Recent applications of covariant density functional theory to spin-isospin excitations

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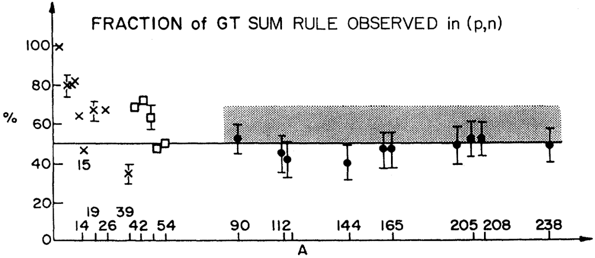
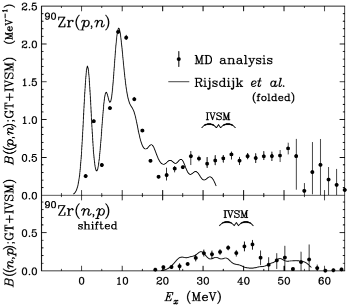
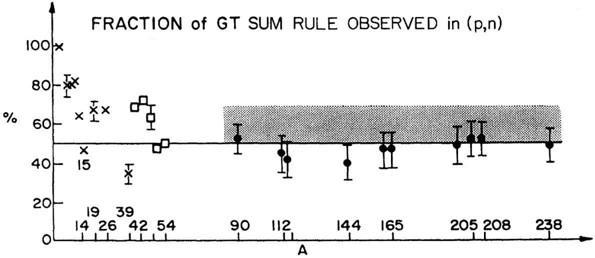
MSU, November 2012



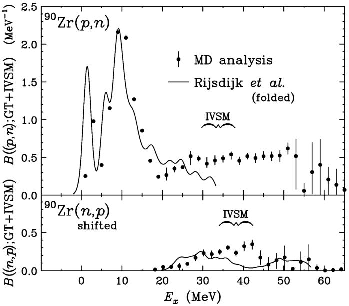
$$\hat{O}_{GT} = \boldsymbol{\sigma}\tau_{\pm}$$
$$S_- - S_+ = 3\,(N - Z)$$
$$Q \approx 0.6$$



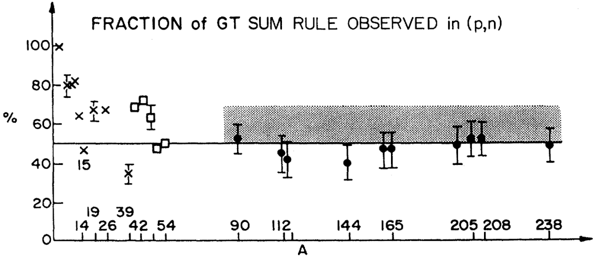
C. Gaarde *et al.*, Nucl. Phys. A 334, 248 (1980)



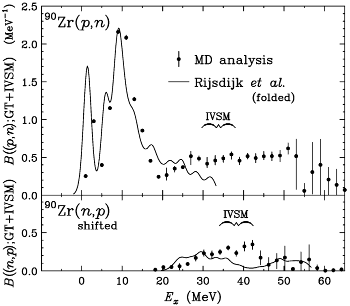
$$\hat{O}_{GT} = \boldsymbol{\sigma}\tau_{\pm}$$
$$S_{-} - S_{+} = 3\,(N - Z)$$
$$Q = 0.88 \pm 0.06 \pm 0.16$$



K. Yako *et al.*, Phys. Lett. B 615, 193 (2005)



$$\hat{O}_{GT} = \boldsymbol{\sigma}\tau_{\pm}$$
$$S_{-} - S_{+} = 3\,(N - Z)$$
$$Q = 0.92 \pm 0.06 \pm 0.05$$



M. Sasano *et al.*, Phys. Rev. C 79, 024602 (2009)

Relativistic Quasiparticle RPA

Transitions are obtained by solving the pn-RQRPA equations

$$\begin{pmatrix} A & B \\ B^* & A^* \end{pmatrix} \begin{pmatrix} X^\lambda \\ Y^\lambda \end{pmatrix} = E_\lambda \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix} \begin{pmatrix} X^\lambda \\ Y^\lambda \end{pmatrix}$$

Residual interaction is derived from the Lagrangian density

$$\mathcal{L}_{\rho+\pi} = -g_\rho \bar{\psi} \gamma_\mu \vec{\rho}^\mu \vec{\tau} \psi - \frac{f_\pi}{m_\pi} \bar{\psi} \gamma_5 \gamma^\mu \partial_\mu \vec{\pi} \vec{\tau} \psi$$

Total strength of a particular transition

$$B_{\lambda,J}(GT) = \left| \sum_{pn} \left\langle p \left\| \hat{O}_J \right\| n \right\rangle \left(X_{pn}^{\lambda,J} u_p v_n - Y_{pn}^{\lambda,J} v_p u_n \right) \right|^2$$

