**Istituto Nazionale di Fisica Nucleare**
**Laboratori Nazionali di Legnaro**

# PROPOSAL FOR THE INSTALLATION OF THE AGATA DEMONSTRATOR COUPLED WITH THE PRISMA MAGNETIC SPECTROMETER AT LNL

The AGATA and PRISMA Collaborations

*Spokespersons*: A.Gadea, J.Simpson, A.Stefanini

**Abstract:** In January 2006 the AGATA steering committee accepted the proposal, made by the INFN-Gamma spectroscopy collaboration, of installing the AGATA Demonstrator at the target position of the magnetic spectrometer PRISMA. The accepted proposal included not only the AGATA demonstration phase, to be done during 2007, but also an experimental campaign during 2008. During the demonstration period, the feasibility of an array based in the gamma-ray tracking concept will be proved; while in the experimental campaign the activity will focus mainly in the structure studies of moderately neutron-rich nuclei, produced by grazing reactions using multi-nucleon transfer or deep-inelastic collisions.

## Introduction

The main goal of the present AGATA phase is to demonstrate the feasibility of the gamma-tracking concept and to validate the AGATA Demonstrator (AD), which will be its first practical implementation. LNL is the site to host the activity of the AD during the commissioning and demonstration period (2007).

The in-beam activity in this period will be focused on the studying the most demanding conditions achievable in a low-energy stable-beam facility, i.e. large $\gamma$-ray multiplicity in fusion-evaporation reactions and binary reactions with velocities of the $\gamma$-emitting products up to $\beta$~10%. The experiments with binary reactions, specifically quasi-elastic and deep-inelastic transfer reactions, will be performed with the AD coupled to the PRISMA magnetic spectrometer.
It is in the interest of the AGATA community to exploit the possibilities offered by this unique combination of instruments beyond the strict commissioning phase and, therefore, the LNL will host an experimental campaign during 2008.

LNL is a stable beam facility providing beams from the XTU Tandem (V<15 MV), and from the super conducting post-accelerator ALPI. During the past years ALPI has undergone an upgrade of the super-conducting cavities that now provides an average accelerating field of 4.4 MV/m (compared with the design value (1994) of 2.7 MV/m) and the equivalent total voltage is now above 40 MV.

The first ALPI beams from the positive-ion injector PIAVE will be available for experiments starting in the second half of 2006 with more species, ranging from light noble gases up to $^{208}$Pb, to be developed in the following years.

As mentioned, the experimental activity proposed will be done by coupling the AGATA Demonstrator to the large-acceptance magnetic spectrometer for heavy ions, PRISMA. The most interesting features of PRISMA are: the large solid angle of approximately 80 msr; a momentum acceptance of ±10%; mass resolution $\Delta A/A \sim 1/190$ achieved via TOF; Z resolution $\Delta Z/Z \sim 1/60$ provided by the segmented focal plane ionisation chamber; energy resolution up to 1/1000. Within the limitation of the Z and mass resolutions, PRISMA allows for the unambiguous identification of the reaction products, as well as of the product velocity.

We are aware of the importance of having an experimental activity campaign, at LNL, associated with the demonstration. In this framework we have proposed the installation of the AGATA Demonstrator in experimental hall I, at the target position of the PRISMA spectrometer. The combined set-up will be used for in-beam test with binary reactions: deep-inelastic and multinucleon-transfer reactions, but the mechanical infrastructure of the setup will be built to be compatible with ancillary detectors for fusion-evaporation reactions and, therefore, it will be suitable to check the functionality of the Demonstrator in all required stable-beam low energy reactions.

The experimental campaign of the AGATA Demonstrator coupled to the PRISMA spectrometer will cover the spectroscopy and lifetime measurements in moderately neutron-rich nuclei.

