Soft QCD Measurements at LHCb

A. T. Grecu on behalf of the LHCb Collaboration

Horia Hulubei National Institute for Physics and Nuclear Engineering (IFIN-HH),
30 Reactorului, RO-077125, Bucharest-Măgurele, Romania

DOI: http://dx.doi.org/10.3204/DESY-PROC-2014-04/249

Its forward acceptance puts the LHCb in a unique position at the LHC to measure soft QCD phenomena at large rapidities and low transverse momenta. Recent results on charged particle multiplicities, energy flow, and inclusive cross-sections are presented.

1 The LHCb experiment at LHC

The LHCb experiment at LHC was designed to test the flavour aspect of the Standard Model through precision measurements of rare b and c hadron decays [1]. The LHCb detector [2] is built as a single arm forward spectrometer fully instrumented for measurements in the forward pseudorapidity (η) region $2 < \eta < 5$. The primary pp interaction region is located within a silicon-strip vertex detector (VELO) which allows reconstruction of tracks without momentum information also in the backward pseudorapidity interval $-3.5 < \eta < -1.5$. The high-precision tracking system [3] continues with a large area silicon tracker located upstream of a magnetic dipole with a bending power of 4 Tm and three stations of silicon-strip detectors and straw drift tubes situated downstream of the magnet. A calorimetry system is used to measure the neutral component and muons are detected by a dedicated system of alternating layers of iron and multi-wire proportional chambers [4]. The LHCb experiment is operated at a low and consistent number of visible proton-proton (pp) interactions.

Monte Carlo (MC) simulated events were used to compute detection efficiencies, estimate systematic uncertainties and compare model predictions with respect to the measurements. Full simulation samples are produced using PYTHIA6.4 [6] configured according to established tunes [7] or the LHCb specific tune [8].

2 Vector meson central exclusive production

Exclusive vector meson photoproduction provides a rich testing ground for QCD. At high meson masses the process can be predicted using perturbative calculations [9]. The light meson production is best described in the frame of the Regge theory [10]. The elastic pp interaction is mediated by the exchange of a colourless object such as a gamma photon or a pomeron, which is replaced by two gluons at hard scales. The colliding protons propagate undetected in the beam pipe. Here, we review the central elastic exclusive production of the J/ψ and $\psi(2S)$ vector mesons decaying to two muons [11] as an update of a previous measurement [12] where a smaller data sample was analysed. The main difference is in the method for determining the background due to production of J/ψ and $\psi(2S)$ mesons in inelastic pp collisions where the additional particles leave the LHCb acceptance and remain undetected. This is the main source of background. It is determined from a fit of the squared momentum of the muon pair (p_T^2) distribution that follows closely HERA measurement [13] extrapolations according to Regge theory. Additional non-resonant background (muon pairs created in the QED process) is estimated from side-bands in the invariant mass spectrum and feed down background from exclusive production of heavier meson decays is evaluated from simulation. The cross-section times the branching fraction of the decay mode to two muons, each inside the LHCb fiducial range ($2.0 < \eta_{\mu^\pm} < 4.5$), is in good agreement with various theoretical predictions. Figure 1 shows the comparison to the LO and NLO predictions from a fit on a combined HERA and LHCb data sample. The NLO prediction tends to better reproduce the differential cross-section shape in data.

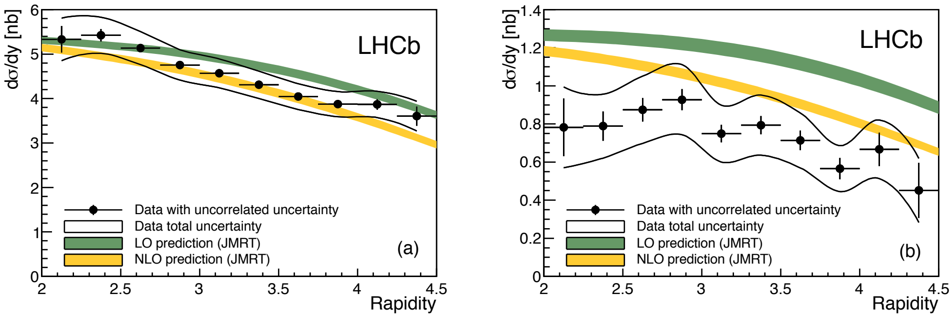

Figure 1: Differential cross-section for (a) J/ψ and (b) $\psi(2S)$ central exclusive production compared to LO and NLO predictions of [14]. The bands indicate the total uncertainties which are mostly correlated between bins. Errors bars contain only the statistical uncertainty.

