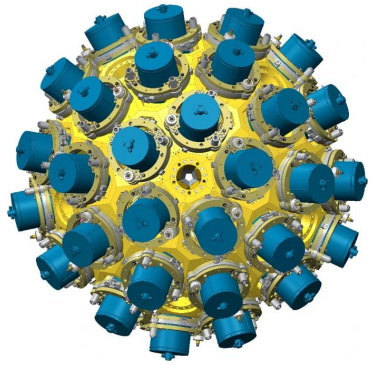
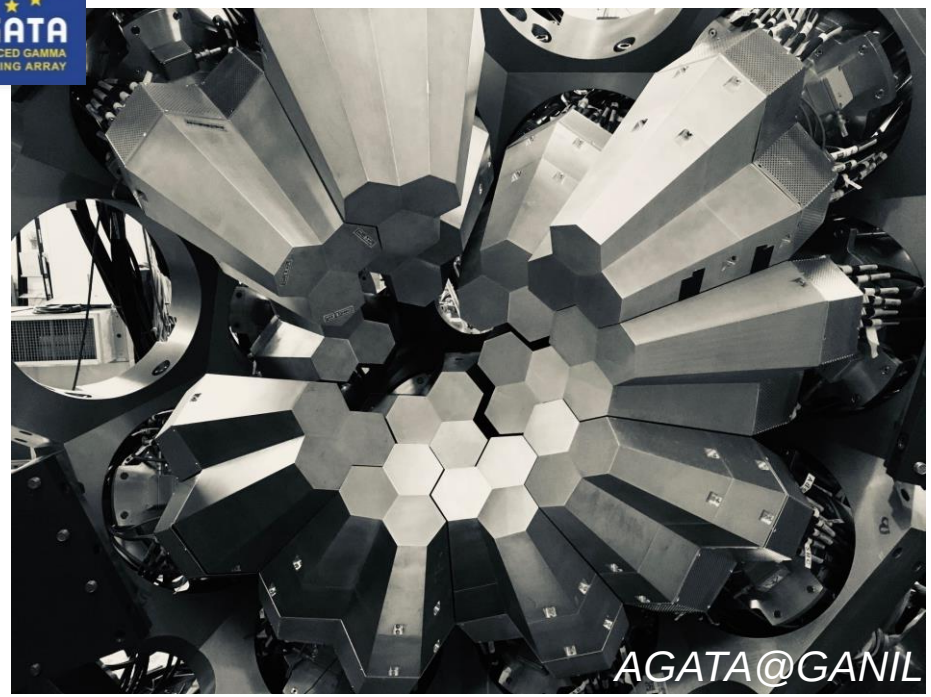
AGATA
GANIL
UK

Emmanuel Clément
October 2023

The AGATA project : THE ultimate spectrometer

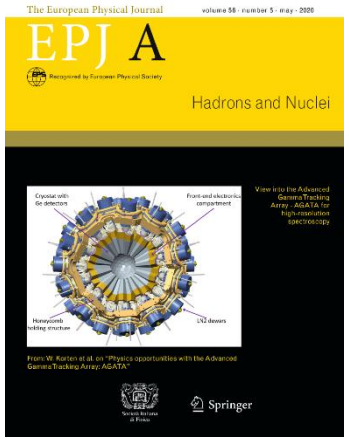


- 180 (60 triple-clusters) crystals
- 362 kg of HPGe
- 82 % solid angle
- 50 kHz per core
- Efficiency: 43% (M_γ=1) , 28% (M_γ=30)
- Angular resolution: ~1º



Fundamentals ingredient:

- ❑ Highly segmented HPGe detectors
- ❑ On-line PSA
- ❑ Complex data analysis algorithms
- ❑ Digital electronic and high bandwidth pipeline



AGATA White Book : W. Korten et al, Eur. Phys. J. A (2020) 56:137
S. Akkoyun *et al.*, Nucl. Instrum. Methods Phys. Res., Sect. A 668, 26 (2012).

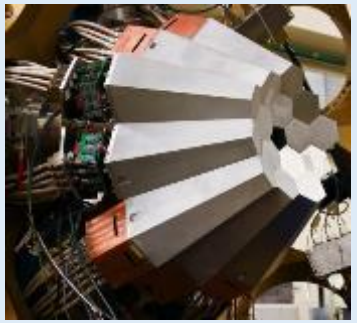
The AGATA project : THE ultimate spectrometer

1st AGATA Steering Committee and Management Board (2002)

MoU Phase 1 + Addendum

MoU Phase 2

2010-2012
Legnaro, Italy
Intense stable beams
15 detectors

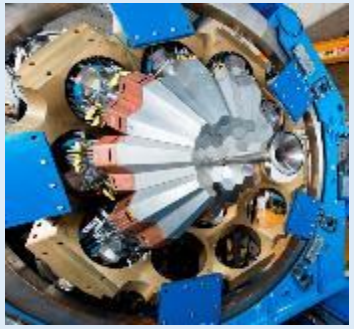


AGATA Demonstrator + PRISMA at LNL

2012-2014
GSI, Germany
Fast fragmentation beams
25 detectors

AGATA at GSI

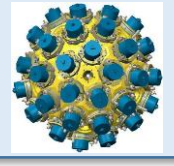
2014- 2021
GANIL, France
ISOL and stable beams
approaching 1π (45)



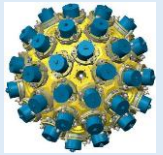
AGATA at GANIL

2021--
LNL, Italy
Stable beams
SPES radioactive beams

AGATA at LNL 2.0



>2025
LNL, SPES, Italy
FAIR, Germany
ISOLDE, CERN
GANIL, France
RIB at low and high energies



March 2022

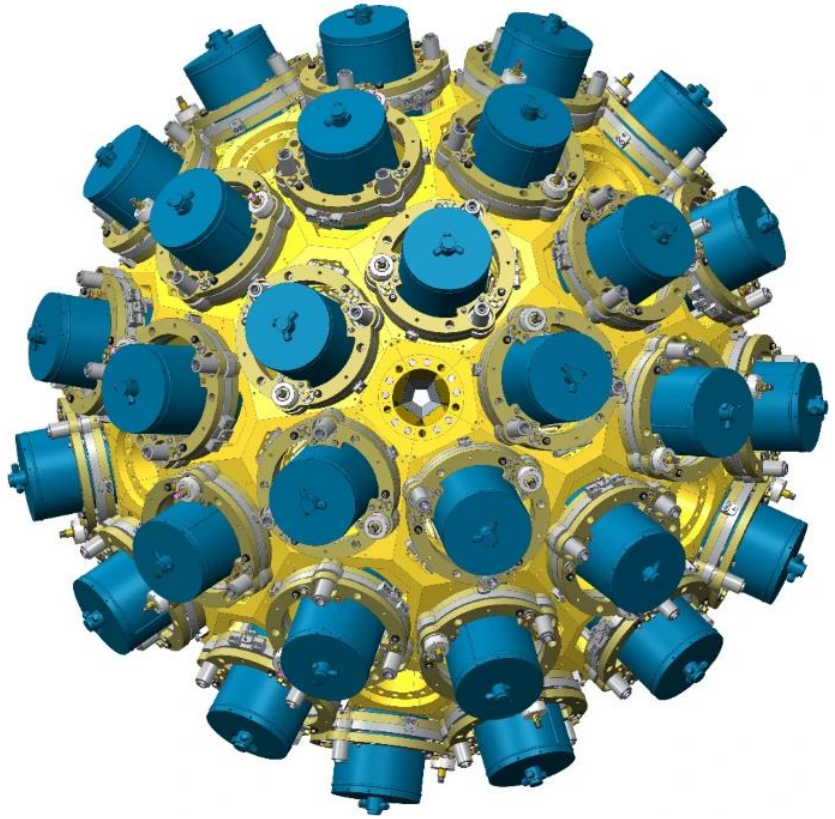
The AGATA project : THE ultimate spectrometer

www.agata.org

Topical Issue EPJA : https://epja.epj.org/component/toc/?task=topic&id=1878

The European Physical Journal A
AGATA: Advancements in Science and Technology

Editors : Nicolas Alamanos, Maria Jose Garcia Borge, Angela Bracco, Emmanuel Clement, Andres Gadea, Wolfram Korten, Silvia Leoni and John Simpson



