N-Z dependence of OMC rates for Double Beta Decays and Astro Antineutrinos

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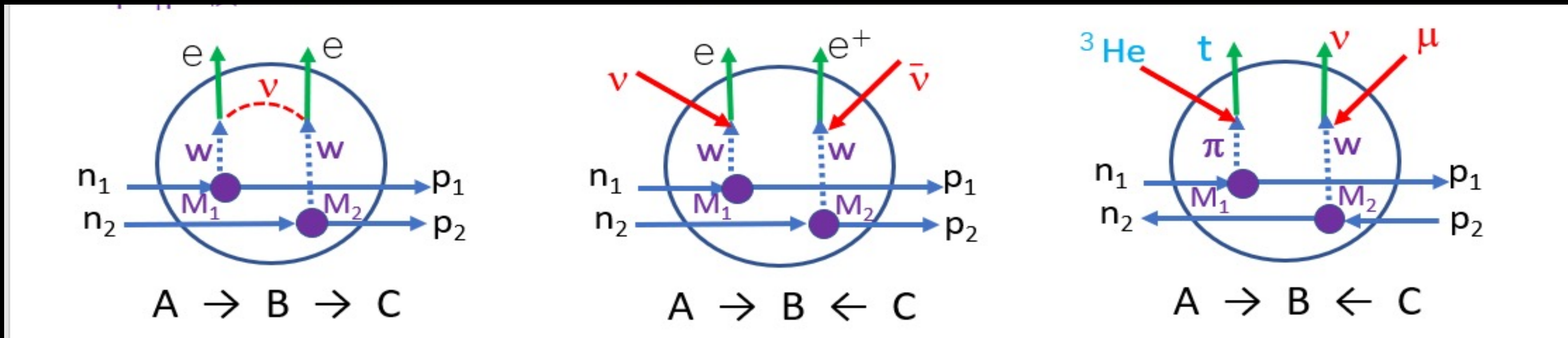
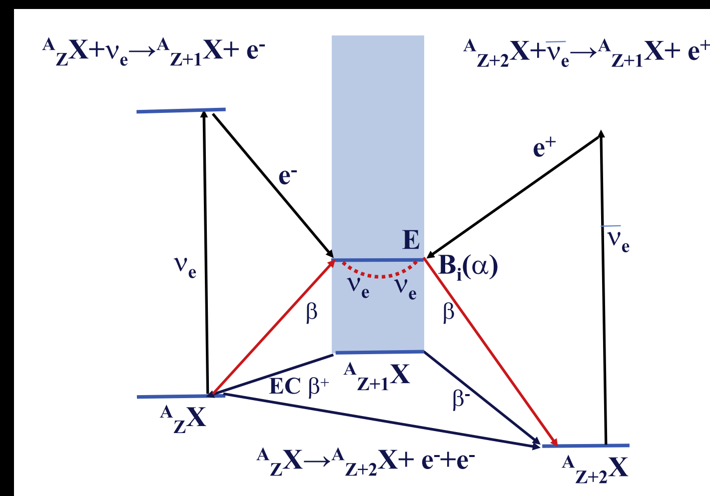
From the Ejiri's place

Double β decay, single β & ν and CERs



- DBD responses (nuclear matrix elements) and neutrino/anti neutrino responses indicate by M_1 and M_2 in the fig. are studied by CERs of (^{3}He,t) and OMC.
- These responses give similar observation to neutrino and antineutrino CC interaction on a nucleus ^A_ZX.