The measured photoproduction cross-section shows a deviation from the power law established at HERA [15] which can be accounted to higher order or saturation effects. In the low parton fractional momentum (x) domain accessible to the LHCb detector saturation effects manifest due to gluon recombination. Thus, theoretical saturation models can be constrained by measurement through their dependence on the gluon parton density function. The considered models [16] are found in good agreement with the LHCb data.

3 Energy flow and charged particle multiplicities

The final state of an inelastic hadron-hadron collision can be described in QCD as the combined effect of hard and soft scattering processes of the hadron constituents, initial- and final-state radiation and the fragmentation of coloured final state into colour-neutral hadrons. While the hard scattering is well predicted by perturbative QCD, the theoretical modelling of the soft component, also called the underlying event (UE), remains a challenge. The phenomenological approach to this issue is done differently in various generators leading to model parameters to be constrained by experiment for specific beam particles and energies. Recently, LHCb studied two basic observables describing the UE in the forward region, the energy flow [17] which is sensitive to the multi-parton interactions arising especially at low x where the parton densities are high, and the prompt charged particle multiplicities and densities [18, 19] as physical quantities characterizing the overall UE activity.

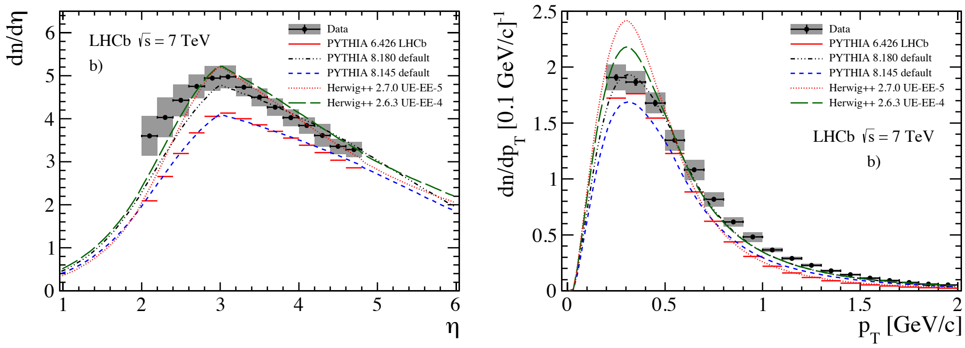

Figure 2: Charged particle density as function of (left) η and (right) p_T compared to PYTHIA8 and HERWIG++ predictions. Error bars represent the statistical negligible uncertainty. Grey bands give the extent of the combined uncertainties.

The energy flow is defined as the average energy created in a particular η range normalised by the range size. The charged forward energy flow measurement was performed using only tracking information, approximating the energy with the value of the momentum. The total energy flow is computed using data-constrained estimates from simulation corrected with informations from the calorimeter system to get the neutral component. The events are split in four classes: inclusive minimum bias, hard scattering with at least one high p_T track, diffractive enriched events requiring that there be no track in the backward region ($-3.5 < \eta < -1.5$) and the alternative non-diffractive enriched ones. Corrections are done in each η bin using MC. The dominant uncertainties come from the simulation model uncertainty on the bin-by-bin correction factors. The energy flow distributions are compared to the predictions of a series of PYTHIA tunes [7, 20] and cosmic-ray interaction models [21]. PYTHIA 8.135 emulates best the data in all event classes except for the hard scattering interactions. Among the cosmic-ray interaction models SYBILL closely follows the PYTHIA8 behaviour. The hard scattering events are better described by QGSJET. Experimental uncertainties are lowest in the forward region where the largest divergences between models are seen. This aspect confirms the energy flow as an important observable for generator tuning.

