# Search for Heavy Neutral Leptons in ATLAS and DUNE Experiments

Deywis Moreno
Moca2018

Universidad Antonio Narino
Bogota, Colombia

July 30, 2018

UNIVERSIDAD ANTONIO NARIÑO

# Content

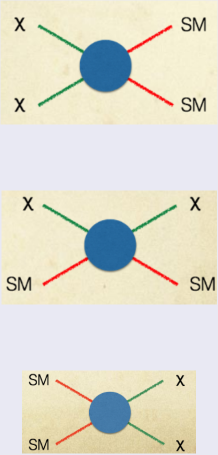
## Dark Matter

1. Unsolved problem
2. No SM particle can explain it
3. DM evidence coming from diverse sources

## How to detect it?

Assuming weakly interaction with SM

1. Indirect detection
2. Direct Detection
3. Colliders production



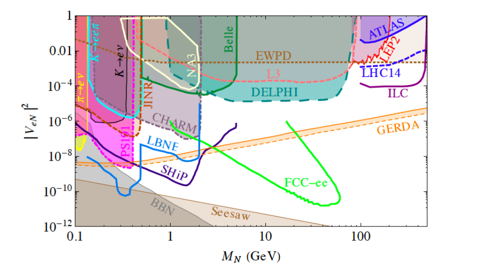

https://cds.cern.ch/record/2262480/files/ATL-COM-PHYS-2017-546.pdf

# Heavy Neutral Leptons (HNL)

## $\nu$Minimal SM

1. Three RH sterile neutrinos with $M_{HNL} << M_W$
2. A see-saw mechanism explains light mass of active $\nu$
3. That implies the existence of heavy Majorana states (HNL)
4. The HNL mixes with SM neutrinos.

## Experimental limits on HNL mixing.



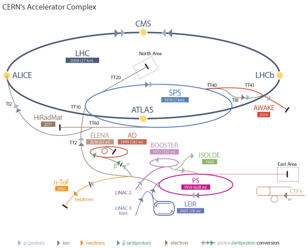

http://arxiv.org/pdf/1502.06541v3.pdf

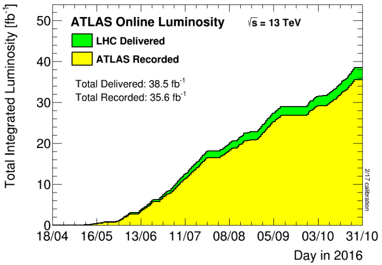
$$M_\nu \sim \frac{F_\nu^2}{M_N} \quad (1)$$

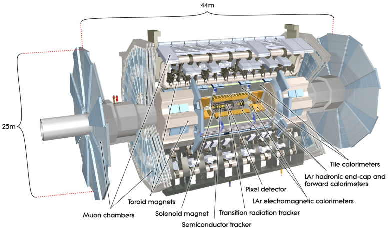
$$V_{\nu N} \sim \frac{F_\nu}{M_N} \quad (2)$$

