Electromagnetic dipole response studies at the southern tip of Africa

Mathis Wiedeking

iThemba LABS, Cape Town
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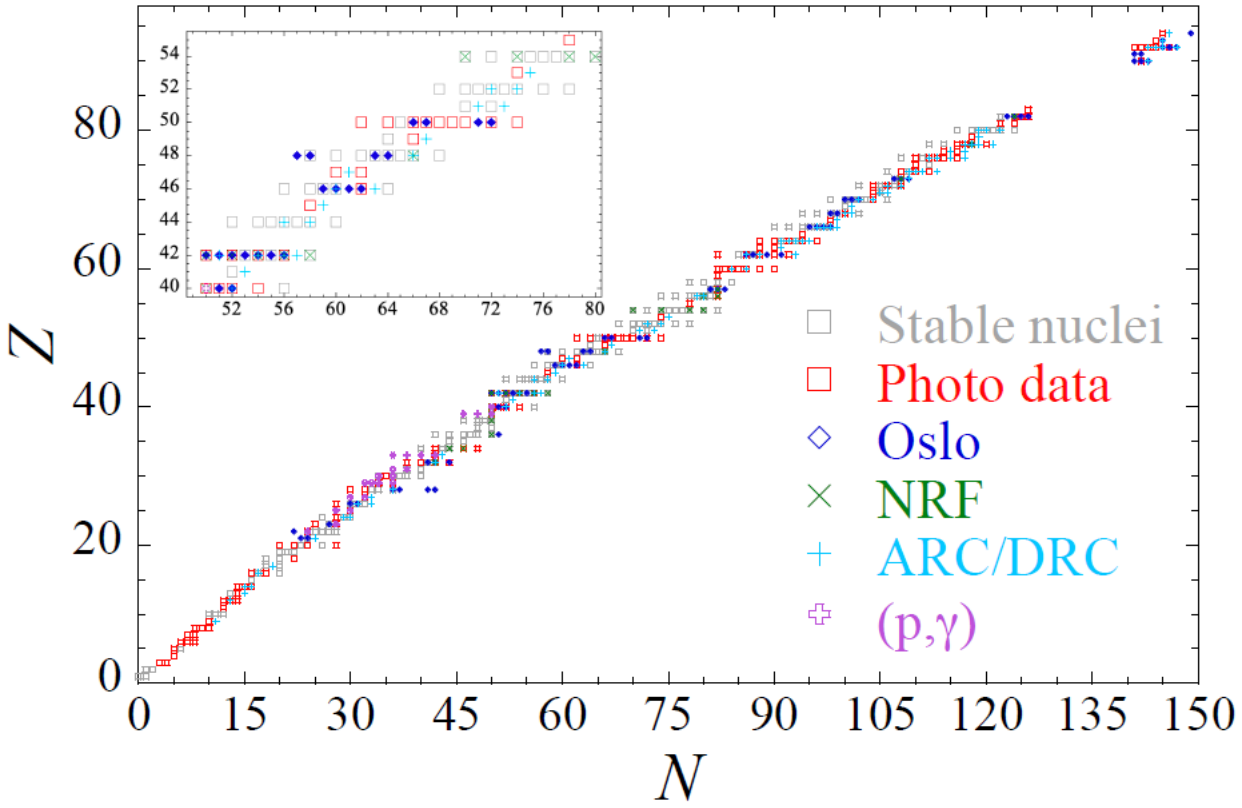
Supported by the National Research Foundation under grant number 118840.

What do we want to achieve?



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

Nuclear Structure → Pygmy, Scissors, LEE

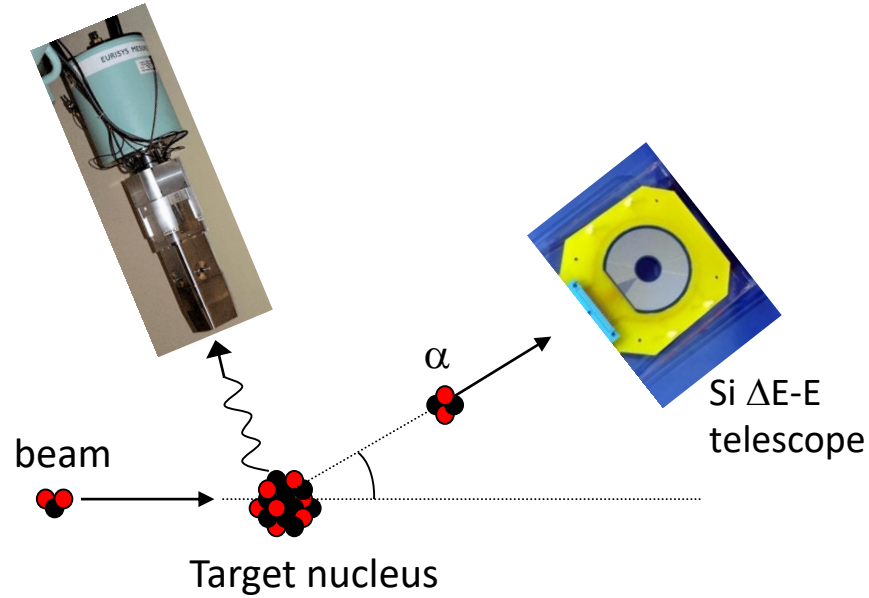
(n,γ) cross sections → Nucleosynthesis

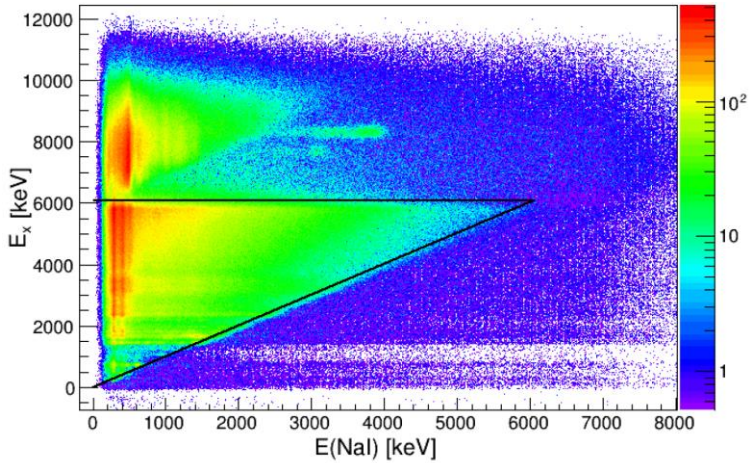
Experimental methods → Inverse OM (p,γ) reactions

