Searching for long-lived particles at the LHC: Fifth workshop of the LHC LLP Community

27-29 May 2019

CERN

indico.cern.ch/e/LHC_LLPC_May_2019
The Large Hadron Collider is a big-data discovery machine

The first nine years have been a triumph

4 July 2012
4 July 2012
4 July 2012

The day everything changed
4 July 2012

The day everything changed

3 June 2015
The day everything changed
4 July 2012

The day everything changed

3 June 2015

First proton-proton collisions at 13 TeV
First proton-proton collisions at 13 TeV

The day everything changed
4 July 2012

The day everything changed

3 June 2015

First proton-proton collisions at 13 TeV

2018

Thus far no new particle discoveries beyond the Higgs
New physics at the LHC in 2018

Our current extensive look at 13 TeV yields impressive agreement with Standard Model expectations and no huge, immediate resonances or excesses.

There are no more guarantees (like a source of electroweak symmetry breaking “just around the corner”) and no ace-in-the-hole motivations; just huge open questions.

Requires us to shift from theory-driven search strategies to signature-driven ones.

We would certainly love some old-school theoretical guidance, but WIMP dark matter in tension, lack of plain vanilla SUSY, lack of twenty-jet events filled with strong gravity, etc.

Where could the new physics be hiding? What are we marginalizing?
Where is new physics at the LHC?

Precision Higgs measurements?

Exotic Higgs decays?

Top quark Higgs production?

Top anomalies?

Lepton flavor asymmetries?

Precision measurements of Standard Model processes?

B physics irregularities?

All of these searches utilize a small number of very well-studied more-or-less prompt objects
Where is new physics at the LHC?

ATLAS EXPERIMENT — PUBLIC RESULTS

Exotic Physics Searches

This page contains public results from the ATLAS Exotics Working Group, which is searching for physics beyond the Standard Model with a signature-based program. Our aim is to cover all experimentally viable signatures focusing on non-supersymmetric models from Extra Dimensions and mini Black Holes to Dark Matter, extended Higgs models, and Compositeness to name a few.

If you have any question, please contact the group conveners (currently Gabriele Facini and Marine-Helene Genaux): atlas-phys-exotics-conveners.

Filter Documents

Select the desired keywords to filter the results. Selections within a section row are combined with a logical OR, while selections among different section rows are combined with a logical AND.

Global Selections: Show All, Deselect All, Show Latest 20

CM Energy: 7 TeV, 8 TeV, 13 TeV, 14 TeV

Analysis characterization: ISR, MVA, machine learning, EFT, High luminosity upgrade studies, Statistical combination, VDF, BSM re-interpretation, Long-lived massive particles, Trigger-level objects, LFV

Min luminosity: [ ] [fb^{-1}]  Filter by minimum integrated luminosity

Searches:

- Search for highly ionizing particles/monopoles
  - Submitted to Phys. Rev. Lett. 24-MAY-19
  - 36 fb^{-1} 36 fb^{-1}
  - Datasets | 1908.10130 | Literature

- Prompt Displaced Heavy Neutral Lepton Search 13 TeV
  - Submitted to JHEP 23-MAY-19
  - 36 fb^{-1} 36 fb^{-1}
  - Datasets | 1908.09787 | Literature

Papers and publications: 20 shown of 221 total
(Full list of ATLAS papers 2016-Jun-08)
New physics $X$ at the LHC

The overwhelming majority of the work of the LHC experiments

New physics could be hiding here

$\mathcal{O}(mm)$

Stable

Outer edge of detector

$O_X$
95% of our analysis effort at the LHC is dedicated to understanding five more-or-less prompt objects.
95% of our analysis effort at the LHC is dedicated to understanding five more-or-less prompt objects

What we want:
• To reduce to negligible the chance that we’ll miss new physics at the LHC

What we have:
• The most sophisticated general-purpose detectors ever built at the highest $pp \sqrt{s}$ ever used, and these interaction points the only good source of Higgses, Ws, etc., for several decades

Shift from model-first / signature-second to signature-first / model-second mindset
Same principles apply to BSM LLPs, which can **generically appear**

- Lifetime is usually best treated as a free parameter
The LHC LLP Community
We map LLP signature space

