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Studies of soft QCD at LHCb

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Due to its unique pseudorapidity coverage and the possibility of extending the measurements to low transverse momenta, LHCb provides important input to the understanding of particle production and energy flow in a kinematical range where QCD models have large uncertainties. Measurements of charged and strange particle production are compared to predictions. In addition, studies of the energy flow probe the underlying event which is modelled in different ways by several Monte Carlo event generators.

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1. Introduction

The main aim of the LHCb experiment [1] is to look for physics beyond the Standard Model by performing precise studies of CP violation and rare decays using hadrons that contain a b or a c quark. To make use of the large and correlated $b\bar{b}$ cross-section in the forward direction, the LHCb detector is designed as a single arm spectrometer covering the pseudorapidity range $2 < \eta < 5$. The spectrometer high precision tracking system consists of a silicon-strip vertex detector surrounding the pp interaction region, a large-area silicon-strip detector located upstream of a dipole magnet with a bending power of about 4Tm, and three stations of silicon-strip detectors and straw drift tubes placed downstream. Two ring-imaging Cherenkov detectors are used for the charged hadrons identification. Photon, electron and hadron candidates are identified by a calorimeter system consisting of scintillating-pad and preshower detectors, an electromagnetic calorimeter and a hadronic calorimeter, and muons by a system composed of alternating layers of iron and multiwire proportional chambers. Although designed to perform studies of CP violation and rare decays, the detectors also enable studies of soft QCD that rely on precision tracking and/or the excellent particle identification. A very simple trigger that requires at least one track to be reconstructed in the LHCb acceptance was used for the measurements presented in this proceedings. Samples of simulated data, referred in what follows as LHCb MC, were used for the reconstruction efficiency and acceptance correction, as well as for providing predictions to compare with measurements. They were produced using PYTHIA 6.4 [2] with a specific LHCb configuration [3] to generate the pp collisions. Decays of hadronic particles are described by EVTGEN [4] in which final state radiation is generated using PHOTOS [5]. The interaction of the generated particles with the detector and its response are implemented using the GEANT4 toolkit [6] as described in Ref. [7]. Other samples of simulated data were used to provide predictions to compare to the experimental results. Among those the Perugia tunes [8] of PYTHIA 6.4, the default PYTHIA 8.130 [9] with a treatment of the diffractive events described in Ref.[10] and samples produced with generators commonly used by the cosmic ray experimental community [11].

The unique, fully instrumented, phase coverage of the LHCb detector, as well as the large coverage in the rapidity loss, Δy, defined as the difference between the rapidity of the beam particle y_b and the rapidity of the reconstructed particle y, were capitalized by the LHCb collaboration from the very first days of the data taking. The K^0_S cross-section measurement [12] exploiting the 0.9 TeV interaction energy data recorded already in 2009, were followed by measurements of the baryon number transport and baryon versus meson suppression at 0.9 TeV and 7 TeV interaction energy using V^0 particles [13] and of the ϕ cross-section at 7 TeV [14], published in 2011. The charged particle multiplicity at 7 TeV was released in the same year [15]. Year 2012 brought two results that will be detailed in this proceedings the measurement of forward energy flow [16] at 7 TeV and the particle ratios at 0.9 and 7 TeV measurements [17].

2. Forward energy flow

As the energy flow (EF) measured in the high η region is strongly dependent on the amount of parton radiation and multiple parton interaction, EF measurements can be used for tuning both collision physics and ultra-high energy cosmic-ray generators. The EF, defined as $\frac{1}{N_{int}}\frac{dE_{tot}}{d\eta}$, where

