The RIB facility EXOTIC and its experimental program at INFN-LNL

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Abstract. In this contribution, I will present a review about the EXOTIC facility and the research field accessible by using its Radioactive Ion Beams. The EXOTIC facility, installed at the INFN-Laboratori Nazionali di Legnaro, is devoted to the in-flight production of light Radioactive Ion Beams in the energy range between 3-5 MeV/nucleon. The scientific activity performed at EXOTIC concerns different aspects of nuclear physics and nuclear astrophysics, such as, the investigation of reaction mechanisms and nuclear structure, resonant scattering experiments and measurements of nuclear reaction cross sections of astrophysical interest.

1. Introduction

During the last decades, the development of Radioactive Ion Beam (RIB) Facilities opened the gates to the investigation of fundamental studies in physics related to nuclei far from the valley of $\beta$-stability. These nuclei might exhibit exotic features, such as, for instance: (i) a very low binding energy (typically 1.0 MeV), (ii) the last neutrons mostly orbiting in the outer part of the nucleus in a “skin-like structure”, (iii) a “halo” structure corresponding to a rather inert core plus one or two neutrons (protons) circulating around in an orbit whose radius is much larger than that observed for stable well-bound nuclei close to the valley of the $\beta$-stability.

These peculiar characteristics give rise to a rather wide variety of phenomena, such as new radioactive decay modes, e.g. one-proton, two-proton and neutron radioactivity, and also the shell closures show an evolution going from the valley of the $\beta$-stability to the neutron- and proton-drip lines. Moreover, experiments with RIBs allow to explore the properties of isotopes with a proton-to-neutron ratio very different from the stable ones, measure reaction cross sections of astrophysical interest occurring in explosive environments, constrain the isospin-dependent nucleon-nucleon interaction in neutron-rich nuclei and in neutron stars, synthesize superheavy elements and test physics beyond the standard model.

2. EXOTIC facility and Experimental Set-up

The EXOTIC facility [1, 2, 3, 4] has been commissioned at INFN-Laboratori Nazionali di Legnaro (INFN-LNL) in the years 2003-2004 and upgraded in 2012 [5]. This facility is dedicated to the in-flight production of low-energy light RIBs, by inverse kinematics nuclear reactions induced by the intense heavy-ion beams delivered from the INFN-LNL Tandem XTU accelerator hitting a light gas target, such as H$_2$, D$_2$, $^3$He and $^4$He.

The main features of the facility, shown in Fig. 1, are a large RIB acceptance of the optics elements and a large capability to suppress all the undesired scattered beams. At the beginning,
there is a production gas target that consists of a 5 cm-long cylindrical cell walled with windows made of 2.2 µm thick Havar foil, operating at room or at liquid N₂ temperatures at pressures up to 1 atm. Then, after the production, the beam can be selected and transported through a system made of: a triplet of large diameter quadrupole lenses, a 30° bending magnet, a Wien filter and a second triplet of quadrupole lenses, placed before the tracking detectors and the reaction chamber. The Wien filter eliminates to a very large extent the tails of the primary beam that pass through the system with the same magnetic rigidity. In order to stop the RIB contaminants, different slit sets are installed along the beamline and can be adjusted to the envelope of the produced RIB. The facility has a length of 8.34 m and presents the following characteristics: \( \Delta E/E = \pm 10\% \), \( \Delta p/p = \pm 5\% \), \( \Delta \theta = \pm 50 \text{ mrad} \), \( \Delta \phi = \pm 65 \text{ mrad} \), \( \Delta \Omega \approx 10 \text{ msr} \), \( B_\rho = 0.98 \text{ Tm} \).

So far, RIBs of \(^7\text{Be}^, \ 8\text{B}, \ 17\text{F}, \ 15\text{O}, \ 8\text{Li}, \ 10\text{C}^, \ 11\text{C} \) at 3-5 MeV/nucleon have been delivered with intensities about \( 10^6 \), \( 10^3 \), \( 10^5 \), \( 4x10^4 \), \( 10^5 \), \( 5x10^3 \) and \( 2x10^5 \) pps, respectively, and with 98-99% purity (except for \(^8\text{B} \) that has a lower purity).

![Diagram of the EXOTIC facility](Image)

**Figure 1.** Layout of the EXOTIC facility.

The experimental set-up [6, 7] of the EXOTIC facility is presented in Fig. 2. It is situated at the end of the beamline and consists of: a) the RIB tracking system and b) the detection system, EXPADDES, a new charged-particle telescope array. EXPADDES is a portable array and is flexible to suit many experiments. It can be also coupled with γ-ray and neutron arrays.

