Perspectives for the gamma–ray spectroscopy at LNL: the GALILEO project

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Abstract. GALILEO is a new 4\(\pi\) high–resolution \(\gamma\)-ray array in which GASP tapered detectors and Gammapool Cluster detectors will be used together. The array will be located at the Laboratori Nazionali di Legnaro and it will make use of the stable beams provided by the Tandem–ALPI–PIAVE accelerator complex and, in the future, of the exotic radioactive ion beams provided by SPES. The project requires the transformation of the original EUROBALL 7–capsules cluster detectors into triple cluster detectors and several R&D activities are ongoing for the development of a triple cluster cryostat and for building the corresponding anti–Compton shields. The development of the front–end, digital sampling, preprocessing and readout electronics is taking advantage of the most recent advances obtained within the AGATA project. A strong physics case was made for the building of the GALILEO array based on Letters of Intent submitted by several research groups from all over the world. In the present paper a brief summary of the status and the perspectives of the GALILEO project is given.

1. Introduction
A new gamma-ray array is proposed to be built and installed at the Laboratori Nazionali di Legnaro (LNL). The original idea was to reshape all the EUROBALL 7-capsules cluster detectors into triple cluster detectors and build with them a full 4\(\pi\) high efficiency gamma-ray array. Arrays of non-segmented Ge detectors require the use of anti-Compton shields in order to provide good quality gamma-ray coincidence data. The cost estimate for building the anti-Compton shields showed that the project would be highly demanding in terms of funding. While this project can be pursued in the future within a wide European collaboration, it was decided to build a Phase I array that makes use of part of the EUROBALL cluster detectors and the GASP detectors. This phase is very important as it includes R&D activities for the development of the triple cluster detectors and their anti-Compton shields, activities that constitute the basis for building the larger array. The proposed configuration of the array offers the possibility to have in short time a competitive device at a reasonable cost. The physics case of the project is supported by a worldwide collaboration of research groups active in the field of gamma-ray and particle spectroscopy whose interest was expressed in Letters of Intent proposing the investigation of isospin symmetry in isobar multiplets or mirror nuclei, critical point symmetries, excitation of exotic collective modes, astrophysical interest cross sections, high–lying isomers acting as waiting points for the s–processes. The proposed experiments require the use of stable beams provided by the Tandem–ALPI–PIAVE accelerator complex of LNL and, in perspective, of the SPES radioactive beams. The new array will benefit of the continuous improvement of the heavy ions beams delivered by the accelerator complex Tandem-ALPI-PIAVE; a lot of effort is put into
developing new beams with the PIAVE ECR source and to increase the intensity and energy of the delivered beams. Several options for the coupling of the array with ancillary detectors for the detection of light charged particles, neutrons or heavy nuclei were considered as solutions to improve the arrays sensitivity.

2. Physics case
Nuclear structure research is evolving towards extreme regions of spin and excitation energies and neutron-proton ratio. Gamma-ray spectroscopy, as the main tool to investigate the structure of nuclei, has to respond to the increasing experimental difficulties. During the last two decades, LNL has hosted several gamma-ray arrays such as GASP [1], EUROBALL [2] and CLARA [3], producing valuable physics results and providing the whole nuclear physics community with excellent and forefront research devices. Presently, the AGATA Demonstrator [4] is installed and running experiments at LNL. The power of the GALILEO array to address new and challenging problems of the nuclear matter lies in a combination of the high gamma-ray detection efficiency with a new highly performant data taking electronics allowing for higher event rates and with the use of state-of-the-art ancillary detectors such as charged-particle and neutron arrays, plunger and recoil detectors, to improve the sensitivity. The physics case of GALILEO is addressing hot topics of the present worldwide nuclear structure research such as: 1) the study of N-Z nuclei that will provide the most relevant information about the properties of the neutron-proton pairing interaction and its evolution with the spin and excitation energy; 2) the study of isospin symmetry as a tool to understand fundamental questions such as the charge-symmetry and charge-independence of the nuclear two-body interaction; 3) the study of neutron-rich nuclei near major shell closures is of considerable interest due to the influence of the neutron excess on the nuclear potential that may lead to the formation of new shell closures and new regions of deformation; 4) accurate mapping of the proton-dripline location through the study of exotic proton and alpha decays of the nuclear states in very neutron deficient nuclei; 5) study of the connection between molecular-like nuclear states, such as superdeformed alpha-cluster states, and nuclear resonances through their particle and gamma-ray decays; 6) study of the gamma-ray decay of the GDR to investigate the isospin symmetry and its breaking by Coulomb interaction in heavy N=Z nuclei, at finite temperature; 7) investigation of the warm rotation regime in nuclei will provide crucial information to understand the transition of the nuclear structure from regular near the ground state to chaotic in the resonance region, and it will also test the robustness of the shell structure with temperature; 8) identification of the critical point symmetries corresponding to the nuclear shape-phase transition, such as the E(5) on the transition from spherical to deformed γ-unstable shape and the X(5) on the transition from spherical to axially deformed shape, requires thorough knowledge of the whole nuclear region around the predicted cases of such symmetries; 9) study of particular cases of triple shape coexistence in neutron-deficient nuclei to understand the underlying nucleon configurations favoring such peculiar phenomena; 10) determination of the n-capture cross section on the s-process branching points through the surrogate nuclear reaction method will be used to test the predictions of s-process calculations.

