

Electromagnetic Dipole Response of Nuclei

Exploring Nuclear Structures and Constraining Nucleosynthesis Processes

Mathis Wiedeking

*iThemba LABS, Cape Town
University of the Witwatersrand, Johannesburg*

Supported by the National Research Foundation under grant number 118840.



science & innovation

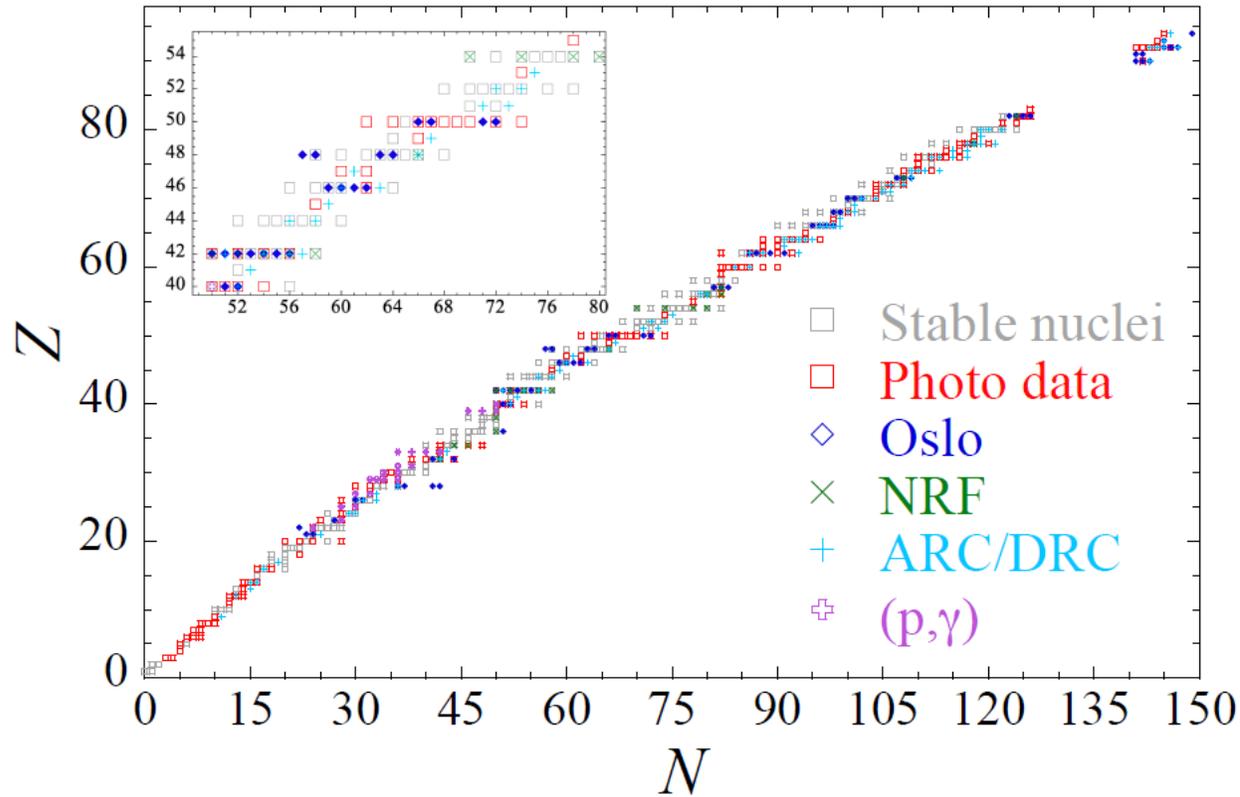
Department:
Science and Innovation
REPUBLIC OF SOUTH AFRICA

WITS
UNIVERSITY



iThemba
LABS
Laboratory for Accelerator
Based Sciences

What do we want to achieve?



S Goriely, P Dimitriou, MW *et al.*, Eur. Phys. J. A 55, 172 (2019).