The Parallel Plate Avalanche Counters (PPACs) of the tracking system are position-sensitive and fast detectors, which can sustain counting rates up to \( \sim 10^6 \) Hz. They are placed 909 mm
(PPAC A) and 365 mm (PPAC B) upstream the reaction target, at the EXOTIC focal plane. The PPACs are filled with C$_4$H$_{10}$ gas at a working pressure of 10-20 mbar. Each PPAC has an active area of 62x62 mm$^2$ and is sealed with 1.5 µm-thick mylar windows. The detector has a central cathode and two anodes, placed symmetrically at a distance of 2.4 mm from the cathode. The cathode is a unique plate of 1.5 µm-thick stretched mylar foil, while each anode is a mesh of 60 gold-plated tungsten 20 µm-thick wires in the x and y directions, with a spacing of 1 mm. The position information of a particle crossing the PPAC is extracted from the anode signals by using a delay-line readout. The 1 mm resolution of the two PPACs allows us to reconstruct the position of the event on the reaction target with a 2.3 mm position resolution. The cathode signal is used as a reference time for Time of Flight measurements (giving a START signal with 0.9 ns FWHM time resolution) and for trigger purposes.

![Diagram of PPACs and EXPADES setup](image)

**Figure 2.** The position sensitive PPACs for the RIB tracking system and the detection system, EXPADES, placed in the reaction chamber (element 10 of Fig. 1) at the end of the EXOTIC facility.

EXPADES is an array of eight telescopes arranged in a cylindrical configuration around the reaction target (Fig. 2). The telescope structure is flexible and is composed of two Double Side Silicon Strip Detectors (DSSSDs) and/or Ionization Chamber (IC), depending on the experimental requests. We use 40/60 µm-thick DSSSDs for the ΔE stage (B in Fig. 2) and 300 µm-thick DSSSDs for the $E_{\text{res}}$ one (A in Fig. 2). Each DSSSD has 64-mm long 32x32 strips, with 2 mm pitch size and 40 µm interstrip separation, defining thus a $\sim 2 \times 2$ mm$^2$ pixel structure. For experiments requiring the detection of more energetic particles than those stopped in the $E_{\text{res}}$, 1 mm-thick DSSSDs can substitute the 300 µm-thick ones or can be used in addition to the previous stages. ASIC-based electronics was employed for the treatment of the $E_{\text{res}}$ signals, with a high granularity and a very low cost. For the signal readout of the ΔE stage a compact low-noise electronics with very good energy and timing characteristics was developed by our collaboration. A valid alternative to allow the $\Delta E$-$E_{\text{res}}$ identification of reaction products with range in silicon shorter than 40/60 µm is the use of a home-made transverse field IC (C in Fig. 2) that can give the possibility to tune the effective thickness of the $\Delta E$ layer by changing the gas pressure. The IC has 65x65 mm$^2$ entrance and exit windows (1.5 µm-thick mylar) and can be filled with CF$_4$ gas at pressures up to 100 mbar. The low-noise charge-sensitive preamplifiers for the $\Delta E$ DSSSDs (D in Fig. 2), those of the ICs (not present in Fig. 2) as well as the electronic boards (E in Fig. 2) for the $E_{\text{res}}$ DSSSDs are placed under vacuum close to the detectors. In this
way, we manage to keep as low as possible the DSSSDs electronic thresholds, typically 300-500 keV.

Fig. 3 shows one of the possible configurations of the detection system installed in the reaction chamber of the EXOTIC facility: in this case, six two-stage DSSSD telescopes of EXPADES array are used.

![Figure 3. Six two-stage DSSSD telescopes of EXPADES array mounted in the reaction chamber of the EXOTIC facility. The RIB comes from the left side, passing through PPAC A and PPAC B (shown in the picture) of the tracking system.](image)

3. Experimental program and Perspectives

The experimental program at EXOTIC is varied and aims at different topics of nuclear physics and nuclear astrophysics.

3.1. Reaction Mechanisms

The scientific activity at EXOTIC facility started with the study of reaction mechanisms induced by light radioactive (exotic) nuclei impinging on medium- and heavy-mass targets at energies near to the Coulomb barrier.

