Neutrinoless double beta decay phenomenology

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Based on the works JHEP 06 (2023) 104,JHEP 08 (2024) 217

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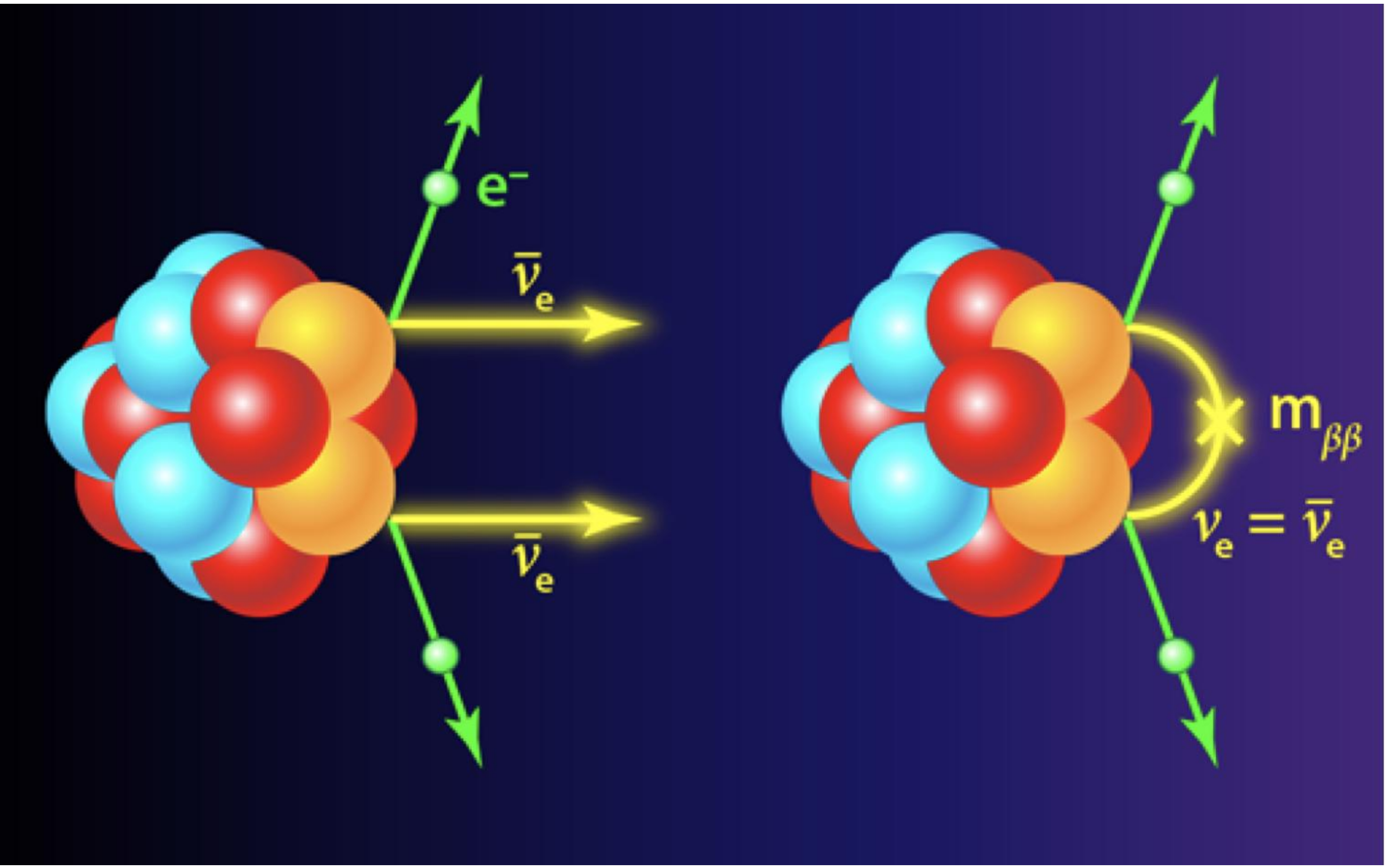
BLV2024, KIT

Outline

- **Brief background**
- **Neutrinoless double data decay (0νββ) in light neutrino exchange mechanism**

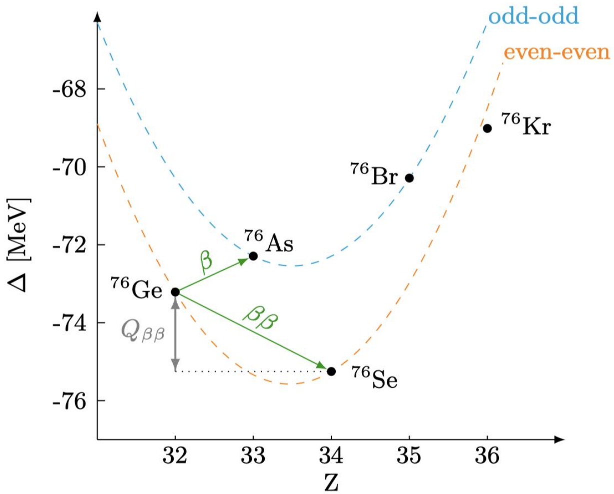
  Different upper limits of $m_{\beta\beta}$ due to NME uncertainties
- **0νββ process in minimal Type-I seesaw**

  Constraints of minimal Type-I seesaw from current and future 0νββ experiments
- **Summary**



Where are you?

Brief background



$$(A, Z) \to (A, Z+2) + 2e^- + 2\overline{\nu}_e$$

Mayer, 1935; first detected in 1987 by Moe

$\nu_i^c = \nu_i$ Majorana, 1937

$$(A, Z) \longrightarrow (A, Z+2) + 2e^-$$

Furry, 1939

Isotope	Daughter	$Q_{\beta\beta}$ (keV)[a]	f_{nat} (%)[b]	f_{enr} (%)[c]	$T_{1/2}^{2\nu\beta\beta}$ (yr)[d]	$T_{1/2}^{0\nu\beta\beta}$ (yr)[e]
^{48}Ca	^{48}Ti	4267.98(32)	30.187(21)	16	$[6.4^{+0.7}_{-0.6}(\text{stat})^{+1.2}_{-0.9}(\text{syst})] \times 10^{19}$	$> 5.8 \times 10^{22}$
^{76}Ge	^{76}Se	2039.061(7)	37.75(12)	92	$(1.926 \pm 94) \times 10^{21}$	$> 1.8 \times 10^{26}$
^{82}Se	^{82}Kr	2997.9(3)	38.82(15)	96.3	$[8.60 \pm 0.03(\text{stat})^{+0.19}_{-0.13}(\text{syst})] \times 10^{19}$	$> 3.5 \times 10^{24}$
^{96}Zr	^{96}Mo	3356.097(86)	32.80(2)	86	$[2.35 \pm 0.14(\text{stat}) \pm 0.16(\text{syst})] \times 10^{19}$	$> 9.2 \times 10^{21}$
^{100}Mo	^{100}Ru	3034.40(17)	39.744(65)	99.5	$[7.12^{+0.18}_{-0.14}(\text{stat}) \pm 0.10(\text{syst})] \times 10^{18}$	$> 1.5 \times 10^{24}$
^{116}Cd	^{116}Sn	2813.50(13)	37.512(54)	82	$2.63^{+0.11}_{-0.12} \times 10^{19}$	$> 2.2 \times 10^{23}$
^{130}Te	^{130}Xe	2527.518(13)	34.08(62)	92	$[7.71^{+0.08}_{-0.06}(\text{stat})^{+0.12}_{0.15}(\text{syst})] \times 10^{20}$	$> 2.2 \times 10^{25}$
^{136}Xe	^{136}Ba	2457.83(37)	38.857(72)	90	$[2.165 \pm 0.016(\text{stat}) \pm 0.059(\text{syst})] \times 10^{21}$	$> 1.1 \times 10^{26}$
^{150}Nd	^{150}Sm	3371.38(20)	35.638(28)	91	$[9.34 \pm 0.22(\text{stat})^{+0.62}_{-0.60}(\text{syst})] \times 10^{18}$	$> 2.0 \times 10^{22}$

10^{18} yr – 10^{21} yr

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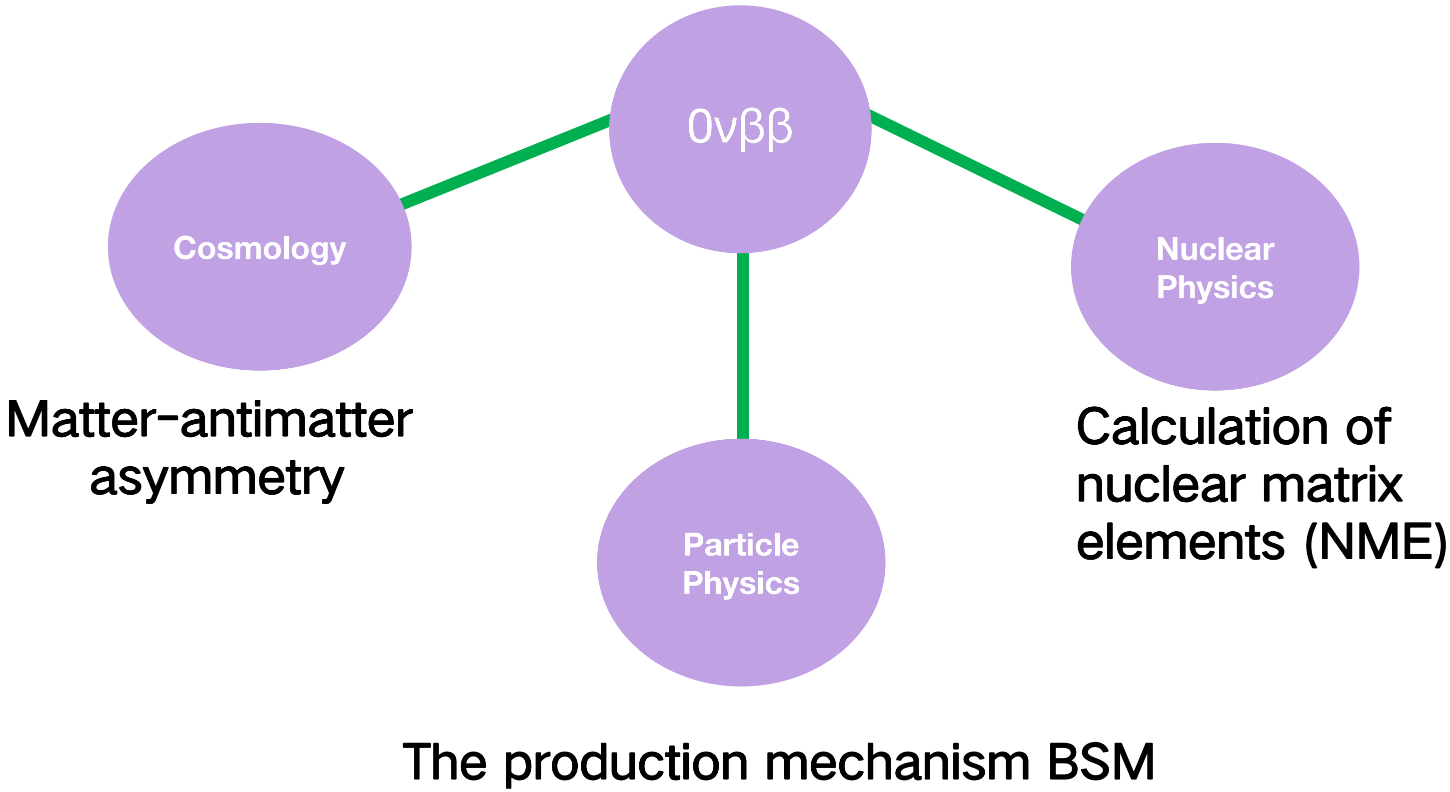
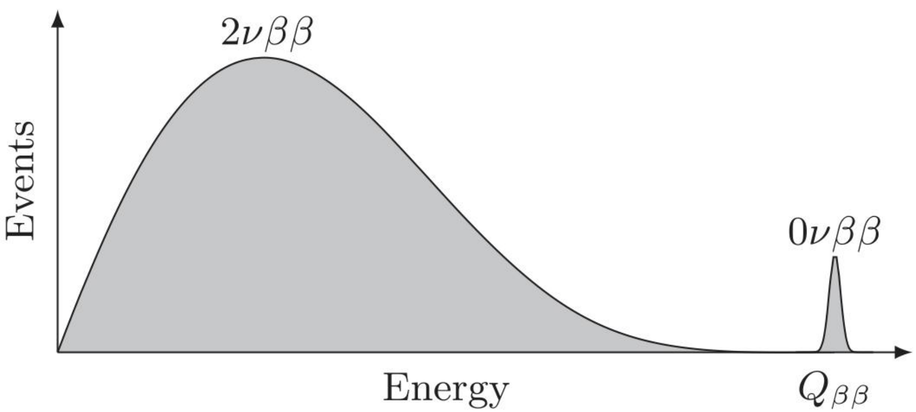
Big picture

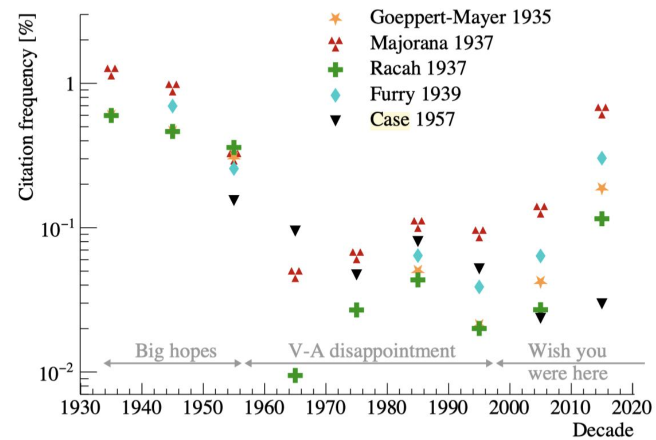


Experiments:

- Find compromises between nature abundance, Q-value, priced enrichment and detector techniques
- Key parameter: background, exposure, energy resolution

Brief background





PHYSICAL REVIEW LETTERS 130, 051801 (2023)

Editors' Suggestion | Featured in Physics

^{136}Xe>10^{26} yr

Search for the Majorana Nature of Neutrinos in the Inverted Mass Ordering Region with KamLAND-Zen

S. Abe,[1] S. Asami,[1] M. Eizuka,[1] S. Futagi,[1] A. Gando,[1] Y. Gando,[1] T. Gima,[1] A. Goto,[1] T. Hachiya,[1] K. Hata,[1]

Article

Search for Majorana neutrinos exploiting millikelvin cryogenics with CUORE

^{130}Te>10^{26} yr

https://doi.org/10.1038/s41586-022-04497-4 The CUORE Collaboration*

Received: 14 April 2021

PHYSICAL REVIEW LETTERS 125, 252502 (2020)

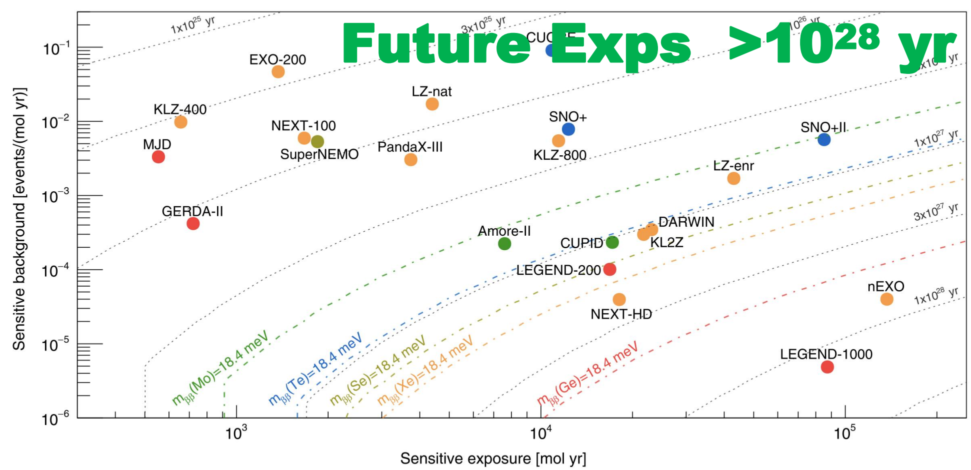
Editors' Suggestion | Featured in Physics

^{76}Ge>10^{26} yr

Final Results of GERDA on the Search for Neutrinoless Double-β Decay

M. Agostini,[9,17] G. R. Araujo,[21] A. M. Bakalyarov,[15] M. Balata,[1] I. Barabanov,[13] L. Baudis,[21] C. Bauer,[8] E. Bellotti,[10,11] S. Belogurov,[14,13,†] A. Bettini,[18,19] L. Bezrukov,[13] V. Biancacci,[18,19] D. Borowicz,[6] E. Bossio,[17] V. Bothe,[8] V. Brudanin,[6]