The measurement of charged particle multiplicities and densities follows closely a previously published measurement [18] adding the measurement of momentum. Prompt charged particles are defined as particles originating from PV or a decay chain in which the sum of the mean lifetimes is below 10 ps, thus the decay products of b and c hadrons are prompt. Only events with at least one track in $2.0 < \eta < 4.8$ having $p_T > 0.2$ GeV/c and $p > 2$ GeV/c are considered. Furthermore only tracks traversing the full tracking system are included in the analysis. The analysis kinematic range is $0.2 < p_T < 2.0$ GeV/c; $2.0 < \eta < 4.5$. Distributions are corrected in each bin for reconstruction artefacts and non-prompt particle contamination, the effect of unobserved events especially at low multiplicities, pile-up events and various other detection inefficiencies. The systematic uncertainties are dominated by the uncertainty on the amount of detector material contributing to the production of non-prompt particles.

Charged particle densities and multiplicities are compared to estimates obtained for various PYTHIA6 tunes and PHOJET [22] which fail to match the magnitude of the distributions. Overall data shape is well described qualitatively by all the generators including PYTHIA8 and HERWIG++ [23] tuned to central region measurements (see Fig. 2). Nevertheless, HERWIG++ largely overestimates at low p_T and PYTHIA8 underestimate the data at large p_T, so none of the considered event generators can describe the entire range of the measurements which make these results valuable reference points toward a successful tuning of generators in the forward region.

Acknowledgements

The author kindly acknowledges financial support through grant PN-II-ID-PCE-2011-3-0749 (56/07.10.2011), IDEI program and contract LHCb 3/03.01.2012, program PN-II:Capacităţi-3.

References

[1] B. Adeva *et al.* arXiv:hep-ex/0912.4179 (2009).

[2] A. A. Alves Jr. *et al.*, JINST **3** S08005 (2008).

[3] R. Aaij *et al.*, JINST **9** 09007 (2014);
R. Aaij *et al.* arXiv:hep-ex/1408.1251 (2014).

[4] A.A. Alves Jr. *et al.*, JINST **8** P02022 (2013);
F. Archilli *et al.*, JINST **8** P10020 (2013).

[5] R. Aaij *et al.*, JINST **8** P04022 (2013).

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

[7] P. Z. Skands, Phys. Rev. **D82** 074018 (2010).

[8] I. Belyaev *et al.*, J. Phys.: Conf. Ser. **331** 032047 (2011).

[9] A.D. Martin, C. Nockles, M. G. Ryskin, and T. Teubner, Phys. Lett. **B662** 252–258 (2008).

[10] P.D.B. Collins, *An Introduction to Regge Theory and High-Energy Physics* (Cambridge Univ. Press, Cambridge, 1977).

[11] R. Aaij *et al.*, J. Phys. G: Nucl. Part. Phys. **40** 045001 (2013).

[12] R. Aaij *et al.*, J. Phys. G: Nucl. Part. Phys. **41** 055002 (2014).

[13] C. Adloff *et al.*, Phys. Lett. **B541** 251-264 (2002); arXiv:hep-ex/0205107.

[14] S.P. Jones, A.D. Martin, M.G. Ryskin, and T. Teubner, JHEP **1311** 085 (2013).

[15] C. Alexa *et al.*, Eur. Phys. J. **C73** 2466 (2013).

[16] L. Motyka and G. Watt, Phys. Rev. **D78** 014023 (2008);
M. B. Gay Ducati, M.T. Griep, and M.V.T. Machado, Phys. Rev. **D88** 017504 (2013).

[17] R. Aaij *et al.*, Eur. Phys. J. **C73** 2421 (2013).

[18] R. Aaij *et al.*, Eur. Phys. J. **C72** 1947 (2012).

[19] R. Aaij *et al.*, Eur. Phys. J. **C74** 2888 (2014).

[20] T. Sjostrand, S. Mrenna, and P. Z. Skands. Comput. Phys. Commun. **178** 852–867 (2008).

[21] T. Pierog and K. Werner, Nucl. Phys. Proc. Suppl. **196** 102–105 (2009);
S. Ostapchenko, AIP Conf. Proc. **928** 118–125 (2007);
E.-J. Ahn, R. Engel, T. K. Gaisser, P. Lipari, and T. Stanev, Phys. Rev. **D80** 094003 (2009).

[22] R. Engel, Z. Phys. **C66** 203–214 (1995).

[23] M. Bahr *et al.*, Eur. Phys. J. **C58** 639–707 (2008);
J. Bellm *et al.*, arXiv:hep-ph/1310.6877 (2013).