Measured strength corresponds to

$$\hat{T}_{(\pm)} = j_0(qr)\boldsymbol{\Sigma}\tau_{\pm}$$

For small momentum transfer

$$j_0(qr) \approx 1 - \frac{q^2 r^2}{6} + \frac{q^4 r^4}{120} - \cdots,$$

$$\hat{O}_{(\pm)} = \boldsymbol{\Sigma}\tau_{\pm} - \frac{q^2}{6} r^2 \boldsymbol{\Sigma}\tau_{\pm}$$

Isovector spin monopole operator

$$\hat{O}^{IVSM}_{(\pm)} = r^2 \boldsymbol{\Sigma}\tau_{\pm}$$

$$S_- - S_+ = 3\left[N\left\langle r^4\right\rangle_n - Z\left\langle r^4\right\rangle_p\right]$$

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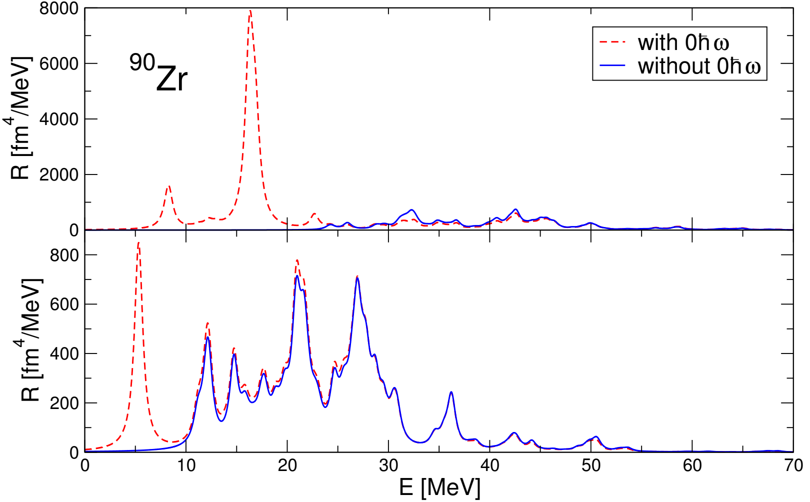
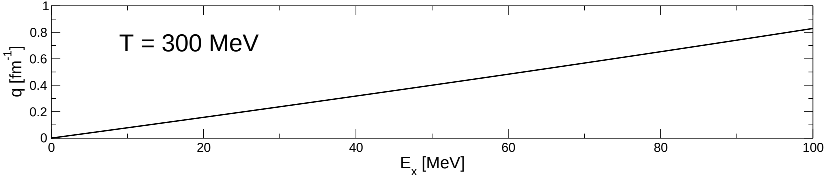
Isovector spin-monopole excitations

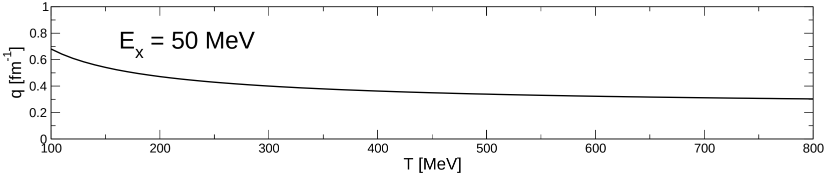


$$E_p = T + m, \qquad p_p = \sqrt{E_p^2 - m^2},$$

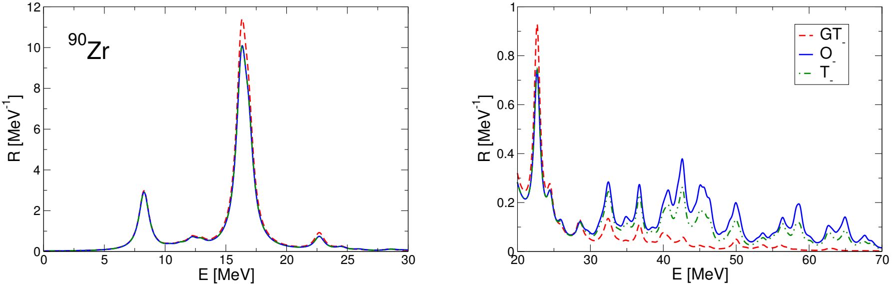
$$E_n = E_p - E_x, \qquad p_n = \sqrt{E_n^2 - m^2},$$

$$|\boldsymbol{q}| = |\boldsymbol{p}_p - \boldsymbol{p}_n| = \sqrt{p_p^2 + p_n^2 - 2p_p p_n \cos\vartheta} \approx |p_p - p_n| \, .$$





$L = 0$ strength



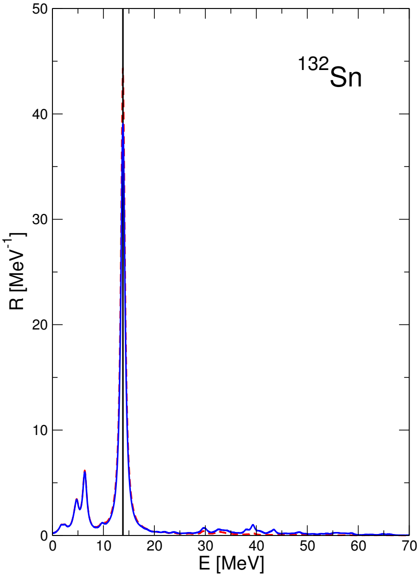
Radial part of the matrix element:

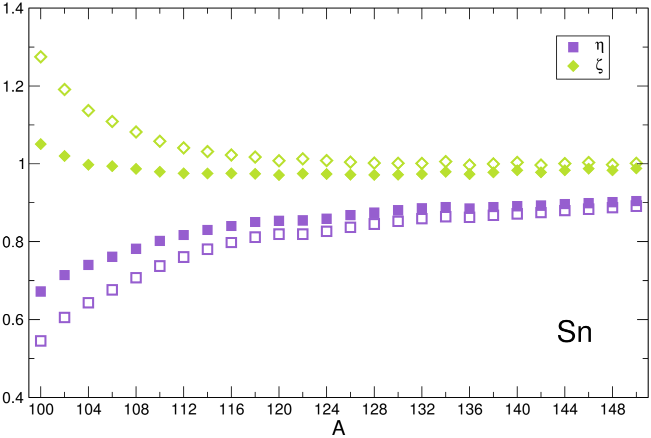
$$\int \left(1 - \frac{q^2 r^2}{6}\right) r^2 dr, \qquad \text{where} \qquad \frac{q^2 r^2}{6} < 1$$

$$0.95 = \frac{\sum_i^{E_i \leq E_{95\%}(N,Z)} B_i(GT)}{\sum_i B_i(GT)}$$

$$\eta = \frac{\sum_i^{E_i \leq E_{95\%}} B_i(T,O)}{\sum_i B_i(T,O)}$$

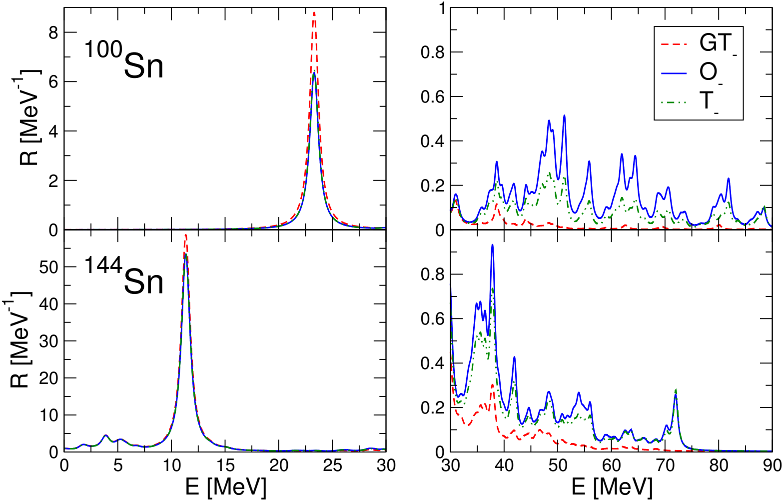
$$\zeta = \frac{\sum_i B_i(T,O)}{\sum_i B_i(GT)}$$





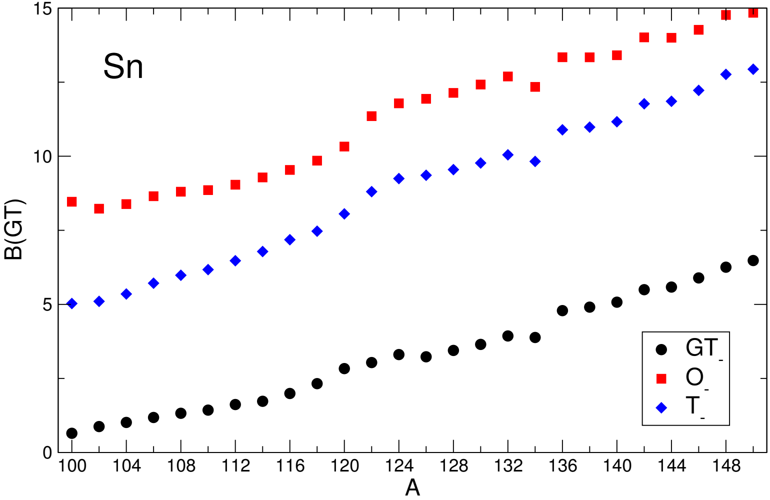
Operators:

$$\hat{T}_{(\pm)} = j_0(qr)\mathbf{\Sigma}\tau_{\pm} \qquad \hat{O}_{(\pm)} = \mathbf{\Sigma}\tau_{\pm} - \frac{q^2}{6} r^2 \mathbf{\Sigma}\tau_{\pm}$$

