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Towards a more precise description of the neutrinoless double beta decay

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Support from DOE grant DE-SC0022538 is acknowledged

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Plan of talk

- Neutrinoless double beta decay: Brief introduction
- Nuclear matrix elements
  - Shell model approach
  - Statistical analysis for ^{136}Xe
- Future work: Interference effects
- Conclusions and outlook

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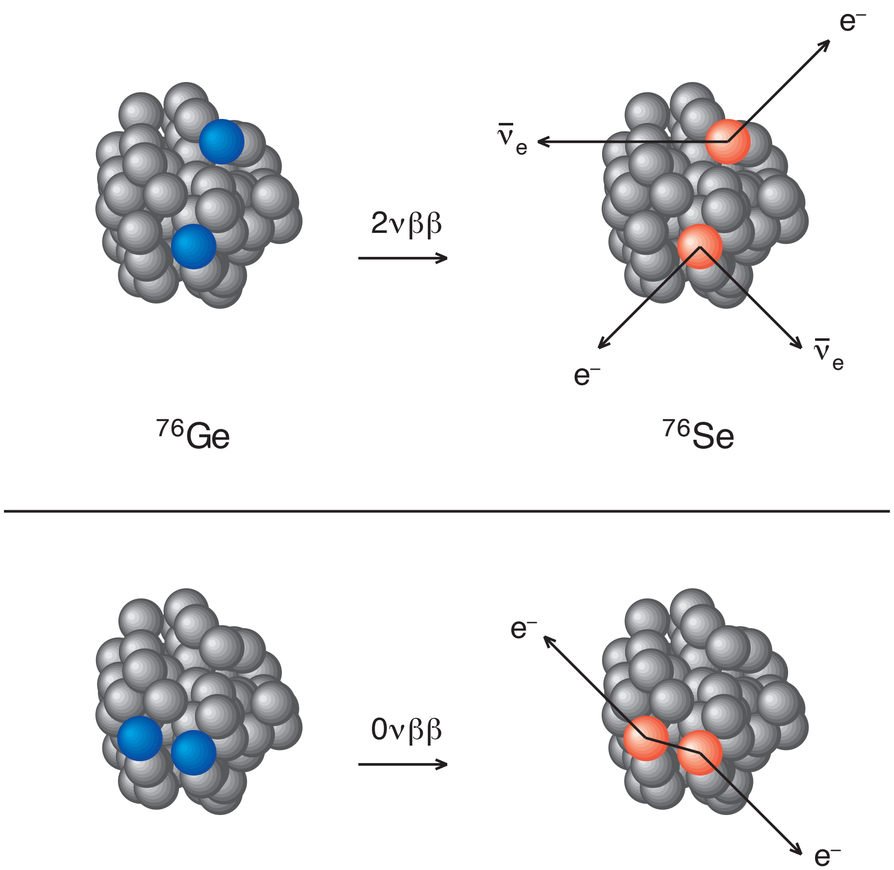
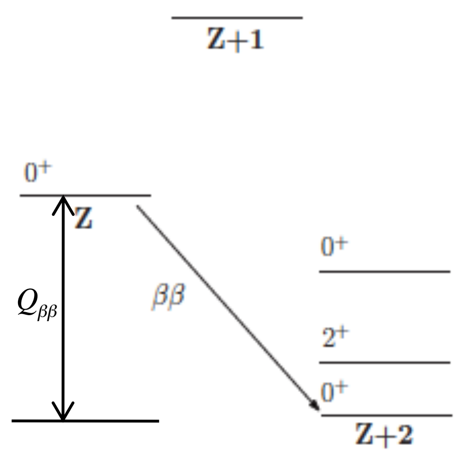
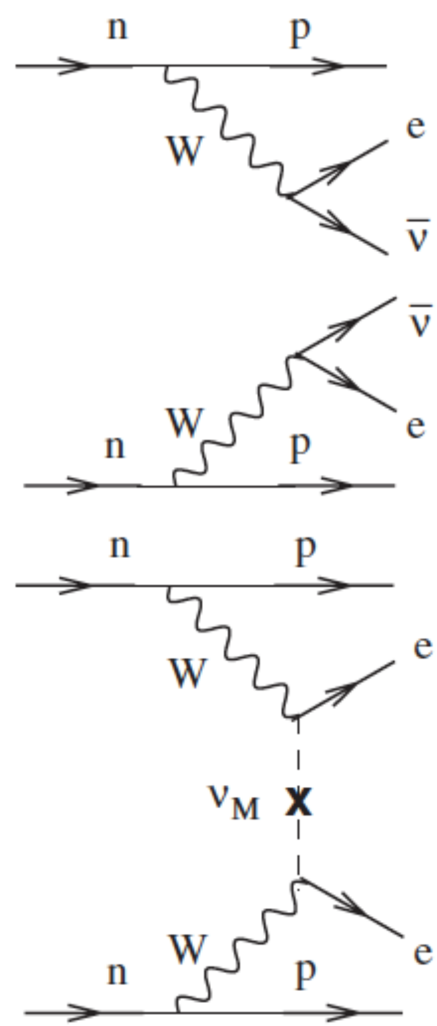
Classical Double Beta Decay Problem







$$\langle m_{\beta\beta} \rangle = \left| \sum_k m_k U_{ek}^2 \right|$$

$$T_{1/2}^{-1}(0\nu) = G^{0\nu}(Q_{\beta\beta}) \left[M^{0\nu}(0^+) \right]^2 \left(\frac{< m_{\beta\beta} >}{m_e} \right)^2$$

$$\nu_e(x) = \sum_i U_{ei} \nu_i(x)$$

$$\left| \nu_e \right\rangle = \sum_i U_{ei}^* \left| \nu_i \right\rangle$$

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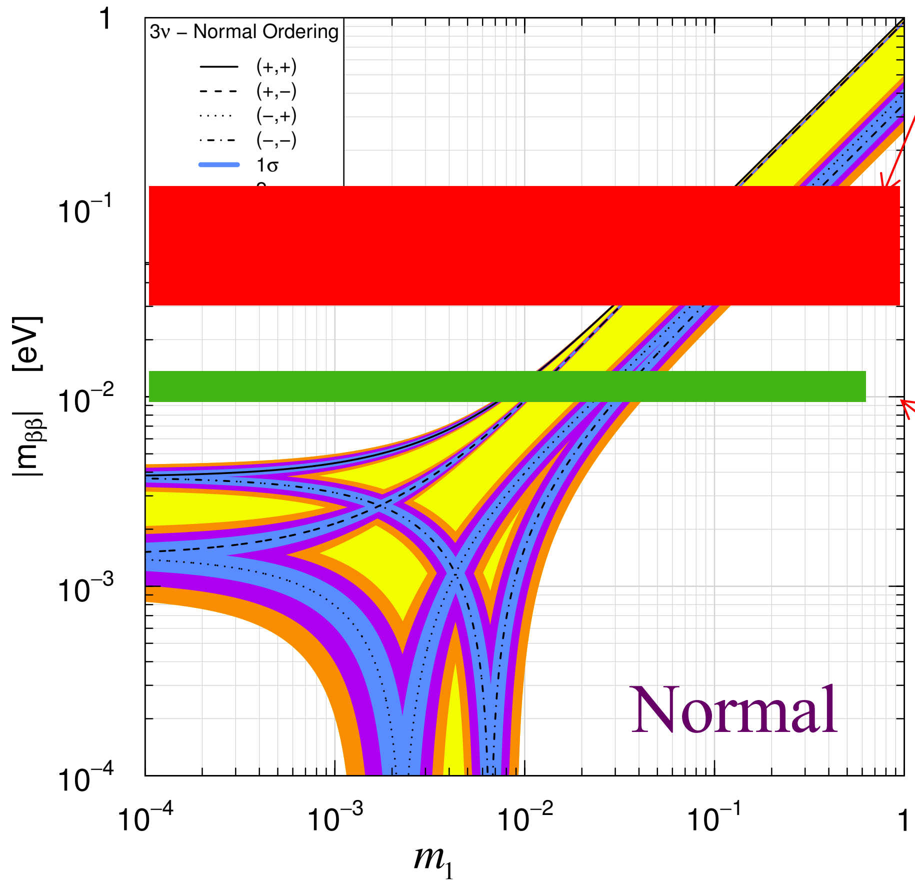
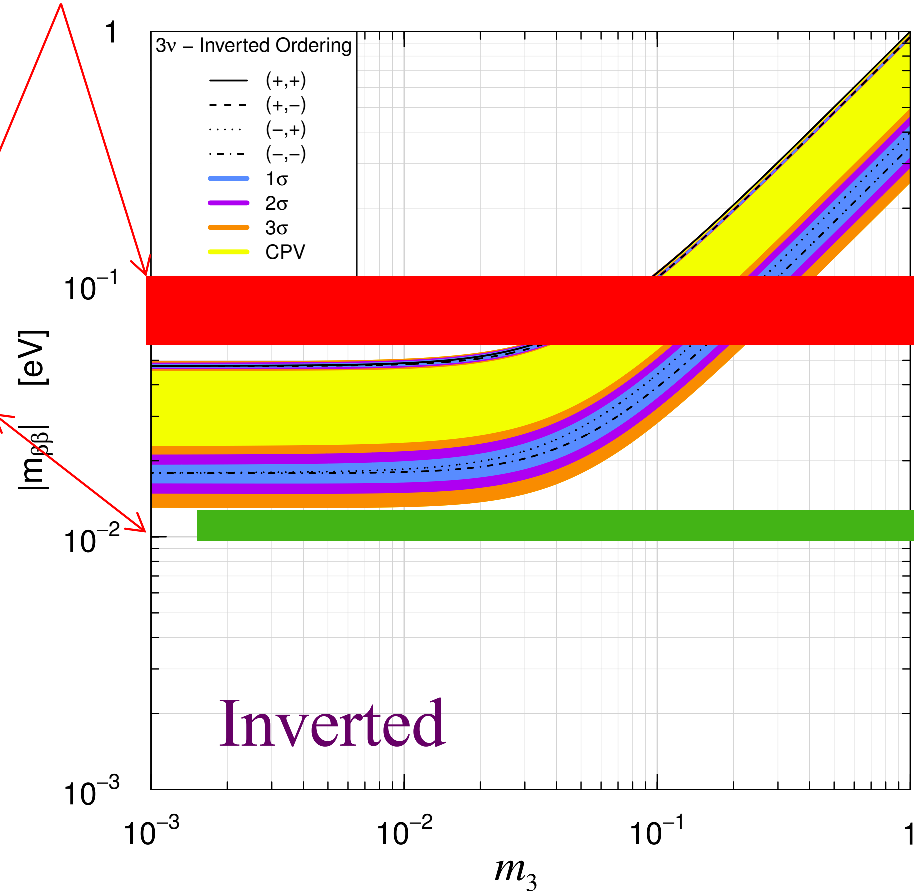
Neutrino ββ effective mass

arxiv:1507.08204

$KamLAND-Zen, PRL\ 117, 082503\ (2016): {}^{136}Xe$



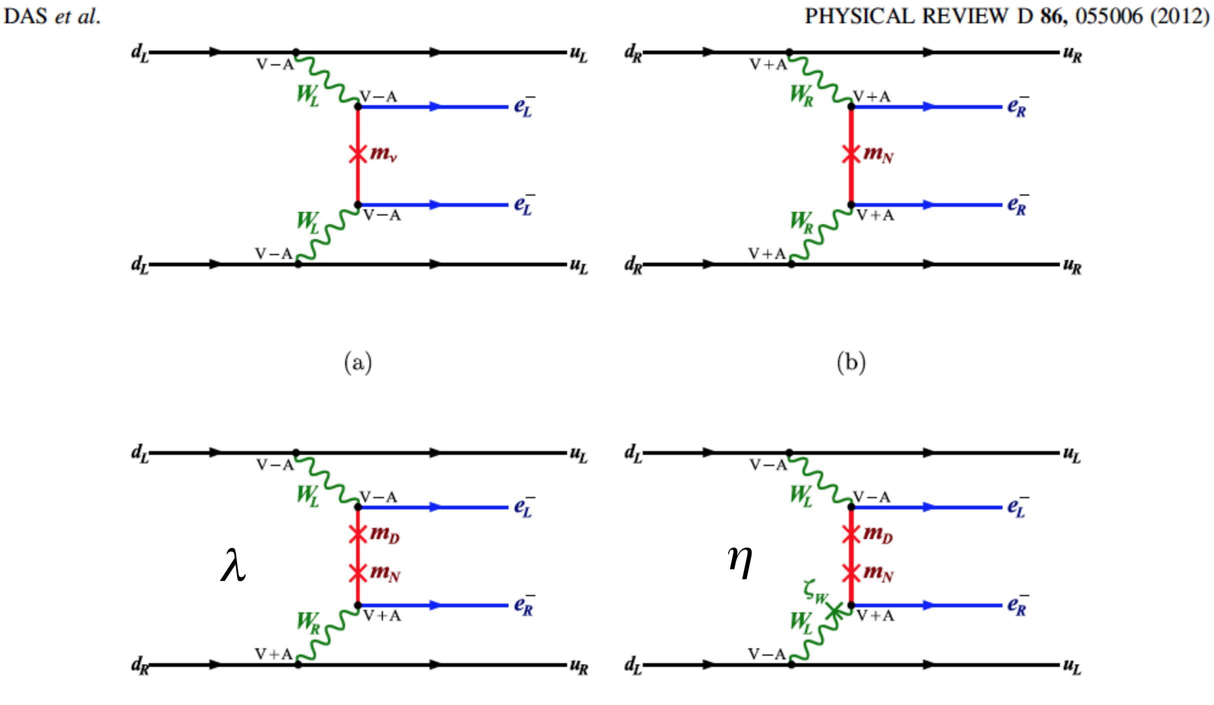


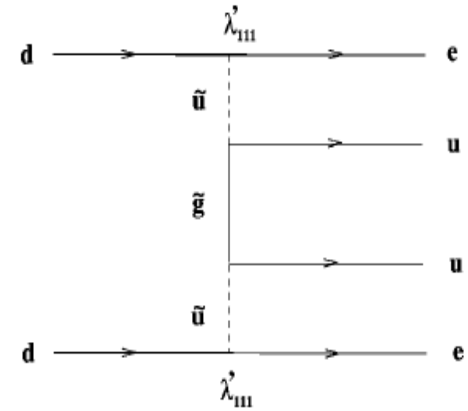
$$\left|m_{\beta\beta}\right| = \left|\sum_{k=1}^{3} m_k U_{ek}^2\right| = \left|c_{12}^2 c_{13}^2 m_1 + c_{13}^2 s_{12}^2 m_2 e^{i\phi_2} + s_{13}^2 m_3 e^{i\phi_3}\right| \qquad \Leftarrow T_{1/2}^{-1}(0\nu) = G^{0\nu}(Q_{\beta\beta})\left[M^{0\nu}(0^+)\right]^2 (\eta_{0\nu})^2$$

$$\phi_2 = \alpha_2 - \alpha_1 \qquad \phi_3 = -\alpha_1 - 2\delta$$

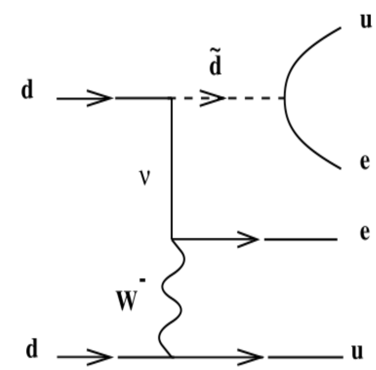
$$\eta_{0\nu} = \frac{\left|m_{\beta\beta}\right|}{m_e}$$

