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A DIS Event Shape at N^{3}LL *

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A high precision calculation of the event shape DIS thrust, with next-to-next-to-next-to-leading-logarithmic resummation and a rigorous treatment of hadronization corrections, is presented. Perturbative resummation uncertainties in the cross section are reduced to the 2% level for a significant region of the HERA phase space in x and Q, thus allowing for new accurate measurements of $\alpha_s(m_Z)$.

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Event shapes provide a key method of measuring jets in deep-inelastic scattering (DIS). This was done successfully by H1 and ZEUS [1, 2, 3, 4, 5, 6] and compared with theoretical calculations with next-to-leading-logarithmic (NLL) resummation [7, 8]. Here we consider the event shape DIS thrust, τ, which is defined in the Breit frame using the momentum of the exchanged γ or Z-boson to determine the z-axis, $q = (0,0,0,Q)$. It can be measured solely from events in the current hemisphere where $z > 0$ via $\tau = 1-(2/Q)\sum_{i\in\mathscr{H}_J} p_{iz}$, thus avoiding the lack of detector coverage in parts of the beam region. The event shape τ also does not suffer from non-global logarithms [8].

Recently an all orders factorization theorem was derived for $d\sigma/d\tau$ [9], which enables higher order perturbative results to be obtained, and a more rigorous treatment of power corrections,

$$\frac{1}{\sigma_0}\frac{d\sigma}{dxdQ^2d\tau} = QH(Q,x,\mu)\int dt_B dt_J d^2p_\perp\, B_q(t_B,x,\vec{p}_\perp^{\,2},\mu)\, J_q(t_J-\vec{p}_\perp^{\,2},\mu)\, S\Big(Q\tau-\frac{t_B+t_J}{Q},\mu\Big). \quad (1)$$

Results with a resummation of the singular $\alpha_s^k \ln^j\tau/\tau$ terms at next-to-next-to-leading-log (NNLL) order were given in [9]. Here we extend this analysis to one higher order, N^3LL, by exploiting the recent 2-loop calculation of the quark beam function B_q [10, 11], the 2-loop DIS soft function S [12, 13, 14, 15], and known results for the 2-loop hard function H and jet function J_q, and their 3-loop anomalous dimensions [16, 17, 18]. The smaller nonsingular contributions to $d\sigma/d\tau$ are also now known analytically at $\mathscr{O}(\alpha_s)$ [19], while numerical results are available at $\mathscr{O}(\alpha_s^2)$ [20, 21]. Power corrections are encoded by a hadronic matrix element Ω_1 appearing in S, using formalism developed in Refs. [22, 23, 24, 25, 9]. (The DIS thrust τ is equal to the Breit frame 1-jettiness τ_1^b, and hence belongs to the class of 1-jettiness event shapes [26]. Results for other 1-jettiness DIS variables were obtained in Refs. [27, 28, 29, 9], currently up to NNLL order.)

Fits for $\alpha_s(m_Z)$ in the tail region of the DIS τ distribution, should simultaneously fit for the power correction Ω_1 (similar to the highly successful fits for the e^+e^- thrust event shape in [30]). This is facilitated by considering $d\sigma/d\tau$ from multiple x and Q values. Interestingly, the factorization theorem in Eq. (1) remains valid for relatively small x, and the fractional contribution from the nonsingular corrections even decreases with decreasing x, as shown at $\mathscr{O}(\alpha_s)$ in [31].

In Fig. 1 we show the convergence of the DIS thrust cross section and decrease in the perturbative resummation uncertainty when going from NLL to NNLL to N^3LL order. Results are displayed for a representative value of x and Q, while cross sections for other values can be found in [31]. In Fig. 2 we show the percent uncertainty of $d\sigma/d\tau$ for various values of x and Q in the region accessible by HERA, demonstrating that the theoretical resummation uncertainties become as low as 2% in accessible regions of the phase space. Values are obtained as the average uncertainty in $d\sigma/d\tau$ in the tail region $0.15 < \tau < 0.35$. In Fig. 3 we show how much the cross section changes with variations of the input parameters $\alpha_s(m_Z)$ and Ω_1, as well as comparing the $\alpha_s(m_Z)$ sensitivity to the N^3LL resummation uncertainties, and to the uncertainties from the NNLO MSTW parton distributions [32]. Figures for other values of x and Q are available in [31]. The degeneracy between $\alpha_s(m_Z)$ and Ω_1 is broken by measurements at multiple Q. The theoretical precision of our N^3LL cross section indicates that measurements with 1-2% uncertainty in $\alpha_s(m_Z)$ should now be possible. A measurement of Ω_1 from DIS is also of broader use, since this same Ω_1 parameter occurs in $pp\to Z+1$-jet, where it yields the power correction for the jet-mass that is linear in the jet radius [33].

