Estimating the intrinsic quark contribution to heavy meson production at forward rapidities in pp collisions

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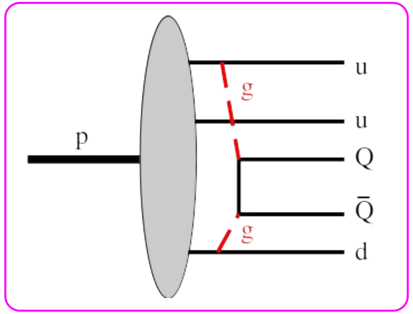
Contents

Introduction

- Heavy quarks production in hadronic collisions allows studying the properties of strong interactions and the partonic structure of the proton.
- The study of heavy meson production at forward rapidity is expected to provide constraints on the large x effects, such as the presence of an **intrinsic heavy quark component** in the proton wave function.



Recently, the LHCb Collaboration has measured D and B meson cross section at forward rapidity and provided data for the transverse momentum and rapidity distributions. Two basic questions arise:

1. **If an intrinsic bottom component is present in the proton wave function, what is its impact on the predictions for B meson production?**
2. **Are theoretical approaches that provide a satisfactory description of D meson production also capable of describing the B meson data?**

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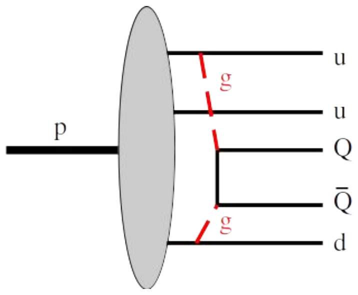

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Hadronic collisions

Usually the description of hadronic collisions is based on the factorization principle.

cross section = perturbative ✖ non-perturbative

Hybrid formalism

linear — non-linear

$$\sigma(pp \to hX) \propto \sum q(x_a, Q^2) \otimes \tilde{N}_F(x_b, p_T) \otimes D_{q/h}(z, \mu^2) + g(x_a, Q^2) \otimes \tilde{N}_A(x_b, p_T) \otimes D_{q/h}(z, \mu^2)$$

$\tilde{N}_{F,A} \propto$ UGD

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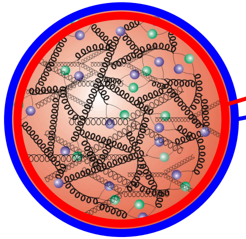
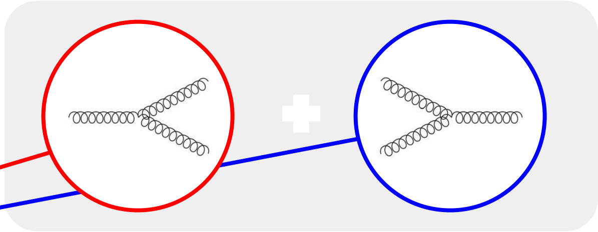
Proton structure

The marked increase in gluons implies a highly dense proton, but this gluon growth is expected to be limited.



Recombination limits the growth of gluon distributions through a mechanism known as “**parton saturation**”.

Color Glass Condensate



In the **saturated regime**, the formation of a new state of matter characterized by highly dense gluon systems is expected: the **Color Glass Condensate**.

Color: type of charge that gluons carry.

Glass: term borrowed from materials that act like solids on short time scales and like liquids on long time scales.

Condensate: the density of gluons is very high.

CGC: F. Gelis, et al, Ann.Rev.Nucl.Part.Sci. 60 (2010) 463-489

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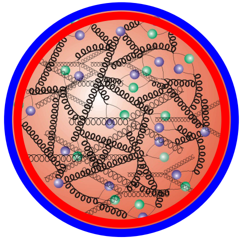

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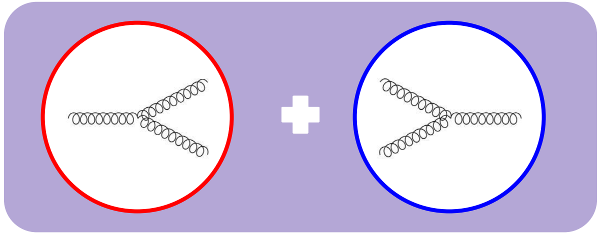

