Searches for LLP at FCC-ee

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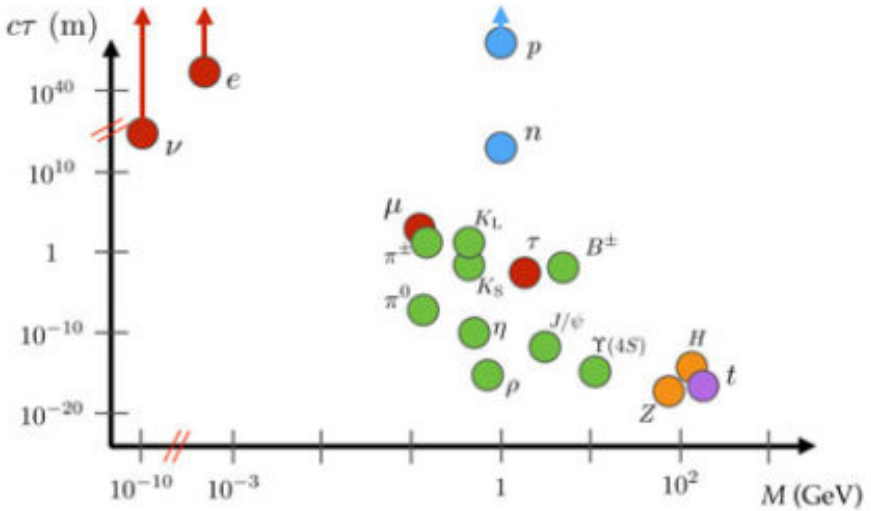
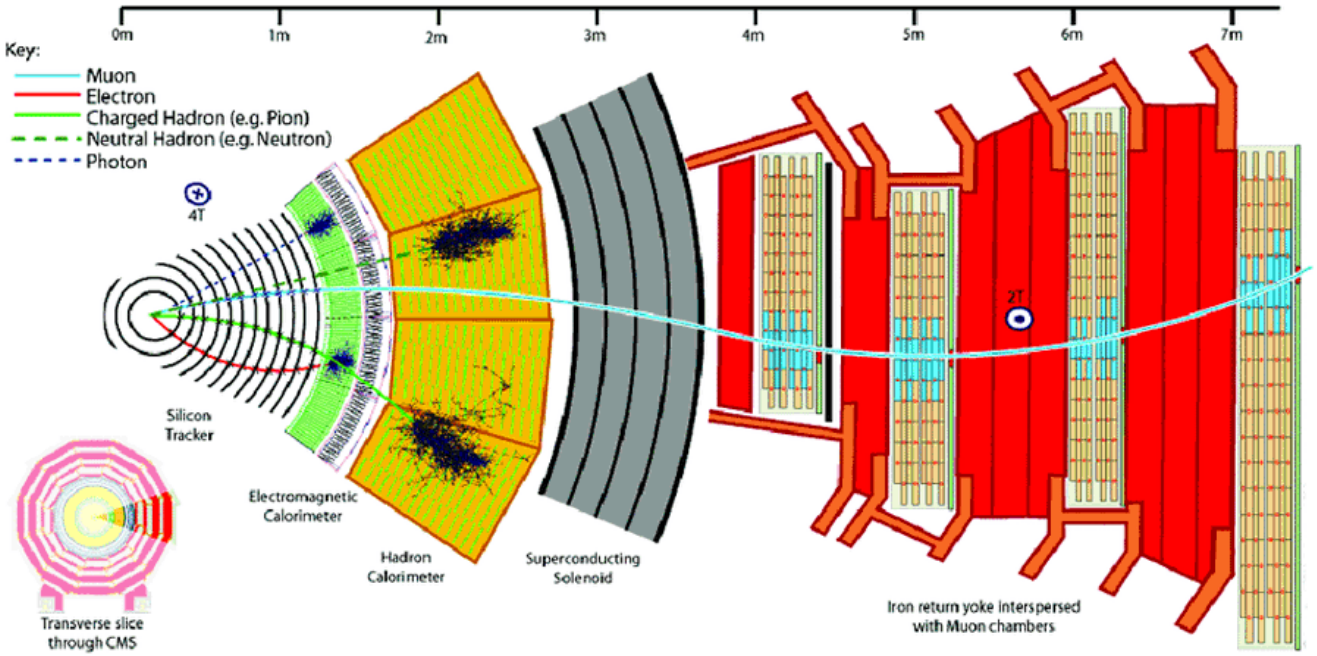
Annecy, 1st Dec 2021