Analytical methods → Shape Method

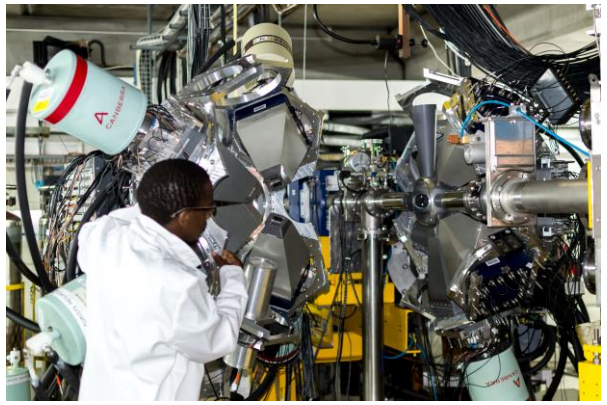
Measuring the PSF and NLD

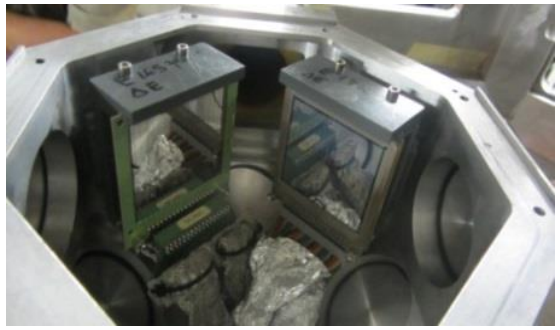
- Photonuclear Reactions (>S_n)
- Primaries from n-capture (>S_n)
- Nuclear Resonance Fluorescence (<S_n)
- Two-step cascade, n/p capture (<S_n)
- Inelastic p scattering with polarized beam (<S_n and >S_n)
- Primaries from p-capture (>S_p and <S_n)
- Primaries from charged particle reactions (<S_n)
  - Oslo, beta-Oslo, inverse Oslo Methods
  - Ratio/Shape Methods



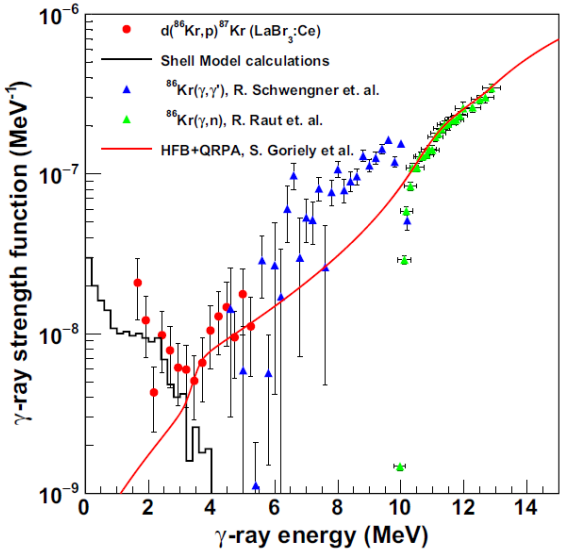


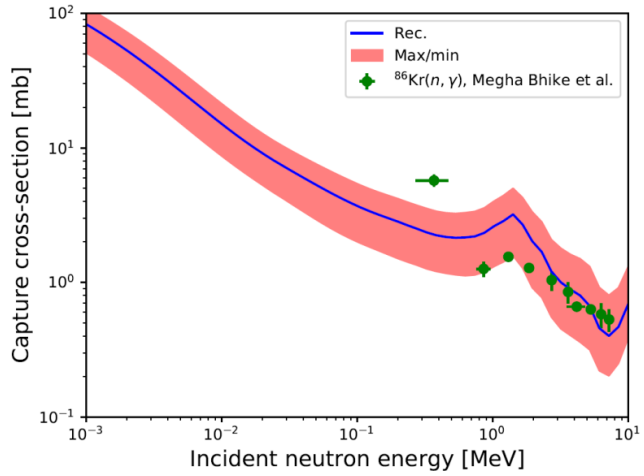
PSF and NLD from Inverse Kinematics at iThemba LABS





300MeV ^{86}Kr, CD targets. HPGe + $LaBr_3$(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

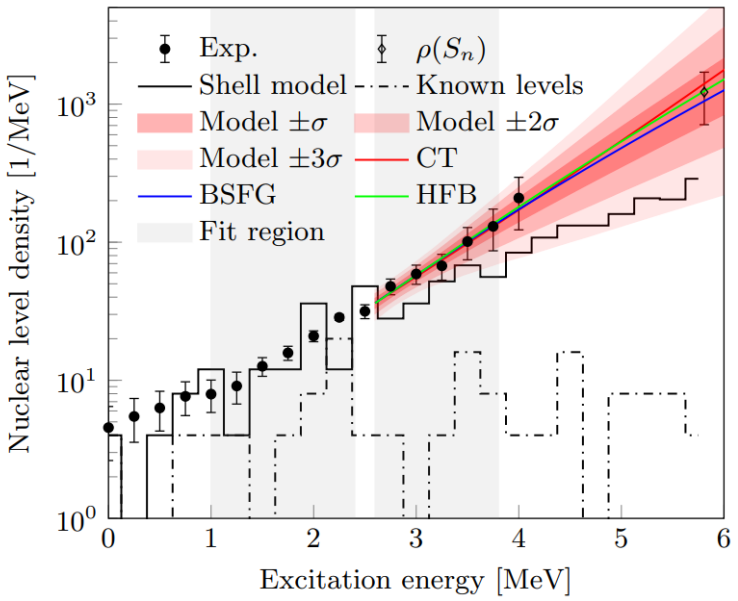
Regular Article - Experimental Physics

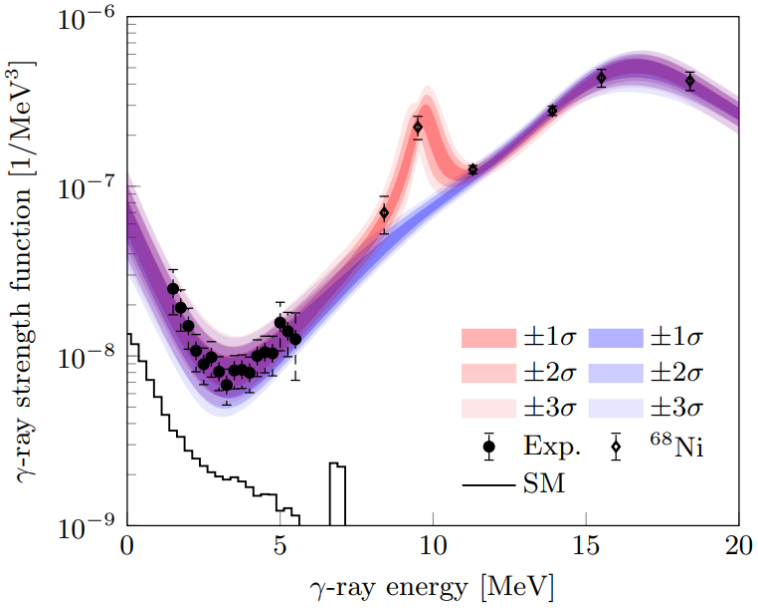
First application of the Oslo method in inverse kinematics

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

V. W. Ingeberg[1,a], S. Siem[1], M. Wiedeking[2], K. Sieja[3,4], D. L. Bleuel[5], C. P. Brits[2,6], T. D. Bucher[2], T. S. Dinoko[2], J. L. Easton[2,7], A. Görgen[1], M. Guttormsen[1], P. Jones[2], B. V. Kheswa[2,8], N. A. Khumalo[2], A. C. Larsen[1], E. A. Lawrie[2], J. J. Lawrie[2], S. N. T. Majola[2,8,9], K. L. Malatji[2,6], L. Makhathini[2,6], B. Maqabuka[2,7], D. Negi[2], S. P. Noncolela[2,7], P. Papka[2,6], E. Sahin[1], R. Schwengner[10], G. M. Tveten[1], F. Zeiser[1], B. R. Zikhali[2,9]

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





- d(^{66}Ni,p)^{67}Ni with 4.5 MeV/u
- CD target 0.7mg/cm^2
- 3.5x10^6 pps for 140 hours
- Miniball + LaBr$_3$(Ce) + C-REX
- LaBr: ~320k p-γ, Miniball: ~1.1m p-γ

Ingeberg, Siem, MW *et al.*, submitted to PRC (2023).