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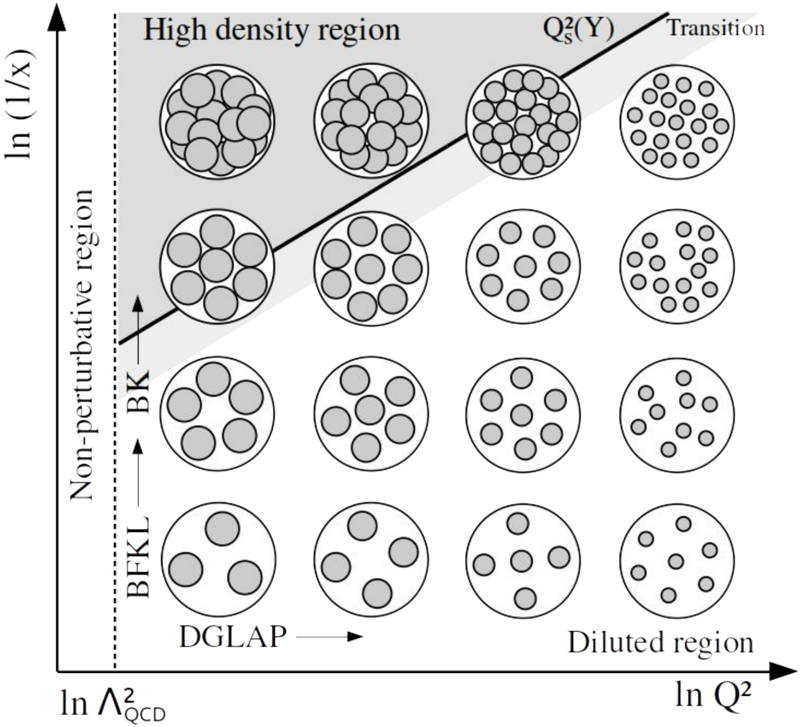
Mapping the evolution of partonic structure



Dilute systems regime:
described by linear dynamics;
governed by linear equations.

Dense systems regime:
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Saturation scale: determines the line between regimes; varies event by event.

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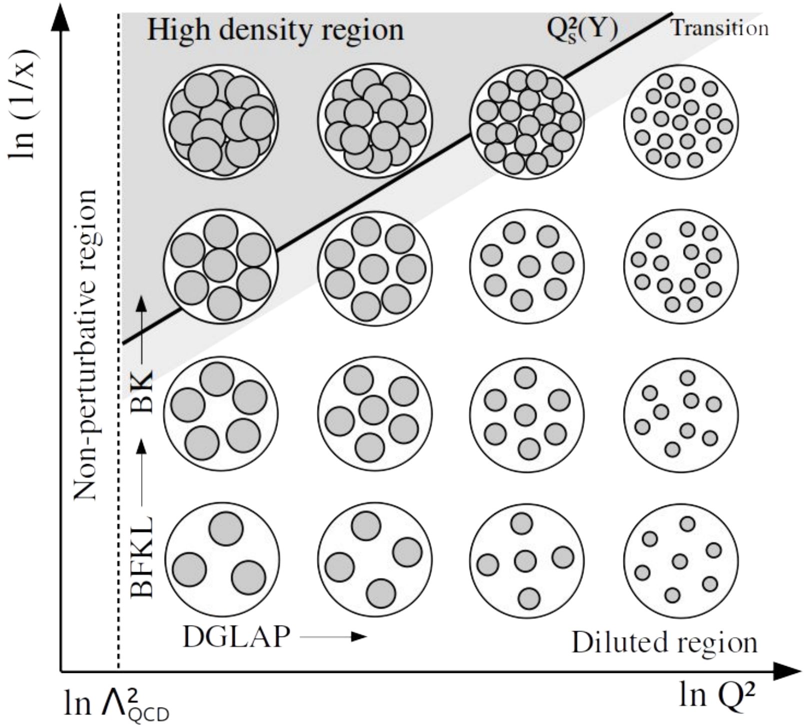

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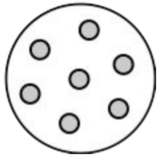

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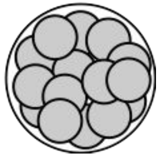