Nuclear Structure

Scissors and LEE

Experimental methods

Inverse OM

(n,γ) cross sections

Nucleosynthesis

Analytical methods

Shape Method



science & innovation

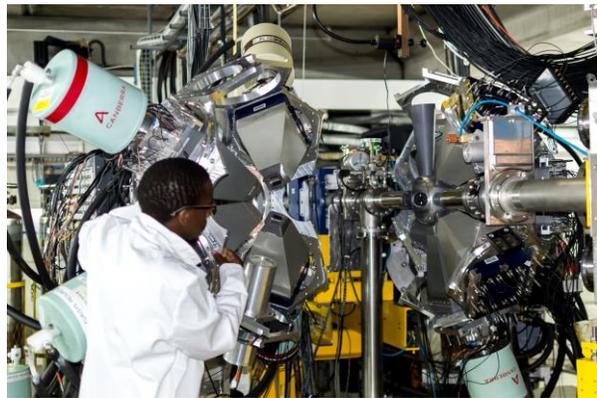
Department:
Science and Innovation
REPUBLIC OF SOUTH AFRICA

WITS
UNIVERSITY



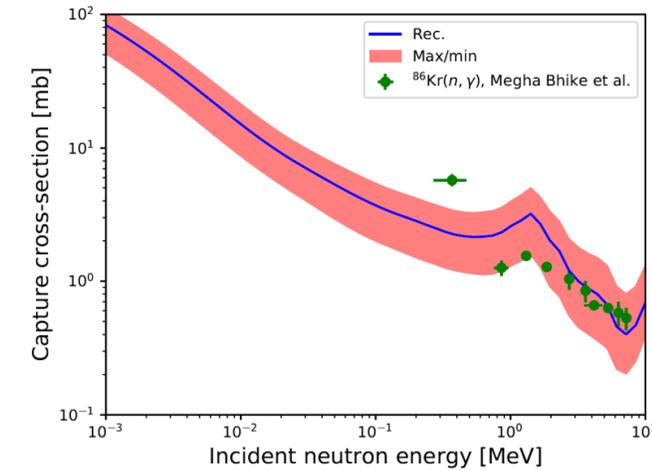
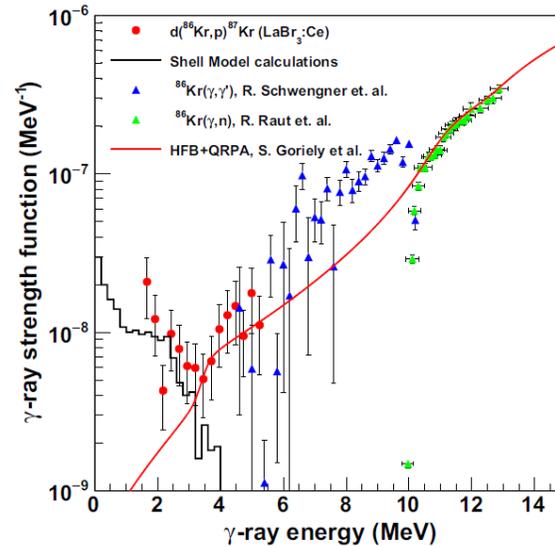
iThemba
LABS
Laboratory for Accelerator
Based Sciences

PSF and NLD from Inverse Kinematics at iThemba LABS



300MeV ^{86}Kr , CD targets. HPGe + $\text{LaBr}_3(\text{Ce})$ + Silicon

- Complementary to Oslo & Beta-Oslo Methods.
- Applicable to **stable & radioactive** beam facilities.
- iThemba LABS: ^{133}Xe , ^{85}Kr , ^{87}Kr



Eur. Phys. J. A (2020) 56:68
<https://doi.org/10.1140/epja/s10050-020-00070-7>

THE EUROPEAN
 PHYSICAL JOURNAL A



Regular Article - Experimental Physics

First application of the Oslo method in inverse kinematics

Nuclear level densities and γ -ray strength functions of ^{87}Kr

V. W. Ingeberg^{1,a}, S. Siem¹, M. Wiedeking², K. Sieja^{3,4}, D. L. Bleuel⁵, C. P. Brits^{2,6}, T. D. Bucher², T. S. Dinoko², J. L. Easton^{2,7}, A. G3rgen¹, M. Guttormsen¹, P. Jones², B. V. Kheswa^{2,8}, N. A. Khumalo², A. C. Larsen¹, E. A. Lawrie², J. J. Lawrie², S. N. T. Majola^{2,8,9}, K. L. Malatji^{2,6}, L. Makhathini^{2,6}, B. Maqabuka^{2,7}, D. Negi², S. P. Noncolela^{2,7}, P. Papka^{2,6}, E. Sahin¹, R. Schwengner¹⁰, G. M. Tveten¹, F. Zeiser¹, B. R. Zikhali^{2,9}



science & innovation

Department:
 Science and Innovation
 REPUBLIC OF SOUTH AFRICA

WITS
 UNIVERSITY



iThemba
 LABS
 Laboratory for Accelerator
 Based Sciences

Shape Method

- D_0 is not known.
- No standard approach in absence of D_0 .
- Unambiguous identification of origin and destination of primaries.
- Functional form is retained between primaries from same excitation energy bin.
- Concepts from Average Resonance Capture, Ratio, and χ^2 methods.

