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The upgrade of the facility EXOTIC

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ABSTRACT

With the installation of the γ-ray spectrometer AGATA at the Laboratori Nazionali di Legnaro (LNL) of the Istituto Nazionale di Fisica Nucleare (INFN), the scientific activity with the Radioactive Ion Beam facility EXOTIC had to be temporarily suspended and the reaction chambers located at its final focal plane had to be removed. In this period of forced inactivity, we reorganized all the services, upgraded all control systems of the facility and developed a new event-by-event tracking system based on MicroChannelPlate (MCP) detectors. These interventions are preparing the ground for coupling EXOTIC and AGATA to perform experiments exploiting the unique features provided by both equipments.

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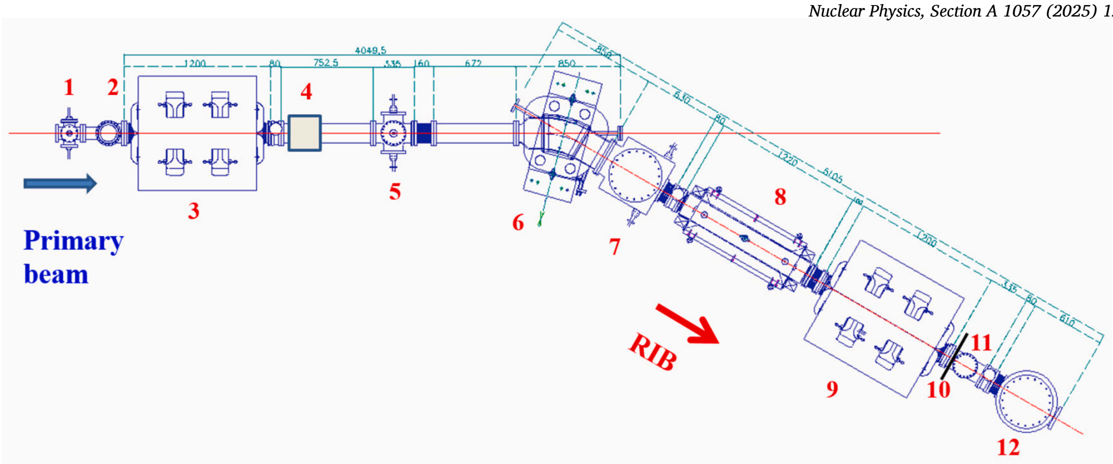

Fig. 1. Schematic view of the EXOTIC facility. No. 2 indicates the cryogenic gas target; No. 3 the first quadrupole triplet (Q1-Q3); No. 4 the *y*-steerer; No. 6 the 30°-dipole magnet; No. 8 the Wien filter; No. 9 the second quadrupole triplet (Q4-Q6); No. 11-12 the final reaction chambers; No. 1-5-7-10 the slit systems.

1. Description of the facility EXOTIC

The facility EXOTIC [1–4] is devoted to the in-flight production of low-energy light Radioactive Ion Beams (RIBs) through inverse kinematics reactions induced by high intensity heavy-ion beams delivered by the XTU-Tandem accelerator impinging on light gas targets.

Fig. 1 displays a schematic view of EXOTIC, consisting of a cryogenic gas target (element 2 in the Figure) and of a sequence of eight ion-optical elements: a first quadrupole triplet (Q1-Q3, element 3), a 30°-dipole magnet (element 6), a velocity filter (element 8) and, finally, a second quadrupole triplet (Q4-Q6, element 9). Four slit systems (elements 1-5-7-10) are located at suitable positions along the beam-line to better define the primary beam spot size and to further purify the RIB under production from unwanted contaminant species.

The following RIBs have been successfully produced within the energy range of 2-5 MeV/nucleon, with respective intensities and purities indicated in parentheses: ^{17}F (10^5 pps, 93-96%), ^{8}B (10^3 pps, 30-43%), ^{7}Be (10^6 pps, 99%), ^{15}O ($4*10^4$ pps, 98%), ^{8}Li (10^5 pps, 99%), ^{10}C ($5*10^3$ pps, 99%), ^{11}C ($2*10^5$ pps, 99%) and ^{18}Ne ($6*10^3$ pps, 95%).

2. Coupling EXOTIC and AGATA

The facility EXOTIC was historically installed along a beam line that could have permitted the connection to the magnetic spectrometer PRISMA [5]. The center of the AGATA array [6], in the PRISMA-AGATA configuration, is located 2.68 m downstream the original final focal plane of EXOTIC. Fig. 2 shows the ion optical layout for the facility EXOTIC in the original stand-alone (bottom panel) and in the future EXOTIC+AGATA (top panel) configurations.

We employed the code GICOSY [7] to calculate the ion optics, and the code MOCADI [8] to evaluate the transmission of the facility in the two configurations for the eight RIBs already produced. The calculations demonstrated that shifting the final focus downstream requires lower magnetic fields for the second quadrupole triplet compared to the original EXOTIC stand-alone configuration. This adjustment ensures that all RIBs previously delivered to the EXOTIC focal plane will also reach the AGATA focal plane, without exceeding the limitations of the existing power supplies and magnets, but with reduced transmission efficiencies.