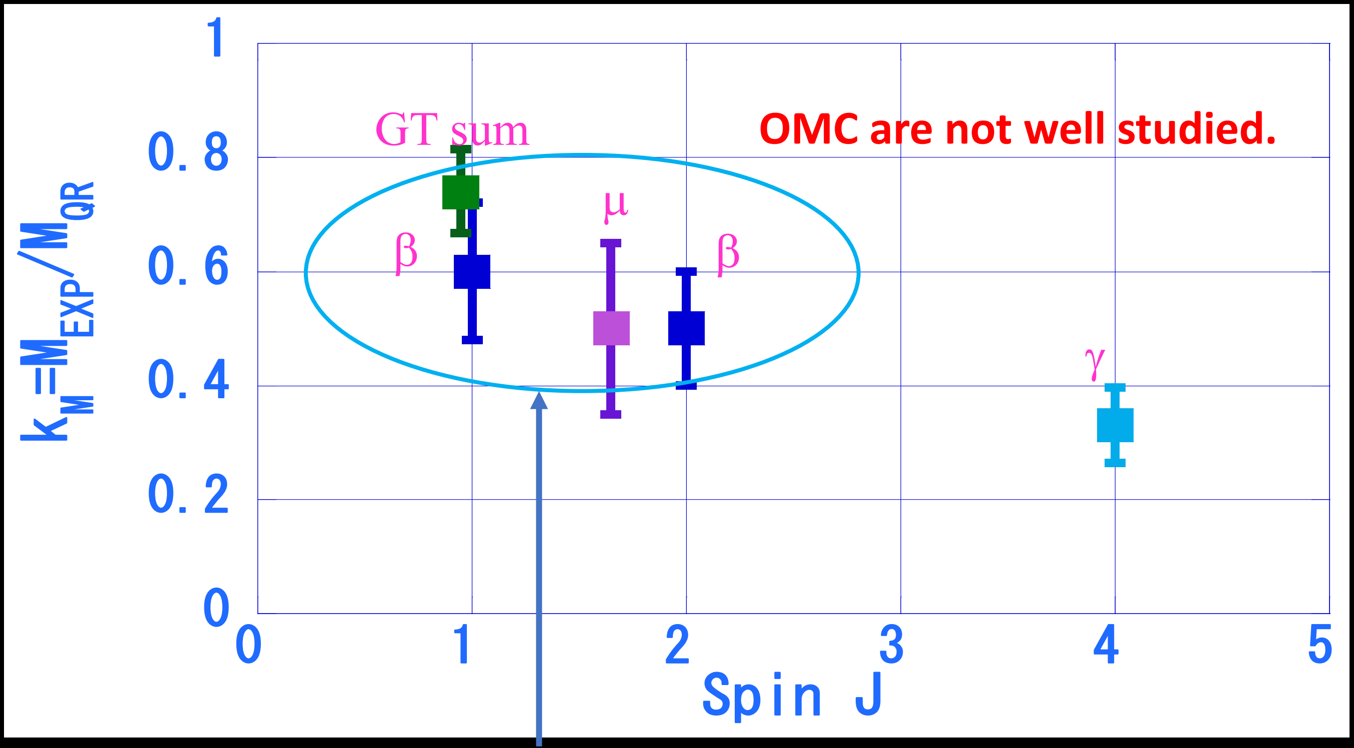


$$^A_ZX + \nu_e \rightarrow {}^A_{Z+1}X + e^- \quad (\text{NME } M^\nu)$$

$$^A_{Z+2}X + \bar{\nu}_e \rightarrow {}^A_{Z+1}X + e^+ \quad (\text{NME } M^{\bar{\nu}}),$$

Current Interest from OMC on nuclei

1. The renormalization (quenching of axial coupling)



$g_A^{eff}(\beta\beta)/g_A \sim 0.55\text{-}0.75$

H, Ejiri J. Suhonen J. Phys. G. 42 2015
H. Ejiri N. Soucouti, J. Suhonen PL B 729 2014 .
L. Jokiniemi J. Suhonen H. Ejiri AHEP2016 ID8417598
L. Jokiniemi J. Suhonen. H. Ejiri and I. Hashim PL B 794 143 (2019)

Current Interest from OMC on nuclei

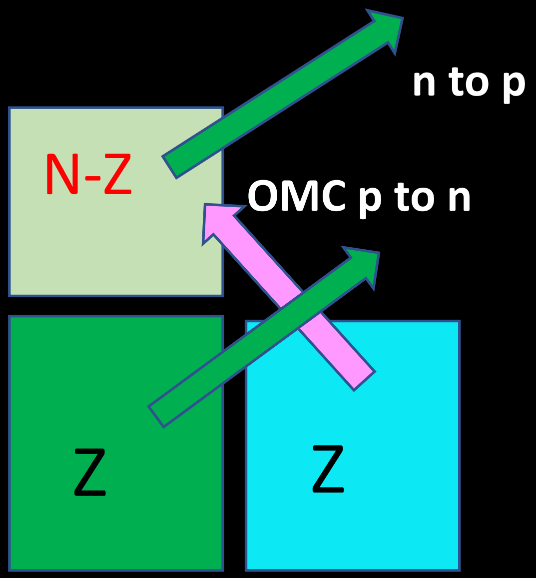
2. DBDs are studied in wide A or N-Z

Ranges of DBD, R=(N-Z)/A for:

^{100}Mo R=0.16

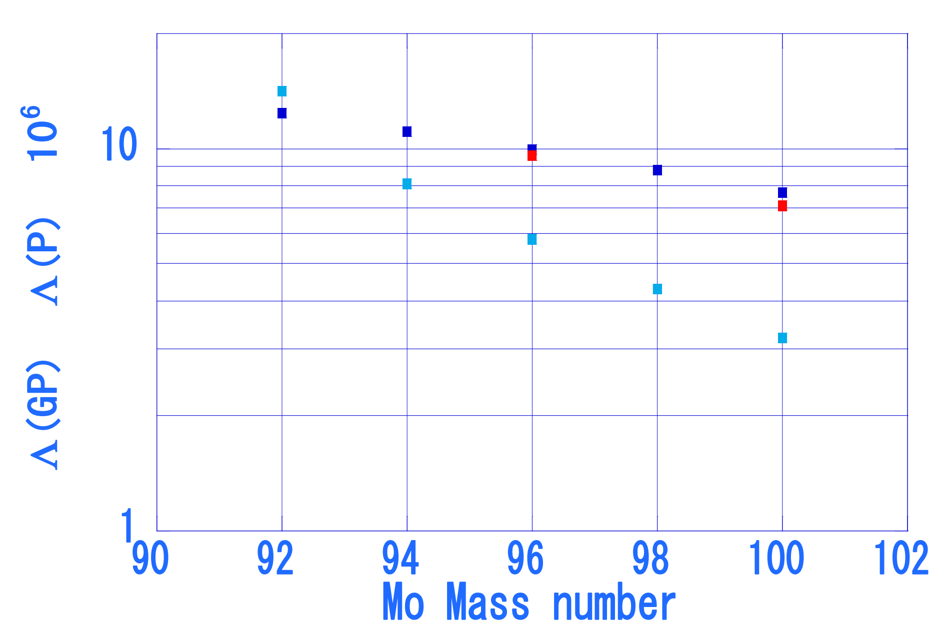
^{116}Cd R=0.172

^{106}Cd R=0.094.



OMC rates depends very much on N-Z or N excess because OMC reaction with transforming p to n is blocked by the excess N-Z.

Semi empirical expressions for the OMC rates



Dark blue : Primakoff

Light blue : Goulard and Primakoff

Red : Experiment

- Semi empirical OMC rates are different from each other, and change by factors of 2-3 for the mass A=92 and 100.
- OMC, where proton is transformed into neutron, OMC rate is blocked by neutron excess as A=92 (N=50) goes to A=100 (N=58).
- It is very interesting to see experimentally how the rate decreases as A=100 to 92.

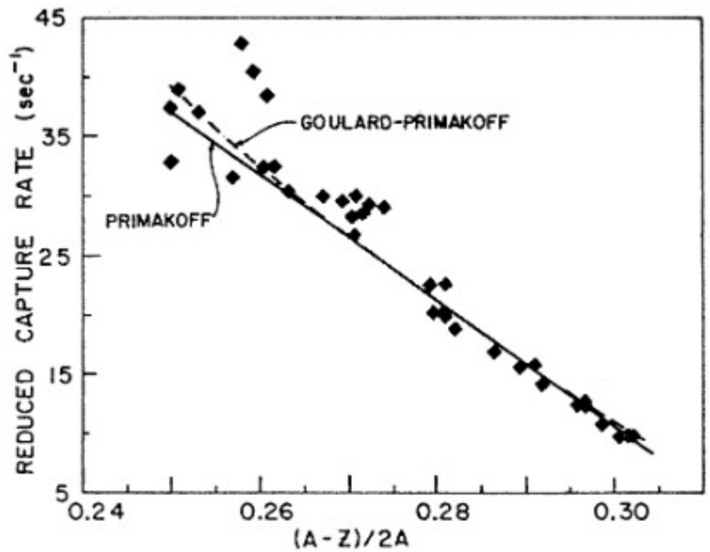


Fig. 4.5. Comparison of the muon total capture rate with the Primakoff formula Eq. (4.53), and the Goulard–Primakoff extension, Eq. (4.55). The data are those of Suzuki et al. [183].

