What can we learn about neutrinoless double beta decay at the LHC ?

MPIK Heidelberg

22 Nov 2010

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Cavendish Laboratory, Cambridge

Outline

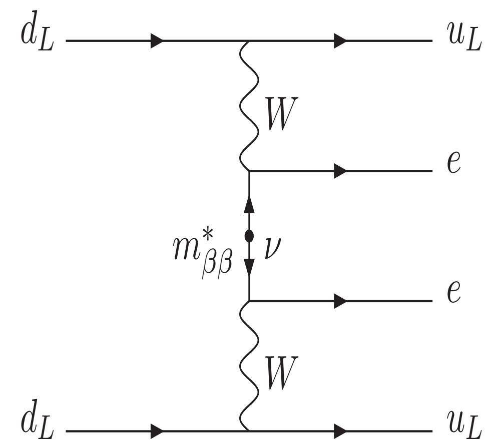
- Introduction
- Why LHC might be relevant for $0\nu\beta\beta$
- Example : resonant selectron production in LNV SUSY

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

  CHK, Stirling 1004.3404, 1010.2988
- Summary

Standard $0\nu\beta\beta$

Standard picture: light mass mechanism



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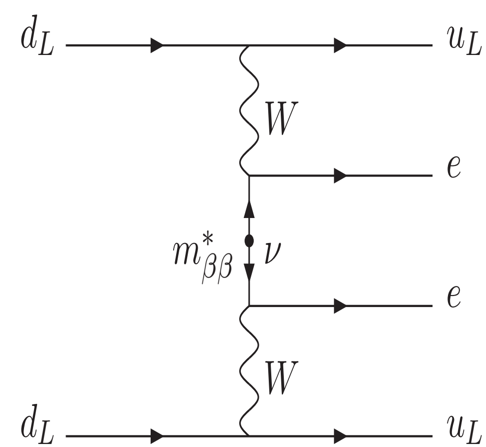

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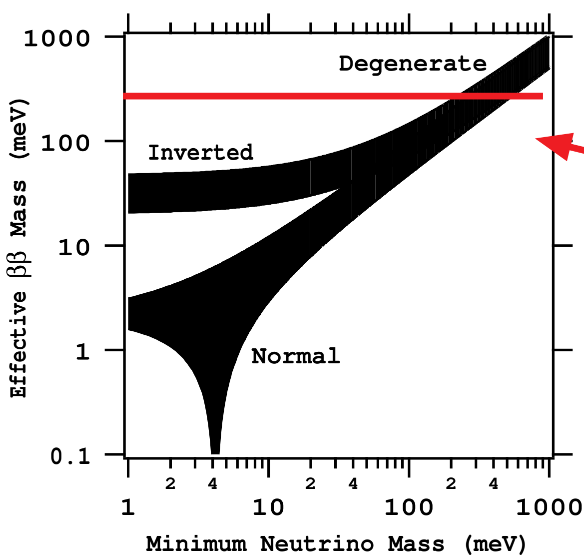

Heidelberg-Moscow , CUORICINO & NEMO3

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

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

Klapdor-Kleingrothaus et. al.)

Other possibilities

- However many lepton number violating theories :
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  - Electron kinematics Ali,Borisov,Zhuridov 07 , SuperNEMO
  - $T_{1/2}^{0\nu\beta\beta}(^{76}\text{Ge})$ ratios of different isotopes
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- Investigate interplay between LHC signatures and $0\nu\beta\beta$ rate predictions.

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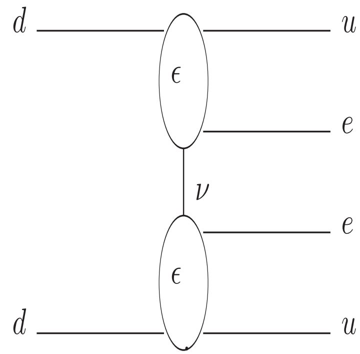

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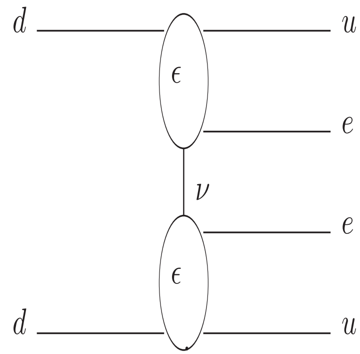

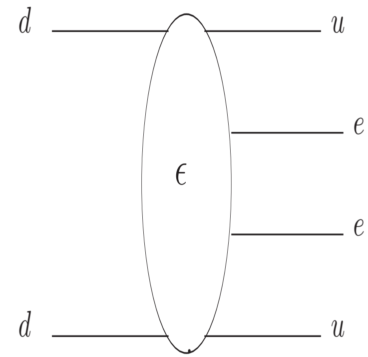

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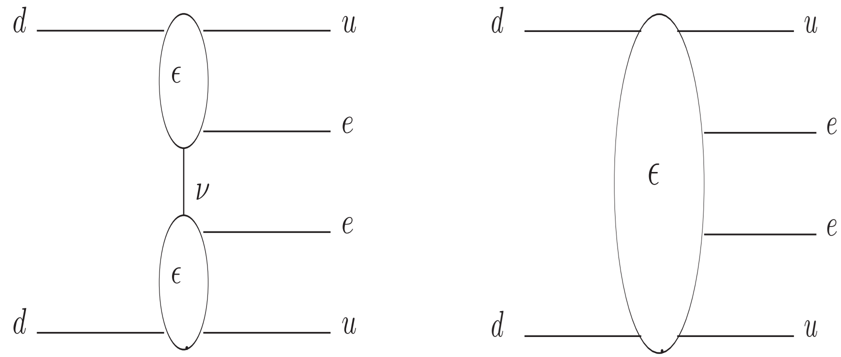

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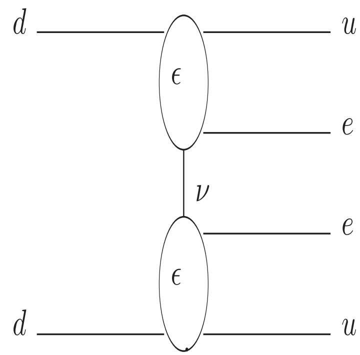

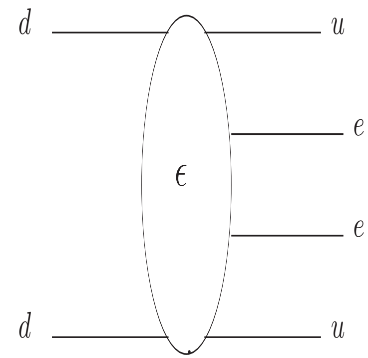

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- $\mathcal{O}(1)$ **TeV resonances via same-sign di-electron + 2 jets :**

  LNV SUSY **Allanach, CHK, Päs 0902.4697, 0903.0347**

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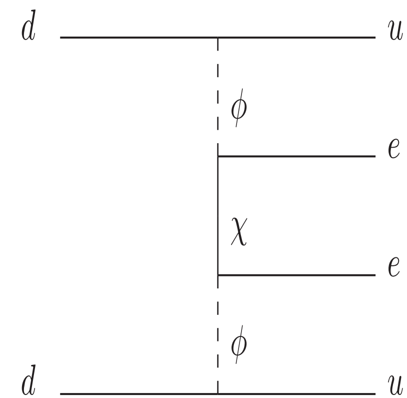
TeV scale particles involved in $0\nu\beta\beta$:



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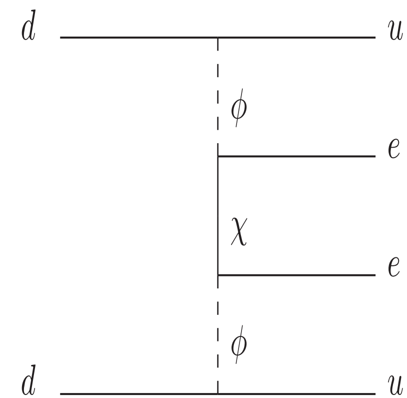

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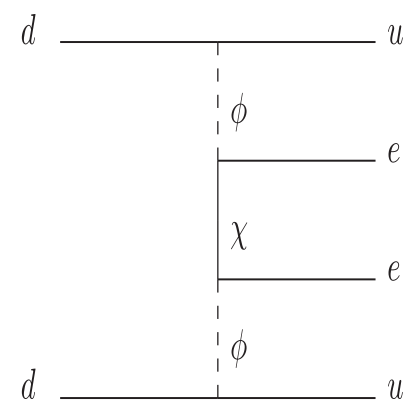

- Look for same sign dielectrons (SSDE) (c.f. SSDE in $0\nu\beta\beta$).
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- Other possibilities exists, e.g.:
  4 leptons f.s. BRs in Higgs triplets Petcov et. al. 09
  B_d^0-$\bar{B}_d^0$ mixing Allanach, CHK, Päs 0903.0347

