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Search for New Physics in ZZ+MET

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We present a search for a heavy unstable fourth generation neutrino N_2 which decays to a heavy stable fourth generation neutrino N_1 and a Z boson. Pair production of N_2 via the process $p\bar{p} \rightarrow N_2N_2 \rightarrow N_1ZN_1Z \rightarrow N_1N_1\ell^+\ell^-q\bar{q}$ leads to a detector signature of two charged leptons, two jets and large missing transverse momentum. In 4 fb^{-1} of data from collisions recorded by the CDF detector in proton-antiproton collisions at the Tevatron with center-of-mass energy of 1.96 TeV, we find agreement between data and standard model backgrounds. We continue to find cross-section limits in the magnitude of 300 fb, and yield limits in the magnitude of 14 events.

I. INTRODUCTION

In the standard model of elementary particles the existence of three generations of particles in the quark and lepton sectors is already well documented. A 4^{th} generation of particles would be a natural extension.

Following the trend of the standard model the least massive particle of this 4^{th} generation may be the neutrino, N_1. Such a neutrino may not be solely a Dirac or Majorana state, but a mixture of the two. Such a particle would partially evade the neutrino mass constraints from Z width studies at LEP[1], leading to a reanalysis of the resulting limits [2].

The two states lead to two mass eigenstates N_1 and N_2, where N_2 is the unstable heavy eigenstate and N_1 is the stable and least massive eigenstate of the 4^{th} generation neutrinos.

The largest production mechanism of which would be via a Drell-Yan process:

$$p\bar{p} \rightarrow Z/\gamma^* \rightarrow N_2N_2 \rightarrow N_1ZN_1Z$$

II. DATASET AND SELECTION

Using 1.96 TeV $p\bar{p}$ collision data corresponding to 4.1fb^{-1} of integrated luminosity collected at CDF II detector we consider the mode in which one Z decays hadronically and the other decays leptonically, giving a detector signature of two charged leptons, two jets and large missing transverse momentum. The final state contains two charged leptons, two jets and large missing transverse momentum.

To isolate this signature, we require

- Two opposite-charge, same-flavor, leptons (e or μ) with $p_T > 20$ GeV.
- Lepton-pair invariant mass consistent with decay from a Z: $M_{\ell\ell} \in [76, 106]$ GeV.
- At least two jets, $p_T > 15$ GeV and $|\eta| < 2.5$, both jets without SECVTX b-tag
- Large missing transverse momentum with $\not{E}_T >$ approximately 40 GeV, depending on the N_1, N_2 masses.

Our signal has peaks in both M_{ll} and M_{jj}. To isolate this in a single variable, we define a "Delta Mass Function",

$$\sqrt{(\frac{M_{ll}-91.6}{10})^2 + (\frac{M_{jj}-85.3}{15})^2}$$

where 91.6 (10) is the fitted Z mass (width) in M_{ll} and 85.3(15) is the fitted Z mass (width) in M_{jj} for signal events. The function aims to increase the sensitivity of our analysis by segregating as much of the signal from the backgrounds as much as possible.

III. BACKGROUNDS

There are several processes that must recognize, that create biproducts similar to our signature of leptons and jets.

- $p\bar{p} \to Z \to ll + jets$ This has M_{ll} close to M_Z, but no peak in M_{jj} and no real missing transverse momentum. We model this using ALPGEN+PYTHIA.
- $p\bar{p} \to Z \to W^+W^- \to l + \nu + jets$ This has a second lepton misidentified from a jet, so M_{ll} is not close to M_W, and M_{jj} close to M_W but there is no real missing transverse momentum. We model this using PYTHIA.
- $p\bar{p} \to Z \to W^+Z \to ll + jets$ In this process M_{ll} and M_{jj} are close to M_W and M_Z but there is no real missing transverse momentum. We model this using PYTHIA.
- $p\bar{p} \to Z \to ZZ \to ll + jets$ Here M_{ll} and M_{jj} are close to M_Z but there is no real missing transverse momentum. We model this using PYTHIA.
- $p\bar{p} \to g \to t\bar{t} \to ll + \nu\nu + jets$ This has M_{ll} and M_{jj} without peaks but there is a real missing transverse momentum from the neutrinos.We model this using PYTHIA.
- $p\bar{p} \to W \to l + \nu + jets$ This only has one real lepton, but a second lepton misidentified from a jet. So this has M_{ll} and M_{jj} without peaks but there is a real missing transverse momentum from the nuetrino. We model this using a data-driven method, following Ref. [5].

