

HNL searches with winter 2023 samples

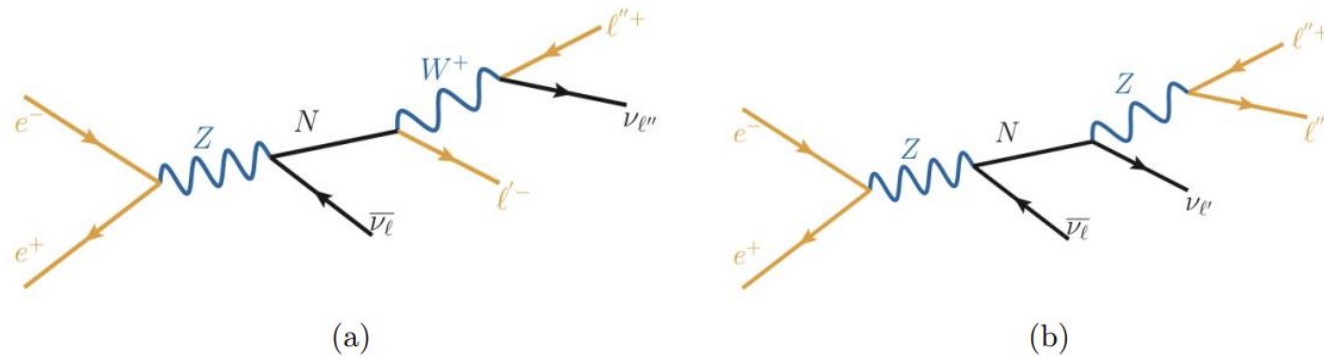
John Hayward, Sarah Williams

Objectives for searches

- Investigate improvements made with winter 2023 statistics
- Further optimisations on selections placed in original snowmass paper
- Look into significance of HNL signals over the backgrounds

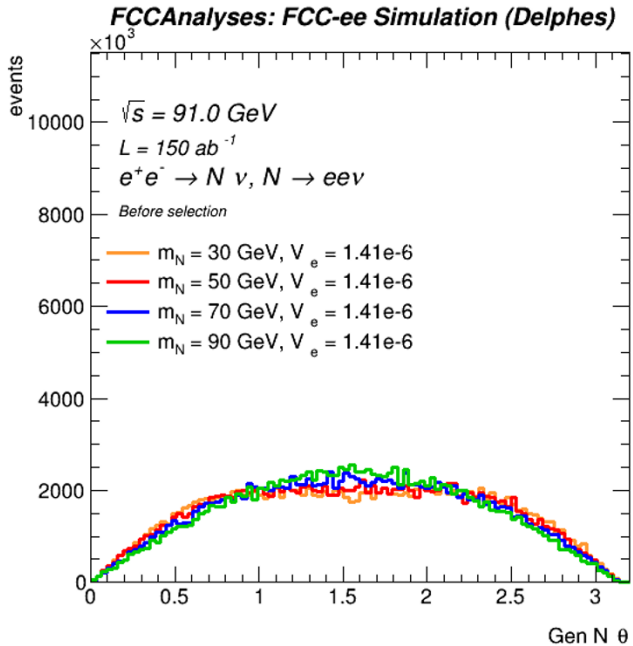
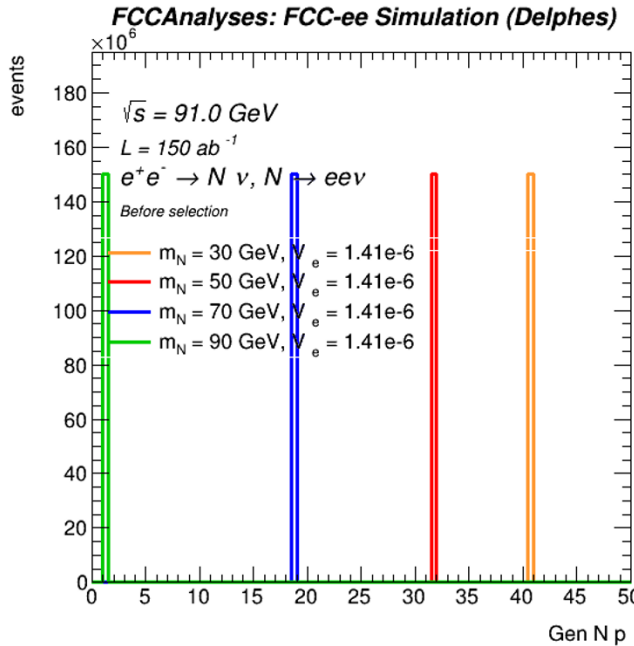
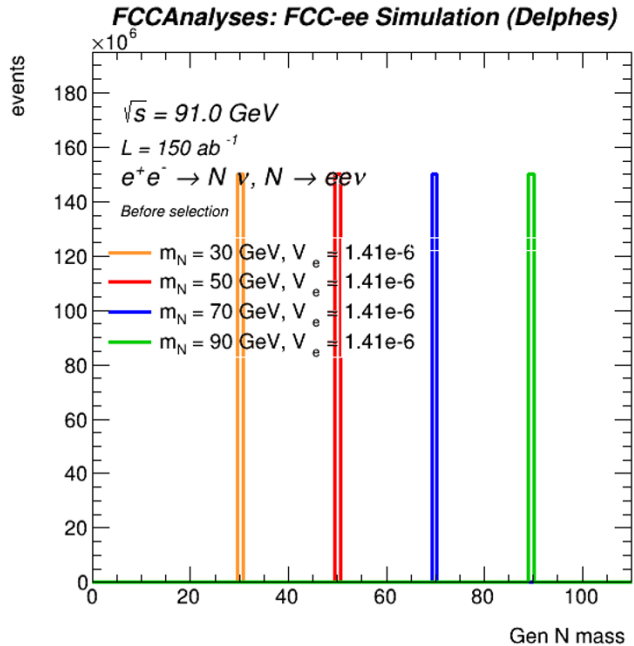
Theoretical model used for HNLs