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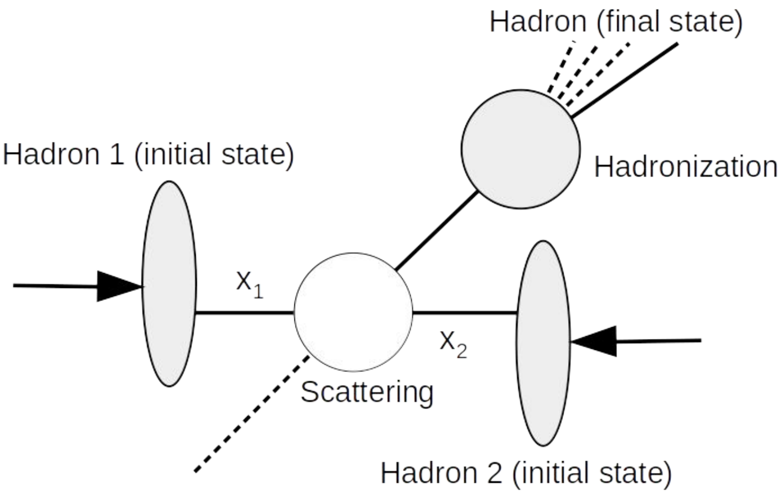
Particle production at CGC



$x_1 = (p_T/s^{1/2}) \exp(+\eta)$
$x_2 = (p_T/s^{1/2}) \exp(-\eta)$

For high energies:
$\eta = -\ln[\tan(\theta/2)] \equiv y$

Central pseudorapidity: $x_1 \approx x_2 \rightarrow 0$; dense system collision; kT factorization.

Forward pseudorapidity: $x_1 \gg x_2$; asymmetric collisions; hybrid formalim.

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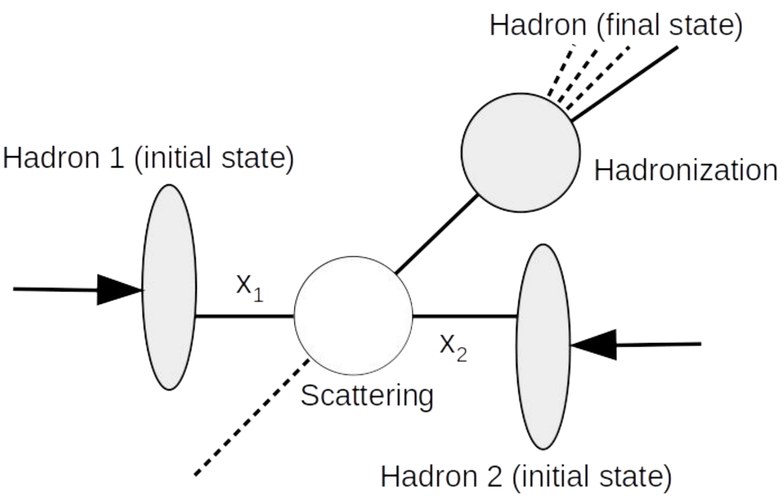

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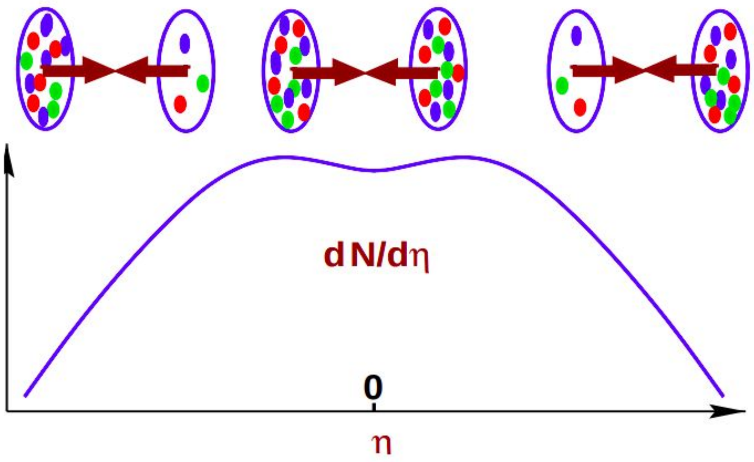

