Gamma Strength Function and Level Density of ^{120}Sn*

Sergej Bassauer and Peter von Neumann-Cosel
Institut für Kernphysik, TU Darmstadt

TECHNISCHE UNIVERSITÄT DARMSTADT

6th Workshop
on
Nuclear Level Density
and
Gamma Strength

*Supported by the DFG within SFB 1245

SFB 1245

Outline

TECHNISCHE UNIVERSITÄT DARMSTADT

- Introduction

Outline

TECHNISCHE
UNIVERSITÄT
DARMSTADT

- Introduction
- E1 and M1 gamma strength functions from inelastic proton scattering

Outline

TECHNISCHE UNIVERSITÄT DARMSTADT

- Introduction
- E1 and M1 gamma strength functions from inelastic proton scattering
- Comparison of gamma strength functions from different experiments

Outline

TECHNISCHE UNIVERSITÄT DARMSTADT

- Introduction
- E1 and M1 gamma strength functions from inelastic proton scattering
- Comparison of gamma strength functions from different experiments
- Level density

Outline

TECHNISCHE UNIVERSITÄT DARMSTADT

- Introduction
- E1 and M1 gamma strength functions from inelastic proton scattering
- Comparison of gamma strength functions from different experiments
- Level density
- Summary

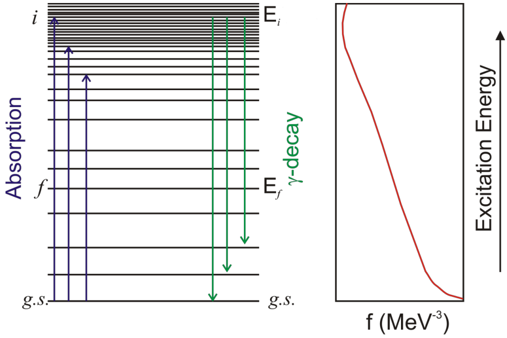
Outline

TECHNISCHE UNIVERSITÄT DARMSTADT

- Introduction
- E1 and M1 gamma strength functions from inelastic proton scattering
- Comparison of gamma strength functions from different experiments
- Level density
- Summary
- Outlook: Systematics of stable tin isotopes

Gamma Strength Function (GSF) for E1 transitions

$$\langle \Gamma(E_i) \rangle = \frac{1}{\rho(E_i)} \int_0^{E_i} E_\gamma^3 f^{E1}(E_\gamma) \rho(E_i - E_\gamma) \mathrm{d}E_\gamma$$

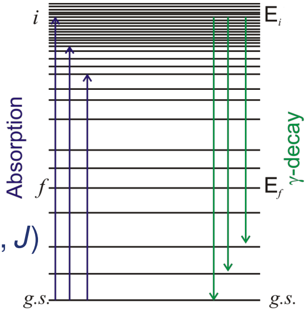


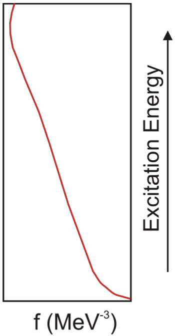
Gamma Strength Function (GSF) for E1 transitions

$$\langle \Gamma(E_i) \rangle = \frac{1}{\rho(E_i)} \int_0^{E_i} E_\gamma^3 f^{E1}(E_\gamma)\rho(E_i - E_\gamma)\mathrm{d}E_\gamma$$

$$f^{E1}(E_\gamma) = \frac{\langle \sigma_{abs}^{E1} \rangle}{3(\pi\hbar c)^2 E_\gamma^3}$$

$$\overset{i.\to g.s.}{=} \frac{\langle \Gamma_0^{E1}(E_\gamma) \rangle}{E_\gamma^3} \rho(E_i, J)$$





Applications of the gamma strength function

TECHNISCHE UNIVERSITÄT DARMSTADT

- Influences the reaction rates in r- and s-process

Applications of the gamma strength function

- Influences the reaction rates in r- and s-process
- Important in reactor technology (i. e. for transmutation of long lived radioactive waste)

Applications of the gamma strength function

- Influences the reaction rates in r- and s-process
- Important in reactor technology (i. e. for transmutation of long lived radioactive waste)
- Test of the Brink-Axel hypothesis

Applications of the gamma strength function

- Influences the reaction rates in r- and s-process
- Important in reactor technology (i. e. for transmutation of long lived radioactive waste)
- Test of the Brink-Axel hypothesis
  - Gamma strength function depends only on E_γ

Applications of the gamma strength function

TECHNISCHE UNIVERSITÄT DARMSTADT

- Influences the reaction rates in r- and s-process
- Important in reactor technology (i. e. for transmutation of long lived radioactive waste)
- Test of the Brink-Axel hypothesis
  - Gamma strength function depends only on E_γ
  - Independent of the structure of the initial state

Applications of the gamma strength function

TECHNISCHE UNIVERSITÄT DARMSTADT

- Influences the reaction rates in r- and s-process
- Important in reactor technology (i. e. for transmutation of long lived radioactive waste)
- Test of the Brink-Axel hypothesis
  - Gamma strength function depends only on E_γ
  - Independent of the structure of the initial state
- Test of models in the Reference Input Parameter Library (RIPL)

Gamma strength function models

TECHNISCHE UNIVERSITÄT DARMSTADT

- Standard Lorentzian Model (SLO)

Gamma strength function models

- Standard Lorentzian Model (SLO)
  - The Lorentz parameters can be obtained from photoabsorption experiments

Gamma strength function models

TECHNISCHE UNIVERSITÄT DARMSTADT

- Standard Lorentzian Model (SLO)
  - The Lorentz parameters can be obtained from photoabsorption experiments
- Enhanced Generalised Lorentzian Model (EGLO)

Gamma strength function models

TECHNISCHE UNIVERSITÄT DARMSTADT

- Standard Lorentzian Model (SLO)
  - The Lorentz parameters can be obtained from photoabsorption experiments
- Enhanced Generalised Lorentzian Model (EGLO)
  - Lorentzian term with energy- and temperature-dependent width

Gamma strength function models

TECHNISCHE UNIVERSITÄT DARMSTADT

- Standard Lorentzian Model (SLO)
  - The Lorentz parameters can be obtained from photoabsorption experiments
- Enhanced Generalised Lorentzian Model (EGLO)
  - Lorentzian term with energy- and temperature-dependent width
  - A term describing the shape of the low-energy part

