LLPs - Long-lived particles

Focus Topics: WG1-SRCH

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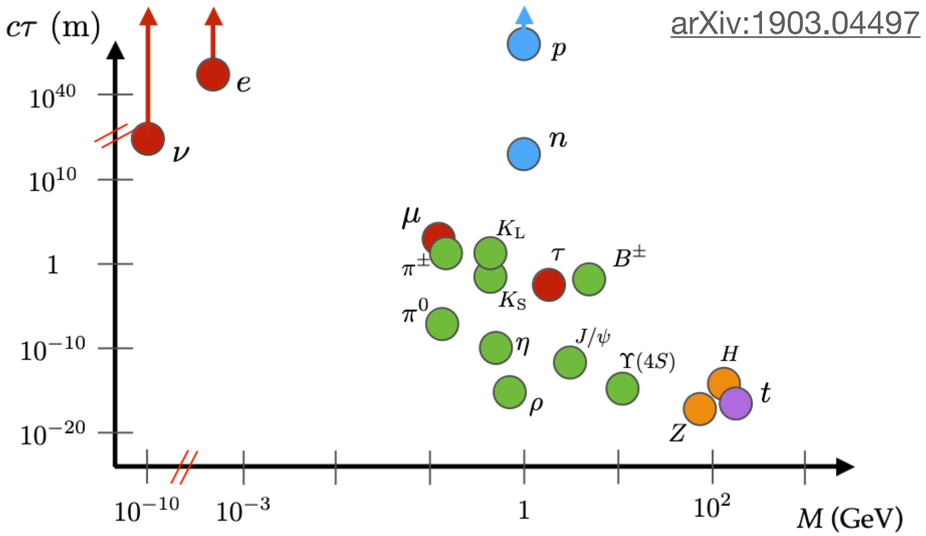
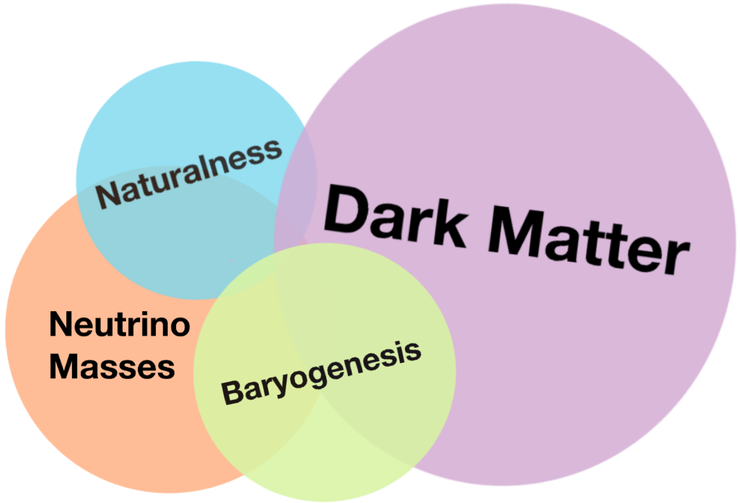
Long-lived particles

LLPs

- SM particles have different lifetimes, even with similar masses
- Many of them are long-lived
  - due to e.g. small couplings or a suppressed decay phase space
- We use **Long-lived particles (LLPs)** as an umbrella term
  - New particles, that we have not discovered yet, with lifetimes long enough to travel measurable distances inside the detectors before decaying
- The same conditions that make some SM particles long-lived are also present in BSM models
  - **LLPs are a generic signature of BSM physics, connected to central questions**



