# THE $\nu$-BALL CAMPAIGN AT ALTO*

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In 2017–2018, the ALTO facility hosted an experimental campaign using a $\gamma$ spectrometer called $\nu$-ball. This device is an hybrid array combining the excellent energy resolution of high purity germanium detectors with the excellent time resolution of new generation of scintillators $LaBr_3$. Despite the short duration of the campaign, 3 200 hours of beam time distributed over eight experimental project have been provided. In this paper, a description of the progress of the campaign as a short description of the $\nu$-ball array will be given.

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## 1. Introduction

For decades, the ALTO facility [1] has demonstrated its capability to propose an innovative experimental campaign. The development of the LICORNE neutron source [2] opened the possibility for $\gamma$-spectroscopy studies of fast neutron induced reactions. Based on the experience acquired in previous ORGAM [3] and MINORCA (using MINIBALL array [4]) campaigns, it was decided to build a new hybrid spectrometer named $\nu$-ball. It had to provide better characteristics in term of energy and time resolution, efficiency and peak-to-total ratio than the previous ones.

To achieve this goal, it has been decided to couple the high-energy resolution of high-purity germanium detectors (HPGe) with the excellent timing resolution of a new generation of scintillators: lanthanum bromide ($LaBr_3$). Based on the outcomes of an international workshop organised in Orsay in

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2016, a formal application has been submitted to the GAMMAPOOL [5] to access the 24 clover detectors and their anti-Compton shields. The demand was accepted for a one-year period from June 2017 to July 2018. It marked the beginning of the $\nu$-ball campaign.

## 2. The $\nu$-ball array

### *2.1. Presentation of the detectors*

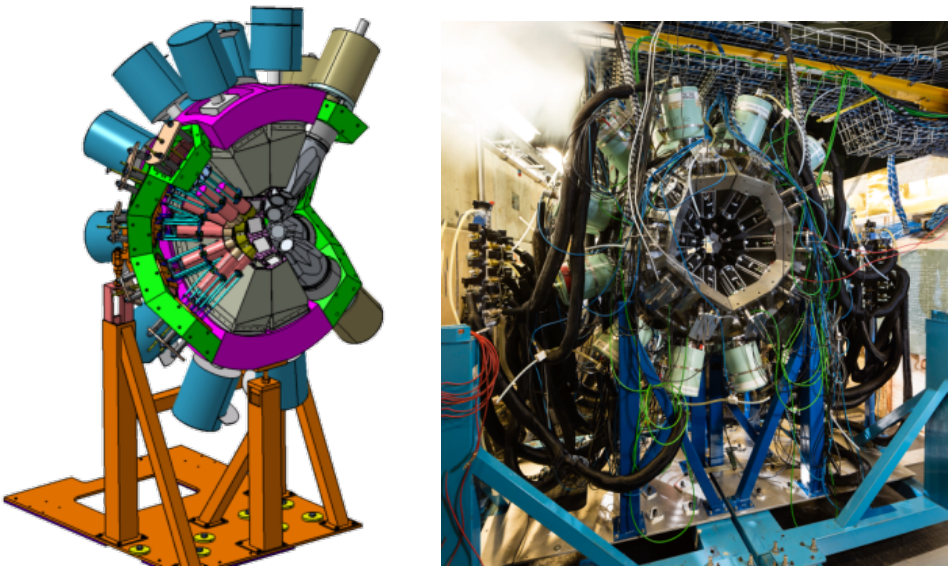

Fig. 1. (Colour on-line) Left — CAD drawing of half of the $\nu$-ball array. $LaBr_3$ detectors are black/pink. On their right, the BGO shields of the clover detectors are drawn. Phase I HPGe detectors are symmetric to $LaBr_3$, with respect to clovers. Right — a photo of the $\nu$-ball array before the commissioning experiment is presented.

