High Spin Evolution of the doubly midshell nucleus ^{170}Dy

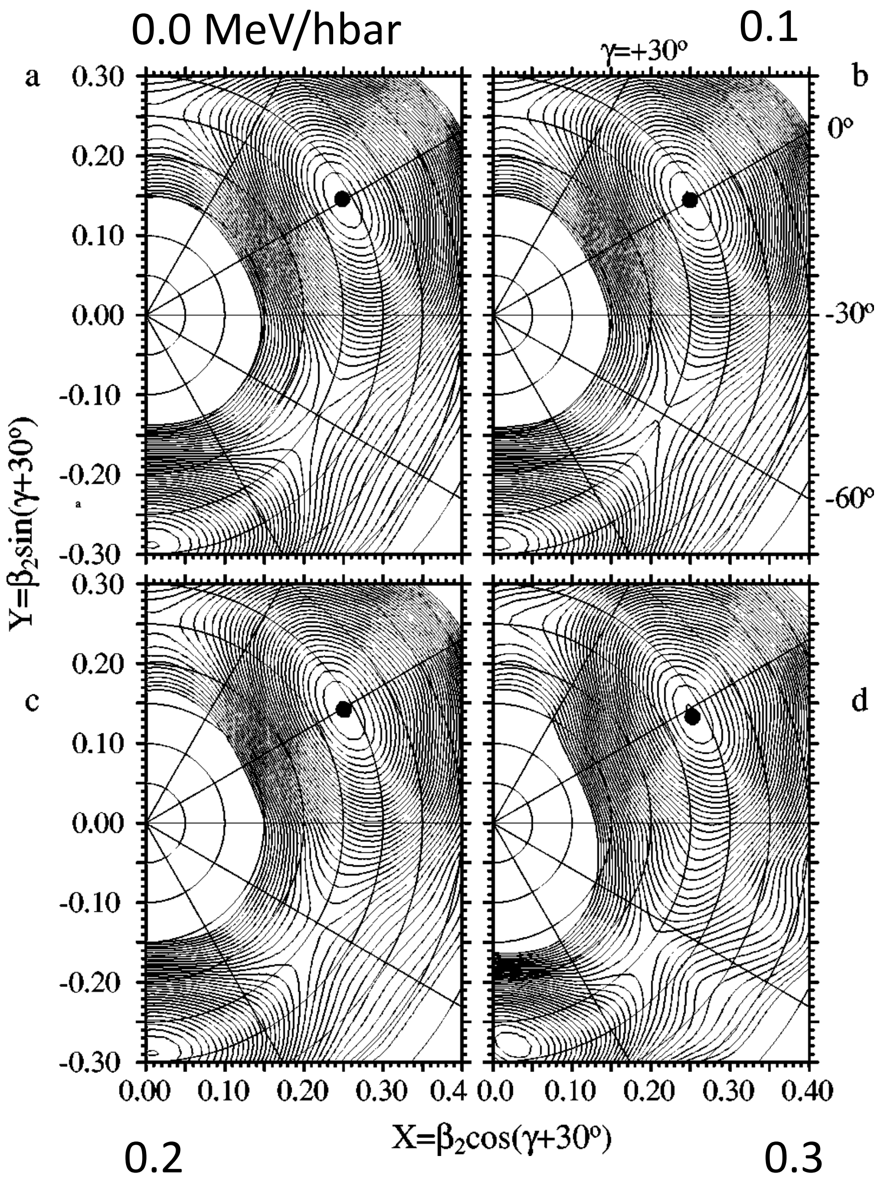
A.J. Boston, J. Nyberg, P. Regan, J Simpson

Presentation overview

- Key Physics motivation
- How can you access ^{170}Dy?
- What is known?
- What could be expected?
- Preliminary simulations
- Expectations
- Summary

Key physics motivation

- The nucleus ^{170}Dy has the largest value of the proton-neutron valence product, N_pN_n, of all nuclei with A < 208.
- Theoretical predictions suggest that ^{170}Dy may be one of the stiffest axially deformed nuclei in nature [1], which has significant consequences for the robustness of the K quantum number.
- In addition, ^{170}Dy may represent the best case of the SU(3) dynamical symmetry of the interacting boson approximation of all nuclei.



[1] P. Regan et al., Phys Rev. C 65, 037302

How to access ^{170}Dy?

- The structure of ^{170}Dy is challenging to study experimentally.
- A number of attempts have been made using projectile fragmentation of a Pb beam [2]
- Multi-nucleon transfer reactions between ^{82}Se and ^{170}Er [3]
- Multi-nucleon transfer between ^{136}Xe and ^{170}Er [6]
- In-flight fission from where an isomeric state was observed [4]
- The most recent work nuclei in the ^{170}Dy region were produced by in-flight fission of a 345 MeV/u ^{238}U beam on a Be target at RIBF in RIKEN [5]

[2] Zs. Podolyák, et al., in: J.H. Hamilton, W.R. Phillips, H.K. Carter (Eds.) 2000, p. 156
[3] P.-A. Söderström, et al., Phys. Rev. C 81 (3) (2010) 034310.
[4] D. Kameda, et al., RIKEN Accel. Prog. Rep. 47 (2014)
[5] Söderström et.al. Physics Letters B 762 (2016) 404–408
[6] A. Gengelbach. Licentiate Thesis, Uppsala Universitet (2021)

Candidate MN transfer reactions

Routes open to populate ^{170}Dy:

