Dysprosium isotopes

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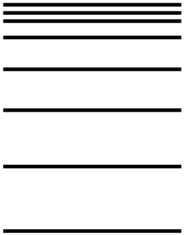
Layout

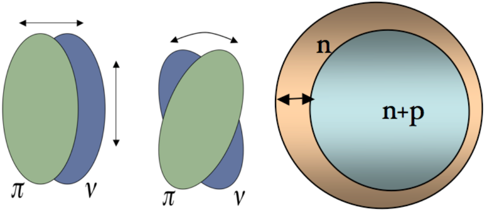
Level density

- Gives the number of levels within a given energy bin as a function of excitation energy.
- Discrete levels at low excitation energy $\sim 2-3$ MeV.
- Quasi-continiuum after a few MeV.
- Gives rich information about nuclear structure, and can derive thermodynamic quantities from the level density.

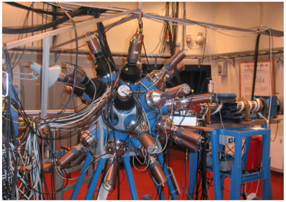


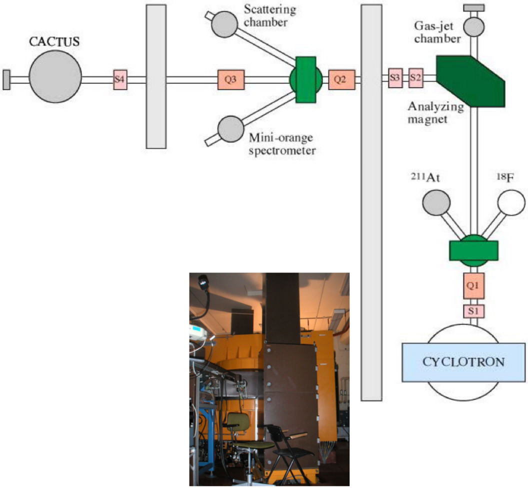
Radiative strength function

- RSF shows which γ-rays which are favorable.
  The main components of the radiative strength function:
  - Giant electric dipole resonance (GEDR)
  - Giant magnetic dipole resonance (GMDR)
  - Other contributions, *M1 pygmy resonance, skin oscillation, upend*... depending on the mass region.



Experimental setup

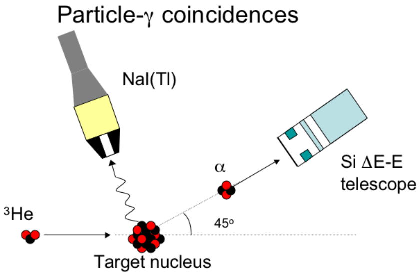


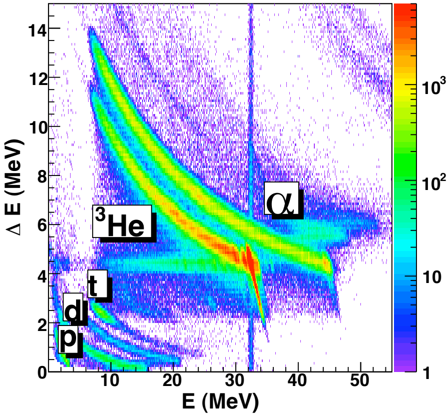


- **Beam**: p, d, $^3\mathrm{He}$, α.
- **Reactions**: (p,p'γ), (^{3}He,^{3}He'γ), (p,dγ), (p,tγ), (^{3}He,$\alpha\gamma$)
- **Target**: $\sim 1 - 2$ mg/cm^2 thick foil of enriched target.

Particle identification

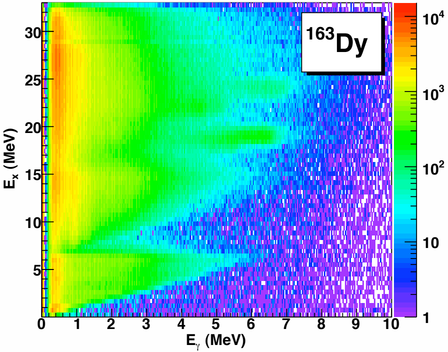
Inelastic scattering ^{164}Dy(^{3}He,^{3}He’) ^{164}Dy
Pick-up ^{164}Dy(^{3}He,α) ^{163}Dy





Particle-γ-coincidence spectra

From the known Q-values the excitation energy of the nuclei are calculated from the detected ejectile energy by using reaction kinematics.