Topical Issue on AGATA: advancements in science and technology

1) Preface
Editors: E. Clement, A. Gadea, S. Leoni, W. Korten

2) Science advancements with AGATA

2.1 Nuclear structure advancements with multi-nucleon transfer reactions
Lead Author: A. Gadea

2.2 Nuclear structure advancements with fission
Lead Author: A. Lemasson

2.3 Nuclear structure advancements with fusion reactions
Lead Authors: J. Nyberg, J.J. Valiente-Dobon

2.4 Nuclear structure advancements direct reactions
Lead Authors: W. Catford, D. Beaumel, D. Mengoni

2.5 Nuclear structure advancements with relativistic beams
Lead Authors: M. Bentley, G. Benzoni, K. Wimmer

2.6 Nuclear structure advancements with high energy gamma rays
Lead Author: F. Camera

3) Technical advancements with AGATA

3.1 Mechanical implementations and infrastructures
Lead Authors: J. Simpson, B. Million

3.2 Electronics
Lead Authors: A. Gadea, E. Clément

3.3 Software developments
Lead Authors: O. Stezowski, J. Dudouet

3.4 Detector technology
Lead Authors: *H. Hess, P. Reiter*

4) Performances of AGATA

4.1 Review of the last decade Pulse Shape Analysis activities
Lead Authors: A. Boston, P. Reiter

4.2 Performances of tracking algorithms
Lead Authors: J. Ljungvall, F. Crespi

4.3 System performances under different conditions
Lead Authors: A. Korichi, A. Goasduff

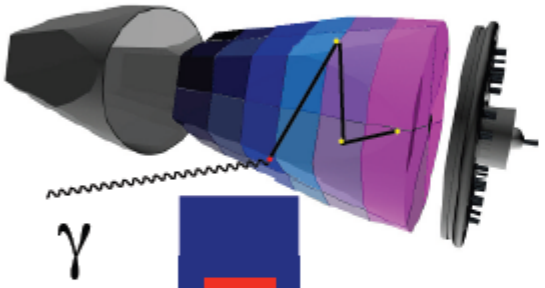
4.4 Simulations of AGATA response and couplings with ancillaries
Lead Author: M. Labiche

4.5 Organization of the collaboration and physics campaigns
Lead Author: E. Clement

AGATA Data Process

1

Highly segmented HPGe detectors



2

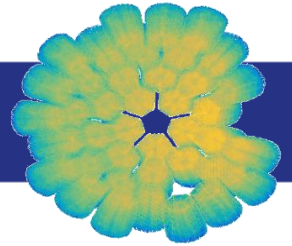
Digital electronics to record and process segment signals

3

Identified interaction points

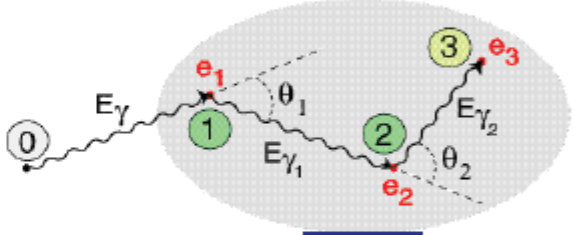
$(x,y,z,E)_i$

Pulse Shape Analysis to decompose recorded waves



4

Reconstruction of scattering sequence from Compton vertices



$$E_{\gamma'} = \frac{E_\gamma}{1 + \frac{E_\gamma}{m_0 c^2}(1 - \cos\theta)}$$

Reconstructed gamma-rays

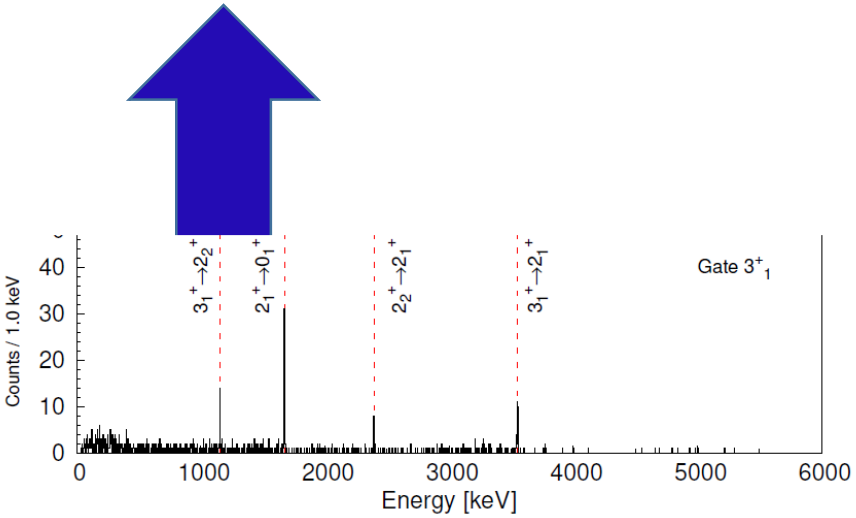
5

Complementary Detectors

β, θ, ϕ, E*

6

Doppler Correction



AGATA Management Board and Teams Phase 2

Project Manager / AMB Chairperson
Working Group Chairpersons, ASC Chairperson (A. Bracco) ACC Chairperson (S. Leoni).
LPM-LNL, LPM-GSI, LPM-GANIL J.Nyberg (Dissemination),

AMB Chairperson
Project Manager
E. Clément

Resource Manager
B. Million

Environmental Officer
R. Perez Vidal

AGATA Working Groups

- Detector Module — H. Hess
- Front-end Electronics — A.Gadea
- Data Processing — O. Stézowski
- Infrastructure — B. Million
- PSA & Tracking R&D — A. Boston
- Performance and Simulation — M. Labiche
- Tech. Coord. — ?

AGATA Teams

Detector & Cryostat — M. Zielinska, M.H. Sigward	Detector CAT &Testing — H. Boston	R & D on gamma Detectors & Applications — D. Judson	
Pre-Amplifier Digitizer — A. Pullia	Pre-processing — I. Lazarus	Global Trigger & Synchronization — GANIL	Coupling To Ancillaries — A. Goasduff
DAQ Infrastructure — IJCLab-LNL	Online/offline Interoperability — G. Baulieu	DAQ Processing — E. Legay	Reprocessing & analysis, Data Manager — J. Dudouet
Detector array Infrastructure — R. Menegazzo	Mechanical Infrastructure — R. Smith	AGATA Array Database — C. Aufranc	
PSA Algorithm Development — L. J. Harkness	Detector Characterisation — A. Boston	Tracking Development — A. Lopez-Martens	
AGATA Performance — R. Perez Vidal	AGATA Commissioning — F. Crespi	AGATA Simulation — M. Labiche	
Quality Control — ?	Documentation — ?		

Local Project Managers (LPM)

- INFN-LNL Legnaro — J.J. Valiente-Dobon
- FAIR Darmstadt — K. Wimmer
- GANIL-SPIRAL2 Caen

AGATA Phase 2 funding

MoU / AMB

Core investments

For material investments
- Detectors
- Electronic
- Mechanics
- Data acquisition
- Infrastructures

Shared between countries (Major countries Fr, Ge, It 20%, UK 15%)

ASC and funding agencies discussion (inc. ARRB) and agreement via MoU

Operation Costs

For repairs, replacement of broken or obsolete material for the Core items

Shared between countries and scaled and re-evaluated annually with capital investments and real cost
Endorsed by ASC via MoU

International ASC - ARRB

Host Lab installation

For all local services and interfaces for all material from the Core investments needed to host and operate AGATA

Fully covered by the Host Laboratory and managed within the local host project breakdown structures

R&D and Travels

For travels between partners institutions and to the host laboratory, annual meetings, workshops, Post-docs, PhD and Techincal Short Terms contracts, Technical or scientific R&D

Not financed by the collaboration. National Grant (ERC, National Grant, EU support, TNA etc …)

Project Plan Phase 2

The detailed Project Plan : ATRIUM-563607, ATRIUM-563609

The present project plan, conceived technically for a 4π array, foresees the construction of a 3π array with capital investment from 2021 to 2030, consistent with the MoU,