PHYSICAL REVIEW C **104**, 014311 (2021)

PHYSICAL REVIEW C **107**, L011602 (2023)

Letter

Independent normalization for γ -ray strength functions: The shape method

M. Wiedeking ^{1,2,*} M. Guttormsen,³ A. C. Larsen,³ F. Zeiser,³ A. G3rgen ³ S. N. Liddick,^{4,5} D. M3cher,^{6,7} S. Siem,³ and A. Spyrou^{4,8}

Extracting model-independent nuclear level densities away from stability

D. M3cher ^{1,2,3,*} A. Spyrou,^{4,5,6,†} M. Wiedeking ^{7,8} M. Guttormsen ⁹ A. C. Larsen ⁹ F. Zeiser,⁹ C. Harris,^{10,5} A. L. Richard ^{10,6} M. K. Smith,¹⁰ A. G3rgen ⁹ S. N. Liddick,^{10,11} S. Siem,⁹ H. C. Berg ^{10,5} J. A. Clark,¹² P. A. DeYoung ¹³ A. C. Dombos,¹⁴ B. Greaves ¹ L. Hicks,^{10,5} R. Kelmar,¹⁴ S. Lyons,¹⁵ J. Owens-Fryar ^{10,5} A. Palmisano,^{10,5} D. Santiago-Gonzalez,¹² G. Savard,¹² and W. W. von Seeger¹³



science & innovation

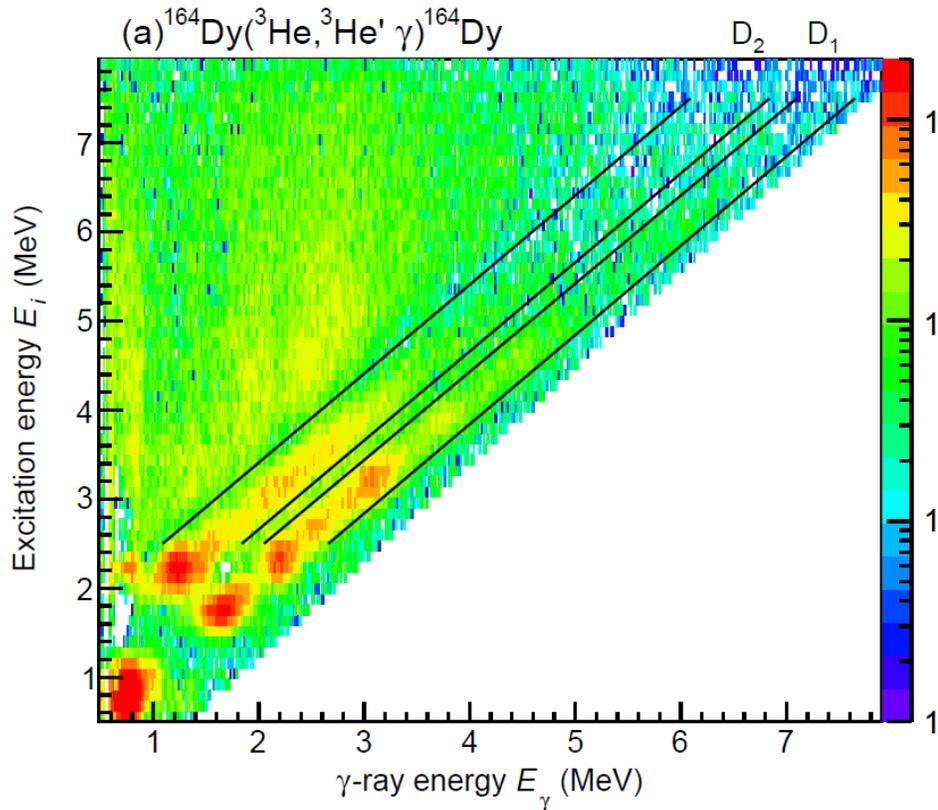
Department:
Science and Innovation
REPUBLIC OF SOUTH AFRICA

