TSR@ISOLDE Workshop 2015

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Book of Abstracts

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Session 1 / **3**

Welcome

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Session 1 / **1**

HIE-ISOLDE The Physics Case

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The high quality and selectivity of the ISOLDE beams allows high-precision measurements of nuclear structure phenomena. In the period of 2001-2012 ISOLDE offered the largest variety of post-accelerated radioactive beams in the world up to an energy of 3 MeV/u. In order to broaden the scientific opportunities, the HIE-ISOLDE (High Intensity & Energy) project will increase the final energy of the post-accelerated beams to 10A MeV throughout the periodic table. The first stage will boost the energy of the current REX LINAC to 4.3 MeV/u in 2015 and 5.5 MeV/u in 2016, energy domain where the Coulomb excitation cross sections are strongly increased and many transfer reaction channels will be opened.

After a submission of thirty-four letters of intend in 2009, twenty-nine experiments have been approved for day-one physics with more than six hundred shifts. The physics cases approved expand over the wide range of post-accelerated beams available at ISOLDE. In this contribution the first cases plan to be addressed this year will be presented together with a general overview of the experiments approved and their associated instrumentation.

Session 1 / **4**

STATUS OF THE HIE-ISOLDE PROJECT

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After 20 years of successful ISOLDE operation at the PS-Booster [1], a major upgrade of the facility, the HIE-ISOLDE (High Intensity and Energy ISOLDE) project was launched in 2010. It is divided into three parts; a staged upgrade of the REX post-accelerator to increase the beam energy from 3.3 MeV/u to 10 MeV/u using a super-conducting Linac, an evaluation of the critical issues associated with an increase in proton-beam intensity and a machine design for an improvement in RIB quality. The latter two will be addressed within the HIE-ISOLDE Design Study. This presentation aims to provide an overview of the present status of the overall project by providing; an insight to the infrastructure modifications, progress on the high beta Quarter Wave Resonant (QWR) cavities and cryomodule assembly as well as the installation and tests of the HEBT lines. Plans for the second phase of the project will be highlighted.
References
[1] A. Herlert, The ISOLDE Facility, Nuclear Physics News, Vol. 20/ No.4, 2010

Session 1 / **5**

TSR Status report

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The TSR will be the first low-energy storage ring at an ISOL-type radioactive
beam facility [1]. Specifically, we intend to setup the heavy-ion, low-energy ring TSR at the ISOLDE facility in CERN, Geneva. Such a facility will provide a capability for experiments with stored secondary beams that is unique in the world. The envisaged physics programme is rich and varied, spanning from investigations of nuclear ground-state properties and reaction studies of astrophysical relevance, to investigations with highly-charged ions and pure isomeric beams. In addition to a brief summary of the exciting physics program and recent developments of the TSR project I will report on collaboration issues and agreements as well as the building and the funding situation.

[1] M. Grieser et al., Eur. Phys. J. ST 207, 1 (2012)

Session 1 / **17**

Status report of the charge breeder upgrade

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The REXEBIS charge breeder provides the HIE-ISOLDE linac with highly charged ions such as 2< A/q<4.5. Only for lighter ions the low A/q-values can be obtained (fully stripped ions to reachable Z=20), partly because of the limited electron beam energy, but also due to the limited electron current density.

As the electron cooling time is inversely proportional to the square of the ion charge, higher charge states out of the breeder are of interest. Likewise the ion storage time benefits from higher charges as the electron stripping cross-section is reduced. Finally, and most challenging, some of the experiments requests fully stripped ions, or Li/Na-like atomic configuration for the very heavy A~200 ions. For these reasons an upgrade of the REXEBIS charge breeder would be of interest.

We are presently pursuing two paths to attain this goal. In a collaboration with Brookhaven National Laboratory we are developing and testing a very high current, high current-density and high energy electron-beam-gun (HEC2). This would be installed in a new 5 T magnet. Since a few months we are also investigating the possibility of producing a scaled-down version of this gun to be installed in the present REX solenoid.

The latest results from these investigations will be discussed.

