AGATA – phase 2

Prepared by the AGATA-France community
(in2p3,GANIL,CEA)
Outline

- Nuclear science & γ-ray emission
- AGATA
- Organisation, Milestones & achievements
- Phase 2: upgrade of AGATA to a $4\pi$ array
The nucleus: a complex system

1) How to understand the rich structure of the atomic nuclei in terms of interactions between nucleons

1) How to relate the strong nuclear interaction to the underlying QCD that governs the physics of quarks and gluons.
A variety of different phenomena
From nucleons, to nuclei, to stars...

Nuclear Astrophysics

Origin & fate of the elements in our universe?
The most sensitive probe of the nuclear wavefunction: its EM radiation

- Angular distribution/correlation
- Doppler shift
- Linear polarization
- Intensity
- Coincidence relation
- ...
Evolution of γ-ray spectroscopy: Arrays of Compton-suppressed Ge detectors

Evolution of High-Spin γ-ray Spectroscopy in $^{156}$Dy

- **1963**: Morinaga & Gugelot ($\alpha$, 4$n$) NaI(Tl)
- **1973**: Ryde et al. ($\alpha$, 4$n$) 2xGe(Li)
- **1978**: Ward et al. ($^{13}$C, 5$n$) 2xGe(Li)
- **1988**: Riley et al. ($^{38}$S, 4$n$) TESSA 2

**Yrast band in $^{156}$Dy**


**Efficiency ~10%**

- **6 Ge detectors + AC shields**

- **Optimized for high γ-ray multiplicities**

- **~100 Compton-suppressed Ge detectors**

**GAMMASPHERE**

**EUROBALL**
Evolution of γ-ray spectroscopy: Arrays of segmented Ge detectors

EXOGAM

MINIBALL

SeGA

Optimized for Doppler correction at low γ-ray multiplicities: Efficiency ~ 20%

Xe-124 without Doppler correction
Energy resolution 6%

Xe-124 with Doppler correction
Energy resolution 1.5%
How to combine the properties of both types of arrays & enhance the overall performance?

- Remove the BGO shields & add more active Ge
- Segment further to determine the interaction points & track the photons
- Increase count rate capability
$\gamma$-tracking arrays

AGATA

GRETINA/GRETA

High position resolution
High efficiency
High resolving power
High counting rate
Background rejection

Large recoil velocities
Low beam intensities
Rare events
Large background
Tracking ingredients

1. 36-fold segmented HPGe detectors
2. 100 Mhz, 14 bit sampling of segment and central contact signals
3. Pulse Shape Analysis to decompose recorded waves
4. Reconstruction of photon trajectories by tracking algorithms

Identified interaction points: \((x, y, z, E, t)_i\)

Reconstructed \(\gamma\)-ray energies, emission & scattering directions
AGATA project

http://www.agata.org

- 180 segmented crystals (60 triple units)
- 362 kg of Ge
- 82% solid angle
- 50 kHz Ge crystal counting rate
- Angular resolution: \(~1^\circ\)
- Efficiency: 35% (\(M_\gamma=1\)), 20% (\(M_\gamma=30\)) Pic/Total: \(~40-50\%\)
- Large inner radius to accommodate ancillary devices
Powers of AGATA

Response to high-multiplicities ($M_\gamma=30$)

Polarization sensitivity

Doppler correction capability ($^{98}$Zr, $v/c\sim10\%$)

AGATA collaboration

AGATA Steering Committee (ASC)

AGATA Collaboration Council (ACC)

AGATA Management Board (AMB)
Demonstrator Phase (2003-2008)

Positive feedback from the Scientific Council of in2p3 in 2001 MoU signed in 2002 by 12 European countries

5 triple clusters, online PSA & tracking, in-beam commissioning at Legnaro


Construction phase 1 (2009-2020) ➔ 4/3π

Positive recommendations from the Scientific Council of in2p3 in 2009
MoU signed in 2009 and renewed in 2015

