Neutrinoless Double Beta Decay via Light Neutralinos

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with Patrick Bolton (SISSA) and Frank Deppisch (UCL), 2112.12658 (JHEP '22)

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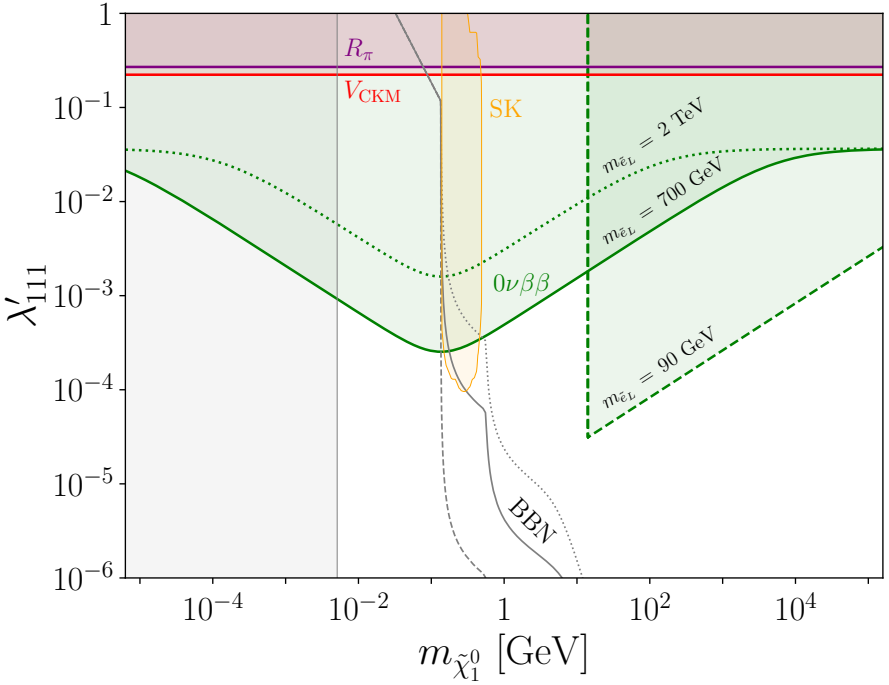
Outline

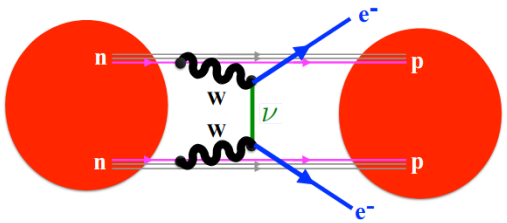
- R-parity Violating SUSY
- RPV Contributions to $0\nu\beta\beta$
- Light vs. Heavy Neutralinos
- Experimental Constraints
- Connection to Muon $g-2$
- Conclusion



Neutrinoless Double Beta Decay

⋆ Profound implications:

- $\Delta L = 2$ Process.
- Majorana nature of neutrinos.
- Neutrino mass ordering.
- Absolute neutrino mass scale and CP phases.
- Leptogenesis and matter-antimatter asymmetry.



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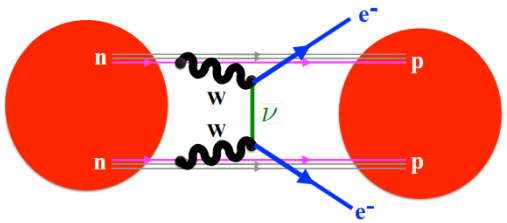
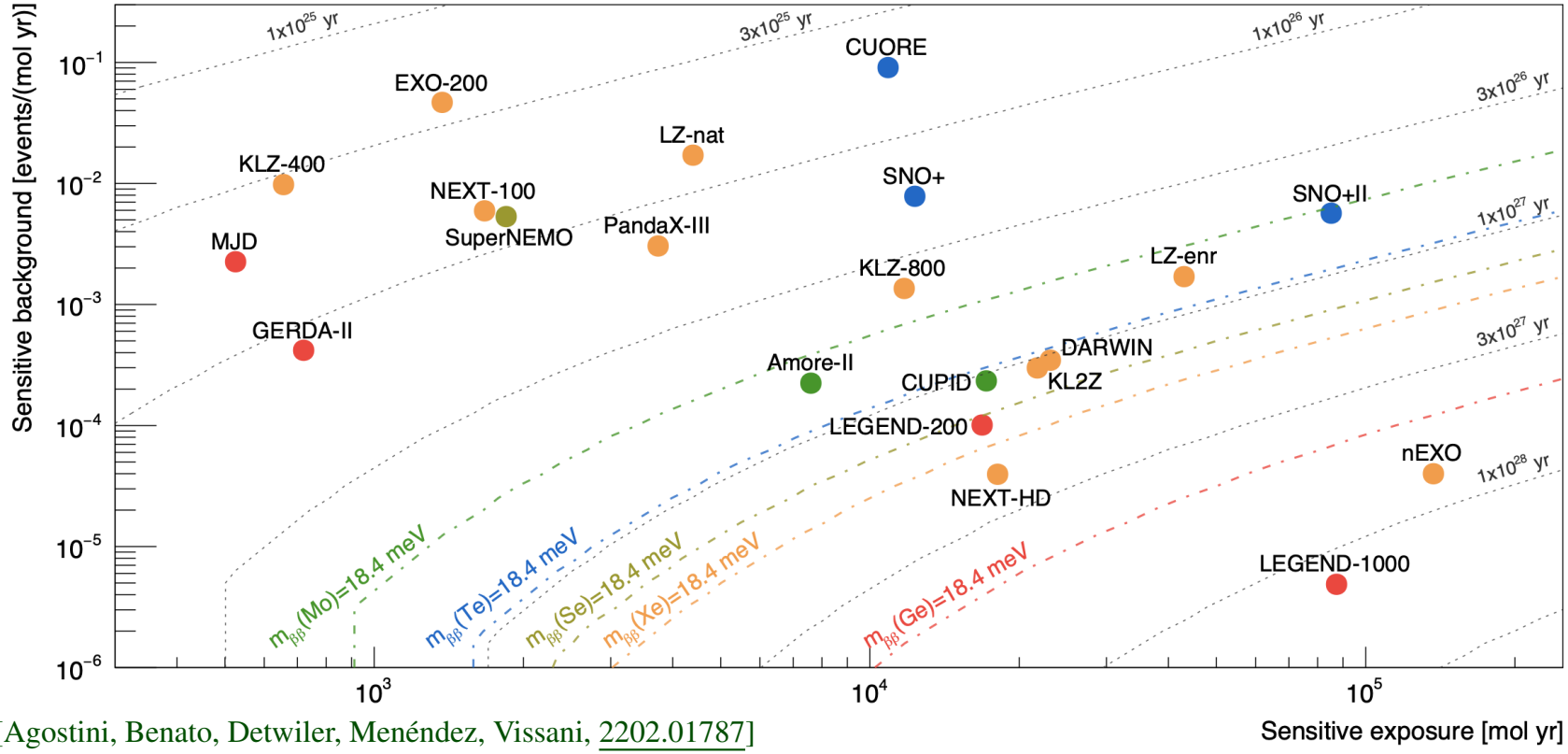


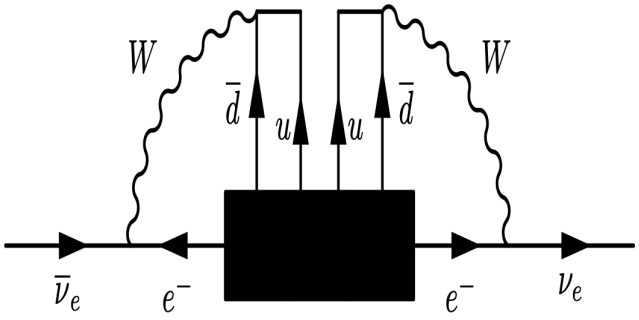
⋆ Tremendous theory and experimental effort. [Snowmass whitepaper: 2203.12169]



[Agostini, Benato, Detwiler, Menéndez, Vissani, 2202.01787]

Interpretation

[Schechter, Valle (PRD '82); Rodejohann (1106.1334)]



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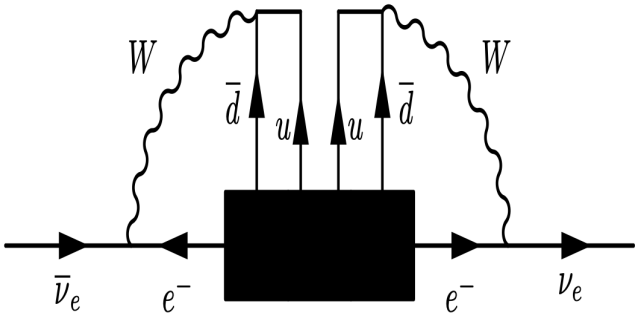

