Neutrinos vs Lepton Flavour Violation Decays

to be Probed at TESLA

To Gain Insight into the Theoretical Problems of ν Nature:

1. Double Beta Neutrinoless Decay;
2. Massive ν Oscillations: Solar and Atmospheric ν's;
3. Possible Theoretical Interpretations;
4. Dark Matter Candidates: ν's and $\tilde{\chi}_1{}^0$;
5. ν_L flips due to magnetic moment into ν_R;
6. Lepton Flavour Violation Decays in the Charge Lepton Sector;
7. Preliminary: SUSY LFV Signatures Expected at Tesla;
8. Preliminary: A Model Parameter Space to be Probed at Tesla.
9. Aims and preliminary outlines.

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Neutrinoless Double Beta Decay

- Double–beta neutrinoless decay is a second–order weak process in which two neutrons inside a nucleus spontaneously transform into two protons exchanging light virtual neutrino.
- Double beta decay with virtual ν exchange:
  $n \rightarrow p + e^- + \bar{\nu}$ & $\bar{\nu} + n \rightarrow p + e^-$
- Result: $(Z, A) \rightarrow (Z + 2, A) + 2e^-$
- Double beta neutrinoless decay can also occur through the exchange of other particles, perhaps some predicted by supersymmetric models, between the nucleons.
- To conserve charge two electrons must be emitted.

Neutrinoless Double Beta Decay

- No matter what the exchange particles are, however, the occurence of $\beta\beta(0\nu)$ decay implies that neutrinos are Majorana particles ($\nu \equiv \bar{\nu}$) with nonzero mass, (Schechter and Valle, Phys. Rev. D 25, 11, 2951–2954, 1982) and $\Delta L = 2$.
- If neutrinos are Dirac type the $\beta\beta(0\nu)$ decays will not occur.

Neutrinoless $\beta\beta$ Decay and Gauge Theories

Schechter and Valle, Phys. Rev. D 25(11), 1982, pp 2951–2954

1. Gauge theories give contributions to neutrinoless double β decay. For a "natural" gauge theory we argue that this is indeed the case. Postulate: 'Strong Naturality' in which no global conservation laws are assumed *a priori*.
2. Neutrinoless double–beta decay induces a $\bar{\nu}_e - to - \nu_e$ transition, that is, an effective Majorana mass term.
3. Any realistic gauge theory will include the ordinary W-gauge field interaction with the left–handed electron and neutrino and with the u and d quarks.
4. Question remains: ν_R Interactions ?

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GENIUS: Evidence for $\beta\beta(0\nu)$ Decays

- $\beta\beta$ experiment in the Gran Sasso Laboratory GENIUS has been most sensitive $\beta\beta$ experiment worldwide. It has results for the period 1990–2003 for $^{76}Ge \rightarrow ^{76} Se + 2e^-$. Last three years data statistics have proven the expectation for $\beta\beta(0\nu)$ decay at 4.2σ level with 99.9% C.L.
  See Ref. hep–ph/0404088.
- See Ref. hep–ph/0304032, 3 April 2003
- Observation of the neutrinoless double beta decay has established that there is lepton number violation in nature
- The neutrino masses are Majorana in nature.

GENIUS: Evidence for $\beta\beta(0\nu)$ Decays

- It also gives the absolute mass of the neutrinos and discriminates between different models of neutrino masses.
- The allowed amount on lepton number violation puts severe constraints on some possible new physics beyond the standard model.
- puts severe constraints on some possible new physics beyond the standard model. The resent results from WMAP are consistent with the consequences of the neutrinoless double beta decay.
- The goal of GENIUS experiment is to confirm the DAMA dark matter result.
- With RpV neutrino masses are strongly hierarchical.
- Absolute Mass of the neutrino 0.12–0.9 eV.

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$B - L$ Violation Mechanism

Since is Majorana particle, they must not have any additive quantum number, local of global. Thus, total lepton number must be broken, more exactly $B - L$ should be broken. This is the only true global symmetry of the model in presence of ν-mixing.

The mechanism of $B - L$ violation: if spontaneously then Goldstone boson called Majoron would be produced in the neutrino decays, e.g. $\nu_i \longrightarrow \nu_j + J$.

Probably the only possible way to search for such decays would be $\beta\beta(0\nu)$.

R–Parity

- When total lepton number L is violated

$$R_p = (-1)^{3B+L+2S} \text{ symmetry}$$

  violation naturally accompanies Majorana neutrino mass term.

- To look for new physics via indirect effects of "heavy" unknown particles is very natural although not trivial.

