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Letter of Intent to the
ISOLDE and Neutron Time-of-Flight Experiments Committee
for experiments with HIE-ISOLDE

Direct and resonant reactions using an Active Target

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Abstract

We propose to use an active-target detector to perform reaction studies at HIE-ISOLDE. The performances of the new-generation instrument, ACTAR, will allow its use with the unique post-accelerated beams of ISOLDE providing spectroscopic information on the most exotic systems.

1. Introduction

Radioactive ion beams have become an essential tool in low-energy experimental nuclear physics. Because of their limited intensity, such beams require detection devices having a high efficiency and good angular resolution. The use of thick solid foils to increase luminosity leads quickly to significant losses in energy resolution and a high detection threshold.
The idea of an active target, based on a gaseous ionization detector where the nuclei of the gas atoms are also the target nuclei, overcomes most of these difficulties. Gaseous detectors potentially have a very good geometric efficiency, a low detection threshold and excellent tracking capabilities (allowing the measurement of angular distributions). They have possibilities in particle identification; and a large target thickness is possible without losing in resolution. In case of short-living or unbound reaction products, the decay and its products can be detected in the gas volume itself. Exploiting the energy loss of the incident beam in the gas, excitation functions can be obtained for selected reactions with a single tuning of the accelerator. First-generation instruments such as the IKAR detector [1], MAYA [2] and the CENBG TPC [3] have obtained motivating results both in reaction [1,4-7] and decay [8] measurements. The active target detector of the new generation (ACTAR) [9,10] will improve on the limitations of present instruments in terms of dynamic range, event multiplicity and event rate. At HIE-ISOLDE, ACTAR can be used for the investigation of the most exotic systems, at the edge of experimental possibilities.

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2. Physics case

A number of physics cases can be covered by the active target set-up (see for example Refs. [9,10]).

- The region of light nuclei offers interesting opportunities at HIE-ISOLDE, where the available beams will not be matched elsewhere for the next five to ten years. Light nuclei are an important testing ground for structure models. Because of the small number of nucleons and the vicinity of breakup thresholds, cluster models are more successful than mean-field approaches in describing the peculiar features of these systems, like nuclear halos and molecular states. Also, ab-initio calculations are now capable of reaching nuclei up to carbon. Clearly, additional experimental information especially on the most exotic systems is desirable. Various reaction methods – elastic and inelastic scattering, resonant reactions, transfer of one, two or few nucleons – can be employed in this region.
  (d,p) reactions can be performed using deuterium gas at a pressure of typically 1 bar, detecting the scattered protons with high efficiency and a low threshold. With a target thickness of about 10^{21} atoms/cm^2, such measurements become feasible at beam intensities of 10^3 pps. Using light exotic beams in combination with different target gases, containing carbon or oxygen, *multi-nucleon transfer reactions* can also be employed to reach states in systems at and beyond the driplines. A case of interest is the transfer reaction ^{9}C(d,p)^{10}C*, using a beam of ^{9}C ions to access high-energy states in ^{10}C (the ^{11}C(p,d) reaction is also a possibility, but the *Q*-value is much less favourable). The states could be studied through their decay: in particular, it would be possible to identify those decaying to the 2α + 2p channel by detecting the emitted particles. Their correlations would then provide information on the possible molecular nature of such states.
  Resonant reactions can be performed in ACTAR using protons or He nuclei as target. With respect to the use of thin foils, with the active target the complete kinematic information would be available: energy and angle of both the light recoil particles, and scattered beam, and position of the vertex of the interaction. This allows identifying the process (for example elastic from inelastic scattering) and using events in a large angular range without losing in resolution, with a gain of a factor 50 to 100 in statistics. For example, at HIE-ISOLDE the ^{12}Be beam could be used in a resonant elastic scattering on protons to form, in ^{13}B, the isobaric analogue states of the unbound ^{13}Be system. The properties of the latter are essential to understand the structure of the two-neutron halo nucleus ^{14}Be.
- Direct nuclear astrophysics measurements can be performed using a hydrogen or helium target gas. Reactions relevant to novae, X-ray bursts and supernovae, such as (α,n), (α,p) and (p,α), can be studied and the extended target allows larger regions of the excitation function to be explored in one measurement, making full use of the available intensities. For example, the ^{18}Ne(a,p)^{21}Na reaction is of current interest in view of its role in breakout from the Hot-CNO cycle in X-ray Bursts. In general, for a strong programme in this area, it will be necessary to design the accelerator structure to enable low energy (ideally few hundred keV/u) beams of light nuclei.
  Also of interest for nuclear astrophysics is the region of neutron-deficient nuclei along the path of the rp-process. A wealth of information on these nuclei can be obtained measuring the elastic, transfer and fusion channels on proton and C targets. A specific LoI has been submitted on this subject.
- In the vicinity of shell closures, one- and two-nucleon transfer reactions can be used to study the single-particle character of states in key nuclei, for nuclei up to Z~50. The active target is specifically designed for use with the most exotic, and thus weakest beams (down to 10^3 pps), and in this respect it is complementary to techniques employing solid-state and gamma-ray detectors in combination.