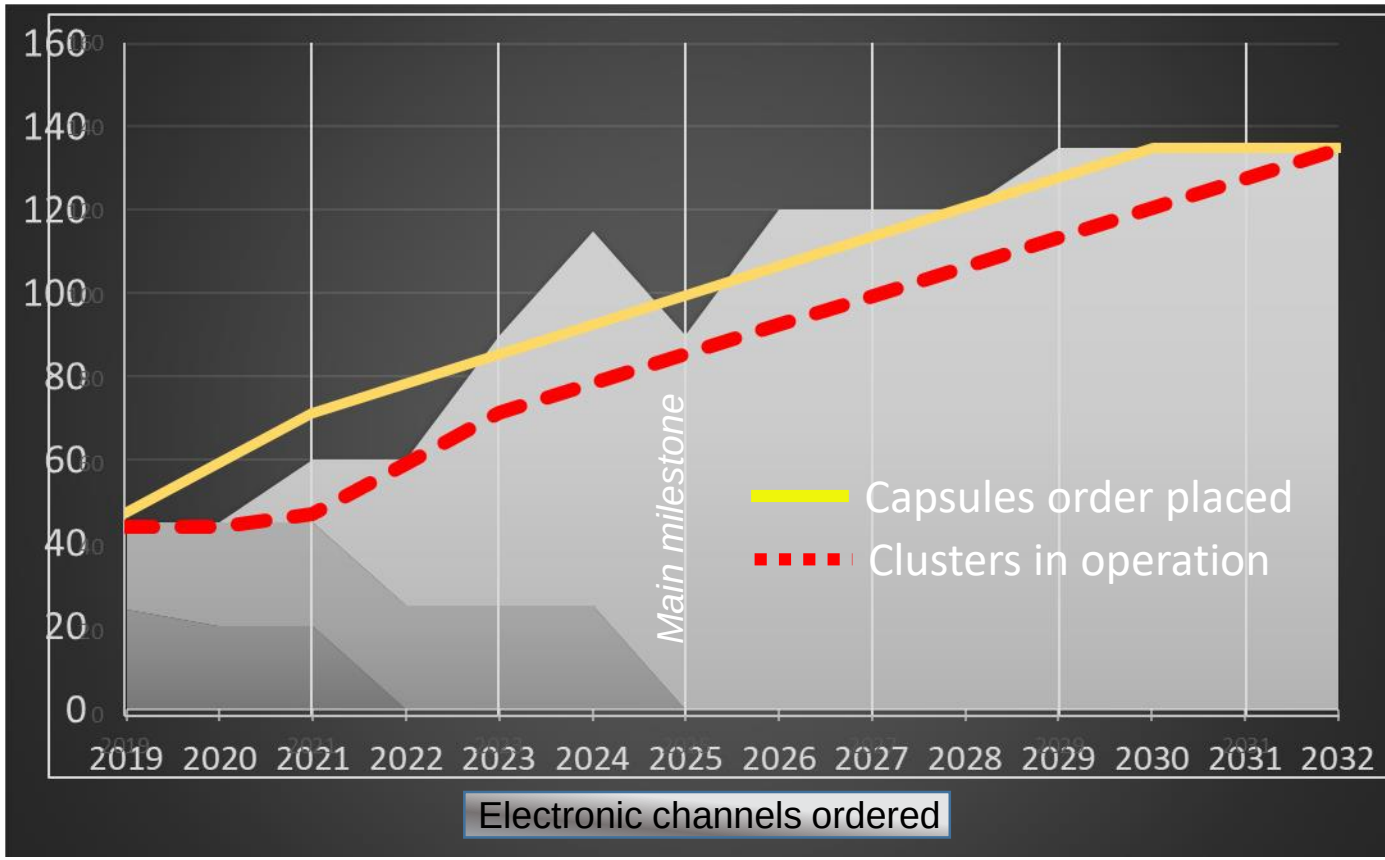
The production of the Triple Clusters constrains the project

The project plan is based on an annual production of 2-3 Triple Clusters (ordered, produced, assembled and tested)

→ A 2π system available by the end of the LNL campaign (~ 2025-2026) and for the start of the next campaign >2026 (SPES, FAIR, GANIL, ISOLDE …)

→ Close to the 3π system delivered by the end 2028-2029
→ The project plan will evolve to the construction of the 4π array

MoU funding scheme (section 3.6)



the Project : Phase 2

The objectives of Phase 2 funded by the MoU are :

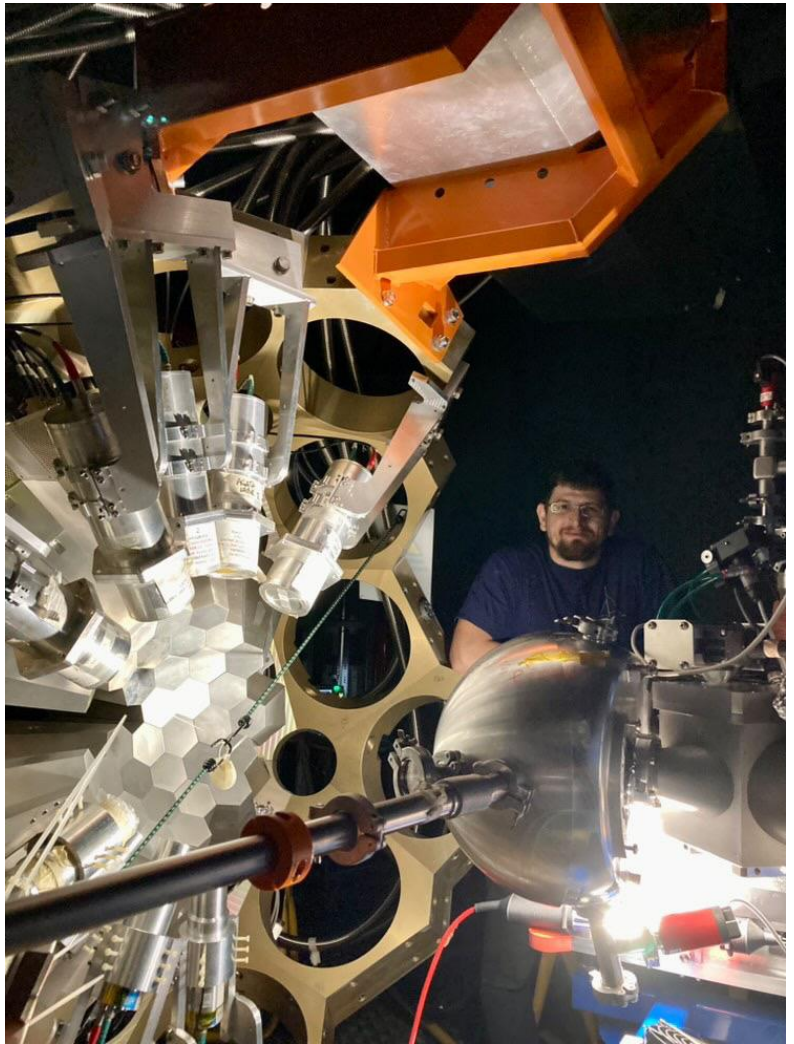
- Acquiring 78 Asymmetric segmented HPGe capsules – 3π available for experiments
- Acquiring 26 AGATA Triple cryostats
- Acquiring 1 Po storage disk
- Acquiring Data Acquisition Infrastructures such as network switches and blades for services
- Acquiring a computer farm (HPC) for the PSA on-line treatment of 135 capsules
- Acquiring a Detector Support System for 135 capsules, Low and High voltages supplies, LN2 auto-fill system and related cables.
- Maintaining An up-to-date Data Base
- Developing and maintaining a set of software algorithms for on-line and off line data processing
- Developing, maintaining and distributing a framework for Data Analysis
- Designing and constructing a unique mechanical structure holding 45 AGATA Triple cryostats
- Developing and maintaining a unique Front and back electronic for 135 capsules (Analog preamps, digitizer DIGOPT12, Processing PACE-STARE with clock and trigger functionalities (GTS/SMART)) and its software control.
- Developing, maintaining and distributing a state of the art simulation package and performances control.

The AGATA Project includes a continuous R&D activities which is included in each Working Group structures but not funded by the MoU.

AGATA campaign #1 at GANIL

After 7 years [2014-2021], the AGATA@GANIL campaign was completed

Presently in LNL for Tandem – ALPI physics runs using stable beams and later with SPES