$^{48}Ca + ^{170}Er$ $^{136}Xe + ^{164}Dy$

$^{82}Se + ^{170}Er$

$^{136}Xe + ^{170}Er$ -> increase in yield of neutron-rich products + angular momentum transferred [-2p +2n] (^{136}Ba)

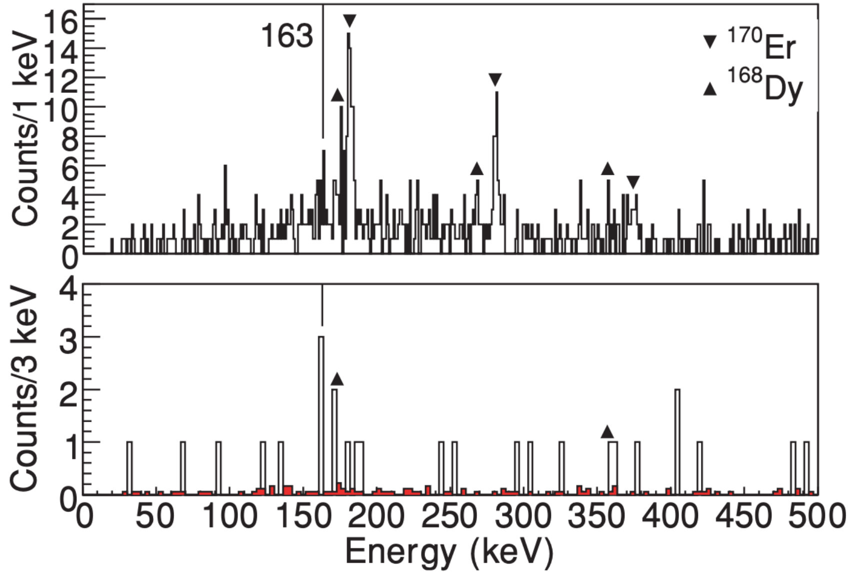
	100	101	102	103	104	105	106
68	Er-168	Er-169	Er-170	Er-171	Er-172	Er-173	Er-174
67	Ho-167	Ho-168	Ho-169	Ho-170	Ho-171	Ho-172	Ho-173
66	Dy-166	Dy-167	Dy-168	Dy-169	Dy-170	Dy-171	Dy-172

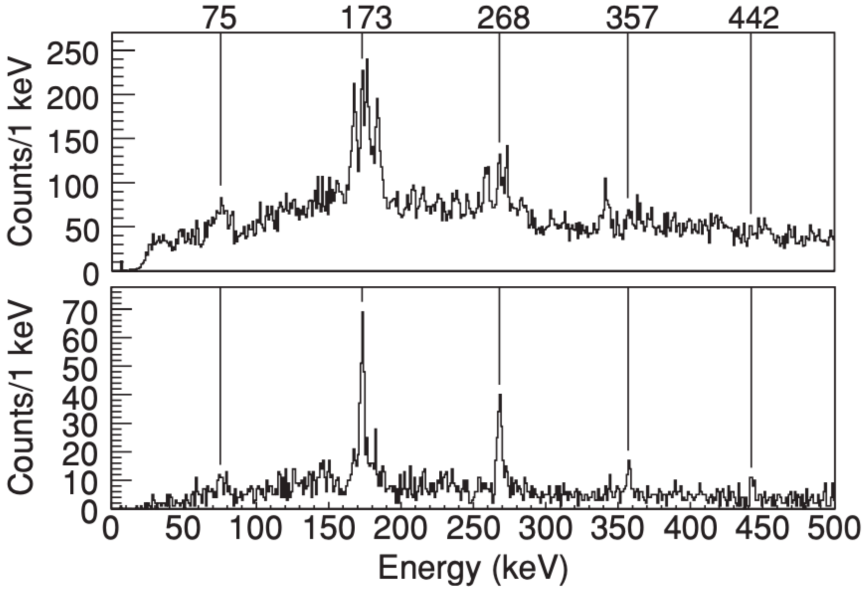
What is known?

CLARA-PRISMA ^{82}Se and ^{170}Er

- Tandem-ALPI 460MeV beam ~2pnA
- 52^0 Grazing angle
- 4^+ -> 2^+ ground-state band transition
- Candidate at 163 keV first reported

BLF	TLF_{max}	Transfer	Y_{rel}
^{81}Kr	^{171}Dy	$+2p-3n$	0.038 ± 0.007
^{82}Kr	^{170}Dy	$+2p-2n$	0.159 ± 0.009
^{83}Kr	^{169}Dy	$+2p-1n$	0.457 ± 0.016
^{84}Kr	^{168}Dy	$+2p$	1.000 ± 0.029
^{85}Kr	^{167}Dy	$+2p+1n$	1.230 ± 0.035
^{86}Kr	^{166}Dy	$+2p+2n$	1.084 ± 0.035
^{87}Kr	^{165}Dy	$+2p+3n$	0.652 ± 0.028
^{88}Kr	^{164}Dy	$+2p+4n$	0.306 ± 0.022
^{89}Kr	^{163}Dy	$+2p+5n$	0.154 ± 0.016
^{90}Kr	^{162}Dy	$+2p+6n$	0.069 ± 0.010



