Shell model neutrinoless double-beta decay NME of ^{136}Xe within a statistical approach

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The NME problem:

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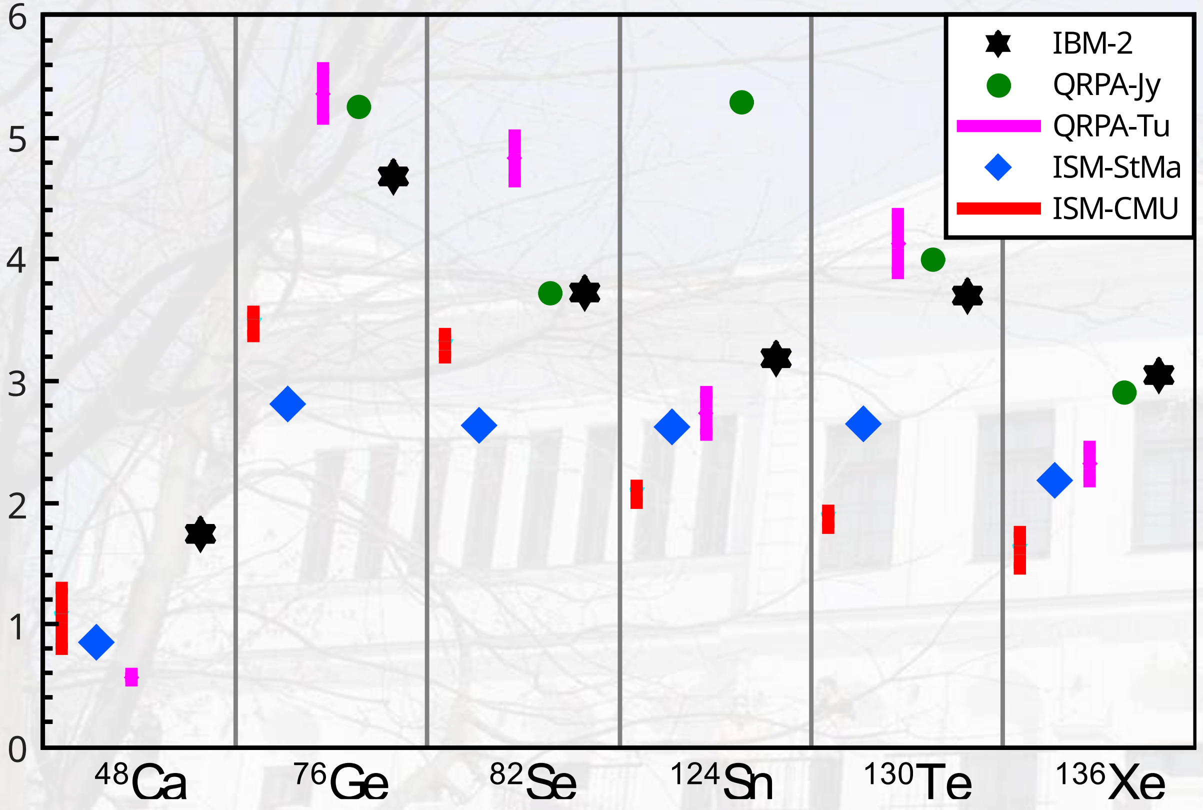
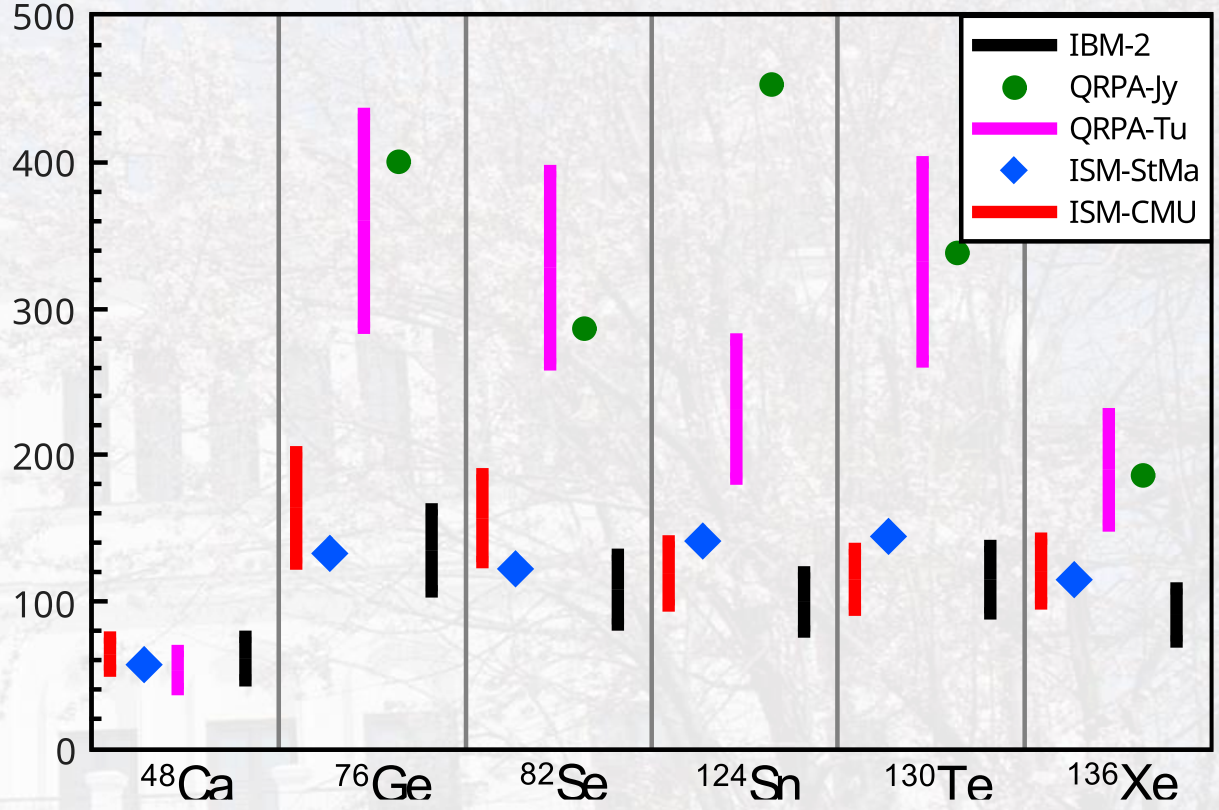