For our purposes, LLP = BSM particle that dies (gives up all its energy or decays to SM) somewhere in the detector acceptance of LHCb, CMS, ATLAS, MilliQan, MoEDAL, FASER, Codex-b, MATHUSLA, etc.
The LHC LLP Community

We map LLP signature space

Because of this, LLP searches are

• Fun: Plenty of novel, innovative work to be done

• Challenging: Small analysis teams, difficult background estimates, hard to estimate systematic uncertainties

If we don’t think about it critically and comprehensively, there’s a danger we’ll miss a potential discovery

For our purposes, LLP = BSM particle that dies (gives up all its energy or decays to SM) somewhere in the detector acceptance of LHCb, CMS, ATLAS, MilliQan, MoEDAL, FASER, Codex-b, MATHUSLA, etc.
One question arose:

How do we best ensure that we don't miss BSM LLP signatures for the remainder of the LHC program and beyond?

Answer: Construct a space for the inter-experiment/theory community to discuss and collect the results

Space: Working-workshops

Results: White papers and website
LHC Long-Lived Particle Community

...in collaboration with the theory/pheno community and MoEDAL, milliQan, MATHUSLA, FASER, Codex-b, AL3X, etc.

LHC LLP white paper:
Submitted for publication in J. Phys. G

Workshops — two per year

Join the CERN egroup: lhc-llp
cern.ch/longlivedparticles

James Beacham [ATLAS/Duke]
The LHC LLP Community Initiative

...in collaboration with the theory/pheno community and MoEDAL, milliQan, MATHUSLA, FASER, Codex-b, etc.

Workshops:

• Oct. 2018 — Fourth — Nikhef
• May 2018 — Third — CERN
• Oct. 2017 — Second — ICTP Trieste
• April 2017 — First — CERN

Continuing the work begun by several prior workshops

• May 2016 — LHC LLP Mini-Workshop — CERN
• May 2016 — “Experimental Challenges” — KITP
• Nov. 2015 — “LLP Signatures” — UMass Amherst
LHC LLP Community: Emphasis on “community”

Community is open to all
• By being here and participating, you’re already a member; welcome!

Workshops are informal and collaboration-centered
• Working-workshops, not a series of talks
• Prioritize discussion over presentations
• Slides are there to guide the discussion

Community is collaboration — Collaboration is respect

To all community members:
• Yes, ask that physics question and make that suggestion!

To all session chairs and discussion leaders:
• Solicit comments from those who haven’t had a chance to talk!

We’re radically inclusive and radically anti-harrassment
• The CERN Code of Conduct is a great place to start

Overall we’re here to find new physics
• Both science and society suffer when ideas and thoughts aren’t heard because someone feels threatened, unwelcome, or marginalized

• Harrassment is antithetical to the intention of this workshop
• We endeavor to create a positive and welcoming space!
The LHC LLP Community white paper

arXiv:1903.04497

On the arXiv
11 March 2019

Submitted for publication in J. Phys. G

257 pages
(301 w/references)

201 authors / contributors / endorsers

21 editors

616 references

16 citations already
Searching for long-lived particles beyond the Standard Model at the Large Hadron Collider

April 23, 2019

Particles beyond the Standard Model (SM) can generically have lifetimes that are long compared to SM particles at the weak scale. When produced at experiments such as the Large Hadron Collider (LHC) at CERN, these long-lived particles (LLPs) can decay far from the interaction vertex of the primary proton-proton collision. Such LLP signatures are distinct from those of promptly decaying particles that are targeted by the majority of searches for new physics at the LHC, often requiring customized techniques to identify, for example, significantly displaced decay vertices, tracks with atypical properties, and short track segments. Given their non-standard nature, a comprehensive overview of LLP signatures at the LHC is beneficial to ensure that possible avenues of the discovery of new physics are not overlooked. Here we report on the joint work of a community of theorists and experimentalists with the ATLAS, CMS, and LHCb experiments — as well as those working on dedicated experiments such as MOEDAL, miliQan, MATHUSLA, CODEX-b, and FASER — to survey the current state of LLP searches at the LHC, and to chart a path for the development of LLP searches into the future, both in the upcoming Run 3 and at the High-Luminosity LHC. The work is organized around the current and future potential capabilities of LHC experiments to generally discover new LLPs, and takes a signature-based approach to surveying classes of models that give rise to LLPs rather than emphasizing any particular theory motivation. We develop a set of simplified models; assess the coverage of current searches, document known, often unexpected backgrounds; explore the capabilities of proposed detector upgrades; provide recommendations for the presentation of search results; and look towards the newest frontiers, namely high-multiplicity “dark showers”, highlighting opportunities for expanding the LHC reach for these signals.