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

LNV SUSY: $\mathcal{Z}_2$ for R-parity $\rightarrow \mathcal{Z}_3$. Results in (renormalisable) lepton number violating parameters.

$$\mathcal{W}_{\rm LNV} = \lambda'_{111} L_1 Q_1 D^c_1 + \kappa_1 L_1 H_u + \cdots \rightarrow \mathcal{L}_{\rm LNV} = \lambda'_{111}(\bar{l^c} q \tilde{d}^c + \tilde{l} \bar{q^c} d^c + \bar{l^c} \tilde{q} d^c) +$$

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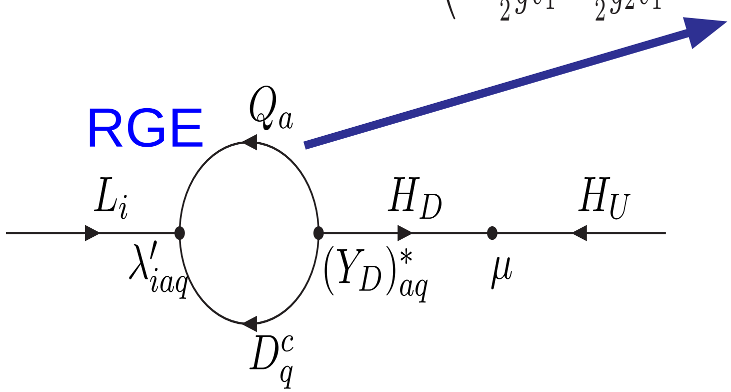

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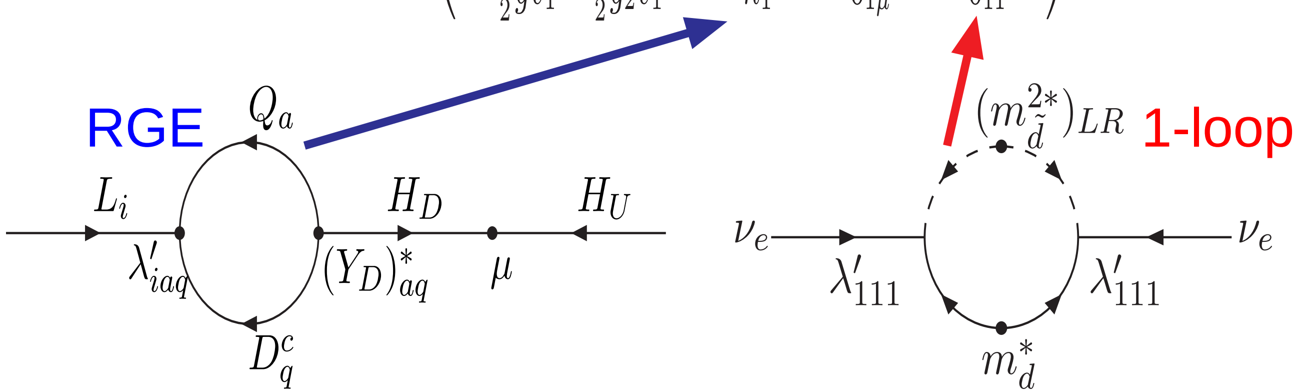

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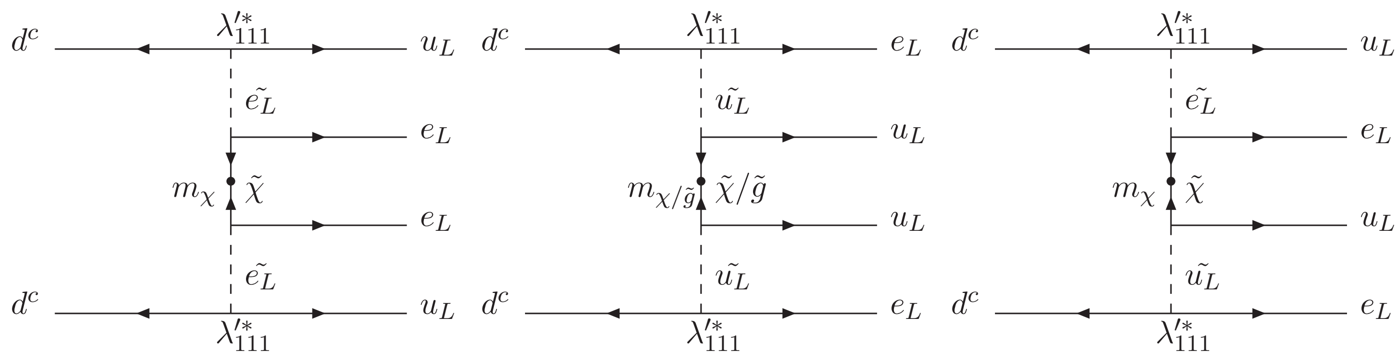
Direct, TeV scale short range mediation w/o intermediate light ν, e.g.



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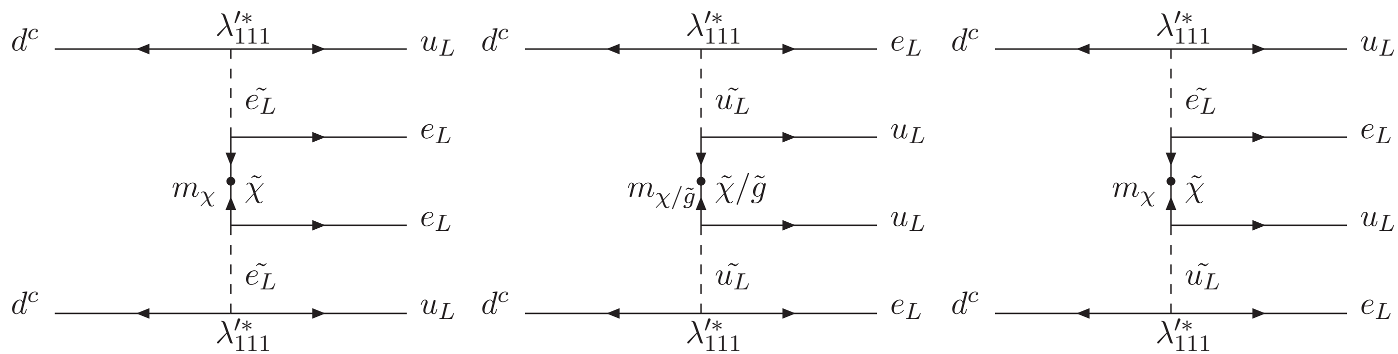

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$$\epsilon_i \sim \pi\alpha_{(\mathrm{Strong,EW})} \frac{\lambda'^2_{111}}{G_F^2} \frac{m_P}{m_{(\tilde{g},\tilde{\chi})}} \frac{1}{m^4_{(\tilde{u},\tilde{d},\tilde{e})}}.$$

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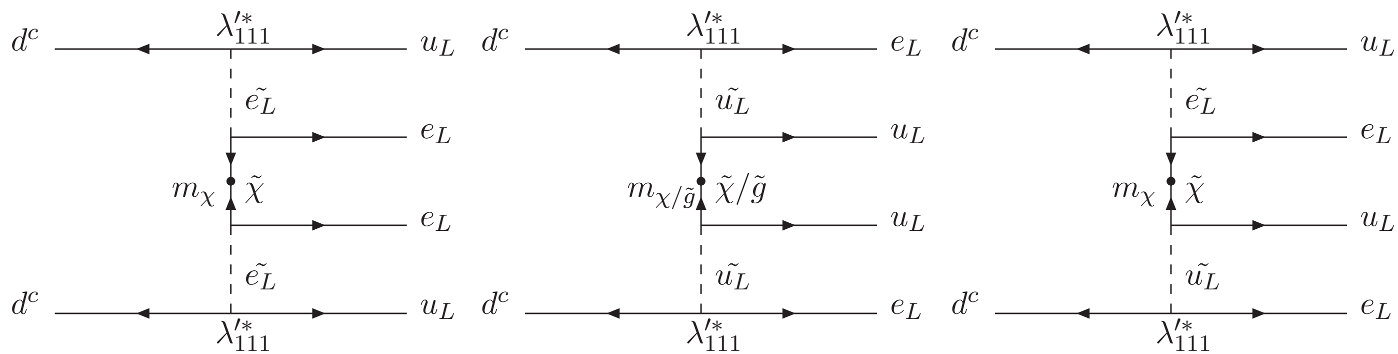

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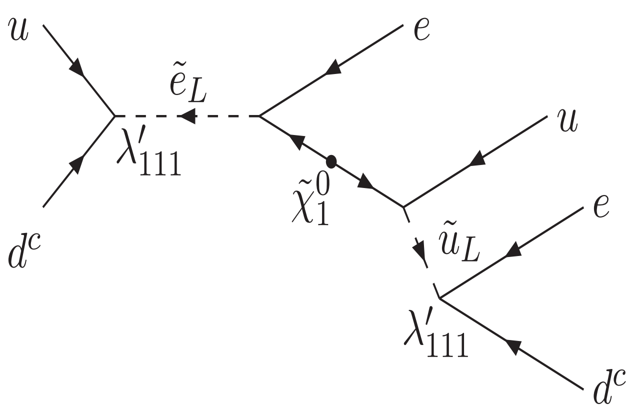
- Dimension 9 operators:
  λ'_{111} bound relaxes rapidly with increasing Λ_{SUSY}.

