Level Densities from High-Resolution Spectra

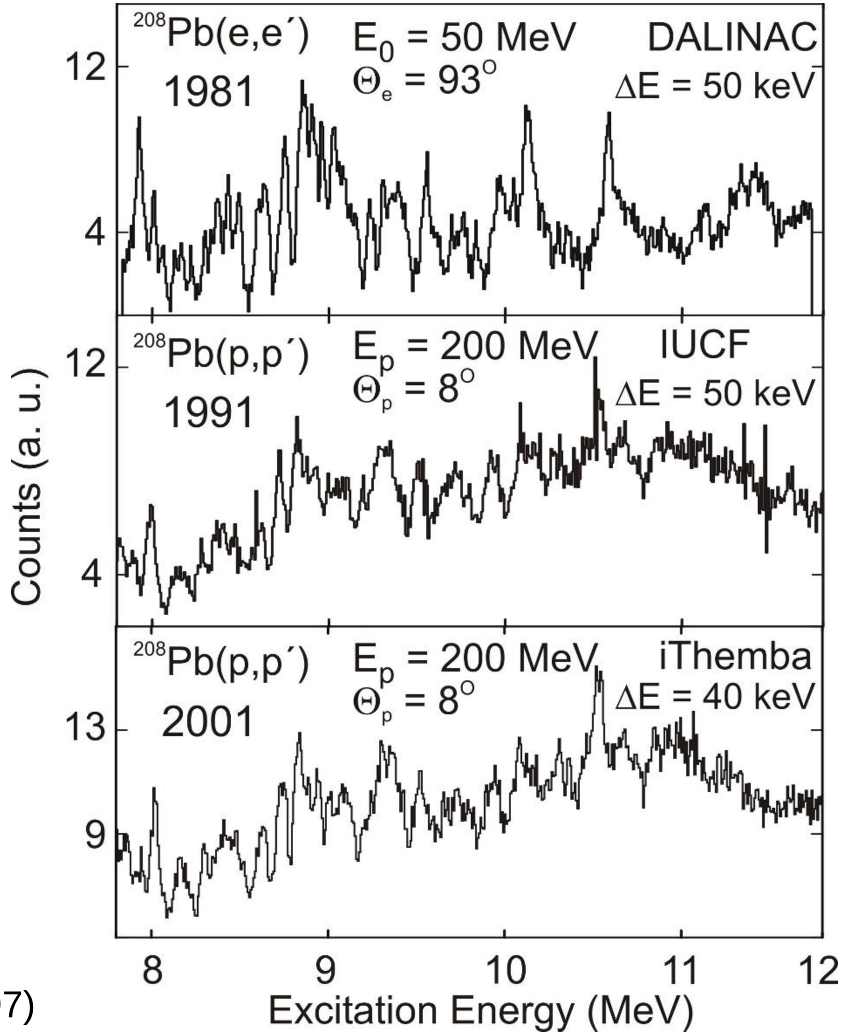
Peter von Neumann-Cosel
Institut für Kernphysik, Technische Universität Darmstadt

- Fine structure in high-resolution spectra of giant resonances
- Fluctuation analysis
- Applications
- Current and planned projects
  - code for general use with proper uncertainty treatment
  - evaluation of $J^{\pi} = 0^{+}, 1^{-}, 2^{+}$ level densities for a set of key nuclei
  - level densities from γ-decay coincidence experiments
  - level densities from NRF selfabsorption experiments

Fine structure in high-resolution spectra of giant resonances

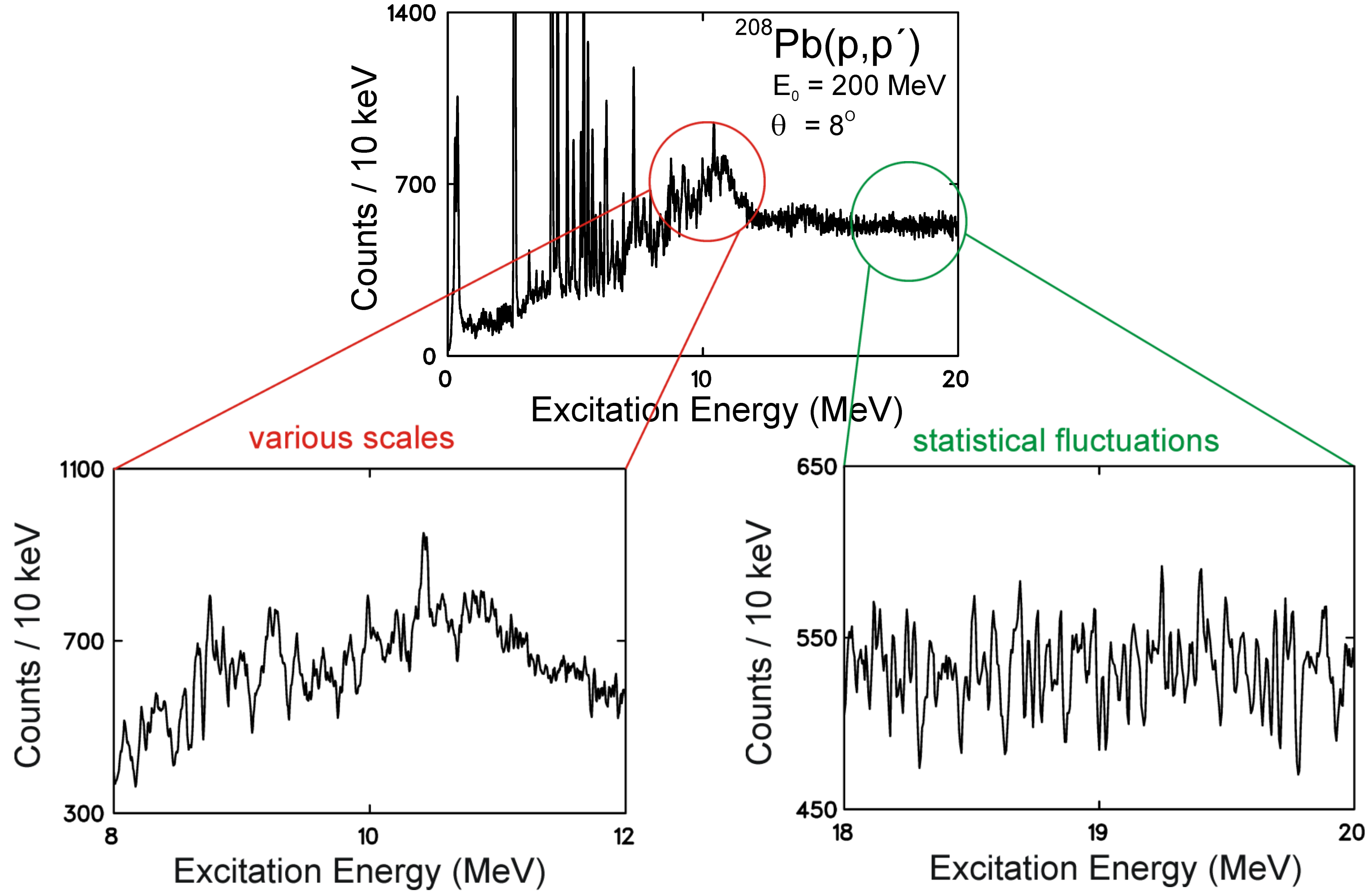
The Case of the ISGQR in ^{208}Pb

- Fine structure independent of exciting probe

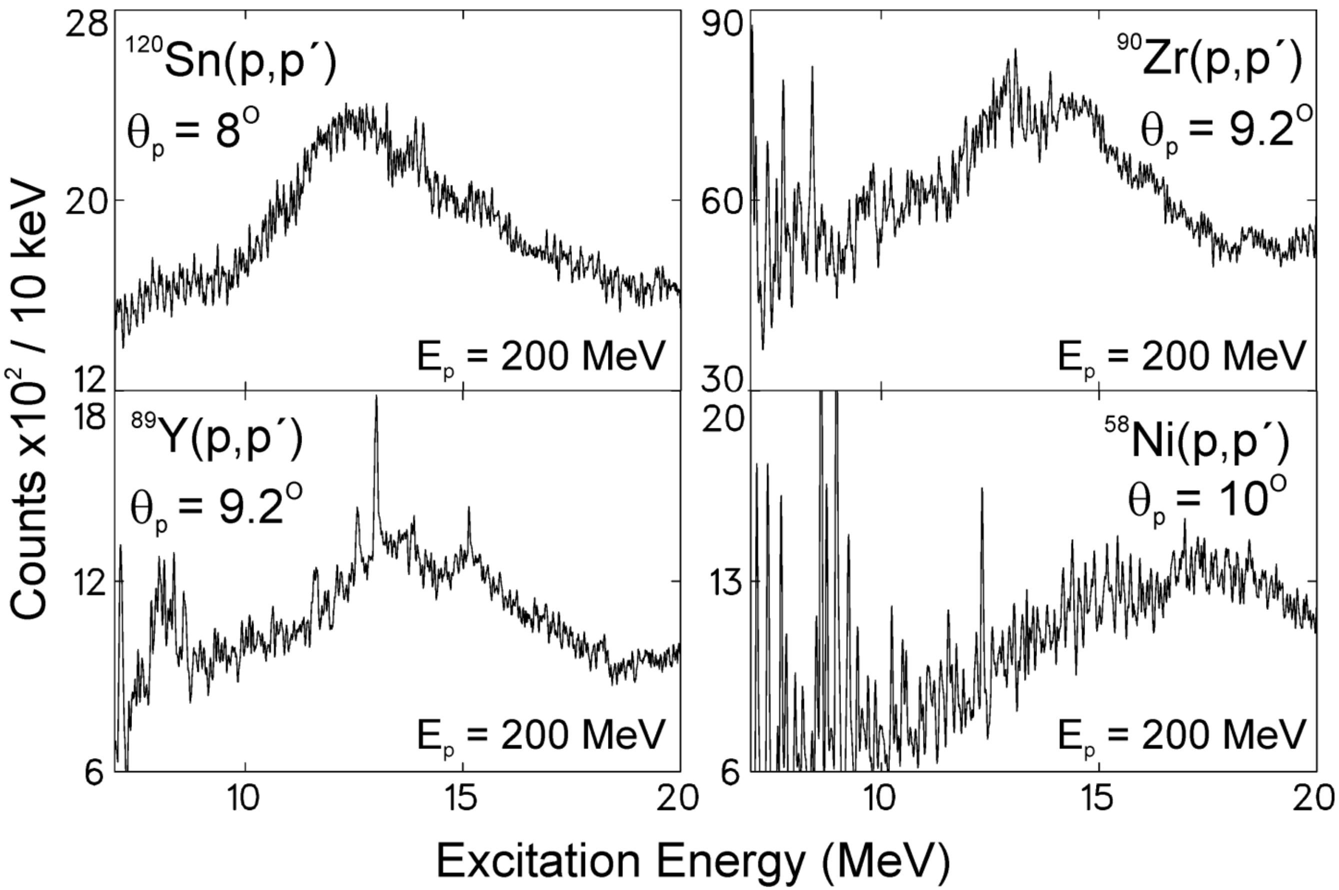


S. Kamerdzhiev et al., Phys. Rev. C 55, 2101 (1997)

Scales and Fluctuations



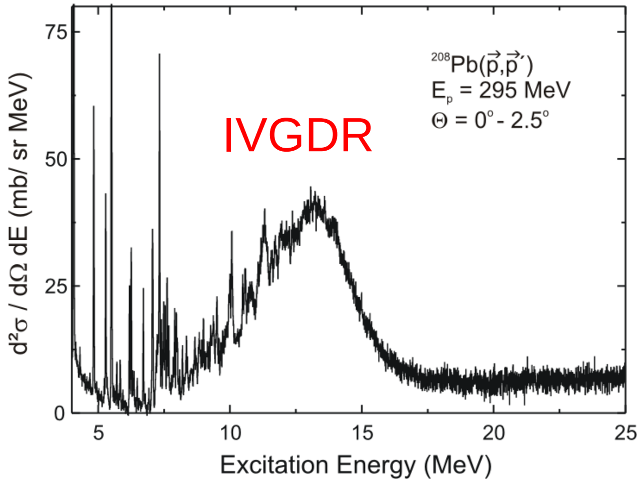
Fine Structure of the ISGQR – a Systematic Phenomenon



