CSS+ACOT

A new type of resummation for heavy flavor production

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Abstract

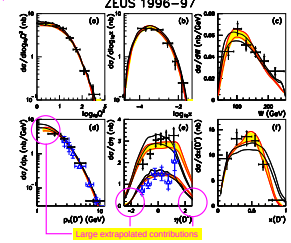
We propose a new method to calculate differential distributions in reactions with heavy quarks. This method can be utilized to reconstruct heavy-flavor contributions $F_2^{c,b}(x,Q^2)$ to the structure function $F_2(x,Q^2)$ at all $Q^2 \geq M_H^2$ (where Q is the DIS momentum transfer, and M_H is the heavy quark mass).Our approach realizes simultaneous summation of powers of mass logarithms $\ln^p(Q^2/M_H^2)$ and logarithms $\ln^{p'}(q_T^2/Q^2)$ of the transverse momentum q_T through all orders of perturbation theory. The joint summation is performed using the impact parameter formalism by Collins, Soper, and Sterman (CSS), realized in the simplified Aivazis-Collins-Olness-Tung (S-ACOT) factorization scheme. As a practical application, we calculate differential distributions of bottom quarks produced at the ep collider HERA.

Statement of the problem

- ✓ $30-80\%$ of the charm production events at the ep collider HERA occur outside of the detector acceptance region
- ✓ To reconstruct the total heavy-flavor production cross sections $d\sigma_{tot}^{c,b}/dxdQ^2$ [or heavy-flavor contributions $F_2^{c,b}(x,Q^2)$ to the inclusive DIS structure function $F_2(x,Q^2)$], the visible cross section has to be extrapolated to all phase space using some theoretical model
- ✓ We demonstrate that the differential distributions, which must be known for such extrapolation, can be consistently calculated at all $Q^2 \geq M_H^2$ using a massive variable-flavor number scheme
- ✓ Such calculation involves resummation of the logarithms $\ln^p(q_T^2/Q^2)$, which is needed to correctly describe the current fragmentation region (where $q_T^2 \ll Q^2$)

Differential distributions of charm quarks

ZEUS 1996–97



Large extrapolated contributions

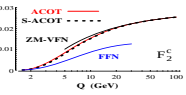
2-loop fixed-flavor-number (FFN) cross section (B. Harris, J. Smith)

FFN is unreliable at $Q^2 \gg M_H^2$, where the logarithms $\ln^p(Q^2/M_H^2)$ must be resummed in a heavy-quark distribution using a variable flavor number (VFN) factorization scheme, e.g., the ACOT scheme.

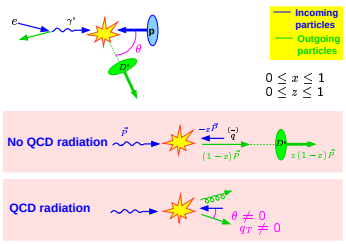
ACOT extrapolates between the FFN cross sections at $Q^2 \sim M_H^2$ and zero-mass VFN (ZM-VFN) cross sections at $Q^2 \gg M_H^2$

Simplified ACOT (S-ACOT) scheme (Collins, 1998; Kramer, Olness, Soper,2000):

Assumes $M_H = 0$ in hard parts with incoming heavy quarks



Charm electroproduction in $\gamma^* p$ c.m. frame



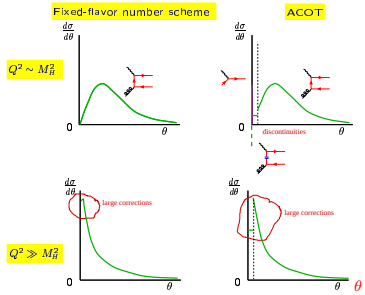
Large logarithms in the current fragmentation region...

✓... appear at $\theta \sim q_T/Q \to 0$ due to radiation of soft partons

✓ ... can be summed through all orders of α_S using the CSS formalism (Collins, 1993; Meng, Olness, Soper, 1996; Nadolsky, Stump, Yuan,1999)

In the present work, the massless resummation ($M_H/Q = 0$) is generalized to the heavy-quark case ($M_H/Q \neq 0$)

Finite-order calculations fail in the small θ region



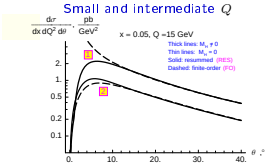
Resummation cures this problem, leading to physical $d\sigma/d\theta$ at all $Q^2 \geq M_H^2$

Properties of the heavy-flavor resummed cross section

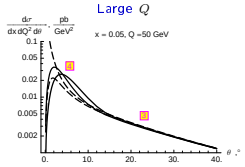
- ✓ Correctly describes all range $Q^2 \geq M_H^2$
- ✓ Reduces to the FFN result at $Q^2 \sim M_H^2$
- ✓ Reduces to the massless q_T resummation at $Q^2 \gg M_H^2$
- ✓ M_H suppresses contributions from scales $\sim \Lambda_{QCD} \ll M_H$
- ✓ Mass decoupling (cross sections are not sensitive to M_H at energies $E \ll M_H$)
- ✓ Allows for systematic implementation of "intrinsic" heavy quarks

Distributions of bottom quarks in the $\gamma^* p$ c.m. frame

Small and intermediate Q



Large Q



1 The massless (ZM-VFN) cross sections are significantly above the massive cross sections

2 The massive resummed (S-ACOT) cross section reduces to the massive finite-order (FFN) cross section at large θ; exceeds the FFN cross section at $\theta \to 0$ due to the resummed logs

3 All cross sections agree at large θ

4 σ_{FO}^{ZM-VFN} is singular at $\theta \to 0$. σ_{RES}^{ZM-VFN} strongly depends on the unknown nonperturbative input at $\theta \to 0$. In contrast, σ_{RES}^{S-ACOT} is calculated unambiguously due to the suppression of the nonperturbative region by $M_H \neq 0$.

*Enhancement in reconstructed $F_2^b(x,Q^2)\big|_{S-ACOT}$ as compared to FFN

Summary

- ✓ $\sum \ln^p(Q^2/M_H^2) + \sum \ln^{p'}(q_T^2/Q^2)$ = consistent description of distributions in heavy quark production at $\Lambda_{QCD}^2 \ll M_H^2 \leq Q^2$
- ✓ The cross section reproduces fixed-order cross sections at $Q \approx M_H$ and resummed massless cross sections at $Q \gg M_H$; leads to larger $F_2^{c,b}(x,Q^2)$ than in the fixed-flavor number scheme
- ✓ An interesting theoretical 3-scale problem
  - ♦ Suppression of perturbative resummed cross section at $b \gtrsim 1/M_H$
  - ♦ transition between 2-particle inclusive and 1-particle inclusive kinematics
  - ♦ Resummation that does not use dimensional regularization for collinear singularities

Further applications

- ✓ Fully differential Monte-Carlo program in the S-ACOT scheme
- ✓ Comparison to charm production data from HERA
- ✓ Extensions to reactions at hadron-hadron colliders:
  - ♦ Single-top production
  - ♦ Drell-Yan process
  - ♦ bbH production in MSSM
  - ♦ other processes involving heavy quarks