light neutrino-exchange 0νββ NME



heavy neutrino-exchange 0νββ NME

BSM predictions with different Hamiltonians

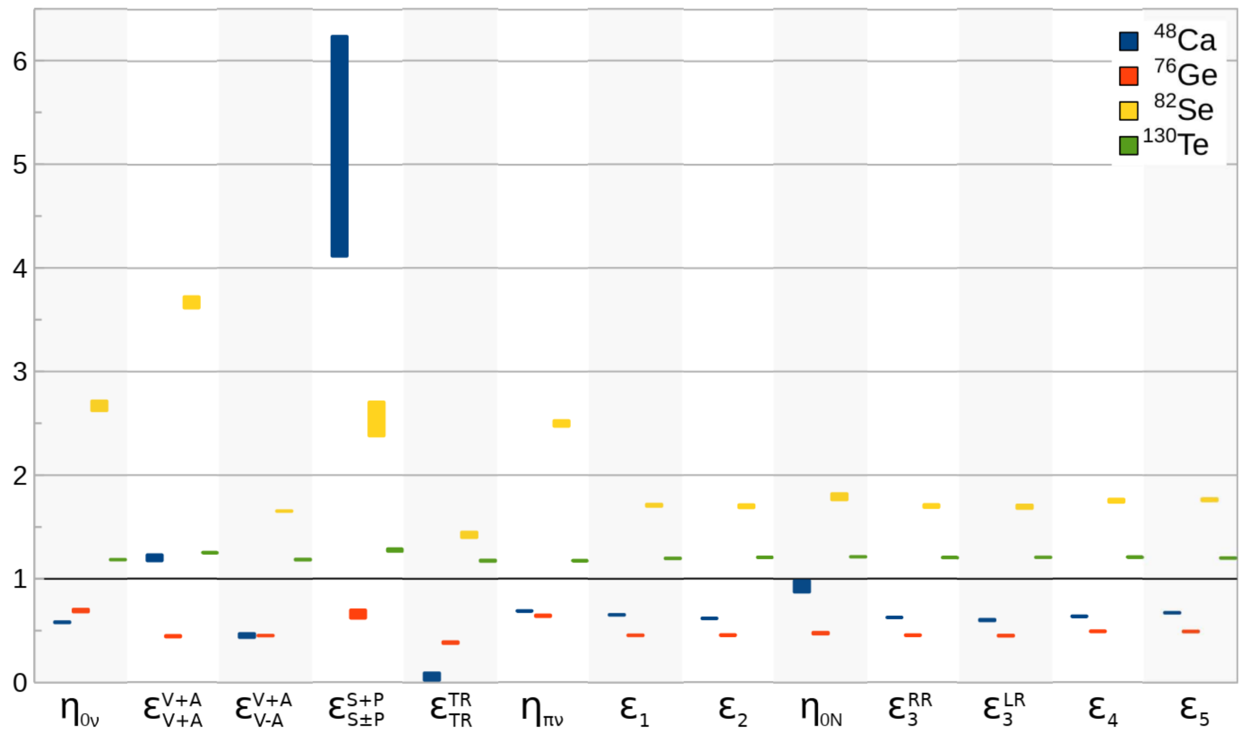


FIG. 3. The ratio between the ^{136}Xe half-life and the T_α half-lives of several experimentally interesting isotopes, in the case of 12 EFT LNV couplings plus η_{0N}. The left to right order of the bars corresponds to up to down order in the Legend. The height of the bars represents the difference between results obtained with different SRC parameterizations. η_{0N} plays a similar role to $\varepsilon_3^{RRz(LLz)}$.