Single slepton production

Direct indication of λ'_{111} !



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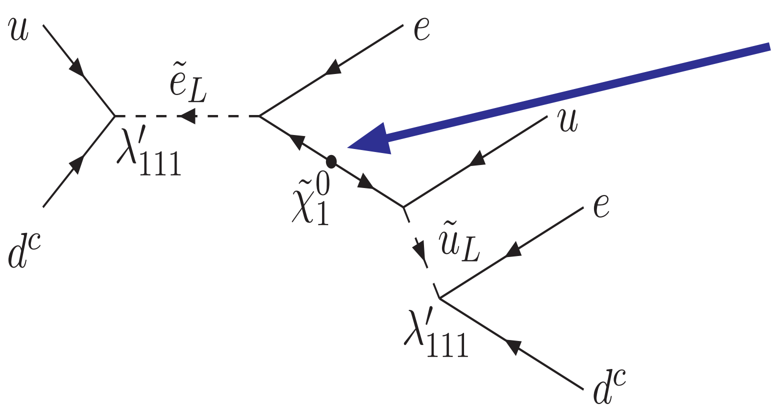

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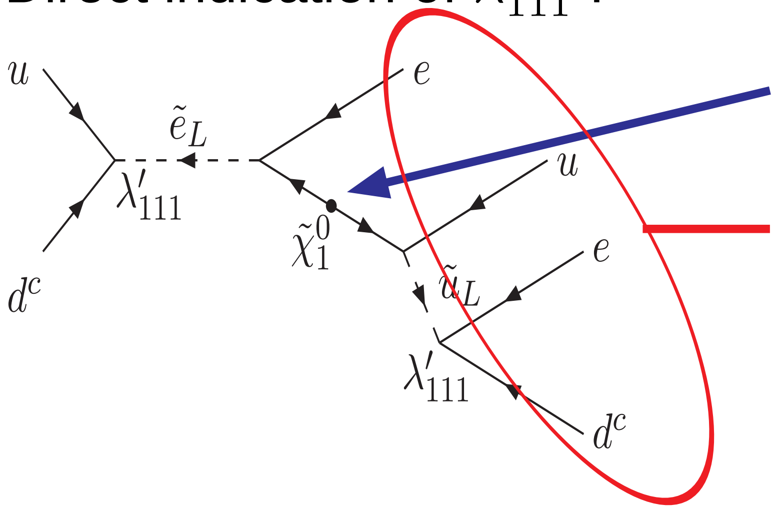

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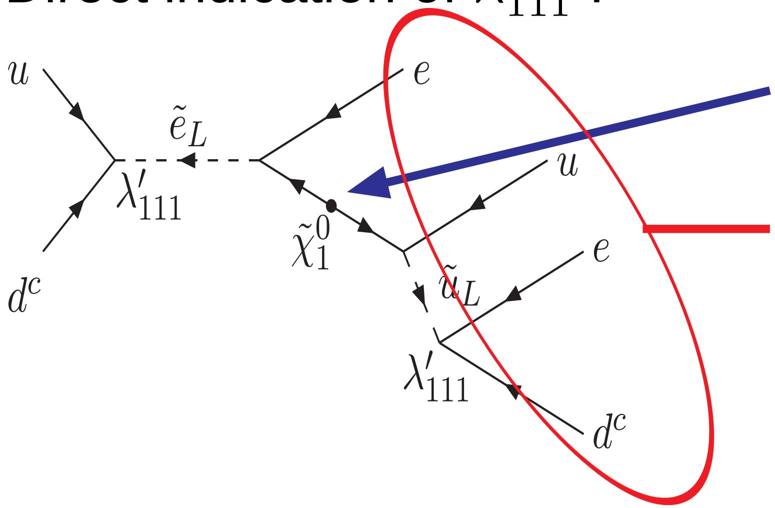

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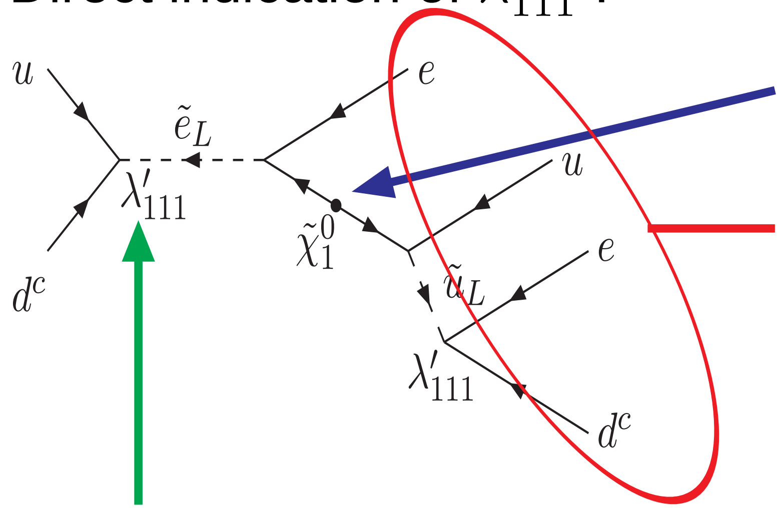

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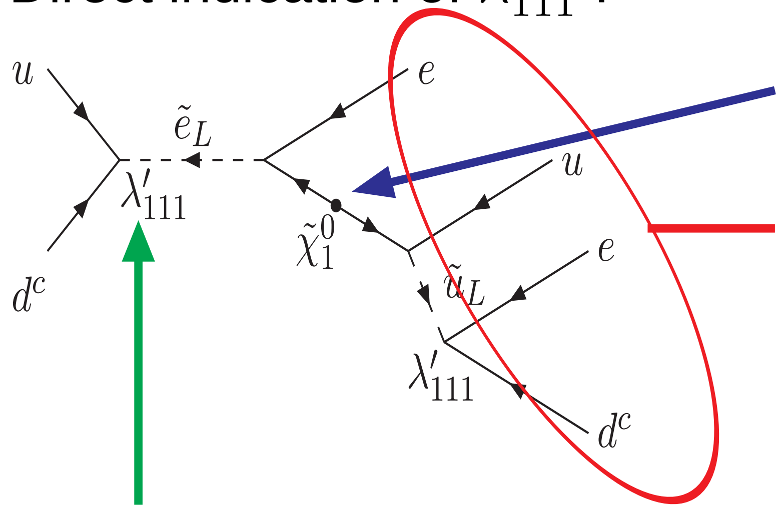

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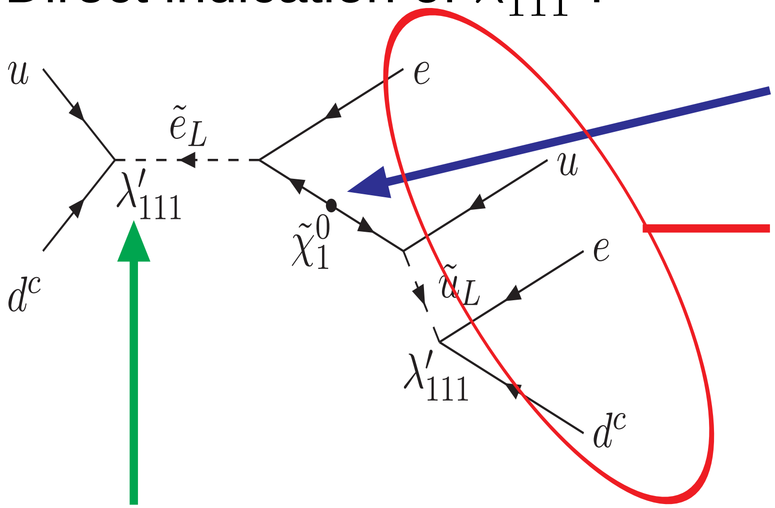

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- To estimate $\epsilon_{\lambda'_{111}}$, need also $\tilde{q}$, $\tilde{\chi}$, $\tilde{g}$ masses.

Model assumptions

LNV MSSM model parameters:

- 'RPC' mSUGRA mass spectrum:
  m_0, $M_{1/2}$, $A_0 = 0$, tan$\beta = 10$, $sgn(\mu) = +1$.
- At $\Lambda_{\rm SUSY}$, set λ'_{111}.
- Only regions with neutralino LSP considered.

