Perspectives for low energy reactions measurements at the new LEMA beam-line

L Acosta¹,²,*, E Chávez¹, L Barrón-Palos¹, E Andrade¹, DJ Marín-Lámbarri¹, J Miranda¹, ME Ortiz¹, F Favela³ and A Huerta¹

¹ Instituto de Física, Universidad Nacional Autónoma de México, Mexico City, Mexico
² Istituto Nazionale di Fisica Nucleare, Sezione di Catania, Catania, Italy
³ Instituto de Ciencias Nucleares, Universidad Nacional Autónoma de México, Mexico City, Mexico

E-mail: *acosta@fisica.unam.mx

Abstract. Towards the end of 2017, a new beam line was commissioned at the Laboratorio Nacional de Espectrometría de Masas con Aceleradores (LEMA) at Instituto de Física of the Universidad Nacional Autónoma de México (IFUNAM). Initially, LEMA was a 1 MV tandemron accelerator just dedicated to Accelerator Mass Spectrometry (AMS); nowadays, the new line adopted the main characteristics of the AMS system in a natural way: i.e., it has a high precision measurement of the beam energy and a very high and stable current (tens of µA) depending of charge state of each isotope. The precise low energy limit around 400 keV opens a window to study reactions in the region of interest for Astrophysics. At the same time, the LEMA beam-line allows to develop experiments combining nuclear reactions with AMS, as well the developing of all of kind of Ion Beam Analysis (IBA) studies. In this work the main characteristics of the line, the ancillary systems and the perspectives for low energy measurements for nuclear studies and applications are described.

1. Introduction
Traditionally, most of the facilities related with particle accelerators in Mexico are related with the Instituto de Física, UNAM, which presently has its main headquarters at Mexico City. Three low energy accelerators are placed at the Institute since more than 30 years. Most of the activities developed with them are related to applications for materials sciences, archaeology and a small part to nuclear physics. In 2013, as part of a big program for the construction of a number of National Laboratories promoted by the Science and Technology National Council (CONACyT), it was financed and commissioned a new accelerator: this new machine, called "Laboratorio Nacional de Espectrometría de Masas con Aceleradores" (LEMA) [1], was proposed to address studies related with the AMS technique, usually radiocarbon dating and the use of other radioisotopes for palaeoclimatological, geological, biological and environmental purposes [2].

In the last 6 years, the studies using radiocarbon have been consolidated at LEMA, at the same time, other radioisotopes as ²⁶Al [3] and ¹⁰Be [4] have started to used for different kind of studies. During the same period, the inclusion of a new beam-line (other than that devoted to AMS) to extract the high precision beam of the LEMA accelerator was proposed. Finally the new beam-line was implemented and commissioned at the ending of 2017.
In the following sections the characteristics of the new beam-line, as well of a number of ancillary systems devoted to nuclear and applied studies are described. Perspectives for new and present measurements will be as well mentioned.

2. LEMA beam-line description

The LEMA beam-line, as well as the accelerator were performed by High Voltage Engineering Europa B.V. (HVE). The line was mounted in the 0° port at the output of the accelerator tank, including a bending magnet to tilt the beam 90° in order to keep the line in parallel with that for AMS one. At the magnet output monitoring and optics systems were mounted with the aim to control the beam optics; after that, a multi-propose chamber was installed. The chamber is a cylinder of 400 mm radius and a heigh of 600 mm. It has 9 ports of different ISO sides and angles to place X-,γ-ray detectors and internal connections. All the vacuum (rough and high) systems as well of the beam parameters can be remotely controlled by a dedicated system provided by HVE. The beam-line mounted and the multi-purpose chamber can be seen in Fig. 1a and b respectively.

![Figure 1](image)

Figure 1. The new LEMA beam-line (a) Layout of LEMA-lines (top view); on the left the previous AMS line and on the right the new beam-line (bending+monitors+chamber). (b) Picture of the new LEMA beam-line where the multi-purpose chamber an all its accessories can be seen.

From the commissioning of the first beams at LEMA beam-line, protons from 500 to 2000 keV could be well produced, as well as $^{12}$C beams from 1 to 6 MeV, for instance. The first characterization of the beams produced in the new line provided an accuracy measurement of energy, with an uncertainty below 10 keV. During this first beam characterization could be reached currents of 82, 20.9 and 0.02 µA for $^{12}$C$^{2+}$, $^{28}$Si$^{2+}$ and $^{48}$Ti$^{3+}$, respectively. The
possibility to change the charge states depending the kind of nuclei, allowed to obtain for instance $^{28}\text{Si}^{+7}$, fairly increasing the nominal energy of the 1 MV machine. With the first RBS studies by using carbon and silicon targets and different energies of proton beams, it was possible to test the perfect correlation between the GVM reading energy of the accelerator and that fitted in the energy spectra. A detailed description of this characterization can be found in [5].

In addition the new beam line have been already used for PIXE studies. In this measurement were well identified X-ray produced by Sr, Y, Zr, Mb and Mo from a MicroMater thin film of compounds, all of them deposited on a thick Mylar substrate. Precise PIXE studies were carried out by using proton beam ranged from 1.335 MeV to 1.835 MeV, in 0.1 MeV steps. A detailed description of these studies can be found in ref [6].

