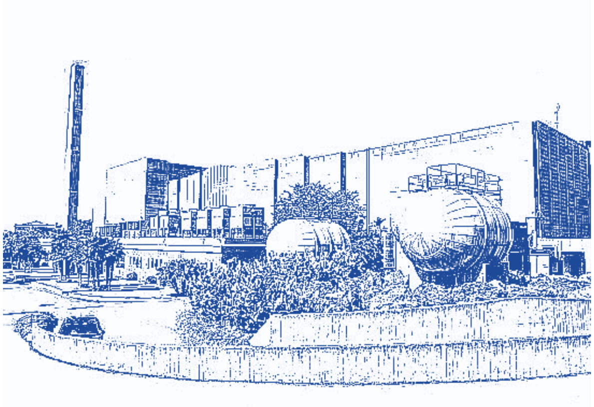

Summary of the LNS Users Meeting 2021

Laboratori Nazionali del Sud, Catania
November 15th, 2021

Foreword

Dear LNS Users,
here you can find the summary of talks and main speeches that were given at the 2021 LNS Users Meeting. It was a very rich edition, with around 80 participants in presence and more than 40 participants remotely connected. The meeting was divided into two main sessions: in the morning session, after the welcome address of the Director and the Coordinator of the Users Committee, we had talks given by the heads of divisions, the responsible of the POTLNS project, and the coordinators of the INFN research lines at LNS. Starting from this edition, we invited a researcher of an experiment based at LNS, to discuss its main results and future perspectives; this year we started with the PANDORA experiment. In addition, we asked to M. Colonna, spokeperson of the EURO-LABS initiative[1], to give further details on the status of this important project for the LNS users.
The afternoon session was fully dedicated to discussing new ideas and initiatives that could improve the research activities at LNS with the use of the new beams available after the upgrade phase. The session was divided into three Sections, each one dealing with the main areas of research that will be impacted by the LNS upgrade: (I) *Radioactive beams and new tandem beams for nuclear structure and dynamics,* (II) *high intensity stable beams at medium energies* and (III) *new possibilities on applied physics.* After a general introduction of the Chair of each Section, we had several solicited talks by researchers from the LNS, form other INFN divisions and from other research institutes. The main ideas and experimental needs suggested by the researchers all along the day were collected by the Users Committee and are summarized at the end of these minutes in the form of keywords and keynotes. For the sake of completeness, we reported also some more extended summaries of contributions that have been sent to us by some of the speakers in the afternoon session.
We warmly thank all the colleagues that contributed to the meeting, with the hope that this event could represent a turning point after two very difficult years of pandemic.
With our best regards of happy new year.

Catania, January 2022

The LNS Users Committee

Ivano Lombardo (Coordinator)
Chiara Guazzoni
Lorenzo Manti
Tommaso Marchi
Sara Palmerini

[1] At the time of writing of these minutes, we had the important news that the EURO-LABS initiative was funded.

MINUTE OF THE LNS USERS MEETING
(LNS, Catania, 15/11/2021)

Welcome address from the Director (*Santo Gammino)*

The Director welcomed all the participants and was happy to see in person a broad audience to a meeting. It was the first meeting organized in person at LNS after the starting of the pandemic.
The re-starting of the LNS activities after the first lockdown (03/2020 – 06/2020) was immediate and implied the difficult decision to close the experimental activities at LNS on June 2020, to start the LNS upgrade activities. There was a worsening of the pandemic in Fall 2020 – Winter 2021, but this fact did not impact on the upgrade activity. There were some problems with the suppliers of some orders related to the LNS upgrade, that are in phase of resolution.
Some possible (and tentative) dates for the restarting of the activities after the upgrade phase are the following: access to the experimental areas, with all the services available, IV quarter 2022; tandem beam to the users, I quarter 2023; first extracted beam from the CS, III quarter 2023; CS beams to users, IV quarter 2023. There are some critical points connected to the LNS upgrade and related to turnover that should be solved with some ongoing competitions to hire new people.

News from the LNS Users Committee (*Ivano Lombardo*)

The Coordinator of the LNS UC welcomes all the participants, especially the colleagues coming from outside Sicily: it was a clear and beautiful signal of rebirth after two difficult years of pandemic. The coordinator acknowledged the previous UC and the immediate past coordinator, G. Politi, for their assistance and help in the handover phase. After describing the structure of the meeting, the coordinator illustrated the activities done by the UC from 02/2021 to now. They were mainly related to: (I) the fulfilment of the GDPR rules on the mailing lists; (II) the participation to the surveys on activities of interest for the users in the context of the EURO-LABS initiative; (III) the participation in the organization of the mid-term plan meeting on Nuclear Physics in Italy; (IV) the discussion with the Director and the responsible persons of the POTLNS project on a possible new multi-purpose experimental area, available to the users, where fragmentation beams and/or high intensity beams could be transported; (V) the starting of a discussion on the possibility of developing new acquisition systems for the LNS community.