Session 2 / **18**

Novel internal target source for future storage ring experiments

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The introduction of cryogenically cooled, few micrometer-sized nozzle geometries and an essential modification of the experimental storage ring (ESR) target station for the first time allowed for a reliable operation using the light target gases helium and hydrogen at area densities up to values of 10^{14} cm^{-2} [1]. In the course of these optimization efforts, a remarkably versatile target source was established, enabling operation over the whole range of desired target gases (from H_2 to Xe) and area densities (~10^{10} to ~10^{14} cm^{-2}).

For more general, future applications at storage rings a completely new inlet chamber was proposed based on the experience gained during previous modification processes [2]. The much more compact chamber design will maintain the demanding storage ring vacuum requirements while enabling the operation of the target beam at an interaction length down to 1 mm. This is of paramount importance with respect to the realization of high precision experiments, e.g. by reducing the inaccuracy of the observation angle causing the relativistic Doppler broadening [3]. While being intended for the deployment at the future high energy storage ring (HESR) within the FAIR project, the new inlet chamber could also be introduced to other storage rings - such as the TSR@ISOLDE - due to its compact size and modularity, which offers numerous experimental possibilities.

[1] M. Kühnel *et al.*, NIM A, 602, 311-314 (2009)

[2] N. Petridis, A. Kalinin, and R. E. Grisenti, "Technical Design Report: SPARC-Target@HESR", Stored Particles Atomic Physics Research Collaboration, 2014

[3] T. Stöhlker *et al.*, NIM B, 205, 210-214 (2003)

Session 2 / **8**

Feasibility of experiments at TSR@ISOLDE from the accelerator point of view

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Recently transfer-induced fission experiments where proposed at TSR@ISOLDE, requiring luminosities in the 1027 1/(s cm2) range. In the talk the feasibility of those experiments from the accelerator point and as well the achievable luminosity will be discussed.
Furthermore experiments with the external spectrometer HELIOS needs ion beams with transverse emittances of about 0.01 mm mrad and an energy spread of roughly 0.025 %. Cold ion beams with emittances below 0.01 mm•mrad and momentum spreads lower than 10-4 can be obtained with electron cooling inside the TSR . In the additional slow extraction process, carried out at the TSR, the emittances as well the momentum spread of the extracted ion beam could not preserve so far. Intra beam scattering effects and rf noise transferred to the extraction kicker leads to an significant increase of the phase space. To maintain the emittances as well the momentum spread the ion beam has to be cooled throughout the whole extraction procedure. A new slow extraction scheme using dispersive electron cooling, to switch off only horizontal electron during extraction, is proposed to maintain the good beam quality of an electron cooled ion beam. In addition fast extraction is investigated to provide a cold ion beam for HELIOS.

Session 2 / **9**

In-ring detector systems

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The talk will consider the types of high resolution measurements that could be performed with an in-ring silicon detector system on the TSR@ISOLDE, with a particular emphasis on nuclear astrophysics applications. Funding has now been obtained through the UK ISOL-SRS project to build this system, and the project has now begun.

Session 2 / **0**

Laser spectroscopy of recirculating beams at the TSR

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Laser spectroscopy is an atomic technique, which gives access to nuclear observables independently of nuclear models. The hyperfine structure reveals the nuclear spin and nuclear electromagnetic moments, while the isotope shift between any two isotopes is related to the change in the nuclear mean square charge radius.

There are limitations to laser spectroscopy related to the atomic system probed. First, the isotope of interest has to be delivered as a single atom (or ion), while some elements at ISOLDE are rather extracted and ionised as molecules. Second, the studied atomic transition has to be accessible with existing laser technologies, with a wavelength close to the visible range, as well as involving an electron orbital, which overlap with the nucleus provides the sensitivity required for the measurement. Finally, the extraction of the nuclear observables is often limited by the knowledge of the atomic parameters, which cannot be exactly calculated beyond a 3-electron system.

