Searching for light neutralinos with a displaced vertex at the LHC

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Outline

- Model and benchark scenarios.
- Event selection and Simulations.
- Results.
- Conclusions.

Model description

Our work focuses on SUSY RPV light neutralinos [1,2]:

$$W_{\mathrm{RPV}} = \sum_i \mu_i L_i H_u + \sum_{i,j,k} \left(\frac{1}{2}\lambda_{ijk} L_i L_j E^c_k + \lambda'_{ijk} L_i Q_j D^c_k + \frac{1}{2}\lambda''_{ijk} U^c_i D^c_j D^c_k \right),$$

- If all RPV terms are presents and unsuppressed, they would allow for a proton decay rate not compatible with current bounds of proton lifetime.
- In this work we assume all the RPV couplings zero except for the second trilinear term.

- This term allows the neutralinos to be produced at the LHC together with a prompt charged lepton (used as a trigger in our analysis).
- We consider $\tilde{\chi}^0_1$ to be the LSP , so it can only decay through the RPV terms, with a total decay width:

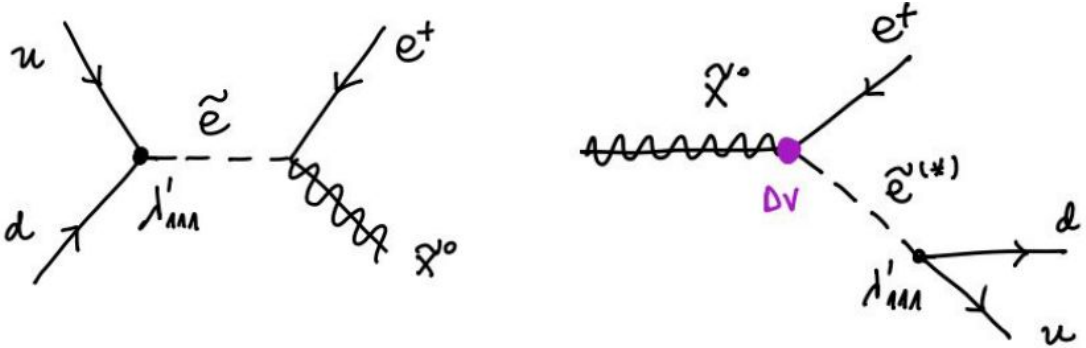
$$\Gamma_{\tilde{\chi}^0_1} \propto m^5_{\tilde{\chi}^0_1} \left(\frac{\lambda'_{ijk}}{m^2_{\tilde{f}}} \right)^2$$

- For small enough RPV coupling and neutralino masses, the neutralino will be long-lived.

- [1] SUSY RPV R. Barbier et al, Phys.Rept. 420 (2005) H. K. Dreiner, G. G. Ross, Nucl. Phys. B365 (1991).
- [2] Displaced SUSY RPV P. W. Graham, D. E. Kaplan, S. Rajendran, P. Saraswat, JHEP 1207 (2012) 149, arXiv:1204.6038

Benchmark Scenarios

We consider λ'_{111}, but the search strategy described is expected to give similar results for λ'_{211}



- We chose 4 benchmark scenarios fixing the selectron mass in 1, 2.5, 5 and 7 TeV, while varying the neutralino mass and the RPV coupling freely.

- For simplicity, all the other superpartners different from the selectron and the neutralino are taken to be heavy (10 TeV).
- So, the phenomenology scenario at the LHC can be controlled by the three parameters

$$\lambda'_{111}, m_{\tilde{e}_L}, m_{\tilde{\chi}_1^0}$$

Event generation and simulations

- We use the RPV-MSSM UFO model implemented in [3] to simulate in MadGraph 5 the process $pp \to \tilde{\chi}_1^0 e$ and Pythia 8 for showering and hadronization.
- We are inspired by ATLAS 13-TeV SUSY search for DV [3].
- Similar DV searches at 8 TeV were done at ATLAS [4], targeting a long-lived neutralino within RPV-SUSY constraining neutralino masses as a function of lifetime above 50 GeV and for neutralinos produced through squarks decaying to a muon (coming from the DV). This implies sensitivity of the RPV couplings

