Long-lived particles at the FCC-ee

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1st FCC Nordic day

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What is a long-lived particle?

- The known particles of the Standard Model have different lifetimes
  - Depending on **Mass**, virtual mediators, mass Splitting, **couplings**
- **Long-lived particles:** umbrella term to cover particles with lifetimes long enough to travel measurable distances inside the detectors before decaying, leaving distinct experimental signatures

Muon: Long-lived
2.2μs

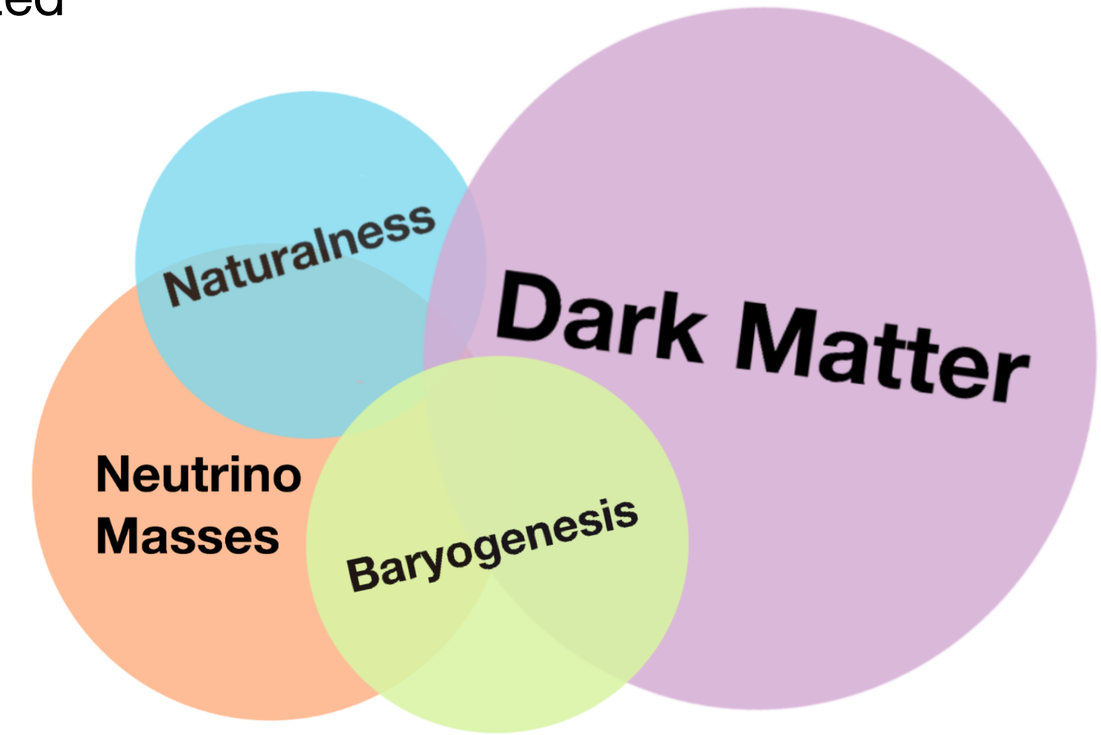
Photon: Long-Lived
Stable
(As far as we know)

And thought there are SM particles that are technically long-lived, we tend to use the term to refer to **NEW particles that we have not discovered yet**

New, long-lived particles

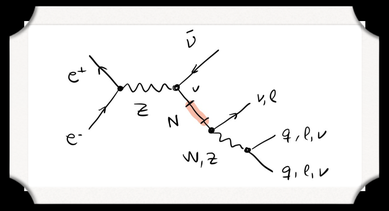
- LLPs are not a prediction of a single new theory, **they fit into virtually all proposed frameworks for BSM physics**
- Theoretically, their presence is strongly motivated

