Gamma decay of giant resonances within the Skyrme framework

Marco Brenna & Gianluca Colò

Università di Milano & INFN

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Outline

Giant Resonances

RPA...

Microscopically: coherent superposition of p – h excitations

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RPA ⇒

- Linear response theory
- Fully self - consistent calculations with microscopic interactions (Skyrme, Gogny, RMF)

...and Beyond

Some features (as decay to low-lying states) need non-linear term.

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Nuclear Field Theory
Bortignon et al.
Phys. Rep. **30**(1977)305 ⇒

- Perturbative theory
- Interweaving between single-particles and phonons

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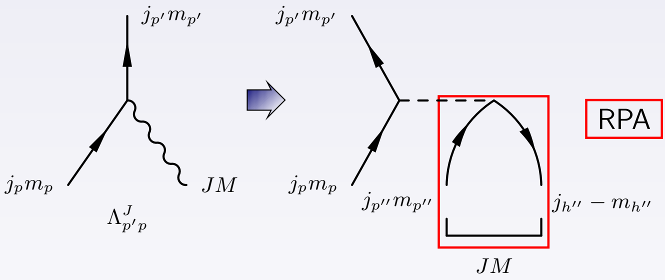
Particle-Vibration Coupling (PVC) vertex



$$\langle i \| V \| j, nJ \rangle = \sqrt{2J+1} \sum_{ph} X^{nJ}_{ph} V_J(ihjp) + (-)^{j_h - j_p + J} Y^{nJ}_{ph} V_J(ipjh)$$

$$V_J(ihjp) = \sum_{\{m\}} (-)^{j_j - m_j + j_h - m_h} \langle j_i m_i j_j - m_j | JM \rangle \langle j_p m_p j_h - m_h | JM \rangle v_{ihjp}$$

Consistent treatment of the coupling vertex in the Skyrme framework: single particle states, RPA phonons, microscopic interaction (G. Colò, H. Sagawa, P. F. Bortignon, *Phis. Rev.* **C82**(2010)64307)

Results – ^{208}Pb

- Decay of Isoscalar Giant Quadrupole Resonance (ISGQR) in ^{208}Pb to the ground state and to the first $J^\pi = 3^-$ state
- Experiment at LNL in June 2010 (talk by R. Nicolini...)
- Consistent approach to the coupling vertex:
    - Single particle states: HF
    - Phonons: self consistent RPA with Skyrme functional
    - PVC Vertex: microscopic Skyrme interaction
- 4 Skyrme interactions: SLy5, SGII, SkP, LNS

Energy and collectivity the states

J^{π}	2^{+}		3^{-}	
	E [MeV]	EWSR [%]	E [MeV]	$B(E3)\uparrow [10^5 e^2 \cdot \mathrm{fm}^6]$
SLy5	12.28	70	3.62	6.54
SGII	11.72	72	3.14	6.58
SkP	10.28	82	3.29	5.11
LNS	12.10	67	3.19	5.67
Exp.	10.9 *3*	100	2.6145 *3*	6.11 *9*

Experimental data from *NDS* **108**(2007)1583

Decay to the GS

Interaction	E_{GQR}[MeV]	Γ_γ [eV]	
		RPA	*RPA'*
SLy5	12.28	231.54	160
SGII	11.72	163.22	138
SkP	10.28	119.18	170
LNS	12.10	176.57	135
Beene et al.,*PRC***39**(1989)1307	10.60	146±36 – *exp.*	
Speth et al.,*PRC***85**(1985)2310	10.60	112 – *theor.*	
Beene et al.,*PLB***164**(1985)19	11.20	175 – *theor.*	

Consistent with experimental value through an energy and EWSR fraction scaling ($\Delta E = 1$ MeV $\Rightarrow$ increase Γ_γ by 40%)

