Neutrinoless Double Beta Decay: Theory

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für Kernphysik

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LowNu
11/11/11

$m_\nu = m_L - m_D^T M_R^{-1} m_D$

MANITOP
Massive Neutrinos: Investigating their Theoretical Origin and Phenomenology

Outline

$(A, Z) \to (A, Z+2) + 2\,e^- \quad (0\nu\beta\beta) \Rightarrow$ Lepton Number Violation

- **Standard Interpretation:**

  Neutrinoless Double Beta Decay is mediated by light and massive Majorana neutrinos (the ones which oscillate) and all other mechanisms potentially leading to $0\nu\beta\beta$ give negligible or no contribution

- **Non-Standard Interpretations:**

  There is at least one other mechanism leading to Neutrinoless Double Beta Decay and its contribution is at least of the same order as the light neutrino exchange mechanism

review on $0\nu\beta\beta$ and particle physics:

W.R., Int. J. Mod. Phys. **E20**, 1833 (2011)

Why should we probe Lepton Number Violation (LNV)?

- L and B *accidentally* conserved in SM
- effective theory: $\mathcal{L} = \mathcal{L}_{\rm SM} + \frac{1}{\Lambda}\,\mathcal{L}_{\rm LNV} + \frac{1}{\Lambda^2}\,\mathcal{L}_{\rm LFV,\,BNV,\,LNV} + \ldots$
- baryogenesis: B is violated
- B, L often connected in GUTs
- GUTs have seesaw and Majorana neutrinos
- chiral anomalies: $\partial_\mu J^\mu_{B,L} = c\,G_{\mu\nu}\,\tilde{G}^{\mu\nu} \neq 0$ with $J^B_\mu = \sum \overline{q_i}\,\gamma_\mu\,q_i$ and $J^L_\mu = \sum \overline{\ell_i}\,\gamma_\mu\,\ell_i$

$\Rightarrow$ Lepton Number Violation as important as Baryon Number Violation

($0\nu\beta\beta$ is much more than a neutrino mass experiment)

Interpretation of Experiments

Master formula:

$$\Gamma^{0\nu} = G_x(Q,Z)\,|\mathcal{M}_x(A,Z)\,\eta_x|^2$$

- $G_x(Q,Z)$: phase space factor
- $\mathcal{M}_x(A,Z)$: nuclear physics
- η_x: particle physics

Interpretation of Experiments

Master formula:

$$\Gamma^{0\nu} = G_x(Q,Z)\,|\mathcal{M}_x(A,Z)\,\eta_x|^2$$

- $G_x(Q,Z)$: phase space factor; calculable
- $\mathcal{M}_x(A,Z)$: nuclear physics; problematic
- η_x: particle physics; interesting

Upcoming experiments: exciting time!!

Name	Isotope	source = detector; calorimetric with			source ≠ detector
		high energy res.	low energy res.	event topology	event topology
CANDLES	^{48}Ca	–	✓	–	–
COBRA	^{116}Cd (and ^{130}Te)	–	–	✓	–
CUORE	^{130}Te	✓	–	–	–
DCBA	^{82}Se or ^{150}Nd	–	–	–	✓
EXO	^{136}Xe	–	–	✓	–
GERDA	^{76}Ge	✓	–	–	–
KamLAND-Zen	^{136}Xe	–	✓	–	–
LUCIFER	^{82}Se or ^{100}Mo or ^{116}Cd	✓	–	–	–
MAJORANA	^{76}Ge	✓	–	–	–
MOON	^{82}Se or ^{100}Mo or ^{150}Nd	–	–	–	✓
NEXT	^{136}Xe	–	–	✓	–
SNO+	^{150}Nd	–	✓	–	–
SuperNEMO	^{82}Se or ^{150}Nd	–	–	–	✓
XMASS	^{136}Xe	–	✓	–	–

multi-isotope determination good for 3 reasons

3 Reasons for Multi-isotope determination

1.) credibility

2.) test NME calculation

$$\frac{T_{1/2}^{0\nu}(A_1, Z_1)}{T_{1/2}^{0\nu}(A_2, Z_2)} = \frac{G(Q_2, Z_2)\, |\mathcal{M}(A_2, Z_2)|^2}{G(Q_1, Z_1)\, |\mathcal{M}(A_1, Z_1)|^2}$$

systematic errors drop out, ratio sensitive to NME model

3.) test mechanism

$$\frac{T_{1/2}^{0\nu}(A_1, Z_1)}{T_{1/2}^{0\nu}(A_2, Z_2)} = \frac{G_x(Q_2, Z_2)\, |\mathcal{M}_x(A_2, Z_2)|^2}{G_x(Q_1, Z_1)\, |\mathcal{M}_x(A_1, Z_1)|^2}$$

particle physics drops out, ratio of NMEs sensitive to mechanism

Experimental Aspects

particle theory:

$$(T^{0\nu}_{1/2})^{-1} \propto \text{(particle physics)}^2$$

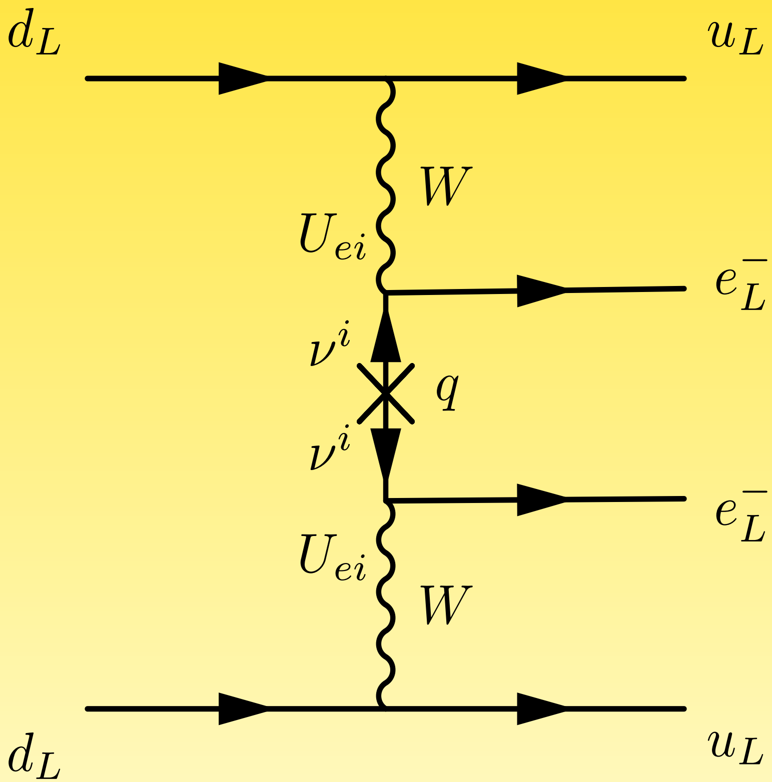
experimentally:

$$(T^{0\nu}_{1/2})^{-1} \propto \begin{cases} a\, M\, \varepsilon\, t & \text{without background} \\ a\, \varepsilon \sqrt{\dfrac{M\, t}{B\, \Delta E}} & \text{background-dominated} \end{cases}$$

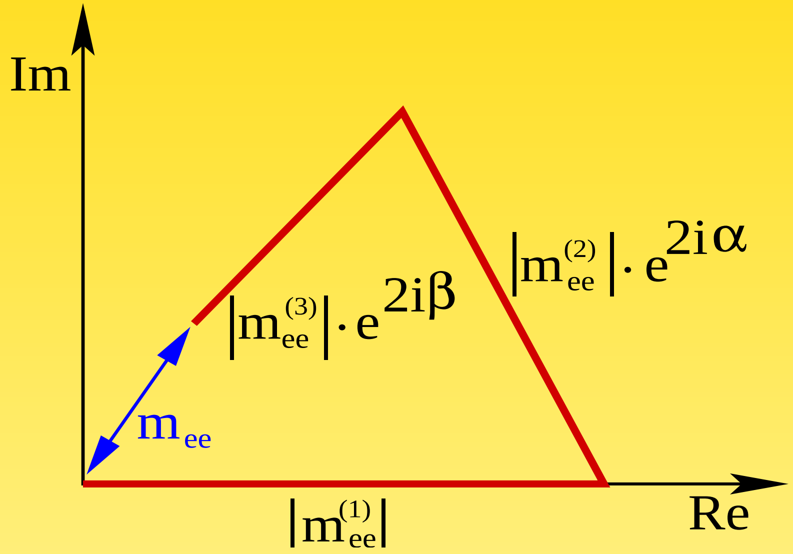
Note: factor 2 in particle physics is combined factor of 16 in $M \times t \times B \times \Delta E$

Standard Interpretation

Neutrinoless Double Beta Decay is mediated by light and massive Majorana neutrinos (the ones which oscillate) and all other mechanisms potentially leading to $0\nu\beta\beta$ give negligible or no contribution



$\Delta L \neq 0$: Neutrinoless Double Beta Decay

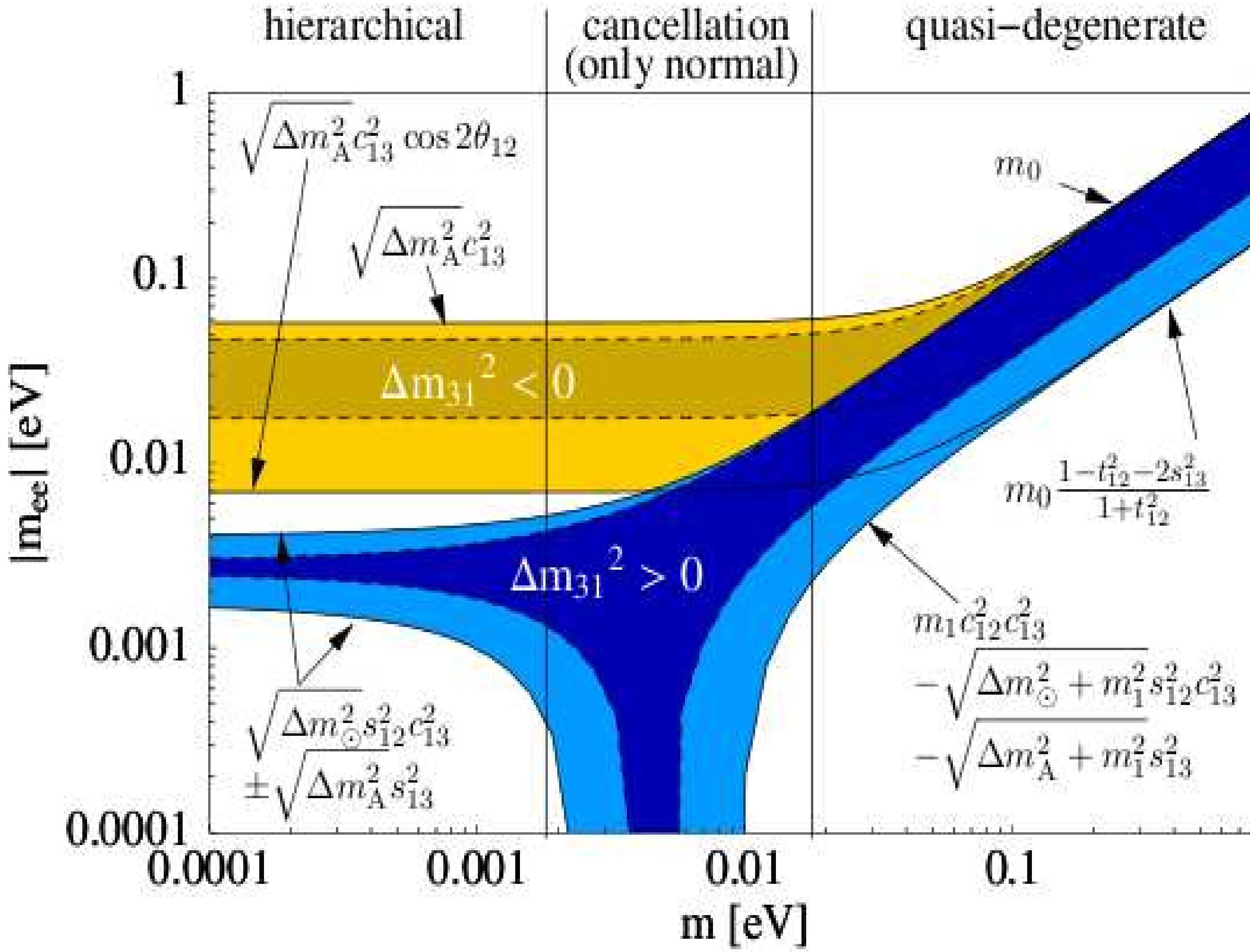


Amplitude proportional to coherent sum (“effective mass”):

