LHC as a complementary probe to study $0\nu\beta\beta$ mechanisms ?

Neutrino Oscillation Workshop 2010

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Steve Chun-Hay Kom

Cavendish Laboratory, Cambridge

Outline

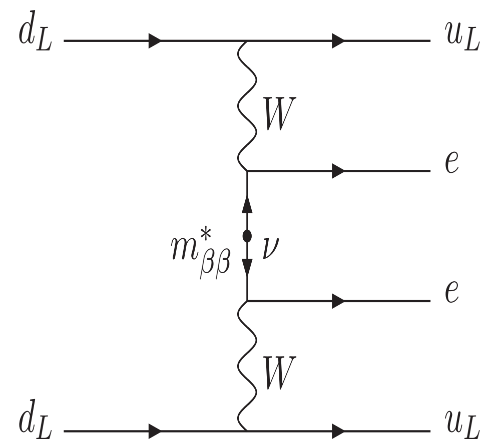
- Why LHC might be relevant for $0\nu\beta\beta$
- Example : same sign di-electron + 2 jets in R-parity violating SUSY

  Allanach, CHK, Päs 0902.4697, 0903.0347
- Charge asymmetry ratio

  CHK, Stirling appear soon

Standard $0\nu\beta\beta$

‘Reference’ model: light mass mechanism



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

$$\times \left[J^\mu_{1,\,V-A}(q) J^\nu_{2,\,V-A}(-q) \right]$$

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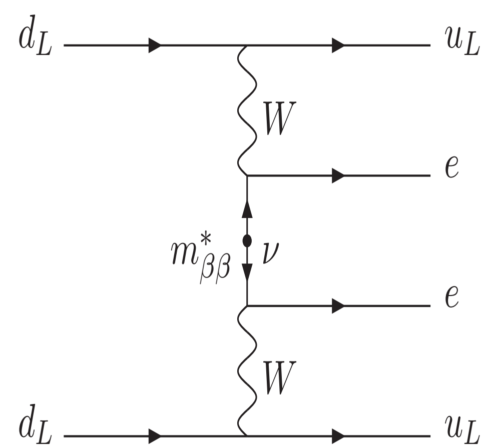

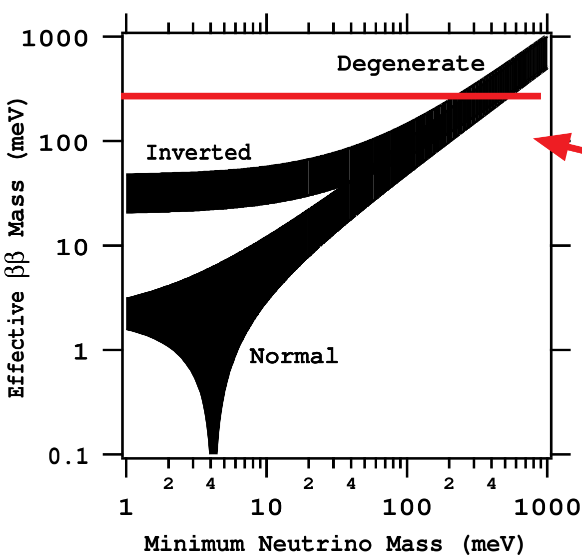

Heidelberg-Moscow , CUORICINO & NEMO3

$$|m_{\beta\beta}| \lesssim 0.35\text{eV}$$

(also $|m_{\beta\beta}| \sim 0.5$eV

Klapdor-Kleingrothaus et. al.)

Other possibilities

- However many lepton number violating theories :
  RPV SUSY, heavy Majorana neutrinos,
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  - Electron kinematics Ali,Borisov,Zhuridov 07 , SuperNEMO & Flack's talk
  - $T_{1/2}^{0\nu\beta\beta}(^{76}\text{Ge})$ ratios of different isotopes
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- We focus on $0\nu\beta\beta$ mediation involving TeV scale particles.
- Investigate interplay between LHC signatures and $0\nu\beta\beta$ rate predictions.

TeV $0\nu\beta\beta$ mechanisms at the LHC

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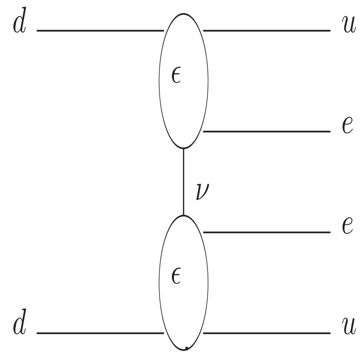

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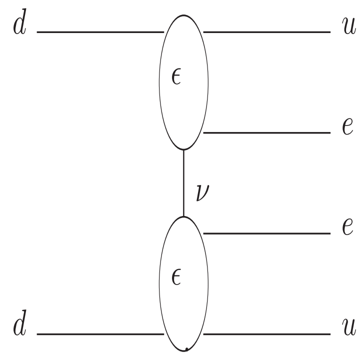

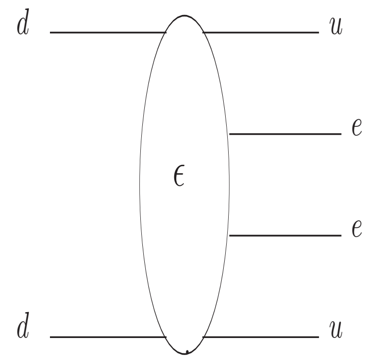

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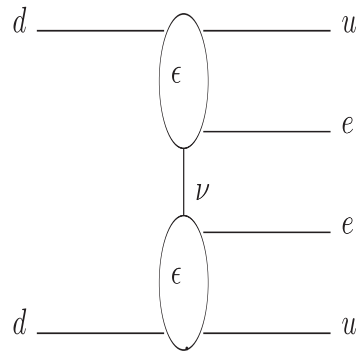

