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STABILIZING BFKL VIA HEAVY-FLAVOR AND NRQCD FRAGMENTATION[*]

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We bring evidence that the recently discovered property of natural stability of the high-energy resummation is directly connected to the fragmentation mechanism of heavy hadrons. As a phenomenological support, we provide predictions for differential distributions sensitive to heavy-hadron tags, calculated at the next-to-leading logarithmic level of the hybrid high-energy/collinear factorization (NLL/NLO), as implemented in the JETHAD multimodular code. We show that the stabilizing mechanism is encoded in gluon channels of both heavy-flavor collinear fragmentation functions extracted from data and the ones evolved from a nonrelativistic QCD input.

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1. Hors d'œuvre

It is widely known that high-energy calculations via the next-to-leading BFKL resummation [1, 2] of energy logarithms (NLL) suffer from strong instabilities that become manifest when renormalization and factorization scales are varied from their natural values, namely the ones dictated by kinematics. For observables featuring light-particle emissions, such as Mueller–Navelet [3–13] and light-hadron correlations [14–23], these instabilities are so strong that hamper any possibility to perform precision studies at natural scales (for further advancements in high-energy QCD phenomenology, see [24–60]). We provide evidence that the LHC final states sensitive to heavy-flavored hadrons exhibit fair and solid stability of these observables under higher-order corrections and scale variations. The stabilization mechanism is encoded in the peculiar behavior of the gluon collinear fragmentation function (FF) describing the heavy hadron. It comes out as there is an intrinsic feature emerging whenever a species with heavy flavor is detected.

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This remarkable property, called *natural stability* of the high-energy resummation, is typical of both heavy-flavor FFs extracted from data and the ones evolved from a nonrelativistic QCD (NRQCD) input [61–63].

2. Natural stability from fragmentation

We study inclusive dihadron tags at the LHC within the NLL/NLO hybrid factorization as implemented in JETHAD [22, 64]. The left panels of Fig. 1 show the μ_F-dependence of: $\Lambda(\bar{\Lambda})$ AKK08 [65], $\Lambda_c^\pm$ KKSS19 [66], and J/ψ ZCW19$^+$ [33] NLO FFs at $z = 5 \times 10^{-1}$. This roughly corresponds to the average value of the momentum fraction, $\langle z \rangle$, at which FFs are typically probed by rapidity distributions at the LHC. They are cross sections differential in the rapidity interval, ΔY, between the two hadrons, see the right panels of Fig. 1. NLO parton distribution functions (PDFs) are taken from NNPDF4.0 [67]. We clearly observe that the ΔY distribution is very sensitive to scale variation (μ_R and μ_F range from one to 30 times their natural values, *i.e.* the transverse masses of the final-state objects) in the lighter $\Lambda(\bar{\Lambda})$ case, whereas it is very stable when heavier hadrons are tagged. As pointed out in [30, 33], a key role is played by the heavy-hadron gluon FF. Its impact on the cross section gets enhanced by the convolution with the gluon PDF at leading order, which dominates also over nondiagonal gq channels at NLO. Smooth-behaved, nondecreasing with μ_F gluon FFs (central and lower left panels of Fig. 1) compensate the falloff with $\mu_{\rm R}$ of the running coupling in the high-energy cross section. This generates the stability observed in heavy-flavor distributions. This *natural stability* is a general feature emerging whenever a heavy-flavored hadron is emitted, independently of *Ansätze* made on corresponding FFs. It holds both for single-charmed hyperons, whose KKSS19 FF determination was extracted from data, and for vector quarkonia, whose ZCW19$^+$ FF set was obtained by evolution from an initial-scale calculation [68–70] within the NRQCD framework. Analogous results were found for bottomed hadrons [31, 34], while milder stabilizing effects were observed for lighter $\Xi^-/\bar{\Xi}^+$ baryons [71].