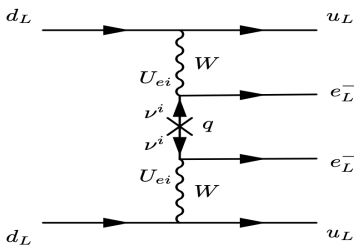

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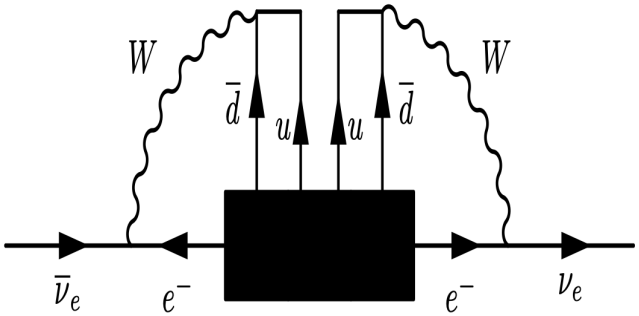

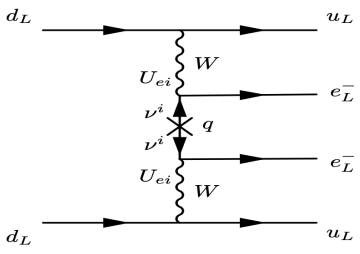

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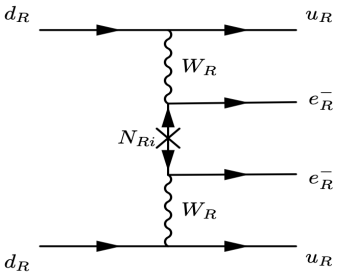

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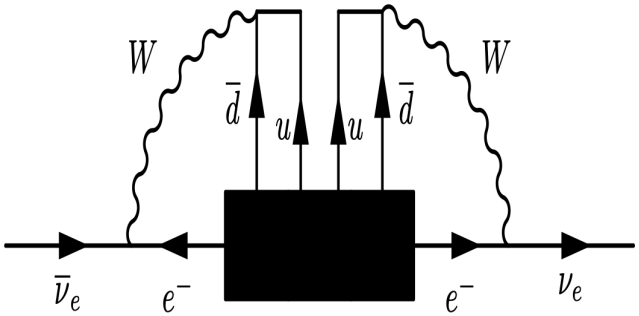

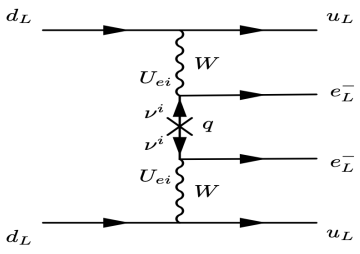

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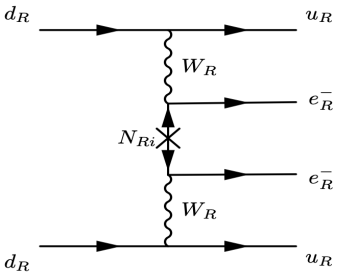

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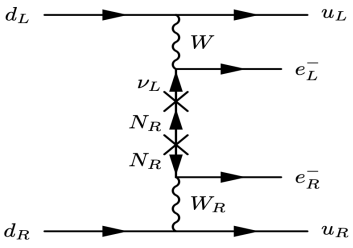

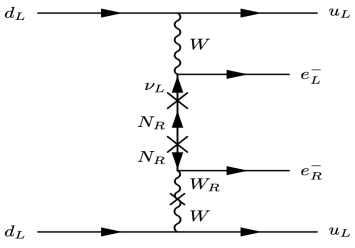

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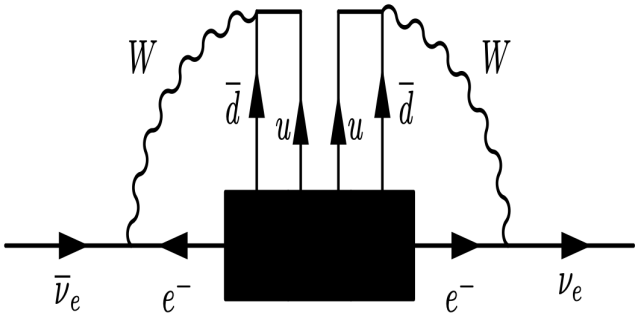

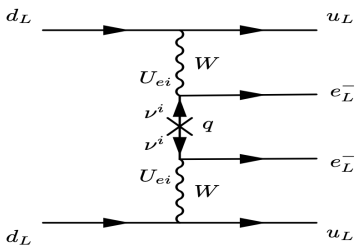

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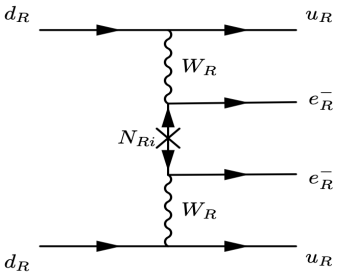

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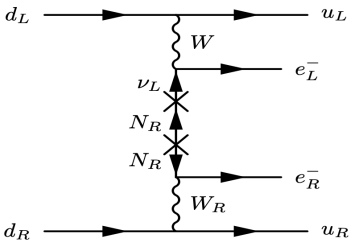

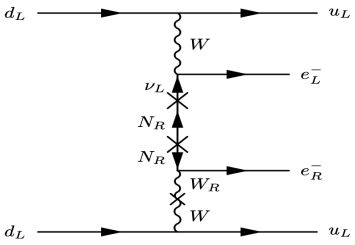

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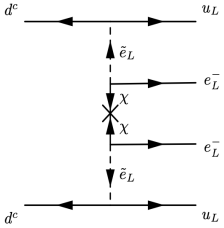

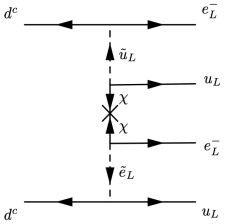

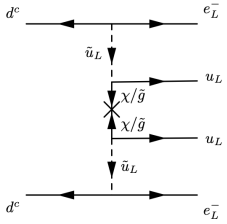

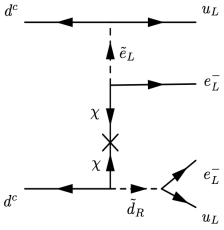

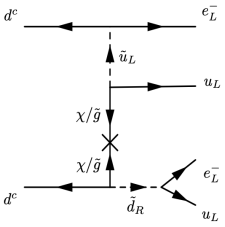

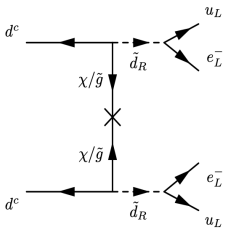

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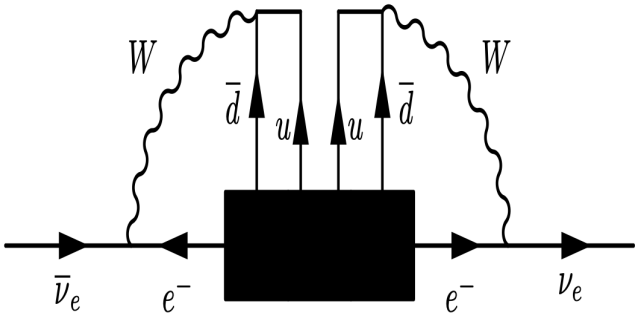

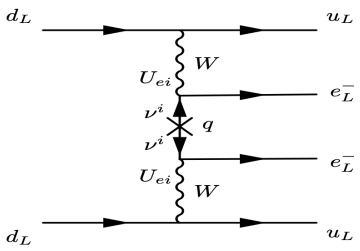

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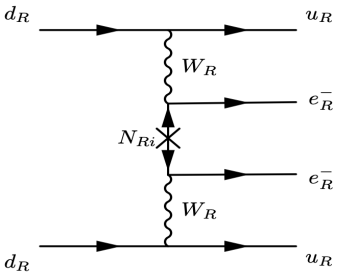

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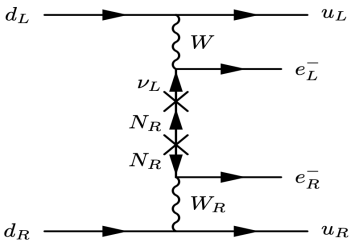

