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LHCb heavy-ion results in collider and fixed-target mode

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Summary. — LHCb is a fully instrumented forward spectrometer at the LHC with a pseudorapidity coverage $2 < \eta < 5$ designed for the study of hadrons containing b and c-quarks in pp collisions. The forward acceptance and its instrumentation for high-precision vertex reconstruction, tracking and particle identification allow for unique studies in heavy-ion collisions. Furthermore, a system for noble gas injections into the beam vacuum at the nominal interaction point can be used for fixed target studies with the LHC beams. With these data sets, it is possible to constrain nuclear modification of heavy-flavour and quarkonium production with high precision in proton-induced reactions. This is of particular interest as a baseline for deconfinement signature studies in ion-ion collisions. Furthermore, in the collider mode, the production of the charm and beauty quarks probe low Bjorken-x values in the initial state of the ions where gluon saturation may start to play a role. The fixed-target data cover a kinematic range which is particular interesting for the search of intrinsic charm at high Bjorken-x. Recent results on heavy-flavour and quarkonium production in proton-lead collisions in collider mode as well as in proton-Helium and proton-Argon collisions are presented.

1. – Introduction

A hot and dense medium of deconfined quarks and gluons, called quark-gluon plasma (QGP), is known to be created in ultra-relativistic heavy-ion collisions at RHIC and LHC. Heavy quarks are particularly suitable probes to study the properties of QGP. They are produced in pairs in the earliest stages of the collision and with a time scale that is shorter than that of the QGP formation ($\sim$ 1 fm/c). While propagating through the medium they interact with the medium constituents and lose energy through radiative gluonic emissions. Studying these processes is of utmost importance for the understanding of the properties and the space-time evolution of the QGP. However, a correct interpretation of these phenomena in terms of QGP formation requires a full understanding of the *cold nuclear-matter effects*, which can be studied in processes where the QGP formation is traditionally not expected, such as in pA collisions. These effects include the modification of the nucleon PDFs (nuclear PDFs, nPDFs), which is typically studied in terms of ratios between the PDF for a nucleon N inside a nucleus A and the corresponding one for a free nucleon. Measurements of prompt open-charm production in pPb collisions at the LHC allow to constrain the nuclear PDFs at very small x ($\sim 10^{-5} - 10^{-6}$), where the cold nuclear-matter effects are expected to be large. In particular, the LHCb experiment can play a crucial role in these studies thanks to its high performances in heavy-flavour measurements and to the possibility to measure prompt heavy flavours at low p_T and forward rapidity. The LHCb detector [1, 2] is a single-arm spectrometer covering the pseudorapidity range $2 < \eta < 5$, and designed for the study of particles containing heavy-quarks. Two different beam configurations are possible for pPb collisions at LHCb: the p (Pb) beam enters from the upstream (downstream) side of the spectrometer, and vice-versa. Due to the different beam energies per nucleon for the p and Pb beams, the two beam configurations correspond to different rapidity regions in the nucleon-nucleon rest frame: $1.5 < y^* < 4.0$ ("forward"), and $-5.0 < y^* < -2.5$ ("backward"), where y^* is defined with respect to the direction of the proton beam. Two sets of data have been collected at LHCb with pPb collisions: one at $\sqrt{s_{NN}} = 5.02$ TeV, with an integrated luminosity of the order of 1 nb^{-1}, and the other at $\sqrt{s_{NN}} = 8.16$ TeV with an integrated luminosity a factor of 20 higher than that of the 5 TeV dataset. Furthermore, LHCb can also operate in fixed-target mode by using the SMOG (System for Measuring Overlap with Gas) system, which allows to inject low density noble gas (He, Ar, Ne) into the beam-pipe, in correspondence of the Vertex-Locator (VELO) tracking detector. Fixed-target results allow to constrain the nPDFs especially at high-x and can help to pin down possible contributions from intrinsic heavy-quarks in the proton.

2. – Prompt D^0 and Λ_c^+ production in pPb collisions at 5.02 TeV

The inclusive yields of D^0 mesons and Λ_c^+ baryons candidates are extracted through a maximum likelihood fit to the $K^-\pi^+$ and $pK^-\pi^+$ invariant mass distributions, respectively [3,4]. The obtained inclusive yields include both "prompt" candidates, i.e. coming from the primary vertex, and "non-prompt" candidates, i.e. those created in the decay of b-hadrons. The two contributions are well separated from the impact parameter with respect to the primary vertex of the collision. Figure 1 shows the measured differential cross sections for prompt Λ_c^+ and D^0 production as a function of p_T. The latter is compared with HELAC-Onia calculations including different nPDFs parametrizations [5, 6] and constrained by existing LHC pp cross section measurements. The agreement with data is very good over the full kinematic range. Noteworthy, the experimental uncertainties are smaller than the theoretical ones.