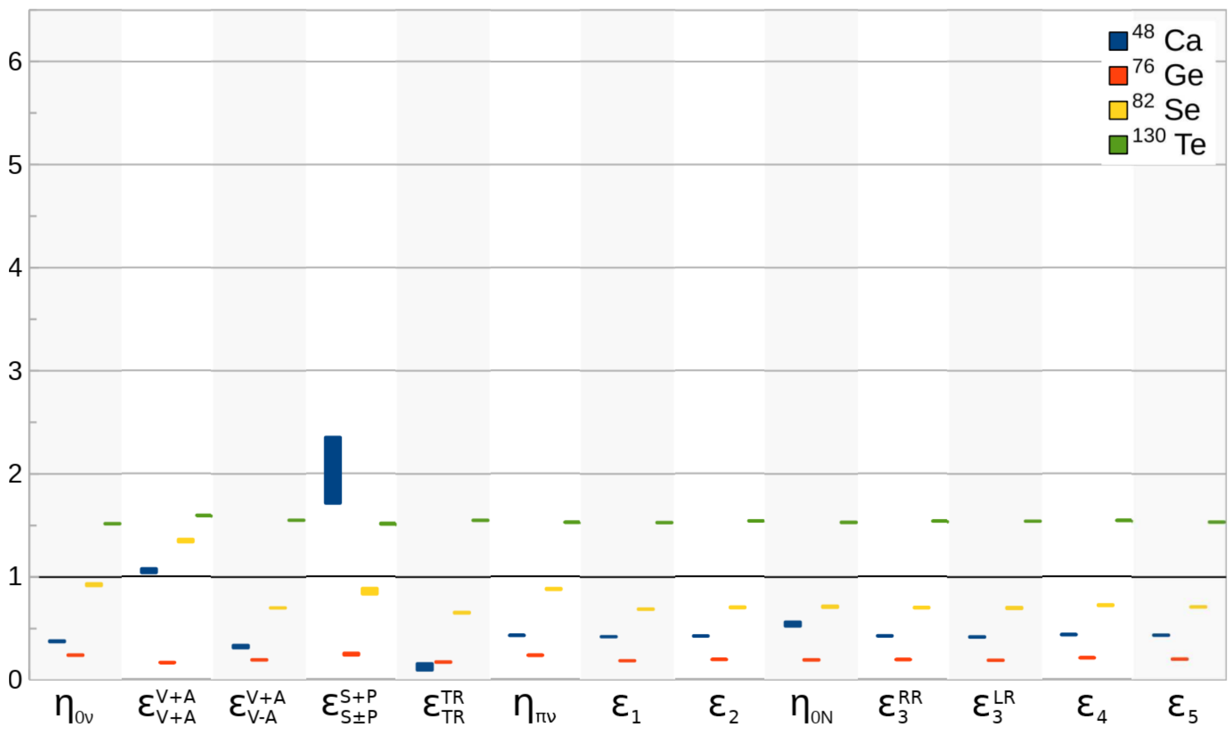


FIG. 4. Same as Fig. 3, but for the Strasbourg-Madrid choice of Hamiltonians.

Looking for the dominant BSM mechanism through ratios of half-lives

The Solution

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

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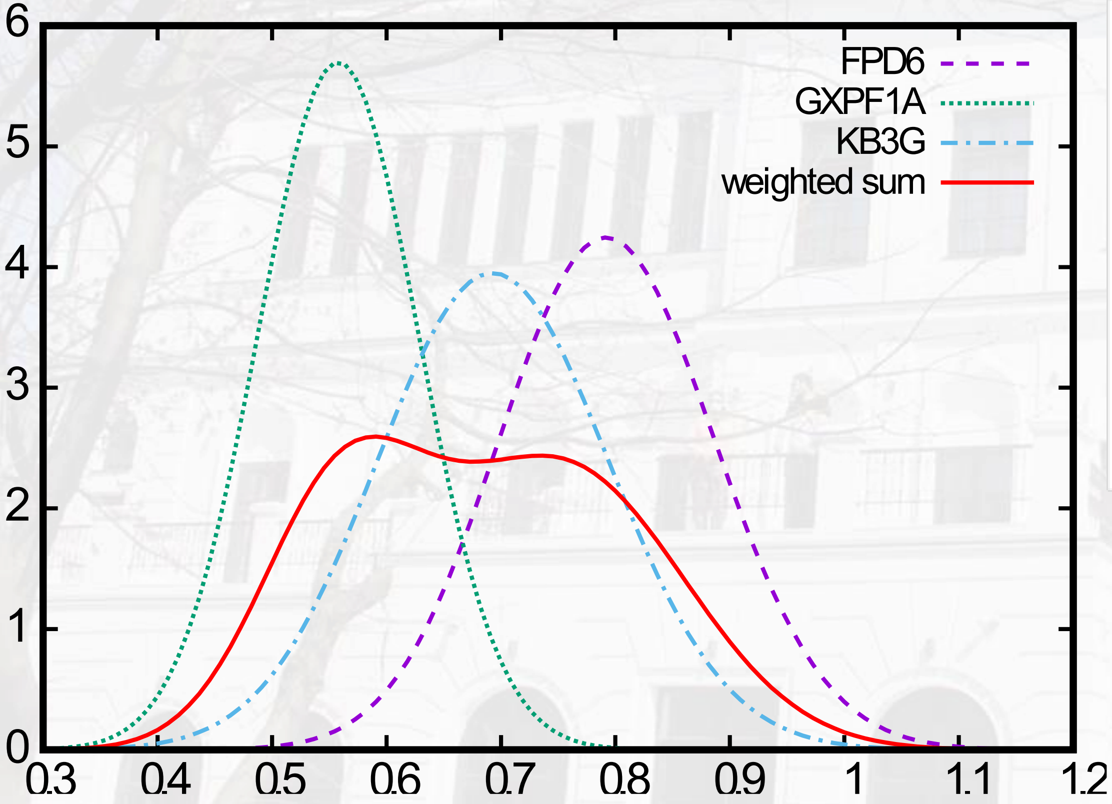