Other models: Left-Right Symmetric Model (LRSM) and SUSY R-parity violation





Gluino exchange



Squark exchange

$$\left[T^{0\nu}_{1/2}\right]^{-1} = G_{01} g_A^4 \left| \eta_{0\nu} M_{0\nu} + \left(\eta^L_{N_R} + \eta^R_{N_R}\right) M_{0N} + \eta_{\tilde{q}} M_{\tilde{q}} + \eta_{\lambda'} M_{\lambda'} + \eta_\lambda X_\lambda + \eta_\eta X_\eta \right|^2 .$$

(e)

M. Horoi, A. Neacsu, PRD 93, 113014 (2016)

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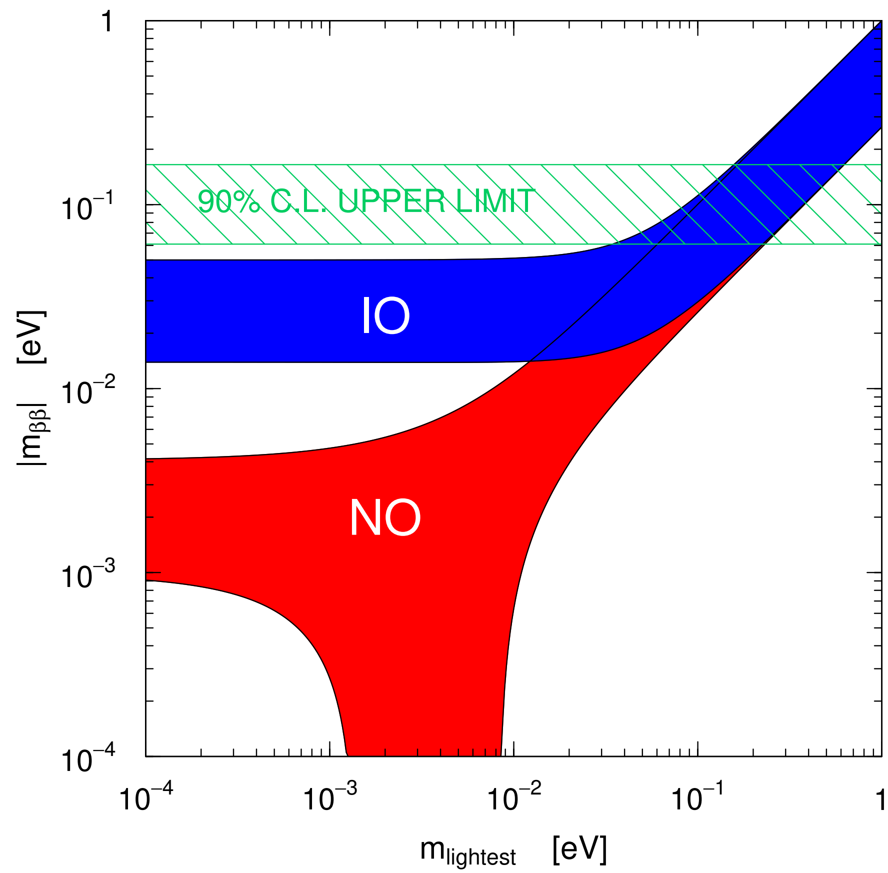
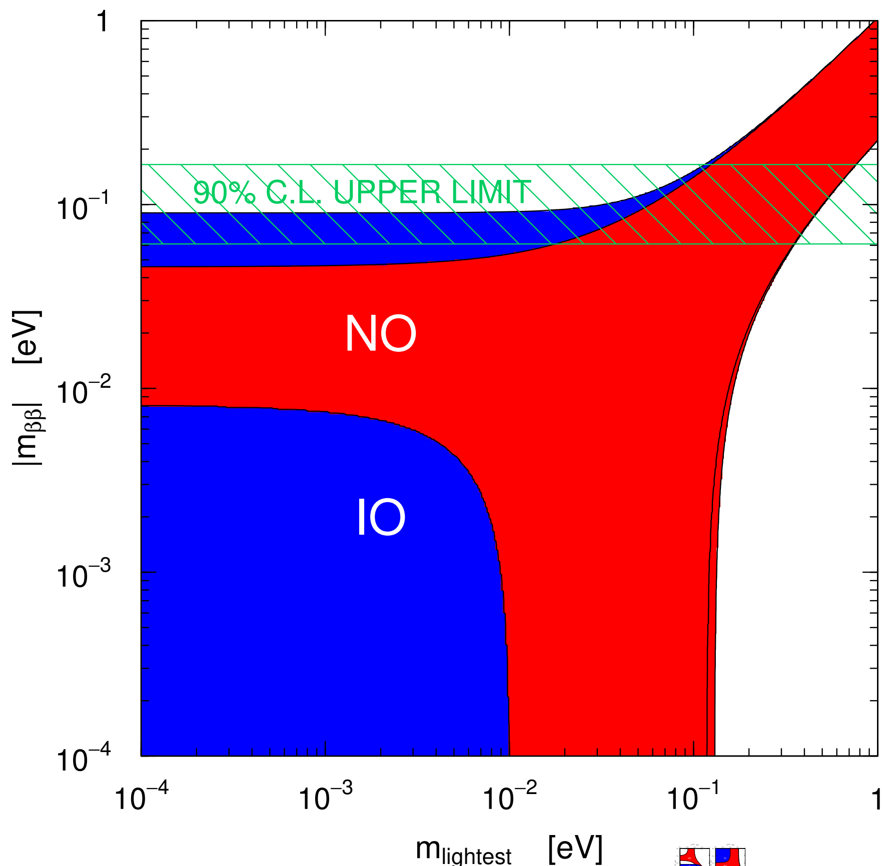
$0\nu\beta\beta$ decay mass mechanism

3 neutrino flavors



3+1(sterile) neutrino flavors



$$\left|m_{\beta\beta}\right| = \left|\sum_{k=1}^{3} m_k U_{ek}^2\right| = \left|c_{12}^2 c_{13}^2 m_1 + c_{13}^2 s_{12}^2 m_2 e^{i\phi_2} + s_{13}^2 m_3 e^{i\phi_3}\right|$$

$$\Leftarrow T_{1/2}^{-1}(0\nu) = G^{0\nu}(Q_{\beta\beta})\left[M^{0\nu}(0^+)\right]^2 (\eta_{0\nu})^2$$

$$\phi_2 = \alpha_2 - \alpha_1 \qquad \phi_3 = -\alpha_1 - 2\delta$$

$$\eta_{0\nu} = \frac{\left|m_{\beta\beta}\right|}{m_e}$$

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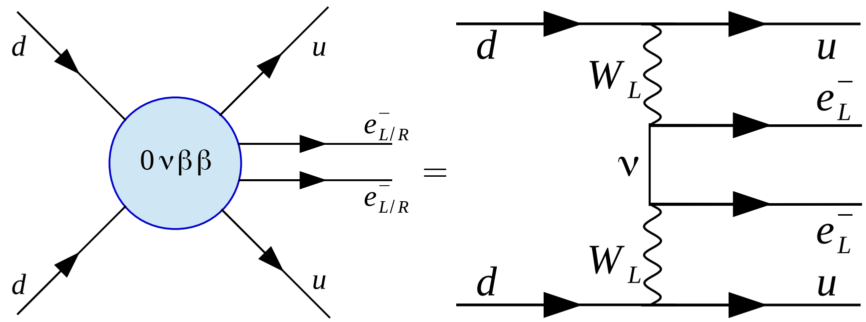
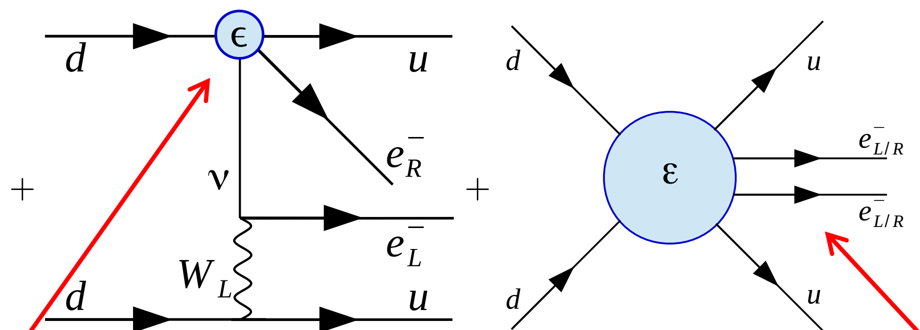
Effective field theory approach



(a) The generic $0\nu\beta\beta$ decay diagram at the quark-level.

(b) Light left-handed neutrino exchange diagram.



(c) The long-range part of the $0\nu\beta\beta$ diagram.

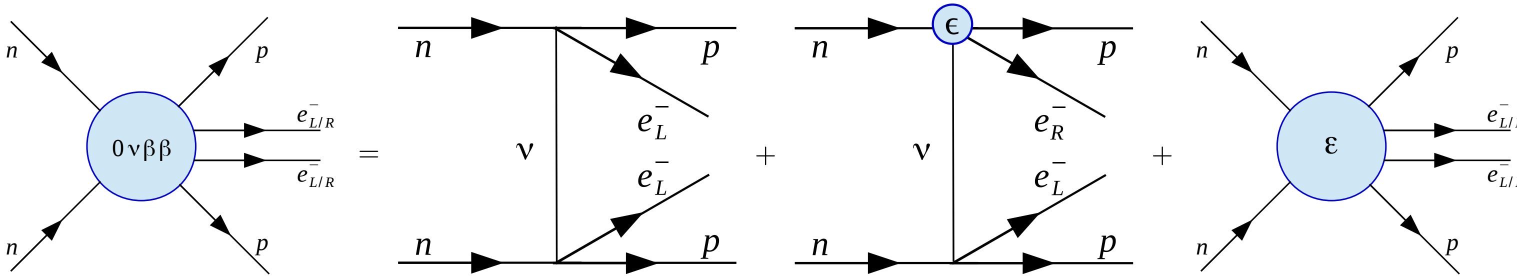
(d) The short-range part of the $0\nu\beta\beta$ diagram.

arxiv:1706.05391

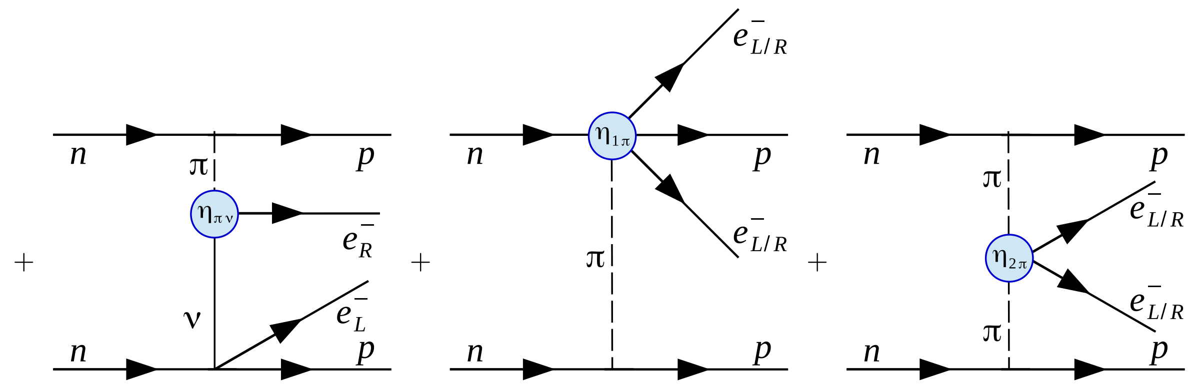
$$\mathcal{L}_6 = \frac{G_F}{\sqrt{2}}\left[j^{\mu}_{V-A} J^{\dagger}_{V-A,\mu} + \sum^{*}_{\alpha,\beta} \epsilon^{\beta}_{\alpha} j_{\beta} J^{\dagger}_{\alpha} \right]$$

$$\mathcal{L}_9 = \frac{G_F^2}{2m_p}\Big[\varepsilon_1 JJj + \varepsilon_2 J^{\mu\nu} J_{\mu\nu} j + \varepsilon_3 J^{\mu} J_{\mu} j + \varepsilon_4 J^{\mu} J_{\mu\nu} j^{\nu} + \varepsilon_5 J^{\mu} J j_{\mu} \Big],$$

Effective field theory after hadronization



(a) The generic $0\nu\beta\beta$ decay process nucleon-level diagram.
(b) Light left-handed neutrino exchange diagram.
(c) The The nucleon-nucleon long-range $\mathcal{L}_6$ mode.
(d) The nucleon-nucleon short-range part of the $0\nu\beta\beta$ diagram.



