Neutrinoless double beta decay in the minimal type-I seesaw model

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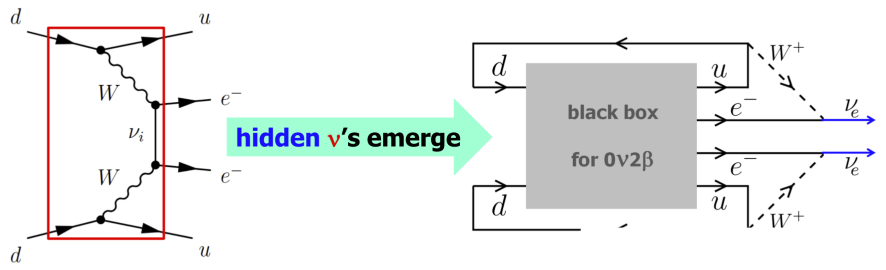
Introduction

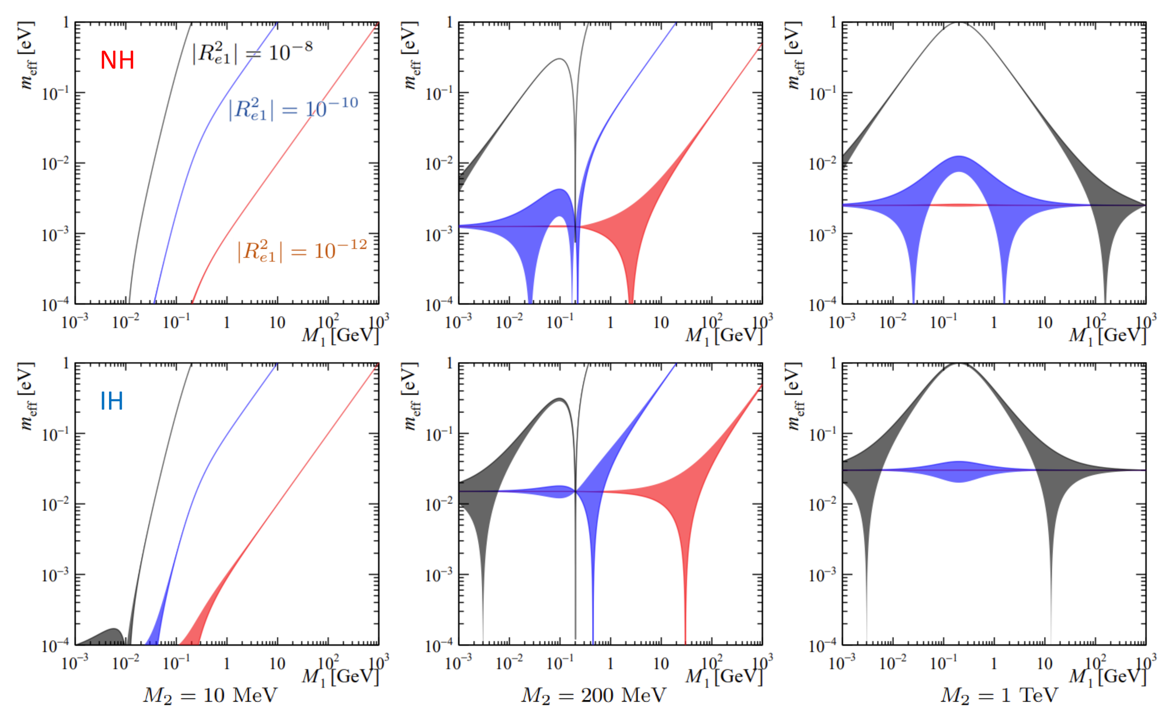
- The discovery of neutrino oscillation phenomena provides a direct evidence of **neutrino masses and lepton flavor mixing**.
  Review of Particle Physics. PTEP, 2020, 2020(8): 083C01
- The most popular type-I seesaw model can explain the smallness of neutrino masses, **requiring the neutrino Majorana nature** and enabling the **existence of the neutrinoless double beta decay (0νββ-decay) process.**
  Minkowski (1977), Yanagida (1979), Gell-Mann, Ramond, Slansky (1979), Glashow (1980), Mohapatra, Senjanovic (1980)
- **Schechter-Valle Theorem:** observation of the 0νββ-decay → Majorana nature of neutrinos. *Schechter, Valle (1982)*



