Charm decay leptons in pA collisions within the CGC framework

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Abstract
We compute electron and muon distributions produced by the charm semileptonic decay in proton-lead collisions at the LHC within the Color Glass Condensate (CGC) framework. High energy collisions at the LHC allow us to open heavy flavor decay channels, where the charm mass is well below the hadronization scale. In this presentation, we show electron and muon spectra from heavy-flavor decays at low p_{T} and their two-particle correlations, and discuss in which kinematical region the saturation effects are well reflected in the lepton distributions.

Introduction
The main objective of this study is to quantify to what extent the small-x gluon distribution in the target nucleus is reflected in heavy-flavoured-decay lepton spectra which go through both the quark fragmentation process and the hadron semileptonic decay. Heavy flavor production is one of the most important processes in high energy scattering to study the strong interaction. Recently, investigations of the so-called parton saturation in the nucleus through the heavy quark production has been worked on [1] since the LHC energy makes Bjorken’s x value of the relevant gluons small (\(x < 10^{-3}\)) even for the heavy flavor production. Open heavy flavor productions (D, B) in pp and pA collisions are well described by the Color Glass Condensate (CGC) framework at mid rapidity at the LHC [2]. However, the RHIC and LHC experiments also study heavy quarks by detecting the decay leptons. e and \( \mu \) at mid and \( \mu \) at forward rapidity. Importantly, the muon detection is the only relevant observable for the heavy flavor production at forward rapidities in the RHIC and LHC experiment setup. Then, we need to evaluate the lepton decay from open heavy flavor mesons in order to study the saturation effects in the observed forward muon spectra.

We use the leading-order formula for the heavy quark pair production and supplement it with the generalized gluon distribution obeying the Balitsky-Kovchegov equation with running coupling constant (cBKK). The rKbbK formula sums up the small-x quantum correction in terms of \( n_{C}, n_{F} \), and furthermore includes important part of the next-leading-order (NLO) contributions. This approach has been successful in phenomenology, while the consistent NLO formulation is also desired.

Field amplitudes
- Heavy quark pair production from the CGC
  \( \mathbf{Q} \) = 0

  The quark pair \( \{ q, \bar{q} \} \) production cross section in pA collisions at leading order is given by the "k_{factorized}" formula:
  \[ \frac{d\sigma}{d^2p_{T}dy} \propto \int d^2Q_{T} f_{qA}(k_{T}) f_{\bar{q}A}(k_{T}) \cdot \frac{d^2\sigma}{d^2Q_{T}} \]
  or hybrid formula (collinear CGC), which is valid at forward rapidity:
  \[ \frac{d\sigma}{d^2p_{T}dy} \propto \int d^2Q_{T} f_{qA}(k_{T}) f_{\bar{q}A}(k_{T}) \cdot \frac{d^2\sigma}{d^2Q_{T}} \]

  where \( f_{qA}(k_{T}) \) is the unintegrated gluon distribution function and \( \frac{d^2\sigma}{d^2Q_{T}} \) is the usual collinear gluon distribution function with \( p_{T} \) being the factorization scale. \( x_{B} \) is the hard matrix elements and \( \langle \omega_{B} \rangle \) is its collinear approximation taken on the proton side. Here \( x_{B} \) is the longitudinal momentum fraction carried by the incoming gluon in the proton (nucleus): \( x_{B} = \frac{y}{\sqrt{y^2 - 1}} \) for quark pair with \( p_{T} \). The 3pt. function of the nucleus \( \vec{r}_{ij} \) is approximated as
  \[ \frac{d^2\sigma_{qA}}{d^2k_{T}d^2\bar{k}_{T}} \propto |S_{qA}(k_{T}, \bar{k}_{T})| = |S_{qA}(k_{T}, \bar{k}_{T})| \]

  in the large \( N_{C} \) limit. \( S_{qA}(k_{T}, \bar{k}_{T}) \) is the transverse size of target nucleus. \( S_{qA}(x_{B}) \) is the Fourier transform of the fundamental dipole amplitude.

- Leptons from heavy flavor semileptonic decay
  \( Q \rightarrow Xl\bar{\nu} \)

  Single meson production with open heavy flavor is obtained by convoluting the quark production cross-section with the fragmentation function:
  \[ \frac{d\sigma_{\mu}}{dp_{T}dy} \propto \int d^2Q_{T} f_{qA}(k_{T}) f_{\bar{q}A}(k_{T}) \cdot \frac{d^2\sigma}{d^2Q_{T}} \]

  Here \( f_{qA}(k_{T}) \) is the probability for a heavy meson with momentum \( p_{T} \) to decay with a lepton with momentum \( p_{l} \) in the laboratory frame, and is given by the following expression;
  \[ f_{qA}(k_{T}) = \int d^2Q_{T} \frac{d^2\sigma}{d^2Q_{T}} \]

   with the normalization constant \( M_{q} \) is the mass of the produced particle \( X \), for which we assume \( M_{q} = M_{N} = 0.497 \) GeV in D decay \( (M_{q} = M_{N} = 1.86 \) GeV) and \( M_{q} = M_{N} = 1.86 \) GeV in B decay \( (M_{q} = M_{N} = 5.28 \) GeV).

- Unintegrated gluon distribution

  The nonlinear effects are taken into account through the unintegrated gluon distribution \( \alpha_{g} \). In order to observe observables, we introduce a new distribution in the target, we use the rKbbK equation for the fundamental dipole amplitude \( (x_{B} \rightarrow x_{B}) \):
  \[ 2 \alpha_{g}(x_{B}, t_{1}) = \alpha_{g}(x_{B}, t_{1}) \cdot \alpha_{g}(x_{B}, t_{2}) \cdot \eta_{t_{1}t_{2}} \]

  In Bjorken’s prescription with \( \eta_{t_{1}t_{2}} = 1 \), the transverse size of the dipole. The initial condition for the rKbbK equation at \( n_{C} = 0.01 \) is constrained by global fit of HERA DIS data, being in the McLerran-Venugopalan-model form:
  \[ S_{0}(x_{B}) = \exp \left( \frac{\alpha_{g}(x_{B})}{4} \right) \]

  where \( Y = \frac{1}{2} \) is the evolution rapidity in association with gluons of the target nucleus. We fix \( \alpha_{g} = 0.241 \) GeV and apply two parametrization sets listed here [3, 4].

  For the target nucleus, we replace the initial saturation scale by \( \alpha_{g}(x_{B}) = \frac{\alpha_{g}(x_{B})}{4} \) with \( c = 0.5 \).