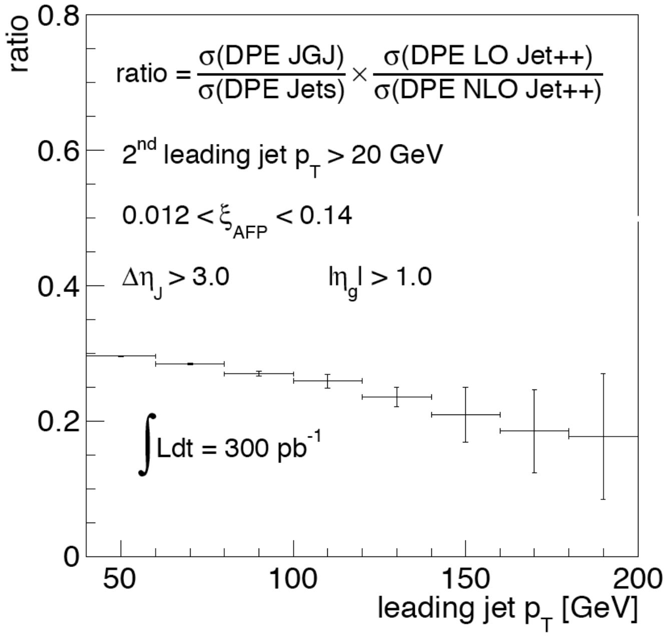

Figure 5: Ratio of DPE Jet gap jet events to standard DPE dijet events as a function of the leading jet p_T [15].

to a better result than the BFKL LL one (note that the best description of data is given by the BFKL LL formalism for $p = 0$ but it does not make sense theoretically to neglect the higher spin components and this comparison is only made to compare with previous LL BFKL calculations). The comparisons with the CDF data is found to be similar.

2.3 Predictions for the LHC

Using the same formalism, and assuming a survival probability of 0.03 at the LHC, it is possible to predict the jet gap jet cross section at the LHC. While both LL and NLL BFKL formalisms lead to a weak jet E_T or $\Delta\eta$ dependence, the normalisation if found to be quite difference leading to higher cross section for the BFKL NLL formalism [5].

2.4 Jet gap jet production in double Pomeron exchanges processes

In this process, both protons are intact after the interaction and detected in the forward proton detectors to be installed in CMS/TOTEM and ATLAS at 210 m, two jets are measured in the ATLAS/CMS central detector and a gap devoid of any energy is present between the two jets [15]. This kind of event is important since it is sensitive to QCD resummation dynamics given by the BFKL [2] evolution equation . This process has never been measured to date and will be one of the best methods to probe these resummation effects, benefitting from the fact that one can perform the measurement for jets separated by a large angle (there is no remnants which 'pollute' the event). As an example, the cross section ratio for events with gaps to events with or without gaps as a function of the leading jet p_T is shown in Fig 5 for 300 pb^{-1}. The measurement has to be performed at medium luminosity at the LHC so that the gap between the jets is not “polluted" by pile up events. The presence of few pile up events in average is still possible for this measurement since central gaps can be identified using central tracks fitted to the main vertex of the event. It is worth noticing that the ratio between the jet gap jet and the dijet cross sections in DPE events is of the order of 20% which is much higher than the expectations for non-diffractive events. This is due to the fact that the survival probability of 0.03 at the LHC does not need to be applied for diffractive events.

References

[1] G. Aad *et al.* [ATLAS Collaboration], JHEP **1109**, 053 (2011).

[2] V. S. Fadin and L. N. Lipatov, Phys. Lett. B **429**, 127 (1998); M. Ciafaloni, Phys. Lett. B **429**, 363 (1998);

[3] B. Abbott *et al.* [D0 Collaboration], Phys. Lett. B **440**, 189 (1998); F. Abe *et al.* [CDF Collaboration], Phys. Rev. Lett. **80**, 1156 (1998).

[4] F. Chevallier, O. Kepka, C. Marquet and C. Royon, Phys. Rev. D **79**, 094019 (2009).

[5] O. Kepka, C. Marquet and C. Royon, Phys. Rev. D **83**, 034036 (2011).

[6] M. Cacciari, G. P. Salam and G. Soyez, JHEP **0804** (2008) 063.

[7] S. Alioli, P. Nason, C. Oleari and E. Re, JHEP **1006** (2010) 043.

[8] T. Sjostrand, S. Mrenna and P. Skands, JHEP **0605** (2006) 026.

[9] M. Bahr, S. Gieseke, M. A. Gigg, D. Grellscheid, K. Hamilton, O. Latunde-Dada, S. Platzer and P. Richardson *et al.*, Eur. Phys. J. C **58** (2008) 639.

[10] J. R. Andersen and J. M. Smillie, Nucl. Phys. Proc. Suppl. **205-206** (2010) 205; JHEP **1106** (2011) 010.

[11] A. Banfi, G. Marchesini and G. Smye, JHEP **0208**, 006 (2002).

[12] Y. Hatta and T. Ueda, Phys. Rev. D **80**, 074018 (2009).

[13] Y. Hatta, C. Marquet, C. Royon, G. Soyez, T. Ueda, D. Werder, Phys. Rev. D**87** (2013) 054016.

[14] O. Kepka, C. Royon, C. Marquet and R. B. Peschanski, Phys. Lett. B **655**, 236 (2007); Eur. Phys. J. C **55**, 259 (2008); C. Marquet and C. Royon, Phys. Rev. D **79**, 034028 (2009); H. Navelet, R. Peschanski, C. Royon, S. Wallon, Phys.Lett. B**385** (1996) 357.

[15] C. Marquet, C. Royon, M. Trzebinski, R. Zlebcik, Phys. Rev. D **87** (2013) 3, 034010.

[16] Z. Nagy and Z. Trocsanyi, Phys. Rev. Lett. **87**, 082001 (2001).

[17] B. Abbott *et al.*, Phys. Lett. B **440**, 189 (1998); F. Abe *et al.*, Phys. Rev. Lett. **80**, 1156 (1998).

PoS(Photon 2013)016