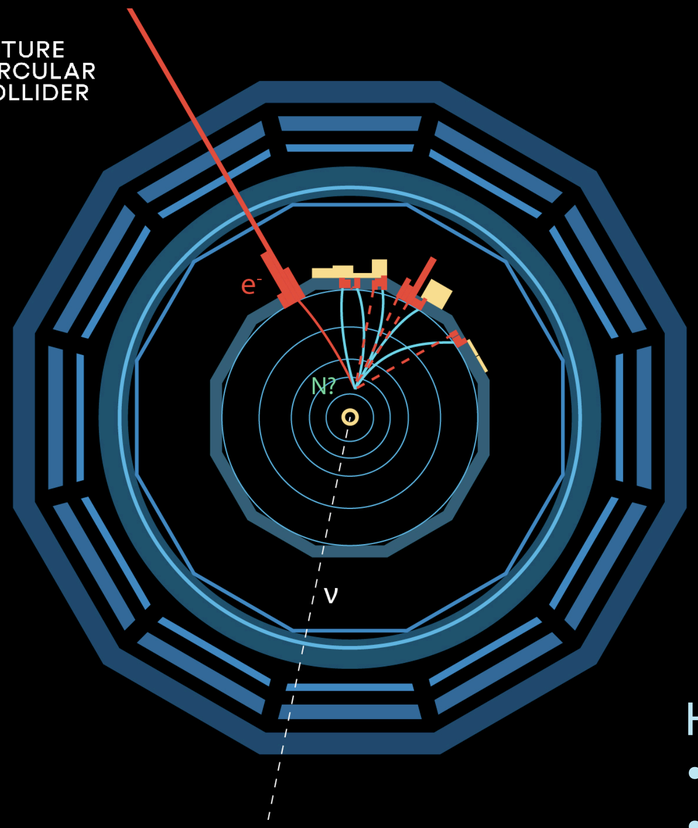
Featured in (including but not limited to):
SUSY
Compositeness
Exotic decays (H, Z, hadrons)
Hidden sectors



A Swedish speciality since before my time!
(C.Ohm PhD thesis)

The Flagship: Heavy Neutral Leptons

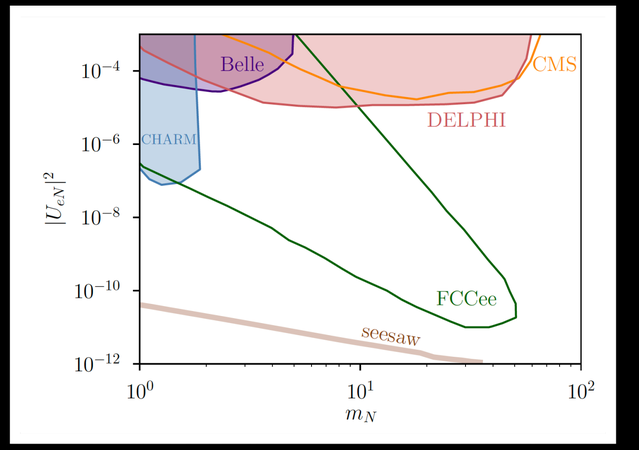




Courtesy of Alain Blondel

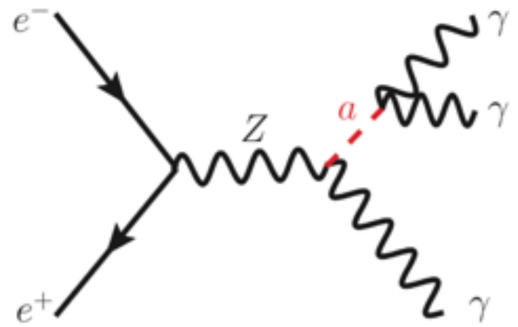
- The FCC-ee will offer an unbeatable reach for HNL at the Z-Pole
  - Z → νN, N → l W
- For or low values of the neutrino mixing angle, the decay length of the heavy neutrino can be significant: Long-lived signatures
- HNL could decay **~1m away from the collision point**

HNL could give an answer to:
- Neutrino masses
- Baryon Asymmetry of the Universe
- Dark Matter



