Nuclear structure close to N=Z=50

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for the COPIGAL project
M. Palacz, G. de France, et al.

Agenda

- History of the collaboration: devices and physics
- The EAGLE-NEDA-DIAMAND setup at HIL-Warsaw
- EAGLE experiments 2023–2024
- ^{57}Cu – HIL105
- ^{134}Sm – HIL114

The collaboration started in 2005

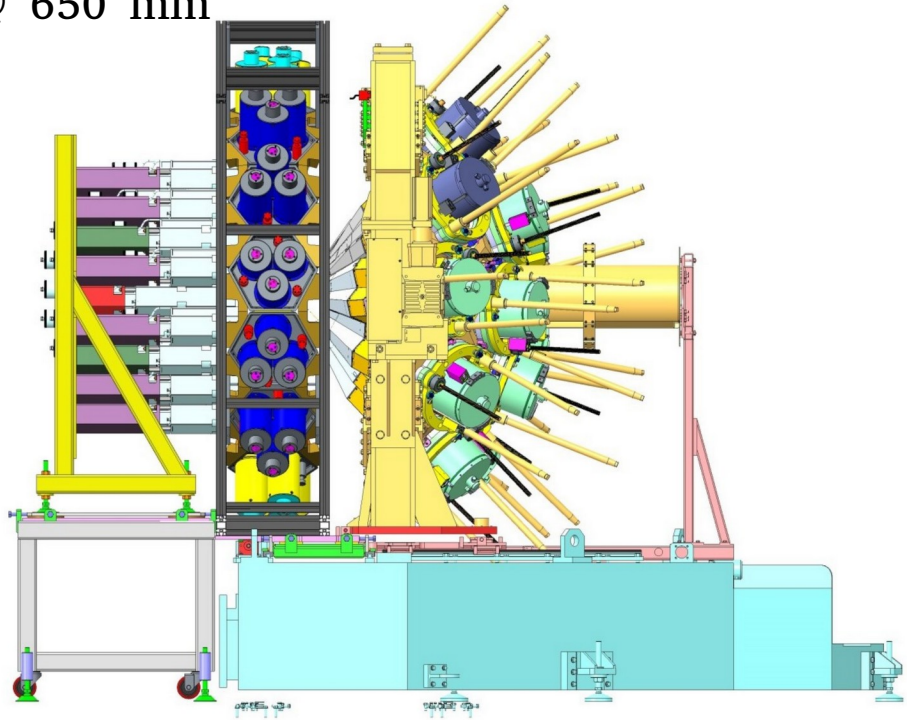
- We were involved in the:
  - Installation of NWALL at GANIL (2005)
  - Experimental campaigns with the EXOGAM+NWall(+DIAMANT) in 2005, 2006, 2009, 2012, 2014, altogether 12 experiments.
  - Construction of NEDA 2007–2018
  - Experimental campaign with AGATA-NEDA in 2018

Physics topics at N~Z in GANIL with EXOGAM/AGATA-NEDA/NWall-DIAMANT

- Isospin symmetry, A =23, A =58, A=63, A =67, A=71 (6 experiments);
  A. Gadea, G. de Angelis, S. Lenzi, F. Recchia, A. Boso et al.
- Search for T = 0 pairing, ^{88}Ru, ^{92}Pd, ^{96}Cd, (5 experiments);
  B. Cederwall, R. Wadsworth, G. De France et al.
- SPE energies and ^{100}Sn core excitations studied in ^{102,103}Sn; (2 experiments);
  J. Nyberg, M. Palacz, A. Ataç et al.
- Octupole and Quadrupole Correlations above ^{100}Sn (1 experiment);
  J.J. Valiente Dobon, E. Clement et al.

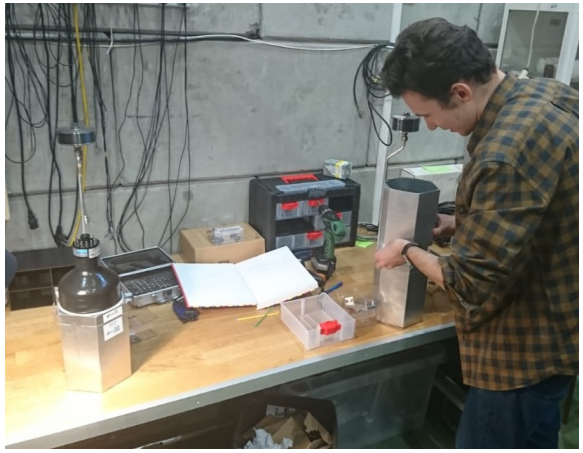
AGATA-NEDA at GANIL (2018)

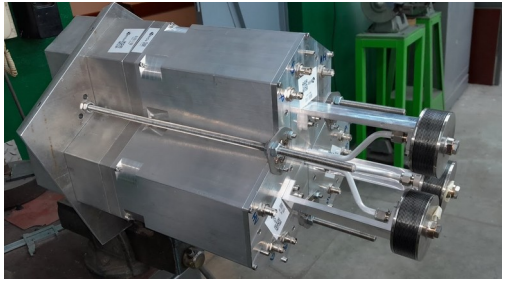
AGATA @ 145 mm
NEDA(54)@ 510 mm
NW (42)@ 650 mm
DIAMANT