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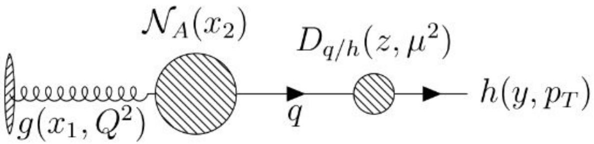
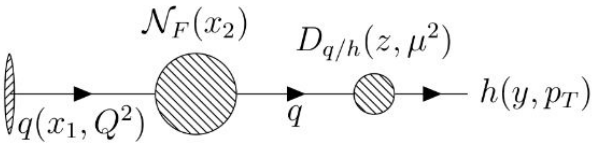
Results

Heavy meson production: D and B

DOI: 10.1103/PhysRevC.106.065206
DOI: 10.1140/epjc/s10052-024-13278-4





Heavy meson production

Ingredients:

D meson:
PDFs: CTEQ6.5, CT14
UGDs: MV and GBW models
FF: BKK05

B meson:
PDFs: CTEQ6.5, CT14
UGDs: MV and GBW models
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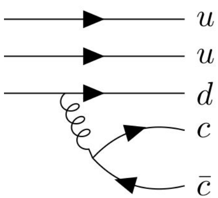
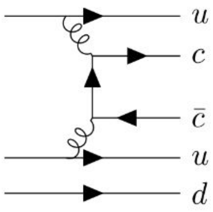
Extrinsic and intrinsic:



Extrinsic component of heavy quarks



Intrinsic component of heavy quarks

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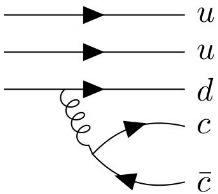

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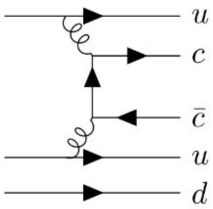

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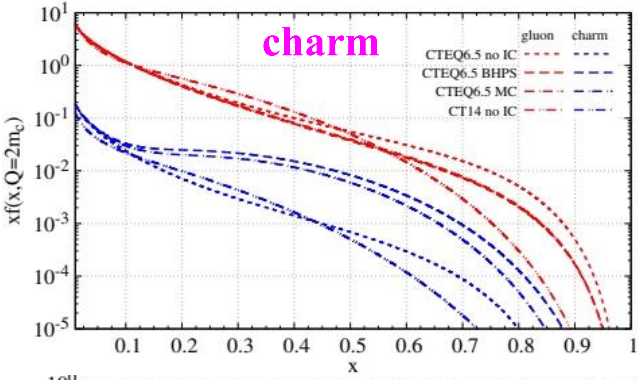