### Description of the setup

The 5-cluster configuration of the AGATA array called the AGATA Demonstrator is shown in Fig.1. While in CLARA the distance of the detectors from the target position is fixed at 29.5 cm, the Demonstrator can be positioned between 23.5 cm (its default design distance) and 14.0 cm, compatible with the radius of the scattering chamber. Accordingly, the solid angle coverage varies between 6.8 and 17.2 % of $4\pi$. In the same figure efficiency of the array as a function of the distance from the target is shown. In this figure it is possible to see that for the proposed experimental activity we can expect an efficiency of greater than 5%. In the lower panel of Fig.1 an experimental CLARA-PRISMA spectrum is compared with a simulation of the Demonstrator at two target distances for the same number of events.

### Summary of the CLARA vs. Demonstrator comparison

CLARA has an efficiency between 2.6 % and 3 % and a FWHM of 0.8 to 1.0 % for product velocities $\beta$ = 8 % to 10 %. (AT WHAT GAMMA ENERGY?) At a target-detector distance of 14 cm, the AGATA Demonstrator will have an efficiency of ~6 % and a FWHM of 0.4%. This means an increase by a factor of 3 to 4 in the $\gamma$–$\gamma$-PRISMA coincidences and a factor of 4 in sensitivity. Moreover, for lifetime measurements a further increase by a factor of 2 has to be considered since the complete Demonstrator can be used compared with half of CLARA.