Editors:
Juliette Alimena(1) (Experimental Coverage, Backgrounds, Upgrades), James Beacham(2) (Document Editor, Simplified Models), Martino Borsato(3) (Backgrounds, Upgrades), Yangyang Cheng(4) (Upgrades), Xavier Cid Vidal5) (Experimental Coverage), Giovanna Cottin(6) (Simplified Models, Reinterpretations), Albert De Roeck(7) (Experimental Coverage), Nishita Desai(8) (Reinterpretations), David Curtin(9) (Simplified Models, Jared A. Evans(10) (Simplified Models, Experimental Coverage), Simon Knapen(11) (Dark Showers, Sabine Kraml(12) (Reinterpretations), Andre Lessa(13) (Reinterpretations), Zhen Liu(14) (Simplified Models, Backgrounds, Reinterpretations), Sascha Mehlaese(15) (Backgrounds), Michael J. Ramsey-Musolf(16,136) (Simplified Models), Heather Russell(17) (Experimental Coverage), Jessie Shelton(18) (Simplified Models, Dark Showers), Brian Shuve(19,20) (Document Editor, Simplified Models, Simplified Models Library), Monica Verdugo(21) (Upgrades), Jose Zurita(22,23) (Experimental Coverage)

A comprehensive document — a combination review paper, set of recommendations, accounting of open discovery possibilities, record of accumulated knowledge, and speculation for the future — that (paired with the MATHUSLA physics case document arXiv:1806.07396) serves as the definitive guide to LLP searches at the LHC ... as of 11 March 2019
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Particles beyond the Standard Model (SM) can generically have lifetimes that are so long that they SM particles at the weak scale. When produced at experiments such as the Large Hadron Collider (LHC) at CERN, these long-lived particles (LLPs) can decay far from the interaction point of the primary proton-proton collision. Such LLP signatures are distinct from those of decaying particles that are targeted by the majority of searches for new physics at the LHC, requiring customized techniques to identify, for example, significantly displaced decay tracks with atypical properties, and short track segments. Given their non-standard premassage overview of LLP signatures at the LHC is beneficial to ensure that potential implications of the discovery of new physics are not overlooked. Here we report on the joint work of theorists and experimentalists with the ATLAS, CMS, and LHCb experiment as those working on dedicated experiments such as MoEDAL, milliQan, MATHUSLA, and FASER — to survey the current state of LLP searches at the LHC, and to discuss the development of LLP searches into the future, both in the upcoming Run 3 and Luminosity LHC. The work is organized around the current and future potential of these experiments to generally discover new LLPs, and takes a signature-based approach to classes of models that give rise to LLPs rather than emphasizing any particular methodology. We develop a set of simplified models: assess the coverage of current search results, often unexpected backgrounds; explore the capabilities of proposed detectors and provide recommendations for the presentation of search results; and look towards future experiments, namely high-multiplicity dark showers, highlighting opportunities for expansion for these signals.

Editors:
Juliette Alimeni1 (Experimental Coverage, Backgrounds, Uplifters), James Becham2, Editor, Simplified Models, Martino Borsato3 (Backgrounds, Uplifters), Yangyan (Uplifters), Xibei Cui Vida4 (Experimental Coverage), Giovanna Cecchi5 (Simplified Models), Albert De Roeck6 (Experimental Coverage), Nishita Desai7 (Simplified Models), David Dutre8 (Simplified Models), Jared A. Evans9 (Simplified Models, Experimental Coverage), Simon Knappen10 (Dark Showers), Sabine Kraml11 (Reinterpretation), Andrea L. Zhen Liu12 (Simplified Models, Backgrounds, Reinterpretations), Sasa Muhich13 (Experimental Coverage), Michael J. Ramsay-Musolf14 (Simplified Models, Lepton Ratios), Andrej J. Sjostrand15 (Simplified Models, Dark Showers), Brian Shuvo16,20 (Document Simplified Models, Simplified Models Library), Monica Verducci21 (Uplifters), Joost (Experimental Coverage)