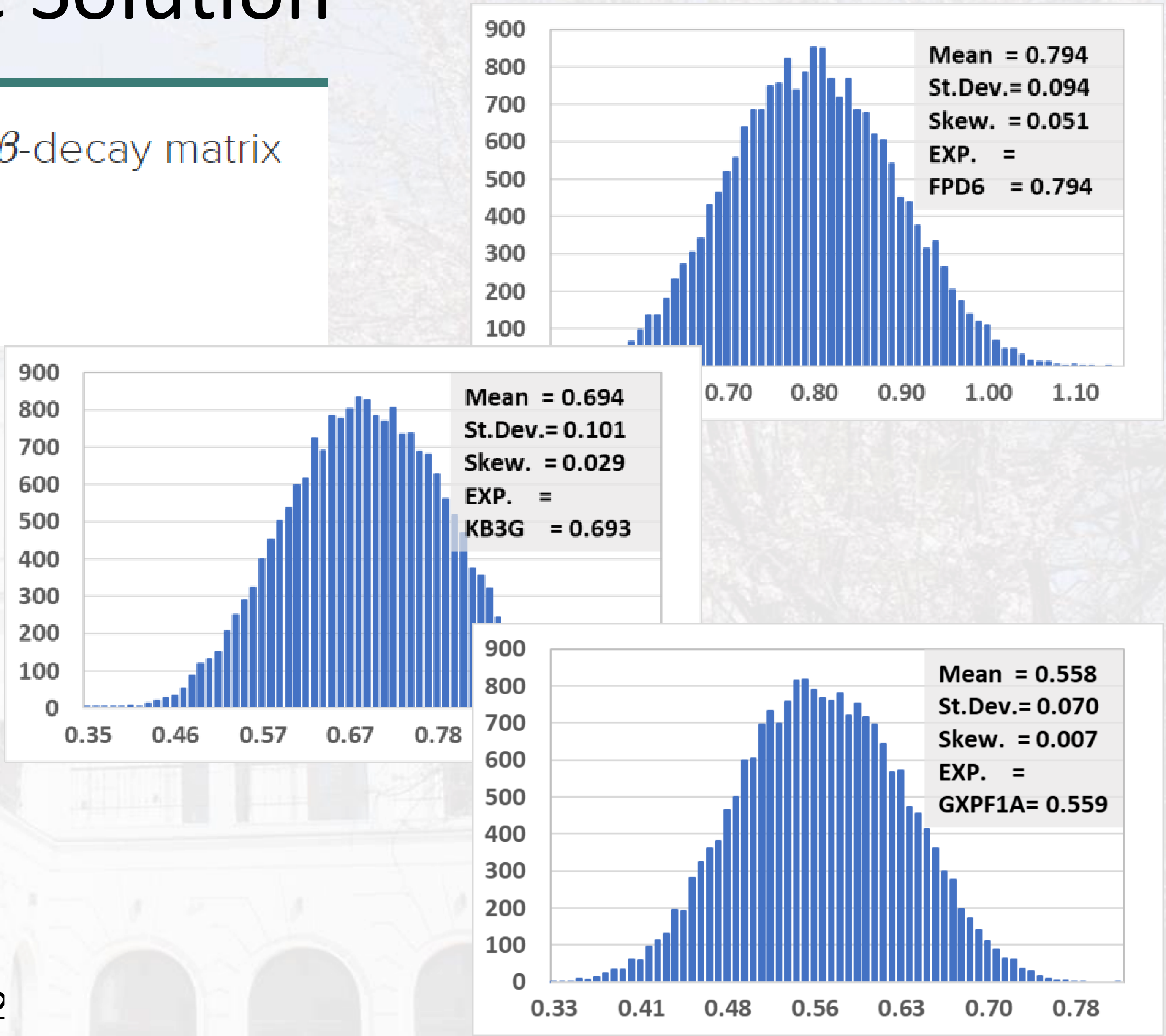

This year

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

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

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The culprits

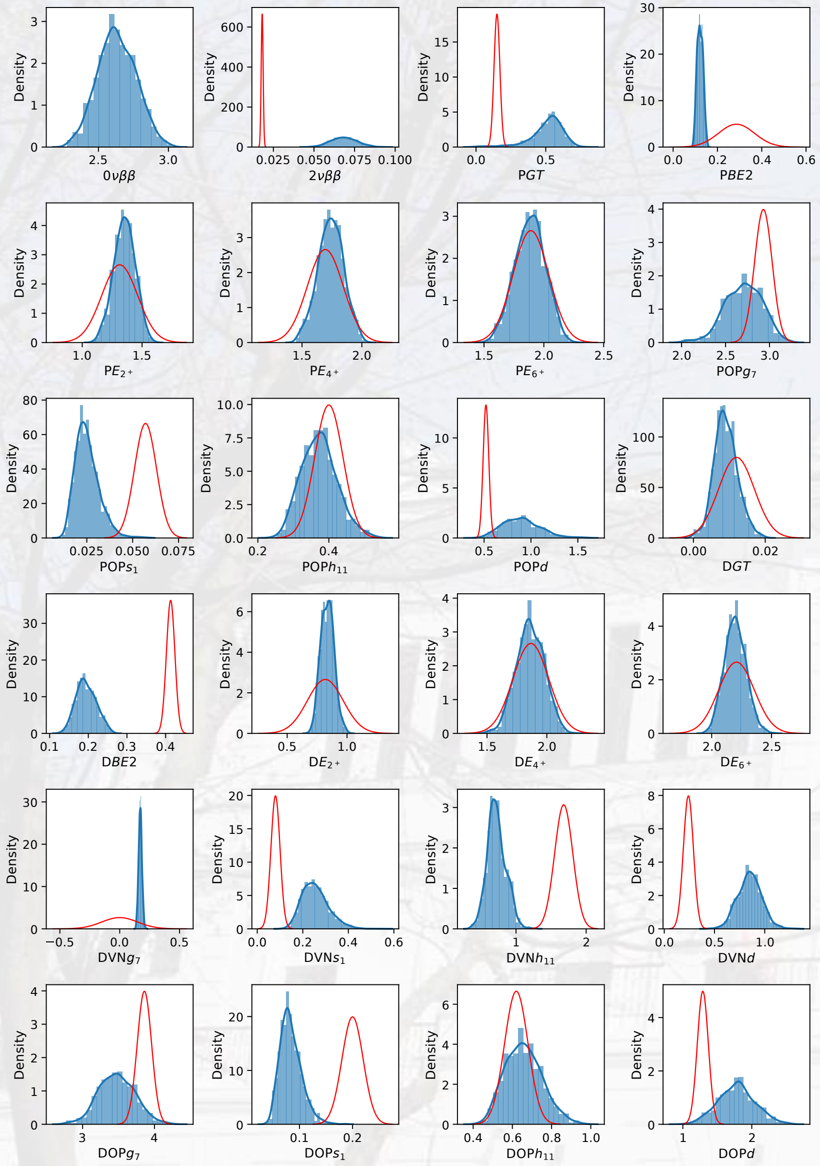
1) **SVD** - C. Qi and Z. X. Xu, Phys. Rev. C **86**, 044323 (2012).
2) **jj55t** - M. Horoi and B. A. Brown, Phys. Rev. Lett. **110**, 222502 (2013).
3) **GCN5082** - E. Caurier, F. Nowacki, A. Poves, and K. Sieja, Phys. Rev. C **82**, 064304 (2010).

