AGATA@GANIL Status-Report

2018 NUSTAR Meeting
GANIL Today

- Complete the SPIRAL2 LINAC for the first experiments
- Provide the maximum possible beam time

Nuclear science
Material science
Atomic physics
Industrial Applications
Accelerator technologies

High Energy Beams [24-95] MeV/u

C01/2 : [0.3,-1.0] MeV/u
CSS1 : Medium energy

SPIRAL1 (Cyclotrons + CIME):
High Energy Exotic Beams 20 MeV/u
Short lived beams (ISOL)

SPIRAL2 LINAC
33 MeV p, 40 MeV d (5mA)
14.5 A MeV HI (1mA)

S3

NFS

DESIR
Superconducting cavities

- 30/11/2017: 1st complete LINAC cooling.
- Regulation in specifications

Ion sources

High energy Beam lines

Test Bench

RFQ

Low energy lines
High-resolution gamma-ray spectroscopy is an optimum tool to study detailed nuclear structure properties and investigate how they emerge from fundamental interactions.
The AGATA project

- 180 (60 triple-clusters) 36-fold segmented crystals
- Amount of germanium: 362 kg
- Solid angle coverage: 82 %
- Singles rate >50 kHz
- Efficiency: 43% ($M_{\gamma}=1$), 28% ($M_{\gamma}=30$)
- Peak/Total: 58% ($M_{\gamma}=1$), 49% ($M_{\gamma}=30$)
- Angular Resolution: $\sim 1^\circ$

Combination of:
- segmented detector
- pulse-shape analysis
- tracking the $\gamma$ rays
- digital electronics

The AGATA project

August 2005 at IKP 3 symmetric capsules

March 2015 at GANIL 24 asymmetric capsules
The GANIL Campaign

2017: 35 detectors on-line: Single efficiency measured at 3.4(1)% in nominal position at 1.408 MeV (GEANT4 = 3.6%)

Lifetime measurements

2015-2017: 93% of performed experiments are lifetime measurements from fs to μs

E. Clément et al., NIMA 855, 1-12 (2017)

FATIMA-PARIS detectors coupled to AGATA
The GANIL Campaign

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- Nucleons transfer
- Fusion-fission
- Transfer-fission
The physics of AGATA@GANIL is the in-beam high resolution $\gamma$-ray spectroscopy of exotic nuclei populated by heavy-ions collisions

- **Nucleon-nucleon(-nucleon) interaction close to magic nuclei**
- **Astrophysical measurements**
- **Collective mode in nuclei**
- **Clusterization phenomena**

- **High resolution $\gamma$-ray spectroscopy of very exotic nuclei**
- **Lifetime measurement of excited states in the range of fs to $\mu$s**
Shell evolution around $Z=28$

Interplay of the monopole terms of the interaction with multipole terms, like pairing and quadrupole, which determines the different phenomena we observe:

- Characterizing the islands of inversion, formed near the magic numbers.
- These are new regions of deformation with configurations involving intruder orbitals from the above main shell.
- While a signature of deformation is given by the energy of the first excited states, their lifetimes allow a better understanding of their properties by comparison with LSSM calculations.
Shell evolution around Z=28

Interplay of the monopole terms of the interaction with multipole terms, like pairing and quadrupole, which determines the different phenomena we observe

Collecting spectroscopic data like transition probability constraining the theoretical description of the Island of inversion from N=28 to N=40:

- What is the influence of the \( \nu g_{9/2} \) and \( \nu d_{5/2} \) orbits?
- What is the influence of the proton excitations across Z=28?
- How collectivity change when decreasing the number of proton in the f\( 7/2 \) orbital

Measurement of lifetimes in \( ^{62;64}\text{Fe} \), \( ^{61;63}\text{Co} \) and \( ^{59}\text{Mn} \)

2015 Data.
Lifetimes of the 4\(^+\) states in \( ^{62;64}\text{Fe} \) and the 11/2\(^-\) in \( ^{61;63}\text{Co} \) and \( ^{59}\text{Mn} \)

M. Klintefjord et al., PRC 95, 024312 (2017)
Shell evolution around $Z=28$

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Collecting spectroscopic data like transition probability constraining the theoretical description of the Island of inversion from $N=28$ to $N=40$:

- What is the influence of the $vg9/2$ and $vd5/2$ orbits?
- What is the influence of the proton excitations across $Z=28$?
- How collectivity change when decreasing the number of proton in the $f7/2$ orbital?

Lifetimes in $^{56}\text{Ti}$ and $^{55}\text{V}$

2016 Data

Shape evolution: subshell closures and development of deformation.
Interplay of the monopole terms of the interaction with multipole terms, like pairing and quadrupole, which determines the different phenomena we observe

Collecting spectroscopic data like transition probability constraining the theoretical description of the Island of inversion from N=28 to N=40:

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Lifetime of the 5/2⁻ state in Ga decaying to the "1/2⁻, 3/2⁻ ground state doublet". Determining the multipolarity

I. Celikovic, C. Michelagnoli et al.
Shell evolution around $Z=28$

- Understanding the single-particle evolution above $N = 50$ towards $^{78}\text{Ni}$
- Shape transition at $N=60$

New lifetimes in $^{88}\text{Kr}$, $^{86}\text{Se}$, $^{83,84}\text{Ge}$

The $7/2^+$ state stemming from $v_{g_{7/2}}$ is predicted to become yrast along the $N=51$ line towards $^{79}\text{Ni}$ → distinguish between $[2^+ \otimes d_{5/2}] 7/2_1$ and $[0^+ \otimes g_{7/2}] 7/2_1$

J. Dudouet et al., to be submitted to PRL

pf-sdg model space
Lifetime at N=52 and Z=32

Sudden rise of collectivity after the N=50 shell closure
Collectivity still rises from Se to Ge at N=52 …
… in contradiction with shell model calculation

courtesy of C. Delafosse
Shape evolution in fission fragments in the A~100 region

AGATA-VAMOS and a plunger + FATIMA for lifetime measurements using the $^9\text{Be}(^{238}\text{U}, \text{FF})$ reaction

100Zr

High resolution spectroscopy of $^{96}\text{Kr}$
Shell evolution around $^{100}\text{Sn}$

$^{92}\text{Mo}$ and $^{94}\text{Ru}$ have similarities with Ni isotopes, filling the same orbitals than protons in $N = 50$ isotones.