arXiv:1903.04497

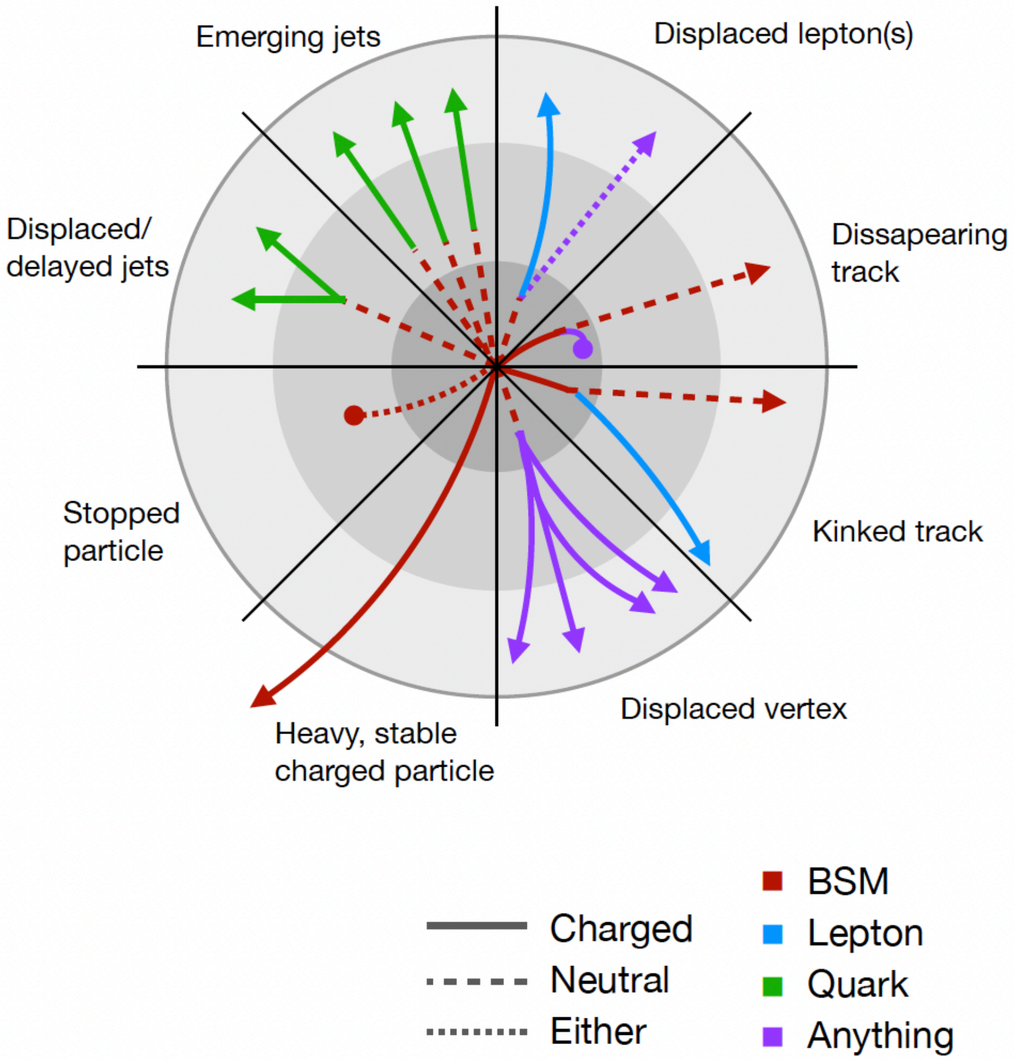


LLPs are becoming very popular

Why?

- Explosion of LLP searches and models in the last few years
- A few reasons:
  - Searches for LLPs often **cover** intermediate areas where there is a **gap of sensitivity** between experiments (eg. dark matter searches between colliders and astro)
  - **Lack of mainstream BSM signals** → LLPs provide accesible areas where BSM could be hiding, hidden sectors of new particles and forces
  - Searches can be model independent, since any LLP observed → smoking gun for new physics
  - LLP searches offer us the opportunity to think outside the box, to be **creative** and to propose new ways to solve problems
    - **Innovation:** in methods and experimental setups (let's expand on that)

Non-standard experimental signatures



- When produced in collisions at the LHC, LLPs can either completely pass through the detectors before decaying or decay inside them in unconventional signatures
- LLP analyses at the LHC IP experiments then:
  - require customisation
    - standard triggers, object reconstruction, background estimation and in general analysis methods are usually designed for promptly decaying particles
  - are affected by challenging backgrounds near the collision points → dedicated experiments

Hadron collider LLP shopping list

- Dedicated triggers
- Custom reconstruction algorithms
- Hermetic detectors with large active volumes, to maximize geometric acceptance
- High granularity at large radii for reconstruction efficiency of displaced tracks/ vertices
- Particle reconstruction capabilities for displaced objects
- Particle ID capabilities: dE/dx, time-of-flight, good vertex & timing resolution
- Shielding: for background mitigation

What about Higgs factories?