3. Toward precision studies

By investigating the LHC final states featuring emissions of heavy-flavored bound states at high rapidities and transverse momenta, we have provided indisputable evidence that a *natural-stabilization* pattern emerges and it permits to perform NLL/NLO studies of related differential distribution. We have discovered that natural stability is a remarkable property shared by all the heavy-flavored species analyzed so far: heavy-light hadrons [30, 31, 35, 64], vector quarkonia [33], and $B_c^{(*)}$ mesons [34]. The possibility of studying

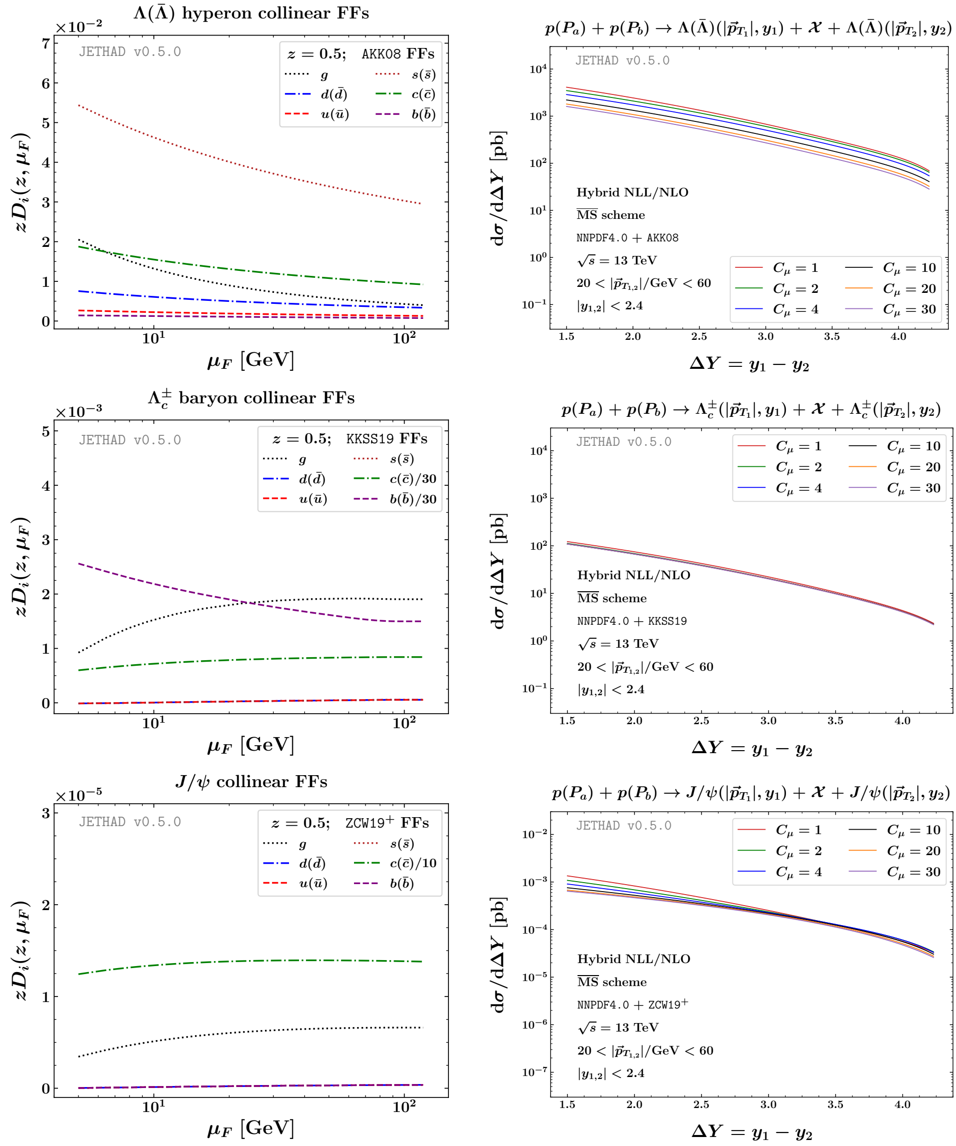

Fig. 1. Left panels: μ_F-dependence on: $\Lambda(\bar{\Lambda})$ AKK08 (upper), $\Lambda_c^{\pm}$ KKSS19 (central), and J/ψ ZCW19^{+} (lower) NLO FFs at $z = 5 \times 10^{-1}$. Right panels: rapidity distribution in dihadron channels at $\sqrt{s} = 13$ TeV.

high-energy QCD at the natural scales provided by the process kinematics was a required point and the first milestone to move our first steps toward the precision level. First, a formal proof of the natural stability, emerged so far as a phenomenological property, needs to be afforded. Then, the hybrid factorization needs to evolve into a *multilateral* and unified formalism where several different resummations are simultaneously embodied. These are required steps to deepen our knowledge of high-energy QCD at new-generation colliding machines [72–89] and access the proton structure at low x via the gluon distributions [90–114].

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