Level Densities and Hidden Strength from the Fluctuation Analysis of High-Resolution Spectra

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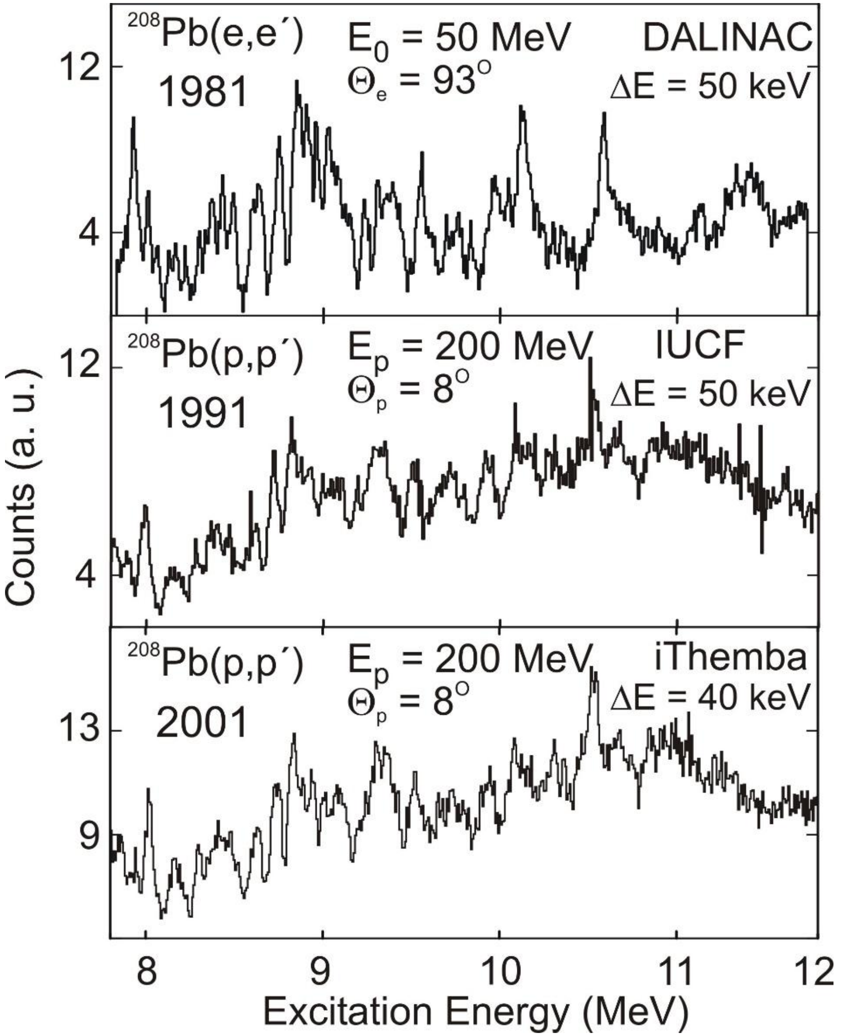
- Fine structure in high-resolution spectra of giant resonances
- Fluctuation analysis
- Applications
- Extraction of unresolved strength

Collaboration: Johann Isaak (TU Darmstadt), Isabelle Brandherm (U Cologne)