Different and the same

- In e+e- Higgs factories
  - trigger will not be a problem
  - many other challenges still there, shared across collider geometry/center-of-mass energy → The point of this expert team
- Planning ahead → optimize design and performance of future collider experiments will make our lives easier
- Who can we attract? people already working in this kind of search at the LHC, good entry point for new physics searches and detector design

LLP expert team

Stablished June 2023

- Diverse team with theory/experimental experience across current and future colliders and collider experiments:
  - Coordinator (Rebeca)
  - FCC-ee contact: Juliette Alimena (DESY)
  - ILD contact: Filip Zarnecki (Warsaw)
  - SiD / CLIC contact: Marcin Kucharczyk (Cracow)
  - Theory contact: Jan Hajer (Lisbon)
  - LHC contact: Emma Torro Pastor (Valencia)
  - Detector/Generator requirements: Sarah Williams (Cambridge)

Theoretical and phenomenological targets

LLP searches are connected to most BSM models

- Three main suspects where small couplings == LLPs
  - **Heavy Neutral Leptons (HNLs)** **GREAT VALUE: 3 questions for the price of one** arXiv:2203.08039
    - Neutrino masses, Baryon asymmetry of the Universe, dark matter
  - **Axion-Like Particles (ALPs)** **A LA CARTE MENU: possible masses and couplings range over orders of magnitude**
    - Dark sector, baryogengesis arXiv:1808.10323 arXiv:2111.01327
  - **Exotic decays of the Higgs boson** **CHEF's CHOICE: We are talking Higgs factories after all** arXiv:1812.05588
    - Interesting Hidden Valley models
- Extra stretch goal: adding more examples (Z', SUSY) **DESSERT?**

Target physics observables

The fun part

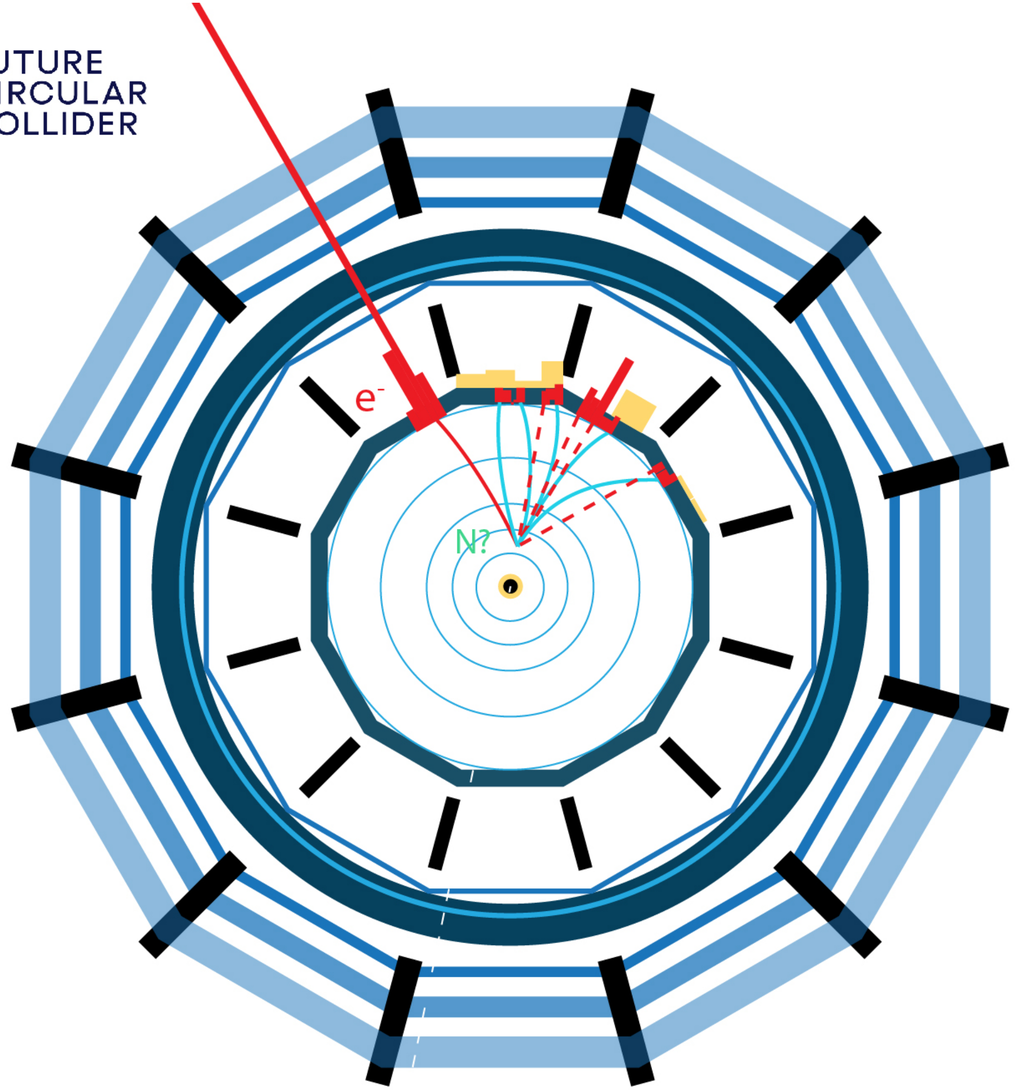
- Displacement — Easiest target
  - displaced tracks and vertices
  - tracking volume and muon systems
- Distinct tracking patterns
  - disappearing tracks
  - uncommon energy loss
- Photons
  - non-pointing / delayed
- Non-standard jets
  - emerging, trackless, unconventional energy distributions in the calorimeters
- Slow-moving/stopped
  - jets with out-of-time decays
  - unusual time-of-flight measurements in the muon system and/or calorimeter
- Boosted neutral LLPs → collimated muons with no tracks in the inner detector