Table 4.3
Fitted parameters for the Goulard–Primakoff formula, Eq. (4.55)

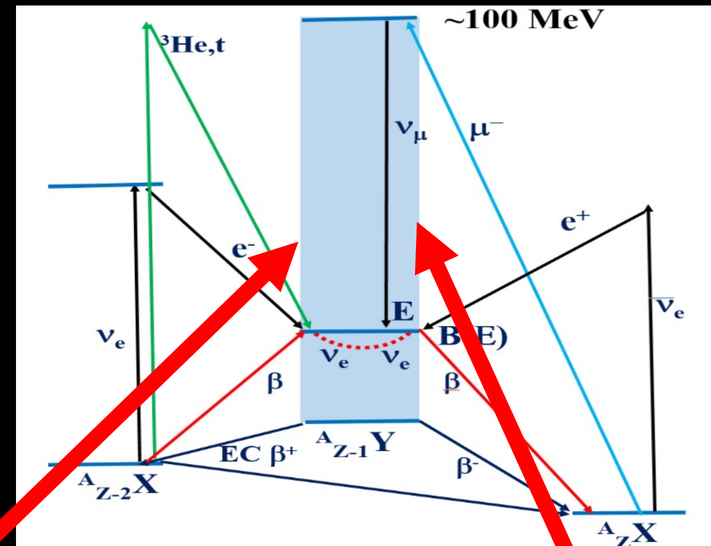
	Number of data	G_1	G_2	G_3	G_4
Pre-TRIUMF data [149]	58	252	−0.038	−0.24	3.23
TRIUMF data [149]	30	261	−0.040	−0.26	3.24
World set 1990 [252]A	91		−0.020	−0.23	3.25
World set 1990 [252]B	91		0.8	−0.02	6.5

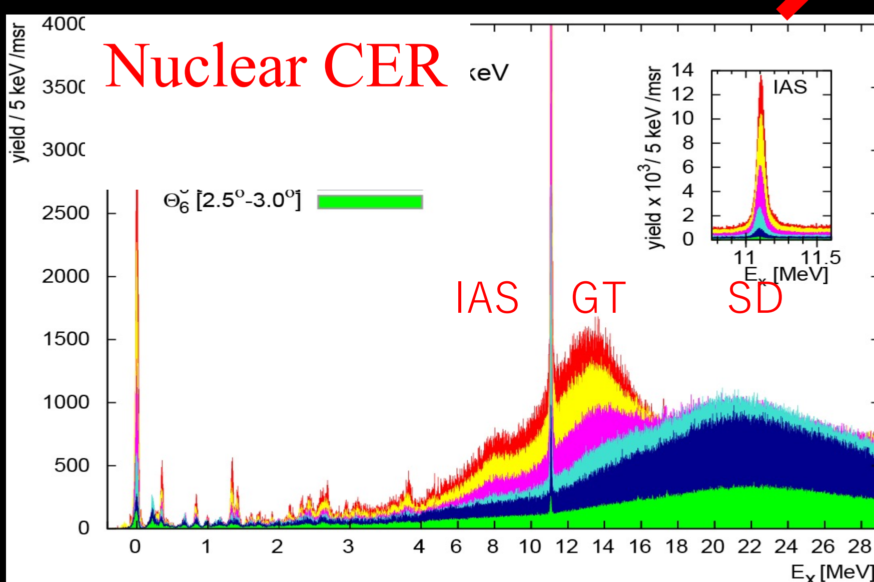
Goulard and Primakoff then extended this formula, adding two more terms, viz:

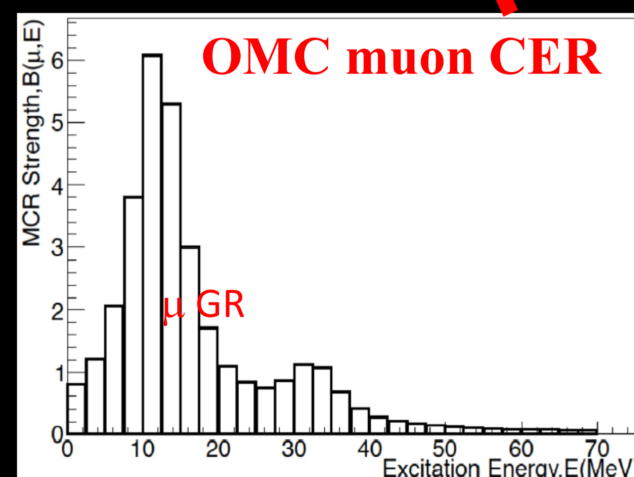
$$\Lambda_c(A,Z) = Z_{\text{eff}}^4 G_1 \left[1 + G_2\frac{A}{2Z} - G_3\frac{A-2Z}{2Z} - G_4\left(\frac{A-Z}{2A} + \frac{A-2Z}{8AZ}\right)\right] . \tag{4.55}$$

Current Interest from OMC on nuclei

3. Experimental OMC strength distribution, which are studied by RI distributions, are used to check the model and the quenching.







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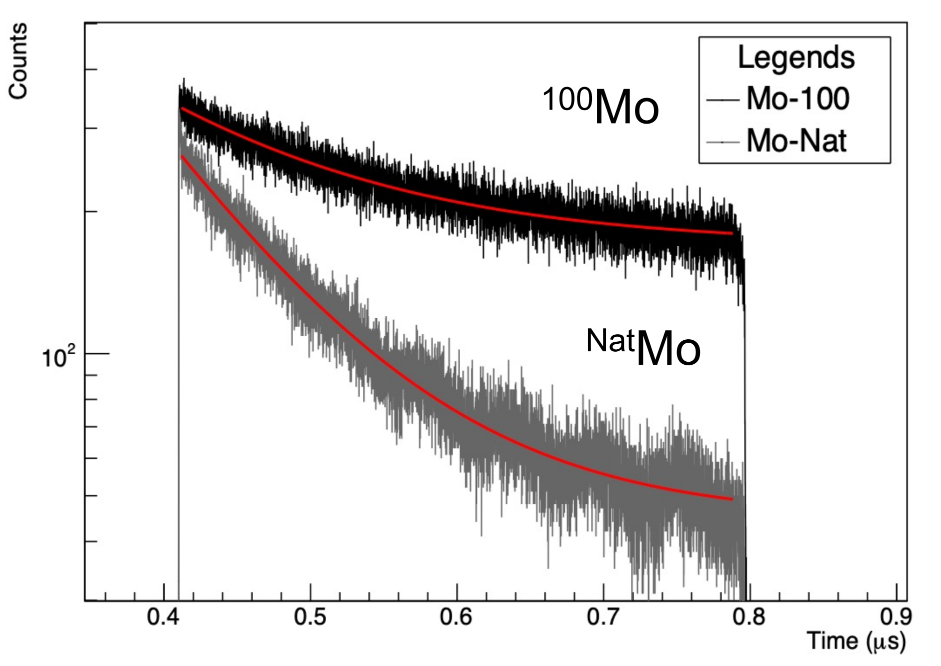
Mass number dependence for OMC rates of ^{100}Mo and ^{96}Mo.

Bern 2019

Result from RCNP2018 Beamtime



- ^{Nat}Mo have shorter lifetime compared to ^{100}Mo.
- The average A for natural Mo is 96, thus the present observation fit with earlier investigations where lower A have lower lifetime (higher capture rate).

calculated τ_μ (GP) for (96,42) = 100.3 ns

calculated τ_μ (GP) for (100,42) = 130.4 ns

TABLE I. Part of the fit results of the ^{100}Mo and ^{Nat}Mo (in ch10, 100 MHz TDC).

