Collectivity of Low-lying Gamow-Teller strength for tin isotopes

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1. Low-lying excitation in neutron- & proton-rich nuclei
2. proton-neutron QRPA (pnQRPA)
3. Low-lying Gamow-Teller strength
4. Summary

Low-lying excitation in neutron- & proton-rich nuclei

◆Pigmy dipole associated with skin structure

◆Large spatial distribution in vibration excitation mode

→ *nuclear structure of exotic nuclei*

◆Low-lying charge-exchanged transition

•*neutrino reaction*
•*β-decay → r-process nucleosynthesis*
•*ββ-decay → Majonara neutrino?*

1. Gross theory	systematic study not applicable for nuclei far from stability
2. proton-neutron QRPA	systematic study applicable for systematic study
3. Shell Model (SM) calc.	predict GT spectrum accurately systematic application is hard

proton-neutron QRPA (pnQRPA)

β-decay : Low-lying Gamow-Teller (GT) distribution

$$|1^+\rangle = Q^\dagger|0\rangle \qquad Q^\dagger = \sum_{pn} X_{pn}\alpha_p^\dagger\alpha_n^\dagger - Y_{pn}\alpha_p\alpha_n$$

1^+ ex. state g.s.

weight of pn component contributing 1^+

$$w_{pn} = X_{pn}^2 - Y_{pn}^2 \quad \sum_{pn} w_{pn} = 1$$

Equation of motion $[H, Q^\dagger] = \omega Q^\dagger$ + quasi-boson approx.

→QRPA Equation $\begin{pmatrix} A & B \\ B & A \end{pmatrix}\begin{pmatrix} X \\ Y \end{pmatrix} = E_{\mathrm{QRPA}}\begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}\begin{pmatrix} X \\ Y \end{pmatrix}$

$$A_{pnp'n'} = (E_p + E_n)\delta_{pp'}\delta_{nn'} + (u_p v_n u_{p'} v_{n'} + v_p u_n v_{p'} u_{n'})\, v_{p\bar{n}'\bar{n}p'} + (u_p u_n u_{p'} u_{n'} + v_p v_n v_{p'} v_{n'})\, v_{pnp'n'}$$

$$B_{pnp'n'} = -(u_p v_n u_{p'} v_{n'} + v_p u_n v_{p'} u_{n'})\, v_{p\bar{n}'\bar{n}p'} + (u_p u_n u_{p'} u_{n'} + v_p v_n v_{p'} v_{n'})\, v_{pnp'n'}$$

Schematic separable force (GT force) when solving QRPA equation

GT force $\sim V_{\mathrm{GT}} \sum_{\mu} (-1)^\mu (\sigma_{1\mu} \cdot \sigma_{2\mu})(\tau_1 \cdot \tau_2)$

Parameters are adjusted to fit known data

→**reproduce reasonably β-decay in isotopic chain**

cf. H.Homma et.al.,PRC54 (1996)

But,

- low-lying GT energy
- Strength B(GT)

} not be reproduced simultaneously

$$T_{1/2} \propto E_{\mathrm{tran}}^2 B(GT)$$

Mean-field approaches X single particle levels near Fermi Energy
Quantitative estimate is difficult in practical

Self-consistent pnQRPA *(cf. J. Engel PRC (1999))*

■**particle-hole (p-h) channel**

$$v_{\mathrm{ph}} = v_{11}(r)(\sigma_1 \cdot \sigma_2)(\tau_1 \cdot \tau_2) \underline{+ v_{01}(r)(\tau_1 \cdot \tau_2) + v^{\mathrm{s.o.}}}$$

cf. GT force $v_{\mathrm{ph}} = \chi_{\mathrm{ph}}(\sigma_1 \cdot \sigma_2)(\tau_1 \cdot \tau_2)$

■**particle-particle (p-p) channel**

$$v_{\mathrm{pp}} = \boxed{V_{pp}}(1 - \rho(r)/\rho_0)$$

(cf. J.Engel finite range force)

Parameter of T=0, S=1 pairing is adjusted
appropriately to reproduce β-decay half-lives