Valence Mirror Symmetry Partners


courtesy of R. Perez Vidal
Shell evolution around $^{100}$Sn

courtesy of R. Perez Vidal

E.Clément
Lifetime measurement in N=Z=50 region

- Examine the robustness of the proton shell closure when N=50 is approached.
- Different experimental approach (not Coulex, not fusion-evaporation)
- Use of the MNT in a charge exchange reaction from a Cd beam and control the entry point

B(E2; 2+ → 0+) suffer from large experimental uncertainties (~20%). Being |Ψ2+> and |Ψ4+> similar, information on the B(E2; 4+→2+) values would help to make a more robust physical interpretation.
Shell evolution around $^{208}\text{Pb}$

Study of the two-phonon vibrational states in the $^{208}\text{Pb}$ region
Case of the $^{207}\text{Pb} \nu(i_{13/2})^{-1}$ state band structure

D. Ralet in preparation
Cluster Structure

Search for the alpha cluster structure in heavy elements: case of $^{212}$Po ($^{208}$Pb+α)

A. Jungclaus, A. Astier et al, 2017 Data

Gate on 432 keV

$T_{1/2} = 15$ ns
3-body contribution

Lifetime measurement in the non-yrast excited states of neutron rich C and O isotopes to probe the 3 body- contribution in the nuclear interaction

S. Leoni, B. Fornal et al., 2017 Data
Performances of AGATA

The lifetime is short; below ps
Ab-initio are in the good order of magnitude
Detailed analysis on-going

On-line
Nuclear Astrophysics

The determination of the rate of destruction of $^{22}\text{Na}$ is crucial for nova models

\[ ^{24}\text{Mg}(^3\text{He},\alpha\gamma)^{23}\text{Mg} \]

$^{22}\text{Na}(p,\gamma)^{23}\text{Mg}$

$^{23}\text{Mg}$ dominated by the resonance at 205 keV above threshold

Measurement: lifetime of the 7.786 MeV state in $^{23}\text{Mg}$,

The lifetime and proton branching ratio obtained from the same experiment will provide a precise determination of the rate of the $^{22}\text{Na}(p,\gamma)^{23}\text{Mg}$ reaction

\[ \text{courtesy of C. Michelagnoli} \]
2018 run *NEDA campaign*

5 experiments scheduled using AGATA+NEDA +DIAMANT+plunger

Pre-installation in G2 with in-beam tests done before Christmas 2017
Mechanical Installation completed in front of AGATA in February 2018
Last commissioning during the first week of April
Studies of excited states in $^{102,103}\text{Sn}$

Isospin Symmetry Breaking in the A=63,71 mirror nuclei

Octupole correlation in $^{112}\text{Xe}$

Search for isoscalar pairing in the N=Z nuclei:

Studies of excited states in $^{102,103}\text{Sn}$
Transfer reactions using post-accelerated ISOL beams from SPIRAL1

- Bound and resonant states
  - Spectroscopic Factors
  - L transferred → Spin
- $B\rho$ and velocity measurement → vertex reconstruction
- Cryogenic Targets
- Lifetimes
  - RDDSAM
  - LaBr$_3$

Safe Coulomb excitation of radioactive using post-accelerated ISOL beams from SPIRAL1

- Reduced Transition probabilities and spectroscopic quadrupole moment
Perspectives with stable beams beyond 2020?

- VAMOS magnetic spectrometer: Isotopical identification - particularly successful with high intensity heaviest ion beams
- The identification techniques of heaviest species, around Pb and U can be improved
- Prompt and delayed $\gamma$-spectroscopy
- Lifetime measurements
- Moving towards better quantification of:
  - angular distributions
  - polarization
  - g-factor
- New stable beams could be developed
Perspectives with stable beams beyond 2020?

- Prompt $\gamma$-spectroscopy of heavy nuclei produced in fusion-evaporation reactions or Multi-Nucleon Transfer
- Physical separation obtained by a $0^0$ degree large acceptance VAMOS gas filled separator

- Recoil decay tagging techniques in MUSETT
- The use of inverse kinematics could be tested $^{48}\text{Ca}(^{208}\text{Pb},2n)^{254}\text{No}$
- Heavy beams with heavy target
- Lifetime measurements using the plunger technique
Conclusion

• AGATA is operated since 2014 at GANIL and 17 experiments have been performed
  4 Papers published (2015-2016 data)
  5 Papers in preparation (2015 data)
  3 Technical papers in preparation
  11 Experiments under analysis (2016-2017)
  3 PhD defended in 2017 and 6 in preparation using GANIL data

• The number of detectors is increasing and stability of the system is improved year after year

• Many results are coming all along the nuclear chart for many different physics topics

• AGATA $1\pi$ setup at GANIL is very competitive for lifetime measurement from fs to ns in transfer, fission and fusion induced reactions

• There are a lot of opportunities which are today limited by the reduced beam time available at the facility leading to difficult choices