IV. OBSERVED DATA

We evaluate the cross-section and yield limits [6] of the $\mathrm{N_2N_2}$ process in 4 fb^{-1} of data from collisions recorded by the CDF detector in proton-antiproton collisions at the Tevatron with center-of-mass energy of 1.96 TeV.

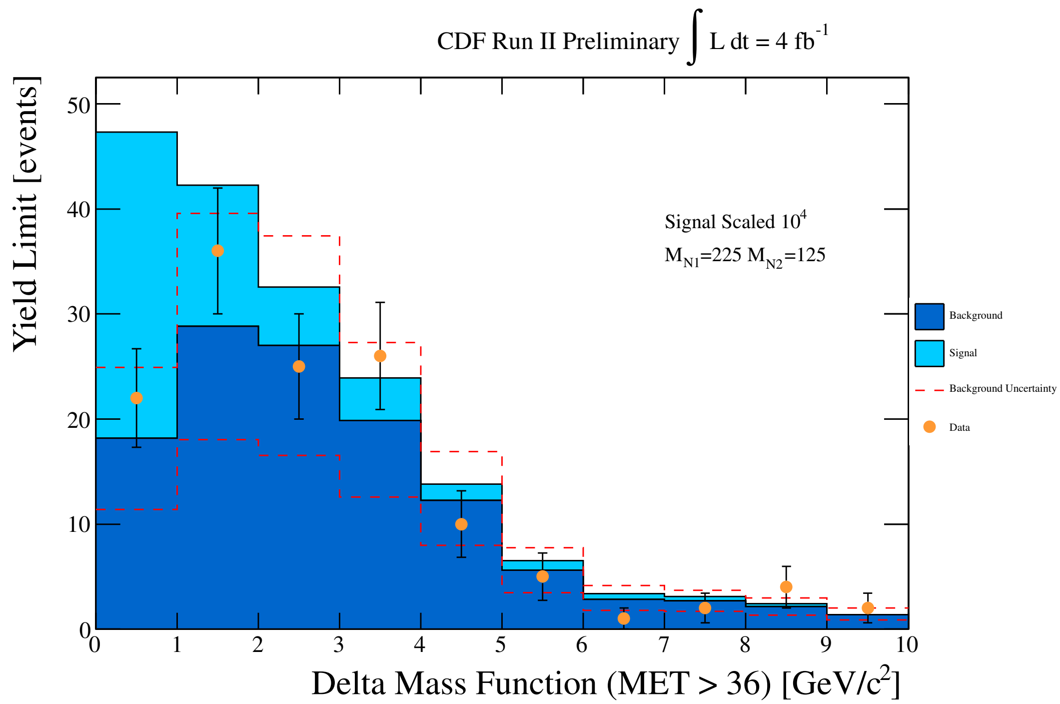

FIG. 1: Delta mass function of signal stacked on background for mass point M$_{N2}$=225 and M$_{N1}$=125 with selection cut of MET>33 GeV. Data points and background uncertainties [4] are shown.

Theoretical cross-section and yields for each mass point are presented in the table below, along with their respective expected and observed limits. Also provided are plots of acceptance and the expected and observed cross-section limits across the spectrum of mass points M$_{N2}$ and M$_{N1}$.

CDF Run II Preliminary $\int Ldt = 4fb^{-1}$ 95% CL

M_{N1} [GeV/c^2]	M_{N2} [GeV/c^2]	Cut [GeV]	Acceptance [%]	Cross-Section [fb] Theory	Cross-Section [fb] Exp. Limit	Cross-Section [fb] Obs. Limit	Yield [events] Theory	Yield [events] Exp. Limit	Yield [events] Obs. Limit
75	175	37	0.99	5.1e-01	511	702	2.1e-02	21	29
75	200	68	1.02	2.1e-01	292	369	8.8e-03	12	16
125	225	35	0.85	1.6e-01	684	1088	5.8e-03	24	39
75	225	92	0.93	8.1e-02	156	273	3.2e-03	6	11
75	275	118	1.01	1.5e-02	94	132	6.2e-04	3	6
125	300	119	1.06	1.3e-02	99	138	5.9e-04	4	6
175	300	80	0.96	2.2e-02	171	315	8.8e-04	6	13
125	350	156	1.05	2.9e-03	75	48	1.3e-04	3	2
225	350	80	1.05	6.3e-03	190	297	2.8e-04	8	13
75	350	167	1.06	1.2e-03	71	55	5.54e-05	3	2