Just phenomenological. its physical role is not understood well

Effect of Phenomenological interactions

which are appropriately
determined for beta-decay

To understand physical meaning of them,

Let's see microscopic structure of
low-lying GT described by pnQRPA ***systematically***

since quantitative estimate is difficult

We discuss on followings from a microscopic point of view

1. Effect of $\tau_1\tau_2$ & spin-orbit terms on low-lying GT states

2. Effect of p-p residual interaction on low-lying GT states

FRAMEWORK

Self-consistent pnQRPA on the basis of Skyrme-Hartree-Fock + BCS

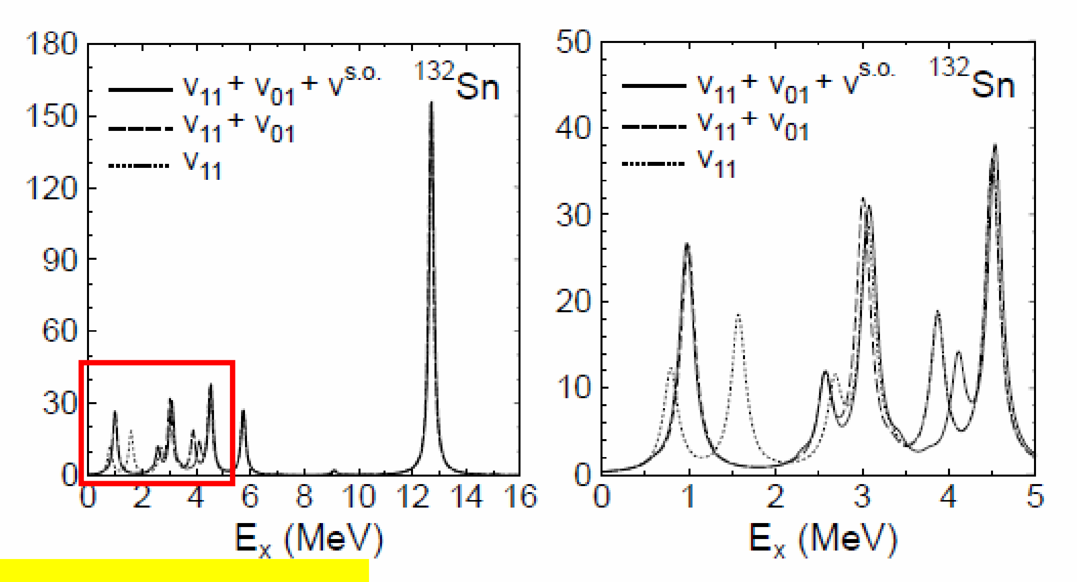
Surface type pairing with a strength V_n=1000 MeV fm^3 ,ρ_0=0.16 fm^{-3}
SLy5 parameter set
(most plausible s.p. l. for ^{132}Sn near Fermi surface comparing exp.)

Discretized box 20 fm with 0.1 fm step,
E_{cut} < 20 MeV, QRPA phonon energy < 70 MeV

Effect of $\tau_1\tau_2$ & spin-orbit terms for ^{132}Sn in case of $V_{pp}=0$

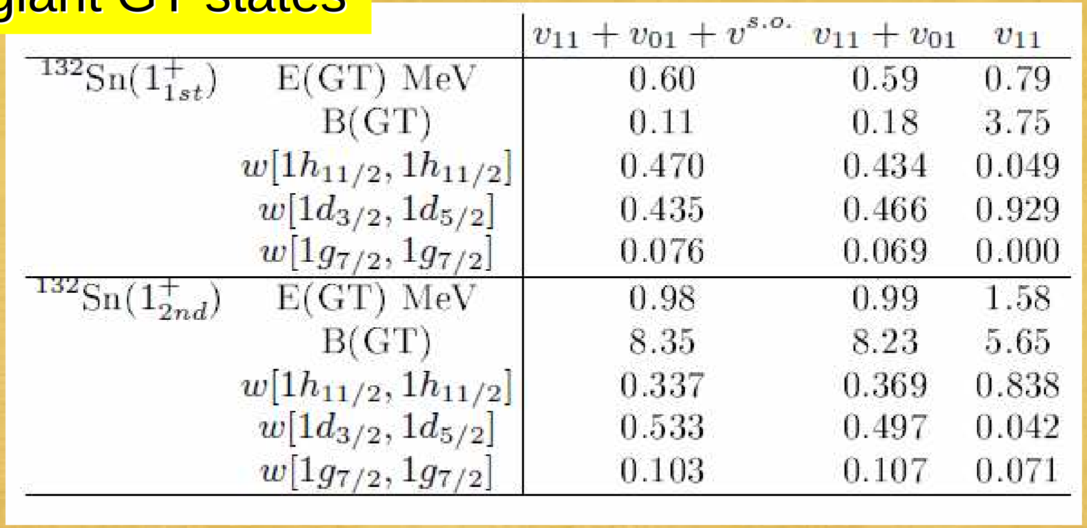
$$v_{\text{ph}} = v_{11}(r)(\sigma_1\cdot\sigma_2)(\tau_1\cdot\tau_2) + v_{01}(r)(\tau_1\cdot\tau_2) + v^{\text{s.o.}}$$