- **Production and decay of single HNL coupling exclusively to electron / electron neutrino**
 - Although most promising seesaw models contain 2 or 3, it is simpler to only consider a single HNL to start
- **This is expected to give Z boson decay to two electron neutrinos, and two electrons in most decays**



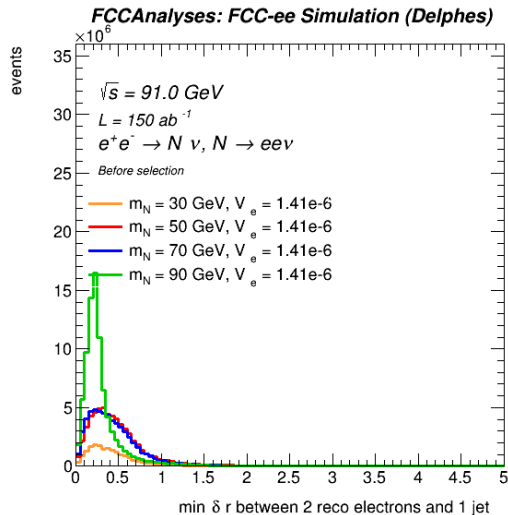
Generation of new HNL signals

- Generated new signals using madgraph v3.5.3 and the winter 2023 Delphes card for the latest IDEA geometry
- 9 new signals generated for various masses and couplings



