Hard probes with pPb and PbPb collisions and fixed target results at LHCb

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Since 2013, LHCb has been developing an ambitious heavy ion physics program which is highly complementary to the other LHC experiments, thanks to the coverage of the forward rapidity region and the detector specialized capabilities on the reconstruction of heavy flavour hadrons. In addition, LHCb has the unique capability to operate as a fixed target experiment. By using its System for Measuring Overlap with Gas (SMOG), reactions of incident LHC proton beams on noble gas targets have been recorded at a centre-of-mass energy of 110 GeV. These proceedings report an overview of the recent results in fixed-target mode as well as measurements of open and hidden heavy-flavour hadron production in pPb and PbPb collisions.

1 Introduction

The LHCb experiment is designed to study heavy-flavour hadron decays in proton-proton collisions. LHCb is a single arm spectrometer that covers the forward pseudorapidity region $2 < \eta < 5$ equipped with a 4 Tm dipole magnet, it is composed of a silicon strips detector, the vertex locator (VELO) close to the interaction point, tracking stations before and after the dipole magnet, two ring-imaging Cherenkov detectors for particle identification, an electromagnetic and a hadronic calorimeters and a system for the identification of muons.

In the recent years, the LHCb collaboration extended its physics programme to the study of ion collisions. Thanks to the excellent tracking and particle identification capabilities, the LHCb experiment is complementary at forward rapidity to the heavy ion studies already established by the other LHC experiments. So far, datasets of proton-Pb collisions at $\sqrt{s_{NN}} = 5$ TeV and $\sqrt{s_{NN}} = 8.16$ TeV as well as PbPb collisions at $\sqrt{s_{NN}} = 5.02$ TeV have been recorded.

The most peculiar feature of the LHCb detector is that it can be operated as a fixed target experiment. The detector is equipped with the SMOG (System for Measuring Overlap with Gas) device that allows to inject small quantities of noble gases (at pressures of about $\sim 10^{-7}$mbar) in the region of the VELO directly into the LHC beam pipe. This device was initially designed for the precise determination of the luminosity in proton-proton collisions. Starting from 2015, special runs have been dedicated to record fixed-target collisions for physics studies. Interactions between the LHC proton beam and helium, neon and argon gases have been recorded at the centre-of-mass energy of $\sqrt{s_{NN}} = 110$ GeV.

2 Open and hidden heavy flavour production in PbPb and pPb collisions

Open and hidden heavy flavour (charm and beauty) hadrons are considered important probes to study ultra-relativistic heavy ion collisions. Heavy quarks are produced in high-$Q^2$ processes
allowing perturbative QCD calculation down to zero transverse momentum ($p_T$). In PbPb collisions, charm and beauty quarks can interact with the formed medium and, consequently, modifications with respect to pp collisions on the yields of quarkonium states are expected as well as modifications of the kinematic distributions of open heavy flavour hadrons. In pPb collisions, nuclear effects on the parton distribution functions as well as interactions with the nuclear environment can be studied by measurements of heavy flavour productions.

LHCb participated for the first time in PbPb data taking in December 2015 collecting about 50 millions events at $\sqrt{s_{NN}} = 5.02$ TeV. The detector has been designed for low pile-up pp collisions data taking and therefore in the high particle multiplicity of central PbPb collisions the tracking detectors show occupancies up to 100% preventing event reconstruction as depicted in Fig. 1. The centrality of the collision is estimated with a Glauber fit to the distribution of the energy measured in the electromagnetic calorimeter. Due to tracking limitation, the current analysis on $J/\psi$ production will only explore the peripheral events in the centrality range 50-100%.

![Figure 1 – PbPb collisions at $\sqrt{s_{NN}} = 5.02$ TeV. Left: $J/\psi$ invariant mass distribution in the centrality bin 50-70%. Right: correlation between the hits in the VELO detector and the energy measured in the electromagnetic calorimeter. Different colours represent 10% centrality intervals.](image)

In pPb collisions, with the data collected at $\sqrt{s_{NN}} = 5$ TeV, LHCb measured the nuclear modification factors ($R_{pPb}$) of prompt $J/\psi^3$, $\psi(2S)^4$ and $D^0_5$ as depicted in Fig. 2. Thanks to the inversion of the beams, LHCb covered the rapidity ranges $-4 < y < -2.5$ (Pb beam entering in LHCb) and $2.5 < y < 4$ (proton beam entering in LHCb). The results are compared with theoretical calculation that include modifications of the parton distribution functions in nuclei$^6$ and that include coherent energy loss effects$^7$. These results show an overall agreement between data and calculations for the $D^0$ and the $J/\psi$ while the $\psi(2S)$ production is more suppressed than expected. These results will be extensively investigated with the larger dataset of pPb collisions at $\sqrt{s_{NN}} = 8.16$ TeV collected in 2016.