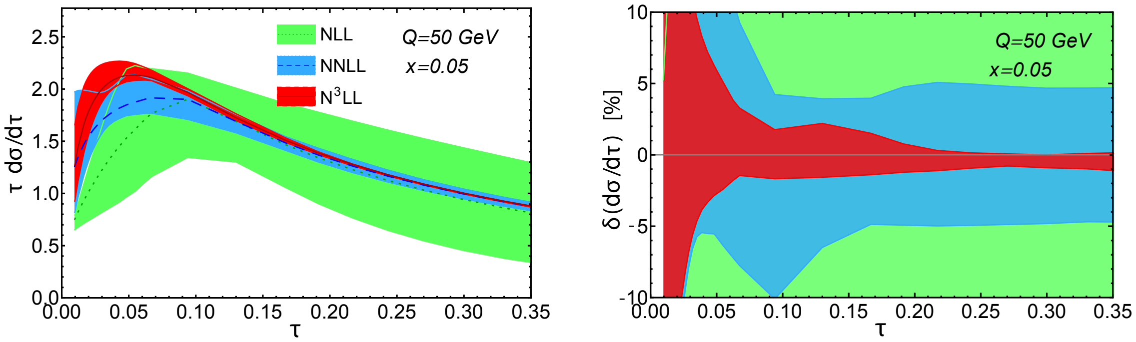

Figure 1: Convergence of the DIS thrust distribution. Results at three orders are shown along with their perturbative uncertainty. Left panel shows $\tau d\sigma/d\tau$. Right panel shows the relative uncertainty for $d\sigma/d\tau$.

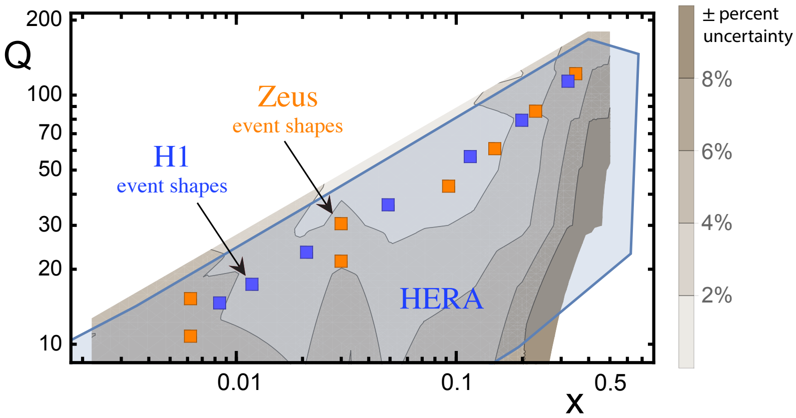

Figure 2: Percent uncertainty of our N^{3}LL cross section for the region in x and Q accessible at HERA. Uncertainties are for the tail of the DIS thrust distribution which can be used to measure $\alpha_s(m_Z)$. Also shown are the points used for past DIS event shape measurements.

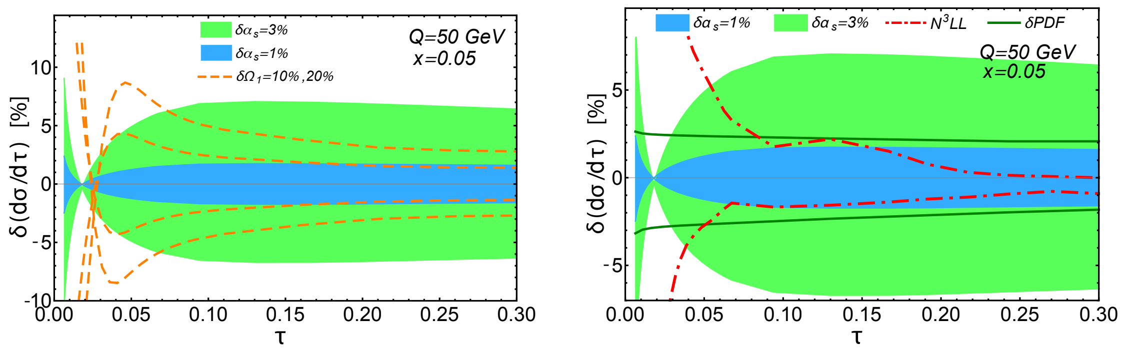

Figure 3: Sensitivity of the DIS thrust cross section to changes in $\alpha_s(m_Z)$ and Ω_1 (left panel) and compared with PDF and N^{3}LL uncertainties (right panel).

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