$\alpha - \gamma$-coincidence matrix, (^{163} Dy).

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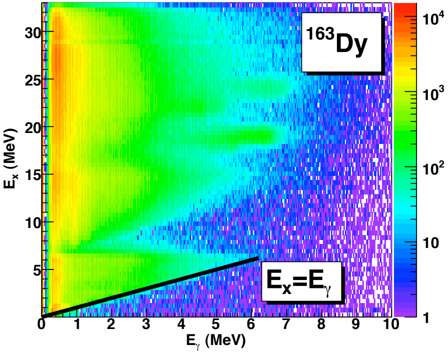

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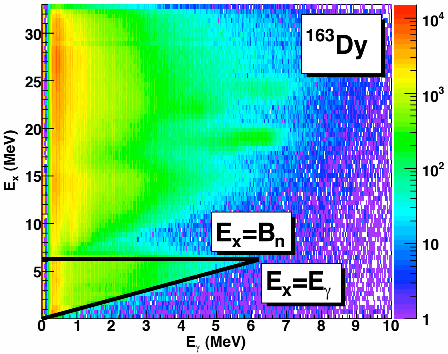

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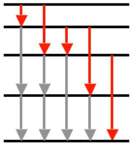
A short introduction to the Oslo method

1. **Unfold the γ-ray spectra.**
(M. Guttormsen *et al.*, NIM A 374, 371 (1996))
2. **Isolate the first (primary) gamma ray from each γ-decay cascade.**
(M. Guttormsen *et al.*, NIM A 255, 518 (1987))

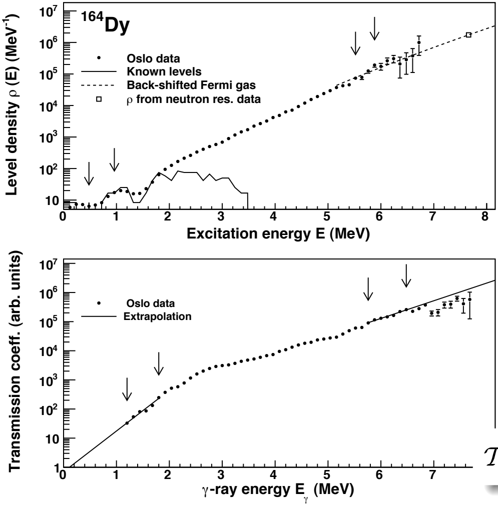


3. **Factorization:**

$$\mathbf{P}(\mathbf{E_i}, \mathbf{E}_\gamma) \propto \mathcal{T}(\mathbf{E}_\gamma)\rho(\mathbf{E_i} - \mathbf{E}_\gamma), \quad \text{where} \quad \mathbf{E_f} = \mathbf{E_i} - \mathbf{E}_\gamma \qquad (1)$$

Least-squares method obtain $\rightarrow \mathcal{T}(E_\gamma)$ and $\rho(E_i - E_\gamma)$
(A. Schiller *et al.*, NIM A 447, 498 (2000))

Normalizing $\mathcal{T}(E_\gamma)$ and $\rho(E_i - E_\gamma)$



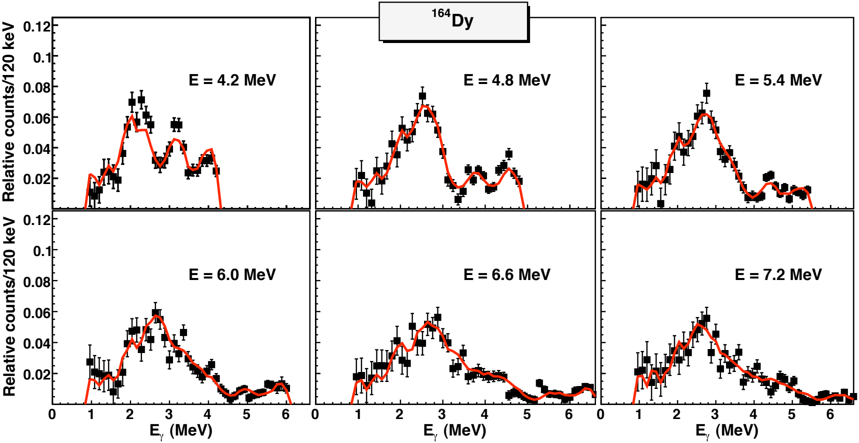
$$\tilde{\rho}(E_i - E_\gamma) = A \exp[\alpha(E_i - E_\gamma)]\, \rho(E_i - E_\gamma)$$