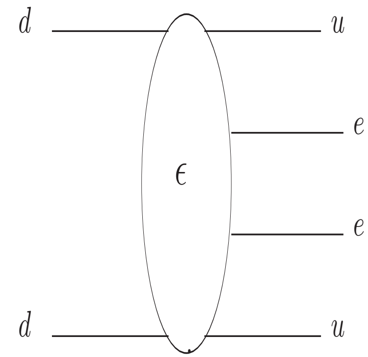

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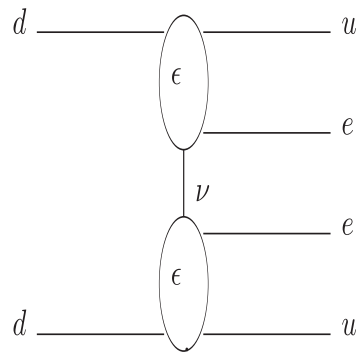

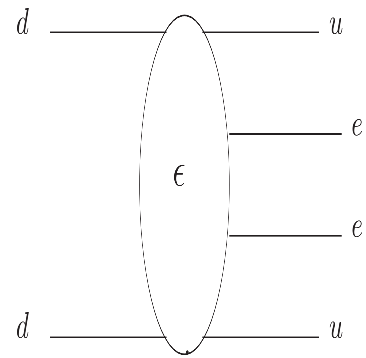

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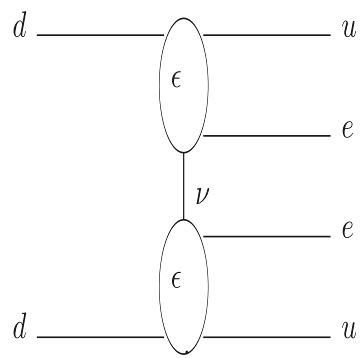

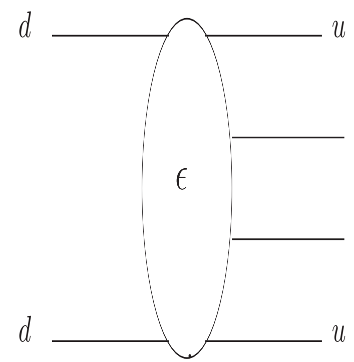

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- 4 leptons f.s. BRs in Higgs triplets Petcov et. al. 09
- B_d^0-$\bar{B}_d^0$ mixing Allanach, CHK, Päs 0903.0347

Example: $0\nu\beta\beta$ in RPV SUSY

RPV SUSY: renormalisable lepton number violating parameters.

$$\mathcal{W}_{\rm RPV} = \lambda'_{111} L_1 Q_1 D_1^c + \cdots$$

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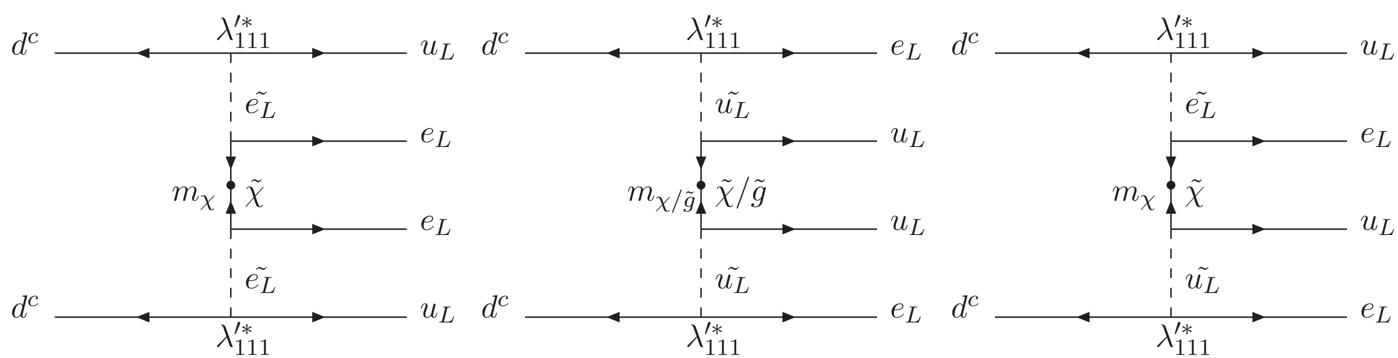
Direct, TeV scale mediation w/o intermediate light neutrino, e.g.



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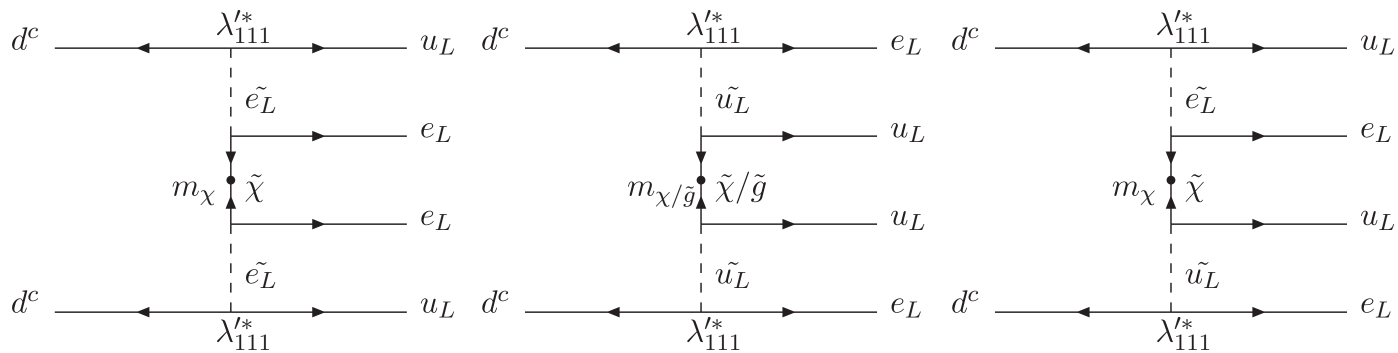