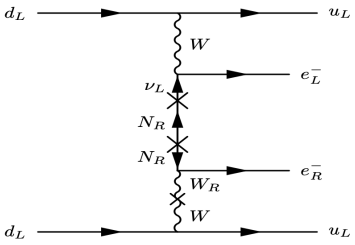

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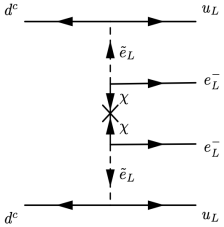
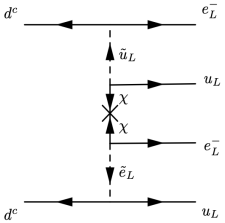
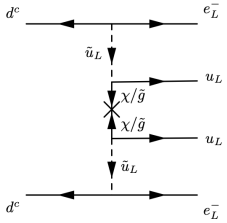
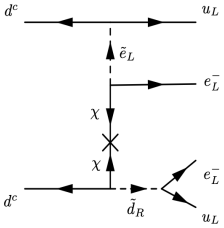
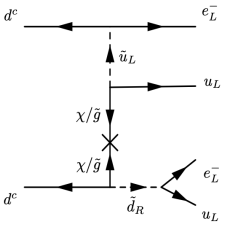
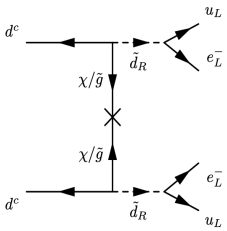






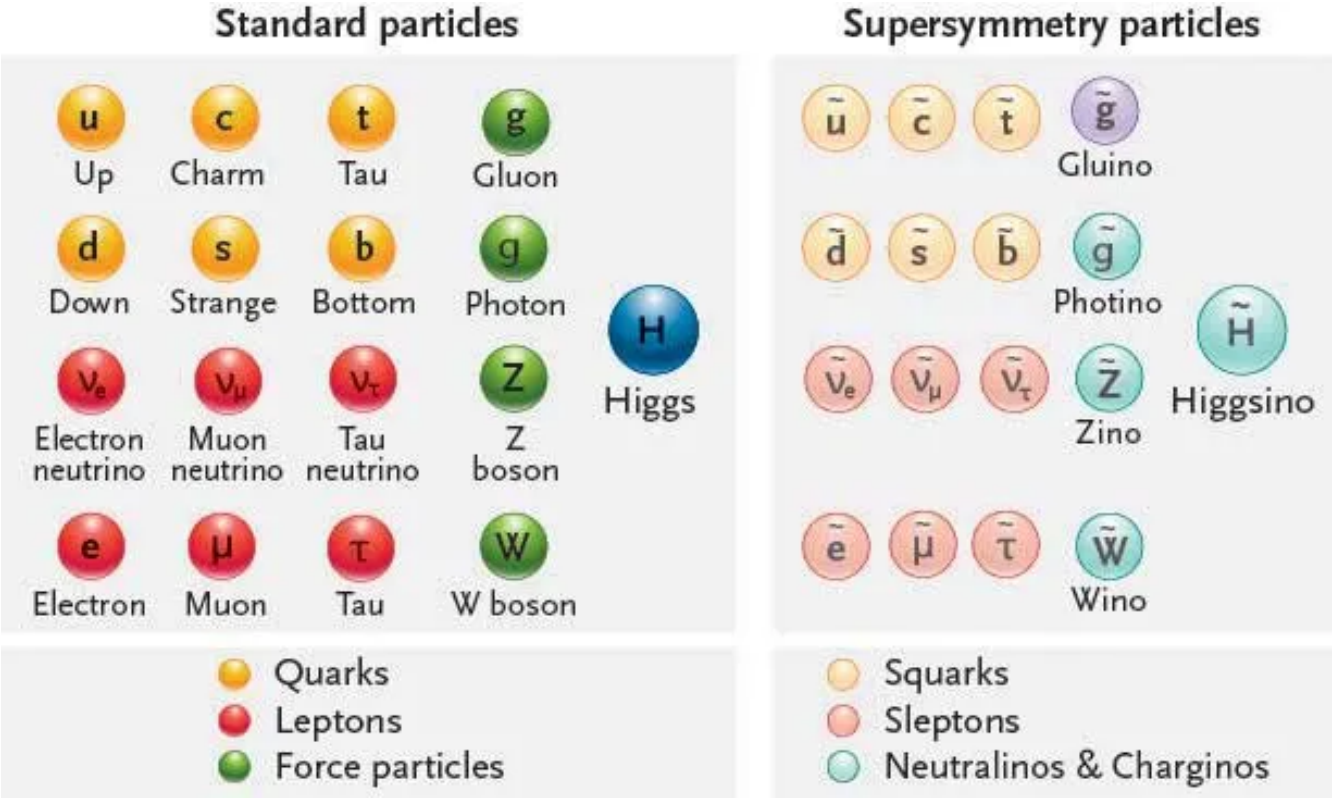






Important to look for complementarity with collider and/or other low-energy probes.

Supersymmetry



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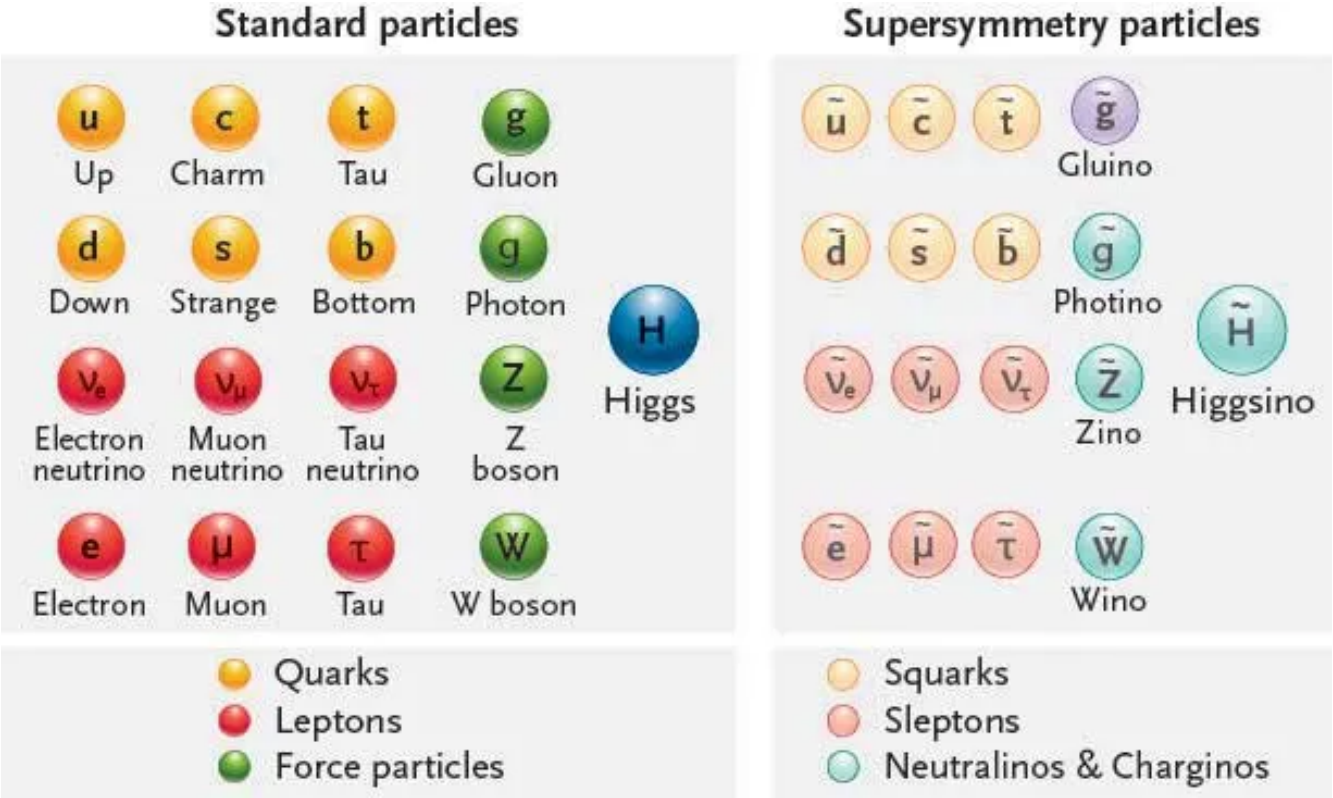
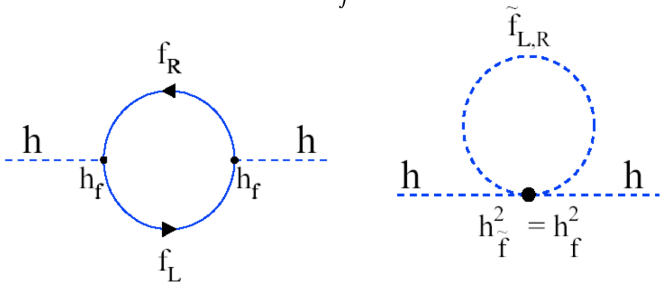


- Solution to the hierarchy problem.
- Unification of gauge couplings.
- Radiative EW symmetry breaking
- Vacuum stability
- Dark matter
- Gravity

$$\Delta\mu^2 \approx g^2_{hf\bar{f}}[m_f^2 - m^2_{\tilde{f}}]\ln(\Lambda^2_{eff}/m_h^2)$$