Accelerator's activities and perspectives at LNS (*Luigi G. Celona*)

The Coordinator of the Accelerators division at LNS illustrated the status of the accelerators and ionic sources at LNS, listing all the available beams that have been already delivered in the past. He also discussed the recent achievements in delivering batch-mode beams of 10Be with Tandem, having a purity of 99.9%. Then, he discussed the status of the NESTOR project, i.e. the development of a source of noble gasses to be coupled with the Tandem accelerator. On this side, the first test of the source has already been performed at the 450 kV platform: the results are encouraging, but some revision of the extraction and transport optics will be done to improve available beam current. Moreover, in the next months, the maintenance of the platform and of the Tandem itself will continue. Concerning the CS status, the new extraction system based on stripping has been discussed: it will allow the production of intense beams after the POTLNS upgrade. Then, the coordinator discussed the status of the ECR sources SERSE and CAESAR. SERSE will serve as the source for the intense beams at LNS, but a review of the cryogenic system and a robust commissioning of the main subsystems of the source is required to ensure the operational reliability required in view of the high intensities required by the CS-upgraded. Moreover, the entire axial injection line is under refurbishment (dipoles, diagnostics, focusing elements, buncher and chopper) to permit an efficient transport of the produced beam to the CS. Finally, the CAESAR source can continue to provide the less critical beams in the first operational years.

Research activities at LNS *(Aurora Tumino)*

The Coordinator of the Research division at LNS provided a general overview of present and future research activities at LNS, several of which were the subjects of dedicated presentations. Then, she moved to introduce the activities within the User Service, the Scientific Information Service, the Computing Service and the forthcoming Service for the Development of Experimental Equipment and Apparata. The aim of this last service will be to assist and support the design, construction and testing of new experimental equipment; it will take care of R&D, scientific and technological aspects. Important activities within the User Service are linked to the support of the Catana, Landis and Lara laboratories for applied physics. The Laboratory of chemical-physical techniques, specialized in the production of targets and other chemical materials, has been recently equipped with a new machine for the target thickness measurement. The Laboratory of electronics and detectors is very active in giving support to the several experimental groups that carry out research activities in nuclear physics at LNS. It is also strongly involved in the KM3NET project with the important tasks of integrating the Detection Units at the TestSite in the port of Catania and of thermal analyses of the electronic boards. Finally, the Research division is strongly involved in the POTLNS project, in particular with the activities connected to the improvement of existing experimental areas and related facilities (e.g., the focal plane of MAGNEX), to the development of new experimental areas for users as well as of a state-of-the-art diagnostic system for the new radioactive beams produced in-flight.

Status of the special project POTLNS *(M. Musumeci, P. Russotto, A. D. Russo)*

The Responsible of the POTLNS project (M. Musumeci) started discussing the rules of the financing related to the project. By July 2021 the contracts for 96% of the PON tenders have been signed. There are only two large tenders remaining, both outside the PON financing. All the tenders related to sub-projects (e.g., liner, stripper, FRAISE line, etc.), excluding the superconductive magnet, are about on time and, in any case, do not represent a bottleneck for the main project. A big issue is represented the superconductive magnet delivery. To avoid delays, INFN is putting he maximum effort to reduce the scheduled delay. Considering all the points here discussed, now, it is possible to estimate the first extracted and delivered beam for user by the end of 2023.

The responsible of the FRAISE project (P. Russotto) discussed the status of the fragment separator and the production target for the new facility at LNS. He discussed some interesting perspectives on the production of very intense radioactive beams with primary beams of ^{12}C, ^{18}O, ^{20}Ne and ^{40}Ar. Then he discussed the activities on the development of a new tagging system for CHIMERA with the use of SiC detectors.

Finally, the responsible of the update of the CS accelerator (A.D. Russo) discussed the new extraction system of the CS, that will be based on stripping. Calculations of energy and intensity of the high-power beams have been done for cases strictly related to the NUMEN activities, but they could be extended to other physical cases, especially under suggestions of users. After showing the details of the FRAISE line, then he discussed the very important opportunity of having at least two new experimental end-stations for high intensity beams: one in the region of the ex CICLOPE hall, and a second in the region of the ex zerodeg hall. In fact, a zero degree exit of the second dipole of FRAISE line allows the connection of the FRAISE line to such new experimental halls. There could be in principle also the possibility of having at least a beam pipe branch in the ex 20deg hall.

Theoretical activities supporting the experiments at LNS *(D. Gambacurta)*

The Coordinator of the Theoretical Group, D. Gambacurta, discussed all the activities supporting the experimental research at LNS. Within the INFN CSN IV (theoretical physics) there are two initiatives mainly involved in the physics of LNS: MONSTRE (MOdeling Nuclear STructure and REactions) and SIM (Strongly Interacting Matter at high density and temperature). Research activities strongly linked with experiments at LNS involve the study of: collective nuclear excitations (especially in neutron-rich and exotic nuclei); the EoS of asymmetric matter (symmetry energy) and modelling of neutron stars; Charge Exchange Excitations (Gamow-Teller, Fermi, etc,); Beta Decay (single and double, with or without neutrinos); Proton-Neutron pairing in nearly symmetric nuclei; dynamical evolution of nuclear reactions at Fermi energies; direct reactions (transfer, charge exchange, probing spin-isospin channel); fragmentation reactions, also for medical applications; Impact of EoS on nuclear reactions; Reactions of astrophysics interest (light systems, cluster structures). Then he discussed some examples of recent achievements on the low-lying dipole response of the neutron rich ^{68}Ni nucleus, monopole and quadrupole modes in Mo isotopes, inspection of the mechanism of double charge exchange in heavy ions and reaction dynamics with Boltzmann-Langevin approaches. All such works are immediately linked with the experimental activities that will start after the POTLNS phase.

