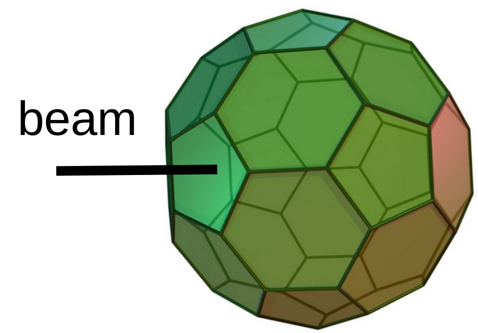
EAGLE*) – γ-ray spectroscopy at HIL

Marcin Palacz
Heavy Ion Laboratory
University of Warsaw

*) central European Array for Gamma Levels Evaluations

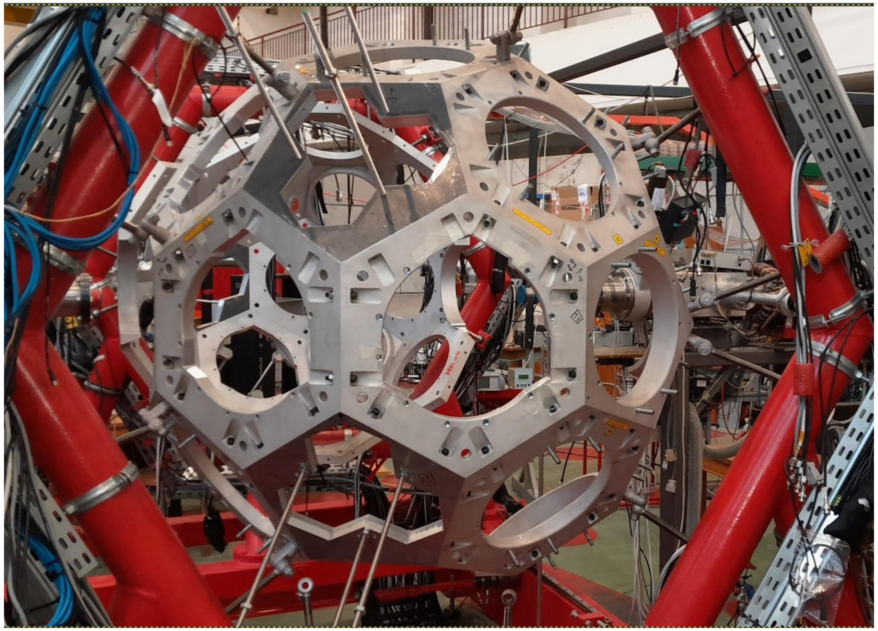
EAGLE



A flexible gamma-ray spectroscopy array able to accommodate up to 30 HPGe detectors with ACS shields and ancillary devices.

- Truncated icosahedron:
  - 20 hexagonal faces, 4x5 theta angle rings: 37°, 79°, 101°, 143°
  - 10 pentagonal faces   2x5 rings: 63°, 117°
- Minimum distance target-detector (collimator):
  hexagon: ~ 11cm   eff=0.001 at 1.3 MeV
  pentagon: ~ 15 cm   eff=0.0008
- Solid angle covered by one detector at minimum distance: ~ 0.0075
- Loan from GAMMAPOOL
  of 16 HPGe detectors (~60%) and 15 ACS.
  HIL owns 19 smaller HPGe's   (20 to 40%) with ACS's.
  Typically ~15 detectors used in experiments, including ~14(+/- 1) GAMMAPOOL,

  total eff. ≈ 1.3 % at 1.3 MeV



empty frame of EAGLE – July 2022 (installation of NEDA)

Agenda

- Summary of experiments fall 2021 – now
- Selected results/status of data analysis 2021 – 2022
- NEDA campaign 2023 – now
- HPGe detector lab
- Future plans:
  - experiments 2024
  - SiICA – Silicon Coulomb excitation Array
  - ULESE ICE spectrometer
  - fast timing campaign
  - Recoil Filter Detector

Summary of experiments
Nov 2021 – Jan 2024

id	dates	spokeperson	title	beam	ancillary devices
HIL 088	29/11–8/12/2021 10 days	R. Zidarova, N. Pietralla	Collective isovector quadrupole excitation in 142Sm — identification via a γγ correlation measurements after ε/β+-decay	32S, 140 MeV	beam on-off device, 150 s/150 s
HIL 093	20/03–5/04/2022 14 days	P.E. Garret, M. Roccini K. Wrzosek-Lipska M. Zielińska	Probing shapes and structures in 100Ru via Coulomb excitation.	32S, 88 MeV	Coulex scattering chamber
HIL 094	5/04-13/04/2022 14/06-18/06/2021 12 days	K. Wrzosek-Lipska, P.E. Garrett, M. Zielińska	Electromagnetic structure of low-lying states in 110Cd — complementary Coulomb excitation measurements with a 14N beam	14N, 34 MeV	Coulex scattering chamber
HIL 087	20/06–29/06/2022 10 days	C. Fransen	Lifetime studies in neutron-deficient 176Pt using the RDDS technique EAGLE + Cologne Plunger	32S, 170 MeV	Köln plunger
HIL 102	4/07–15/07/2022 11 days	A. Nałęcz-Jawecki	Search for chiral to not chiral transition by lifetime measurement of I=10+ state in 128Cs with a plunger technique	10B, 50–55 MeV	Köln plunger, LEPS
					NEDA installation
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 nucle	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 8(+6) days	B. Saygi, M. Palacz	Gamma-ray spectroscopy of 134Sm	32S, 145 MeV	NEDA, DIAMANT

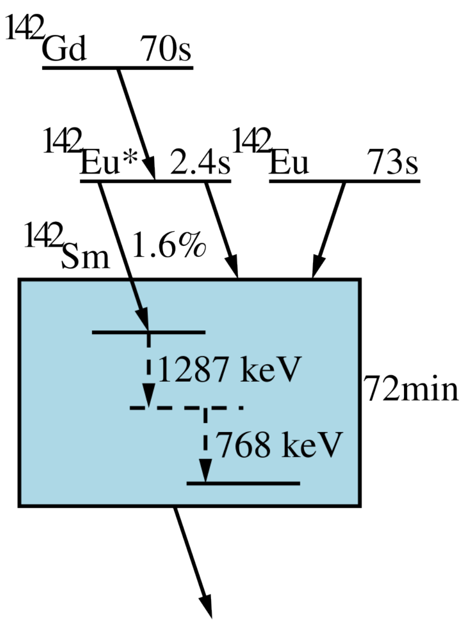
11 experiments, 135 days (+6 to go) beam on target
additionally 3 in-beam test/commissioning runs (~12 days)

Collective isovector quadrupole excitation in ^{142}Sm — identification via a γγ correlation measurements after ε/β+-decay

T. Stetz, N.Pietralla et al.

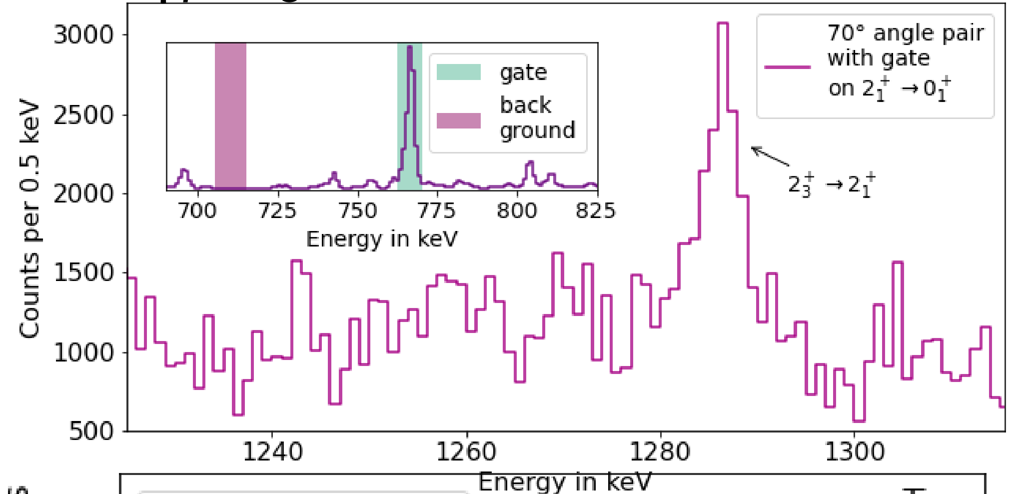
2^+_3 of ^{134}Sm – a candidate for a one-quadrupole mixed symmetry state (MSS).
Multipole mixing ratio needed to obtain the M1 strength of $2^+_3 \rightarrow 2^+_1$ from a projectile Coulomb-excitation HIE-ISOLDE at CERN

