Spin cutoff studies from ^{6,7}Li and α-induced reactions

The spin cutoff is an important parameter in level density models

$$\rho(U) = \frac{\exp[2\sqrt{a(U-\delta)}]}{12\sqrt{2}\sigma a^{1/4}(U-\delta)^{5/4}}.$$

Which determines the spin distribution of the nuclear level density

$$\rho(U,J) = \rho(U) \cdot \frac{2J+1}{2\sigma^2} \exp\left[-\frac{(J+0.5)^2}{2\sigma^2}\right]$$

Most popular spin cutoff parameter model formulas

- Rigid body (RB) model (RIPL, Talys)

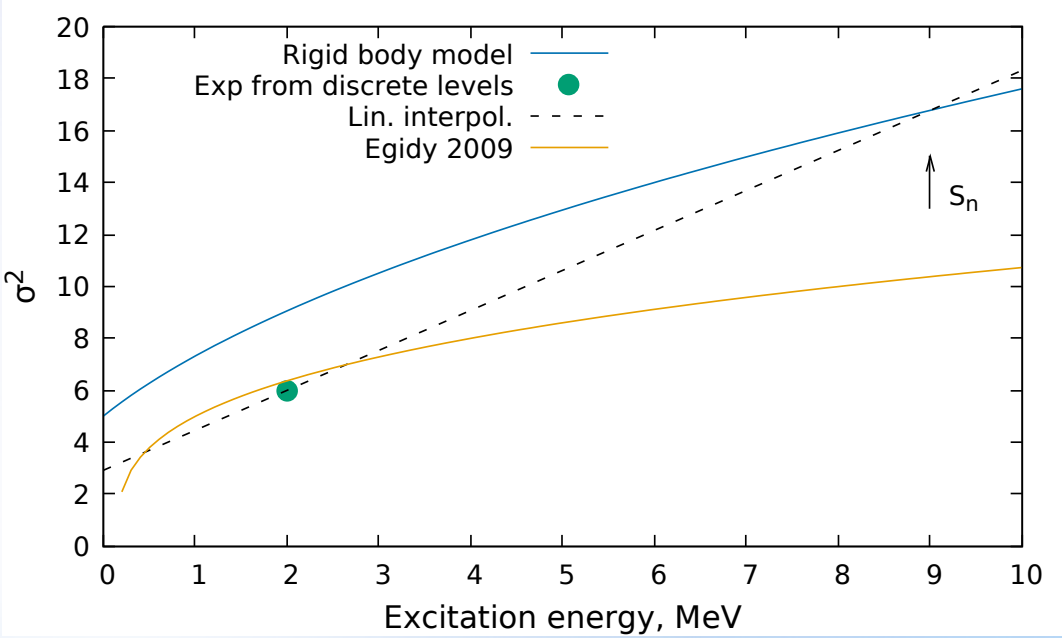
$$\sigma^2(U) = 0.0138 \cdot A^{5/3} \cdot \frac{\sqrt{(U-\Delta)\cdot a}}{\tilde{a}}$$

- T.von Egidy, D. Bucurescu, PRC 80, 054310(2009)

$$\sigma^2(U) = 0.391 A^{0.675}(U - 0.5Pa)$$

- Linear interpolation between $\sigma(U_d)$ and $\sigma(S_n)$, U_d – average excitation energy for discrete levels (Talys, Empire)

$$\sigma^2(U) = \sigma^2(U_d) + \frac{U - U_d}{S_n - U_d}(\sigma^2(S_n) - \sigma(U_d))$$



Effect of the spin cutoff parameter on calculation of the total radiative width of neutron resonances

Total radiative widths :

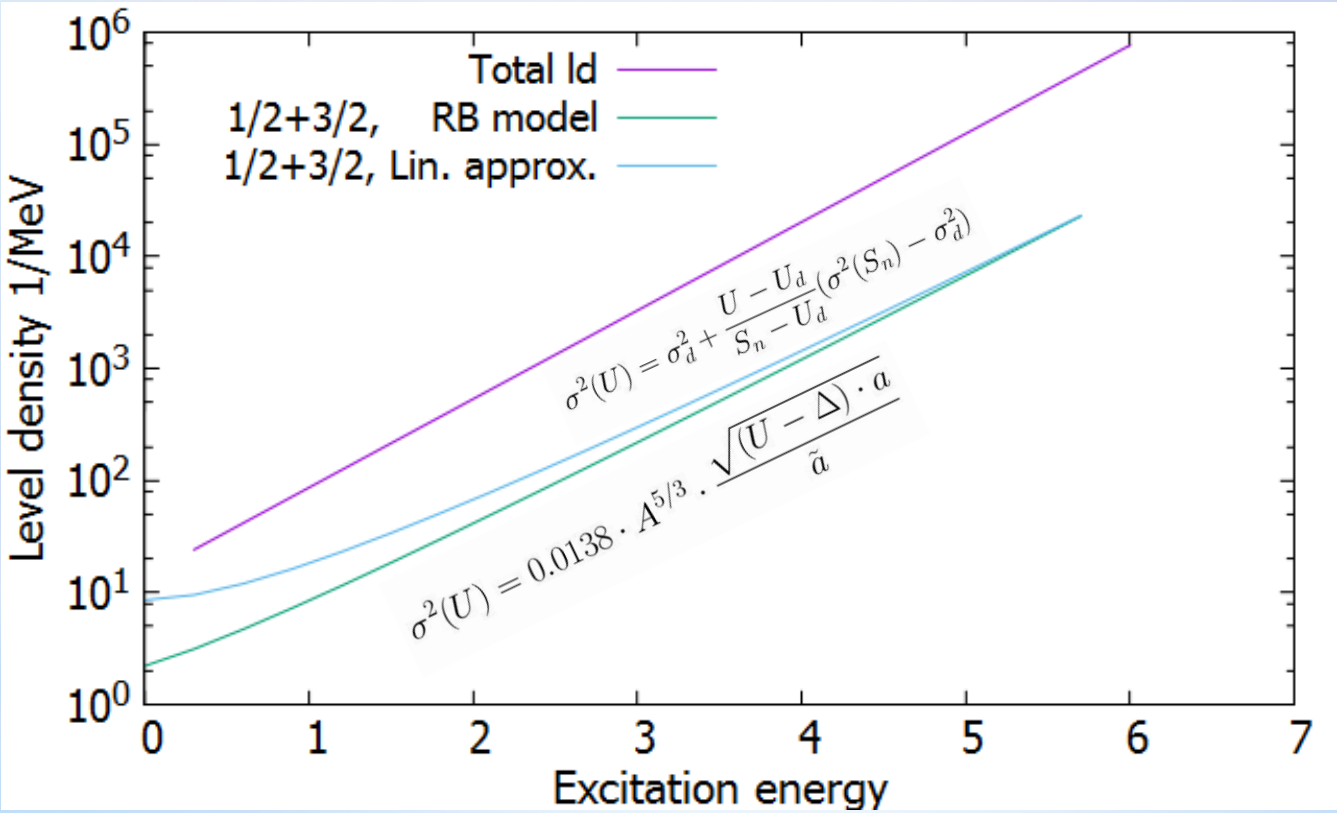
$$< \Gamma_\gamma(S_n, I_i, \Pi_i) >= \frac{D_0}{2} \int_{E_\gamma=0}^{S_n} dE_\gamma f(E_\gamma) \cdot E_\gamma^3 \cdot \rho(S_n - E_\gamma) \times \sum_{J=-1}^{J=1} g(S_n - E_\gamma, I_i + J))$$