29 experiments

558 To of data

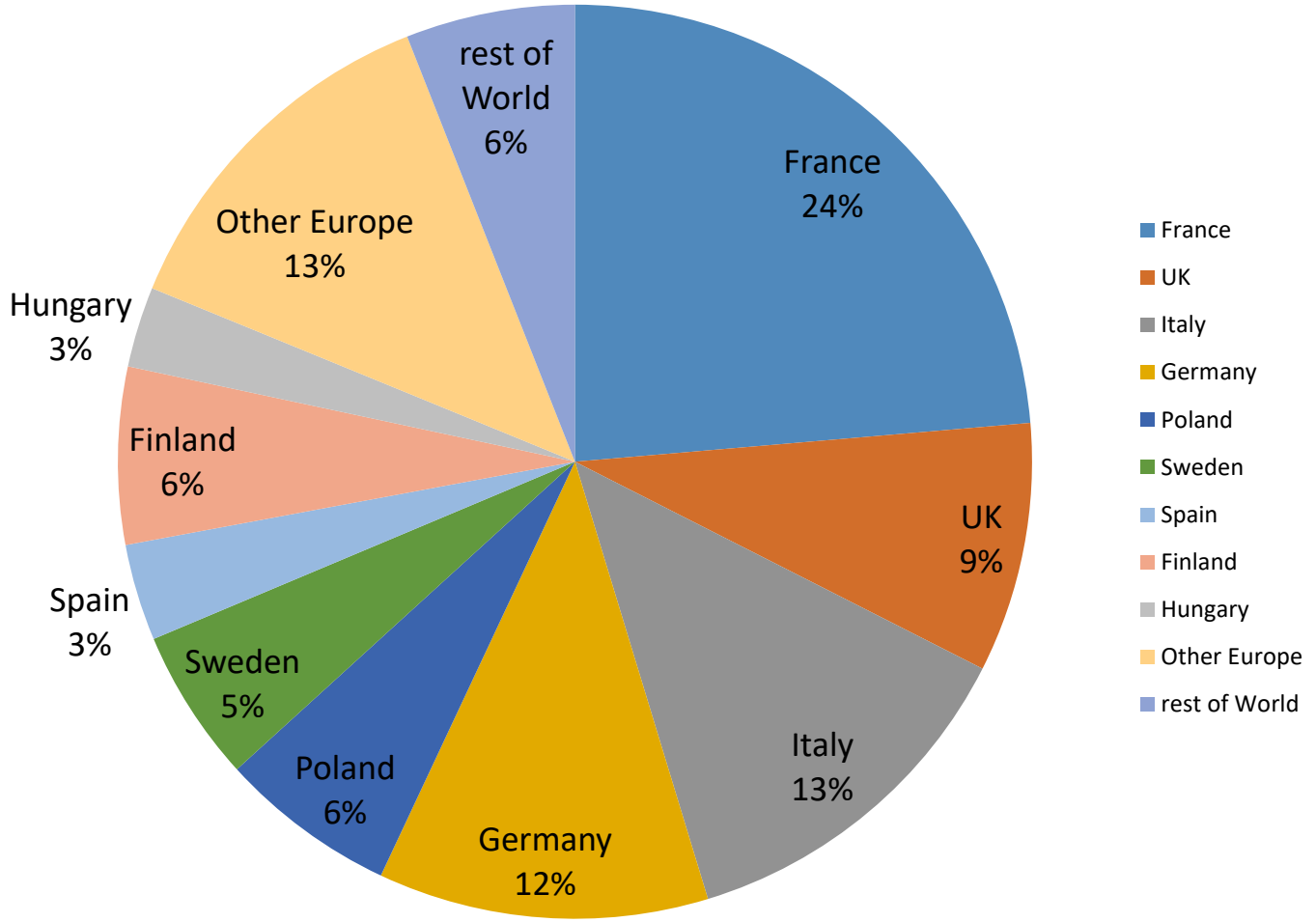
6568 hours beam on target

14 034 elog entries

2386 days of LN2 surveillance

11,5 Tons of scientific equipment

AGATA campaign #1 at GANIL

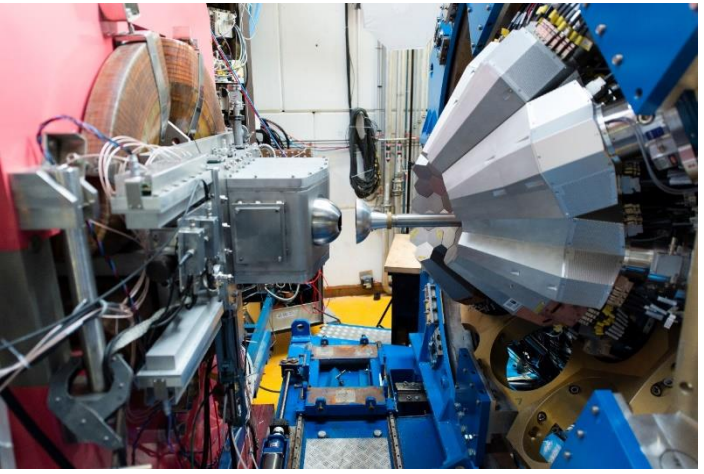


Initial LoI Country involvement

AGATA@GANIL.1 were many sub-campaigns

laboratoire commun CEA/DRF — spiral2 — CNRS/IN2P3

2015-2017

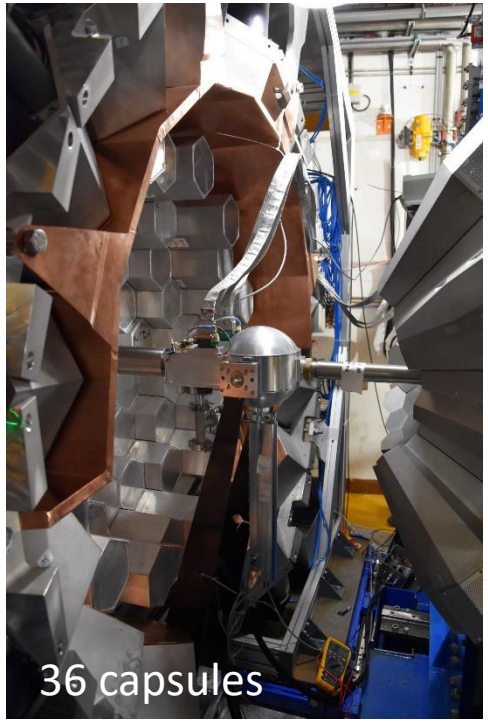


AGATA coupled to VAMOS, FATIMA, PARIS

24-34 capsules

Exotic nuclei spectroscopy by MNT transfer and fission reaction

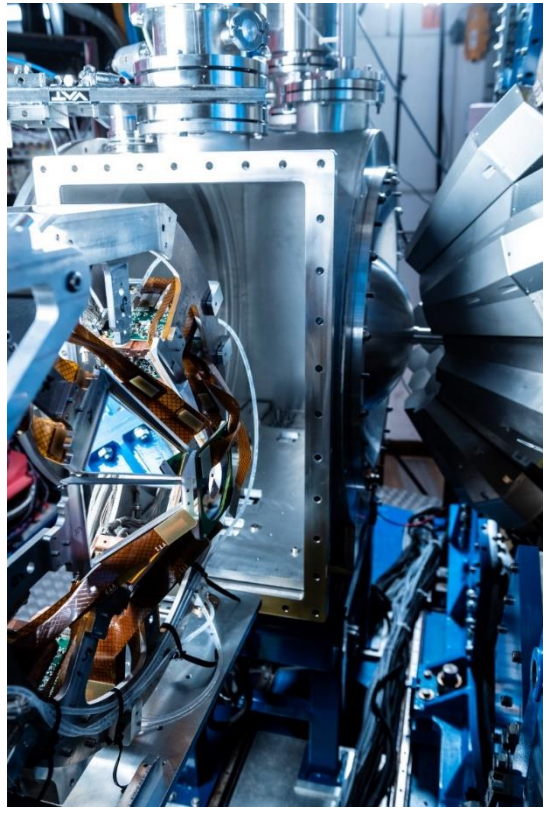
2018



AGATA coupled to NEDA- DIAMANT

N~Z nuclei spectroscopy by fusion evaporation

2019-2021

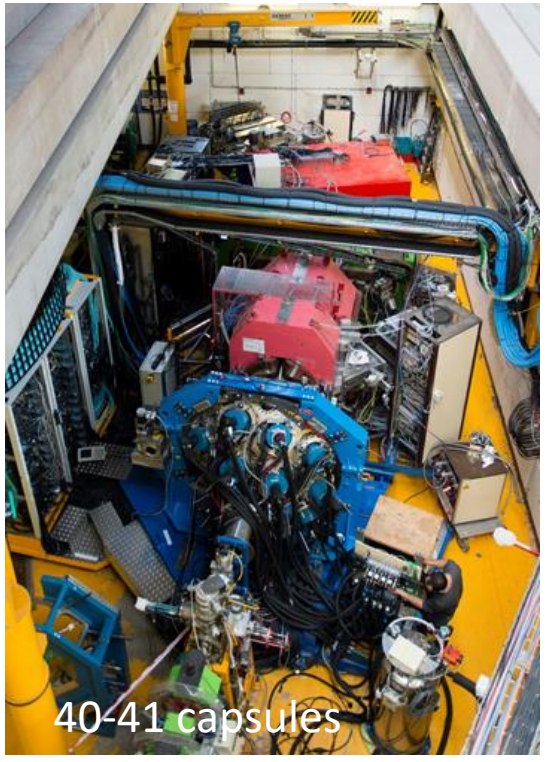


AGATA coupled to VAMOS MUGAST

40-41 capsules

Exotic nuclei spectroscopy by transfer reaction using RIB

2021



AGATA coupled to VAMOS, EXOGAM, 2nd Arm, LEPS

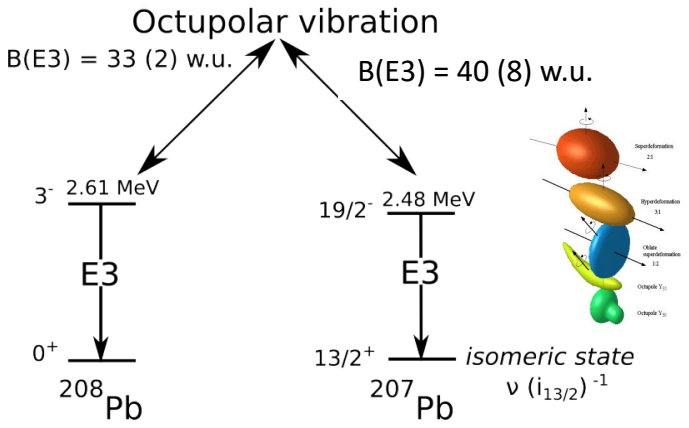
Exotic nuclei spectroscopy by MNT transfer

Each GANIL PAC had a “PrePac” workshop (8 in total) with a specific call ***without filters*** : ***AGATA Collaboration Meeting***

927 UT have been approved
821 UT have been performed over 29 experiments (90 % done)

Some highlights of AGATA@GANIL.1

Evidence of octupole-phonon at high spin in ^{207}Pb : Study of the octupole phonon in the ^{208}Pb region.