- The minimal type-I seesaw model incorporates two right-handed neutrinos to explain non-zero neutrino masses and leptogenesis.
  Frampton, Glashow, Yanagida (2002), see recent review Xing, Zhao (2021)
- The current and future experiments of searching for the 0νββ-decay are booming, and the leading limits are obtained from the **Xe136 (KamLAND-Zen, EXO-200), Ge76 (GERDA, MAJORANA), and Te130 (CUORE).** *See the experimental results in 2203.02139, 1906.02723, 2009.06079., 1902.02299, 2104.06906.*
- **In this poster, we discuss the 0νββ-decay process in the minimal type-I seesaw model.**
  (a) The effective masses of active neutrinos are **[1.5, 3.5] meV and [18, 48] meV** for the normal and inverted hierarchies, respectively.
  (b) We summarize the mass-dependent nuclear matrix elements of the 0νββ-decay, discuss the role of two right-handed neutrinos, and present the combined constraints from the current 0νββ-decay experimental data.

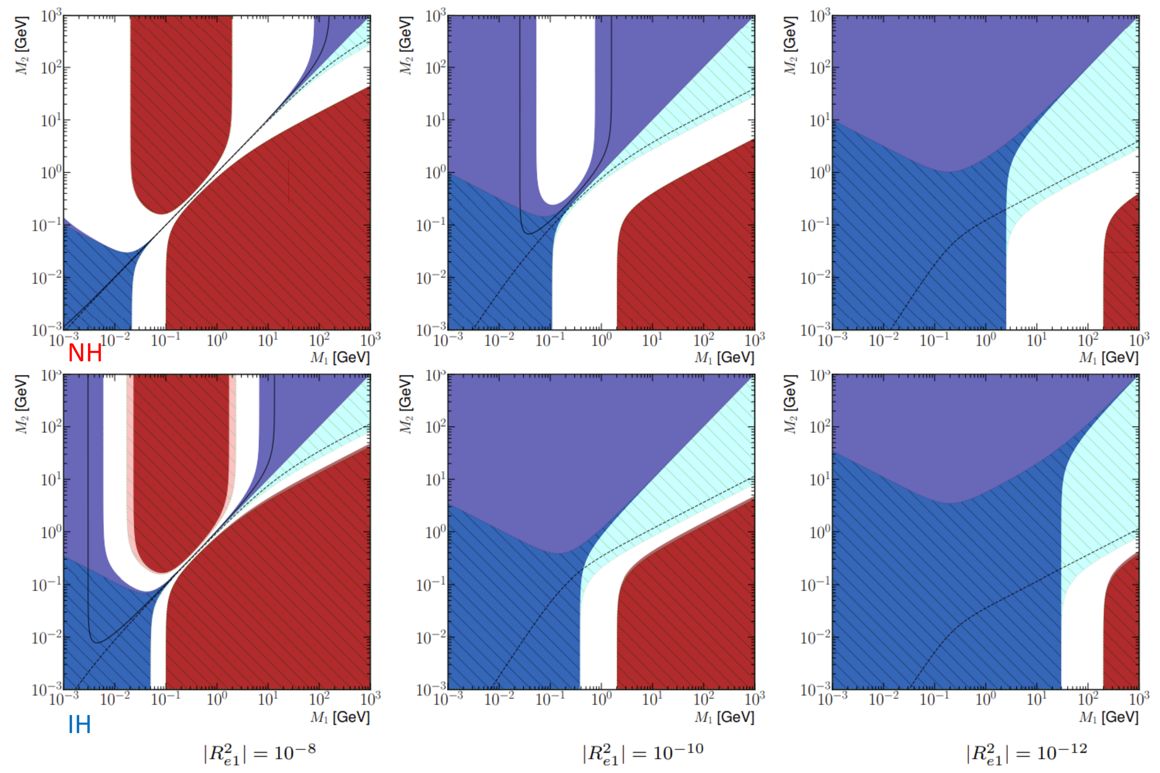
Contribution of the RHNs

1. $m_{\rm eff}$ **as a function of** M_1 for the NH (upper panels) and IH (lower panels) cases.



- The shadow regions illustrate the effect of the phase variation with free δ_{14}.
- **left panels**: a tiny mass of M_1 will make $m_{\rm eff}$ close to zero.
- **right panels**: the disappearance of the contribution from RHNs when M_1 large.