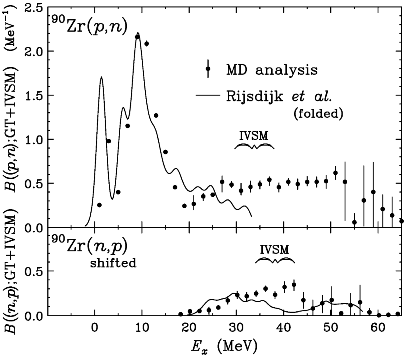


Resonance reduced by:

$$^{100}\text{Sn} : \Delta B = 3.7 \qquad ^{144}\text{Sn} : \Delta B = 8.0$$


Sn
B(GT)
A
GT-
O-
T-
0
5
10
15
100
104
108
112
116
120
124
128
132
136
140
144
148

	$S^{L=0}$	S^{GT}	S'	S''
β^-	33.5	29.3	33.5	35.6
β^+	5.4	2.9	6.3	6.3



Sum rule:

$$S'_{\beta-} - S'_{\beta+} = 27.2$$

$$S''_{\beta-} - S''_{\beta+} = 29.3$$

K. Yako *et al.*, Phys. Lett. B 615, 193 (2005)

	$S^{L=0}$	S^{GT}	S'	S''
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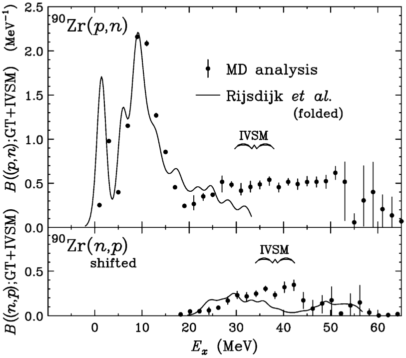

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K. Yako *et al.*, Phys. Lett. B 615, 193 (2005)

Particle-vibration coupling model

The response function:

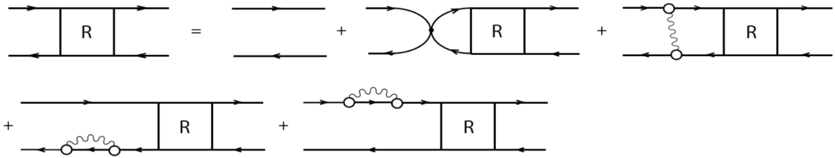
$$R(\omega) = \tilde{R}^0(\omega) + \tilde{R}^0(\omega)W(\omega)R(\omega)$$

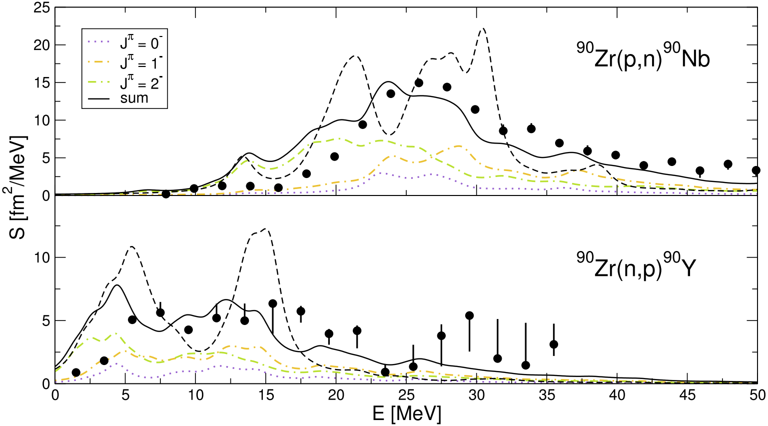
with the interaction

$$W(\omega) = V_\rho + V_\pi + V_{\delta\pi}^{LM} + \Phi(\omega) - \Phi(0)$$

The strength function is

$$S(E,\Delta) = -\frac{1}{\pi}\Im\left\langle P^+ R(E+i\Delta)P\right\rangle$$

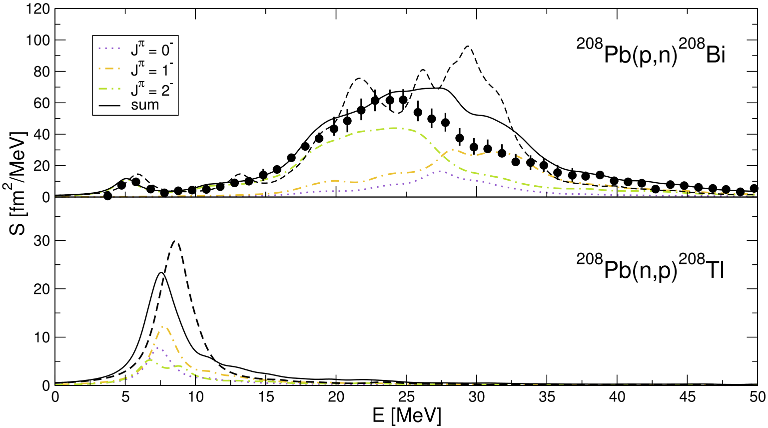




Transition operator:

$$\hat{O}^{\lambda}_{L=1} = r\,[\boldsymbol{\sigma} \otimes Y_1]_{\lambda}\,\tau_{\pm}$$

