Towards reliable nuclear matrix elements for neutrinoless $\beta\beta$ decay

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Nuclear physics and neutrinoless $\beta\beta$ decay

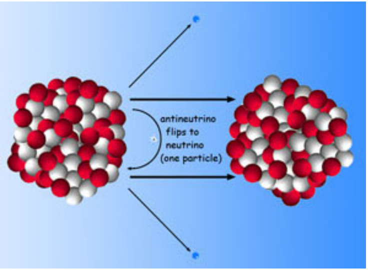
Neutrinos, dark matter studied in experiments using nuclei

Nuclear matrix elements depend on nuclear structure crucial to anticipate reach and fully exploit experiments

$0\nu\beta\beta$ decay: $\left(T_{1/2}^{0\nu\beta\beta}\right)^{-1} \propto \left|M^{0\nu\beta\beta}\right|^2 m_{\beta\beta}^2$

Dark matter: $\frac{d\sigma_{\chi\mathcal{N}}}{d\mathbf{q}^2} \propto \left|\sum_i c_i\, \zeta_i\, \mathcal{F}_i\right|^2$

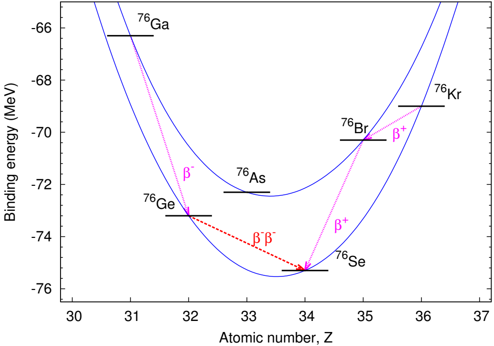
$M^{0\nu\beta\beta}$: Nuclear matrix element
$\mathcal{F}_i$: Nuclear structure factor



Neutrinoless $\beta\beta$ decay

Lepton-number violation, Majorana nature of neutrinos

Second order process only observable in rare cases with β-decay energetically forbidden or hindered by ΔJ



Present best limits $T_{1/2}^{0\nu\beta\beta} \gtrsim 10^{25}$ y:

^{76}Ge (GERDA, Majorana), ^{130}Te (CUORE), ^{136}Xe (EXO, KamLAND-Zen)

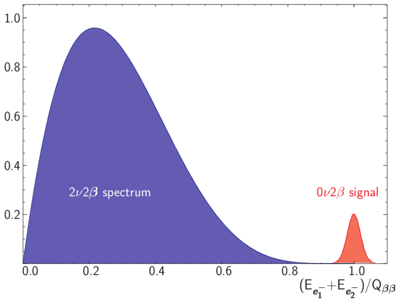
Signature of neutrinoless $\beta\beta$ decay

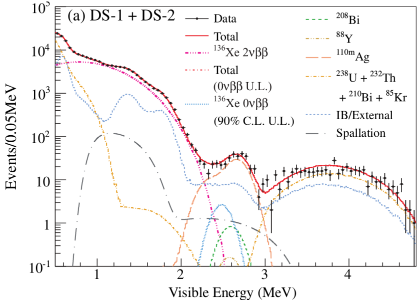
Very different signatures for neutrinoless and two-neutrino $\beta\beta$ decays

$$2\nu\beta\beta: \quad E_{e_1} + E_{e_2} + E_{\bar{\nu}_1} + E_{\bar{\nu}_2} = Q_{\beta\beta}$$

$$0\nu\beta\beta: \quad E_{e_1} + E_{e_2} = Q_{\beta\beta}$$

because only the electrons are detected in experiments



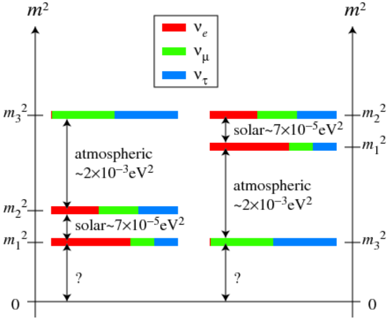


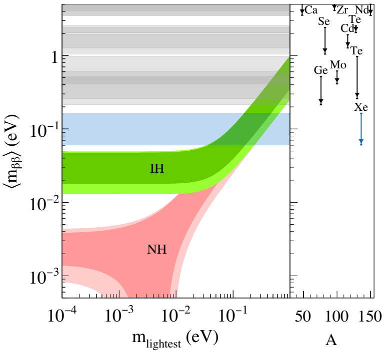
KamLAND-Zen, PRL110 062502 (2013)

Next generation experiments: inverted hierarchy

The decay lifetime is $$T_{1/2}^{0\nu\beta\beta}\left(0^+ \to 0^+\right)^{-1} = G_{01}\left|M^{0\nu\beta\beta}\right|^2 m_{\beta\beta}^2$$

sensitive to absolute neutrino masses, $m_{\beta\beta} = |\sum U_{ek}^2 m_k|$, and hierarchy





Matrix elements needed to make sure next generation ton-scale experiments fully explore "inverted hierarchy"

KamLAND-Zen, PRL117 082503(2016)

Outline

Present status of $0\nu\beta\beta$ decay nuclear matrix elements

Future prospects for $0\nu\beta\beta$ nuclear matrix element calculations

How can other nuclear experiments help $0\nu\beta\beta$ decay studies?

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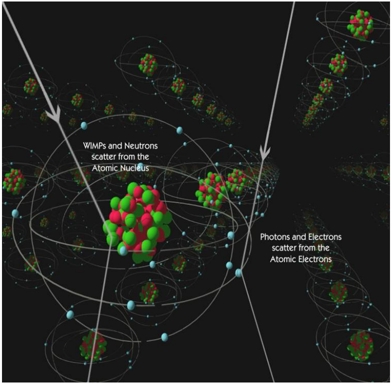
Calculating nuclear matrix elements

Nuclear matrix elements needed to study fundamental symmetries

$$\langle \text{Final} | \mathcal{L}_{\text{leptons}-\text{nucleons}} | \text{Initial} \rangle = \langle \text{Final} | \int dx\, j^{\mu}(x) J_{\mu}(x) | \text{Initial} \rangle$$

- Nuclear structure calculation of the initial and final states:
  Shell model Retamosa, Poves, JM, Horoi...
  Energy-density functional Rodríguez, Yao...
  QRPA Vogel, Faessler, Šimkovic, Suhonen...
  Interacting boson model Iachello, Barea...
  Ab initio many-body methods
  Green's Function MC, Coupled-cluster, IM-SRG...