Fine structure in high-resolution spectra of giant resonances

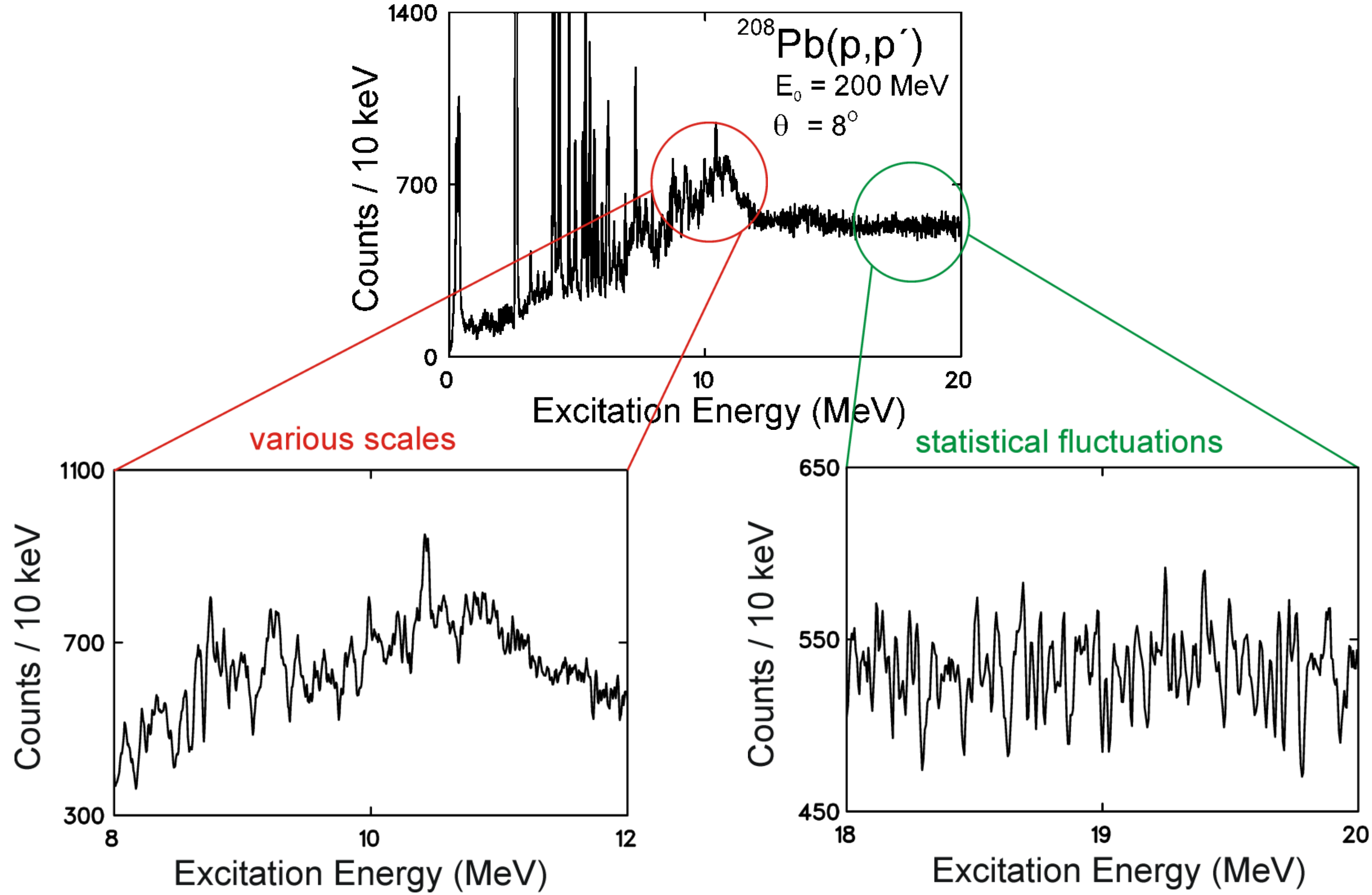
The Case of the ISGQR in ^{208}Pb

- Fine structure independent of exciting probe

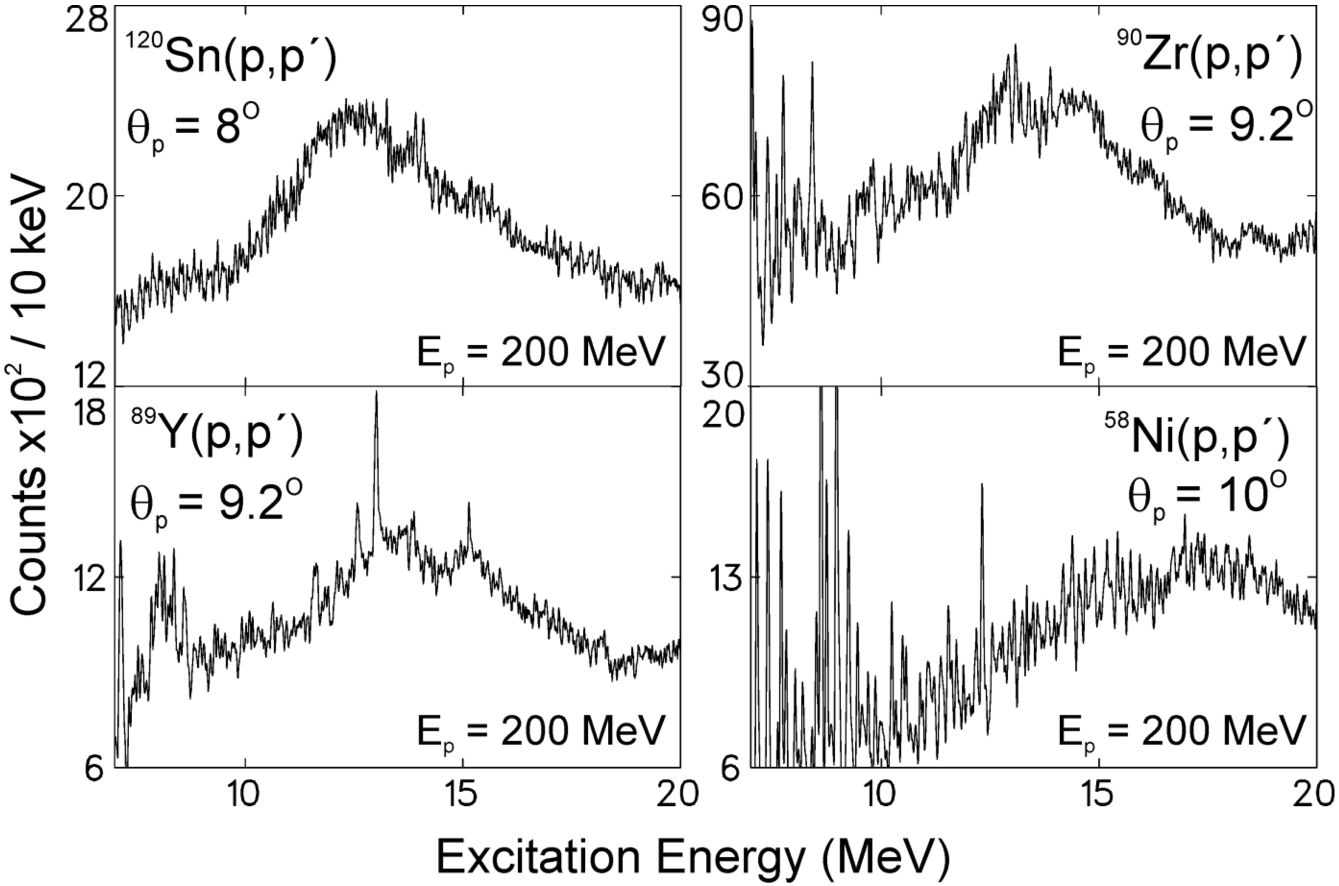


S. Kamerdzhiev et al., Phys. Rev. C 55, 2101 (1997)

Scales and Fluctuations

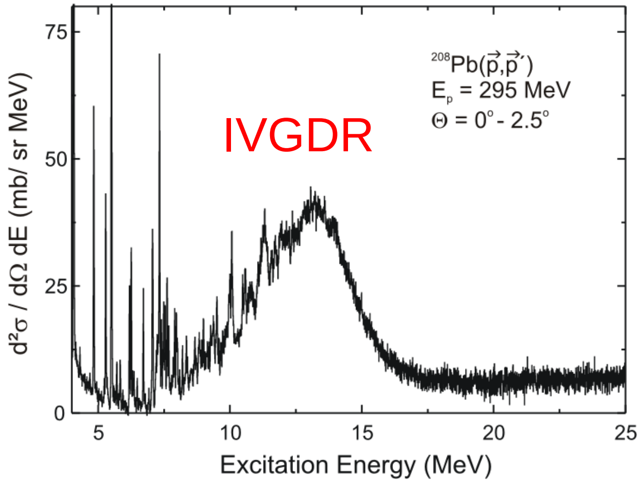


Fine Structure of the ISGQR – a Systematic Phenomenon

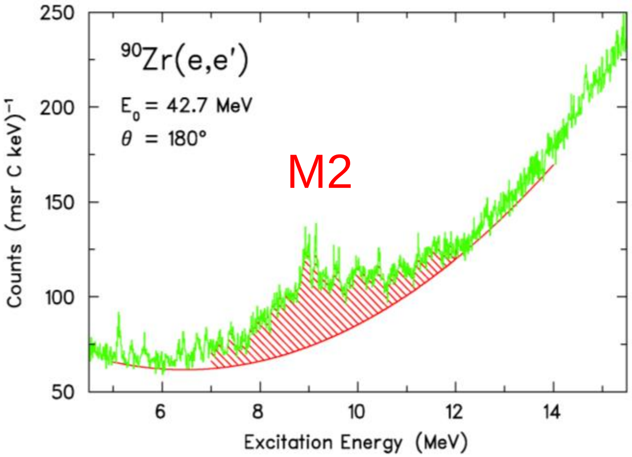


A. Shevchenko et al., Phys. Rev. C 79, 044305 (2009)

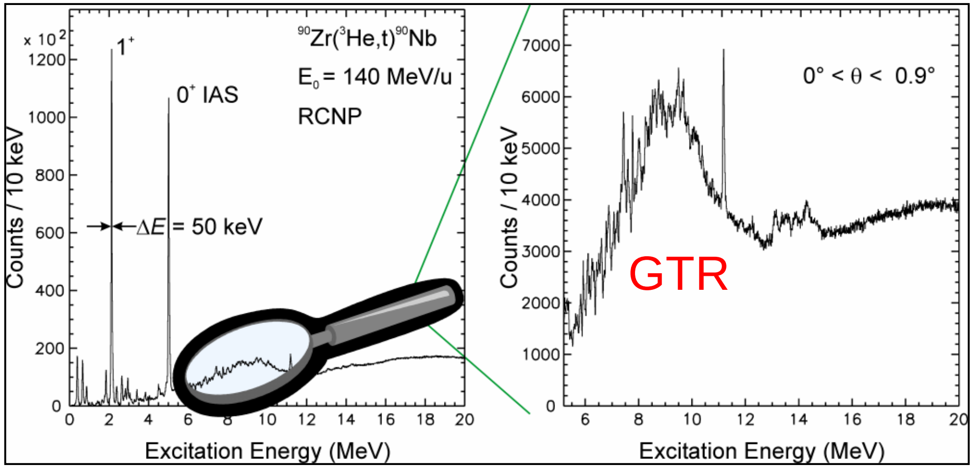
Fine Structure of GRs – a Global Phenomenon