WITS
UNIVERSITY

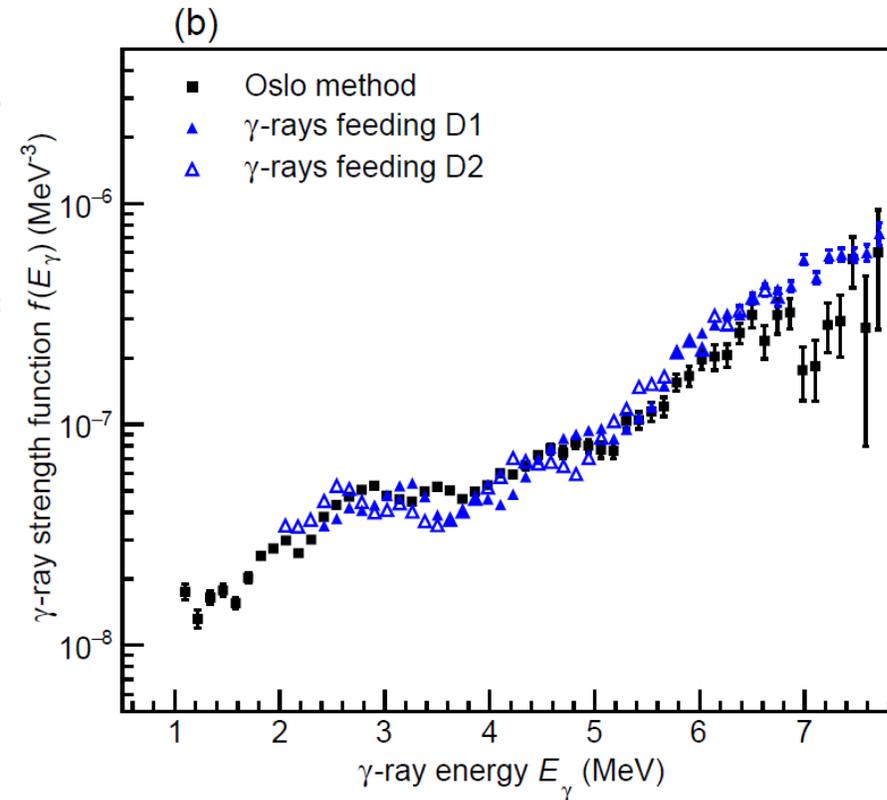


iThemba
LABS
Laboratory for Accelerator
Based Sciences

Shape Method in practice: ^{164}Dy



$D_1 = 0^+, 2^+, 4^+, 6^+, 0 - 0.5$ MeV
 $D_2 = 14$ levels $0.76 - 1.39$ MeV



MW, Guttormsen, Larsen *et al.*, Phys. Rev. C 104 014311 (2021).



science & innovation

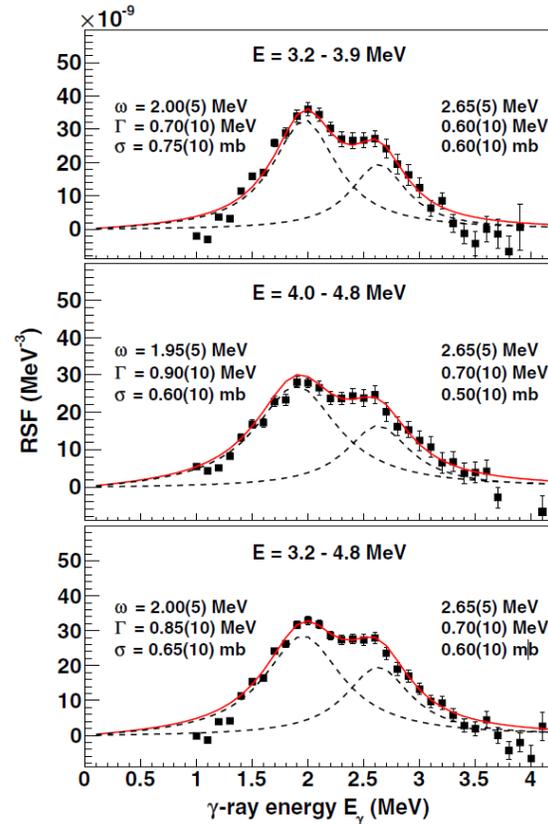
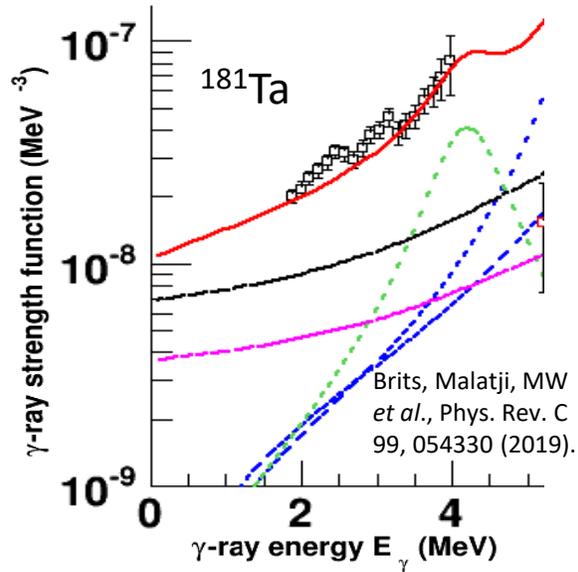
Department:
Science and Innovation
REPUBLIC OF SOUTH AFRICA