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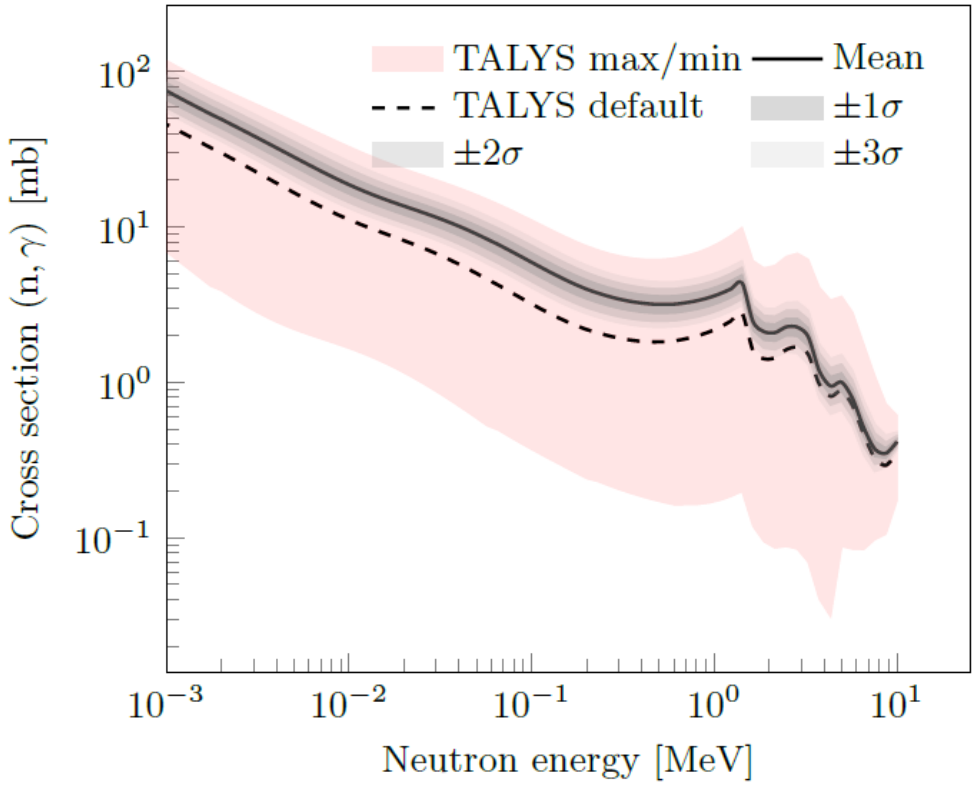
^{66}Ni(n,γ) for nucleosynthesis



"The ^{66}Ni(n,γ) reaction is found to behave as a major bottleneck for the i-process nucleosynthesis."

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

^{66}Ni(n,γ) acts as bottleneck when using one-zone models in agreement with McKay et al.

Impact is marginal in multi-zone low-metallicity AGB stellar models experiencing i-process nucleosynthesis.

Ingeberg, Siem, MW *et al.*, submitted to PRC (2023).

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)

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. Görgen,[3] S. N. Liddick,[4,5] D. Mücher,[6,7] S. Siem,[3] and A. Spyrou[4,8]

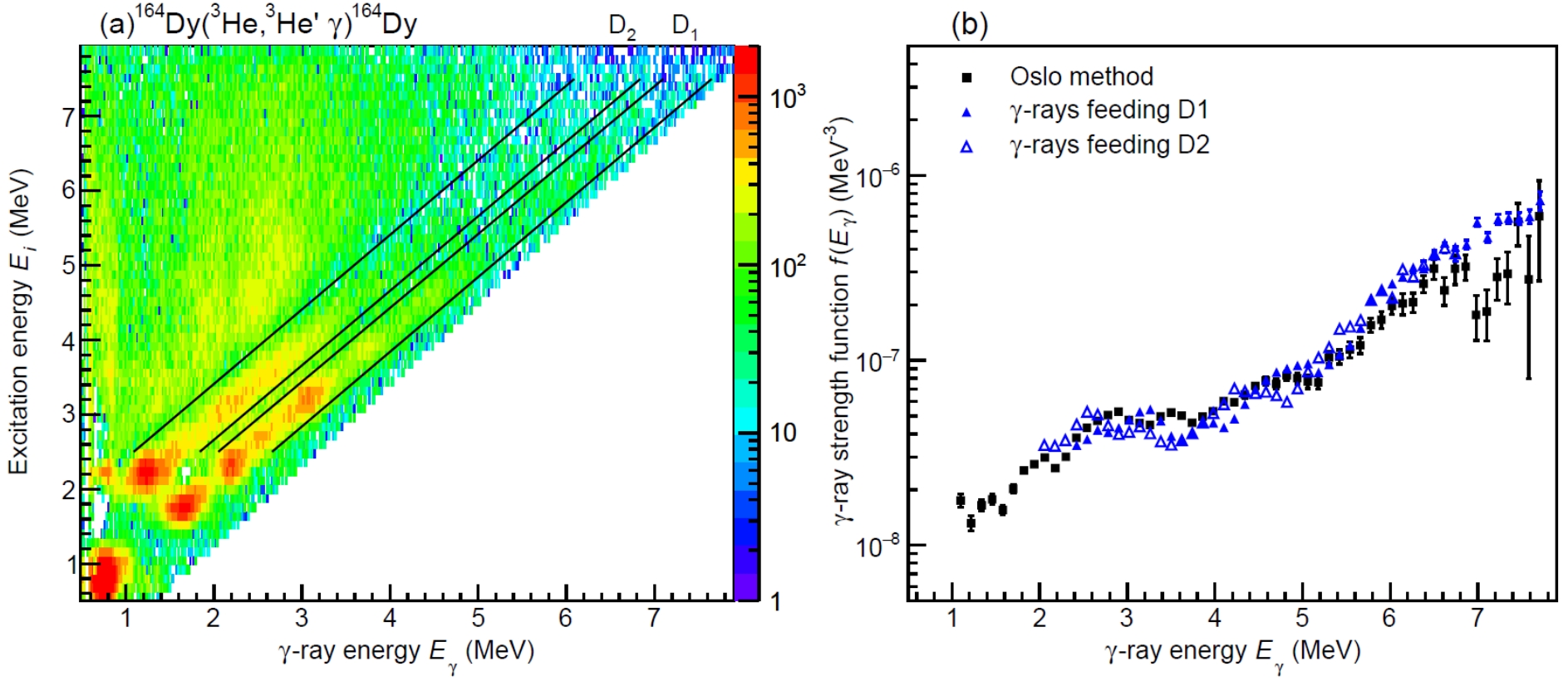
PHYSICAL REVIEW C **107**, L011602 (2023)

Letter

Extracting model-independent nuclear level densities away from stability

D. Mücher,[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. Görgen,[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 Seeger[13]

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).