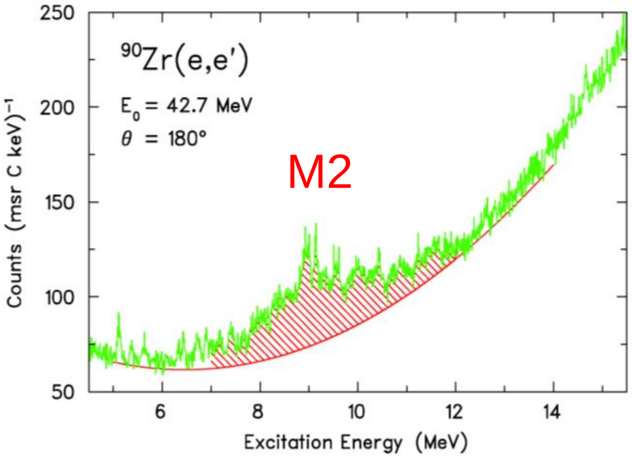
A. Shevchenko et al., Phys. Rev. C 79, 044305 (2009)

Fine Structure of GRs – a Global Phenomenon

TECHNISCHE UNIVERSITÄT DARMSTADT

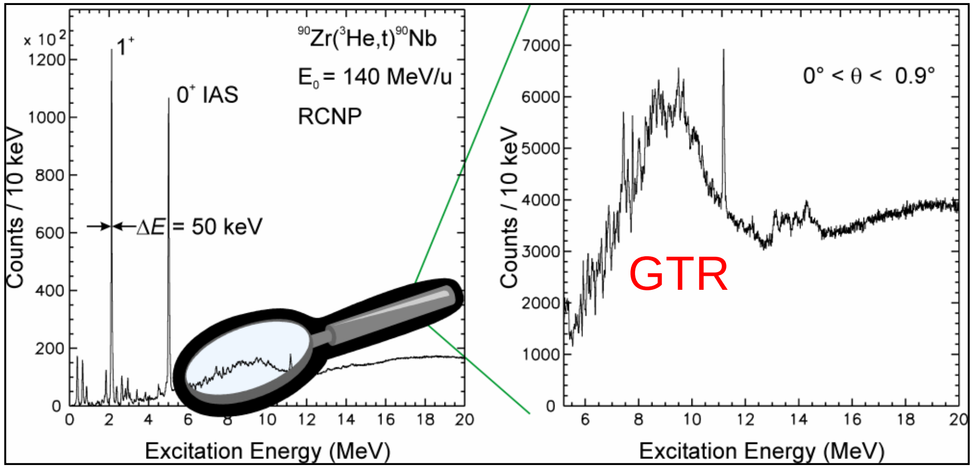


I. Poltoratska et al., Phys. Rev. C 89, 054322 (2014)



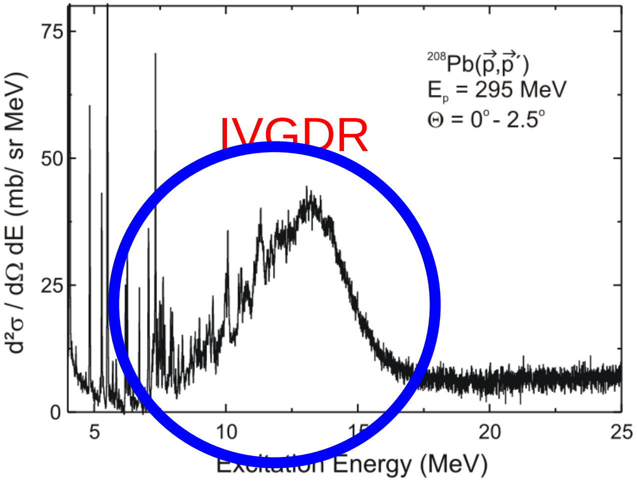
P. von Neumann-Cosel et al.,
Phys. Rev. Lett. 82, 1105 (1999)

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

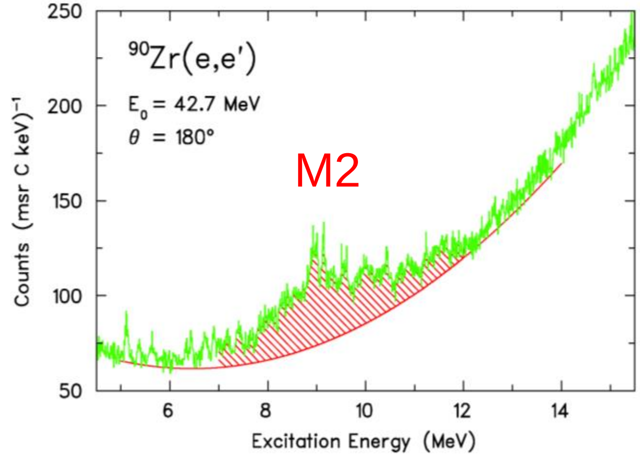


Fluctuation analysis

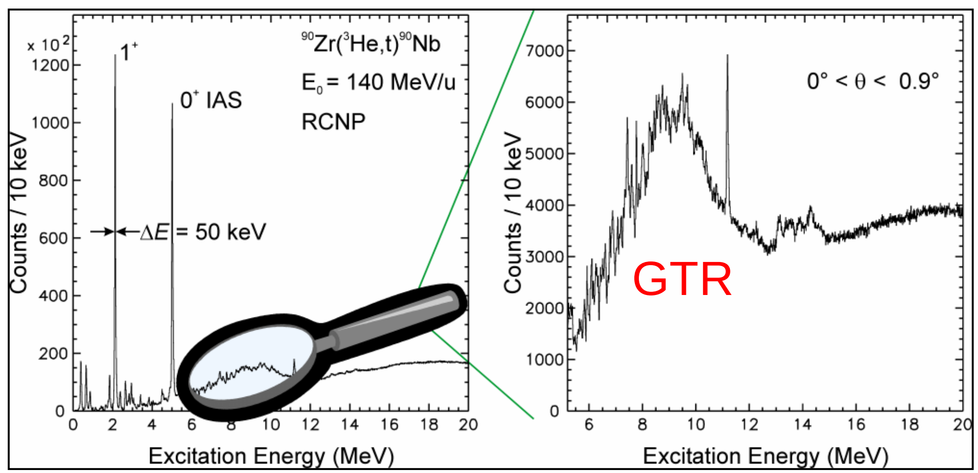
Fine Structure of GRs – a Global Phenomenon



