Probing HNLs at the FCC-ee using Machine Learning Methods

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Thomas Critchley[†] Supervisors: Prof. Anna Sfyrla[†], Dr. Pantelis Kontaxakis[†]

[†]thomas.critchley@etu.unige.ch [†]anna.sfyrla@unige.ch [†]pantelis.kontaxakis@unige.ch



UNIVERSITÉ DE GENÈVE

FACULTÉ DES SCIENCES



FUTURE CIRCULAR COLLIDER

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Introduction

- HNLs introduced as a massive, sterile RH object that can generate small SM neutrino masses via Type I see-saw mechanism (Dirac or Majorana).
- Consequential lifetime (τ∝M⁻⁵|U|⁻²)[†] can result in displaced signatures giving us LLPs to search for at the FCC in this framework
- We look for Dirac HNLs in the mass range 10 80 GeV with $10^{-4} < |U_{eN}|^2 < 10^{-10}$ in electron dijet final state





Variable	Selection
Missing energy	> 12 GeV
Leading electron energy	> 35 GeV
3D di-jet Angle	< 2.4 rad
Di-jet – Electron ΔR	< 3

ML approaches to HNLs: BDT

- A unique BDT model was trained using XGBoost with TMVA for each signal mass point and compared with the background proccess (4 lepton, Z → bb and Z → cc) and normalised to 10 fb⁻¹
- BDT Hyperparameters optimised via gridsearch cross-validation → final result ~20% improvement on cut and count method
- Input features for BDT :

Object	Variables
Leading electron Neutrino Di-jet system	$egin{array}{llllllllllllllllllllllllllllllllllll$
Vertex and tracks	$n_{ m tracks}, n_{ m primary\ tracks}, \chi^2_{ m vertex}$



ML approaches to HNLs: DNN

- A DNN is being trained using keras for the same classification task optimisation of the model underway, fine tuning of the hyperparameters necessary to match or improve upon BDT performance.
- Optimisation of the model underway, fine tuning of the hyperparameters necessary to match or improve upon BDT performance.
- Input features for the DNN (same as BDT so far):

Object	Variables
Leading electron Neutrino Di-jet system Vertex and tracks	$egin{aligned} E, \phi, D_0, \sigma_{D_0}, \Delta R_{ejj} \ E_{ ext{miss}}, heta, \phi \ \Delta R_{jj}, \phi \ n_{ ext{tracks}}, n_{ ext{primary tracks}}, \chi^2_{ ext{vertex}} \end{aligned}$



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Improved Limits

- Most successful improvement (so far) from the use of BDTs
- ~20% improvement on existing 95% CL limits compared with the same final state for cut and count study
- ejj only ~15% of the total HNL branching ratio, hence we do not see the same full coverage as for expected FCC
- Next steps: DNN optimisation and searches for viable filters working with Sarah, improving our ability to scale to full lumi





Backup slides



Lead electron energy distribution



Missing energy distribution



Correlation matrix (50 GeV $|V_{eN}|^2 = 10^{-6}$)

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	Correlation Matrix									-10			
RecoDiJet_delta_R -	1.00	0.73	0.04	0.00	0.00	-0.37	-0.22	0.00	-0.03	0.06		1.0	
RecoElectron_DiJet_delta_R -	0.73	1.00	0.03	0.00	-0.00	-0.38	-0.10	0.00	0.02	0.07		- 0.8	
RecoElectronTrack_absD0 -	0.04	0.03	1.00	-0.00	0.00	-0.06	-0.09	-0.00	-0.11	0.01		- 0.6	
RecoDiJet_phi -	0.00	0.00	-0.00	1.00	0.00	-0.00	-0.00	-0.00	0.00	0.00			ent
RecoMissingEnergy_theta -	0.00	-0.00	0.00	0.00	1.00	0.00	0.00	-0.00	0.00	0.00		- 0.4	coeffici
RecoMissingEnergy_e -	-0.37	-0.38	-0.06	-0.00	0.00	1.00	0.24	-0.00	-0.07	-0.30		- 0.2	relation
RecoElectron_lead_e -	-0.22	-0.10	-0.09	-0.00	0.00	0.24	1.00	-0.00	-0.10	-0.21			Col
Vertex_chi2 -	0.00	0.00	-0.00	-0.00	-0.00	-0.00	-0.00	1.00	-0.00	0.00		- 0.0	
n_primt -	-0.03	0.02	-0.11	0.00	0.00	-0.07	-0.10	-0.00	1.00	0.65		0.2	
ntracks -	0.06	0.07	0.01	0.00	0.00	-0.30	-0.21	0.00	0.65	1.00			
	RecoDijet_delta_R -	RecoElectron_Dijet_delta_R -	RecoElectronTrack_absD0 -	RecoDijet_phi -	RecoMissingEnergy_theta -	RecoMissingEnergy_e -	RecoElectron_lead_e -	Vertex_chi2 -	n_primt -	ntracks -			

LLP vs Prompt Decay BDTs



FCCee Simulation (DELPHES)

Use of a lead electron energy filter E > 15 GeV for inclusive BDT output

Combined with D_0 significance > 5 for LLP

Z-significance at 10fb

Combined with D_0 significance < 5 for Prompt decay

Not much improvement from seperating processes likely because BDT trains for each signal point \rightarrow displaced vertex mass points already have the D_0 as their most important input feature for the inclusive BDT