Reference

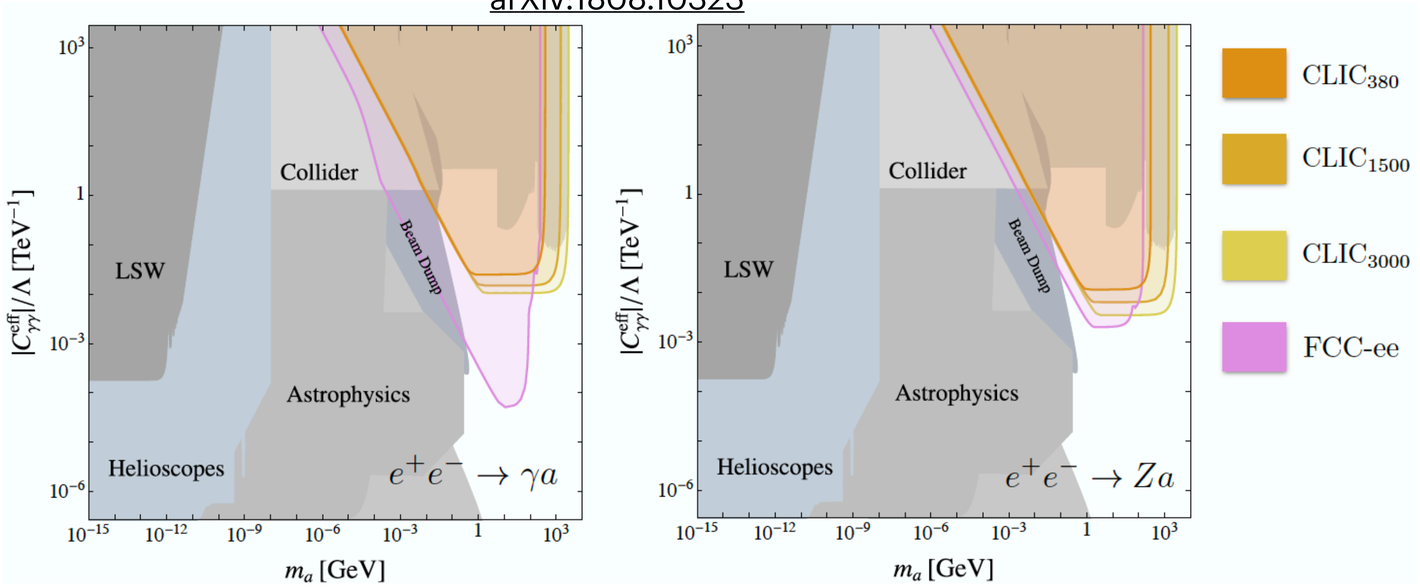
Axion-Like Particles

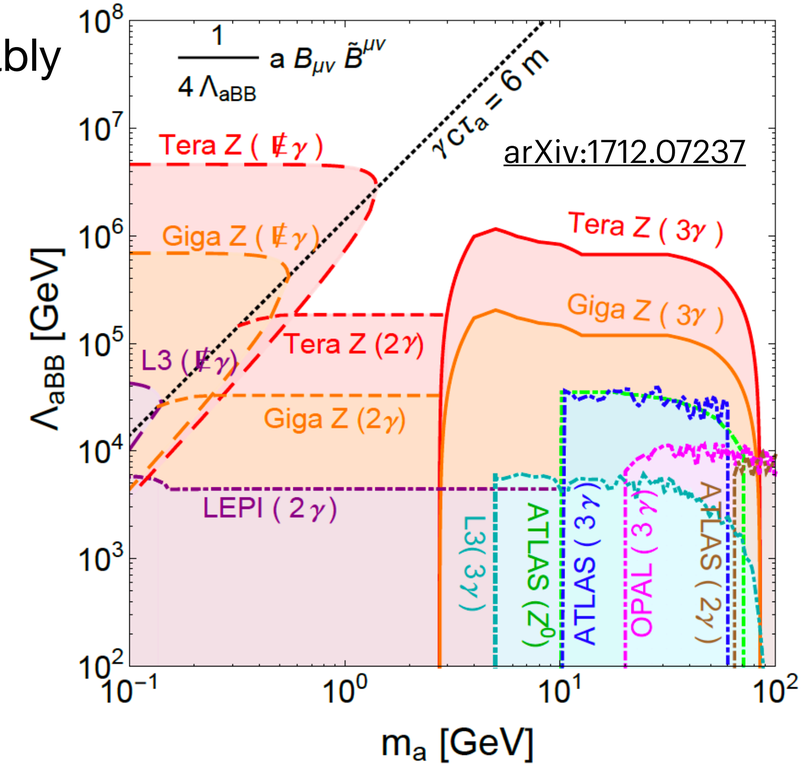


- Searches for Hidden (Dark) Sectors parallel to the SM with new particles and forces are gaining a lot of traction specially linked to important questions like Dark Matter

