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Resolving Color and Kinematics for QCD Amplitudes

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We explore implications of the color-kinematics duality for quantum chromodynamics with massive quarks. We work out a decomposition n-point tree amplitudes in a small basis of color-ordered "primitive" amplitudes, using general properties of color and kinematics. First, we decompose the full scattering amplitude with 2k quarks and (n-2k) gluons in terms of the Melia basis, which consists of (n-2)!/k! primitives independent under color-algebra (Kleiss-Kuijf) relations. We find their color factors in that decomposition for an arbitrary gauge group. Then we analyze the kinematic-algebra amplitude relations that follow from the color-kinematics duality. The duality is shown to hold in amplitudes with massive Dirac fermions in the fundamental representation for up to eight particles. This gives strong evidence that QCD obeys the color-kinematics duality, at least at tree level. We identify the new (massive) amplitude relations in QCD and show that they map to a well-defined subset of the familiar BCJ relations for gluons. They restrict the amplitude basis further down to (n-3)!(2k-2)/k! primitives, in case of two or more quark lines. We give a decomposition of the full amplitude in that basis. All results in this paper generalize to supersymmetric extensions of QCD.

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