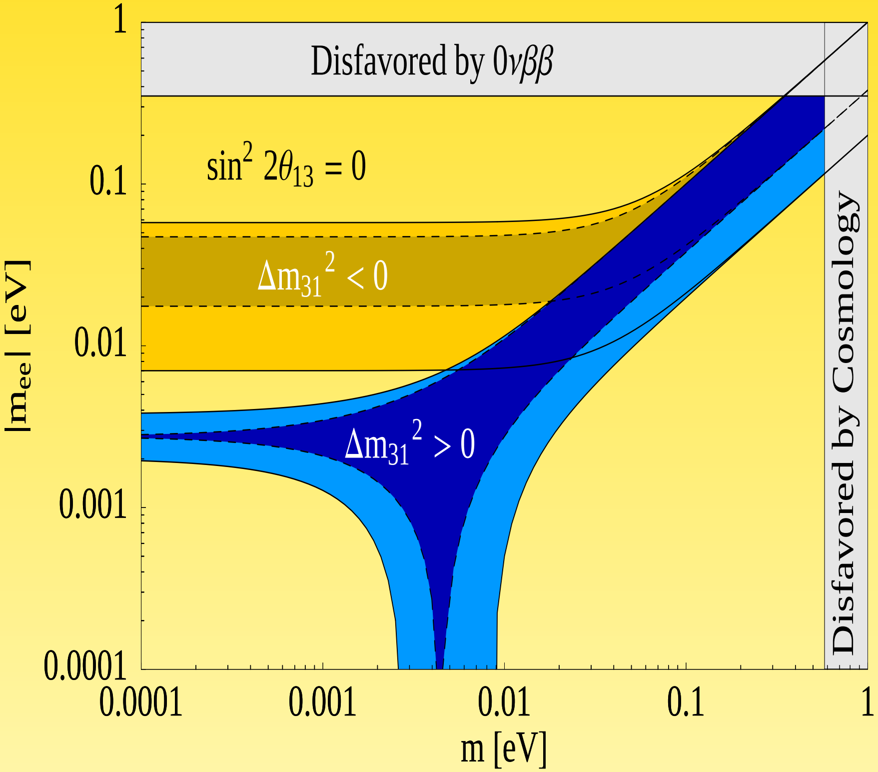
$$|m_{ee}| \equiv \left|\sum U_{ei}^2\, m_i\right| = \left||U_{e1}|^2\, m_1 + |U_{e2}|^2\, m_2\, e^{2i\alpha} + |U_{e3}|^2\, m_3\, e^{2i\beta}\right|$$

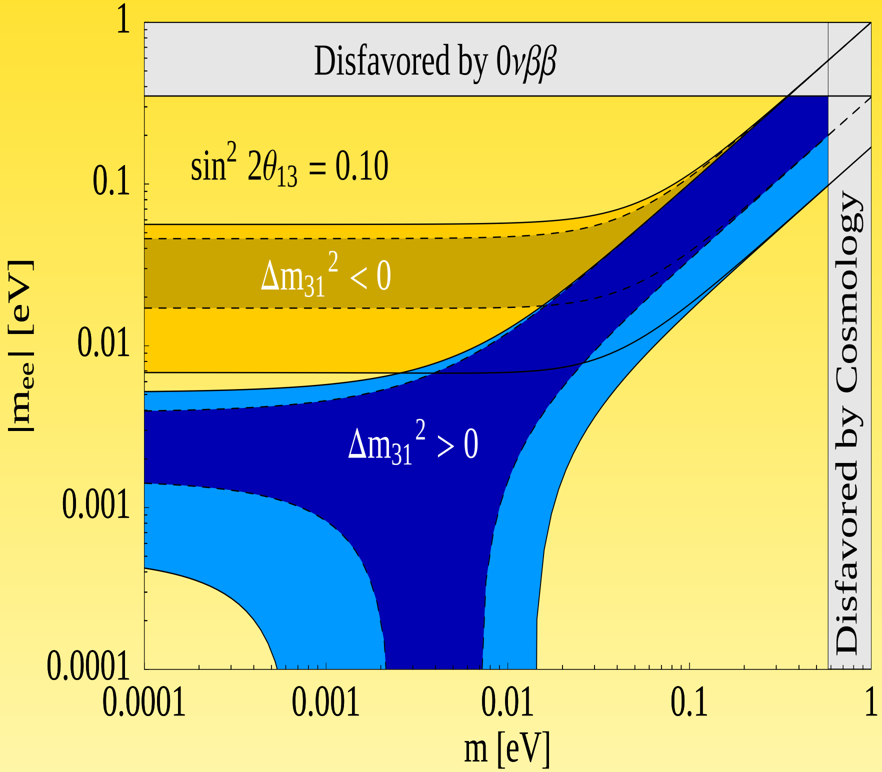
7 out of 9 parameters of m_ν!

The usual plot

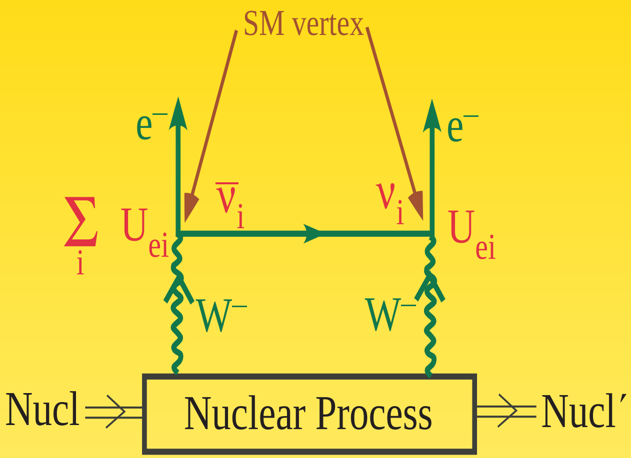


$0\nu\beta\beta$ and U_{e3}





From life-time to particle physics: Nuclear Matrix Elements



- 2 point-like Fermi vertices; "long-range" neutrino exchange; momentum exchange $q \simeq 1/r \simeq 0.1$ GeV
- NME $\leftrightarrow$ overlap of decaying nucleons...
- different approaches (QRPA, NSM, IBM, GCM, pHFB) imply uncertainty
- plus uncertainty due to model details
- plus convention issues (Cowell, PRC **73**; Smolnikov, Grabmayr, PRC **81**; Dueck, W.R., Zuber, PRD **83**)

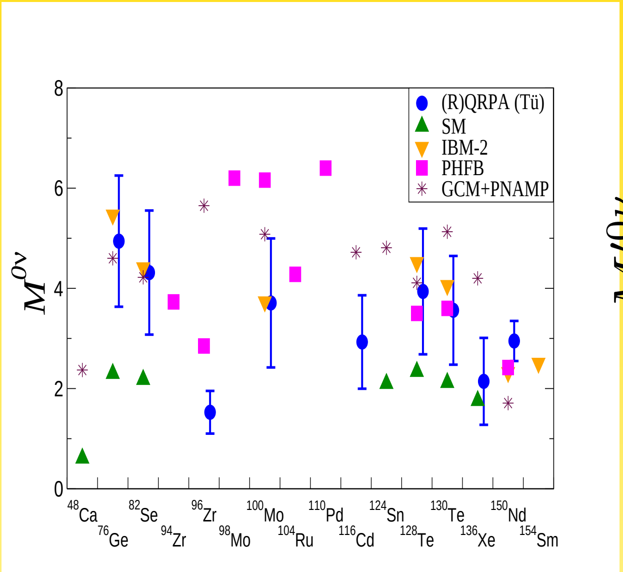
typical model for NME: set of single particle states with a number of possible wave function configurations; solve $\mathcal{H}$ in a mean background field

- Quasi-particle Random Phase Approximation (QRPA) **(many single particle states, few configurations)**
- Nuclear Shell Model (NSM) **(many configurations, few single particle states)**
- Interacting Boson Model (IBM) **(many single particle states, few configurations)** **(many single particle states, few configurations)**
- Generating Coordinate Method (GCM) **(many single particle states, few configurations)**
- projected Hartree-Fock-Bogoliubov model (pHFB)

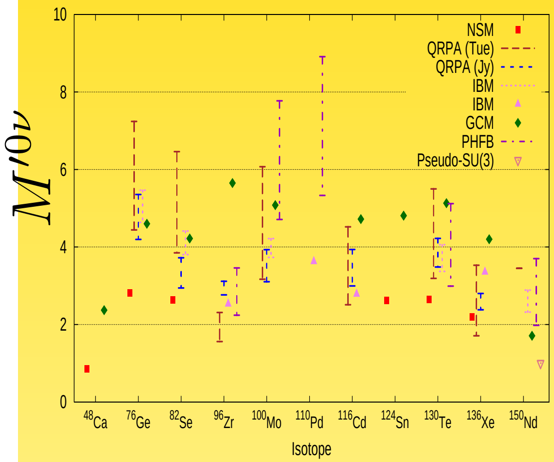
tends to overestimate NMEs

tends to underestimate NMEs

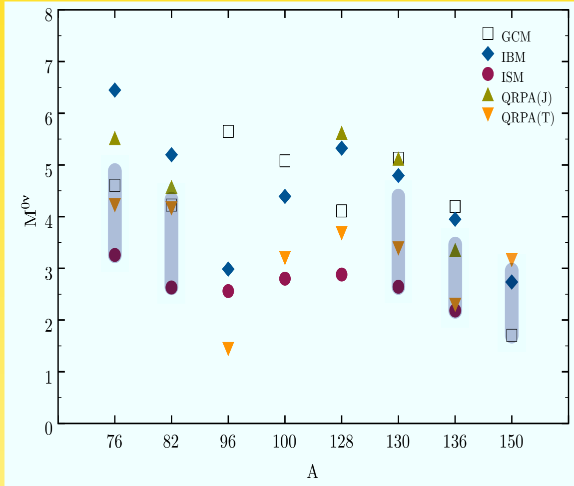
From life-time to particle physics: Nuclear Matrix Elements



Faessler, 1104.3700

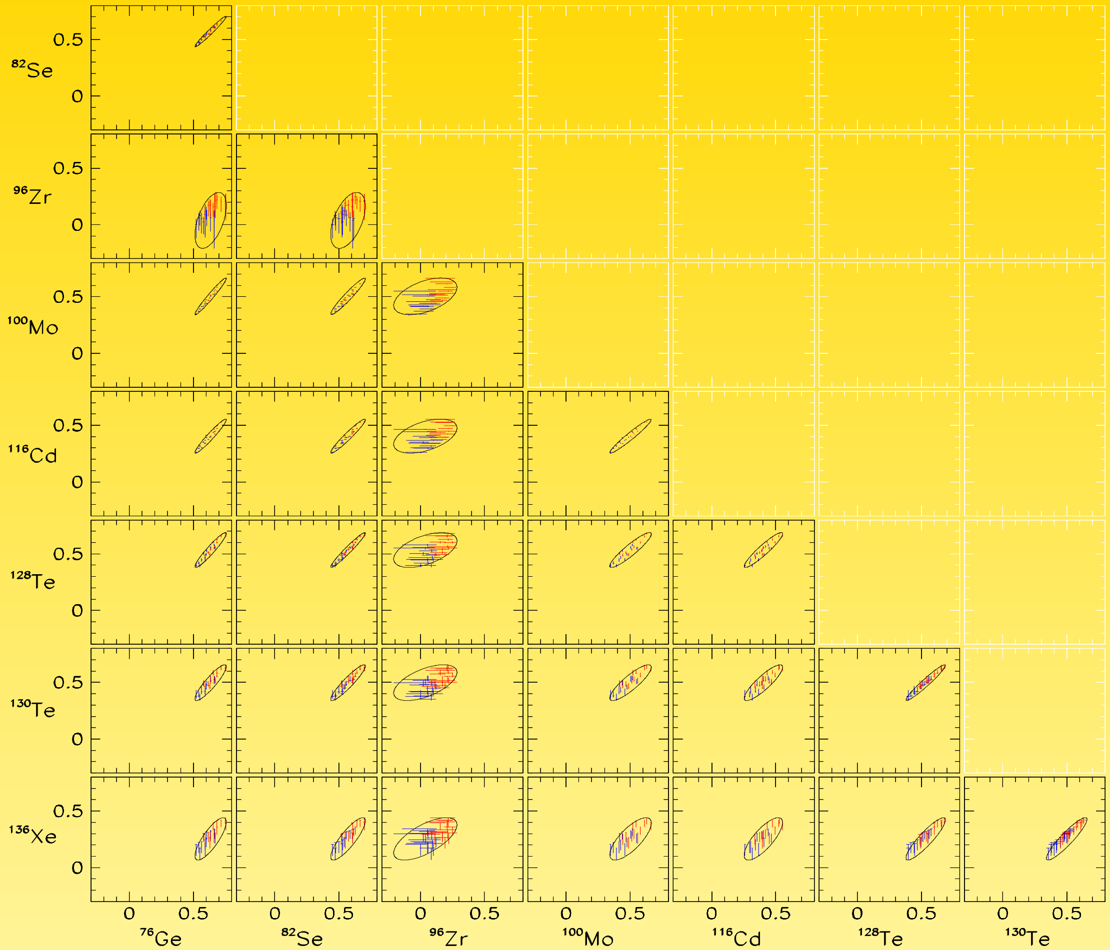


Dueck, W.R., Zuber, PRD **83**



Gomez-Cadenas *et al.*, 1109.5515

to better estimate error range: correlations need to be understood



Faessler, Fogli *et al.*, PRD **79**

ellipse major axis: SRC (blue, red) and g_A

ellipse minor axis: g_{pp}

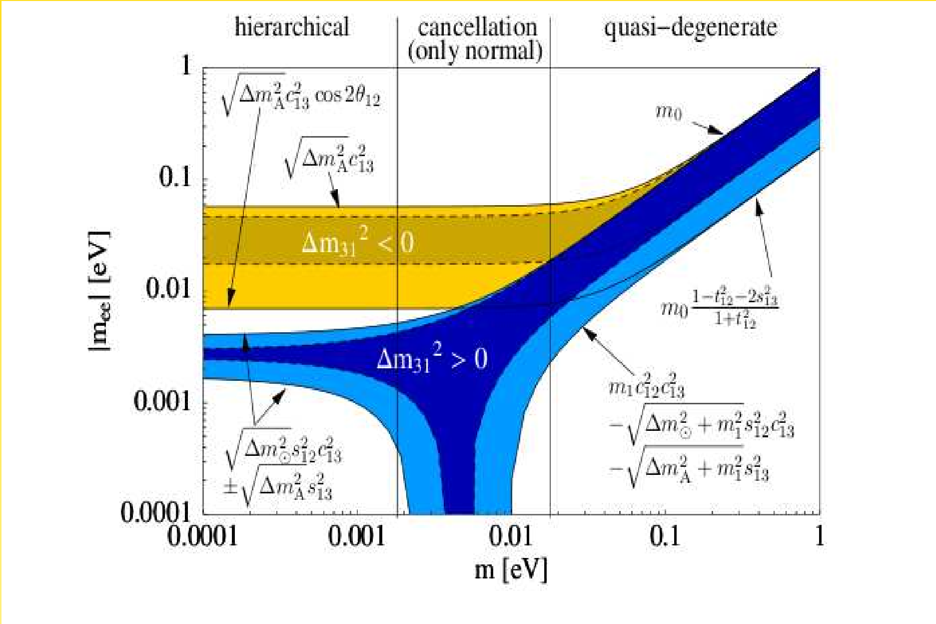
$0\nu\beta\beta$ and Neutrino physics

Isotope	$T^{0\nu}_{1/2}$ [yrs]	Experiment	$\|m_{ee}\|^{\rm lim}_{\rm min}$ [eV]	$\|m_{ee}\|^{\rm lim}_{\rm max}$ [eV]
^{48}Ca	5.8×10^{22}	CANDLES	3.55	9.91
^{76}Ge	1.9×10^{25}	HDM	0.21	0.53
	1.6×10^{25}	IGEX	0.25	0.63
^{82}Se	3.2×10^{23}	NEMO-3	0.85	2.08
^{96}Zr	9.2×10^{21}	NEMO-3	3.97	14.39
^{100}Mo	1.0×10^{24}	NEMO-3	0.31	0.79
^{116}Cd	1.7×10^{23}	SOLOTVINO	1.22	2.30
^{130}Te	2.8×10^{24}	CUORICINO	0.27	0.57
^{136}Xe	5.0×10^{23}	DAMA	0.83	2.04
^{150}Nd	1.8×10^{22}	NEMO-3	2.35	5.08