The peculiar features of these nuclei influence the reaction mechanisms giving a picture that is rather different from that of well bound species because of the appearance of new phenomena. The loose binding of the weakly bound nuclei yields in a strong breakup and/or transfer channel which could influence the elastic scattering (i.e. the total reaction cross section) and the fusion cross section. Indeed, different theoretical models have predicted both enhancement and hindrance of the sub-barrier fusion cross section due to this coupling. Several review articles have recently been written on this topic [20, 21, 22, 23, 24, 25]. From an experimental point of view, many studies with weakly bound stable and radioactive species (RIBs) were undertaken to disentangle the different reaction mechanisms, also at the EXOTIC facility [8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19].

In 2010 we started the study of \(^7\)Be-induced reactions. This RIB can be produced at EXOTIC facility through the charge exchange reaction \(^1\)H\(\rightarrow\)\(^7\)Li, \(^7\)Be\) and, then, selected by a careful tuning of the quadrupole lenses, the dipole magnet and the Wien filter of the facility. This projectile was chosen because is a weakly-bound proton-rich nucleus with a very pronounced \(^3\)He - \(^4\)He cluster configuration in its ground state. The \(^7\)Be (\(S_n =1.586\) MeV) represents,
among all light nuclei, the cleanest case where the study of the breakup/transfer interplay into the reaction dynamics can be addressed in detail. Indeed, the two $^7$Be inner clusters are very stable fragments with similar masses, while all breakup studies previously performed always involved the complicated and low-efficiency detection of neutrons (like in the case of the $^6$He and $^9,^{11}$Be breakup processes), the emission of a weakly-bound fragment (e.g., the deuteron emission in the $^6$Li breakup), the emission of a radioactive fragment (as for the triton emission in the $^7$Li breakup) or a very small breakup probability, as in the case of the $^{17}$F breakup process into $^{16}$O + p. Moreover, the $^7$Be nuclear structure is quite similar to that of its mirror nucleus $^7$Li ($S_\alpha = 2.468$ MeV), while its binding energy is rather close to that of the lightest particle stable lithium isotope $^6$Li ($S_\alpha = 1.475$ MeV). A better comparison between the $^7$Be and $^6,^7$Li reaction dynamics at Coulomb barrier can easily be achieved thanks to the large amount of data available for the reactions induced by the stable projectiles on several different targets.

First, the energy and angular distributions of $^3$He and $^4$He ions produced in the $^7$Be + $^{58}$Ni reaction at a bombarding energy of 22 MeV have been measured for the first time. The quasi-elastic data, displayed in Fig. 4, were in remarkable agreement with an earlier measurement performed at the University of Notre Dame [26], while the $^4$He production (measured for the first time) turned out to be 4-5 times more abundant than that of its lighter counterpart. This result clearly rules out the possibility that in this energy range the $^7$Be reaction dynamics is dominated by the exclusive breakup process $^7$Be $\rightarrow$ $^3$He + $^4$He ($S_\alpha = 1.586$ MeV), otherwise similar yields for the two helium isotopes would have been observed. Unfortunately, due to small geometrical efficiency and limited beam-time availability, no coincidences between projectile fragments were recorded. Therefore, extensive theoretical calculations were undertaken in order to determine the possible contributions of the n-stripping, n-pickup and exclusive breakup processes to the inclusive production cross section of $^3$He and $^4$He [10].

![Figure 4. Quasi-elastic angular distribution for the $^7$Be + $^{58}$Ni system at 21.5 MeV. Black circles represent the present measurement, while blue diamonds are taken from an earlier measurement performed in [26]. The solid black line denotes the result of an optical model calculation, as explained in [10].](image)

Recently, we performed the $^7$Be + $^{208}$Pb reaction for the first time at three near-barrier energies. The goals of this experiment were to measure for the first time the near-barrier quasi-elastic angular distribution and to detect (at least) a few coincidences between projectile
fragments, in order to get a deeper insight on the reaction dynamics induced by this exotic projectile. The experiment benefited from the upgrade of our facility EXOTIC [5], which is now able to deliver $^7$Be beams energetic enough to match the energy range around the Coulomb barrier also for reactions on heavy targets. We measured the quasi-elastic scattering differential cross section (shown in Fig. 5) and extracted the total reaction cross section. The comparison with the reaction cross sections obtained for the mirror projectile $^7$Li and the similarly weakly-bound nucleus $^6$Li interacting with the same target clearly suggests that the $^7$Be data essentially follow the trend individuated by the heavier lithium isotopes. This result indicates that, for these projectiles, nuclear structure might play a more relevant role in the reaction dynamics rather than the projectile binding energy. In addition, we started the investigation of the energy spectra and angular distributions for the inclusive production of $^3$He and $^4$He nuclei. We immediately observed that the $^4$He production is a factor 4-5 higher than the $^3$He one. This confirms that also for the interaction with heavy targets the $^7$Be reaction dynamics at near barrier is not dominated by the breakup process, as found in the $^7$Be + $^{58}$Ni system. The detailed analysis of these events is presently in progress.

