Resonant Production of Scalar Leptons by RPV Couplings at the FCC

O. Bolukbasi[1], S. Kartal[1], A. Yilmaz[1], C. Pagliarone[2,3] K. Ozdemir[4], S. Sultansoy[5,6], M. Sahin[7]

1. Istanbul University, Istanbul
2. Laboratori Nazionali del Gran Sasso (LNGS/INFN)
3. DICeM, Università degli Studi di Cassino e del Lazio Meridionale
4. Piri Reis University, Istanbul
5. TOBB ETU, Ankara
6. Institute of Physics, Baku
7. Usak University, Usak

ABSTRACT

Resonant production of and $\tilde{l}$ and $\tilde{\nu}$ at the FCC-pp has been considered. For example, scalar neutrino may be investigated through subprocess $\bar{d}d \to \tilde{\nu} \to l^+l'^-$. These processes have great potential for determination of RPV couplings

INTRODUCTION

Supersymmetry (SUSY) predicts a new bosonic (fermionic) partner for each fundamental Standard Model (SM) fermion (boson) as well as an additional Higgs doublet. These new particles can be scalar particles known as squarks and sleptons. They are carry baryon (B) or lepton (L) quantum numbers, potentially leading to interactions violating B or L conservation [1, 2].

R-parity quantum number defined as $R_p = (-1)^{3B+L+2S}$ SM particles have R-even quantum number ($R_p = +1$) and Supersymmetric particles have R-odd quantum number ($R_p = -1$). R-parity violation (RPV) interactions have rich phenomenological potential [1]. In this work, we studied resonant production of stauneutrino ($\tilde{\nu}_\tau$) by RPV violation interactions (pp collisions by $d\bar{d}$ annihilation and subsequently decay to final state) at the Future Circular Collider (FCC).

RPV interaction Lagrangian for slepton are given bellow [1]:

$$\mathcal{L}_{L_iL_jE_k^c} = -\frac{1}{2}\lambda_{ijk}\left(\tilde{\nu}_{iL}\bar{l}_{kR}l_{jL} + \tilde{l}_{jL}\bar{l}_{kR}\nu_{iL} + \tilde{l}^*_{kR}\bar{\nu}^c_{iR}l_{jL} - (i \leftrightarrow j)\right) + \text{h.c.}$$

$$\mathcal{L}_{L_iQ_jD_k^c} = -\lambda'_{ijk}\left(\tilde{\nu}_{iL}\bar{d}_{kR}d_{jL} + \tilde{d}_{jL}\bar{d}_{kR}\nu_{iL} + \tilde{d}^*_{kR}\bar{\nu}^c_{iR}d_{jL} - \tilde{l}_{iL}\bar{d}_{kR}u_{jL} - \tilde{u}_{jL}\bar{d}_{kR}l_{iL} - \tilde{d}^*_{kR}\bar{l}^c_{iR}u_{jL}\right) + \text{h.c.}$$

Where L and Q are SU(2) doublet superfields of leptons and quarks; l and d are the SU(2) singlet superfields of leptons and downlike quarks; λ and λ' are Yukawa couplings; and the indices i, j, and k denote fermion generations. Direct decays of sleptons via trilinear operators are given Table I

Table I. Direct decays of sleptons via trilinear 6Rp *operators* $\lambda_{ijk}L_iL_jE_k$ *and* $\lambda'_{ijk}L_iQ_jD_k$ [1].

Supersymmetric particles	Couplings λ_{ijk}	Couplings λ'_{ijk}
$\tilde{\nu}_{i,L}$	$\ell^+_{j,L}\ell^-_{k,R}$	$d_{j,L}d_{k,R}$
$\tilde{\ell}^-_{i,L}$	$\bar{\nu}_{j,L}\ell^-_{k,R}$	$\bar{u}_{j,L}d_{k,R}$
$\tilde{\nu}_{j,L}$	$\ell^+_{i,L}\ell^-_{k,R}$	
$\tilde{\ell}^-_{j,L}$	$\bar{\nu}_{i,L}\ell^-_{k,R}$	
$\tilde{\ell}^-_{k,R}$	$\nu_{i,L}\ell^-_{j,L}$, $\ell^-_{i,L}\nu_{j,L}$	

PRODUCTION AND DECAYS

2a. Sleptons

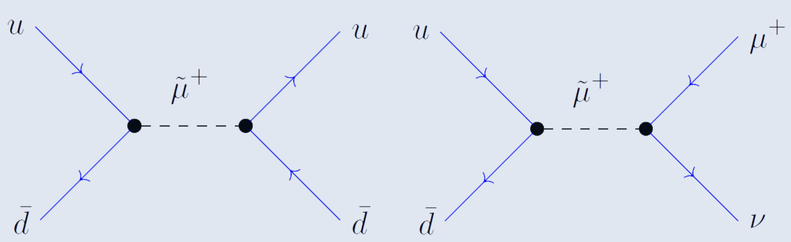

Figure 1. Resonant production followed by RPV decays (Dark circle denotes RPV vertices.).