Experiment	Isotope	Mass of Isotope [kg]	Sensitivity $T^{0\nu}_{1/2}$ [yrs]	Status	Start of data-taking	Sensitivity $\langle m_\nu \rangle$ [eV]
GERDA	^{76}Ge	18	3×10^{25}	running	$\sim$ 2011	0.17-0.42
		40	2×10^{26}	in progress	$\sim$ 2012	0.06-0.16
		1000	6×10^{27}	R&D	$\sim$ 2015	0.012-0.030
CUORE	^{130}Te	200	$6.5 \times 10^{26*}$	in progress	$\sim$ 2013	0.018-0.037
			$2.1 \times 10^{26**}$			0.03-0.066
MAJORANA	^{76}Ge	30-60	$(1-2) \times 10^{26}$	in progress	$\sim$ 2013	0.06-0.16
		1000	6×10^{27}	R&D	$\sim$ 2015	0.012-0.030
EXO	^{136}Xe	200	6.4×10^{25}	in progress	$\sim$ 2011	0.073-0.18
		1000	8×10^{26}	R&D	$\sim$ 2015	0.02-0.05
SuperNEMO	^{82}Se	100-200	$(1-2) \times 10^{26}$	R&D	$\sim$ 2013-15	0.04-0.096
KamLAND-Zen	^{136}Xe	400	4×10^{26}	in progress	$\sim$ 2011	0.03-0.07
		1000	10^{27}	R&D	$\sim$ 2013-15	0.02-0.046
SNO+	^{150}Nd	56	4.5×10^{24}	in progress	$\sim$ 2012	0.15-0.32
		500	3×10^{25}	R&D	$\sim$ 2015	0.06-0.12

Note: with *same* lifetime: ^{150}Nd and ^{100}Mo do best. . .

Inverted Ordering

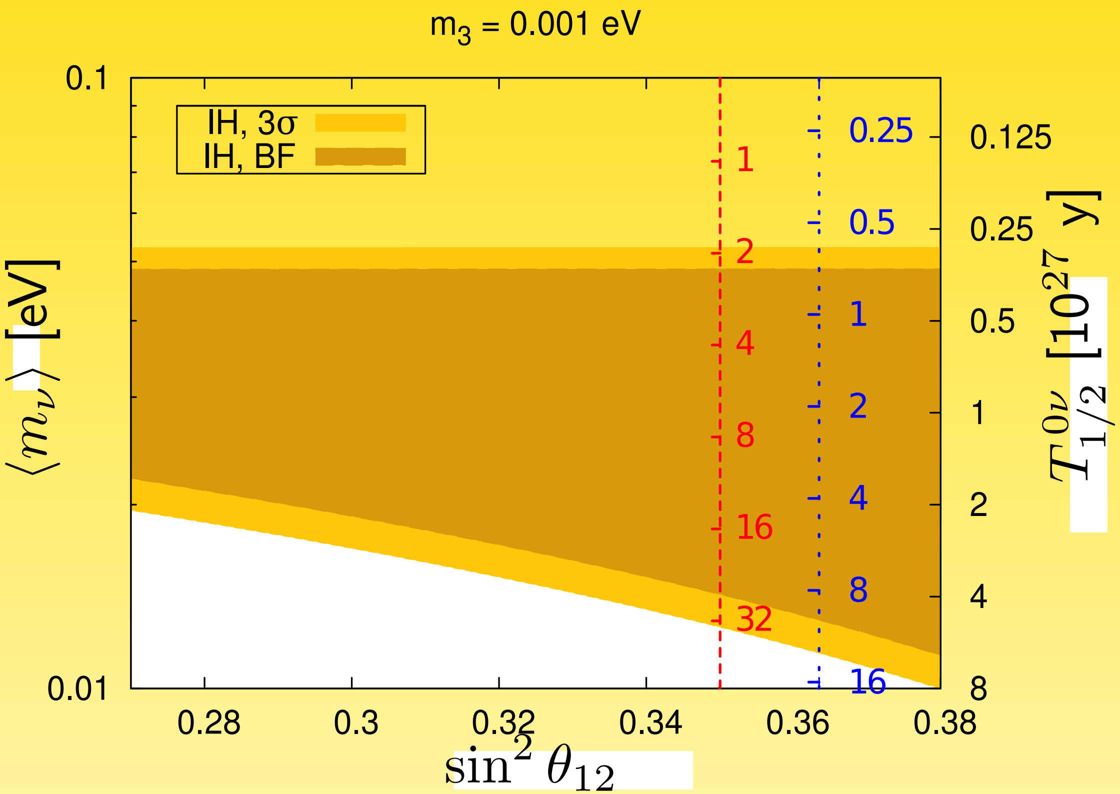


Nature provides 2 scales:

$$\langle m_\nu \rangle^{\text{IH}}_{\text{max}} \simeq c_{13}^2 \sqrt{\Delta m_{\text{A}}^2} \quad \text{and} \quad \langle m_\nu \rangle^{\text{IH}}_{\text{min}} \simeq c_{13}^2 \sqrt{\Delta m_{\text{A}}^2} \cos 2\theta_{12}$$

requires $\mathcal{O}(10^{26} \ldots 10^{27})$ yrs

Ruling out Inverted Hierarchy



Dueck, W.R., Zuber, PRD **83**

Ruling out Inverted Hierarchy

$$|m_{ee}|^{\rm IH}_{\rm min} = \left(1 - |U_{e3}|^2\right) \sqrt{|\Delta m^2_{\rm A}|} \left(1 - 2 \sin^2\theta_{12}\right) = \begin{cases} (0.015 \ldots 0.020)~{\rm eV} & 1\sigma \\ (0.010 \ldots 0.024)~{\rm eV} & 3\sigma \end{cases}$$

- small $|U_{e3}|$
- large $|\Delta m^2_{\rm A}|$
- small $\sin^2\theta_{12}$

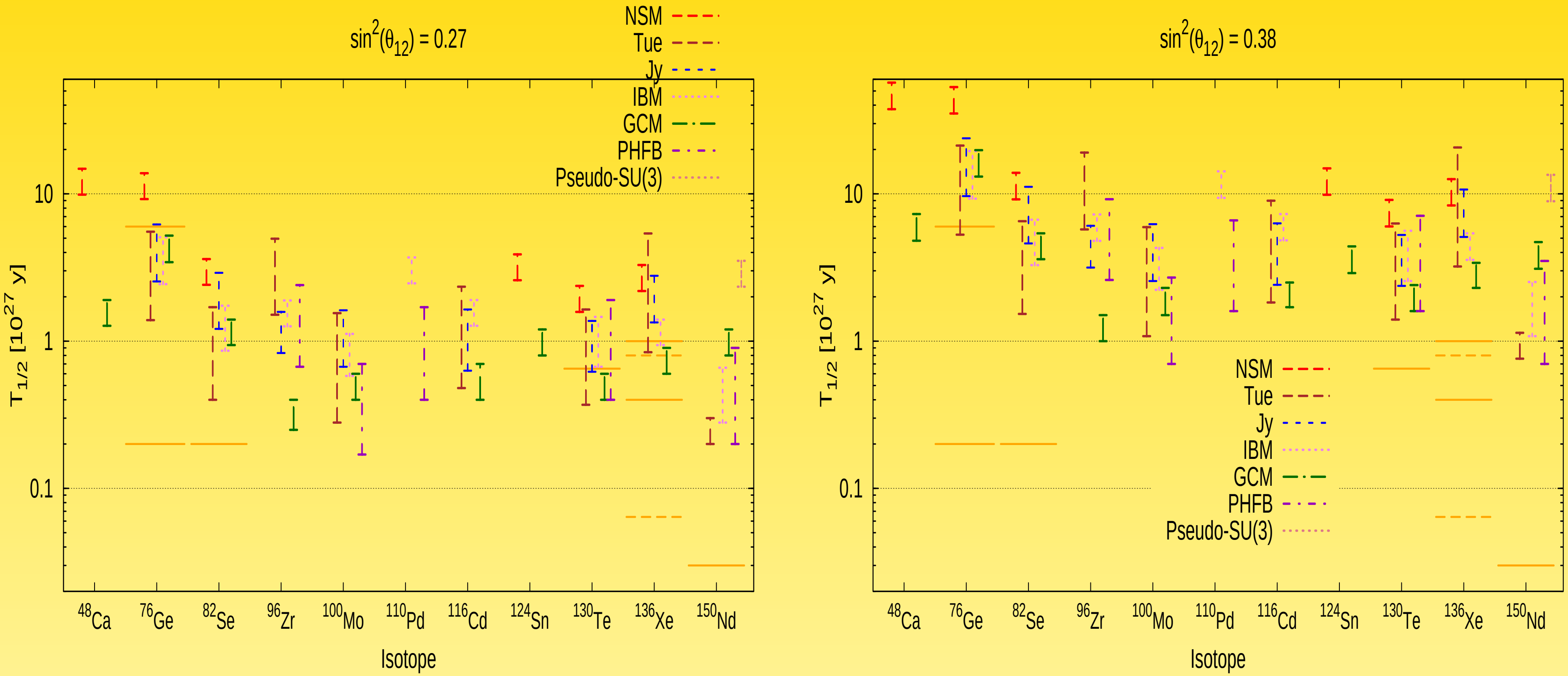
Current 3σ range of $\sin^2\theta_{12}$ gives factor of 2 uncertainty for $|m_{ee}|^{\rm IH}_{\rm min}$

$\Rightarrow$ combined factor of 16 in $M \times t \times B \times \Delta E$

$\Rightarrow$ need precision determination of θ_{12}

Dueck, W.R., Zuber, PRD **83**

Ruling out Inverted Hierarchy

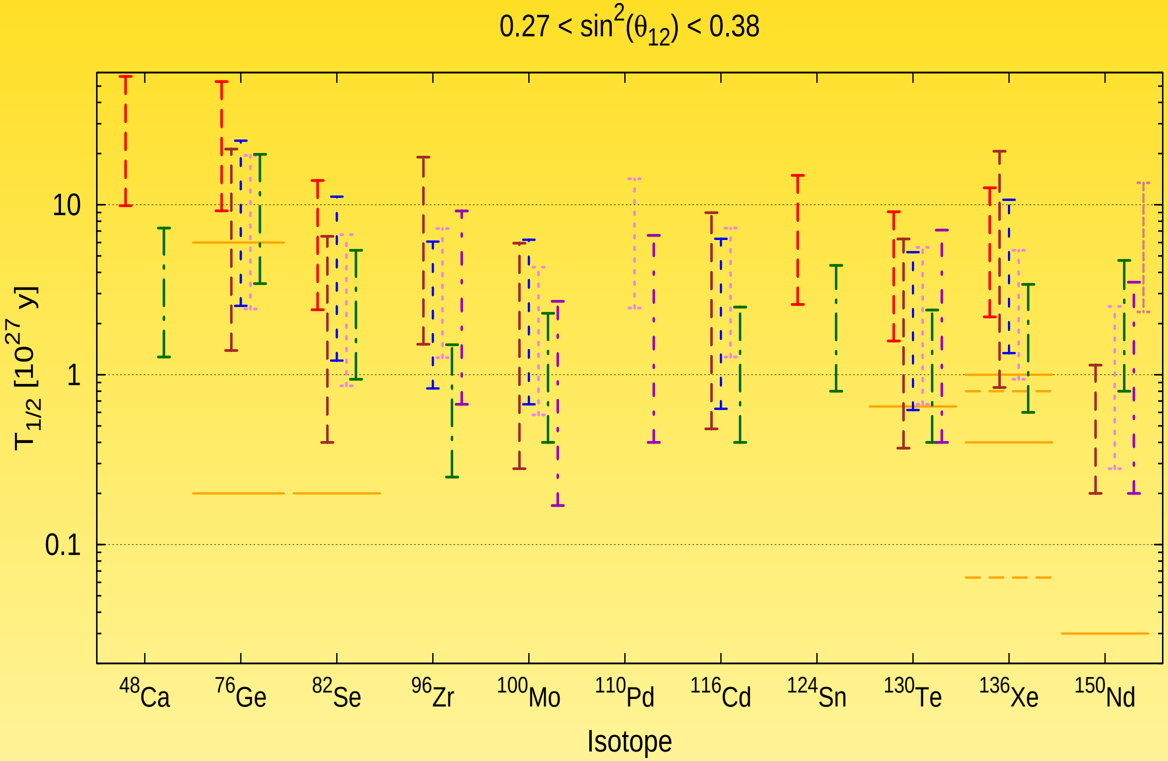


$\sin^2\theta_{12} = 0.27$ $\sin^2\theta_{12} = 0.38$

spread due to NMEs **and due to θ_{12}!!**

Note: ^{100}Mo and ^{150}Nd do best. . .