The simulations were performed considering either the highest primary beam energy achievable with the LNL-XTU Tandem accelerator (14 MV high voltage and the most probable primary beam charge state) or the maximum secondary beam magnetic rigidity which can be efficiently bent and focused with EXOTIC ($B\rho_{max}$ = 0.635 Tm, this second limit actually applies only to the $^{8}Li^{3+}$ RIB). The ion-optical calculations indicated a potential reduction in transmission of approximately 50%. Therefore, based on the secondary beam intensities achieved in the EXOTIC stand-alone configuration, the expected RIB intensities and maximum energies for the EXOTIC-AGATA configuration on target are summarized in Table 1.

3. Upgrade of the facility

In spring 2023, a series of major interventions were carried out on the EXOTIC facility to accomplish the connection with the AGATA array. In particular, (*i*) a small reaction chamber was installed in front of the gas target to house a new primary beam diagnostic box, (*ii*) the water collector and the pipelines for cooling the magnets and the power supplies were replaced, (*iii*) all power lines and signal cables were removed from the ground and orderly rearranged, (*iv*) the software of the remote control systems for the ion-optical elements were rewritten within the EPICS platform. In spring-summer 2024, the facility upgrade was completed, which involved replacing sections of the liquid nitrogen pipelines and installing an additional scattering chamber approximately 1 m downstream from the existing chamber to accommodate the newly developed RIB tracking system.

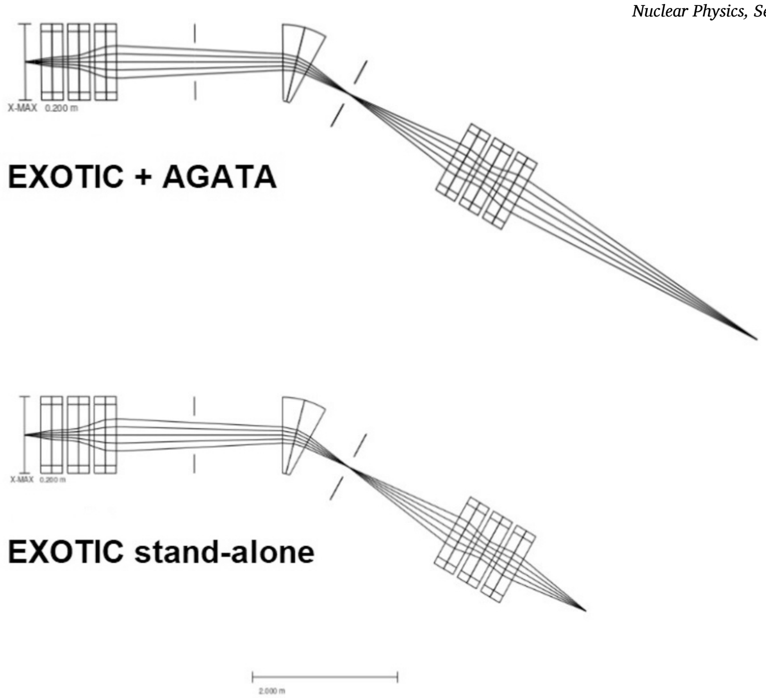

Fig. 2. Ion optical layout of the facility EXOTIC in the new EXOTIC+AGATA configuration (top panel) and in the original EXOTIC stand-alone configuration (bottom panel). The calculations were performed with the code GICOSY [7].

Table 1
Intensities and maximum energies expected for the RIBs delivered by EXOTIC and possibly available for experiments with AGATA.

RIB	Intensity (pps)	E_{max} (MeV)
$^{8}Li^{3+}$	5×10^4	21.7
$^{7}Be^{4+}$	5×10^5	44.2
$^{8}B^{5+}$	4×10^2	45.5
$^{10}C^{6+}$	2×10^3	51.8
$^{11}C^{6+}$	10^5	54.2
$^{15}O^{8+}$	2×10^4	70.6
$^{17}F^{9+}$	4×10^4	79.6
$^{18}Ne^{10+}$	2×10^3	78.1

This new system comprises two large-area (104 mm diameter) $x - y$ sensitive MicroChannel Plate (MCP) detectors, which replace the previously installed tracking system that utilized Parallel Plate Avalanche Counters (PPACs). These MCP detectors, acquired from the German company RoentDek [9], were arranged in a Chevron configuration. All the mechanics, delay lines, and readout electronics were built in-house and will be described in detail in a forthcoming publication [10].

4. Commissioning runs and perspectives

The first (re-)commissioning run of EXOTIC was performed on October 2023. During this run, a ^{7}Be secondary beam at approximately 42 MeV was produced, and we successfully replicated the beam conditions from November 2013-the last instance when this RIB was delivered by our facility at this energy. This ensured that the new software developed for the remote control of the magnets was perfectly able to guarantee the proper fine tuning of all the ion optical elements.

A second run was held on December 2023 aimed at testing the online capabilities of the first newly developed MCP detector. This data, combined with the detailed offline characterization of the system, focused on optimizing the readout electronics and developing an event-by-event algorithm for the online reconstruction of the beam particle trajectory.

Two commissioning runs of the full setup involving both MCP detectors are scheduled for November-December 2024. At this stage, the complete connection of the beamline up to the PRISMA-AGATA focal plane will be tested, providing an opportunity to evaluate the reliability of the ion-optical calculations.

If the final commissioning runs are successful, a campaign of scientific experiments can be pursued from the first semester of 2025, exploiting the unique features provided by the RIB delivered by EXOTIC and state-of-art gamma ray tracking array AGATA.

CRediT authorship contribution statement

M. Mazzocco, S. Pigliapoco and D. Brugnara: Investigation, Methodology, Supervision, Writing - original draft. All other authors contributed to the investagation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

No data was used for the research described in the article.

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