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Past, present and future of radioactive ion beams produced In-Flight at LNS

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Summary. — The FRIBs@LNS facility produces Radioactive Ion Beams (RIBs) at intermediate energies, by projectile fragmentation. The possibility of using the produced RIBs as secondary beams in nuclear physics experiments by applying the tagging technique, *i.e.* the identification, event-by-event, in charge, mass and energy of each ion of the RIBs cocktail selected by the fragment separator, before it interacts with the secondary target, has been demonstrated. In 2010 an upgrade of the facility has been performed. Status and perspectives of the FRIBs@LNS facility are discussed.

PACS `29.38.-c` – Radioactive beams.
PACS `25.70.Mn` – Projectile and target fragmentation.
PACS `29.30.Aj` – Charged-particle spectrometers: electric and magnetic.

1. – Introduction

The study of nuclei far from the valley of stability has introduced new dimensions of nuclear physics. The merits of exotic nuclear beams have been demonstrated with exciting new discoveries, particularly near the borderlines of particle stability, where new characteristics of nuclear structure and decay have been found. Presently, the production of exotic beams is realized either by applying nuclear production mechanisms at intermediate-relativistic energies and in-flight separation (In-Flight method) or by using the isotope separator online (ISOL) method in combination with a post-accelerator. The success of the present exotic nuclear beam facilities is the motivation for new projects and plans for next-generation devices. However, at present, only few facilities produce RIBs at intermediate energies. This circumstance has motivated the development of the In-Flight FRIBs@LNS facility at the Laboratori Nazionali del Sud in Catania (Italy).

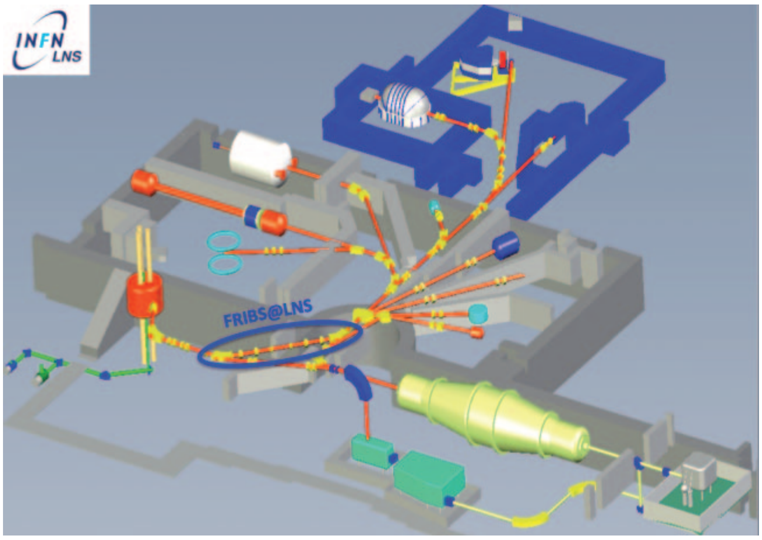

Fig. 1. – Layout of the Laboratori Nazionali del Sud. The position of the FRIBs@LNS fragment separator is indicated.

2. – The FRIBs@LNS facility

The production of RIBs at intermediate energies at LNS was achieved by the In-Flight method, using primary stable beams accelerated by the Superconductive Cyclotron (SC) at energies between 62 and 40 A MeV. In order to optimize the RIBs production, we have used a Be, 500 μm thick, and Al, 100 μm thick, production targets for the light and heavier projectiles, respectively. Targets have been set in a rotating holder just at the exit of the SC whose extraction line was used as an achromatic fragment separator (FRS) (fig. 1).

Different neutron- and proton-rich nuclei have been produced by using, for example, ^{12}C, ^{20}Ne, ^{40}Ar and ^{58}Ni projectiles and individual rate up to 10^5 ions/s were measured for primary beam currents up to 500 enA [1]. In order to discriminate the number of nuclei at the exit of the fragment separator, the leading idea of the FRIBs@LNS project was to apply the tagging technique: namely, the identification, on an event-by-event basis, of each nucleus of the secondary beam cocktail, before it impinges on the secondary target. The tagging detector must, obviously, not stop the incoming ions and should modify as less as possible their characteristics. Therefore, we applied the ΔE-ToF method to identify each incident fragment using the energy loss (ΔE) signal from a silicon detector and the time of flight measured from the same signal generated by the silicon detector with respect to the radiofrequency signal supplied by the accelerator (fig. 2).