CDF Run II Preliminary $\int Ldt = 4fb^{-1}$ 95% CL

M_{N1} [GeV/c^2]	M_{N2} [GeV/c^2]	Cross-Section [fb] *Exp. Limit	Obs. Limit	Yield [events] *Exp. Limit	Obs. Limit
75	175	[243.2 , 901.3]	701.6	[10 , 38]	29
75	200	[107.1 , 649.2]	368.9	[5 , 28]	16
125	225	[332.3 , 1182.6]	1087.9	[12 , 42]	39
75	225	[53.7 , 329.2]	273.2	[2 , 13]	11
75	275	[49.2 , 211.5]	132.2	[2 , 9]	6
125	300	[44.2 , 209.6]	137.5	[2 , 9]	6
175	300	[67.0 , 369.7]	315.4	[3 , 15]	13
125	350	[41.0 , 161.6]	47.7	[2 , 7]	2
225	350	[76.6 , 420.0]	297.0	[3 , 19]	13
75	350	[42.2 , 153.7]	54.9	[2 , 7]	2

* Expected Values shown are the 2 sigma boundaries

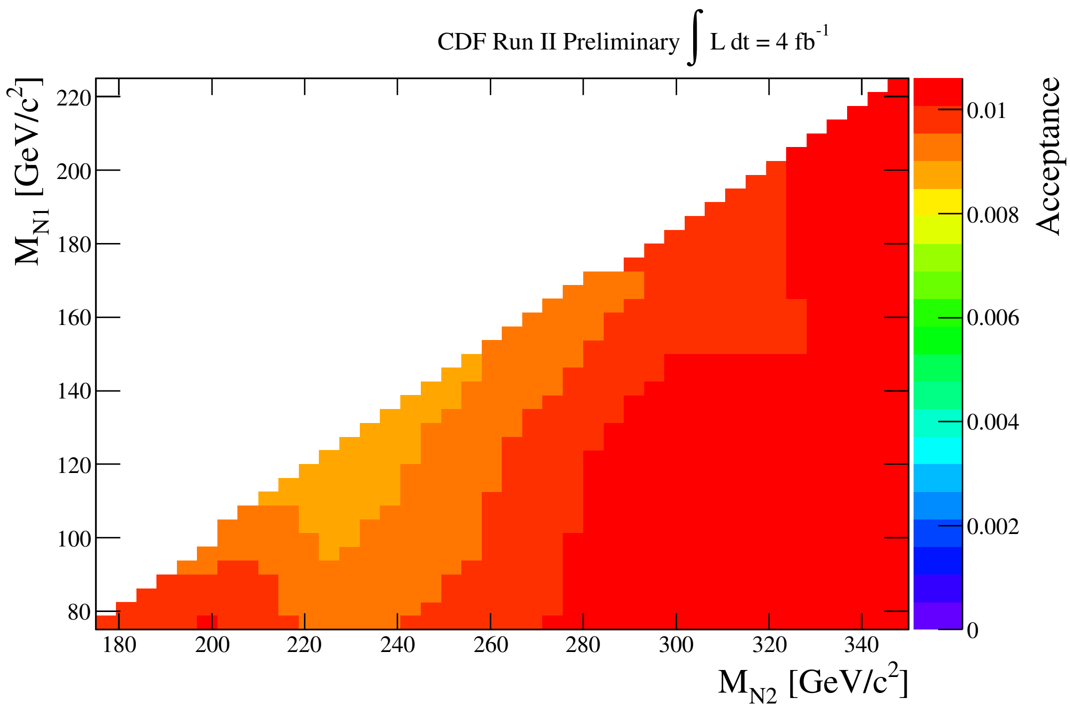

FIG. 2: Plot of acceptance for spectrum of M_{N2} and M_{N1} mass points.