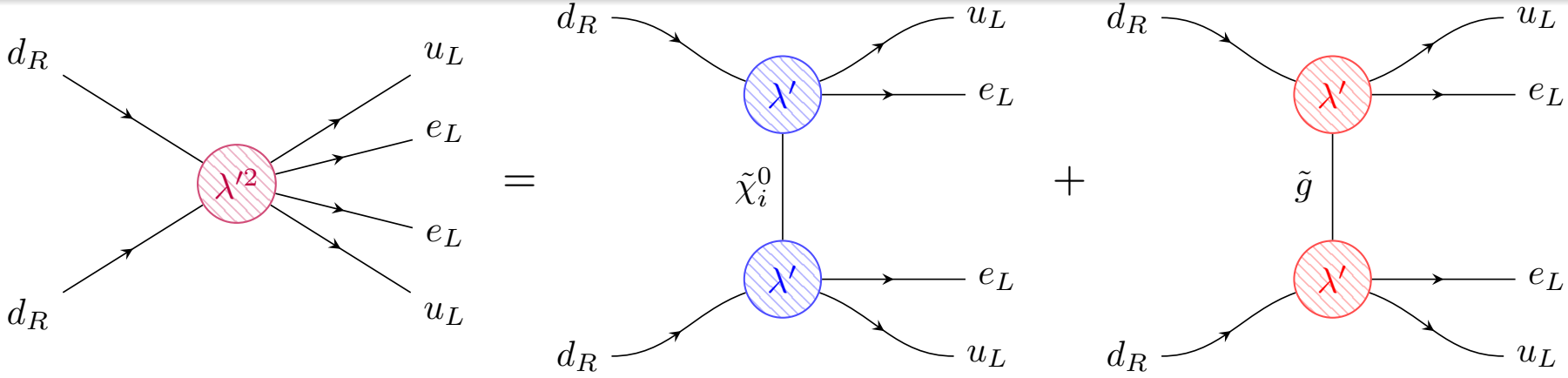


R-parity Violating SUSY

$$W \supset \frac{1}{2}\lambda_{ijk} L_i L_j E^c_k + \lambda'_{ijk} L_i Q_j D^c_k + \frac{1}{2}\lambda''_{ijk} U^c_i D^c_j D^c_k + \kappa_i L_i H_u,$$

- Typically a Z_2 symmetry $R_p = (-1)^{3B+L+2S}$ is imposed to forbid these terms.
- Makes the lightest SUSY particle stable.
- If the lightest neutralino is the LSP, a natural WIMP dark matter candidate.
- However, there is no rigorous theoretical argument for R-parity conservation.
- More natural to include the RPV couplings rather than imposing R-parity by hand.
  [Brust, Katz, Lawrence, Sundrum (1110.6670); BD, Soni, Xu (2106.15647)]
- Requirement from proton decay constraints: Cannot simultaneously have L and B violating terms large.
- We will focus on the λ' couplings only.
- Recent phenomenological interest in the context of flavor anomalies. [Deshpande, He (EPJC '17); Altmannshofer, BD, Soni (PRD '17); Trifinopoulos (EPJC '18); Altmannshofer, BD, Soni, Sui (PRD '20)]

RPV Contributions to $0\nu\beta\beta$



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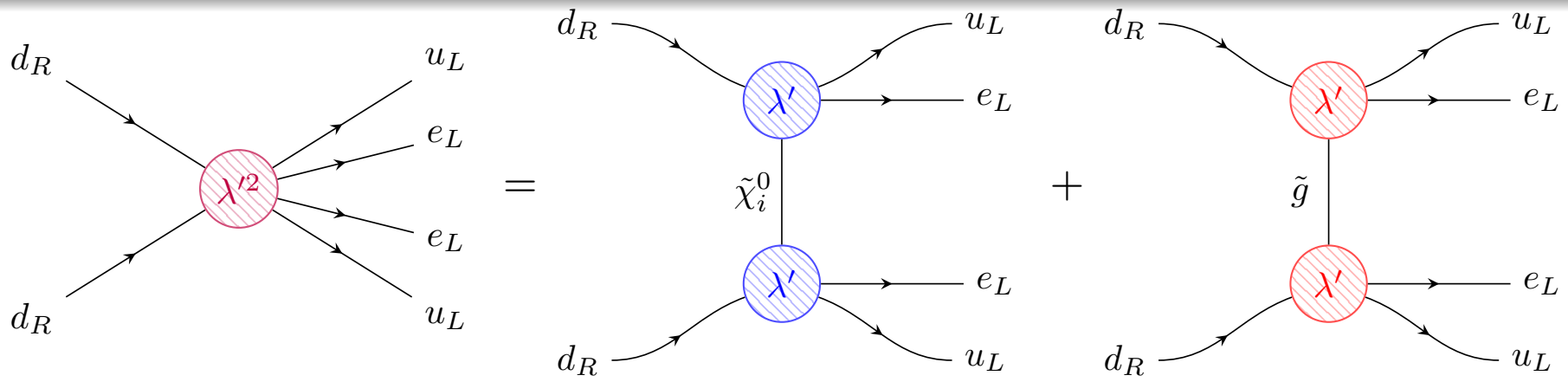

