Probing mechanisms of $0\nu\beta\beta$ at the LHC

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11 March 2010

Outline

- Introduction
- Examples of $0\nu\beta\beta$ mechanisms
- Information from $0\nu\beta\beta$ experiments alone
- Complementary information from the LHC
- Single slepton production and $0\nu\beta\beta$

  Allanach, CHK, Päs arXiv:0902.4697,0903.0347
- Summary

What is $0\nu\beta\beta$

- $2n \to 2p + 2e^- \quad [(Z,A)\ (\to (Z+1,A)^*) \to (Z+2,A)]$
- Possible only in even-even nuclei, dominated by $0^+ \to 0^+$ transition (e.g. ${}^{76}_{32}Ge \to {}^{76}_{34}Se$).
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- $0\nu\beta\beta$ provides stringent limit to many (1st gen.) LNV processes.

Neutrino mass measurements

Neutrino Oscillations:

- $|\Delta m^2_{23}| \simeq 2.5 \cdot 10^{-3}eV^2, sin^2(2\theta_{23}) > 0.9$ SK,MINOS

  $\Delta m^2_{12} = 7.6 \cdot 10^{-5}eV^2, tan^2(\theta_{12}) = 0.47$ SNO,KamLAND

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- $T^{0\nu\beta\beta}_{1/2}(^{76}Ge) > 1.9 \cdot 10^{25}$yr $\rightarrow |m_{\beta\beta}| < 0.35$eV Heidelberg-Moscow
  (claimed observation $|m_{\beta\beta}| \sim 0.5$eV Klapdor-Kleingrothaus et. al. 01)
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Related mass bounds:

- Cosmology $\sum_i m_i < (0.17 - 2.0)$eV Seljak,Slosar,McDonald 06
- Tritium decay $m_{\nu_e} < 2.2$eV Mainz,Troitsk 01

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$$\begin{aligned}\mathcal{L} &= \frac{G_F}{\sqrt{2}}(j^{SM}_{V-A}J^{SM}_{V-A} + \sum \epsilon_{NP}j_{NP}J_{NP}) \\ J &= \bar{u}\mathcal{O}_\beta d, \qquad j = \bar{e}\mathcal{O}_\beta \nu, \qquad \beta = V \pm A, PS, T \ \ldots\end{aligned}$$

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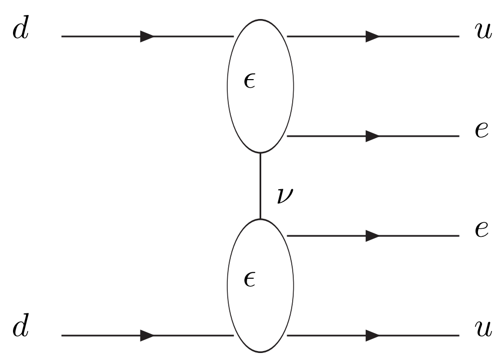

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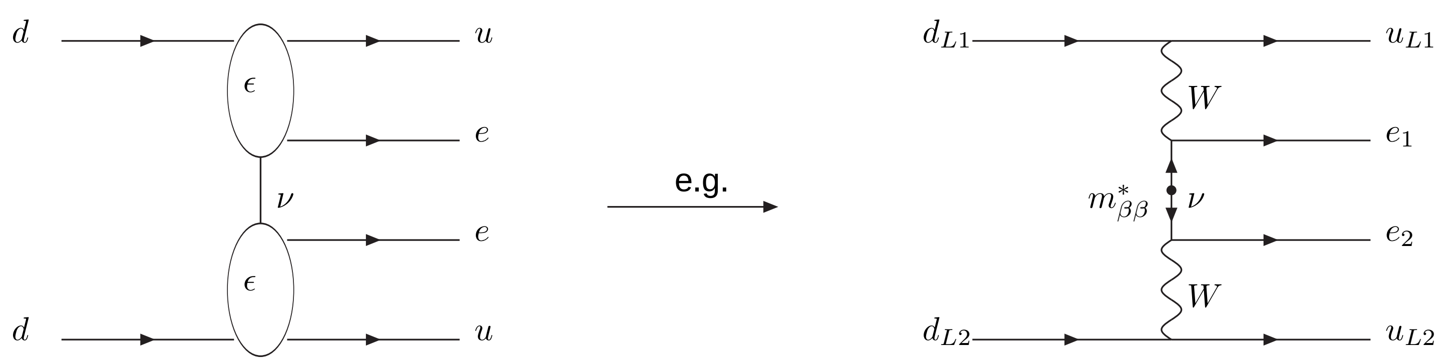
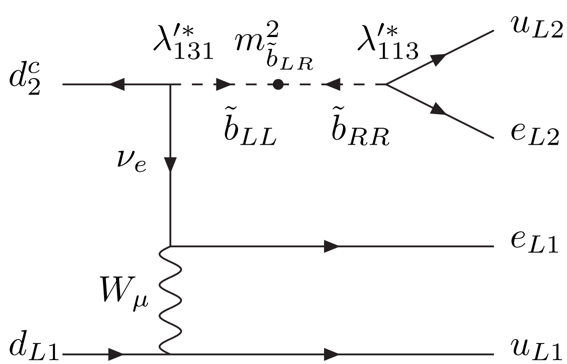


$$\mathcal{L}^{eff,\,\Delta L_e=2}_{EW}(x) = \frac{G_F^2}{2}\left[\bar{e}_1\gamma_\mu(1-\gamma_5)\frac{m_{\beta\beta}}{q^2}\gamma_\nu e_2^c\right] \times \left[J^\mu_{1,\,V-A}(q) J^\nu_{2,\,V-A}(-q)\right]$$

