Measuring dark neutrinos at ILC Preliminary results

Simon Hayakawa Supervised by Junping Tian

Image source: Sterile Neutrino Contraints

Goal

- Hypothesized dark sector model with a weak-like force
 - Can explain matter-antimatter asymmetry
 - Heavy dark neutrinos
 - My focus: $m_Z < m_{ND} < m_H$
 - Higgs decay product
- Goal: Investigate the sensitivity of ILC for detecting the dark neutrino



Dataset

1. Background: MC-2020 full simulation data

- 1000 fb⁻¹ each of (-0.8, +0.3), (+0.8, -0.3).
- iLCSoft v02-02
- 2f, 4f, 6f, **qqh**
- 2. Signal: Full simulation data
 - m_{ND} = 100 GeV
 - Only muon channel
 - eLpR, eRpL (~200 000 events each)
 - Electron channel and more masses in the making



Lepton angle distribution

signal

background



Dark neutrino angle distribution

signal

background



Machine learning

- Boosted decision tree (TMVA)
- 100 trees, 4 nodes at most, optimize gini index
- Updated input parameters:
 - Production angles of lepton, neutrino, Z, dark neutrino
 - Dark neutirno angle in Higgs rest frame
 - Lepton angle in dark neutrino rest frame
 - With and without corrected dark neutrino mass
- B-tagging and c-tagging did not result in a meaningful improvement

Significance output of BDT

Significance curve with beam polarization elpr

Significance curve with beam polarization erpl



Total significance for different BRs

Without dark neutrino mass

Significance for different values of BR(H $\rightarrow vN$)•BR(N $\rightarrow IW$)

With dark neutrino mass

Significance for different values of BR(H $\rightarrow vN$)•BR(N $\rightarrow IW$)



Dark neutrino mass (BR = 0.5%)

Dark neutrino corrected mass | Beam (-0.8, 0.3)



Dark neutrino corrected mass | Beam (0.8, -0.3)



Future work

- More dark neutrino samples
 - Electron channel
 - Other dark neutrino masses

Significance output of BDT – with mass

Significance curve with beam polarization elpr



Significance curve with beam polarization erpl

Branching ratio

10.0%

5.0%

1.0%

0.5%

0.1%

2 σ

0.6

BDT cut value

0.4

0

0.2

---5σ

Dark neutrino mass (BR = 0.5%)

Dark neutrino corrected mass | Beam (-0.8, 0.3)



Dark neutrino corrected mass | Beam (0.8, -0.3)