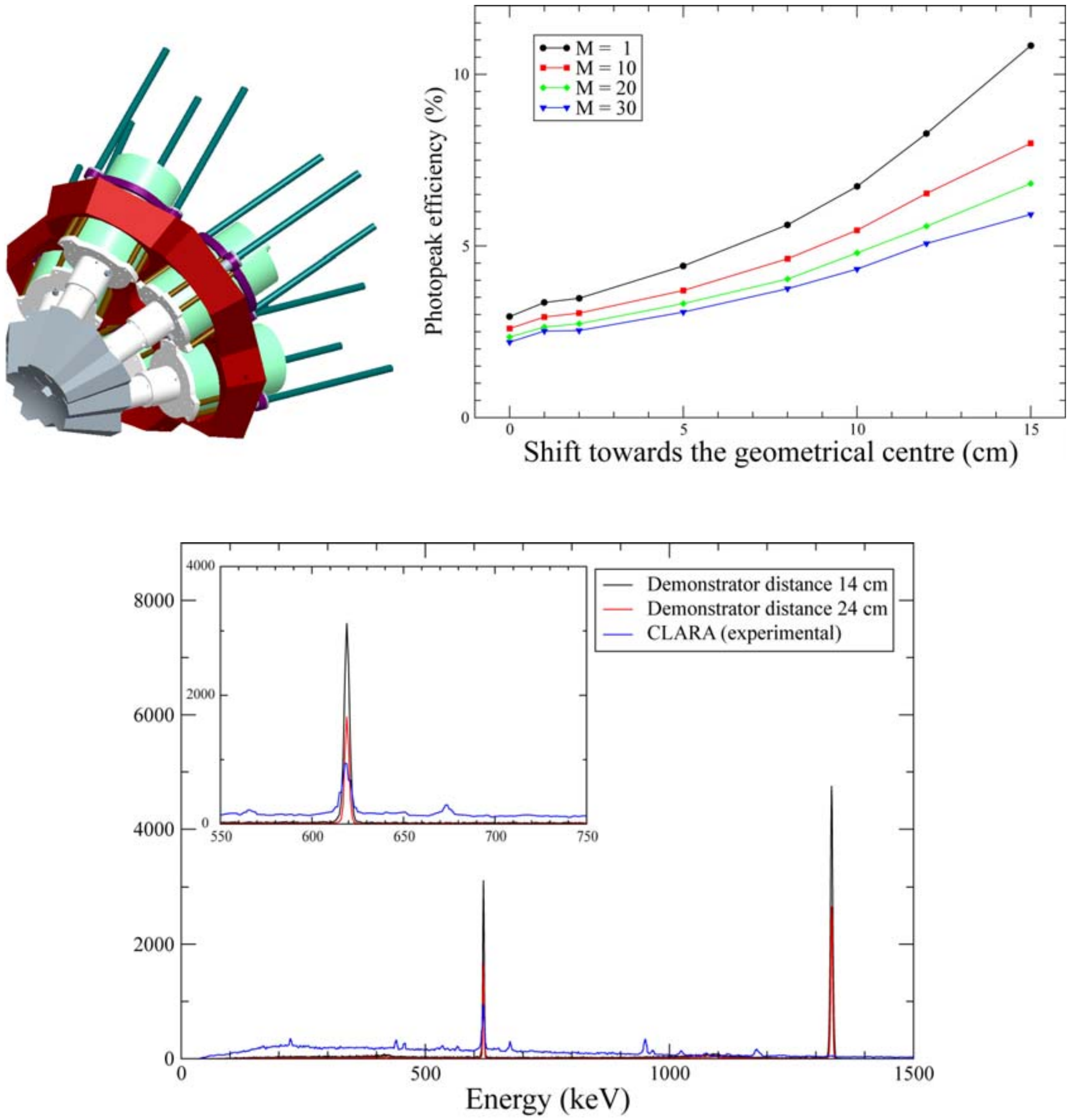


**Figure1: Upper panel left; schematic view of the AGATA Demonstrator (5 Clusters) in the mounting flanges. Upper panel right; efficiency of the Demonstrator as a function of the shift towards the geometrical center. Zero is the default distance of 23.5 cm. The minimum distance at PRISMA is 14 cm (shift of 10 cm). Lower panel; CLARA spectrum from the $^{78}$Se experiment compared with the results of a Monte-Carlo simulation in the same experimental conditions (i.e. β distribution from 7 to 10%) for 2 Demonstrator-to-target distances.**

## Experimental Campaign

The large increase of sensitivity of the Demonstrator-PRISMA setup compared with CLARA-PRISMA, will allow to proceed further with some studies already initiated at LNL and to explore new regions with the heavier beams of PIAVE-ALPI.

As an example, there are still open questions concerning the evolution of the N=50 magic gap with decreasing the atomic number. With the Demonstrator at

PRISMA we plan to perform experiments with $^{82}$Se (Tandem-ALPI) or $^{86}$Kr (PIAVE-ALPI) beams on $^{238}$U targets in order to study higher angular momentum states in $^{82}$Ge and $^{81}$Ga and investigate possible changes in the N=50 gap.The evolution of the gap can be also observed by the evolution of the shape in the N=52 Nuclei. The ratio between the excitation energy of the $4^+$ and $2^+$ states have a maximum at the middle of the shell i.e. $^{86}$Se. The observation of the $4^+$ in $^{84}$Ge can also elucidate whether there is down-slope towards Z=28 and, therefore, the presence of a double shell closure. We expect the $^{84}$Ge, with a production cross section of several $\mu$b, to be within the sensitivity limit of the new Demonstrator-PRISMA setup.

The calculated cross section for $^{80}$Zn in the quasi-elastic 6 proton-stripping channel with $^{86}$Kr beam is of the order of the $\mu$b. This cross-section gives a rate of few Demonstrator-PRISMA coincidences per day. With the increased sensitivity of the Demonstrator it should be possible to build a spectrum of $^{80}$Zn in approximately two weeks of beam time. The knowledge of the first excited states in $^{80}$Zn, the two valence nucleus with respect to the $^{78}$Ni core, is of primary importance for the discussion of the residual interaction in the region and, therefore, for the evolution of the N=50 gap.