15 detectors
**LNL**
Coupled to the magnetic spectrometer PRISMA

22 detectors
**GSI**
Fast radioactive beams coupled to Lycca

41 detectors (2019)
**GANIL**
Coupled to VAMOS, NEDA/N-Wall, DIAMANT, FATIMA, PARIS, MUGAST

**LNL 2010-2011**

**GSI 2012-2014**

**GANIL 2015-2021**

~60 weeks of beam on target, 57 scientific and 40 technical papers since 2010
Achievements

Data accumulation at GANIL

\[ \text{Time} \]

Hit patterns from PSA analysis

\( \gamma-\gamma \) coincidences

- Crystal
- Tracked
Achievements

M. Ciemala, S. Leoni, B. Fornal et al.

Unique lifetime measurements

\[^{181}\text{Ta}(^{18}\text{O},^{20}\text{O})\]

AGATA+PARIS @ VAMOS++

EXOGAM-VAMOS (simulated)
AGATA-VAMOS++ (measured)
AGATA-VAMOS++ (simulated for \(\tau > \text{ps}\))

\(2^+_2 \rightarrow 2^+_1\)

Counts/keV

Transition energy (keV)
Some highlights

M. Ciemala, S. Leoni, B. Fornal et al.

$^{181}\text{Ta}(^{18}\text{O}, ^{20}\text{O})$

Preliminary result: $\tau = 150^{+80}_{-30}$ fs

M. Ciemala et al., Letter in preparation

This result is not compatible with theoretical lifetimes calculated including 2-body terms only.
Sharp shape transition at N=60 when moving from Sr to Kr

Challenge for theory to reproduce all the observables in this region, which is important for the r-process
Some highlights

AGATA+OUPS @ VAMOS++

Be production target → Mg degrader → VAMOS

$^{238}\text{U}$ → $\beta^-$ → $\beta_\text{measured}^-$ → $\gamma$ → $\gamma$

Shifted S → Unshifted U

First lifetimes measured in very exotic $^{84}\text{Ge}$

Sudden rise of collectivity at $Z=32$

Effect understood as the manifestation of pseudospin symmetry

C. Delafosse et al., PRL 121, 192502 (2018)

Sieja et al. PRC 88, 034327 (2013)
AGATA upgrade:
construction phase 2 $\rightarrow 4\pi$
AGATA upgrade: Physics Program

- Nuclei at the highest spins
- Super Heavy nuclei
- N~Z nuclei
- Neutron rich nuclei
- Drip-line nuclei
- Nuclei around double shell closures
Pushing the limits of Z & A

+ huge gain in $\gamma^n$ statistics

Pushing the limits of Z & A

Enhanced resolving power gives access to detailed sub-\(\mu\)b spectroscopy

\(254\)No, \(\sigma \sim 2\mu\)b

\(255\)Lr, \(\sigma \sim 0.4\) \(\mu\)b

\(\gamma\gamma 1/2^-\)

\(\gamma\gamma 7/2^-\)

\(S.\ Ketelhut\ et\ al.,\ Phys.\ Rev.\ Lett.\ 102,\ 212501\ (2009)\)
Pushing the limits of isospin

From 1\textsuperscript{st} spectroscopy to high-precision measurements north & south east of \(^{132}\)Sn: particle-hole excitations and transition probabilities
Pushing the limits of isospin

Access to heavier N~Z systems than currently accessible

Fusion-evaporation reactions with stable beams
AGATA
+ 1π neutron array
+ charged-particle detector

(3He,p) reactions with SPIRAL1 beams
AGATA + GRIT + VAMOS

\[
\begin{align*}
S = 0, & \quad T = 1 \\
S = 1, & \quad T = 0 \\
0^+, & \quad T = 0 \\
1^+, & \quad T = 0 \\
0^+, & \quad T = 1 \\
2\pi, & \quad 3\pi
\end{align*}
\]
Exotic shapes

‘Top unexpected physics discoveries of the last five years’
(D. Kleppner, Physics Today, 1991)

High Tc superconductivity
Atom cooling and atom optics
Large-scale structure of the universe
Supernova 1987A
Superdeformed Nuclei
Buckyballs

Many questions remain unanswered:

Decay-out from superdeformed states?
Clusterisation & exotic decays in light nuclei?
Superdeformation in neutron-rich nuclei?
High-K superdeformed states?
Population mechanism?
Can we observe the signatures of more exotic shapes of the nucleus?