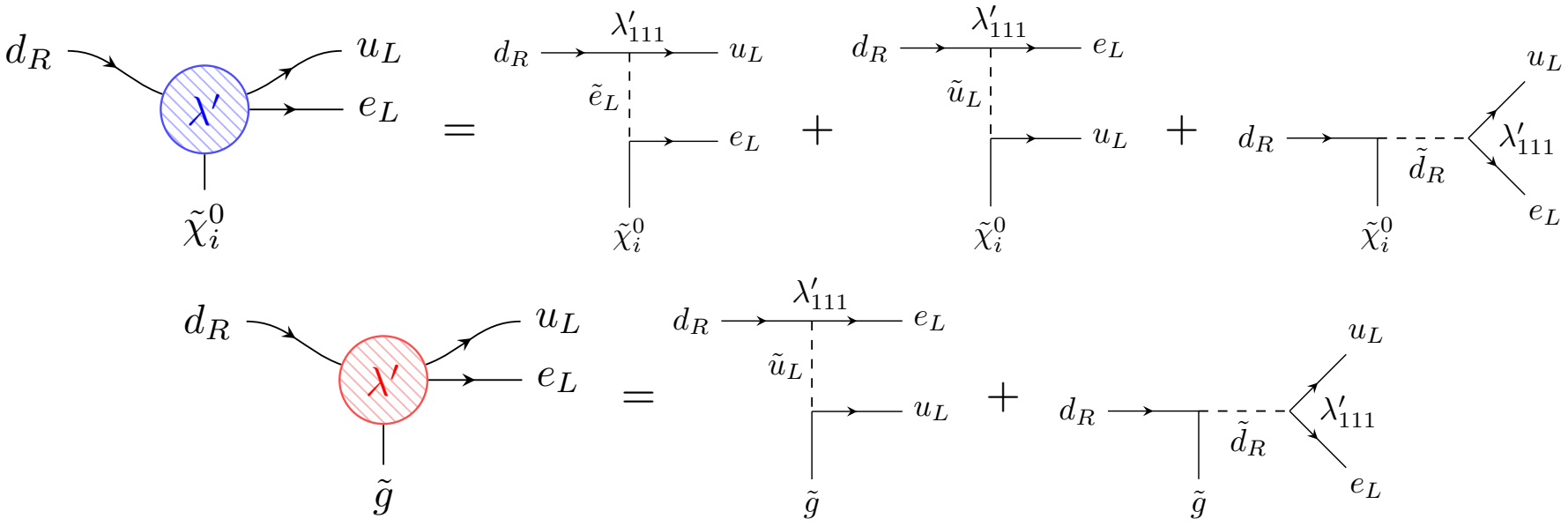

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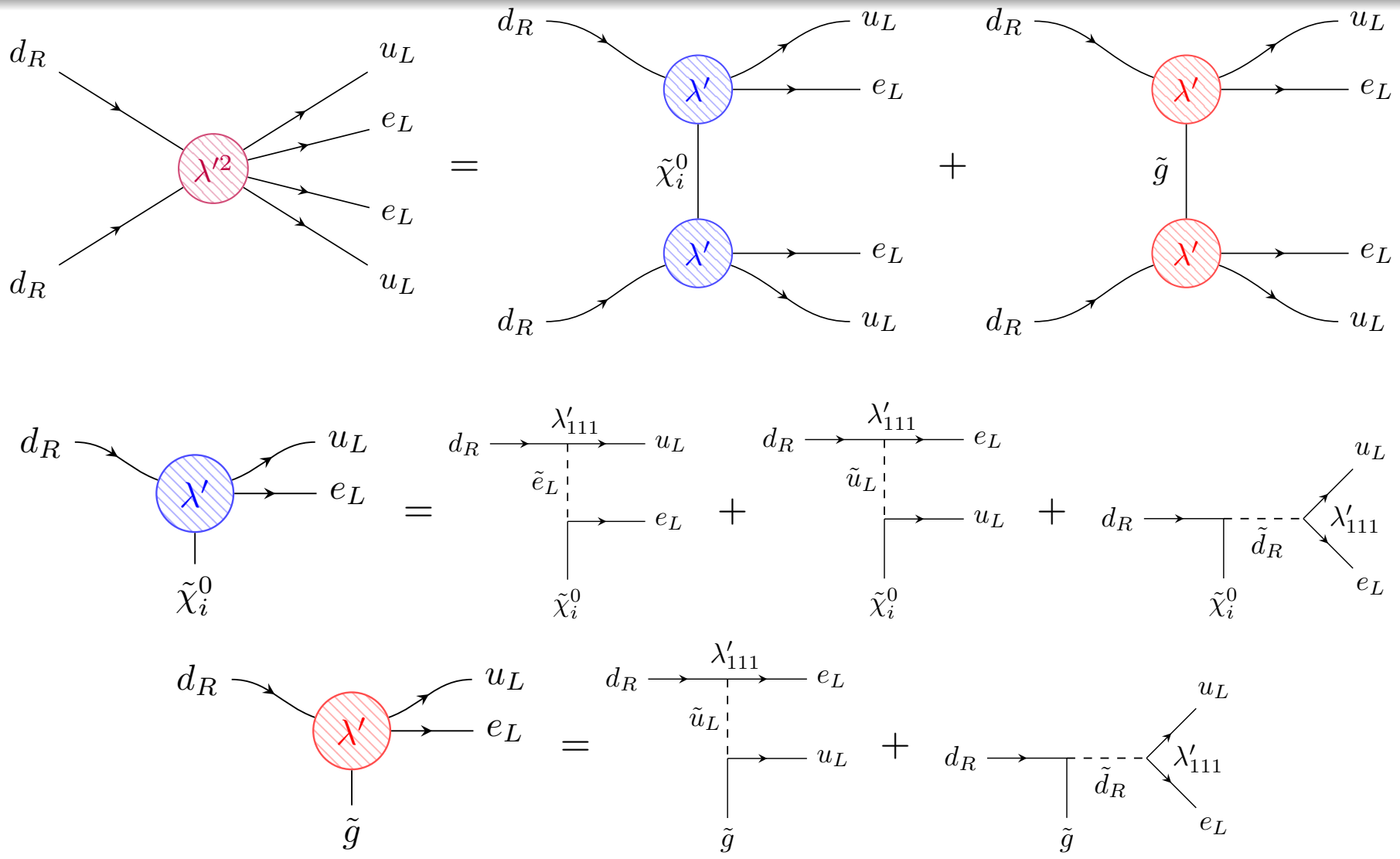
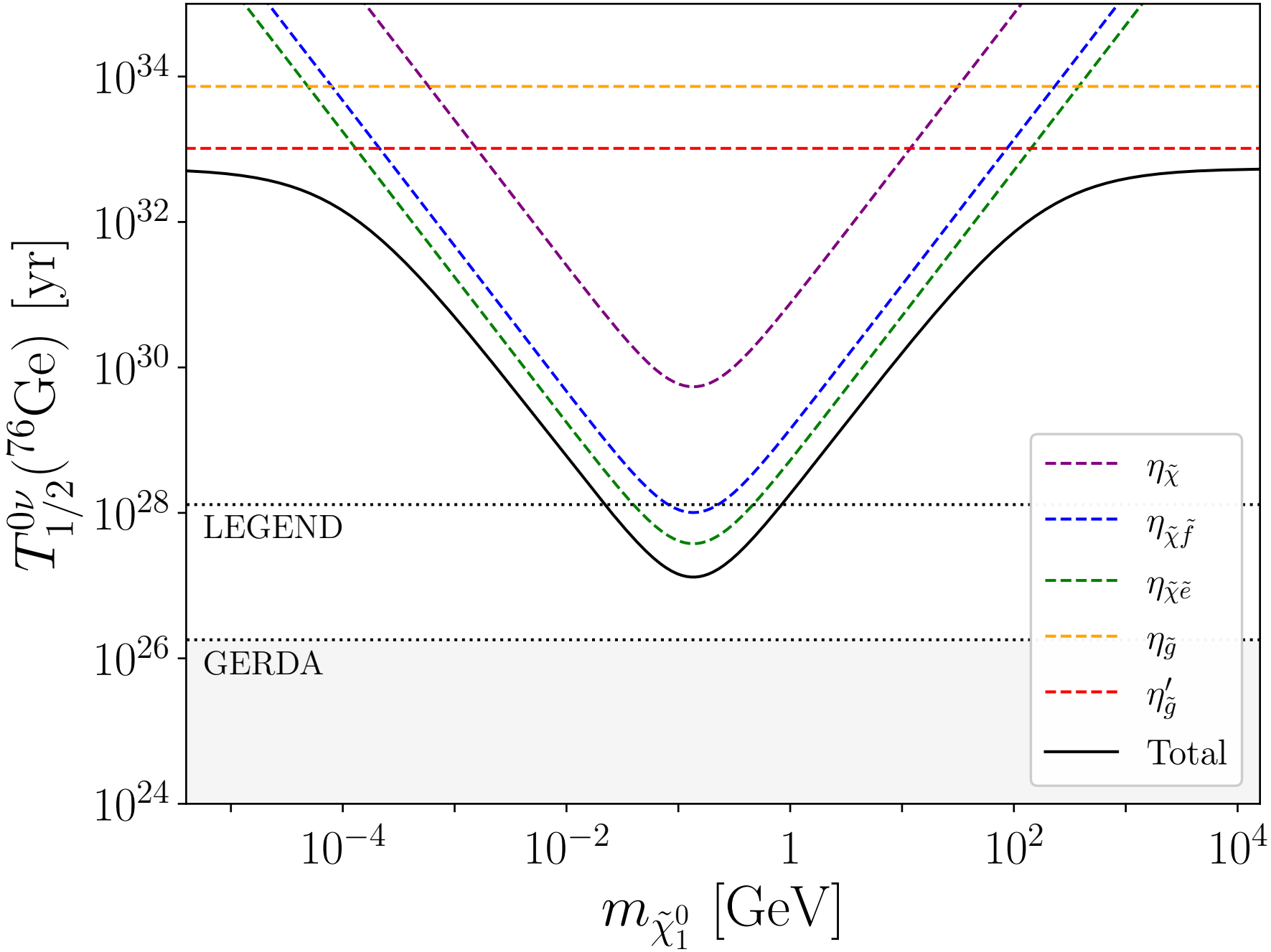
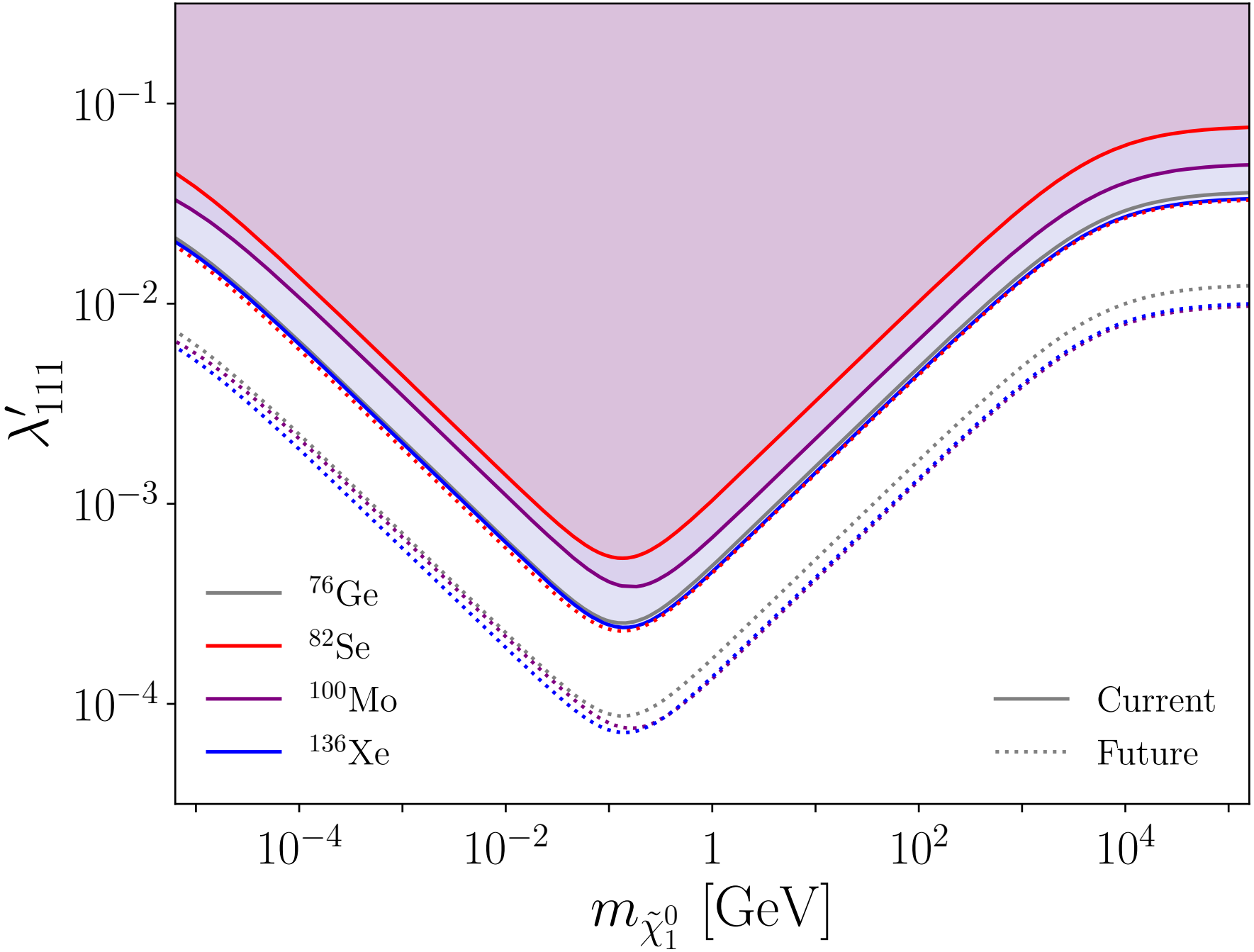