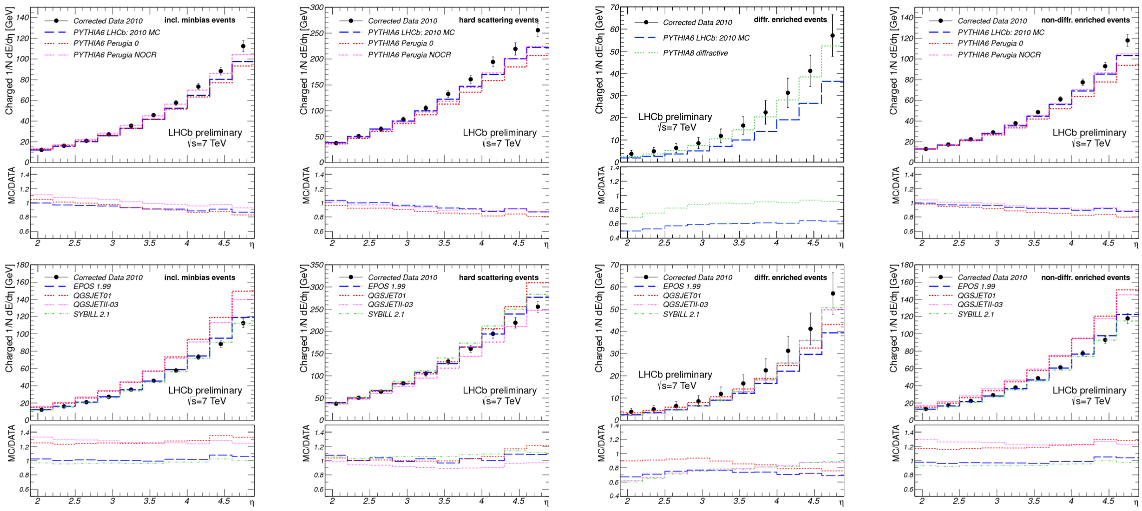

Figure 1: Corrected charged energy flow for all event classes used in this study. The measurements are indicated by points with error bars while the predictions given by PYTHIA 6 tunes, PYTHIA 8 (top four plots) and the cosmic-ray interaction generators (bottom four plots) are shown as histograms. The ratios between the model predictions and corrected data are also shown [16]

N_{int} is the number of inelastic pp interactions, and dE_{tot} is the energy (charged or total) of the stable particles in each $d\eta$ range, can be measured experimentally by summing the energy of each individual particle $E_{i,\eta}$, per pp interaction, in a given range $\Delta\eta$. A sample of low luminosity LHC run data, 0.1 nb^{-1}, recorded at 7 TeV is used. Four categories of events are defined: inclusive minimum bias with at least one well reconstructed track with momentum $p > 2$ GeV/c; hard scattering with at least one well reconstructed track with $p_T > 3$ GeV/c; diffractive enriched consisting of minimum bias events without backward tracks - $-3.5 < \eta < -1.5$; non-diffractive enriched which contain at least one such track. The EF carried by the charged particles, charged EF, is measured using the momentum information provided by the tracking system and neglecting the masses of the particles, while the total energy EF is determined adding a data constrained simulation estimate of the neutral component using information provided by the electromagnetic calorimeter. The main sources of the systematic uncertainties were given by the difference in the tracking efficiencies in data and simulation, the presence of multiple interaction events (in the data sample used less than 5% of events contained more than one pp interaction), and the interaction model used in the simulation. The results for the charged energy flow measurement can be seen in Fig. 1. The PYTHIA 6 tunes used for the comparison underestimate the charged EF at high η for all the type of events studied, while PYTHIA 8 describes the best the charged EF for diffractive enriched events. The cosmic-ray generators overestimate the charged EF for three of the four categories of events considered, with SYBILL/EPOS giving the best description of the charged EF in the inclusive minimum bias events, QGSJETII-03 offering a reasonable description of the charged EF in hard scattering events, and the charged EF underestimated in the diffractive enriched events by all the cosmic-ray generators. Similar behaviour is seen when comparing the total energy flow measurement to the generator predictions [16].

3. Charged particle ratios

The charged particle production ratio measurement is an important input for model building and generator parameter optimization, as it provides input to tune the proportion in which various species of hadrons are produced. Data recorded at a centre of mass interaction energy of 0.9 TeV (0.3 nb^{-1}) and during the low luminosity LHC run at 7 TeV (1.8 nb^{-1}) were used for this study. The particle ratios considered are:

$$\frac{\bar{p}}{p},\ \frac{K^-}{K^+},\ \frac{\pi^-}{\pi^+},\ \frac{p+\bar{p}}{\pi^+ + \pi^-},\ \frac{K^+ + K^-}{\pi^+ + \pi^-},\ \frac{p+\bar{p}}{K^+ + K^-}.$$

Events simulated as LHCb MC (see section 1), are used to correct for effects of non-prompt contamination, geometrical acceptance losses, reconstruction and track finding efficiency as well as to estimate most systematic uncertainties. PID calibration is performed using data samples of $K^0_S \rightarrow \pi^+\pi^-$, $\Lambda \rightarrow p\pi^-$, $\phi \rightarrow K^+K^-$. The largest contribution to the systematic uncertainties comes from the PID efficiency and is given by the size of the calibration sample. Other important contributions are connected to the interaction cross-section and the amount of detector material considered, tracking efficiency and non-prompt contamination estimations. No single PYTHIA 6 tune used in this study is able to describe all the observables tested [17] well. The largest discrepancies appear for $\frac{p+\bar{p}}{\pi^+ + \pi^-}$, $\frac{K^+ + K^-}{\pi^+ + \pi^-}$, as shown in Fig. 2. The baryon transport $\frac{\bar{p}}{p}$ has been studied as function of Δy over a range from 3.1 to 6.3, as shown in Fig. 3. The results obtained on strangeness production, baryon suppression and baryon transport are in agreement with previous publications [13] [14].