3. – Selected observables in prompt D^0 and Λ_c^+ production at 5.02 TeV

The *nuclear modification factor*, defined as $R_{pPb}(p_T, y^*) = \frac{1}{A}\frac{d^2\sigma_{pPb}(p_T,y^*)/dp_T dy^*}{d^2\sigma_{pp}(p_T,y^*)/dp_T dy^*}$, has been extracted for the case of prompt D^0 production in pPb collisions [3]. The results are presented in Fig. 2 as a function of p_T for the forward configuration, and compared with HELAC-Onia predictions [5, 6]. The ratio $R_{pPb}(p_T, y^*)$ is significantly suppressed at forward rapidity, though slightly increasing with p_T, whereas it is consistent with unity in the backward rapidity region (not shown). The measurements are consistent with model calculations, with the experimental uncertainties smaller than the theoretical ones. Another very interesting observable, which also constitutes an excellent probe to constrain the nPDFs uncertainties, is the *forward-backward production ratio*, defined as $R_{FB}(p_T, y^*) = \frac{d^2\sigma_{pPb}(p_T,+|y^*|)/dp_T dy^*}{d^2\sigma_{pPb}(p_T,-|y^*|)/dp_T dy^*}$. It is shown in Fig. 2 for prompt D^0 production

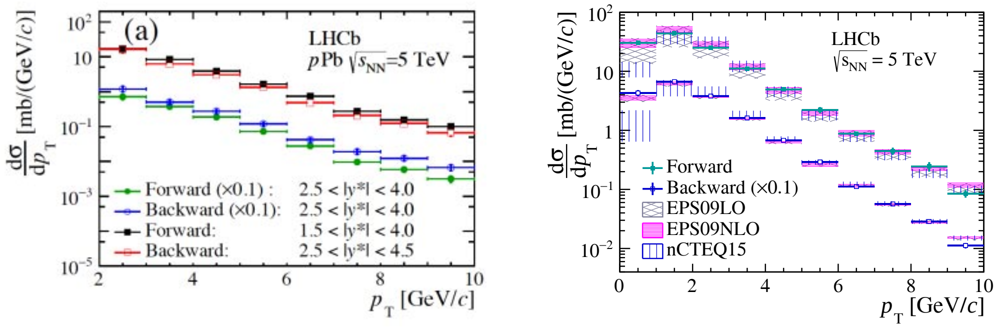

Fig. 1. – Differential cross sections for prompt Λ_c^+ (left) and D^0 (right) production in pPb collisions at $\sqrt{s_{NN}}$ = 5 TeV as a function of p_T. The D^0 results are compared with HELAC-Onia predictions [5, 6]. The error bars indicate the sum in quadrature of the statistical and systematic uncertainties.

as a function of p_T. The ratio is significantly smaller than unity, indicating a larger production rate in the backward region compared to the forward region. The results are compared with HELAC-Onia calculations (including different LO and NLO nPDFs parametrizations) [5, 6]. Data are consistent with the theory predictions in the full kinematic range.

Finally, the charmed *baryon-to-meson ratio* was also measured. It is defined as $R_{\Lambda_c^+/D^0}(p_T, y^*) = \sigma_{\Lambda_c^+}(p_T, y^*)/\sigma_{D^0}(p_T, y^*)$ and provides information on the hadronization mechanisms in the charm sector, being sensitive to the ratio of the fragmentation functions of a c-quark into Λ_c^+ and D^0 hadrons. From the theoretical point of view, it constitutes an ideal observable since most of the nPDFs uncertainties cancel out in the ratio. The results are shown in Fig. 3 as a function of p_T, separately for the backward and the forward regions. The theoretical predictions [5, 6], tuned to *pp* data, indicate a slight increase of $R_{\Lambda_c^+/D^0}$ with p_T and are consistent with data within the experimental uncertainties, except for the forward configuration in the high-p_T region, where they overestimate the data.

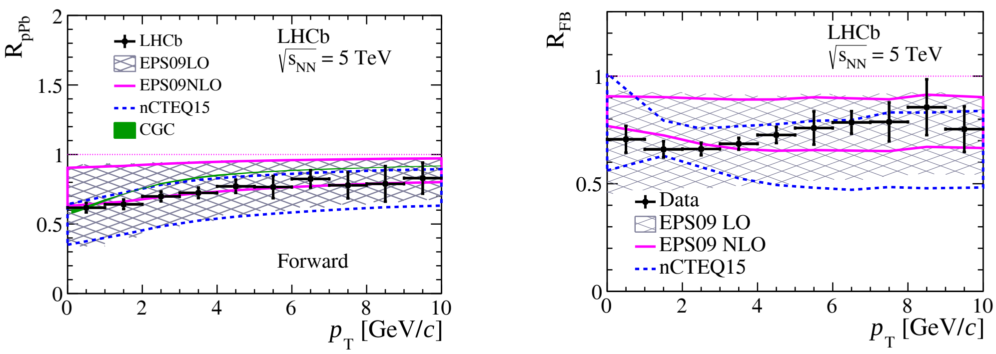

Fig. 2. – Nuclear modification factor (left) and forward-backward production ratio (right) for prompt production of D^0 mesons in pPb collisions at $\sqrt{s_{NN}}$ = 5 TeV as a function of p_T. Data are compared with HELAC-Onia predictions [5, 6]. The error bars represent the quadratic sum of the statistical and the systematic uncertainties.