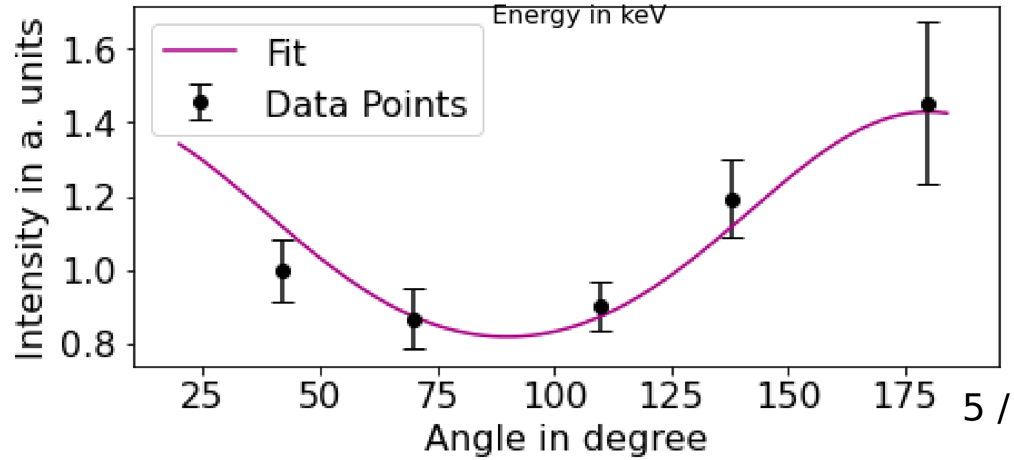
^{114}Cd(^{32}S, 4n)^{142}Gd
beam 150s on / 150s off



preliminary: >95% M1

γγ angular correlation measurement

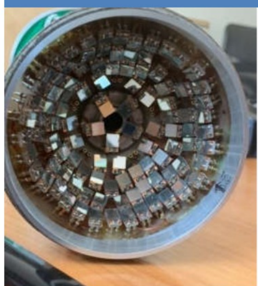




Probing shapes and structures via Coulomb excitation

Courtesy of K. Wrzosek-Lipska

48 PiN-diodes

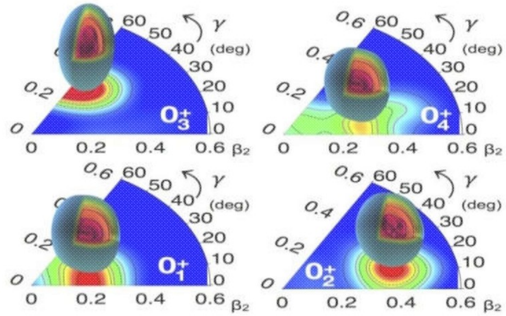


119°– 168° LAB

SilCA (DSSSD)

^{110}Cd

multiple shapes [1-3]

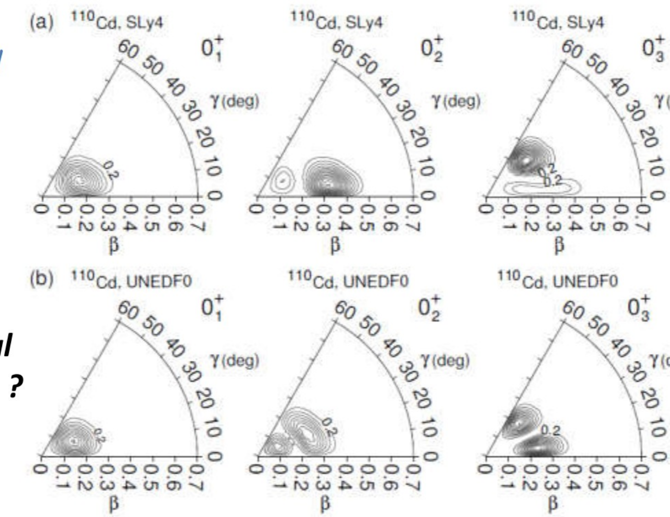


***T.R. Rodriguez*: BMF with SCCM + Gogny D1S [1,2]**

Fig.: Shape Coexistence Workshop - 2023 | Physics (uoguelph.ca)

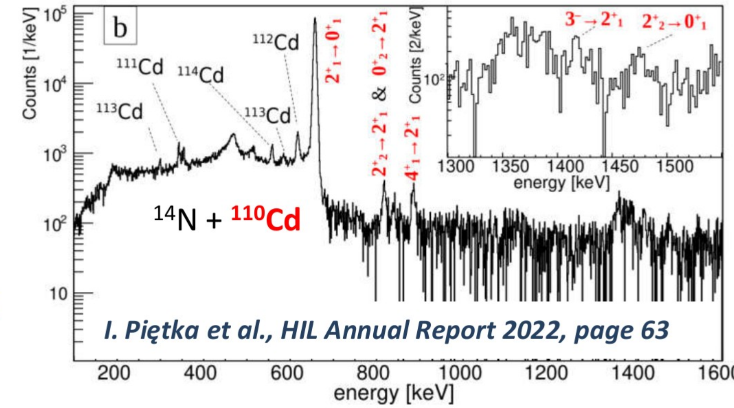
OR

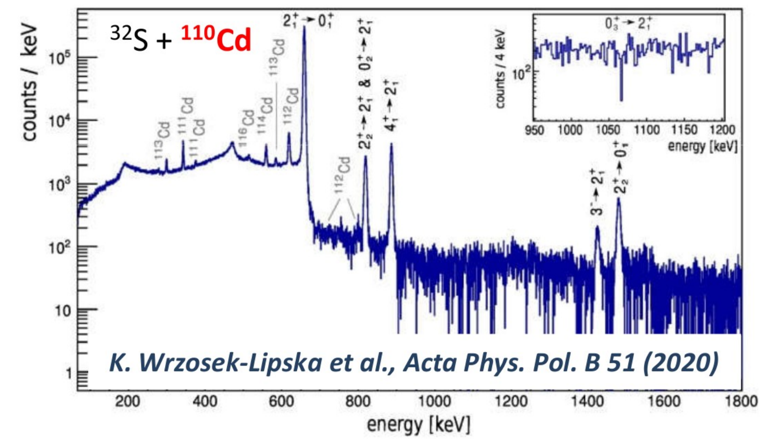
vibrational character ?



***L. Próchniak*: GBH + SLy4 (UNEDF) [3]**

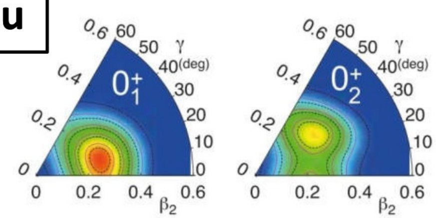
MsC thesis of I. Piętka, Univ. of Warsaw 2023



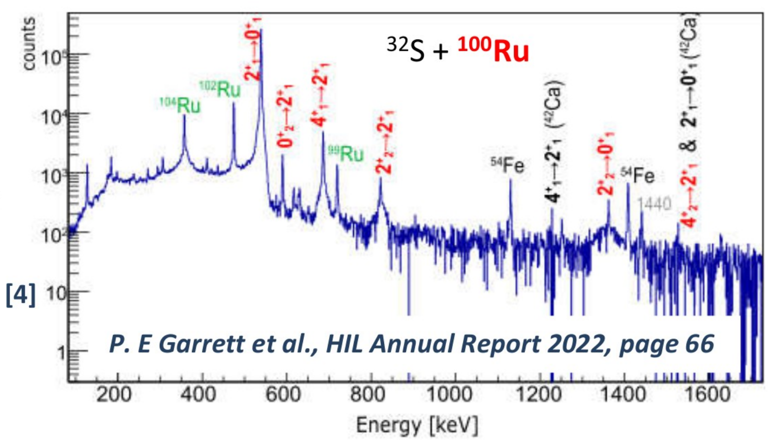


- Do the lighter Ru, N- mid-shell Cd behave as **spherical vibrators?**
- Do they display **shape coexistence?**
- Might there be multiple shape coexistence as suggested by the BMF calculations ?