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

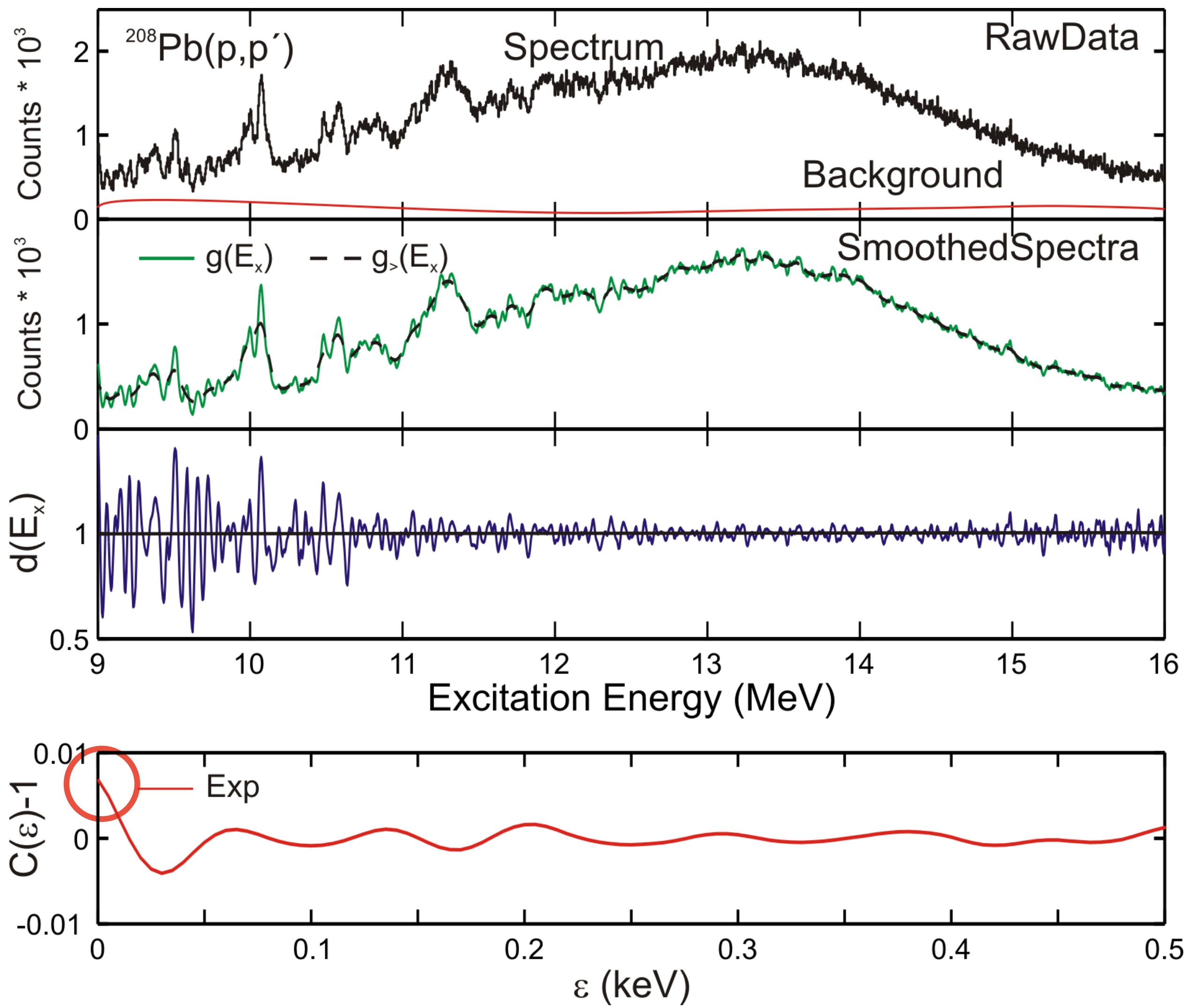


P. von Neumann-Cosel et al.,
Phys. Rev. Lett. 82, 1105 (1999)



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

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 ⟨D⟩

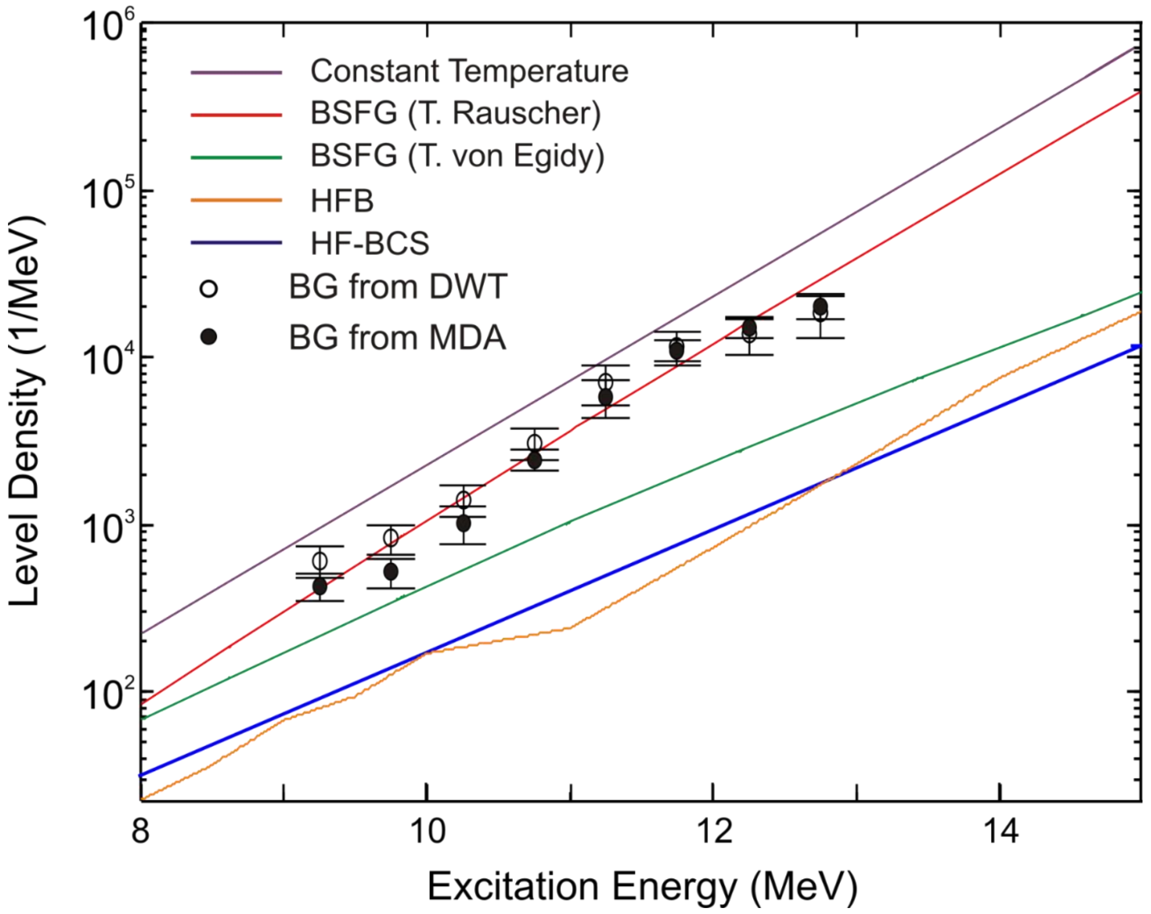
- $\alpha = \alpha_{PT} + \alpha_W$ statistical properties

- σ resolution

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

TECHNISCHE UNIVERSITÄT DARMSTADT

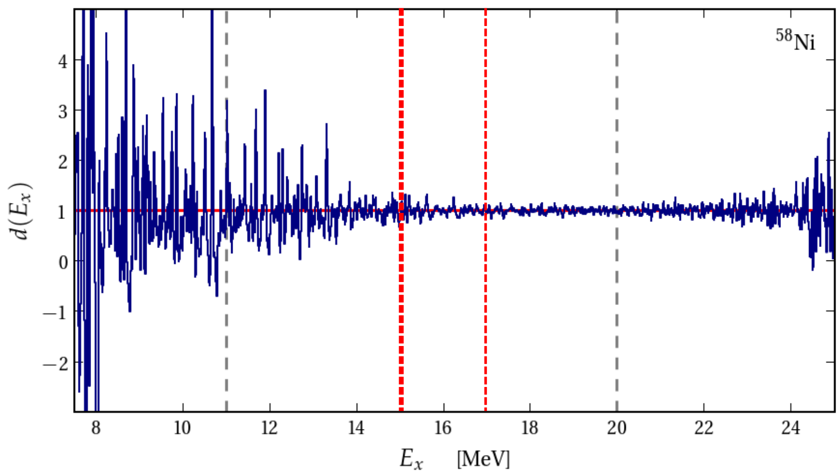
I. Poltoratska et al., Phys. Rev. C 89, 054322 (2014)



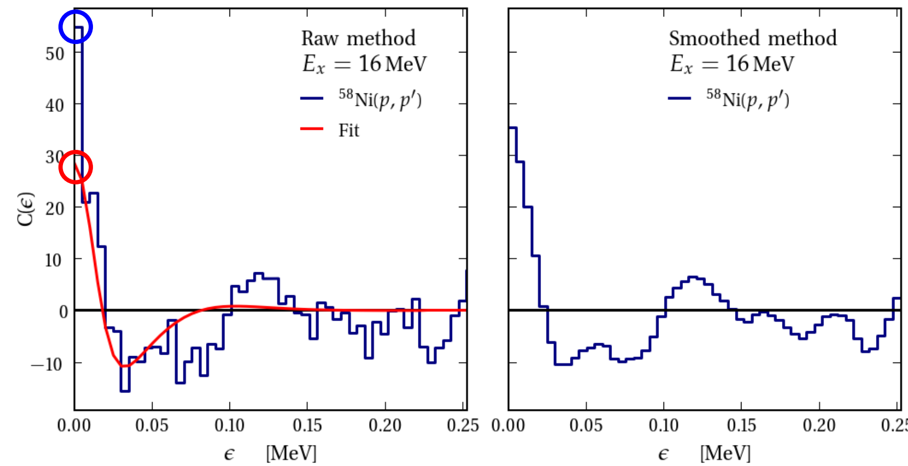
Analysis without Presmoothing: Example ^{58}Ni

TECHNISCHE UNIVERSITÄT DARMSTADT

- Stationary spectrum



- Autocorrelation function at 16 MeV



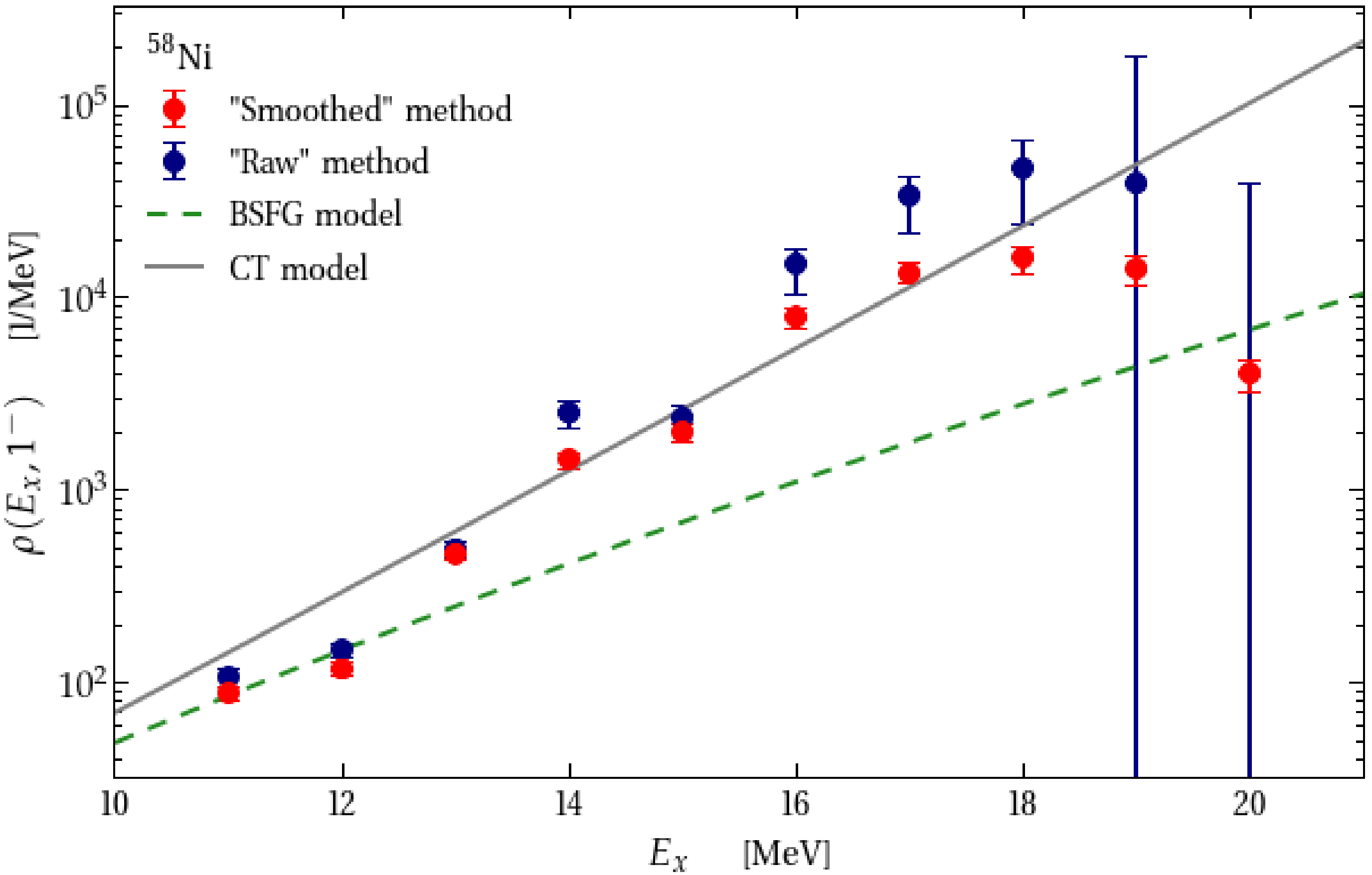
- Fit to theoretical function (Hansen and Jonson)