- To explore how well $R-$parity violating supersymmetric models can explain the observed neutrino mass and mixing pattern.
  See Ref. hep–ph/0011248 May 2001, W. Porod, J. Valle et al. "Testing ν mixing at future collider experiments".

R–Parity

- Bilinear breaking of $R - parity$ leads to a weak–scale seesaw mechanism for the atmospheric neutrino scale and a radiative mechanism for the solar neutrino scale.
- Taking into account data from atmospheric neutrino experiments the authors derived predictions for neutralino decays. It provides as well some prediction of SUSY parameters of MSSM model to be checked at colliders. thus,
- The model has implication for the collider searches of SUSY particles.

ν and SUSY without R–Parity

1. Symmetry Breaking and LSP-Phenomenology, Ralf Hempfling.
Davis Institute for High Energy Physics, *Davis*, *CA*95616, *USA*
E-mail: hempf@bethe.ucdavis.edu

The model without R–parity: the $\tilde{\chi}_1^0$ decays if Unified Supergravity is radiatively broken.
Assuming that Higgs/slepton mixing is the only source of R–parity breaking and responsible for the observed neutrino oscillations we obtain predictions for the LSP life–time and branching fractions.

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$\tilde{\chi}_1^0$ Decays with broken $R-$parity

When R_p is violated the produced event topologies are remarkably different

See as well hep–ph/0011248 May 2001, W. Porod, J. Valle et al.:

- $\tilde{\chi}_1^0 \to \nu_i \nu_j \nu_k$
- $\tilde{\chi}_1^0 \to \nu_i q \bar{q}$
- $\tilde{\chi}_1^0 \to \nu_i \ell_i^+ \ell_j^-$
- $\tilde{\chi}_1^0 \to \ell_i^\pm q q'$
- $\tilde{\chi}_1^0 \to \nu_i \gamma$ with $Br \sim 10^{-7}$
- To be added the constraints from the Dark Matter Searches
- and “Flavor Changing Supersymmetry Interactions in a Supernova”, hep–ph/0407130 11 July 2004.

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SUSY $\beta\beta(0\nu)$ Decays with bilinear $R-$parity breaking

See Ref. hep–ph/0201277 and hep–ph/9812463 M. Hirsch and J. Valle

- The origin of $R-$parity conservation is unknown.
- The $R-$parity could arise as a residual effect in larger theories or spontaneously due to a sneutrino vacuum expectation value (VEV). The modern variants of supersymmetric models with spontaneous $R - parity$ breaking are viable.
- SUSY $\beta\beta(0\nu)$ decays could constrain only the first generation R-parity violating coupling $W = \lambda'_{111} L_1 Q_1 D_1^c$.

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SUSY $\beta\beta(0\nu)$ Decays with bilinear $R-$parity breaking

See Ref. hep–ph/0201277 and hep–ph/9812463 M. Hirsch and J. Valle

- $R-$parity conserving SUSY contributions to $\beta\beta(0\nu)$ decay occur at the level of box diagrams. Double beta decay then yields information on the mass splitting in the sneutrino–antisneutrino system. These constraints leave room for accelerator searches for certain manifistations of the second and third generation $(B-L)$ violating sneutrino masses to be searched for directly.
- $\beta\beta(0\nu)$ decays provide very stringent limit on RpV parameters of the first generation. For any reasonable choice of MSSM parameters in the bilinear R_p model the mass mechanism is the dominant contribution to $\beta\beta(0\nu)$ decays.

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ν_R

- ν has its magnetic moment and thus is massive. If this moment is large enough, the ν_L from the nuclear reactions can flip their helicity in the solar magnetic field and turn into ν_R.
- The ν_R have smaller cross–section and are harder to detect.
- Ref: hep–ph/0311014, 6 June 2004, Constraining the ν magnetic moment with $\bar{\nu}$ from the Sun, J. W. F. Valle et al.
  $\mu_\nu \leq few \times 10^{-12} \mu_B$

ν in Big Bang Cosmology

- Relic νs are nonluminous halo and having the mass they are very important for cosmology. The number of density of ν is about 8 orders of magnitude larger than the average number density of baryons in the universe. ν affect the evolution of the Universe as a whole. However, this fact depends on neutrino mass and is important issue of ν mixing.
- ν mass has crucial impact on Cosmology and its right component should be $\geq 10^8$ GeV.

ν in Big Bang Cosmology

- Leptogenesis is a possible and likely explanation for the observed baryon asymmetry of the universe. Several other alternative proposals are on the verge of being ruled out. Moreover, leptogenesis scenario implies constraints on both light and heavy neutrino masses, which are consistent with present value obtained from the double beta decay of ^{76}Ge.