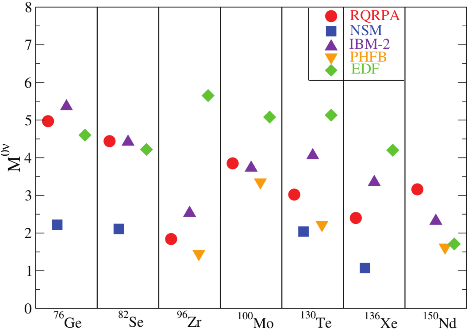
- Lepton-nucleus interaction:
  Study hadronic current in nucleus: phenomenological approaches, effective theory of QCD



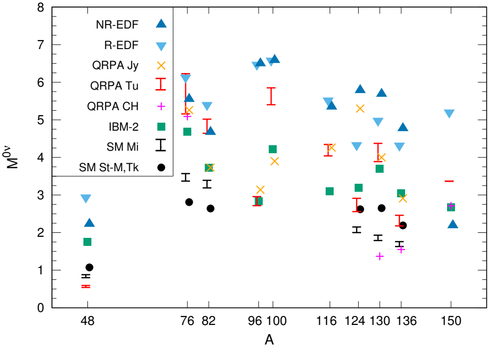
CDMS Collaboration

$0\nu\beta\beta$ nuclear matrix elements: last 5 years

Comparison of nuclear matrix element calculations: 2012 vs 2017



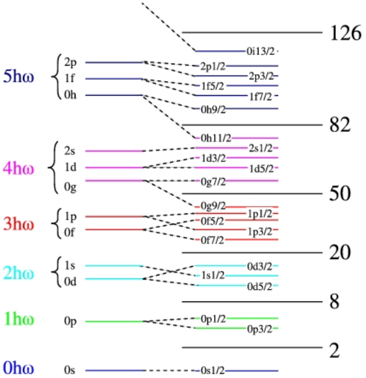
Vogel, J. Phys. G 39 124002 (2012)



Engel, JM, Rep.Prog.Phys. 80 046301(2017)

What have we learned in the last 5 years?

Configuration space



Nuclear shell model configuration space only keep essential degrees of freedom

- High-energy orbits: always empty
- Configuration space: where many-body problem is solved
- Inert core: always filled

$$H\,|\Psi\rangle = E\,|\Psi\rangle \;\rightarrow H_{eff}\,|\Psi\rangle_{eff} = E\,|\Psi\rangle_{eff}$$

$$|\Psi\rangle_{eff} = \sum_{\alpha} c_\alpha\,|\phi_\alpha\rangle\,, \quad |\phi_\alpha\rangle = a^+_{i1}a^+_{i2}...a^+_{iA}\,|0\rangle$$

Shell model codes (1 major oscillator shell) $\sim 10^{10}$ Slater dets. Caurier et al. RMP77 (2005)

QRPA calculations suggest larger spaces ($\gtrsim$ 2 major shells) needed

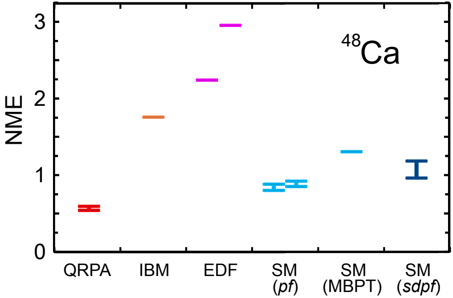
Dimension $\sim$

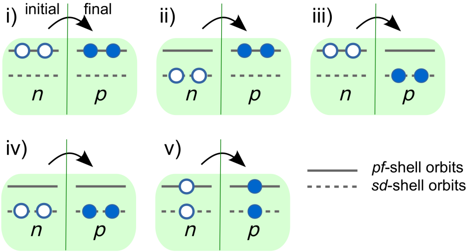
$$\binom{(p+1)(p+2)_\nu}{N}\binom{(p+1)(p+2)_\pi}{Z}$$

Shell model configuration space: two shells

For ^{48}Ca enlarge configuration space
from *pf* to *sdpf*
4 to 7 orbitals, dimension 10^5 to 10^9
increases matrix elements
but only moderately 30%

Iwata et al. PRL116 112502 (2016)



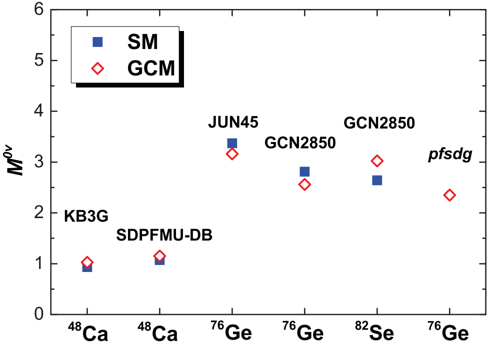


Contributions dominated by pairing
2 particle – 2 hole excitations
enhance the $\beta\beta$ matrix element,

Contributions dominated by
1 particle – 1 hole excitations
suppress the $\beta\beta$ matrix element

^{76}Ge matrix element in two shells: approximate

Large configuration space calculations in 2 major oscillator shells
Include all relevant correlations: isovector/isoscalar pairing, deformation
Many-body approach: generating coordinate method (GCM)



GCM approximates
shell model calculation

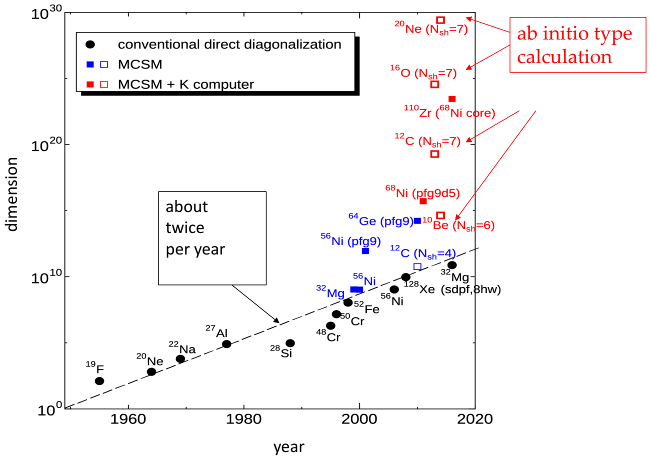
Degrees of freedom,
or generating coordinates,
validated against
exact shell model
in small configuration space

Jiao et al. PRC96 054310 (2017)

^{76}Ge nuclear matrix element in 2 major shells
very similar to shell model nuclear matrix element in 1 major shell

^{76}Ge matrix element in two shells: exact

Dimension of the shell-model many-body Hilbert space



From T. Otsuka, INT-18-1a program

^{76}Ge matrix element in two shells: exact

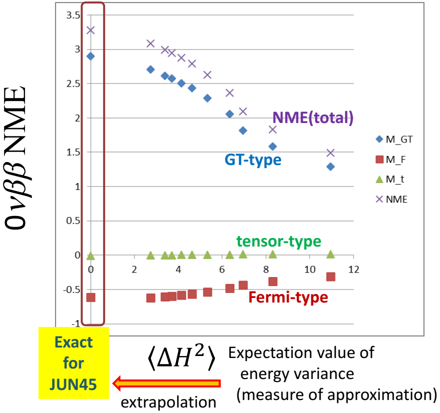
$0\nu\beta\beta$ decay Nuclear Matrix Element
by Monte Carlo shell model (MCSM)