Examples

Sbottom exchange in LNV SUSY



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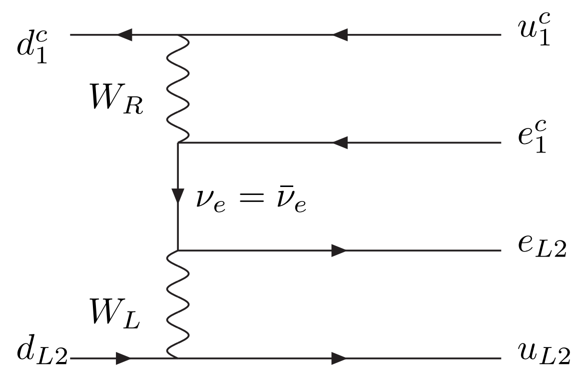
LR symmetric Model



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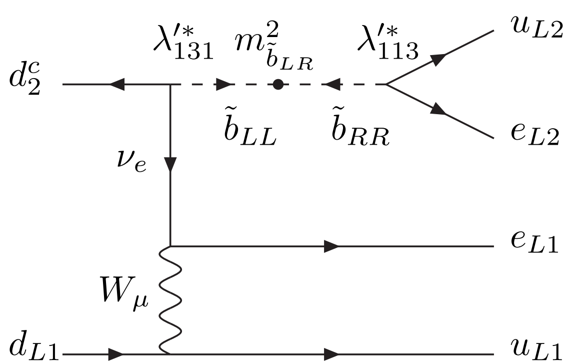

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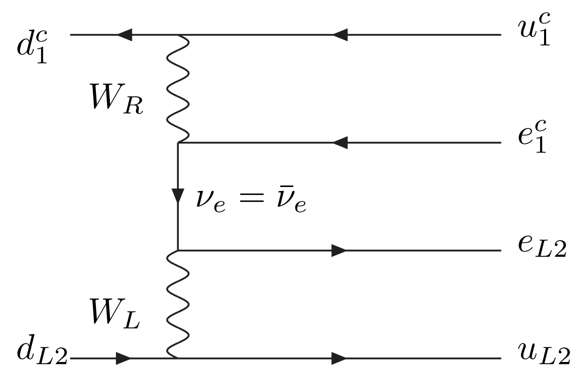

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- (Scalar) lepto-quark contributions similar to sbottom exchange.
- W_R-W_R contributions ...

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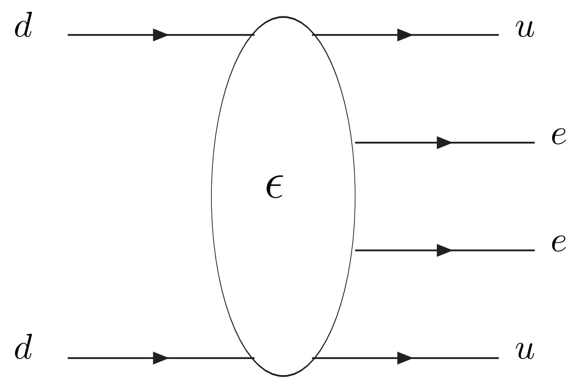

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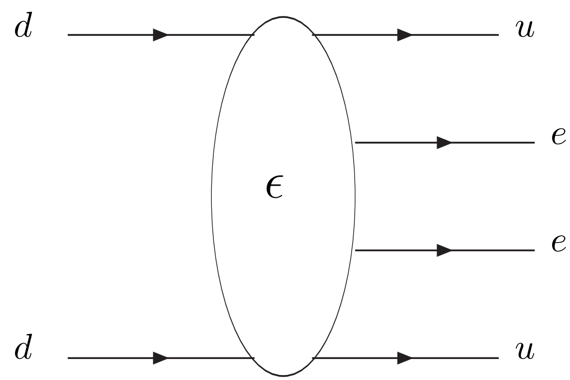

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- New physics (NP): LNV SUSY with gaugino exchange, [$\mathcal{O}$(TeV)] heavy neutrinos...

From NP to rates

Total rate (if dominated by one mechanism)

$$\Gamma_{0\nu\beta\beta} \quad \propto \quad \epsilon^2 G_{0\nu} |M_{0\nu}|^2$$

ϵ: LNV physics parameter,

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Bottom line: take the numerical values with a grind of salt...

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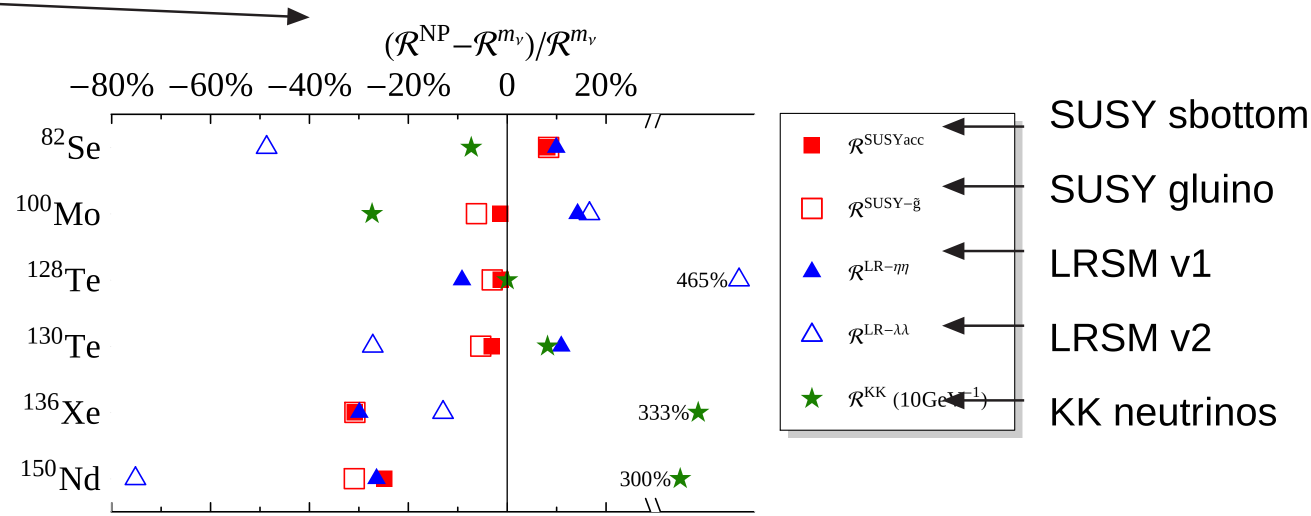

