PROCEEDINGS OF SCIENCE

Precision QCD measurements from LHCb

Marcin Kucharczyk *on behalf of the LHCb collaboration*[a,*]

[a] *Henryk Niewodniczanski Institute of Nuclear Physics PAN, Krakow, Poland*

E-mail: marcin.kucharczyk@cern.ch

The LHCb detector, thanks to its unique coverage of the forward region of pseudorapidity of $2 < \eta < 5$, together with high-precision tracking and excellent particle identification, is a universal tool allowing to study a wide spectrum of QCD processes. The present document focuses on the recent results on the production of charged hadrons within jets recoiling against a Z boson at $\sqrt{s} = 8$ TeV as well as the Bose-Einstein correlations of same-sign pions at $\sqrt{s} = 7$ TeV, both performed using large samples of proton-proton collision data accumulated with the LHCb detector. The results on Central Exclusive Production at $\sqrt{s} = 13$ TeV based on new forward shower counters installed upstream and downstream of the LHCb detector are also discussed.

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*Speaker

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1. Introduction

The LHCb detector is a general-purpose detector in the forward rapidity region [1]. It has a potential to investigate QCD effects at small angles with respect to the beam direction, therefore, to obtain results complementary to the ones from the general-purpose detectors with the coverage of the central rapidity region. Full instrumentation in the forward direction, $2 < \eta < 5$, together with efficient track reconstruction and excellent particle identification, allows to provide high precision results at the highest available collision energies. Furthermore, the forward shower counters system (HeRSCheL) [2] installed upstream and downstream for the Run 2 period allows to increase the rapidity coverage of the LHCb spectrometer.

The production of charged hadrons in jets recoiling against a Z boson measured in proton-proton collisions at $\sqrt{s} = 8$ TeV, or the first LHCb results on the Bose-Einstein correlations of same-sign pions in proton-proton collisions at $\sqrt{s} = 7$ TeV, together with recent results on central exclusive particle production (CEP) for J/ψ and ψ(2S) at $\sqrt{s} = 13$ TeV are reviewed.

2. Hadronization in quark-initiated jets at $\sqrt{s} = 8$ TeV

The analysis aimed at the measurement of the production of charged hadrons in jets recoiling against a Z boson, also referred to as Z-tagged jets, in the forward region of proton-proton collisions at $\sqrt{s} = 8$ TeV. The jets are measured in the fiducial region of $20 < p_T < 100$ GeV and $2.5 < \eta < 4$, while the hadrons are required to have $p_T > 0.25$ GeV, $p > 4$ GeV, and to be located within the jet cone of distance parameter $R = 0.5$. The longitudinal momentum fraction z, momentum transverse to the jet axis j_T as well as radial distribution r of charged hadrons have been measured with respect to the jet axis in the laboratory frame [3]. The distributions of z in three jet p_T bins are approximately constant as a function of jet p_T at high z, however at low z the fragmentation functions differ due to the requirement on the track momentum. Therefore, higher p_T jets can probe smaller z. Fig. 1 shows r distributions of charged hadrons within jets. It may be observed that larger energy in higher p_T jets leads to more hadrons, mainly close to the jet axis. Moreover, reduced jet p_T dependence at larger r may indicate that nonperturbative contributions do not depend strongly on jet p_T. A comparison of the LHCb results in the forward rapidity region, probing predominantly light-quark jets, to the inclusive jet measurements dominated by gluon jets at central rapidity in ATLAS [4] indicates the differences between light-quark and gluon fragmentation. Quark-initiated jets are found to be more longitudinally and transversally collimated with respect to the jet axis when compared to the previous gluon dominated measurements.

3. Bose-Einstein correlations for pion pairs in proton-proton collisions at $\sqrt{s} = 7$ TeV

The study of the Bose-Einstein correlations (BEC) of same-sign charged pions in proton-proton collisions at 7 TeV [5] is based on the construction of a two-particle correlation function, $C_2(Q)$, commonly studied in the four-momentum difference Q, which gives an invariant measure of the phase-space separation of the two-particle system. The correlation function is defined as a ratio of the inclusive density distribution for two identical particles and the reference density.

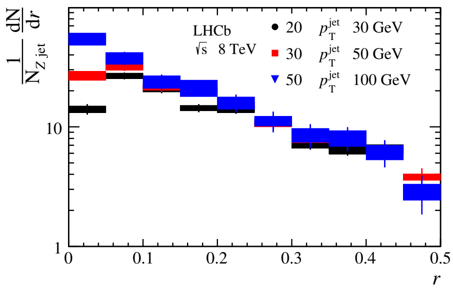

Figure 1: Radial profile distributions of hadrons in three bins of jet p_T. The bars show statistical uncertainties, while boxes indicate the systematic ones. Figure adopted from [3].