$$\lambda'_{211}, \lambda'_{212}, \lambda'_{213}$$

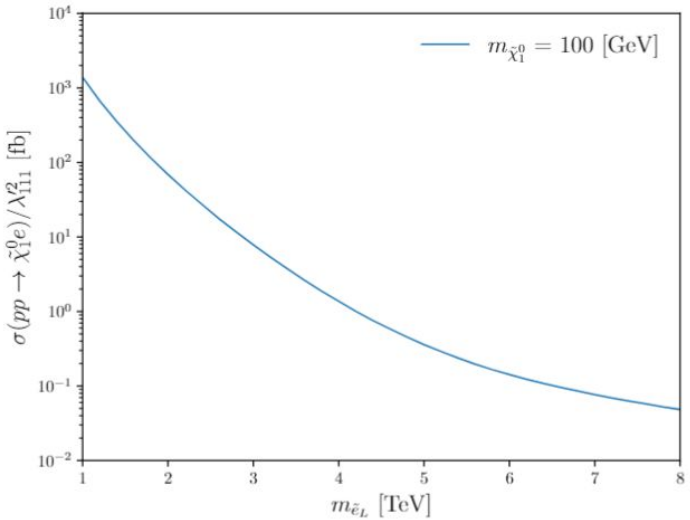


Figure 2: Production cross-section of the neutralino divided by the RPV coupling squared as a function of the selectron mass [5].

[3] Model:GitHub - ilmonteux/RPVMSSM_UFO: UFO model file for RPV SUSY - includes parameter cards and an example
[4] M. Aaboud et al. (ATLAS), Phys. Rev. D97, 052012 (2018), 1710.04901
[5] G. Cottin, J. C. Helo, N. A. Neill, F. Hernández-Pinto, and Z. S. Wang, JHEP 10,095 (2022),2208.12818

Search strategy for DV

- We start by selecting events triggering on a prompt, isolated electron with p_T> 25 GeV and $|\eta| < 2.47$.
- DVs are made from tracks with $|d_0|$ > 2 mm and p_T> 1 GeV.
- Vertices are required to be within the inner tracker acceptance, with 4 mm < r_{DV} < 300 mm.
- Additionally, DVs must have at least 5 tracks and $m_{DV} \geq$ 10 GeV. These last 2 cuts defines the region where the signal is expected to be found free of SM and instrumental background.

