Nuclear level densities

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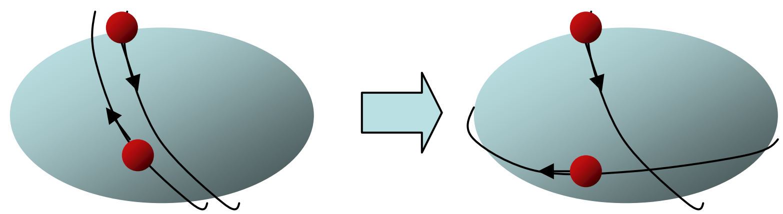
- Introduction
- Experimental method
- Thermodynamics
- Far from β-stability
- Conclusions

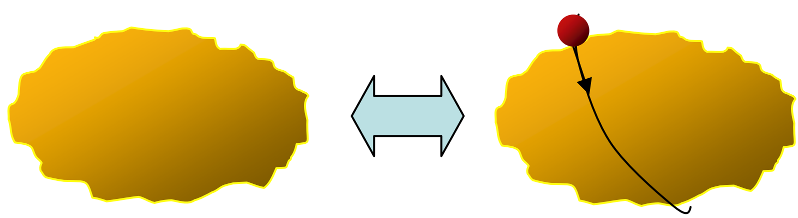
Entropy in nuclei

Cooper pair   Broken pair



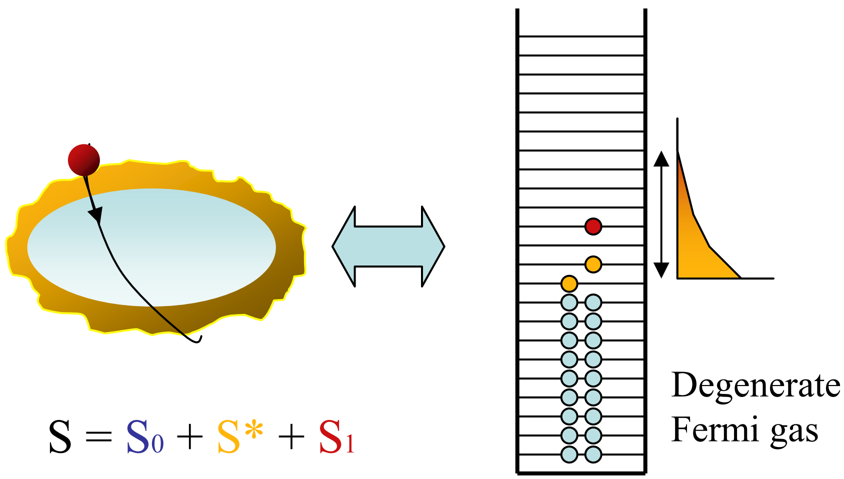
$S = 0$ $S = S_2$

How to measure?