3 Fixed target physics

The interest to study collisions between the LHC proton beams and a fixed target is manifold. On the one hand, the centre-of-mass energy of the collision sits in between the SPS and RHIC hence representing the possibility to bridge past measurements in an energy range not yet explored. On the other hand, interactions of primary cosmic rays with the interstellar medium or with the atmosphere of the Earth are in a similar collision energy range. Hence, thanks to its excellent performance, LHCb can provide important inputs both to the heavy ion collision physics and to the cosmic ray physics.

LHCb studied the production of prompt antiprotons in pHe collisions at $\sqrt{s_{NN}} = 110$ GeV$^8$. The data sample has been collected during five hours of data taking during one LHC fill in May 2016. In this period, helium gas has been injected in the beam pipe with the SMOG device.
A minimum bias trigger has been used to maximise the data taking efficiency. The antiproton yield is extracted via a two-dimensional template fit to the distribution of the differences in the particle identification likelihoods proton-pion versus proton-kaons. The double-differential in momentum and transverse momentum cross section shown in Fig. 3 is compared with EPOS-LHC 10 Monte Carlo predictions, that underestimate the experimental result by a factor 1.2–1.5.

LHCb studied the production of $J/\psi$ and $D^0$ in $p$Ar collisions at $\sqrt{s_{NN}} = 110$ GeV. $J/\psi$ candidates have been reconstructed and selected in the $J/\psi \rightarrow \mu^+\mu^-$ decay channel and $D^0$ candidates in the $D^0 \rightarrow K^-\pi^+$ channel. The centre-of-mass of the collisions is boosted of 4.77 rapidity units and the candidates in the LHCb acceptance are in the rapidity range $-2.3 < y^* < 0.2$ ($y^* = y_{laboratory} - 4.77$).

Since the determination of integrated luminosity is still under study, the results shown in the right plots of Fig. 3 represent the efficiency corrected yields. The transverse momentum distribution of the $D^0$ yield is compared with predictions obtained with Pythia8 11 and normalized to the total $D^0$ yield. The shape of the distribution obtained with Pythia8 is compatible within uncertainties with the experimental data. In the bottom right plot, the ratio of the yields of $J/\psi$ and $D^0$ is shown as a function of the rapidity. This ratio does not show any dependence on the rapidity highlighting that the $D^0$ and $J/\psi$ production mechanisms have the same rapidity dependence and any nuclear effect on the $c\bar{c}$ bound state is independent from the rapidity.

4 Summary

In this proceedings, an overview of the heavy ion physics programme at the LHCb has been presented. In particular, results in $p$Pb collisions at $\sqrt{s_{NN}} = 5$ TeV on open and hidden charm hadrons showed intriguing patterns that will be precisely studied with the larger dataset collected in 2016 in $p$Pb collisions at $\sqrt{s_{NN}} = 8.16$ TeV.

In PbPb collisions, the large detector occupancies reached in high particle multiplicity events prevent the study of central collisions, but the foreseen detector upgrades for the LHC Run 3 will allow to extend the physics reach also to central PbPb collisions.

The possibility to operate the detector to record fixed target collisions makes LHCb unique. Results on antiproton production in $p$He collisions will have a important impact on models for primary cosmic ray interactions with the interstellar medium. The measurement of the production of open and hidden charm hadrons in $p$Ar collisions can help in the understanding of parton distribution function modification in nuclei as well as on the interaction of the final states with the nuclear environment.
LHCb already collected data in $p$He at $\sqrt{s_{NN}} = 87$ GeV, $p$Ne collisions and Pb-Ar collisions at $\sqrt{s_{NN}} = 110$ GeV. LHCb will be able to compare results obtained with different colliding system and at different energies, hence shedding more light on the understanding of relativistic nuclear collisions.

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References

2. R. Aaij et al. [LHCb Collaboration], JINST 9 (2014) no.12, P12005
3. R. Aaij et al. [LHCb Collaboration], JHEP 1402 (2014) 072
4. R. Aaij et al. [LHCb Collaboration], JHEP 1603 (2016) 133
5. The LHCb Collaboration, LHCb-CONF-2016-003.
7. F. Arleo and S. Peigne, JHEP 1303 (2013) 122
8. The LHCb Collaboration, LHCb-CONF-2017-002