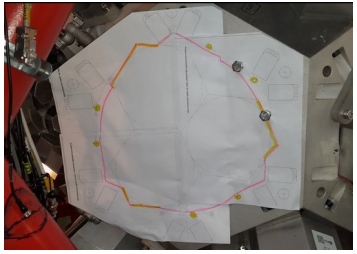


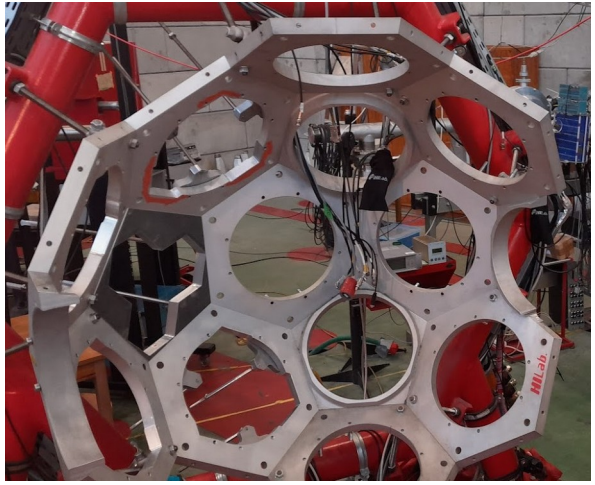
Drawing courtesy Ian Burrows

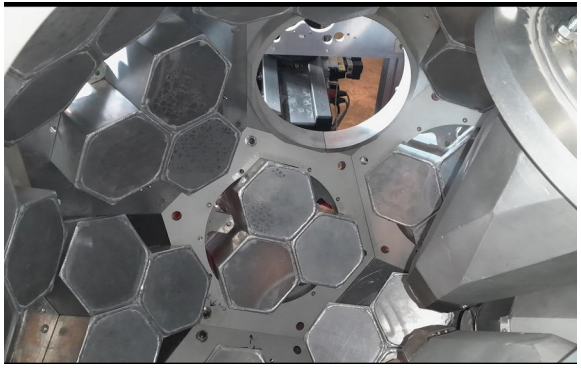
NEDA moved to HIL-Warsaw in December 2021



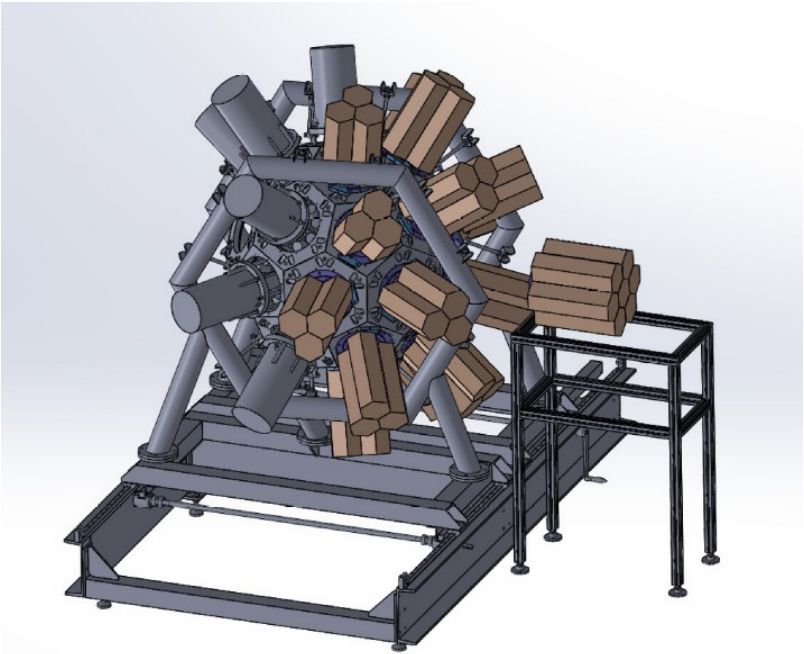


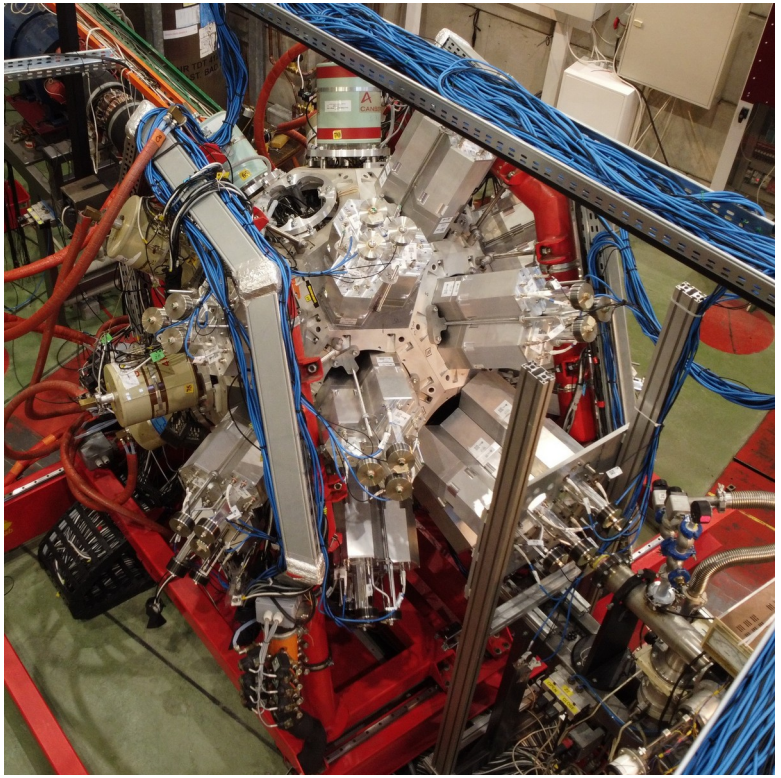






NEDA@HIL





EAGLE (HPGe):

- 5 dets @ 101°
- 5 dets @ 117°
- 5 dets @ 143°

NEDA:

