# Intrinsic charm production at the Electron-Ion Collider[1]

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**Abstract**

Projected parameters of the EIC are well-suited for testing for the existence of the nonperturbative "intrinsic" mechanism for charm quark production. We present estimates for semi-inclusive DIS charm production for various EIC configurations and examine the effects of intrinsic charm contributions.

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In the variable flavor number (VFN) factorization scheme [1, 2, 3], heavy quark flavors are actively included in the PDF evolution via gluon splitting to a heavy quark pair $g \to Q\bar{Q}$. While the heavy quark PDF $f_Q(x, \mu)$ is often taken to vanish below the mass threshold ($\mu < m_Q$), there is the possibility that the proton contains non-vanishing heavy quark constituents even for scales below $m_Q$; this component of the heavy quark PDF is identified as the *intrinsic* parton distribution [4, 5, 6, 7, 8, 9, 10, 11], in contrast to the extrinsic distribution generated by gluon splitting $g \to Q\bar{Q}$.

While we can introduce intrinsic parton distributions for both charm and bottom quarks, we will focus here on the intrinsic charm (IC). Operationally, the total charm PDF is then composed as $f_c(x, \mu) = f_c^{ext}(x, \mu) + f_c^{int}(x, \mu)$. For the extrinsic component, we generally take the boundary condition $f_c^{ext}(x, \mu) = 0$ for $\mu < m_c$. Conveniently, this means that we do not need to assume an initial functional form for $f_c^{ext}$, as it is determined purely by the gluon evolution.

Conversely, for the IC component $f_c^{int}$ we do need to assume a functional form. In this contribution, we consider two typical shapes of $f_c^{int}$ at the initial scale $\mu = m_c$ , assuming $m_c = 1.3$ GeV.

- In the BHPS model [4, 5, 12], the intrinsic charm is concentrated at large $x$.
- In sea-like models [7], the intrinsic charm is spread over all $x$ values.

Sample distributions of IC PDFs were obtained in a global QCD fit of hadronic data [7]. We display them in figure 1 and use in our numerical analysis. In these models, the momentum fraction carried by the charm can be varied in some range. Roughly, an intrinsic momentum fraction of 2% or 3% is at the outer limit of what is allowed in the context of a global fit.

For comparison, in figure 2-a) we display the momentum fractions of the extrinsic charm and bottom quarks arising from gluon splitting as a function of $\mu$; reference lines at 1% and 2% are indicated. The fraction of the intrinsic PDF component is, of course, the largest at low scales. Therefore, if we study heavy quark production in the threshold region ($\mu \sim m_Q$), the magnitude of the intrinsic component will be large on the relative scale compared to the extrinsic contribution.

At higher $\mu$ scales, the DGLAP evolution will increase the extrinsic component via $g \to Q\bar{Q}$ splitting. However, we observe in figure 1-b) that even at scales of order 100 GeV

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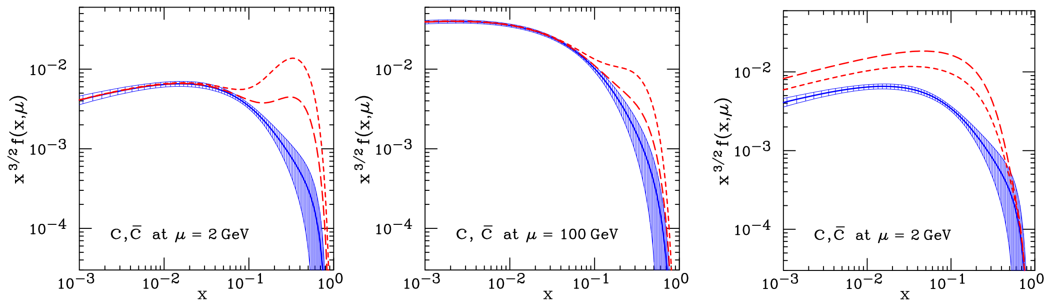


Figure 1: a), b) The charm PDFs for the BHPS model, at scale 2 and 100 GeV. The upper dashed curve is for a momentum fraction of 2%, and the lower for 0.57%. The filled band is the CTEQ6.5 PDF uncertainty. c) The charm PDFs for the sea model. The upper curve is for a momentum fraction of 2.4%, and the lower for 1.1%. Figures are from Ref. [7].

the intrinsic component can be distinguishable. In particular, the distinctive shape of the BHPS distribution, with its characteristic large-$x$ enhancement, is clearly evident and can affect certain LHC measurements.