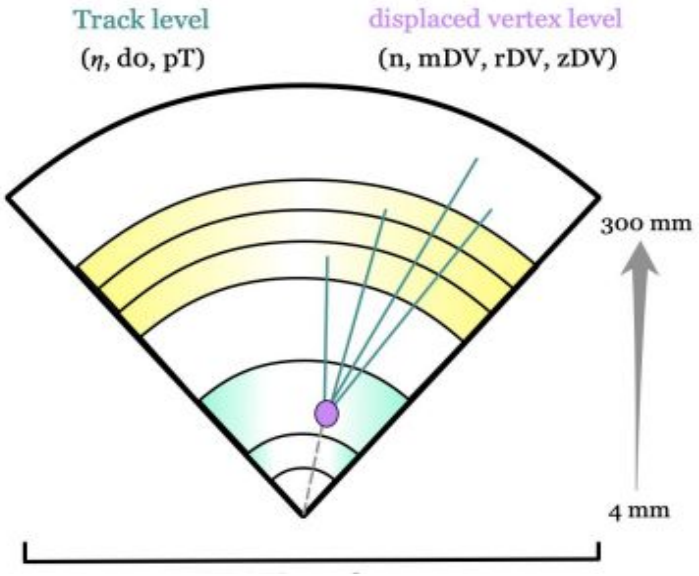
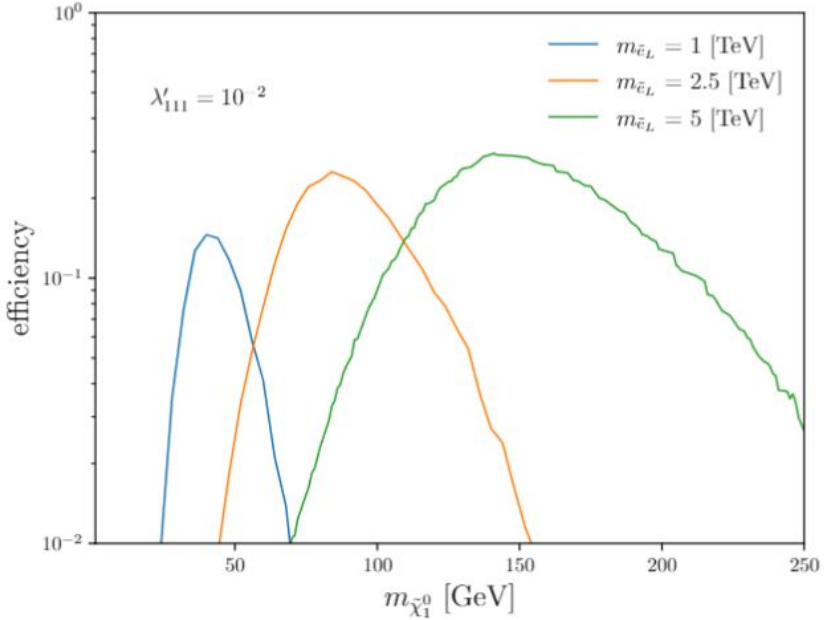
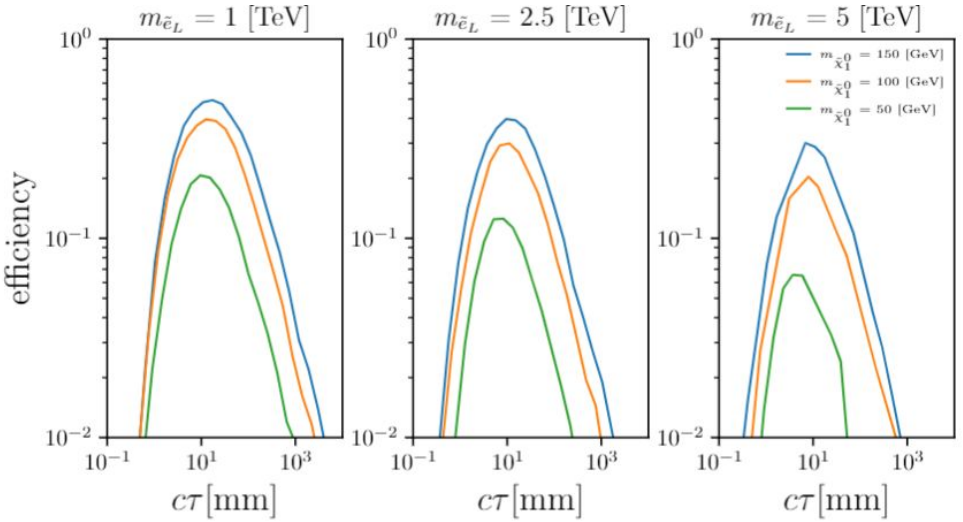


Figure 3: Inner tracker simplified geometry.

