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Probing the Space-Time Structure of Parton Showers with the Quark-Gluon Plasma

Parton showers are a cornerstone of high-energy physics phenomenology, modelling how energetic quarks and gluons radiate and fragment into jets of hadrons. While traditionally formulated in momentum space, a space-time understanding of parton showers remains elusive, even though it is essential to probe the underlying dynamics of QCD in both perturbative and semi-perturbative regimes. In this talk, I will explore the emergent space-time picture of QCD radiation and how ultra-relativistic heavy-ion collisions provide a unique environment to test it.

The formation of a hot and dense QCD medium —the Quark-Gluon Plasma (QGP —in such collisions offers a rare opportunity: not only modifies jet evolution but also serves as a dynamical medium that encodes the temporal unfolding of the parton shower. By studying how jets interact with this evolving QCD medium, we gain access to the time ordering of emissions, the coherence properties of radiation, and the possible interplay between vacuum-like and medium-induced structures.

I will present a proof-of-principle study demonstrating that the space-time structure of parton showers has observable consequences, using a controlled toy Monte Carlo framework to isolate and quantify formation-time effects. Building on this, I introduce a novel reclustering technique—the τ-algorithm—that uses parton formation time as an ordering variable. This tool enables the dynamical selection of jets based on their in-medium propagation history, opening the way for time-resolved studies of jet-medium interactions and offering a new lever arm to connect jet observables with the evolving QCD background.

Author: APOLINARIO, Liliana (LIP (PT))

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