Lifetimes of Particles

⇛ Not all particles of SM have the same

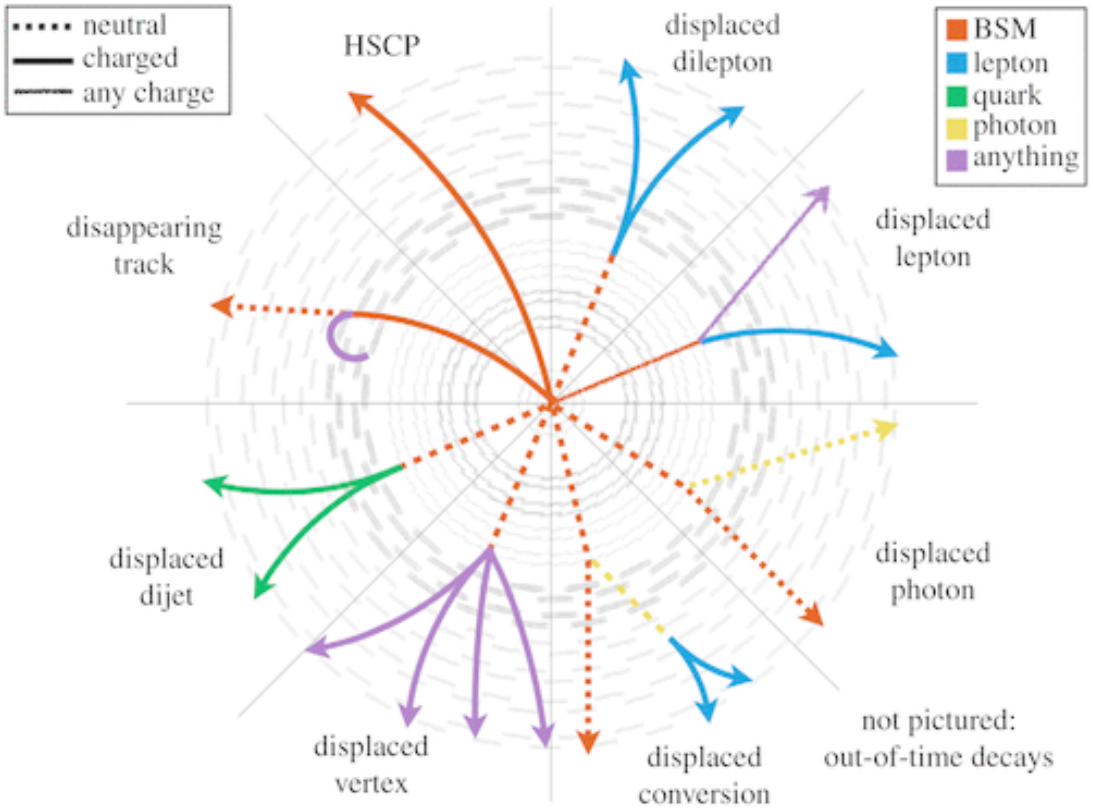


Identifying particles in the detector



⇒ Long Living particles are not like SM particles. Detector doesn't see them

LLP are weirdos

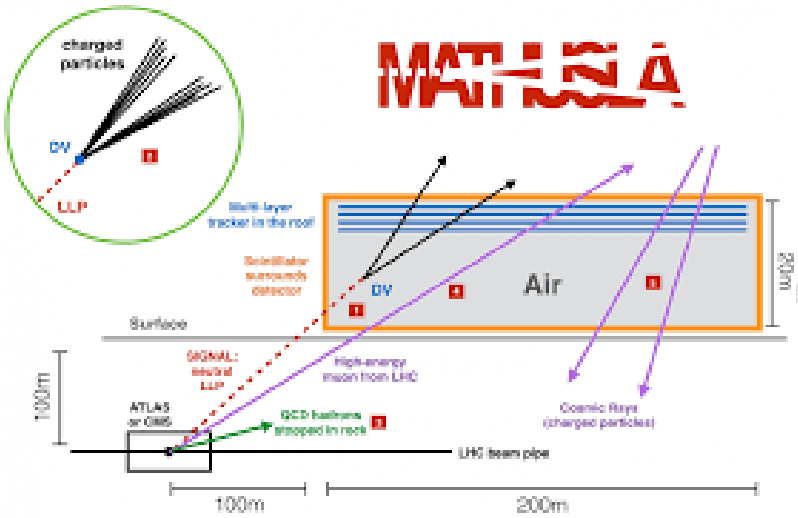


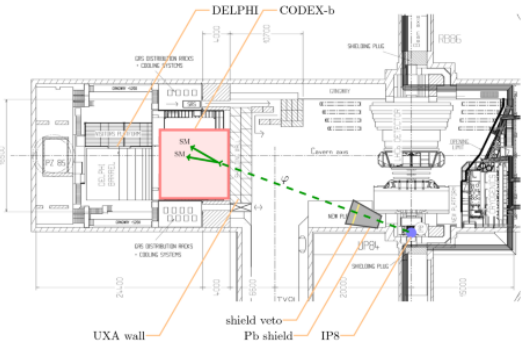
- Displaced tracks/vertices
- Disappearing/kinded tracks
- Anomalous tracks (dE/dX)
- Slow/stopped particles (out of time)
- Emerging signatures

⇒ But this also means:

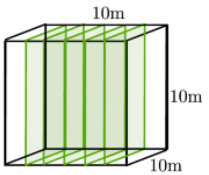
- Non or small background.
- Need dedicated techniques.