Gamma strength function models

TECHNISCHE UNIVERSITÄT DARMSTADT

- Standard Lorentzian Model (SLO)
  - The Lorentz parameters can be obtained from photoabsorption experiments
- Enhanced Generalised Lorentzian Model (EGLO)
  - Lorentzian term with energy- and temperature-dependent width
  - A term describing the shape of the low-energy part
- Modified Lorentzian Model (MLO)

Gamma strength function models

TECHNISCHE UNIVERSITÄT DARMSTADT

- Standard Lorentzian Model (SLO)
  - The Lorentz parameters can be obtained from photoabsorption experiments
- Enhanced Generalised Lorentzian Model (EGLO)
  - Lorentzian term with energy- and temperature-dependent width
  - A term describing the shape of the low-energy part
- Modified Lorentzian Model (MLO)
  - Lorentzian with energy- and temperature-dependent width

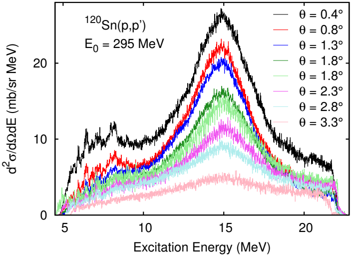
Gamma strength function models

TECHNISCHE UNIVERSITÄT DARMSTADT

- Standard Lorentzian Model (SLO)
  - The Lorentz parameters can be obtained from photoabsorption experiments
- Enhanced Generalised Lorentzian Model (EGLO)
  - Lorentzian term with energy- and temperature-dependent width
  - A term describing the shape of the low-energy part
- Modified Lorentzian Model (MLO)
  - Lorentzian with energy- and temperature-dependent width
  - Scaling factor which accounts for the enhancement of the GSF with increasing temperature

Determination of the E1 gamma strength function

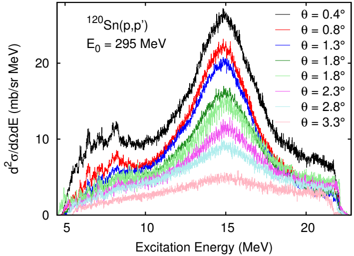
- ^{120}Sn(p,p') experiment conducted at RCNP, Japan



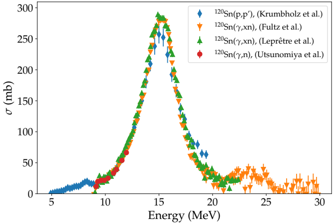
A. Krumbholz *et al.*, Phys. Lett. **B** 744 (2015) 7
T. Hashimoto *et al.*, Phys. Rev. C **92** (2015) 031305

Determination of the E1 gamma strength function

- ^{120}Sn(p,p') experiment conducted at RCNP, Japan
- Double differential cross section converted to photoabsorption cross section using Virtual Photon Method

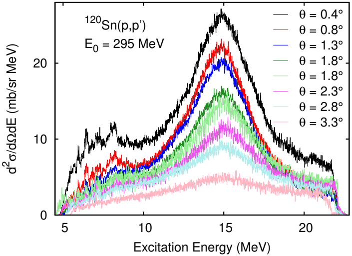


A. Krumbholz *et al.*, Phys. Lett. **B** 744 (2015) 7
T. Hashimoto *et al.*, Phys. Rev. C **92** (2015) 031305

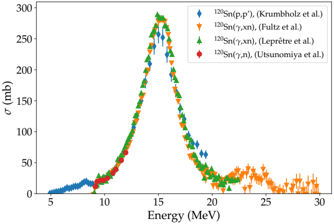


Determination of the E1 gamma strength function

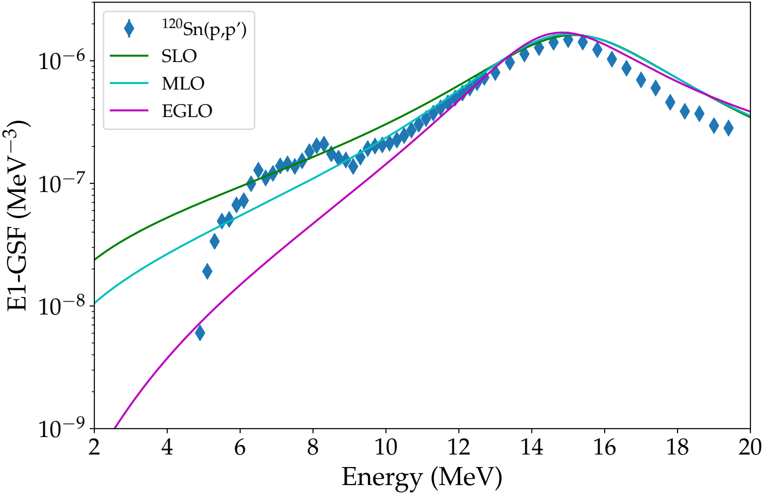
- ^{120}Sn(p,p') experiment conducted at RCNP, Japan
- Double differential cross section converted to photoabsorption cross section using Virtual Photon Method
- Gamma strength function determined from photoabsorption cross section



A. Krumbholz *et al.*, Phys. Lett. **B** 744 (2015) 7
T. Hashimoto *et al.*, Phys. Rev. C **92** (2015) 031305



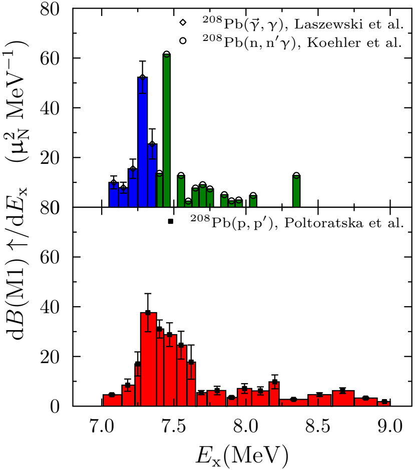
E1 contribution to the gamma strength function