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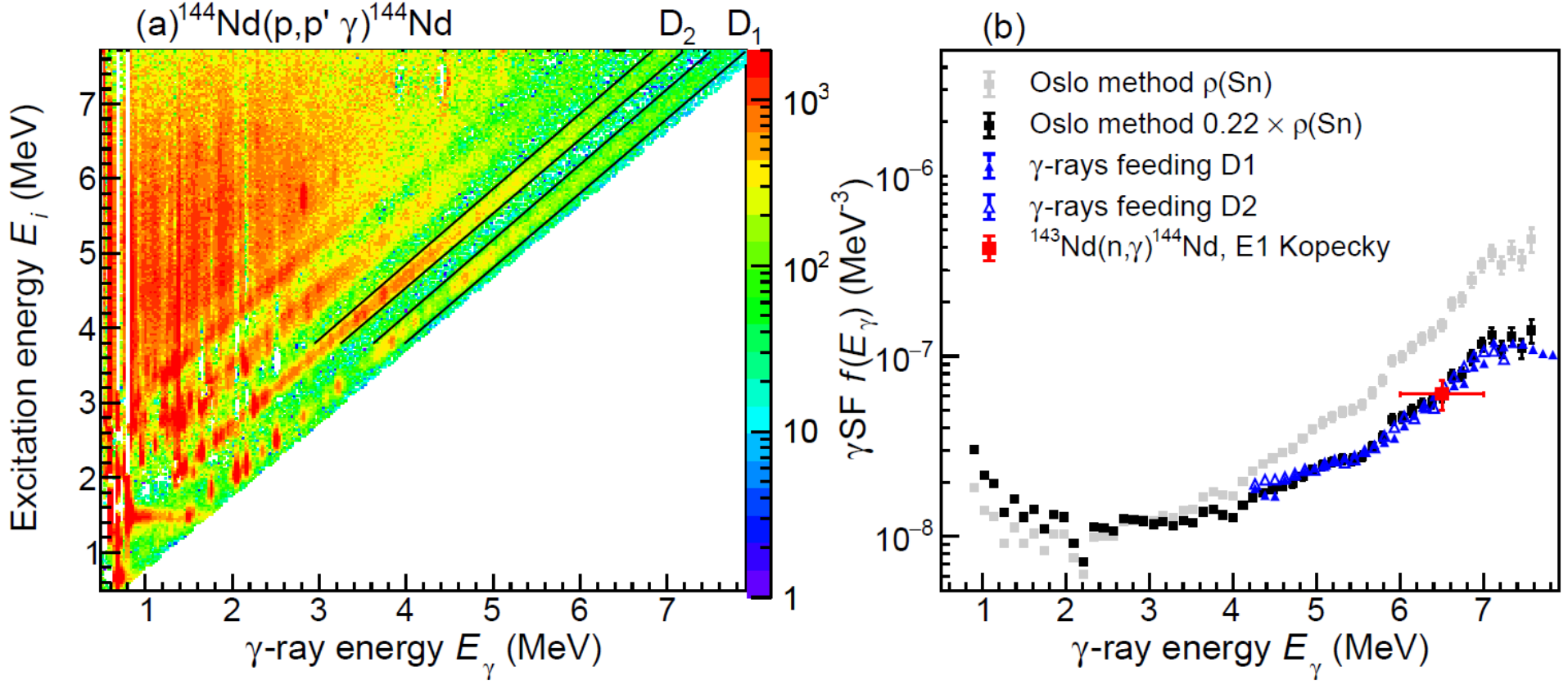
Shape Method in practice: ^{144}Nd

Comprehensive study on PSF evolution for 9 Nd isotopes.



Guttormsen, Ay, Ozgur et al., Phys. Rev. C 106, 034314 (2022).

Tandetron: low-energy nuclear physics beam line

Half-sphere frame
7 HPGe or large $LaBr_3$:Ce
+4 Small $LaBr_3$:Ce detectors
Angular range (45, 90, 135 deg.)

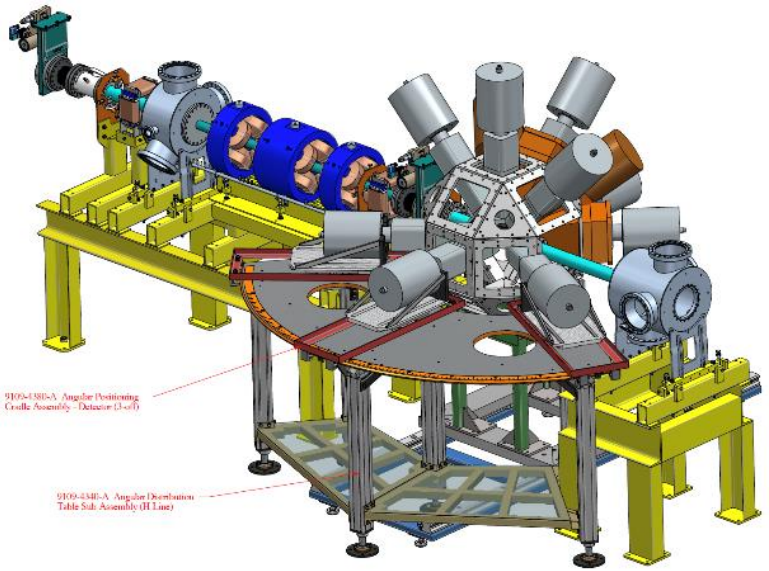
Angular distribution table, 3 detectors on carriages (20-160 deg.)