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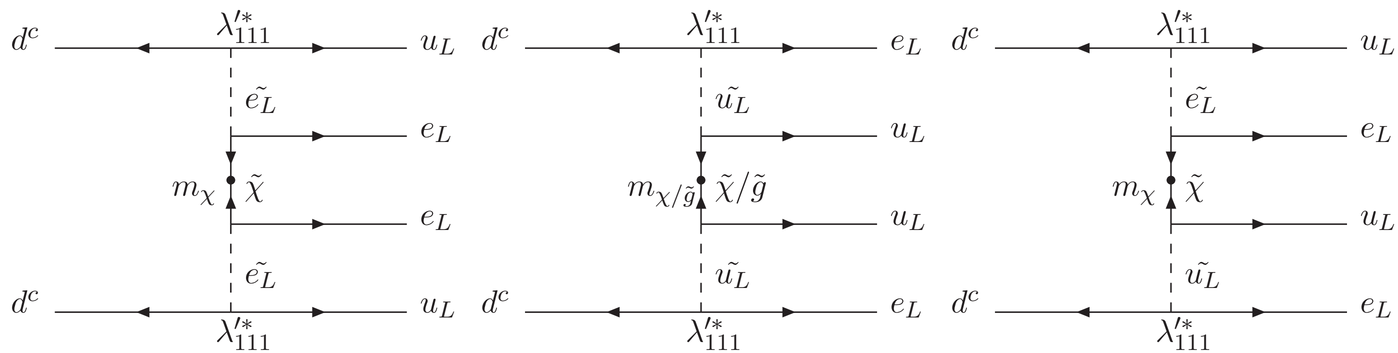

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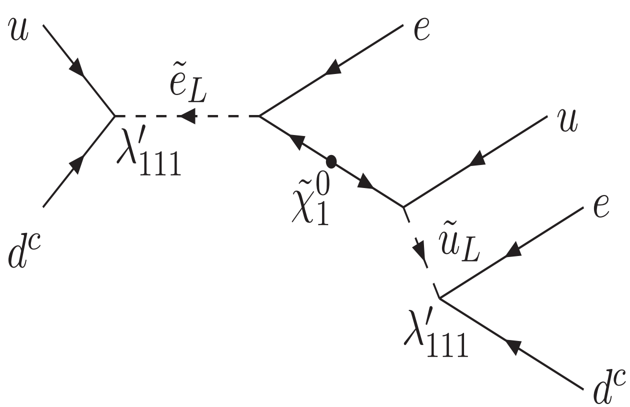
$\epsilon \sim \lambda'^2_{111}\left(\frac{\Lambda_{SM}}{\Lambda_{SUSY}}\right)^5$:

λ'_{111} bound relaxes rapidly with increasing Λ_{SUSY}.

Resonant selectron production

Direct indication of λ'_{111} !



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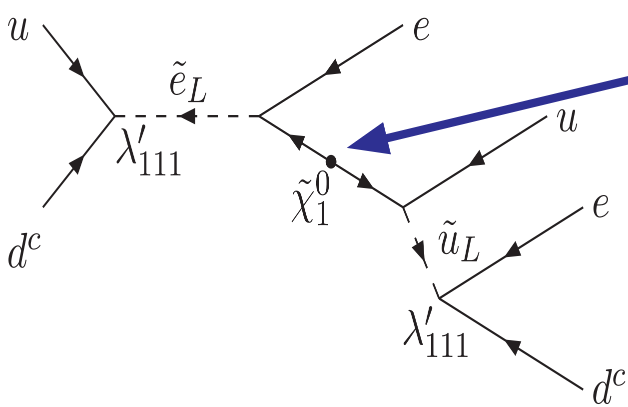

Majorana $\tilde{\chi}_0$: SSDL possible.

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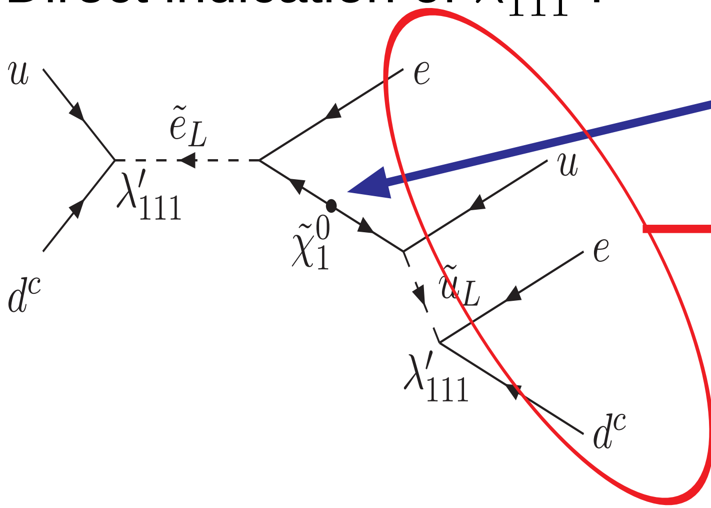

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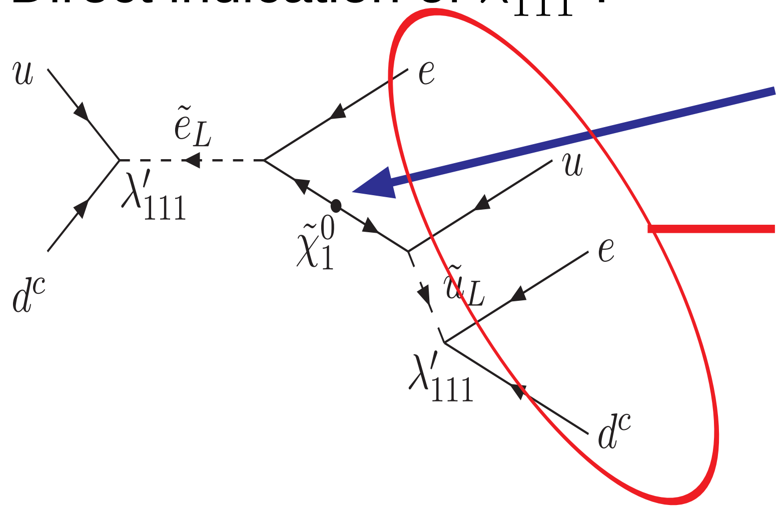