^{100}Ru



***T.R. Rodriguez*: BMF with SCCM + Gogny D1S [4]**



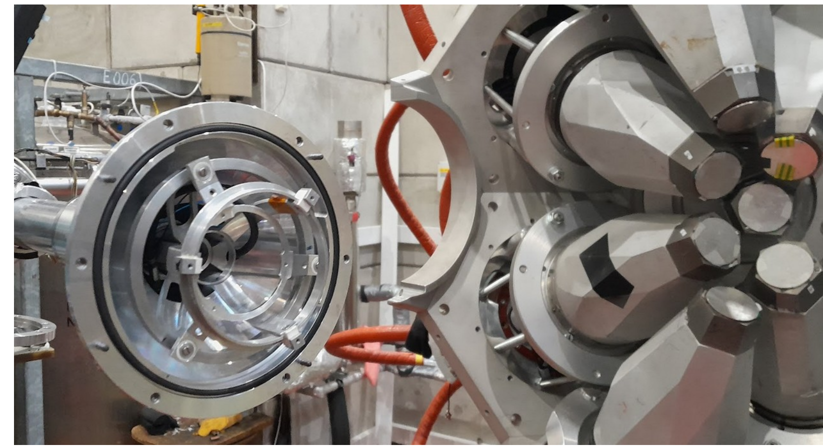
[1] P.E. Garrett et al., PRL 123 (2019) 142502, [2] P.E. Garrett et al., PRC 101 (2020) 044302
[3] K. Wrzosek-Lipska et al., Acta Phys. Pol. B 51 (2020), [4] P. E. Garrett et al., PLB 809 (2020) 135762
[5] P.E. Garrett, M. Zielińska, E. Clément Progress in Part. and Nucl. Phys 124 (2022) 103931

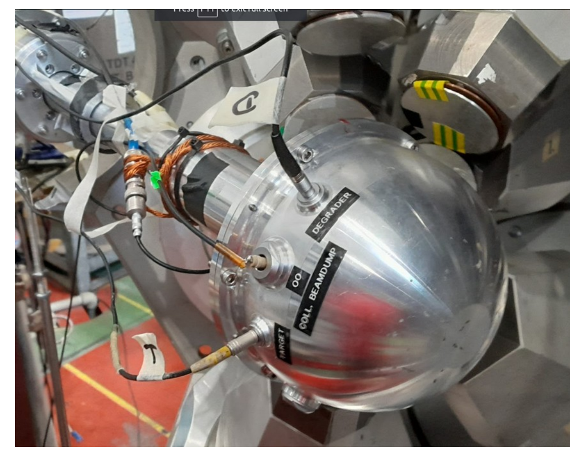
Lifetime studies in yrast band of ^{176}Pt

M. Novak, Ch. Fransen et al.

- Motivation: Evidence of shape coexistence in neutron-defficient A~180 nuclei. Different predictions for ^{176}Pt in IBM (spherical g.s.) and MF (prolate, as in heavier Pt nuclei). Existing data on transition strengths in ^{176}Pt not conclusive, and suffer from possible delayed feeding[1].
- ^{148}Sm(^{32}S, 4n)^{176}Pm,
  10 target-degrader distances, 15–600µm
- Lifetimes of 2^+, 4^+, 6^+ determined with „gating from above” (no delayed feeding),
  41(2) ps, 15(3) ps, 12(5) ps
  B(E2, $2^+ \rightarrow 0^+$), B(E2, $4^+ \rightarrow 2^+$) larger than in [1].
- Analysis of 8^+, 10^+ in progress, only „gating from below possible” due to limited statistics.

[1] G.D. Dracoulis et al. J.Phys: Nucl. Phys. 12 (1986) 283



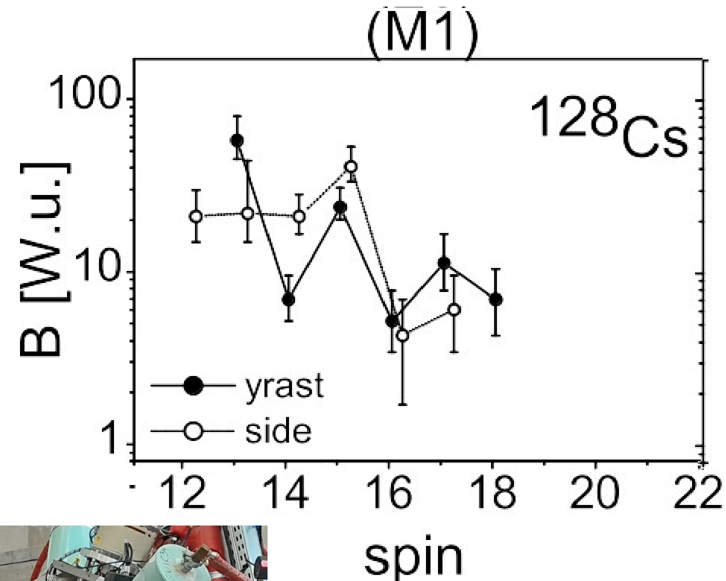


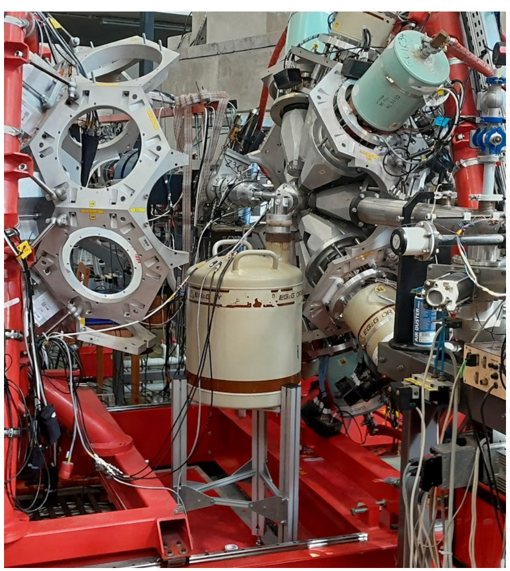
Köln plunger mounted inside EAGLE

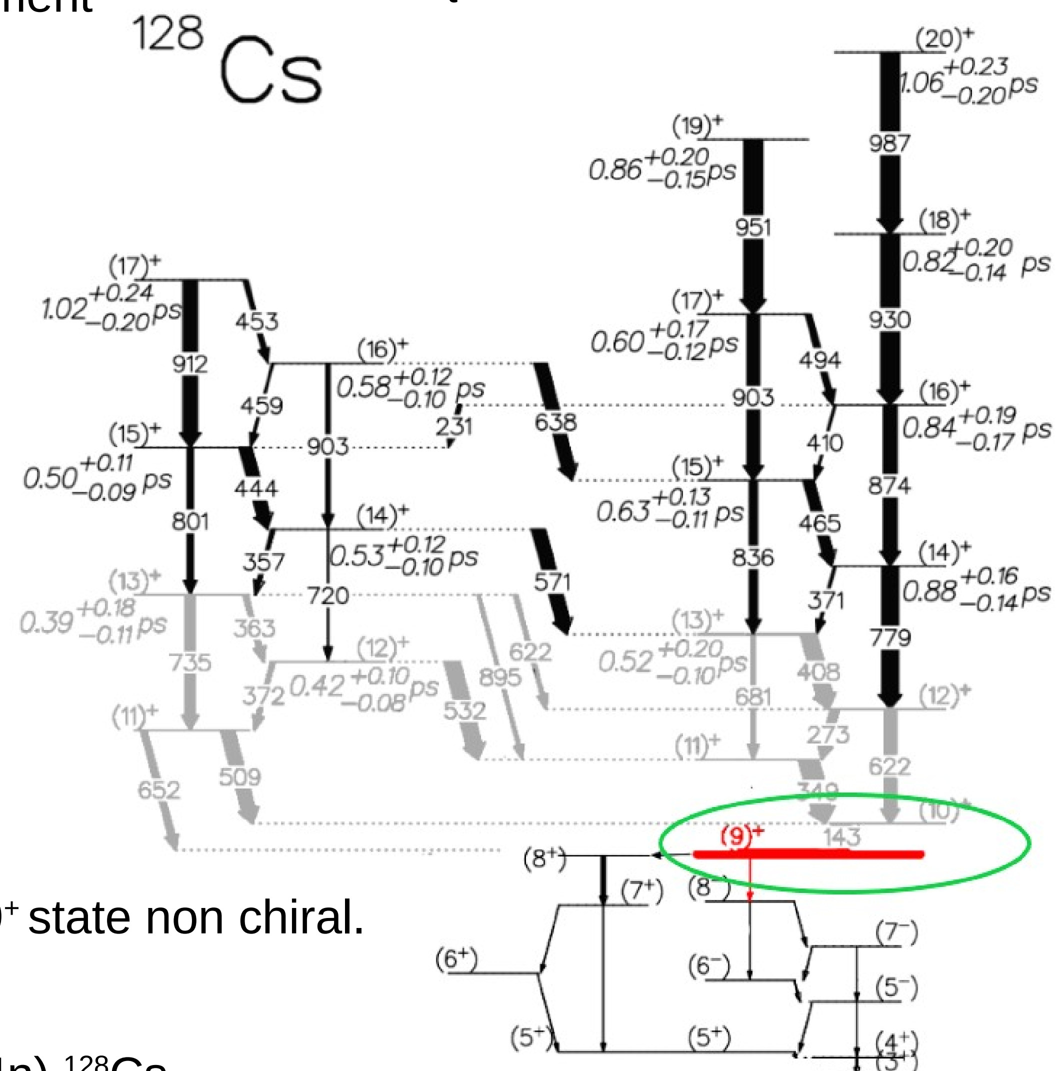
Search for chiral to not chiral transition by lifetime measurement of the I=10$^+$ state in ^{128}Cs

A. Nałęcz–Jawecki, E. Grodner et al.

^{128}Cs – a perfect case to study development chirality as a function of spin.
Chiarilty observed at spins >=13