WITS
UNIVERSITY



iThemba
LABS
Laboratory for Accelerator
Based Sciences

Nuclear Structure from the PSF: SR and LEE



Guttormsen, Bernstein, Bürger *et al.*, Phys. Rev. Lett. 109, 162503 (2012).

Nature of splitting?

i) Triaxiality

Iudice *et al.*, Phys. Lett. B 161, 18 (1985).
 Lipparini, Stringari, Phys. Rep. 175, 103 (1989).
 F. Palumbo, Phys. Rev. C 99, 034319 (2019).

ii) Spin Scissors Mode

Balbutsev, Molodtsova, Schuck, Phys. Rev. C 88, 014306 (2013).
 Balbutsev, Molodtsova, Schuck, Phys. Rev. C 97, 044316 (2018).
 Balbutsev *et al.*, Phys. Rev. C 105, 044323 (2022).



science & innovation

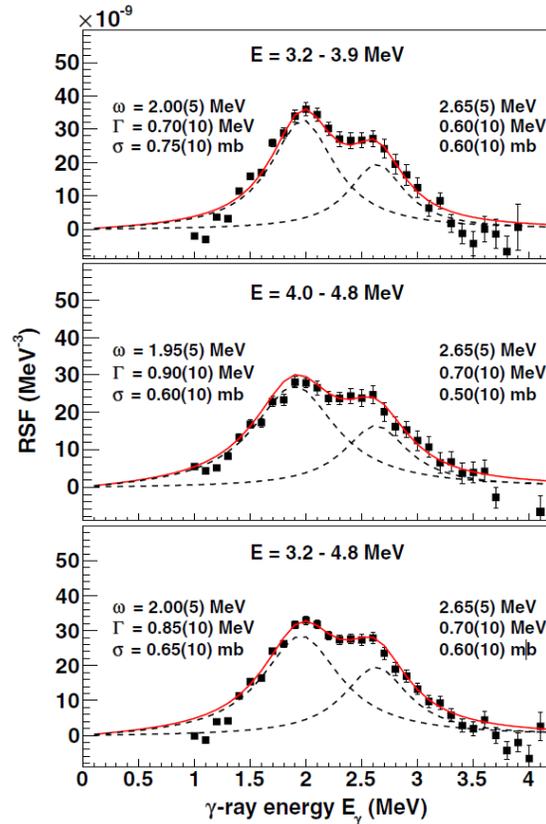
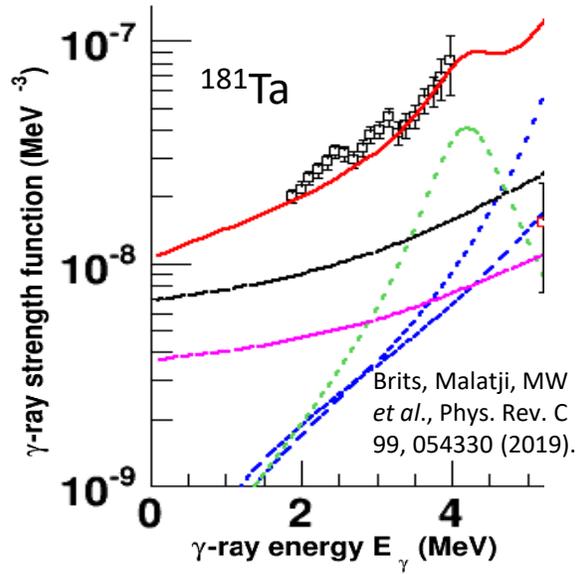
Department:
 Science and Innovation
 REPUBLIC OF SOUTH AFRICA