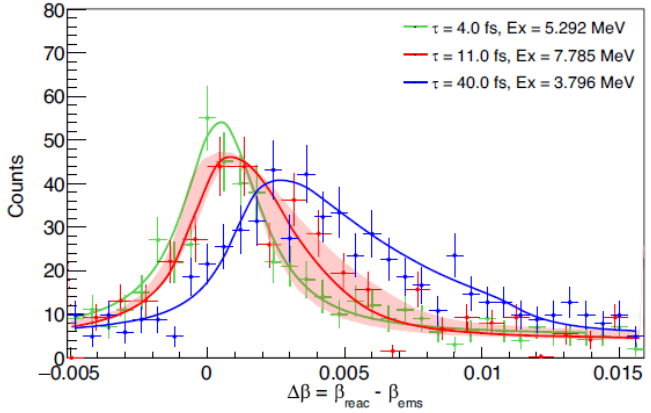


D. Ralet et al Phys.Lett. B 797, 134797 (2019),

1st AGATA Nature paper

Search for ^{22}Na in novae supported by a novel method for measuring femtosecond nuclear lifetimes

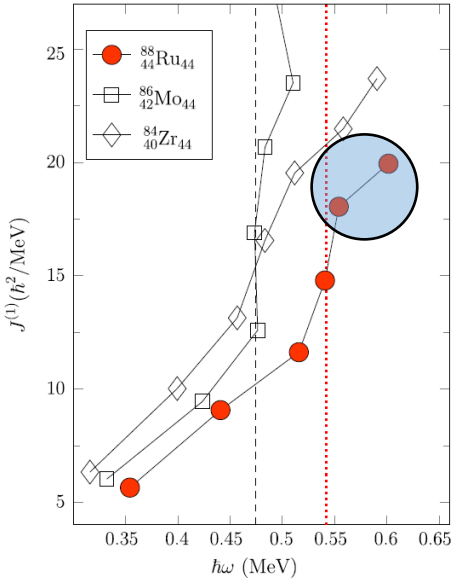
Constraining the ^{22}Na(p,γ)^{23}Mg reaction from the spectroscopy of the 7785.0(7) keV resonance in ^{23}Mg.

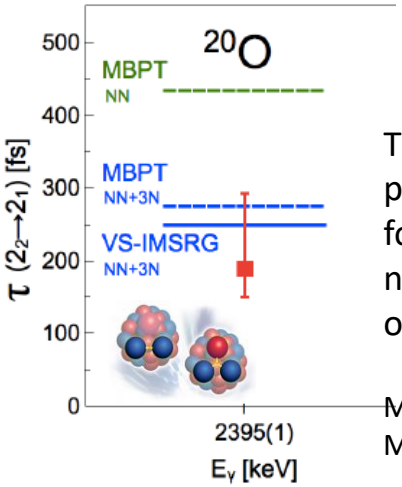


Ch. Fougère et al Nature Communications volume 14, 4536 (2023)

Direct observation of a "delayed" rotational alignment in a deformed N = Z nucleus (^{88}Ru), in agreement with theoretical predictions related to the presence of strong isoscalar neutron-proton pair correlations.

B. Cederwall et al, Phys. Rev. Lett. 124,062501 (2020)

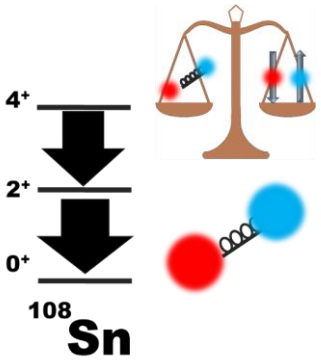


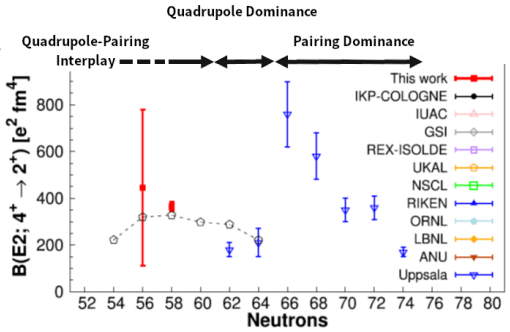


The achieved results agree well with predictions from MBPT and ab initio VS-IMSRG for ^{20}O, showing that 3N interactions are needed to accurately describe electromagnetic observables in neutron-rich nuclei.

More accurate and holystique description from MUGAST-AGATA data, I. Zanon (LNL) submitted to PRL

M. Ciemala et al, Phys. Rev. C101, 021303(R) (2020)

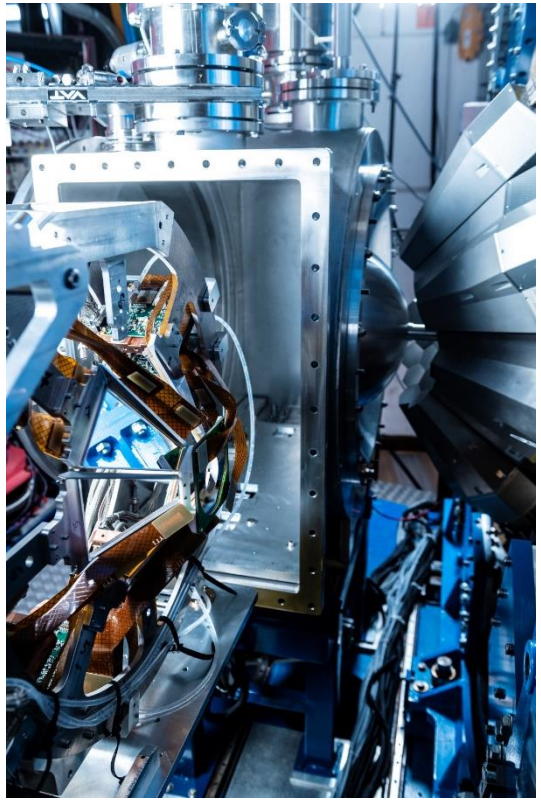




M.Siciliano et al, Physics Letters B 806 (2020) 135474

- 2^+ wave function is dominated by the p-n quadrupole interaction
- 4+ wave function is a balance between p-n quadrupole and pairing interactions
- Revisit our predictions on the ^{100}Sn structure to be investigated at S3

AGATA- MUGAST – SPIRAL1 campaign 2019-2021



NUCLEAR ASTROPHYSICS

Determining the α+^{15}O radiative capture rate

C. Diget (York), N De Séréville (IPN)

PhD : J. Sanchez Rojo

^{15}O(^{7}Li,tγ)^{19}Ne indirect measurement

GOAL:

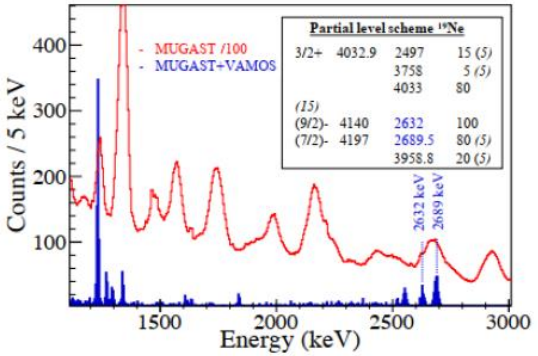
Important reaction for breakout from Hot-CNO cycle to rp-process in Type I X-ray bursts

SPECIFICITIES:

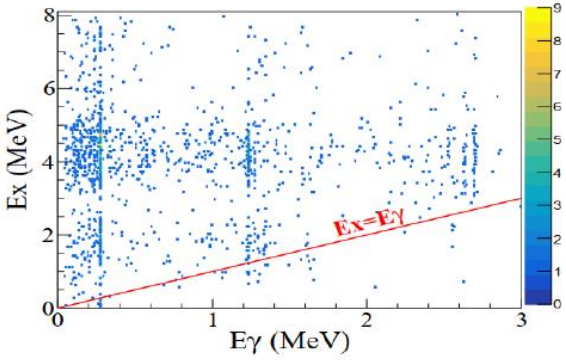
- ➟ High intensity beam : up to 10^8 pps
  - No beam tracking
  - PId by reconstructing trajectories in VAMOS (new!)
- ➟ High energy gammas (~4 MeV)
- ➟ Triple coincidences: background free

Determining the α+^{15}O radiative capture rate

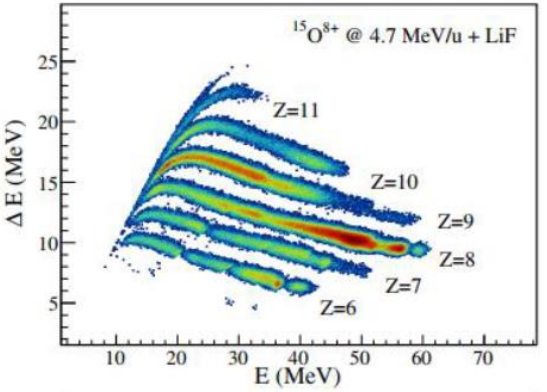
Gamma spectrum in triple coincidence

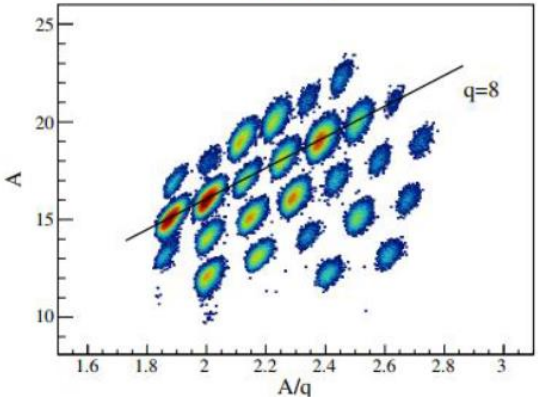


--> Very clean spectrum : almost no background



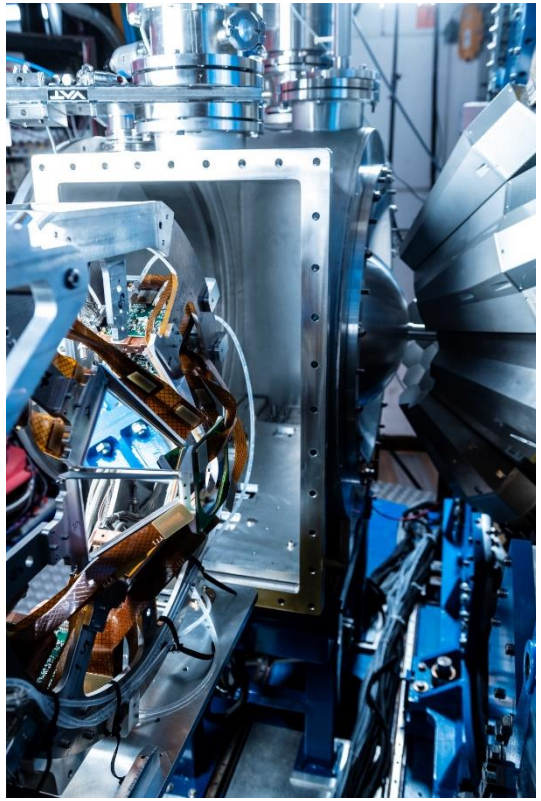
VAMOS identification





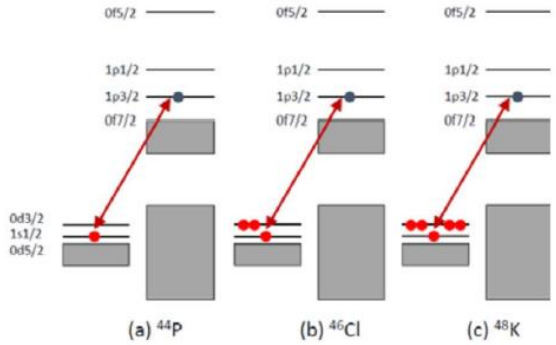
AGATA- MUGAST – SPIRAL1 campaign 2019-2021

laboratoire commun CEA/DRF CNRS/IN2P3

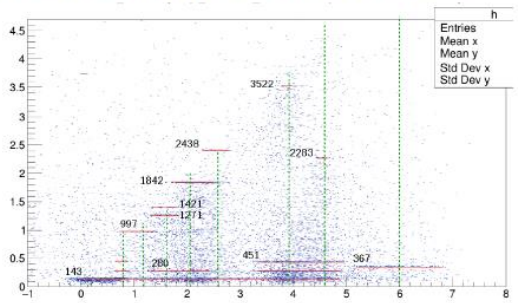


Proton-neutron interactions across N=28 via ^{47}K(d,p)^{48}K

Experiment SP: W. Catford (Surrey), A. Matta (LPC Caen) / PhD : C. Paxman (Surrey)

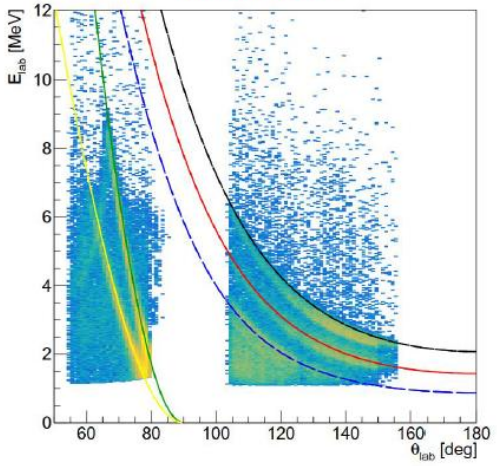


- Odd proton $1s_{1/2}$ interaction with odd neutron above N=28
- Spectroscopy of N=29 nuclei towards ^{44}P

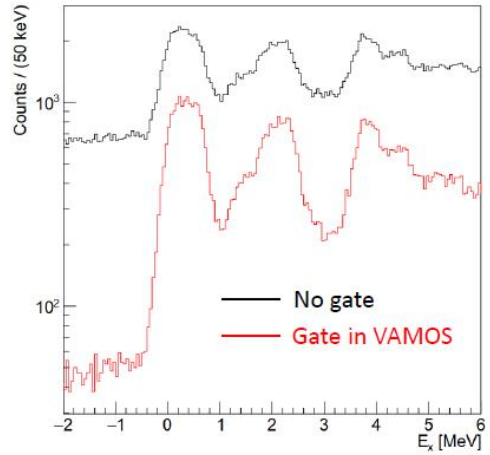


The (d,p) channel is normally quite clean at backward angles. VAMOS was used in «reduced mode», asking only a coincidence with its focal plane detector, to remove background from fusion-evaporation.

Kinematics



Ex distribution



- E_x vs E_γ and γ-γ matrices could produced -> level scheme of ^{48}K extended
- Elastic scattering could be measured close to 90°

Experiment finished today!

AGATA@GANIL.1 summary

laboratoire commun CEA/DRF CNRS/IN2P3

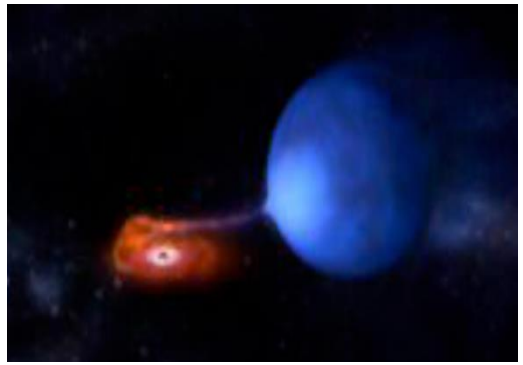
The scientific program of AGATA benefited :

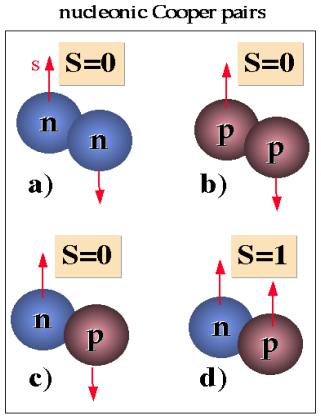
- ❑ **From the high intensity, heavy ions, high quality, stable beams from CSS and post-accelerated RIB from SPIRAL1.**
- ❑ **Unique complementary instruments for high resolution γ-ray spectroscopy (VAMOS++, NEDA-DIAMANT, PARIS and MUGAST)**