Decay to the 3^- state

Interaction	E_{tran} [MeV]	Γ_γ [eV]
SLy5	8.66	5.07
SGII	8.58	36.86
SkP	6.99	10.99
LNS	9.00	48.21
Beene et al., *PRC* **39**(1989)1307	7.99	5±5 – *exp.*
Speth et al., *PRC* **85**(1985)2310	7.99	4.00 – *theor.*
Bortignon et al., *PLB* **148**(1984)20	8.60	3.50 – *theor.*

Decay to the 3^- state

The SLy5 case

Γ_γ for a typical ph at 8.5 MeV [eV]		$1.2{\cdot}10^3$
Quenching factors	Recoupling	3
	$\pi - \nu$ cancellation	3
	p − h cancellation	3 − 4
	Polarization factor	4
	Γ_γ [eV]	5.07

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$$Q_{ij} = \left(\tau_z - \frac{N - Z}{A} \right)_j \langle i \| r^\lambda Y_\lambda \| j \rangle$$

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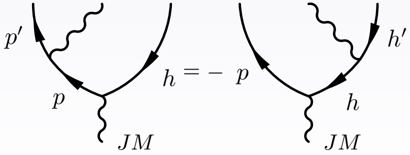

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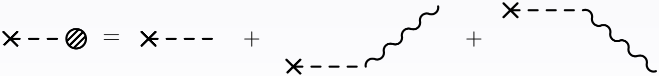
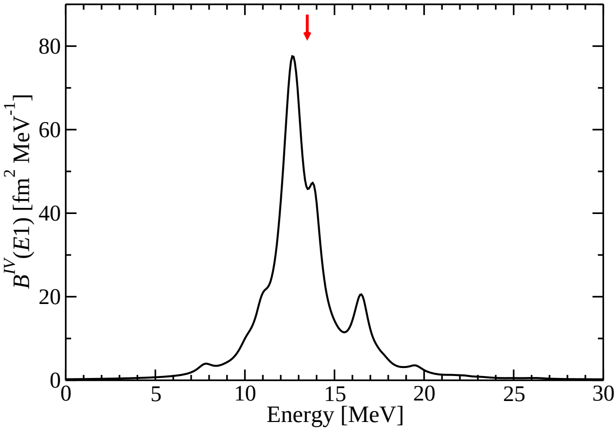


Conclusions

- Microscopic and consistent treatment of the γ decay
- γ decay width to the GS not so able to discriminate between models
- γ decay width to the 3^- very sensitive to the interaction used
  - Dipole states
- Comparison with the experiment at LNL – INFN (June 2010)
- Other closed shell nuclei: ^{90}Zr (LNL - 2010),...

Backup Slides

The dipole spectum



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γ decay width

A brief resumé...

Decay Width

$$\Gamma_\gamma(E\lambda; i \to f) \propto E^{2\lambda+1} B(E\lambda; i \to f)$$

Reduced Transition Probability

$$B(E\lambda; i \to f) = \frac{1}{2J_i + 1} |\langle J_f \| Q_\lambda^{(E)} \| J_i \rangle|^2$$

Electromagnetic operator (long-wavelength limit)

$$Q_{\lambda\mu}^{(E)} = \sum_{i=1}^{A} e_i^\lambda i^\lambda r_i^\lambda Y_{\lambda\mu}(\hat{\boldsymbol{r}}_i)$$

Effective charge due to nuclear recoil in $E\lambda$ transitions

$$e_p^\lambda = e\left[\left(1 - \frac{1}{A}\right)^\lambda + (-)^\lambda \frac{Z-1}{A^\lambda}\right] \qquad e_n^\lambda = eZ\left(-\frac{1}{A}\right)^\lambda$$