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White paper: Focused on experimental signature

arXiv:1903.04497

Searching for long-lived particles beyond the Standard Model at the Large Hadron Collider

April 23, 2019

Particles beyond the Standard Model (SM) can generically have lifetimes that are short compared to SM particles at the weak scale. When produced at experiments such as the Large Hadron Collider (LHC) at CERN, these long-lived particles (LLPs) can decay far from the interaction point in the detectors. Such LLP signatures are distinct from those associated with decaying particles that are targeted by the majority of searches for new physics at the LHC requiring customized techniques to identify, for example, significantly displaced decay tracks with atypical properties, and short track segments. Given their non-standard and unexplained nature, LLP searches at the LHC are beneficial for identifying new phenomena that are not well understood. However, new trends of discovery in the discovery of new physics are not observed. Here we report on the joint work of theorists and experimentalists with the ATLAS, CMS, and LHCb experiments as well as others working on dedicated experiments such as MoEDAL, MiLan, MATHUSLA, and TESER — to survey the current state of LLP searches at the LHC, and to highlight the possibilities for the future of LLP searches into the future, both in the upcoming Run 3 and beyond. The work is organized around the current and future potential candidate experiments to generally discover new LLPs and takes a signature-driven approach to different classes of models that give rise to LLPs rather than emphasizing any particular physics approach. We develop a set of simplified models, assess the coverage of current searches, often unexpected backgrounds; explore the capabilities of proposed detector configurations for the presentation of search results; and look towards the frontiers, namely high-multiplicity “dark showers,” highlighting opportunities for experiments to explore these signals.

Editors:
Juliette Almera (Experimental Coverage, Backgrounds, Upgrades), James Beacham (Simplified Models), Martino Bonacini (Backgrounds, Upgrades), Yangyao (Upgrades), Xiaobin Cai (Experimental Coverage), Giovanni Cottin (Simplified Models, Reinterpretations), Albert De Roeck (Experimental Coverage), Ichita Desai (Simplified Models), Jared A. Evans (Simplified Models, Experimental Interpretations), Simon Knapp (Dark Searches), Sabine Kramer (Reinterpretations), Andrea Zuren (Simplified Models, Backgrounds, Reinterpretations), Saso Muhar (Simplified Models, Simplified Models Library), Monica Vendruscolo (Upgrades), James Beacham (Experimental Coverage)

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Simplified model proposal organized around generic classes of LLP production and decay mode, always with an eye toward what the detectors might be able to do.
Searching for long-lived particles beyond the Standard Model at the Large Hadron Collider

April 23, 2019

Particles beyond the Standard Model (SM) can generically have lifetimes that are long compared to SM particles at the weak scale. When produced at experiments such as the Large Hadron Collider (LHC) at CERN, these long-lived particles (LLPs) decay far from the interaction point of the primary proton-proton collision. Such LLP signatures are distinct from those of decaying particles that are targeted by the majority of searches for new physics at the LHC, requiring customized techniques to identify, for example, significantly displaced decays, tracks with atypical properties, and short track segments. Given their non-standard and non-prevalent overwhelming of LLP signatures at the LHC, it is beneficial to ensure that such possibilities are covered. We report on results, both theoretical and experimental, from the ATLAS, CMS, and LHCb experiments, as well as those working on dedicated experiments such as MuEDAL, MiliQan, MATHUSLA, and FASER — to survey the current state of LLP searches at the LHC, and to outline the possibilities for the future development of LLP searches in the future, both in the current Run 3 and potentially in future colliders.

We develop a set of simplified models: assess the current understanding and progress of present and future experimental LLP experiments to generally discover new LLPs, and take a signature-based approach to classes of models that give rise to LLPs rather than emphasizing any particular feature. We then develop a set of simplified models: assess the current understanding of LLPs and their detection signatures, explore the capability of proposed detectors to provide recommendations for the selection of best detectors, and look towards the future of LLP searches, namely high-multiplicity “dark showers,” highlighting opportunities for new LLPs.
Experimental coverage: How well do the existing searches cover the parameter space?