I. Poltoratska et al., Phys. Rev. C 89, 054322 (2014)

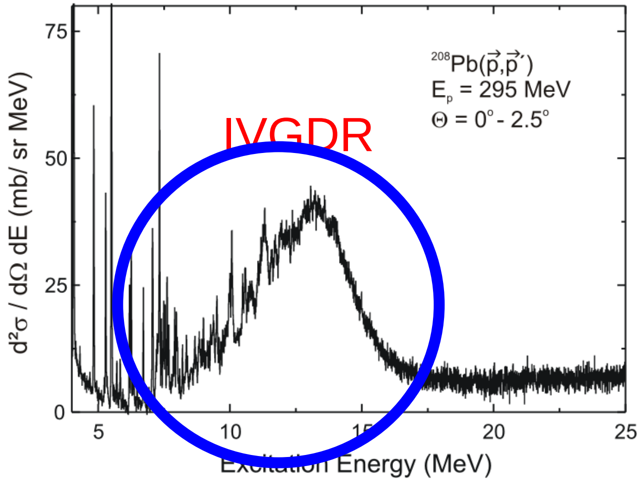


P. von Neumann-Cosel et al.,
Phys. Rev. Lett. 82, 1105 (1999)

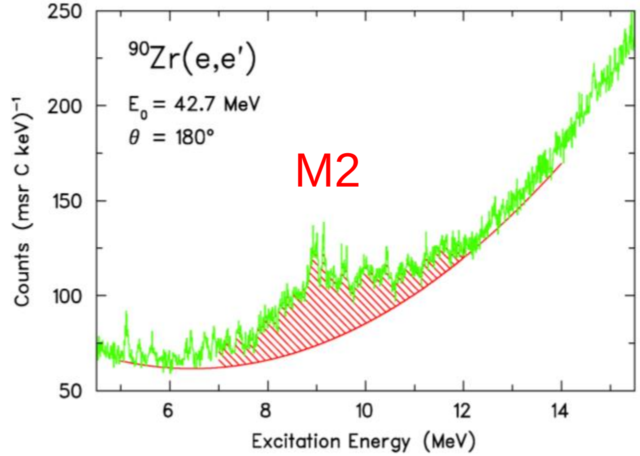


Y. Kalmykov et al.,
Phys. Rev. Lett. 96, 012502 (2006)

Fine Structure of GRs – a Global Phenomenon



I. Poltoratska et al., Phys. Rev. C 89, 054322 (2014)



P. von Neumann-Cosel et al.,
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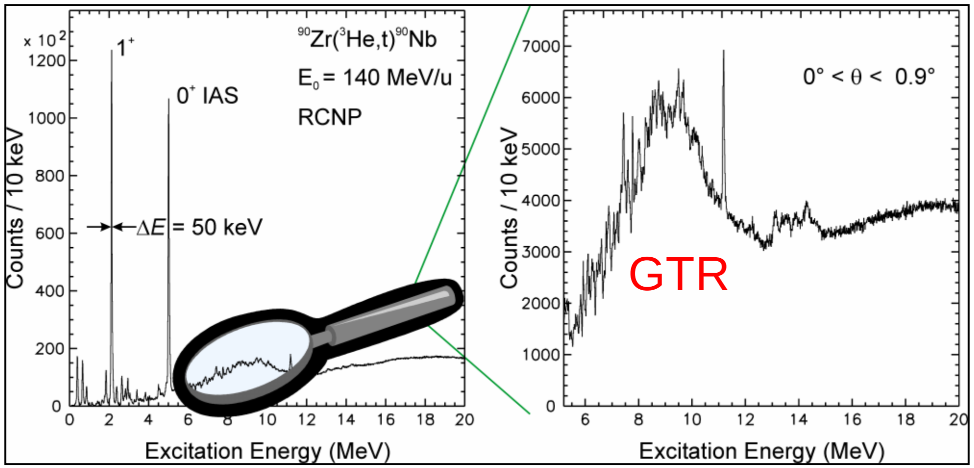
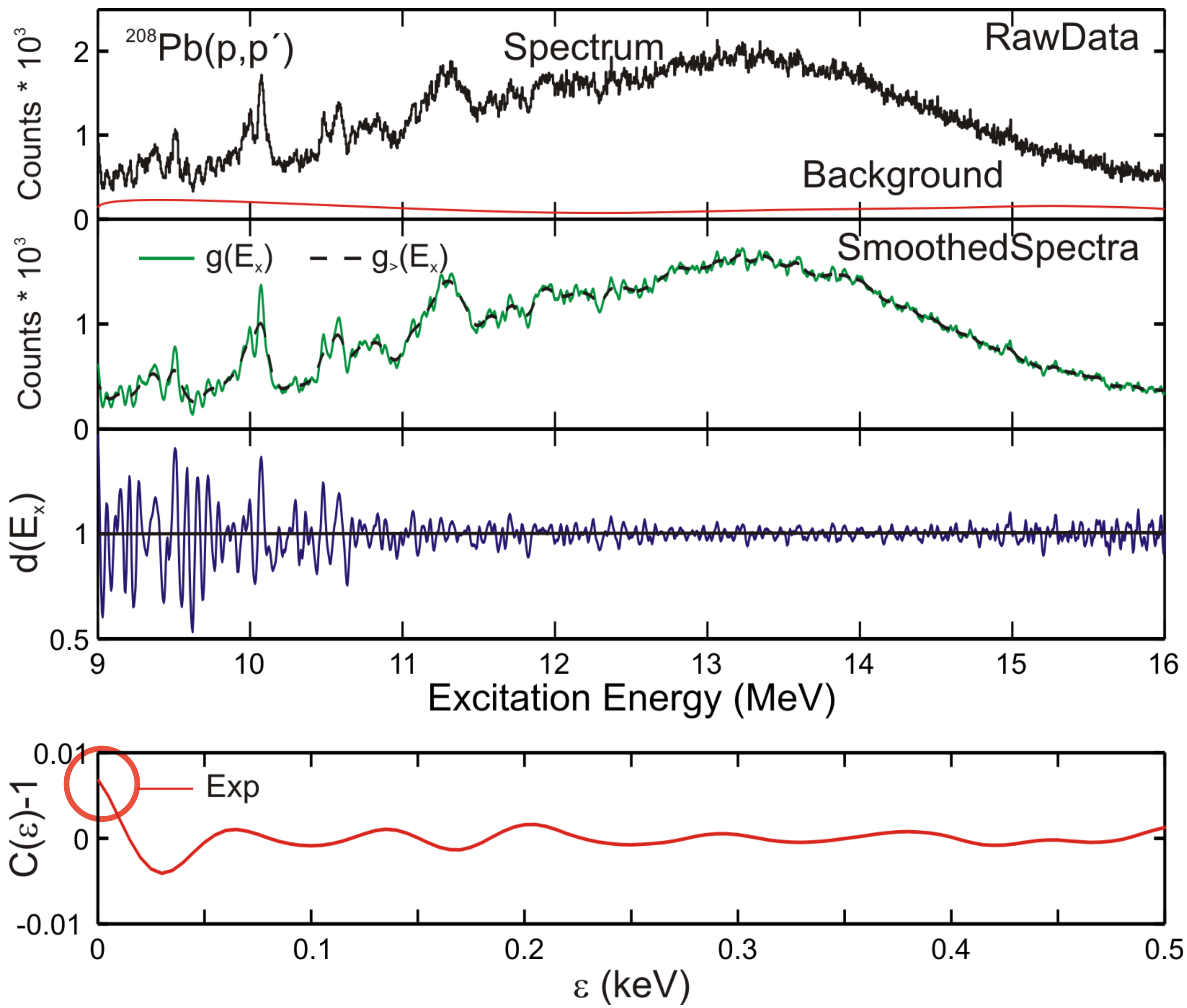


Y. Kalmykov et al.,
Phys. Rev. Lett. 96, 012502 (2006)

Fluctuation analysis

Example: IVGDR in ^{208}Pb



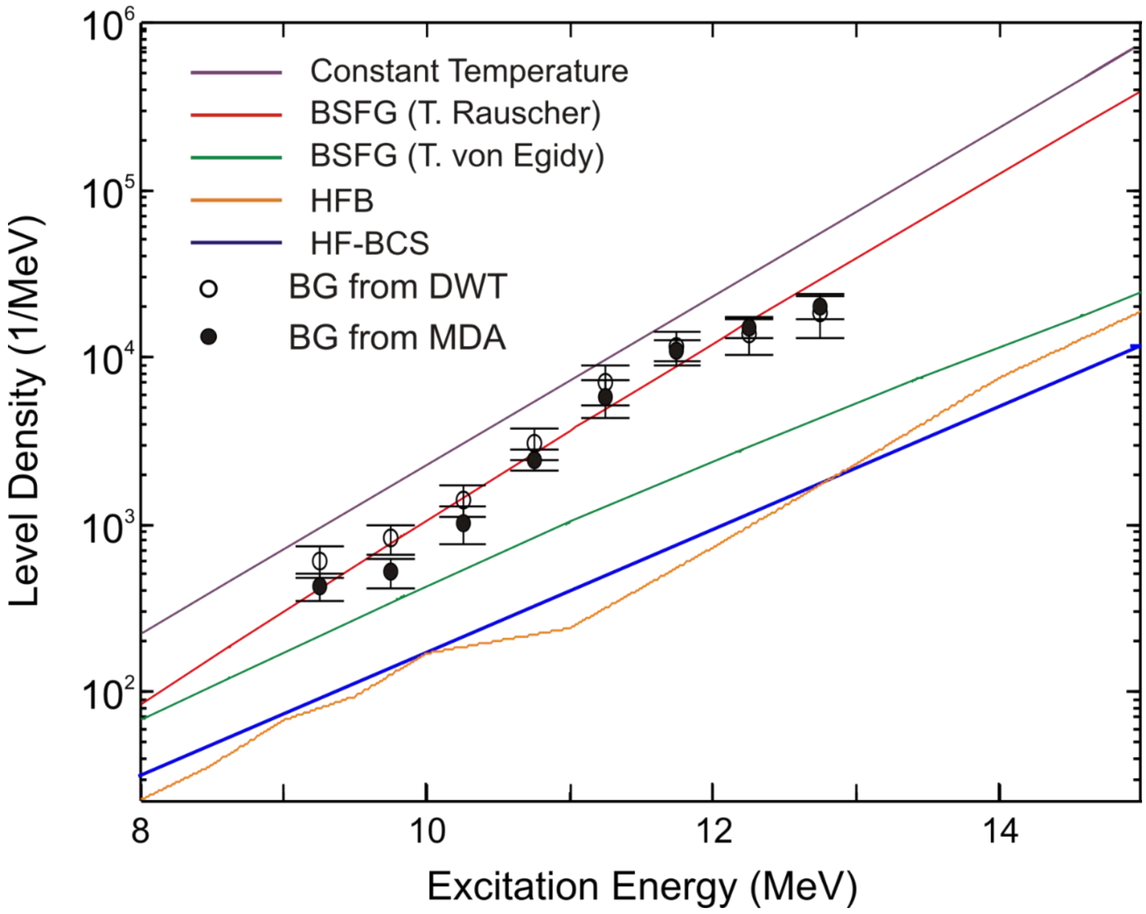
- Background from MDA or wavelet analysis
- Stationary spectrum $\dfrac{g(E_x)}{g_>(E_x)}$
- Autocorrelation function

Autocorrelation Function and Mean Level Spacing

- $$C(\varepsilon)=\frac{\langle d(E_x)\cdot d(E_x+\varepsilon)\rangle}{\langle d(E_x)\rangle\cdot\langle d(E_x+\varepsilon)\rangle}$$ autocorrelation function
- $$C(\varepsilon=0)-1=\frac{\langle d^2(E_x)\rangle-\langle d(E_x)\rangle^2}{\langle d(E_x)\rangle^2}$$ variance
- $$C(\varepsilon=0)-1=\frac{\alpha\langle D\rangle}{2\sigma\sqrt{\pi}}$$ level spacing $\langle D\rangle$
- $$\alpha=\alpha_{PT}+\alpha_W$$ statistical properties
- σ resolution

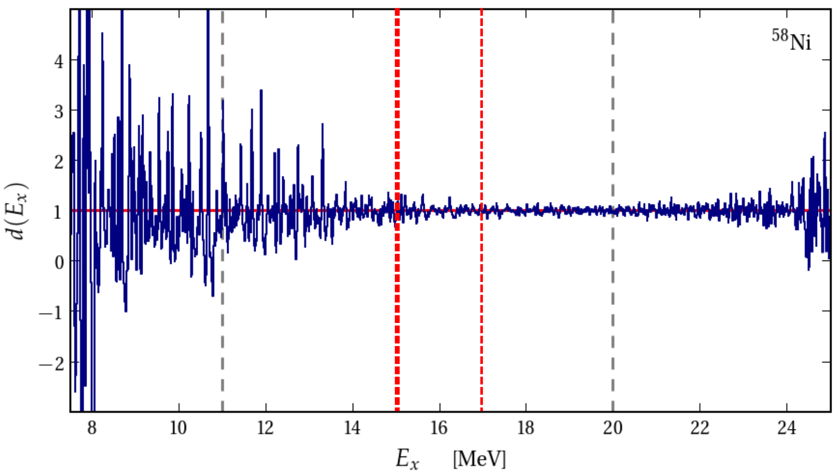
Level density of $J^{\pi} = 1^{-}$ states in ^{208}Pb

