

Production asymmetry of D and \bar{D} mesons in the LHCb fixed target experiment and intrinsic charm in the nucleon

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We discuss production of D^0 and \bar{D}^0 mesons in proton-nucleus collisions in fixed target experiments. We include gluon-gluon fusion, intrinsic charm and perturbative recombination. We compare rapidity and transverse momentum distributions obtained within our approach with recent fixed target LHCb experimental data. All the mechanisms seem important for inclusive production of $D^0 + \bar{D}^0$ mesons. The recombination mechanism seems crucial to understand asymmetry in production of D^0 and \bar{D}^0 mesons.

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1. Introduction

Recently the LHCb collaboration measured production of D^0 and \bar{D}^0 mesons in proton-nucleus fixed target experiment [1]. They observed an asymmetry in the production of D^0 and \bar{D}^0 . In general, there can be different reasons of the asymmetry. One is asymmetric charm in the nucleon as due to meson cloud. Another is a recombination mechanism [2]. Here we summarize our recent results for fixed target LHCb experiments [3, 4]. We shall consider different mechanisms:

- gluon-gluon fusion, dominant in the collider mode.
- mechanism of c/\bar{c} knock-out, related to intrinsic charm (IC) in the nucleon as formulated in [5] or within meson cloud model.
- recombination mechanism of perturbative nature.

2. Sketch of the formalism

In Fig.1 we show the dominant at high energies mechanism of gluon-gluon fusion.

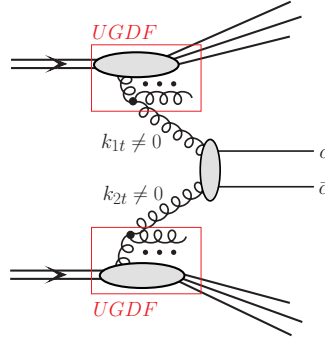


Figure 1: The dominant gluon-gluon fusion mechanism.

In addition to the dominant high-energy mechanism at “our” low energy $\sqrt{s} = 68.5$ GeV we include also intrinsic charm contribution (see the left panel of Fig.2). Here the intrinsic charm quark or antiquark (identical distribution in the most simple approach of Ref.[5]) is kicked off by the interaction with gluon from the proton. The second mechanism with the approximations made leads to symmetric production of c and \bar{c} and in the consequence identical production of D^0 and \bar{D}^0 mesons, also differentially. In the presented analysis we included also perturbative recombination mechanism first proposed by Braaten, Jia and Mehen (BJM) [2] (see the right panel of Fig.2)). As discussed in [3] this leads to D^0 - \bar{D}^0 asymmetry.

The gluon-gluon fusion is calculated in the k_t -factorization mechanism as:

$$\frac{d\sigma}{dy_1 dy_2 d^2 p_{1,t} d^2 p_{2,t}} = \int \frac{d^2 k_{1,t}}{\pi} \frac{d^2 k_{2,t}}{\pi} \frac{1}{16\pi^2 (x_1 x_2 s)^2} \overline{|\mathcal{M}_{g^* g^* \rightarrow Q \bar{Q}}|^2} \times \delta^2(\vec{k}_{1,t} + \vec{k}_{2,t} - \vec{p}_{1,t} - \vec{p}_{2,t}) \mathcal{F}_g(x_1, k_{1,t}^2, \mu) \mathcal{F}_g(x_2, k_{2,t}^2, \mu) .$$

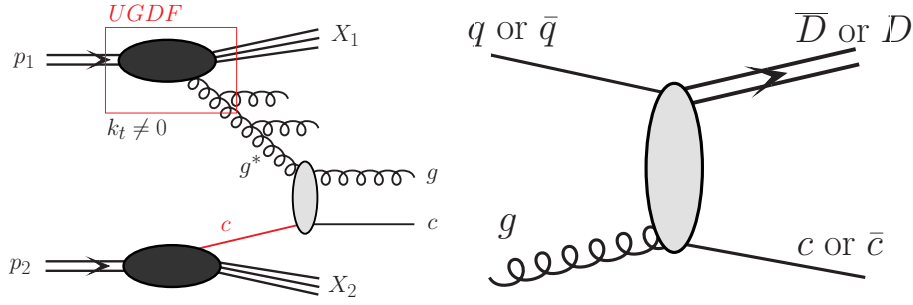


Figure 2: A diagrammatic representation of: the gluon - charm mechanism for charm production within the hybrid model, with the off-shell gluon and the on-shell charm quark in the initial state (left), and the generic leading-order diagrams for D meson production via the BJM recombination model (right).

