Rapport d'Activité pour la Plateforme ALTO

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Summary

The IN2P3 ALTO platform, is a facility that possesses two accelerators to produce heavy-ions beams for nuclear reactions or radioactive ions beams thanks to the ^{238}U(g,f) mechanism for nuclear structure studies. From 1970 to now, ALTO always managed to reinvent itself to respond to the beam demands required by the recent scientific advances. This constant rejuvenation maintained the competitiveness/complementarity of this “niche” installation at an international level.

First, the TANDEM, is a machine capable of accelerating a wide range of heavy-ions (HI) and even clusters. These beams were mainly used for reaction studies, γ/charged particle-spectroscopy of HI induced reactions (ORGAM, MINORCA, ν-ball, Split-pole) for nuclear structure and nuclear astrophysics that forms the core of its scientific activity. Cluster beams were used for astro-chemistry studies to understand the formation of organic molecules in nebulae. A recent addition, in 2013, of a fast neutron source (LICORNE), also opened the world of spectroscopy of neutron induced reactions, and nuclear data measurement.

Second, the LINAC was built in the early 2000’s and commissioned in 2006. Since that moment, ALTO became the only facility is the world to use photofission of ^{238}U as a production mechanism for neutron rich fission fragments. It is the very step of the DESIR physics program that can be performed in Orsay.

Nowadays, ALTO rely on the excellent technical skills of the 15 technicians and engineers that works at IJCLab. The recent fusion of the 5 laboratories on the Orsay is also a good occasion to allow ALTO to change gears: a new organisation, a new economic model, a new rejuvenation of the facility is being discussed at the moment to allow the passage to ALTO2.0

Description of the ALTO facility

ALTO ("Accélérateur et Tandem d'Orsay") is a two-accelerator facility at the IJCLab (see fig. 1). The first accelerator is a 15 MV tandem accelerating ions, from proton to gold, as well as clusters and molecules. It is operated since 1970, with constant maintenance and upgrades. It is for instance the first installation in the world to have accelerated fullerene molecules. The second accelerator is a Linear accelerator ("LINAC") which accelerates electrons up to 50 MeV, that are used to photo-fission a Uranium carbide target in order to produce neutron-rich radioactive beams. It is the first facility in the world using this pioneering technique. After ~10 years R&D work, it has been hosting physics experiments for the past few years and has published original results on the physics of exotic nuclei.

The ALTO Tandem

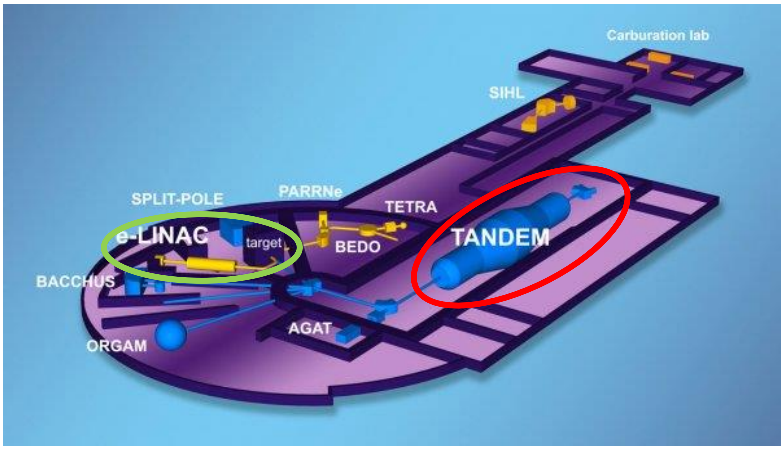


Figure 1 : ALTO Platform Layout.

The Tandem is a 15 MV electrostatic accelerator. It consists of three successive parts: the injector, a pulsation system and the accelerator itself.

The injector is the ion source platform which produces the negative ions beam injected in the accelerator. To produce the requested nuclear beams, the selected atoms are first negatively charged in a dedicated ion source. They are then injected in the accelerator at 100 keV. As the ions are negative, they are accelerated towards the centre of the accelerator by the positive high voltage. At the centre, they go through a thin layer of gas or carbon. This way, they get stripped and become positive ions which then have a second step acceleration, towards the end of the accelerator which is at ground. Depending on the charge state of the positive ions, the final energy ranges from ten to hundreds of MeV. It provides more than 75 different beams ranging from proton to Au. The machine also produces cluster beams (C_n, C_nH_m), micro-droplets, carbon and gold aggregates (C_{60} - Au_{400}).

In addition, LICORNE neutron source and its high flux and directional fast neutrons is unique worldwide. We are thus in the fortunate position to be able to carry out a highly competitive physics program using directional neutrons for neutron-induced fission studies in the range 0.5 to 7 MeV. Other facilities currently lack the combination of both very high fast neutron fluxes and very high directionality. LICORNE could be considered a precursor of the NFS facility due to come online at GANIL in 2018. NFS and LICORNE are highly complementary, since NFS is intended to produce neutrons in the 5 to 40 MeV range, with peak flux at 15 MeV.

The ALTO e^- LINAC

An electron linac produces electron beams with an energy up to 50 MeV and an intensity of 10 µA. It is used to produce radioactive ion beams by Bremsstrahlung induced photofission in a uranium carbide (UCx) target heated to 2000°C. Fission fragments are ionized using different ions sources: MK5 plasma, resonant laser ionization, or surface ionization sources. The intensities of the beams extracted from the UC_x target are of the order of 10^2 to 10^8 pps (particles per second), for example: 3 x 10^7 pps for ^{132}Sn, 7 x 10^5 pps for ^{78}Ga, 1 x 10^5 pps for ^{78}Zn. These beams are then analysed with a mass separator (PARRNe) and distributed to the 6 RIB lines. Over the past few year a strong effort has been put in developing the laser ionization source (RIALTO project) to get the best isotopic selectivity that the ISOL technique can provide. Over several upgrades of the setup, the reliability of the source has been improved. For the last three campaigns, new ionization scheme has been validated and the source is now considered fully operational.

The ALTO instrumentation

ALTO facility hosts several instruments, distributed over 11 experimental zones, necessary to pursue its scientific activity:

- Two on-line and off-line isotope separators (PARRNe, SIHL)
- Two mass spectrometers (Bacchus and Split-pole)
- Several experimental devices (AGAT, ORGAM,MINORCA, ν-ball, BEDO, TETRA, POLAREX, LINO, LICORNE, MLLTRAP)

The platform also has a stable source test bench, a laser platform, an R&D and manufacturing laboratory for uranium carbide targets (UCx) and an R&D manufacturing laboratory for thin film/target layers.

The ALTO organization

Governance model

Up to December 2019, the ALTO facility was part of the “Division Accélérateur” directed by Sébastien Bousson. Two persons were at the head of the facility: the technical manager Abdelhakim Said, and the scientific coordinator Matthieu Lebois. Several times a year, a steering committee was held to report on the facility activity and evolution. Members of this comity were: Michel GUIDAL (Laboratory Director), Bruno ESPAGNON (Deputy director), Fadi IBRAHIM (Chargé de mission prospective ALTO), Matthieu LEBOIS (Scientific Coordinator), Abdelhakim SAID (Technical director).

In January 2020, the “Institut de Physique Nucléaire” d’Orsay and 4 others laboratory merged to form the new entity named IJCLab. The ALTO platform governance model was changed. Now, ALTO directly depends on the three director and deputy directors. A new scientific coordinator, and technical manager of the facility will soon be named. The steering committee members will be changed accordingly.

Since 2018, ALTO is recognized as a IN2P3 “Platform”. As a consequence, an IN2P3 steering committee has been created. Until Dec 2019 it included the same members as the ALTO COPIL in addition to Fanny FARGET (IN2P3 Scientific deputy director) and Jean-Luc Biarotte (IN2P3 Scientific deputy director). It is normally attended up to twice a year.