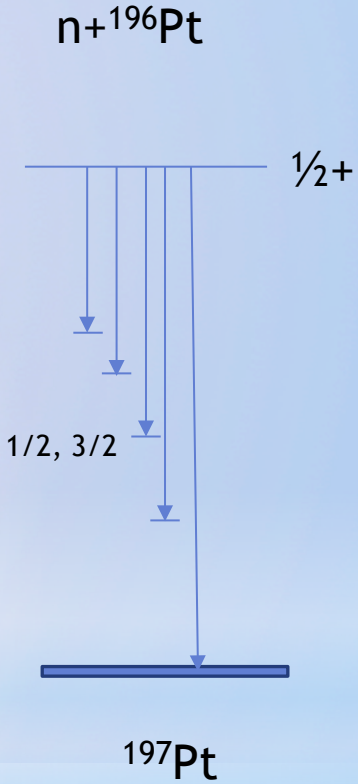
Neutron capture cross section :

$$\sigma_{n,\gamma} \sim \sigma_{CN} \times \frac{< \Gamma_\gamma >}{< \Gamma_n + \Gamma_\gamma >}$$

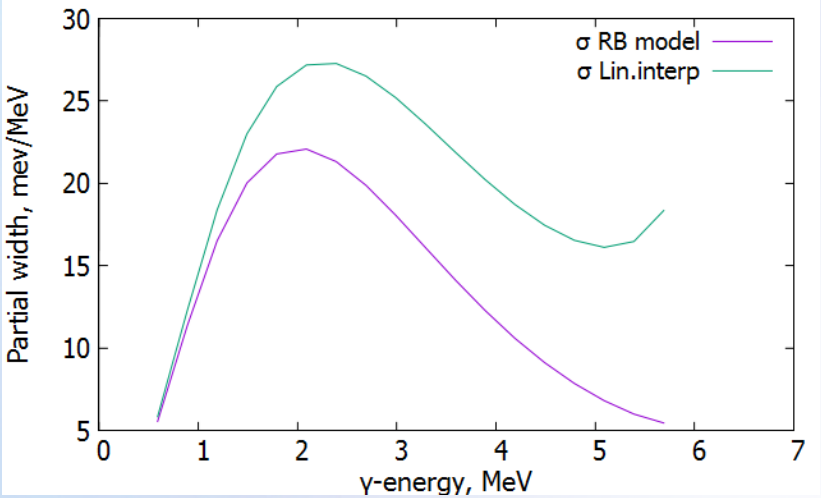
Effect of the spin cutoff on <Γ_γ>, the case of ^{197}Pt

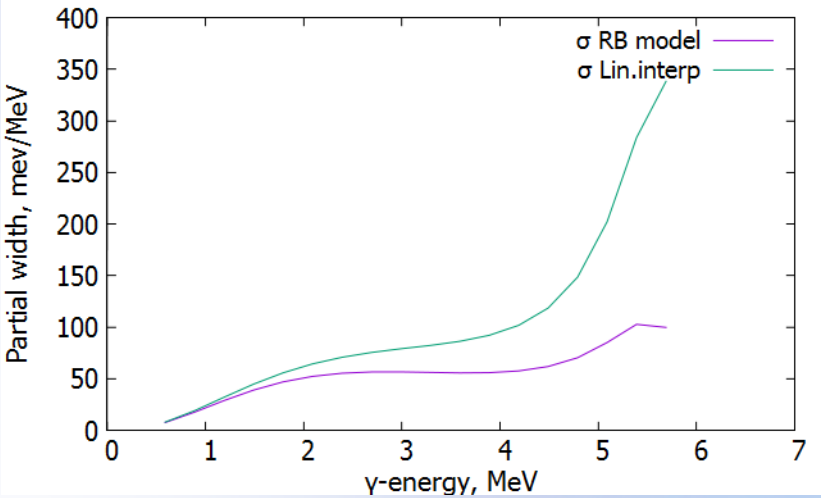
Model level density for ^{197}Pt





Effect of the spin cutoff on $<\Gamma_\gamma>$, the case of ^{197}Pt





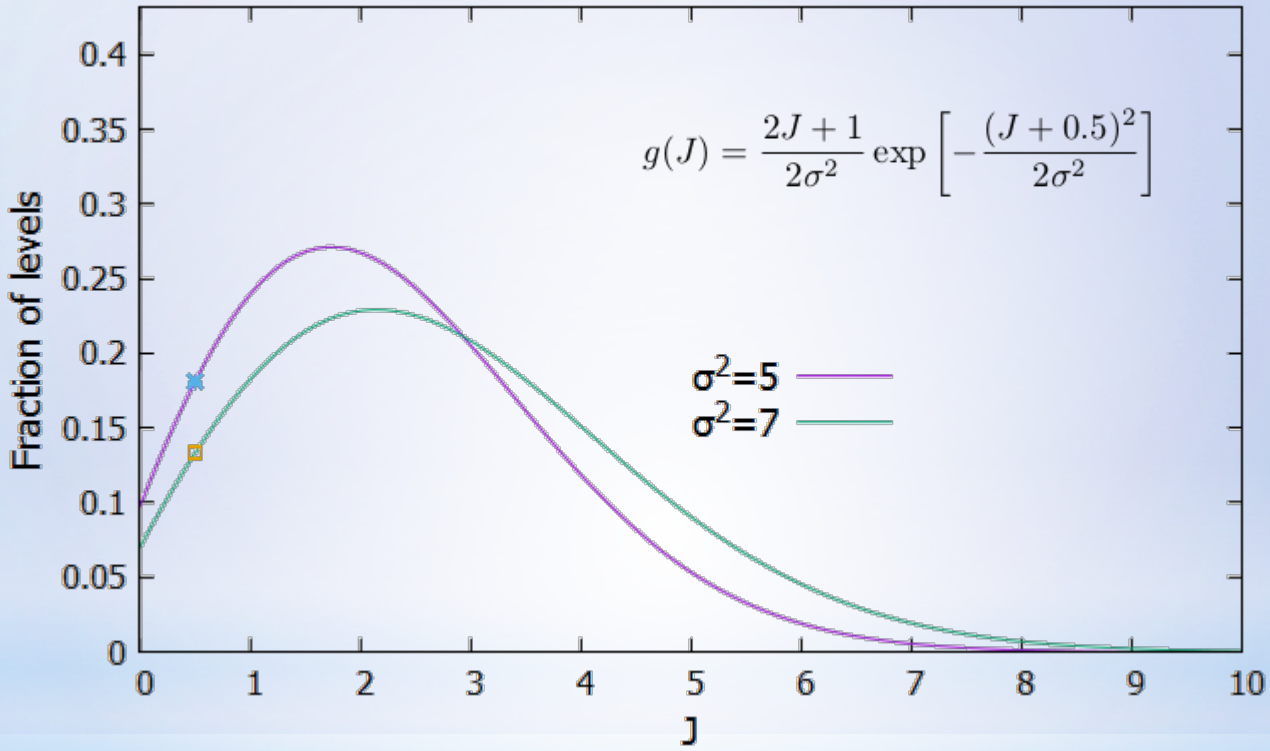
Average	total $<\Gamma_\gamma>$	of neutron	resonances
	RB model	Lin. Interp.	Ratio
$<\Gamma_\gamma>$ no pygmy	78	113	1.45
$<\Gamma_\gamma>$ pygmy	382	656	1.71