3. Ancillary systems
In order to take the maximum advantage of the new beam-line, a complex system of silicon telescopes is been constructed. The so called SIMAS, by its meaning in Spanish, is a mobile system of high segmentation, which is composed of ultra-thin surface barrier detectors of 8 $\mu$m thickness (20 mm$^2$ of active area) and DSSSD of 20 $\mu$m (5×5 cm$^2$ active area and 16+16 strips) as a first stage and, thicker PIP’s and PAD detectors for the second stages (500 $\mu$m and 130 $\mu$m, respectively). In Fig. 2a the present telescopes of SIMAS are shown.

The system allows to discriminate in charge and mass low energy light particles as protons of 2 MeV and alphas of 4 MeV by using $\Delta$E-E technique. The whole array is managed with a digital data acquisition system composed and MBS system, performed by GSI-FAIR electronics team [7]. FEBEX system directly digitizes preamplified signals in the range of ±1 V, with a maximum rate of 65 Ms/s, excluding the amplification step of the conventional data acquisition systems, doing the electronic chain more compact and economic. The SIMAS array modularity will allow to use either the whole or partially system to perform experiments not just in LEMA beam-line but also in many other facilities dedicated to nuclear studies.

As a complement of the beam-line, previously was performed at IFUNAM the Supersonic Gas Jet Target (SUGAR), a complex system of differential vacuum and power pumping with the capability to produce a thin windowless gas target of $1 \times 10^{18}$ atoms/cm$^2$, which eventually can be coupled to any beam-line to take advantage of a large variety of pure gas targets, to explore reactions with difficult access when solid targets are used. The commissioning and first results of the SUGAR array are well described on ref. [8]. A layout of the SUGAR system can be seen in Fig. 2b.

4. Perspectives for nuclear studies
One of the first measurements using the new beam-line was related with the tolerance of thin targets to a high intensity beam. The important of this kind of experiments is associated to the targets to be used for the main measurements of the NUMEN Project [9], a large international collaboration dedicated to study double charge exchange reaction mechanisms, in order to provide experimental information to model matrix elements for the neutrinoless double beta decay. The main experiments of NUMEN will imply high beam intensity for several days, hence it is very important to have target systems able to bear such a extreme conditions.

The beams for LEMA were ideal to perform this kind of test, where the heating in target was monitored by using thermo-cameras across of germanium windows transparent to the infra-red. The analysis of the results using $^{12}\text{C}$ beam at 10 $\mu$A are still in progress. In Fig. 3 can be seen the increase of temperature in target (without cooling) and the target cooler holder designed for the experiment.

On the other hand, by using the low energy proton beam could be possible to combine AMS side of the LEMA lab with reaction production of radioisotopes, to study low cross sections...
Figure 2. Ancillary Systems: (a) Telescopes of the SIMAS array. The Surface Barrier + PIP’s telescopes (top); The DSSSD + PAD telescopes (bottom). See the text for details. (b) The SuperSonic Jet Target SUGAR layout. See the text for details.

of astrophysical reactions. Such is the case of the $^{25}\text{Mg}(p,\gamma)^{26}\text{Al}$ reaction, where the $^{26}\text{Al}$ can be produced by irradiating a Mg target and later to make a radiochemical separation of Al to produced cathodes that may be studied with the AMS system [10]. Previous successful studies were developed using AMS technique at LEMA with the reaction $^{28}\text{Si}(d,\alpha)^{26}\text{Al}$ [3, 11]. These measurements were carried out using deuterium beams from 1 to 2 MeV produced by other local accelerators at IFUNAM and National Institute of Nuclear Research (ININ). The new line will allow the development of this kind of accurate measurements using the same accelerator to carry out the irradiation and later the AMS study.

Finally, again taking advantage of the high intensity found for $^{12}\text{C}$ beams, reactions as the famous $^{12}\text{C}+^{12}\text{C}$ one [12], can be approached. With the help of SIMAS array, the protons and alphas resulting from the open channels of such reaction above 1 MeV may be discriminated with thin silicon telescopes as such of SIMAS. Our first attempt with the 4 small telescopes attained promising results. In further measurements the detection solid angle will be drastically increased by using the additional DSSSD telescopes of SIMAS, which worked properly in a very recent experiment performed with radioactive beams at TwinSol Lab (Notre Dame USA).

5. Conclusions
In this work the main characteristics of the new LEMA beam-line were presented. The commissioning of the line and the first characterization of beams show a good behaviour of the new device for the production of precise beam with high intensities. Line was tested for RBS and PIXE techniques achieving good results. In parallel for nuclear measurements perspectives, the new beams have been used to test target tolerance (as a tool for biggest facilities) and to probe nuclear reactions of astrophysical interest. Ancillary systems such as the SIMAS array and the SUGAR system are increasing the capabilities of the line, regarding limits of measure and gas target production. With the new line and its ancillary systems, the LEMA lab is now ready to be part of the nuclear facilities available for nuclear and applied studies at low energies around the world.
Figure 3. Experiment for target tolerance to high beam intensity. (a) The cooling target holder performed for the experiment. (b) Pictures taken with a thermo-camera showing the heating of target due to the beam interaction for 44°C and 99°C without cooling (see the text for details).

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