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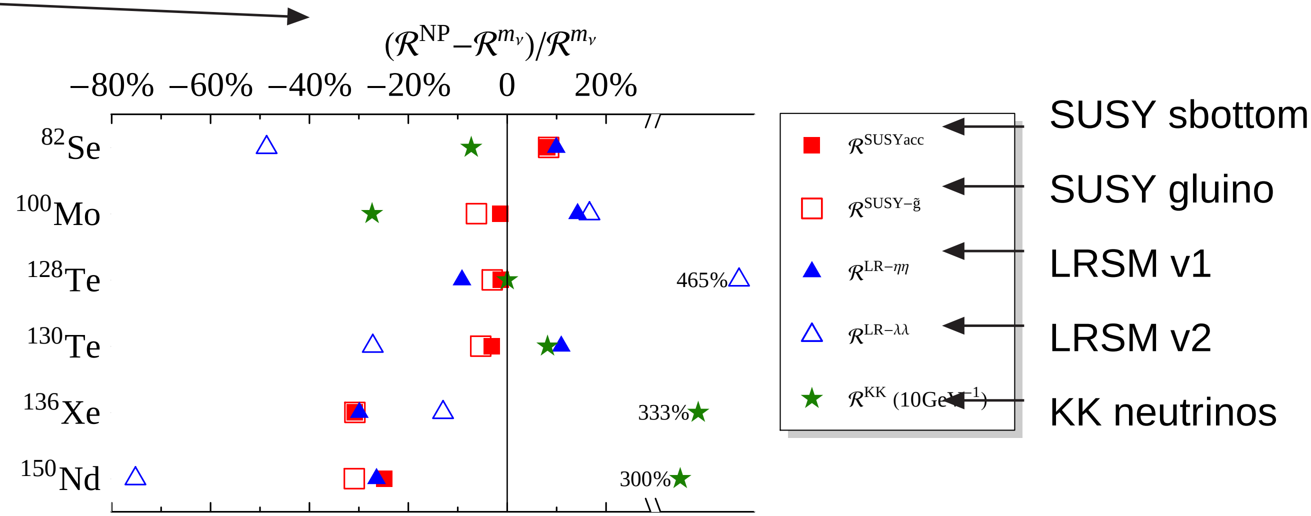

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- Many isotopes required.

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- E.g. SuperNEMO is sensitive to single electron kinematics.

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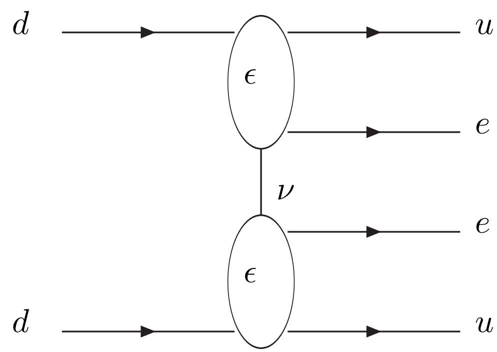

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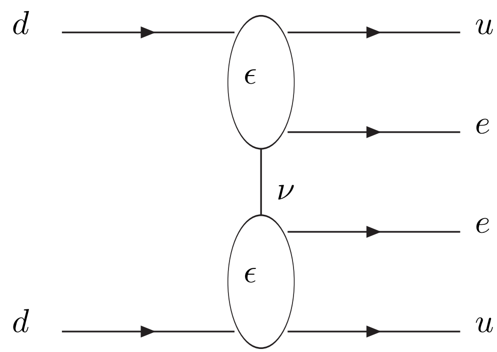

$0\nu\beta\beta$ **?**

Hard process ?

Direct ϵ determination ?

- Particularly suitable for short range interactions
- Focus on $0\nu\beta\beta$ in LNV SUSY and signals at the LHC.

  Allanach, CHK, Päs arXiv:0902.4697,0903.0347

$0\nu\beta\beta$ in LNV SUSY

LNV SUSY contains superpotential term:

$$W \supset \lambda'_{111} L_1 Q_1 D^c_1 \rightarrow$$
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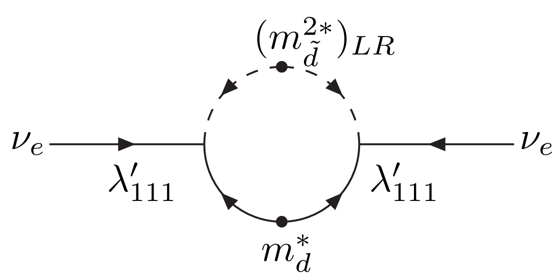
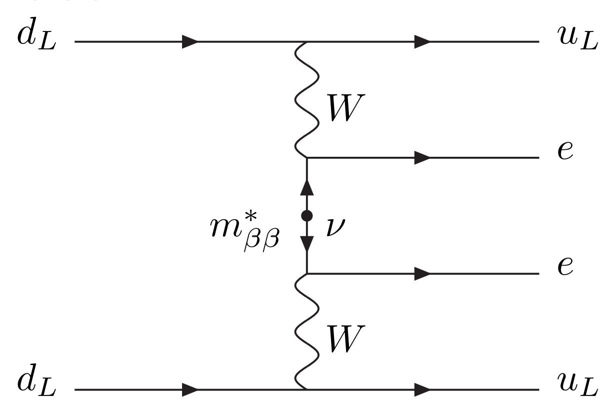
Contribute to $0\nu\beta\beta$ via:

- Loop induced Majorana neutrino mass.