$^{76}\text{Ge} \Rightarrow {}^{76}\text{Se}$

MCSM:
wave function composed of a superposition of selected optimal Slater determinants with projection onto J and P

Benchmark

f5pg9 shell,
JUN45 int.
(Honma 2009)

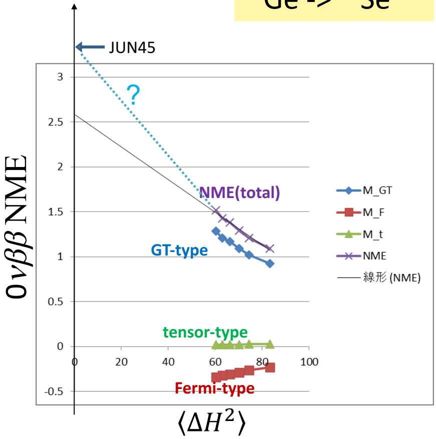


From T. Otsuka, INT-18-1a program

^{76}Ge matrix element in two shells: exact

$0\nu\beta\beta$ decay Nuclear Matrix Element by the Monte Carlo shell model

^{76}Ge -> ^{76}Se



pf-shell + 0g9/2 + 1d5/2
A3DA-m int.

The exact value by the conventional shell model calculation cannot be obtained due to the prohibitively large dimension of the Hamiltonian matrix.

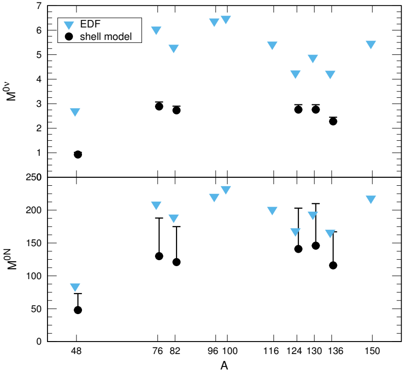
ca. 3.17 x 10^{17} dim.
against current limit
10^{10} dim.

in progress

From T. Otsuka, INT-18-1a program

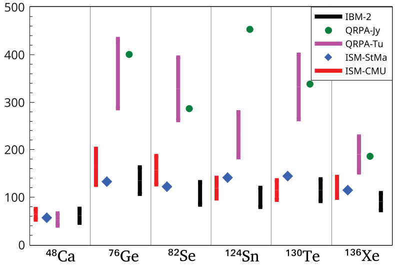
Heavy-neutrino exchange nuclear matrix elements

Contrary to light-neutrino-exchange, for heavy-neutrino-exchange decay shell model, IBM, and EDF matrix elements agree reasonably!



Song et al. PRC95 024305 (2017)

JM, JPG 45 014003 (2018)



Neacsu et al. PRC100 052503 (2015)

Suggests differences in treating longer-range nuclear correlations dominant in light-neutrino exchange

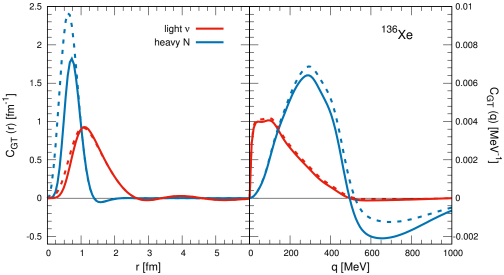
Heavy-neutrino matrix element

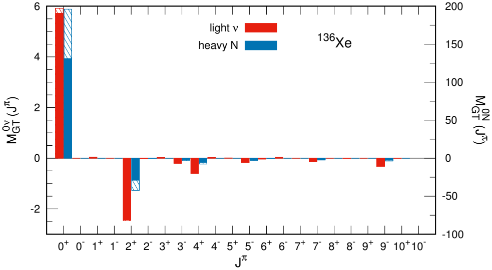
Compared to
light-neutrino exchange

heavy neutrino exchange
dominated by
shorter internucleon range,
larger momentum transfers

heavy neutrino exchange
contribution
from $J > 0$ pairs smaller:
pairing most relevant

$\Rightarrow$
Long-range correlations
(except pairing)
not under control



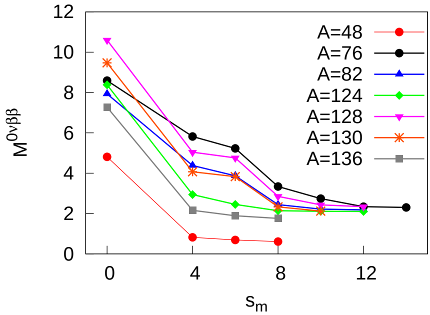


JM, JPG 45 014003 (2018)

Pairing correlations and $0\nu\beta\beta$ decay

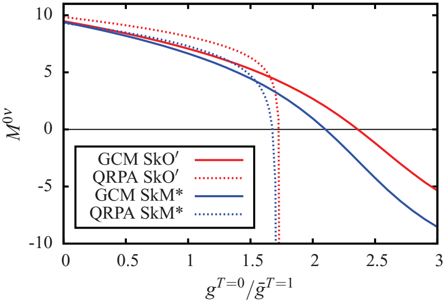
$0\nu\beta\beta$ decay favoured by proton-proton, neutron-neutron pairing, but it is disfavored by proton-neutron pairing

Ideal case: superfluid nuclei reduced with high-seniorities



Caurier et al. PRL100 052503 (2008)

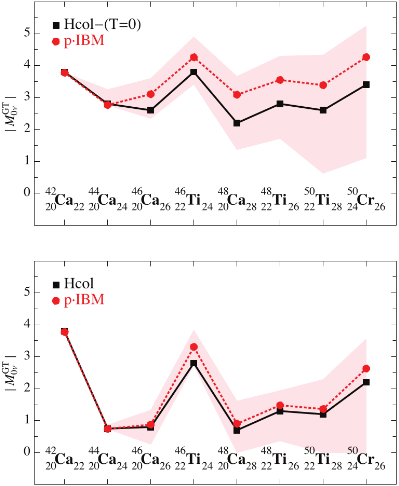
Addition of isoscalar pairing reduces matrix element value



Hinohara, Engel PRC90 031301 (2014)

Related to approximate $SU(4)$ symmetry of the $\sum H(r)\boldsymbol{\sigma}_i\boldsymbol{\sigma}_j\tau_i\tau_j$ operator

IBM matrix elements with proton-neutron pairing



van Isacker et al. PRC96 064505 (2018)

Energy-density functional (EDF) theory and interating boson model (IBM) calculated nuclear matrix elements do not include explicitly proton-neutron pairing correlations

This effect (partially) accounted for by other degrees of freedom present in these approaches

Include p-boson ($L = 1$) to IBM in addition to s and d bosons ($L = 0, 2$)