$$\tilde{\mathcal{T}}(E_\gamma) = B \exp(\alpha E_\gamma)\, \mathcal{T}(E_\gamma),$$

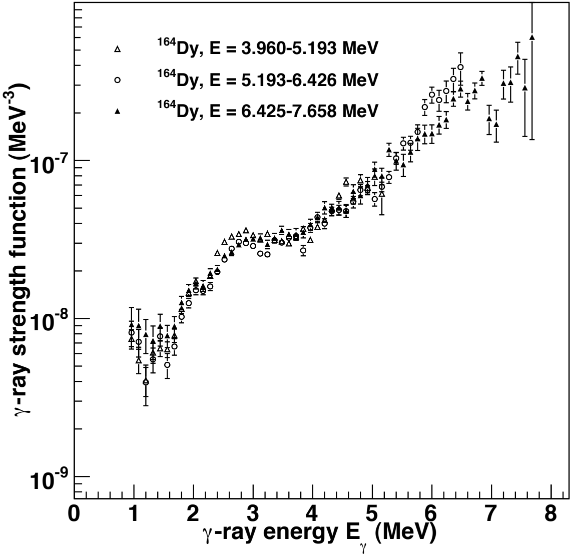
- Discrete levels
- Neutron resonance data → extrapolated by the BS Fermi-gas model
- $\mathcal{T}$ normalized with data from average total radiative width $< \Gamma_\gamma >$

$$\mathcal{T}_{XL}(E_\gamma) = 2\pi E_\gamma^{2L+1} f_{XL}(E_\gamma)$$

Does it work?

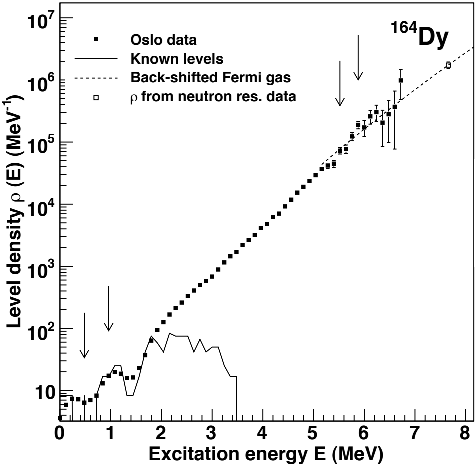

164Dy
E = 4.2 MeV
E = 4.8 MeV
E = 5.4 MeV
E = 6.0 MeV
E = 6.6 MeV
E = 7.2 MeV
Relative counts/120 keV
Relative counts/120 keV
Eγ (MeV)
Eγ (MeV)
Eγ (MeV)

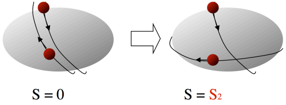
Does it work?



- Strength function extracted for 3 sets of initial excitation energies
- Striking similarity ⇒ indicates no strong temperature dependence in the strength function