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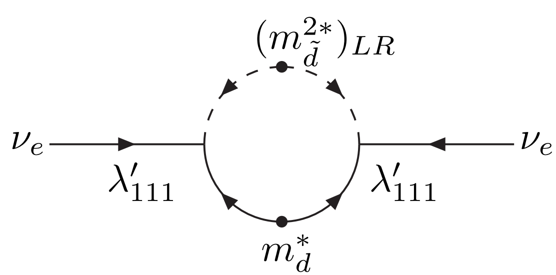
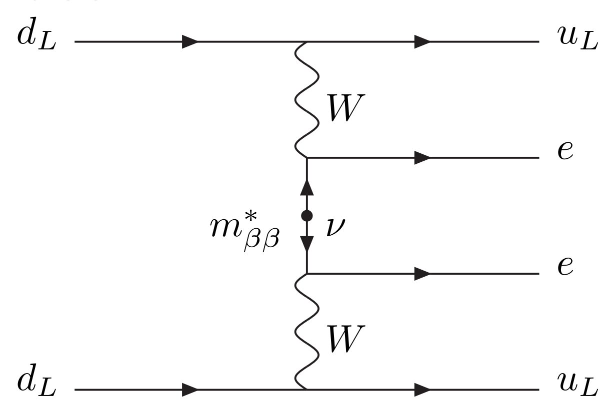
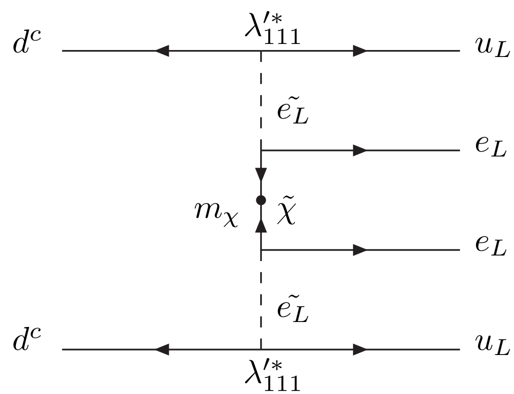


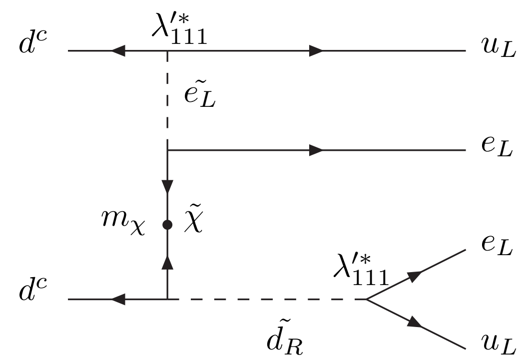


- Also tree level m_ν via RG effect.

$0\nu\beta\beta$ in LNV SUSY 2

- Direct, short range mediation without intermediate neutrino, e.g.





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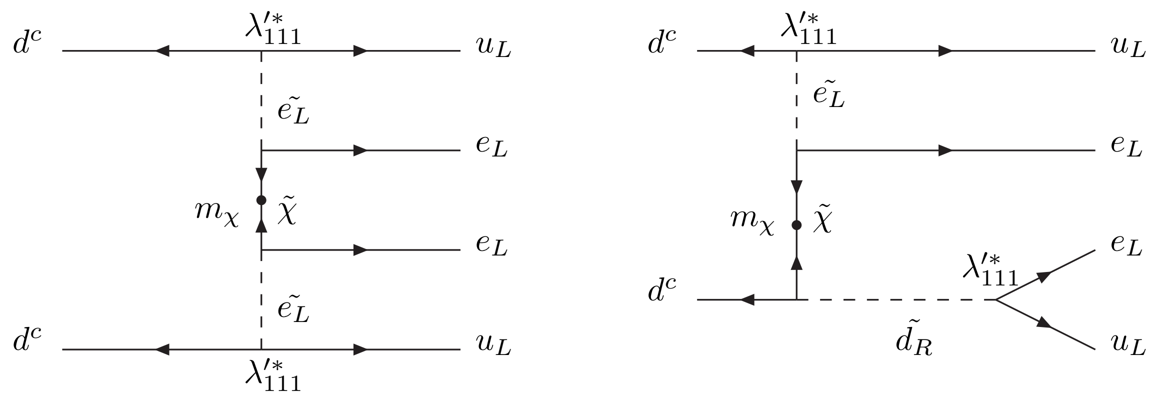

$$\mathcal{L}^{eff,\,\Delta L_e=2}_{\lambda'_{111}\lambda'_{111}}(x) = \frac{G_F^2}{2} m_p^{-1} [\bar{e}(1+\gamma_5)e^c] \times \left[(\epsilon_{\tilde{g}}+\epsilon_\chi)(J_{PS}J_{PS} - \frac{1}{4}J_T^{\mu\nu}J_{T\mu\nu}) + (\epsilon_{\chi\tilde{e}} + \epsilon'_{\tilde{g}} + \epsilon_{\chi\tilde{f}})J_{PS}J_{PS}\right]$$

$$\epsilon_i \sim \pi\alpha_{(S,W)} \frac{\lambda'^2_{111}}{G_F^2} \frac{m_P}{m_{(\tilde{g},\tilde{\chi})}} \frac{1}{m^4_{(\tilde{u},\tilde{d},\tilde{e})}}.$$

Single slepton production

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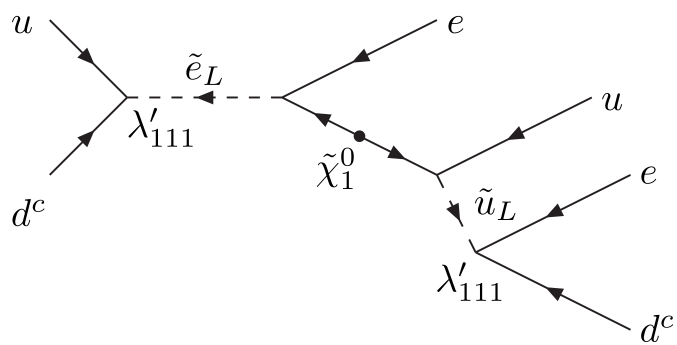
  YES: single selectron production.