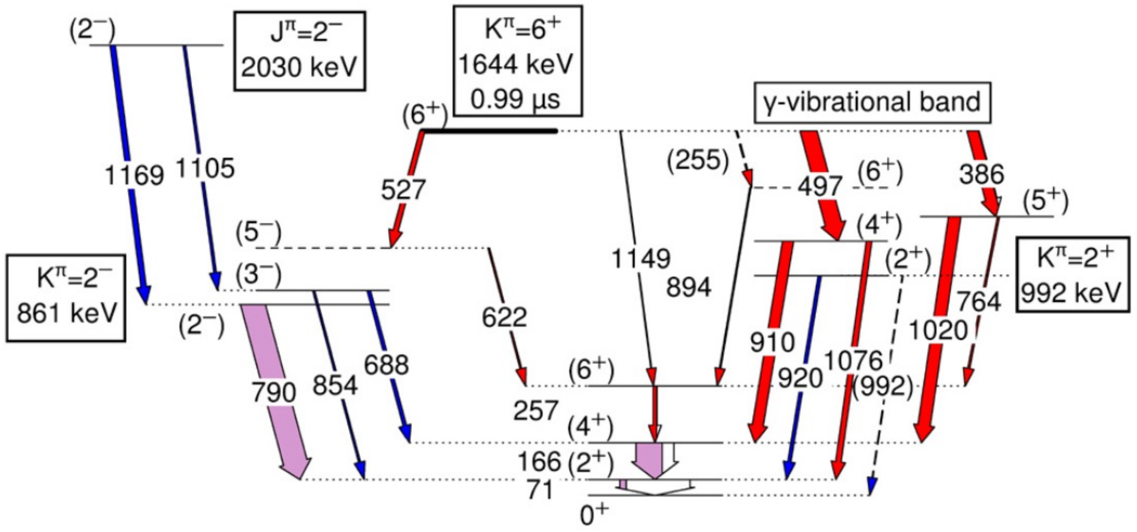


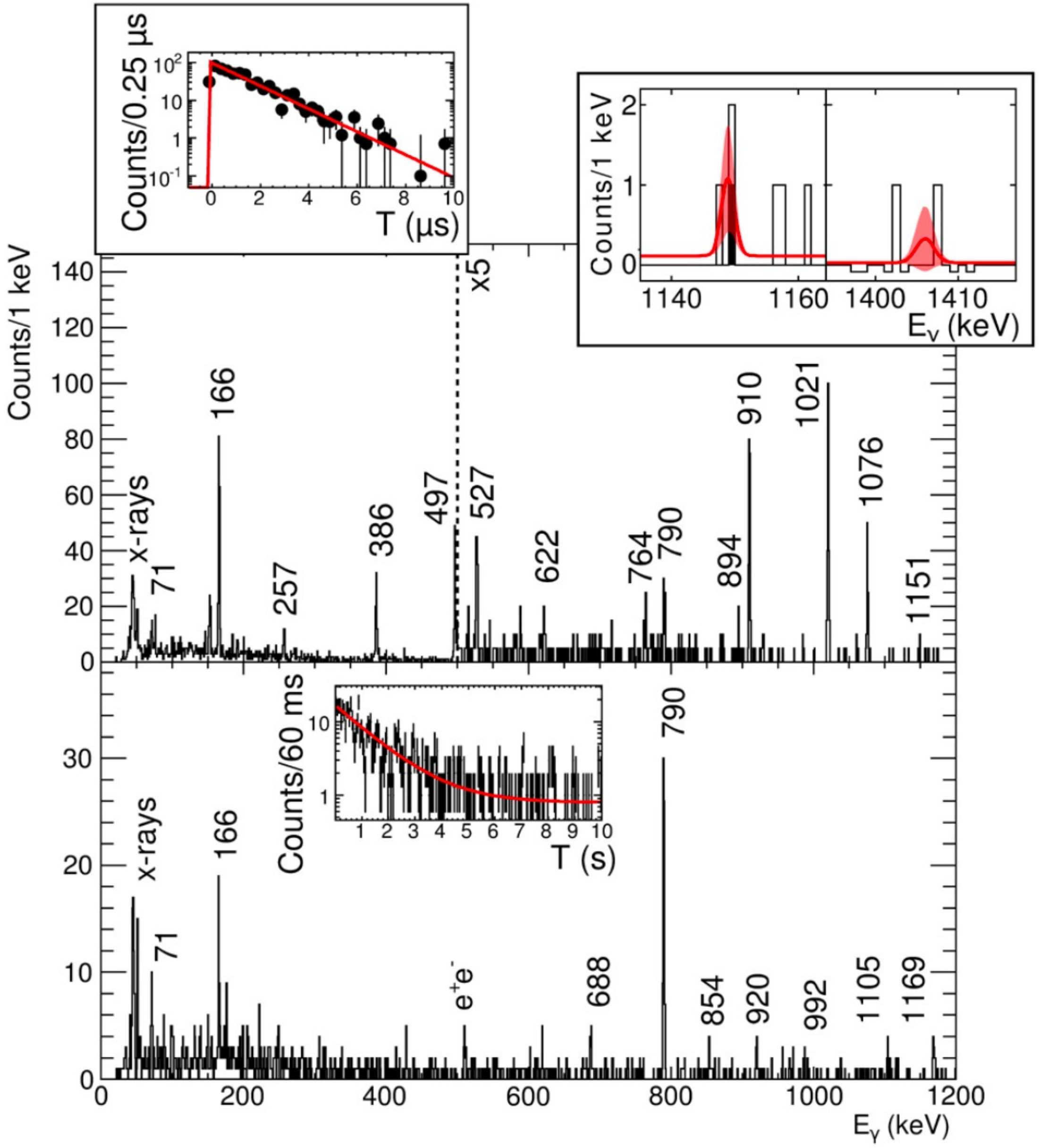
[3] P.-A. Söderström, et al., Phys. Rev. C 81 (3) (2010) 034310.