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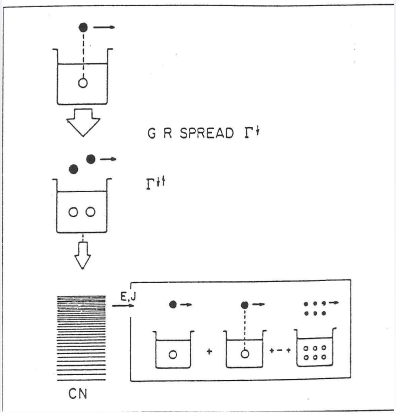
The decay of the compound nucleus

$$\langle \Gamma_{\gamma 0}^{CN} \rangle = \frac{X(\lambda) b_{E\lambda}(E) \left(\frac{E}{\hbar c}\right)^{2\lambda+1}}{\rho_I(E)}$$

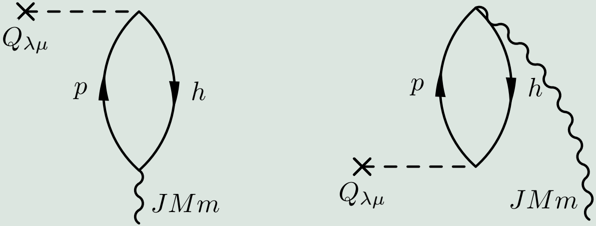
$$X(\lambda) = \frac{8\pi(\lambda+1)}{\lambda[(2\lambda+1)!!]^2}$$

- $\rho_I(E)$ density of compound states with spin I at energy E
- $b_{E\lambda}(E)$ reduced transition probability per unit energy



γ decay to the ground state

$\langle 0|Q_{\lambda\mu}|mJM\rangle$



$$\langle 0\|Q_\lambda\|mJ\rangle = \sum_{ph}\langle p\|Q_\lambda\|h\rangle\left(\frac{\langle p\|V\|h,nJ\rangle}{E_J-\epsilon_{ph}+i\eta} - \frac{\langle h\|V\|p,nJ\rangle}{E_J+\epsilon_{ph}+i\eta'}\right)$$

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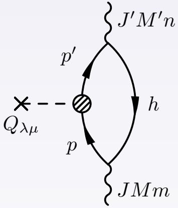
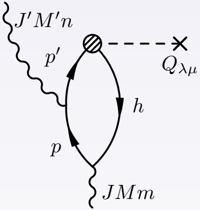
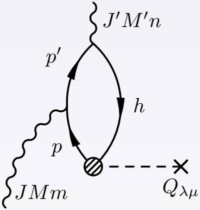
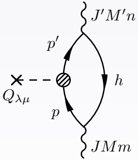
γ decay to low-lying states

- NFT: 12 diagrams contribute to the matrix element









An example...

$$= \sum_{pp'h} (-)^{J+\lambda+J'+1} \begin{Bmatrix} J & \lambda & J' \\ j_{p'} & j_h & j_p \end{Bmatrix} \frac{\langle p \| V \| h, nJ \rangle \langle h, mJ' \| V \| p' \rangle Q^{\lambda pol}_{pp'}}{(E_J - \epsilon_{ph} + i\eta)(\hbar\omega_{J'} - \epsilon_{p'h})}$$

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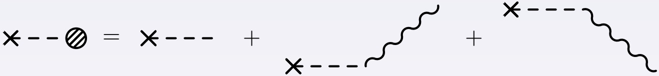
The polarization contribution



Polarization

External field partially screened by the interaction with intermediate states

$$Q_{ij}^{\lambda pol} = \langle i \| Q_\lambda \| j \rangle +$$

$$\sum_{n'} \frac{1}{\sqrt{2\lambda+1}} \left[\frac{\langle 0 \| Q_\lambda \| n'\lambda \rangle \langle i, n'\lambda \| V \| j \rangle}{(E_J - \hbar\omega_{J'}) - \hbar\omega_\lambda + i\frac{\Gamma_D}{2}} - \frac{\langle i \| V \| j, n'\lambda \rangle \langle n'\lambda \| Q_\lambda \| 0 \rangle}{(E_J - \hbar\omega_{J'}) + \hbar\omega_\lambda + i\frac{\Gamma_D}{2}} \right]$$

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