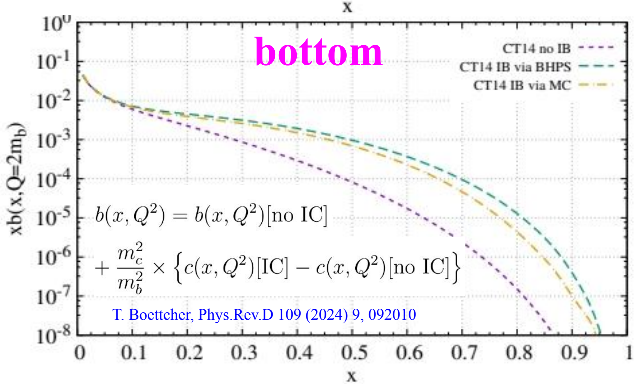

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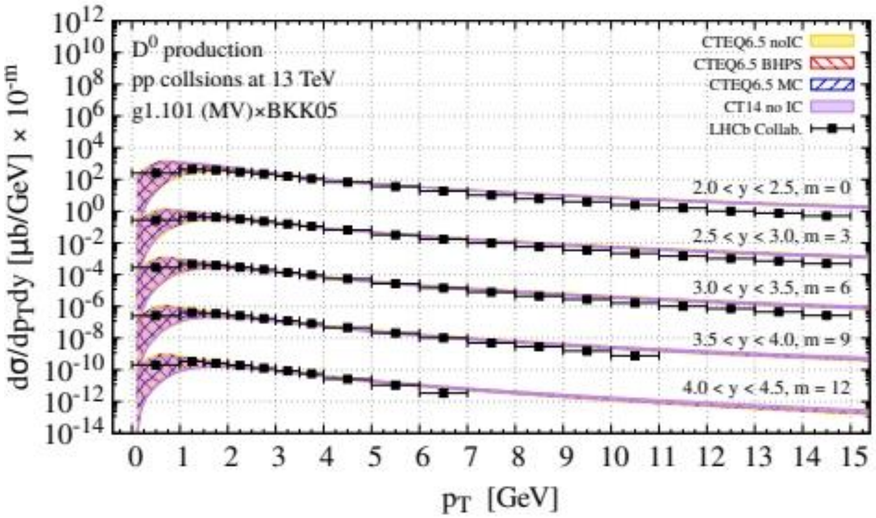
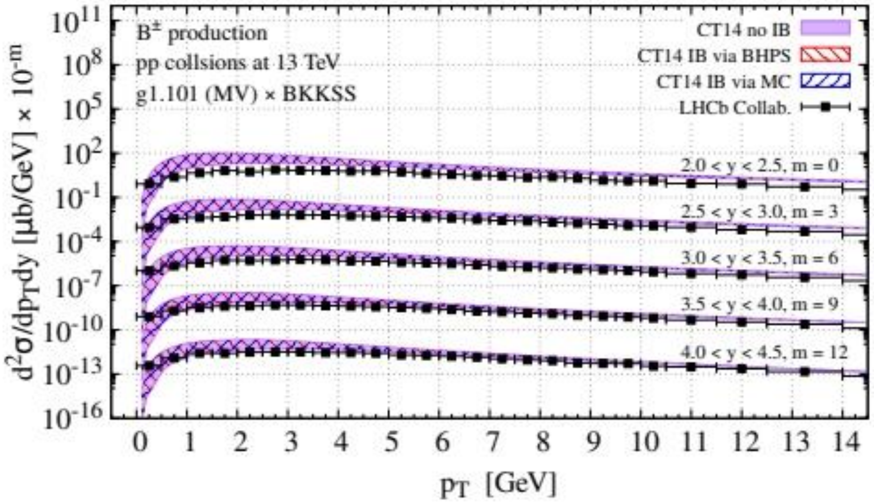
Heavy meson production

D meson production



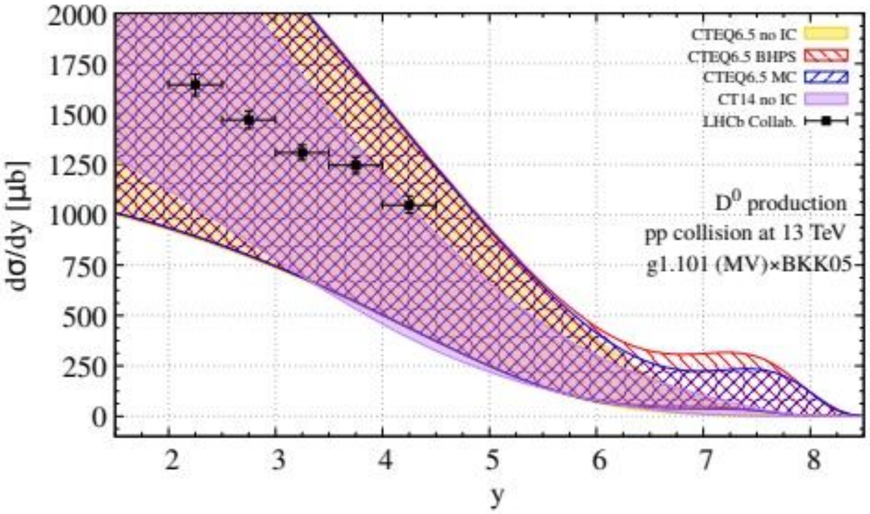
B meson production



The ingredients considered satisfactorily describe the momentum spectrum and **there is no** sensitivity of this observable to the intrinsic quantity of heavy quark.

