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Charm production in high multiplicity pp events

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Abstract. Studying proton-proton scattering at 7 TeV, the ALICE collaboration found the unexpected result that the D meson multiplicity increases more than linear as a function of the charged particle multiplicity. We try to understand this behavior using the EPOS3 approach. Two issues play an important role in this context: multiple scattering, in particular its impact on multiplicity fluctuations, and the collective hydrodynamic expansion. These data contain therefore valuable information about very basic features of the reaction mechanism in proton-proton collisions.

Recently, several experimental groups investigated the dependence of heavy quark production on the event activity, both for open and hidden charm or bottom, in high energy proton-proton collisions. We will focus here on D meson production, where the term "D meson multiplicity" refers in the following to the average multiplicity of D^+, D^0 and D^{*+}. The ALICE collaboration found a quite unexpected result [1]: When plotting the D meson multiplicity versus the charged particle multiplicity, both divided by the corresponding minimum bias mean values, one obtains a dependence which is very significantly more than linear (where "linear" means $N_D/\left\langle N_D\right\rangle = N_{\mathrm{ch}}/\left\langle N_{\mathrm{ch}}\right\rangle$). The effect seems to be bigger for larger transverse momentum (p_t). Both D meson and charged particle multiplicity refer to central rapidities.

It is clear that the experimental observations are very interesting, and provide valuable insight into the very nature of the reaction mechanism in *pp* scattering, in particular in case of high event activity. So we try in this paper to provide an analysis of the phenomenon in the EPOS3 framework. Two key aspects are: Multiple scattering and collectivity.

EPOS3 [2] is a universal model in the sense that for pp, pA, and AA collisions, the same procedure applies, based on several stages:

Initial conditions. A Gribov-Regge multiple scattering approach is employed ("Parton-Based Gribov-Regge Theory" PBGRT [3]), where the elementary object (by definition called Pomeron) is a DGLAP parton ladder, using in addition a CGC motivated saturation scale [4] for each Pomeron, of the form $Q_s \propto N_{\mathrm{part}}\,\hat{s}^{\lambda}$, where N_{part} is the number of nucleons connected the Pomeron in question, and $\hat{s}$ its energy. The parton ladders are treated as classical relativistic (kinky) strings.

Core-corona approach. At some early proper time τ_0, one separates fluid (core) and escaping hadrons, including jet hadrons (corona), based on the momenta and the density of string segments (First described in [5], a more recent discussion in [2]). The corresponding energy-momentum tensor of the core part is transformed into an equilibrium one, needed to start the hydrodynamical evolution. This is based on the hypothesis that equilibration happens rapidly and affects essentially the space components of the energy-momentum tensor.

Viscous hydrodynamic expansion. Starting from the initial proper time τ_0, the core part of the system evolves according to the equations of relativistic viscous hydrodynamics [2, 6], where we use presently $\eta/s = 0.08$. A cross-over equation-of-state is used, compatible with lattice QCD [7, 8]. The "core-matter" hadronizes on some hyper-surface defined by a constant temperature T_H, where a so-called Cooper-Frye procedure is employed, using equilibrium hadron distributions, see [8]. After hadronization, there occur still hadron-hadron rescatterings, realized via UrQMD [9].

The above procedure is employed for each event (event-by-event procedure).

Heavy quarks (Q) are produced during the initial stage, in the PBGRT formalism, in the same way as light quarks. We have several parton ladders, each one composed of two space-like parton cascades (SLC) and a Born process. The time-like partons emitted in the SLC or the Born process are in general starting points of time like cascades (TLC). In all these processes, whenever quark–antiquark production is possible, heavy quarks may be produced. We take of course into account the modified kinematics in case of non-zero quark masses (we use $m_c = 1.3$, $m_b = 4.2$). D meson production in the EPOS3 framework has been studied extensively, comparing to data and other calculation, in ref. [10].

We try to understand the dependence of the D meson multiplicity on the charged particle multiplicity, first for EPOS basic (without hydro). We study the case, where both multiplicities refer to central rapidities ($|y| \leq 0.5$ for the D mesons, and $|\eta| \leq 1$ for the charged particles). We use the variables N_{ch} for the charged particle multiplicity, and N_{Di} for the D meson multiplicities for different p_t ranges (N_{D1} for $1 < p_t[\mathrm{GeV/c}] < 2$, and N_{D8} for $8 < p_t[\mathrm{GeV/c}] < 12$).