Weirdos are getting attenchion

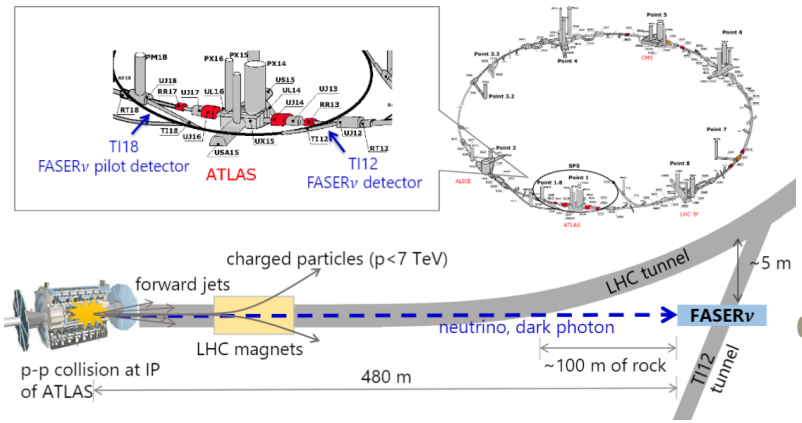


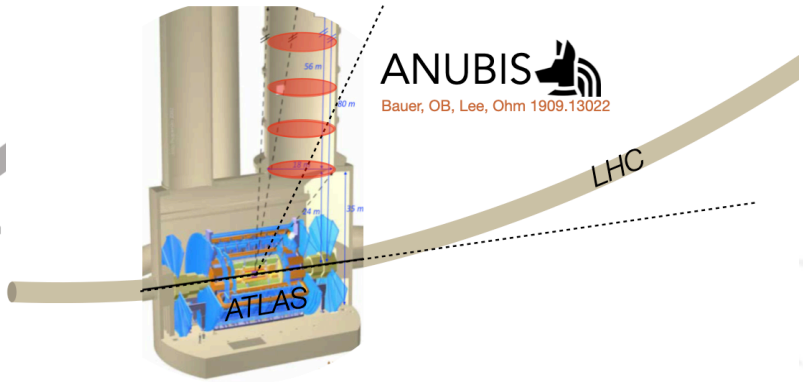


(a) Location in the cavern



(b) Detector geometry

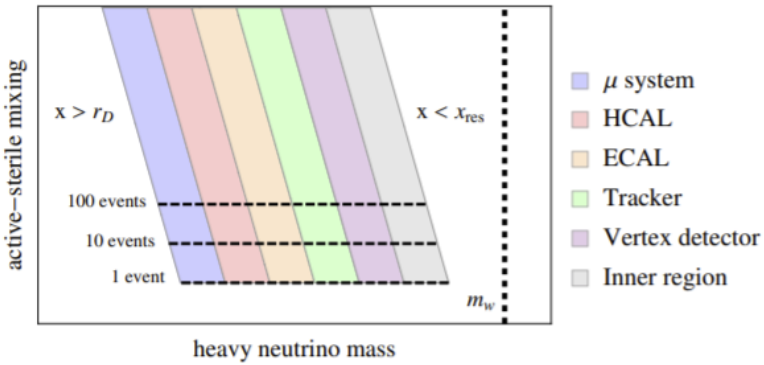




All have something in common:

They need to fit into existing infrastructure.

We need to think ahead



arxiv::1604.02420

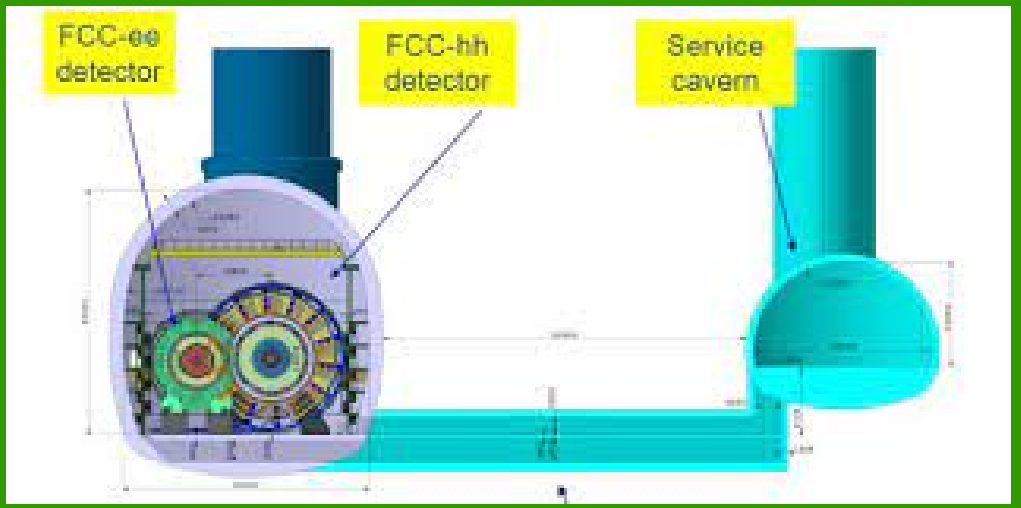
$\Rightarrow$ We can tackle this problem in 2 ways:

- Kick the can down the road as we did with LHC.
  From LHC we know this is not ideal. Lots of "lumi" was lost for LLP this way.
- Be smart and creative and design the detectors to be able to detect LLP.

HECATE

HErmetic CAvern TrackEr (HECATE), arxi::2011.01005, Jan Hajer, Marco Drewes, MC

- Use the HUGE FCC caverns and cover them detectors.
- Most space & cost efficient design.