(e) The pion-neutrino long-range diagram.
(f) The one-pion long-range diagram.
(g) The two-pion long-range diagram.

$$\left[T_{1/2}^{0\nu}\right]^{-1} = g_A^4 \left[\sum_i |\mathcal{E}_i|^2 \mathcal{M}_i^2 + \mathrm{Re}\left[\sum_{i\neq j} \mathcal{E}_i \mathcal{E}_j \mathcal{M}_{ij}\right]\right]$$

$$\mathcal{E}_{2-7} = \{\epsilon_{V-A}^{V+A},\ \epsilon_{V+A}^{V+A},\ \epsilon_{S\pm P}^{S+P},\ \epsilon_{TR}^{TR},\ \eta_{\pi\nu}\}$$

$$\mathcal{E}_{8-15} = \{\varepsilon_1,\ \varepsilon_2,\ \varepsilon_3^{LLz(RRz)},\ \varepsilon_3^{LRz(RLz)},\ \varepsilon_4,\ \varepsilon_6,\ \eta_{1\pi},\ \eta_{2\pi}\}$$

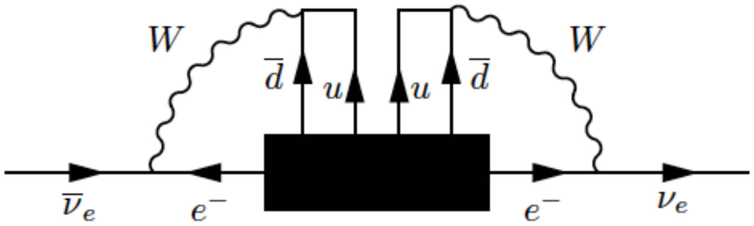
The Black Box Theorems

Black box I (electron neutrino)

J. Schechter and J.W.F Valle, PRD 25, 2951 (1982)

E. Takasugi, PLB 149, 372 (1984)

J.F. Nieves, PLB 145, 375 (1984)



0νββ observed at some level ⇔ (i) Lepton number conservation is violated by 2 units.

(ii) Electron neutrinos are Majorana fermions (with m > 0).

However:

M. Duerr et al, JHEP 06 (2011) 91

$$\left(\delta m_{\nu_e}\right)_{BB} \sim 10^{-24}\, eV << \sqrt{\left|\Delta m_{32}^2\right|} \approx 0.05\, eV$$

Black box II (all flavors + oscillations)

M. Hirsch, S. Kovalenko, I. Schmidt, PLB 646, 106 (2006)

0νββ observed at some level ⇔ (i) Lepton number conservation is violated by 2 units.

(ii) Neutrinos are Majorana fermions.

$$(iii)\quad \left\langle m_{\beta\beta}\right\rangle = \left|\sum_{k=1}^{3} m_k U_{ek}^2\right| = \left|c_{12}^2 c_{13}^2 m_1 + c_{13}^2 s_{12}^2 m_2 e^{i\phi_2} + s_{13}^2 m_3 e^{i\phi_3}\right| > 0$$

Regardless of the dominant 0νββ mechanism!

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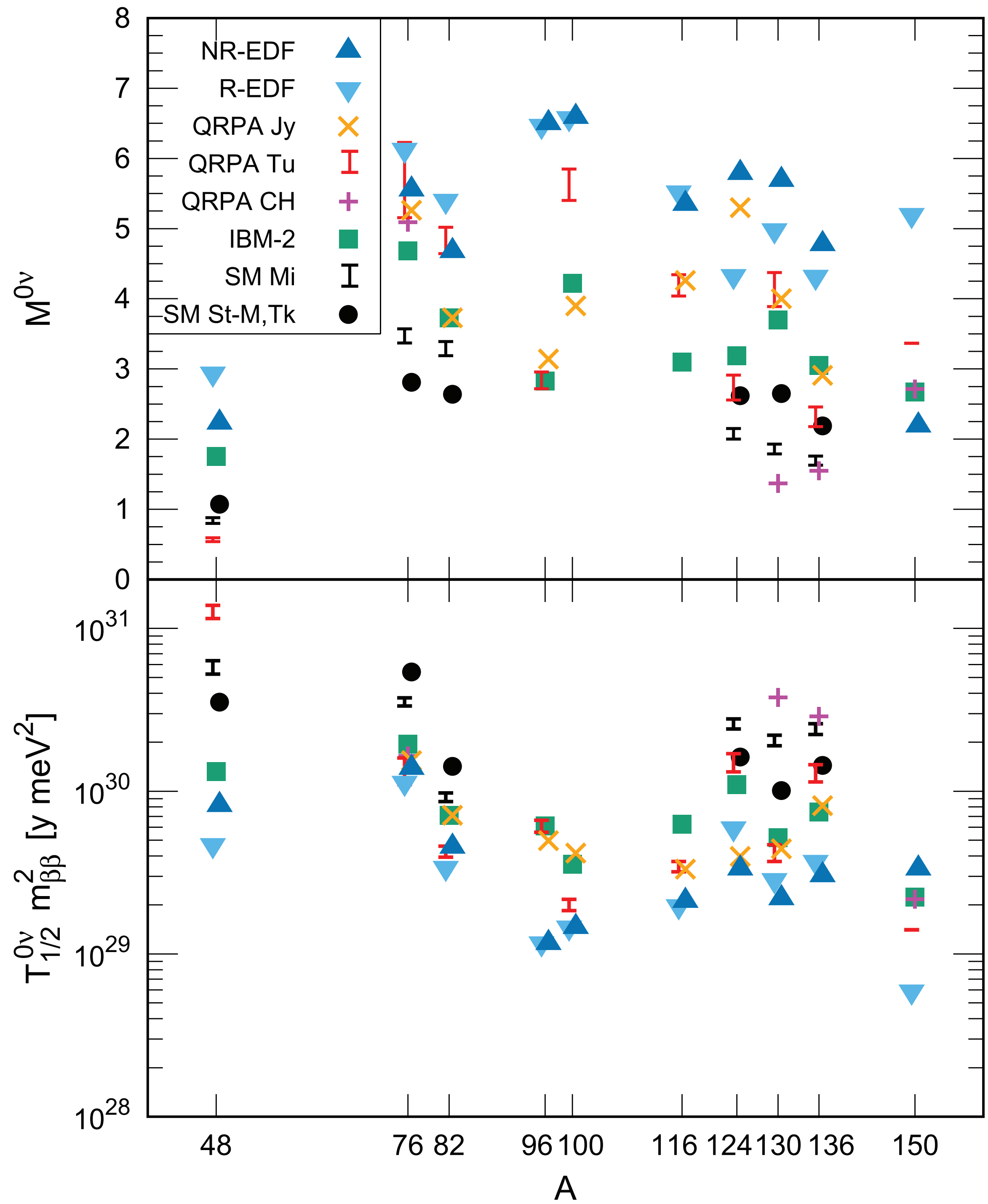
Nuclear matrix element: mass mechanism

$$M_{0\nu} = M_{GT} + M_F + M_T + \ldots$$

$$\left(T_{1/2}^{0\nu}\right)^{-1} = G_{01} g_A^4 |M_{0\nu}|^2 \left|m_{\beta\beta}\right|^2$$

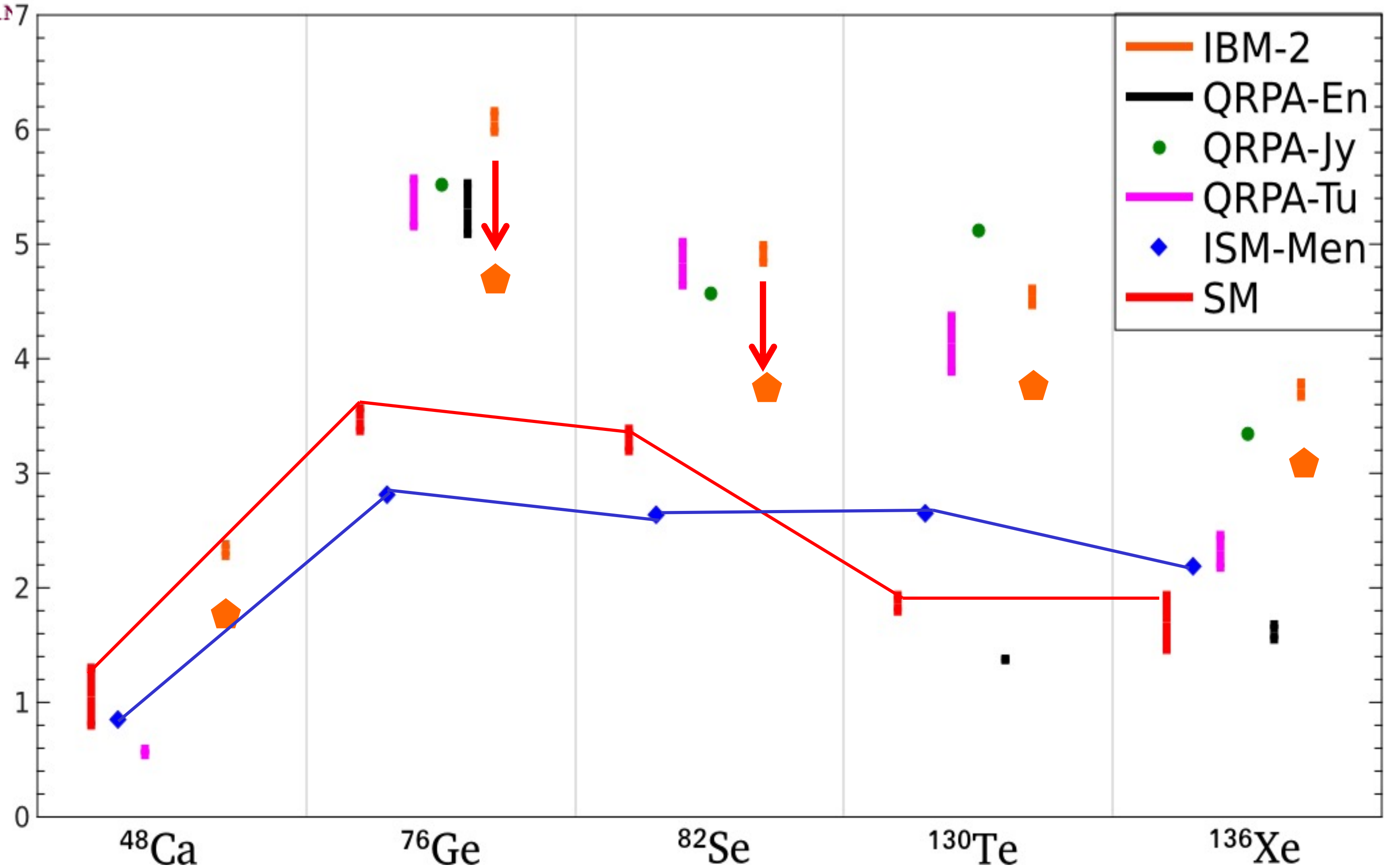
Rep. Prog. Phys. **80** (2017) 046301



INT23-1b May 15 2023

NME for the light-neutrino exchange mechanism

$M_{0\nu}$



IBA-2 J. Barea, J. Kotila, and F. Iachello, Phys. Rev. C **87**, 014315 (2013). → IBM-2 PRC **91**, 034304 (2015)

QRPA-En M. T. Mustonen and J. Engel, Phys. Rev. C **87**, 064302 (2013).

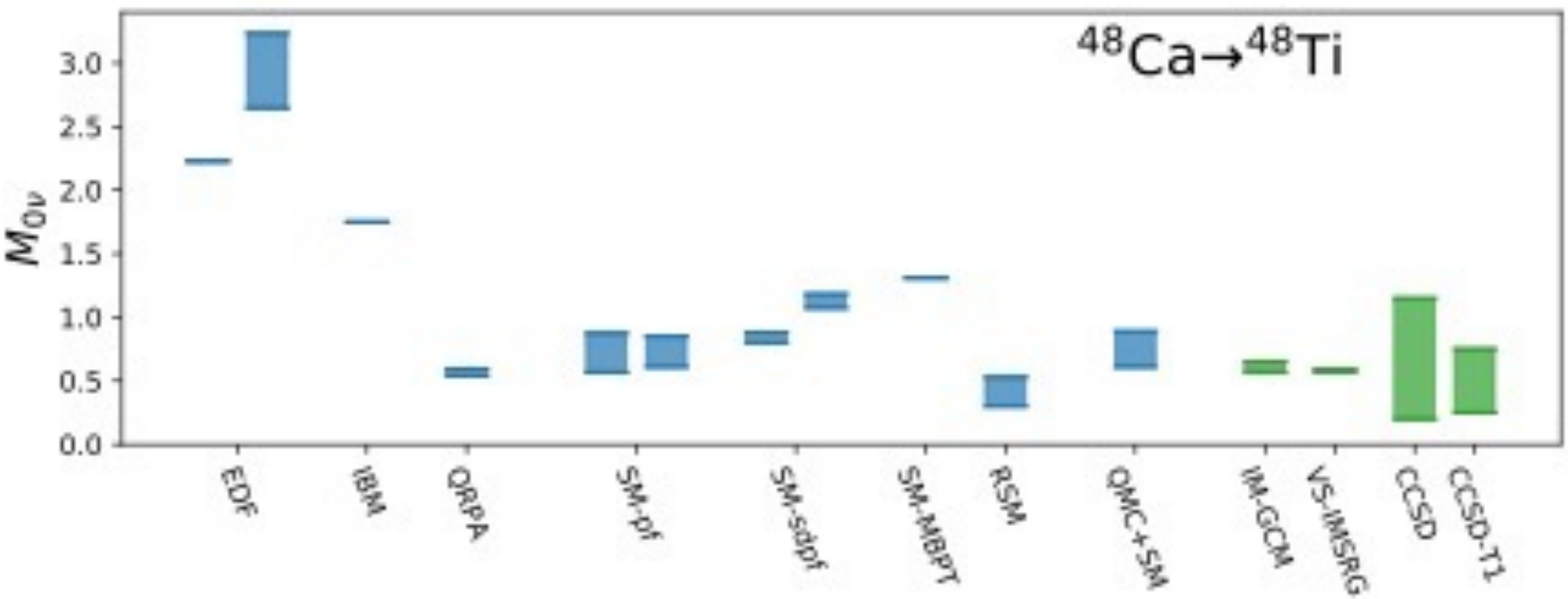
QRPA-Jy J. Suhonen, O. Civitarese, Phys. NPA **847** 207–232 (2010).