Future Exps >10^{28} yr



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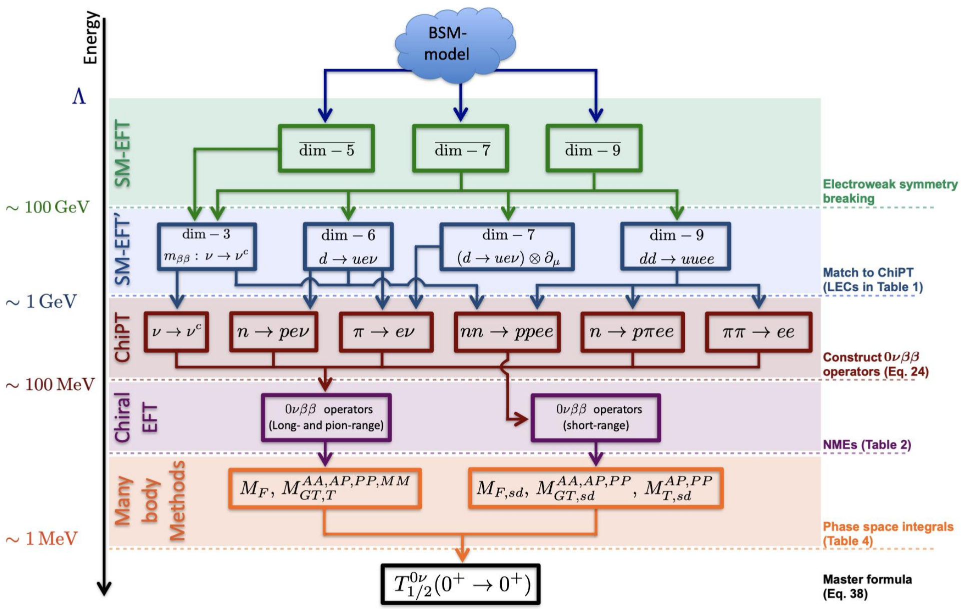
A general theoretical framework



Cirigliano et al., JHEP 2018

Naive Dimensional Analysis(NDA) problem

D. B. Kaplan, M. J. Savage, and M. B. Wise, Nucl. Phys. **B478**, 629 (1996).

S. R. Beane, P. F. Bedaque, M. J. Savage, and U. van Kolck, Nucl. Phys. **A700**, 377 (2002).

A. Nogga, R. G. E. Timmermans, and U. van Kolck, Phys. Rev. C **72**, 054006 (2005).

B. Long and C.-J. Yang, Phys. Rev. C **86**, 024001 (2012).

M. Pavón Valderrama and D. R. Phillips, Phys. Rev. Lett. **114**, 082502 (2015).

and $F_\pi = 92.2$ MeV is the pion decay constant. However, it is known that Weinberg's power counting leads to inconsistent results in nucleon-nucleon scattering [34–37] and nuclear processes mediated by external currents [38], due to a conflict between naive dimensional analysis and nonperturbative renormalization. We therefore investigate the scaling of $g_\nu^{\rm NN}$ by studying the amplitude $\mathcal{A}(nn \to ppee) \equiv \mathcal{A}_{\Delta L=2}$ with strong interactions $H_{\rm strong}$ included nonperturbatively.

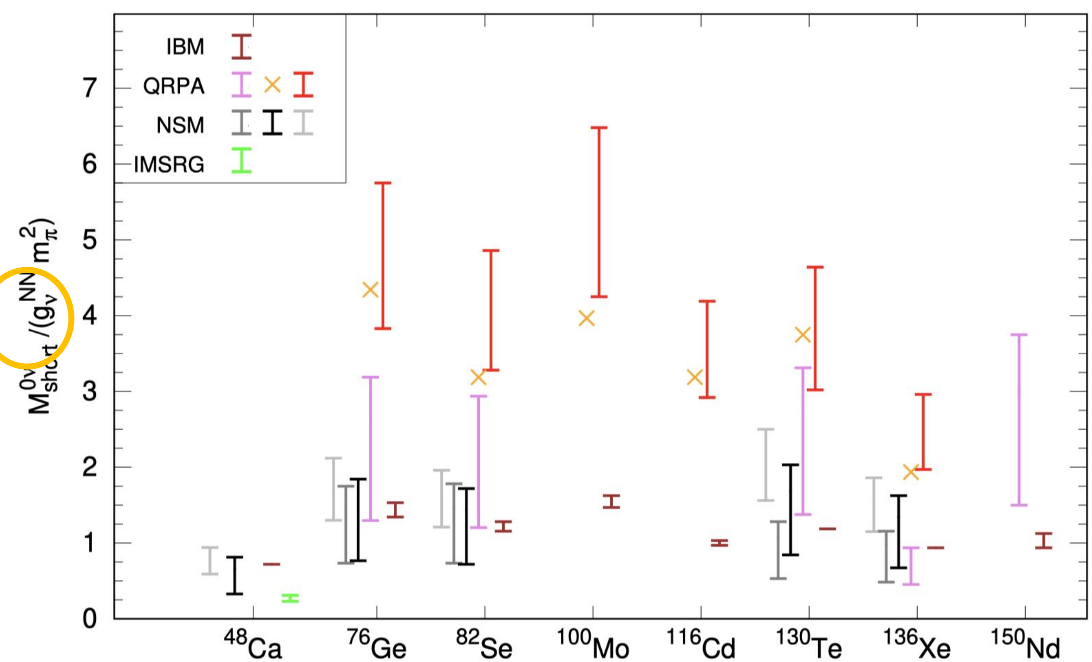
Cirigliano et al , Phys.Rev.Lett. 120 (2018) 20, 202001

Short-range NME

$$n_{\alpha i} = \frac{M_{\alpha i}^{\text{short}}}{M_{\alpha i}^{\text{long}}}$$

Isotope	NSM %	QRPA %
^{76}Ge	15–42	32–73
^{82}Se	15–41	30–70
^{100}Mo	-	49–108
^{130}Te	17–47	34–77
^{136}Xe	17–47	30–70

Phys. Lett. B 823 (2021) 136720



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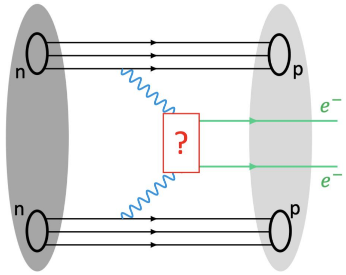
Recent discussion: arXiv:2405.10503

Theoretical mechanism→which one dominates?

mechanism	amplitude and particle physics parameter	current limit	test
light neutrino exchange	$\frac{G_F^2}{q^2}\left\|U_{ei}^2\, m_i\right\|$	0.5 eV	oscillations, cosmology, neutrino mass
heavy neutrino exchange	$G_F^2 \left\|\frac{S_{ei}^2}{M_i}\right\|$	2×10^{-8} GeV^{-1}	LFV, collider
heavy neutrino and RHC	$G_F^2\, m_W^4 \left\|\frac{V_{ei}^2}{M_i\, M_{W_R}^4}\right\|$	4×10^{-16} GeV^{-5}	flavor, collider
Higgs triplet and RHC	$G_F^2\, m_W^4 \left\|\frac{(M_R)_{ee}}{m_{\Delta_R}^2\, M_{W_R}^4}\right\|$	10^{-15} GeV^{-1}	flavor, collider e^- distribution
λ-mechanism with RHC	$G_F^2\,\frac{m_W^2}{q}\left\|\frac{U_{ei}\,\tilde{S}_{ei}}{M_{W_R}^2}\right\|$	1.4×10^{-10} GeV^{-2}	flavor, collider, e^- distribution
η-mechanism with RHC	$G_F^2\,\frac{1}{q}\,\tan\zeta\,\left\|U_{ei}\,\tilde{S}_{ei}\right\|$	6×10^{-9}	flavor, collider, e^- distribution
short-range $\not{R}$	$\frac{\left\|\lambda'^2_{111}\right\|}{\Lambda^5_{\rm SUSY}}$ $\Lambda_{\rm SUSY}=f(m_{\tilde g}, m_{\tilde u_L}, m_{\tilde d_R}, m_{\chi_i})$	7×10^{-18} GeV^{-5}	collider, flavor
long-range $\not{R}$	$\frac{G_F}{q}\left\|\sin 2\theta^b\,\lambda'_{131}\,\lambda'_{113}\left(\frac{1}{m^2_{\tilde b_1}}-\frac{1}{m^2_{\tilde b_2}}\right)\right\|$ $\sim \frac{G_F}{q}\, m_b\,\frac{\left\|\lambda'_{131}\,\lambda'_{113}\right\|}{\Lambda^3_{\rm SUSY}}$	2×10^{-13} GeV^{-2} 1×10^{-14} GeV^{-3}	flavor, collider
Majorons	$\propto \left\|\langle g_\chi\rangle\right\|$ or $\left\|\langle g_\chi\rangle\right\|^2$	$10^{-4}\ldots1$	spectrum, cosmology

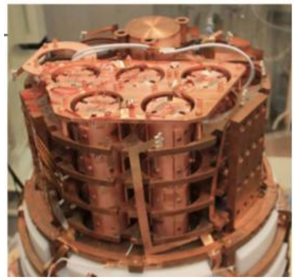


Rodejohann, Int.J.Mod.Phys.E 20 (2011)

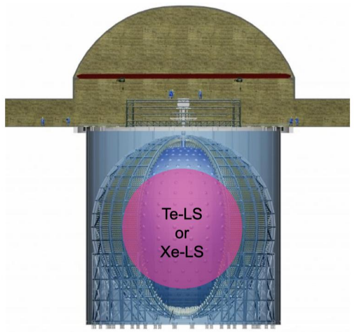
Phase factor + nuclear matrix element **?** + new physics parameter **?** (effective neutrino mass)

Experimental techniques

CUPID-Mo

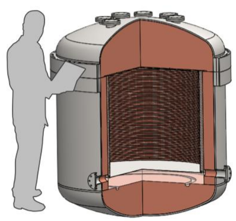


JUNO



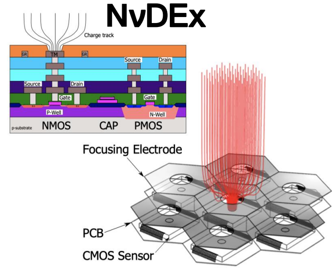
CANDLE CaF scintillating crystal

PandaX-4T LXe TPC



PandaX-III GXe TPC

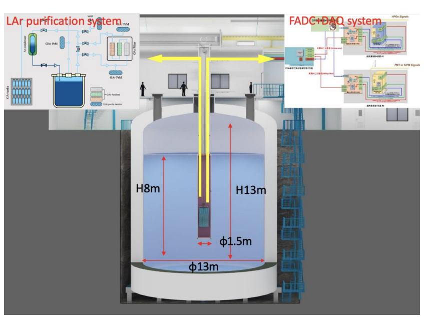
NvDEx



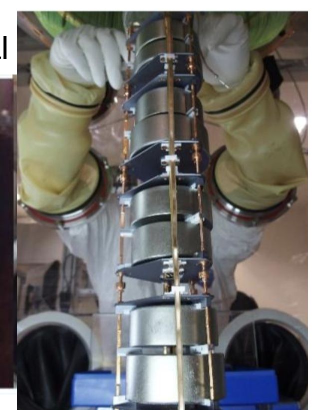
Topmetal CMOS Technology

EXO, KamLAND-Zen Liquid Xe

CDEX

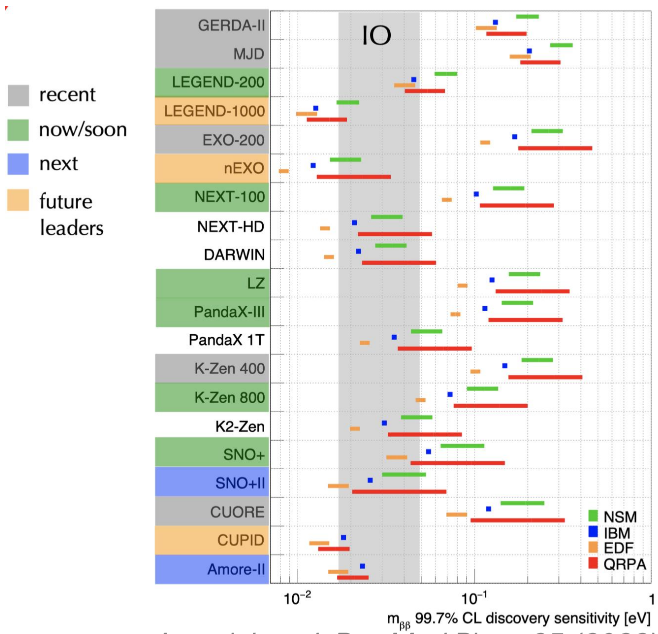


GERDA, MAJORANA Ge crystal



etc.

NME → $m_{\beta\beta}$



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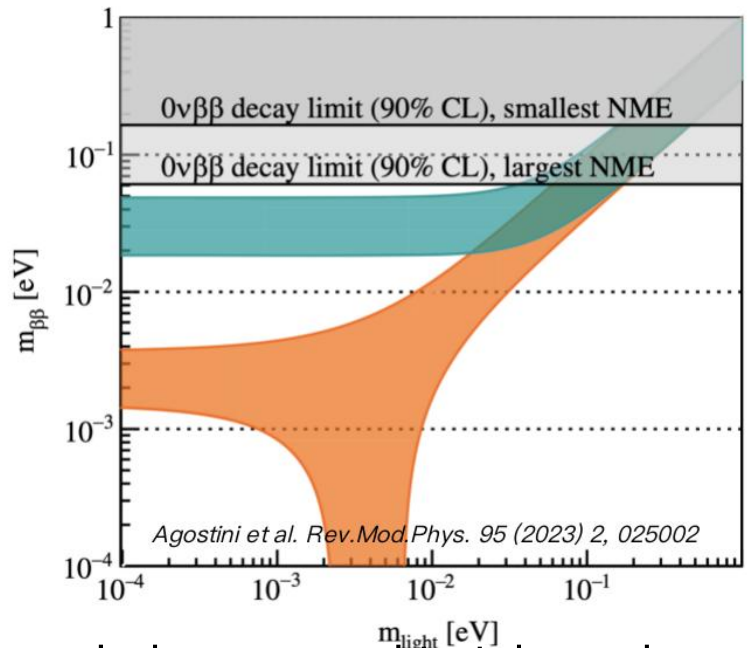

New techniques and more exposure are being pursued to take us beyond the IO. Discovery could come at any time!