3. The GALILEO array
Ten triple clusters can be obtained from five original EUROBALL cluster detectors. Thorough Monte Carlo simulations were performed with a GEANT4 code derived from the AGATA simulation package [5]. Calculations with ten triple clusters indicate as the most powerful configuration when they are placed at 90° 24 cm from the target position. The forward and backward angles with respect to the beam direction are filled with GASP tapered HPGe detectors placed 22.5 cm from the target position and distributed in five rings ranging from 21° to 159°. The original anti–Compton shields will be used for the GASP detectors. The cluster detectors will be surrounded with new anti-Compton shields built of the single crystals recovered from
the original cluster shields. An artistic view of the array from the backside is shown in Fig. 1. Simulations give for this configuration a total photopeak efficiency of 8% and a peak-to-total ratio of 50

![Artistic view of the GALILEO array. One can see the 90° ring of ten triple cluster detectors and the compact shell of 15 HPGe GASP detectors at the backward angles.](image)

**Figure 1.** Artistic view of the GALILEO array. One can see the 90° ring of ten triple cluster detectors and the compact shell of 15 HPGe GASP detectors at the backward angles.

### 3.1. The triple cluster detectors

While the GASP detectors can be used as they are, in the case of the triple cluster detectors a completely new development is required for building a dedicated cryostat to hold the three capsules. The end-cap is proposed to be realized in carbon fiber. Carbon fiber is as resistant as aluminum from the mechanical point of view. Vacuum tightness was tested with a prototype made for a GASP detector end-cap. The Zeolites container is made such to ensure easy access, mounting and dismounting when reconditioning is needed. The cold finger was designed such to minimize the heat transfer between the cold part and the outside environment and the transmission of mechanical vibration from dewar to capsules. A new concept dewar is also developed. The whole ensemble is optimized for a better thermal insulation, less heat transfer, lower LN2 consumption and better mechanical rigidity.

The performance of the array at high fold gamma-ray coincidence is strongly dependent on the peak-to-total ratio. In case of a low value the coincidence is dominated by the Compton scattered events. To increase the peak-to-total ratio one needs to surround the Ge detectors with anti-Compton shields made of BGO scintillator crystals. In the case of the GASP detectors their original shields can be used but for the ten triple cluster detectors one needs to develop new shields. The possibility to build the new anti-Compton shields out of the single crystals from the original EUROBALL cluster shields is under investigation. The proposed geometry for these shields would leave empty spaces corresponding to the corners of the triple cluster. This lack can be overcome by doing a shared Compton suppression with the neighboring shields standing
in front of the openings. The complete ensemble of triple cluster detector and anti-Compton shield is shown in Fig. 2.

### 3.2. The holding structure

A new mechanical frame was designed and is currently under construction for the GALILEO array. The new design was specifically made to allow easy access to the reaction chamber and special care was taken for the integration of different ancillary detectors. The frame consists of a modular structure as shown in Fig. 3. There is a central ring for holding the 10 triple cluster detectors with their anti-Compton shields. The backward part of the frame will hold 15 GASP-type detectors. On the forward part of the frame other 15 GASP-type detectors will be placed in the same geometry as in the backward direction but divided into two structures: one close to the central ring, holding 10 detectors and another one holding 5 detectors. This makes possible to dismount completely the 5 most forward detectors to allow for the insertion of ancillary detectors such as neutron detectors or recoil filter detectors. A preliminary design of the holding structure is shown in Fig. 3.

### 3.3. Electronics

A common preamplifier is developed for both the GASP-type detectors and the triple cluster detectors, based on the AGATA SingleCore-type preamplifier [6]. The main characteristics of the preamplifier are: differential output, compatibility with different types of FET (BF862 or IF1320), variable threshold fast reset circuit, output energy range of up to 10 MeV.

A new electronics for readout and preprocessing of the digital data is under development in collaboration with the AGATA project. The experienced gained until now in the handling of the digital signals and the advances in the electronic components allowed for the development of a very compact PCI express based solution. The new solution has the advantage of a lower power consumption, no need of dedicated cooled racks, use of all the services already implemented in the host workstations, such as network connection or CPU processing, in a transparent and cost effective way. The boards are based on the use of the XILINX VIRTEX-6 FPGA.
Figure 3. Preliminary layout of the GALILEO frame. The four different structures of the frame are illustrated. They will move on rails to give access to the reaction chamber.

4. Conclusions
The development of the gamma–ray array is important for the extension of the nuclear structure studies towards exotic nuclei populated with small cross–sections. Recent developments in the detector and electronics technologies allow for new designs. The present paper reported on the status of the GALILEO project. The new array will be dedicated to gamma–ray spectroscopy studies with stable and exotic beams at the Laboratori Nazionali di Legnaro. The project involves the development of a triple cluster detector with a new conception cryostat and of a new front–end and read–out electronics in collaboration with the AGATA project.

Acknowledgments
The author gratefully acknowledges the substantial contribution of C.Fanin for the mechanical design, E.Farnea for the GEANT4 simulations, M.Bellato, D.Bortolato, A.Pullia and R.Isocrate for the electronics development, D.Rosso, P.Cocconi and L.Costa for the cryogenic and vacuum systems development. He also acknowledges the support of the mechanical workshops of INFN Padova and Laboratori Nazionali di Legnaro for the work done.

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