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A theory of dark pions

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We present a complete model of a dark QCD sector with light dark pions, broadly motivated by hidden naturalness arguments. The dark quarks couple to the Standard Model via irrelevant Z- and Higgs-portal operators, which encode the low-energy effects of TeV-scale fermions interacting through Yukawa couplings with the Higgs field. The dark pions, depending on their CP properties, behave as either composite axion-like particles (ALPs) mixing with the Z or scalars mixing with the Higgs. The dark pion lifetimes fall naturally in the most interesting region for present and proposed searches for long-lived particles, at the LHC and beyond. This is demonstrated by studying in detail three benchmark scenarios for the symmetries and structure of the theory. Within a coherent framework, we analyze and compare the GeV-scale signatures of flavor-changing meson decays to dark pions, the weak-scale decays of Z and Higgs bosons to hidden hadrons, and the TeV-scale signals of the ultraviolet theory. New constraints are derived from B decays at CMS and from Z-initiated dark showers at LHCb, focusing on the displaced dimuon signature. We also emphasize the strong potential sensitivity of ATLAS and CMS to dark shower signals with large multiplicities and long lifetimes of the dark pions. As a key part of our phenomenological study, we perform a new data-driven calculation of the decays of a light ALP to exclusive hadronic Standard Model final states. The results are provided in a general form, applicable to any model with arbitrary flavor-diagonal couplings of the ALP to fermions.

Author: LI, LINGFENG (Brown U.)

Presenter: LI, LINGFENG (Brown U.)

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