3x1000 effective Hamiltonians from random perturbations within the range of ±10% to their two-body matrix elements (TBME) – the single-particle energies are kept untouched.

The observables

- 2νββ NME, the energies of the first 2^+, 4^+, and 6^+ states in the parent (^{136}Xe) and daughter (^{136}Ba) nuclei,
- B(E2) ↑ transition probabilities for ^{136}Xe and ^{136}Ba to the first 2^+ states,
- Gamow-Teller transition probability for the transition from ^{136}Xe and from ^{136}Ba to the 1^+ excited state in ^{136}Cs,
- the neutron and proton occupancies for ^{136}Xe and ^{136}Ba above the ^{100}Sn core in the jj55 model space shells.

The number of observables that we calculate for each sample is 24, including the 0νββ NME.



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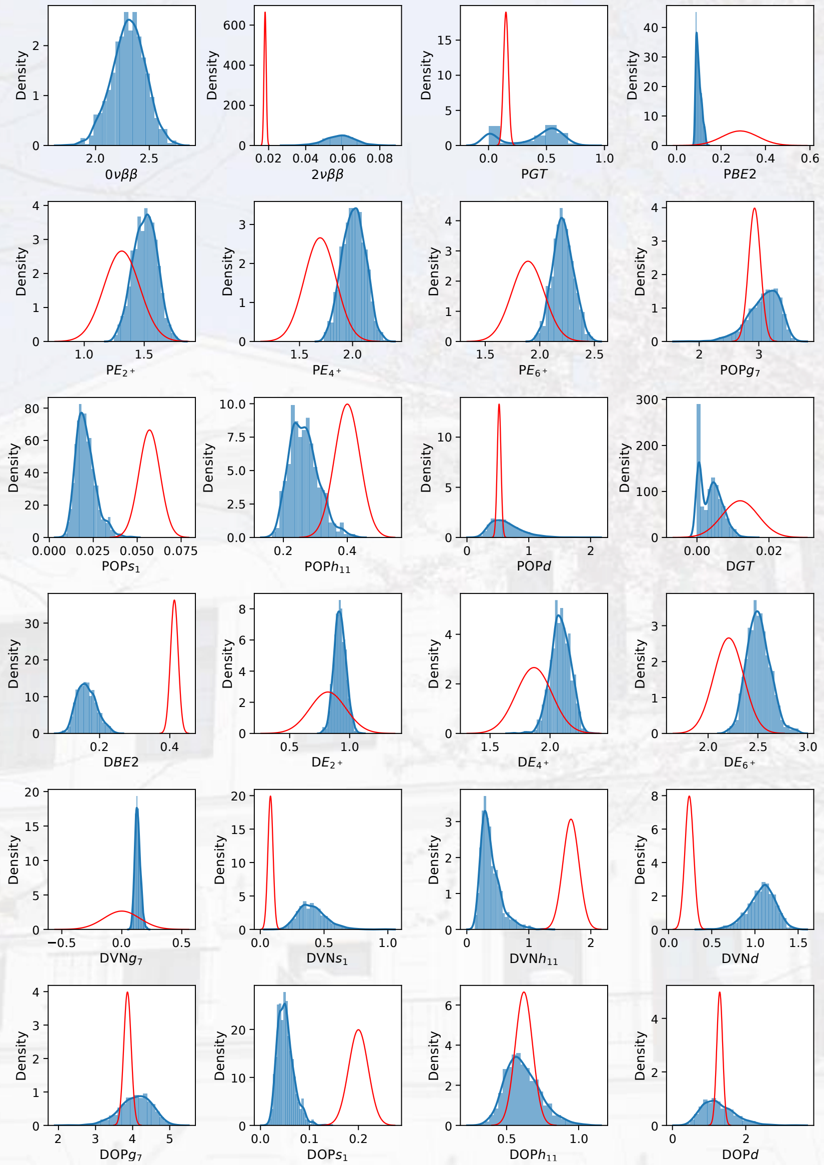
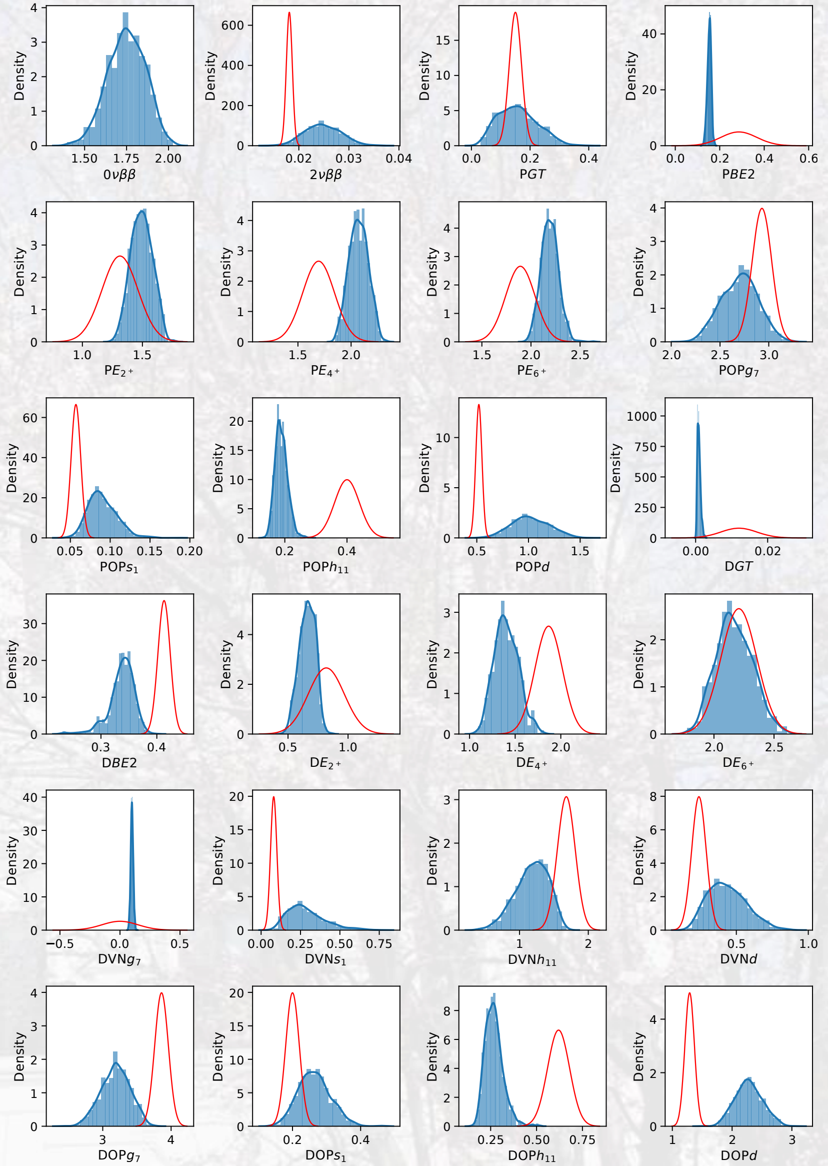