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NME model $\Gamma_{0\nu\beta\beta} = G_{0\nu}|M|^2$:

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

LHC SS di-lepton cuts

From Dreiner,Richardson,Seymour 99

- Lepton $|\eta| < 2.0$.
- Lepton $p_T > 40$ GeV.
- Lepton isolation: $E_T < 5$ GeV in cone R=0.4.
- Reject 60 < M_T < 85 GeV.
- $\not{E}_T$ < 20 GeV.
- OSSF lepton veto.
- No more than 2 $p_T > 50$ GeV jets.

Results

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

Allanach,CHK,Päs PRL09

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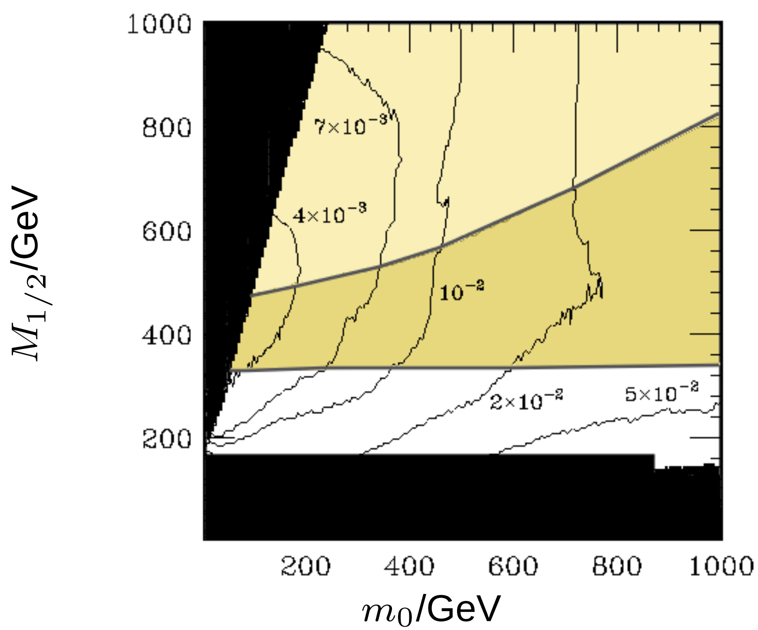

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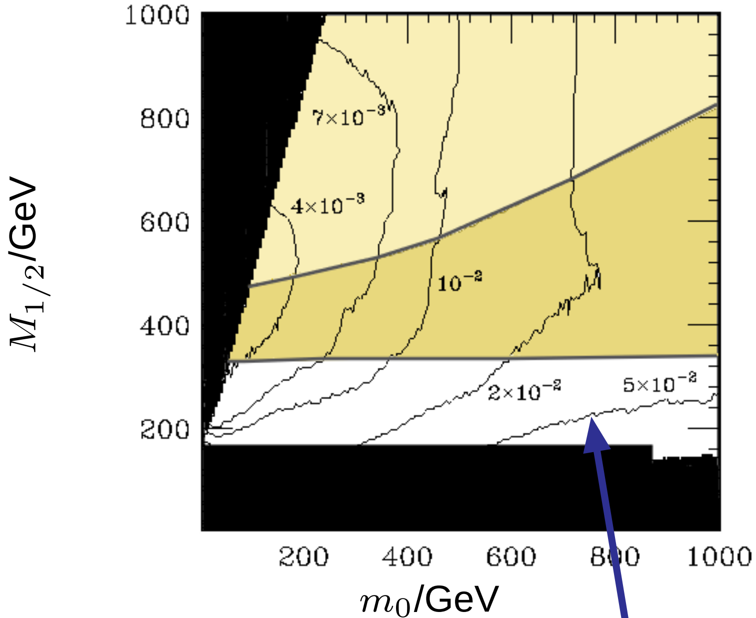

$T_{1/2}^{0\nu\beta\beta}(^{76}\text{Ge}) < 1.9 \cdot 10^{25}$ yrs

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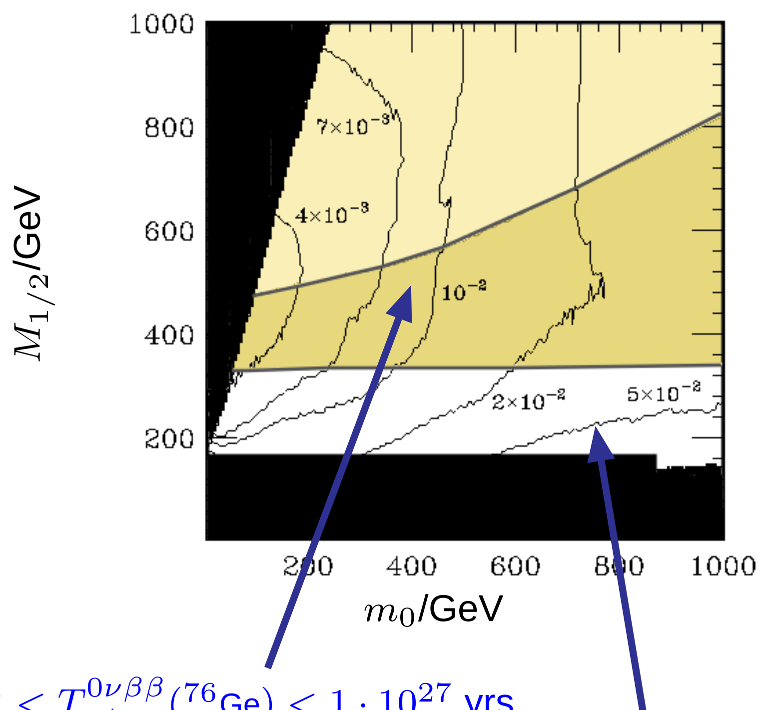
Allanach,CHK,Päs PRL09



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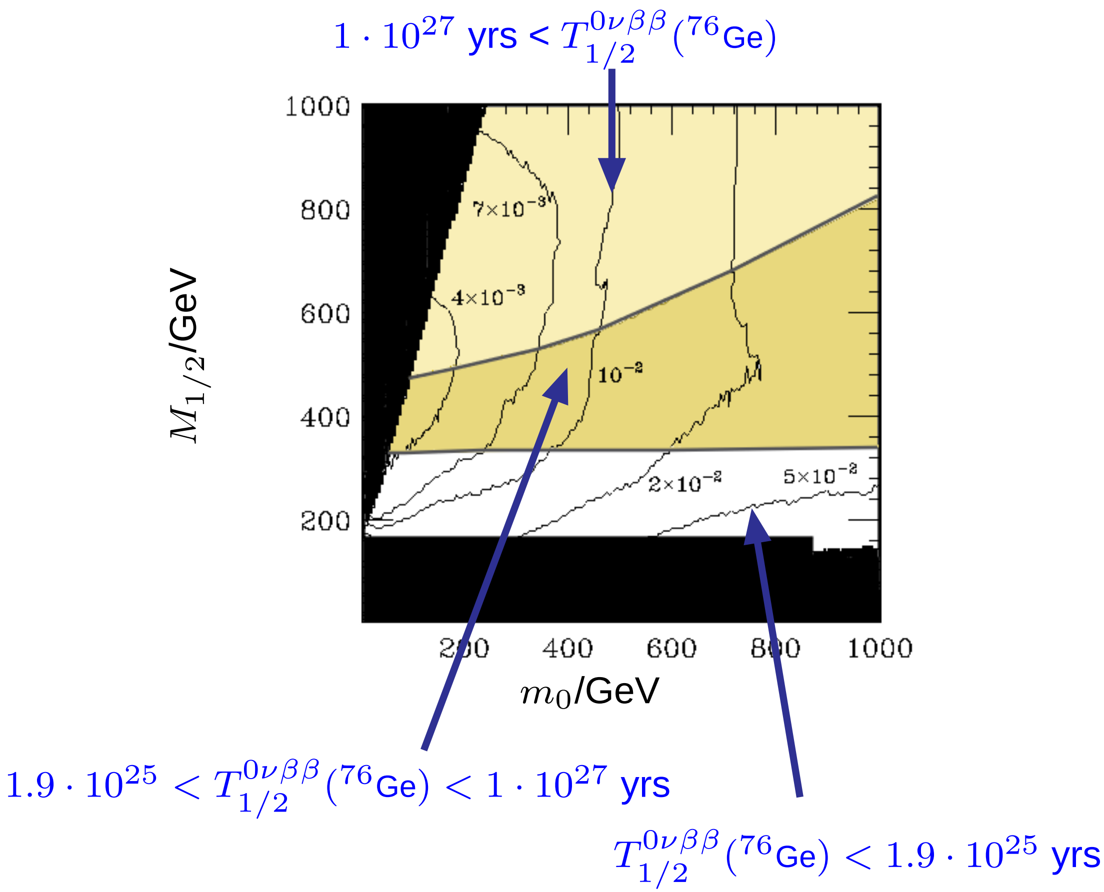

