Explaining the CMS $eejj$ Excess with R-parity Violting Supersymmetry and Implications for Neutrinoless Double Beta Decay

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Outline

- CMS excess in the $eejj$ chanel
- The resonant slepton production
- Predictions for lepton number violating neutrinoless double beta decay

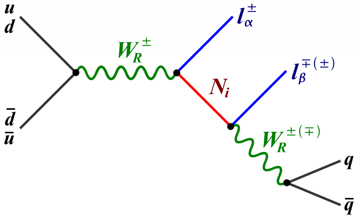
Correlation between BSM searches at collider and the lepton number violating neutrinoless double beta decay.

Contd

Few CMS and ATLAS excesses at LHC

- 2.8σ excess in $eejj$ channel (CMS, 2014, arXiv: 1407.3683)
- 2.4σ in $eejj$ and 2.6 σ excess in $e\nu jj$ channel (CMS, 2014, CMS-PAS-EXO-12-041)
- ATLAS searches in $pp \to X \to VV$ with $V = W, Z$ fully hadronic decays (arXiv:1506.00962) (Talk by Veronica Sanz, Michaelangelo Mangano)
- ...

CMS excess at $eejj$ channel- W_R search (arXiv: 1407.3683)



Left-Right symmetry

Left-Right symmetric theory

Pati; Salam; Mohapatra, Senjanović, 74, 75

Enlarged gauge sector $\rightarrow SU(2)_L \times SU(2)_R \times U(1)_{B-L}$

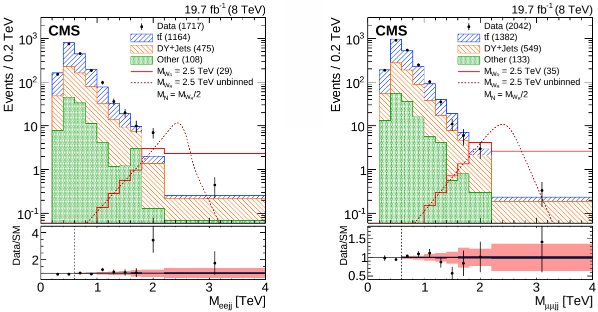
- Sterile neutrino N is part of the gauge multiplet $\begin{pmatrix} N \\ e \end{pmatrix}_R$. Natural way to embed sterile neutrino
- Two Higgs triplet $\Delta_L = (3,1,2)$, $\Delta_R = (1,3,2)$. The vacuum expectation value of Δ_R breaks the symmetry
- Additional gauge bosons W_R and Z'. $M_{W_R} \propto \langle \Delta_R \rangle$
- The light neutrino mass

$$m_\nu \simeq m_L - m_D^{\mathsf{T}} M_R^{-1} m_D = f_L v_L - \frac{v^2}{v_R^2} f_\nu^T f_R^{-1} f_\nu$$

SUSY Left-Right symmetry-C. S. Aulakh, K. Benakli, G. Senjanovic, PRL, 1997; C. S. Aulakh et al., PRD, 1998

contd

- 14 events in the $eejj$ channel in the energy bin 1.8 TeV-2.2 TeV on an expected background ~ 4.
- The signal badly fails with the prediction of minimal Left-Right symmetry
- For Left-Right symmetry most simplestic approach $g_L = g_R$ implies excess in the $\mu\mu jj$ signal



Possible explanations

- Non-minimal Left-Right model with $g_L \neq g_R$ can explain the excess (F. Deppisch et al., Phys.Rev. D91 (2015) 1, 015018) W', Z' vector bosons (arXiv: 1408.2456)
- R-parity violating supersymmetry

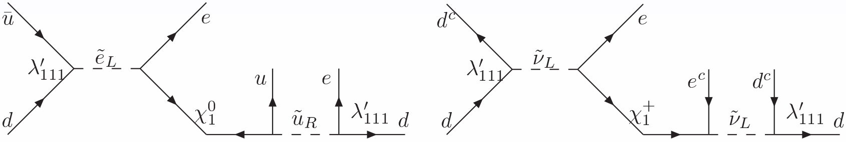
Most generic supersymmetric Standard Model includes R-parity violation

- R-parity violating MSSM $\rightarrow$ L and B number violation
- Defined as $R_p = (-1)^{3(B-L)+2S}$
- $W = \epsilon L H_u + \lambda L L E^c + \lambda' L Q D^c + \lambda'' Q Q D^c$
- Phenomenological consequence $\rightarrow$ LSP decay, Neutrino mass, FCNC processes, proton decay,....

(Masiero, 1982; Baltz et al., PRD 1998; B. Mukhopadhyaya, S Roy, F Vissani, PLB 1998,N. E. Bomark, D. Choudhury, S. Lola, P. Osland, JHEP 2011...)

