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Charm physics at the Compact Muon Solenoid experiment(*)

M. E. Ascioti on behalf of the CMS Collaboration
Department of Physics and Geology, University of Perugia - Perugia, Italy

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Summary. — In this contribution, we illustrate the first measurement (The CMS Collaboration, *JHEP*, **2021** (2021) 225) of the cross-section for open charm production at the Compact Muon Solenoid experiment (CMS) (The CMS Collaboration, *JINST*, **3** (2008) S08004). The analysis encompasses three distinct open-charm mesons and their respective charge conjugates. The dataset employed in this study corresponding to an integrated luminosity of 29 nb^{-1}, was collected in 2016, during the second Run of the Large Hadron Collider (LHC), from proton-proton collisions at $\sqrt{s} = 13$ TeV. For this analysis, we define the fiducial region as characterised by $4 < p_T < 100$ GeV and $|\eta| < 2.1$. To conclude, we will illustrate the implications and the future potential of this research.

1. – Introduction

Charm physics, the study of excited states of charmonium ($c\bar{c}$) and open charm mesons - a c quark plus one or more quarks of different flavours - represents a fascinating laboratory for investigating Quantum Chromodynamics (QCD). In a detector like CMS [2], which lacks a specific particle identification system (PID), the reconstruction and identification of charmed states are particularly challenging.

In this contribution, we will discuss the first measurement of open charm cross-section in CMS [1] at $\sqrt{s} = 13$ TeV from proton-proton collisions and future prospects.

The interest in this measurement is reinforced by the evidence that charmed states are an excellent probe for the study of Multiple Parton Interactions (MPI) [3]: rare events where two or more parton pairs from the same protons interact strongly. Recently, the observation of triple J/Ψ production provided the first evidence of Triple Parton Scattering (TPS) as a production mechanism [4]. After a brief description of the measurement, we will discuss the potential of including an open charm meson in the final state for TPS analysis [5].

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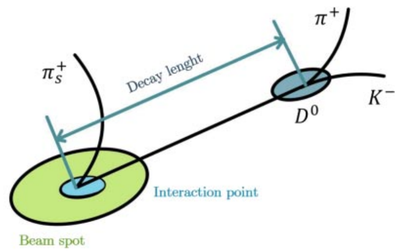

Fig. 1. – Schematic representation of Primary Vertex and Secondary Vertex displacement.

2. – Measurement of prompt open-charm production cross sections

In [1], the analysis is focused on the measurement of cross sections for the prompt production of D^{*+}, D^0, and D^+ mesons and their respective charge-conjugates (charged conjugation is implied throughout this proceeding). With the term prompt, we are referring to particles directly produced from partons interaction. The charmed mesons are identified via their exclusive decays:

- $pp \to D^{*+}X \to D^0\pi^+X \to K^-\pi^+\pi^+X$
- $pp \to D^0X \to K^-\pi^+X$
- $pp \to D^+X \to K^-\pi^+\pi^+X$

where X corresponds to any set of possible particles. The designation π_s^+ indicates that, because of the specific kinematics of the D^{*+} decay, this *slow* pion has significantly lower momentum than the kaon and pion decay products of the D^0. The charge of the π_s tags the charge of the initial D^*. The D^{*+}, D^0, and D^+ mesons are reconstructed in the range of transverse momentum $4 < p_T < 100$ GeV and pseudorapidity $|\eta| < 2.1$. The most inclusive trigger was applied and the dataset used was collected during the second Run at LHC in 2016 and corresponded to an integrated luminosity of 29 nb^{-1}.

The differential cross-section is defined as:

$$\frac{d\sigma(pp \to D + X)}{dp_T} = \frac{N_i(D \to f)}{\Delta p_T \mathcal{B}(D \to f)\mathcal{L}\epsilon_{i,TOT}(D \to f)}$$

where N_i is the number of bins, Δp_T is the bin width, $\mathcal{B}$ the branching ratio, $\mathcal{L}$ the integrated luminosity and $\epsilon_{i,TOT}$ is the reconstruction efficiency evaluated bin per bin. To reconstruct the D^* meson, it is essential to accurately reconstruct the Primary vertex (PV) and the secondary vertix (SV): the cosine of the angle ($cos\alpha$) between the charm candidate p_T and the vector pointing from the PV to the SV is used to ensure the D meson is consistent with originating from the PV (see fig. 1). Additionally, cuts on decay length are applied.