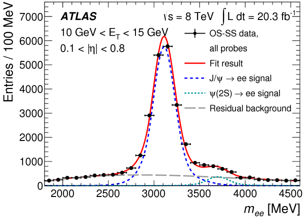
# Content

# The LHC



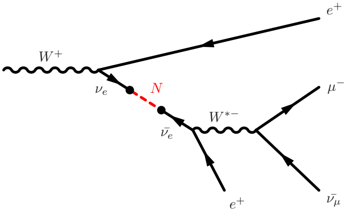



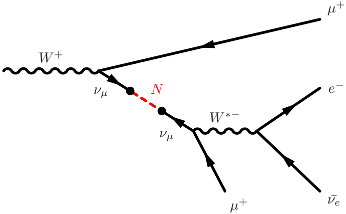




http://arxiv.org/pdf/1502.06541v3.pdf

# HNL Signature in ATLAS



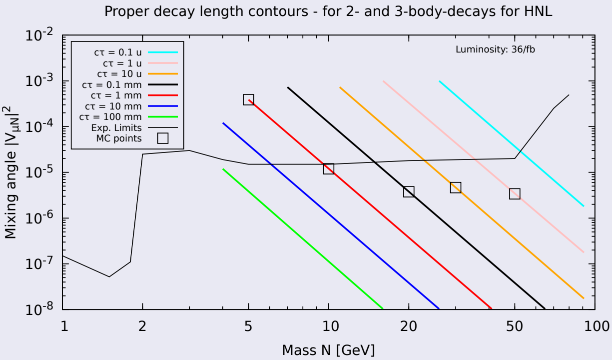




1. No OSSF-Lepton Pair
2. Hight $p_T$ isolated lepton
3. Missing Energy
4. Small displaced vertex

## Data sample Used

1. 2015 and 2016 with the LHC
2. centre-of-mass energy $\sqrt{s} = 13$ TeV.
3. Integrated luminosity of 36.1 $fb^{-1}$.

# MC Simulation




## MC parameters

1. Pythia 8
2. NN PDF2.3LO
3. HNL Mass: $5, 10, 20, 30, 50\,\mathrm{GeV}$
4. Decay lengths: $0.1, 1.0, 10.0, 100\,\mathrm{mm}$