Jet reclustering

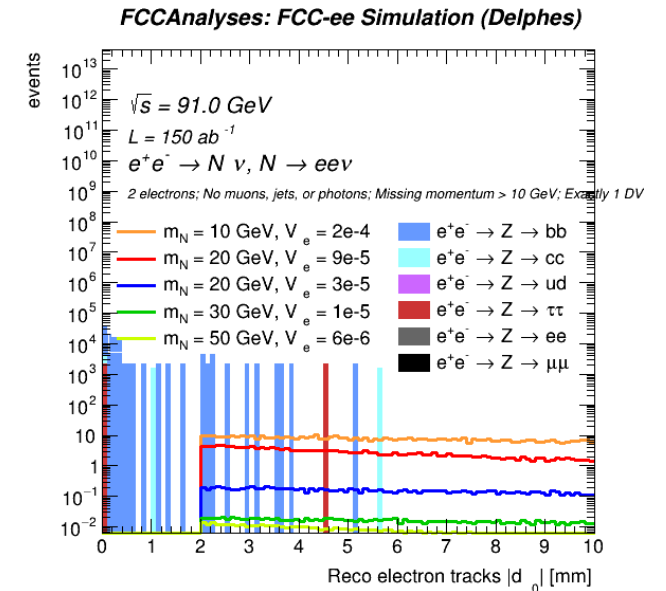
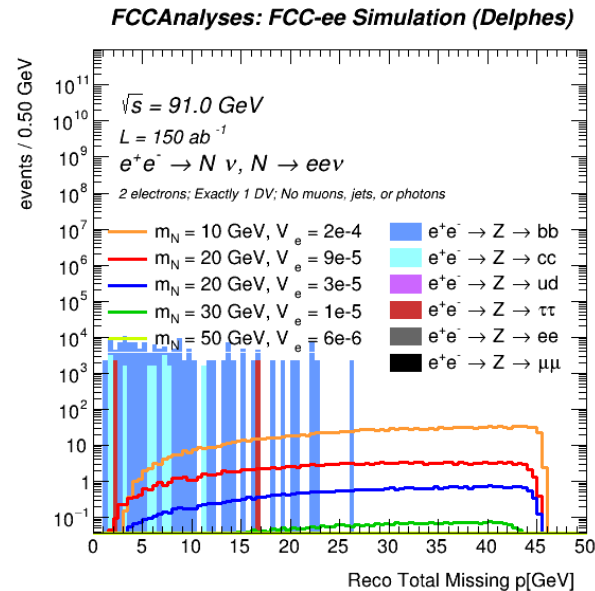
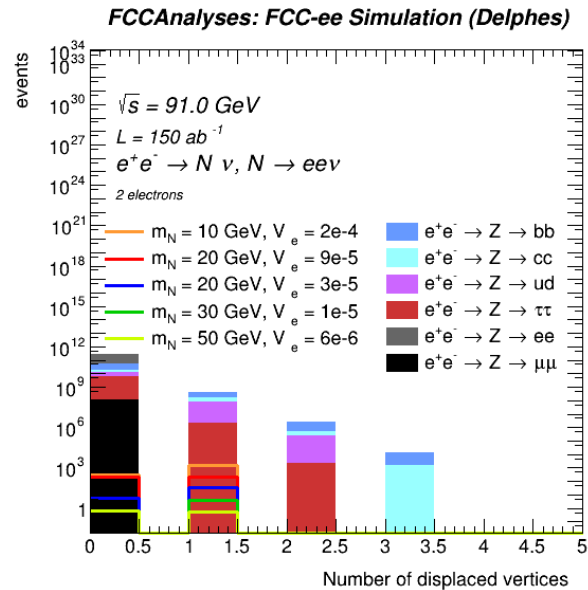
- HNL signals had unexpected number of jets with small angular separation from reconstructed electrons
 - Some form of overlap removal was required -> jet reclustering using antikt algorithm
- Same jet reclustering applied to spring 2021 backgrounds as recommended giving different number of events after applying all cuts for hadronic decay
 - Published results may use the buggy jets, or a different jet reclustering algorithm



	N events with all cuts from snowmass paper	N events with all cuts and antikt reclustering
$Z \rightarrow ee$	$\leq 3.94e+06$	$\leq 3.97e+06$
$Z \rightarrow \tau\tau$	$6.64e+04 \pm 3.84e+04$	$6.64e+04 \pm 3.84e+04$
$Z \rightarrow bb$	$1.72e+03 \pm 1.72e+03$	$1.04e+05 \pm 1.41e+04$
$Z \rightarrow cc$	$\leq 1.23e+03$	$\leq 3.13e+03$
$Z \rightarrow uds$	$\leq 2.79e+03$	$\leq 2.79e+03$

Improvements on cuts

- Expect HNL decay to have at least one displaced vertex which can be used to filter backgrounds
- With at least one displaced vertex can look into tweaking values used in snowmass paper



Number of events with backgrounds

- Large uncertainties in number of events makes significance of signal low
- Upper bound on number of background events still orders of magnitude larger than number of HNL signal events
- Significance of 0.002, summing errors in quadrature