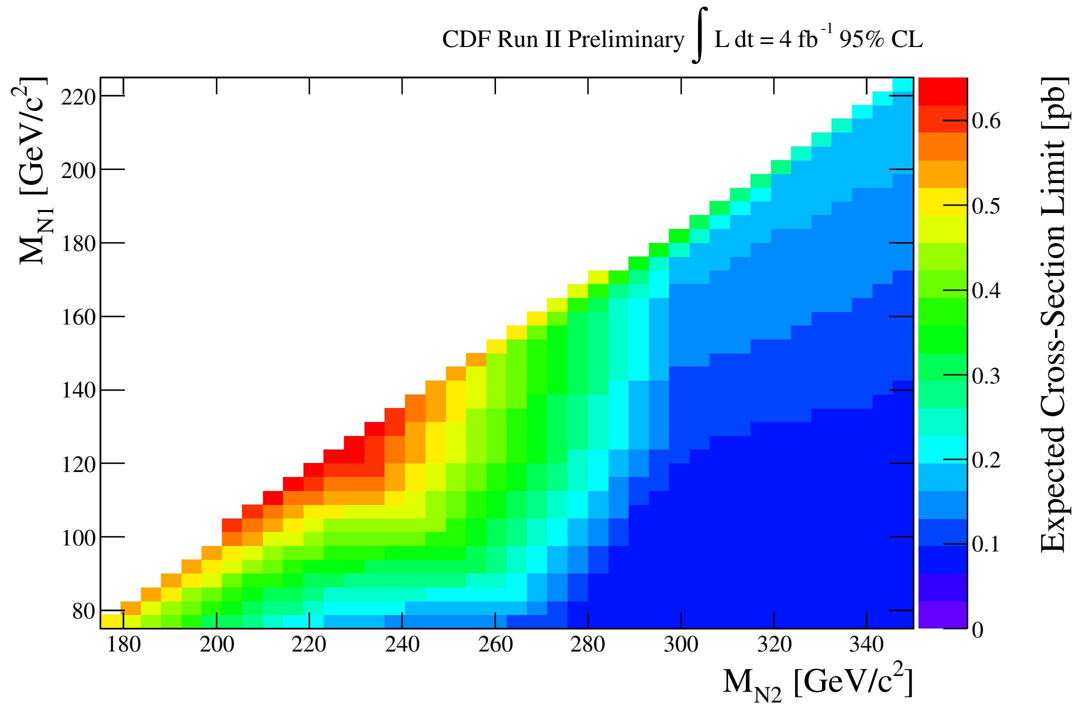

FIG. 3: Plot of expected cross-section limit for spectrum of M_{N2} and M_{N1} mass points.

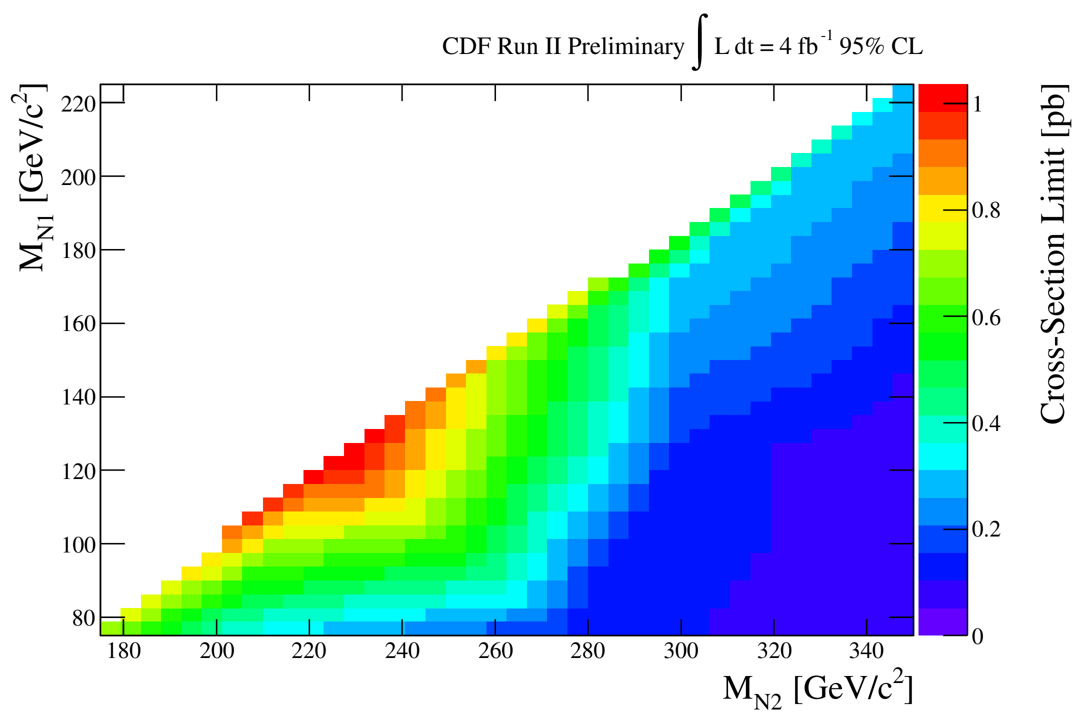

FIG. 4: Plot of observed cross-section limit for spectrum of M_{N2} and M_{N1} mass points.

V. CONCLUSIONS

We explored a new theory of physics in where a heavey massive neutrino has both a Dirac and Majorana eigenstate. We compared the new physics characteristics to 4 fb^{-1} of data from Run II Tevatron to find cross-section limits in the magnitude of 300 fb and yield limits in the magnitude of 14 events across a spectrum of generated mass points M_{N2} and M_{N1}.

Acknowledgments

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[1] LEP Z width
[2] L Carpenter et al
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