Heavy meson production

D meson production



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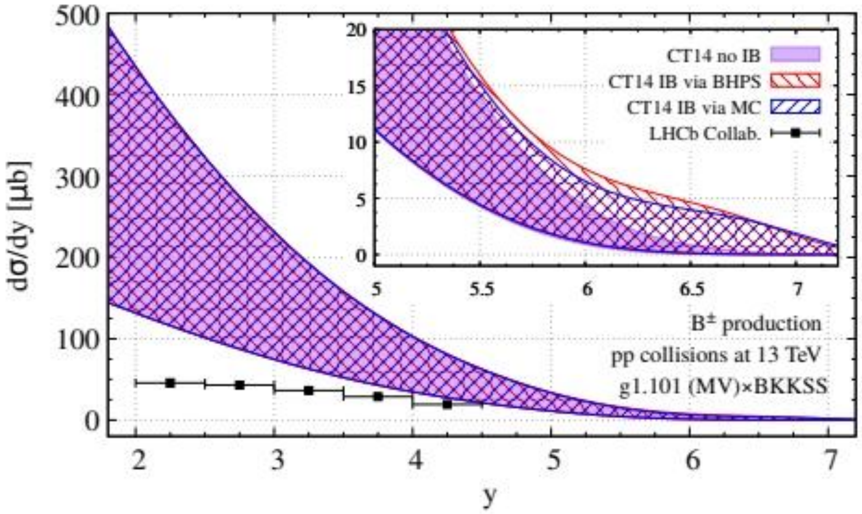
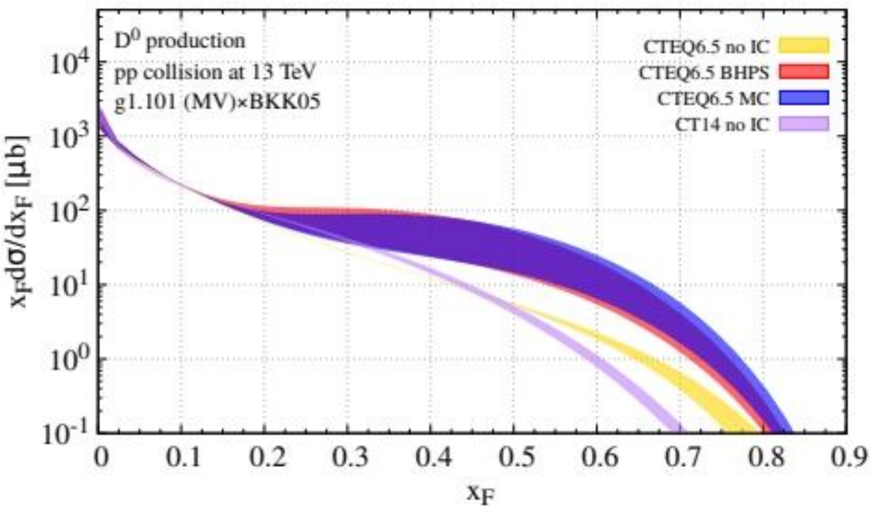


The data for the production of D mesons are described in the hybrid formalism. On the other hand, in the production of B mesons, only the data at higher y are achieved. **There is** sensitivity of this observable to the intrinsic quantity of heavy quark.

Heavy meson production

D meson production



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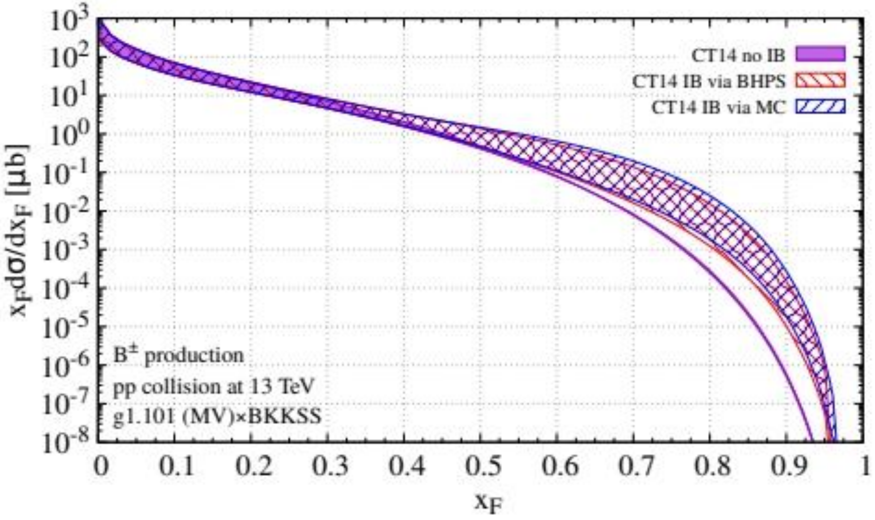


The inclusion of an intrinsic component of heavy quarks implies an enhancement of the projections, more expressively for higher values of xF.