Target like fragments gated on the beam like ^{84}Kr. ^{168}Dy

What is known?

- The three lowest-lying excited states identified were assigned as the 2^+, 4^+ and 6^+ members of the yrast ground-state rotational band
- Confirming the earlier assignment as the $4^+ \rightarrow 2^+$

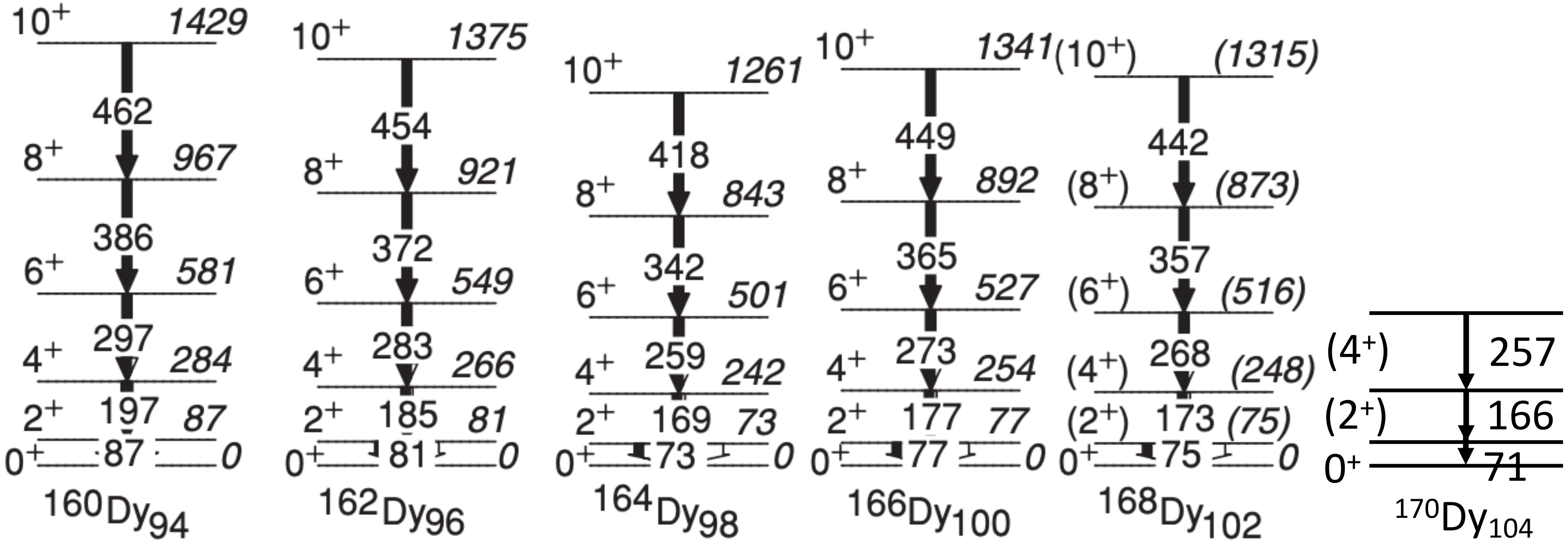




[5] Söderström et.al. Physics Letters B 762 (2016) 404–408

What is known?

Dy systematics and known yrast transitions



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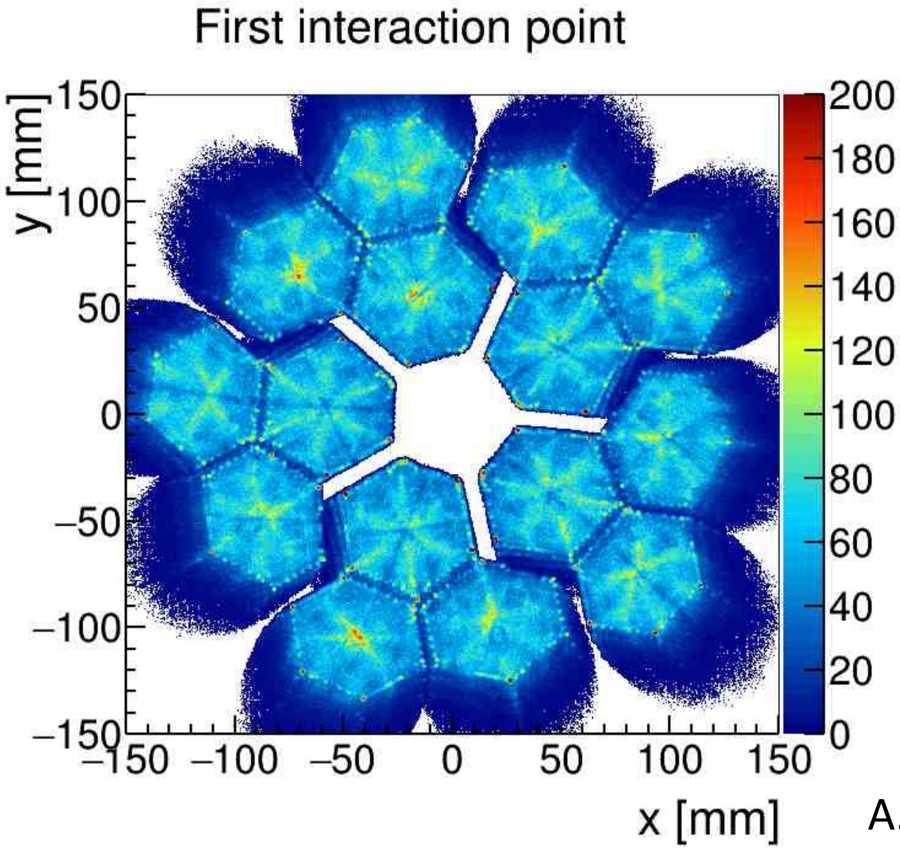
A programme of measurements

