Nuclear Structure Studies on Exotic Nuclei by Light-Ion Induced Direct Reactions with Stored Radioactive Beams

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Motivation and Research Objectives

The experimental conditions at the future facility FAIR [1, 2, 3] will provide unique opportunities for nuclear structure studies on nuclei far off stability, and will allow for exploring new regions in the chart of nuclides of high interest for nuclear structure and astrophysics. In particular, the predicted intensities of radioactive beams provided by the new superconducting fragment separator SFRS, and the corresponding luminosities will allow for the investigation of direct reactions with stored and cooled radioactive beams at internal H, He, etc. targets of the new storage ring NESR. This technique enables high resolution measurements down to very low momentum transfer and provides a gain in luminosity from accumulation and recirculation of the radioactive beams.

The objective of the EXL-project (EXotic nuclei studied in Light-ion induced reactions at the NESR storage ring), which is part of the NUSTAR-program [4] (NUclear Structure, Astrophysics and Reactions) at FAIR, is to capitalise on light-ion induced direct reactions in inverse kinematics by using novel storage ring techniques, and a universal detection system providing high resolution and large solid angle coverage in kinematically complete measurements.

To address the key physics issues of the EXL project (formulated in details in [2, 5, 6]), such as the investigation of:

- nuclear matter distributions near the neutron drip line (halo -, skin - structures),
- isospin-dependence of single-particle and shell structure (magic numbers, shell gaps, spectroscopic factors),
- nucleon-nucleon correlations, clusters,
- new collective modes (different deformations for protons and neutrons, giant resonance strengths),
- in-medium interactions in asymmetric and low-density nuclear matter,
- astrophysical r- and rp-processes (Gamow-Teller strength, neutron-capture),

a variety of light-ion induced direct reactions, such as for example elastic scattering (p, p), (α, α), etc., inelastic scattering (p, p'), (α, α'), etc., charge exchange reactions (p, n), (^{3}He, t), (d, ^{2}He), etc., quasi-free scattering (p, 2p), (p, pn), (p, pα), etc., and transfer reactions (p, t), (p, ^{3}He), (p, d), (d, p), etc., need to be investigated. Having in mind that for most of these reactions the relevant nuclear structure in-

** The EXL collaboration: http://ns.ph.liv.ac.uk/∼mc/EXL/collaboration/EXL-collaboration.html*

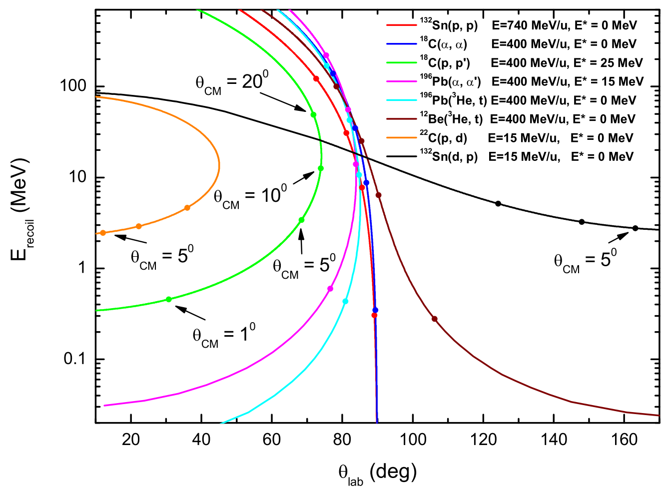

Figure 1: Kinematics of target-recoil particles for selected reactions.

formation is located in the region of moderate to very small momentum transfer, it becomes obvious from Fig 1 that the use of cooled stored beams interacting with a thin internal gas target is mandatory for most of these investigations, as it provides

- high resolution detection of low energy recoil particles,
- high luminosities due to the continuous beam accumulation and recirculation,
- low-background conditions due to pure, windowless ^{1,2}H, ^{3,4}He, etc. targets.

The EXL Detector Setup

Within the Technical Proposal [6], recently submitted to the FAIR management, the design of a complex detection setup was investigated with the aim to provide a highly efficient, high-resolution universal detection system, applicable to a wide class of reactions. The apparatus foreseen being installed at the internal target of the NESR storage cooler ring is displayed in Fig. 2. It includes a Si-detector array for recoiling target-like reaction products, completed by gamma-ray and slow-neutron detectors, as well as forward detectors for fast ejectiles and an in-ring spectrometer for the detection of beam-like reaction products. Whereas the design of the forward detectors and in-ring spectrometers are based on technology already currently available at the present LAND setup [7] at GSI for the investigation of reactions with radioactive beams at external targets, and at the present storage ring ESR, respectively, the design and construction of a highly-efficient, universal recoil and gamma detector system will be one of the most challenging tasks of the present research project. In particular, the detector components need to fulfil strong demands concerning angular and energy resolution, energy threshold, dynamic range, granularity, vacuum capability, etc., partly not available from standard detection systems.