$S = S_0$ $S = S_0 + S_1$

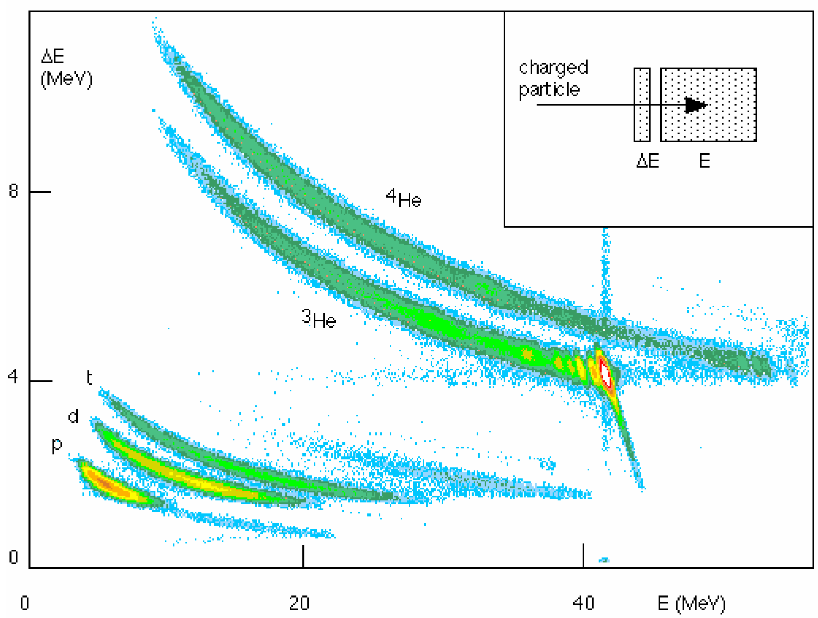
Thermal single quasiparticles



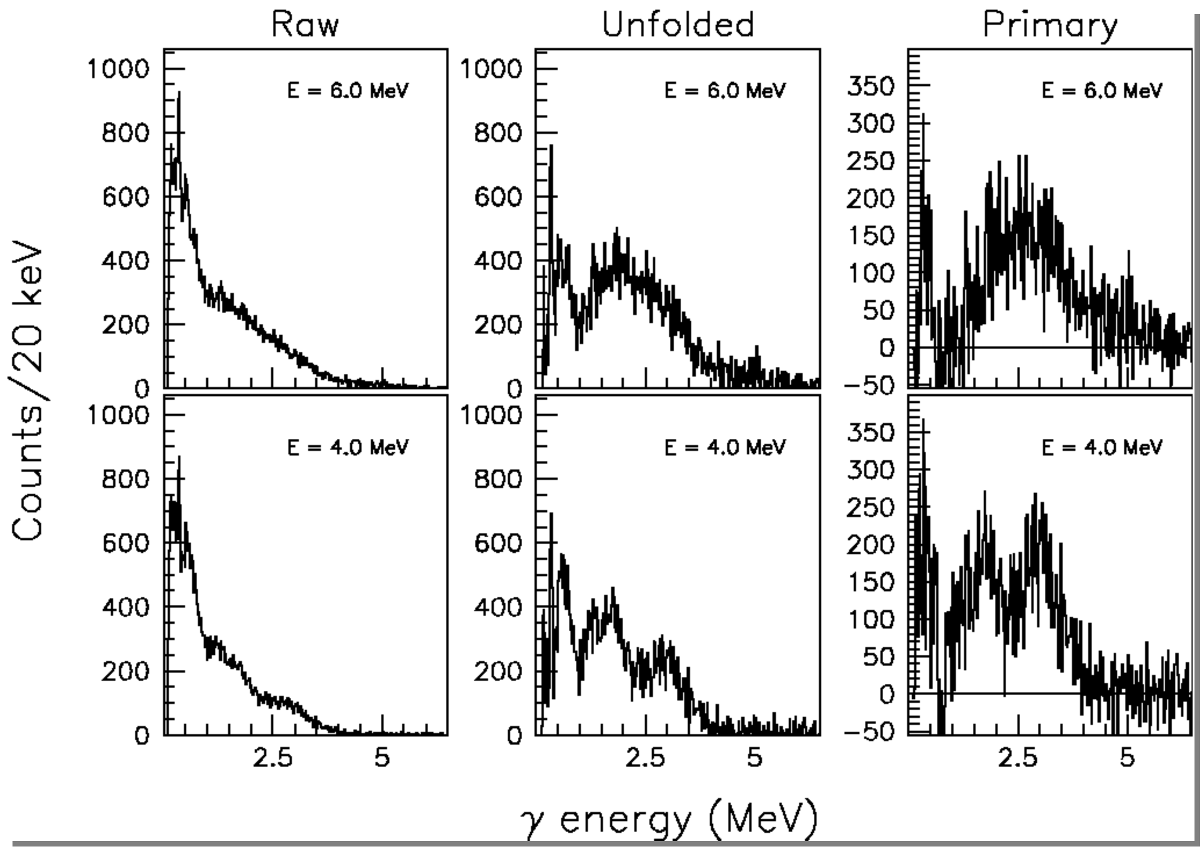
$S = S_0 + S^* + S_1$

Cactus

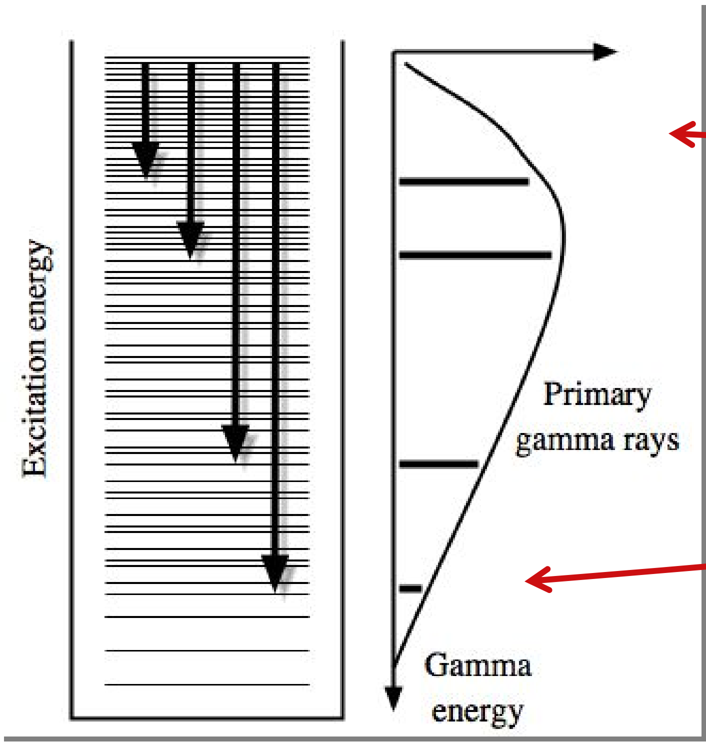
Silicon telescopes