AGATA demonstrator – PRISMA ^{136}Xe + ^{170}Er

- Tandem-ALPI 859MeV beam ~1pnA (q=+28)
- 44^{0} Grazing angle 56.9x10^{6} AGATA-PRISMA



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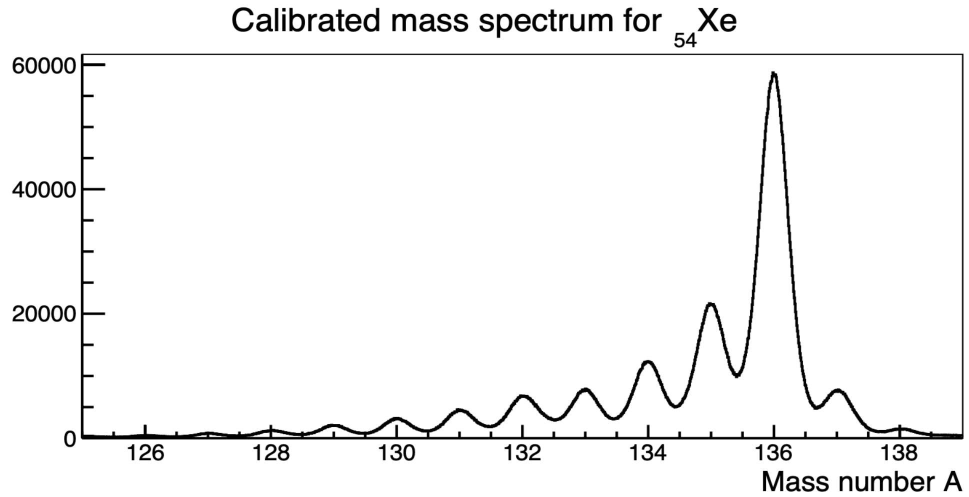

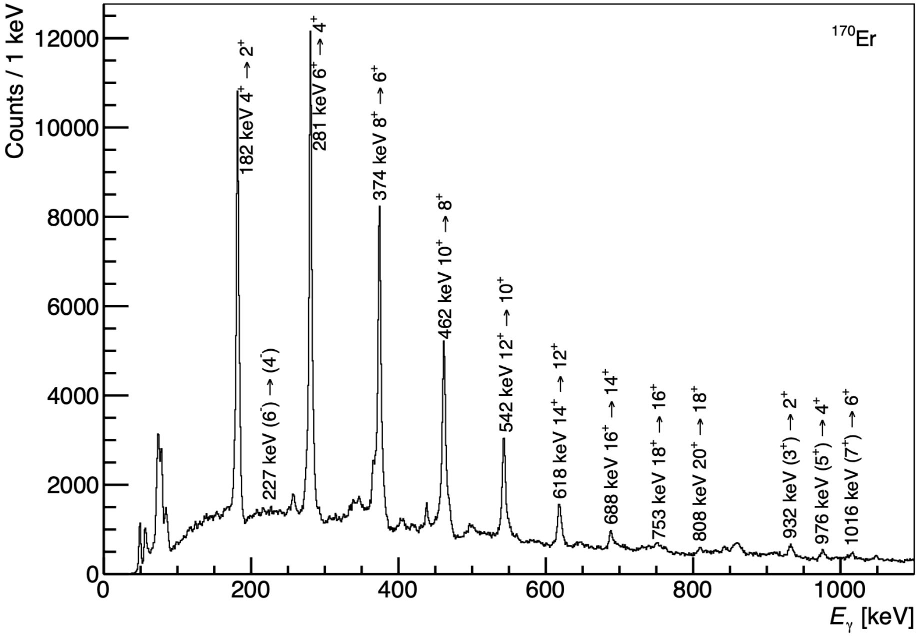

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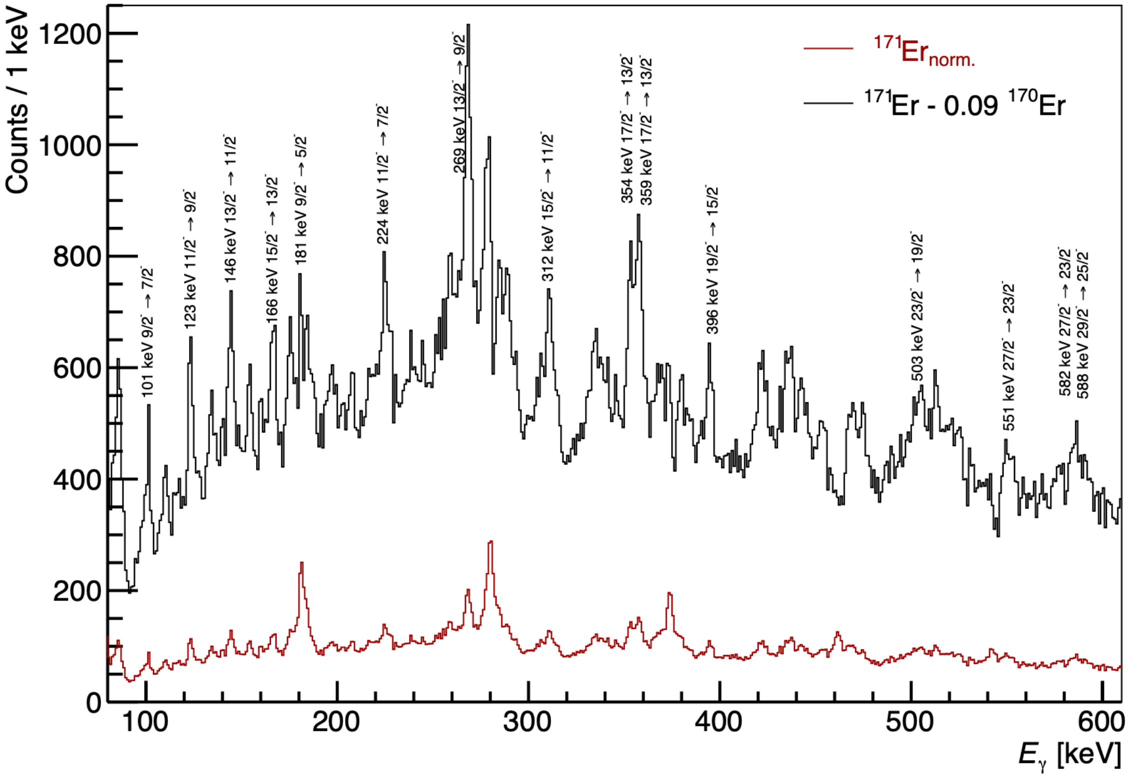
AGATA demonstrator – PRISMA ^{136}Xe + ^{170}Er