- "Axion-Like Particles" (ALPs) are very-weakly-coupled window to the dark sector
  - Orders of magnitude of parameter space accessible at the FCC-ee
  - For small couplings and light ALPs, the ALP decay vertex can be considerably displaced from the production vertex.

arXiv:1808.10323





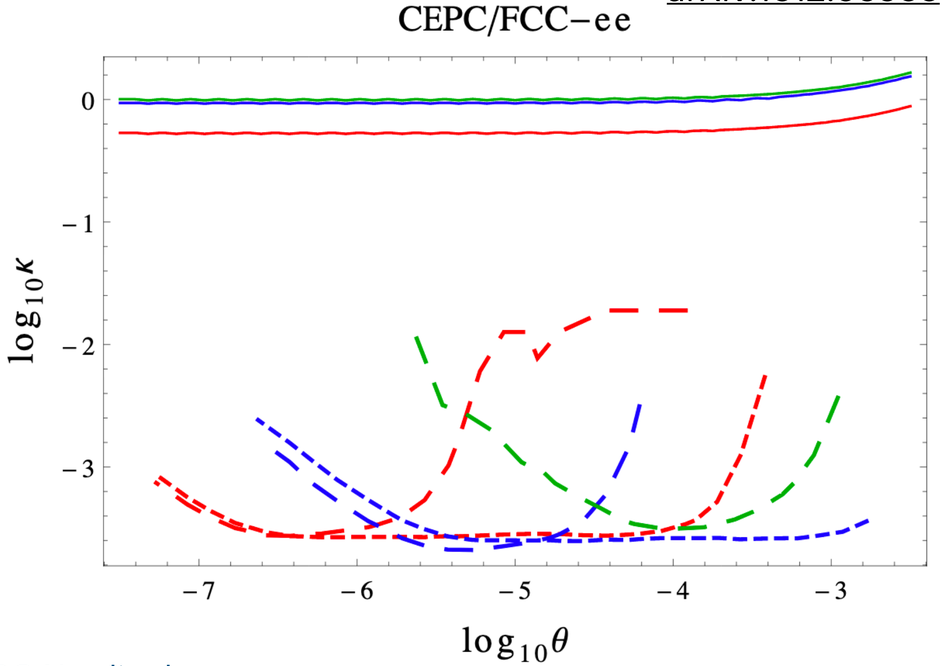
Hidden Higgs sectors, SUSY…

- **Twin Higgs** models: solving the hierarchy problem, some propose an entire Twin copy of the SM, with many new light states that the SM Higgs boson can decay to.
  - displaced exotic Higgs boson decays (long decay lengths for small ineraction)
  - FCC-ee: most relevant regions of parameter space experimentally accessible