Experimental techniques to study the spin cutoff parameter

1. Spin cutoff from the total level density and
   the neutron resonance spacing

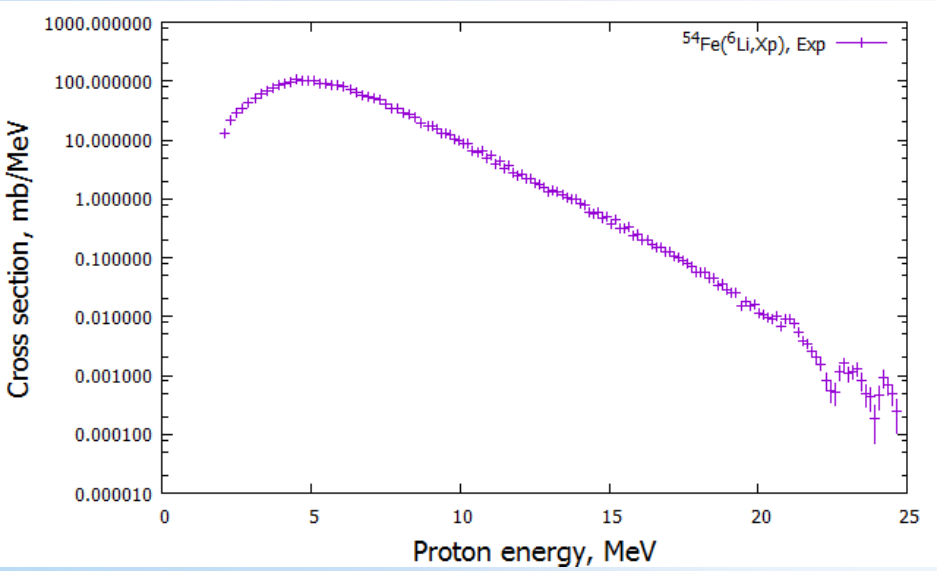
2. Spin cutoff parameter from studying the angular distribution
   of reaction products

Spin cutoff from the total level density and the neutron resonance spacing

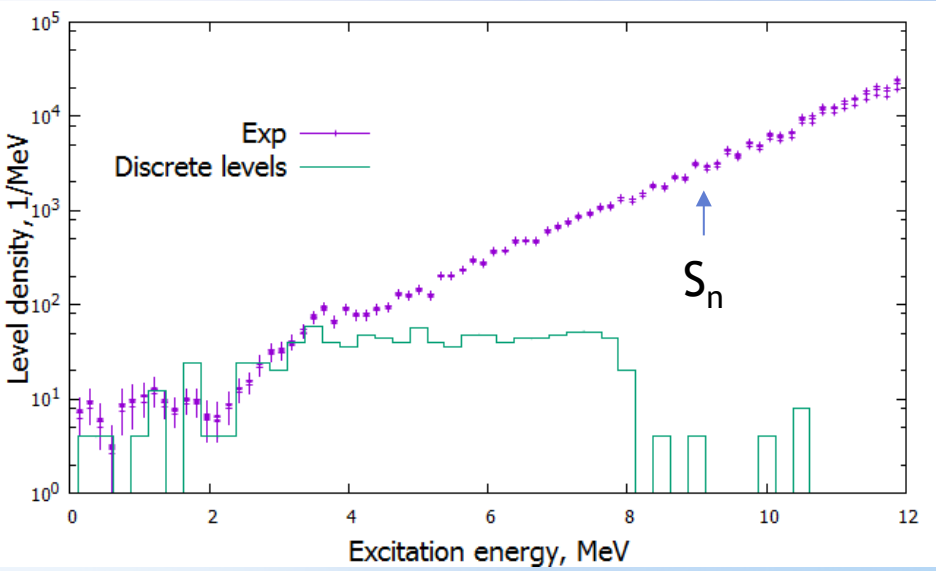


Spin cutoff for nickel isotopes
Experiment

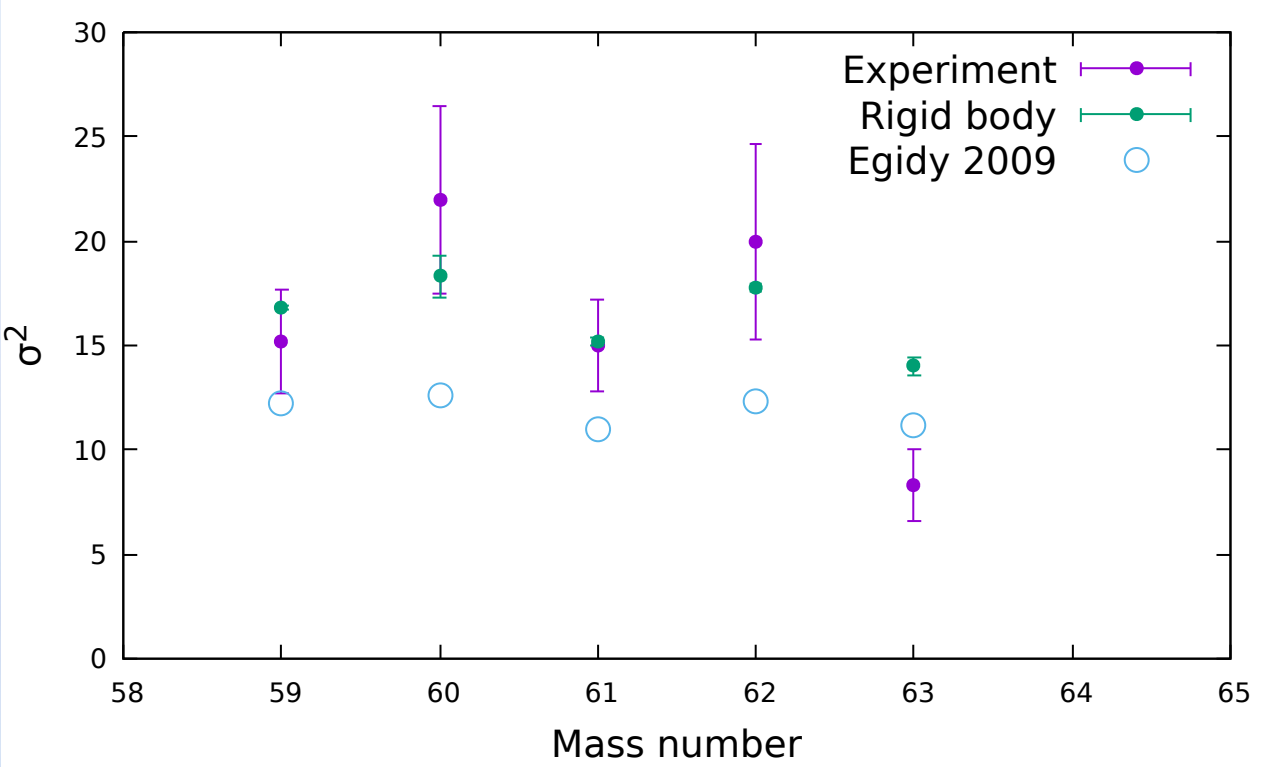
$^{6,7}Li + ^{54,56,57,58}Fe \longrightarrow ^{59,60,61,62,63,64}Ni + p$