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

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

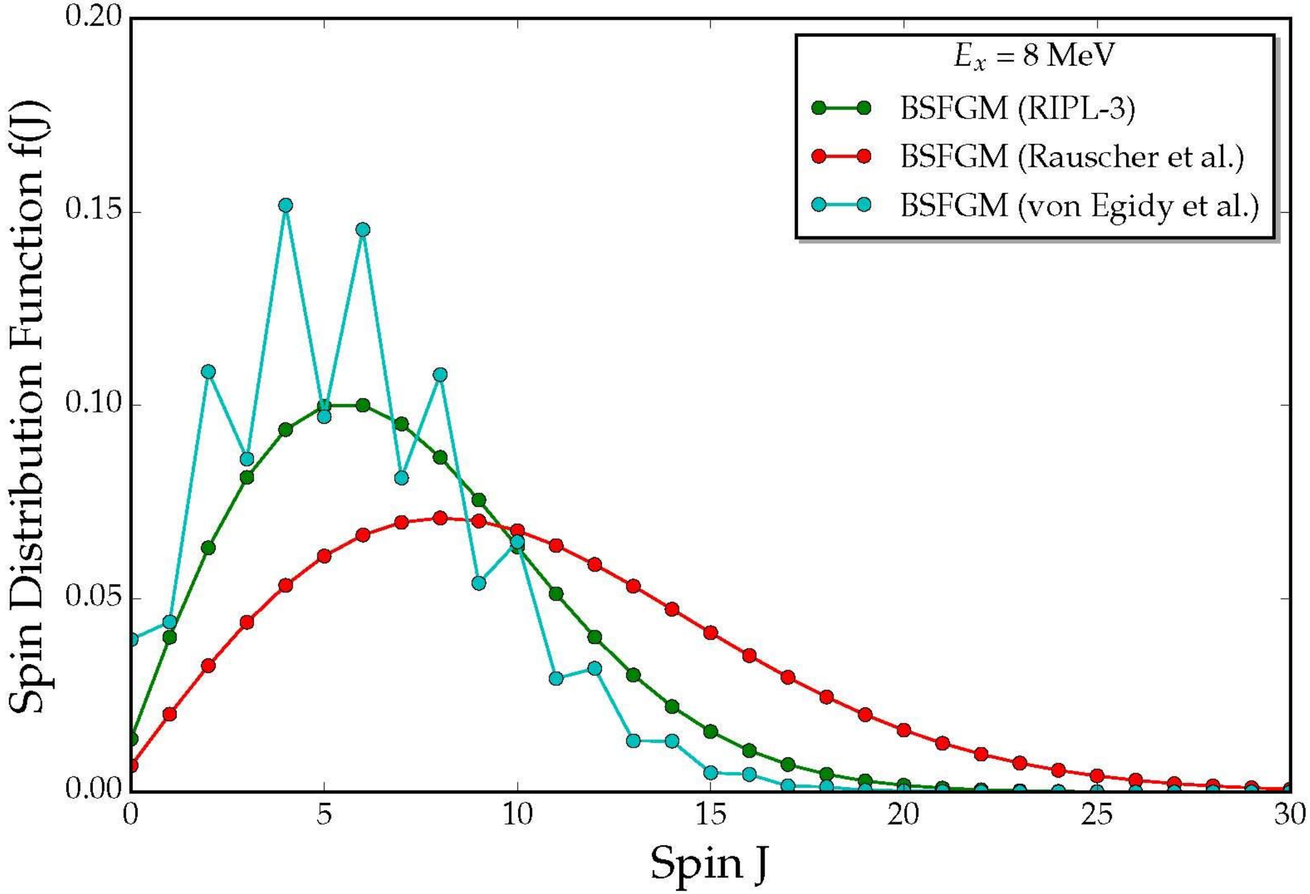
Level Density of $J^{\pi} = 1^{-}$ States in ^{58}Ni with and without Presmoothing

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



Applications

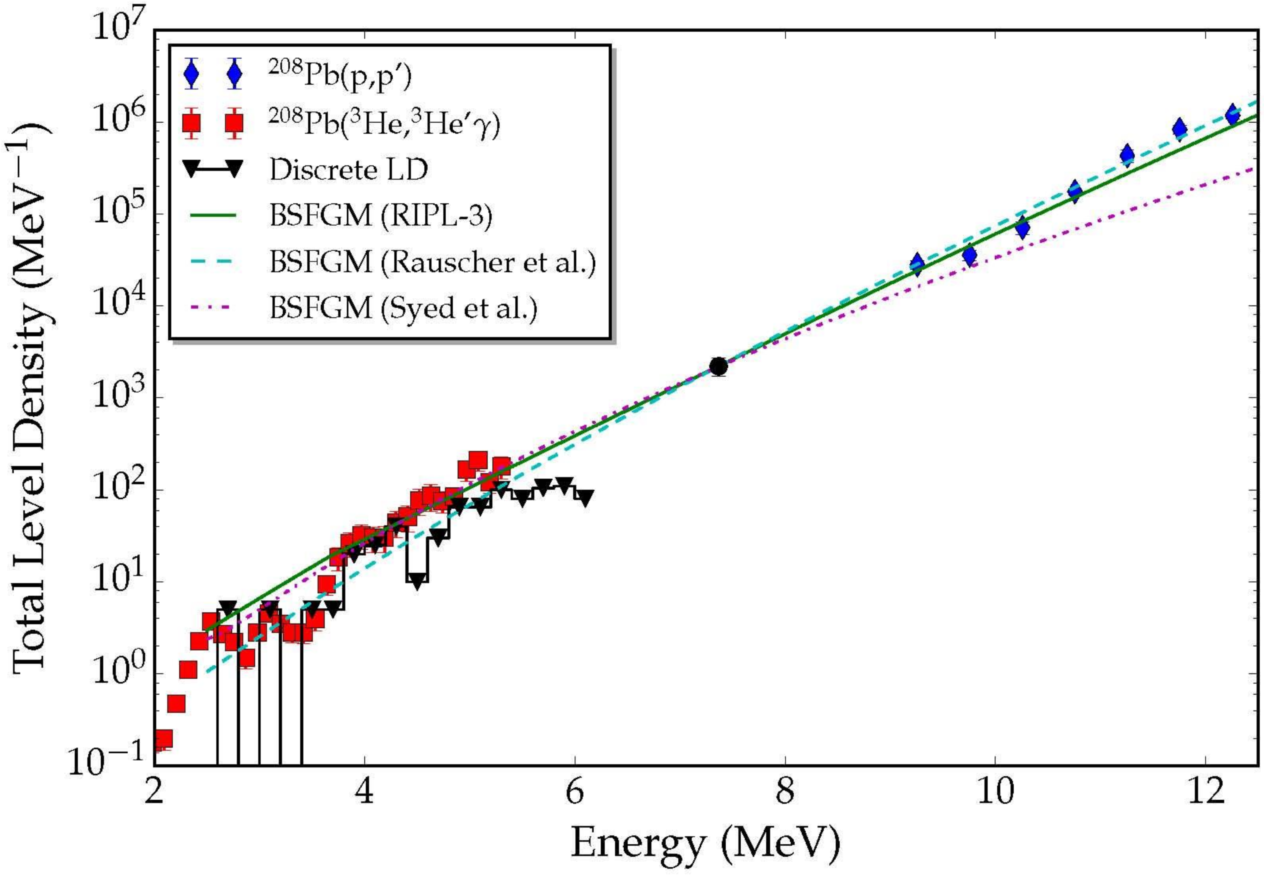
Level Density Spin Distribution in ^{208}Pb



- Average over different models

Total Level Density in ^{208}Pb

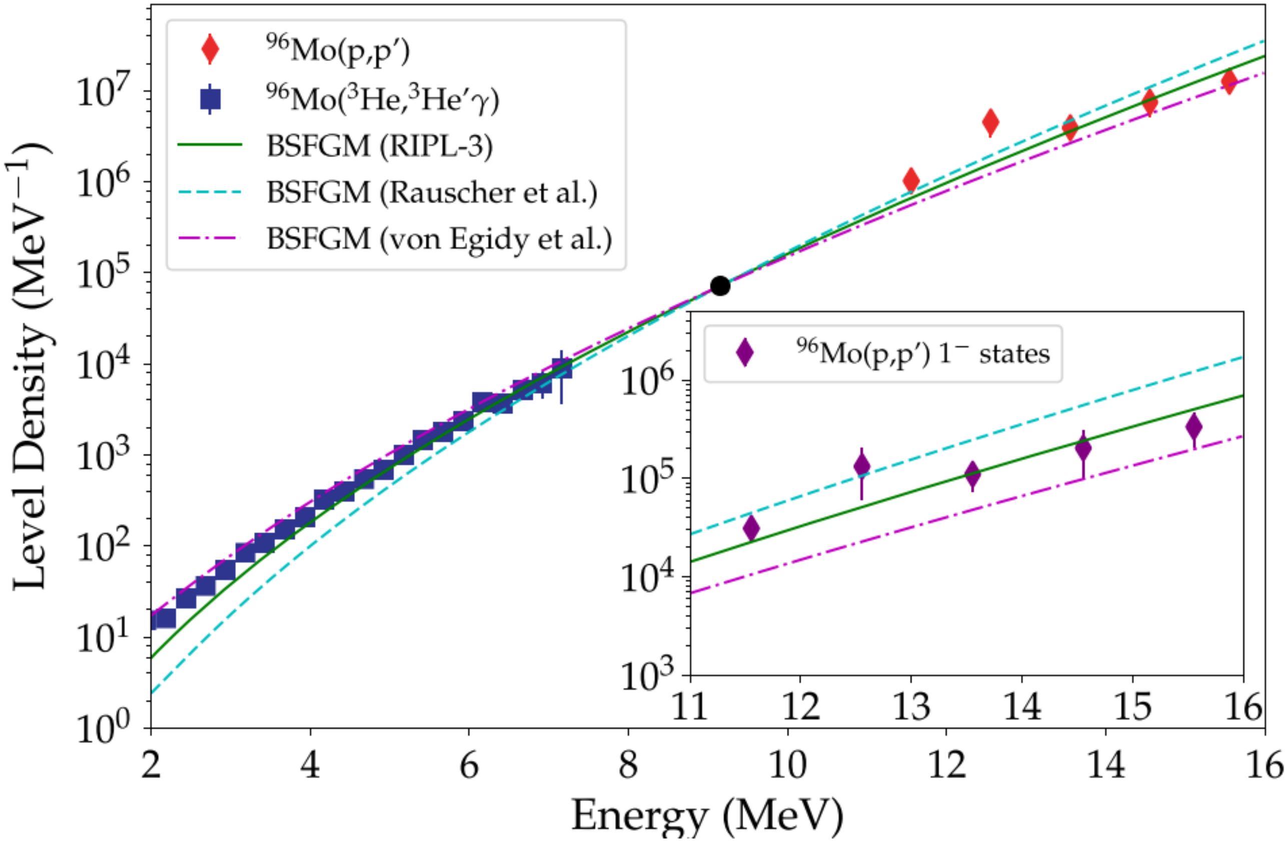
S. Bassauer, PvNC, A. Tamii, Phys. Rev. C 94, 054313 (2016)