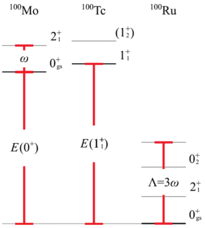
First IBM results in calcium region suggest nuclear matrix elements could be somewhat reduced

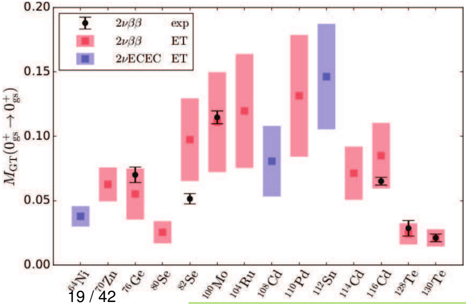
Matrix elements: theoretical uncertainty

Systematic uncertainty hard to estimate
for phenomenological matrix elements

Effective theory for $\beta\beta$ decay:
spherical core coupled to one nucleon

Couplings adjusted to experimental data,
uncertainty given by effective theory
(breakdown scale, systematic expansion)





Take β decay data to predict $2\nu\beta\beta$

$$M^{2\nu\beta\beta} =$$

$$\sum_k \frac{\langle 0^+_f | \sum_n \boldsymbol{\sigma}_n \tau^-_n \, | 1^+_k \rangle \langle 1^+_k | \sum_m \boldsymbol{\sigma}_m \tau^-_m \, | 0^+_i \rangle}{E_k - (M_i + M_f)/2}$$

Good agreement with large errors
(leading-order calculations)

Coello-Pérez, JM, Schwenk, arXiv:1708.06140

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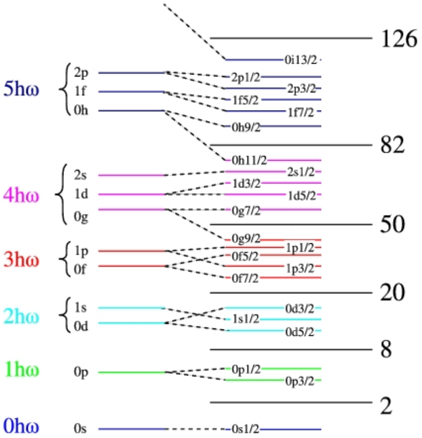
Present status of $0\nu\beta\beta$ decay nuclear matrix elements

Future prospects for $0\nu\beta\beta$ nuclear matrix element calculations

How can other nuclear experiments help $0\nu\beta\beta$ decay studies?

Ab initio methods: No core shell model



No core shell model

Many-body wave function
linear combination of
Slater Determinants
from single particle states in the basis
(3D harmonic oscillator)

$$|i\rangle = |n_i l_i j_i m_{j_i} m_{t_i}\rangle$$

$$|\phi_\alpha\rangle = a^+_{i1} a^+_{j2} \ldots a^+_{kA} |0\rangle$$

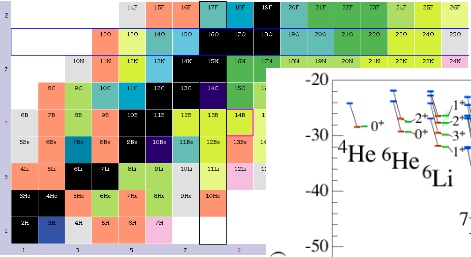
$$|\Psi\rangle = \sum_\alpha c_\alpha |\phi_\alpha\rangle$$

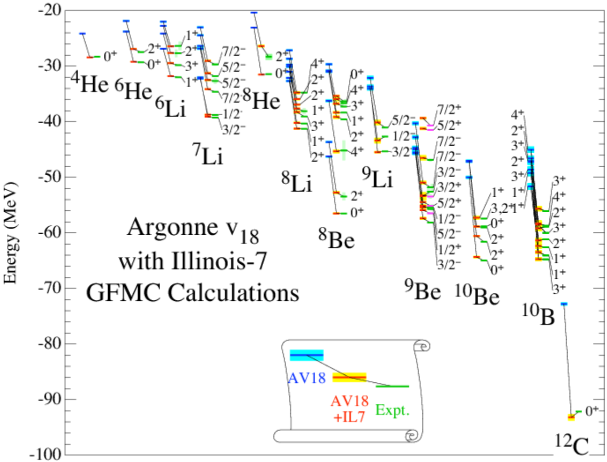
$$H|\Psi\rangle = E|\Psi\rangle$$

$$\text{Dim} \sim \begin{pmatrix} (p+1)(p+2)_\nu \\ N \end{pmatrix} \begin{pmatrix} (p+1)(p+2)_\pi \\ Z \end{pmatrix}$$

Dimensions increase
combinatorially...

Green’s function Monte Carlo





Green’s function Monte Carlo
Pieper, Wiringa, Carlson...

NN forces
do not reproduce
binding energies
and spectra:
need 3N forces

Good agreement
with 3N forces

Coupled Cluster, In-Medium SRG

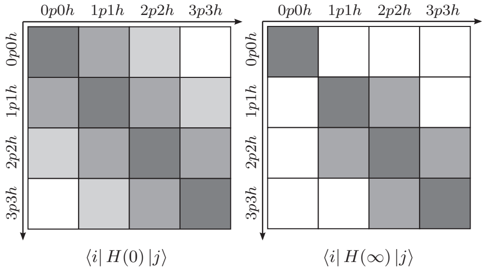
Coupled Cluster method: operators (correlations) acting on reference
impose no particle-hole excitations present in the reference state
Hagen, Papenbrock, Hjorth-Jensen...

$$|\Psi\rangle = e^{-(T_1+T_2+T_3\cdots)}\,|\Phi\rangle$$

$$\text{with} \quad T_1 = \sum_{\alpha,\bar{\alpha}} t_{\alpha}^{\bar{\alpha}} \left\{ a_{\bar{\alpha}}^{\dagger}, a_{\alpha} \right\} , T_2 = \sum_{\alpha\beta,\bar{\alpha}\bar{\beta}} t_{\alpha\beta}^{\bar{\alpha}\bar{\beta}} \left\{ a_{\bar{\alpha}}^{\dagger} a_{\bar{\beta}}^{\dagger}, a_{\alpha} a_{\beta} \right\} , \cdots$$

$$\text{solve} \quad \left\langle \Phi_{\alpha}^{\bar{\alpha}} \right| e^{\sum T_i} H e^{-\sum T_i} \left|\Phi\right\rangle = 0 \, , \left\langle \Phi_{\alpha\beta}^{\bar{\alpha}\bar{\beta}} \right| e^{\sum T_i} H e^{-\sum T_i} \left|\Phi\right\rangle = 0$$

In-medium similarity renormalization group method: apply a similarity (unitary) transformation
to decouple reference state
from particle-hole excitations
Bogner, Schwenk, Hergert, Stroberg...