QRPA-Tu A. Faessler, M. Gonzalez, S. Kovalenko, and F. Simkovic, arXiv:**1408.6077**

ISM-Men J. Menéndez, A. Poves, E. Caurier, F. Nowacki, NPA **818** 139–151 (2009).

SM M. Horoi et. al. PRC **88**, 064312 (2013), PRC **89**, 045502 (2014), PRC **89**, 054304 (2014), PRC **90**, 051301(R) (2014), PRC **91**, 024309 (2015), PRL **110**, 222502 (2013), PRL **113**, 262501(2014).

Light left-handed neutrino-exchange NME update arxiv:2207.01085



Statistical analysis of the NME

PHYSICAL REVIEW C **107**, 045501 (2023)

Predicting the neutrinoless double-β-decay matrix element of ^{136}Xe using a statistical approach

M. Horoi,[1] A. Neacsu,[2,3] and S. Stoica[2]
[1]*Department of Physics, Central Michigan University, Mount Pleasant, Michigan 48859, USA*
[2]*International Center for Advanced Training and Research in Physics (CIFRA), Magurele 077125, Romania*
[3]*Horia Hulubei National Institute of Physics and Nuclear Engineering (IFIN-HH), Magurele 077125, Romania*

PHYSICAL REVIEW C **106**, 054302 (2022)

Statistical analysis for the neutrinoless double-β-decay matrix element of ^{48}Ca

M. Horoi,[1] A. Neacsu,[2,3] and S. Stoica[2]
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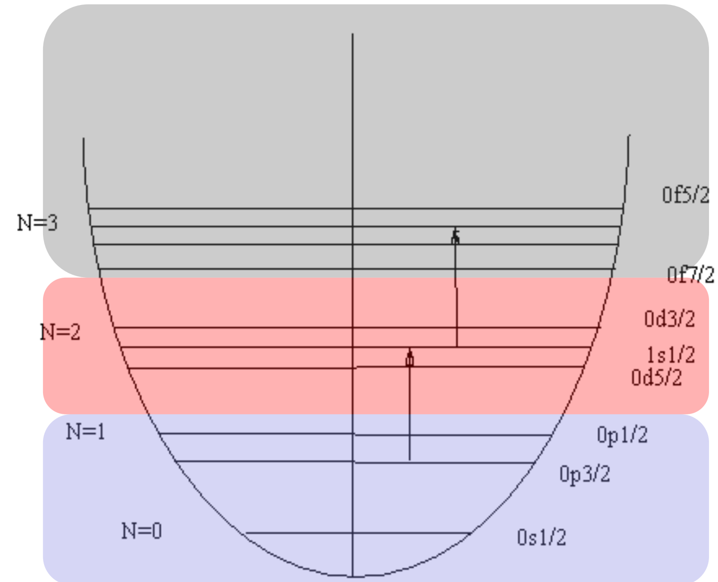
[2]*International Center for Advanced Training and Research in Physics (CIFRA), Magurele 077125, Romania*
[3]*Horia Hulubei National Institute for Physics and Nuclear Engineering (IFIN-HH), Magurele 077125, Romania*

IOP Publishing — Journal of Physics G: Nuclear and Particle Physics
J. Phys. G: Nucl. Part. Phys. **49** (2022) 120502 (30pp) https://doi.org/10.1088/1361-6471/aca03e

Towards precise and accurate calculations of neutrinoless double-beta decay

V Cirigliano[1], Z Davoudi[2], J Engel[3,*], R J Furnstahl[4], G Hagen[5,6], U Heinz[4], H Hergert[7], M Horoi[8], C W Johnson[9], A Lovato[10,11,12], E Mereghetti[13], W Nazarewicz[14,*], A Nicholson[3,15], T Papenbrock[5,6], S Pastore[16], M Plumlee[17,18], D R Phillips[19,*], P E Shanahan[20], S R Stroberg[10], F Viens[21], A Walker-Loud[15], K A Wendt[22] and S M Wild[18,23]

Shell Model Effective Hamiltonians



$g_A \sigma \tau \xrightarrow{quenched} g_A 0.77 \sigma \tau$

empty

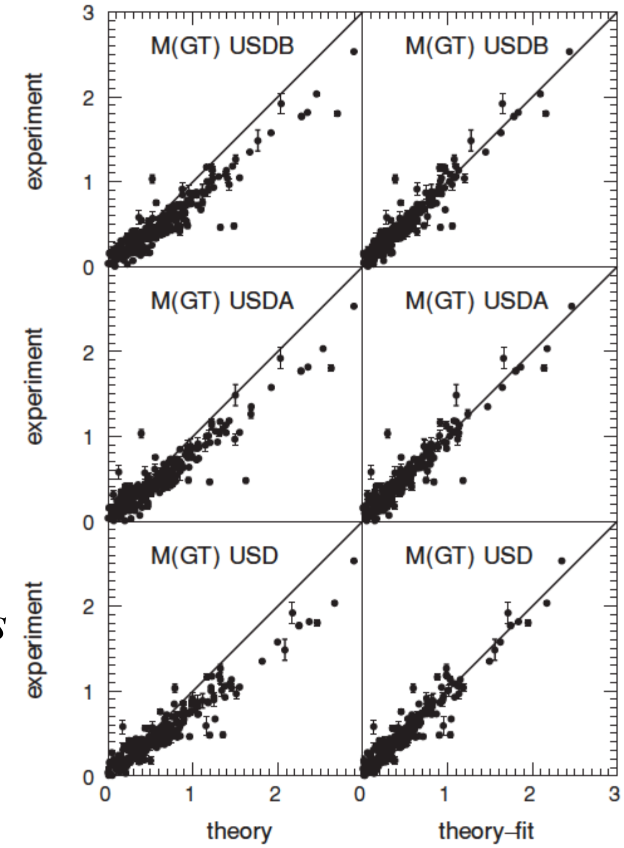
valence

frozen core

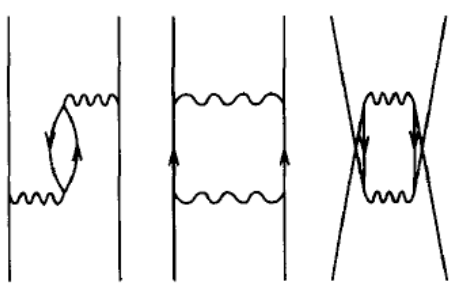
$$H_{valence} \Psi = E_n \Psi$$

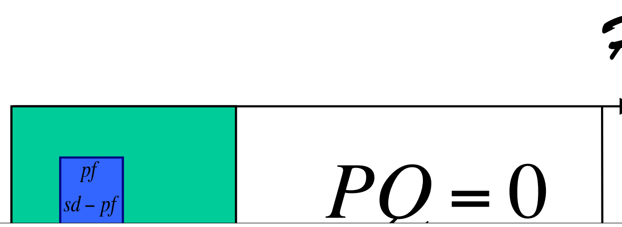
$$H_{valence} = H_{2-body}$$

can describe most correlations around the Fermi surface!

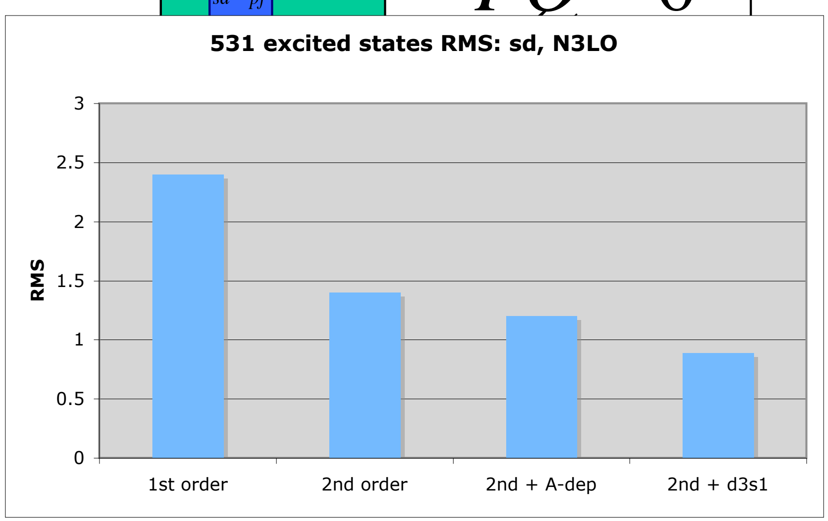


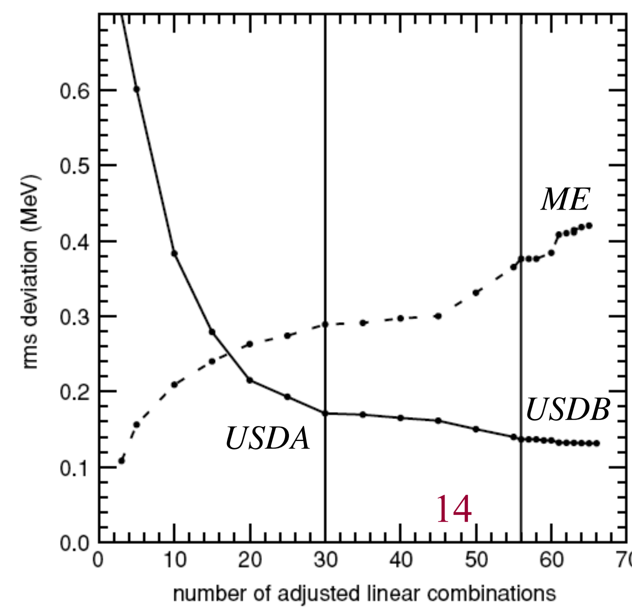
core polarization: Phys.Rep. **261**, 125 (1995)





PRC 74, 34315 (2006), 78, 064302 (2008)





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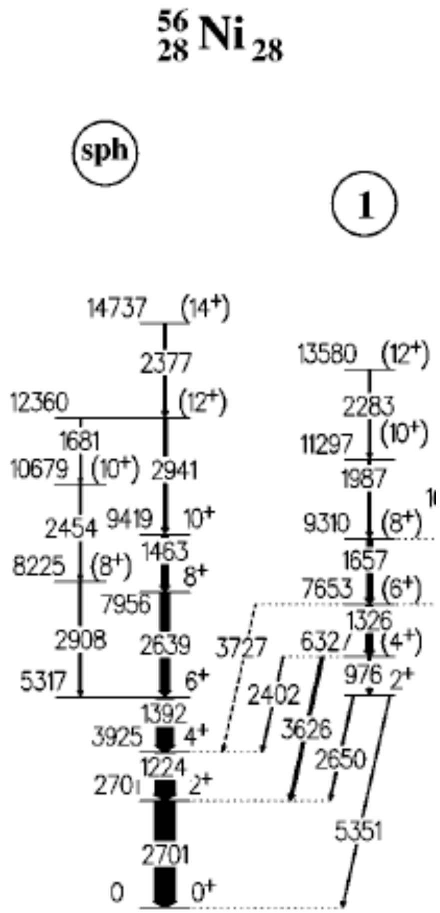
Koeln Low Spin States in ^{56}Ni: complete spectroscopy

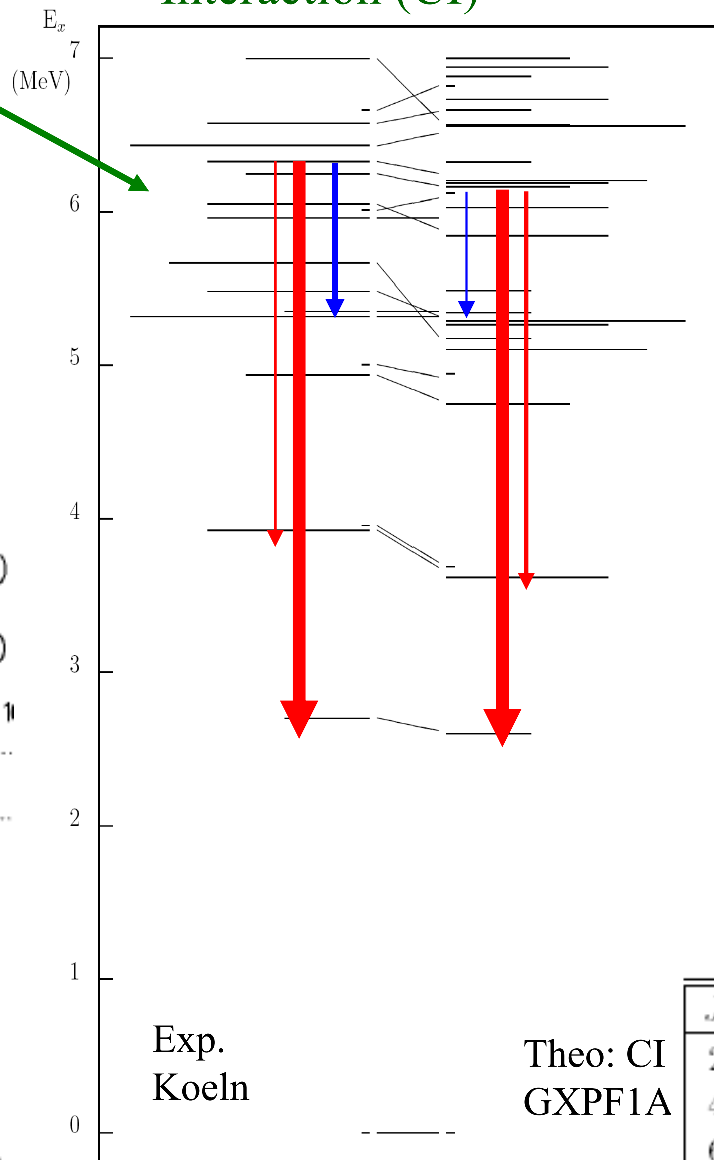
Configuration Interaction (CI)