Nuclei in the region of the double magic $^{132}$Sn can be populated in quasi-elastic and deep inelastic reactions with Xe and Te beams on $^{208}$Pb or $^{238}$U targets. The Xe beams have been already tested at the PIAVE ion source and should be available to the users already in 2006. Of particular interest in the vicinity of $^{132}$Sn are the one and two particle and hole valence nuclei. However, just one-hole state is known in the N=82 nuclei $^{131}$In and $^{133}$Sb have been studied extensively only recently. Similarly, the study of the one neutron valence N=83 nuclei is of particular interest but the experimental knowledge is almost nonexistent. The physics of the low-lying states in these nuclei is connected to the evolution of the tensor interaction. The unpaired neutron is in the shell built by the orbitals $f_{7/2}$, $h_{9/2}$, $p_{3/2}$, $p_{1/2}$ and $i_{13/2}$. The closer is the N=83 isotone to Z=50, the emptier are the proton orbitals and therefore the spin-flip tensor interaction will be less attractive and the non-spin-flip less repulsive. Nuclei with N=83, such as $^{137}$Xe and $^{135}$Te can be produced with large cross sections from a $^{136}$Xe beam as 1 neutron pickup and 2 proton stripping and?1 neutron pickup quasi-elastic channels.These few-nucleon transfer reaction channels can populated both yrast and non-yrast states.

Regarding lifetime measurements, the differential plunger (Differential RDDS) technique for CLARA-PRISMA is presently being developed in collaboration with the IKP-University of Cologne. The idea is to place a thin metallic foil at suitable distances after the production target. The metallic foil will act as energy degrader, and will not stop the projectile-like reaction products going toward PRISMA (see Fig.2).

Depending on the velocity distribution of the projectile-like nuclei and on the desired lifetime range, the target-degrader distance will vary from few microns to hundreds of microns. Since the setup must be very compact, instead of the usual one-foil PRISMA targets, one must employ differential plunger targets consisting of a thin production target and an energy degrader foil placed at fixed distance, everything in one mechanical set-up. Several differential plunger targets, corresponding to different fixed distances, will be placed in the normal target holder inside the reaction chamber. Figure 2 compares schematically

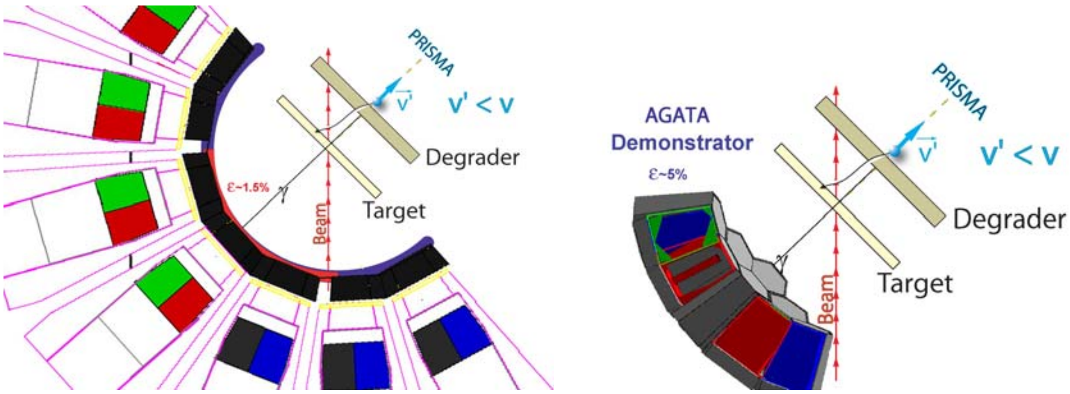


**Figure 2: Use of CLARA (left) and the Demonstrator (right) for RDDS measurements. Only half of CLARA detectors can be used for RDDS and, therefore, the effective efficiency of CLARA for RDDS is about 1.5%, compared with 5% to 6% for the Demonstrator.**

the set-up for RDDS measurements with CLARA and the AGATA Demonstrator. Lifetime techniques based on DSAM, such as the one developed for the Krakow Recoil Filter Detector (RFD), will also gain from the larger efficiency of the Demonstrator.