Resonant slepton production

CMS excess can be explained with resonant slepton and sneutrino production via RPV $\lambda'_{111} \to \lambda' L Q D^c$ (B. Allanach, S. Biswas, S. Mondal, M. Mitra, Phys.Rev. D91 (2015) 1, 011702)



- Slepton and sneutrino production via λ'_{111} coupling.
- The produced slepton and sneutrino decays to neutralino $\tilde{\chi}$ and chargino $\tilde{\chi}^{\pm}$.
- Three body decays of the neutralino $\tilde{\chi}$ and chargino $\tilde{\chi}^{\pm}$.

$\sigma(pp \to \tilde{l}) \sim 1 - 130$ fb for $\lambda'_{111} \sim 0.03 - 0.5$ with $m_{\tilde{l}} = 2.1$ TeV.

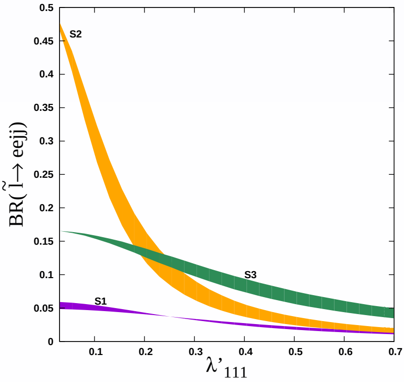
Resonant slepton production- S. Dimopoulos, R. Esmailzadeh, L. J. Hall and G. D. Starkman, PRD, 1990; Dreiner et al., 2001; Allanach et al., PRL 2009; Debajyoti Choudhury, Swapan Majhi, V Ravindran, JHEP, 2005

Few exciting possibilities depending on the gaugino mass parameters M_1, M_2, μ:

- Lightest neutraino $\tilde{\chi}_1^0$ is
  - Bino like- $M_1 < M_2 + 200 << \mu$. However slepton $\tilde{l}$ decays to second lightest neutralino $\tilde{l} \to \tilde{\chi}_2^0 l$ and $\tilde{\chi}^{\pm}\nu$.
  - Bino like $M_1 < \mu < M_2$. Increases the branching ratio of $\tilde{l}$ decaying to lightest neutralino $\tilde{l} \to l\tilde{\chi}_1^0$.
  - Wino like $M_2 < M_1 \simeq \mu$. Slepton decays $\tilde{l} \to \tilde{\chi}_1^0 l$ can be large.

The slepton mass is 2.1 TeV, $m_{\tilde{\chi}_1^0} = 400\,\mathrm{GeV} - 1000\,\mathrm{GeV}$, $m_{\tilde{q}} = 2$ TeV.

The branching ratio vs λ'. For S_2 and S_3, large branching ratio of $\tilde{l} \to eejj$.



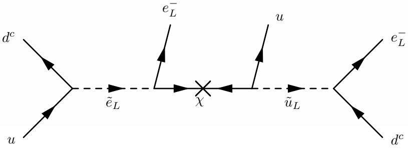
For large λ', the slepton can have large di-jet branching ratios.

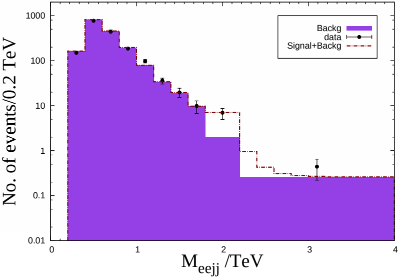
Di-jet bound $\to \sigma_{jj} < 45$ fb for 2.1 TeV.

CMS di-jet resonance search Phys. Rev. D 87, no. 11, 114015 (2013).

For scenario S_3 with wino like LSP.

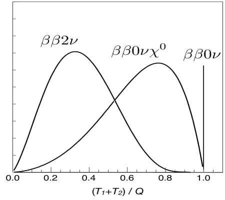
Choces of mass and couplings $\rightarrow \lambda' = 0.105$, $m_{\tilde{l}} = 2.1$ TeV and $m_{\tilde{\chi}_1^0} = 532$ GeV.

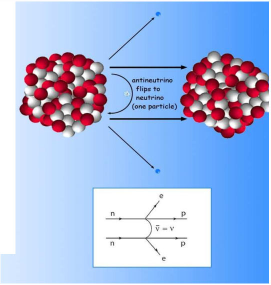


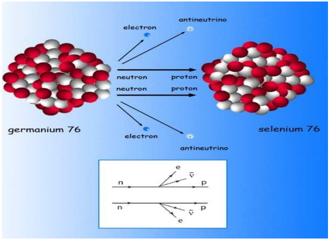


Background $t\bar{t}$, DY+jets and others

Neutrinoless double beta decay







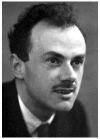
The process is $(A, Z) \to (A, Z+2) + 2e^-$

G Racah 1937; W. H. Furry 1939

Probing lepton number violation

Why important

Neutrino Mass



Dirac or Majorana?