M. Horoi et al., Phys.Rev. C 73, 061305(R) (2006)

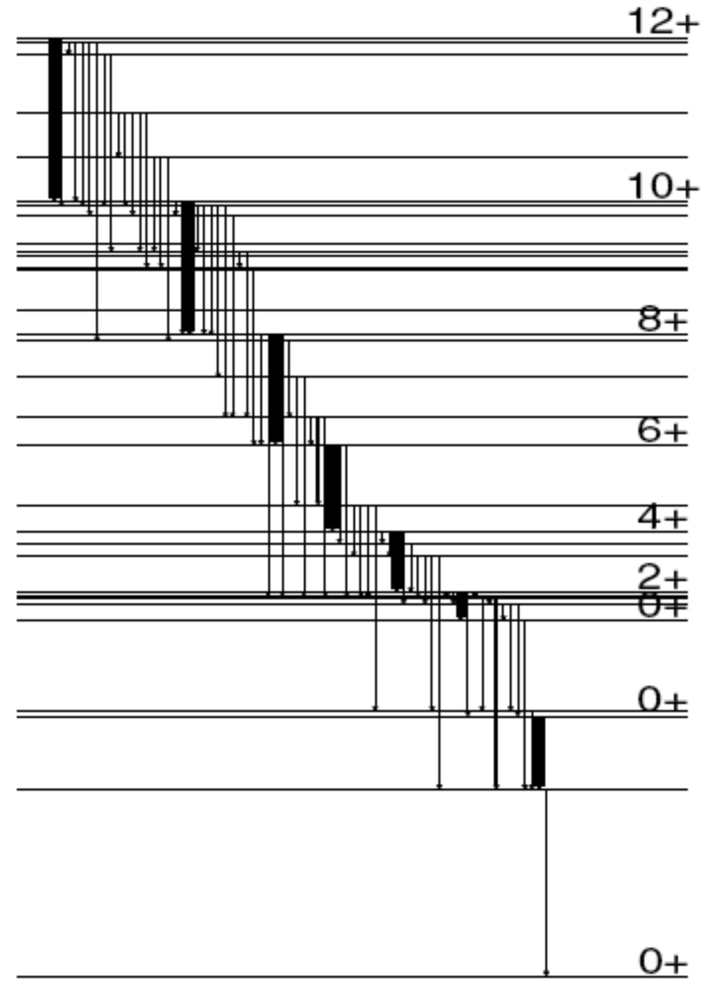


LBNLhigh spin **experiment**

D.Rudolf et al.,PRL88,1999



M. Horoi et al., 2006



J_n	E_x (MeV)	$< Q >_{J0}$	$(Q_0)_{sp}$	B(E2; $J \rightarrow J-2$)	$\vert Q_0 \vert_{tr}$
2_3	5.342	-41.6	+145.3	413.2	144.1
4_5	6.027	-55.2	+151.9	598.0	143.8
6_3	7.556	-56.2	+140.6	609.3	139.5
8_4	9.300	-47.2	+112.2	558.4	130.5
10_6	10.782	-63.9	+147.0	591.1	132.5
12_5	13.071	-62.7	+141.1	612.3	133.7

$e^{p}_{eff} = 1.5 \quad e^{n}_{eff} = 0.5$

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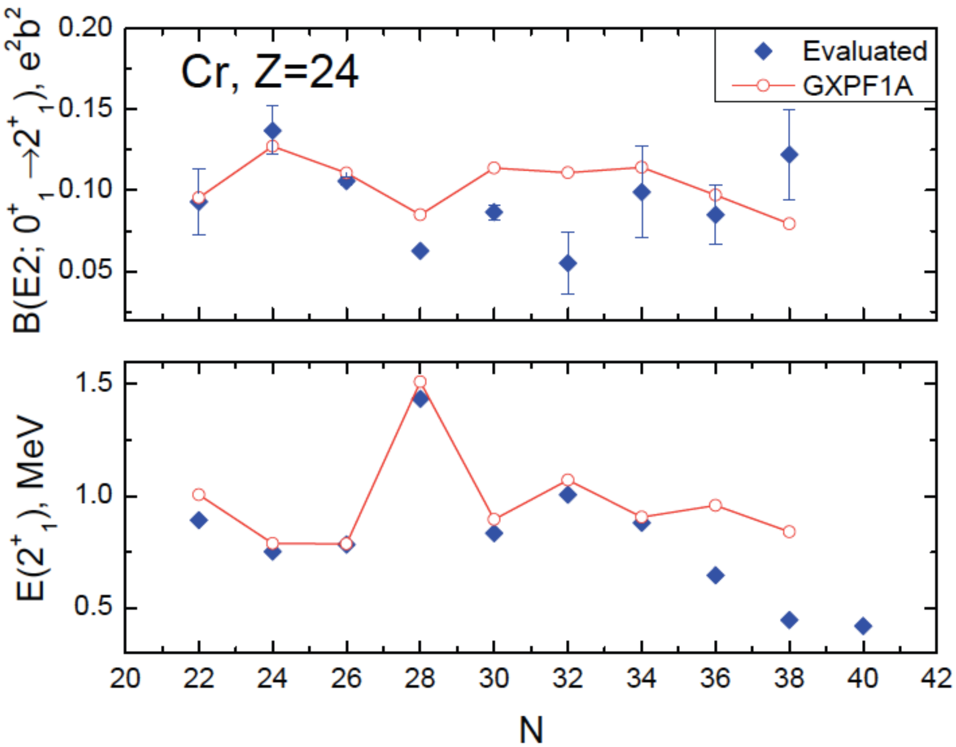
B. Pritycenko, J. Choquette, M. Horoi, B. Karamy, B. Singh, Atomic Data and Nuclear Data Tables, **107**, 1 (2016)

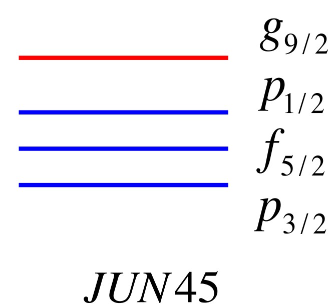
Shell-model Calculations

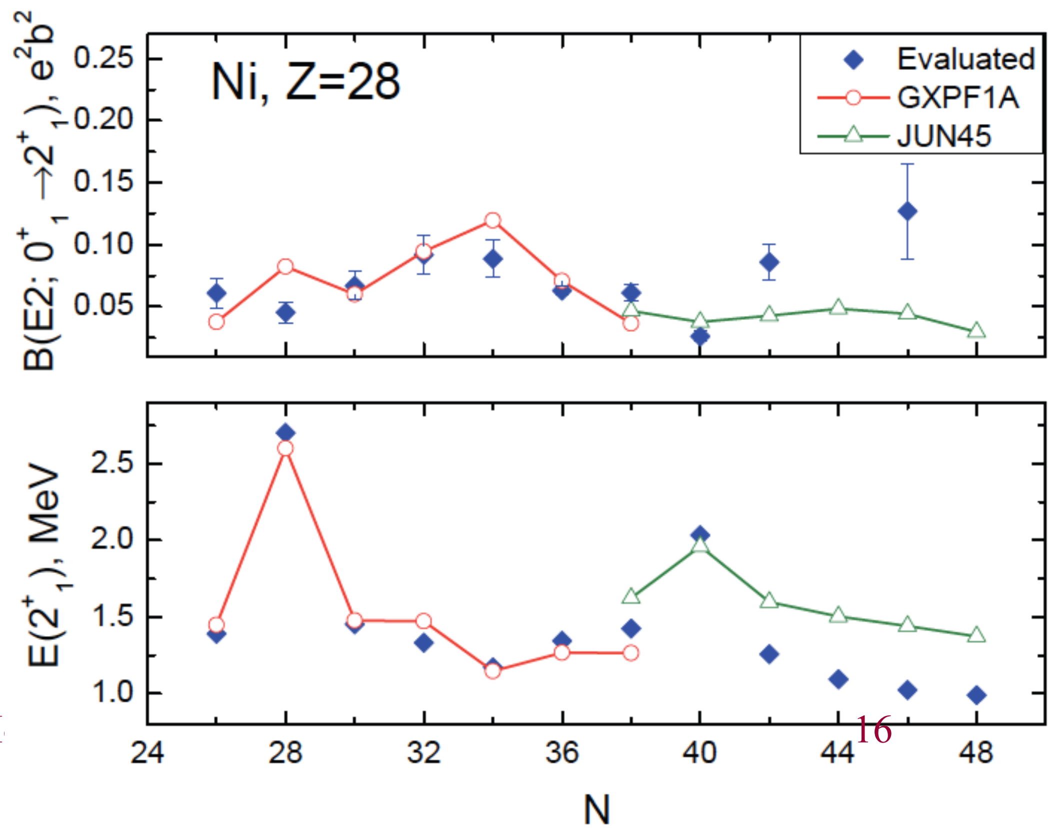


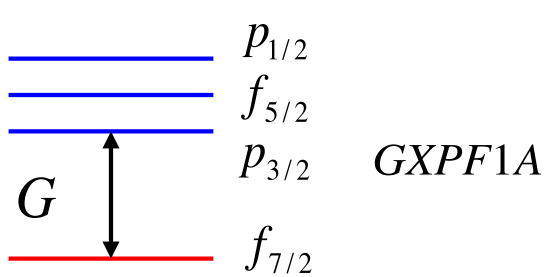
e been

GXPF1A and

$e_{eff}^{p} = 1.5 \quad e_{eff}^{n} = 0.5$







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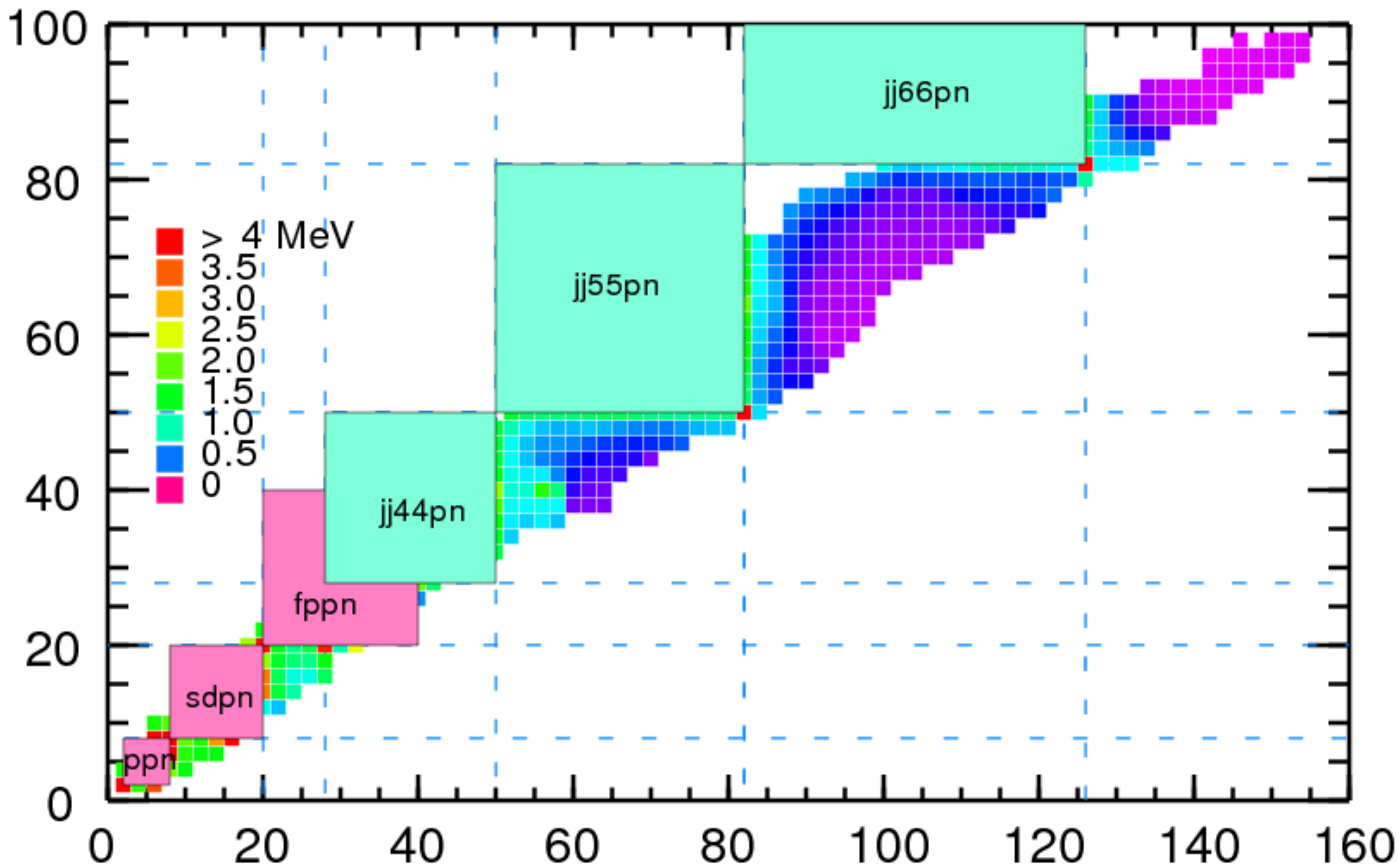
Shell Model Spaces



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Statistical Model: why ^{136}Xe?