I. Poltoratska et al., Phys. Rev. C 89, 054322 (2014)

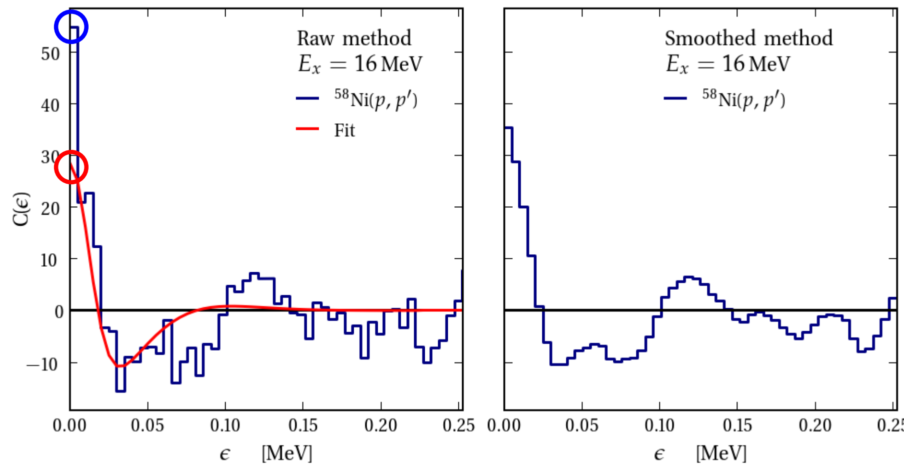


Analysis without Presmoothing: Example ^{58}Ni

- Stationary spectrum



- Autocorrelation function at 16 MeV



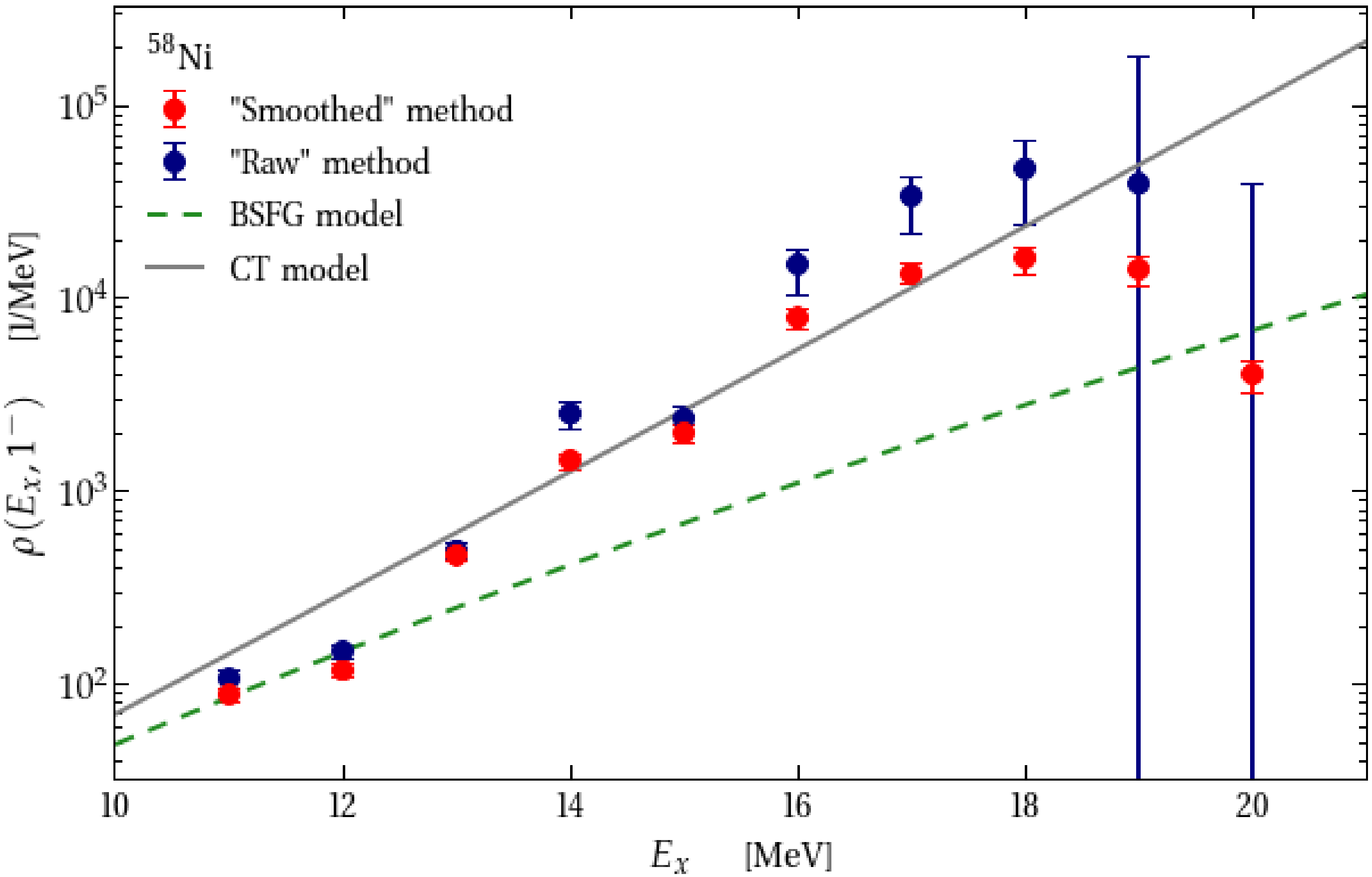
- Fit to theoretical function (Hansen and Jonson)

$$C(\varepsilon) = 1 + \frac{\alpha \langle D \rangle}{2\sigma_< \sqrt{\pi}} \left[\exp\left(-\frac{\varepsilon^2}{4\sigma_<^2} \right) + \frac{1}{y} \exp\left(-\frac{\varepsilon^2}{4\sigma_<^2 y^2} \right) - \sqrt{\frac{8}{1+y^2}} \exp\left(-\frac{\varepsilon^2}{2\sigma_<^2 (1+y^2)} \right) \right]$$

$$y = \sigma_> / \sigma$$

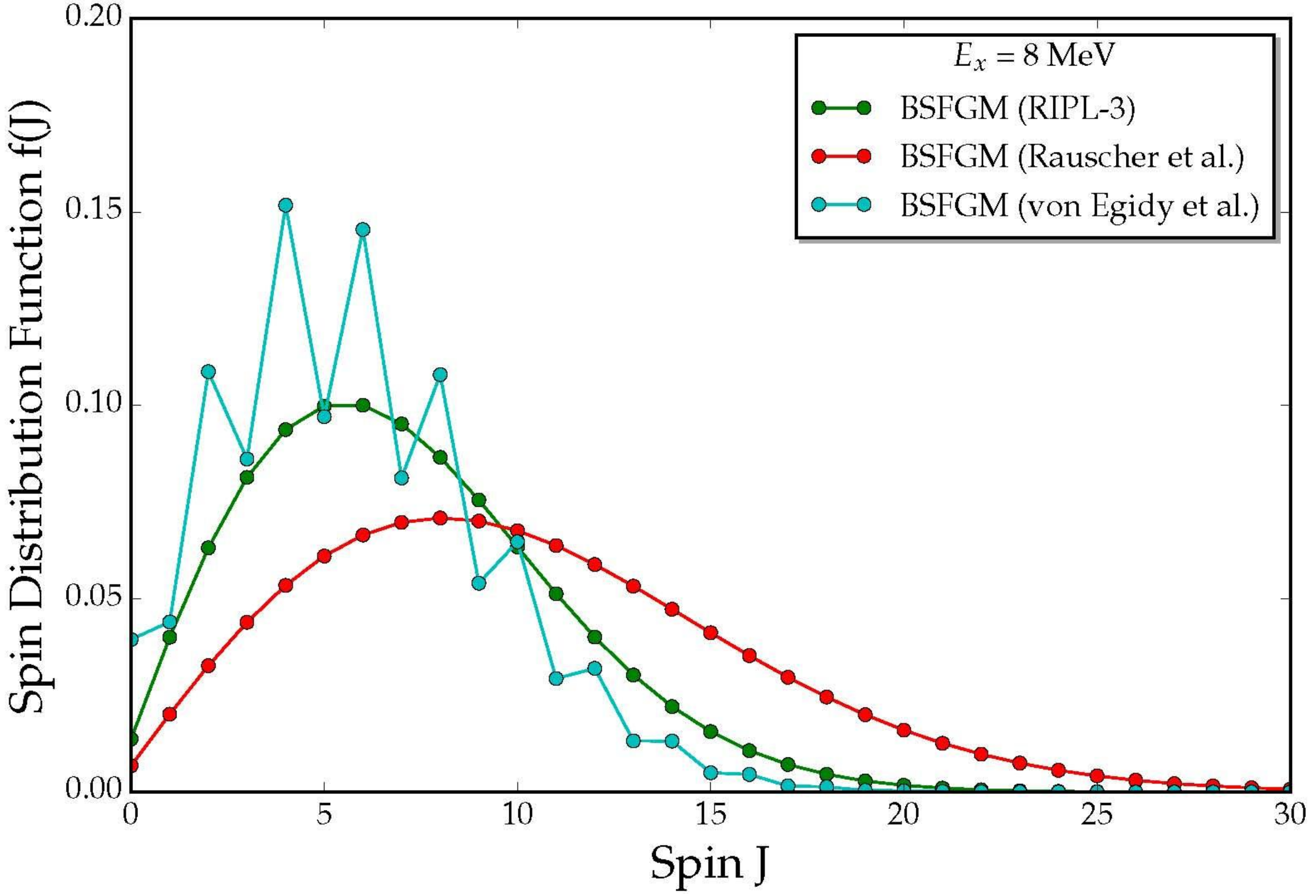
Level Density of $J^{\pi} = 1^{-}$ States in ^{58}Ni with and without Presmoothing