- Good agreement with Oslo results

Total Level Density in ^{96}Mo

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

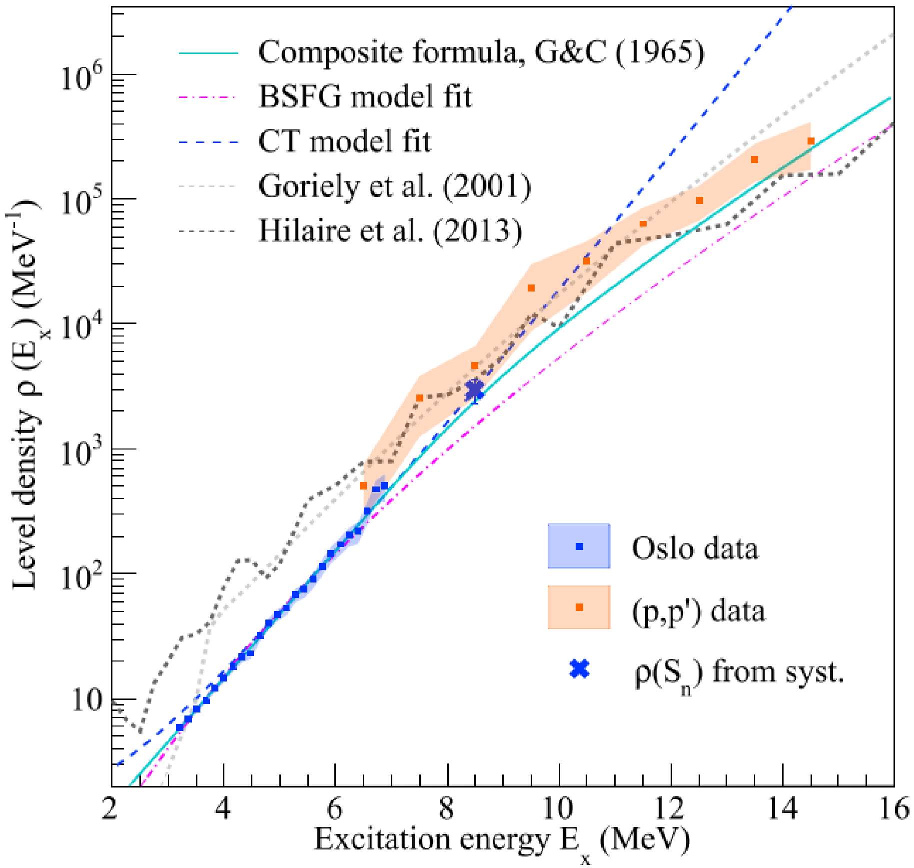


- Consistent with Oslo results

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

TECHNISCHE UNIVERSITÄT DARMSTADT

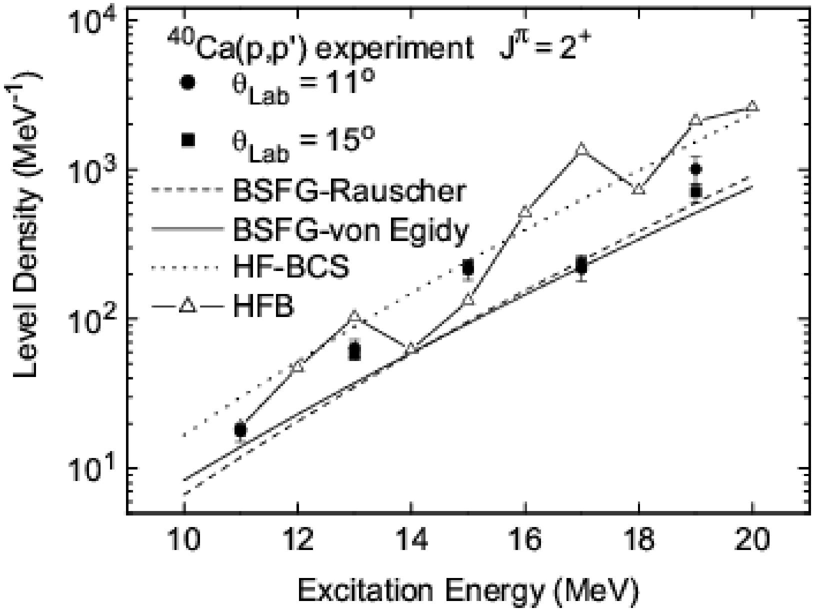
M. Markova et al., Phys. Rev. C 106, 034322 (2022)



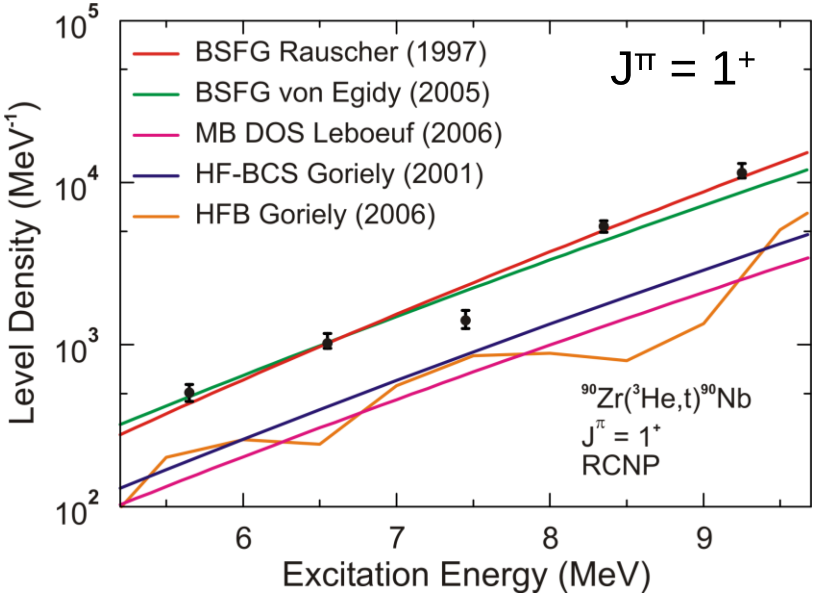
- Constraints on spin range of Oslo data

Further Examples of Level Density Results

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

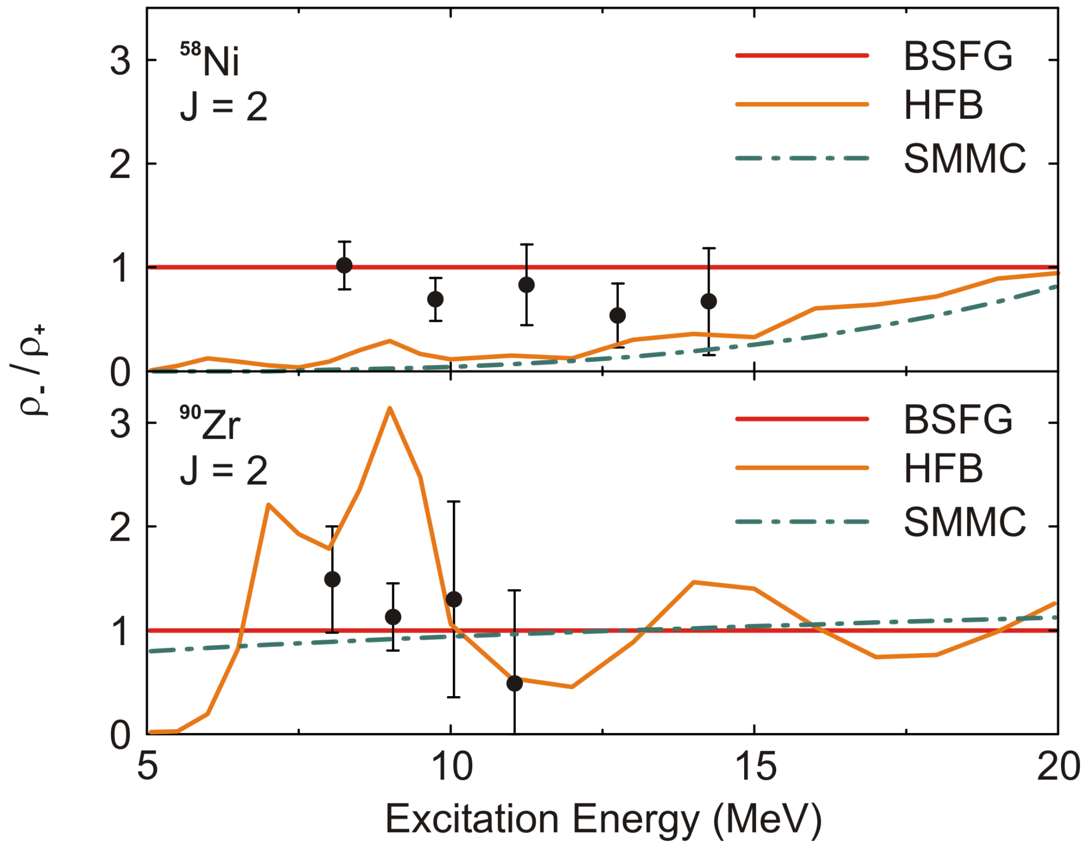


Y. Kalmykov et al., Phys. Rev. Lett. 96, 012502 (2006)



Parity Dependence of Level Densities

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



- No parity dependence in *fp* shell

Current projects:

Preparation of code for general use

Code for General Use

- Includes analysis with presmoothed and raw spectra
- Monte Carlo treatment of statistical errors
- Systematic errors from variation of parameters σ, $\sigma_{>}$, $\sigma_{<}$, ΔE_{bin}
- Will be made available on Github and as Python library

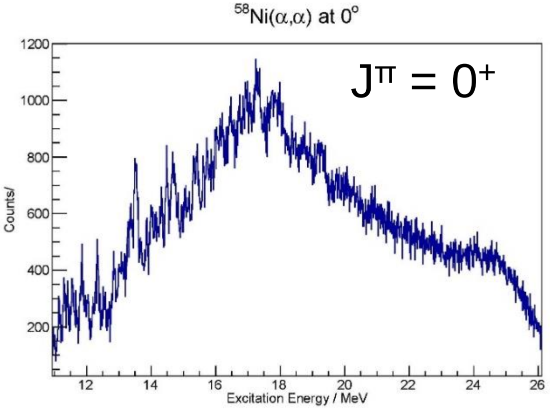
Current projects:

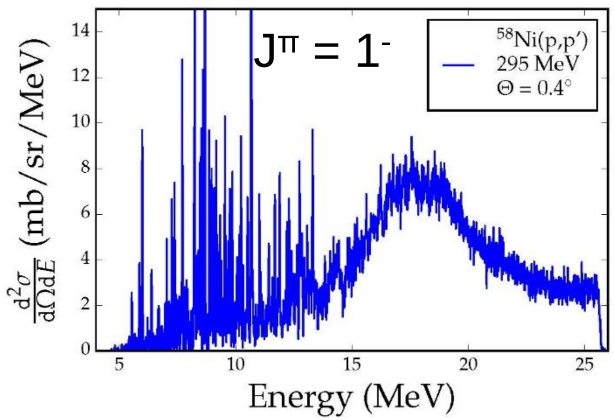
Evaluation of $J^{\pi}= 0^{+},1^{-},2^{+}$ level densities for a set of key nuclei

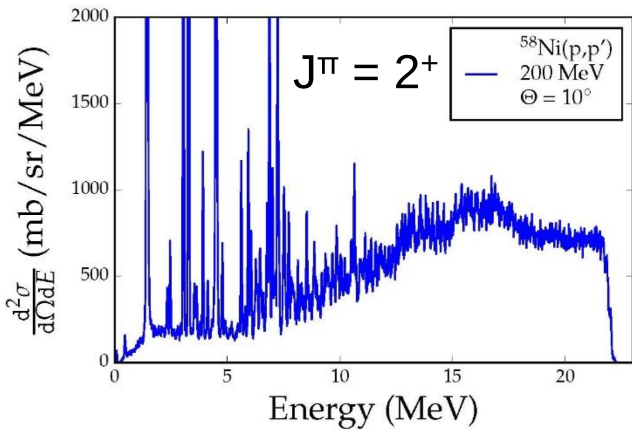
High-Resolution Spectra of ISGMR, IVGDR and ISGQR: Example ^{58}Ni

