

Charm hadronization in fixed-target collisions at LHCb

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Abstract. The innovative fixed-target programme initiated by the LHCb experiment during the LHC Run 2 has been enhanced for Run 3 with the introduction of a dedicated gas injection system, SMOG2. This upgrade features a gas cell to boost fixed-target luminosity and that allows the injection of non-noble gases. SMOG2 enables the collection of large datasets from pA and PbA fixed-target collisions, including high-statistics samples of charm hadrons. Recent results on charm hadronization in fixed-target collisions with SMOG are reported and the latest open charm samples recorded with SMOG2 during Run 3 are also presented.

1 Introduction

The production of charm hadrons can be described by the factorization of two successive processes: the production of a $c\bar{c}$ pair by interaction between initial-state partons, and its hadronization into a charm hadron. While the former can be calculated with perturbative QCD, the latter is modelled phenomenologically via fragmentation functions. The parameters of these functions are extracted from e^+e^- collisions data and assumed to be universal across collision systems. However, significant deviations from e^+e^- results have been observed by the ALICE collaboration in pp collisions for both D^0 and Λ_c hadrons, challenging our understanding of hadronization [1]. A possible mechanism proposed to explain this difference is coalescence, where quarks produced close in phase space can recombine to form hadrons. In particular, in events involving a high Bjorken- x parton, a quark from a $c\bar{c}$ pair produced at large rapidity may recombine with valence quarks from the incoming proton [2]. This mechanism favors the production of hadrons sharing valence quarks with the beam, such as the \bar{D}^0 , and consequently, an asymmetric production of D^0 and \bar{D}^0 mesons is expected. In addition, this asymmetry can provide insights into the intrinsic charm content of the nucleon.

2 The LHCb detector

The LHCb detector is a single-arm forward spectrometer, originally designed for the study of heavy-flavors. It features a forward geometry, covering the pseudorapidity region $2 < \eta < 5$. Its subdetectors provide a precise reconstruction of primary and secondary vertices, excellent tracking performances and high-quality particle identification [3, 4]. A distinctive feature of LHCb is its ability to operate both as a collider and as a fixed-target experiment. During the

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Run 2 of the LHC, fixed-target collisions were achieved thanks to the System for Measuring the Overlap with Gas (SMOG) which allows the injection of noble gases into the beam pipe around the interaction point [5]. In this configuration, the center-of-mass energy is significantly reduced, ranging from $\sqrt{s_{NN}} = 68.5$ to 113 GeV for beam energies between 2.5 and 6.8 TeV. Due to the boost of the beam, the rapidity in the center-of-mass of the reaction is shifted to $-2.5 \leq y^* \leq 0$. This kinematic domain probes the high Bjorken- x region of the target ($10^{-2} \lesssim x_2 \lesssim 4 \times 10^{-1}$) where valence quarks dominate. This region, relatively unexplored so far, is therefore particularly relevant for studying hadronization mechanisms.

3 Results on charm hadronization in Run 2

The $D^0 - \bar{D}^0$ asymmetry has been measured by LHCb in p Ne collisions at the center-of-mass energy of $\sqrt{s_{NN}} = 68.5$ GeV [6]. The asymmetry is defined as

$$\mathcal{A} = \frac{Y_{corr}(D^0) - Y_{corr}(\bar{D}^0)}{Y_{corr}(D^0) + Y_{corr}(\bar{D}^0)}, \quad (1)$$

where $Y_{corr}(D^0)$ and $Y_{corr}(\bar{D}^0)$ correspond to the efficiency-corrected yields of the $D^0 \rightarrow K^-\pi^+$ and $\bar{D}^0 \rightarrow K^+\pi^-$ decays respectively. The measured asymmetry is shown in Figure 1 as a function of the center-of-mass rapidity y^* . A negative asymmetry is observed, ranging from $\sim 0\%$ at $y^* = 0$ to $\sim -15\%$ at $y^* \approx -2.5$, although the precision of the measurement is limited by large uncertainties. The experimental results are compared with Pythia 8 [7] predictions which give an asymmetry of about -6% , independent of y^* . An upper limit on the asymmetry is provided by Vogt predictions with (Vogt 1% IC) and without (Vogt no IC) intrinsic charm [8]. The model from Maciula and Szczurek (MS), including 1% of intrinsic charm and 10% of recombination mechanism, reproduces well the trend observed in the data [2].