I. Brandherm, Doctoral thesis, TU Darmstadt (2024)



Applications

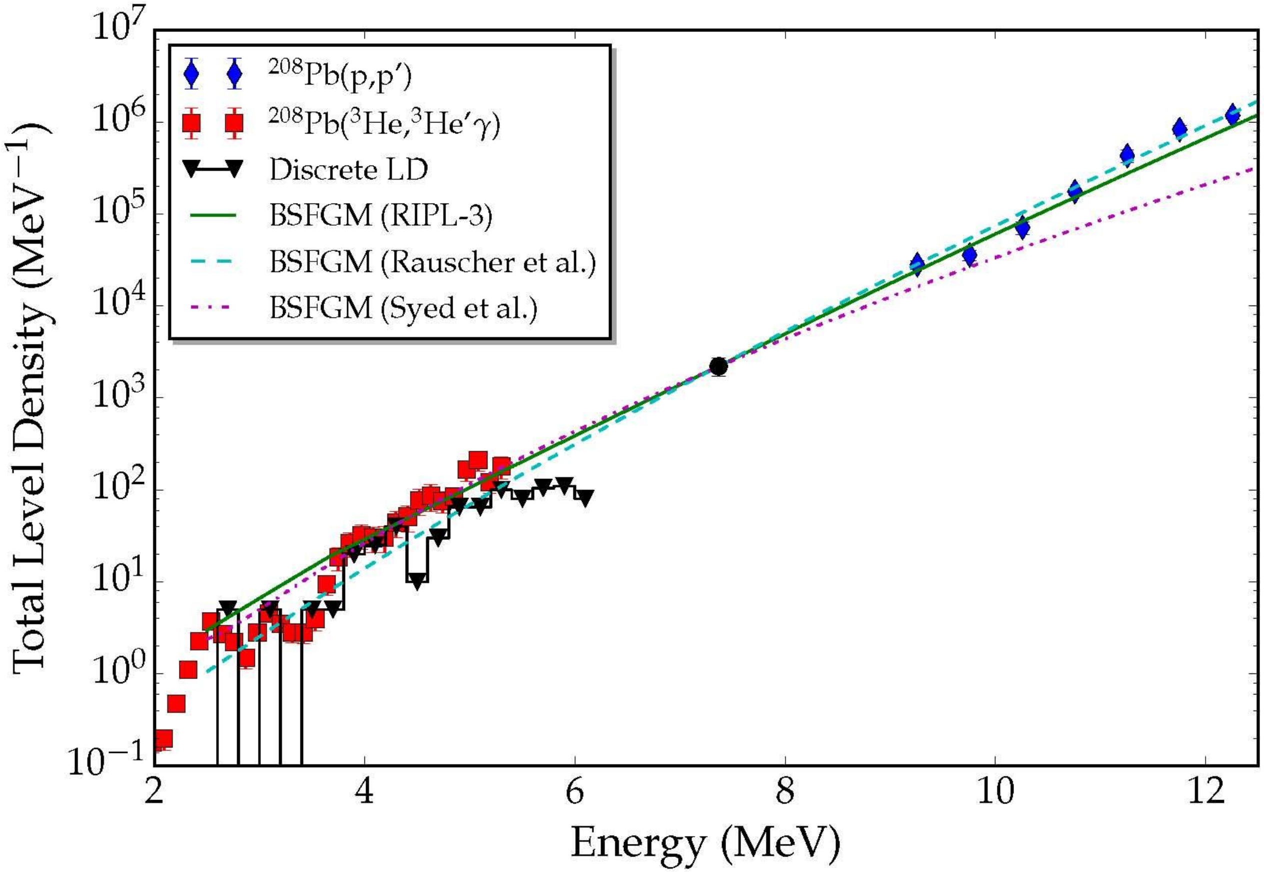
Level Density Spin Distribution in ^{208}Pb



- Average over different models

Total Level Density in ^{208}Pb

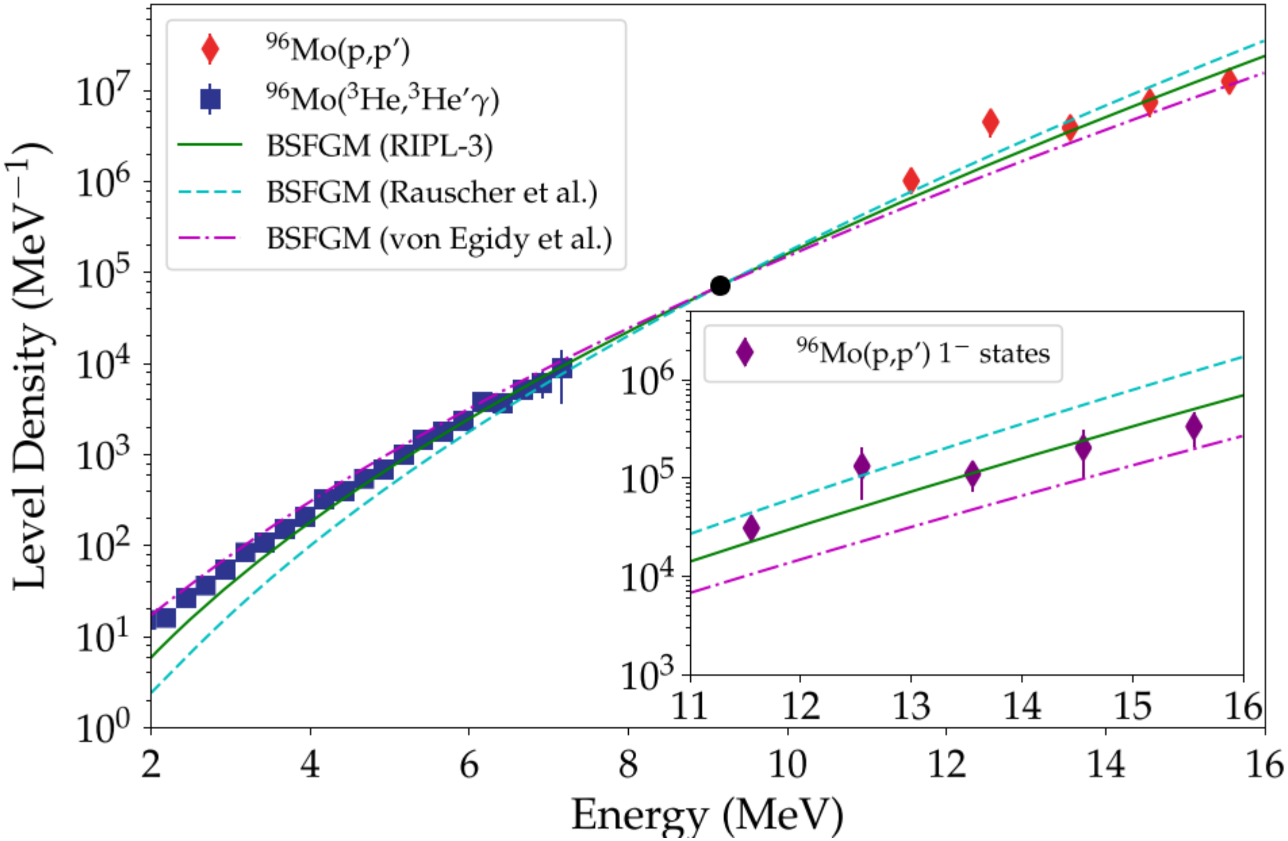
S. Bassauer, PvNC, A. Tamii, Phys. Rev. C 94, 054313 (2016)