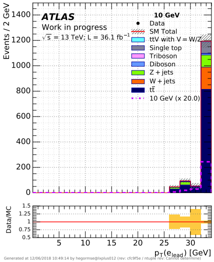
# Cuts Optimization

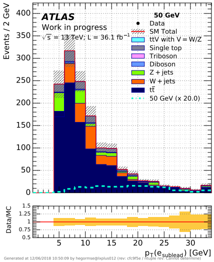
| Selection | 5GeV 1mm v25.9 | $\varepsilon_{\mathrm{tot}}$ | $S$ | 10GeV 1mm v25.9 | $\varepsilon_{\mathrm{tot}}$ | $S$ | 20GeV 0.1mm v25.9 | $\varepsilon_{\mathrm{tot}}$ | $S$ | 30GeV 0.01mm v25.9 | $\varepsilon_{\mathrm{tot}}$ | $S$ | $Backg_{\mathrm{tot}}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Initial | $24\,000.00 \pm 0.00$ | 1.00 | 0.00 | $25\,000.00 \pm 0.00$ | 1.00 | 0.00 | $25\,000.00 \pm 0.00$ | 1.00 | 0.00 | $24\,000.00 \pm 0.00$ | 1.00 | 0.00 | $745\,203\,800.00 \pm 0.00$ |
| After obj. def. | $627.00 \pm 0.00$ | 1.00 | 0.00 | $1221.00 \pm 0.00$ | 1.00 | 0.00 | $2590.00 \pm 0.00$ | 1.00 | 0.00 | $2915.00 \pm 0.00$ | 1.00 | 0.00 | $902\,518.00 \pm 0.00$ |
| After obj. def. (weighted) | $613.36 \pm 28.88$ | 1.00 | 0.32 | $35.62 \pm 1.25$ | 1.00 | 0.02 | $22.87 \pm 0.55$ | 1.00 | 0.01 | $33.61 \pm 0.74$ | 1.00 | 0.02 | $217\,381.98 \pm 1859.61$ |
| $e == 2$ and $\mu == 1$ | $613.36 \pm 28.88$ | 1.00 | 0.32 | $35.62 \pm 1.25$ | 1.00 | 0.02 | $22.87 \pm 0.55$ | 1.00 | 0.01 | $33.61 \pm 0.74$ | 1.00 | 0.02 | $217\,381.98 \pm 1859.61$ |
| $e^{\pm}e^{\pm}\mu^{\mp}$ | $567.98 \pm 25.49$ | 0.93 | 0.96 | $34.44 \pm 1.22$ | 0.97 | 0.06 | $22.36 \pm 0.54$ | 0.98 | 0.04 | $32.96 \pm 0.73$ | 0.98 | 0.06 | $19\,454.21 \pm 569.04$ |
| HLT single e | $424.19 \pm 21.96$ | 0.69 | 0.88 | $27.59 \pm 1.08$ | 0.77 | 0.06 | $16.98 \pm 0.46$ | 0.74 | 0.04 | $23.52 \pm 0.62$ | 0.70 | 0.05 | $13\,232.82 \pm 463.40$ |
| $\|\eta\|$ | $424.19 \pm 21.96$ | 0.69 | 0.88 | $27.56 \pm 1.08$ | 0.77 | 0.06 | $16.93 \pm 0.46$ | 0.74 | 0.04 | $23.48 \pm 0.62$ | 0.70 | 0.05 | $13\,228.22 \pm 462.75$ |
| IdLeadTight | $402.43 \pm 21.47$ | 0.66 | 0.86 | $26.34 \pm 1.06$ | 0.74 | 0.06 | $16.47 \pm 0.46$ | 0.72 | 0.04 | $22.60 \pm 0.61$ | 0.67 | 0.05 | $12\,416.62 \pm 447.46$ |
| IdsubLeadloose | $386.55 \pm 20.96$ | 0.63 | 0.99 | $26.19 \pm 1.06$ | 0.74 | 0.07 | $16.25 \pm 0.44$ | 0.71 | 0.04 | $22.46 \pm 0.60$ | 0.67 | 0.06 | $9380.91 \pm 373.10$ |
| Idmuon | $386.55 \pm 20.96$ | 0.63 | 0.99 | $26.19 \pm 1.06$ | 0.74 | 0.07 | $16.25 \pm 0.44$ | 0.71 | 0.04 | $22.46 \pm 0.60$ | 0.67 | 0.06 | $9380.91 \pm 373.10$ |
| Iso | $191.38 \pm 14.73$ | 0.31 | 0.73 | $22.77 \pm 1.01$ | 0.64 | 0.09 | $15.28 \pm 0.43$ | 0.67 | 0.06 | $21.46 \pm 0.59$ | 0.64 | 0.08 | $5379.82 \pm 250.19$ |
| TriggerMatch | $170.37 \pm 13.70$ | 0.28 | 0.68 | $19.67 \pm 0.95$ | 0.55 | 0.08 | $13.27 \pm 0.40$ | 0.58 | 0.05 | $18.79 \pm 0.55$ | 0.56 | 0.08 | $4987.20 \pm 237.98$ |
| $\|b\mathrm{-Jets}\| == 0$ | $166.74 \pm 13.58$ | 0.27 | 0.72 | $19.27 \pm 0.92$ | 0.54 | 0.08 | $13.00 \pm 0.40$ | 0.57 | 0.06 | $18.53 \pm 0.55$ | 0.55 | 0.08 | $2769.72 \pm 220.96$ |
| $\sum H_T < 120\,\mathrm{GeV}$ | $145.40 \pm 12.54$ | 0.24 | 0.80 | $16.13 \pm 0.80$ | 0.45 | 0.09 | $11.06 \pm 0.37$ | 0.48 | 0.06 | $15.33 \pm 0.49$ | 0.46 | 0.09 | $1528.58 \pm 171.50$ |
| $E_T^{miss} < 60\,\mathrm{GeV}$ | $145.40 \pm 12.54$ | 0.24 | 0.83 | $16.05 \pm 0.79$ | 0.45 | 0.09 | $10.97 \pm 0.37$ | 0.48 | 0.06 | $15.21 \pm 0.49$ | 0.45 | 0.09 | $1288.26 \pm 165.53$ |
| $40\,\mathrm{GeV} < \mathrm{M}_{ee\mu} < 90\,\mathrm{GeV}$ | $142.95 \pm 12.45$ | 0.23 | 1.27 | $15.77 \pm 0.78$ | 0.44 | 0.15 | $10.72 \pm 0.37$ | 0.47 | 0.10 | $14.97 \pm 0.48$ | 0.45 | 0.14 | $491.17 \pm 100.69$ |
| IP | $48.65 \pm 7.46$ | 0.08 | 1.57 | $3.55 \pm 0.44$ | 0.10 | 0.14 | $7.21 \pm 0.29$ | 0.32 | 0.27 | $10.61 \pm 0.40$ | 0.32 | 0.40 | $61.13 \pm 24.28$ |