-M. Aaboud et al. (ATLAS), Phys. Rev. D 97, 052012 (2018), 1710.04901. (ATLAS search for DV)
-G. Cottin, J. C. Helo, M. Hirsch, and D. Silva, Phys. Rev. D99, 115013 (2019), 1902.05673. (similar strategy in the left-right model context)

Results

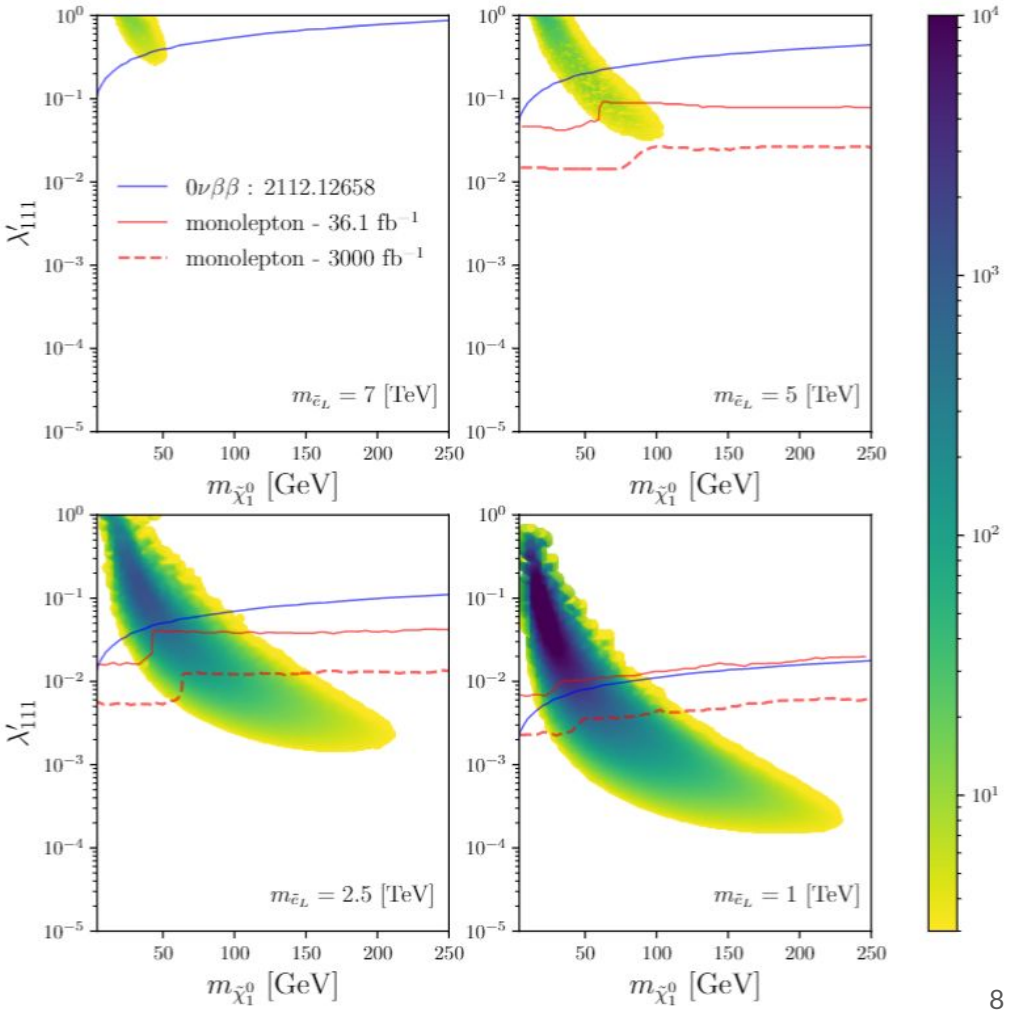




[7] G. Cottin, J. C. Helo, N. A. Neill, F. Hernández-Pinto, and Z. S. Wang, JHEP 10,095 (2022),2208.12818.