Level density of ^{59}Ni

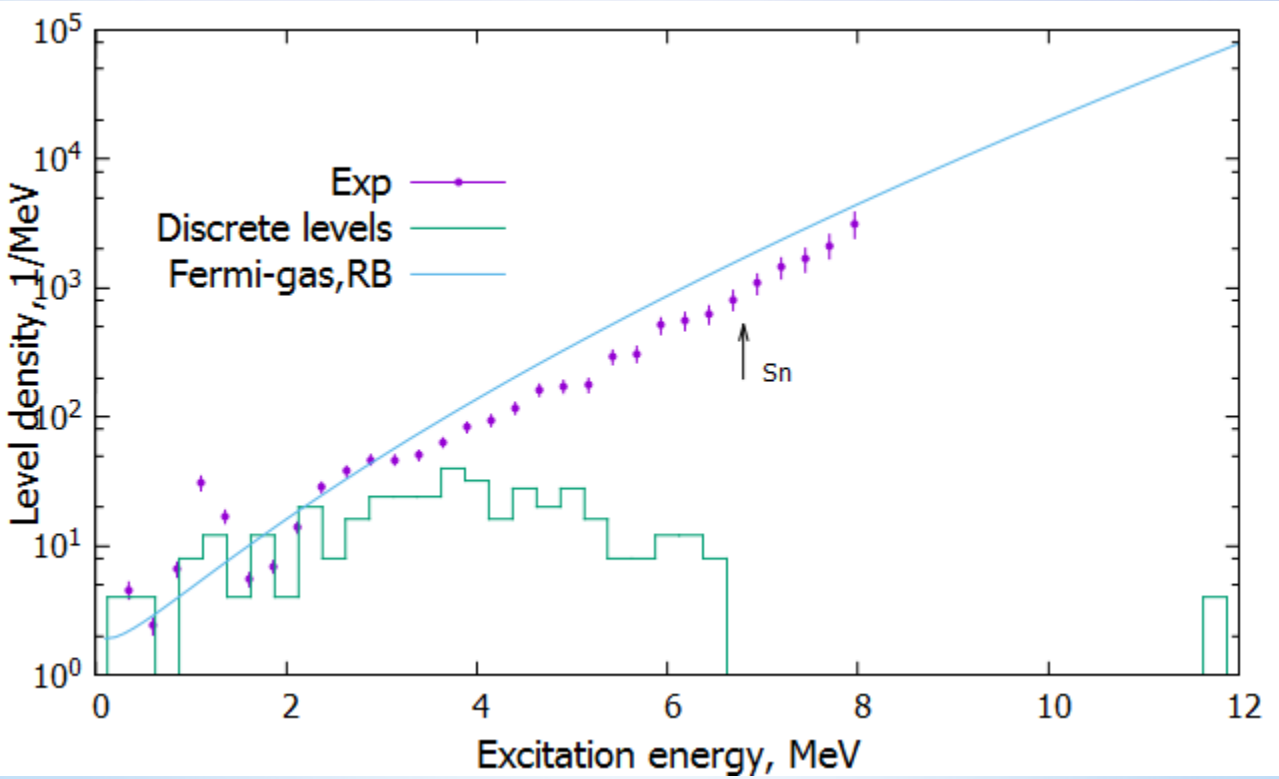


Spin cutoff for nickel isotopes at the neutron binding energy, Sn



	^{59}Ni	^{60}Ni	^{61}Ni	^{62}Ni	^{63}Ni
ρ_{exp}	2250(200)	8200(800)	2260(200)	5500(1100)	1150(180)
σ^2_{exp}	15.2(2.5)	22(4.5)	15(2.2)	20(4.7)	8.3(1.7)
σ_{RB}^2	16.8(1)	18.3(10)	15.2(2)	17.8(2)	14.0(4)

Level density for ^{63}Ni

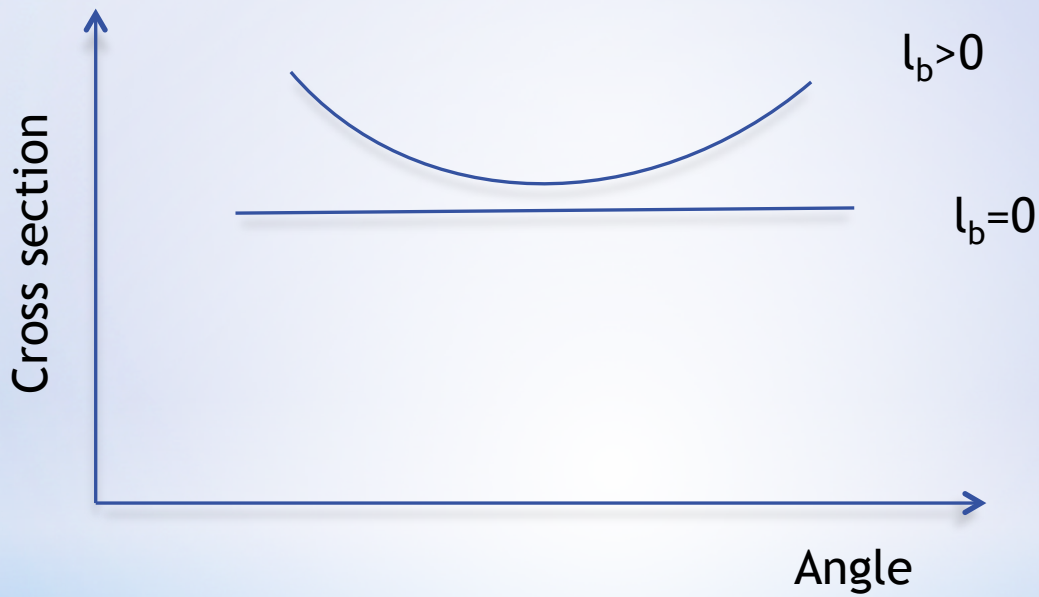


Spin cutoff σ from angular distribution of particles from compound nuclear reactions