Determination of the M1 contribution to the gamma strength function

TECHNISCHE UNIVERSITÄT DARMSTADT

- Extract B(M1) strength from (p,p') data using unit cross section technique

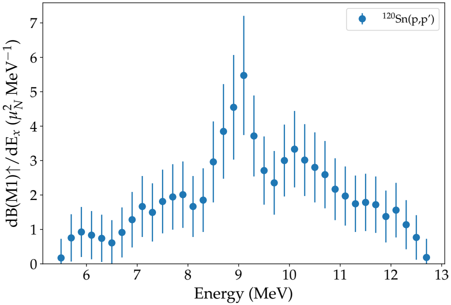


J. Birkhan *et al.*, Phys. Rev. C **93** (2016) 041302

Determination of the M1 contribution to the gamma strength function

TECHNISCHE UNIVERSITÄT DARMSTADT

- Extract B(M1) strength from (p,p’) data using unit cross section technique



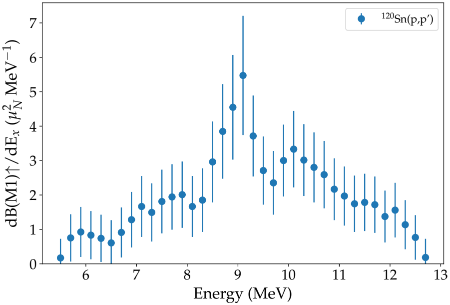
Determination of the M1 contribution to the gamma strength function

TECHNISCHE UNIVERSITÄT DARMSTADT

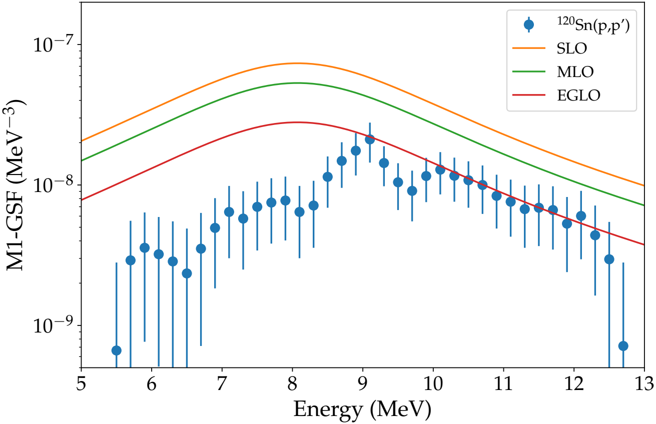
- Extract B(M1) strength from (p,p') data using unit cross section technique
- Theoretical description of M1 gamma strength function

$$f^{M1}(E) = \frac{f^{E1}(S_n)}{\mathcal{R}} \frac{\Phi^{M1}(E)}{\Phi^{M1}(S_n)}$$

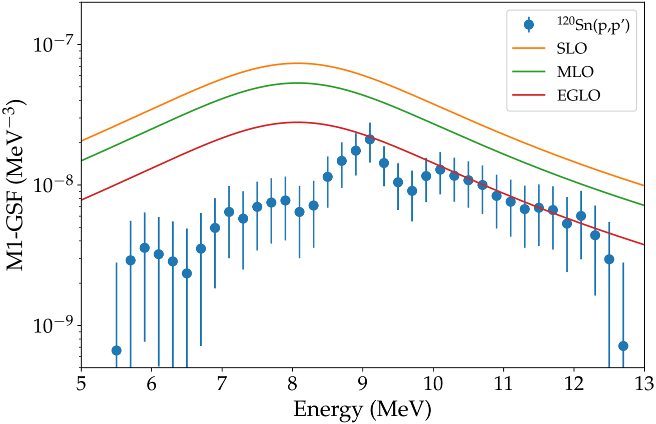
$$\mathcal{R} = \frac{f^{E1}(S_n)}{f^{M1}(S_n)} = 0.0588A^{0.878}$$



M1 contribution to the gamma strength function

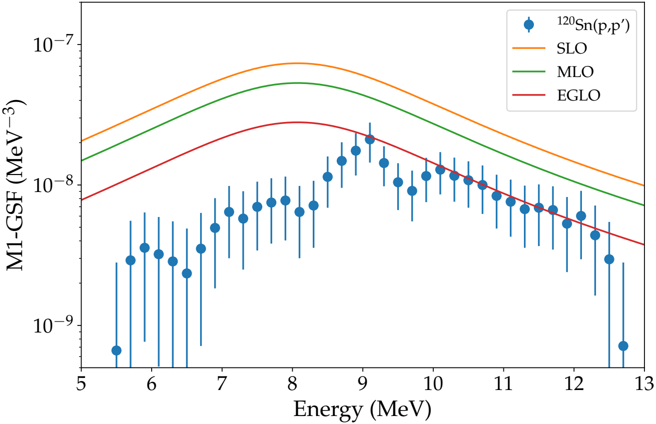


M1 contribution to the gamma strength function



- Theory: E_r = 8.3 MeV, Γ_r = 4 MeV

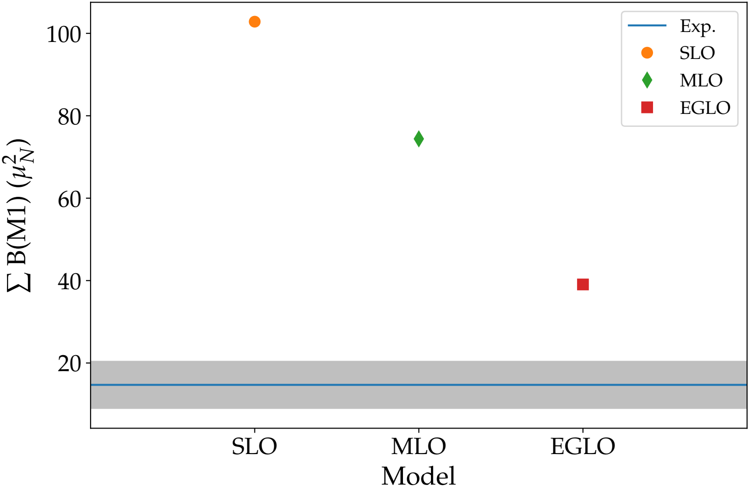
M1 contribution to the gamma strength function