- One of the longest half-life limit measured, ~2×10^{26} years
- One of the potential isotopes chosen for the next "tonne experiment"
- Relatively low shell model dimensions in the *jj55* ($0g_{7/2}, 2s, 1d, 0h_{11/2}$) model space

Statistical Model: Shell Model Effective Hamiltonians

- Isospin conserving effective Hamiltonians in *jj55* model space ($0g_{7/5}$, *2s1d*, $0h_{11/2}$)
- 327 TBME of starting Hamiltonians $\pm$10% uniformly random changes
- Three starting effective Hamiltonians:

=> SVD, PRC 86 044323 (2012)

=> GCN5082, PRC 82 064304 (2010)

=> jj55t, PRL 110 222502 (2013)

Statistical Model: Observables (24)

- 0nbb NME (1): $M_{0\nu}$, short-range correlator CD-Bonn
- 2nbb NME (1): $M_{2\nu}$, $q = 0.7$
- Energies 2+, 4+, 6+ (6): PE_{2+}, PE_{4+} , PE_{6+} , DE_{2+} , DE_{4+} , DE_{6+}
- B(GT) to 1+1 state (2): PGT, DGT, $q = 0.7$
- B(E2) 2^+ -> 0^+ (2): PBE2, DBE2 $e^p_{eff} = 1.5$ $e^n_{eff} = 0.5$
- Proton occupation (8): $POPg_7$, $POPs_1$, POPd, $POPh_{11}$, $DOPg_7$, $DOPs_1$, DOPd, $DOPh_{11}$
- Neutron vacancies (4): $DVNg_7$, $DVNs_1$, DVNd, $DVNh_{11}$
- Muon Capture rate (0)
- B(M1) (0)

Overview

Observable	Data	Error	svd_s	gcn_s	$j5t_s$	μ_{svd}	σ_{svd}	μ_{gcn}	σ_{gcn}	μ_{j5t}	σ_{j5t}
$M_{0\nu}$	N/A	N/A	1.763	2.645	2.314	1.749	0.111	2.632	0.135	2.306	0.156
$M_{2\nu}$	0.018	0.001	0.025	0.069	0.060	0.022	0.003	0.061	0.007	0.052	0.007
PGT	0.150	0.021	0.163	0.545	0.512	0.141	0.059	0.457	0.105	0.333	0.220
P$BE2$	0.286	0.081	0.154	0.121	0.096	0.153	0.009	0.122	0.013	0.099	0.012
PE_{2+}	1.313	0.150	1.498	1.363	1.513	1.494	0.089	1.352	0.089	1.507	0.098
PE_{4+}	1.694	0.150	2.073	1.747	2.012	2.070	0.089	1.740	0.107	2.011	0.107
PE_{6+}	1.892	0.150	2.178	1.892	2.254	2.192	0.088	1.884	0.125	2.212	0.096
POPg_7	2.930	0.100	2.705	2.716	3.143	2.702	0.187	2.705	0.209	3.082	0.267
POPs_1	0.057	0.006	0.089	0.025	0.020	0.090	0.018	0.025	0.006	0.021	0.006
POPh_{11}	0.400	0.040	0.190	0.375	0.265	0.189	0.020	0.373	0.050	0.265	0.045
POPd	0.520	0.030	1.016	0.884	0.572	1.019	0.180	0.896	0.197	0.632	0.250
DGT	0.012	0.005	0.001	0.009	0.004	0.001	0.000	0.008	0.003	0.003	0.003
D$BE2$	0.413	0.011	0.342	0.194	0.158	0.337	0.023	0.195	0.026	0.163	0.028
DE_{2+}	0.819	0.150	0.662	0.842	0.917	0.660	0.067	0.836	0.056	0.919	0.049
DE_{4+}	1.867	0.150	1.389	1.873	2.113	1.403	0.131	1.861	0.116	2.087	0.082
DE_{6+}	2.207	0.150	2.157	2.196	2.502	2.171	0.151	2.197	0.090	2.507	0.117
DVNg_7	0.000	0.150	0.102	0.174	0.130	0.100	0.010	0.172	0.014	0.132	0.023
DVNs_1	0.080	0.020	0.271	0.251	0.415	0.286	0.117	0.255	0.058	0.407	0.110
DVNh_{11}	1.680	0.130	1.205	0.726	0.347	1.177	0.237	0.724	0.132	0.385	0.162
DVNd	0.240	0.050	0.423	0.850	1.108	0.437	0.132	0.850	0.118	1.076	0.158
DOPg_7	3.860	0.100	3.189	3.475	4.145	3.187	0.209	3.477	0.249	4.078	0.436
DOPs_1	0.200	0.020	0.263	0.083	0.049	0.264	0.047	0.084	0.020	0.052	0.017
DOPh_{11}	0.620	0.060	0.264	0.658	0.625	0.269	0.049	0.658	0.093	0.613	0.121
DOPd	1.290	0.080	2.285	1.785	1.181	2.280	0.227	1.781	0.265	1.258	0.447

Table I. All relevant data and statistics for all selected observables.

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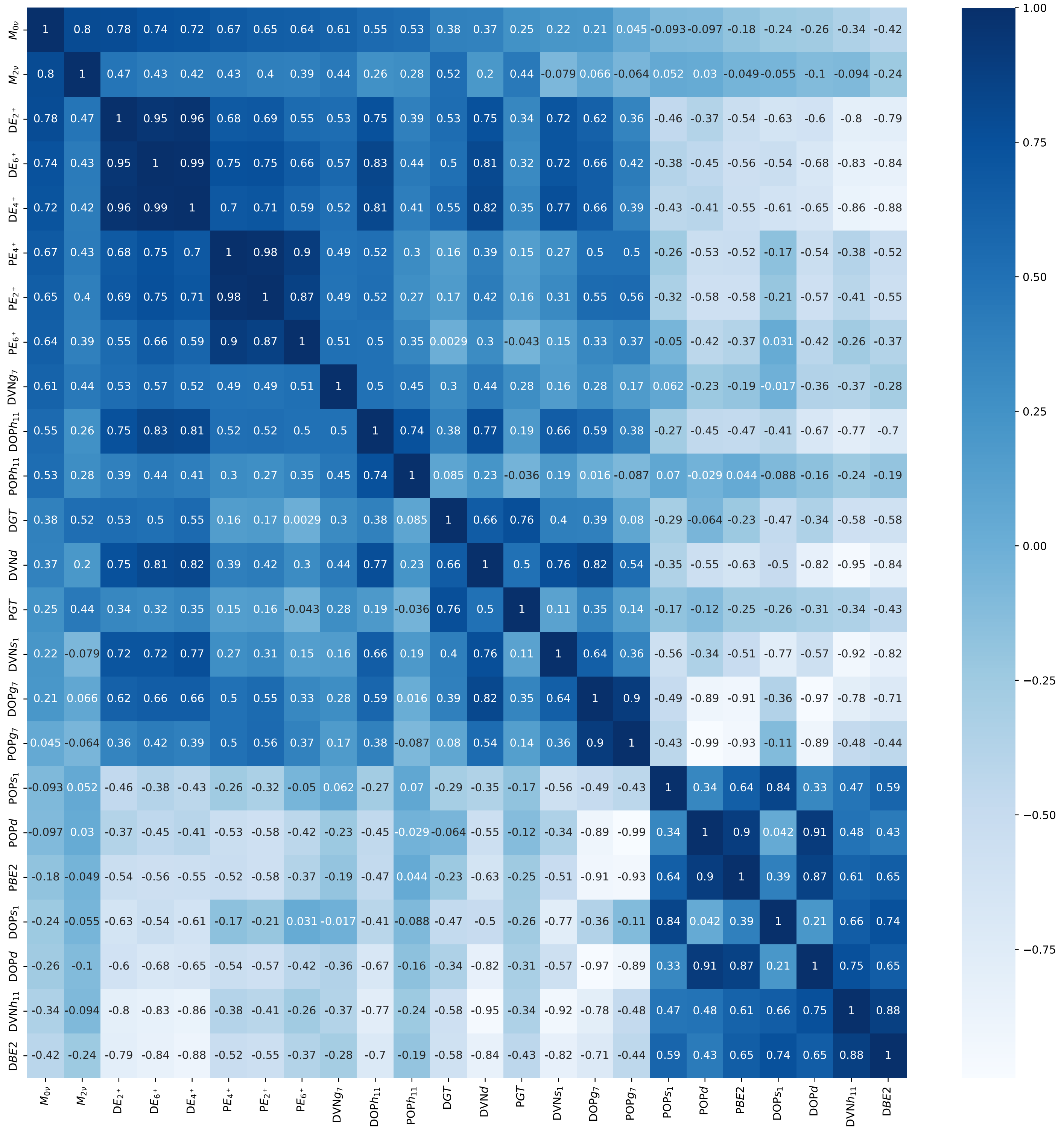
Statistical Model: Heat Map

samples=1,000



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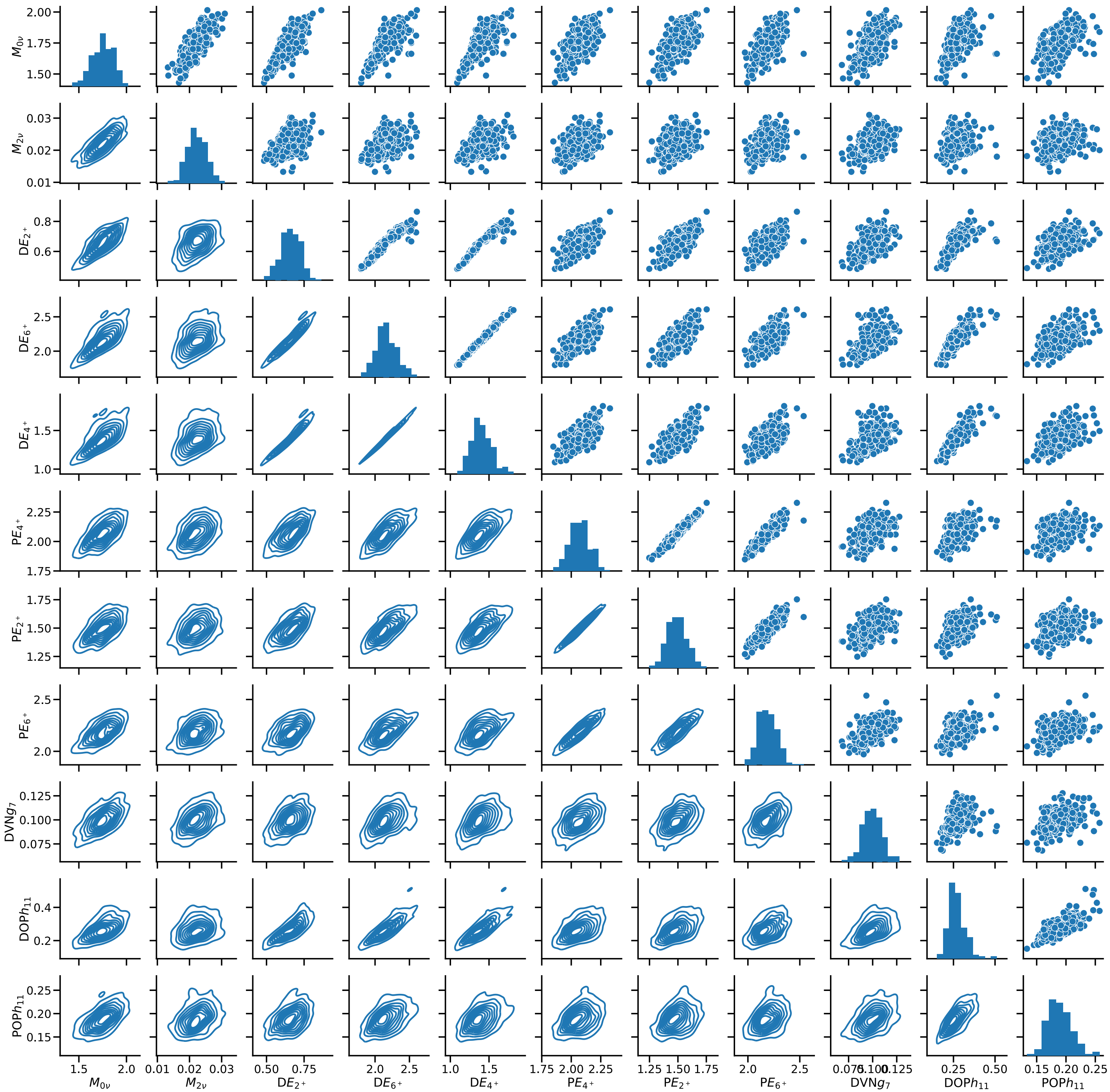
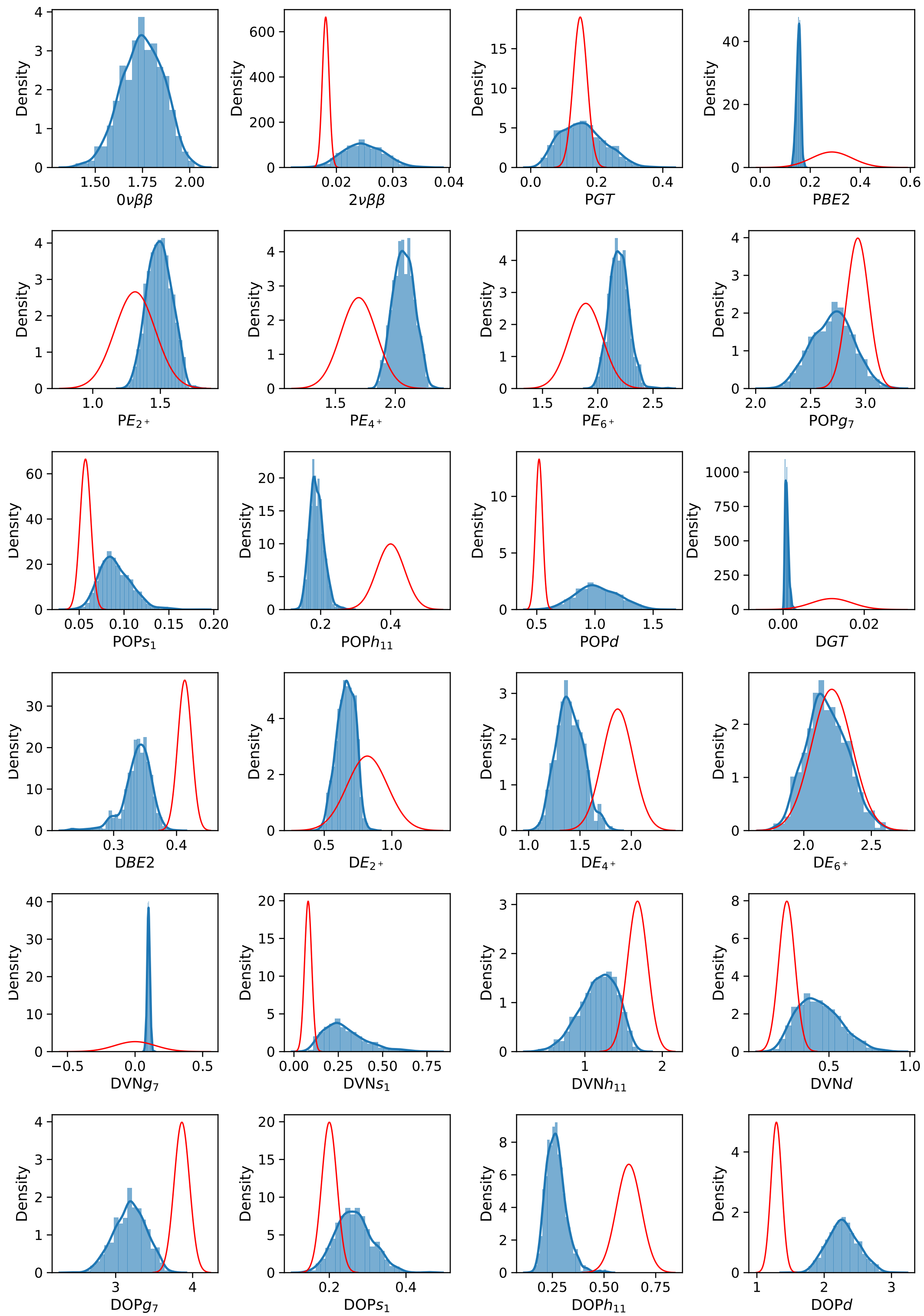
Statistical Model: Correlations Map