Astro-particle physics at LNS (*Simone Biagi)*

The Coordinator of the Astroparticle Group, S. Biagi, discussed all the activities related to the experiments on astroparticle physics involving LNS researchers (KM3NET, DARKSIDE, NU@FNAL, VIRGO). In particular, he focused on the very important progresses of the KM3NET experiment, that is mainly based at LNS. The KM3NET experiment is subdivided into two facilities: ORCA (in France, near Toulon) and ARCA (Capo Passero, Italy): both are huge detectors, mainly based on PM tubes, surrounding a large volume (1 km^3) of sea water to detect the Cherenkov light due to neutrinos coming from different sources. In details, the ARCA site is mainly involved in the study of high energy neutrinos for multi-messenger astrophysics, dark matter studies and neutrinos from supernova explosions. The main features of ARCA are the presence of two main Building Blocks, made by 115 Detection Units (DUs) each one, interspaced by 90 meters. There are 18 Digital Optical Modules (DOM) per DU, and they have been assembled mainly at LNS; inter-DOM spacing is 36 meters. The power supply and data traffic from detectors to the laboratory is given by 2 Main Electro-Optical Cables (MEOC) for connection to shore of a network of 9+8 junction boxes and inter-link cables. All these parts of the detectors, and the deployment of detectors in the Mediterranean Sea, have been made with a fundamental contribution of the LNS researchers and technicians. The first results of ORCA show the presence of neutrino oscillations, while a strong characterization of the ARCA detectors clearly pointed out a strong sensitivity in the detection of neutrinos from Core Collapse SN. The deployment phase will continue also in 2022.

The DarkSide experiment at LNS is mainly linked to the ReD project, whose goals are the demonstration that a LAr TPC has a potential sensitivity to the direction of Ar recoil in dark matter studies. The collaboration was able to obtain good results on such aspects thanks to the use of neutron beams available at LNS. Researchers of LNS contributed also to the DUNE and SBN experiments on neutrino physics at FNAL and have also a strong participation in the VIRGO and ET projects on the detection and analysis of gravitational waves.

Nuclear Physics at LNS *(Marco La Cognata)*

Nuclear physics is a pivotal research topic at LNS since its foundation. The activities discussed by the Coordinator, M. La Cognata, are mainly linked to the research of the CHIRONE, NUMEN, ASFIN, n_TOF and NUCL-EX experiments, which are those mostly using LNS facilities to carry out their research program. Since many presentations already discussed about the CS status, a special emphasis was put in evidencing the paramount importance of the Tandem accelerator in the research activities: the forthcoming updates of this accelerator, with the availability of noble gas beams and of new radioactive beams in batch-mode, will open a broad spectrum of experimental opportunities.

The CHIRONE collaboration has used the CHIMERA and FARCOS arrays for several types of investigations both with Tandem and CS, ranging from nuclear dynamics, the nuclear equation of state, nuclear structure and astrophysics. In recent times the collaboration used CHIMERA also for gamma detection in the study of the structure of ^{12}C states; there are also projects to detect neutron and charged particles with a single hodoscope. The NUMEN collaboration has recently performed several consistent studies (both on the experimental and theoretical sides) of all the reaction channels competing with the double charge exchange, to obtain a reliable description of the reaction mechanism and structure of this mechanism, at the basis of the NUMEN project. In parallel, all the activities on the update of the MAGNEX spectrometer (e.g., the use of THGEM for the focal plane detector) for the post-POTLNS phase

are currently ongoing. The ASFIN collaboration has recently made several experiments with Tandem beams by exploiting the THM to deduce the S-factor for astrophysical relevant reactions and also by using batch-mode beams for studies on clustering in light nuclei. In 2021 the collaboration performed studies on reactions of the Mg-Al cycle and on the structure of ^{14}C via the ^{10}Be+alpha scattering in inverse kinematics; the collaboration is also involved in the use of lasers for studies in nuclear astrophysics.
The activities of the n_TOF collaboration at LNS are related to the analysis of data of (n,γ) reactions useful for nuclear astrophysics and applications and to the development of complex detection arrays able to detect charged particles in such an hostile environment. An example of the reactions that could be studied in the future is $^{16}O(n,\alpha)^{13}C$, interesting for the *s*-process.