A schematic view of the detector setup surrounding the internal gas-jet target is displayed in Fig. 3. It is foreseen to separate two regions of the setup with different

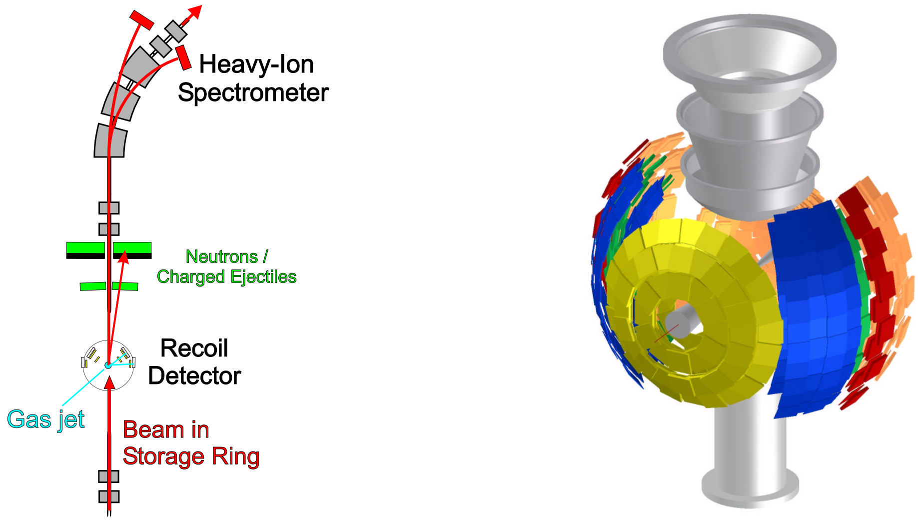

Figure 2: Schematic view of the EXL detection systems. Left: Setup built into the NESR storage ring. Right: Target-recoil silicon detector surrounding the internal gas-jet target.

vacuum conditions by a thin window. The inner "high vacuum" part will house the silicon particle array which will be bakeable to temperatures in the vicinity of 130^0 C in order to reach a vacuum of at least 10^{-8} - 10^{-9} mbar. The outer "low vacuum" part of the detector chamber will house the array of scintillation detectors, which is dedicated to detect the gamma-rays, as well as the residual energy of fast recoil particles, which punch through the silicon detectors. A vacuum of about 10^{-5} mbar will be sufficient for that part of the scattering chamber. Different regions A-E of the lab-angular range correspond to a colour code as defined in Fig. 3. Except for the regions C and D, where particle tracking is foreseen, the angular resolution will be determined in all other regions by the dimension of the gas-jet target and the distance of the detectors from the beam-target interaction point. The choice of the detector geometry and detector types for the different regions A-E are optimized with respect to the kinematical conditions and demands on energy and angular resolution for the various types of reactions to be studied (for details see [6]). For angular regions A, B and E telescopes consisting of double-sided silicon strip detectors, 300 μm thick, and 9 mm thick lithium-drifted silicon detectors behind are foreseen, whereas regions C and D will be equipped with tracking detectors consisting of double-sided silicon strip detectors, 100 (300) μm thick. To optimise the detection efficiency of the recoil detector, a maximum solid angle cover allowed by the installations needed for the gas-jet target is investigated. At angles close to $\Theta_{lab} = 90^0$ a coverage of at least $\phi = \pm\ 45^0$ in azimuthal angle is foreseen, which can be increased in forward and backward directions. A first attempt at a possible 3D detector geometry is displayed in Fig. 2. It should be pointed out that this concept is subject to further detailed investigations in the near future to define a final optimum solution.

The scintillator hodoscope consisting of about 1500 individual crystals, built of scintillator material (CsI or others) is supposed to detect γ-rays emitted from excited beam-like reaction products, as well as the residual kinetic energy of fast target-like reaction products, which punch through the silicon detectors discussed above.

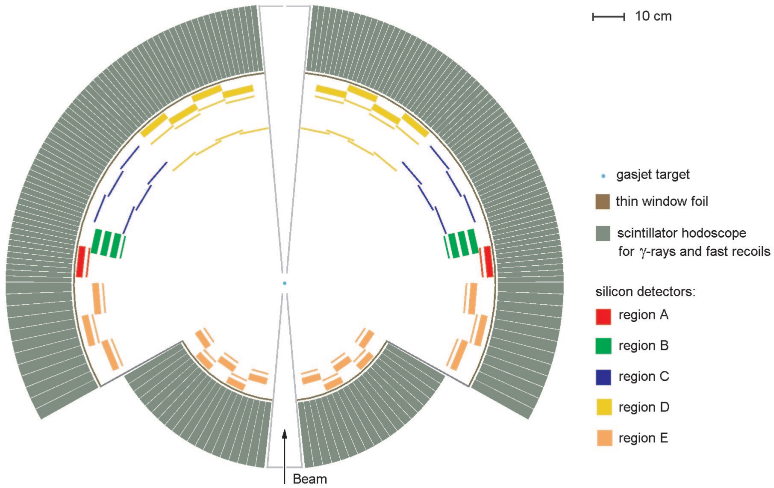

Figure 3: Schematic view of the detector setup of the EXL recoil and gamma array (cross section through the mid plane).

Concerning the detection of γ-rays, aside of the γ-sum energy for missing-mass reconstruction in case the excited beam-like reaction product is particle unstable (for example after GR excitation), the detector has also to provide γ-multiplicities and individual γ-energies for spectroscopic purposes. By detecting the γ-rays from the decay of excited beam-like reaction products it also serves in separating elastic and inelastic reaction channels in cases of low-level spacing where the angular and energy resolution of the silicon detectors are not sufficient to resolve these reaction channels. It is clear from these considerations that only a highly efficient, high-resolution device will satisfy the demands formulated above. An almost 4π coverage, sufficient detector thickness for $\sim$80% γ-detection efficiency at $E_\gamma = 2$ - 4 MeV and for stopping of up to 300 MeV protons, an energy resolution of 2-3% for γ-rays and 1% for fast protons are required. In the case of γ-rays, the line broadening due to the Doppler shift, most substantial at highest beam energies, imposes a high detector granularity.

References

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