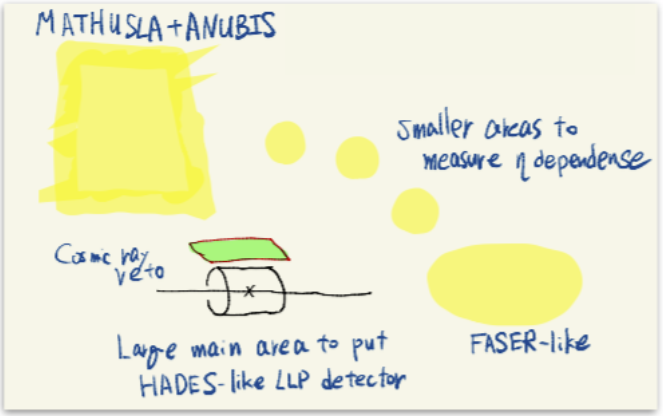


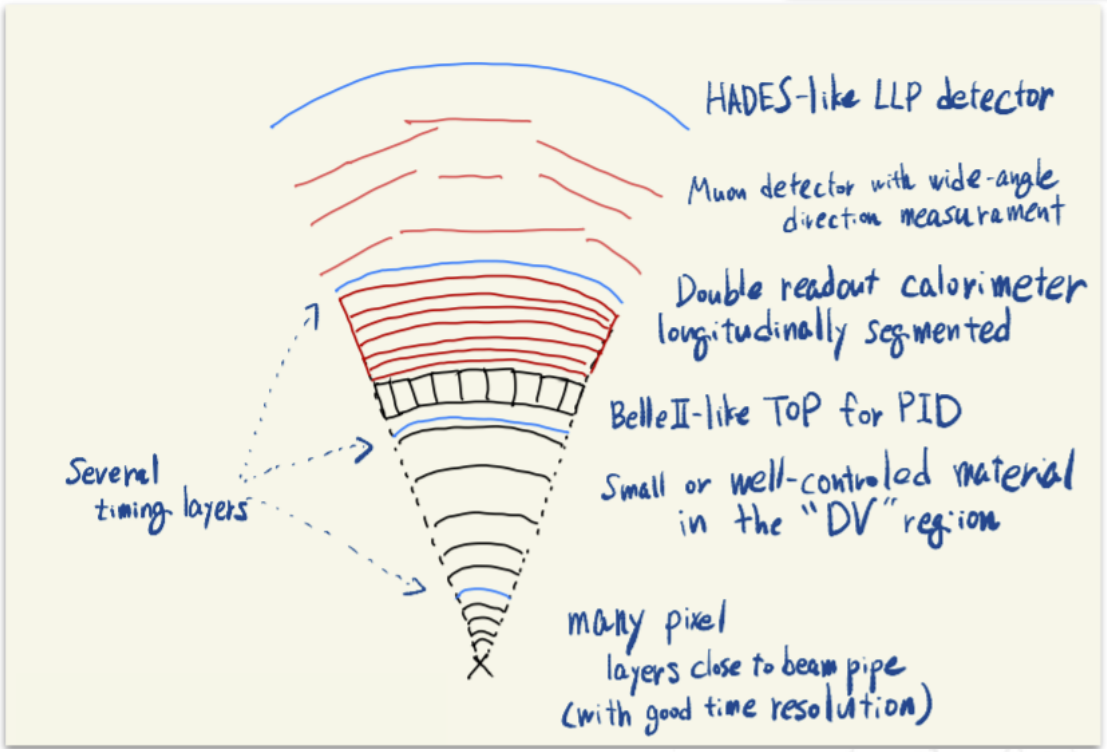
The sweat spot

- Hermetic 4π detector.
- No additional civil engineering.
- Cheap: $10\mathrm{MCHF}$.
- Needs timing.
- Scintilators, RPC
- Discussion with Imad Laktine started

HECATE fits between other experiments

A dream LLP detector?