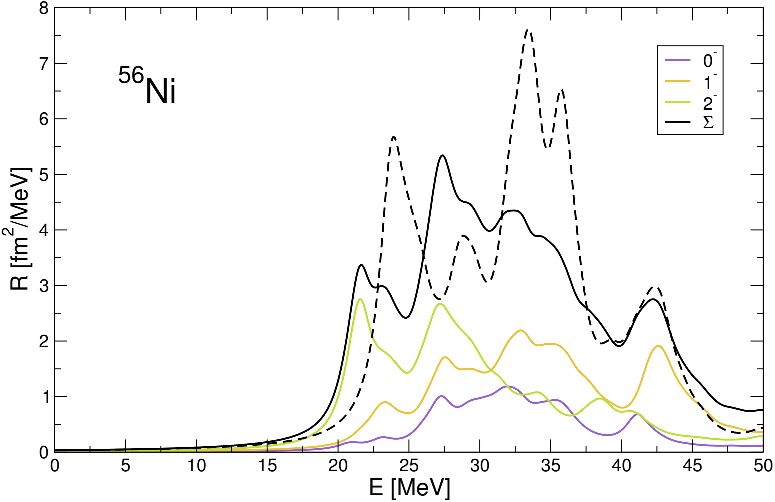
K. Yako *et al.*, Phys. Rev. C 74, 051303(R) (2006)



Sum rule:

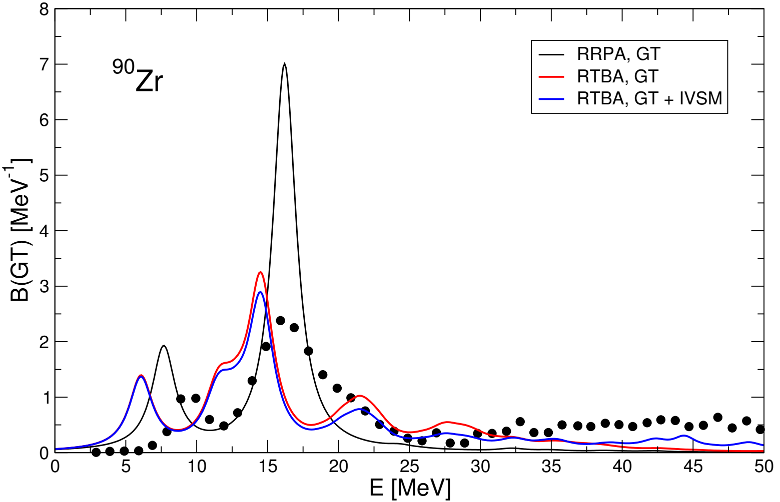
$$S_-^\lambda - S_+^\lambda = \frac{2\lambda+1}{4\pi}\left[N\left\langle r^2\right\rangle_n - Z\left\langle r^2\right\rangle_p\right]$$

T. Wakasa *et al.*, Phys. Rev. C 85, 064606 (2012)

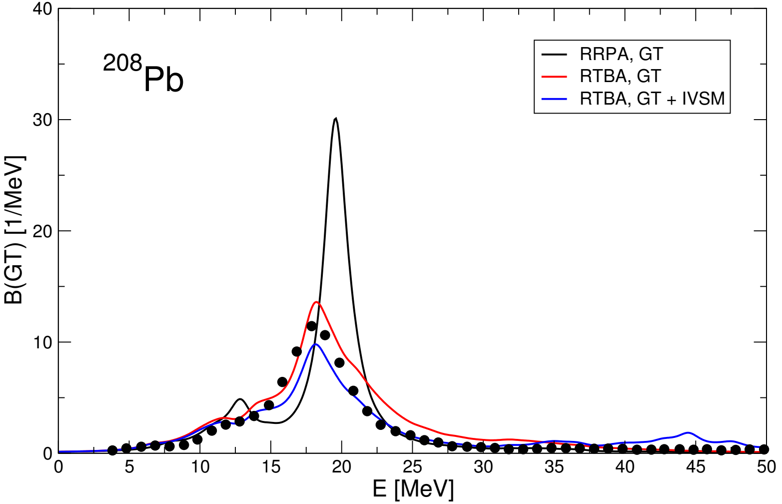


56Ni
0-
1-
2-
Σ
R [fm2/MeV]
E [MeV]
0
1
2
3
4
5
6
7
8
0
5
10
15
20
25
30
35
40
45
50

Gamow-Teller resonance

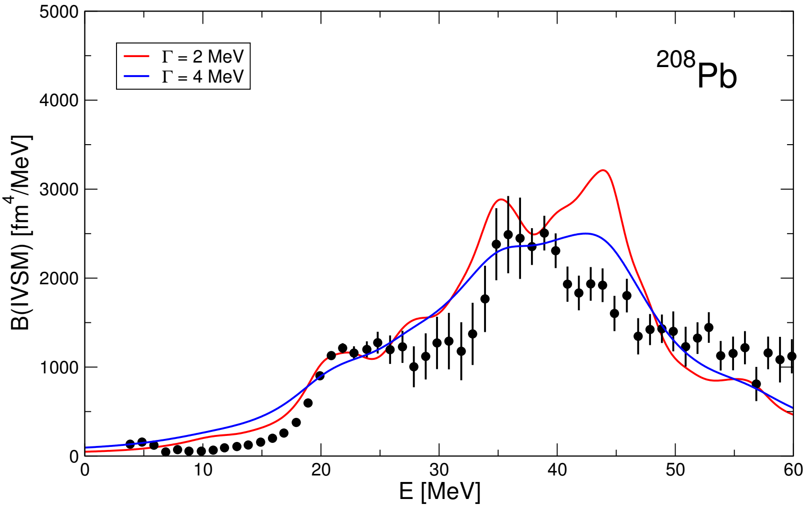


T. Wakasa *et al.*, Phys. Rev. C 55, 2909 (1997)



T. Wakasa *et al.*, Phys. Rev. C 85, 064606 (2012)

Isovector spin monopole mode



T. Wakasa *et al.*, Phys. Rev. C 85, 064606 (2012)

β-decay

Decay rate:

