Long-lived particle signatures at the energy frontier

A Letter of Interest for Snowmass 2021

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Introduction

It is well-established that long-lived particle (LLP) signatures represent an excellent opportunity for the possible discovery of physics beyond the Standard Model (BSM) at high-energy colliders and other facilities, both existing and planned. Due to the often non-standard signatures that can arise from LLPs, typical detector designs at current high-energy collider facilities are sub-optimal for LLPs and LLP searches can require dedicated triggers, analysis methods, object definitions, and separate detectors. Thus, it is imperative that LLPs remain within the standard set of signatures considered for the near and far future of high-energy physics, lest this rich avenue for the potential discovery of BSM physics be overlooked.

The LLP Community initiative was founded in 2016 and encompasses experimentalists and theorists exploring the lifetime frontier at both the Large Hadron Collider (LHC) and at numerous accelerator, collider, and astrophysics experiments around the globe. In keeping with our history of providing a platform for the discussion and workshopping of the most cutting edge ideas and projects related to LLPs, this *Letter of Interest* briefly summarizes the most vital directions of research related to LLPs that will be of high importance for Snowmass 2021. This *Letter of Interest* selects and summarizes key findings from the LLP white paper and also distills the results of many discussions and presentations at the Community workshops that have occurred since the completion of the white paper and. As such, it can be considered a submission on behalf of all of those who edited and contributed to the white paper and/or participated in the workshops. The final author list of any further work in this direction will be determined at a later date, and we welcome all new collaborators, as well.

Benchmarking

Searches for LLPs tend to (and should be) signature- rather than model-driven, but it can be challenging to directly compare results from different analyses due to differences among models chosen upon which to present limits. Because of the wide range of analyzers, model choices, and experiments -- both current and proposed -- a common set of community LLP benchmarks (building upon the set of simplified models presented in Chapter 2 of the LLP white paper: https://arxiv.org/abs/1903.04497) could be widely beneficial to compare results and to inform the design of proposed detectors and facilities.

Recasting / reinterpretations

The need for experimental collaborations to present their results with sufficient and sufficiently flexible information to maximally enable recasting and reinterpretation by the broader theory and phenomenology community cannot be overstated. The recommendations of Chapter 6 of the LLP white paper should be adopted by any current and future experimental collaborations and further studies -- such as those ongoing by the reinterpretations community -- should continue to adapt and improve these recommendations moving forward.

LLP connection to dark matter

As the research programs of the experiments at the LHC and other facilities have matured, the connections between LLP signatures and dark matter have emerged as some of the most interesting and least-explored elements of both realms of research. Further studies to understand dark matter and LLPs should be undertaken, including but not limited to the formulation of dark matter LLP benchmarks (related to the above) and cross-community collaborations, e.g., between the LLP Community and the Dark Matter Working Group.

Dark showers / dark QCD

As explored in detail in Chapter 7 of the LLP white paper, the theoretical and phenomenological understanding of dark QCD and dark hadronic showers -- ideas that can give rise to detector signatures containing a high multiplicity of low-energy, low-mass LLPs -- is currently quite limited. It is vital that this exciting and underexplored avenue -- both theoretical and experimental -- receive continued, adequate attention, including but not limited to further theoretical studies of dark QCD, detector phenomenology for various dark coupling constants / ‘t Hooft couplings, model benchmarking to ensure sufficient understanding of how the various signatures (emerging jets, semi-visible jets, SUEPs, etc.) relate, and new experimental searches.

Full approval of dedicated LLP experiments at the LHC

Several dedicated LLP detectors that use the nominal interaction points of the LHC as the source of the LLP have either been installed and running for years (MoEDAL); have been approved (FASER); have been proposed and have run with small-scale demonstrators (Milliqan and MATHUSLA) but are not yet approved; or are being proposed (CODEX-b, ANUBIS, a forward spectrometer at CMS, and the Forward Physics Facility at the LHC) and have yet to be approved. Each of these dedicated experiments and projects is sensitive to different LLP lifetimes, masses, and production modes based on their position and orientation and thus each can be considered a necessary component of a comprehensive, coordinated search program for very long-lived particles at the LHC. It is imperative that these are carefully evaluated and that most, if not all, of these projects receive full and complete funding and approval as soon as possible to benefit from the LHC Phase 2 run.

Detector and accelerator complex design for proposed future collider facilities

Proposed future accelerators and collider facilities -- such as the Future Circular Collider (FCC) at CERN, the Circular Electron-Positron Collider (CEPC) in China, and the International Linear Collider (ILC) in Japan and the Compact Linear Collider (CLiC) at CERN -- should ensure that LLPs are a vital element of the core set of experimental signatures considered when designing detectors and facilities. Central detectors around the nominal interaction points (IPs) should be designed to provide optimal sensitivity to LLPs from the beginning, avoiding the need to perform highly atypical searches with, e.g., ATLAS and CMS, or to build large surface facilities or find spare drainage pathways, unused tunnels, or space in existing caverns within which to construct dedicated LLP detectors, such as is being done at the LHC now. This need to consider LLP signatures when designing future detectors can be greatly facilitated with an adequate and comprehensive set of common LLP benchmarks, as mentioned previously.

Detector technologies and machine learning

Detectors tailored for LLP searches can strongly benefit from new emerging detector technology developments and even drive some required R&D programs. In particular, precise position measurements and precise timing of signals have already been shown to be key for maximizing phase space coverage for LLP signatures. Developments at the trigger level such as LLP-specific hardware signals or fast machine learning algorithms implemented at the FPGA level enhance the flexibility to record signatures presently difficult to filter out of the background. Machine learning techniques may become an indispensable tool in the near future for higher level software triggers as well as off-line analysis techniques to uncover new, otherwise difficult-to-access, LLP signatures.

Conclusions

Long-lived BSM particles should remain a vital and central component of energy frontier projects, both current and proposed. We have briefly outlined some of the most important issues related to LLPs that are relevant to the Snowmass 2021 process, and we endorse and highly encourage studies, projects, and proposals that work to address these issues.