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First feasibility experiment for the EXL project with prototype detectors at the ESR storage ring

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A B S T R A C T

The investigation of light-ion reactions with exotic beams in inverse kinematics gives access to a comprehensive range of nuclear structure information in the region far off stability. The future FAIR facility at GSI will provide new opportunities to extend and advance these investigations. The present paper will focus on the results of the first feasibility experiment for the EXL project in which we used a stored ^{136}Xe beam with $E = 350$ MeV/nucleon interacting with an internal hydrogen gas-jet target at the ESR storage ring of GSI. In this experiment we made use of at least one element of every detector part of the future experimental setup. Selected results from this measurement will be presented.

1. Introduction

It is a well-known fact that the study of light-ion induced direct reactions, like elastic and inelastic scattering, transfer, and charge-exchange reactions, provides important information on the structure of nuclei. Before the availability of radioactive ion beams (RIB), such studies were limited to the use of stable or long-lived nuclei as targets in direct kinematics experiments. With the advent of RIB facilities there is a possibility to extend the nuclear structure investigations to exotic nuclei as well. In this way, the whole chart of the nuclei opens up for research so that theoretical models can be tested and verified all the way up to the limits of nuclear existence: the proton and neutron drip lines. In particular, using stored radioactive beams and exploiting reactions in inverse kinematics inside a storage ring using thin internal targets enables, comparing to investigations with external targets, high-resolution measurements down to very low-momentum transfers. This technique allows to deduce essential nuclear structure information. It also provides a gain in luminosity from accumulation and recirculation of the radioactive beams [1]. The high luminosities provided in these kind of ring experiments (of the order of 10^{28} cm^{-2} s^{-1} for the case of ^{132}Sn

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with a life time of the order of several seconds [5]) allow measurements at very small momentum transfers with high accuracy; the very thin targets permit the low-energy scattered target-like recoil ions to make it through the target-beam interaction region and to enter the detectors installed around the target without major distortion of energy and trajectory. The possibility of studying these low-energy recoil particles is especially important when getting away from the region of stable nuclei, since it allows us to study the periphery of the exotic nuclei. For example, one of the most outstanding discoveries was the finding that the nuclear matter may appear under certain conditions with a qualitatively new type of nuclear structure, the so-called “halo” structure [2,3]. The need to study the size and shape of neutron halo and skin structures magnifies, among other nuclear structure aspects, the importance of studying such systems in the limits of very low-momentum transfers. Other aspects like the isospin and density dependence of the effective in-medium interactions and of pairing and clusterization phenomena in extreme proton–neutron asymmetric nuclear matter, giant resonances with strength distributions totally different from those known in stable nuclei could also be studied well in the low-momentum-transfer region complementing the large-momentum-transfer measurements. These aspects were the motivations to start with the design of a new detection system within the EXL (EXotic nuclei studied in Light-ion induced reactions at the NESR storage ring) project as part of the upcoming FAIR (Facility for Antiproton and Ion Research) facility [4]. The universal detector system EXL is applicable to a wide class of reactions and would provide high resolution and large solid angle coverage in kinematically complete measurements. The setup includes:

- a Si-strip and Si(Li) detector array for recoiling target-like reaction products, completed by slow-neutron detectors, and a scintillator array of high granularity for gamma rays and for the total-energy measurement of more energetic target recoils;
- detectors in forward direction for fast ejectiles from the excited projectiles, i.e., for neutrons and light charged particles; and
- heavy-ion detectors for the detection of beam-like reaction products.

All detector components will practically cover the full relevant phase space and have detection efficiencies close to unity. The setup will allow to measure energies of recoil particles ranging from sub-MeV to around 100 MeV. In order to perform a feasibility study for the EXL setup [5], a test experiment was set up at the existing storage ring ESR (Experimental Storage Ring [6]) at GSI Darmstadt, Germany. In this feasibility test the ESR storage ring was used to study the reactions resulting from the interaction of a stable ^{136}Xe beam with an internal hydrogen target. The test experiment was performed in order to investigate the performance of the detector systems and the background conditions in a realistic storage ring scenario.