When analyzing the cross section measurement obtained on data and comparing it to model predictions, several interesting observations emerge:

- None of the MC generators can completely and accurately model the data across the entire kinematic region. The measurements tend to favour higher cross sections compared to what both PYTHIA [6] and fixed-to-next-to-the-leading order (FONLL) predict.

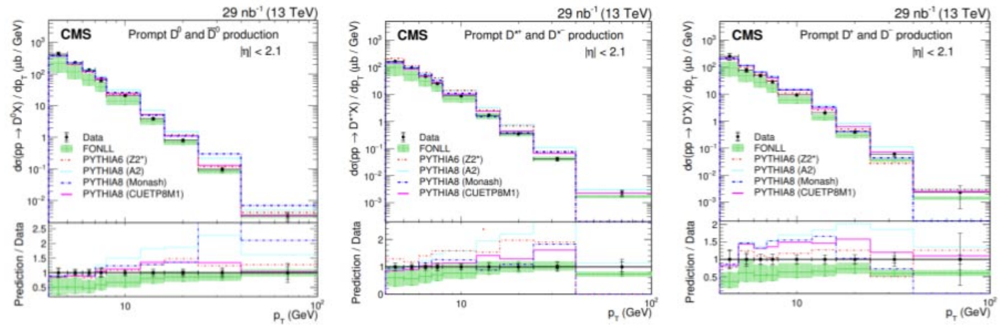

Fig. 2. – Starting from the left we can see the D^{*+}, D^0 and D^+ and their respective charge conjugate differential cross section as a function of the meson p_T [1].

- As one delves into the high p_T region, the agreement between different Monte Carlo simulations and the data worsens. This suggests that modelling particle behaviour becomes more challenging at higher momenta.

- FONLL predictions show that the upper limits of the uncertainty band are the closest to describing the data. This observation highlights the importance of quantifying uncertainties in theoretical predictions.

- The sensitivity of cross section predictions to the parameters used in PYTHIA simulations confirms the model dependency inherent in these predictions. This variability serves as an incentive for the development of more accurate models. However, achieving this improvement is contingent on increasing the availability of experimental data measurements. More and better data are essential to refining our understanding of particle interactions and enhancing the accuracy of theoretical predictions.

3. – Future perspective

The study of charmed mesons provides an ideal opportunity to investigate MPI [3], which involves rare events where two or more parton pairs from the same protons interact strongly. In 2021, the CMS collaboration confirmed triple J/Ψ production [4]: five triple J/Ψ events were found using the data collected during Run 2. The $\approx 20\%$ of the signal events is consistent with TPS production mechanism.

The measurement of open-charm mesons has been demonstrated as feasible in CMS, as evidenced in [1]. Among the studied D mesons, the D^* meson stands out as the one that can be reconstructed with the highest purity. Given this result and the fact that D^* mesons exhibit a larger cross-section compared to J/ψ, our objective is to investigate a new final state involving double J/Ψ and a D^* meson to examine TPS as a production mechanism. We wish to emphasise that the study of Triple and Double Parton Scattering carries implications for model development and a better understanding of proton-parton interactions [5].

4. – Summary

The originality of the analysis presented in [1] lies in its development of an analytical strategy tailored for identifying open-charm mesons in an environment, like CMS, which is not traditionally conducive for such analyses.

The feasibility of conducting CMS-based analyses focused on open-charm mesons demonstrates new opportunities, as previously presented. Furthermore, the comparison of experimental data with Monte Carlo (MC) simulations and FONLL predictions sheds light on the challenges associated with modelling these interactions. While the current models may not achieve complete accuracy, they play an essential role in advancing our understanding of particle physics, underlining the ongoing necessity for refinement and further data-driven progress in the field.

Additionally, CMS measurements show good agreement with measurements from other experiments (LHCb, Alice and ATLAS), accounting for the evolution in the centre-of-mass energy scale and kinematic dependencies, as described in [1].

Finally, these results pave the way for further analysis such as the study of Triple Parton Scattering (TPS) with a double J/Ψ and a D^* meson which is of extreme interest not only for the development of the model itself but also for the insights it can provide into our understanding and modelling of the proton.

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