TECHNISCHE UNIVERSITÄT DARMSTADT

ISGMR@iThemba	IVGDR@RCNP	ISGQR@iThemba
A. Bahini et al., Phys. Rev. C 109, 014325 (2024)	I. Brandherm et al., Phys. Rev. C 111, 02443 (2024)	A. Shevchenko et al., Phys. Rev. C 79, 044305 (2009)







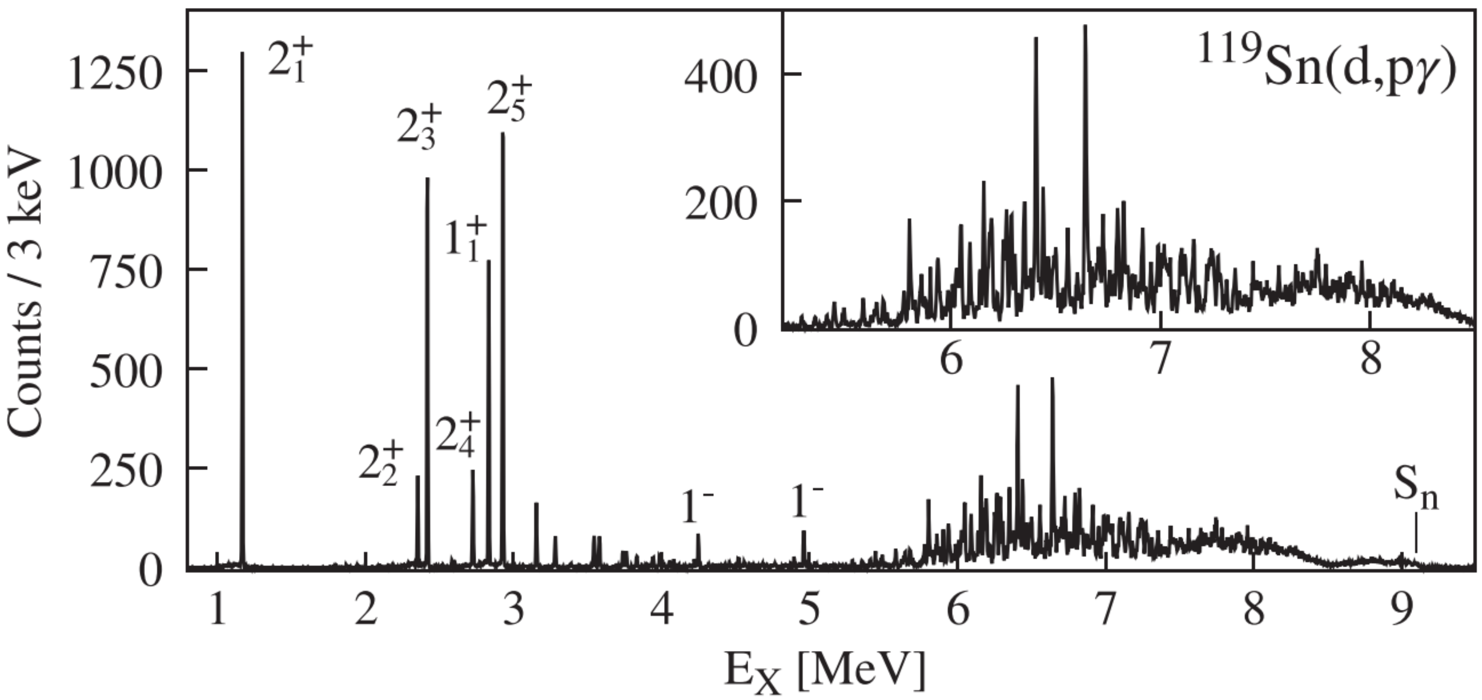
- Data for ^{40}Ca, ^{58}Ni, ^{90}Zr, ^{120}Sn, ^{208}Pb
- J = 0,1,2 level densities in the same nuclei → spin distribution
- Mass dependence → spin cutoff parameter

Current projects:

Level densities from γ-decay coincidence experiments

Example: Reaction ^{119}Sn(d,pγ)^{120}Sn

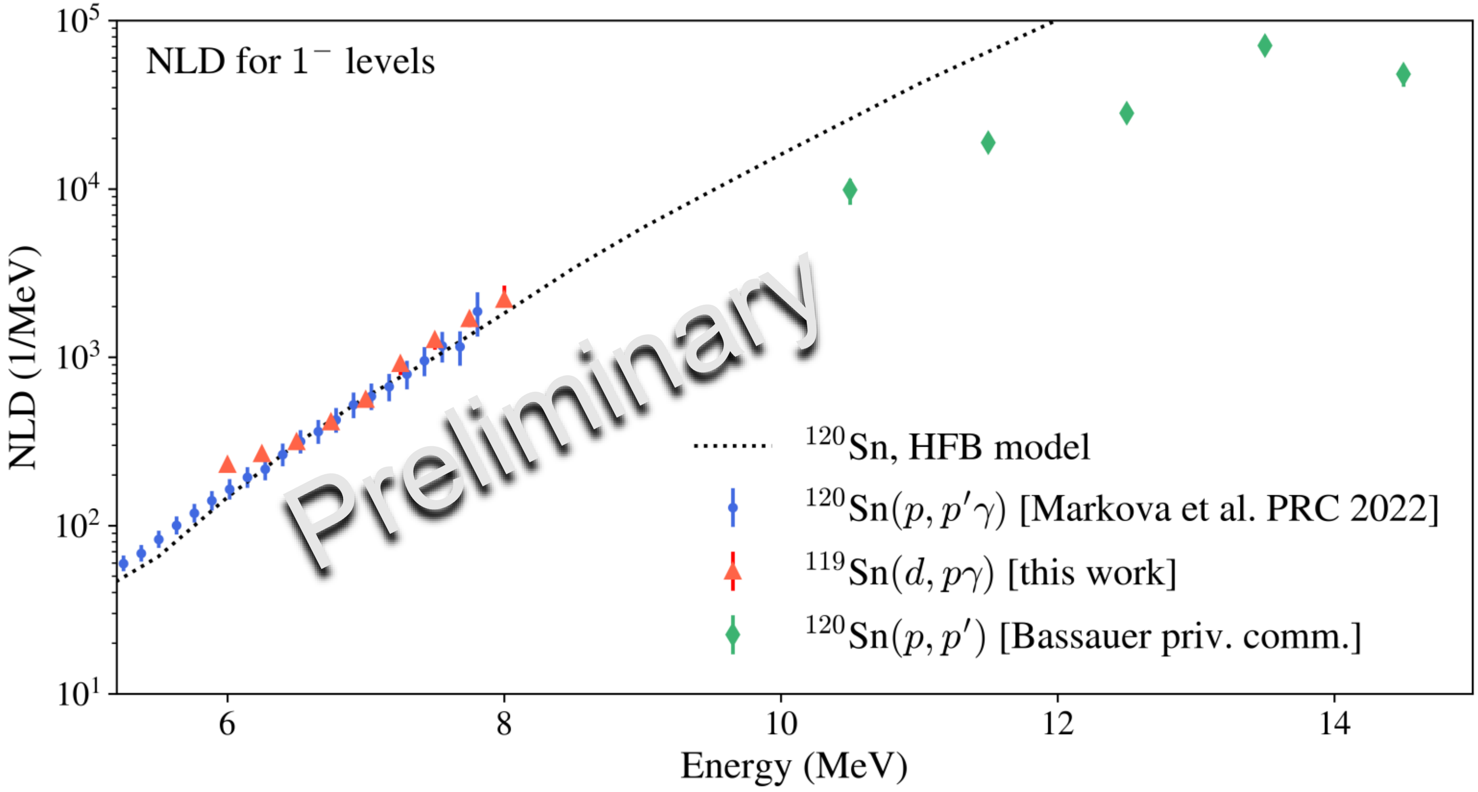
M. Weinert et al., Phys. Rev. Lett. 127, 242501 (2021)



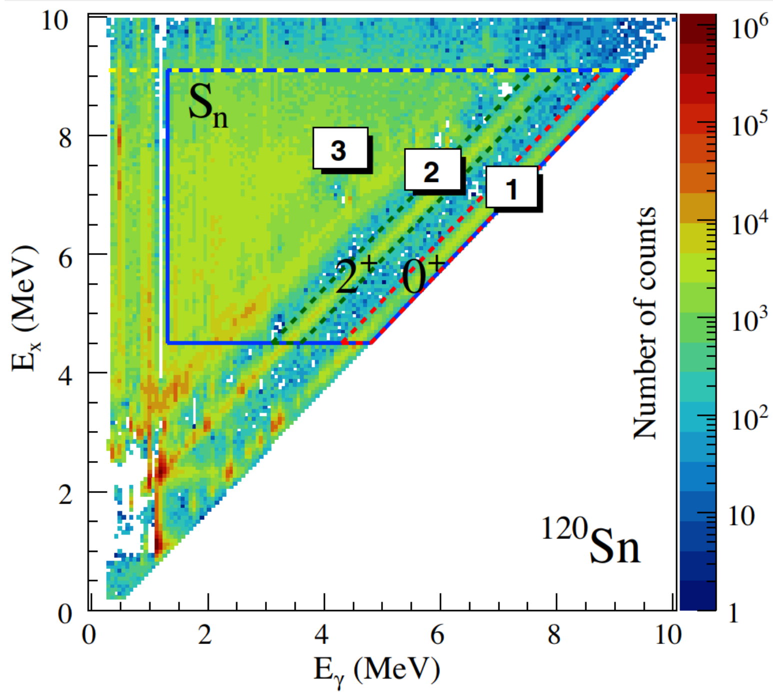
- ^{119}Sn ground state has $J^\pi = ½^+$
- Gate on ^{120}Sn ground state decay ensures $J^\pi = 1^-$ of excited states

Comparison of J^π = 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)