A special working group “ISOL ALTO”, having weekly meetings, dedicated to the ISOL facility projects was created in 2018. The aim of the group is to insure the best development of the ISOL projects and RIB campaigns.

Staff and Budget

The ALTO technical team currently counts 15 engineers and technicians, funded by CNRS/IN2P3, needed for operating, maintaining, upgrading, developing the two accelerators. Excluding salaries and projects, the installation requires a budget of ~300 k€/year, supplied by CNRS/IN2P3, Université Paris-Sud, European programs and laboratory auto-generated funds. The facility is, since 2010, labelled as a Trans-National Access (TNA) facility by the European program ENSAR/ENSAR2 (European Nuclear Science and Applications Research) programs and, more recently, as a “CNRS/IN2P3” platform, which testifies of its international and national reach, influence and recognition.

In addition, roughly 360 k€/year are funded by IN2P3 to support the master projects (R&D and instrumentation for physics) developed at ALTO.

Beam Time Allocation

The selection of users by the PAC (Programme Advisory Committee) is made only on the scientific merit of the proposals submitted. The proposals are reviewed independently of their country of origin. Experiments are evaluated and awarded a number of 8-hour shifts of beam time, according to the number requested and the number deemed suitable by the PAC. In Annex 2, one can find the list of the Selection Panel members of the last ALTO PAC that was held in June 2019.

Every year, between 2800 and 3900 hours of beam time are delivered. The distribution of the beam time towards French or foreign researchers greatly varies from one year to the next. For example, in 2018, only 30% of the beam time was given to French researchers (spokespersons). In 2019, more than 70% of the beam time was given to French researchers.

ALTO Scientific Activities

The ALTO facility is a research facility providing beams to pursue scientific programs of international research teams. The range of activity is broad: from solid state physics, to astro-chemistry, ALTO embrace the full scope of experiments that can use its available beams. However, nuclear physics remains the core of ALTO activity as it is described in the following.

Nuclear structure and dynamics at ALTO

Spectroscopy of nuclear excited states is key to studying nuclear structure. Energy, spin, parity and lifetimes are observables which are linked to how the nucleon-nucleon interaction gives rise to the nuclear bound system. Due to the complexity of the Hamiltonian of the system, these observables are not directly linked to a specific term of the nuclear interaction. As a consequence, a holistic approach often ought to be employed, where several quantities concerning the same state are measured to better constrain theoretical model. This in turn allows pining down the key terms determining nuclear shell formation and evolution as a function of isospin.

Neutral/Charged Particle spectroscopy is a versatile tool to measure several observables of interest in a single experiment. When excited states are unbound towards neutron or proton emission, competition between gamma decay and particle emission takes place, hence requiring neutron or proton spectroscopy for a complete measurement. An often-important complement to gamma spectroscopy is provided by conversion electron measurements, which are also the only easy to detect electric monopole transitions. With the production of radioactive ion beams, ALTO is a place where many of these technics can be used.

ALTO LOW ENERGY IONS PRODUCED *VIA* ISOL TECHNIQUE

Scientific Program with ALTO ISOL beams

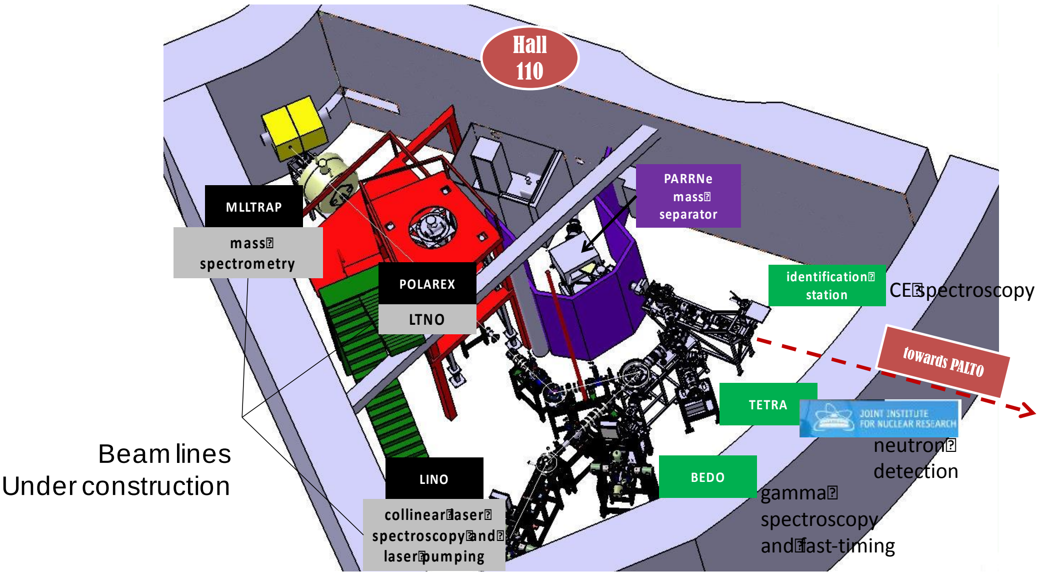


Figure 2: Layout of the ISOL beam experimental cave.

The use of the photofission of ^{238}U allow the production of neutron rich fission fragments beam from Zn to Ba. In the absence of post-acceleration device only the decay of these nuclei can be studied. However, several research activities are now conducted, based on the spectroscopy of the particles emitted in or following the decay process:

1- β-delayed particle spectroscopy:

The main research objectives are the study of β-decay gross properties such as half-lives and decay branching (important inputs for modelling of nucleosynthesis processes), the study of nuclear structure in terms of evolution of magic numbers and possible shape coexistence phenomena. The large Q_β windows, typical of decays far from stability, allow accessing a large fraction of the strength function, sensing phase-space regions characterised by dense states. Complementary information such as those coming from the study of delayed neutron emission, will give insight on low-energy tail of giant resonances.

First, β-delayed conversion-electron spectroscopy is a tool well adapted to low-noise radioactivity measurements. The detection of electron conversion of gamma transitions can help assign their spin and parity, and it is the only way to detect an E0 transition. In this regard, β-delayed conversion-electron spectroscopy provides a unique way to investigate the existence of low-lying excited 0^+ states, often a signature of shape coexistence. The occurrence of shape coexistence around N=50 towards Z=28, revealed by the measurement of the E0 transition from the second 0^+ state in N=48 ^{80}Ge performed at the ALTO's β-decay station BEDO, is an experiment which paves the way for future studies in the region around ^{78}Ni. The ISOL facility at ALTO could investigate the existence of such phenomenon in the N=50 isotones, making high-statistics long measurements to look for low-lying intruder 0^+ states (or corresponding coupled states in odd-even nuclei).

When a high Q_β-value is available, so that Gamow-Teller (GT) transitions which require shell-closure breaking are energetically allowed. The question of the distribution of the GT strength is still opened. Several papers suggest the existence of doorway states through which the GT strength would preferentially go. Recently, the availability of radioactive beams of very exotic species, beyond the neutron shell closures N=28, N=50 and N=82, has brought a renewed attention on these issues. In recent works with the VANDLE detector it has been observed that the GT strength is going mainly through selected states which are p-h excitations across the shell closures. However, the neutron-rich isotopes which have Q-values high enough to make it possible p-h excitations across one or two shell closures (>10 MeV) are in regions where the neutron-separation energies are low. This leads to a dominance of β-delayed neutron emission in many of these neutron-rich regions of the nuclide chart. Therefore, neutron spectroscopy is required to reconstruct the level scheme, or GT distribution, above the neutron separation threshold.