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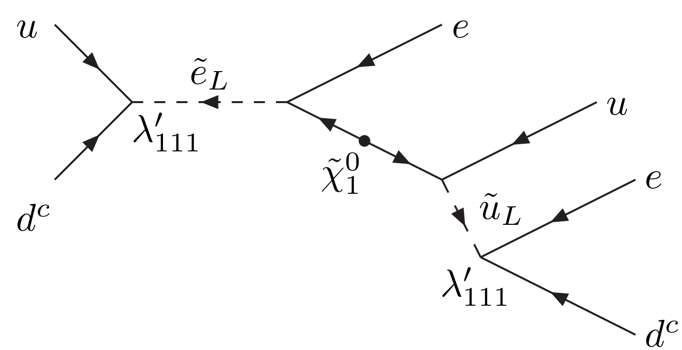

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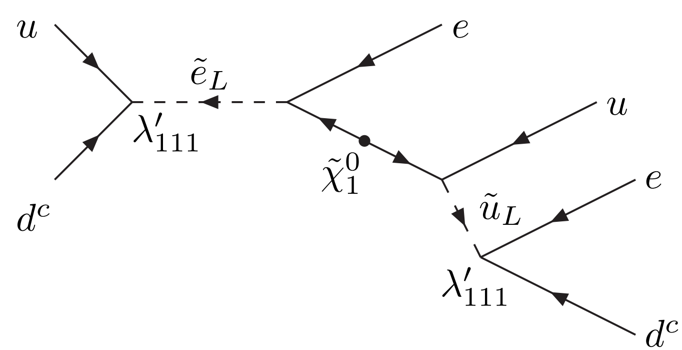

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- Lower $T_{1/2}^{0\nu\beta\beta}(^{76}\mathrm{Ge})$ limit: $\lambda'_{111} \lesssim 5 \cdot 10^{-4}(\frac{\Lambda_{SUSY}}{100GeV})^{2.5}$.
  Single slepton production: $\sigma(pp \to \tilde{l}) \propto |\lambda'_{111}|^2/m_{\tilde{l}}^3$
  $\to$ *production upper limit increases with* Λ_{SUSY}.

Single slepton production 2

- Signal: *Same* sign (SS) di-electron, 2 jets, little $\not{E}_T$.
- Previous analysis on SS di-muon signals for λ'_{211} Dreiner,Richardson,Seymour 99 .
- SS di-electron signal for λ'_{111} believed to be mathsize due precisely to ‘stringent’ $0\nu\beta\beta$ bound !!
- To estimate $\epsilon_{\lambda'_{111}}$, need also $\tilde{q}$, $\tilde{\chi}$, $\tilde{g}$ masses. Assumed to be obtained from other channels

Model assumptions

MSSM model parameters:

- Masses defined by mSUGRA input
  m_0, $M_{1/2}$, $A_0 = 0$, tan$\beta = 10$, $sgn(\mu) = +1$.
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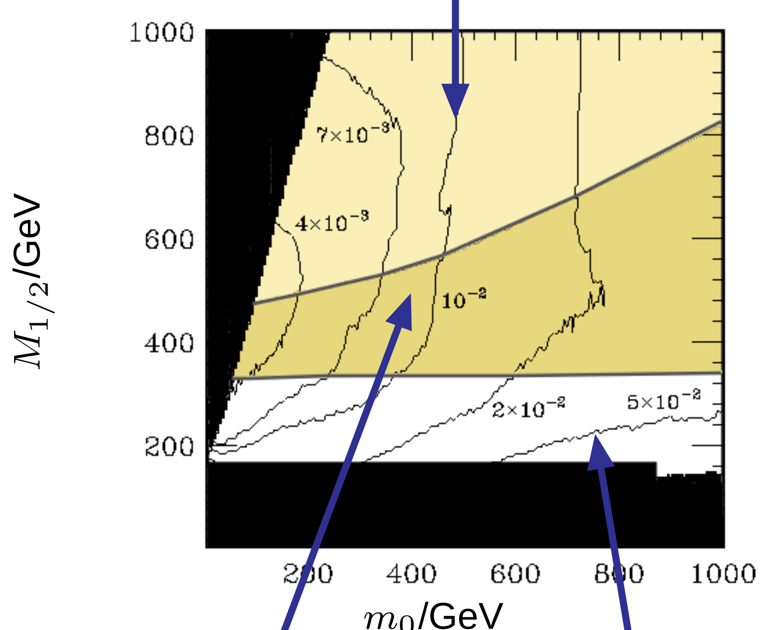
NME model parameters (^{76}Ge):

- Pion and nucleon modes included.
  $$M_{\lambda'_{111}} = \epsilon M_{\tilde{g}}^{2N} + \epsilon' M_{\tilde{f}}^{2N} + \left(\epsilon + \frac{5}{8}\epsilon'\right)\left(\frac{4}{3}M^{1\pi} + M^{2\pi}\right)$$
- $M_{\tilde{g}}^{2N} = 283$, $M_{\tilde{f}}^{2N} = 13.2$, $M^{1\pi} = -18.2$, $M^{2\pi} = -601$
  Hirsch,Klapdor-Kleingrothaus,Simkovic 96 , Faessler,Kovalenko,Simkovic 98

Results

Infer $T_{1/2}^{0\nu\beta\beta}(^{76}\text{Ge})$ from SS di-electron 5-σ signal at 10 fb^{-1}, 14 TeV (no $m_{\beta\beta}$ contribution):