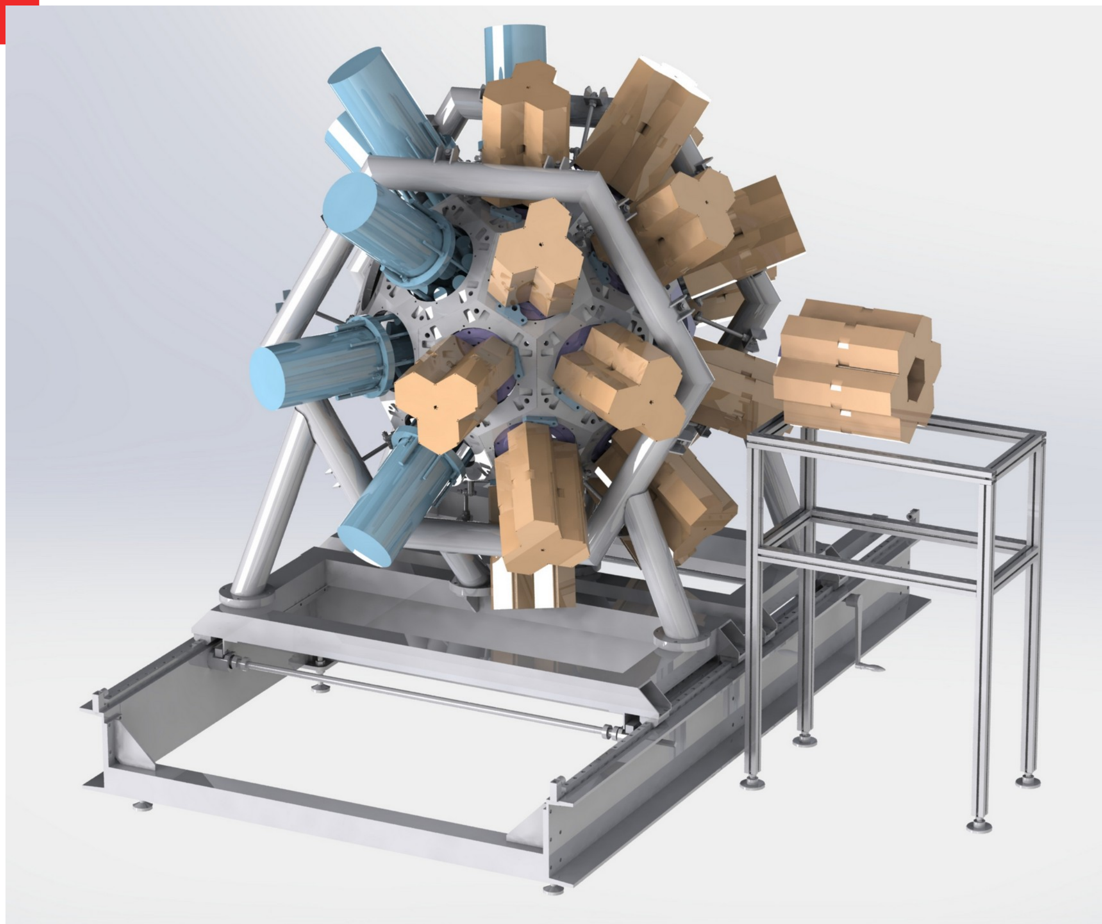
The 9$^+$ state non chiral.

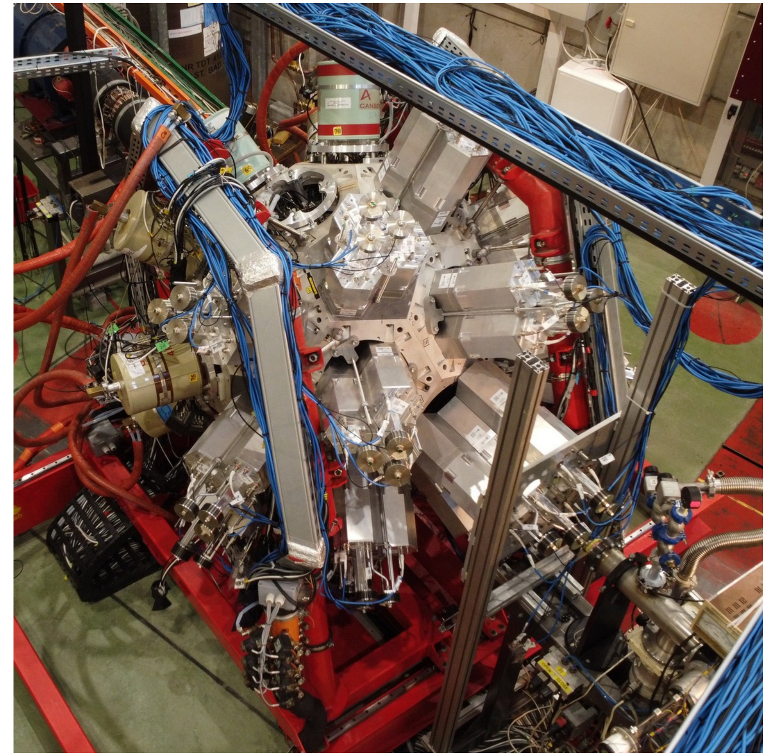
^{122}Sn (^{10}B,4n) ^{128}Cs
Köln plunger, LEPS

Preliminary result: $\tau_{10+} < 20$ ps –> not chiral

EAGLE – NEDA at HIL (NEEDLE)

G. Jaworski et al.





NEDA constructed in years 2007–2018.
Used at GANIL in 2018 in 5 experiments
In December 2021 moved from GANIL to HIL,
EAGLE-NEDA commissioned in Jan. 2023

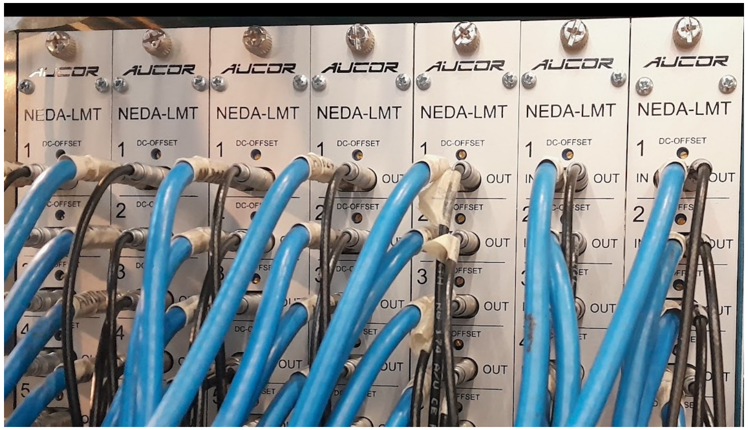
NEDA at HIL depends on when NEDA needed at LNL
(for the zero-degree campaign of AGATA):
agreed until summer 2024,
pending request to NMB to extend until end of 2024

- 15x3 NEDA detectors are placed in the forward half of EAGLE
- 7 (or 6) NEDA detectors in a separate stand form a forward wall
- 15 HPGe detecors are placed in the backward half of EAGLE

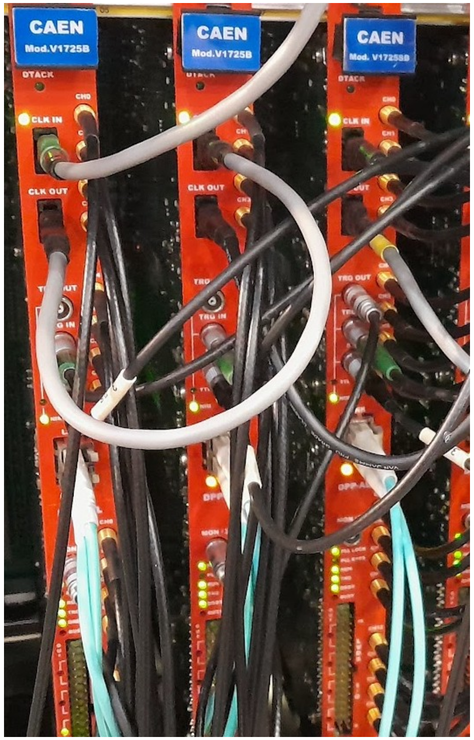
EAGLE-NEDA data acquisition

Transformation from:

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



- Custom made amplitude limiters restrict the NEDA signals to 2V (Aucor, Warsaw);
- 6 CAEN V1725S(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 (NEDA: not only PSD discriminated neutrons – gamma-ray time ref. and multiplicity filtering possible);
- 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.).