![Figure 5. Quasi-elastic angular distribution for the $^7$Be + $^{208}$Pb system at three beam energies: 37.4 MeV (squares), 40.5 MeV (circles) and 42.2 MeV (triangles). Lines are the results of a best-fit analysis of the experimental data within the framework of the optical model, as described in detail in [12].](image)

3.2. Clustering

Clustering phenomena [27] are well known in nuclear physics for stable nuclei, both $\alpha$-conjugate (N=Z, A=2N), like $^8$Be, $^{16}$O, $^{20}$Ne, and non-$\alpha$-conjugate, like $^6$Li and $^7$Li. In general, it is expected that light exotic nuclei may also exhibit cluster behavior. Moving out of the valley of stability, configurations can be found where at least one of the clusters is unbound or weakly bound, thus not satisfying the strong internal correlation requirement of classical clusters. This is the so-called exotic clustering regime. The study of such systems presents many difficulties, due to, mainly, the low intensities typical of RIBs. Therefore, few significant experimental studies have been performed so far.

We started to study $\alpha$-clustering phenomena in light exotic nuclei, employing the Thick Target Inverse Kinematics (TTIK) scattering technique [28], with the RIB impinging on a $^4$He gas target. As the projectiles slow down in the gas, elastic scattering reactions across a wide
range of center-of-mass energies can take place (corresponding to a range of depths within the gas). The pressure of the gas is tuned such that the RIB completely stops in the gas, allowing a detector to be placed at 0°, i.e., on the beam axis, while the energetic recoiling light target nuclei, due to their low rate of energy loss, can traverse the gas and be detected. The TTIK method is useful for measurements with low-intensity RIBs since it allows to measure the elastic scattering excitation function and the reduced α-width directly, over a wide energy range by using a single beam energy, since the gas acts as a target but also as a degrader. In the following case, the technique has been refined by using Time of Flight information [29, 30] to remove contributions from processes other than elastic scattering [31]. Moreover, modifications of the EXOTIC facility were performed in early 2015, to allow the realization of experiments by employing RIBs impinging on reaction gas targets. Indeed, a new small chamber was built hosting the PPAC B that separates, through a 2.2 μm thick Havar window, the scattering chamber (filled with 4He gas) from the beamline (at high vacuum).

In particular, we searched for α-cluster states in 19Ne above its α-decay threshold measuring, for the first time, the 15O(4He, 4He)15O elastic scattering excitation function with the TTIK technique. The 28.5 MeV 15O RIB was produced with the EXOTIC facility by means of the in-flight technique via the p(15N, 15O)n reaction, with the 15N beam delivered by the INFN-LNL Tandem XTU accelerator.

19Ne has attracted much interest due to the astrophysical importance of the 15O(α,γ)19Ne reaction, identified as a break-out from the hot-CNO cycles (shown in Fig. 6) and a trigger for the following rp-capture populating masses higher than neon [32]. Neon isotopes exhibit strong α-clustering phenomena, even in the ground states. Therefore, the idea has been to investigate the possible cluster nature of the neutron-poor side of the neon isotopes, almost totally unknown [33]. After the elastically scattered α particles have been selected, the final excitation function
is obtained and shown in Fig. 7. The excitation function has been analysed by using a full R-Matrix fit performed using Azure2 code [34], revealing a significant number of new resonances. The results show evidence for $^{15}\text{O} + \alpha$ cluster structure which could explain the increased role played by some levels in the astrophysical $^{15}\text{O}(\alpha,\gamma)^{19}\text{Ne}$ reaction in the break-out from the hot-CNO cycles.

We extended this research field to the neutron-poor side of the oxygen isotopes, that is, at the moment, almost totally unknown concerning the clustering point of view, while neutron-rich oxygen isotopes have been intensively investigated for their cluster nature. By using the same technique as before, recently we investigated the presence of possible $\alpha$-cluster states in $^{15}\text{O}$ measuring the elastic scattering excitation function of the system $^{11}\text{C} + ^{4}\text{He}$ with a $^{11}\text{C}$ RIB produced by the EXOTIC facility. The analysis is still ongoing.