Data analysis $^{167}Er(^{3}He,^{3}He')^{167}Er$

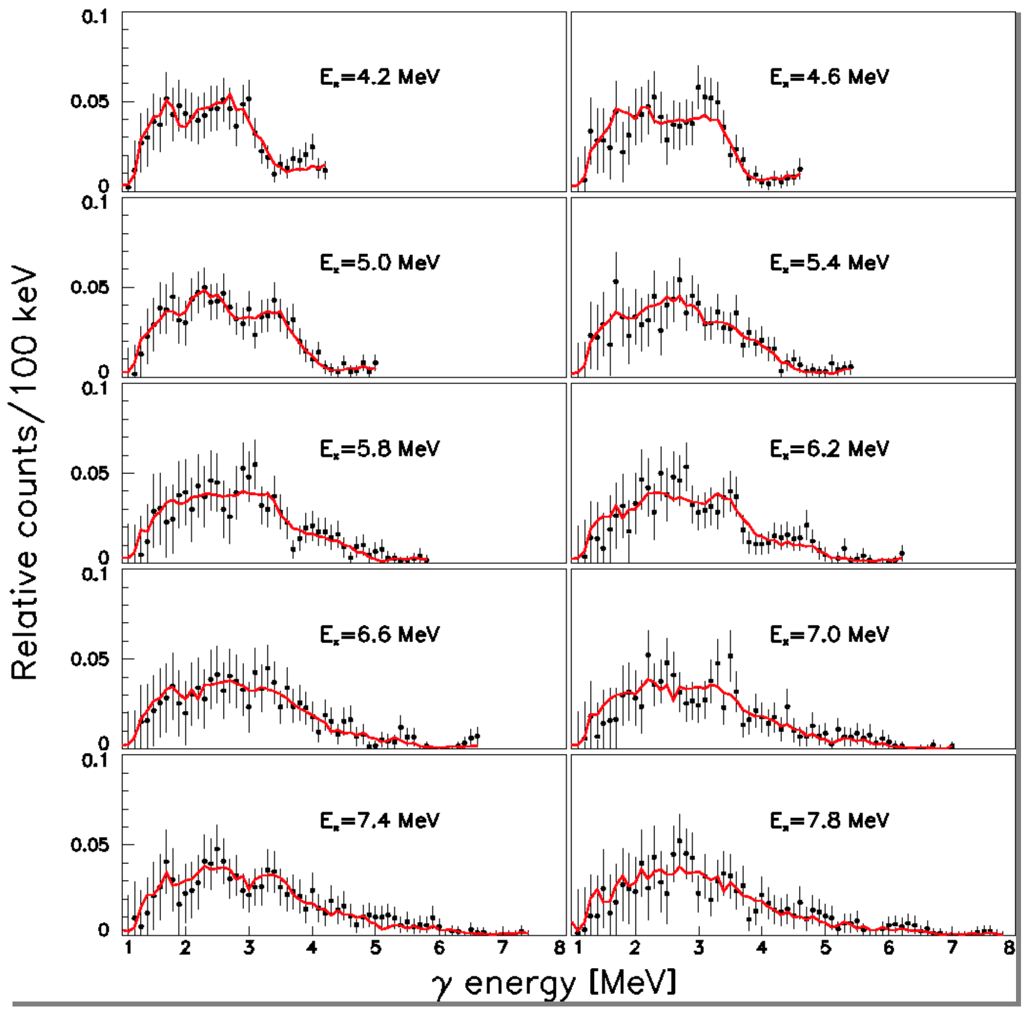


The Brink Axel hypothesis

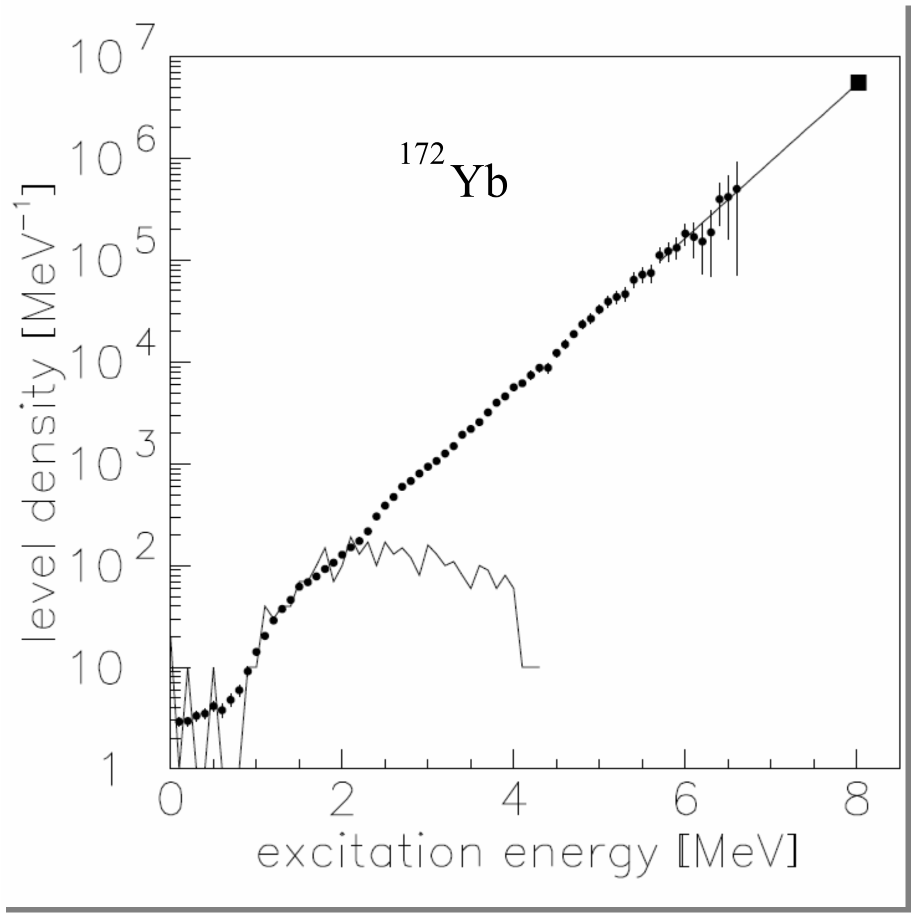


$$P(E_i, E_\gamma) \propto \rho(E_f) \cdot \mathcal{T}(E_\gamma)$$

Does it work?