T.Ericson and V. Strutinski, Nucl.Phys. 8, 284 (1958)

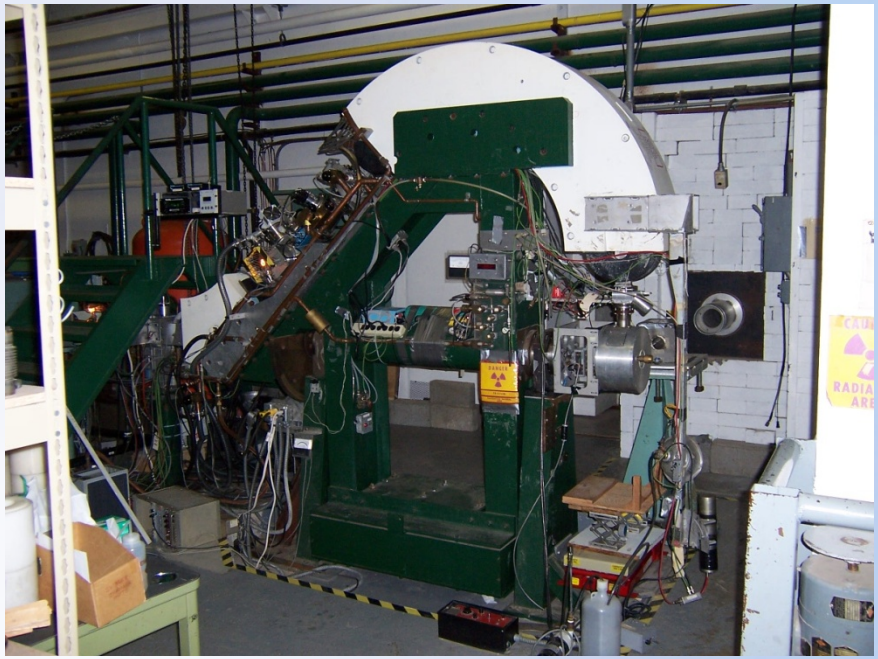
- Due to orbital momentum conservation, spin of compound nuclei tend to be aligned with orbital momentum of incoming particles
- Compound nucleus “remembers ” direction of incoming beam.
- Angular distributions become non-isotropic but symmetric about 90 degree
- Degree of anisotropy is determined by the angular momenta of outgoing particles which are mainly determined by spin distribution of residual nucleus