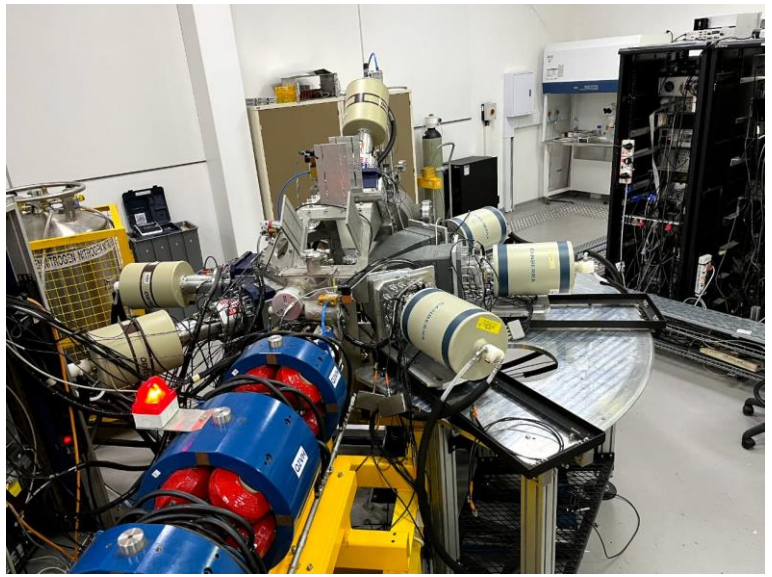
Beams: p, α, ^{3}He

Energies: 0.5-6 MeV p

1-9 MeV α

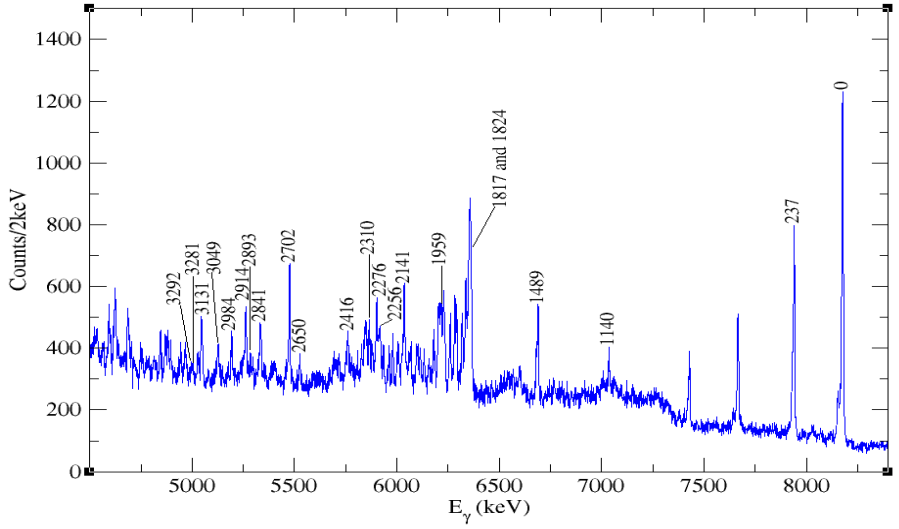
Intensities: ~ 10 nA - 10 ***μ***A

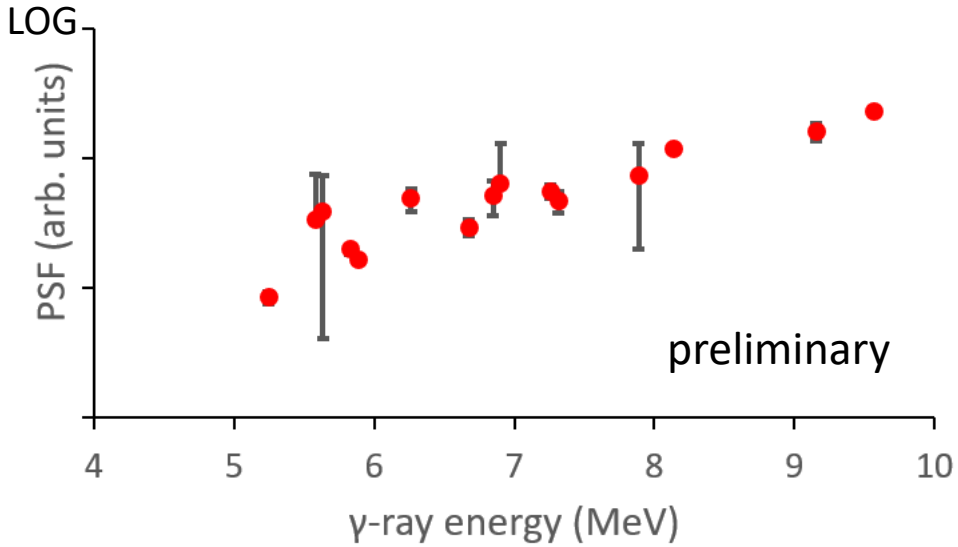




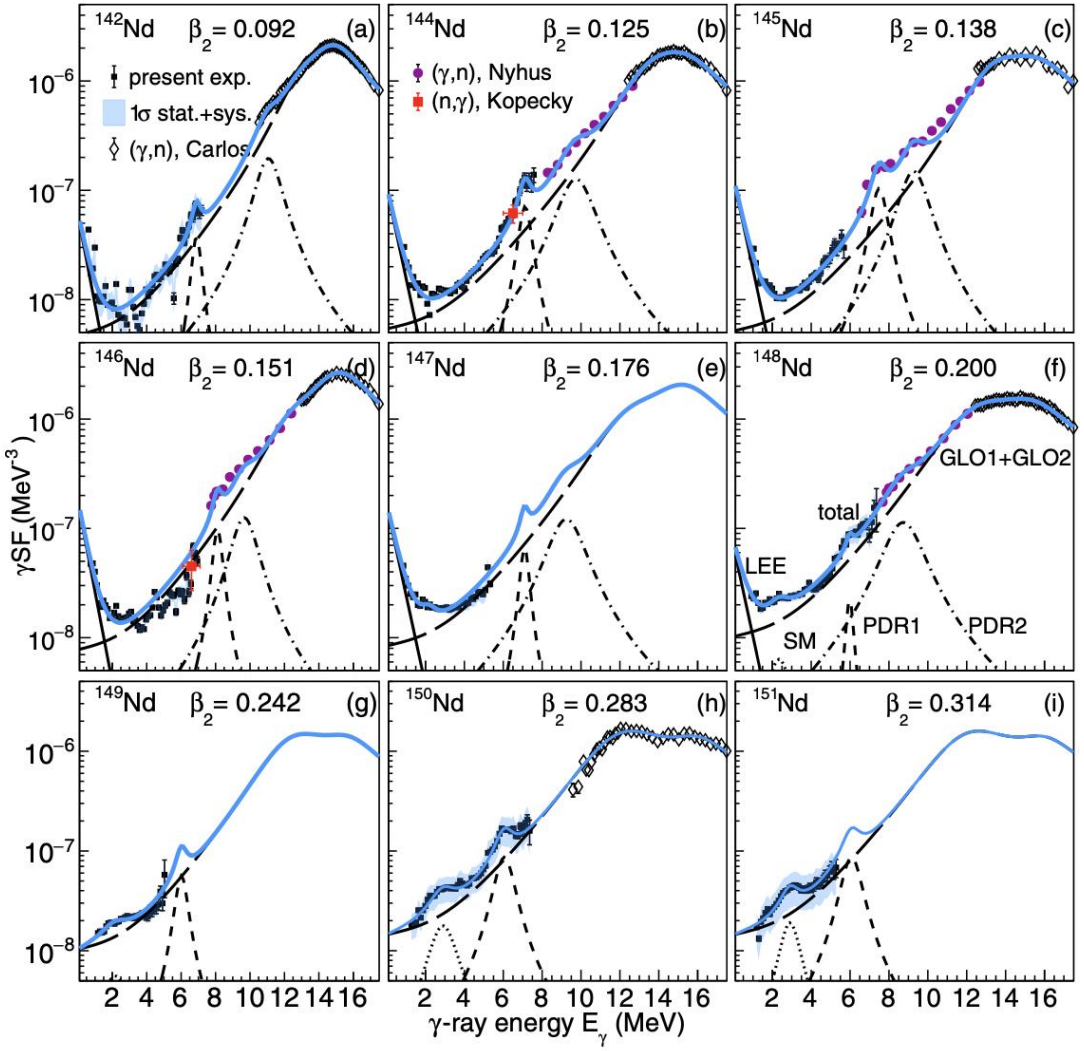
Photon strength functions from (p,γ) reactions

- $^{50}Cr(p, \gamma)^{51}Mn$.
- 1 Clover and 1 $LaBr_3$:Ce detector
- ^{50}Cr targets of 200-350 $\mu g/cm^2$
- Proton beams of 2.5 to 3 MeV and 3.7 to 4.5 MeV in 20-25 keV intervals.
- A total of 64 γ-ray spectra were collected.
- ARC method.
- Pairs of primary transitions feeding discrete states to extract shape of PSF.