White paper: Focused on experimental signature

arXiv:1903.04497
Searching for long-lived particles beyond the Standard Model at the Large Hadron Collider

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Particles beyond the Standard Model (SM) can generically have lifetimes that are long compared to SM particles at the weak scale. When produced at experiments such as the Large Hadron Collider (LHC) at CERN, these long-lived particles (LLPs) can decay far from the interaction point of the primary proton-proton collision. Such LLP signatures are distinct from those of short-lived decaying particles that are targeted by the majority of searches for new physics at the LHC, requiring customized techniques to identify, for example, significantly displaced decay tracks with atypical properties, and short track segments. Given their non-standard properties, the LLP signatures at the LHC are beneficial to enhance the overlap of the discovery of new physics and LLP searches. Here we report on the joint work of theorists and experimentalists with the ATLAS, CMS, and LHCb experiments as well as those working on dedicated experiments such as MoEDAL, MilQuan, MATHUSL, and FASER — to survey the current state of LLP searches at the LHC, and to guide the development of LLP searches into the future, both in the upcoming Run 3 and Luminosity LHC. The workshop is organized around the current and future potential capabilities of LHCb experiments to generally discover new LLPs and takes a signature-based approach to different classes of models that give rise to LLPs rather than emphasizing any particular model. We develop a set of simplified models, assess the coverage of current searches, explore the capabilities of proposed detectors, and look towards future experiments, namely high-multiplicity “dark showers,” highlighting opportunities for experiments to search for such signals.

Editors:
Juliette Almeida (Experimental Coverage, Backgrounds, Upgrades), James Beacham (Editor, Simplified Models), Martino Borsato (Backgrounds, Upgrades), Yangyan (Upgrades), Xianer Cao (Experimental Coverage), Giovanni Cozzi (Simplified Models, Reinterpretations), Albert De Roeck (Experimental Coverage), Nieves Desalvo (Simplified Models), Jared E. Evans (Simplified Models, Experimental Reinterpretations), David Guo (Simplified Models), Ira E. Evans (Simplified Models, Experimental Reinterpretations), Simon Knapen (Dark Showers), Sabine Kraml (Reinterpretations), Andrea L. Zhen Liu (Simplified Models, Backgrounds, Reinterpretations), Sacha Mehnert (Simplified Models, Upgrades), Michael J. Ramsey-Musolf (Simplified Models), Heather Russell (Experimental Coverage), Josie Shelton (Simplified Models, Dark Showers), Brian Snow (Simplified Models, Simplified Models Library), Monica Verduco (Upgrades), James Beacham (Experimental Coverage)

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arXiv:1903.04497
White paper: Focused on experimental signature
arXiv:1903.04497

Searching for long-lived particles beyond the Standard Model at the Large Hadron Collider

April 23, 2019

Backgrounds to LLP searches can be small but unexpected. Collected wisdom and reference here.


Simplified Models Yielding Long-Lived Particles

Goals of the Present Simplified Model Framework

Existing Well-Motivated Theories for LLPs

The Simplified Model Building Blocks

A Simplified Model Proposal

Proposal for a Simplified Model Library

Challenges in Simulating Charged or Colored LLPs

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Searching for long-lived particles beyond the Standard Model at the Large Hadron Collider

April 23, 2019

Particles beyond the Standard Model (SM) can generically have lifetimes that are longer than the uncertainties in SM particle decay amplitudes. When produced at experiments such as the Large Hadron Collider (LHC) at CERN, these long-lived particles (LLPs) can decay far from the interaction point of the primary proton-proton collision. Such LLP signatures are distinct from those of decaying particles that are targeted by the majority of searches for new physics at the LHC, requiring customized techniques to identify, for example, significantly displaced decay tracks with atypical properties, and short track segments. Given their non-standard decay properties, the discovery of new physics is not guaranteed. Here we report on the joint work of theorists and experimentalists with the ATLAS, CMS, and LHCb experiments, and on dedicated experiments such as McEDAL, milliQan, MATHUSLA, and FASER — to survey the current state of LLP searches at the LHC, and to provide the development of LLP searches into the future, both in the upcoming Run 3 and Luminosity LHC. The work is organized around the current and future potential to use LLP searches to generally discover new LLPs, and takes a signature-based approach to classes of models that give rise to LLPs rather than emphasizing any particular hypothesis. We develop a set of simplified models, assess the coverage of current searches, identify, explore the capabilities of proposed detectors, and look towards frontiers, namely high-multiplicity “dark showers”, highlighting opportunities for exploration of these signatures.