Motivations: *Schwetz, Popma, Zhu, JHEP 06 (2023) 104*

- **Interpreting the constraints/sensitivities on $m_{\beta\beta}$ of current/future 0νββ experiments**
- **Checking the possibilities of discriminating NME models in future 0νββ experiments**

Formula (light neutrino exchange mechanism)

$$(T_{1/2}^{-1})_\alpha = \widetilde{\Gamma}_\alpha(m_{\beta\beta}, M_{\alpha i}) = \frac{\Gamma_\alpha(m_{\beta\beta}, M_{\alpha i})}{\ln 2} = G_\alpha \, |M_{\alpha i}|^2 \, m_{\beta\beta}^2$$

$$m_{\beta\beta} = \left| \sum_j U_{ej}^2 m_j \right|$$

$$M_{\alpha i} = M_{\alpha i}^{\text{long}} + M_{\alpha i}^{\text{short}} = M_{\alpha i}^{\text{long}}(1 + n_{\alpha i}) \qquad n_{\alpha i} = \frac{M_{\alpha i}^{\text{short}}}{M_{\alpha i}^{\text{long}}}$$

$$g_A^{\text{eff}} = q \, g_A^{\text{free}} \qquad g_A^{\text{free}} = 1.27$$

- **Quenching effect: correct the NME by q^2 and the decay rate by q^4**
  (Ab initio many- body theory**)**

- Short- range NME: Contact operator suggested to contribute to light- neutrino exchange, *Cirigliano et al. PRL2018*
- We do not know neither the value or the sign of short- range NME well.
- Unknown value of the hadronic coupling g_ν^{NN}, to be determined experimentally or Lattice QCD calculations

Long-range NME

Nuclear Model	Index [Ref.]	^{76}Ge	^{82}Se	^{100}Mo	^{130}Te	^{136}Xe
NSM	N1 [25]	2.89	2.73	-	2.76	2.28
	N2 [25]	3.07	2.90	-	2.96	2.45
	N3 [26]	3.37	3.19	-	1.79	1.63
	N4 [26]	3.57	3.39	-	1.93	1.76
	N5 [27, 28]	2.66	2.72	2.24	3.16	2.39
QRPA	Q1 [29]	5.09	-	-	1.37	1.55
	Q2 [30]	5.26	3.73	3.90	4.00	2.91
	Q3 [31]	4.85	4.61	5.87	4.67	2.72
	Q4 [32]	3.12	2.86	-	2.90	1.11
	Q5 [32]	3.40	3.13	-	3.22	1.18
	Q6 [33]	-	-	-	4.05	3.38
EDF	E1 [34]	4.60	4.22	5.08	5.13	4.20
	E2 [35]	5.55	4.67	6.59	6.41	4.77
	E3 [36]	6.04	5.30	6.48	4.89	4.24
IBM	I1 [37]	5.14	4.19	3.84	3.96	3.25
	I2 [13]	6.34	5.21	5.08	4.15	3.40

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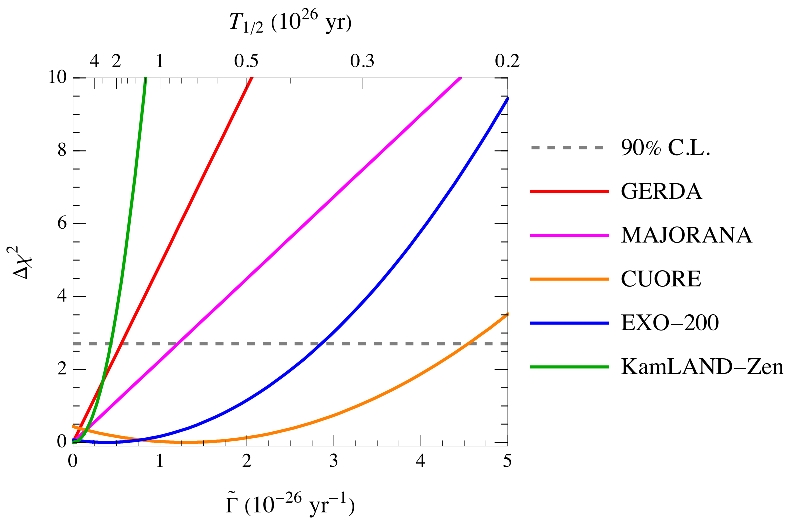
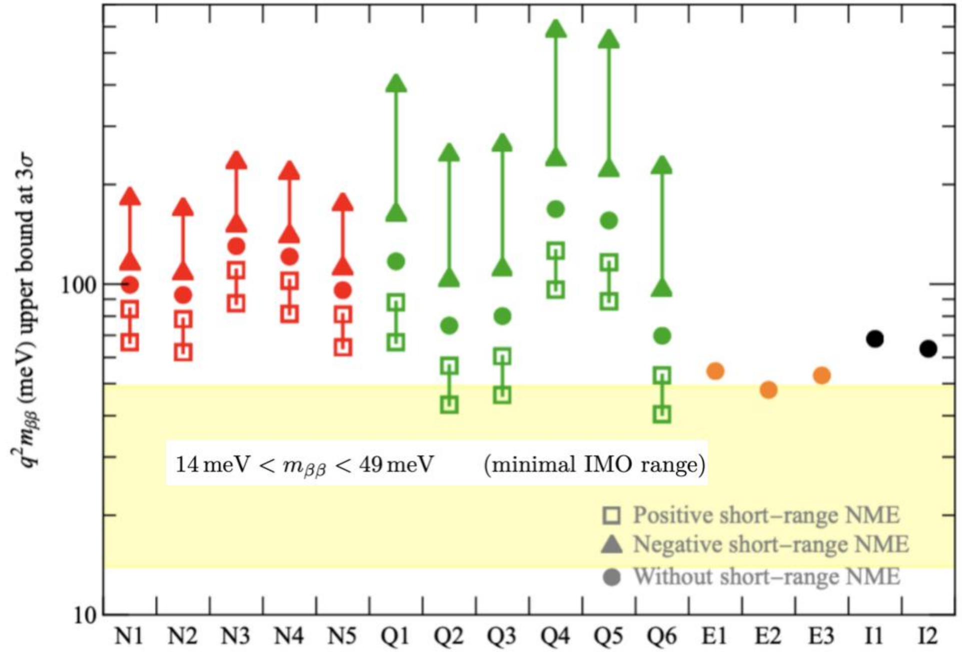
Current constraints

$$\Delta\chi_r^2(\widetilde{\Gamma}_\alpha) = a_r\,(\widetilde{\Gamma}_\alpha)^2 + b_r\,\widetilde{\Gamma}_\alpha + c_r$$





Sensitivities to $(q^2 m_{\beta\beta})^{True}$ at 3σ

Experiment	Isotope	ε [mol·yr]	b [events/(mol·y)]	PSF [yr^{-1} eV^{-2}]
LEGEND-1000	^{76}Ge	8736	$4.9 \cdot 10^{-6}$	$2.36 \cdot 10^{-26}$
SuperNEMO	^{82}Se	185	$5.4 \cdot 10^{-3}$	$10.19 \cdot 10^{-26}$
CUPID	^{100}Mo	1717	$2.3 \cdot 10^{-4}$	$15.91 \cdot 10^{-26}$
SNO+II	^{130}Te	8521	$5.7 \cdot 10^{-3}$	$14.2 \cdot 10^{-26}$
nEXO	^{136}Xe	13700	$4.0 \cdot 10^{-5}$	$14.56 \cdot 10^{-26}$

$$N_{\text{LEGEND-1000}} = \left\{ 0.97 \times \left[\frac{(q^2 m_{\beta\beta})^{\text{True}}}{40\ \text{meV}} \right]^2 \left(\frac{M_{\text{Ge}}^{\text{long}}}{2.66} \right)^2 + 0.04 \right\} \times \frac{T}{1\ \text{yr}}$$

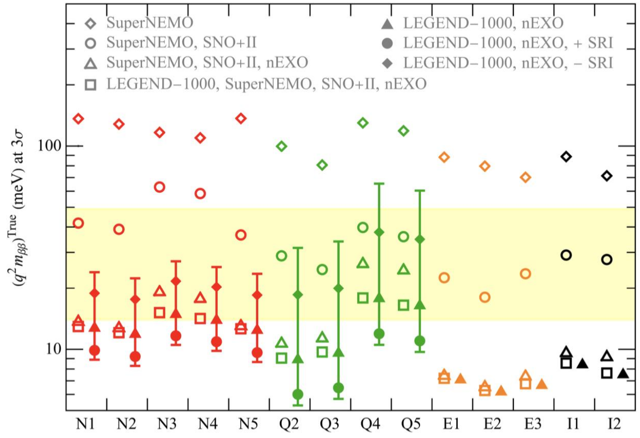
$$N_{\text{SuperNEMO}} = \left\{ 0.09 \times \left[\frac{(q^2 m_{\beta\beta})^{\text{True}}}{40\ \text{meV}} \right]^2 \left(\frac{M_{\text{Se}}^{\text{long}}}{2.72} \right)^2 + 1.0 \right\} \times \frac{T}{1\ \text{yr}}$$

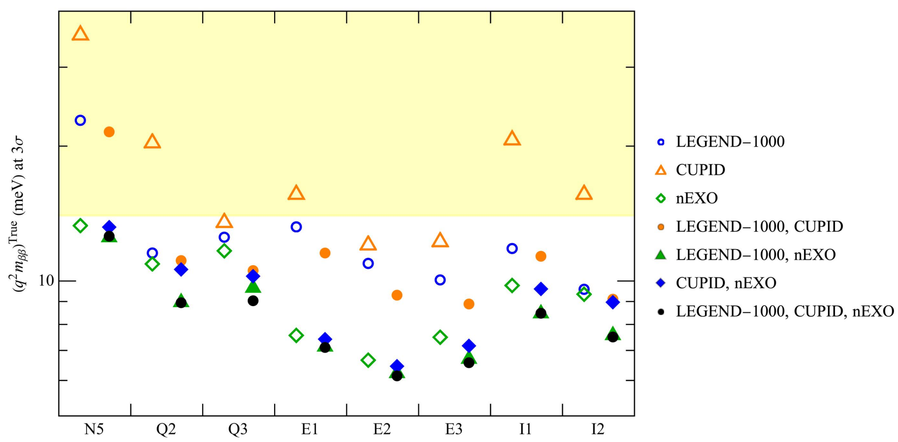
$$N_{\text{nEXO}} = \left\{ 1.64 \times \left[\frac{(q^2 m_{\beta\beta})^{\text{True}}}{40\ \text{meV}} \right]^2 \left(\frac{M_{\text{Xe}}^{\text{long}}}{1.11} \right)^2 + 0.5 \right\} \times \frac{T}{1\ \text{yr}}$$

$$N_{\alpha i} = S_{\alpha i} + B_\alpha \qquad B_\alpha = b_\alpha \cdot \varepsilon_\alpha \cdot \left(\frac{T}{1\ \text{yr}} \right)$$

$$S_{\alpha i}(m_{\beta\beta}, M_{\alpha i}) = \ln 2 \cdot N_A \cdot \varepsilon_\alpha \cdot \left(\frac{T}{1\ \text{yr}} \right) \cdot \widetilde{\Gamma}_\alpha(m_{\beta\beta}, M_{\alpha i})$$

$$\Delta\chi^2_{ij}(m_{\beta\beta}, M_{\alpha j}\,;\, m_{\beta\beta}^{\text{True}}, M_{\alpha i}^{\text{True}}) = 2 \sum_\alpha \left(N_{\alpha j} - N_{\alpha i}^{\text{True}} + N_{\alpha i}^{\text{True}} \ln \frac{N_{\alpha i}^{\text{True}}}{N_{\alpha j}} \right)$$

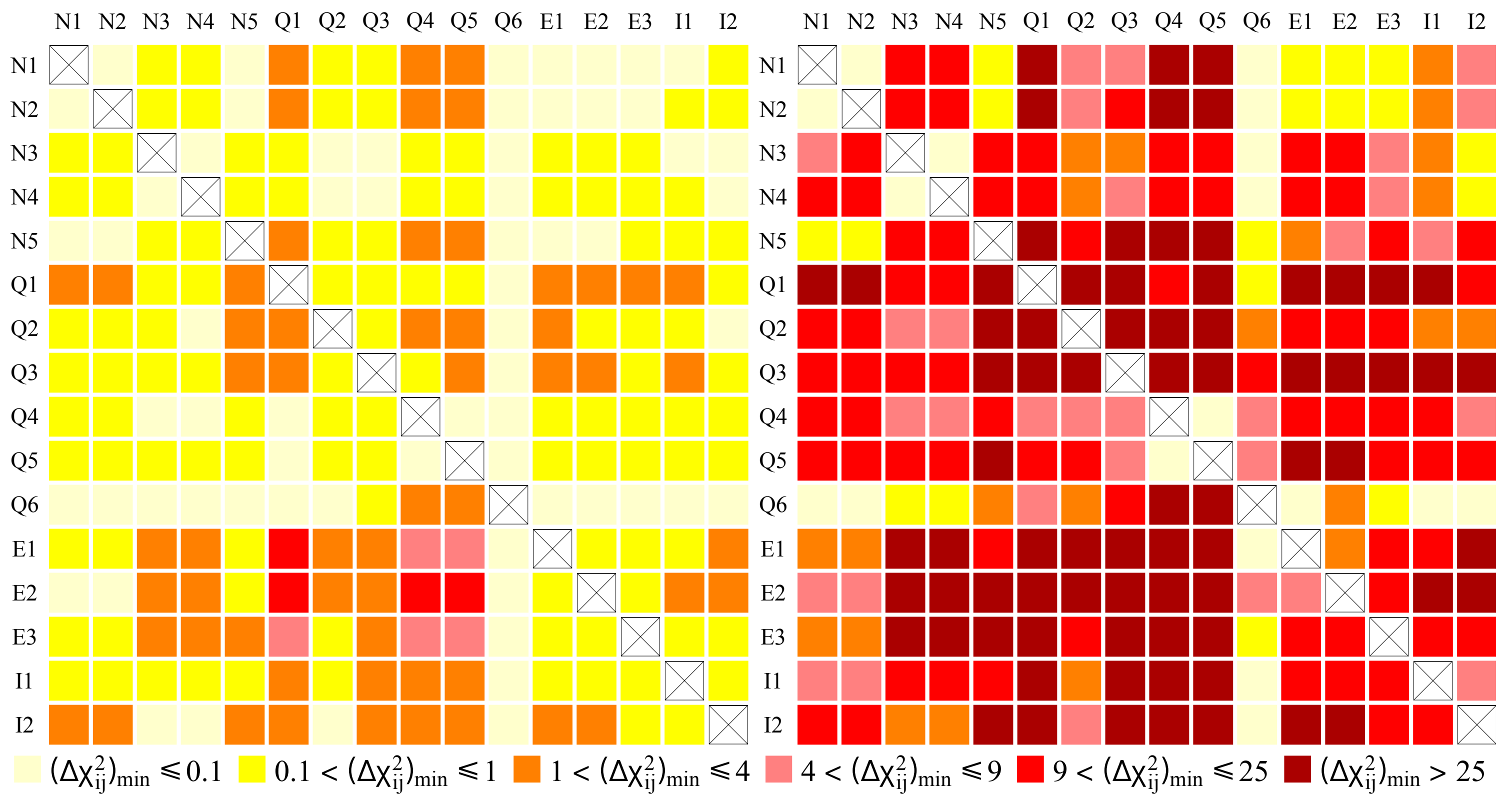




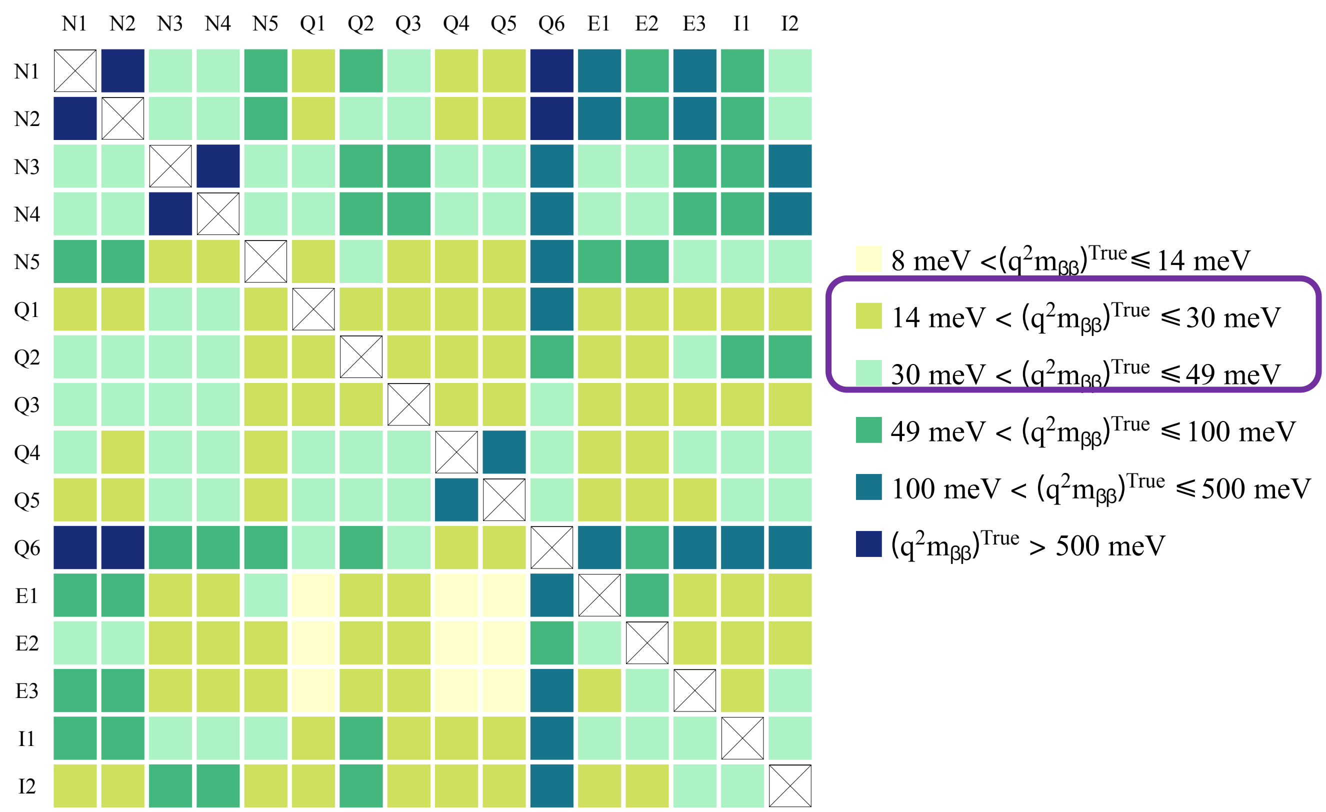
Discrimination without short-range NME

$$(\Delta\chi^2_{ij})_{\rm min} = \min_{m_{\beta\beta}} \Delta\chi^2_{ij}(m_{\beta\beta}, M_{\alpha j}\,;\,(q^2 m_{\beta\beta})^{\rm True}, M^{\rm True}_{\alpha i})$$