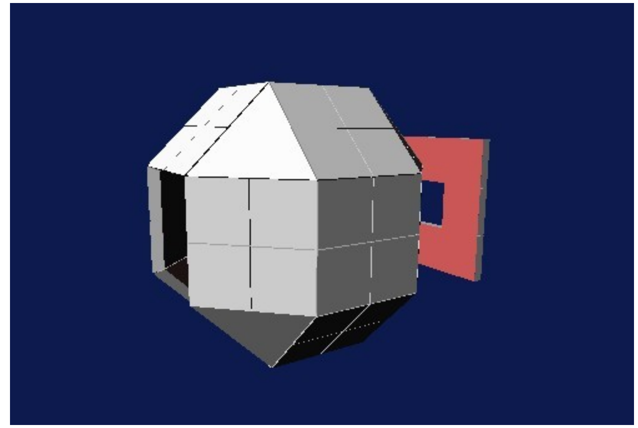
G. Jaworski, A. Goasduff, N.Toniollo, M. Kowalczyk, P. Kulessa

stays at HIL after NEDA leaves

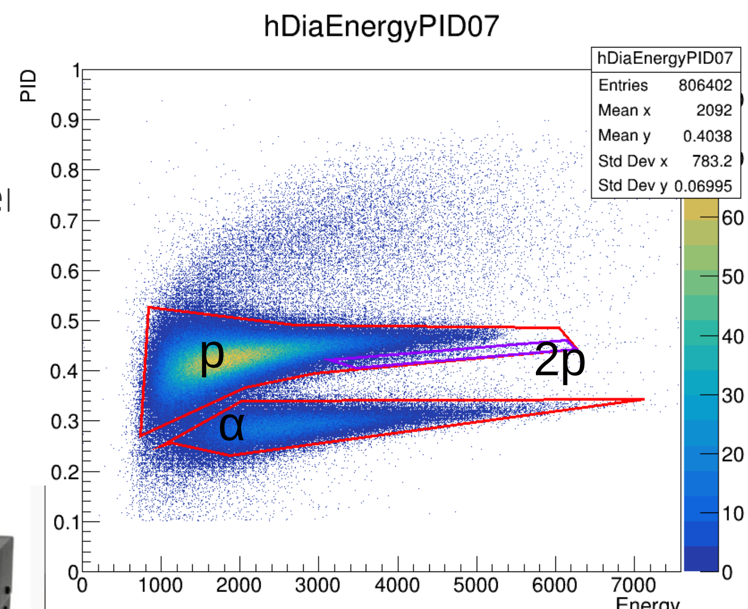
EAGLE-DIAMANT

I. Kuti, J.Molnar et al. (ATOMKI)

- 80 CsI detectors, rhombicuboctahedron, plus f.w. able to register and distinguish protons and alpha particles emitted in
  a fusion-evaporation reaction
  $\epsilon_p \approx 0.6$ $\epsilon_\alpha \approx 0.4$

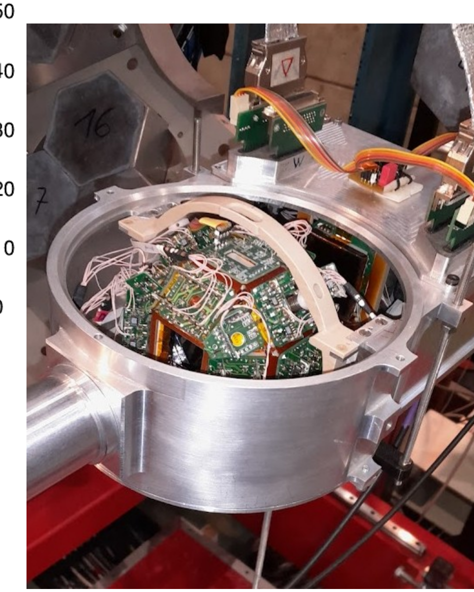


- comissioned at HIL in July 2023



- present: NUMEXO2 digitizers and GANIL software, AGAVA

- future: new CAEN R5560 digitizer purchased by ATOMKI
  to replace NUMEXO2
  128 channels/125 MHz/14 bit
  (double trapezoid firmware development in progress)



EAGLE-NEDA experiments 2023 (including Jan. 2024)

- 3 EAGLE-NEDA–plunger experiments to:
  - study evolution B(E2) as a function of spin 2^+–10^+ in ^{134}Sm, in order to examine possible X(5) symmetry;
  - examine shape coexistence and octupole correlations in the light Xe, Cs and Ba nuclei
- 3 EAGLE-NEDA-DIAMANT (NEEDI) experiments, to identify excited states in neutron defficient ^{57}Cu, ^{70}Br, and ^{134}Sm (^{135}Eu)

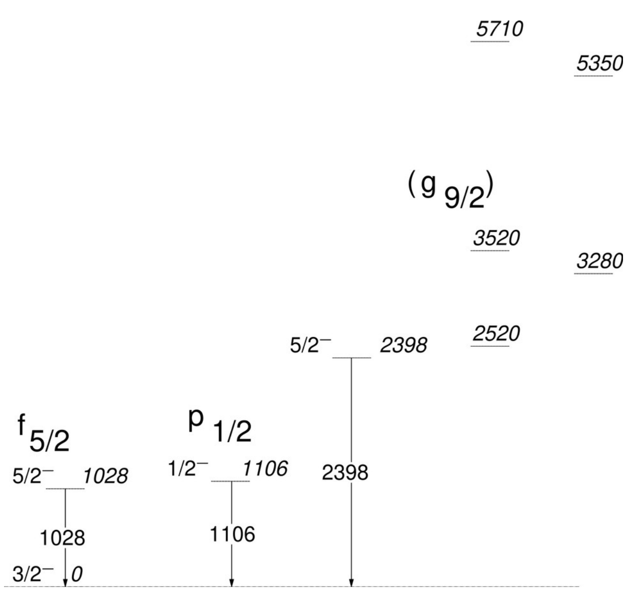
Single-proton states at N = Z = 28 and core excitations in ^{57}Cu

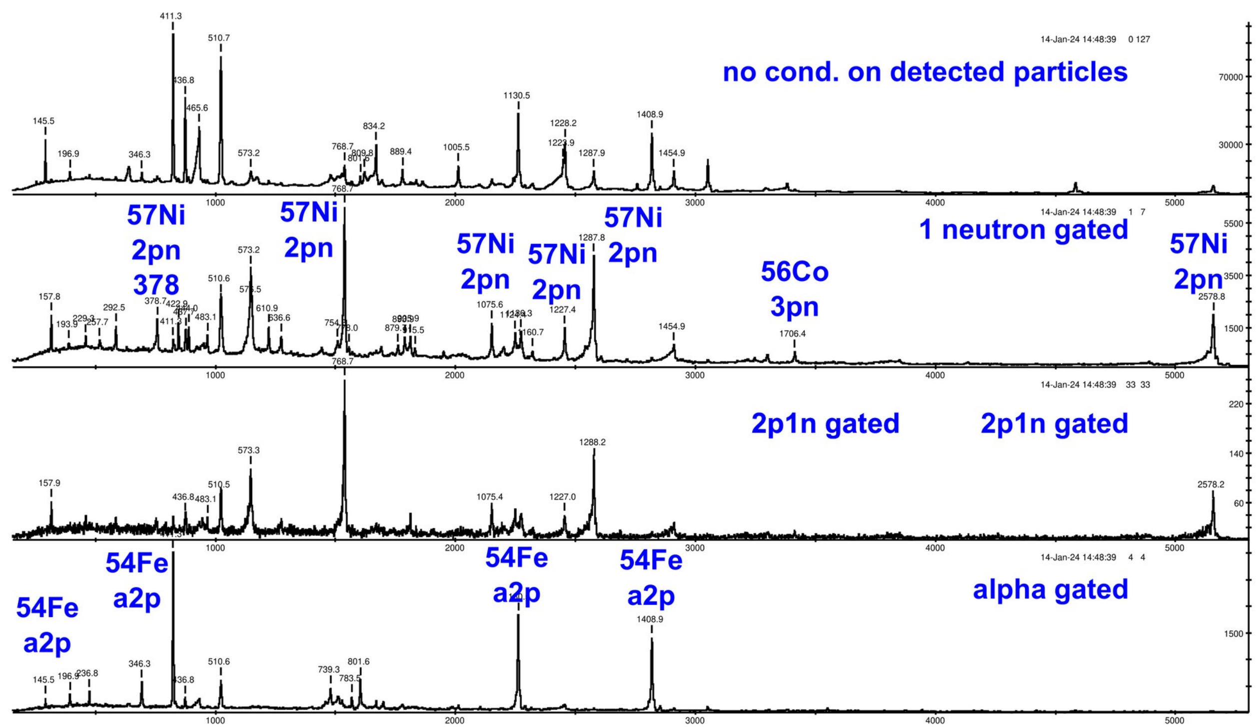
^{56}Zn 32.4 ms	^{57}Zn 45.7 ms	^{58}Zn 86 ms	^{59}Zn 178.7 ms	^{60}Zn 142.8 s	^{61}Zn 89.1 s
^{55}Cu 55.9 ms	^{56}Cu 80.8 ms	^{57}Cu 196.4 ms	^{58}Cu 3.204 s	^{59}Cu 81.5 s	^{60}Cu 23.7 m
^{54}Ni 114.1 ms	^{55}Ni 203.9 ms	^{56}Ni 6.075 d	^{57}Ni 35.6 h	^{58}Ni	^{59}Ni 81 ky
^{53}Co 244.6 ms	^{54}Co 193.27 ms	^{55}Co 17.53 h	^{56}Co 77.236 d	^{57}Co 271.811 d	^{58}Co 70.844 d
^{52}Fe 8.275 h	^{53}Fe 8.51 m	^{54}Fe	^{55}Fe 2.7562 y	^{56}Fe	^{57}Fe