To pursue these research activities, the ALTO facility has developed a unique experimental setup known as the IN2P3 master project BESTIOL. BESTIOL (alias BEDO) is the modular device allowing the study of exotic nuclei by collection and decay of the beams produced at ALTO in the perspective of DESIR. It is composed of 3 sub-assemblies fed by 3 beam lines from the separator:

- "BEDO" line: γ spectroscopy, fast timing, PARIS, MONSTER. BEDO has been dimensioned and optimized for the use of the 4 small CLOVERS prototypes EXOGAM in close geometry. These detectors have the ideal geometry (size and position of the Ge crystals) and resolution for beta-delayed gamma-ray spectroscopy measurements of the most exotic nuclei produced at ALTO. BEDO has been successfully coupled to a fraction of the PARIS array in June 2019 – 2 PhD ongoing program. It is planned that BEDO will be coupled with the MONSTER neutron detector in the next years.
- "TETRA" line: a 4π ^{3}He neutron counter. This line has been mainly used for P_n measurements.
- "PARRNe" line, based on LN_2 cooled Si(Li) serves as an identification station and measurement point for internal conversion electrons.

2- New devices for In-trap decay spectroscopy/laser spectroscopy/mass measurement:

Three other setups are being developed and/or installed at ALTO:

- POLAREX: nuclear orientation at low temperature. It uses a ^{3}He-^{4}He dilution cryostat to measure the nuclear orientation that is obtained by cooling nuclei to ≈10 mK in the presence of a strong (10-100T) magnetic field. The study of short-lived nuclei is possible with this technique by implanting directly a radioactive beam into a foil in contact with the cold finger of the cryostat but it suffers from the limitation that the thermal equilibrium between the nuclei and the medium is not instantaneous and requires up to few seconds to be established. A superconducting magnet with a maximum field of 1.5T provides an applied field, which magnetizes the foil. The implanted nuclei are oriented through the internal hyperfine field.

- LINO: laser nuclear orientation and laser spectroscopy. Collinear laser spectroscopy is a versatile experimental technique capable of high-precision measurement of nuclear properties by means of atomic laser excitations. The electromagnetic interaction of the atomic nucleus with the electron shells results in a splitting of the atomic energy levels, about a million times smaller than the fine structure. The ion-beam velocity is made variable in order to scan for the hyperfine-structure components via the corresponding variation in the Doppler shift. The atomic excitations are then identified through the beam fluorescence. Furthermore, in combination with nuclear magnetic resonance (β-NMR station) the spins can be determined with absolute certainty, and the setup can be used as a platform for providing polarized beam for other research domains such as solid-state studies and related applications. The LINO setup has been successfully commissioned with a stable beams in November 2019 – see next paragraph.
- MLLTRAP: mass measurement and trap assisted spectroscopy. It consists of two trap-electrode modules. The first is a cylindrical double Penning trap for high precision mass measurement, which was commissioned with an offline source at MLL. The ions are cooled and manipulated in the first trap and then injected into the second trap where the actual mass measurement takes place by determining the cyclotron frequency of the ions. This module will be used to measure masses of fission fragments

These last three setups will allow the extension of the physics program in the mass region relevant at ALTO. They will give access to others observables whose are unreachable with the already running β-decay setups. In particular, ALTO will take the leadership in nuclear orientation studies with the simultaneous commissioning of POLAREX and LINO.

Physics Highlights with the ALTO ISOL Beams

In the following are presented selected highlights of the ALTO ISOL beams. The list is not exhaustive and intends to present the activity of each item/instrument presented previously.

1- β-delayed particle spectroscopy:

“First Evidence of Shape Coexistence in the ^{78}Ni Region: Intruder 0_2^+ State in ^{80}Ge”
A. Gottardo *et al.*, Phys. Rev. Lett., **116**, 182501 (2016)

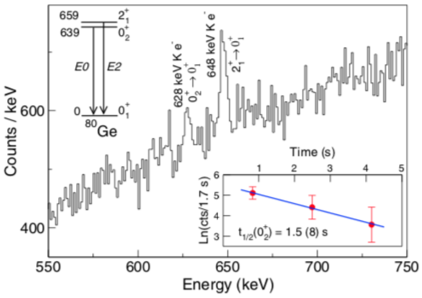


Figure 3: Energy Spectrum obtained for the Si(Li)detector from the decay of ^{80}Ga. The inset shows the decay curve of the 628 keV e$^-$, which is compatible with the ^{80}Ga lifetime(s). The deduced partial level scheme of ^{80}Ge is also drawn.

The N = 48 ^{80}Ge nucleus is studied by means of β-delayed electron-conversion spectroscopy at ALTO. The radioactive ^{80}Ga beam was produced through the isotope separation on line photofission technique and collected on a movable tape for the measurement of γ and e$^-$ emission following β-decay. An electric monopole E0 transition, which points to a 639(1) keV intruder 0_2^+ state, was observed for the first time. This new state is lower than the 2_1^+ level in ^{80}Ge, and provides evidence of shape coexistence close to one of the most neutron-rich doubly magic nuclei discovered so far, ^{78}Ni. This result is compared with theoretical estimates, helping to explain the role of monopole and quadrupole forces in the weakening of the N = 50 gap at Z = 32.

“Unexpected high-energy γ emission from decaying exotic nuclei”
A. Gottardo *et al.*, Phys. Lett. B, **772**, p. 359-362 (2017)

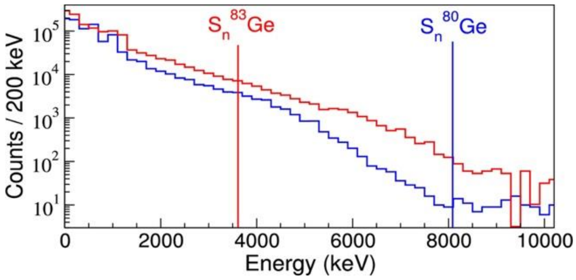


Figure 4: The γ-ray energy spectrum as measured in coincidence with β electrons from the decay of ^{80,83}Ga. The neutron separation energies of the daughter nuclei ^{80,83}Ge are also indicated. The two spectra are normalized to the same number of β-decay events.

The β–decay of ^{83}Ga was studied at ALTO. The radioactive ^{83}Ga beam was produced through the ISOL photofission technique and collected on a movable tape for the measurement of γ-ray emission following β–decay. While β–delayed neutron emission has been measured to be 56–85% of the decay path, in this experiment an unexpected high-energy 5–9 MeV γ-ray yield of 16(4)% was observed, coming from states several MeV above the neutron separation threshold. This result is compared with cutting-edge QRPA calculations, which show that when neutrons deeply bound in the core of the nucleus decay into protons via a Gamow–Teller transition, they give rise to a dipolar oscillation of nuclear matter in the nucleus. This leads to large electromagnetic transition probabilities which can compete with neutron emission, thus affecting the β–decay path. This process is enhanced by an excess of neutrons on the nuclear surface and may thus be a common feature for very neutron-rich isotopes, challenging the present understanding of decay properties of exotic nuclei.

“Pygmy Gamow-Teller resonance in the N=50 region: New evidence from staggering of β-delayed neutron-emission probabilities”
D. Verney, D. Testov *et al.*, Phys. Rev. C, **95**, 054320 (2017)

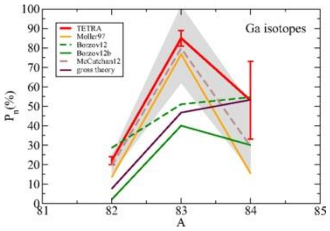


Figure 5: Experimental P_{1n} for the $^{82-84}$Ga precursors from the present work (“TETRA”) compared to theoretical results using QRPA approaches. Results from the use of the empirical formula by McCutchan *et al.* are also represented with the associated uncertainties materialized by the grey zone.