The upgrade to HIE-ISOLDE will provide beams up to an energy of 10 MeV/nucleon, which is particularly indicated to perform transfer reactions, as cross sections are higher and angular distribution are more characterised with respect to the present situation. Also, in resonant reactions a larger range in excitation energy of the compound nucleus becomes accessible. Of course the increase in intensity will allow pushing the limits of feasibility of these measurements further towards the most exotic systems.

3. Experimental setup

The completion of ACTAR is foreseen for mid-2013 (downsized prototypes will be built in the process). References [9,10] present a detailed description of the detector design and characteristics, of which we only summarise here the main aspects. The detector works on the principle of a time-projection chamber (TPC), where the ionizing particles traversing the gas volume produce electrons, which are guided to an amplification and detection region by an electric drift field. The pads on the detection plane provide a two-dimensional projection of the tracks; the third dimension is reconstructed from the drift time. Particle identification is based on the kinematics, the length of the tracks and the deposited energy. In the present design, more than 15000 electronic channels are read out by a novel electronic system, developed specifically for this sort of instruments (GET – General Electronics for TPCs). The electronics should ensure a rate of 1 kHz for accepted events.

While the active detection volume is modest (a cube of about 25 cm in size), the vessel containing the detector will be somewhat larger, to accommodate ancillary solid-state detectors; however its dimensions will probably not exceed about 60 cm on each side. The whole setup is designed with the aim of being portable, for use at various facilities. Typically, it would be installed on a general-purpose beam line end with about 1 to 1.5 meters of available space. The gas system is an integral part of the setup, and gas parameters (composition, pressure, temperature) will be controlled remotely by a system connected with the acquisition electronics. In the same way, all parameters of the electronics will be adjustable via a remote connection, so that access to the setup should be limited to a minimum during measurements.

Exploiting the York Group's expertise with the TACTIC detector [11], a complementary cylindrical detector geometry is also available which allows higher intensity beams to be exploited. Beam intensities up to 10^7 pps are feasible due to the "blind" beam region.

ACTAR could be used in combination with a spectrometer: either placed in front of it, for example in transfer reactions induced by a heavy beam which would fully traverse the active target; or placed behind, to further purify and select the beam in the spectrometer.

4. Beam requirements

The developments of specific beams will be indicated in future proposals; light beams (Be, C and possibly up to Ne-Mg) and beams around shell closures are certainly of interest.

The detector is specifically designed for use with the most exotic, and thus weakest beams (a few pps for elastic scattering, 10^3 pps for transfer reactions). At ISOLDE , the time structure can be a problem since the active target has an intrinsic limit in the acceptable instantaneous rate. With ACTAR an effort is being made in order to improve this limit, which is mainly determined by the information to be recorded: if only scattered particles are retained and beam tracks are ignored, high instantaneous rates (>10^6 pps) could be used. If the correlation between incoming beam track and scattered tracks is required, the instantaneous rate should not exceed a few 10^5 pps. Typical values for the duty factor at REX (beam compressed in 100 μs with a repetition rate of 50 Hz) result in a reduction of a factor 200 on the acceptable beam intensity. It is therefore very important to spread the beam pulses in time as much as possible.

Beam purity is also an important issue: by running at the limit of acceptable beam rate, any contamination would proportionally affect the collected statistics. Beam energy resolution and emittance are, instead, less of a concern, because of the tracking capabilities of the detector itself. As stated in the physics case, to fully exploit the high intensities available at HIE-ISOLDE for nuclear astrophysics measurements, it is important to have the capability to deliver low energy (< 0.7 MeV/u) beams.

5. Safety aspects

The active target operates using different detection gases, according to the measurement to be performed. Isobutane (C_4H_{10}) and helium (He) are the most used; occasionally hydrogen (H_2 or D_2) could also be employed (deuterium was already used in measurements with Maya [5]). The ACTAR setup includes a full gas supply and control system; the vessel itself is designed in order to sustain pressures up to 3 bar.

Because of the weak intensity of the beam used, no concerns with radioactivity are foreseen.

6. References

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