- Dirac mass, $m_D \bar{\nu}_L N_R \rightarrow$ lepton number is conserved
- Majorana mass, $m \nu^T C^{-1} \nu \rightarrow$ lepton number is violated by two unit

Lepton number is a Global $U(1)$ symmetry of standard model

Neutrinoless double beta decay

- Light Majorana neutrinos can mediate the process
- L and B numbers are accidental symmetries of the standard model. The low energy effective Lagrangian

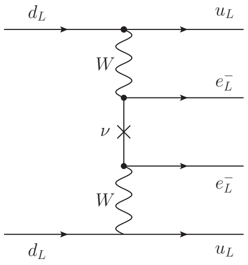
$$\mathcal{L}_{eff} = \mathcal{L}_{SM} + \xi_1 \frac{\mathcal{O}_5}{M} + \xi_2 \frac{\mathcal{O}_6}{M^2} + \ldots$$

Weinberg, PRL 43, 1979

- $\mathcal{O}_5 \rightarrow$ LNV, $\mathcal{O}_6 \rightarrow$ LFV, BNV. Lepton and Baryon number violation might originate from high scale theory.

$0\nu 2\beta$ is a probe of lepton number violation

Positive signal $\rightarrow$ Light neutrinos are Majorana (Schechter-Valle, PRD, 82)



- Experiments at GRAN SASSO, Italy, Japan, Sudan...
- Existing bound on half-life from GERDA, KamLAND-Zen...
- Claim of observation of $0\nu\beta\beta$-decay...
- Promising forthcoming experiments $\rightarrow$ GERDA Phase-II, Majorana, Supernemo

Experimental Results

- GERDA/GERDA combined (IGEX+Heidelberg-Moscow)
  $T^{0\nu}_{1/2} > 2.1, 3.0 \times 10^{25}\text{yr}$, 90% C.L
  GERDA collaboration, 2013

- KamLAND-Zen+EXO-200, $T^{0\nu}_{1/2} > 3.4 \times 10^{25}\text{yr}$ at 90% C.L
  KamLAND-Zen collaboration, 2012

Positive Claim

- The half-life for ^{76}Ge, $T^{0\nu}_{1/2} = 1.19^{+037}_{-0.23} \times 10^{25}$ yr, 68% CL.
  H. V. Klapdor-Kleingrothaus *et al.*, 2004
- The half-life for ^{76}Ge, $T^{0\nu}_{1/2} = 2.23^{+0.44}_{-0.31} \times 10^{25}$ yr, 68% CL.
  H. V. Klapdor-Kleingrothaus *et al.*, 2006

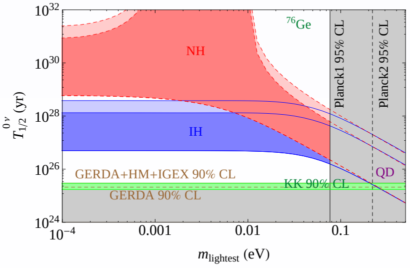
Individual bound from GERDA does not rule out the positive claim. However, tension between the GERDA combined and positive claim

(GERDA collaboration, 2013, **Dev, Goswami, Mitra and Rodejohann, PRD, 2013**)

Future experiments

GERDA-Phase II, Majorana, SuperNEMO, SNO+, CUORE, EXO.
Expected sensitivity $T^{0\nu}_{1/2} \sim 10^{26}/10^{27}$ yrs

(**P. S. Bhupal Dev, S. Goswami, M. Mitra and W. Rodejohann, Phys. Rev. D 88, 091301 (2013)**)



- The most stringent bound from Planck $\rightarrow \Sigma_i m_i < 0.23$ eV.
- The light neutrino contribution saturates the $0\nu 2\beta$ in quasi degenerate region

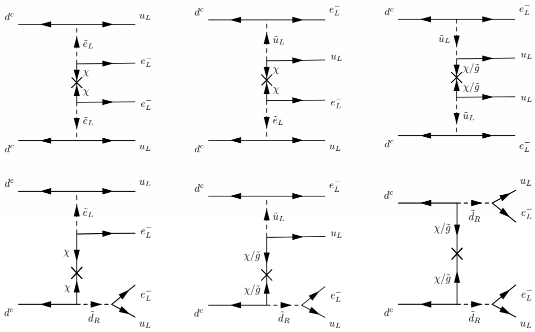
Strong tension with cosmology!! (Fogli et al., 2008; **Mitra et al., 2012, 2013**)

More than one order of magnitude improvement in half-life is required $\rightarrow$ Additional contributions!!!