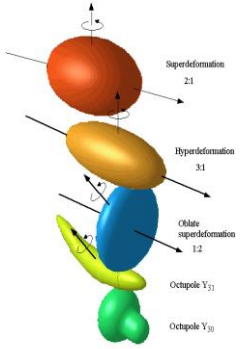
Between 2015 and 2021, GANIL reserved a major position to AGATA experiments in its scientific program : 55% of the scientific production involved AGATA experiments

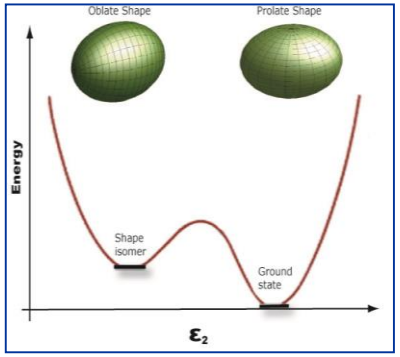
- 27 peer-review paper published including 30% high impact letters with GANIL Data
- 18 PhD theses have been defended or in preparation with GANIL data
- 0.5 Po of data recorded at GANIL placing nuclear physics experiment in the big data management area

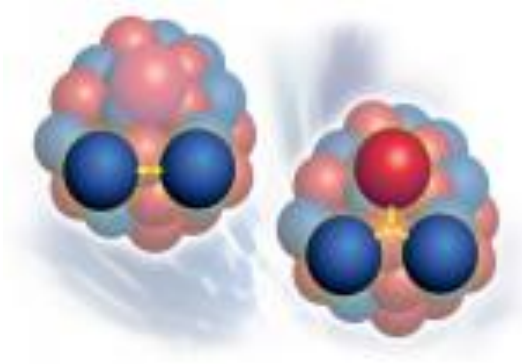
Combined to state-of the art GANIL instrumentation : VAMOS and RIB facility SPIRAL1 as well as high quality stable and heavy ion beams, AGATA reached the ultimate high-resolution in-beam spectroscopy in exotic nuclei with collaborative instrumentation MUGAST, NEDA…











AGATA@GANIL.2 Proposal

« Data taking » between : March 2026 – July 2028

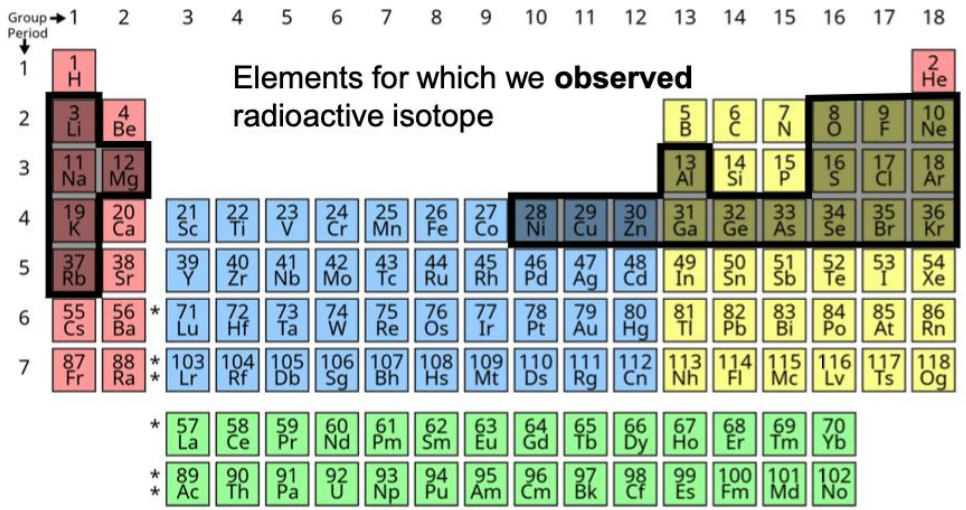
laboratoire commun CEA/DRF — CNRS/IN2P3

0° degree campaign using the SPIRAL1 beams with MUGAST/GRIT and VAMOS

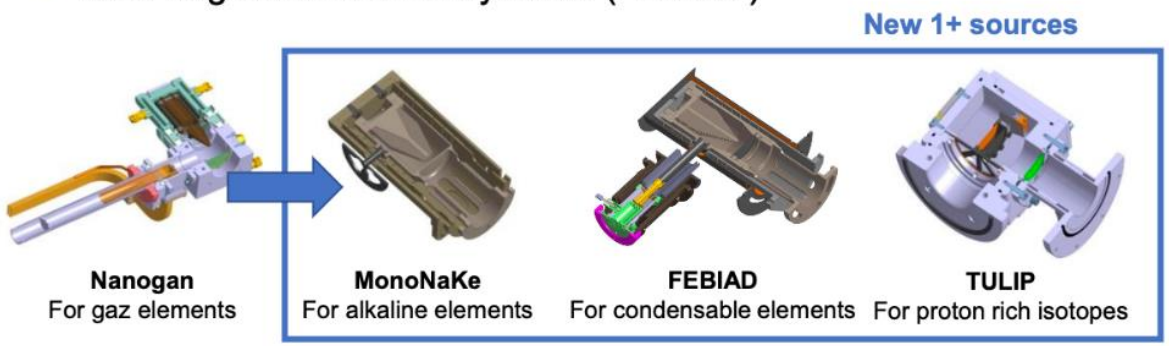
- SPIRAL1 + AGATA experiments have a strong impact : 1 PRL and 1 Nature with AGATA+MUGAST under referee procedure at the moment
- SPIRAL1 + AGATA experiments are unique in the fields of nuclear structure, astrophysics and dynamic, using coulomb excitation and transfer reactions
- **He, Ne, Ar, Kr, O, N, F, K radioactive beams are operational.**

GANIL is putting a strong effort on SPIRAL1 in-beam tests.

Tests in 2021-2023 lead to **50 new isomers/isotopes** with intensities suitable for acceleration using CIME



- New target Ion Source Systems (FEBIAD)



See P. Chauveau's presentation

see : https://www.ganil-spiral2.eu/scientists/ganil-spiral-2-facilities/available-beams/

AGATA@GANIL.2 Proposal

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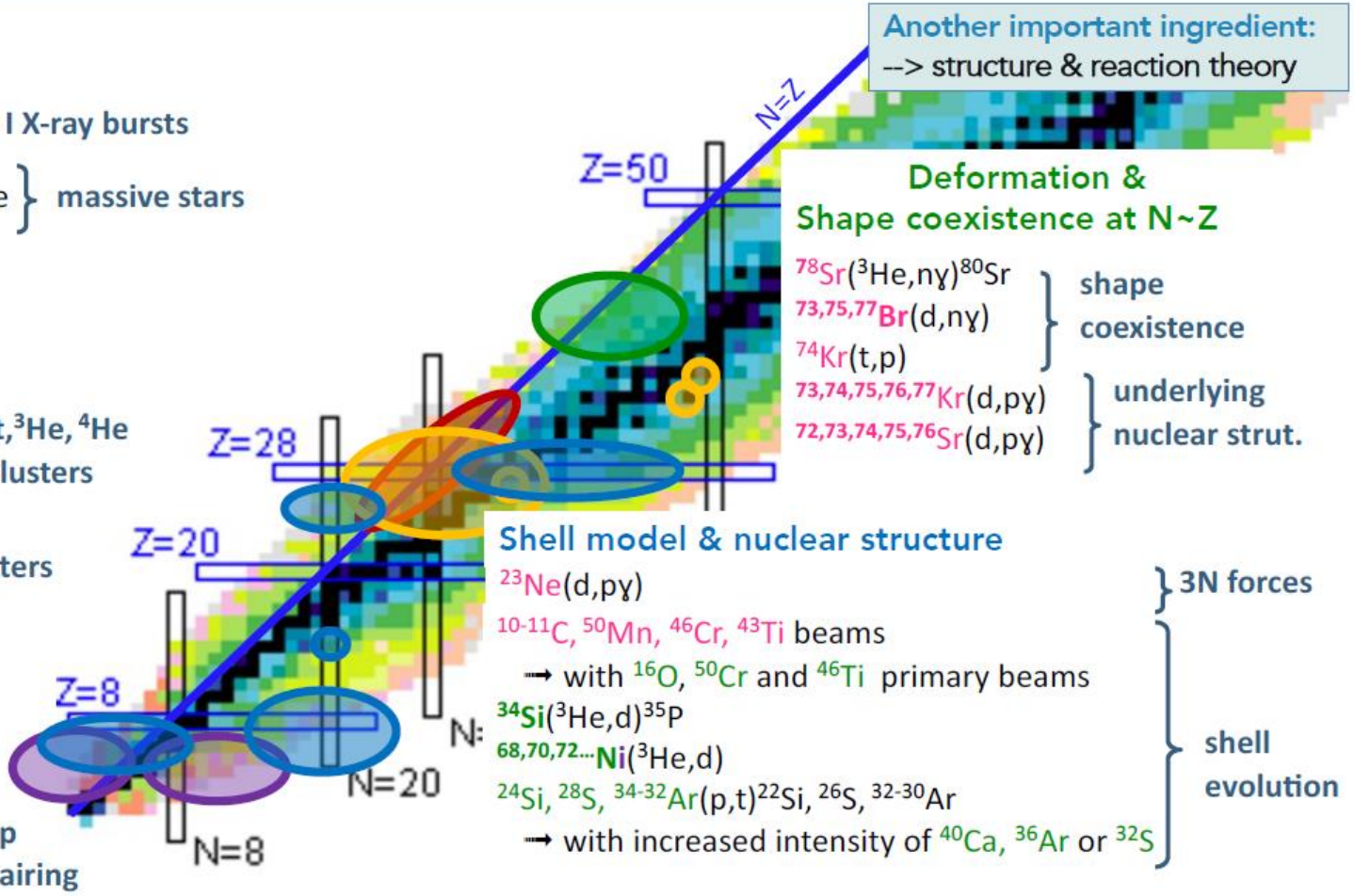
Summary of the perspectives for nuclear physics at GANIL