jj55t



SVD

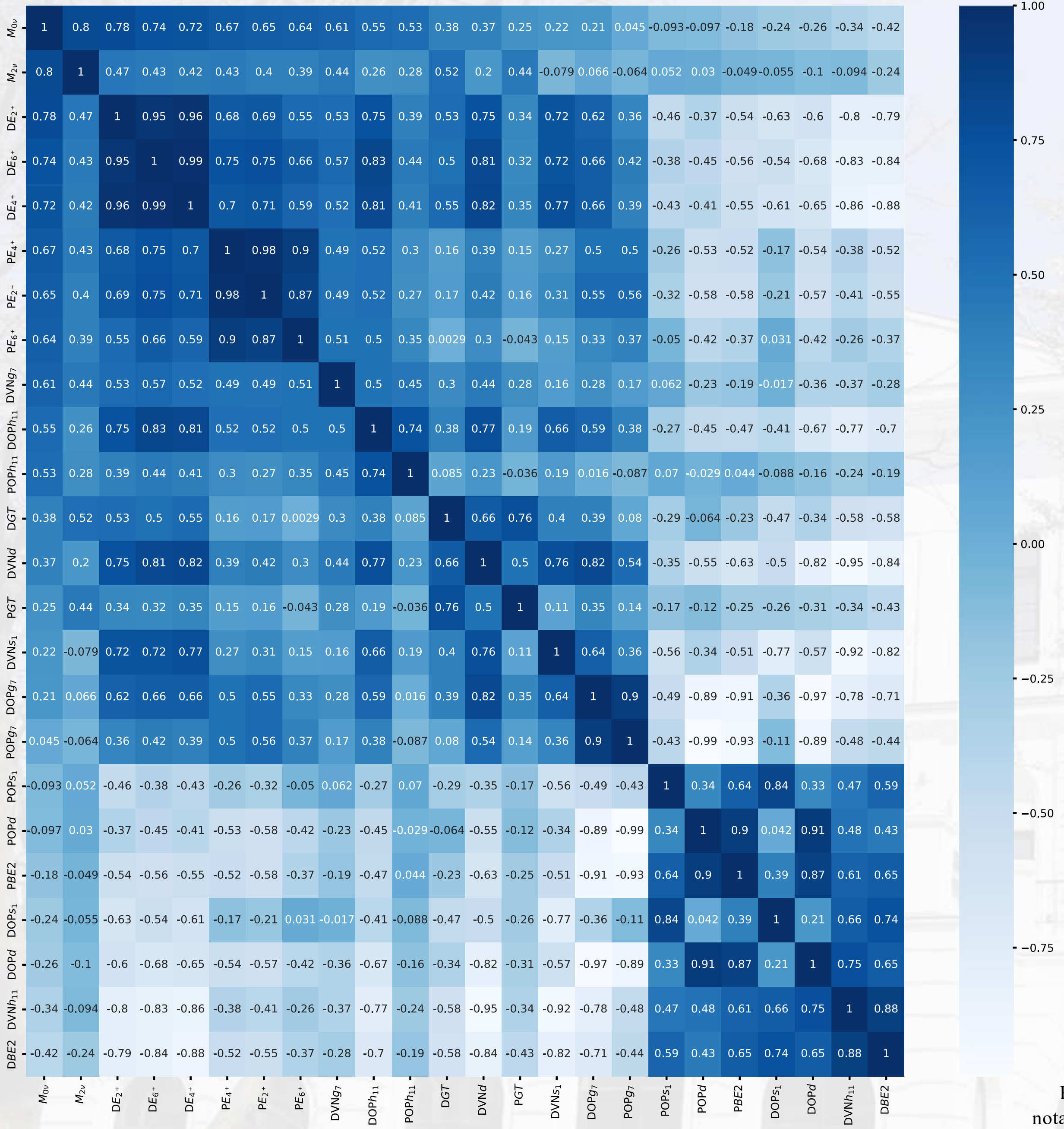


FIG. 1. The heat-map for all 24 observables when using the SVD effective Hamiltonian. See Sec. III for notations and analysis.