This experiment studied the β-delayed neutron emission probability (P_{1n}) measurements of the ^{82,83,84}Ga (N=51,52,53) precursors performed in one single experiment using the ^{3}He neutron-counter TETRA at the ALTO facility in Orsay. Altogether our results for the three A=82,83, and 84 Ga precursors point towards a sizable P_{1n} staggering in the N=50 region, similar to the one already observed just after the N=28 shell closure in the K isotopes chain, hinting at a similar mechanism. We will discuss the possible microscopic origin of this behaviour, i.e., the existence in the light N=51 isotones of low-lying components of the so-called pygmy Gamow-Teller resonance, already well established at Z=36, and persisting toward ^{79}Ni.

“Trial for the long neutron counter TETRA using ^{96,97}Rb radioactive sources”
D. Testov *et al.*, JINST., **14**, P08002 (2019)

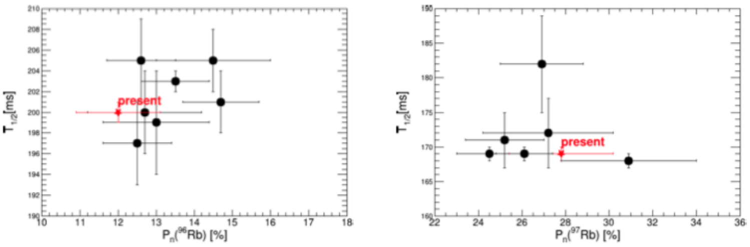


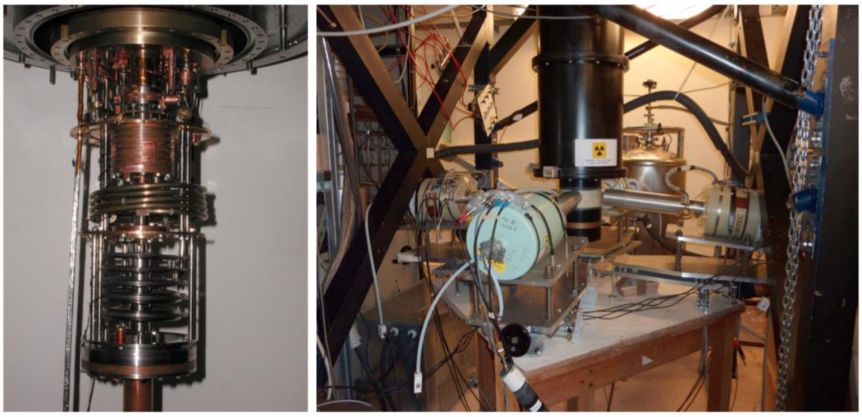
Figure 6: $T_{1/2}$ versus P_{1n} for ^{96}Rb and ^{97}Rb known from previous works as well as the values obtained in the present work

The TETRA long neutron counter is operated at ALTO ISOL facility behind the PARRNe mass separator. TETRA has been proven to be a unique instrument for measurements of β-decay properties of short-lived neutron-rich nuclei having applications for the nuclear structure and/or astrophysical r-process calculations. A proper calibration of TETRA can allow validation of the experimental procedure used for determination of β-delayed one-neutron emission probabilities (P_{1n}). It requires the use of a well-known β-neutron decaying radioactive source which can be only produced and measured on-line due to its short half-life. Thus, the present paper reports on measurements of P_{1n} and $T_{1/2}$ of ^{96,97}Rb nuclei using TETRA. The results obtained are in a good agreement with the values available in the literature. This proves that the developed techniques can be applied to unknown P_{1n} and $T_{1/2}$ of neutron-rich species.

2- New devices for In-trap decay spectroscopy/laser spectroscopy/mass measurement:

"PolarEx, A Future Facility for On-Line Nuclear Orientation at ALTO Multipolarity Mixing Ratio Data Analysis"

R. Thoer, Act. Phys. Pol. B, **51**, p. 591 (2019)



(a) The dilution unit

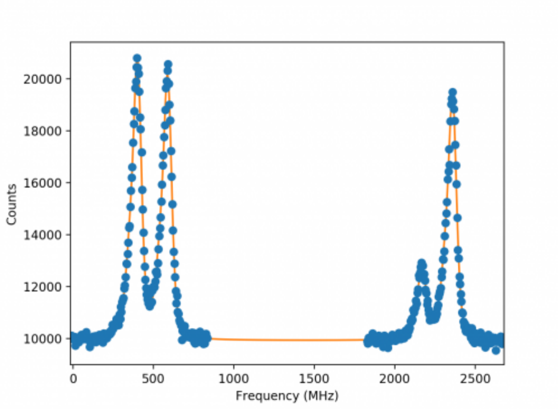
(b) The cryostat and detection system

Figure 7: The PolarEx setup

Experimentally, the mixing ratio can be derived from angular distribution measurements using the Low Temperature Nuclear Orientation (LTNO) technique. One can measure such a distribution from an oriented nucleus, strongly improving the sensitivity. This paper focuses on the analysis methods to extract multipole mixing ratio δ values for a given g-ray transition are obtained with LTNO experiments.

"The LINO Setup commissioning"

D. Yordanov *et al.*, IPN News (2019)



In November 2019, at the ALTO laboratory, singly-charged ions were first accelerated to an energy of 30 keV, then passed through a volume of vaporized sodium for neutralization and overlapped with a co-propagating laser beam. Before neutralization the velocity of the ions was varied in order to scan for the transitions of the hyperfine structure via the Doppler effect. At each transition the atomic beam resonantly, absorbed photons from the laser and began to fluoresce. The fluorescence light was detected with a pair of photomultiplier tubes designed for single-photon counting.

The spectrum shows the atomic hyperfine structure of the only naturally occurring isotope of sodium composed of 11 protons and 12 neutrons. The spacing between the resonances is determined by the magnetic moment of this nucleus, which is thus measured. The hyperfine splitting caused by the nuclear electromagnetism is extremely small, about a millionth of the transition energy. To achieve such precision, narrow-band lasers are used, and the atom-laser interaction is performed on a fast beam to remove the Doppler broadening associated with the thermal motion in the ion source. Such measurements can be performed also on radioactive isotopes. Apart from magnetic moments, nuclear charge radii, spins, and quadruple moments can be measured as well.

ALTO TANDEM BEAMS

Scientific Program with ALTO TANDEM beams

In-beam spectroscopy is the second leg of gamma-ray spectroscopy at the ALTO facility. Excited states in nuclei can be produced using a multitude of reaction mechanisms, such as Coulomb excitation, nucleon-transfer reaction, incomplete fusion as well as heavy-ion fusion. This allows for detailed studies neutron-deficient exotic nuclei up to mass A=200 region and nuclei one or two neutron richer than stable nuclei up to mass A=70. Several projects have been identified as a potential research activity for ALTO using ion beams accelerated with the TANDEM accelerator:

1- Dynamical Symmetries in Nuclear Structure:

Dynamic symmetry – or spectrum generating algebras is a concept that has applications in many different branches of modern physics. The concept of dynamic symmetries has been adopted to study atomic nuclei, and this results to a deeper understanding of nuclear properties. Within this concept we can classify the atomic nuclei based on their symmetries as vibrators, axially symmetric rotors and axially-asymmetric, gamma-soft rotors. The phase transitions, which correspond to the breaking of the dynamic symmetries, occur as the number of nucleons changes in the nucleus. The study of these transitions is a topic of high interest in current physics research. A question on which we still have no answer is why particular symmetries describe specific nuclei—why these idealized structural paradigms are manifested empirically. In addition, it is desirable to study the evolution of the nuclear structure between the critical point symmetries and the dynamical symmetries. ALTO offers unique opportunities for such studies due to the variety of accelerated beams and the availability of unique apparatus such as plunger device and excellent detector array, which can be used for measurements of the nuclear lifetimes in wide range. Potentially such studies can be focused on nuclei in the different mass regions like A ~ 80, 130 (^{78}Sr, ^{128}Ce).