Editors:
Juliette Almeida (Experimental Coverage, Backgrounds, Searches), James Beacham (Editor, Simplified Models), Martino Borosato (Backgrounds, Searches), Yangyan (Upgrades), Xinhe Cui (Experimental Coverage), Giovanni Curtin (Simplified Models, Reinterpretations), Albert De Roeck (Experimental Coverage), Nithita Desai (Experimental Coverage), David Curtin (Simplified Models), Jared A. Evans (Simplified Models, Experimental Coverage), Simon Knapp (Dark Showers), Sabine Kraml (Reinterpretations), Andrea L. Zhen Liu (Simplified Models, Backgrounds, Reinterpretations), Sascha Mehlhop (Dark Showers), Michael J. Ramsey-Musolf (Simplified Models), Heather Russell (Experimental Coverage), Josselin Shilton (Simplified Models, Dark Showers), Brian Stiebel (Document Production, Simplified Models, Simplified Models Library), Monica Vendetti (Upgrades), Joao (Experimental Coverage)
What triggers are missing? What upgrade studies should be done to advocate for new detector components?

Long-term discussion, addressed at this week’s workshop and in the future.
Searching for long-lived particles beyond the Standard Model at the Large Hadron Collider

April 23, 2019

Particles beyond the Standard Model (SM) can generically have lifetimes that are longer than to SM particles at the weak scale. When produced at experiments such as the Large Hadron Collider (LHC) at CERN, these long-lived particles (LLPs) can decay far from the interaction point of the primary proton-proton collision. Such LLP signatures are distinct from those of weakly decaying particles that are targeted by the majority of searches for new physics at the LHC, requiring customized techniques to identify, for example, significantly displaced decay vertices, unusual kinematics, and off-shell decays. To exploit the potential of LLPs for the discovery of new physics, we propose to search for LLPs using dedicated searches that target LLP signatures, which are less sensitive to backgrounds.

We report here on the development of a dedicated search for LLPs at the LHC Run 3 and beyond. The work is organized around the current and future potential capabilities of the LHC experiments to generally discover LLPs, and takes a signature-based approach of selecting specific classes of models that give rise to LLPs, rather than emphasizing any particular technique. We develop a set of simplified models, assess the coverage of current search channels, and choose a set of model parameters that allow for the discovery of LLPs, with an emphasis on those that are likely to be experimentally accessible. We also provide a review of the current experimental long-lived particle program at the LHC and the existing challenges in developing LLP searches for the future.

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   5.3 Dedicated Detectors for LLPs
How should we present our results to ensure optimal re-interpretation and re-cast-ability?
Searching for long-lived particles beyond the Standard Model at the Large Hadron Collider

April 23, 2019

Particles beyond the Standard Model (SM) can generically have lifetimes that are long compared to other SM particles at the weak scale. When produced at experiments such as the Large Hadron Collider (LHC) at CERN, these long-lived particles (LLPs) can decay far from the interaction point of the primary proton-proton collision. Such LLP signatures are distinct from those from decays that are triggered by the majority of searches for new physics at the LHC, requiring customized techniques to identify, for example, significantly displaced decay vertices or unusual tracks and short track segments. Given their non-standard physics, the discovery of new physics is not observed. Here we report on the joint wok of theorists and experimenters with the ATLAS, CMS, and LHCb experimenters on models and results in a dedicated experiment such as MEGAL. The most recent results were achieved by the DELPHI Collaboration. The development of LLP searches into the future is both in the LHC and LHCb. The work is organized around the current and future potential for the Higgs boson to be a long-lived particle. We review the current status of LLP searches and take a signature-based approach to the classes of particles that give rise to the LLPs. The results are emphasized in the experimental analysis. We develop a set of simplified models that help to understand the current state of LLP searches, often expected in the current context. We explore the possibility of simplified models for the presentation of search results, and look towards the future, namely high-multiplicity dark showers, highlighting opportunities for exploring these signals.

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QCD-like (more or less) dark sectors: What kinds of experimental signatures are between emerging jets and SUEP?

Longer-term work on uncharted territory; still examining how we know what we don't know.
Signature first, model second

• General classes of motivations that can give rise to LLPs are many
  • Dark photons
  • Hidden valleys
  • R-parity-violating supersymmetry
  • Dark QCD-like sectors
  • Heavy neutral leptons
  • Etc.