Hyperdeformation?

Fission?

Jacobi shape transition?

Low-energy component of the GDR?
AGATA upgrade: $4\pi$ in 2030
Timeline & host laboratories

- **LNL 2022-2025**: Stable beams & accelerated ISOL beams
- **FAIR/ISOLDE 2026-2028 ?**: Radioactive ion beams (projectile fragmentation & fission)
- **JYFL/GANIL 2029-2030 ?**: Stable beams & accelerated ISOL beams
AGATA upgrade – Technical Details

New honeycomb holding & detector-mounting structures

New Electronics with 10 GB ethernet readout

Upgraded DAQ based on NARVAL/DCOD & improved Algorithms

New Detector Support System
Estimated capital investment

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<th>Item</th>
<th>2021</th>
<th>2022</th>
<th>2023</th>
<th>2024</th>
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In2p3 contribution is calculated on the basis of the actual sharing between French partners.

An application to become Infrastructure de Recherche will be made in 2020.
Estimated Operation Costs

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<tr>
<th>Operational / Maintenance Costs</th>
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<th>2022</th>
<th>2023</th>
<th>2024</th>
<th>2025</th>
<th>2026</th>
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French contribution should be ~17% of the total
In the present MoU, the In2p3 share is 2/3 of the French contribution
Falling ETPs up to 2022 are due to end of phase 2 development (DSS, electronics, DAQ) and start of maintenance regime
From 2025->2030, the expected manpower should stay stable

The numbers do not include the manpower to perform & analyze experiments, which also involve physicists from many other collaborations
Conclusion & Perspectives

- AGATA is a successful collaboration
- AGATA is a precision tool to be used in conjunction with other state-of-the-art detectors at European RIB and stable beam facilities
- Broad program of studies
- Of interest to a large community

Support to the completion of AGATA in full geometry

AGATA represents the state-of-the-art in gamma-ray spectroscopy and is an essential precision tool underpinning a broad programme of studies in nuclear structure, nuclear astrophysics and nuclear reactions. AGATA will be exploited at all of the large-scale radioactive and stable beam facilities and in the long-term must be fully completed in full 60 detector unit geometry in order to realise the envisaged scientific programme. AGATA will be realised in phases with the goal of completing the first phase with 20 units by 2020.
Backup
Exotic modes

Exploit AGATA’s efficiency and polarization capabilities to measure new collective modes

Pygmy Dipole Resonance in neutron rich nuclei

Scissors resonance in deformed super heavy nuclei
Can decay as a cascade of two gamma (P \( \propto 2 \times 10^{-6} \)) with a dominant M2-E2 and a minor E3-M1 contribution.


Could \( \gamma \gamma \) decays be used to obtain information on 0νββ Nuclear Matrix Elements?
Detector laboratory

**Capsules**
- Capsule FAT at MIRION -> tests and validation
- Capsule CAT at IPHC -> mounting of the capsule in test cryostat, cabling, tests and validation

**Triple detector**
- Triple detector mounting (ATC14 – IN2P3) at IPHC and IKP Cologne
- Triple detector maintenance (ATC3) at GANIL and IKP Cologne

Collaboration with LNL on Ge surface treatment
Ge scans + simulations

Fast scanning table based on PSCS technique (48500 points in 2 weeks)

CNRS-MIRION cofinanced PhD for detector and pulse-shape simulations

OASIS ANR -> collimator upgrade and 152Eu source (unique)
AGATA performance

J. Ljungvall et al., AGATA@GANIL Performance, submitted

Singles & coincidence tracking efficiency

Understanding the measured P/T

ANR OASIS (Optimization of AGATA science production, 2018-2021)
Implementation of machine learning techniques
PSA