Applied physics at LNS (*Giuseppe P. Cirrone)*

The talk on the activities of applied physics at LNS was given by the former Coordinator, G. Cirrone. There are many activities on this side: biophysics research with in-vivo and in-vitro experiments, irradiation studies, improvements, and research on proton-therapy for cancer treatments, developments of codes for applied physics (as GEANT4), non-destructive analyses on artworks.
Several irradiation studies and various test points have been used for radiobiology and other applications; a peculiar project, ASIF, is operative since 2017 to support ASI in irradiation studies for space applications. On the radiobiologic side, the availability of an in-vivo and in-vitro laboratory allows performing delicate experiments on irradiated cells that are unique, since it is difficult to find facilities coupling such laboratories close to irradiation points. In this respect, such facilities are a catalyst for several international collaborations lead by LNS. LNS researchers are strongly involved also in the development of the GEANT4 code and in promising collaboration with ESA. Furthermore, in the last years they continued their studies on the effectiveness of the boron proton capture therapy, on the use of antiproton beams for cancer treatments and of biologic irradiation of cells in flash conditions.
From the cultural heritage side, in 2021 the LNS researchers have performed XRF analyses on important paintings by Raffaello Sanzio at the Capodimonte museum of Naples and on an important papyrus from the Museo Egizio in Turin. A strong activity has been also performed on the characterization and development of SiC detectors for application in the field of dosimetry, micro-dosimetry and diagnostic of laser-driven beams. A Marie Curie individual fellow has been funded to G. Petringa in this field.
An interesting perspective, the I-LUCE facility (INFN-Laser Induced particles acceleration), on the use of an intense laser beam for accelerating protons, has been discussed: this initiative would involve several physics domains (e.g., plasma physics, cultural heritage, material analysis, test of fundamental physics, nuclear astrophysics in stellar environment, studies of fast-ignition processes for energy production) and could represent an interesting opportunity for LNS users.

PANDORA: status and perspectives (*D. Santonocito)*

D. Santonocito made an overview of the PANDORA experiment, and a timeline of the future activities. The main aim of the PANDORA experiment is the study of the decay of radioisotopes in a plasma that can simulate specific stellar conditions. The idea is to use a plasma trap where ion species are confined by a magnetic field and to map the dependence of beta decay rates as a function of plasma temperature and density. Important variations in the decay rates are in fact expected due to the high degree of ionization of radioisotopes in the plasma which opens a new decay channel represented by the bound beta decay. The decay will be tagged detecting the gamma-rays emitted by the daughter nuclei, using an array of 14 HPGe detectors placed around the trap. For the first experimental campaign Galileo detectors will be used thanks to a Collaboration Agreement signed with GAMMA experiment which will lend us the detectors up to the end of 2025. Three physics cases have been selected for the first experimental campaign: ^{176}Lu, ^{94}Nb and ^{134}Cs. Other research lines include the study of plasma opacity in kilonovae. The experiment is expected to perform a complete characterization of the plasma within 2023, the commissioning of the trap coupled to the HPGe array in 2024 and to start the first experimental runs in 2025.

Status of the EURO-LABS initiative *(M. Colonna)*

EURO-LABS is a consortium of 39 Research Infrastructures: 15 for Nuclear Physics and 24 for High Energy Physics, involving laboratories working on nuclear experiments, accelerators and detectors. The main aims of this project are: (1) to provide a major fraction of the large community of users with efficient access to the available resources; (2) to foster the sharing of knowledge and technologies across scientific fields, for conducting high impact research; (3) implementation of good practices for data management and activities relating to targeted service improvement at research infrastructures; (4) providing broad and focused joint training activities; (5) to build a super community of sub-atomic researchers and the associated technical staff. This proposal brings together for the first time in Europe the three communities engaged in Nuclear Physics and accelerator/detector technology for High Energy Physics. The budget requested from the EC was 14.5 MEuro.

Note added in proof: the LNS Users Committee is happy to announce that the EURO-LABS initiative was supported by the EC. We congratulate Maria Colonna (LNS) for her important contribution to the success of this initiative!

Special session: "New possibilities at LNS for the **next decade"**

Topic I: ***Radioactive beams and new tandem beams for nuclear structure and dynamics***
Chair: ***Josè-Javier Valiente Dobon*** (Laboratori Nazionali di Legnaro, Italy)
Contributions by: *G. Cardella* (INFN-CT), *A. Gottardo* (INFN-LNL), *L. Lamia* (Univ. CT), *P. Russotto* (INFN-LNS), *M. Mazzocco* (Univ. PD), *E.V. Pagano* (LNS), *S. Piantelli* (INFN-FI), *S. Pirrone* (INFN-CT)

Topic II: ***High intensities stable beams at medium energies***
Chair: ***Emanuele Vardaci*** (Università Federico II, Napoli)
Contributions by: *D. Carbone* (INFN-LNS), *G. Casini* (INFN-FI), *M. Cavallaro* (INFN-LNS), *A. Pagano* (INFN-CT), *M. Papa* (INFN-CT), *S. Valdrè* (INFN-FI)

Topic III: ***New possibilities on applied physics***
Chair: ***Gaia Pupillo*** (Laboratori Nazionali di Legnaro, Italy)
Contributions by: *F. Cammarata* (CNR), *C. Ciampi* (INFN-FI), *G. Cosentino* (INFN-LNS), *D. Mascali* (INFN-LNS), *G. Petringa* (INFN-LNS), *A. Trifirò* (Univ. ME)

KEYWORDS FROM USERS

In the following, the LNS Users Committee reports a list of keywords or keynotes on future improvements of the LNS facilities that could have a strong impact on future research activities of users. They have been collected during the discussions in the morning and the afternoon sessions. For the sake of completeness, in the following paragraph we include some further information on some proposals discussed in the afternoon and sent us by the users. The following keywords and keynotes are randomly reported.