Above \mathcal{F}_g are unintegrated gluon distributions in proton or nucleus, respectively. The same functional form is used for ^{20}Ne as for the proton, i.e. no nuclear effects are taken into account in order to concentrate on individual contributions (gluon-gluon fusion, intrinsic charm, recombination).

The intrinsic charm contribution to c and \bar{c} distributions is calculated in a hybrid model as:

$$d\sigma_{pp \rightarrow \text{charm}}(cg^* \rightarrow cg) = \int dx_1 \int \frac{dx_2}{x_2} \int d^2k_t \times c(x_1, \mu^2) \cdot \mathcal{F}_g(x_2, k_t^2, \mu^2) \cdot d\hat{\sigma}_{cg^* \rightarrow cg},$$

where $c(x_1, \mu^2)$ is collinear c -quark distribution. Similar formula can be written for production of \bar{c} antiquark.

The differential cross section for the recombination reads:

$$\frac{d\sigma}{dy_1 dy_2 d^2p_t} = \frac{1}{16\pi^2 \hat{s}^2} [x_1 q_1(x_1, \mu^2) x_2 g_2(x_2, \mu^2) \overline{|\mathcal{M}_{qg \rightarrow \bar{D}c}(s, t, u)|^2} + x_1 g_1(x_1, \mu^2) x_2 q_2(x_2, \mu^2) \overline{|\mathcal{M}_{gq \rightarrow \bar{D}c}(s, t, u)|^2}].$$

In the formula above: $\overline{|\mathcal{M}_{qg \rightarrow Dc}(s, t, u)|^2} = \overline{|\mathcal{M}_{qg \rightarrow (\bar{c}q)^n c}|^2} \cdot \rho$, where ρ can be interpreted as a probability to form real meson. The parameter cannot be directly calculated and has to be extracted from the data. Above q is a collinear quark/antiquark distribution in proton or neutron, components of the nucleus, with the flavour relevant for D^0 or \bar{D}^0 production and g is a collinear gluon distribution.

The fragmentation from $c \rightarrow D^0$ or $\bar{c} \rightarrow \bar{D}^0$ is done using phenomenological fragmentation functions known from e^+e^- collisions. More details are explained in [3, 4].

3. Selected results

In this section we present some representative results. In Fig. 3 we present our predictions for the rapidity (left panel) and transverse momentum (right panel) distributions of D^0 meson (plus \bar{D}^0 antimeson) in $p + ^{20}\text{Ne}$ collisions at $\sqrt{s} = 68.5$ GeV together with the LHCb data [1]. The inclusion of the gluon - charm mechanism due to intrinsic charm improves the description of the

experimental data. In particular, in the region of the most backward rapidities both the gluon - charm and the recombination contributions dominate over the standard mechanism. There, the gluon - charm contribution is about factor 2 and factor 5 larger than the recombination and the standard mechanism, respectively. Considering the transverse momentum spectra, we see that at low p_T 's the cross section is dominated by the standard contribution, however, for the highest transverse momentum bin the contribution from the gluon - charm mechanism starts to play important role. Although the data indicates that the inclusion of the IC contribution is important, we also found that the quality of the description of the LHCb data for the distinct models of asymmetric intrinsic charm is very similar. There are no big differences in the obtained normalization and shapes of the differential cross-sections for the inclusive single charm meson spectra between the CT18FC MBMC and CT18FC MBME parametrizations.