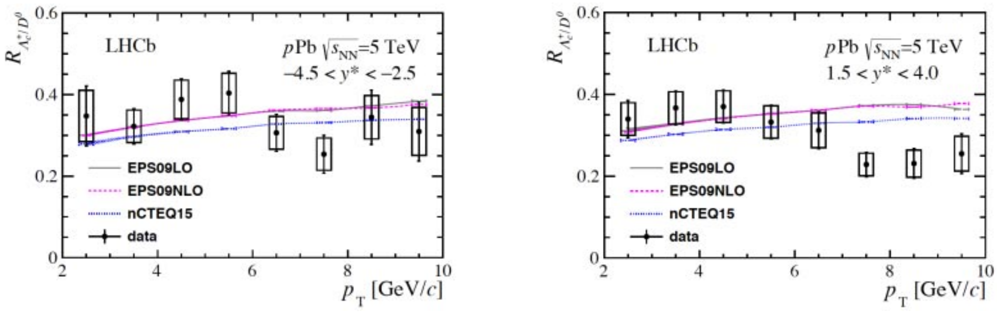

Fig. 3. – Λ_c^+/D^0 production ratios as a function of p_T for the backward (left) and forward (right) configurations, compared with HELAC-Onia predictions [5, 6].

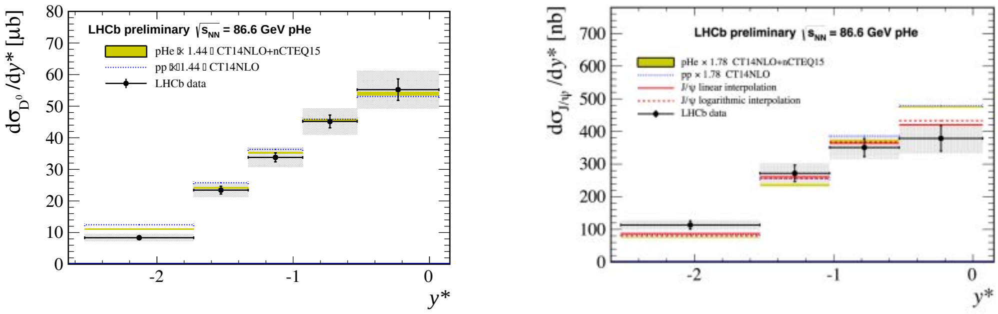

Fig. 4. – Differential cross section for D^0 (left) and J/ψ (right) production in fixed-target pHe collisions at $\sqrt{s_{NN}} = 86.6$ GeV compared with HELAC-Onia predictions [5, 6].

4. – D^0 and J/ψ production in fixed-target collisions

Recently, LHCb reported the first measurement of D^0 and J/ψ production in fixed-target pHe and pAr collisions [7]. The signal yields are extracted in a maximum likelihood fit of the $pK^-\pi^+$ and $\mu^+\mu^-$ invariant mass distributions, respectively. The measured differential cross sections are shown as a function of y^* in Fig. 4 for the case of pHe collisions at $\sqrt{s_{NN}} = 86.6$ GeV.
Given the relatively good agreement between data and HELAC-Onia predictions [5, 6], which do not include contributions from intrinsic charm, there is no hint for a large intrinsic-charm contribution in the data.

REFERENCES

[1] AAIJ R. *et al.* [LHCb Collaboration] *JINST* **3** (2012) S08005.
[2] AAIJ R. *et al.* [LHCb Collaboration] *Int. J. Mod. Phys.* A **30** 143 (2015) 1530022.
[3] AAIJ R. *et al.* [LHCb Collaboration] *JHEP* **10** (2017) 090.
[4] AAIJ R. *et al.* [LHCb Collaboration] *arXiv:1809.01404v1 [hep-ph]* (2018).
[5] LANSBERG J. P. and SHAO H. S. *Eur. Phys. J.* C **77** (2017) 1.
[6] SHAO H. S., HELAC-Onia *Comput. Phys. Commun.* **198** (2016) 238.
[7] AAIJ R. *et al.* [LHCb Collaboration] *arXiv:1810.07907 [hep-ex]* (submitted to *Phys. Rev. Lett.*).