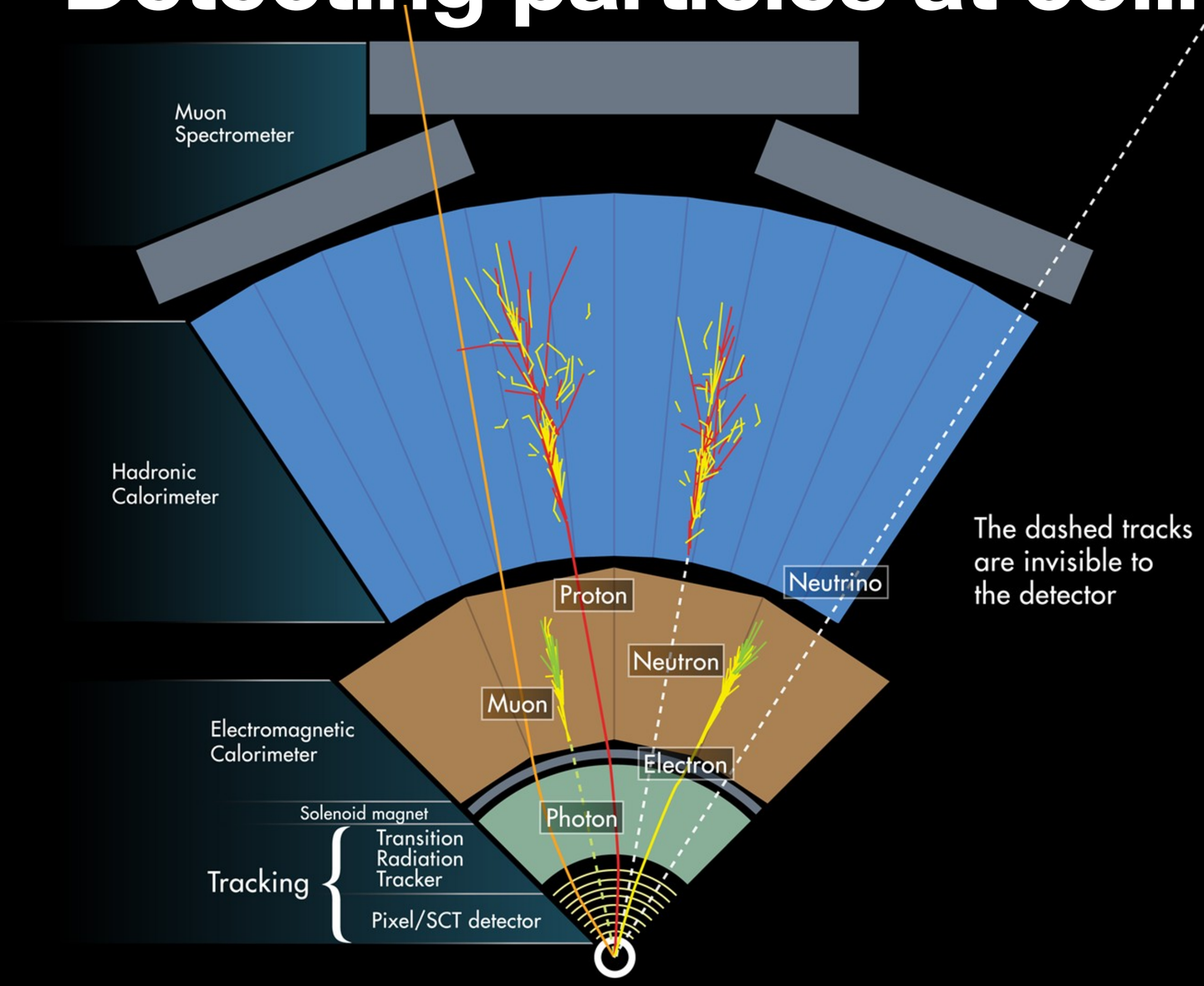
- **Hidden Valley** models: a new sector, weakly coupled to the SM results in neutral long-lived particles that the Higgs boson can decay to.
  - exotic, long-lived Higgs decays that the FCC-ee could be sensitive to

- Plus many other models with LLP at the FCC-ee: Higgs portal, dark glueball (arXiv:1911.08721), Neutral naturalness (arXiv:1506.06141), Folded SUSY (arXiv:1911.08721), Neutralinos (arXiv:1904.10661)...