^{132}Sn



Lorenztian with a width 0.2 MeV

Minor effect on giant GT states

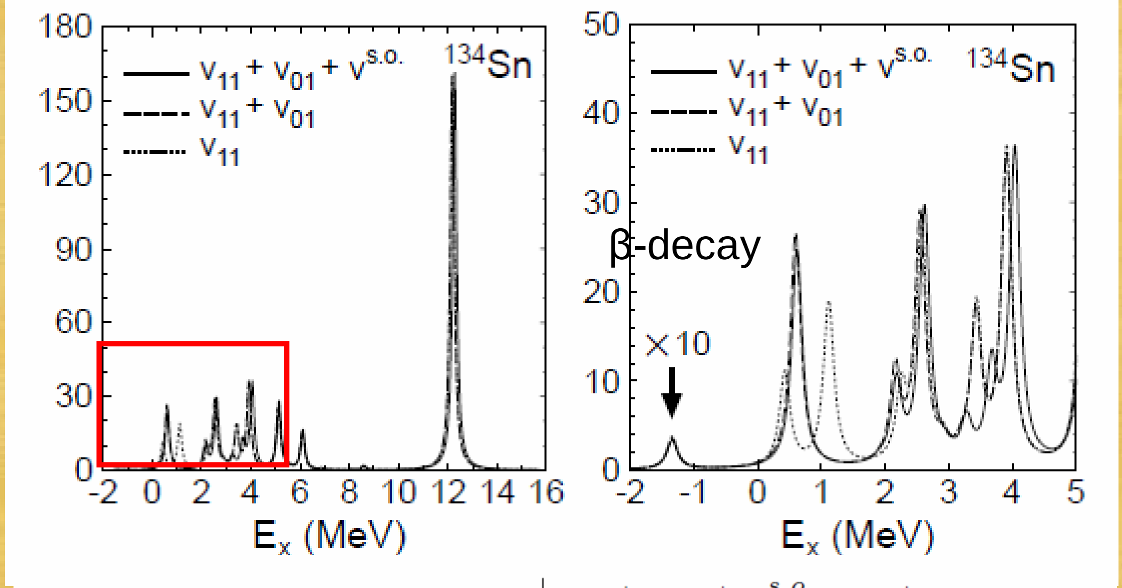


		$v_{11} + v_{01} + v^{s.o.}$	$v_{11} + v_{01}$	v_{11}
^{132}Sn(1^+_{1st})	E(GT) MeV	0.60	0.59	0.79
	B(GT)	0.11	0.18	3.75
	$w[1h_{11/2}, 1h_{11/2}]$	0.470	0.434	0.049
	$w[1d_{3/2}, 1d_{5/2}]$	0.435	0.466	0.929
	$w[1g_{7/2}, 1g_{7/2}]$	0.076	0.069	0.000
^{132}Sn(1^+_{2nd})	E(GT) MeV	0.98	0.99	1.58
	B(GT)	8.35	8.23	5.65
	$w[1h_{11/2}, 1h_{11/2}]$	0.337	0.369	0.838
	$w[1d_{3/2}, 1d_{5/2}]$	0.533	0.497	0.042
	$w[1g_{7/2}, 1g_{7/2}]$	0.103	0.107	0.071