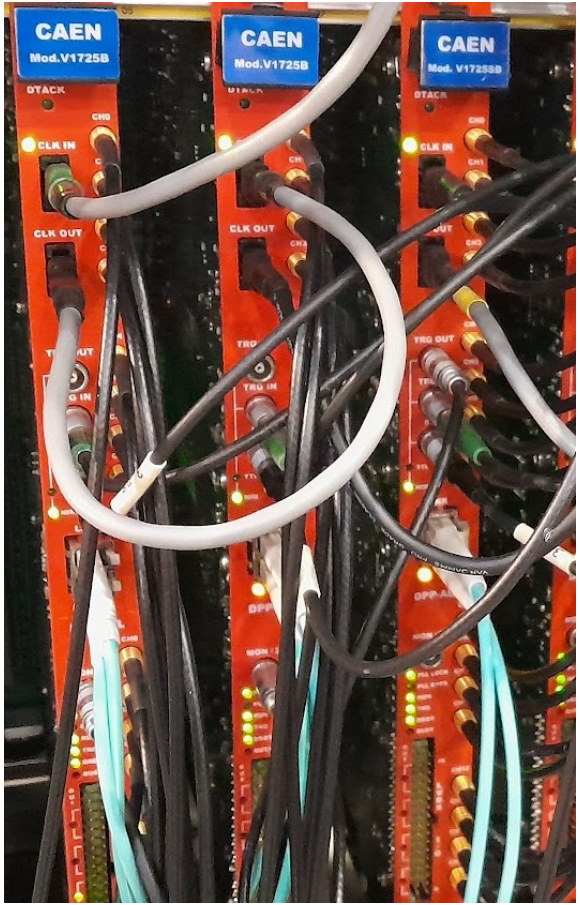
- 6/7 dets ~0°
- 15 dets @ 37°
- 15 dets @ 63°
- 15 dets @ 79°

- eff(γ) = 1.5% @1.3 MeV
- eff(1n) = 20-25%, eff(2n) = 3%

EAGLE-NEDA: electronics, DAQ

Transformation from:
EAGLE: analog CAMAC based system, some digital elem.
NEDA: numexo2 (diff. input), GTS, Trigger Processor

- New system built both for NEDA and EAGLE
- 6 CAEN V1725(S)(B) digitizers (6x16 channels, 14-bit, 250 MHz sampling):
  - 2 units with PHA firmware for HPGe and ACS
  - 4 units with PSD firmware for NEDA
    („at least one PSD discriminated neutron" signal available for the trigger request)
- trigger validation logic implemented in external NIM units;
  for validated events: readout of all non-zero channels
- Software:
  - XDAQ (CERN) with LNL applications;
  - Spy and GreWare for on-line spectra;
  - GRAFANA for monitoring of rates;
  - ROOT selector for off-line (→ RadWare, TV, etc.).
- Reasons to and advantages of developing a new DAQ system for NEDA
  - lack of numexo2 style hardware to support EAGLE as well;
  - possibility to use NEDA as a time ref. and a γ-ray multiplicity filter
  - 2x better NEDA dynamic range;
  - basing the system on commercial digitizers opens prospects for further development
    (ex. coulex DSSD array recently commissioned, soon fast scintillators, electron spectrometer, etc.)

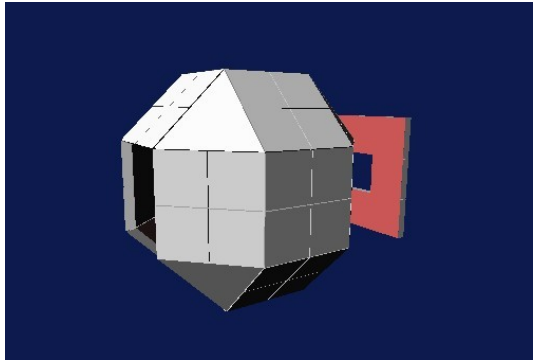


DIAMANT

I. Kuti, J. Molnar et al. ATOMKI Debrecen

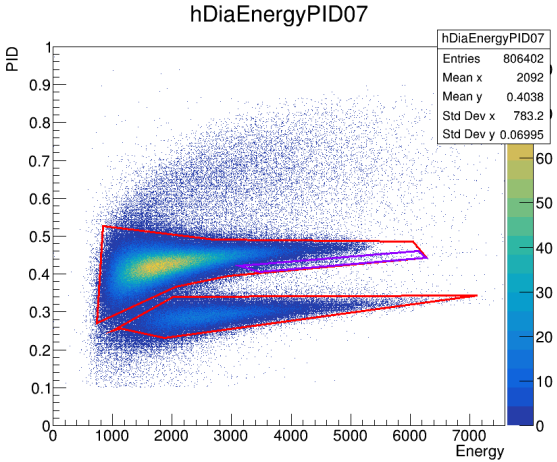
80 CsI detectors, rhombicuboctahedron, plus f.w.
able to register and distinguish
protons and alpha particles
emitted in a fusion-evaporation reaction

$\epsilon_p \approx 0.6$ $\epsilon_\alpha \approx 0.4$



DAQ:

- present: NUMEXO2 digitizers
  and GANIL software, AGAVA;
- in progress: new CAEN R5560 digitizer
  purchased by ATOMKI to replace NUMEXO2
  128 channels/125 MHz/14 bit
  (double trapezoid firmware
  development in progress)



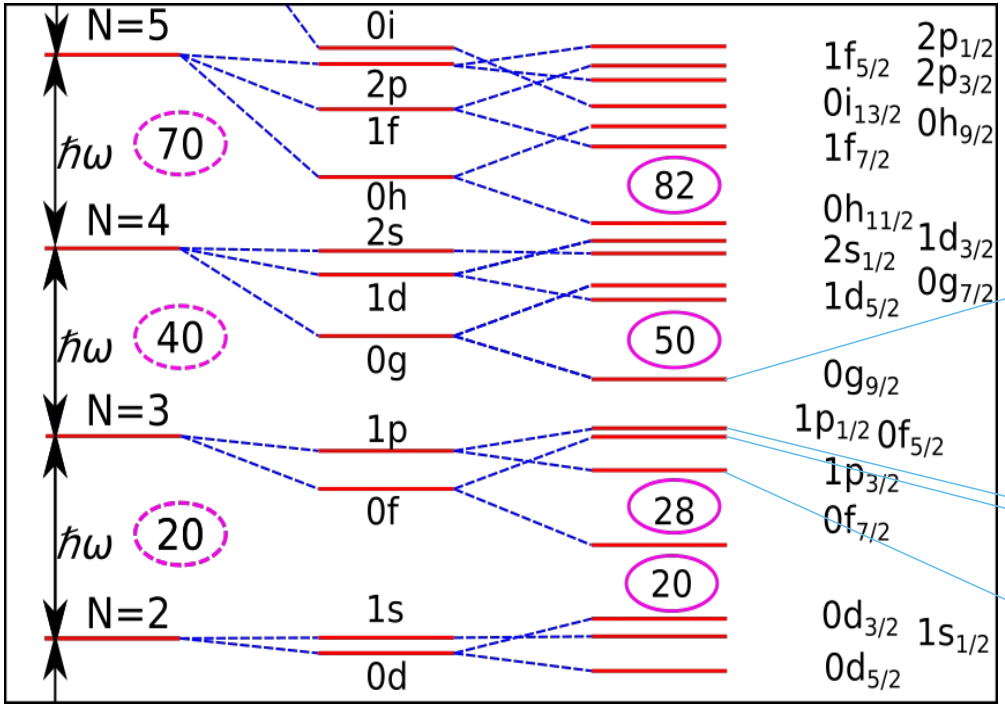
Will be available at HIL also after NEDA leaves