| Selection | 50GeV 0.001mm v25.9 | $\varepsilon_{\mathrm{tot}}$ | $S$ | $Backg_{\mathrm{tot}}$ |
|---|---|---|---|---|
| Initial | $25\,000.00 \pm 0.00$ | 1.00 | 0.00 | $745\,203\,800.00 \pm 0.00$ |
| After obj. def. | $3185.00 \pm 0.00$ | 1.00 | 0.00 | $902\,518.00 \pm 0.00$ |
| After obj. def. (weighted) | $30.49 \pm 0.64$ | 1.00 | 0.01 | $243\,508.84 \pm 2055.24$ |
| $e == 2$ and $\mu == 1$ | $30.49 \pm 0.64$ | 1.00 | 0.01 | $243\,508.84 \pm 2055.24$ |
| $e^{\pm}e^{\pm}\mu^{\mp}$ | $30.09 \pm 0.64$ | 0.99 | 0.05 | $21\,061.68 \pm 617.47$ |
| HLT comb | $18.99 \pm 0.52$ | 0.62 | 0.05 | $11\,378.78 \pm 346.06$ |
| $\|\eta\|$ | $18.91 \pm 0.52$ | 0.62 | 0.05 | $11\,361.79 \pm 346.04$ |
| IdLeadLoose | $18.78 \pm 0.52$ | 0.62 | 0.06 | $10\,577.39 \pm 321.07$ |
| IdsubLeadloose | $18.64 \pm 0.51$ | 0.61 | 0.07 | $7973.54 \pm 252.69$ |
| Idmuon | $18.64 \pm 0.51$ | 0.61 | 0.07 | $7973.54 \pm 252.69$ |
| Iso | $17.94 \pm 0.51$ | 0.59 | 0.07 | $4925.24 \pm 233.75$ |
| TriggerMatch | $15.28 \pm 0.47$ | 0.50 | 0.09 | $3792.40 \pm 167.37$ |
| $\|b\mathrm{-Jets}\| == 0$ | $15.08 \pm 0.47$ | 0.49 | 0.10 | $1539.35 \pm 152.58$ |
| $\sum H_T < 140\,\mathrm{GeV}$ | $13.10 \pm 0.42$ | 0.43 | 0.09 | $1021.49 \pm 148.04$ |
| $E_T^{miss} < 60\,\mathrm{GeV}$ | $13.03 \pm 0.42$ | 0.43 | 0.09 | $777.94 \pm 140.56$ |
| $40\,\mathrm{GeV} < \mathrm{M}_{ee\mu} < 90\,\mathrm{GeV}$ | $12.55 \pm 0.42$ | 0.41 | 0.09 | $533.59 \pm 136.49$ |
| IP | $10.35 \pm 0.38$ | 0.34 | 0.40 | $53.77 \pm 23.50$ |

1. Tables normalized to $36 fb^{-1}$
2. Bottom table shows cut flow for 50 GeV HNL mass.

# Exclusion Limits

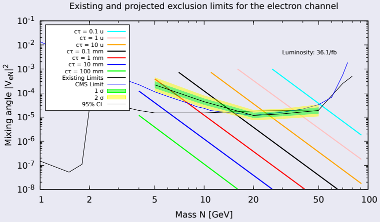



## Background estimation

1. CR were defined inverting specific cuts
2. A shape extrapolation was made from CRs to SR
3. Exclusion strengths were obtained

## Exclusion



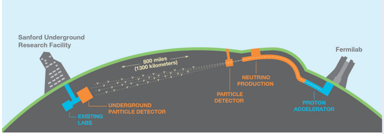
# Content

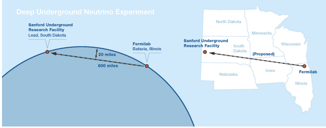
- Introduction
- The $\nu$ Minimal SM
- HNL Search at ATLAS
- HNL Search at DUNE
- Summary