2- Mirror Symmetry in Nuclear Structure:

Isobaric multiplets along N=Z line have been object of constant interest during the last years. This region, in fact, is the only place where it is possible to find answers to fundamental problems in nuclear physics, such as the role of the proton-neutron pairing or the isospin symmetry of the nuclear interaction. One of the consequences of this symmetry is that the level schemes of mirror nuclei (obtained interchanging neutrons and protons) should be identical. The isospin selection rules impose also some constrains on the transition probabilities. For example, $E1$ transitions between analogue states should have the same strength in both mirror partners and are forbidden in self-conjugate nuclei.

In mirror nuclei, signatures of the isospin symmetry breaking are, therefore, the differences between the excitation energy of analogue states, called mirror energy differences (MED), and the different strengths of analogue $E1$ transitions. Although the Coulomb interaction is responsible for the isospin symmetry breaking, it has been pointed out that Isospin Symmetry Breaking (ISB) terms could arise from the residual nuclear interaction. The study of mirror energy differences between excited states, for many decades confined to low excitation energy and angular momentum, has been extended in the last decade to high-spin yrast states. The large increase in sensitivity and resolving power resulting from the advent of large arrays coupled to light-particle detectors have allowed the study of N~Z nuclei up to high spin and to extend the investigation to medium-mass nuclei. The heaviest (and the only one above mass A=54) mirror pair observed so far at high spin is the A=67, T=1/2 mirror pair.

There are several cases already identified in gamma-ray spectroscopy that deserve such measurements which can be performed with a plunger device, or electronically using fast-timing scintillator detectors, depending on the range of the lifetime of the states to be studied.

3- Gamma Decay from unbound states in B, C, O and N nuclei:

Neutron-rich isotopes of Be, B, C, O, N and Ne offer an extremely fertile ground for nuclear structure studies. On the one hand, they may serve as examples of nuclear clustering. For instance, in ^{8}Be, ^{12}C, ^{16}O and ^{20}Ne, many states have a well-established α-cluster structure and a few cluster models have been developed in order to account for these structures as well as for the structure of neighbouring systems with valence neutrons. On the other hand, in the same nuclei also observed are distinctive features of shell-model: in ^{14}C, for example, a comprehensive analysis of the known excitations provided evidence for states with single-particle structure and states which have strong α-clustering and form rotational bands.

In recent years, ab-initio type of calculations became capable of computing excitation energies and decay properties for these isotopes even above the threshold for particle emission, i.e. in the continuum – in this excitation energy region the impact of the continuum on the shell structure has to be considered. Our collaboration is here proposing to carry out, at the ALTO Tandem accelerator in Orsay, a research program aiming at the measurement of the γ-decay from unbound states in neutron-rich isotopes from Boron (Z=5) to Nitrogen (Z=7). The focus will be on narrow resonances with a width of up to few tens of keV, i.e. corresponding to γ-decay branchings of the order of 10^{-4} -10^{-3}. To this end, fusion reactions with intense ^{6,7}Li and ^{14}C beams on ^{9}Be, ^{12,13}C, ^{6,7}Li and ^{10}B targets are planned, leading to the population of unbound states in ^{13}B, ^{15}C, ^{17,19,20}O and ^{16,17}N, after a single proton evaporation.

4- Coulomb Excitation:

Coulomb excitation is one of the rare methods available to obtain information on static electromagnetic moments of short-lived exited nuclear states including non-yrast collective states. It is thus an ideal tool to study shape coexistence and shape evolution throughout the nuclear chart. Present radioactive beam facilities deliver post-accelerated exotic beams with intensities several orders of magnitude lower than those typically available for stable beams and, consequently, the results obtained by applying the Coulomb excitation method to unstable nuclei are not always conclusive, as the experiments suffer from low statistics. Another issue may be the lack of complementary data that would constrain the multi-dimensional fit performed in order to extract nuclear structure parameters (electromagnetic matrix elements) from the measured gamma-ray intensities. The experiments on stable nuclei can reach much higher precision on static quadrupole moments and transition probabilities, probe higher-lying states, and, consequently, provide a stringent test for predictions of the latest theoretical models. A recent example, demonstrating the scientific potential of the Coulomb excitation method to investigate properties of stable nuclei, is the study of ^{42}Ca which yielded for the first time a static quadrupole moment of a state belonging to the superdeformed band.

The ALTO facility, with beams of ^{32}S and ^{58}Ni at energies of 2-4 MeV/A and intensities of about 1 pnA, provides excellent conditions for Coulomb excitation studies of medium-mass stable nuclei. Possible physics cases include: shape coexistence at Z=40 or Z=50, superdeformation studies, octupole collectivity in the rare-earth region.

5- Fission Studies:

At ALTO, the fission process studies concern both fundamental and applied fields. On one side, the experimental program was focused on the study of fusion reactions with heavy ions and the decay channels that can open during the time scale of the reaction and on the fast-neutron induced fission on ^{238}U target. On the other side, the application field, the study program concerned the prompt gamma emission in nuclear fission. Prompt γ emission in nuclear fission is one of the least understood parts of the fission process. Its study can give information on the partition of energy and angular momentum, and on the competition between neutron and γ emission during fission fragment deexcitation. Furthermore, information on prompt fission γ -ray emission has practical applications in nuclear reactors.

The dynamics of a heavy-ion collision, via the competition between deep-inelastic collisions, fusion and quasifission, depends on the complex interplay between various features such as the projectile and target composition and nuclear structure, energy and angular momentum dissipation in the approach phase, etc. Next, the decay of the formed compound remnant, by either evaporation or fission, is governed by poorly-known fundamental nuclear properties, including microscopic shell and pairing effects at large deformation, level densities, and nuclear viscosity.

6- Nuclear Astrophysics Studies:

Over the last decades, our understanding of nucleosynthesis and star evolution has been largely improved thanks to the research performed in nuclear physics, astrophysics modelling, astronomical observations which range from radio to gamma rays, cosmic rays, neutrinos and meteoritic composition studies. All these fields are in constant development: new telescopes and satellites open more and more windows on the cosmos, stellar modelling relies on ever-increasing computational power and nuclear physics takes advantage of new facilities (radioactive beams, …) and sophisticated detection systems.

Three nucleosynthesis types are identified:

- Primordial nucleosynthesis in the first three minutes after Big-Bang which led to the production of hydrogen and helium.
- Stellar nucleosynthesis; quiescent reactions which occur during the life of the star and provide the energy which stabilizes the star against gravitational collapse (hydrostatic equilibrium nucleosynthesis) and explosive reactions at the end of the life cycle of the star (supernovae) and in objects such as novae and X-ray bursters.
- Cosmic ray nucleosynthesis; spallation reactions of cosmic rays with the interstellar medium.

Nuclear reaction rates are vital ingredients in describing how stars evolve. The study of the nuclear reactions involved in different astrophysical sites is thus mandatory to address most questions in nuclear astrophysics. Experimental techniques for reaction rates determination lie in two main categories: direct measurements, in which the reaction of interest is reproduced, although the energy range is often much larger than the one in the stellar site; and indirect measurements, in which a different reaction is coupled with theoretical modelling to access the spectroscopic properties (Ex, J^{π}, decay widths…) of the involved nuclei and/or to get the cross section of interest.

Instrumentation for ALTO TANDEM beams

For the nuclear astrophysics research program, the Split-Pole spectrometer continues to be a very useful tool to study key nuclear astrophysics reactions which require the use of transfer reactions or inelastic scattering reactions (angular distribution measurements and excitation energy spectrum measurement with high energy resolution) to access with high precision the spectroscopic information (E_x, C^2S, partial widths...) needed to calculate the reactions rates. Moreover, in the last five years the coupling of this spectrometer to an array of double-sided-silicon strip detectors (DSSSD) in the reaction chamber has opened up opportunities to have access to the charged-particle decay branching ratios.