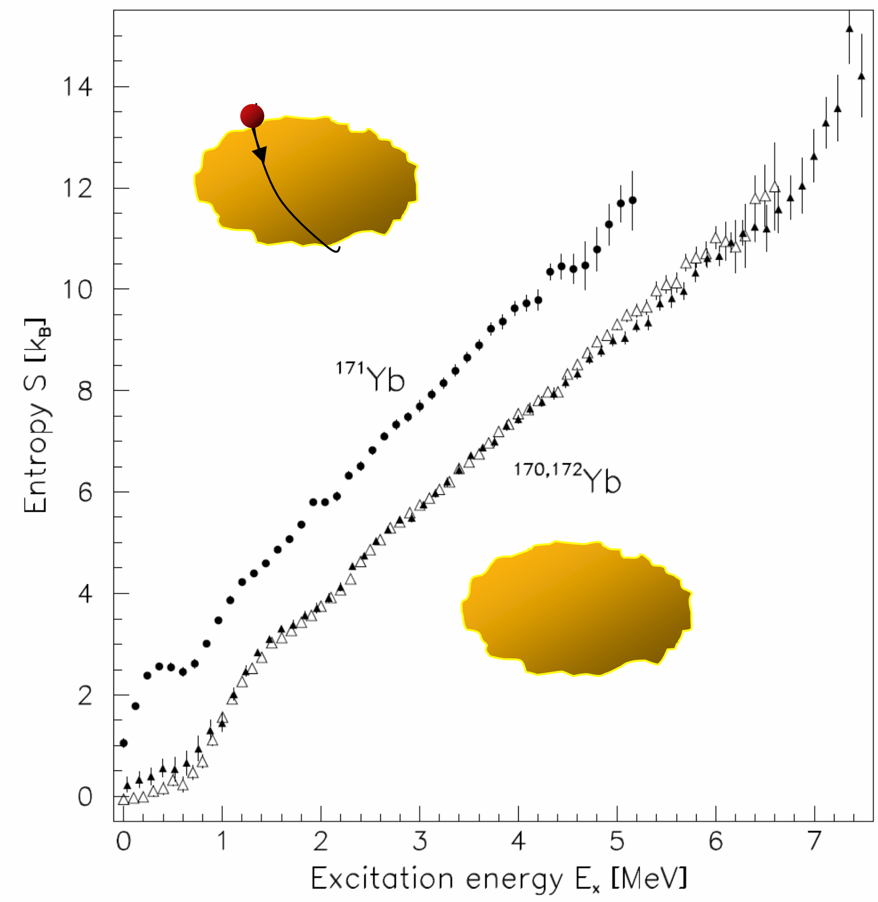

Relative counts/100 keV
γ energy [MeV]
E$_x$=4.2 MeV
E$_x$=4.6 MeV
E$_x$=5.0 MeV
E$_x$=5.4 MeV
E$_x$=5.8 MeV
E$_x$=6.2 MeV
E$_x$=6.6 MeV
E$_x$=7.0 MeV
E$_x$=7.4 MeV
E$_x$=7.8 MeV
0.1
0.05
0
1 2 3 4 5 6 7 8

Experimental level densities



Experimental nuclear entropy

$$S(E) = k_B \ln \Omega(E)$$
$$\Omega(E) = \rho(E) / \rho_0$$
$$\rho_0 = 2.2 \text{ MeV}^{-1}$$



