Status and activities of the LAFN (Laboratório Aberto de Física Nuclear)

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Abstract. A brief panorama is given about the status and the research activities of the LAFN - Laboratório Aberto de Física Nuclear (the “Open Nuclear Physics Laboratory”). The LAFN is an internal organization of the Nuclear Physics Department of the Institute of Physics of the University of São Paulo, São Paulo, SP, Brazil, which was created in the late 90’s in order to facilitate the participation of users from other institutions in Brazil or abroad. Presently the Laboratory has more than 70 registered users, most of them active in proposing and performing experiments with the 8MV Pelletron-Tandem particle accelerator, which is a mayor nuclear physics research facility in Brazil. The experiment proposals are evaluated by a project advisory committee. It is characteristically a University based facility, with abundant participation of students, and production of several MSc and PhD theses regularly. The organizational structure of the Laboratory, and the characteristics of the Accelerator and peripherals will be described, as well as selected topics of the ongoing research both on basic and applied nuclear physics, such as nuclear structure and reaction mechanism studies with stable and radioactive beams, and tests of irradiation damage and other effects on electronic devices. Presently, the LAFN is part of the INCT-FNA (“Instituto Nacional de Ciência e Tecnologia - Física Nuclear e Aplicações”), supported by several Federal and State institutions from Brazil.

1. Introduction
The main facility of the LAFN is the 8UD Pelletron-Tandem heavy-ion accelerator, developed by NEC – Nuclear Electrostatics Corp., and installed at IFUSP in the early seventies [1]. It is the only one of its kind in Brazil, and with its akin facility TANDAR [2] in Argentina, the only ones in Latin America. Presently its ion source is a multicathode SNICS (NEC) capable of producing ions from $^6$Li to $^{108}$Ag or, in principle, even heavier ions. Typically, energies of around 5 MeV per nucleon are used. The Experimental Hall has 7 beam lines dedicated to various experimental setups. Presently one line is
deactivated, and another is transporting the beam to the LINAC post-accelerator (under construction). The other lines are used for basic nuclear structure and reaction research, as well as physical applications. At the 90’s the LAFN was created as an organizational structure responsible for the maintenance of the Accelerator, and for making the facility available for users from inside or outside the University of São Paulo.

2. The LAFN organization
The organization of LAFN is defined in its statute, last revised in 2016. Its integral version is available at the Laboratory web site under the IFUSP website.

2.1. The Superior Council
The Superior Council is composed of the members of the Nuclear Physics Department (DFN) of IFUSP. It nominates the Director from a list of names provided by the Users Board.

2.2. The Director
The Laboratory Director administrates the budget and operations of the Laboratory for a mandate of 2 years, allowed one extension.

2.3. The Program Advisory Committee.
The PAC is composed of eminent nuclear physics researchers chosen by the Director, the Superior Council and the Users Board. It yearly evaluates the experiment proposals and allocates time of Accelerator use for each based on merit and technical feasibility. The approved projects are publicly available at the Laboratory website.

2.4. The Users Board.
The users board is composed of all graduate researchers which have approved experiments evaluated by the PAC in the last 4 years, and which manifests interest in composing the board. It elects its own President, and discusses any issue relevant for the research at the laboratory and proposes improvements to the Direction. Presently, about 75 users are officially listed from a variety of countries, including Argentina, Canada, Colombia, France, Germany, Italy, Spain, and USA.

2.5. The Technical Coordinator
Coordinates the operation of the staff distributed in the executive sectors of the Laboratory: Development and Maintenance (Ion Optics, Vacuum, Machine shop), Electronics, Target Making, Data Acquisition, Secretary, and User Support. The staff is composed of 11 technicians in total.

3. The facility and peripherals
The research equipment available for the LAFN users consists of the accelerator and peripherals installed at the Oscar Sala 9-floor building at IFUSP, São Paulo, SP.

3.1. The accelerator
The 8UD Pelletron-Tandem is an 8MV electrostatic Tandem accelerator developed by NEC, and described in [1]. Figure 1 presents an overall view of the facility. Originally, the voltage distribution along the accelerator tube and equipotential rings was made by corona needles. Near the end of 2010 the corona needles were substituted by passive resistors which improved a lot the reliability and stability of the accelerator by preserving the SF6 gas quality. Shortly after that, the steel contact blades
of the charging pulleys, which was causing erosion of the pellets and chain break downs, was eliminated. As a consequence of this, the original 8MV terminal voltage of the Accelerator has been routinely available ever since. Presently the analog control devices of the ion optics is being gradually replaced by digitally controlled devices (interfaced with PXI, with Labview). New constant current magnet power supplies of the mass and energy magnetic selectors were installed. The 32 cathode MC-SNICS provides the negative ions, accelerated to about 90 keV to be injected into the accelerator. The Carbon stripper foils at the terminal center are about 10\(\mu\)g/cm\(^2\) thick, and are produced by the Target Laboratory of the LAFN. Typical beam intensities of 100 nA to 1\(\mu\)A are available for the users at their scattering chamber, depending on the ion species. An updated list is available at the LAFN website.

3.2. The experimental hall lines
Presently 6 of the 7 beam lines at the experimental hall are operational and dedicated to special research lines, comprising different scattering chamber and detector arrays.