$(q^2 m_{\beta\beta})^{True}$=10 meV | $(q^2 m_{\beta\beta})^{True}$=40 meV

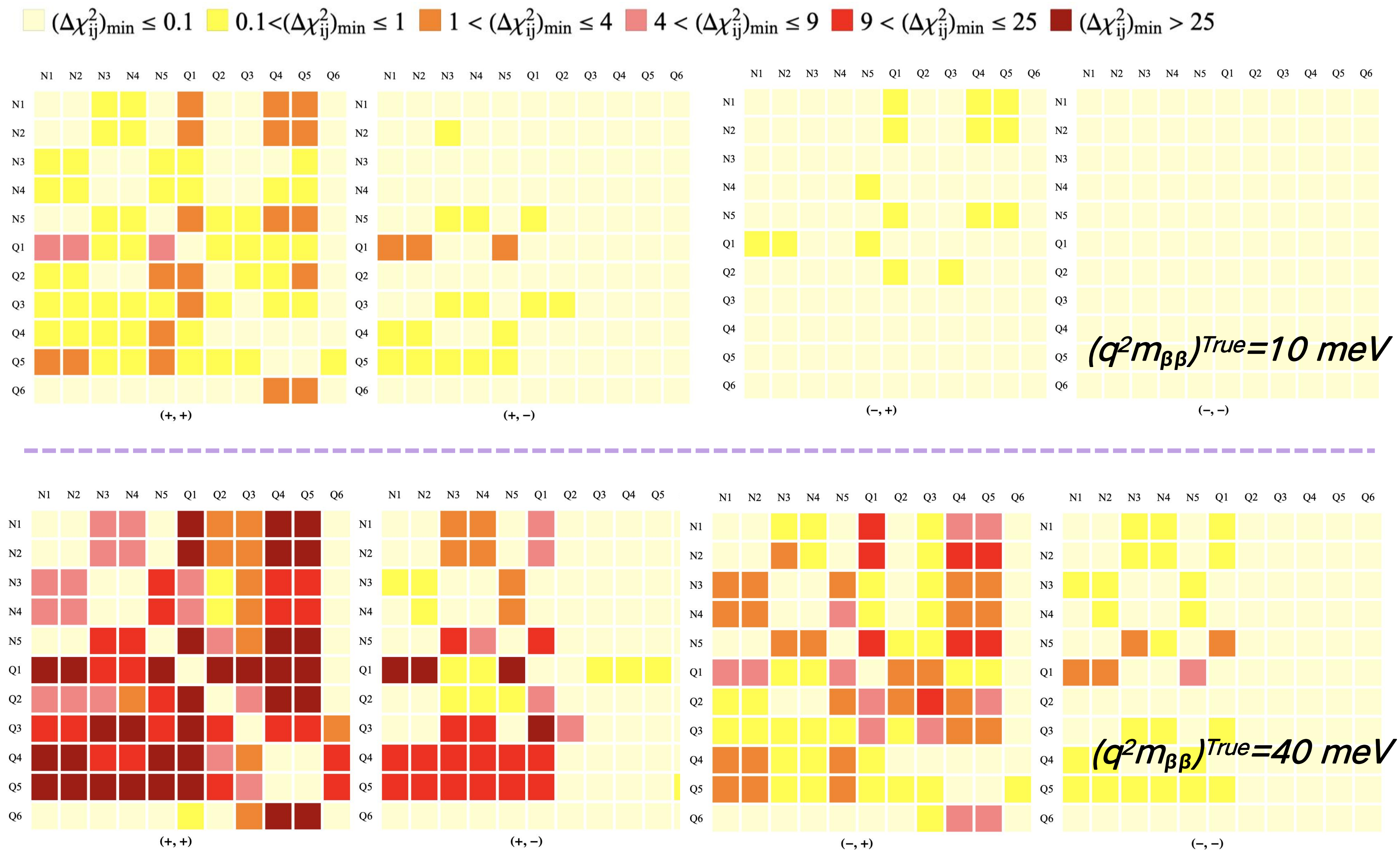


$m_{\beta\beta}^{True}$ corresponding to discrimination at 3σ

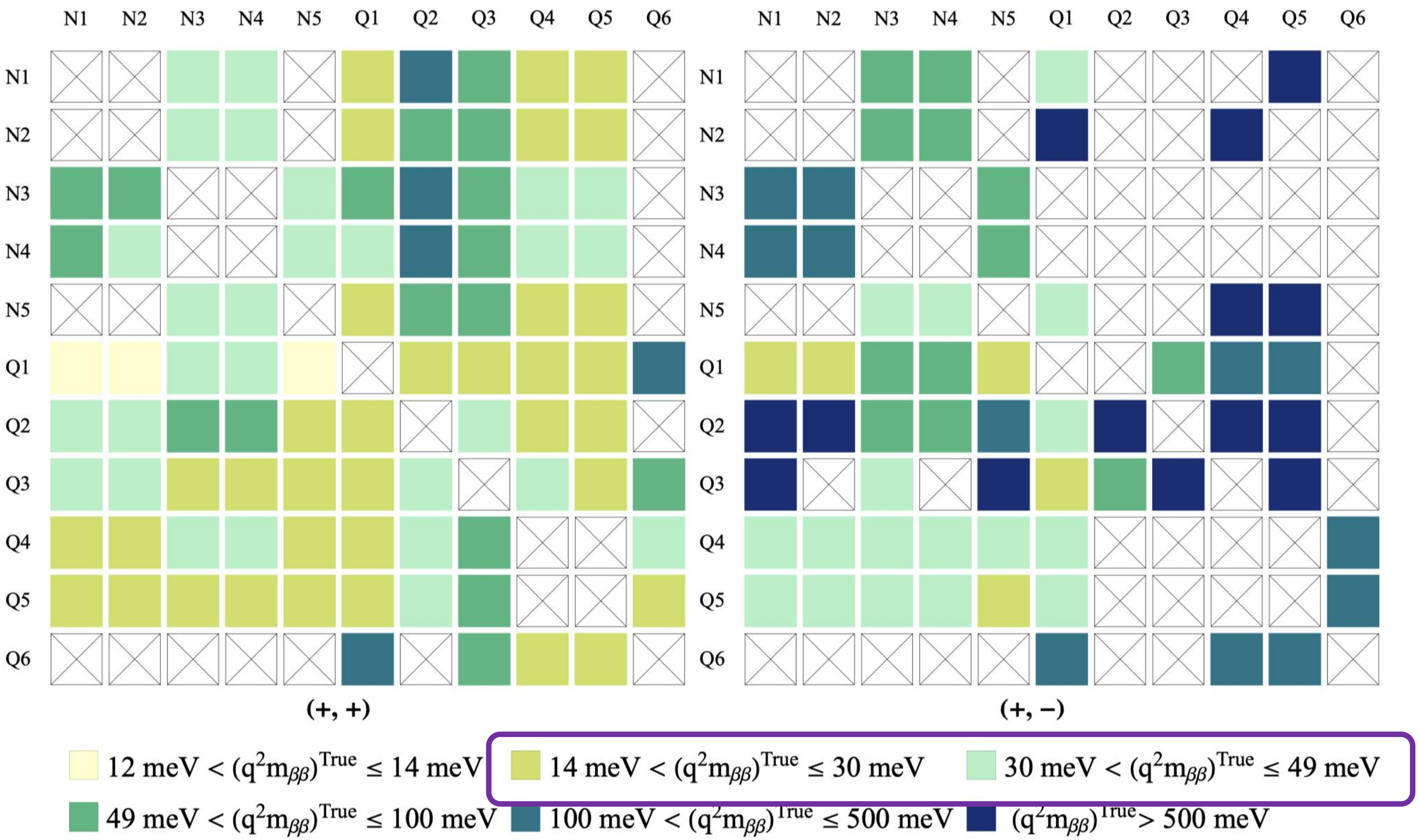


(without short- range NME)

Discrimination with short-range NME, T=10 yr



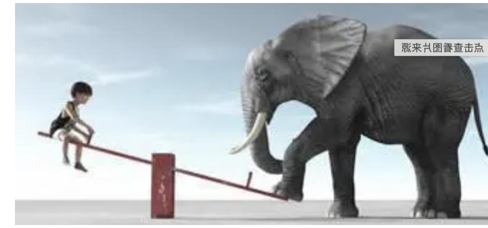
$m_{\beta\beta}^{\rm True}$ corresponding to discrimination at 3σ



(with short- range NME)

Formulas (minimal type-I seesaw)

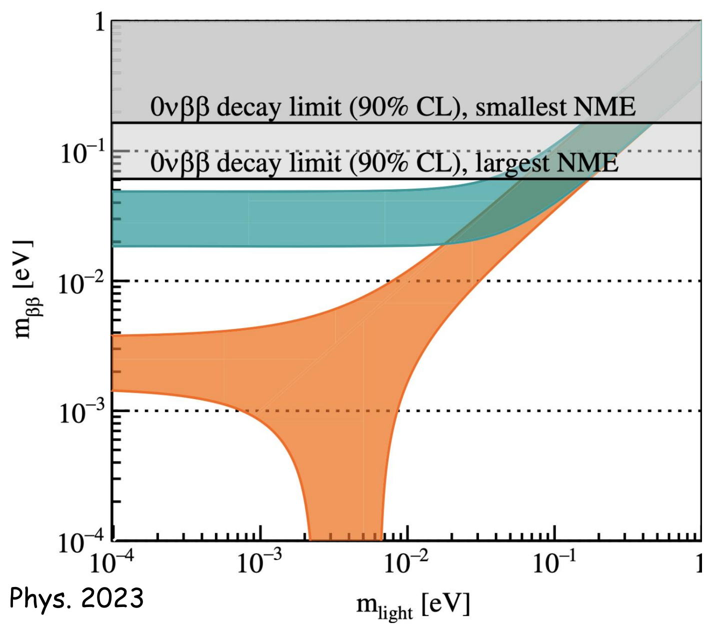
$$\mathcal{L}_{\rm mass} = -\frac{1}{2}\overline{(\nu_{\rm L}, N_{\rm R}^c)} \begin{pmatrix} 0 & M_{\rm D} \\ M_{\rm D}^{\rm T} & M_{\rm R} \end{pmatrix} \begin{pmatrix} \nu_{\rm L}^c \\ N_{\rm R} \end{pmatrix} + {\rm h.c.}$$



$$1/T_{1/2}^{0\nu} = G|M_{0\nu}(0) \cdot m_{\rm eff}|^2$$

$$|m_{\rm eff}| = \left| |m_{\rm eff}^{\nu}| - |m_{\rm eff}^{\nu}| f_\beta(M_2) + |R_{e1}^2| e^{2i\delta_{14}} M_1 \left[f_\beta(M_1) - f_\beta(M_2) \right] \right|$$

$$f_\beta(M_N) = M_{0\nu}(M_N)/M_{0\nu}(0)$$ **Mass dependent nuclear matrix element (NME)**



Agostini et al., Rev. Mod. Phys. 2023

minimal Type-I seesaw
NMO, [1,4] meV
IMO, [15, 50] meV

NME of light neutrinos

	g_A	src	dQRPA [74]	sQRPA-Tu [75]	sQRPA-Jy [77]	IBM-2 [87]	CDFT [80]	ISM [81]
^{76}Ge	1.27	w/o	3.27	-	-	-	7.61	-
		Argonne	3.12	5.157	-	5.98	7.48	2.89
		CD-Bonn	3.40	5.571	6.54	6.16	7.84	3.07
		Miller-Spencer	-	-	-	5.42	6.36	-
	1.00	w/o	2.64	-	-	-	-	-
		Argonne	2.48	3.886	-	-	-	1.77
		CD-Bonn	2.72	4.221	5.26	-	-	1.88
^{82}Se	1.27	w/o	3.01	-	-	-	7.60	-
		Argonne	2.86	4.642	-	4.84	7.48	2.73
		CD-Bonn	3.13	5.018	4.69	4.99	7.83	2.90
		Miller-Spencer	-	-	-	4.37	6.48	-
	1.00	w/o	2.41	-	-	-	-	-
		Argonne	2.26	3.460	-	-	-	2.41
		CD-Bonn	2.49	3.746	3.73	-	-	2.56
^{130}Te	1.27	w/o	3.10				9.55	
		Argonne	2.90	3.888		4.47	9.38	2.76
		CD-Bonn	3.22	4.373	5.27	4.61	9.82	2.96
		Miller-Spencer	-	-	-	4.03	8.03	
	1.00	w/o	2.29					
		Argonne	2.13	2.945	-	-	-	1.72
		CD-Bonn	2.37	3.297	4.00	-	-	1.84
^{136}Xe	1.27	w/o	1.12	-	-	-	6.62	
		Argonne	1.11	2.177		3.67	6.51	2.28
		CD-Bonn	1.18	2.460	3.50	3.79	6.80	2.45
		Miller-Spencer	-	-	-	3.33	5.58	
	1.00	w/o	0.85					
		Argonne	0.86	1.643	-	-	-	1.42
		CD-Bonn	0.89	1.847	2.91	-	-	1.53

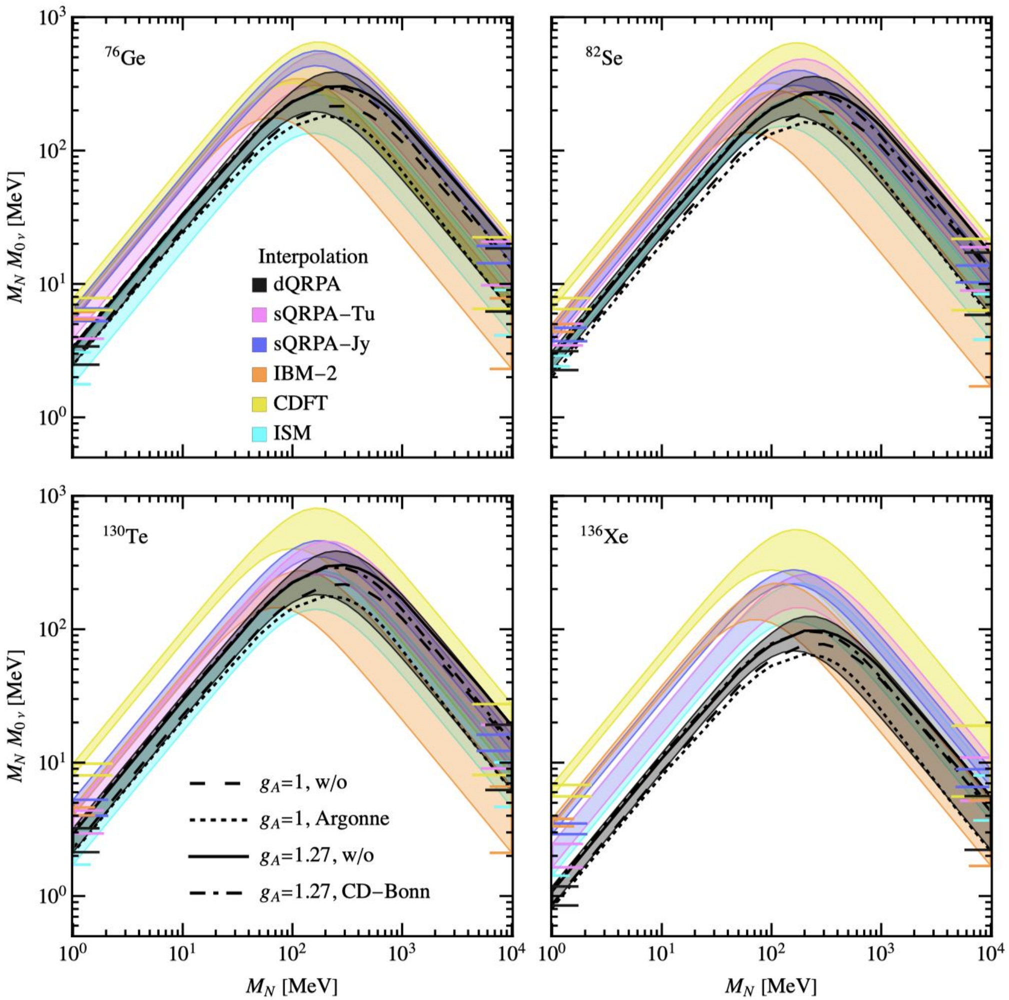
- CDFT biggest
- ISM/dQRPA smallest
- different NME ratios between different isotopes