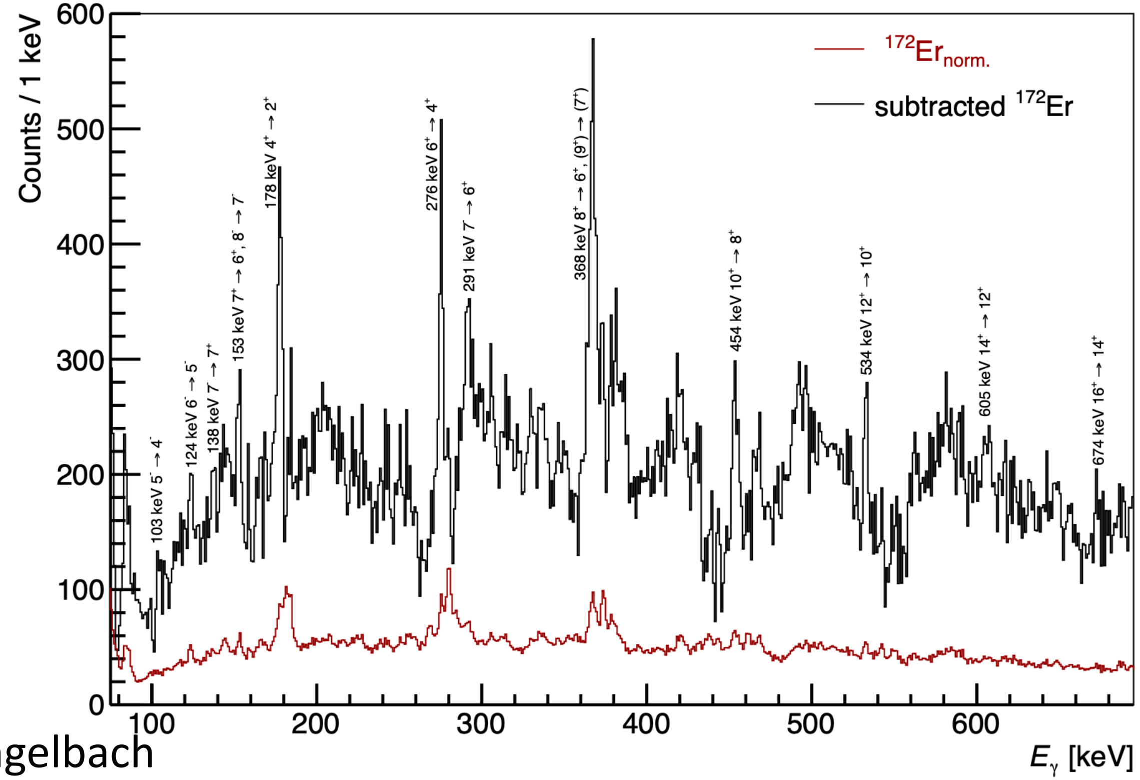
Observations: Limited γ-γ, potentially further optimisation of grazing angle required

