Introduction to Heavy Neutrinos

J. Siado, D. Claes, S. Chauhan

University of Nebraska
UNL HEP Meeting

June 3, 2020

Introduction

- Standard model unanswered questions
  - Dark Matter
  - Baryon Asymmetry
  - Smallness of neutrino masses
- A heavy neutrino could explain the latter using the see-saw mechanism
- The Neutrino Minimal Standard Model (νMSM) could solve all three problems by postulating three new right-handed heavy neutrinos, RHN
  - If RHN are sterile and massive, they would be good candidates for dark matter
  - Consider neutrino oscillations during the the big bang formation of particles, Leptogenesis $\rightarrow$ baryon asymmetry
  - Next slide

Introduction: See-saw Mechanism

- Consider the SM Lagrangian with the addition of a single new RH neutrino

$$L \supset F_\alpha \bar{L}_\alpha H N + \frac{1}{2} M \bar{N}^c N$$

- Only one flavor of N is produced at a time for a given interaction
- After electroweak symmetry breaking the mass eigenstates are

$$M_{\nu\alpha} \sim \frac{F_\alpha^2 \left\langle H \right\rangle^2}{M}$$

$$M_N \sim M$$

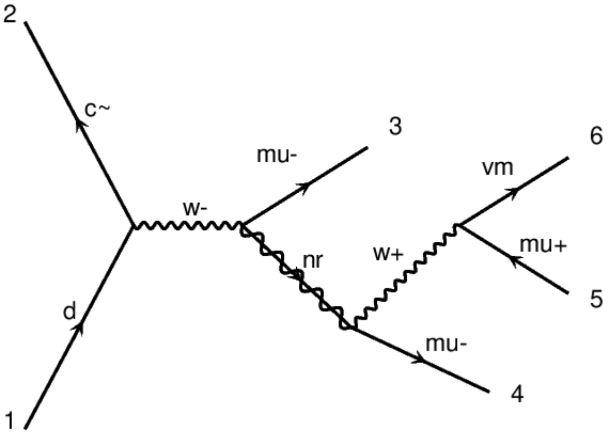
- Then, if the mass of one ν increases the mass of the other decreases, hence the name see-saw

Introduction

- Issues with the see-saw mechanism
  - What is the scale of M_R and what determines it?
  - Is there a natural reason for the existence of the right handed neutrinos?
  - Is the see-saw mechanism by itself enough to explain all aspects of neutrino masses and mixings?

Event signature

- Event signature consist of three charged leptons (e, μ) plus missing energy



- item 2

The Analysis

- Consider the case where N mixes only with ν_μ
- Production
  - From W bosons,$W^{\pm} \rightarrow \mu^{\pm} N$
  - When allowed, from $B^{\pm} \rightarrow D\mu^{\pm} N$
  - N is produced in association with prompt muons and other objects
- Decay
  - N could decay via off-shell W/Z bosons to SM particles
  - Leptonic $N \rightarrow \mu^{\pm} l^{\mp} \nu_l$ and $N \rightarrow \nu_\mu l^+ l^-$, with a distinctive final state of multiple charged leptons
  - Semileptonic $N \rightarrow \mu^{\pm} q\bar{q}$, larger backgrounds

The Analysis

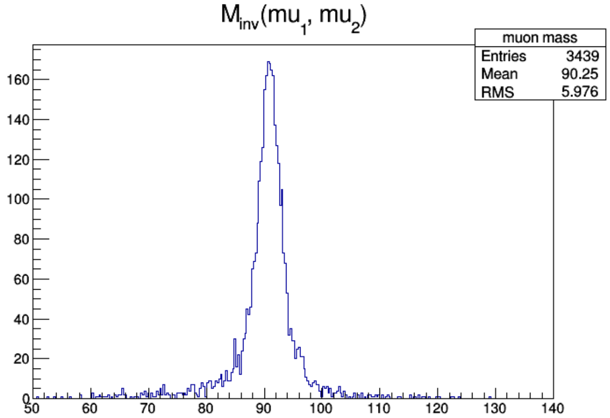
- The search includes
- Displaced lepton jet
  - $\mathrm{M}_N < M_W$
  - RN is boosted in $W^\pm \to \mu^\pm N$
  - Signature: prompt lepton + a single displaced lepton jet
- Prompt trilepton
  - For $M_W > M_N > 15 GeV$
  - RH is not boosted nor substancially displaced
  - $W^\pm \to \mu^\pm N \to \mu^\pm \mu^\pm e^\mp \nu$, small SM background
  - Studied for $M_N \geqslant 100 Gev$

First Simulations

- Used madgraph and pythia to simulate the processes
  - Started with $Z- > \mu^+\mu^-$
  - $pp \rightarrow w \rightarrow \mu nr(nr \rightarrow w\mu, w \rightarrow \nu_\mu \mu)$
  - Energy 13 TeV
  - $M_N = 30$ Gev
  - 10k events
- Used delphes to make preliminary plots

Reconstructed Z peak

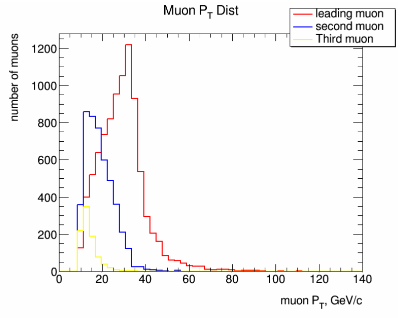
- Reconstructed the Z mass peak to test Madgraph, Delphes, and Pythia



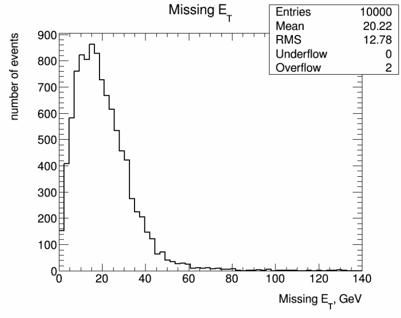
- If things work well move to the RHN

Preliminary Plots

- P_t Distribution of all muons in the event



- Missing energy distribution



Next

- **Next**
  - Reconstruct the full decay chain
  - Produce MC samplels
- **References**
  - arXiv:1504.02470v2 [hep-ph]
  - arXiv:1802.02965v2 [hep-ex]

References

- arXiv:1504.02470v2 [hep-ph]
- arXiv:1802.02965v2 [hep-ex]