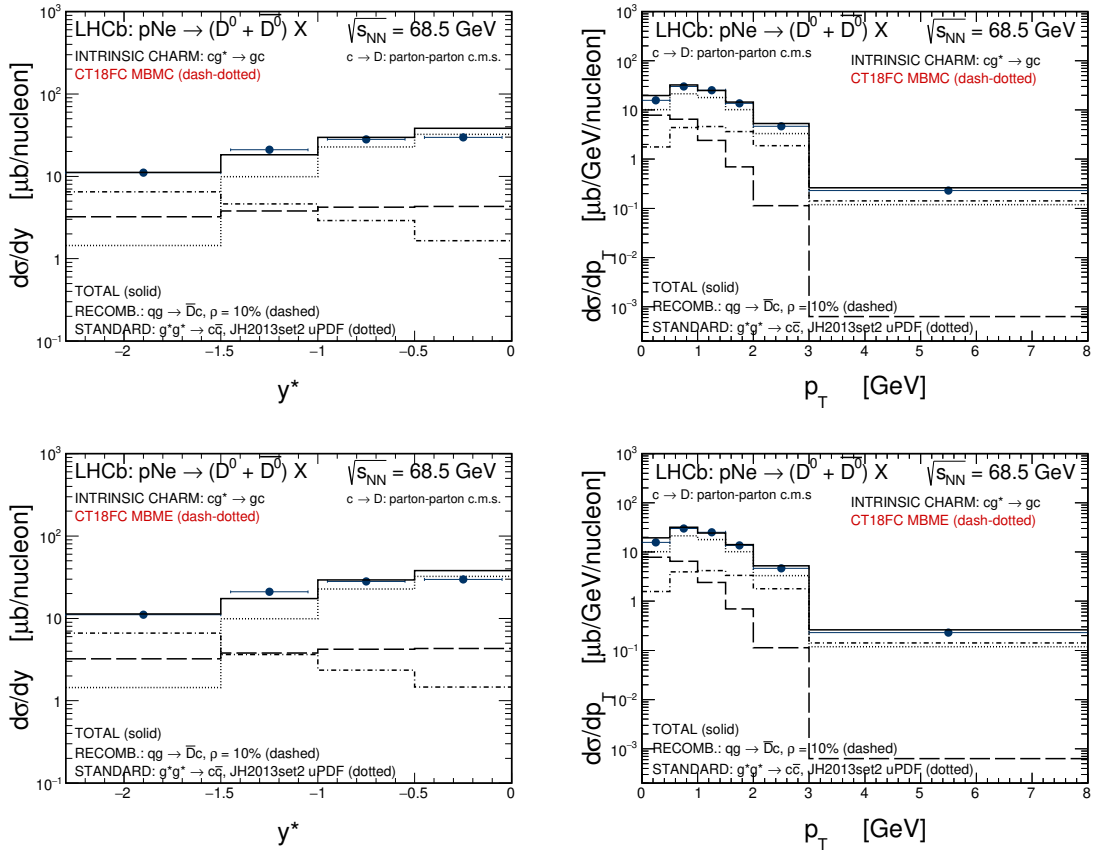


Figure 3: The rapidity (left) and transverse momentum (right) distributions of D^0 meson (plus \bar{D}^0 antimeson) for $p + {}^{20}\text{Ne}$ collisions at $\sqrt{s} = 68.5$ GeV together with the LHCb data [1]. The three different contributions to charm meson production are shown separately, including the standard $g^*g^* \rightarrow c\bar{c}$ mechanism (dotted), the gluon - charm contribution (dot-dashed) and the recombination component (dashed). The solid histograms correspond to the sum of all considered mechanisms. Results derived using the CT18FC MBMC (upper panels) and CT18FC MBME (lower panels) parametrizations are shown here.

As was mentioned in the Introduction, the LHCb experimental data indicates a sizeable production asymmetry of D^0 and \bar{D}^0 for negative rapidities and large transverse momenta. Description

of these results in the full kinematical range is still a theoretical challenge. The associated results of our predictions are presented in Fig. 4 for the distinct models of intrinsic charm PDFs. The data can be described when both the recombination and intrinsic charm mechanisms are taken into account. However, the description of the data for large transverse momentum is still a challenge. Clearly, more data in this kinematical region is needed in order to constrain the IC and recombination mechanisms better.