Target methods

Where to put the work

- Displaced tracks and vertex reconstruction
  - inner detector and muon spectrometers
  - calorimeters

Work in progress



- Tracking algorithms for anomalous dE/dx patterns
- Timing capabilities in the calorimeters and tracking
- Jet reconstruction and “tagging”
- Background estimation:
  - Instrumental backgrounds, such as beam-induced background, pileup, and cavern noise, as well as backgrounds from cosmic-ray muons

Detector performance and simulation

- This focus topic sets requirements in the whole detector
  - emphasis on tracking, timing, and calorimetry
- Additional experiments like those proposed/running at the LHC/HL-LHC can be considered: on and off-axis, beam dump

arXiv:2011.01005
arXiv:1911.06576 arXiv:2201.08960

- Signature-driven still has MC needs, related to the physics case studied, the facility, and the running conditions.
  - One example: HNL in Z decays at FCC-ee requires high stats of Z →bb,$\tau\tau$ and filtering strategies to enhance tails of distributions where displacement is
- Tutorials available:
  - FCC-ee (by J.Alimena): https://github.com/jalimena/LLPFCCTutorial/blob/main/README.md

Master theses: Sissel Bay Nielsen, Rohini Sengupta, Lovisa Rygaard, Tanishq Sharma, Magdalena Vande Voorde, Dimitri Moulin

Work in progress

Much more to do

- Some papers:
  - Snowmass BSM report: https://arxiv.org/abs/2209.13128
  - FCC-ee LLP snowmass paper: https://arxiv.org/abs/2203.05502
  - EPJ Plus on LLPs at FCC-ee: https://arxiv.org/abs/2106.15459
- Talks:
  - Emma's talk at the 2nd Topical Meeting on Reconstruction
    - https://indico.cern.ch/event/1283129/#15-reconstruction-needs-for-ll
  - Sarah's talk at the 2nd ECFA Topical Meeting on Generators
    - https://indico.cern.ch/event/1266492/#20-focus-topic-mc-needs-bsm
  - Other related talks: Marco's at the HNL focus meeting https://indico.cern.ch/event/1242038/#4-searches-for-long-lived-hnl and Magda at the new scalars meeting https://indico.cern.ch/event/1253605/#3-long-lived-scalars-from-exot