WITS
 UNIVERSITY

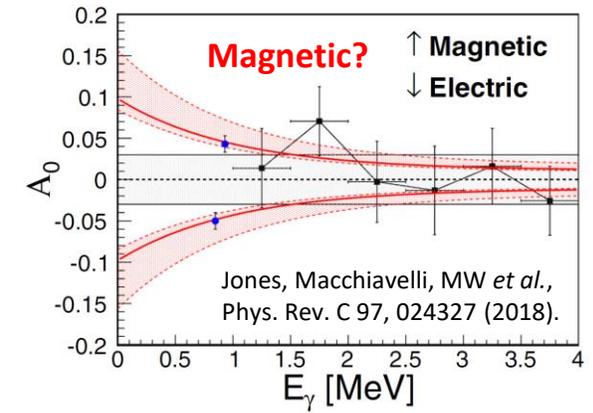
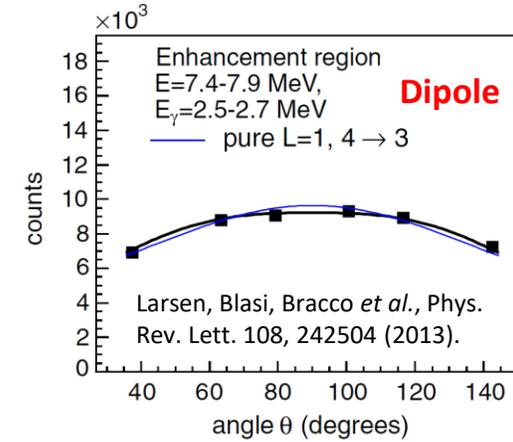
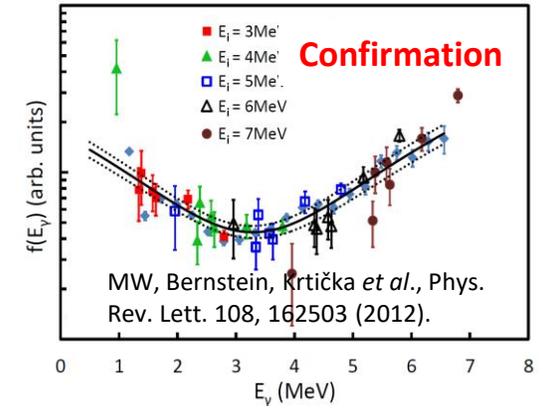
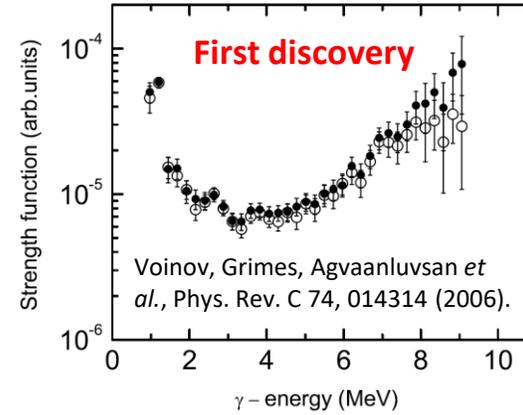


iThemba
 LABS
 Laboratory for Accelerator
 Based Sciences

Nuclear Structure from the PSF: SR and LEE



Guttormsen, Bernstein, Bürger *et al.*, Phys. Rev. Lett. 109, 162503 (2012).



Nature of splitting?

i) Triaxiality

Iudice *et al.*, Phys. Lett. B 161, 18 (1985).
 Lipparini, Stringari, Phys. Rep. 175, 103 (1989).
 F. Palumbo, Phys. Rev. C 99, 034319 (2019).

ii) Spin Scissors Mode

Balbutsev, Molodtsova, Schuck, Phys. Rev. C 88, 014306 (2013).
 Balbutsev, Molodtsova, Schuck, Phys. Rev. C 97, 044316 (2018).
 Balbutsev *et al.*, Phys. Rev. C 105, 044323 (2022).

Connection between LEE and SR.