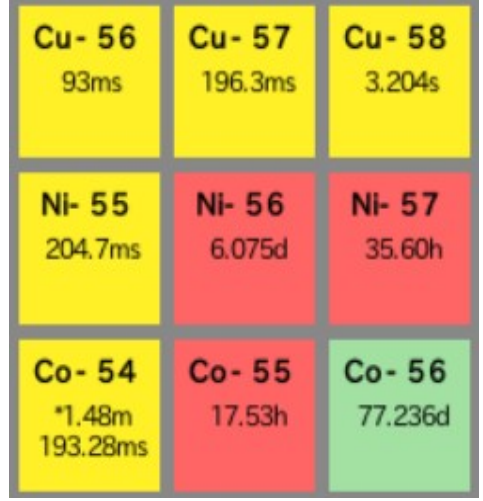
EAGLE experiments January 2023 – November 2024

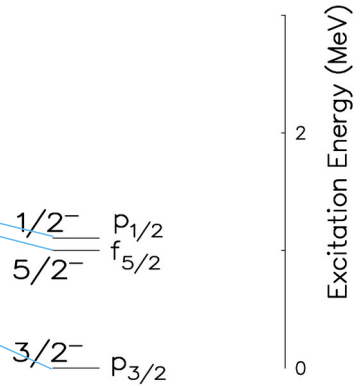
id	dates	spokeperson	title	beam	ancillary devices
HIL 099	1/03–12/03/2023 11 days	B. Saygi	Lifetime measurement of excited states in 134Sm	32S, 150 MeV	NEDA, Köln plunger
HIL 097	20/03–4/04/2023 14 days	C. Petrache	Shape coexistence and octupole correlations in the light Xe, Cs and Ba nuclei	16O, 86 MeV	NEDA, Köln plunger
HIL 106	13/06–29/06/2023 14 days	C. Petrache	Shape coexistence and octupole correlations in the light Xe, Cs and Ba nuclei (continuation of HIL097)	32S, 150 MeV	NEDA, Köln plunger
HIL 105	13–30/11/2023 16 days	M. Palacz	Single-proton states and N=Z=28 core excitations in 57Cu	32S, 82 MeV	NEDA, DIAMANT
HIL 115	5-20/12/2023 15 days	M. Matejska-Minda P. Bednarczyk	Study of the anomalous behavior of the Coulomb energy difference in the A = 70,T = 1 izobaric multiplet	32S, 88 MeV	NEDA, DIAMANT
HIL 114	17–31/01/2024 14 days	B. Saygi, M. Palacz	Gamma-ray spectroscopy of 134Sm	32S, 145 MeV	NEDA, DIAMANT
HIL 117	18–26/03/2024 7 days	K. Miernik	144Dy fission studies	32S, 212 MeV	NEDA, DIAMANT
HIL 126	10–24/05/2024 14 days	I. Kuti	Search for candidate wobbling bands in 103Pd and in 101Ru	32S, 212 MeV	NEDA, DIAMANT
HIL 109	21–27/11/2024 6 days	C. Fransen	Lifetime studies in neutron-deficient 172Os	32S, 170 MeV	Köln plunger

9 experiments, 111 beam-on-target days, additionally 3 commissioning runs (~12 days)

Single proton-particle levels at N = Z = 28 and core softness by studying excited states of ^{57}Cu – HIL105