$$\lambda_i = D \int_1^{W_{0,i}} W \sqrt{W^2 - 1} \left(W_{0,i} - W\right)^2 F(Z, W) C(W) dW$$

$$T_{1/2} = \frac{1}{\lambda}, \qquad D = \frac{1}{\ln 2} \frac{(G_F V_{ud})^2}{2\pi^3} \frac{\left(m_e c^2\right)^5}{\hbar}$$

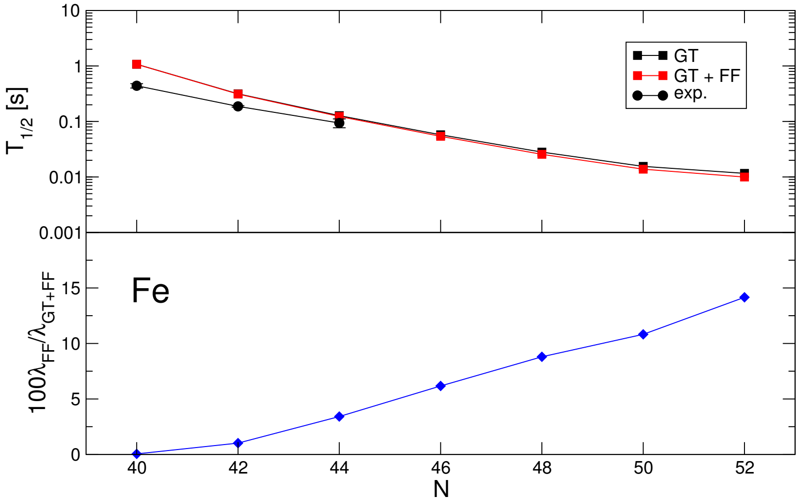
Allowed decays shape factor:

$$C(W) = B(GT)$$

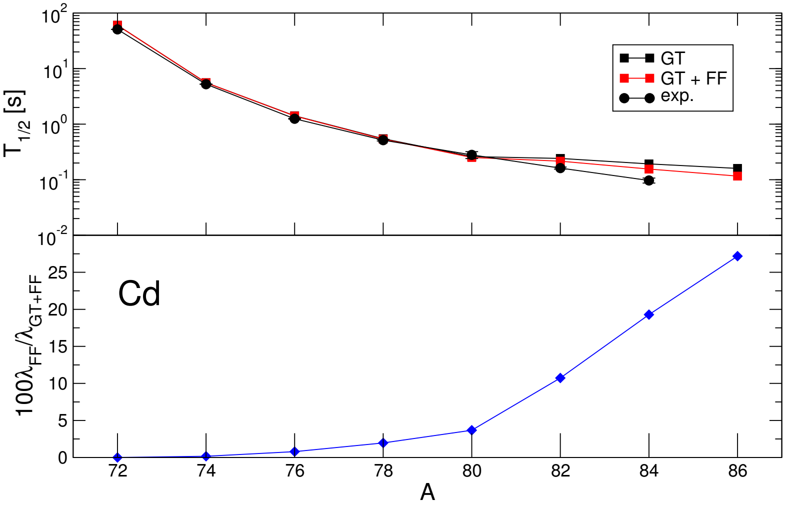
First-forbidden decays shape factor:

$$C(W) = k \left(1 + aW + bW^{-1} + cW^2\right)$$

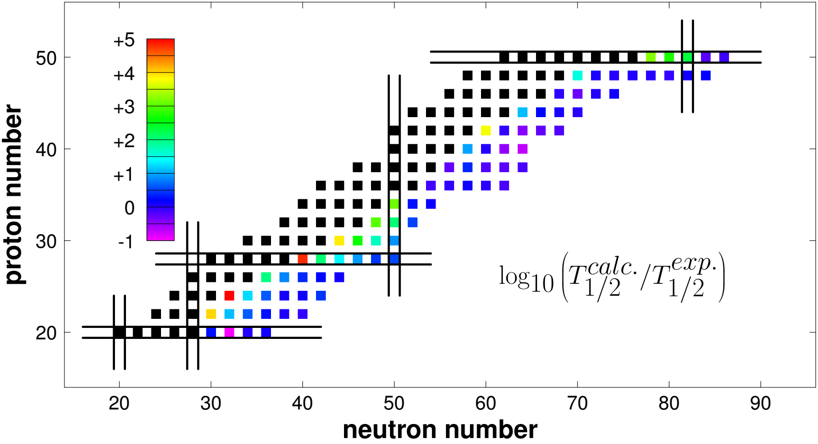
$Z = 26$ isotopes



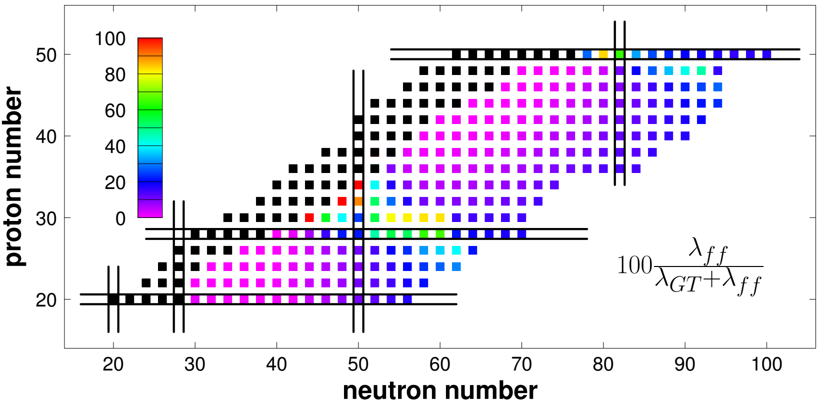
$Z = 48$ isotopes



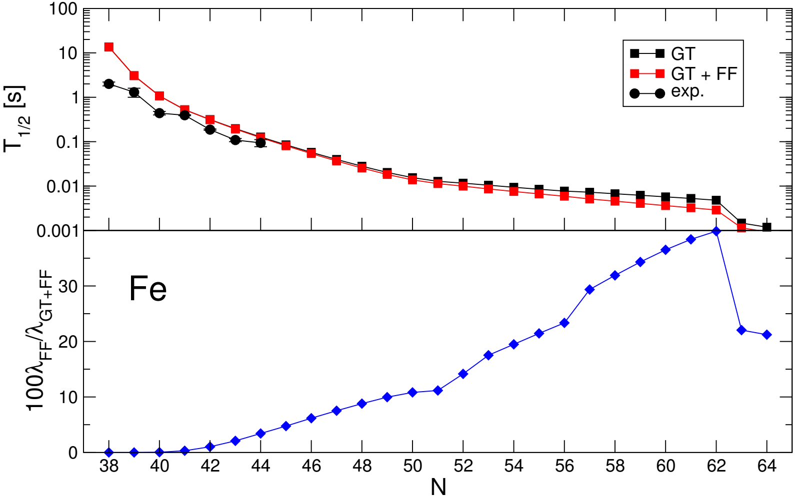
$20 \leq Z \leq 50$ mass region



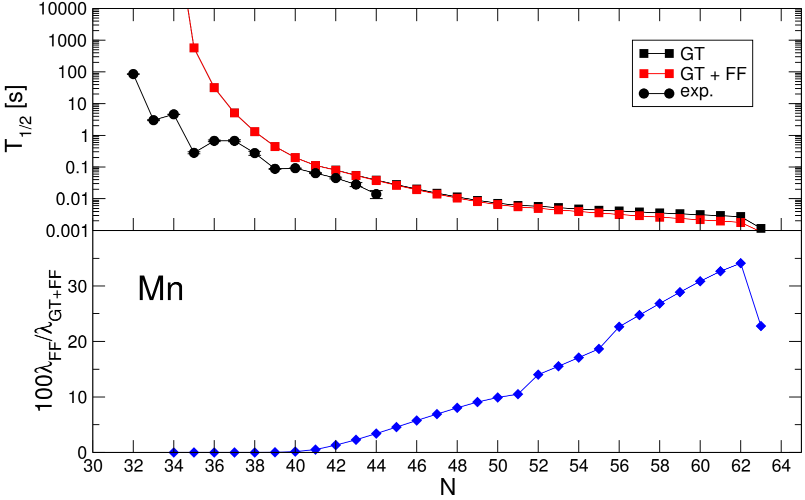
$20 \leq Z \leq 50$ mass region



Iron revisited

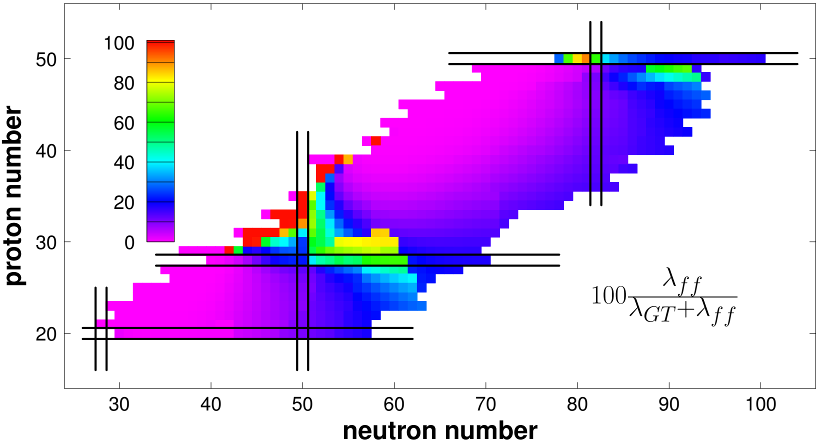


$Z = 25$



10000
1000
100
10
1
0.1
0.01
0.001
$T_{1/2}$ [s]
GT
GT + FF
exp.
Mn
$100\lambda_{FF}/\lambda_{GT+FF}$
0
10
20
30
30 32 34 36 38 40 42 44 46 48 50 52 54 56 58 60 62 64
N

Odd nuclei?