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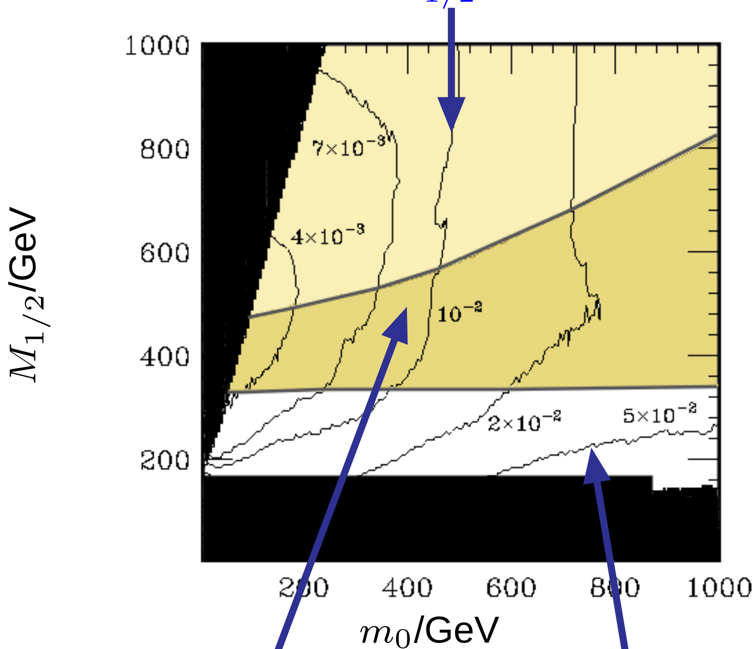

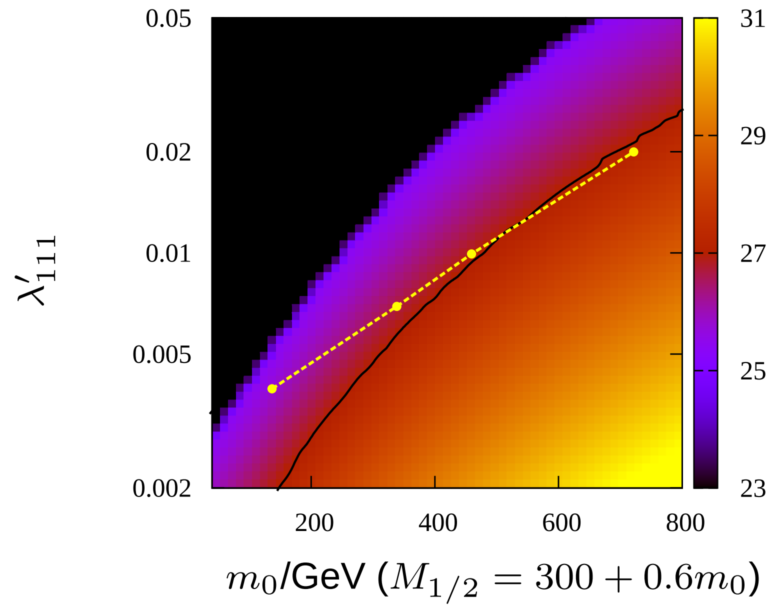

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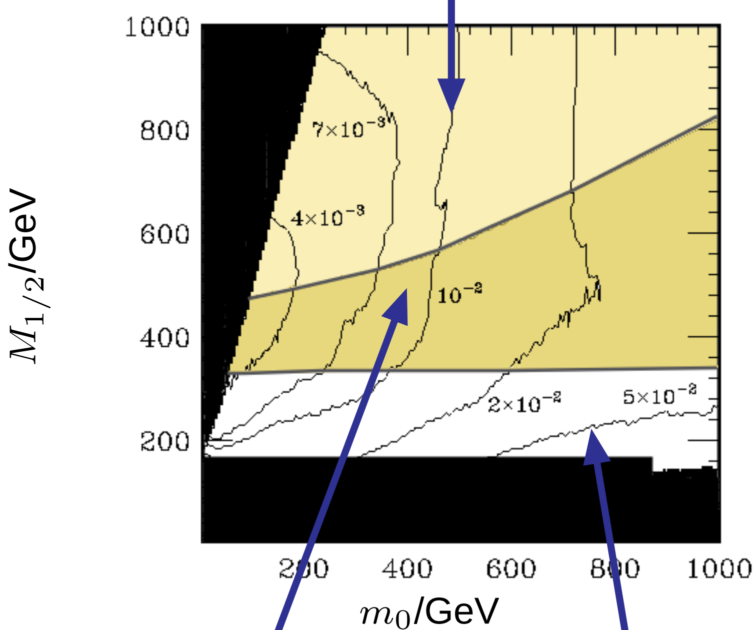

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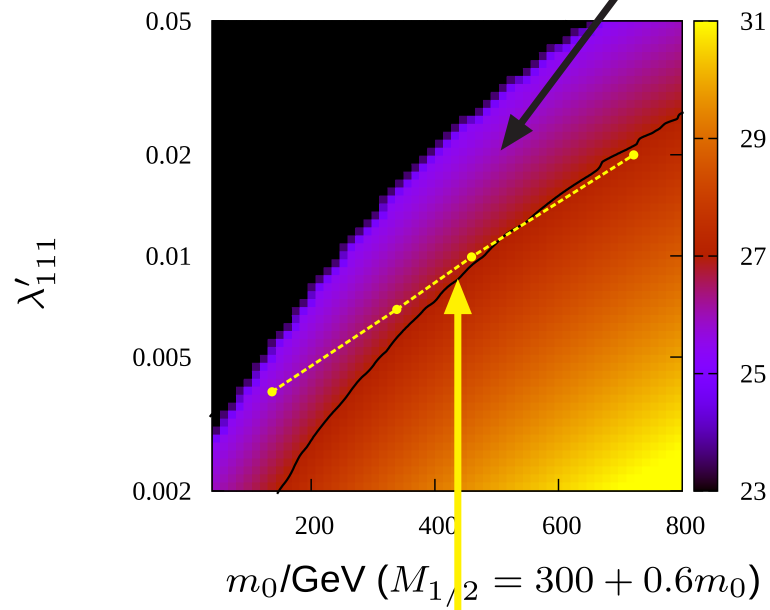
Sensitive to future $0\nu\beta\beta$ expts.



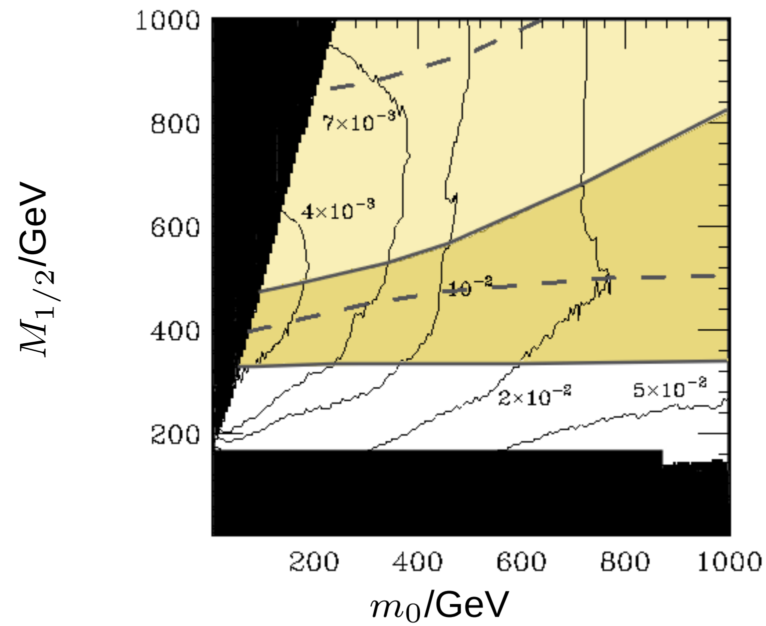
LHC single slepton discovery limit

Results

Including

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

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



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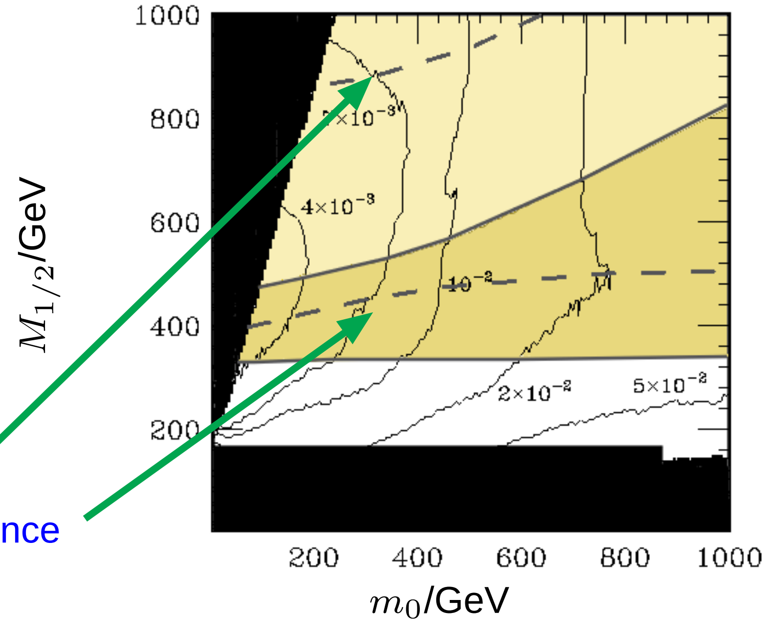