Summary and perspectives

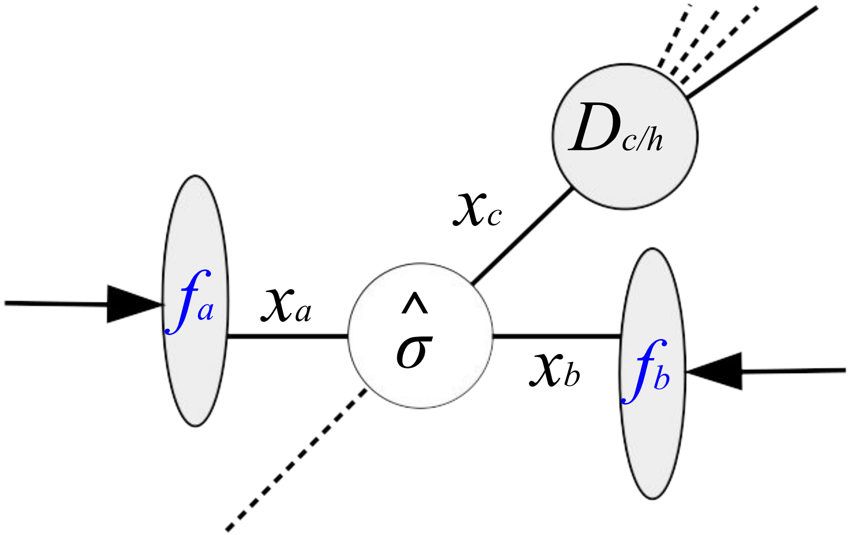
- We demonstrate that the hybrid formalism describes the current data on the momentum spectrum of heavy meson production.
- We estimate the production of D and B mesons considering the intrinsic quark contribution. We demonstrate that the impact is small in the LHCb region and important in the region that determines the prompt neutrino flux in IceCube.
- Future comparison of these predictions with experimental data will allow testing the CGC formalism and determining necessary improvements.
- Future comparisons with data from FoCal (new sub-detector in ALICE to be installed during LHC Long Shutdown 3 for LHC Run 4) may corroborate this discussion.

Thank you!

Backup

Hadronic collisions: collinear approach

Collinear factorization:



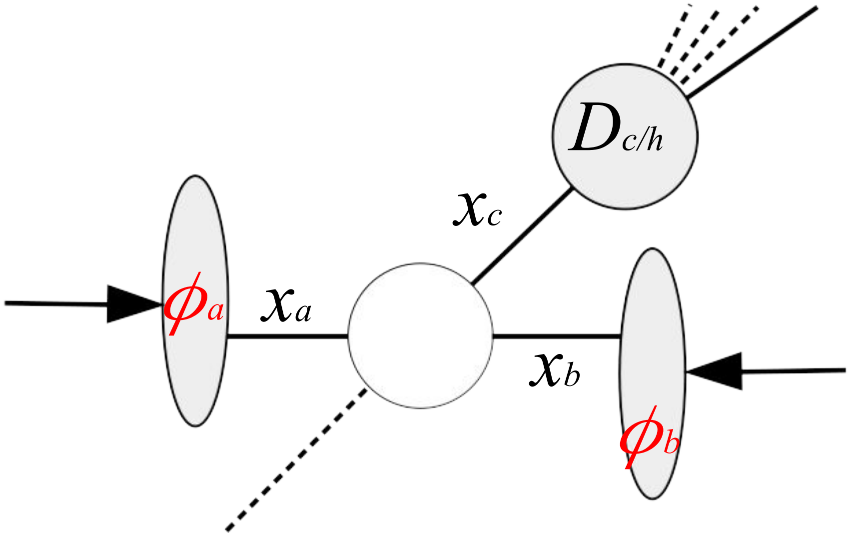
$$\sigma(pp \to hX) \propto$$
$$\propto f_a(x_a, Q^2) \otimes f_b(x_b, Q^2) \otimes d\hat{\sigma}(Q^2) \otimes D_{q/h}(z, Q^2)$$

$f_{a,b}$ = PDF

The intrinsic transverse momentum and the corrective terms of the energy evolution are not considered.