Only the short-range case (with heavy mediator $m_{\widetilde{X}} \gg p_F \sim 100$ MeV) had been considered before. [Mohapatra (PRD '86); Vergados (PLB '87); Hirsch, Klapdor-Kleingrothaus, Kovalenko (PRD '96); Faessler, Kovalenko, simkovic (PRD '98); Allanach, Kom, Pas (JHEP '09)]

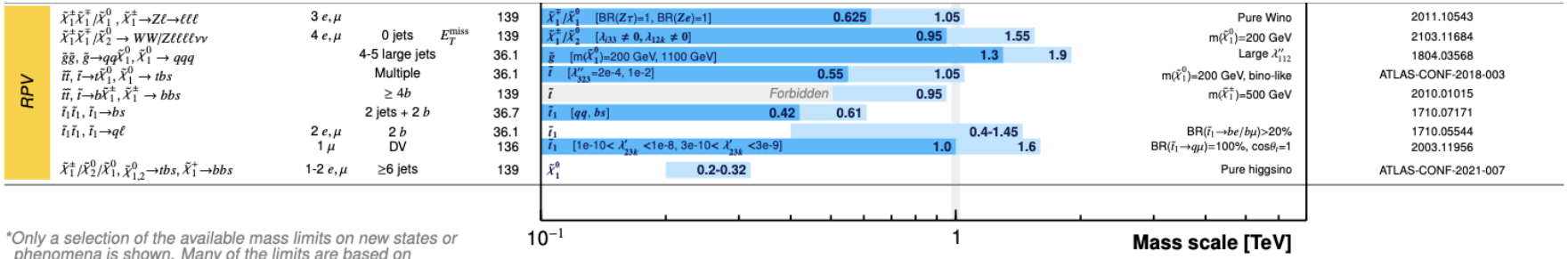
Light vs. Heavy Neutralino Exchange



With Different Isotopes



Collider Constraints



*Only a selection of the available mass limits on new states or phenomena is shown. Many of the limits are based on simplified models, c.f. refs. for the assumptions made.

[Particle Data Group '22]

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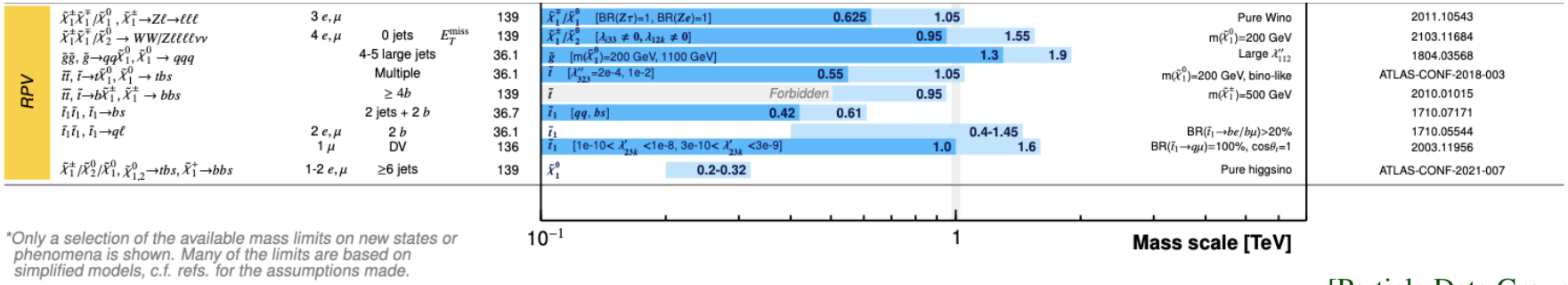

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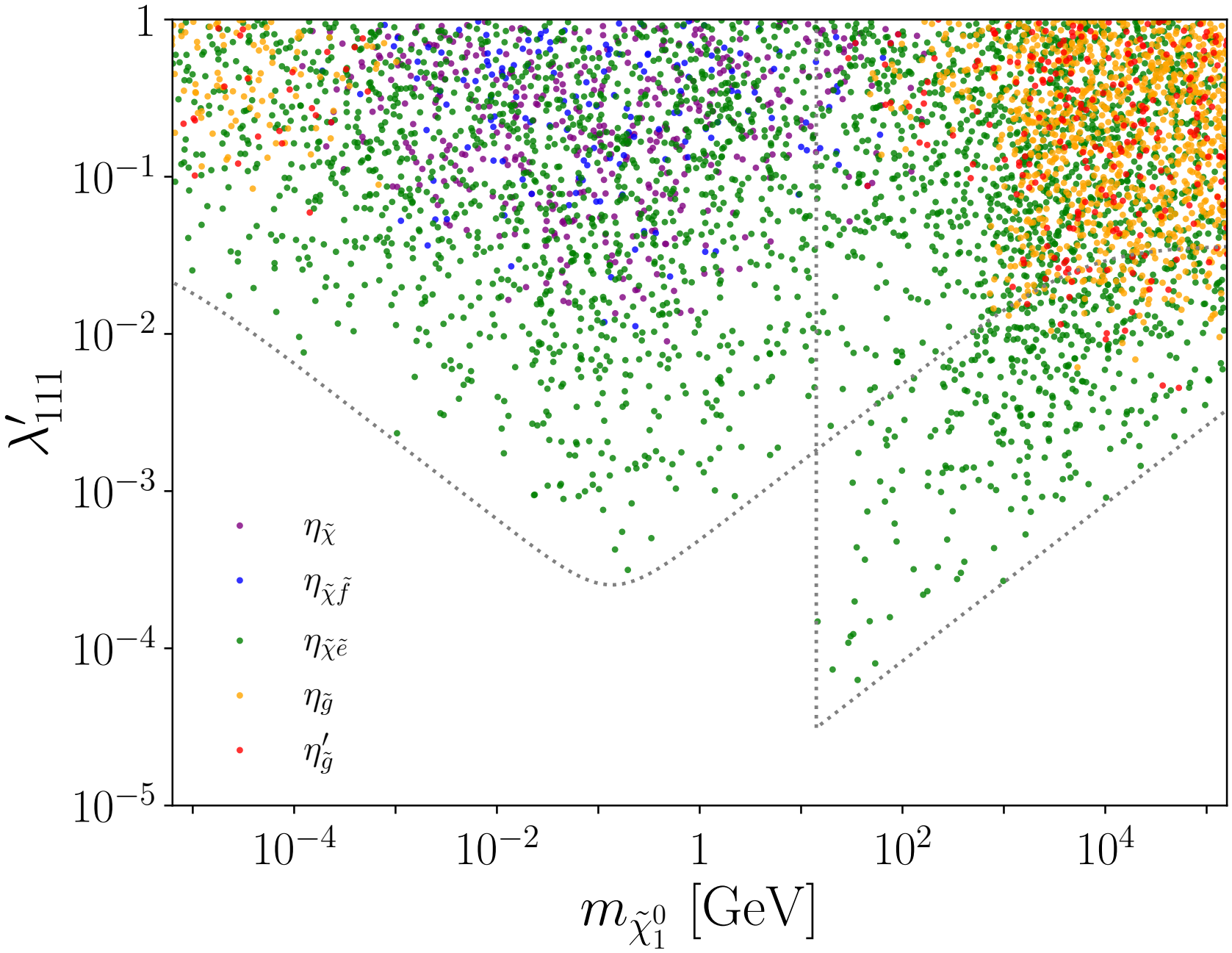
[Particle Data Group '22]