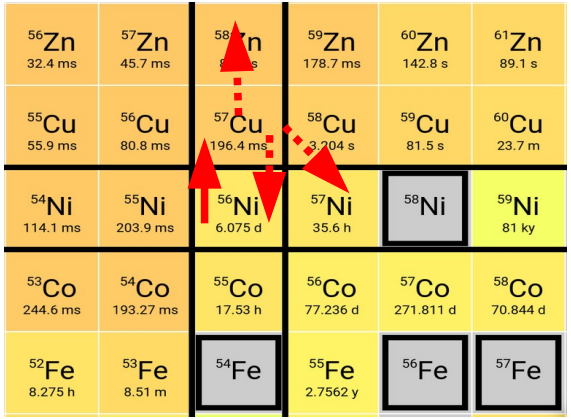


^{57}Cu, ^{56}Ni and the astrophiscal rp-process

$T_{1/2}$ (^{56}Ni) = 6.08 d
S_p(^{57}Cu)=690 keV

→ proton capture followed by proton emission from excited states in ^{57}Cu

→ waiting point at ^{56}Ni

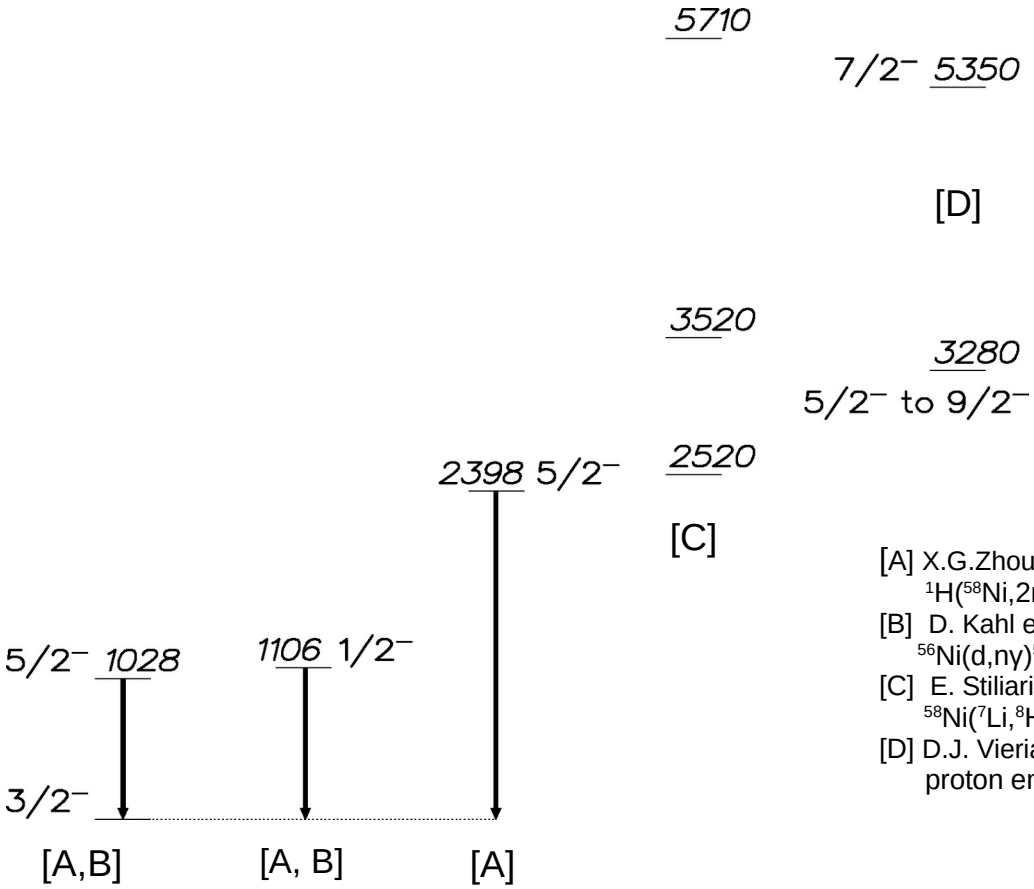


competition of β^+ decay of ^{57}Cu with ^{57}Cu(p,γ)^{58}Zn

structure of excited states in ^{57}Cu essential for the rate of flow of material along the proton drip-line above ^{56}Ni.

Known excited states in ^{57}Cu

aiming at observation of:
- **7/2$^-$ (possibly 2520 keV ?)**
- **9/2$^+$**
- **core excited states**
- **firm confirmation of known spins**

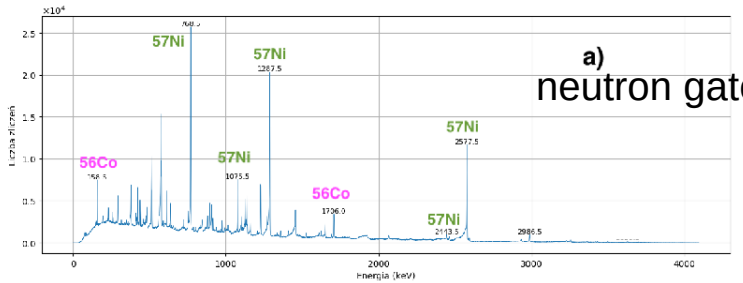


[A] X.G.Zhou et al. PRC 53 (1996) 982
^{1}H(^{58}Ni,2nγ)^{57}Cu
[B] D. Kahl et al. PLB 797 (2019) 134803
^{56}Ni(d,nγ)^{57}Cu
[C] E. Stiliaris, et al. Z.Phys. A 326 (1987) 139
^{58}Ni(^{7}Li,^{8}He)^{57}Cu, ^{58}Ni(^{14}N,^{15}C)^{57}Cu
[D] D.J. Vieria et al. PLB B60 (1976) 261
proton emission after ^{57}Zn β+ decay

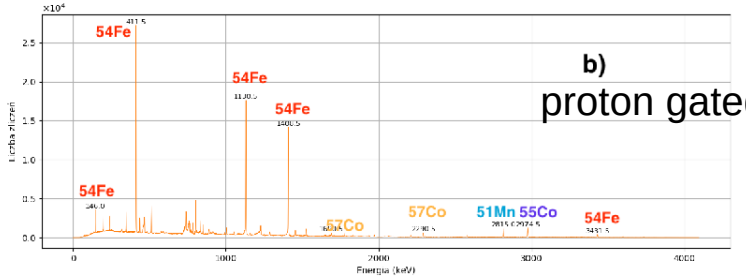
^{57}Cu – the experiment (HIL105)

- ^{32}S (82 MeV) + ^{28}Si (3.4 mg/cm^2 on Au backing)
  → ^{60}Zn (CN) → 1p2n + ^{57}Cu
- A method to produce the ^{28}Si targets developed by A. Stolarz
- Total fusion-evaporation x-section 400 mb
  ^{57}Cu x-section: ~0.1 mb (HIVAP)
- EAGLE-NEDA-DIAMANT, 16 beam-on-target days,
  13-30/11/2023