Ab initio many-body methods

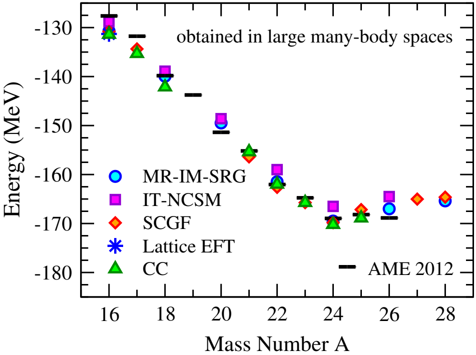
Oxygen dripline using chiral NN+3N forces correctly reproduced
ab-initio calculations treating explicitly all nucleons
excellent agreement between different approaches

No-core shell model
(Importance-truncated)

In-medium SRG
Hergert et al. PRL110 242501(2013)

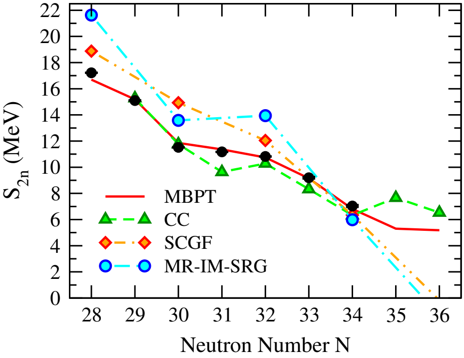
Self-consistent Green's function
Cipollone et al. PRL111 062501(2013)

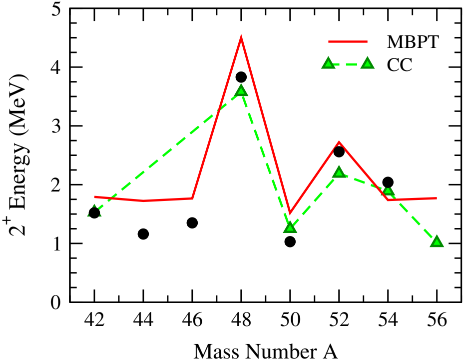
Coupled-clusters
Jansen et al. PRL113 142502(2014)



Calcium isotopes with NN+3N forces

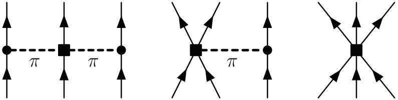
Calculations with NN+3N forces predict shell closures at ^{52}Ca, ^{54}Ca





$^{51-54}$Ca masses [TRIUMF/ISOLDE]

^{54}Ca 2_1^+ excitation energy [RIBF,RIKEN]



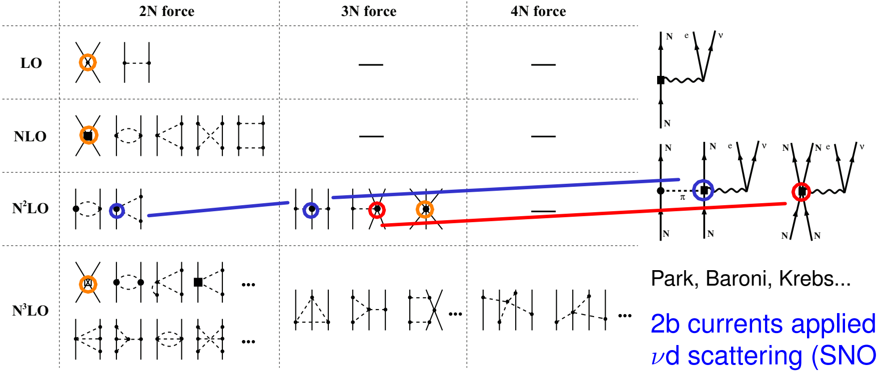
Hebeler et al. ARNPS 65 457 (2015)

Chiral effective field theory

Chiral EFT: low energy approach to QCD, nuclear structure energies

Approximate chiral symmetry: pion exchanges, contact interactions

Systematic expansion: nuclear forces and electroweak currents



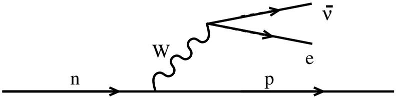
Weinberg, van Kolck, Kaplan, Savage, Epelbaum, Kaiser, Meißner...

Park, Baroni, Krebs...

2b currents applied to νd scattering (SNO), ^{3}H β-decay, μ moment...

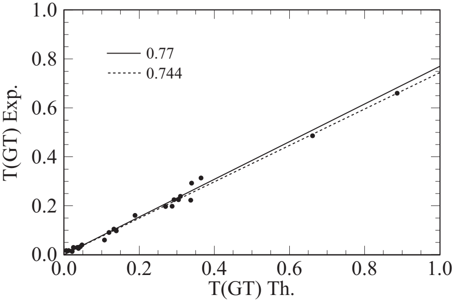
Gamow-Teller transitions: quenching

Single β decays well described by nuclear structure (shell model)



$$\langle F | \sum_i g_A^{\text{eff}} \, \boldsymbol{\sigma}_i \tau_i^- \, | I \rangle$$

$$g_A^{\text{eff}} = q g_A, \quad q \sim 0.7 - 0.8.$$



Martínez-Pinedo et al. PRC53 2602 (1996)

Theory needs to “quench“ Gamow-Teller operator to reproduce Gamow-Teller lifetimes: problem in nuclear many-body wf or operator?

This puzzle has been the target of many theoretical efforts:

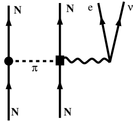
Arima, Rho, Towner, Bertsch and Hamamoto, Wildenthal and Brown...

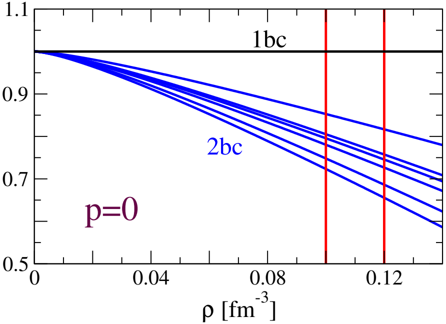
2b currents in medium-mass nuclei

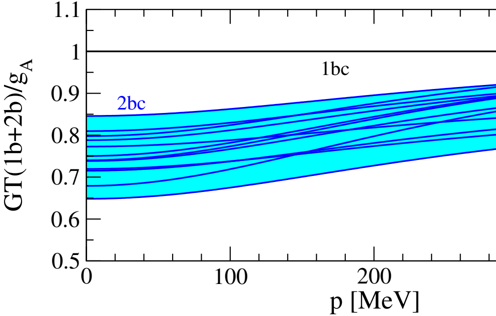
Normal-ordered 2b currents modify GT operator