We now consider different combinations of projected EIC parameters [13] and investigate the degree to which these machines can distinguish the IC component based on the measurement of the charm contribution to the DIS cross section. (Alternatively, the IC can be searched for by measuring the longitudinal structure function $F_L$ or angular distributions [9]). In figures 2-b) ,c) and d) we display the reduced cross section $\sigma_{r,c}$ for semi-inclusive DIS charm production at an EIC, $e+p \to e + \overset{(-)}{c} + X$. The reduced cross section is defined implicitly by

$$\frac{d^2\sigma_c}{dx\, dQ^2} = \frac{2\pi\alpha^2}{x\, Q^4} \left[1 + (1-y)^2\right] \sigma_{r,c}(x, Q^2),$$

where $y$ is the inelasticity parameter that satisfies the relation $Q^2 \simeq sxy$. The probed ranges of $y$ are displayed in the figures. The number of events for a typical integrated luminosity $\mathcal{L} = 10\ \text{fb}^{-1}$ has been computed as

$$\frac{dN_e}{dx} = \mathcal{L}\langle \frac{d\sigma_c}{dx} \rangle$$

where $\langle \frac{d\sigma}{dx} \rangle$ is the average cross section in a $Q$ bin of size 0.15 GeV, evaluated at NLO in QCD coupling strength. The red band represents the error on the cross section induced by the CTEQ6.6 PDF uncertainty [14].

For both the BHPS and sea configurations, we observe that the cross sections with intrinsic charm significantly exceed the nominal CTEQ6.6 values. While a momentum fraction of 3.5% is easily distinguished, even the intrinsic charm models with 1% can also be resolved with typical integrated luminosity.

In summary, we find that various EIC configurations are capable of readily distinguishing intrinsic charm components with momentum fractions of 3.5%, and with sufficient statistics they could resolve momentum fractions of 1% or less.

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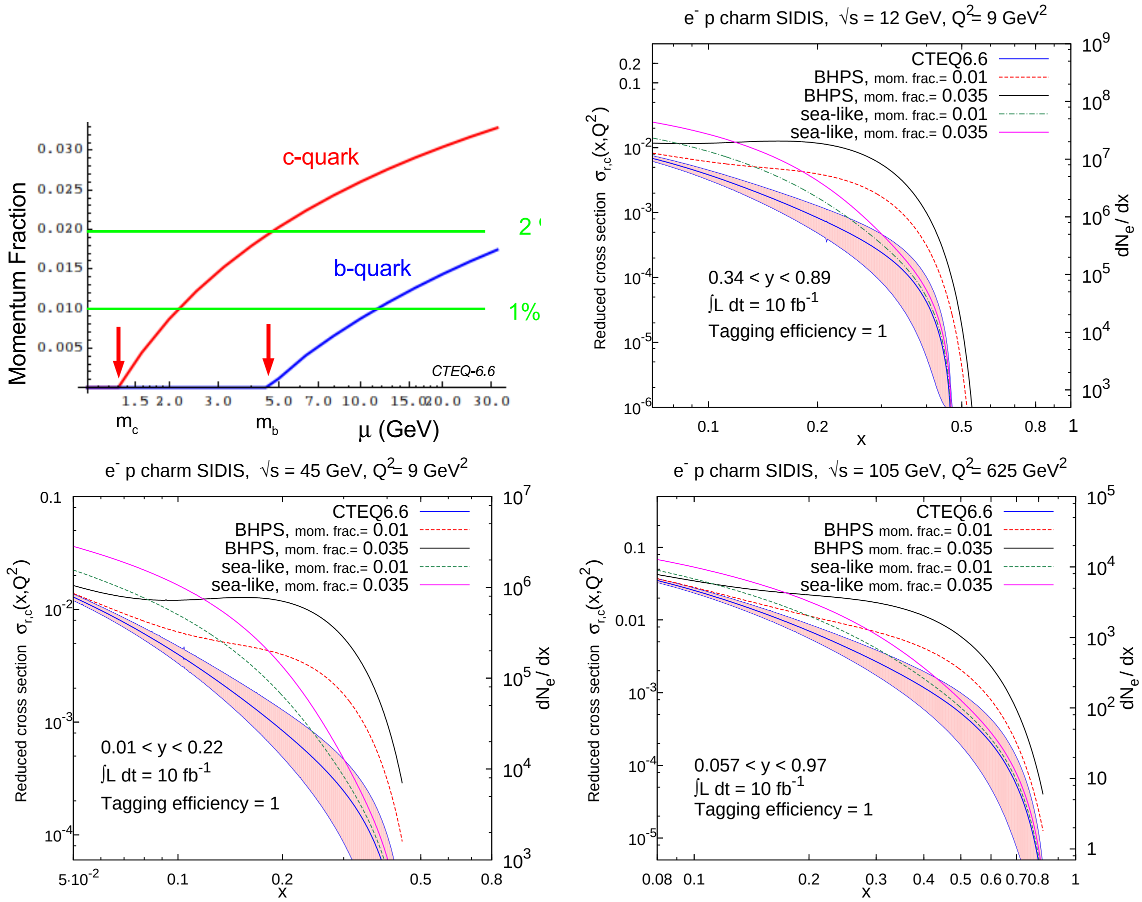


Figure 2: a) Integrated momentum fractions for *extrinsic* charm and bottom contributions as a function of scale $\mu$. Reference lines are indicated at 1% and 2%. b), c), d) Charm-anticharm contributions to the reduced neutral current (NC) $e^-p$ DIS cross section at $\sqrt{s} = 12$, 45, and 105 GeV. For each IC model, curves for charm momentum fractions of 1% and 3.5% are shown. For comparison we display the number of events $dN_e/dx$ for $10\,\text{fb}^{-1}$, assuming perfect charm tagging efficiency.

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