Isotope	τ (ns)	$\Delta\tau$ (ns)	N_0	ΔN_0	N_{BG}	ΔN_{BG}
^{100}Mo	133.4	6.0	3568	142.7	170.2	6.8
^{Nat}Mo	99.1	4.5	13924	542.7	43.3	0.8

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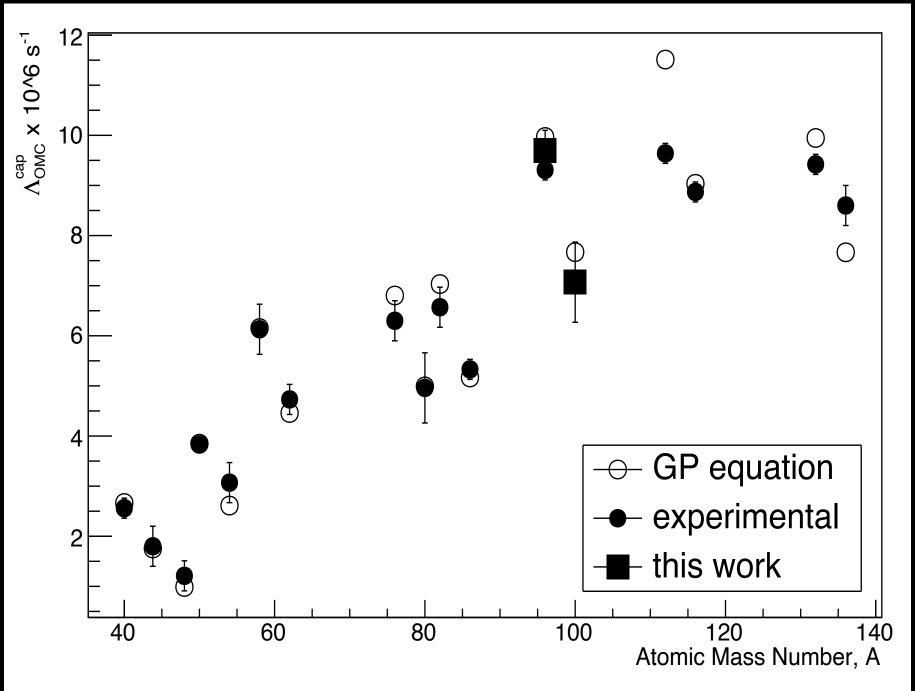
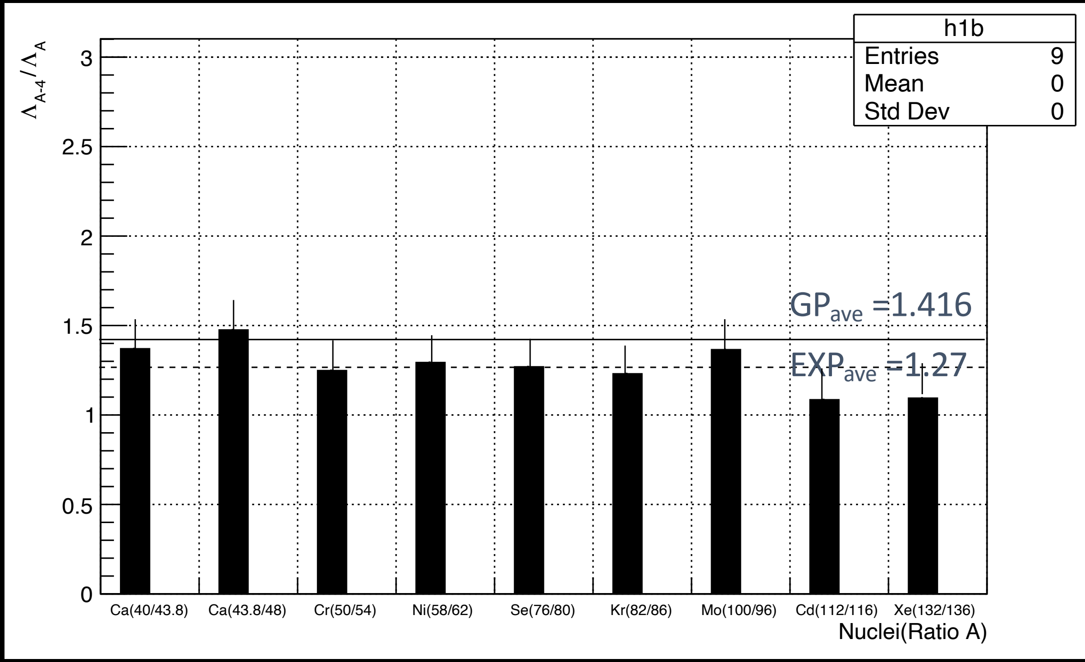
PRC2022 in review



- Present work gives about similar with the one calculated using GP prediction and comparison with ^{96}Mo data reported in [1] gives uncertainty less than 10% errors.
- For other nuclei reported in previous work, also shows increasing pattern when the A increases.
- However, for isotope within the same series with ΔA=4 showing decreasing pattern for all nuclei.
- Neutron excess in medium-heavy nuclei blocked the 0^+ Fermi and the 1^+ Gamow-Teller (GT) excitations and thus reduced the β^+ and the antineutrino responses[2].