In EPOS3, we have in each individual event a certain number of parton ladders (cut Pomerons). Each ladder contributes (roughly, on the average) the same to both charged particle and charm production, so both corresponding multiplicities are proportional to the number N_{Pom} of cut Pomerons: $N_{Di} \propto N_{\mathrm{ch}} \propto N_{\mathrm{Pom}}$, which leads to a "natural" linear relation between the charged particle multiplicity N_{ch} and the D meson multiplicities N_{Di} (to first approximation).

We define normalized multiplicities, $n = N/\langle N\rangle$, both for charged particles (n_{ch}) and D meson multiplicities (n_{Di}). In the following, we consider fixed values n^*_{ch} of normalized charged multiplicities.

We will study the average normalized D meson multiplicity for the largest p_t range, for some given n^*_{ch}, which may be expressed in terms of the Pomeron number distribution $\mathrm{prob}(N_{\mathrm{Pom}}, {n_{\mathrm{ch}}}^*)$ at fixed n^*_{ch} and the number $n_{D8}(N_{\mathrm{Pom}}, {n_{\mathrm{ch}}}^*)$ of D mesons for fixed N_{Pom} and ${n_{\mathrm{ch}}}^*$, as

$$n_{D8}(n^*_{\mathrm{ch}}) = \sum_{N_{\mathrm{Pom}}} \mathrm{prob}(N_{\mathrm{Pom}}, {n_{\mathrm{ch}}}^*) \times n_{D8}(N_{\mathrm{Pom}}, {n_{\mathrm{ch}}}^*) \quad . \tag{1}$$

The two curves representing $\mathrm{prob}(N_{\mathrm{Pom}}, {n_{\mathrm{ch}}}^*)$ and $n_{D8}(N_{\mathrm{Pom}}, {n_{\mathrm{ch}}}^*)$ are shown in fig. 1 (left). We see in the figure that $n_{D8}(N_{\mathrm{Pom}}, {n_{\mathrm{ch}}}^*)$ increases strongly towards small N_{Pom} with an increasing slope. Let us compare the expression of eq. (1) with the corresponding sum (as a reference) where we use $n_{D8}(N_{\mathrm{Pom}}, {n_{\mathrm{ch}}}^*) = {n_{\mathrm{ch}}}^*$, which would lead to $n_{D8}(n^*_{\mathrm{ch}}) = n^*_{\mathrm{ch}}$. For large N_{Pom}, the contribution to the sum in eq. (1) will be less than the reference case, but this is more than compensated at small N_{Pom}. Therefore, we have $n_{D8}(n^*_{\mathrm{ch}}) > {n_{\mathrm{ch}}}^*$, which is confirmed by the precise calculation shown in fig. 1 (right) as red point. Also shown is the complete curve $n_{D8}(n_{\mathrm{ch}})$ as obtained from EPOS basic. Indeed, we get a more than linear increase.