- Have the FRIBS beams in the *measurement point* 2
- Prepare a reaction chamber of at least 250×120 *cm* dimensions, with operating vacuum values of the order of 10^{-6} mbar, in the *measurement point* 2
- Make efforts to have Tandem pulsed beam
- Make efforts to have noble gas beams at the Tandem
- Make efforts to have isomeric beams with the Tandem
- Explore the possibility of having a hydrogen and deuterium feeding and purge system allowing the use of hydrogen target in the *measurement point 2*
- Explore the possibility of using laser sources for measurements of nuclear cross sections
- Extend the collaboration already in place with the ISOLpharm project on preclinical in vitro and in vivo studies to the LARAMED collaboration, pending that these studies can be conducted at the LNL in collaboration with the University of Padua and the Veneto Oncology Institute (IOV)
- Make detailed transport and purity checks of stable intense beams of mass between 40 and 130, beam currents on targets> 120 particle-nA, energies between 15 and 35 MeV/u
- Improve the availability and quality (in terms of stability, intensity and focusing) of Tandem (few MeV/nucleon) and CS (10-40 MeV/nucleon) beams of Ca and Ni isotopes, making accurate checks on their purity
- Put the FRIBS line in LISE ++ framework
- Radioactive light ion beam production for reactions with protons at near Coulomb barrier energies in batch mode
- Availability of heavy ion beams as ^{82}Se, ^{136}Xe and ^{160}Gd at 15 to 25 MeV/nucleon
- Have an extra output of the LN2 – PANDORA system at *measurement point* 2
- Option for subnanosecond pulsed beam (500ps FWHM)
- Improve the availability of beams of various isotopes of Ar, Ni, Kr, Sn
- Improve and, if possible, extend the variety of batch-mode beams
- Make calculations on the extraction yield of Ca, Ti, Fe, Zn intense beams (2-3 kW) from the CS with the new stripping method, especially in the lowermost part of available energy (10 MeV/nucleon)
- Make dosimetry studies on high intensity beams (2-3 kW) on the new measurement points 1, 2
- Investigate the possibilities for a gaseous (or similar) beam degrader at the beginning of the FRAISE line to degrade and purify medium mass intense stable beams
- Try to reactivate the old LNS Time of Flight spectrometer, with its sliding seal vacuum chamber

SOME FURTHER DETAILS ON INITIATIVES SUGGESTED BY THE USERS

New experiments with in-flight radioactive beams

G. Cardella (INFN-CT)

Among the things I presented, I would like to point out the request to take new measures by taking advantage of the higher intensity of the fragmentation beams produced with FRAISE in the framework of the activities undertaken with CHIMERA in recent years. In particular, we would like to continue to make measurements in search of exotic clusters observed in the breakup of nuclei far from the stability valley. These are experiments that continue the line of activities undertaken with the UNSTABLE and CLIR experiments in search of those states in which alpha particles and neutrons bound together form exotic clusters such as ^{6}He or even in search of even more exotic clusters such as ^{9}Li. We will propose the CLUB experiment to be used for the commissioning of the FRAISE facility to the PAC. In fact, this is one of the most used beams with FRIBS, and is in principle available after the upgrade of the CS. We would also like in the next few years to extend the topic with other beams by exploring the Beryllium chain up to ^{14}Be, of Carbon possibly up to ^{18}C and of oxygen at least up to ^{20}O, developing and using ^{22}Ne as primary beam as well.

A second opportunity is to continue the study of the gamma decay of excited pygmy resonances with both scalar and vector probes in unstable nuclei. Apart from the ^{68}Ni study, which should also be completed with the study of the isovectorial probe (Pb or Au targets) (proposal pygmy2 postponed for covid), it would be interesting to explore medium-light nuclei using presumably available beams such as those generated by ^{40}Ar (^{38}S, ^{34}Si, and nearby isotopes) and also going to even lighter nuclei such as the aforementioned O20 or heavier such as ^{46}Ar if a primary beam of ^{48}Ca will sooner or later be available. It will be necessary to use scalar probes such as ^{12}C, isovectorial probes such as ^{208}Pb as a target, and it is also interesting to explore the resonance population with an intermediate probe such as protons to verify the effect of the proton spin on the resonance population.

I also pointed out in some interventions made during the meeting the need to be able to use tandem beams with FRAISE for example to produce isomeric beams such as that of 26Al (starting from a 26Mg beam) in reactions on hydrogen targets. Another path to be explored complementary to that of fragmentation is the production of unstable beams of low energy of astrophysical interest. These beams will certainly also be needed for the first FRAISE tests pending the availability of CS beams.

We are obviously also very interested in the use of Tandem beams from the new source of noble gases, especially for the use of alpha beams, with which we could propose an extension of the study already carried out on the decay of the state of Hoyle and neighbouring states in 12C.