- Theory: E_r = 8.3 MeV, Γ_r = 4 MeV
- Experiment: E_r = 9 MeV, Γ_r = 1.2 MeV

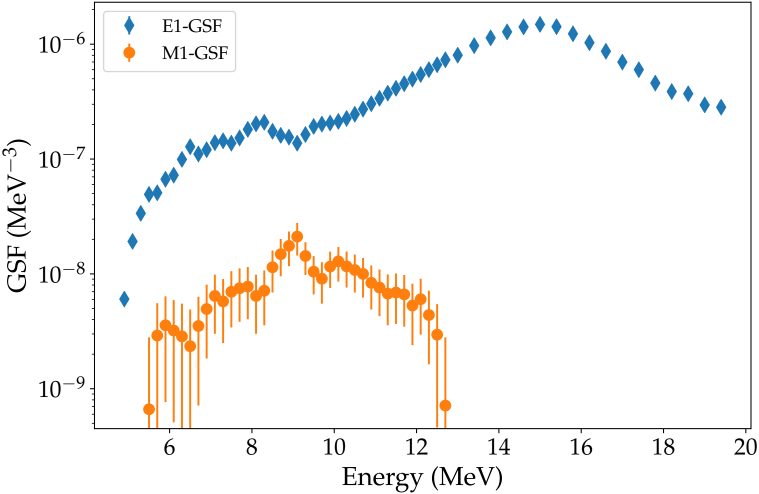
Sum of B(M1) strength in ^{120}Sn

TECHNISCHE UNIVERSITÄT DARMSTADT

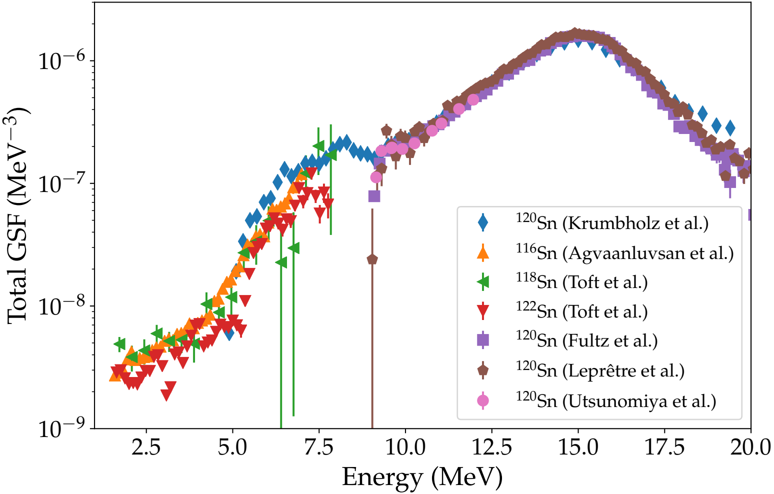


E1 and M1 gamma strength functions

TECHNISCHE UNIVERSITÄT DARMSTADT

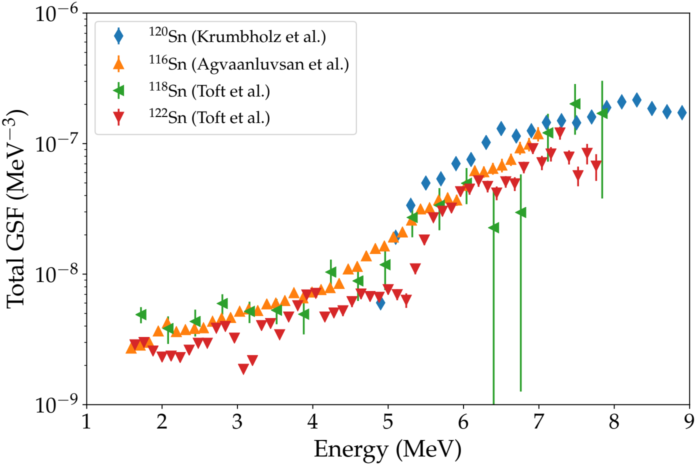


Total gamma strength function



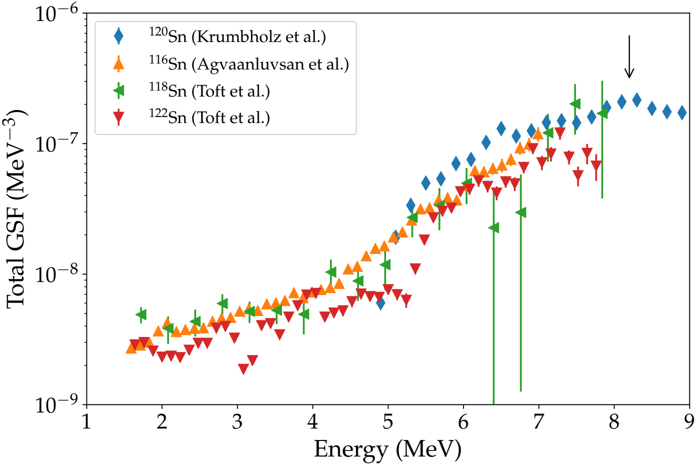
Total gamma strength function

TECHNISCHE UNIVERSITÄT DARMSTADT

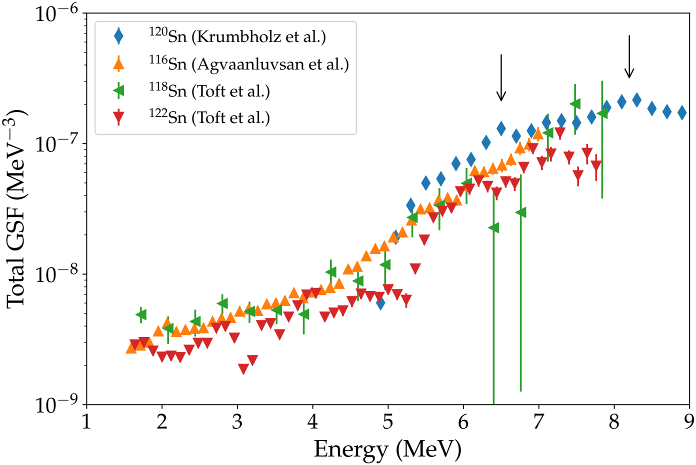


Total gamma strength function

TECHNISCHE UNIVERSITÄT DARMSTADT

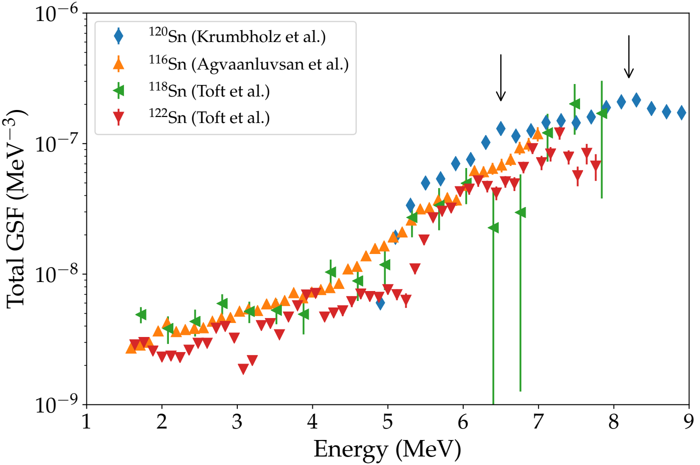


Total gamma strength function



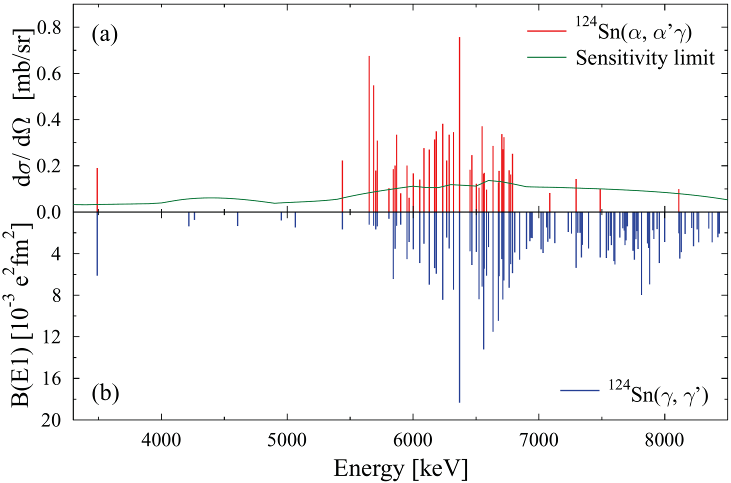
Total gamma strength function

TECHNISCHE UNIVERSITÄT DARMSTADT



- Brink-Axel hypothesis violated?

Comparison with isoscalar probe

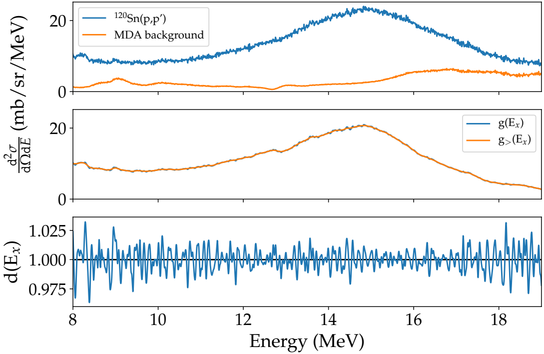


J. Endres *et al.*, Phys. Rev. C **85** (2012) 064331

Determination of the level density

TECHNISCHE UNIVERSITÄT DARMSTADT

- Background from MDA