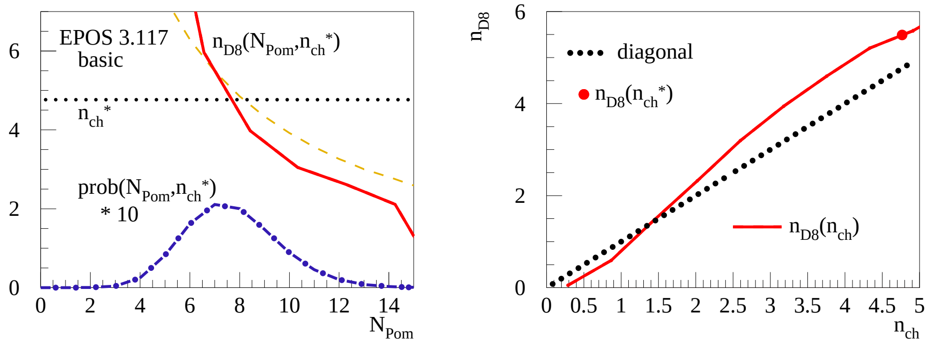

Figure 1. (Color online) Left: Pomeron number distribution at fixed charged multiplicity, prob$(N_{\mathrm{Pom}}, n_{\mathrm{ch}}{}^*)$ (blue line), and number $n_{D8}(N_{\mathrm{Pom}}, n_{\mathrm{ch}}{}^*)$ of D mesons (large p_t) for fixed N_{Pom} and $n_{\mathrm{ch}}{}^*$ as a function of the Pomeron number N_{Pom} (red line). The dotted line represents the constant value $n_{\mathrm{ch}}{}^*$.
Right: Average multiplicity $n_{D8}(n_{\mathrm{ch}})$ of D mesons (large p_t) as a function of n_{ch} (red line) and the diagonal ($n_{D1} = n_{\mathrm{ch}}$, dotted line). The red point refers to $n_{D8}(n^*_{\mathrm{ch}})$ for the particular value of $n_{\mathrm{ch}}{}^*$ used in eq. (1).

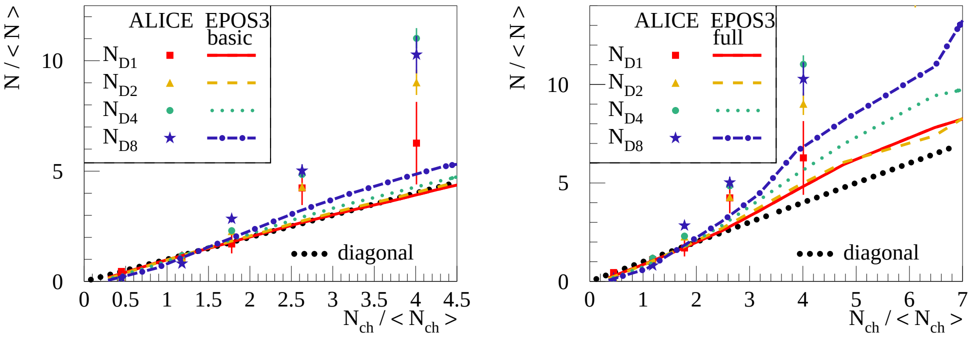

Figure 2. (Color online) D meson multiplicities versus the charged particle multiplicity, both divided by the corresponding minimum bias mean values. The different symbols and the notations N_{D1}, N_{D2}, N_{D4}, N_{D8} refer to different p_t ranges: 1-2, 2-4, 4-8, 8-12 (in GeV), N_{ch} refers to the charged particle multiplicity. We compare our calculations (lines) to ALICE data (points). Left plot : EPOS basic. Right plot : full EPOS.

The results of our calculation agree qualitatively with the trend in the data, namely a more than linear increase, in particular for high transverse momentum D mesons. But the effect is actually too small, as seen in fig. 2 (left), where we plot the D meson multiplicities versus the charged particle multiplicity, both for our calculation and data from ALICE [1].

But anyhow, EPOS basic (w/o hydro) reproduces neither spectra nor correlations, we have to consider the full approach, i.e. EPOS with hydrodynamical evolution (with or without hadronic cascade makes no difference). In fig. 2 (right), we plot again the D meson multiplicities versus the charged particle, EPOS3 compared to data, but here we refer to the calculations based on the full EPOS model (with hydro). We see a significant non-linear increase, much more pronounced as in the case of EPOS basic (without hydro), mainly due to the fact that the multiplicities from full EPOS are considerably below the results from EPOS basic. A much more detailed discussion will be provided in a separate publication.

To summarize: We analyzed the dependence of D meson multiplicities (in different p_t ranges) on the charged particle multiplicity in proton-proton collisions at 7 TeV, using the EPOS3 approach. We find a non-linear increase. Two issues play an important role: Multiplicity fluctuations due to multiple scattering (realized via multiple Pomerons), and the collective hydrodynamic expansion. Multiplicity fluctuations are important since in particular high p_t D meson production at given (large) charged particle multiplicity is very much favored for small Pomeron numbers, which is responsible for the strong increase of the D meson production with multiplicity. In addition, the effect is amplified when turning on the hydrodynamical expansion, due to a reduction of the charged particle multiplicity with respect to the model without hydro.

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