2. **Contours of** $|m_{\rm eff}|$ **in the 0νββ-decay** as functions of M_1 and M_2 for the NH (top) and IH (bottom) cases



- **dark colored region without slash lines:** $\delta_{14} = \pi/2$.
- **light colored region with slash lines:** $\delta_{14} = 0$.
- **Red regions:** $|m_{\rm eff}| > 200$ meV.
- **Blue regions:** $|m_{\rm eff}| < |m_{\rm eff}^{\nu}|$.
- **Black lines:** the full cancellation. (solid for $\delta_{14} = \pi/2$ and dashed for $\delta_{14} = 0$.

When δ_{14} is changed, the regions of strong enhancement change slightly, while the regions of cancellation change drastically.

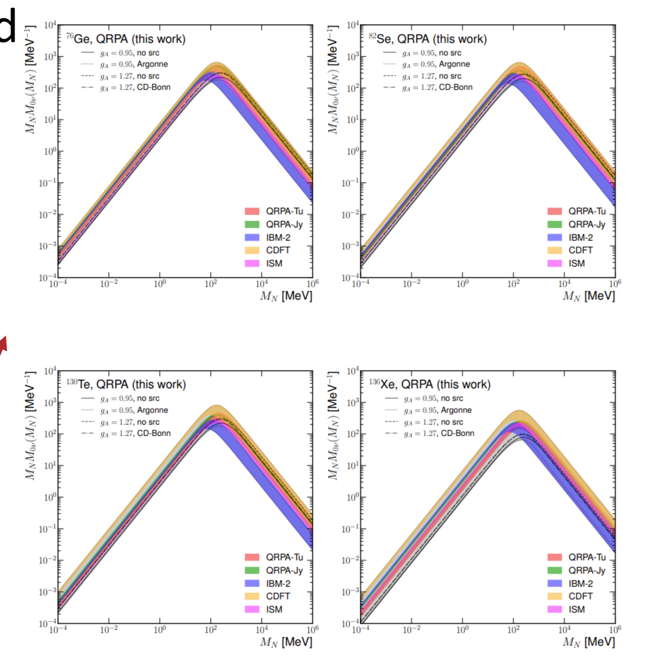
Mass-dependent nuclear matrix elements

The NME for current calculations can be derived from the combination of the nuclear weak current and the neutrino propagators

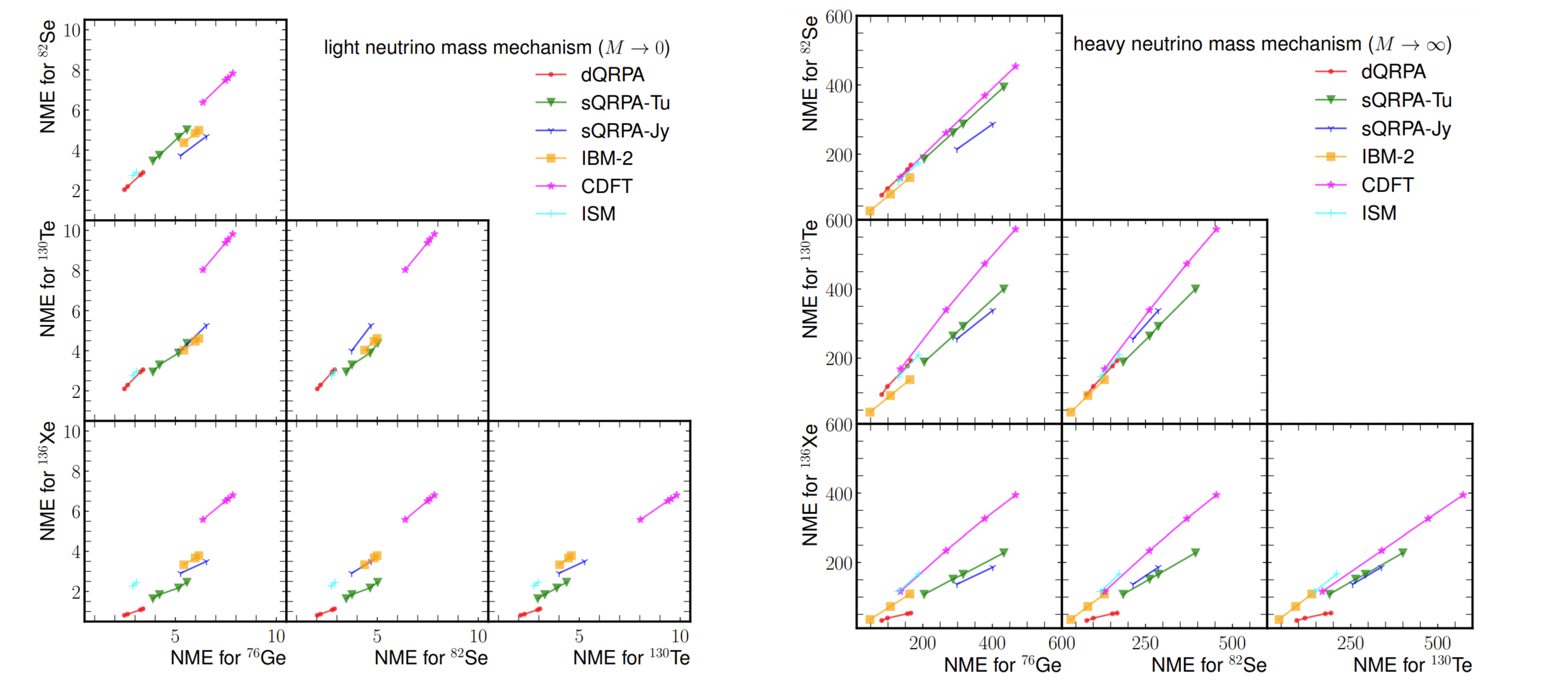
$$M^{0\nu} = \sum_{IJ,\alpha,jk} \mathcal{U}_{ek}\mathcal{U}_{ej} M_{jk}^{IJ,\alpha}$$