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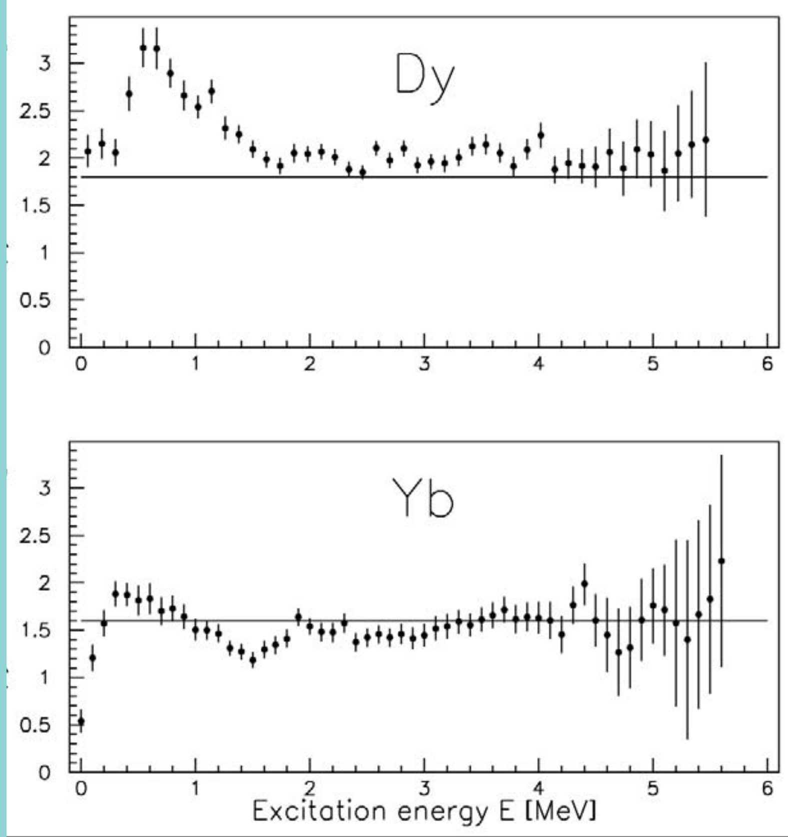
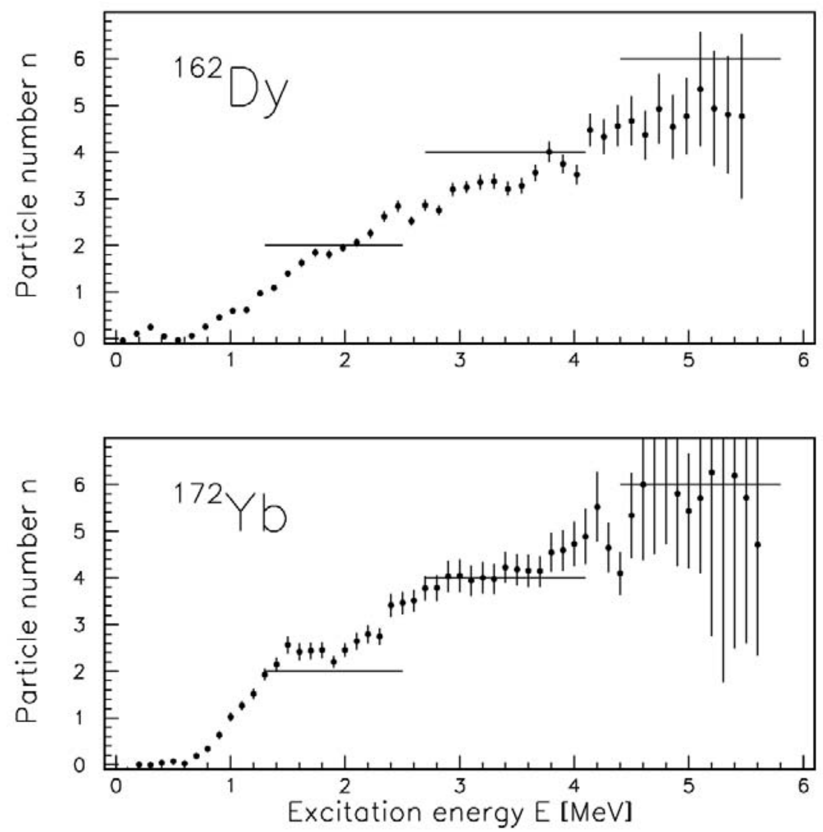
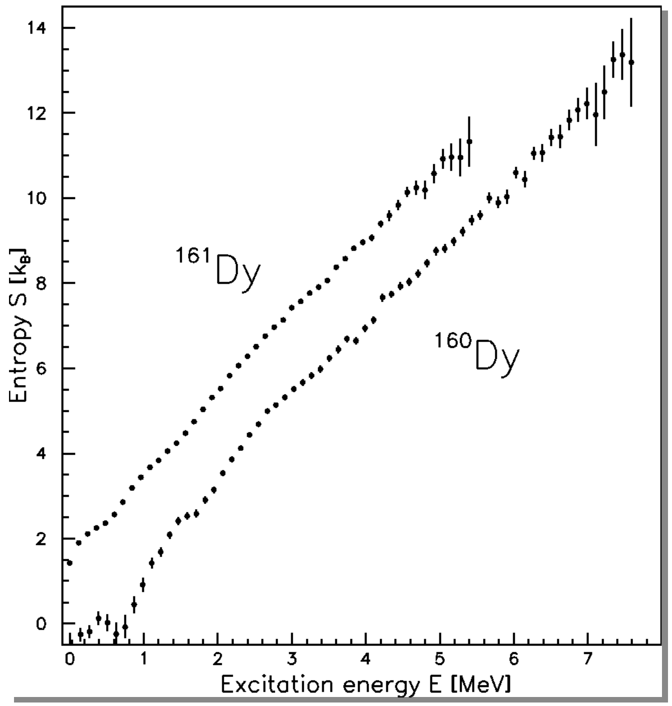
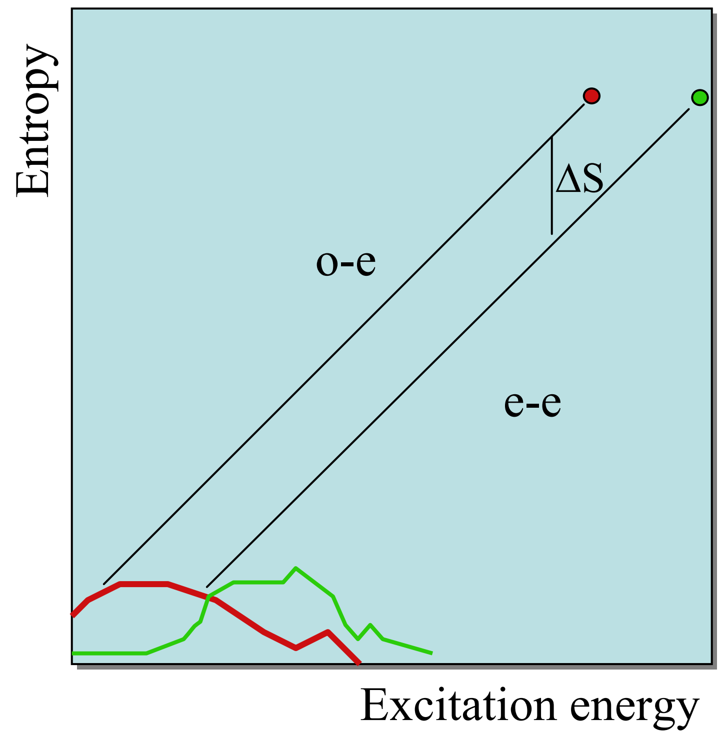
$\Delta S = S(\mathrm{oe}) - S(\mathrm{ee})$



$n = S(\mathrm{ee}) / \Delta S$




Entropy S [k_B]
Excitation energy E [MeV]
161Dy
160Dy
0
1
2
3
4
5
6
7
0
2
4
6
8
10
12
14