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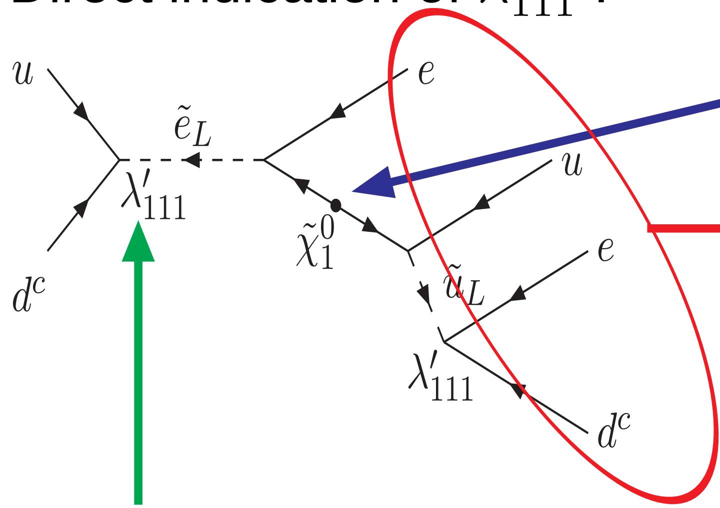

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Lower $T_{1/2}^{0\nu\beta\beta}({}^{76}\text{Ge})$ limit: $\lambda'_{111} \lesssim 5 \cdot 10^{-4} (\frac{\Lambda_{SUSY}}{100GeV})^{2.5}$.

Single slepton production: $\sigma(pp \to \tilde{l}) \propto |\lambda'_{111}|^2/m_{\tilde{l}}^3$

$\rightarrow$ *production upper limit increases with* Λ_{SUSY}.

Numerical analysis

RPV MSSM model parameters:

- 'RPC' mSUGRA mass spectrum:
  Vary m_0, $M_{1/2}$, keeping other SUSY parameters fixed
- Consider regions with neutralino LSP.
- Determine λ'_{111} for 5σ excess.
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NME model $\Gamma_{0\nu\beta\beta} = G_{0\nu}|M|^2$:

- Include both π and nucleon modes (^{76}Ge):
  $$M_{\lambda'_{111}} = \epsilon M^{2N}_{\tilde{g}} + \epsilon' M^{2N}_{\tilde{f}} + \left(\epsilon + \frac{5}{8}\epsilon'\right)\left(\frac{4}{3}M^{1\pi} + M^{2\pi}\right)$$
- $M^{2N}_{\tilde{g}} = 283$, $M^{2N}_{\tilde{f}} = 13.2$, $M^{1\pi} = -18.2$, $M^{2\pi} = -601$
  Hirsch et. al. 96 , Faessler et. al. 98

Results

Infer $T_{1/2}^{0\nu\beta\beta}(^{76}\text{Ge})$ from SSDL @ 5-σ (10 fb^{-1}, 14 TeV, $m_{\beta\beta} = 0$):

Allanach,CHK,Päs PRL09

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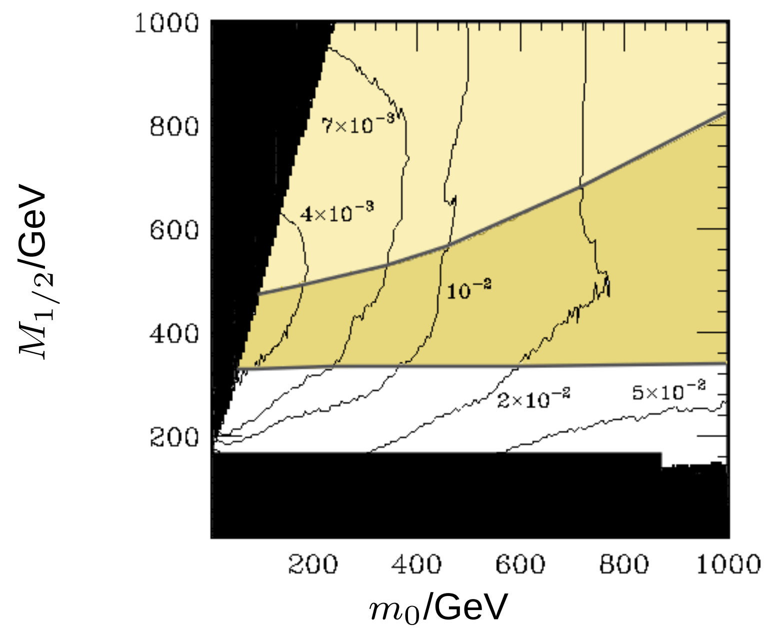