3. – Tagged RIBs induced reactions

Due to the Bq acceptance, many different isotopes are transmitted through the fragment separator. The main idea behind the FRIBs@LNS project is then to keep all the fragments transmitted through the FRS and to tag them on an event-by-event basis, before they interact with a secondary target. It is then possible to relate the detected reaction products with only one tagged projectile, among the incoming RIBs cocktail.

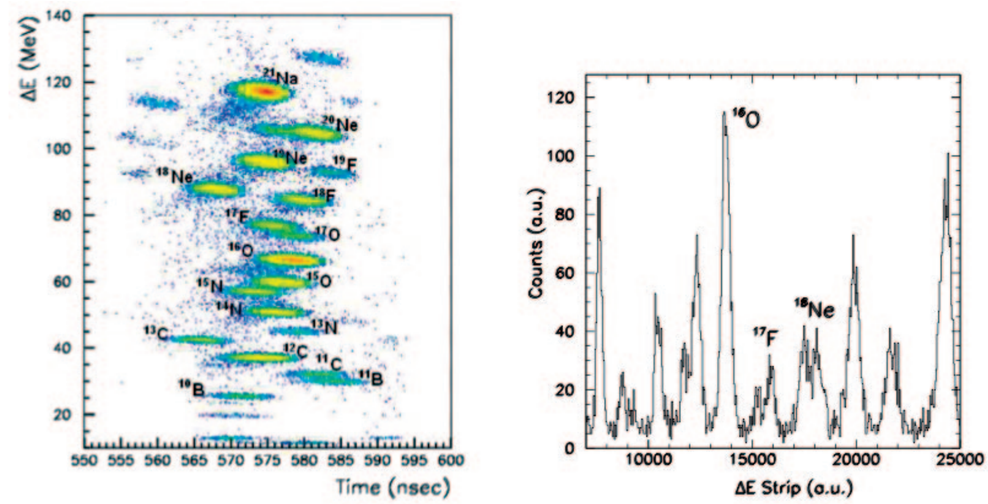

Fig. 2. – Left: ΔE-ToF identification from the Si-Strip detector. Right: Particle IDentification Spectrum on the Si-Strip detector.

This technique avoids the reduction of the RIBs intensities and it is particularly convenient for systematic studies since several projectiles are available at the same time. We have demonstrated the feasibility of measurements with tagged RIBs by performing a series of experiments devoted to nuclear structure studies of exotic nuclei: among them are the Diproton [2] and Flubber experiments [3]. The first aimed to search and study diproton decay of ^{18}Ne excited states [2], the second addresses the study of Coulomb and Nuclear Breakup in ^{17}F and its astrophysical implications [3].

Primary beams of $45\,A$ MeV ^{20}Ne interacting with a ^{9}Be production target has lead to the formation of a radioactive cocktail containing ^{18}Ne and ^{17}F (right plot of fig. 2) of about $30\,A$ MeV. For the selected RIBs the measured rates at the tagging detector (a 24×24 Double-sided Silicon Strip Detector (DSSD) detector) were of the order of 5×10^5 pps. Here again we would like to point out the uniqueness of the tagging method, *i.e.* the possibility to simultaneously carry out a variety of experiments with different exotic nuclei, by selecting offline the isotope of interest before it impinges on the interaction target.

4. – The FRIBs@LNS upgrade

The In-Flight technique joint with the tagging method, introduced at LNS by Giovanni Raciti, has proved the capability to provide useful rates of radioactive beams for nuclear physics experiments at LNS. The international relevance of some results obtained by using the beams delivered by the FRIBs@LNS facility stimulated the management of INFN to approve an upgrade [4] of the facility that has been performed in 2010. The beam line that transports the beam extracted from the cyclotron up to the Switching magnet inside the accelerator room has been fully dismounted and rebuilt in the period September-December 2010. The main changes performed to the beam line involved the insertion of 4 new magnetic quadrupoles and 2 new magnetic sextupoles, the removing of two existing magnetic quadrupoles and the repositioning of the existing 13 quadrupoles.