$$a+A \longrightarrow C \longrightarrow B+b$$

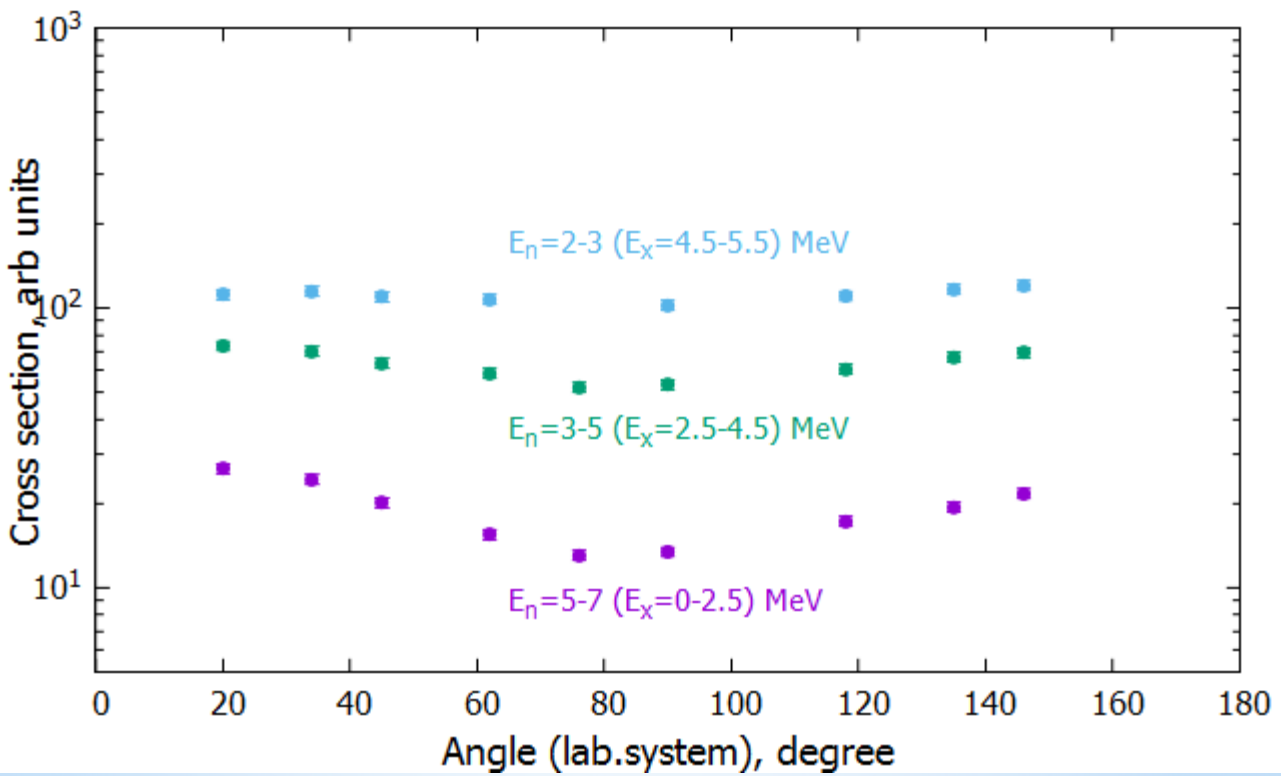


Orbital momenta are determined by spin of both compound C and residual nucleus B

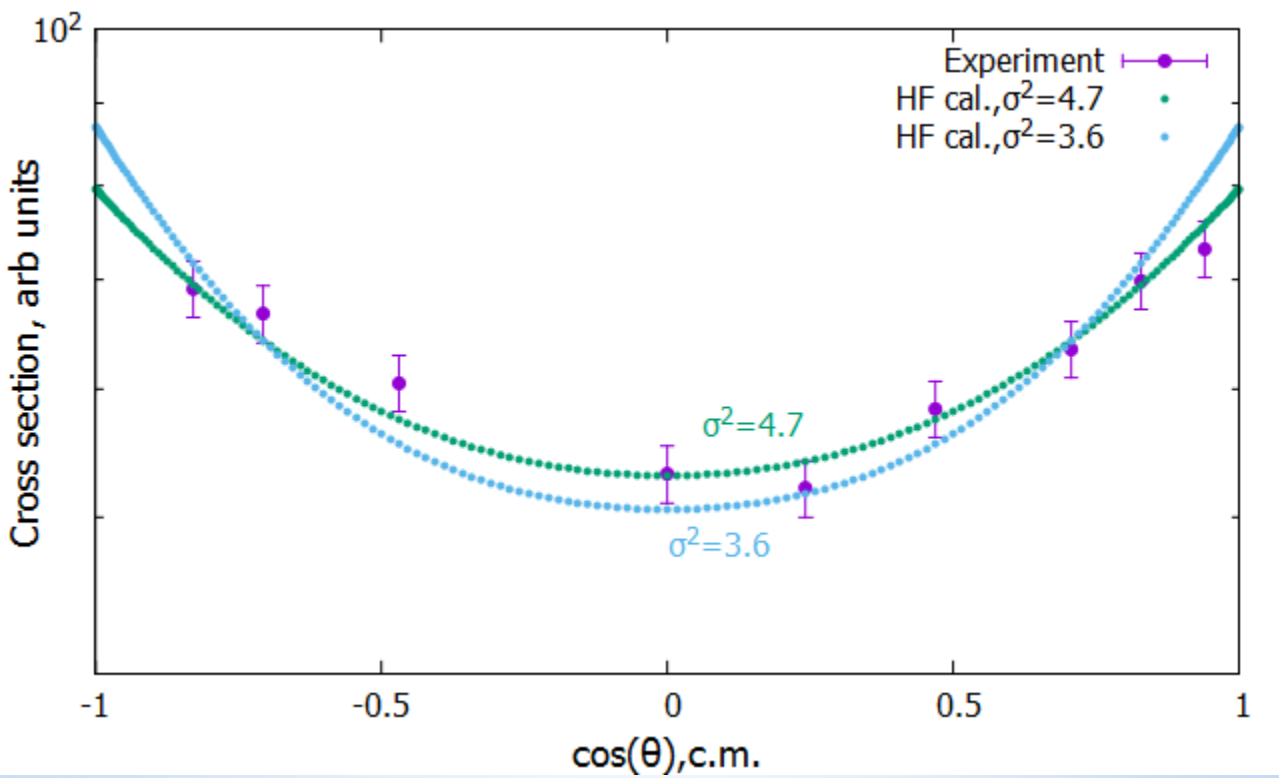
Neutron angular distributions from $^{56,57}Fe(a,n)^{59,60}Ni$ reactions, 13.5 MeV beam



Experimental angular distributions of neutrons from $^{56}Fe(\alpha,n)^{59}Ni$, $E_\alpha = 13.5$ MeV

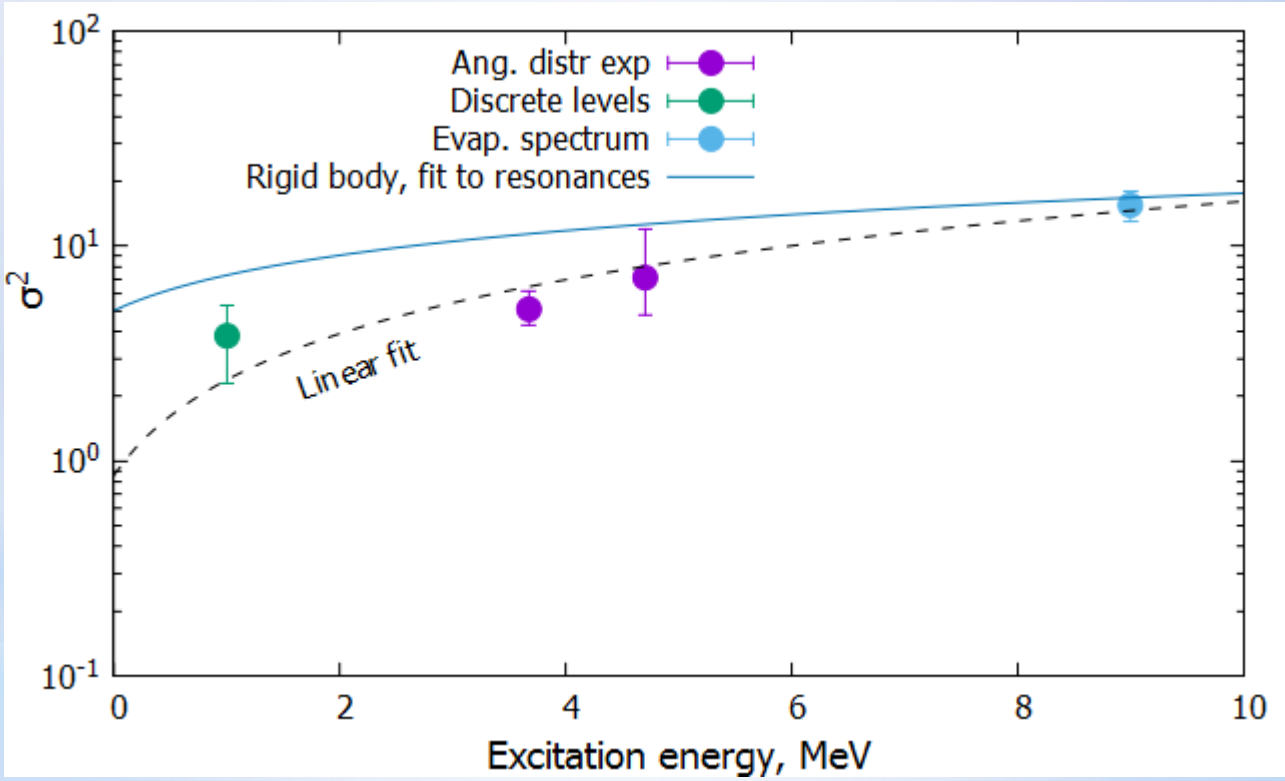


Experimental neutron angular distributions have been analyzed with Hauser Feshbach code developed at Ohio University (S. Grimes).
The spin cutoff parameter has been adjusted to reproduce experimental angular distributions.