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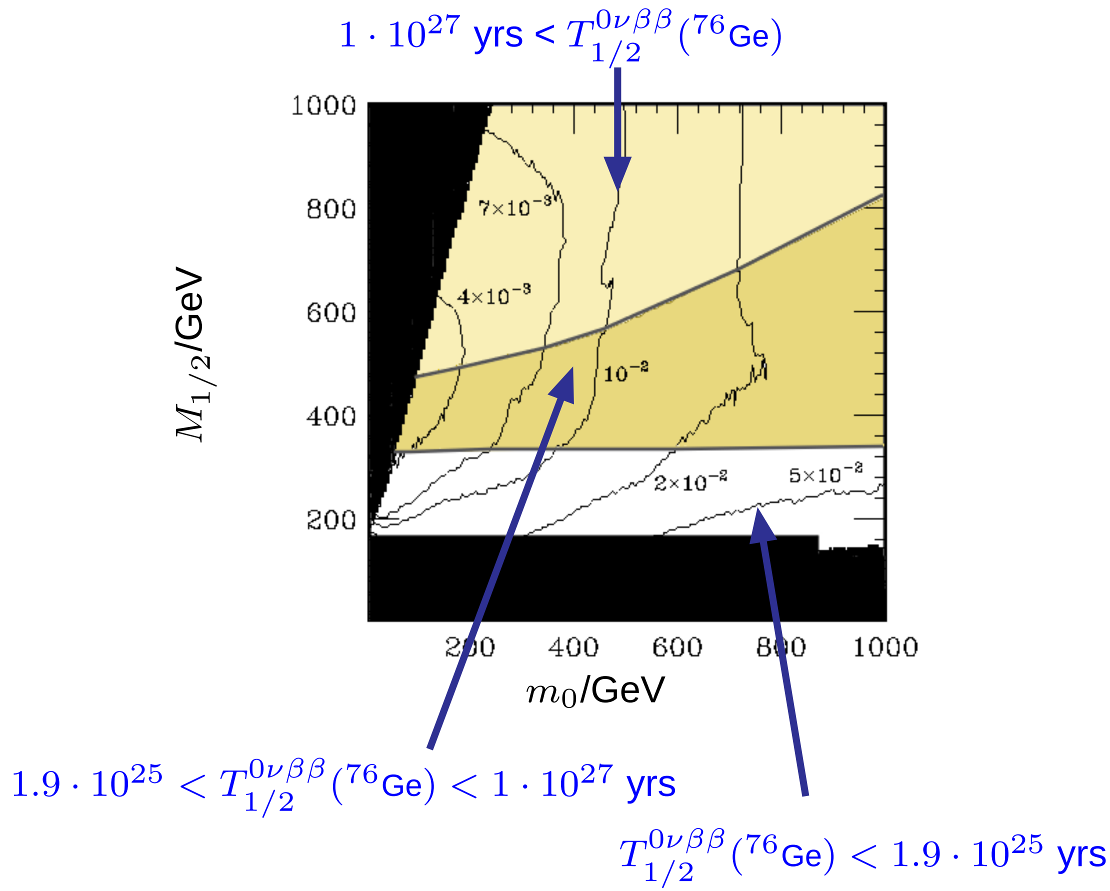
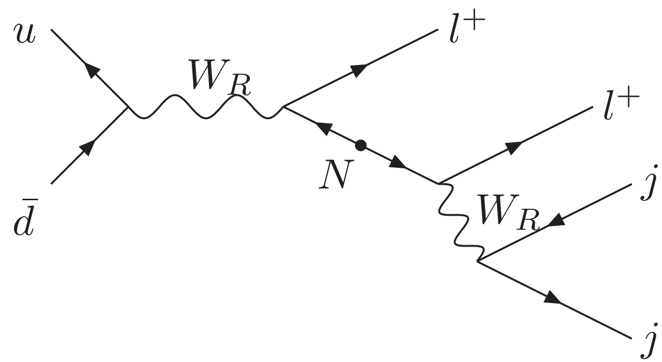


Charge asymmetry ratio

Other models (e.g. Heavy neutrinos (N) in W' models) can have same signal:



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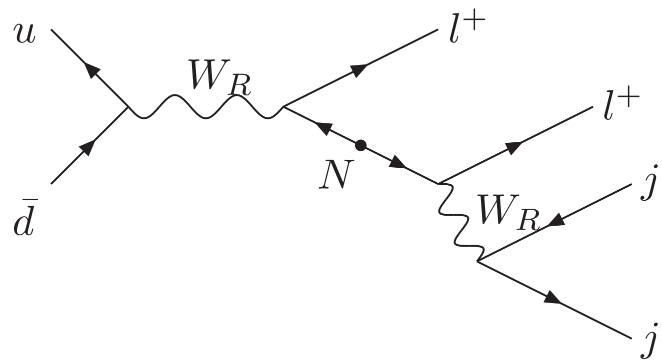

However quark coupling structure different can be very different

- LHC (p-p) produces more +ve over -ve charged final states.
- Proton has non-universal flavour content of course !

$\Longrightarrow$ Charge asymmetry ratio $R^{\pm} \equiv \frac{N(+)}{N(-)}$ depends on how quarks couple to the resonance.

Charge asymmetry ratio

- $R^{\pm}$ tracks parton luminosity ratio $\tilde{R}^{\pm}$:

$$\tilde{R}^{\pm} = \frac{\int \frac{\mathrm{d}x}{x} \, |\tilde{V}_{ab}|^2 f_a(x) f_b(\frac{M_V^2}{xs})|_{(+)}}{\int \frac{\mathrm{d}x}{x} \, |\tilde{V}_{cd}|^2 f_c(x) f_d(\frac{M_V^2}{xs})|_{(-)}} \qquad (c.f. \quad R^{\pm} = \frac{N(+)}{N(-)})$$

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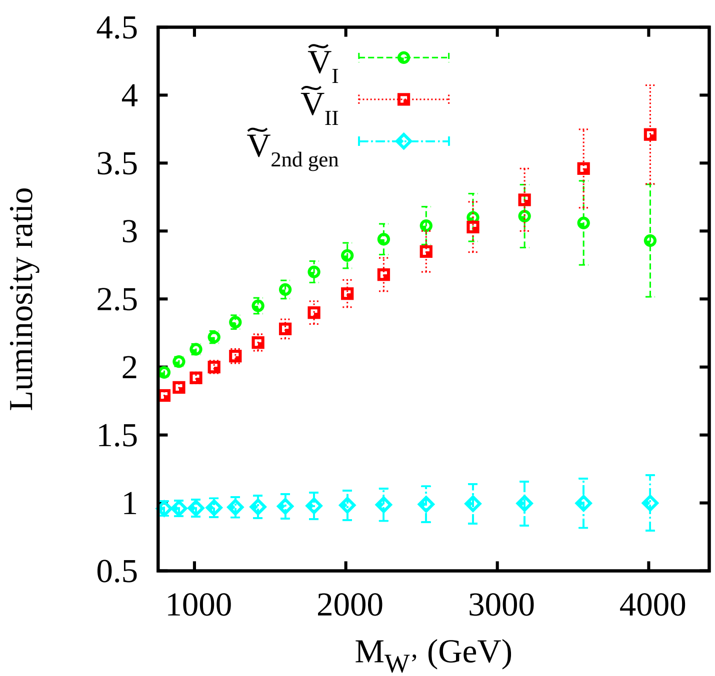


