CSS+ACOT
A new type of resummation for heavy flavor production
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Abstract
We present a new method to calculate differential distributions in reactions with heavy quarks. This method can be utilized to
reconstruct heavy-flavor contributions \( F_2(x,Q^2) \) to the structure function \( F_2(x,Q^2) \) at all \( Q^2 > M_b^2 \) (where \( Q^2 \) is the DIS momentum transfer, and \( M_b \) is the heavy quark mass). Our approach realizes simultaneous summation of powers of mass logarithms \( \ln \frac{Q^2}{M_b^2} \) and logarithms \( \ln \frac{Q^2}{Q_0^2} \) of the transverse momentum \( Q_0 \) 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 Alvarez-Collins-Olness-Tung (S-ACOT) factorization scheme. As a practical application, we calculate differential distributions of bottom quarks produced at the \( e^+e^- \) collider HERA.

Differential distributions of charm quarks

\[ F_{2c}(x,Q^2) \] for 3-flavor and 4-flavor quantum chromodynamics (QCD) at various values of \( Q^2 \). The 3-flavor FFN cross section is shown for comparison. In the small-\( \theta \) region, the luminosity is limited by the finite acceptance of the detector, while at high \( \theta \), it is limited by the finite acceptance of the detector.

Properties of the heavy-flavor resummed cross section

- Correctly describes all range \( Q^2 \geq M_b^2 \)
- Reduces to the FFN result at \( Q^2 \sim M_b^2 \)
- Reduces to the massless \( q\bar{q} \) resummation at \( Q^2 \gg M_b^2 \)
- \( M_b \) suppresses contributions from scales \( \sim M_{QCD} \approx M_{QCD} \)
- Mass decoupling (cross sections are not sensitive to \( M_b \) at energies \( E \ll M_b \))
- Allows for systematic implementation of “intrinsic” heavy quarks

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

\[ F_2(x,Q^2) \] for small and intermediate \( Q \) and large \( Q \). In the small-\( Q \) region, the cross section is in agreement with the fixed-order (FFN) predictions. In the large-\( Q \) region, the cross section is enhanced compared to the fixed-order predictions.

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
  - \( W^\pm \) production in MSSM
- Other processes involving heavy quarks

Statement of the problem

- 30 - 80% of the charm production events at the \( e^+e^- \) collider HERA occur outside of the detector acceptance region
- To reconstruct the total heavy-flavor production cross sections \( \sigma_{QCD}^{(\mu)}/d^2 \sigma/Q^2 \) for heavy-flavor contributions \( F_2(x,Q^2) \) to the inclusive DIS structure function \( F_2(x,Q^2) \), the differential 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 \( Q^2 \geq M_b^2 \) using a massive variable-flavor number scheme
- Such calculation involves resummation of the logarithms \( \ln \frac{Q^2}{Q_0^2} \), which is needed to correctly describe the current fragmentation region (where \( Q^2 < Q_0^2 \))