Entropy
Excitation energy
ΔS
o-e
e-e

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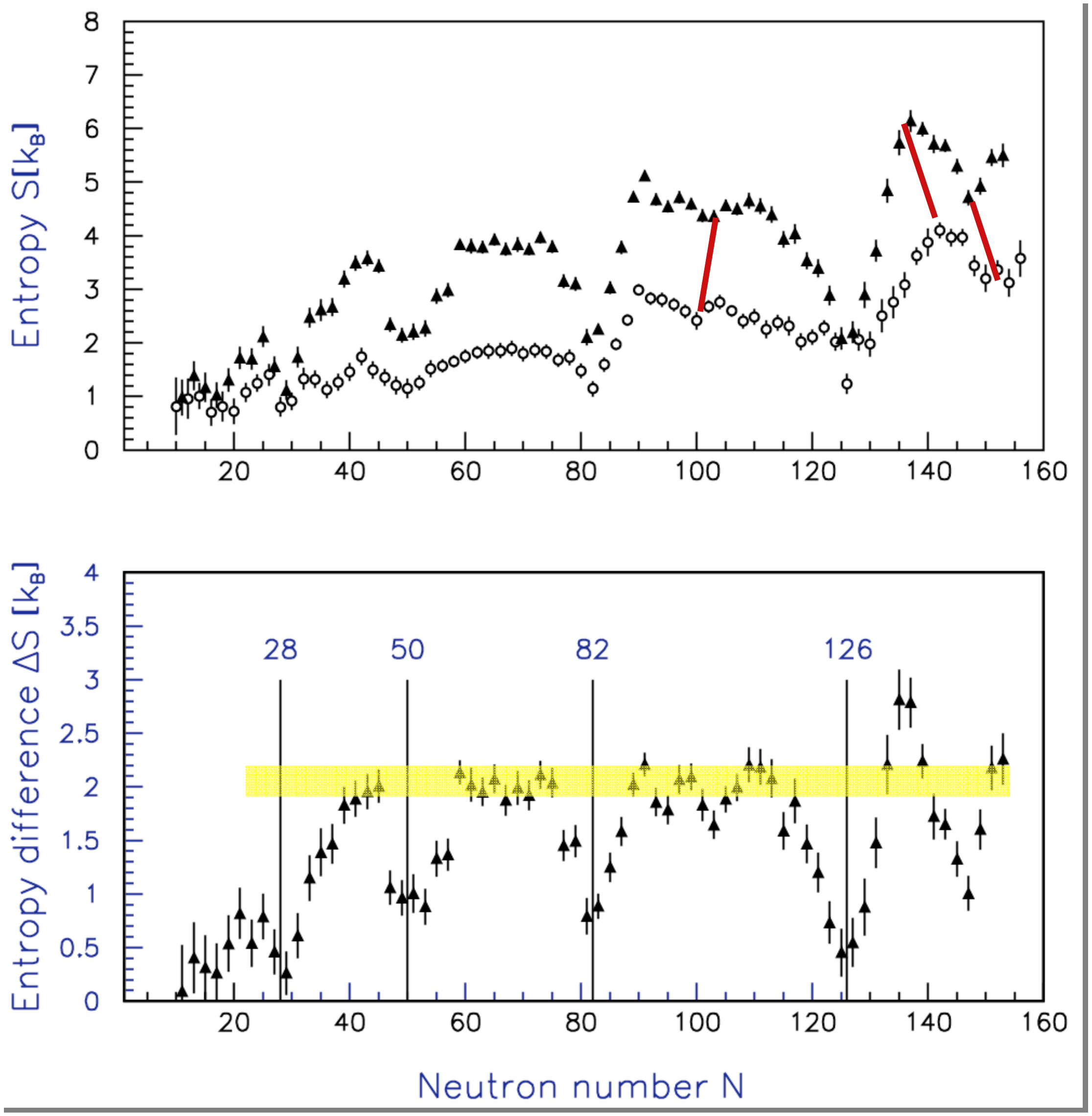
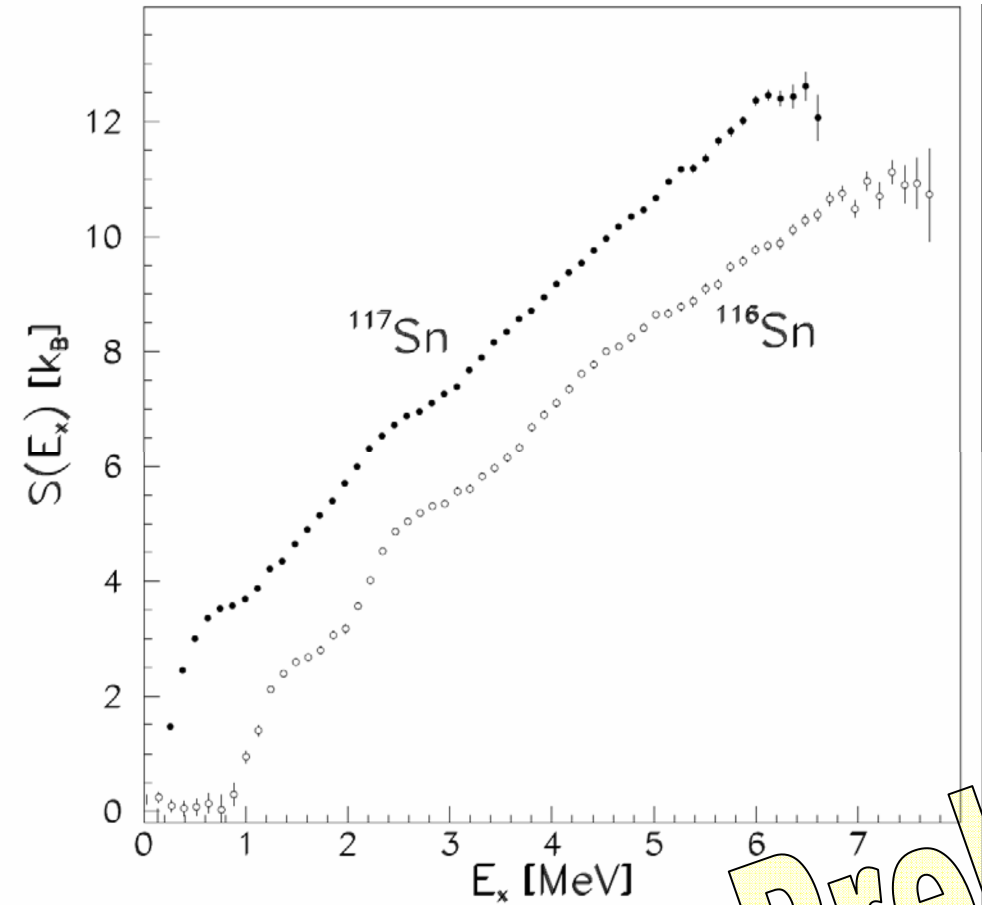




