Long Lived Heavy Neutral Leptons through Z' decays at the FCC-ee

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Abstract

We study the phenomenology of a $U(1)_{B-L}$ extension of the SM predicting long-lived heavy neutral leptons (HNLs), which are pair produced from a new gauge boson Z' with displaced vertex signatures at the electron positron mode of the Future Circular Collider (FCC-ee). Progress on sensitivity prospects are provided on the 1-100GeV mass scale for g'$\sim 10^{-4}$, and $|V_{lN}|^2 = 10^{-8} - 10^{-20}$, a region that has not been constrained by LHC [7][8].

The B-L model

The B-L model consists of the Standard Model with one extra $U(1)$ gauge symmetry, $SU(3)_c \times SU(2)_L \times U(1)_Y \times U(1)_{B-L}$.

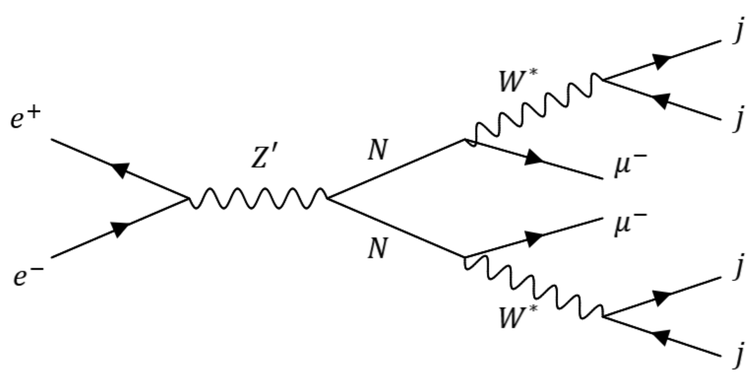
Tables 1 and 2: Particle content of the B-L extension and our scanned parameters.

particle	type
N	fermion
χ	scalar
Z'	vector boson

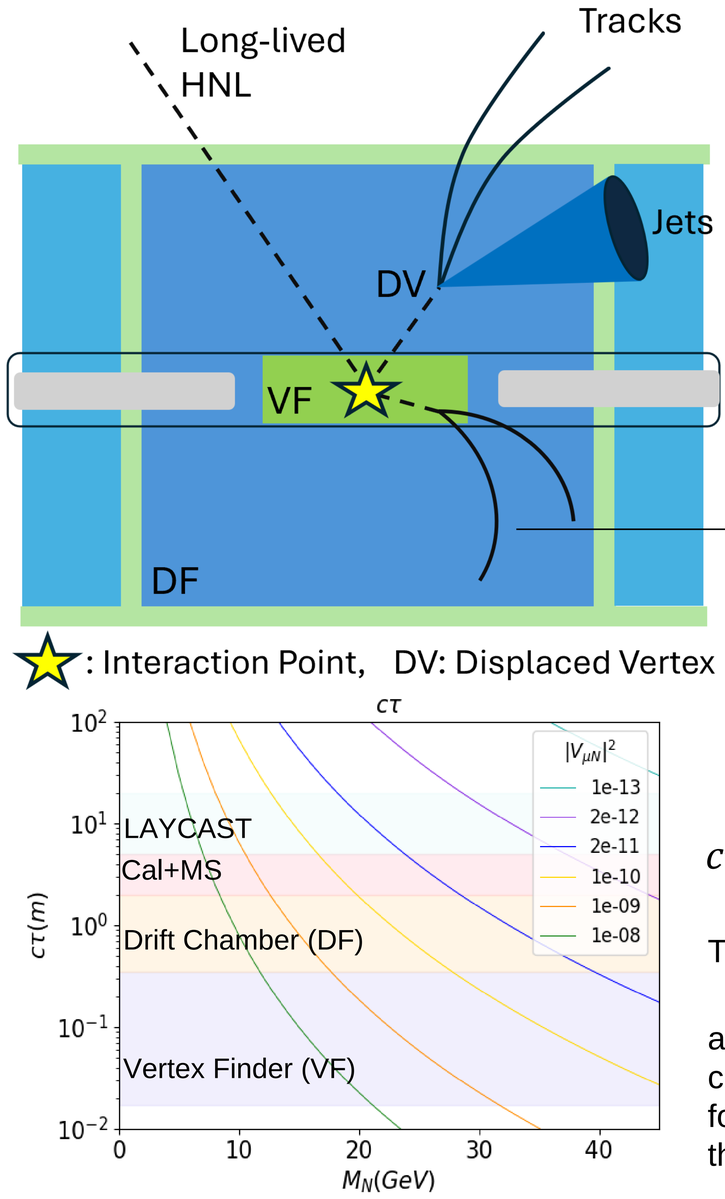
parameter	description
g'	B-L gauge coupling
$M_{Z'}$	Z' boson mass
M_N	HNL mass
$\|V_{lN}\|^2$	heavy light neutrino mixing

Long lived HNLs at the FCC-ee

Using MadGraph 3.5.4 [1] and MadSpin[2] we simulated the B-L process of a Z' producing two HNLs and their posterior decay to a muon and two jets through an off-shell W boson.



Displaced activity at IDEA



The decay width of the HNL is given by

$$\Gamma \approx M_N^5 G_F^2 |V_{lN}|^2$$

At the GeV scale, for an (allowed) small enough heavy-light neutrino mixing, $|V_{\mu N}|^2$, the HNLs behave as LLPs due to the supressed width.