- single-proton nucleus – softness of the ^{56}Ni core
- rp-process: structure of ^{57}Cu essential for the rate of flow of material along the proton drip-line above ^{56}Ni

^{32}S + ^{28}Si → ^{60}Zn (CN) → p2n + ^{57}Cu
~ 0.1 mb

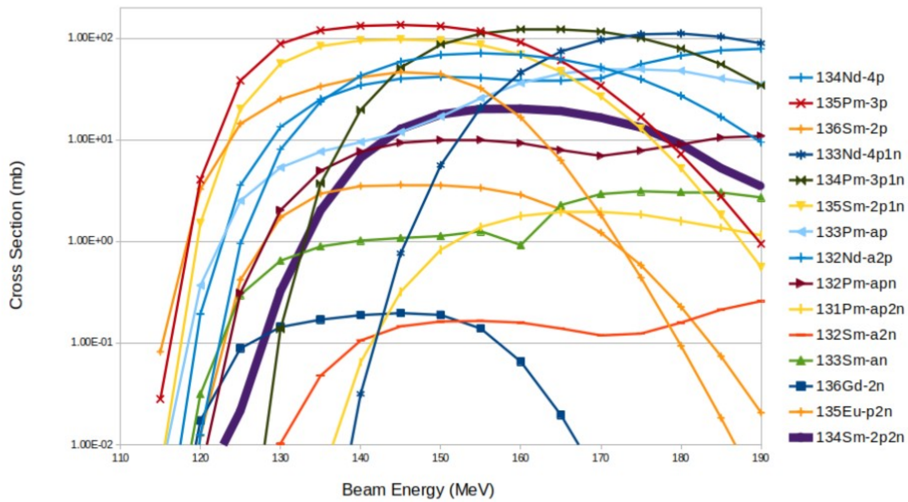
challenging ^{28}Si target (A. Stolarz et al.)
data taken, 16 days of beam on the target

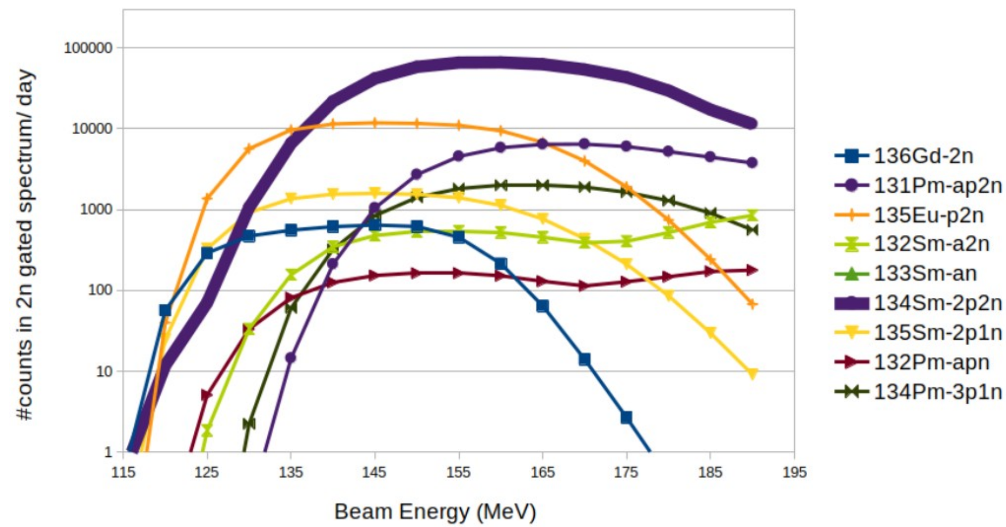




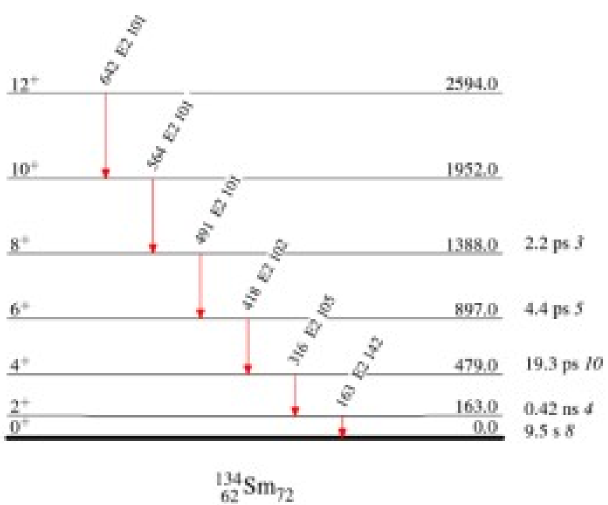
Running now: spectroscopy of ^{134}Sm (^{135}Eu ?)

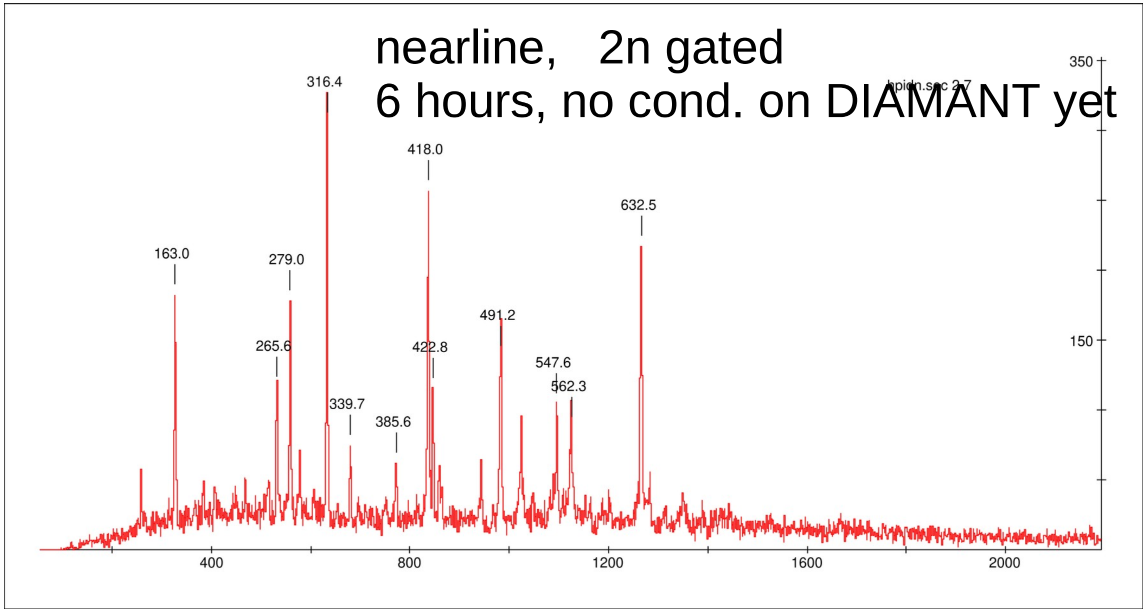
^{106}Cd(^{32}S,2p2n)^{134}Sm





HIVAP calculations





HIL Heavy Ion Laboratory

Detectors Lab at the Heavy Ion Laboratory

- Maintenance and Diagnostics

Two pumping stations capable of evacuating detectors to a vacuum level of approximately 10^{-7} mbar

Helium detector to perform leak checks

Low noise electronics setup for test measurements

- Annealing

Heating Rods for detectors with portable dewars

Heating Tapes for dip-stick cryostats

Canberra NRK-200 neutron damage repair kit

- FET Replacements

- Preamplifier Repairs

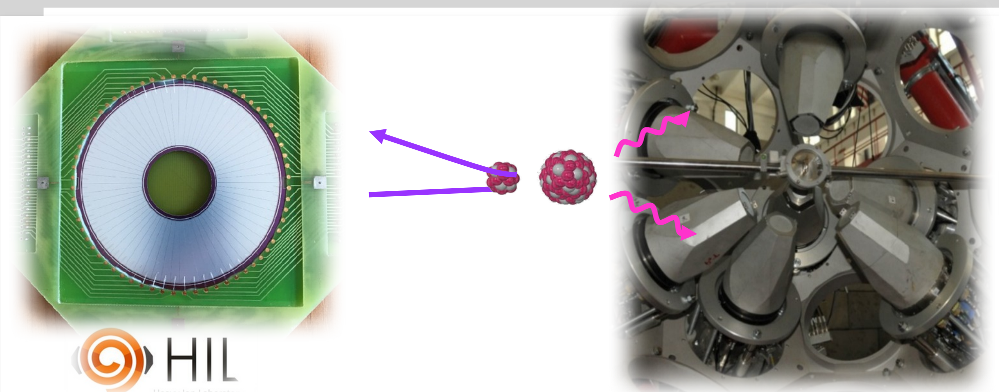
M. Komorowska, M. Kisieliński et al.