Instead of probing the parameter space of your favorite model, think about the more generic kinds of ways an LLP could be produced at the LHC interaction points and then how it could appear in the detector

• Much clearer way of comparing searches and noting whether and to what extent certain signatures have been covered
• Creates a useful grammar of LLP signatures/searches across experiment
A critical component of any discussion of long-lived particle searches at the LHC is the comprehensive review of the existing searches from ATLAS, CMS, and LHCb, and an assessment of their coverage and any gaps therein. This is an inherently challenging task, given the varied and atypical objects often defined and utilized in LLP analyses and the differences among the experiments. As such, the following discussion assumes little-to-no background on LLP search strategies and includes a high level of detail regarding the current analyses. The focus of the discussion is on the existing studies, while acknowledging that the landscape for new physics models and LLP signatures can be broader than the ones described here.

3.6 Discovery Opportunities: Overview of Gaps in Coverage

In the preceding sections (3.1–3.5.3), we have examined the so-called “coverage” of existing searches for LLPs at the LHC with the explicit and express purpose of identifying uncovered realms and places where discoveries could be hiding. Here, we summarize these gaps and potential opportunities for LLP discovery in bullet form, as a to-do list for the experimental community.

1. All-hadronic LLP decays
   - Associated-object triggers (especially motivated by Higgs-like VBF and VH production modes) need to be more comprehensively used to improve sensitivity to low-$p_T$ objects
   - Improvements are needed in sensitivity at lower masses & lifetimes (e.g., for LLPs produced in Higgs decays)
   - Single hadronic DVs need to be looked for in searches that currently use two (such as decays in ATLAS HCAL and MS)
   - Possibilities need to be explored for online reconstruction

3. Semi-Leptonic
   - Searches do not exist and need to be done for masses below or about 30 GeV, theoretically well motivated by Majorana neutrinos.
   - Searches need to be performed for all flavor combinations (for example, one CMS search only covers $e^\pm\mu^\mp$), as well as same-sign vs. opposite-sign leptons.
   - Currently unknown improvements need to be made to relax or modify isolation criteria wherever possible to recover sensitivity to boosted semi-leptonic decays.
   - Searches need to be done that better exploit triggering on associated objects for improved sensitivity to low-mass objects, or to employ high-multiplicity lepton triggers if there are multiple LLPs.

5. Other exotic long-lived signatures
   - Disappearing tracks with $\sqrt{s} \sim$ mm are very hard to probe, and new ideas and detector components are needed to extend sensitivity to this potential discovery regime. It’s unclear if the ATLAS insertable B-layer will be present in HL-LHC run and how sensitivity to the disappearing track topology will improve with the replacement of the current inner detector with the new ITx (Inner Tracker), or whether new tracking layers very close to the beam line can be added. It’s an open question as to what is the lowest distance at which new layers (or double layers) can be inserted. Another open question that needs to be answered is whether there are any prospects for disappearing tracks at LHCb with an upgraded detector.
   - No dedicated searches for quirks exist at the LHC, a huge, open discovery possibility for ATLAS, CMS, and LHCb.
Experimental coverage chapter
Both a review document and a list of discovery opportunities

A critical component of any discussion of long-lived particle searches at the LHC is the comprehensive review of the existing searches from ATLAS, CMS, and LHCb, and an assessment of their coverage and any gaps therein. This is an inherently challenging task, given the varied and atypical objects often defined and utilized in LLP analyses and the differences among them. The following discussion assumes little-to-no strategies and includes a high level of analyses. The focus of the discussion is on dark showers, phenomena of dark-QCD-like sectors, from emerging jets to SUEPs (soft, unclustered energy patterns) — an uncharted territory (beginning to be charted).

3. Semi-Leptonic
- Searches do not exist and need to be done for masses below or about 30 GeV, theoretically well motivated by Majorana fermions, including all flavor combinations (except only covers $e^\pm \mu^\mp$), as well as dark leptons.
- Improvements need to be made to raw data somewhere possible to recover semi-leptonic decays.
- It's important to exploit triggering on events with low-mass observables, such as leptonic multiplicity lepton triggers if there are any.