The scientific program will cover measurements of lifetimes of excited states above the $2^+$, which cannot be performed easily at the present generation of radioactive beam facilities. The purpose of such measurements is to gain spectroscopic information for more stringent tests of the models describing the neutron-rich nuclei far from stability

## Installation program

In Fig.3 the installation program for the Demonstration at LNL it shown. As it can be seen, if the number of detectors is sufficient and the other components of the setup are ready, it is planed to start the installation in May 2007, conclude the demonstration period in December 2007 and start the experimental campaign at the beginning of 2008.

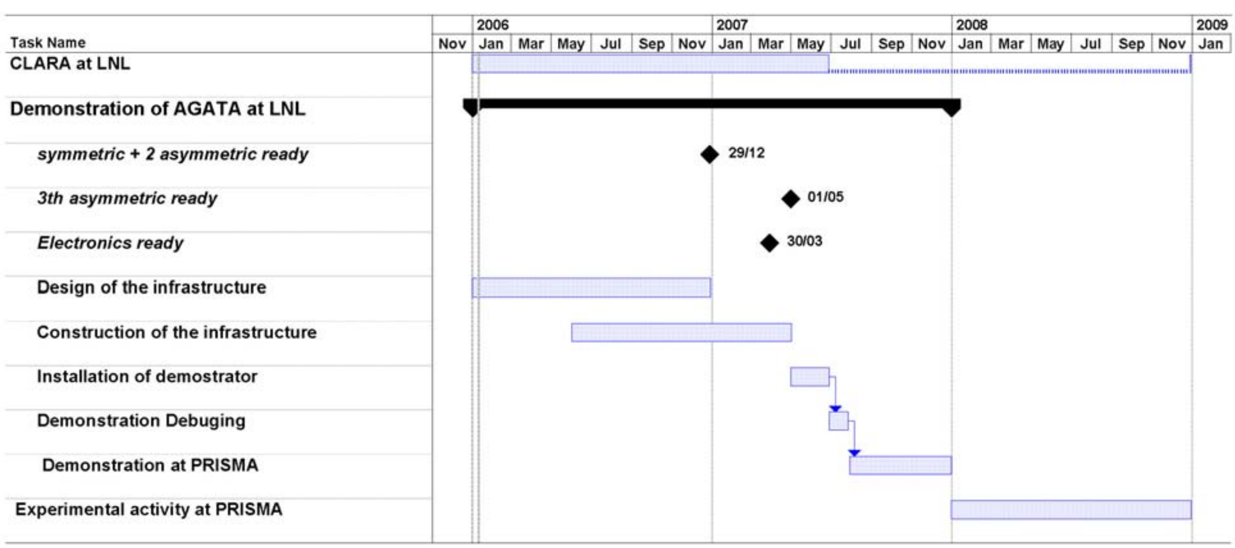


**Figure 3: Proposed plan for the installation, demonstration and experimental activity**

## Conclusion

With this proposal is our intention to present to the LNL PAC committee the project as well as ask for its necessary approval to initiate the installation.A limited support from the EURONS LNL access support funds will be requested for the installation.

The demonstration of the tracking concept requires a consistent amount of beam-time (up to 6 weeks) to be allocated probably in the second semester 2007. The reactions and aspects of interest that can be studied at LNL are:

- Binary Reactions (Coulomb excitation, quasi-elastic reactions, etc...)
  - Feasibility of tracking with Doppler corrections for $v/c \leq 0.1$
  - Large scattering angle for the products
  - Reconstruction of low multiplicity "simple" spectra.

- Reactions close to the Coulomb barrier (Fusion-Evaporation reactions / Deep Inelastic Collisions)
  - Tracking with high gamma multiplicity for $\sim 0^{o}$ recoils (Fusion-Evaporation reactions).
  - Tracking with high multiplicity and large scattering angle for the products (Deep Inelastic)
  - High spin, reconstruction of high multiplicity spectra.

- GDR and high-energy gamma detection (Fusion-evaporation at the limits of angular momentum).
  - Tracking efficiency for high energy gammas
  - Explore the reconstruction on non-Compton processes (pair production)

A detail proposal for the activity will be presented to the pertinent PAC meeting.