$M_{W'}$	$\tilde{V}_I$ $\tilde{R}^{\pm}$	$\tilde{V}_I$ $R^{\pm}$	$\tilde{V}_{II}$ $\tilde{R}^{\pm}$	$\tilde{V}_{II}$ $R^{\pm}$
1.0 TeV	2.12(4)	1.97(1)	1.92(4)	1.76(1)
1.5 TeV	2.50(6)	2.45(3)	2.22(7)	2.11(4)
2.0 TeV	2.82(9)	2.76(7)	2.53(10)	2.38(10)

with PDF (68%) &

statistical (100 fb^{-1}) uncertainties

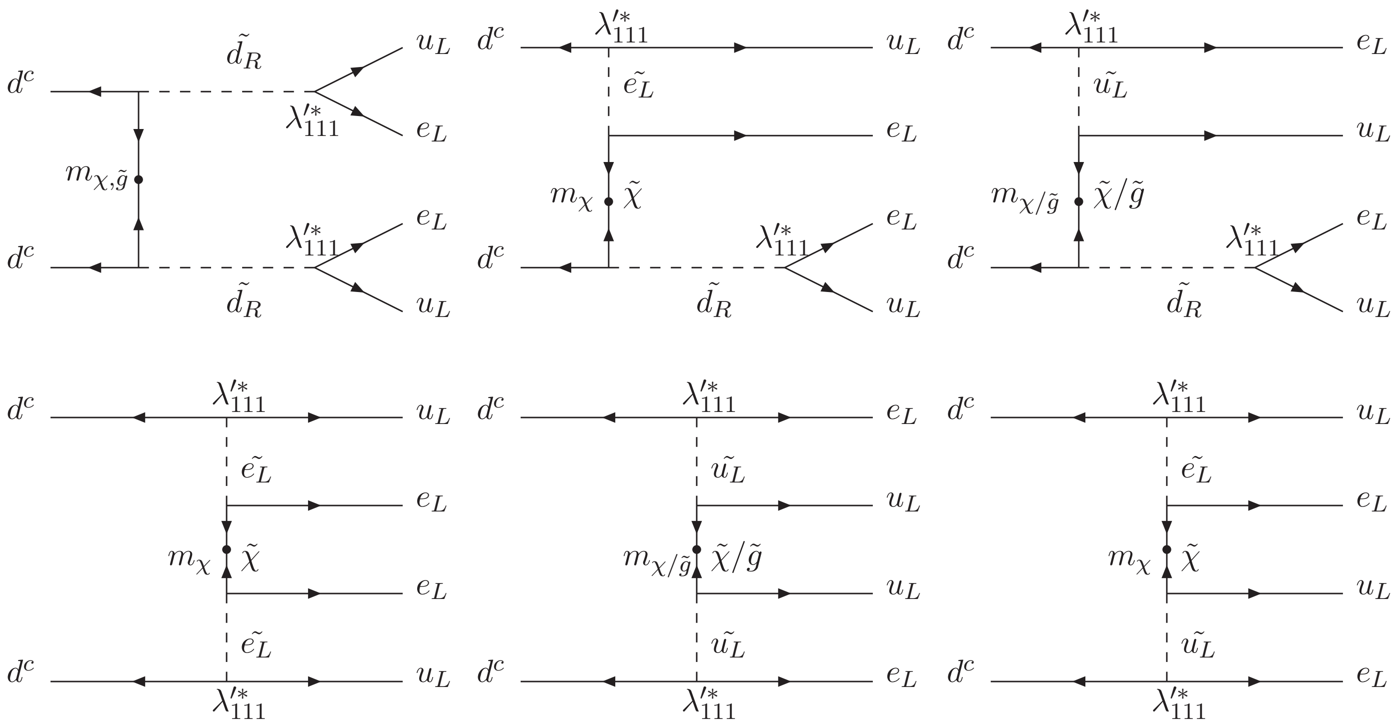
Summary

- Many candidate $0\nu\beta\beta$ mechanisms.
- LHC could provide complementary information to direct $0\nu\beta\beta$ observation.
- More possibilities along this direction.