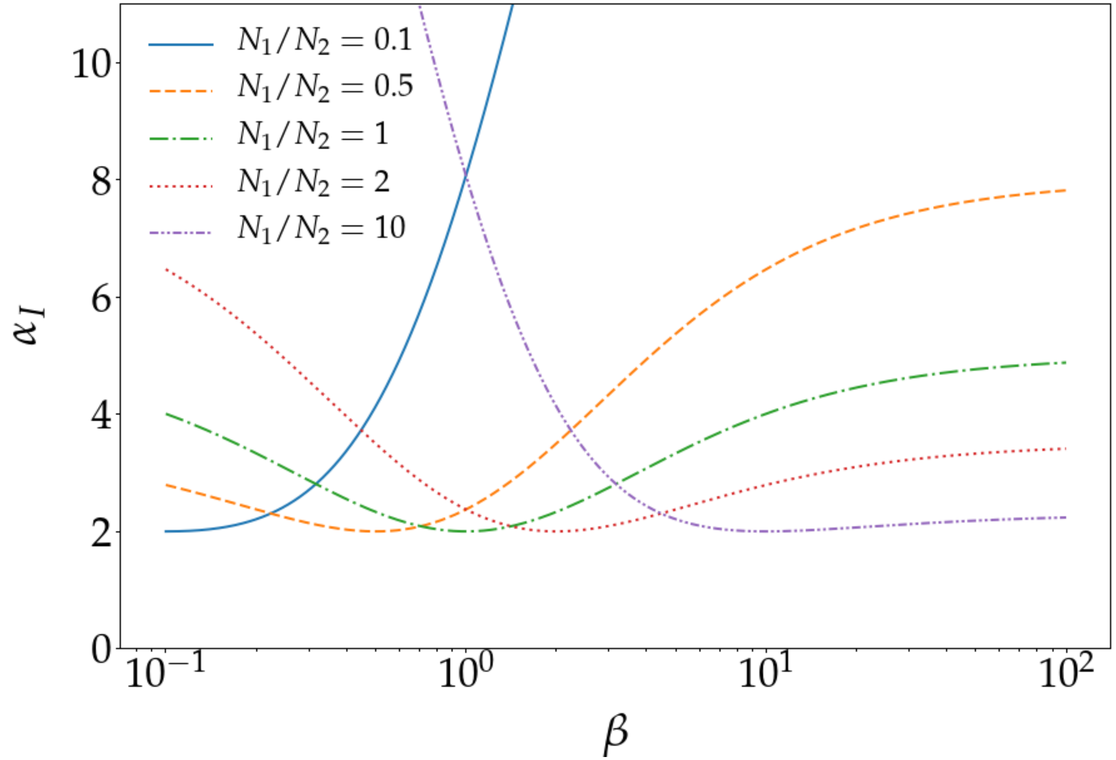


Application to Shape Method



- 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



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

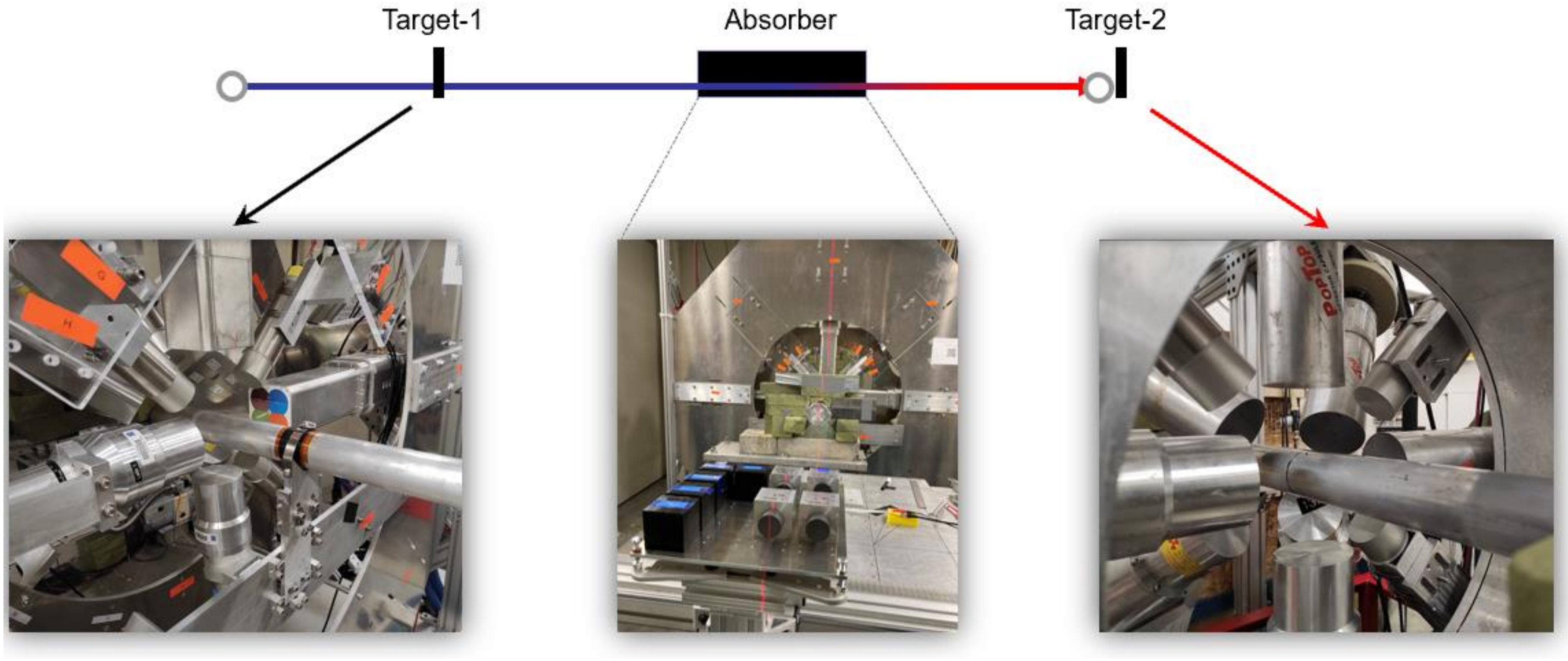
- Depends on number of states $N_{1,2}$ and averaged intensities $\langle I_{1,2}\rangle$

Current projects:

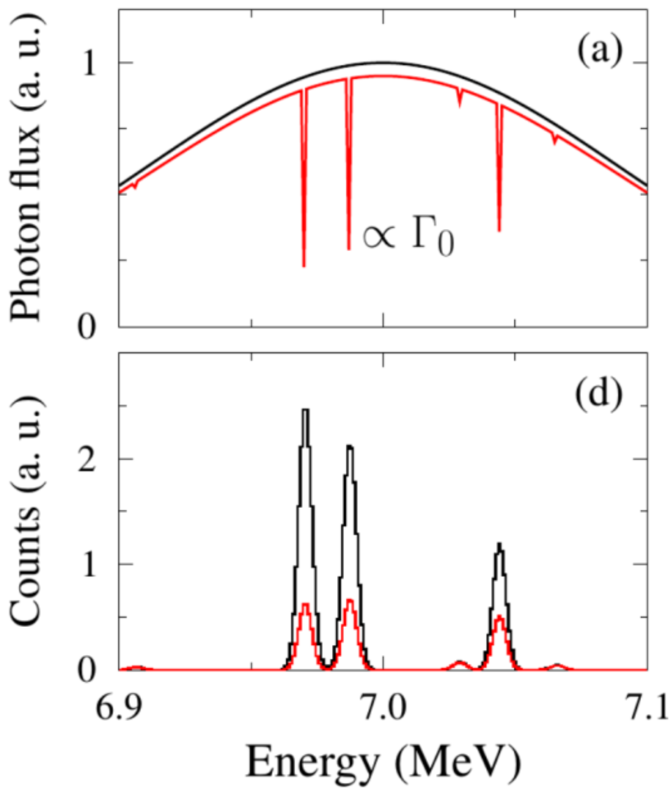
Level densities from NRF selfabsorption experiments

NRF Selfabsorption Experiments

D. Savran and J. Isaak, Nucl. Instrum. Meth. A 899, 28 (2018)

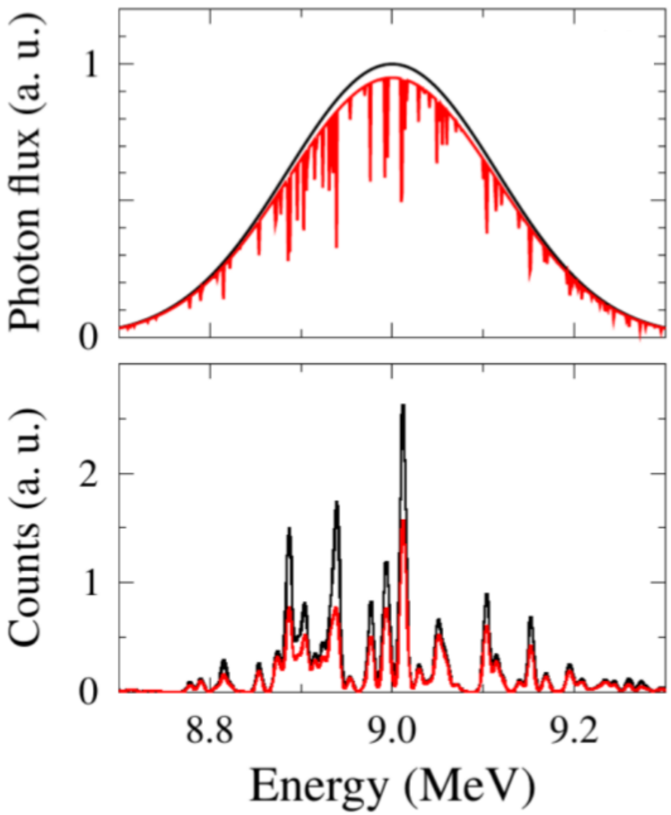


NRF Selfabsorption Experiments



- For resolved states $I_{abs} \sim \Gamma_0$
- Model-independent determination of transition widths