- Good agreement with Oslo results

Total Level Density in ^{96}Mo

D. Martin et al., Phys. Rev. Lett. 119, 182503 (2017)



- Consistent with Oslo results

Level Density of $J^\pi = 1^-$ States in ^{124}Sn

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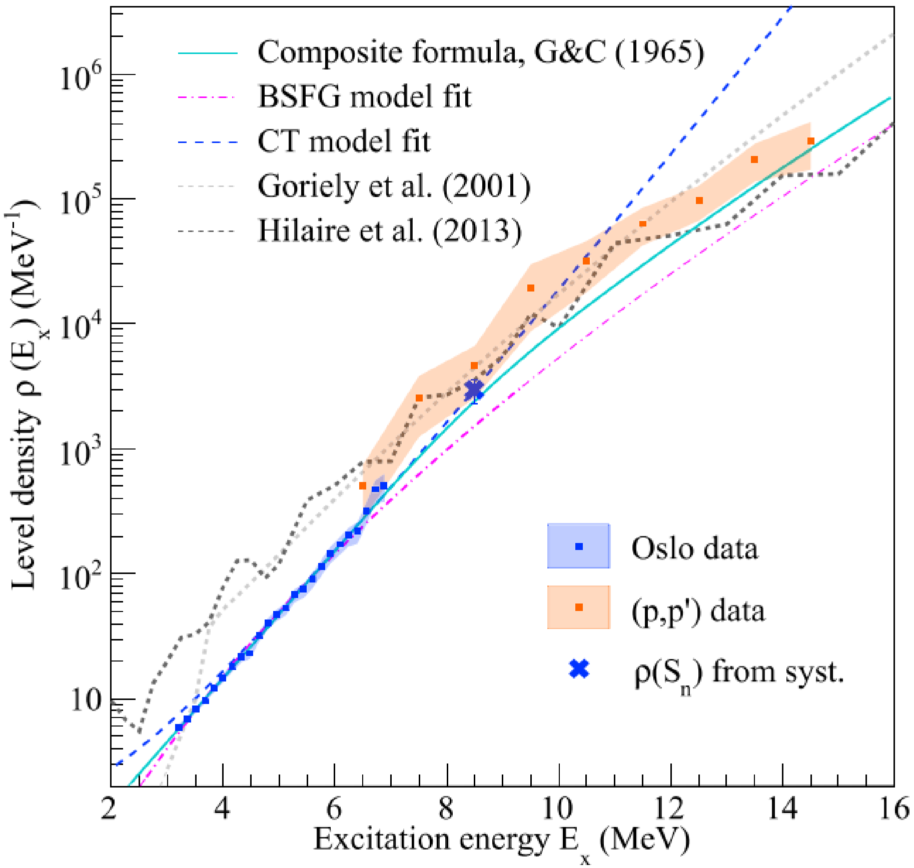
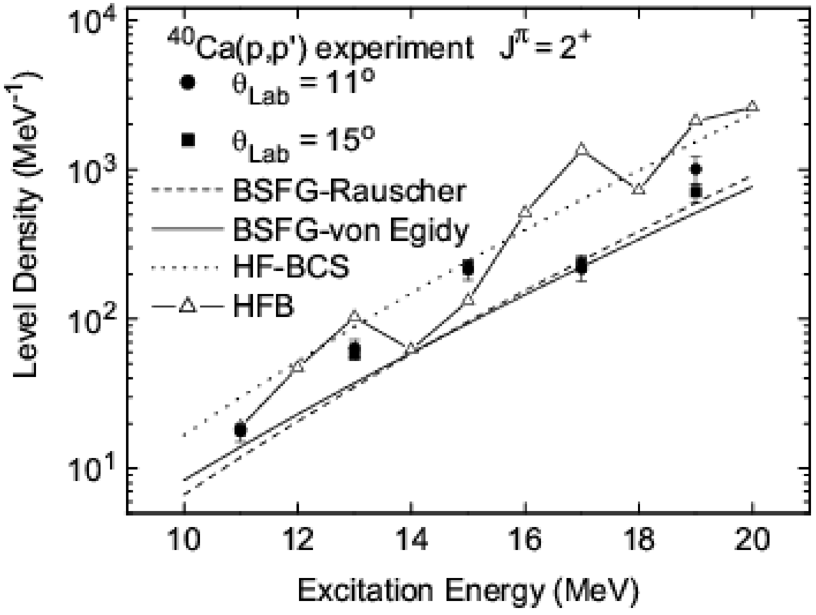
M. Markova et al., Phys. Rev. C 106, 034322 (2022)



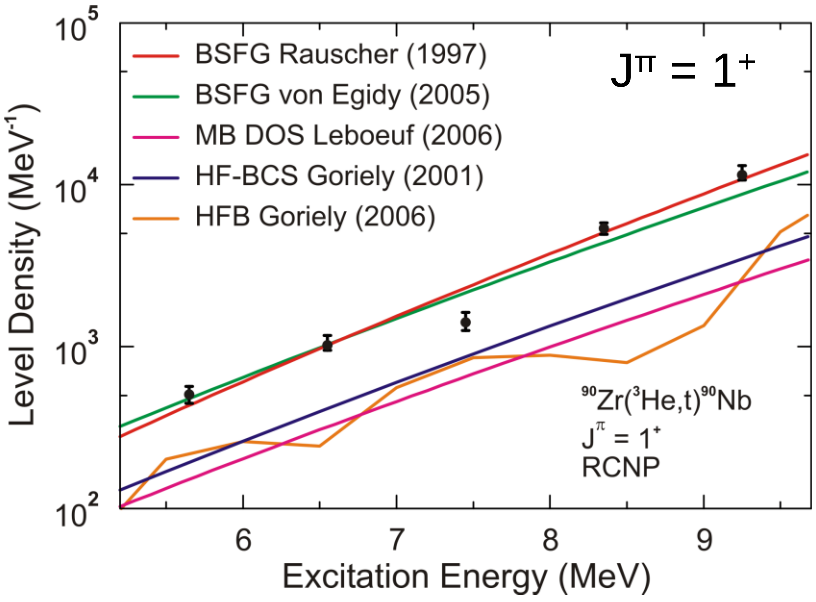
- Constraints on spin range of Oslo data