Backup slides

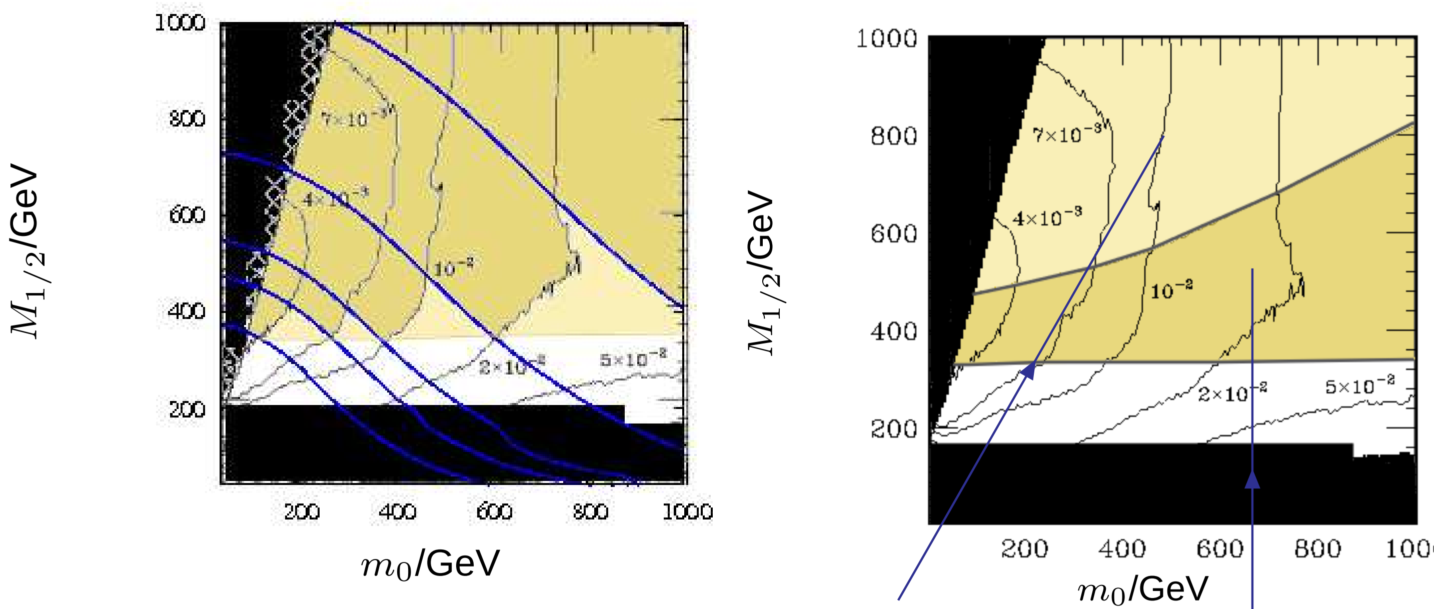
$0\nu\beta\beta$ diagrams in RPV SUSY

Gluino/neutralino mediation



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}:



$1 \cdot 10^{27}$ 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

LHC SS di-lepton cuts

From Dreiner,Richardson,Seymour 99

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

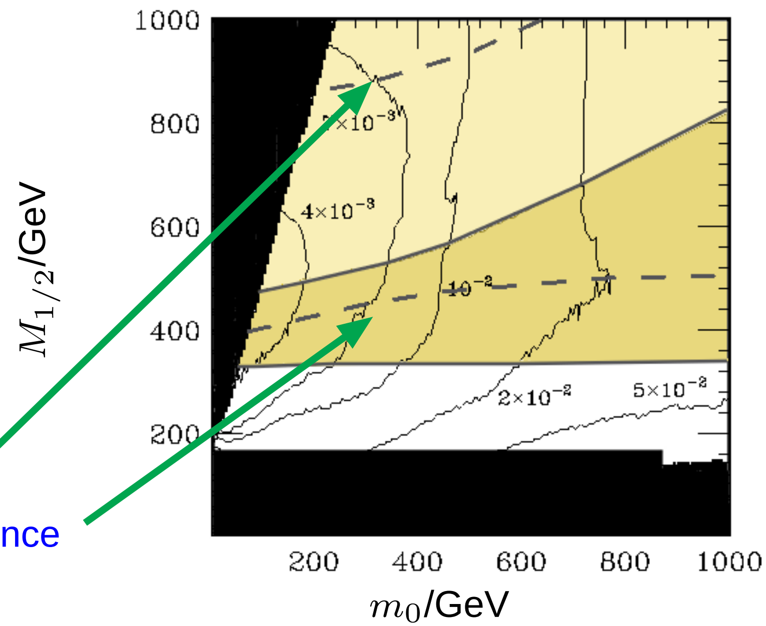
Main bkgd after cuts from WZ. Other non-trivial bkgds include $t\bar{t}\,b\bar{b}$, single top, SUSY, detector ...

Results

Including

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

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



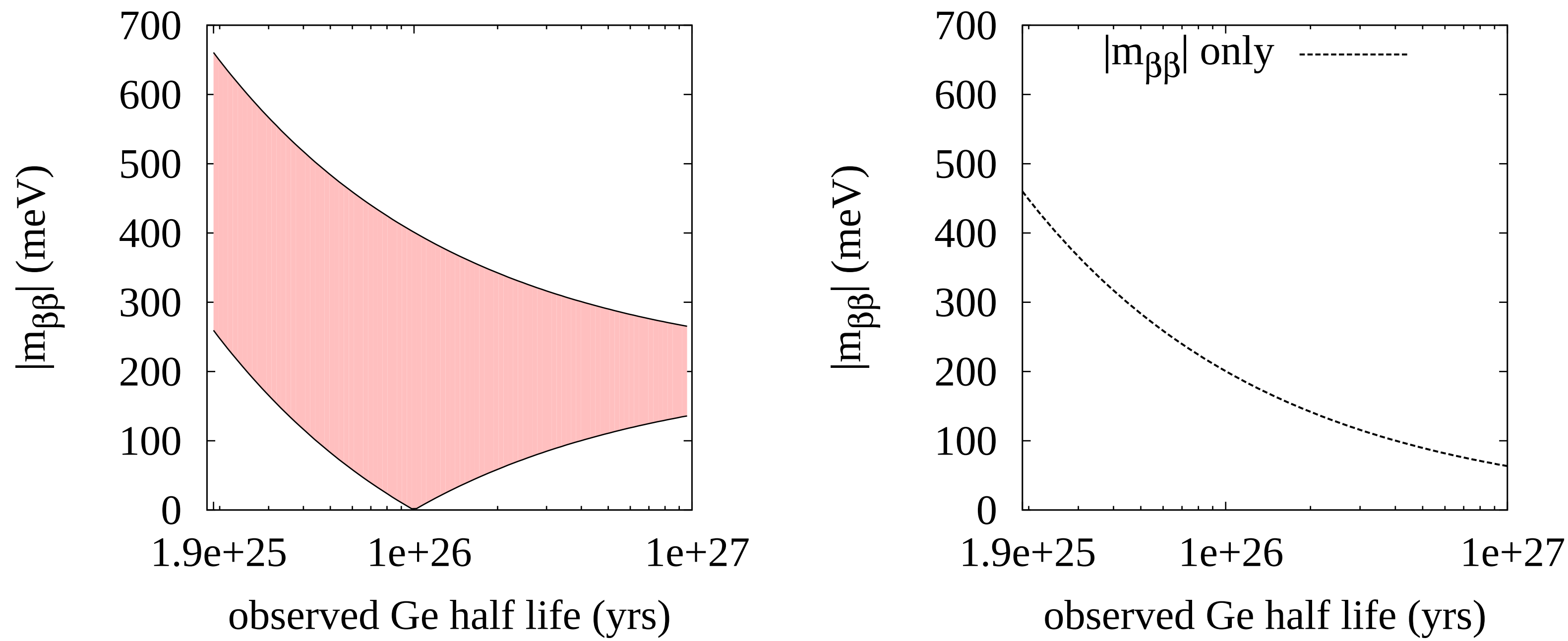
Constructive interference

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.



