PROCEEDINGS OF SCIENCE

Precision QCD measurements with LHCb

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While being originally designed to study b- and c-hadron physics, the LHCb experiment is a general purpose forward detector that is able to perform precision QCD measurements. Due to its forward angular coverage, complementary to ATLAS and CMS, and its cleaner collision environment, the LHCb detector is able to test perturbative QCD, Parton Distribution Functions and nuclear effects in heavy ions collisions. In this proceeding, some of the latest precision QCD results obtained by the LHCb experiment are presented.

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1. QCD physics at the LHCb experiment

The LHCb detector [1] is a forward spectrometer originally designed to study b- and c-hadron physics. It covers a phase space region which is complementary to ATLAS and CMS, in the pseudorapidity range $2 < \eta < 5$. It can be considered a General Purpose Forward Detector, and its specific angular coverage, combined with a cleaner environment with reduced pile-up, make LHCb an interesting place to study QCD physics. In particular, at LHCb it is possible to study perturbative QCD (pQCD) physics and Parton Distribution Functions (PDFs) in the region at low x and moderate Q^2 (x being the longitudinal momentum fraction of the parton and Q^2 the energy scale of the interaction) which is partially unexplored by other experiments, as shown in Fig. 1.

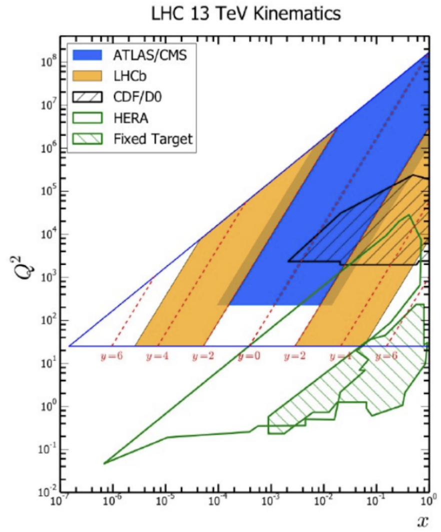

Figure 1: $x - Q^2$ plot [2] showing the LHCb coverage (yellow) with respect to ATLAS and CMS (blue), CDF/D0 (black contour and shaded area), HERA (green contour) and fixed target (green counter and shaded area) experiments.

2. Prompt-charged particles production

Prompt long-lived charged particles are a proxy for light hadrons production, and measuring these processes is fundamental to get phenomenological models describing soft QCD processes. At LHCb, a double (p_{T}, η) differential cross-section measurement with respect to p_{T} and η has been performed using $\mathcal{L} = 5.4\ \mathrm{nb}^{-1}$ of data at $\sqrt{s} = 13$ TeV [3]. Particles are selected in the range $80 < p_{\mathrm{T}} < 10000$ MeV and $2.0 < \eta < 4.8$, simulations are corrected to match data and several background contributions are taken into account (non-prompt particles, fake tracks, material interactions). Comparisons with theoretical predictions for differential cross-sections and cross-sections ratios show that models tend to overestimate the differential cross sections, as shown in Fig. 2 for differential cross section for a specific η range.

3. $b\bar{b}$ and $c\bar{c}$ differential cross-sections

A measurement of heavy-flavour di-jets differential cross-section production has been performed at the LHCb experiment using 2016 data, for a total integrated luminosity of 1.6 fb^{-1} [4]. Differential cross section have been measured with respect to four di-jet kinematic variables and two multivariate analysis (MVA) methods based on Boosted Decision Trees have been used to extract the jets' flavour composition. A differentiable measurement of the cross section ratio $R = \sigma_{c\bar{c}}/\sigma_{b\bar{b}}$ has also been computed. The integrated value for R is 1.37 ± 0.27, where the uncertainty is the combination of statistical and systematic errors. Results are in agreement with next-to-leading order predictions [4].

4. Intrinsic charm

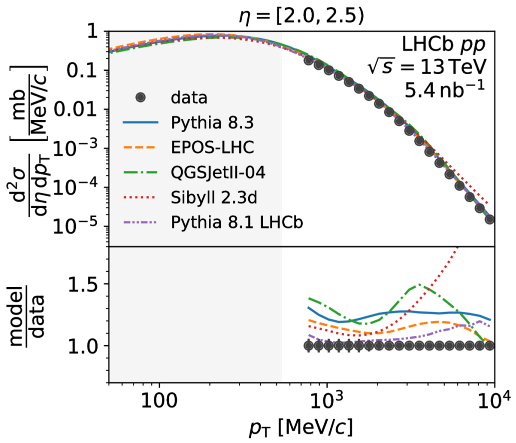

Figure 2: Double (p_T, η) differential cross section as a function of p_T in the $2.0 < \eta < 2.5$ range, showing data distribution (black dots) and several theoretical models (coloured lines) [3].

Several theories predict the proton to have an intrinsic (*i.e.* bound to valence quarks) charm component: particularly, this intrinsic component might show a signature in the forward region, where LHCb could perform its measurements. The $Z + c$-jet production in the forward region is sensitive to the intrinsic charm component, and this process has been analysed using $\mathcal{L} = 5.4\ \text{fb}^{-1}$ of data taken during Run 2 at LHCb [5]. Heavy-flavour jets have been tagged using a displaced vertex (DV) technique [6]. The DV corrected mass and its number of tracks are fitted to obtain flavour component. The cross section ratio $R = \sigma(Zc)/\sigma(Zj)$ is computed with respect to the Z boson rapidity: results show a hint of the intrinsic charm component in the high rapidity interval $3.5 < y(Z) < 4.5$, where one of the initial partons must have large x. More data are needed to confirm the intrinsic charm component scenario, since this measurement is dominated by statistical uncertainties.