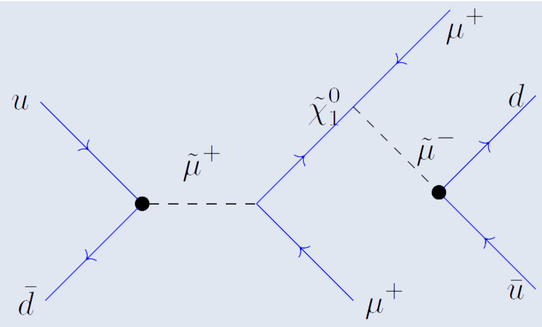

Figure 2. Most spectacular signature for $\tilde{\mu}^+$(Dark circle denotes RPV vertices.).

2b. Sneutrinos

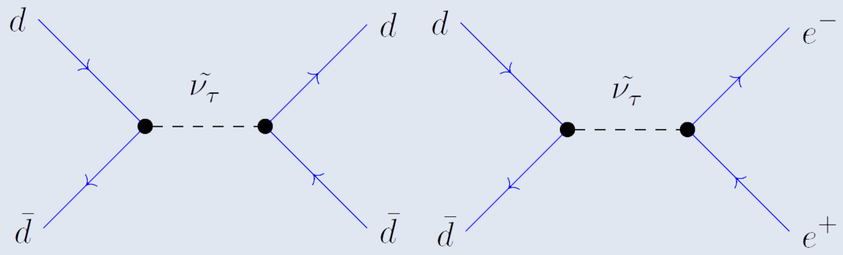

Figure 3. Resonant $\tilde{\nu}_\tau$ production followed by RPV decays (Dark circle denotes RPV vertices.).

Final state similar to Z' but $\bar{\nu}\nu$ and $\bar{u}u$ final states are absents. Again can be differantiate from Z' because of different distributions of final particles.

Most spectacular signature [5, 6]:

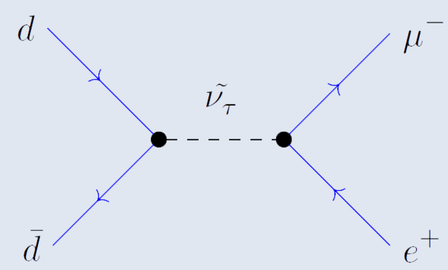

Figure 4. Most spectacular signature for $\tilde{\nu}_\tau$ (Dark circle denotes RPV vertix.).

PROCESS EXAMPLE

$$pp \to \tilde{\nu}_\tau X \to \mu^\pm e^\mp X$$

This process is analyzed both at ATLAS [5, 6] and CMS [7]. Using $\lambda_{132} = 0.07$ and $\lambda_{311} = 0.11$ ATLAS obtain $m_{\tilde{\nu}_\tau} > 2.0$ (2.3) TeV at $\sqrt{s} = 8$ (13) TeV and $L_{int} = 20$ (3.2) fb^{-1} .Coupling λ_{132} and λ_{231} correspond to μ^-e^+ and μ^+e^- final states, respectively. As such, for $e^\pm\mu^\mp$ final state it is assumed $\lambda_{312} = \lambda_{321} = 0.07$. Using extrapolation framework [8] one can estimate that LHC will cover $m_{\tilde{\nu}_\tau}$ up to 5.0 TeV with $L_{int} = 1$ ab^{-1}.

For numerical calculations we use CompHEP simulation program [9-11] in Figure 5 we present partial decay widths for $\tilde{\nu}_\tau \to \mu^+e^-$ and $\tilde{\nu}_\tau \to \bar{d}d$.

