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Searching for dark radiation at the LHC

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There are interesting connections between searches for long-lived particles (LLPs) at the LHC and early universe cosmology. We study the non-thermal production of ultra-relativistic particles (i.e. dark radiation) in the early universe via the decay of weak-scale LLPs. The cosmologically interesting parameter space we find corresponds to LLP decay lengths which lie at the boundary between prompt and displaced signatures at the LHC and can be comprehensively explored by combining searches for both. To illustrate this point, we consider a scenario where the LLP decays into a charged lepton and a (nearly) massless invisible particle. By reinterpreting searches for promptly decaying sleptons and for displaced leptons at both ATLAS and CMS we can then directly compare LHC exclusions with cosmological observables. We find that the CMB-S4 target value of $\Delta N_{\rm eff} = 0.06$ is already excluded by current LHC searches and even smaller values can be probed for LLP masses at the electroweak scale.

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