Statistical Model: Density Distributions



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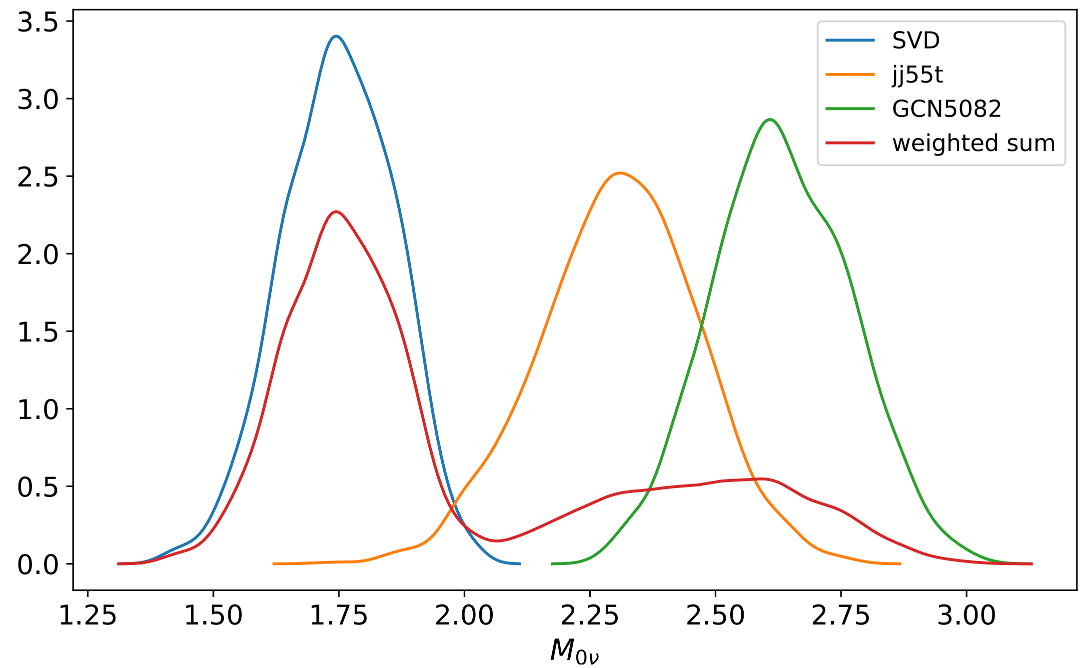
Statistical Model: joint distribution

$$P(x = M_{0\nu}) = W_{svd}P_{svd}(x) + W_{gcn}P_{gcn}(x) + W_{j5t}P_{j5t}(x) \ ,$$



Statistical Model: Bayesian Model Averaging

$$p(x = M_{0\nu}|y_e, \sigma_e) = \sum_{k=svd}^{j5t} p(x = M_{0\nu}|y_e, \sigma_e, \mathcal{M}_k)p(\mathcal{M}_k|y_e, \sigma_e),$$

$M_{0\nu}$ =1.99 ± 0.37

$$p(\mathcal{M}_k|y_e, \sigma_e) = \frac{p(y_e, \sigma_e|\mathcal{M}_k)\pi(\mathcal{M}_k)}{\sum_{k=svd}^{j5t} p(y_e, \sigma_e|\mathcal{M}_k)\pi(\mathcal{M}_k)}$$

W_H

$$p(y_e, \sigma_e|\mathcal{M}_k) = \int \prod_i^{N_{obs}} dy_i p_{y_e,\sigma_e}(y_i) \left[\int \prod_j^{N_{tbme}} d\theta_j p(y_i|\theta_j, \mathcal{M}_k)\pi(\theta_j|\mathcal{M}_k) \right]$$

Evidence integrals

$$p_{y_e,\sigma_e}(y_i) \propto \prod_i^{N_{obs}} exp[-(y_i - y_{e_i})^2/(2\sigma_{e_i}^2)]$$

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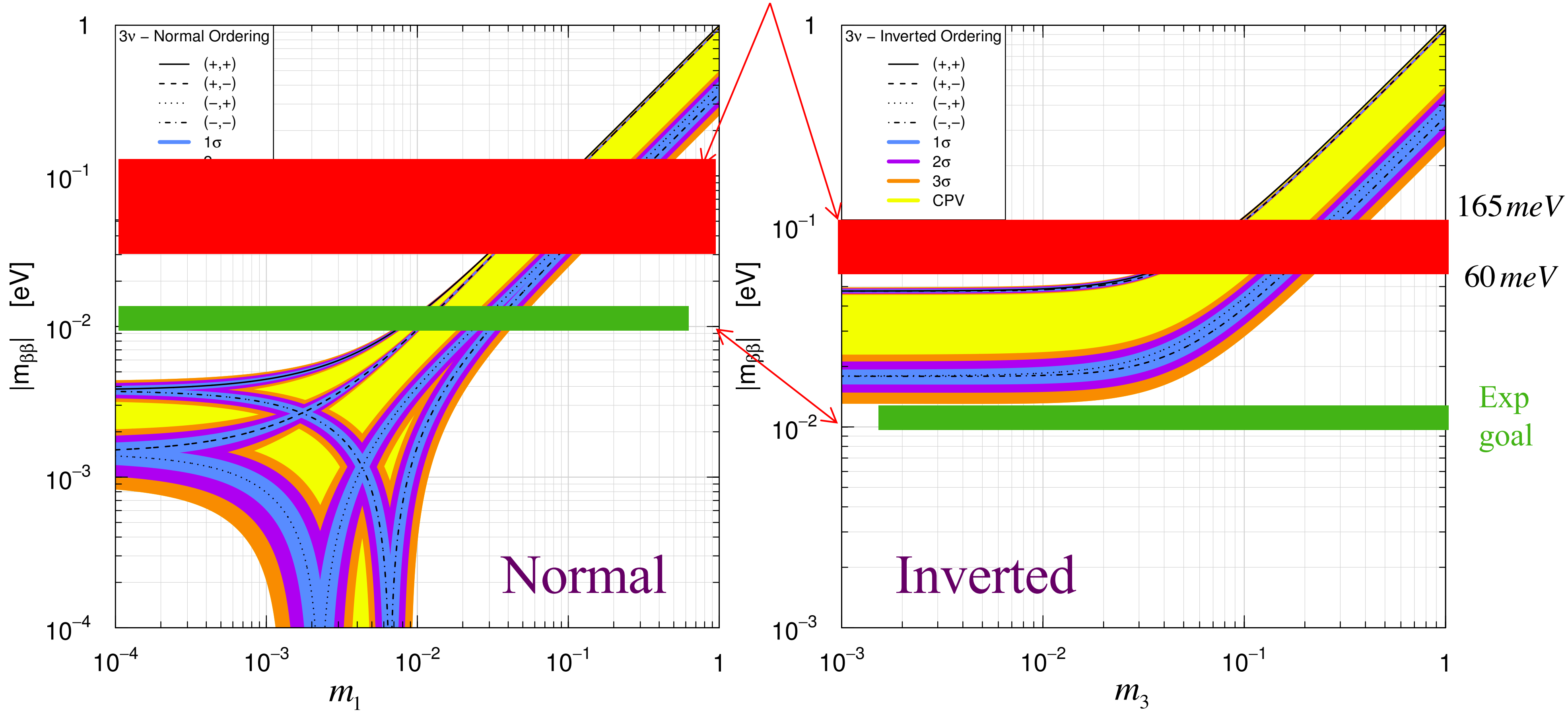
Neutrino ββ effective mass

arxiv:1507.08204

KamLAND – Zen, PRL 117, 082503 (2016) : ^{136}Xe



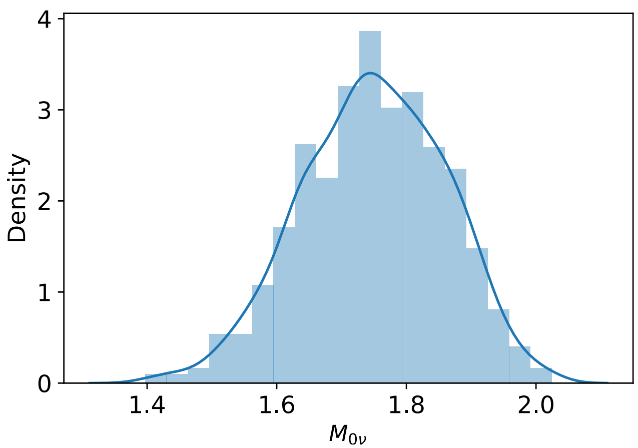
$$\left|m_{\beta\beta}\right| = \left|\sum_{k=1}^{3} m_k U_{ek}^2\right| = \left|c_{12}^2 c_{13}^2 m_1 + c_{13}^2 s_{12}^2 m_2 e^{i\phi_2} + s_{13}^2 m_3 e^{i\phi_3}\right|$$

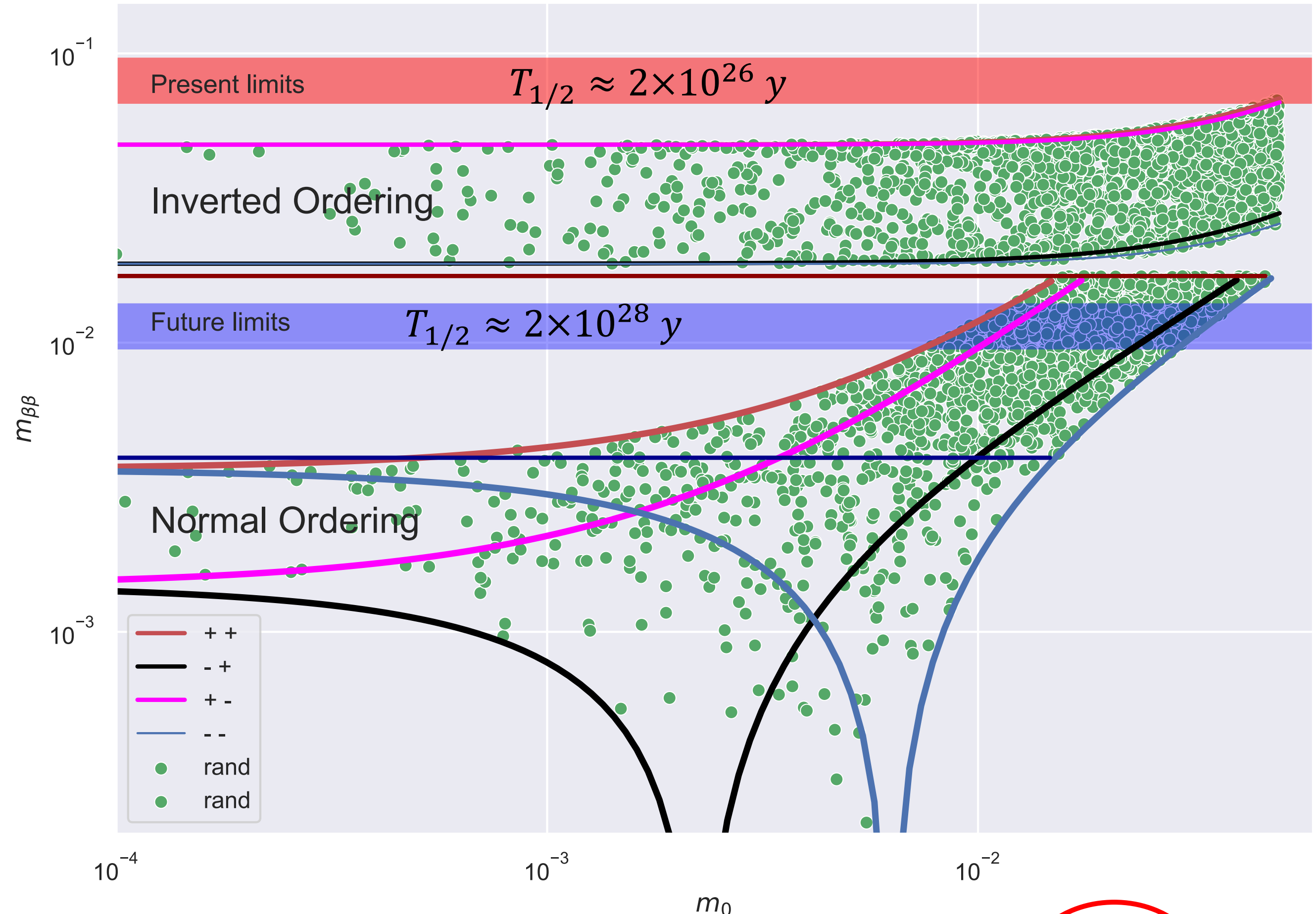
$$\Leftarrow T_{1/2}^{-1}(0\nu) = G^{0\nu}(Q_{\beta\beta})\left[M^{0\nu}(0^+)\right]^2 (\eta_{0\nu})^2$$