Low-lying state is sensitive to $\tau_1\tau_2$ terms

Effect of $\tau_1\tau_2$ & spin-orbit terms in case of $V_{pp}=0$

^{134}Sn



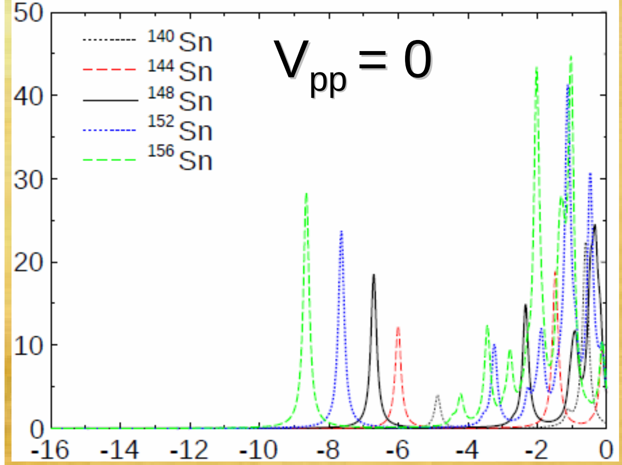
		$v_{11} + v_{01} + v^{s.o.}$	$v_{11} + v_{01}$	v_{11}
$^{134}\mathrm{Sn}(1^+_{1st})$	E(GT) MeV	-1.34	-1.34	-1.34
	B(GT)	0.10	0.11	0.11
	$w[1h_{9/2}, 1h_{11/2}]$	0.999	0.999	0.999
$^{134}\mathrm{Sn}(1^+_{2nd})$	E(GT) MeV	0.20	0.18	0.42
	B(GT)	0.01	0.01	3.35
	$w[1h_{11/2}, 1h_{11/2}]$	0.247	0.513	0.062
	$w[1d_{3/2}, 1d_{5/2}]$	0.616	0.373	0.913
	$w[1g_{7/2}, 1g_{7/2}]$	0.093	0.082	0.000
$^{134}\mathrm{Sn}(1^+_{3rd})$	E(GT) MeV	0.62	0.59	1.12
	B(GT)	7.76	8.32	5.83
	$w[1h_{11/2}, 1h_{11/2}]$	0.255	0.296	0.828
	$w[1d_{3/2}, 1d_{5/2}]$	0.622	0.583	0.053
	$w[1g_{7/2}, 1g_{7/2}]$	0.088	0.089	0.069

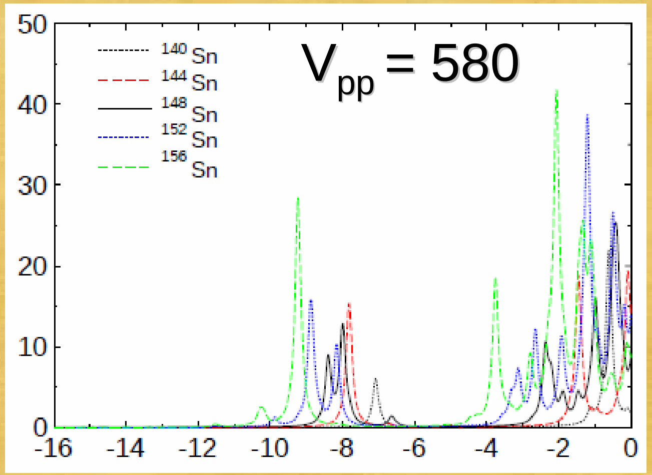
Same results in
other tin isotopes

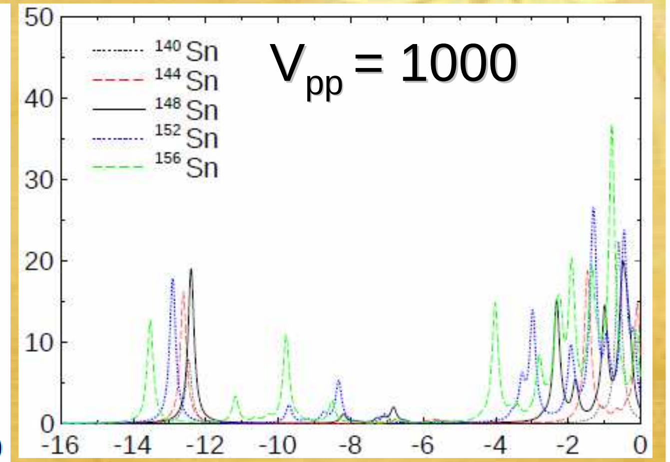
First low-lying peak at negative energy is insensitive!