Z = 50
Only breaking
neutron Cooper pairs

Structural transition when:

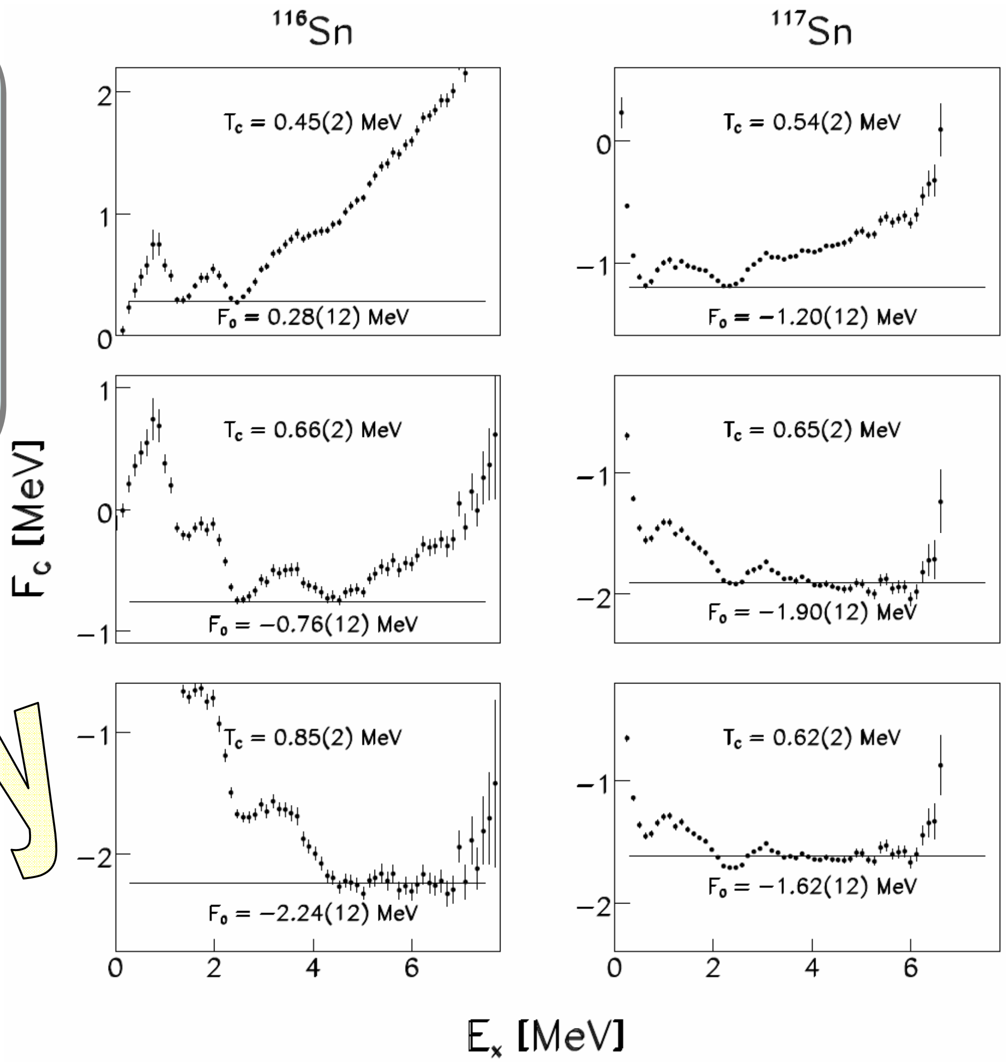
$F_C(E_1) = F_C(E_2)$ for a given T_C

Linearized free energy:

$F_C(E) = E - T_C \cdot S(E)$

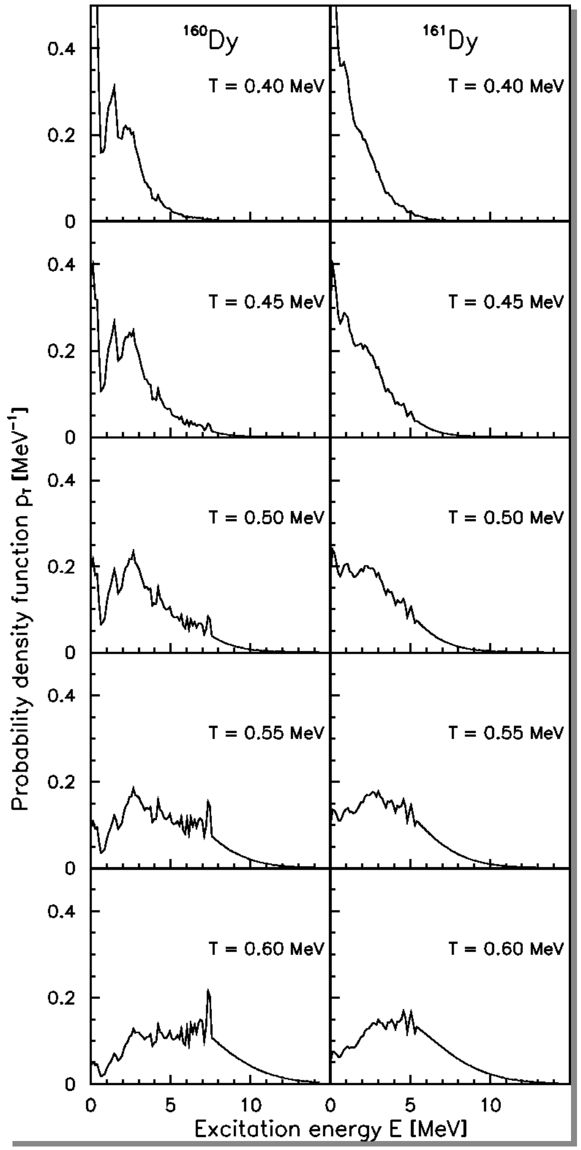
J.Lee and J.M.Kosterlitz,
Phys. Rev. Lett. **65**, 137 (1990)