Nuclear astrophysics

^{55}Co(*d*,*p*) and ^{57}Ni(*d*,*p*) } Type I X-ray bursts

^{59}Cu ^{56}Ni, ^{57}Cu (^{3}He,dγ)

^{59}Fe,^{85}Kr,^{79}Se (d,p) <-- surrogate } massive stars

(New) clustering

^{8,9,11}Li (^{4}He,p) & (^{4}He,^{4}He′) } t,^{3}He, ^{4}He clusters

^{10,12}Be (^{4}He,p) & (^{4}He,^{4}He′)

^{14,16}C (p,^{4}He) ^{11,13}B

^{9,10}C (t,^{6}Li)

^{48}Cr, ^{52}Fe,^{56}Ni (d,^{6}Li)

^{17}F(p,α)^{14}O } 2p-emitters

Pairing and np correlations

^{6}He(^{208}Pb, ^{210}Pb)^{4}He } GPV

^{6}He(^{116}Sn, ^{118}Sn)^{4}He

^{52}Fe(d,^{4}Heγ)

^{60}Zn (^{3}He,pγ)

and N=Z beams above Zn } np pairing

Deformation & Shape coexistence at N~Z

^{78}Sr(^{3}He,nγ)^{80}Sr

^{73,75,77}Br(d,nγ) } shape coexistence

^{74}Kr(t,p)

^{73,74,75,76,77}Kr(d,pγ)

^{72,73,74,75,76}Sr(d,pγ) } underlying nuclear strut.

Shell model & nuclear structure

^{23}Ne(d,pγ) } 3N forces

$^{10\text{-}11}$C, ^{50}Mn, ^{46}Cr, ^{43}Ti beams

→ with ^{16}O, ^{50}Cr and ^{46}Ti primary beams

^{34}Si(^{3}He,d)^{35}P

$^{68,70,72\ldots}$Ni(^{3}He,d)

^{24}Si, ^{28}S, $^{34\text{-}32}$Ar(p,t)^{22}Si, ^{26}S, $^{32\text{-}30}$Ar

→ with increased intensity of ^{40}Ca, ^{36}Ar or ^{32}S } shell evolution

M. Assié courtesy (Target-Ions sources 2023 – GANIL)

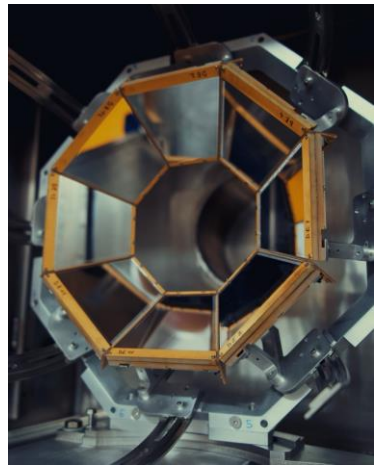
AGATA@GANIL.2 Proposal :

« Data taking » between : March 2026 – July 2028

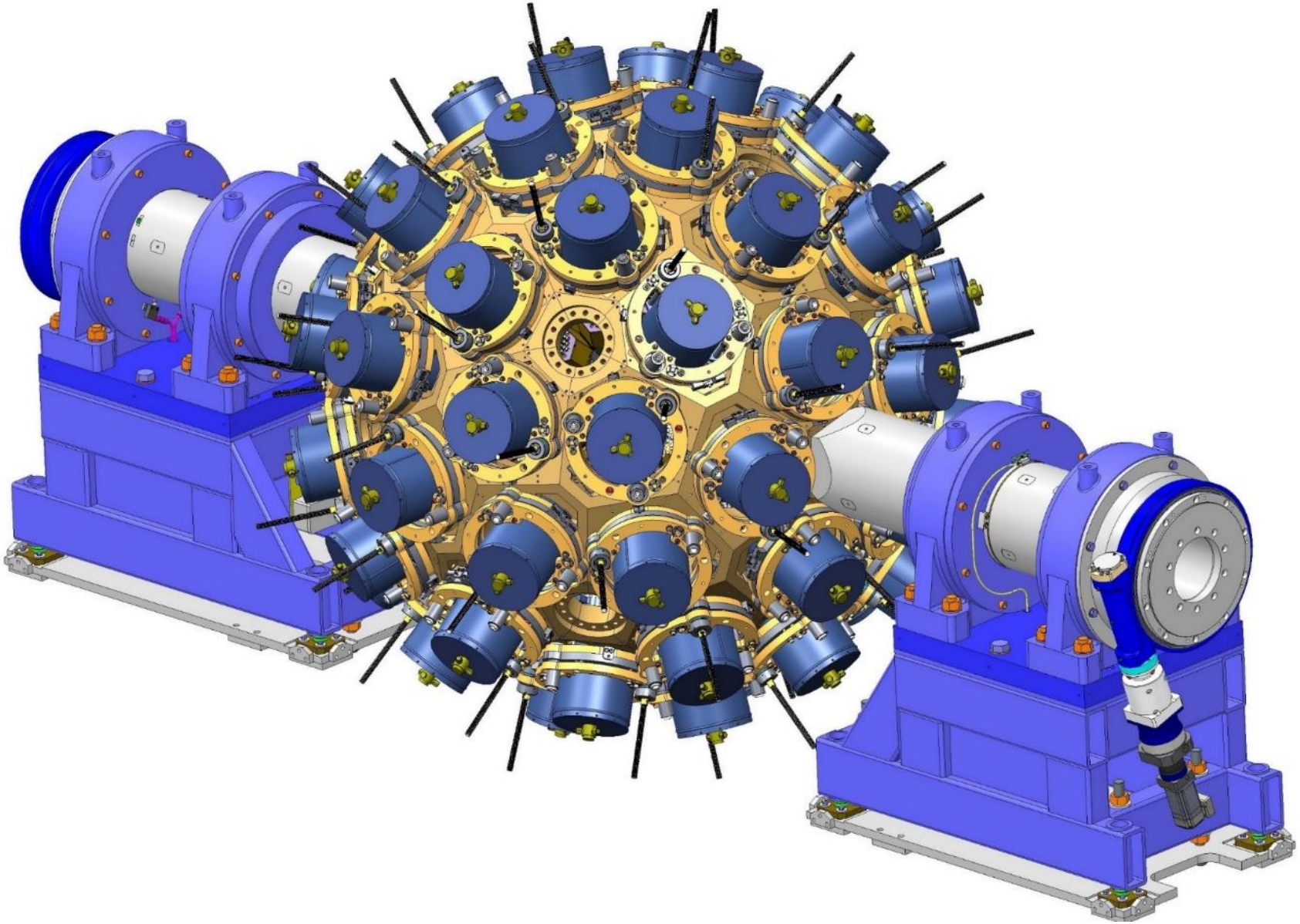
- In 2024, 3 tests are scheduled for developments of new SPIRAL1 beams :
  - n-rich Li, ^{56}Ni-Co from ^{58}Ni fragmentation, and Rb →Zn n-deficient from the ^{78}Kr fragmentation secondary RIB using the FEBIAD ions source.
- On-going developments on cryogenic targets at IJCLab (H, He) *(F. Galtarossa et al, NIMA 108 (2021), 165830)*
- *New project ATRACT for ^{3}He active target*
  - *Rich and powerful possible program on transfer reactions ! (common expertise between GANIL/France and UK)*

Fusion-fission in inverse kinematics with New PISTA array at forward angle for E* and fissioning system precise determination

- *High-intensity and high-quality Pb, Th (new) and U beams are available*
- Isotopic identification of fission fragments from Ni to Gd elements



On-going procedure in the AGATA collaboration for the future location of AGATA >2026



STFC® for the AGATA collaboration