4 Prospects for Run 3

The fixed-target system of LHCb has been upgraded for Run 3 with the installation of a dedicated gas injection cell called SMOG2 [9]. Its position upstream of the LHCb interaction point enables simultaneous data-taking in both collider and fixed-target modes. In addition, the reduced volume of SMOG2 leads to an increased luminosity, improving measurements precision. SMOG2 also offers the possibility to inject non-noble gases, broadening the range of accessible colliding systems. Using this upgraded setup, the D^0 meson has been reconstructed in p H₂, p D₂, p He and p Ar collisions at the center-of-mass energy of $\sqrt{s_{NN}} = 70.9$ GeV. The corresponding invariant mass distributions are presented in Figure 2. The large available statistics should allow for a precise measurement of the $D^0 - \bar{D}^0$ asymmetry, providing key insights into hadronization mechanisms.

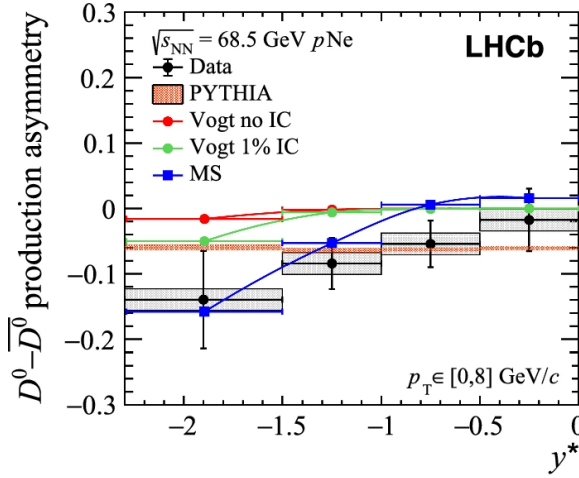


Figure 1. $D^0 - \bar{D}^0$ asymmetry as a function of the rapidity in the center-of-mass y^* in $p\text{Ne}$ collisions at $\sqrt{s_{NN}} = 68.5$ GeV [6]. The error bars represent the quadratic sum of statistical and uncorrelated uncertainties while the grey boxes represent the correlated systematic uncertainties.