JM, Gazit, Schwenk PRL107 062501 (2011)

$$\mathbf{J}^{\rm eff}_{n,2b} \simeq -\frac{g_A\rho}{f_\pi^2}\tau_n^- \sigma_n \left[I(\rho,P)\,\frac{(2c_4-c_3)}{3}\right] - \frac{g_A\rho}{f_\pi^2}\tau_n^- \sigma_n \frac{2}{3}\, c_3\, \frac{\mathbf{p}^2}{m_\pi^2+\mathbf{p}^2},$$







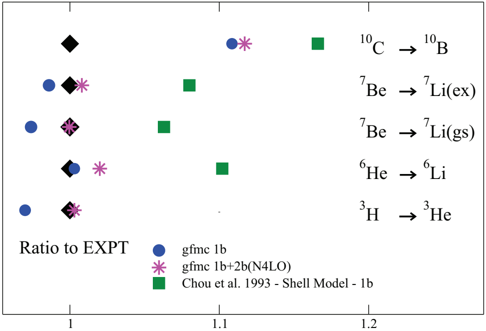
2b currents predict g_A quenching $q = 0.85 \ldots 0.66$

Quenching reduced at $p > 0$, relevant for $0\nu\beta\beta$ decay where $p \sim m_\pi$

β decay in very light nuclei: GFMC

Ab initio Green Function Monte Carlo β decay matrix elements in $A \leq 10$

Pastore et al. PRC97 022501 (2018)

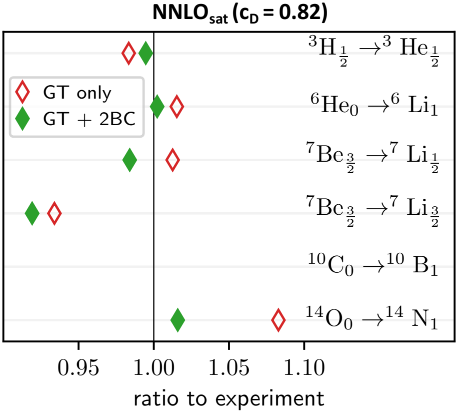


Very good agreement to experiment in all cases
except for ^{10}C, very sensitive to nuclear structure details

Impact of 2b currents small (few %) enhancement of matrix elements

β decay in very light nuclei: NCSM

Theory to experiment ratios for beta decays in light nuclei from NCSM



From G. Hagen, INT-18-1a program

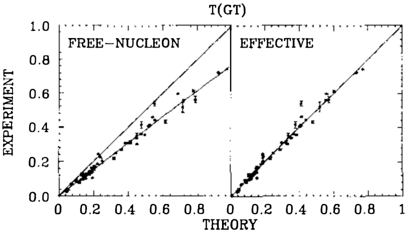
β decay in medium-mass nuclei: IMSRG

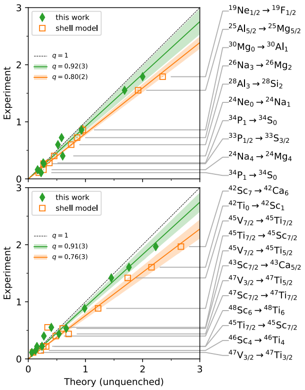
TRIUMF “Quenching” of g_A in Gamow-Teller Decays

VS-IMSRG calculations of GT transitions in sd, pf shells

Minor effect from consistent effective operator

Significant effect from neglected 2-body currents

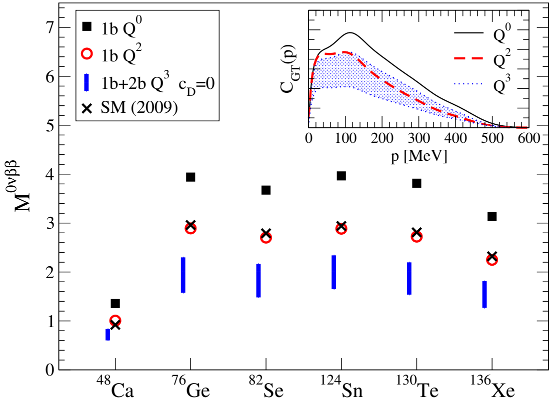




Ab initio calculations explain data with unquenched g_A

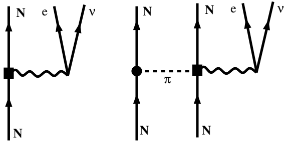
From J. Holt, INT-18-1a program

Nuclear matrix elements with 1b+2b currents



JM, Gazit, Schwenk PRL107 062501 (2011)

Order Q^0+Q^2 similar to phenomenological currents
JM, Poves, Caurier, Nowacki
NPA818 139 (2009)



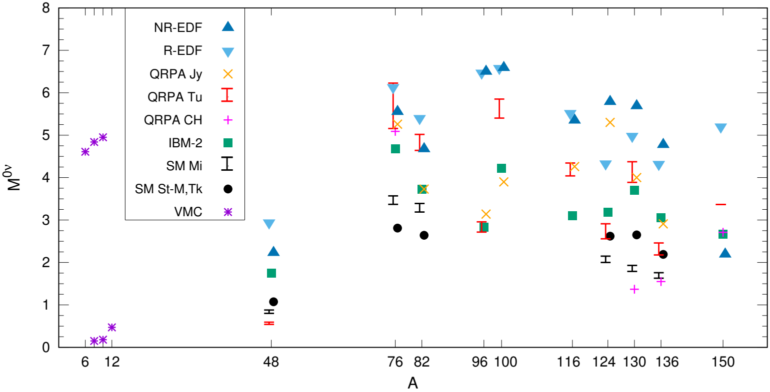
Order Q^3 2b currents reduce NMEs $\sim 20\% - 50\%$

Improved, ideally ab initio calculations are needed!

$0\nu\beta\beta$ decay matrix elements in very light nuclei

Variational Monte Carlo $0\nu\beta\beta$ decay matrix elements in $A \leq 12$

Pastore et al. PRC97 014606 (2018)



Larger/smaller matrix elements given by same/different nuclear isospin

Anchor for other ab initio approaches that can extend to heavier nuclei

Outline

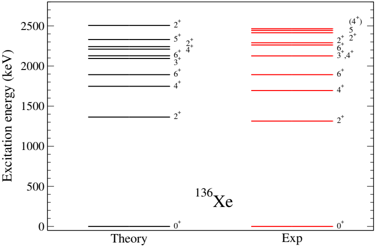
Present status of $0\nu\beta\beta$ decay nuclear matrix elements

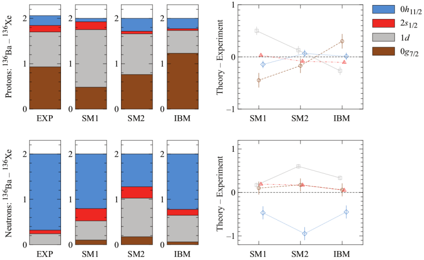
Future prospects for $0\nu\beta\beta$ nuclear matrix element calculations

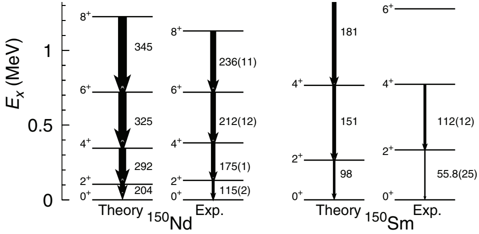
How can other nuclear experiments help $0\nu\beta\beta$ decay studies?