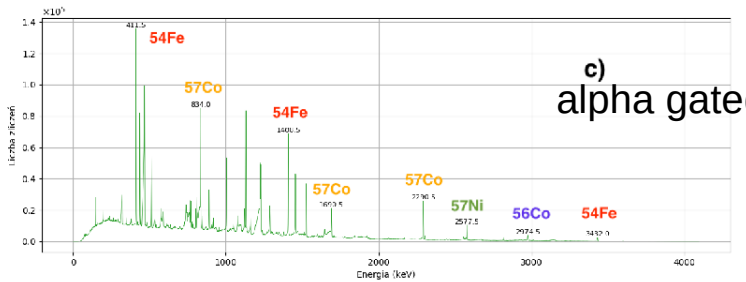
HIL105(^{57}Cu) – data analysis



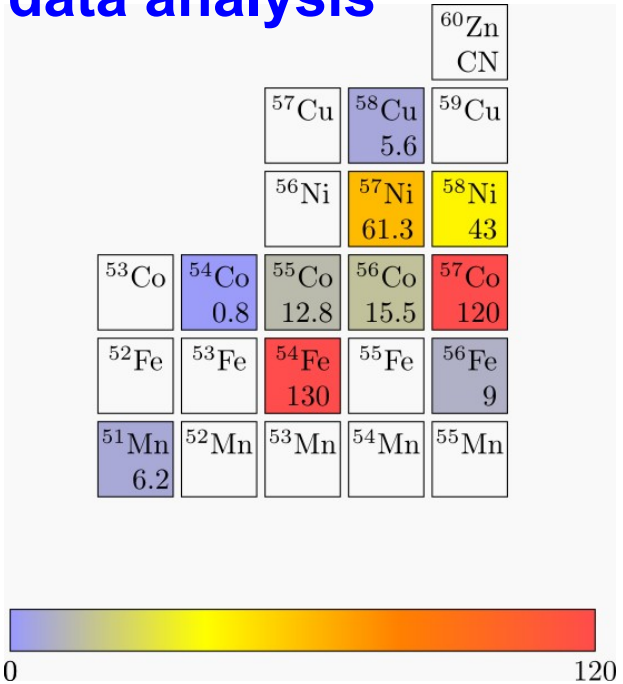
a)
neutron gated



b)
proton gated



c)
alpha gated



M. Regulska bachelor thesis, completed July 2024
based on 24 hours of data taking,
preliminary gates

A. Malinowski, master thesis, in progress

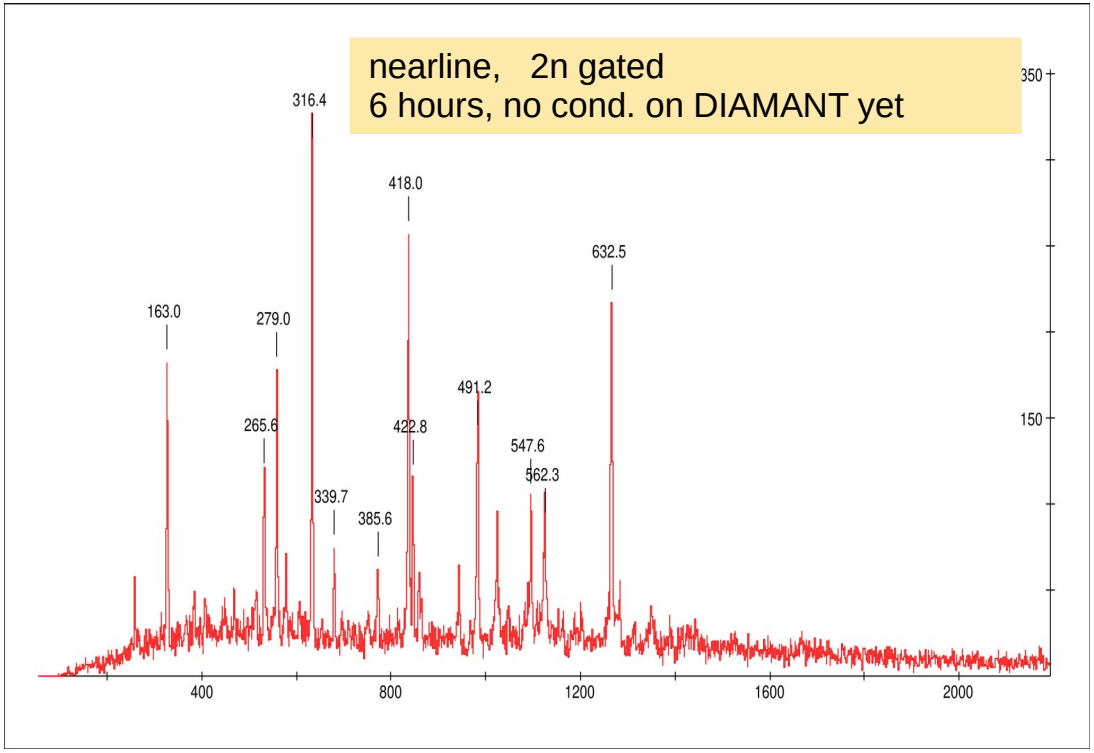
Spectroscopy of ^{134}Sm (^{135}Eu) – HIL114

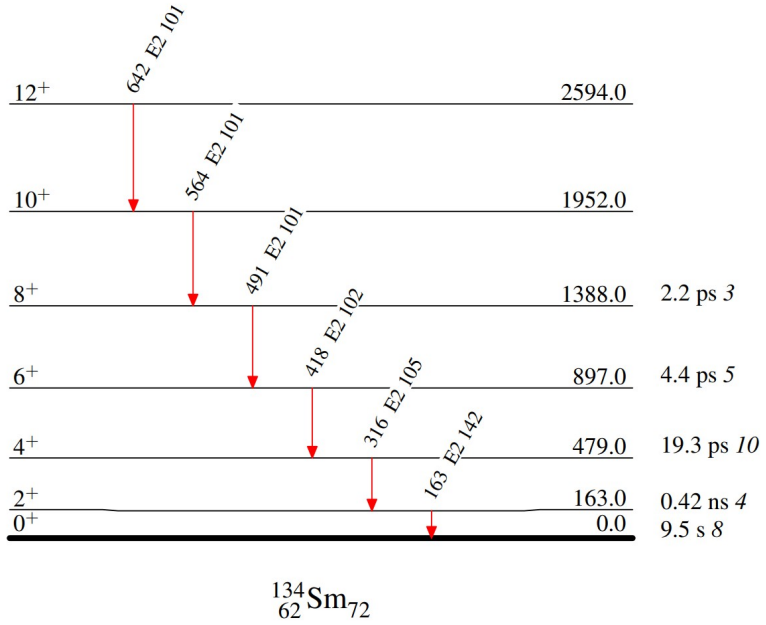
- ^{134}Sm (N=72, Z=62): 6 excited states known
  Aim: to extend the level scheme, for indications of shape change from prolate g.s. to oblate and/or to identify gamma-vibrational states
- $^{135, 136}$Eu – no excited states known
  (HIL127 EAGLE-NEDA-DIAMANT proposal accepted
  A. Fijałkowska, G. Jaworski et al., specifically aiming at ^{136}Eu, ^{135}Eu)