The TSR at ISOLDE offers the solution to these limitations in a number of cases. Molecules can be broken down in the EBIS, so that single-isotope ions are delivered to the TSR. The EBIS can also produce high charge states that provide simplified electronic systems, for which the atomic parameters can be calculated. Finally, the high and adjustable velocity of the ion beam allows to tune the Doppler shift by which visible light can be used in the laboratory to probe deep ultra-violet transitions of interest in these ions. A science programme is currently being developed, focused on halo-like structures in boron, carbon, and oxygen.

Additionally, it may be envisioned to use the laser spectroscopy technique at the TSR to polarise the stored ion beam in order to support the transfer reaction programme.

Session 3 / **10**

Status report on the TSR building

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Since last year a few iterations have been done on the TSR building. More detailed studies have been carried out on the handling, the crane inside the building and the necessary height of the building. Calculations were done on the construction itself taking the different weights of the machine and its elements in account.
Integration of the power supplies and equipment for the machine and the transfer lines that will be housed in the basements has been done as well as a more detailed study of the necessary cooling and ventilation systems and their integration in the building. A so called IPP, Infrastructure Project Proposal, in which the feasibility and costs for the construction of the building and the necessary

infrastructure are described, will be submitted to the Enlarged Directorate this month.
This talk will give you an overview with drawings on the building and the infrastructure.

Session 3 / **2**

Status of the External Solenoidal Spectrometer for the TSR

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Injecting beams of radioactive nuclei into the TSR and cooling them will make it possible to perform charged-particle spectroscopy experiments with excellent energy resolution. For low-Z beam species, nuclear reactions in a gas-jet target can be studied in the ring, with the beam passing through the target repeatedly to achieve high luminosities. However, for heavier beam species higher luminosities can be achieved by extracting the cooled beam and bombarding solid targets. A soleniodal external spectrometer is being designed to measure charged products of the nuclear reactions induced by these extracted beams. The current status of the external spectrometer will be presented.

Session 3 / **11**

In-ring decay measurements

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Beta-decay is a well-established technique to investigate the structure of nuclei. In light exotic nuclei the decay is characterised by large Q-values and low breakup thresholds in the daughter nuclei, so that feeding to continuum states and delayed emission of nucleons and light ions become possible. These processes have been used to study the peculiar features of those systems, such as halos and cluster structures (for example in 6He, 11Li, 12C, and others).

The low energy of the emitted fragments, combined with the background of the beta particles, is a problem for the technique. The storage ring offers a solution, by letting the decay take place in flight: this way, the fragments would profit from the large momentum of the mother nucleus and could be detected in charged-particle arrays as they are emitted in a narrow cone around the circulating beam. We will present possible experiments that make use of this technique.

Session 4 / **12**

Fission studies at HIE-ISOLDE with the TSR

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Studies of nuclear fission in direct kinematics are limited by the availability of targets and the reduced velocity of the fission fragments, which makes their identification in charge rather complicated, in particular for the heavy fragment. Experiments in inverse kinematics carried out at GSI [1, 2] and GANIL [3] have strongly contributed to a revival of fission studies. The
GSI experiments have shown the interest of measuring fission-fragment yields and kinetic energies over long isotopic chains for the understanding of the fission process. These studies have considerably helped in revealing hidden regularities on the influence of shell effects on the fission process. Still, there remain unexplored regions. Moreover, there is a great interest
in studying the evolution of fission observables with the excitation energy of the fissioning nucleus, which was not possible in the experiments done at GSI. For instance, fission probabilities as a function of excitation energy are extremely sensitive to the properties of the fission barriers and nuclear level densities. In addition, many experiments have shown that fission probabilities can be used to obtain neutron-induced fission cross sections of short-lived
nuclei of interest for astrophysics and reactor physics, but for which direct measurements with neutron beams are not possible [4]. Another example of the need for measurements as a function of excitation energy is the odd-even staggering in the fission-fragment elemental yields, which is one of the most prominent manifestations of the influence of pairing correlations in nuclei. Recent studies have shown that the odd-even effect can be explained as
a consequence of the complete transfer of excitation energy from the light to the heavy fission fragment [5]. To further investigate this peculiar process of energy transfer, systematic measurements of the odd-even staggering in elemental yields as a function of excitation energy and for a broad range of fissioning nuclei are needed.