# Introduction

1. International science collaboration
2. **D**eep **U**nderground **N**eutrino **E**xperiment
3. "do for neutrinos what the LHC did for the Higgs"
4. Three Colombian Institutions involve in DUNE:
   Univ. Atlantico, Univ. Sergio Arboleda and UAN
5. In particular the UAN is participating in the Photon Detector System

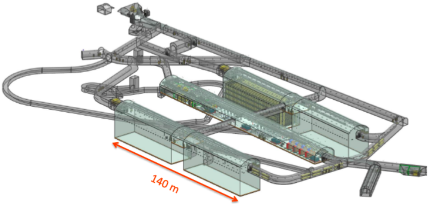
# DUNE Overview




## DUNE Features

1. A powerful (MW) neutrino beam fired from Fermilab(LBNF)
2. Near Detector: Constraining of the neutrino flux
3. Far Detector: A massive LAr TPC
   (70000 t $=4\times17.5kt$)

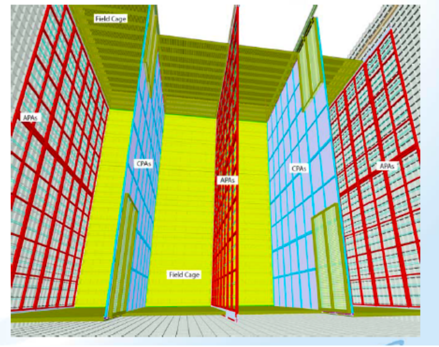


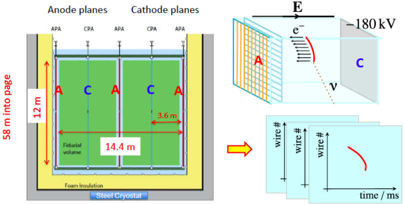
# Introduction

## More DUNE Features

1. Four Detector:
   Two Single Phase and Two Dual Phase
2. $10\,\mathrm{kt}$ fiducial cryostat each
3. Width $= 14.5\,\mathrm{m}$, Height$=12\,\mathrm{m}$, Length$=58\,\mathrm{m}$
4. 150 APAs, 200 CPAs
5. 385000 Readout Channels
6. One Functional Prototype at CERN: ProDUNE
7. TDR to be released April 2019
8. TP made public yesterday

   https://arxiv.org/abs/1807.10327
9. Start of Construction 2022
10. Operational by 2026



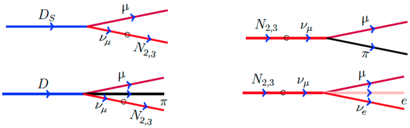



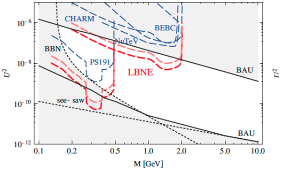

FNAL.gov

# DUNE Physics Program

1. Neutrino oscillation:
    1. Precision Oscillation Physics.
    2. Mass Hierarchy
    3. CP violation in the leptonic sector
2. Nucleon Decay (ND):
    1. $p \to K^+ \bar{\nu}$ (SUSY Models predictions)
    2. Have many Protons and wait until decay happen
3. Supernova Burst Physics (SPB):
    1. Astrophysics program
    2. Galatic Core Collapse Supernova
    3. Black Hole Formation

# HNL Signature in DUNE




http://arxiv.org/pdf/1307.7335

1. HNL produced through weak decay of heavy mesons and baryons
2. The mesons produced by scattering off of LBNE beam
3. HNL detected in the ND
4. For $500 MeV < M_N < 2 GeV$ production via D-Mesons
5. For $140 MeV < M_N < 500 MeV$ production via K-Mesons
6. For $50 MeV < M_N < 140 MeV$ production via $\pi$-Mesons

# Summary

1. $\nu$MSM is the most economical solution to the main open questions in physics.
2. Lightest HNL is a good candidate to dark matter particle.
3. ATLAS results on HNL almost ready to be published
4. Search for HNL with DUNE is possible.
5. Final detector design needed to understand full detection capacities

# Backup Slides

# Neutrino-Nucleon Interactions