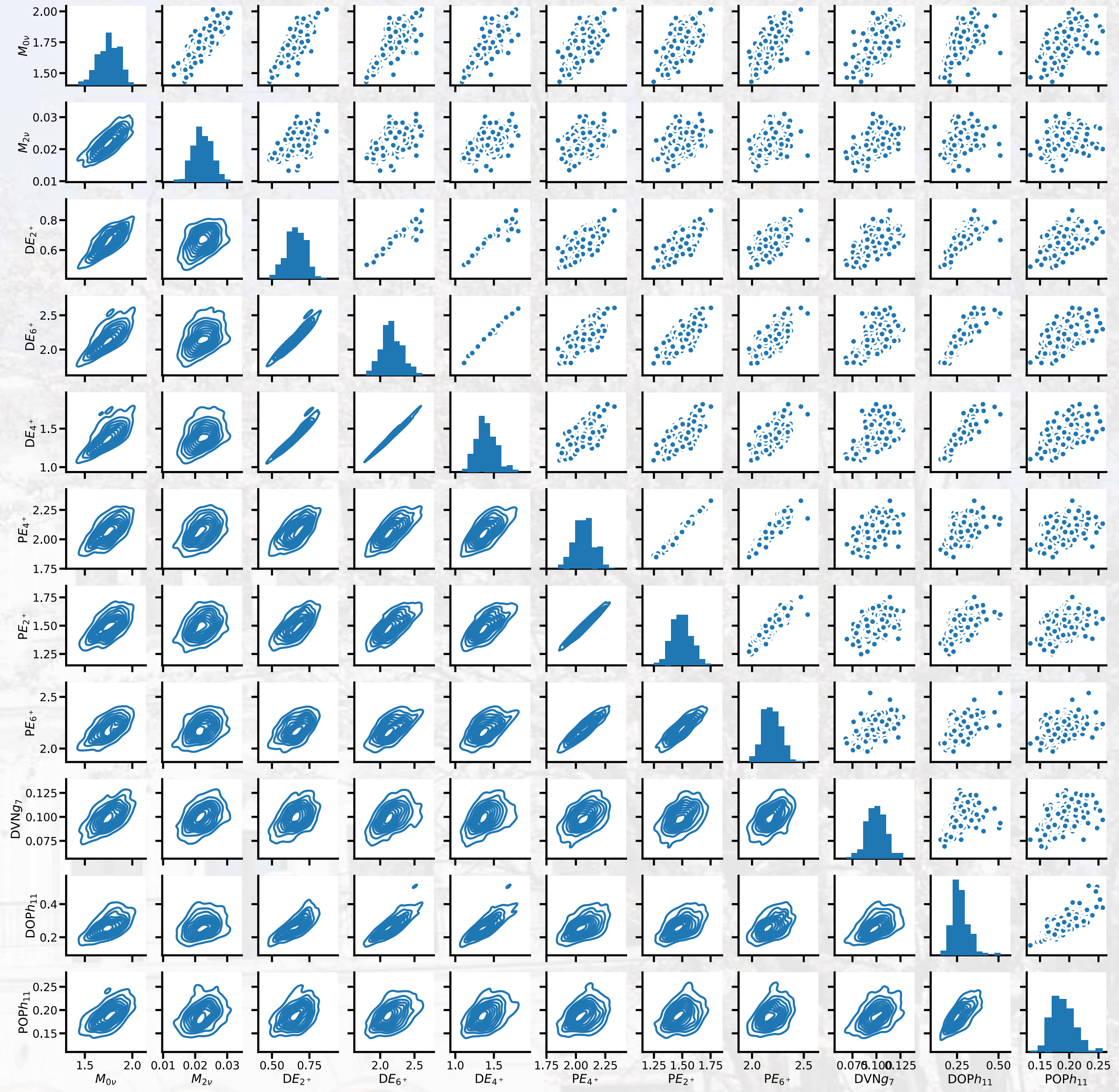


FIG. 2. Correlation matrix for observables that have correlation factor greater than 0.5, when using the SVD Hamiltonian. See Sec. III notations and analysis.