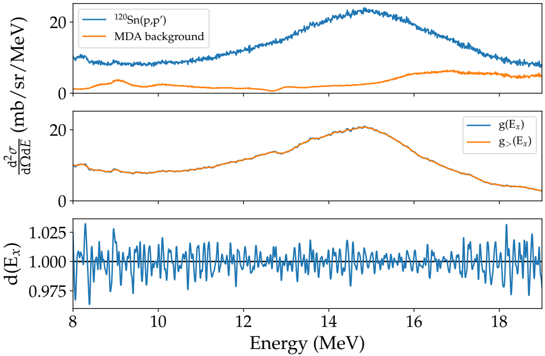


Determination of the level density

TECHNISCHE UNIVERSITÄT DARMSTADT

- Background from MDA
- Stationary spectrum

$$d(E_x) = \frac{g(E_x)}{g_>(E_x)}$$



Determination of the level density

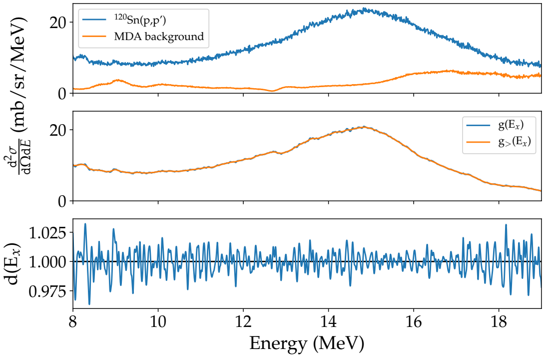
TECHNISCHE UNIVERSITÄT DARMSTADT

- Background from MDA
- Stationary spectrum

$$d(E_x) = \frac{g(E_x)}{g_>(E_x)}$$

- Autocorrelation function

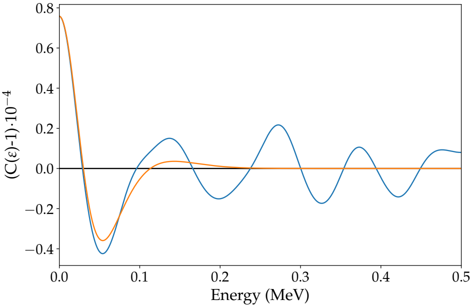
$$C(\varepsilon) = \frac{\langle d(E_x) \cdot d(E_x + \varepsilon) \rangle}{\langle d(E_x) \rangle \cdot \langle d(E_x + \varepsilon) \rangle}$$



Determination of the level density

- Variance of the autocorrelation function

$$C(0) - 1 = \frac{\langle d(E_x)^2 \rangle - \langle d(E_x) \rangle^2}{\langle d(E_x) \rangle^2}$$

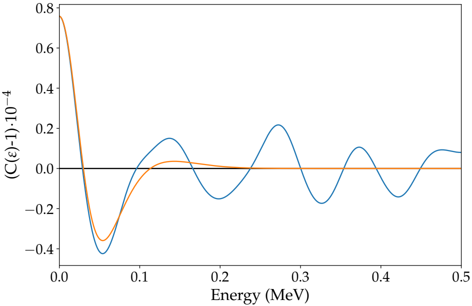


Determination of the level density

- Variance of the autocorrelation function

$$C(0) - 1 = \frac{\langle d(E_x)^2 \rangle - \langle d(E_x) \rangle^2}{\langle d(E_x) \rangle^2}$$