Effect of particle-particle residual interaction

V_{pp}=580 MeV fm^3 is determined to reproduce ^{134}Sn β half-life







p-p channel attracts first low-lying GT peaks

■w [ν1h9/2→ π1h11/2] : Dominant contribution to first low-lying state

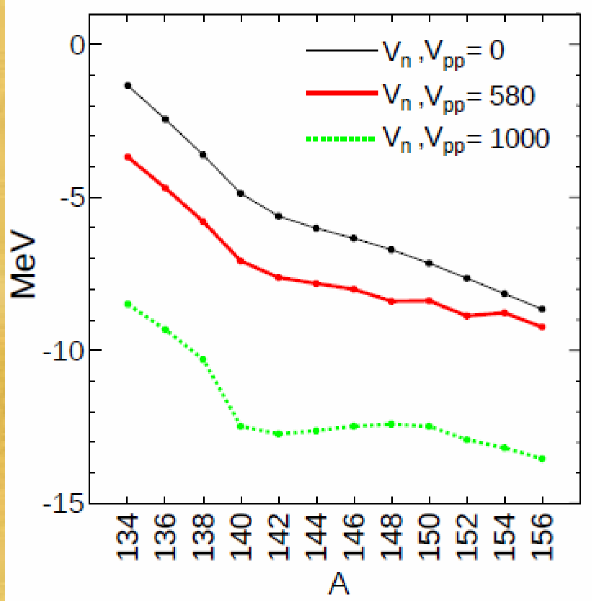
	140Sn	144Sn	148Sn	152Sn	156Sn
V_{pp} = 0	0.997	0.992	0.987	0.984	0.981
V_{pp} = 580	0.898	0.882	0.305	0.478	0.864
V_{pp} =1000	0.663	0.573	0.489	0.363	0.218

Contributions from other proton-neutron configuration ↑ by V_{pp}

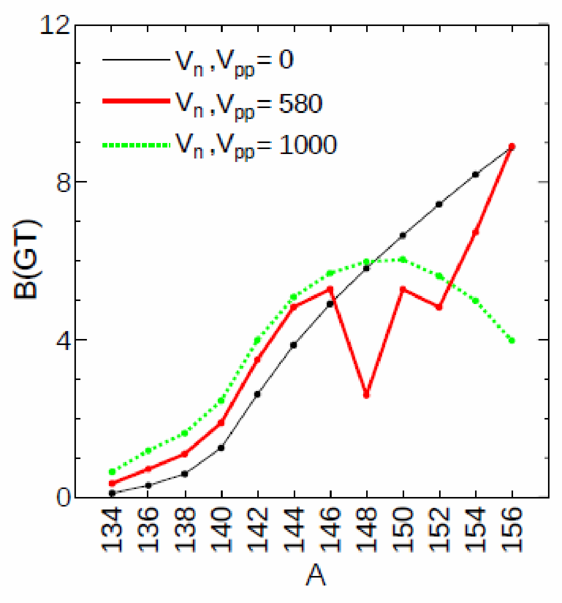
particle-particle channel works for β-decay?

Comparison with future experimental result,
or other model, for instance, SM calculations

Energy of first strong GT peak



B(GT) of first strong GT peak



V_{pp}=0 : decrease monotonically
since potential depth of p become deeper
V_{pp}≠0 : weaker dependence on A (V=580)
almost constant from A= 140 to 150

V_{pp}=0 : increase monotonically
V_{pp}≠0 : complex dependence on A

$$B(GT) = |\langle 1^+_{1st}|\sigma\tau|0\rangle|^2$$

Summary

In order to investigate the effect of phenomenological forces in QRPA, we calculate low-lying GT described by pnQRPA ***systematically.***

1. Effect of $\tau_1\tau_2$ & spin-orbit terms

Minor effect on giant GT states

Low-lying state is sensitive to $\tau_1\tau_2$ terms

First strong low-lying peak at negative energy is insensitive

support use of GT force for β-decay study

2. Effect of particle-particle channel

Low-lying GT peak become collective

→ *β-decay is just transition between single particle levels, or a kind of "collective mode"?*

Comparison with SM calculation / future experimental analysis

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