Issue with DANTE detector during experiment and resulting limited efficiency

-n channel ^{171}Er



-2n channel ^{172}Er



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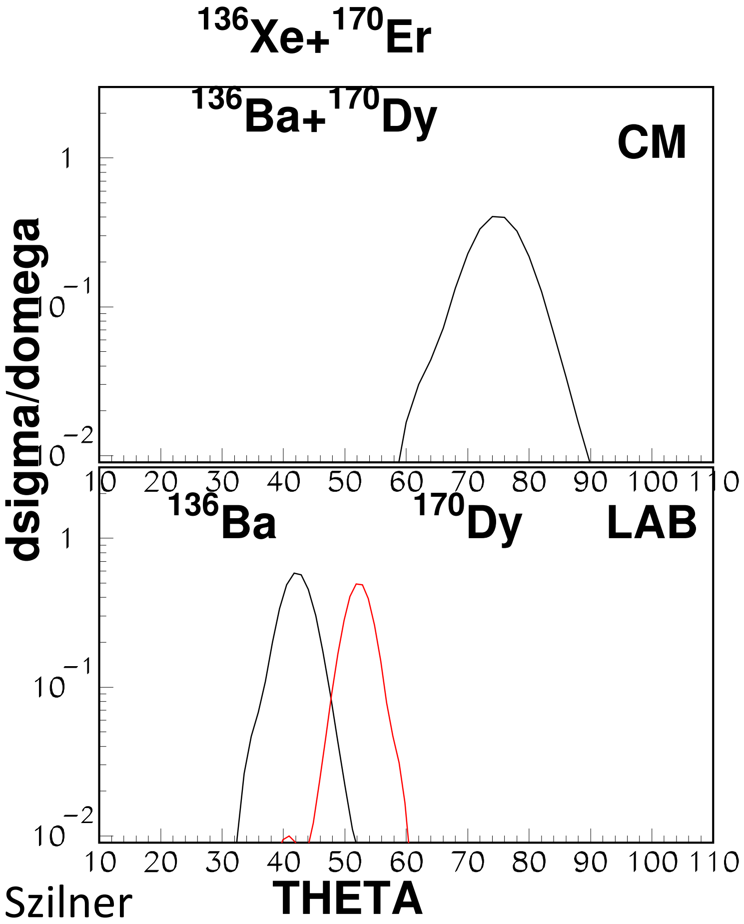
A programme of measurements

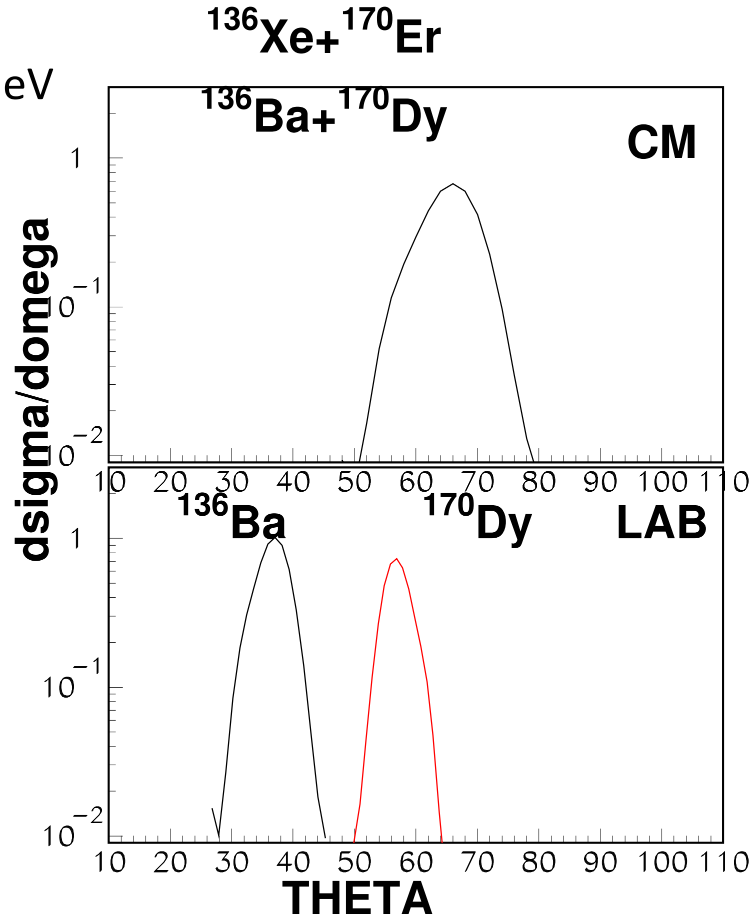
AGATA demonstrator – PRISMA ^{136}Xe + ^{170}Er 44^0 Grazing angle