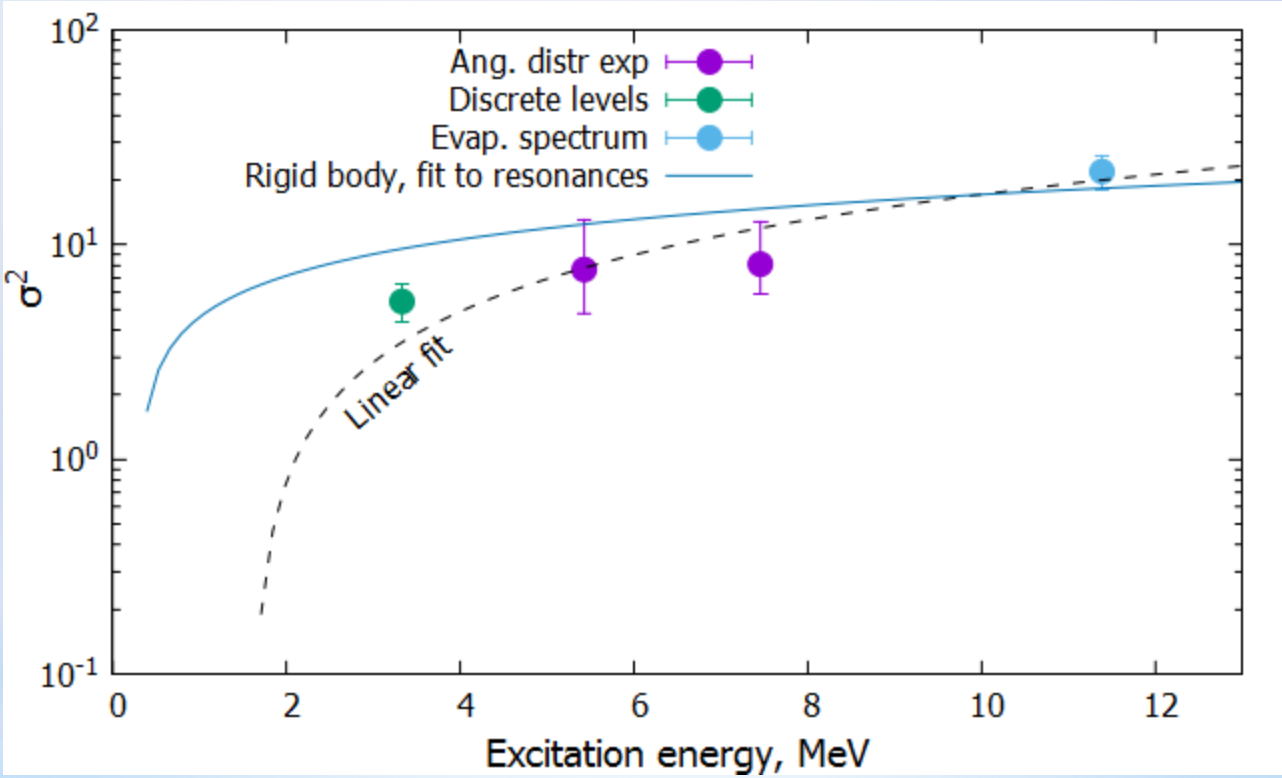


Spin cutoff parameters from evaporation spectra and neutron angular distributions