$\tilde{X}$	$m_{\tilde{X}}$ Lower Bound [GeV]		
	pMSSM [80]	$m_{\tilde{\chi}_1^0}=0$	Experiment
$\tilde{e}_L$	~ 90	700 (700)	$\tilde{e}_L\to e\tilde{\chi}_1^0$, ATLAS [94] (CMS [95])
$\tilde{u}_L$, $\tilde{d}_R$	~ 600	1900 (1750)	$\tilde{q}\to q\tilde{\chi}_1^0$, ATLAS [96] (CMS [97])
$\tilde{g}$	~ 1200	2350 (2000)	$\tilde{g}\to q\bar{q}\tilde{\chi}_1^0$, ATLAS [96] (CMS [98])
$\tilde{\psi}$	1.35×10^{-14}		$e^+e^-\to\tilde{\psi}\tilde{\psi}\gamma$, L3 [99]

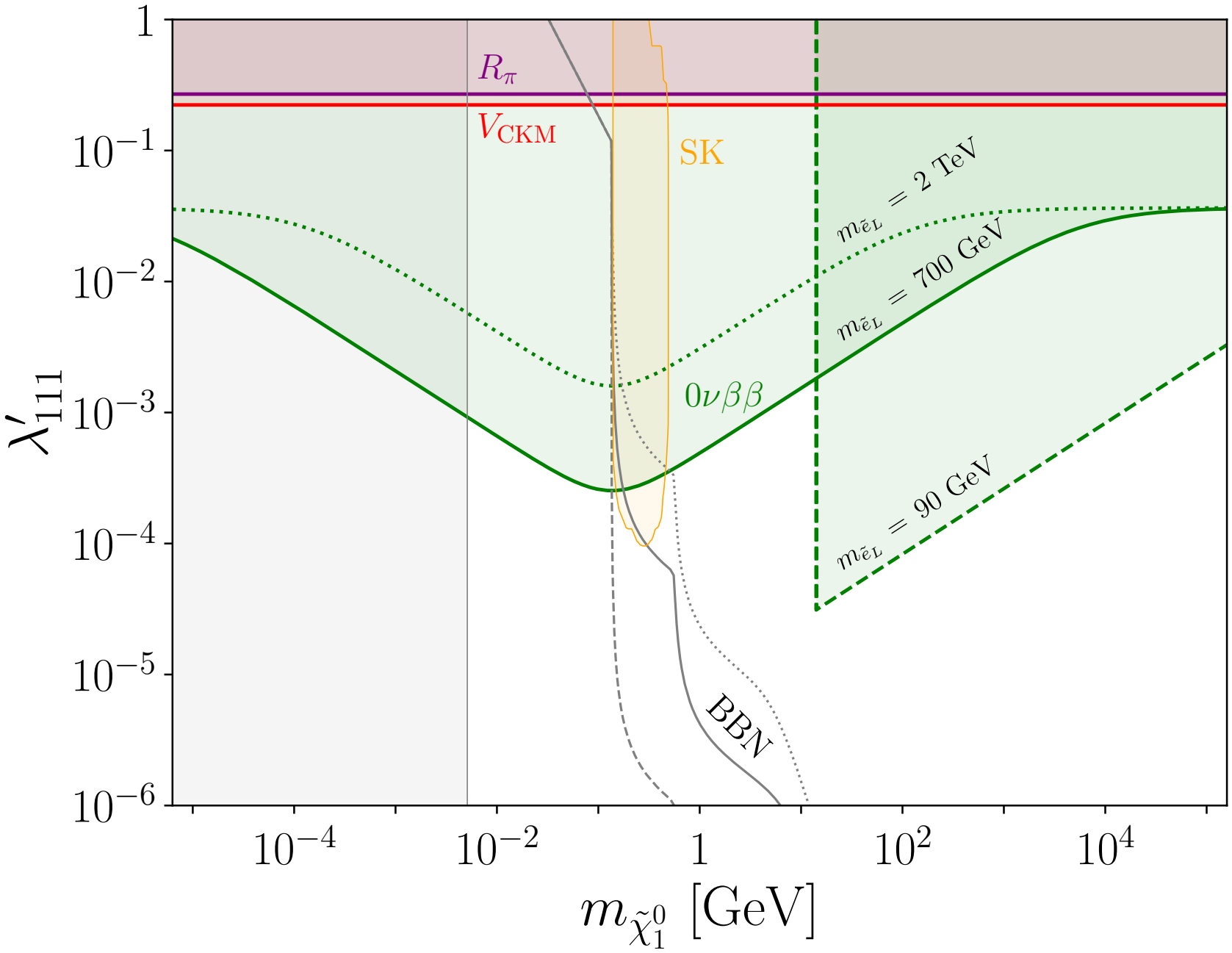
[Bolton, Deppisch, BD (2112.12658)]

Neutralino can be essentially massless in the general MSSM. [Hooper, Plehn (PLB '03); Belanger, Boudjema, Cottrant (JHEP '04); Dreiner, Heinemeyer, Kittel, Langenfeld, Weber and Weiglein (EPJC '09)]