3.2.1. The RIBRAS system. The Radioactive Ion Beams Brasil (RIBRAS) system is dedicated to the production of radioactive ion beam (RIB) species [3,4]. It consist of two identical superconducting solenoids with a maximum magnetic field of about 6 T. The radioactive species are produced by an intense primary beam (usually \(^7\)Li) on a primary target (usually \(^9\)Be) and the secondary beam of interest is separated and purified by a system of slits and lollipops, and focused by the solenoids onto a secondary target surrounded by an array of silicon detectors. Typical RIB intensities of \(10^5\) particles/s can be produced. The reaction mechanisms of light weakly bound unstable nuclei are investigated with this system.

3.2.2. The Saci-Perere spectrometer. This is a gamma-ray spectrometer [5] composed of 4 GeHP detectors with Compton suppressors, with a total photopeak efficiency of about 0.5\%, and an ancillary system of phoswich plastic scintillators (\(\Delta E-E\) telescopes) covering about 83\% of the 4\(\pi\) solid angle of the sphere. It was designed for high-spin nuclear structure studies, but has also been used for reaction mechanism investigation by charged particle-gamma coincidence method [6].

3.2.3. The Enge Split-pole Spectrograph. This magnetic dipole spectrometer has a maximum field of 17kGauss, an acceptance angle of 2.7 msr and an excellent energy resolution of 1/2750 [7]. Its typically used for Coulomb-nuclear interference measurements and investigation of shape transitions and coexistence in mid-mass transitional nuclei [8].

3.2.4. The 30B multipurpose chamber. This is a 1 m diameter camera equipped with a goniometer for the positioning of particle detectors. Presently a particle detector telescope array (SATURN) is installed for nuclear reaction mechanism studies with stable weakly-bound beams [9,10].

3.2.5. The SAFIIRA line (0 degrees). This is the newest beam line built at the LAFN. Its set of beam scatterer/collimators allows for the production of a wide, low intensity uniform beam for irradiation of electronic devices. It is used for radiation tolerance tests as well as Single Event Upset and similar effects on electronic components and chips [11]. A large collaboration of many national institutions (CITAR project) is involved in this research, and has strategical importance for satellite/aerospace technology in Brazil.
3.2.6. The LINAC injection line. This line is intended for the injection of the Pelletron accelerated beam into the LINAC post-accelerator, under construction. Presently a scattering chamber after the superbuncher system is installed, which will allow for pulsed beam measurements. A LYSO(Ce) with Silicon Photomultipliers (SiPM) scintillator array [12], insensitive to magnetic fields, is being mounted in this line together with plastic scintillators for gamma-particle coincidence measurements dedicated to the study of nuclear reaction mechanisms with stable weakly-bound beams, and which can also be used with the RIBRAS radioactive beam facility.

![Diagram of Pelletron Tandem Facility of LAFN](image)

**Figure 1.** The 8UD Pelletron Tandem Facility of LAFN.

4. Statistical records

The simplest indicator of accelerator activity is the Pelletron chain hour counter. Figure 2 presents the number of hours of operation per year since 1980. The average value for this period is about 2300 hours per year. In spite of its age, there is no clear trend of reduction of activity of the Accelerator over the 40 year time span of the data, particularly considering the apparent recovery of the last two years.
The number MsC and PhD theses and of refereed articles published every year, with use of the LAFN equipment, is shown in Fig. 3. A change of pattern seems to have occurred around 1989, with a predominance of theses productions in the early periods, and a rather steady production of articles afterwards, with an average of 9 per year, with a standard deviation of 3. This rather stable production happened in spite of a reduction of more than 50% in University staff associated with experimental nuclear physics with accelerators which gradually occurred during the same period of time.

5. Recent research topics

In the last PAC meeting, held in October, 2018, 24 different projects were approved for a total use of 179 days of Accelerator beam with high priority, and 141 with low priority. The themes of these projects related to applied nuclear physics involve ion beam analysis of materials (by ERDA and PIXE techniques, -1 project each), irradiation with ion beams, such as of electronic devices (1 project), analysis and material modification (1 project), or development of instrumentation or experimental techniques (3 projects). Most of this research is important for aerospace technology and other engineering areas, and some for biology. The other projects are related to basic nuclear physics research, 10 of which with the use of radioactive beams (RIBRAS), and 7 with use of stable beams. Most of the basic nuclear physics research have great importance to astrophysics or to the general understanding of nuclear structure and reactions.

6. Final remarks

The LAFN has strategical importance for the field of low energy basic and applied nuclear physics in Brazil, and in Latin America to a large extent. Its structure, which allows for experiment proposals from external institutions from inside or outside Brazil, has motivated collaborations and helped to maintain an active production with use of the 8UD Pelletron Accelerator in its long lifetime, in spite of the funding instability which has accompanied its story. The recent association of the Laboratory to the INCT-FNA- “Instituto Nacional de Ciência e Tecnologia - Física Nuclear e Aplicações” - has helped with the basic maintenance of the equipment, and an indication of increase of activity has appeared in the last two years. There are perspectives of growth of the low energy nuclear physics
field at an international level in face of the recent theoretical and computational advances, as well as the large investments in accelerator and detection systems, mostly involving radioactive beams [13]. It is generally recognized that small and mid-size facilities such as LAFN are important for their specific programs, for the development of instrumentation and formation of the new generation of qualified researchers. It is hoped that the scientific community and society in general can recognize the importance of maintaining and improving such a structure in order to keep up with the challenges and discoveries that lie ahead in the development of nuclear science.

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