As far as beam diagnostics are concerned, it is essential for us that the laboratory devotes significant resources to the development of diagnostic systems for the transport of radioactive beams to which we will obviously also contribute. The contribution of the laboratories will be essential for the integration of diagnostics in transport systems that are as automated as possible to make the selection of beams faster, safer, and easier, as already reported in various initiatives.

As for the CS beams of high intensity (at least 0.5-1 kW) to be developed, as mentioned above, we would be very interested in beams of ^{70}Zn to produce ^{68}Ni in beams of ^{22}Ne, ^{26}Mg, for the development of new fragmentation beams. in the oxygen and carbon chains. The ^{54}Cr beam also seems interesting as a possible alternative to the expensive ^{48}Ca to produce neutron rich nuclei around mass 40-50.

Brief report of the LNS User Meeting: the ASFIN contribution

L. Lamia (Univ. di Catania, Italy – for the ASFIN experiment*)*

Nuclear astrophysics studies the nuclear processes occurring in the Cosmos for both energy generation and nucleosynthesis of the elements. In the last '30 years, an intense research program has been carried out at INFN-LNS by the ASFIN experiment to study nuclear reactions of astrophysical relevance mainly via indirect methods [1]. Among these, the Trojan Horse Method (THM) [2] allows one to study charged particle induced reactions, overcoming Coulomb barrier penetration and electron screening effects, as well as neutron induced reactions. THM experiments typically need beam energies of few MeVs per nucleon (2-4 MeVA) thus strongly requiring the use of the Tandem accelerator both with stable and unstable beams. The use of the scattering chamber "CAMERA-2000" is of fundamental importance since its large diameter (2000 mm) allows one to use highly segmented Si-telescopes to reach angular resolutions of 0.1-0.2° demanded for THM purposes. Moreover, its dimensions also allow the usage of TOF techniques useful in some of the experiments we perform. Therefore CAMERA-2000 is a unique scattering chamber useful for different studies.

The availability of the new NESTOR ion source at INFN-LNS opens new frontiers for THM studies, thanks to the possibility of accelerating, for instance, helium isotopes. A *letter-of-intent (Lithe - LOI)* was already approved in 2019 for using ^{3}He beams to induce the ^{6,7}Li(^{3}He,$\alpha\alpha$)d THM reactions for studying the astrophysically relevant ^{6,7}Li(p,α)^{4}He ones [3]. In addition, ^{3}He beams represents also a unique opportunity to perform (^{3}He,d) or (^{3}He,p) transfer reactions for ANC [1] experiments, mainly based on angular distribution measurements feasible at the CAMERA-2000 facility. Further, ^{3}He beams can be used to study nuclear structure effects in ^{3}He induced fusion cross section measurements around the Coulomb barrier and comparison with similar ^{4}He or ^{6}He processes already measured by our group. Indeed, a complete understanding of fusion reactions induced by n-rich and n-deficient isotopes is needed to better calculate not measurable cases of astrophysical interest. Beside the interest on helium-isotopes, it is of interest to use NESTOR for producing neon-isotopes, such as ^{20}Ne or ^{22}Ne, at energies of few MeVs per nucleon and intensities of 5-10 nA at the target position. This would allow THM studies of astrophysically relevant reactions such as the ^{16}O+^{16}O fusion, taking advantage of the ^{20}Ne cluster structure ^{16}O-^{4}He, and ^{22}Ne(α,n)^{25}Mg from ^{22}Ne+^{6}Li .

The TANDEM accelerator can also accelerate long-lived radioactive beams (RIB's) produced in "batch-mode". This technique has been recently adopted at INFN-LNS for accelerating ^{10}Be beams with intensities up to 10^{9} pps and purity higher than 99% [4]. The same technique could be adopted in the future to accelerate other nuclei such as ^{26}Al, of paramount importance for the nucleosynthesis in the cosmos, thanks to the already ongoing collaboration with several institutions (PSI-Swiss, Univ. of Caserta & Circe Labs-Italy, Ithemba-South Africa). Because of the possibility of accelerating the ^{26}Al beam at INFN-LNS in Catania, a dedicated LOI has been already presented at INFN-LNS for THM experiments with ^{26}Al beams [5]. These activities will be complementary to the foreseen ASFIN activities at the SPES facility in Legnaro (INFN-LNL) for which a dedicated LOI has been already accepted [6].

[1] Tribble R.E. et al., Rep. Prog. Phys. 77 (2014) 106901
[2] Tumino A. et al., Annu. Rev. Nucl. Part. Sci. (2021) 71:345–76
[3] Pizzone R.G., Lamia L. et al. *LOI* "LITHE" 2019, INFN-LNS PAC
[4] Figuera P. et al., Nuclear Inst. and Methods in Phys. Research, A 972 (2020) 164120
[5] La Cognata M., Acosta L. & Kiss G.G. LOI "26ALFA: 26Al for astrophysics", INFN-LNS
[6] La Cognata M., Palmerini S., Busso M. et al *LOI "Measurement of astrophysical relevant reactions induced by alpha, protons and neutrons at the Gamow peak using the Trojan Horse Method"*, INFN-LNL