Results

Sensitivity reach in the λ'_{111} vs $m_{\tilde{\chi}_1^0}$ plane with the proposed DV search strategy with 3000 fb^{-1} . The number of expected signal events depicted in the color bar starts from 3. Red lines show the recasted monolepton limits for 36.1 fb^{-1} (solid red line) and our high-luminosity LHC projection to 3000 fb^{-1} (dashed red line).
Constraints from $0\nu\beta\beta$ are shown in solid blue. [7]



[7] G. Cottin, J. C. Helo, N. A. Neill, F. Hernández-Pinto, and Z. S. Wang, JHEP 10,095 (2022),2208.12818.

Conclusions

- Our final results show that for 1 TeV selectron mass, the proposed displaced search at the HL-LHC can probe values of λ'_{111} up to two orders of magnitude smaller than current bounds from neutrinoless double beta decay experiments, as well as up to 40 times smaller than our recast of an LHC monolepton search with an integrated luminosity of 36.1 fb^{-1}, projected to the final HL-LHC target, 3000 fb^{-1}, for neutralino masses between 10 GeV and 230 GeV.

- For a heavy selectron of mass 7 TeV, our sensitivities are rather limited, and at most comparable with the bounds from neutrinoless double beta decay at $m_{\tilde{\chi}_1^0} \sim 50$ GeV.

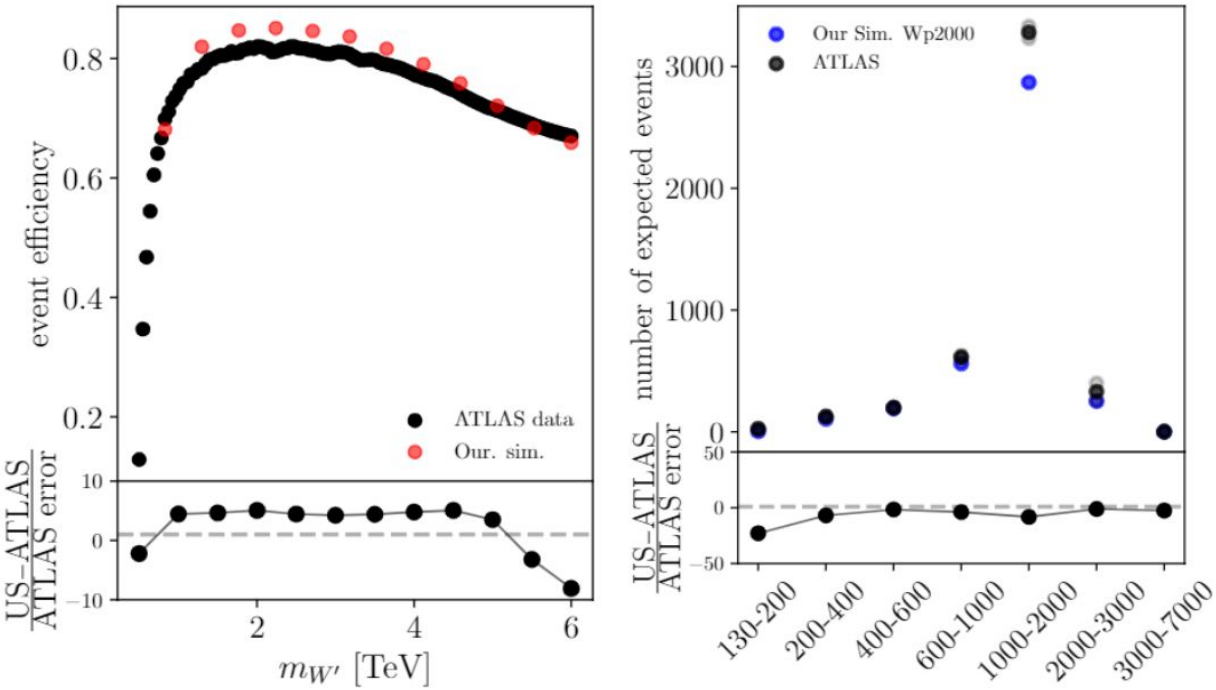
Backup: Monolepton Reinterpretation in SUSY RPV scenario