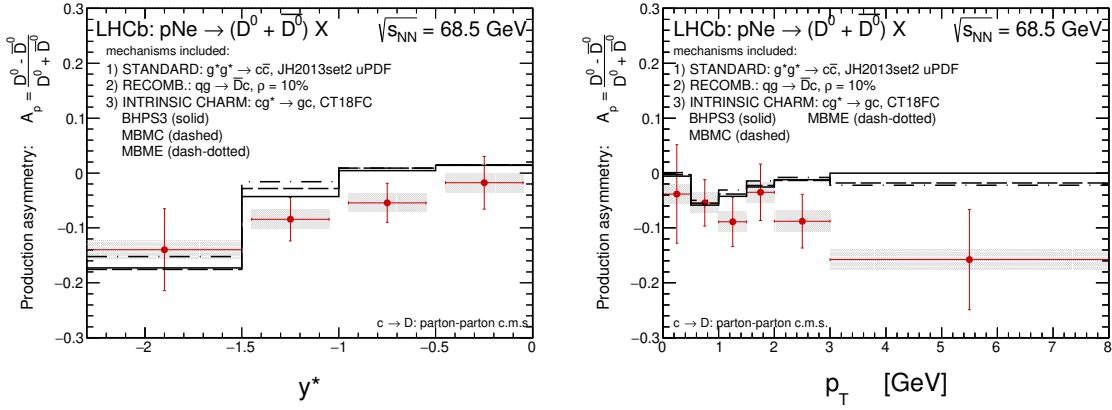


Figure 4: The production asymmetry A_p for D^0 -meson and \bar{D}^0 -antimeson as a function of rapidity (left) and transverse momentum (right) for $p + {}^{20}\text{Ne}$ collisions at $\sqrt{s} = 68.5$ GeV together with the LHCb data [1]. Results derived assuming the standard $g^*g^* \rightarrow c\bar{c}$, gluon - charm and recombination mechanisms, and different parametrizations for the intrinsic charm distributions are shown.

4. Conclusions

At low $\sqrt{s} = 68.5$ GeV $p+A$ scattering all mechanisms: gluon-gluon fusion, intrinsic charm and perturbative recombination mechanisms may play important role in the measured region. Each of the components is a bit unsure. We do not know very well unintegrated gluon distribution relevant for the low energies (larger longitudinal fractions). The intrinsic charm component depends e.g. on the probability of the $uudc\bar{c}$ (proton) or $dduc\bar{c}$ (neutron) Fock components in proton or neutron, respectively. While the 1 % intrinsic charm knock-out mechanism improves the description of the LHCb rapidity distribution, the recombination mechanism is necessary to generate the D^0 - \bar{D}^0 asymmetry as a function of D -meson rapidity. The $\rho \approx 0.1$ allows to describe the asymmetry for the fixed target LHCb rapidity distribution. It is more difficult to describe asymmetry as a function of D -meson transverse momentum. This may be due to usage of leading-order colinear formalism which may be not adequate for description of transverse momentum distribution. It simply generates too small transverse momenta. This could be easily improved by including primordial (nonperturbative) distributions of partons (gluons, quarks, antiquarks) in the nucleon.

In this presentation we studied the case of symmetric intrinsic charm distribution as in our first paper [3]. In Ref.[4] we included also asymmetric intrinsic charm as dictated by the meson cloud picture. However, such an asymmetric mesonic IC is not able to describe alone (without

the recombination mechanism) the measured $D^0 - \bar{D}^0$ asymmetries. Therefore the recombination seems necessary.

Another mechanism, not discussed in the presentation at ICHEP2024, was discussed recently in [6]. There the production of D^0 and \bar{D}^0 is asymmetric as D^0 and \bar{D}^0 come from different terms in the nucleon Fock expansion.

References

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