Searching for long-lived particles at the LHC and beyond

Seventh workshop of the LHC Long-Lived Particle Community

indico.cern.ch/e/LHC(LLP_May_2020)

25-27 May 2020
Virtually everywhere

James Beacham [Duke University]
**Burning questions and answers in 2020**

- **Electroweak symmetry breaking**
  - Does the Higgs boson exist?
  - Is $m_h$ natural or fine-tuned?
  - If natural, what new physics/symmetry governs this?
  - Does it regularize divergent $V_1V_L$ cross-section at high $m_{V_L}$? Or new dynamics?
  - Elementary or composite Higgs?
  - Is it alone or does the Higgs have siblings and cousins?
  - Origin of couplings to fermions?
  - Coupling to dark matter?
  - Connection to hidden sectors?
  - Does it violate CP?
  - Cosmological EW phase transition?

- **Quarks and leptons**
  - Why three families?
  - Why these masses and mixings?
  - CP violation in the lepton sector
  - Matter/anti-matter asymmetry
  - Baryon and charged lepton number violation

- **Physics toward the Planck scale**
  - How does gravity play with the other forces?
  - Are there more than three dimensions of space?
  - Do all forces unify at high energy?
  - Are there other forces?

- **Dark matter**
  - What is it? WIMP, sterile neutrino, axion, NLSP, other hidden sector particle?
  - Only one type?
  - Only gravitational or other interactions?
  - Are we wrong about gravity? An emergent phenomenon?

- **Neutrinos**
  - Why do neutrinos have masses? And what are these masses?
  - What’s the role of $h_{125}$?
  - Majorana or Dirac?
  - CP violation
  - Are there more (sterile) neutrinos?

- **Two epochs of Universe’s accelerated expansion**
  - Primordial: Is inflationary model correct? Which (scalar) field? Role of quantum gravity?
  - Today: Dark energy (why is $\Lambda$ so small?) or gravity modification?

Inspired by I. Shipsey

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But the LHC has been taking data since 2010!

What could we be missing?

Inspired by I. Shipsey

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Planck scale
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- Is gravity modification possible at high energy?
- Dark energy (why is $\Lambda$ so small?) or gravity modification?
The lifetime frontier at the LHC

The overwhelming majority of the work of LHC experimentalists

A discovery could be hiding here

$m_X$

$O(mm)$

$C T_X$

Outer edge of detector

Stable
The lifetime frontier at the LHC

The overwhelming majority of the work of LHC experimentalists

A discovery could be hiding here

Large majority of ATLAS, LHCb, and CMS searches and analysis strategies assume the new particle decays promptly (i.e., before or around the range of b-hadron lifetimes)

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Stable

Outer edge of detector
Long-lived particles (LLPs) in the Standard Model

B. Shuve
Long-lived particles (LLPs) in the Standard Model

Particle lifetimes in the SM span a very wide range, and typically arise when approximate symmetries make the particle stable (small mass splittings, tiny couplings, etc.)

Small symmetry-breaking parameters can suppress the decay rate

Same principles apply to BSM particles; see Nathaniel Craig’s talk in a bit for more details and theoretical perspective
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Experimentally, this obliges us to perform dedicated, signature-based searches for long-lived BSM particles
Long-lived particles from the main interaction points of the LHC

- Displaced multitrack vertices
- Displaced leptons, lepton-jets, or lepton pairs
- Multitrack vertices in the muon spectrometer
- Disappearing or kinked tracks
- Non-pointing (converted) photons
- Emerging jets
- Trackless, low-EMF jets
- Quasi-stable charged particles

Heather Russell
At the LHC, \textit{LLP} = BSM particle with a non-negligible lifetime that gives up most of its energy or decays to SM somewhere in the detector acceptance of LHCb, CMS, ATLAS, MilliQan, MoEDAL, FASER, CODEX-b, MATHUSLA, AL3X, ANUBIS, etc.
At the LHC, LLP = BSM particle with a non-negligible lifetime that gives up most of its energy or decays to SM somewhere in the detector acceptance of LHCb, CMS, ATLAS, MilliQan, MoEDAL, FASER, CODEX-b, MATHUSLA, AL3X, ANUBIS, etc.

We’ve been doing these searches since day one of the LHC (and at LEP, & Tevatron), but until ~2016, they were always considered fringe, and they still make up less than 10% of our “exotic” searches.

Public results with the central LHC detectors:

- CMS Exotica LLP
- CMS SUSY RPV
- LHCb Public Results
- ATLAS Exotics
- ATLAS SUSY
LHC Long-Lived Particle Community

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

Workshops — two per year

LHC LLP white paper: March 2019 — arXiv:1903.04497
To appear in J. Phys. G

Formed in 2016 to address one question: How do we best ensure that we don't miss BSM LLP signatures for the remainder of the LHC program?