Non-homogeneous hit distributions <- non fidelity of the pulse shape basis
No improvement with experimentally determined basis
Application of GRETA PSA: ongoing

Better PSA is required for tracking & also neutron damage correction
DAQ

Evolution to DCOD – Posix Memory Handler

Server 1

- DCOD actor
  - Blue producer

- DCOD actor
  - Blue to yellow filter

PMH

- Blue data
- Yellow data

CTL

Server 2

PMH

- Yellow data

CTL

DCOD actor

Yellow consumer

Yellow data

I provide yellow data

Ask for yellow data
DAQ

Trigger soft scheme (4 Channels)

- Data 1
  - HC 1
  - Header 1
- Data 2
  - HC 2
  - Header 2
- Data 3
  - HC 3
  - Header 3
  - Pattern builder
- Data 4
  - HC 4
  - Header 4
  - Trigger
  - Pattern + validation

DMF 1
- Validation 1

DMF 2
- Validation 2

DMF 3
- Validation 3

DMF 4
- Validation 4

Optional Specific Processing

- Procedure 1
- Procedure 2
- Procedure 3
- Procedure 4

Event builder

Build events
Data processing / analysis

**Infrastructure**

- **svn**
- **make**
- **cmake**
- **AGAPRO**: online installation

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**LNL**

**GSI**

**GANIL**

**FUTURE**

- git, modern cmake
- continuous integration
- unit testing
- containerised applications

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**Schools on data analysis**... documents... **... Schools on data analysis**

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**Developments**

- **ADF** library to deal with:
  - AGATA data format, data files
  - algo integrations in NARVAL
  - Integration of ancillaries

- **GW** online/offline analysis
  - adf to spectra/TTree
  - Integration of ancillaries
  (data, algorithms)

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- **PRESPEC**
  - dev. @ GSI

- **VAMOS**
  - dev. @ GANIL

- **NEDA/DIAMANT**
  - **GANPRO** package
  - PSD NEDA ML online

- **TTree in AGAPRO**

- **AGASPY**
  - dev. @ CSNSM/IP2I
  - Online monitoring

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**Machine Learning [ML]**:
- PSA / tracking processing: quality checks
- Processing on GPU / FPGA, CLOUDS...
Reaction chamber for AGATA/NEDA/DIAMANT campaign

Pre-installation in G2 with in-beam tests done in November-December 2017
Mechanical Installation completed in front of AGATA in February 2018

3 experiments using AGATA+NEDA +DIAMANT+plunger with 35 AGATA detectors in 2018
Electronique Phase 0

- Designed in 2004
- 24 channels available
  - 2006-2009 : 15 channels
  - 2010-2012 : 19 channels
  - 2012- Now : 24 channels
- Price : 90-100 k€ / crystal
- Not included cost :
  - 7 optical fibers from digitizer to ATCA
  - 4 optical fibers from ATCA to computing node
  - 1 server per crystal
Electronique phase 1

- Designed in 2012
- 10 channels available (+ Galileo)
  - 2014-2018: 10 channels
  - 2018-: 22 channels
- Price: 30 k€
- Hidden cost
  - 4 Optical fibers from digitizer to computing node
  - 1 server per crystal
Electronique Phase 2 – R&D (2016-now)

- Digitization – Milano
- Hardware – Valencia
  - IDM
  - CAP
- Pre processing – IPHC
- Control & Monitoring – CSNSM
- Readout – CSNSM
- Trigger/Timestamp: proposition à l'étude au GANIL

Demonstrator ready mid-2019
Electronics phase 2

FPGA firmware development for data pre-processing (get 36 signals, trigger, time stamp, energy calc, pulse shape selection, generation of an event block, transfert of the blocks to 10GB-Ethernet card)

10 Gb readout card : Stare prototype

Fast digital oscilloscope software development
DETECTOR DATABASE

Barcodes on objects & transfer boxes

Set up also for: EXOGAM, PARIS, NEDA ...