2. Experimental setup

For the feasibility experiment, detector elements representing almost all the major detector systems of the future EXL setup were installed at the ESR (Fig. 1). Most of the various detector elements in this experiment covered only a small fraction of the total available solid angle. A ^{136}Xe beam with an energy of 350 MeV/nucleon was injected into the ESR from the heavy-ion synchrotron SIS, periodically exposed to electron cooling and moderately bunched by an RF cavity. We had two bunches of totally 100 ns length; the circumference of the ESR storage ring is about 108 m (≈ 500 ns). The beam storage lifetime was about 30 min. On average more than 10^9 ions were circulating with a revolution frequency of 2×10^6/ s, scattering off an internal hydrogen gas-jet target (with a thickness of $\approx 10^{12}$ atoms/cm^2) which was installed inside the vacuum chamber [7]. The detector setup for fast ejectiles consisted of two arrays with a total of 15 organic scintillators, each coupled with an iron converter, for detection of fast neutrons and light charged particles which are detectable mostly at forward angles due to their relativistic velocities when produced in beam-target interaction. The two scintillator arrays were installed at about 230 and 400 cm downstream from the target (Figs. 1 and 2). Each scintillator and iron element had a rectangular cuboid shape with the dimensions of $10 \times 50 \times 4$ and $10 \times 50 \times 5$ cm^3, respectively. Each iron–scintillator couple was mounted in such a way that we had 4 cm of scintillator material in the beam direction preceded by 5 cm of iron. In total we had eight iron–scintillator couples put together in a square-like frame forming the first array, and seven put together as a wall forming the second array.

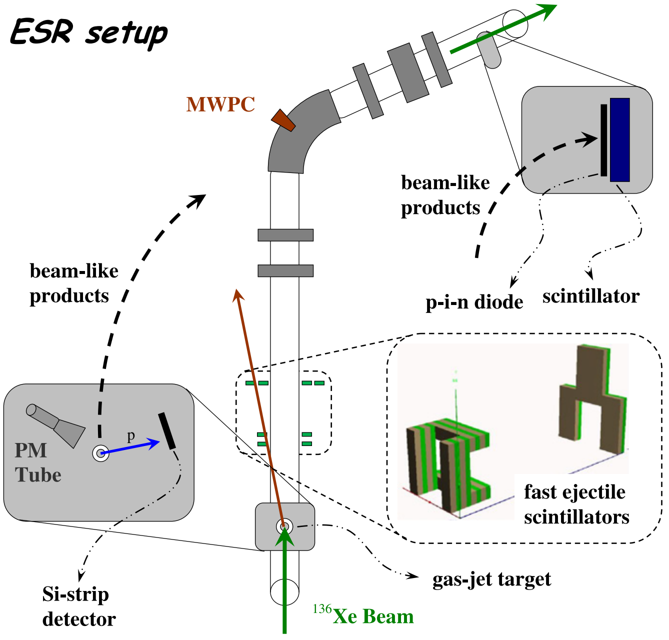

Fig. 1. Experimental setup for the EXL test experiment performed at the storage ring ESR at GSI. For details see text.

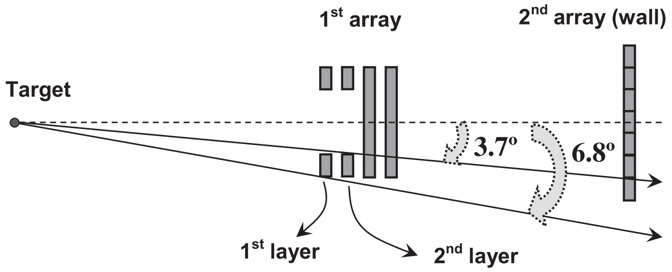

Fig. 2. Top view of the organic scintillators used for detection of fast ejectiles. The angular ranges that are shown here represent the range of the scattering angle θ that covers the whole of the two detector layers labeled as “1st layer” and “2nd layer”. Note that the iron converters in front of the scintillator bars are not shown here.

For detection, identification, and fast timing of the beam-like reaction products we had a position sensitive silicon p-i-n diode of 300 μm thickness and 45×45 mm^2 surface area followed by a 1 mm thick scintillation detector. They were installed further downstream the target after the first dipole magnet in a movable vacuum pocket driven in and out of the beam tube. Furthermore, a multi-wire proportional chamber (MWPC) for detection of the products of atomic charge-exchange reactions and a photomultiplier (PM) for