Collective oscillations and cross section measurements with radioactive beams

S. Piantelli (INFN – Sezione di Firenze, Italy)

Proposals for new ideas to be performed with the new in-flight beams at LNS:

a) *Collective oscillations with exotic beams*
The idea is to follow the evolution of the giant resonances as a function of the N/Z of the projectile, in order to put into evidence the effect of the possible deformation of the emitting nucleus on the shape of the resonance. Some of the beams which could be used are S beams from ^{32}S to ^{38}S, O beams from ^{16}O to ^{20}O, Ar beams from ^{34}Ar to ^{36}Ar, with a target of ^{12}C or and heavy element (Sn, Au) to "open" the kinematics. The Quasi-Projectile must be weakly excited not to damp the giant resonance and to be sure that the QP is the emitting source, therefore very peripheral collisions must be selected. The envisaged setup consists of some forward placed FAZIA-like detectors to detect the QP in mass and charge, coupled to detectors for hard gammas (BaF2 or GAGG:Ce).

b) *Cross section measurements*
It would be interesting to measure the cross section of exotic beams on ^{12}C at very forward angles, scanning the N/Z of the projectile. In this case very low intensities are necessary; the setup requires FAZIA-like blocks at forward angles and a monitor (e.g. a fast scintillator) for the Rutherford scattering and possibly a Faraday cup.

Necessary improvements:
1) A scattering chamber with minimum size 2.5m x 1.2m where the radioactive beams of FRAISE can be delivered.

Exploring n-p asymmetry dependence of the Nuclear Caloric Curve

S.Pirrone (INFN-Sezione di Catania) for CHIRONE experiment

The caloric curve, that is the relation between the temperature and the excitation energy of a system, is of fundamental relevance for many physical systems. This contribution proposes an investigation on the dependence of the nuclear caloric curve on the neutron-proton asymmetry. In fact a clear mass-dependence of the caloric curve has been demonstrated for finite nuclei [1], while the dependence on the neutron/proton asymmetry, (N-Z)/A, remains uncertain due to the conflicting from different theoretical calculations predictions and to a relatively small quantity of experimental data on the subject. Besides that, the available data show that the dependence of the caloric curve on the neutron-proton asymmetry is determined also by the dynamics of the reaction, i.e. if it is a Fusion-Evaporation or a Multifragmentation process, [2].

We would like to extend the study on this subject, actually already started on the data of the ISODEC experiment, in which we realized the reactions 78,86Kr+40,48Ca at 10 AMeV at INFN-LNS [5,6]. To this aim we propose the study of the reactions 34Ar + 58Ni and 46Ar+64Ni at energies between 15 and 30 AMev, taking advantage of the FRAISE beams and by using the 4 π CHIMERA detector and the FARCOS correlator. We strongly support the development of beams with A=30-70, that will allow us to face up many relevant physics cases.

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Fission studies with medium mass nuclei

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We suggest measuring the absolute cross sections and some characteristics of the nuclear fission processes in the mass range between about 70 and 130 (e.g., mass asymmetry of the emitted fragments, their isotopic content, partial access to their decay). The fission process is not dominant as for heavy nuclei and has obviously already been studied in the past, but some aspects are still poorly known, as, for example, parameters like the value of the barrier, the excitation of the spin, the relationship of the spin itself with the shape transition and collective excitations. Some observables could help in discriminating among various theoretical models of fission which include dissipative terms acting during the phases leading from the formation of a transient system to its division into two parts.

METHOD

For this purpose, well-identified pairs of fragments could be measured in coincidence by means of telescopes arms, allowing excellent particle identification, placed at appropriate angles (possibly changing from remote with appropriate control systems). Having in mind tools like FAZIA blocks that require relatively large spaces, it is essential to have an available vacuum chamber large at least 250 cm × 120 cm. Fission could be studied in reactions induced by stable beams with mass between Ar and Sn, various stable isotopes, of high intensity (> 120 particle-nA). To take advantage of the geometry and the kinematic boost we think to X+C type reactions at energies between 20 and 35 MeV/nucleon, X being isotopes of Kr, Mo, Sn.

Otherwise, with the lighter beams of Ar, Zn of similar intensity, one can imagine performing more symmetrical collisions such as Ar, Zn + Zn, Ni at comparable energies.

A large reaction chamber could also contain an apparatus for the detection of gamma in coincidence to better characterize the fission process also allowing the study of giant resonances excited in the process. For these very exclusive measures (fragment – gamma coincidences) very high currents are evidently even more imperative. A monitor for the Rutherford normalization is fundamental at small angles.

REQUESTS

- reaction chamber of at least 250 cm × 120 cm, with operating vacuum values of the order of 10^{-6} mbar
-Good transport of stable intense beams of mass between 40 and 130
- beam currents on targets > 120 particle-nA
-energies between 15 and 35 MeV / u
- option for subnanosecond pulsed beam (500psFWHM)
-beams of Ar, Ni, Kr, Sn various isotopes.