Cut table – 1% BR

(-0.8, +0.3)	Total signal	Total background	Significance	2f_l	2f_h	4f_l	4f_sl	4f_h	6f	qqh
No cuts	1397	136859842	0.12	12982897	77324421	10379315	19163106	16800470	1278	208355
Pre-selection	1215	30132034	0.22	7366002	1606336	7651845	13260215	220833	872	25932
elep/50. + emis/90. < 1.	1085	1565721	0.87	75113	265900	857303	209602	147613	705	9485
0.8 < mvalep	902	882872	0.96	54525	41290	623639	138607	18676	585	5550
(180. < mvis) && (mvis < 225.)	845	391342	1.35	34476	21865	237881	82092	9918	383	4728
0.007 < y34	726	27311	4.34	160	2109	406	13519	6778	346	3993
2 < min_n	711	16305	5.45	4	1223	7	4376	6541	314	3841
(10. < mis.P()) && (mis.P() < 50.)	702	8703	7.24	2	564	4	2207	2449	102	3376
MVA cut	521	1457	11.72	0	14	0	180	52	7	0
(+0.8, -0.3)	Total signal	Total background	Significance	2f_	_l 2f_l	h 4f_	l 4f_sl	4f_h	6f	qqh
(+0.8, -0.3) No cuts	Total signal 954	Total background 66651497	Significance	2f_ 1031487	l 2f_l 0 4567258	n 4f_ 8 6114301	l 4f_sl 2839022	4f_h 1570051	6f 260	qqh 140405
(+0.8, -0.3) No cuts Pre-selection	Total signal 954 830	Total background 66651497 12565351	Significance 0.12 0.23	2f_ 10314870 569674	I 2f_I 0 4567258 8 97969	h 4f_ 8 6114301 3 4109167	l 4f_sl 2839022 7 1739683	4f_h 1570051 22431	6f 260 194	qqh 140405 17434
(+0.8, -0.3) No cuts Pre-selection elep/60. + emis/100. < 1.	Total signal 954 830 799	Total background 66651497 12565351 1526118	Significance 0.12 0.23 0.65	2f_ 10314870 5696744 9998	I 2f_I 0 4567258 8 97969 7 18980	h 4f_ 8 6114307 3 4109167 4 1016886	I 4f_sl 1 2839022 7 1739683 5 193442	4f_h 1570051 22431 17855	6f 260 194 167	qqh 140405 17434 7978
(+0.8, -0.3) No cuts Pre-selection elep/60. + emis/100. < 1. 0.6 < mvalep	Total signal 954 830 799 769	Total background 66651497 12565351 1526118 1212198	Significance 0.12 0.23 0.65 0.70	2f_ 10314870 5696744 9998 88820	I 2f_l 0 4567258 8 97969 7 18980 6 6240	h 4f_ 8 6114307 3 4109167 4 1016886 1 890288	I 4f_sl 1 2839022 7 1739683 5 193442 8 159199	4f_h 1570051 22431 17855 5357	6f 260 194 167 156	qqh 140405 17434 7978 5971
(+0.8, -0.3) No cuts Pre-selection elep/60. + emis/100. < 1. 0.6 < mvalep (160. < mvis) && (mvis < 220.)	Total signal 954 830 799 769 755	Total background 66651497 12565351 1526118 1212198 564514	Significance 0.12 0.23 0.65 0.70 1.00	2f_ 10314870 5696744 9998 88820 63930	I 2f_l 0 4567258 8 97969 7 18980 6 6240 6 3323	4f_ 8 6114307 3 4109167 4 1016886 1 890288 3 359843	I 4f_sl 1 2839022 7 1739683 5 193442 3 159199 3 99486	4f_h 1570051 22431 17855 5357 2819	6f 260 194 167 156 96	qqh 140405 17434 7978 5971 5100
(+0.8, -0.3) No cuts Pre-selection elep/60. + emis/100. < 1. 0.6 < mvalep (160. < mvis) && (mvis < 220.) 0.004 < y34	Total signal 954 830 799 769 755 708	Total background 66651497 12565351 1526118 1212198 564514 38358	Significance 0.12 0.23 0.65 0.70 1.00 3.58	2f_ 10314870 569674 9998 88820 63930 565	I 2f_l 0 4567258 8 97969 7 18980 6 6240 6 3323 5 657	h 4f_ 8 6114301 3 4109167 4 1016886 1 890288 3 359843 5 2378	 4f_sl 2839022 1739683 193442 159199 99486 21820 	4f_h 1570051 22431 17855 5357 2819 2369	6f 260 194 167 156 96 93	qqh 140405 17434 7978 5971 5100 4558
(+0.8, -0.3) No cuts Pre-selection elep/60. + emis/100. < 1. 0.6 < mvalep (160. < mvis) && (mvis < 220.) 0.004 < y34 4 < min_n	Total signal 954 830 799 769 755 708 621	Total background 66651497 12565351 1526118 1212198 564514 38358 9269	Significance 0.12 0.23 0.65 0.70 1.00 3.58 6.24	2f_ 10314870 5696744 9998 88820 63930 565	I 2f_l 0 4567258 8 97969 7 18980 6 6240 6 3323 5 657 0 177	4f_ 8 6114301 3 4109167 4 1016886 1 890288 3 359843 5 2378	4f_sl 2839022 7 1739683 5 193442 8 159199 3 99486 3 21820 0 1881	4f_h 1570051 22431 17855 5357 2819 2369 1910	6f 260 194 167 156 96 93 71	qqh 140405 17434 7978 5971 5100 4558 3631
(+0.8, -0.3) No cuts Pre-selection elep/60. + emis/100. < 1. 0.6 < mvalep (160. < mvis) && (mvis < 220.) 0.004 < y34 4 < min_n (10. < mis.P()) && (mis.P() < 50.)	Total signal 954 954 830 799 769 755 708 621 613	Total background 66651497 12565351 12565351 1526118 1212198 564514 38358 9269 5895	Significance 0.12 0.23 0.65 0.70 1.00 3.58 6.24 7.59	2f_ 10314870 5696744 99988 88820 63930 569 569 569 569 569 569 569 569 569 569	I 2f_l 0 4567258 8 97969 7 18980 6 6240 6 3323 5 657 0 177 0 879	4f_ 8 6114301 3 4109167 4 1016886 1 890288 3 359843 5 2378 5 0 9 0	4f_sl 2839022 7 1739683 5 193442 3 159199 3 99486 3 21820 0 1881 0 1049	4f_h 1570051 22431 17855 5357 2819 2369 1910 902	6f 260 194 167 156 96 93 71 23	qqh 140405 17434 7978 5971 5100 4558 3631 3042