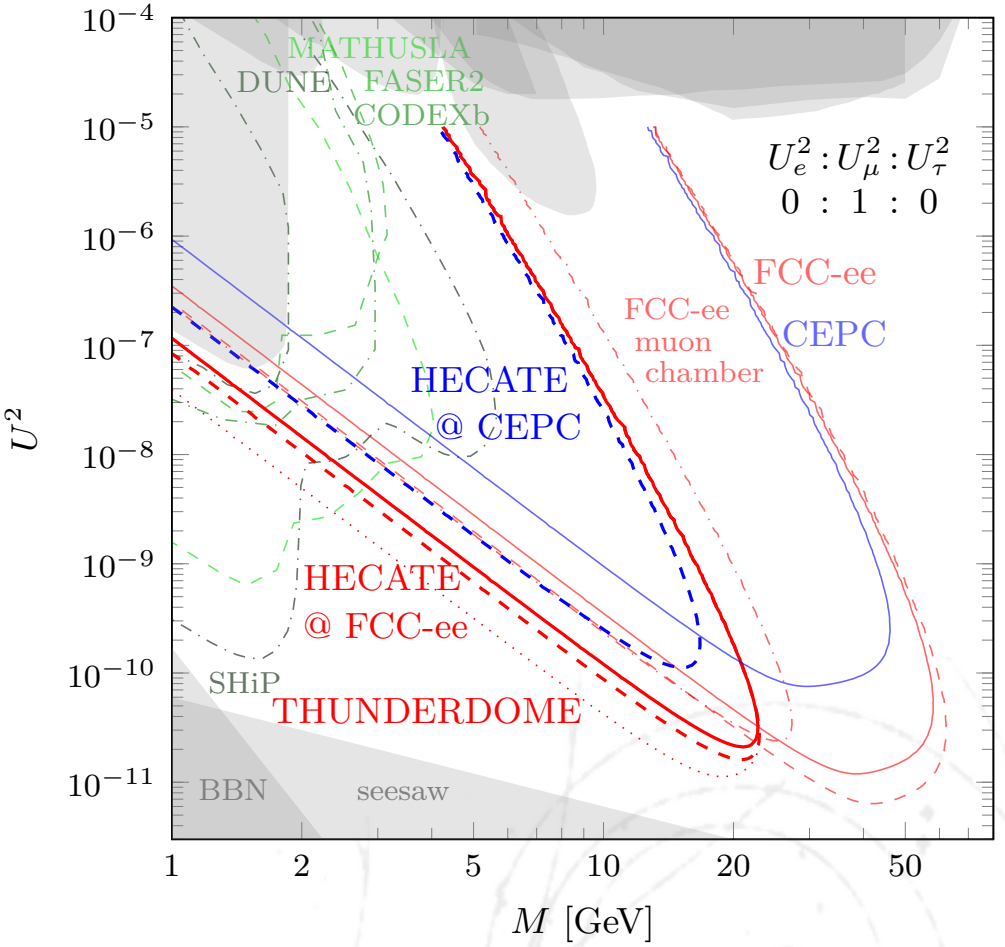


Credit to Ryu Sawada

HNL sensitivity

⇛ Simple SM extension:

$$\mathcal{L} \supset$$
$$-\frac{m_W}{v}\overline{N}\theta_a^*\gamma^\mu e_{La}W_\mu^+$$
$$-\frac{m_Z}{\sqrt{2}v}\overline{N}\theta_a^*\gamma^\mu \nu_{La}Z_\mu$$
$$-\frac{M}{v}\theta_a h\overline{\nu_{L\alpha}}N + \text{h.c.}\ ,$$



Dirac - Majorana neturinos? Credit: arxiv::2105.06576

⇛ The nature of neutrinos boils down to distinction:

$$e^+e^- \to Z \to \nu_4\bar{\nu}_i \to \ell^-(W^*)^+\bar{\nu}_i \ ,$$
$$e^+e^- \to Z \to \bar{\nu}_4\nu_i \to \ell^+(W^*)^-\nu_i \ .$$

⇛ One can just look at th energy spectra of the decay:

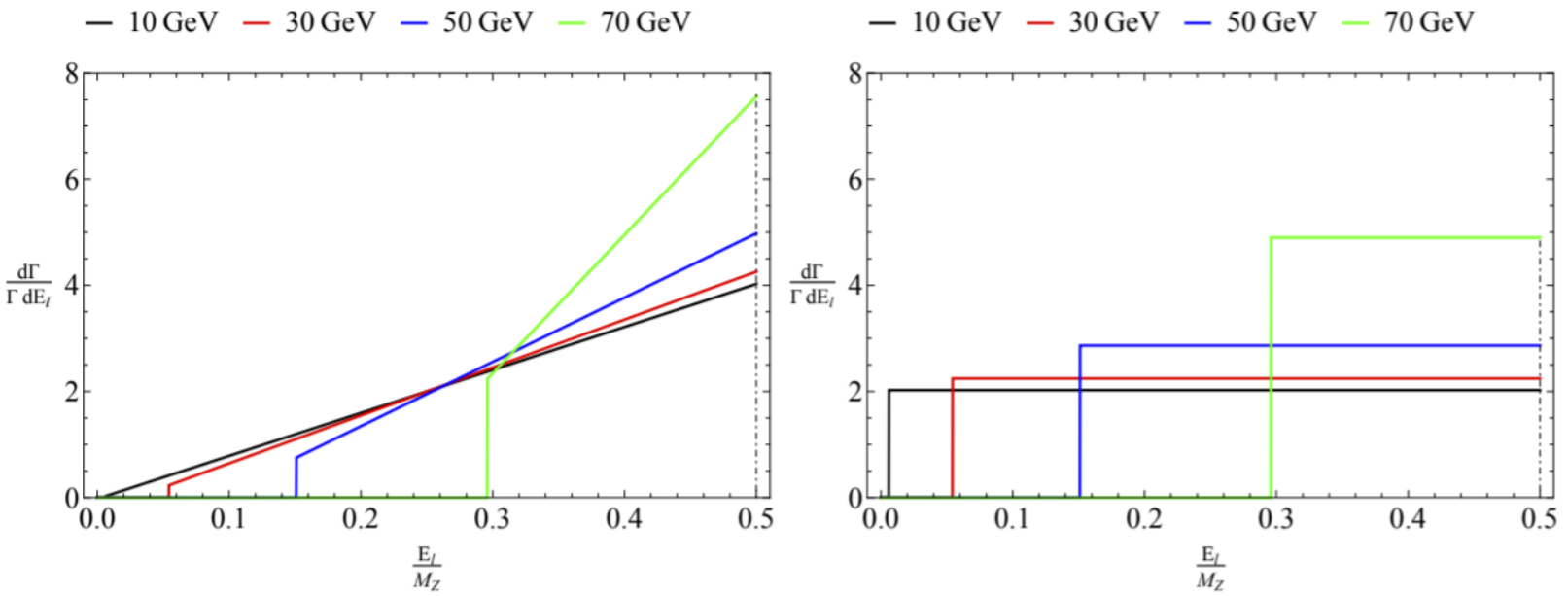


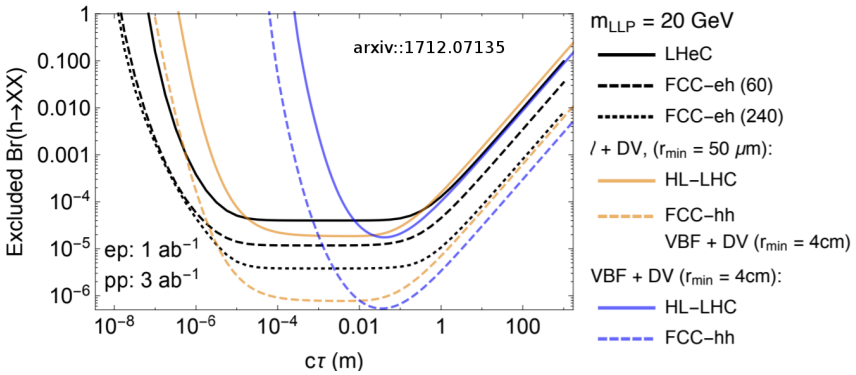
FIG. 7: Averaged, normalized differential decay widths of $\nu_4 \to \ell^-\pi^+$ as a function of the energy of the charged-lepton, averaged over the heavy-neutrino production angle, for ν_4 produced in Z-decay-at-rest assuming the heavy neutrinos are Dirac (left) and Majorana (right) fermions. The different curves correspond to different values of m_4. The same curves apply, both in the left-hand and in the right-hand panels, to the $\ell^+\pi^-$ final-states.