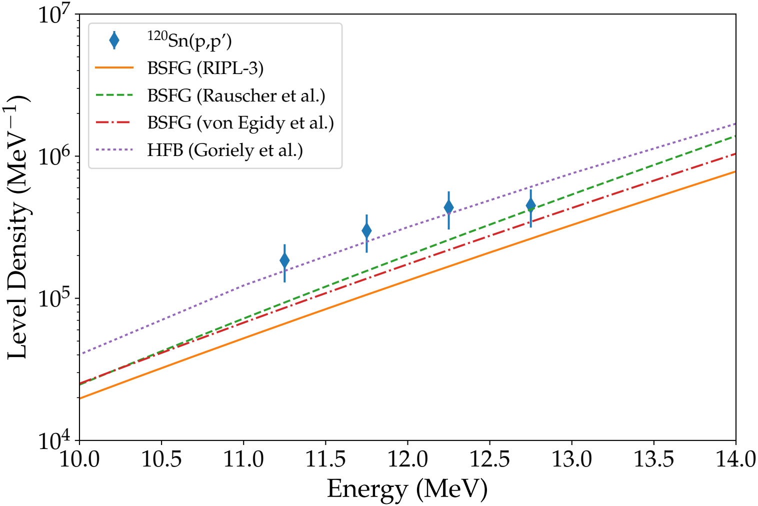
- Model for the approximation of the exp. autocorrelation function



$$C(0) - 1 = \frac{\alpha \langle D \rangle}{2\sigma\sqrt{\pi}} \left(1 + \frac{\sigma}{\sigma_>} - \sqrt{\frac{8}{1 + (\frac{\sigma_>}{\sigma})^2}} \right) \quad \text{where} \quad \rho(E) = \frac{1}{\langle D \rangle}$$

Level densities of 1^- states

TECHNISCHE UNIVERSITÄT DARMSTADT



Determination of the total level density

- Total level density

$$\rho^{tot}(E) = \frac{2\rho(E, J, \Pi)}{f(J)}$$

Determination of the total level density

TECHNISCHE UNIVERSITÄT DARMSTADT

- Total level density

$$\rho^{tot}(E) = \frac{2\rho(E, J, \Pi)}{f(J)}$$

$$f(J) = \frac{2J+1}{2\sigma^2} \exp\left(-\frac{(J+\frac{1}{2})^2}{2\sigma^2}\right)$$

Determination of the total level density

TECHNISCHE UNIVERSITÄT DARMSTADT

- Total level density

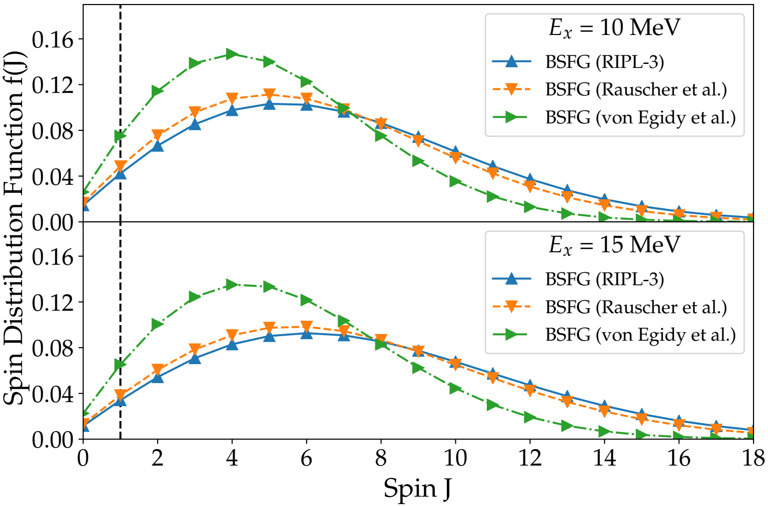
$$\rho^{tot}(E) = \frac{2\rho(E,J,\Pi)}{f(J)}$$

$$f(J) = \frac{2J+1}{2\sigma^2}\exp\left(-\frac{(J+\frac{1}{2})^2}{2\sigma^2}\right)$$

$$\rho^{tot}_{BSFG} = \frac{1}{\sqrt{2\pi}\sigma}\frac{\sqrt{\pi}}{12}\frac{\exp\left(2\sqrt{a(E-\Delta)}\right)}{a^{1/4}(E-\Delta)^{5/4}}$$

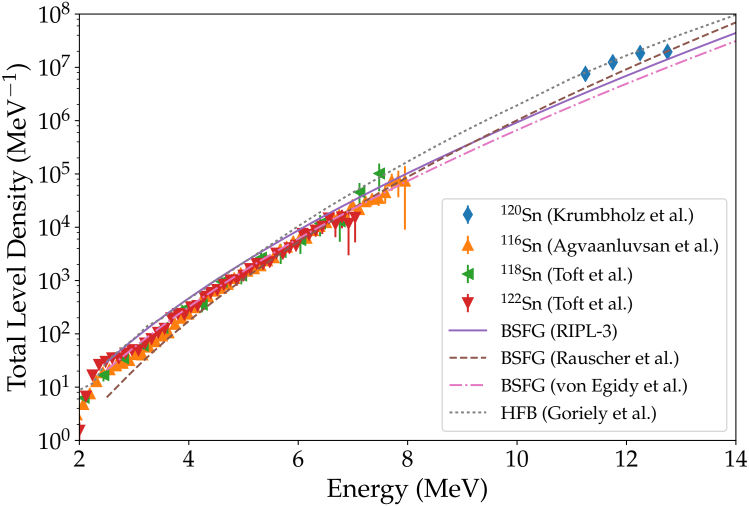
Spin distribution function of ^{120}Sn

TECHNISCHE UNIVERSITÄT DARMSTADT



Comparison of the total level density

TECHNISCHE UNIVERSITÄT DARMSTADT



Summary

TECHNISCHE
UNIVERSITÄT
DARMSTADT

- The gamma strength function and level density is independently determined from (p,p') data

Summary

TECHNISCHE UNIVERSITÄT DARMSTADT

- The gamma strength function and level density is independently determined from (p,p’) data
- Parametrisation of the M1 strength in RIPL-3 overestimates the exp. data