Otherwise, all the research program mentioned above rely on state-of-the-art γ spectrometer. Since 2008, several arrays have been installed at ALTO: ORGAM (based on French/UK LoanPool resources), MINIBALL for the MINORCA Campaign. The most recent, in 2017-2018, is the ν-ball hybrid spectrometer which combined high energy resolution High Purity Germanium (HPGe) detectors (from the GAMMAPOOL) with high timing resolution $LaBr_3$ (from the FATIMA collaboration or PARIS collaboration). The ν-ball project was strongly supported by IN2P3: 140 k€/3 years and 1 post-doctoral fellowship were given.

In addition, the neutron source LICORNE opening the possibility of performing spectroscopy (γ or neutron) of fast neutron induced reaction has been built. The reaction $p(^7Li,n)^7Be$, use in inverse kinematics, allows the production of naturally forward focused fast neutrons with energies corresponding to nuclear energy applications. The measured fluxes were about 10^7 n/s in a cone of 25° about the beam axis.

Physics Highlights with the ALTO TANDEM Beams

In the following are presented selected highlights of the ALTO TANDEM beams. The list is not exhaustive and intends to present the activity of each item/instrument presented previously.

“Multi-quasiparticle sub-nanosecond isomers in ^{178}W”
M. Rudigier *et al.*, Phys. Lett. B, **801**, 135140 (2020)

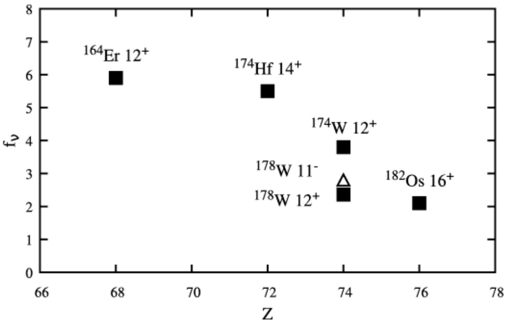


Figure 8 : Reduced hindrance values for $E2$ (filled symbols) and $E1$ (open symbol) transitions which go directly from 4 qp isomers, with the given K^π values, to their respective GSB, bypassing the 2 qp states. For the $E1$ transition, the Weisskopf hindrance has been divided by 10^4

This experiment was the first of the ν-ball campaign and authors performed the first measurement of the half-lives of $K^\pi = 11^-$ and 12^+ four-quasiparticle states in the even-even nucleus ^{178}W. The sub-nanosecond half-lives were measured by applying the centroid shift method to data taken with $LaBr_3$(Ce) scintillator detectors of the ν-ball array at the ALTO facility in Orsay, France. The half-lives of these states only became experimentally accessible by the combination of several experimental techniques - scintillator fast timing, isomer spectroscopy with a pulsed beam, and the event-by-event calorimetry information provided by the n-ball array. The measured half-lives are 476(44) ps and 275(65) ps for the $I^\pi = 11^-$ and 12^+ states, respectively. The decay transitions include weakly hindered $E1$ and $E2$ branches directly to the ground-state band, bypassing the two-quasiparticle states. This is the first such observation for an $E1$ transition. The interpretation of the small hindrance hinges on mixing between the ground-state band and the t-band.

“The ν-ball campaign at ALTO”
M. Lebois, Acta Phys. Pol. B, **50**, p. 425 (2019)

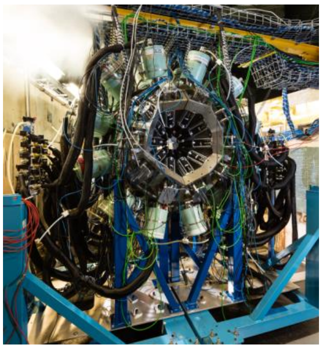


Figure 9: The ν-ball array setup

In 2017-2018, the ALTO facility hosted an experimental campaign using a γ spectrometer called ν-ball. this device is a hybrid array combining the excellent energy resolution of high purity germanium detectors with the excellent time resolution of new generation of scintillators LaBr3. Despite the short duration of the campaign 3200 hours of beam time distributed over eight experimental projects have been provided. A description of the progress of the campaign as a short description of the ν-ball array is be given.

“Statistical study of the prompt-fission γ-ray spectrum for ^{238}U(n, f) in the fast-neutron region”
L. Qi *et al.*, Phys. Rev. C **98** 014612 (2018)

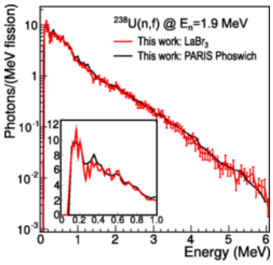


Figure 10: Averaged unfolded spectra with the time window ± 2.5 ns for the ^{238}U(n,f) reaction in logarithmic scale, as obtained for two different types of γ detectors. The error bar of PARIS is omitted for better visibility. The inset shows the region below 900 keV in linear scale.

Prompt-fission γ-ray spectra (PFGS) have been measured for the ^{238}U(n,f) reaction using fast neutrons produced by the LICORNE directional neutron source. Fission events were detected with an ionization chamber containing actinide samples placed in the neutron beam, and the coincident prompt-fission γ-rays were measured using a number of $LaBr_3$ scintillation detectors and a cluster of nine phoswiches detectors from the PARIS array. Prompt-fission γ-rays (PFGs) were discriminated from prompt-fission neutrons using the time-of-flight technique over distances of around 35 cm. PFG emission spectra were measured at two incident neutron energies of 1.9 and 4.8 MeV for ^{238}U(n,f) and also for ^{252}Cf(sf) as a reference. Spectral characteristics of PFG emission, such as mean γ multiplicity and average total γ-ray energy per fission, as well as the average γ-ray energy, were extracted. The sensitivity of these results to the width of the time window and the type of spectral unfolding procedure used to correct for the detector responses was studied. Iteration methods were found to be more stable in low-statistics data sets. The measured values at E_n=1.9 MeV were found to be the mean g multiplicity M_γ=6.54±0.19, total released energy per fission $E_{\gamma,tot}$=5.25±0.20 MeV, and the average γ-ray energy ε_γ=0.80±0.04 MeV. Under similar conditions, the values at E_n=4.8 MeV were measured to be M_γ =7.31±0.46, $E_{\gamma,tot}$=6.18±0.65 MeV, and ε_γ=0.84±0.11 MeV.

“Lifetime measurements in ^{100}Ru”
T. Konstantinopoulos *et al.*, Phys. Rev. C, **95**, 014309 (2017)

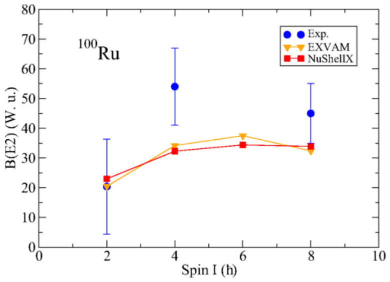


Figure 11: The comparison of the experimental transition strengths of the yrast band measured in this work (circles), to the ones calculated with EXVAM (triangles) and nushellx (squares)

The nucleus ^{100}Ru appears to be a good candidate for the E(5) critical point symmetry which describes the U(5)-SO(6) shape phase transition. To investigate this point with respect to the electromagnetic transition strengths, lifetime measurements of its yrast states have been performed using the recoil distance Doppler shift technique as well as the Doppler shift attenuation method with MINORCA. As a result, the lifetimes of the yrast 2^+, 4^+ and 8^+ states were determined. The deduced transition strengths are compared to the E(5) predictions as well as to the results of excited Vampir and shell-model calculations.

“Experimental Study of the ^{30}P(p,γ)^{31}S Reaction in Classical Novae”
A. Meyer et al., Nuclei in the Cosmos XV, 195-200 (2019)

The P(p, γ)S reaction is one of the few remaining reactions whose rate uncertainty has a strong impact on classical novae model predictions. To reduce the nuclear uncertainties associated to this reaction, we measured the P(He,t)S reaction at the ALTO facility. Simultaneous detection of the triton and proton decays from the populated resonances will provide the proton branching ratios. The astrophysical context of this work, the current situation of the P(p, γ)S reaction rate, the experimental set-up and the analysis of the single and coincidence events will be presented.