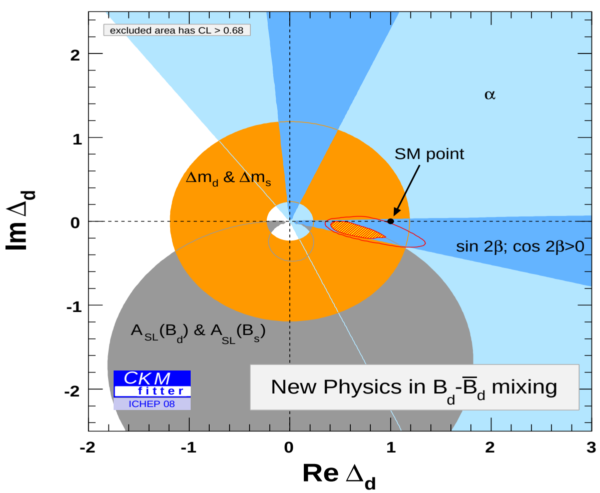
- Band of $m_{\beta\beta}$ depending on relative phase.
- Normal hierarchy possible if $0\nu\beta\beta$ observed.

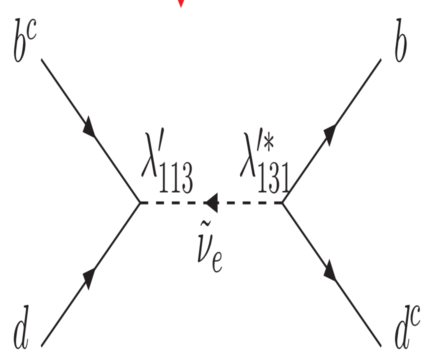
B_d^0-$\bar{B}_d^0$ mixing and RPV $0\nu\beta\beta$

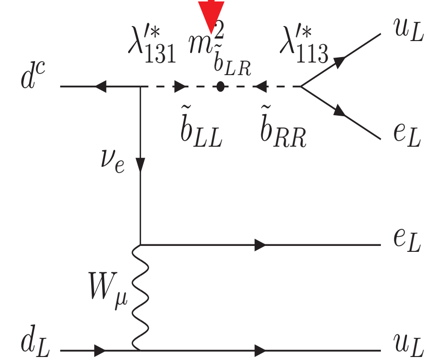
B_d^0-$\bar{B}_d^0$ mixing limit: $\langle B_d | M_{12}^{\text{SM+New Physics}} | \bar{B}_d \rangle = \Delta_d \langle B_d | M_{12}^{\text{SM}} | \bar{B}_d \rangle$

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

$$\lambda'_{113}\lambda'_{131} \lesssim 2 \cdot 10^{-8} \left(\frac{\Lambda_{SUSY}}{100\text{GeV}}\right)^3$$



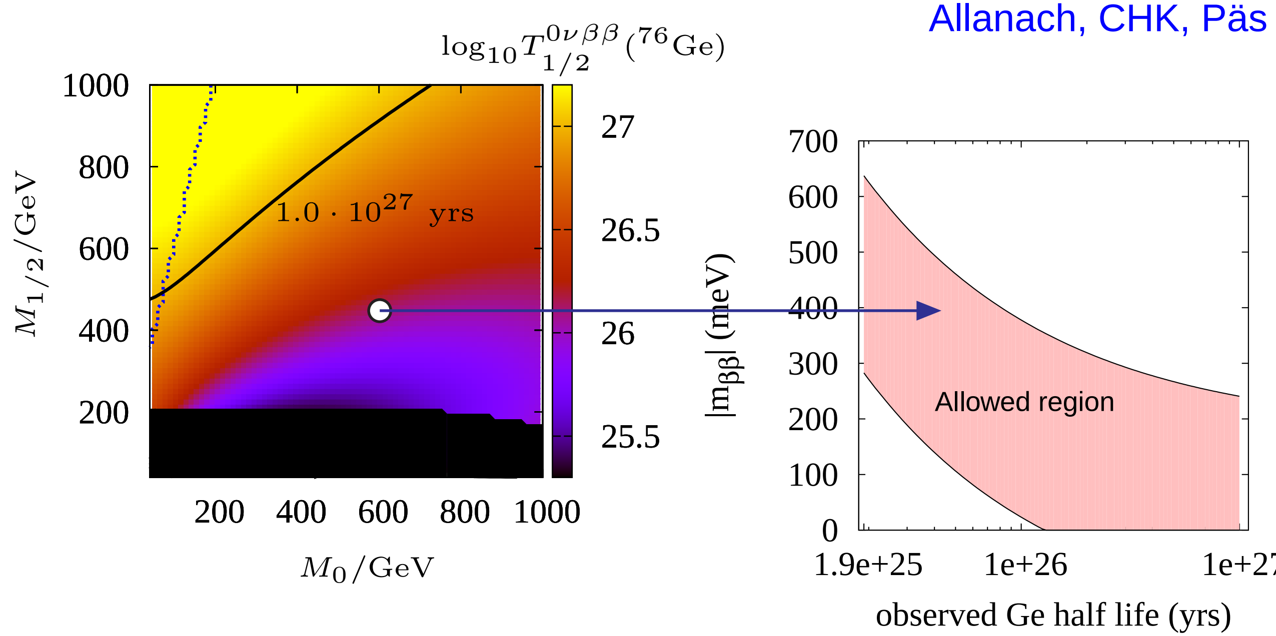




- Bounds comparable, but with different mass dependence.

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

Allanach, CHK, Päs 0903.0347



Left: lower limit on $T_{1/2}^{0\nu\beta\beta}(^{76}\text{Ge})$ given upper bound from B_d^0-$\bar{B}_d^0$.

Right: Effect of a near-future measurement of $T_{1/2}^{0\nu\beta\beta}(^{76}\text{Ge})$ for $m_0 = 680$ GeV, $M_{1/2} = 440$ GeV, given current B_d^0-$\bar{B}_d^0$ constraints.