As mentioned before, the main feature of the $\nu$-ball array is the coupling of the best possible time resolution with the highest peak-to-total ratio for fine $\gamma$ spectroscopy. It is achieved by combining the quality of new generation of scintillation materials such as $LaBr_3$ with HPGe coupled with Compton shields. The germanium detectors were of two kinds. First, ten high efficiency coaxial Phase I germanium detectors from EUROGAM. They were borrowed to the French–UK loan pool. They were coupled to their BGO shield to perform Compton suppression. Their energy resolutions were measured to be 2.5 keV at 1 MeV on average. The expected peak-to-total ratio is about 35% — based on Geant4 [6] simulations. Then, twenty-four clovers and their Compton shield were borrowed from the GAMMAPOOL. Their energy resolutions were measured to be, on average, 1.9 keV at 1 MeV. With these detectors, the combination of Compton suppression and addback procedure could provide a peak-to-total ratio of 50%.

These detectors formed the backbone of the $\nu$-ball array. To achieve the high-time resolution, we added two types of scintillator detectors. First, ten conical ($1'' \times 1.5'' \times 2''$) and ten cylindrical ($1.5'' \times 1.5''$) $LaBr_3$ detectors were placed in the narrowest geometry. For two experiments, these $LaBr_3$ were replaced with 34 PARIS [7–9] phoswitches. With these detectors, a 250 ps time resolution was achieved and a 3% energy resolution at 662 keV was measured. The array geometry is presented in Fig. 1. The left part presents a CAD drawing used in the mechanical design process. The right part is a photo taken on the experimental area 420 of the ALTO facility before the commissioning of the spectrometer.

### *2.2. The Data Acquisition (DAQ) system*

All the signals from the preamplifiers were digitised using the FASTER data acquisition system [10]. This system is based on two types of digitisers. First, the MOSHAR cards support a 125 Msps and 14 effective bits digitiser which were used for HPGe and BGO. The second are the CARAS cards that are based on a 500 Msps and 12 effective bits digitisers. They were used for the scintillators. Every detectors' signals were fully digitised making possible the use of the BGOs for calorimetry purpose. This extra information will be used to enhance the reaction mechanism selection in the event building process.

This FASTER system was first used in a trigger mode where two detectors among $LaBr_3$, Phase I, and Clovers were fired. It was initially set to minimise the data flux from the FASTER crate to disk and avoid disk space saturation. Later, the preference was given to a full triggerless system to avoid any important data loss for the experiment that required a more complex trigger condition. Over the course of the campaign about 0.2 Po of data is stored on disk. About 60% of these were produced in one single experiment. All the data of the experiment are now stored in Centre de Calcul de Lyon [11] and remain accessible for any users.

## 3. The progress of $\nu$-ball campaign

In 2016, a international workshop has been held in Orsay to advertise about the preparation of $\gamma$-spectroscopy experimental campaign. It helped preparing the call to proposal for the 2017 ALTO PAC which accepted seven proposals:

— Half-life measurement and isomer spectroscopy in the neutron rich deformed nucleus $^{166}$Dy (*cf.* [12]).

— Electromagnetic transition rates in the nucleus $^{136}_{58}$Ce.

— Pinning down the structure of $^{66}$Ni by $2n$- and $2p$-heavy-ion transfer reactions and g-factor measurement (*cf.* [13]).

— Feeding of low-energy structures of different deformations by the GDR decay: the nuBall array coupled to PARIS.

— A study on the transition between seniority-type and collectivity excitations in the yrast $4_1^+$ state of $^{206}$Po.

— Spectroscopy above the shape isomer in $^{238}$U (*cf.* [14]).

— Spectroscopy of the neutron-rich fission fragments produced in the $^{238}$U$(n,f)$ and $^{232}$Th$(n,f)$ reactions (*cf.* [14]).

An experiment from the backlog, proposed for the MINORCA campaign, was also scheduled during the runs. The last experiment of the previous list consisted of collecting data about fission fragments produced *via* the fast neutron induced fission. This proposal was, in fact, a collection of fifteen sub-proposals. This experiment has been granted five weeks of beam time and represents 60% of the total amount of data collected during the campaign.