Ruling out Inverted Hierarchy

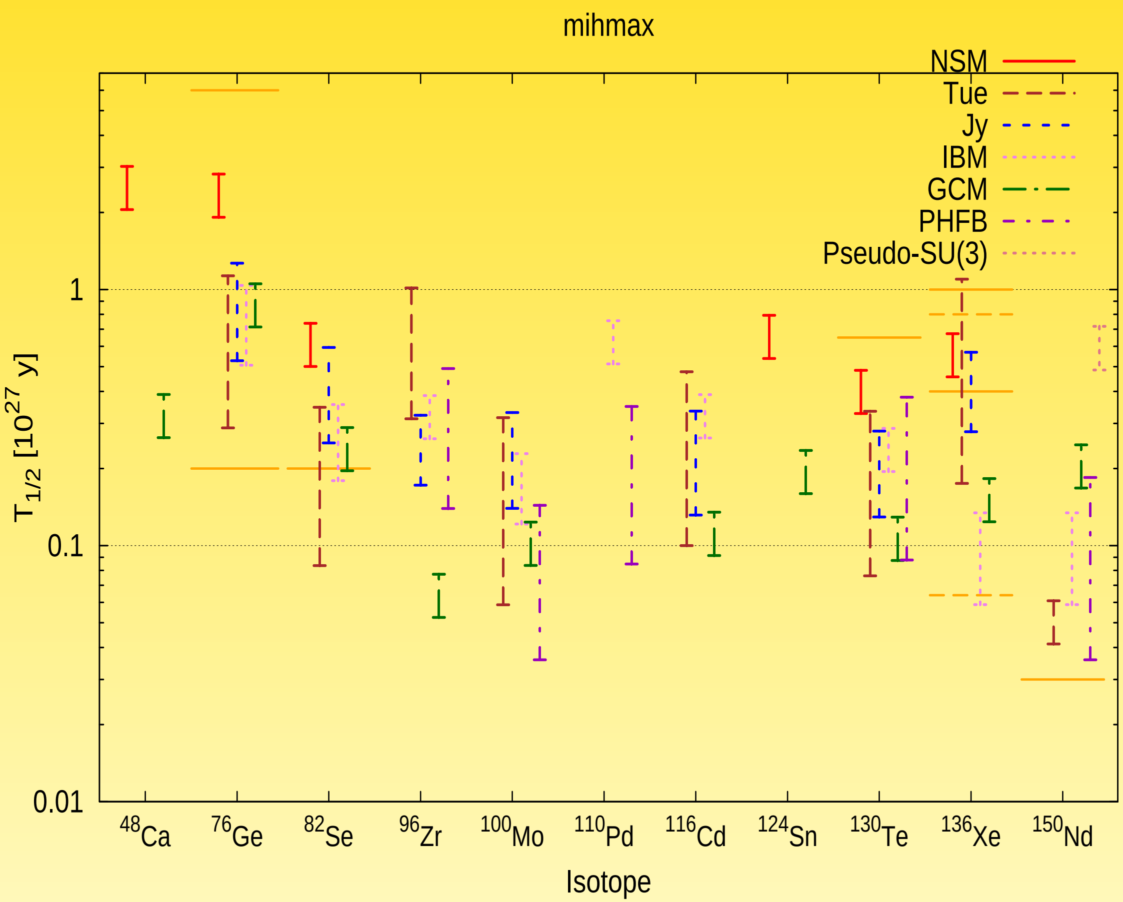


spread due to NMEs **and due to θ_{12}!!**

Note: ^{100}Mo and ^{150}Nd do best...

Testing Inverted Hierarchy

lifetime to enter the IH regime



The Zoo (of A_4 models)

Type	L_i	ℓ_i^c	ν_i^c	Δ	References
A1				-	[1–14] [15]#
A2	$\underline{3}$	$\underline{1}, \underline{1}', \underline{1}''$	-	$\underline{1}, \underline{1}', \underline{1}'', \underline{3}$	[16–18]
A3				$\underline{1}, \underline{3}$	[19]
B1	$\underline{3}$	$\underline{1}, \underline{1}', \underline{1}''$	$\underline{3}$	-	[4, 20–27]# [28–30]* [31–45]
B2				$\underline{1}, \underline{3}$	[46]#
C1				-	[2, 47, 48]
C2	$\underline{3}$	$\underline{3}$	-	$\underline{1}$	[49, 50] [51]#
C3				$\underline{1}, \underline{3}$	[52]
C4				$\underline{1}, \underline{1}', \underline{1}'', \underline{3}$	[53]
D1				-	[54, 55]# [56, 57]* [58]
D2	$\underline{3}$	$\underline{3}$	$\underline{3}$	$\underline{1}$	[59] [60]*
D3				$\underline{1}'$	[61]*
D4				$\underline{1}', \underline{3}$	[62]*
E	$\underline{3}$	$\underline{3}$	$\underline{1}, \underline{1}', \underline{1}''$	-	[63, 64]
F	$\underline{1}, \underline{1}', \underline{1}''$	$\underline{3}$	$\underline{3}$	$\underline{1}$ or $\underline{1}'$	[65]
G	$\underline{3}$	$\underline{1}, \underline{1}', \underline{1}''$	$\underline{1}, \underline{1}', \underline{1}''$	-	[66]
H	$\underline{3}$	$\underline{1}, \underline{1}, \underline{1}$	-	-	[67]
I	$\underline{3}$	$\underline{1}, \underline{1}, \underline{1}$	$\underline{1}, \underline{1}, \underline{1}$	-	[68]*
J	$\underline{3}$	$\underline{1}, \underline{1}, \underline{1}$	$\underline{3}$	-	[12, 39, 69, 70]
K	$\underline{3}$	$\underline{1}, \underline{1}, \underline{1}$	$\underline{1}, \underline{1}$	$\underline{1}$	[71]*
L	$\underline{3}$	$\underline{1}, \underline{1}, \underline{1}$	$\underline{1}$	-	[72]*
M	$\underline{1}, \underline{1}', \underline{1}''$	$\underline{1}, \underline{1}'', \underline{1}'$	$\underline{3}, \underline{1}$	-	[73, 74]
N	$\underline{1}, \underline{1}', \underline{1}''$	$\underline{1}, \underline{1}'', \underline{1}'$	$\underline{3}, \underline{1}', \underline{1}''$	-	[75]

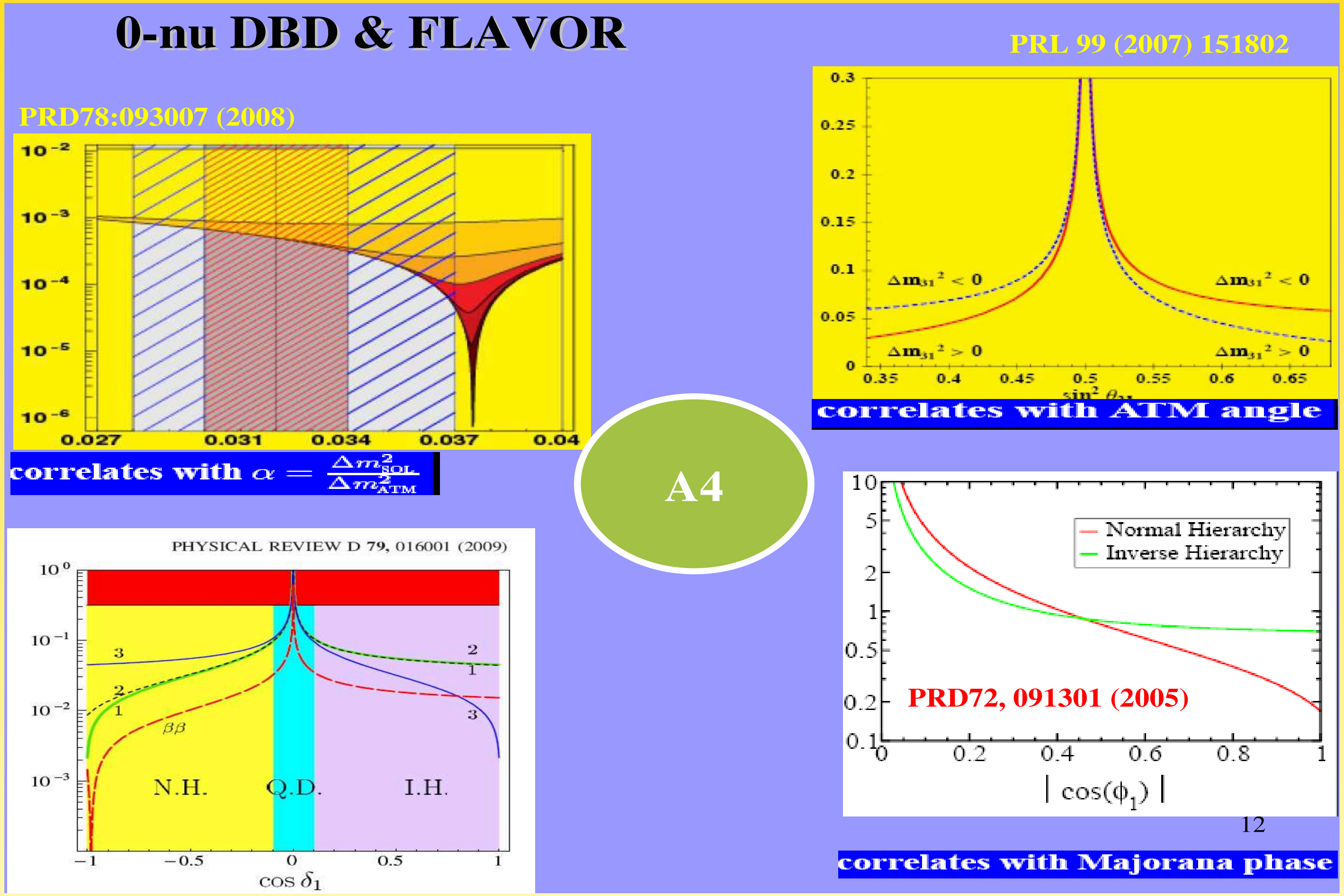
Barry, W.R., PRD **81**, updated regularly on

http://www.mpi-hd.mpg.de/personalhomes/jamesb/Table_A4.pdf

How to distinguish?

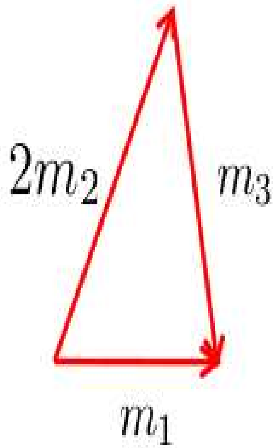
- LFV
- low scale scalars: Higgs, LFV
- compatible with GUTs?
- leptogenesis possible?
- **neutrino mass observables**

correlation with observables



Slide by J. Valle

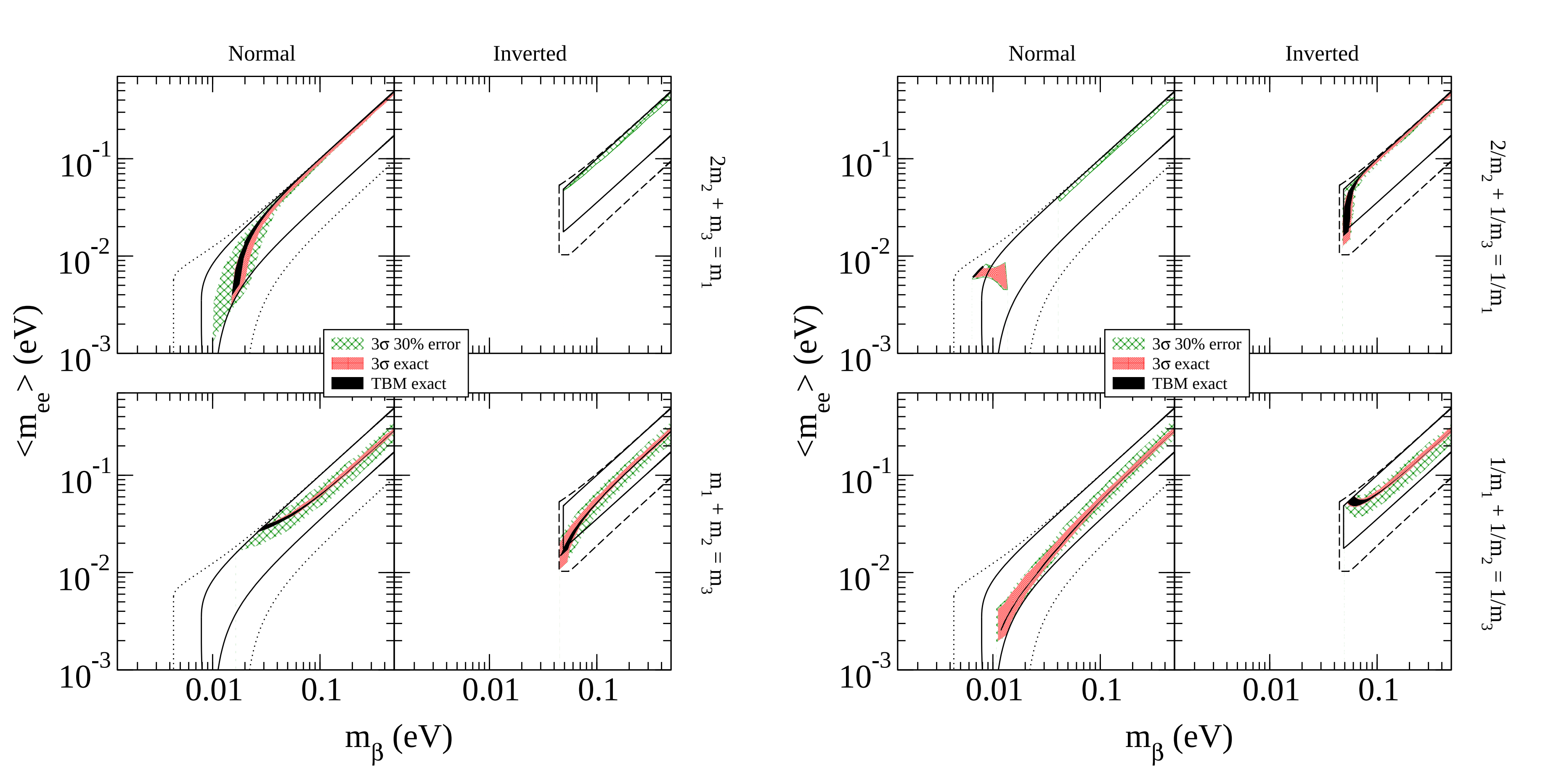
Sum-rules in Models and $0\nu\beta\beta$