Summary

TECHNISCHE UNIVERSITÄT DARMSTADT

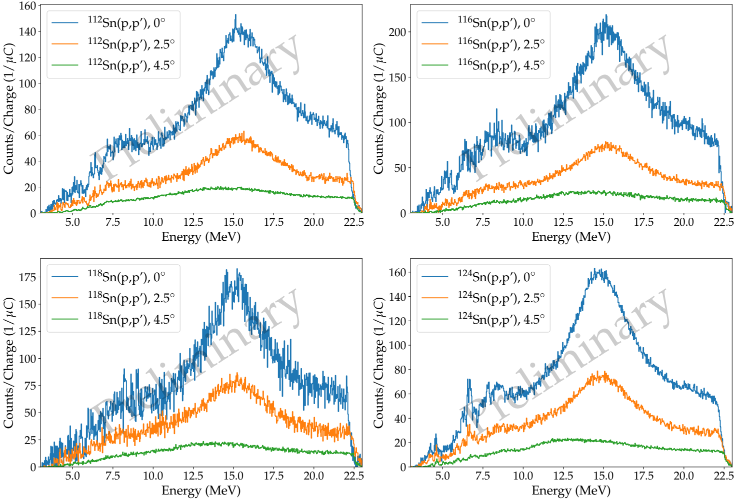
- The gamma strength function and level density is independently determined from (p,p') data
- Parametrisation of the M1 strength in RIPL-3 overestimates the exp. data
- In the PDR region the (p,p') data is higher than the Oslo data
  $\rightarrow$ Possible violation of Brink-Axel hypothesis?

Summary

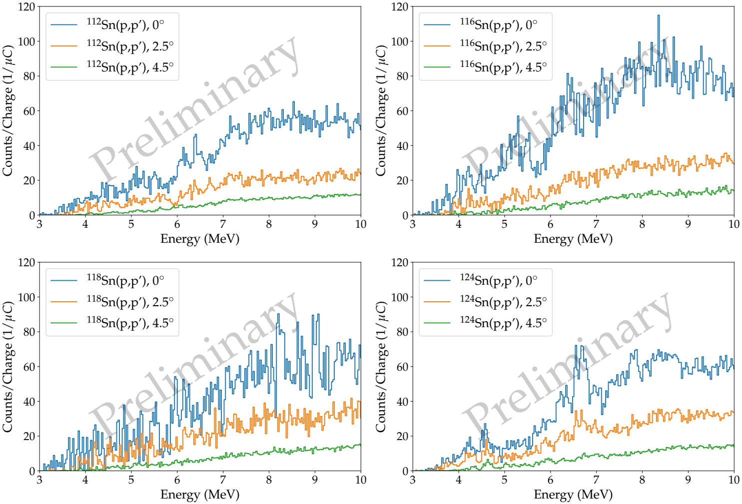
- The gamma strength function and level density is independently determined from (p,p') data
- Parametrisation of the M1 strength in RIPL-3 overestimates the exp. data
- In the PDR region the (p,p') data is higher than the Oslo data $\rightarrow$ Possible violation of Brink-Axel hypothesis?
- No model can describe the level density from (p,p') and (^{3}He,^{3}He'γ) at the same time

Outlook: Systematics of tin isotopes

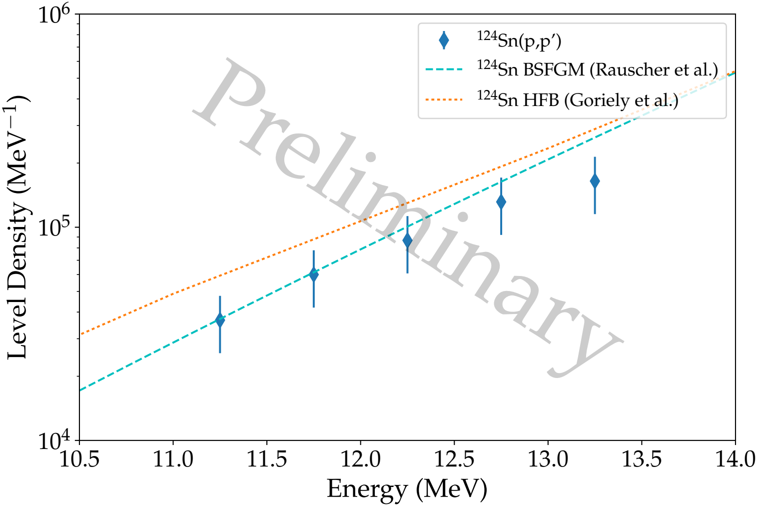
TECHNISCHE UNIVERSITÄT DARMSTADT



Outlook: Systematics of tin isotopes



Outlook: Level density of 1^- states in ^{124}Sn



Collaborators

TECHNISCHE UNIVERSITÄT DARMSTADT

Institut für Kernphysik, TU Darmstadt, Germany

S. Aslanidou, M. Hilcker, A. Krugmann, A. M. Krumbholz, P. von Neumann-Cosel, N. Pietralla, V. Yu. Ponamorev, R. Roth, M. Singer, G. Steinhilber, V. Werner, J. Wambach, M. Zweidinger

RCNP, Osaka, Japan

S. Adachi, T. Adachi, N. Aoi, P. Y. Chan, H. Fujita, Y. Fujita, G. Gey, H. T. Ha, T. Hashimoto, K. Hatanaka, F. Hattori, E. Ideguchi, A. Inoue, T. Ito, C. Iwamoto, H. J. Ong, I. Ou, A. Tamii, Y. N. Watanabe, T. Yamamoto, M. Yosoi

...and many others!

References I

- T. Hashimoto *et al.*, Phys. Rev. C **92** (2015) 031305.
- J. Birkhan *et al.*, Phys. Rev. C **93** (2016) 041302.
- J. Endres *et al.*, Phys. Rev. C **85** (2012) 064331.
- U. Agvaanluvsan *et al.*, Phys. Rev. C **79** (2009) 014320.
- S. Bassauer, P. von Neumann-Cosel, und A. Tamii, Phys. Rev. C **94** (2016) 054313.
- R. Capote *et al.*, Nuclear Data Sheets **110** (2009) 3107 , ISSN 0090-3752, special Issue on Nuclear Reaction Data.
- S. Goriely, S. Hilaire, und A. J. Koning, Phys. Rev. C **78** (2008) 064307.
- A. Krumbholz *et al.*, Physics Letters B **744** (2015) 7 , ISSN 0370-2693.
- P. Hansen, B. Jonson, und A. Richter, Nuclear Physics A **518** (1990) 13 , ISSN 0375-9474.