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Radionuclides and radiopharmaceuticals

G. Pupillo (INFN-LNL)

The cyclotron-based production of radionuclides for medicine is one of the research activities carried out in the framework of the SPES (Selective Production of Exotic Species) project at the INFN-LNL. As known, the heart of SPES is the 70 MeV proton-cyclotron with a dual-beam extraction, that will be used for nuclear physics and astrophysics studies, as well as to perform multidisciplinary activities, such as radionuclides production for medical applications. The presentation given was focused on this research field, the activities carried out in the new unit “Radionuclides for medicine and applied physics”, showing the major results obtained with the interdisciplinary projects LARAMED (LAboratory of RAdionuclides for MEDicine) [1] and ISOL-pharm [2]. The first one is based on the direct-activation method and it includes the proton-based production of ^{99m}Tc, ^{67}Cu, $^{52/51}$Mn, ^{47}Sc and recently Tb-isotopes, from the nuclear cross section measurements to the preclinical studies. ISOL-pharm uses the ISOL technique for the development and the production of radioisotopes with high-specific activity, such as ^{111}Ag, going beyond the state-of-art in the field. Thanks to a consolidated network of collaborations with national and international facilities, including ARRONAX (Nantes, France), the PRISMAP European consortium and several Italian universities and hospitals, the ongoing research activities on radionuclides production and their perspectives at the INFN-LNL have been presented at the LNS User Meeting.

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Possible future activities at LNS exploiting SiC detectors

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Silicon carbide is a well-known promising radiation-hard alternative to silicon. In the past few years a thorough R&D activity in the field of silicon carbide production technology has been carried out by the SiCILIA collaboration, with a successful outcome. SiC detectors suitable for many nuclear physics applications have been produced [1] and tested from multiple points of view: besides their general characteristics as radiation detectors, their performance for nuclear fragment identification [2], for neutron detection [3] and for dosimetric applications [4] have been tested, showing really promising results. The possible future applications of radiation-hard SiC detectors can be manifold, from beam diagnostic systems [5] to their use to perform measurements at zero degrees (e.g. for the study of cross sections at very forward directions), also with exotic beams, or more in general for the experiments exploiting high intensity beams. For many of these applications, however, further tests on the produced SiC sensors can be really of use. We already foresee a more detailed study of Pulse Shape Analysis (PSA) identification performance and a test of the timing performance of SiC detectors, also extending the study to their Time of Flight identification capability; for the latter it would be useful to have access to an experimental chamber offering a sufficient flight path length. A key information that has to be evaluated on the new SiC detectors is their actual radiation hardness, also compared to silicon detectors. Some data are currently being analysed, but the study can be further extended. In this respect, the use of high intensity beams would allow the test of the performance of SiC detectors even at high fluences in a short time. The effect of different damage patterns could also be studied, with the damaging ion either in transmission or stopped in the active layer. In addition to the study of the evolution of the SiC detector basic properties with fluence, it would also be useful to test the operability limit of SiC detectors also specifically for particle identification applications, e.g. with PSA, which is very sensitive to radiation damage [6].

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Pulsed neutron sources fed with ion beams and laser beams

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By exploiting reactions of the type (p, n), (p, 2n), (d, n), (4He, n) pulsed neutron sources could be produced, making use of the beams available with the LNS accelerators. As an example, consider a proton beam produced with the Tandem, with energy between 10 and 26 MeV, pulsed in temporal bunches around 50ns with 106 protons per bunch, which affects a target of 9Be or 181Ta. Pulses with 103 - 104 neutrons per second can be produced, with an energy spectrum dependent on the reaction. If there is sufficient space available in the experimental room, a flight base of a few meters between source and secondary target could be exploited.

A further perspective is represented using the 250 TW laser beam that will be available in the coming years. By exploiting a configuration known as 'pitcher-catcher', it is possible to produce pulsed neutron beams with fluxes of around 10^4 neutrons/sr per second and repetition rates up to a few Hz.

At the measuring point, instruments could be installed to measure the neutron flux and the energy spectrum. It should be emphasized that the energy spectra can be modified, if necessary, with the development of adequate moderation using polyethylene and / or borate water and with the aid of FLUKA type codes.

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Detectors R&D: RIBs tagging and beam monitoring

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In recent years the Chimera group developed a tagging system [1] devoted to the event-by-event identification of ions present in cocktail radioactive ion beams. The system, based on a microchannel plate and a double-sided silicon strip detector, has an overall time resolution of about 500 ps and shows good performances up to a workload of 10^5 pps, but is characterized by a poor radiation hardness and its performances worsen after 1-2 weeks of operation with medium masses nuclei. For this reason, the development of new multi-pad sensors based on SiC has been started.
SiC is a material characterized by an important radiation hardness. These sensors should tolerate a flux of 10^7 pps and provide a time resolution of 100 ps, corresponding to 0.1% of energy resolution for a 25 m base of flight. Simultaneously, it will be developed dedicated compact front-end electronics particularly suited for amplitude and time measurements, coupled to a digitizer system in order to acquire the full waveform. These sensors are fundamental for the tagging of RIBs in the final user point, as will be delivered by the new fragment separator, but could find use also as diagnostics elements for the optimization of RIBs production and transport; for this reason, they will be developed in synergy by Chimera group, LNS Research Division and Sicilia collaboration.

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