"Charged-Particle Decays of Highly Excited States in ^{19}F"
P. Adsley et al., Nuclei in the Cosmos XV, 271-275 (2019)

Neutron-capture reactions on ^{18}F in the helium-burning shell play an important role in the production of ^{15}N during core-collapse supernovae. The competition between the ^{18}F($n,p/\alpha$)^{18}O/^{15}N reactions controls the amount of ^{15}N produced. The strengths of these reactions depend on the decay branching ratios of states in ^{19}F above the neutron threshold. We report on an experiment investigating the decay branching ratios of these states in order to better constrain the strengths of the reactions.

ALTO ECOSYSTEM

A brief history of the ALTO platform

In the following, the major milestones of the ALTO construction are described:
- 1971: Tandem Commissioning
- 1987: Tandem Upgrade. The terminal High Voltage has been increased from 12 to 15 MV. Acceleration beam pipes have been changed.
- 1990: World First production and acceleration of high energy cluster beam.
- 2002: Official beginning of the ALTO as a R&D project.
- 2005: First electron beam extracted from the LINAC.
- 2006: First radioactive ion beam produced *via* photofission at ALTO.
- 2010: ALTO becomes a European Trans-National Access.
- 2013: The National Safety Agency delivers an Operating Authorization
- 2017: Beginning of ALTO 2.0 Project. Start of ALTO rejuvenation operation and prospects. - 2018: ALTO becomes an IN2P3 plateform.

ALTO complementarity with other platforms

Local Complementarity with Paris-Saclay other platforms

The ALTO facility was the first accelerator to accelerate cluster beams. In 2014, an EQUIPEX “named” ANDROMEDE was created. The acceleration capabilities of this new machine were more appropriate for the physics program associated to cluster physics. Naturally, this scientific activity migrated (and the AGAT experimental setup) from ALTO to ANDROMEDE during 2016.
The valorisation of TANDEM beam activity will be performed through an integrative network of facilities that belongs to IJCLab and Paris-Saclay in order to provide a global and comprehensive offer to industry – *cf.* Space ALTO project:
https://ipnshare.in2p3.fr/owncloud/index.php/s/DBTpwzuSBgc2IN7.

Complementarity at the National Level

Over the course of the years, ALTO has proven its capability to pursue a coherent scientific program, renew its beam offering to always be capable of competitiveness at any level. In addition, for the moment ALTO is the only French facility capable of producing radioactive neutron rich ion beams – which is an essential requirement for the DESIR physics program. For this reason, IN2P3 has now started to consider GANIL and ALTO as one national facility. Bringing the platforms together is one axis that is considered by IN2P3: common scientific strategy, common program advisory committee, …
As a matter of fact, the tight collaboration with GANIL is already a daily reality through the Master Project (MP) “Ions Radioactifs”. As part of the master project Radioactive Ions, the ALTO facility is involved in the development of target-source, ISOL target and molecular beam assemblies. Since 2016, two prototypes of the ISOL short target have been developed, the last of which was a great success. Compared to a conventional ALTO UC_x target, this new UC_x short target contains three times less uranium but releases fission products better. For example, for Cs nuclei with half-lives of less than 1 second, a gain factor between 5 and 8 was observed. For Cs R&D, a new prototype of the IRENA ion source, using electron impact ionization, has been developed. These developments lasted 24 months and allowed optimization of the ionization process, the thermal scheme and the mechanics. The adaptation of this source to the ISOL ALTO standard frontend is one of the important achievements of this study. For molecular beams, a new system for injecting gas into the target-source assemblies has been specially developed for the fluorination of lanthanides. With this new system, the fluorination process was again validated off-line by producing stable fluorinated lanthanide beams. Another part of this MP is the TULIP project which is dedicated to build a target ion source setup for the production of proton rich isotopes is ISOL technique using fusion-evaporation mechanism. Some of the preliminary steps and

measurements have been performed at ALTO. The TISS prototype will be tested on-line at ALTO within the next two years.

Complementarity at the International Level

As a European trans-national access facility, ALTO is already integrated in a network of installation around Europe (see below). This visibility and connection to other major facilities insure that the scientific activity is performed at a European level. For example in the context of ENSAR2 program, a work package named “BeamLab” and dedicated to the development of new beam production technique is performed in tight collaboration with the others ENSAR2 partners (ISOLDE, JYFL, SPES, GANIL,…). The sulphidation of radioactive tin beams has been successfully performed. For tin sulphidation, sulphur injection has been performed using the solid-state route and by developing a dedicated boron nitride evaporation furnace. To validate this process, an off-line experiment was carried out in October 2019 in the ALTO installation at the PARRNe separator. Following this experiment, the location of the sulphur evaporation furnace was redesigned for the on-line experiment in November 2019. During this online experiment, radioactive tin sulphide 132, 133 and 134 were well observed. It should be noted that tin 134 was not detected by the conventional technique but was observed by the sulphide route. Sulphidation will be applied soon for radioactive germanium nuclei.

The ALTO visibility

ALTO Trans National Access in the ENSAR & ENSAR2 European Integrated Activity

In 2012, the ALTO facility joined the ENSAR European framework. This grant has been created to subsidize either facilities or research and development projects for nuclear physics at the European scale. For facilities, the ENSAR grant agreement recognized several trans-national access facilities among which is the TNA7-ALTO. In that context, ALTO must provide of explicit number of hours of beam time to eligible experiments. Thanks to its success, the ENSAR framework has been renewed in 2016 to ENSAR2 — Grant Agreement number: 654002. Again, ALTO is registered as TNA7. Over the period of 2016-2020, the ALTO facility must provide 2539 hours of beam time. The beam hour is paid 103.40 €, providing a total amount of 262 532.60 € of access costs to the ALTO facility. Part of this funding is dedicated to cover travel cost and stays of experimentalist coming at ALTO to perform selected experiments. The actual distribution is 50 € per hotel night and 30€ per diem to cover meals.

After being accepted by the ALTO Program Advisory Committee (PAC), the spokesperson of an experiment can demands ENSAR2 financial support if the following rules apply:

- a spokesperson or a co-spokesperson belong to an Institution of a Member or Associated State (excluding those from French laboratories),
- Most of the users must work in a country other than France.
- Most of the users must belong to an Institution of a Member or Associated State

Then, the demand is examined by the ENSAR2 committee to validate the application. After receiving a positive reply, the spokesperson can start the administrative procedure to get ENSAR2 funding. After the experiment has been performed the spokesperson must return a report to the scientific coordinator of the facility that might be used by the E.U. to evaluate and audit the use of the ENSAR2 funding.

Beyond the access of users to funding, the person in charge of the work package must report three times over the course of the grant: 18-month, 36 month and at the end. In this report, a detailed distribution of the beam time, the number of users and some information about them (names, host institutions, country of origin, …), details about the application procedure must be provided. Of course, the facility highlight over the period must also be given. This report is peer reviewed at the end of the reporting period before being submitted to the European Commission.

ALTO within the former EURISOL Distributed Facility

The EURISOL project is together with FAIR, one of the major aims of the Nuclear Physics community in Europe. In order to reach the long-term goal of EURISOL a new European strategy is proposed with an intermediate and ambitious step: EURISOL Distributed Facility (EURISOL-DF), http://www.eurisol.org/eurisol_df/).

The EURISOL-DF membership will be open to all European RIB ISOL facilities. The core facilities of the new distributed infrastructure will be GANIL-SPIRAL2-ALTO, CERN-ISOLDE, INFN-SPES and ISOL@MYRRHA as a candidate for the future core member. The JYFL and COPIN will be the associated members of the EURISOL-DF consortium.