3.6 Discovery Opportunities: Other cases

In the preceding sections (3.1–3.5.3), we've discussed the explicit and express purpose of identifying places where discoveries could be made, and potential opportunities that form, as a to-do list for the experiment.

1. All-hadronic LLP decays
   - Associated-object triggers (especially motivated by Higgs-like VBF and VH production modes) need to be more comprehensively used to improve sensitivity to low-$p_T$ objects.
   - Improvements are needed in sensitivity at lower masses & lifetimes (e.g., for LLPs produced in Higgs decays).
   - Single-hadronic DVs need to be looked for in searches that currently use two (such as decays in ATLAS HCAL and MS).
   - Possibilities need to be explored for online reconstruction.

and how sensitivity to the disappearing track topology will improve with the replacement of the current inner detector with the new ITx (Inner Tracker), or whether new tracking layers very close to the beam line can be added. It’s an open question to what is the lowest distance at which new layers (or double layers) can be inserted. Another open question that needs to be answered is whether there are any prospects for disappearing tracks at LHCb with an upgraded detector.

- No dedicated searches for quirks exist at the LHC, a huge, open discovery possibility for ATLAS, CMS, and LHCb.
LHC LLP: Moving forward

LHC LLP Community now and in the future

• Twice yearly workshop schedule, spring (at CERN) and fall (mobile) — sounding board for your ideas
• New LLP ideas, new signatures, improvements in coverage, evolving high-priority searches and studies, etc.
• Simplified models are just that, simplified, so already some organic interest in studying some of the classes of motivations in detail, leveraging the strength of the community
• HNL enthusiasts have already started a study group / task force to do this for displaced heavy neutrino signatures — An entire breakout working group devoted to this at the present workshop!
• DM/dark photon version of this would be interesting, too, and some strong interest shown recently
  • Will likely be a key component of the fall workshop
• And as an example of how last workshop’s idea becomes the next workshop’s focus, this week we have an entire breakout working group devoted to exploring the way machine learning can aid LLP searches
• Reinterpretations of LLP searches is a continually vital topic — our third breakout working group this week
LHC LLP: Moving forward

• Future work: A follow-up white paper dedicated to very blue-sky upgrade ideas and studies?

• Community consideration of LLP signatures at both future detectors *and* future colliders — *many talks this week*

• Some work already done for FCC-hh/ee, CEPC, electron-proton, CLIC, ILC, etc., but still some opportunities

• Lessons learned from detector design at the LHC can inform the priorities of future machines

• Closer collaboration between ML and LLP communities
  • Working group this week
  • Dedicated workshop in the future

• Dedicated detectors for LLPs at the LHC
  • FASER recently approved — wonderful! Now how to we get all of the other proposals to the same stage?

• Your idea goes here

• Join us on Wednesday afternoon for a roundtable discussion about next-steps and priorities for the community

The strength of the community isn’t white papers or recommendations but *as a platform where new ideas can foment and flourish*
The future is experimental

Our job as physicists is not to find SUSY or WIMP dark matter or sequential SM Z’ or QBH or VLQs or...

After our first look at 13 TeV, our traditional motivation paradigms are fading or dead

The Higgs discovery only answered one open question — does the SM Higgs exist? — and raised a bunch of others!

But these other questions are no longer accompanied by guaranteed discoveries

Scary: Where do we look?

Freedom: Everywhere! We have one of the most sophisticated devices ever built at our disposal, and our job is to push it to its limits, to map out all available experimental object space

This means bold new ideas involving LLPs. 2019 is the perfect time to be bold!
In a simulated event, the track of a decay particle called a muon (red), displaced slightly from the center of particle collisions, could be a sign of new physics. *ATLAS EXPERIMENT © 2019 CERN*

**Atom smasher could be making new particles that are hiding in plain sight**

By Adrian Cho   May 22, 2019, 12:20 PM

Are new particles materializing right under physicists’ noses and going unnoticed? The world’s great atom smasher, the Large Hadron Collider (LHC), could be making long-lived particles that slip through its detectors, some researchers say. Next week, they will gather at the LHC’s home, CERN, the European particle physics laboratory near Geneva, Switzerland, to discuss how to capture them. They argue the LHC’s next run should emphasize such searches, and some are calling for new detectors that could sniff out the fugitive particles.
Workshop goal:

Map the future.
You’re doing it right now.