Sum-rule	Flavour symmetry
$2m_2 + m_3 = m_1$	$A_4, T', (S_4)$
$m_1 + m_2 = m_3$	$S_4, (A_4)$
$\frac{2}{m_2} + \frac{1}{m_3} = \frac{1}{m_1}$	A_4, T'
$\frac{1}{m_1} + \frac{1}{m_2} = \frac{1}{m_3}$	S_4

constrains masses and Majorana phases

Barry, W.R., NPB **842**



$$m_1 + m_2 - m_3 = \epsilon\, m_{\rm max}$$

stable: new solutions not before $\epsilon \simeq 0.2$

Sterile Neutrinos??

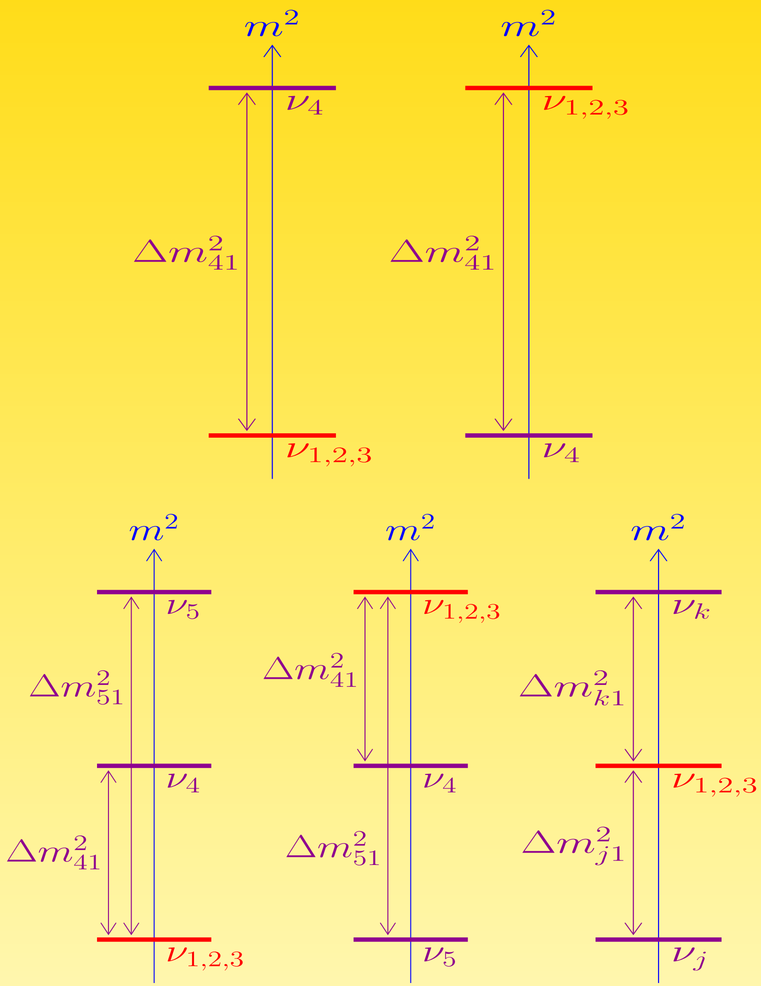
- LSND/MiniBooNE
- cosmology
- BBN
- reactor anomaly (Mention *et al.*, PRD **83**)

	$\Delta m^2_{41}[\mathrm{eV}^2]$	$\vert U_{e4}\vert$	$\vert U_{\mu 4}\vert$	$\Delta m^2_{51}[\mathrm{eV}^2]$	$\vert U_{e5}\vert$	$\vert U_{\mu 5}\vert$
3+2/2+3	0.47	0.128	0.165	0.87	0.138	0.148
1+3+1	0.47	0.129	0.154	0.87	0.142	0.163

or $\Delta m^2_{41} = 1.78$ eV^2 and $|U_{e4}|^2 = 0.151$

Kopp, Maltoni, Schwetz, 1103.4570

Mass Orderings



3 active neutrinos can be normally or inversely ordered

Sterile Neutrinos and $0\nu\beta\beta$

- recall $|m_{ee}|^{\rm act}_{\rm NH}$ can vanish and $|m_{ee}|^{\rm act}_{\rm IH} \sim 0.02$ eV cannot vanish
- $|m_{ee}| = |\underbrace{|U_{e1}|^2 m_1 + |U_{e2}|^2 m_2\, e^{2i\alpha} + |U_{e3}^2| m_3\, e^{2i\beta}}_{m_{ee}^{\rm act}} + \underbrace{|U_{e4}|^2 m_4\, e^{2i\Phi_1}}_{m_{ee}^{\rm st}}|$
- $\Delta m^2_{\rm st} \simeq 1$ eV^2 and $|U_{e4}| \simeq 0.15$
- sterile contribution to $0\nu\beta\beta$:

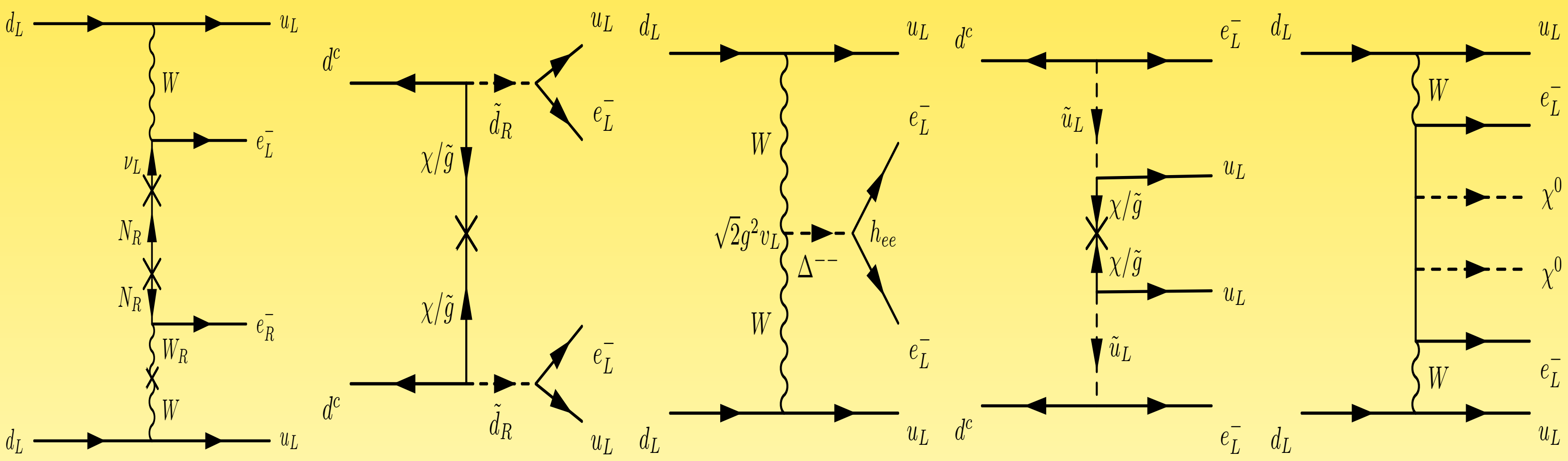
$$|m_{ee}|^{\rm st} \simeq \sqrt{\Delta m^2_{\rm st}}\, |U_{e4}|^2 \simeq 0.02 \text{ eV} \left\{ \begin{array}{c} \gg |m_{ee}|^{\rm act}_{\rm NH} \\ \simeq |m_{ee}|^{\rm act}_{\rm IH} \end{array} \right.$$

- $\Rightarrow$ $|m_{ee}|_{\rm NH}$ cannot vanish and $|m_{ee}|_{\rm IH}$ can vanish!

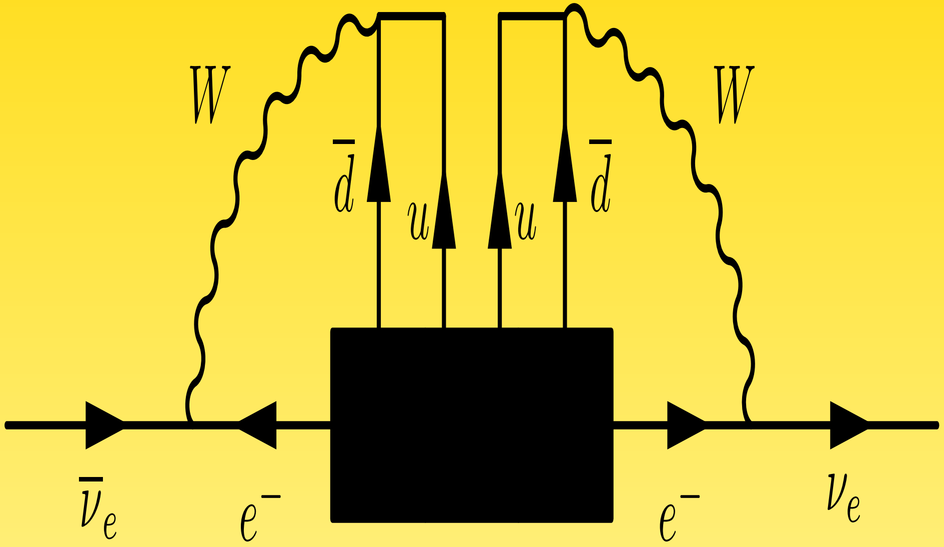
`Barry, W.R., Zhang, JHEP` **1107**

Non-Standard Interpretations:

There is at least one other mechanism leading to Neutrinoless Double Beta Decay and its contribution is at least of the same order as the light neutrino exchange mechanism



Schechter-Valle theorem: no matter what process, neutrinos are Majorana:



Blackbox diagram is 4 loop:

$$m_\nu \sim \frac{1}{(16\pi^2)^4}\frac{\text{MeV}^5}{m_W^4} \lesssim 10^{-23}\,\text{eV}$$

explicit calculation: `Duerr, Lindner, Merle, 1105.0901`

mechanism	physics parameter	current limit	test
light neutrino exchange	$\left\lvert U_{ei}^2\, m_i \right\rvert$	0.5 eV	oscillations, cosmology, neutrino mass
heavy neutrino exchange	$\left\lvert \frac{S_{ei}^2}{M_i} \right\rvert$	2×10^{-8} GeV^{-1}	LFV, collider
heavy neutrino and RHC	$\left\lvert \frac{V_{ei}^2}{M_i\, M_{W_R}^4} \right\rvert$	4×10^{-16} GeV^{-5}	flavor, collider
Higgs triplet and RHC	$\left\lvert \frac{(M_R)_{ee}}{m_{\Delta_R}^2\ M_{W_R}^4} \right\rvert$	10^{-15} GeV^{-1}	flavor, collider, e^- distribution
λ-mechanism with RHC	$\left\lvert \frac{U_{ei}\, \tilde{S}_{ei}}{M_{W_R}^2} \right\rvert$	1.4×10^{-10} GeV^{-2}	flavor, collider, e^- distribution
η-mechanism with RHC	$\tan\zeta\ \left\lvert U_{ei}\, \tilde{S}_{ei} \right\rvert$	6×10^{-9}	flavor, collider, e^- distribution
short-range $\not{R}$	$\frac{\lvert \lambda'^2_{111} \rvert}{\Lambda_{SUSY}^5}$ $\Lambda_{SUSY} = f(m_{\tilde{g}}, m_{\tilde{u}_L}, m_{\tilde{d}_R}, m_{\chi_i})$	7×10^{-18} GeV^{-5}	collider, flavor
long-range $\not{R}$	$\left\lvert \sin 2\theta^b\ \lambda'_{131}\ \lambda'_{113} \left(\frac{1}{m_{\tilde{b}_1}^2} - \frac{1}{m_{\tilde{b}_2}^2} \right) \right\rvert$ $\sim \frac{G_F}{q}\, m_b \frac{\lvert \lambda'_{131}\ \lambda'_{113} \rvert}{\Lambda_{SUSY}^3}$	2×10^{-13} GeV^{-2} 1×10^{-14} GeV^{-3}	flavor, collider
Majorons	$\lvert\langle g_\chi \rangle\rvert$ or $\lvert\langle g_\chi \rangle\rvert^2$	$10^{-4} \ldots 1$	spectrum, cosmology

