Probing new physics in the laboratory and in space

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Stellingen

Behorend bij het proefschrift

Searches for new physics
in the laboratory and in space

1. While the Standard Model of particle physics (SM) is extremely successful in describing accelerator data in a great detail, we can claim today that it is incomplete, as it fails to explain some of the observed phenomena: neutrino oscillations, dark matter, and the matter-antimatter asymmetry of the Universe. As a result, it has to be extended.

   (*Chapter 1*)

2. Currently, there is no guiding principle on how exactly the SM has to be extended. To search for a wide class of extensions that add Feebly Interacting Particles (FIPs) in a model-independent way, during the last decade there has been proposed a number of Intensity Frontier experiments.

   (*Chapter 1*)

3. The negative results of an old Intensity Frontier experiment CHARM implies much stronger constraints on FIPs than it was reported in the original paper and consequent literature. This affects scientific programs of many proposed Intensity frontier experiments, restricting in particular the potential of atmospheric beam dumps – IceCube and KM3NeT – to search for Heavy Neutral Leptons (HNLs).

   (*Chapter 2*)

4. The scattering of LDM off nucleons, the signature that was not accounted for in the literature, allows SND@LHC to probe the parameter space inaccessible by direct DM detection experiments.

   (*Chapter 2*)

5. For a several interesting FIPs, including dark scalars and HNLs, the strongest constraints from BBN come on hadronically decaying FIPs, which inject light mesons π, K in the primordial plasma.

   (*Chapters 1, 3*)

6. Counter-intuitively, short-lived FIPs that decay mostly into high-energy neutrinos may decrease (rather than increase) the effective number of neutrinos, N_{eff}. This weakens e.g. the CMB constraints on the properties of the particles.

   (*Chapters 1, 3*)

7. A novel DV scheme exploiting muon trackers at CMS is sensitive to Heavy Neutral Leptons, Higgs-like scalars, and vector particles interacting via the Chern-Simons portal.

   (*Chapter 2*)

8. There is a large unexplored parameter space for models that may resolve the BSM problems. In order to probe the parameter space, we need a combination of different experiments, including LHC experiments, and dedicated beam experiments.

   J. Beacham *et al.*, "Physics Beyond Colliders at CERN: Beyond the Standard Model Working Group Report," arXiv:1901.09966 [hep-ex].

9. Displaced vertices (DV) at the LHC suit perfectly for searches for new feebly interacting particles.

   P. Agrawal *et al.*, "Feebly-Interacting Particles:FIPs 2020 Workshop Report" (2020)

10. Light dark matter (LDM) can be searched not only at the devoted direct dark matter detection experiments such as XENONnT and CRESST-III, but also at the LHC-based experiments, like the new experiment SND@LHC.

    S. Knapen, T. Lin and K. M. Zurek, "Light Dark Matter: Models and Constraints", Phys. Rev. D 96, no. 11, 115021 (2017)

11. While Intensity Frontier experiments can only probe relatively short FIP lifetimes, the complementary parameter space of long-lived FIPs can be constrained using cosmological observations, such as primordial abundances of light elements (BBN) and Cosmic Microwave Background (CMB).

    P. Agrawal *et al.*, "Feebly-Interacting Particles:FIPs 2020 Workshop Report" (2020)

12. New intensity frontier experiments require strong synergy between particle physics, astrophysics, and cosmology. This should affect how the training of the new generation of researchers should be approached.

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