	2 electrons $ d_0 > 4.0$ mm; 0 $\gamma, \mu, jets$; $\cancel{p} > 10$ GeV; Exactly 1 DV
$Z \rightarrow ee$	$\leq 6.20e+03$
$Z \rightarrow \tau\tau$	$\leq 2.21e+03$
$Z \rightarrow bb$	$\leq 3.21e+03$
$Z \rightarrow cc$	$\leq 1.57e+03$
$Z \rightarrow ud$	$\leq 5.48e+05$
$Z \rightarrow ss$	$\leq 1.57e+03$
$Z \rightarrow \mu\mu$	$\leq 5.23e+05$
$m_N = 10$ GeV, $ V_{eN} = 2 * 10^{-4}$	$1.49e+03 \pm 8.69e+00$
$m_N = 20$ GeV, $ V_{eN} = 9 * 10^{-5}$	$1.23e+02 \pm 1.06e+00$
$m_N = 20$ GeV, $ V_{eN} = 3 * 10^{-5}$	$3.33e+01 \pm 1.84e-01$
$m_N = 30$ GeV, $ V_{eN} = 1 * 10^{-5}$	$3.44e+00 \pm 1.86e-02$
$m_N = 50$ GeV, $ V_{eN} = 6 * 10^{-6}$	$3.35e-01 \pm 2.87e-03$

$$Z = \frac{s}{\sqrt{b + \sigma_b^2}}$$

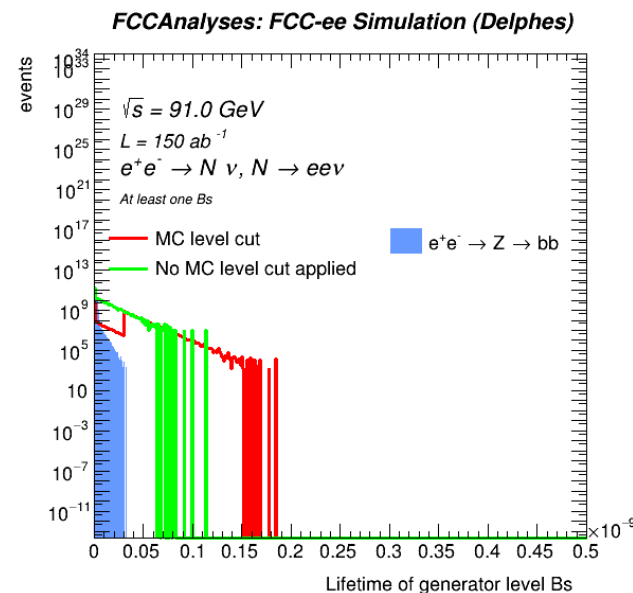
Background weighting

- Current weighting on background signals larger than unfiltered number of HNL events for most favourable parameters (2532)
- Due to error calculations with MC samples, observing HNL signal over backgrounds currently not possible with minimum significance < 0.5

	Weighting at integrated luminosity $150ab^{-1}$
$Z \rightarrow ee$	2193
$Z \rightarrow bb$	2272
$Z \rightarrow \mu\mu$	2193
$Z \rightarrow \tau\tau$	2215
$Z \rightarrow cc$	1565
$Z \rightarrow ud$	3578
$Z \rightarrow ss$	1565

MC level filtering for signal generation

- Placing filters at MC level allows for larger number of events to be generated quickly, and reduces storage space required
- Have been testing a basic first filter for $Z \rightarrow bb$ decay, requiring at least one Bs with lifetime $> 3e-11$ seconds
 - An inclusive sample generated this way doesn't match the winter 2023 inclusive background



Summary and next steps

- **New HNL signals using winter 2023 statistics have been created and compared to winter 2023 backgrounds**
 - Selections have been further optimised using displaced vertex and tweaking values from snowmass paper
 - With current statistics this reduces all backgrounds to just upper bounds
- **Weighting of backgrounds is currently too large to see HNL signals over with high confidence**
 - Looking into applying MC level filters to generate larger backgrounds quickly that fit the current selection criteria