5. Modification of b quark hadronization

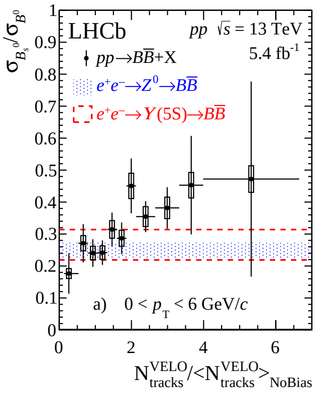

Figure 3: $\sigma_{B_s^0}/\sigma_{B^0}$ as a function of multiplicity [7]. Error bars (boxes) represent point-to-point uncorrelated (fully correlated) uncertainties, while blue (red) points show results for Z^0 ($Y(5S)$) at e^+e^- colliders.

Besides fragmentation, a process where shower of partons produced by quarks form into hadrons, there might be other hadronization processes, such as quark coalescence. Studying B mesons might offer interesting insights into hadronization: particularly, the fraction f_s (f_d) of b quarks pairing with s (d) quarks to form B_s^0 (B^0) mesons is related to the hadronization process involved. At LHCb, a measurement of the ratio $\sigma_{B_s^0}/\sigma_{B^0}$ has been performed [7] by reconstructing B mesons decaying into $J/\psi\pi^+\pi^-$, using $\mathcal{L} = 5.4\ \text{fb}^{-1}$ of data taken during Run 2. The multiplicity metrics used in this analysis are the total number of charged tracks reconstructed in the Vertex Locator (VELO) detector, $N^{\text{VELO}}_{\text{tracks}}$, and the subset of VELO tracks that point in the backward direction, away from the LHCb spectrometer, $N^{\text{back}}_{\text{tracks}}$. Results are quoted in terms of normalized multiplicity. A fit to the invariant mass of $J/\psi\pi^+\pi^-$ is performed to extract the ratio, and the measurement is performed as a function of p_T and multiplicity. Results show an enhancement of B^0_s mesons with respect to B^0 mesons at high multiplicity and low p_T, as shown in Fig. 3, which is qualitatively consistent with quark coalescence as an additional hadronization mechanism.

6. Nuclear modification factor of neutral pions

Measurements of neutral pion production are a good test of nuclear effects in heavy ions collisions, since π^0 production is sensitive to cold nuclear matter effects that are encoded into nuclear PDFs (nPDFs). A measurement of the π^0 nuclear modification factor at forward and backward rapidities in proton-lead collisions has been performed at LHCb [8], at a center-of-mass energy per nucleon $\sqrt{s_\mathrm{NN}} = 8.16$ TeV, collecting $\mathcal{L} = 328 \pm 9\ \mu\mathrm{b}^{-1}$ ($267 \pm 7\ \mu\mathrm{b}^{-1}$) of data for forward (backward) rapidities; this measurement can constrain nPDFs in the range $10^{-6} < x < 10^{-1}$. Events are selected by requiring at least one track in the VELO and π^0 are reconstructed as pairs of photons. Results show the first evidence of an enhancement of π^0 production for backward rapidities in the $2 < p_\mathrm{T} < 4$ GeV range, as shown in Fig. 4, while no enhancement is visible in forward rapidities. This measurement has also been compared with results coming from charged-particle nuclear modification factor measurement performed at LHCb in proton-lead collisions at $\sqrt{s_\mathrm{NN}} = 5$ TeV, showing agreement: further studies for heavier and unflavored mesons might help in understanding the lower enhancement for backward rapidities.

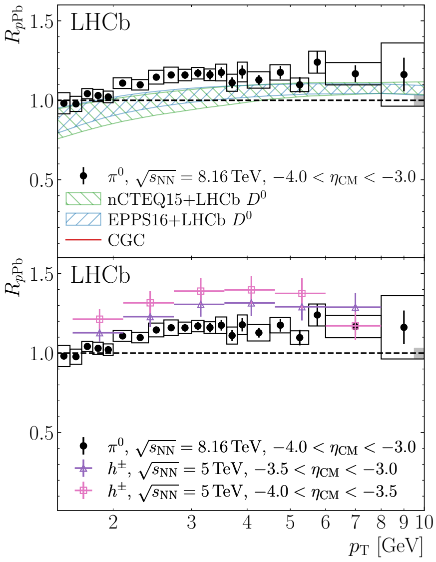

Figure 4: π^0 nuclear modification factor as a function of p_T for backward rapidities, compared with theoretical models (up) and with charged-particle nuclear modification factor at $\sqrt{s_\mathrm{NN}} = 5$ (down) [8].

7. Conclusions

Several precision QCD measurements have been performed at LHCb, exploiting its forward angular coverage and its low pile-up environment: the latest results on prompt-charged particle production, heavy-flavor jets physics, proton charm content, b quark hadronization and nuclear factor of π^0 show that LHCb is able to get competitive results. These measurements might further help us in understanding pQCD in a region unexplored by other experiments, by constraining PDFs and testing theories on nuclear effects.

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