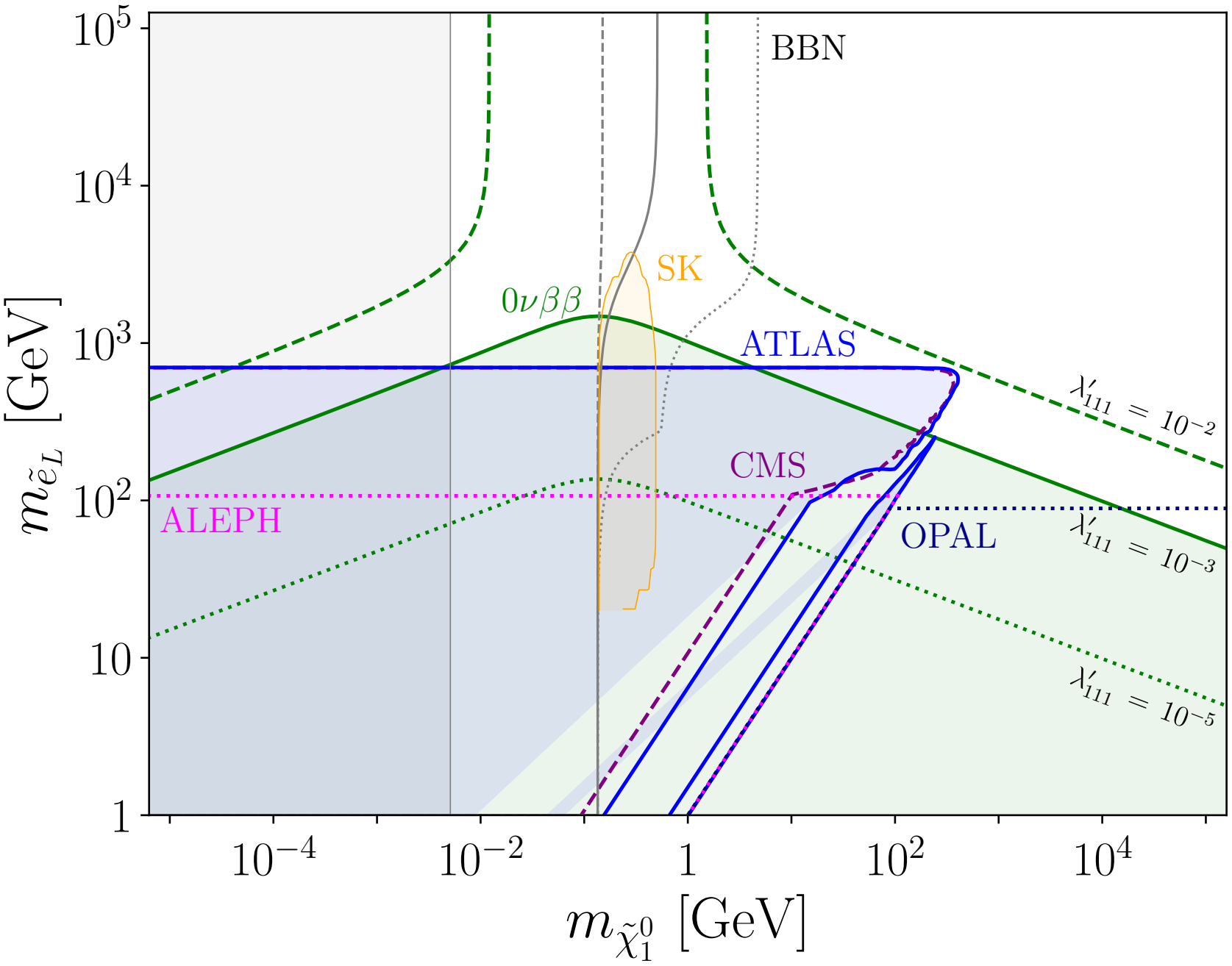
Collider Constraints



Complementarity of $0\nu\beta\beta$ with Other Constraints



Complementarity of $0\nu\beta\beta$ with Other Constraints



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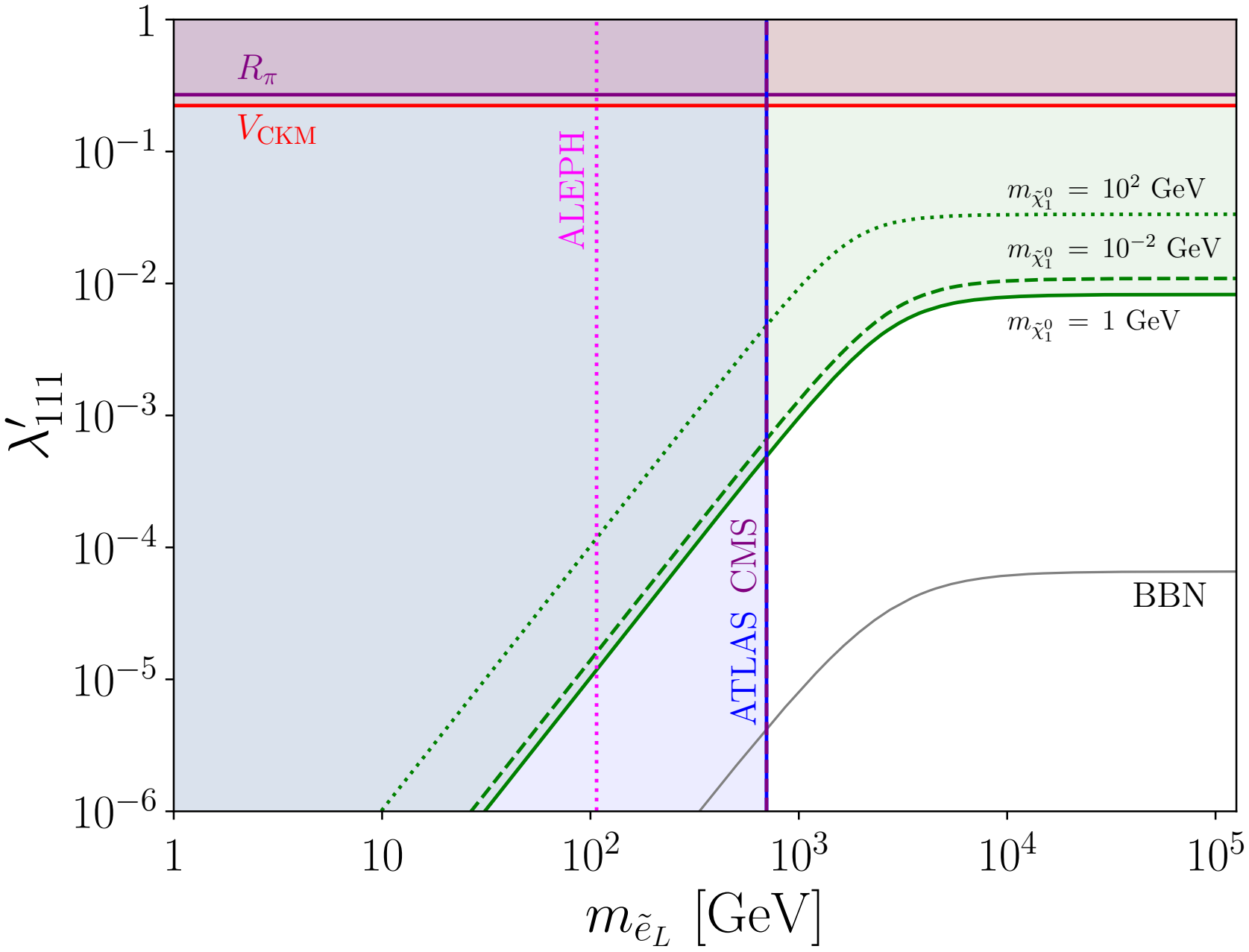
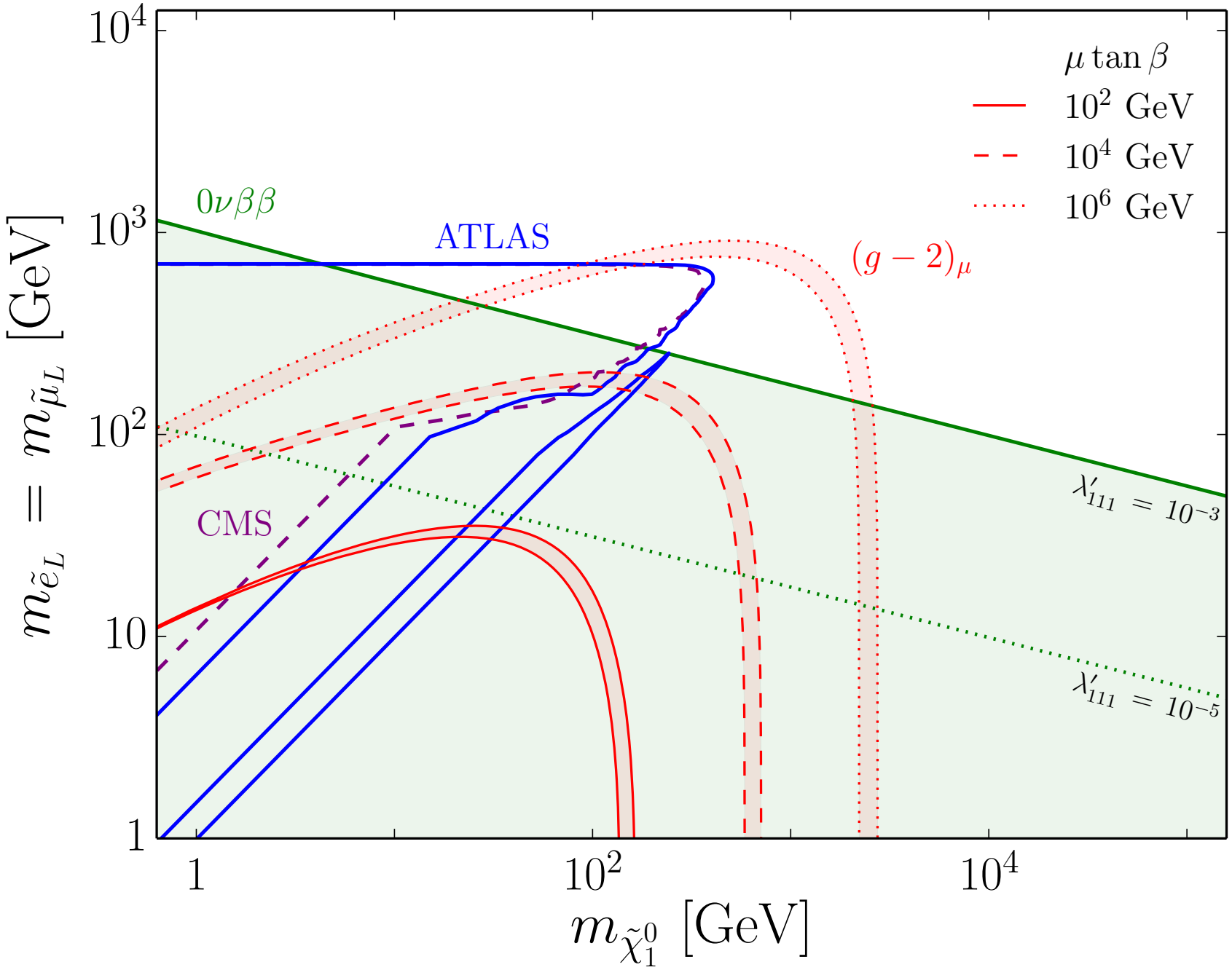


Complementarity with Muon $g-2$



Conclusions

- New contribution to $0\nu\beta\beta$ in RPV SUSY via neutralino exchange.
- Can be either short-range or long-range, depending on the neutralino mass.
- We derived new constraints on RPV parameter space using current limits on $0\nu\beta\beta$ half-life.
- Current limits exclude λ'_{111} down to $\lesssim 10^{-3}$ for $m_{\tilde{\chi}_1^0} \approx 100$ MeV, and future $0\nu\beta\beta$ searches can improve this to $\lambda'_{111} \lesssim 10^{-4}$.
- Observed anomalous magnetic moment of the muon can be related to an observable $0\nu\beta\beta$ decay rate in future ton-scale experiments.

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