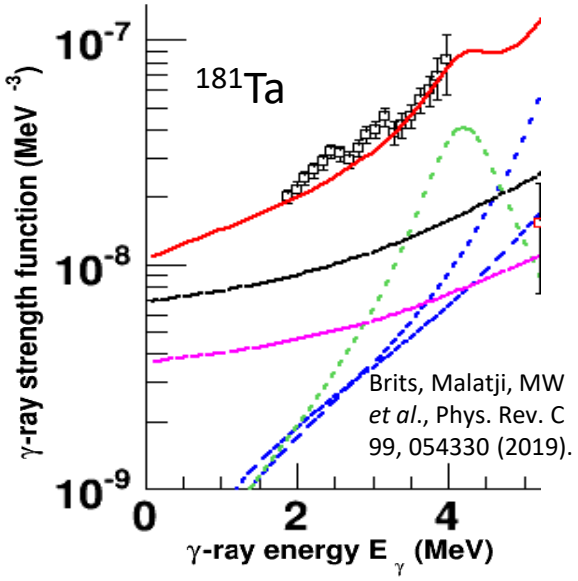


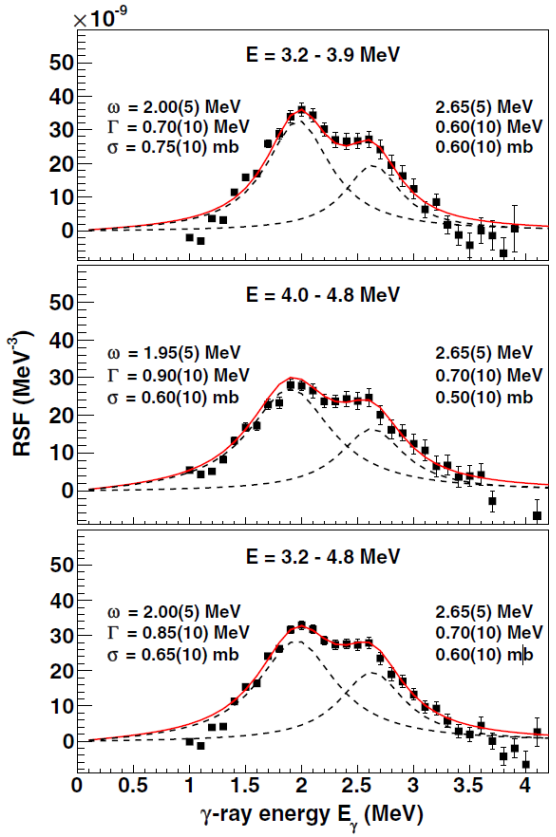
Photon strength function and resonances



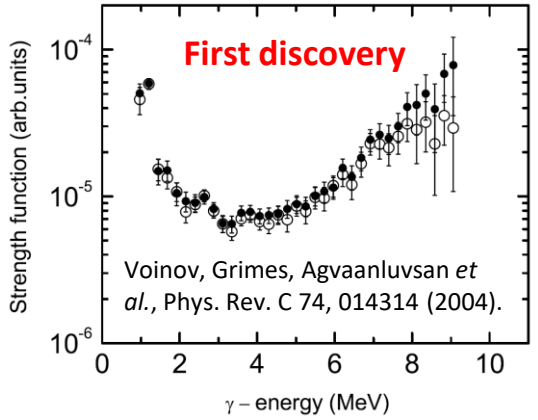
Guttormsen, Ay, Ozgur et al.,
Phys. Rev. C 106, 034314 (2022).

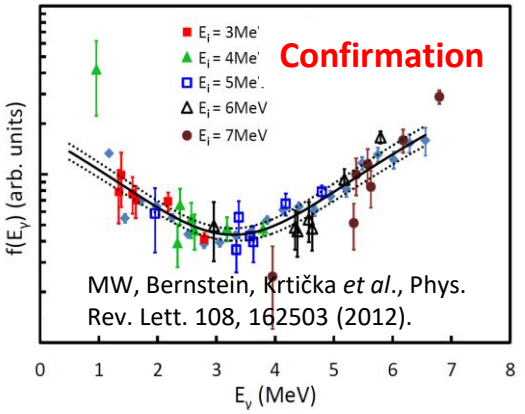
Nuclear Structure from the PSF: SR and LEE

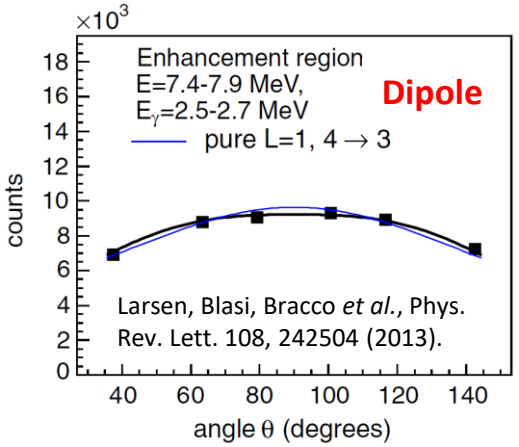


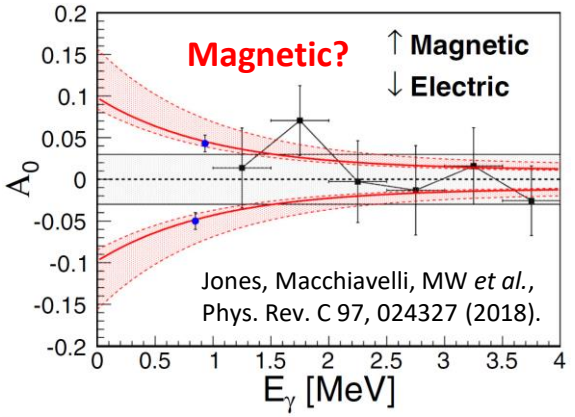


Guttormsen, Bernstein, Bürger *et al.*, Phys. Rev. Lett. 109, 162503 (2012).









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).
Frauendorf, Schwengner Phys. Rev. C 105, 034335 (2022).

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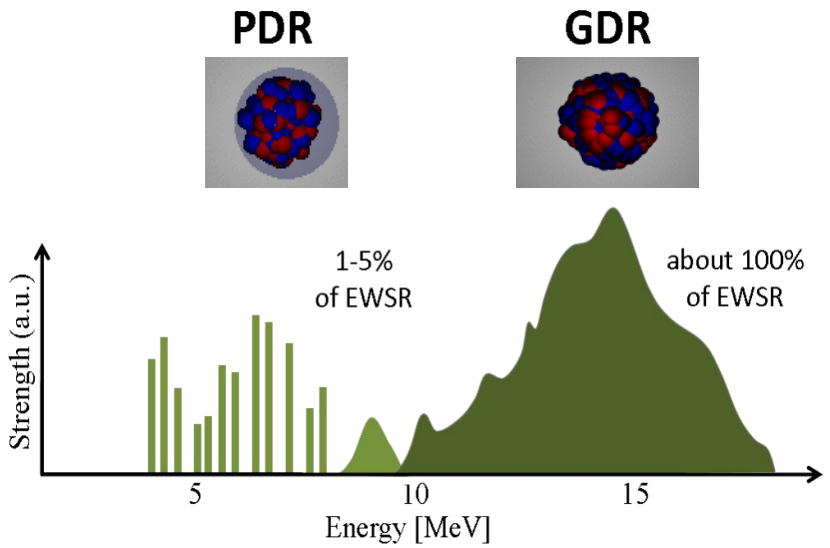
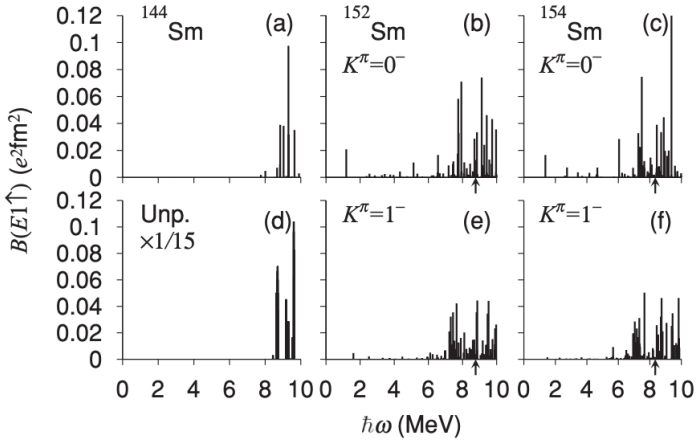
Pygmy Dipole Resonance: spherical vs deformed nuclei