Schwengner, Frauendorf, Brown, Phys. Rev. Lett. 118, 092502 (2017).



science & innovation

Department:
 Science and Innovation
 REPUBLIC OF SOUTH AFRICA

WITS
 UNIVERSITY

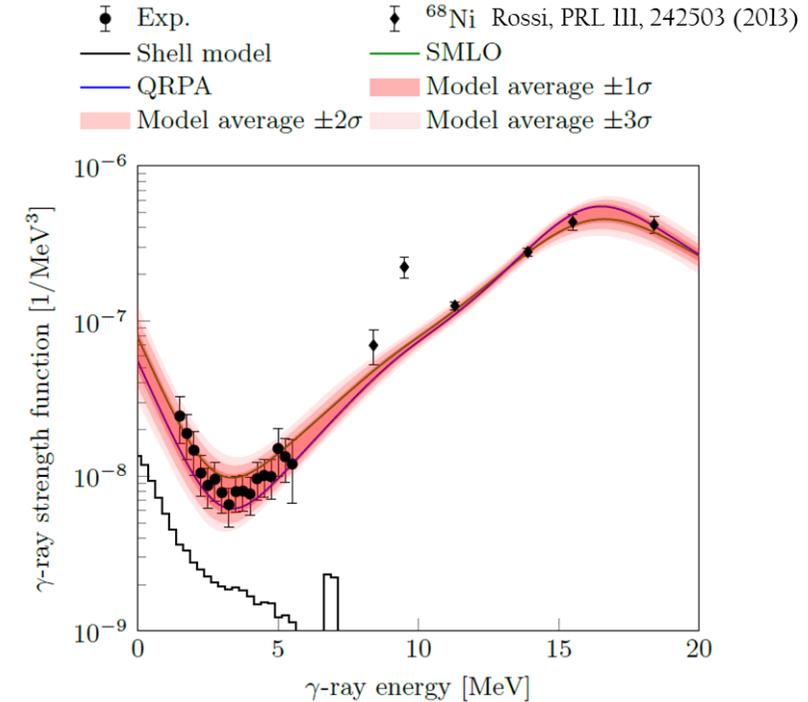
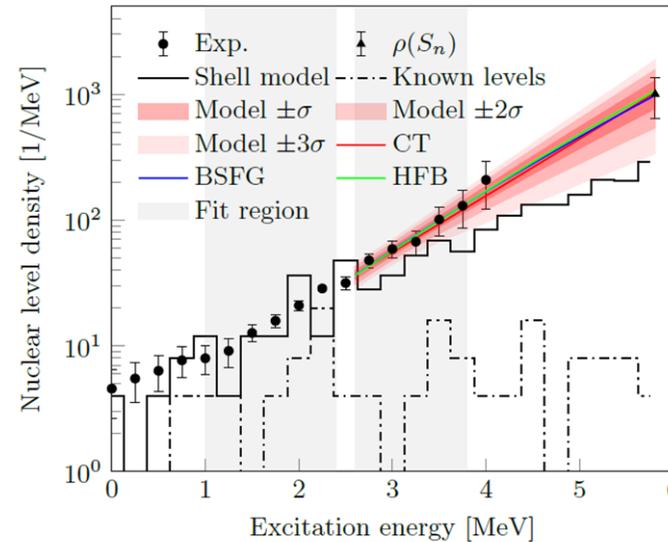


iThemba
 LABS
 Laboratory for Accelerator
 Based Sciences

^{67}Ni : PSF and NLD from inverse-Oslo



Ingeberg, Siem, MW *et al.*,
manuscript in preparation.



V. Ingeberg, Ph.D. thesis, University of Oslo, 2022.

V. Ingeberg *et al.*, manuscript in preparation.

- $d(^{66}\text{Ni}, p)^{67}\text{Ni}$ with 4.5 MeV/u
- CD target $0.7\text{mg}/\text{cm}^2$
- 3.5×10^6 pps for 140 hours
- Miniball + LaBr₃(Ce) + C-REX
- LaBr: $\sim 320\text{k}$ p- γ , Miniball: $\sim 1.1\text{m}$ p- γ