Lepton Vlavour Violation Decays

hep–ph/0407325 28 July 2004, A. Masiero, S. Vempati, O. Vives.

- In spite of the LFV observed in ν oscillations, within the Standard Model, we do not expect any visible LFV in the charged lepton sector. On the contrary, the presence of new physics close to the electroweak scale can enhance the amplitudes of these processes. We discuss this in general and focus on a particularly interesting case: the marriage of low-energy supersymmetry (SUSY) and seesaw mechanism for ν masses (SUSY seesaw). Several ideas presented in this context are reviewed both in the bottom–up and top–down approaches. We show that there exist attractive models where the rate for LFV processes can attain values to be probed in pre–LHC experiments.

Lepton Vlavour Violation Decays

hep–ph/0407325 28 July 2004, A. Masiero, S. Vempati, O. Vives.

Present Limits	Upcoming Limits
$Br(\mu \to e\gamma) \leq 1.2 \times 10^{-11}$	$Br(\mu \to e\gamma) \leq 10^{-13} - 10^{-14}$
$Br(\tau \to \mu\gamma) \leq 3.1 \times 10^{-7}$	$Br(\tau \to \mu\gamma) \leq 10^{-8}$
$Br(\tau \to e\gamma) \leq 3.7 \times 10^{-7}$	$Br(\tau \to e\gamma) \leq 10^{-8}$

Lepton Number Violating Decay $\tau \to \mu\gamma$

- Present Limits from **BaBar** between 1999 and 2001, hep–ex/0212009, 04.12.2002
  $Br(\tau \to \mu\gamma) \leq 2.0 \times 10^{-6}$ at 90% C.L.
- Taking into account Solar, Atmospheric Neutrino Oscillations Lepton Flavour Violating Processes can be well described in the minimal supersymmetric standard model with right handed neutrinos, assuming mSUGRA scenario.
- $Br \sim \tan\beta^2$ (See Ref. hep/ph–9810479 for MSSMRN).
  For $\tan\beta = 30$ – $Br(\tau \to \mu\gamma) \leq 3.0 \times 10^{-6}$), $m_{\tilde{\ell}_L} \geq 170 GeV$.

SUSY LFV ℓ, $\tilde{\chi}_i^0$ and $\tilde{\chi}_j^\pm$ decays and Signatures

The Decays:

1. $e^+e^- \longrightarrow \tilde{e}\tilde{\mu}$
2. $e^+e^- \longrightarrow \tilde{\tau}\tilde{\mu}$
3. $e^+e^- \longrightarrow \tilde{e}\tilde{\tau}$
4. $\tilde{\ell}^i_{L,R} \longrightarrow \ell_j \gamma$
5. $\tilde{\ell}^i_{L,R} \longrightarrow \ell_i \tilde{\chi}_1^0$
6. $\tilde{\chi}_2 \longrightarrow \tilde{\tau}\mu$
7. $\tilde{\tau} \longrightarrow \mu\gamma$

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mSUGRA: some draft estimations

- Minimal supergravity unification (mSUGRA) model have been formulated in 1982 by Pran Nath and Richard Arnowitt.
- hep–ph/0407158 Y. Mambrini, C. Munoz
  Gamma–ray detection from neutralino annihilation in non–universal SUGRA scenarios. See the $(m_0, m_{1/2})$ plots therein for various $\tan\beta$.
  My preliminary conclusions on parameters to be probed at TESLA:
- Almost entire parameter $(m0, m_{1/2})$ space for TESLA is well constrained with $b \to s\gamma$ decays.
- Expected well in accordance with hep–ex/0212009 $\tan\beta$ provides plausible region for searches at TESLA.

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Aims and Conclusions

1. A real problem today: Thousands of the theoretical papers published.
2. Gaining insight to the ν's mass origin and its interactions to check completeness of the list of possible Lepton Flavour Violation decays and to study them at TESLA.
3. To outline LVF parameter range which can be probed at TESLA.

   Range of interest: $3 \tan\beta \leq 45$ with $170\ \mathrm{GeV} \leq m_{\tilde{\ell}} \leq 500\ \mathrm{GeV}$.
4. "LFV is possible to simulate with PYTHIA 6.2", Torbjorn Sjostrand.
5. To simulate Signal vs Background with GEANT to handle

proper γ reconstruction in the rare $Br(\tau \rightarrow \mu\gamma) \sim 10^{-6} - 10^{-7}$ decays.

6. With LFV signal observability in different topologies possibly to constraint theory model parameters.
7. To compare theory model parameter reach with LHC. The complementarity will help to constraint parameters globally.