arXiv:1812.05588



Detecting particles at colliders nowadays

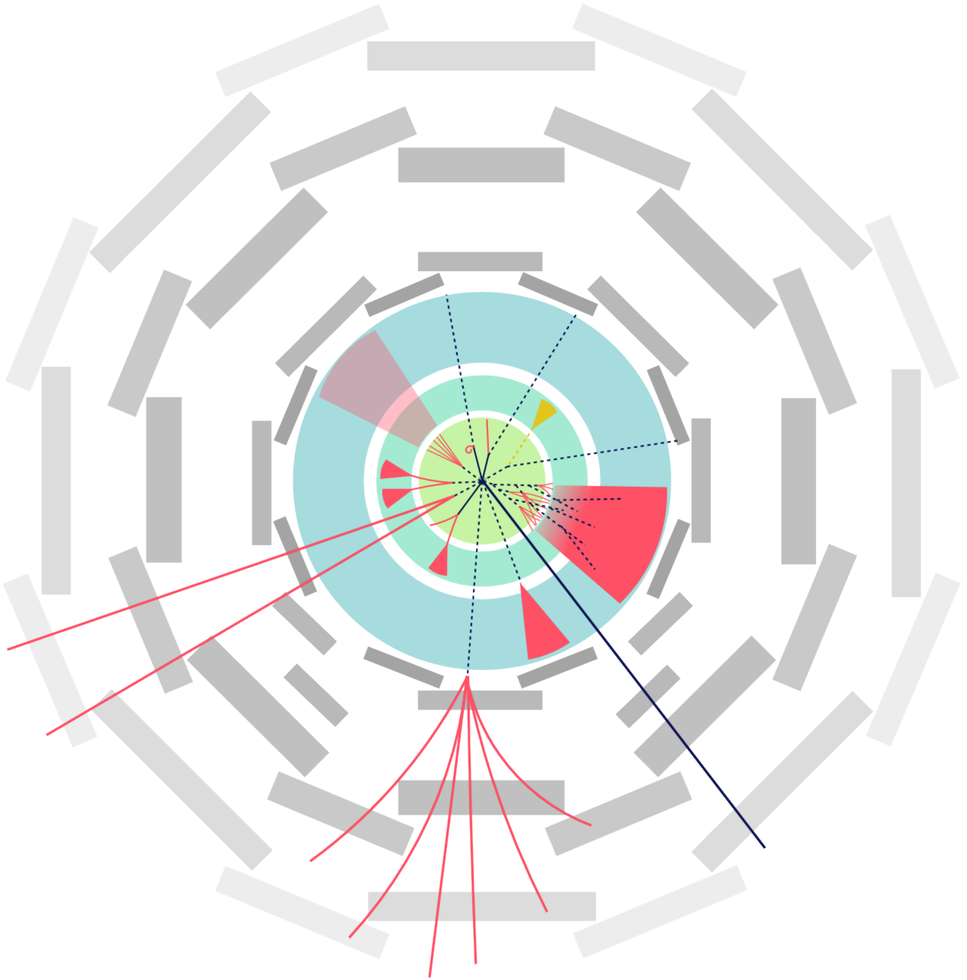


We are biased towards new, heavy particles: see for example the Higgs boson at the LHC

- A Higgs boson is produced in collisions and decays 10^{-22} seconds after being produced, it is very SHORT-lived
- It often decays into two Z bosons, each of them decaying in about 10^{-25} s (notoriously SHORT-lived as well) in for example a couple of muons each
- In practice this means that we see 4 muons coming from the collision point