Distinguishing Mechanisms

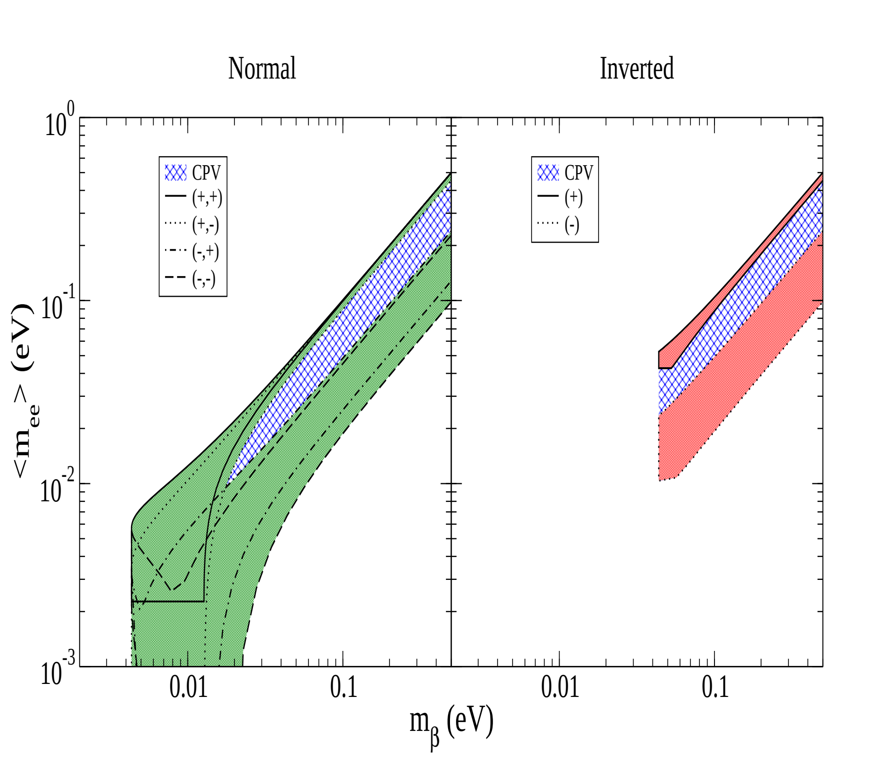
The inverse problem of $0\nu\beta\beta$

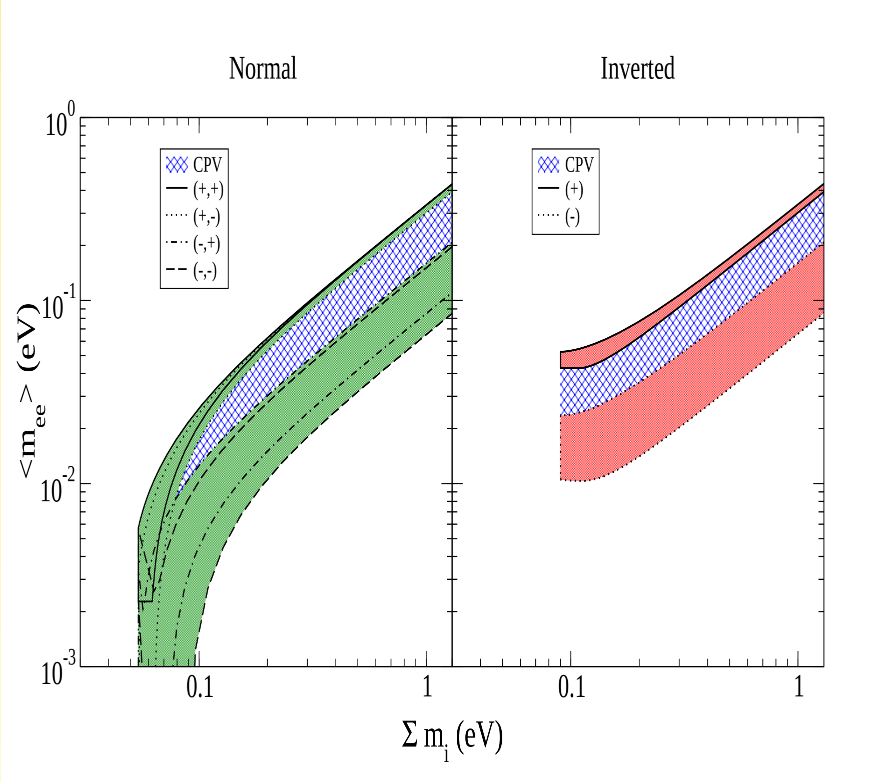
1.) Other observables (LHC, LFV, KATRIN, cosmology,...)

2.) Decay products (individual e^- energies, angular correlations, spectrum,...)

3.) Nuclear physics (multi-isotope, 0νECEC, $0\nu\beta^+\beta^+$,...)

1.) Distinguishing via other Observables





standard mechanism: KATRIN, cosmology

Energy Scale:

Note: *standard amplitude* for light Majorana neutrino exchange:

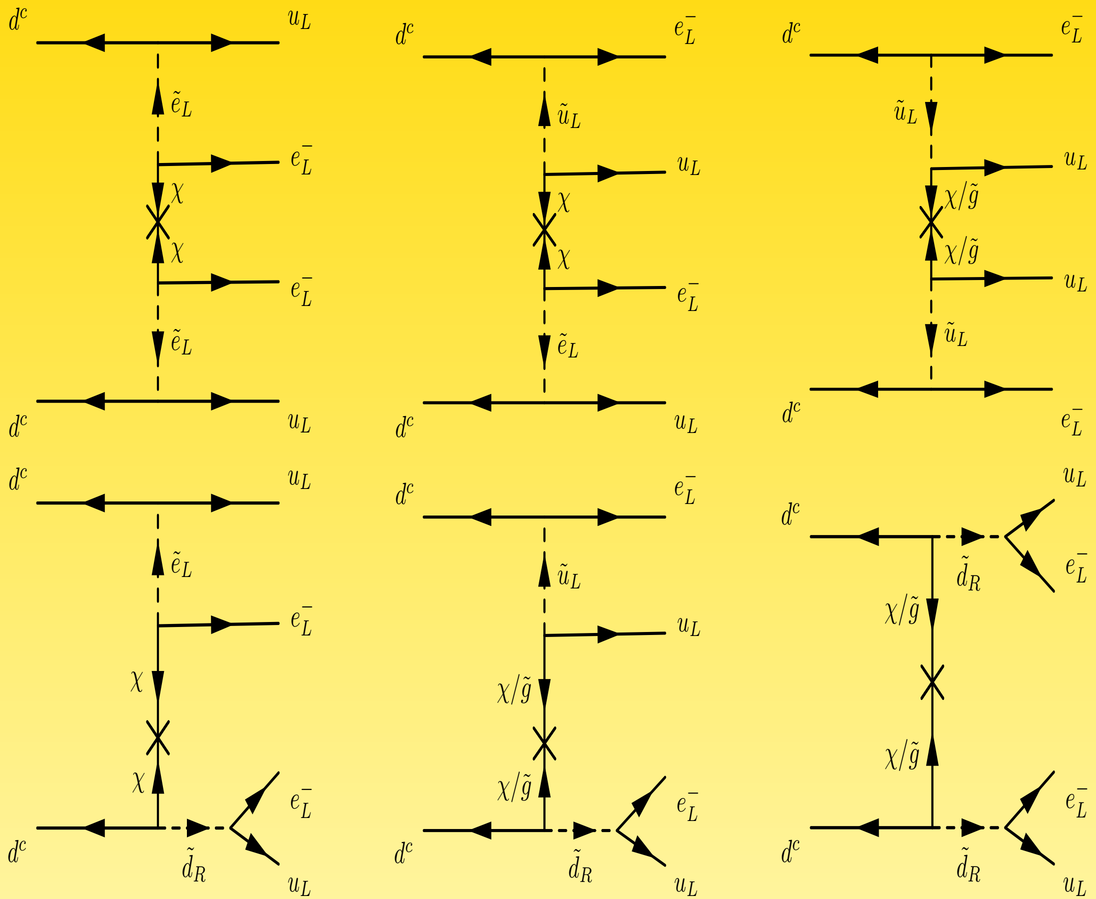
$$\mathcal{A}_{\rm l} \simeq G_F^2 \, \frac{|m_{ee}|}{q^2} \simeq 7 \times 10^{-18} \left(\frac{|m_{ee}|}{0.5 \text{ eV}} \right) \text{GeV}^{-5} \simeq 2.7 \text{ TeV}^{-5}$$

$\Rightarrow$ for $0\nu\beta\beta$ holds:

$$\boxed{1 \text{ eV} = 1 \text{ TeV}}$$

$\Rightarrow$ Phenomenology in colliders, LFV

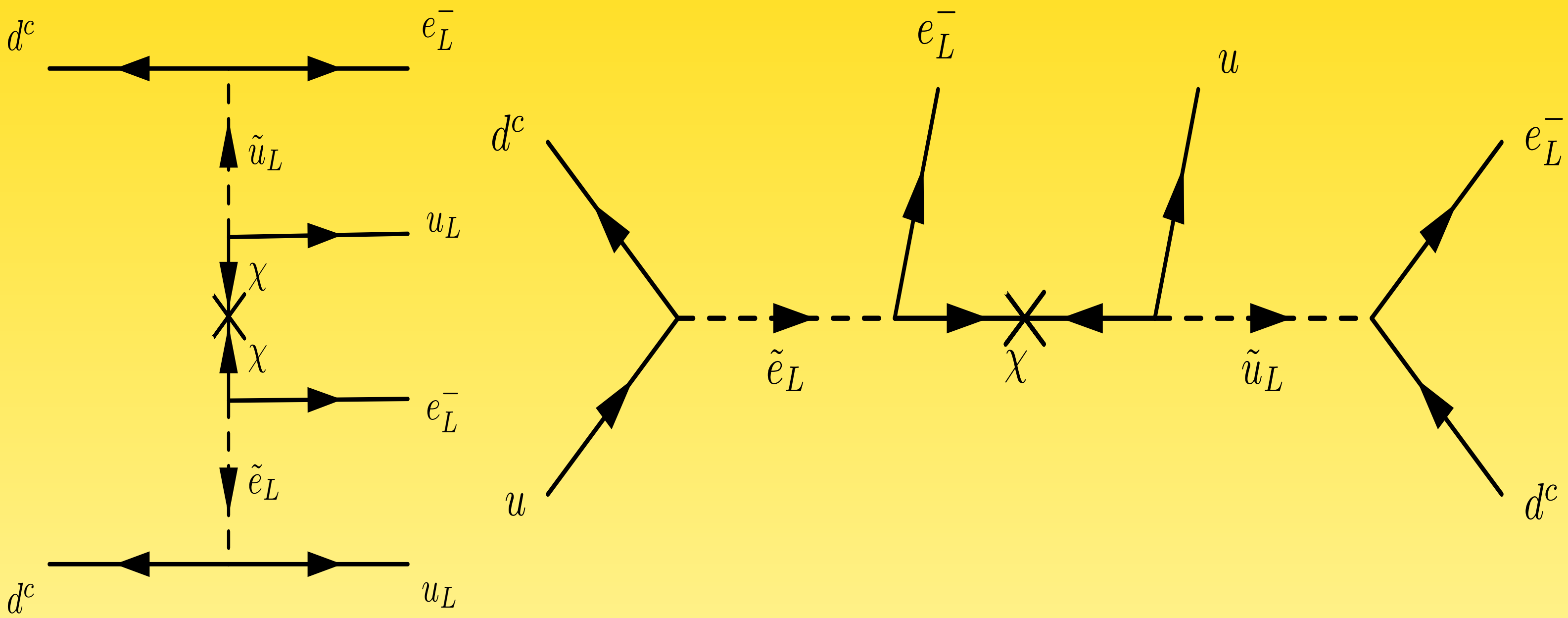
Supersymmetry: short range



$$\mathcal{A}_{\not R_1} \simeq \frac{\lambda'^2_{111}}{\Lambda^5_{\mathrm{SUSY}}}$$

Supersymmetry: short range

interplay with LHC:

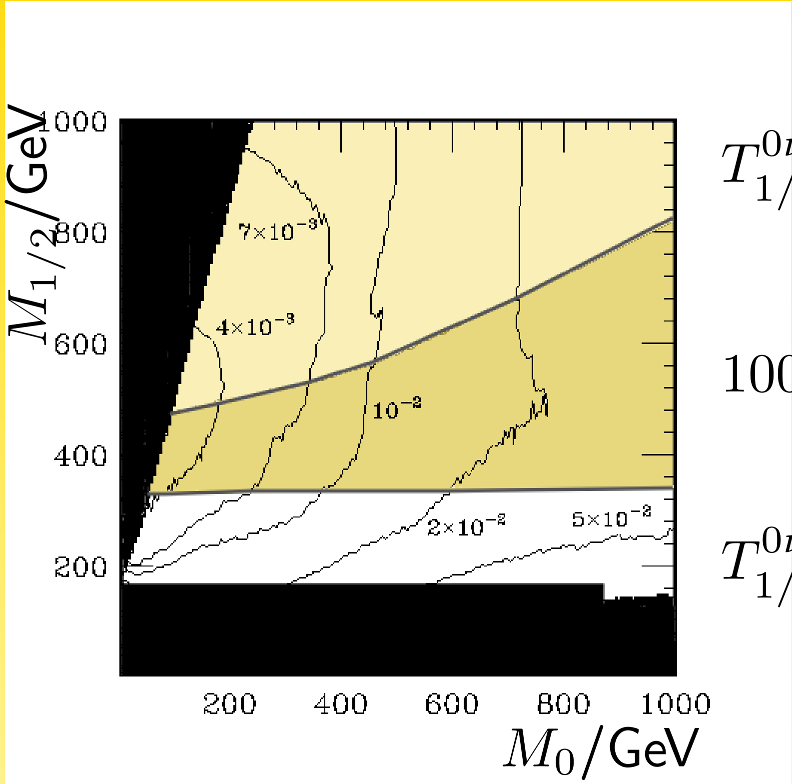


"resonant selectron production"

$$\hat{\sigma} \propto \frac{\lambda'^2_{111}}{\hat{s}}$$

Allanach, Kom, Paes, 0903.0347

$\tan\beta = 10,\ A_0 = 0,\ 10\ \mathrm{fb}^{-1}$



$T_{1/2}^{0\nu\beta\beta}(\mathrm{Ge}) > 1 \times 10^{27}$ yrs

$100 > T_{1/2}^{0\nu\beta\beta}(\mathrm{Ge})/10^{25}$ yrs > 1.9

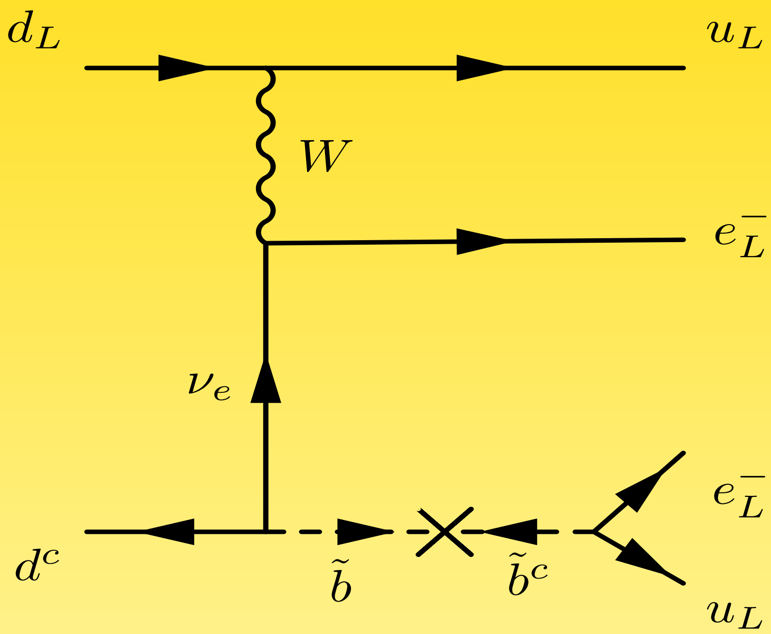
$T_{1/2}^{0\nu\beta\beta}(\mathrm{Ge}) < 1.9 \times 10^{25}$ yrs

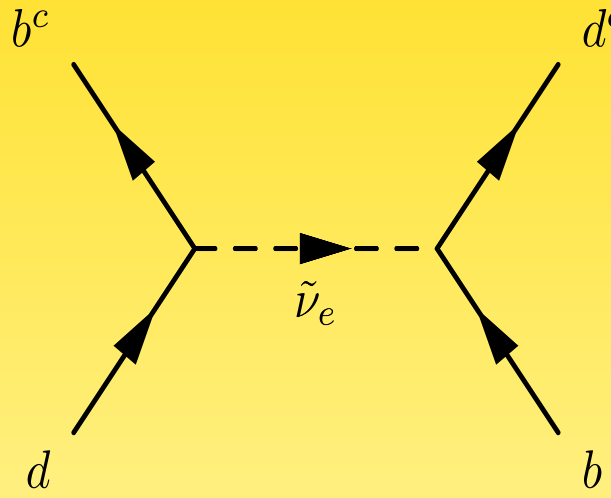
$\longrightarrow$ observation in white region in conflict with $0\nu\beta\beta$

$\longrightarrow$ if $0\nu\beta\beta$ observed: dark yellow region tests $\not R$ SUSY mechanism

$\longrightarrow$ light yellow region: no significant $\not R$ contribution to $0\nu\beta\beta$

Supersymmetry: long range





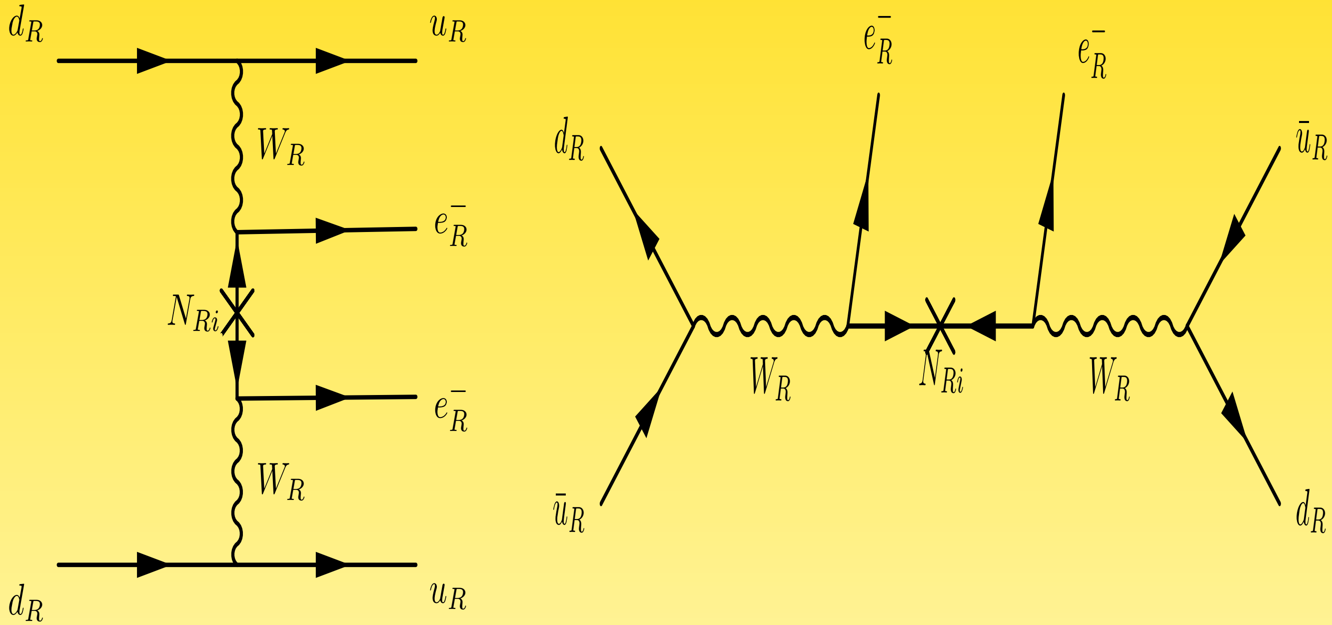
$$\mathcal{A}^b_{\not R_2} \simeq G_F \, \frac{1}{q} \, U_{ei} \, m_b \, \frac{\lambda'_{131} \, \lambda'_{113}}{\Lambda^3_{\rm SUSY}}$$