Observations Limited γ-γ, further optimisation of grazing angle required

859 MeV



815 MeV

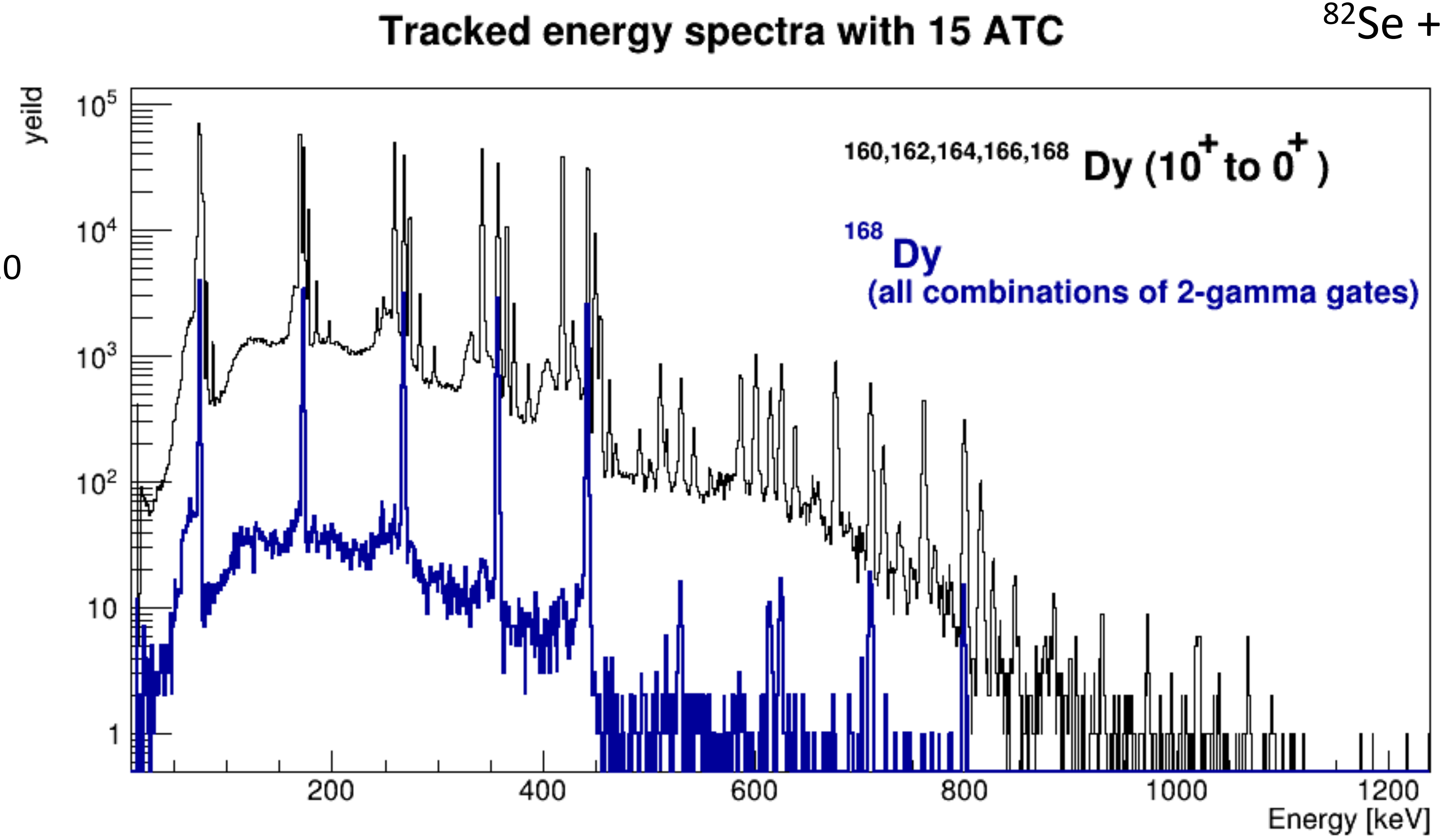


Courtesy Suzana Szilner

Preliminary simulations

$^{82}Se + ^{170}Er$

Reach spin 20 for ^{168}Dy



Courtesy Marc Labiche

What could we expect?

Gating on the delayed γ rays in ^{134,136}Ba, it will be possible to identify decays in the binary partners ^{168,170}Dy

The advantages of using AGATA coupled to PRISMA and DANTE in this experiment is the high γ-ray efficiency (particularly the γ - γ efficiency)

GRAZING calculations ^{170}Dy can be populated with a cross-section of 1.3 mb for this reaction

	100	101	102	103	104	105	106
68	Er-168	Er-169	Er-170	Er-171	Er-172	Er-173	Er-174
67	Ho-167	Ho-168	Ho-169	Ho-170	Ho-171	Ho-172	Ho-173
66	Dy-166	Dy-167	Dy-168	Dy-169	Dy-170	Dy-171	Dy-172
67	Tb-165	Tb-166	Tb-167	Tb-168	Tb-169	Tb-170	Tb-171
68	Gd-164	Gd-165	Gd-166	Gd-167	Gd-168	Gd-169	Gd-170

Questions to address

We were not able to assess the interest of DANTE in the measurement. Is it really useful?

- Neutron-evaporation suppression using a time-of-flight gate means it is possible to obtain clean gamma spectra for the target-like fragments
- This technique will be complemented using the DANTE detector array and the detection of known delayed gamma-rays in AGATA (isomer tagging).
- The target will produce the projectile-like nuclei ^{134}Ba and ^{136}Ba
  - contain 10+ isomeric states (half-lives of 2.63 μs and 91 ns), respectively
- Those that do not enter PRISMA or the beam dump will be stopped in the vicinity of the target chamber.
  - By gating on the strongly populated delayed gammas in ^{134,136}Ba, it will be possible to identify decays in the binary partners ^{168,170}Dy.
  - It could be used also to gate the A~170 fragments and increase yeild

What would the requirement be?

1. Beam: ^{136}Xe, energy = 900 MeV, current ~ 2 pnA
2. Target: ^{170}Er of thickness 0.5 mg/cm^2, cross-section: ^{170}Dy = 1.3 mb
3. Average AGATA efficiency with 15 ATC
4. Beam-like fragments will be identified in the PRISMA
5. Neutron-evaporation suppression using a time-of-flight gate to obtain clean gamma-ray spectra for the target-like fragments
6. Isomer gating with DANTE and increase of yield target like fragments
7. Trigger condition will be an OR of the AGATA Ge core signals and either DANTE or PRISMA.

Taking into account the solid angle for the PRISMA spectrometer and an efficiency of 30% for the detection of the target-like fragments in DANTE, estimated 5 days of beamtime.

Summary

1. The advantages of using AGATA coupled to PRISMA and DANTE in this experiment is
   1. the high γ-ray efficiency, excellent Doppler correction and isomer tagging capabilities of AGATA
   2. the very good A, Z identification and velocity vector determination of PRISMA
   3. the high efficiency and precise determination of the angle of the target-like fragments of DANTE.
2. The use of a ^{136}Xe beam will give a large increase of the yield of neutron-rich reaction products as well as of the angular momentum transferred to the fragments, compared to the ^{82}Se induced reaction
3. We expect to establish the knowledge of the high-spin structure of ^{168}Dy up to and beyond the backbending region and significantly increase the knowledge of ^{170}Dy
4. ^{166}Gd , ^{168}Gd , ^{172}Dy and ^{174}Dy are within reach

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