NME of heavy neutrinos

	g_A	src	dQRPA [74]	sQRPA-Tu [75]	sQRPA-Jy [77]	IBM-2 [87]	CDFT [80]	ISM [81]
^{76}Ge	1.27	w/o	385.4				466.8	
		Argonne	187.3	316		107	267	130
		CD-Bonn	293.7	433	401.3	163	378.1	188
		Miller-Spencer				48.1	135.7	
	1.00	w/o	275.9					
		Argonne	129.7	204				86
		CD-Bonn	207.2	287	298.3			122
^{82}Se	1.27	w/o	358.7				454	
		Argonne	175.9	287		84.4	261.4	121
		CD-Bonn	273.6	394	287.1	132	369	175
		Miller-Spencer				35.6	132.7	
	1.00	w/o	257.4					
		Argonne	122.1	186	-	-	-	80
		CD-Bonn	193.4	262	214.3	-	-	113
^{130}Te	1.27	w/o	401.1				573	
		Argonne	191.4	292		92	339.2	146
		CD-Bonn	303.5	400	338.3	138	472.8	210
		Miller-Spencer				44	168.5	
	1.00	w/o	281.2					
		Argonne	130.2	189	-	-	-	97
		CD-Bonn	209.5	264	255.7	-	-	136
^{136}Xe	1.27	w/o	117.1				394.5	
		Argonne	66.9	166		72.8	234.3	116
		CD-Bonn	90.5	228	186.3	109	326.2	167
		Miller-Spencer	-	-	-	35.1	116.3	
	1.00	w/o	82.7					
		Argonne	46.3	108	-	-	-	77
		CD-Bonn	62.8	152	137.3	-	-	108

- CDFT biggest
- IBM-2 smallest
- different NME ratios between different isotopes

Mass-dependent NME

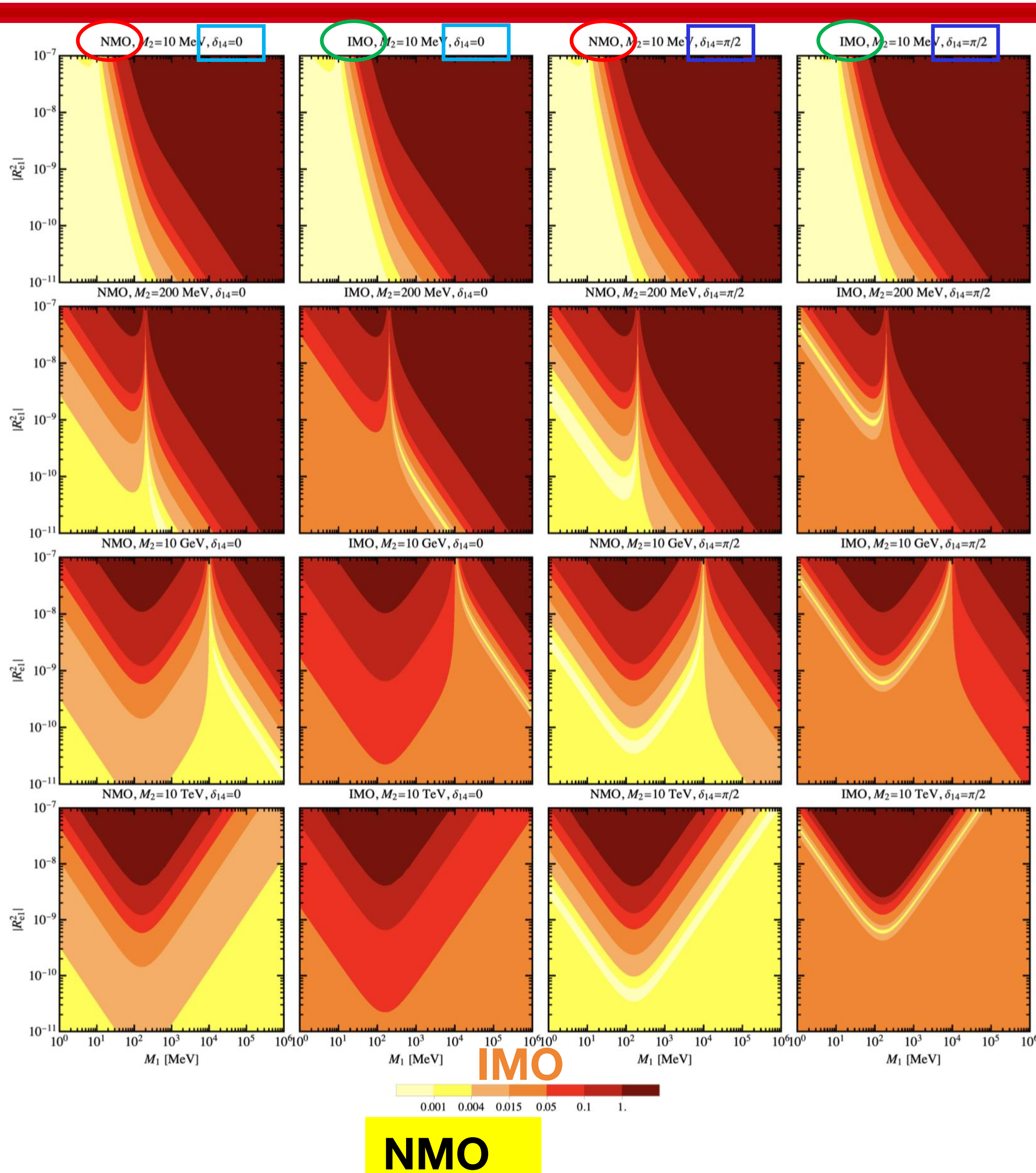


- **dQRPA:** Numerical calculation
- **Others:** interpolation with two extreme values

$$M_{0\nu}(m_j) = \frac{m_p m_e}{\langle p^2 \rangle + m_j^2} M_{\mathrm{H}}$$

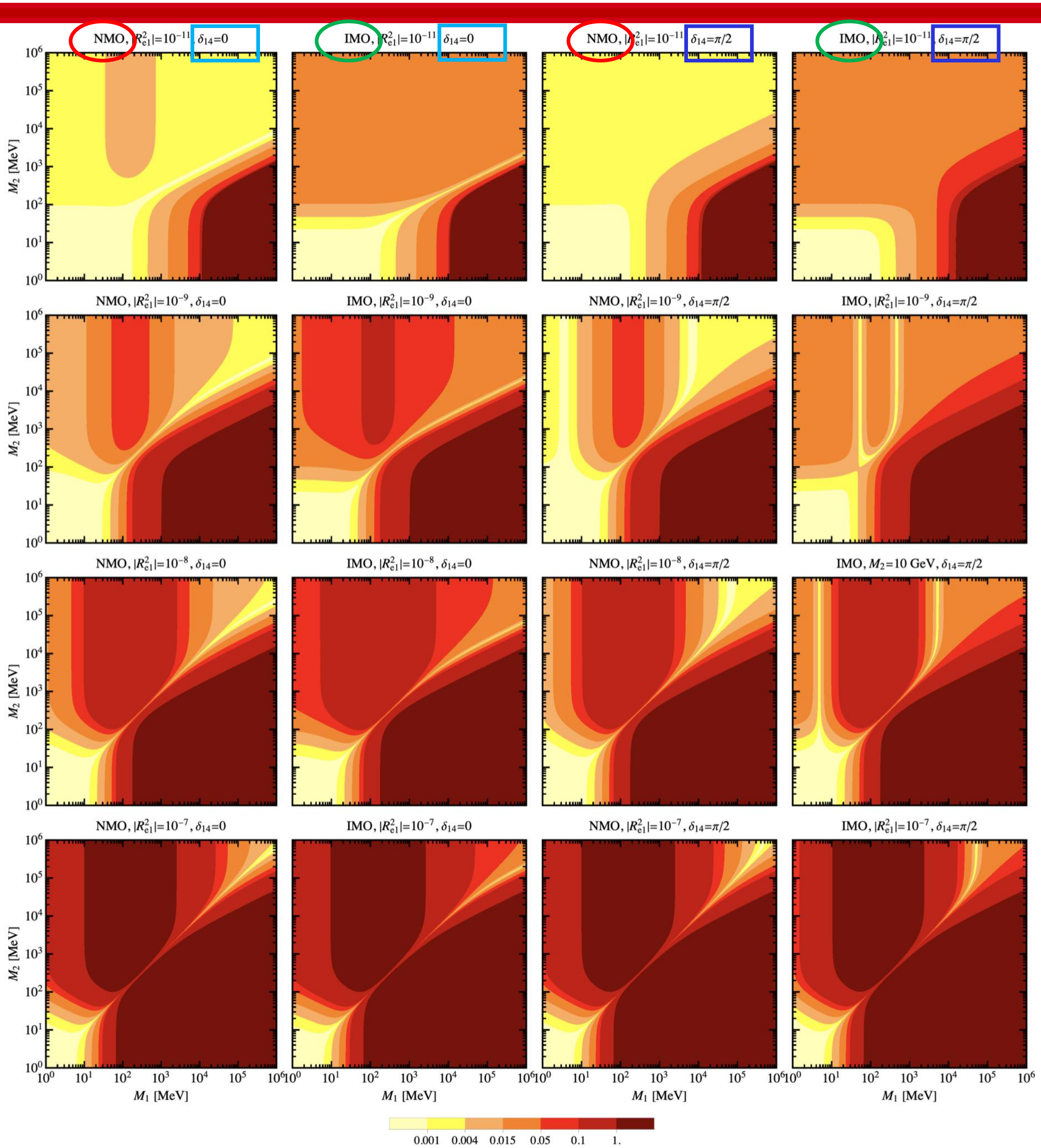
- **dQRPA:** agrees with ISM for light neutrinos and tends to be consistent with CDFT for heavy neutrinos
- **In light neutrino mass** the NME from **dQRPA** model is smaller than that of the **IBM-2** model, and in heavy neutrino mass the reverse applies.

Parameter space of m_{eff}

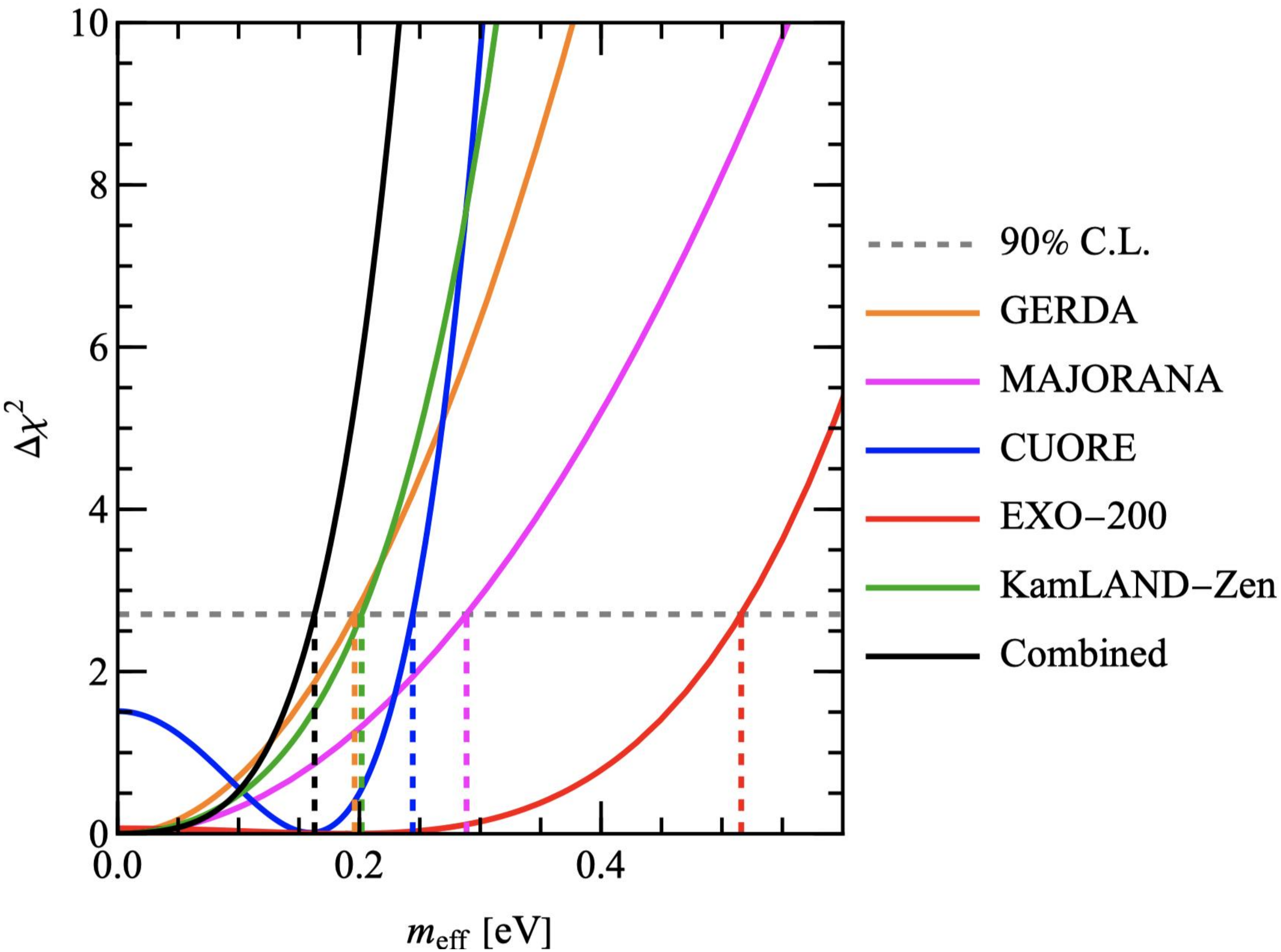


- g_A=1, Argonne src
- Some parameter space can be very easily/hardly excluded by current/future 0νββ experiments
- The NMO/IMO can be very different and δ_{14} matters