- Present in N>Z nuclei
- Mixed isospin nature
- Surface Excitation



Open Questions

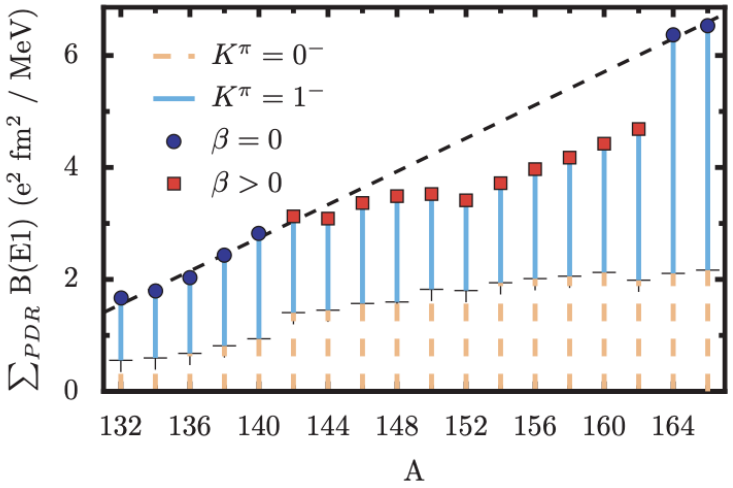
- Collective or single particle
- IS vs IV interplay
- Role of deformation



Nd and Sm isotopes - HFB plus QRPA with Skyrme interaction

K. Yoshida and T. Nakatsukasa, PRC 83, 021304(R) (2011).

Substantial Increase of dipole strength with deformation



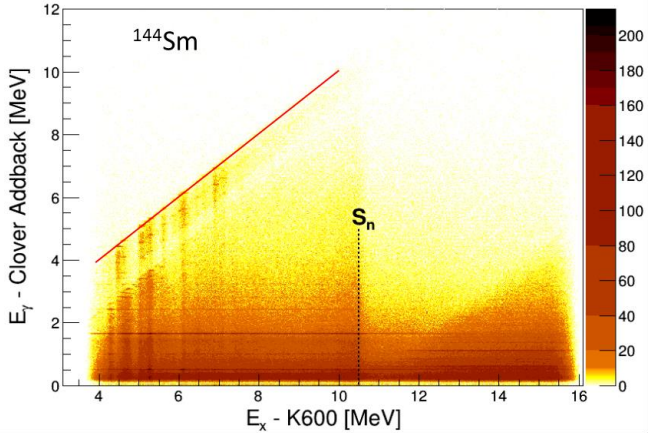
Tin isotopes – RHB + QRPAD.

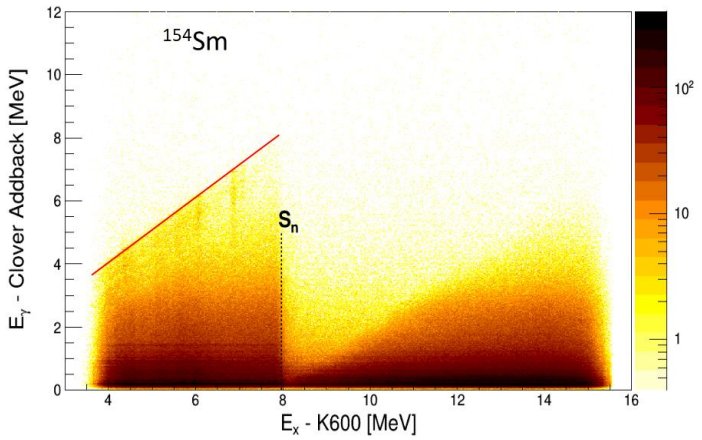
Peña Arteaga, E. Khan and P. Ring, PRC 79, 034311 (2009).

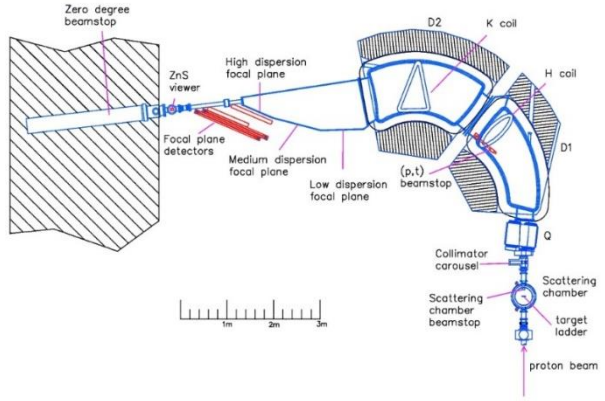
Quenching of dipole strength with deformation

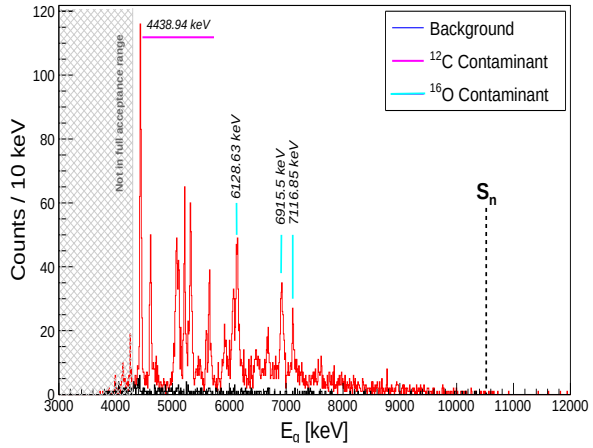
Pygmy Dipole Resonance: spherical vs deformed nuclei