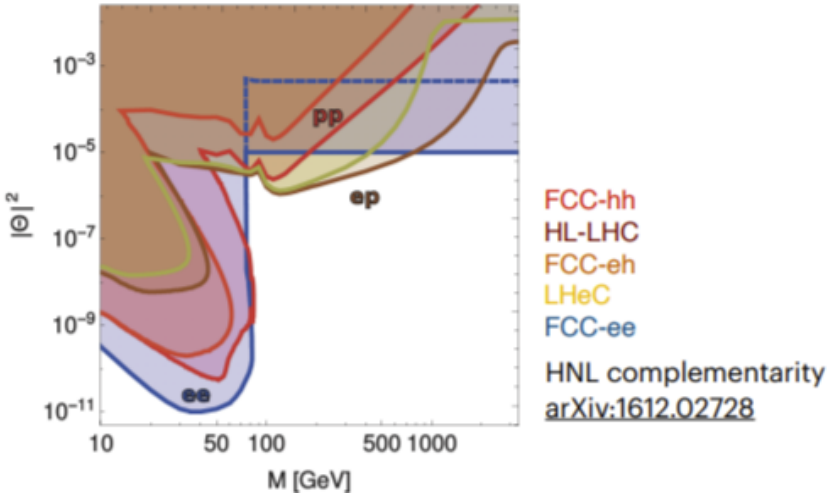
Other LLP at FCCee

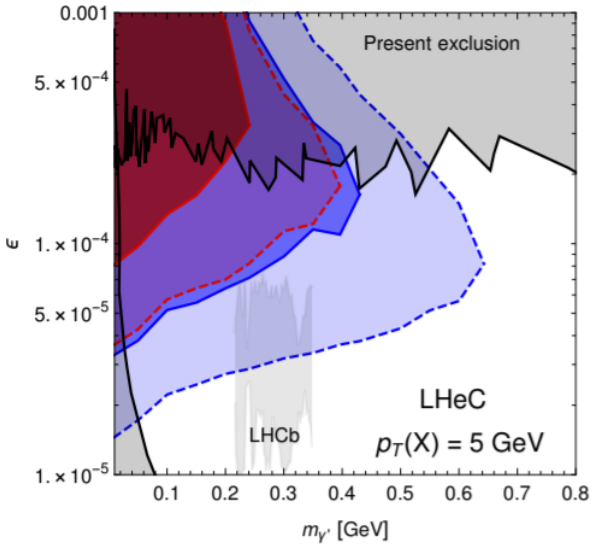
$\Rightarrow$ There number of models with LLP that can be discovered at FCC is enormous:

- Hidden Valley models with neutral, long-lived particles that the Higgs boson can decay to (arXiv:1812.05588) .
- Higgs portal, dark glueball(arXiv:1911.08721)
- Neutral naturalness (arXiv:1506.06141)
- Folded SUSY (arXiv:1911.08721)
- Neutralinos (arXiv:1904.10661)
- ALPs (arxiv:1808.10323)
- Dark photon (arxiv:1906.10608)

Complementarity with FCChh

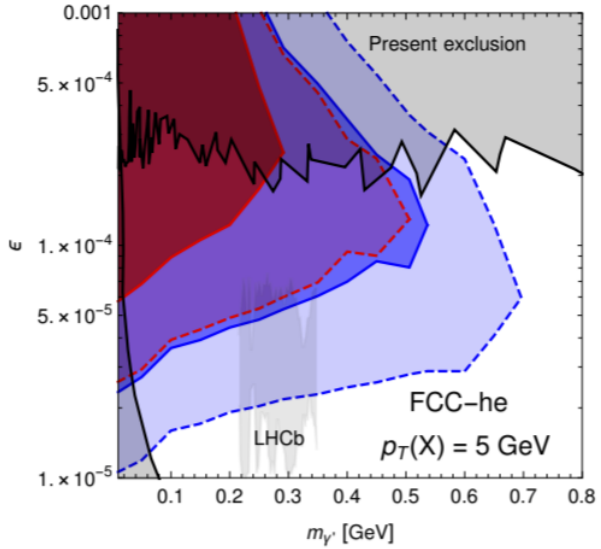






arxiv::1909.02312

Nbkg=0, signal efficiency = 100%
Nbkg=0, signal efficiency = 20%
Nbkg=100, signal efficiency = 100%
Nbkg=100, signal efficiency = 20%



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Take home msg

- ⇛ FCC is an ideal environment to look for LLP.
- ⇛ We are in unique spot to start thinking about them ahead of time.
- ⇛ Possible Majorana - Dirac distinction.
- ⇛ Complementarity with hadron machines.
- ⇛ We cannot waste this opportunity!!

Backup