Parameter space of m_{eff}

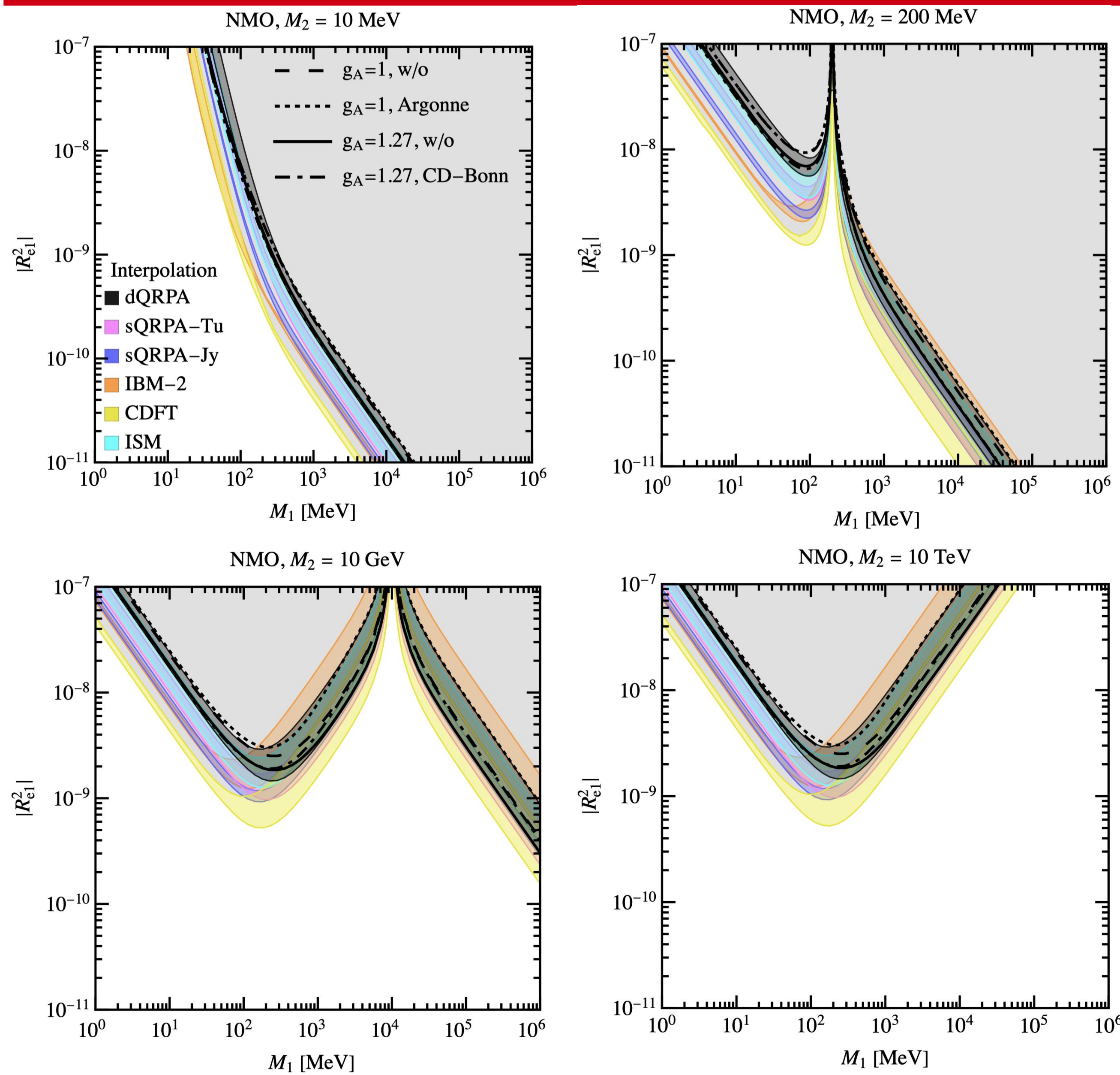


$\Delta\chi^2$ functions of m_{eff}



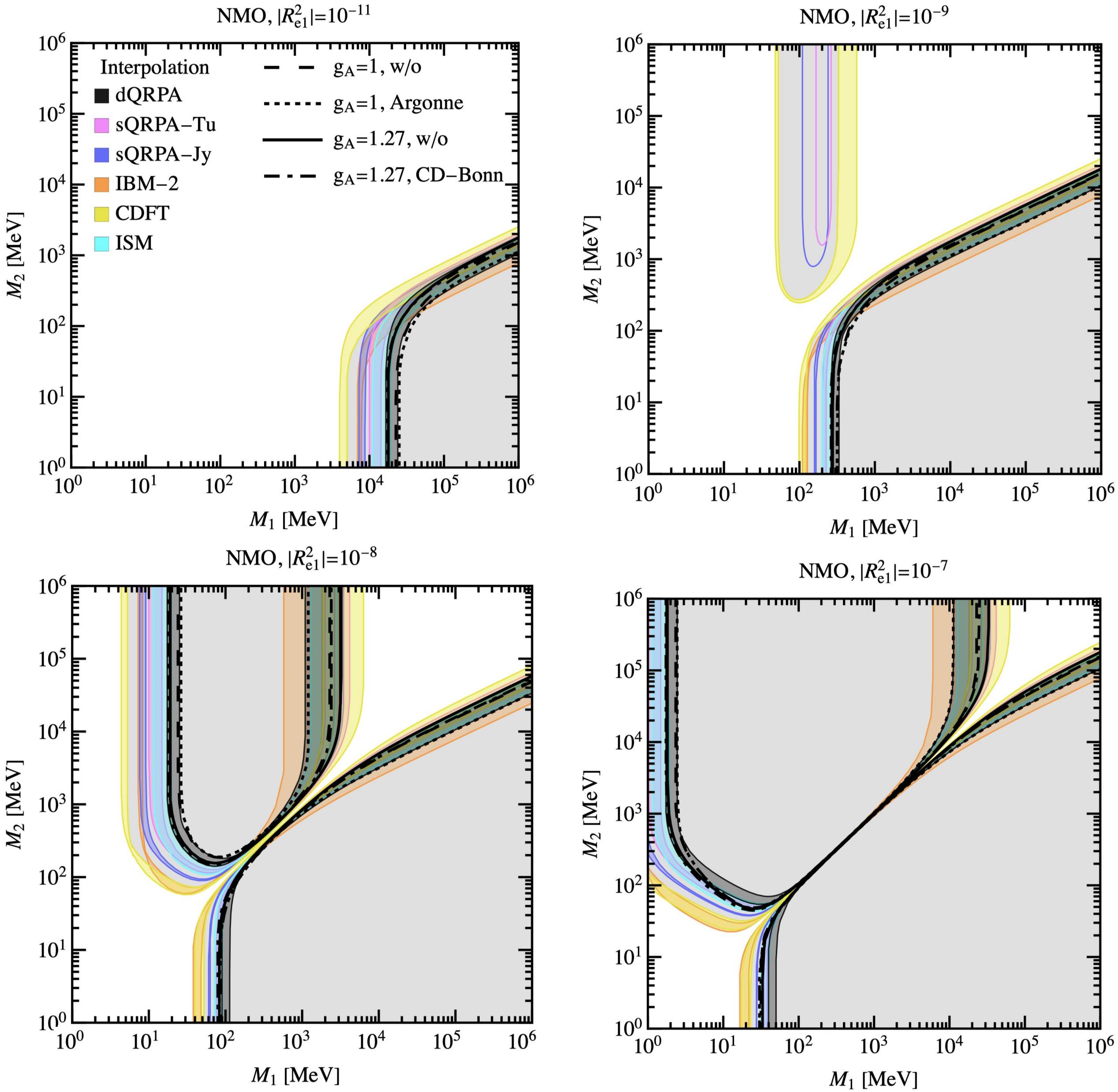
g_A=1, Argonne src

Current limits (M_1 & $|R_{e1}|^2$)



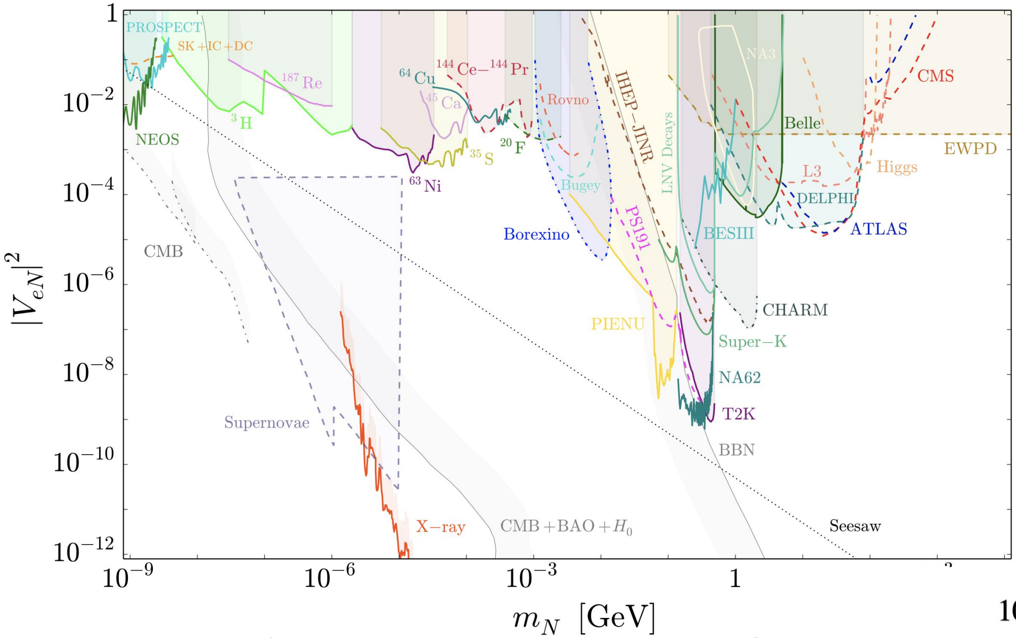
- 3σ C.L
- Gray regions: excluded regions in the case of CDFT model
- Different choices of parameters and models are scanned (not as Gaussian)
- Both the **0νββ-decay** and **oscillation data** are used
- The **IMO** case is similar
- The peak shape

Current limits (M_1 & M_2)



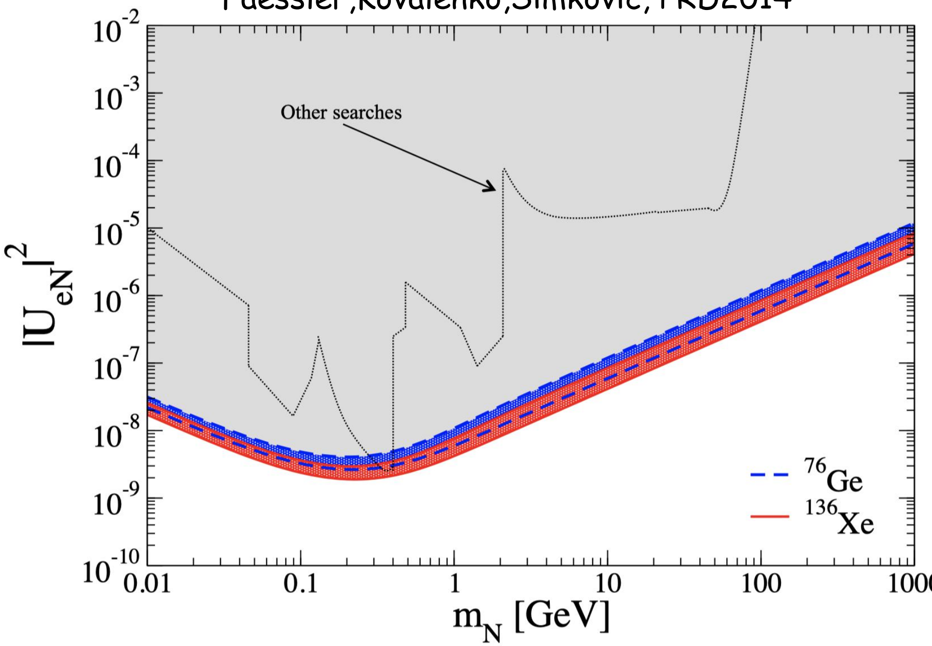
- The IMO case is similar
- The NME hierarchy changes with neutrino mass

Constraints from other probes



Bolton, Deppisch, Bhupap Dev, JHEP 2020

Faessler,Kovalenko,Simkovic, PRD2014



- 3+1case: similar to the case $M_2 \gg M_1$
- $0\nu\beta\beta$ data provide strongest limits in the mass range considered here

Future sensitivities

$$\Delta\chi^2_{ij}(m_{\rm eff},(M_{0\nu})_{\alpha j};m_{\rm eff}^{\rm True},(M_{0\nu})_{\alpha i}^{\rm True}) = 2\sum_\alpha (N_{\alpha j} - N_{\alpha i}^{\rm True} + N_{\alpha i}^{\rm True}{\rm In}\frac{N_{\alpha i}^{\rm True}}{N_{\alpha j}})$$

Assumed number events

$$N_{\alpha i}^{\rm True} = B_{\alpha i} + S_{\alpha i}(m_{\rm eff}^{\rm True},(M_{0\nu})_{\alpha i}^{\rm True})$$

$$N_{\alpha j} = B_{\alpha j} + S_{\alpha j}(m_{\rm eff}, M_{\alpha j})$$

Assuming no positive 0νββ signal is observed,
Leading to sensitivities independent of true NME model

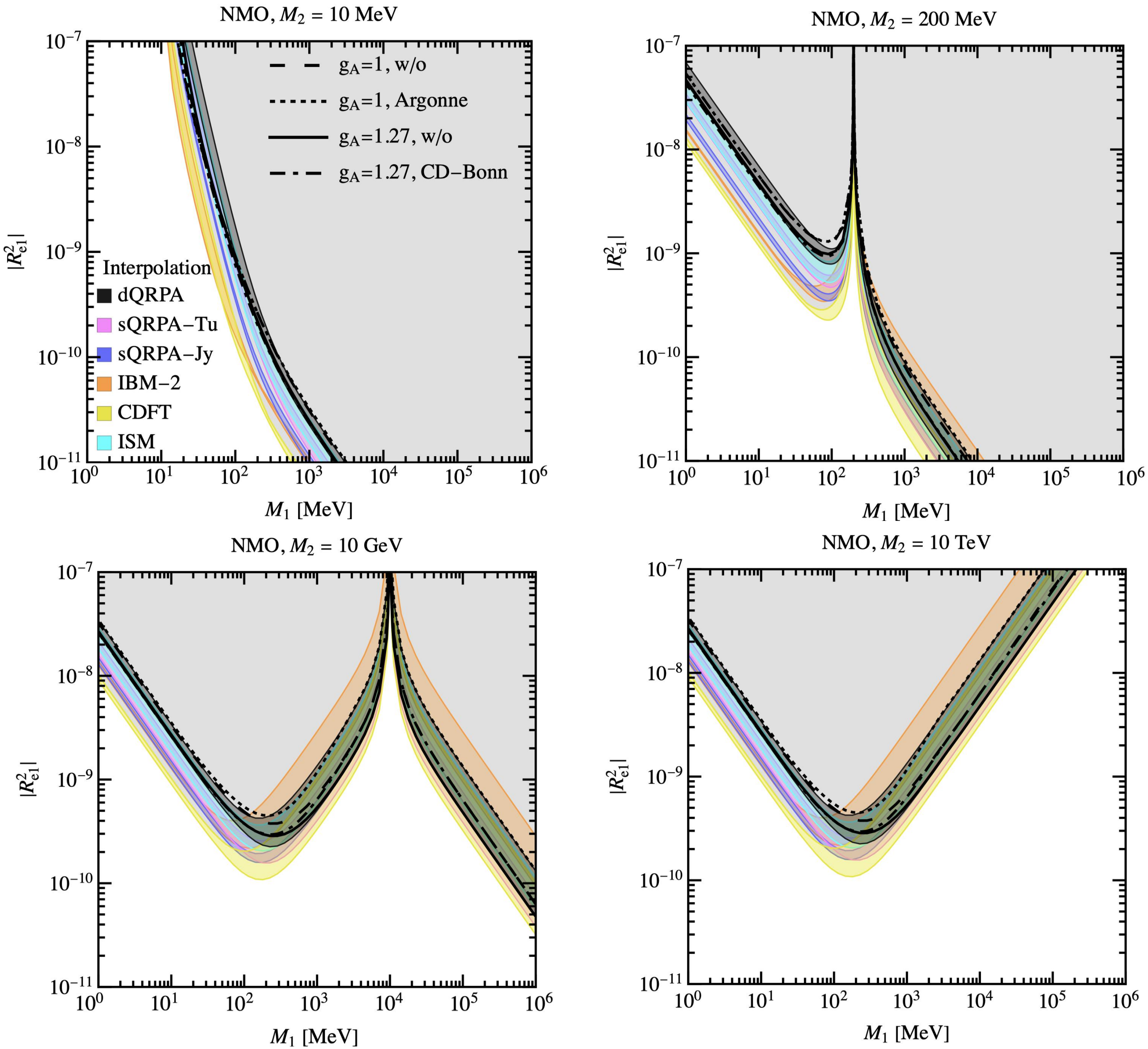
$$S_{\alpha i}(m_{\rm eff},\ M_{\alpha i}) = {\rm In2}\cdot N_A\cdot\varepsilon_\alpha\cdot(T^{0\nu}_{1/2})^{-1}_{\alpha i}\cdot T/(1\ {\rm yr})$$

$$B_\alpha = b_\alpha\cdot\varepsilon_\alpha\cdot T/(1\ {\rm yr})$$

T=10 yr

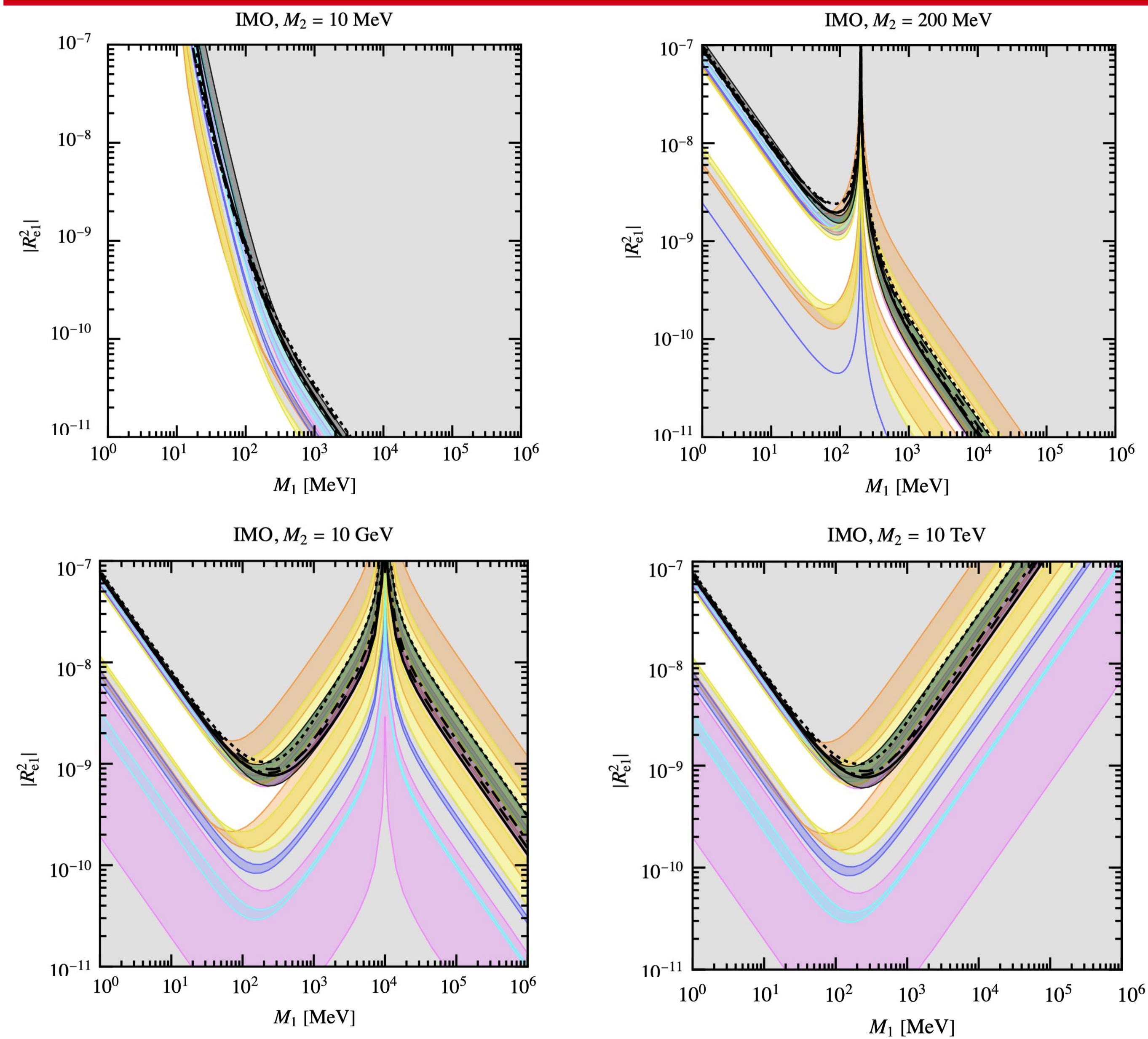
Experiment	Isotope	ε [mol· yr]	b [events/(mol· yr)]
LEGEND-1000	^{76}Ge	8736	$4.9\cdot 10^{-6}$
SuperNEMO	^{82}Se	185	$5.4\cdot 10^{-3}$
SNO+II	^{130}Te	8521	$5.7\cdot 10^{-3}$
nEXO	^{136}Xe	13700	$4.0\cdot 10^{-5}$