In this contribution we will show that the coupling of HIE-ISOLDE to the TSR opens up highly interesting possibilities for fission studies. We propose to study fission by means of transfer reactions with radioactive beams in inverse kinematics. HIE-ISOLDE will produce numerous beams of pre-actinides and actinides over unprecedented long isotopic chains, spanning new regions of the chart of nuclei for which fission has never been studied. The quality of these beams will be highly improved by cooling and storing them in the Test
Storage Ring (TSR). The cooled beams can then interact with a gas-jet target to induce fission. We will discuss possible setups based on the detection of the target-like and the fission fragments in coincidence, which aim to determine the fission probability, as well as the kinetic energy and the elemental yields of the fission fragments as a function of excitation energy. The good beam quality and the limited straggling in the gas-jet target are particularly relevant for obtaining a good excitation energy resolution, which is needed to measure the fission probabilities at the fission threshold. In addition, one of the major problems in the measurement of fission probabilities is the presence of spurious events originating from reactions on the target backing (or windows) and on target contaminants (e.g. oxygen).
Therefore, the use of windowless, pure gas-jet targets represents an enormous advantage. Finally, the increased beam energy provided by HIE-ISOLDE and the good beam quality provided by the TSR shall considerably help in the identification in charge of the fissionfragments.

[1] K.-H. Schmidt et al., Nucl. Phys. A 665, 221 (2000)

[2] J. Taieb et al., submitted to Phys. Rev. Lett.

[3] M. Caamano et al., Phys. Rev. C 88, 024605 (2013)

[4] J. E. Escher et al., Rev. Mod. Phys. 84 (2012) 353

[5] B. Jurado and K.-H. Schmidt, J. Phys. G: Nucl. Part. Phys. 42 (2015) 055101

Session 4 / **19**

Atomic Physics Experiments with Multiply Charged Ions in TSR@ISOLDE

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With online radioactive beams or with a standalone ion source, and with a suitable injector, the TSR storage ring can be used to study multiply charged ions of many elements and in many charge states. This makes the storage ring a unique tool for studies at the borderline of atomic and nuclear physics, also serving astrophysics and fusion energy research. Recent achievements in this research field will be discussed, focusing on merged beams experiments and metastable atomic lifetime measurements on multicharged ions.

The ionization balance in hot astrophysical or fusion-energy plasmas crucially depends on electron impact ionization rates and photorecombination rates, in particular dielectronic recombination. Both processes are governed by excited many-electron configurations and a large number of resonances produced by them in the electron collision continuum. Merged-beams electron-ion collision studies, making use of the storage ring to ensure the relaxation of long-lived metastable beam components, have started on complex many-electron charge states of astrophysical important ions such as Fe, Si and Mg and on even more complex (open f-shell) configurations of W, important for fusion-energy plasmas.

Using photoemission or collisions as a probe, also the lifetimes of long-lived metastable states in multicharged ions can be investigated. For nuclides of Ti and S, isotopic dependences in atomic state lifetimes were observed, providing a signature of hyperfine-induced radiative decay. Hyperfine-induced decay rates could sensitively probe nuclear magnetic moments for a number of other nuclides where they are still uncertain. These examples illustrate atomic physics studies on multicharged ions that could complement the future experimental program of TSR@ISOLDE.

Session 4 / **14**

Storage rings: present and planned

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In this presentation I will try to give an overview of the present and planned storage ring projects worldwide. I will concentrate on the planned research program and will discuss the unique as well as overlapping physics cases.

Session 4 / **15**

Cryring at GSI

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The former Swedish heavy-ion storage ring CRYRING has been shipped to Darmstadt as in-kind contribution to FAIR. We are presently in the progress of setting it up downstream of ESR. This enables a new access to stored highly charged ion beams at low energies for experiments on atomic and nuclear physics, their intersection and beyond. I will report on the present project status, summarize the planned experiments and review their boundary conditions and expected performance.

Session 4 / **16**

Open discussion/Conclusions