- **the QRPA approach:**
  - dQRPA (this work)
  - QRPA-Tu, QRPA-Jy
- **other approaches**
  - IBM-2, CDFT, ISM

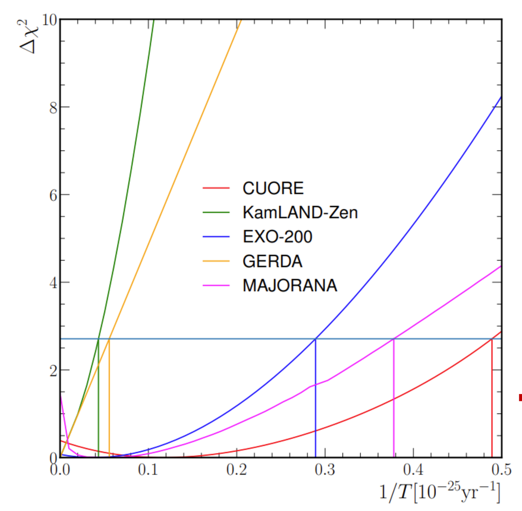
The NMEs as a function of the neutrino mass.



NMEs of several isotopes in different models for light and heavy masses

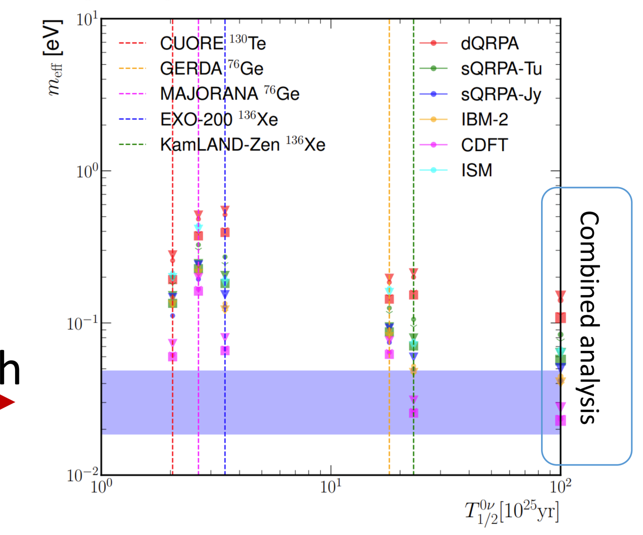


Constraints on the half-time from various 0νββ-decay experiments



Experiment	Isotope
CUORE	^{130}Te
KamLAND-Zen	^{136}Xe
EXO-200	^{136}Xe
GERDA	^{76}Ge
MAJORANA	^{76}Ge