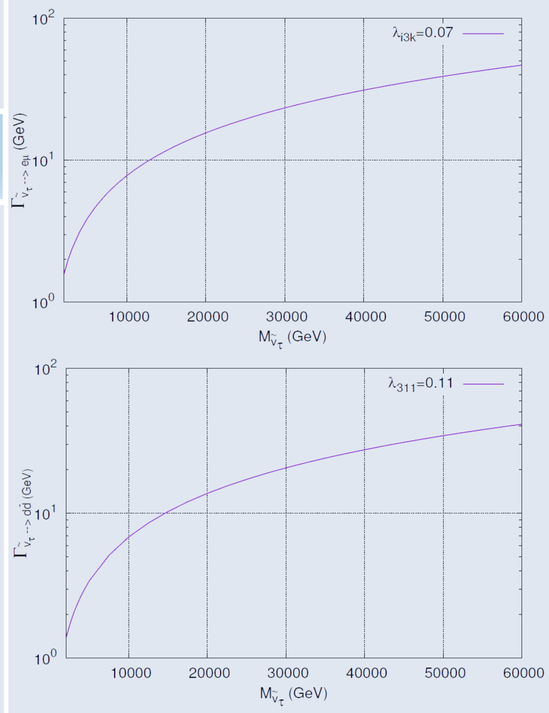

Figure 5. Partial decay widths of $\tilde{\nu}_\tau$: $\tilde{\nu}_\tau \to \mu^+e^-$ (up) and $\tilde{\nu}_\tau \to \bar{d}d$ (down). Cross-sections for the process under consideration is given in Figure 6.

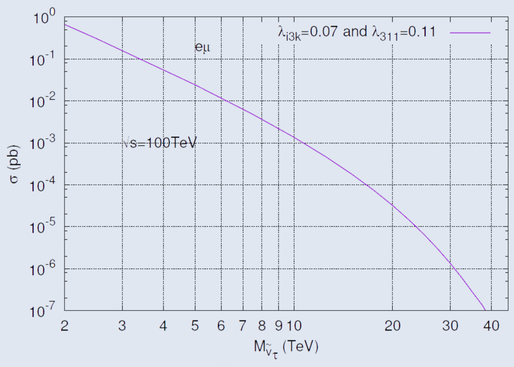

Figure 6. Cross-Sections versus mass graphic for $pp \to \tilde{\nu}_\tau X \to \mu^\pm e^\mp X$

It is seen that sufficiently high cross section values allow to exploration of stau-neutrino ($\tilde{\nu}_\tau$) high mass values.

SIGNAL AND BACKGROUND PROCESS

Our signal process is $pp \to \tilde{\nu}_\tau X \to \mu^\pm e^\mp X$ The SM process that produce $\mu^\pm e^\mp$ final states can be divided in to two categories: processes that produce two prompt lepton such as $pp \to t\bar{t}X$ and $pp \to W^+W^-$ and processes occur when jets mis-reconstructed as leptons predominantly $W/Z + \gamma$, $W/Z + jets$ and multijet events.

Dominant background contributions originate from and diboson production. Other contributions to background mainly comes from W+jets and multijet processes. The background of muons originating from hadronic decays is found to be negligible compared to the contribution from fake electrons and taus. Therefore, in the channel $e\mu$ where the contribution of W+jets and multijet processes to background is expected to be small. This reason we only take in to account $pp \to t\bar{t}X$ and $pp \to W^+W^-$ background processes in our calculations. We use the CalcHEP [9-11] simulation program for the calculation of signal process and MadGraph [12] simulation program for the calculations of background processes.

In order to extract $\tilde{\nu}_\tau$ signal and to suppress the backgrounds, the following cuts are applied: $p_T > 1000$ GeV and $|\eta| < 2.5$ for all final state muons (anti-muons) , electrons (positrons). For the signal $\lambda_{312} = \lambda_{321} = 0.07$ calculations have been used. Statistical significance has been calculated by using following formula: $S = \frac{\sigma_s}{\sqrt{\sigma_s + \sigma_B}}\sqrt{L_{int}}$ where σ_s and σ_B represent signal and background cross sections, respectively. L_{int} represent integrated luminosity of FCC. In Figure 7 we plot the attainable mass limit for the stau-neutrino.

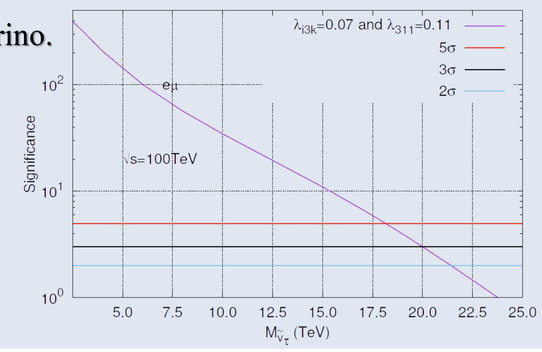

Figure 7. Attainable mass limits for stau-neutrino at the FCC-hh.

CONCLUSION

We investigated resonant production of stau-neutrino by RPV interaction at the FCC-hh collider. As a result of our calculations, if $\lambda_{312} = \lambda_{321} = 0.07$ FCC will give opportunity for discovery of stau-neutrino up to 18.1 TeV, observation up to 20 TeV and exclusion up to 21.4 TeV with L_{int}=1ab^{-1} . Large number of RPV coupling constants and parameters still remain unconstrained. That is way FCC will give the opportunity to detail probe RPV coupling λ_{ijk} and parameters.

ACKNOWLEDGMENTS

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