4. Summary

LHCb is not only a beauty and charm physics experiment but provides an excellent environment for performing soft-QCD studies at high y and η. Some of the recent LHCb results on this topic are presented here. PYTHIA 6 tunes underestimate the EF at high η while most of the cosmic ray generators overestimate it. None of the generators investigated describe the EF correctly

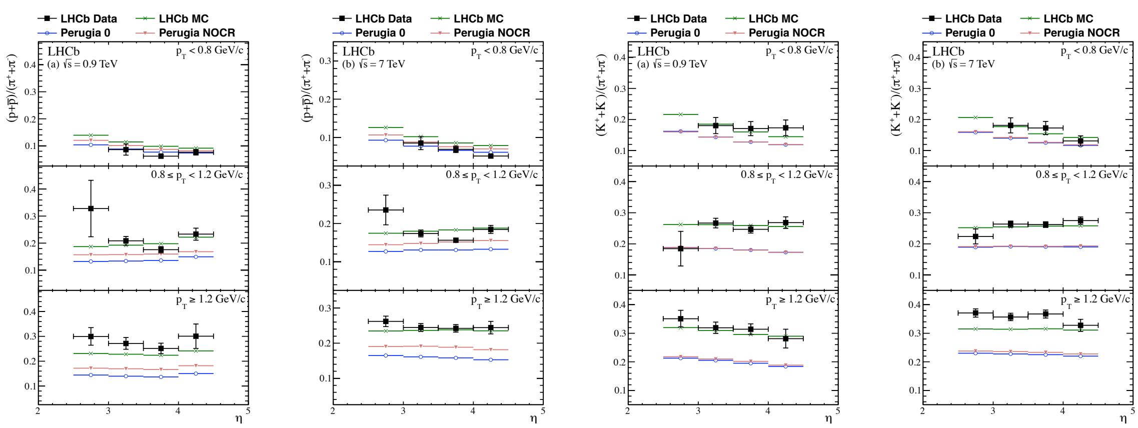

Figure 2: Left: Results for the $\frac{p+\bar{p}}{\pi^+ + \pi^-}$ ratio at 0.9 TeV (a) and 7 TeV (b). Right: Results for $\frac{K^+ + K^-}{\pi^+ + \pi^-}$ ratio at 0.9 TeV (a) and 7 TeV (b) [17].

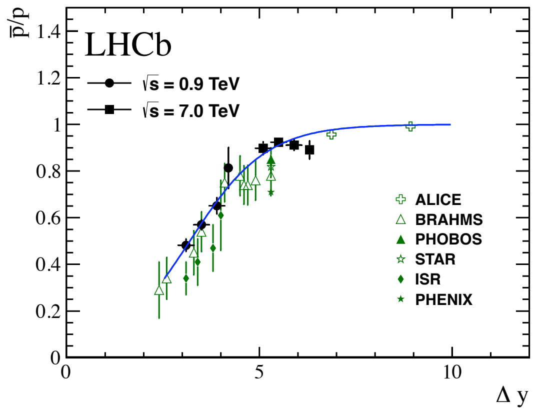

Figure 3: Results for the $\bar{p}/p$ ratio against the Δy from LHCb. Results from other experiments are also shown [18]. Superimposed is a fit [17] to the LHCb and ALICE measurements [17].

for all the classes of events studied. Measurements of $\frac{\bar{p}}{p}, \frac{K^-}{K^+}, \frac{\pi^-}{\pi^+}, \frac{p+\bar{p}}{\pi^++\pi^-}, \frac{K^++K^-}{\pi^++\pi^-}, \frac{p+\bar{p}}{K^++K^-}$ have been performed using data recorded at 0.9 and 7 TeV, first such studies at the latter energy. No single PYTHIA 6 tune is able to describe all the observables. The baryon transport has been studied using the $\bar{p}/p$ ratio providing a precise measurement over the largest Δy range covered by a one experiment.

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