$0\nu\beta\beta$

$$\frac{\lambda'_{131} \, \lambda'_{113}}{\Lambda^2_{\rm SUSY}}$$

B^0-$\bar{B}^0$ mixing

Left-right symmetry

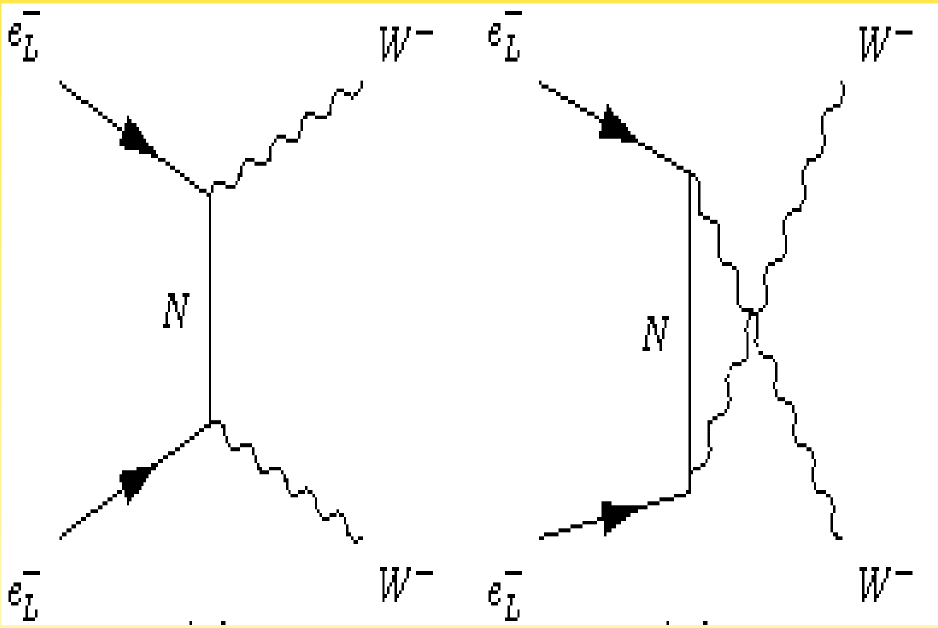


Tello *et al.*, 1011.3522

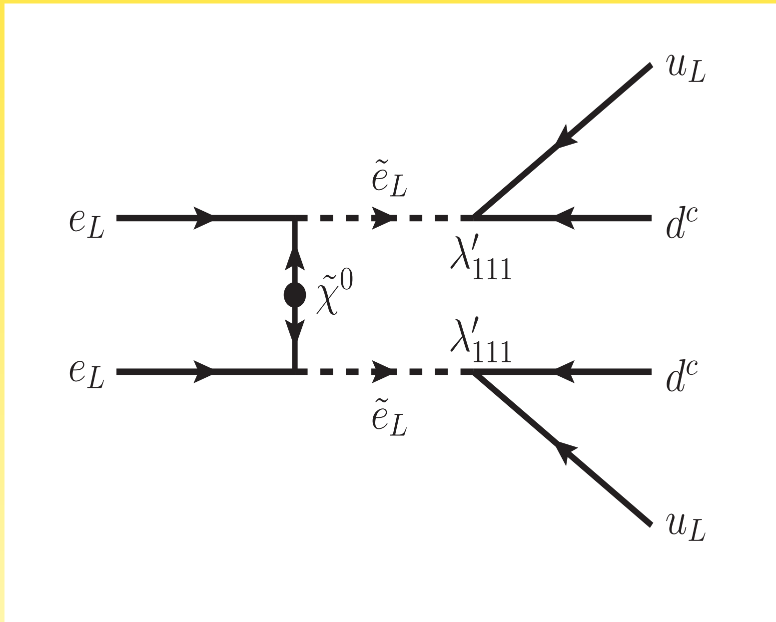
Cleanest probe of $0\nu\beta\beta$

Linear collider in like-sign mode

$$e^- e^- \longrightarrow 4 \text{ jets}$$

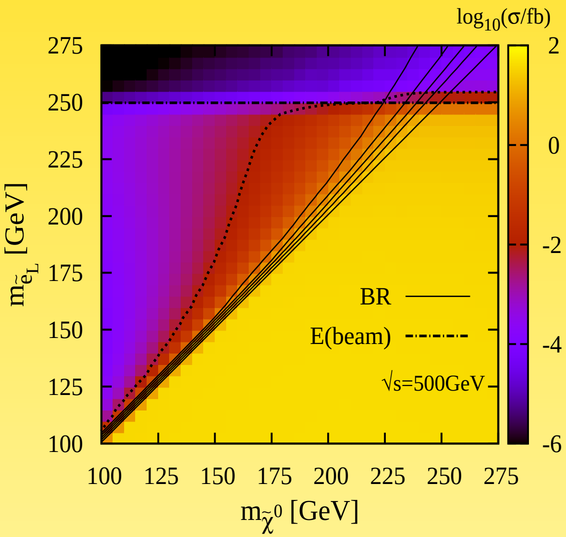


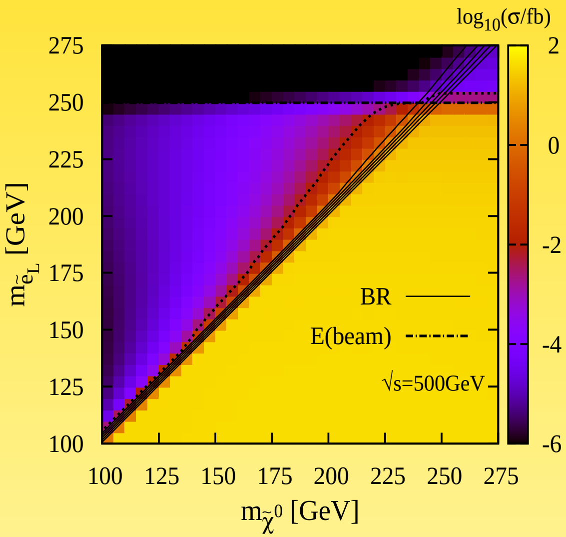
inverse $0\nu\beta\beta$



resonant selectron production

Cleanest probe of $0\nu\beta\beta$

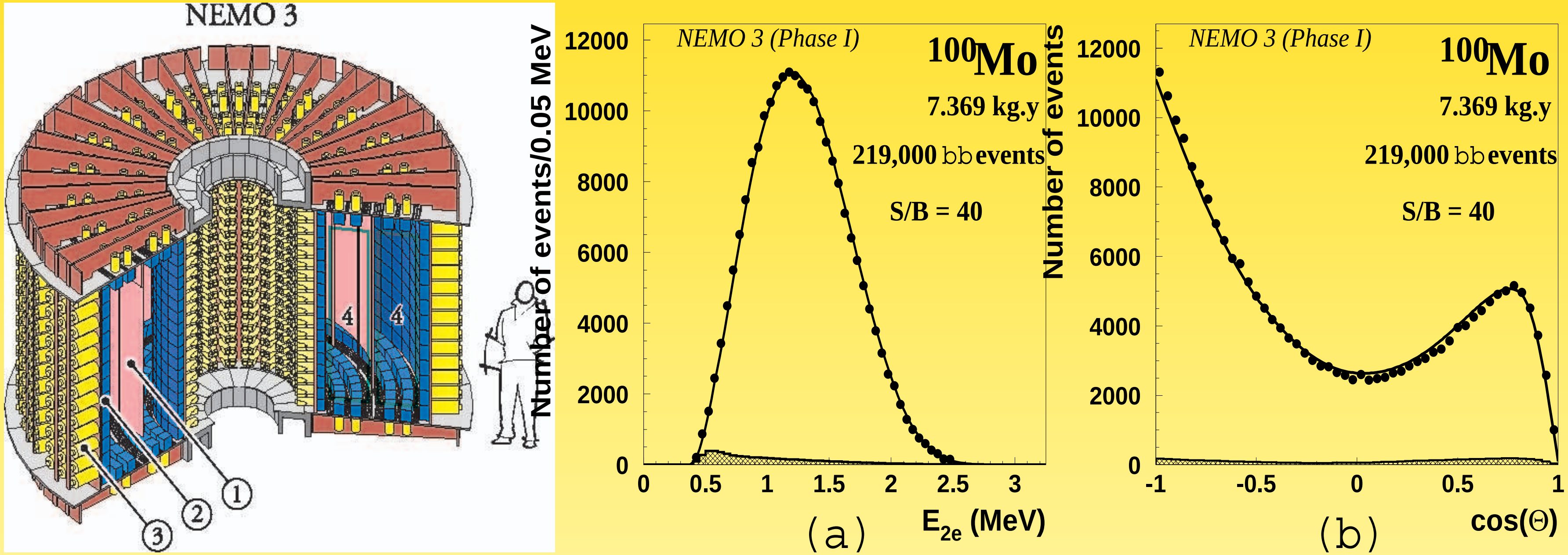




Kom, W.R., 1110.3220

2.) Distinguishing via decay products

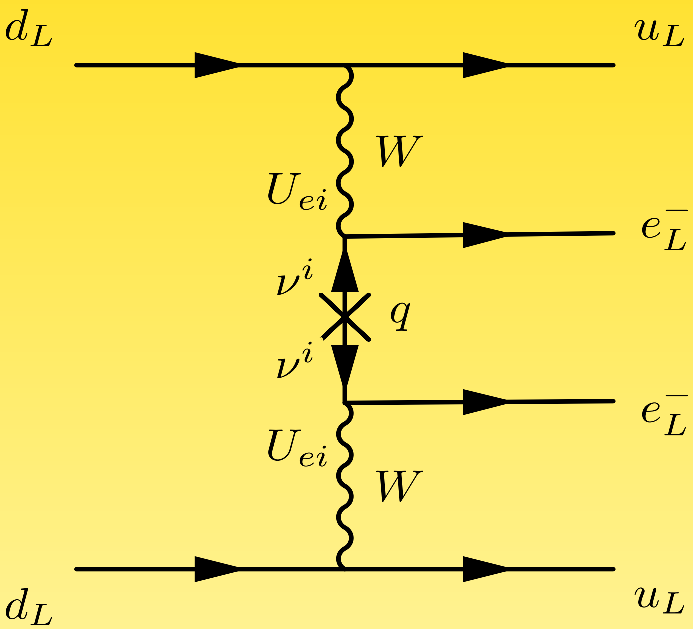
SuperNEMO

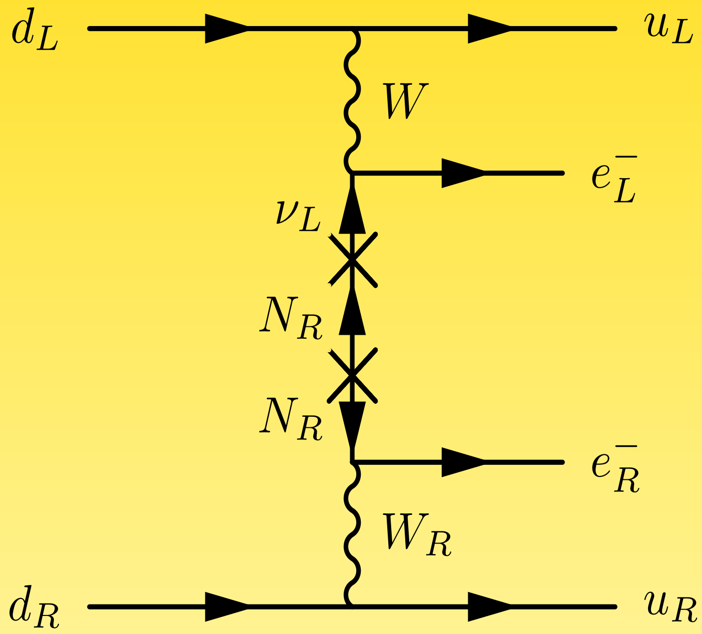


- source foils in between plastic scintillators
- individual electron energy, and their relative angle!

Distinguishing via decay products

Consider standard plus λ-mechanism





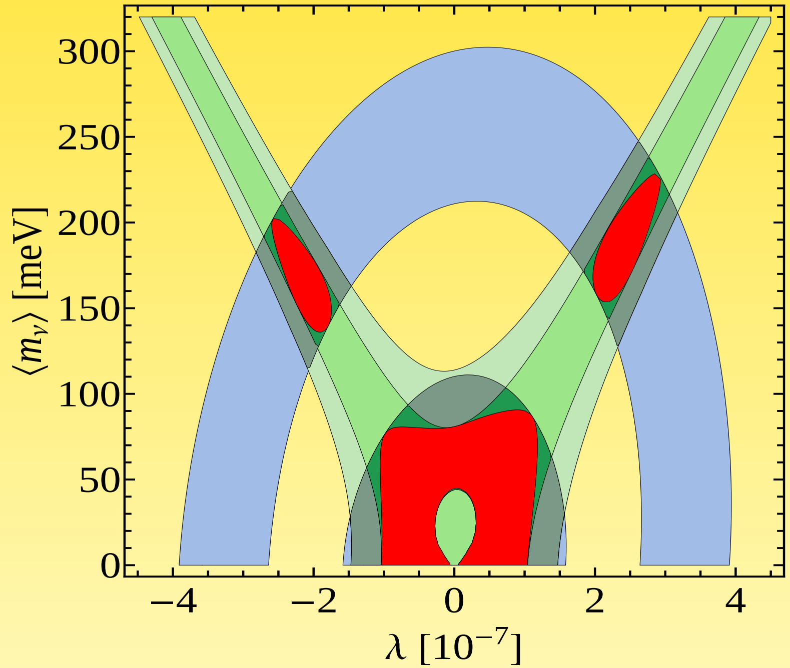
$$\frac{d\Gamma}{dE_1\, dE_2\, d\cos\theta} \propto (1 - \beta_1\, \beta_2\, \cos\theta) \qquad \frac{d\Gamma}{dE_1\, dE_2\, d\cos\theta} \propto (E_1 - E_2)^2\, (1 + \beta_1\, \beta_2\, \cos\theta)$$

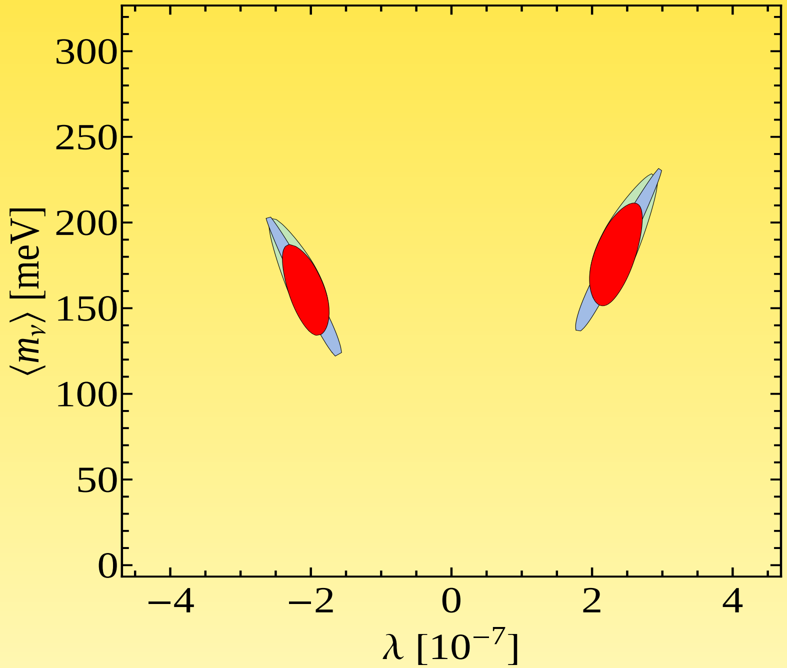
Arnold *et al.*, 1005.1241

Distinguishing via decay products

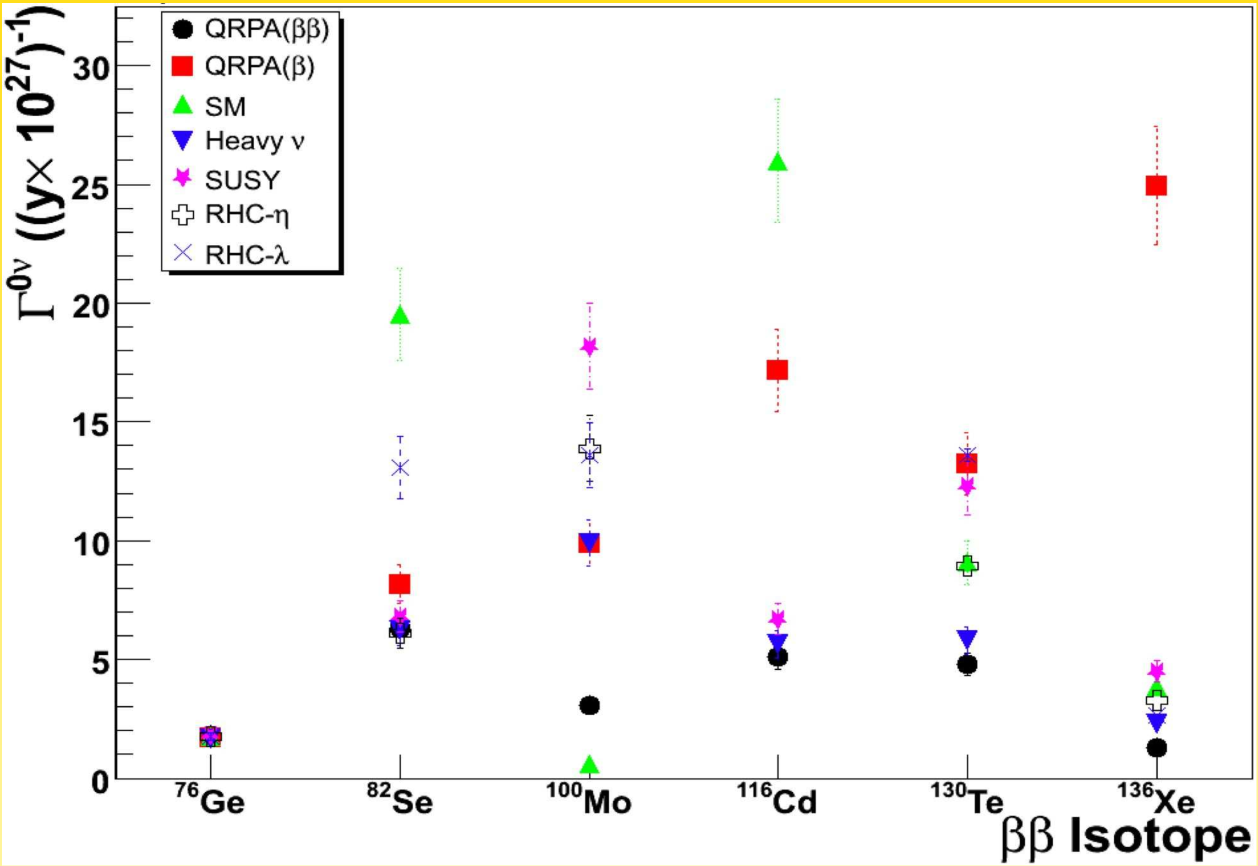
Defining asymmetries

$A_\theta = (N_+ - N_-)/(N_+ + N_-)$ and $A_E = (N_> - N_<)/(N_> + N_<)$





3.) Distinguishing via nuclear physics



Gehman, Elliott, hep-ph/0701099

3 to 4 isotopes necessary to disentangle mechanism

Summary

Chi l'ha visto?

Ettore Majorana, ordinario di fisica teorica all'Università di Napoli, è misteriosamente scomparso dagli ultimi di marzo. Di anni 31, alto metri 1,70, snello, con capelli neri, occhi scuri, una lunga cicatrice sul dorso di una mano. Chi ne sapesse qualcosa è pregato di scrivere al R. P. E. Marianecci, Viale Regina Margherita 66 - Roma.