Join the CERN egroup: lhc-llp
cern.ch/longlivedparticles
On the arXiv
11 March 2019

257 pages
(301 w/references)

201 authors / contributors / endorsers

2 document editors

21 chapter editors

616 references

83 citations to date


James Beacham [Duke]
Searching for Long-Lived Particles beyond the Standard Model at the Large Hadron Collider

Juliette Alimena (Ohio State U.), James Beacham (Duke U.), Martino Borsato (Heidelberg U.), Yangyang Cheng (Cornell U., LNS), Xabier Cid Vidal (Santiago de Compostela U.) et al. (Mar 11, 2019)
e-Print: 1903.04497 [hep-ex]

Community initially focused on the LHC, but the world of LLPs is larger


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Long-lived particles beyond the LHC

Our ability, as a field, to discover BSM LLPs, is not defined only by the interaction points of the LHC

• Many other experimental projects search for, are potentially sensitive to, or could be designed to be sensitive to LLPs
• If it’s a BSM particle you can produce in an experiment that has a $c\tau$ in the cm to km range before it decays and its decay products hit your detector, then it’s a long-lived particle
• This leads to obvious and clear connections among multiple projects around the globe, complementary to those at the LHC
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• Thus, the LHC LLP Community workshops have become a regular platform to discuss, compare, and collaborate on LLP searches around the world (and beyond) and ideas to maintain discovery potential now and in the future

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The message is clear: Don’t overlook the lifetime frontier

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

Workshop is informal and collaboration-centered
• Discussion is of the highest priority
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To all community members:
• Yes, ask a question and make a suggestion!

To all session chairs:
• Give ample space in discussion periods for those who haven’t had a chance to talk!

We’re radically inclusive and radically anti-harrassment
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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
• This applies whether virtually or in person

• Harrassment is antithetical to the intention of this workshop
• We endeavor to create a positive and welcoming space!

James Beacham [Duke]
#LHCLLP7 is our first fully virtual workshop

Adapting to the circumstances

• Format of fully plenary talks and discussions rather than featuring working breakout parallel sessions as usual
• Start at 13h and aim to end at ~19h Geneva time each day

Monday, 25 May
• 13:00 — Session 1 — Intro, dedicated detectors at the LHC, and new theory developments
• 15:45 — Session 2 — Theoretical overview, PBC & FIPs, HL-LHC, new theory/pheno ideas

Tuesday, 26 May
• 13:00 — Session 3 — More dedicated LLP detectors at the LHC and other LLPs at CERN
• 16:25 — Session 4 — New results from ATLAS and CMS, dark shower / dark QCD phenomenology

Wednesday, 27 May
• 13:00 — Session 5 — Triggering ideas for ATLAS and CMS and a new result from CMS
• 15:05 — Session 6 — Triggers for Run 3 for ATLAS, CMS, and LHCb: Why can’t we trigger for X?
• 16:40 — Session 7 — LHC LLP Working Group kick-off

Speaking of which...
LHC LLP Working Group

LHC LLP Community has thrived as an LPCC activity since 2016

• Newly-formed formal “LHC LLP WG” within the LPCC (similar to others like ML, Top, DM, etc.) recently proposed to build on the experience of the LLP LHC Community and, preserving its main scientific objectives, it serves as a formal bridge with the relevant physics groups of the approved LHC experiments, to streamline the official endorsement of the WG’s recommendations to the experiments

• Generally LLP WG meetings are going to be open and accessible to the whole community

• Discussion topics will be specifically related to needs formulated for the LHC program (but may need wider input)

• This WG is expected to produce formal conclusions and, if useful, documents on these relevant topics

• The outcome will be endorsed by the LHC management structures, ie as with other LHC WG groups that exist already
LHC LLP Working Group

You can help define the activities of the LHC LLP WG!

• Thus, our LHC LLP Community workshop will feature the first meeting of the LLP WG on Wednesday at 16:40 [Indico]

• The meeting is focused on the presentation of the foreseen activities of the WG, and on the collection of inputs and feedback from the community. We welcome explicit contributions during this meeting, and invite colleagues to begin now expressing their views through this collaborative document

• We have a few ideas already, but any comments added to the document will help trigger the discussions and inform the WG conveners

• If you would like to be assigned few minutes for a short contribution to the agenda of the WG meeting, please send mail to the WG conveners at lhc-llpwg-admin@cern.ch

• These contributions should not address specific physics models, etc. (i.e., “your last paper”), but general aspects of the WG activities, expected deliverables, and operation mode

• If you’re interested in the future activities of the WG, please sign up to the WG mailing list (separate from the LLP community list), here

James Beacham [Duke]
Informal satellite brainstorming session for Snowmass 2021

The Snowmass 2021 process is underway
• Multiple frontier groups and topical groups within the Snowmass structure that are related to LLPs, and they have several meetings planned for the coming months that will feature LLPs prominently
• In the LHC LLP Community spirit of providing a platform for brainstorming and discussion, we'll be holding an informal satellite session of our workshop dedicated to possible Snowmass contributions on Friday, 29 May 2020, at 4 PM Geneva time

indico.cern.ch/e/LHC_LLP_May_2020_Satellite_Session

• Very informal, strictly a brainstorming / idea-tossing meeting of those who might be thinking about studies they'd like to contribute to Snowmass, to potentially connect people and facilitate collaboration in support of the Snowmass effort
• If you're already planning a contribution and would like to let everyone know, or if you simply have an idea for a contribution and are looking for collaborators, feel free to prepare a slide or two
• Otherwise, just bring ideas!
LHC
Long-Lived Particle Community

Next workshop

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

Tentative:
November 2020 at the Tokyo Institute of Technology

https://indico.cern.ch/e/LHC_LLP_Nov_2020

Join the CERN egroup: lhc-llp
What are FIPs? Roughly: Any new physics with coupling $<< 1$ and mass below the EW scale

Complementary to high-energy searches

Our LLP workshop was originally planned to be held at CERN right next to FIPs, this week

Still TBD whether FIPs happens in September at CERN, or virtually, or next year

See Joerg Jaeckel’s talk in a few hours and stay tuned for updates
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Workshop goal:

Map the future of the lifetime frontier.
You’re doing it right now.

Welcome!