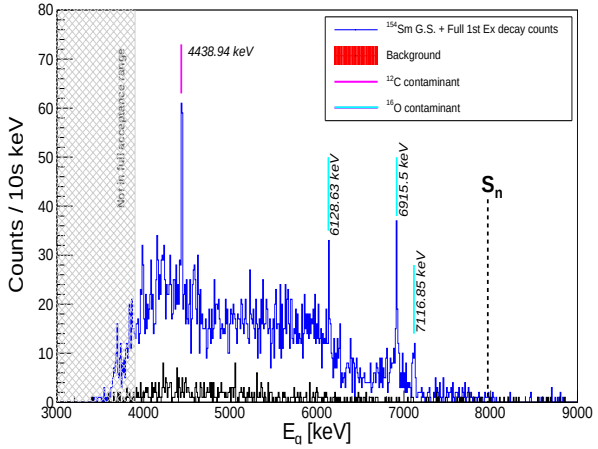
^{154}Sm and ^{144}Sm with (α,α'γ) at 120 MeV: K600 at 0° + HPGe + $LaBr_3$:Ce

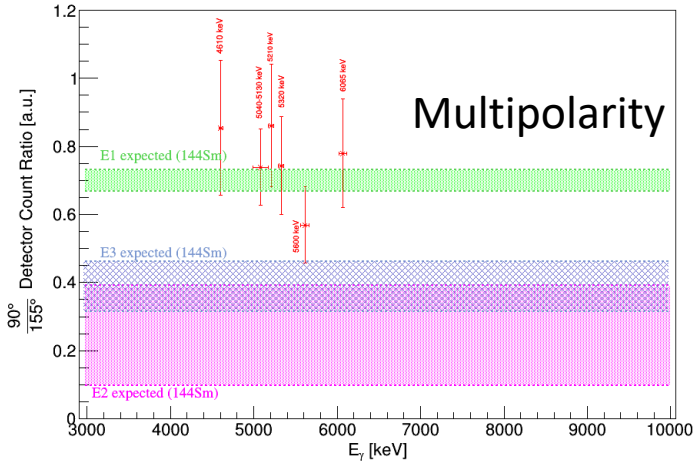












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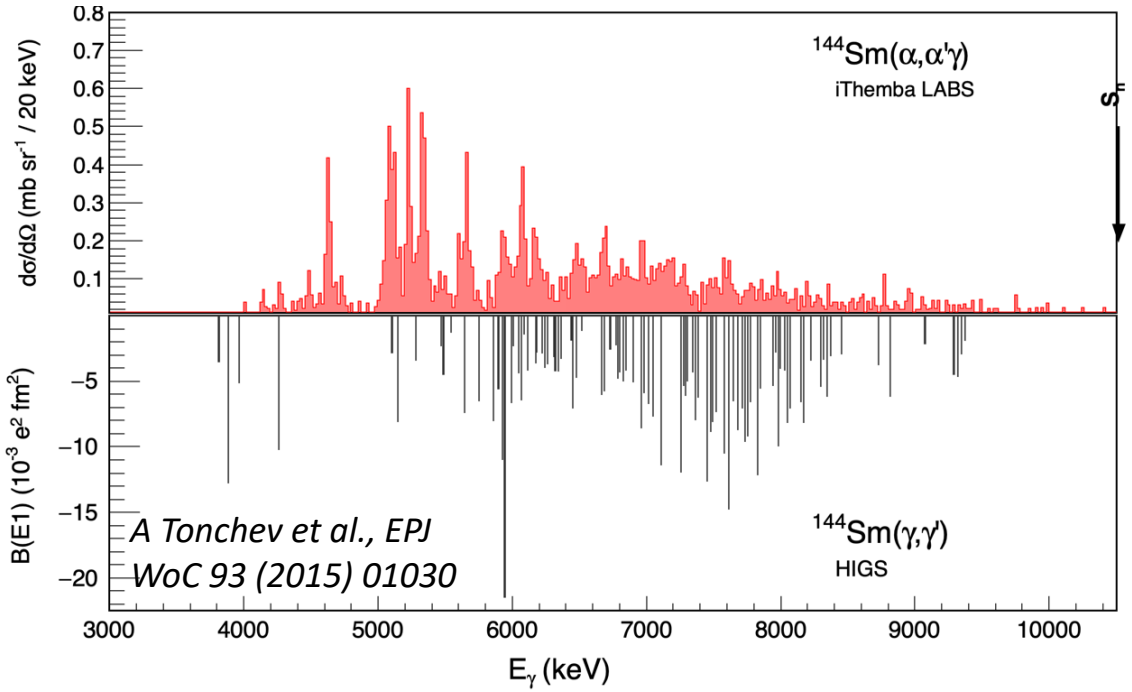
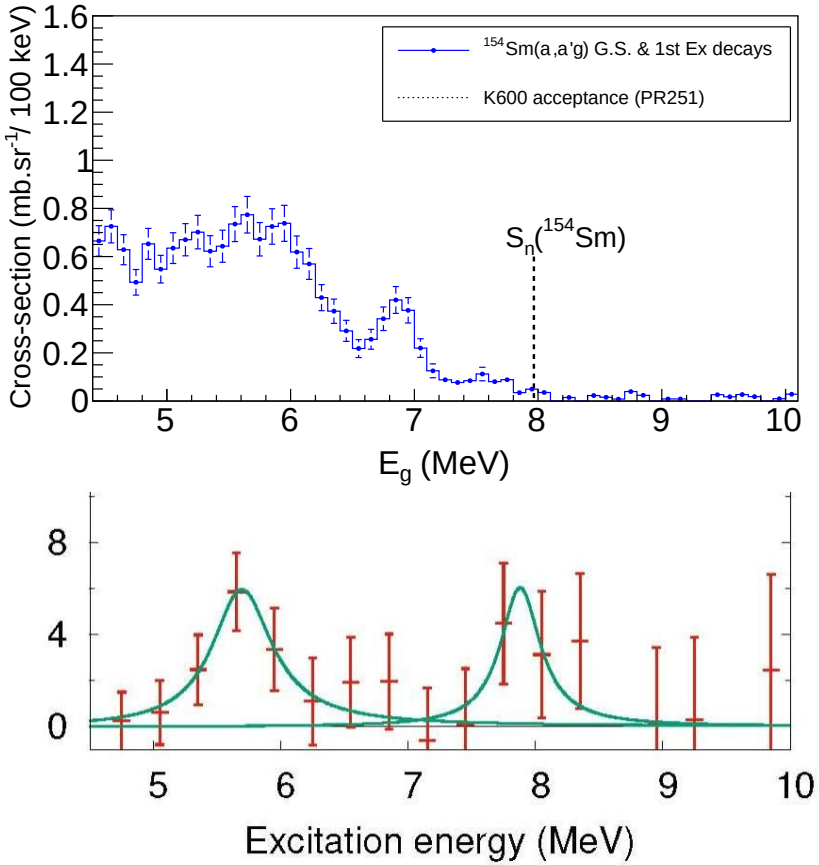
Pygmy Dipole Resonance: spherical vs deformed nuclei





- Isospin splitting observed but no K-splitting in the IS response.
- Direct decay strength appears hindered, more fragmented with deformation
- ^{144}Sm response agrees with predictions but not ^{154}Sm: Statistical decay component? Individual structures of states?

^{154}Sm(p,p') at 295 MeV isovector response.
P. von Neumann-Cosel, private communication

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Summary

Majority of tools now available for next generation PSF and NLD measurements

Experimental techniques: Beta-Oslo, Inverse Oslo

Analytical: Shape Method

Significant increase in detection efficiencies worldwide

Nuclear Structures

Pygmy Dipole Resonance

Scissor's Resonance

Low-Energy Enhancement

(n,γ) cross sections for nuclear astrophysics

^{66}Ni(n,γ) bottleneck