The latter is a two-particle density distribution which approximates the distribution without BEC effects. In the analysis a data-driven event-mixed reference sample was used, based on the choice of two identical pions, each originating from different events. The correlation function $C_2(Q)$ is commonly parameterised as a Levy exponential function corresponding to the radial distribution of the static source [6], $C_2(Q) = N \times (1 + \lambda \cdot e^{-RQ}) \times (1 + \delta \cdot Q)$, where the parameter R, the correlation radius, can be interpreted as the radius of the spherically symmetric source of the emission volume, N accounts for the overall normalisation and λ is the chaoticity parameter, which accounts for the partial incoherence of the source. Parameter λ, describing a correlation strength coming from two-pion correlations, can vary from zero for completely coherent source to unity for an entirely chaotic source. The δ parameter accounts for long-range correlations, like those coming from transverse momentum conservation. The correlation function can be improved by implementing double ratio, i.e. the ratio of the correlation function for data and the correlation function calculated for Monte Carlo sample with Bose-Einstein correlations switched off. The dependence of the correlation radius and chaoticity parameter on event activity was measured in the forward acceptance region of $2 < \eta < 5$ for single pions with transverse momentum $p_T > 0.1$ GeV/c. Activity bins are defined based on fractions of multiplicity of charged particles reconstructed in the vertex detector. Fig. 2 shows the dependence of the BEC parameters on event activity, where the correlation radius increases with event activity, while the chaoticity parameter is decreasing. The trends observed agree well with the previous dependencies measured at LEP and other LHC experiments [7].

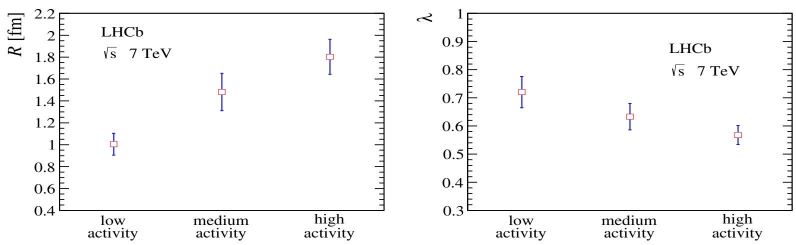

Figure 2: Correlation radius (left) and chaoticity parameter (right) as a function of event activity. Error bars indicate the sum in quadrature of the statistical and systematic uncertainties. The points are placed at the centres of the activity bins. Figure adopted from [5].

4. Central Exclusive Production of J/ψ and ψ(2S) at $\sqrt{s}$ = 13 TeV

The analysis of the central exclusive production of J/ψ and ψ(2S) in proton-proton collisions at a centre-of-mass energy of 13 TeV [8] has been performed. Background is significantly reduced compared to previous measurements made at lower energies through the use of new forward shower counters (HeRSCheL) [2], installed upstream and downstream of the LHCb detector. The selection is based firstly on two muons within the pseudorapidity range $2 < \eta < 4.5$ and no other track in the LHCb vertex detector. Then a HeRSCheL veto was applied. Such a threshold was set on the discriminating variable related to combined charged particle activity in the HeRSCheL scintillating pads, effectively halving the dissociation background as compared to the Run 1 measurements [9]. The signal and background contributions were estimated from the fit by two exponential functions, where the background considered non-resonant muons, feed-downs and undetected interacting protons. The cross-sections times branching fractions for the decays to dimuons within $2 < \eta < 4.5$ were measured to be $\sigma_{J/\psi\to\mu^+\mu^-} = 435 \pm 18 \pm 11 \pm 17$ pb and $\sigma_{\psi(2S)\to\mu^+\mu^-} = 11.1 \pm 1.1 \pm 0.3 \pm 0.4$ pb. The first uncertainty is statistical, the second one systematic, and the third is due to the luminosity determination. In addition, the cross-section times branching fraction to two muons was determined in bins of meson rapidity. Both the J/ψ and ψ(2S) results are in better agreement with the next-to-leading order predictions rather than leading order ones. A model-dependent determination of J/ψ photoproduction cross-section, $\sigma(\gamma p \to J/\psi p)$, based on the LHCb differential cross-section measurement assuming the power-law result from a fit to the HERA data [10], is shown in Fig. 3. A deviation from a pure power-law extrapolation of lower energy data may be observed.

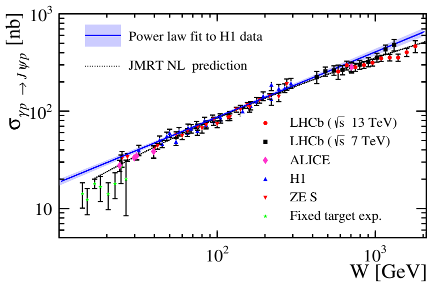

Figure 3: Compilation of photoproduction cross-section results for various experiments for J/ψ. Figure adopted from [8].

5. Conclusions

As LHCb provides the results in a unique forward acceptance, it is complementary to the results from general purpose LHC detectors. The first measurements of jet hadronization at forward rapidities can provide valuable information on differences between quarks and gluons regarding nonperturbative hadronization dynamics. Furthermore, the Bose-Einstein correlations between two indistinguishable pions have been observed for the first time in the forward region as well as the first measurement of exclusive J/ψ and ψ(2S) meson production was performed on the 13 TeV data following the installation of HeRSCheL scintillators. The derived cross-section for J/ψ photoproduction shows a deviation from a pure power-law extrapolation of H1 data.

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