HIL114 – the experiment

- ^{32}S (145 MeV) + ^{106}Cd (4 mg/cm^2 on Au backing) → ^{138}Gd (CN)
  → 2p2n + ^{134}Sm
  → 1p2n + ^{135}Eu, 1p1n + ^{136}Eu
- X-sections (HIVAP):
  total fusion-evaporation 500 mb
  ^{134}Sm ~5 mb
  ^{135}Eu, ^{136}Eu, x-section similar but channels more difficult to discriminate
- EAGLE-NEDA-DIAMANT, 14 beam-on-target days,
  17-31/01/2024

HIL114 – data analysis



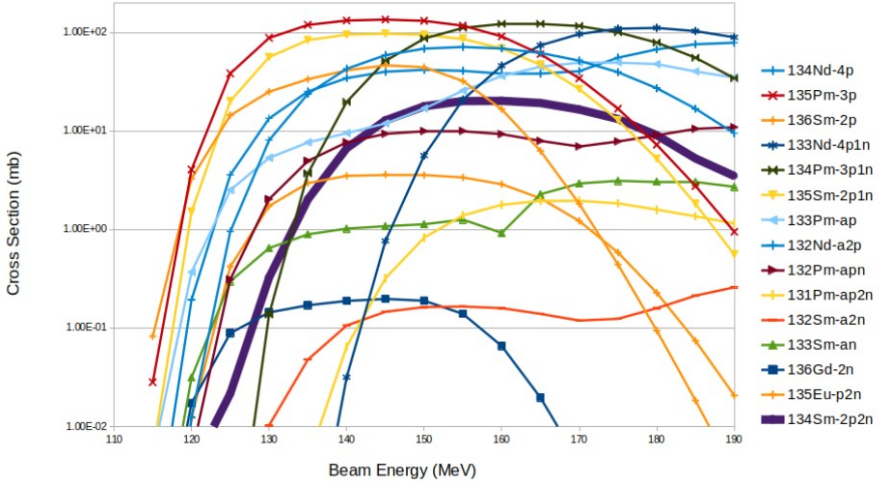


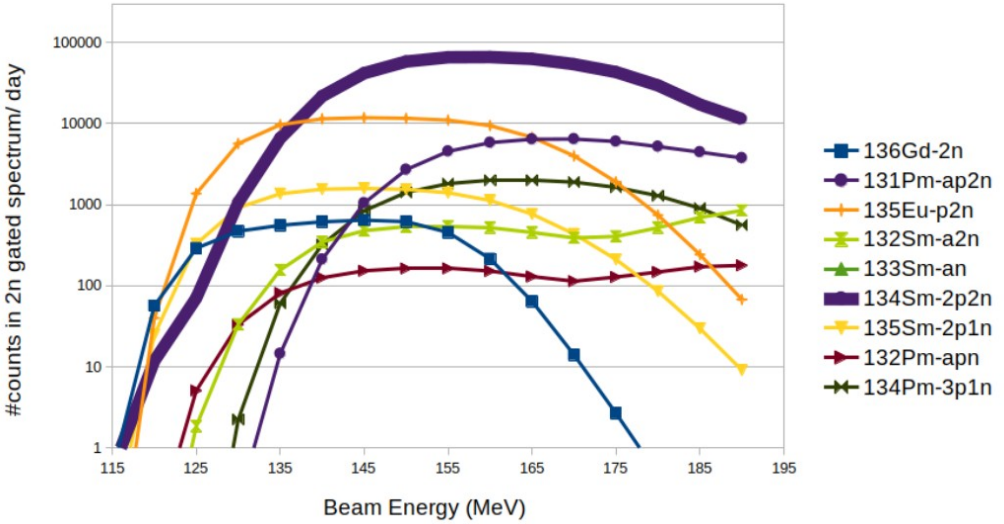
P. Sekrecka PhD work

HIL114 – ^{134}Sm, xsection and 2n gating

^{106}Cd(^{32}S,2p2n)^{134}Sm

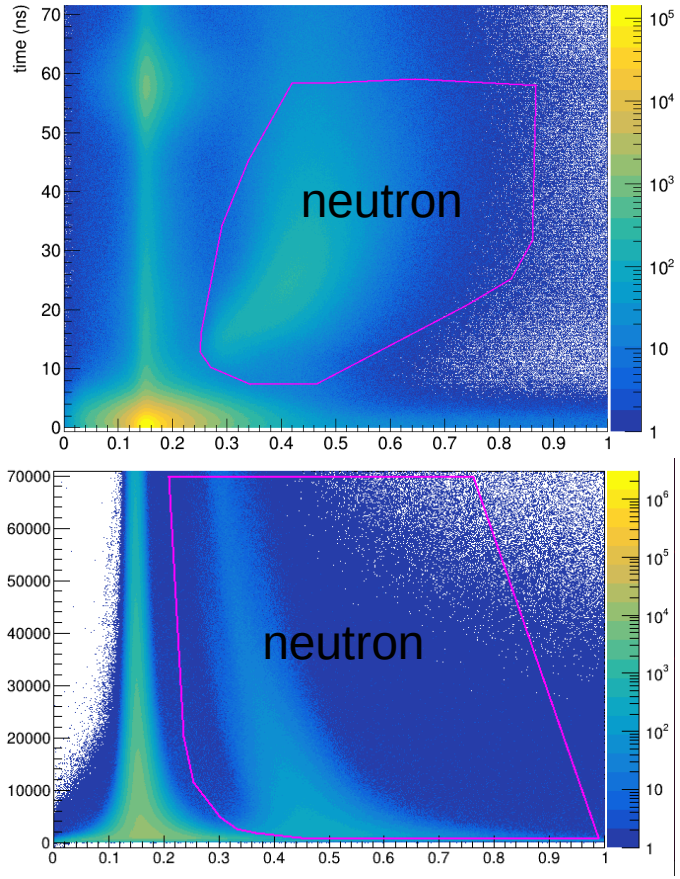
HIVAP calculations



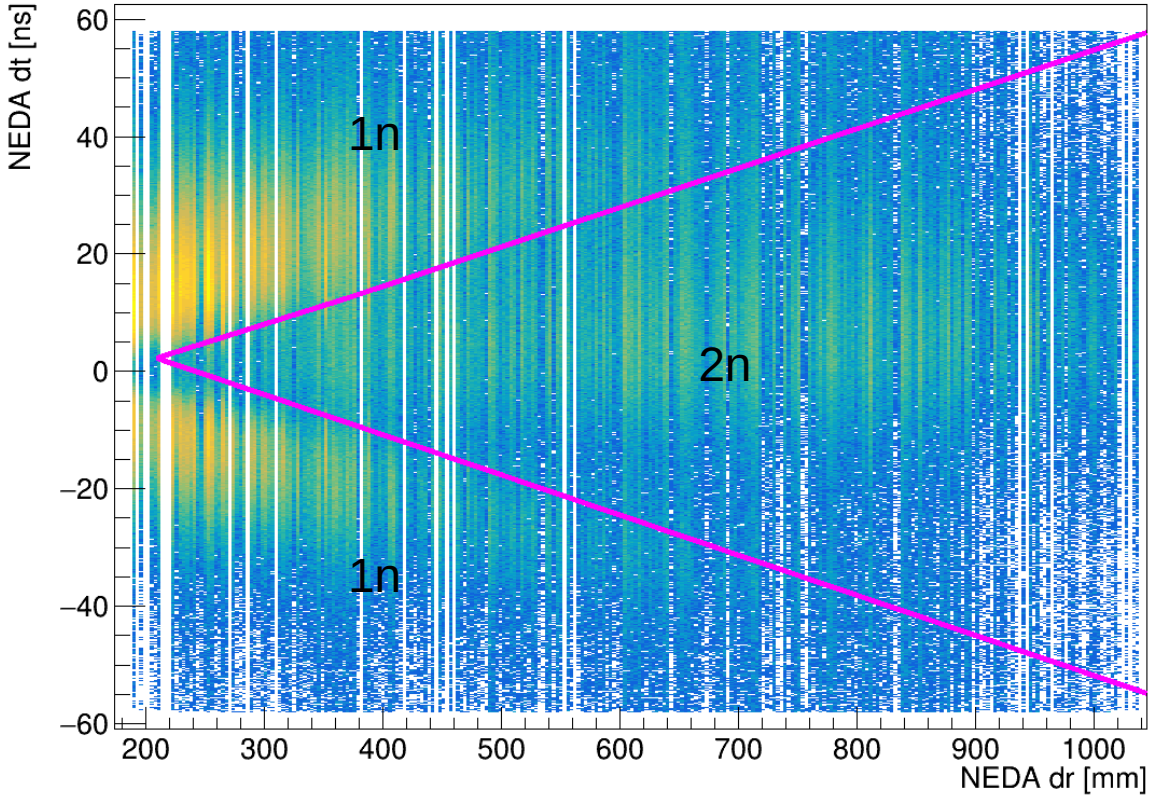


HIL114 – neutron/gamma and 1n/2n discrimination

neutron/gamma



2n/1n



Summary

- Studies of proton-rich nuclei at N~Z extensively pursued at GANIL in years 2005–2018, are now continued at HIL-Warsaw
- Several experiments have been performed with EAGLE-NEDA-DIAMANT
- Data analysis is in progress at HIL, aiming at identification of new excited states in ^{57}Cu, ^{134}Sm (and neighbouring nuclei)...