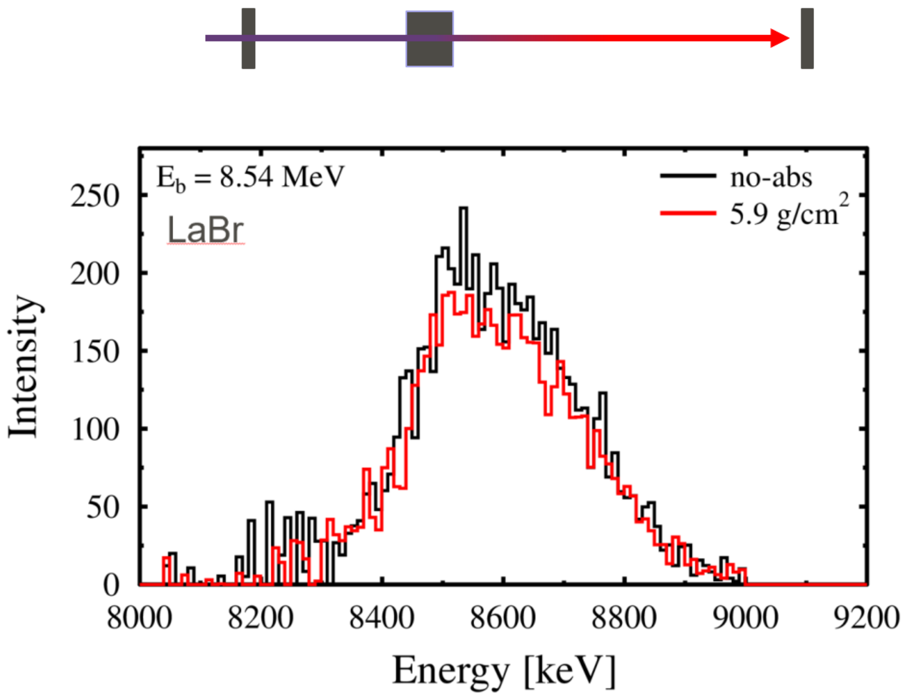
NRF Selfabsorption Experiments

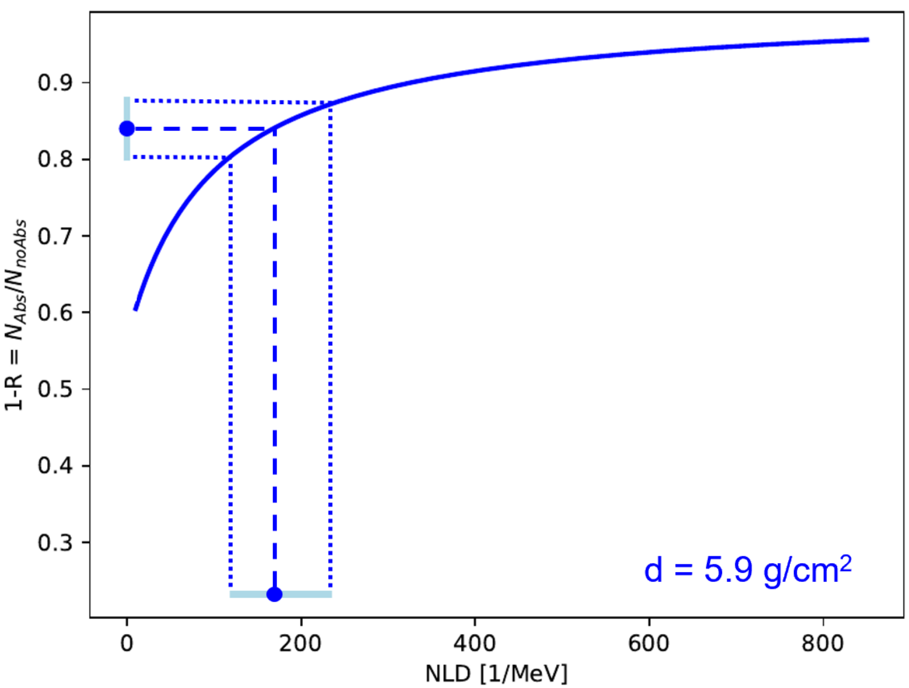


- For unresolved states $\Sigma I_{abs} \sim \Sigma \Gamma_0$
- assume PT distribution around average Γ_0
- Absorption related to level density

Example ^{88}Sr

J. Isaak et al., to be published

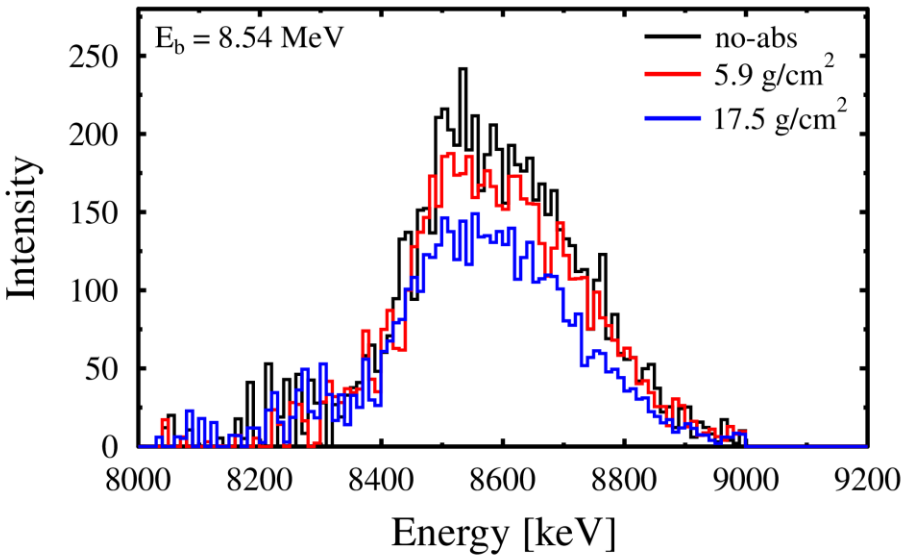


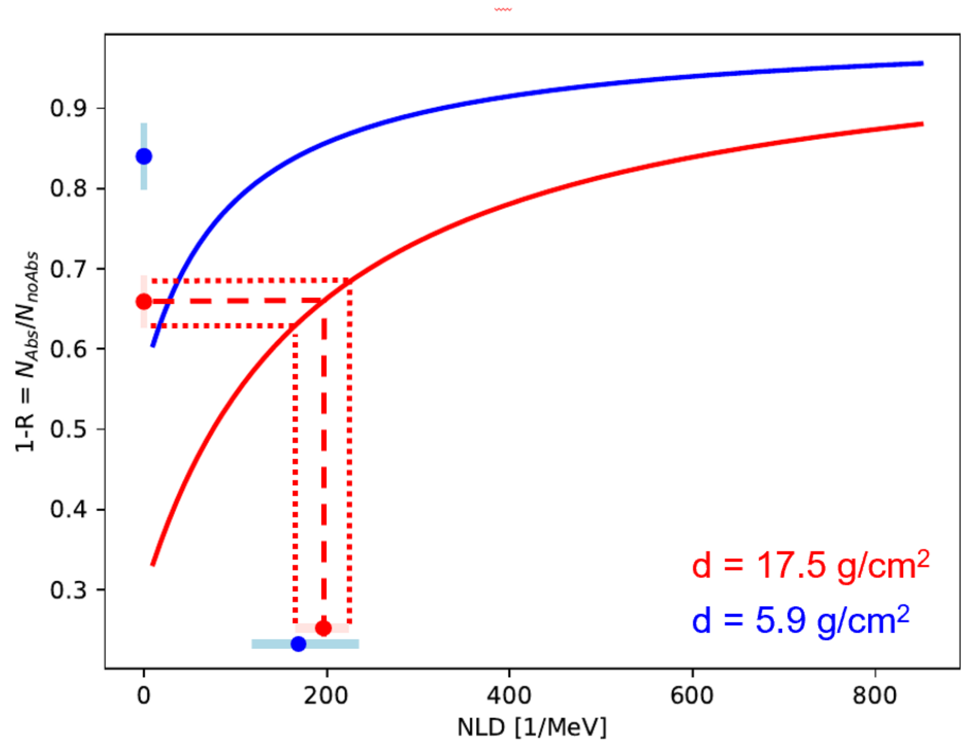


- Experiment at HIγS with linearly polarized photon beam → sensitive to $J^\pi = 1^-$ states

Example ^{88}Sr

J. Isaak et al., to be published

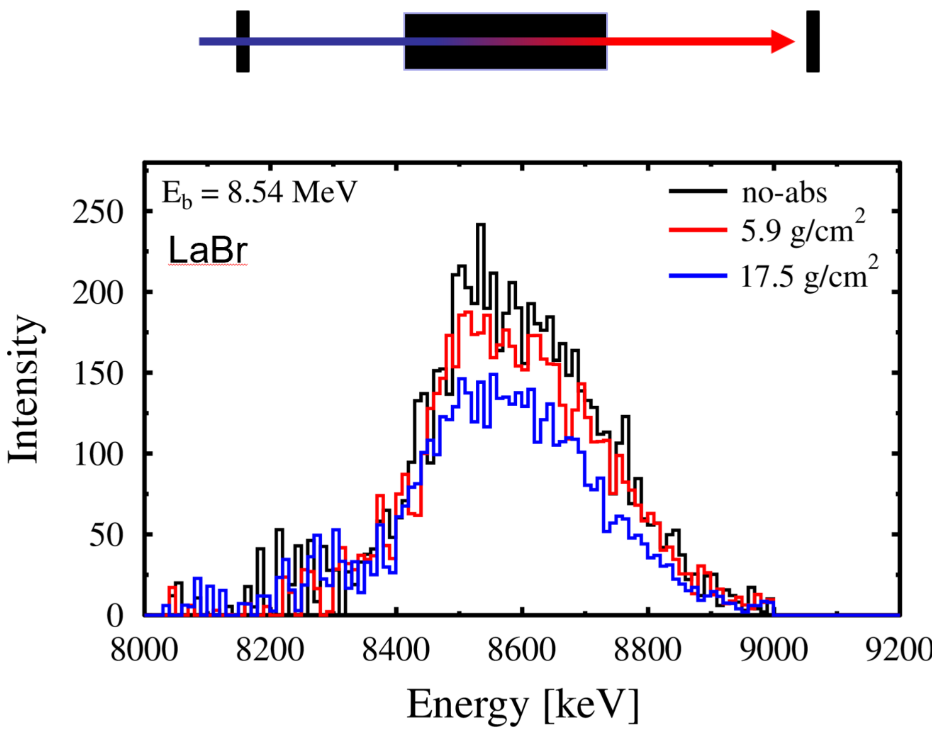


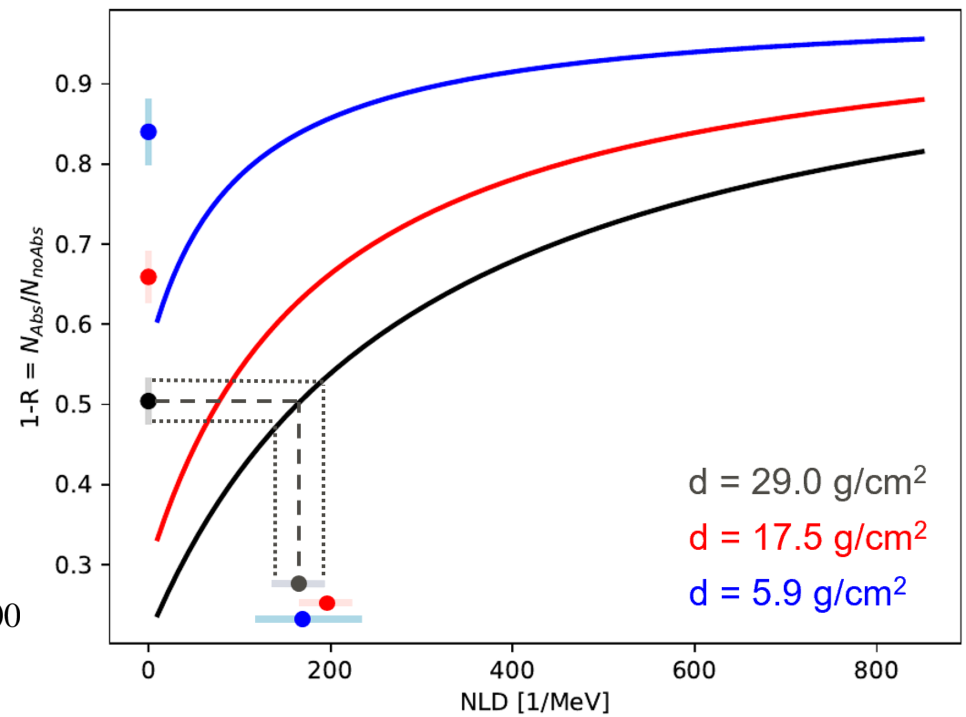


- Independent measurements with different absorber thicknesses

Example ^{88}Sr

J. Isaak et al., to be published





- Results agree within error bars

Summary

- 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

  - finish code for public use

  - study possible constraints on spin distribution

  - utilize selectivity of γ-decay coincidence experiments

  - NRF selfabsorption experiments

Collaborators

TECHNISCHE UNIVERSITÄT DARMSTADT

Johann Isaak, Bastian Hesbacher (TU Darmstadt)

Isabelle Brandherm (U Köln)

Lindsay Donaldson, Retief Neveling (iThemba LABS)

Deniz Savran (GSI)