We want to use fast-simulation softwares for the reconstruction of displaced tracks at the Vertex Finder [3].

The particle's proper length is given by

$$c\tau = \frac{c\hbar}{\Gamma} \approx \frac{c\hbar}{M_N^5 G_F^2 |V_{lN}|^2}$$

The decay length is given by

$$\lambda = \beta\gamma c\tau$$

and it is used for the calculation of the probability for the HNL to decay whithin the fiducial volumen as

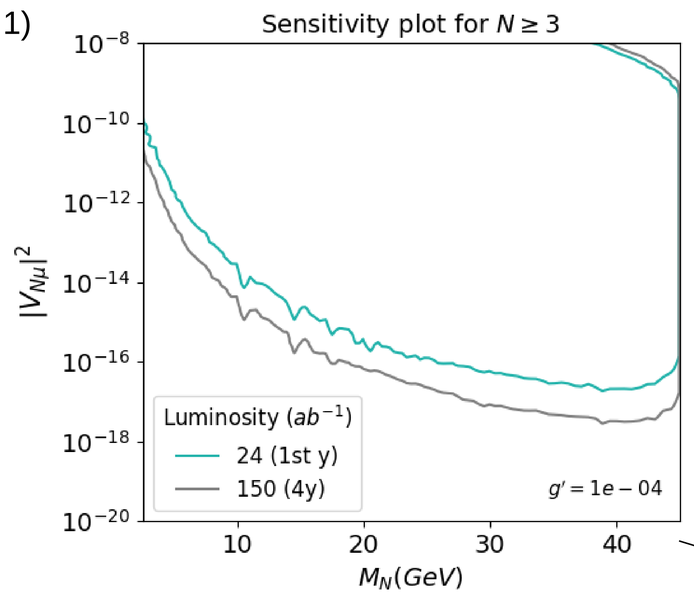
$$P(\theta_i) = e^{-L_1(\theta_i)/\lambda_i}(1 - e^{-L_2(\theta_i)/\lambda_i})$$

L_1: Distance from the IP to the begining of the inner detector wall. L_2:Distance traveled inside the detector,

HNL sensitivity prospects at FCC-ee

IDEA detector

1)



Figures 1 and 2: Sensitivity plots at a 95% CL for $N \geq 3$ expected efents for the shown Feynman diagram, calculated with a geometrical acceptance given by the probability of the HNL to decay inside the VF.

- $\sqrt{s} = M_{Z'} = 91GeV$
- $g' = 10^{-4}$
- $\mathcal{L} = 150 \times 10^6 pb^{-1}$ $(4y)$
- N=50k events

NON CONSTRAINED BY EXP

LAYCAST: A far detector proposal

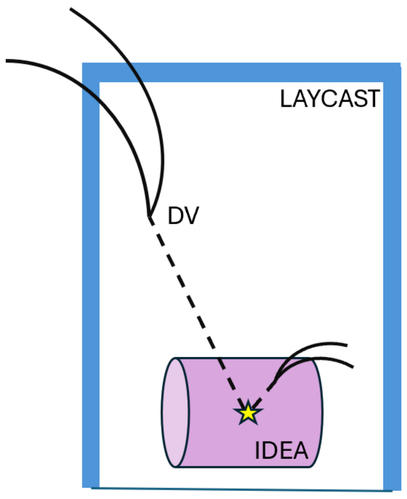
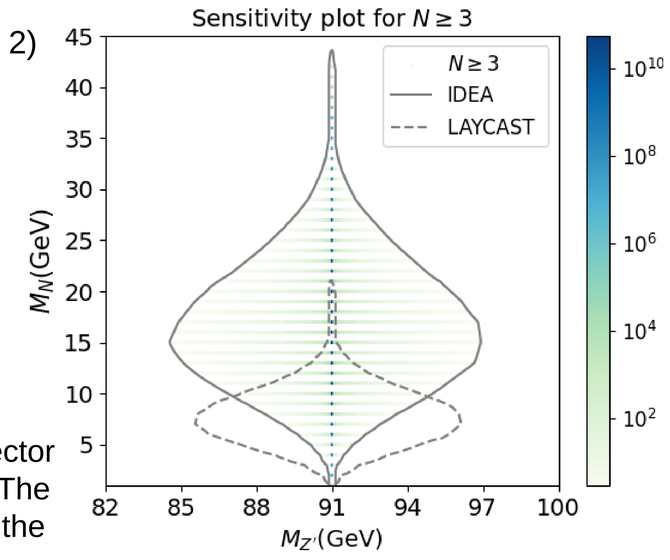


Fig.3: Displaced activity on a far detector that consists oF a one-layer tracker. The color bar on the right plot represents the number of expected events.

2)



Trying coupled B-L masses

Using the condition $\boldsymbol{M_N = 0.3 M_{Z'}}$ to couple B-L masses, we note that there is resonance produced at $\sqrt{s} = M_{Z'}$.

Figure 4: Cross-section as a function of the HNL mass for $\sqrt{s} = M_{Z'} = 91GeV$

Conclusions

- We studied an unconstrained parameter space that is accesible to FCC-ee operating at an energy scale where its luminosity is máximum, and we can generate SM neutrino masses through Majorana HNLs that behave as LLPs and can produce a DV inside the Vertex Finder.
- HNLs can decay inside the IDEA+LAYCAST configuration for $|V_{\mu N}|^2$ as low as 10^{-13}.
- As expected, the far detector shifted the constraint in the sensitivity plot toward lower mixings or longer lifetimes.

References:
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