Tests of nuclear structure

Spectroscopy well described: masses, spectra, transitions, knockout...







Schiffer et al. PRL100 112501(2009)

Kay et al. PRC79 021301(2009)

...

Szwec et al., PRC94 054314 (2016)

Rodríguez et al. PRL105 252503 (2010)

...

Vietze et al. PRD91 043520 (2015)

Two-neutrino $\beta\beta$ decay

Test of $0\nu\beta\beta$ decay: comparison of predicted $2\nu\beta\beta$ decay vs data

Shell model reproduce $2\nu\beta\beta$ data including "quenching" common to β decays in same mass region

Shell model prediction previous to ^{48}Ca measurement!

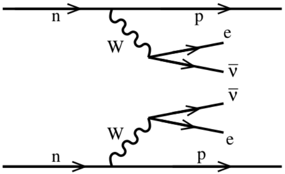


Table 2
The ISM predictions for the matrix element of several 2ν double beta decays (in MeV^{-1}). See text for the definitions of the valence spaces and interactions.

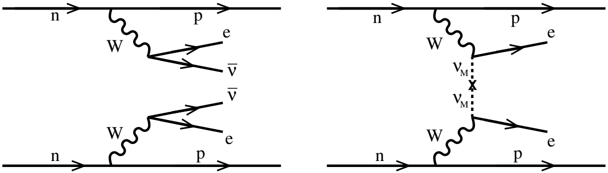
	$M^{2\nu}$(exp)	q	$M^{2\nu}$(th)	INT
$^{48}Ca \to {}^{48}Ti$	0.047 ± 0.003	0.74	0.047	kb3
$^{48}Ca \to {}^{48}Ti$	0.047 ± 0.003	0.74	0.048	kb3g
$^{48}Ca \to {}^{48}Ti$	0.047 ± 0.003	0.74	0.065	gxpf1
$^{76}Ge \to {}^{76}Se$	0.140 ± 0.005	0.60	0.116	gcn28:50
$^{76}Ge \to {}^{76}Se$	0.140 ± 0.005	0.60	0.120	jun45
$^{82}Se \to {}^{82}Kr$	0.098 ± 0.004	0.60	0.126	gcn28:50
$^{82}Se \to {}^{82}Kr$	0.098 ± 0.004	0.60	0.124	jun45
$^{128}Te \to {}^{128}Xe$	0.049 ± 0.006	0.57	0.059	gcn50:82
$^{130}Te \to {}^{130}Xe$	0.034 ± 0.003	0.57	0.043	gcn50:82
$^{136}Xe \to {}^{136}Ba$	0.019 ± 0.002	0.45	0.025	gcn50:82

Caurier, Nowacki, Poves PLB711 62(2012)

$$M^{2\nu\beta\beta} = \sum_k \frac{\langle 0_f^+ | \sum_n \sigma_n \tau_n^- | 1_k^+ \rangle \langle 1_k^+ | \sum_m \sigma_m \tau_m^- | 0_i^+ \rangle}{E_k - (M_i + M_f)/2}$$

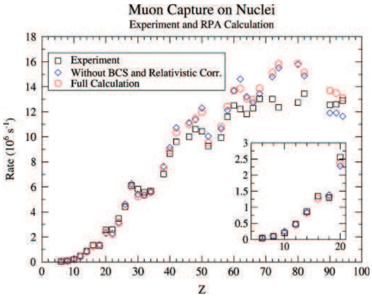
μ-capture, ν-nucleus scattering

Momentum transfers very different in $\beta\beta$ decays:
$2\nu\beta\beta$ decay ($q \sim 1$ MeV) and $0\nu\beta\beta$ decay ($q \sim 100$ MeV)



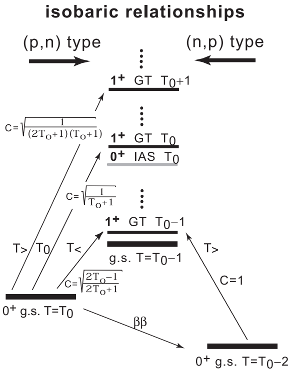
Muon-capture,
neutrino-nucleus scattering
(to low-energy states)
probe similar momentum
transfers than $0\nu\beta\beta$ decay

Several multipolarities (J values)
contribute, like in $0\nu\beta\beta$ decay

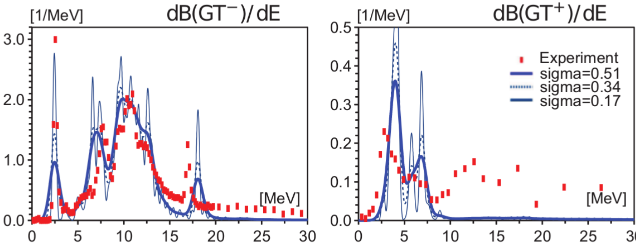


Gamow-Teller strength distributions

Gamow-Teller (GT) distributions well described by theory (quenched)



Freckers et al.
NPA916 219 (2013)



Iwata et al. JPSCP 6 03057 (2015)

$$\langle 1_f^+ | \sum_i [\sigma_i \tau_i^\pm]^{\rm eff} | 0_{\rm gs}^+ \rangle , \quad [\sigma_i \tau^\pm]^{\rm eff} \approx 0.7 \sigma_i \tau^\pm$$

$$M^{2\nu\beta\beta} = \sum_k \frac{\langle 0_f^+ | \sum_n \sigma_n \tau_n^- | 1_k^+ \rangle \langle 1_k^+ | \sum_m \sigma_m \tau_m^- | 0_i^+ \rangle}{E_k - (M_i + M_f)/2}$$

Double Gamow-Teller strength distribution

Measurement of Double Gamow-Teller (DGT) resonance
in double charge-exchange reactions ^{48}Ca(pp,nn)^{48}Ti proposed in 80's

Auerbach, Muto, Vogel... 1980's, 90's

Recent experimental plans in RCNP, RIKEN (^{48}Ca), INFN Catania

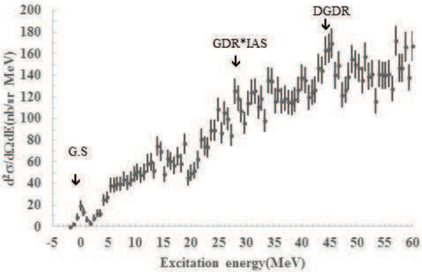
Takaki et al. JPS Conf. Proc. 6 020038 (2015)