- The ATLAS collaboration has presented a search for the monolepton signal, based on $\mathcal{L}$ = *36.1 fb*$^{-1}$ statistics taken at √s = 13 TeV.
- Because of the similitude with our RPV signal, this is, the decay of the selectron in to a displaced neutralino and a lepton with the prompt search of a new gauge boson W' into a lepton and a neutrino, we reinterpetate this prompt search in the context of the RPV signal.
- The main reason is to see how competitive are the exclusion limits with our DV search for the relevant parameters of the model (RPV coupling and neutralino mass).

$$W' \rightarrow e\nu$$

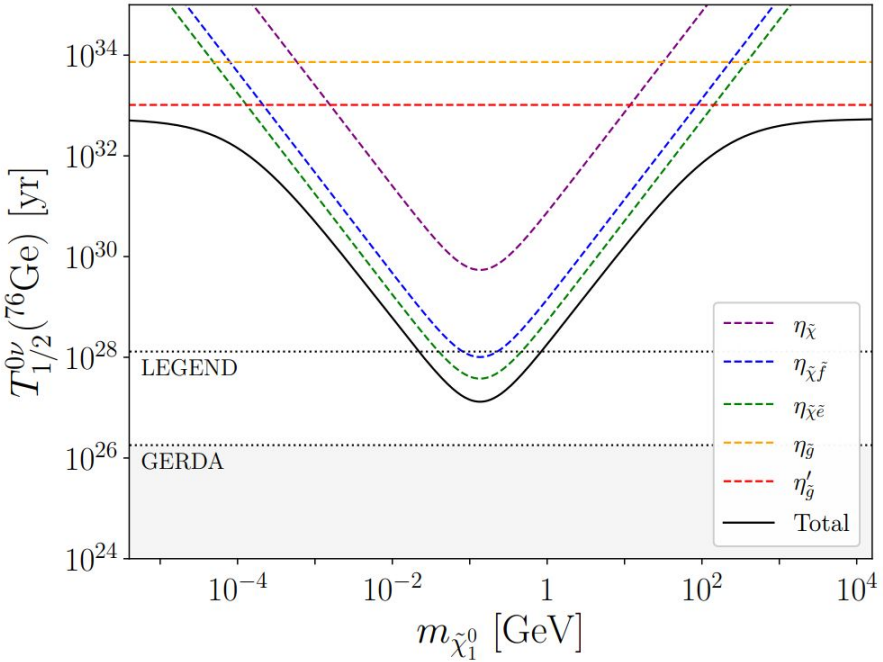
$$\tilde{e} \rightarrow e\tilde{\chi}_1^0$$

- M. Aaboud et al. (ATLAS), Eur. Phys. J. C 78, 401 (2018), 1706.04786
- M. Nemevsek, F. Nesti, and G. Popara, Phys. Rev. D97, 115018 (2018), 1801.05813



- Left (up): validation per W' mass point.
- Right (up): validation per m_T bins provided by ATLAS.
- Left (down): comparison with ATLAS expected values in function of W' mass.
- Right (down): comparison with ATLAS expected values in function of m_T bins.