The states selectron, gluino, neutralino and squark can mediate the process .

$0\nu\beta\beta$ with collider searches (Allanach et al., 2009)

λ'_{111} mediated diagrams



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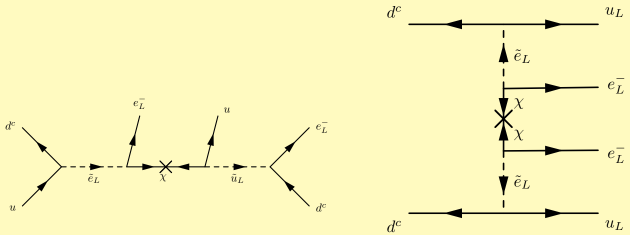
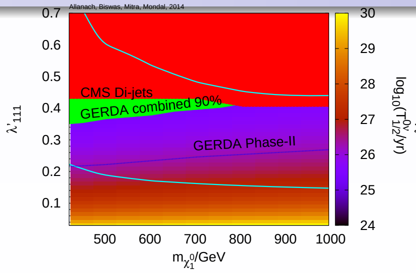
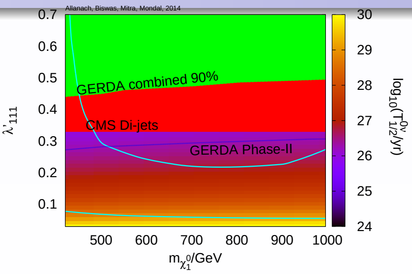
Correlation between $0\nu\beta\beta$ and collider searches $\rightarrow$ for R-parity violating supersymmetry (B. Allanach et al., 2009) ${\lambda'_{111}}^2$ $\rightarrow$ dilepton signal from resonant selectron production at LHC

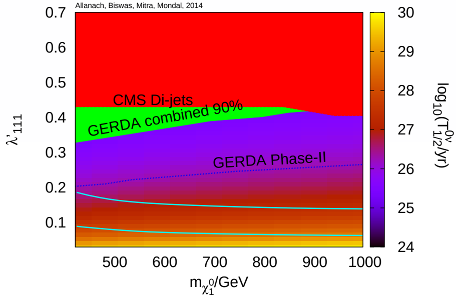


$$\sigma(pp \rightarrow \tilde{l}) \propto \frac{|\lambda'_{111}|^2}{m^3_{\tilde{e}_L}}, \; T^{0\nu}_{1/2}(Ge)^{-1} \propto \frac{|\lambda'_{111}|^4}{\Lambda^{10}_{susy}}$$

Resonant slepton production- S. Dimopoulos, R. Esmailzadeh, L. J. Hall and G. D. Starkman, PRD, 1990; Dreiner et al., 2001; Allanach et al., PRL 2009; Debajyoti Choudhury, Swapan Majhi, V Ravindran, JHEP, 2005







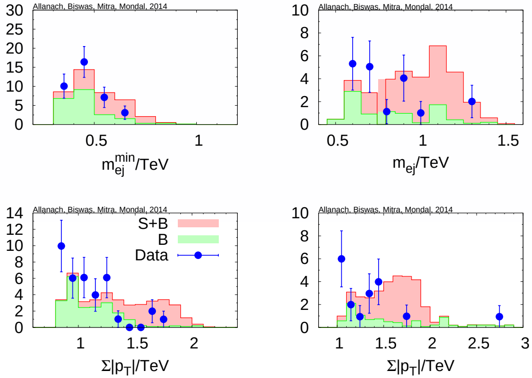
- For S1, the CMS excess region can be accessed in the GERDA Phase-II
- For S2, only possible if $m_{\tilde{\chi}_1^0} < 500$ GeV
- S3 scenario not accessible in GERDA Phase-II

Other CMS searches

$eejj$ and $e\nu jj$ excesses in di-leptoquark searches. (CMS-PAS-EXO-12-041)

- 36 events on a background of 20.5 ± 3.5 for $eejj$ channel.
- Also 18 events on the background of 7.5 ± 1.8 events.

Possible explanation with RPV susy and $0\nu\beta\beta$ implications (Phys.Rev. D91 (2015) 1, 015011)



Summary

- CMS excess in the $eejj$ channel.
- Slepton and sneutrino of mass 2.1 TeV can reproduce the excess.
- A bino-like LSP scenario is within the experimental reach of the forthcoming neutrinoless double beta decay experiment.
- Correlation between lepton number violating processes at collider and at neutrinoless double beta decay is interesting to study.

Thank You