Level density





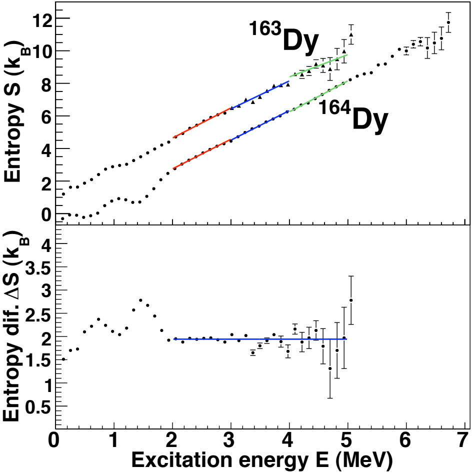
Microcanonical ensemble

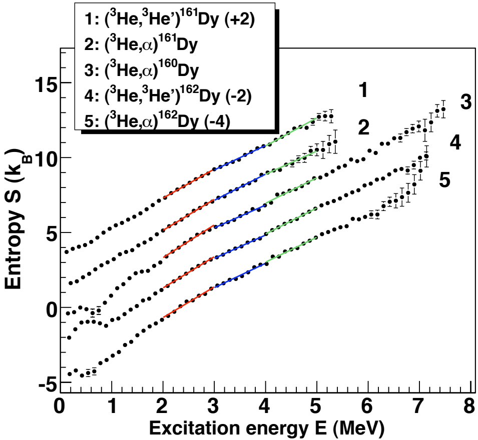
Entropy

$$S(E) = \ln \rho(E) + S_0$$

Temperature

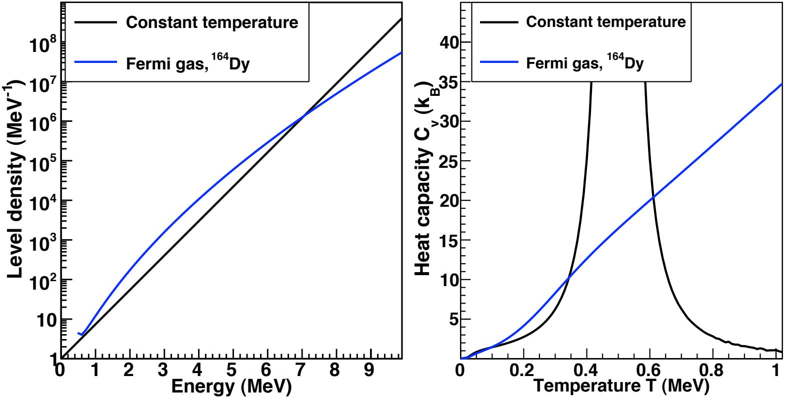
$$T = \left(\frac{\delta S}{\delta E}\right)_V^{-1}$$



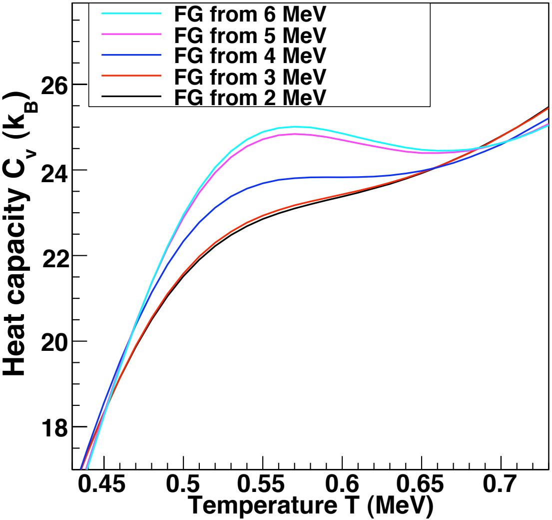


- 2-3 MeV: T=0.51(2) MeV
- 3-4 MeV: T=0.60(2) MeV
- 4-5 MeV: T=0.57(3) MeV

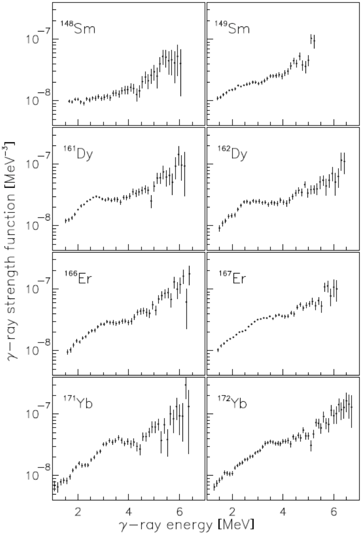
Calculating heat capacity



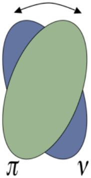
Heat capacity of ^{164}Dy



Scissor mode



- An excitation mode that can be built on every excited state.
- When it decays to the state it is built on it emits a ~ 3 MeV γ.