Capuzzello et al. EPJA 51 145 (2015), Takahisa, Ejiri et al. arXiv:1703.08264

Promising connection to $\beta\beta$ decay,
two-particle-exchange process,
especially the (tiny) transition
to ground state of final state

Two-nucleon transfers related to
$0\nu\beta\beta$ decay matrix elements

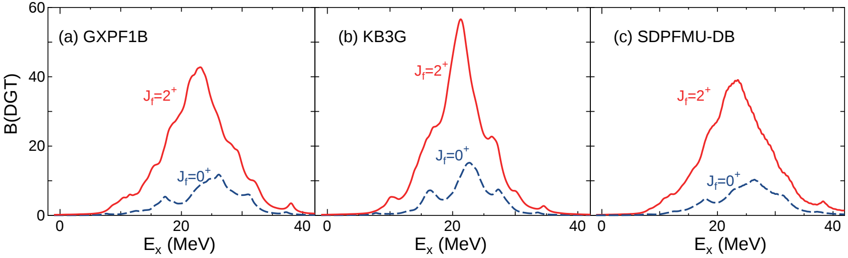
Brown et al. PRL113 262501 (2014)



^{48}Ca Double Gamow-Teller distribution

Calculate with shell model ^{48}Ca 0^+_{gs} Double Gamow-Teller distribution

$$B(DGT^-;\lambda;i\to f)=\frac{1}{2J_i+1}\left|\left\langle {}^{48}\mathrm{Ti}\left|\left|\left[\sum_i \boldsymbol{\sigma}_i\tau_i^- \times \sum_j \boldsymbol{\sigma}_j\tau_j^-\right]^{(\lambda)}\right|\right|{}^{48}\mathrm{Ca}_{gs}\right\rangle\right|^2$$



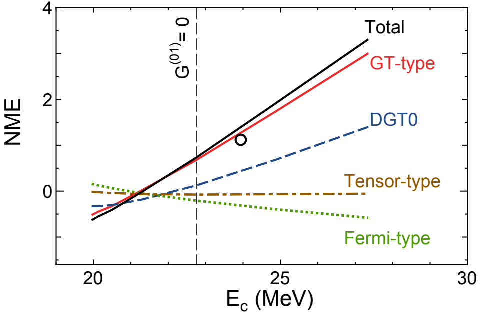
Shell model calculation with Lanczos strength function method

Double GT resonances in one and two shells rather similar result

Shimizu, JM, Yako, PRL accepted

^{48}Ca double GT resonance and $0\nu\beta\beta$ decay

Correlation between Double Gamow-Teller resonance in ^{48}Ca and $0\nu\beta\beta$ decay nuclear matrix element



Energy of DGT resonance with accuracy to $\sim$1MeV, can give insight on the value of $0\nu\beta\beta$ decay matrix element

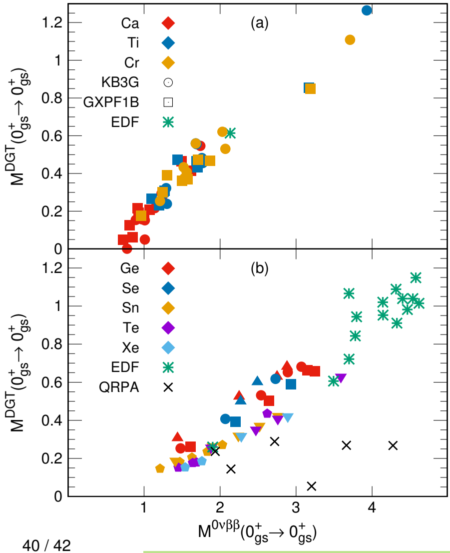
$$E_{\rm av} = \frac{\sum_f E_f B(DGT^-, i \to f)}{\sum_f B(DGT^-, i \to f)}$$

Might be feasible in near future at LNS Catania or RIBF RIKEN

Uesaka, Takaki, Cappuzzello, Ejiri...

Shimizu, JM, Yako, PRL accepted

Double Gamow-Teller and $0\nu\beta\beta$ decay



DGT transition to ground state

$M^{DGT} =$
$\langle F_{gs} || [\sum_i \boldsymbol{\sigma}_i \tau_i^- \times \sum_j \boldsymbol{\sigma}_j \tau_j^-]^0 || I_{gs} \rangle|^2$

very good linear correlation
with $0\nu\beta\beta$ decay
nuclear matrix elements

Correlation holds
across wide range of nuclei,
from Ca to Ge and Xe

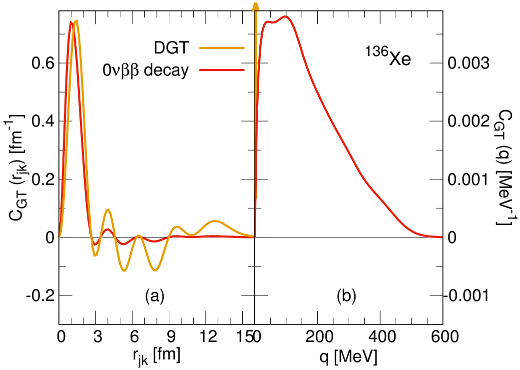
Common to shell model and
energy-density functional theory
$0 \lesssim M^{0\nu\beta\beta} \lesssim 5$
disagreement to QRPA

Shimizu, JM, Yako, PRL accepted

Short-range character of DGT, $0\nu\beta\beta$ decay

Correlation between DGT and $0\nu\beta\beta$ decay matrix elements explained by transition involving low-energy states combined with dominance of short distances between exchanged/decaying neutrons

Bogner et al. PRC86 064304 (2012)



$0\nu\beta\beta$ decay matrix element limited to shorter range

Short-range part dominant in double GT matrix element due to partial cancellation of mid- and long-range parts

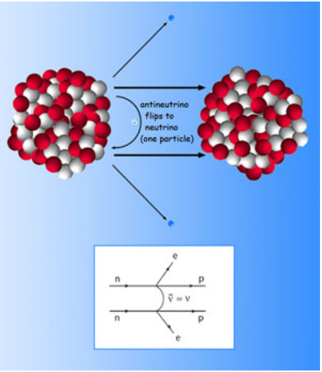
Long-range part dominant in QRPA DGT matrix elements

Shimizu, JM, Yako, PRL accepted

Summary

Reliable nuclear matrix elements needed to plan and fully exploit impressive experiments looking for neutrinoless double-beta decay

- Matrix element differences
  between present calculations, factor $2-3$
  besides addional "quenching"?
- ^{48}Ca and ^{76}Ge matrix elements
  in large configuration space increase $\lesssim 30\%$,
  missing correlations introduced in IBM, EDF
- First ab initio calculations of β decays
  do not need additional "quenching",
  stay tuned for ab initio ^{48}Ca matrix elements
- $2\nu\beta\beta$ decay, μ-capture/ν-nucleus scattering
  and double Gamow-Teller transitions
  can give insight on $0\nu\beta\beta$ matrix elements



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