References II

H. K. Toft *et al.*, Phys. Rev. C **83** (2011) 044320.

H. K. Toft *et al.*, Phys. Rev. C **81** (2010) 064311.

GSF models

- Standard Lorentzian Model (SLO)

$$f_{SLO}(E) = \frac{\sigma_r \Gamma_r}{3(\pi\hbar c)^2} \frac{\Gamma_r E}{(E^2 - E_r^2)^2 + (\Gamma_r E)^2}$$

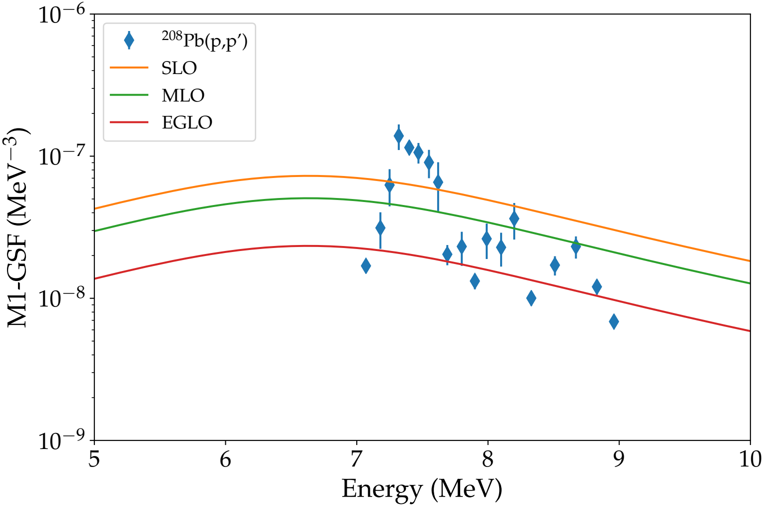
- Enhanced Generalized Lorentzian Model (EGLO)

$$f_{EGLO}(E) = \frac{\sigma_r \Gamma_r}{3(\pi\hbar c)^2} \left[\frac{\Gamma_K(E,T)E}{(E^2 - E_r^2)^2 + (\Gamma_K(E,T)E)^2} + 0.7 \frac{\Gamma_K(E=0,T)}{E_r^3} \right]$$

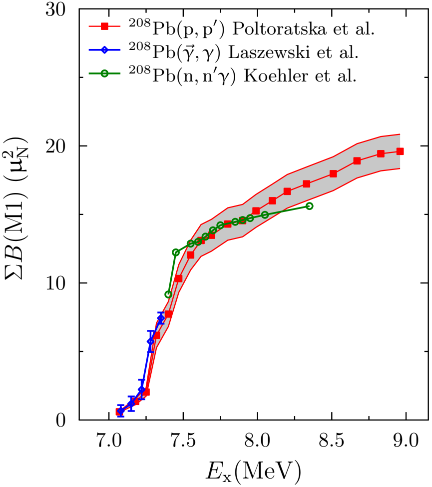
- Modified Lorentzian Model (MLO)

$$f_{MLO}(E) = \frac{\sigma_r \Gamma_r}{3(\pi\hbar c)^2} \frac{\Lambda(E,T)\Gamma(E,T)E}{(E^2 - E_r^2)^2 + (\Gamma(E,T)E)^2}$$

M1 contribution to the gamma strength function in ^{208}Pb



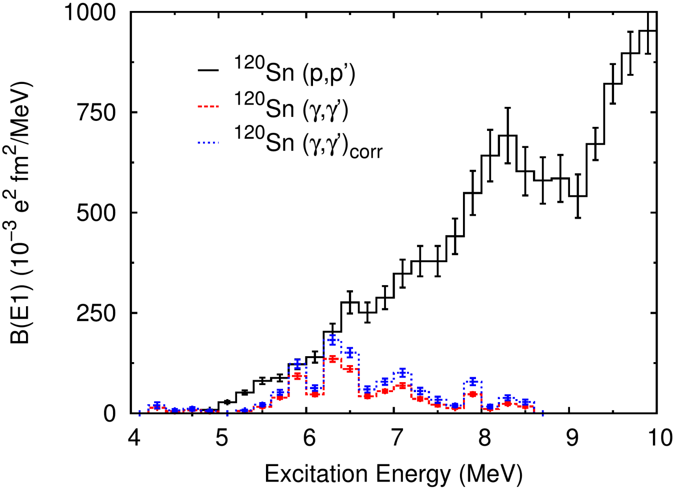
Sum of B(M1) strength in ^{208}Pb



J. Birkhan *et al.*, Phys. Rev. C **93** (2016) 041302

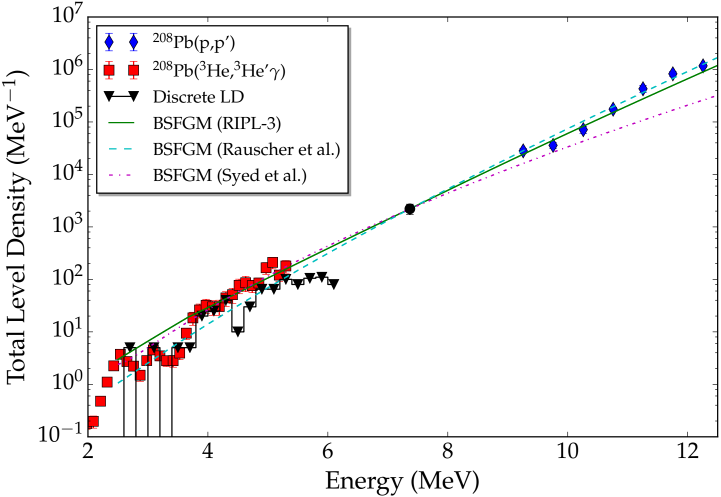
Low energy B(E1) in ^{120}Sn

TECHNISCHE UNIVERSITÄT DARMSTADT



Total level density in ^{208}Pb

TECHNISCHE UNIVERSITÄT DARMSTADT



S. Bassauer, P. von Neumann-Cosel, und A. Tamii, Phys. Rev. C **94** (2016) 054313