$$\phi_2 = \alpha_2 - \alpha_1 \qquad \phi_3 = -\alpha_1 - 2\delta$$

$$\eta_{0\nu} = \frac{\left|m_{\beta\beta}\right|}{m_e}$$

Mass mechanism interference effects





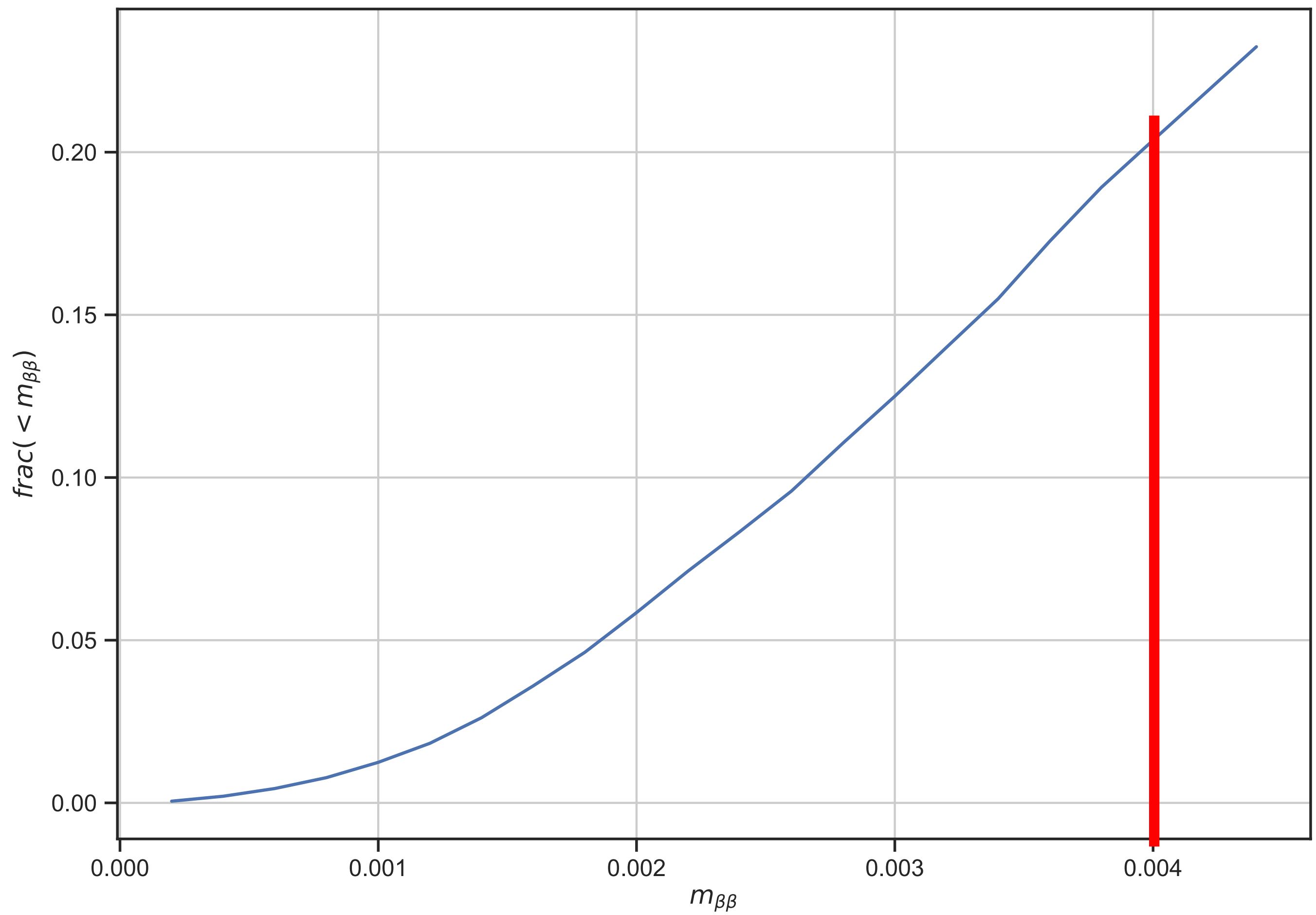
$$\left|m_{\beta\beta}\right| = \left|\sum_{k=1}^{3} m_k U_{ek}^2\right| = \left|c_{12}^2 c_{13}^2 m_1 + c_{13}^2 s_{12}^2 m_2 e^{i\phi_2} + s_{13}^2 m_3 e^{i\phi_3}\right|$$

$$\Leftarrow T_{1/2}^{-1}(0\nu) = G^{0\nu}(Q_{\beta\beta})\left[M^{0\nu}(0^+)\right]^2 (\eta_{0\nu})^2$$

$$M^{0\nu} = M_{GT}^{0\nu} - \left(\frac{g_V}{g_A}\right)^2 M_F^{0\nu} + M_T^{0\nu}$$

$$\eta_{0\nu} = \frac{\left|m_{\beta\beta}\right|}{m_e}$$

Mass mechanism interference effects



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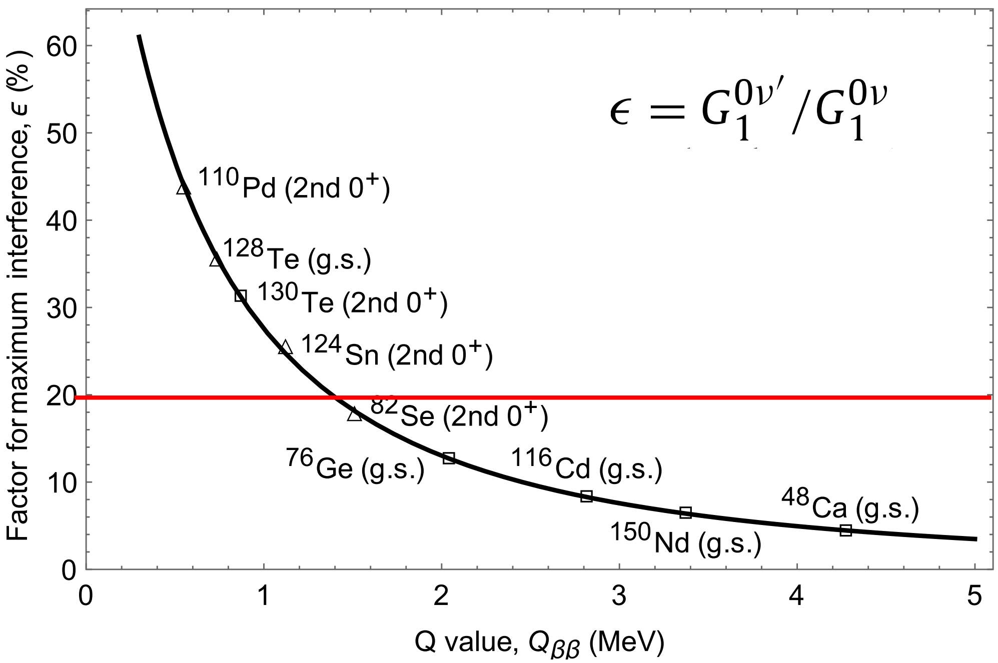
LRSM interference effects

$$\left[T_{1/2}^{0\nu}\right]^{-1} \approx 2 g_A^4 G_1^{0\nu} \left|\eta\right|^2 \left|M\right|^2 \left[1 - \epsilon \cos\phi\right]$$



Interference between mass mechanism and heavy neutrino mechanism: F. Ahmed, A. Neacsu, and M. Horoi, Phys. Lett. B 769, 299 (2017).

In LRSM:

$$\left[T_{1/2}^{0\nu}\right]^{-1} = \left|\mathcal{M}_{GT}^{0\nu}\right|^2 \Big[C_m|\eta_m|^2 + C_N|\eta_N|^2 + C_\lambda|\eta_\lambda|^2 + C_\eta|\eta_\eta|^2 + C_{mN}|\eta_m||\eta_N|\cos(\phi_m - \phi_N) + C_{m\lambda}|\eta_m||\eta_\lambda|\cos(\phi_m - \phi_\lambda) + C_{m\eta}|\eta_m||\eta_\eta|\cos(\phi_m - \phi_\eta) + C_{N\lambda}|\eta_N||\eta_\lambda|\cos(\phi_N - \phi_\lambda) + C_{N\eta}|\eta_N||\eta_\eta|\cos(\phi_N - \phi_\eta) + C_{\lambda\eta}|\eta_\lambda||\eta_\eta|\cos(\phi_\lambda - \phi_\eta) \Big]$$

Interference between mass mechanism and eta mechanism: F. Ahmed, and M. Horoi, PRC 101, 035504 (2020).

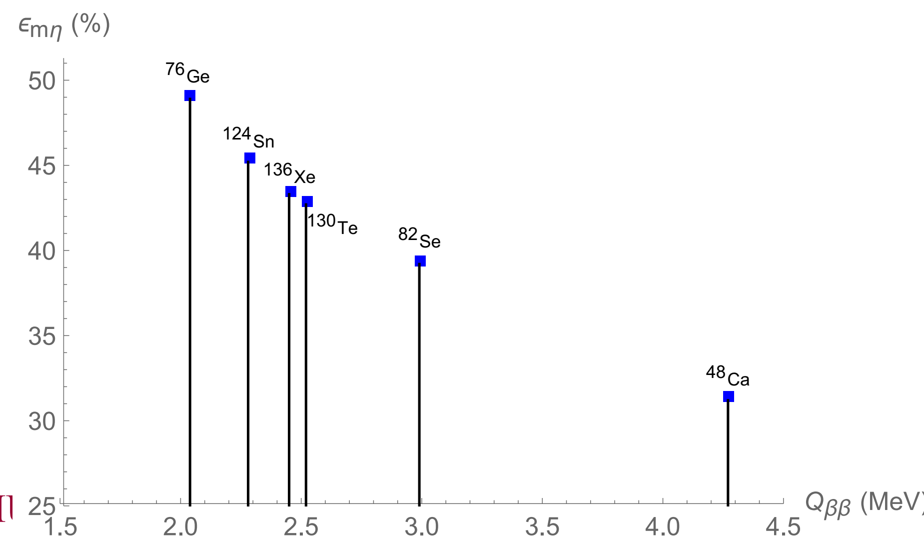


FIG. 5. Coefficient of maximum interference $\epsilon_{m\eta}(1)$ plotted against $Q_{\beta\beta}$ values.

LRSM interference effects

$$[T_{1/2}^{0\nu}]^{-1} \simeq g_A^4[C_i|\eta_i|^2 + C_j|\eta_j|^2 + C_{ij}|\eta_i||\eta_j|\cos(\phi_i - \phi_j)],$$

$$C_{m\eta} = \left[M_{GT} - \left(\frac{g_V}{g_A}\right)^2 M_F + M_T\right] \times [G_{03}\mathcal{M}_{2+} - G_{04}\mathcal{M}_{1-} - G_{05}M_P + G_{06}M_R]$$

Phase space factors

$$C_j|\eta_j|^2 = \alpha C_i|\eta_i|^2 \Rightarrow |\eta_j| = \sqrt{\alpha\frac{C_i}{C_j}}|\eta_i|.$$

$$\epsilon_{ij}(\alpha) = \frac{\sqrt{\alpha}}{1+\alpha}\frac{|C_{ij}|}{\sqrt{|C_i||C_j|}}$$

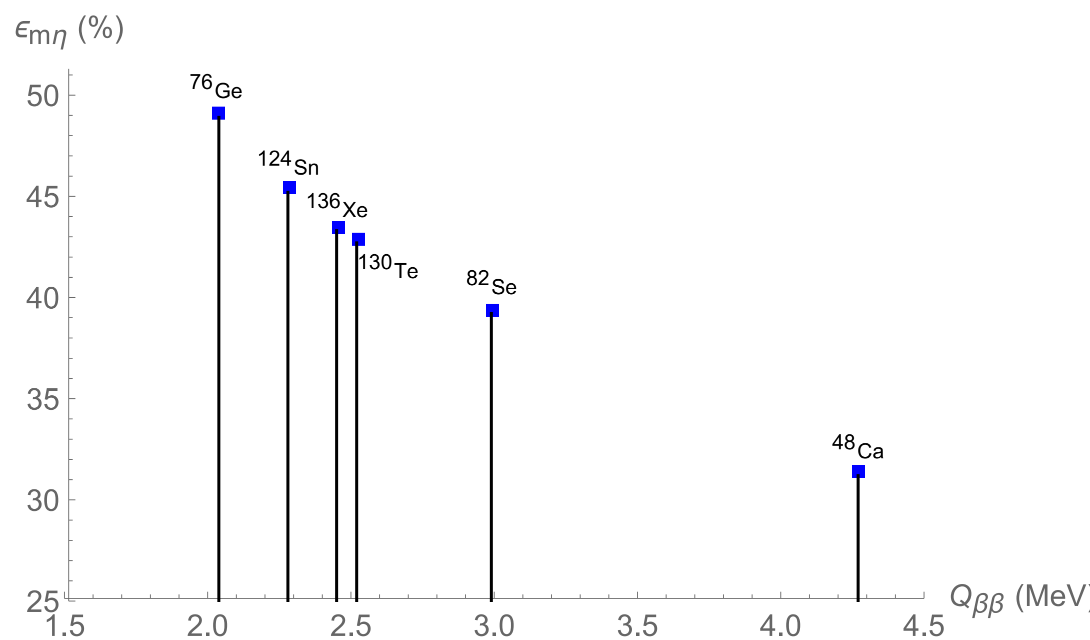


FIG. 5. Coefficient of maximum interference $\epsilon_{m\eta}(1)$ plotted against $Q_{\beta\beta}$ values.

$$\alpha = 1$$

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Statistical Model: Results

- Shell model observables show robustness relative to small random changes of the effective Hamiltonian
- $M_{0\nu}$ shows significant correlations with about half of the observables considered
- The outcome of our **Bayesian Averaging model** is a joint distribution of the ^{136}Xe $M_{0\nu}$ with a range of 1.55 – 2.65 at 90% confidence level
- We propose a $M_{0\nu}$ NME of 1.99 $\pm$ 0.37 for ^{136}Xe

Future work:

- Statistical investigation of the maximal interference effects

- Investigate other random changes, e.g. 15%, GOA, etc

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