science & innovation

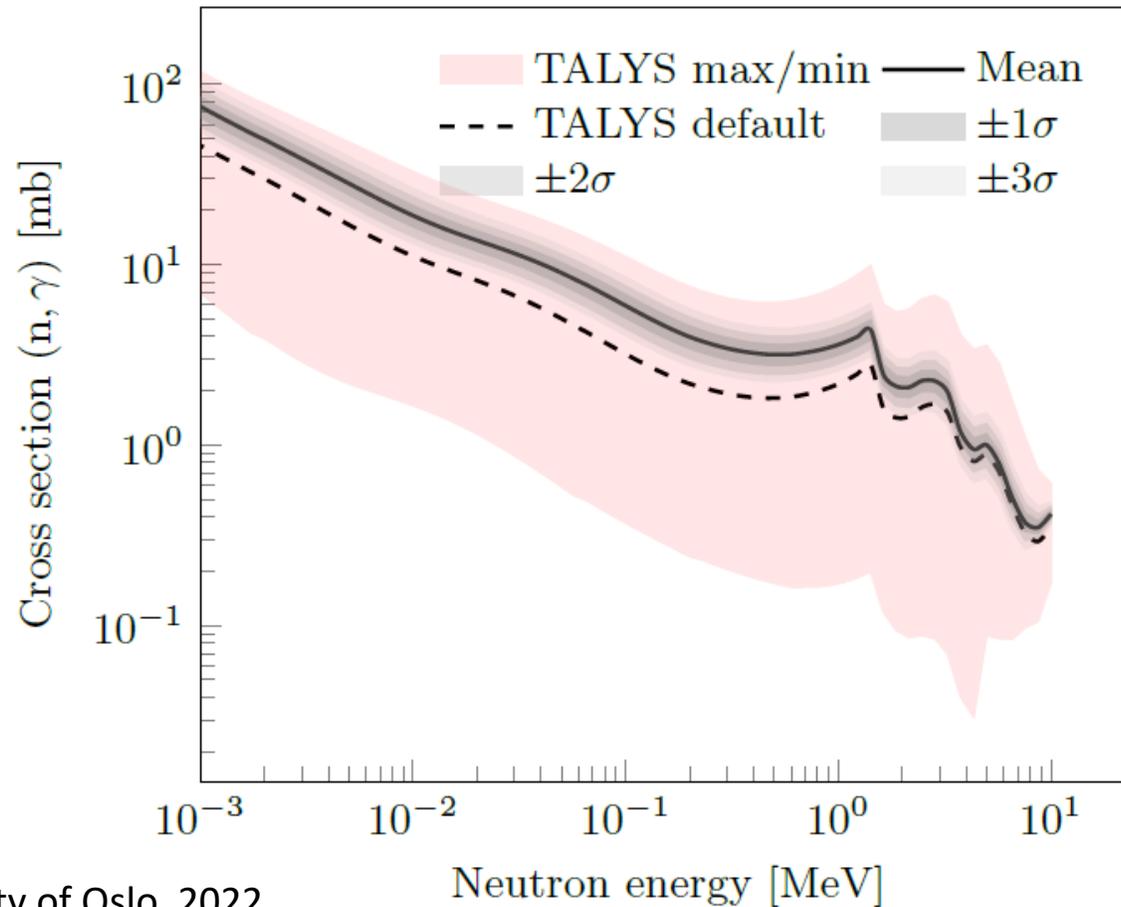
Department:
Science and Innovation
REPUBLIC OF SOUTH AFRICA

WITS
UNIVERSITY



iThemba
LABS
Laboratory for Accelerator
Based Sciences

$^{66}\text{Ni}(n,\gamma)$ for nuclear astrophysics



“The $^{66}\text{Ni}(n,\gamma)$ reaction is found to behave as a major bottleneck for the i-process nucleosynthesis.”

McKay *et al.*, MNRAS 491, 5179 (2020).

V. Ingeberg, Ph.D. thesis, University of Oslo, 2022.
V. Ingeberg *et al.*, manuscript in preparation.



science & innovation

Department:
Science and Innovation
REPUBLIC OF SOUTH AFRICA

WITS
UNIVERSITY



iThemba
LABS
Laboratory for Accelerator
Based Sciences

Summary

- Majority of tools now available with experimental/analytical techniques
 - Inverse-Oslo method
 - Shape Method
- Nuclear structure
 - Scissor's Resonance
 - Low-Energy Enhancement
- Nucleosynthesis processes
 - ^{67}Ni : bottleneck



science & innovation

Department:
Science and Innovation
REPUBLIC OF SOUTH AFRICA

WITS
UNIVERSITY



iThemba
LABS
Laboratory for Accelerator
Based Sciences

Collaborators



UiO
University of Oslo



This work is supported by the National Research Foundation of South Africa under grant number 118840.