Highlights

- energy levels that correlate with each other and, significantly for this study, the $0\nu\beta\beta$ NME and the $2\nu\beta\beta$ NME with R = 0.8 in the case of the SVD Hamiltonian; this is inherited by the BE(2) ↑-s that depend on the 2+ states;
- correlations between the $0\nu\beta\beta$ NME and the strengths of the parent and daughter Gamow-Teller transitions to the first 1^+ state in ^{136}Cs are significantly reduced, while the correlation with the $2\nu\beta\beta$ NME is very strong (maybe, the product of the GT matrix elements describing transitions to the first 1^+ state in ^{136}Cs does not significantly contribute to the total sum of all excited 1^+ states in the intermediate nucleus);
- other observables that have relatively high correlations with the $0\nu\beta\beta$ NME are the energies of the 2^+, 4^+, and 6^+ states in both ^{136}Xe and ^{136}Ba with the correlators R between 0.64 and 0.78;
- $g_{7/2}$ neutron vacancies in ^{136}Ba correlate with the $0\nu\beta\beta$ NME at R = 0.61;
- proton occupancies of the $h_{11/2}$ orbital in ^{136}Ba correlate with the $0\nu\beta\beta$ NME at R = 0.55, while the proton occupancies of the $h_{11/2}$ orbital in ^{136}Xe correlate with the $0\nu\beta\beta$ NME at R = 0.53;
- B(E2)↑ of the ^{136}Xe and ^{136}Ba cases (R = 0.65); PBE2 correlates very strongly with POPd (R = 0.9) and DOPd (R = 0.91), while it anticorrelates significantly with DOPg7 (R = −0.91) and POPg7 (R = −0.93);
- PBE2 correlations with DOPs1 (R = 0.74) and DVNh11 (R = 0.88), anticorrelating with DVNd (R = −0.84), DVNs1 (R = −0.82) and the energy levels DE2+ (R = −0.79), DE4+ (R = −0.88), DE6+ (R = −0.84);

Statistical Inference based on the Bayesian model averaging

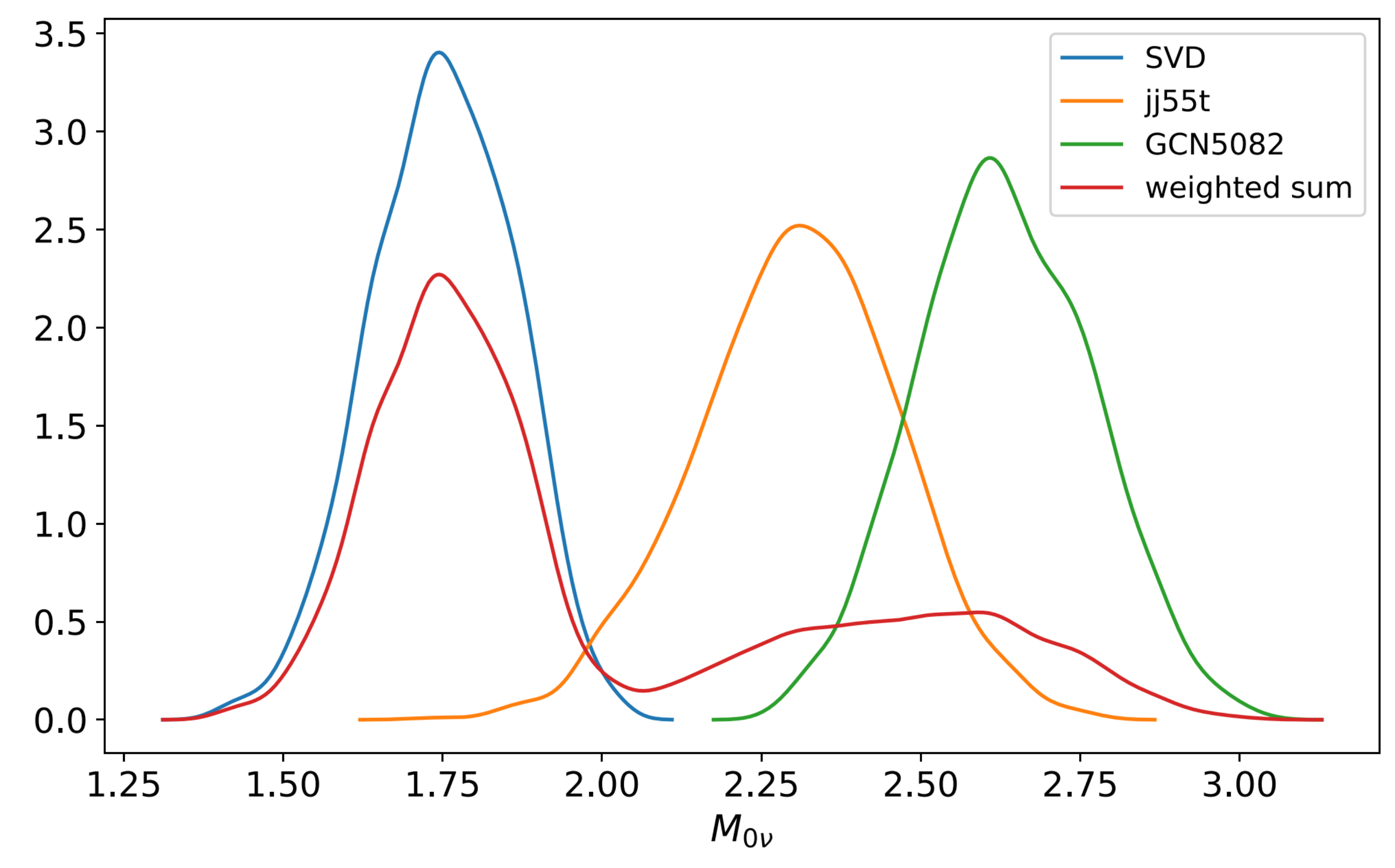
Optimal values and a potential range of error for the 0νββ NME

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

x is the random value of the 0νββ NME. The normalized weights W_k can be inferred using the statistical distributions of the evidence observables and their correlations with the calculated M0ν NME.

In our case, using a standard quenching factor of 0.7 for all GT matrix elements one gets a clearly dominant contribution of the SVD model.
However, we take W_{svd} = 4/6, W_{gcn} = W_{j5t} = 1/6.

The final 0νββ NME result



PDFs of the 0νββ NME distributions

At 90% confidence, the 0νββ NME lies in the range between 1.55 and 2.65, with a mean value of about 1.99 and a standard deviation of 0.37

Thank you!