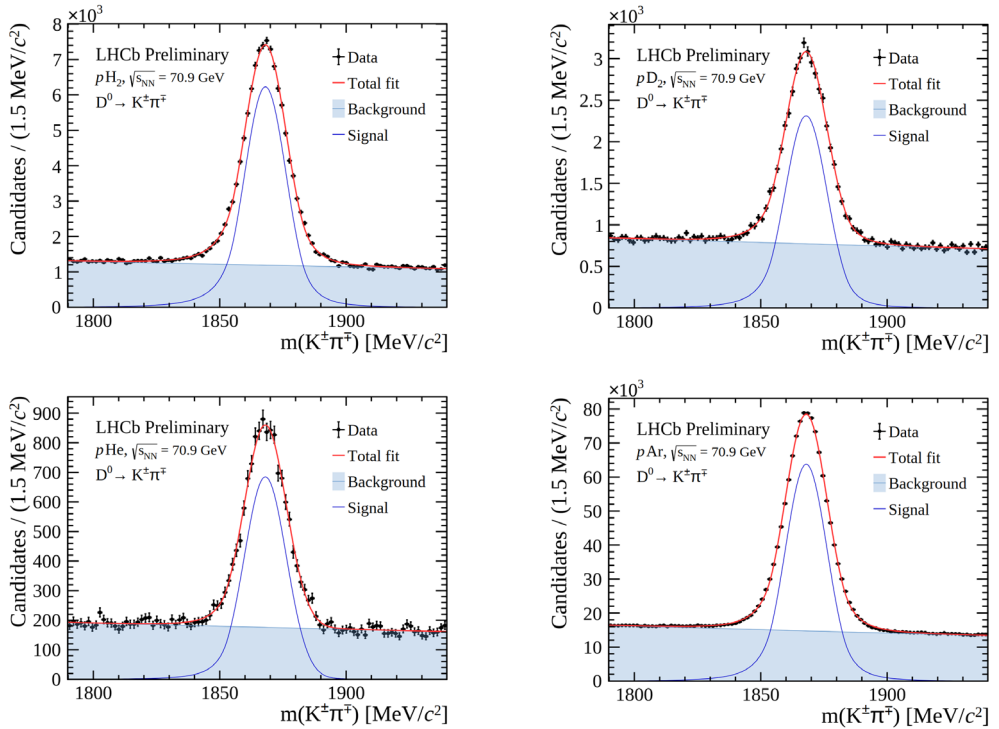


Figure 2. Invariant mass distributions of $K^{\mp}\pi^{\pm}$ candidates in $p\text{H}_2$ (top left), $p\text{D}_2$ (top right), $p\text{He}$ (bottom left) and $p\text{Ar}$ (bottom right) collisions. The data are overlaid with the fit results [10].

5 Conclusion

The production asymmetry of D^0 and \bar{D}^0 mesons in $p\text{Ne}$ collisions at $\sqrt{s_{NN}} = 68.5$ GeV has been measured by the LHCb detector in its fixed-target configuration. A negative asymmetry is observed at backward rapidity, where valence quarks of the target are expected to contribute the most. In Run 3 data, clear D^0 signal peaks are observed in $p\text{H}_2$, $p\text{D}_2$, $p\text{He}$ and $p\text{Ar}$ collisions at $\sqrt{s_{NN}} = 70.9$ GeV. The precision of the $D^0 - \bar{D}^0$ asymmetry measurement should be improved thanks to the large statistics available with SMOG2.

References

- [1] S. Acharya et al. (ALICE Collaboration), Charm production and fragmentation fractions at midrapidity in pp collisions at $\sqrt{s} = 13$ TeV. *JHEP* **12** (2023). [http://doi.org/10.1007/JHEP12\(2023\)086](http://doi.org/10.1007/JHEP12(2023)086)
- [2] R. Maciuła, A. Szczurek, Recombination mechanism for D^0 -meson production and $D^0 - \bar{D}^0$ production asymmetry in the LHCb $p+^{20}\text{Ne}$ fixed-target experiment. *Physics Letters B* **835** (2022). <https://doi.org/10.1016/j.physletb.2022.137530>
- [3] A. A. Alves et al. (LHCb Collaboration), The LHCb Detector at the LHC. *JINST* **3**, S08005 (2008). <https://doi.org/10.1088/1748-0221/3/08/S08005>
- [4] R. Aaij et al. (LHCb Collaboration), LHCb Detector Performance. *Int. J. Mod. Phys. A* **30**, 1530022 (2015). <https://doi.org/10.1142/S0217751X15300227>
- [5] R. Aaij et al. (LHCb Collaboration), Precision luminosity measurements at LHCb. *Journal of Instrumentation* **9** (2014). <https://doi.org/10.1088/1748-0221/9/12/P12005>
- [6] R. Aaij et al. (LHCb Collaboration), Open charm production and asymmetry in $p\text{Ne}$ collisions at $\sqrt{s_{NN}} = 68.5$ GeV. *The European Physical Journal C* **83**, (2023). <http://doi.org/10.1140/epjc/s10052-023-11641-5>
- [7] T. Sjöstrand et al., A brief introduction to PYTHIA 8.1. *Computer Physics Communications* **178** (2008). <http://dx.doi.org/10.1016/j.cpc.2008.01.036>
- [8] R. Vogt, Limits on intrinsic charm production from the SeaQuest experiment. *Physical Review C* **103** (2021). <http://doi.org/10.1103/PhysRevC.103.035204>
- [9] O. Boente Garcia et al., High-density gas target at the LHCb experiment. *Physical Review Accelerators and Beams* **27** (2024). <http://doi.org/10.1103/PhysRevAccelBeams.27.111001>
- [10] LHCb Collaboration, D^0 mass peak in SMOG2 2024 pp reference runs. (2025) <https://cds.cern.ch/record/2929357>