Hadronic collisions: non-collinear approach

kT factorization:



$$\sigma(pp \to hX) \propto$$
$$\propto \phi_a(q_T, y) \otimes \phi_b(k_T - q_T, Y - y) \otimes D_{g/h}(z, \mu^2)$$

$\phi_{a,b}$ = UGD

Finite virtualities effects and the transverse momentum of incident partons are taken into account.

Balitsky-Kovchegov equation

$$\frac{\partial \mathcal{N}(r,x)}{\partial \ln(x_0/x)} = \int d\vec{r}_1 K(\mathbf{r},\mathbf{r}_1,\mathbf{r}_2)[\mathcal{N}(r_1,x)+\mathcal{N}(r_2,x)-\mathcal{N}(r,x)-\mathcal{N}(r_1,x)\mathcal{N}(r_2,x)]$$

Model for BK solution:

i) $N^{GBW}(r, x = x_0) = 1 - \exp\left[-\frac{(r^2 Q_{s0}^2)^\gamma}{4}\right]$

ii) $N^{MV}(r, x = x_0) = 1 - \exp\left[-\frac{(r^2 Q_{s0}^2)^\gamma}{4}\ln\left(\frac{1}{r\Lambda_{QCD}} + e\right)\right]$

Ingredients:

Modelo	Q^2_{s0}(GeV²)	γ	Identificação
MV	0,157	1.101	g1.101 (MV)
MV	0,1597	1.118	g1.118 (MV)
GBW	0,24	1	g1 (GBW)

Equação BK: I. Balitsky, Nucl.Phys.B 463 (1996) 99-160; Y. Kovchegov, Phys.Rev.D 60 (1999) 034008
GBW: J. Golec-Biernat, M. Wusthoff, Phys.Rev.D 59 (1998) 014017
MV: D. McLerran, R. Venugopalan, Phys.Lett.B 424 (1998) 15-24

Heavy meson production

Setor de quarks pesados: $$\left.\frac{d\sigma_{pp\to hX}}{dyd^2p_T}\right|_{quark} = \frac{\sigma_0}{2(2\pi)^2}\int_{x_F}^1 dx_1 \frac{x_1}{x_F}\left[Q(x_1,Q^2)\tilde{\mathcal{N}}_F\left(\frac{x_1}{x_F}p_T, x_2\right)D_{Q/h}\left(z=\frac{x_F}{x_1},\mu^2\right)\right]$$

$$\tilde{\mathcal{N}}_{F,A}(x,p_T) = \int d^2r e^{ip_T\cdot r}[1-\mathcal{N}_{F,A}(x,r)]$$

Setor de glúons: $$\left.\frac{d\sigma_{pp\to hX}}{dyd^2p_T}\right|_{glúon} = \int_{z_{min.}}^1 \frac{dz}{z^2}x_1 g(x_1,Q^2)\int_{\alpha_{min.}}^1 d\alpha \frac{d^3\sigma_{gp\to Q\bar{Q}X}}{d\alpha d^2q_T}D_{Q/h}(z,\mu^2)$$

$$\frac{d^3\sigma_{gp\to Q\bar{Q}X}}{d\alpha d^2q_T} = \frac{1}{6\pi}\int\frac{d^2\kappa_T}{\kappa_T^4}\alpha_s(\mu^2)\mathcal{K}_{dip}(x_2,\kappa_T^2)\left\{\left[\frac{9}{8}\mathcal{H}_0(\alpha,\bar{\alpha},q_T) - \frac{9}{4}\mathcal{H}_1(\alpha,\bar{\alpha},q_T,\kappa_T)\right.\right.$$
$$\left.\left. + \mathcal{H}_2(\alpha,\bar{\alpha},q_T,\kappa_T) + \frac{1}{8}\mathcal{H}_3(\alpha,\bar{\alpha},q_T,\kappa_T)\right] + [\alpha\longleftrightarrow\bar{\alpha}]\right\}$$

$$\mathcal{K}_{dip.}(x,\kappa_T^2) = \frac{C_F}{(2\pi)^3}\int d^2r e^{-i\kappa_T\cdot r}\nabla_r^2\mathcal{N}_A(x,r).$$