![Figure 7. Excitation function for $^{19}\text{Ne}$ at 0°. The data points are overlaid by the R-matrix fit (solid red line). The fit without the newly observed levels is shown for comparison (dashed blue line). See [33] for more details.](image)

### 3.3. Nuclear Astrophysics

Another possibility offered by the EXOTIC facility is to perform measurements of astrophysical interest with RIBs impinging on solid or gas light targets in inverse kinematics. Among the different processes of stellar nucleosynthesis forming elements heavier than $^{9}\text{Be}$, the $rp$-capture and $\alpha p$ processes, occurring in explosive astrophysical environments, are those than can be investigated by using the EXOTIC RIBs.

We want to develop a radioactive $^{18}\text{Ne}$ beam through the $^{3}\text{He}(^{16}\text{O},^{18}\text{Ne})n$ reaction. The $^{18}\text{Ne}$ RIB is of primary importance for nucleosynthesis of heavier elements. Indeed, it allows the break-out from the second hot-CNO cycle through the $^{18}\text{Ne}(\alpha,p)^{21}\text{Na}$ reaction (see Fig. 6), converting the initial CNO isotopes into heavier elements [32]. However, the actual astrophysical conditions under which this occurs depend critically on the $^{18}\text{Ne}(\alpha,p)^{21}\text{Na}$ rate. This rate has been studied through direct and indirect measurements (see [35] and references therein).

The importance for nuclear astrophysics of the $^{18}\text{Ne}(\alpha,p)^{21}\text{Na}$ reaction and the disagreement between direct and indirect measurements call for further investigation. For these reasons, it is important to perform a new measurement in the overlapping region, where the different experiments disagree, and to extend toward lower energies, thus populating the region of interest for hot-CNO breakout in x-ray bursts. We plan to perform a direct measurement of the cross section for the $^{18}\text{Ne}(\alpha,p)^{21}\text{Na}$ reaction with an extended gas target at the EXOTIC facility in the next future, after testing the $^{18}\text{Ne}$ production at our facility.
Another measurement relevant to the astrophysics can be performed at EXOTIC such as the $^{30}\text{P}(p,\gamma)^{31}\text{S}$ with a $^{30}\text{P}$ RIB. The $^{30}\text{P}(p,\gamma)^{31}\text{S}$ reaction is thought to be the bottleneck for the production of heavy elements (from Si to Ca) in the explosion of ONe novae due, in part, to the long $\beta$ decay half life ($t_{1/2}=2.5$ min) of $^{30}\text{P}$, which is comparable to the duration of nova nucleosynthesis (Fig. 8). Consequently, uncertainties in the thermonuclear $^{30}\text{P}(p,\gamma)^{31}\text{S}$ reaction rate affect the interpretation of several observables that could elucidate the astrophysics of nova [36]. A related problem involves the anomalously high $^{30}\text{Si}/^{28}\text{Si}$ rate in pre-solar grains of possible ONe nova origin [37]. Uncertainties in the $^{30}\text{P}(p,\gamma)^{31}\text{S}$ reaction rate hinder accurate quantitative comparisons to the silicon isotopic ratios from nova models.

Up to now, there is enough experimental information about the $^{30}\text{P}(p,\gamma)^{31}\text{S}$ reaction thanks to various indirect measurements (see [38] and references therein). Unfortunately, comparing various interpretations of this information reveals ambiguities and discrepancies. Direct measurements with $^{30}\text{P}$ RIB and hydrogen targets are not currently possible due to the lack of sufficiently intense, high-quality $^{30}\text{P}$ beams at the relevant energies. Therefore, in future, we intend to develop this RIB at EXOTIC, through the $^{4}\text{He}(^{27}\text{Al},^{30}\text{P})n$ or $^{2}\text{H}(^{29}\text{Si},^{30}\text{P})n$ reactions, in order to perform a direct measurement and try to give relevant information to this astrophysical quest.

