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Quarkonium Production: NRQCD Confronts Experiment

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The effective field theory NRQCD is a convenient formalism for separating physics at the scale of the heavy-quark mass from physics at the scale of quarkonium bound-state dynamics. It is the basis for the NRQCD factorization approach, which provides a systematic method for calculating quarkonium production (and decay) rates as a double expansion in powers of α_s and the heavy-quark velocity v. An all-orders proof of NRQCD factorization for inclusive production rates has not yet been constructed. However, there are now proofs of NRQCD factorization for exclusive charmonium production in B-meson decays and e^+e^- annihilation. Predictions of NRQCD factorization for quarkonium production are in apparent agreement with the experimental data for a number of processes: quarkonium production at the Tevatron, $\gamma\gamma \to J/\psi + X$ at LEP, quarkonium production in deep-inelastic scattering at HERA, and exclusive double-charmonium production at Belle and BABAR. The NRQCD factorization predictions for other quantities are not in good agreement with the data: $\sigma(e^+e^- \to J/\psi + c\bar{c} + X)/\sigma(e^+e^- \to J/\psi + X)$ at Belle, quarkonium polarization at the Tevatron, and inelastic quarkonium photoproduction at HERA. Corrections of higher order in α_s and v, as well as resummations of the α_s and v expansions near endpoint singularities, seem to be essential to obtain reliable theoretical predictions. Corrections to quarkonium production at the Tevatron at next-to-leading order in α_s and next-to-next-to-leading order in α_s yield large increases in the color-singlet contribution. These results suggest that the additional color-octet contribution that is needed to obtain a fit to the data may be much smaller than previously thought. The resulting smaller values for the color-octet matrix elements might resolve a number of the outstanding discrepancies between NRQCD factorization predictions and experimental data. A systematic study of the phenomenology of color-octet and color-singlet contributions to inclusive cross sections at next-to-leading order in α_s, and, in some cases, next-to-next-to-leading order in α_s is needed to test this hypothesis. An accurate measurement of polarization in direct-J/ψ or $\psi(2S)$ production at large p_T at the Tevatron would help to fix the relative sizes of color-singlet and color-octet contributions.

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