Confrontation with Models

I. Usman et al., Phys. Rev. C 84, 054322 (2011)

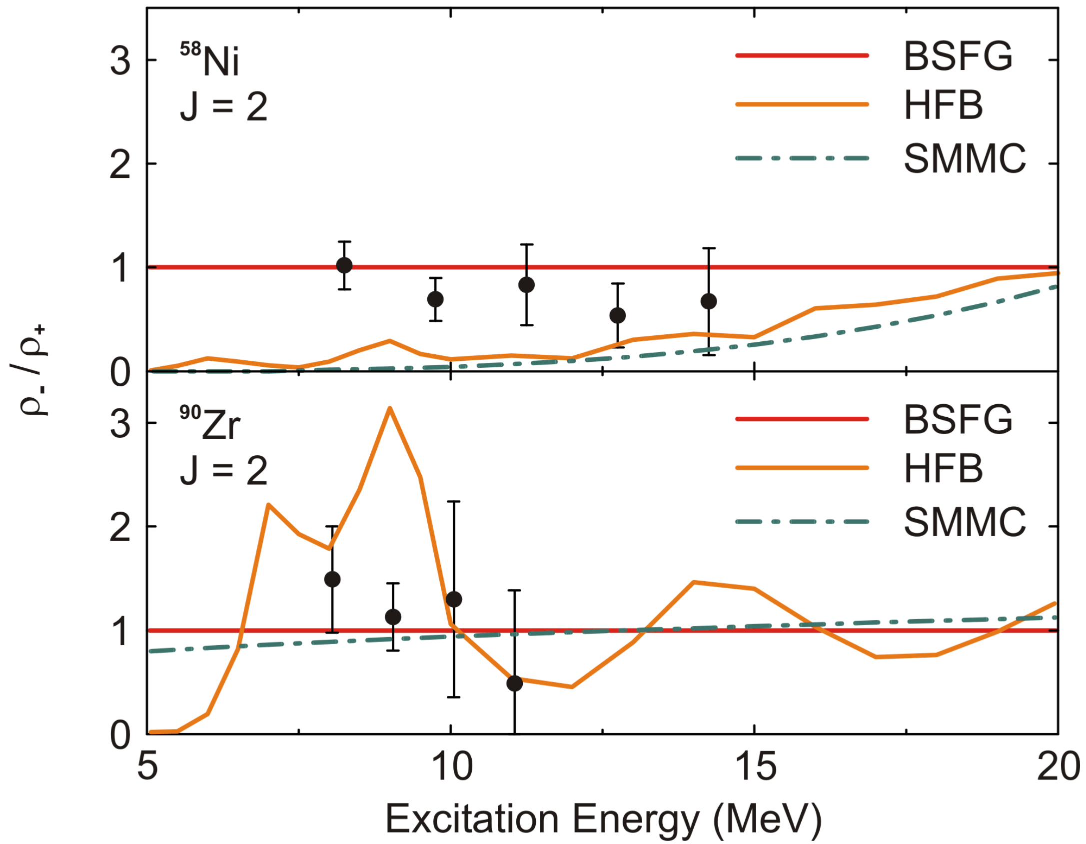


Y. Kalmykov et al., Phys. Rev. Lett. 96, 012502 (2006)



Parity Dependence of Level Densities

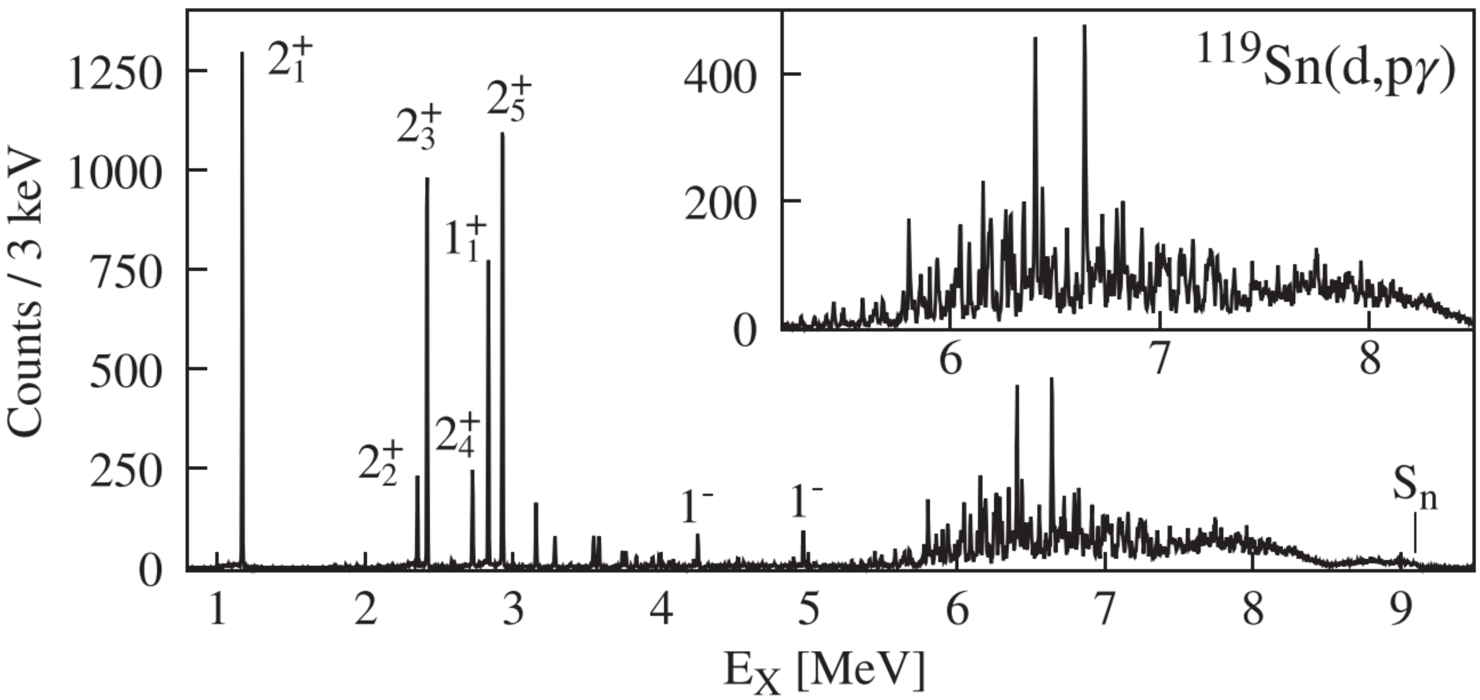
Y. Kalmykov et al., Phys. Rev. Lett. 99, 202502 (2007)



- No parity dependence in *fp* shell

Comparison of $J^\pi = 1^-$ Level Densities in ^{120}Sn from Different Reactions

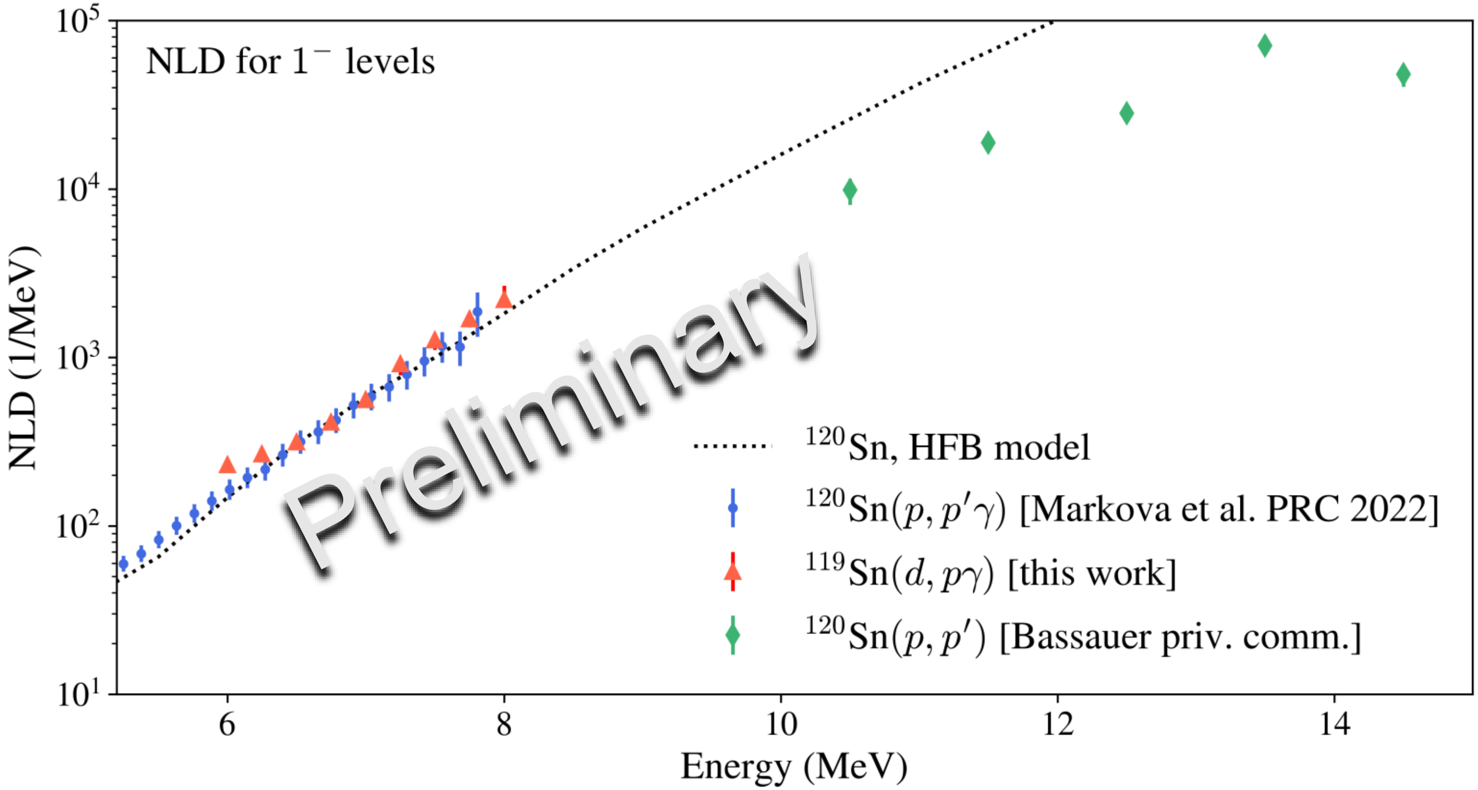
M. Weinert et al., Phys. Rev. Lett. 127, 242501 (2021)



- ^{119}Sn ground state has $J^\pi = ½^+$
- Gate on ^{120}Sn ground state decay ensures $J^\pi = 1^-$ of excited states

Comparison of $J^{\pi} = 1^{-}$ Level Densities in ^{120}Sn

(d,pγ): M. Weinert et al., Phys. Rev. Lett. 127, 242501 (2021)
(p,p'γ): M. Markova et al., Phys. Rev. C 106, 034322 (2022)
(p,p'): S. Bassauer, Doctoral thesis, TU Darmstadt (2019)



Extraction of unresolved strength

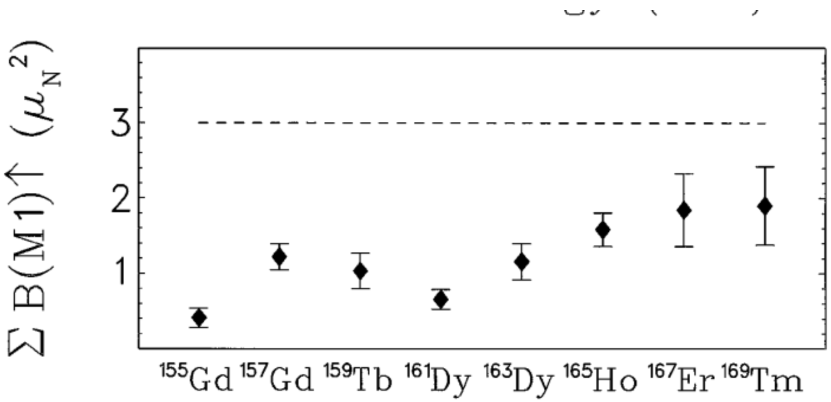
Idea

- Reverse analysis to extract unresolved strength on top of a background
  - background must be smooth
  - take level density from models
  - uncertainty estimate by model variation

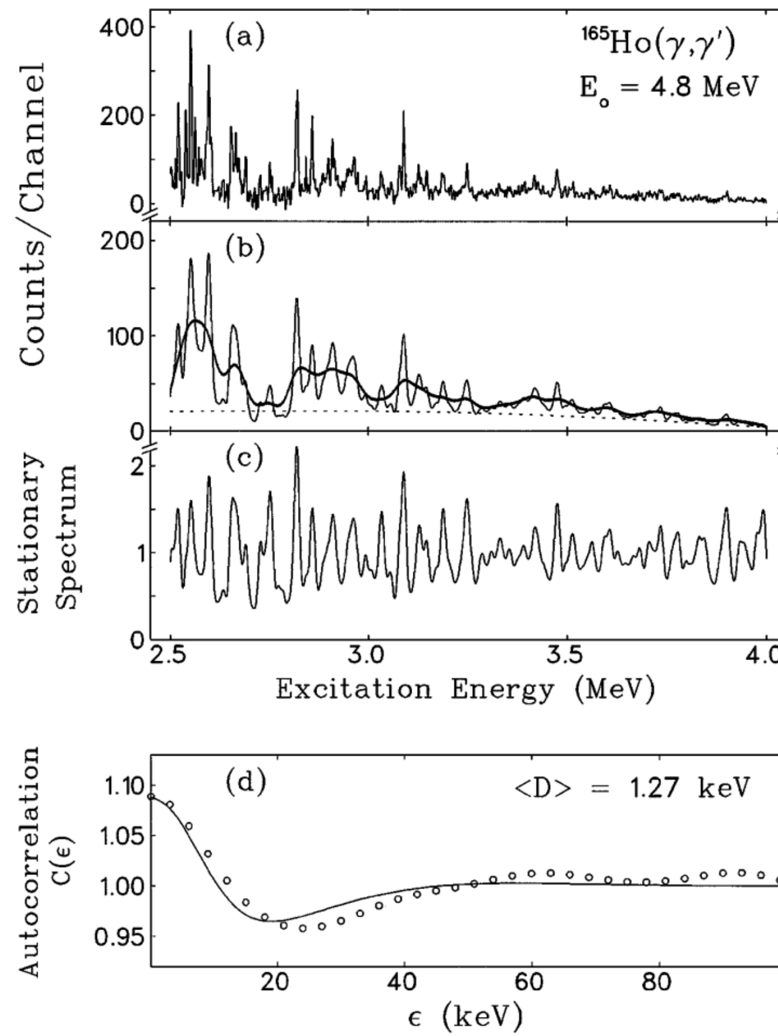
- Reactions of interest
  - NRF (atomic background)
  - inclusive electron scattering (radiative tail)
  - hadronic scattering above particle thresholds