Future sensitivities (M_1 & $|R_{e1}|^2$)



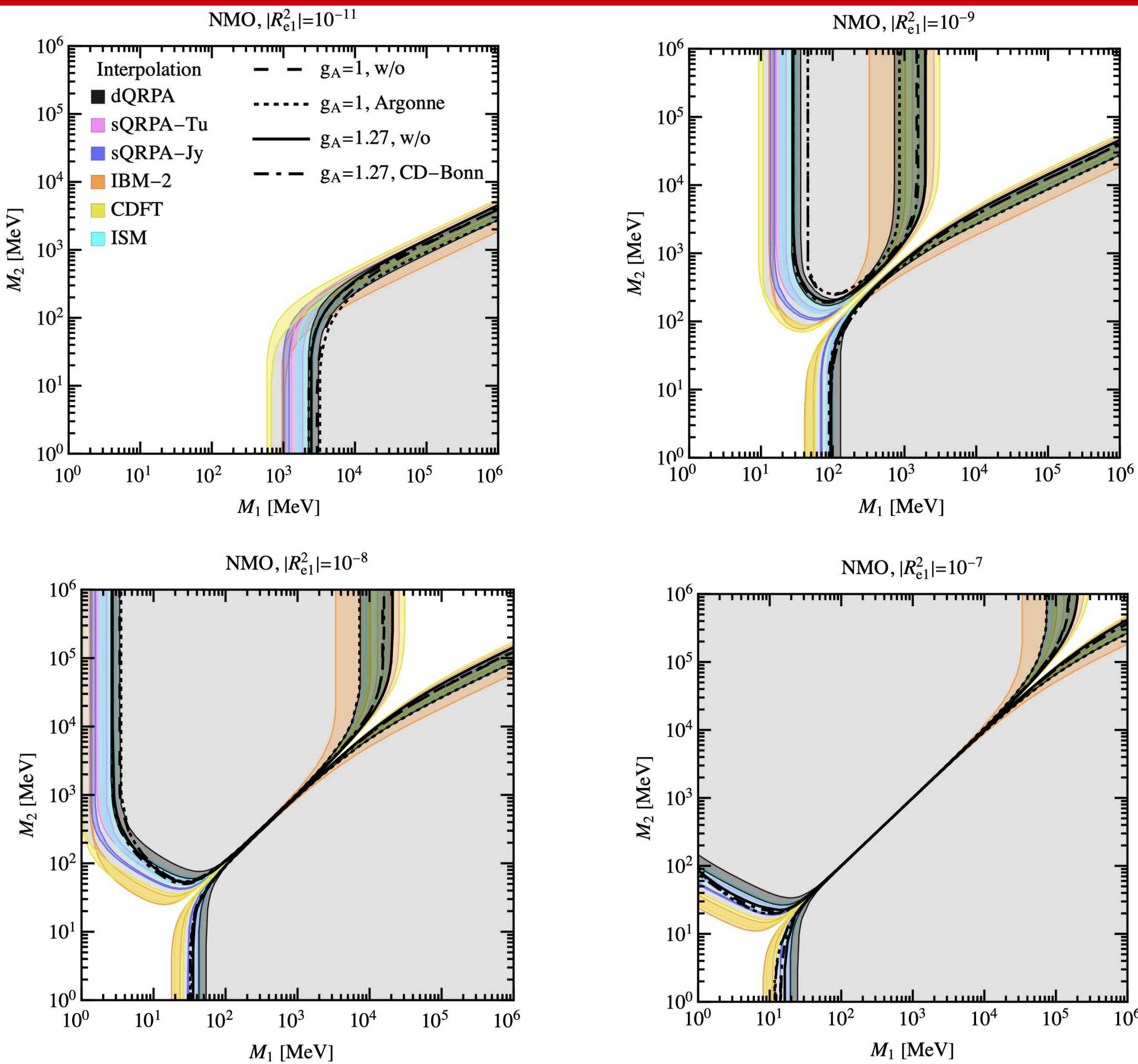
- The NMO case
- More parameter space can be tested compared the current experiments

Future sensitivities (M_1 & $|R_{e1}|^2$)



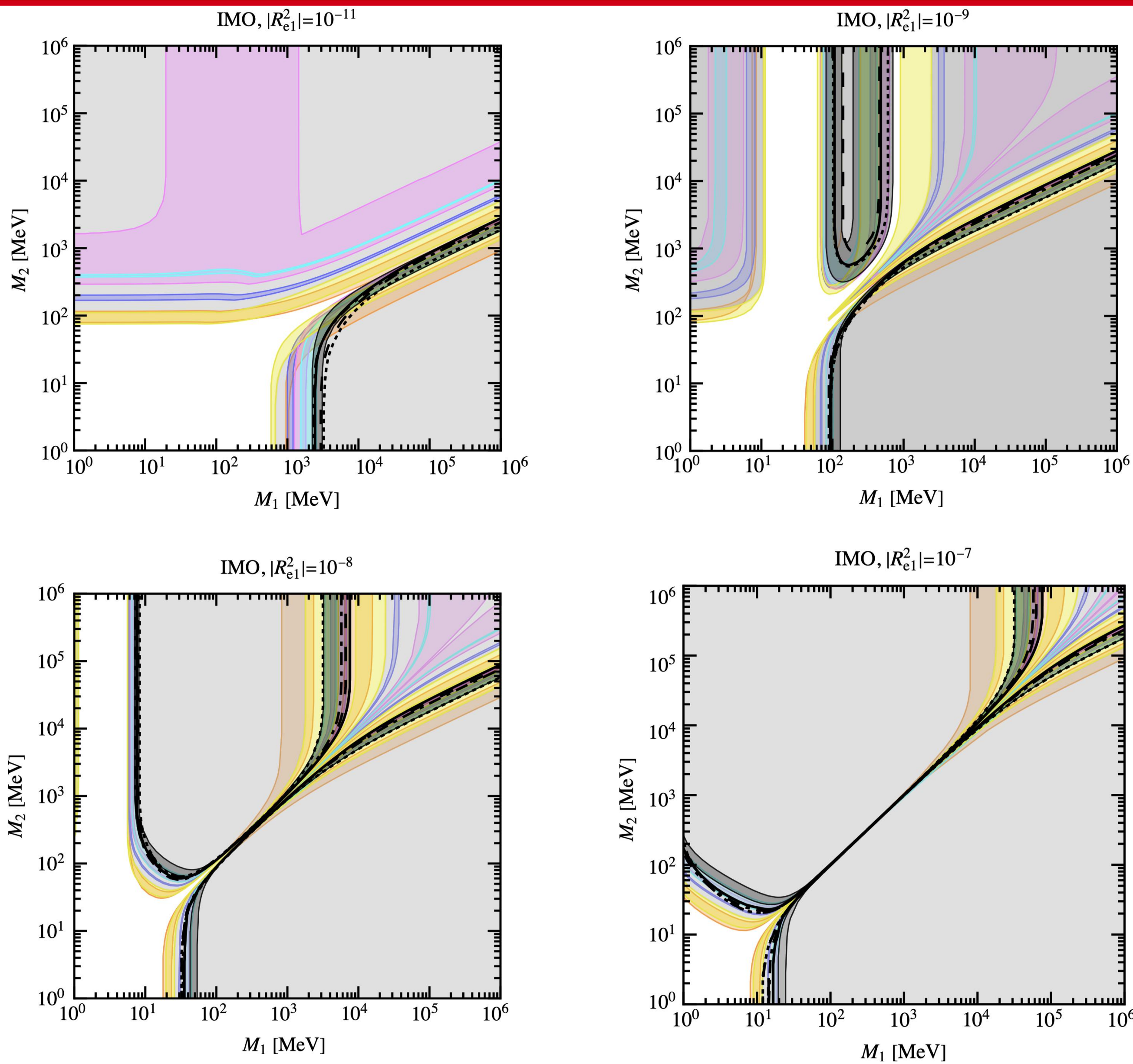
- The IMO case
- Much more parameter space are expected to exclude than NMO case due to zero positive 0νββ signal assumed
- By assuming **enough positive 0νββ signal**, possible to **discriminate NME calculations** and more parameter space can be **excluded in the NMO case**

Future sensitivities (M_1 & M_2)



The NMO case

Future sensitivities (M_1 & M_2)

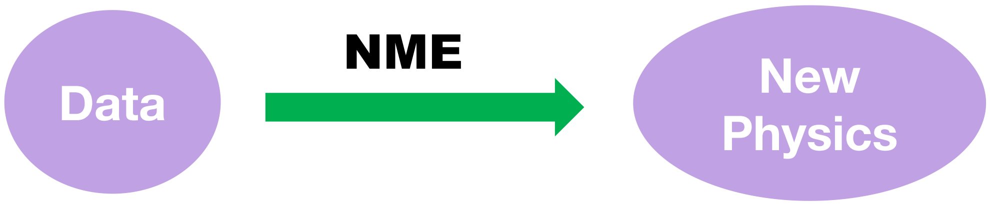


- The IMO case
- The wide pink region in the upper left panel: mainly different δ_{14} values

Summary

- **NME uncertainties due to the SRI may lead to the bound on $q^2 m_{\beta\beta}$ varying by a factor of order 10**
- **Promising discrimination of different NMEs if $(q^2 m_{\beta\beta})$True > 40 meV, positive SRI and 10 year exposure**
- Comparison of mass dependent NMEs in different nuclear models
- Derivation of limits and sensitivities on the parameter space of minimal type-I seesaw from current and future 0νββ experiments

Outlook



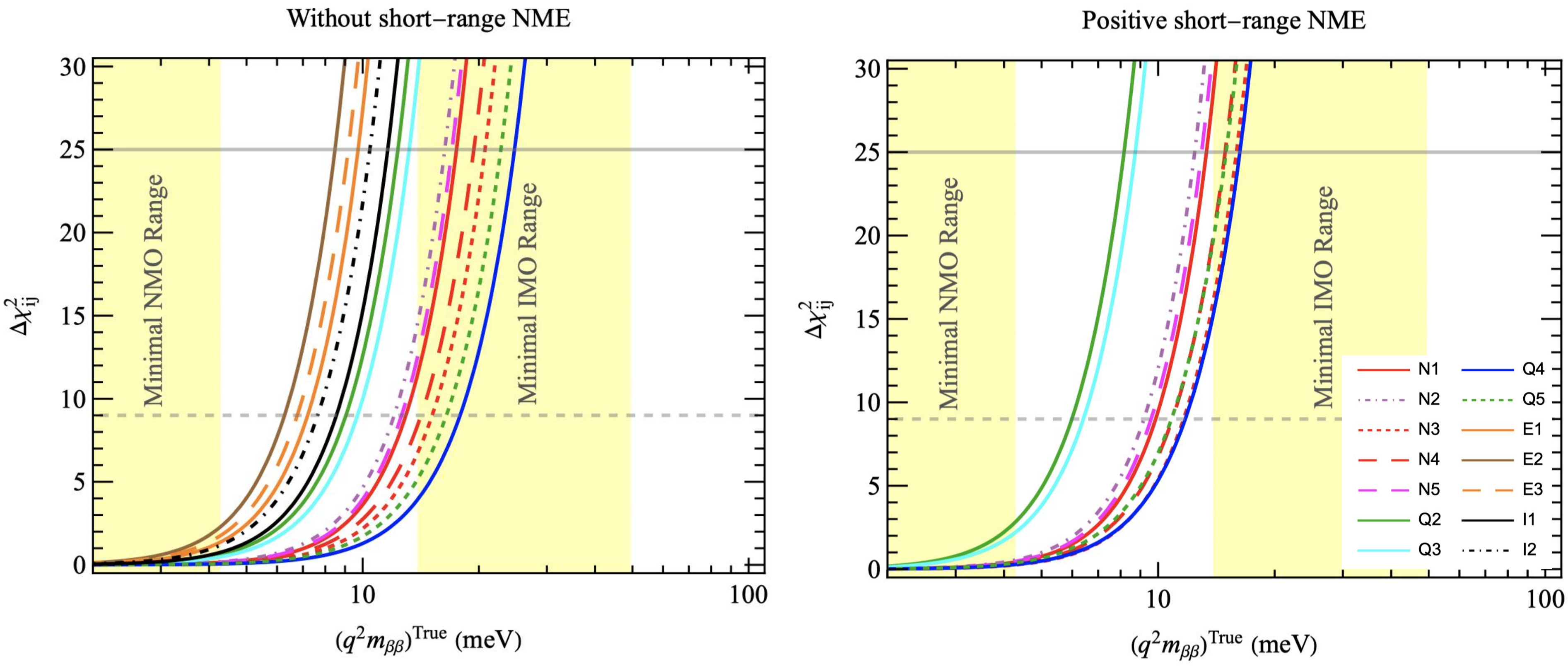
- **Better understanding the short-range NME in 0νββ**
- **Better understanding the nuclear structure**
- **The quenching problem**
- **NME statistical uncertainties**
- **LEC from lattice calculations**
- **Sensitivities to different particle physics mechanisms and how to distinguish them**

- **From 0νββ to $m_{\beta\beta}$: improving the calculations of NME**
- **From 0νββ to discriminating NME models: more information on $m_{\beta\beta}$**

Thank you!

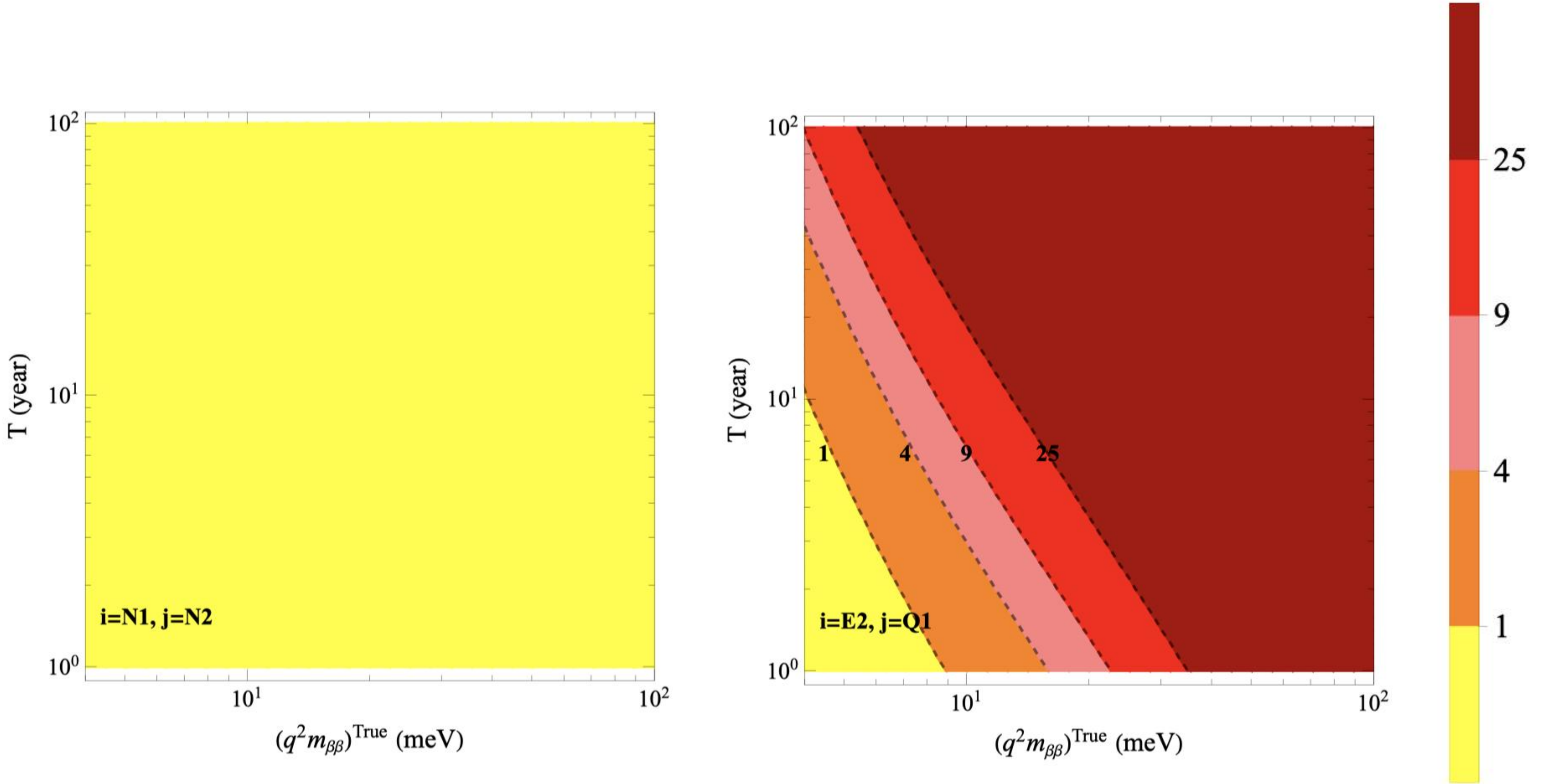
Backups

The significance of observing one positive signal:



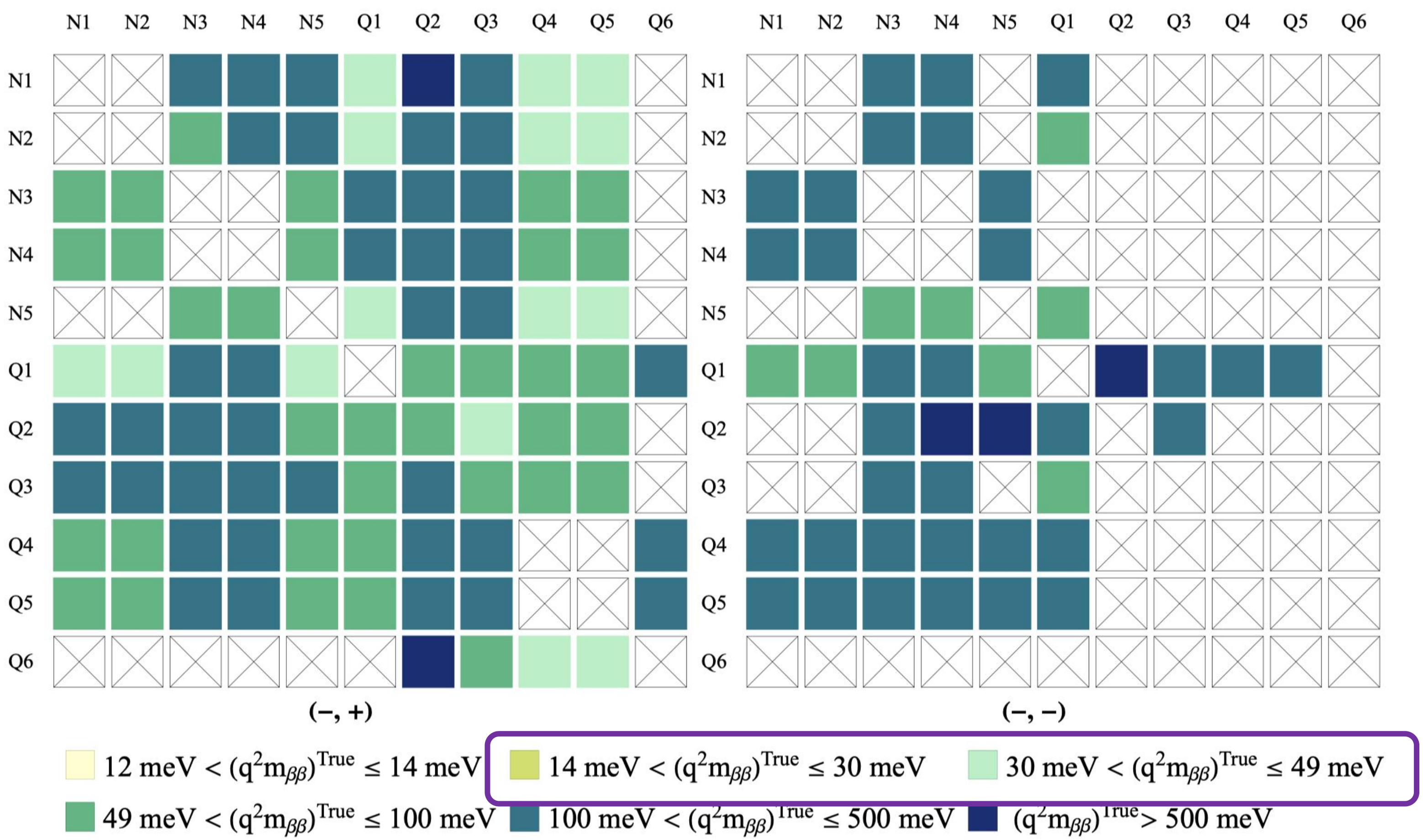
$m_{\beta\beta}$=0, T=10 yr

Contours of $(\Delta\chi^2_{ij})_{min}$ as function of T and $(q^2 m_{\beta\beta})^{True}$



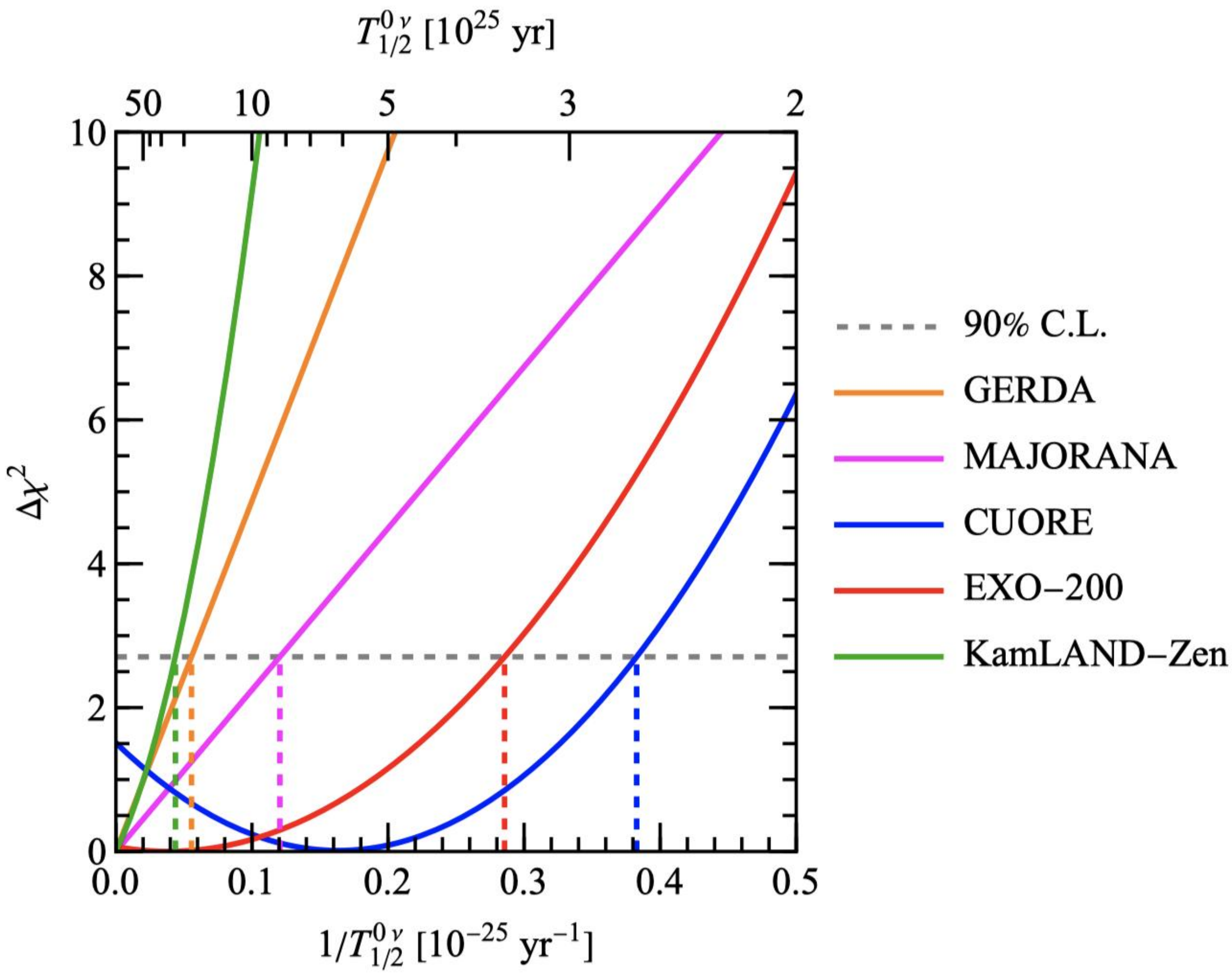
(without short- range NME)

$m_{\beta\beta}^{True}$ corresponding to discrimination at 3σ

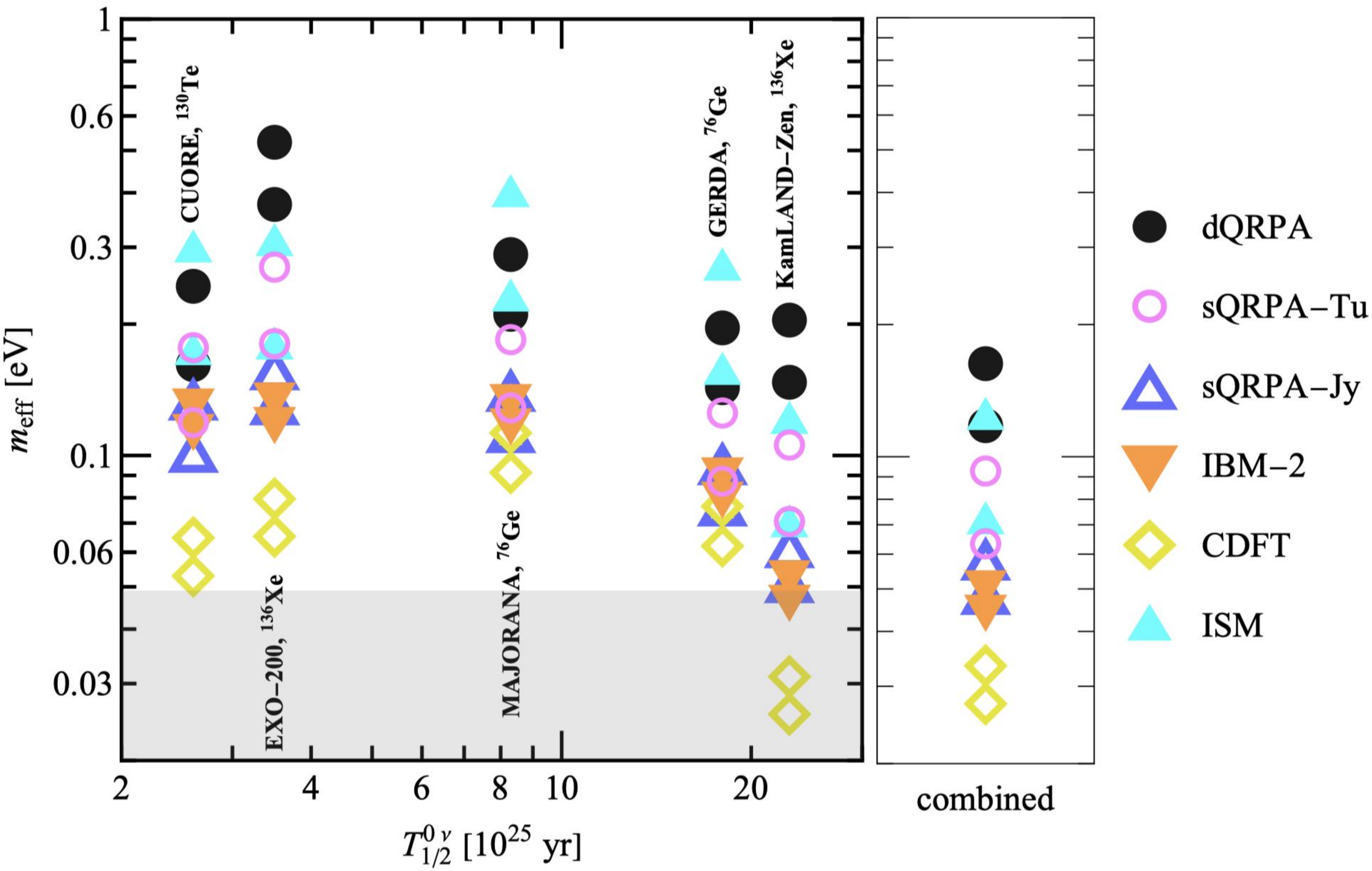


(with short- range NME)

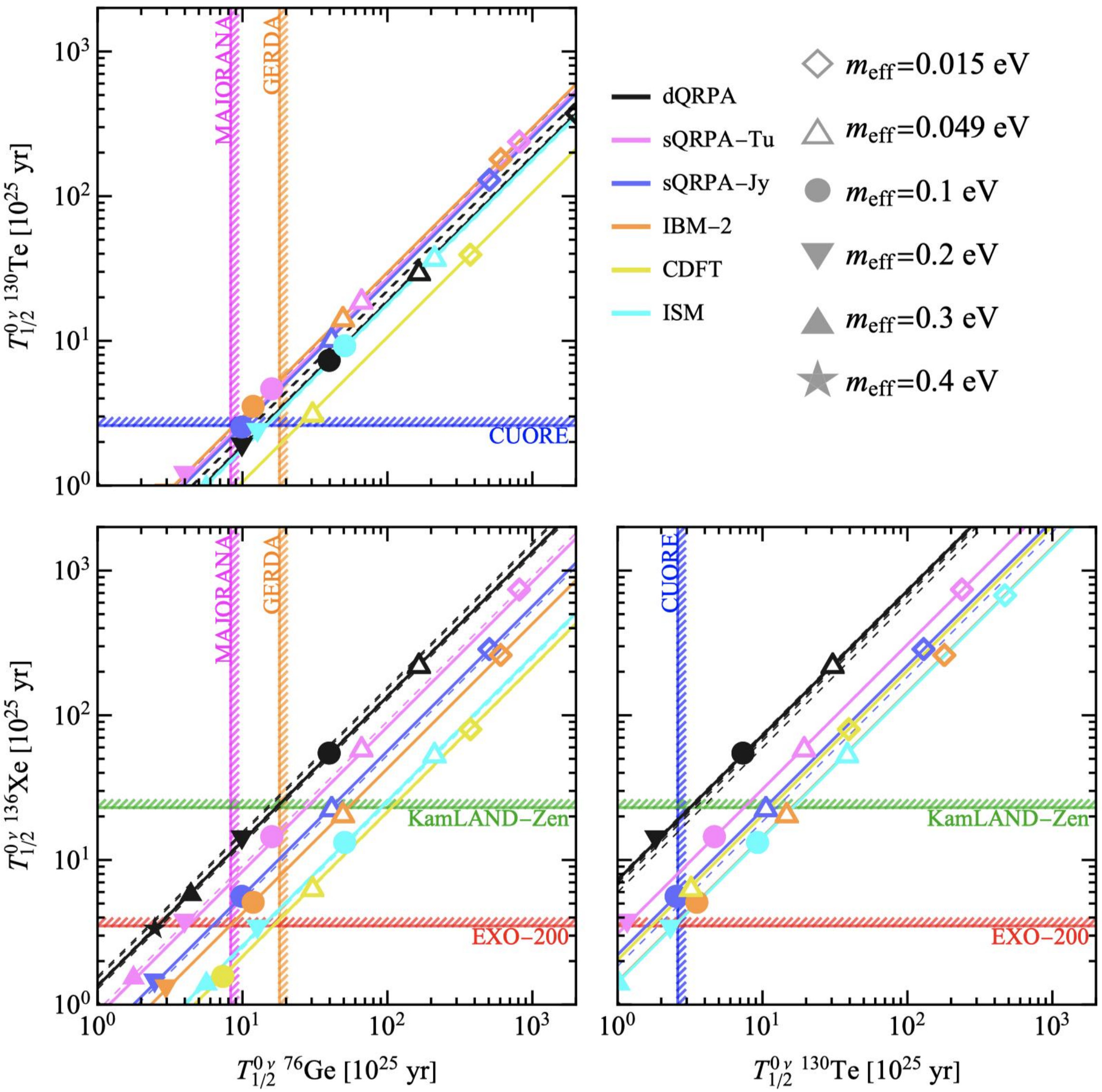
$\Delta\chi^2$ functions of inverse half-life



The upper limit of m_{eff}



Half-life relations of different isotopes



g_A=1.27, CD-bonn src

0νββ half life

- m_{eff} value
- NME value