Moreover, experiments based on the Trojan Horse Method (THM) [39, 40, 41, 42] are considered. In this direction, a first experiment was performed to investigate the $^{7}\text{Be}(\text{n},\alpha)^{4}\text{He}$ reaction to shed light on the cosmological lithium-problem, of interest in the Big Bang Nucleosynthesis [43]. To this aim, the THM has been applied to the quasifree reaction $^{2}\text{H}(^{7}\text{Be},\alpha^{4}\text{He})p$, by using a 20.4 MeV $^{7}\text{Be}$ RIB impinging on a CD$_2$ target. By referring to the polar diagram of Fig. 9, deuteron represents the TH-nucleus, undergoing its breakup in neutron (participant) and proton (spectator). In the same research program, an independent experiment has been performed at Center-for-Nuclear-Study Radioactive Isotope Beam (CRIB) (Riken, Japan) [44, 45] to study simultaneously the $^{7}\text{Be}(\text{n},p)^{7}\text{Li}$ and $^{7}\text{Be}(\text{n},\alpha)^{4}\text{He}$ reactions by applying the THM. The preliminary results of both experiments have been presented recently at the Nuclear Physics in Astrophysics (NPA) VIII Conference, held in Catania last June [46, 47].

3.4. Sub-barrier fusion measurements
Recently, we have also explored the possibility to perform measurements of fusion cross sections at near- and sub-barrier energies. In this case, our facility works as a separator of evaporation.
residues from the incident beam, delivered by the INFN-LNL Tandem XTU accelerator. For this purpose, the facility was slightly modified to allow the transport, identification and detection of the fusion-evaporation residues (ER) at the focal plane of the facility [48]. We measured the fusion reactions for the two systems $^{32}\text{S} + ^{48}\text{Ca}$ and $^{32}\text{S} + ^{64}\text{Ni}$ where the cross sections are known from previous experiments performed at LNL [49, 50]. The ion optical parameters of EXOTIC were set to maximize the ER yield in the detector system for the various cases. A good and clean separation of the ER from beam-like particles was obtained in the experimental Energy-Time of Flight correlation plots. These encouraging results were compared with the performance of the electrostatic deflector set-up PISOLO, routinely used at LNL for sub-barrier fusion experiments. The beam rejection factor of EXOTIC facility at $0^\circ$ is comparable to the one of PISOLO deflector at $2^\circ - 3^\circ$, while a gain of overall efficiency up to a factor 3 has been obtained with EXOTIC.

4. Conclusion

The EXOTIC facility is dedicated to the in-flight production of low-energy light RIBs and its experimental set-up is fully operational at INFN-LNL. An intense and various experimental program has been performed by using the RIBs delivered by this facility, in the framework of international collaborations.

We performed several experiments aimed to a better comprehension of the interplay between different reaction mechanisms induced by the peculiar features of exotic and weakly-bound nuclei, as shown in section 3.1. In particular, we investigated the reaction dynamics of the $^7\text{Be}$ RIB interacting with medium- and heavy-mass targets at Coulomb barrier energies, demonstrating that the $^7\text{Be}$ reaction dynamics at Coulomb barrier is not dominated by the breakup process. The detailed analysis of the different channels involved is in progress.

Recently, we extended our interest to the investigation of $\alpha$-clustering phenomena in light exotic nuclei, employing the TTIK scattering technique with a $^4\text{He}$ gas target (section 3.2). We found evidence for $\alpha$-cluster structure for $^{19}\text{Ne}$, by using the $^{15}\text{O}$ RIB. This could help to understand the role of this nucleus in the astrophysical $^{15}\text{O}(\alpha,\gamma)^{19}\text{Ne}$ reaction in the break-out from the hot-CNO cycles. Another experiment was performed to study the cluster nature of the $^{15}\text{O}$ nucleus, with the $^{13}\text{C}$ RIB produced at EXOTIC. The analysis is in progress.

An important challenge will be to perform measurements of astrophysical interest with EXOTIC RIBs impinging on solid or gas light targets (section 3.3). In this direction, we will test the production of $^{18}\text{Ne}$ and $^{30}\text{P}$ RIBs, involved in reactions of astrophysical relevance in explosive environments. At the end of 2015, an experiment based on the THM method was performed to investigate the $^7\text{Be}(n,\alpha)^4\text{He}$ reaction to shed light on the cosmological lithium-problem, of interest in the Big Bang Nucleosynthesis. The data analysis is in progress and the
preliminary results were presented at the NPA VIII conference held in Catania in June 2017.

Moreover, EXOTIC can be used as a velocity filter to perform fusion-evaporation experiments at near- and sub-barrier energies with stable beams (section 3.4). The feasibility of these experiments has been recently demonstrated for the two systems $^{32}$S + $^{48}$Ca and $^{32}$S + $^{64}$Ni. In future, EXOTIC could be also used as a velocity filter with the neutron-rich RIBs delivered by the next generation ISOL-type facility SPES (Selective Production of Exotic Species) [51], that now is in construction at INFN-LNL.

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