Example: Scissors Mode in Odd-Mass Nuclei

J. Enders et al., Phys. Rev. Lett. 79, 2010 (1997)



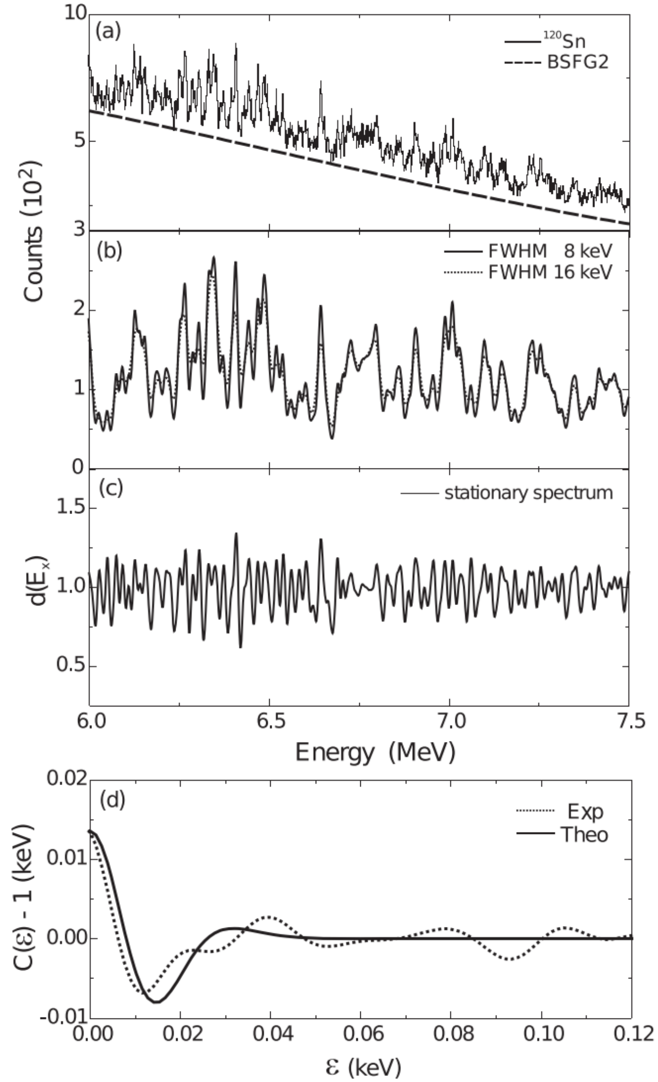
- Strength in resolved peaks only about 1/3 of even-mass neighbors
- Can be explained by unresolved strength



Example: E1 Strength in Sn Isotopes

B. Özel-Tashenov et al., Phys. Rev. C 90, 024304 (2014)

- Increase of E1 strength by a factor of 2



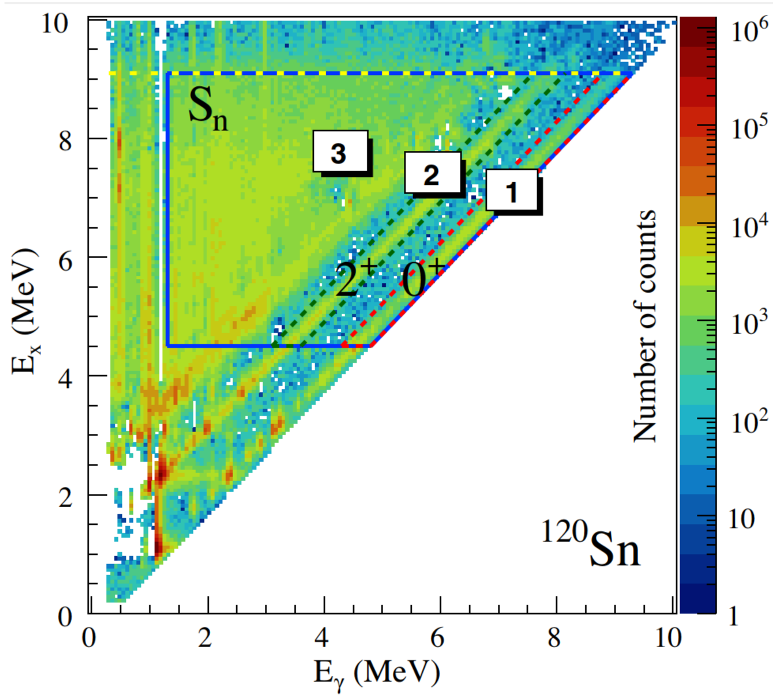
Summary and Outlook

- Level densities from a fluctuation analysis of high-resolution spectra
  - model-independent
  - excitation energies above particle threshold accessible
  - spin-parity resolved → direct comparison with microscopic models

- Ongoing projects
  - preparation of code for public use with proper uncertainty analysis
  - study possible constraints on spin distribution
  - utilize selectivity of γ-decay coincidence experiments

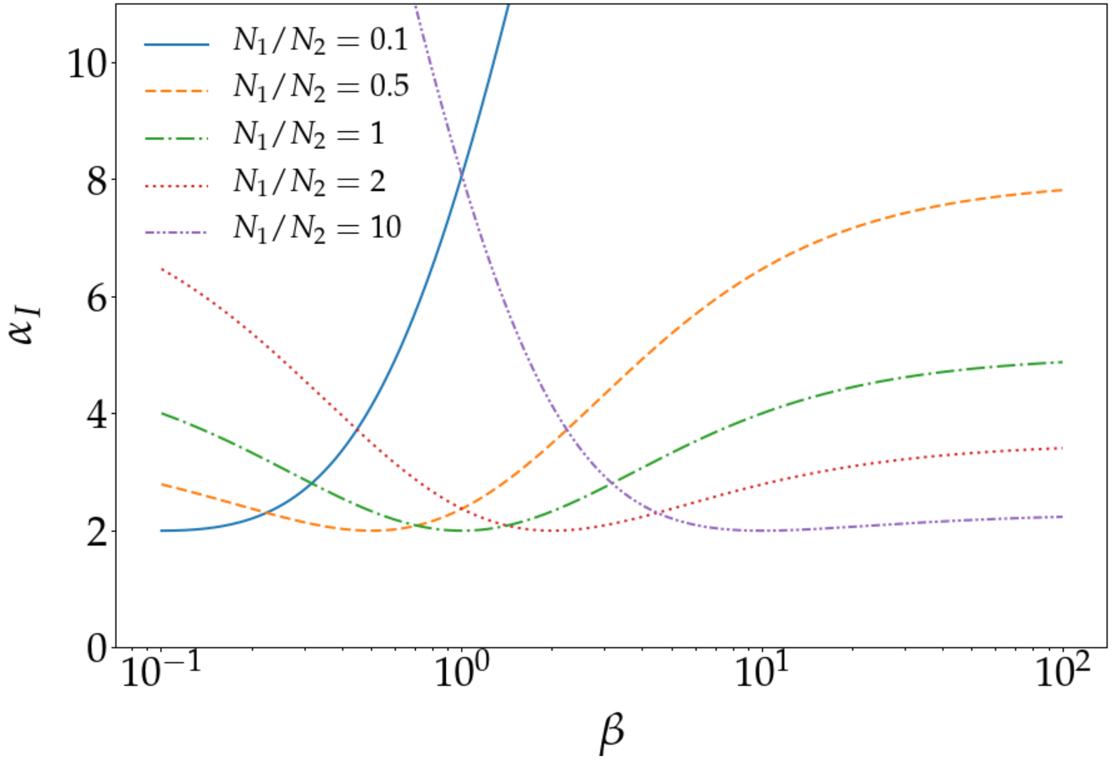
Thank you for your attention!

Application to Shape Method



- Decay to $J^\pi = 0^+$ ground state → $J_{excited} = 1^\pm$
- Decay to first $J^\pi = 2^+$ state → $J_{excited} = 1\text{-}3$
- (n,γγ) reaction on $J = ½$ ground state → $J_{capture} = 0,1$
- In general constraints on possible spins

Extension to 2 Classes of States



$$\alpha_I = 3\frac{(N_1\langle I_1\rangle^2 + N_2\langle I_2\rangle^2)(N_1 + N_2)}{(N_1\langle I_1\rangle + N_2\langle I_2\rangle)^2} - 1 \qquad \beta = \langle I_1\rangle / \langle I_2\rangle$$

- Depends on number of states $N_{1,2}$ and averaged intensities $\langle I_{1,2}\rangle$