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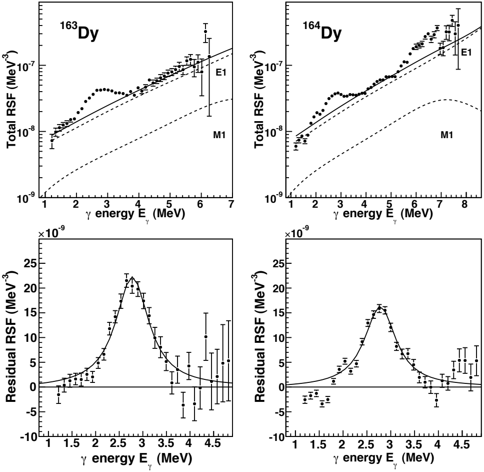

- The width of the resonance seems to vary for different nuclei.
- The total integrated strength is about the same. Average value of 6.6(4) μ_N^2

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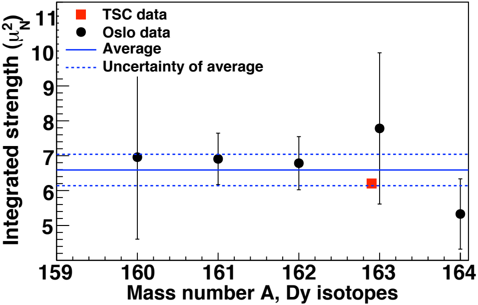

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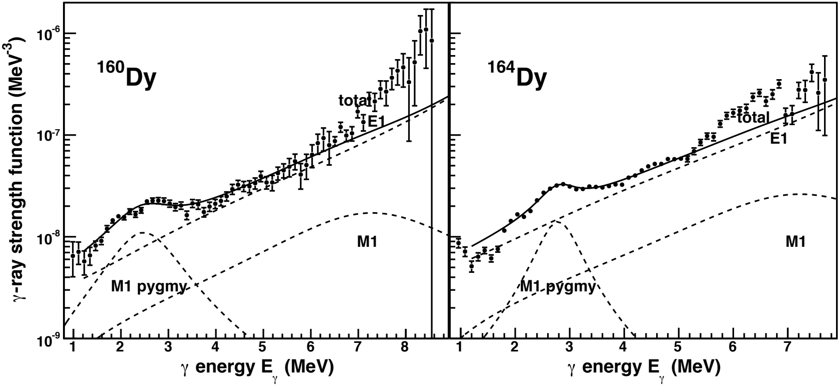
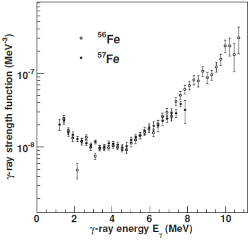
Another resonance?

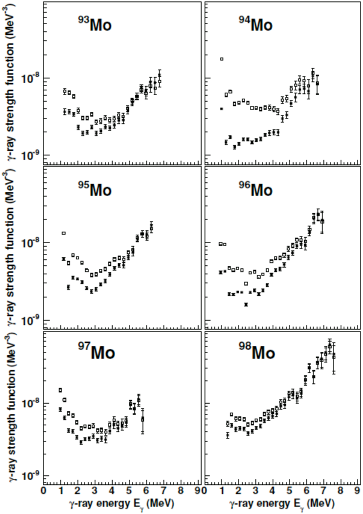


Upbend

- An unexpected strongly enhanced strength function at $E_\gamma < 3$ MeV.
- Seen in Mo isotopes ($Z = 42$), but not in Sn isotopes ($Z = 50$), $\rightarrow$ will it be present in Cd ($Z = 48$) and Pd ($Z = 46$)?

A. C. Larsen and S. Goriely, PRC 82, 014318 (2010) $\rightarrow$
E. Algin et. al., PRC 78, 054321 (2008) $\downarrow$





Summary

- **With the Oslo method one can simultaneously extract the level density and RSF**
- **The level density and radiative strength function give rich information about nuclear structure**
  - **Resonances**
  - **Splitting of nuclear Cooper pairs**