GANIL-SPIRAL2-ALTO will be considered as one integrated French facility. The EURISOL-DF initiative is coordinated by the EURISOL Steering Committee. GANIL-SPIRAL2-ALTO will have one representative with voting rights and one observer in the committee in order for the information to flow to and from both components (GANIL-SPIRAL2 and ALTO).

Early 2020, the EURISOL DF has been abandoned and is transformed into a “league” of facilities. But all the details before mentioned remains valid.

Projects for the ALTO facility future

Identification of ALTO future needs

This introspective work has been performed in 2018 at the start of ALTO 2.0 project. The scientific program of the facility for the future has been defined – *cf.* chp. "ALTO Scientific Activities". Four work-packages have been identified:

- *WP 1 - Physics at ALTO:* define clearly the physics program for the incoming years in articulation with the scientific opportunities created by the activity of other installations.
- *WP2 – Reliability:* identify all the technical needs to improve the platform reliability and pass from a R&D dedicated facility to a full-scale research facility.
- *WP3 – Environment:* define a common scientific strategy with GANIL/SPIRAL2. Ensure the complementarity of ALTO with other installation at local/national/international level.
- *WP 4 – Valorisation:* Develop the interface to industry and education. This is the Space Alto project.

All these WP will be fully detailed in the incoming ALTO White Book.

A special emphasis can be put on the development of RIB using sulfidation/fluoration technique which is essential to extract the refractory elements from the UC_x target that is now used at ALTO. This development is considered a one deliverable of the BeamLab workpackage of the ENSAR2 european program.

ALTO comparison with future platforms

As mentioned previously, ALTO profits from a "niche" activity (at the French level) based on the production of neutron rich fission fragment. The missing post-accelerator allows the facility to pursue a physics program in preparation of the scientific activity of DESIR.

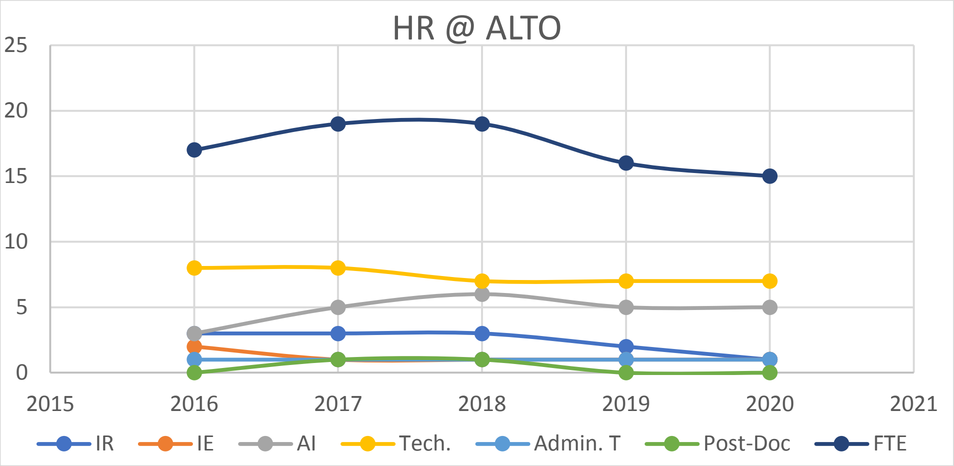
In addition, the LICORNE neutron source allowed IJCLab to develop skill and knowledge about neutron physics that will be exported to NFS.

Otherwise, researchers working at the ALTO facility are also pursuing research activities in other facility worldwide. Thus, the complementarity of ALTO with other platforms will naturally emerge. As a matter of fact, many setups now available for RIB based experiments prepare the future ones at DESIR: LINO as an initial step of LUMIERE, BEDO for BESTIOL and MLL-Trap for the DETRAP project.

ALTO Resources

ALTO Human Resources

The Human Resources Balance over the last four years is presented on the following graph:



For 2020, IN2P3 announced that it opens a “CDD IE” for separators, who is in charge of the lines for ISOL beams. An “IR” permanent position for targets production and R&D has also been opened.
In the future, to secure and make the valorisation activity reliable (at the level of exigence of industry), it will be necessary to find an FTE dedicated to this task only.

ALTO financial balances

The last four years ALTO financial balance is represented on the following graphe (in k€). For readability, it has been chosen to show running costs, Master Project “AP” for ISOL and Tandem beams and other sources. This table, (see next page) do not include any financial support given to external labs for ALTO projects.

Future ALTO financial model

In the context of ALTO 2.0 a large-scale facility rejuvenation has been planned. First some projects such as ALTO Front-End upgrade (switch to 60 kV extraction voltage, implementation of a robot for TISS, operation evaluated up to 100 k€), LINAC/TANDEM C&C upgrade, beam diagnostics, have been planned. Discussion is already taking place with IN2P3 representatives on that matter.
In the future, the development of the valorisation should be capable to cover the vast majority of the running costs. A discussion on how to finance the beginning of this activity is going on at the moment.

	2016	2017	2018	2019	2020
Running Costs					
IN2P3 dotation (M&O)	202	175	160	205	145
RP					
IPNO (labo)	12	29	32	26	74
ALTO	20	18	37,5	8	
Europe (ENSAR2, CHANDA)	50	50	50	95	71
Running Costs Total:	284	272	279,5	334	290
IN2P3 Master Projects					TBA
ISOL	149,5	84	128,4	46	
Tandem	23,5	102	103,5	35	
Space-ALTO					40
T&S			15	30	
IN2P3 Master Projects Total:	173	186	246,9	111	40
Total IN2P3:	375	361	406,9	316	
Other Sources					
ISOL (Labex P2IO+ SESAME & UPSud in 2018)	43,75	43,75	649,95	43,75	
Tandem					
TOTAL:	500,75	501,75	1176,35	488,75	330

APPENDIX

Annex 1: ALTO SWOT Analysis

SWOT Analysis performed for the ENSAR2 Impact Studies in 2018-2019.

Strength:

☐ Excellence and diversity of ion beams and scientific equipment,
☐ Interdisciplinarity and innovation
☐ Open access based on scientific excellence
☐ Local support on experimental areas and availability of competent technical service.
☐ Unique photofission ISOL based facility worldwide
☐ LICORNE neutron source
☐ Strong user community

Weaknesses:

☐ Limited beam time due to lack of operators,
☐ Conflict between the use of the electron linac and the SPLITPOLE mass spectrometer.
☐ Space available for RIB activities (no general purpose line)
☐ Actual design of beam lines limits some projects (needs of new front-end for LINO, Polarex, MLL-Trap,…)

Opportunities:

☐ Strong demand for valorisation of Tandem beam
☐ Strong partnerships with local Universities/Schools and companies,
☐ Increase of recruitement opportunities thanks to development of « Plan vallée » in Université Paris-Saclay framework
☐ Increase of financial support thanks to development of « Plan vallée » in Université Paris-Saclay framework
☐ Tighter collaboration with GANIL

Threats:

☐ Increase of administrative burden (Nuclear Safety Agency…),
☐ Decrease of permanent staff and increase of non permanent staff involved in the operation of the facility,
☐ Financial shortfall for running the facility.
☐ Aging of the accelerating devices (modulator)

Annex 2: ALTO user selection panel

Program Advisory Committee members:

Chairman of the PAC :
Richard F. CASTEN – WNSL, Yale University – New Haven – USA: richard.casten@yale.edu
Tandem-ALTO Scientific coordinator:
Matthieu LEBOIS – IPN Orsay – France: lebois@ipno.in2p3.fr
Facility chief engineer:
Abdelhakim SAÏD - IPN Orsay - France: said@ipno.in2p3.fr
Member:
Denis DAUVERGNE (CIMAP – France): dauvergne@lpsc.in2p3.fr
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