$1 \cdot 10^{27}$ yrs < $T_{1/2}^{0\nu\beta\beta}(^{76}\text{Ge})$



$1.9 \cdot 10^{25} < T_{1/2}^{0\nu\beta\beta}(^{76}\text{Ge}) < 1 \cdot 10^{27}$ yrs

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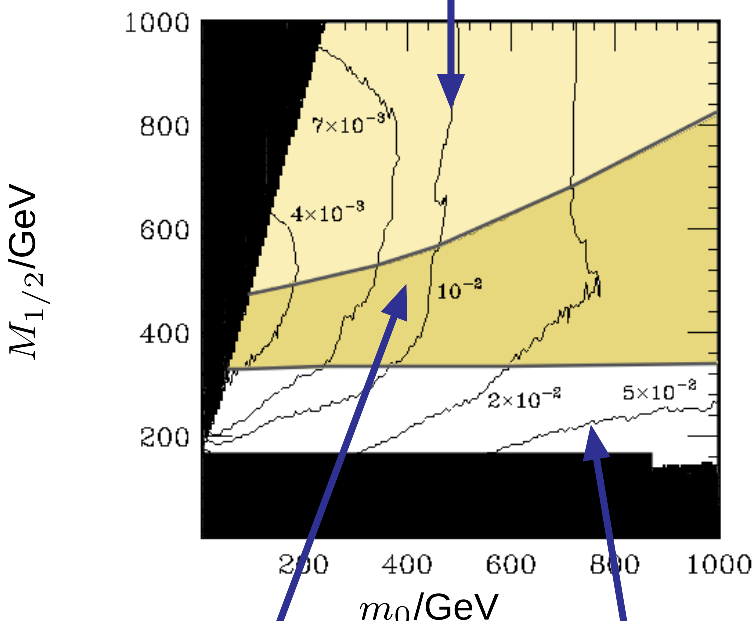

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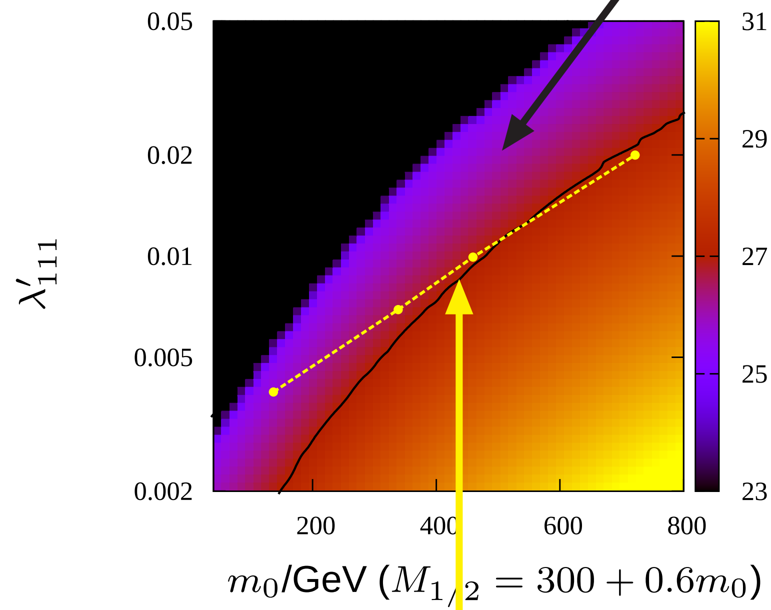
Sensitive to future $0\nu\beta\beta$ expts.