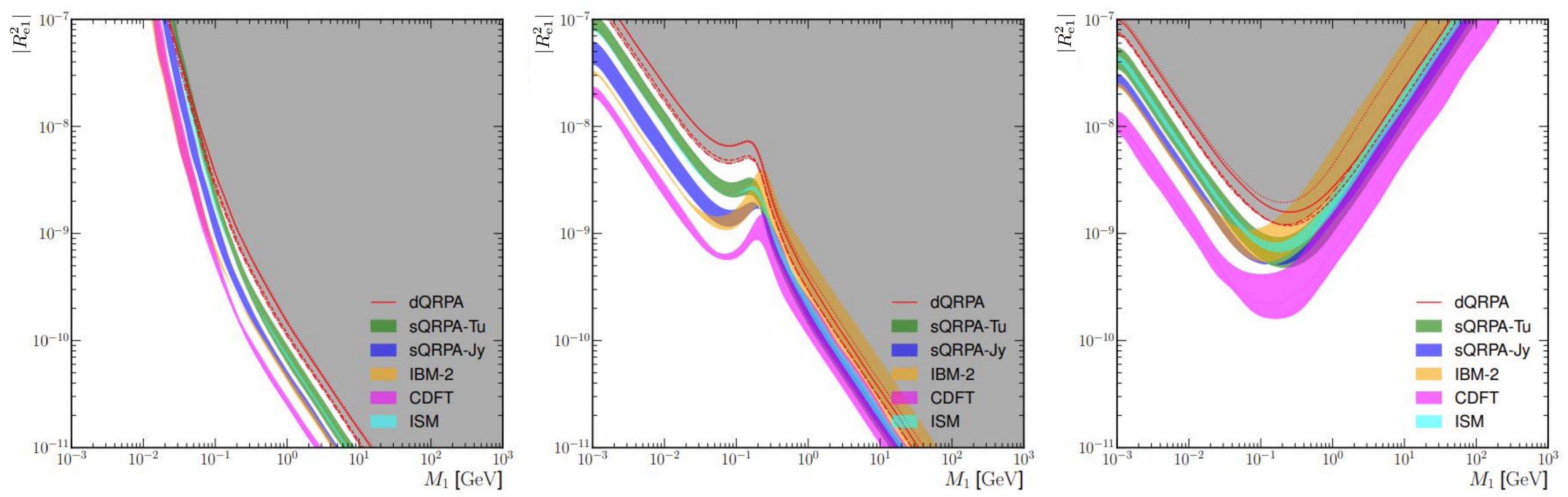
Constraints on $m_{\rm eff}$ with various NME models



Experimental constraint of the right-handed neutrinos (RHNs)

Excluded regions of the M_1 **and** $|R_{e1}^2|$ **with varying** M_2

- **Combined analyses of CUORE, GERDA, MAJORANA, EXO-200, KamLAND-Zen experiments.**
- **shadow regions:** the 90 % confidence level excluded regions with various NME models.
- **Colored bounds**: uncertainty from the NME calculations.



(a) $M_2 = 10$ MeV (b) $M_2 = 200$ MeV (c) $M_2 = 10$ TeV

- The dQRPA model derived weaker constraints of RHNs parameters.
- Both the different models of NMEs and the uncertainties make a big variance on these constraints.

Conclusion

In this poster, we have discussed the 0νββ-decay process in the minimal type-I seesaw model.

- **The effective masses of three active neutrinos are [1.5, 3.5] meV and [18, 48] meV for the normal and inverted mass hierarchy, respectively.**
- **The mass-dependent NMEs make the contributions of RHNs rather non-trival, both enhancement and calc.**
  a) when the RHNs are both much lighter (than ~ 200 MeV), the 0νββ-decay process is vanishing (seesaw relation).
  b) when any of the RHNs is much heavier (than ~ 200 MeV), its contribution to the 0νββ-decay scales as 1/M.
  c) The general case with the masses of RHNs shows non-trival constraints from current experimental data.

Reference

- **The study presented in this poster is based on the following papers:**
Fang, YFL, Zhang, Neutrinoless double beta decay in the minimal type-I seesaw model: How the enhancement or cancellation happens? arXiv: 2112.12779 [hep-ph]
Fang, YFL, Zhang, Neutrinoless double beta decay in the minimal type-I seesaw model: Mass-dependent nuclear matrix elements and current limits, To appear soon
- **Recent reviews on NMEs can be found in:**
2203.12169, 1610.06548, 2111.15543, 2202.01787, etc.