The $\nu$-ball campaign lasted a year from June 2017 to July 2018. The clover detectors and mechanics were shipped from Jyväskylä late June 2017. It took two months to mount the mechanical structure of the array and prepare the cabling of the detectors. In September 2017, we proceeded to the gain matching of the clover's BGO. The HPGe were mounted in October. The full array was fully operational for the first time at the end of the same month. It was commissioned mid-November using an ionisation chamber containing $^{252}$Cf deposit. The activity of the fission source was $\sim 1$ kBq. We used the fission as a trigger condition for the DAQ. A brief data analysis confirmed the Geant4 simulated performances of the array in terms of energy and time resolutions. It also confirmed the interest of calorimetry to tag the reaction mechanisms. The first two $\nu$-ball experiments were performed before the end of 2017. After a mandatory maintenance for the Tandem accelerator, the campaign started again in mid-January without interruption until June 2018.

To satisfy the specific needs of each experiments, the setup underwent major changes three times. First, a standard reaction chamber was used for all the heavy-ions experiments. Then, for the LICORNE experiments, this chamber had to be replaced with the neutron production chamber. At the same time, one ring of $LaBr_3$ had to be moved further away from the target loosing 30% of total $LaBr_3$ detection efficiency. It also required the removal of one Phase I detector (*cf.* right-hand side of Fig. 2). The last two experiments of the campaign used the PARIS detectors. This required a major modification of the mechanical support and DAQ system. This last modification can be seen on the left of Fig. 2.

From November 2017 to June 2018, about 100 researchers participated to the campaign and $\sim$ 3200 hours of beam time were provided. Based on online observations, all the scientific goals of each experiment seem to be within reach. We are now confident that the data analysis will provide many important scientific results attesting for the success of the $\nu$-ball campaign.

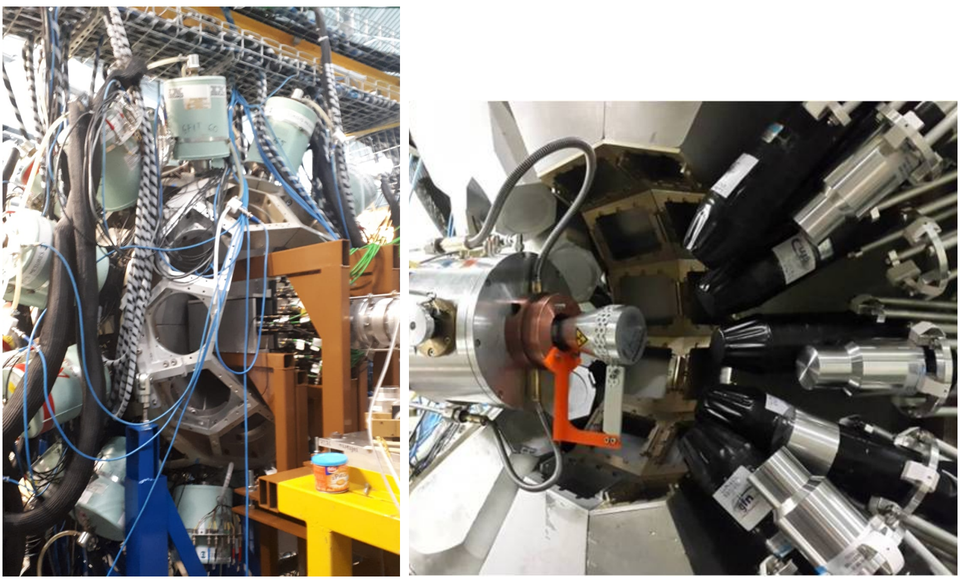

Fig. 2. Left — picture taken of the experimental setup of $\nu$-ball coupled to the PARIS array. Right — picture of the $\nu$-ball array coupled to the LICORNE neutron production chamber.

## 4. Conclusion

Despite the challenge caused by the short period of detectors availability, the $\nu$-ball campaign took place at ALTO. In six months as many hours of beam time as what is usually given in a year have been provided. The very intense pace allows for the facility to perform up to eight different experiments. Their success have been confirmed online but, of course, thorough data analysis is required.

It is reasonable to state that the $\nu$-ball project in Orsay was a success. ALTO has proved itself capable of hosting international level experiment campaigns. An official demand to the GAMMAPOOL, to borrow again the Clover detectors, has been positively received. As we are confident with the effective scientific impact of this campaign, a future $\nu$-ball2 project can be now foreseen and prepared.

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