- … which may result in obtaining new information on SPE and core excitations at the N=Z=28 double shell closure, as well as on shape coexistance/transitions in proton-rich mid-shell rare earth nuclei.

Installation and use of NEDA at HIL is financed by the NCN grant no. 2020/39/D/ST2/00466.
EURO-LABS support is acknowledged
GAMMAPOOL is acknowledged for providing HPGe detectors.

EAGLE-NEDA contributors

- G. Jaworski (NEDA, DAQ)
- A. Goasduff, N.Toniollo (DAQ)
- I. Kuti, J. Molnar (DIAMANT, DAQ)
- M. Kowalczyk, P. Kulessa, M. Ciemała (DAQ, nearline)
- J. Grębosz (spy, GreWare – online spectra)
- M. Komorowska, M. Kisieliński, M. Spaček, T. Abraham, W. Okliński (HPGe detectors, EAGLE front-end hardware)
- C. Fransen et al. (plunger)
- G. Colucci, A. Fijałkowska, K. Hadyńska-Klęk, A. Korgul, K. Wrzosek-Lipska, I. Piętka, P.J. Napiorkowski, J.Samorajczyk-Pyśk, P.Sekrecka, A. Tucholski (various on-site support)
- B. Radomyski, M. Matuszewski (mechanical design)
- R. Kopik, P. Jasiński, M. Antczak (mechanical workshop)
- A. Stolarz, J. Kowalska (targets)
- undergraduate students:
  A. Malinowski, A. Otręba, W. Poklepa, M. Regulska, K. Solak, K. Szlęzak, K. Zdunek
- All HIL staff: https://www.slcj.uw.edu.pl/en/staff/
- spokepersons and participants of the experiments