100
80
60
40
20
0
proton number
50
40
30
20
30
40
50
60
70
80
90
100
neutron number
$100\frac{\lambda_{ff}}{\lambda_{GT}+\lambda_{ff}}$

Acknowledgements

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Uni Zagreb

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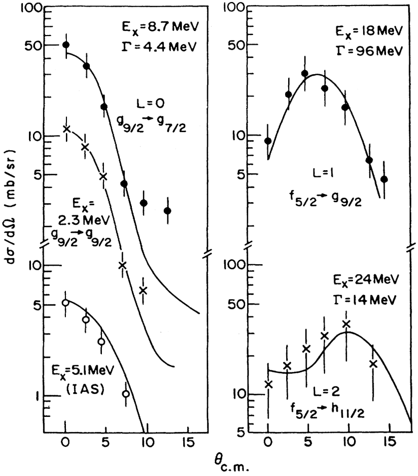
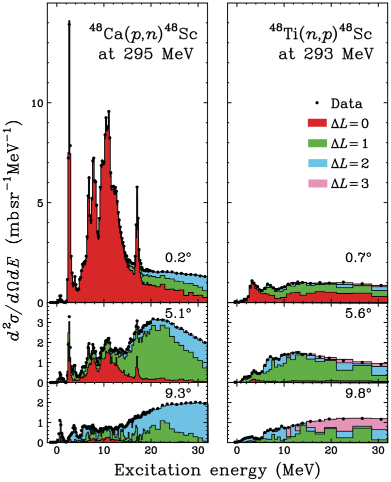
- D. Vretenar

HIC for FAIR
Helmholtz International Center

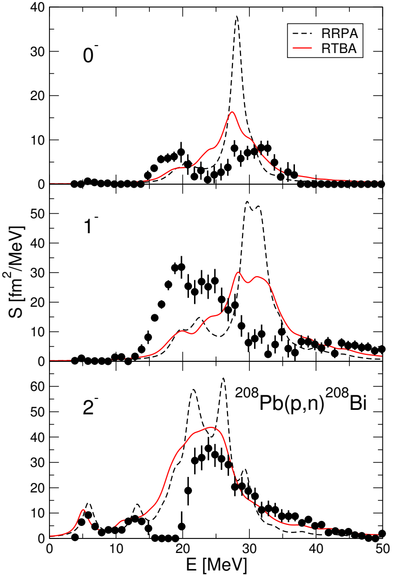
GEFÖRDERT VOM
Bundesministerium
für Bildung
und Forschung



E_x=8.7 MeV
Γ=4.4 MeV
L=0
$g_{9/2}\rightarrow g_{7/2}$
E_x= 2.3 MeV
$g_{9/2}\rightarrow g_{9/2}$
E_x=5.1 MeV (IAS)
E_x=18 MeV
Γ=96 MeV
L=1
$f_{5/2}\rightarrow g_{9/2}$
E_x=24 MeV
Γ=14 MeV
L=2
$f_{5/2}\rightarrow h_{11/2}$
dσ/dΩ (mb/sr)
$\theta_{c.m.}$



^{48}Ca(p,n)^{48}Sc at 295 MeV
^{48}Ti(n,p)^{48}Sc at 293 MeV
Data
ΔL=0
ΔL=1
ΔL=2
ΔL=3
0.2°
0.7°
5.1°
5.6°
9.3°
9.8°
$d^2\sigma/d\Omega dE$ (mb sr^{-1}MeV^{-1})
Excitation energy (MeV)



T. Wakasa *et al.*, Phys. Rev. C 85, 064606 (2012)

	^{90}Zr	^{208}Pb
$S_- - S_+$ (g.s.)	160.925 fm^2	1222.044 fm^2
$S_- - S_+$ (calc.)	160.963 fm^2	1213.562 fm^2
$S_- - S_+$ (exp.)	$148 \pm 6 \pm 7 \pm 7$ fm^2	
$\sqrt{\langle r^2 \rangle_p}$ (g.s.)	4.193 fm	5.459 fm
$\sqrt{\langle r^2 \rangle_n}$ (calc.)	4.308 fm	5.731 fm
$\sqrt{\langle r^2 \rangle_n}$ (exp.)	4.26 ± 0.04 fm	
δ_{np} (calc.)	0.115 fm	0.272 fm
δ_{np} (exp.)	0.07 ± 0.04 fm	$0.083 < \delta_{np} < 0.111$ fm
		$0.156^{+0.025}_{-0.021}$ fm
		0.19 ± 0.09 fm