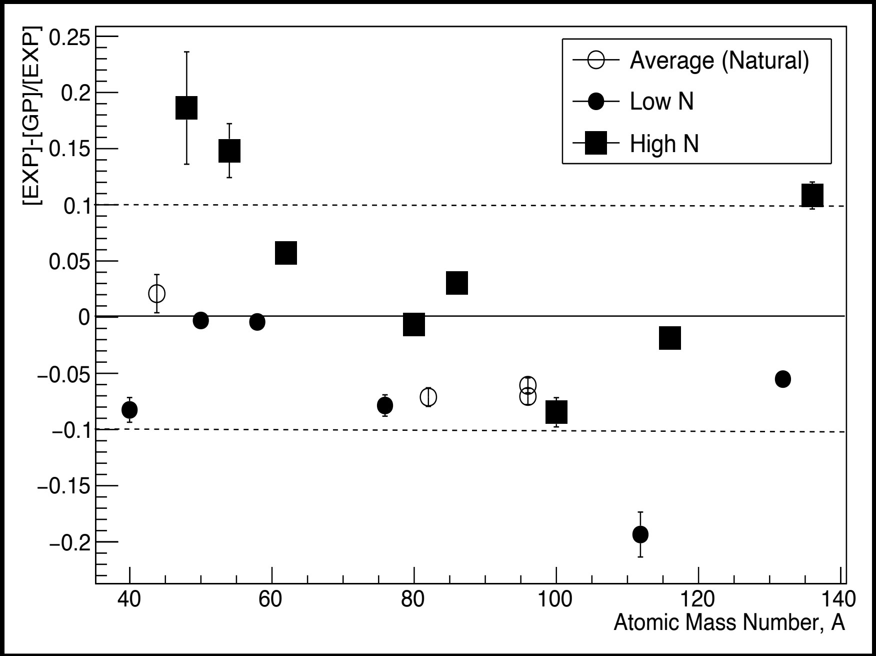
[1] T. Suzuki, et al. Rev. C 35 6 (1987) 2212
[2] H.O.U. Fynbo, Nuclear Physics A 724 (2003) 493–501

Ratio of same isotope series



- Ratio $\Lambda_\mu^{A-4}/\Lambda_\mu^{A}$ (GP) gives that nuclei with lower N have higher capture rates by average of 1.4x.
- $\Lambda_\mu^{A-4}/\Lambda_\mu^{A}$ (EXP) much lower ratio (1.27x) - low N nuclei have higher capture rate.
- Experimental observation is within 20% error with the GP prediction.
  - same amount of neutron excess reduces about the same β^+ response.

Neutron excess nuclei



- The fluctuation error of present work is within< 10 % from GP prediction, whereas some old experimental value are within 25% error.
- The nuclei with high N tends to have larger deviation compared to natural and low N nuclei.
- We prefer to be in conservative position that nuclear structure effects are at the bottom of all these variations of the total muon capture rates.

Conclusion

- The OMC on nuclei is a weak semileptonic process that is useful for studying the antineutrino nuclear responses relevant to double beta decay.
- The absolute lifetime from negative muon on ^{100}Mo and ^{Nat}Mo shows a systematic ratio between A=100 and A=96, where A=100 have a much lower capture rate due to neutron excess.
  - The total muon capture rate describes the overall final states distribution after the muon capture process.
- Deviation of present experimental value and others using enriched nuclei shows consistency with the GP calculated value proving that the slight g_A quenching in nuclear structure effects is observed.
- Double beta decay nuclei experiment uses stable multi-ton (10^{28-29}) isotopes to get signals for rare decays
  - Largest N-Z excess to get large phase space (Q-value)
- Muon capture involve transformation from p to n, OMC rates is blocked if many neutrons around.
  - OMC and DBD rate are reduced