Constructive interference

Destructive interference

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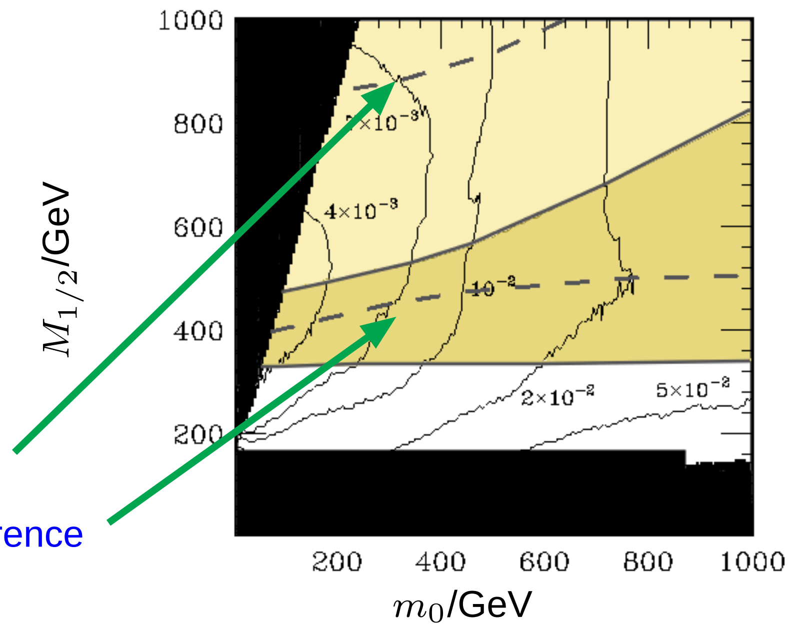


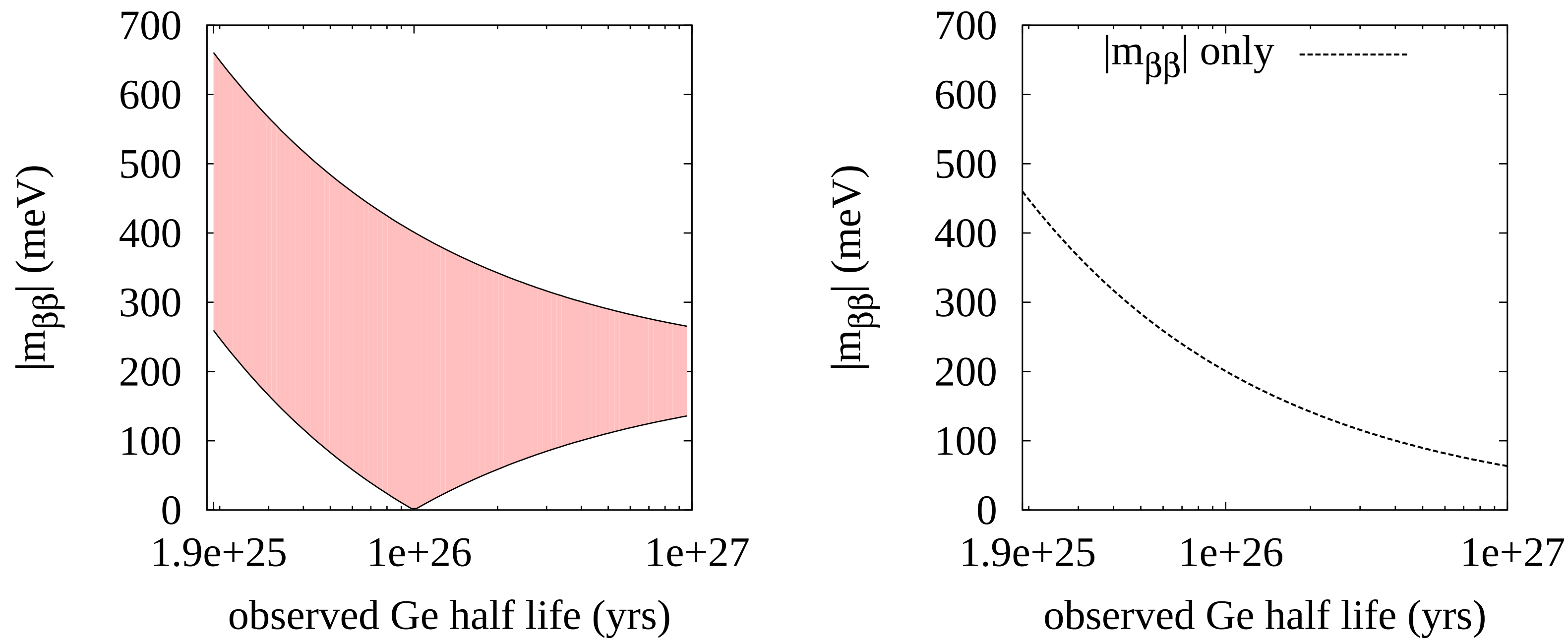
Constructive interference

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 SSDE rate $\rightarrow$ better SSDE discovery prospect.

Inference on $m_{\beta\beta}$

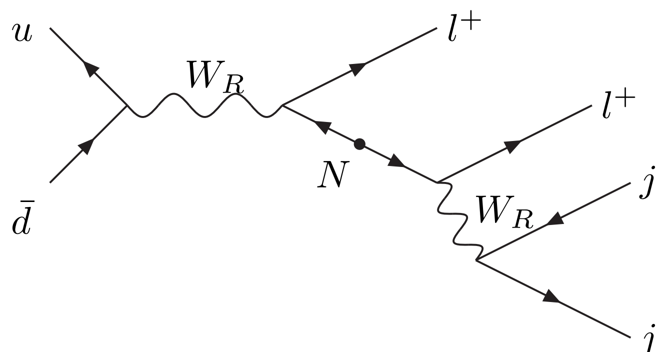
Given 5σ SSDE observation ($M_0 = 680$GeV, $M_{1/2} = 440$GeV)
$\rightarrow T_{1/2}^{0\nu\beta\beta}(^{76}\text{Ge}) = 1 \cdot 10^{26}$yrs if direct contribution only.



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

SSDE at the LHC 1

- Heavy Majorana neutrinos (N) can lead to the same final states !
- Similar structure as type I see-saw, with
  $L \to R$ and $\frac{m_{\beta\beta}}{\langle k^2 \rangle} \to (M_N)^{-1}_{\beta\beta}$



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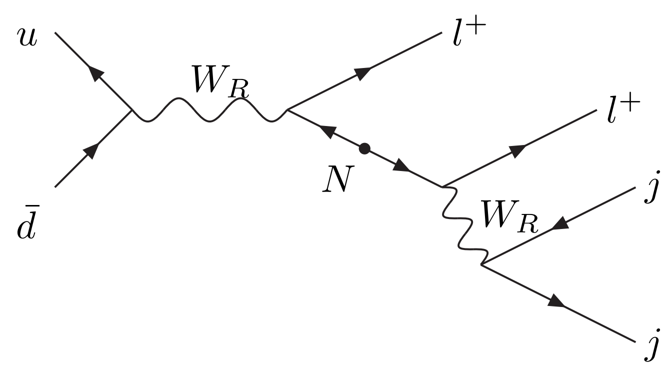
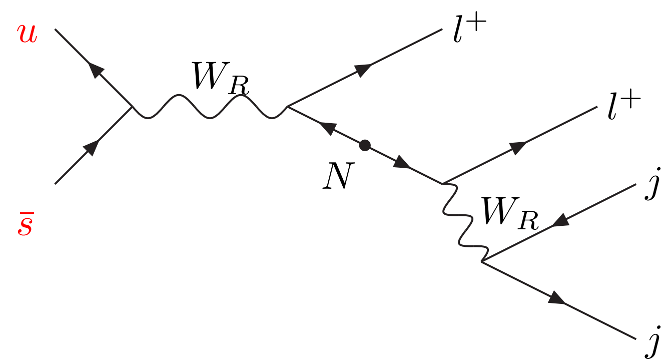


- Again Majorana nature of N leads to SSDE.
- Angular distribution of charged resonance decay products ?
- At 30 fb^{-1} discovery of $(m_{W_R}, m_N) < (4.6, 2.8)$ TeV Ferrari et. al. 00

SSDE at the LHC 2

- Contributions from other initial state partons ? e.g.