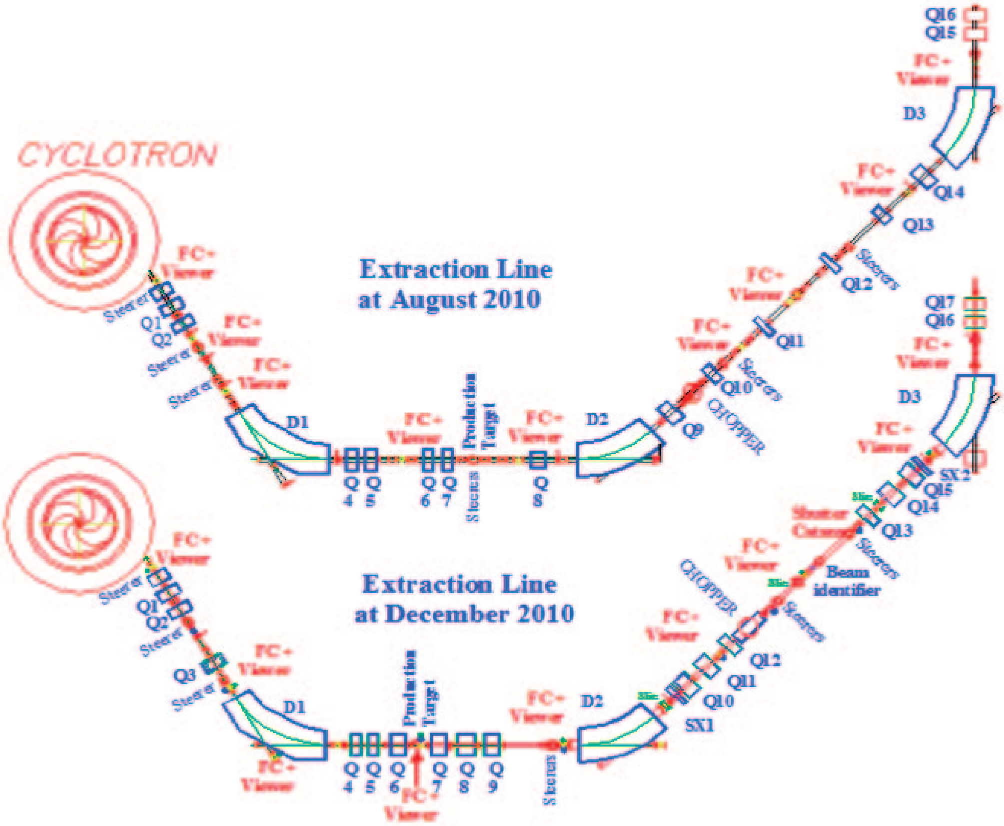

Fig. 3. – Layout of the extraction line from the cyclotron exit to the switching magnet, before August 2010 and after December 2010.

Figure 3 shows the layouts of the previous extraction beam line and of the new one. It is evident that the positions of the three main dipole magnets were unchanged. But all the other magnetic quadrupoles were moved. Also the steering dipole and the two quadrupoles, near the cyclotron, called, respectively, EXT, EQ1 and EQ2 were shifted of about 10 mm in horizontal plane, just to reduce the 5–10% beam losses detected in this region. Also the last two quadrupoles Q16 AND q17, after the dipole ED3, were realigned.

Another possibility to increase the FRIBs@LNS yields is based on the reduction of the beam emittance of the FRIBs@LNS line, without reduction of angular acceptance. To achieve this result we need to shrink as much as possible the beam size at the production target position on a spot smaller than 3 mm in diameter. On the other side, when the cyclotron beam is focused on such a small beam spot, a lot of power has to be dissipated in a small volume. This can be a serious problem for a beam power of 100 W or more, even if not all the power will be dissipated in the target. To solve this problem a new water-cooled and moving target has been constructed. With the new production target beam power up to 600 W could be used.

5. – Outlooks

The FRIBs@LNS facility upgrade has been successfully achieved in 2010. The new configuration should allow to increase the yields of the produced radioactive beams by a factor about 20 to the final users. Really this goal will be fully achieved when all the 30 mm diameter beam collimators, installed along the beam lines, are removed. These collimators, installed in front of the Faraday cups of safety controlled by the health safety service, have the scope to prevent that the beam could reach accidentally the experimental area. In the near future the present Faraday cups will be replaced by new ones with larger size and larger coarseness made by us. These new Faraday cups, when inserted, fully fill the beam pipeline, so the collimators will be unnecessary.

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