Accepted EAGLE experiments (PAC 15 Jan 2024)

to be run in 2024 (?) – 91 days

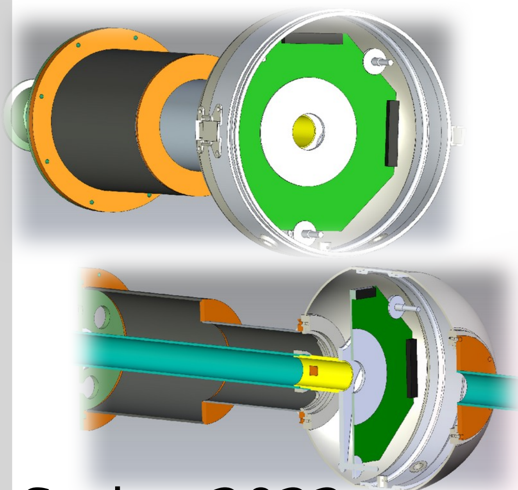
id	days	spokeperson	title	beam	anc. dev.
HIL 109	6	C. Fransen	Lifetime studies in neutron-deficient ^{172}Os using the RDDS technique	^{32}S, 170 MeV	Köln plunger
HIL 117	7	K. Miernik	^{144}Dy fission studies	^{32}S, 200 MeV	(NEDA), DIAMANT
HIL 119	7	J. Heery, J. Henderson	Coulomb excitation of ^{34}S	^{34}S, 92, 129 MeV	SilCa
HIL 120	12	C. Liu, S. Y. Wang	Search for the new chiral nucleus in the 80 mass region: ^{72}As	^{11}B, 50 MeV	
HIL 121	3	J. Perkowski	Test of new magnetic selector and digital electronics system for ULESE spectrometer	^{14}N, 90 MeV	ULESE
HIL 124	12	A. Nałęcz–Jawecki	Search for transition between chiral and non-chiral configuration in ^{128}Cs by lifetime measurement of I=11^{+} ,12^{+} states with a plunger technique	^{22}Ne 85 –90 MeV	Köln plunger
HIL 126	14	I. Kuti	Search for candidate wobbling bands in ^{103}Pd and in ^{101}Ru	^{12}C 69 MeV	(NEDA), DIAMANT
HIL 127	15	A. Fijałkowska, G Jaworski	The discovery of excited states in very neutron defficient europium nuclei	^{40}Ca 180–190 MeV	NEDA DIAMANT
HIL 129	15	G. Jaworski, A. Fijałkowska	The discovery of excited states in very neutron deficient ^{63}Ge nucleus	^{40}Ca 100–110 MeV	NEDA, DIAMANT

SilCA – Silicon Coulex Array



IJC Lab, Orsay

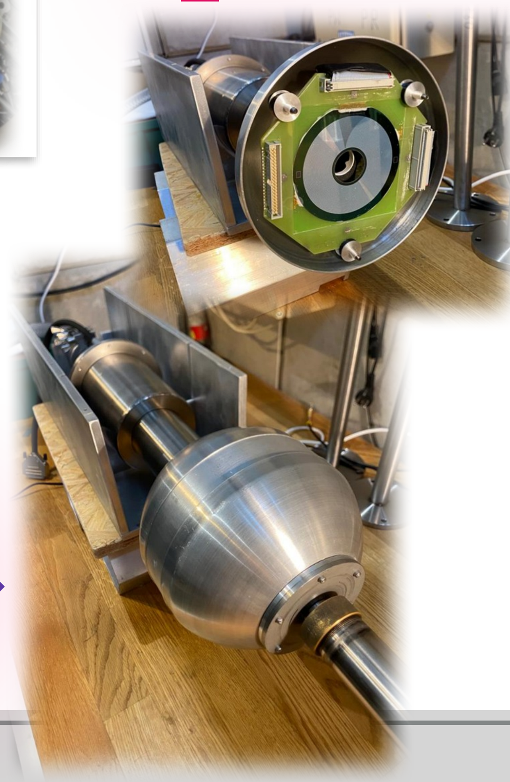
Campaign I-VI 2023

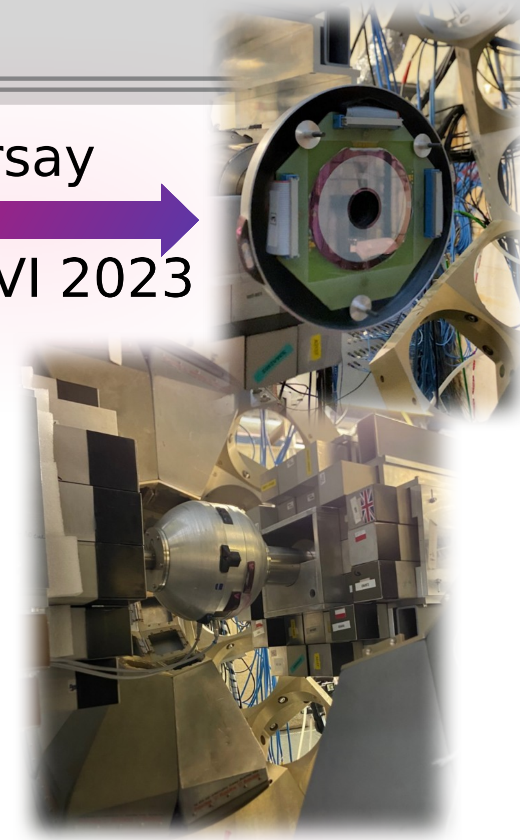


r_{in} = 1.6 cm
r_{out} = 4.2 cm
64 sectors
(32 readout)
32 rings
(16 readout)
Digital electronics

October 2022

Spring 2022

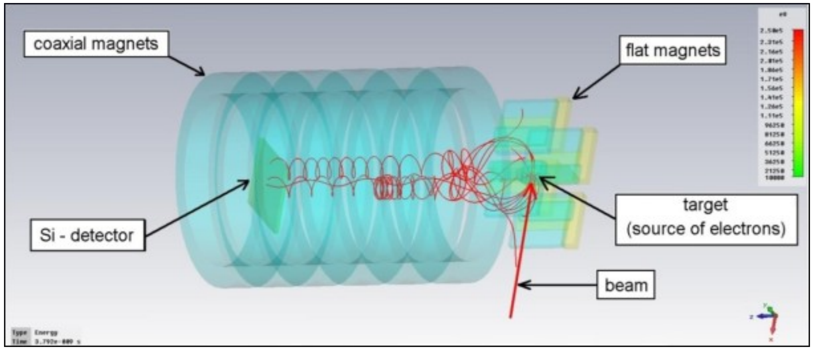


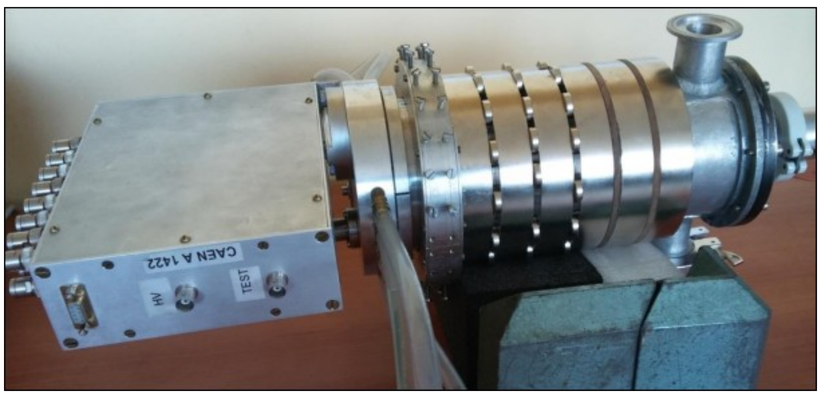


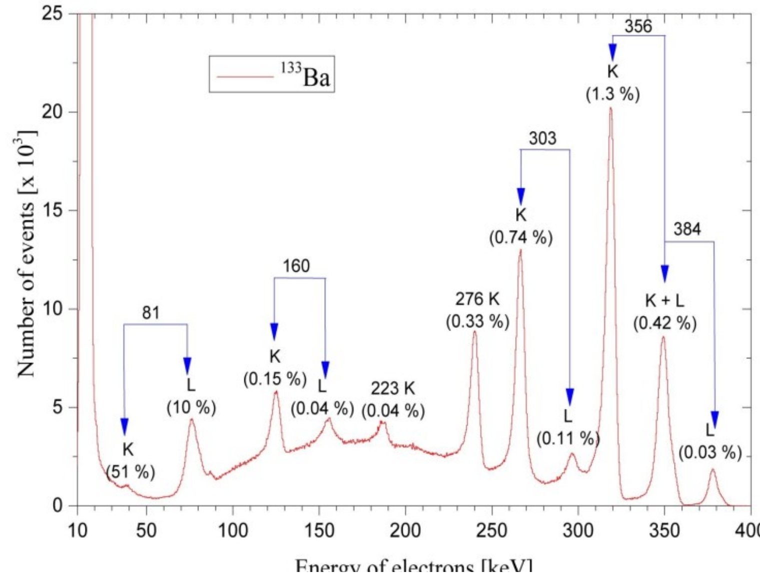
Project: P. Napiorkowski, J. Iwanicki, A. Iwanicki, J. Mierzejewski, KHK