^{59}Ni

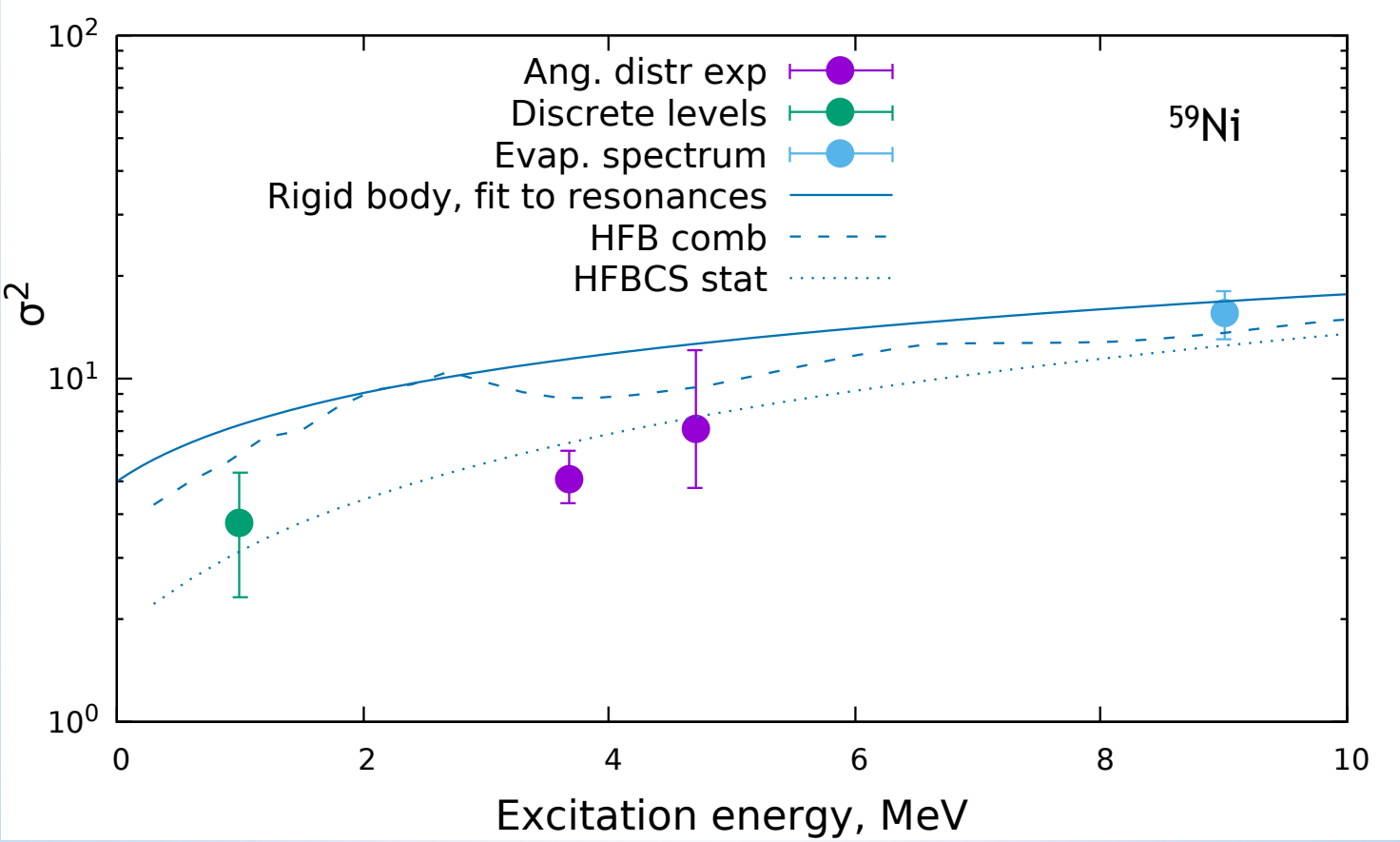


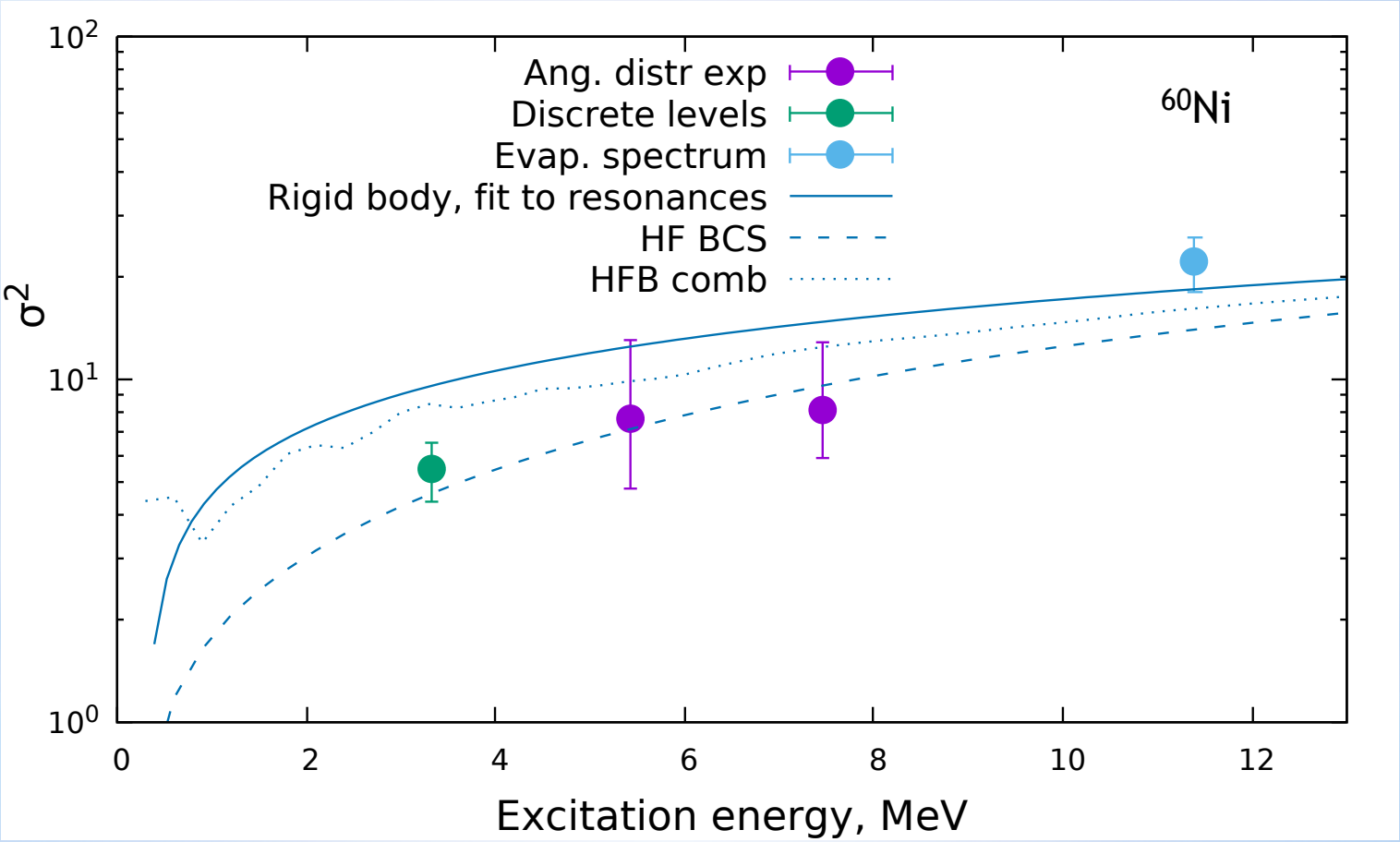
Spin cutoff parameter of ^{60}Ni



HFBCS statistical: P.Demetriou, S.Goriely, Nucl.Phys. A695, 95 (2001)

HFB comb: S.Goriely, S.Hilaire, A.J.Koning, Phys.Rev. C 78, 064307 (2008)



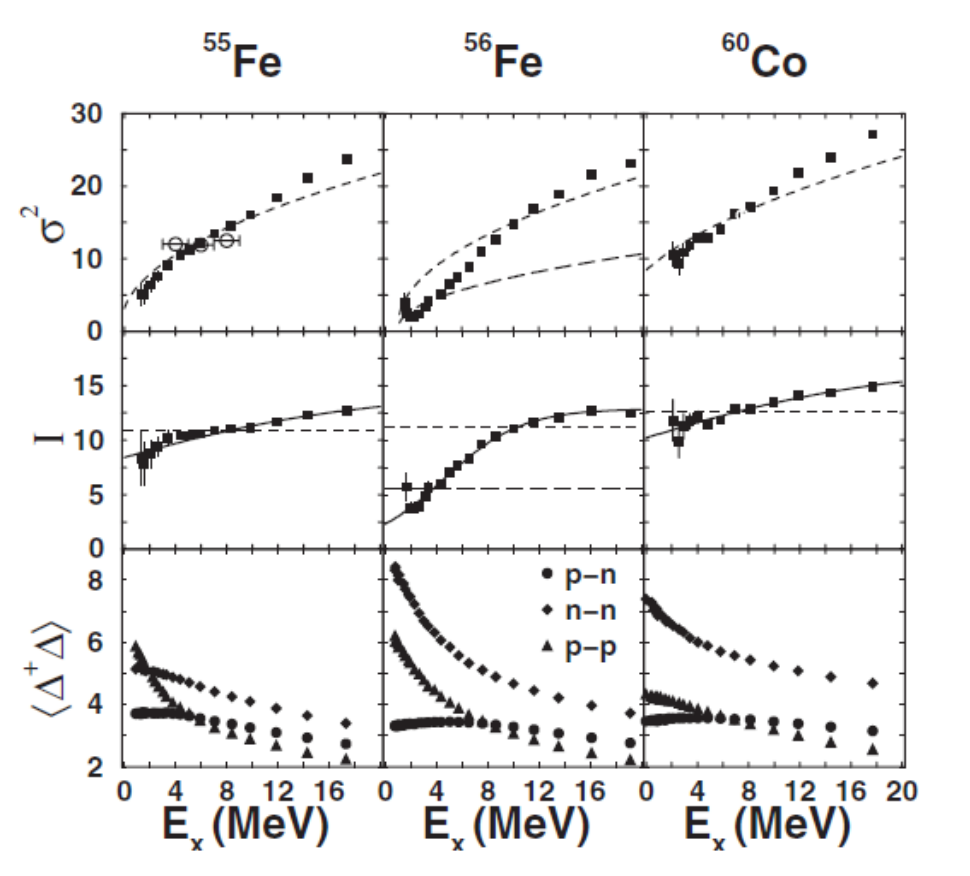


A.Voinov, Oslo workshop 2017

Spin Projection in the Shell Model Monte Carlo Method and the Spin Distribution of Nuclear Level Densities

Y. Alhassid,[1] S. Liu,[1] and H. Nakada[2]

PRL **99,** 162504 (2007)



Conclusion

- Important physics quantities such as total radiative width of neutron resonances and (n,γ) cross sections depend on the spin cutoff parameter below the neutron binding energy. The specific energy dependence below the neutron separation energy is very important to know.

- At the neutron resonance spacing, the spin cutoff parameter might be well estimated with the model based on RB moment of inertia and data on neutron resonance spacing. There might also be exceptions (^{63}Ni ?)

- Below the neutron separation energy, the spin cutoff parameter tends to be lower than estimations based on RB model. Pairing correlations play a role.