SSDE at the LHC 2

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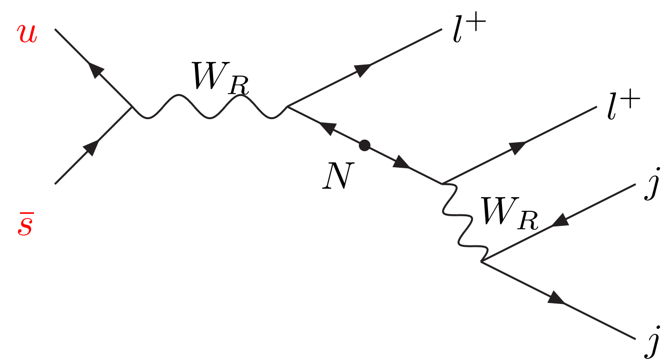

- Charge asymmetry ratio as a possible discriminator

CHK, Stirling 1010.2988

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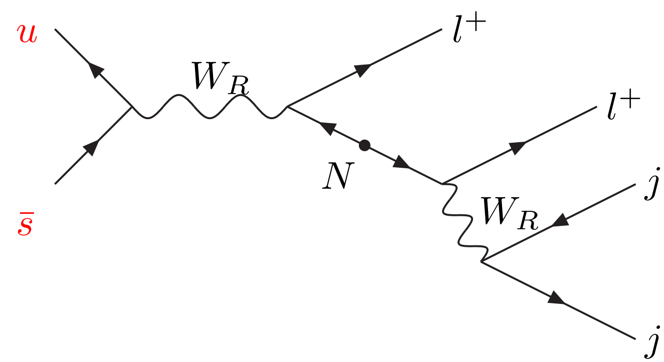

- Charge asymmetry ratio as a possible discriminator

  CHK, Stirling 1010.2988

- More general usage of charge asymmetry ratio as diagnostic tools for new physics see

  CHK, Stirling 1004.3404

Charge asymmetry ratio

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

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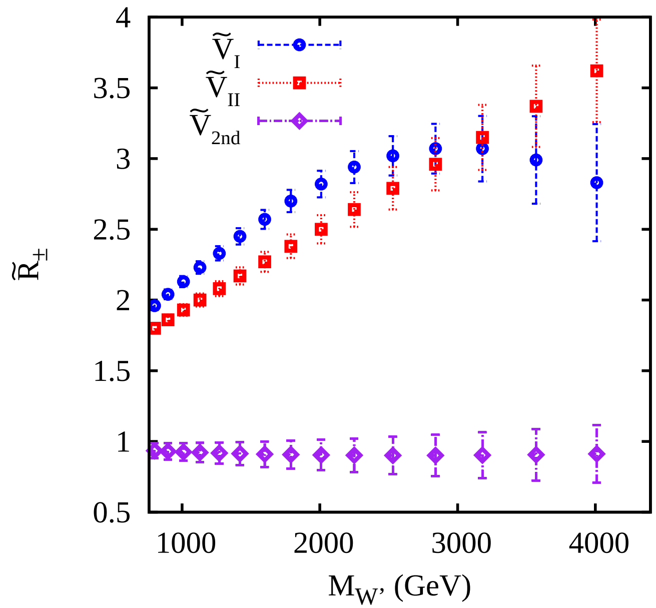
Charge asymmetry ratio

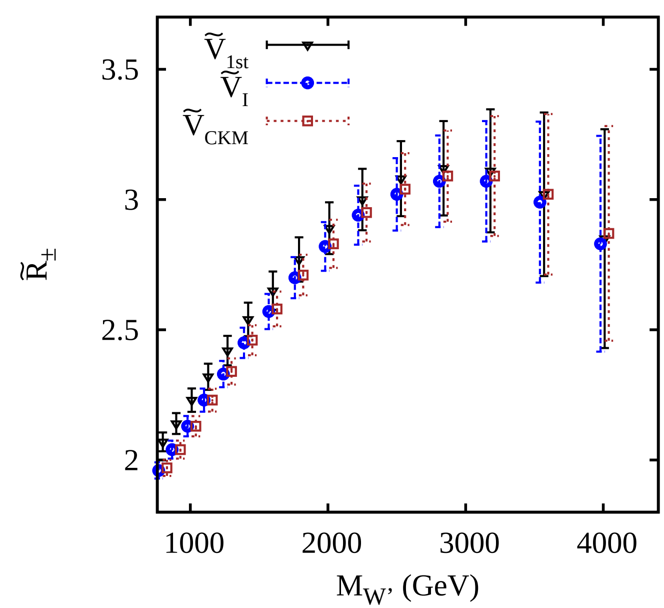
- LHC (p-p) produces more +ve over -ve charged final states.
- Proton has non-universal flavour content of course !
  $\Longrightarrow$ Charge asymmetry ratio $R^{\pm} \equiv \frac{N(+)}{N(-)}$ depends on how quarks couple to the resonance.
- Also, $R^{\pm}$ tracks 'weighted' parton luminosity ratio $\tilde{R}^{\pm}$:

$$\tilde{R}^{\pm} = \frac{\int \mathrm{d}y \, |\tilde{V}_{ab}|^2 f_a(x_1, M_V) f_{\bar{b}}(x_2, M_V)|_{(+)}}{\int \mathrm{d}y \, |\tilde{V}_{cd}|^2 f_{\bar{c}}(x_1, M_V) f_d(x_2, M_V)|_{(-)}}$$

$\tilde{R}^{\pm}$ in W' models

$\tilde{R}^{\pm}$ for certain types of quark flavour mixings are distinguishable.





$$|\tilde{V}_{II}| \sim \begin{pmatrix} 0 & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 1 & 0 & 0 \\ 0 & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{pmatrix}$$

Buras et. al. 1007.1993

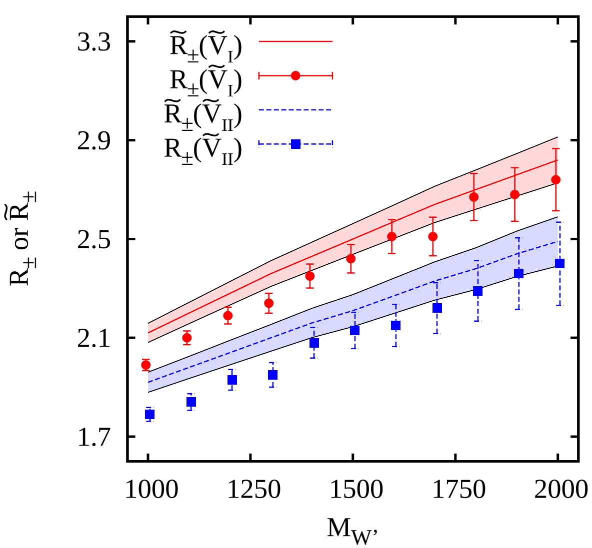
$R^{\pm}$ in W' models

- Implement W' into `Herwig++`
- Impose cuts similar to the SSDE analysis for LNV selectron (hard $p_T^l > 75$ GeV, $p_T^j > 50$ GeV, wrong sign lepton veto, $lljj$ invariant mass constraint)
- main background from $t\bar{t}$ (`Herwig++`), $WZ(\gamma*)jj$ (`Alpgen`), but $\mathcal{O}(1)$% compared to signal at 14 TeV.

$M_{W'}$	Process	$\sigma_{\rm tot}$	$\sigma_{\rm cut}$
1.0 TeV	$W'(\tilde{V}_{\rm I})$	4.78$\cdot 10^3$	1.02$\cdot 10^3$
	$W'(\tilde{V}_{\rm II})$	2.62$\cdot 10^3$	542
	$t\bar{t}$	6.06$\cdot 10^5$	2.8
	$WZ(\gamma*)jj$	-	0.37
2.0 TeV	$W'(\tilde{V}_{\rm I})$	226	72.9
	$W'(\tilde{V}_{\rm II})$	92.8	29.3
	$t\bar{t}$	6.06$\cdot 10^5$	0.53
	$WZ(\gamma*)jj$	-	0.14

$R^{\pm}$ vs $\tilde{R}^{\pm}$ in W' models

$\tilde{V}_{\rm I}$ and $\tilde{V}_{\rm II}$ are distinguishable for $M_{W'}$ below $\sim$ 2 TeV.
(14 TeV, 30 fb^{-1})



	$\tilde{V}_{\rm I}$		$\tilde{V}_{\rm II}$	
$M_{W'}$	$\tilde{R}^{\pm}$	$R^{\pm}$	$\tilde{R}^{\pm}$	$R^{\pm}$
1.0 TeV	2.12(4)	1.99(1)	1.92(4)	1.79(2)
1.5 TeV	2.50(6)	2.42(3)	2.21(7)	2.13(4)
2.0 TeV	2.82(9)	2.74(7)	2.49(10)	2.40(10)
	$t\bar{t}$:	$R^{\pm} \sim 1.0$		
	$WZ(\gamma*)jj$:	$R^{\pm} \sim 1.2$		

- However at 7 TeV 1 fb^{-1} the prospect is not as promising.