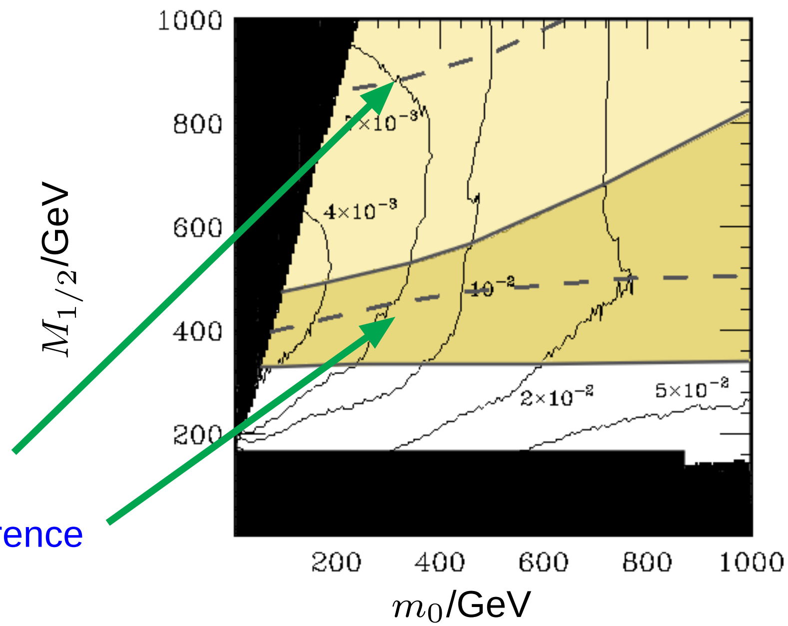
LHC single slepton discovery limit

Results 2

Including

$$|m_{\beta\beta}| = 0.05 \text{ eV}$$

$$(\sim \sqrt{\Delta m_{23}^2})$$



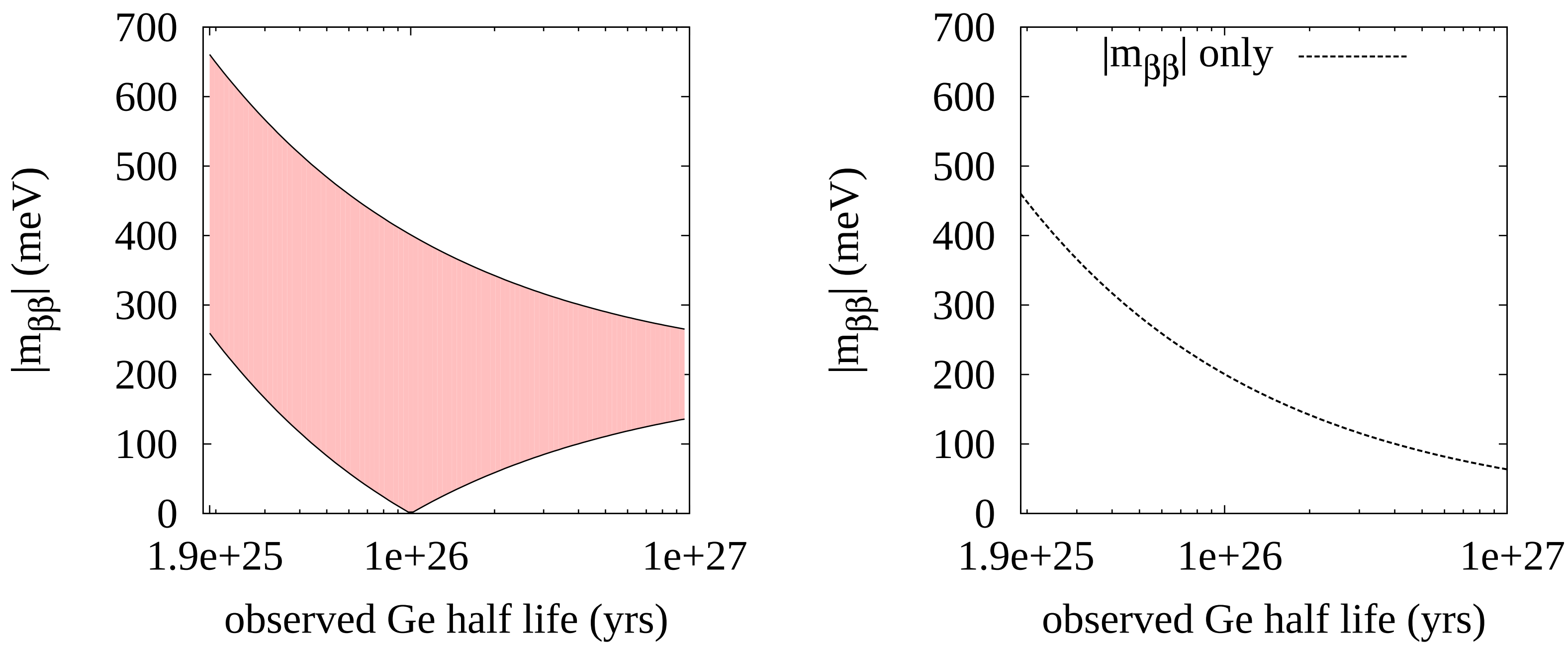
Constructive interference

Destructive interference

- Destructive interference with $m_{\beta\beta}$ increases $T_{1/2}^{0\nu\beta\beta}(^{76}\text{Ge}) \rightarrow$ dark yellow region shrinks.
- Fixing $T_{1/2}^{0\nu\beta\beta}(^{76}\text{Ge})$, destructive int. with $m_{\beta\beta}$ increases SSL rate $\rightarrow$ better SSL discovery prospect.

Inference on $m_{\beta\beta}$

Given 5σ SSL observation ($M_0 = 680$GeV, $M_{1/2} = 440$GeV)
$\rightarrow T_{1/2}^{0\nu\beta\beta}(^{76}\text{Ge}) = 1 \cdot 10^{26}$yrs if direct contribution only.



- Band of $m_{\beta\beta}$ depending on relative phase.
- Normal hierarchy possible if $0\nu\beta\beta$ observed.

Summary

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- Half life ratios and electron correlations can distinguish $0\nu\beta\beta$ mechanisms.
- LHC allows direct determination of LNV parameters in $0\nu\beta\beta$.
- Discussed interplay between $0\nu\beta\beta$ and single slepton production at the LHC in LNV SUSY.
- If $0\nu\beta\beta$ is discovered, single slepton production could test the λ'_{111} hypothesis.

Planned $0\nu\beta\beta$ experiments

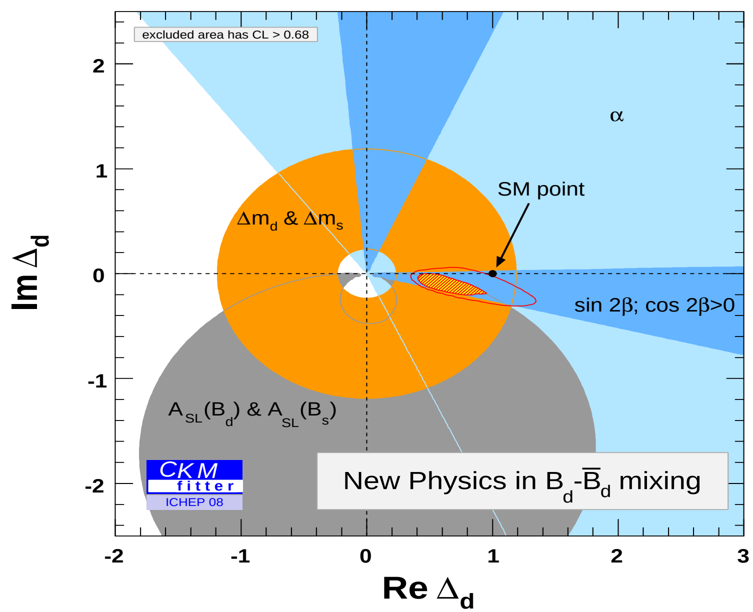
Need $\sim$ 1 ton of active isotopes to investigate the IH.
An incomplete list of experiments here:

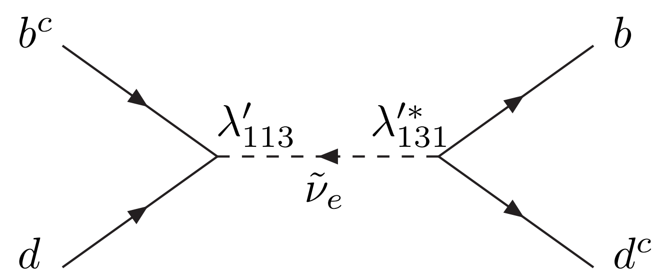
CUORE(^{130}Te)	750kg, TeO_2 bolometers	Setup completion in 2012
GERDA(^{76}Ge)	18kg (Phase I), Ge detector	Construction being completed
MAJORANA(^{76}Ge)	60kg (initial phase), Ge detector	R&D
EXO(^{136}Xe)	1-10 ton, TPC, Ba^{++} tagging	EXO-200 run expected in 2009
SuperNEMO(^{82}Se)	100kg, track + calor.	1st module in 2011. Rest in 2012

Thankyou

B_d^0-$\bar{B}_d^0$ mixing and $0\nu\beta\beta$

B_d^0-$\bar{B}_d^0$ mixing limit: $\langle B_d | M_{12}^{\text{SM+New Physics}} | \bar{B}_d \rangle = \Delta_d \langle B_d | M_{12}^{\text{SM}} | \bar{B}_d \rangle$





$$\lambda'_{113}\lambda'_{131} \leq 4.0 \cdot 10^{-8} \frac{m^2_{\tilde{\nu}_e}}{(100\text{GeV})^2}$$

- For $0\nu\beta\beta$, $\lambda'_{113}\lambda'_{131} \lesssim 2 \cdot 10^{-8} \left(\frac{\Lambda_{SUSY}}{100\text{GeV}} \right)^3$
- B_d^0-$\bar{B}_d^0$ bound more stringent than $0\nu\beta\beta$ with high Λ_{SUSY}, though with different SUSY mass dependence.

Nuclear structure model

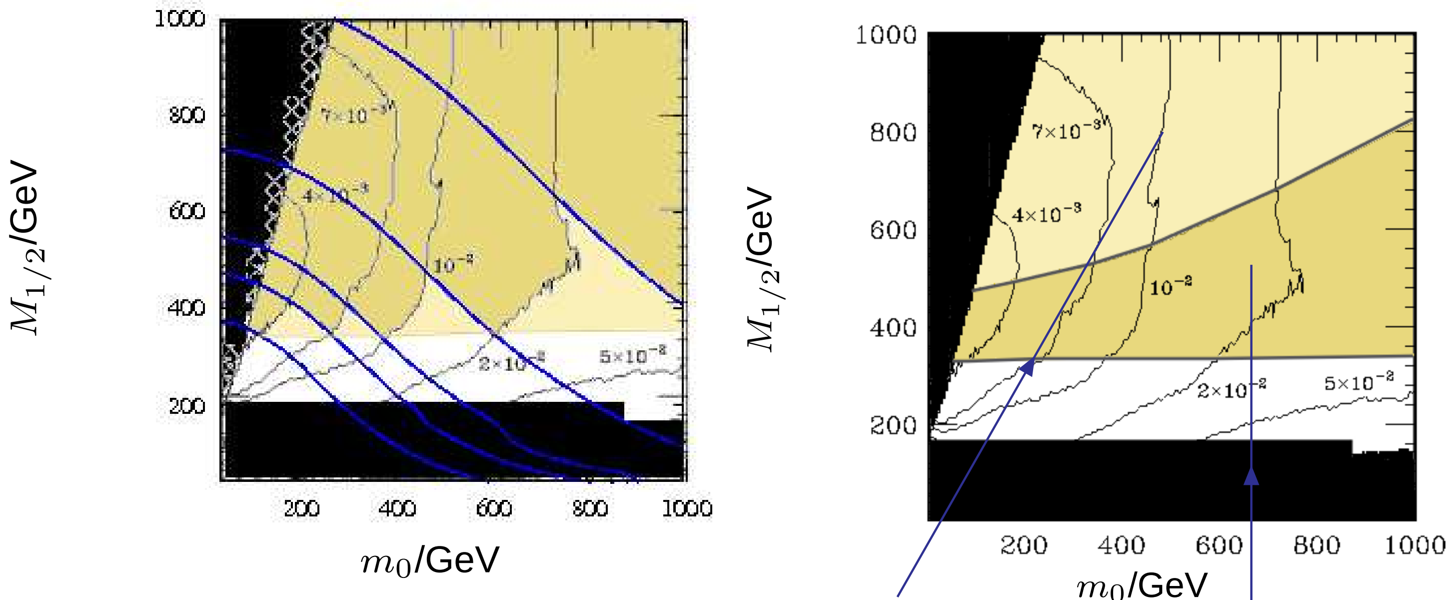
Examples of approximations used:

- Mean field theory, truncated single particle basis.
- Energy of states, interactions adjusted to reproduce data.
- Quenching of the axial vector coupling g_A.
- Short range correlations included explicitly.
- QRPA: quasiboson approx., pairing parameter g_{pp} adjusted...

More advanced tools available in ‘simpler’ nuclear properties ...

Comparing λ'_{111} bounds

- Infer $T_{1/2}^{0\nu\beta\beta}(^{76}\text{Ge})$ from SS di-election 5-σ discovery reach at 10 fb^{-1}:



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LHC SS di-lepton cuts

From Dreiner,Richardson,Seymour 99

- Lepton $|\eta| < 2.0$.
- Lepton $p_T > 40$ GeV.
- Isolation cut: $E_T < 5$ GeV in cone R=0.4.
- Reject 65 < M_T < 80 GeV.
- $\not{E}_T$ < 20 GeV.
- OSSF lepton veto.
- No more than 2 jets, each with $p_T > 50$ GeV.