Preliminary



Canonical ensemble :

$$P(E,T) = \frac{\Omega(E)\exp(-E/T)}{\int_0^\infty \Omega(E')\exp(-E'/T)dE'}$$



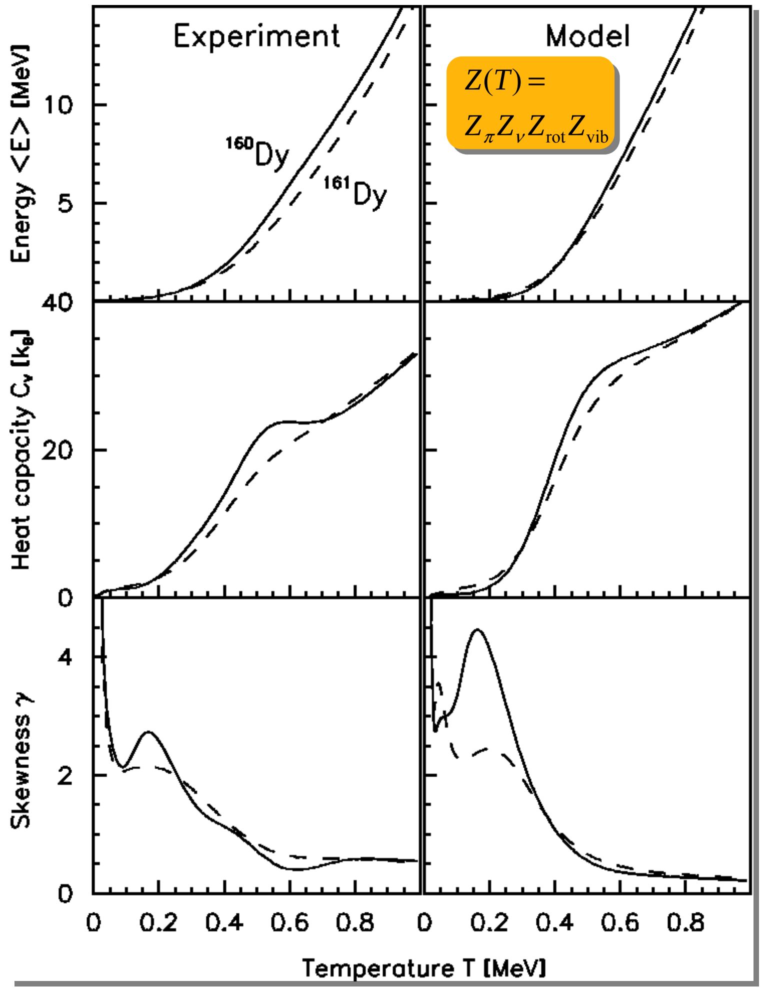
$P(E,T)$ gives $\langle E \rangle$, $\langle E^2 \rangle$ and $\langle E^3 \rangle$

$$\mu_2(T) = \langle E^2 \rangle - \langle E \rangle^2$$

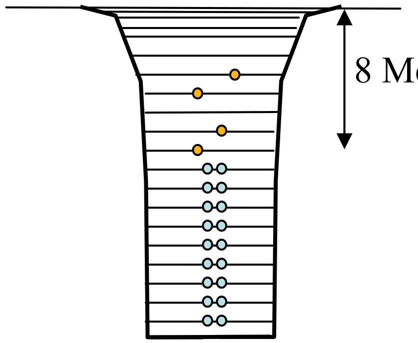
$$\mu_3(T) = \langle E^3 \rangle - 3\langle E \rangle^2 \langle E \rangle + 2\langle E \rangle^3$$

Heat capacity $C_V(T) = \mu_2 / T^2$

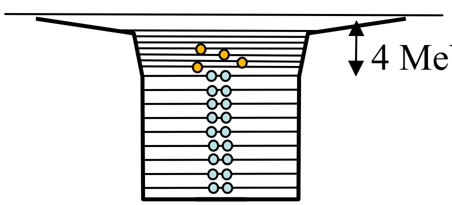
Skewness $\gamma(T) = \mu_3 / \mu_2^{3/2}$



At β-stability



Away from β-stability



Expecting high level density parameter a :

$$\rho \propto \exp\left(2\sqrt{aE}\right) \text{ and } S \propto \ln\rho = 2\sqrt{aE}$$

$$T = \left(\frac{\partial S}{\partial E}\right)^{-1} \propto \sqrt{\frac{E}{a}} \quad \text{and} \quad C_V = T\left(\frac{\partial S}{\partial T}\right)^{-1} \propto 2\sqrt{aE}$$

BUT :

S.I. Al-Quraishi et al. PRC67, 015803 (2003)

$$a = \frac{\alpha A}{\gamma (Z - Z_0)^2} \quad \text{excluding low isospin T levels}$$

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Summary and conclusions

- Experimental level density -> entropy
- Extensive single particle (hole) entropy of $S_1 = 1.5 - 2.0 k_B$ for mid-shell nuclei
- Number of excited particles with E_x
- Critical T for various processes
- Canonical ensemble quantities
- Level density far from β-stability
- Inverse reaction on deuteron target?