Summary

- Many candidate $0\nu\beta\beta$ mechanisms.
- LHC searches complementary to direct $0\nu\beta\beta$ observation.
- Needs both direct $0\nu\beta\beta$ and indirect LHC searches to understand structure of Majorana ν sector.
- Charged resonances decaying to same-sign di-electron + 2 jets might be relevant.
- Charge asymmetry ratio could provide further information on the relevance of SSDE+2j observed to $0\nu\beta\beta$.

Backup slides

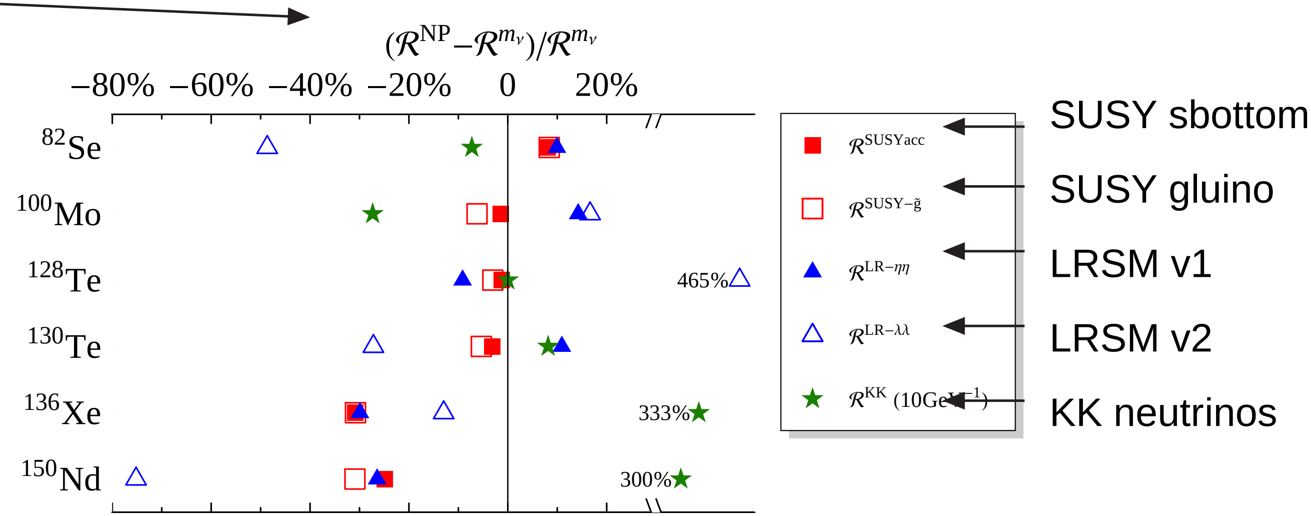
Half life ratios of different isotopes

- Different mechanisms result in different NMEs.
- New physics parameters cancel in ratio.

$$\frac{T_{1/2}(^{A}X)}{T_{1/2}^{0\nu\beta\beta}(^{76}\text{Ge})} = \frac{|M(^{76}\text{Ge})|^2 G_{0\nu}(^{76}\text{Ge})}{|M(^{A}X)|^2 G_{0\nu}(^{A}X)}$$

- Systematic uncertainties in NMEs tend to cancel.

$$R^{(NP,m_\nu)}(^{A}X) = \frac{T_{1/2}^{(NP,m_\nu)}(^{A}X)}{T_{1/2}^{(NP,m_\nu)}(^{76}Ge)}$$



Deppisch,Päes 06

- Many isotopes required.

Eletron angular correlations

Different lepton current structure leads to different angular correlations

$$\frac{\mathrm{d}\Gamma}{\mathrm{d}cos\theta} = \frac{\Gamma}{2}(1 - Kcos\theta).$$

- Only weakly dependent of NME models.
- In m_ν mechanism, $K \sim 0.8 - 0.9$ for a range of isotopes (^{76}Ge, ^{82}Se, ^{100}Mo, ^{130}Te, ^{136}Xe). Ali,Borisov,Zhuridov 07
- For LR symmetric model, $K \sim -0.8$. Deppisch,Jackson
- E.g. SuperNEMO is sensitive to single electron kinematics.

Triplet Higgs model

Akeroyd et. al., Garayoa et. al., Kadastik et. al. 08, Petcov et. al. 09

$$V_{\rm Higgs} = m^2\,(\Phi^\dagger\Phi) + \lambda_1\,(\Phi^\dagger\Phi)^2 + M_\Delta^2\,{\rm Tr}(\Delta^\dagger\Delta) + \lambda_2\,[{\rm Tr}(\Delta^\dagger\Delta)]^2 + \lambda_3\,{\rm Det}(\Delta^\dagger\Delta)$$
$$+\lambda_4\,(\Phi^\dagger\Phi){\rm Tr}(\Delta^\dagger\Delta) + \lambda_5\,(\Phi^\dagger\tau_i\Phi){\rm Tr}(\Delta^\dagger\tau_i\Delta) + \left(\frac{1}{\sqrt{2}}\mu\,(\Phi^T i\tau_2\Delta^\dagger\Phi) + h.c\right)\,,$$

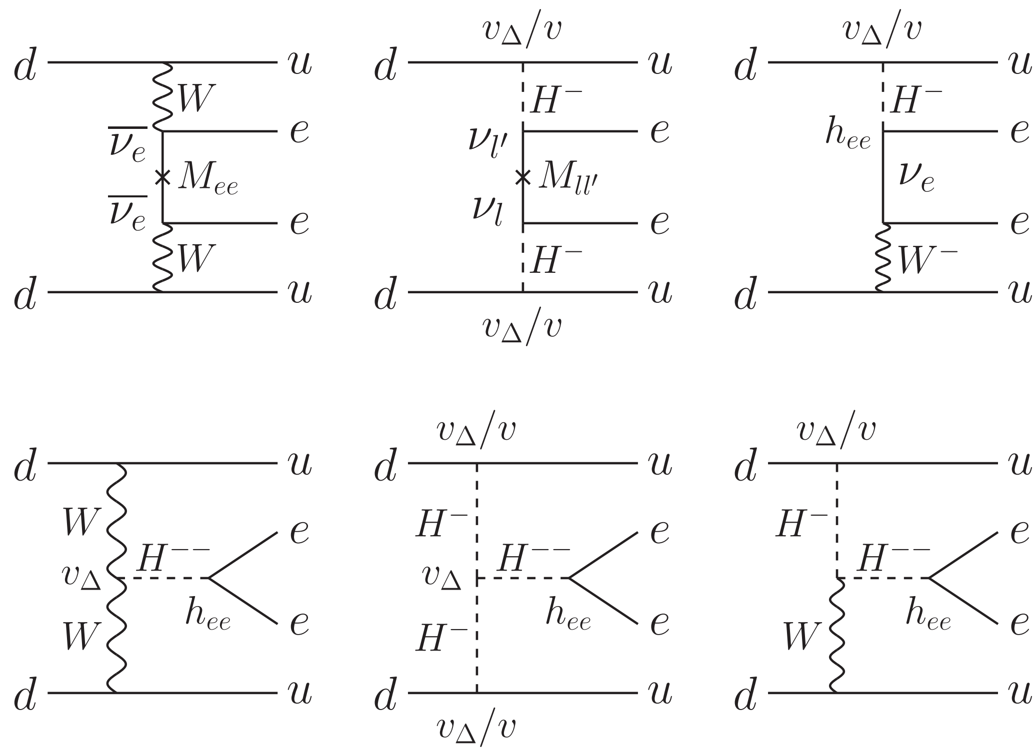
$$\Delta = \begin{pmatrix} \Delta^+/\sqrt{2} & \Delta^{++} \\ \Delta^0 & -\Delta^+/\sqrt{2} \end{pmatrix}\ \text{(Higgs triplet)}$$

$$\Phi^T = (\phi^+\ \ \phi^0)^T\ \text{(Higgs doublet)}$$

- Absence of the last term in $V_{\rm Higgs}$ lead to Majoron (LEP excluded).
- $\langle\Delta^0\rangle < 8$ GeV from ρ constraint. Petcov et. al. assumed $v_\Delta \lesssim 1$ MeV. Also $M_{H^{\pm\pm}} \leq M_{H^\pm}$ to forbid HW decays.
- Tevatron limit : $m_{H^{\pm\pm}} \sim$ 130GeV.

$0\nu\beta\beta$ in Triplet Higgs Model

From Petcov et. al. 0904.0759



- All diagrams (bar the first) are suppressed by powers of $v_\Delta \equiv \langle \Delta^0 \rangle$.