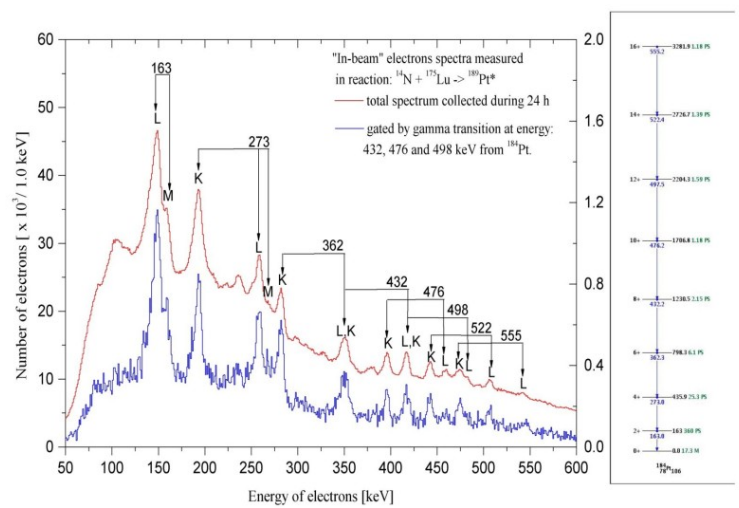
courtesy of K. Hadyńska-Klęk

ULESE – ICE spectrometer









Motivation:

- Kπ=8- isomers in nuclei with N=74 and N=106
- E0 transitions.

Used previously with EAGLE,
beam time allocated to test digital DAQ

J. Perkowski et al. (Univ. of Łódź)

Future plans: fast timing campaign

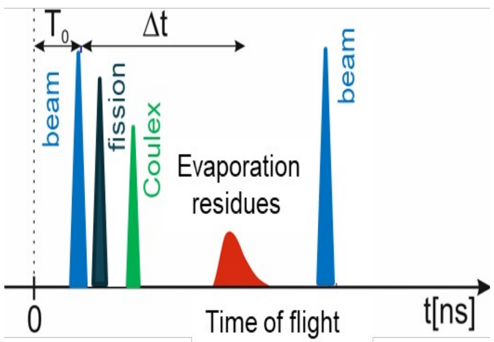
A LoI to study was presented at the PAC meeting on 15 Jan 2024
Installation of 15 $LaBr_3$ (ex. of FATIMA type) in anti-compton shields planned.

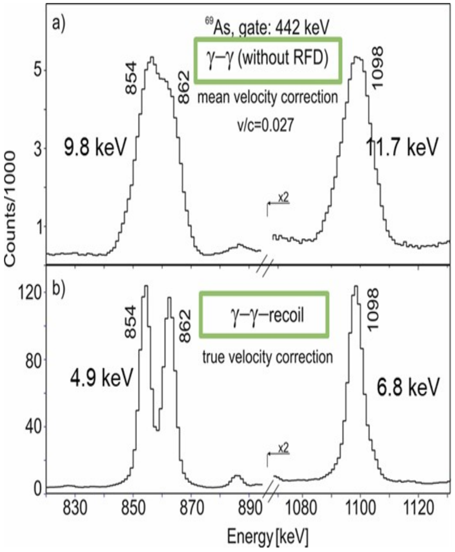
- Physics:
  - α-clustering along N=128
    lifetimes of the first 2+, 4+ and 6+ states for even-even isotopes
  - Test of seniority in neutron deficient $^{200,202}Po$
  - Chiral to not chiral transition ^{126}Cs, ^{128}Cs
  - Evolution of deformation in the rare-earth region

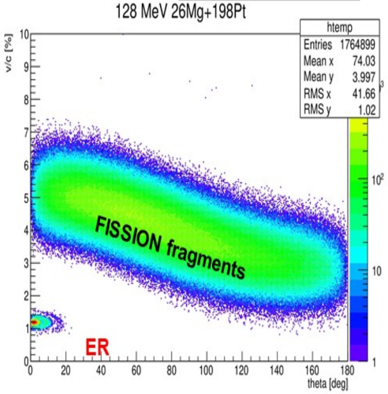
Th. Kröll, A Spaček et al.

Future plans:
Coupling Recoil Filter Detector (RFD) with the EAGLE array

- RFD is a Kraków heavy ion detector which measures evaporation residues in coincidence with γ-rays
- ToF technique allows to reconstruct velocity of every recoil.
- And to filter out unwanted reaction channels: scattered beam, Coulomb excitations, fission fragments, target impurities

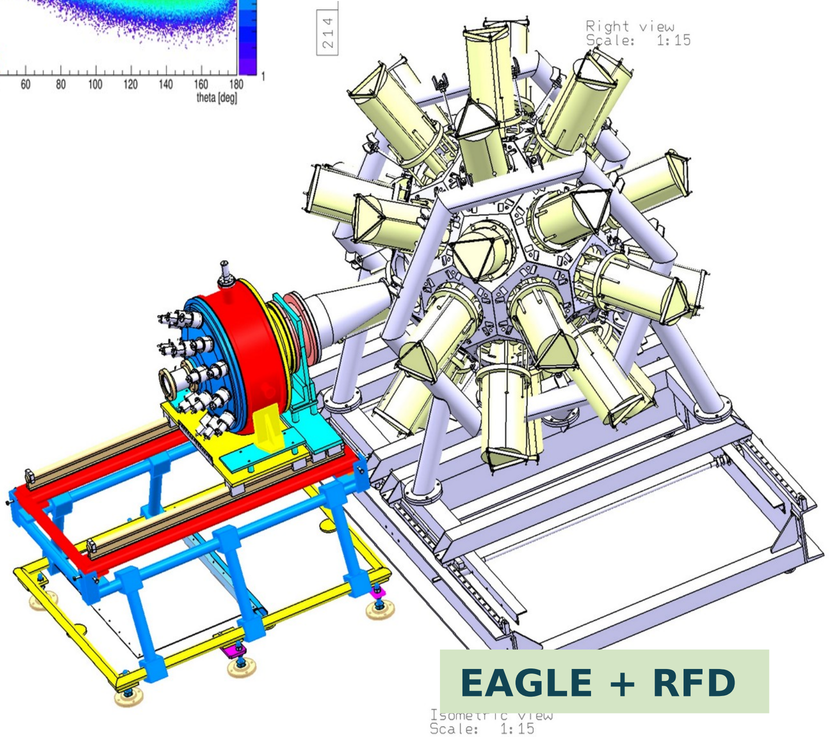






Plans for scientific program

- Investigation of a high spin structure in nuclei near **^{40}Ca** and **^{56}Ni** to **extend the known and unknown structures** up to or beyond the terminating states.
- Study collective bands in these regions, and **excited states lifetimes determination**.
- **Detailed γ-ray spectroscopy** in the **actinide region**, where γ-ray spectra are dominated by a large background from fission.



Courtesy of M. Matejska–Minda
grant application in evaluation

SUMMARY

- EAGLE is a modest (and not really the youngest) gamma-ray spectroscopy array, which is extensively used at HIL.
- 11 (long) experiments with EAGLE run in a ~2 year period
(including 6 with NEDA),
8 planned in 2024.
- NEDA, plunger, DIAMANT, ULESE, SilCa, ...
RFD, fast timing
- EAGLE DAQ digitized, new on-line, near-line processing
(legacy of the NEDA installation)

- next PAC meeting beginning of Dec. 2024

EURO-LABS support is acknowledged.

Installation and use of NEDA at HIL is financed by the NCN grant no. 2020/39/D/ST2/00466.

GAMMAPOOL is acknowledged for providing HPGe detectors.

People – thanks to everybody

- G. Jaworski (NEDA, DAQ)
- A. Goasduff, N.Toniollo ((X)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)
- K. Hadyńska-Klęk, 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)
- All HIL staff: https://www.slcj.uw.edu.pl/en/staff/
- spokepersons and participants of the experiments
- undergraduate students:
  A. Malinowski, A. Otręba, W. Poklepa, M. Regulska, K. Solak, K. Szlęzak, K. Zdunek