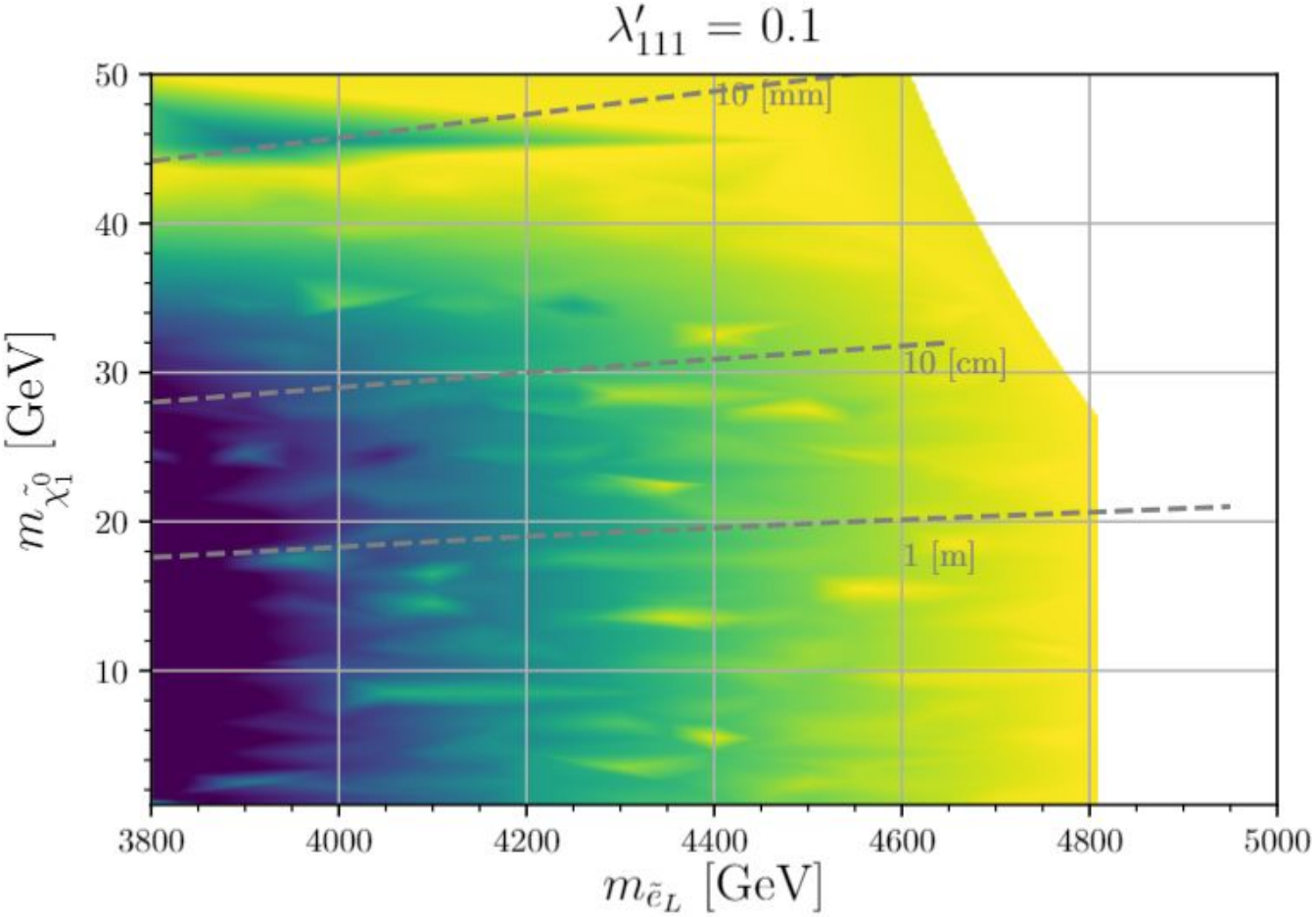
Backup: Double beta decay



- The neutrinoless double beta decay limits were obtained by comparing the theoretical calculations from [6]of the RPV SUSY contribution to 0νββ half-life, mediated by light neutralinos and selectrons

$$(T^{0\nu\beta\beta}_{1/2})^{-1} \propto |\lambda'^{2}_{111}/m^{4}_{\tilde{e}_L}|^2$$

- [6] P. D. Bolton, F. F. Deppisch, and P. S. B. Dev (2021), 2112.12658


$\lambda'_{111} = 0.1$
10 [mm]
10 [cm]
1 [m]
$m_{\tilde{\chi}_1^0}$ [GeV]
$m_{\tilde{e}_L}$ [GeV]
50
40
30
20
10
3800
4000
4200
4400
4600
4800
5000