Our detectors, trigger, and reconstruction are aware of that

Long-lived particles are not like that

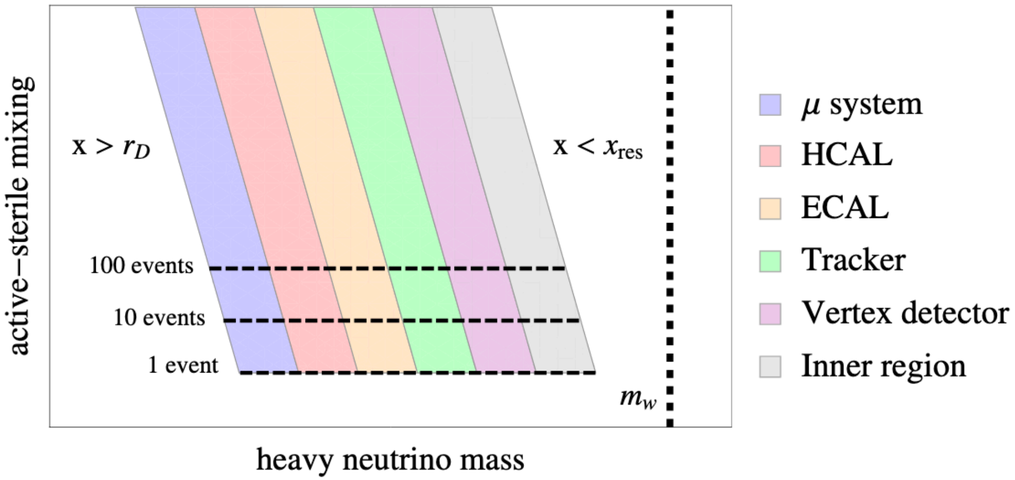


- New, long-lived particles display a collection of different signatures which are quite **weird**
  - *Displaced tracks/vertices*
  - *Disappearing/kinded tracks*
  - *Anomalous tracks (dE/dX)*
  - *Slow/stopped particles (out of time)*
  - *Emerging signatures …*
- Which means
  - Little/no backgrounds
    - Potential instrumental background (how to model?)
  - Dedicated techniques
    - **Reconstruction, Trigger, and Detector Design**

https://hrussell.web.cern.ch/

This won’t be different at the FCC-ee either

arXiv:1604.02420



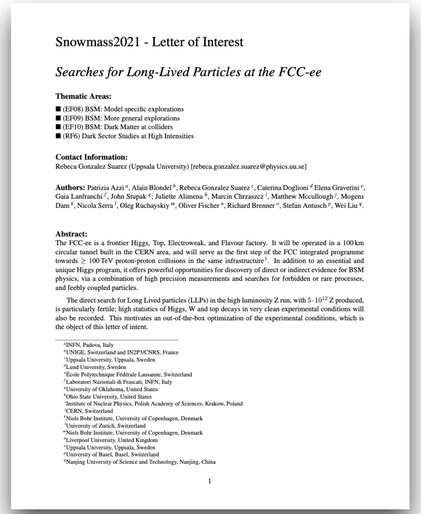
Sensitivity of the different detector components to RHN decays as a function of the mixing parameter and mass

- At this point we have two ways to go:
  - Design the FCC-ee detectors as usual and then try to make the best out of them for LLPs
    - which can be done but won’t be easy as we know from the experience at the LHC -and before-
  - Design the FCC-ee detectors with LLP in mind, prioritising for example displaced tracking and timing, and budgeting for unexpected signals

experimental opportunities!

Ongoing work in Uppsala University

- In Uppsala we have an interest in Long-Lived particles, specifically within the tracker volume since a while (JINST 14 P11009 (2019))
- R Gonzalez Suarez → **Long-Lived Particles at FCC-ee case study**
  - submitted Letter of Interest on LLP at the FCC-ee for ongoing Snowmass (link)
  - **Currently coordinate the informal group working on it**
    - Agendas + minutes/recording here: https://indico.cern.ch/category/5664/
    - mailing list that you can subscribe to: LLP-FCCee-informal@cern.ch
      - Join us!
  - **Collaboration with Suchita Kulkarni (Graz)**
    - Ongoing: Rohini Sengupta studying displaced HNL at the FCC-ee for her master thesis
  - Master and project students involved in different FCC-ee (and hh) studies
  - Some talks, e.g.: XIX International Workshop on Neutrino Telescopes Epiphany 2021, FCC workshop 2020, Snowmass Community Planning Meeting



Snowmass2021 - Letter of Interest

Searches for Long-Lived Particles at the FCC-ee

Thematic Areas:
- (EF08) BSM: Model specific explorations
- (EF09) BSM: More general explorations
- (EF10) BSM: Dark Matter at colliders
- (RF6) Dark Sector Studies at High Intensities

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Abstract:
The FCC-ee is a frontier Higgs, Top, Electroweak, and Flavour factory. It will be operated in a 100 km circular tunnel built in the CERN area, and will serve as the first step of the FCC integrated programme towards $\geq$ 100 TeV proton-proton collisions in the same infrastructure [1]. In addition to an essential and unique Higgs program, it offers powerful opportunities for discovery of direct or indirect evidence for BSM physics, via a combination of high precision measurements and searches for forbidden or rare processes, and feebly coupled particles.

The direct search for Long Lived particles (LLPs) in the high luminosity Z run, with $5 \cdot 10^{12}$ Z produced, is particularly fertile; high statistics of Higgs, W and top decays in very clean experimental conditions will also be recorded. This motivates an out-of-the-box optimization of the experimental conditions, which is the object of this letter of intent.

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